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

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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 Global Ocean Monitoring and Observing Program (GOMO)
Outline

• Overview

• Recent highlights
  – Pacific/Arctic Ocean
  – Indian Ocean
  – Atlantic Ocean

• Global SSTA Predictions
  ➢ NOAA 2020 Hurricane Outlooks
  ➢ North Pacific Marine Heatwave status and prediction
Overview

- Pacific Ocean
  - ENSO neutral conditions persisted, but cooled in the eastern basin (NINO3.4 = -0.17°C).
  - Positive SSTAs continued in the NE Pacific in May 2020. The PDO was in a negative phase (PDOI = -0.22).

- Indian Ocean
  - Positive SSTAs were present in the tropical Indian Ocean in May 2020.

- Atlantic Ocean
  - NAO remained in a negative phase in May 2020 with NAOI= -0.33.
  - The prolonged tripole SSTA pattern persisted in the north Atlantic in May 2020.

- Arctic Ocean
  - The sea ice extent in May 2020 was ranked as the 4th lowest since 1979, and its pace of loss was near average.
Global Oceans
Global SST Anomaly (°C) and Anomaly Tendency

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.

- Negative SSTAs appeared in the eastern equatorial Pacific.
- Positive SSTAs persisted in the NE Pacific.
- Weak tripole SSTA pattern persisted in the North Atlantic.
- Weak positive SSTAs were present across the tropical Indian basin.
- Positive SSTAs were present in the South Pacific.

- Negative SSTA tendencies were present across the tropical Pacific.
- Negative SSTA tendencies presented in the Kuroshio and Gulf Stream regions.
Longitude-Depth Temperature Anomaly and Anomaly Tendency in 2°S-2°N

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.

- Negative temperature anomalies presented along the thermocline in both the equatorial Pacific and Atlantic Oceans.

- Positive temperature anomalies were observed in the upper equatorial Indian Ocean.

- Temperature anomaly tendency was negative along the thermocline in the eastern Pacific and Atlantic.
The SSHA pattern was overall consistent with the HC300A pattern, but with a significant trend component in SSHA.

Much better consistency for tendencies. Both SSHA and HC300A tendencies were negative in the eastern equatorial Pacific.
Positive SSS anomalies were present across most of the Pacific and Atlantic Oceans.

The tendency distribution similar to the anomaly one, suggesting a persistence and enhancement of the April state.

Blended Analysis of Surface Salinity (BASS) V0.Z (Xie et al. 2014)

Courtesy of Dr. Li Ren
Tropical Pacific Ocean and ENSO Conditions
Evolution of Pacific NINO SST Indices

Monthly Tropical Pacific SST Anomaly (OISST, 1981-2010 Climatology)

- All Nino indices cooled considerably in May 2020, with Nino3.4 = -0.17°C.
- Compared with May 2019, the central and eastern (western) equatorial Pacific was cooler (warmer) in May 2020.
- The indices may have slight differences if calculations are based on different SST products.

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.
- Warm pool and ENSO-Modoki indices were positive since 2018, but weakened in May 2020 (Modoki index became slightly negative).
Tropical Pacific: SST Anom., SST Anom. Tend., OLR, Sfc Rad, Sfc Flx, 925-mb & 200-mb Winds

Fig. P2. 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; positive means heat into the ocean), 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.
- Easterly wind anomaly was present across the equatorial central and eastern Pacific, and maximized in the eastern basin in May 2020.
- Below-average HC300 was observed in the eastern Pacific in May 2020.
- Negative SSTA appeared in the eastern equatorial Pacific.
- Negative ocean temperature anomalies were present along the thermocline (less propagating feature because the maximum zonal wind anomalies were close to the eastern boundary).

- The features of the ocean temperature anomalies were similar between GODAS and TAO analysis.
Anomalous westward currents were observed across much of the equatorial Pacific in both OSCAR and GODAS since late March 2020.
- WWV is defined as average of depth of 20°C in [120°E-80°W, 5°S-5°N]. Statistically, peak correlation of Nino3 with WWV occurs at 7 month lag (Meinen and McPhaden, 2000).

- Since WWV is intimately linked to ENSO variability (Wyrtki 1985; Jin 1997), it is useful to monitor ENSO in a phase space of WWV and NINO3.4 (Kessler 2002).

- Increase (decrease) of WWV indicates recharge (discharge) of the equatorial oceanic heat content.

- Equatorial Warm Water Volume (WWV) has been in a discharge phase since Mar 2020.

Fig. P3. Phase diagram of Warm Water Volume (WWV) and NINO 3.4 SST anomalies. WWV is the average of depth of 20°C in [120°E-80°W, 5°S-5°N] calculated with the NCEP's global ocean data assimilation system. Anomalies are departures from the 1981-2010 base period means.
Equatorial subsurface ocean temperature monitoring:
The equatorial Pacific switched to a discharge phase after Mar 2020.

