International Atmospheric River Conference 2022 (IARC 2022)

Book of Abstracts

First edition: 29 November 2022

The fourth version of the International Atmospheric River Conference (IARC 2022) was successfully conducted between 10-14 October 2022. More than 130 presentations were made both in-person and virtually. The in-person component was held in Santiago, Chile, with more than 70 attendees. Another 70 attendees connected on-line. We are very grateful to all participants, who shared their work, established new connections and advanced the AR Science.

This document includes all the abstract submitted to IARC 2022. The abstracts are presented as submitted by the authors, sorted by session.

All the presentations were recorded and are now available at the conference website https://cw3e.ucsd.edu/iarc2022/

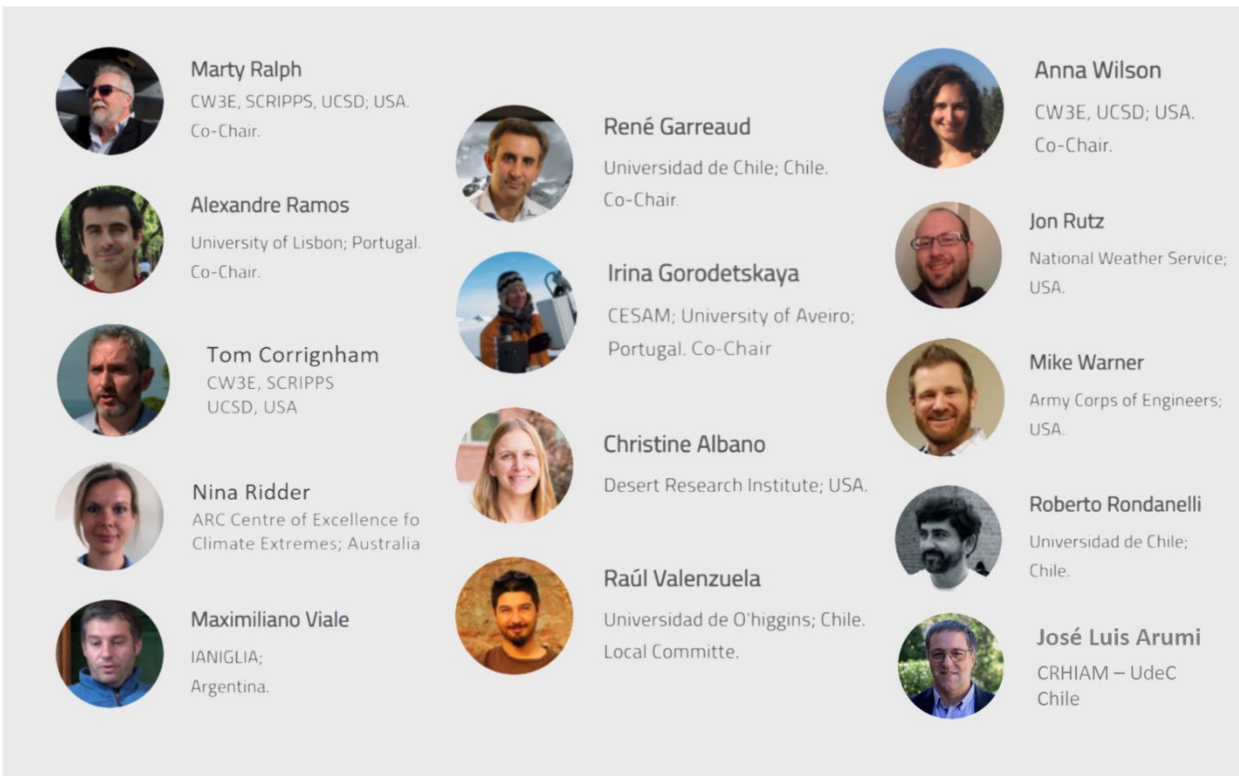
The abstracts and recorded presentations are the legacy of IARC 2022, and we hope they are useful for the broad research and professional community working on the science and impact of Atmospheric Rivers.

René Garreaud, Anna Wilson, Marty Ralph, Irina Gorodetskaya and Alexandre Ramos

IARC 2022 Co-chairs

International Atmospheric River Conference 2022 (IARC 2022)

The International Atmospheric River Conference 2022 was organized by an ad-hoc implementation committee integrated by an international, multi-disciplinary group of researchers, led by five co-chairs: René Garreaud, Anna Wilson, Alexandre Ramos, Irina Gorodetskaya, and Marty Ralph.



International Atmospheric River Conference 2022 (IARC 2022)

We acknowledge the contribution of several institutions that help to support the IARC 2022

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The role of Atmospheric Rivers in compound events in The Netherlands and the Australian east coast

Nina N. Ridder[1,2], Hylke de Vries[3], Michael Barnes[4], and Tess Parker[4]

[1] Australian Research Council Centre of Excellence for Climate Extremes, University of New South Wales, Sydney, Australia

[2] Climate Change Research Centre, University of New South Wales, Sydney, Australia

[3] Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands

[4] Australian Research Council Centre of Excellence for Climate Extremes, Monash University, Melbourne, Australia

The simultaneous occurrence of heavy rainfall and high storm surges can cause severe socioeconomic impacts in coastal regions that far exceed those induced if either of the two hazards occurs in isolation. These events are classified as multivariate compound events (CEs) and can be caused by the landfall of Atmospheric Rivers (ARs). Here we analyse the role of ARs in the co-occurrence of heavy rainfall and high storm surges in two very different coastal systems, namely the coast of the Dutch Waddenzee and the Australian eastern seaboard. Using local observations and modelled storm surge levels based on ERA-Interim reanalysis data we assess the likelihood of events and compare the importance of ARs in the two regions for the co-occurrence of heavy rainfall and high storm surges. Finally, we identify the major synoptic conditions leading to these CEs. The information gathered in this study can be used for early warning and resilience planning.

R_CE2

Large-scale environments of successive atmospheric river events leading to compound precipitation extremes in California

Meredith A. Fish[1], James M. Done[2], Daniel L. Swain[3,2,4], Anna M. Wilson[5], Allison C. Michaelis[6], Peter B. Gibson[5,7], F. Martin Ralph[5]

[1]Department of Earth and Planetary Sciences, Rutgers University, Piscataway, NJ and Rutgers Institute of Earth, Ocean, and Atmospheric Sciences, Rutgers University, New Brunswick, NJ
[2]Capacity Center for Climate and Weather Extremes, National Center for Atmospheric Research, Boulder Colorado, U.S.
[3]Institute of the Environment and Sustainability, University of California, Los Angeles
[4]The Nature Conservancy of California
[5]Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, University of California San Diego
[6]Department of Earth, Atmosphere, and Environment, Northern Illinois University, DeKalb, IL
[7]National Institute of Water and Atmospheric Research, Wellington, New Zealand

Successive atmospheric river (AR) events—known as AR families—can result in prolonged and elevated hydrological impacts relative to single ARs due to the lack of recovery time between periods of precipitation. Despite the outsized societal impacts that often stem from AR families, the large-scale environments and mechanisms associated with these compound events remain poorly understood. In this work, a new reanalysis-based 39-year catalog of 248 AR family events affecting California between 1981 and 2019 is introduced. Nearly all (94%) of the inter-annual variability in AR frequency is driven by AR family versus single events. Using K-means clustering on the 500-hPa geopotential height field, six distinct clusters of large-scale patterns associated with AR families are identified. Two clusters are of particular interest due to their strong relationship with phases of the El Niño/Southern Oscillation (ENSO). One of these clusters is characterized by a strong ridge in the Bering Sea and Rossby wave propagation, most frequently occurs during La Niña and neutral ENSO years and is associated with the highest cluster-average precipitation across California. The other cluster, characterized by a zonal elongation of lower geopotential heights across the Pacific basin and an extended North Pacific Jet, most frequently occurs during El Niño years and is associated with lower cluster-average precipitation across California but a longer duration. In contrast, single AR events do not show obvious clustering of spatial patterns. This difference suggests that the potential predictability of AR families may be enhanced relative to single AR events, especially on sub-seasonal to seasonal timescales.

R_CE3

Links between subseasonal precipitation extremes in the U.S. and temporal clustering of atmospheric rivers

Benjamin J. Moore
NOAA Physical Sciences Laboratory

Precipitation extremes on subseasonal timescales can result in prolonged, high-impact flooding and can make significant contributions to water resources. Motivated by these impacts, this study investigates synoptic-scale processes driving these extremes, with a particular focus on the role of atmospheric rivers (ARs). Subseasonal extreme precipitation events are first identified in gridded 31-day accumulated precipitation analyses over the conterminous U.S. computed from the PRISM dataset for 1981–2020. Extreme events are defined at each grid point as the top 2% of 31-day precipitation totals. AR activity during the events is then quantified as the 31-day count of ARs that were objectively identified in column-integrated water vapor transport (IVT) fields from the ECMWF ERA5 reanalysis. At a given grid point, a significant statistical association between subseasonal extreme precipitation events and temporal clustering of ARs is considered to exist if the mean 31-day AR count for the events is significantly greater than the expected count for a random 31-day period, as determined from a Monte Carlo resampling approach. Significant associations between extreme precipitation events and clustering of ARs are found across parts of the U.S. West Coast, the south-central U.S., and the northeastern U.S.

Composite analysis for a sample of 31-day extreme precipitation events over the south-central U.S. reveals that temporal clustering of ARs tends to occur in connection with recurrent synoptic-scale Rossby wave patterns over North America. In these patterns, baroclinic waves repeatedly propagate across the central U.S. and induce poleward water vapor transports from the Gulf of Mexico, supporting successive episodes of heavy precipitation.

Atmospheric rivers clustering and impacts in the Iberian Peninsula

Alexandre M. Ramos, Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Karlsruhe, Germany and Instituto Dom Luiz (IDL), Faculdade de Ciências, Universidade de Lisboa, Portugal; amramos@fc.ul.pt

Ricardo M. Trigo, Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa, Portugal

Margarida L.R. Liberato, Escola de Ciências e Tecnologia, Universidade de Trás-os-Montes e Alto Douro, UTAD, 5001-801 Vila Real, Portugal

The major areas affected by Atmospheric Rivers (ARs) generally correspond to the western regions of the continents. The most intense ARs can be hazardous and have important socioeconomic impacts, but on the other hand less extreme ARs can provide beneficial water supply to watersheds. Given the importance of the ARs in terms of their associated impacts, they play a critical role in the water cycle.

A compound weather event refers to a combination of drivers and/or hazards that contribute to societal or environmental risks. Recently, four compound event types were introduced, namely (a) preconditioned, (b) multivariate, (c) temporally compounding, and (d) spatially compounding events. In the case of Atmospheric Rivers clustering (or families), they are included as temporally compounding events.

In recent years, a strong relationship has been found between ARs and extreme precipitation and floods across western Europe, and particularly in the case of the Iberian Peninsula.

In this work, we will revisit the December 2019 floods in western Iberian Peninsula in the framework of compound events. Three ARs, associated with three consecutive storms, affected the region on successive days from 15 to 23 of December, producing extreme precipitation events leading to anomalous accumulated precipitation, and runoff leading to multiple socio-economic impacts along mainland Portugal.

Processes Linking Atmospheric Rivers and Heat Stress in the United States

Lead Author/Presenter: Colin Raymond (University of California, Los Angeles*)

The occurrence of multiple climate hazards in close proximity can result in severe impacts when infrastructure networks (e.g. health, communication, transportation) are strained or damaged. Such an occurrence is of particular concern when extreme events are physically linked and therefore correlated in time and/or space. Here we consider how summertime atmospheric rivers (ARs) affect the relative probability of 95th-percentile heat stress across the United States. We find that the confluence of heat stress and ARs is most likely in the northern US, and in the interior Southwest affected by the North American Monsoon. The relationship is physically characterized by the ARs' integrated vapor transport, which is centered on the equatorward side of the precipitation zone. As a result, heat stress tends to occur about 100-300 km equatorward of the AR centroid, and where weather systems move predominantly southwest-to-northeast, ARs thus lag heat stress by 1-2 days. We also find that the risk of AR-related heat stress is strongly correlated with AR scale; for example, in the Northeast US, the risk of heat stress is about 2.5 times higher than normal within 2 days of a category 4 or 5 AR. In contrast, the Southeast sees a distinct separation between ARs and heat stress, marking an important reduction of joint risk relative to chance, and one which we analyze in terms of differences between dominant summer weather regimes. We lastly consider future changes in the risk of rapid sequences of AR-driven heat stress and heavy precipitation across the US, and find an expected poleward shift that tracks the expanding edge of the semi-permanent subtropical high.

Co-authors:
Michelle de Luna (UCLA), Kai Kornhuber (Columbia Univ), Anamika Shreevastava (JPL), Emily Slinskey (UCLA), Duane Waliser (JPL)

*Will be commencing appointment at UCLA on August 1.

R_OTM 1

Potential aerosol transport to the Antarctic Peninsula driven by an atmospheric river event in austral summer 2022

Nicolas Huneeus , Deniz Bozkurt , Cristobal Galbán-Malagón , , Eduardo Castro-Nallar , , Ignacio Poblete-Castro , Sergio Guajardo-Leiva , , Jorge Gallardo-Cerda , Irina Gorodetskaya

Department of Geophysics, University of Chile, Santiago, Chile
Department of Meteorology, University of Valparaíso, Valparaíso, Chile
GEMA, Center for Genomics, Ecology & Environment, Universidad Mayor, Camino La Pirámide, 5750 Huechuraba, Santiago, Chile.
Centre for Environment, Florida International University, Miami, Fl, USA
Departamento de Microbiología, Facultad de Ciencias de la Salud, Universidad de Talca, Campus Talca, Avda. Lircay s/n, Talca, Chile.
Centro de Ecología Integrativa, Universidad de Talca, Campus Talca, Avda. Lircay s/n, Talca, Chile.
Biosystems Engineering Laboratory, Department of Chemical and Bioprocess Engineering, Universidad de Santiago de Chile (USACH), Santiago, Chile.
Instituto Ciencias Biológicas, Universidad de Talca, Campus Talca, Avda. Lircay s/n, Talca, Chile.
Centre for Environmental and Marine Studies, University of Aveiro, Aveiro, Portugal

Several studies show that Atmospheric Rivers (ARs) are effective mechanisms to transport mineral dust from the Saharan Desert to Northern Europe (Francis et al., 2022). However, ARs have not been examined as a potential mechanism to transport aerosol poleward in the Southern Hemisphere. In this work we explore the effectiveness of an AR event occurring between 6 and 8 February 2022 transporting moist and warm air to the Antarctic Peninsula from the southern Pacific Ocean passing via the southern South America, and potentially carrying aerosols and/or microorganisms.

Simultaneous measurements were conducted at two locations in the northern Antarctic Peninsula (Yelcho Base = 64°52’55”S, 63°35’03”W; Rispotatrón Base = 62°22’55”S 59°39’50”W) during the Austral summer of 2022 (Jan-Feb). We recorded daily levels of aerosols and microorganisms during this period in both locations along with standard meteorological parameters. These observations will allow us to examine changes in the measured parameters during the AR event, while the use of the HYSPLIT model will shed light on the origins of air masses arriving at the sampling locations. In addition, synoptic conditions together with cloud and precipitation patterns during the AR event will also be explored to further delve into long-range moisture transport and potential aerosol transport and removal processes.

The main results of this work will be presented, as well as future activities conducive to further developing this subject.

Reference

Francis, D., Fonseca, R., Nelli, N., Bozkurt, D., Picard, G., & Guan, B. (2022). Atmospheric rivers drive exceptional Saharan dust transport towards Europe. Atmospheric Research, 266, 105959. https://doi.org/https://doi.org/10.1016/j.atmosres.2021.105959

The impact of a north Pacific atmospheric river (AR) on the flux of subtropical moisture across Idaho's Salmon River Mountains and precipitation over the mountains is evaluated using the Weather, Research, and Forecasting model with water vapor tracers (WRF-WVT). The AR impacted the northwestern United States between 17-19 Jan 2017 during the Seeded and Natural Orographic Wintertime Clouds: The Idaho Experiment (SNOWIE) field campaign. WRF-WVT is configured to isolate the subtropical moisture contribution to the AR, the moisture flux, and precipitation. Water vapor originating from latitudes south of 35 N and advected by the AR into the Payette River Basin of Idaho is tagged and tracked in 3-dimensional space throughout the model run. This allows the contribution of the subtropical moisture to the vertical distribution of water vapor and the precipitation to be directly calculated. In addition, simulated cloud structure is compared with airborne radar data collected during two SNOWIE intensive operation periods (IOP).

This study found that more than 70% of the moisture flux across the Salmon River mountains and more than 80% of the precipitation over Idaho during SNOWIE IOP 4 could be attributed to subtropical moisture within the AR. Nearly all of the moisture flux in the upper cloud and 50% of the moisture in the lower cloud during IOP 5 was attributable to the subtropical moisture. The subtropical moisture contribution within the AR to IOP 5 precipitation ranged from 35% in northern Idaho to more than 90% in southern Idaho. Across the entire period of impact of the AR, more than 60% of precipitation in Idaho was attributable to the subtropical moisture within the AR, with this percentage increasing towards the south across the state.

The Impact of Subtropical Moisture within an Atmospheric River on Moisture Flux, Cloud Structure, and Precipitation over the Salmon River Mountains of Idaho using Moisture Tracers

Relationship Between Atmospheric Rivers and the Dry Season Extreme Precipitation in Central-Western Mexico.

Héctor A. Inda-Díaz[1,*], Travis O'Brien[2,1]

[1] Earth and Environmental Sciences Area, Lawrence Berkeley National Laboratory
[2] Department of Earth and Atmospheric Sciences, Indiana University Bloomington
[*]Corresponding author: haindadiaz@lbl.gov

Atmospheric rivers (AR) are long, narrow jets of moisture transport responsible for over 90% of moisture transport from the tropics to higher latitudes, covering only between 2% and 10% of the earth's surface. ARs have a significant impact on the hydrological cycle of midlatitudes and polar regions. This has developed great interest and community effort to study ARs and their impacts on these regions. It is not until recently that ARs in tropical latitudes are starting to generate interest within the scientific AR community. We use data from the ERA-20C reanalysis and the Bayesian AR detector `TECA-BARD` to show the relationship between extreme precipitation and atmospheric rivers in central-western Mexico (CWM) during the dry-seasons (November-March) in the 1900-2010 period. We find that more than 25% extreme precipitation amount and frequency are associated with ARs, with a maximum of 60%-80% during December and January near the coast of Sinaloa (∼107.5W,∼25N). During these events, composites of the mean meteorological state show "ideal" conditions for orographic precipitation due to landfalling ARs: high plume of horizontal vapor transport perpendicular to the mountain range. We observe high horizontal vapor transport perpendicular to the Sierra Madre mountain range, and a tropospheric wave pattern in vertical velocity, surface pressure, and geopotential height associated with these events. The nature and evolution of these waves need to be further studied in depth. Our results suggest that TECA-BARD provides a reasonable estimation for AR presence in CWM. Nevertheless, we recommend using more than one ARDT or one tuned explicitly for tropical latitudes. This will allow investigating the response of CWM landfalling ARs to climate change, which could be critical for studying the region's hydroclimatology under future climate scenarios.

Exploring the utility of stochastic parameter perturbations in high-resolution ensemble forecasts of orographic precipitation from landfalling atmospheric rivers

Accurate numerical forecasts of orographic precipitation from atmospheric rivers are difficult due to a variety of challenges including uncertainties in model physics parameterizations. One way to represent this uncertainty is to design convection-permitting ensemble forecasts using stochastic parameter perturbation (SPP) to vary individual uncertain parameters. This research works to evaluate and improve the utility of SPP for representing uncertainty in ensemble forecasts of orographic precipitation, with a focus on microphysical (MP) and turbulent mixing processes. We do so by running ensembles varying parameters within a single physics scheme (e.g., SPP applied only to MP), ensembles with SPP applied to several schemes concurrently, and ensembles using SPP combined with perturbations to initial and boundary conditions (IC/BCs).

This presentation focuses on an atmospheric river storm observed during the Olympic Mountains Experiment (OLYMPEX) during 12–13 November 2015. Observed precipitation amounts exceeded 370 mm on the western slopes of the Olympics. We run simulations of the event at convection-permitting horizontal grid spacing using the Weather Research and Forecasting (WRF) model configured similarly to the operational High-Resolution Rapid Refresh (HRRR) model using Thompson-Eidhammer aerosol-aware MP and Mellor-Yamada-Nakanishi-Niino planetary boundary layer and surface layer (PBL/SL) schemes. Ensemble forecasts are evaluated against OLYMPEX precipitation observations. SPP perturbations generate less spread in precipitation forecasts than IC/BC perturbations, however the spread generated is complementary and represents different aspects of forecast uncertainty. For instance, SPP-MP perturbations primarily affect local precipitation processes over and near the slopes of the terrain whereas IC/BC perturbations affect precipitation by altering atmospheric river position and intensity. Ongoing work is investigating the utility of the SPP approach for landfalling ARs on the west coast of the US through analysis of testbed experiments wherein experimental HRRR-ensemble forecasts were run with and without PBL/SL/MP SPP perturbations during the winter of 2021–2022.

R_OTM_5

Quantitative Precipitation Forecast Performance Along Central-Southern Chile

Raul Valenzuela[1,2], René Garreaud[2,3] and Roberto Rondanelli[2,3]

[1]*Instituto de Ciencias de la Ingeniería, Universidad de O'Higgins*
[2]*Departamento de Geofísica, Universidad de Chile*
[3]*Centro de Ciencia del Clima y la Resiliencia, Universidad de Chile*

Do atmospheric rivers (ARs) imply better quantitative precipitation forecast (QPF) performance? In this study we consider a few heavy storm cases affecting central-southern Chile, including atmospheric rivers arriving along the coast of midlatitude Chile during wintertime. To examine ARs QPF performance, 5 classical verification metrics are computed: probability of detection (POD), false alarm ratio (FAR), frequency bias (FBIAS), critical success index (CSI) and Gilbert Skill Score (GSS). Experiments are build using 6-h and 24-h rainfall accumulations, lead times ranging between 24 to 120 hours before the event, and 6 accumulation thresholds (from ≥0.1 mm to ≥20 mm). Given its public availability, the numerical model examined is the Global Forecast System (GFS). To contrast the atmospheric river QPF performance, QPF metrics are also computed and compared for cutoff-low cases. In addition, twenty members of the Global Ensemble Forecast System (GEFS) are used to assess the uncertainty in the forecast through the spread in rainfall accumulation and the spread in the AR location and extension.

Preliminary results indicate that the QPF has a better performance for atmospheric river cases compared to cutoff-low cases. The lead-time has little or no effect on the performance, regardless the case. Also, forecast tend to show a better performance for lower accumulation threshold only in the atmospheric river cases, while the performance in cutoff-low cases tend to be threshold independent.

R_OTM_6

Strategies for Targeted Aircraft Reconnaissance Observations: A Unified Approach for Improving Forecasts for Atmospheric Rivers and Winter Storms

Vijay Tallapragada, NOAA/NWS/NCEP/EMC, Anna M. Wilson (CW3E/SIO/UCSD) and F. Martin Ralph (CW3E/SIO/UCSD)

AR Reconnaissance (Recon) campaign has evolved from a demonstration phase to an operational requirement, and is front and center in the Interagency Council for Advancing Meteorological Services (ICAMS) National Winter Season Operations Plan (NWSOP). AR Recon reflects a Research and Operations partnership between Center for Western Weather and Water Extremes (CW3E) and NOAA's National Center for Environmental Prediction (NCEP) in collaboration with NOAA Aircraft Operations Center (AOC) and US Air Force (USAF). AR Recon Program includes a dedicated team of scientists from various US Federal agencies, international operational centers, academic community, and private sector for supporting operational missions, and a Modeling and Data Assimilation Steering Committee for conducting systematic assessment and evaluation of impact of AR observations on operational forecasts.

With six years of successful AR Recon field campaigns (2016, 2018-2022), AR Recon has gathered data collected over more than 86 intense observing periods (IOPs) and 140 individual aircraft missions, with each IOP having one or more aircraft sampling the areas of interest determined by using objective sampling strategies. Data impact experiments conducted using the NCEP operational Global Forecast System (GFS) have shown significant improvements in the precipitation forecast skill for the US West Coast, especially in the regions impacted by landfalling ARs.

Based on the success of the objective targeting strategies operationally implemented for AR Recon missions in the Eastern and Central Pacific, similar sensitivity-monitoring tools and sampling approaches are being introduced and tested for the Winter Storm Recon (WSR) missions over the Western Atlantic and Gulf of Mexico. This talk will highlight future plans for expanding the AR Recon from current partial cool season to full winter season, and unification of sampling strategies for all winter storms for improved precipitation forecasts from operational models at NCEP.

Impact of Dropsonde Data on NCEP Operational GFS Forecasts: Case Studies from 2021-2022 Atmospheric River Reconnaissance

Xingren Wu[1], Keqin Wu[2], Vijay Tallapragada[3], and Marty Ralph[4]

[1]IMSG@EMC/NCEP/NOAA, College Park, MD 20740
[2]NGI@EMC/NCEP/NOAA, College Park, MD 20740
[3]EMC/NCEP/NOAA, College Park, MD 20740
[4]CW3E, Scripps Institution of Oceanography, UC San Diego, CA 92093

Atmospheric rivers (ARs) are long narrow corridors of water vapor transport that serve as the primary mechanism to advect moisture into mid-latitude continental regions, including the U.S. West Coast. They are responsible for most of the horizontal water vapor flux outside of the tropics and a source of precipitation. The AR Reconnaissance (ARR) Campaigns that took place during winter 2016, and 2018-2022 provided additional data by supplementing conventional data assimilation with dropsonde observations of the full atmospheric profile of water vapor, temperature, and winds within and around ARs.

In this study we used NCEP GFS version 16 (GFSv16, which was implemented for operations in March 2021), to examine the impact of the AR supplemental dropsonde data on GFS forecasts. GFSv16 is a major upgrade at NCEP with the finite volume cubed-sphere dynamical core, improved physical parameterization, and doubling the vertical resolution to 127 levels with the model top of 80 km height. The Global Data Assimilation System uses a Local Ensemble Transform Kalman Filter (LETKF) with model space localization and linearized observation operator using 4-Dimensional Incremental Analysis Update (4D-IAU) technique.

The cases selected were from ARR 2021-2022 over California during January 27-29, 2021, and over Washington during January 12-13, 2022 for AR landfall events. When the dropsonde data were used in the GFSv16 run, there is an improvement in the forecasted precipitation and the AR landfall compared to the cases when the dropsonde data were denied in GFSv16. Both cases will be evaluated and compared to examine the impacts and benefit of adding the dropsondes data to GFSv16, with the details presented at the conference.

R_OTM_8

Optimal Sampling Strategies for Atmospheric River Reconnaissance

*[1]Minghua Zheng, [2]Ryan Torn, [1]Luca Delle Monache
[3]James Doyle, [1]F. Martin Ralph, [4]Vijay Tallapragada
[1]Daniel Steinhoff, [5]Xingren Wu, [1]Alison Cobb

**Presenter*

[1]*Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, University of California San Diego, La Jolla, California*

[2]*University at Albany, State University of New York, Albany, New York*

[3]*Marine Meteorology Division, U.S. Naval Research Laboratory, Monterey, California*

[4]*National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP)/ Environmental Modeling Center (EMC), College Park, Maryland*

[5]*I. M. Systems Group Inc. at NOAA NCEP / EMC, College Park, Maryland*

Abstract

To improve the skill of numerical weather prediction models in forecasting landfalling Atmospheric Rivers (ARs) on the US West Coast, AR Reconnaissance (AR Recon) observational campaign has been conducted since 2016, as a multi-agency effort led by the Center for Western Weather and Water Extremes (CW3E) at the University of California San Diego. AR Recon observations are demonstrated to be critical in filling observation gaps in the Northeast Pacific and improving the forecast skill of ARs and the downstream precipitation. Starting in 2020, AR Recon has been officially designated as an “operational” requirement, as directed by the National Winter Season Operations Plan (NWSOP). With limited flight resources (i.e., available aircraft and dropsondes), there is a need to explore how to maximize the benefit of their use. In this study, we will present results from a series of data denial experiments to examine the impact of different scenarios of flight plans on the forecast skill of heavy precipitation events that were sampled in a 6-day sequence of Intensive Observation Periods (IOPs) during AR Recon 2021.

The modeling system used is the CW3E’s in-house Weather Research and Forecast model (West-WRF) and the hybrid 4-Dimensional Ensemble-Variational data assimilation system. Experiments include two baseline experiments (Ctrl and Deny_All) to assess the impact from all high-vertical-resolution dropsondes, a set of temporal-sampling experiments (TS1–TS3) to compare impacts from assimilating

data from different IOPs, two horizontal sampling experiments (SS1 and SS2) to assess impacts of dropsondes at different horizontal spacing, two aircraft experiments (SS3-C130 and SS4-G4) to assess impacts of different aircraft, and an experiment called “OCtrl” as a comparison with Ctrl to quantify the impact of different vertical resolutions. Validation results for forecast skills of ARs and the precipitation in California will be summarized. Implications on the guidance for planning future flight tracks are discussed.

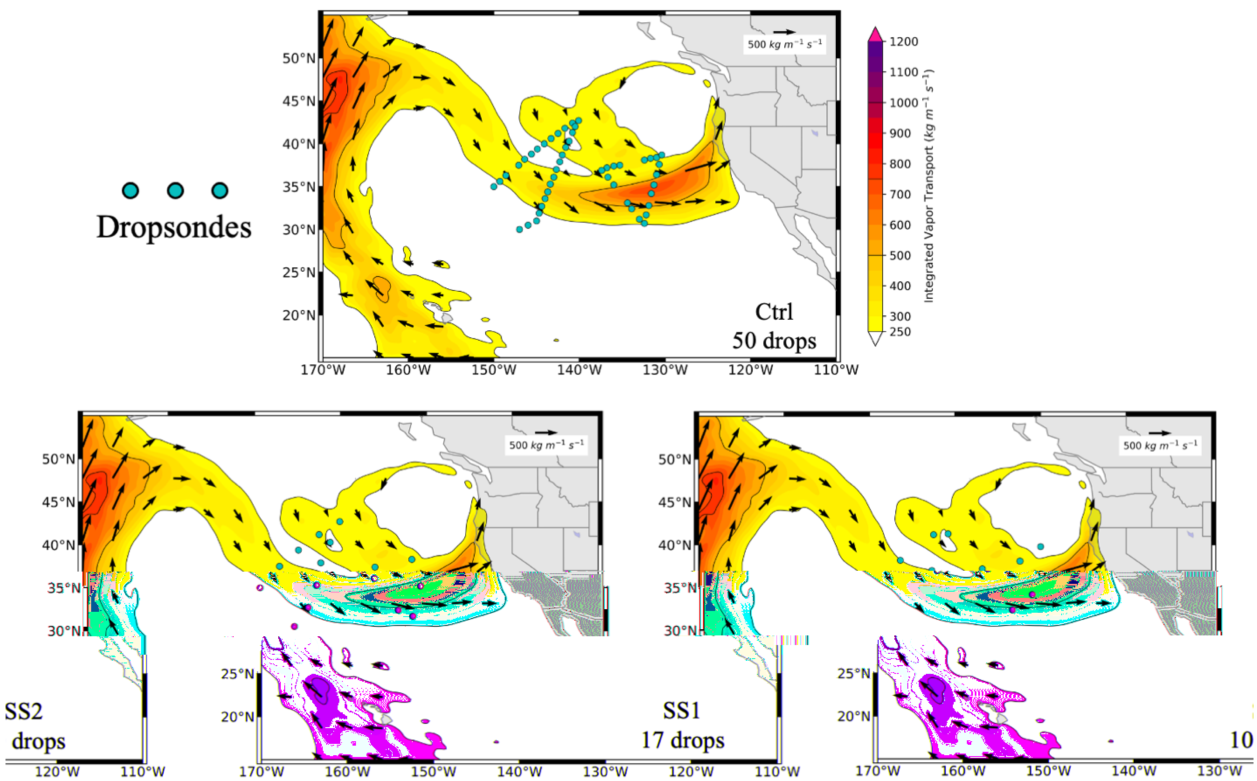


Figure Caption: The ERA-5 integrated vapor transport (shades and vectors, [kg m^{-1} s^{-1}]) and locations of dropsondes (Aqua markers) assimilated in three experiments for analysis valid at 0000 UTC 27 Jan 2021. Top: in the Ctrl experiment; Bottom left: in the SS1 experiment, Bottom right: in the SS2 experiment. The dropsondes are collected from two C-130 aircraft during AR Recon 2021 IOP7.

IARC 2022

Research and Development at the Center for Western Weather and Water Extremes

Luca Delle Monache, Douglas Alden, Duncan Axisa, William Brandt, Quian Cao, Chris Castellano, Alison Cobb, Ava Cooper, Jason Cordeira, Tom Corringham, Laurel Dehaan, Mike DeFlorio, Chris Delaney, Mohammadvaghef Ghazvinian, Colin Grudzien, Kristen Guirguis, Chad Hecht, Weiming Hu, Julie Kalansky, Brian Kawzenuk, Nora Mascioli, Patrick Mulrooney, Nina Oakley, Luke Odell, Caroline Papadopoulos, Kerstin Paulsson, Shawn Roj, Cody Poulsen, Agniv Sengupta, Mike Sierks, Matthew Simpson, Daniel Steinhoff, Edwin Sumargo, Jiabao Wang, Rachel Weihs, Anna Wilson, Mu Xiao, Zhenhai Zhang, Minghua Zheng, Xun Zou, Marty Ralph

The mission of the Center for Western Weather and Water Extremes (CW3E) is *to provide 21st Century water cycle science, technology, and outreach to support effective policies and practices that address the impacts of extreme weather and water events on the environment, people, and the economy of Western North America*. To fulfill CW3E's mission, a strong interdisciplinary team including atmospheric scientists, hydrologists, engineers, data scientists and high-performance computing specialists is engaged in research and development (R&D) on a variety of topics.

Our team leverages extensive data sets collected in the field, both over land and ocean, and unprecedented computational resources to improve our understanding of the genesis, evolution, and landfall of atmospheric rivers and the associated extreme events. We develop predictive capabilities at a range of scales from weather to subseasonal, seasonal and climate, by developing data assimilation procedures, physics-based dynamical models, and machine learning algorithms to better inform the decision-making process related to water management.

In this talk several examples of the above R&D activities will be described along with some of the challenges our community will face in the future to advance our knowledge and predictive tools.

Global Application of the Atmospheric River Scale

Bin Guan[1,2,*], Duane E. Waliser[2,1], and F. Martin Ralph[3]

[1]*Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, California, USA*

[2]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA*

[3]*Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, University of California, San Diego, California, USA*

Abstract

Atmospheric rivers (ARs) are narrow, elongated, transient corridors of enhanced water vapor transport that play important roles in the global water cycle. Increasing scientific and societal interests in ARs prompted the introduction of an AR scale (ranks 1–5, from weak to strong) initially focused on western North America. Aided by a global AR detection algorithm, the current study explores the insights the AR scale can help provide from a global perspective. It is found that AR event count is inversely related to AR rank and peaks in midlatitude oceans. Out of all precipitation occurrences, ARs account for an increasing fraction as the precipitation intensity considered increases. Over the oceans, this fraction is composed of comparable contributions from the five AR ranks, but the contribution of AR 5 is much smaller over land. Higher-ranked ARs tend to initiate at lower latitudes, terminate at higher latitudes, but follow a less sloped track due to longer zonal displacement. Sensitivity analysis indicates that if ARs are defined using a sole IVT threshold of 250 kg m^{-1} s^{-1} globally but with the tropics excluded, the spatiotemporal patterns of key AR event characteristics are largely similar to those described above, except AR events are more frequent by a factor of ~1.5–2 depending on the AR rank. The

results demonstrate the potential of the AR scale in helping evaluate and communicate ARs' influences globally, where the uniform scaling facilitates intercomparisons across different regions and the perception of impacts can be adjusted according to local climatology.

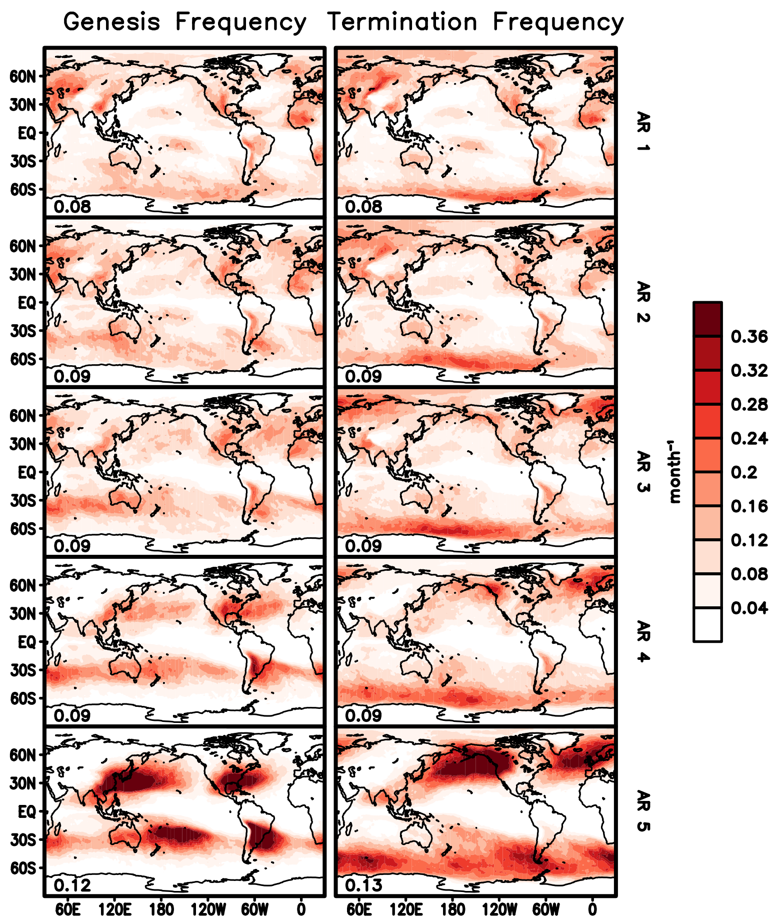


Figure caption: (left) Genesis frequency (month^{-1}) for each of the AR ranks. At each grid cell, the number indicates the number of times the grid cell is located within the shape boundary of an AR at the time of its genesis, divided by the total number of months. The rank refers to the highest rank an AR receives during its life cycle. The number in the bottom-left of each panel indicates the spatial mean of the shaded values. (right) As in the left but for AR termination frequency.

