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 Ocean Climate Observation Program (OCO)
Outline

• Overview

• Recent highlights
  – Pacific/Arctic Ocean
    (NOAA 2013 E. Pacific hurricane prediction)
  – Indian Ocean
  – Atlantic Ocean
    (NOAA 2013 Atlantic hurricane prediction)

• Global SST Predictions
Overview

- **Pacific and Arctic Oceans**
  - ENSO-neutral condition continued during May 2013 and cooling tendency was strengthened in the eastern Pacific with Nino3.4 = -0.3°C.
  - NOAA officially forecast ENSO-neutral condition to continue in the Northern Hemisphere summer 2013.
  - Negative PDO phase weakened since Apr 2013 and PDO index = -0.6 in May 2013, and NCEP CFSv2 predicted negative phase of PDO will continue.
  - Arctic sea ice extent in May 2013 was below-normal.

- **Indian Ocean**
  - SSTs were above in the east and slightly blow-normal in the west, and negative dipole index was strengthened in May 2013.

- **Atlantic Ocean**
  - NAO switched from negative to positive phase in Apr 2013 and NAO index = 0.6 in May 2013.
  - SSTs were above-normal in the tropical North Atlantic main hurricane development region in May 2013.
Global Oceans
Global SST Anomaly (°C) and Anomaly Tendency

- Negative SSTA presented in the e. Pacific.
- Negative phase PDO associated SSTA pattern continued in N. Pacific.
- Positive SSTA was observed in the e. Indian and w. Pacific Oceans.
- Tripolar SSTA presented in N. Atlantic.

- Cooling tendency presented in the equatorial e. Pacific.
- Weakening tendency of negative phase of PDO associated SSTA was observed in N. Pacific.
- Cooling (warming) tendency was seen in the w. (e.) tropical N. Atlantic.
- An overall cooling tendency was observed in the tropical Indian Ocean.
- The SSH anomalies were overall consistent with SSTA for large-scale pattern: Positive (negative) SSTA is tied up with positive (negative) SSH anomaly.
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.

- Positive (negative) temperature anomalies occupied around the thermocline in the w. (e.) Pacific Ocean, suggesting an intensified w-e contrast.
- Positive anomalies around the thermocline occurred in the Atlantic and Indian Oceans.
- Warming (cooling) tendency was observed in the w. (e.) Pacific around the thermocline, and warming tendency was seen in both e. and w. coasts.
- Obvious warming tendency around the thermocline was noted the Indian Ocean.
- Both positive and negative tendency presented in Atlantic Ocean.
- Positive TCHP anomalies presented in the w. Pacific and negative ones in the c. and e. Pacific.
- Positive anomalies were observed over the w. Atlantic Ocean.
- The tendency was small in both the tropical N. Atlantic and E. tropical Pacific.

*TCHP field is the anomalous heat storage associated with temperatures larger than 26 °C.*
NOAA Predict an Above-Normal Atlantic Hurricane Season in 2013
(www.cpc.ncep.noaa.gov/products/outlooks/hurricane.shtml
http://en.wikipedia.org/wiki/Accumulated_cyclone_energy)

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<th>2013 prediction (issued on May 23) (1981-2010)</th>
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<tbody>
<tr>
<td>Named storms</td>
<td>13-20 (12.1)</td>
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<tr>
<td>Hurricanes</td>
<td>7-11 (6.4)</td>
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<td>Major hurricanes</td>
<td>3-6 (2.7)</td>
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<tr>
<td>ACE %</td>
<td>120-205</td>
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- The ongoing set of atmospheric and oceanic conditions include:
- An expected continuation of above-average sea surface temperatures (SSTs) across the tropical Atlantic Ocean and Caribbean Sea, that have been producing increased Atlantic hurricane activity since 1995;
- A likely continuation of ENSO-neutral conditions in 2013 (i.e., no El Niño or La Niña); meaning El Niño is not expected to develop and suppress the hurricane season.
AMO is a major factor for Atlantic hurricane forecast. AMO was above normal since around 1995.
NOAA Predict a Below-Normal E. Pacific Hurricane Season in 2013
(http://en.wikipedia.org/wiki/2013_Pacific_hurricane_season
http://en.wikipedia.org/wiki/Accumulated_cyclone_energy)

