Global Ocean Monitoring: Recent Evolution, Current Status, and Predictions

Prepared by

Climate Prediction Center, NCEP/NOAA

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http://www.cpc.ncep.noaa.gov/products/GODAS/

This project to deliver real-time ocean monitoring products is implemented

by CPC in cooperation with NOAA's Ocean Observing and Monitoring Division (OOMD)

Outline

- Overview
- Recent highlights
  - Pacific/Arctic Ocean
  - Indian Ocean
  - Atlantic Ocean
- Global SST Predictions

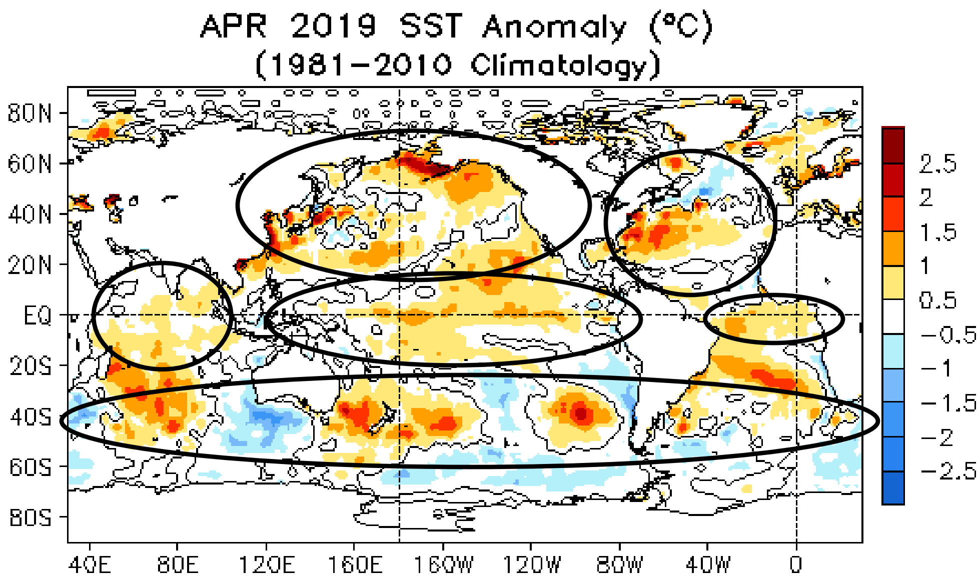
- Ocean indicators for a 2nd year El Nino in 2019/20
- Sudden warming in GODAS and CFSR around Sep 2018
- Experimental salinity and freshwater flux monitoring products

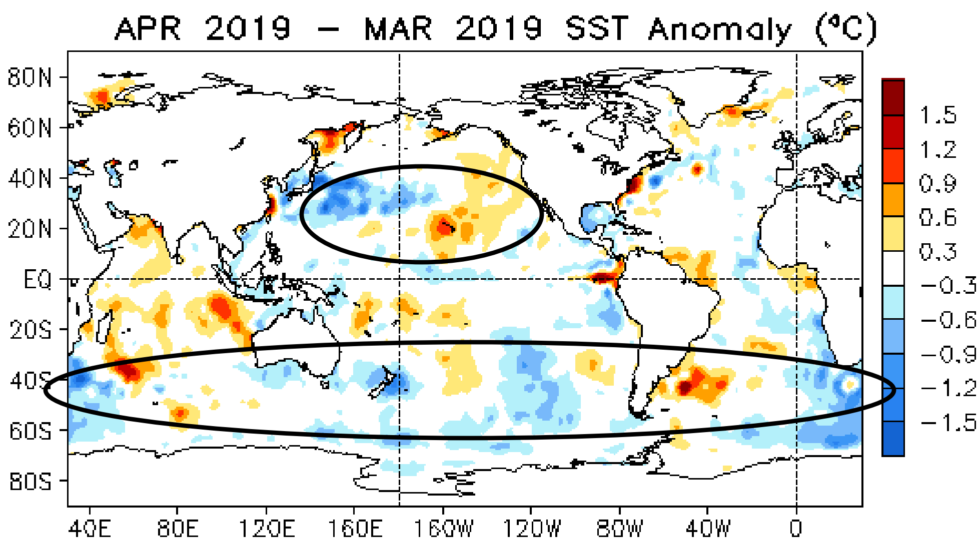
Overview

- **Pacific Ocean**
  - **NOAA "ENSO Diagnostic Discussion" on May 9 2019 continuously issued *"El Nino Advisory"* and indicated that *"El Niño is likely to continue through the Northern Hemisphere summer 2019 (70% chance) and fall (55-60% chance)."***
  - **Positive SSTAs weakened in the central and eastern tropical Pacific with NINO3.4=+0.8^{o}C in Apr 2019.**
  - **Due to upwelling oceanic Kelvin wave, positive subsurface ocean temperature anomalies weakened substantially in the central-eastern equatorial Pacific, while negative temperature anomalies strengthened in the western equatorial Pacific.**
  - **Positive SSTAs dominated in the N. Pacific in Apr 2019.**
- **Indian Ocean**
  - **Positive SSTAs occupied most of the tropical Ocean in Apr 2019.**
- **Atlantic Ocean**
  - **Positive SSTAs presented in the equatorial and subtropical South Atlantic.**
  - **NAO was in a positive phase with NAO=0.36 in Apr 2019, and SSTAs were a tripole/horseshoe pattern with positive anomalies in the middle latitudes of N. Atlantic during 2013-2019.**

Global Oceans

Global SST Anomaly (^{0}C) and Anomaly Tendency



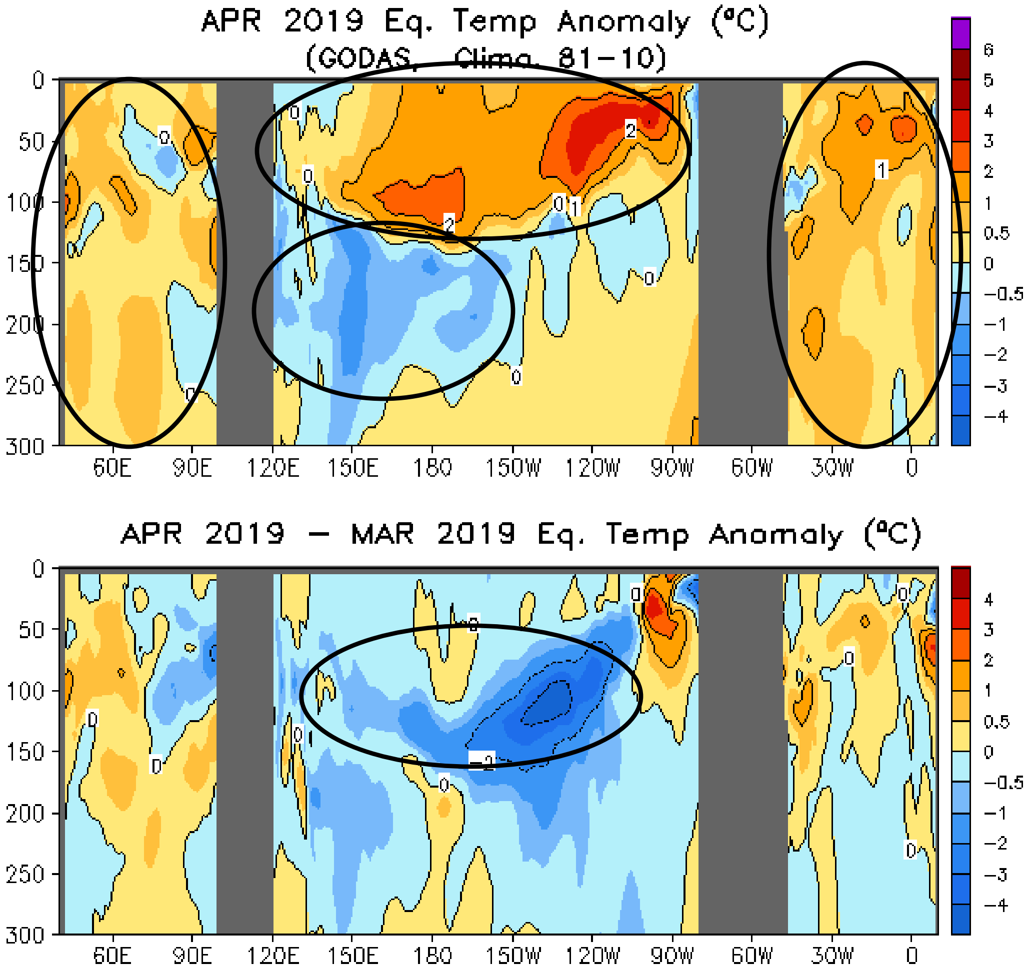


- Positive SSTAs continued in the central-eastern equatorial Pacific, consistent with El Nino conditions.
- Positive SSTAs dominated in the North Pacific.
- Horseshoe/tripole-like SSTA pattern persisted in the North Atlantic.
- Positive SSTAs dominated in the tropical Indian Ocean, tropical Atlantic and mid-latitude Southern Oceans.

- Both positive and negative SSTA tendencies were observed in the N. Pacific.
- SSTA tendencies were mostly negative in mid-latitude Southern Oceans.

Fig. G1. Sea surface temperature anomalies (top) and anomaly tendency (bottom). Data are derived from the NCEP OI SST analysis, and anomalies are departures from the 1981-2010 base period means.

Longitude-Depth Temperature Anomaly and Anomaly Tendency in 2°S-2°N



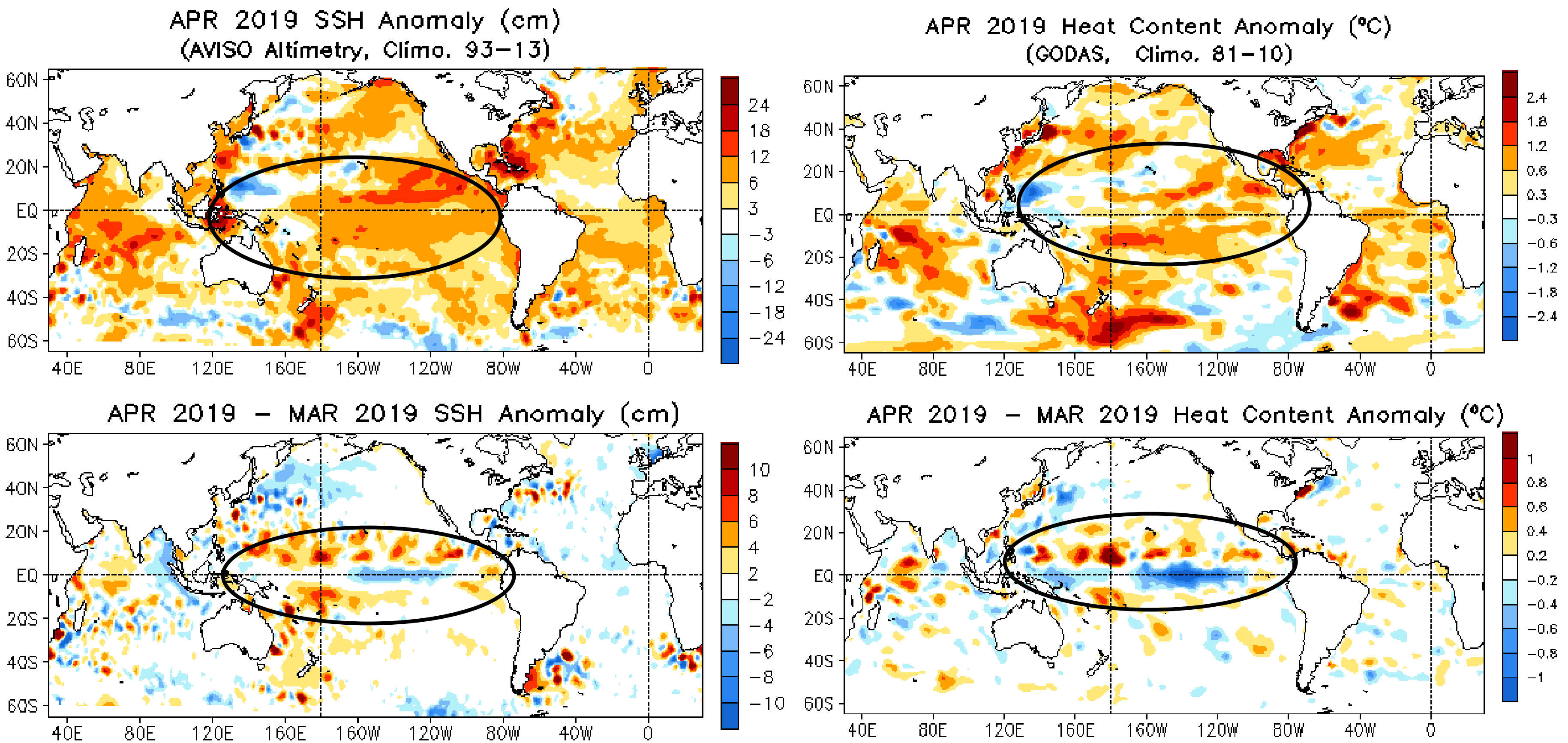
- Positive ocean temperature anomalies presented in upper 100m across the Pacific, while negative anomalies presented below 100m in the western Pacific.

- Positive ocean temperature anomalies dominated in the equatorial Atlantic and Indian Ocean.

- Negative tendency of ocean temperature anomalies dominated in the central-eastern equatorial Pacific near the thermocline.

Fig. G3. Equatorial depth-longitude section of ocean temperature anomalies (top) and anomaly tendency (bottom). Data are derived from the NCEP's global ocean data assimilation system which assimilates oceanic observations into an oceanic GCM. Anomalies are departures from the 1981-2010 base period means.

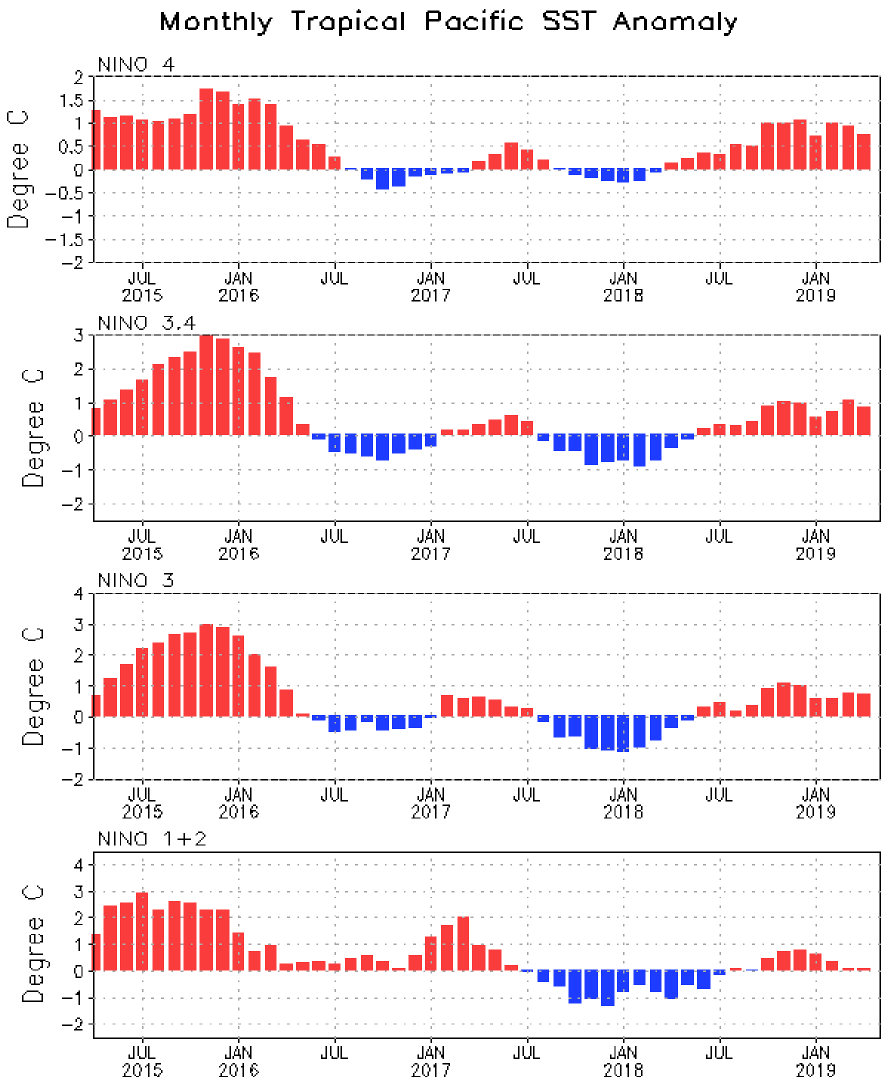
Global SSH and HC300 Anomaly and Anomaly Tendency

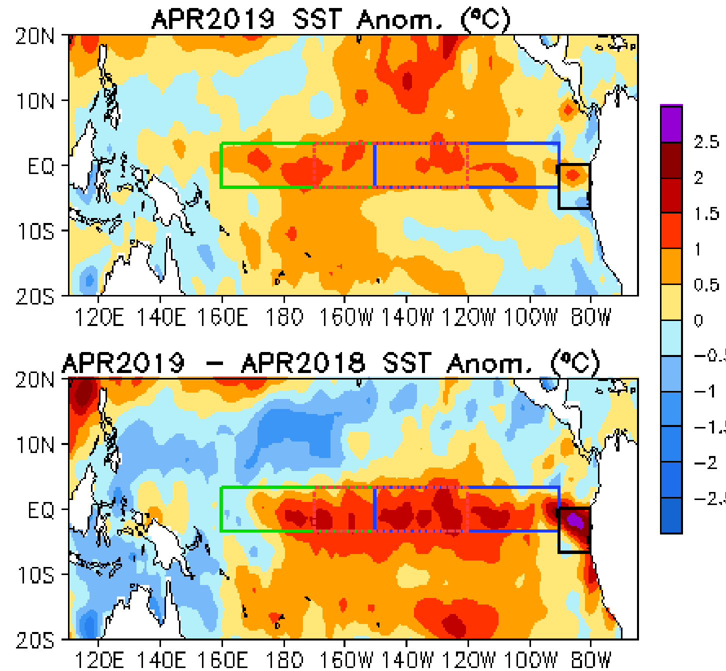


- **Both SSHAs and HC300As in the tropical Pacific were consistent with El Nino conditions.**
- **Negative (positive) tendencies of SSHAs and HC300As presented in the central-eastern equatorial Pacific (off the equator).**

Tropical Pacific Ocean and ENSO Conditions

Evolution of Pacific NINO SST Indices



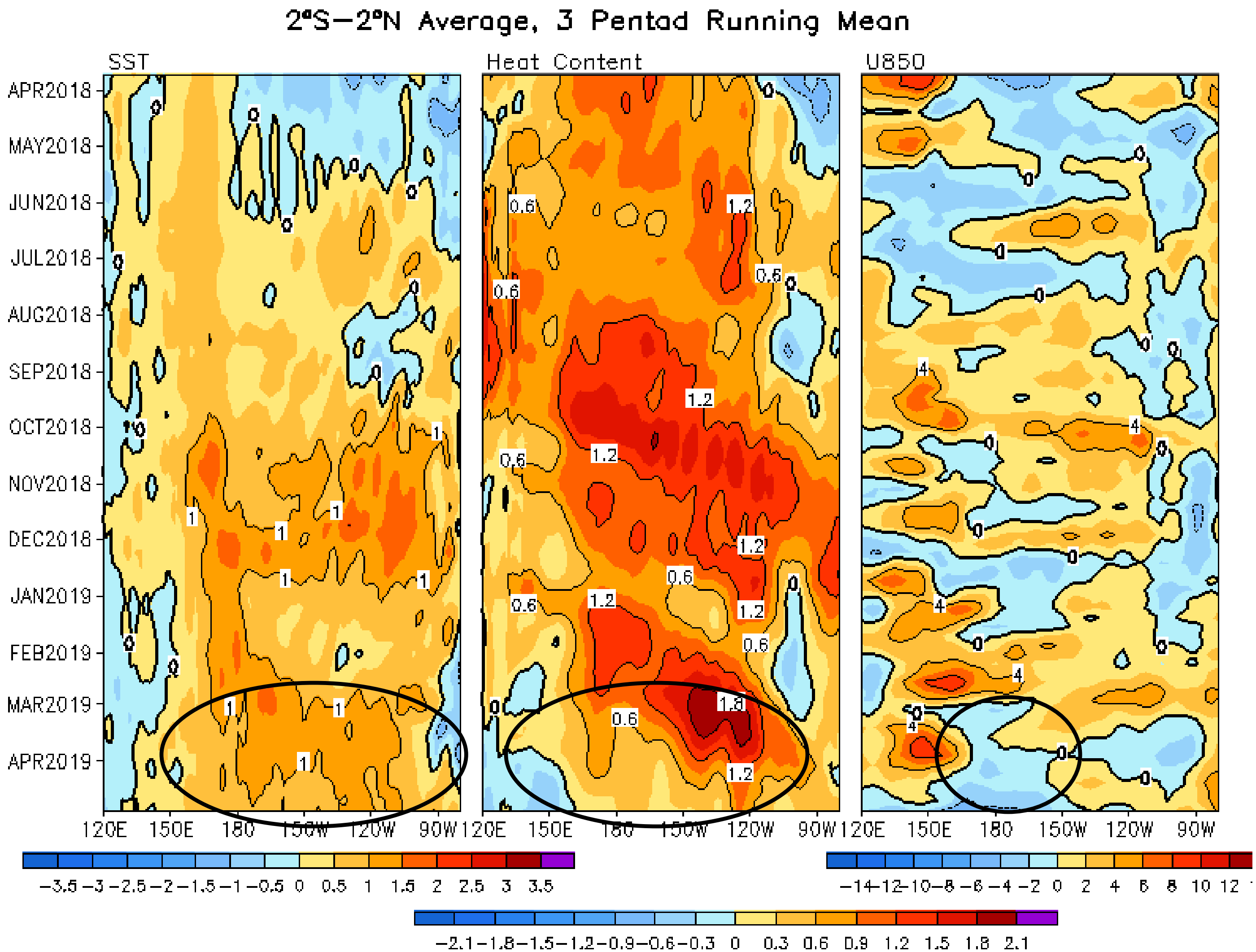


- **All NINO indices weakened in Apr 2019, with Niño 3.4 = 0.8 C.**

-The indices were calculated based on weekly OISST. They may have some differences compared with those based on ERSST.v5.

