The Annual Cycle of Steric Height and Sea Surface Height in the Equatorial Pacific

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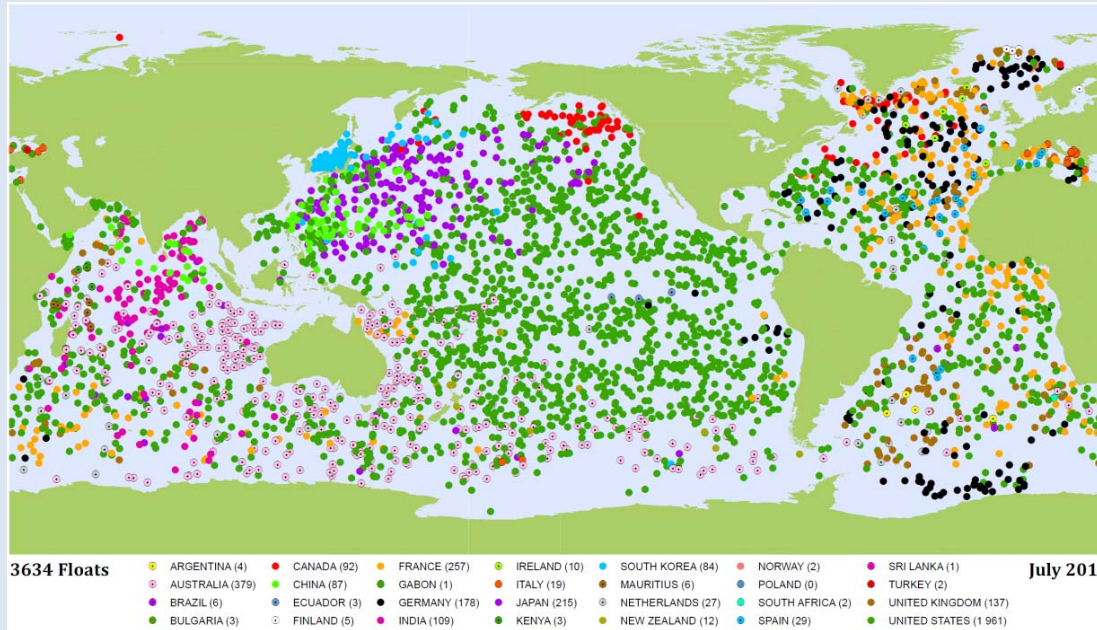
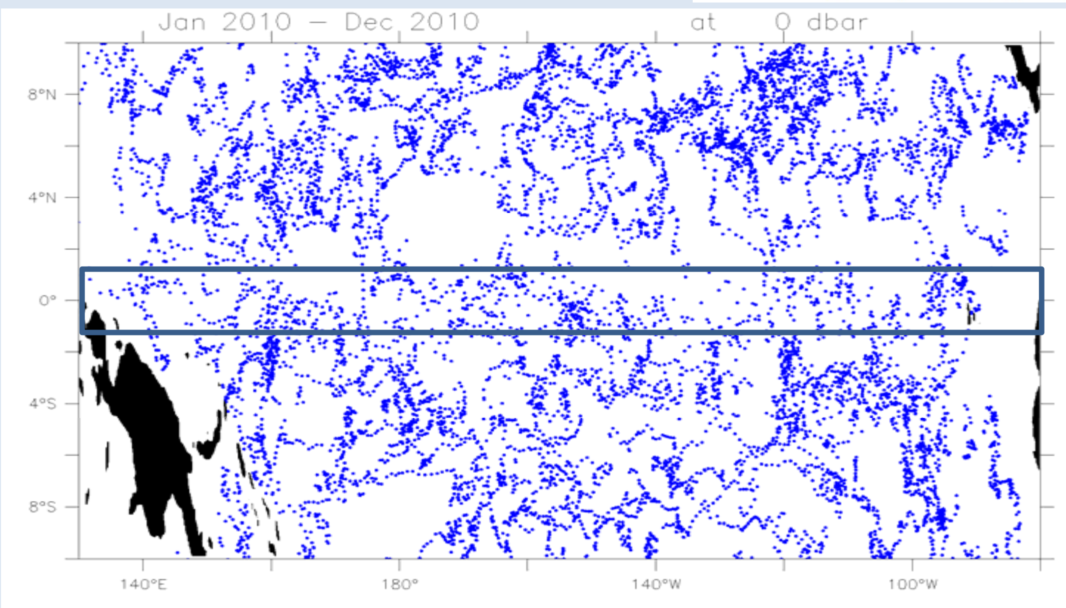
Outline

- Present Argo coverage and float technology improvements related to equatorial sampling.
- The annual cycle of Argo steric height (SH) and altimetric sea surface height (SSH).
- Plans for enhancement: (i) doubling the Argo array along the equator and (ii) adding Deep Argo.

Present Argo coverage

There are (Oct 2013) 51 active Argo floats between 1.5°S – 1.5°N in the Pacific, (~1800 profiles per year, near Argo design), many deployed by U.S. Argo (PMEL) on TAO cruises.





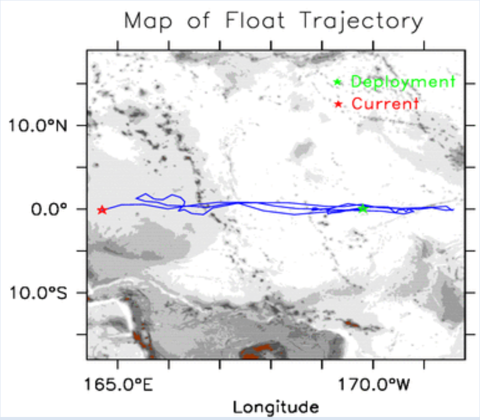
Left: A typical year (2010) of Argo coverage in the equatorial Pacific

Kessler and McCreary (1993) analyzed 20,000 historical profiles between 10°S and 10°N. Argo has 85,000.

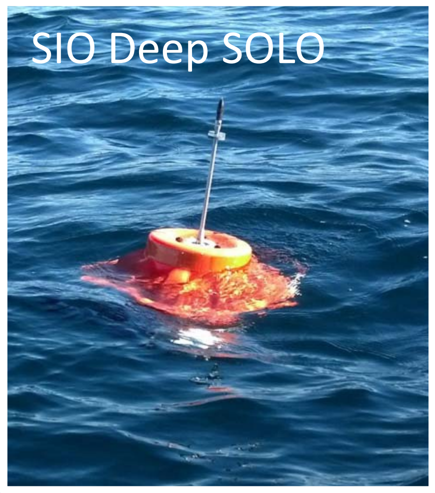
Float technology improvements

New generation floats (SOLO-II, Navis, ARVOR, NOVA)

- Profile 0-2000 dbar anywhere in the world ocean.
- Use Iridium 2-way telecoms:
  - Short surface time (15 mins) greatly reduces equatorial divergence, grounding, bio-fouling, damage.
  - High vertical resolution (2 dbar full profile).
  - Improved surface layer sampling (1 dbar resolution, with pump cutoff at 1 dbar).
- Lightweight (18 kg) for shipping and deployment.
- Increased battery life for > 300 cycles (6 years @ 7-days).



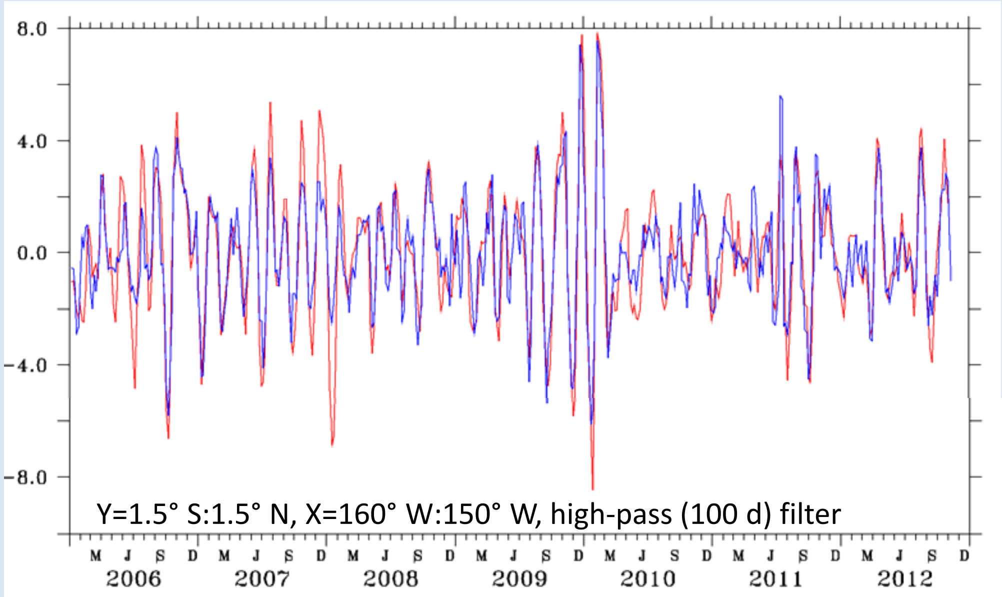
SOLO-II, WMO ID 5903539 (left), deployed 4/2011. Note strong (10 cm/s) annual zonal velocity at 1000 m



Deep Argo: This prototype Deep Argo float was recovered after completing 65 cycles to 4000 m, and is capable of 6000 m.

