History of Seasonal Forecasting

David Anderson,
Oxford University

With thanks to Magdalena Balmaseda, Tim Stockdale.

- In the mid 70’s there was a sense that there were definite connections between ocean and atmosphere on climate timescales and the hope that understanding these connections could lead to an improved ability to forecast climate variability. Namias had presented some evidence that there was some predictability of the atmosphere from the underlying ocean. However, Davis an oceanographer from Scripps institute felt that Namias’s approach was intuitive and lacked rigour. He set out to test Namias results but using a more rigorous statistical approach, in effect using EOFs.

Davis 1976

- SST anomalies can be predicted (to some degree) from SST observations months in advance
- SLP variability can be specified (to some extent) from simultaneous SST
- Future SLP can NOT be predicted from SST.
- The observed connection between SST and SLP is the result of the atmosphere driving the ocean.

- Namias 1972: Space scales of sea-surface temperature patterns and their causes. Fishery Bulletin 70, 611-617.
- Namias Large-scale and long-term fluctuations in some atmospheric and oceanic variables. Nobel Symposium 20.
- Davis 1976: Predictability of sea surface temperature and sea-level pressure anomalies over the North Pacific ocean. JPO 6, 249-266.
- Davis 1978:Predictability of sea level pressure anomalies over the North Pacific Ocean. JPO 8, 233-246.

This Week's Citation Classic®

CC/NUMBER 22
JUNE 3, 1985

Davis R E. Predictability of sea surface temperature and sea level pressure anomalies over the North Pacific Ocean. *J. Phys. Oceanogr.* **6**:249-66, 1976.
[Scripps Institution of Oceanography, University of California, San Diego, CA]

This paper examines the statistical relation between anomalous patterns of sea-level pressure and sea-surface temperature in the North Pacific basin. The correlation of these patterns is examined for evidence that the ocean influences future atmospheric development. None is found. [The *SCI*® indicates that this paper has been cited in over 160 publications since 1976, making it this journal's most-cited paper.]

Russ E. Davis
Scripps Institution of Oceanography
University of California
La Jolla, CA 92093

April 5, 1985

This paper was motivated by the pioneer-

communicated. My intent in starting this study was to discover a simple quantitative description of the ocean-atmosphere connections that he uses in forecasting and to demonstrate that knowledge of the ocean does make forecasting possible. The statistical examination indicated that the correlation of SST patterns and sea-level pressure (SLP) patterns over the North Pacific is largely the result of the atmosphere driving the upper ocean. While SST could be partially predicted from previous SST, and SLP could be partially specified from simultaneous SST, no reliable connection between SST and SLP was found.

This finding was, of course, not what we wanted. It continues to impress me how Namias accepted the results. He correctly pointed out that the correlation approach would not find all kinds of predictability and that the possible seasonality of SST/SLP connections was not really accounted for (in fact, a subsequent study[2] showed some sig-

ence that short-
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for many years,
nal weather pat-
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fluctuations in
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y contribution

that of many
and not readily

ter SLP). What is remarkable is that Namias regarded the study, which might have been thought to threaten a major element of his life's work, with objectivity and supported continuation of similar work. In a field where charlatanry is the rule rather than the exception, this attitude stands out as an important commentary on the man.

Why is the paper widely cited? I suspect the answer lies in the methodology employed rather than in the results. The analysis challenge was to separate chance co-occurrences among many variables from genuine statistical correlations. I discovered, during review, that the approach used was essentially that which Edward Lorenz had used years earlier in an atmospheric predictability study that appeared only in a Massachusetts Institute of Technology project report.[3] If this wonderful piece of work had been more widely available, my paper would have been lost in obscurity, and I would have lost the opportunity to rediscover a great wheel.

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n fluctuations in some atmospheric and oceanic variables. (Dyrssen D &

HOWEVER

- Namias pointed out that Davis had used annual mean values and so would fail to detect a seasonality to the predictability. So Davis 1977 sought to test this aspect. He found:
- SLP could be partly predicted from SST on a 2/3 month timescale. Autumn SLP could be predicted from July SST. Winter SLP from Oct SST.
- He pointed out, however, that all SST and SLP anomalies could be responses to an external influence and are not themselves significantly coupled dynamically.

- He then developed a statistical prediction model where for example Nov SST is used to predict DJ SLP. He trained the model on the 20 year period1947-66 and then used it to predict winter for the 10 years 67-76.
- Skill was at best low but over enough events useful.

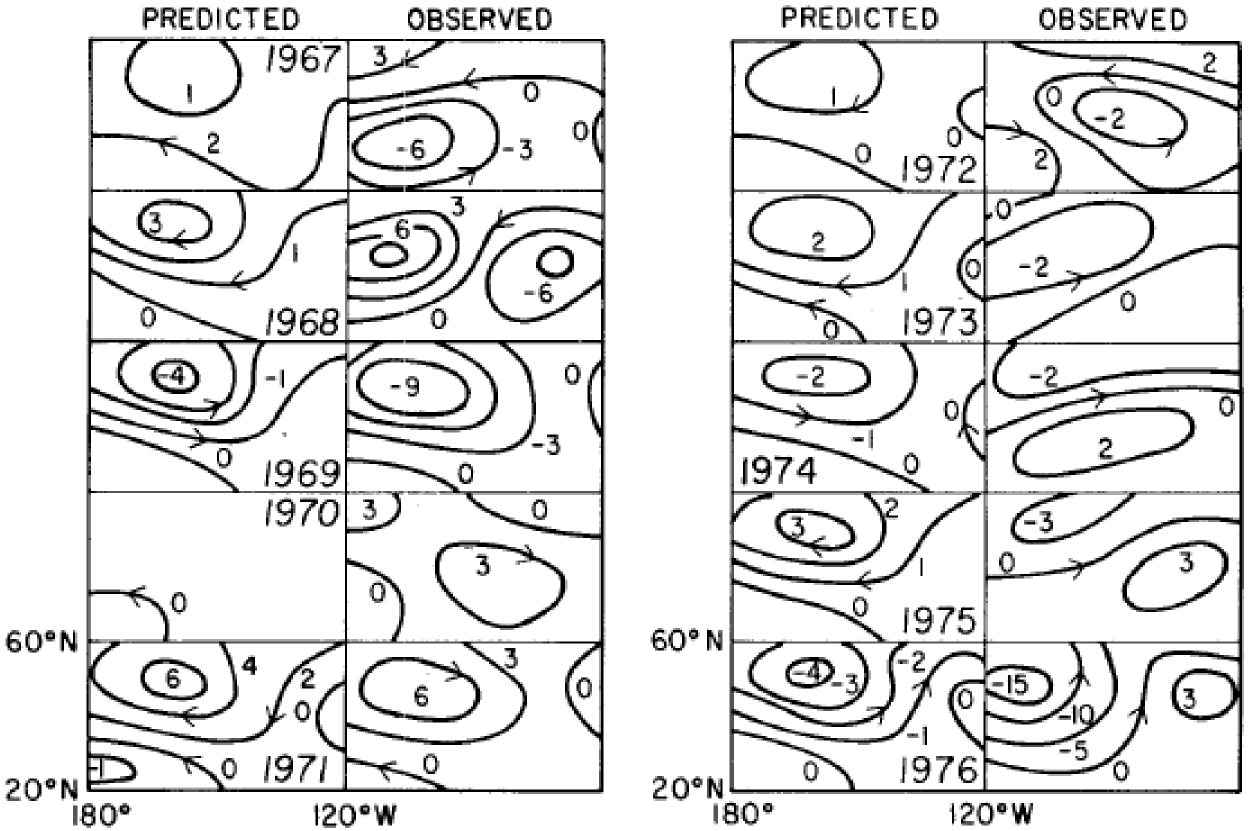


FIG. 6. Forecast and observed SLP anomalies for winters of 1967–76. Each map covers 20–60°N and 120–180°W and refers to the December–January average. Forecasts are based on the monthly SST anomaly in November. The statistics for the predictor are derived from the years 1947–66. The units are mb.

Note 1976/7 was an El Nino year. The anomaly in 1976 was record breaking. 1972/3 was also an El Nino year.

See Arnauld Czaja this afternoon for more on midlatitudes

Noise (white)

$$\frac{dy}{dt} = \xi(t) - \lambda y$$

$$G(\omega) = \frac{\sigma^2}{(\lambda^2 + \omega^2)}$$

σ = std dev^{n} of noise

⇒ White noise forcing ⇒ red spectrum response

Hasselmann.

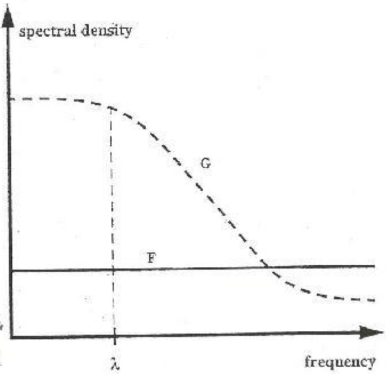


Fig. 9.5 Schematic input spectrum F and response spectrum G which result from the simplest version of the stochastic climate model (1). The atmospheric input spectrum is white, while the oceanic response spectrum is red down to a frequency which is determined by the damping λ.

158 Mojib Latif, Axel Timmermann, Anselm Grötzner, Christian Eckert, Reinhard Voss

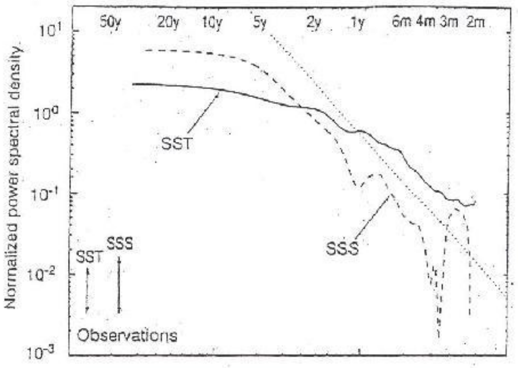
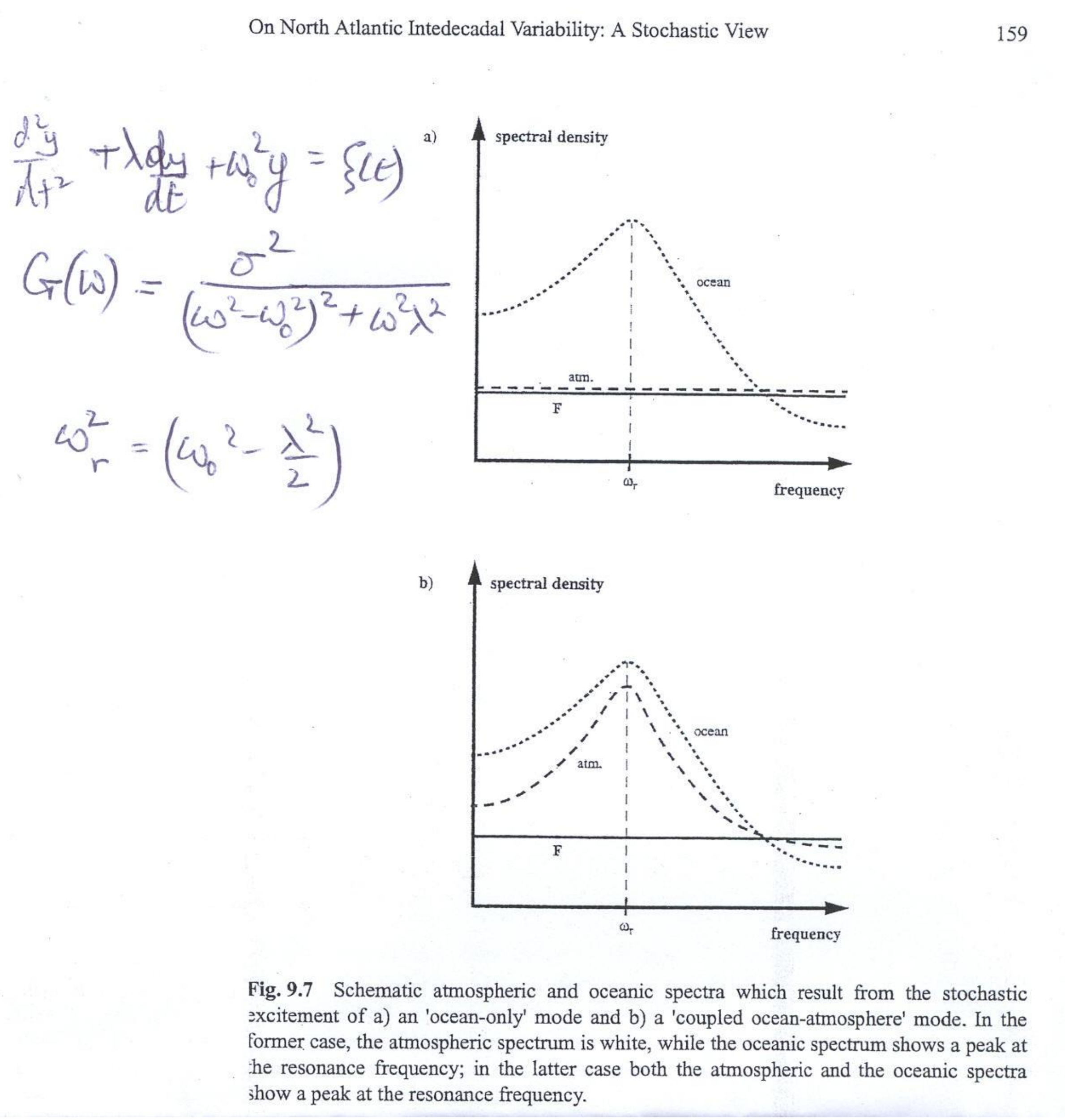


Fig. 9.6 Spectra of anomalous North Atlantic SST and SSS observed at ocean weather ship 'I' (60.8°N, 20.6°W). The dotted line shows the slope ω^{-2}. From Hall and Manabe (1997).

- The ocean response to white noise forcing is a red spectrum- the ocean integrates the noise to give low frequency variability. This is not a bad approximation in many parts of the extratropical world.



$$\frac{d^2y}{dt^2} + \lambda\frac{dy}{dt} + \omega_0^2 y = \xi(t)$$

$$G(\omega) = \frac{\sigma^2}{(\omega^2-\omega_0^2)^2+\omega^2\lambda^2}$$

$$\omega_r^2 = \left(\omega_0^2 - \frac{\lambda^2}{2}\right)$$

Fig. 9.7 Schematic atmospheric and oceanic spectra which result from the stochastic excitement of a) an 'ocean-only' mode and b) a 'coupled ocean-atmosphere' mode. In the former case, the atmospheric spectrum is white, while the oceanic spectrum shows a peak at the resonance frequency; in the latter case both the atmospheric and the oceanic spectra show a peak at the resonance frequency.

- The ocean can have a resonance forced by noise.