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<th>2013 prediction (issued on May 23) (1971-2006)</th>
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<tr>
<td>Named storms</td>
<td>11-16 (15.3)</td>
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<tr>
<td>Hurricanes</td>
<td>5-8 (8.8)</td>
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<tr>
<td>Major hurricanes</td>
<td>1-4 (4.2)</td>
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<tr>
<td>ACE %</td>
<td>60-105</td>
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- The ongoing climate conditions include:
- Expected ENSO-neutral conditions in 2013, meaning El Niño is not expected to develop and strengthen the seasonal activity;
- Expected near-average or below-average sea-surface temperatures in the eastern equatorial Pacific Ocean.
Tropical Pacific Ocean and ENSO Conditions
Positive temperature anomalies in the central and western Pacific persisted and did not have clear propagation.

Negative temperature anomalies in the central and eastern Pacific also did not have clear propagation.

However, the differences between TAO and GODAS were still large in the central and eastern Pacific (150W, 120W). What causes the differences?
Ocean Temperature Anomaly in 2S–2N (°C, 1999–2010 Climatology)

TAO GODAS CFSR

Last 3-Month Mean Equatorial Pacific Temperature Anomaly

- The monthly mean differences between TAO and GODAS, and between TAO and CFSR were also large in the c. and e. Pacific.

- What causes the differences?
- The TAO/TRITON array has encountered significant outages in before Apr 2013, particularly in the eastern part of the array.
- However, some of the arrays were repaired and the data were available since Apr 2013.
NINO3.4 Heat Budget

- SSTA tendency \(\frac{dT}{dt}\) in NINO3.4 region (dotted black line) was near zero in May 2013.

- All the advection terms were small since mid-Jan 2013.

- The thermodynamical term \(Qq\) were positive most time in May 2013.

- The RHS and \(\frac{dT}{dt}\) had large differences during Mar-May 2013.


**Qu**: Zonal advection; **Qv**: Meridional advection;
**Qw**: Vertical entrainment; **Qzz**: Vertical diffusion
**Qq**: \(\frac{(Q_{\text{net}} - Q_{\text{pen}} + Q_{\text{corr}})}{\rho c_{\text{ph}}}\); \(Q_{\text{net}} = SW + LW + LH + SH\);
**Qpen**: SW penetration; **Qcorr**: Flux correction due to relaxation to OI SST
Since Feb 2013, eastward anomaly current was observed, and weakened since Apr 2013.

- Some detailed differences were noted for both anomaly and climatology between OSCAR and GODAS.
- Since Mar 2013, Kelvin wave-like propagation was less evident, and almost stationary variation is consistent with the pentad ocean temperature anomaly shown in slide 12.

- Oceanic Kelvin wave indices are defined as standardized projections of total anomalies onto the 14 patterns of Extended EOF 1 of equatorial temperature anomalies (Seo and Xue, GRL, 2005).
All Nino indices were negative:
Nino1+2=-1.4°C, Nino3=-0.7°C, NINO 3.4=-0.3°C.

The indices were calculated based on OISST. They may have some differences compared with those based on ERSST.v3b.

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 (bar) and last ten year (green line) means.
Fig. P4. Time-longitude section of anomalous pentad sea surface temperature (left), upper 300m temperature average (heat content, middle-left), 850-mb zonal wind (U850, middle-right) averaged in 2°S-2°N and Outgoing Long-wave Radiation (OLR, right) averaged in 5°S-5°N. SST is derived from the NCEP OI SST, heat content from the NCEP’s global ocean data assimilation system, U850 from the NCEP CDAS. Anomalies for SST, heat content and U850/OLR are departures from the 1981-2010 base period pentad means respectively.

http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_mjo_index/mjo_index.shtml

Equatorial Pacific SST (ºC), HC300 (ºC), u850 (m/s) and OLR(W/m²) Anomalies

CPC MJO Indices
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), 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.

- The suppressed (enhanced) convection near the Dateline (over the Maritime Continent), low level (upper level) easterly (westerly) wind anomalies in the western-central Pacific are consistent with La Nina-like conditions.
North Pacific & Arctic Oceans
Pacific Decadal Oscillation Index

- Negative PDO phase since May 2010 has persisted for more than 3 years (37 months) now, and the PDO index weakened since Apr 2013 and PDO index=-0.6 in May 2013.

