Annual Ocean Review in 2009

Prepared by

Climate Prediction Center, NCEP

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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 Office of Climate Observation (OCO)

Overview

- A series of westerly wind bursts and downwelling oceanic Kelvin waves contributed to the development and strengthening of the 2009/10 El Nino, which reached a strong strength in early winter and in boreal winter had maximum warming in the central Pacific;

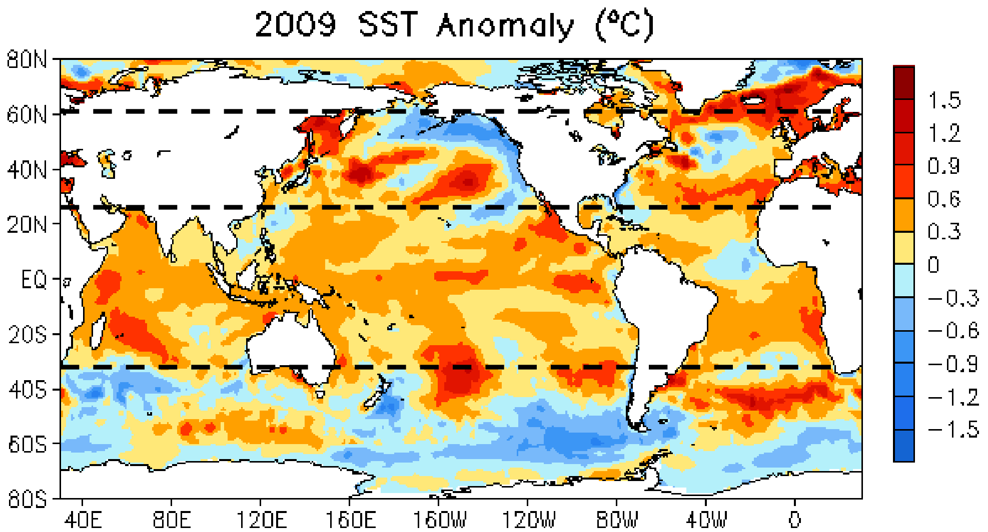
- Persistent negative PDO transitioned to a positive phase;

- Tropical Indian SST in 2009 was the second warmest behind the record warming in 1998;

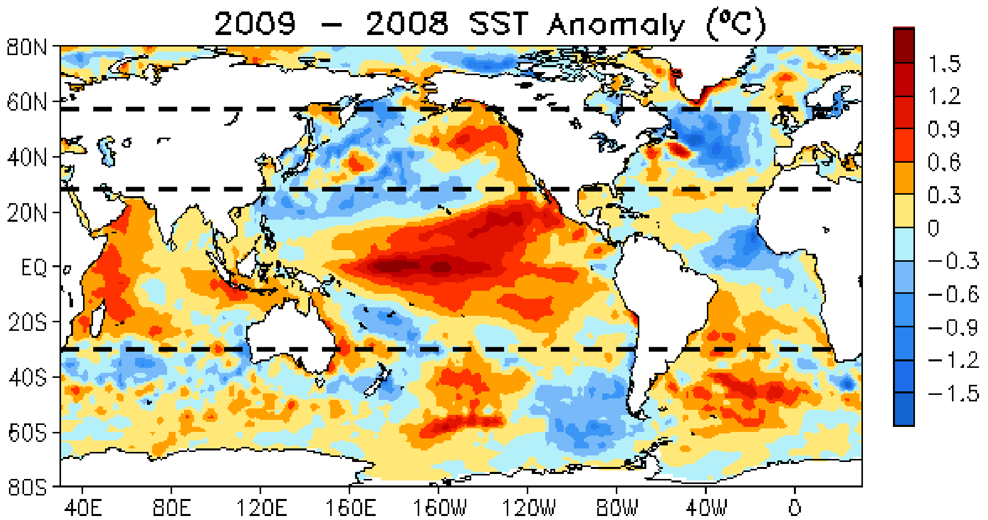
- Despite of above-normal SST in tropical North Atlantic, Atlantic hurricane activity was below – normal, suggesting impacts of the 2009/10 El Nino on hurricane activity dominated;

- North Atlantic Ocean was the coolest year since 2002, which is probably attributable to strong negative NAO during summer and subsequent winter.

Yearly Mean SST Anomaly



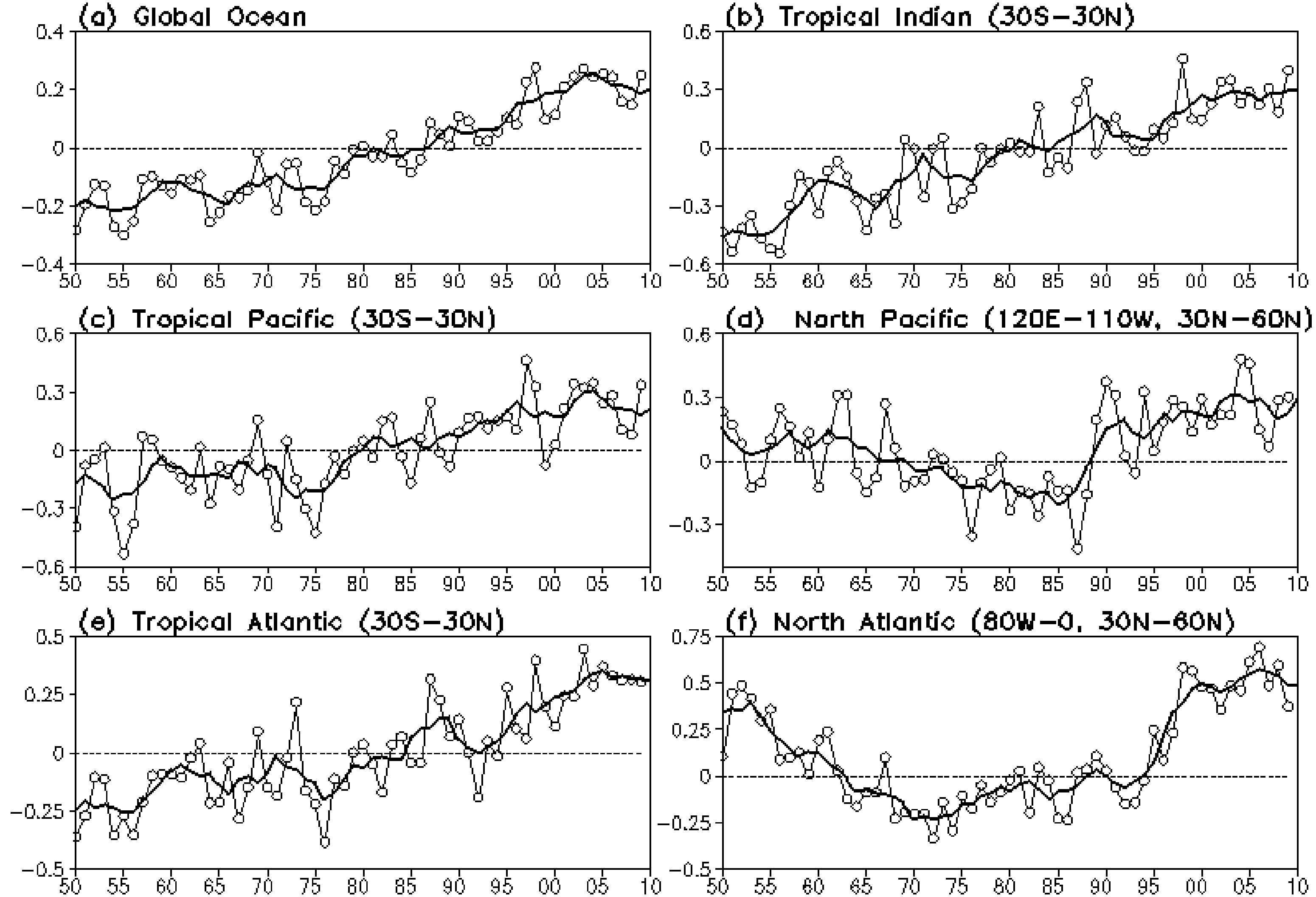
- An overall dominance of positive SST anomalies;
- Negative PDO pattern in N. Pacific;
- Tripole SST pattern in N. Atlantic;
- Positive anomaly in tropical Pacific due to the 2009/10 El Nino;
- Positive anomaly in tropical Indian Ocean;
- Positive anomaly in subtropical Atlantic.



- PDO transitioned from negative to near-normal in fall 2009;
- SST cooled down substantially in midlatitude N. Atlantic and tropical Atlantic;
- SST warmed up substantially in tropical Pacific and Indian Ocean.

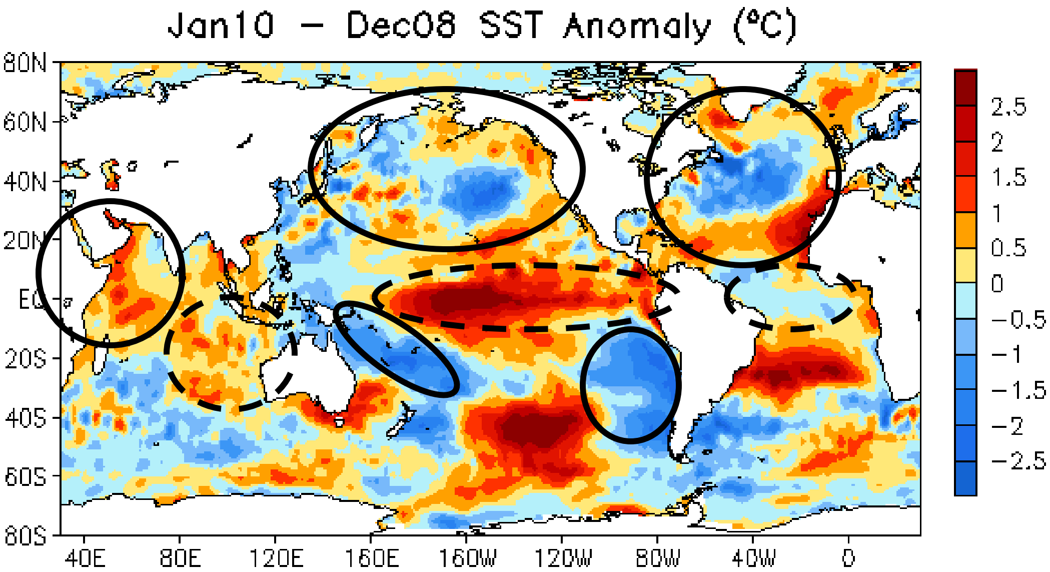
Yearly Mean SST Anomaly Indices

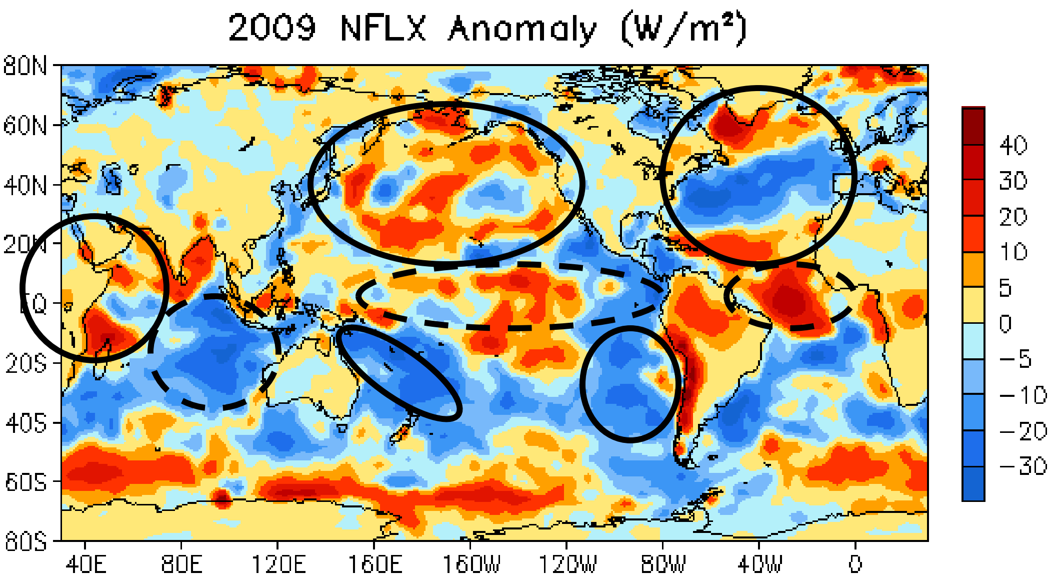
5 Year-Running-Mean (solid line)



- Global mean SST in 2009 was the fourth warmest since 1950; Tropical Pacific SST in 2009 was also the fourth warmest since 1950;
- Tropical Indian SST in 2009 was the second warmest behind the record warming in 1998;
- Tropical Atlantic SST peaks in 2003, and then decreased slowly since then;
- North Pacific SST has been persistently positive since 1990; North Atlantic SST was the coolest since 2002.

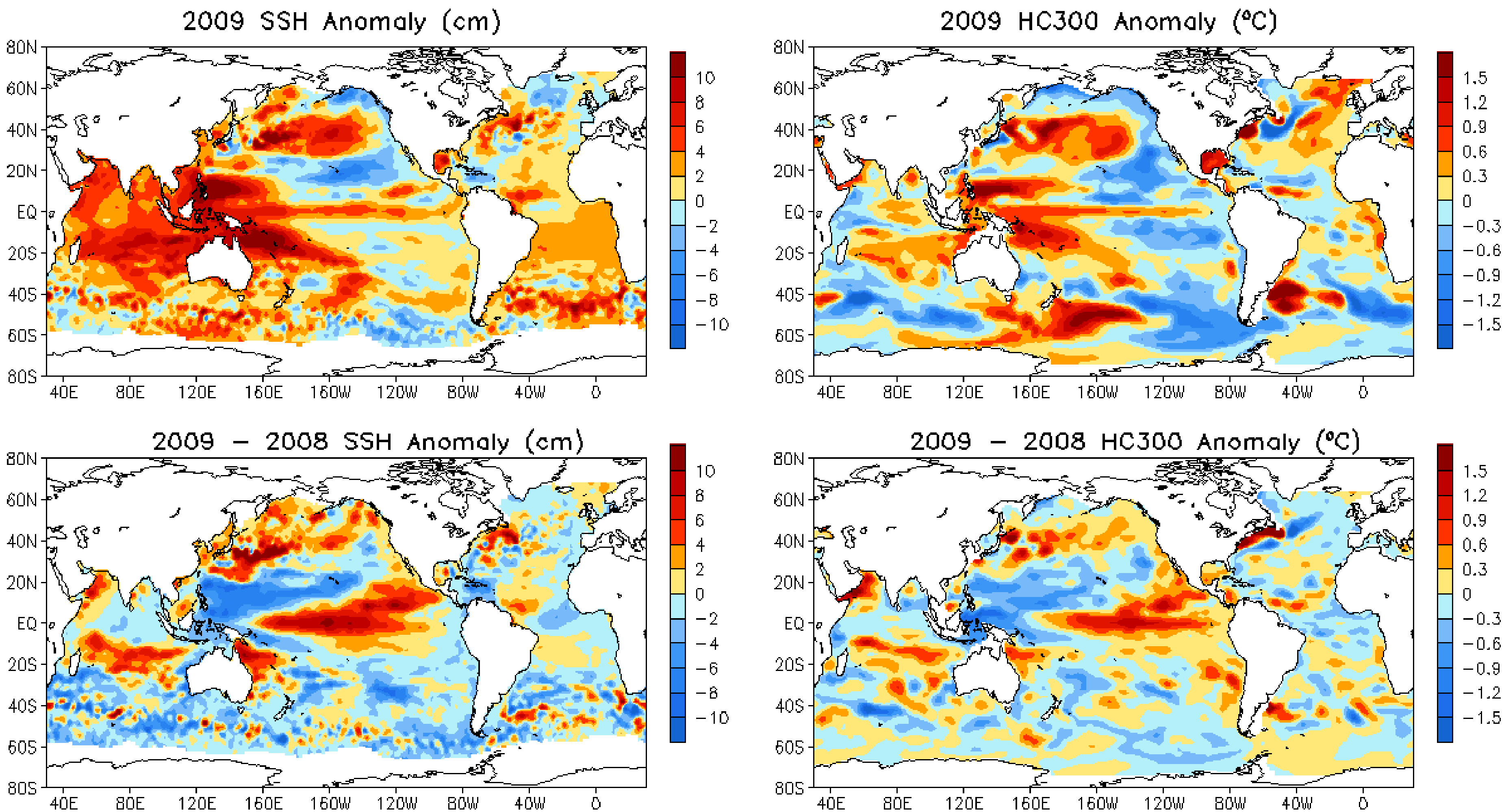
SSTA Tendency and Net Surface Flux Anomaly





- **The SSTA tendency in 2009 is largely consistent with the mean net surface heat flux anomaly in 2009 in N. Pacific, N. Atlantic, western tropical Indian Ocean, southwestern and southeastern Pacific;**
- **The SSTA tendency is inconsistent with the net surface heat flux anomaly in the tropical Pacific, tropical Atlantic, and southeastern tropical Indian Ocean, and might indicate that ocean dynamics was important in those regions.**

Yearly Mean SSH and HC300 Anomaly



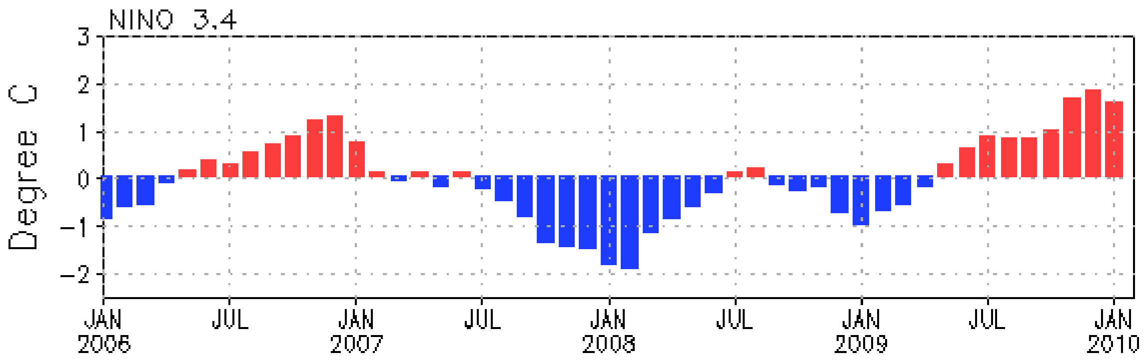
- Sea surface height (SSH) and upper 300m temperature average (HC300) anomaly are largely consistent except in the tropical Indian and Southern Oceans where biases in GODAS climatology are large (not shown).