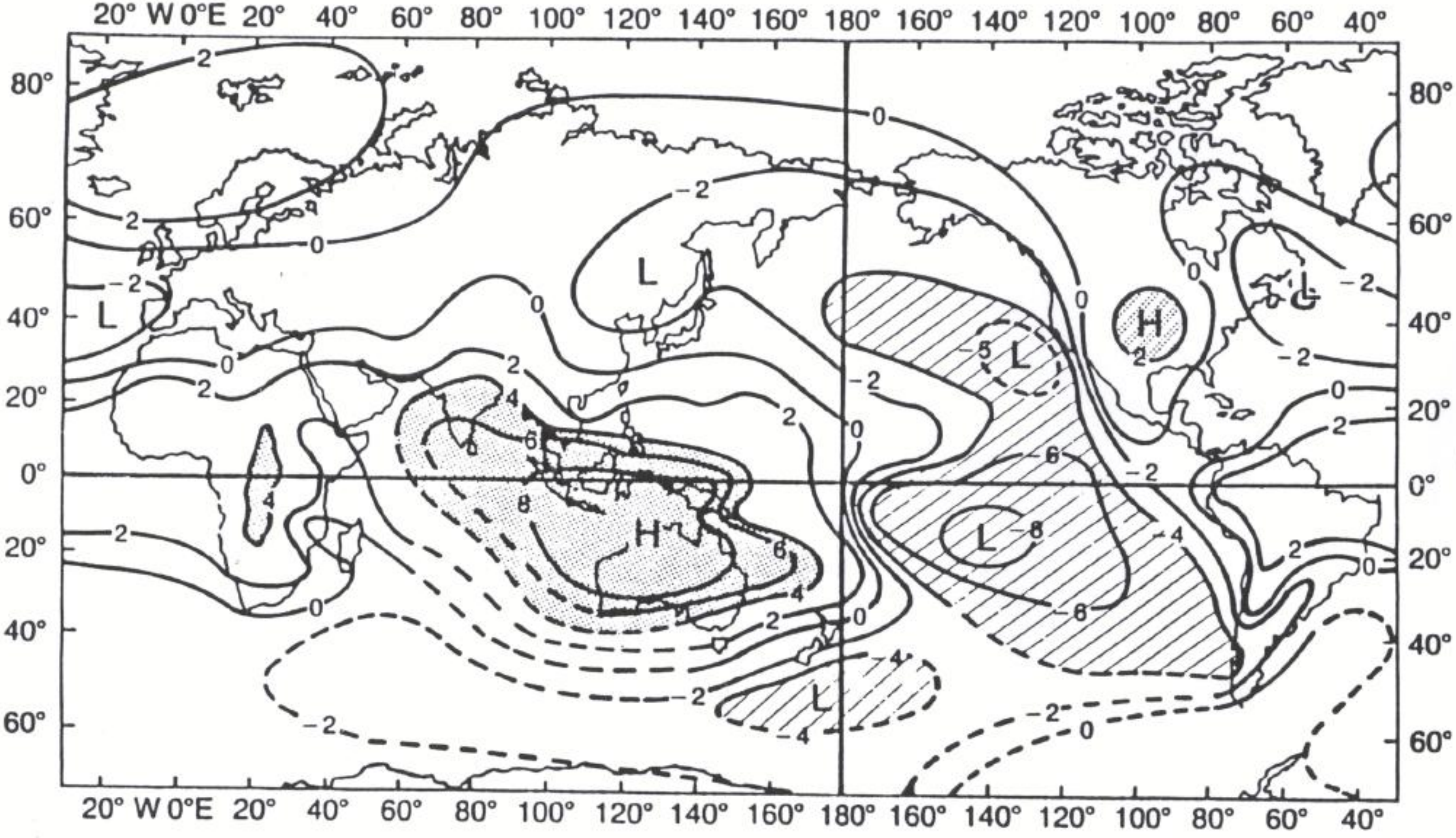
- Or there can be a coupled response.

- From Latif et al MPI.

Southern oscillation and El Nino

- Southern Oscillation
- Lockyer, Blanford, Todd, Walker,….
- In the early1870’s Norman Lockyer looked for links between the 11 year sunspot cycle and monsoonal rainfall, in the hope of finding a predictor. Gave up this work for a while but returned to it in the early 1900s. Found large areas on the globe to be out of phase.
- (Lockyer discovered Helium, and founded Nature)

- Walker developed regression equations for predicting the Indian monsoon and identified and named the southern oscillation, (and the northern oscillation).
- He too was interested in solar terrestrial atmosphere links
- (There had been serious droughts in 1876-8, and 1896-7, and 1899-1900. After the drought in 1897, rains were abundant leading to a malaria epidemic) An estimated 1million people died.
- (- tomorrow Sulo Gadgil, and Franco Molteni)

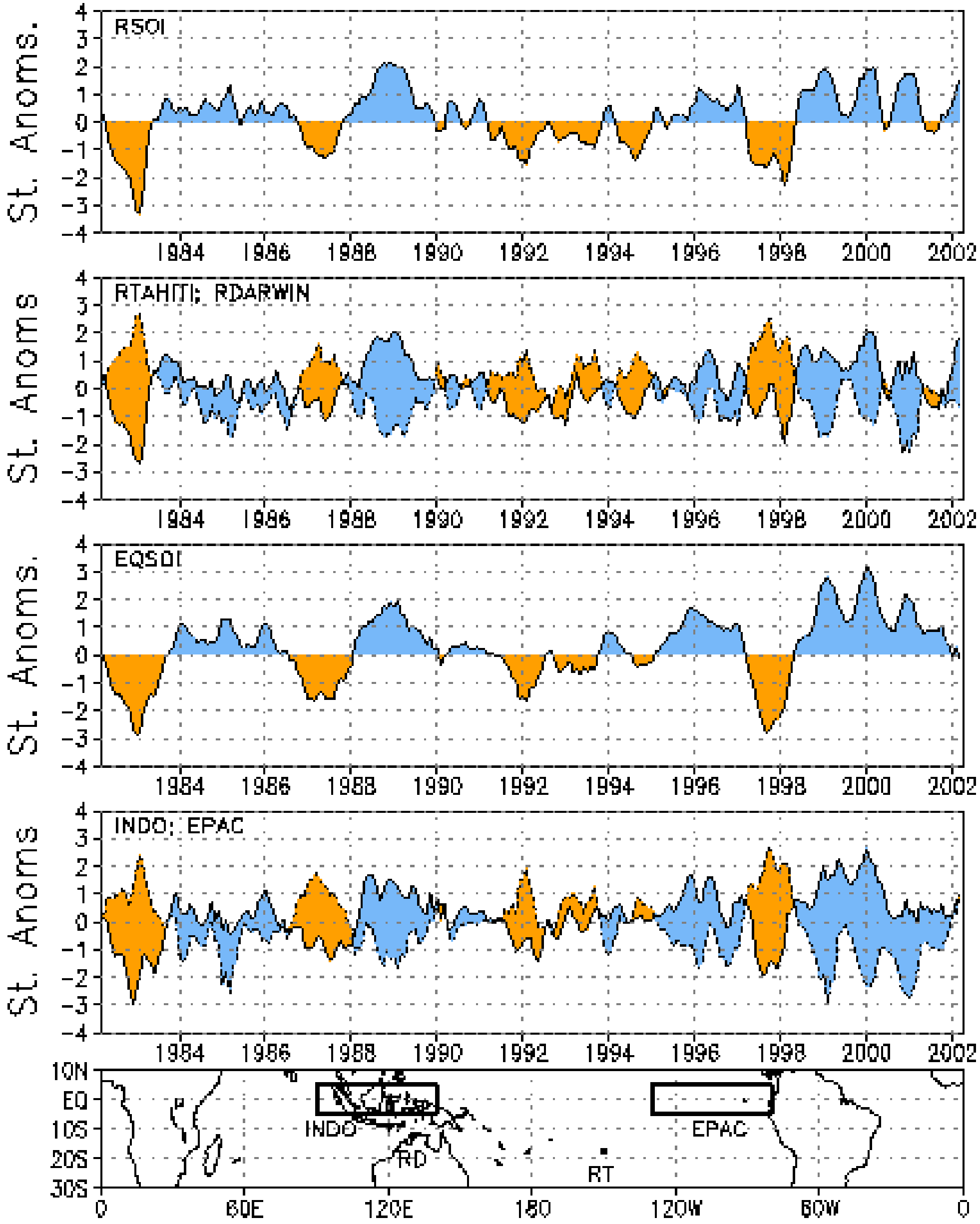


Correlations of Annual Mean Sea Level Pressures with Darwin

From Trenberth, showing the large scale of pressure swings.

El Nino

- Originally a warm counter current in the Gulf of Guayaquil against the cold northward flowing Humboldt current. It occurred around Christmas.
- During the IGY 1957/8, a major El Nino took place and it was clear to Bjerknes that the warming off the coast of Ecuador/Peru was not a local phenomenon, but affected a large part of the Pacific.
- He suggested a tropical coupling between the SO and El Nino and a positive feedback though the surface winds.



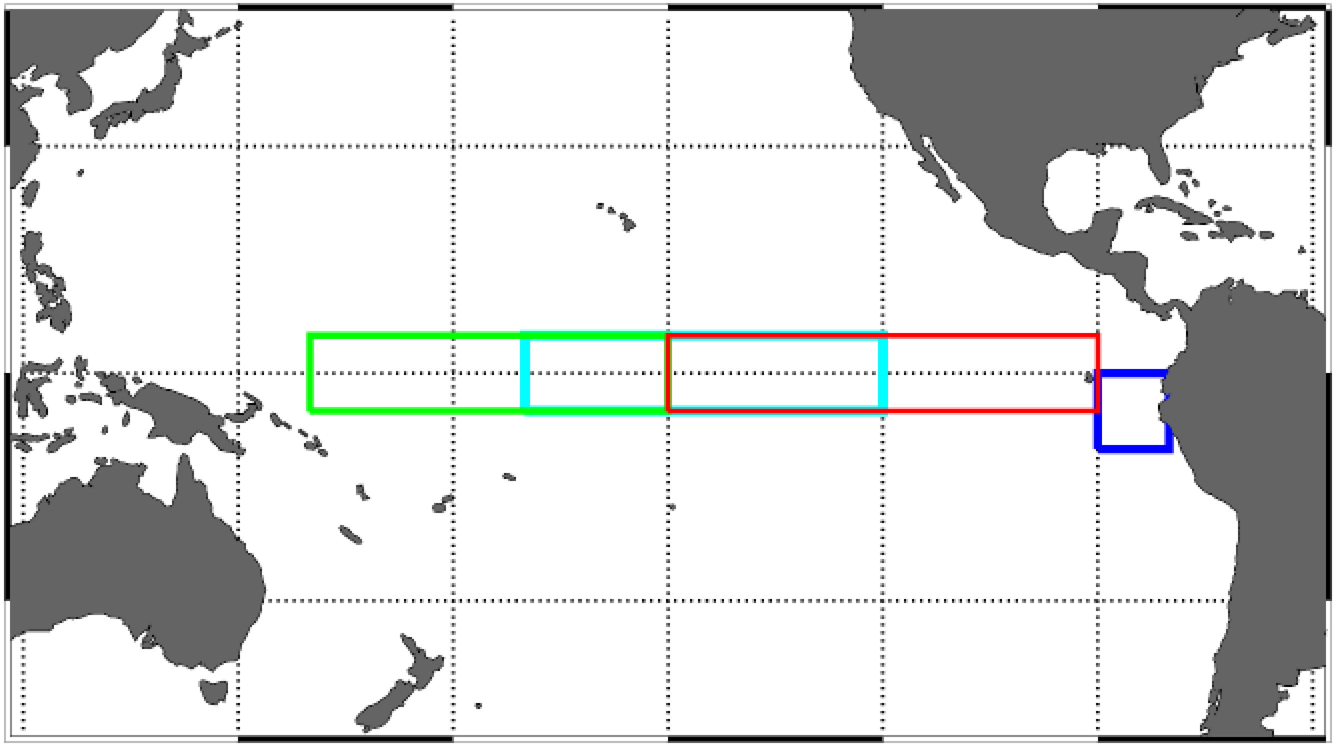
- In the equatorial Pacific, there is considerable interannual variability. The EQSOI (INDO-EPAC) is especially useful: it is a measure of pressure shifts in the tropical atmosphere but may be more representative than the usual SOI (Darwin – Tahiti). Note 1983, 87, 88, 97, 98 .

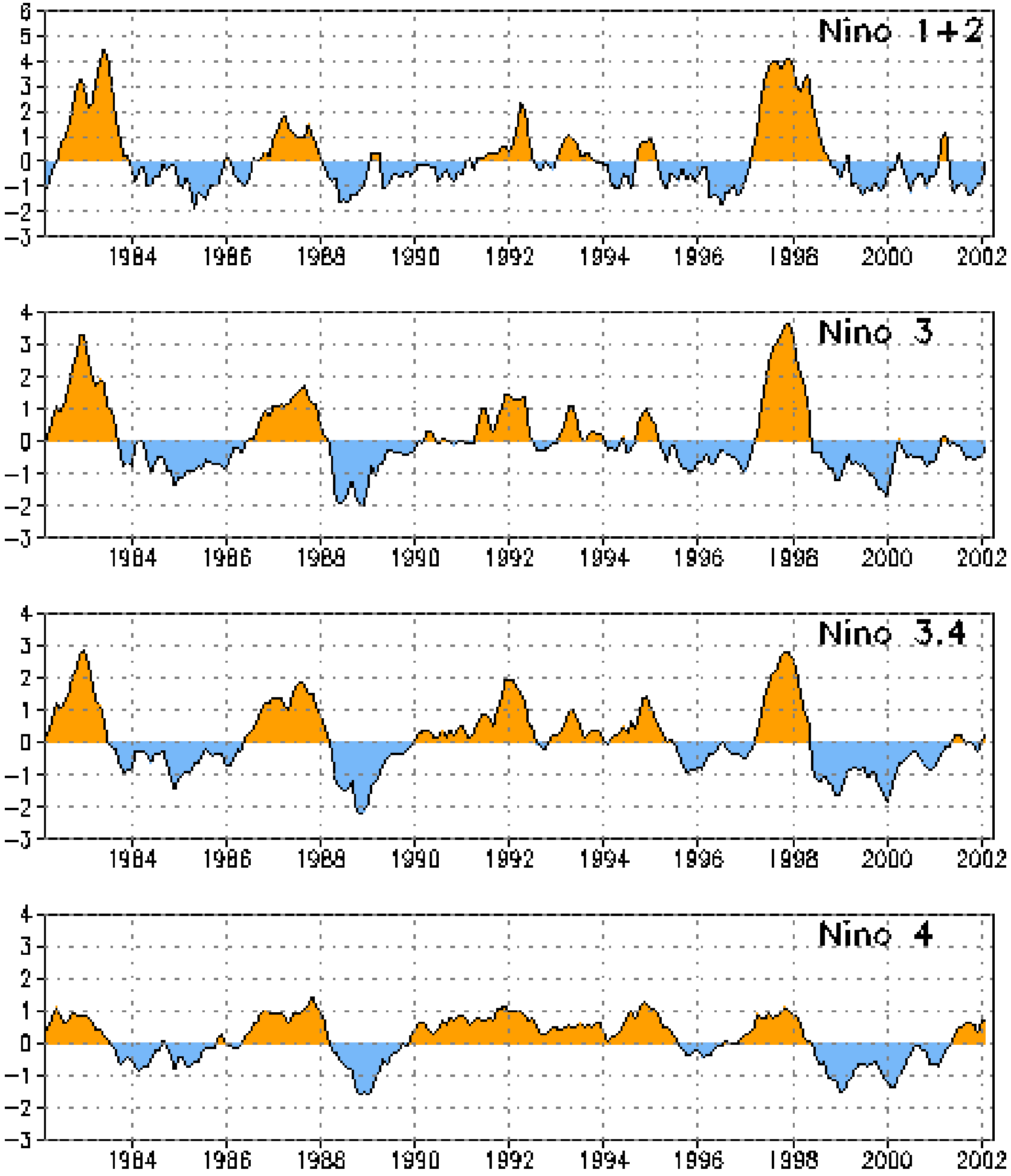
Nino3.4, Lon = [-170, -120], Lat = [-5, 5]

Nino12, Lon = [-90, -80], Lat = [-10, 0]

Nino4, Lon = [160, -150], Lat = [-5, 5]

Nino3, Lon = [-150, -90], Lat = [-5, 5]





SST variability is linked to the atmospheric variability seen on previous slide suggesting a strongly coupled

process.

