



The potential of radio occultation data for climate wind field monitoring: an overview of latest results

J. Danzer⁽¹⁾, I. Nimac⁽¹⁾, M. Pieler⁽¹⁾, J. Unegg⁽¹⁾, and G. Kirchengast^(1,2)

⁽¹⁾ Wegener Center for Climate and Global Change (WEGC) and
Field of Excellence Climate Change Graz, University of Graz, Austria

⁽²⁾ Institute of Physics, University of Graz, Austria

julia.danzer@uni-graz.at

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FWF

Climate Change Graz

Field of Excellence
University of Graz

Motivation

Problem with the observational basis for global wind field monitoring:

- Most wind data show either:
 - High vertical resolution or
 - Global coverage



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Are radio occultation data suitable for wind field monitoring?



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Are radio occultation data suitable for wind field monitoring?

- **Global coverage**, typically with highest profile numbers at mid-latitudes
- Dense **multi-satellite** coverage of equatorial to mid-latitudes with COSMIC-2 mission
 - We test this multi-satellite coverage, focusing our studies on the years 2007-2020
- Provision of **high-vertical resolution** atmospheric profiling
- Essentially **independent of cloud influences**; near-global troposphere coverage
- Best accuracy in **upper troposphere and lower stratosphere**

Estimation of wind fields



Local approximations of the dynamical equations

- Geostrophic balance:
 - Pressure gradient force and Coriolis force
- Gradient wind balance:
 - Includes also centrifugal force
- Equatorial balance:
 - Solution when Coriolis force approaches zero towards the equator
- Friction not relevant in the free atmosphere (above the boundary layer)

Brief outlook

- Including advection into the dynamic solution

Evaluation



Based on ...

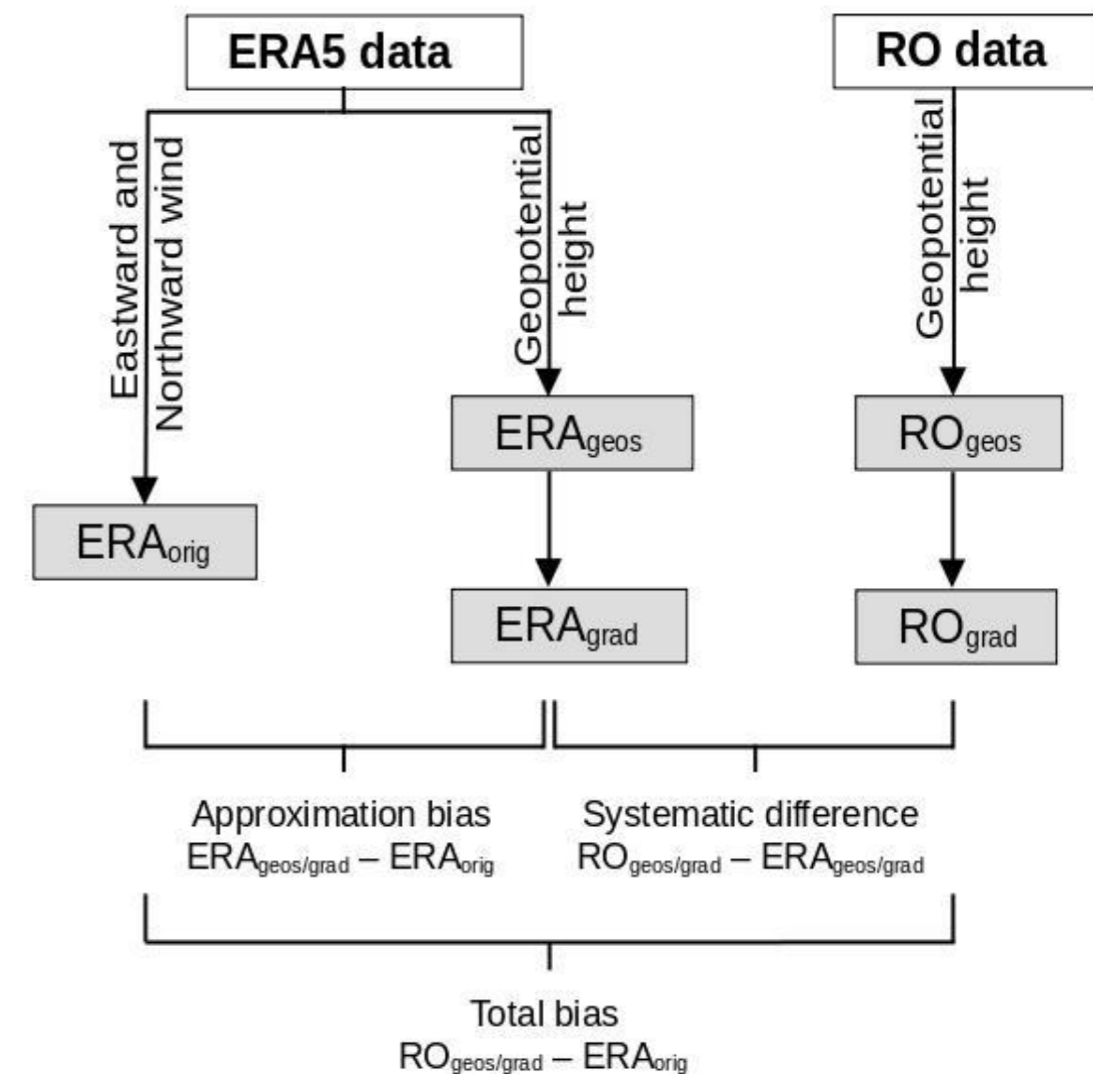
- ERA5 reanalysis data over 2007 - 2020
- Multi-satellite RO data from 2007 - 2020

