2011 Annual Ocean Review

Prepared by

Climate Prediction Center, NCEP

February 8, 2012

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 Climate Observation Division (COD)

Global SST Anomaly in 2011

- The 2011 SST anomaly (SSTA) was characterized by reemergence of second year La Nina since August 2011, strengthening of negative PDO in the second half of 2011, development of positive Indian Ocean Dipole in fall 2011, and above-normal SST in tropical N. Atlantic and mid-latitude southern oceans.

- The 2011 minus 2010 SSTA shows a substantial cooling (more than 0.6^{o}C) near Maritime Continent and NW Pacific, central tropical Pacific, tropical Atlantic, subpolar North Atlantic, and a significant warming (more than 1^{o}C) in central North Pacific.

- The 2011/12 La Nina was established in August 2011 and reached weak-to-moderate strength in winter 2011/12, and was weaker than the 2010/2011 La Nina.

- Negative PDO less than -1 standard deviation has persisted since Jul 2010.

- Tropical Indian Ocean SST was below-normal in early 2011 due to remote influences of the 2010/11 La Nina. Positive SSTA developed in spring/summer 2011, and strengthened in fall 2011, connected with positive Indian Ocean Dipole conditions in Jul-Oct 2011.

Xue et al. (2012) to appear in the BAMS State of the Climate in 2011

Historical Perspective of 2011 SST Anomaly

- The tropical Pacific SST became below-normal in 2011 and was the coolest since 2000, partially attributed to the cooling influences of the 2011/12 La Nina.

- The tropical Indian Ocean SST reached a historical high in 2010, and cooled by 0.24°C from 2010 to 2011.

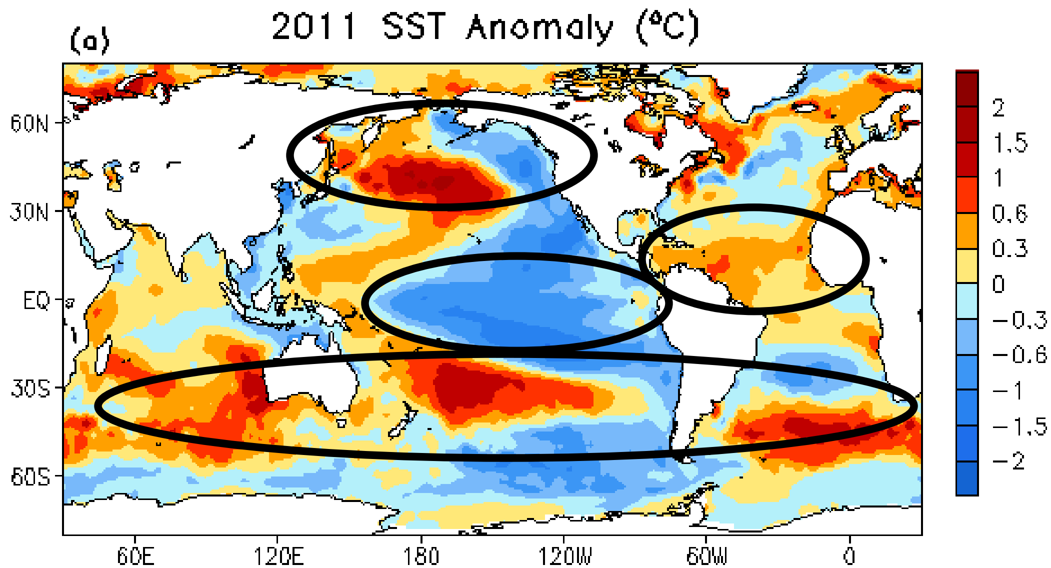
- The tropical Atlantic SST reached a historical high in 2010, and cooled by 0.33°C from 2010 to 2011.

- The North Pacific SST increased slightly, while the North Atlantic SST continued a downward trend since 2006.

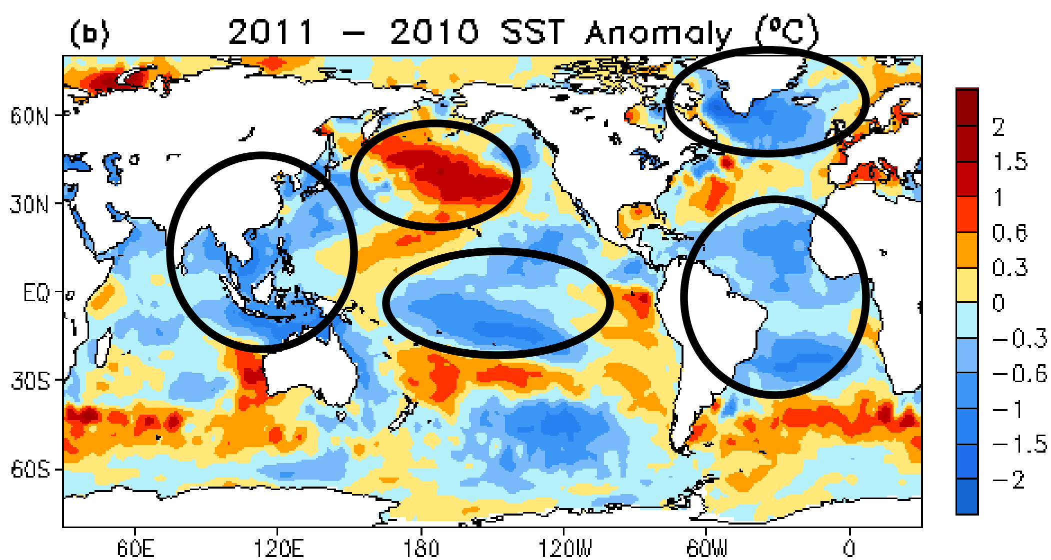
- The global SST was near the peak value in 2009-2010, and cooled by 0.1°C from 2010 to 2011, associated with cooling influences of the 2010-2012 La Nina.

Xue et al. (2012) to appear in the BAMS State of the Climate in 2011

2011 Yearly Mean SST Anomaly and Tendency

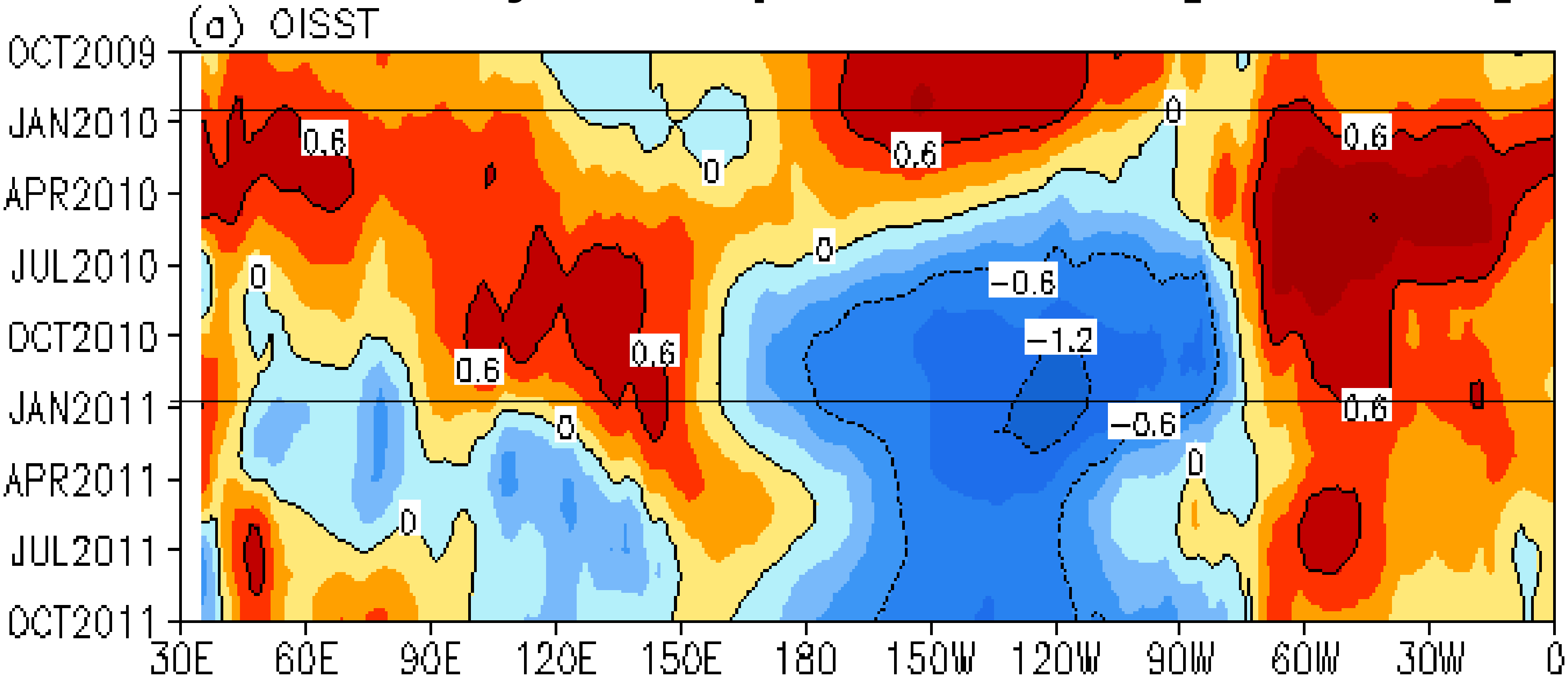


- The 2011 SSTA was dominated by La Nina conditions in the tropical Pacific, negative phase of PDO in N. Pacific, positive phase of Indian Ocean Dipole in fall 2011, and above-normal SST in tropical N. Atlantic and mid-latitude southern oceans.

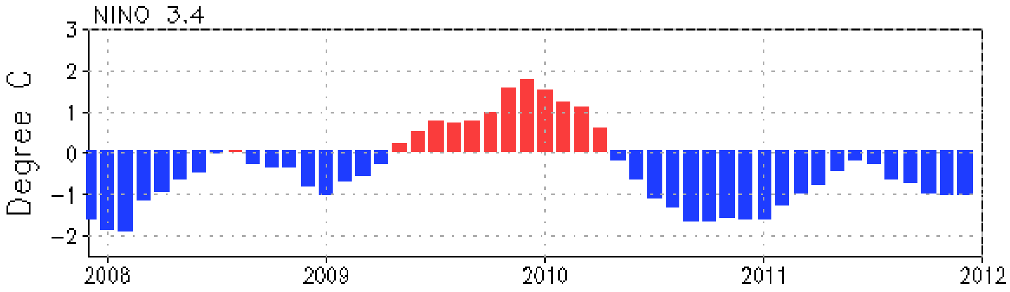


- The 2011 minus 2010 SSTA shows a substantial cooling (more than 0.6C) near Maritime Continent and NW Pacific, central tropical Pacific, tropical Atlantic, and subpolar N. Atlantic, and a significant warming (more than 1C) in central N. Pacific.

SST Anomaly in Tropical Oceans [20S-20N]



- Under remote influences of the 2009/10 El Nino, SST in the tropical Indian and Atlantic Ocean warmed up substantially during the winter 2009/10 and early spring 2010.
- The 2010/11 La Nina initiated around Jun 2010, coincident with warming up of SST near the Maritime Continent.
- Following the peak of the 2010/11 La Nina, SST in the tropical Indian and Atlantic Ocean cooled down in spring 2011 due to remote influences of La Nina.
- The second year La Nina emerged in Aug 2011, reaching the peak phase in the winter 2011/2012.
- Positive SSTA emerged in the western and central tropical Indian Ocean in summer/fall 2011, which combines with negative SSTA in the southeast tropical Indian Ocean to form positive Indian Ocean Dipole conditions during JASO 2011.
- There were clear propagations of the anomalies from Indian Ocean to the Central and western Pacific.

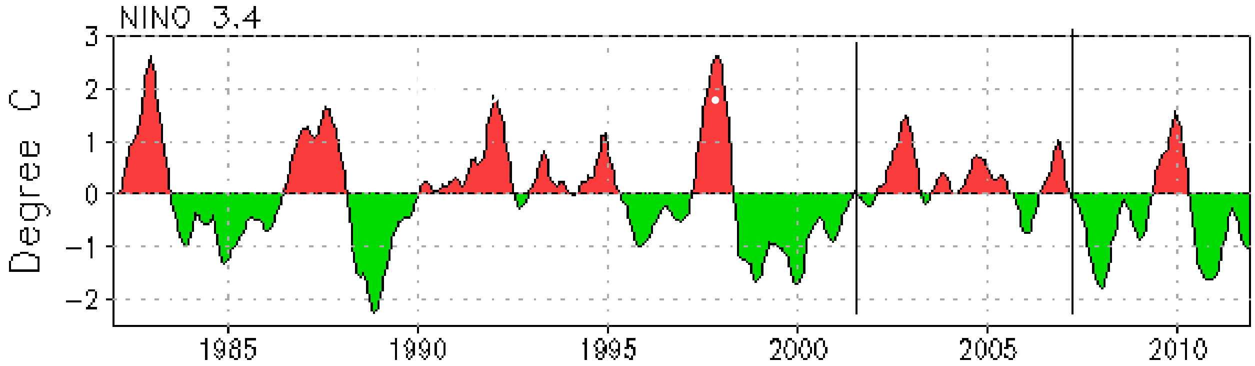


NINO3.4 SST Index

- The definition of ENSO is keyed on the NINO3.4 Index.

- La Nina is referred to as NINO3.4 =< -0.5ºC.

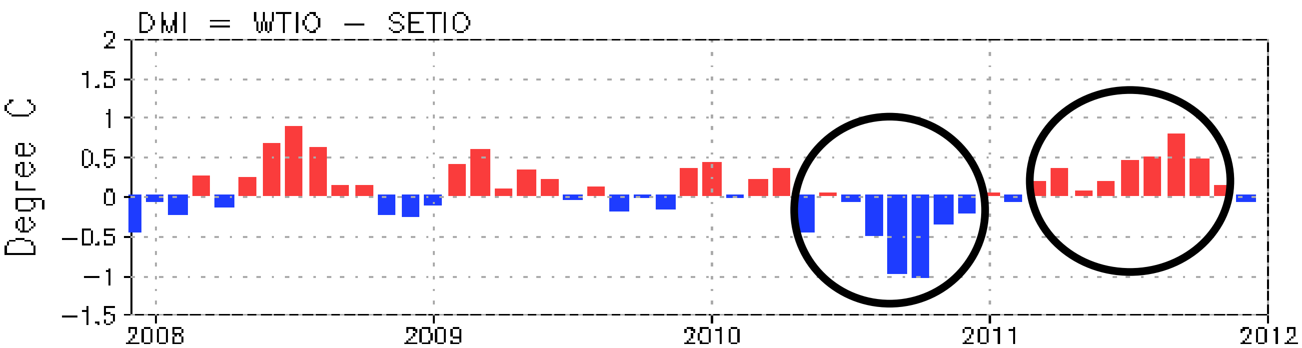
- The 2010/11 La Nina started in June 2010 and the second year La Nina re-emerged in Aug 2011.



- The 2010-2012 La Nina cycle has a similar strength and duration to the 2007-2009 La Nina.

- During 2007-2012, there were three La Nina winters, one El Nino winter and one ENSO-neutral winter, while during 2002-2006 there were three El Nino winters and two ENSO-neutral winters (see CPC's official ENSO events at http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

DMI Index

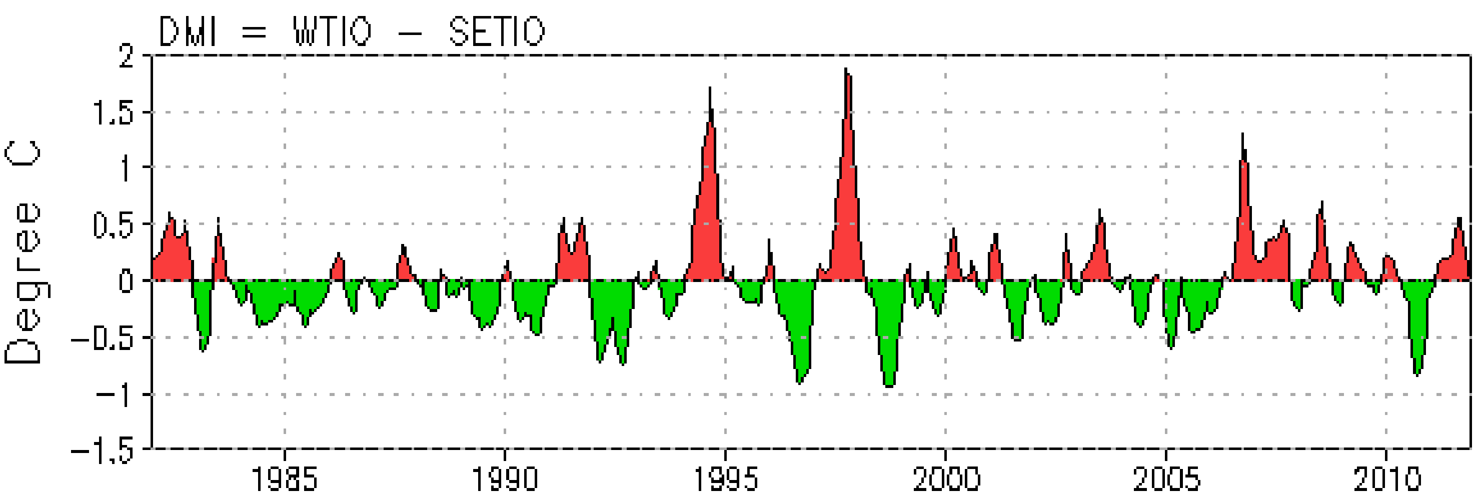


DMI = WTIO- SETIO

SETIO = SST anomaly in [90ºE-110ºE, 10ºS-0]

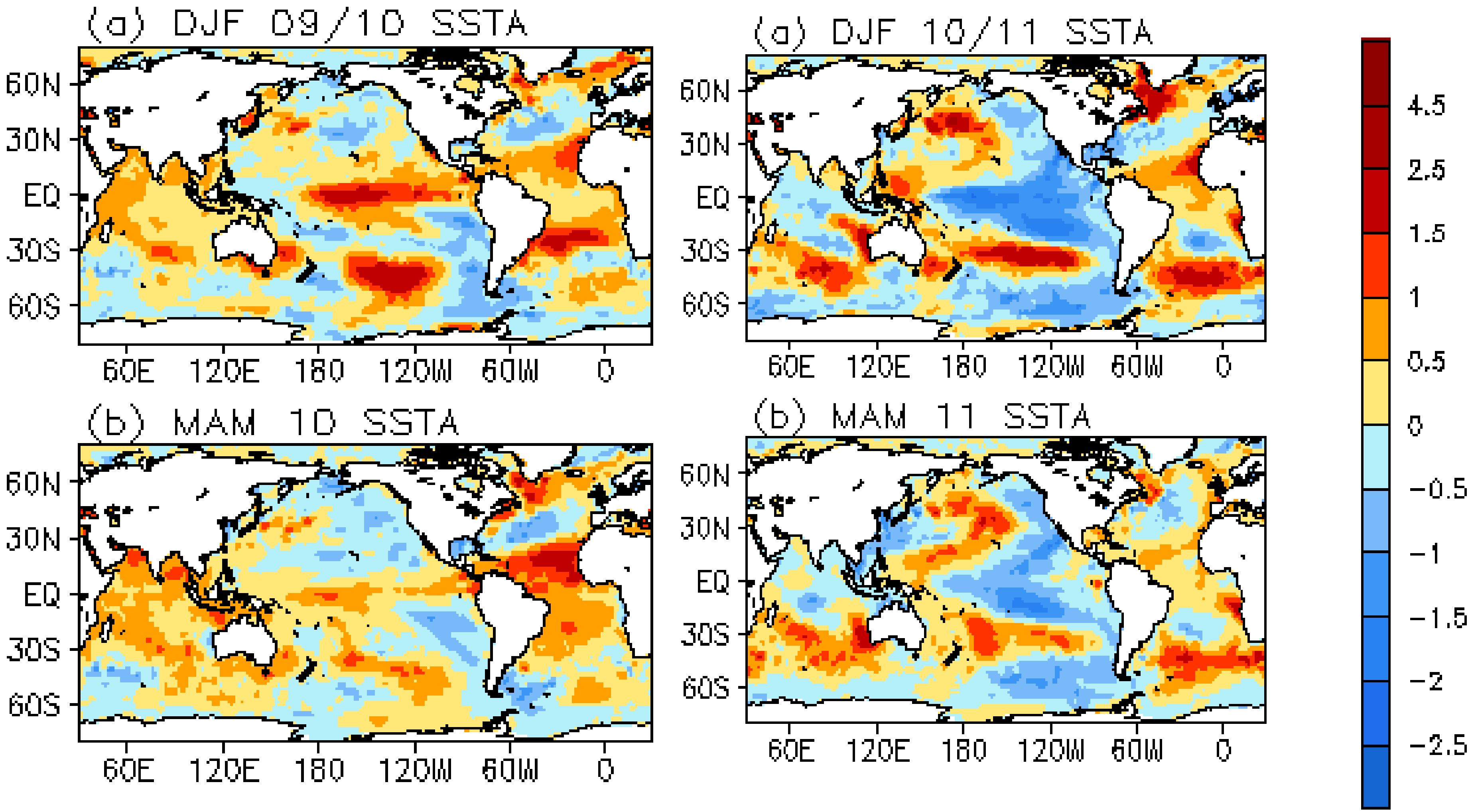
WTIO = SST anomaly in [50ºE-70ºE, 10ºS-10ºN]

- **DMI=+0.56ºC in Aug-Oct 2011, indicating positive IOD conditions.**
- **DMI=-0.83 ºC in Aug-Oct 2010, indicating negative IOD conditions.**



- **Positive IOD conditions dominated since 2006.**

Winter/Spring SST Anomaly: 2010 vs. 2011



Winter

2009/10: El Nino, warm trop. Indian Ocean, warm trop. Atlantic.

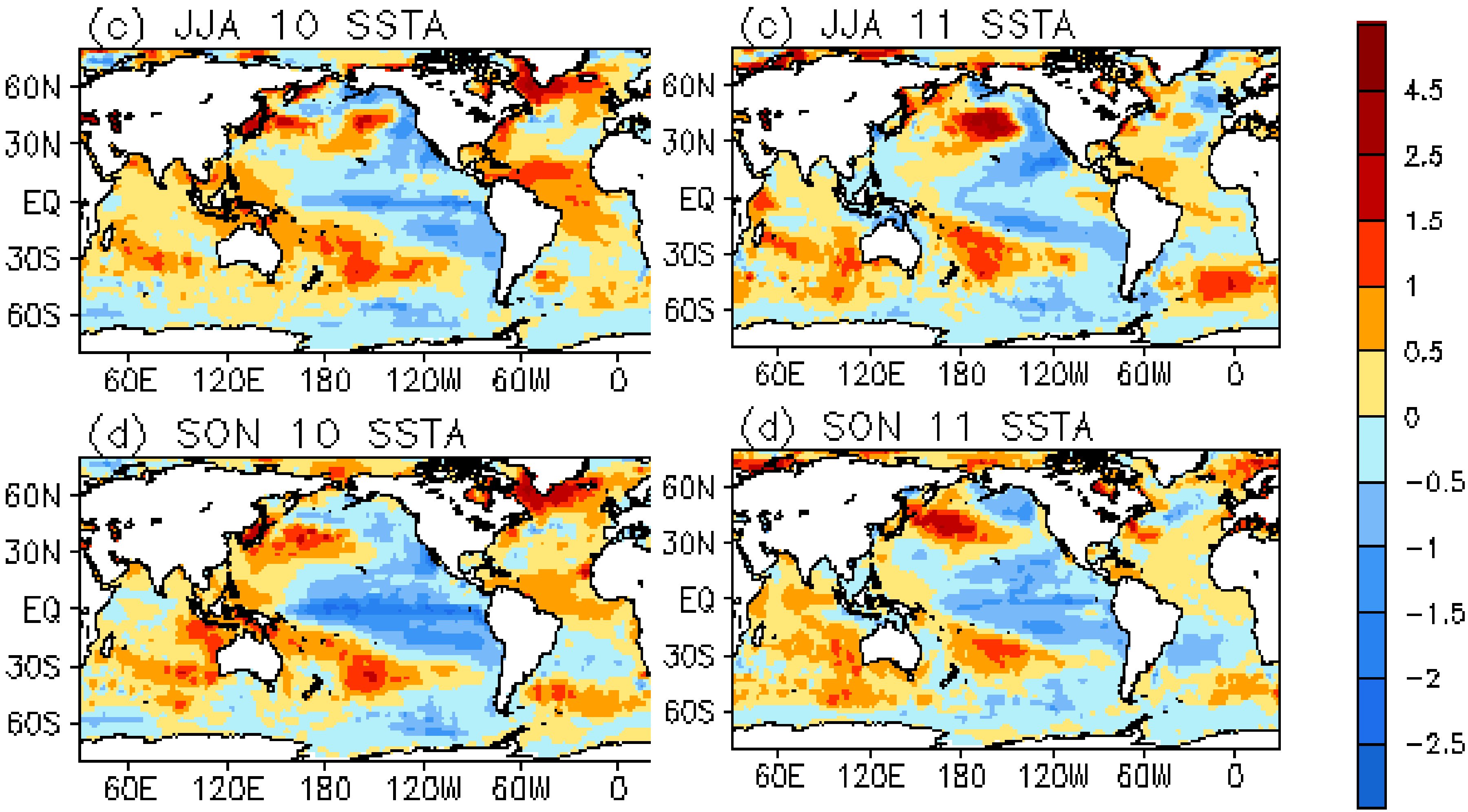
2010/11: La Nina, negative PDO, cool trop. Indian Ocean, warm trop. Atlantic.

Spring

2010: ENSO-neutral, warm trop. Indian Ocean, warm trop. Atlantic.

2011: La Nina, negative PDO, cool trop. Indian Ocean, warm trop. Atlantic.

Summer/Fall SST Anomaly: 2010 vs 2011



Summer

2010: La Nina, Negative PDO, warm trop. Indian Ocean, warm trop. Atlantic.