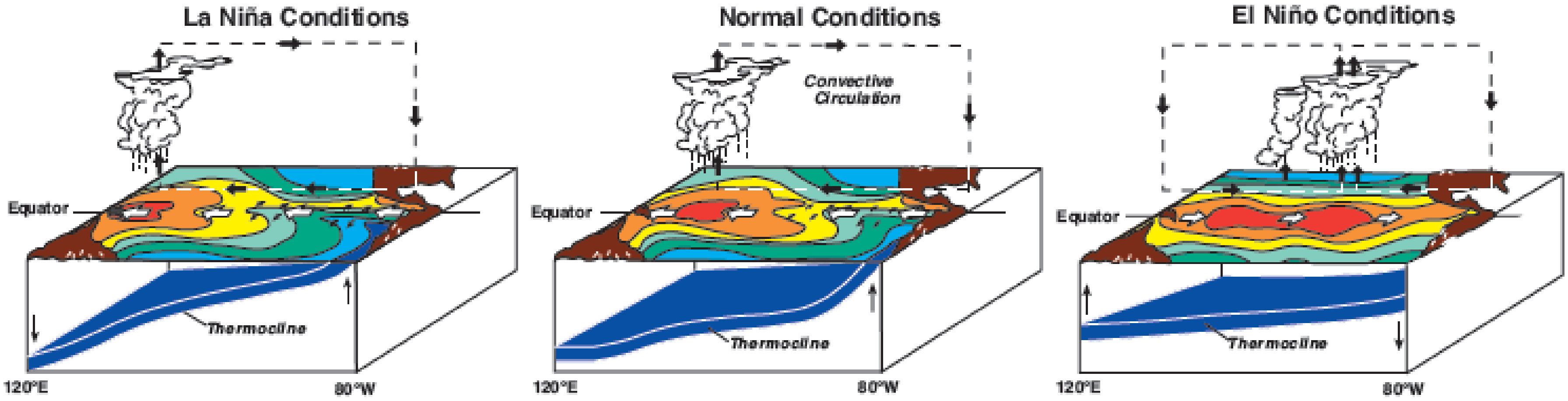
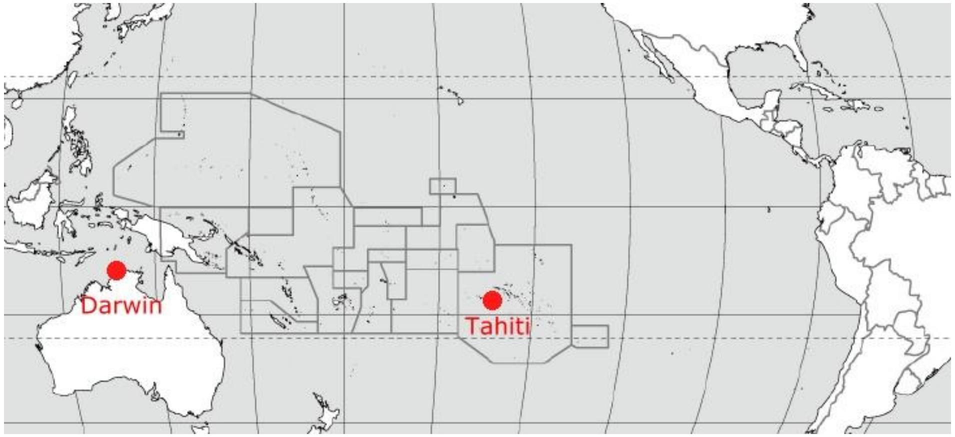
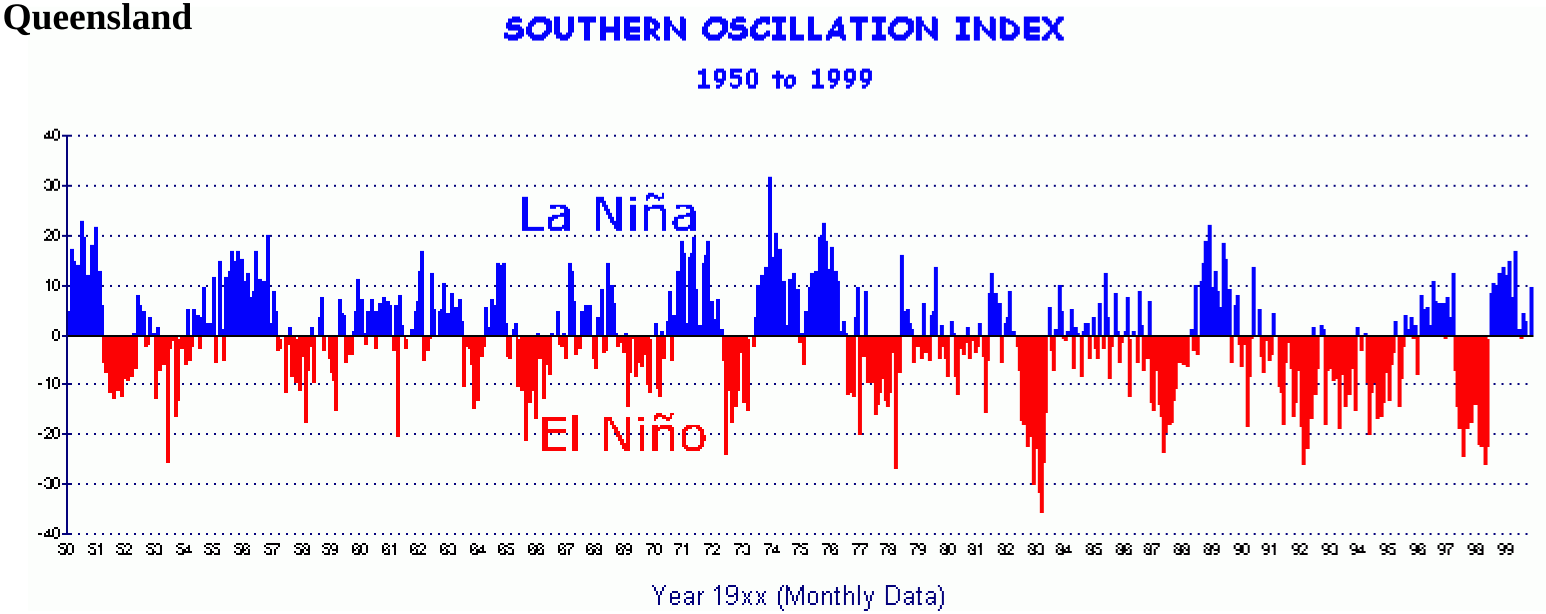


Figure 1. Schematic showing the El Niño/Southern Oscillation cycle of warm events (El Niño), cold events (La Niña), and normal conditions in the tropical Pacific.

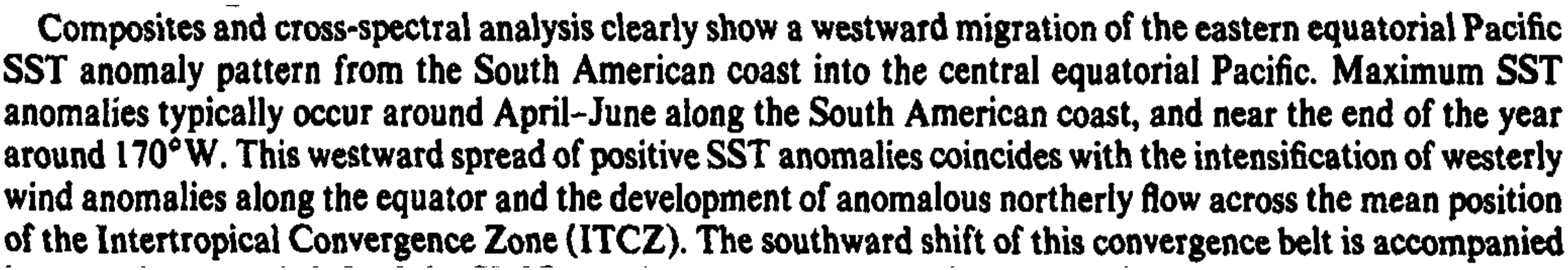
From McPhaden, et al
Oceanography Vol 23, Sept 2010



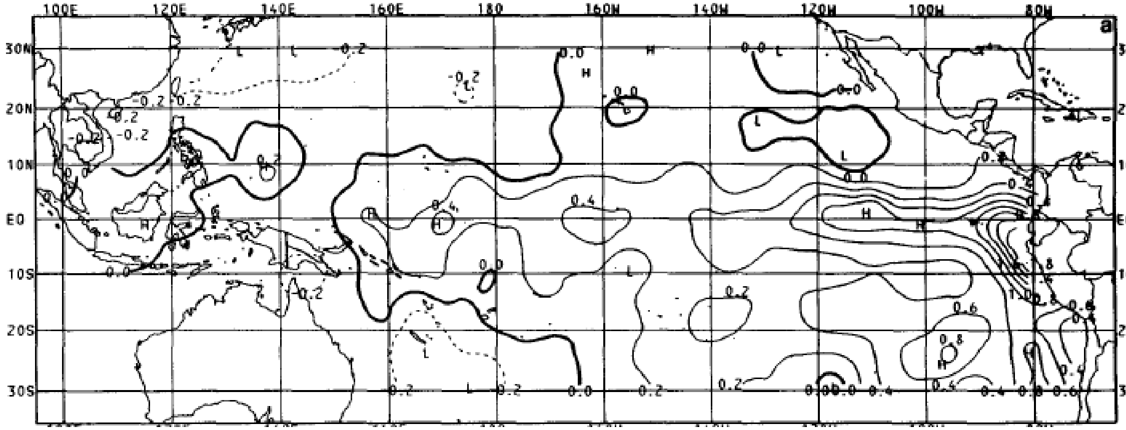
The southern oscillation index SOI. Strong negative red values stand for El Niño events, strong positive blue values stand for La Niña conditions. Source: Long Paddock website, Gov. of Queensland