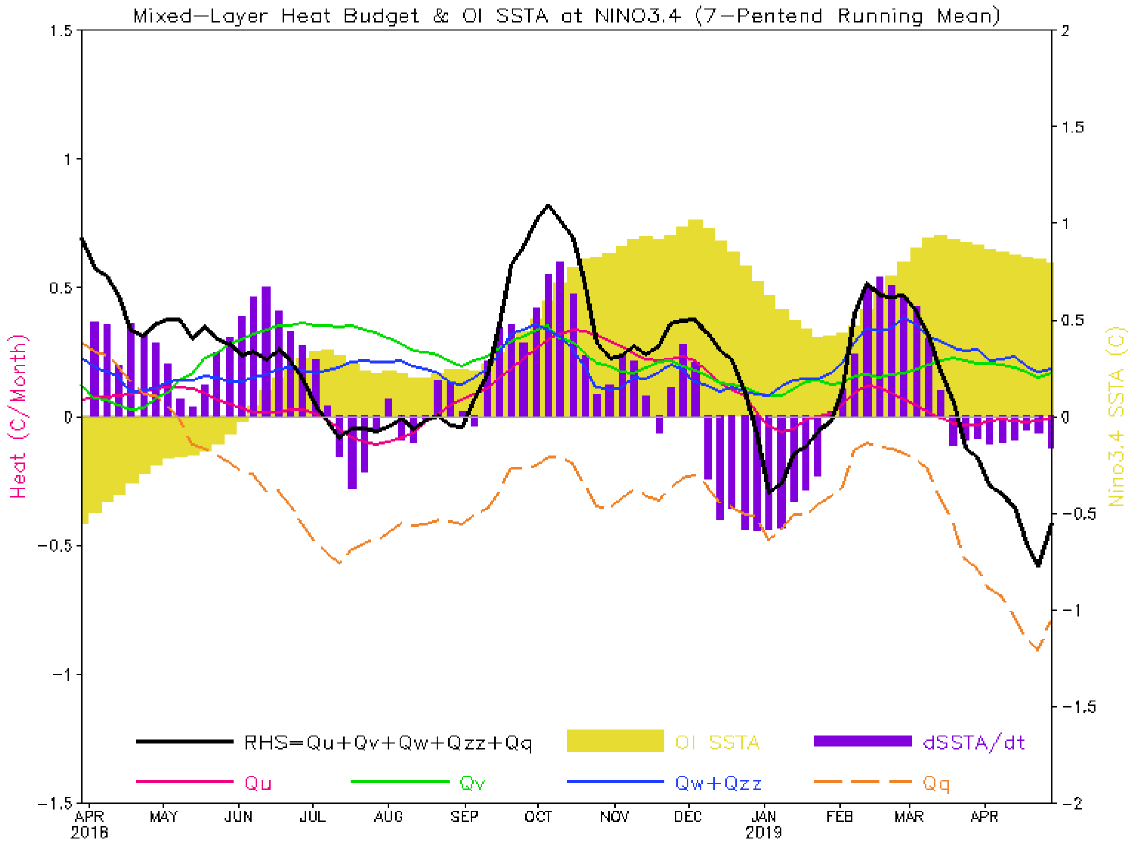
Fig. P1a. Nino region indices, calculated as the area-averaged monthly mean sea surface temperature anomalies (°C) for the specified region. Data are derived from the NCEP OI SST analysis, and anomalies are departures from the 1981-2010 base period means.

Equatorial (2S-2N) Pacific SST (°C), Surface Zonal Wind (m/s) and HC300 (°C) Anomalies



- **Positive SSTAs in the central equatorial Pacific weakened in Apr 2019.**
- **Positive HC300As weakened substantially in Apr 2019, probably forced by persistent easterly wind anomalies near the date line in the past two months.**

NINO3.4 Heat Budget



- The observed SSTA tendencies (dSSTA/dt; bar) were near zero, but the total heat budget (RHS; black line) was strongly negative, implying a large imbalance in the heat budget.

- Dynamical terms (Qv, Qw+Qzz) were positive, while the heat-flux term (Qq) were strongly negative in Apr 2019.

Huang, B., Y. Xue, X. Zhang, A. Kumar, and M. J. McPhaden, 2010 : The NCEP GODAS ocean analysis of the tropical Pacific mixed layer heat budget on seasonal to interannual time scales, J. Climate., 23, 4901-4925.

Qu: Zonal advection; Qv: Meridional advection;

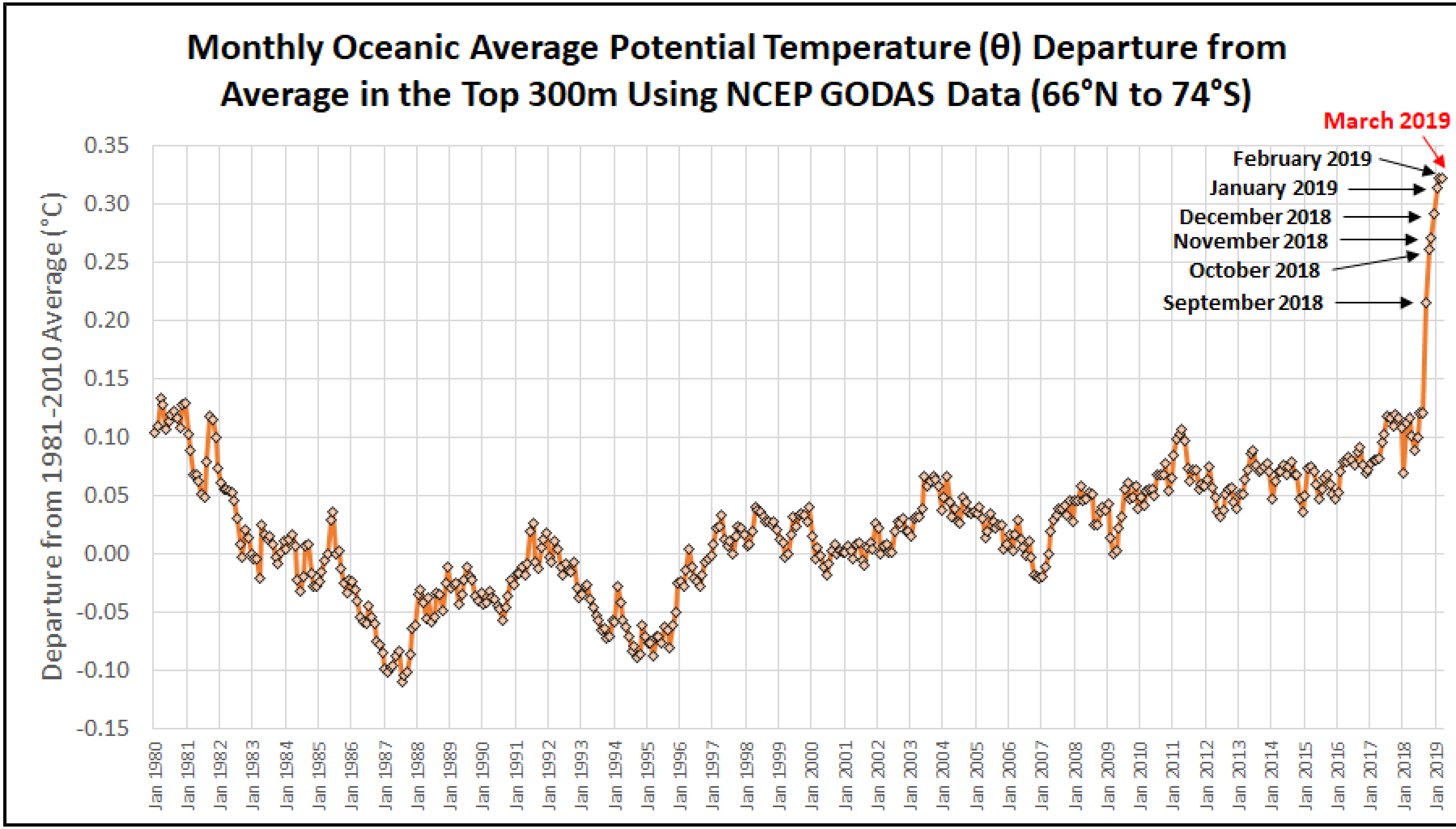
Qw: Vertical entrainment; Qzz: Vertical diffusion

Qq: (Qnet - Qpen + Qcorr)/ρcph; Qnet = SW + LW + LH +SH;

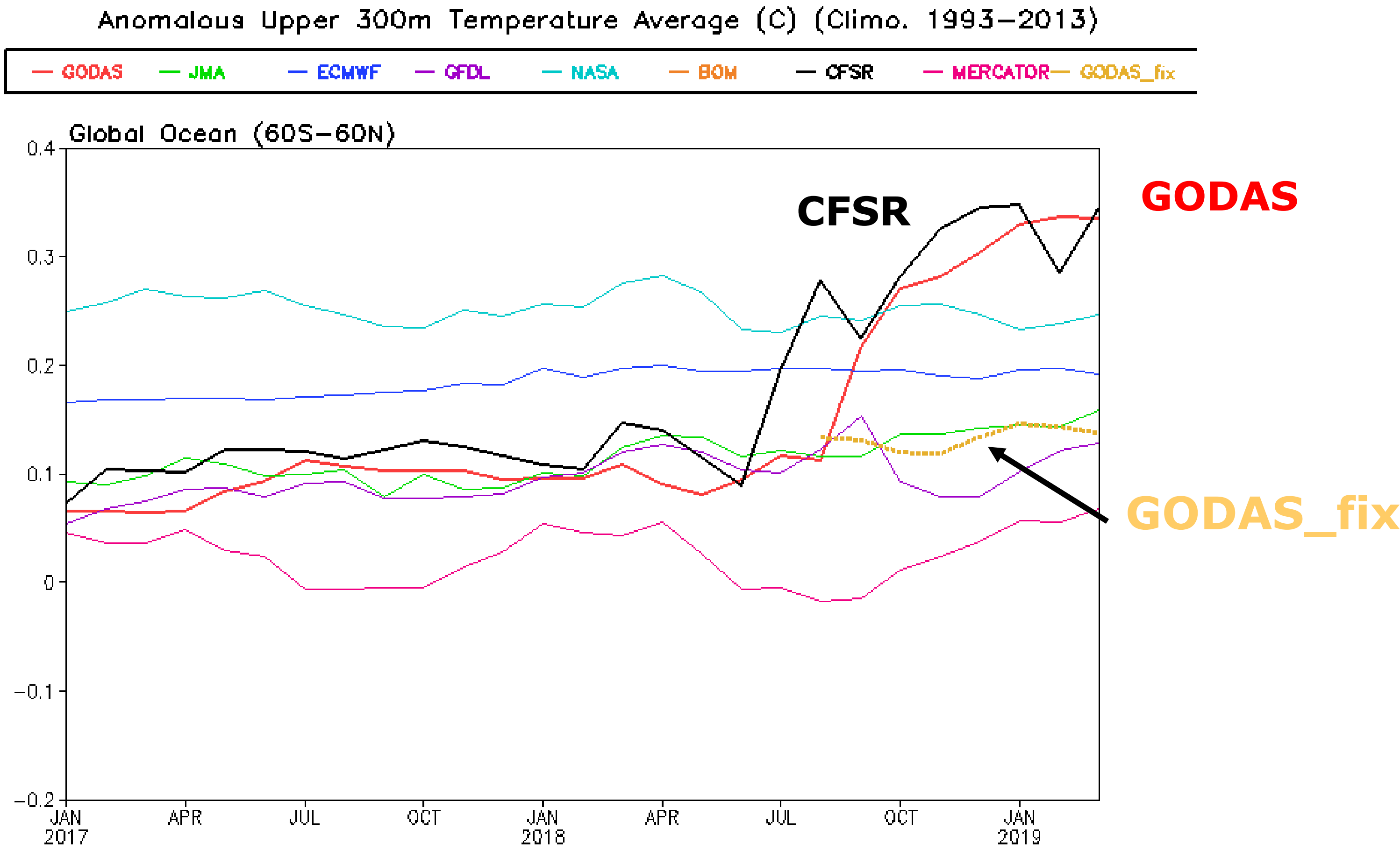
Qpen: SW penetration; Qcorr: Flux correction due to relaxation to OI SST

Recent Warm Biases in GODAS and CFSR

(Some Implications for ENSO and Hurricane Forecast)

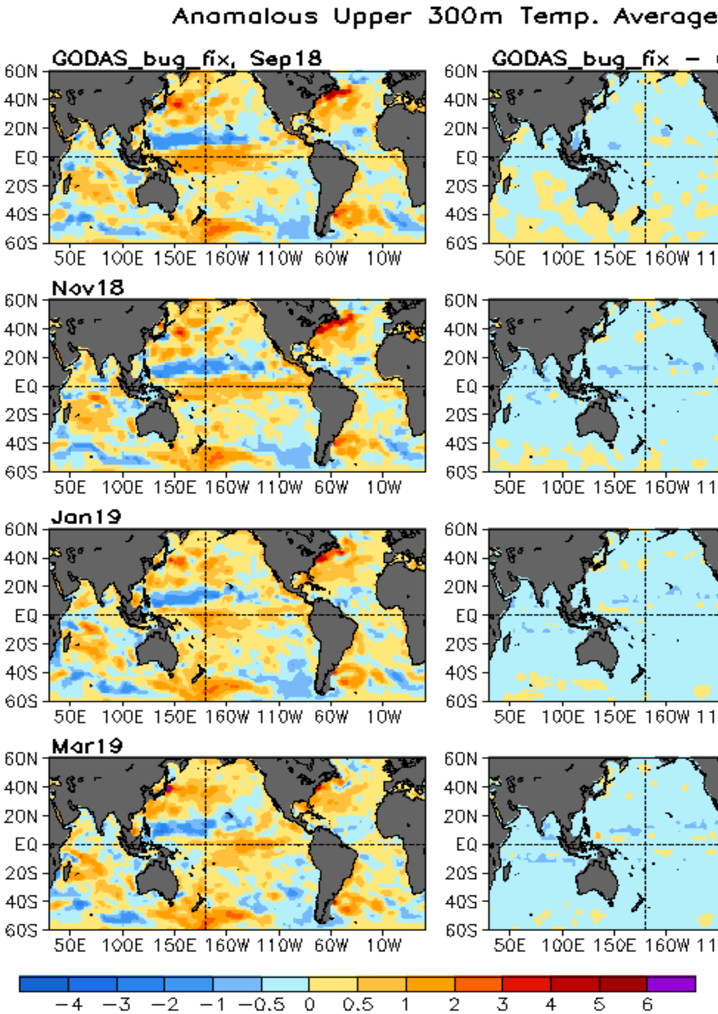


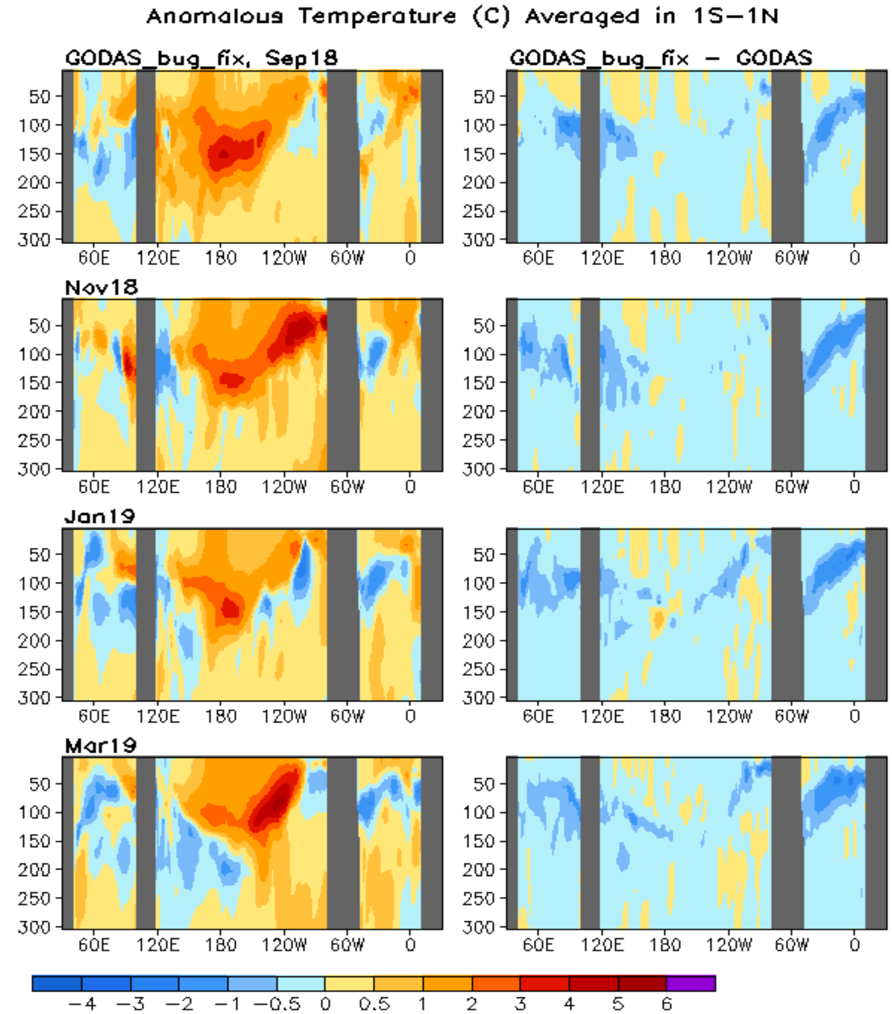
Courtesy of Brian Brettschneider, brbrettschneider@alaska.edu



- The sudden warming around Sep 2018 in GODAS and CFSR was caused by an error in decoding the Argo profile data in the new BUFR format.

- The warming was largely removed in a parallel run with a bug fix (dash yellow line). An operational code change is on the way.





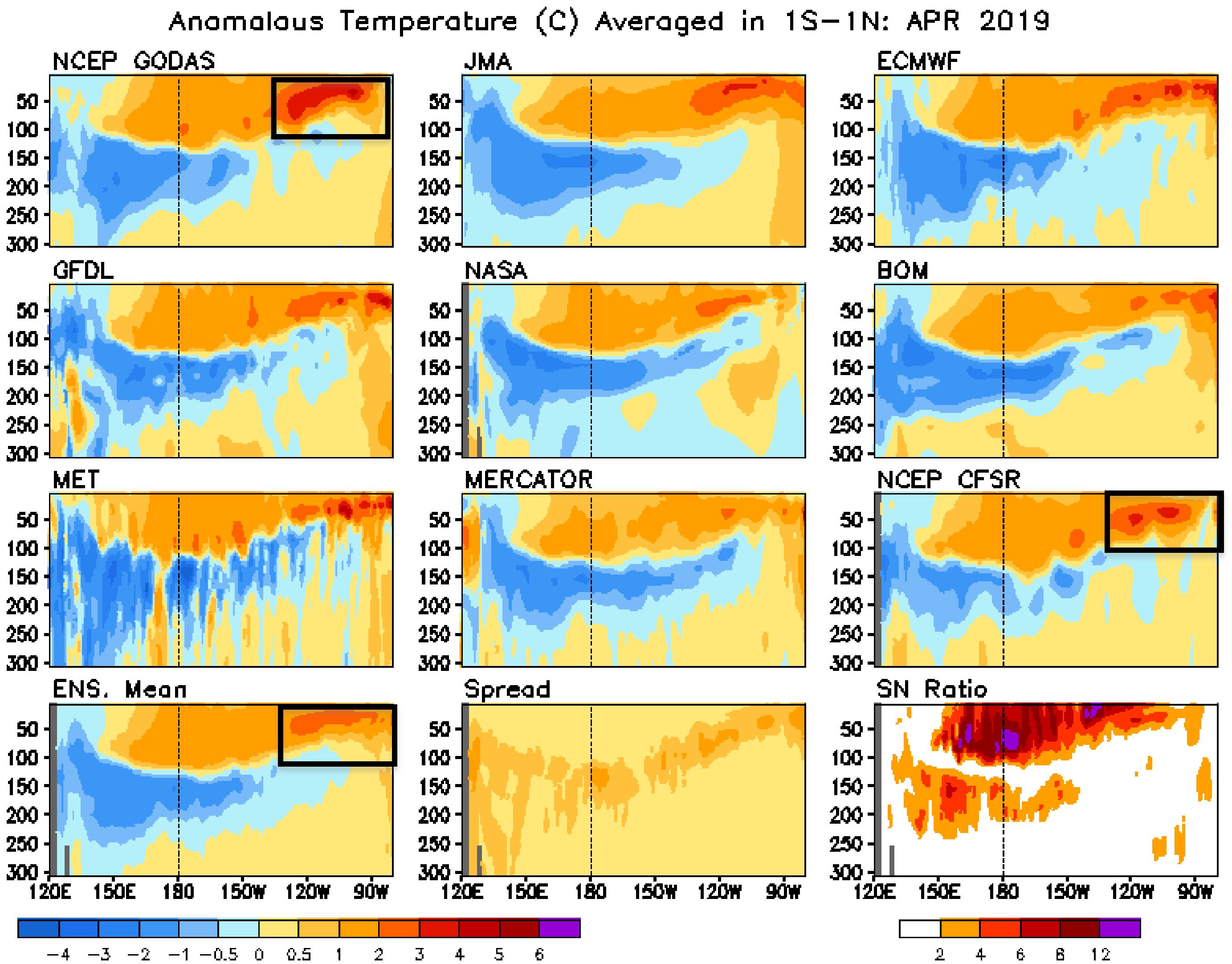
- After the bug fix, the upper 300m temperature average cooled by 0.3-0.5C with the largest cooling in the tropical ocean.