ABSTRACT FOR THE 4TH INTERNATIONAL ATMOSPHERIC RIVERS CONFERENCE
ASSESSING ATMOSPHERIC RIVER DETECTORS TO DETERMINE THE UNDERLYING PHENOMENA

The impact of atmospheric rivers (ARs) on a changing climate cannot be overemphasised as they are responsible for a substantial amount of extreme events in the midlatitudes. Over the northwest and western coasts of North America, these filaments of water vapour transport move inland and cause substantial amounts of precipitation over the region. Although this atmospheric phenomenon has been studied for over 50 years, researchers are still working progressively to attain a full understanding of the entire phenomenon. Various researchers have developed AR detection tools (ARDTs), which identify ARs by implementing heuristic, quantitative algorithms for defining ARs. Although results from these ARDTs are broadly similar with respect to strong ARs, there are notable differences associated with moderate and weak ARs. We hypothesise that there are distinct synoptic weather patterns that lead these ARDTs to detect different frequencies and intensities of ARs. In this study, we examine landfalling ARs in the western U.S. during (a) 'consensus times' in which AR are detected by all ARDTs (b) 'non-consensus times' where all ARDTs are in disagreement on ARs detected. We further compare the composite atmospheric fields (eg: IVT, upper level potential vorticity, mean sea level pressure, etc.) for these consensus and non-consensus times for the various algorithms. If this hypothesis is correct, then we expect that the various non-consensus composites will have significantly different patterns. We present preliminary results from this analysis.

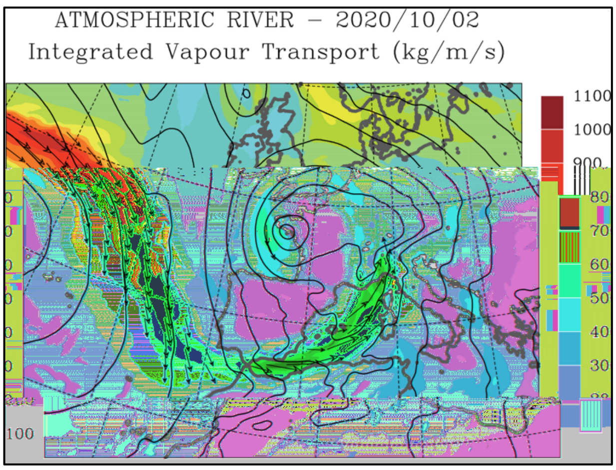
R_OTM_12

The role of Atmospheric Rivers in the Mediterranean in heavy precipitation events over the Alps

Silvio Davolio[1], Mario Marcello Miglietta[2], Marco Vercellino[3], Lucia Drago Pitura[4], Lorenzo Giovannini[5], Francesco Sioni[6], Federico Grazzini[7], Sante Laviola[1], Vincenzo Levizzani[1]

[1] Institute of Atmospheric Sciences and Climate, National Research Council of Italy, (ISAC-CNR), Bologna, Italy
[2] Institute of Atmospheric Sciences and Climate, National Research Council of Italy, (ISAC-CNR), Padua, Italy
[3] formerly Dep. of Physics, University of Bologna, Bologna, Italy
[4] 3BMeteo S.r.l., Italy, formerly Dep. of Physics, University of Bologna
[5] Dep. of Civil, Environmental and Mechanical Engineering, University of Trento, Trento, Italy
[6] OSMER-ARPA FVG, Palmanova (UD), Italy; formerly Dept. of Civil, Environmental and Mechanical Engineering, University of Trento, Trento, Italy
[7] ARPAE, Bologna, Italy & LMU, Munich, Germany

On 2-3 October 2020, a heavy precipitation event severely affected northern Italy and in particular the western Alps, with rainfall amount exceeding 600 mm over 24 hours. This event was associated with a large-scale environment characteristic of heavy precipitation phenomena on the southern side of the Alps, i.e. an upper-level trough over the western Mediterranean basin. At the mesoscale, this configuration often induces a northward transport of large amount of moisture, organized in the form of a pre-frontal low-level jet that impinges on the orography and determines the distribution and the intensity of the rainfall.
The present study shows that a relevant amount of moisture moved towards the Mediterranean basin within a long and narrow filament-shaped structure crossing the whole Atlantic Ocean. The presence of an atmospheric river (AR) represented a distinguishing aspect of the event, superimposed on the well-known dynamics-thermodynamics of heavy precipitation over the Alps. High-resolution numerical simulations are undertaken to investigate how the transport of water vapour associated with the AR has influenced the severity and dynamics of the heavy precipitation processes. The results add further details to the theoretical framework of heavy precipitation mechanisms in the area and improve our understanding of the complex interaction between large-scale flows and mesoscale dynamics during extreme precipitation episodes.
The presence of ARs across the Mediterranean has been recently associated with heavy precipitation over southern Europe and Italy in particular. Together with previous findings, this study shows that, in addition to the local contribution from the Mediterranean Sea, a relevant amount of moisture may move from the tropics towards the Mediterranean, feeding precipitation systems. The assessment of AR characteristics and frequency, as well as their role on rainfall and on Mediterranean cyclone development, represents the framework of this ongoing research activity.



L_OTM_1

Moisture Transfer from Amazonia by Aerial Rivers and its influence on the Paraiba do Sul River Basin: an analysis of the water cycle from 2016 until 2021 summers

Murilo Ruv Lemes[1]; Peterson Augusto Barbosa[2], Rodrigo Cesar da Silva[3], Gilvan Sampaio de Oliveira[1], Gilberto Fisch[2]

1 - National Institute for Space Research (INPE)
2 - Taubaté University (UNITAU)
3 - Paula Souza State Technological Education Center

The global warming effects have been intensified in the world, including the South America continent. In addition, the Amazon deforestation process has been increased in recent years, which provokes a climate disequilibrium in local, regional, and global scales. It is already known that the moisture transport from Amazonia by the atmospheric rivers can influence the water budget cycle in southern Brazil, specifically within Paraiba do Sul River region, a local basin that supplies water to either São Paulo (indirectly) and Rio de Janeiro (directly) cities. So, the objective of this work is to evaluate this moisture transport during the austral summer (December-January-February-DJF) between the years 2016 and 2021 and precipitation because of this transport. Both study regions were demarcated by the following domain/coordinates: the Amazon forest (10° S up to 3° N and 75° W up to 50° W) and the southeastern region (20° S up to 27° S and 53° W up to 45° W). The moisture transport was calculated through the vertically integrated moisture transport (from surface up to 500 hPa), which used such variables: specific moisture, wind components, surface pressure (all of them extracted from ERA5 reanalysis). The climatology was computed from 1979 up to 2015. The precipitation dataset was obtained from the CHIRPS dataset considering the Paraiba do Sul River Basin. As a result, the moisture transport had a slight decrease around 4.7% (-0.88 kg m^{-1} s^{-1}), leading by the years 2019 and 2020 (-0.80 kg m^{-1} s^{-1} and -0.35 kg m^{-1} s^{-1} respectively). As a consequence, the precipitation reduced about -4.1 mm, which was associated with a moisture transport reduction in the austral summer. The water level of reservoirs had also a severe reduction.

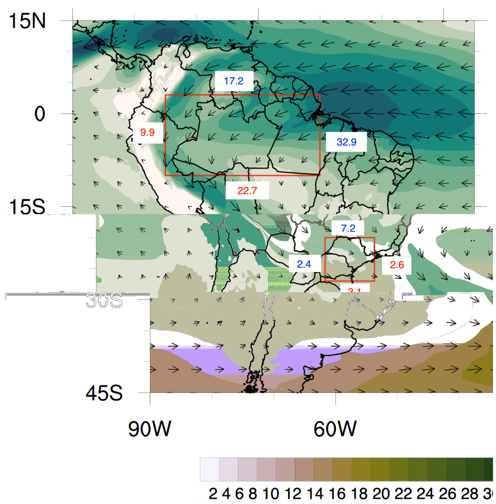


Figure 1- Climatological vertically integrated moisture flow (kg m^{-1} s^{-1}) for 1979-2015 period.

L_OTM_2

Abstract for International Atmospheric Rivers Conference Santiago, Chile, 10-14 Oct 2022

Title: Analysis of atmospheric rivers during the DACAPO-PESO experiment (Dec 2018-Nov 2021) in Punta Arenas, Chile

Julia Wieltsch[1], Willi Schimmel[1], Andreas Foth[1], Heike Kalesse-Los[1], Patric Seifert[2], Boris Barja[3]

[1] Leipzig Institute for Meteorology (LIM), University of Leipzig, Leipzig, Germany
[2] Leibniz Institute for Tropospheric Research (TROPOS), Leipzig, Germany
[3] Laboratorio de Investigaciones Atmosféricas, Universidad de Magallanes (UMAG), Punta Arenas, Chile

In the Southern Ocean region where long-term, high-temporal resolution atmospheric observations are rare, the impact of atmospheric rivers (AR) include intense precipitation and anomalously high temperatures and that might even lead to major melt events in Antarctica, e.g. the Antarctic Peninsula.

A high-quality continuous aerosol-cloud-precipitation dataset was obtained at the Southern tip of South America in Punta Arenas, Chile during the three-year period Dec 2018- Nov 2021 within the project DACAPO-PESO (Dynamics, Aerosol, Cloud and Precipitation Observations in the Pristine Environment of the Southern Ocean). The project was realized by the Leibniz Institute of Tropospheric Research (TROPOS), Leipzig, Germany and partners from University of Leipzig and University of Magallanes, Punta Arenas, Chile (http://dacapo.tropos.de).

Based on microwave radiometer (MWR) retrievals of integrated water vapor (IWV) and liquid water path (LWP) as well as radio soundings performed during the DACAPO-PESO field experiment, atmospheric rivers and their frequency of occurrence were identified and characterized. Micro rain radar (MRR) observations or surface weather station data were used to quantify how much precipitation was observed at the ground during the AR events.

L_OTM_3

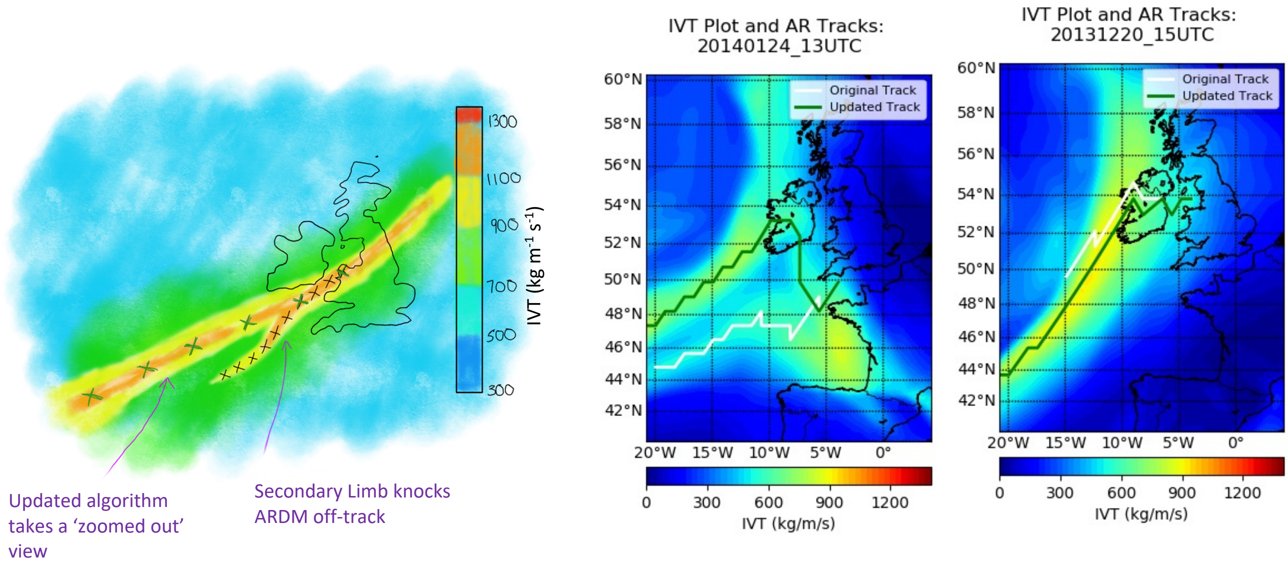
Title: The Complexity of Detecting ARs across the UK.

Theme: Observing, tracking, modelling and forecasting ARs

Dr. Helen Griffith (University of Reading, UK), Prof. Andrew Wade (UoR, UK), Dr. David Lavers (ECMWF, UK), Dr. Glenn Watts (Environment Agency, UK)

Note: This work formed part of my recently completed PhD and is in the process of being submitted for publication (I am working full-time as a PDRA on a different project!)

Previous work (Griffith et al. 2020) has highlighted several limitations in the ability of the atmospheric river detection method (ARDM) presented by Lavers et al. (2012) to successfully detect persistent atmospheric rivers in high-resolution datasets such as ERA5. This could be due to the increased ability of such reanalysis products to detect physical phenomena such as Mesoscale Frontal Waves (Ralph et al. 2011) and so-called secondary IVT limbs (defined in the attached figure). In response, several adjustments to the Lavers et al. (2012) AR detection algorithm are proposed and implemented. The modified algorithm is applied to the Dyfi and Teifi catchments; investigating its ability to (successfully!) detect further flood generating ARs as compared to its original counterpart. As such, several recommendations for future ARDMs are made, when intending to be applied to high-resolution input data.



Secondary Limb Modifications. Secondary limbs, defined as plumes of IVT existing separate to the main AR axis may act to push a detection algorithm 'off-course' and away from the main IVT track. ARs are large scale features and, despite the extra information gained from the higher resolution reanalysis, it is likely that such information is not essential for their detection alone. As such the Lavers et al. (2012) algorithm is modified to detect every 'third' grid cell (as opposed to adjacent cells), as outlined in the figure above. The high-resolution dataset is retained however for later analysis of the AR.

L_OTM_4

Analysis and Forecasts Leading to a High-Impact Landfalling AR in California in January 2021

B. Kawzenuk, S. Bartlett, C. Castellano, J. Cordeira, C. Hecht, M. Ralph, S. Roj
Center for Western Weather and Water Extremes, UCSD/Scripps

A landfalling AR during 26–28 January 2021 along the U.S. West Coast ranked as an AR2 on the Ralph et al. (2019) scale and produced heavy rain and snow throughout much of California. The stalling of the AR along the coast focused upslope moisture flux in Central California where the Upper Yuba watershed received 4.6 inches of mean areal precipitation in a 72-hour period and more than 4 feet of snow accumulated in the higher elevations of the Northern Sierra Nevada. The landfalling AR also contained both high-impact mesoscale features such as a narrow, cold-frontal rainband that led to destructive flooding and debris flows in Monterey County and large-scale multi-model forecast uncertainty at lead times of more than 5–7 days. The GFS and GFS ensemble forecasts were more successful than ECMWF and EPS forecasts at lead times from 7 to 21 days as visualized and quantified by CW3E's multi-scale forecast tools. Even at lead times inside 7 days, IVT magnitude forecasts derived from the GFS model nearly matched verification in magnitude and position, while the forecasts derived from the ECMWF model failed to even resolve a landfalling AR. Two key sources of uncertainty in this event include the interaction of synoptic-scale features over the western and central North Pacific more than one week prior to the formation of the AR and the subsequent stalling and pivoting of the AR over central California that prolonged the duration of the event.

L_OTM_5

Modelling aerosol effects on clouds and precipitation during atmospheric river events in Portugal using the WRF-CHIMERE coupled model

Carla Gama[1], Cátia Lavínia Gonçalves[1], Alexandra Monteiro[1], Diogo Luís[2], Irina Gorodetskaya[2]

[1] CESAM & Department of Environment and Planning, University of Aveiro, Aveiro, Portugal
[2] CESAM & Department of Physics, University of Aveiro, Aveiro, Portugal

carlagama@ua.pt, catialavinia@ua.pt, alexandra.monteiro@ua.pt, diogo.luis9@ua.pt, irina.gorodetskaya@ua.pt

In the Iberian Peninsula, the most extreme precipitation events are frequently associated with atmospheric rivers (ARs). In this study, in the scope of the ATLACE research project and aiming to better understand the processes involved in the development of those events, we analyse the aerosol-cloud-precipitation interactions during two specific AR events affecting Portugal: on January 19, 2013, associated with the explosive development of the cyclone Gong; and on December 2017, associated with the storm Ana. Both these events brought intense rain and snowfall in mainland Portugal.

Aerosol-cloud interactions, and their effect on precipitation formation, were studied using the recent WRF-CHIMERE coupled model (online coupling between the WRF meteorological model and the CHIMERE chemical transport model), which provides information on the spatial and temporal variability of emissions, transport and deposition, aerosol composition and size distribution, and simulates the two-way interaction between meteorological and chemical variables. Aerosol amounts and chemical properties were characterized in the North Atlantic/Portugal, focusing on the contribution from long-range transport of desert dust, sea salt, biogenic and anthropogenic aerosols. A set of numerical simulations was performed, considering distinct aerosol types and emissions. Modelled aerosol loadings and their impact on cloud microphysical properties and precipitation simulation will be discussed in this presentation.

This work contributes to a better understanding of the importance of aerosols serving as ice and cloud condensation nuclei, and their contribution to generating extreme precipitation in Portugal/ Iberian Peninsula.

L_OTM_6

Evaluating Atmospheric River Representation in Reanalysis Products with Satellite Observations

Atmospheric rivers (ARs) are filaments of enhanced horizontal moisture transport in the atmosphere. Due to their prominent role in the meridional moisture transport and regional weather extremes, ARs have been studied extensively in recent years. Reanalysis products have long been used as proxies of observations in AR studies. However, reanalyses are produced by numerical models which incorporate information from observations through data assimilation. These products thus have biases intrinsic to the models used to produce them. In this study, we developed an AR detection algorithm specifically for satellite observations (AIRS+AMSU) based on moisture and thermal winds derived from 3D temperature fields. This algorithm enables us to develop the first AR catalogue based solely on satellite observations. The satellite-based AR catalogue is then combined with the satellite-based precipitation (IMERG) to evaluate the representations of AR and AR-induced precipitation in reanalysis products.

Our results show that all reanalyses overestimate the AR frequency over midlatitudes. Such overestimates are especially pronounced over the Southern Ocean. Reanalyses seem to exhibit higher skills in reproducing the AR frequency over midlatitudes of Northern hemisphere, possibly due to more observations over this region available for data assimilation. Further analyses indicate that the overestimates of the AR frequency in reanalyses are mostly caused by the AR size biases: ARs in reanalyses tend to be too broad. In terms of the AR-induced precipitation, both AR-induced mean and extreme precipitation are too weak nearly everywhere in reanalyses. The strongest bias again occurs over the Southern Ocean. This weak bias in the AR-induced precipitation over the Southern Ocean may have important implication on the Antarctic climate. Overall, the biases uncovered in this study can help to improve the AR representation in reanalyses as well as climate models.

L_OTM_7

Abstract (IARC2022)

Air Quality Modulates the Monsoonal Moisture feed for North Pacific Atmospheric Rivers

by Melinda M. Brugman, Gerald Holdsworth and G.K.W. Moore

During 2020 through 2022 a distinctive atmospheric pattern developed producing a La Nina-like negative Pacific Decadal Oscillation (PDO) conditions over the North Pacific Ocean that favoured the formation of intense atmospheric rivers (ARs) that impacted the Pacific Northwest. The path could be traced back to strong monsoonal activity in south and eastern Asia and western tropical Pacific. This intense AR activity may have been enhanced by cleaner air resulting from a reduction in a number of activities during lock-downs caused by concurrent COVID19 pandemic regulations. In this paper, we examine the role of air quality over the Indian subcontinent and southeast Asia on North Pacific atmospheric river flux and influence on dominant ENSO (and PDO) patterns. During 2020-2022 the Aleutian low was relatively weak and displaced westward. This helped steer storms across the Pacific in an exceptionally long westerly storm track, which caused detrimental flooding in some areas and often culminated in a northwesterly flow path into the British Columbia interior causing record breaking snowpacks, late season flooding threats and a dizzying array of unusual weather patterns. These results may help to identify rapid anomalous climate events in the past that might have been associated with variability in the intensity of North Pacific severe AR's. Historical records and paleoclimate proxy data from ice cores retrieved from Mt Logan, Yukon are examples of where to search for such anomalous event data.

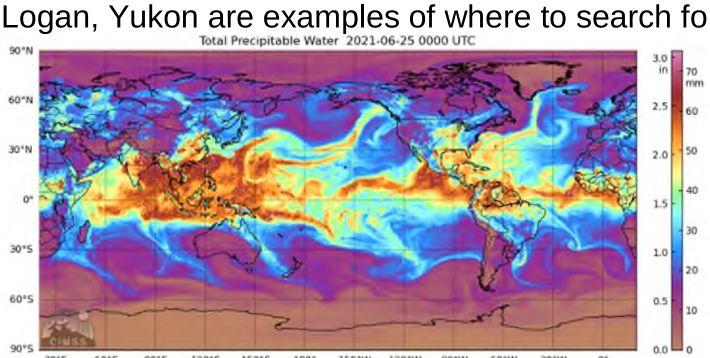
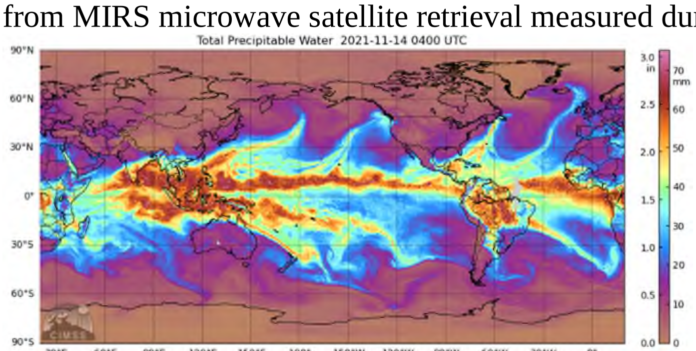


Fig 1 a) Atmospheric Rivers tapping into tropical convection and monsoonal moisture are shown by the Total Precipitable Water (TPW) from MIRS microwave satellite retrieval measured during the BC Heat Dome of June 25, 2021.



b)AR Flood Event of Nov 14-15, 2021
Ref: [MIMIC-TPW2 (wisc.edu)]

L_OTM_10

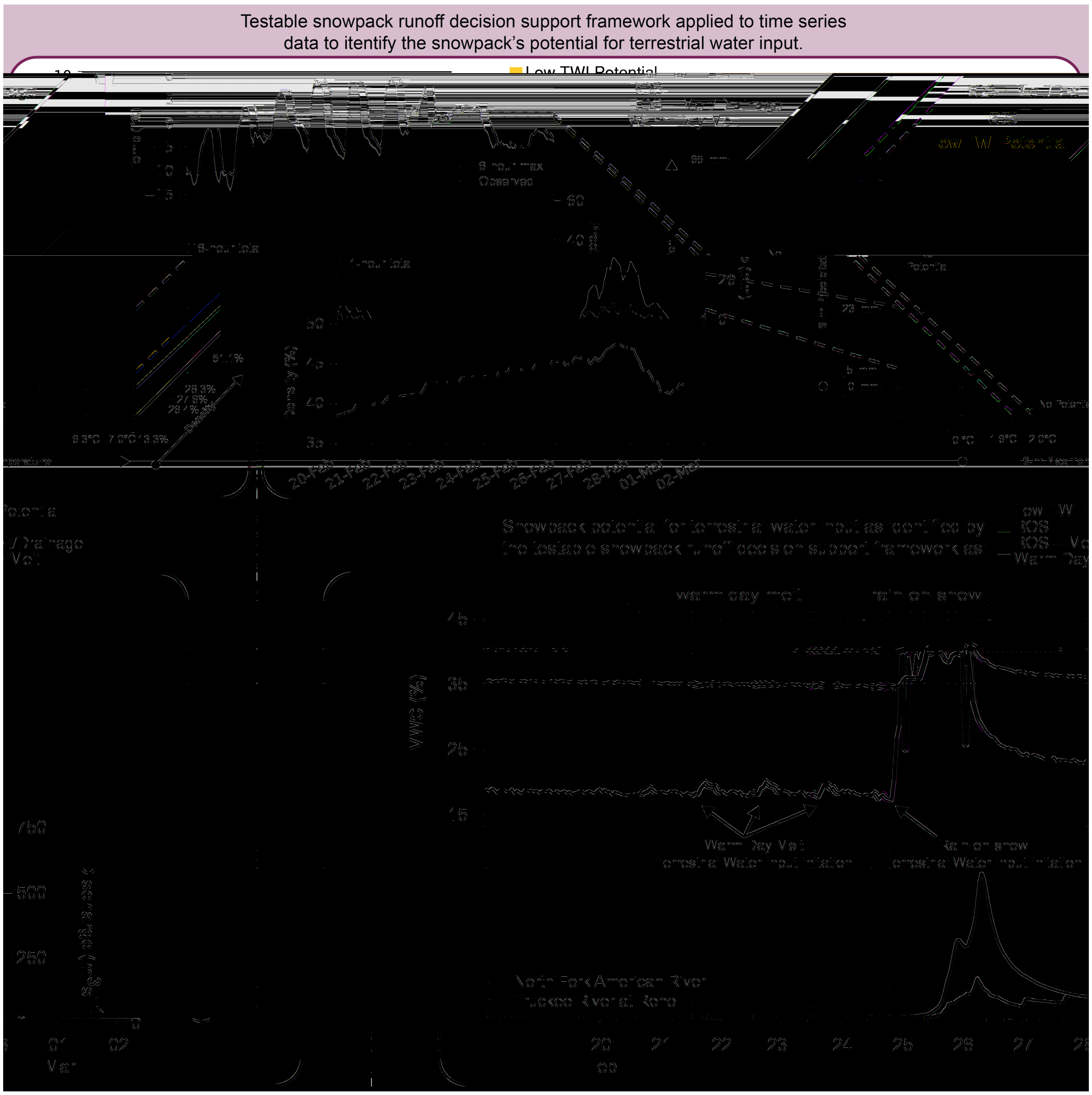
Towards Snowpack Runoff Decision Support

Anne Heggli[a,e], Benjamin Hatchett[a], Andrew Schwartz[b], Tim Bardsley[c], Emily Hand[d]

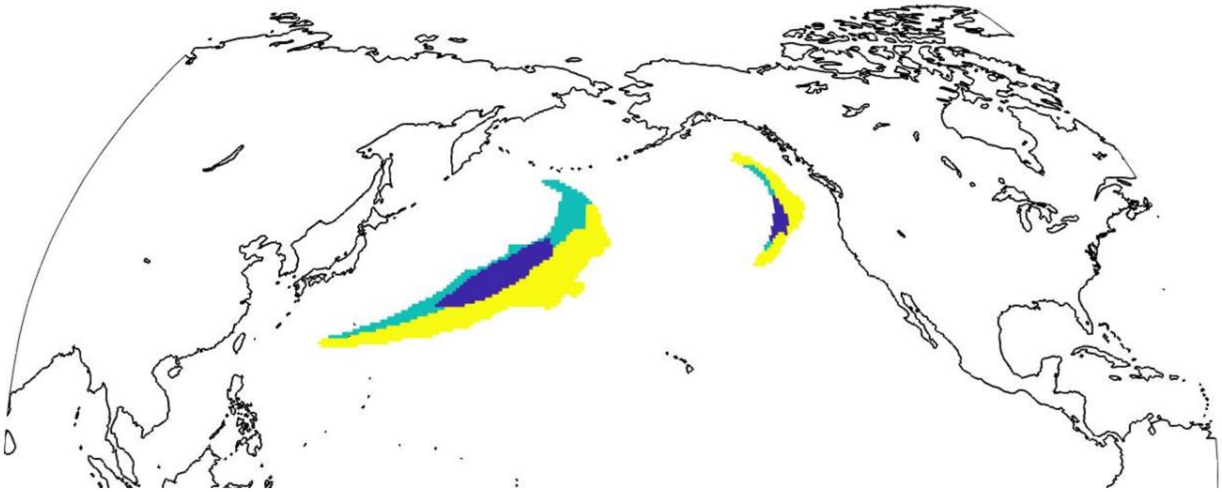
[a]*Desert Research Institute, Reno, Nevada*
[b]*Central Sierra Snow Laboratory, University of California, Berkeley, Soda Springs, California*
[c]*National Weather Service, Reno, Nevada*
[d]*University of Nevada, Reno, Reno, Nevada*
[e]*Corresponding author: anne.heggli@dri.edu*

Keywords:

Warm, land-falling atmospheric rivers that produce rainfall over snow covered areas are efficient generators of runoff that can produce 50-80% higher peak flows than spring snowmelt. As a consequence, rainfall and snowmelt together can produce greater floods than either rainfall or snowmelt alone. Forecasting runoff in snow covered areas prone to flooding is complicated due to the difficult nature of predicting and observing the rain-snow transition elevation and the variation in runoff efficiency and magnitude when snow is present. Looking at forecasts, reservoir operators must constantly weigh decisions to store water for economic and ecological benefits (resource) or to release water to mitigate downstream flooding potential (hazard). Rain-on-snow events are projected to increase in frequency and magnitude as the climate warms, multiplying uncertainties and risks in operational decision making related to extreme weather. To meet these mounting challenges, we introduce a framework for an empirically-based mesoscale Snowpack Runoff Decision Support system, which considers the likelihood of snowmelt runoff through risk quantification. Our work demonstrates how (1) present weather and (2) antecedent snowpack risk can be "learned" from hourly data to support eventual development of basin-specific snowpack runoff decision support systems aimed at providing real-time guidance for water resource management.


Testable snowpack runoff decision support framework applied to time series
data to itentify the snowpack's potential for terrestrial water input.
Low TWI Potential
VWC (%)
Warm Day Melt
Rain on snow
North Fork American River
Truckee River at Reno

L_OTM_9



Atmospheric River Sector Identification

Sol Kim[1], Alison Cobb[2], John CH Chiang[1]
[1]University of California, Berkeley, Berkeley, CA, USA
[2]Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, University of California, San Diego, La Jolla, CA, USA

Observational data from atmospheric rivers (ARs) impacting the U.S. West Coast have been gathered from the CalWater and AR Recon projects from 2014-2022. Using dropsonde data, Cobb et al., 2021 defined AR regions as core, cold sector, and warm sector along with non-AR cold and warm sides. Based on the observational definitions, we develop a post-processing algorithm applied to ARs detected with tARget v3 (Guan and Waliser, 2019) to segment the core, cold sector, and warm sector of individual ARs over the north Pacific. We compare characteristics, including various vertical profiles, from the algorithm sectors to those defined with observations.

L_OTM_10

Evolution and Future of Atmospheric River Reconnaissance: US Air Force Reserve 53 Weather Reconnaissance Squadron Perspective

Lt. Col. Ryan Rickert, US Air Force Reserve Command, 53rd Weather Reconnaissance Squadron

From 2016 to 2022, the 53 Weather Reconnaissance Squadron (WRS) has participated in aircraft reconnaissance missions focused on improving atmospheric river forecasts to support western United States water and emergency management. It has evolved from a Research to Operations perspective to a Research and Operations partnership, thus garnering the National Winter Season Operations Plan communities' support and the implementation into the National Plan for the past 3 years. The 53 WRS has participated not only in the Recon effort launching dropsondes and providing high density flight level data into the storms but also has deployed more than 100 buoys in the Pacific in support of this effort. The 53 WRS has also benchmarked a best practice integrating a Flight Meteorologist and Planning Navigator with the forecast team to come up with the best possible routes and to get the most out of the resources. This presentation will cover how the Air Force began this partnership, where we have come and potential future growth in this program.

L_OTM_11

Fourth International Atmospheric Rivers Conference 2022
Observing, Tracking, Modeling and Forecasting ARs
Santiago, Chile
10-14 October, 2022

Dropsonde observation of the atmospheric river associated with Typhoon Aere (2022) during the T-PARCII aircraft campaign

Kazuhisa Tsuboki[1], Taro Shinoda[1], Tadayasu Ohigashi[2], Soichiro Hirano[3], Masaya Kato[1], Sachie Kanada[1], Hiroyuki Yamada[3], Satoki Tsujino[4], Kensaku Shimizu[5], Norio Nagahama[5], and Shingo Shimizu[2]

[1]Institute for Space-Earth Environmental Research,Nagoya University, Nagoya, Japan
[2]National Research Institute for Earth Science and Disaster Resilience, Tsukuba, Japan
[3]Department of Physics and Earth Sciences, University of the Ryukyus, Okinawa, Japan
[4]Meteorological Research Institute, Japan Meteorological Agency, Tsukuba, Japan
[5]Meisei Electric CO., LTD., Isezaki, Japan

In East Asia, an atmospheric river (AR) occasionally forms in association with Baiu front or a typhoon. ARs transport a large amount of water vapor to the mid-latitude from the tropical water vapor reservoir. Quasi-stationary mesoscale convective systems (MCSs) associated with an AR often cause severe disasters in Japan. An accurate prediction of the MCSs is critical for the disaster prevention. However, that is highly difficult because water vapor for MCSs is transported from the ocean where no in situ observation of water vapor is present.

A dropsonde observing system was developed by the T-PARCII (Tropical cyclone-Pacific Asian Research Campaign for Improvement of Intensity estimations/forecasts) project. This system has been used for aircraft observations of tropical cyclones and was applied for AR observation in 2022. The synoptic weather on July 5 was complicated because a tropical depression changed from Typhoon Chaba was located over the southern China and Typhoon Aere was present to the west of the western Japan. Two major streams of water vapor extended from the South China Sea to the western Japan. One is located in between China and Taiwan (AR1) and the other to the east of Taiwan (AR2). They made a confluence to the southwest of Japan and the merged AR reached the western Japan (Fig. 1).

To measure the accurate water vapor amount of the ARs, the T-PARCII team performed dropsonde observations along the white arrows in Fig. 1 on July 5, 2022. A total of 53 dropsondes were launched from a height of 43,000 ft during the round-trip flight. The water vapor mixing ratio was more than 20 kg/kg below a height of 1 km to the south of the western Japan. A southwesterly transported the low-level large water vapor toward Japan. Consequently, heavy rainfall occurred along the Pacific side of the western Japan.

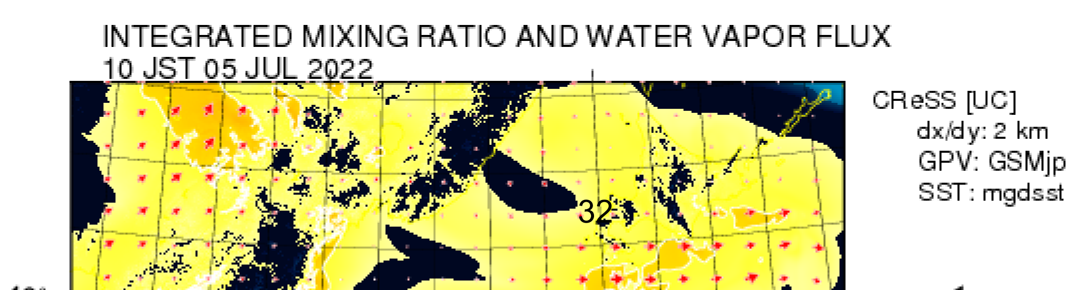


Figure 1: Horizontal distribution of integrated water vapor mixing ratio and vertically average water vapor flux obtained from the simulation experiment using the cloud-resolving model CReSS. The white allows indicate the flight pass of G-IV from Nagoya to Miyako Island.

L_OTM_12

Medium Range Forecast Sensitivity for Landfalling ARs along the US West Coast

Ryan D. Torn
University at Albany, SUNY

Atmospheric Rivers (AR) are the source of significant precipitation along the West Coast of the United States. These features originate over the open Pacific Ocean, meaning that they are not often sampled by a dense network of in situ observations. Consequently, modeling systems can have significant initial condition uncertainty associated with these features, which in turn could translate into higher precipitation forecast variability. One method to address this gap is to use sensitivity analysis to identify locations and fields where the forecast outcome is sensitive to and sample it with additional observations. During the 2021 AR Recon experiment, there was an unprecedented sequence of six consecutive days of aircraft missions in late January, leading up to the substantial landfalling AR that occurred on the Central California coast on 27-28 January. This event exhibited some predictability 6-7 days in advance, but also had large variability in outcome; therefore, this study uses ensemble-based sensitivity applied to ECMWF ensemble forecasts initialized 22 January to investigate the dynamical features 3-5 days prior to the event that yielded the largest precipitation forecasts differences for this event. The precipitation forecasts for this event exhibited sensitivity to two distinct cyclogenesis events in the Western North Pacific, the first of which occurs off the coast of Japan on 23 January, and a second near the Aleutian Islands two days later. Each of these events yields a complex modification of the upper-tropospheric waveguide, which subsequently impacts the location and shape of the trough that influences the location of the landfalling AR.

L_OTM_13

Subseasonal Forecasting of Extreme Rainfall using Atmospheric Rivers in ACCESS-S2

Kimberley Reid[1,2], Debbie Hudson[3], Andrew King[1,4], Todd Lane[1,4], Andrew Marshall[3] & Matt Wheeler[3]
1 ARC Centre of Excellence for Climate Extremes, Australia
2 Monash University, Australia
3 Bureau of Meteorology, Australia
4 The University of Melbourne, Australia

Atmospheric Rivers (ARs) are associated with extreme rainfall over many parts of the world including Australia (Reid et al., 2022). Due to their strong correlation with climate modes including ENSO, the IOD and MJO, ARs have been shown to have some predictability at multiweek timescales (Mundhenk et al., 2018, Ramos et al., 2020) over the US. Moreover, at medium-range weather forecasting time scales, it has been shown that horizontal water vapour transport can extend the lead time of extreme precipitation forecasts relative to precipitation forecasts themselves (Lavers et al., 2014 & 2016). Given this, our study is testing the hypothesis that Atmospheric Rivers could be used to increase the skill of extreme rainfall forecasts at multiweek scales. We are using horizontal winds, specific humidity and precipitation hindcasts from the Australian Community Climate and Earth System Simulator subseasonal-to-seasonal model (ACCESS-S2) and observed gridded precipitation based on in-situ measurements (AWAP/AGCD) to assess the skill of the model precipitation and model ARs at forecasting the observed precipitation at 1-to-6-week lead times over Australia. While the model precipitation dominates at one week lead time, the model ARs have comparable skill at 3+ weeks.