Rasmussen and Carpenter Monthly Weather Rev 1982, 110, 354-384



Composites and cross-spectral analysis clearly show a westward migration of the eastern equatorial Pacific SST anomaly pattern from the South American coast into the central equatorial Pacific. Maximum SST anomalies typically occur around April–June along the South American coast, and near the end of the year around 170°W. This westward spread of positive SST anomalies coincides with the intensification of westerly wind anomalies along the equator and the development of anomalous northerly flow across the mean position of the Intertropical Convergence Zone (ITCZ). The southward shift of this convergence belt is accompanied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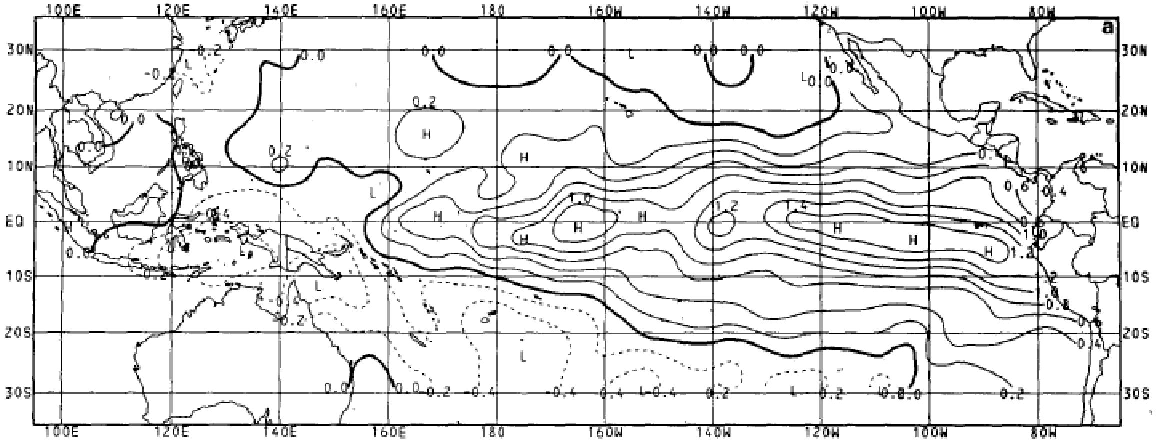
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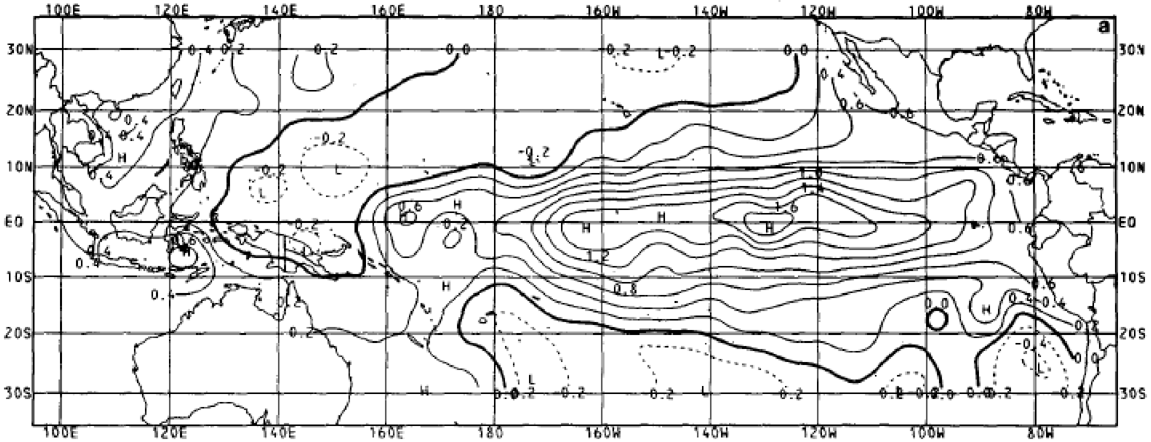
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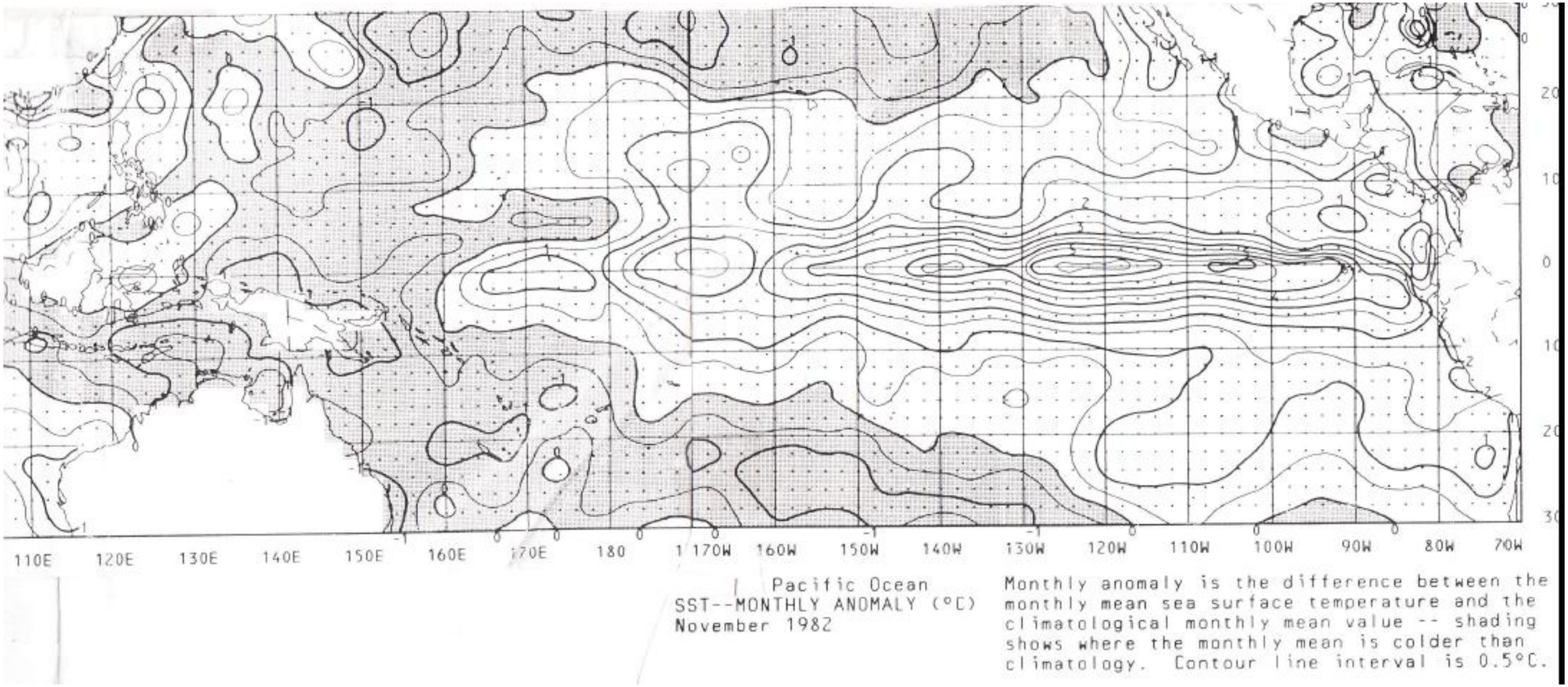
DJF

Then came the 1982/3 El Nino

No El Nino

- **"To call this event an El Nino would be a case of child abuse." a famous oceanographer remarked, October 1982**
- **Some SST observations were high but there was no build up of sea level in the west Pacific by stronger trade winds and no high SSTs along South American coast- thought to be necessary precursors.**
- **Ship Observations in Nov 1982 that the thermocline was 50- 100m deeper than normal set the alarm bells ringing. Toole and Borges 1984.**

SST, as analysed in Nov 1982. A major El Nino is clearly in progress. Climate Analysis Bulletin



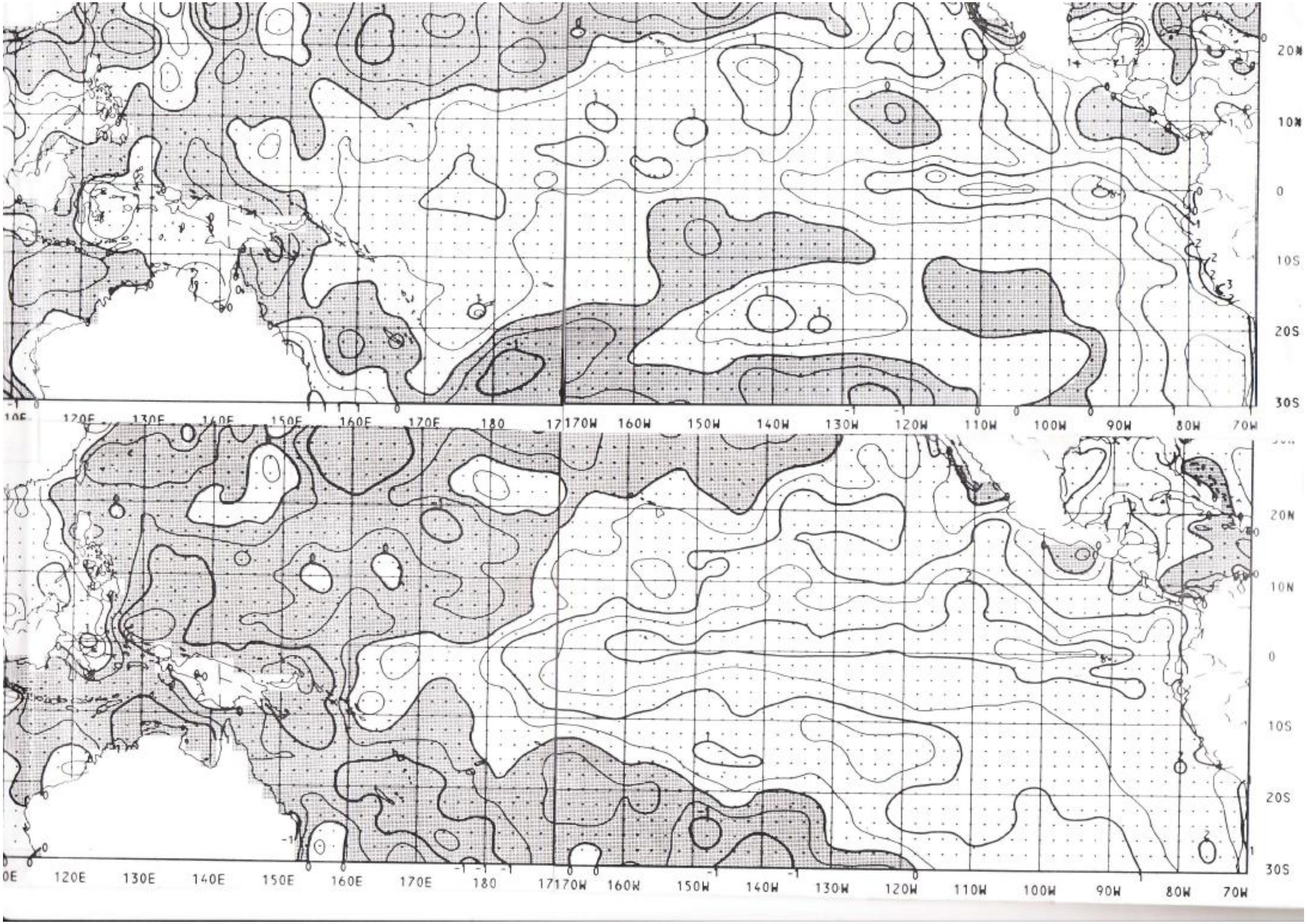
Pacific Ocean
SST--MONTHLY ANOMALY (°C)
November 1982

Monthly anomaly is the difference between the monthly mean sea surface temperature and the climatological monthly mean value -- shading shows where the monthly mean is colder than climatology. Contour line interval is 0.5°C.

Contour Interval 0.5C

Plot would not have been available until Dec 82 or Jan 83

SST as analysed May 82 Upper, Oct 82 lower



A hint of El Nino is present even in May 82 but was not appreciated.

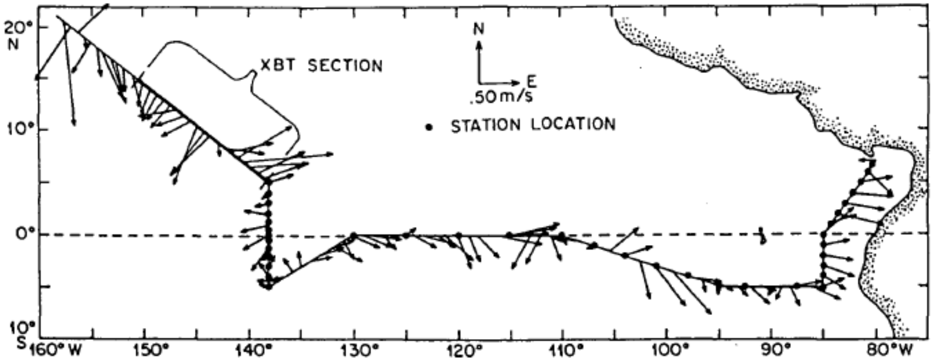


FIG. 1. The cruise track of the R.V. *Conrad* from Hawaii to Panama with station locations demarked. Arrows depict the surface drift experienced along the track determined from satellite fixes and the ship's log.

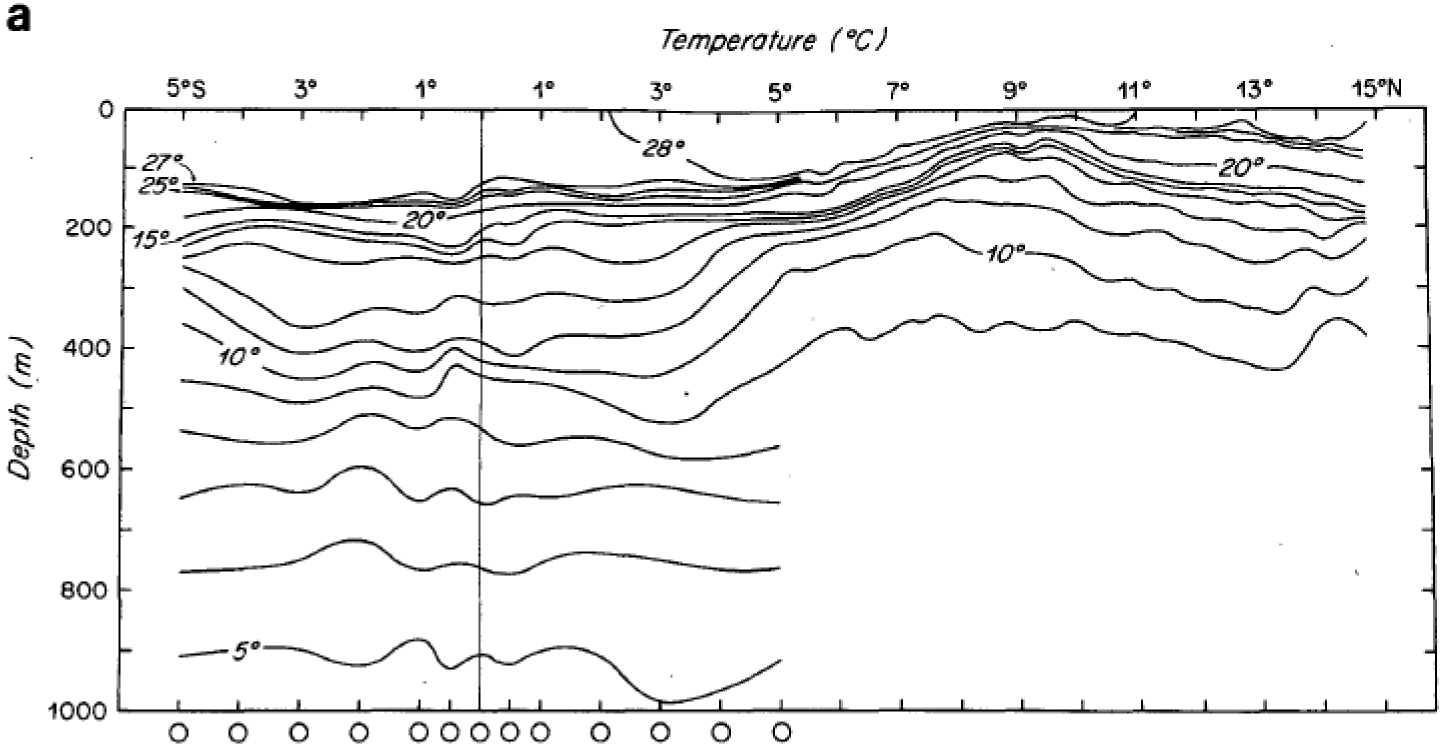
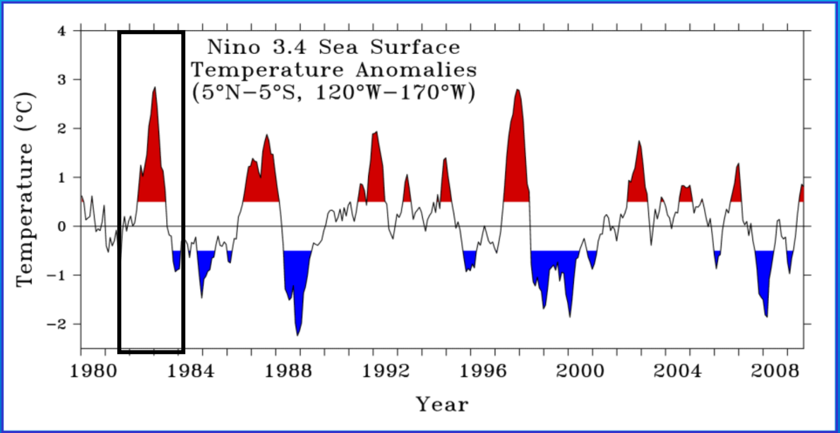


FIG. 3. Meridional sections along 138°W of (a) temperature, (b) salinity (‰, practical salinity scale), (c) dissolved oxygen and (d) zonal velocity. (eastward velocity is cross-hatched, contour interval is 20 cm s^{-1}, and broken line is the 5 cm s^{-1} isotach). Data collected north of 5°N came from XBTs launched along the diagonal track shown in Fig. 1. CTD–O$_2$ casts (marked with open circles) define the hydrographic structure equatorward of ±5° latitude, and the zonal-velocity structure (geostrophic relative to 1000 db) where no transponder sites were located. Transponder sites are marked with filled circles.