- The apparent connection between Nino3.4 and PDO indices suggests connections between tropics and extratropics.

- However, the negative phase of PDO during Jun-Nov 2012 seems not connected with the positive Nino3.4 SSTA.

- 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.
- Negative phase of PDO associated SSTA persisted and the positive SSTA propagated eastward.
- Both wind and SLP anomalies were small in N. Pacific in May 2013.
North America Western Coastal Upwelling

Both downwelling in high latitudes (50-57°N) and upwelling in low latitudes (24-48°N) were suppressed in May 2013.

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.
Averaged sea ice extent for May 2013 was still below-normal, and it is similar to May 2012.
Indian Ocean
Evolution of Indian Ocean SST Indices

Fig. 11a. Indian Ocean Dipole region indices, calculated as the area-averaged monthly mean sea surface temperature anomalies (°C) for the SETIO [90°E-110°E, 10°S-0] and WTIO [50°E-70°E, 10°S-10°N] regions, and Dipole Mode Index, defined as differences between WTIO and SETIO. Data are derived from the NCEP OI SST analysis, and departures from the 1981-2010 base period means and the recent 10 year means are shown in bars and green lines.

- DMI was negative since Apr 2013, consistent with above (below) normal in the e. (w.) Indian Ocean.
- Negative DMI was intensified in May 2013.
Tropical and North Atlantic Ocean
Evolution of Tropical Atlantic SST Indices

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 departures from the 1981-2010 base period means and the recent 10 year means are shown in bars and green lines.

- Basin-wide SST was above-normal in May 2013.
- SSTA in the tropical N. Atlantic (TNA) was positive since May 2012.
- Meridional Gradient Mode index (TNA-TSA) was positive since May 2011.
- ATL3 SSTA was positive since Aug 2012.
- Above-normal SST presented in the hurricane Main Development Region (MDR).
- The vertical wind shear was below-normal in the hurricane Main Development Region, favorable for hurricane activities.
- Cooling tendency was observed in the western Atlantic and Gulf of Mexico.
- Both suppressed and enhanced convection was observed in the tropical N. Atlantic.
- TCHP was positive and mainly in the NW Atlantic Ocean.
NAO and SST Anomaly in North Atlantic

- NAO switched from negative to positive phase in Apr 2013, with NAO index = 0.6 in May 2013. That may not favor the positive SSTA in the tropical N. Atlantic.

- The zonal mean SSTA in North Atlantic is generally related to NAO and ENSO impact (Hu et al. 2011: *J. Climate*, 24(22)).

Fig. NA2. Monthly standardized NAO index (top) derived from monthly standardized 500-mb height anomalies obtained from the NCEP CDAS in 20°N-90°N (http://www.cpc.ncep.noaa.gov). Time-Latitude section of SST anomalies averaged between 80°W and 20°W (bottom). SST are derived from the NCEP OI SST analysis, and anomalies are departures from the 1981-2010 base period means.
Fig. NA1. 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), sum of latent and sensible heat flux anomalies (bottom-right). 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 1979-1995 base period means except SST anomalies are computed with respect to the 1971-2000 base period means.

- Positive SLP anomaly in the south and negative in the northeast was consistent with the positive NAO index in May 2013.
Global SST Predictions
- Majority of the models predicted ENSO-neutral in the Northern Hemisphere summer-winter.
- Average of forecast Nino3.4 of dynamical models were warmer than that of statistical models.
- The consensus forecast favors ENSO-neutral conditions in the summer-autumn 2013.
The Nino3.4 predictions of CFSv2 shifted from positive SSTA in summer-autumn with IC in Feb 2013 to negative with IC in Mar 2013, near normal with IC in Apr 2013, then positive again with IC in May 2013, may imply the impact of short-term fluctuation and challenge of ENSO prediction with IC in spring.