Step 1: Evaluation of the approximation bias

- Geostrophic wind, gradient wind, equatorial-balanced wind

Step 2: Evaluation of the systematic difference

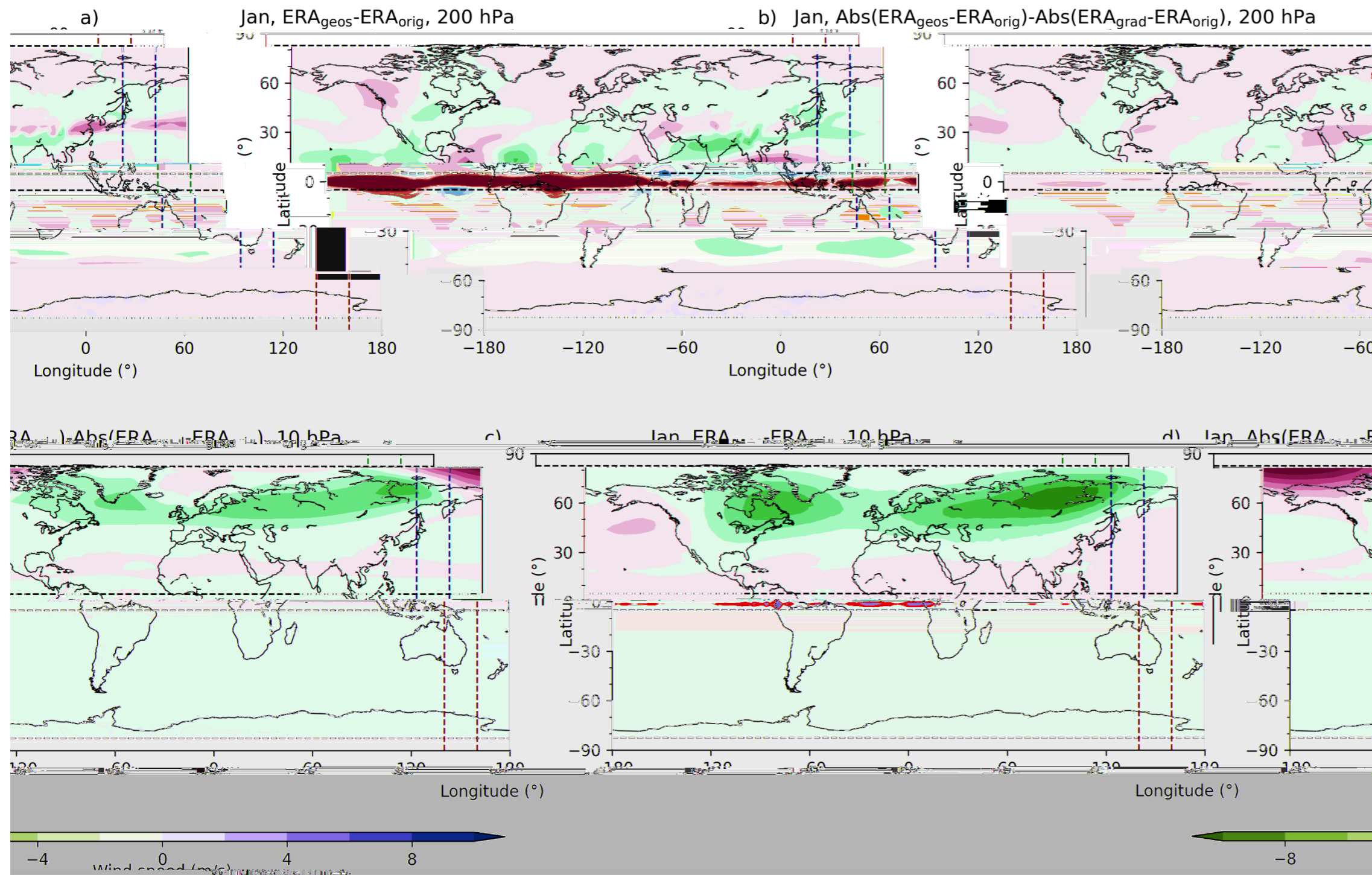
- Agreement between wind speed datasets
- Potential and added value of RO





Step 1: The approximation bias

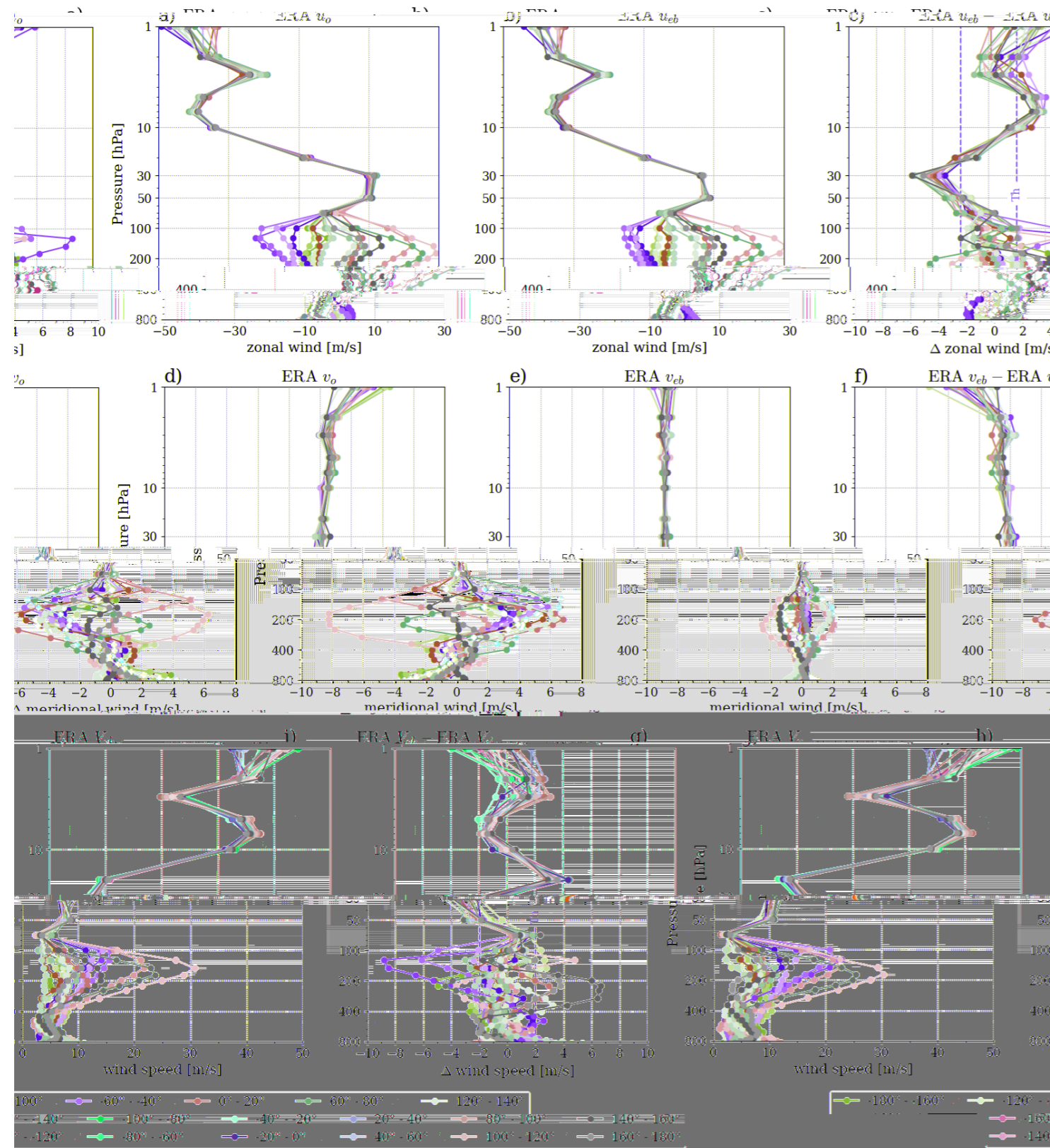
Horizontal latitude-vs-longitude cross section



Geostrophic vs gradient approximation

- Long-term wind speed difference
- Example: January (two altitude layers)
- Note the polar region