1982-83 El Niño:

- Strongest of the 20th century up to that time
- Not predicted (no forecast models)
- Not detected until nearly at its peak--satellites biased cold by El Chicon
- No real-time in situ data



El Chichon, Mexico From Mike McPhaden Eruptions 28/3 and 3 and 4 April 82.

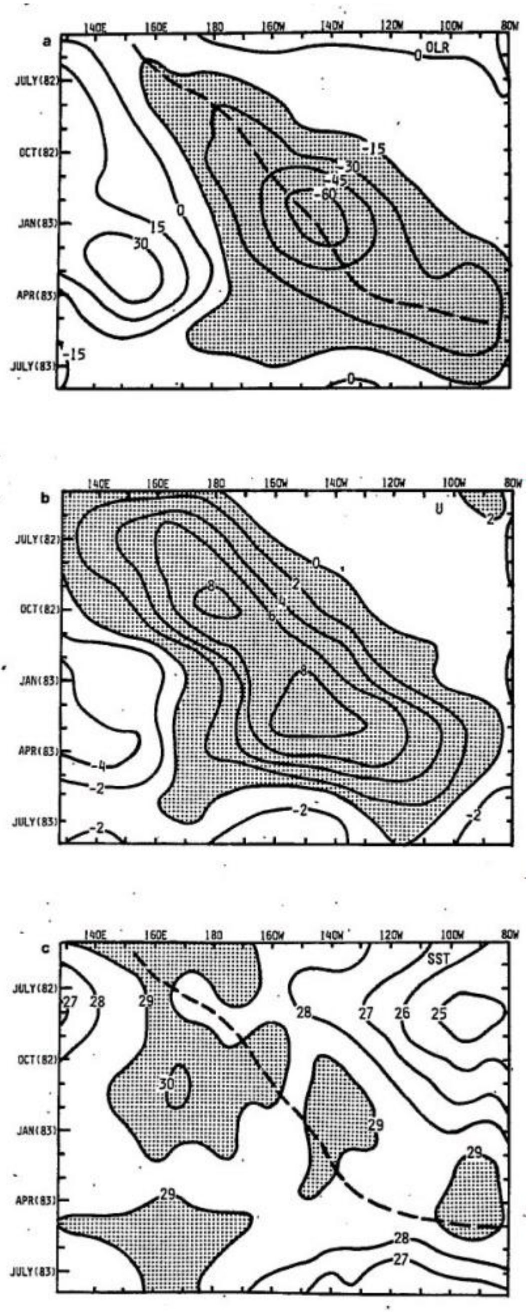


FIG. 8. Time evolution of (a) outward longwave radiation (a measure of convective activity); (b) anomalous winds; (c) SST for the 1982–83 ENSO, showing the eastward movement of all fields. Compare with Figs. 6 and 7. From Gill and Rasmusson (1984).

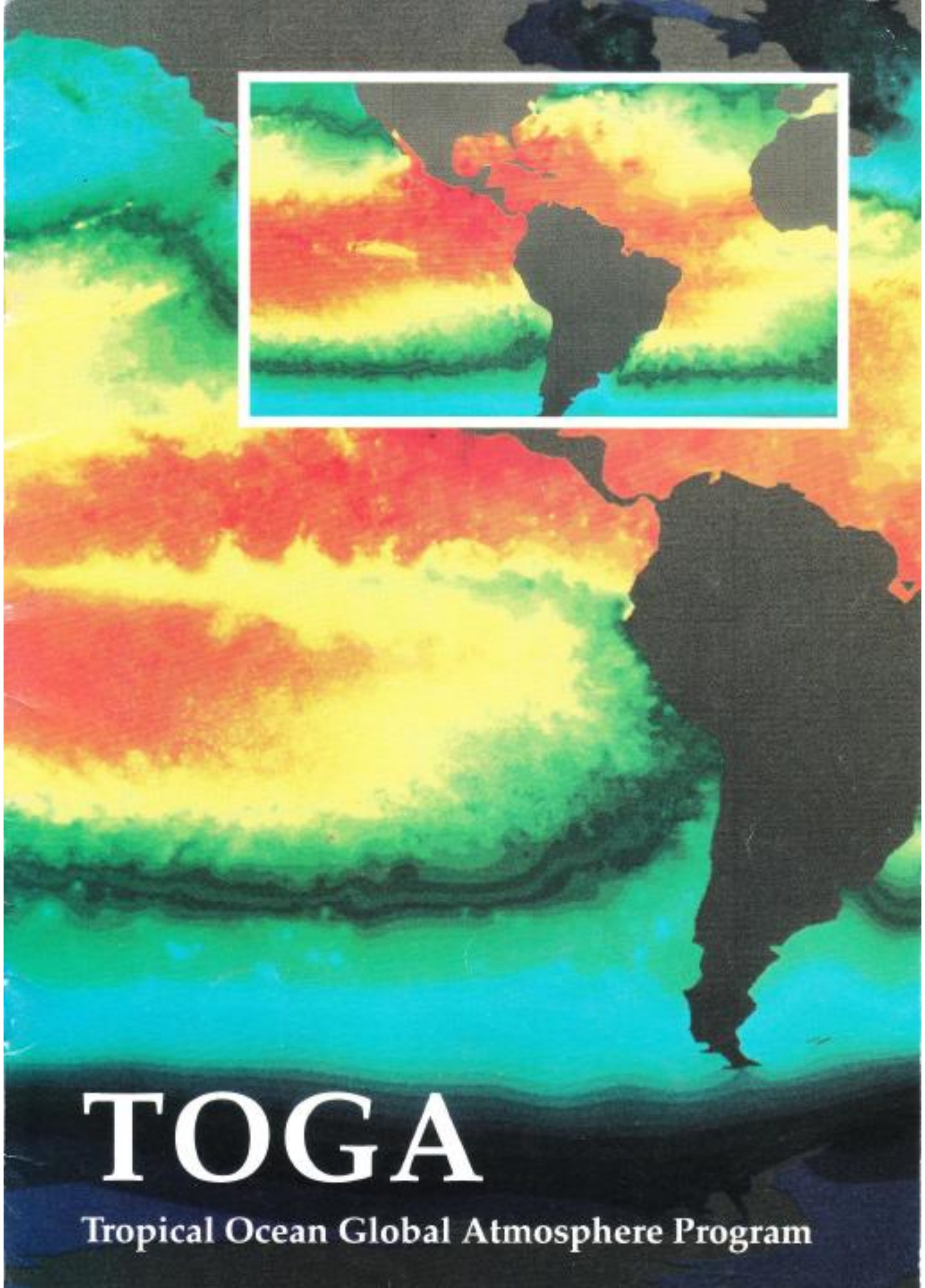
The 82/3 El Nino
showed clear Eastward
development.
Gill and Rasmusson
Nature 306, 229-234.

Contrary to the
Rasmussen and
Carpenter paradigm

TOGA

(Tropical Ocean Global Atmosphere)

- The failure to alert the community to the 82/3 El Nino lead scientists to develop the TOGA programme.
- A key component of the TOGA observing system was the development of first the XBT network and then the TAO array.
- TOGA brought a major change in the way oceanographers worked. Data was to be made freely available as quickly as possible, like in meteorology.
- It is still amazing that from my office, I can see instantly what is happening in the subsurface tropical Pacific ocean, one of the remotest spots on earth.



TOGA

Tropical Ocean Global Atmosphere Program

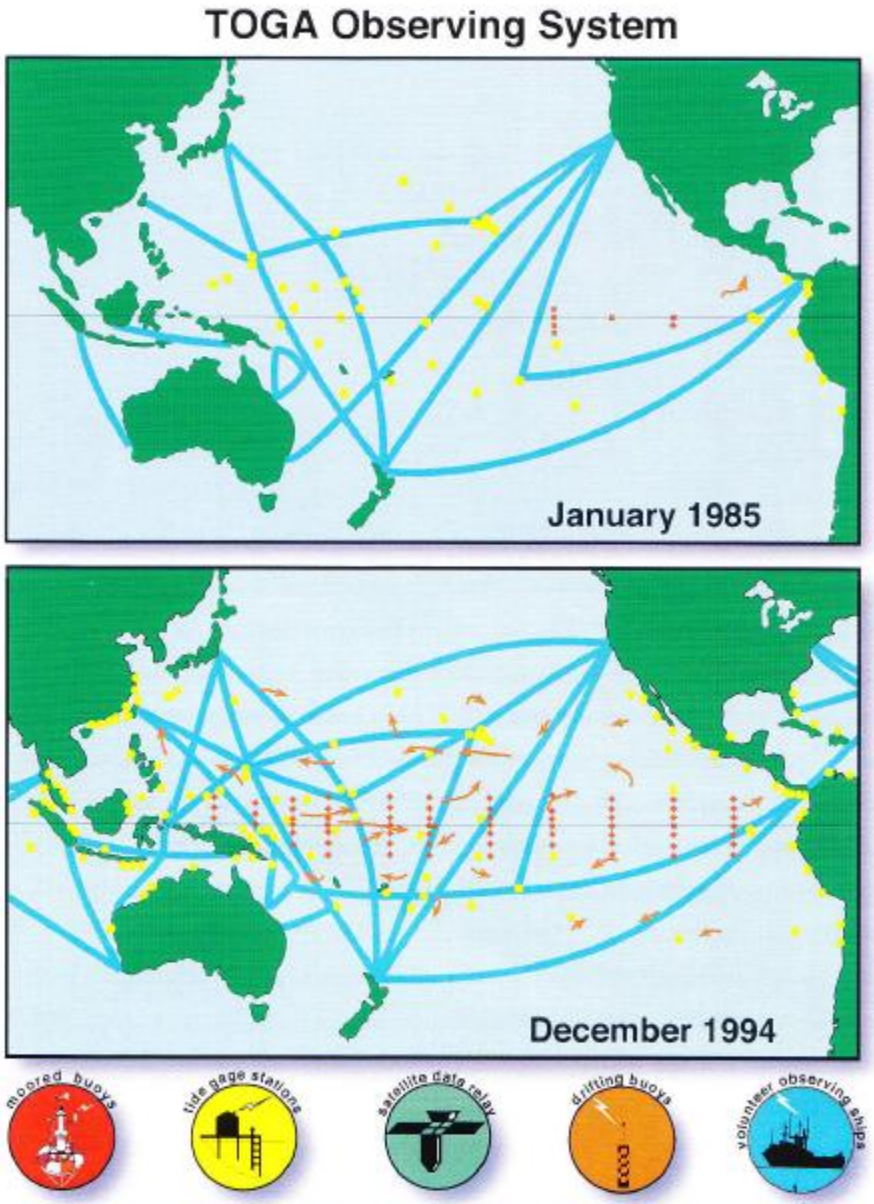


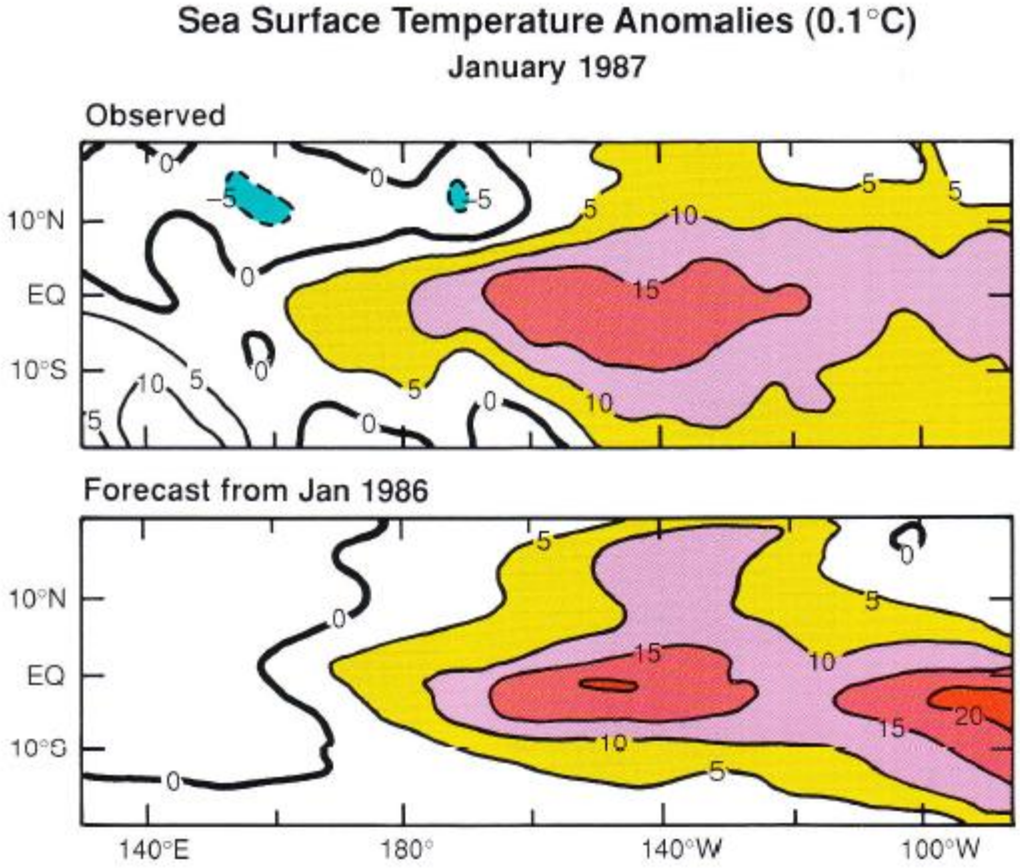
Figure 2. In situ components of the Tropical Ocean Global Atmosphere (TOGA) observing system at (top) the start of TOGA in January 1985 and (bottom) the end of TOGA in December 1994. Color coding indicates the moorings (red symbols), drifting buoys (orange arrows, one for approximately every 10 drifters), ship-of-opportunity lines (blue), and tide gauges (yellow). *After McPhaden et al., 1998*

A major experiment, called TOGA=Tropical Ocean Global Atmosphere was planned so that we would never again be taken by surprise by El Nino.

Adrian Gill was a major driving force and first chairman of the scientific steering group. Peter Webster was second.

Observation, Understanding, Prediction were the goals

One of the earliest forecasts. This one was influential in the development of TOGA. From Cane et al Nature, June 1986, v322, 817-832.
A footnote to the paper says ‘ No indication of El Nino is apparent as of the end of May 1986. There is no known precedent for an event to begin later than June’. Very honest appraisal However, but an El Nino did in fact develop.