Adequacy of present Argo sampling

1. Intraseasonal variability in Argo SH (blue) and altimetric SSH (red)

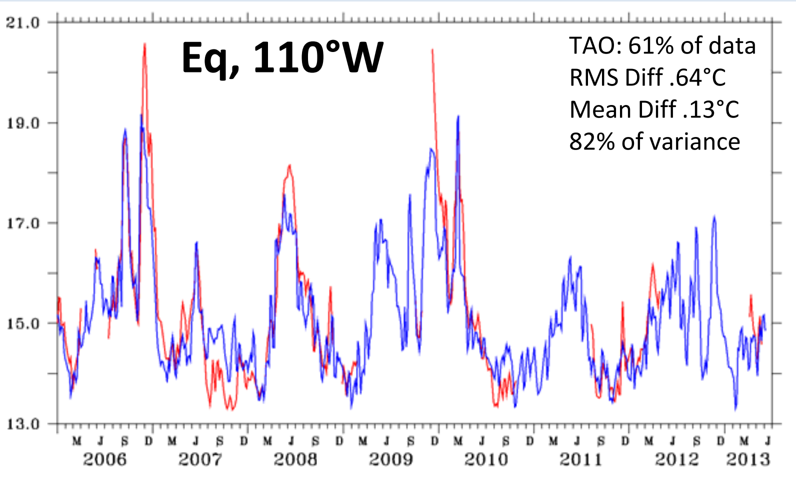


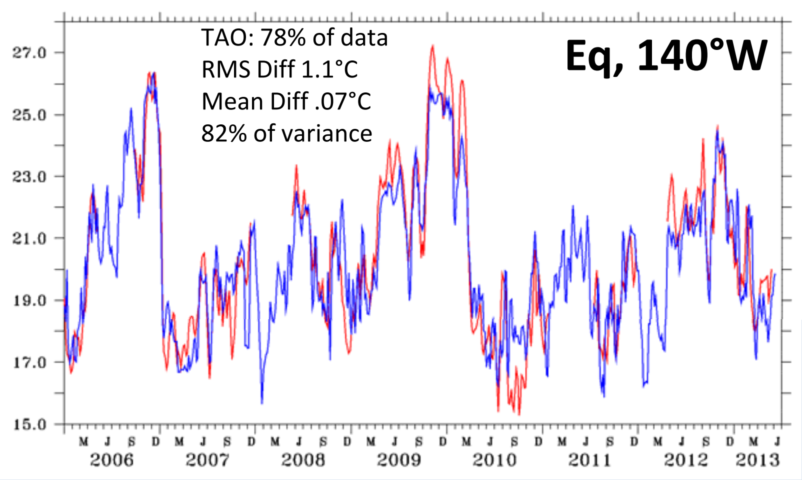
Argo SH captures > 80% of high-passed SSH variance in central equatorial Pacific.

"Missing variance" in SH can be due to Argo undersampling or to deep SH below 2000 m.

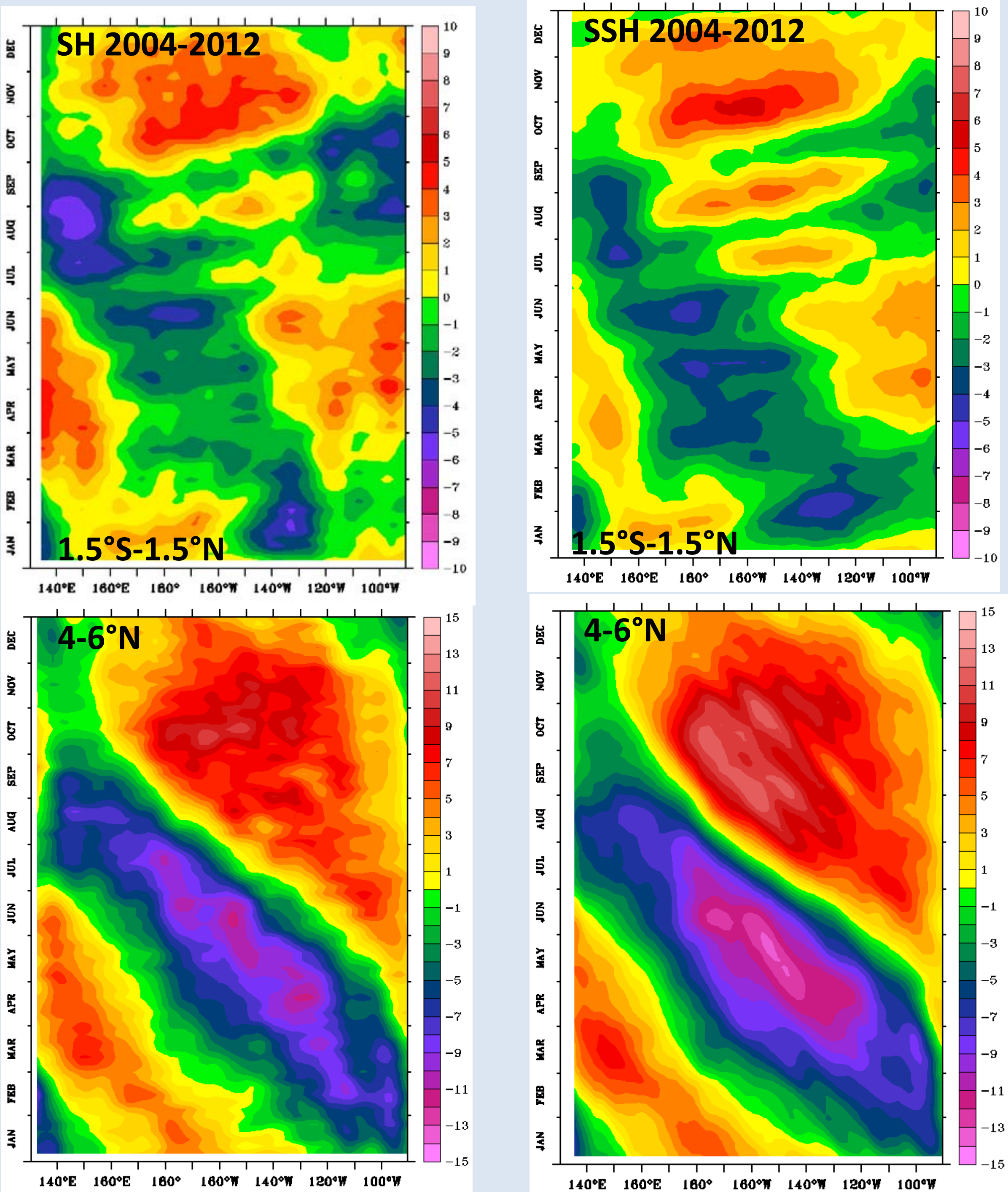
Argo can be improved with more equatorial floats and with Deep Argo floats.

2. Argo 100 m T (blue), and TAO moored 100 m T (red, 10-day smoothing).





Argo captures > 80% of the variance in thermocline temperature on time scales of 10 days and longer.



The Annual Cycle

Time/longitude

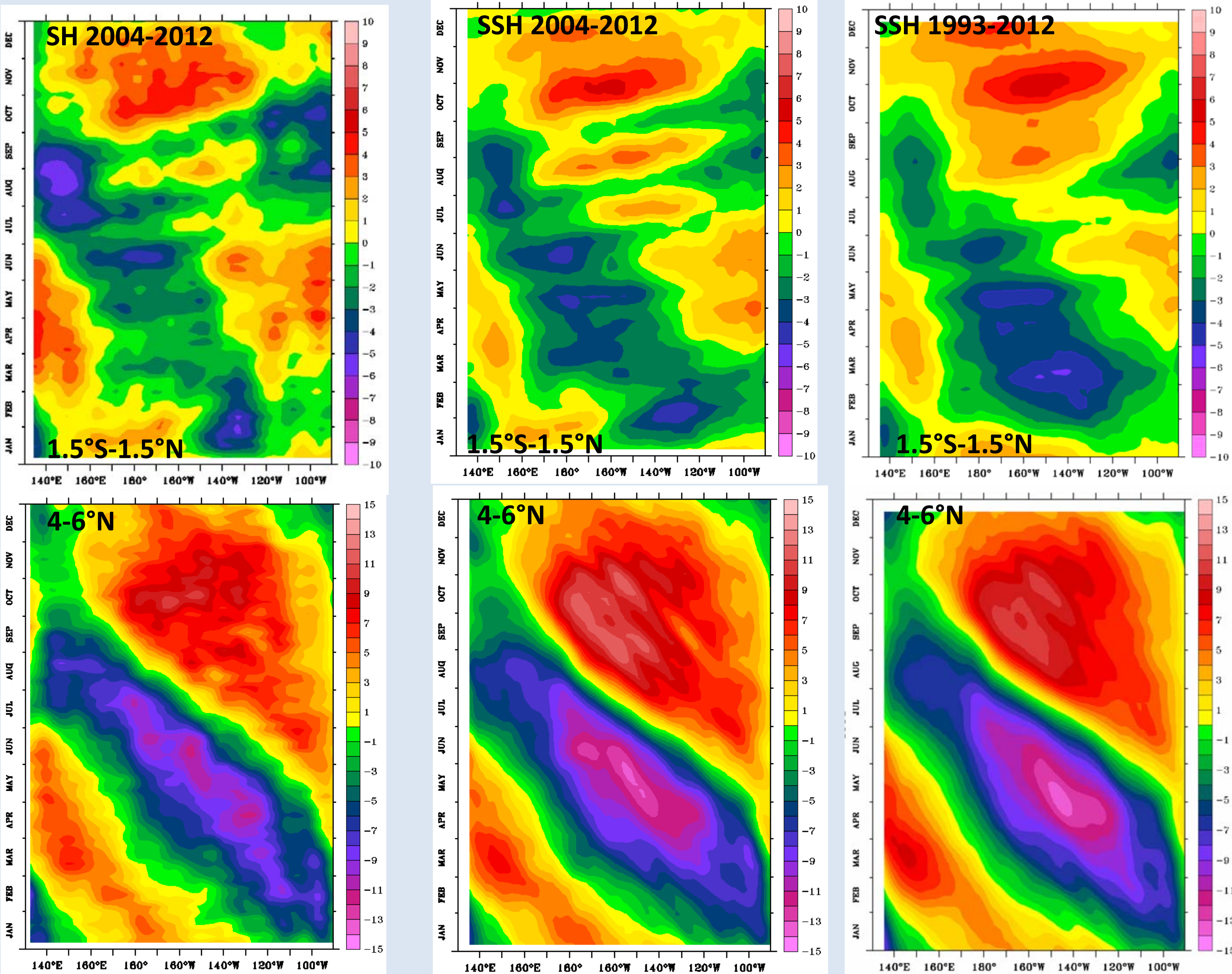
Mean annual cycle (cm, 2004-2012 mean for each time step) from Argo steric height (0/2000 dbar) and altimetric sea surface height.