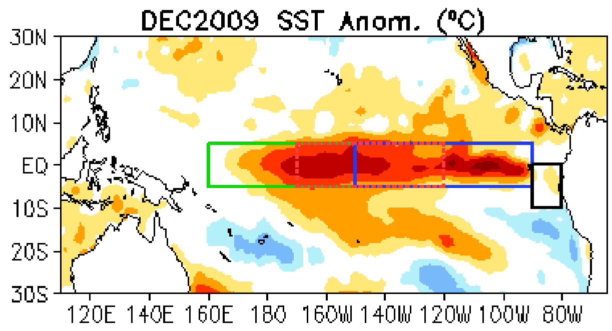
- Major features: negative PDO in N. Pacific, the 2009/10 El Nino, enhanced Subpolar Gyre and Subtropical Gyre in N. Atlantic; above-normal SSH in tropical Indian Ocean and western tropical Pacific due to recent trend;

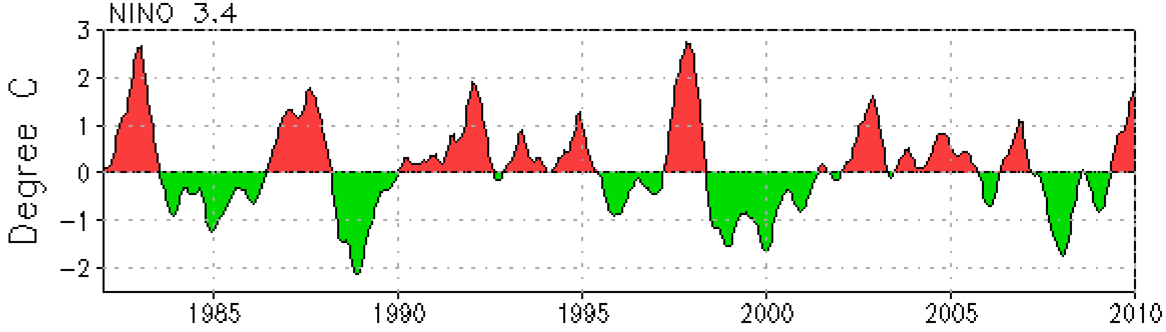
- Tendency in SSH and HC anomaly is largely consistent, indicating decreased (increased) SSH in the western and southeastern (central) tropical Pacific, increased SSH in N. Pacific and N. Atlantic, decreased SSH in highlatitude N. Atlantic and tropical Atlantic.

Tropical Indo-Pacific Ocean

NINO3.4 Index







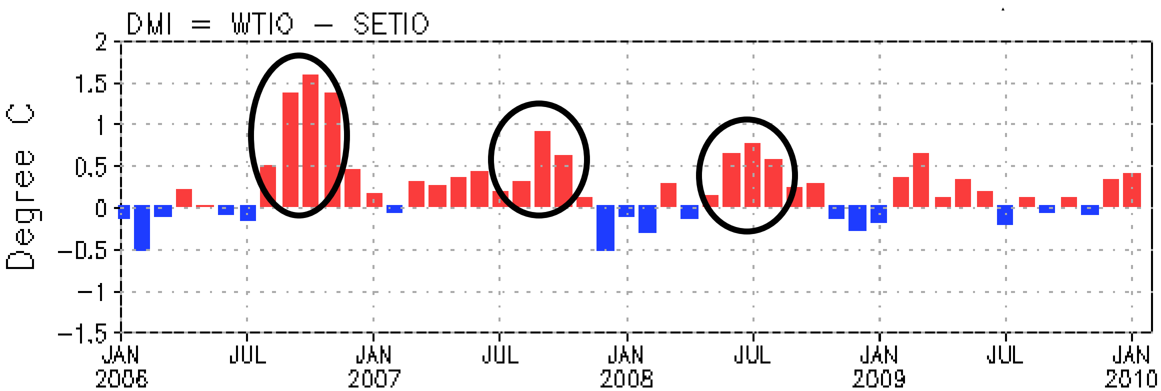
- **El Nino conditions (NINO3.4 SST > +0.5°C) present from June 2009 to January 2010;**

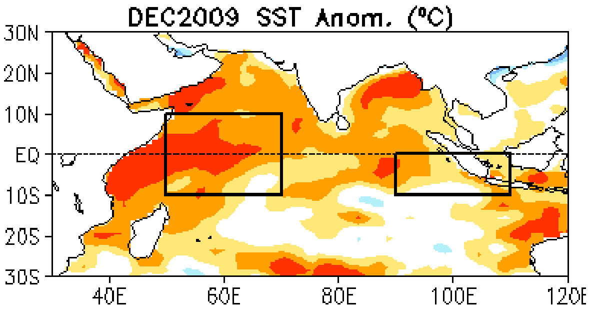
- **NINO3.4 largely persisted during July – October and strengthened significantly in November 2009, and the 3-month-running mean NINO3.4 SST was 1°C above-normal in SON 2009 and 1.5°C above-normal in OND 2009 and NDJ 2009/10, indicating a moderate–to-strong strength of El Nino;**

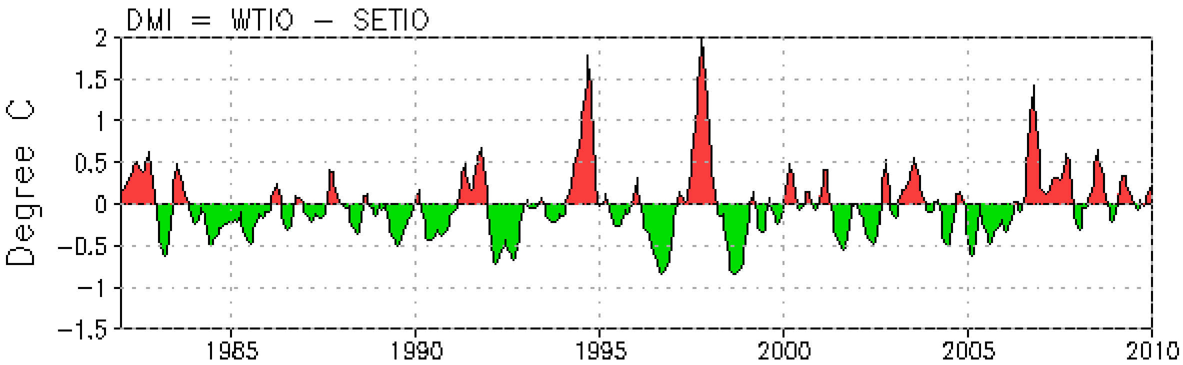
- **The amplitude of the 2009/10 El Nino was weaker than that of the 1982/83 and 1997/98 events, but was similar to the strength of the 2002/03 event.**

(http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml)

DMI Index



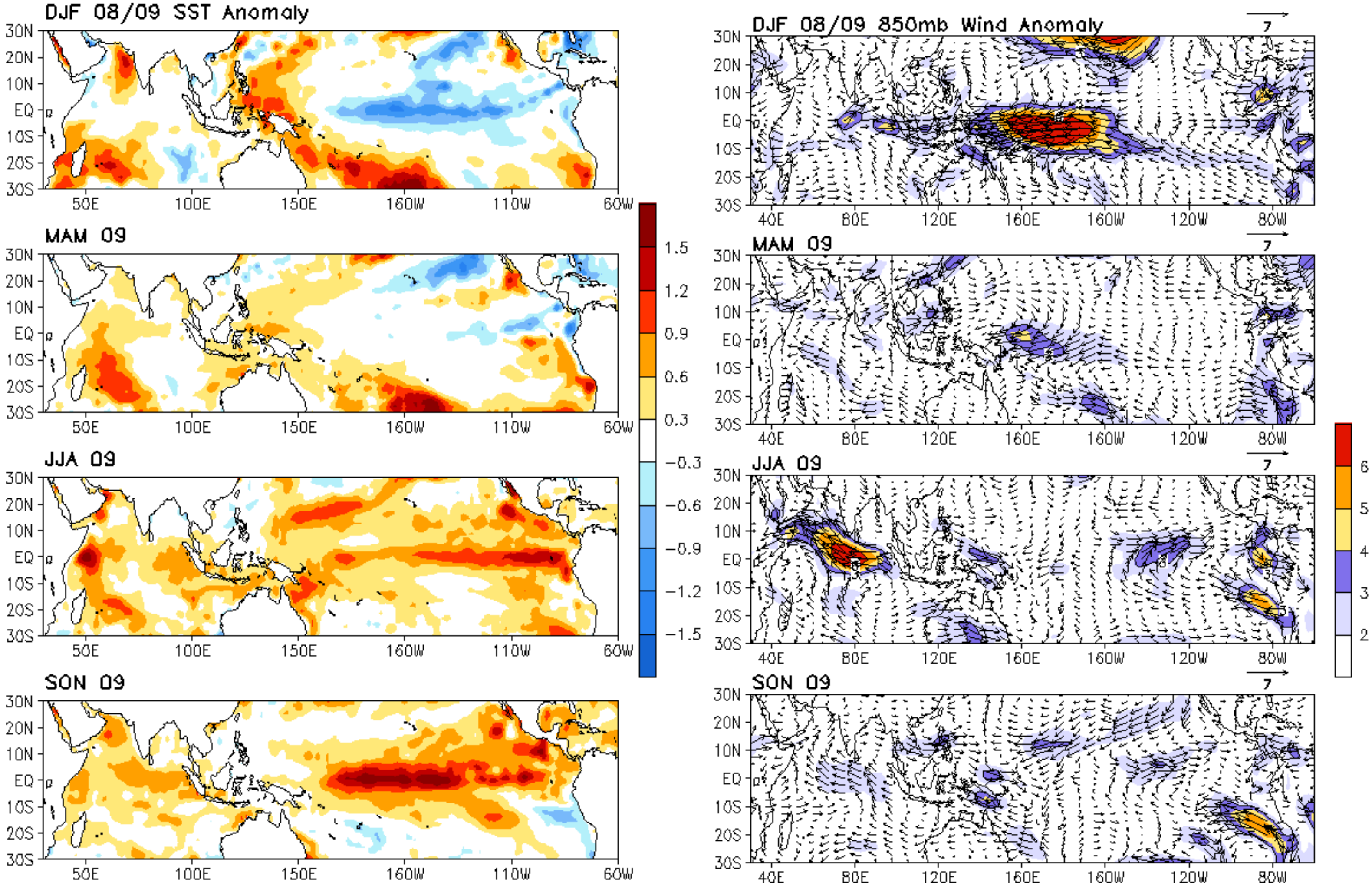




- **Dipole Mode Index (DMI), SST anomaly differences in SETIO [90ºE-110ºE, 10ºS-0] and WTIO [50ºE-70ºE, 10ºS-10ºN] , was near-normal in 2009.**

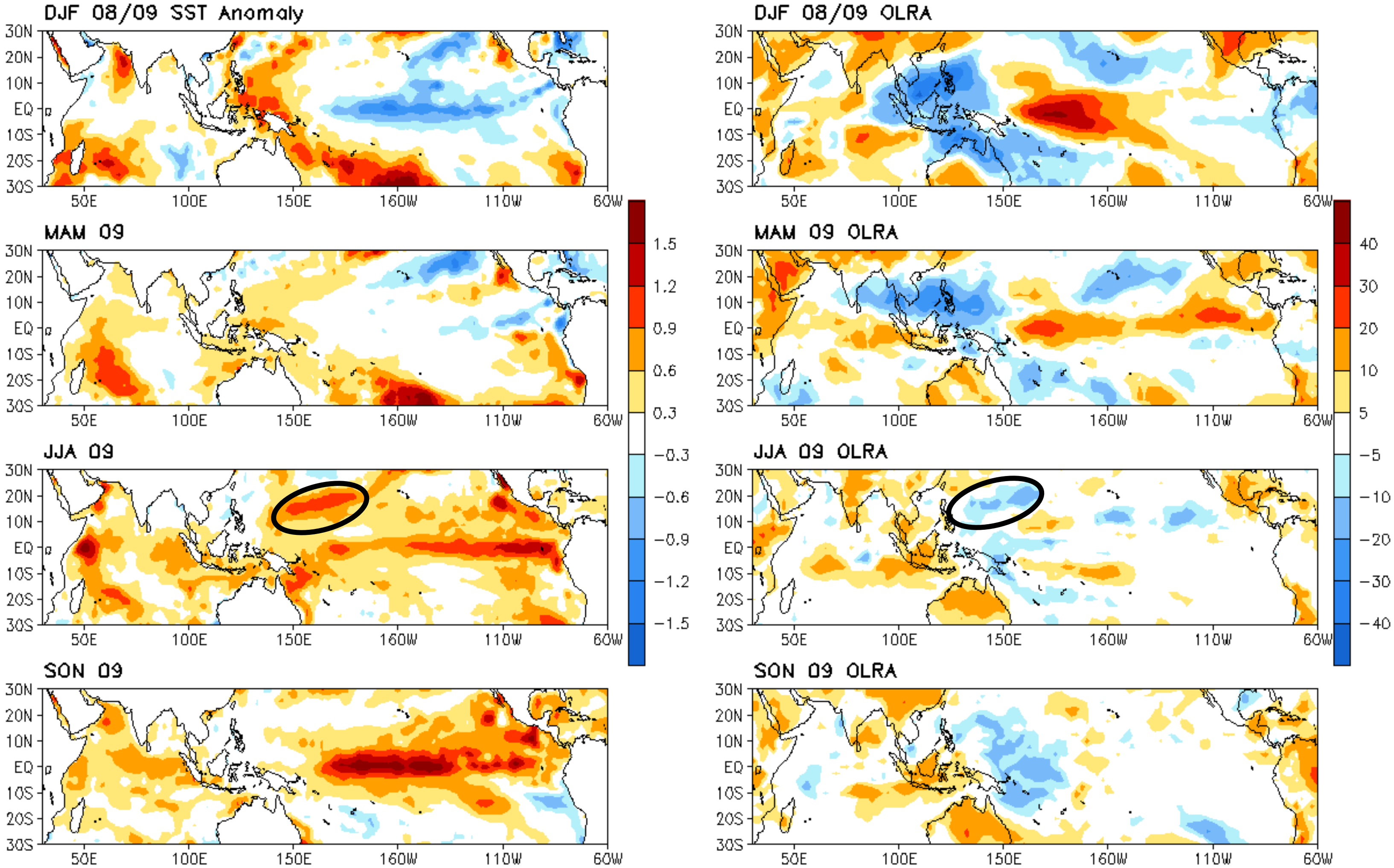
- **It is interesting that DMI has been above-normal (3 month-running-mean DMI > 0.5ºC) in three consecutive years (2006, 2007 and 2008), indicating western Indian Ocean warmed more than the eastern part.**

Seasonal SST and 850mb Wind Anomaly



- **DJF 08/09: La Nino conditions prevailed with strong easterly wind anomaly in W. and C. tropical Pacific;**
- **MAM 09: Near-normal SST presented in C.-E. tropical Pacific, but stronger than normal low-level easterly presented in C.-W. tropical Pacific, which might be associated with the enhanced west-east SST gradient there;**
- **JJA 09: Above-normal SST presented cross the equatorial Pacific with maximum warming in E. Pacific, and westerly wind anomaly presented in far W. and E. Pacific;**
- **SON 09: El Nino reached a moderate strength with westerly wind anomaly in W. and E. tropical Pacific.**