Sea Surface Temperature Anomalies (0.1°C)
January 1987

Observed

Forecast from Jan 1986

Prediction of El Niño One Year in Advance
Comparison of observed sea-surface-temperature anomalies in January of 1987 and those predicted a year earlier by the atmosphere-ocean model.

This is a hindcast but made up to 2 years in advance. This, together with the previous plot gave rise to optimism about El Nino forecasting, even though the authors were quite measured (modest) in their appraisal of their skill.

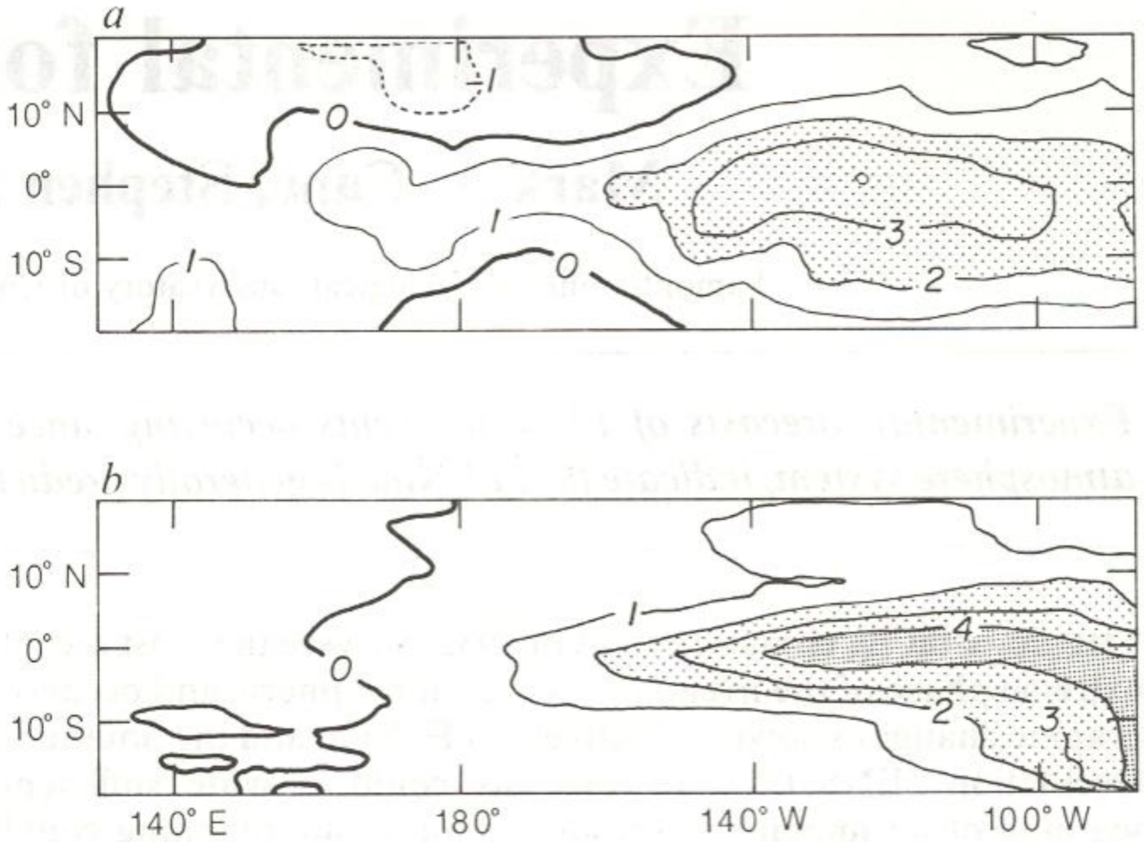
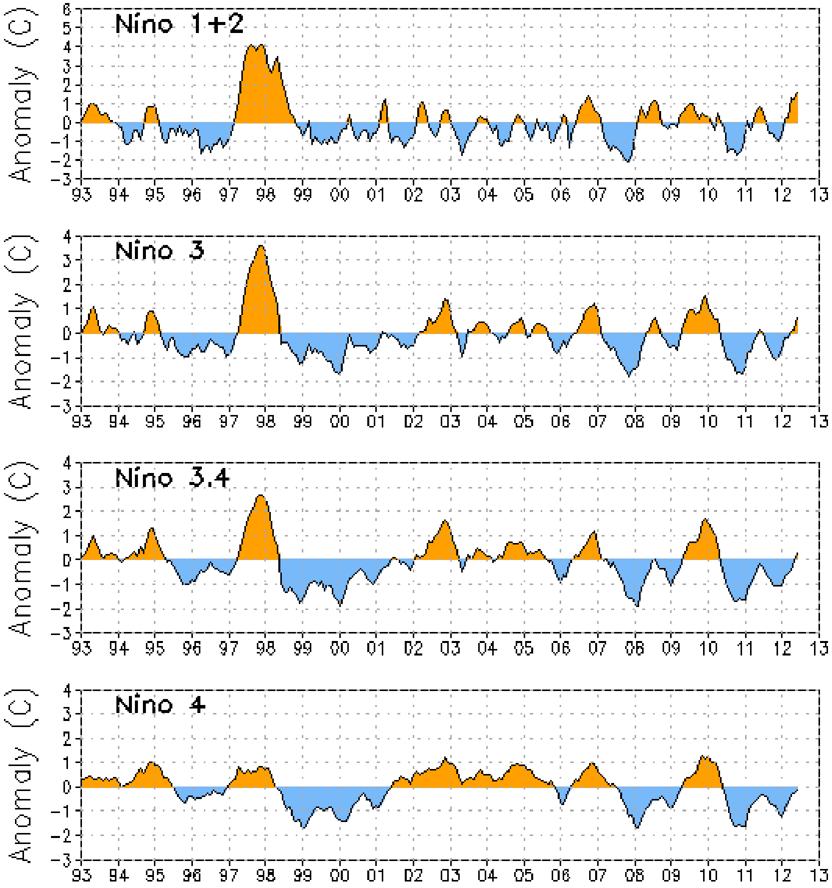
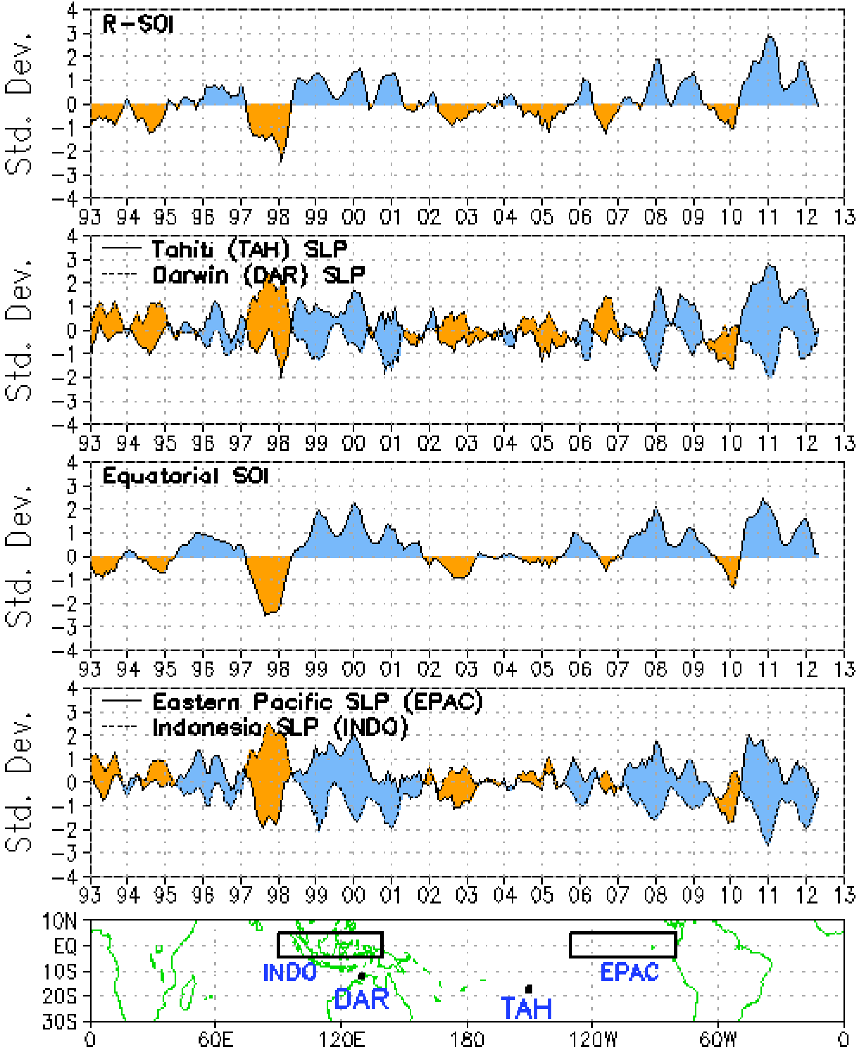


Fig. 1 Sea surface temperature (SST) anomalies (°C) in January 1983. *a*, Observed, based on the analysis of the Climate Analysis Center (CAC) of NOAA. *b*, Predicted by the model forecast initiated in January 1981, 2 years earlier.



Data updated through June 2012

CDAS/Reanalysis-Based SOI and Equatorial SOI

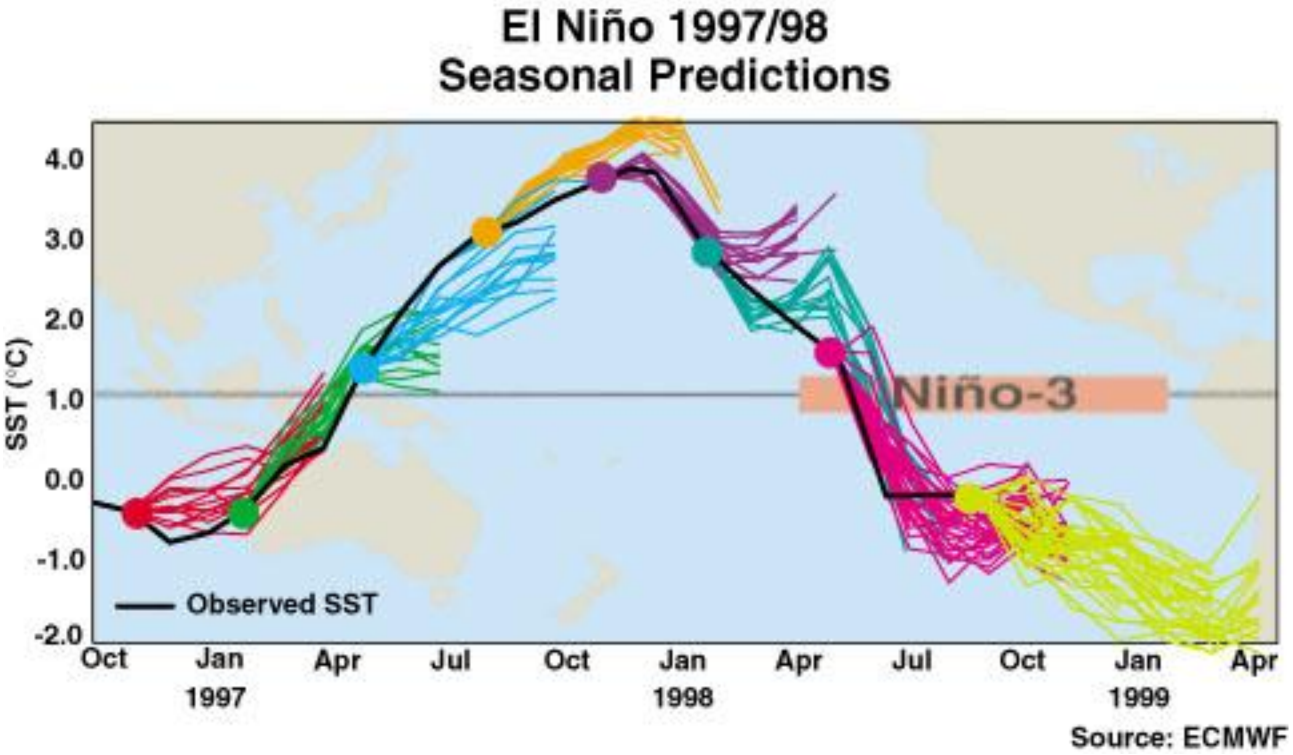


Data updated through June 2012

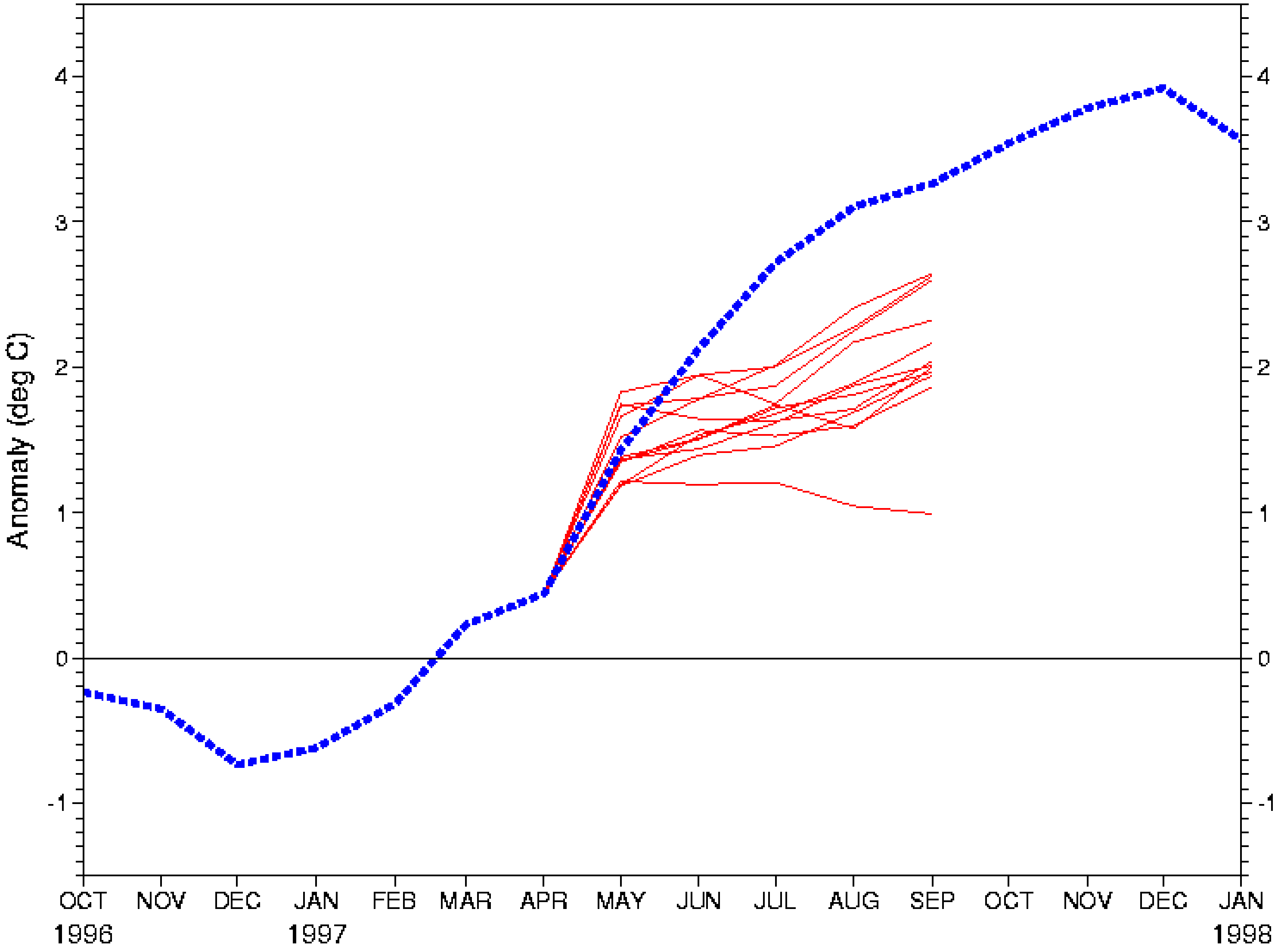
Several people in this room contributed to the ECMWF initiative.