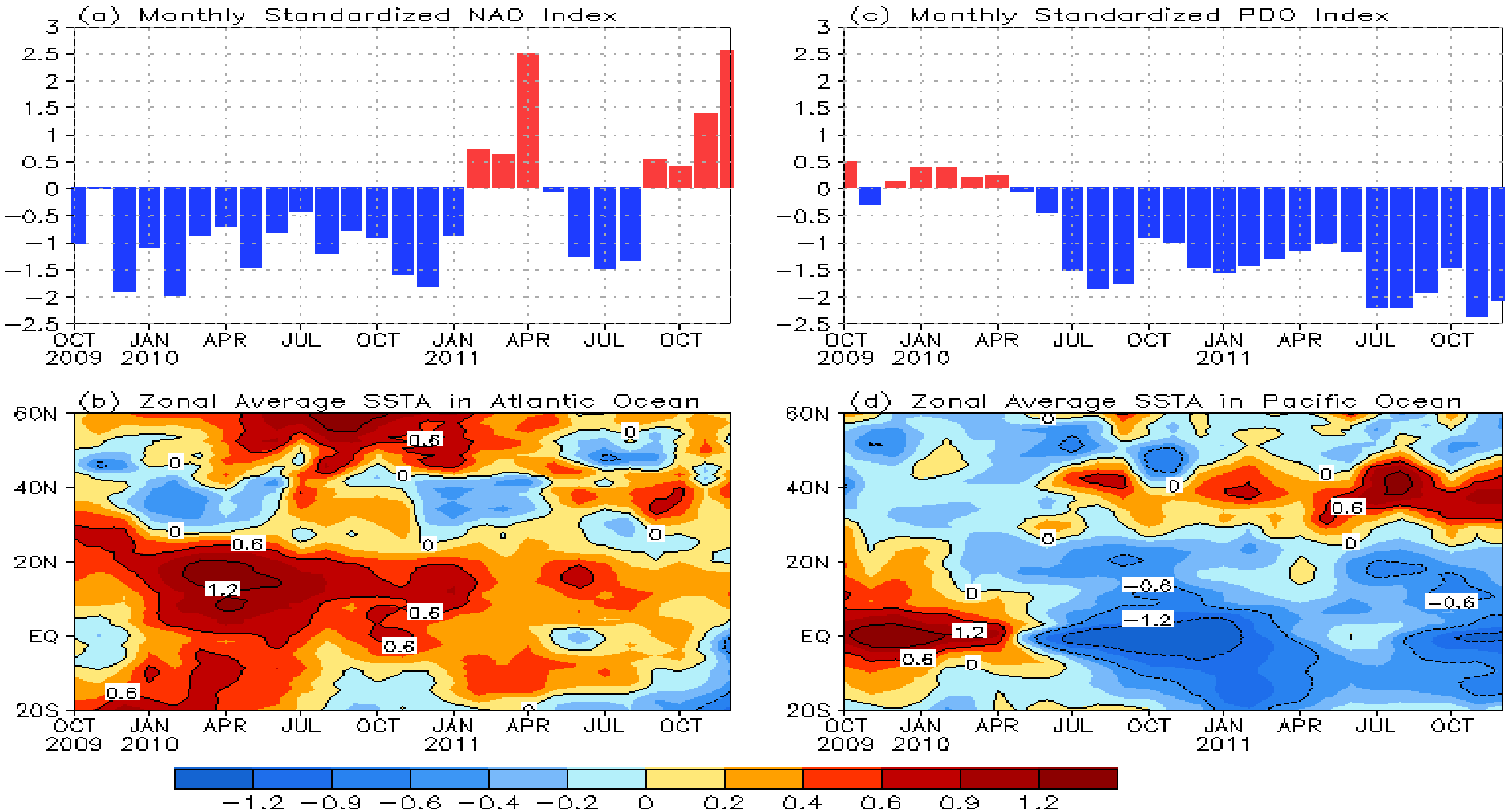
2011: ENSO-neutral, negative PDO, warm trop. Indian Ocean, warm trop. Atlantic.

Fall

2010: La Nina, Negative PDO, Negative IOD, warm trop. Atlantic.

2011: La Nina, negative PDO, Positive IOD, warm trop. Atlantic.

SST Anomaly in North Atlantic and North Pacific



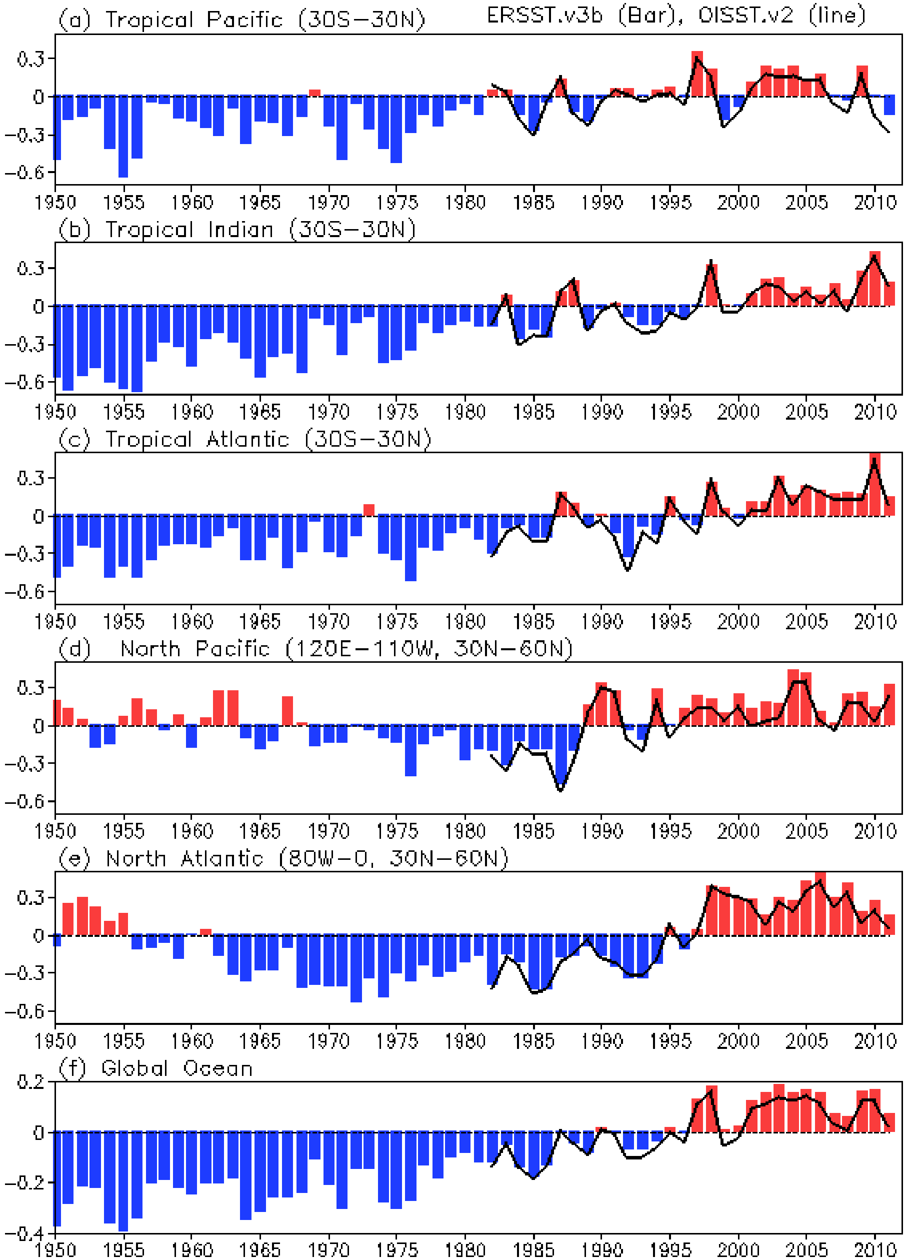
- SST was 1.2C above-normal in tropical N. Atlantic in spring 2010, attributed to the warming influences of the 2009/10 El Nino, persistent negative NAO and warming trend (Hu et al. 2011).

- SST in subtropical and high-latitude N. Atlantic in 2011 was much cooler than that in 2010, which might be attributed to the cooling influences of the 2010/11 La Nina and positive NAO in spring and fall 2011.

- Negative phase of PDO emerged in Jun 2010 in phase with the onset of the 2010/11 La Nina.

- The negative phase of PDO strengthened in Jul 2011 one month earlier than the emerge of the second year La Nina in Aug 2011.

Yearly Mean SST Anomaly Indices



-The tropical Pacific SST became below-normal in 2011 and was the coolest since 2000, partially attributed to the cooling influences of the 2011/12 La Nina.

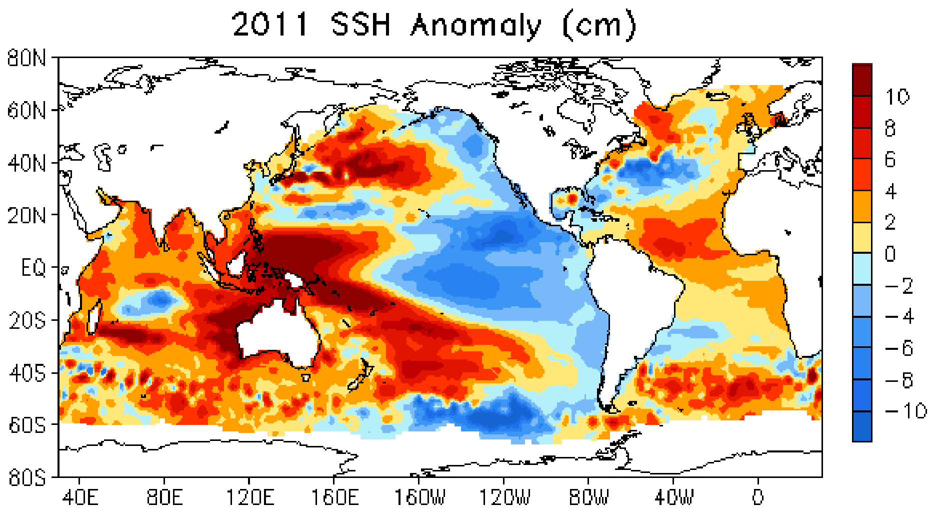
- The tropical Indian Ocean SST reached a historical high in 2010, and cooled by 0.24°C from 2010 to 2011.

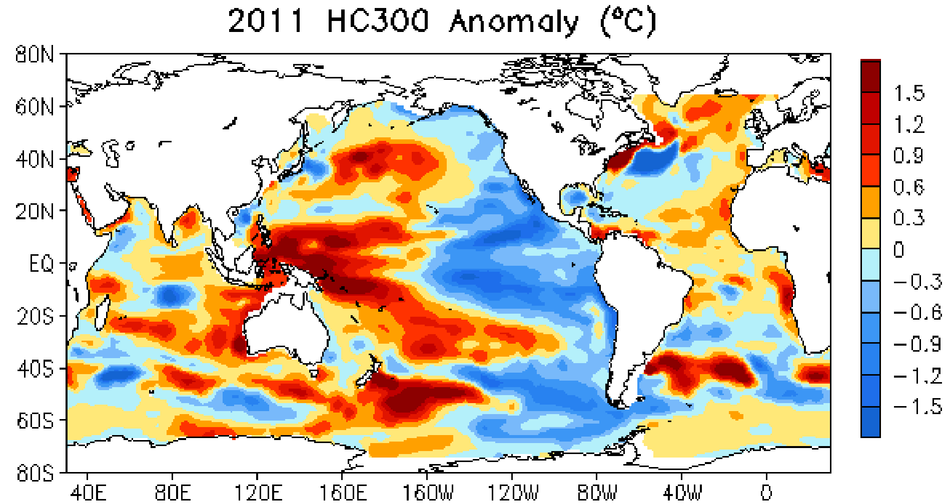
- The tropical Atlantic SST reached a historical high in 2010, and cooled by 0.33°C from 2010 to 2011.

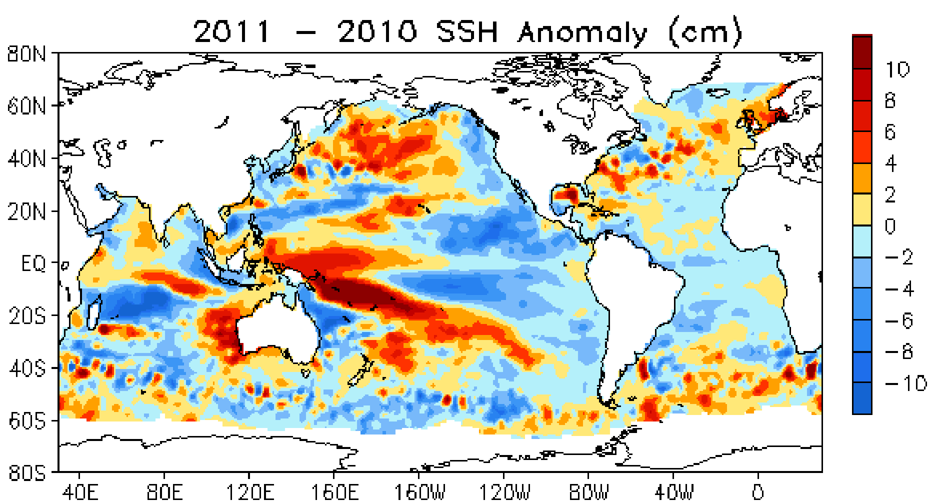
-The North Pacific SST increased slightly, while the North Atlantic SST continued a downward trend since 2006.

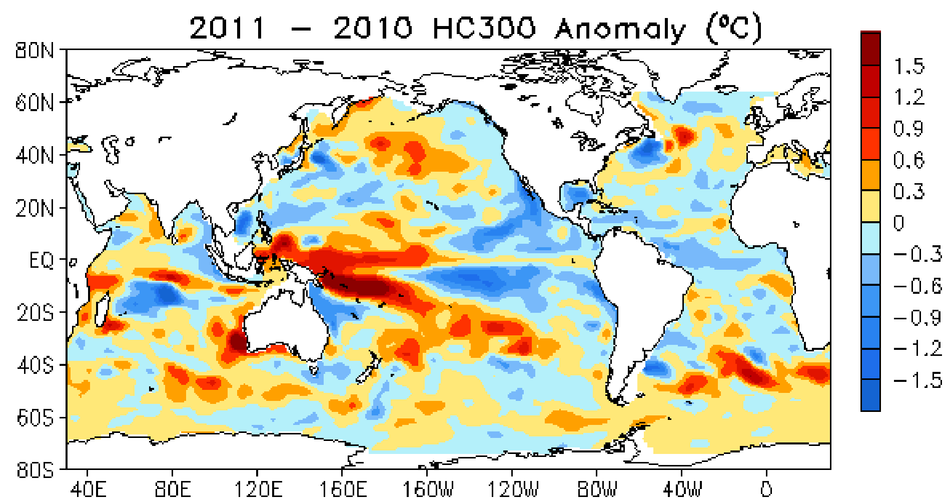
-The global SST was near the peak value in 2009-2010, and cooled by 0.1°C from 2010 to 2011, associated with cooling influences of the 2010-2012 La Nina.

2011 Yearly Mean SSH / HC300 Anomaly and Tendency



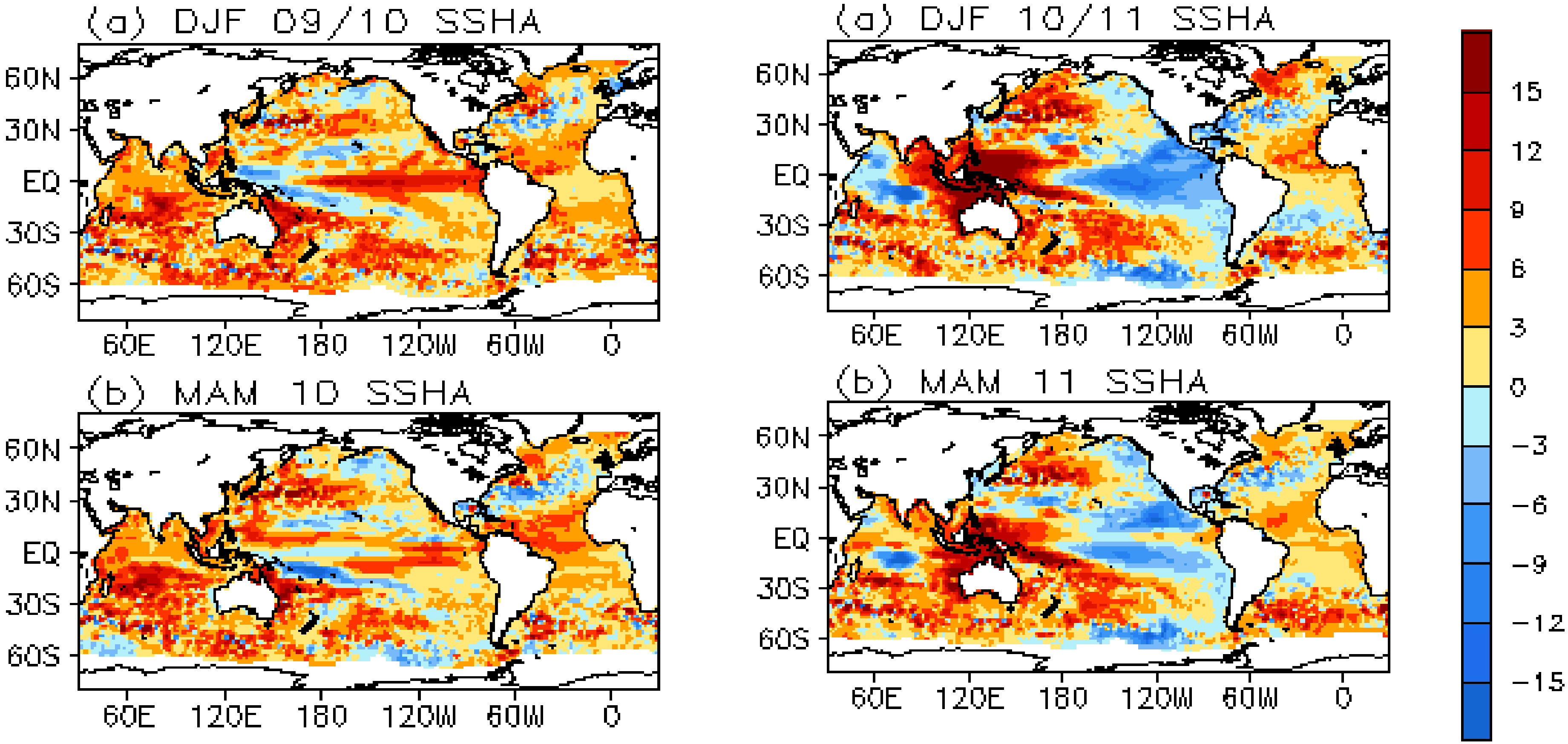






- **The 2011 SSHA was dominated by dipole pattern of La Nina conditions in the tropical Pacific, negative PDO in N. Pacific, above-normal SSH in tropical Indian Ocean, and tripole pattern in N. Atlantic. HC300 anomaly is consistent with SSH anomaly except in the tropical Indian Ocean.**
- **The 2011 minus 2010 SSHA shows dipole pattern of La Nina conditions in the tropical Pacific, negative PDO in N. Pacific, positive IOD pattern in the tropical Indian Ocean, and below-normal SSH in the tropical Atlantic . HC300 anomaly tendency is consistent with SSH anomaly tendency.**

Winter / Spring SSH Anomaly: 2010 vs 2011



Winter

2009/10: El Nino, negative PDO, above-normal SSH in trop. Indian Ocean and trop. Atlantic.

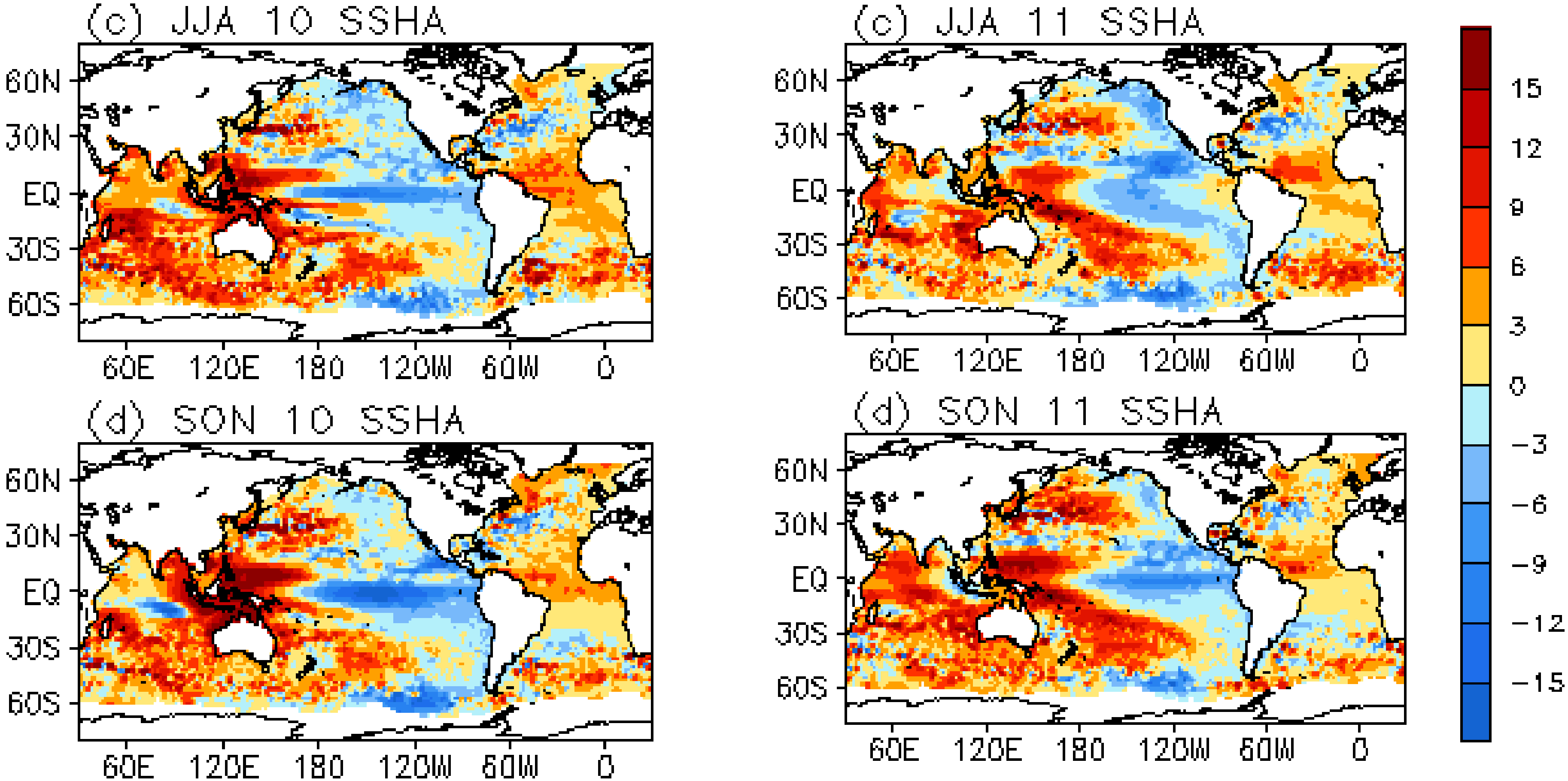
2010/11: La Nina, negative PDO, negative IOD pattern, above-normal SSH in trop. Atlantic.

Spring

2010: ENSO-neutral, negative PDO pattern, above-normal SSH in trop. Indian Ocean and trop. Atlantic.

2011: La Nina, negative PDO pattern, negative IOD pattern, above-normal SSH in trop. Atlantic.

Summer/Fall SSH Anomaly: 2010 vs 2011



Summer

2010: La Nina, Negative PDO, above-normal SSH in trop. Indian Ocean and trop. Atlantic.

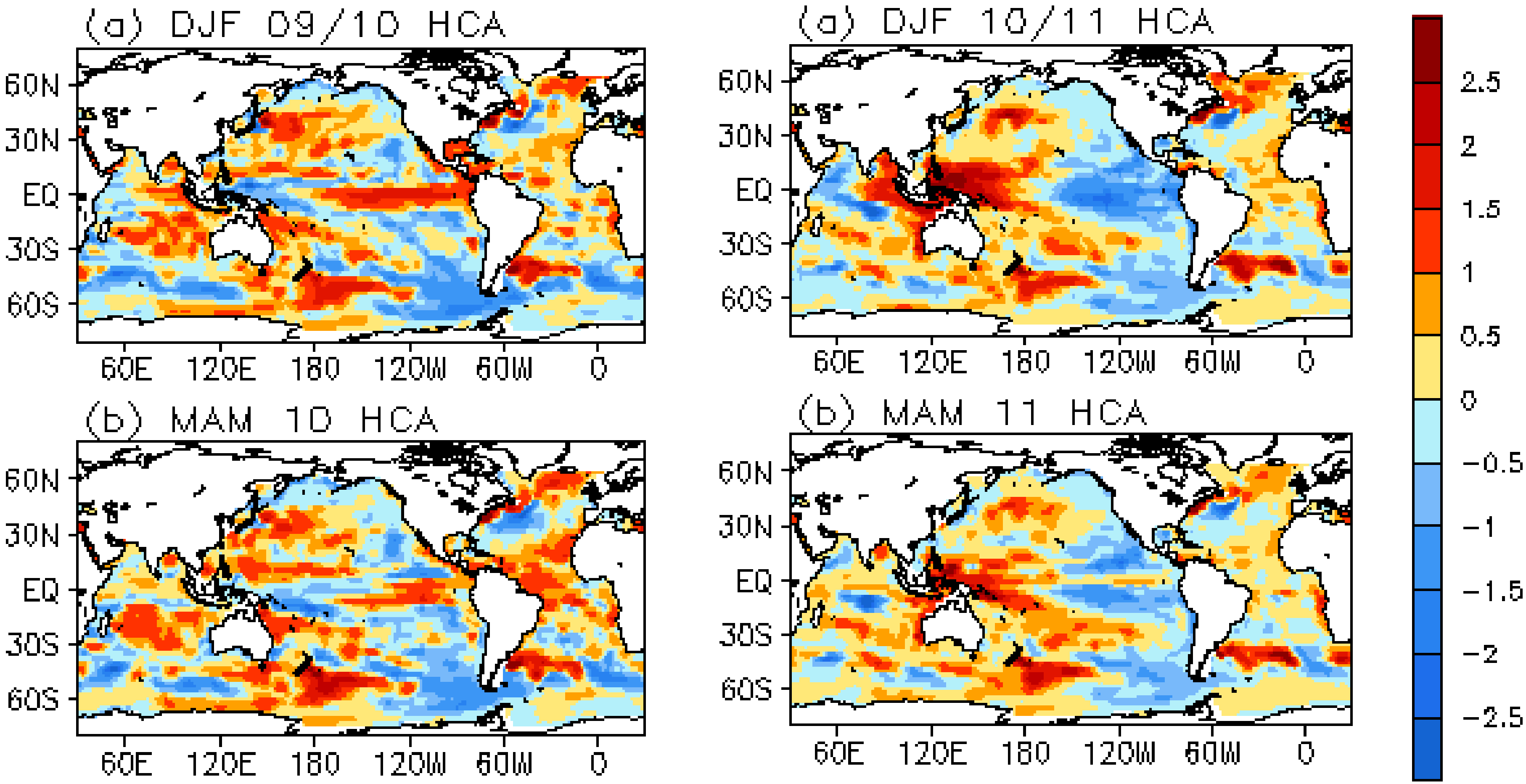
2011: ENSO-neutral, negative PDO, above-normal SSH in trop. Indian Ocean and trop. Atlantic.