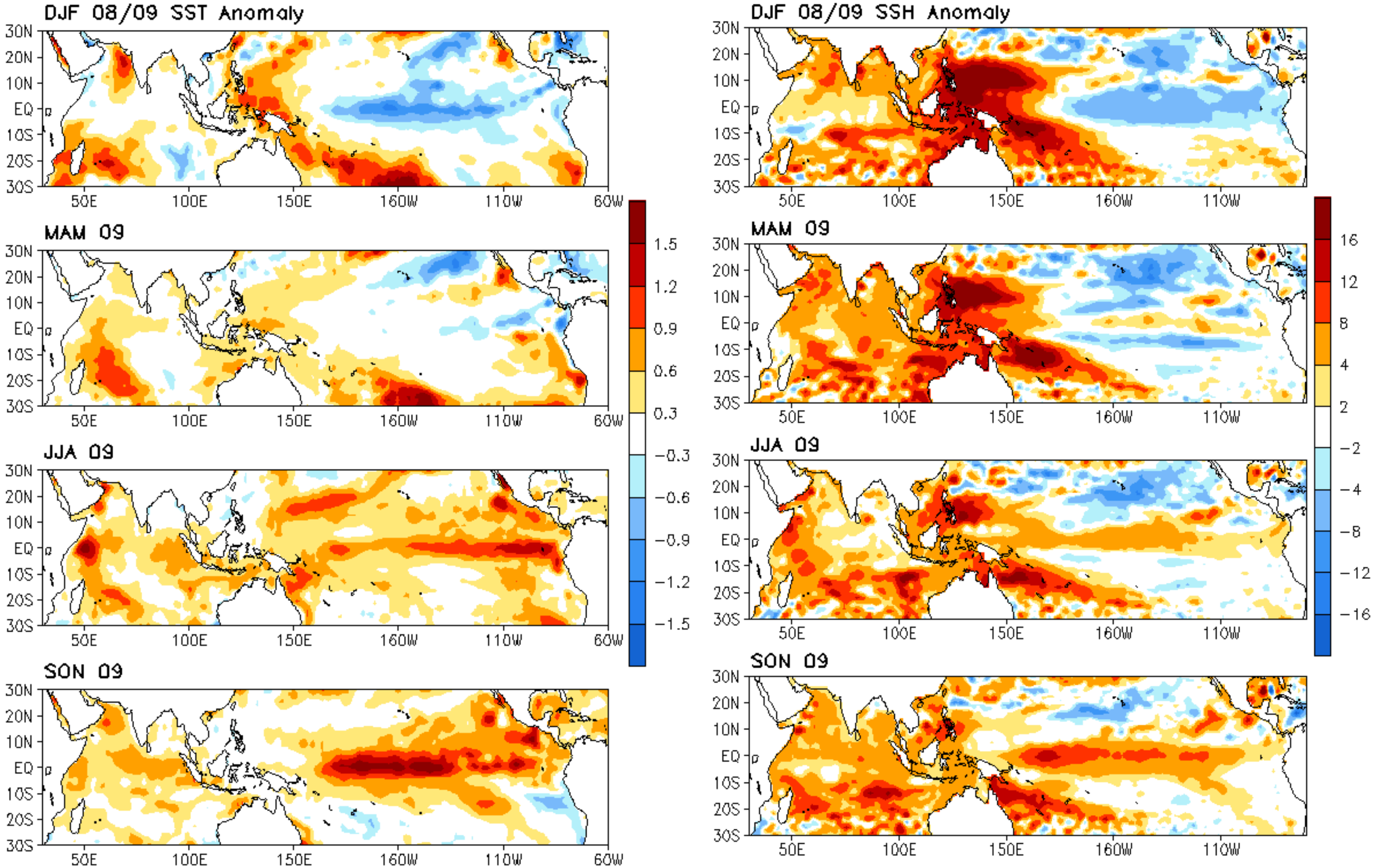
Seasonal SST and OLR Anomaly



Negatitive (positive) OLR anomaly indicate enhanced (suppressed) convection

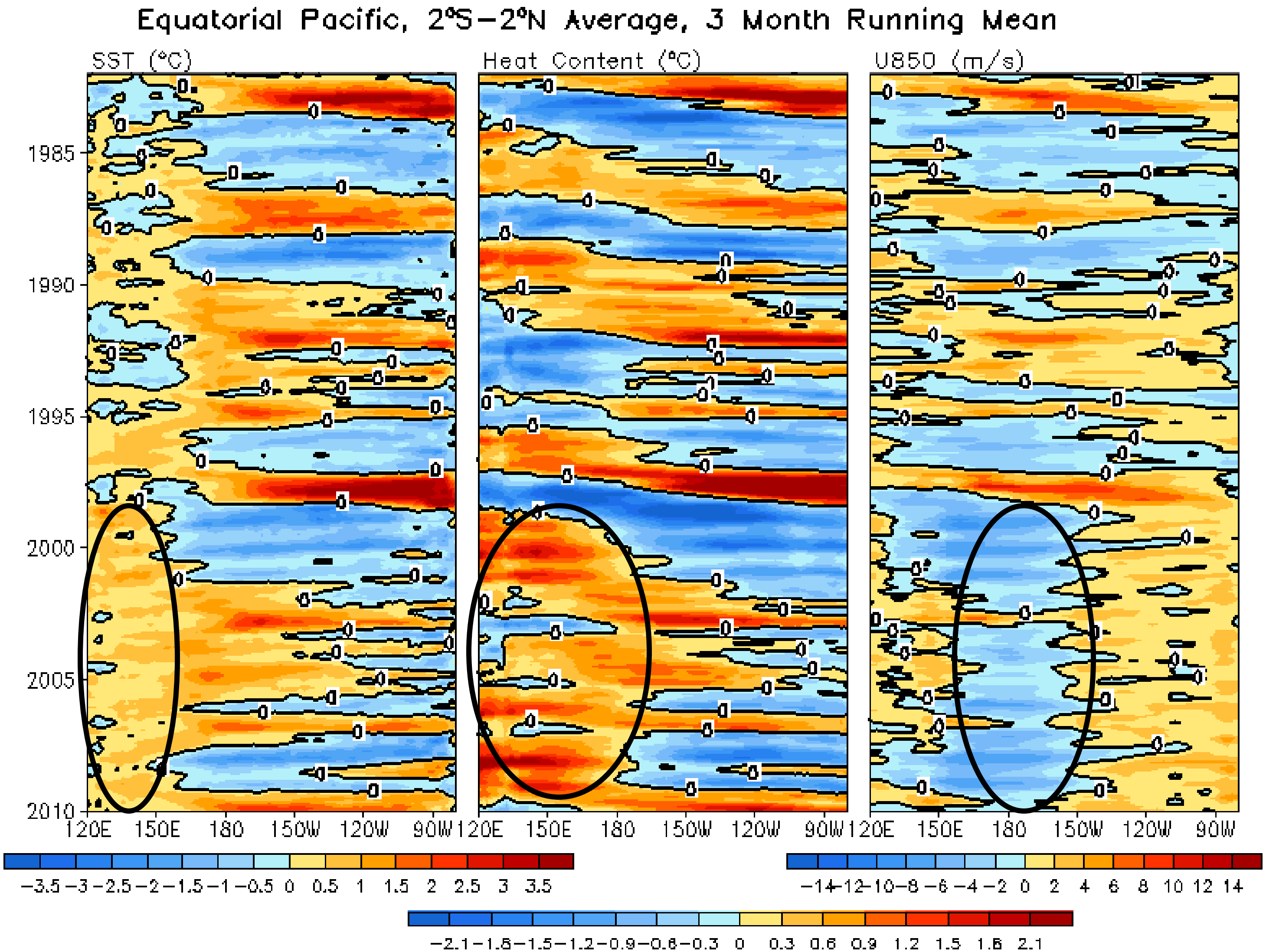
- **DJF 08/09: Enhanced (suppressed) convection presented over the Maritime Continent (in C. Pacific);**
- **MAM 09: Enhanced (suppressed) convection presented in northwestern tropical Pacific (C.-E. equatorial Pacific);**
- **JJA 09: Enhanced convection appears associated with positive SSTA in northwestern subtropical Pacific.**
- **SON 09: Enhanced (suppressed) convection presented in the western Pacific (over the Maritime Continent).**

Seasonal SST and SSH Anomaly



- **DJF 08/09: Strong positive SSH anomaly presented in the western tropical Pacific, attributed to both the La Nina conditions and trend;**
- **MAM 09: Positive SSH anomaly about 2-4 cm presented in C.-E. equatorial Pacific;**
- **JJA 09: Positive SSH anomaly about 4-8 cm presented in W.-C. equatorial Pacific;**
- **SON 09: Positive SSH anomaly about 8-12 cm presented in C.-E. equatorial Pacific, and positive SSH anomaly in the northwestern tropical Pacific dissipated.**

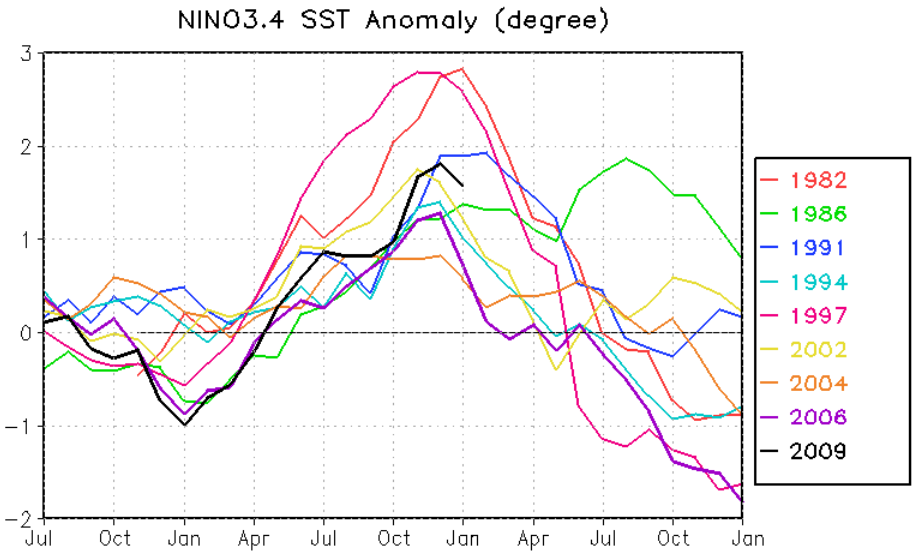
Persistent Anomaly in Tropical Pacific since 1999

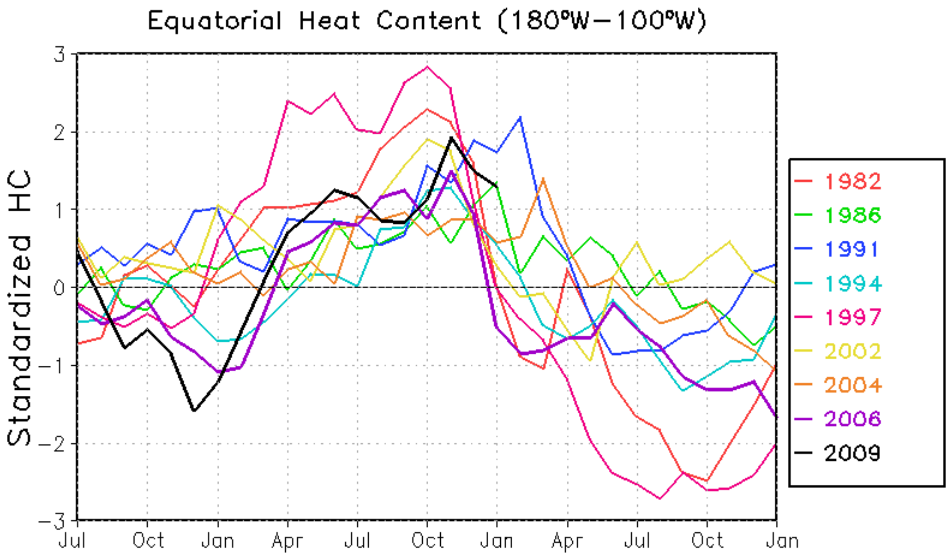


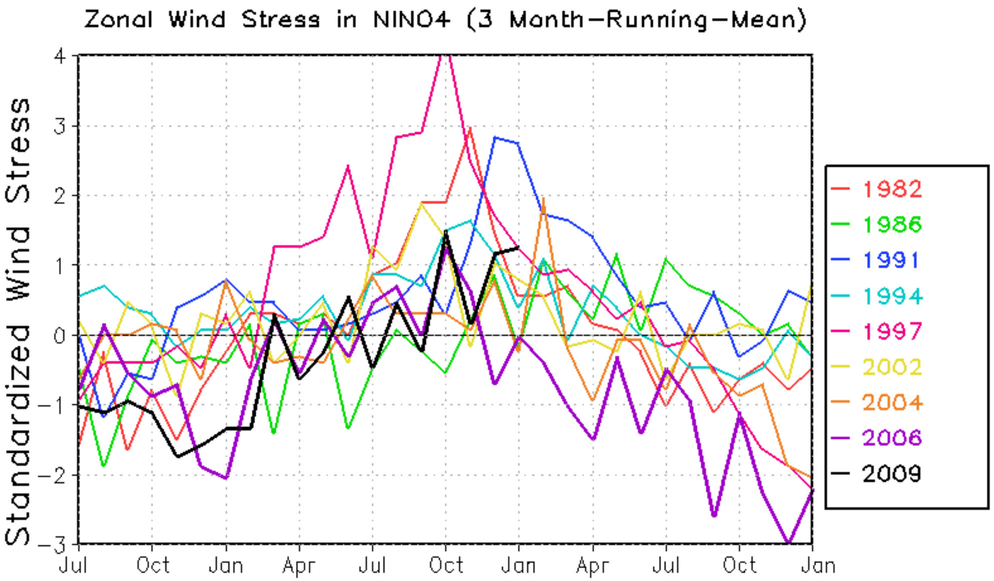
- Above-normal SST persisted in the far western tropical Pacific since 1999;
- Above-normal heat content has persisted west of the Dateline since 1999;
- Above-normal surface zonal winds have persisted near the Dateline since 1999.

The 2009-2010 El Nino

NINO3.4, Eq HC and C. Pacific Winds







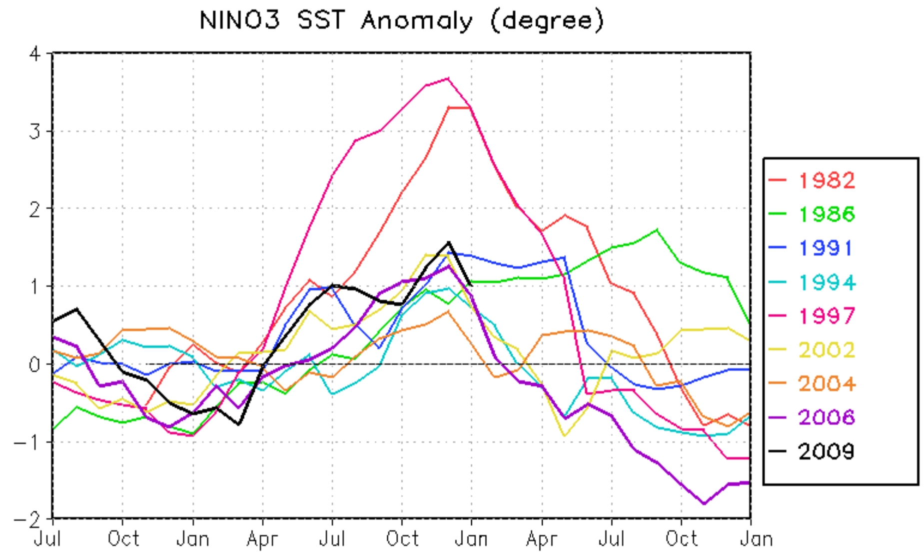
- **NINO3.4 underwent a transition from negative to positive phase in spring 2009, similar to that in spring 2006;**