Lavers, D.A., D.E. Waliser, F.M. Ralph and M.D. Dettinger (2016): Predictability of horizontal water vapor transport relative to precipitation: Enhancing situational awareness for forecasting western US extreme precipitation and flooding. GRL https://cw3e.ucsd.edu/wp-content/uploads/2016/03/lavers_etal_grl_mar2016.pdf

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Mundhenk, B. D., Barnes, E. A., Maloney, E. D., & Baggett, C. F. (2018). Skillful empirical subseasonal prediction of landfalling atmospheric river activity using the Madden–Julian oscillation and quasi-biennial oscillation. *Npj Climate and Atmospheric Science*, https://doi.org/10.1038/s41612-017-0008-2

Ramos, A.M., P.M., Sousa, E., Dutra, R.M., Trigo (2020): Predictive skill for atmospheric rivers in the western Iberian Peninsula. Nat. Hazards Earth Syst. Sci https://nhess.copernicus.org/articles/20/877/2020/

Reid, K.J., A.D., King, T.P., Lane & D. Hudson (2022): Tropical, Subtropical and Extratropical Atmospheric Rivers in the Australian Region. *J. Clim.* https://journals.ametsoc.org/view/journals/clim/35/9/JCLI-D-21-0606.1.xml

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Use of targeted Global Sounding Balloons (GSBs) to augment atmospheric profiling in data-sparse environments within and near Extreme Weather Events such as Atmospheric Rivers

Todd Hutchinson[1]
and
Peter Black[1,2]

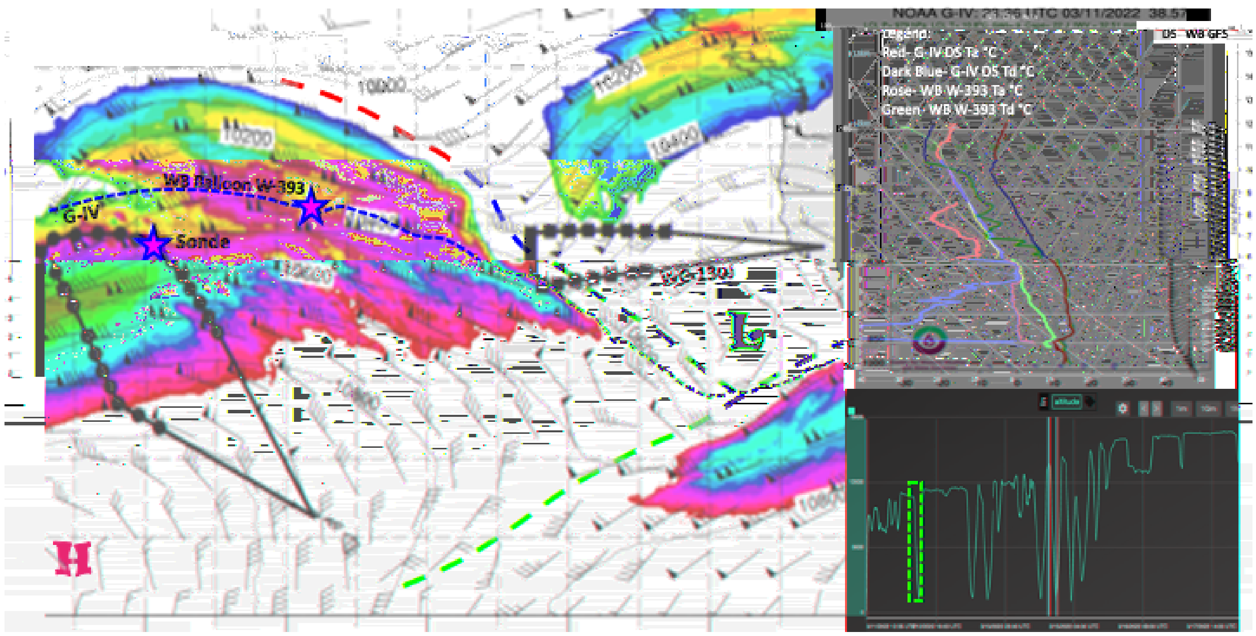
[1]WindBorne Systems, Inc.
Palo Alto, CA USA
[2]NOAA/Environmental Modeling Center (Associate)
College Park, MD USA

WindBorne has developed a novel balloon-based system that collects atmospheric observations throughout the troposphere over extended periods of time. The Global Sounding Balloons (GSBs) are autonomously navigated to ascend and descend, collecting observations of temperature, humidity, wind speed and direction, from 1-17 km. GSBs are propelled toward targeted locations of greatest forecast uncertainty assessed by controllers using global model ensemble sensitivity analysis techniques.

As of June 2022, WindBorne has conducted more than 330 flights, with primary objectives of collecting observations in over-ocean, data-sparse regions where Extreme Weather Events (EWE) are most common and where suitable upwind launch sites are available. Events such as EPAC Atmospheric Rivers Recon (ARRecon) over the central and eastern North Pacific and Thin Ice over Arctic Polar Vortices were sampled with 62 balloons over 20 days from 23 Feb – 15 Mar, 2022. The number of balloon profiles per Intensive Observing Period (IOP) ranged from 5-60.

Plans are underway to target regions during the 2022 Atlantic hurricane season from June-October across the tropical North Atlantic in the environments around developing disturbances and mature hurricanes as well as Saharan Air Layer (SAL) regimes where observations would be most beneficial for improvement in multi-day forecasts. In the future, it is conceivable that launch sites over South America could be identified that would allow GSBs to fly over and offshore from remote regions of southern Chile and Patagonia where Atmospheric Rivers develop and have strong coastal impacts.

The attached data plot shows an example of a WindBorne balloon trajectory for balloon # W-323 for 11-17 March 2022 and Skew-T descent plot for ~08Z 12 March. This illustrates how the balloon is navigated across the AR domain. The comparison, while showing significant differences in the thermodynamic profile parameters, does show good agreement with dropsonde and GFS model estimates of the wind speed and direction depicted by wind barbs. In addition, while the dropsonde shows saturated conditions typical of the so-called ‘wet bulb’ sensor wetting effect near the ‘exit region’ of the sub-tropical jet from 850 to 500 mb, the downstream WindBorne balloon along the nearby polar jet shows only a thin saturated layer, likely due to clouds, just below 500 mb, with an extremely dry layer just above the top of the near-surface boundary layer. Both instruments show the tropopause height to be near 250 mb.



P_OTM 1

Atmospheric River Categories on the West Coastline of South America

Maximiliano Viale[1] , Rene D. Garreaud[2] , and Jorge Eiras-Barcas[3]

[1]Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA) - CONICET, Mendoza, Argentina.
[2]Departamento de Geofísica, Universidad de Chile, Santiago, Chile.
[3] Universidad de Vigo - Spain

Atmospheric Rivers (AR) Category conditions have been recently established on the Western North America based on criteria stated in Ralph et al 2019. This categorization has been an efficient way to communicate, especially in the weather forecast, and easily understood by the public. The AR Categorization further provide further sense of the AR storm intensity and their possible impacts. In South America, the AR categories has been recently included in the AR forecast products on an AR forecast web site based on GFS model, however, it is not known about of the climatology and frequency of occurrences of different AR categories along the west coastline. This work presents the first results of the climatology of the AR categories occurrences along the west coastline of South America by using the ERA5 reanalysis data over the long period from 1959 to 2021. Their impacts on precipitation and its variations from one year to another are also analyzed. An example of AR category during an AR storm making landfall in South America is illustrated in Figure 1.

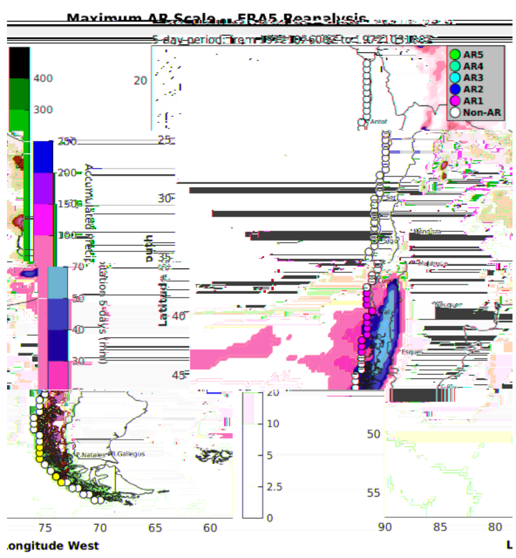


Figure 1. An example of the AR Category Conditions documented by the ERA5 during a late season AR event on the subtropical coastline of South America on October 29th, 1972. Shaded is the precipitation accumulation from the ERA5.

IARC 2022 – Observing ARs

In person - Regular (10-15min)

Atmospheric River Reconnaissance – A Research and Operations Partnership

Anna M. Wilson, F.M. Ralph, V. Tallapragada, C. Davis, L. Delle Monache, J. Doyle, F. Pappenberger, C. Reynolds, A. Subramanian, D. Lavers, L. Centurioni, J.S. Haase, B. Cao, A. Cobb, J. Cordeira, C. Hecht, B. Kawzenuk, A. Lundry, R. Rickert, J. Rutz, R. Torn, X. Wu, M. Zheng

Atmospheric River Reconnaissance (AR Recon) is an interagency, international Research and Operations Partnership (RAOP) that collects unique observations in the northeast Pacific to improve AR landfall forecasts and associated weather during the winter. Atmospheric rivers (ARs), narrow corridors of intense water vapor transport, contribute to 30-50% of the annual precipitation over the western U.S. that can be both beneficial and destructive. Forecasts of landfalling ARs and the associated precipitation are sensitive to initial condition errors in and around the ARs while offshore, where there are significant gaps in observations in the presence of thick clouds and precipitation. Increased demands driven by other collaborative, interagency RAOPs like Forecast Informed Reservoir Operations, which require improved AR landfall forecast accuracy to maximize success, highlight the need to advance numerical modeling through improved observations. Motivated by early demonstrations of value, AR Recon observations are now officially called for in the U.S. National Winter Season Operations Plan. Beginning in 2019, AR Recon partnered with the Scripps Lagrangian Drifter Laboratory-based NOAA funded Global Drifter Program to explore the potential of drifting ocean buoys with surface pressure sensors, in concert with dropsondes and data assimilation efforts, to support the project's forecast improvement objectives. In addition, prototype data streams for airborne radio occultation, an innovative technique making use of both GPS and satellites, were demonstrated in near real-time beginning in 2022, in preparation for NRT processing. This presentation will cover the accomplishments of the AR Recon RAOP, including a summary of targeting methods and data collection, plans for the coming years, and some highlights of results to date of impact assessments and science advances made possible by these important observations. Potential applications to other areas of the globe will be discussed.

An Overview of Atmospheric Rivers in Australia

Kimberley Reid[1,2], Andrew King[2,3], Todd Lane[2,3] and Debbie Hudson[4]

1 Monash University, Australia

2 ARC Centre of Excellence for Climate Extremes, Australia

3 University of Melbourne, Australia

4 Bureau of Meteorology, Australia

Studies of Atmospheric Rivers (AR) over Australia have, so far, only focused on Northwest Cloudband-type weather systems. Here we perform a comprehensive analysis of AR climatology and impacts over Australia that includes not only northwesterly systems, but easterly and extratropical ARs too. We quantify the impact of ARs on mean and extreme rainfall including assessing how the origin location of ARs can alter their precipitation outcomes. We found a strong relationship between ARs and extreme rainfall in the agriculturally significant Murray-Daring Basin region. We test the hypothesis that the tropical and subtropical originating ARs we observe in Australasia differ from canonical extratropical ARs by examining the vertical structure of ARs grouped by origin location. We found that in the moisture abundant tropics and subtropics, wind speed drives the intensity of ARs, while in the extratropics, the strength of an AR is largely determined by moisture availability. Finally, we examine the modulation of AR frequency by different climate modes. We find weak (but occasionally significant) correlations between ARs frequency and the El Niño Southern Oscillation, the Indian Ocean Dipole and Southern Annular Mode. However, there is a stronger relationship between the phases of the Madden-Julian Oscillation and tropical AR frequency, which is an avenue for potential skill in forecasting ARs on subseasonal timescales.

Extreme weather events (EWEs) over the western CONUS in recent years have been associated with large-amplitude upper-level atmospheric ridges that have resulted in strong offshore flow, elevated surface temperatures, and anomalously dry conditions. Notable western CONUS EWEs occurred in September 2020 and in late June 2021. The 2020 EWE featured widespread wildfires across California and Oregon initiated by numerous high-base thunderstorms fueled by midlevel moisture associated with atmospheric rivers (ARs) emanating from decaying eastern Pacific tropical cyclones (TCs) Elida, Fausto, and Genevieve. Recurving and transition western Pacific TCs Bavi, Maysak, and Haishen triggered downstream baroclinic development (DBD) and anticyclonic wave breaking (AWB). Poleward-directed ARs emanating from these TCs exacerbated DBD and AWB due to negative advection of potential vorticity (PV) by the irrotational wind in the upper troposphere and contributed to the formation of a high-amplitude upper-level ridge centered over eastern Alaska and western Canada that enabled very hot, dry air to reach the Pacific coast.

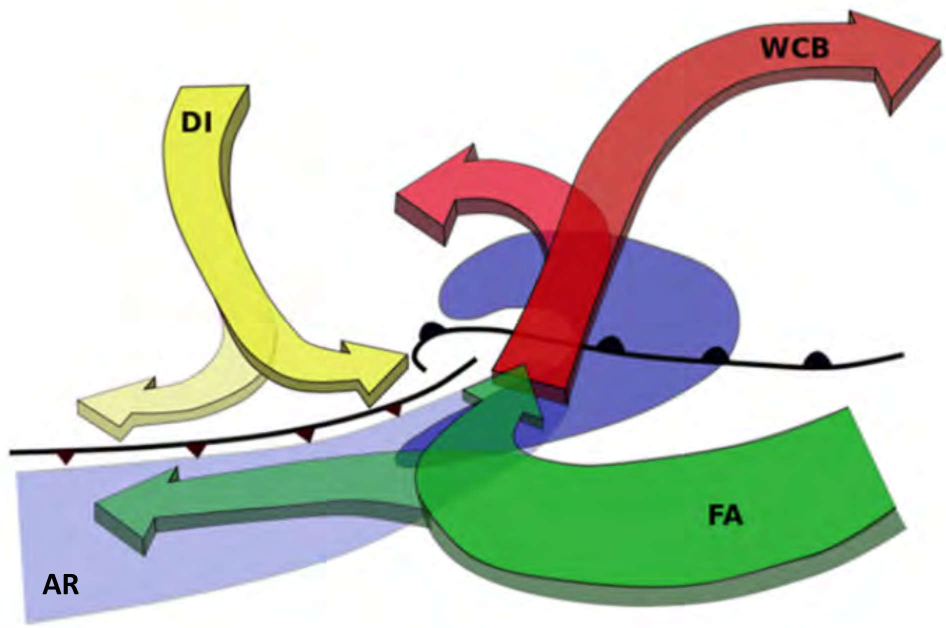
The heat wave event that impacted western North America in late June 2021 was without peer in the modern data record. All-time maximum temperature records were exceeded on consecutive days over parts of Oregon, Washington, and British Columbia. An antecedent eastward-directed surge of hot air from the Tibetan Plateau and an anomalously strong North Pacific jet stream enabled upper-level ridge building over British Columbia and soaring surface temperatures. Ridge building was further enhanced by negative PV advection by the irrotational wind from an AR emanating from WPC TC Champi as a subsynoptic-scale cutoff cyclone formed near Hawaii. This cutoff cyclone and a strong inland ridge enabled anomalously hot easterly flow to reach the Pacific coast as a deep surface-based mixed layer was established. The antecedent meteorological conditions and the subsequent large-scale flow evolution that governed the June 2021 heat wave will be discussed.

R_PD_3

Linking atmospheric rivers and warm conveyor belt airflows

Helen Dacre[1], Oscar Martinez-Alvarado[1], Cheikh Mbengue[2]
1. University of Reading, 2. University of Oxford

In this study we examine the dynamical mechanisms by which moist air is transported into cyclones resulting in precipitation at the centre of the cyclone. We analyse cyclone-relative airflows within a climatology of cyclones to understand how these airflows redistribute moisture stored in the atmosphere. This analysis shows that within a cyclone's warm sector the cyclone-relative airflow is rearwards relative to the cyclone propagation direction. This low-level airflow (termed the feeder airstream) slows down when it reaches the cold front, resulting in moisture flux convergence, which acts to extend the tip of an atmospheric river poleward. One branch of the feeder airstream turns toward the cyclone centre, supplying moisture to the base of the warm conveyor belt where it ascends and precipitation forms. The other branch turns away from the cyclone centre exporting moisture from the cyclone. As the cyclone travels, this export results in a filament of high moisture content marking the track of the cyclone. We find that both cyclone precipitation and integrated vapour transport (IVT) increase when moisture in the feeder airstream increases, thus explaining the link between atmospheric rivers and the precipitation associated with warm conveyor belt ascent.



*Schematic of cyclone-relative airflows overlaid on cyclone surface features. Cold and warm fronts (black), precipitation (dark blue shading), **atmospheric river** (AR; light blue shading). Ascending **warm conveyor belt** (WCB; red). Low-level rearward flowing feeder airstream (FA; green). Descending dry intrusion (DI; yellow).*

R_PD_4

Impact of Atmospheric Rivers in the Mixing Layer on the Southeastern Pacific Ocean

Ben Alessio (1,2), Diego Narváez (2), Deniz Bozkurt (2,3,4), Martín Jacques-Coper (2,4,5), Maximiliano Viale (6), Yosvany García (2,7)

1 *U.S. Fulbright Student Program*
2 *Centro de Investigación Oceanográfica COPAS COASTAL, Departamento de Oceanografía, Universidad de Concepción, Chile*
3 *Departamento de Meteorología, Universidad de Valparaíso*
4 *Center for Climate and Resilience Research (CR2), Chile*
5 *Departamento de Geofísica, Universidad de Concepción, Chile*
6 *Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Mendoza, Argentina*
7 *Programa Doctorado, Facultad de Ciencias Naturales y Oceanográficas, Universidad de Concepción, Chile*

Atmospheric Rivers (ARs) are narrow regions of intense water vapor transport that can lead to warm air advection, extreme precipitation events and flooding over the midlatitude coastal regions. Understanding their physical characteristics such as life cycle, landfall location, and strength is crucial to assessing their impact, improving forecasting techniques, and predicting their role in a changing climate. Previous work has characterized the climatology of ARs using meteorological records of precipitation and oceanographic-atmospheric reanalysis datasets. However, the upper ocean dynamical response of temperature and salinity to ARs and the compound effects of atmospheric and marine heat waves (HWs and MHWs, respectively) with ARs are poorly understood despite the data available from buoys and reanalysis products. Furthermore, recent developments in AR detection algorithms which track the events in time have enabled empirical characterization of dynamical properties of ARs and their associated impacts. To address this, we employ the General Ocean Turbulence Model (GOTM) to quantify the response of the upper ocean to AR conditions in the Southeastern Pacific Ocean. Using ideal scenarios that capture the major characteristics of ARs, we demonstrate the range of mixing time and length scales that can be associated with ARs. Furthermore, we simulate realistic scenarios using a multi-decade state-of-the-art AR catalog, ERA5 reanalysis data, and ARGO float profiles to validate our model against ARs in the Southern Pacific from 1948 to present day. Our results indicate that upper oceanic data used in conjunction with atmospheric reanalysis products can improve the characterization of ARs and their compound effect with HWs and MHWs, and furthermore demonstrate the possibility of utilizing ARGO floats to predict AR landfall as they form over the open ocean.

R_PD_5

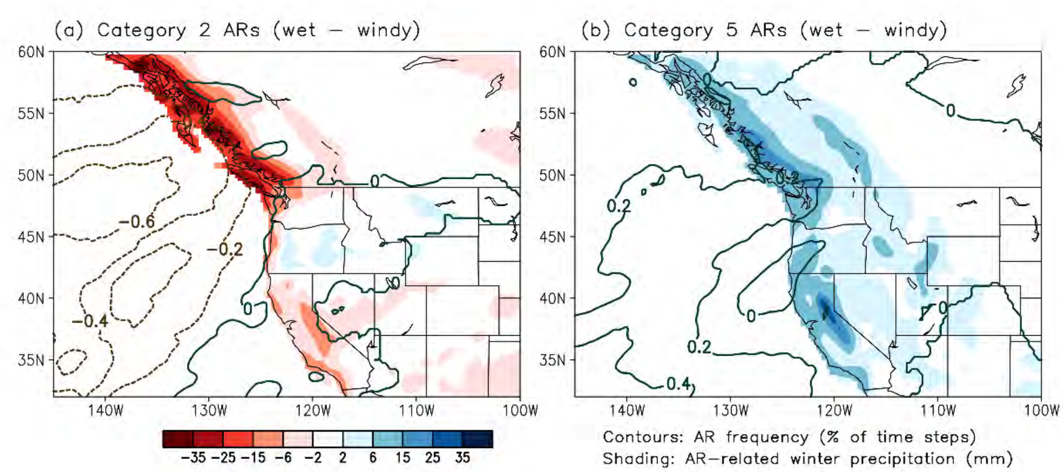
Distinct Characteristics of Atmospheric River Flavors

Yang Zhou[1*], Travis A. O'Brien[2,1], William D. Collins[1,3], Christine A. Shields[4], Burlen Loring[5], and Abdelrahman A. Elbashandy[5]

[1]Climate and Ecosystem Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California, USA
[2]Department of Earth and Atmospheric Sciences, Indiana University, Bloomington, IN, USA
[3]Department of Earth and Planetary Science, University of California, Berkeley, Berkeley, California, USA
[4]National Center for Atmospheric Research, Boulder, CO, USA
[5]Computational Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, California, USA
*Presenting Author

Abstract

Atmospheric rivers (ARs) are intensive poleward moisture transport events that are essential to the global hydrological cycle and are often linked to extreme weather events. It remains unclear how AR activity can change with various ranges of meteorological components (e.g. wind and moisture). Given similar integrated vapor transport, we categorize the winter North Pacific ARs into two "flavors": wind-dominated (windy ARs) and moisture-dominated (wet ARs) using 40 years of hourly data from ERA5 reanalysis. We compare the distinct lifecycle characteristics between windy ARs and wet ARs including intensity, frequency, landfall impacts, and variability. The windy ARs are more likely to occur in the midlatitudes, while wet ARs are more active in the subtropics. Windy ARs are associated with intensive surface pressure lows, where the strong pressure gradient can support the strong wind within ARs. Due to the rich moisture content, wet ARs are more likely to cause heavy precipitation. By scaling the landfalling ARs, we show that wet ARs dominate the high-category ARs (Category 4 and 5), and windy ARs have higher contributions in the lower AR categories. Windy ARs are modulated by El Niño Southern Oscillation (ENSO) teleconnections via the anomalous geopotential height and shifted subtropical jet. Wet ARs are affected by the anomalous sea surface temperature over the midlatitudes related to ENSO. Sensitivity analysis with an alternate AR detection algorithm show consistent results on AR flavors but with disagreement to some extent.



R_PD_6

Effects of atmospheric rivers in the coastal ocean off Chile

Yosvany Garcia (1,2), Diego Narváez (2), Martín Jacques-Coper (2,3,4), Aldo Montecinos (3), Maximiliano Viale (5), Deniz Bozkurt (2,4,6), Ben Alessio (2,7)

1 Programa Doctorado, Facultad de Ciencias Naturales y Oceanográficas, Universidad de Concepción, Chile
2 Centro de Investigación Oceanográfica COPAS COASTAL, Departamento de Oceanografía, Universidad de Concepción, Chile
3 Departamento de Geofísica, Universidad de Concepción, Chile
4 Center for Climate and Resilience Research (CR2), Chile
5 Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Mendoza, Argentina
6 Departamento de Meteorología, Universidad de Valparaíso
7 U.S. Fulbright Student Program

Atmospheric rivers (ARs) are important components of the global water cycle that can cause extreme precipitation events largely on the western coasts of the midlatitude continents. In recent years, this phenomenon has drawn the attention of multiple researchers, and several works have been carried out mostly on determining the associated atmospheric processes and the impacts on the terrestrial sector. There have been only a few studies focused on the influences of the ARs on the ocean environment. ARs contribute between 45 and 60% of the annual rainfall in central and southern Chile, indicating a potential region to further study the AR influences on the coastal ocean system through several AR events with different characteristics. In this study, AR events influencing the coastal regions of Chile (32°-55° S) were studied for the period 2000-2020. ERA5 reanalysis data and oceanographic buoys and meteorological stations were used for this aim. Our results indicate that ARs impose winds with angles between 200° and 365° over coastal areas during landfalling, and the range 270° and 365° (W-N) predominates. Extreme AR events (the fourth quadrant events) featuring intensified winds are expected to cause strong surface oceanic currents towards the coast, leading to a rise of the mean sea level. There is a close relationship between the AR intensity and accumulated precipitation at the landfall areas, where the increase in the flow of terrestrial rivers is also observed. After the passage of the AR, a decrease in surface salinity and sea surface temperature can be perceived, as well as an increase in turbidity and fluvial plumes in the AR region, depending on the AR category. The results appear to have an unfavorable impact on the upwelling system of central and southern Chile, and the implications for marine ecosystems and fishing sector will have to be analyzed.

R_PD_7

Influence of zero degree line on Atmospheric Rivers in High Mountain Asia: WRF case studies of orographic precipitation extremes

Deanna Nash

June 2022

Abstract

Atmospheric Rivers (ARs) reach High Mountain Asia (HMA) roughly 10 days per month during the winter and spring, resulting in roughly 20 mm day^{-1} of precipitation. However, there are a few events each season that result in over 100 mm of precipitation, providing the vast majority of total winter precipitation, indicating that an individual AR event may significantly change water availability within the region in which it occurs. Furthermore, dynamical changes, such as the warming anticyclonic trend in Central Himalaya, have influenced the moisture within ARs and their freezing level height when they reach HMA, impacting the resulting rain to snow ratio and ultimately water resources. To understand the mesoscale processes associated with the orographic precipitation during these extreme events, we compare two Northwestern-transitioned-to-Western HMA ARs associated with extreme precipitation during a below-average and above-average freezing level height. We use dynamically downscaled data from the Weather Research and Forecasting model at 20 km and 6.7 km spatial resolution to investigate the atmospheric flow interactions of ARs with the complex terrain of HMA. We show that there is less frozen precipitation during the AR with an above-average height of the 0°C isotherm, or zero degree line. Additionally, the axis of the AR relative to the complex topography is a better indicator of the resulting precipitation than the IVT magnitude in the AR. This study indicates the importance of exploring dynamical changes in HMA via ARs and the contribution of ARs and the freezing level to orographic precipitation, providing information for future work to improve forecasting skill in a region vulnerable to the impacts of climate change.

R_PD8

Summer Atmospheric River-like structure along the subtropical West Coast of South America

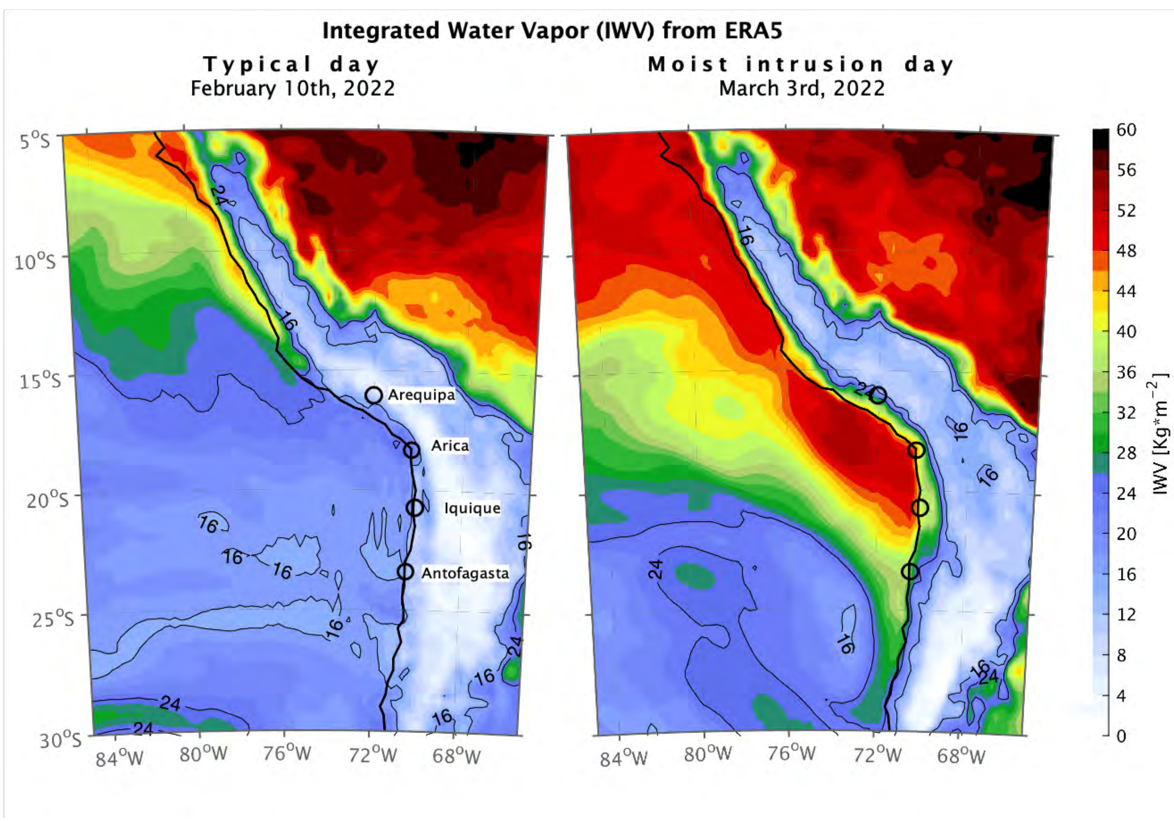
Authors: José Vicencio Veloso, Christoph Böhm, Mark Reyers, Ulrich Löhnert, and Susanne Crewell

Institute for Geophysics and Meteorology, University of Cologne, Germany

Several humidity intrusions events (HIEs) have been observed in the Atacama Desert during the last 10 years. Events like these supply essential moisture via precipitation, fog, and enhanced humidity to this unique desert ecosystem and pose problematic conditions for high quality astronomical observations, which require low water vapor contents.

Here we investigate the associated atmospheric dynamics, in particular for the summer season for which the understanding of moisture supply mechanisms for the Atacama Desert is still limited. To this end, we use state-of-the-art reanalysis, satellite observations, and surface-weather stations, as well as the 1-year campaign in Iquique Airport (22ºS) which include vertical profiles of humidity, winds and temperature.

The summer HIEs in the Atacama Desert are associated with a moisture transport structure resembling an atmospheric river or a moisture conveyor belt. They exhibit strong water vapor transport in a band-like corridor right above the marine boundary layer (900-700hPa) along the Peruvian coast towards northern Chile. Total column integrated water vapor reaches values usually observed for the moist tropical continental interior of South America. Once the humidity arrives at the Atacama's coast, it is transported inland by the afternoon Andean pumping. In addition, the topographic forced ascent in the precordillera (2,000-3,600masl) produce the formation of a stratiform cloud deck. It is also possible for convective thunderstorms to be embedded in between the stratus clouds, generating strong downpours. During the HIEs, water vapor is even able to arrive at the western margin of the Altiplano, indicating a strong and extended influence of this un-explored mechanism of humidity transport towards the subtropical west coast of South America.



R_PD_9

A case study of climate sensitivity of AR-induced precipitation to warm sea surface temperatures

Miguel Lagos-Zúñiga[1,2,3], Deniz Bozkurt[4,1], and Roberto Rondanelli[5,1]

1: Center for Climate and Resilience Research, Universidad de Chile.
2: Advanced Mining Technology Center, Universidad de Chile.
3: Department of Civil Engineering, Universidad de Chile.
4: Meteorology Department, Universidad de Valparaiso.
5: Department of Geophysics, Universidad de Chile.

Summer precipitation events present a dangerous potential in mountain areas due to the possible impacts on landslide triggering and flooding. In mountain zones, and depending on the dynamic of the phenomena, atmospheric rivers (AR) can be potentially hazardous due to the combined effect of the orographic enhancement and high instability associated with warm surface conditions. In this study, we aim to explore the potential influences of warm sea surface temperatures (SSTs) on ARs affecting central Chile. We investigate an AR event with categories between 1 and 3 occurring in January 2021 in central Chile, making the fourth highest summer precipitation day on record in Santiago since 1900. The event produced numerous landslide victims, road closures, and agricultural losses. A series of convection-permitting simulations (~4km) through a pseudo-global warming approach (i.e., end-of-century SSP5-8.5-like conditions) are conducted with WRF to analyze the sensitivity of precipitation intensity, atmospheric instability, and spatial extent of the event to warming SSTs. Our results help to disentangle the potential effects of the spatial variability of SST hot spots on water vapor content and transport- due to enhanced sea evaporation and latent heating – as well as the landfall of AR in the continent, associated freezing level, and instability.

R_PD_10

Dust Atmospheric Rivers over Europe.

Diana Francis[1], **Deniz Bozkurt[2]**, Ricardo Fonseca[1], Narendra Nelli[1], Ghislain Picard[3], Bin Guan[4]

1 Environmental and Geophysical Sciences (ENGEOS) Lab, Khalifa University, P.O. Box 127788, Abu Dhabi, United Arab Emirates

2 Department of Meteorology, Universidad de Valparaíso, 2340000 Valparaíso, Chile

3 University Grenoble Alpes, CNRS, Institut des Géosciences de l'Environnement (IGE), UMR 5001, 38041 Grenoble, France

4 Joint Institute for Regional Earth System Science and Engineering, University of California, Los Angeles, CA, USA

This study highlights the occurrence of atmospheric rivers (ARs) over northwest Africa towards Europe, which were accompanied by intense episodes of Saharan dust transport all the way to Scandinavia, in the winter season. Using a combination of observational and reanalysis data, we investigate two extreme dusty AR events in February 2021 and assess their impact on snow melt in the Alps. The warm, moist, and dusty air mass (spatially-averaged 2-meter temperature and water vapour mixing ratio anomalies of up to 8 K and 3 g kg−1, and aerosol optical depths and dust loadings of up to 0.85 and 11 g m−2, respectively) led to a 50% and 40% decrease in snow depth and surface albedo, respectively, in less than one month during the winter season. ARs over northwest Africa show increasing trends over the past 4 decades, with 78% of AR events associated with severe dust episodes over Europe.

More details can be found here:

https://www.sciencedirect.com/science/article/pii/S0169809521005159?via%3Dihub

Climate change, atmospheric rivers and the November 14/15 2021 Pacific Northwest extreme rainfall event

G.W.K. Moore
Department of Physics
University of Toronto

Abstract

In mid-November 2021, an extreme rainfall event severely impacted all aspects of society throughout southern British Columbia and northern Washington State. The event was associated with an atmospheric river, a filamentary region of enhanced water vapour transport, and it has been suggested that climate change contributed to extreme nature of the event. Here we show that the observed monthly mean November rainfall in the region has also increased by over 40% since the late 1930s. In addition, the event's precipitation exceeded the 99th percentile for November and that over the past 70 years, this threshold has increased by over 30%. We furthermore show that this increase has been associated with northward shift as well as a more perpendicular orientation at landfall of the atmospheric rivers associated with extreme events that allows for a more direct route for moisture to reach southern British Columbia. Climate models suggest that there will an intensification of these atmospheric rivers this century that will be associated with more intense rainfall in southern British Columbia. The results presented suggest that we are already dealing with this consequence of a changing climate.

AR Conference Abstract:
Understanding the two-way interactions between ARs and amplified Northern Hemisphere persistent flow regimes

Weather regimes have been widely studied to identify recurrent weather patterns in specific regions, or less frequently, across the entire Northern Hemisphere (NH). Results from my master's thesis have found that persistent ridges across the eastern North Pacific Ocean or western North America can be linked to amplified flow patterns across the entire NH. Amplified persistent flow regimes (PFRs) across the NH can last for 1–5 weeks, with major impacts to precipitation and temperature anomalies on the subseasonal timescale. The goal of this presentation is to more clearly identify these NH PRFs, understand how they can impact atmospheric river (AR) frequency, and understand how ARs can have an impact on the formation of PFRs.

PFRs will be identified as periods of widespread persistent anomalies as defined by Dole and Gordon (1983) and further modified by Miller et al. (2020) using CFSR reanalysis data for DFJ from 1979–2022. All PFRs will be aggregated into five clusters using k-means clustering on the 500-hPa geopotential height data at the start of each PFR. To compare these PFRs with ARs, AR events will be taken from the Guan and Waliser AR Reanalysis Database using ERA-Interim data at 1.5°. The effect of PFRs of AR frequency will be assessed for periods before, during, and after each of the five regime clusters. To assess the role of ARs on the formation of PFRs, time-lag composites of the flow leading up to the start of each PFR will be created to highlight regions of ARs in the vicinity of amplifying flow in each regime cluster. In addition, calculations of moisture flux convergence (MFC) will be performed to quantify how much latent heating is occurring in the vicinity of amplifying flow within the developing PFR.

R_PD_13

The effect of SST anomalies on surface fluxes in U.S. West Coast atmospheric rivers and their downstream precipitation

Alison Cobb, Rui Sun, Matt Mazloff, Bruce Cornuelle

Atmospheric rivers and their impacts at landfall have been a growing topic of research over recent years, but with few studies on the air-sea interaction at locations away from western boundary currents. This study investigates the effect of SST anomalies in the open ocean on an overlying atmospheric river, analyzing the changes in surface fluxes and precipitation intensity and distribution.

A case study of an atmospheric river is simulated in atmosphere-only runs using WRF. Alongside simulations of the observed conditions and SST climatology, we simulate the atmospheric river forcing with SST climatology plus three anomalies: The Blob of winter 2013-2014, the 97-98 El Niño, and the 2015-16 El Niño. We examine the question, **how does the presence of the anomalously warm SSTs affect the moisture content, and subsequent rainfall associated with ARs tracking over The Blob and El Niño SST anomalies?**

Alongside changes in surface fluxes, we find associated changes in the stability of the atmosphere with impacts on convection and thus precipitation. Future projections of precipitation are uncertain in relatively coarse resolution climate models and this study provides some insight into how potential changes in the SST alter the dynamics of impactful AR systems.

An analysis of the surface latent heat flux (SLHF) influence on the accumulated precipitation associated with an idealized extratropical cyclone using the Coupled Ocean-Atmosphere Mesoscale Prediction System is presented. There are two distinct precipitation regions found to be strongly influenced by the SLHF, referred to as the primary maximum and the cold-frontal precipitation. A substantial reduction by approximately 30 mm (35%) and 15 mm (75%) is observed in the accumulated precipitation of the two regions respectively when the SLHF is eliminated domain wide at 96 h – the starting time of the most rapid cyclone deepening. The source of this reduction is investigated by systematically controlling the SLHF in three cyclone sectors, which are the low-latitude, baroclinic, and high-latitude sectors. The precipitation in the primary maximum is most strongly controlled by the baroclinic sector, which experiences strong upward SLHF due to its dry environmental air. In contrast, the precipitation in the cold-frontal zone is most strongly controlled by the low-latitude sector, which experiences only a moderate amount of upward SLHF into the already warm and moist boundary layer air. The results underscore the crucial role of SLHF and boundary layer processes in precipitation predictions and demonstrate the need for accurate forecasts of air-sea temperature contrast, surface level winds and moisture to properly simulate air-sea interactions.

Climate change, atmospheric rivers and the November 14/15 2021 Pacific Northwest extreme rainfall event

G.W.K. Moore
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Abstract

In mid-November 2021, an extreme rainfall event severely impacted all aspects of society throughout southern British Columbia and northern Washington State. The event was associated with an atmospheric river, a filamentary region of enhanced water vapour transport, and it has been suggested that climate change contributed to extreme nature of the event. Here we show that the observed monthly mean November rainfall in the region has also increased by over 40% since the late 1930s. In addition, the event's precipitation exceeded the 99th percentile for November and that over the past 70 years, this threshold has increased by over 30%. We furthermore show that this increase has been associated with northward shift as well as a more perpendicular orientation at landfall of the atmospheric rivers associated with extreme events that allows for a more direct route for moisture to reach southern British Columbia. Climate models suggest that there will an intensification of these atmospheric rivers this century that will be associated with more intense rainfall in southern British Columbia. The results presented suggest that we are already dealing with this consequence of a changing climate.