- Other initiatives in the US, and through EU projects.

ECMWF forecasts (CLIVAR)

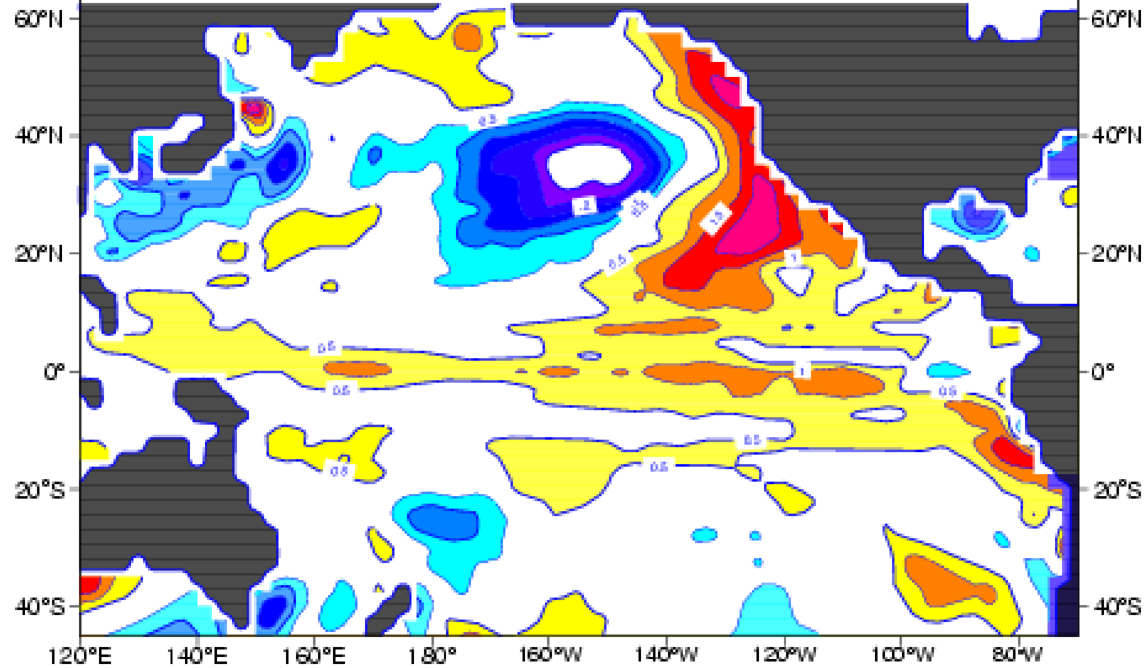


NINO-3 SST anomaly plume
ECMWF forecasts from dates in Apr 1997

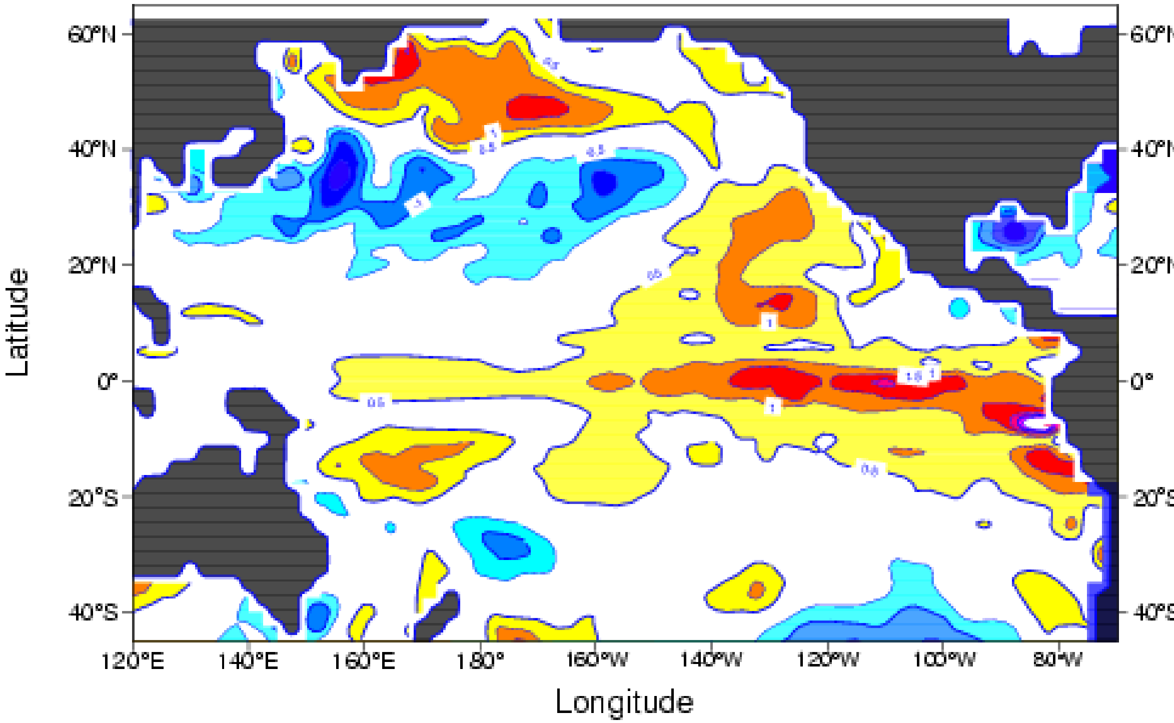


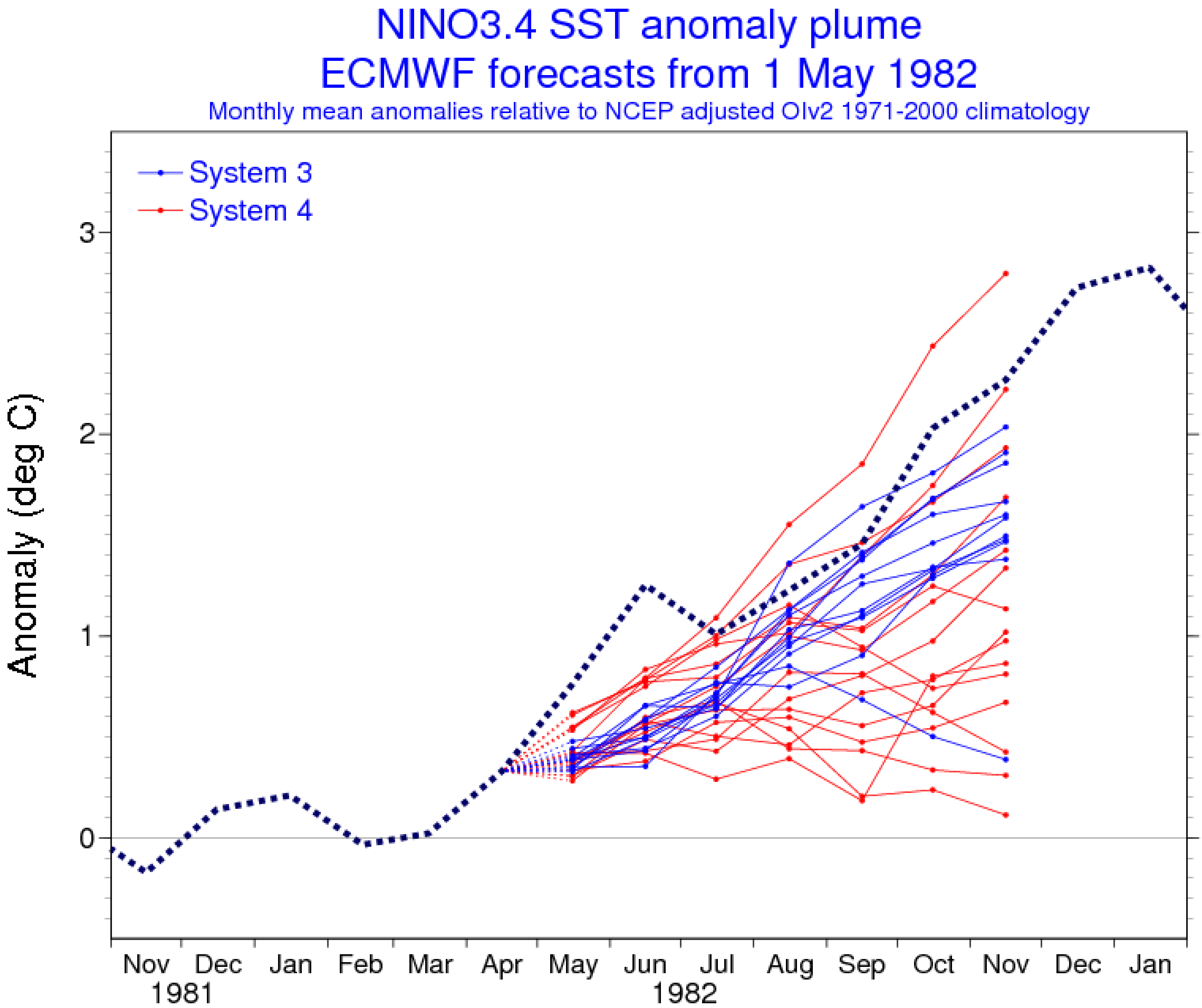
MAGICS 6.0 styx - net Tue May 11 08:56:08 1999

Chaos in SST



Two forecasts of the 97 El Nino, made from small perturbations in ocean initial conditions in Dec 96.





NINO3.4 SST anomaly plume
ECMWF forecasts from 1 May 1982
Monthly mean anomalies relative to NCEP adjusted OIv2 1971-2000 climatology