- The equatorial temperature cooled by 0.5-1C (1-2C) near the thermocline in the equatorial Pacific and Indian Ocean (the equatorial Atlantic).

Real-Time Ocean Reanalysis Intercomparison: Temp. Anom. in Eq. Pacific

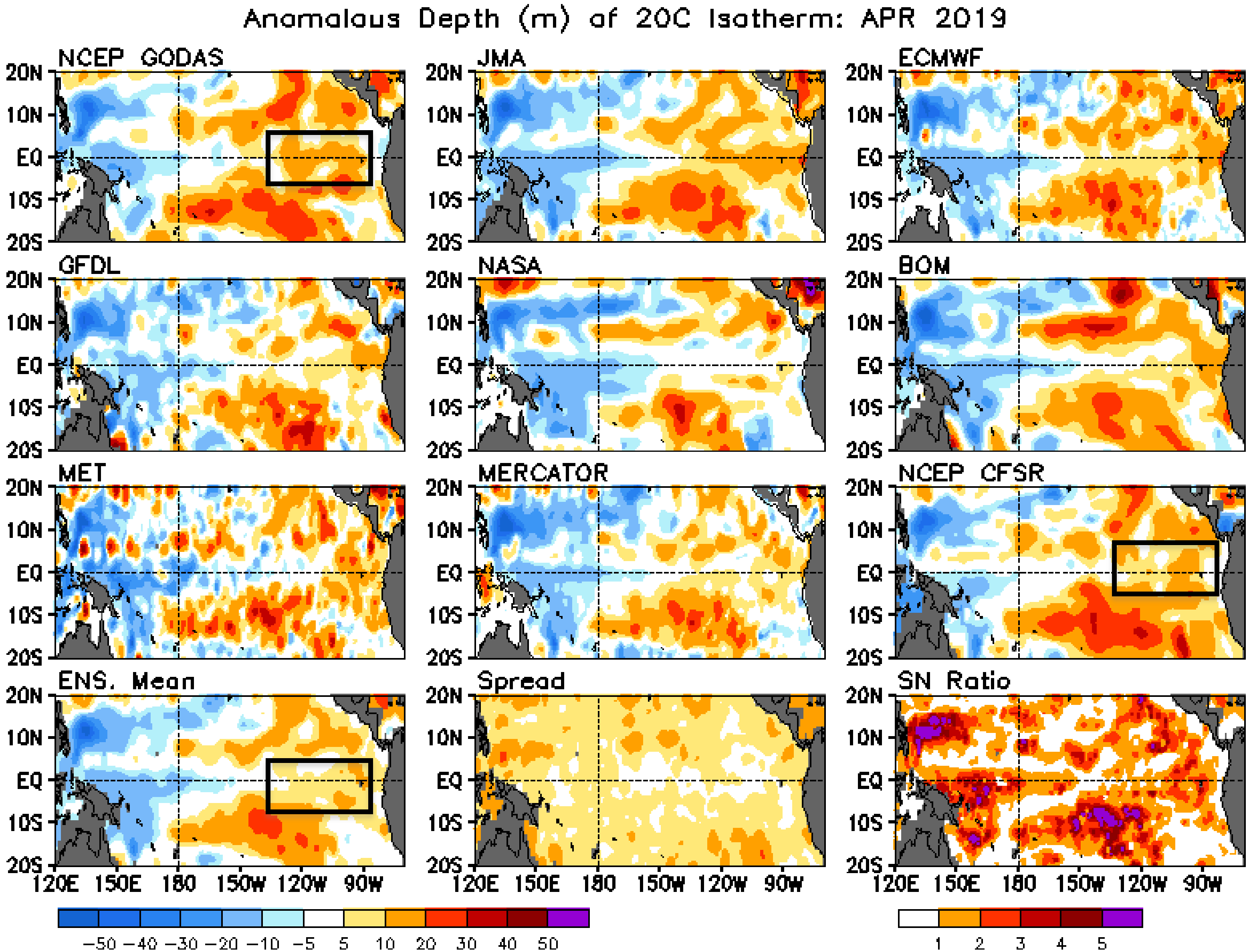
Climatology : 1993-2013

(http://www.cpc.ncep.noaa.gov/products/GODAS/multiora93_body.html)



D20 Anom. in Trop. Pacific

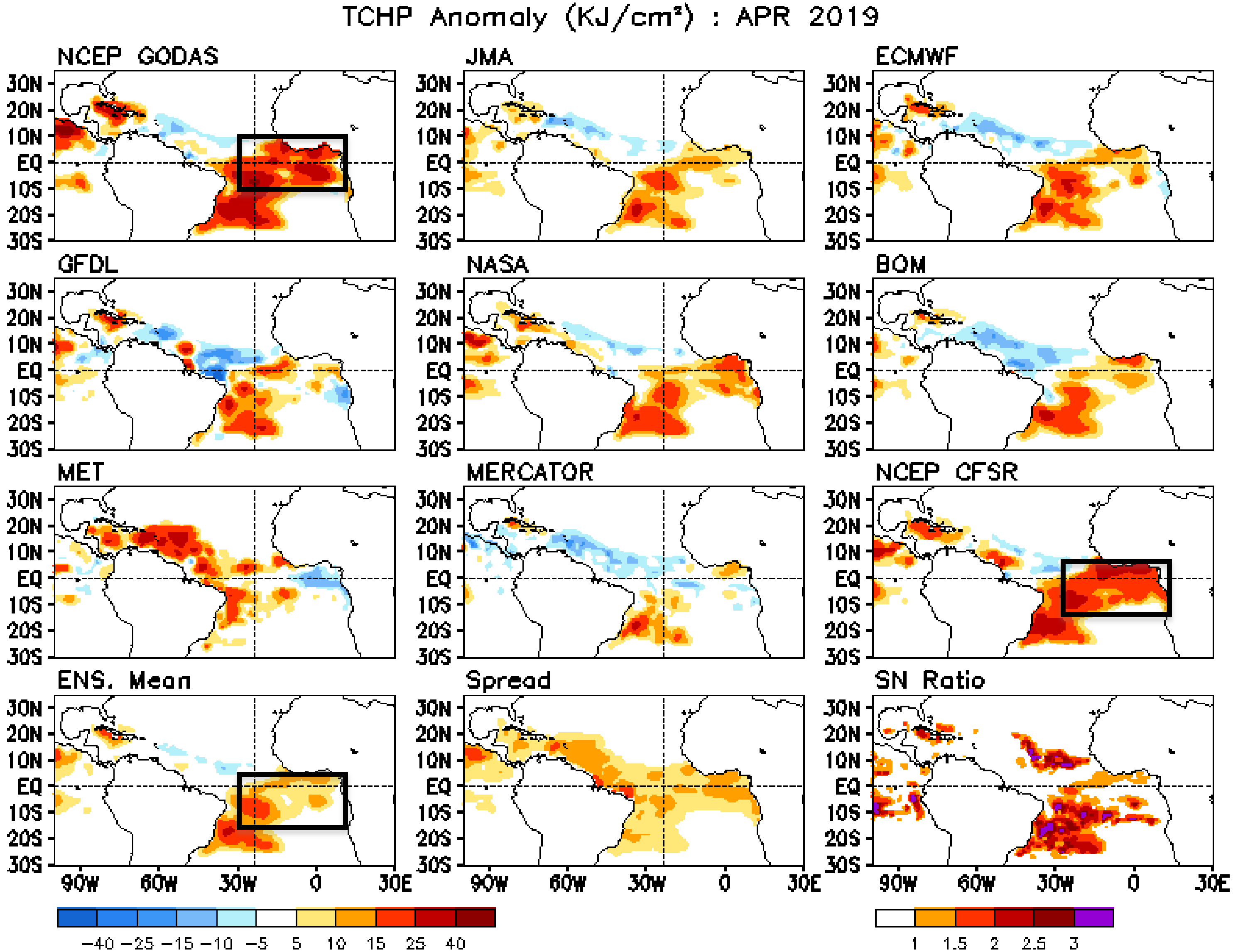
(http://www.cpc.ncep.noaa.gov/products/GODAS/multiora93_body.html)



Tropical Cyclone Heat Potential (TCHP) Anom. in Trop. Atlantic

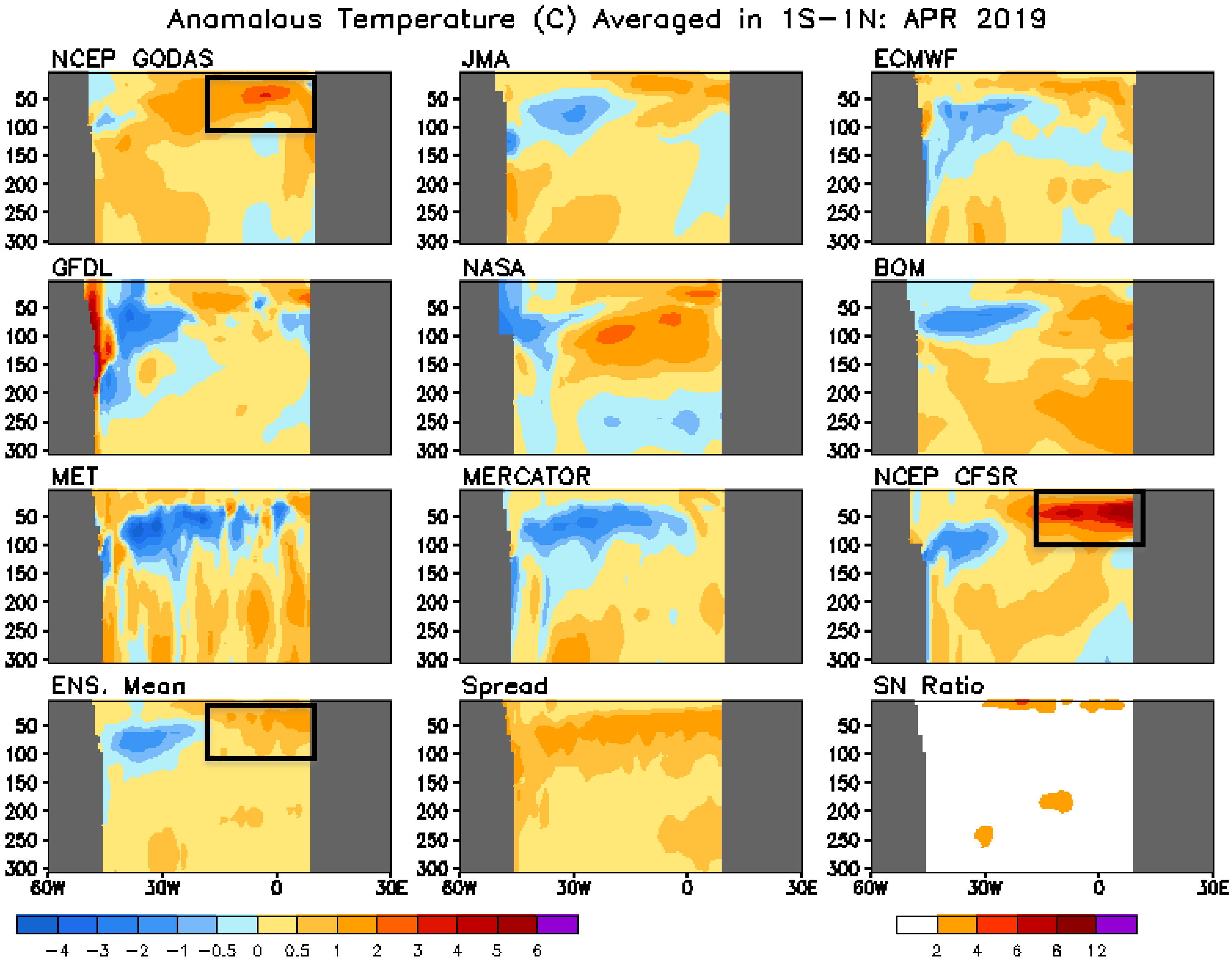
Climatology : 1993-2013

(http://www.cpc.ncep.noaa.gov/products/GODAS/multiora93_body.html)



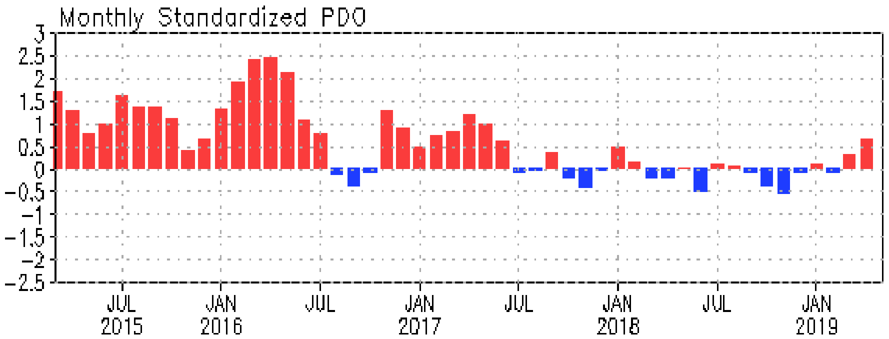
Temp. Anom. in Eq. Atlantic

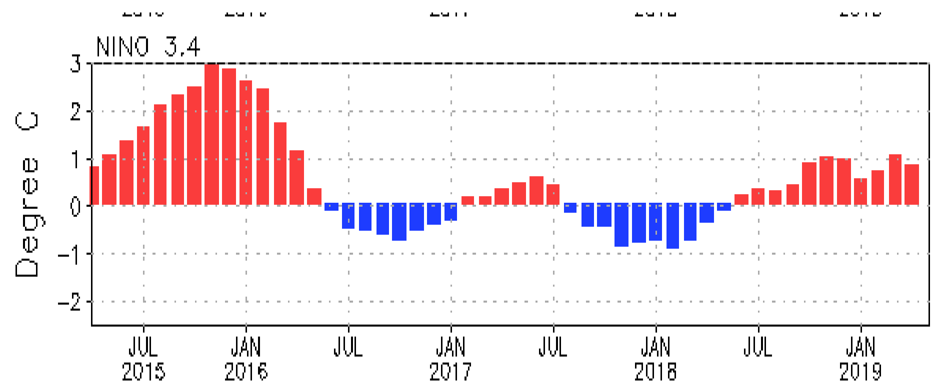
(http://www.cpc.ncep.noaa.gov/products/GODAS/multiora93_body.html)

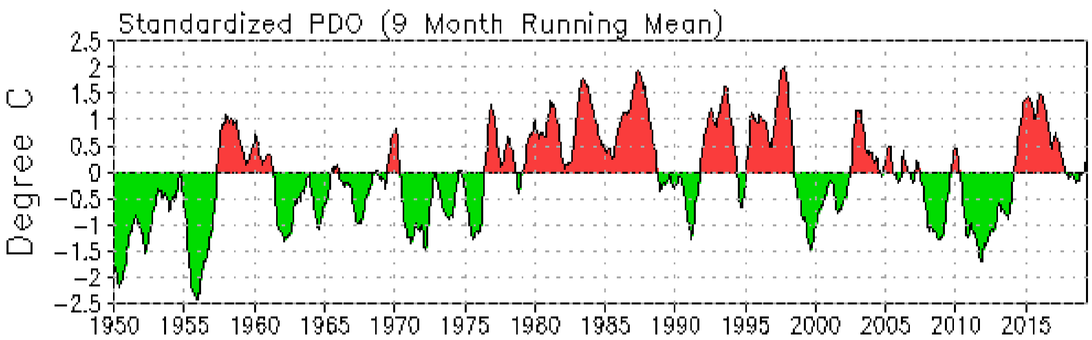


North Pacific & Arctic Oceans

PDO index

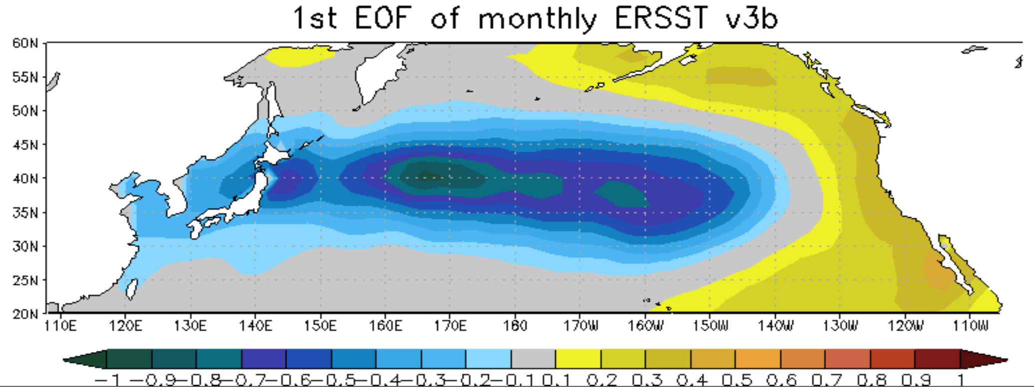






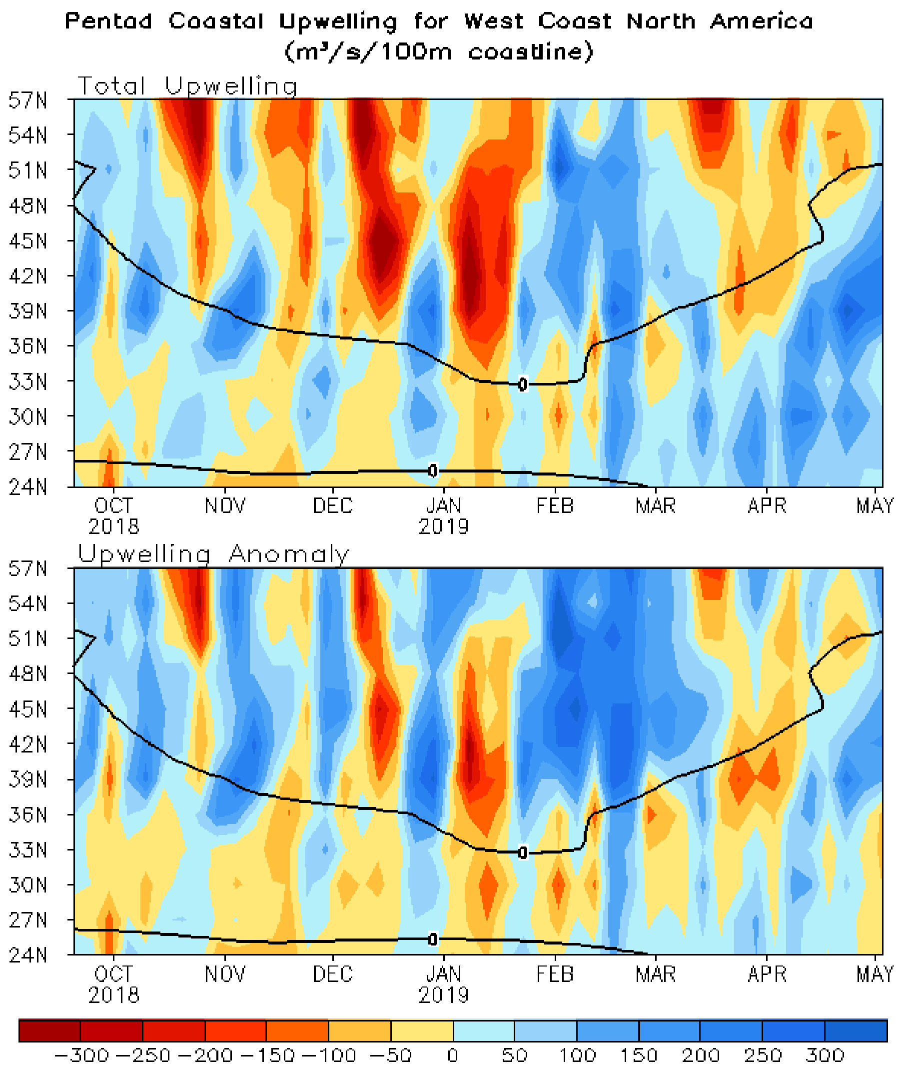
- **PDO index = +0.63 in Apr 2019.**

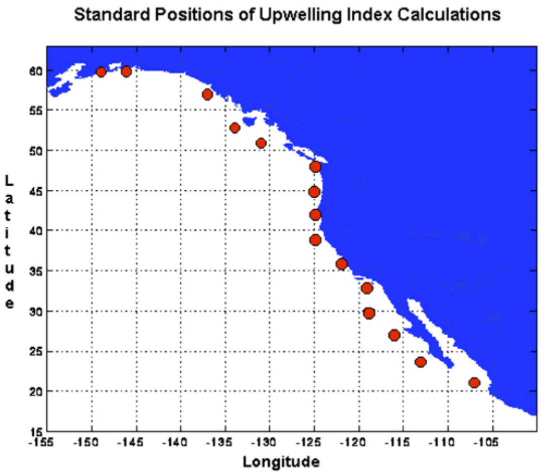
- **Statistically, ENSO leads PDO by 3-4 months, may through atmospheric bridge.**