L_PD_2

Recent case-study work has identified that jetstreaks induced by North American mesoscale convective systems amplify the downstream development of a Rossby wave packet (RWP). The misrepresentation of RWP amplification results in reduced forecast skill over the Euro-Atlantic in state-of-the-art global forecasting models several days later. The case-study coincided with a landfalling atmospheric river (AR) and its strength was observed to be modulated by upstream jetstreak magnitude in all state-of-the-art forecasting models. Here, it is hypothesized that the numerical misrepresentation of diabatically induced jetstreaks over North America could serve as a mechanism that deteriorates the forecast skill of landfalling ARs over Europe. In order to generalize the observations from the case-study work, a composite study is performed to better understand the relationship between diabatically induced jetstreaks on AR intensification. Ensemble sensitivity analysis is used to deduce the statistical significance of upstream jetstreaks on AR intensification and lagged composites are produced to provide a process-level understanding of the relevant dynamics. We discuss the implications of the composite results for forecasting high-impact ARs over the Euro-Atlantic as well in other regions impacted by frequent land falling ARs.

L_PD_3

Two flavors of atmospheric rivers in the North Pacific

Chanil Park and Seok-Woo Son

School of Earth and Environmental Sciences, Seoul National University, Seoul, South Korea

Abstract

Atmospheric rivers (ARs) are often considered to be transient and concurrent with extratropical cyclones. However, this definition is not necessarily true for all ARs. In this study, we explain that ARs in the North Pacific have two distinct flavors: *transient* and *quasi-stationary*. By evaluating the nature of all individual ARs based on their high- and low-frequency components of integrated water vapor transport anomaly, it turns out that most cold-season ARs are transient (86.9%) in a good spatial agreement with the midlatitude storm track. However, warm-season ARs could be either transient (66.9%) or quasi-stationary (33.1%). The latter feature is particularly prevalent along the western and northern boundaries of the North Pacific subtropical high. Although similar in large-scale background, such seasonality is not observed in the North Atlantic. Furthermore, while transient ARs are governed by midlatitude baroclinic disturbances analogous to canonical ARs, quasi-stationary ARs are associated with the enhanced pressure gradient established by low-frequency circulation anomalies. This study demonstrates that not all ARs follow the same underlying dynamics, offering new insights into the diversity and seasonal/regional manifestation of ARs.

L_PD_4

How Does Secondary Cyclogenesis Impact Landfalling US West Coast Atmospheric Rivers?

Andrew Martin
Sweta Das
Paul Loikith

Secondary extratropical cyclones and their precursor disturbances, frontal waves, have been linked to increases in mean atmospheric river intensity, duration, and decreases in their forecast skill. Though a formal relationship between atmospheric rivers and the extratropical cyclone lifecycle has been described, a comprehensive description of how frequently secondary cyclones form on landfalling atmospheric rivers and how impacts of the landfalling river change in response has not been offered. In this study, we use the MERRA2 reanalysis to compile a twenty-year (2000-2019) record of secondary cyclogenesis occurring during the landfalling phase of US West Coast atmospheric rivers. Landfalling events are chosen using the recently developed Atmospheric River Scale, allowing both the presence and impacts of West Coast AR conditions to be catalogued. Landfalling atmospheric rivers were broadly separated into events that 1) did not include secondary cyclogenesis, 2) included the development of waves or ephemeral cyclones, and 3) included at least one developing secondary cyclone on the river's frontal zones during the landfalling phase. Initial results reveal that secondary cyclogenesis is relatively common during west coast landfalls, occurring in approximately 39% of events. Secondary cyclogenesis is also associated with a large increase in AR scale. Local AR conditions of AR scale 3 or higher occurred 12.5% of the time when secondary cyclogenesis was not observed, compared to 31.2% when secondary cyclogenesis was observed. We present comparisons of event-total precipitation and frequency of extreme precipitation events between secondary cyclone and non-cyclone cases; and we present largescale meteorological patterns associated with cyclone and non-cyclone landfalls to yield insights that may be useful to the operational weather forecast community when anticipating a landfalling atmospheric river.

Atmospheric Rivers (ARs) play an important role in shaping the regional hydroclimate of the United States (US) with important implications for water resource management, emergency preparedness and response planning. The precipitation resulting from ARs is strongly related to the strength and duration of orographic lift, a property successfully used to design early warning and forecast diagnostic tools used by Western US water managers. However, observational records demonstrate that non-orographic lift is important in explaining AR precipitation and may be critical during extreme or difficult to forecast events. This observational study seeks to isolate the non-orographic vapor flux convergence term of the water vapor budget equation and estimate its importance relative to other precipitation formation mechanisms, including orographic lift, during mountain rainfall episodes. Hourly observations, provided through the National Oceanic and Atmospheric Administration's Earth System Research Laboratory, are collected from an AR observatory (ARO) at Bodega Bay, California, established to continuously monitor surface and upper-air meteorological conditions associated with landfalling ARs. Building on an existing formula for orographic precipitation, ARO measured integrated water vapor, horizontal wind, and total precipitation are used together with a digital elevation map to estimate the likely orographic contribution of rainfall at the rain gauge, and thus its non-orographic counterpart. Several impactful AR events exhibit non-orographic contribution, notably during hourly periods with the highest total accumulation. Between 2010-2019, ~25% of mean accumulated precipitation from November through April is attributed to the non-orographic term. Furthermore, results show the cumulative contribution of non-orographic precipitation at BBY exceeds that of the orographic for 99th percentile rain rates. This observational approach is further applied as a model diagnostic and used to identify several key meteorological mechanisms associated with non-orographic lift. Results aim to inform the Forecast Informed Reservoir Operations effort to improve hydrologic prediction and management of flows during AR-driven precipitation.

L_PD_5

L_PD_6

Bringing water to the west: Atmospheric river influence on orographic cloud microphysics and dynamics

Meghan Stell [1,2], Sarah Tessendorf [3], Christine Shields [3], Courtney Weeks [3] Divya Rea [4]

1. *University Corporation for Atmospheric Research (UCAR), Boulder, CO*
2. *Arizona State University, Tempe, AZ*
3. *National Center for Atmospheric Research (NCAR), Boulder, CO*
4. *University of Illinois Urbana Champaign, Champaign, IL*

Abstract

Atmospheric Rivers (ARs) are known to be important sources of moisture and influence precipitation along the Western U.S. coast, but also inland regions. This study focuses on inland-penetrating AR impacts on microphysics and dynamics of orographic clouds. During the Seeded and Natural Orographic Wintertime Clouds: the Idaho Experiment (SNOWIE) field campaign, multiple ARs reached Idaho, providing a unique opportunity to study the impacts of inland-penetrating ARs.

Data from the Atmospheric River Tracking Method Intercomparison Project (ARTMIP) was used to identify ARs over Idaho. AR impact on orographic clouds was analyzed for two SNOWIE Intensive Observation Periods (IOPs), IOP12 (February 7, 2017), a case with strong convection, and IOP23 (March 9, 2017) with deep stratiform clouds. Weather Research and Forecasting (WRF) model simulations were used to quantify and track the percentage of water vapor of subtropical origin in the ARs over Idaho, and observations from SNOWIE were used to analyze the thermodynamics and microphysics in these cases.

Sounding analysis of IOP12 indicated enhanced moisture between 3000-4000 m as the AR impacted the region, which increased instability above 4000 m. This instability led to elevated convection and mixed-phase conditions and snow in the convective clouds, in contrast to adjacent shallow orographic cloud tops that were mostly liquid and contained supercooled drizzle. This contrast provided evidence that convection enhanced ice-based precipitation formation.

This presentation will illustrate the importance of moisture from inland-penetrating ARs for orographic cloud thermodynamics, microphysics, and the resulting precipitation processes. Because ARDTs specific to inland ARs provide insight into inland precipitation, comparison of ARDTs and IVT values that align with thermodynamic changes will be presented to identify IVT values that may better detect inland ARs.

IDENTIFICATION OF LARGE-SCALE PATTERNS LEADING TO THE FORMATION OF ATMOSPHERIC RIVERS IN MAINLAND CHILE

Aiming to identify large-scale patterns leading to the occurrence of ARs, IVT fields during AR-related dates ranging from 1980 to 2018 (based on the Guan & Walliser catalog) were separated into clusters using an unsupervised classification algorithm - Gaussian Mixture Models – using several classification schemes, allowing for different numbers of target clusters and diverse regions of analysis. Composites of relevant variables to the dynamics of ARs - such as geopotential height and precipitable water – based on the classification performed by the algorithm for the event day, as well as the days building up to the landfall of the AR, allowed a first tentative identification of large-scale atmospheric circulation patterns that lead to the occurrence of ARs along the western coast of South America.

Using this methodology, we identified six distinctive large scale patterns that lead to the formation of ARs along South Western South America. These patterns show some key differences, such as landfall location, intensity and seasonality. Some already known physical mechanisms related to the meteorology in Chile are identified, such as Rossby wave trains of different wavelengths. However, several additional mechanisms are identified and described (such as the Pacific Standing Wave, Polar Low and Atmospheric Gearing). Some common elements arise from the unsupervised classification, such as the importance of tropical variability (which influences their seasonality), as well as the differences in intensity of the events contributing to each of the mechanisms.

The identification of these patterns adds to the basic knowledge of the processes relevant to the occurrence of AR that make landfall in Chile and provides strong evidence for the use of unsupervised classification algorithms in helping to identify physical mechanisms behind ARs formation in other regions of the world.

L_PD_8

Abstract for the International Atmospheric River Conference 2022

Relationship between atmospheric rivers, extratropical fronts and intense precipitation in the Iberian Peninsula

Diogo Luís (1), Cátia Gonçalves (2), Carla Gama (2), José M. Castanheira (1), Alexandre M. Ramos (3, 4), Michael Sprenger (5), Irina V. Gorodetskaya (1)

(1) CESAM, Department of Physics, University of Aveiro, Aveiro, Portugal; (2) CESAM, Department of Environment and Planning, University of Aveiro, Aveiro, Portugal; (3) Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Karlsruhe, Germany; (4) Instituto Dom Luiz (IDL), Faculty of Sciences, University of Lisbon, Lisbon, Portugal; (5) ETHZ, Zurich, Switzerland

Atmospheric rivers (AR) have an important role in the hydrological cycle of the Iberian Peninsula (IP) region. This work aims to better understand the mechanisms behind ARs that affect the IP, and to quantify their contribution to precipitation. In this sense, we apply an AR identification algorithm to the ERA5 reanalysis with a 31-km horizontal resolution to identify the ARs that affected the IP in the 1979-2020 period. Using the algorithm results, we investigate the relationship between Iberian ARs and the fronts of extratropical cyclones. Furthermore, the contribution of ARs to IP precipitation is evaluated using regional observational products (E-OBS, IB01) and meteorological station data (Porto, Lisbon, and Faro). Three AR events (unnamed storm in October 1979, storm Gong in January 2013, and storm Ana in December 2017) were chosen as illustrative case studies and analysed in more detail. In the 1979-2020 period, 580 persistent ARs (lasting at least 18 hours) have been identified as affecting the IP, with an annual mean of 13.8 ± 2.8 AR. The most affected region was the northern IP coast and the maximum number of ARs in a year (20) occurred in 2013. During the 42-year period, most of the Iberian ARs were associated to extratropical fronts, with a stronger relationship found on cold fronts. Precipitation analysis showed a considerable contribution of persistent ARs to the annual precipitation over the IP. Using the latest high-resolution reanalysis and observational data, our study evidence the importance of ARs to the Iberian precipitation. Case studies analysis shows that the relationship between extratropical cyclones and fronts changes throughout their lifecycle.

L_PD_9

Moisture sources projections under climate change for Atmospheric Rivers landfalling the Iberian Peninsula

José C. Fernández-Alvarez[1,2*], Albenis Pérez-Alarcón[1,2], Jorge Eiras-Barca[1,3], Alexander M. Ramos[4], Raquel Nieto[1], Luis Gimeno[1]

[1]*Centro de Investigación Mariña, Universidade de Vigo, Environmental Physics Laboratory (EPhysLab), Campus As Lagoas s/n, Ourense, 32004, Spain.* [2]*Departamento de Meteorología, Instituto Superior de Tecnologías y Ciencias Aplicadas, Universidad de la Habana, La Habana 10400, Cuba.* [3]*Defense University Center, The Spanish Naval Academy, Marín, Spain.* [4]*Instituto Dom Luiz (IDL), Facultade de Ciências, Universidade de Lisboa, Lisbon, Portugal*

*e-mail: jose.carlos.fernandez.alvarez@uvigo.es

In the field of moisture transport, Atmospheric Rivers (ARs) are known as narrow corridors of water vapor, generally 2000 km or more in length. ARs account for more than 90% of total the meridional moisture transport and latent. Even though it has been demonstrate that most ARs are somehow beneficial, the most intense cases are associated with extreme precipitation events, floods, landslides, extensive property damage, and losses of life. In the context of climate change, it is projected that the water-holding capacity of the atmosphere will be increasing at a rate close to 7 % K^{-1} in the both in lower troposphere and in the column. Despite this, future changes in moisture sources which contribute to the cited moisture transported by ARs to higher latitudes are still not known. In order to analyze these changes, a set of simulations using the Weather Research and Forecasting (WRF-ARW) model forced with Community Earth System Model (CESM2) as well as the FLEXPART-WRF model forced with the WRF-ARW outputs are used in this work. The analyses were carried out mainly by determining the anomaly moisture uptake for the mid-century (MC, 2049-2053) and end-century (EC, 2096-2100) periods, considering the annual and seasonal changes. We report that the moisture uptake anomaly increased with maximum values, ~ 7-8 % K^{-1} , in winter for MC and EC. In addition, a latitudinal increase in the anomalous moisture uptake pattern is projected over the central Atlantic and a longitudinal expansion towards the Gulf of Mexico is observed.

P_PD_1

Characterization and analysis of the atmospheric river event during the southern summer at extratropical latitudes in January 2021

Javiera Ramírez Delgado[1] (ramirezd.javiera@gmail.com)

Johana Gallardo Álvarez[1] (jpga07@gmail.com)

[1] Departamento de Geofísica, Universidad de Chile, Santiago, Chile

Abstract

The prominent topography due to the Andes Mountain Range and the proximity that exists with the South Pacific Ocean, can cause the western coast of South America (Chilean coast) to be deeply affected by the Atmospheric Rivers (ARs). These events often result in flooding and landslides with serious consequences for society. ARs in Chile arrive more frequently between 38°-50°S. These contribute between 42% to 56% of the annual precipitation in this region, while at 32°-38°S contribute between 49% to 63%.

At the end of January 2021, a frontal system associated with an AR was forecast to landfall the Chilean coast at 39°S. However, the AR moved north. This system caused a lot of precipitation for the season, thunderstorms and landslides. The uncertainty associated with the intensity of precipitation, produced by the AR, leads to pay special attention and preparation to the affected areas, to prevent human and material losses. Due to the above, we want to understand the dynamics of the phenomenon. Understanding this, it is possible in the future to interpret weather forecasts properly and to be better prepared.

The following methodology was used to better understand AR. The AR that caused precipitation in January 2021 was first identified by NCEP-NCAR reanalysis. Then, the error between the reanalysis and the observed by MERRA was calculated from the IWV index.
Furthermore, we examined which type of AR corresponds and subsequently whether it meets the parameters of precipitation magnitude according to the characterization of Ralph et al., (2019). Because of this, the dynamics and synoptics of the study case were characterized, comparing the vertical rates of NCEP/NCAR reanalysis with those of vector *q*, which corresponds to a synoptic ascent.

P_PD_2

Sources of Moisture to Extreme Atmospheric Rivers: a storm Denis case study

López-Martí F. [1], Wu L.[1], Messori G.[1], Rutgersson A. [1]

[1] Department of Earth Sciences, Uppsala University, Uppsala, Sweden

Moisture transport within atmospheric rivers (ARs) is a complex combination of processes, with convergence of moisture with different origin and it changes over the life cycle of an AR. The water vapour budget in an AR enables us to understand the contribution of each component (horizontal transport, local evaporation and precipitation). Here, we focus on how these processes and the different moisture sources contributed to the formation and development of the exceptional AR associated with storm Denis that occurred in February 2020 leading to the 3rd highest UK average daily rainfall since 1891.

We use the WRF-ARW numerical limited-area atmospheric model to simulate the life-cycle of the AR in the North Atlantic basin. We use a resolution of 0.09º, and a domain covering the formation close to the Gulf of Mexico to the landfall in northern and central Europe. Moreover, we performed two main sets of sensitivity experiments by reducing the tropical moisture transport, and the sensible heat flux in specific areas of the oceanic basin to assess how these two main components affect the water vapour balance within the AR. We also defined a threshold to map the AR and used a centroid-based method to track its path in order to measure the shift of location and its intensity through time in the different experiments.

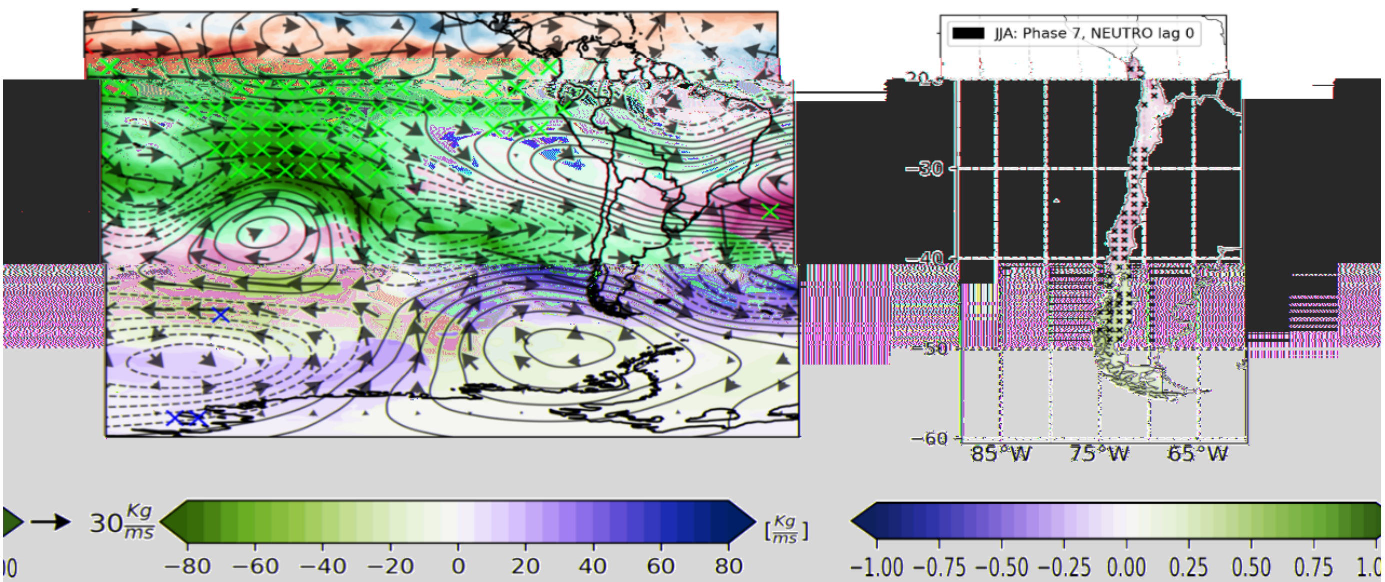
Our findings revealed significant relationships between the reduction of tropical moisture and a change of the location of the AR. The analysis also detected regional and temporal changes in the water vapour balance due to the perturbations done in the sensitivity experiments associated with the February 2020 storm Denis. In addition, relative importance of moisture sources are assessed. As such, our work provides a new case study to unravel feedback processes and the influence to the AR indicators when perturbing the water vapour balance.

[1] Last retrieved January 2022

P_PD_3

Mechanism for the influence of MJO in precipitation over Chile

Previous work has established that MJO influences circulation and precipitation in Central and Northern Chile. Moreover, there is evidence that in the austral winter, phases 8, 1, and 2, are associated with positive precipitation anomalies, and on the contrary, phases from 3 to 7 to negative anomalies. However, the focus has been given only to the rainy season and with no major discussion of the mechanisms that explain these anomalies. Here we analyze the mechanisms of the MJO relation with precipitation over Chile using ERA5 reanalysis. We focus our results on phase 7 as an example of the circulation anomalies. We diagnose teleconnections over the Pacific using wave activity flux which shows a marked seasonality with train waves to mid and low latitudes in austral winter. Given the teleconnection mechanism the impact of a given MJO phase activity propagates along the Pacific with a lag of several days so the impacts associated with a given MJO phase at lag-0 are actually due to the MJO activity 5 or even 15 days before the precipitation anomalies occur in the South American continent. Finally, a relation was observed between the development of a wave train through time, the associated circulation anomalies, and the development of moisture transport along the Pacific from tropical latitudes.



MJO phase 7 composites of anomalous (left column) 200[hPa] Streamfunction (contours, every 10e6 m/s2) and IVT (color and vector), and (right column) standardized anomalous precipitation. Red and black crosses demonstrate the anomalies found to be 99% significantly different from zero.

Sharpening of Future Western US Cold Season Storms Modifies Area-Intensity Relationship for Safe Design

Winter storms are responsible for billion dollars of economic loss in the western US. As storm structures are not well resolved by global climate models, event-scale storm response to global warming has not been well established. Here regional storm-resolving simulations are used to investigate the response of western US winter storms to climate change. In the mid-century under the RCP8.5 scenario, precipitation amount from the top 10% extreme storms, mostly associated with atmospheric rivers, is projected to increase by up to 40% across the region. Increased area coverage and storm intensity explain 80% and 50% of the increase, respectively, while a robust sharpening of the spatial structure of future storms slightly offsets the increase. Ignoring the changing area-intensity relationship due to storm sharpening could result in as much as 30% overestimations of the 100-year return period design storms. Future changes in peak intensity and spatial structure of storms, which are larger for extreme storms, have broad implications for flood characteristics critical to resource planning and hazard management.

An Improved Understanding of the Impacts of Anthropogenic Forcing on Atmospheric Rivers and Extreme Precipitation over the North American West Coast

Atmospheric Rivers (ARs) can account for more than half of west coast precipitation and significantly impact flooding, drought, agriculture, and water management operations. The average annual cost of flooding damage from ARs is $1.1 billion and is expected to increase in the future. Global temperatures are increasing at an unprecedented rate due to high levels of greenhouse gas emissions since the start of the industrial revolution. Regional climate change projections are particularly complicated to make and are currently not well understood. The relationship between global and regional climate change, the change in AR characteristics over the Northeast Pacific Ocean and the changes in precipitation characteristics over the North American West Coast will be analyzed in this work.

Here, we identify the main contributors to the changes in precipitation over the region in addition to quantifying the trends in future AR events using a unique high-resolution climate model run at unprecedented ensemble size. Data computed from the Weather@Home regional climate modeling project will be analyzed. Weather@Home is unique because it uses computing power from volunteers' computers to run regional climate simulations. This will be the first Weather@Home project to examine eastern Pacific ARs and precipitation. This analysis will include boreal winter AR events with historical forcings from the early 21st century as well as future forcing relevant to 1.5°C and 2° warming using output from HadAM4. The model has horizontal resolutions of around 60km, higher than the CMIP5 and CMIP6 deck experiment model resolutions. All datasets have unprecedented ensemble sizes greater than 1000 (Typical current climate model ensembles are on the order of 100s). The ensemble sizes and resolutions of this data are far superior to those of past studies and thus will show a robust contrast between internal variability (ensemble variance) and forced response (ensemble mean response.

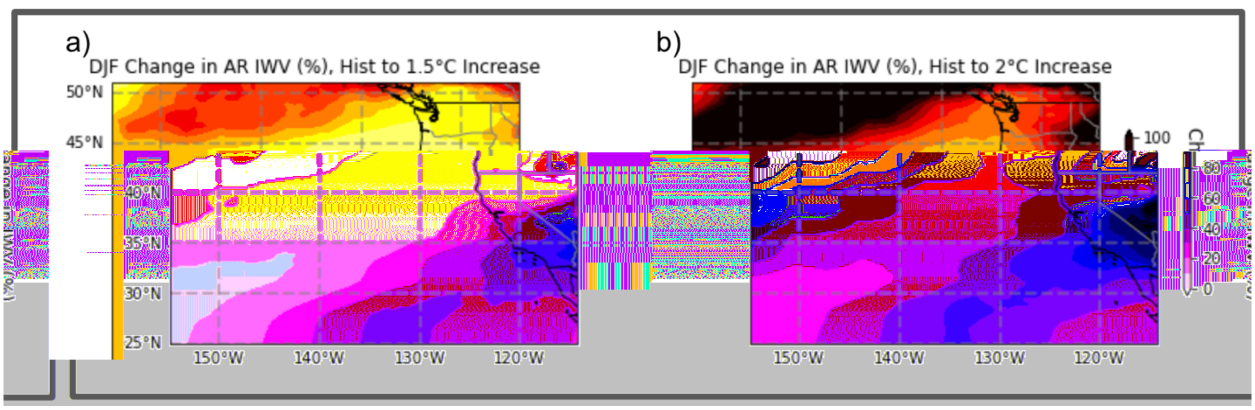


Figure: The mean percentage change in AR IWV from the a) Hist to 1.5°C increase scenario and b) Hist to 2° increase scenario during winter months

R_PF_2

International research efforts related to atmospheric rivers (ARs) have expanded substantially in the past 10 years, with numerous articles related to AR variability, AR impacts on the global and local hydrologic cycle, and the effects of climate change on ARs. A large set of these recent advances in AR science have benefitted from the application of objective, automated AR detection tools (ARDTs). A growing number of ARDTs have been applied in the literature, with different studies sometimes yielding different results. These challenges motivated the formation of the Atmospheric River Tracking Method Intercomparison Project (ARTMIP); an international collaborative effort with the goal of understanding how ARDT design choices impact scientific results.

ARTMIP is a community effort to systematically assess how the uncertainties from ARDTs impact our scientific understanding of ARs. This study describes the ARTMIP Tier 2 experimental design and initial results using the Coupled Model Intercomparison Project (CMIP) Phases 5 and 6 multi-model ensembles. We show that AR statistics from a given ARDT in CMIP5/6 historical simulations compare remarkably well with the MERRA-2 reanalysis. In CMIP5/6 future simulations, most ARDTs project a global increase in AR frequency, counts, and sizes, especially along the western coastlines of the Pacific and Atlantic oceans. We find that the choice of ARDT is the dominant contributor to the uncertainty in projected AR frequency when compared with model choice. These results imply that new projects investigating future changes in ARs should explicitly consider ARDT uncertainty as a core part of the experimental design.

R_PF_4

Title: Atmospheric river variability over the last millennium driven by annular modes

Authors: Seung H. Baek[1*], J. Michael Battalio[1], Juan M. Lora[1]

Affiliations:

[1]Department of Earth & Planetary Sciences, Yale University, New Haven, Connecticut, USA

*Corresponding author. Email: seunghun.baek@yale.edu

Abstract: Atmospheric rivers (ARs) are filamentary conduits of intense moisture transport crucial for water delivery to mid-latitude coastal regions. How ARs have responded to extratropical climate variability remains poorly understood despite ARs being features of the extratropical atmosphere. Here, using "Last Millennium" simulations, we characterize the role of annular modes of extratropical variability on ARs and moisture transport. We find that positive (negative) phases of the annular modes intensify (weaken) and weaken (intensify) ARs over the subpolar and subtropical latitudes, respectively, with up to ~20-25 mm/month associated changes in precipitation. Importantly, the annular modes comprise the primary mode of AR variability over the last ~1000 years, eclipsing in magnitude any changes induced by prominent modes of tropical variability (e.g., Madden-Julian Oscillation and the El Niño–Southern Oscillation). We replicate these AR changes in the observational record, indicating that our model results are robust and representative of real-world influences. Collectively, our results provide a robust paleoclimate baseline from which to contextualize projected 21st century AR intensification. Notably, the ~20-25 mm/month changes in AR-driven precipitation induced by the annular modes are comparable in magnitude to the up to ~20 mm/month increases in AR-driven precipitation expected over 2006-2080 under high-emissions global warming (i.e., Representative Concentration Pathway 8.5 W/m^2). This is alarming, as it indicates that AR intensification from severe global warming over the next few decades may rival in magnitude the most prominent natural changes to AR activity.

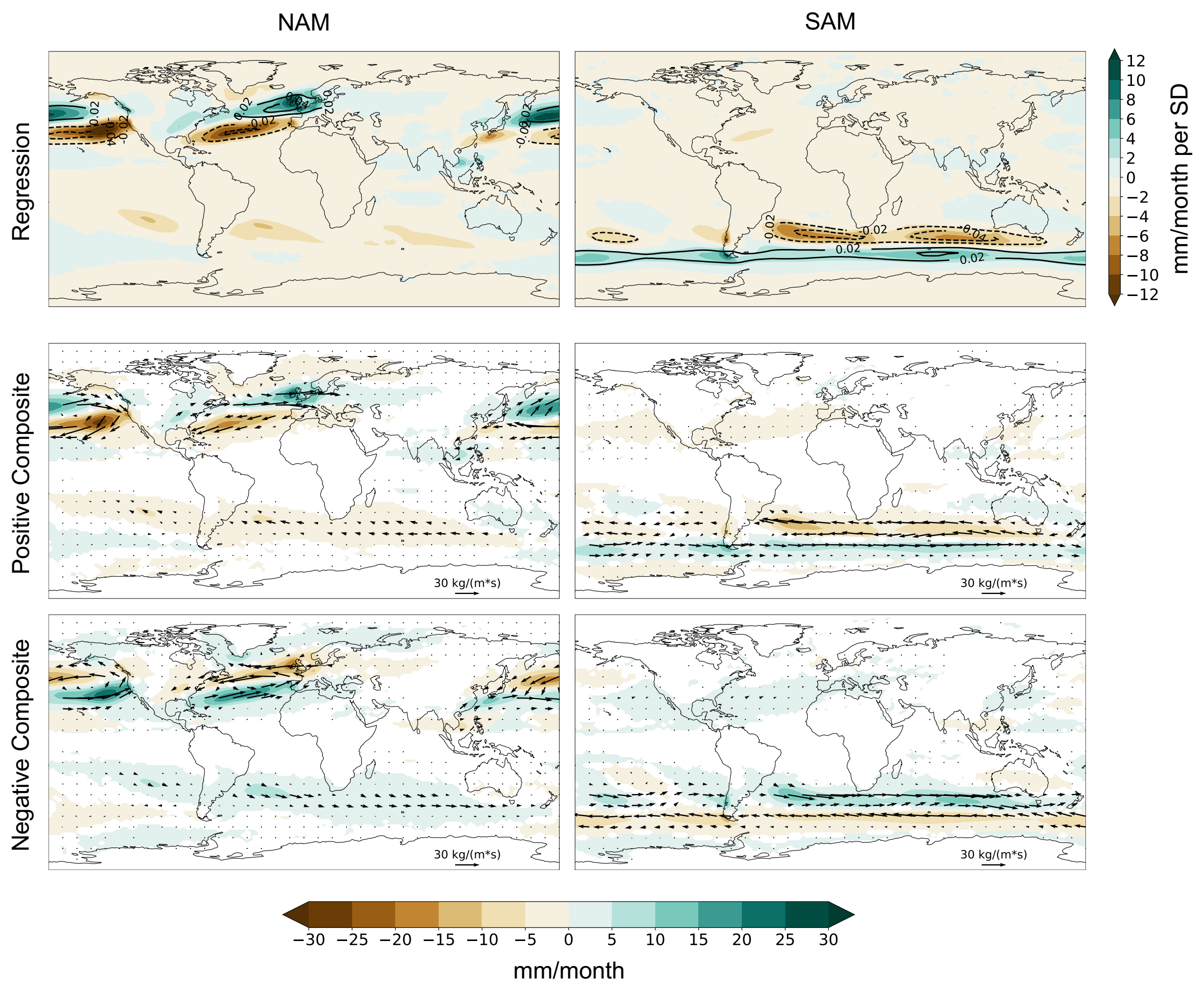


Figure 1: (top) Regression of AR-driven precipitation and integrated vapor transport onto (left) Northern Annular Mode and (right) Southern Annular Mode. Contours show regression of AR frequency (with seasonal cycle removed) onto the annular modes (units are in AR fraction per standard deviation). (middle) Difference in AR-driven precipitation and integrated vapor transport between positive phases and average of 850–2005 for (left) Northern Annular Mode and (right) Southern Annular Mode. (bottom) Same as middle, but for negative phases of Northern Annular Mode and Southern Annular Mode. Only significant ($p<0.01$) values are plotted.

IVT during the 2021 East Australian Floods and Future Climate Projections

Kimberley J. Reid[1], Travis A. O'Brien[2], Andrew D. King[1] and Todd P. Lane[1]
[1]The School of Geography, Earth and Atmospheric Sciences, The University of Melbourne and ARC Centre of Excellence for Climate Extremes, Melbourne.
[2]Earth and Atmospheric Sciences Department, Indiana University Bloomington, IN, and Climate and Ecosystem Sciences Division, Lawrence Berkeley National Lab, Berkeley, CA, USA.

During March 2021, large regions of Eastern Australia experienced prolonged heavy rainfall and extensive flooding. The maximum daily mean column integrated water vapor transport (IVT) over Sydney during this event was within the top 0.3% of all days since 1980, and the 10-day mean IVT was in the top 0.2%. In this study, we have examined the change in frequency of extreme IVT events over Sydney in sixteen climate models from the Coupled Model Intercomparison Project 6 under two Shared Socioeconomic Pathways (SSP245 and SSP585). Generalized Extreme Value modelling was used to further analyze the change in frequency of extreme IVT events. We found the probability of long duration high IVT events is projected to increase by 80% at the end of the century, but the future change in IVT is correlated to the rate of global and regional warming in each model.

R_PF_6

A 440-Year Reconstruction of Heavy Precipitation in California from Blue Oak Tree Rings*

Ian Howard[1], David Stahle[1], Michael Dettinger[2], Cody Poulsen[3], F. Martin Ralph[3], Alexander Gershunov[3]

[1]Department of Geosciences, University of Arkansas, Fayetteville, AR, USA
[2] Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, Carson City, NV, USA
[3]Center for Western Weather and Water Extremes, Scripps Institution of Oceanography

The variability of water year precipitation and blue oak tree-ring chronologies in California are both dominated by precipitation extremes delivered during just a few heavy rain days per year. These heavy precipitation events can spell the difference between deficit or surplus water supply, and elevated flood risk. Blue oak chronologies are highly correlated with water year precipitation totals ($r = 0.84$) but are equally well correlated ($r = 0.82$) with extreme precipitation ≥25.4 mm (one inch, ≈95th percentile of daily totals, 1949-2004). The blue oak correlation with non-extreme daily totals <25.4 mm is much weaker ($r = 0.55$). Consequently, blue oak chronologies represent a selective proxy for heavy precipitation and are used to reconstruct the amount and number of days of heavy precipitation (≥25.4 mm) in northern California from 1582-2021. Decadal surges in the amount, frequency, and inter-annual reversals or volatility of heavy precipitation extremes are reconstructed, likely reflecting elevated atmospheric river activity.

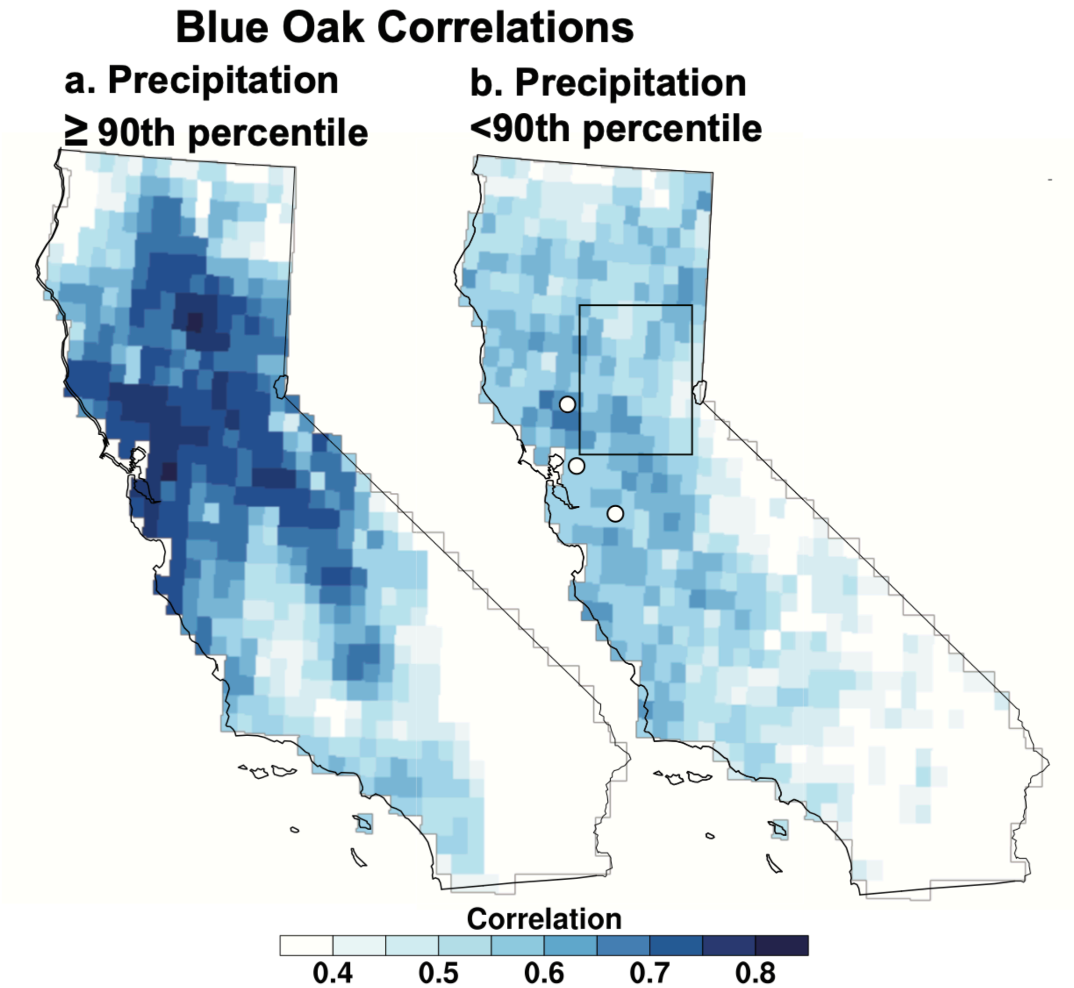


Figure 1. The blue oak chronology is correlated with the CPC daily precipitation dataset at each grid point in California for two fractions, (a) the extreme totals $\geq 90^{th}$ percentile of days with precipitation and (b) the non-extreme totals ($<90^{th}$ percentile) for the common period 1949-2004. The three blue oak chronologies included in the regional ring width average are located with white symbols in panel b (i.e., Pacheco Pass, Mt. Diablo, and Putah Creek, south to north), along with the study area (black outline).