Fall

2010: La Nina, Negative PDO, Negative IOD pattern, above-normal SSH in trop. Atlantic.

2011: La Nina, negative PDO, Positive IOD pattern, above-normal SSH in trop. Atlantic.

Winter / Spring HC300 Anomaly: 2010 vs 2011



Winter

2009/10: El Nino, negative PDO pattern, above-normal H300 in trop. Indian Ocean and trop. Atlantic.

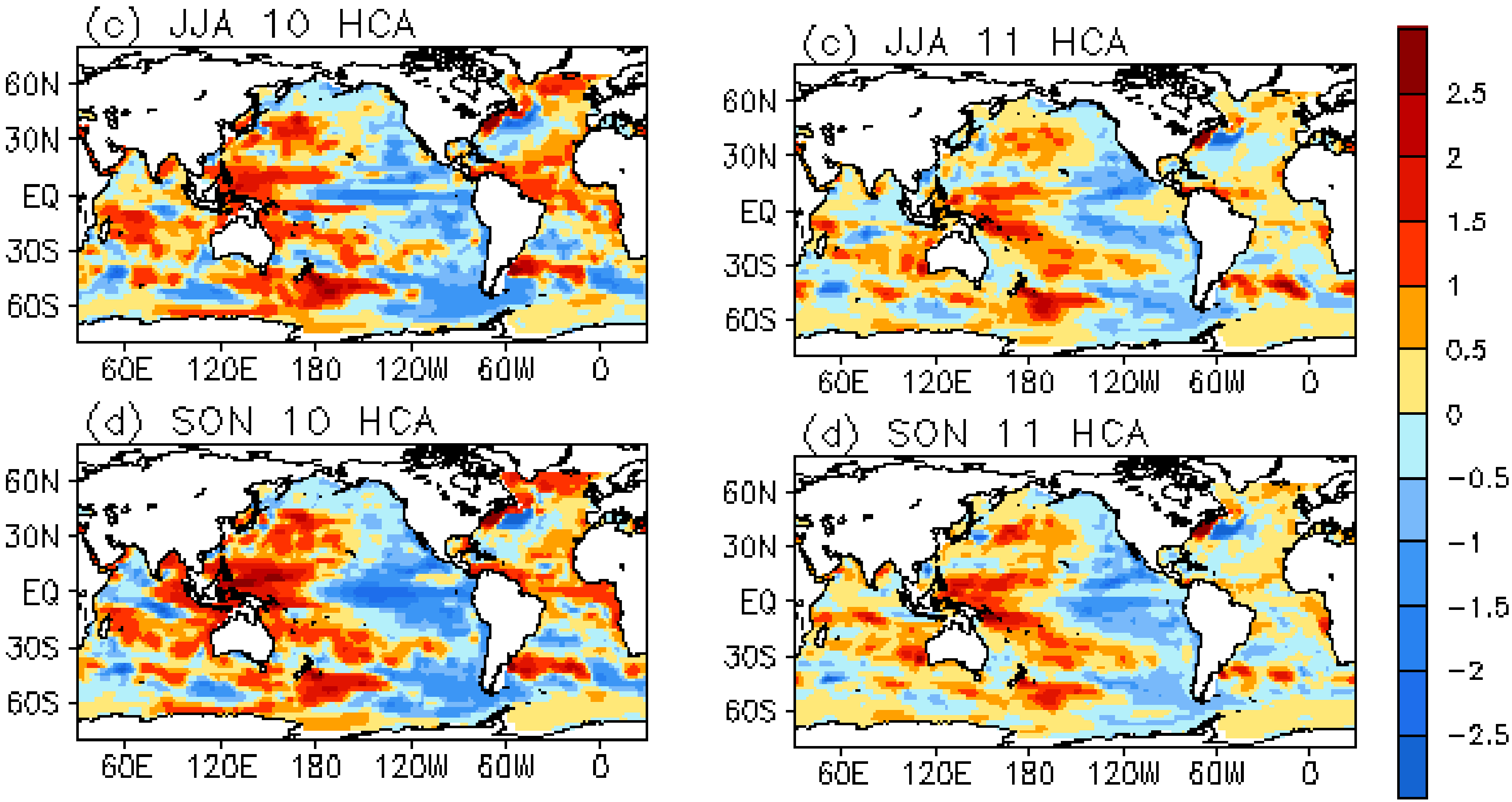
2010/11: La Nina, negative PDO pattern, negative IOD pattern, above-normal H300in trop. Atlantic.

Spring

2010: ENSO-neutral, negative PDO pattern, above-normal H300 in trop. Indian Ocean and trop. Atlantic.

2011: La Nina, negative PDO pattern, negative IOD pattern, near-normal H300 in trop. Atlantic.

Summer/Fall HC300 Anomaly: 2010 vs 2011



Summer

2010: La Nina, Negative PDO pattern, above-normal H300 in trop. Indian Ocean and trop. Atlantic.

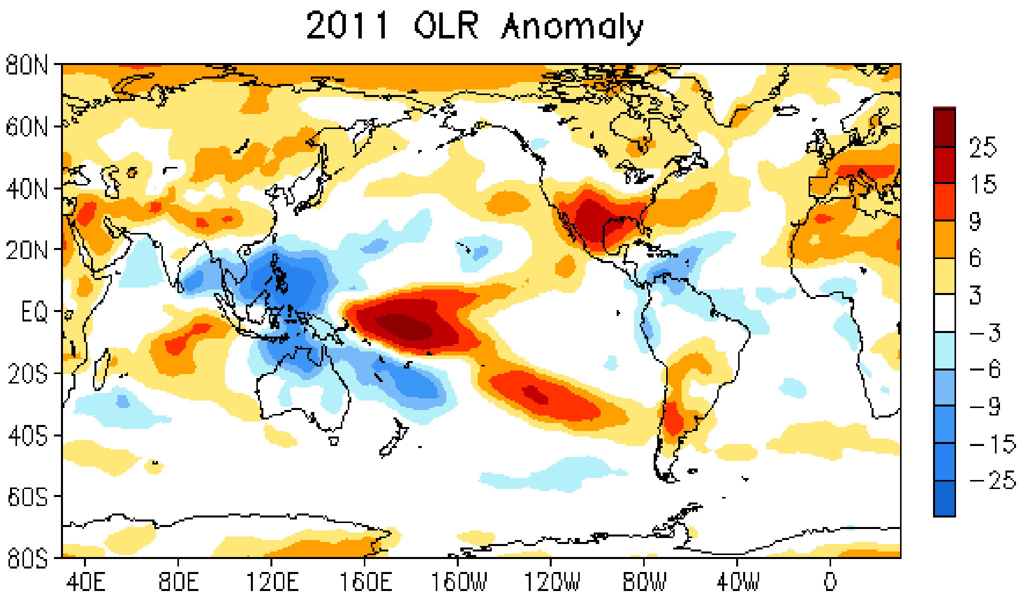
2011: ENSO-neutral, negative PDO pattern, near-normal H300 in trop. Indian Ocean and trop. Atlantic.

Fall

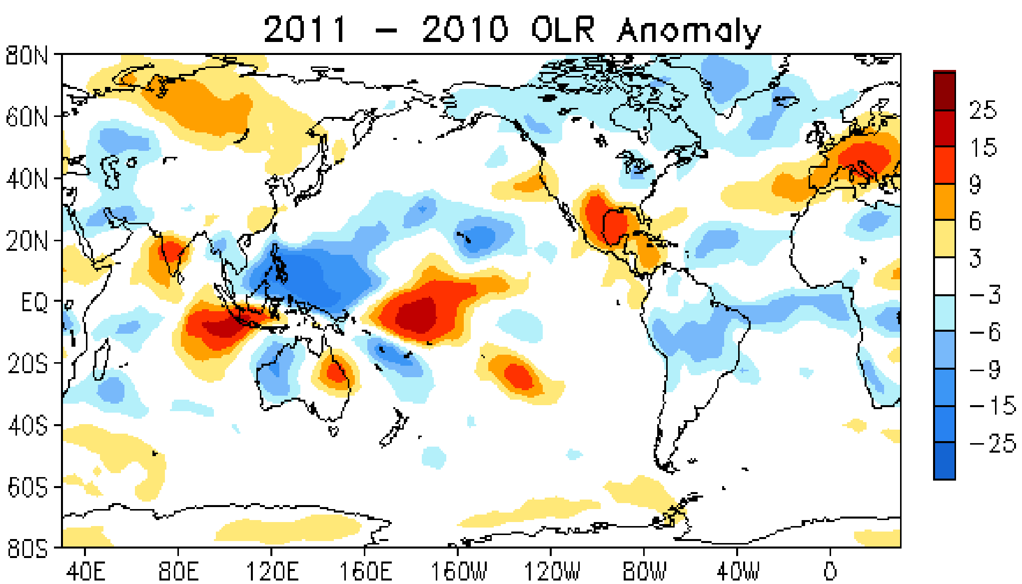
2010: La Nina, Negative PDO pattern, Negative IOD pattern, above-normal H300 in trop. Atlantic.

2011: La Nina, negative PDO pattern, Positive IOD pattern, near-normal H300 in trop. Atlantic.

2011 Yearly Mean OLR Anomaly and Tendency

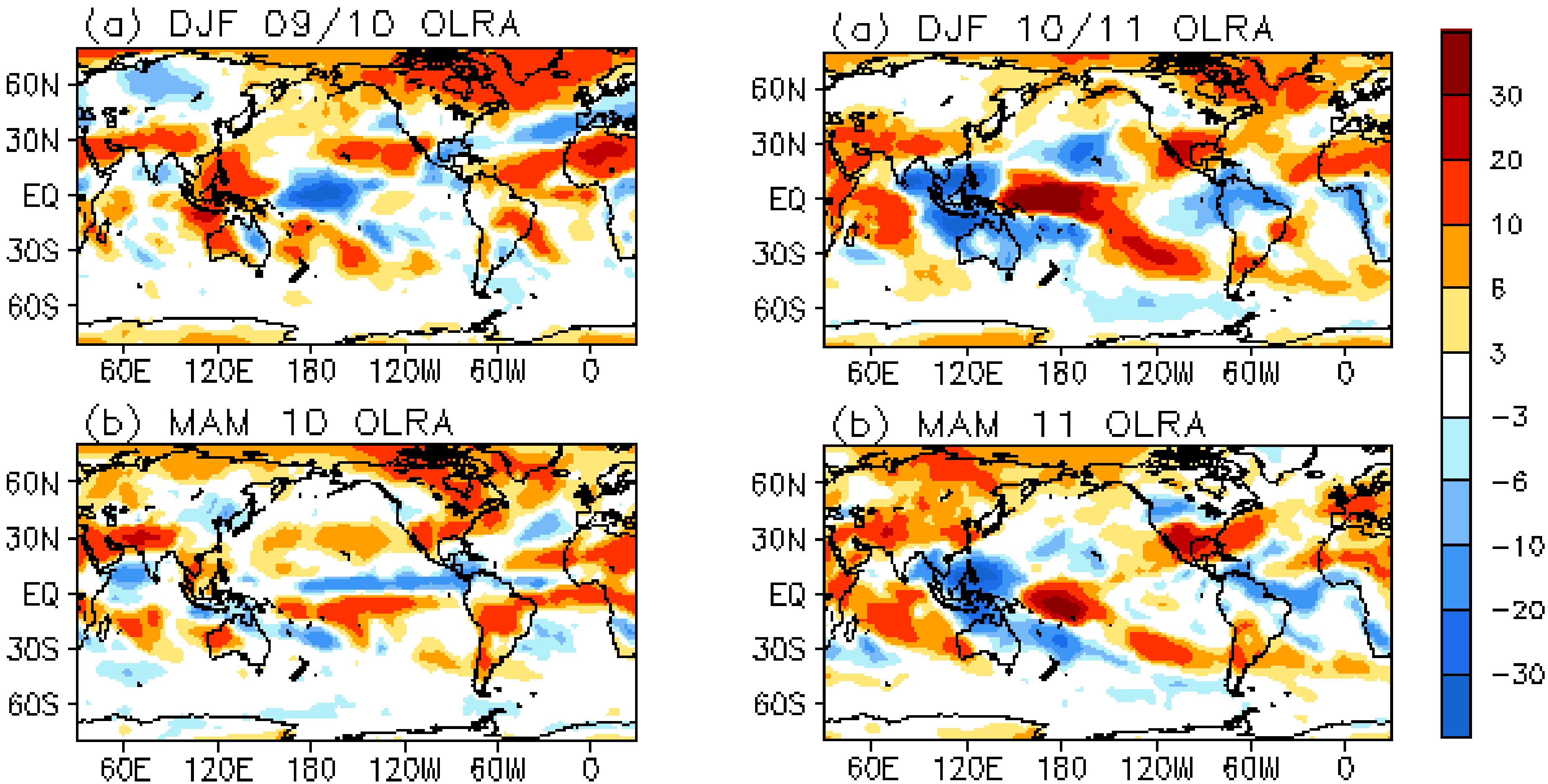


- The 2011 OLR anomaly was dominated by enhanced (suppressed) convection over Maritime Continent and tropical Atlantic (near the Dateline), consistent with La Nina conditions.
- Convection was suppressed (enhanced) in the southern U.S. and northern Africa (Caribbean Sea).



- The 2011 minus 2010 OLR anomaly shows enhanced (suppressed) convection near Philippian Sea, central America and equatorial Atlantic (southeast tropical Indian Ocean, south-central tropical Pacific, Texas and Gulf of Mexico and central W. Europe).

Winter/Spring OLR Anomaly: 2010 vs 2011



Winter

2009/10: El Nino pattern, suppressed convection in the tropical Atlantic.

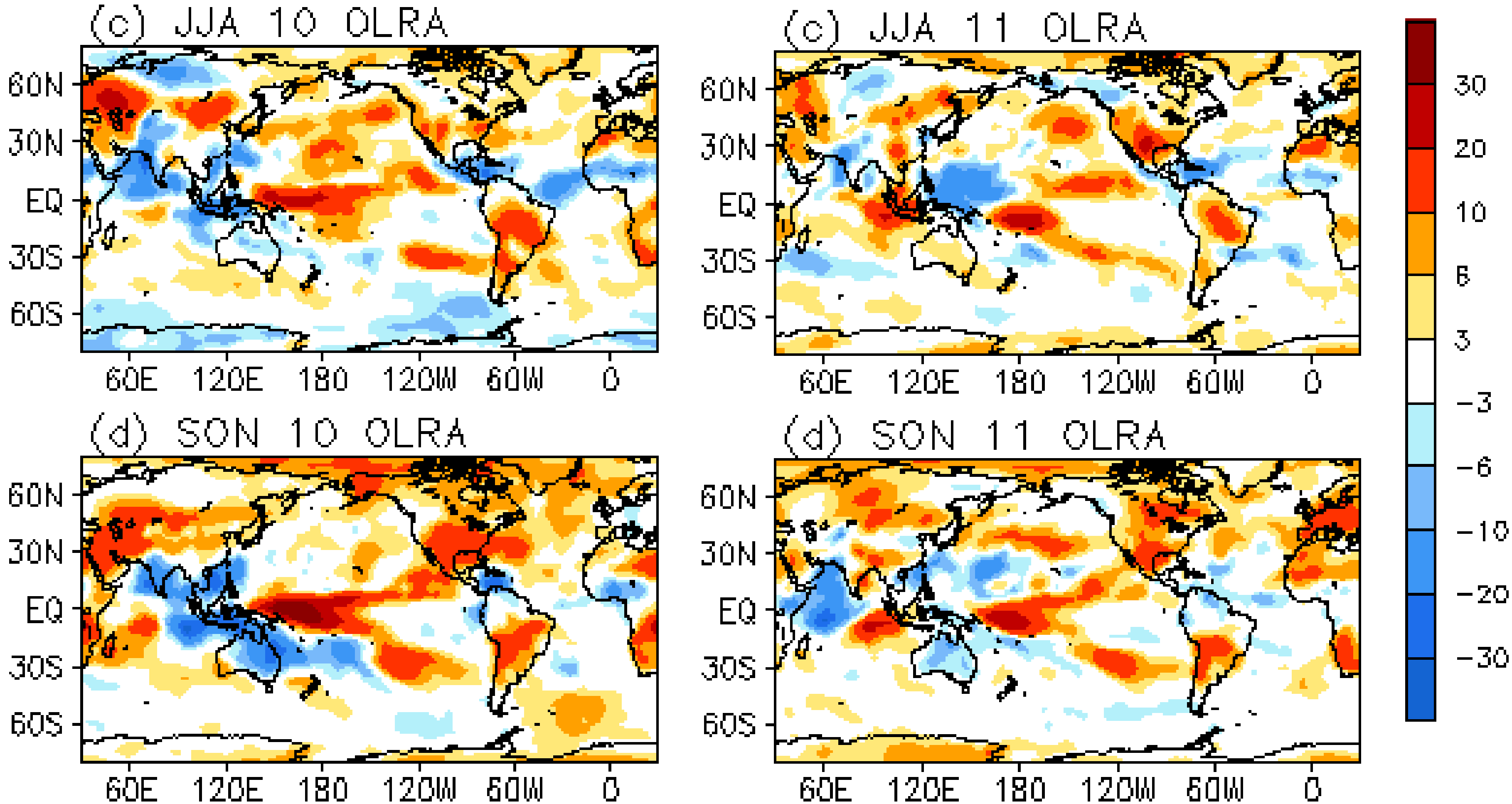
2010/11: La Nina pattern in Indo-Pac., suppressed (enhanced) convection in southern U.S. (central America).

Spring

2010: ENSO-neutral

2011: La Nina pattern, suppressed (enhanced) convection in southern U.S. (equatorial Atlantic).

Summer/Fall OLR Anomaly: 2010 vs 2011



Summer

2010: weak La Nina pattern, suppressed (enhanced) convection in southern U.S. (Caribbean Sea, equatorial Atlantic).

2011: ENSO-neutral, suppressed (enhanced) convection in southern U.S. (Caribbean Sea).

Fall

2010: La Nina pattern, suppressed (enhanced) convection in southern U.S. (Caribbean Sea).

2011: weak La Nina pattern, strong positive IOD pattern.

Atmospheric Circulation Anomaly in 2011

- The 2011 SST anomaly (SSTA) was characterized by a cooling in tropical ocean basins, particularly in the equatorial Pacific;

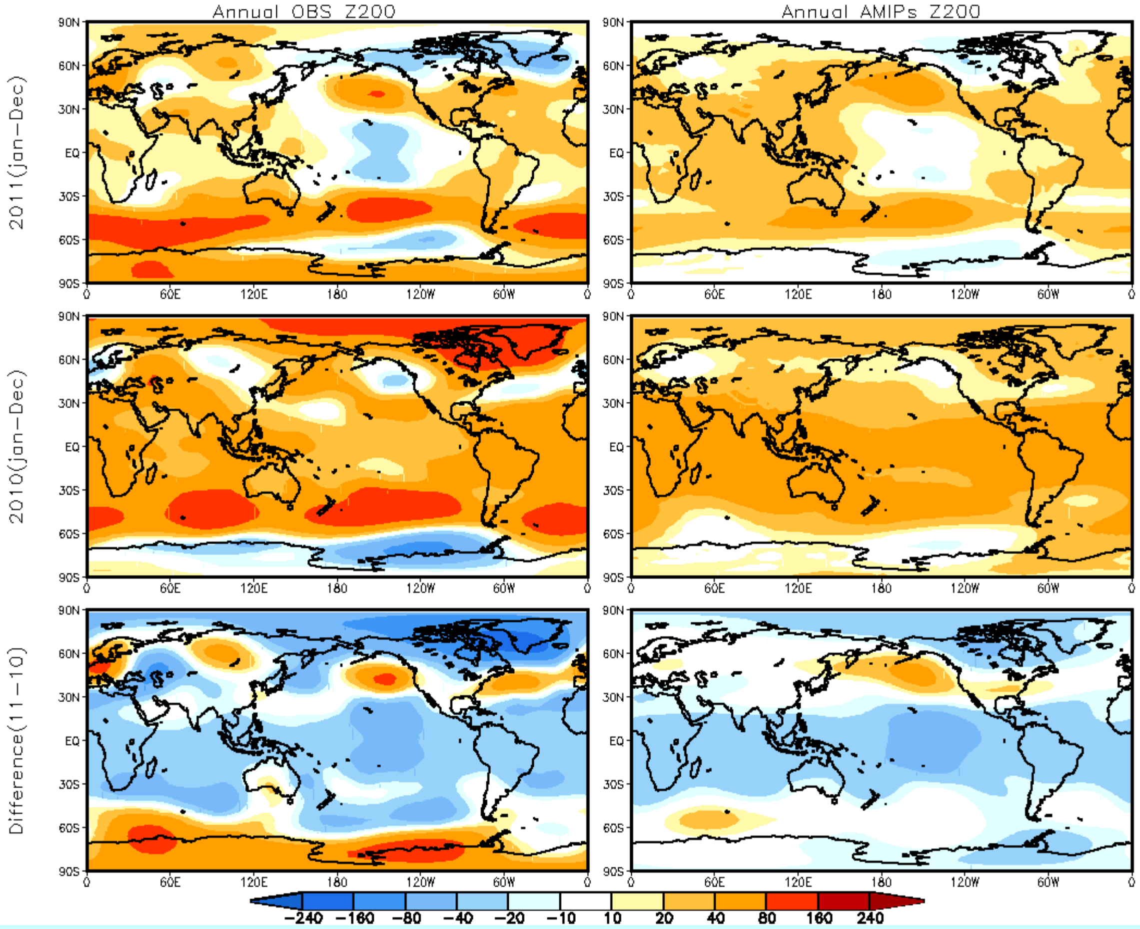
- The dominant precipitation response in the equatorial Pacific was related to the La Nina conditions, and precipitation was lower (higher) near the date line (maritime continent), and was typical of La Nina conditions. That observed precipitation was response to SST is confirmed from the AMIP simulations;

- Consistent with the cooling in tropical oceans, and reduced precipitation in the equatorial Pacific, 200-mb heights were lower in 2011 compared to in 2010 for both observations and in the AMIP simulations;

- For both observations and the AMIP simulations, tropical land areas had cooler temperatures in 2011 (relative to 2010), and the relative change over NA were consistent with La Nina SSTs (and associated response in tropical precipitation)

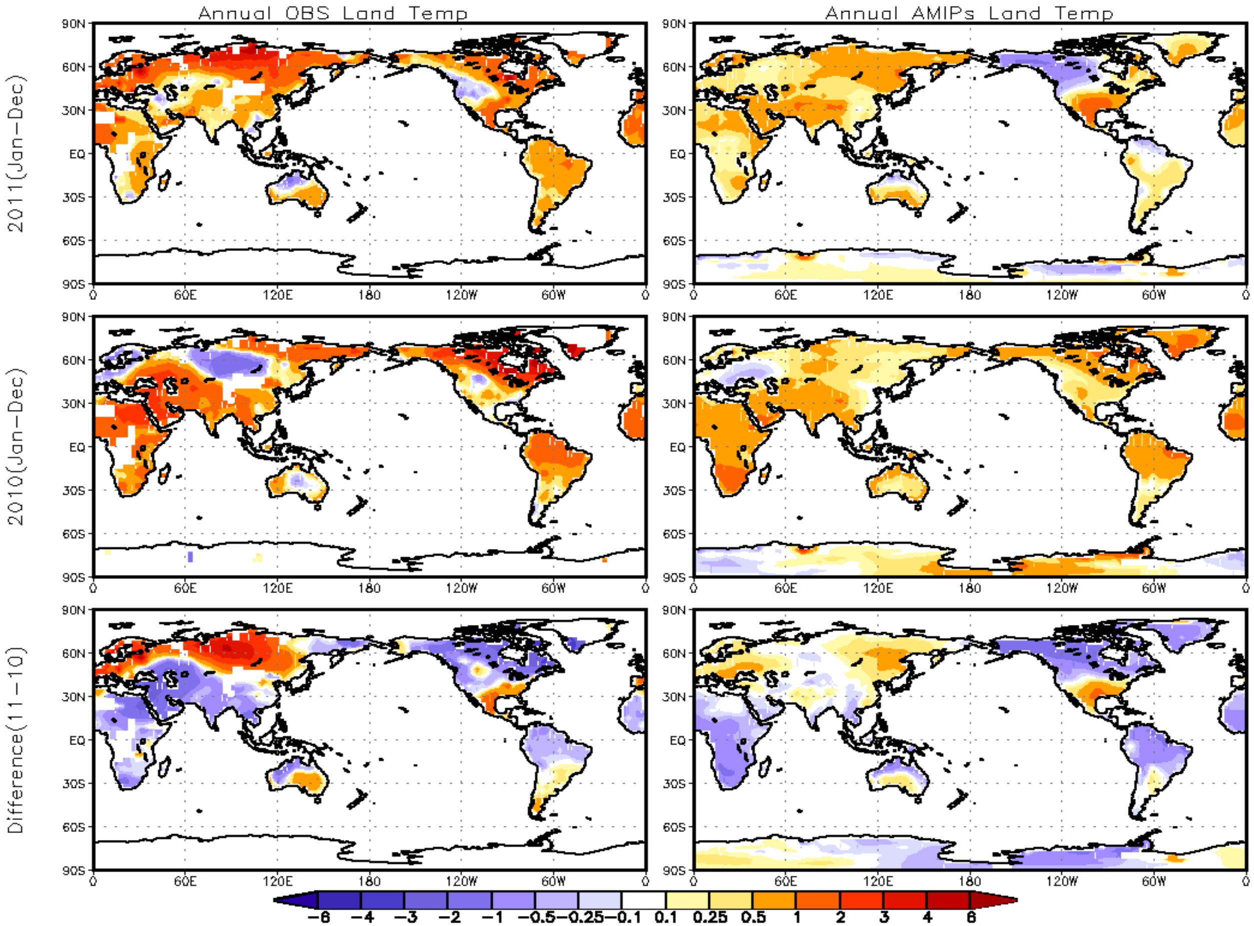
- In summary, changes in annual mean features for the atmospheric variables were consistent with changes in SSTs, and are confirmed by the AMIP simulations