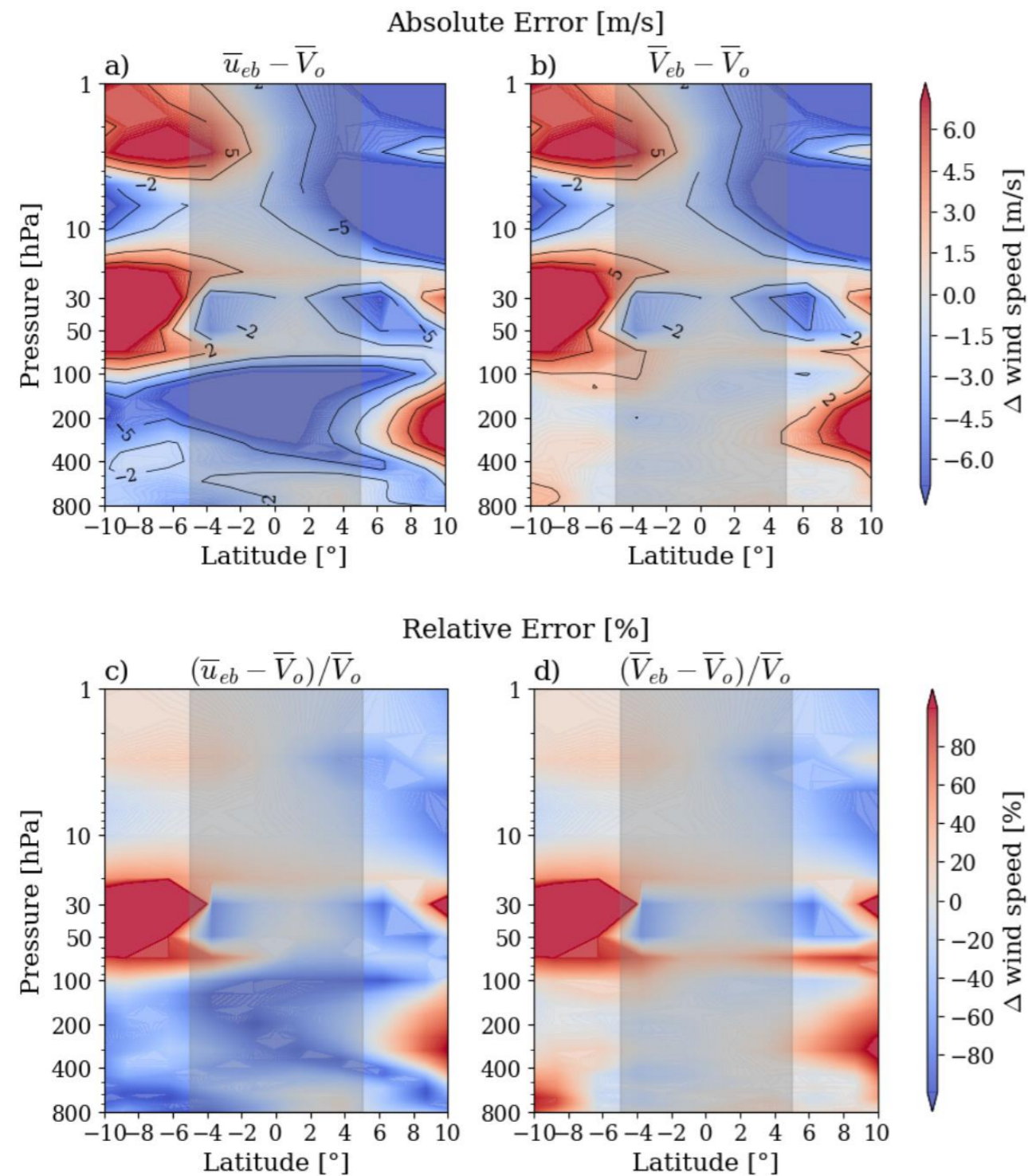
Analyzing winds across the equator



Equatorial balance equation

- Approximation bias
- 20° longitude sectors
- Comparison:
 - Zonal wind
 - Meridional wind
 - Wind speed

Analyzing winds across the equator



Vertical altitude-vs-latitude cross section

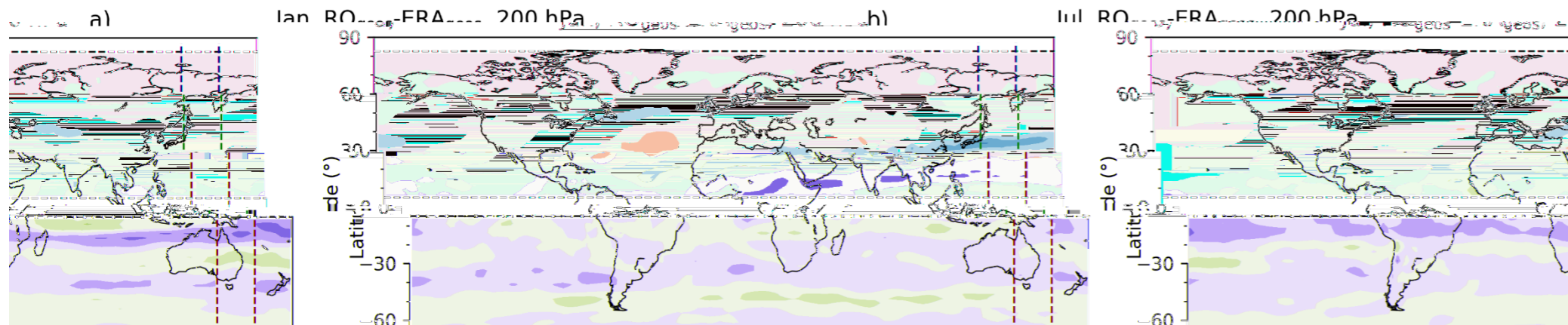
- Equatorial balance approximation
 - Zonal wind
 - Meridional wind
 - Wind speed