- **Pacific Decadal Oscillation is defined as the 1st EOF of monthly ERSST v3b in the North Pacific for the period 1900-1993. PDO index is the standardized projection of the monthly SST anomalies onto the 1st EOF pattern.**
- **The PDO index differs slightly from that of JISAO, which uses a blend of UKMET and OIv1 and OIv2 SST.**

North America Western Coastal Upwelling





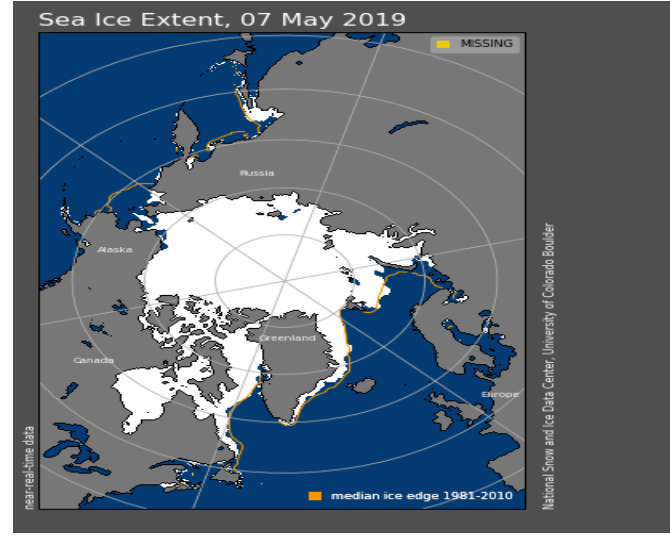
- Upwelling was abnormally strong in Apr 2019.

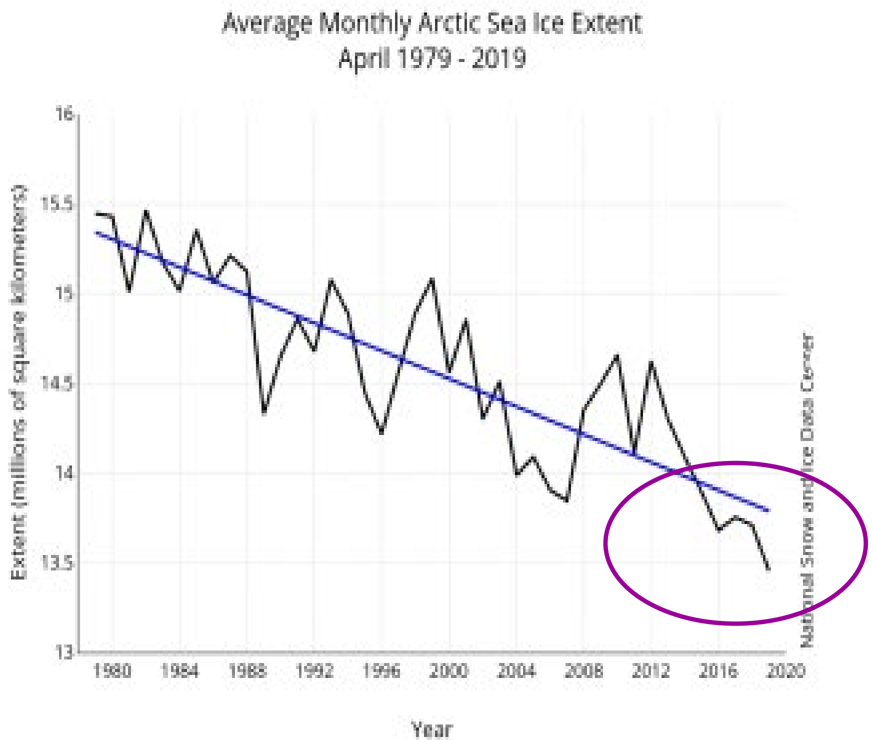
Fig. NP2. Total (top) and anomalous (bottom) upwelling indices at the 15 standard locations for the western coast of North America. Upwelling indices are derived from the vertical velocity of the NCEP's global ocean data assimilation system, and are calculated as integrated vertical volume transport at 50 meter depth from each location to its nearest coast point ($m^3/s/100m$ coastline). Anomalies are departures from the 1981-2010 base period pentad means.

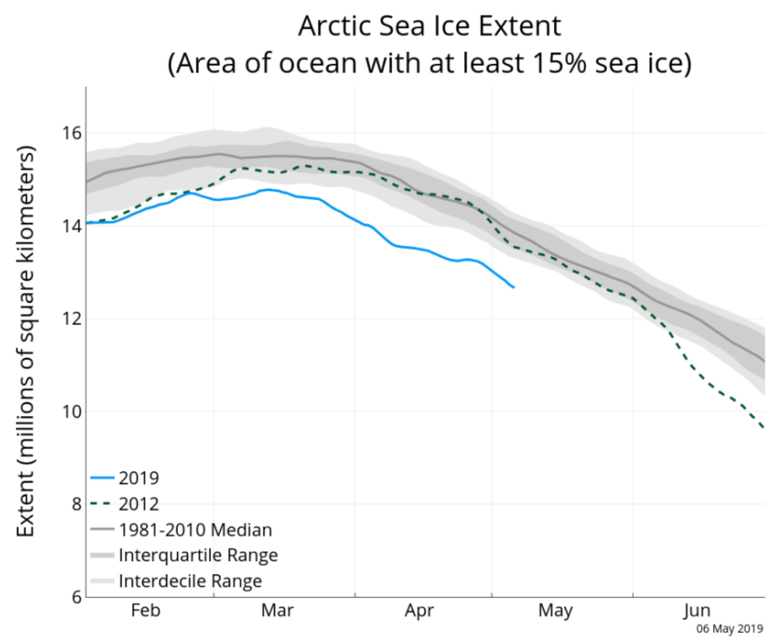
- **Area below (above) black line indicates climatological upwelling (downwelling) season.**
- **Climatologically upwelling season progresses from Mayil to July along the west coast of North America from 36ºN to 57ºN.**

Arctic Sea Ice

National Snow and Ice Data Center
http://nsidc.org/arcticseaicenews/index.html



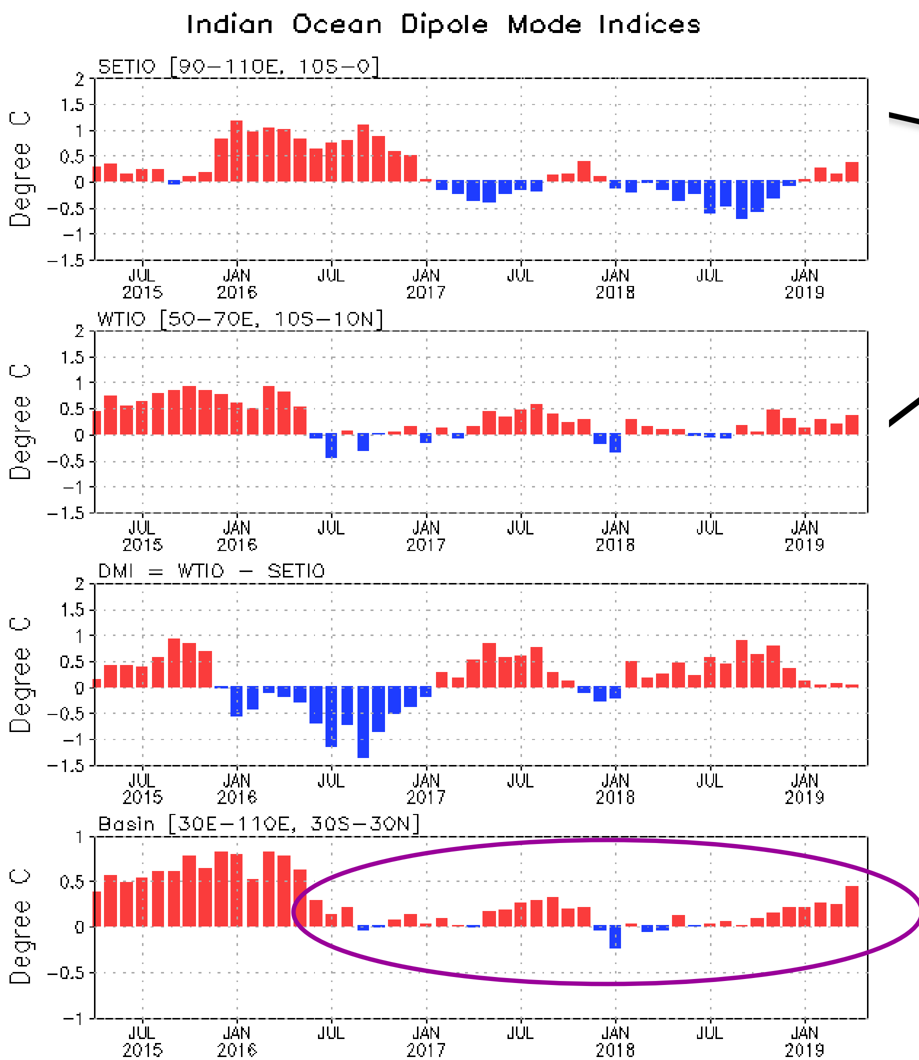


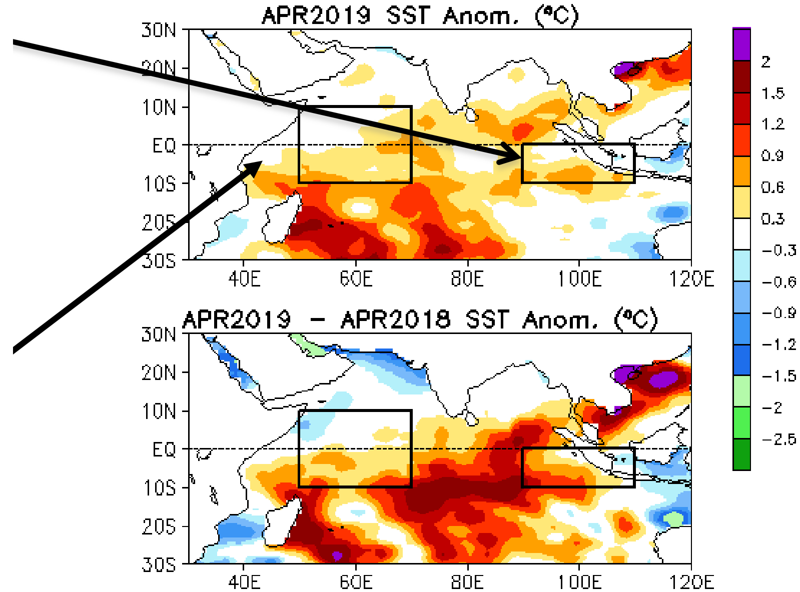


- Arctic sea ice extent for Apr 2019 was the lowest in the 40-year satellite record, below the previous record low in Apr 2016.

Indian Ocean

Evolution of Indian Ocean SST Indices





- The basin-wide SST index increased, becoming the warmest since May 2016.

Fig. I1a. Indian Ocean Dipole region indices, calculated as the area-averaged monthly mean sea surface temperature anomalies (ºC) for the SETIO [90ºE-110ºE, 10ºS-0] and WTIO [50ºE-70ºE, 10ºS-10ºN] regions, and Dipole Mode Index, defined as differences between WTIO and SETIO. Data are derived from the NCEP OI SST analysis, and anomalies are departures from the 1981-2010 base period means.

Tropical Indian: SST Anom., SST Anom. Tend., OLR, Sfc Rad, Sfc Flx, 925-mb & 200-mb Wind Anom.

- **Positive SSTAs dominated in the tropics.**
- **Convections were suppressed (enhanced) in the western and Maritime Continent (eastern) tropical Indian Ocean.**

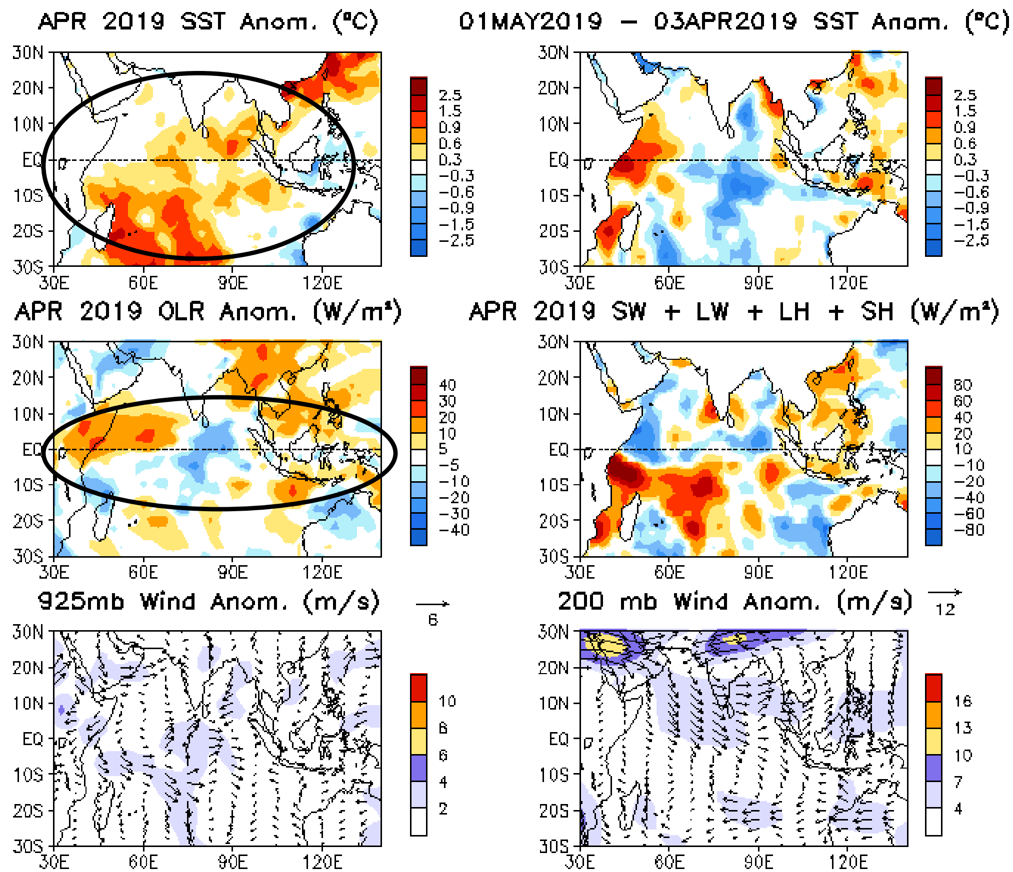
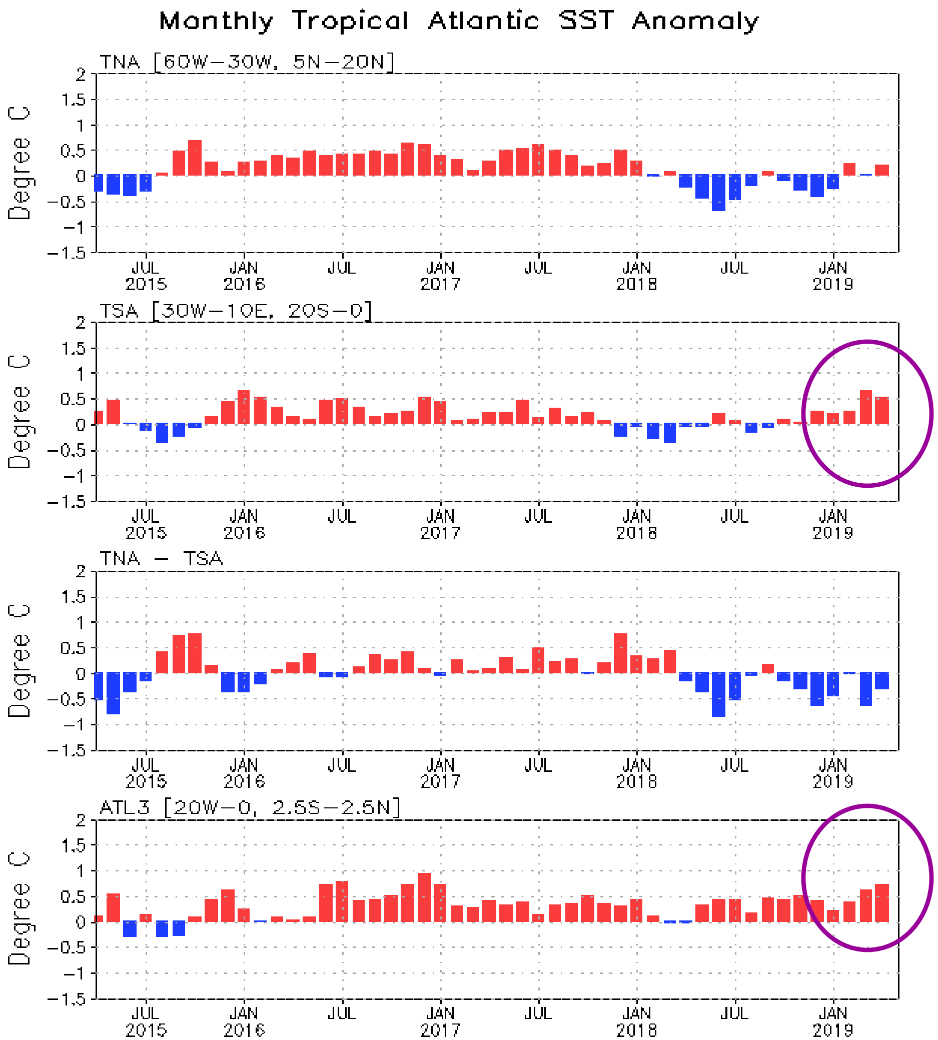
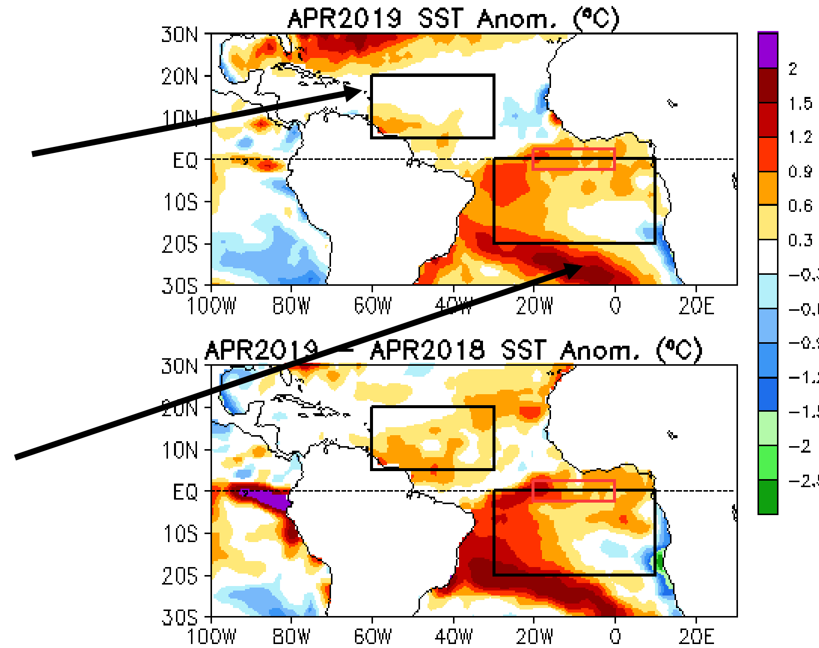


Fig. I2. Sea surface temperature (SST) anomalies (top-left), anomaly tendency (top-right), Outgoing Long-wave Radiation (OLR) anomalies (middle-left), sum of net surface short- and long-wave radiation, latent and sensible heat flux anomalies (middle-right), 925-mb wind anomaly vector and its amplitude (bottom-left), 200-mb wind anomaly vector and its amplitude (bottom-right). SST are derived from the NCEP OI SST analysis, OLR from the NOAA 18 AVHRR IR window channel measurements by NESDIS, winds and surface radiation and heat fluxes from the NCEP CDAS. Anomalies are departures from the 1981-2010 base period means.