Top panel is the average from 1.5°S to 1.5°N.

Residuals of intraseasonal eastward propagation are seen in the 9-year means.

Bottom panel: 4°-6°N.

Differences between SH and SSH are dynamically significant. The observing system and its synthesis should account for the combined physical state (wind stress, air-sea fluxes, SST, SSH, and subsurface variability).



SH 2004-2012
1.5°S-1.5°N
SSH 2004-2012
1.5°S-1.5°N
SSH 1993-2012
1.5°S-1.5°N
4-6°N
4-6°N
4-6°N
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
140°E 160°E 180° 160°W 140°W 120°W 100°W

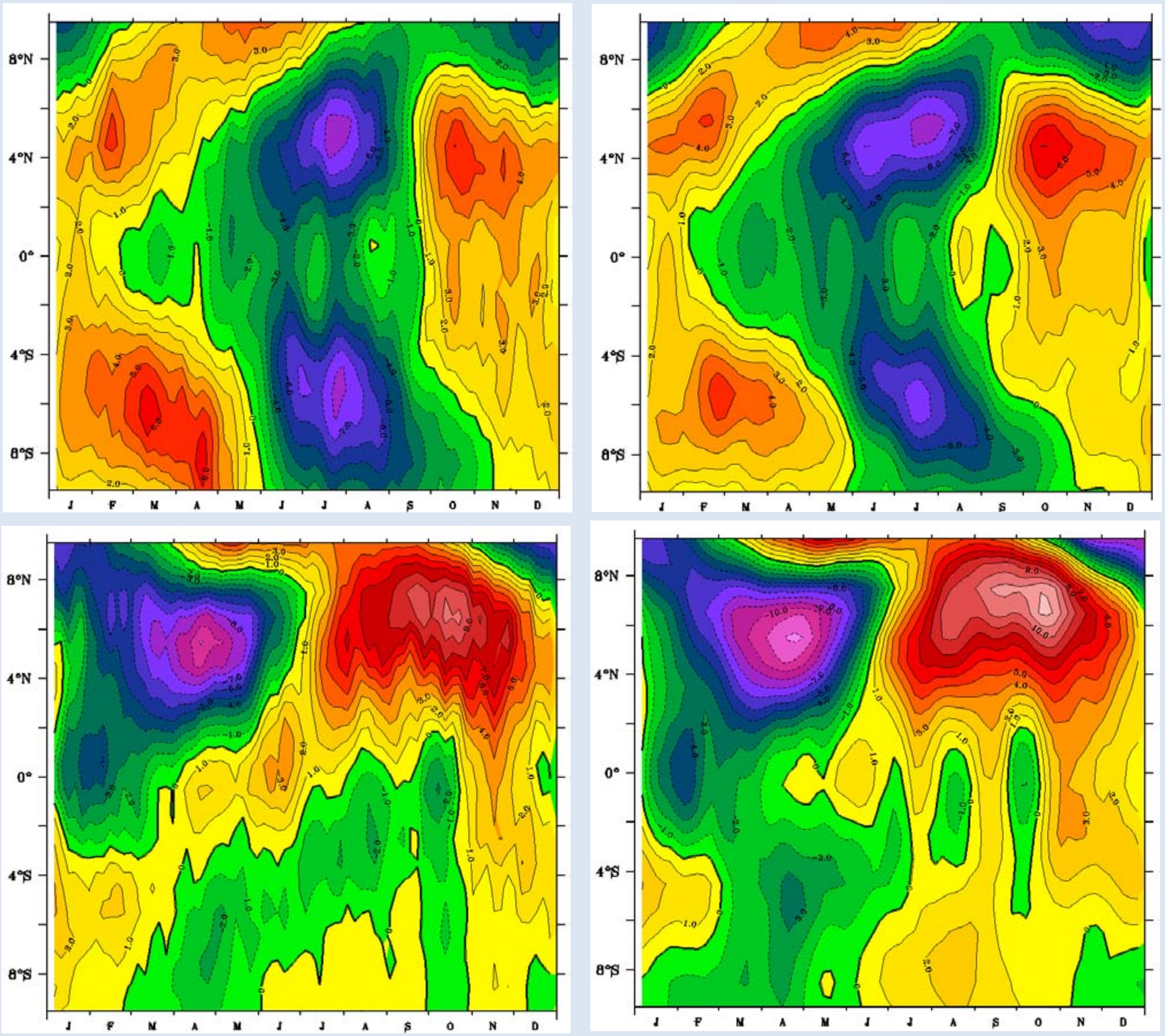
The Annual Cycle

Latitude/time

SH **SSH**

160°E-180°E

140°W-120°W



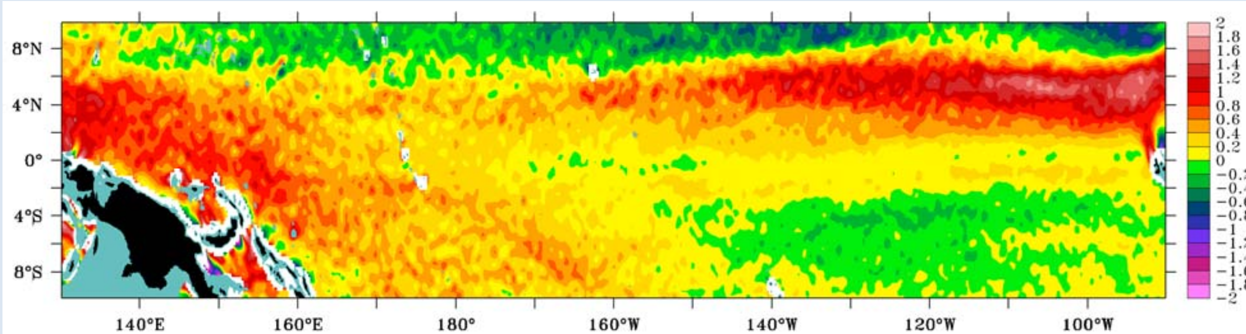
SH and SSH annual cycles are nearly symmetric about the equator in the western Pacific, but the northern hemisphere signal is much larger in the central and eastern Pacific.

Similar to Kessler and McCreary (1993).

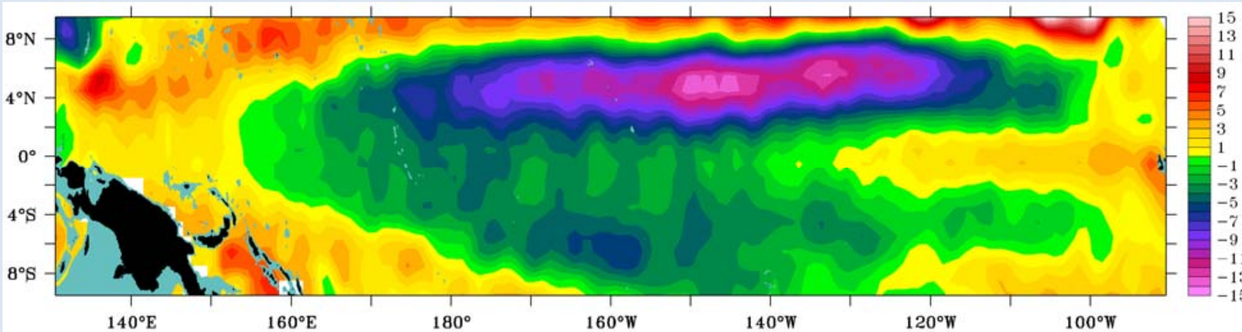
The Annual Cycle

Latitude/longitude monthly anomalies

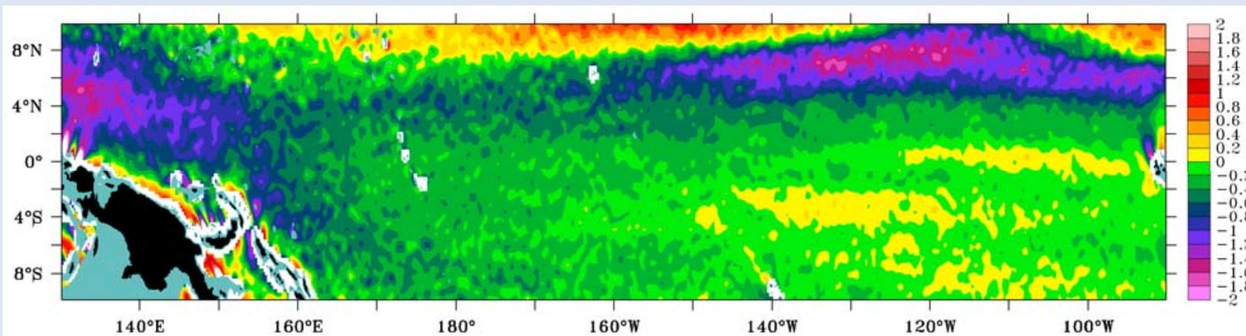
Feb (curl τ)'
N/m² *10⁷
SCOW



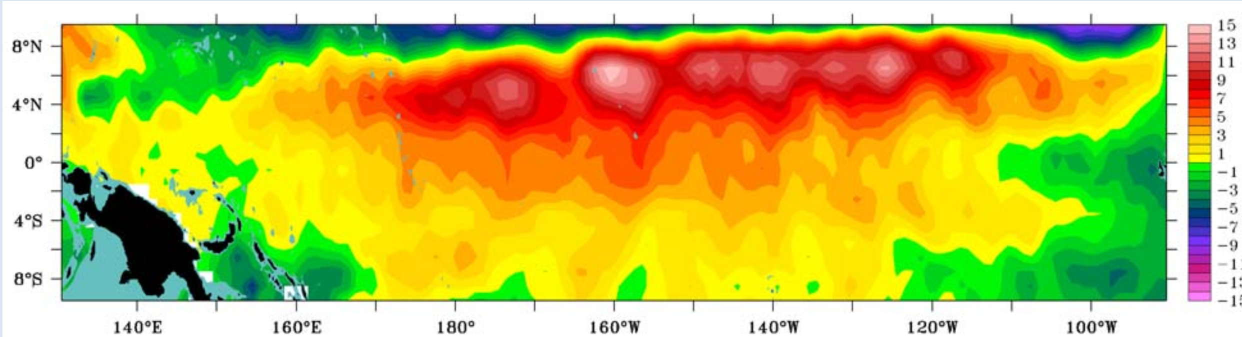
May 1 SSH'