2011 200-mb Height Anomaly and Tendency: Obs. vs AMIP



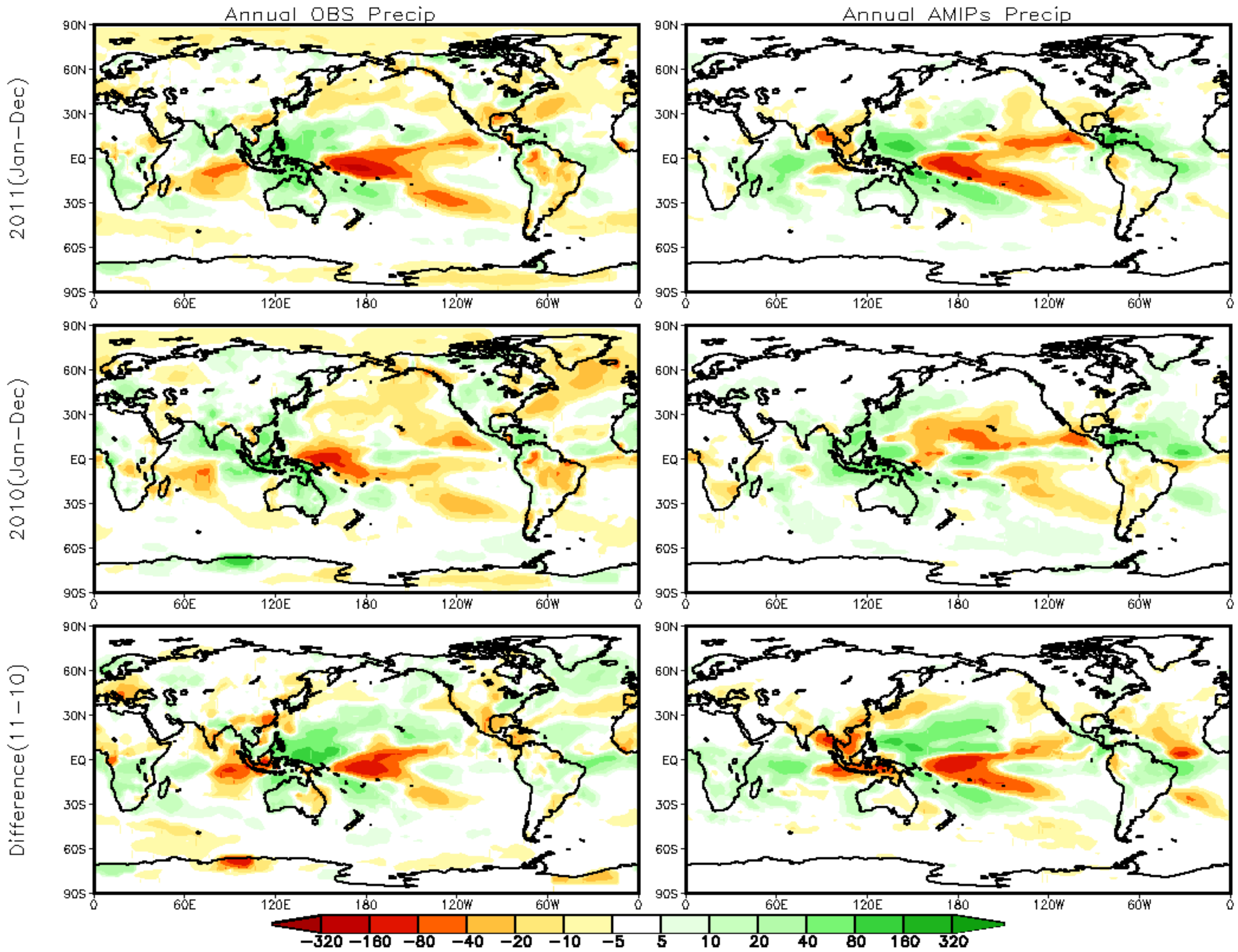
- Consistent with cooler tropical SSTs in 2011 relative to 2010, 200-mb heights were lower in 2011, and the relative change was typical of La Nina conditions
- This feature is well simulated in the ensemble of AMIP simulations, confirming the influence of tropical SSTs on heights.
- Lower 200-mb heights in 2011, therefore, could be attributed to changes in SSTs from 2010 to 2011.

2011 Temperature Anomaly and Tendency: Obs. vs AMIP



- Compared to 2010, land temperatures in 2011 were generally on the cooler side, particularly in the tropical land areas; over NA change in annual mean surface temperature was typical of La Nina conditions in 2011.
- Once again this feature is well simulated in the ensemble of AMIP simulations, confirming the influence of SSTs.

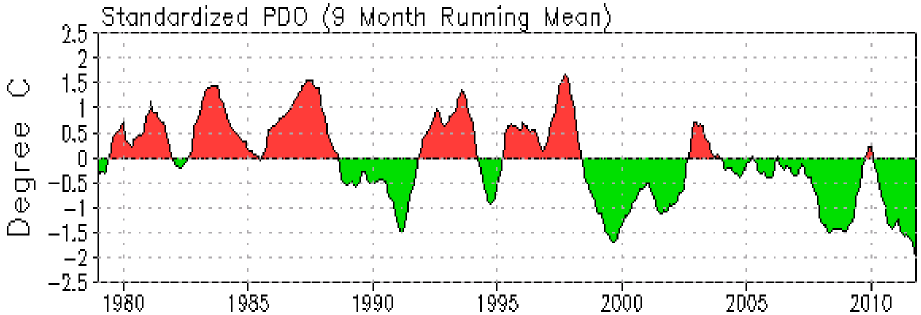
2011 Precipitation Anomaly and Tendency: Obs. vs AMIP

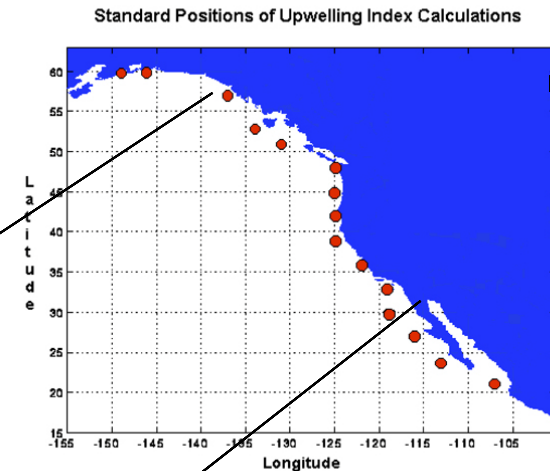


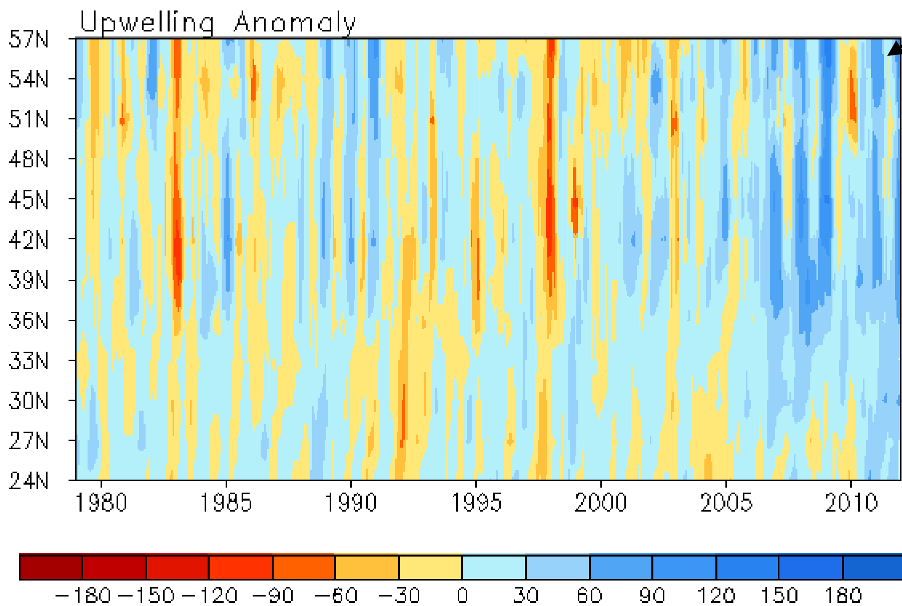
- Observed change in the 2011 tropical rainfall, compared to 2010 rainfall, are well replicated in the AMIP simulations, and were consistent with La Nina SST forcing (e.g., suppressed rainfall near the Dateline, and SPCZ; enhanced rainfall over the Maritime Continent; enhanced rainfall in the tropical Atlantic etc.)
- Influencing role of changes in the SSTs is confirmed by the AMIP simulations

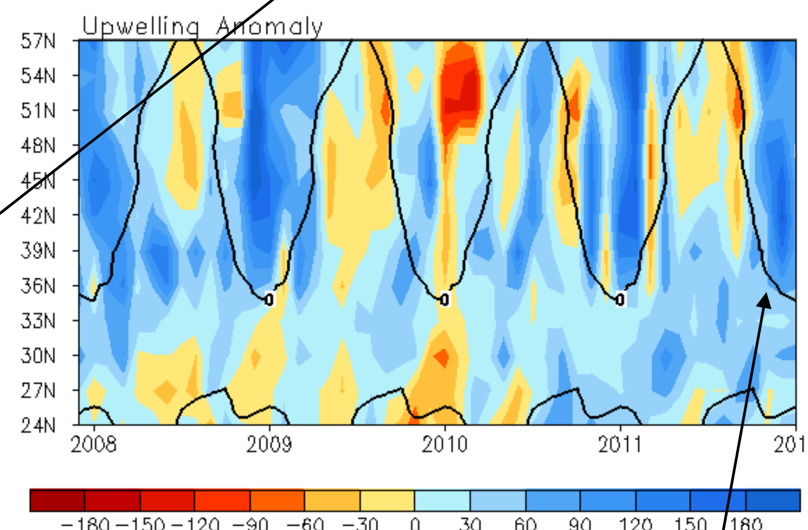
North America Western Coastal Upwelling from GODAS

SWFSC, NOAA Fisheries Service





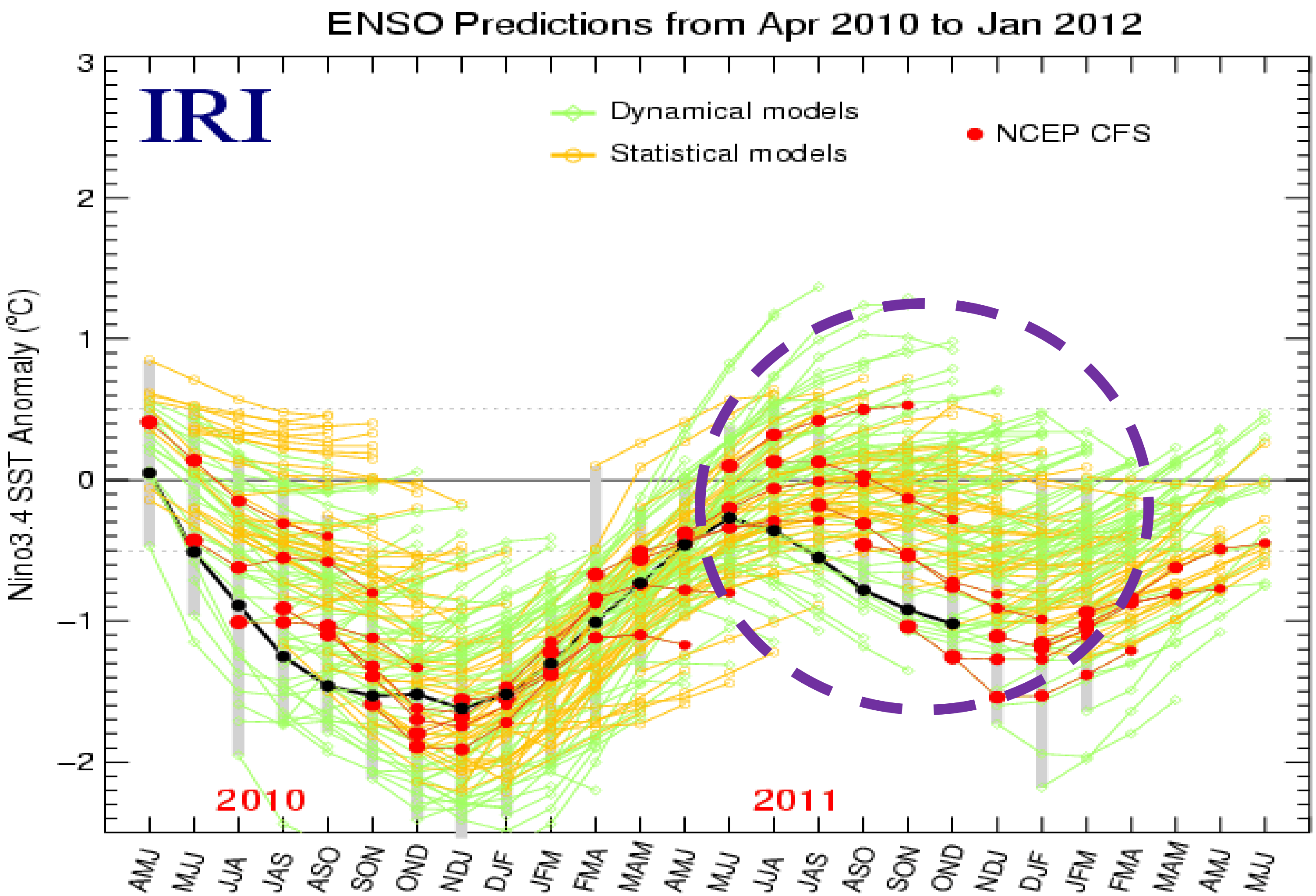




- **Upwelling has been abnormally strong since 2000 when negative phase of PDO persisted.**
- **Upwelling was above-normal during every winter since 2007 except the winter 2009/10.**

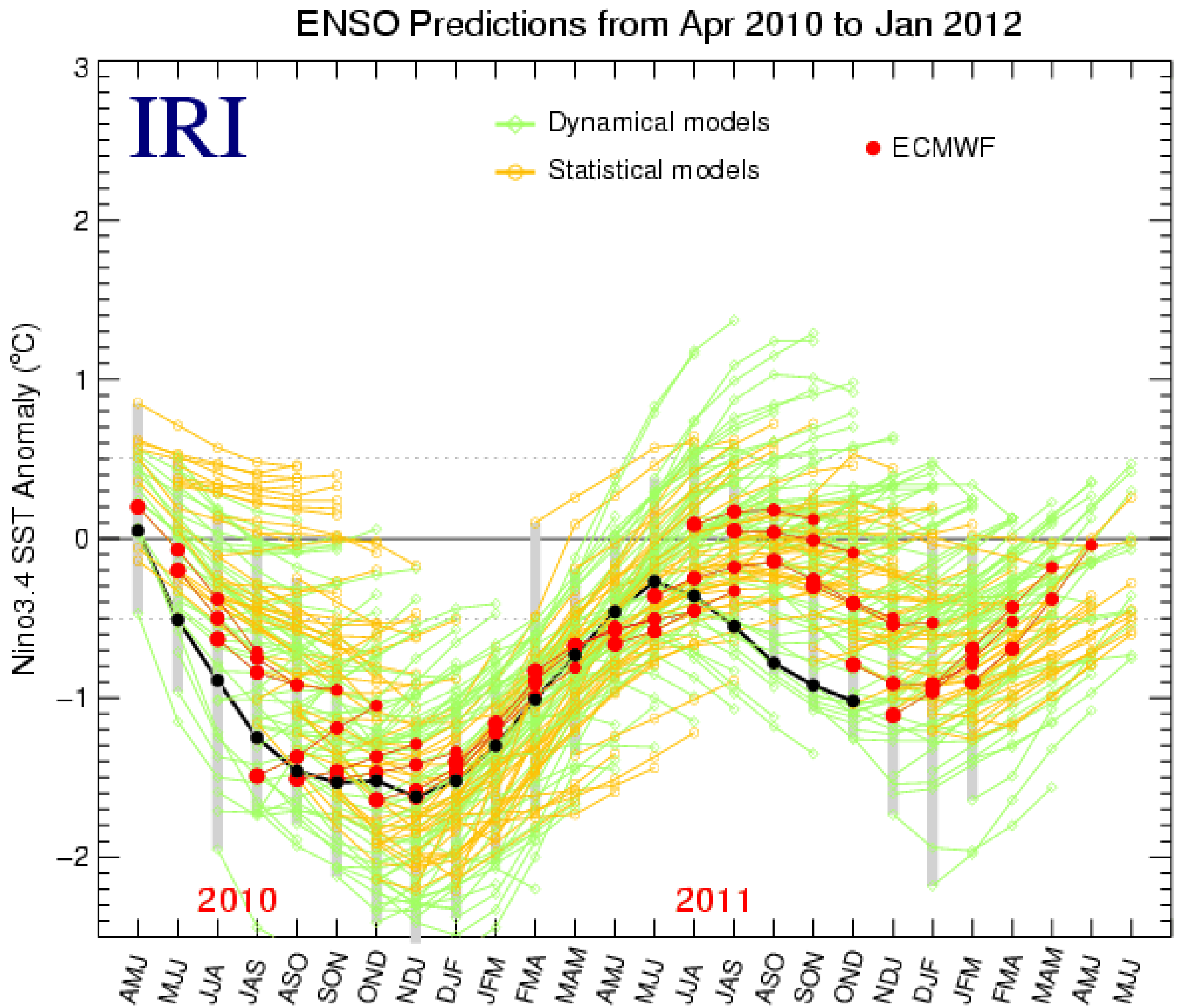
- **Area below (above) black line indicates climatological upwelling (downwelling) season**
- **Climatologically upwelling season progresses from March to July along the west coast of North America from 36°N to 57°N.**

Prediction of the onset of 2011/12 La Nina



From: http://iri.columbia.edu/climate/ENSO/currentinfo/modelviews.html

- **Majority of the models, including the NCEP CFS and ECMWF, did not predicted the onset of the 2011/2012 La Nina with IC around Spring 2011.**


ENSO Predictions from Apr 2010 to Jan 2012
IRI
Dynamical models
Statistical models
ECMWF
Nino3.4 SST Anomaly (°C)
3
2
1
0
−1
−2
2010
2011
AMJ
MJJ
JJA
JAS
ASO
SON
OND
NDJ
DJF
JFM
FMA
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AMJ
MJJ
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JAS
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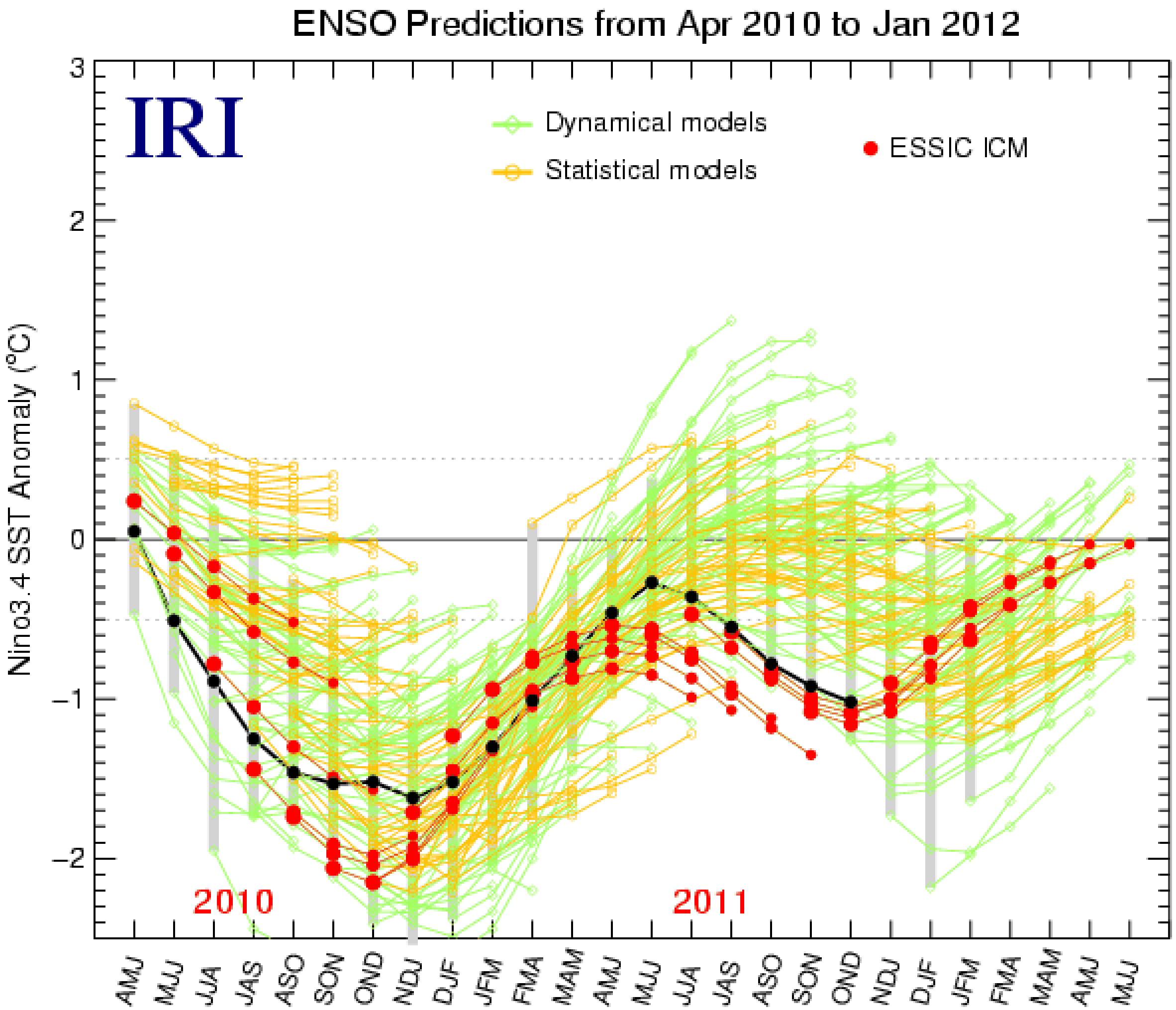
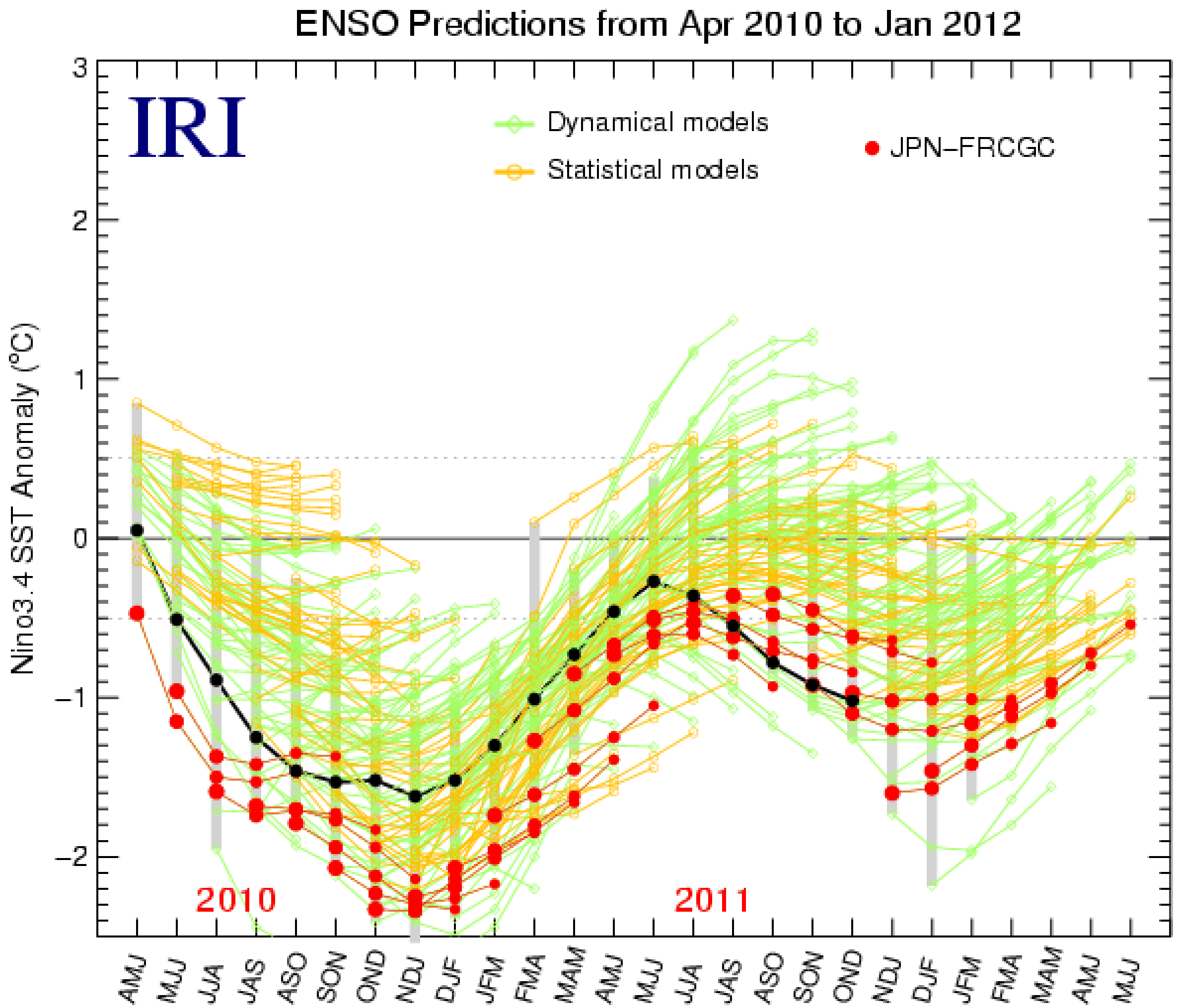
FMA
MAM
AMJ
MJJ



- **However, ESSIC and JPN-FRCGC (next slide) predicted the onset of the 2011/2012 La Nina with IC around the winter 2010/2011.**