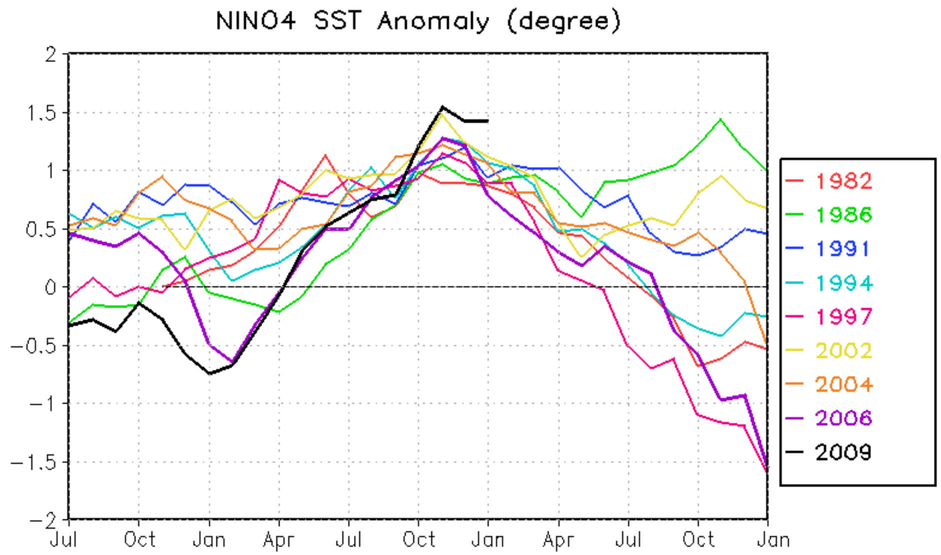
- **The 2009/10 El Nino surpassed the 2006/07 El Nino in strength, which became comparable to that of the 2002/03 event by early winter;**

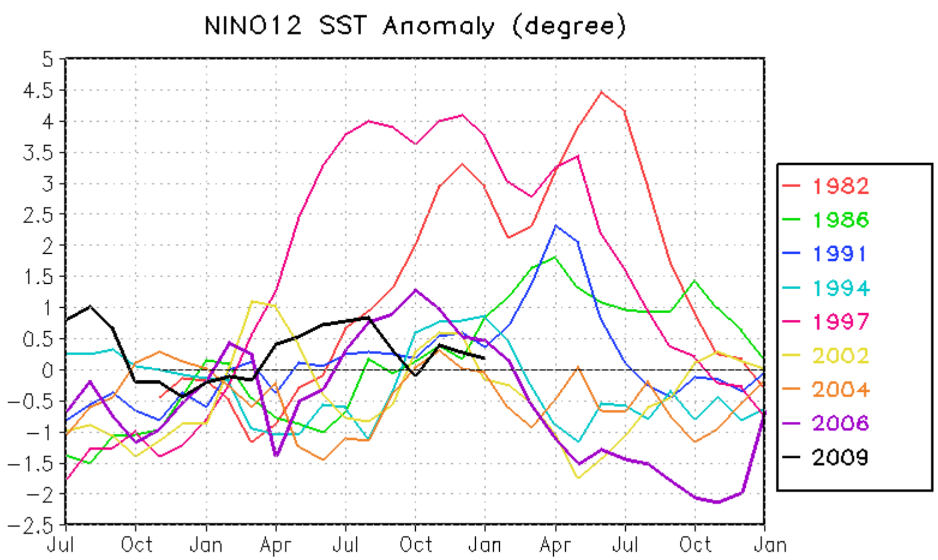
- **Equatorial heat content anomaly in E. Pacific underwent a transition from negative to positive phase in spring 2009, similar to that in spring 2006;**

- **Zonal wind stress in NINO4 is dominated by intraseasonal variability, which is very similar to that during the 2006/07 event.**

El Nino Indices







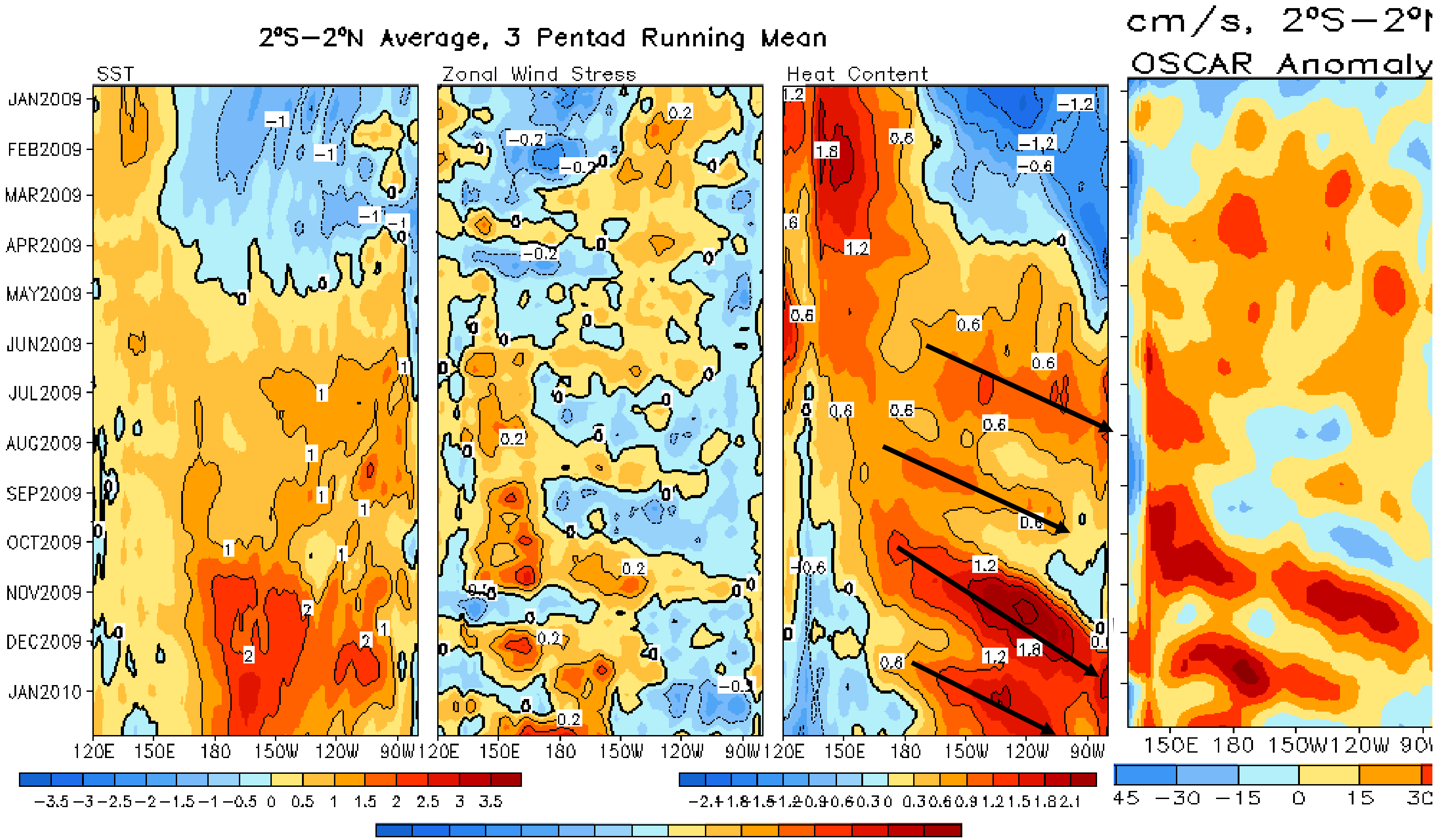
- **NINO3 increased rapidly in spring and early summer, and reached a peak amplitude of about 1°C by early winter;**

- **NINO4 transitioned from negative to positive phase in spring, and reached a peak amplitude of 1.5°C by early winter. The value in Dec 09 - Jan 10 is the highest among all events during similar calendar months;**

- **The 2009/10 El Nino has a maximum warming in the central Pacific (NINO4 > NINO3) in NDJ.**

- **NINO1+2 reached a peak amplitude of 0.8°C in summer, and then declined to near-normal in fall/winter 2009.**

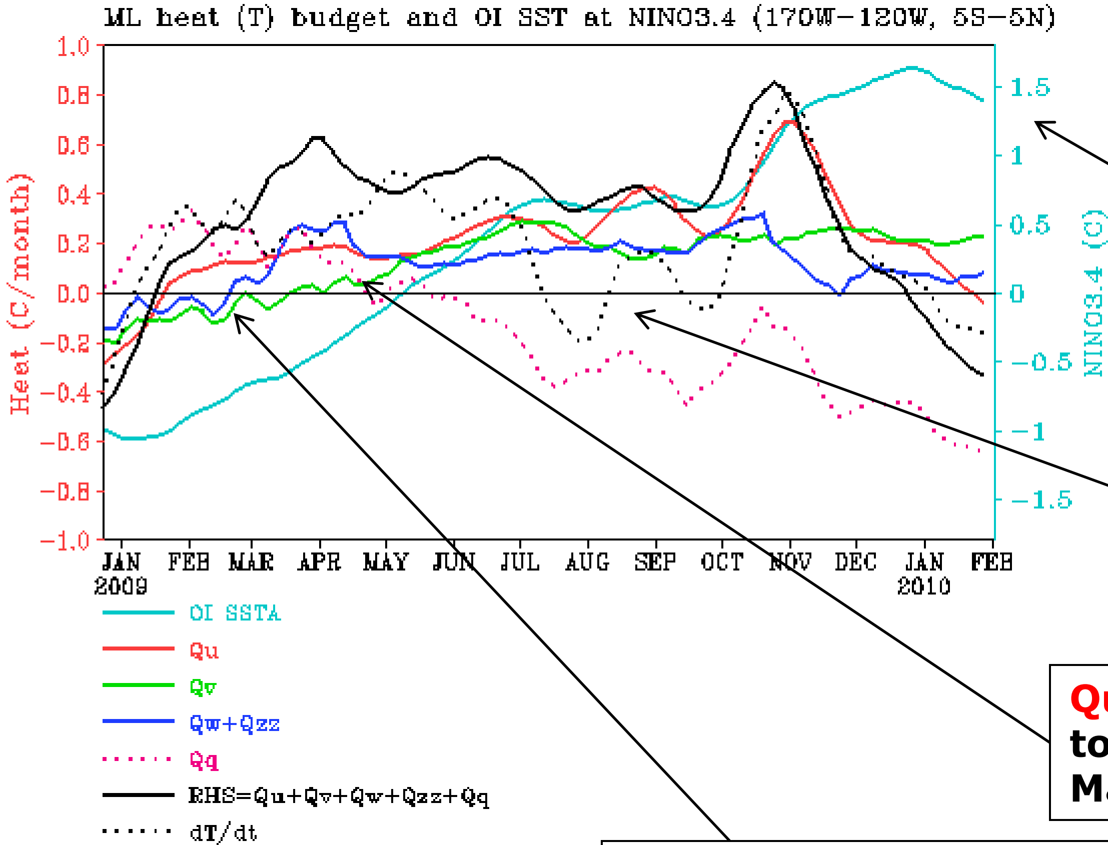
Evolution of Equatorial Pacific SST, Heat Content, Zonal Wind Stress, and Surface Zonal Current Anomaly



- Positive SST anomaly developed in June 2009 in E. Pacific, which largely persisted during summer. SST anomaly then strengthened significantly in Oct 2009 in C. Pacific reaching 2°C above-normal. The SSTA in C. Pacific largely persisted in fall/winter, but that in E. Pacific declined rapidly in Jan 2010.

- Westerly wind bursts dominated zonal wind stress anomalies in C. Pacific, which forced four episodes of downwelling oceanic Kelvin waves that were evident in heat content anomalies since June 2009. Therefore, the 2009/10 El Nino developed and strengthened by a series of westerly wind burst events.

NINO3.4 Heat Budget: 09/10 El Nino



The large warming tendency in Oct-Nov was largely due to Qu, suggesting that influences of subsurface temperature anomalies on the recent SSTA changes were likely small. The negative tendency in Jan 2010 suggests that the El Nino has likely transitioned into its decay phase.

Balance in heat budget (dT/dt = RHS) was poor in Jul-Sep when intraseaonal variability is large.

Qu and Qw+Qzz contributed to the warming tendency in Mar-May.

Qq and Qu contributed to the decay of the cold anomaly in the early spring 09.

Qu: Zonal advection; Qv: Meridional advection;

Qw: Vertical entrainment; Qzz: Vertical diffusion

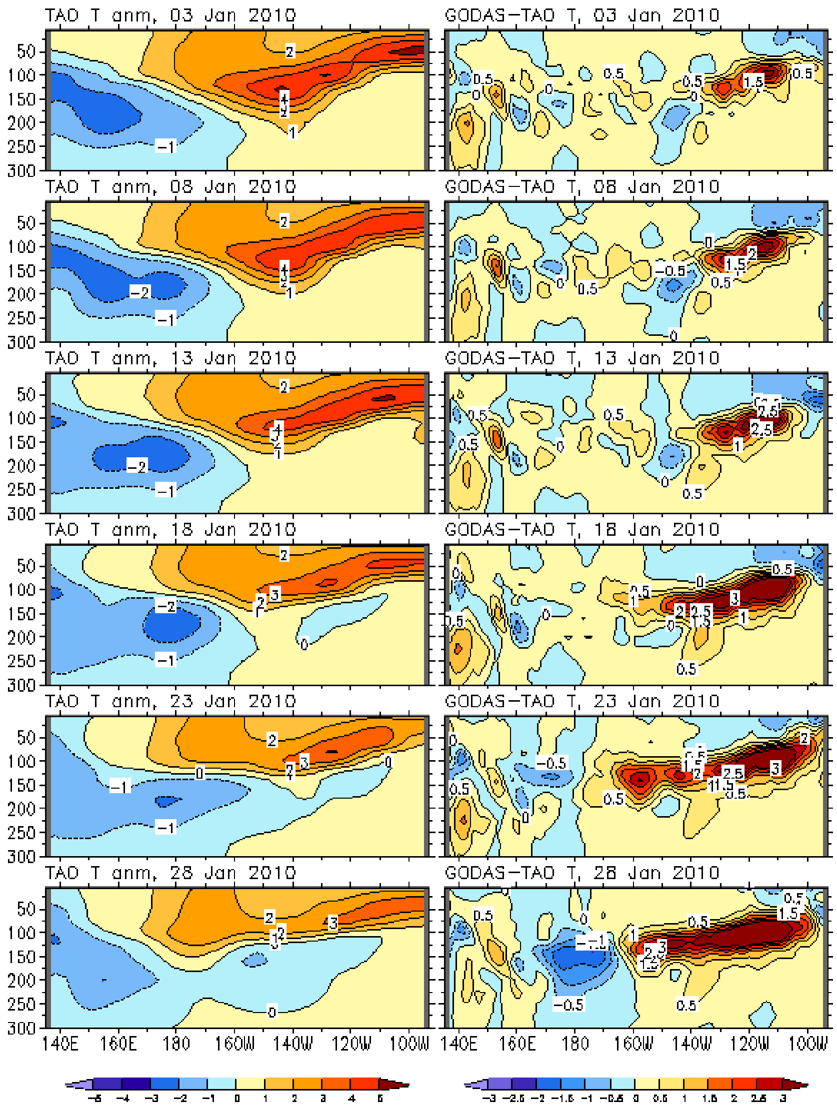
Qq: (Qnet - Qpen + Qcorr)/ρcph; Qnet = SW + LW + LH +SH;

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

Equatorial Pacific Temperature Anomaly

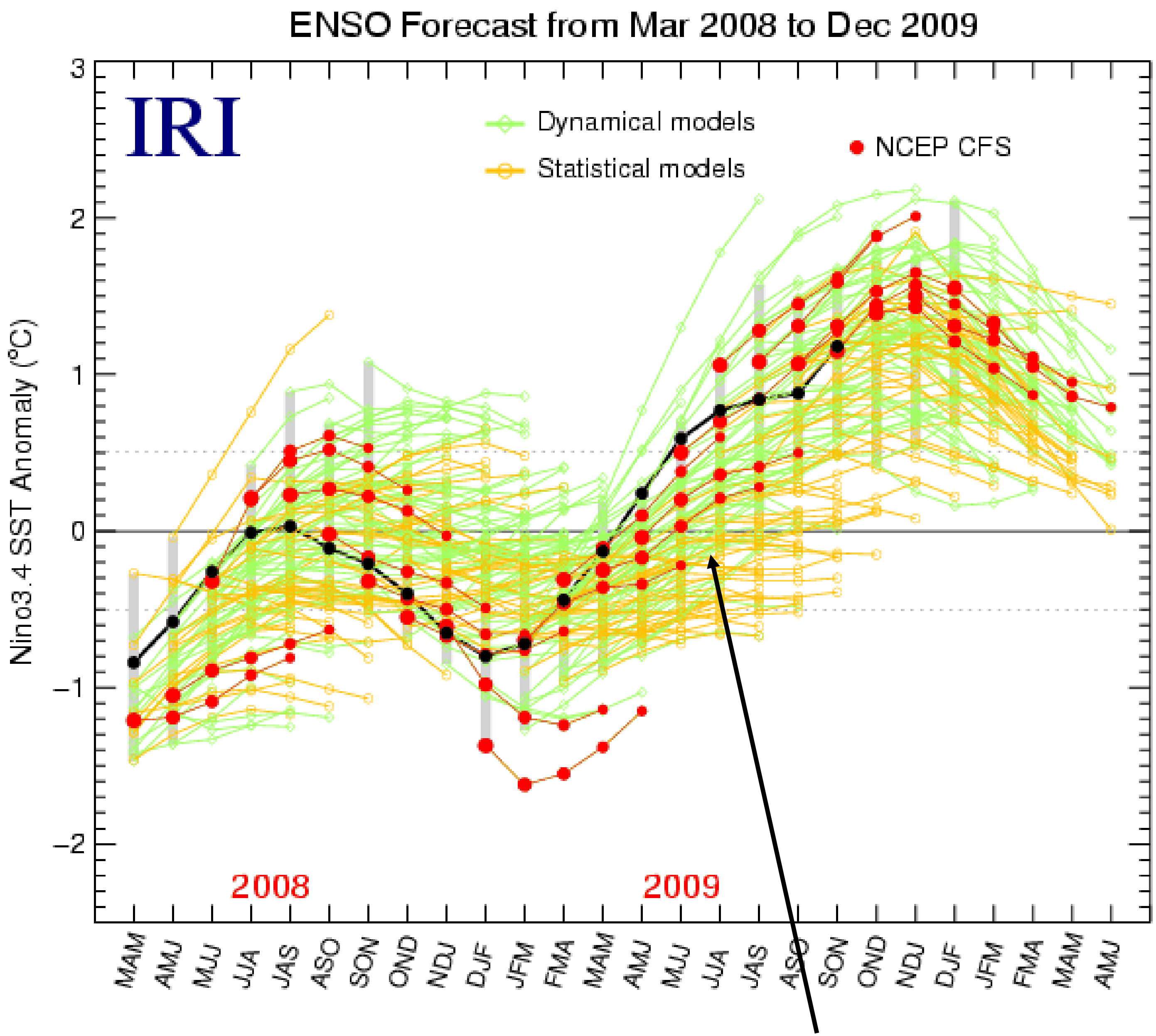
TAO GODAS

TAO climatology used



- **Note the differences between GODAS and TAO temperature are as large as 2-3C in the eastern equatorial Pacific near the thermocline since mid Jan 2010.**