- Absolute and relative differences



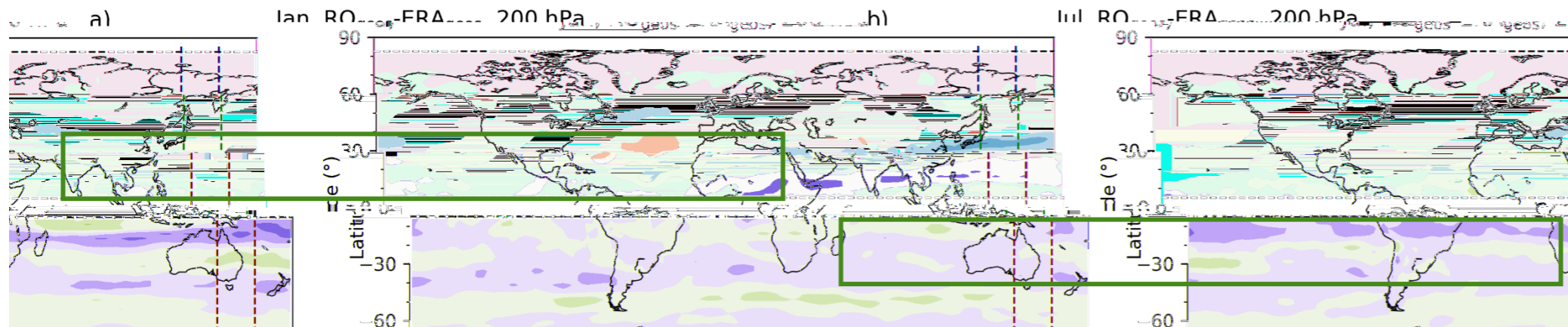
Step 2: The systematic difference

Horizontal latitude-vs-longitude cross section



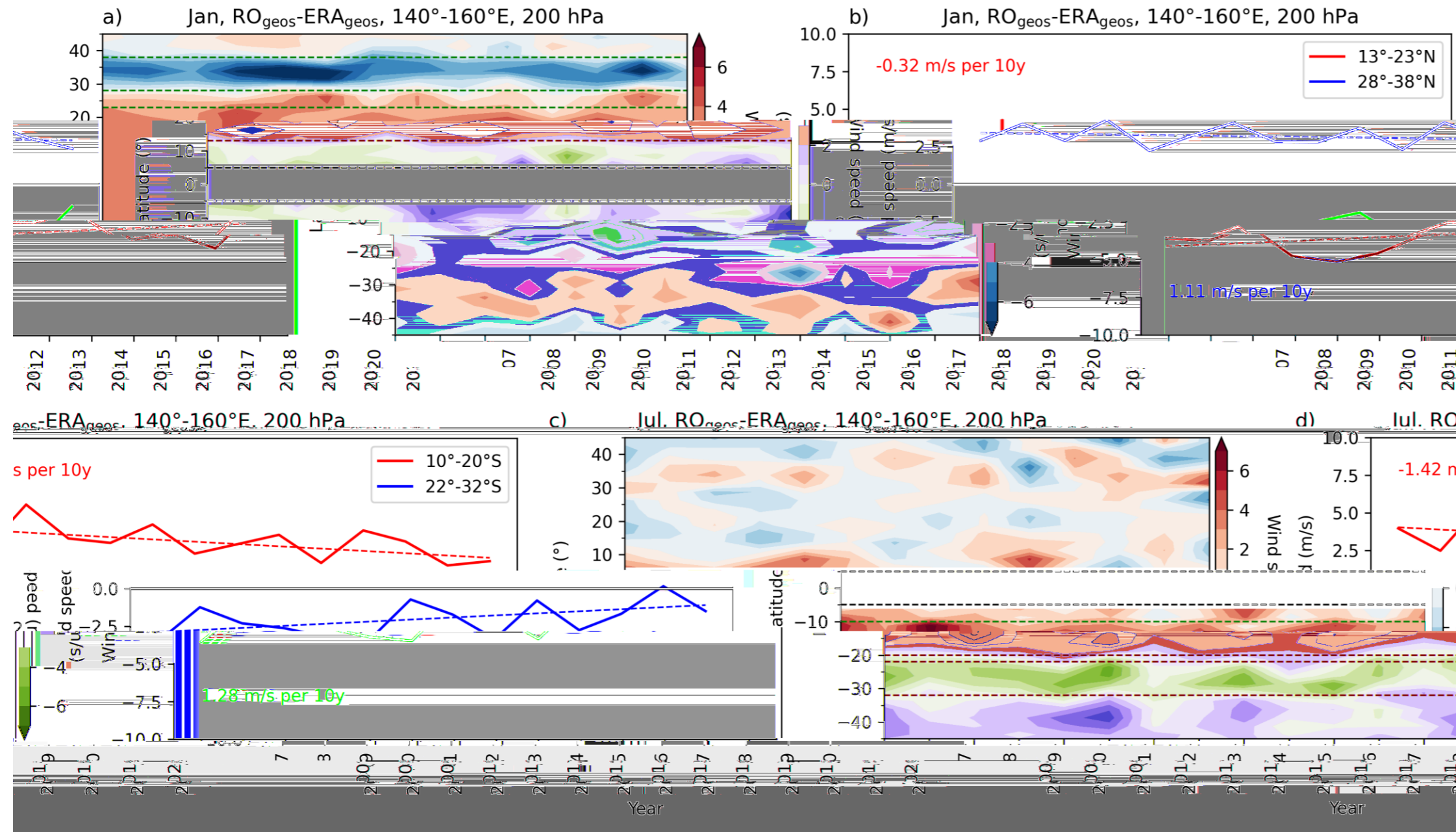
- Systematic difference between RO & ERA5
- Jan & Jul, 200 hPa and 10hPa

Horizontal latitude-vs-longitude cross section



- Systematic difference between RO & ERA5
- Note the difference at 200 hPa in the jet stream region

Temporal stability



- Systematic difference
- Check in jet stream core regions
- WMO wind speed stability requirement: 0.5 m/s per decade
- Threshold exceeded in the jet stream core region

Intermediate summary



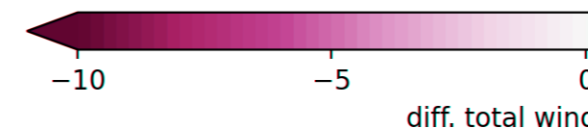
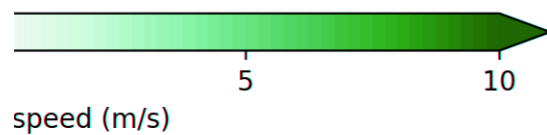
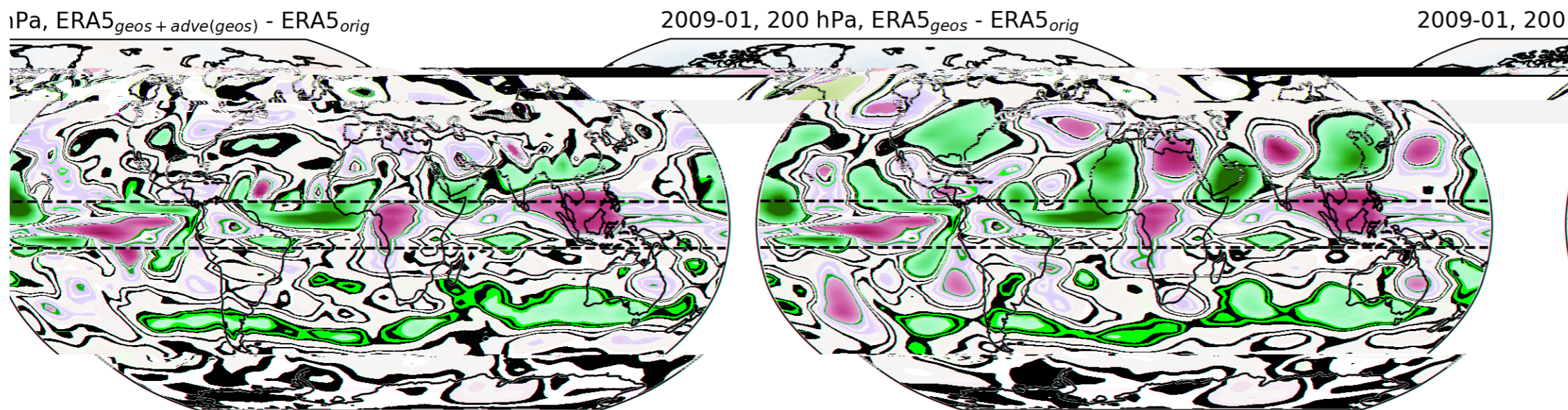
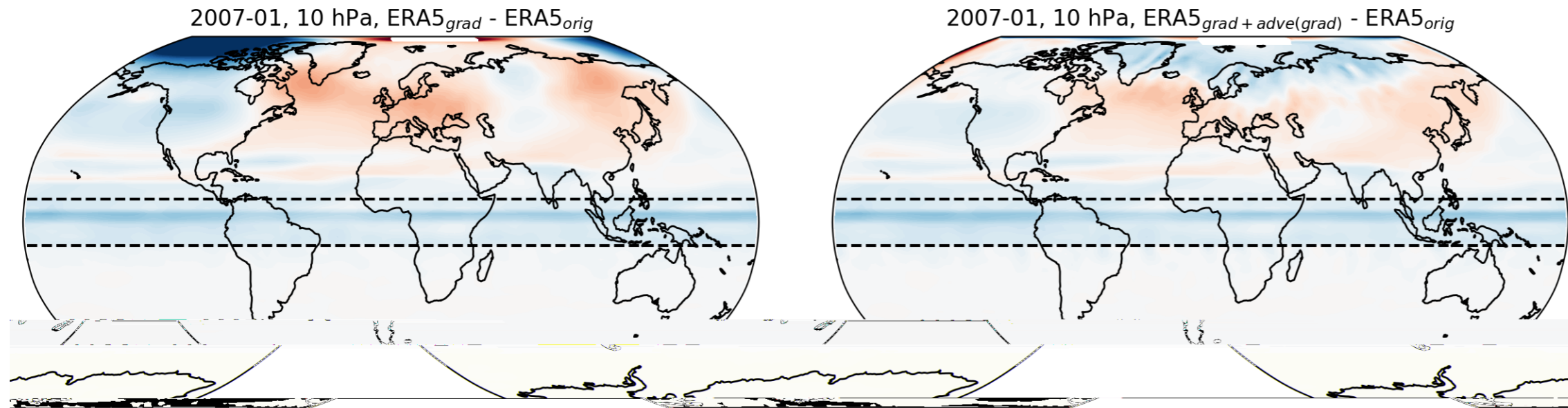
- Geostrophic approximation works better in the **troposphere**
- Gradient wind works better in the **stratosphere**
- Systematic difference small, except in the **jet stream** region
- Equatorial balance approximation:
 - Possible to compute zonal & meridional components
 - Zonal wind dominates in the stratosphere, meridional wind essentially zero
 - However, focus on wind speed: including both components improves the wind speed estimate