Aug (curl τ)'
N/m² *10⁷
SCOW



Nov 1 SSH'



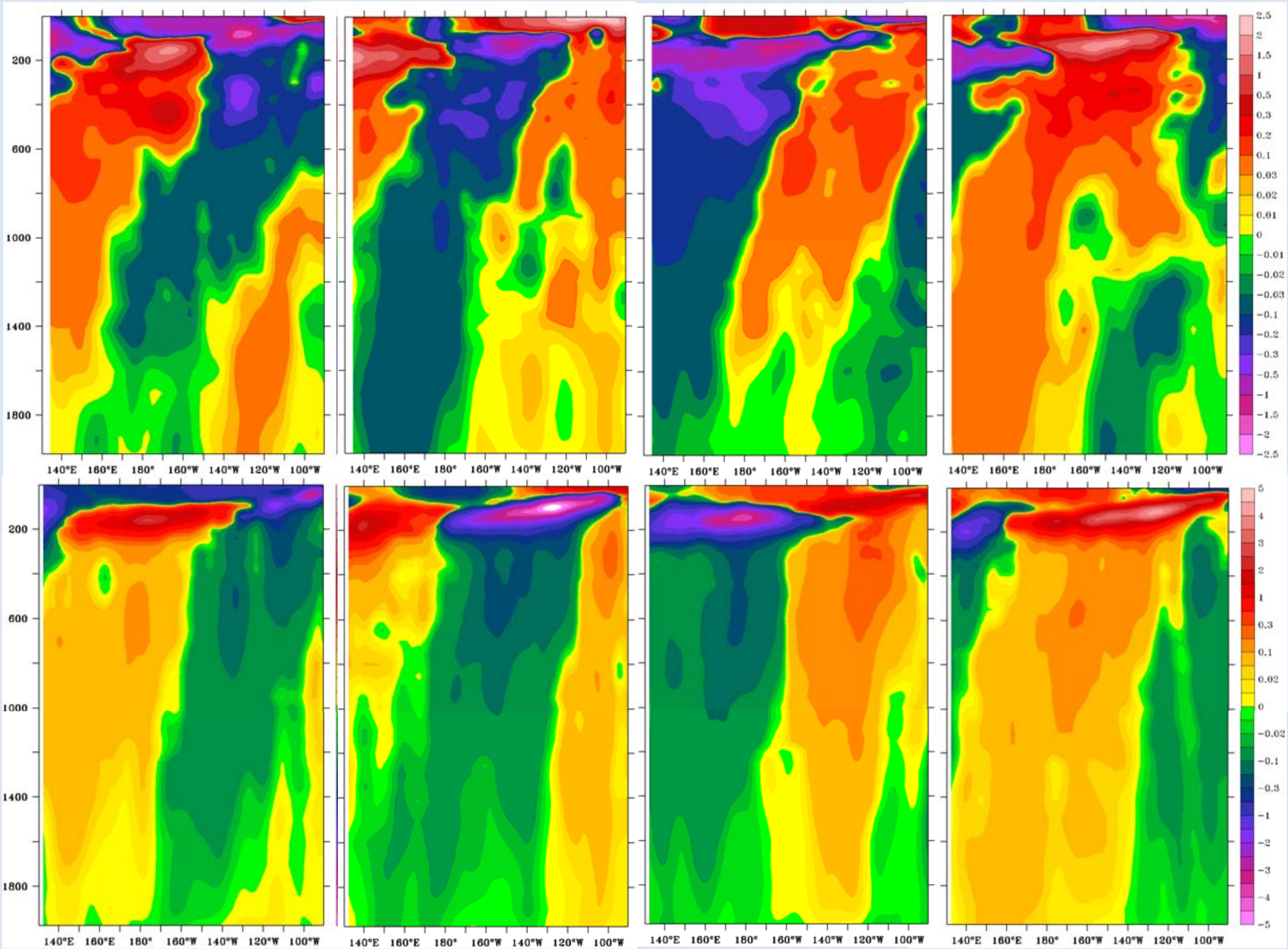
The asymmetry is likely due to wind stress curl forcing in the ITCZ, causing annual variability in the North Equatorial Countercurrent.

The Annual Cycle

Temperature on depth/longitude

Eq

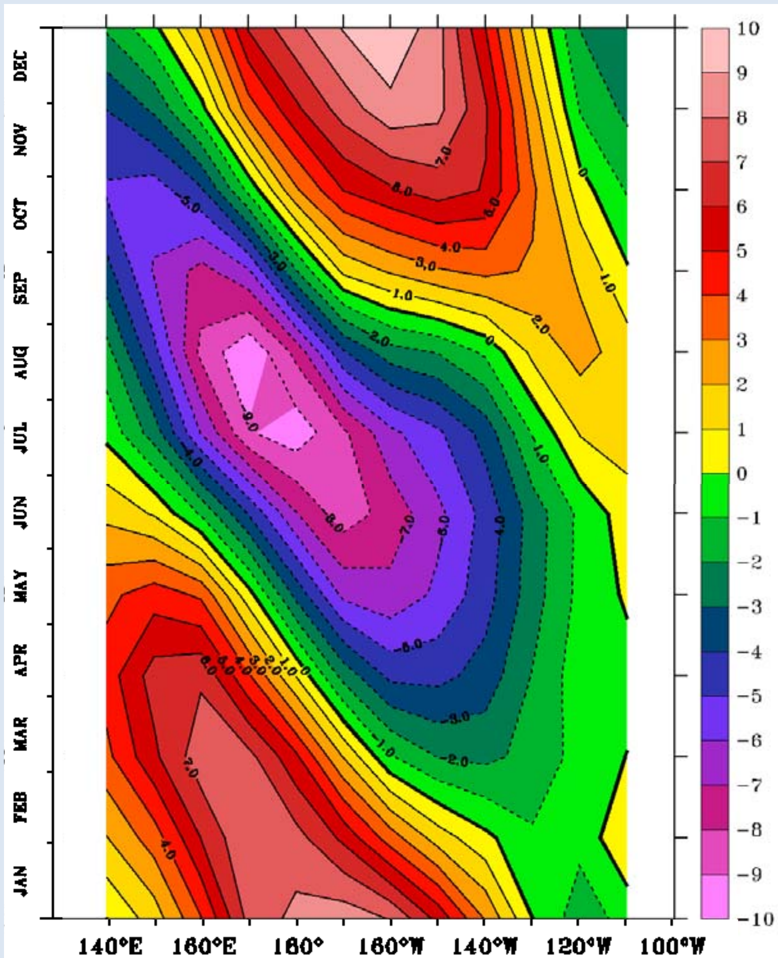
5°N



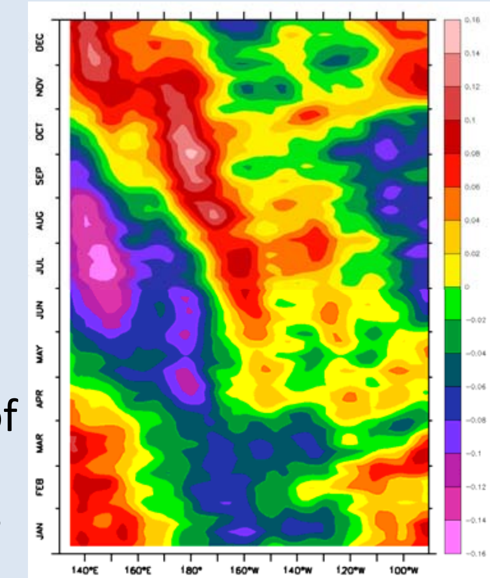
1 Feb 1 May 1 Aug 1 Nov

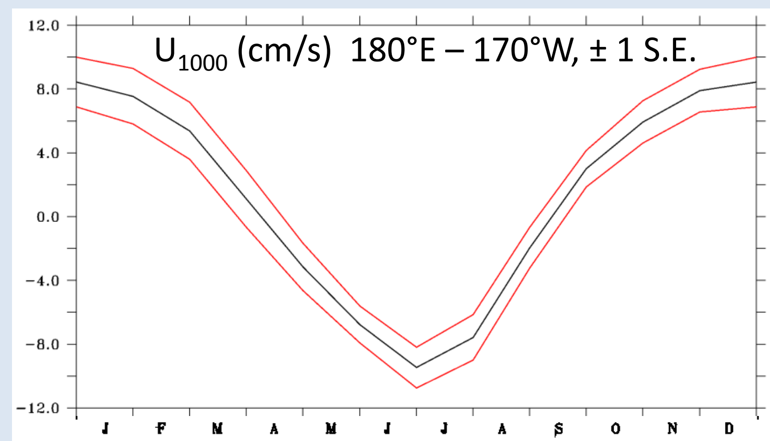
The Annual Cycle

Zonal velocity at 1000 m time/longitude



Right: 1000 m temperature (with less smoothing). Can the granularity of temperature be seen in velocity?