Projection of OTA onto EOF1 and EOF2 (2S-2N, 0-459m, 1979-2010)
EOF1: Tilt mode (ENSO peak phase);
EOF2: WWV mode, Recharge/discharge oscillation (ENSO transition phase).

Recharge process: heat transport from outside of equator to equator:
Negative -> positive phase of ENSO

Discharge process: heat transport from equator to outside of equator:
Positive -> Negative phase of ENSO

For details, see:
North Pacific & Arctic Oceans
- 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.

- The PDO was in a negative phase with PDOI = -0.22 in May 2020.

- Statistically, ENSO leads PDO by 3-4 months, through teleconnection via atmospheric bridge, with El Nino (La Nina) associated with positive (negative) PDO Index.
North America Western Coastal Upwelling

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.

- Upwelling was weaker than average north of 36°N in May 2020.

- Area below (above) black line indicates climatological upwelling (downwelling) season.

- Climatologically upwelling season progresses from March to July along the west coast of North America from 36°N to 57°N.
North America Western Coastal Upwelling

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- Climatologically upwelling season progresses from March to July along the west coast of North America from 36°N to 57°N.
North Pacific & Arctic Ocean: SST Anom., SST Anom. Tend., OLR, SLP, Sfc Rad, Sfc Flx

Fig. NP1. Sea surface temperature (SST) anomalies (top-left), anomaly tendency (top-right), Outgoing Long-wave Radiation (OLR) anomalies (middle-left), sea surface pressure anomalies (middle-right), sum of net surface short- and long-wave radiation anomalies (bottom-left; positive means heat into the ocean), sum of latent and sensible heat flux anomalies (bottom-right; positive means heat into the ocean). SST are derived from the NCEP OI SST analysis, OLR from the NOAA 18 AVHRR IR window channel measurements by NESDIS, sea surface pressure and surface radiation and heat fluxes from the NCEP CDAS. Anomalies are departures from the 1981-2010 base period means.
CFS NE Pacific Marine Heatwave Index Predictions from Different Initial Months

SST anomalies (K) \([150W-130W, 40N-50N]\)

- Earlier CFSv2 predictions underestimated the strength of NP Marine Heatwave;
- Latest CFSv2 predictions suggest that the current warm state will continue in 2020.

Fig. M3. CFS NE Pacific 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.
- Arctic sea ice extent was well below normal in May 2020.
- The monthly average extent for May 2020 of 12.36 million square kilometers ended up as the fourth lowest since satellite observations in 1979.
- The pace of sea ice decline in May was near average.
Arctic sea ice extent (SIE) forecast
Experimental CFSv2 initialized May 21–25, 2020

First sea ice melt date of 2020
Experimental CFSv2 initialized May 21–25, 2020

Indian Ocean
Evolution of Indian Ocean SST Indices

Indian Ocean Dipole Mode Indices
(OISST, 1981–2010 Climatology)

Fig. I1a. Indian Ocean Dipole region indices, calculated as the area-averaged monthly mean sea surface temperature anomalies (°C) 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.

- Positive SSTAs were present in the tropical Indian Ocean in May 2020.
- SSTAs were overall positive in the entire tropical Indian Ocean.
- Convection was enhanced over the central and eastern Indian Ocean.
- Westerly wind anomalies were present at low/high levels.

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
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.

- Indices representing the Atlantic Meridional and Nino modes were small (<0.5° C) in May 2020.
NAO and SST Anomaly in North Atlantic

- NAO switched to a negative phase in Apr 2020 with NAOI = -0.33 in May 2020.
- The prolonged tripole SSTA pattern persisted in May 2020.

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.
ENSO and Global SST Predictions
- Predictions with ICs in May 2020 diverged with most models predicting a ENSO-neutral state through boreal summer/fall 2020; Dyn. AVG. versus Stat. AVG.

- NOAA “ENSO Diagnostic Discussion” on 11 June 2020 stated that “There is a ~60% chance of ENSO-neutral during Northern Hemisphere summer 2020, with roughly equal chances (~40-50%) of La Niña or ENSO-neutral during the autumn and winter 2020-21.”
Individual Model Forecasts: **ENSO-Neutral or Boardline La Nina**

**EC: Nino3.4, IC=01June 2020**

NINO3.4 SST anomaly plume
ECMWF forecast from 1 Jun 2020

**JMA: Nino3.4, Updated 10 June 2019**

**Australian BOM: Nino3.4, Updated 23 May 2020**

Monthly sea surface temperature anomalies for NINO3.4 region

**UKMO: Nino3.4, Updated 11June 2019**

Monthly mean anomalies relative to NCEP-CDG 1981-2010 climatology

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EC: Nino3.4, IC=01June 2020

JMA: Nino3.4, Updated 10 June 2019
Individual Model Forecasts: ENSO—Neutral or Boardline La Nina