Outlook: Including advection

(preliminary work of I. Nimac & J. Unegg et al.)

Improved estimates ERA5 – vertical level maps

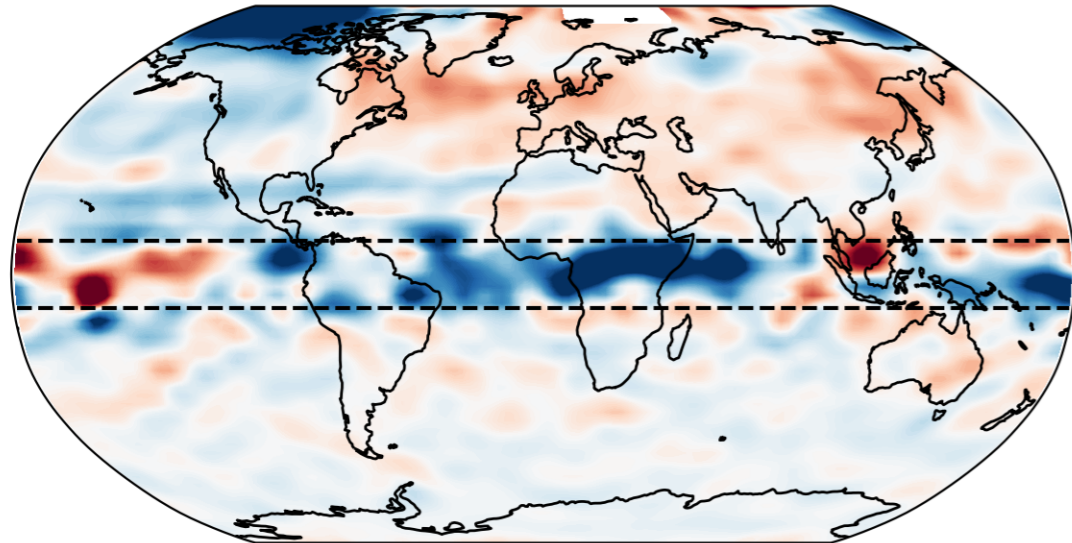


- Systematic wind differences ERA5 estimates vs. ERA5 orig
- Jan 2007, 10 hPa and Jan 2009, 200 hPa

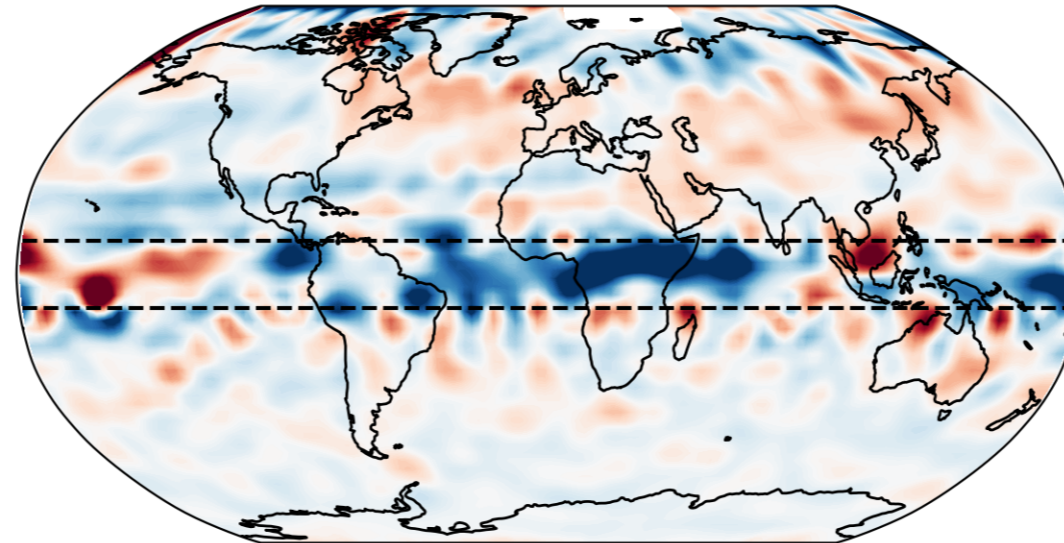
Improved estimates RO data – vertical level maps



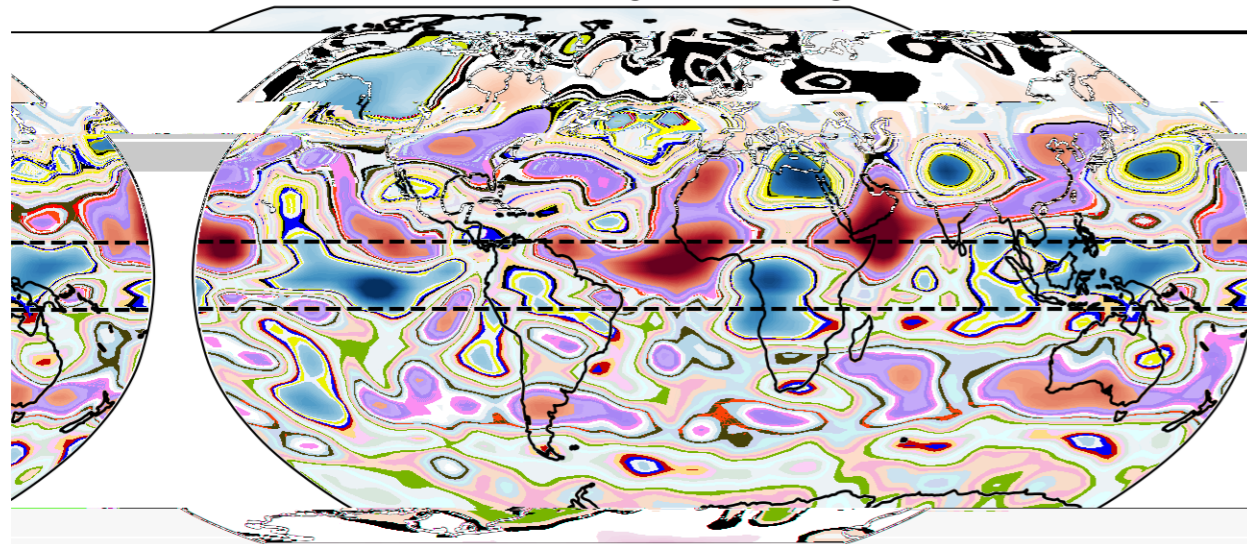
2007-01, 10 hPa, $RO_{grad} - ERA5_{orig}$