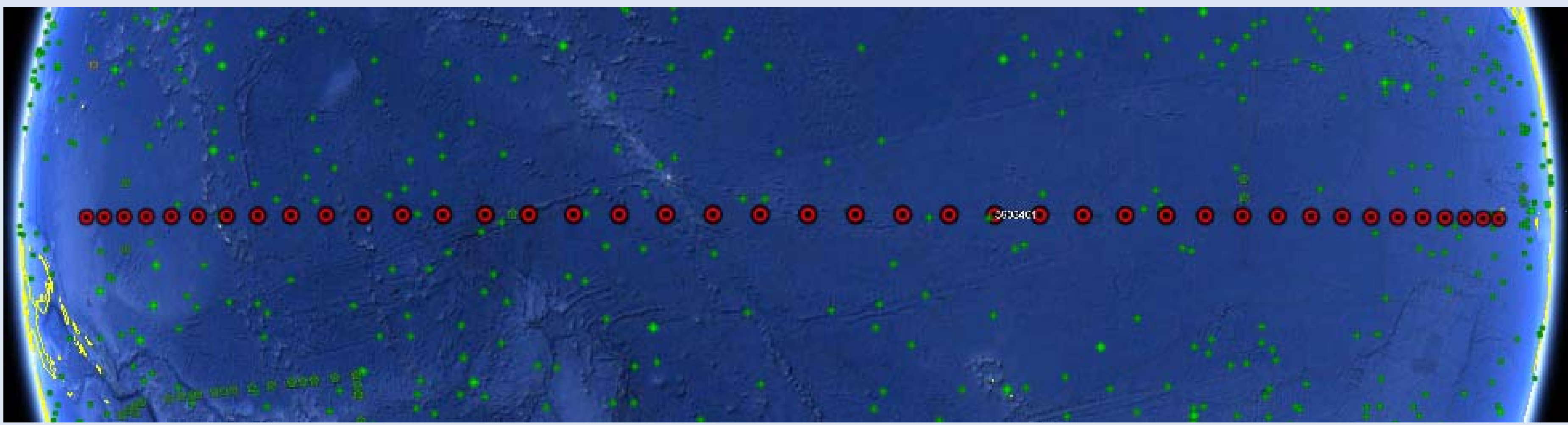
9275 velocity estimates 1.5°S – 1.5°N

Mean of 55 estimates per 10° x 1 month bin

Similar to Cravatte et al. (2012)

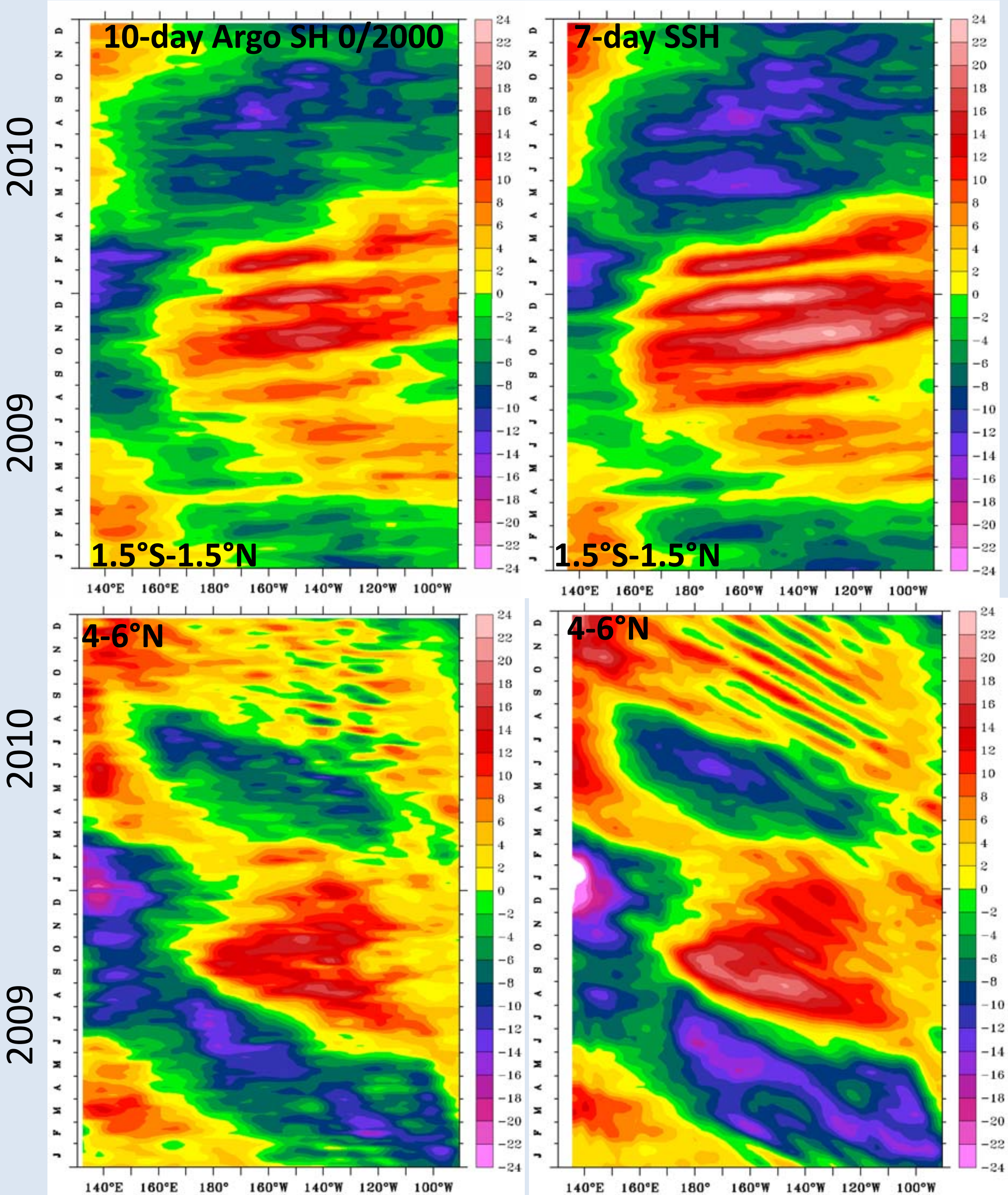
Plans for enhancement – Equatorial floats

- 41 floats will be deployed along the equator from 100°W to 160°E beginning in late 2013.
- 7-day cycling, so 2000 additional profiles per year; (8,000 -10,000 added profiles over 4-5 year lifetime).
- All data immediately available (Argo data system).
- The present program is an enhancement, not a substitution (Argo continues deployment as previously).



Summary

- Advances in profiling float technology have facilitated sampling of the equatorial ocean.
- The present Argo array captures over 80% of the variance in temperature and steric height/sea surface height on time-scales of 10 days and longer.
- Argo and altimetric data describe the annual cycle of the equatorial Pacific in good detail.
  - Westward propagating annual Rossby wave.
  - Asymmetric latitude distribution, likely due to wind stress curl.
  - Pervasive eastward intraseasonal features are not averaged out of annual cycle even in the 20-year SSH record.
- Doubling of equatorial Pacific Argo coverage will be in place by early 2014, enabling improved ocean analysis/synthesis. Deep Argo is needed to observe variability between 2000 m and the ocean bottom.



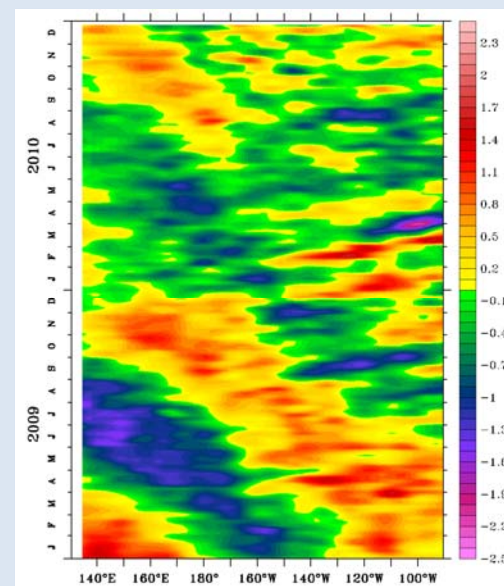
El Niño/La Niña

2009-2010 Argo steric height (0/2000 dbar) and altimetric sea surface height.

Upper panels are the averages from 1.5°S to 1.5°N.

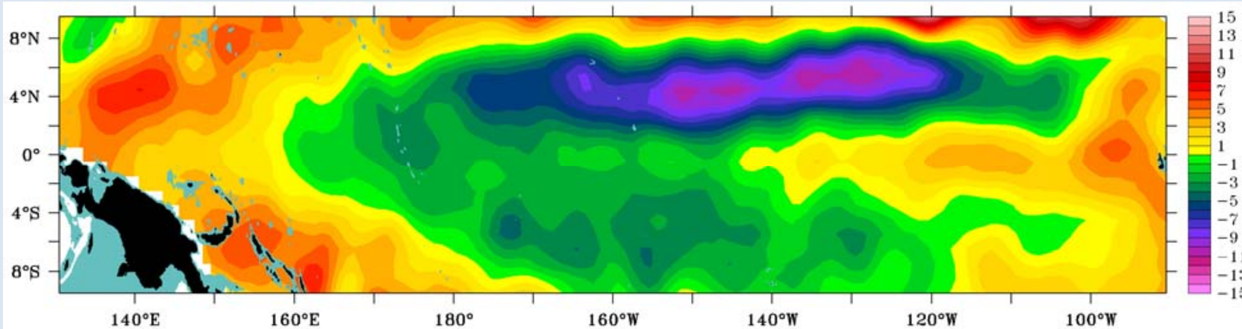
Lower panels: 4°-6°N.