Tropical and North Atlantic Ocean

Evolution of Tropical Atlantic SST Indices

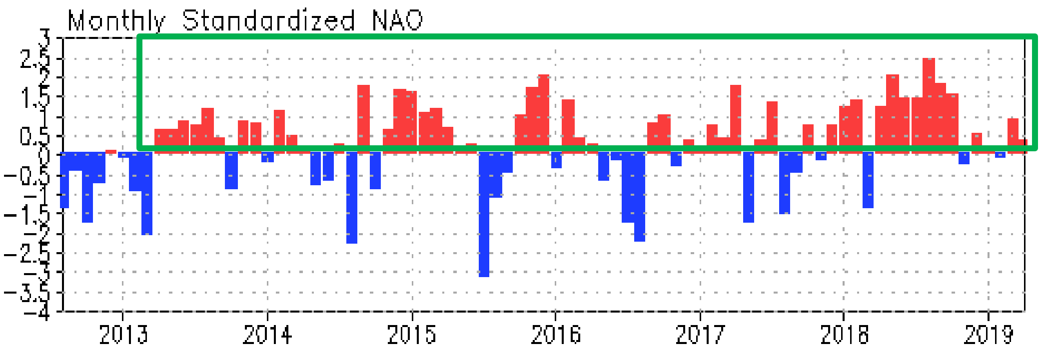


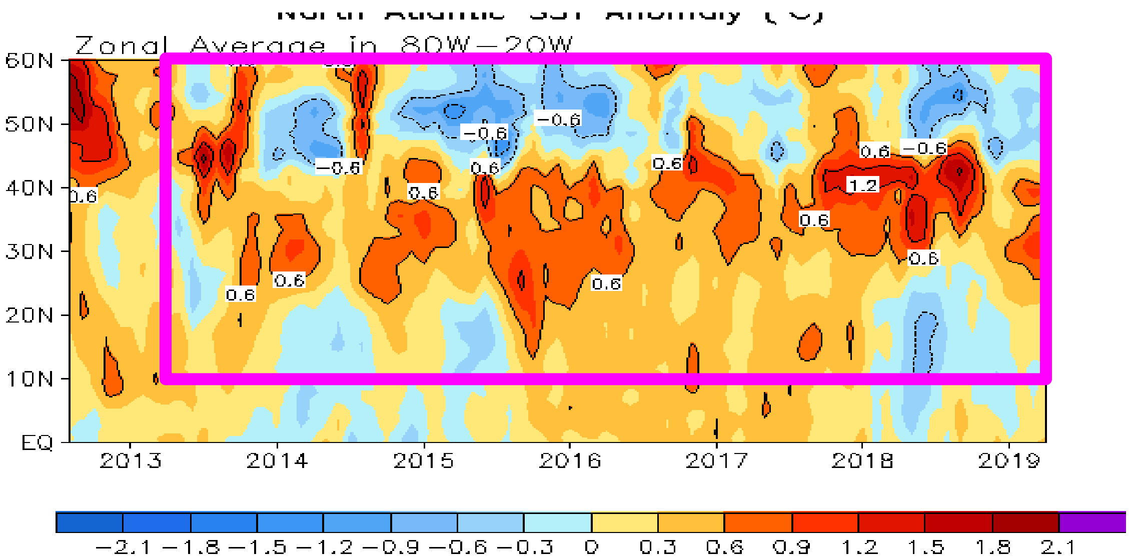


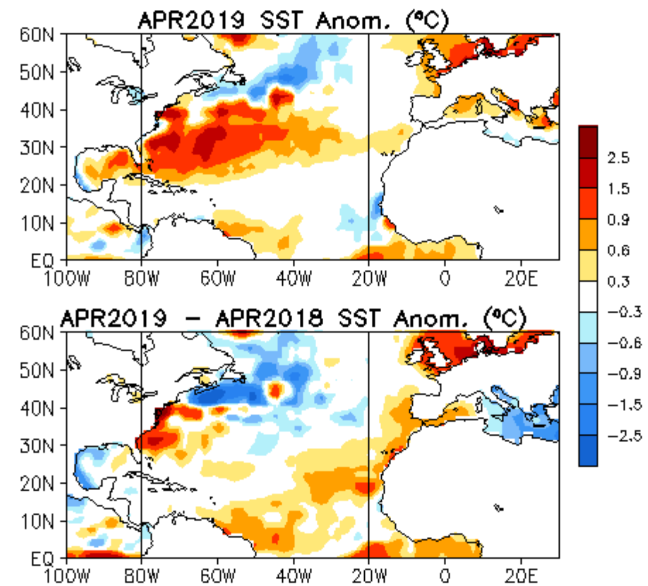
- **The TSA and ATL3 indices increased, becoming the warmest since Feb 2017.**

Fig. A1a. Tropical Atlantic Variability region indices, calculated as the area-averaged monthly mean sea surface temperature anomalies (°C) for the TNA [60°W-30°W, 5°N-20°N], TSA [30°W-10°E, 20°S-0] and ATL3 [20°W-0, 2.5°S-2.5°N] regions, and Meridional Gradient Index, defined as differences between TNA and TSA. Data are derived from the NCEP OI SST analysis, and anomalies are departures from the 1981-2010 base period means.

NAO and SST Anomaly in North Atlantic





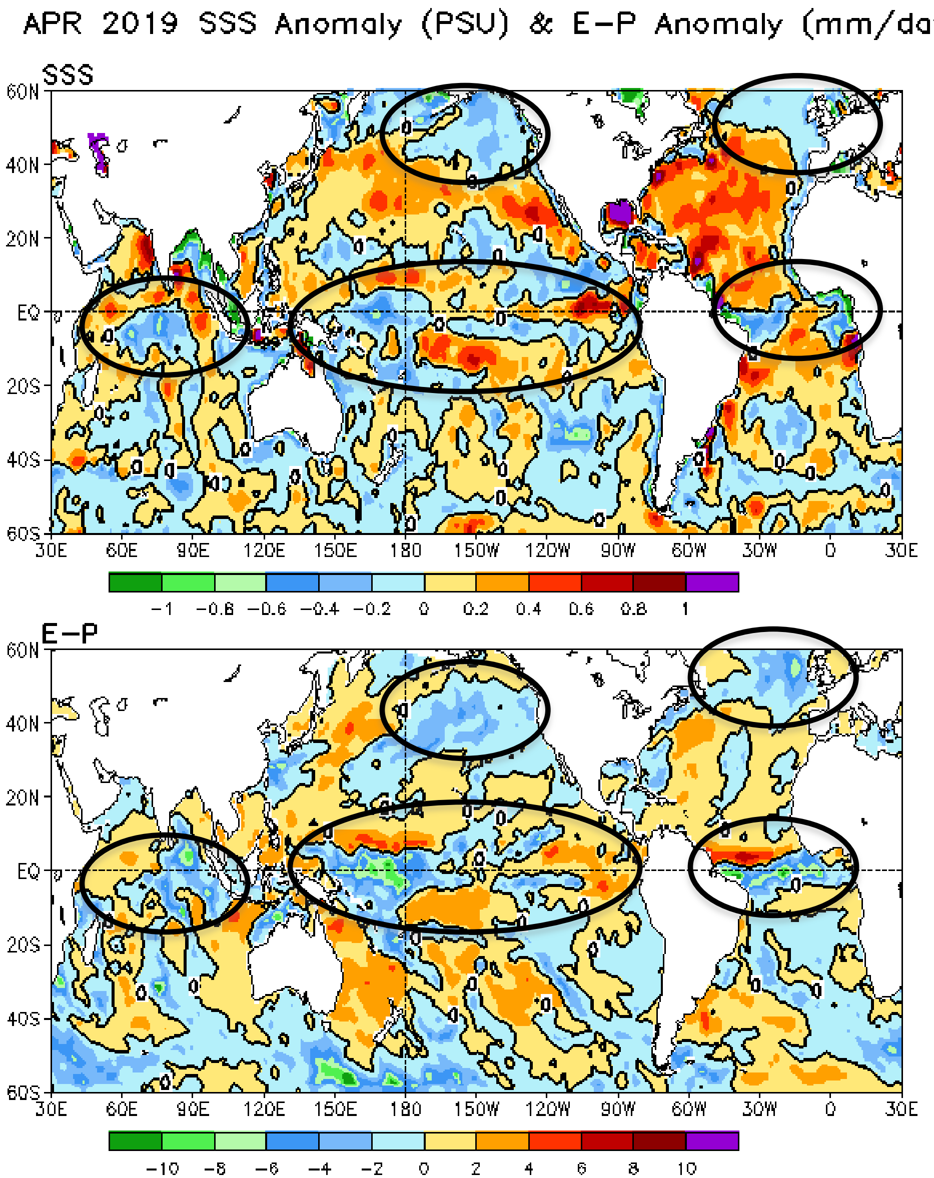


- NAO was in a positive phase with NAO=0.36 in Apr 2019.
- SSTA was a tripole/horseshoe-like pattern with positive in the mid-latitudes and negative in the lower and higher latitudes, due to the long-term persistence of positive phase of NAO.

Fig. NA2. Monthly standardized NAO index (top) derived from monthly standardized 500-mb height anomalies obtained from the NCEP CDAS in 20ºN-90ºN (http://www.cpc.ncep.noaa.gov). Time-Latitude section of SST anomalies averaged between 80ºW and 20ºW (bottom). SST are derived from the NCEP OI SST analysis, and anomalies are departures from the 1981-2010 base period means.

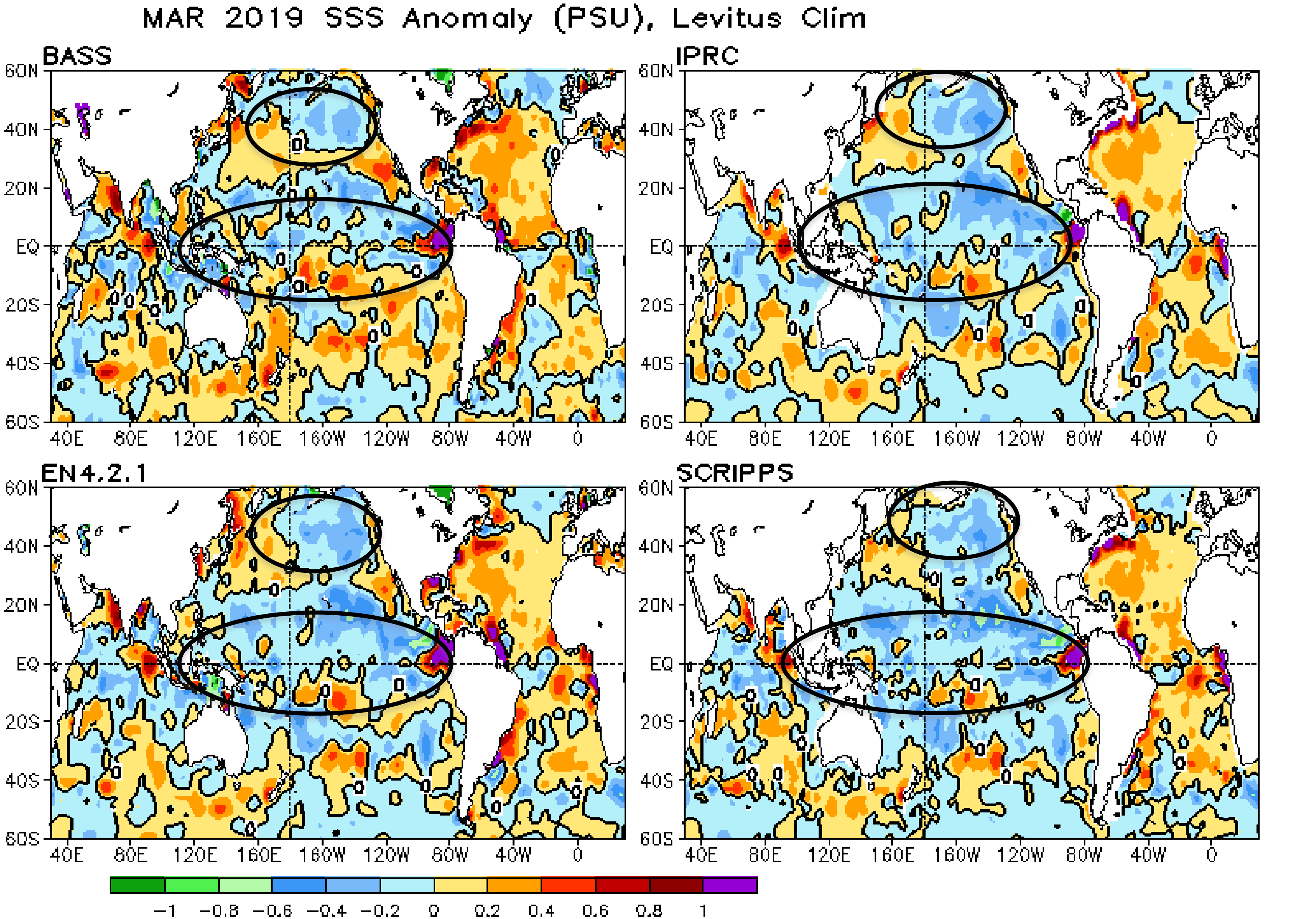
Experimental Salinity and Freshwater Flux Monitoring Products

Monitoring SSS and Freshwater Flux Variability



- Blended Analysis of Surface Salinity (BASS) including in situ, SMOS, Aquarius and SMAP obs.
- 2010-present, Monthly and Pentad
- CPC/NODC/NESDIS joint effort (Xie et al. 2014)
- Precipitation: CMORPH
- Evaporation: CFSR adjusted to OAFlux ftp.cpc.ncep.noaa.gov/precip/BASS

- SSS anom. and E-P anom. are largely consistent.

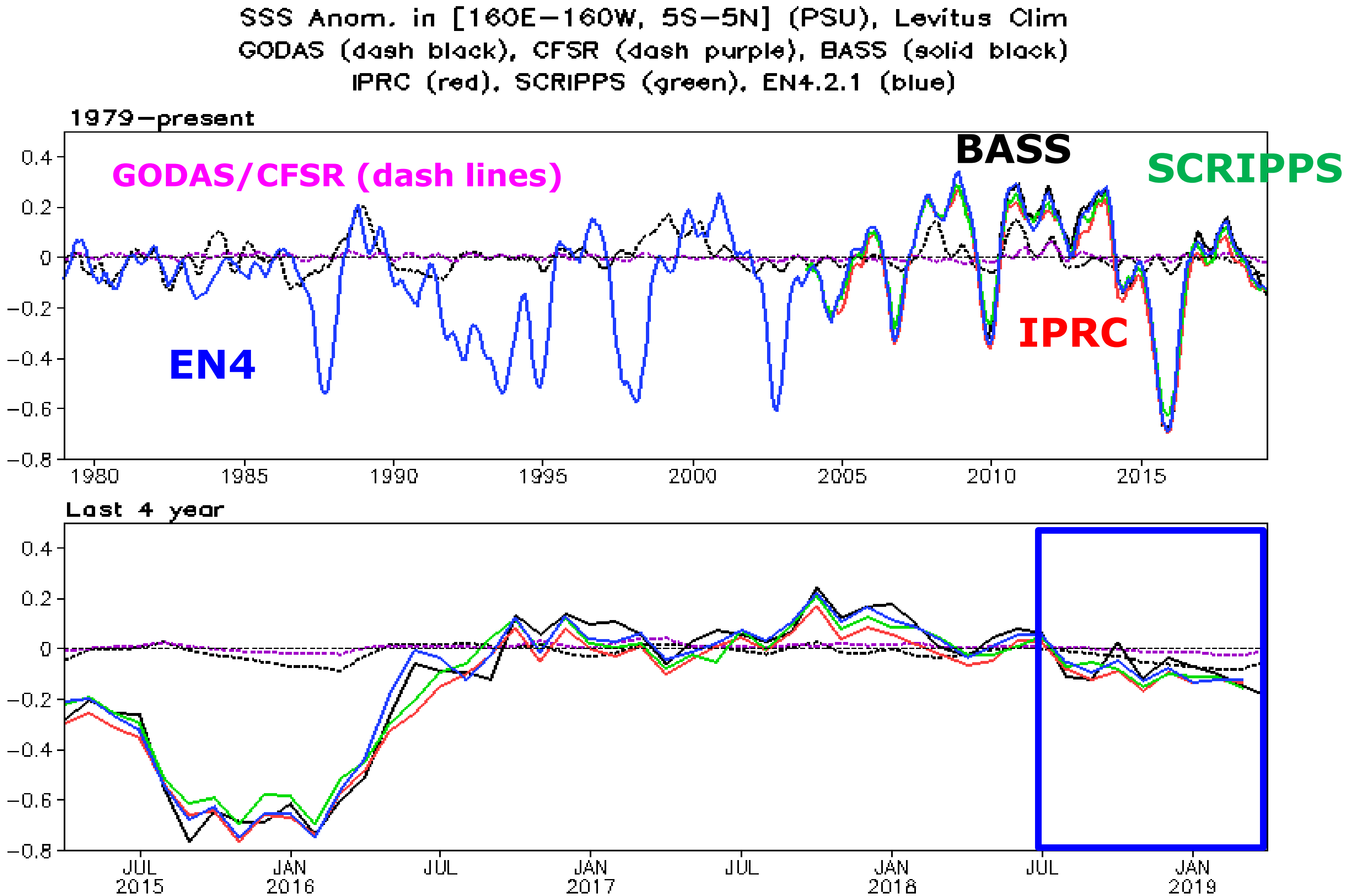


SCRIPPS Argo (2004-present, real-time): http://sio-argo.ucsd.edu/RG_Climatology.html

IPRC Argo (2005-present, real-time): http://apdrc.soest.hawaii.edu/projects/argo/

EN4.2.1 (1900-present, one-month delay): https://www.metoffice.gov.uk/hadobs/en4/download-en4-2-1.html

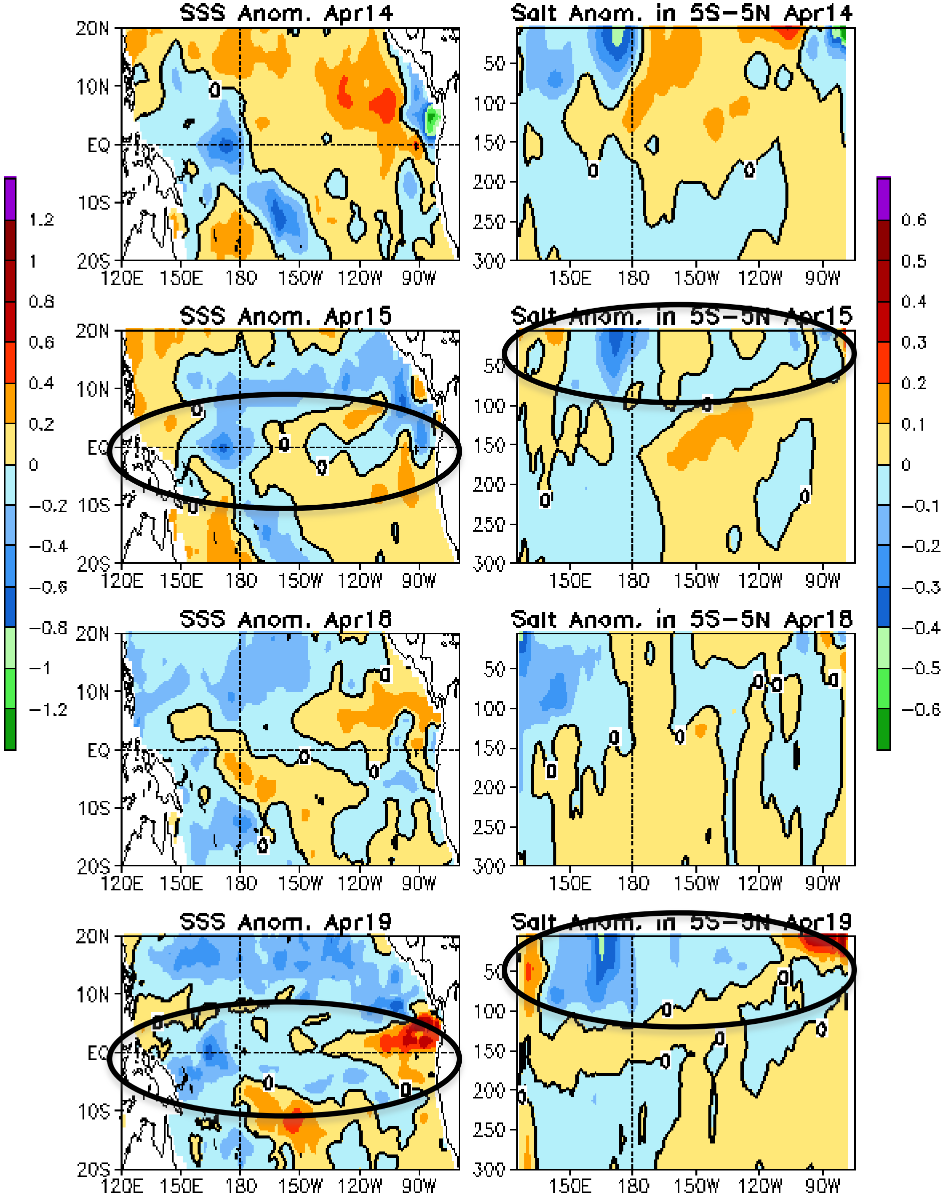
SSS Anom. in the NINO4 Region



- **SSS anom. in the NINO4 region is consistent among BASS, SCRIPPS and IPRC, and EN4.2.1.**