ENSO Predictions from Apr 2010 to Jan 2012
IRI
Dynamical models
Statistical models
JPN–FRCGC
Nino3.4 SST Anomaly (°C)
3
2
1
0
−1
−2
2010
2011
AMJ
MJJ
JJA
JAS
ASO
SON
OND
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FMA
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AMJ
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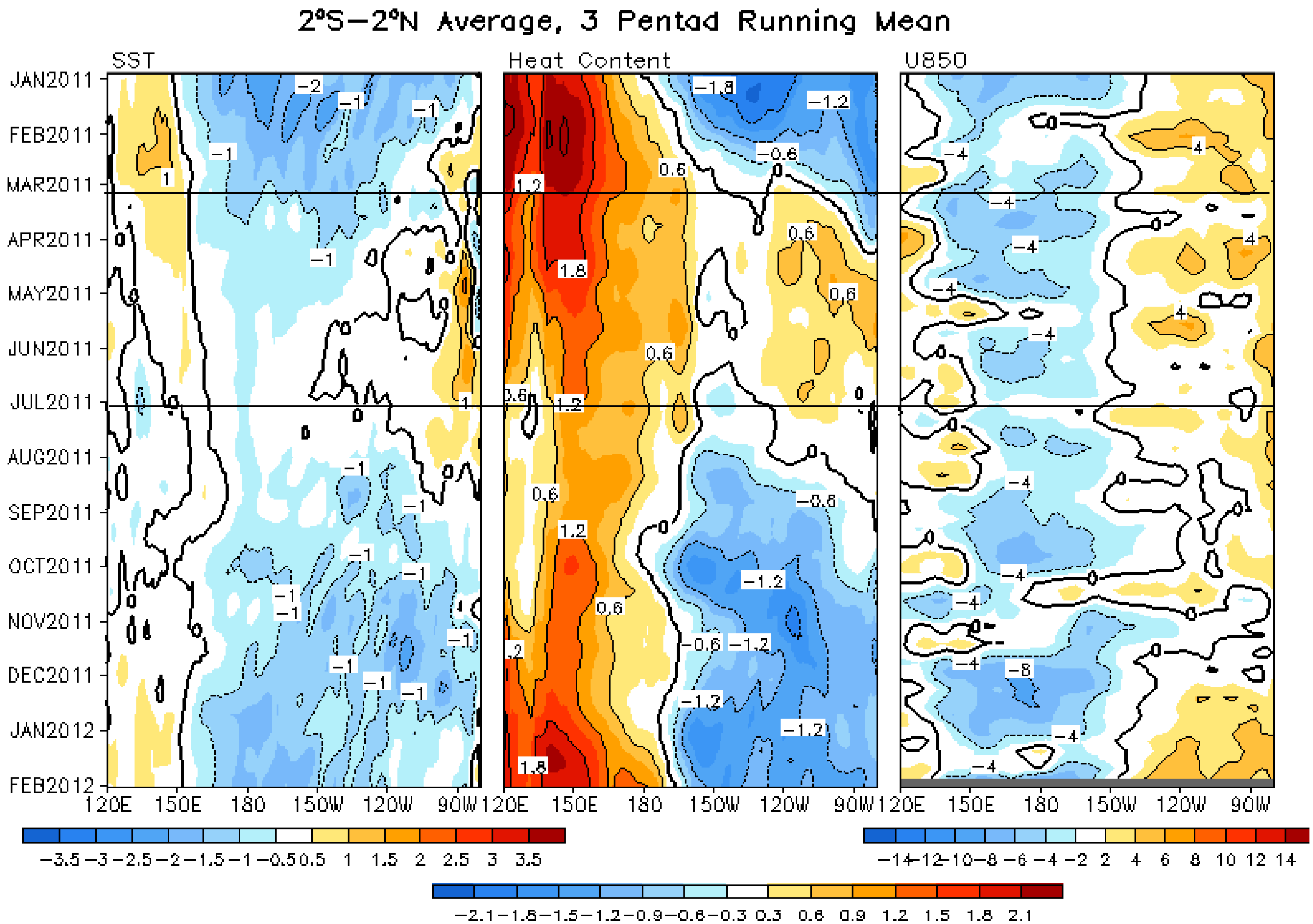
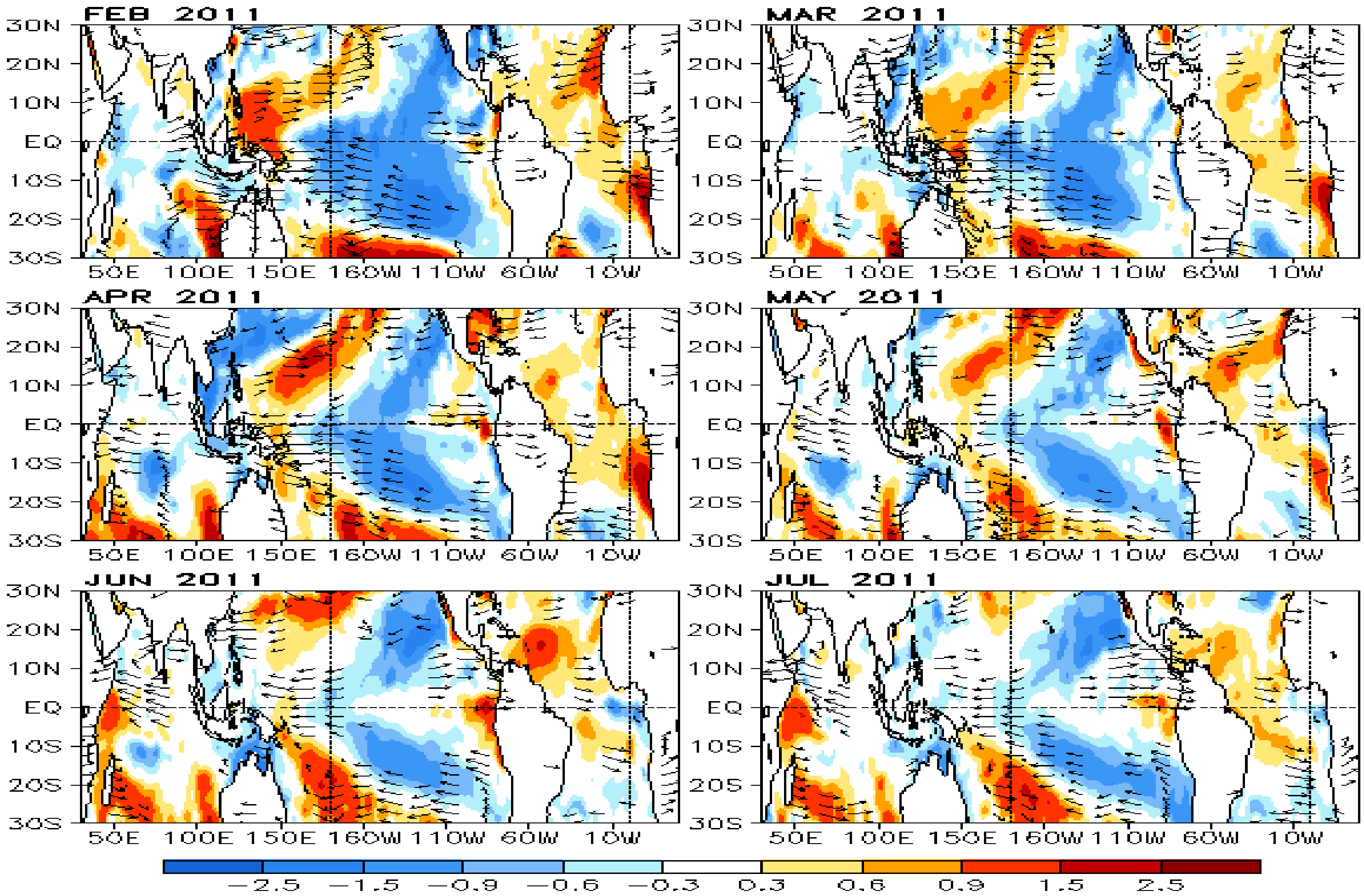
Evolution of Equatorial Pacific SST (°C), 0-300m Heat Content (°C), 850-mb Zonal Wind (m/s) Anomaly



- Most of models forecast ENSO-neutral conditions in summer/fall 2011 from spring 2011, probably due to unrealistic response to positive heat content anomaly in the tropical Pacific and failure in capturing the persistent easterly wind anomalies in the central Pacific.

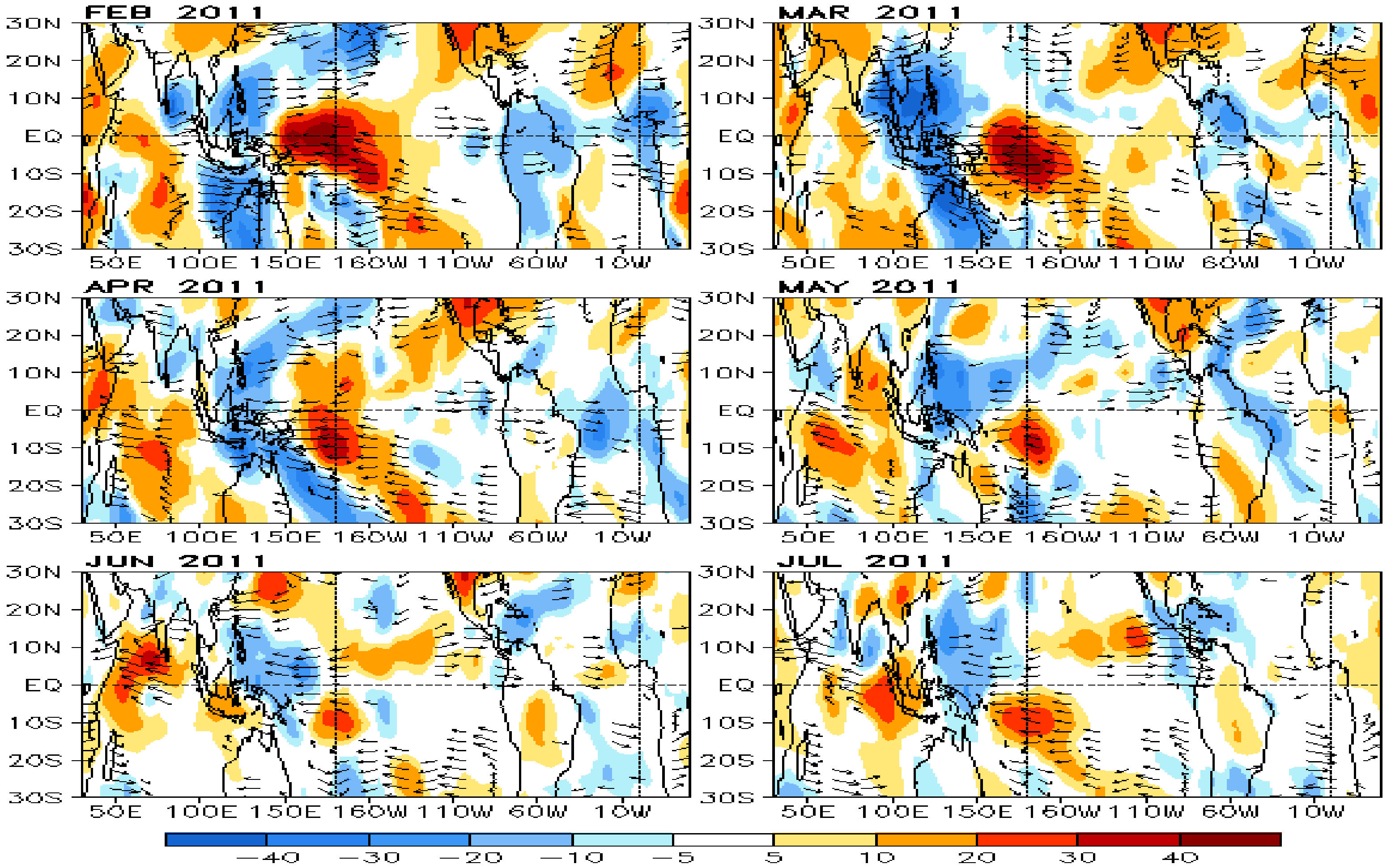
Evolution of SST and 850mb Wind Anom. in Spring/Summer 2011



- **Although the tropical Pacific returned to ENSO-neutral conditions during May-Jul 2011, easterly wind anomalies in the western-central Pacific persisted, probably related to the persistence of horse-shoe pattern of negative SSTA.**

- **To be able to forecast the onset of La Nina from spring, models need to be able to maintain the horse-shoe SSTA and eastern wind anomalies.**

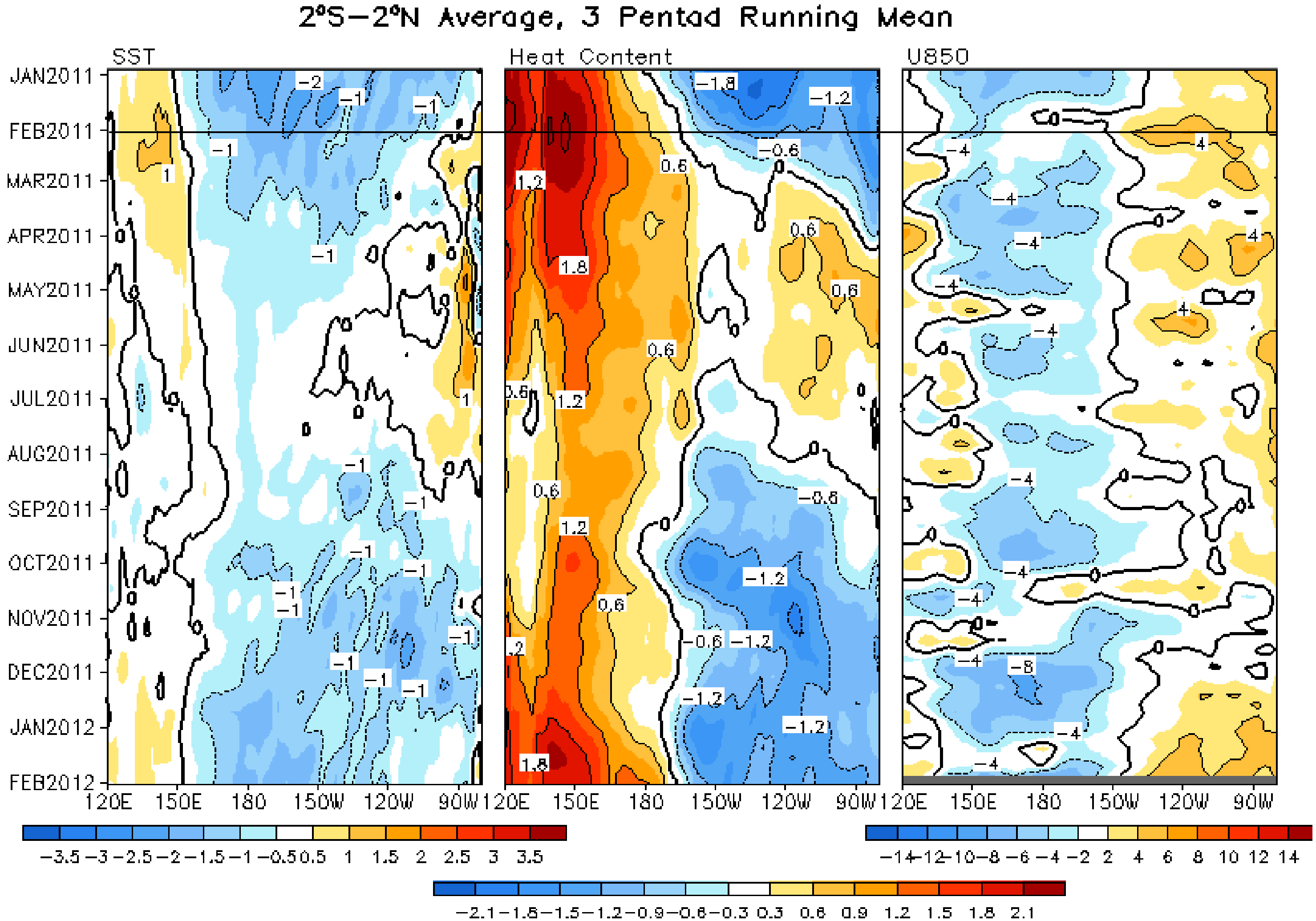
Evolution of OLR and 850mb Wind Anom. in Spring/Summer 2011



- **Although the tropical Pacific returned to ENSO-neutral conditions during May-Jul 2011, enhanced (suppressed) convection persisted in N.W Pacific (south central Pacific) , probably related to the persistence of horse-shoe pattern of negative SSTA.**

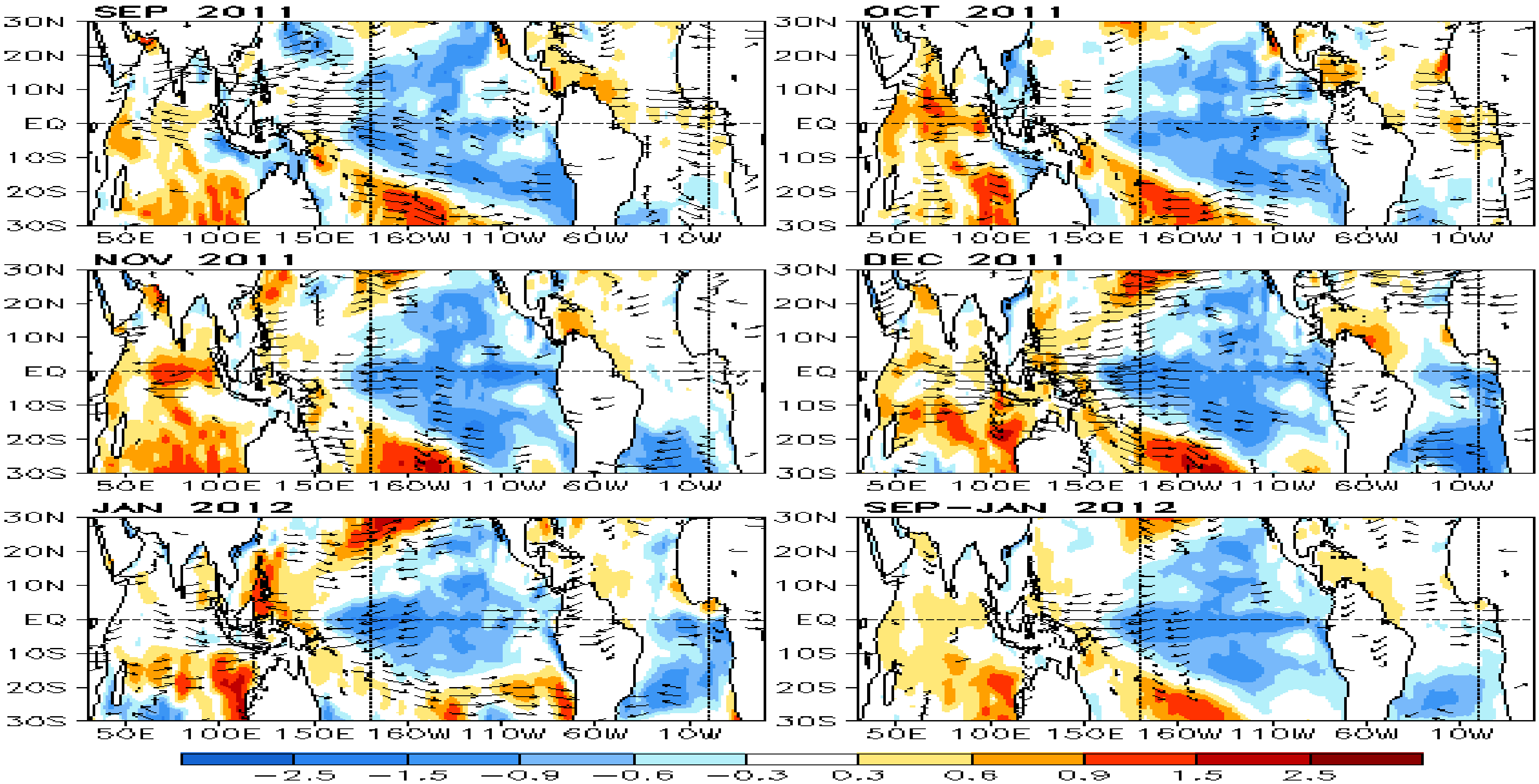
Current ENSO Prediction

Evolution of Equatorial Pacific SST (°C), 0-300m Heat Content (°C), 850-mb Zonal Wind (m/s) Anomaly



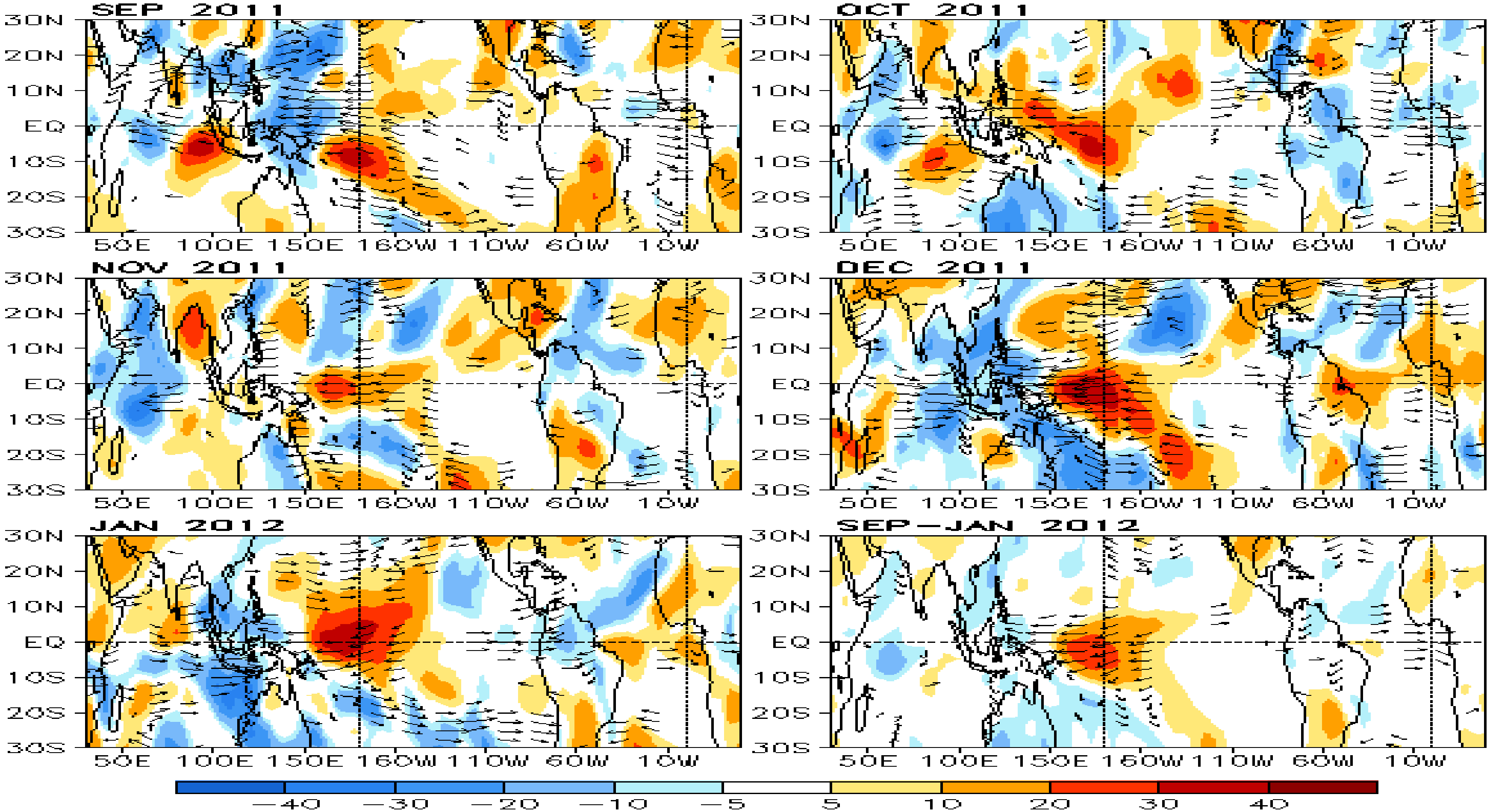
- Most of models forecast ENSO-neutral conditions in summer/fall 2011 from spring 2011, probably due to unrealistic response to positive heat content anomaly in the tropical Pacific and failure in capturing the persistent easterly wind anomalies in the central Pacific.

Evolution of SST and 850mb Wind Anom.

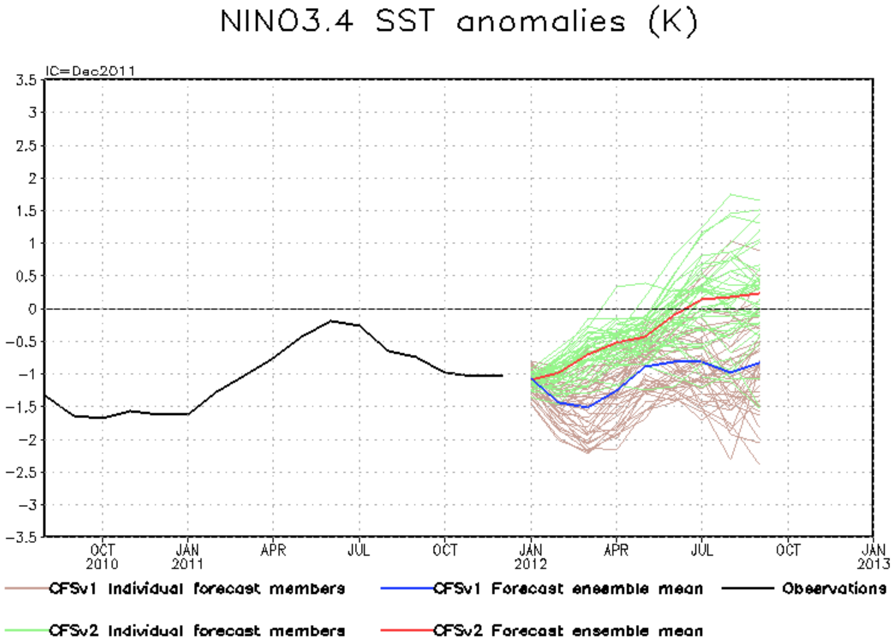


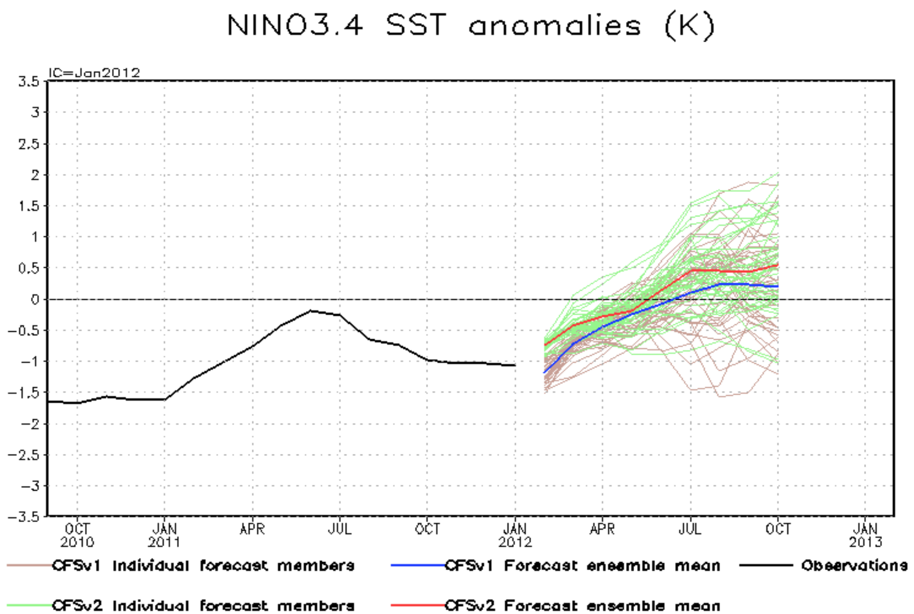
- Negative SSTA in the tropical Pacific persisted during Sep 11 – Jan12.
- Negative SSTA in the equatorial Atlantic and subtropical South Atlantic persisted during Dec 11- Jan 12.
- Tropical Indian Ocean returned to near-normal in Jan 12.
- Westerly wind anom. in trop. Indian Ocean (trop. Atlantic) persisted during Dec 11 – Jan12 (Sep 11 – Jan 12).
- Easterly wind anom. in western and central trop. Pacific persisted during Sep 11 – Jan 12.