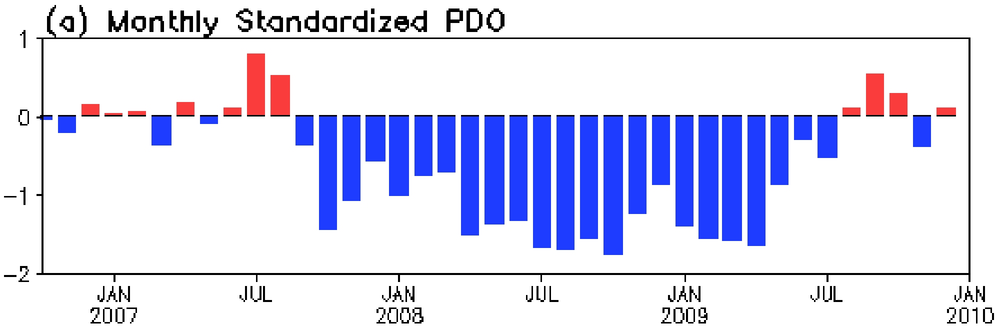
- **The large departures from observations might be related to the failure of the three eastern most equatorial buoys (http://tao.noaa.gov).**



Most of models underestimated the rapid onset of the 2009/10 El Nino in spring, so did the CFS.

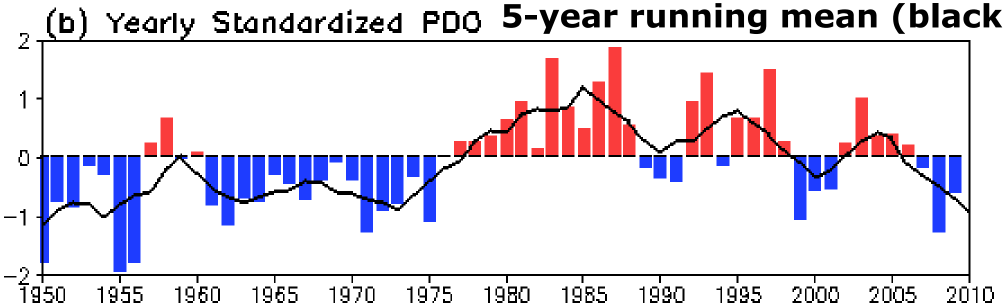
North Pacific Ocean

PDO index downloaded from UW/NOAA JISAO PDO page



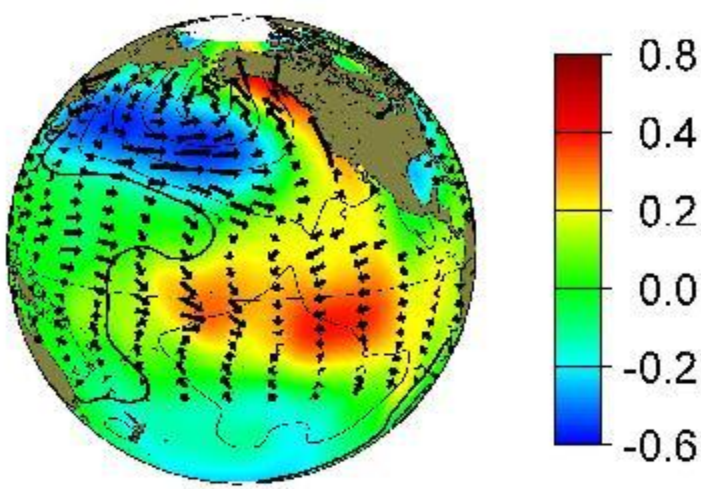
- PDO has been in a negative phase from September 2007 to July 2009, and had a duration of 23 months.
- PDO has been slightly above-normal in fall/winter 2009.

5-year running mean (black line)

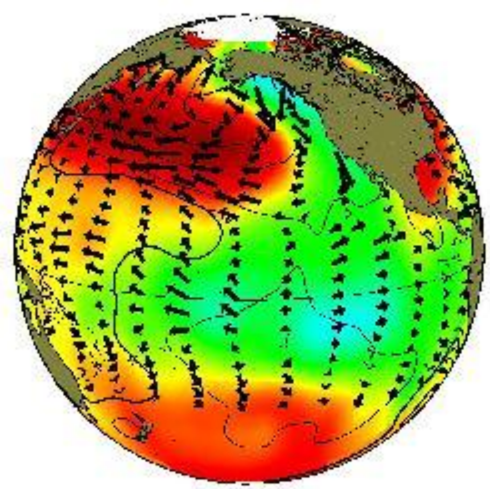


- The yearly mean PDO had been largely in a negative phase in 1950-1975, and a positive phase in 1976-1998.
- Since 1999, the yearly mean PDO has been in either negative or weakly positive phase.

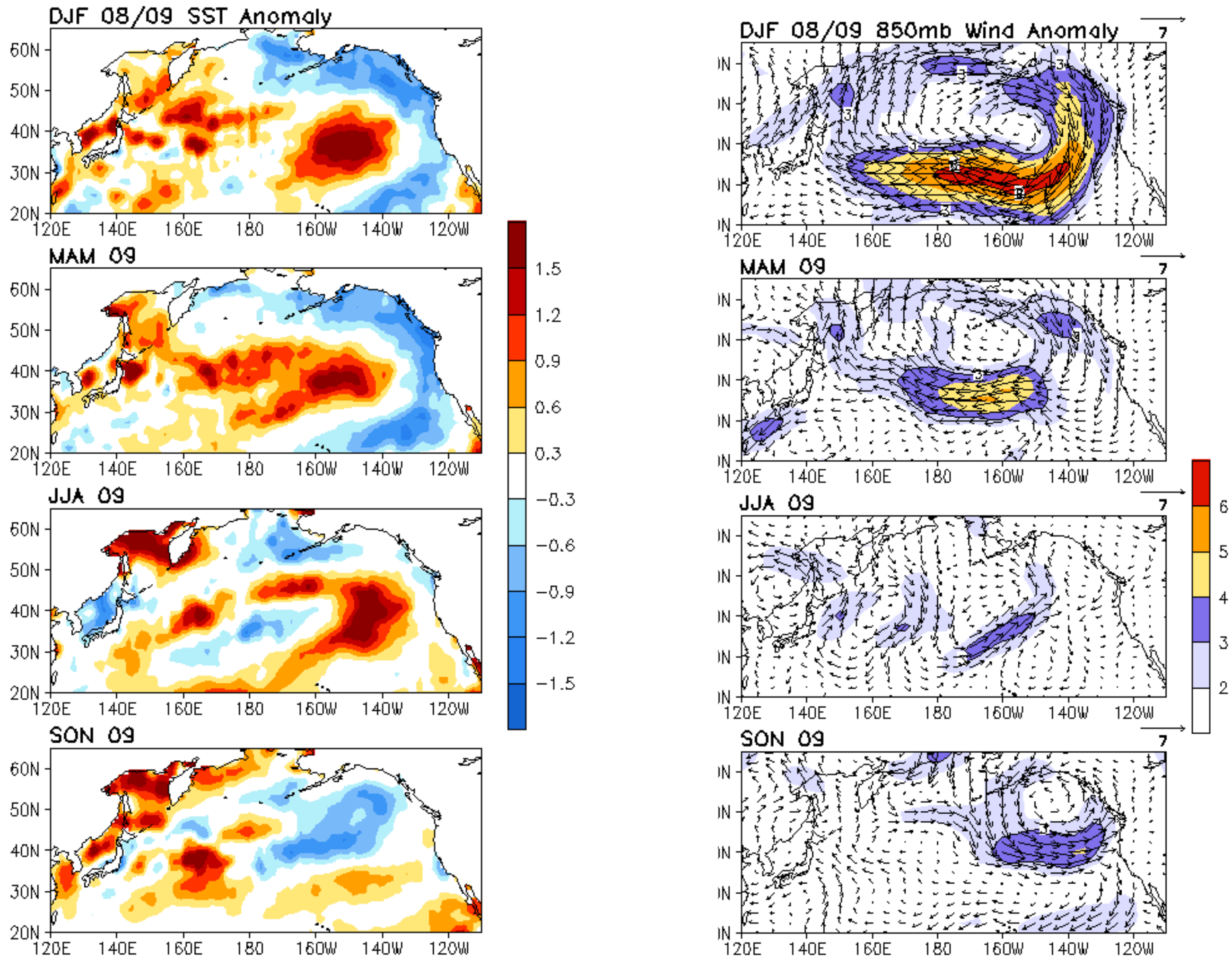
Positive PDO



Negative PDO

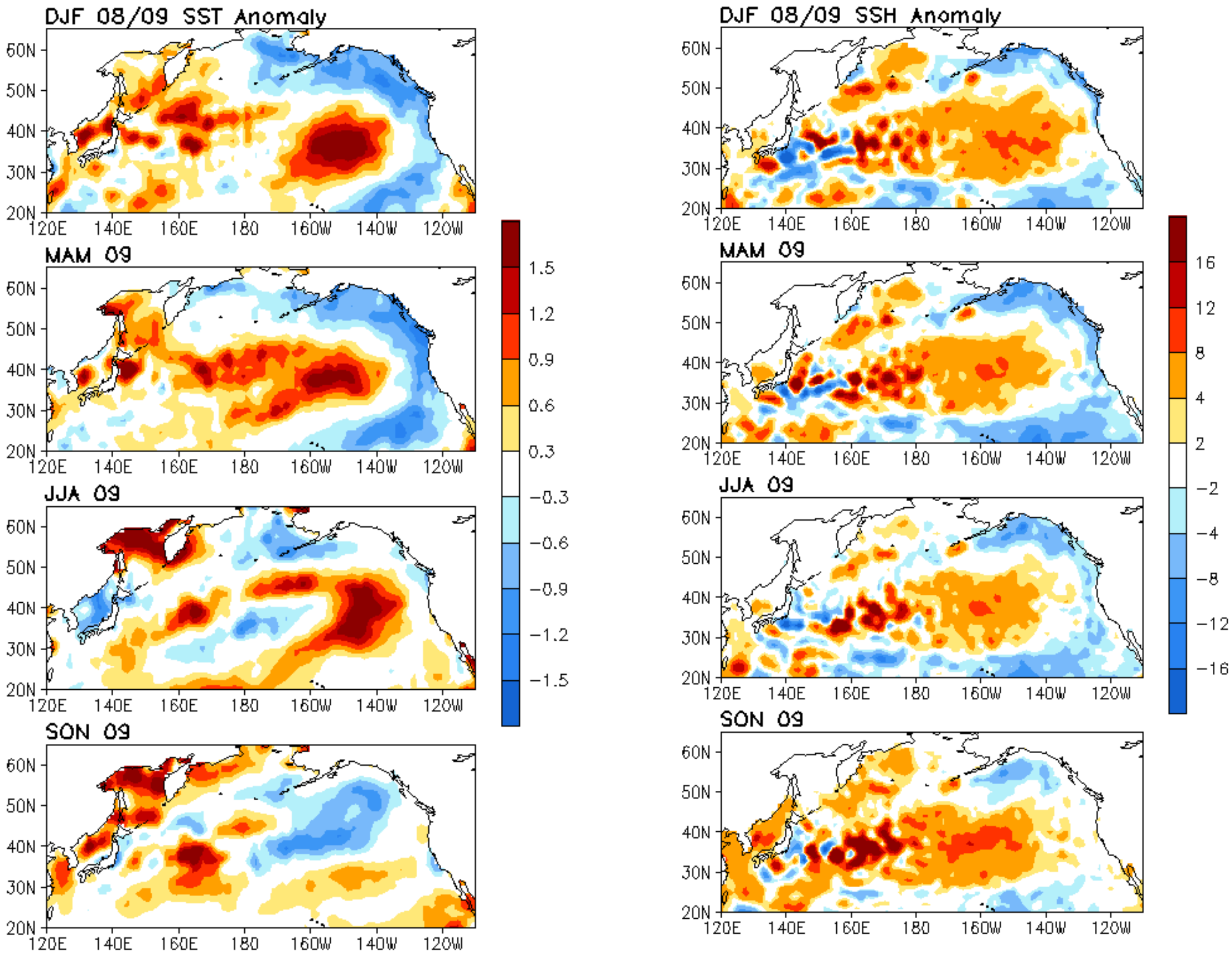


Seasonal SST and 850mb Wind Anomaly



- Negative PDO was prominent during DJF 08/09 and MAM 09, and consistent with the negative PDO was low-level westerly wind anomaly in the central N. Pacific and northerly wind anomaly along the west coast of N. America favorable for upwelling;
- PDO transitioned into near-normal during JJA 09, when low-level wind anomaly weakened;
- During SON 09, low-level wind anomaly became cyclonic, forcing PDO to be weakly above-normal.

Seasonal SST and SSH Anomaly

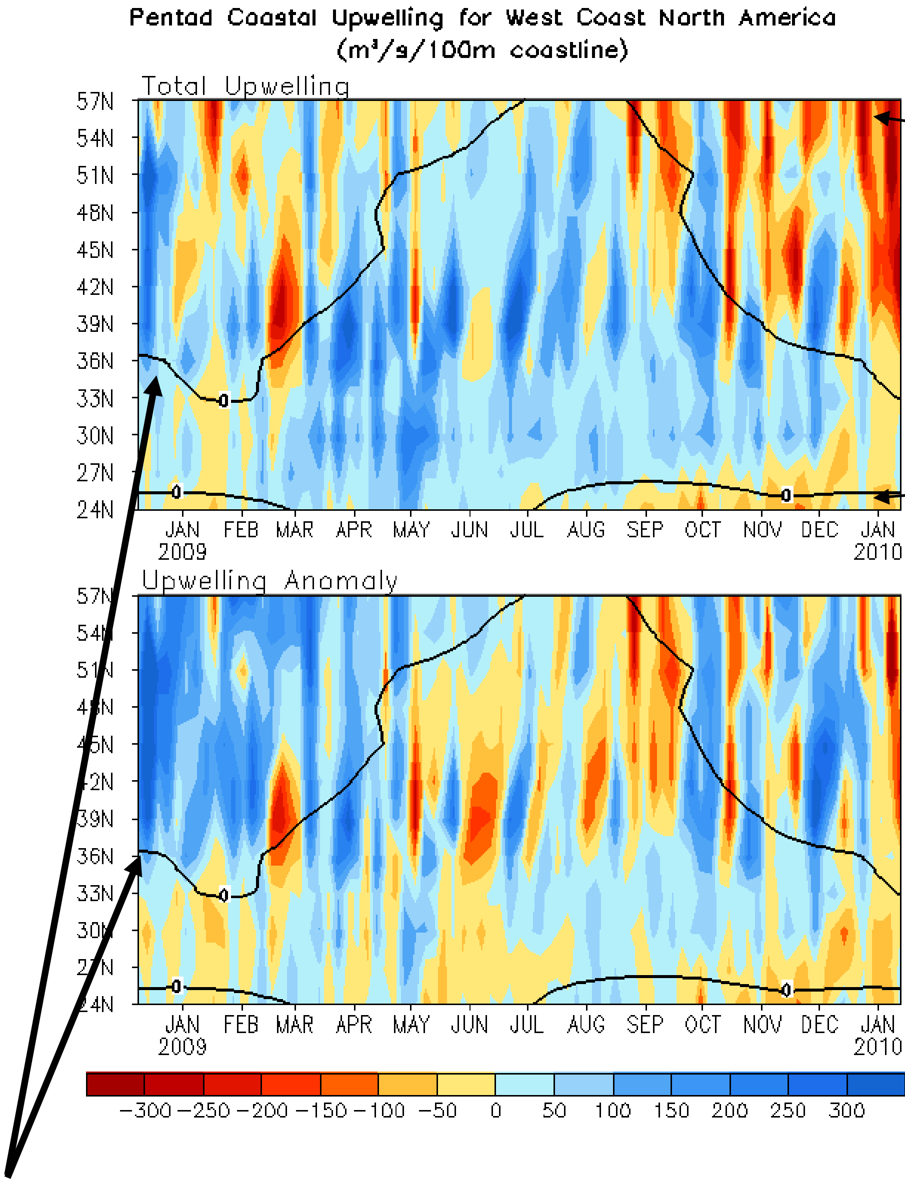


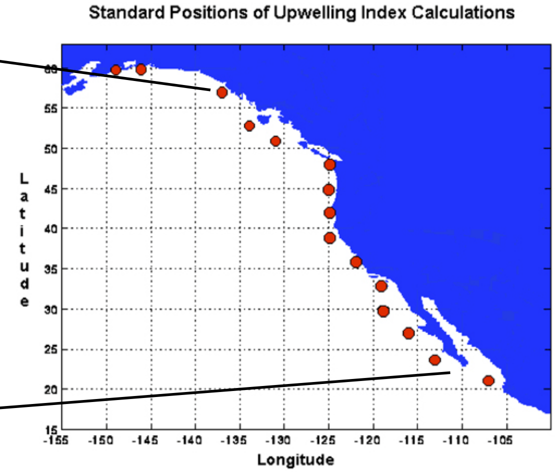
- Sea surface height (SSH) anomaly had a negative PDO pattern during DJF 08/09 and MAM09, consistent with SST anomaly;

- Although the negative PDO pattern weakened substantially in SST from MAM to JJA 09, the negative PDO pattern in SSH largely persisted;

- In SON 09, SST was in a weak positive PDO phase, while SSH remained in a negative PDO phase largely due to the persistence of SSH in the central N. Pacific.