EC: Nino3.4, IC=01May 2020

JMA: Nino3.4, Updated 12May 2019

Australian BOM: Nino3.4, Updated 25 Apr 2020

UKMO: Nino3.4, Updated 11May 2019
CFS Niño3.4 SST Predictions from Different Initial Months

NINO3.4 SST anomalies (K)

- The latest CFSv2 forecasts call for a La Nina state through this summer/fall peaking in winter.

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 Pacific Decadal Oscillation (PDO) Index Predictions from Different Initial Months

standardized PDO index

PDO is the first EOF of monthly ERSSTv3b anomaly in the region of [110°E-100°W, 20°N-60°N].

CFS PDO index is the standardized projection of CFS SST forecast anomalies onto the PDO EOF pattern.

- CFSv2 predicts a negative phase of PDO in coming seasons.

Fig. M4. CFS Pacific Decadal Oscillation (PDO) index 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.
CFS Tropical North Atlantic (TNA) SST Predictions from Different Initial Months

Tropical N. Atlantic SST anomalies (K)

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


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.
NOAA 2020 Atlantic Hurricane Season Outlook: a 60% chance of an above-normal season, a 30% chance of a near-normal season and a 10% chance of a below-normal season.

https://www.noaa.gov/media-release/busy-atlantic-hurricane-season-predicted-for-2020
Reasoning behind the outlook: main (favorable) climate factors

**Expected Atlantic Conditions**

1. Ongoing high-activity era conditions favor more hurricane activity, and include above-average sea surface temperatures in the Main Development Region, along with

2. Weaker trade winds, weaker vertical wind shear, and a stronger, wetter west African monsoon.

3. ENSO-neutral or possible La Niña, meaning either no suppression of, or a reinforcement of, the high-activity era conditions.

Expect ongoing high-activity era conditions (warm phase of AMO), and either ENSO-neutral or La Niña

Near- or weaker-than-average vertical wind shear
Above-average SSTs
Weaker easterly trade winds and vertical wind shear

Stronger, wetter West African monsoon

[Image: https://www.cpc.ncep.noaa.gov/products/outlooks/Slide2.JPG]
The Atlantic Multi-Decadal Oscillation (AMO)

Caption: Schematic showing sea surface temperature and west African monsoon conditions for opposing phases of the Atlantic Multi-Decadal Oscillation (AMO): (Top) warm phase and (Bottom) cold phase.

https://www.cpc.ncep.noaa.gov/products/outlooks/Slide6.JPG
Predicted Sea Surface Temperature (SST) Anomalies

Caption: Predicted SST anomalies (°C) for August-October (ASO) 2020, from (Left) NOAA’s Climate Forecast System (CFS) and (Right) the North American Multi-Model Ensemble (NMME). Green box denotes the Main Development Region (MDR) and Blue box highlights the El Niño/ La Niña region. Anomalies are departures from the 1981-2010 means.

Both the CFS and NMME models are predicting above-average SSTs in the MDR (green box) during the peak months (ASO) of the Atlantic hurricane season.

These models are predicting either La Niña or somewhat below-average SSTs in the central and east-central equatorial Pacific (Blue box).

https://www.cpc.ncep.noaa.gov/products/outlooks/Slide10.JPG
Model Forecasts for the Anomalous Magnitude of Vertical Wind Shear during August-October 2020

NOAA Climate Forecast System (CFS)  North American Multi-Model Ensemble (NMME)

Caption: Predicted anomalous magnitude of the vertical wind shear (m s⁻¹) for August-October 2020, from (Left) NOAA’s Climate Forecast System (CFS) and (Right) the North American Multi-Model Ensemble (NMME). Green box denotes the Atlantic Main Development Region (MDR). Blue (Red) shading indicates anomalously weak (strong) shear. Anomalies are departures from the 1981-2010 means.

NOAA’s CFS and the NMME are predicting below-average vertical wind shear (Blue shading) during ASO 2020 across much of the MDR. These forecasts are consistent with the combination of La Niña and a stronger West African monsoon system.

https://www.cpc.ncep.noaa.gov/products/outlooks/Slide11.JPG
Last 45 days: Mid-Level and Upper-Level Atmospheric Anomalies Related to the West African Monsoon

Anomalous 700-hPa Wind Speed and Vector

Westerly anomalies indicate weaker tropical easterly winds.

Anomalous 200-hPa Velocity Potential and Divergent Wind

Early start to the west African monsoon.