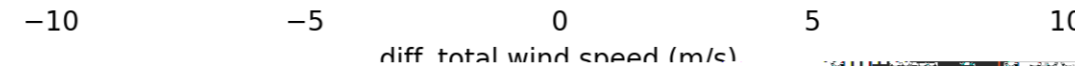
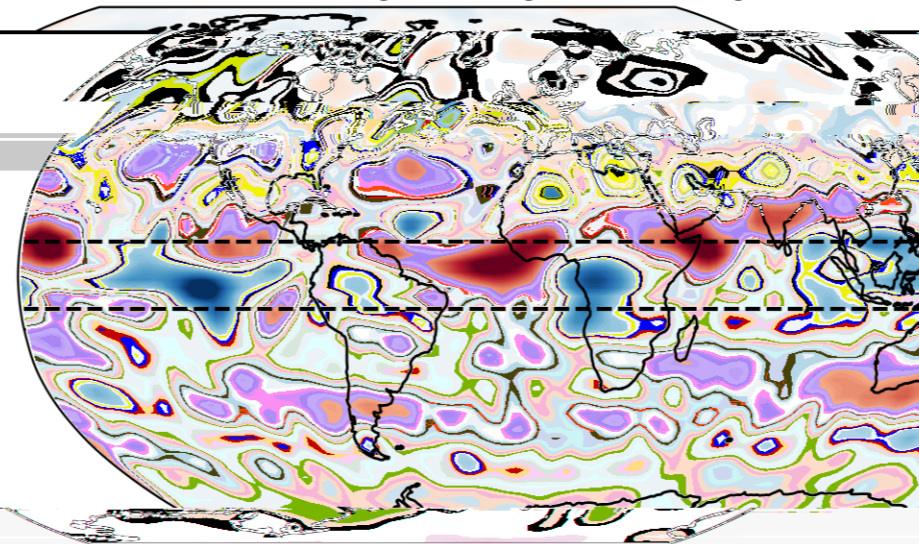
2007-01, 10 hPa, $RO_{grad + adve(grad)} - ERA5_{orig}$



2009-01, 200 hPa, $RO_{geos} - ERA5_{orig}$



2009-01, 200 hPa, $RO_{geos + adve(geos)} - ERA5_{orig}$



diff total wind speed (m/s)