- **However, GODAS and CFSR severely underestimates SSS variability due to assimilation of synthetic salinity.**

SSS Anom. and Salinity Anom. in 5S-5N
(Ensemble Mean of SCRIPPS, IPRC and EN4)



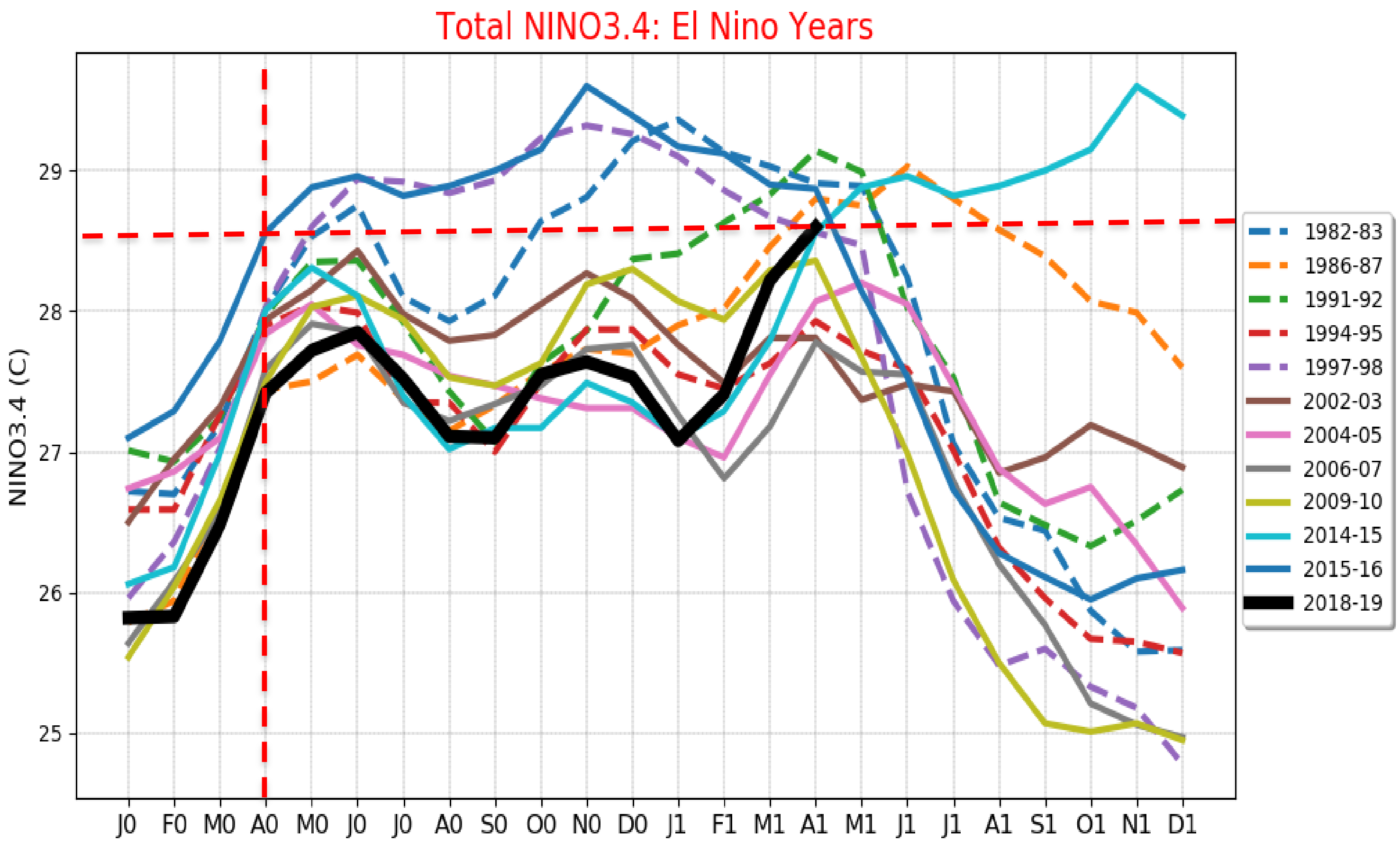
- **Salinity anom. in Apr 2019 were compared with those in Apr 2014, Apr 2015 and Apr 2018.**

- **The patterns of salinity anom. in Apr 19 were mostly similar to those in Apr 15 when negative salinity anom. was observed near the date line in upper 100m.**

- **However, the negative salinity anom. in Apr 2019 extended further eastward than in Apr 2015.**

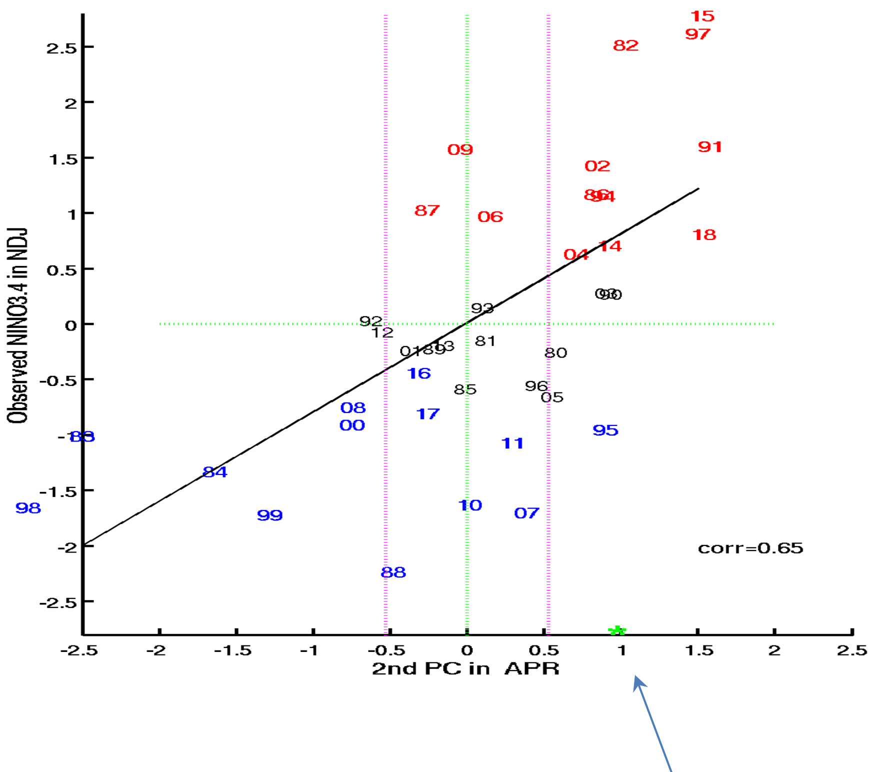
ENSO and Global SST Predictions

Total NINO3.4 Index



- The total NINO3.4 in Apr 2019 was among **the highest Apr value in all the El Nino years since 1980 similar to that in Apr 2015**, which favors a 2nd year El Nino development.

Markov Model 2nd PC vs. NINO3.4 in NDJ



* 2nd PC in Apr2019

2x2 contingency table El Nino (1980-2018)	April > +0.53 (0.5 STD)
Percent correct rate	0.85 (33/39)
Hit rate	0.77 (10/13)
False alarm rate	0.23(3/13)

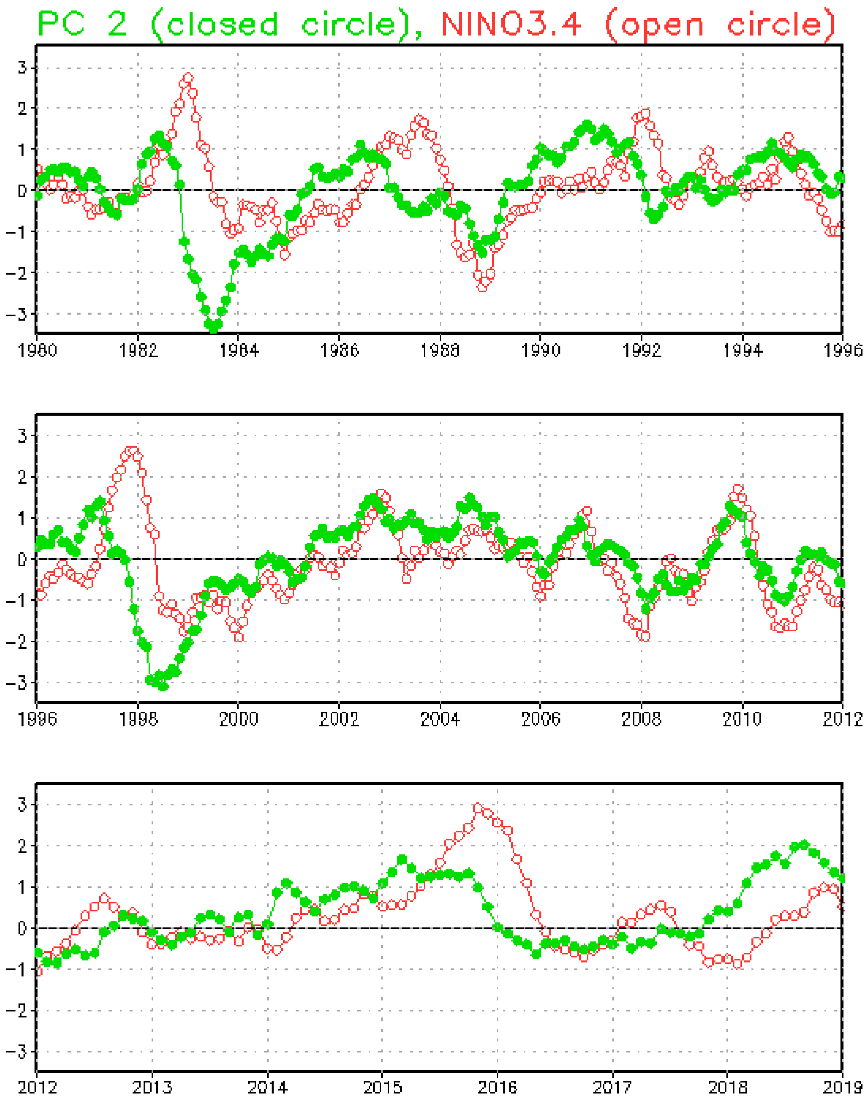
2x2 contingency table La Nina (1980-2018)	April < -0.53 (-0.5 STD)
Percent correct rate	0.8(31/39)
Hit rate	0.54 (7/13)
False alarm rate	0.2 (2/9)

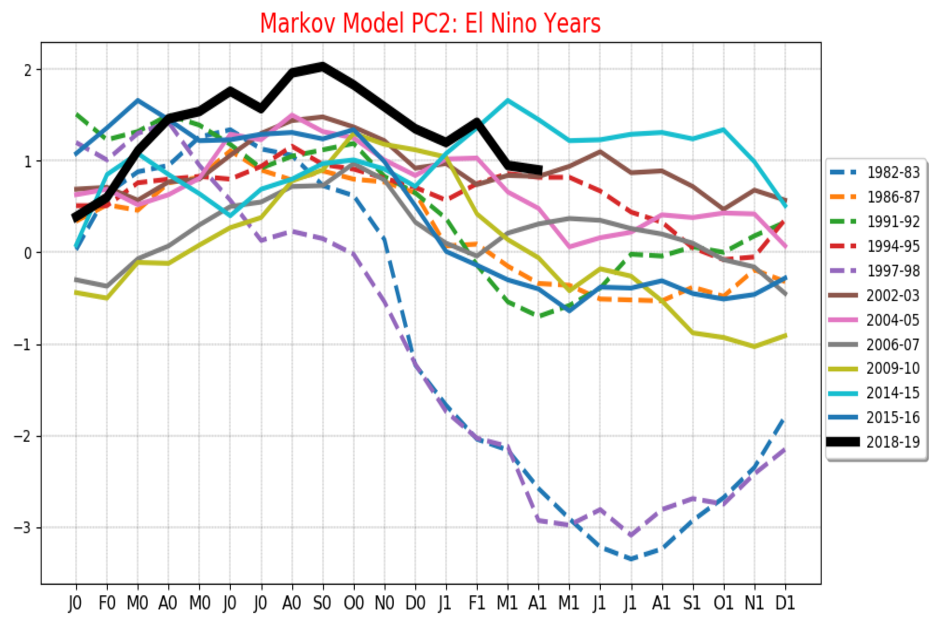
2x2 contingency table Neutral (1980-2018)	April -0.53< PC2 < +0.53
Percent correct rate	0.7 (27/39)
Hit rate	0.7 (9/13)
False alarm rate	0.47 (8/17)

- **Markov model PC2 in Apr is very skillful in forecasting El Nino winter with a hit rate of 0.8 and false alarm rate of 0.2.**

- **Markov PC2 favors a 2nd year El Nino in 2019/20.**

Markov Model PC2

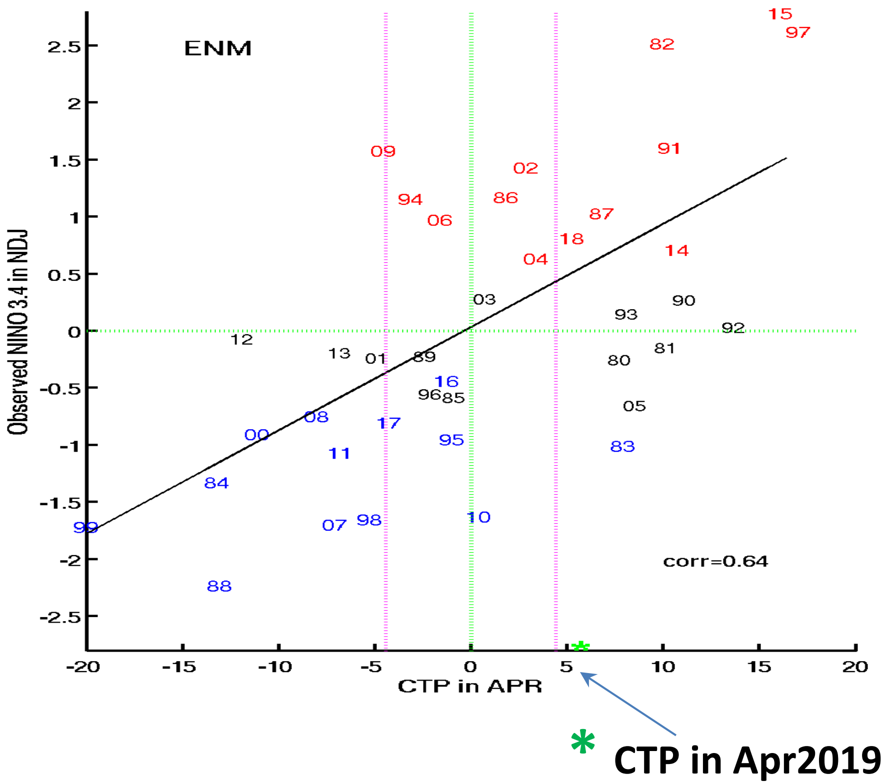




https://www.cpc.ncep.noaa.gov/products/people/yxue/ENSO_forecast_clim81-10_godas.html

Central Tropical Pacific (CTP) vs. NINO3.4 in NDJ

https://www.cpc.ncep.noaa.gov/products/GODAS/multiora_body.html



- CTP favors a 2nd year El Nino in 2019/20, but it has a moderate skill in forecasting El Nino (hit rate of 0.46 and false alarm rate of 0.54).

- CTP in Apr has a high skill in forecasting La Nina with a hit rate of 0.7 and false alarm rate of 0.3.

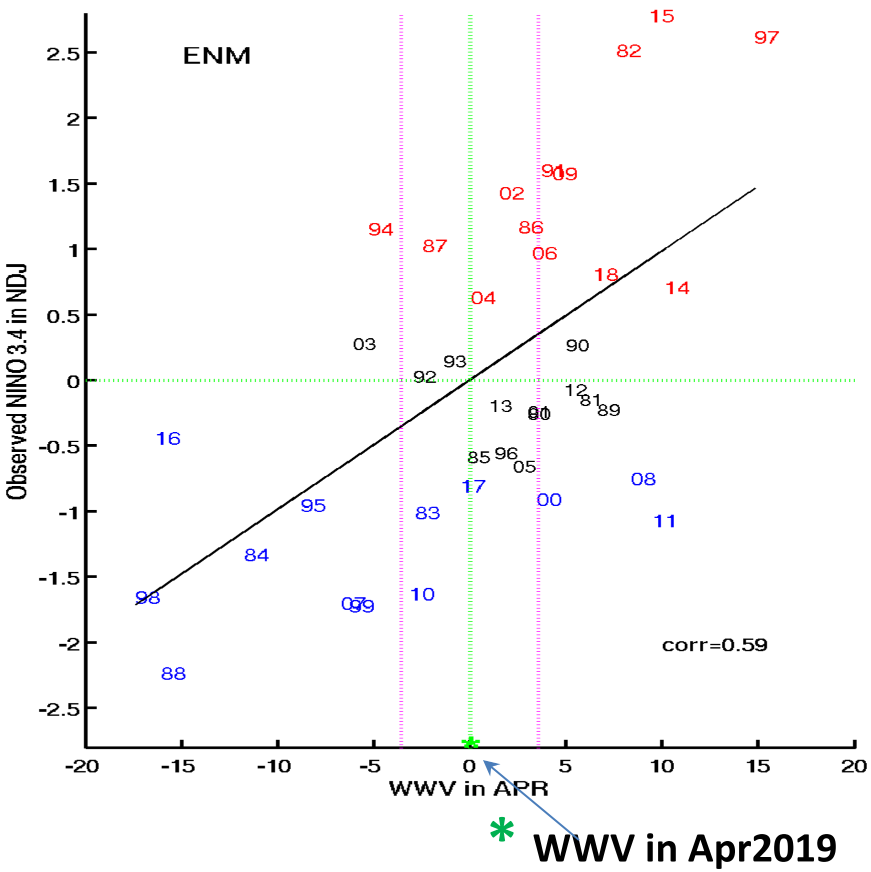
2x2 contingency table El Nino (1980-2018)	April > + 4.4 (0.5 STD)
Percent correct rate	0.64 (25/39)
Hit rate	0.46 (6/13)
False alarm rate	0.54 (7/13)

2x2 contingency table La Nina (1980-2018)	April < -4.4 (-0.5 STD)
Percent correct rate	0.8 (31/39)
Hit rate	0.7 (9/13)
False alarm rate	0.3 (4/13)

2x2 contingency table Neutral (1980-2018)	April -4.4<CTP<+4.4
Percent correct rate	0.54 (21/39)
Hit rate	0.31 (4/13)
False alarm rate	0.7 (9/13)

Warm Water Volume (WWV) vs. NINO3.4 in NDJ

https://www.cpc.ncep.noaa.gov/products/GODAS/multiora_body.html



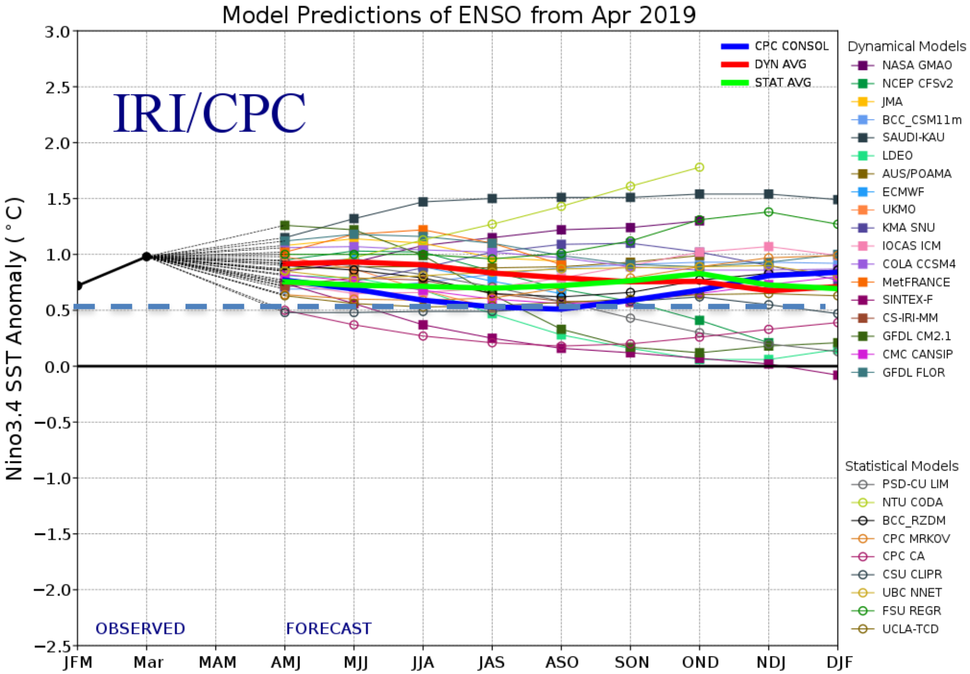
2x2 contingency table El Nino (1980-2018)	April > +3.5 (0.5 STD)
Percent correct rate	0.7 (27/39)
Hit rate	0.54 (7/13)
False alarm rate	0.46 (6/13)