Below: SH(1000/2000), 1.5°S to 1.5°N

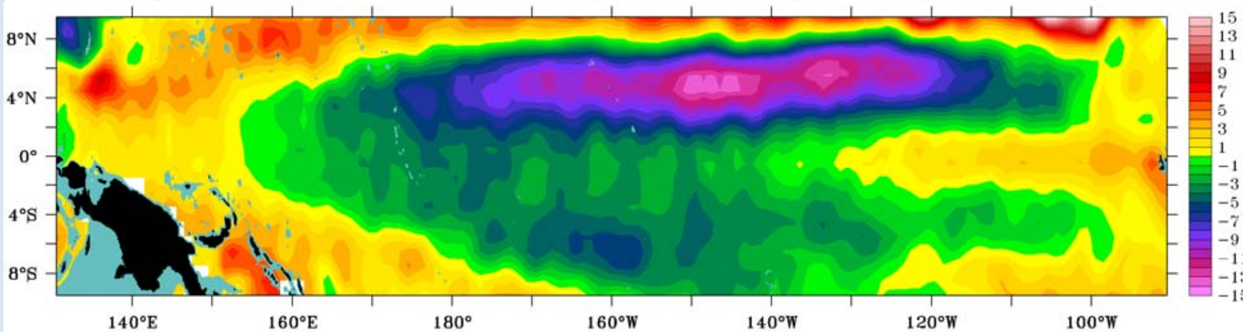


May 1

SH

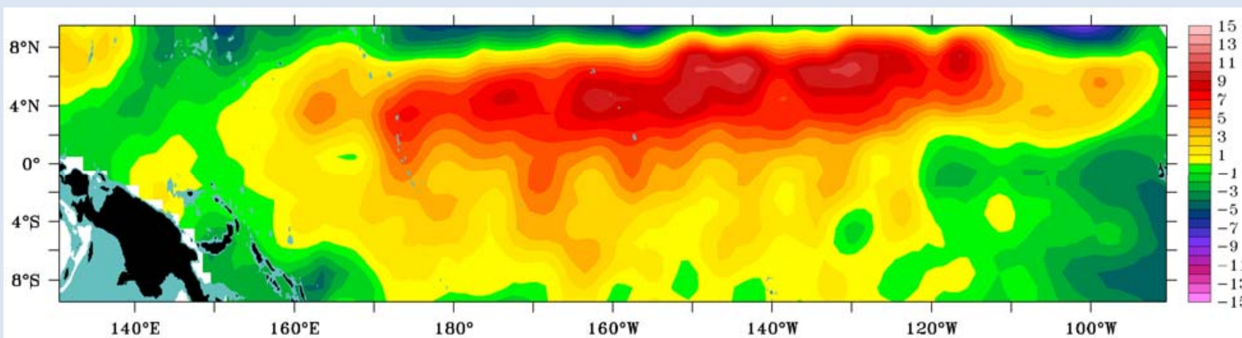


SSH

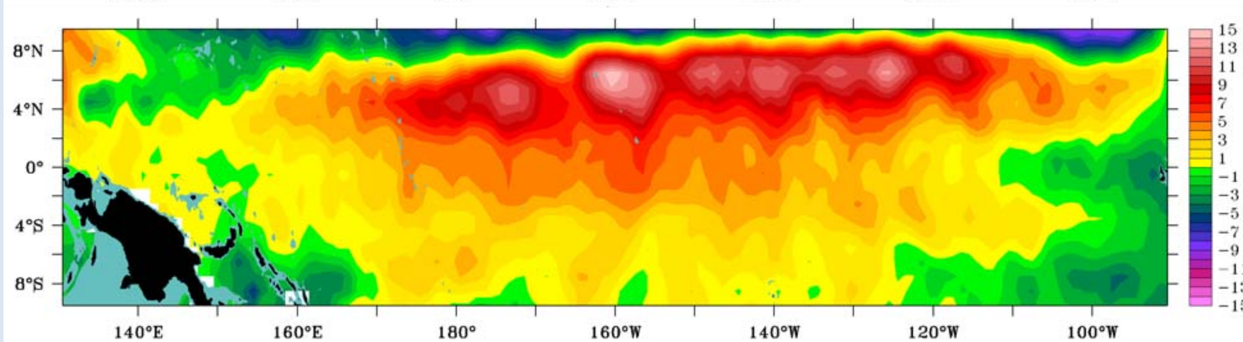


Nov 1

SH

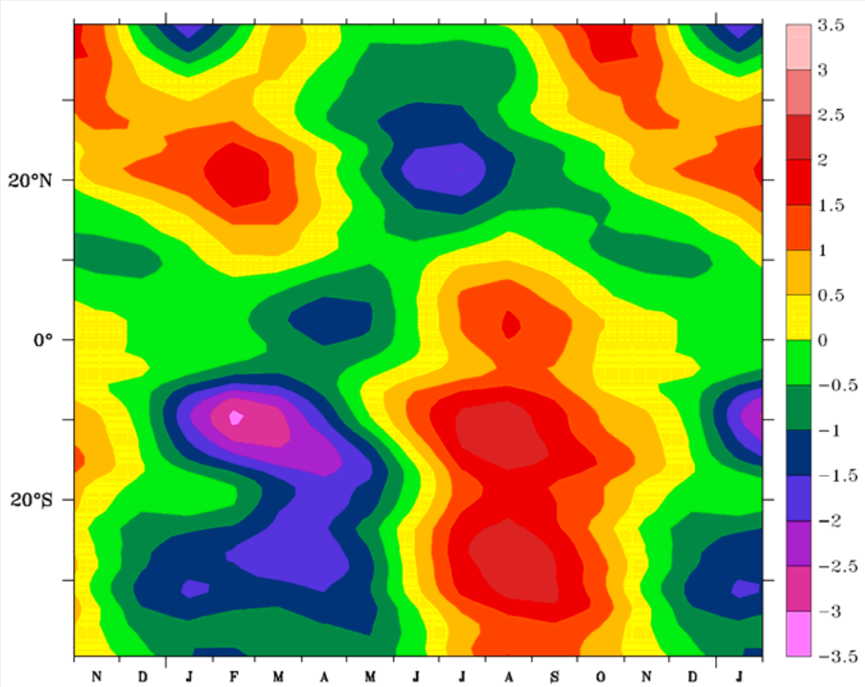


SSH

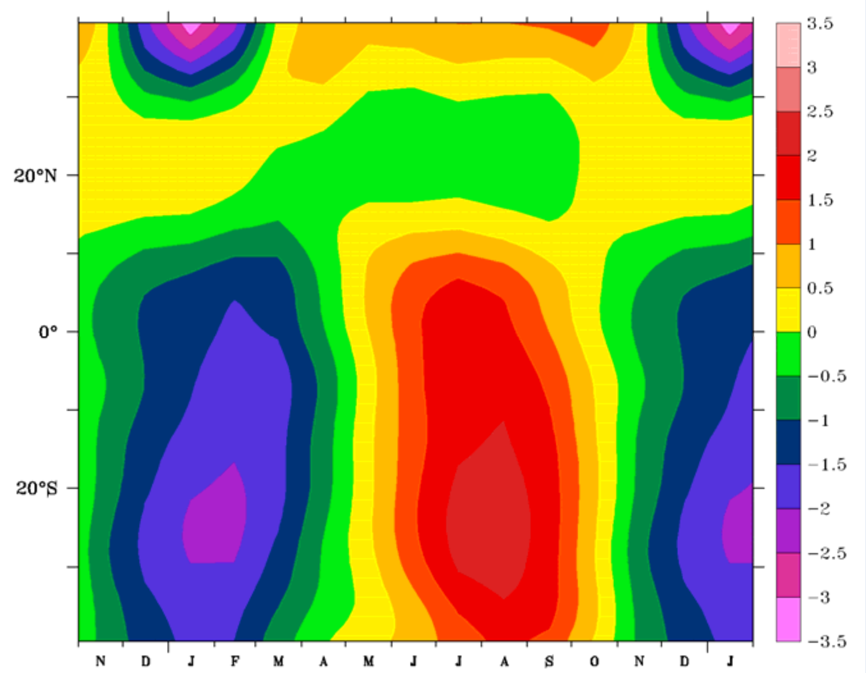


Are the mass and sea level budgets closing?