L_PF_1

Climate Change Impacts the Storm that Contributed to California's Oroville Dam Crisis

Allison C. Michaelis[1], Alexander Gershunov[2], Alexander Weyant[2], Meredith A. Fish[3,4], Tamara Shulgina[2], and F. Martin Ralph[2]

[1]Department of Geographic and Atmospheric Science, Northern Illinois University, DeKalb, IL
[2]Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA
[3]Department of Earth and Planetary Sciences, Rutgers, The State University of New Jersey, Piscataway, NJ
[4]Rutgers Institute of Earth, Ocean, and Atmospheric Sciences, Rutgers, The State University of New Jersey, New Brunswick, NJ

An increasingly volatile hydroclimate increases California's reliance on precipitation from atmospheric rivers (ARs) for water resources. Extreme ARs, however, are often more hazardous than beneficial, challenging water resource management. Here, we simulate the AR that contributed to the Oroville Dam crisis in early-February 2017 under global climate conditions representing pre-industrial, present-day, mid-, and late-21st century environments. This event consisted of two AR pulses: the first snowy, westerly, and cool followed by a southwesterly and warm pulse producing copious rain-on-snow. We estimate that climate change-to-date results in a ~11% and ~15% increase in precipitation over the Feather River Basin in Northern California for the first and second pulses, respectively, with late-21st century enhancements upwards of ~21% and ~59%, respectively. Although both pulses were enhanced by the imposed climate changes, the precipitation increases were most substantial during the second pulse, highlighting that not all ARs will respond similarly in a warmer world.

International Atmospheric River Conference 2022
Santiago, Chile, October 10th to 14th, 2022

Atmospheric Rivers of Past, Present and Future

Arjun Babu Nellikkattil[1,2*], June-Yi Lee[1,2,3], Axel Timmermann[1,4], and Sun-Seon Lee[1]

[1]Center for Climate Physics, Institute for Basic Science, Busan, South Korea

[2]Department of Climate System, Pusan National University, Busan, South Korea

[3]Research Center for Climate Sciences, Pusan National University, Busan, South Korea

[4]Pusan National University, Busan, South Korea

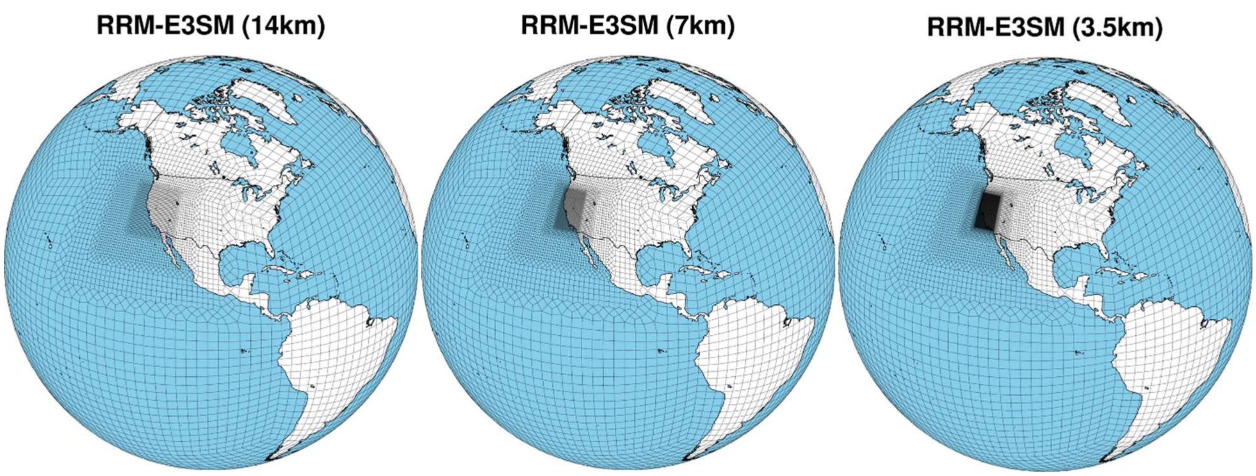
The estimated frequency, size and strength of Atmospheric Rivers (ARs) depend on the mean state of the climate system, the large-scale atmospheric circulation, and the AR detection method used. While many detection methods use physical thresholds in integrated water vapor transport/content based on historical values, we developed a general feature extraction method that does not rely on historical thresholds and instead detects the general AR shape. This method is particularly useful for detecting ARs within different modelled mean states, especially in high-CO_2 past and future scenarios. Our detection method, Scalable Feature Tracking (SCAFET) is used to compare AR characteristics from a variety of mean states using ultra-high-resolution (0.25^o in atmosphere and 0.1^o in ocean) CESM 1.2.2 coupled climate simulations. We compare AR characteristics in present climate with that of various CO_2 concentrations such as 2xCO2, 4xCO2 future scenarios and last interglacial (MIS5e, ~125 ka) and glacial sub-stage (MIS5d, ~115 ka) past scenarios. The primary goal of the experiment is to understand how the frequency, strength, and precipitation of ARs are related to the other large-scale extra-tropical circulation features like the jet streams and cyclonic and anticyclonic vorticities. Additionally, we hope that shape-based feature extraction such as SCAFET could bring clarity and build consensus around AR past and future estimation. The results would not only help us project the AR responses of future warming but will also give us insights into how changes in large-scale circulation feed back into the ice-sheet dynamics via precipitation.

L_PF_3

Title: Recreating the California New Year's flood event of 1997 using regionally refined Earth system modeling across multiple warming levels

Authors: Alan M. Rhoades (Lawrence Berkeley National Laboratory), Colin M. Zarzycki (Penn State University), Ben J. Hatchett (Desert Research Institute), and Andrew D. Jones (Lawrence Berkeley National Laboratory)

Abstract: The California New Year's flood event of 1997 remains one of the largest and most costly floods in recorded history. The week-long flood event resulted from extreme atmospheric river (AR) conditions that deposited orographic precipitation on an above average snowpack. The triple-whammy of pre-conditioned soil moisture content, extreme precipitation totals, and abrupt snowmelt led to California water managers rapidly releasing water from reservoirs throughout the State that were at, or near, capacity. 48 of 58 counties were declared disaster areas, 120,000 people were evacuated, and damages totaled $1.8 billion. The compound nature and sheer impact of the flood event warrants its use as a stress test case of cutting-edge variable-resolution Earth system models. It further allows exploration of how the characteristics of this flood event differs across several warming scenarios. This approach has been termed a climate storyline and demonstrates promise for scientist-stakeholder engagement related to climate impacts. Here, we leverage the regionally refined mesh (RRM) capabilities of the Energy Exascale Earth System Model (E3SM) to recreate and explore alternate storylines of the California New Year's flood event of 1997. These storylines assess how the flood event is represented across three horizontal resolutions focused over California (14km, 7km, 3.5km) and differs based on 14 forecast lead times (initialized at 12-hour increments between 12-25-96 and 12-31-96). In addition to resolution and forecast lead times, storylines are performed across six warming levels (pre-industrial, control, +1 °C through +4 °C). The AR conditions are tracked using TempestExtremes, an AR detection and tracking algorithm, and distilled into AR categories to investigate how the characteristics of the landfalling AR conditions change with horizontal resolution, forecast lead time, and warming level. We describe the resulting alterations to precipitation intensity, efficiency, and rain-snow partitioning, soil moisture content, snowpack dynamics, and runoff efficiencies to downstream reservoirs.



L_PF_4

Influence of Atmospheric Rivers on the precipitation regime and change in Western Patagonia

Juan P. Boisier[1,2] and David Trejo[1]

[1]Center for Climate and Resilience Research (CR2, FONDAP 15110009), Chile
[2]Department of Geophysics, Universidad de Chile, Santiago, Chile

Atmospheric Rivers (ARs) produce near half of annual precipitation in Western Patagonia (WP), a region featuring areas with very large rainfall accumulation (> 3000 mm yr^{-1}). The particular hydroclimatology of this region supports unique natural systems, notably the Southern Ice Fields. Those systems, being sensitive to long-term precipitation variability, are potentially threatened by anthropogenic climate change. In contrast to the robust drying pattern in subtropical Chile simulated by current Earth System models, there is a less clear precipitation response to global anthropogenic forcing farther south in WP. A better understanding of large-scale mechanisms controlling precipitation in WP, as well as the assessment of these mechanisms in models, are needed to reduce the uncertainties in climate projection in this region.

Here we present a framework to classify weather regimes in the southeastern Pacific region producing large rainfall events in WP —ARs particularly—, based on clustering of daily precipitation and of other atmospheric variables. We then evaluate how well these atmospheric conditions are characterized in the present-day climate simulated in CMIP6 Earth System models. Changes of these phenomena projected in responses to global anthropogenic forcing are presented and discussed in terms of modeled precipitation uncertainties in the WP region.

L_PF_5

Change in Size of Atmospheric Rivers Under Future Climate Scenarios. A Perspective Independent of the Detection Algorithm.

Héctor A. Inda-Díaz[1,*], Yang Zhou[1], Travis O'Brien[2,1], William Collins[1,3]

[1] Earth and Environmental Sciences Area, Lawrence Berkeley National Laboratory
[2] Department of Earth and Atmospheric Sciences, Indiana University Bloomington
[3] Earth and Planetary Science, University of California Berkeley
[*]Corresponding author: haindadiaz@lbl.gov

There has been a growing interest in atmospheric rivers research over the last few decades. It has been observed that AR detectors (ARDTs) are heavily influenced by how researchers quantitatively define this phenomenon. In particular, AR size depends highly on the numerical definition of AR embedded in the design of ARDTs, producing significant uncertainty in the AR size estimation. We use data from the ARTMIP Tier 2 CMIP5/6 experiment to calculate the AR confidence index and create global composites of AR objects. Then, we estimate the AR composite size using four independent methods to understand how AR size responds to future simulations with strong radiative forcing (CMIP5: RCP-8.5, CMIP6: SSP-858).

Our results show an increase in the background IVT field between 10% and 21% from historical to future simulations, with a broader inter-model variability of ∼27%. The mean AR area is $3.15\text{x}10^6$ ($\pm 0.83\text{x}10^6$ km^2) and $3.42\text{x}10^6$ km^2 ($\pm 0.70\text{x}10^6$ km^2) for historical and future runs, respectively. We find that AR width is more sensitive than AR length and contributes more to the change in the AR area. Increases in AR size dominate across models and methods. However, the methods that compare to the background IVT show both positive and negative changes in AR size. Regardless of the sign in AR size difference, the mean AR cross-section water vapor transport increases between 8% and 37%. We also find that North American landfalling ARs are more likely to penetrate further inland for future simulations.

We provide an objective insight into the change in AR size with climate change from an independent perspective of the ARDTs design and algorithms, which could help as a reference for tuning and constraining existing ARDTs or designing new AR detection algorithms.

L_PF_6

Euro-Atlantic Atmospheric Rivers and the Upper Ocean Variability

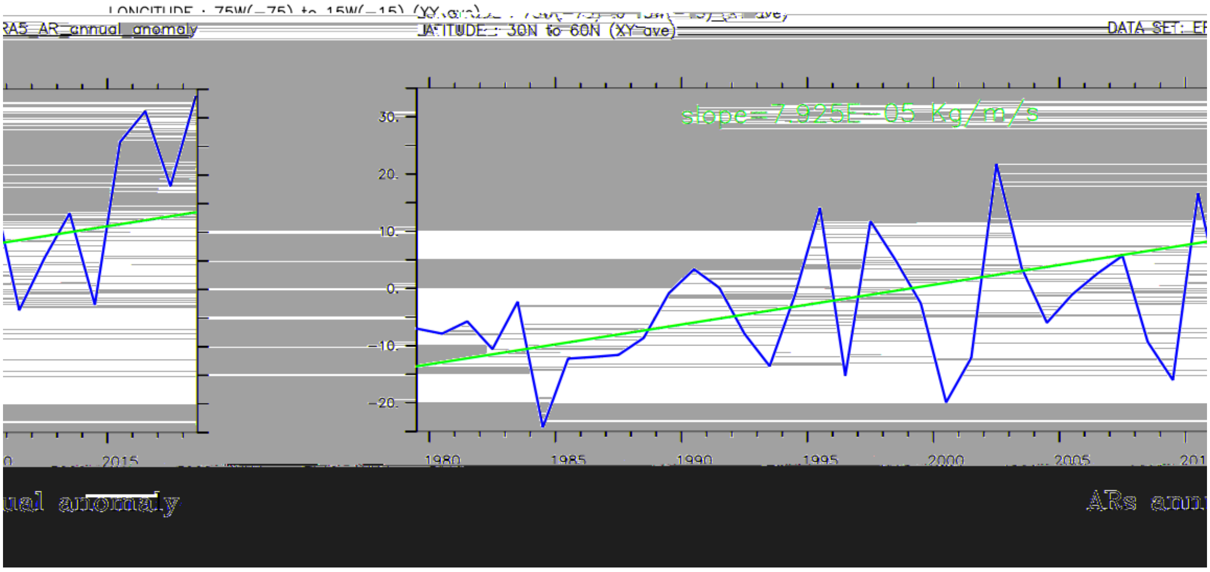
Venugopal Thandlam[1], Anna Rutgersson[1] and Erik Sahlee[1]

Department of Earth Sciences

Uppsala University, Sweden

Abstract

In the present work, we use long term ERA5 reanalysis dataset over the north Atlantic Ocean to study the Atmospheric Rivers (ARs) and the upper ocean variability over Euro-Atlantic region. The significant increase in the sea surface temperature (SST) over the Gulf stream coupled with its poleward shift in the recent decades impact the intensity and frequency of ARs over the region. The intensity of ARs in the north Atlantic has been increasing in the recent times with large decadal variability and poleward shift in landfalling of intense events. Surface latent heat flux anomalies shows the latitudinal dependence of source of moisture flux in the open ocean contributing to formation and enhancing ARs strength. These flux changes along with the SST decadal variability drives the decadal spatial deviations in the path and landfalling ARs over Euro-Atlantic region. The study also finds that the increasing zonal and meridional components of winds in the central Atlantic drives the excess moisture from western Atlantic towards the western Europe. While meso-scale eddies could impact the ARs; upper ocean parameters such as SST in the open ocean, sea level anomalies near the coasts of western Europe varies with AR occurrence and landfalling.



L_PF_7

Dynamics and Precipitation of Atmospheric Rivers that Impact South America in Present, Last Glacial Maximum, and Future Climate Conditions

Carlos Ordaz, City University of New York, The Graduate Center

Allegra LeGrande, NASA Goddard Institute for Space Studies

James Booth, City University of New York, City College and The Graduate Center

Dan Litchmore, Columbia University

Catherine Naud, Columbia University

Atmospheric rivers (ARs) play a crucial role in the meridional transport of water vapor and the precipitation associated with ARs is a critical component of regional water supply. In Chile, precipitation associated to AR landfalls accounts for the bulk of freshwater supply, making it critical that we understand how ARs may change in the future. To approach this issue, our work uses integrations of the NASA Goddard Institute for Space Studies climate model ModelE version 2.1 (GISSE2.1). We consider three integrations of the model: one simulating conditions from the Last Glacial Maximum, another using current-era conditions, and a future run simulating emission conditions as per Representative Concentration Pathway (RCP) 8.5. To expand our understanding of AR events that impact Chile and other parts of South America, we have chosen to focus our efforts on ARs making landfall on South America poleward of 37 degrees latitude. We investigate how precipitation associated with AR events differs over the three integrations. We contrast frequency and distribution of AR landfall events in the three runs by analyzing changes in the storm track and baroclinicity. We find that latitudinal shifts in the ARs in our simulations are not as tightly coupled to these two storm-related climatological metrics as expected. We examine the role of changes in the stationary waves and upper-level jets to examine potential links between mean state changes and changes in the intensity and frequency of the ARs. Finally, thermodynamic factors influencing the precipitation associated with landfalling ARs over South America are probed through a separation of dynamical and thermodynamical contributors to AR trends. We then contextualize the modeled AR precipitation results by comparing the model output to observational data retrieved using the Integrated Multi-satellite Retrievals for Global Precipitation Measurement (IMERG) using an AR-centered compositing analysis.

L_PF_8

Atmospheric River Contributions to Ice Sheets at the Last Glacial Maximum

Christopher Skinner and Juan Lora

Atmospheric rivers (ARs) are an important driver of surface mass balance over today's Greenland and Antarctic ice sheets. Using paleoclimate simulations with the Community Earth System Model (CESM), we find that ARs also had a key influence on surface mass fluxes along the extensive ice sheets of the Last Glacial Maximum (LGM). Because of widespread glaciation into the mid latitudes, the ice sheet margins intersect the poleward flanks of the climatological AR storm tracks, leading to orographic lift within landfalling ARs, and some of the greatest AR-derived precipitation totals of any terrestrial region at the time. Ice sheet-AR interactions are especially pronounced in the North Atlantic basin as ice sheet-driven enhancements to regional baroclinicity lead to frequent AR activity. ARs provide up to 15-25% of total precipitation along the margins of the South American, western North American, and European ice sheets, and 40-50% of total precipitation along the margins of the eastern North American ice sheet. During the winter, spring, and fall seasons, surface temperatures within AR events are 10 – 20°C warmer on average than seasonal climatological temperatures, though most of the AR precipitation falls as snow. However, during summer, warm AR temperatures often lead to substantial amounts of rain along the margins of the ice sheets, suggesting that ARs may have also had an important role in surface melt events during previous glacial periods.

R_PO_1

Towards a circumpolar view of synoptic drivers for Antarctic atmospheric rivers

Benjamin Pohl (CNRS/U. Bourgogne), Rebecca Baiman (U. Colorado), Jonathan Wille (CNRS/U. Grenoble-Alpes), Vincent Favier(CNRS/U. Grenoble-Alpes), Kyle Clem (U. Wellington), Andrew Winters (U. Colorado)

Previous studies have emphasized the importance of wave patterns over the Southern Ocean to channel moisture from the mid-latitudes towards Antarctica, thereby forming the most favorable conditions for the development of atmospheric rivers (ARs). An atmospheric low to the west of an AR with an atmospheric high to the east, evident in both the lower and middle troposphere, were identified as necessary but not sufficient for ARs to occur, and the available moisture in the subtropical to middle latitudes may be another important feature to consider to explain the space-time variability of ARs.

Here, we attempt to provide a circumpolar view of AR-favorable conditions by considering longitudinal profiles of 500-hPa geopotential height anomalies. ARs are locked to the steepest geopotential gradients, between a low and a high. The geopotential height anomaly profiles from timesteps with and without ARs will be used (i) to compare the conditions favorable to AR development that result in an AR to those same conditions when an AR does not occur, in order to better understand the mechanisms driving AR variability, (ii) to relate these AR-favorable conditions to modes of climate variability in the Southern Hemisphere, including the Zonal Wave 3 pattern and transient synoptic-scale disturbances propagating in the mid-latitudes, (iii) to connect the variability of AR environments to the variability of AR impacts, (iv) to assess the physical causes of AR co-occurrences: when several ARs occur at the same time at different longitudes or when several AR events impact a given region in short succession.

The methodological developments proposed in this work could help provide a global view of AR-favorable conditions around Antarctica, to better understand the time and space variability in their (co-) occurrence.

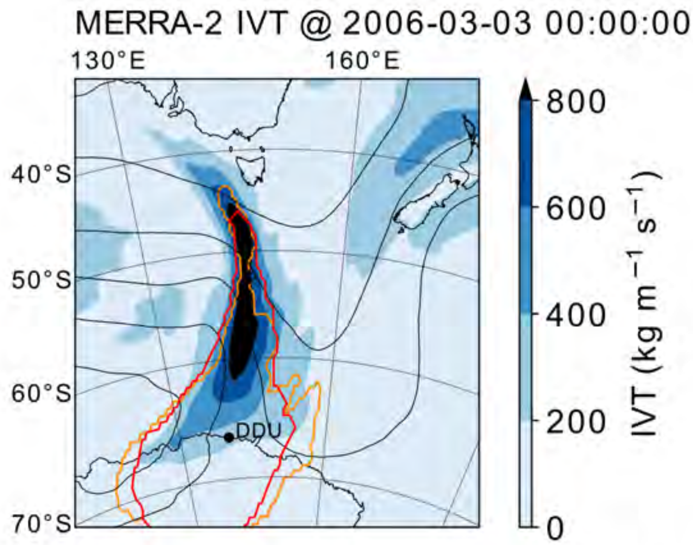


Figure 1. Example of an atmospheric river (AR) event detected by both vIVT and integrated water vapor (IWV) detection schemes on 3 March 2006. The red outline shows the delineation of the AR according to the vIVT scheme and the orange outline according to the IWV scheme. Colors represent the integrated vapor transport. Black contours show the corresponding Z700.

R_PO_2

Summer 2022 temperature extremes at the Antarctic Peninsula triggered by a strong atmospheric river and foehn

Irina Gorodetskaya[1], Xun Zou[2], Claudio Durán-Alarcón[1], Penny Rowe[3], Sergi González-Herrero[4], Niels Dutrievoz[1,5], Paola Imazio[6], Jonathan Wille[7], Sangjong Park[8], Diego Campos[9], Raul Cordero[10], Jorge Carrasco[11], Steve Colwell[12], Adriana Gulisano[13], Anastasiia Chyhareva[14], Svitlana Krakovska[14], [3]F. Martin Ralph

[1]Centre for Environmental and Marine Studies, Department of Physics, University of Aveiro, Portugal
[2]Scripps Institution of Oceanography, UCSD, Ja Jolla, CA, USA
[3]NorthWest Research Associates, Redmond, WA, USA
[4]Antarctic Group, Spanish Meteorological Agency (AEMET), Barcelona, Spain
[5]Ecole Normale Supérieure Paris-Saclay, Université Paris-Saclay, 91290 Gif-sur-Yvette, France
[6]Consejo Nacional de Investigaciones Científicas y Técnicas, Buenos Aires, Argentina; Servicio Meteorológico Nacional, Buenos Aires, Argentina
[7]Institut des Géosciences de l’Environnement, CNRS/UGA, Saint Martin d'Hères, France
[8]Korea Polar Research Institute, Incheon, South Korea
[9]Dirección Meteorológica de Chile, Santiago de Chile, Chile
[10]University of Santiago, Santiago, Chile
[11]University of Magallanes, Punta Arenas, Chile
[12]British Antarctic Survey, Cambridge, UK
[13]Instituto Antártico Argentino, Buenos Aires, Argentina
[14]Ukrainian Hydrometeorological Institute and National Antarctic Scientific Center of Ukraine

The year 2022 started with several record-breaking events at the Antarctic Peninsula (AP): a breakup of the fast ice in the Larsen B embayment in January, record-high temperatures observed in the northern Antarctic Peninsula (AP) in February, and a record-low sea ice extent in March. Our study focuses on the heatwave affecting the AP on 7-8 February, which was triggered by a strong atmospheric river (AR), reaching category 5 (according to the classification by Ralph et al., 2019) at the western coast of Chile, continuing further south over the Drake passage and hitting the AP coast as a category 3 AR (with IVT above 750 kg m^{-1} s^{-1} lasting longer than 24 hours). The event analysis is based on ground-based in situ, remote sensing and radiosonde observations, GFS and ERA5 reanalysis data and dynamical downscaling using the Polar-WRF model at 2.67-km and at 1.2 km horizontal resolution over the AP domain. Observed near-surface temperatures ranged between +5ºC and +13ºC during the event at various stations in northwestern AP, while even higher temperatures were achieved in the leeside of the AP. Large-scale analysis using ERA5 shows that extreme temperatures in the northern and northwestern AP are directly linked to the AR warm/moist advection combined with cloud radiative forcing. A close-up look using high-resolution Polar-WRF output suggests the AR triggered strong foehn warming in the northeastern AP. Both on the upwind and leeside, the warm core is found above the surface at ~925 hPa. High temperature anomalies were concentrated over the northern Larsen C ice shelf and over the Larsen B embayment. Large-scale temperature anomalies are better captured in ERA5, while Polar-WRF at 1.2 km resolution shows more details, such as mountain waves and gap flows. Both models underestimate temperature maxima observed at the stations.

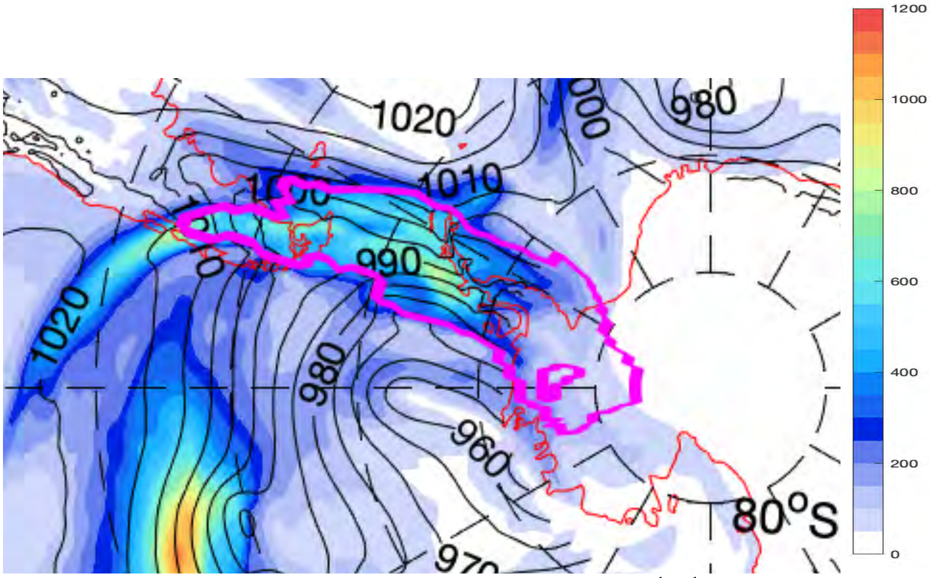


Figure: Integrated water vapour transport (colors, kg m^{-1} s^{-1}) and mean sea level pressure (contours, hPa) on 8 February 2022, 00 UTC, based on ERA5 reanalysis. The magenta contour depicts the AR shape based on Wille et al (2021) vIVT AR-tracking algorithm.

R_PO_3

Case study of the extraordinary March 2022 East Antarctic heat wave

Jonathan D. Wille presenting on behalf of the Heatwave Team

Through mid-March 2022, East Antarctica experienced an unprecedented “heat wave” with temperatures in the higher elevation Antarctic Plateau rising 30-45° C above the March average. In the backdrop of the Antarctic continent quickly transitioning to its coreless winter, these temperature extremes rivaled record maximum temperatures observed during peak summer. In one case, the Dome C II automatic weather station installed in 1980 set an all-time temperature record of -9.4 °C on March 18^{th}. The magnitude and extent of these astonishing temperature anomalies generated large public interest in mainstream media outlets and the Antarctic scientific community.

A historically intense atmospheric river (AR) event was the culprit for the extreme temperature advection into the East Antarctica interior. The origins of the AR extend back to an extra-tropical cyclone emerging from the Intertropical Convergence Zone in the South Atlantic that picked up moisture from a tropical temperate trough over South Africa and tropical cyclones over the Indian Ocean. Using the AR intensity scale originally designed for the mid-latitudes, this AR event in mid-March was just shy of being a category 5. During and shortly after the event, relatively heavy snow was observed on the Antarctic Plateau, high rainfall amounts and modest melting were simulated along some coastal regions, and the small Conger Ice Shelf coincidently collapsed.

This presentation will share results from the nearly 50-member team of researchers examining the synoptic-scale meteorological drivers, atmospheric river landfall, temperature and isotope observations, surface energy balance, surface mass balance, and link with the Conger Ice Shelf collapse.

R_PO_4

Far infrared radiative signatures of polar atmospheric rivers in simulated PREFIRE observations

Kyle S. Mattingly[1], Stephanie A. Henderson[2], Tristan S. L'Ecuyer[2,3], Aronne Merrelli[4], Nathaniel B. Miller[1]

[1]*Space Science and Engineering Center, University of Wisconsin–Madison, Madison, WI, USA*

[2]*Department of Atmospheric and Oceanic Sciences, University of Wisconsin–Madison, Madison, WI, USA*

[3]*Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin–Madison, Madison, WI, USA*

[4]*Department of Climate and Space Sciences and Engineering, University of Michigan, Ann Arbor, Michigan, USA*

Intense moisture transport by atmospheric rivers (ARs) influences a number of coupled earth system processes in the polar regions, including ice sheet surface melt, sea ice variability, atmospheric blocking, and liquid and solid precipitation. Although these AR impacts on other earth system processes are increasingly well documented, the underlying physical mechanisms are in many cases poorly observed and understood. In particular, the modification of far infrared radiation by water vapor and clouds within ARs has not been reliably quantified, as no systematic spectrally-resolved measurements of emissions within this portion of the electromagnetic spectrum have been taken from space.

The upcoming NASA Polar Radiant Energy in the Far InfraRed Experiment (PREFIRE) mission will address this observation gap by measuring the spectral, spatial, and temporal variations of polar far infrared emission at wavelengths up to 50 micrometers. These measurements will be accomplished by a pair of CubeSats in sun-synchronous orbits with widely spaced equator crossing times, each carrying a Thermal InfraRed Spectrometer (TIRS) instrument with spectral channels spanning 4–54 µm.

In advance of PREFIRE launch, a dataset of simulated far infrared spectra along simulated CubeSat orbits has been developed by applying a model of the TIRS instrument to modelled radiances from the Principal Component-based Radiative Transfer Model coupled to GEOS FP-IT reanalysis. Here we identify the intersection of these orbits with Arctic and Antarctic ARs identified in MERRA-2 reanalysis, and analyze the influence of ARs on simulated far infrared radiation by comparing within-AR simulated spectra to those outside of AR boundaries. These results preview the insights into earth system processes that PREFIRE measurements will provide after launch.

R_PO_5

Foehn Warming over the Antarctic Peninsula Amplified by Strong Atmospheric Rivers

Penny Rowe[1], Xun Zou[2], Irina Gorodetskaya[3], Raul Cordero[4], Jonathan Wille[5], Anastasiia Chyhareva[6,7], F. Martin Ralph[1], David Bromwich[8], Brian Kawzenuk[2], and Zhenhai Zhang[2]

[1] NorthWest Research Associates, Redmond, WA, USA.
[2] CW3E, Scripps Institution of Oceanography, University of California San Diego, CA, USA
[3] University of Aveiro, Centre for Environmental and Marine Studies, Department of Physics, Aveiro, Portugal.
[4] University of Santiago, Santiago, Chile.
[5] IGE/CNRS, University Grenoble-Alpes, France.
[6] Ukrainian Research Hydrometeorological Institute, Department of Applied Meteorology and Climatology, Kyiv, Ukraine.
[7] National Antarctic Scientific Center of Ukraine, Kyiv, Ukraine.
[8] Byrd Polar and Climate Research Center, The Ohio State University, Columbus, OH, USA.

The Antarctica Peninsula (AP) has experienced more-frequent and intensified warm events in the past few decades. Foehn events (strong, warm downslope winds) are major contributors to surface melting on the leeside of the AP, and contributed to the collapse of the Larsen A and B ice shelves in 1995 and 2002. When atmospheric rivers (ARs) propagate over the AP mountain barrier, strong leeside foehn warming can occur due to latent heat release via precipitation on the upwind side; foehn cloud clearance, which allows strong downward shortwave radiation (DSR) to reach the surface; and enhancement of sensible heat transfer from the upper foehn flow to the surface. The detailed mechanisms and their strengths vary from case to case, affecting the magnitude of warming.

Here we present an analysis of two extreme surface warming/melting cases over the AP, occurring in 2018 and 2022, with the goals of improving our understanding of the relationship between ARs and foehn warming and the impact of clouds on the surface energy balance (SEB). High-resolution Polar WRF (PWRF) V4.3.3 with modified P3 scheme, Reference Elevation Model of Antarctica (REMA) high-resolution topography, and surface observed MODIS albedo are used to identify and quantify the contribution of each physical mechanism. Observations, including radiosoundings and broadband radiation, are used to contextualize the SEB and validate model results. Radiative transfer calculations are used to quantify the radiative contribution and cloud forcing. Both 2018 and 2022 cases were characterized by extensive leeside foehn warming and strong AR impacts. With heavy precipitation on the upwind side, we find enhanced DSR due to foehn clearance to be the major driver for warming over the northeastern AP during the daytime (DSR > 750 Wm^{-2}). Peak warming occurred at night, when the sensible heat flux was found to be the dominant contributor.

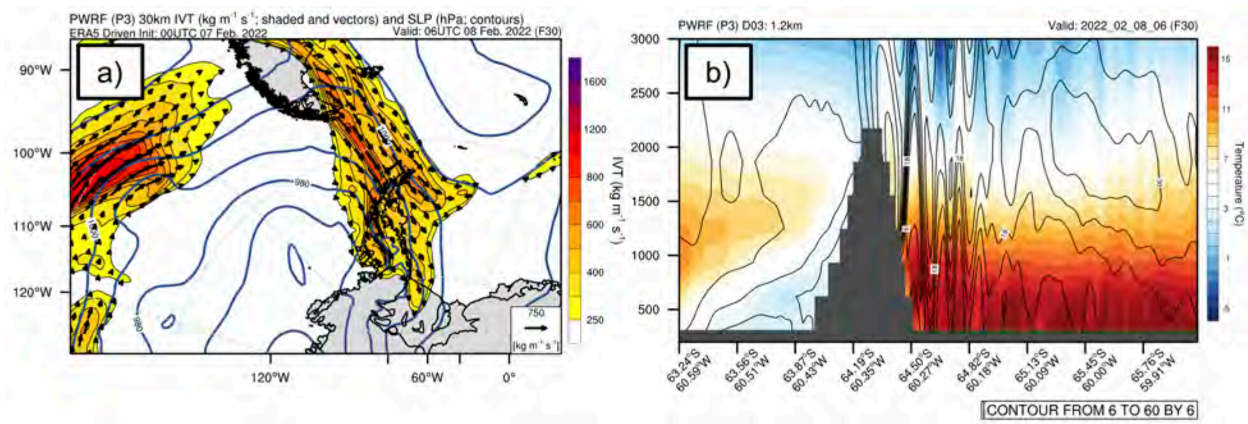


Figure 1. a) Atmospheric river making landfall on the AP on 2022/02/08 06 UTC, indicated by integrated vapor transport (IVT), based on Polar WRF (driven by ERA5). Contours show sea level pressure (SLP; hPa). b) Cross section of the northern AP region showing the foehn effect: temperatures (colors) and winds (contours, m/s) on the lee (east) side, based on Polar WRF (driven by ERA5).

R_PO_6

Rainfall and snowfall during two strong atmospheric river events in the Antarctic Peninsula in summer 2022: characterization and evaluation of impact on surface mass balance

Claudio Durán-Alarcón[1], Irina V. Gorodetskaya[1], Anastasiia Chyhareva[2,3], Penny Rowe[4], Xun Zou[5], Niels Dutrievoz[1,6], Svitlana Krakovska[2], Oleksandr Afteniuk[2], Vincent Favier[7], Diego Campos[8], Raul Cordero[9], Fernanda Cabello[9], Giovanni Jiménez-Sánchez[10], Kevin Chicaeme[10]

[1]*Centre for Environmental and Marine Studies, Department of Physics, University of Aveiro, Aveiro, Portugal.*

[2]*Ukrainian Research Hydrometeorological Institute, Department of Applied Meteorology and Climatology, Kyiv, Ukraine.*

[3]*National Antarctic Scientific Center, State Institution of the Ministry of Education and Science of Ukraine, Kyiv, Ukraine.*

[4]*NorthWest Research Associates, Seattle, WA, USA.*

[5]*Center for Western Weather and Water Extremes, Scripps Institution of Oceanography, USA.*

[6]*Ecole Normale Supérieure Paris-Saclay, Paris, France.*

[7]*CNRS, IRD, Grenoble INP Institute of Engineering, Université Grenoble Alpes, Grenoble, France.*

[8]*Dirección Meteorológica de Chile, Chile.*

[9]*Universidad de Santiago de Chile. Av. Bernardo O'Higgins 3363, Santiago, Chile.*

[10]*Fuerza Aérea Colombiana, Bogota, Colombia.*

Abstract

During February 2022 two intense atmospheric rivers (ARs) affected the Antarctic Peninsula (AP), bringing with them significant amounts of water vapour and heat to this polar region. Both events reached an AR3 ("strong") scale in the northernmost part of the AP, based on the intensity and duration of the integrated vapour transport (IVT) (Ralph et al., 2019). The first event, which occurred between February 7 and 8, was responsible for extreme air temperature records at several weather stations in the area and produced significant precipitation in the western part of the Antarctic Peninsula, mainly in the form of rain (Fig1A). Snowfall also occurred during this AR event in the western AP, but it was accompanied by significant melting (Fig1E), while in the northernmost part of the AP the precipitation was light. The second event, between 21 and 24 February, was characterized by more intense precipitation, mainly in the form of snow, in the western part of the AP, especially near the coast between Anvers and Adelaide islands (Fig1D). This study focuses on investigating the precipitation component of these two AR events, using observations at Escudero Station, located in the northern part of AP, and Vernadsky Station, located in the western AP, as well as reanalysis data. The vertical structure and the evolution over time of precipitation is analyzed using vertically-pointing radar observations, a micro rain radar (MRR) at Escudero and a MRR-PRO at Vernadsky station, surface weather data, and radiosondes (only at Escudero). ERA5 reanalysis data is compared with in-situ and ground-based remote sensing observations, and is applied to evaluate the impact of rainfall and snowfall on the surface mass balance in the AP, in combination with polar-WRF outputs.