Evolution of OLR and 850mb Wind Anom.



- Weak La Nina pattern during Sep 11 – Nov 11, while strong La Nina pattern during Dec 11 – Jan 12.
- Positive IOD pattern during Sep 11 – Oct 11.
- Surface wind anomalies converged to (diverged from) the center of enhanced (suppressed) convection.



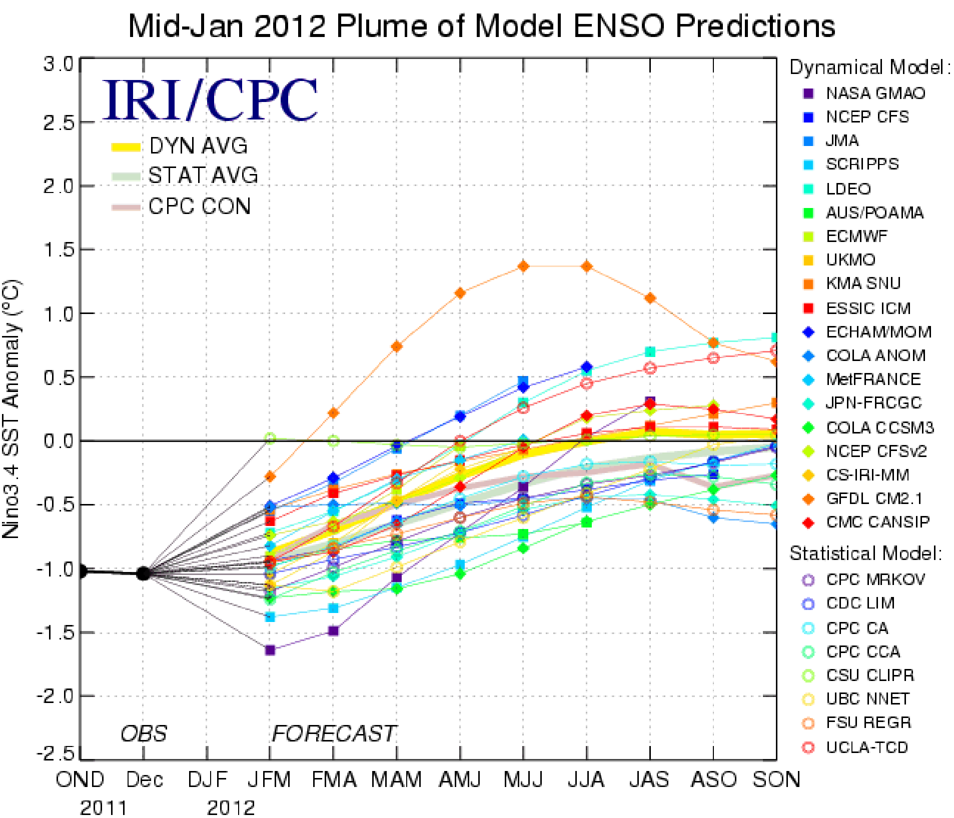


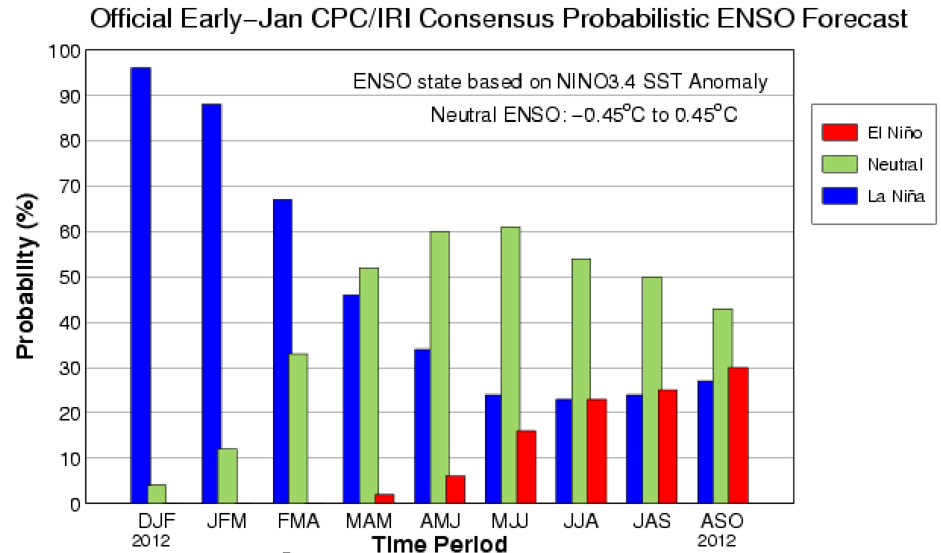
NCEP CFSv1 and CFSv2 NINO3.4 Forecast

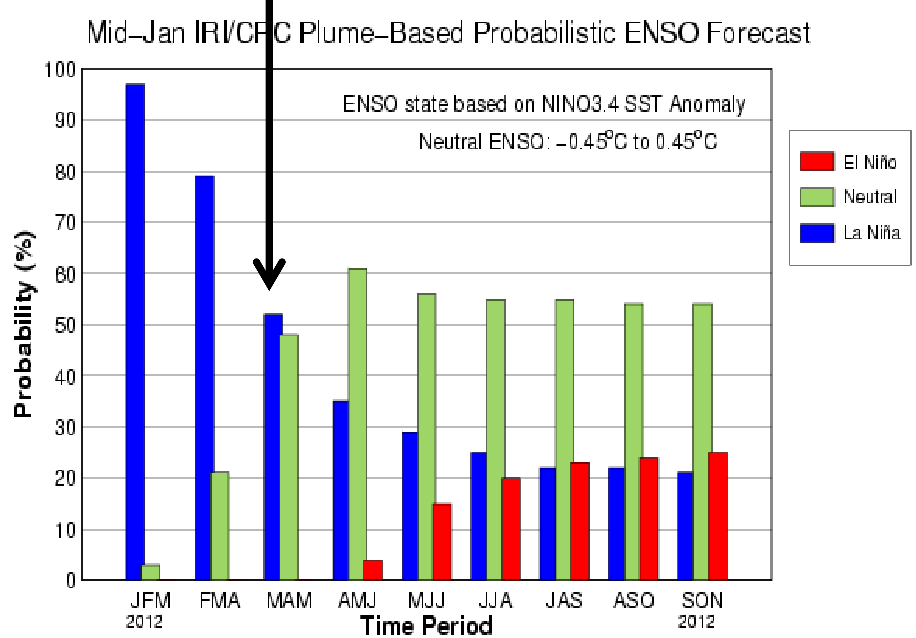
- CFSv2 suggests La Nina will transition to ENSO-neutral conditions during Apr-Jun 2012.

- CFSv1 predicted La Nina to continue into summer / fall from Dec 2011 I.C., but it predicted a transition to ENSO-neutral conditions during Apr-Jun 2012 from Jan 2012 I.C., consistent with the CFSv2 prediction.

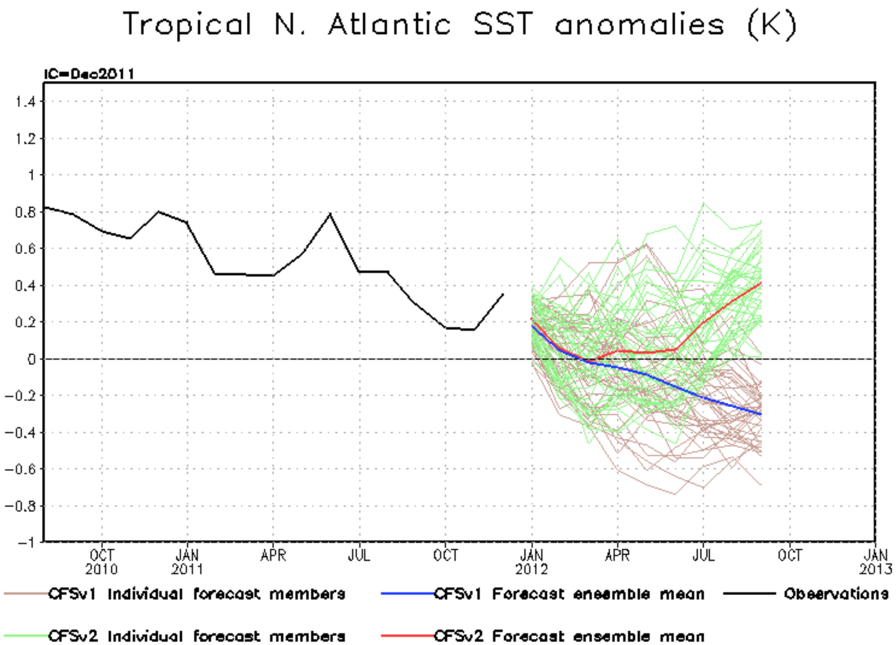
NOAA Official ENSO Forecast





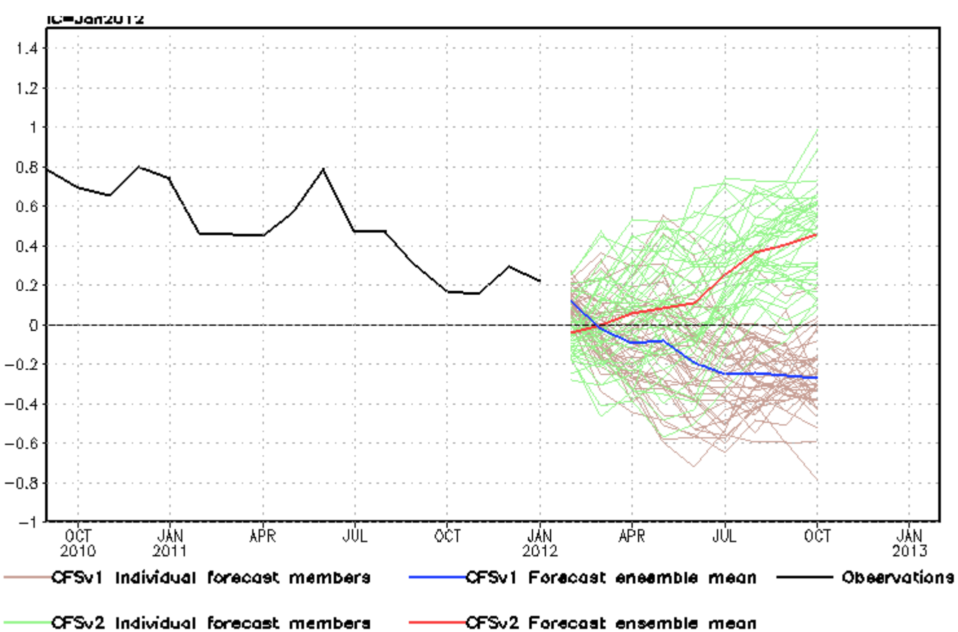


- **NOAA "ENSO Diagnostic Discussion" suggests La Niña is likely to transition to ENSO-neutral conditions during Mar-May 2012.**



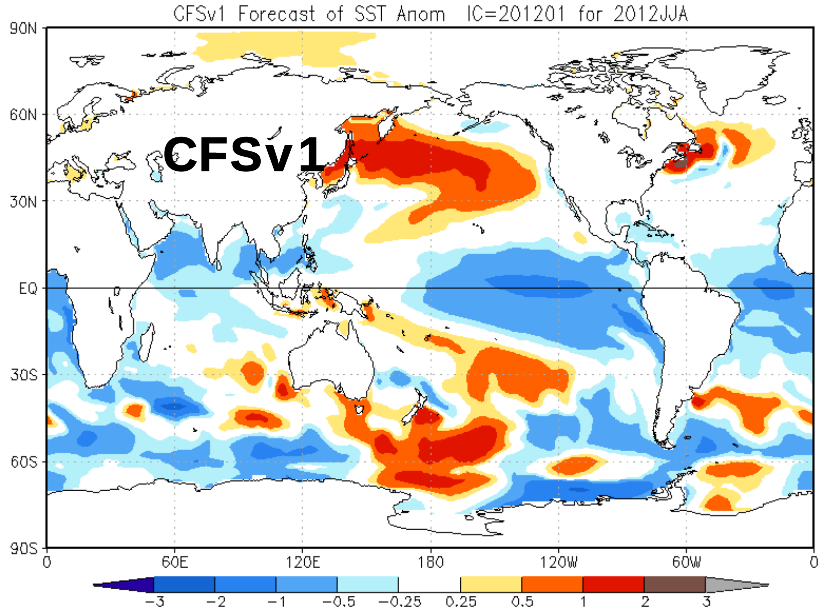
NCEP CFSv1 and CFSv2 Tropical North Atlantic SST Forecast

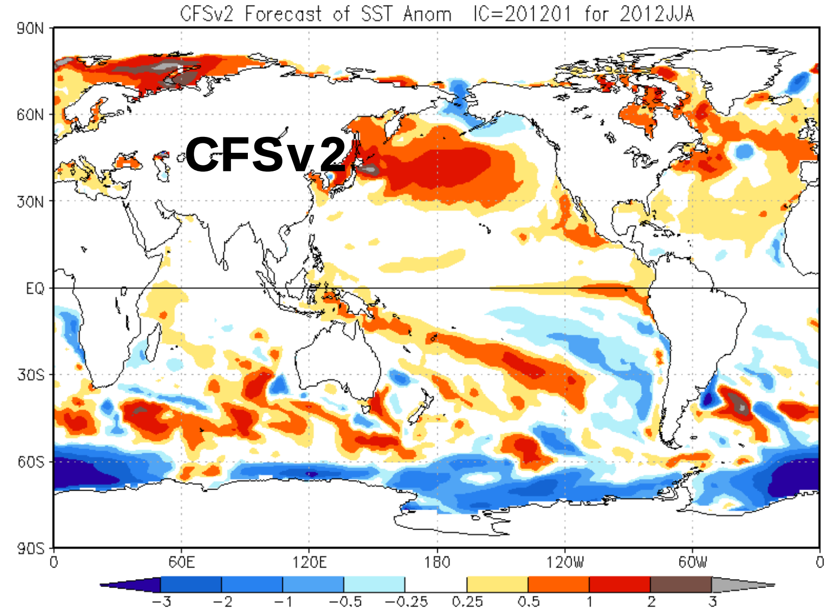
- CFSv2 (CFSv1) suggests tropical North Atlantic SST to be above-normal (below-normal) during summer 2012, favorable (unfavorable) for Atlantic hurricane activity.

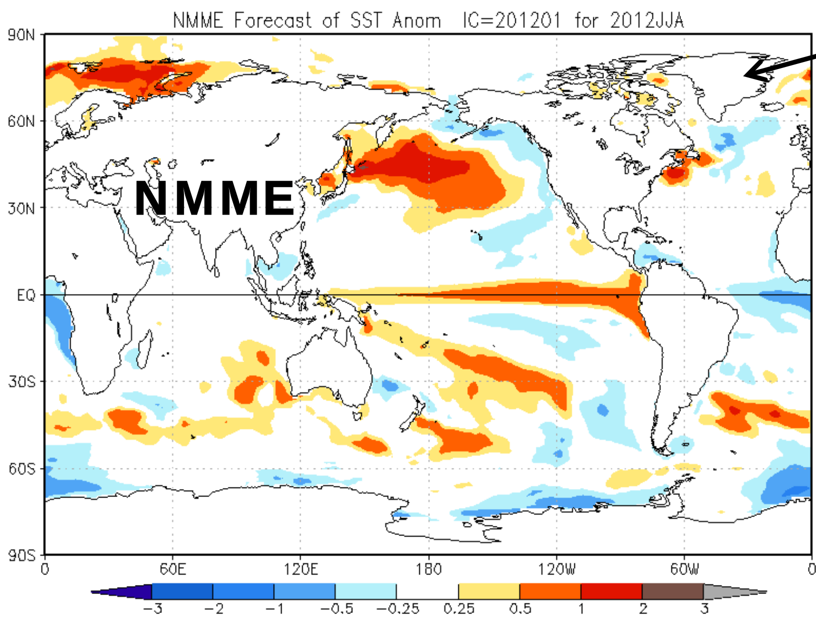


National Multi-Model Ensemble (NMME) SST Forecast for JJA 2012

(Dec 2011 I.C.)







Ensemble Mean of 7 Models
(CFSv1, CFSv2, ECHAMA, ECHAMF, GFDL, NCAR, NASA)

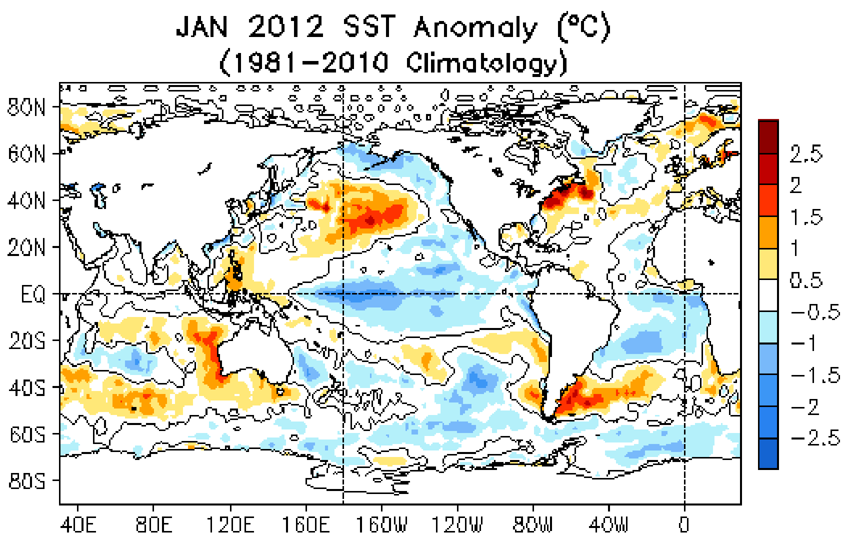
http://www.cpc.ncep.noaa.gov/products/people/wd51yf/NMME
experimental product

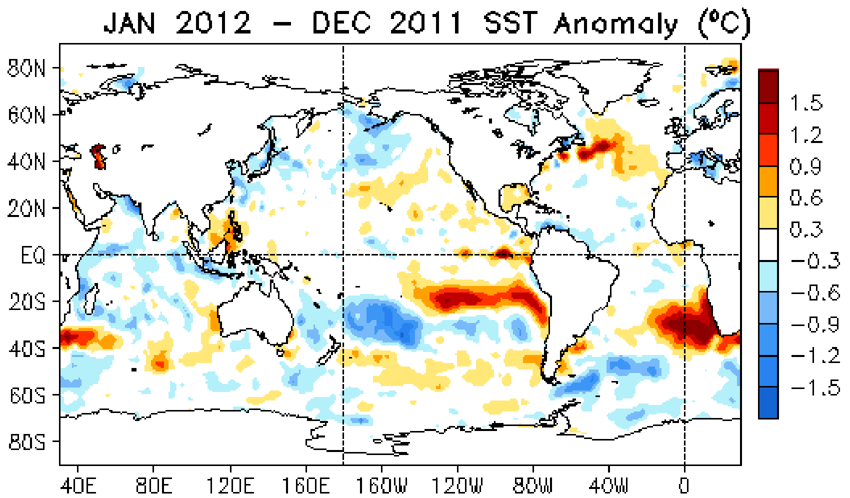
Thanks Qin Zhang, Huug van den Dool, Suru Saha, Malaquias Pena Mendez, Patrick Tripp, Peitao Peng and Emily Becker plus the originators at NASA, NCAR, GFDL, IRI (all coupled models)

- **National Multi-Model Ensemble (NMME) forecast favors EL Nino conditions, negative PDO, near-normal (below-normal) tropical North Atlantic SST (equatorial Atlantic SST) in JJA 2012.**
- **CFSv2 forecast agrees with NMME forecast better than CFSv1 forecast does.**

Backup Slides

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





y tendency (bottom). Data are derived from the
1981-2010 base period means.

Global SSH / HC Anomaly (cm / ^{o}C) and Anomaly Tendency

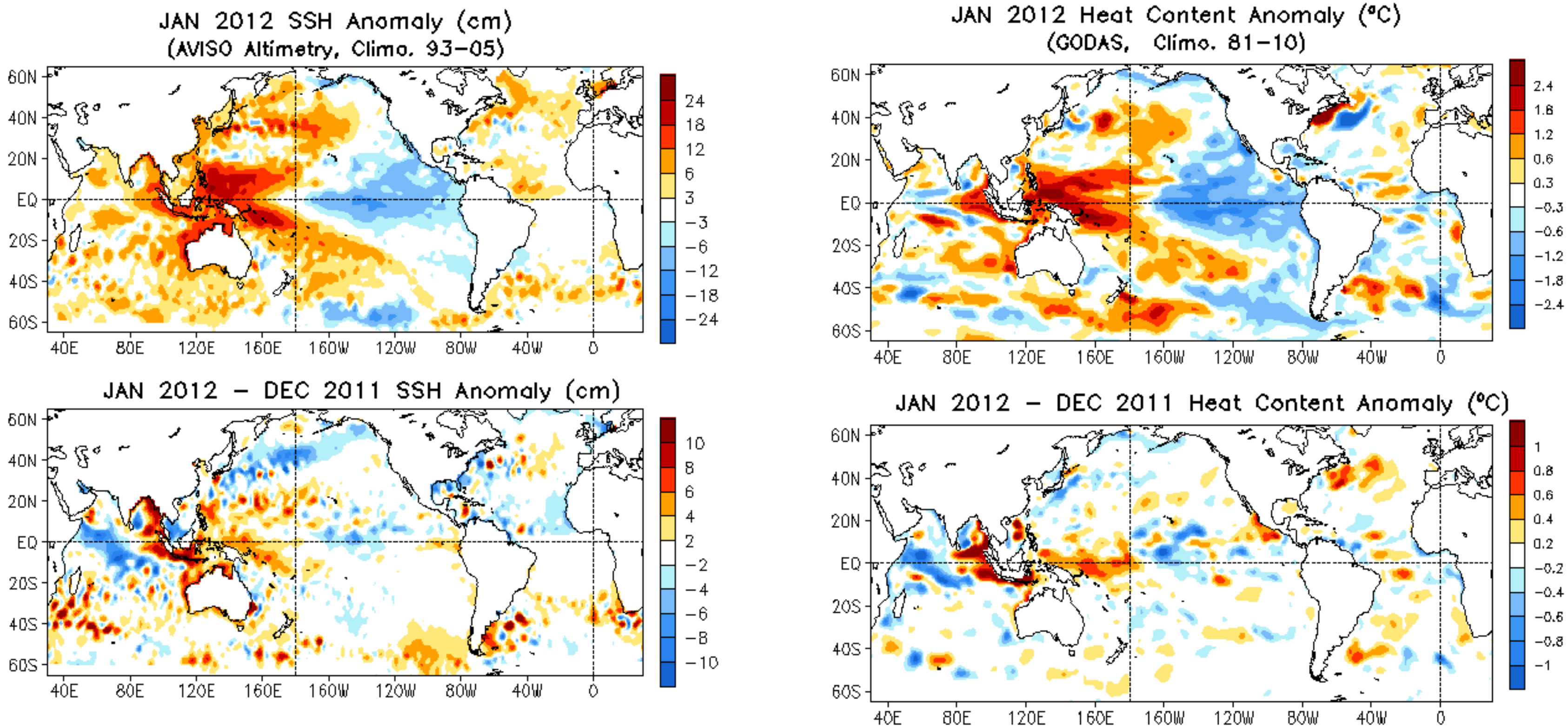


Fig. G2. Sea surface height anomalies (SSHA, top left), SSHA tendency (bottom left), top 300m heat content anomalies (HCA, top right), and HCA tendency (bottom right). SSHA are derived from http://www.aviso.oceanobs.com, and HCA from GODAS.