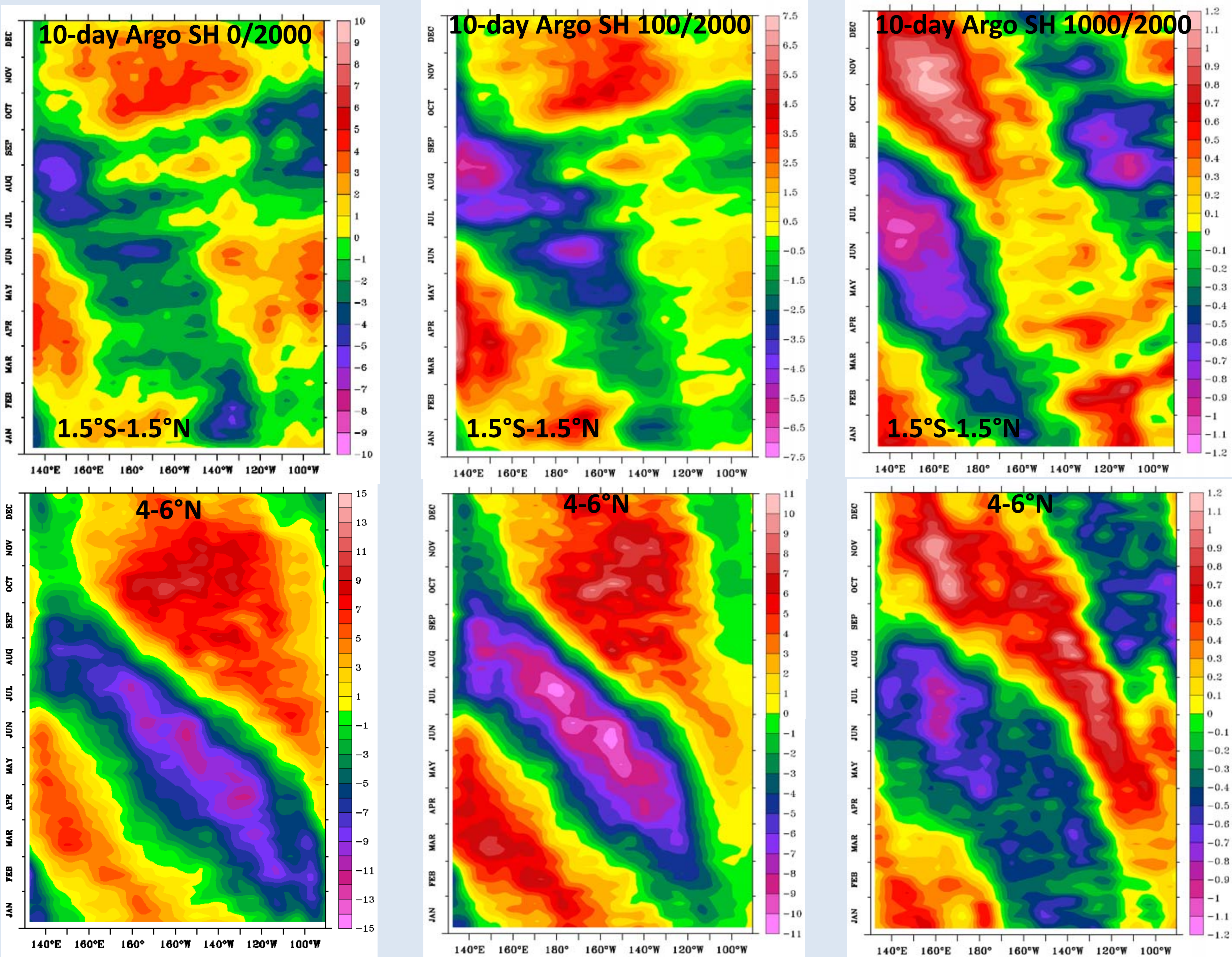
SSH – SH, 10° latitude smoothing, 2004-2012, 180°W-160°W mean



Grace, GFZ version, 2004-2012, 180°W-160°W

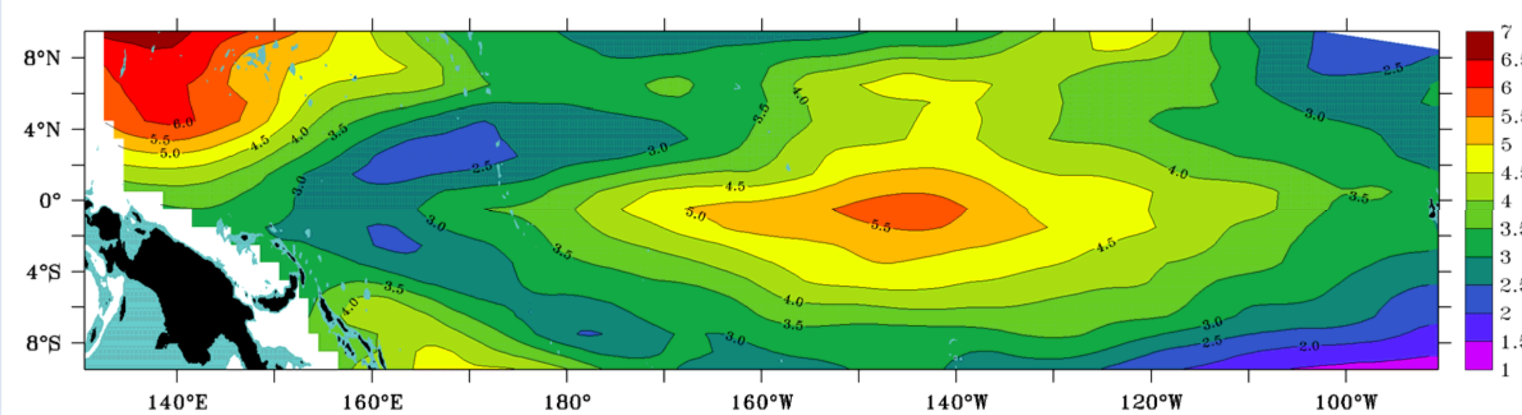


Residuals of sea surface height minus steric height resemble the GRACE mass field.
However, GRACE does not resolve the equatorial wave guide.
And, low frequency variability extends below 2000 m, e.g. Kessler and McCreary (1993).
Deep Argo needed?

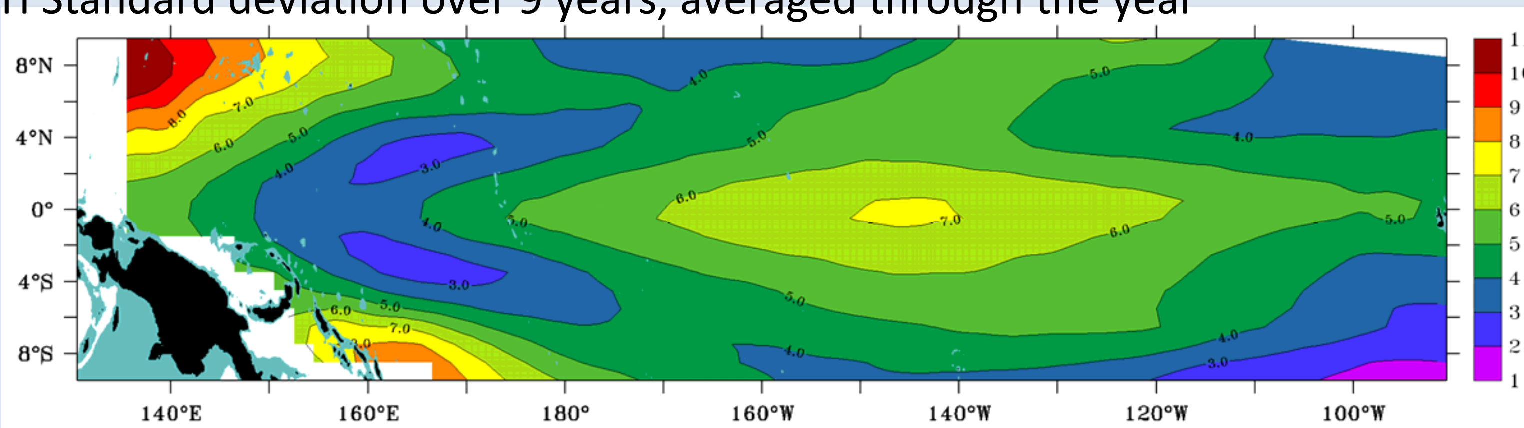


10-day Argo SH 0/2000
10-day Argo SH 100/2000
10-day Argo SH 1000/2000
1.5°S-1.5°N
1.5°S-1.5°N
1.5°S-1.5°N
4-6°N
4-6°N
4-6°N
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
140°E 160°E 180° 160°W 140°W 120°W 100°W
10 9 8 7 6 5 4 3 2 1 0 −1 −2 −3 −4 −5 −6 −7 −8 −9 −10
7.5 6.5 5.5 4.5 3.5 2.5 1.5 0.5 −0.5 −1.5 −2.5 −3.5 −4.5 −5.5 −6.5 −7.5
1.2 1.1 1 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0 −0.1 −0.2 −0.3 −0.4 −0.5 −0.6 −0.7 −0.8 −0.9 −1 −1.1 −1.2
15 13 11 9 7 5 3 1 −1 −3 −5 −7 −9 −11 −13 −15
11 10 9 8 7 6 5 4 3 2 1 0 −1 −2 −3 −4 −5 −6 −7 −8 −9 −10 −11

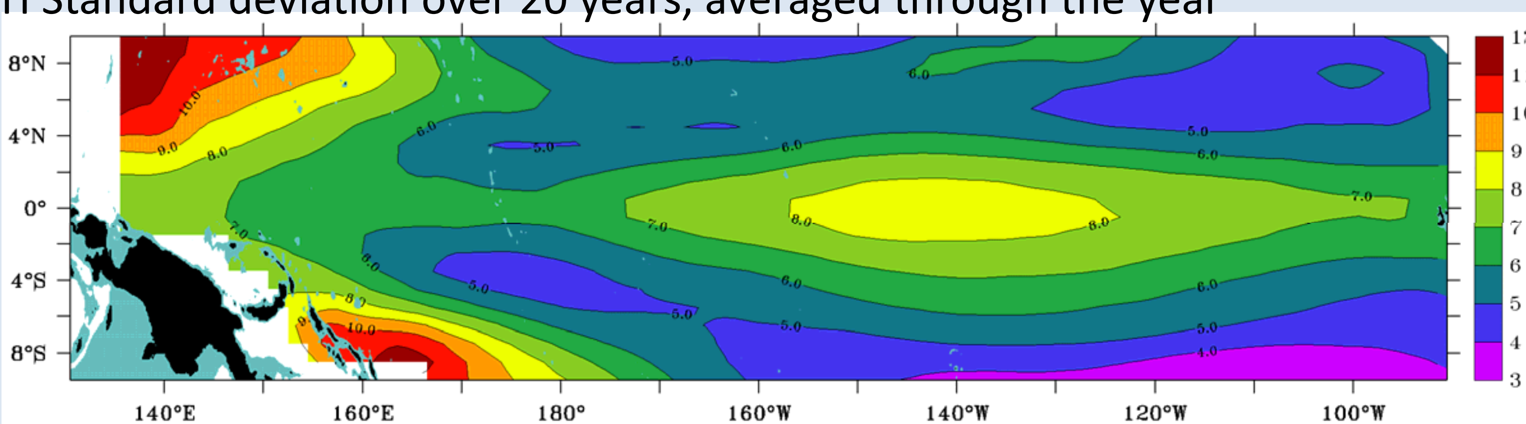
SH Standard deviation over 9 years, averaged through the year