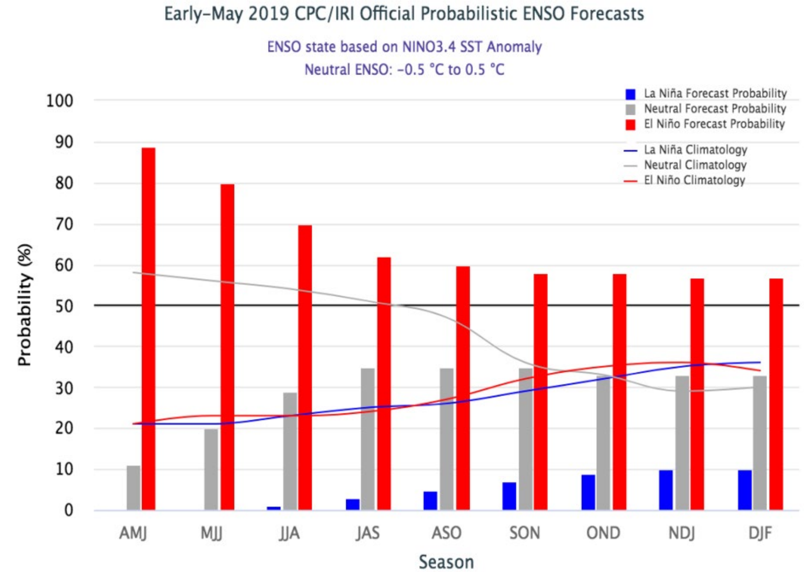
2x2 contingency table La Nina (1980-2018)	April < -3.5 (-0.5 STD)
Percent correct rate	0.8 (31/39)
Hit rate	0.54 (7/13)
False alarm rate	0.2 (2/9)

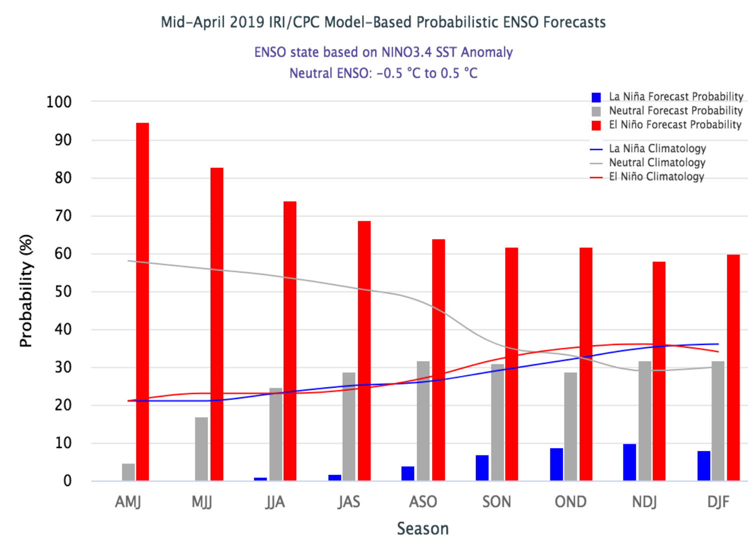
2x2 contingency table Neutral (1980-2018)	April -3.5 < WWV < +3.5
Percent correct rate	0.64 (25/39)
Hit rate	0.62 (8/13)
False alarm rate	0.53 (9/17)

- WWV in Apr has a moderate skill in forecasting El Nino (La Nina) with a hit rate of 0.54 (0.54) and false alarm rate of 0.46 (0.2).
-
- WWV favors neutral conditions in winter 2019/20.

Model Predictions of ENSO from Apr 2019

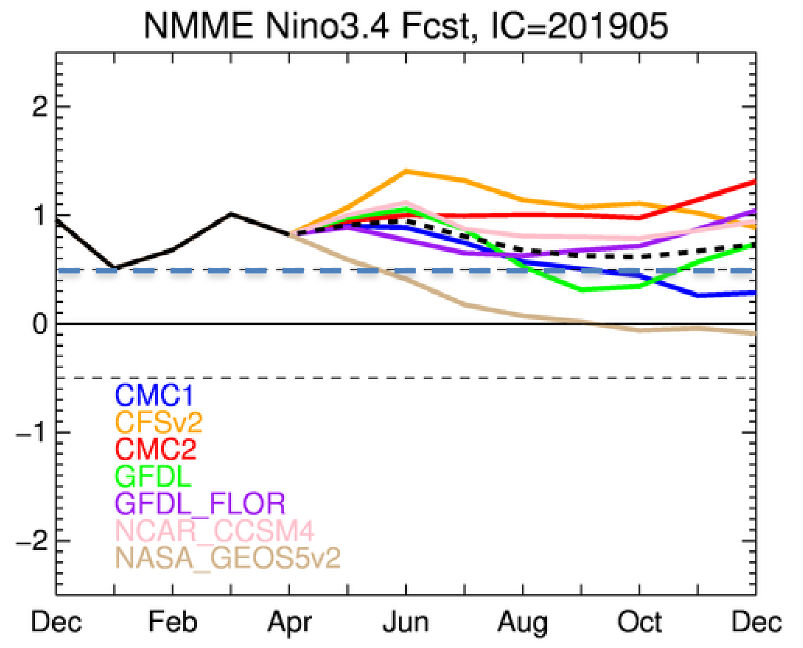


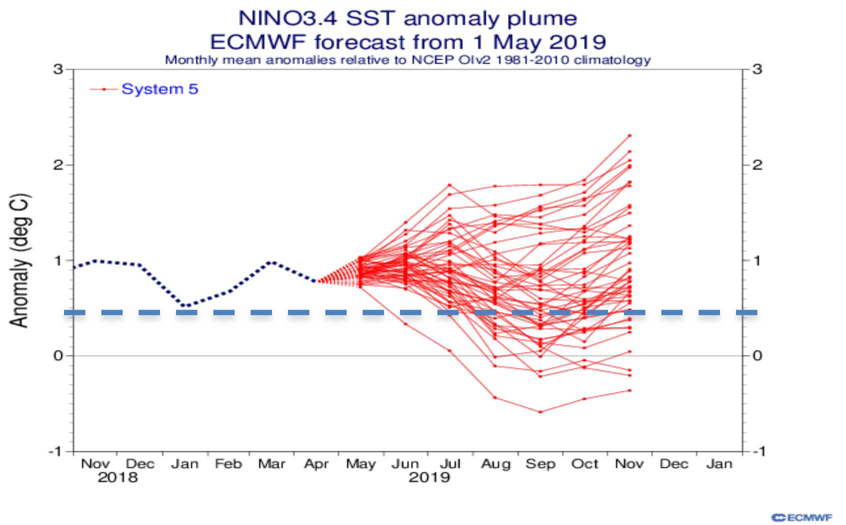


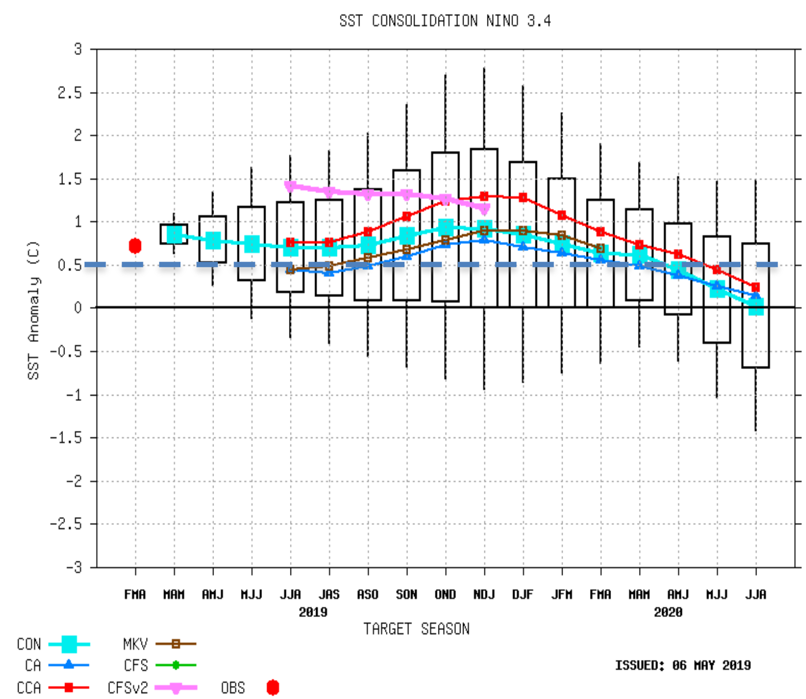


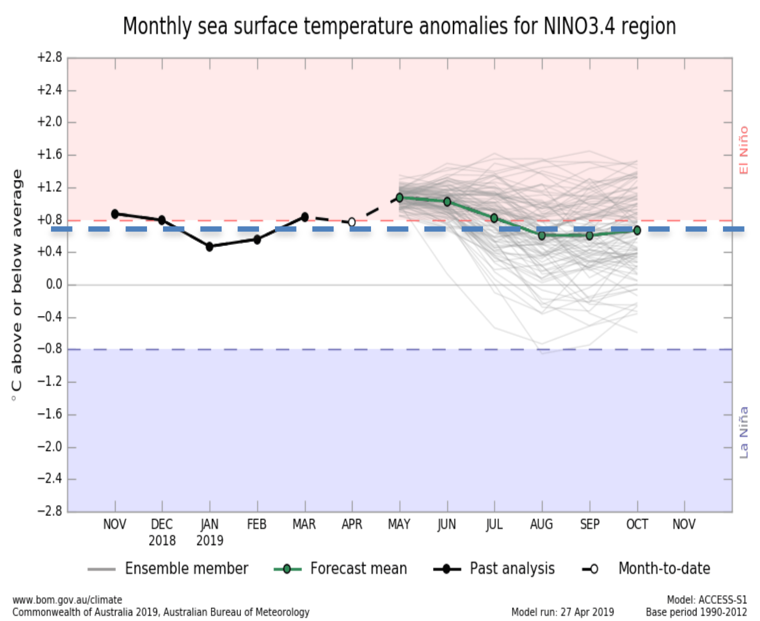
- **Majority of models predict continuation of El Nino in 2019.**
- **NOAA "ENSO Diagnostic Discussion" on 10 May 2019 continuously issued "*El Nino Advisory*" and indicated that *"El Niño is likely to continue through the Northern Hemisphere summer 2019 (70% chance) and fall (55-60% chance)."***

Model Predictions of ENSO from May 2019

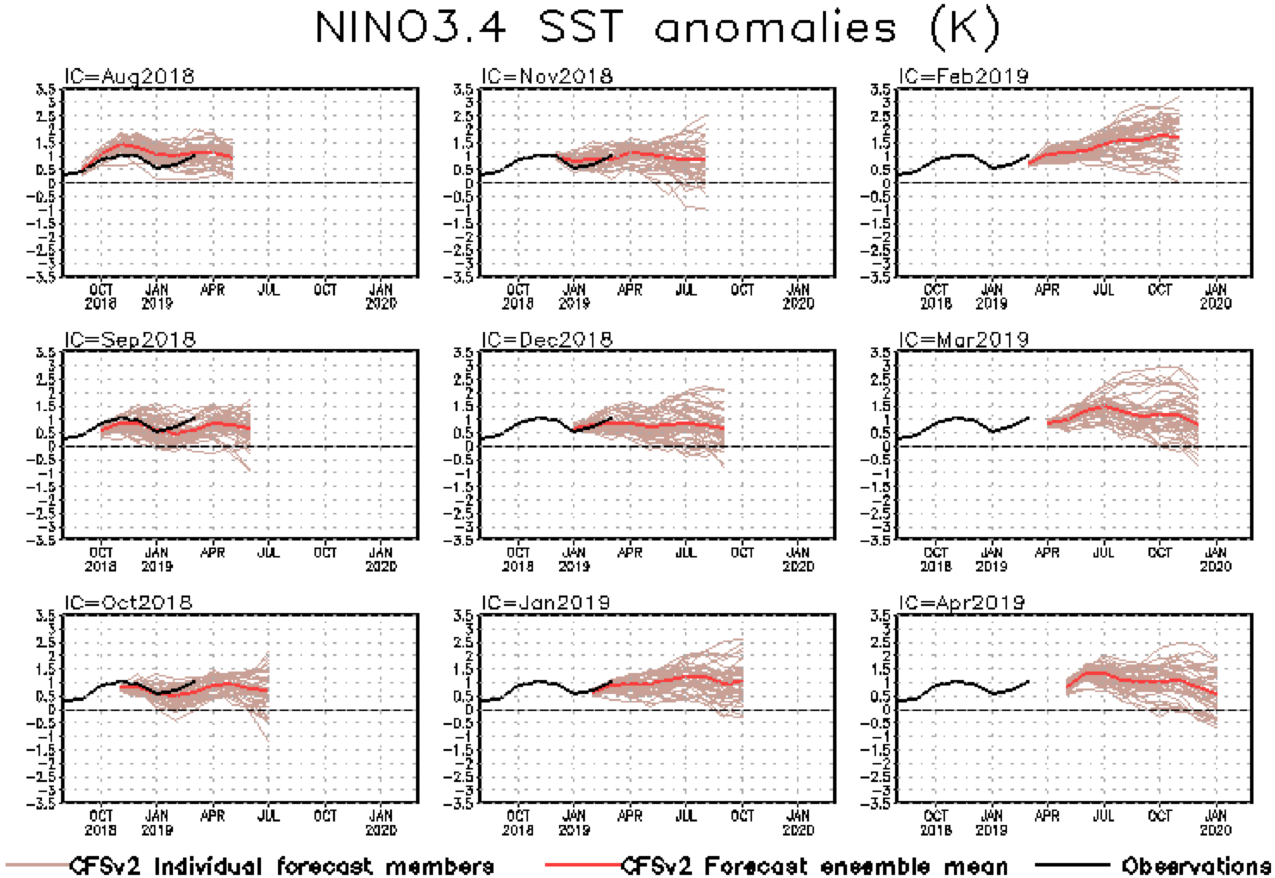








CFS Niño3.4 SST Predictions from Different Initial Months

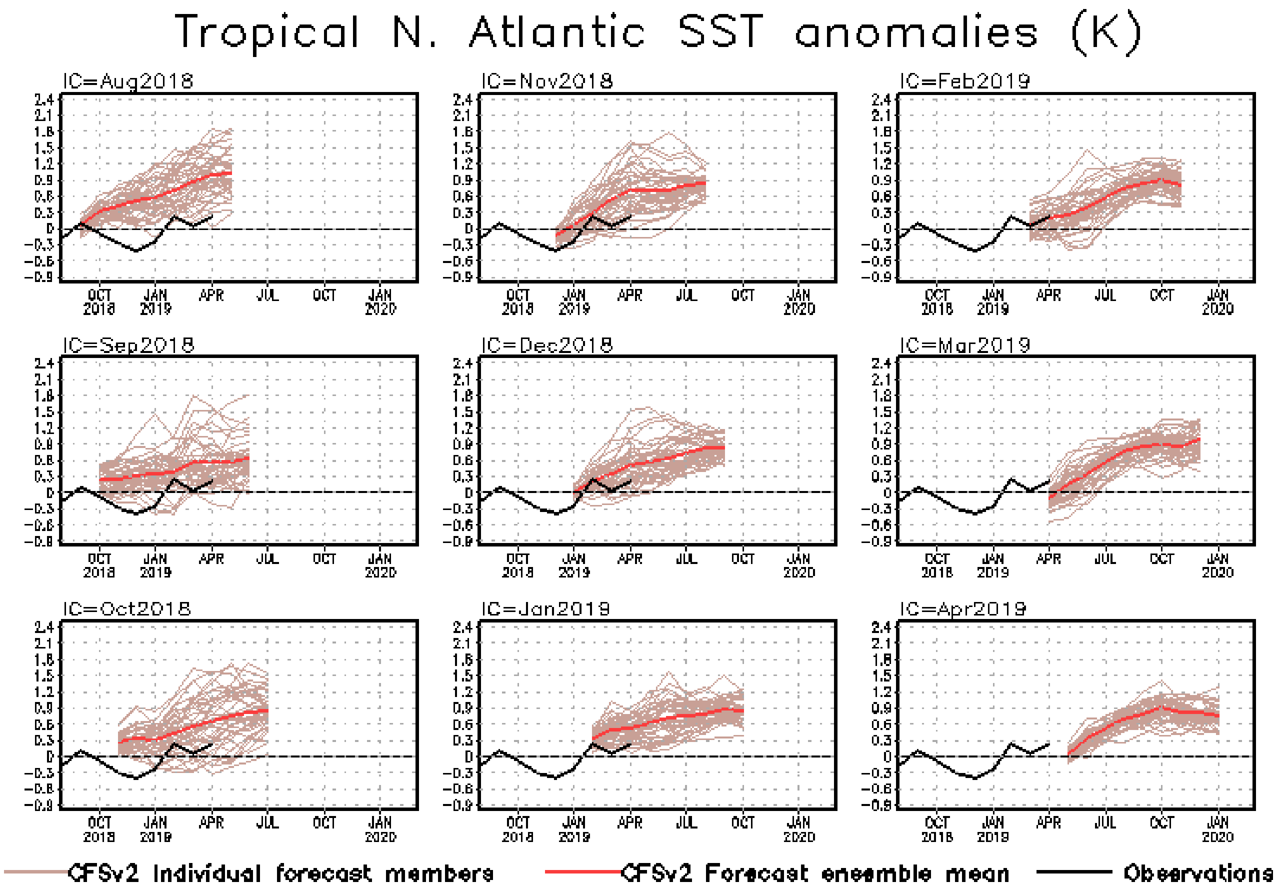


- **Latest CFSv2 forecasts call for persistency of El Nino during summer-autumn 2019.**

Fig. M1. CFS Nino3.4 SST prediction from the latest 9 initial months. Displayed are 40 forecast members (brown) made four times per day initialized from the last 10 days of the initial month (labelled as IC=MonthYear) as well as ensemble mean (blue) and observations (black). Anomalies were computed with respect to the 1981-2010 base period means.

CFS Tropical North Atlantic (TNA) SST Predictions from Different Initial Months

TNA is the SST anomaly averaged in the region of [60°W-30°W, 5°N-20°N].



- **Latest CFSv2 predictions call above normal SSTA in the tropical N. Atlantic in summer-autumn 2019**

Fig. M3. CFS Tropical North Atlantic (TNA) SST predictions from the latest 9 initial months. Displayed are 40 forecast members (brown) made four times per day initialized from the last 10 days of the initial month (labelled as IC=MonthYear) as well as ensemble mean (blue) and observations (black). Anomalies were computed with respect to the 1981-2010 base period means.