Longitude-Depth Temperature Anomaly and Anomaly Tendency in 2^{O}S-2^{O}N

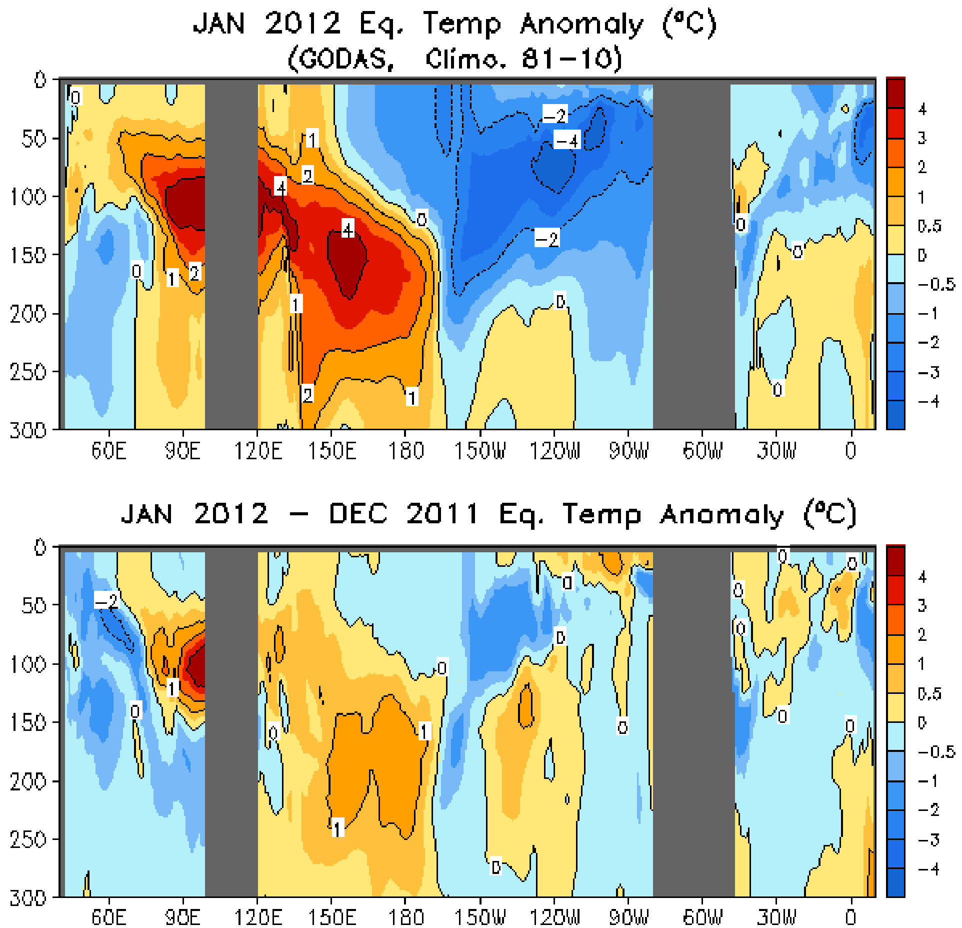


Fig. G3. Equatorial depth-longitude section of ocean temperature anomalies (top) and anomaly tendency (bottom). Data are derived from the NCEP's global ocean data assimilation system which assimilates oceanic observations into an oceanic GCM. Anomalies are departures from the 1981-2010 base period means.

Evolution of Pacific NINO SST Indices

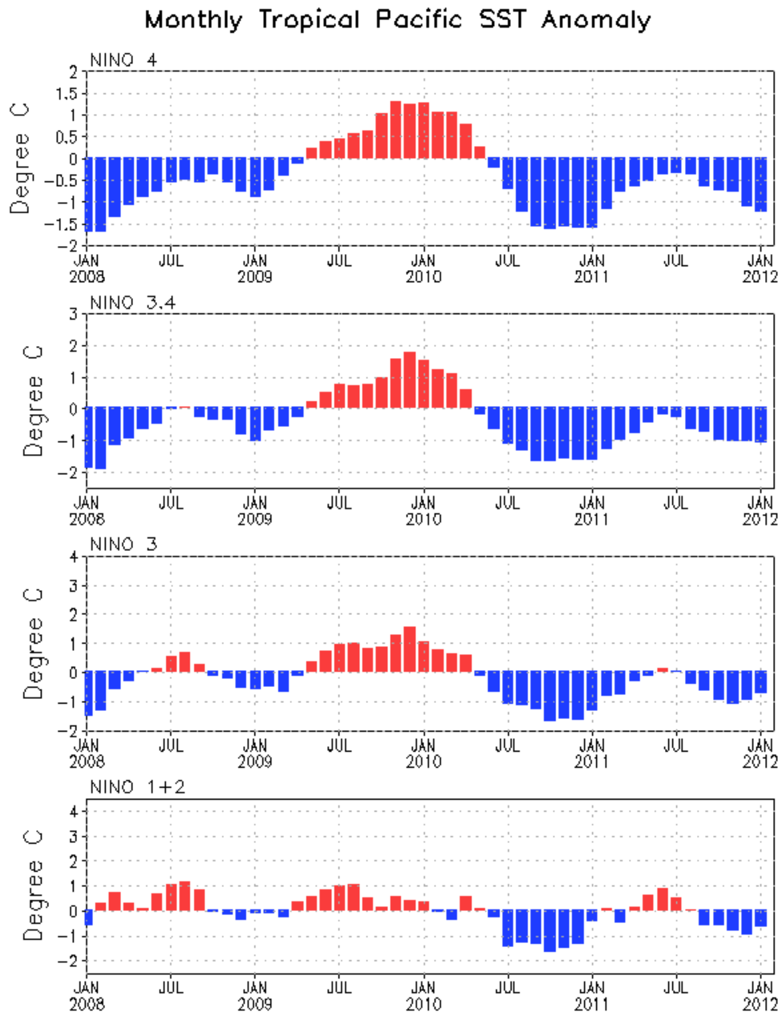
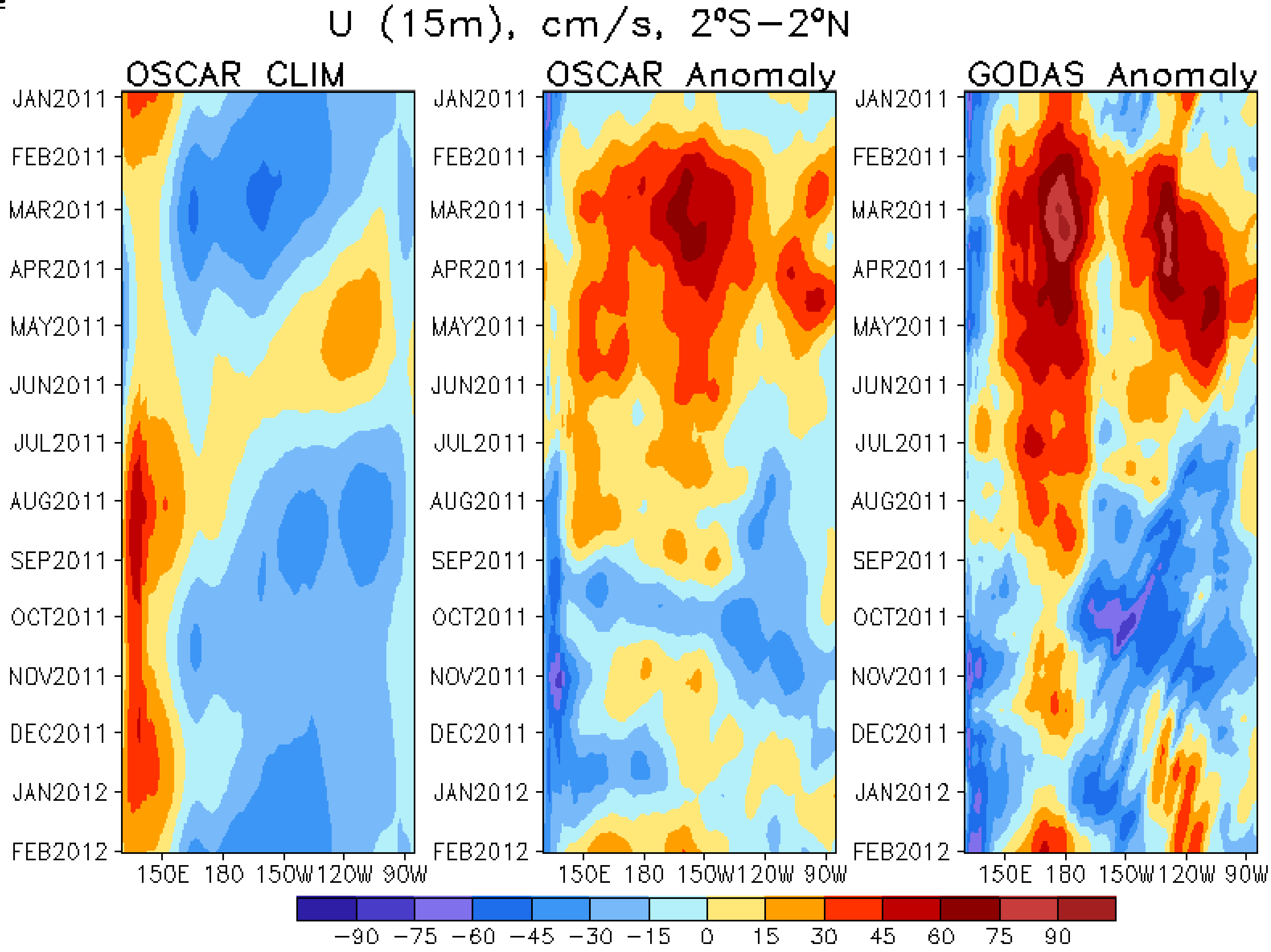


Fig. P1a. Nino region indices, calculated as the area-averaged monthly mean sea surface temperature anomalies (ºC) for the specified region. Data are derived from the NCEP OI SST analysis, and anomalies are departures from the 1981-2010 base period means.

Evolution of Equatorial Pacific Surface Zonal Current Anomaly (cm/s)



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

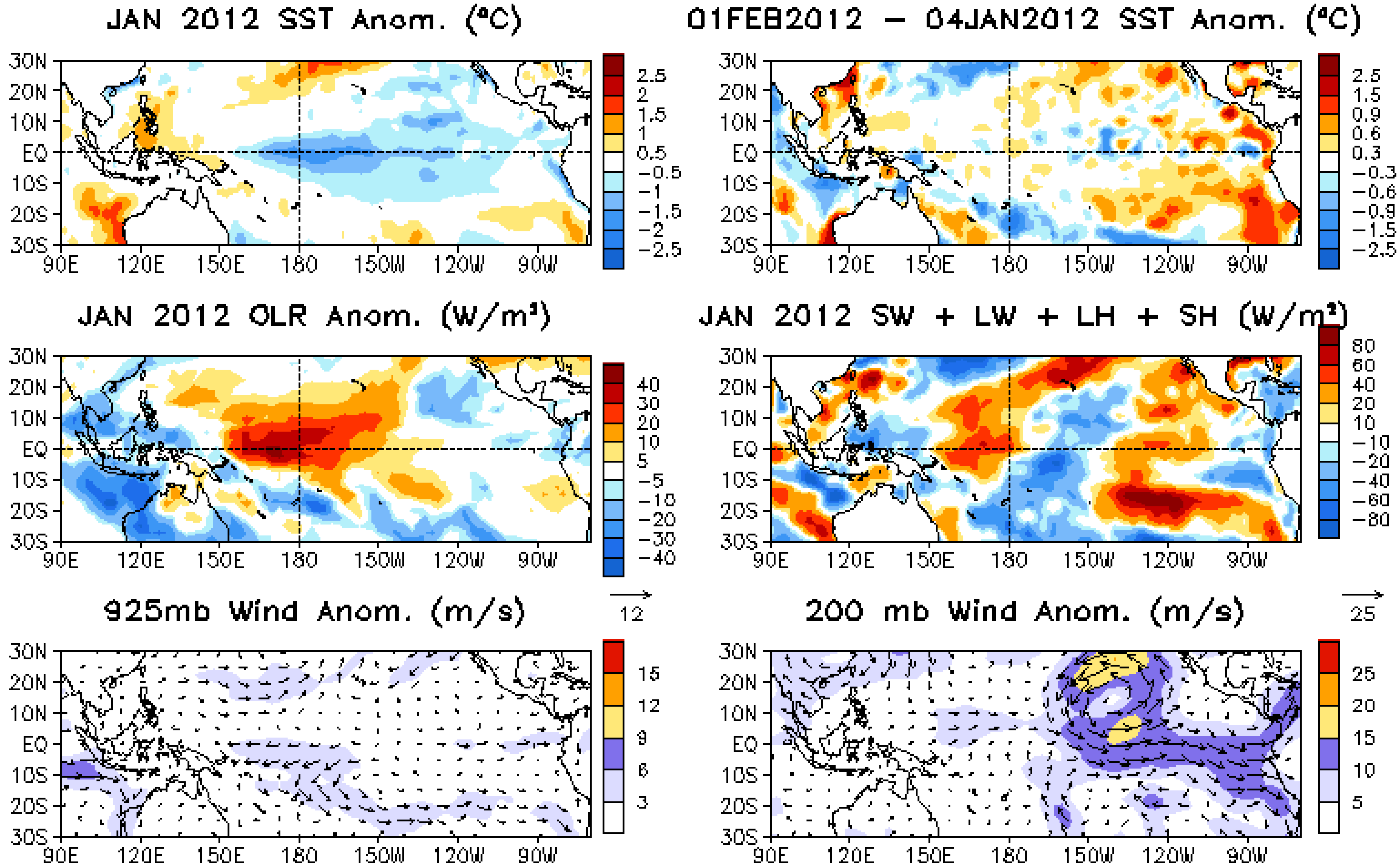
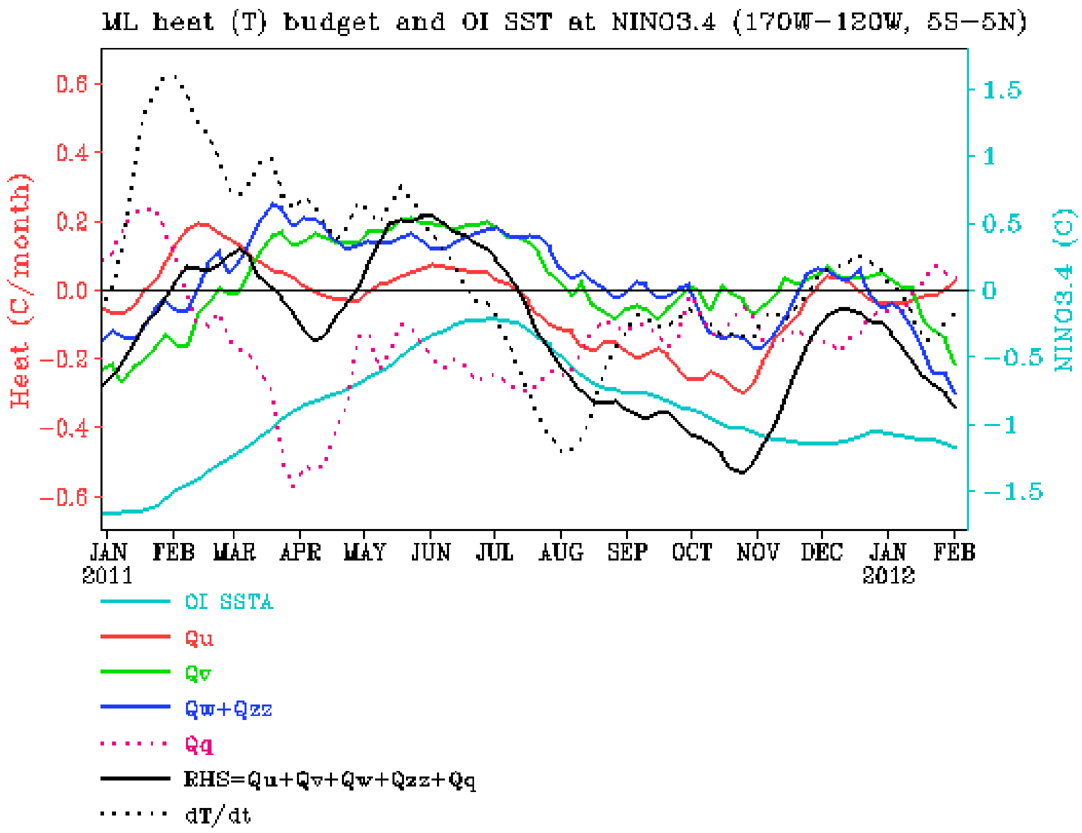


Fig. P2. Sea surface temperature (SST) anomalies (top-left), anomaly tendency (top-right), Outgoing Long-wave Radiation (OLR) anomalies (middle-left), sum of net surface short- and long-wave radiation, latent and sensible heat flux anomalies (middle-right), 925-mb wind anomaly vector and its amplitude (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.

NINO3.4 Heat Budget



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

North Pacific & Arctic Ocean: SST Anom., SST Anom. Tend., OLR. SLP. Sfc Rad. Sfc Flx

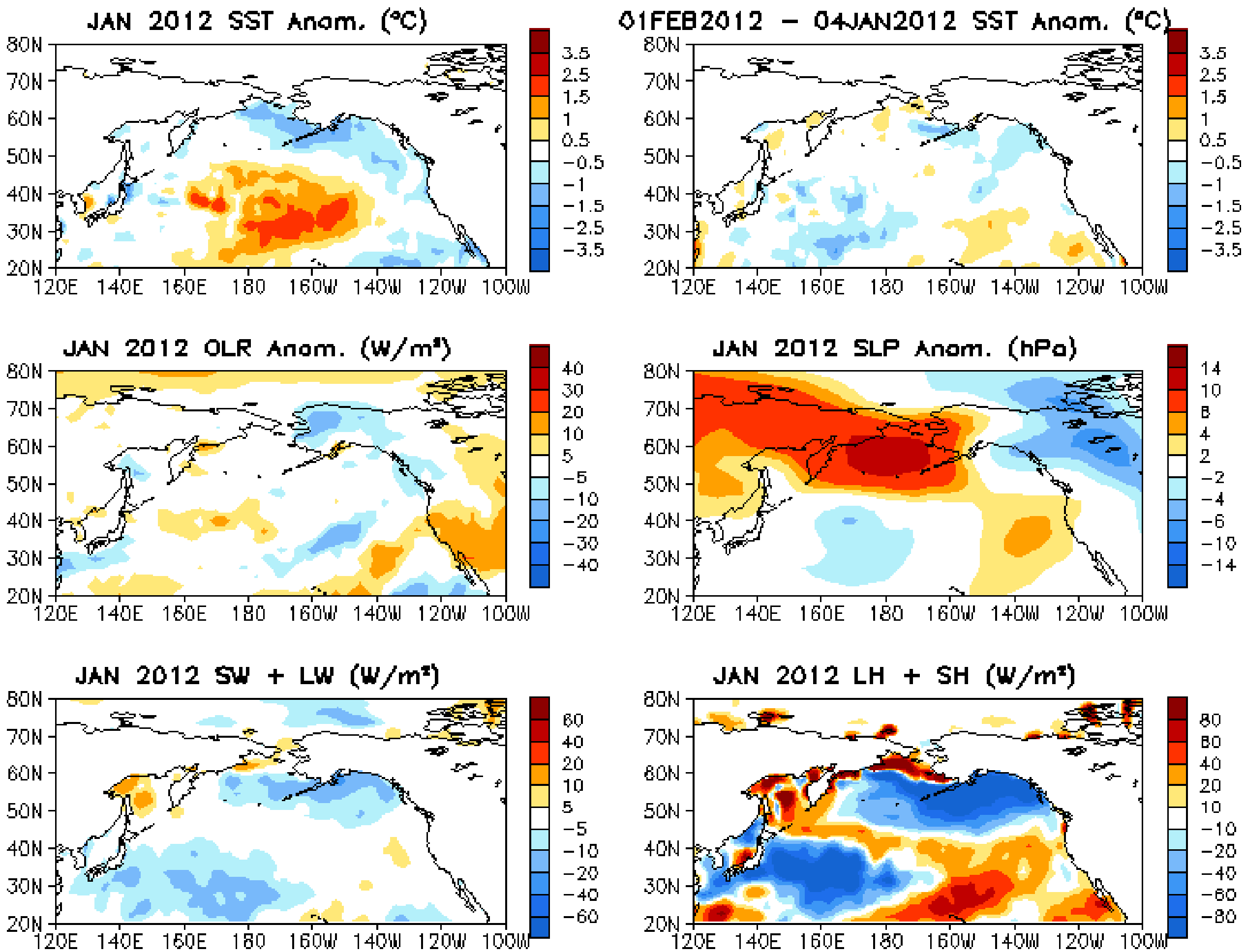
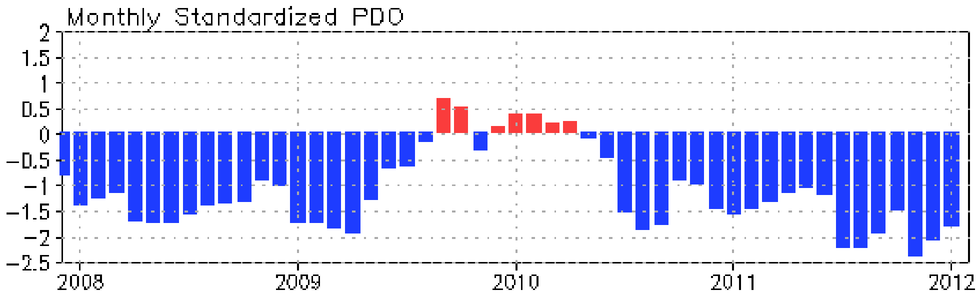
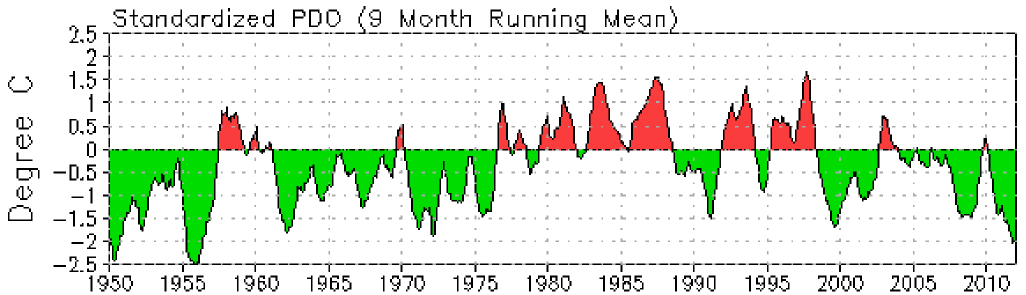
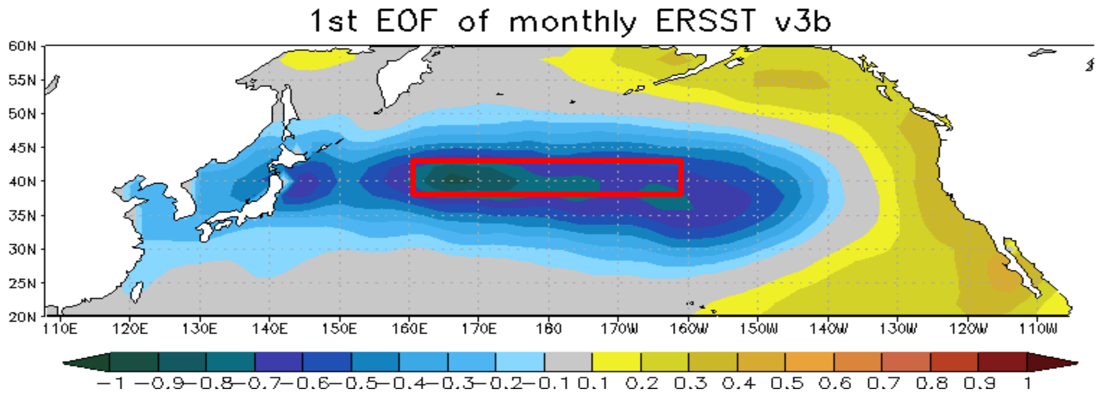


Fig. NP1. Sea surface temperature (SST) anomalies (top-left), anomaly tendency (top-right), Outgoing Long-wave Radiation (OLR) anomalies (middle-left), sea surface pressure anomalies (middle-right), sum of net surface short- and long-wave radiation anomalies (bottom-left), sum of latent and sensible 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.

PDO index

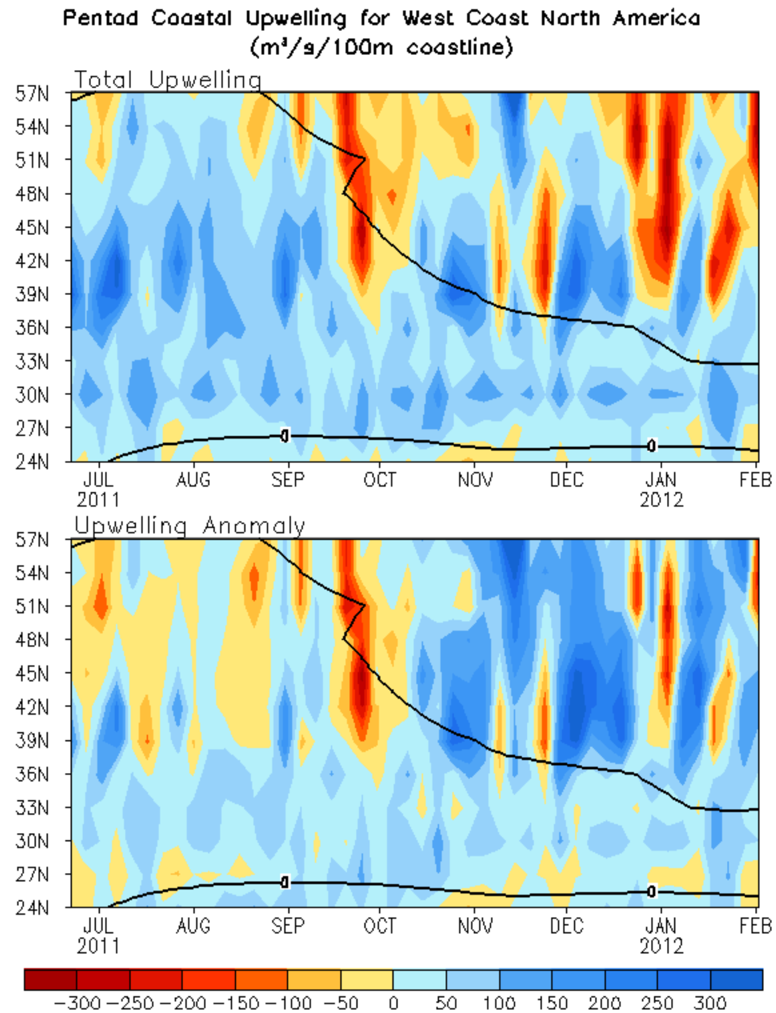






- **Pacific Decadal Oscillation is defined as the 1st EOF of monthly ERSST v3b in the North Pacific for the period 1900-1993. PDO index is the standardized projection of the monthly SST anomalies onto the 1st EOF pattern.**
- **The PDO index differs slightly from that of JISAO, which uses a blend of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

North America Western Coastal Upwelling



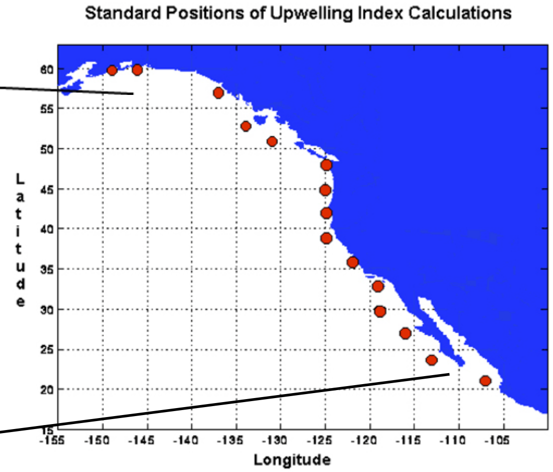


Fig. NP2. Total (top) and anomalous (bottom) upwelling indices at the 15 standard locations for the western coast of North America. Upwelling indices are derived from the vertical velocity of the NCEP's global ocean data assimilation system, and are calculated as integrated vertical volume transport 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 March to July along the west coast of North America from 36°N to 57°N.