SSH Standard deviation over 9 years, averaged through the year

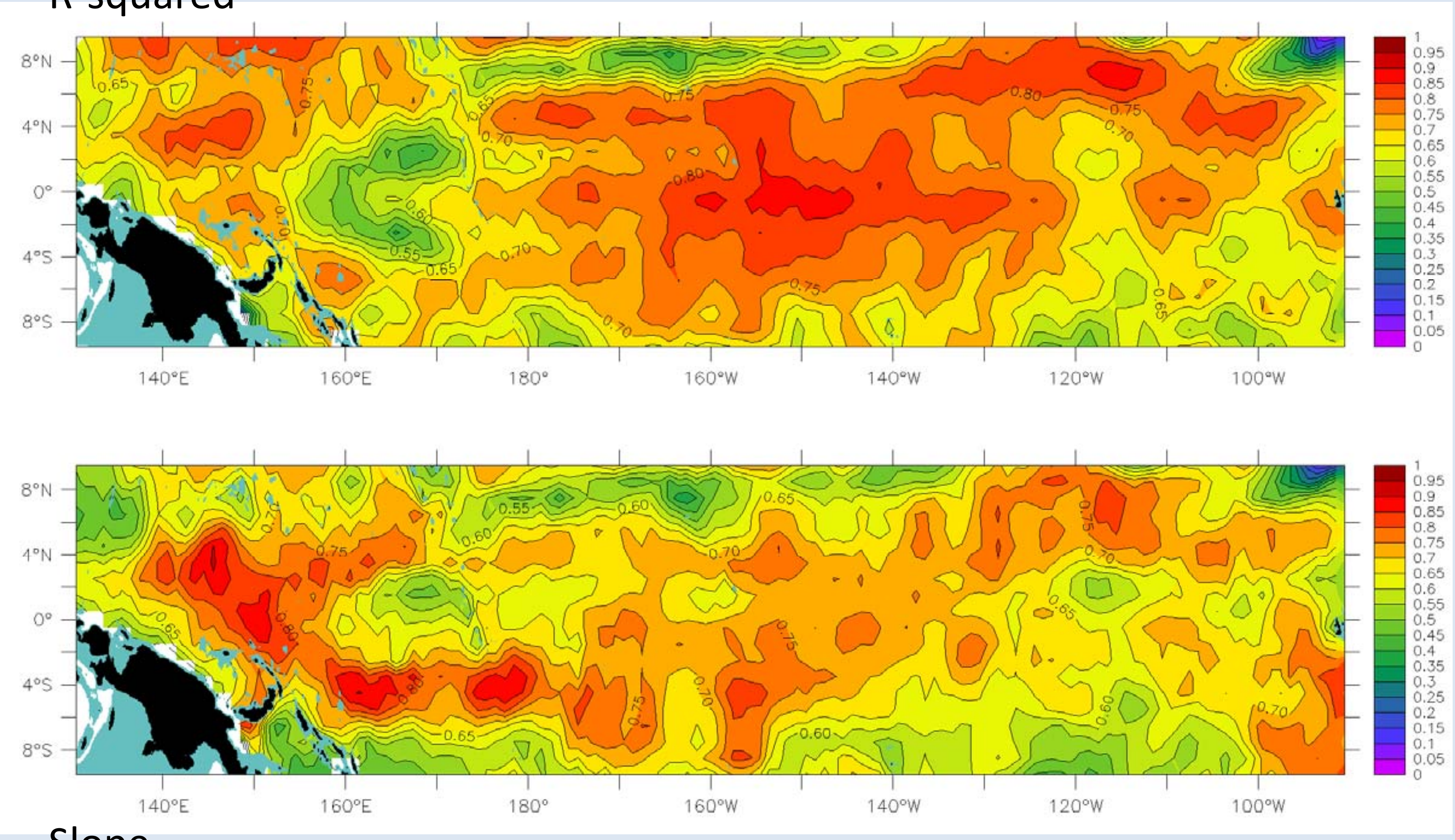


SSH Standard deviation over 20 years, averaged through the year



Linear regression of 10-day SH onto SSH

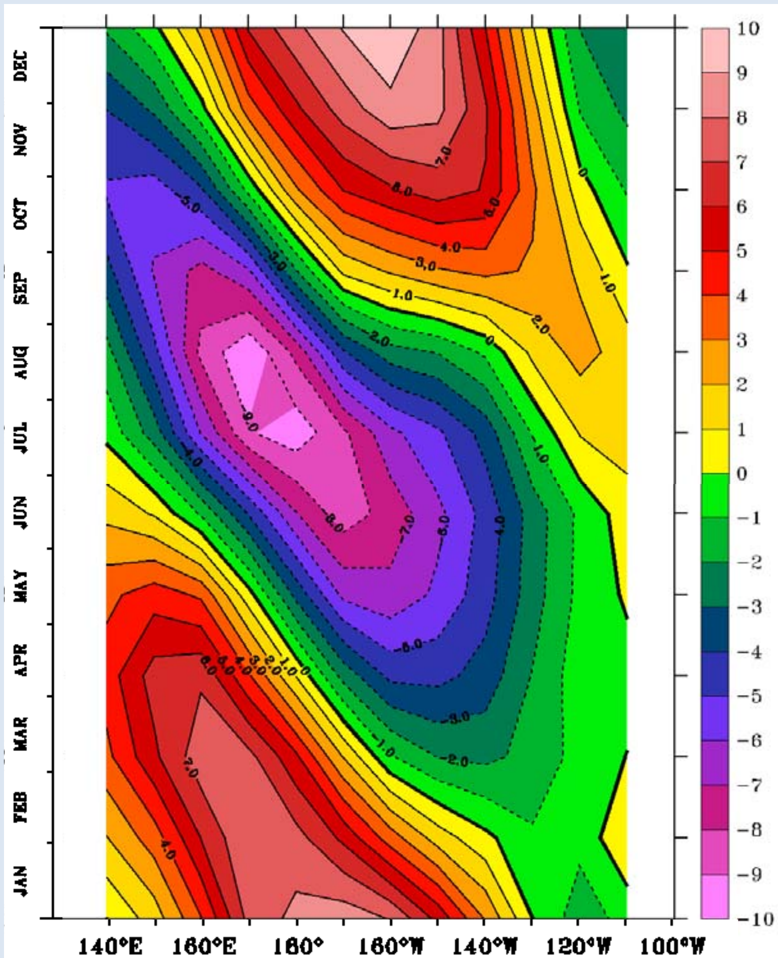
R-squared

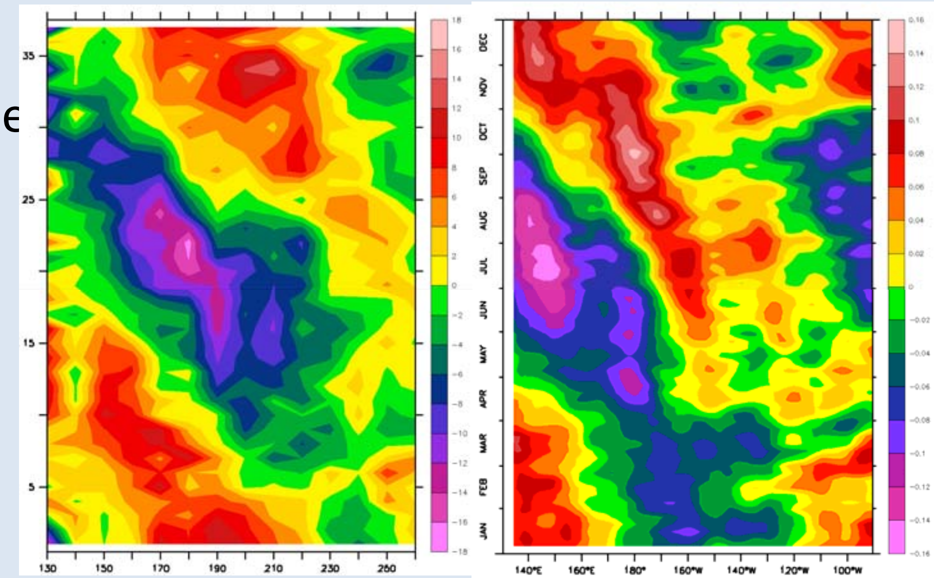


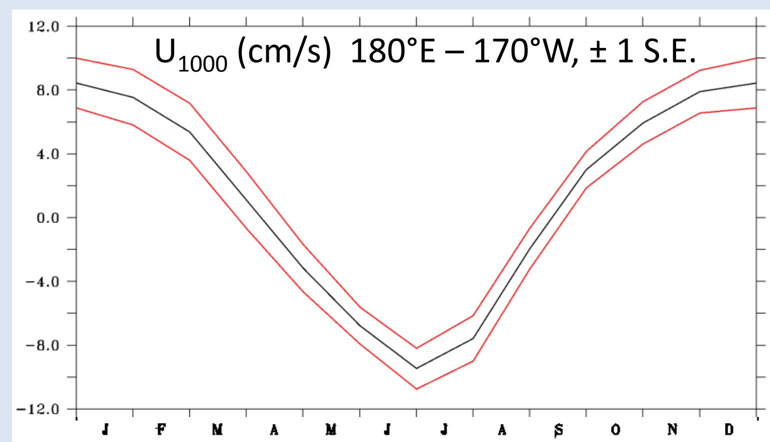
Slope

The Annual Cycle

Zonal velocity at 1000 m time/longitude







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