North America Western Coastal Upwelling





- Consistent with the negative PDO phase, upwelling along the west coast of North America was mostly above-normal during the winter 2008/09 and spring 2009;

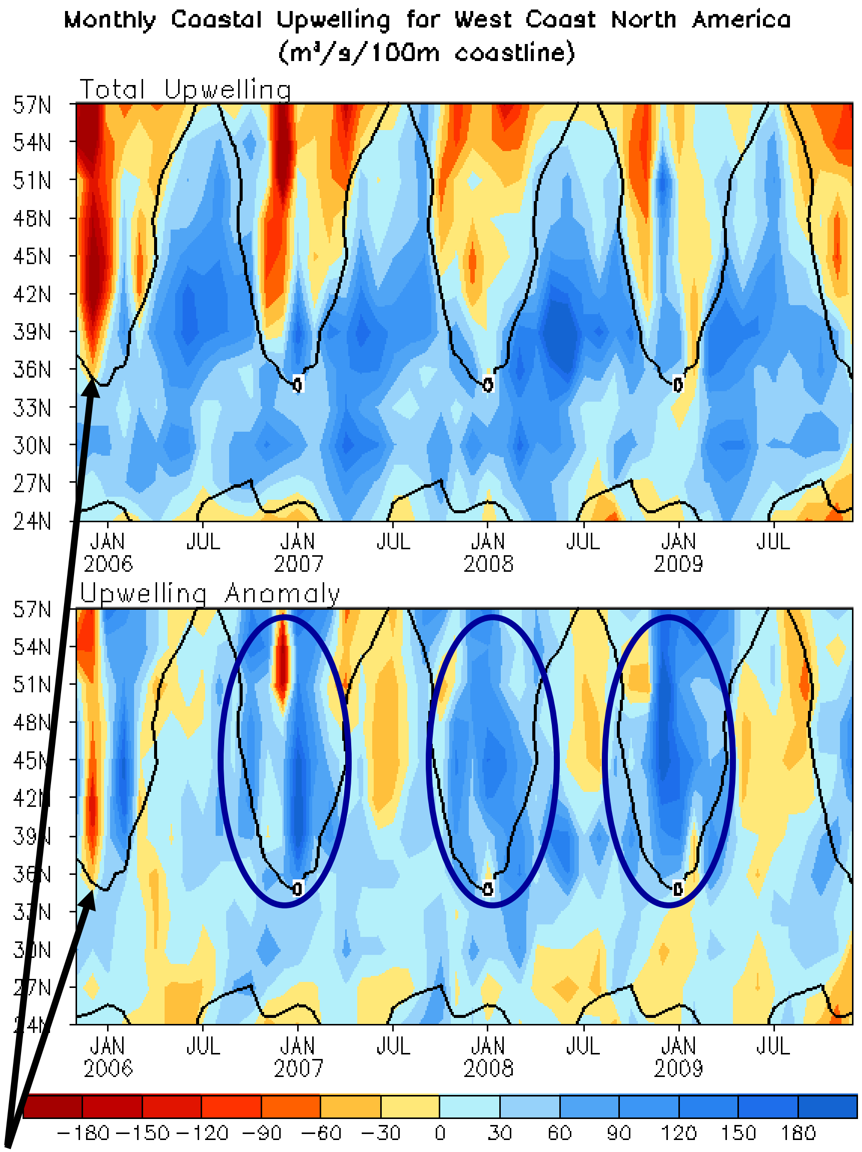
- When the El Nino conditions developed in the tropical Pacific in June 2009, upwelling became mostly below-normal north of 36ºN during late spring and summer 2009.

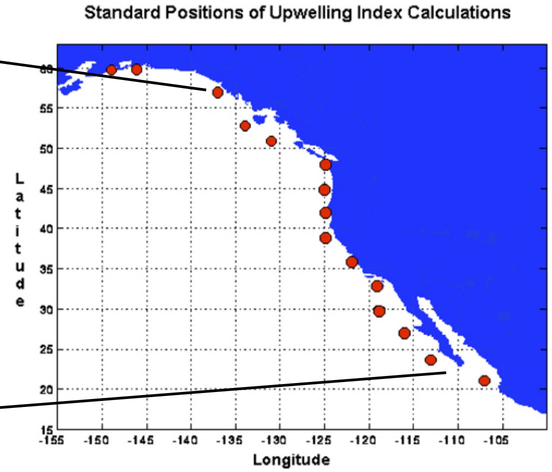
Fig. NP2. Total (top) and anomalous (bottom) upwelling indices at the 15 standard locations for the western coast of North America. Upwelling indices are derived from the vertical velocity of the NCEP's global ocean data assimilation system, and are calculated as integrated vertical volume transport at 50 meter depth from each location to its nearest coast point ($m^3/s/100m$ coastline). Anomalies are departures from the 1982-2004 base period pentad means.

- 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 36ºN to 57ºN.

North America Western Coastal Upwelling





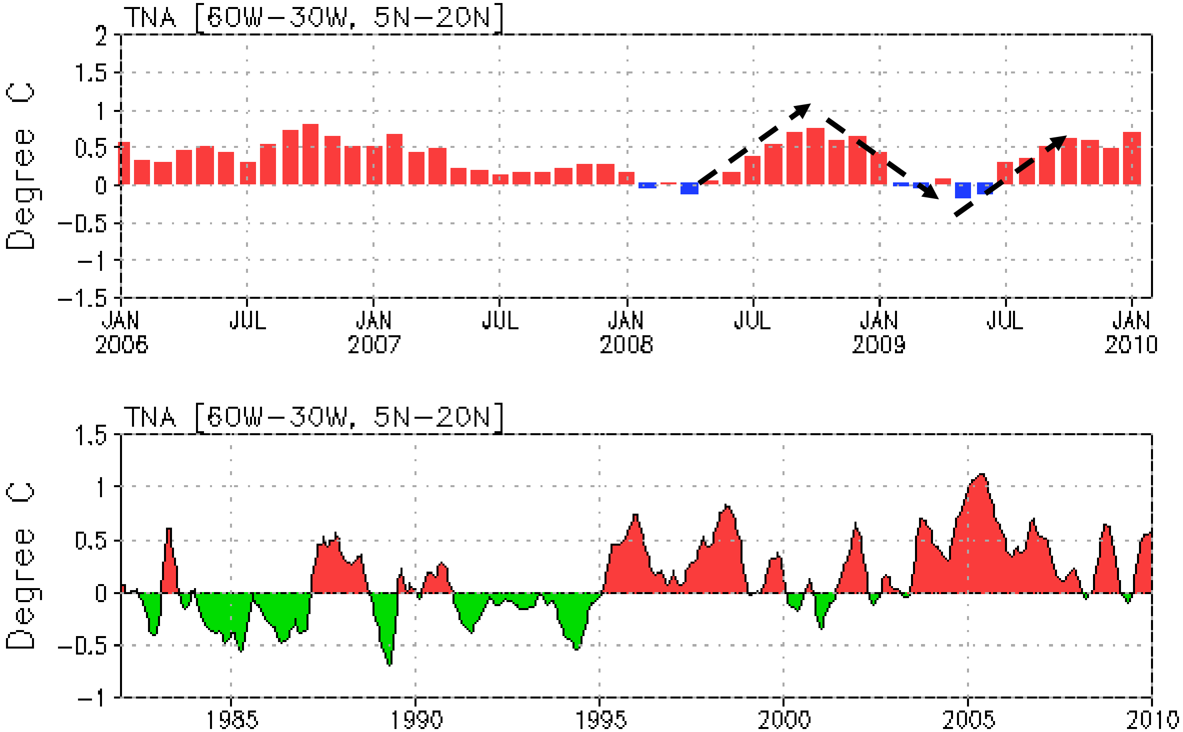
- Upwelling has been above-normal during the winter of 06/07, 07/08 and 08/09.

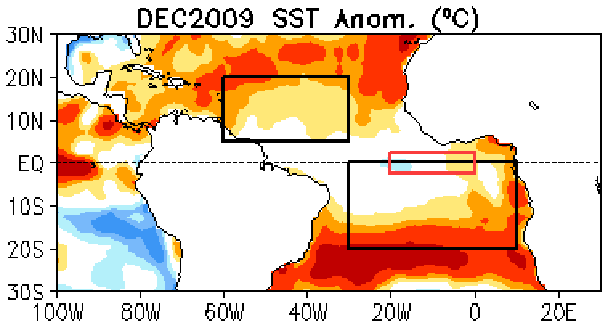
Fig. NP2. Total (top) and anomalous (bottom) upwelling indices at the 15 standard locations for the western coast of North America. Upwelling indices are derived from the vertical velocity of the NCEP's global ocean data assimilation system, and are calculated as integrated vertical volume transport at 50 meter depth from each location to its nearest coast point ($m^3/s/100m$ coastline). Anomalies are departures from the 1982-2004 base period pentad means.

- **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.**

Tropical Atlantic Ocean

TNA Index

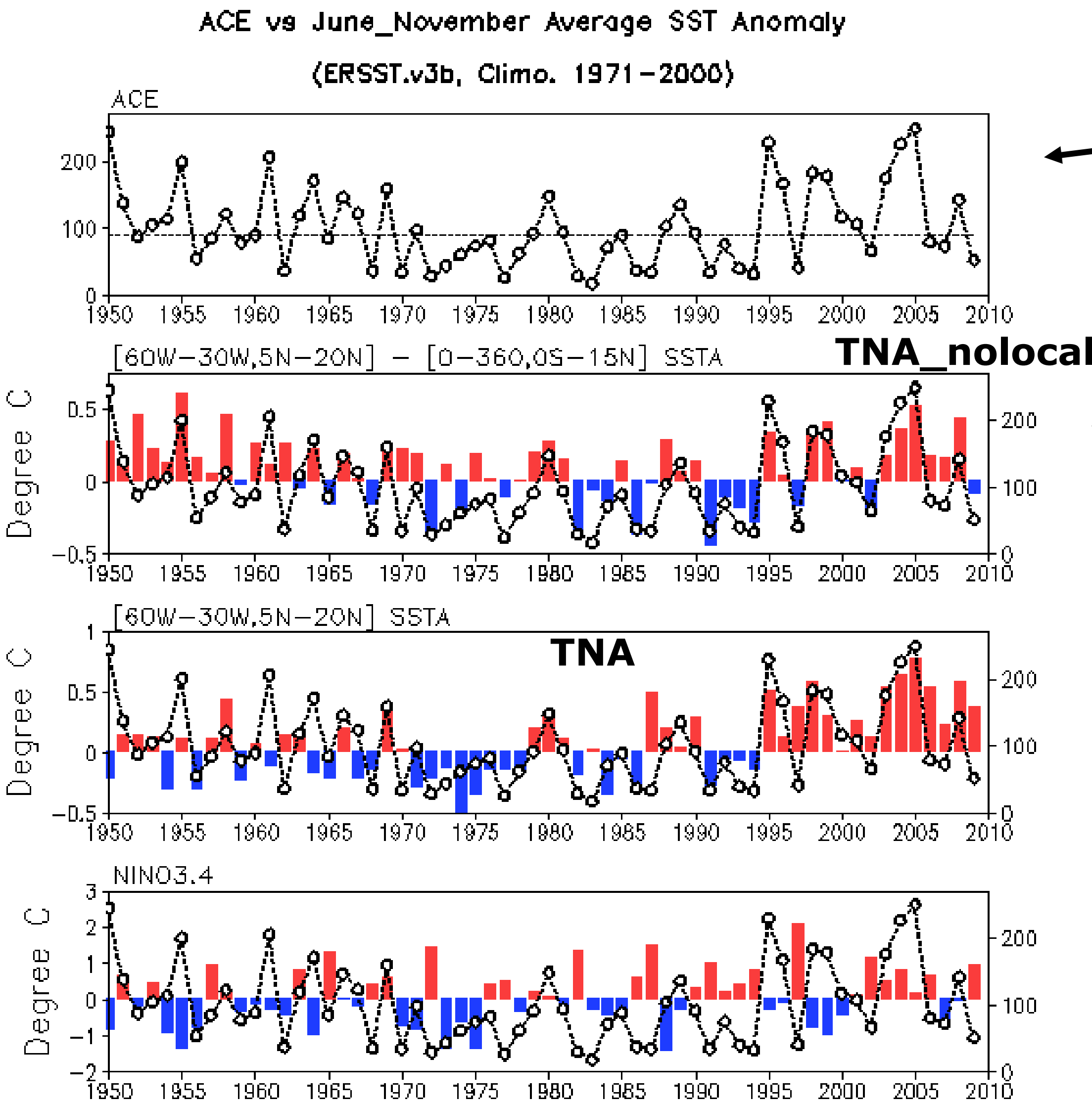




- **Tropical North Atlantic SST (TNA) cooled down rapidly in 2008/09 winter, was weakly below-normal in spring 2009, and then warmed up quickly in summer 2009;**

- **TNA was about 0.5°C above-normal during 2009 Atlantic hurricane season, similar to the 2006 and 2008 hurricane season.**