Evolution of Indian Ocean SST Indices

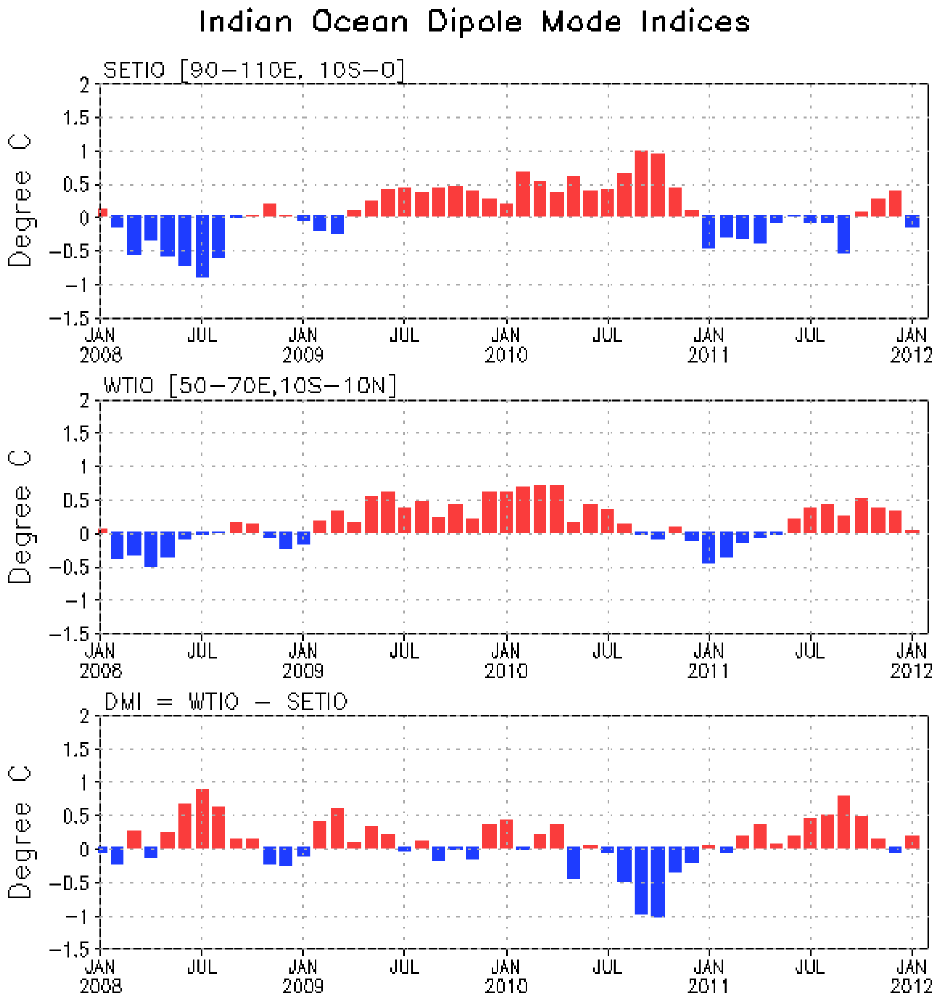


Fig. I1a. Indian Ocean Dipole region indices, calculated as the area-averaged monthly mean sea surface temperature anomalies (°C) for the SETIO [90°E-110°E, 10°S-0] and WTIO [50°E-70°E, 10°S-10°N] regions, and Dipole Mode Index, defined as differences between WTIO and SETIO. Data are derived from the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

Recent Evolution of Equatorial Indian SST (°C), 0-300m Heat Content (°C), and 850-mb Zonal Wind (m/s) Anomalies

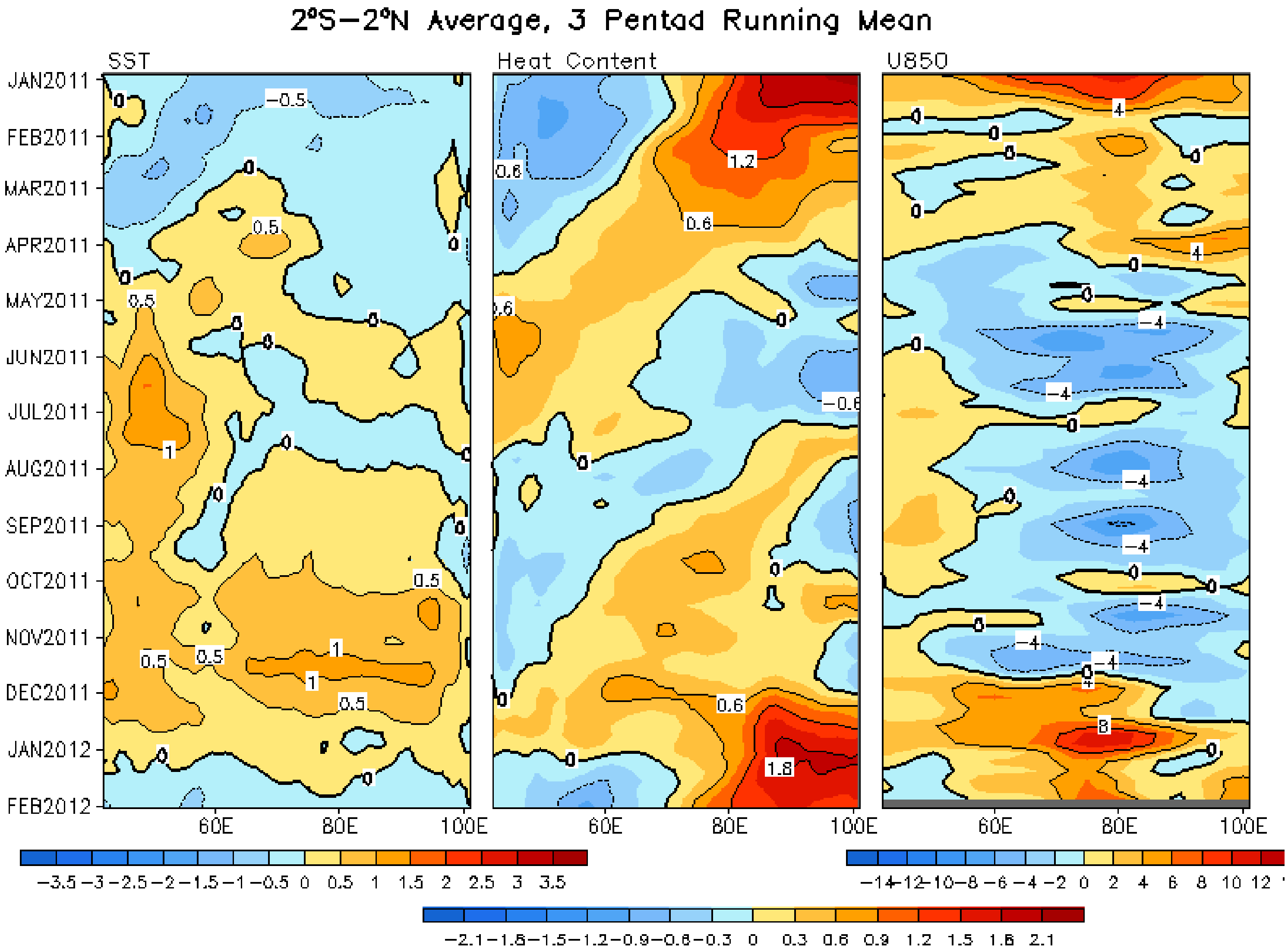


Fig. 13. Time-longitude section of anomalous pentad sea surface temperature (left), upper 300m temperature average (heat content, middle-left), 850-mb zonal wind (U850, middle-right) averaged in 2°S-2°N and Outgoing Long-wave Radiation (OLR, right) averaged in 5°S-5°N. SST are derived from the NCEP OI SST, heat content from the NCEP's global ocean data assimilation system, and U850 from the NCEP CDAS. Anomalies are departures from the 1981-2010 base period pentad means.

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

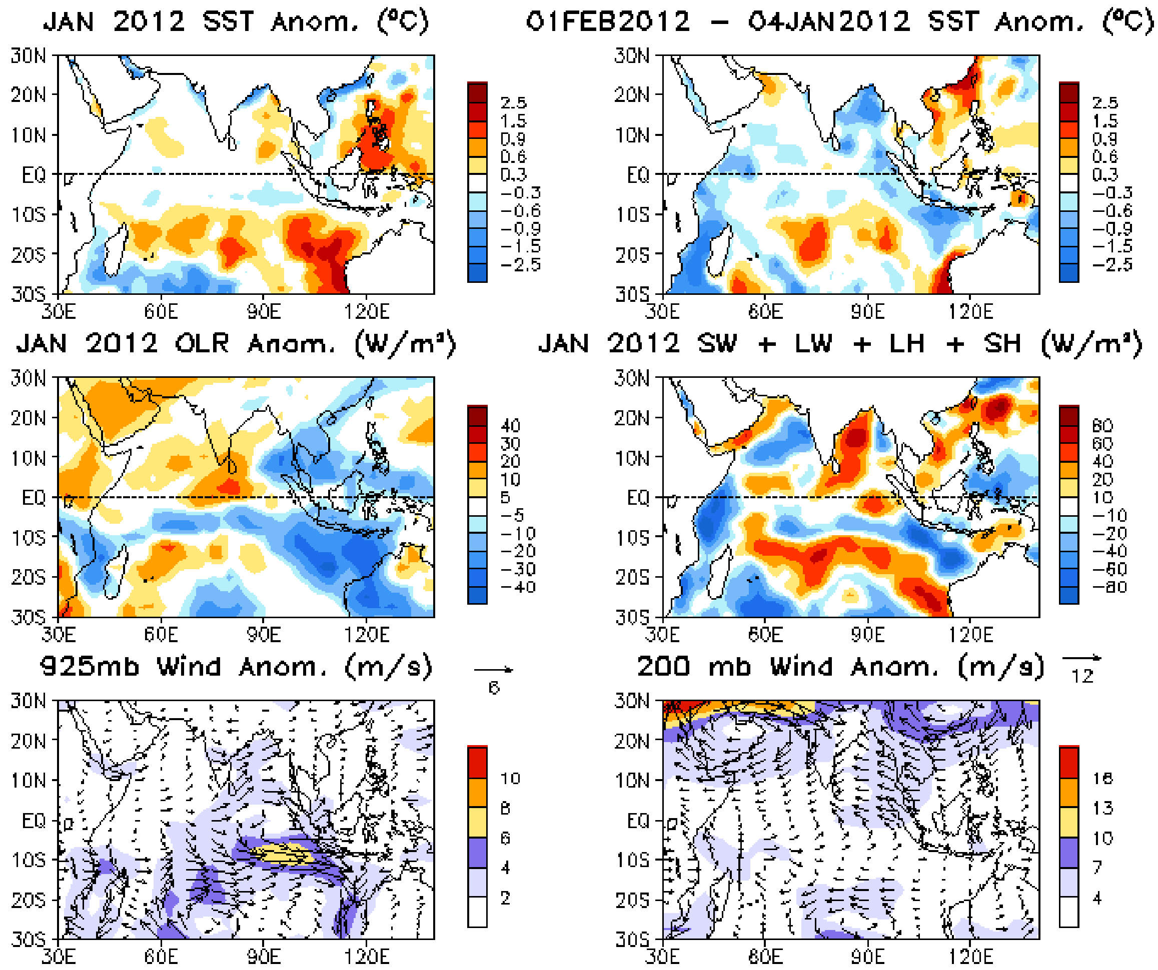


Fig. I2. Sea surface temperature (SST) anomalies (top-left), anomaly tendency (top-right), Outgoing Long-wave Radiation (OLR) anomalies (middle-left), sum of net surface short- and long-wave radiation, latent and sensible heat flux anomalies (middle-right), 925-mb wind anomaly vector and its amplitude (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.

Evolution of Tropical Atlantic SST Indices

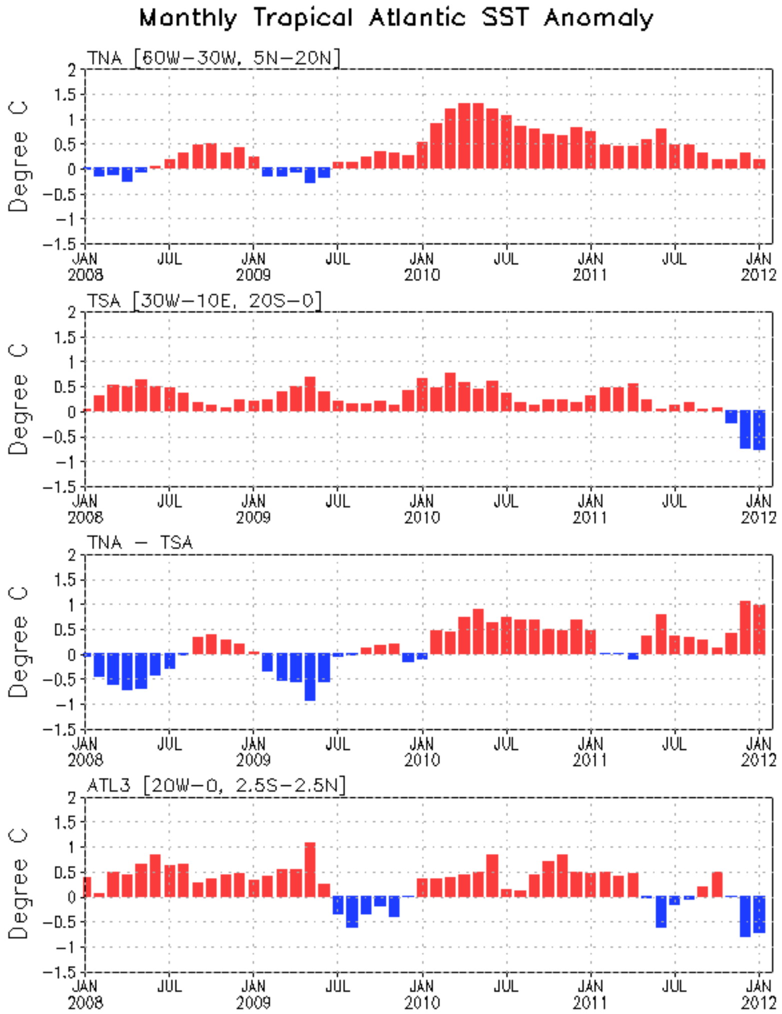
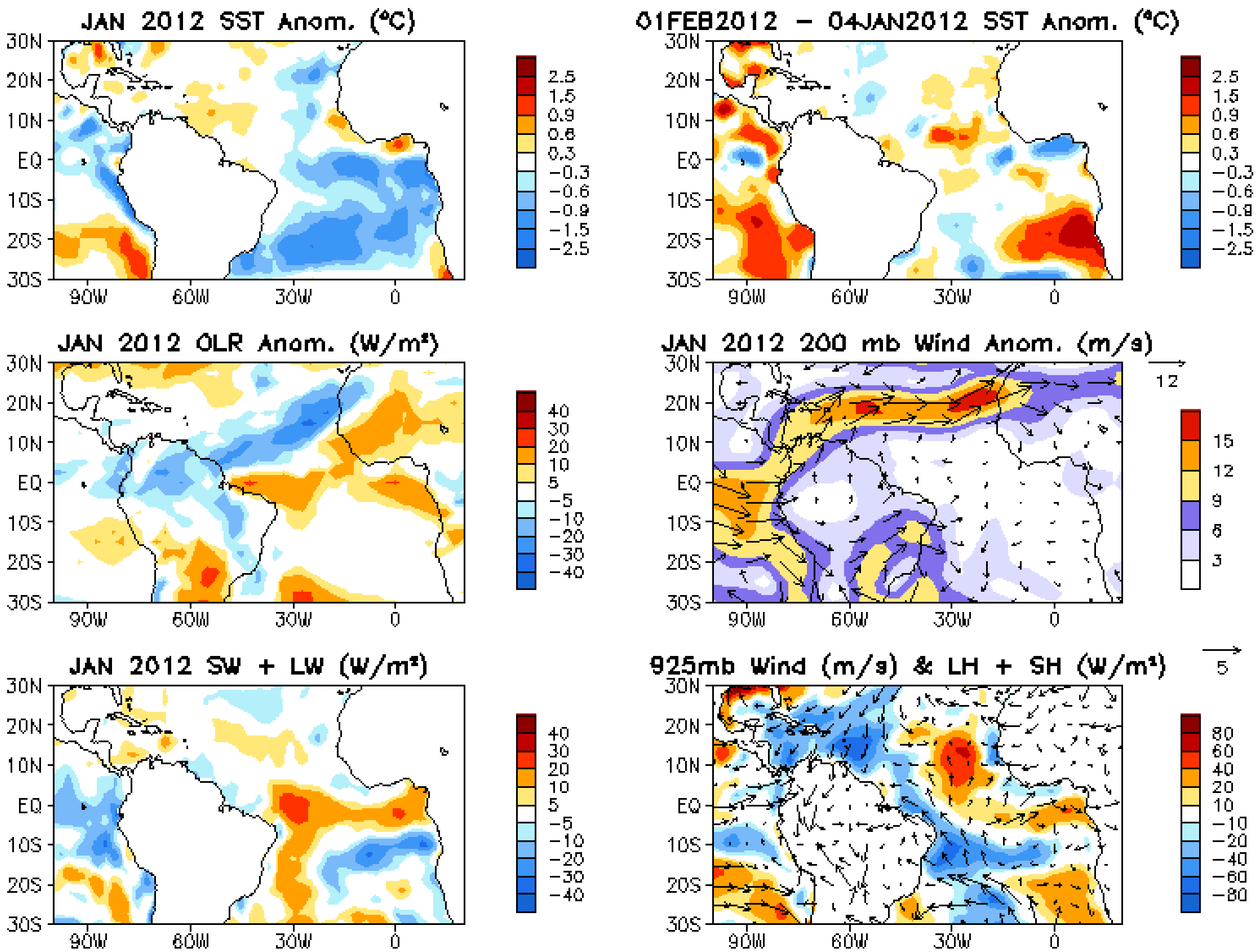


Fig. A1a. Tropical Atlantic Variability region indices, calculated as the area-averaged monthly mean sea surface temperature anomalies (°C) for the TNA [60°W-30°W, 5°N-20°N], TSA [30°W-10°E, 20°S-0] and ATL3 [20°W-0, 2.5°S-2.5°N] regions, and Meridional Gradient Index, defined as differences between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

Tropical Atlantic:



North Atlantic: SST Anom., SST Anom. Tend., OLR, SLP, Sfc Rad, Sfc Flx

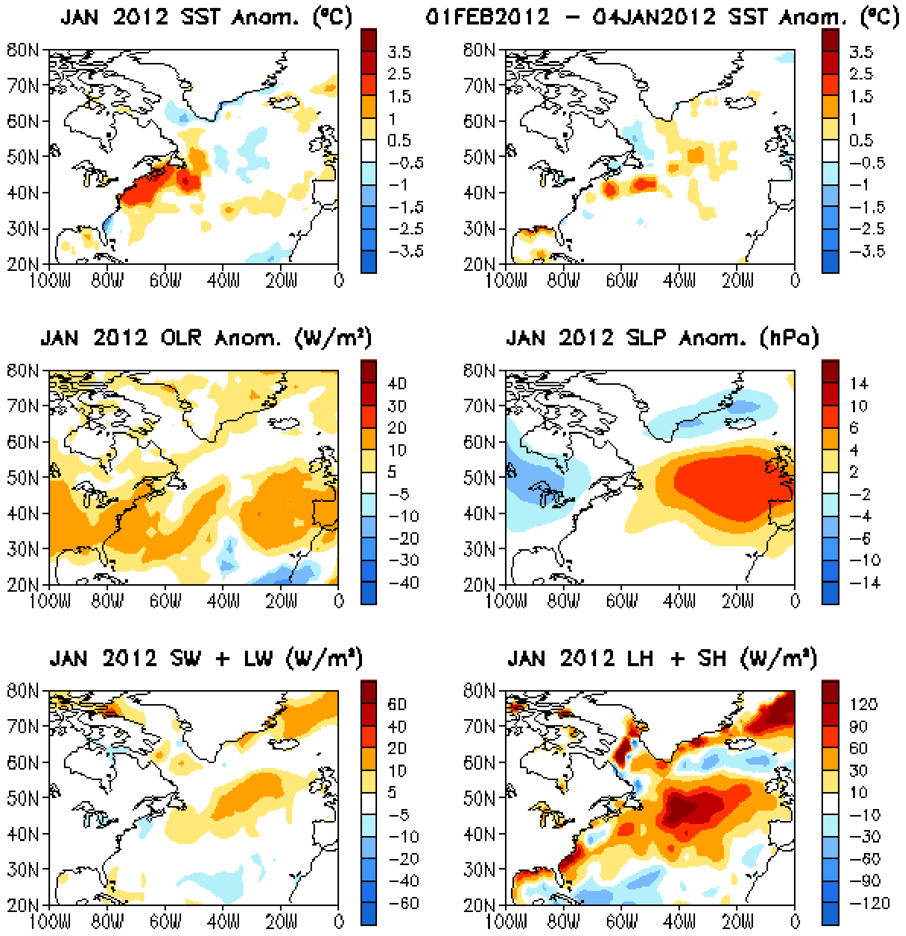


Fig. NA1. Sea surface temperature (SST) anomalies (top-left), anomaly tendency (top-right), Outgoing Long-wave Radiation (OLR) anomalies (middle-left), sea surface pressure anomalies (middle-right), sum of net surface short- and long-wave radiation anomalies (bottom-left), sum of latent and sensible 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 1981-2010 base period means.

NAO and SST Anomaly in North Atlantic

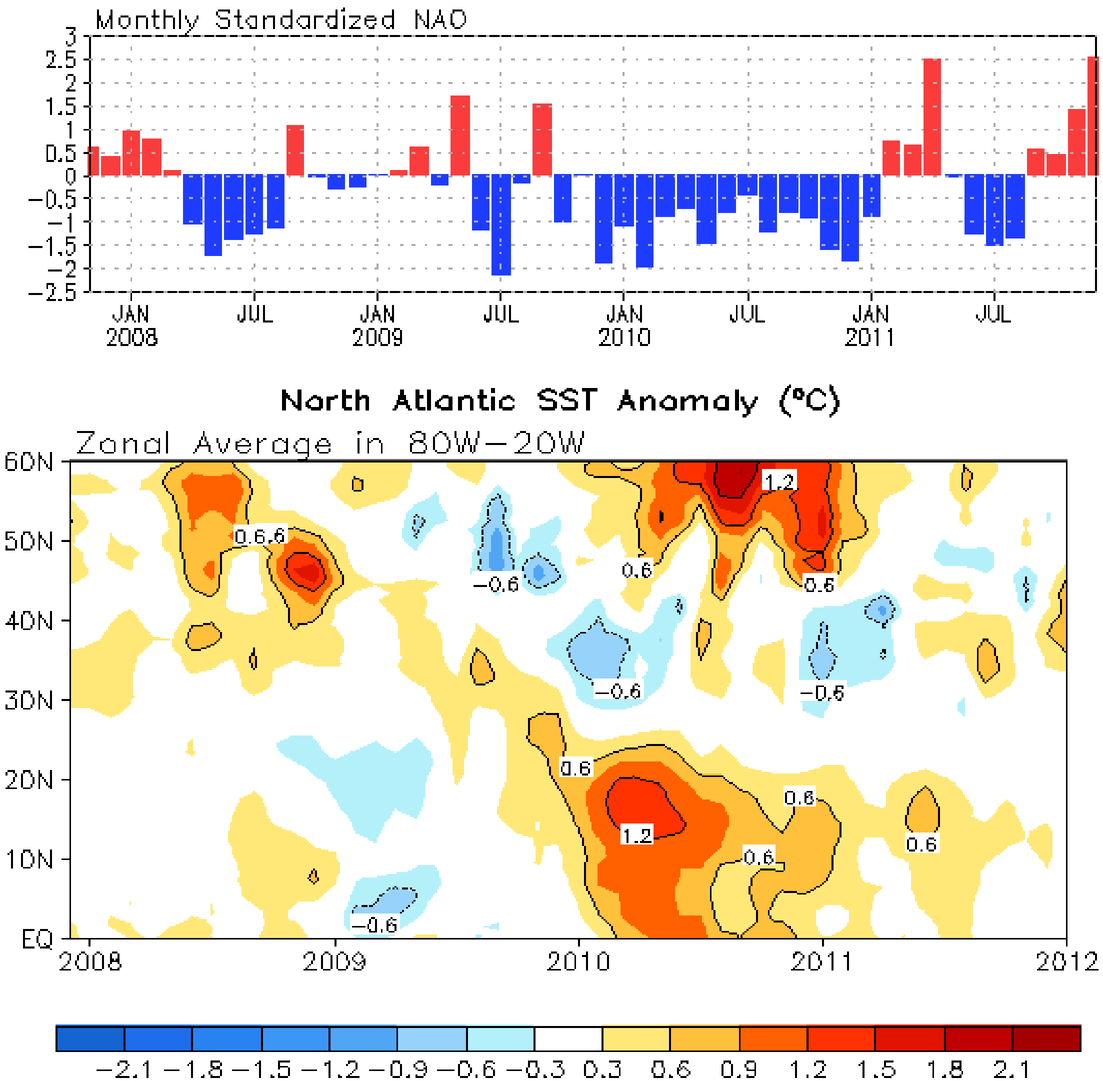


Fig. NA2. Monthly standardized NAO index (top) derived from monthly standardized 500-mb height anomalies obtained from the NCEP CDAS in 20°N-90°N (http://www.cpc.ncep.noaa.gov). Time-Latitude section of SST anomalies averaged between 80°W and 20°W (bottom). SST are derived from the NCEP OI SST analysis,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