Acknowledgements

- Dr. Caihong Wen reviewed PPT, and provide insight and constructive suggestions and comments

- Drs. Li Ren and Pingping Xie provided the BASS/CMORPH/CFSR EVAP package

- Dr. Emily Becker provided the NMME NINO3.4 plot

- Dr. Dan Collins provided the CPC ENSO Consolidation plot

Data Sources and References

(climatology is for 1981-2010)

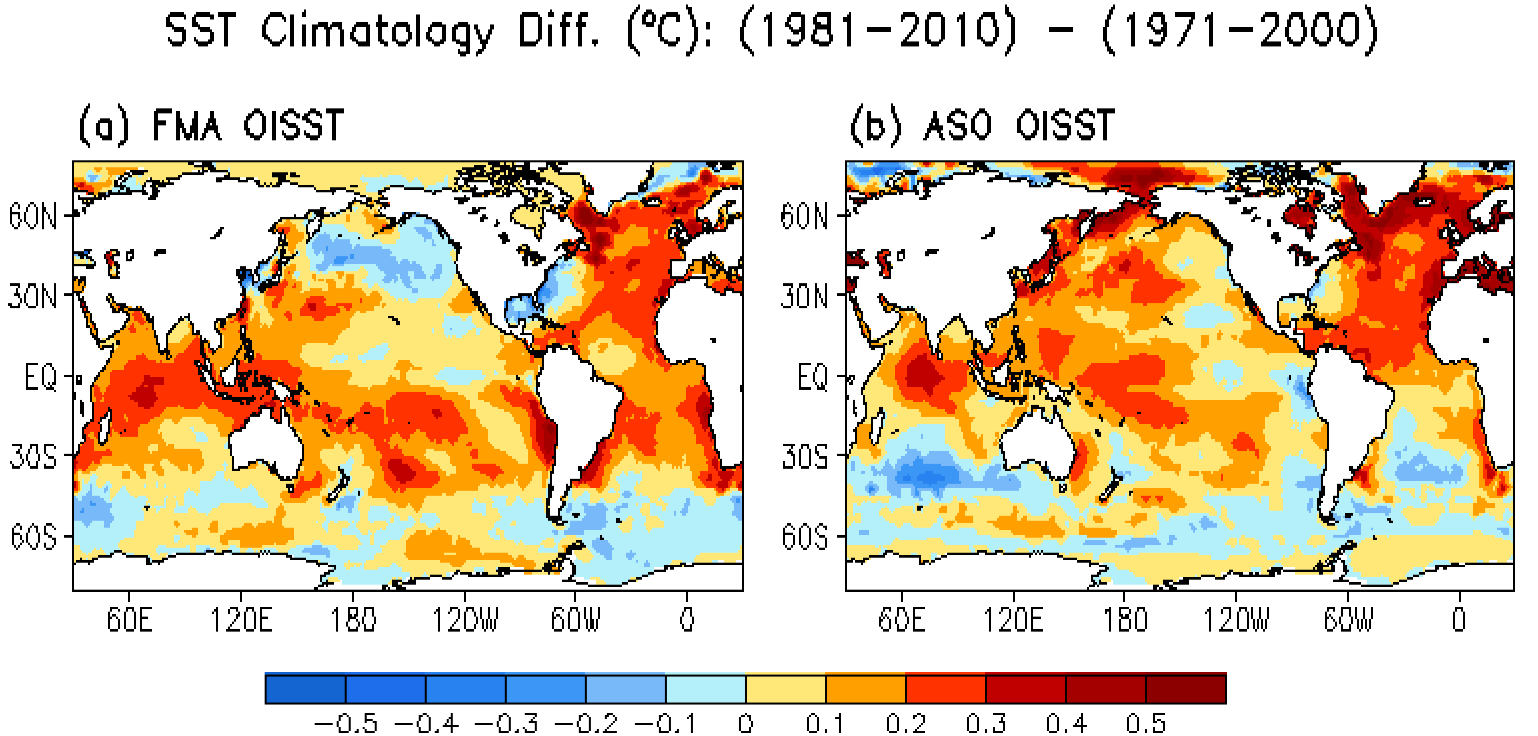
- **Weekly Optimal Interpolation SST (OI SST) version 2 (Reynolds et al. 2002)**
- **Extended Reconstructed Sea Surface Temperature (ERSST) v5 (Huang et al. 2017)**
- **Blended Analysis of Surface Salinity (BASS) (Xie et al. 2014)**
- **CMORPH precipitation (Xie et al. 2017)**
- **CFSR evaporation adjusted to OAFlux (Xie and Ren 2018)**
- **NCEP CDAS winds, surface radiation and heat fluxes (Kalnay et al. 1996)**
- **NESDIS Outgoing Long-wave Radiation**
- **NCEP's Global Ocean Data Assimilation System temperature, heat content, currents (Behringer and Xue 2004)**
- **Aviso altimetry sea surface height from CMEMS**
- **Ocean Surface Current Analyses – Realtime (OSCAR)**
- **In situ data objective analyses (IPRC, Scripps, EN4.2.1, PMEL TAO)**
- **Operational ocean reanalyses from Real-time Ocean Reanalysis Intercomparison Project**

http://www.cpc.ncep.noaa.gov/products/GODAS/multiora_body.html

http://www.cpc.ncep.noaa.gov/products/GODAS/multiora93_body.html

Please send your comments and suggestions to Yan.Xue@noaa.gov. Thanks!

Be aware that the new climatology (1981-2010) was applied since Jan 2011



1971-2000 SST Climatology (Xue et al. 2003): http://www.cpc.ncep.noaa.gov/products/predictions/30day/SSTs/sst_clim.htm

1981-2010 SST Climatology: http://origin.cpc.ncep.noaa.gov/products/people/yxue/sstclim/

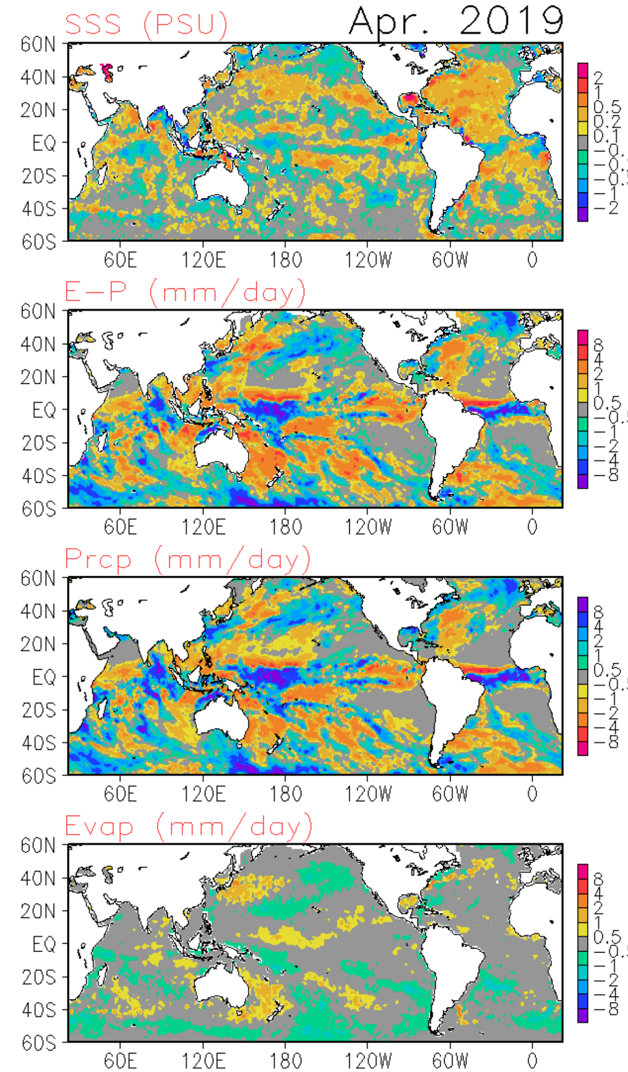
- **The seasonal mean SST in February-April (FMA) increased by more than 0.2°C over much of the Tropical Oceans and N. Atlantic, but decreased by more than 0.2°C in high-latitude N. Pacific, Gulf of Mexico and along the east coast of U.S.**
- **Compared to FMA, the seasonal mean SST in August-October (ASO) has a stronger warming in the tropical N. Atlantic, N. Pacific and Arctic Ocean, and a weaker cooling in Gulf of Mexico and along the east coast of U.S.**

Backup Slides

Global Sea Surface Salinity (SSS)

Anomaly for April 2019

- **New Update: The input satellite sea surface salinity of SMAP from NSAS/JPL was changed from Version 4.0 to Near Real Time product in August 2018.**
- **Attention: There is no SMAP SSS available in July 2018**
- In the equatorial Pacific and Atlantic ITCZ region, negative SSS anomalies are co-incident with increased precipitation. Negative SSS anomalies also appear in the equatorial Pacific SPCZ region. A large scale of negative SSS signal in the Northeast pacific region continues, which is accompanied with heavier precipitation. Meanwhile, in the Indo-Pacific region, negative SSS anomalies is co-incident with increased precipitation.



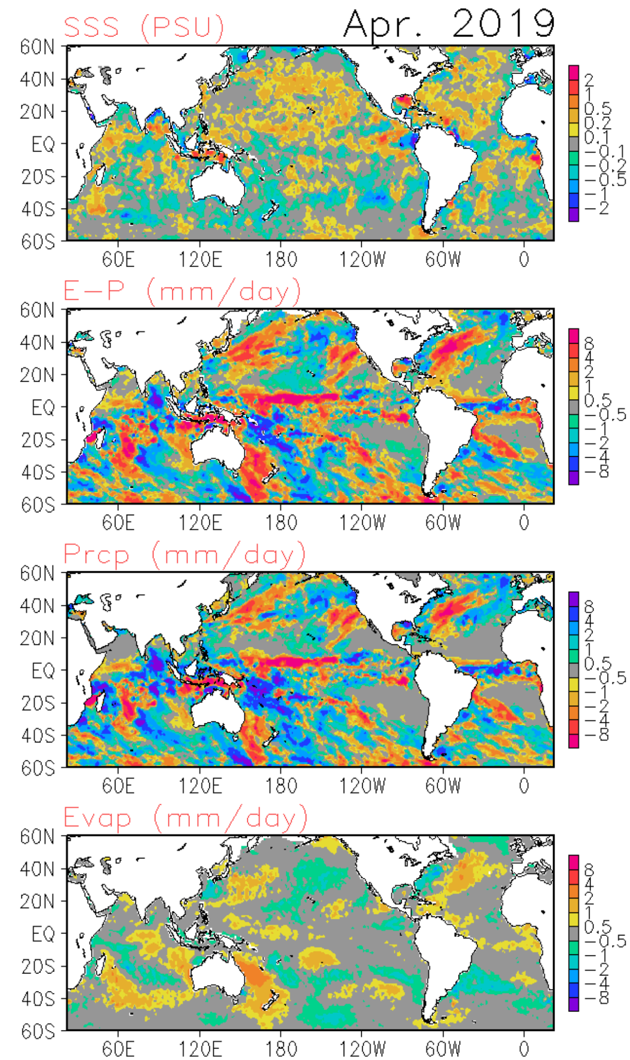
- **Data used**

SSS : Blended Analysis of Surface Salinity (BASS) V0.Z
(a CPC-NESDIS/NODC-NESDIS/STAR joint effort)
(Xie et al. 2014)
ftp.cpc.ncep.noaa.gov/precip/BASS
Precipitation: CMORPH adjusted satellite precipitation estimates
Evaporation: Adjusted CFS Reanalysis

Global Sea Surface Salinity (SSS)

Tendency for April 2019

Compared with last month, the SSS decreased in the Equatorial Pacific and Atlantic ITCZ region. Such SSS decreasing is likely caused by increasing precipitation. The SSS continues increasing between equator and 40ºN in both Pacific and Atlantic ocean. The SSS decreases in most of the areas in the southern Ocean (south of 30ºS), which is likely caused by oceanic advection and/or entrainments.

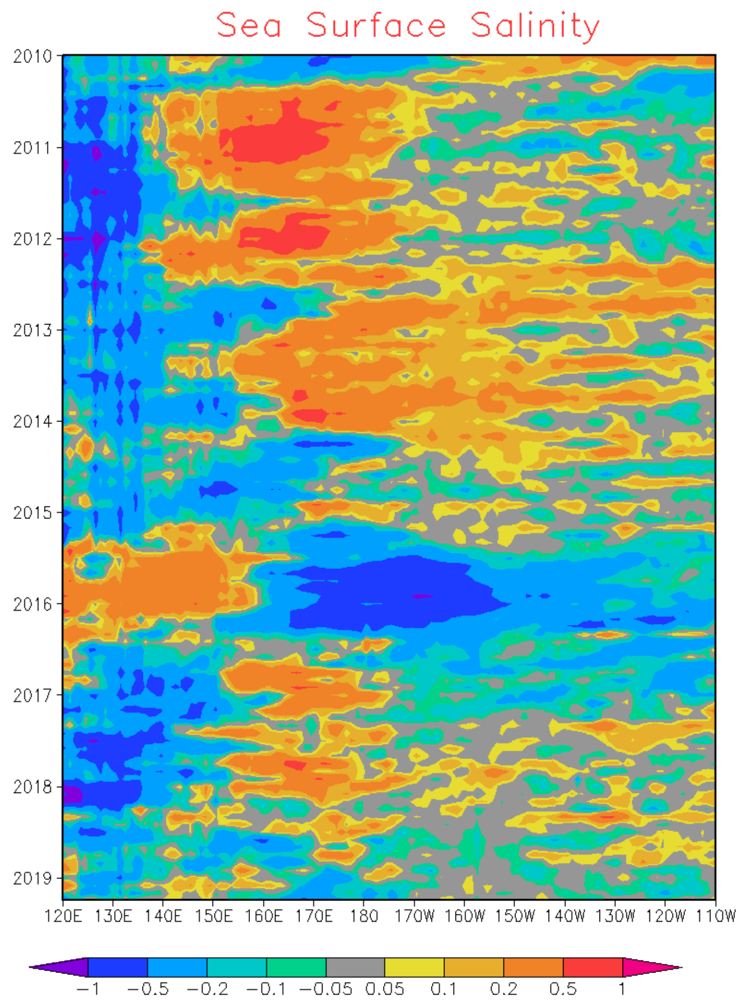


Global Sea Surface Salinity (SSS)

Anomaly Evolution over Equatorial Pacific from Monthly SSS

NOTE: Since June 2015, the BASS SSS is from in situ, SMOS and SMAP; before June 2015,The BASS SSS is from in situ, SMOS and Aquarius.

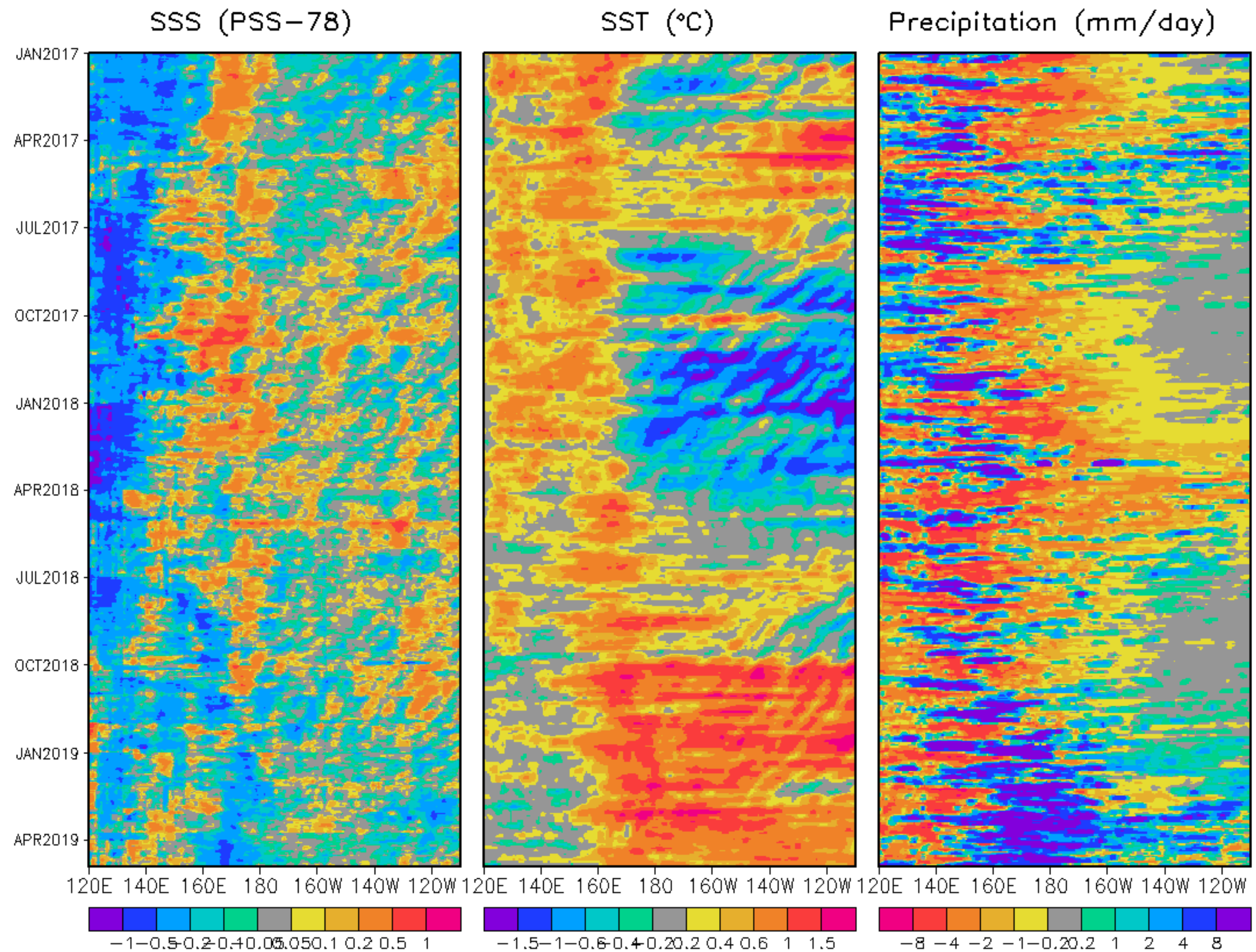
- Hovemoller diagram for equatorial SSS anomaly **(5° S-5° N);**
- In the equatorial Pacific Ocean, the positive SSS signal continues from 140° E to 160° E, the SSS shows negative anomalies between 165° E and 170° W, and stays in neutral or weakly negative east of 170° W.



Global Sea Surface Salinity (SSS)

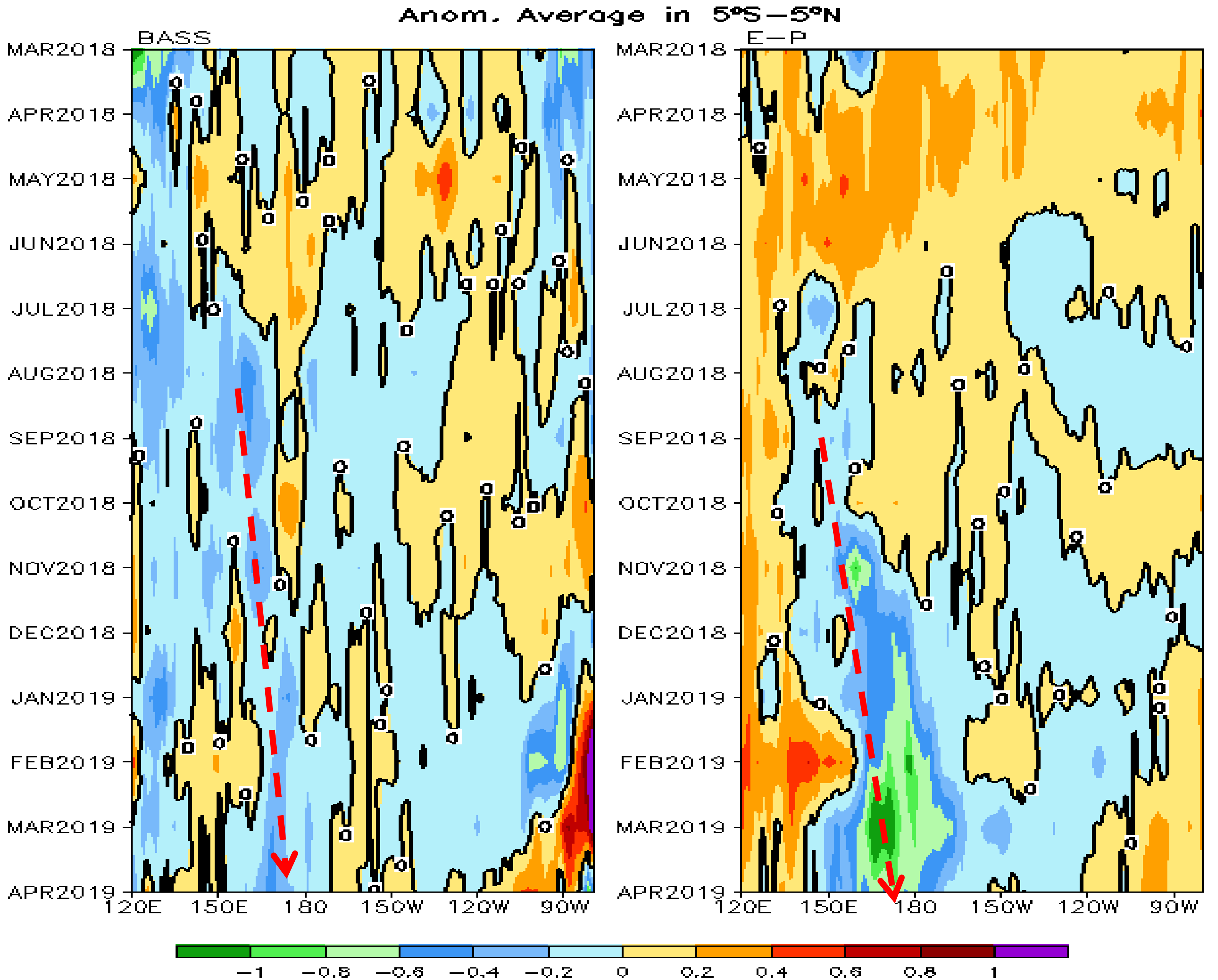
Anomaly Evolution over N. of Equatorial Pacific from Pentad SSS

Figure caption: Hovemoller diagram for equatorial (5° S-5° N) 5-day mean SSS, SST and precipitation anomalies. The climatology for SSS is Levitus 1994 climatology. The SST data used here is the OISST V2 AVHRR only daily dataset with its climatology being calculated from 1985 to 2010. The precipitation data used here is the adjusted CMORPH dataset with its climatology being calculated from 1999 to 2013.



SSS Anom

E-P Anom



Tropical Atlantic:

SST, SST Anom. Tend., OLR, Sfc Rad, Sfc Flx, TCHP, 925-mb/200-mb Winds anom.