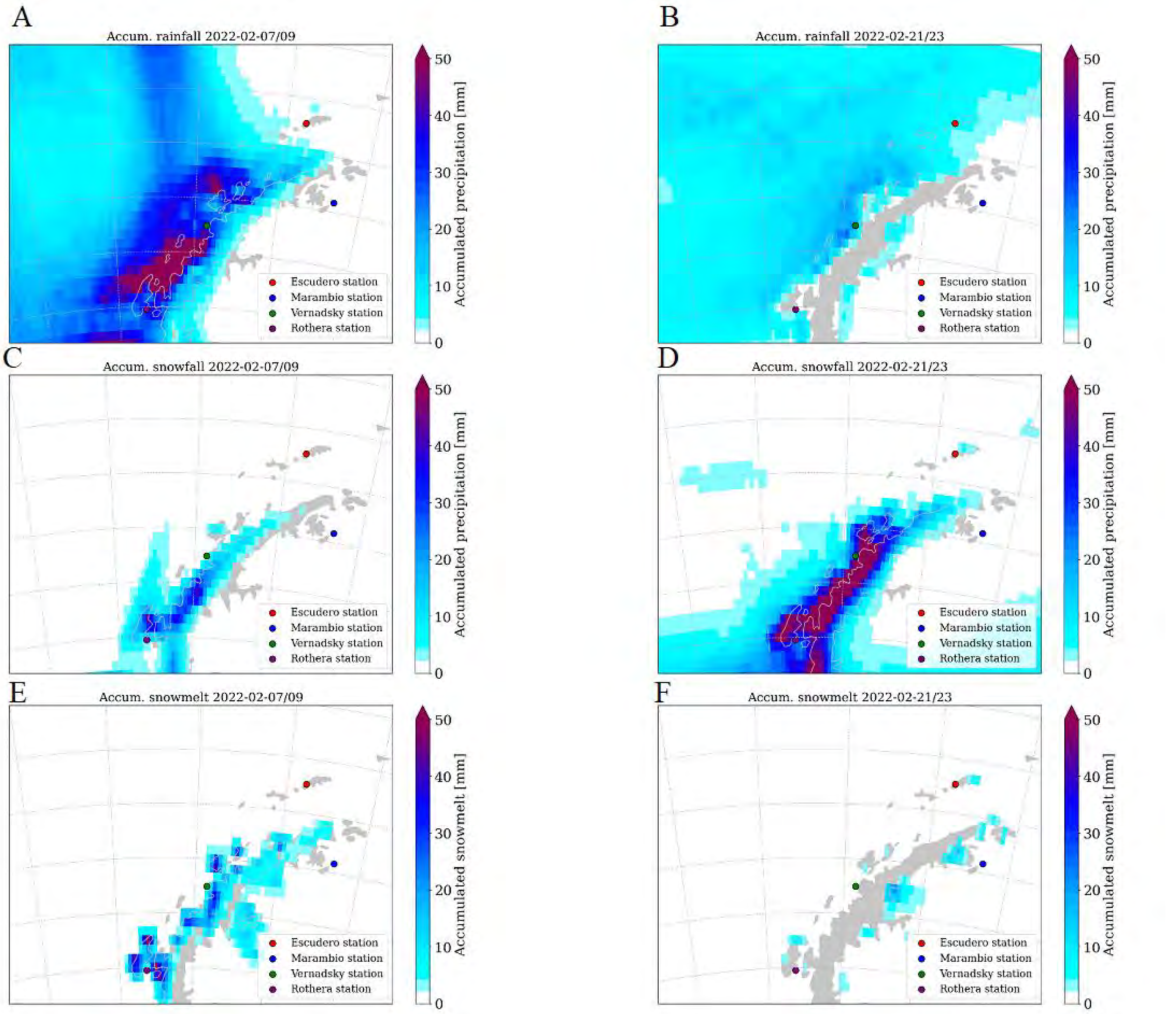


Figure 1. ERA5 rainfall (A, B), snowfall (C, D) and snowmelt (E, F) during the two atmospheric river (ARs) events analyzed in this study.

R_PO_7

Atmospheric River during MOSAiC in Mid-November 2019: Transformation Processes and Impact on the Surface Energy Budget

Sofie Tiedeck[1], Benjamin Kirbus[2], Irina Gorodetskaya[3], Susanne Crewell[4], Annette Rinke[1]

[1]Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2]Insitute for Meteorology, University of Leipzig, Leipzig, Germany
[3]Department of Physics and CESAM, University of Aveiro, Aveiro, Portugal
[4]Institute for Geophysics and Meteorology, University of Cologne, Cologne, Germany

Atmospheric Rivers (ARs) can carry anomalously high amounts of water vapor into the Arctic. It has been shown that the associated enhanced moisture in the atmosphere leads to increased downward longwave radiation and related surface warming. In this work we focus on an event which occurred in mid-November 2019, where an AR penetrated the Arctic from the northern North Atlantic and passed over the RV Polarstern during the MOSAiC expedition.

We provide a comprehensive study of this AR event, its spatiotemporal structure and impact on the surface energy budget (SEB) with respect to the surface type. We use ERA5 reanalysis data and model output from limited area simulations of ICON (ICON-LAM). The Eulerian view is complemented by Lagrangian trajectories to evaluate the transformation of air masses. Furthermore, results from ICON-LAM sensitivity studies concerning different parameters (e.g., amount of intruding moisture) are discussed to provide enhanced process understanding.

We find that the event shows a less negative SEB over open ocean and a change from negative to positive SEB over sea ice. The main contribution of this effect over open ocean is due to both a less negative surface sensible heat flux and less negative longwave net radiation, whereas over sea ice the dominant factor is a positive sensible heat flux. Reducing the inflowing moisture causes a reduced impact on the SEB, especially due to less clouds over open ocean and less downward longwave radiation.

R_PO_8

Title: The changing climate and Atmospheric Rivers (ARs) in the Arctic.

Authors:

Rudradutt Thaker[1,2], Christine A. Shields[3], Stephen Vavrus[2], Alice K. DuVivier[3], Marika M. Holland[3], Laura Landrum[3]

[1] Dept. of Atmospheric and Oceanic Sciences, University of Wisconsin, Madison, WI, USA

[2] Nelson Institute Center for Climatic Research, University of Wisconsin, Madison, WI, USA

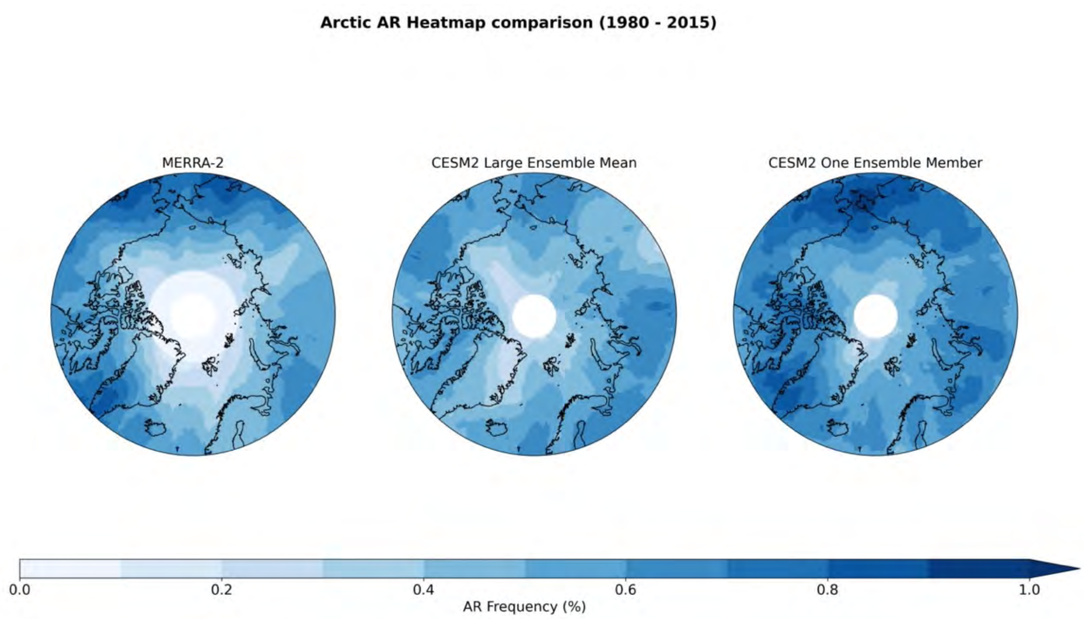
[3] National Center for Atmospheric Research, Boulder, CO, USA

Abstract: *(Words: 270)*

Arctic sea ice has been declining rapidly in recent decades due to the warming and moistening Arctic. Previous studies have shown that temperature and moisture advection due to Atmospheric Rivers (ARs) contribute to both increasing precipitation and surface melting in the Arctic. An overall increasing trend in Arctic ARs is found using the MERRA-2 reanalysis for the years 1980-2020, using a restrictive Atmospheric River Detection and Tracking (ARDT) algorithm. Enhanced sea-ice loss is observed during AR conditions, prominently in the winter season (NDJFM) and regions near the Greenland, Barents, and Kara Seas. Moreover, the increasing background trend of sea-ice loss may lead ARs to penetrate farther into the Arctic, highlighting that it is crucial to understand the evolution of ARs in a warming climate and their contribution to sea-ice loss. Due to the limited time period of the reanalysis datasets, we use the Community Earth System Model version 2 (CESM2) Large Ensemble dataset to investigate the longer-term effects of climate change on ARs in historical times from 1850 - 2015 and in a future climate scenario through the end of the 21st century. The 40 ensemble members for the historical simulation and the 50 ensemble members for the future climate scenario provide sufficient data points to distinguish natural variability from the forced signal affecting atmospheric rivers in the past, present, and future. We have run the ARDT using output from the historical simulation for

the years 1980-2015 to compare model results with MERRA-2 to determine biases. We are extending the analysis to the entire historical and future simulation (1850-2100) to analyze the evolution of ARs and the associated sea-ice loss.

Figure:



Atmospheric River Impacts in Arctic and Alpine regions: Development of an AR alerting tool for cold regions in a rapidly warming climate

By Melinda M. Brugman(ECCC), Ruping Mo(ECCC), Aaron Jacobs (USA NOAA National Weather Service Juneau AK WFO), Matthias Jakob(BGC Engineering), Alex Cannon(ECCC), Ka Hing Yau(ECCC), Philip Jarrett(ECCC), Rita So (ECCC), Eimile McSorley(ECCC), Juris Almonte (ECCC). Ashlee Jollymore (BC, RFC), Armel Castellan(ECCC), Sara Hoffman (ECCC), Shannon Hicks-Jalali(ECCC), Anthony Liu(ECCC) and Roxanne Vingarzan(ECCC)

Atmospheric Rivers in cold climates can lead to profound impacts that are distinct from those encountered in warmer climates. So far, when the AR rating scale (Ralph et al, BAMS 2019) is applied in northern latitudes, it rarely yields high ratings despite the fact that many storms create dangerous impacts. In this paper, we discuss the development and application of a new atmospheric river alerting tool for Canada and Southeast Alaska (called "ECAR") which builds upon the AR storm rating, based on IVT and storm duration, by addressing impacts. Specifically, we explore application of (AR and ECAR) storm rating tools developed for the mountain and northern areas of western Canada and nearby Alaska which have similar forecast challenges. Recent record-breaking storms in northern and alpine areas have led to heavy snowfalls, dangerous blizzards, rapidly changing snow levels, unexpected freezing rain, icing, flooding, landslides, avalanches, high winds and/or unusual river and sea ice conditions and major impacts. The AR storm ratings are examined and compared with the ECAR ratings using our best operational guidance. For ECAR, a weighted approach is used to include critical storm tracking variables (such as IVT and duration) and weather event return periods (such as precipitation based on Intensity Duration Frequency and runoff annual exceedance probability). Recent record breaking events examined include the locally catastrophic December 2020 event at Haines, Alaska that also affected critical transportation routes into the southwestern Yukon and northwestern BC. Preliminary results indicate that measuring atmospheric rivers with an impacts-based rating scale linked to consequences adds value to decision-making. Climate change projections of AR storms in cold regions highlight the critical need for improved forecasts in those regions. Next steps include consultation with local communities to improve the usefulness of ECAR predictions in arctic, alpine and northern regions.

R_PO_10

Detecting Moisture Pathways – Linking Atmospheric Rivers and Warm Moist Intrusions

Clemens Spensberger[1], Kjersti Konstali[1] & Thomas Spengler[1]

[1] Geophysical Institute, University of Bergen, and Bjerknes Centre for Climate Research, Bergen, Norway

The water vapor transport in the extratropics is mainly organized along narrow elongated filaments. These filaments are often referred to with a variety of names depending on the contexts. When making landfall on a coastline, they are generally be referred to as atmospheric rivers; when occurring at high latitudes, many authors regard them as warm moist intrusions; when occurring along a cold front and near a cyclone core, the most commonly used term is warm conveyor belt. Here, we propose an algorithm that detects these various moisture pathways in instantaneous maps of the vertically integrated water vapor transport.

The detection algorithm extracts well-defined maxima in the water vapor transport and connects them to lines of maximum transport, i.e., moisture pathways. By requiring only a well-defined maximum in the vapor transport, we avoid imposing a threshold in the absolute magnitude of this transport (or the total column water vapor). Consequently, the algorithm is able to pick up moisture pathways at all latitudes without requiring region-specific tuning or normalization.

We demonstrate that the algorithm can detect both atmospheric rivers and warm moist intrusions. Atmospheric rivers sometimes consist of several distinct moisture pathways, indicating the merging of several moisture filaments into one atmospheric river. Finally, we showcase the synoptic situations and precipitation patterns associated with the occurrence of the identified moisture pathways in example regions in the low, mid, and high latitudes.

R_PO_12

Atmospheric River Scale for the Polar Regions

Zhenhai Zhang[1], F. Martin Ralph[1], Xun Zou[1], Brian Kawzenuk[1], and Irina V. Gorodetskaya[2]

[1] *Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, University of California, San Diego, USA*

[2] *Centre for Environmental and Marine Studies, Department of Physics (CESAM), University of Aveiro, Aveiro, Portugal*

An atmospheric river (AR) is a long, narrow, and transient corridor of strong horizontal water vapor transport. Recent studies found that ARs are often associated with heavy precipitation, strong wind, high temperature, and surface melt in the polar regions. Both intensity and duration of ARs are of critical importance to their impacts. Ralph et al. (2019) introduced a scale to characterize the strength and impacts of ARs. For a specific location, the AR scale is determined based on the AR intensity measured as the maximum integrated water vapor transport (IVT) and the duration of AR conditions. A minimum IVT threshold, 250 kg m^{-1} s^{-1}, is used to define AR conditions. However, this minimum IVT threshold is selected mainly based on the IVT climatology at the middle latitudes. It is not applicable for the polar regions due to the nature of low temperature and low moisture there. In this study, we examine the climatology of IVT in the Antarctic and Arctic regions, and then select a new minimum IVT threshold, 100 kg m^{-1} s^{-1}, to determine AR conditions there. The climatology of AR durations is investigated at selected latitudes in the polar regions. Based on these results, we introduce a new polar AR scale for the Antarctic and Arctic regions in addition to the regular AR scale from Ralph et al. (2019). The new polar AR scale better characterizes the strength and impacts of ARs in the Antarctic and Arctic regions and aims to enhance situational awareness and forecast communication for those regions.

R_PO_13

IARC Polar Session

Machine Learning for High Latitude AR Detection

***Christine A. Shields**, National Center for Atmospheric Research, Boulder, CO
Sol Kim, University of California, Berkeley, Department of Geography, Berkeley, CA
Katie Dagon, National Center for Atmospheric Research, Boulder, CO
Annette Greiner, Lawrence Berkeley National Laboratory, Berkeley, CA
Karthik Kashinath, Lawrence Berkeley National Laboratory, Berkeley, CA

*Presenting/in-person author

Traditional ARDTs (Atmospheric River Detection Tools) apply a set of criteria to define an atmospheric river (AR), typically in gridded datasets, based on threshold values that can be characterized with absolute and/or relative values, where relative values refer to either spatial or temporal environments. Threshold-free methods have now emerged in the field of feature detection as a means of avoiding the pitfalls of threshold values, especially when defining ARs across different climate states. Machine learning (ML) methods are one example of a threshold-free technique used to identify ARs. Machine learning applied to ARs is a form of artificial intelligence where computer programs automatically identify ARs, but first must be trained with data. The vast majority of ML ARDTs use training data designed for mid-latitudes and are not always appropriate for high latitude regions such as the Arctic or Antarctica. Here, we introduce a Climate Contouring Tool, developed by Lawrence Berkeley National Lab, specifically designed to create a training dataset for high latitude ARs. A previous version of this tool has been successfully deployed for mid-latitudes ML ARDTs and is described in Kashinath et al., 2021, a participating member of ARTMIP, the Atmospheric River Tracking Method Intercomparison Project. We seek to create an appropriate training dataset for polar latitudes and introduce the Climate Contouring Tool to the workshop community. We invite attendees to participate in a polar AR labeling campaign during the workshop and encourage its application via web interface at any time. Once the training dataset is compiled, we will develop both Arctic and Antarctic-specific ARDTs. Collaborators are welcome.

Kashinath, Karthik, et al. "ClimateNet: an expert-labeled open dataset and deep learning architecture for enabling high-precision analyses of extreme weather." *Geoscientific Model Development* 14.1 (2021): 107-124. https://doi.org/10.5194/gmd-14-107-2021

https://www.nersc.gov/research-and-development/data-analytics/climatenet/

R_PO_14

Atmospheric Blocking Patterns around the Antarctic Peninsula and Their Influences on Temperature and Moisture Transport

Deniz Bozkurt[1,2,3], Julio C. Marín[1], and Bradford S. Barrett[4]

[1]Department of Meteorology, University of Valparaíso, Valparaíso, Chile
[2]Center for Climate and Resilience Research (CR)2, Santiago, Chile
[3]Center for Oceanographic Research COPAS COASTAL, Universidad de Concepción, Concepción, Chile
[4]Oceanography Department, U.S. Naval Academy, U.S., and Air Force Office of Scientific Research, Santiago, Chile

This study analyzes the seasonal evolution and trends of atmospheric blocking and their influences on moisture transport and extreme temperature events around the Antarctic Peninsula for the period 1979-2020. A geopotential height-based method based on the ECMWF's ERA5 and its predecessor ERA-Interim was applied over two domains, one located to the west (150-90W, 50-70S) and the other over and to the east (90-30W, 50-70S) of the Antarctic Peninsula. Spatial patterns of geopotential heights on days with blocking feature well-defined ridge axes over and west of much of South America, and days with the most extreme blocking (above the 99th percentile) show upper-tropospheric ridge and cut-off low features that have been associated with extreme weather patterns. Meteorological observations in the Antarctic Peninsula indicate colder conditions than the observed climatology in the Antarctic Peninsula during the blocking days over the western domain (Amundsen-Bellingshausen Sea). On the contrary, mean blocking days over and to the east of the Peninsula yield warmer conditions than the climatology. Similar to the observed pattern, ERA5 also shows statistically significant colder and warmer conditions during the blocking days over the western and eastern domains, respectively. A further analysis with reanalysis indicates that blocking days over the Drake Passage and to the east of the Peninsula are associated with statistically significant positive moisture transport anomalies towards the Peninsula coinciding with atmospheric river (AR) events, which trigger warm and humid conditions over the Peninsula, particularly in austral autumn. The largest percentages of blocking days coinciding with landfalling ARs are evident in austral autumn on extreme blocking days. These results suggest that blocking patterns around the Antarctic Peninsula can have notable impacts on AR frequency and intensity as well as extreme temperature events, particularly over the leeward side of the Peninsula and Larsen C Ice Shelf.

L_PO_1

The high-top cloud plays an efficient part in the moisture transport to the Antarctic

Kazue Suzuki[1], Terumasa Tokunaga[2], Takashi Yamanouchi[3], and Hideaki Motoyama[3]

[1]Hosei University, JAPAN

[2]Kyushu Institute of Technology, JAPAN

[3]National Institute of Polar Research, JAPAN

Corresponding author: Kazue Suzuki (kazue.suzuki.88@hosei.ac.jp)

Abstract.

We verified that the high-top cloud from satellite imaging contributed to the accumulation of snow at Syowa Station, Antarctica in the blizzard for 2009. From the snow stakes data, the accumulation in 2009 increased the most during 1993–2010 through the traverse route in East Antarctica. Focusing on the events in 2009, the high-top cloud structure in the merged satellite image often linked the atmospheric river and the values of the high-top cloud area; the heavy snow conditions were different from the light snow conditions. Some snow depth data are lacked because of strong snowstorms. We predicted a lack of data from the Kalman Filtering. The distributions between the wind direction/speed and snow depth indicated that the wind-driven erosion/deposition were equal in the snow depth data. We cannot separate the snowfall and wind-driven erosion/deposition from the snow depth, but we can still treat them as accumulation from our analysis. The distribution of snow depth and the high-top cloud area indicated a weak correlation and high accumulation. Finally, we found the seven atmospheric river events in 2009 with high positive/negative accumulations and high-top cloud areas. A comparison of precipitable water and cloud area for the seven events and other precipitation events shows that the cloud area tends to be larger on average for the events designated as Atmospheric Rivers. There was no significant difference in the amount of precipitable water, however, the arrival of continuous clouds with large values of precipitable water can be expected to bring heavy snowfall to Antarctica. Using satellite imaging and in-situ glacial and meteorological data, this method is a new fusion for finding moisture transport to the Antarctic.

L_PO_2

Atmospheric River Observations in the Canadian Arctic and Future Projections

Authors: Shannon Hicks-Jalali[1], Zen Mariani[1], Melinda M. Brugman[2], George Duffy[4], Alex J. Cannon[3], Ruping Mo[2], Jason Milbrandt[1]

1. *Meteorological Research Division, Environment and Climate Change Canada, Canada,* ***shannon.hicks-jalali@ec.gc.ca***
2. *Meteorological Service of Canada, Environment and Climate Change Canada, Canada*
3. *Climate Research Division, Environment and Climate Change Canada, Canada*
4. *University of Syracuse, New York, USA*

Session: ARs and Polar Meteorology and Climate

Atmospheric river (AR) events are increasingly making headlines as their impact on society increases due to climate change. Recent studies have shown that as global temperatures increase, ARs will begin to move farther north, even as far as the Canadian Arctic. In this study, we will show evidence that ARs and AR-like events are already affecting the Canadian Arctic and discuss climate projections for the region.

In 2015, Environment and Climate Change Canada (ECCC) established a research supersite in Iqaluit, Nunavut (63.75°N, 68.55°W) to study polar processes in support of the World Meteorological Organization's Year of Polar Prediction as part of the Canadian Arctic Weather Science project. We present case studies of AR and AR-like events in Iqaluit using ground- and satellite-based remote sensing observations and evaluate ECCC's operational weather forecast model, GEM-HRDPS (Global Environmental Model – High Resolution Deterministic Prediction System), and the new experimental/operational post-processed HRDPS performance. We use lidars, co-located precipitation sensors, and the space-based Ku/Ka-band dual-frequency precipitation radar on the Global Precipitation Measurement (GPM) satellite to observe the extent of the precipitation over the Iqaluit region during these events.

We find that the wind and water vapour lidars are excellent tools for observing conditions prior to the onset of heavy precipitation. GEM-HRDPS is generally able to forecast the 48 hr moisture and wind fields with minor discrepancies. However, comparisons with co-located ground-based precipitation sensors and GPM satellite measurements show that while GEM-HRDPS generally forecasts the magnitude of the precipitation, the timing of the precipitation is several hours later than observed. Climate projections for the Canadian Arctic show an increasing number of AR events with increasing severity over the next century. Finally, we discuss suggestions for improving impact-based Arctic weather forecasting of AR in a rapidly warming climate.

The stronger warming in the Arctic compared to the global mean – a phenomenon called as Arctic Amplification - has different effects, including changes in the hydrological cycle and thus the precipitation. In the Arctic, there are two major sources of moisture leading to increased precipitation formation: These are the enhanced local evaporation due to the missing insulation of sea ice and the poleward moisture transport which is often associated with atmospheric rivers (ARs).

Preliminary results have shown that ARs are a significant source for rain and snow in the Arctic. However, precipitation associated with an AR was not only concentrated within the AR itself. Precipitation also occurs within a wider area of the cyclones often connected to ARs. Therefore, we developed a new method based on ERA5 reanalysis to distinguish precipitation within the AR shape and the precipitation related to cyclones. The application of this method for case studies during two campaigns (ACLOUD May/June 2017; AFLUX March/April 2019) has shown seasonal differences. During the early summer campaign, precipitation (both rain and snow) was more confined within the AR shapes. Whereas during the late winter and early spring campaign, precipitation (predominantly snow) was more restricted to the cyclone regions. Generally, a higher precipitation intensity was found in cases where ARs and cyclones were connected to each other. However, how do the seasonal differences look like when analyzing the last few decades? To answer this question, we apply this method to quantify the occurrence and influence of ARs and related cyclones during the last decades. For this climatological analysis we use the ERA5 reanalysis data for the period from 1979-2020 as input for two AR detection algorithms (Guan & Waliser, 2018; and Gorodetskaya, 2020).

This work is supported by the DFG funded Transregioproject TR 172 "Arctic Amplification (AC)³".

L_PO_3

L_PO_4

Climatology of Atmospheric Rivers and Associated Surface Warming in the Arctic: Regional Relationships With Teleconnection Patterns

Chen Zhang[1], Wen-wen Tung[1], and William S. Cleveland[2]
[1]Department of Earth, Atmospheric, and Planetary Sciences
[2]Department of Statistics
Purdue University, West Lafayette, IN

Atmospheric rivers (ARs) has been known to interact with Arctic warming and sea ice decline in the boreal winter. Through a detailed climatological study of ARs penetrating the Arctic, we highlight the evidence that teleconnection patterns modulate AR activities over several distinct Arctic regions. We analyzed the climate variability of an ensemble of 12 AR indices based on Integrated water vapor transport or integrated water vapor using 3-hourly, 0.25^o x 0.25^o ERA5 data or 3-hourly, 0.625^o x 0.5^o NASA MERRA-2 data from 1980 to 2019. In addition, we used NASA CERES SYN1deg surface radiation, passive-microwave sea ice concentration from Nimbus-7 SMMR and DMSP SSM/I-SSMIS, and NOAA Climate Prediction Center teleconnection indices. The AR tracking and analysis were executed via distributed-parallel computing on a Hadoop cluster using the Divide & Recombine approach.

We divided the Arctic according to the K-means clustering of AR's monthly variability into four regions: (1) the central Arctic, (2) Arctic Pacific sector covering the margins of sea ice zone over Chukchi Sea, (3) Northeast Canada/Greenland, and (4) Arctic Atlantic sector extending to the Eurasian continent. AR spatial recurrences according to the K-means clustering analysis were roughly consistent across all 12 indices in ERA5 and MERRA2, and effectively reflect the teleconnection patterns' modulation of ARs. Synoptic circulations associated with the teleconnection patterns, the jet stream, and the storm track appeared to modulate the most extreme Arctic ARs in both reanalysis. Along AR's track, strong eddy kinetic energy, enhanced warming and moistening, increased downward longwave radiation, and associated sea ice concentration decline were observed. Particularly, during the negative phase of the Pacific-North American pattern in the winter, Arctic warming and North American continent cooling were detected at the same time. While during the positive phase of Arctic Oscillation, North America warming and Eurasian warming were observed simultaneously.

Divergence of Moisture Transport inside Arctic Atmospheric Rivers from Long-Range Research Aircrafts – A Feasibility Study in High-Resolution Model Data

Quantifying the divergence of moisture transport in arctic atmospheric rivers (ARs) is key to understand processes in their precipitation efficiency. However, since sparse observations hamper the determination of arctic moisture transport, dedicated research flights aim to fill this gap. We investigate to what extent long-range research aircrafts can derive this moisture transport divergence in arctic ARs. Dropsondes quantify integrated water vapour transport (IVT) along AR cross sections. Yet, limited number of dropsondes may deteriorate calculations of IVT divergence so that uncertainties have to be assessed.
Synthetically, we consider nine ARs from spring season covering Greenland Sea pathways being typical for arctic ARs. The new C3S Arctic Regional Reanalysis (CARRA) and an adapted ICON model configuration monitor arctic ARs with horizontal resolutions of around 2.5 km. To assess airborne capabilities in deriving IVT divergence, we generate synthetic flights and mirror airborne soundings in both gridded datasets. We identify sources of error arising in the IVT variability and its divergence.

For those ARs, moisture and wind speed contribute most to IVT below 1500 m. Some ARs show low-level jets where only frequent soundings resolve the IVT variability. Sounding spacing above 100 km causes biases of total IVT higher than 10 %. We emphasize that moisture transport divergence behaves different across the frontal structure of arctic ARs. While mass convergence and moisture advection are highest prefrontal close to the AR centre, divergence dominates in post-frontal sectors. Using regression methods, dropsondes reproduce these sector-based tendencies, in general, but strong biases partially occur for individual AR events. With the overall aim to analyse all moisture budget components of arctic ARs, we give first insights on preliminary observations from the HALO-(AC)³ flight campaign in spring 2022.

L_PO_5

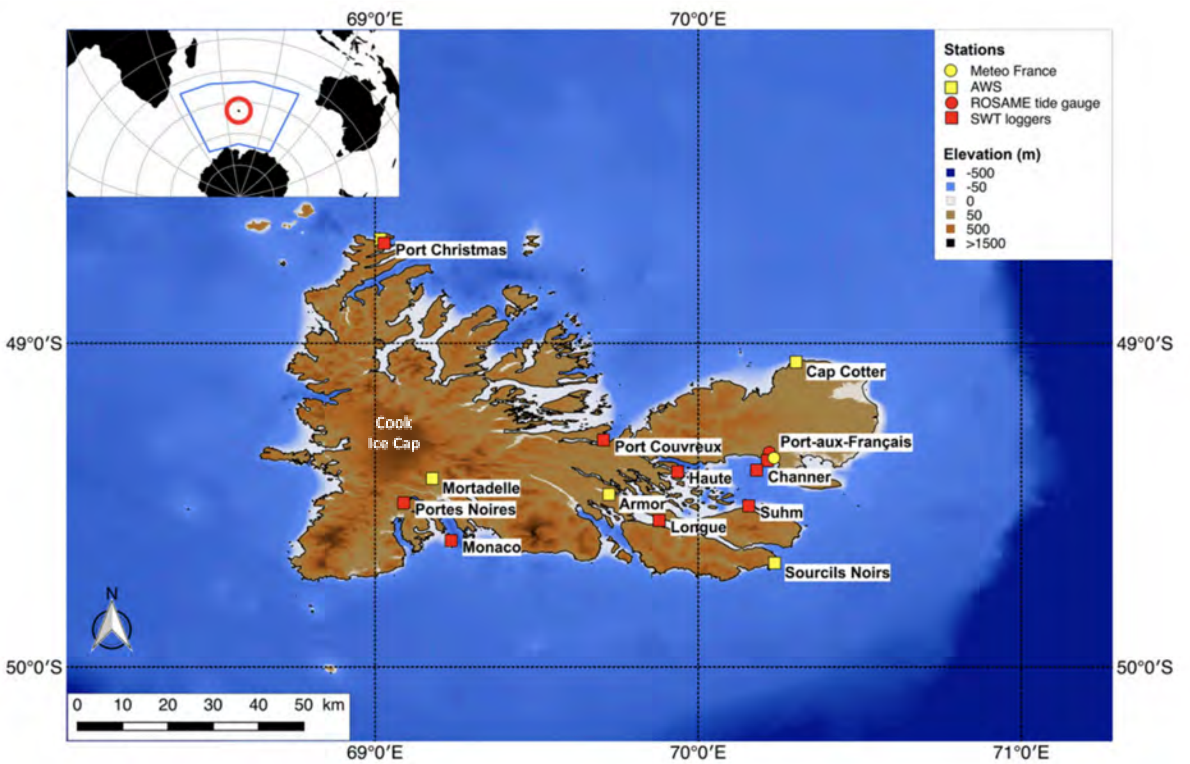
L_PO_6

Atmospheric Rivers, Weather Types, changes in the general circulation, and their influence on the Cook Ice Cap (Kerguelen Island)

Victoire Buffet[1,2], Benjamin Pohl[1], Vincent Favier[2], Jonathan Wille[2], Thomas Saucède[1]

1 Biogéosciences, CNRS / univ. Bourgogne Franche-Comté, Dijon, France
2 IGE, CNRS / univ. Grenoble-Alpes, Grenoble, France

The Kerguelen Islands in the Southern Ocean are dominated by the Cook Ice Cap, which shows one of the most negative surface mass balance on Earth. Understanding the causes of such rapid glacier wastage is challenging in this isolated region, far from dense observational networks.
Previous work has identified a series of 10 weather types (WTs) that shape the climate of the region, and can be used as a key to understand the space and time variability of the climate variables that control the glacier mass balance. Here, we propose to complement this approach with a new set of descriptors that monitor the intensity and location of atmospheric centers of action, that is, atmospheric highs and lows, over and around the region of Kerguelen. Following approaches that cross-compare atmospheric rivers (AR) and WTs over the New Zealand sector, our next step will be to consider the AR events that make landfall at Kerguelen, and estimate to which extent they affect the mass balance of the local glaciers, including the main Ice Cap. The specific and combined influence of ARs and WTs in the occurrence of climate extremes in Kerguelen will finally be addressed, using two complementary and original networks that monitor the main atmospheric and subsurface oceanic variables at contrasted sites in these islands.



Location of the Kerguelen Island (Southern Ocean), and the main sites where atmospheric or subsurface oceanic measurements are performed.

L_PO_7

Increase in Interannual Variability of Poleward Moisture Transport to the Arctic linked to Atmospheric Rivers

Marlen Kolbe[1], Jeroen Sonnemans[2], Richard Bintanja[1,3], Karin van der Wiel[3], Kirien Whan[3], and Imme Benedict[2]

1 Groningen University, Groningen, Netherlands (m.kolbe@rug.nl)
2 Wageningen University & Research, Wageningen, Netherlands
3 Royal Netherlands Meteorological Institute (KNMI), RDWK, Netherlands

Owing to the significant contribution of remote processes on Arctic climate, there is great interest in understanding and predicting future trends and variability of poleward moisture transport (PMT). Numerical studies predict a significant increase in PMT, mainly linked to the larger moisture holding capacity of warmer air masses. Along with this mean increase, interannual variability of PMT to the Arctic is increasing at an unexpectedly high rate. As there is no strong consensus for why this is the case, we studied the extent to which this increase in interannual PMT variability can be explained by an increase in interannual variability of atmospheric rivers (ARs).

To do this, we examined Arctic ARs in present and future climates simulated in a global climate model (2°C and 3°C warmer than the pre-industrial climate). It is found that most PMT variability is driven by Arctic ARs, especially over the Atlantic Ocean and to a lesser extent over the Bering Strait. In years with high PMT, a relatively large share is transported by ARs, up to 50% in the present-day climate. Moreover, our findings suggest that interannual AR-related PMT variability is more sensitive to variations in AR-intensity compared to AR-frequency in the present as well as in warmer climates. This implies that increasing interannual PMT variability is dominantly driven by the increase in PMT per AR rather than the increase in AR-occurrence. Finally, our results point at a strong contribution of ARs to interannual variability of Arctic precipitation and temperature patterns.

Is there Evidence for Short-Term Fluctuations in Ice Flow and Glacier Retreat at Glaciers in Fuego-Patagonia due to Landfalling of Atmospheric Rivers

Lukas Langhamer[1], Tobias Sauter[1], Franziska Temme[2], Niklas Werner[3], Florian Heinze[1], Inti Gonzalez[4,5], Jorge Arigony-Neto[6], Ricardo Jaña[7], Stephanie Weidemann[1,8], and Christoph Schneider[1]

[1]Geography Department, Humboldt-Universität zu Berlin, Berlin, Germany
[2]Institut für Geographie, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
[3]Department of Physcial Geography, Stockholm University, Sweden
[4]Programa Doctorado Ciencias Antárticas y Subantárticas, Universidad de Magallanes, 6200000 Punta Arenas, Chile
[5]Centro de Estudios del Cuaternario de Fuego-Patagonia y Antartica, 6200000 Punta Arenas, Chile
[6]Universidade Federal do Rio Grande - FURG, Rio Grande, Brasil
[7]Instituto Antártico Chileno, 6200000 Punta Arenas, Chile
[8]Department of Geography, RWTH Aachen University, Aachen, Germany

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Correspondence: Lukas Langhamer (Lukas.Langhamer@hu-berlin.de)

Submitted to: International Atmospheric Rivers Conference 2022

Abstract

Glaciers along the Andean Cordillera are among the fastest shrinking ice bodies in the world, with most of the glacier melt occurring in Patagonia. In Patagonia the majority of glaciers are calving to sea or proglacial lakes. Their continuous contribution to global sea level rise is subject to temporal fluctuations modulating the long-term climate-induced retreat of glaciers. Strong ablation events in austral summer due to warm phases interrupted by land-falling atmospheric rivers have been observed in the past. We hypothesize that this combination is responsible for an event-based immense ice loss of glaciers in Fuego-Patagonia and might become more frequent under future climate conditions as a response to global climate warming.

Two exemplary glaciers (Glacier Grey, Southern Patagonia Icefield, and Glacier Schiaparelli, Cordillera Darwin) are studied with respect to extreme events such as heat, cold, wet and dry spells. Ice flow velocity is estimated by feature tracking technologies based on in-situ time lapse camera photography and remote sensing data. Extreme events are identified by automatic weather stations in vicinity of the glacier and reanalysis data from numerical weather prediction models. Glacier melt is continuously monitored by a lake level sensor and modelled by the coupled snowpack and ice surface energy and mass balance model (COSIPY). This study focuses on the interplay between ice dynamical processes and atmospheric variability from 2015 to 2022. The key question is: Do individual extreme events such as heat waves or heavy precipitation associated with land-falling atmospheric rivers have a direct impact on the ice flow velocity and the glacier calving activity?

The ice flow velocity increases by $\sim 50\%$ during the cold winter months. During this period the velocity is most sensitive to temperature changes. Enhanced calving activities can be triggered by extreme events.

L_PO_9

Influence of atmospheric rivers on extreme high temperature events over the Antarctic Peninsula

Victoria Moya[1,2], Roberto Rondanelli[1,2], Deniz Bozkurt[1,3], Martin Jacques[1,4]

[1]Center for Climate and Resilience Research (CR)2, Santiago, Chile.
[2]Department of Geophysics, University of Chile, Santiago, Chile.
[3]Department of Meteorology, University of Valparaíso, Valparaíso, Chile.
[4]Department of Geophysics, University of Concepción, Concepción, Chile.

Corresponding author: moyav.victoria@gmail.com

In recent decades, a general warming trend has been detected in the Antarctic continent, specifically in the western and northern areas of the Antarctic Peninsula (AP). This temperature increase is largely associated with large-scale circulation changes, such as the Antarctic Oscillation.

In addition to changes in large-scale westerlies, the AP has also been influenced by large-scale meridional forcing, which has resulted in episodic extreme weather events in the AP. Recently, record high-temperatures accompanied with heat waves (HW) on the eastern side of the AP were linked to atmospheric rivers (ARs), such as the last two absolute records of temperature in the Antarctic continent at the Esperanza station (March 24, 2015 and February 6, 2020).

The present work seeks to analyze how ARs can condition the HW events in the AP. For this purpose, HWs and ARs were quantified between 1980-2019 at five Antarctic bases (Frei, Vernadsky, Rothera, Esperanza and Larsen). The results show that autumn season (MAM) appears to have the highest number of HW events with ARs (32.2%). A further analysis was performed to characterize synoptic conditions during these events for the Frei (windward side) and Esperanza (leeward side) stations.

The results show that the HW with ARs landfall over the AP are warmer and longer in both stations, especially in Esperanza compared to the climatology. However, observations at the Esperanza station highlight that the HWs events with and without ARs were mainly caused by local foehn events which were more intense during the AR conditions.

Conversely, in the case of Frei station, the analysis showed that interestingly the HW events without AR conditions yield also relatively large IVT values considering the climatology, which appears to be linked with warm and moist air advection due to the ARs landfall over the southern tip of South America.