○ Systematic wind differences
RO estimates vs. ERA5orig

○ Jan 2007, 10 hPa and
Jan 2009, 200 hPa

Best-approximation classes ERA5 – vertical level maps

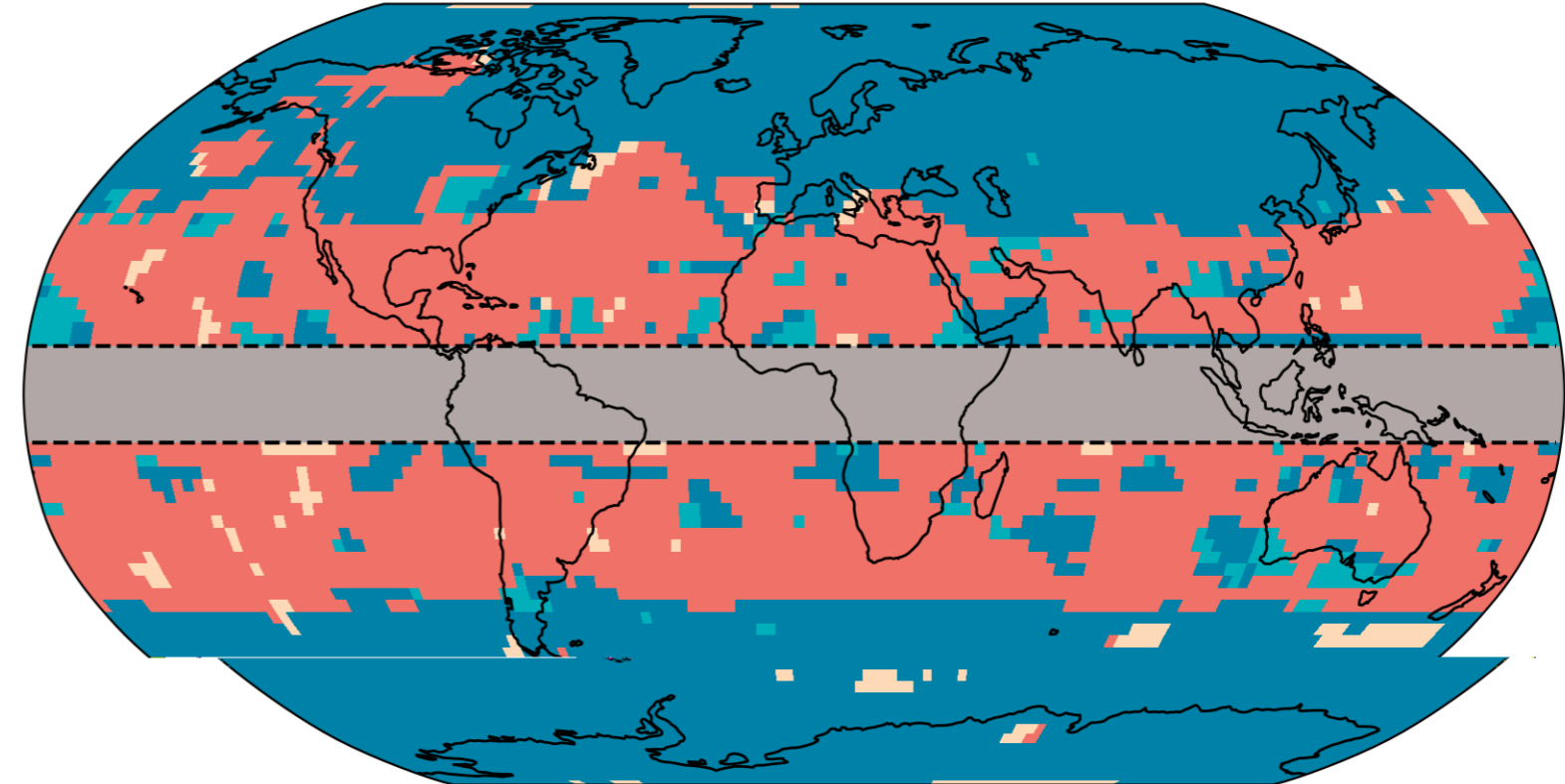
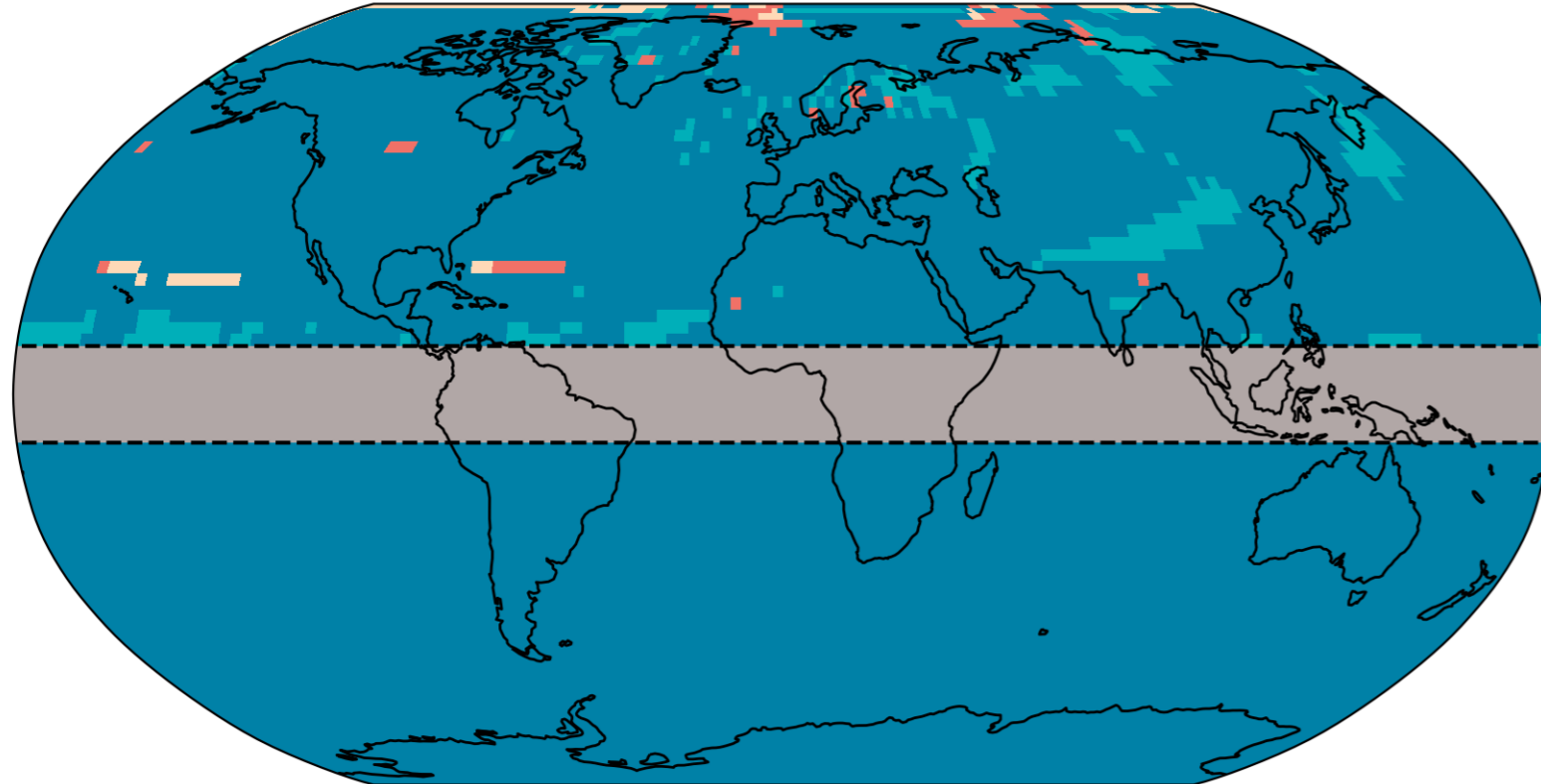


stratosphere (10hPa level)

troposphere & stratosphere (200hPa level)

2007-01, 10 hPa, ERA5_{iter} best estimate for ERA5_{orig}

2009-01, 200 hPa, ERA5_{iter} best estimate for ERA5_{orig}



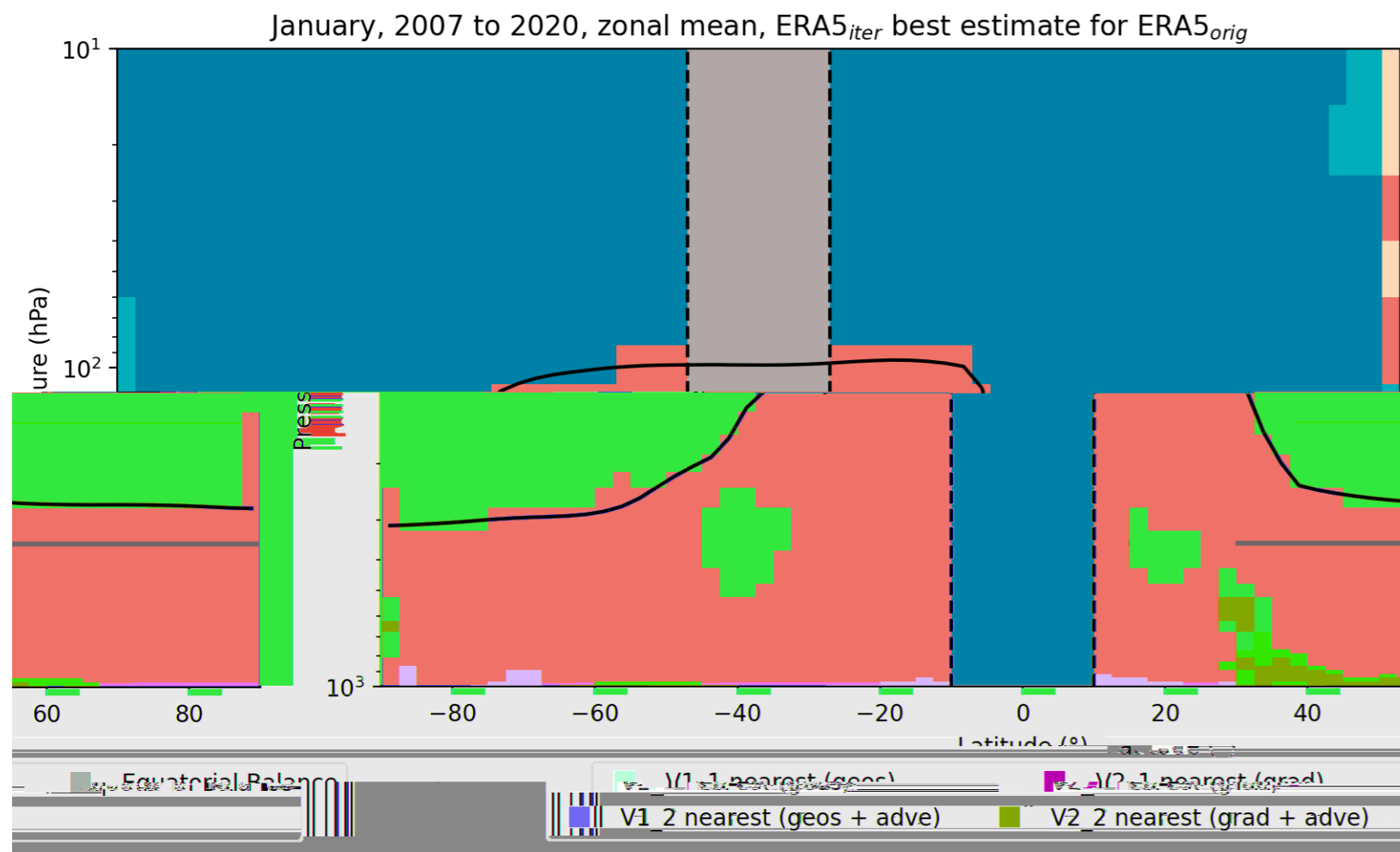
- V1_1 nearest (geos)
- V2_1 nearest (grad)
- Equatorial Balance
- V1_2 nearest (geos + adve)
- V2_2 nearest (grad + adve)