Caption. Last 45-day averaged anomalies of: (Top) 700-hPa wind speed (shading, m s$^{-1}$) and wind vectors, and (Bottom) 200-hPa velocity potential (shading, x $10^6$ m$^2$ s$^{-1}$) and divergent wind vectors (m s$^{-1}$). Vector scale is below each plot at right. Green box denotes the Atlantic Main Development Region (MDR). At Bottom, green (orange) shading is associated with anomalous upper-level divergence (convergence). Anomalies are departures from the CDAS 1981-2010 period means.

(Top) Strong westerly wind anomalies (i.e., weaker easterly winds) across the tropical Atlantic are consistent with the warm phase of the AMO, and also with the expected enhanced west African monsoon system.

(Bottom) The upper-level circulation shows anomalous divergence (green) over Africa, suggesting an early start to the west African monsoon.

https://www.cpc.ncep.noaa.gov/products/outlooks/Slide12.JPG
CPC/IRI Probabilistic ENSO Forecast
Issued 14 May 2020

ENSO-neutral or La Niña most likely throughout the hurricane season (based on the May ENSO outlook)

The official CPC/IRI forecast issued in mid-May indicates a 50% chance of ENSO-neutral during JAS and ASO 2020, and a 40% chance of La Niña. There is only a 10% chance of El Niño. Such forecasts issued at this time of the year can have low skill and are issued with limited confidence.

Recent Model SST Anomaly Forecasts for Niño-3.4 Region

Caption: Model predicted seasonal SST anomalies (°C) for the equatorial Pacific Ocean Niño-3.4 region (see inset, between 170°W-120°W, 5°N-5°S). Colored lines correspond to the models indicated at right. NOAA's thresholds for El Niño, Neutral, and La Niña, are shown in pink, yellow, and blue shading, respectively. Blue (red) dashed lines indicate thresholds for weak, moderate, and strong La Niña (El Niño). Issued jointly by International Research Institute for Climate and Society (IRI) and NOAA Climate Prediction Center (CPC).

Both the dynamical model average (thick red line) and statistical model average (thick green line) predict ENSO-neutral to persist through the peak months of the hurricane season (ASO time period). Such forecasts issued at this time of the year typically have low skill and are issued with limited confidence.
Accumulated Cyclone Energy (ACE) measures the overall strength of the hurricane season.
For the Central Pacific, Tropical Cyclones (TCs) include tropical depressions, tropical storms and hurricanes.

For the Atlantic hurricane season, climate signals and model forecasts indicate that an above-normal season is most likely (60% chance), followed by a 30% chance of a near-normal season and a 10% chance of a below-normal season.

For the eastern and central Pacific hurricane regions, the outlooks indicate that a near- or below-normal season is most likely (75% combined chance).
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Backup Slides
Spatial Distribution of SSTA prediction skill with CFSv2

(Guan et al. 2014)

- ENSO-related SST presents the highest prediction skill;
- Other skillful regions include: tropical North Atlantic, South Pacific, tropical Indian Ocean, part of extratropical North Pacific,...
Global Sea Surface Salinity (SSS) Anomaly for May 2020

- New Update: The NCEI SST data used in the quality control procedure has been updated to version 2.1 since May 2020
- Positive SSS anomalies continue and/or strengthen in most areas within the latitudes between 0° and 40°N in the N. Pacific Ocean and N. Atlantic Ocean. Meanwhile, positive SSS anomalies appear in the latitudes between 0° and 40°S in the S. Pacific Ocean and S. Atlantic Ocean. While, negative SSS signal is persistent in the equatorial Atlantic Ocean with increased precipitation. Negative SSS anomalies continue and expand in the northern region of Bay of Bengal and is likely caused by oceanic advection/entrainment.

Data used

SSS: Blended Analysis of Surface Salinity (BASS) V0.2
(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
Compared with last month, the SSS continued increasing in most areas of N. Pacific ocean and N. Atlantic between equator and 40°N. The SSS signal also became positive in most areas of S. Pacific Ocean and S. Atlantic Ocean between equator and 40°S. The SSS continued decreasing in the Bay of Bengal, and such signal is likely caused by oceanic advection/entrainment.
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 SSS signal is negative and tend to became neutral west of 160°E; the positive SSS signals expanded and such positive anomalies show east of 160°E, while some negative SSS signals are in the east of 125°W.
Global Sea Surface Salinity (SSS)
Anomaly Evolution along the 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.
Data Sources (climatology is for 1981-2010)

- Weekly Optimal Interpolation SST (OI SST) version 2 (Reynolds et al. 2002)
- Extended Reconstructed SST (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 (Liebmann and Smith 1996)
- NCEP’s GODAS 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 Reanalysis Intercomparison Project