Atlantic Hurricane Activity & SST Anomaly



Accumulated Cyclone Energy (ACE) downloaded from http://en.wikipedia.org

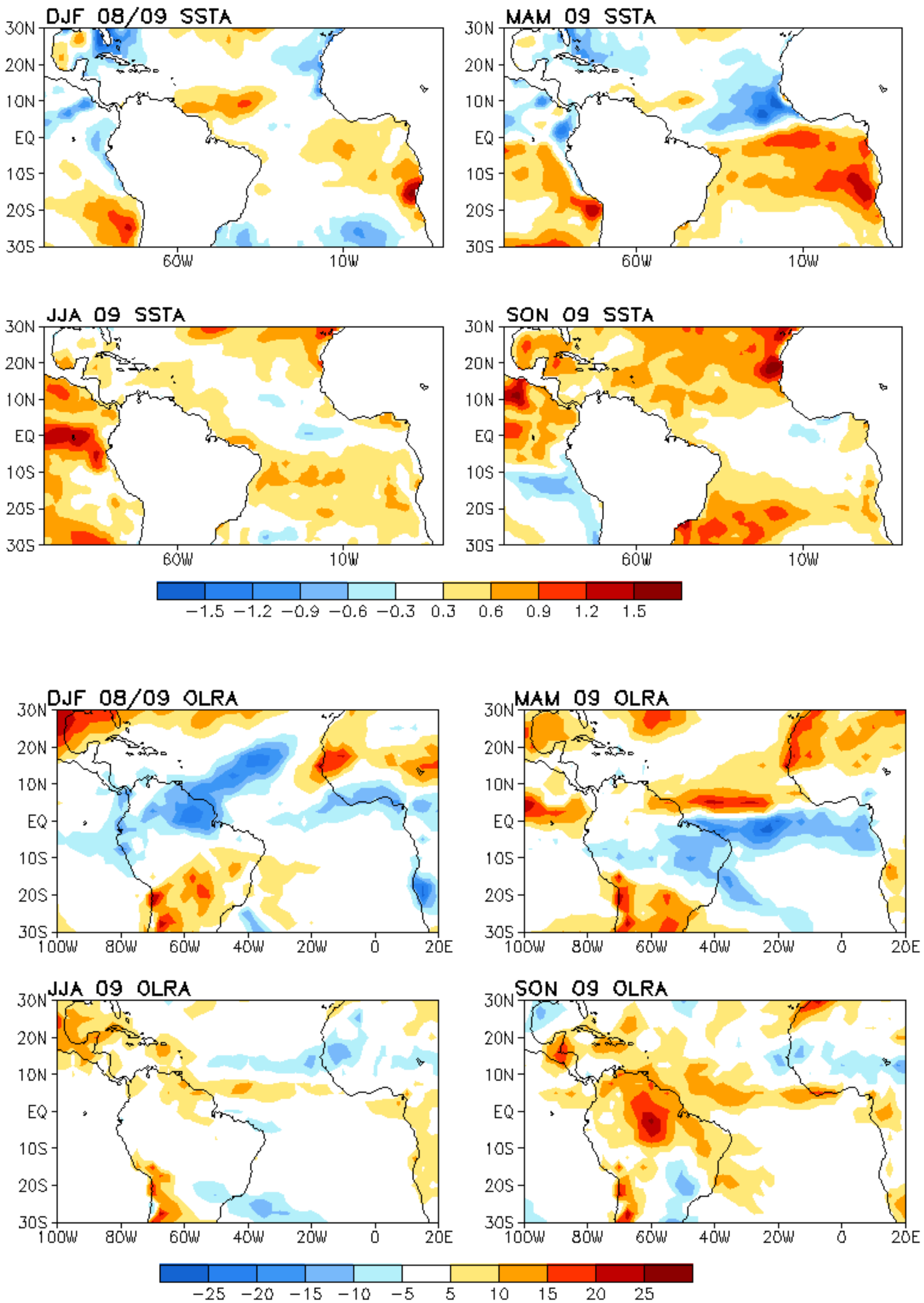
Non-local SST index:

Swanson (2008);

Vecchi & Soden (2007)

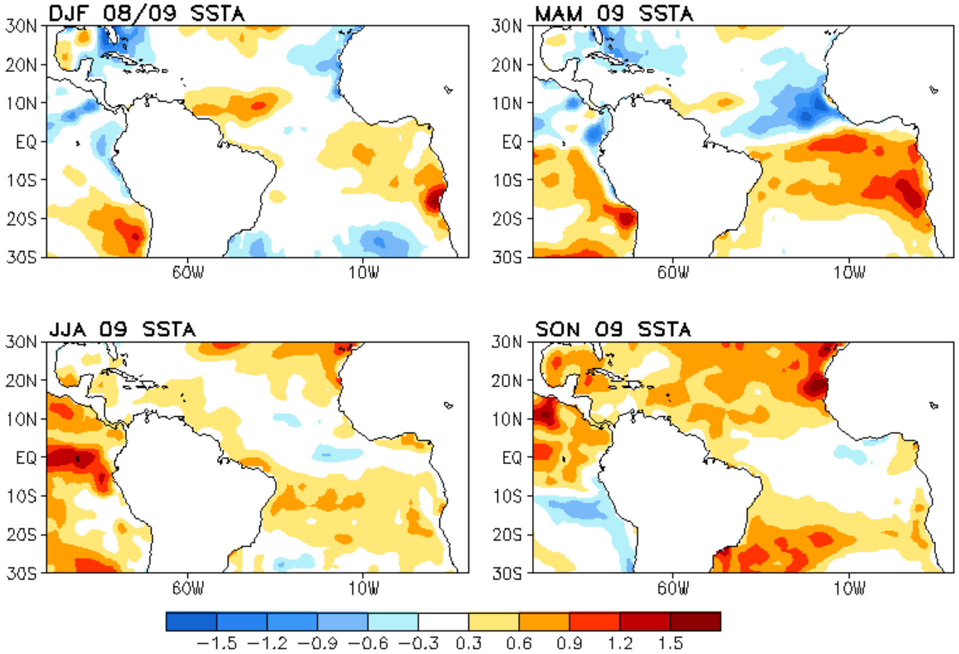
Correlation with ACE	
TNA_nolocal	0.62
TNA	0.40
NINO3.4	-0.15

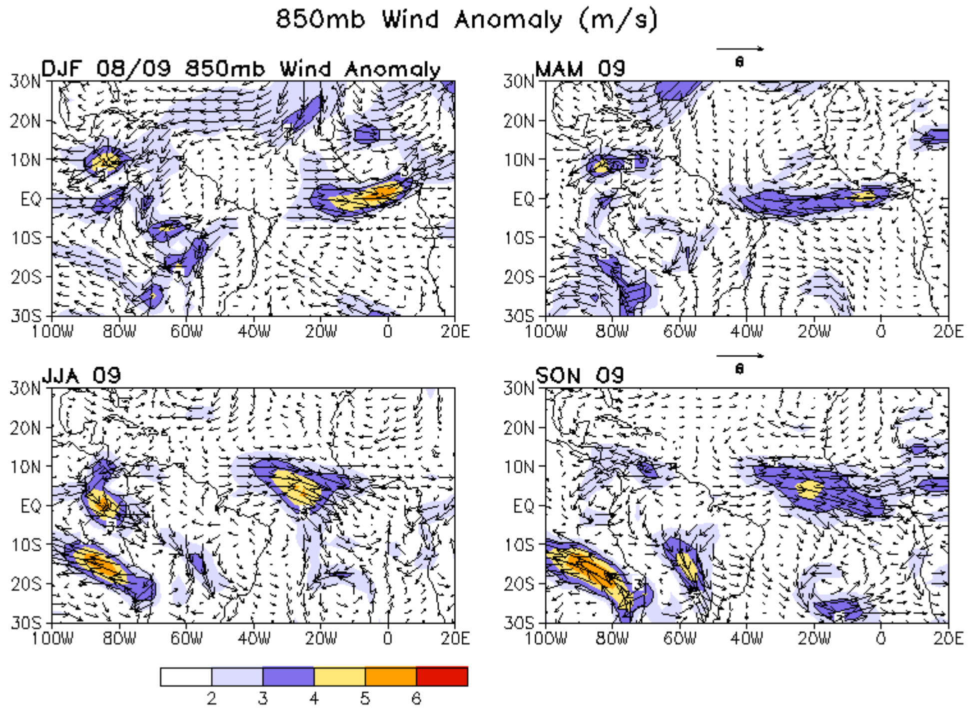
- TNA relative to the global tropical mean SSTA is a better index for explaining Atlantic hurricane activity than either TNA or NINO 3.4 alone.



Seasonal SST and OLR Anomaly

- DJF 08/09: SST was above-normal in the southeastern Atlantic and near-normal in tropical N. Atlantic. Enhanced convection extended from northern Brazil to tropical N. Atlantic;
- MAM 09: Tropical N. Atlantic cooled down (strong Amazon convection during winter might cause the cooling in tropical N. Atlantic, personal communication with David Enfield) and tropical S. Atlantic warmed up. Consistently, enhanced (suppressed) convection moved to south (north) of the equator
- JJA 09: Tropical N. Atlantic warmed up (related to negative NAO?), and equatorial Atlantic cooled down substantially, and Africa monsoon was above-normal;
- SON 09: Tropical N. Atlantic further warmed up and tropical S. Atlantic cooled down. Convection was suppressed over the Amazon basin, which might be associated with the 2009/10 El Nino.





Seasonal SST and 850mb Wind Anomaly

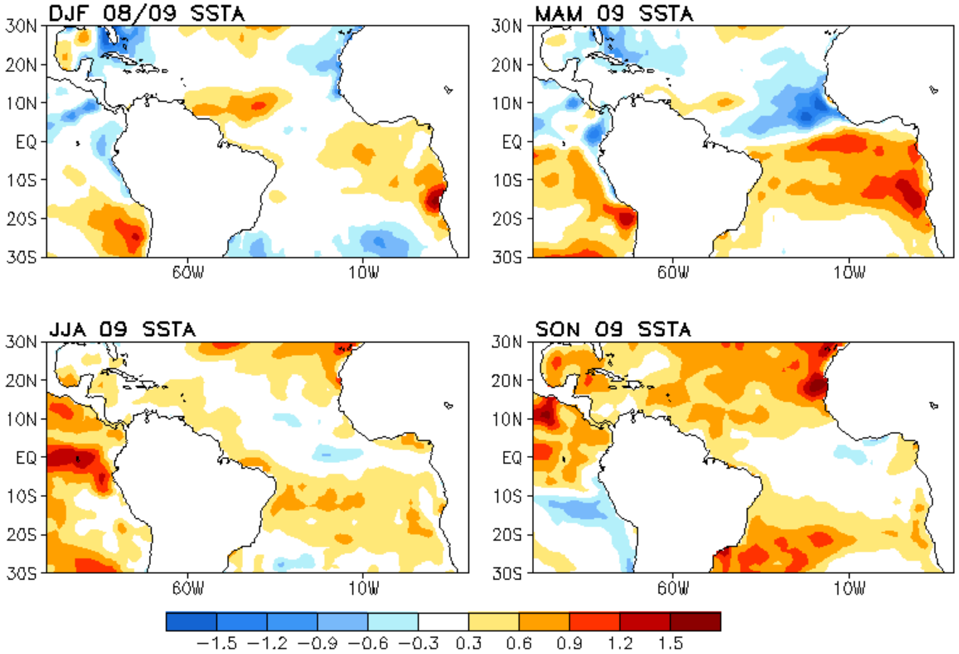
- DJF 08/09: Westerly wind anomaly might be associated with above-normal SST in southeastern Atlantic. Easterly wind anomaly in subtropical N. Atlantic appear associated with the La Nina conditions;

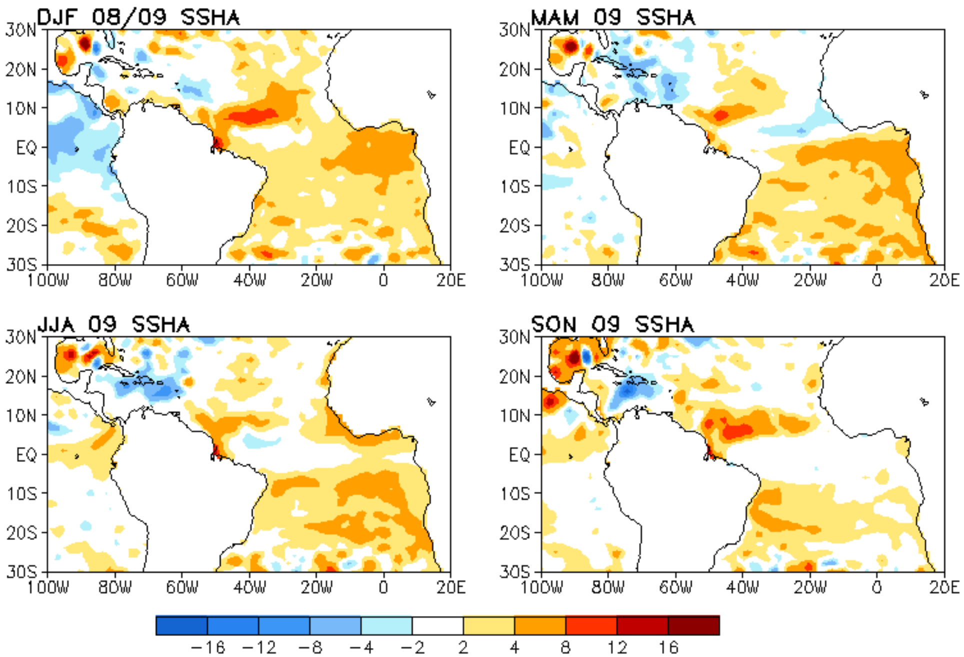
- MAM 09: Equatorial westerly wind anomaly was consistent with the above-normal SST along the equatorial Atlantic;

- JJA 09: Westerly wind anomaly moved to north of the equator, which was consistent with the above-normal Africa Monsoon;

- SON 09: Westerly wind anomaly moved eastward, extending into the continent of Africa.

Seasonal SST and SSH Anomaly

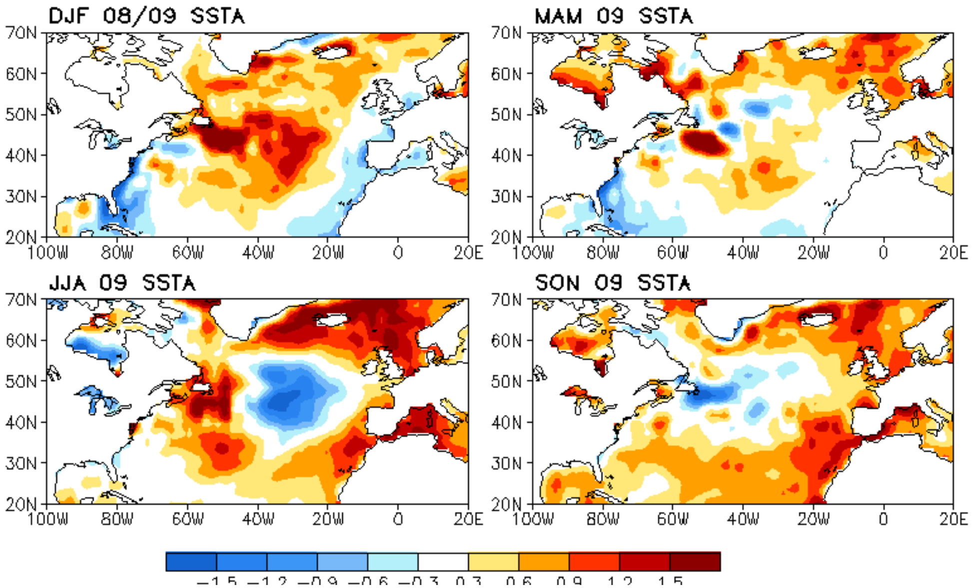


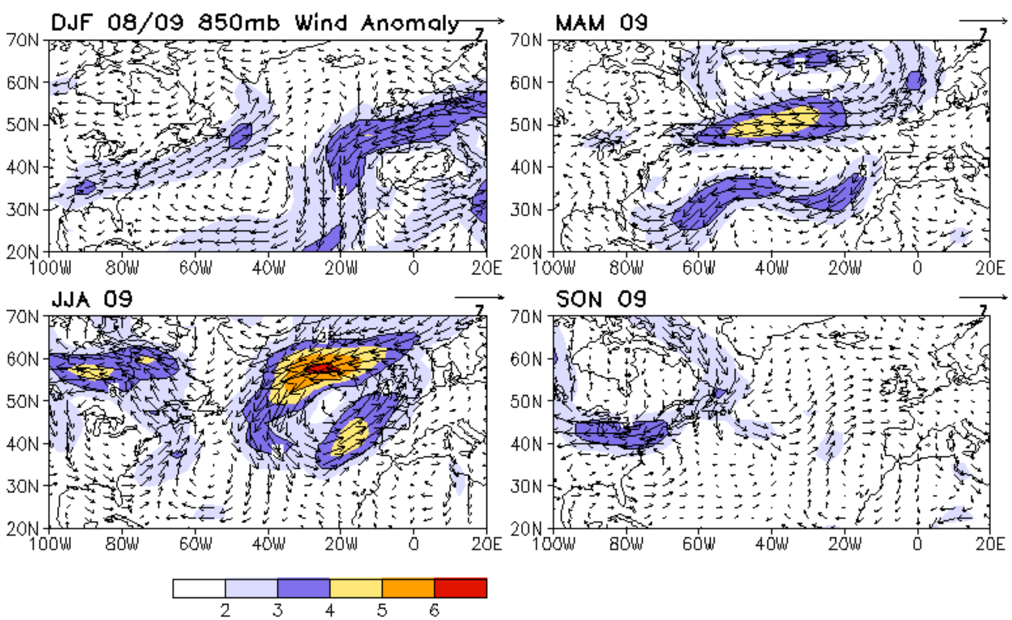


- DJF 08/09: Sea surface height (SSH) was above-normal in southeastern Atlantic, consistent with above-normal SST there;
- MAM 09: Positive SSH anomaly in the equatorial Atlantic was forced by westerly wind anomaly;
- JJA 09: Consistent with the shift of westerly wind anomaly to north of the equator, equatorial SSH decreased substantially;
- SON 09: SSH decreased in subtropical S. Atlantic, consistent with the cooling in SST.