L_PO_10

Abstract for the International Atmospheric Rivers Conference 2022:
https://cw3e.ucsd.edu/iarc2022/

Summer atmospheric rivers during February 2022 at the Antarctic Peninsula: large-scale circulation, moisture sources and precipitation

Niels Dutrievoz[1,2], Irina Gorodetskaya[1], Claudio Durán-Alarcón[1], Christophe Leroy-Dos Santos[1], Anastasiia Chyhareva[3], Svitlana Krakovska[3], Cecile Agosta[4], Elise Fourre[4], Amaelle Landais[4], Jonathan Wille[5], Vincent Favier[5], Thomas Dethinne[6], Christoph Kittel[6]

[1]Centre for Environmental and Marine Studies, Department of Physics, University of Aveiro, Portugal
[2]Ecole Normale Supérieure Paris-Saclay, Université Paris-Saclay, 91290 Gif-sur-Yvette, France
[3]Ukrainian Hydrometeorological Institute and National Antarctic Scientific Center of Ukraine
[4]Laboratoire des Sciences du Climat et de l'Environnement, LSCE-IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, Gif-sur-Yvette, France
[5]Institut des Géosciences de l'Environnement, CNRS/UGA, Saint Martin d'Hères, France
[6]Department of Geography, UR SPHERES, University of Liège, Liège, Belgium

Max number of words: 300, current: 297

Atmospheric rivers (ARs) are strong intrusions of moisture and heat that play a fundamental role in the Antarctic surface mass and energy balance. Despite that 90% of the moisture transfer from mid-latitudes to the poles is caused by ARs, the characteristics and the impacts of these events are still poorly understood in Antarctica. Our study focuses on the ARs affecting the Antarctic Peninsula (AP) during 7-8 and 21-22 February 2022, which led to positive temperature records and heavy rainfall on the AP, respectively. The objectives of this study are to understand how these ARs are embedded into the large-scale atmospheric circulation, and to improve our understanding of the contribution of ARs to moisture transport and their representation in models.

The study is based on the dataset collected during the field campaign at the AP (Vernadsky and Escudero stations) in January-March 2022, including radiosonde/weather observations, and isotopic measurements of precipitation, combined with ERA5 reanalysis and high-resolution simulation by regional climate model MAR. The 500-hPa geopotential height anomalies (from ERA5) show a positive phase of the Southern Annular Mode. February also shows a strong positive integrated vapor transport (IVT) anomaly in the southern central Pacific corresponding to the sea surface temperature and evaporation anomalies. The back-trajectory analysis combined with ERA5 thermodynamic parameter changes along the trajectories of the first AR event showed that subtropical central Pacific played an important role in supplying moisture at the Vernadsky site at the level of precipitation formation where the melt layer was observed. In contrast, for the second AR event, the moisture source was more confined to the southeast Pacific and in midlatitudes. The analysis of the isotopic signatures from precipitation samples collected at both sites is ongoing and will be used to validate/interpret moisture sources and air mass transformation along the way.

L_PO_11

Arctic atmospheric rivers in historical and future climates and associated impacts

Irina V. Gorodetskaya (1), Annette Rinke (2), Alfredo Rocha (1), and Susanne Crewell (3)

1. CESAM – Centre for Environmental and Marine Studies, Department of Physics, University of Aveiro, 3810-193 Aveiro, Portugal

2. Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI), Potsdam, Germany

3. Institute for Geophysics and Meteorology, University of Cologne, Cologne, Germany

Atmospheric rivers (ARs) play a crucial role in the transport of heat and moisture to the polar latitudes, which can cause extreme precipitation and heat events, influencing the surface mass and energy balance. Thus, with the continuous increase of temperature, and consequent transition towards a rain dominated Arctic, that has already been noticed during the last years, ARs might even become more important to the Arctic and global climate system.

In this study we use three different tracking algorithms (Gorodetskaya et al. (2020) and Wille et al. (2021), both adapted to the Arctic, and Guan and Waliser (2019) global algorithm). The analysis of historical climate (from 1980 to 2021) based on MERRA-2 reanalysis points to the warming and moistening of the near-surface and upper atmosphere, together with a transition from snowfall to rainfall due to increasing temperatures. The Barents and Kara Seas show the larger temperature increases, while the largest changes in snowfall (decrease) and rainfall (increase) occur in Greenland Sea. An important influence of ARs on air temperature and precipitation phase was also found. Furthermore, the results indicate a large sensitivity to the algorithm choice.

The analysis is extended to the future climate (from 2081 to 2100), using CMIP6 global model outputs, based on two socioeconomic pathways (SSP1-2.6 and SSP5-8.5), comparing with the 1995 to 2014 historical period. The CMIP6 models were selected considering the availability of the data needed to apply the AR algorithm and to assess their impacts. Based on these datasets, the results point to a warming with no regional agreement between models. Also, it is expected a continuous increase of rainfall, mainly in Greenland, Barents and Kara Seas, concurrently with decreasing snowfall. However, in continental Siberia and Greenland snowfall might increase. Further analysis of the changes of ARs and their impacts is still ongoing.

Isotopic signature of winter extreme precipitation events at Dumont D'Urville

Christophe Leroy-Dos Santos[1,2], I. Gorodetskaya[1], C. Durán-Alarcón[1], C. Agosta[2], E. Fourré[2], A. Landais[2], J. Wille[3], C. Genthon[4]

[1] Universidade de Aveiro, Portugal
[2] Laboratoire des Sciences du Climat et de l'Environnement, Paris
[3] Institut des Géosciences de l'Environnement, Grenoble
[4] Laboratoire de Météorologie Dynamique, Paris

In a context of global warming and sea level rise acceleration, it is key to estimate the evolution of the atmospheric hydrological cycle in the polar regions, which directly influences the surface mass balance (SMB) of Antarctic ice caps, the biggest fresh water reservoir. The positive component of SMB is associated with synoptic events that bring precipitation toward the inlandsis. Recent research has categorized some of these particularly intense poleward moisture fluxes as atmospheric rivers (ARs), and connected them to highest precipitation events across the Antarctic ice sheet. Those particular events can be associated with at least 10% of the annual snowfall budget in East Antarctica with only a few occurrences per year. The high moisture content within the AR is often related to moisture export from the lower latitudes.

AR specificities, such as the primary moisture source more in the lower latitudes (as far as subtropics), distinguish them from other "normal" synoptic events, therefore it could result in a specific isotopic signal.

Here, we have used a unique data set (3 years of continuous monitoring) of stable isotopic composition of water vapour at Dumont D'Urville in parallel with back-trajectories analyses, micro rain radar observations and ECHAM6-wiso (an isotope-enabled global climate model) to understand what drives the isotopic signals during major precipitation events. We focus on 4 winter events (see Figure) that are associated with nearly 10% of the cumulative precipitation over this period (3 of those are detected as AR by detection algorithm (Wille et al., 2019)).

First, we link the recorded d-excess (a second order parameter) signal to evaporation conditions at the identified moisture sources. Second, we evaluate the influence of katabatic wind and associated snowfall sublimation on d-excess in other cases. Finally, we study the differences between measurements and ECHAM6 at DDU and assess how the model reproduces the mechanisms at play.

Asymmetrical pattern of meridional atmospheric sensible and latent heat fluxes at the entrance to the Arctic

Mikhail Latonin[a,b,*], Leonid Bobylev[a], Igor Bashmachnikov[a,b]

[a]*Nansen International Environmental and Remote Sensing Centre, Saint Petersburg, Russia*

[b]*Saint Petersburg State University, Saint Petersburg, Russia*

*Corresponding author.

E-mail address: mikhail.latonin@niersc.spb.ru

L_PO_14

Abstract

High-latitude atmospheric meridional energy transport is of essential importance for the Arctic climate system. However, despite numerous studies, there are no established clear regional features of the atmospheric energy transport components from a large-scale perspective. This study investigated the internal energy and its instantaneous sensible and latent heat transports in the troposphere across the Arctic gate at 70°N using the high-resolution climate reanalysis ERA5. We have done a regional analysis of the time series of heat fluxes across the zonal section and found by decomposing them into empirical orthogonal functions that they have opposing features for the Eastern and Western Hemispheres. In particular, the variability of sensible heat transport dominates in the Western Hemisphere, whereas that of the latent heat transport dominates in the Eastern Hemisphere. Moreover, the existence of an anti-phase pattern between the hemispheres for each of these components in the entire troposphere was detected for the entire studied period 1950–2019. We hypothesize that there is a large-scale convergence of moisture transport into the Arctic in the Eastern Hemisphere. This might be due to the combined influence of the predominant extratropical cyclone tracks from the North Atlantic and North Pacific and the Siberian atmospheric rivers.

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R_SE_1

The Social Value of Hurricane Forecasts

Renato Molina (Presenting author)
University of Miami
renato.molina@rsmas.miami.edu

Ivan Rudik
Cornell University
irudik@cornell.edu

Keywords: value of information, hurricanes, forecast
JEL Codes: H41, Q54

Hurricanes are amongst the most common and costliest type of natural disaster in the United States. To help reduce their impact, the government has devoted significant efforts to improve hurricane forecasting capabilities, and since 2005, track and wind speed error have been reduced by about 40% each. However, and despite these remarkable achievements, the economic benefits of these improvements remain uncertain. In this paper, we shed light on this issue by empirically deriving the ex-ante value of hurricane forecast information, and the aggregated demand for hurricane forecast precision.

To credibly establish the social value of hurricane forecast, our study overcomes several challenges. First and foremost, the task requires a seamless integration between atmospheric modelling and economics. Second, we are also required to establish the causal relationship between a forecast, the emergency actions taken by private households, and the additional economic losses that result from less or more precise hurricane forecasts. These challenges imply that any negative effects attributed to poor forecasting abilities, and more importantly the expected benefits of improving the forecast, cannot be established unless explicitly controlling for the quality of a forecast and how it drives decision-making. Documenting and pricing this relationship are the main contributions of this paper.

Using atmospheric modeling and highly granular data on responses to forecasts, we link forecast error, adaptive actions, and negative impacts of a hurricane in the continental United States since 2005, and derive multiple relationships of interest, including: the cost of forecast error, the responses to forecast signals, the prediction of damages using forecasts, and the marginal willingness to pay for forecast precision. Finally, we propose several measurements of interest for public policy, such as the social benefits associated with past and future improvements in forecast precision, as well as the overall welfare generated by publicly funded research activities.

R_SE_2

The Short-Run, Dynamic Employment Effects of Natural Disasters: New Insights

Alessandro Barattieri* Patrice Borda † Alberto Brugnoli ‡

Martino Pelli § Jeanne Tschopp¶

May 2022

Abstract

We study the short-run, dynamic employment effects of natural disasters. We exploit monthly data for 70 3-digits NAICS industries and 78 Puerto Rican counties over the period 1995-2019. Our exogenous measure of exposure to natural disasters is computed using the maximum wind speed recorded in each county during each hurricane. Using panel local projections, we find that after the "average" hurricane, employment falls by 0.5% on average. Across industries, we find substantial heterogeneity in the employment responses. In some industries employment increases, while in others employment decreases after a hurricane. This heterogeneity can be partly explained by input-output linkages.

Keywords: Hurricanes, Employment, High-Frequency Data, Local Projections
JEL Codes: E24, Q54.

*ESG UQAM. Mail: Case Postale 8888, sucursale Centre-ville Montreal (Quebec) H3C 3P8, Canada; barattieri.alessandro@uqam.ca.

†Université des Antilles, UFR des Sciences Juridiques et Economiques Campus de Fouillole - BP 270 97157 Pointe–Pitre, Guadeloupe; patrice.borda@univ-antilles.fr.

‡University of Bergamo, Department of Economics. Via dei Caniana 2 - 24127, Bergamo, Italy; alberto.brugnoli@unibg.it.

§University of Sherbrooke, Department of Economics, 2500 Blvd de l'Université, Sherbrooke, Q.C., Canada, CIREQ, CIRANO, and GREDI; Martino.Pelli@USherbrooke.ca.

¶University of Bern, Department of Economics, Schanzeneckstrasse 1, 3001 Bern, Switzerland; jeanne.tschopp@vwi.unibe.ch.

Applied Atmospheric River Science in 2032: Where Do We Go from Here?

Katerina R. Gonzales
University of Minnesota
Department of Soil Water & Climate
University of Minnesota Climate Adaptation Partnership

Research on atmospheric rivers (ARs) has risen exponentially in the past two decades. At the same time, the tangible realities of climate change have hit home. This underscores the need for actionable, usable science. Here I present a vision for actionable AR science. I highlight examples of three kinds of work: Basic science, use-inspired science, and applied science.

In example 1, I share results from a study on atmospheric river temperature. This study was inspired by work we previously published and investigates pre-landfall characteristics of ARs and their association with landfall temperature. We find that origin latitude is associated with warmer landfall temperatures, and that Pineapple Express-type ARs are warmer than other ARs in the core of winter.

In example 2, I share results from analyzing how ARs are portrayed in mass media. We look at geographic distribution and the framing of ARs as beneficial vs. harmful, and the impacts of climate change. I discuss how collaborations with social scientists are foundational to advancing the public's knowledge and attitudes about AR impacts. Ultimately, I argue that use-inspired social science research can advance climate action.

In example 3, I share highlights from a co-productive research and application project with Seattle Public Utilities (SPU). This project investigates the current state of communication related to AR impacts in the utility and aims to enhance adaptive capacity by engaging the utility's frontline workers. I share lessons learned about our research process and engagement with SPU as a project partner. I suggest that engaging practitioners and climate information users should be a top priority for the climate research community in the next decade.

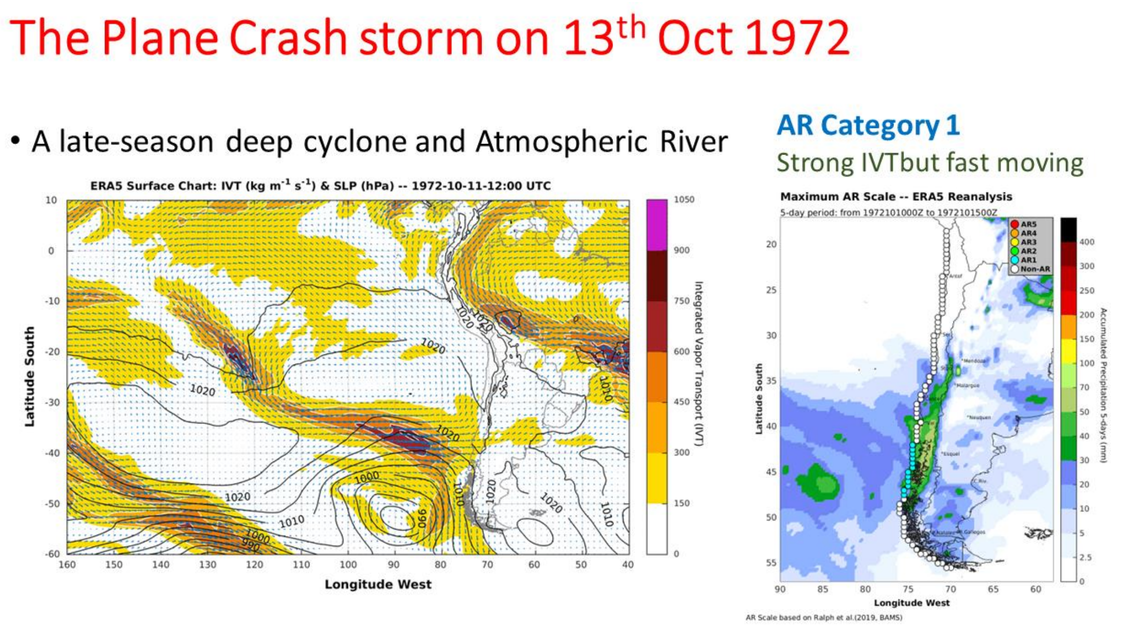
Finally, I outline a vision for applied, transdisciplinary AR research over the next decade and how we as a research community can tackle it. I argue that investment in social science, community engagement, and partnerships across sectors need to be at the forefront.

Atmospheric Rivers Storms determinant in the 1972 Andes Plane Crash and Tragedy

Maximiliano Viale

Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales IANIGLA-CONICET, Mendoza, Argentina

On October 13, 1972, Uruguayan Air Force flight 571 crashed in the middle of the Andes around 35°S. Onboard travelled an Uruguayan rugby team, along with friends and relatives. Sixteen out of the forty-five passengers survived, and their story of struggle in the high mountains during 72 days became the subject of many books and films. However, the sequence of bad weather events, related with two late season Atmospheric River (AR) storms, and the snowy seasonal conditions has not been told in details. This work describes the sequence of AR storms, and the active AR seasonal leaving one of the snowiest seasons in records that make the long survival in the Andes even more extraordinary. In the year of the 50th anniversary of the tragedy, the intention of this mountain weather work is to provide further evidences of the extreme difficulties the survivors overcame, becoming an example of fortitude and self-survival worldwide.



Occurrence and Impacts of Atmospheric River Sequences in Present and Future Climates

Back-to-back sequences of multiple atmospheric rivers (ARs) can amplify hydrologic and economic impacts relative to what would be predicted from the individual events. For example, the 2017 Oroville Dam crisis stemmed from a series of multiple moderate and strong ARs over a period of about two months. Each event on its own was unlikely to cause severe consequences, but together they filled Lake Oroville to near-overflowing and led to the evacuation of almost 200,000 downstream residents. Recent research has also indicated that sequences of back-to-back ARs like those that occurred in 2017 are likely to become more common in California due to projected shifts in the seasonality of future landfalling ARs. While we have anecdotal evidence that AR sequences are more damaging, the additional loss expected due to temporal compounding has not yet been systematically quantified.

We propose a new method to quantify the consequences of temporally compounding AR events in present and future climates. We first introduce and compare new metrics to define an AR sequence. The metrics focus on impact-relevant timescales as identified from local and state emergencies and federal disaster declarations. We then use historical observations of floods and damages in California to identify instances where losses were compounded, i.e., losses due to an AR sequence exceeded the additive losses expected from the individual component events. Lastly, we discuss how the frequency and magnitude of these sequences are anticipated to change under different warming scenarios. This work helps to reduce the uncertainty in the existing relationship between AR intensity category and expected loss and has important implications for regions like California that will be exposed to greater hydrologic volatility in the future.

R_SE_6

Climate change contributions to future atmospheric river flood damages in the western United States

Authors: Thomas W. Corringham[1]*, James McCarthy[1], Tamara Shulgina[1], Alexander Gershunov[1], Daniel R. Cayan[1], F. Martin Ralph[1].

Affiliations

[1]Center for Western Weather and Water Extremes (CW3E), Scripps Institution of Oceanography, University of California San Diego, La Jolla, California, USA.

*Correspondence to: tcorringham@ucsd.edu.

Abstract

Atmospheric rivers (ARs) generate most of the economic losses associated with flooding in the western United States and are projected to increase in intensity with climate change. This is of concern as flood damages have been shown to increase exponentially with AR intensity. To assess how AR-related flood damages are likely to respond to climate change, we constructed county-level damage models for the western 11 conterminous states using 40 years of flood insurance data linked to characteristics of ARs at landfall. Damage functions were applied to 14 CMIP5 global climate models under the RCP4.5 "intermediate emissions" and RCP8.5 "high emissions" scenarios, under the assumption that spatial patterns of exposure, vulnerability, and flood protection remain constant at present day levels. The models predict that annual expected AR-related flood damages in the western United States could increase from $1 billion in the historical period to $2.3 billion in the 2090s under the RCP4.5 scenario or to $3.2 billion under the RCP8.5 scenario. County-level projections were developed to identify counties at greatest risk, allowing policymakers to target efforts to increase resilience to climate change.

The World Meteorological Organization has encouraged a shift in the development of early-warning systems from a weather-based paradigm to an impact-based approach. Impact-Based Warning Systems (IBWS) have been adopted by many meteorological and hydrological agencies around the world. However, the development of these models comes with significant challenges due to the complex factors involved. The November 2021 atmospheric rivers (ARs) that devastated south-western British Columbia (BC), on Canada's west coast, demonstrated the large number of landslides that can be triggered by such events. With mounting concerns about public safety and transportation network interruptions, it has become apparent that the region requires a robust IBWS that incorporates the landslide impacts of future weather events. At present, there are fundamental gaps in our understanding of the number and spatial distribution of landslides associated with ARs in BC. The research presented here aims to fill these gaps by first constraining the spatial distribution of landslides with the aid of Synthetic Aperture Radar (SAR). Due to SAR's ability to map through clouds, as well as its insensitivity to light, it is one of the most capable sensors for characterising landslide events within narrow time windows, and particularly events triggered by heavy rainfall. An event window utilizing the variance in coherence between three interferograms is proposed as a method for the detection of rapid, shallow landslides in mountainous and highly vegetated terrain. The utility of this method is demonstrated using a case study centred along the storm track of BC's November 2021 AR. A comparison between the SAR results and field observations reported by various agencies immediately following the event is also discussed.

R_HM_1

Wet – Wetter – Weather: Attributing precipitation to weather features

Kjersti Konstali, Clemens Spensberger, Thomas Spengler, Asgeir Sorteberg.

Atmospheric rivers are known to link to extreme precipitation both in the high- and midlatitudes. However, there is no systematic study that considers the total contribution of atmospheric rivers to annual precipitation and its relative importance in mean versus extreme precipitation. To close this gap, we introduce a novel method to attribute precipitation to atmospheric rivers, extratropical cyclones, fronts, cold air outbreaks, as well as their combinations. For atmospheric rivers, we use a new detection scheme that requires a well-defined maximum in the moisture transport field rather than using a fixed threshold. Using this attribution method, we decompose the total precipitation into contributions by extratropical cyclones, fronts, atmospheric rivers, cold air outbreaks, and their combinations.

We assign 70% of all precipitation in the extratropics in ERA5 between 1979-2020. We find that atmospheric rivers and their combinations contribute to more than 80% of the precipitation poleward of 30 degrees while being present only 30% of the time when it rains. At high latitudes, atmospheric rivers contribute up to 50% of the precipitation around Antarctica, despite atmospheric river combinations being responsible for less than 10% of the precipitation events. Thus, although atmospheric rivers occur seldomly at these latitudes, they tend to be associated with relatively heavy precipitation. Along the stormtracks, atmospheric rivers contribute most to annual mean precipitation in combination with extratropical cyclones and fronts. Along the stormtracks, the combination of extratropical cyclones, fronts, and ARs accounts for more than 50% of the total precipitation and more than 90% of the extreme precipitation.

R_HM_2

Atmospheric Rivers (ARs) are frequent visitors to California with a very large spectrum of impacts. These ARs typically affect the state by moving ashore as strong ARs in Northern and Central California. Later, when they reach Southern California there is typically a significant loss in dynamics. As a result, much of the rainfall is of the light, steady, variety, (pockets of brief, heavier rain can occur), but overall, impacts are reduced. When there are good dynamics however, rainfall amounts (and more importantly, rainfall rates) increase, resulting in flooding. In addition, there can be severe weather, strong damaging winds, and the associated non-routine products for such phenomena (such a watches, warnings, and advisories) issued by the NWS. These products increase based on the magnitude of the AR moisture/wind/duration combined with dynamics. Locally we have been combining atmospheric river data with Model Output Statistics (MOS) data, including thunderstorm probabilities and precipitation amount forecasts (QPF). We have seen relationships between the combination of AR and MOS guidance, and the number of non-routine products issued. Based on approximately 10 years of data, the differences between mainly wind-driven, mainly moisture-driven, and mainly dynamics driven events (events with strong dynamics as the main driver) are quite apparent. Two ARs with the exact same IVT magnitude and duration can have vastly differing impacts based on their MOS thunderstorm probability values and MOS forecasted rainfall amounts. By using MOS guidance to help represent dynamics, ARs with larger MOS thunderstorm probability values and larger MOS forecasted rainfall amounts typically have resulted in enhanced impacts. The results from this research showing the impacts of added dynamics to ARs are included.

R_HM_3

Characterizing the roles of antecedent conditions as drivers of flood magnitudes from atmospheric rivers along the West Coast of the United States

Mariana Webb, Christine Albano, Adrian Harpold, Daniel Wagner, Daniel McEvoy

The precipitation regime along the west coast of the United States (U.S.) is dominated by atmospheric rivers. Given the projected shift to more variable atmospheric river magnitudes and frequencies, there is a growing need to better understand the risks associated with these storm events. Antecedent snowpack and soil moisture conditions have the potential to play an essential role in mitigating or amplifying flood impacts for a given precipitation input, as do watershed characteristics such as elevation, basin size, and subsurface water storage capacity. This study evaluates the relative roles of antecedent watershed and climate conditions as drivers of flood magnitudes resulting from atmospheric rivers in 87 watersheds along the west coast of the U.S. We use high-resolution (1km) model output from the Western Land Data Assimilation System (WLDAS) to evaluate the land surface and climate conditions, including soil moisture, snowpack, subsurface water storage, and surface temperature, associated with flooding in California, Nevada, Oregon, and Washington from 1980 to 2021. We characterize a watershed's hydrologic response to atmospheric river precipitation input using estimates of gaged peak daily discharge magnitudes corresponding to various annual exceedance probabilities determined using the updated Federal guidelines for performing peak-flow frequency analysis in Bulletin 17C. We then examine how antecedent flood drivers vary spatially among watersheds with different characteristics. While a watershed's flood response is primarily moderated by the magnitude of precipitation input, which varies with storm intensity, duration, and orientation, we aim to identify the antecedent watershed and climate conditions that amplify this flooding. This study contributes to a larger body of atmospheric river research that can potentially help to inform water supply management and mitigate flood risk.

R_HM_4

Impact of Winter Atmospheric Rivers on the Snowpack in the Headwaters of the Euphrates and Tigris Basin

Yasemin Ezber[1], Deniz Bozkurt[2,3,4] and Omer Lutfi Sen[1]

[1]Eurasia Institute of Earth Sciences, Istanbul Technical University, Istanbul, Turkey
[2]Department of Meteorology, University of Valparaíso, Valparaíso, Chile
[3]Center for Climate and Resilience Research (CR)2, Santiago, Chile
[4]Center for Oceanographic Research COPAS COASTAL, Universidad de Concepción, Concepción, Chile

Atmospheric rivers (ARs) carry a significant amount of moisture mainly from over the extratropical oceans and make landfall on the west coasts of the midlatitude continents. Apart from the hydrometeorological influences on the west coasts of the large ocean basins, ARs can also have considerable influences such as orographic precipitation, warm air advection and snowmelt over the inland areas of the continents. In these areas, ARs can be beneficial, hazardous, or both depending on the water vapor content and duration. In particular, ARs can provide efficacy for the regions with limited water resources contributing to the snow accumulation during the cold season. The Near East region including the headwaters of the Euphrates-Tigris Basin, is one of such water-stress regions, nonetheless, AR studies are lacking over this region. Therefore, this study aims to characterize impacts of winter ARs on the snowpack in the headwaters of the Euphrates-Tigris Basin. We use ERA5 reanalysis data and a state-of-the-art AR database for the winter season (1979-2019, December-January-February). Preliminary results indicate that AR conditions lead to more snowfall events than those in non-AR conditions. Moreover, we also highlight that warm air advection, snowmelt and runoff are evident under the AR conditions. This ongoing study also investigates inter-annual and spatial variations of AR-induced hydrological variables in winter in the region.

R_HM_5

On Hurricane Ida's aftermath and associated extreme rainfall

Sofia Menemenlis (1), Gabriel Vecchi (2), David Luet (2), Lucas Harris (3), Kai-Yuan Chen (3), Kun Gao (3), Matthew Morin (3), Linjiong Zhou (3), James Smith (4), Mary Lynn Baeck (4), Stephan Fueglistaler (1)

(1) Program in Atmospheric and Oceanic Sciences, Princeton University, Princeton, NJ, USA
(2) Department of Geosciences, Princeton University, Princeton, NJ, USA
(3) NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA
(4) Department of Civil and Environmental Engineering, School of Engineering and Applied Science, Princeton University, Princeton, NJ, USA

Hurricane Ida made landfall over Louisiana as a category 4 hurricane on 29 August 2021. Ida's extratropical transition involved an atmospheric river with elevated water vapor transport stretching to the northeastern United States, where supercell thunderstorms brought extreme short-duration rainfall and deadly flooding to eastern Pennsylvania, New Jersey, and New York City on the evening of 1 September 2021.

To investigate relationships between extreme rainfall and the large-scale environment, we simulate Ida and Ida's aftermath using a version of GFDL's System for High-resolution prediction on Earth-to-Local Domains (SHiELD). The model configuration includes a global 13-km grid with a nested 3.5-km tropical Atlantic domain, with the ability to resolve many aspects important to mesoscale convection. We analyze the distributions of precipitation and environmental characteristics in an ensemble of 31 simulations: one baseline and 30 with slight random perturbations added to their initial conditions.

When compared to polarimetric radar-based precipitation reconstructions, the ensemble of SHiELD simulations initialized on 30 August captures the overall spatial pattern of 24-hour (from 12 UTC on 1 September to 12 UTC on 2 September) rainfall accumulations across the northeastern US. Corridors of elevated vertically integrated water vapor transport, and precipitable water exceeding 60 mm, appear consistently across the ensemble. However, the spatial and temporal locations of hourly-scale rainfall extremes vary substantially between simulations. Although Ida's remnants and associated atmospheric river create an environment favorable for extreme precipitation in the northeastern US, the evolution of mesoscale convection—which is highly sensitive to initial conditions in these simulations—determines which locations are most severely impacted.

R_HM_6

Contributions of an Atmospheric River to the Severe Thunderstorms in Eastern Canada on 21 May 2022: Occurrence of a Windy AR

Ruping Mo[1], Melinda M. Brugman[1], Cindy Yu[2], Daniel Brown[3], Anthony Q. Liu[3], Bin Yu[4], and Hai Lin[5]

[1]National Laboratory–West, Environment and Climate Change Canada, Vancouver, BC, Canada

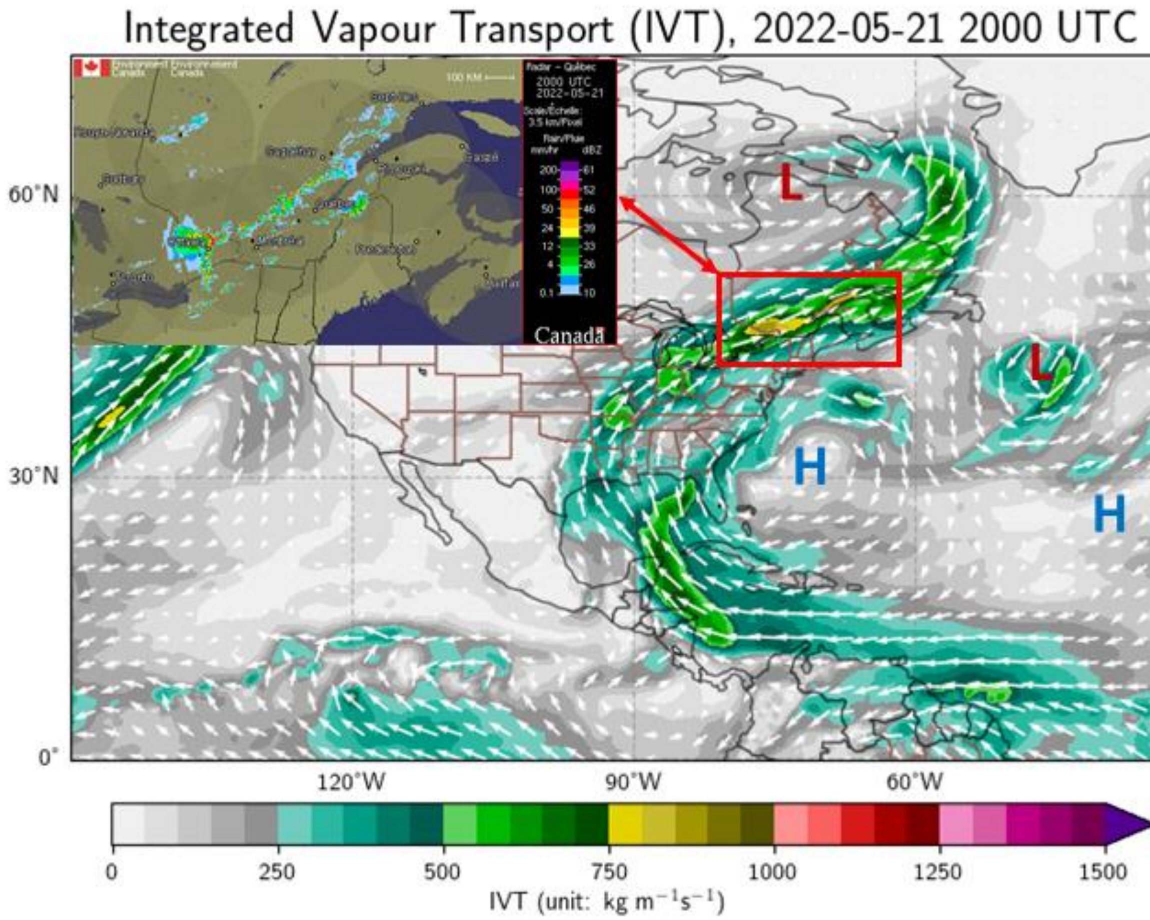
[2]Dissemination Systems, Environment and Climate Change Canada, Vancouver, BC, Canada

[3]National Laboratory-West, Environment and Climate Change Canada, Edmonton, Alberta, Canada

[4]Climate Research Division, Environment and Climate Change Canada, Toronto, Ontario, Canada

[5]Meteorological Research Division, Environment and Climate Change Canada, Dorval, Quebec, Canada

Abstract: A cluster of severe thunderstorms known as derecho developed in Eastern Canada on 21 May 2022. This strait-line convective system caused widespread wind damage, affecting millions of people with lengthy power outages, property destructions, and body injuries with at least 11 fatalities. In this study, we perform a detailed analysis of the associated meteorological conditions, focusing on the contributions of an atmospheric river (AR) to the development of this rare event. It is shown that a developing cyclone acted as the major engine to drive a quasi-stationary AR across central and eastern North America. This corridor of strong moisture transport provided an almost inexhaustible source of warm and humid air to support the thunderstorm development. The warm layer aloft with the AR formed a cap to trap low-level convective energy, leading to stronger thunderstorms in the afternoon. The slow-moving cold front with the cyclone provided the dynamic instability to trigger elevated convection. The strong unidirectional wind shear with the AR provided another favourable condition for severe convection. The derecho formed in the afternoon right under the AR core. The associated downdraft produced strong wind gusts near the ground. The dry conveyor belt behind the cold front could enhance the evaporation of raindrops and lead to stronger downdraft wind. A stable high-pressure system over the Atlantic Ocean facilitated the moisture transport from the tropical Atlantic through the Gulf of Mexico into the United States. The AR section in Eastern Canada were further augmented by continental moisture sources from the Great Lakes and the United States. The combined effect of the Madden-Julian Oscillation and the lingering La Niña on the extratropical atmospheric circulation is also investigated. The main features of this AR were well forecast by the Canadian numerical weather prediction models with useful lead times up to four days.



Vertically integrated vapor transport (IVT) based on the European Centre for Medium-Range Weather Forecasts ERA5 reanalysis, valid at 2000 UTC 21 May 2022. The embedded image shows the corresponding radar echoes in Eastern Canada.

R_HM_7

Influence of atmospheric rivers in the variation of rain shadow strength across the southern Andes (34-38°S)

Yazmina Rojas, Justin Minder
University at Albany, State University of New York

The complex terrain of south-central Chile (34 – 38°S), including a coastal mountain range, a central valley, and the Andes Mountains, with elevation from 1000 to 2000 m, can be hit by midlatitude cyclones arriving from the Pacific Ocean. The interaction of these frontal systems, often accompanied by atmospheric rivers, with the topography of the area enhances the precipitation on the west side of the Andes, and suppresses it on the east side, producing a strong climatological rain shadow. Nevertheless, event-to-event variability in winter precipitation shows that some storms produce substantial spillover precipitation over the Argentinian side, leading to variations in rain shadow strength. Processes and mechanisms responsible for the differences between strong and weak rain shadows, and the modulation of these differences by atmospheric rivers, remain to be explained.

Using rain gauge observations, we characterized variability of heavy precipitation events (80th percentile) in Chile and Argentina for the winter months (May to September). We defined a rain shadow index and classified strong rain shadow (SRS) and weak rain shadow (WRS) events, as the 20% of the higher and 20% of the lower values of the index, respectively. Composite analysis using ERA5 suggest that SRSs have larger integrated vapor transport values, that might be associated with atmospheric rivers in the warm sector of midlatitude cyclones. ERA5 will be also used to investigate the variation of rain shadow strength depending on AR intensity and orientation. To investigate the mechanisms that lead to rain shadow variation in more detail, including the role of atmospheric rivers, we used the Weather Research and Forecasting Model (WRF), to simulate and analyze SRS and WRS events.

Analyzing the impact of atmospheric rivers on severe storms development in Chile

Authors: Julio C. Marín, Martin Jacques-Coper, Diana Pozo, Felipe Gutiérrez R_HM_8

Abstract

Severe storms and tornadoes a not usual phenomena in Chile. However, a number of tornadoes have been reported in recent years partially associated with a growing population in usually deserted areas of south-central Chile, and an easier access to record and post the occurrence of these events in social media.

After the tornado outbreak of May 2019 in south-central Chile, recent studies explored the synoptic and mesoscale conditions present during these events, as well as the influence of the ocean temperature and geographic factors on their occurrence. These studies have helped us to better understand some of the aspects favoring severe storms and tornadoes in Chile, also indicating that these events seem to occur more often than previously thought. However, there are still other aspects that need to be investigated. In particular, it would be interesting to analyze the possible role of atmospheric rivers on the occurrence of severe storms and tornadoes in Chile, which is motivated by the fact that tornado formation seems to have a maximum from May to August, coinciding with the maximum frequency of landfalling ARs in the region. This work aims to shed some light on this topic.

L_HM_1

An Evaluation of High-Resolution Regional Climate Model Simulations of Atmospheric River Impacts on Orographic Precipitation and Snowpack in the Southern Andes

Atmospheric Rivers (ARs) provide necessary, and sometimes extreme, moisture in the hydroclimate of the Andes mountains, where orographic precipitation is enhanced and snow accumulation increased, particularly for cold season ARs. As the climate warms, South American ARs are expected to increase in frequency and intensity, leading to increased orographic precipitation. Reduced snowpack is expected due to elevated snowlines and more rain versus snow. Improved understanding of the relationship between AR activity, orographic precipitation, and snowpack in a warming climate is needed to provide a foundation for understanding future hydroclimate change over the Andes. The goal of this research is to evaluate and understand variations in AR-associated orographic precipitation patterns and their impact on snowpack over the southern Andes (35-55°S) in high-resolution regional climate simulations. Specifically, we use ERA-5-forced Weather Research and Forecasting (WRF) simulations with 4-km grid spacing that were run for 2000-2018 over all South America by the NCAR-led South America Affinity Group (SAAG). The fine grid spacing of these SAAG-WRF simulations relative to most regional climate simulations allows them to better resolve the complex terrain of the Andes and its impact on AR-associated precipitation. The preliminary work in this study detects ARs using the IPART method (Image-Processing-based Atmospheric River Tracking), determining their orientation, intensity, and placement. Precipitation-events are classified depending on the presence/absence of an AR and on AR characteristics to examine the modulation of orographic precipitation patterns and mountain snowpack by ARs in the SAAG-WRF simulations. Simulated variations in orographic precipitation are evaluated against rain gauge observations from national networks in Argentina and Chile. Variations in snowpack are evaluated against Andean Snow Reanalysis (ASR) by Cortés and Margulis (2017). Future work will examine changes in AR-associated orographic precipitation and snow cover with pseudo-global warming simulations from SAAG.