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- V2_1 nearest (grad)
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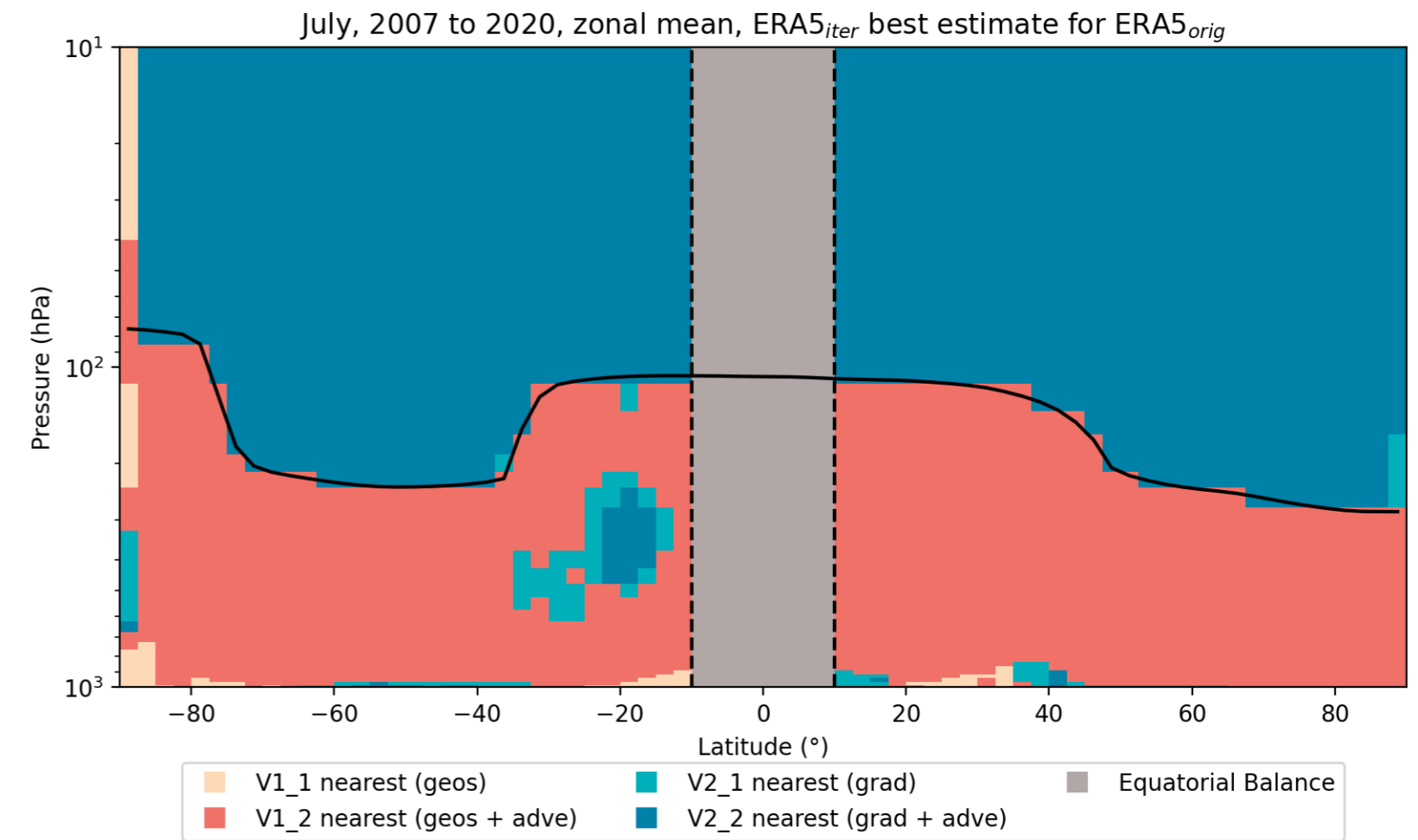
Best-approximation classes ERA5 – lat-vs-alt. sections



January conditions (zonal mean 2007-2020)



July conditions (zonal mean 2007-2020)



Summary



Geostrophic, gradient, equatorial-balance wind approximations:

- Wind speed differences generally **within ± 2 m/s WMO requirement**
- Larger **wind speed differences**
 - partially in the winter hemisphere
 - over polar regions in the stratosphere
- **Gradient** wind (influence of centrifugal force) takes over with improved quality in the **stratosphere**
- **Systematic difference small, except** in the regions of the **jet stream**
- **Equatorial-balance approximation:**
 - Zonal wind dominates in the stratosphere
 - Wind speed benefits from both components, especially in the troposphere

Conclusion and outlook



Conclusion

- Possible to derive monthly $2.5^\circ \times 2.5^\circ$ RO wind fields for climate monitoring
- Expected added value due to high vertical resolution, global coverage, long-term stability
 - Reanalysis shows observing system changes in their time series; uncertainties are less clear

Outlook

- Derivation of complete three-dimensional wind fields based on RO reprocessing
- Dynamic application of the joint best-estimate approximations
- Including **advection in the wind-field estimate**
- ... **more StratoClim work in progress & research proposal in preparation**

StratoClim-Literature



<https://wegcenter.uni-graz.at/de/forschen/forschungsgruppe-arsclisys/projekte/stratoclim/>

<https://homepage.uni-graz.at/de/julia.danzer/>

Danzer, J., Pieler, M., & Kirchengast, G. (2024). Closing the gap in the tropics: the added value of radio-occultation data for wind field monitoring across the equator. *Atmospheric Measurement Techniques*, Vol. 17, Issue 16, 4979-4995, <https://doi.org/10.5194/amt-17-4979-2024>.

Nimac, I., Danzer, J., & Kirchengast, G. (2024). The added value and potential of long-term radio occultation data for climatological wind field monitoring. *Atmospheric Measurement Techniques Discussions*, <https://doi.org/10.5194/amt-2024-59>, preprint, April 2024.

Nimac, I., Danzer, J., & Kirchengast, G. (2023). Validation of the geostrophic approximation using ERA5 and the potential of long-term radio occultation data for supporting wind field monitoring. *Atmospheric Measurement Techniques Discussions*, 2023, 1-24, <https://doi.org/10.5194/amt-2023-100>.

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Thank you for your attention!

julia.danzer@uni-graz.at



We work for
tomorrow