North Atlantic Ocean

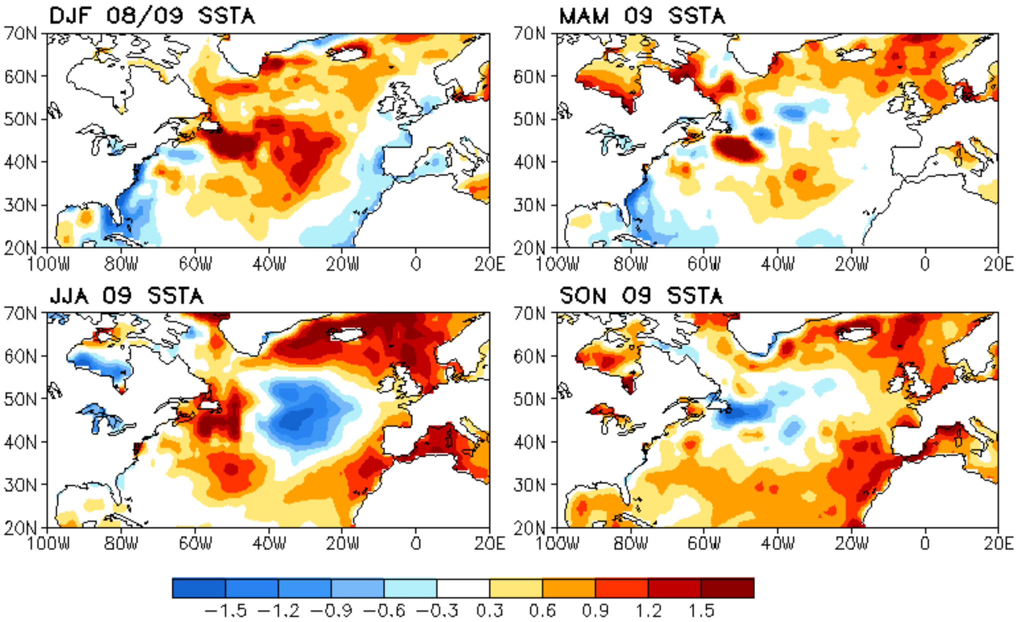
Seasonal SST and 850mb Wind Anomaly



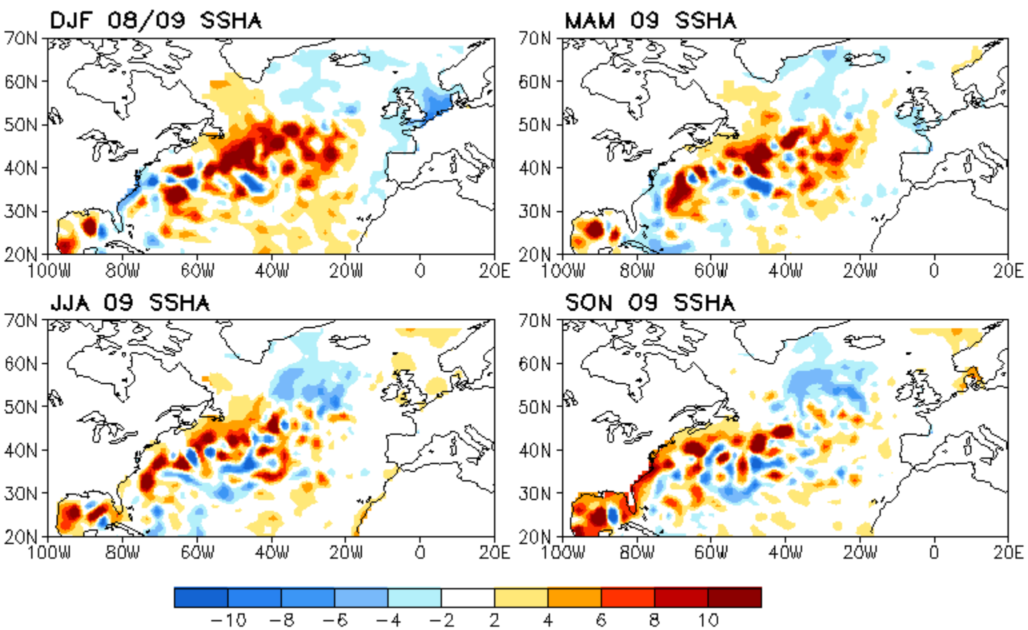


- **DJF 08/09: Above-normal SST presented in mid- and high-latitude N. Atlantic. Northerly wind anomaly caused cooling in SST near the coast of West Africa.**
- **MAM 09: SST cooled down substantially in midlatitude N. Atlantic, which was largely forced by strong westerly wind anomaly in the region;**
- **JJA 09: NAO became strongly negative, which favored a tripole SST pattern with a cooling near 40N and warming near 30N and 60N;**
- **SON 09: Weak westerly wind anomaly centered at 40N help maintain the below-normal SST in central N. Atlantic.**

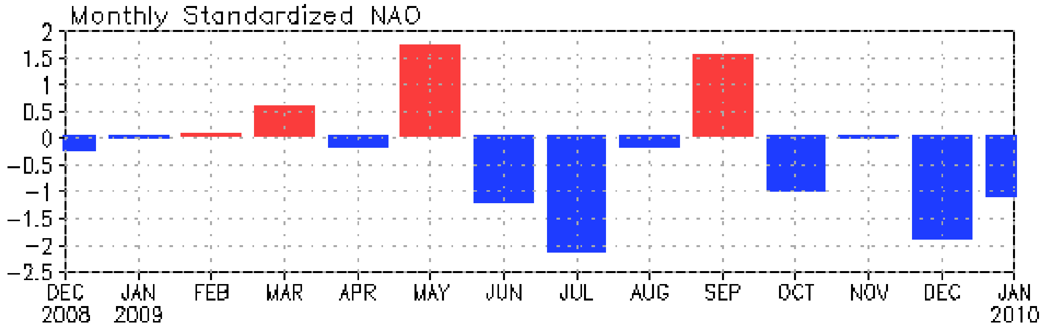
Seasonal SST and 850mb Wind Anomaly

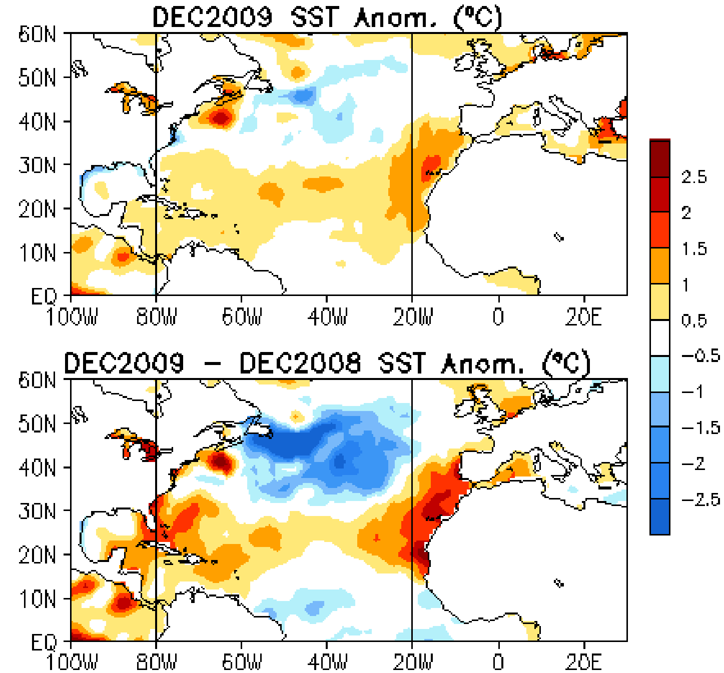


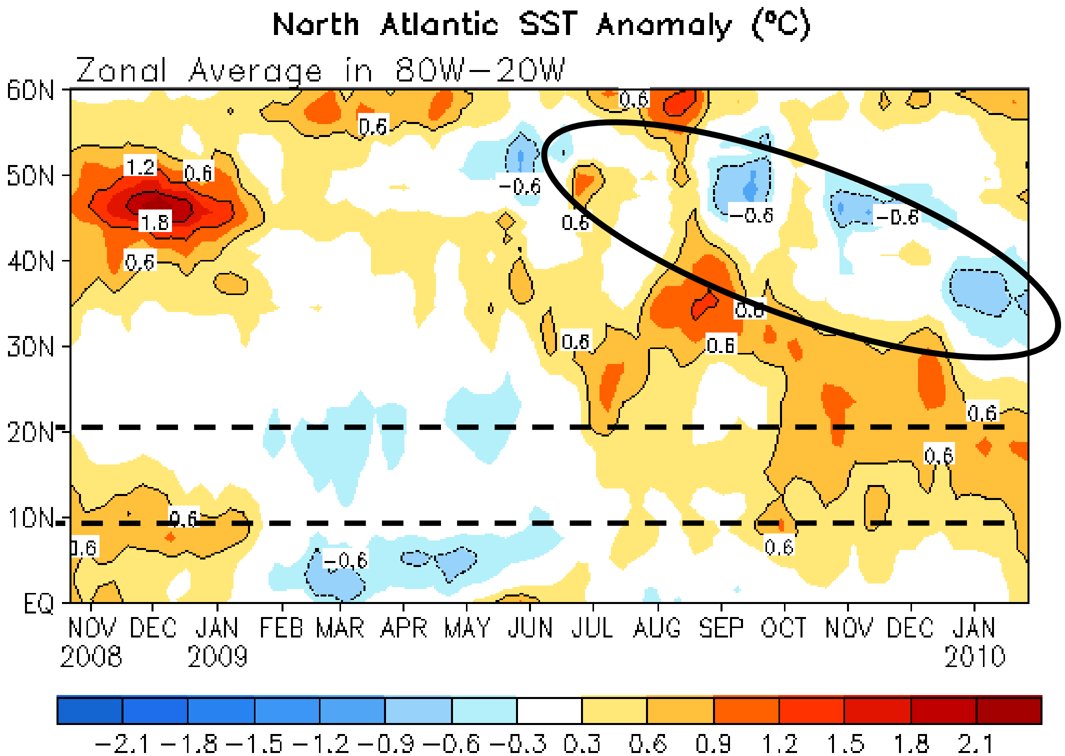
- Sea surface height (SSH) was above-normal (below-normal) in midlatitude (highlatidue) N. Atlantic, indicating an enhanced subtropical gyre and subpolar gyre;
- Subpolar (subtropical) gyre strengthened (weakened) during summer 2009;



NAO and SST Anomaly in North Atlantic



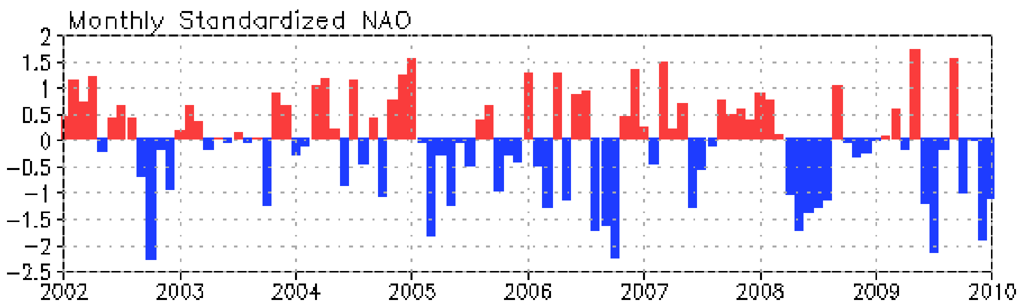


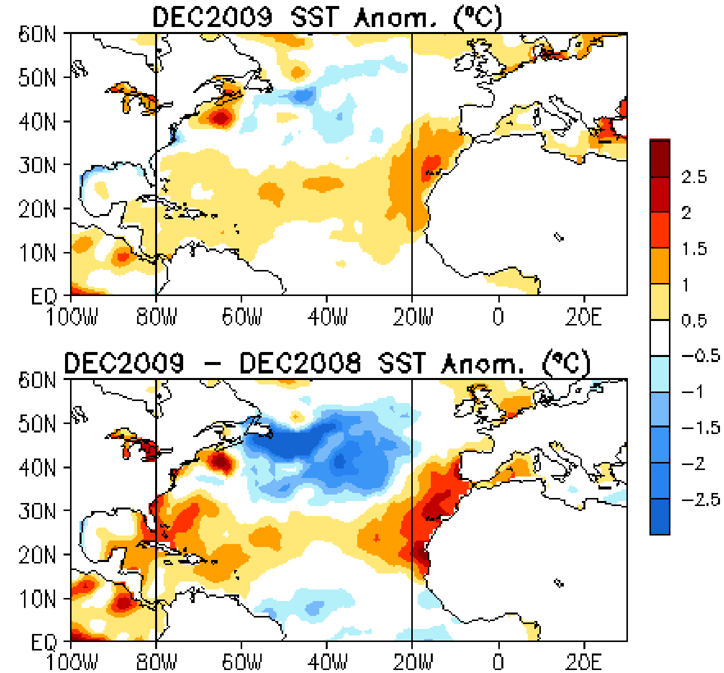


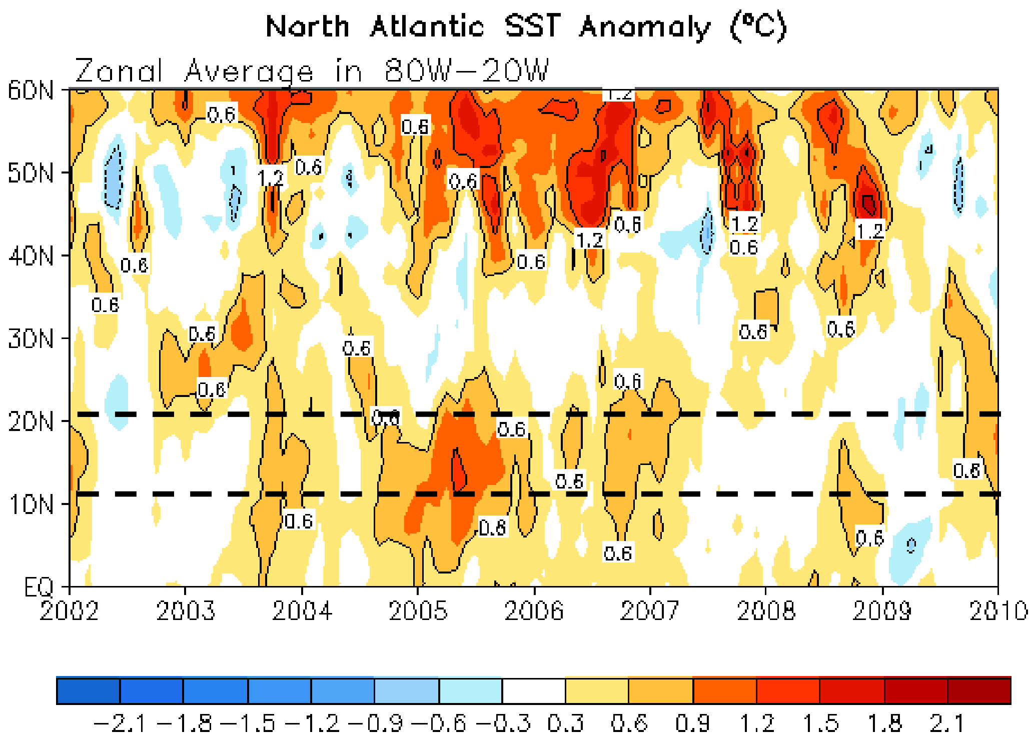
- **High-latitude North Atlantic SSTs cooled down and became slightly below-normal since May 09.**
- **Negative SST anomaly persisted and shifted gradually southward;**
- **SST in the Hurricane Main Development Region was weakly above-normal in summer/fall 09, similar to that last year.**

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 1971-2000 base period means.

NAO and SST Anomaly in North Atlantic







- **North Atlantic SST was the coolest since 2002;**
- **NAO has the lowest summer value during the period.**

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 1971-2000 base period means.

Conclusions

- **A series of westerly wind bursts and downwelling oceanic Kelvin waves contributed to the development and strengthening of the 2009/10 El Nino, which reached a strong strength in early winter and in boreal winter had maximum warming in the central Pacific;**
- **Persistent negative PDO transitioned to a positive phase;**
- **Tropical Indian SST in 2009 was the second warmest behind the record warming in 1998;**
- **Despite of above-normal SST in tropical North Atlantic, Atlantic hurricane activity was below – normal, suggesting impacts of the 2009/10 El Nino on hurricane activity dominated;**
- **North Atlantic Ocean was the coolest year since 2002, which is probably attributable to strong negative NAO during summer and subsequent winter.**

Data Sources and References

- **Optimal Interpolation SST (OI SST) version 2 (Reynolds et al. 2002)**
- **Merged Land-Ocean Surface Temperature Analysis (ERSST v3b, Smith et al. 2008)**
- **SST 1971-2000 base period means (Xue et al. 2003)**
- **NCEP/NCAR CDAS winds, surface radiation and heat fluxes**
- **NESDIS Outgoing Long-wave Radiation (OLR)**
- **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 (SSH)**
- **Ocean Surface Current Analyses – Realtime (OSCAR)**

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