Individual Models: **diverged results**

**ECMWF: Nino3, IC=01May2013 (large spread)**

**JMA: Nino3, IC=May2013 (near normal)**

**Australia: Nino3.4, IC=02May2013 (u-type)**

**UKMO: Nino3.4, IC=15May2013 (near normal)**
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.

Latest CFSv2 prediction suggests negative phase of PDO will persist through the coming summer and autumn.
NCEP CFSv2 Tropical North Atlantic SST Forecast

Latest CFSv2 prediction suggests that above-normal SST in the tropical N. Atlantic will continue in summer-autumn 2013 (hurricane season).
Backup Slides

http://www.cpc.ncep.noaa.gov/products/GODAS/
Last Three Month SST, OLR and 925hp Wind Anom.
Equatorial subsurface ocean temperature monitoring: Right now, in recharge phase; recharge/discharge were weak in last 2 years.

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:
Warm Water Volume (WWV) and NINO3.4 Anomalies

- WWV is defined as average of depth of 20°C in [120ºE-80ºW, 5ºS-5ºN]. 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.

Fig. P3. Phase diagram of Warm Water Volume (WWV) and NINO 3.4 SST anomalies. WWV is the average of depth of 20ºC in [120ºE-80ºW, 5ºS-5ºN] calculated with the NCEP’s global ocean data assimilation system. Anomalies are departures from the 1981-2010 base period means.
North Pacific & Arctic Ocean: SST Anom., SST Anom.
Tendency, 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), sum of latent and sensible heat flux anomalies (bottom-right). 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.
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.
Indian Ocean Dipole SST anomalies (K)

**MDM = WTIO - SETIO**

**SETIO = SST anomaly in [90°E-110°E, 10oS-0]**

**WTIO = SST anomaly in [50°E-70°E, 10oS-10°N]**

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Fig. M2. CFS Dipole Model Index (DMI) 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). The hindcast climatology for 1981-2006 was removed, and replaced by corresponding observation climatology for the same period. Anomalies were computed with respect to the 1981-2010 base period means.
Evolution of Pacific NINO SST Indices

- Positive SSTA in 2012 propagated from the eastern to western Pacific.

- Both Cold Tongue, Warm Pool, and ENSO-Modoki indices were slightly negative, consistent with overall small SSTA in the equatorial Pacific.

- The indices were calculated based on OISST. They may have some differences compared with those based on ERSST.v3b.

The 4 years that had a similar juxtaposition of a warm ENSO (decay phase) and negative phase of the NAO, i.e., 1958, 1998, 2005, and 2010 had above normal Atlantic hurricane seasons.


For 1950-2009, the mean of ACE is 101 and the median is 88.0.
The ocean temperature anomaly differences between CFSR and GODAS are larger when TAO data are missed compared with that they are not missed. Statistically, it seems to suggest that without constraint of TAO data, the differences become larger between GODAS and CFSR. It seems that both the data assimilation system and data inputs may cause biases in the reanalysis data.
Possible Impact of TAO Data Missing on NCEP Data Assimilations
(CFSR and GODAS; 1981-2010 Climatology) at (0, 95W)
Possible Impact of TAO Data Missing on NCEP Data Assimilations
(CFSR and GODAS; 1981-2010 Climatology) (0, 110W)
Switch to 1981-2010 Climatology

- SST from 1971-2000 to 1981-2010
  - Weekly OISST.v2, monthly ERSST.3b

- Atmospheric fields from 1979-1995 to 1981-2010
  - NCEP CDAS winds, sea level pressure, 200mb velocity potential, surface shortwave and longwave radiation, surface latent and sensible fluxes, relative humidity
  - Outgoing Long-wave Radiation

- Oceanic fields from 1982-2004 to 1981-2010
  - GODAS temperature, heat content, depth of 20°C, sea surface height, mixed layer depth, tropical cyclone heat potential, surface currents, upwelling

- Satellite data climatology 1993-2005 unchanged
  - Aviso Altimetry Sea Surface Height
  - Ocean Surface Current Analyses – Realtime (OSCAR)
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.

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/

Be aware that new climatology (1981-2010) was applied since Jan 2011
Data Sources and References

- Optimal Interpolation SST (OI SST) version 2 (Reynolds et al. 2002)
- NCEP CDAS winds, surface radiation and heat fluxes
- NESDIS Outgoing Long-wave Radiation
- NDBC TAO data (http://tao.noaa.gov)
- PMEL TAO equatorial temperature analysis
- NCEP’s Global Ocean Data Assimilation System temperature, heat content, currents (Behringer and Xue 2004)
- Aviso Altimetry Sea Surface Height
- Ocean Surface Current Analyses – Realtime (OSCAR)

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