L_HM_2

COMPARISON OF TWO CASES OF STUDY OF PRECIPITATION ASSOCIATED WITH ATMOSPHERIC RIVERS THROUGH RAIN GAUGE AND SATELLITE DATA

Florencia Ghetti Paciaroni
florenciaghettipaciaroni@gmail.com

Here we are studying Atmospheric Rivers(Ars), which show the most significant impact when they interact with topography causing intense precipitation to the east of the Andes. Two events of ARs that penetrate argentine Patagonia and make landfall along the border crossing Paso Pichachen in the Neuquen province(Argentina) have been analyzed.
In the study region, defined between 37°S- 38°S and 70°W-72°W, rainfall data was obtained from 5 meteorological stations (Antuco, Lagunilla, Chocoy Mallín, El Cholar y Chos Malal) for June 8-11(Event 1, 395.6mm accumulated) and June 26-27(Event 2, 576mm accumulated) 2018. These observations were compared with the dataset from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) to study the ability of this product to represent precipitation during these events. CHIRPS incorporates satellite information and in-situ observations to create gridded rainfall time series with 0.05° resolution.
A point-pixel analysis was performed to compare the rain gauge data from the days of the events with the observations from CHIRPS. The estimates from CHIRPS for the 5 grid points that were closer to the locations of the analyzed rain gauges were selected and both data sets were compared through statistics measures. The results obtained until now show that for Event 1, CHIRPS overestimates rainfall data from the rain gauge in the Paso Pichachén stations (linear correlation=0.132, bias=63,33% and mean absolute error=50,1mm)(Fig.1 a) while for the Event 2, CHIRPS underestimates rainfall in comparison with the rain gauge data(linear correlation=0.197, bias=-48,3% and mean absolute error=139,1mm)(Fig.1b).
Further investigation of the events includes comparing rain gauge data with sub-daily satellite data sets to analyze the diurnal evolution and also the analysis of the associated synoptic conditions.

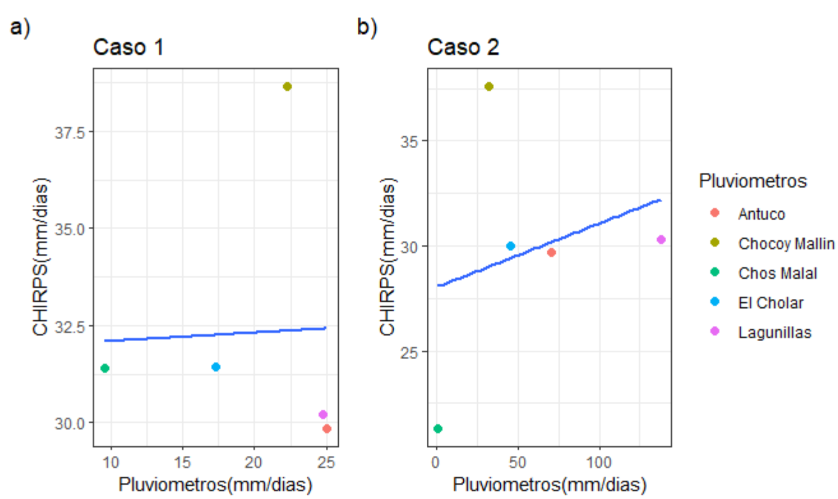


Fig. 1. Scatter plot comparing the data from the 5 rain gauges and that from CHIRPS for the Event 1(a) and the Event 2(b) with the linear regression(blue line).

L_HM_3

Zonal Atmospheric Rivers impinging south-central Chile

René D. Garreaud
Department of Geophysics and Center for Climate and Resilience Research
University of Chile, Santiago, Chile

Atmospheric Rivers (AR) landfall in the extratropical west coast of South America about 35-45 days per year -one of the largest frequencies worldwide- and contribute 45%–60% of the annual precipitation in south-central Chile. As in other regions, most ARs are located ahead of a cold front impinging the coast with its long axis oriented from NW to SE (~45° with respect to the coastline) causing moderate precipitations under cold conditions. This is a generally beneficial condition that builds up a much-needed snowpack over the Andes cordillera. A few ARs, however, develops ahead of stationary fronts extending thousands of kilometers across the South Pacific with a zonal direction and little displacement in the cross-front direction. This structure is referred to as a Zonal Atmospheric River (ZAR).

In this work we reveal the ZAR structure at the synoptic and local scale. A distinctive subtropical low and blocking high are generally present over the central Pacific several days before the storm in Chile (**Figure 1**). Poleward flow downstream of the low transports moist, warm air from its tropical reservoir into midlatitudes, and equatorward flow downstream of the blocking high steepened the north-south temperature contrast over the eastern Pacific. These two ingredients provide the conditions for the formation of the ZAR that rapidly moved eastward to reach South America. Once the ZAR landfalls, substantial prefrontal precipitation (up to 100 mm) can accumulate at the coast, inland valleys and western slope of the Andes over periods of 24-72 hours under relatively warm conditions thus increasing the pluvial area in the mountain basins. Periods of high rainfall intensity have also been observed during ZAR events. Thus, Zonal Atmospheric Rivers pose significant hydro-meteorological hazards for south-central Chile.

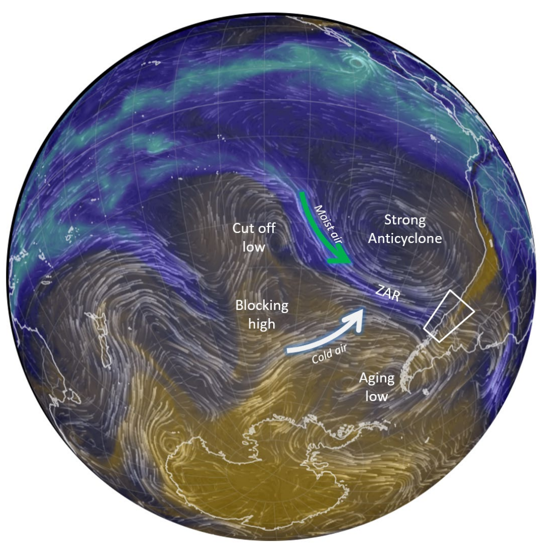


Figure 1. Precipitable water (shaded) and 850 wind vectors for 8 July 2020 when a ZAR landfall in south-central Chile (white box). Main synoptic features are identified.

L_HM_4

Identification of Atmospheric Rivers and their Impacts in Mexico 2016 – 2021

Daniela Fernanda Cuauhtémoc Vargas (Student), Leticia Gómez Mendoza (Assessor)

Colegio de Geografía, Universidad Nacional Autónoma de México (UNAM)

Atmospheric Rivers (ARs) are elongated structures responsible for the transport of moisture concentrated in the atmosphere globally. These events cause rain and snowfall that reduce the indicators of drought and forest fires and although most of them are weak, some can generate extreme precipitation. Due to its geographical location, Mexico presents a certain degree of exposure to these events that have not been previously studied in the territory. In this work, the synoptic characteristics of the ARs and their impacts in Mexico are identified, considering the temporality, duration, and volume of daily accumulated precipitation within the period 2016 - 2021, detected in official bulletins of the Center for Western Weather and Water Extremes (CW3E) of the University of California. Subsequent analysis employing satellite products of Integrated Water Vapor Transport (IVT) and Total Precipitable Water (TPW) was generated by the Cooperative Institute for Meteorological Satellite Studies (CIMSS). After the events, their impacts (floods, landslides, among others) have been identified through a hemerographic search. Nearly thirty ARs events have been detected within the period studied, which constitutes a relevant precedent in Mexico, in addition to providing critical knowledge necessary for decision-makers and risk management while taking advantage of the rainfall generated, without forgetting the opportunities opened by this new area of research at a national and international level.

L_HM_5

Influence of Atmospheric Rivers on Regional Precipitation in South Korea

Yeeun Kwon, Chanil Park, Seung-Yoon Back, Seok-Woo Son, Jinwon Kim, and Eun Jeong Cha

This study investigates the influence of atmospheric river (AR) on precipitation over South Korea with a focus on regional characteristics. The 42-year-long catalog of ARs, which is obtained by applying the automatic AR detection algorithm to ERA5 reanalysis data and the in-situ precipitation data recorded at 56 weather stations across the country are used to quantify their relationship. Approximately 51% of the climatological annual precipitation is associated with AR. The AR-related precipitation is most pronounced in summer by approximately 58%, while only limited fraction of precipitation (26%) is AR-related in winter. The heavy precipitation (> 30 mm day^{-1}) is more prone to AR activity (59%) than weak precipitation (5~30 mm day^{-1}; 33%) in all seasons. By grouping weather stations into the four sub-regions based on orography, it is found that the contribution of AR precipitation to the total is largest in the southern coast (57%) and smallest in the eastern coast (36%). Similar regional variations in AR precipitation fractions also occur in weak precipitation events. The regional contrast between the northern and southern stations is related to the seasonal variation of AR-frequency. In addition, the regional contrast between the western and eastern stations is partly modulated by the orographic forcing. The fractional contribution of AR to heavy precipitation exceeds 50% in all seasons, but this is true only in summer along the eastern coast. This result indicates that ARs play a critical role in heavy precipitation in South Korea, thus routine monitoring of ARs is needed for improving operational hydrometeorological forecasting.

In this study, we present a comparative analysis of Atmospheric Rivers (ARs) and Great Plains low-level jets (GPLLJ) during April–September 1901–2010 using ECMWF's CERA-20C. To identify potential overlap and synergistic opportunities between AR and GPLLJ research, we classified, compared, and contrasted GPLLJ and AR days in the central U.S in terms of their synoptic environments and extreme weather impacts. Using the Guan-Walliser integrated vapor transport (IVT)-based AR classification and Bonner-Whiteman-based GPLLJ classification, we identify days with either an AR and/or GPLLJ spanning 15% of the central U.S. These days are grouped into five event samples:1) all GPLLJ, 2) AR GPLLJ, 3) non-AR GPLLJ, 4) AR non-GPLLJ, and 5) all AR. We mainly focus on differences between AR GPLLJ and non-AR GPLLJ days. Notably, one-third of GPLLJ days are associated with an AR. GPLLJ frequency peaks in mid-summer compared to ARs, which show less monthly variability during April–September. A decreasing trend in GPLLJ frequency is observed whereas the annual number of AR events is unchanged over 110-years. On average, AR GPLLJ days have 72% higher daily precipitation accumulation than non-AR GPLLJ days. The AR GPLLJ 95th percentile 24-hour precipitation is 4.4 mm day-1 greater than non-AR GPLLJ precipitation. Both the average and 95th percentile 850 hPa wind speeds and IVTs are also lower for non-AR GPLLJs. A 500 hPa geopotential height comparison shows a persistent ridge over the central U.S for non-AR GPLLJ days, whereas on AR GPLLJ days, a trough and ridge pattern is present over western to eastern CONUS.

L_HM_6

L_HM_7

Water management at BC Hydro generation facilities during the 14-15 November 2021 AR

Greg West, Tim Ashman, Joanna Glawdel, Helen Hamilton Harding, Georg Jost, Wolf Read, and Frank Weber
BC Hydro

An AR on 14-15 November 2021 and anomalously wet antecedent conditions brought challenging water management conditions to BC Hydro's hydroelectric generation facilities in southwestern British Columbia, Canada. Despite a state-of-the-practice large ensemble forecast system, which provided good advanced notice of the event, precipitation totals verified at the top end of, or outside of, the ensemble envelope. Precipitation totals and reservoir inflows were among the highest on record, requiring timely flood routing operations to manage reservoir levels and downstream river flows, and activation of the corporate-level emergency coordination centre. This presentation will overview the event, how it was handled by our forecast system, the hydrological factors on inflows (e.g., snow melt), and to what extent system operations were able to mitigate downstream flows above flood thresholds. We'll also present lessons learned (e.g., event and conditions monitoring, forecast ensemble changes) in hopes that others in AR-affected regions might consider implementing such action items before seeing a similar event.

L_HM_9

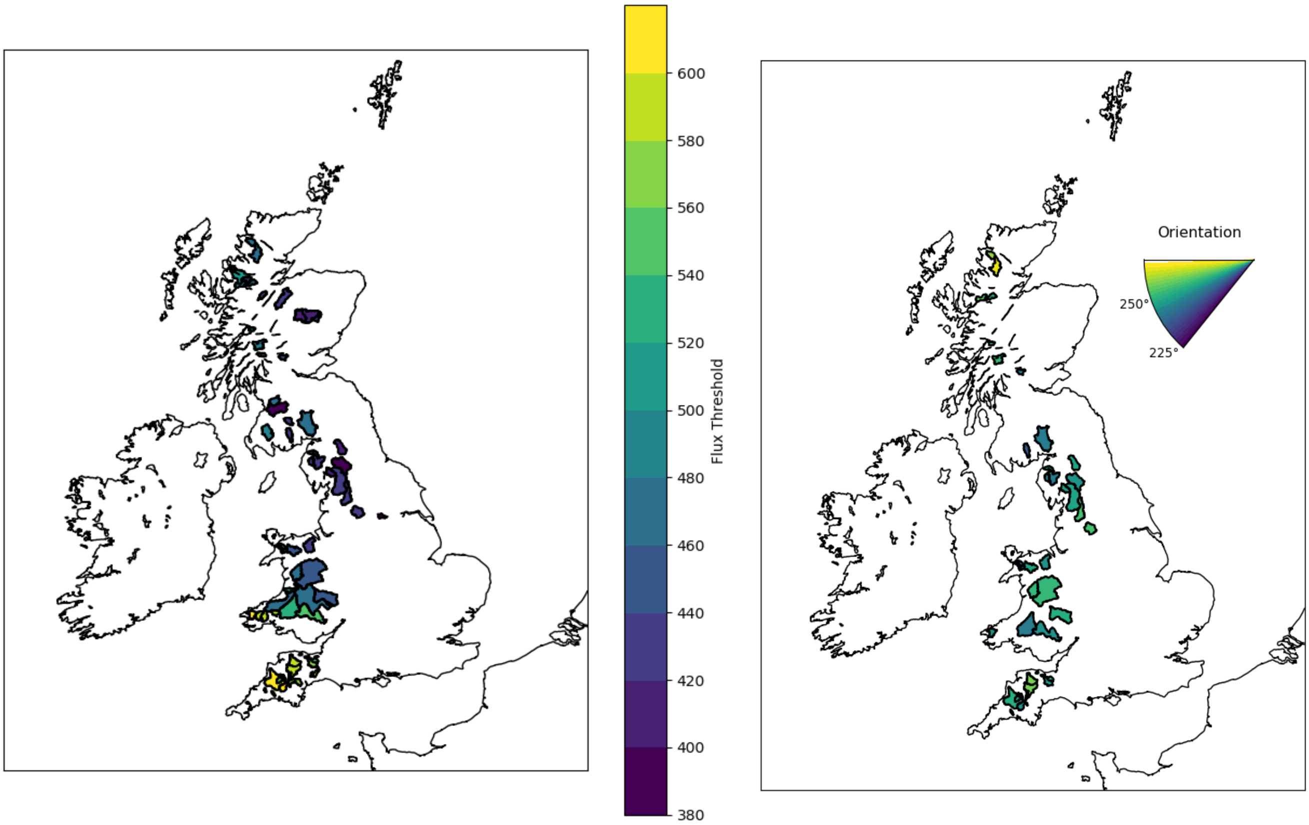
Title: The role of land surface in enhancing or suppressing AR-driven floods.

Theme: Hydro-meteorological impacts of ARs

Dr. Helen Griffith (University of Reading, UK), Prof. Andrew Wade (UoR, UK), Dr. David Lavers (ECMWF, UK), Dr. Glenn Watts (Environment Agency, UK)

Note: This work formed part of my recently completed PhD and is in the process of being submitted for publication (I am working full-time as a PDRA on a different project!)

Atmospheric Rivers (ARs) are intense regions of moisture flux in the lower regions of the atmosphere which when aligned with winter storms, can result in heavy or persistent rainfall (e.g., Storm Desmond in 2015, Ciara and Dennis in 2020 and Christoph in 2021). Previous work has suggested that the orientation of the landfalling AR relative to local catchment topography is an important factor in understanding the most impactful ARs (Griffith et al., 2020). In this work, we have analysed the influence of ARs upon the strongest (POT3) floods of the last 30-years along the western coastline of the UK (a total of 81 catchments), attempting to understand how the land-surface and/or catchment processes can either intensify or dampen the effects of an overhead AR. The results we hope will further the potential of ARs in modern day flood-forecasting.



Properties of the most impactful UK ARs . Most catchments in the study require a specific orientation of AR if the largest floods are to be generated and, although some nearby catchments demonstrate similar preferential orientations, some do not. Thus, a subtle interplay between local catchment slopes and large-scale topography is expected to control the most efficient rainout. There is a decreasing trend within the IVT threshold results moving northward. We have been able to successfully correlate this threshold with various land-surface properties, in the form of Flood Estimation Handbook's Catchment Descriptors.

L_HM_10

Quantifying the role of atmospheric rivers as drivers of wintertime flood extents in the Central Valley of California

Christine M. Albano, Desert Research Institute
Christopher Soulard, U.S. Geological Survey
Jessica Walker, U.S. Geological Survey
Eric Waller, Contractor to the U.S. Geological Survey

Along the west coast of the U.S., the links between atmospheric rivers (ARs) and floods are well established. Although many studies in this region have explored the relationship between ARs and streamflow magnitudes, the relationship between ARs and the areal extent of surface water is not well documented. Satellite platforms are increasingly being used for flood monitoring, albeit each of them has strengths and weaknesses. In this study, we assess the utility of a surface water classification product based on Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data for characterizing flood extents associated with AR runoff in the Central Valley of California. Although the MODIS spatial resolution is coarse (250 m), its daily temporal resolution increases the odds of capturing images that are unobscured by clouds, providing the opportunity to detect more immediate and short-duration changes that occur in association with precipitation events. Our analysis explores how AR storm severity, timing, antecedent conditions, and landfall location affect variabilities in flood extents across the study area from 2003-2021. Better understanding of the location, frequency, and extent of surface water inundation during AR-induced flood events has the potential to inform assessments of community and critical infrastructure flood vulnerabilities, as well as land use, evacuation, and emergency response planning.

L_HM_11

Mud and Debris Flow Post-Wildfire Impacts in Southern California

Alex Tardy, NOAA National Weather Service, San Diego, CA
W. Paul Burgess, Engineering Geologist | Regional Geologic & Landslides Mapping Program
California Geological Survey
Nina S. Oakley,Center for Western Weather and Water Extremes, Scripps Institution of Oceanography,
University of California, San Diego

Since the summer of 2018, several wildfires have occurred across southern California. The largest fires scorched thousands of acres of steep high elevation terrain. The United States Forest Service Burn Area Emergency Response (BAER) Team, United States Geological Survey (USGS), CalFire Watershed Emergency Response Team (WERT) and California Geological Survey conducted field assessments and developed models that assessed the Holy and Cranston burn scars in Riverside County and determined there were high likelihood of debris flows following intense rainfall rates. The runoff volumes from the canyons were expected to increase 3 to 5 times in magnitude. Meetings between the National Weather Service (NWS), USGS, and the California Geological Survey developed specific thresholds that the lead warning agencies would use in the event of intense rainfall meeting or exceeding debris flow thresholds. These findings prompted about a dozen partner meetings led by Orange, Riverside and San Bernardino Counties Emergency Management Departments, Public Works and Flood Control Districts. Each county developed specific response and evacuation protocols for the burn areas and enhanced dashboards for monitoring real-time networks with live monitoring systems equipped with cameras and rain gauges and pressure sensors to detect debris flows. The NWS office began providing 10 specialized briefings to support emergency management decision making to protect lives and property downstream of the burn scars. Once partner agencies developed strategic emergency plans and procedures there were several separate community and social media outreach efforts to inform potentially impacted citizens.

The summer and fall of 2020 experienced record-breaking temperatures and total acres burned from wildfires across California. Across the NWS San Diego service area there were 7 separate wildfires (117,000 acres) that required post-fire debris flow hazard analysis by USFS and CalFire. The El Dorado and Bond fire scars remain the two highest risk areas in California due to burn severity, steep terrain, available debris, history of debris flows and flash floods, values at risk below the scars, and USGS modeling of debris flow potential. There were four incidents on the Bond and El Dorado burn scars, which produced mud and debris flow in January 2021, March 2021, July 2021 and December 2021. This presentation will provide a timeline of activities including rainfall forecast decision support services and impacts from heavy rainfall events.

L_HM_12

Assessing relationships among IVT, Precipitation, and Reservoir Inflow across Northern California

J. Cordeira[1], S. Bartlett[1], and J. Cunningham[2]
[1]Center for Western Weather and Water Extremes, UCSD/Scripps
[2]National Weather Service, Salt Lake City, Utah

This study investigated the NASA MERRA-derived IVT associated with landfalling ARs in the North-Central Valley of California and cross-referenced their start times with hourly precipitation at Brush Creek (BRS), CA within the Feather River watershed and hourly inflow into Lake Oroville for water years 1998–2017. Whereas average 5-day time-integrated IVT magnitudes for AR3–5 events were 51% larger than AR1–2 events (128 x 10^6 kg/m versus 85 x 10^6 kg/m associated with IVT maxima of 514 kg/ms and 356 kg/ms, respectively), the average 5-day time-integrated precipitation and inflow volumes were 145% and 173% larger, respectively. The latter 5-day average inflow volume into Lake Oroville was ~98,050 Acre Feet (AF) associated with AR1–2 events and 268,071 AF associated with AR3–5 events, affirming that more intense and longer duration ARs following the Ralph et al. (2019) AR scale produce significantly more precipitation and larger reservoir inflows as compared to less intense and shorter duration ARs in the Yuba–Feather region of California. The 5-day periods following the start of all AR events represented 53% of all precipitation at BRS and 32% of all inflow into Lake Oroville over the 20-year study, with AR1–2 and AR3–5 events producing 32% and 22% of the total precipitation and 19% and 13% of the total inflow, respectively. The presented study will include an updated analysis using hourly ECMWF ERA5 reanalysis IVT data to define landfalling ARs coincident with the hourly precipitation and inflow data at multiple reservoirs across northern California.

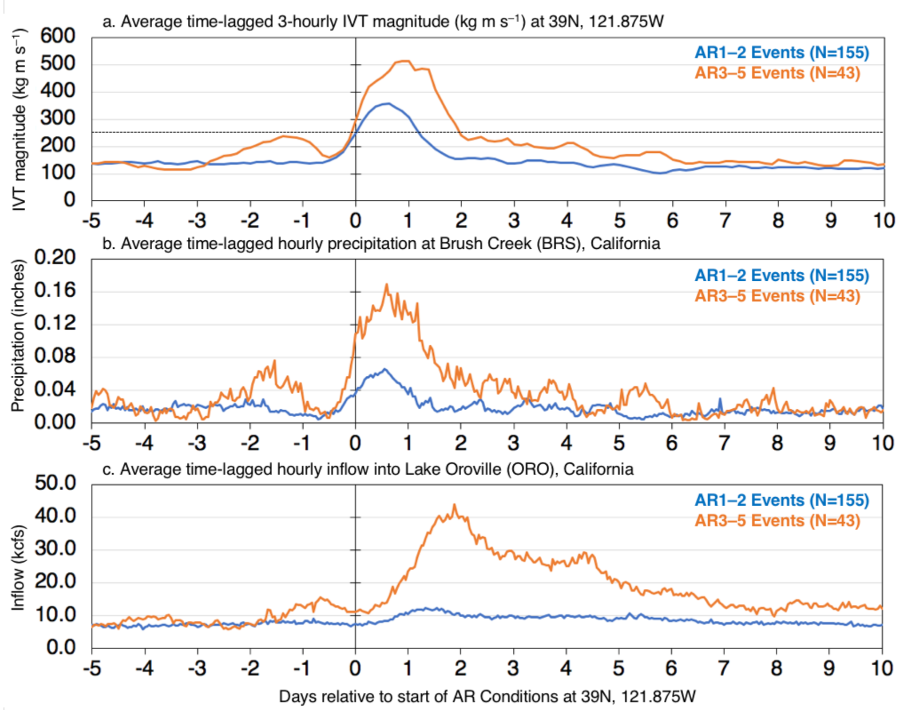


Fig.: Time-lagged average time series of (a) 3-hourly IVT magnitude, (b) hourly precipitation at Brush Creek (BRS), California, and (c) hourly inflow into Lake Oroville (ORO), California for AR1-2 events (blue) and AR3-5 events (orange) lagged relative to the start date of AR conditions at 39N, 121.875W.

j_HM_13

Role of atmospheric rivers affecting vegetation and fire patterns over the western US during wet and dry years

Ju-Mee Ryoo[1, 2], Taejin Park[1, 3]

1. **NASA Ames Research Center, Moffett Field, CA**
2. **Science and Technology Corporation, Moffett Field, CA**
3. **Bay Area Environmental Research Institute, Moffett Field, CA**

Wildfires in the western U.S. have increased in frequency, intensity, and area burned in recent years. Previous studies showed that these increases are mainly due to changing climate, human land management, and variability of natural- and anthropogenic-driven environmental conditions, leading to a significant impact on the terrestrial ecosystem. One of the key elements in the western U.S. climate system is the atmospheric river (AR), which is responsible for a significant portion (> 50 %) of annual total precipitation and other climate impacts in the western U.S. It is thus important to characterize ARs and understand how ARs control the wildfires (frequency and size) and their impact on the ecosystem.

In this study, we investigate ARs and pre-fire vegetation conditions during two wet and dry years, 2016 and 2020, in the western U.S. We focus on two seasons because there are large differences in i) area burned during wildfire season (Sep.-Oct.-Nov.), particularly in California and ii) precipitation patterns associated with ARs during the pre-wildfire season (Dec.-May). We find that 1) ARs tend to be more intense and frequent in the 2016 pre-wildfire season, but the pattern is reversed with shorter-lived ARs during Jun.-Jul.-Aug. 2020 over the Pacific Ocean. 2) The synoptic-scale upper-level waves are less pronounced and retreated poleward with the ridges centered over the western U.S. in 2020, resulting in dry conditions. 3) The inland surface wind is stronger in 2020 compared to 2016. Our analysis further shows that the drier 2020 pre-fire season, especially over the land, is strongly linked to satellite-observed lower soil moisture, vegetation greenness, and vegetation moisture content. It indicates a significant increase in vegetation flammability in 2020 leading to a record-setting fire activity together with extreme lightning events. How ARs are associated with these conditions will be presented.

P_HM_1

Linking Spring-time Heavy Precipitation Events and Major Floods in Iran to Atmospheric River Conditions

Mojtaba Sadeghi[1], Eric J. Shearer[1,*], Hamidreza Mosaffa[2], Vesta Afzali Gorooh[1], Matin Rahnamay Naeini[1], Negin Hayatbini[1], Pari-Sima Katiraie-Boroujerdy[3], Bita Analui[1], Phu Nguyen[1], Soroosh Sorooshian[1,4]

[*] Presenting Author. Email: eshearer@uci.edu

[1]Center for Hydrometeorology and Remote Sensing (CHRS), The Henry Samueli School of Engineering, Department of Civil and Environmental Engineering, University of California, Irvine, Irvine, USA

[2]Water Engineering Department, Shiraz University, Shiraz, Iran

[3]Department of Meteorology, Faculty of Marine Science and Technology, Tehran North Branch, Islamic Azad University, Tehran, Iran

[4]Department of Earth System Science, University of California Irvine, Irvine, USA

In recent years, the number of floods following unprecedented rainfall events have increased in Iran during early spring (March 21st to April 20th, referred to in Iran as the month of “Farvadin”). This study assesses the variations in heavy precipitation (precipitation with intensities greater than or equal to 3 mm/3 h) at 0.04° spatial and 3-hourly temporal resolution during the month of Farvardin. In addition, the effect of atmospheric river conditions over Iran and their possible link to intensifying heavy precipitation is explored. For this purpose, the CONNected-objECT (CONNECT) algorithm is applied on a precipitation dataset, Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks-Cloud Classification System (PERSIANN-CCS), and an Integrated Water Vapor Transport (IVT) dataset from the NASA Modern-Era Retrospective Analysis for Research and Applications Version-2 (MERRA-2). The results suggest that the increase in the number of floods in recent years is related to the increase in the intensity and volume of heavy precipitation events, although the frequency and duration of heavy precipitation events have not changed significantly. Furthermore, the results show that atmospheric river conditions over the country are present during the same window as each year’s most extreme events. It is found that 8 out of 13 of the largest ARs over Iran come from moisture plumes with pathways over the African and Red Sea.

Link to published work: https://doi.org/10.1016/j.jhydrol.2021.126569

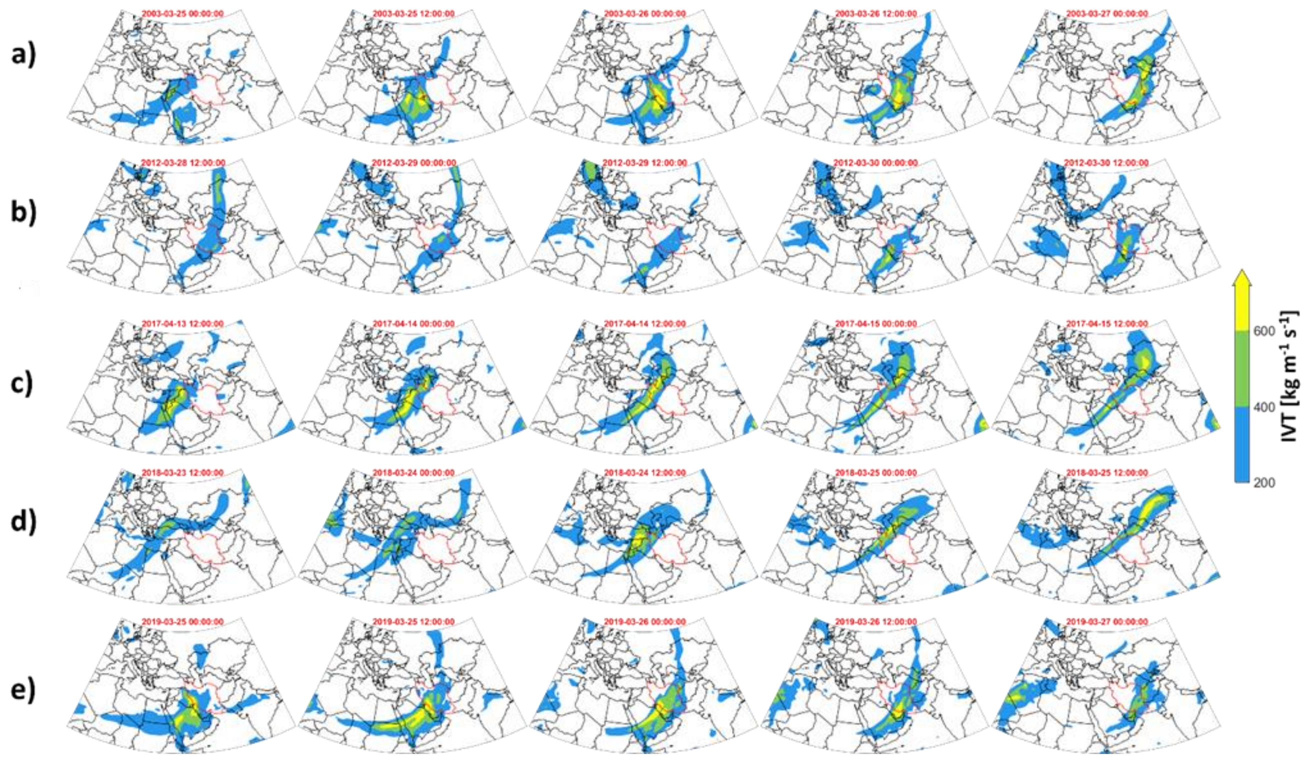


Fig. AR presence during the most severe heavy precipitation events during 2003–2020: a) 2003 b) 2012 c) 2017 d) 2018 e) 2019.

P_HM_3

The interplay between Atmospheric Rivers and rain driven snowmelt leads to large flooding: a case of study in the central Andes.

Lucas Glasner and René Garreaud
Department of Geophysics, and Center for Climate and Resilience Research, University of Chile, Santiago, Chile

Rain on snow events (ROS) have the potential of melting snow, and because of the increase of available water for runoff they represent a risk of extreme flooding, especially downstream of mountainous areas. In this work, we study a ROS event that impacted the Central Chilean Andes (33°S-38°S) on June 4, 2008. Using field measurements and satellite images we found that the event is a clear example of a flood with rain driven snowmelt since some mountain basins of the region suffered a streamflow increase of more than $500 m^3 s^1$ in less than 24hrs with a clear snow cover loss after the rainfall. The event was caused due to a Zonal Atmospheric River (ZAR), with relatively warm conditions that caused heavy liquid precipitation on a recently accumulated snowpack. For the Maipo en el Manzano river basin (3000m ASL), we found that a previous cold event had the key role of causing a snowlimit as low as 1855m ASL while the ZAR came with a zero degree level of 3100m ASL. The basin wide precipitation is estimated in 113mm, where the liquid fraction makes up only to 28mm, in addition, 3.1 % of the basin snow cover was lost, so with precipitation of the previous event we estimate an increase in the total available water for runoff of 10.6 %. Regardless, the specific process and mechanisms of ROS events on river runoff continue to be unknown, mainly due to a lack of precise in-situ snow information during rainfall, and because even if snow cover is lost after the storm, the total precipitation over the basin seems to be the main flood driving mechanism.

P_HM_4

Impacts of an unseasonal atmospheric river on the surface mass balance of glaciers in the Andes of central Chile

Claudio Bravo[1], Sebastián Cisternas[1], Pablo Paredes[1] and Maximiliano Viale[2]

[1]Centro de Estudios Científicos (CECs), Valdivia, Chile.

[2]Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), Mendoza, Argentina.

One of the consequences of climate change is the increased occurrence of extreme weather events such as heat waves and heavy precipitation. The impact of these events on the Andean glaciers has not been quantified yet in detail. In the case of heat waves, the expected consequence is the increase in surface melting. For extreme precipitation events associated with atmospheric rivers (ARs), the impact on glaciers can be as accumulation or melt events, as shown elsewhere. To assess the impact of ARs on Andean glaciers, an event that occurred at the end of January 2021 was analyzed. Available meteorological observations in the glaciated Olivares upper basin (33°S) allowed us to characterize this event and feed a glacier surface mass balance (SMB) model to quantify the impact in the Olivares-Alfa glacier (OA), located at an elevation between 4290 and 4700 m a.s.l. During the event, 0°C isotherm reaches minimum elevations around 3250 m a.s.l., which in conjunction with the intense precipitation rate, determines a high snow accumulation rate on the surfaces of the glaciers (Figure 1). Before the event, the SMB model applied to the OA glacier during the hydrological year 2020/21 showed a clear tendency towards a negative value, as has been the tendency in the last decade. This AR event changed this negative tendency, and the SMB, reaches a magnitude close to equilibrium, even though highly melt rate was estimated. This case study gives insights into the conditions of accumulation events on the glaciers of central Chile in the summer dry season and associated with ARs.

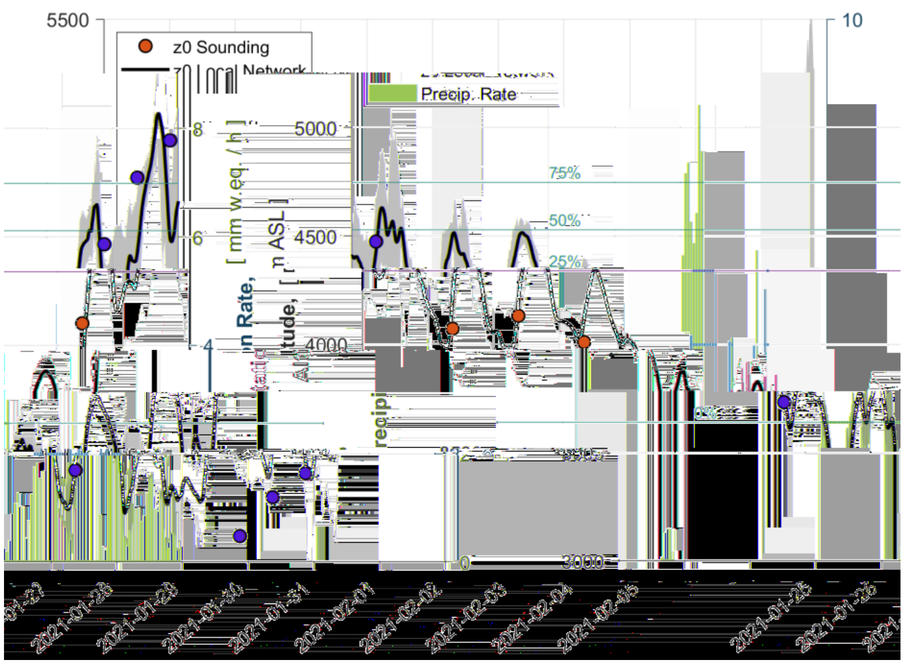


Figure 1. The freezing level and precipitation rate during the end of January 2021 AR event. 0°C isotherm calculated using Automatic Weather Stations installed in the basin (black line) and atmospheric sounding from Santo Domingo (orange circle). The blue bars are the precipitation rate, and the percentages are the glaciated area of the basin.

Climate change is expected to contribute to a combination of increased wildfires, drought, and less frequent but more intense precipitation events in California. This combination can have dramatic effects on soil and vegetation, and may therefore significantly alter hydrology in burned basins, with effects such as flash flooding, decreased groundwater recharge, and post-fire debris flows. In the past five years, many fires have affected the Lake Mendocino watershed in northern California, including the 2018 Mendocino Complex Fire, which is among the largest California fires on record. Preliminary explorations of precipitation, soil moisture, and streamflow downstream of and adjacent to burned areas of the Lake Mendocino basin demonstrate several post-fire hydrologic signatures: (i) increased post-fire quickflow, (ii) decreased post-fire baseflow, and (iii) altered soil moisture profiles.

This work uses streamflow data from six stream gauges that have data from before and after the fire occurred. Specifically, we perform a paired basin study comparing the completely burned watershed upstream of the Mewhinney Creek gauge to the unburned watershed upstream of the Perry Creek gauge. Then, data from the other four gauges are analyzed to further investigate the findings of the paired basin study. Accurate streamflow measurements on ephemeral streams in the Russian River watershed are extremely difficult to attain as they require long hours of field work from our field team, data processing to convert stream level to streamflow, complex data analysis including machine learning using field camera photos, and comparison of field data to modeled data. The methods for observing and processing streamflow data in this watershed could help provide real-time data from these streams to modeling efforts that support water management in the Russian River watershed while also providing methods that could bolster the efficacy of other remote stream gauge networks.

P_HM_5