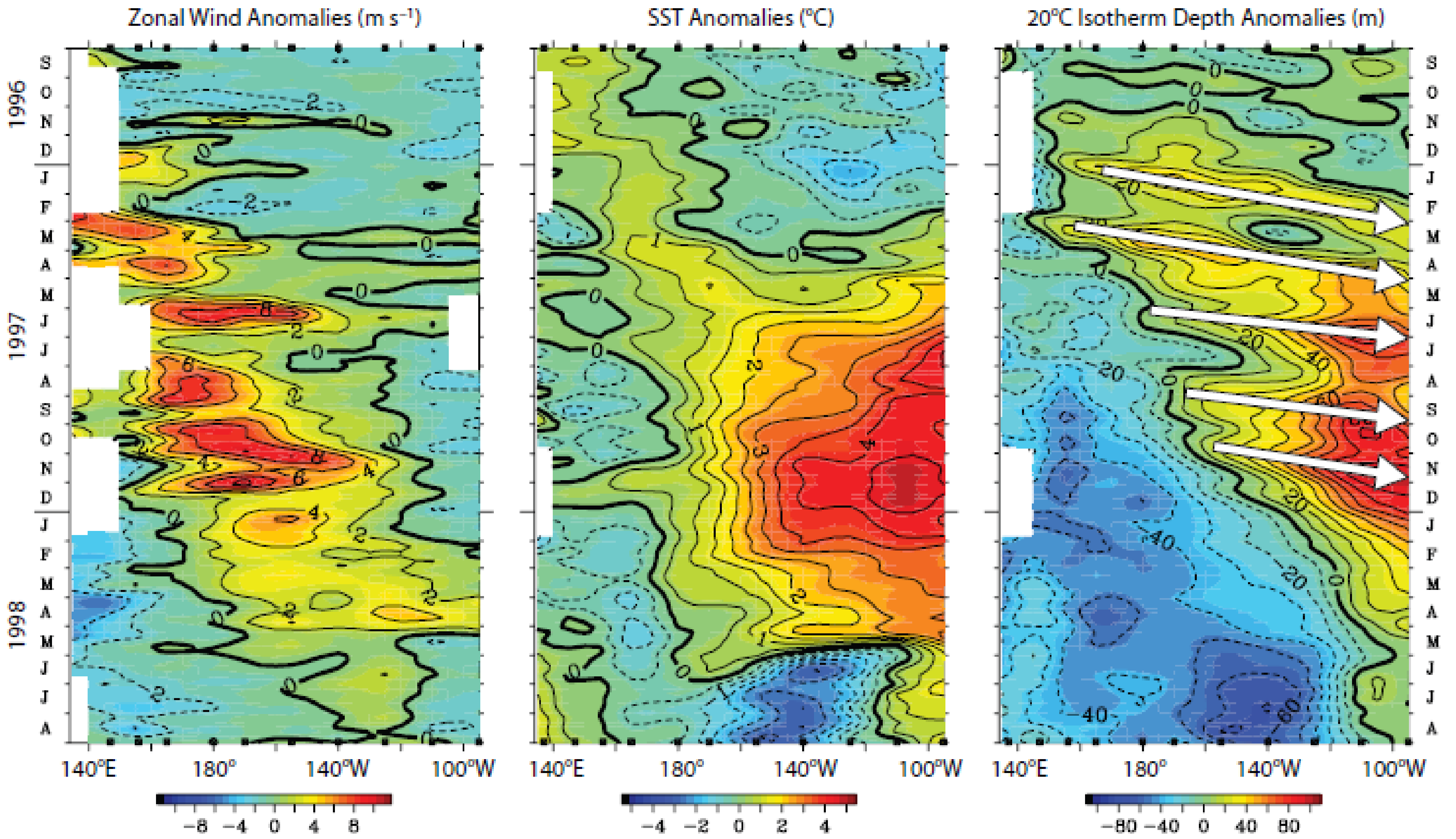
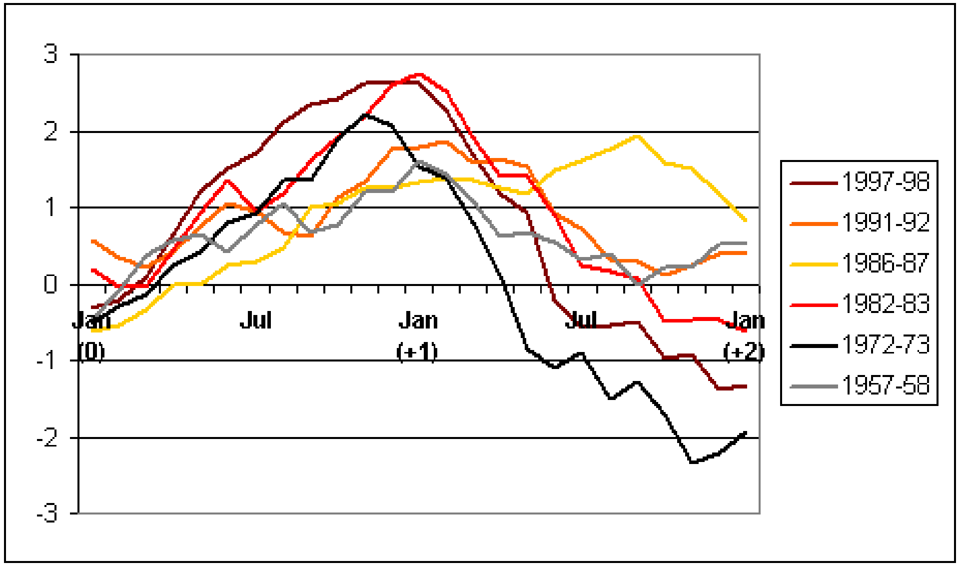
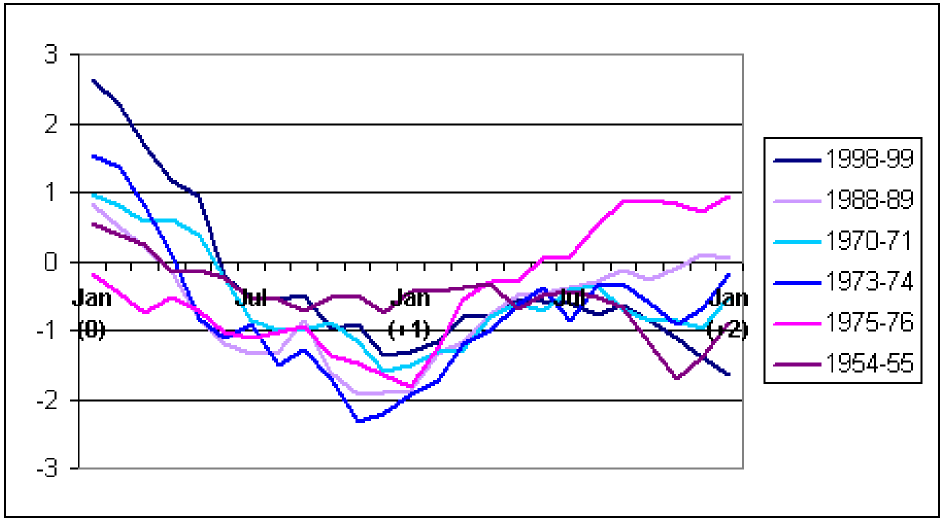
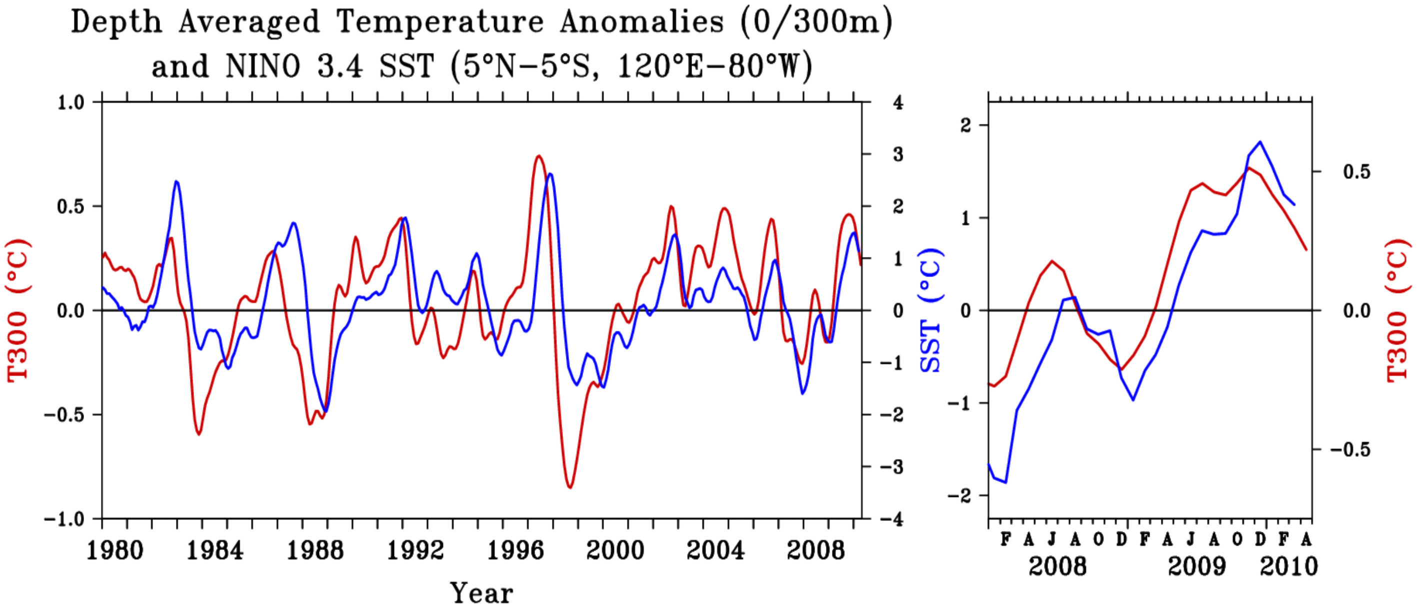


Figure 5. Time versus longitude sections of anomalies in surface zonal wind (left), SST (middle), and 20°C isotherm depth (right) from September 1996 to August 1998. Analysis is based on five-day averages of moored time-series data from the TAO array between 2°N and 2°S. Anomalies are relative to monthly climatologies that were cubic spline fit to five-day intervals. The 20°C isotherm is an indicator of thermocline depth along the equator. Black squares on the abscissas indicate longitudes where data were available at the start (top) and end (bottom) of the time series. Arrows indicate the eastward propagation of downwelling equatorial Kelvin waves in response to the episodic westerly wind burst forcing.
After McPhaden, 1999

Large El Ninos and la Ninas





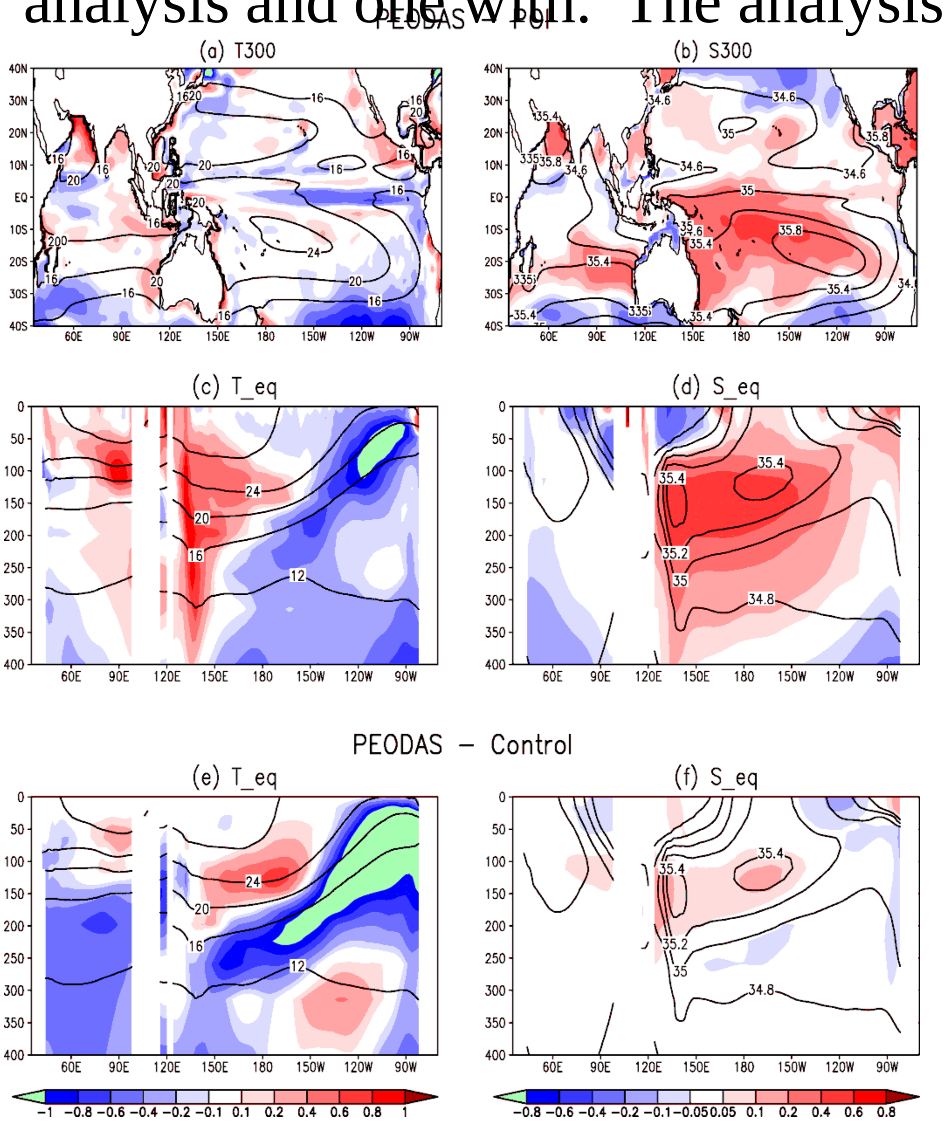


Heat content (as measured by the average temperature in the upper 300 m) and NINO3.4 SST anomalies for 1980 to 2010. Monthly values in left panel have been smoothed with a 5-month running mean. The right panel shows July 2008 to June 2010 (unsmoothed) to highlight the El Niño in 2009-10. Note the different scales for heat content and NINO3.4 SST in the two panels. Heat content variations generally lead NINO3.4 SST by 1-3 seasons, with a build up of heat content preceding El Niño and a deficit preceding La Niña. This lead-lag relationship illustrates the role of upper ocean heat content as the source of predictability for ENSO (after Meinen and McPhaden, 2000). Balmaseda had shown this much earlier to explain why you could predict through the spring predictability barrier.

The role of salinity

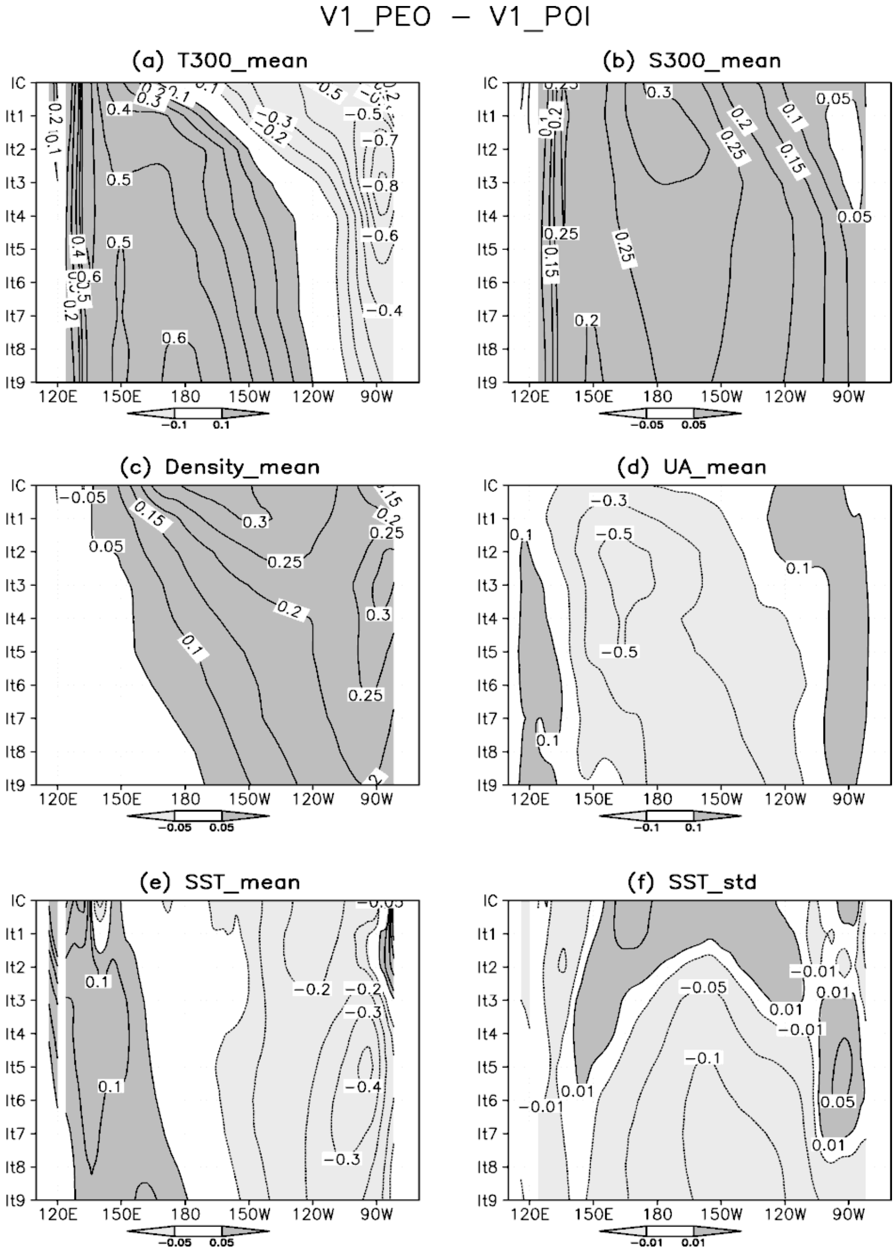
- One of the early notions was that salinity wasn’t that important. There were very few observations of salinity and so an analysis of the salinity field was out of the question. But the atmosphere didn’t really know about salinity; what it responded to was SST. So this was not considered a show-stopper. I think the NCEP analysis just let salinity drift. At ECMWF we initially relaxed salinity to climatology. So the salinity field wasn’t correct but it wasn’t that far away. Since then a scheme to correct salinity based on water mass conservation has been introduced and as well as a scheme to analyse salinity anomalies.

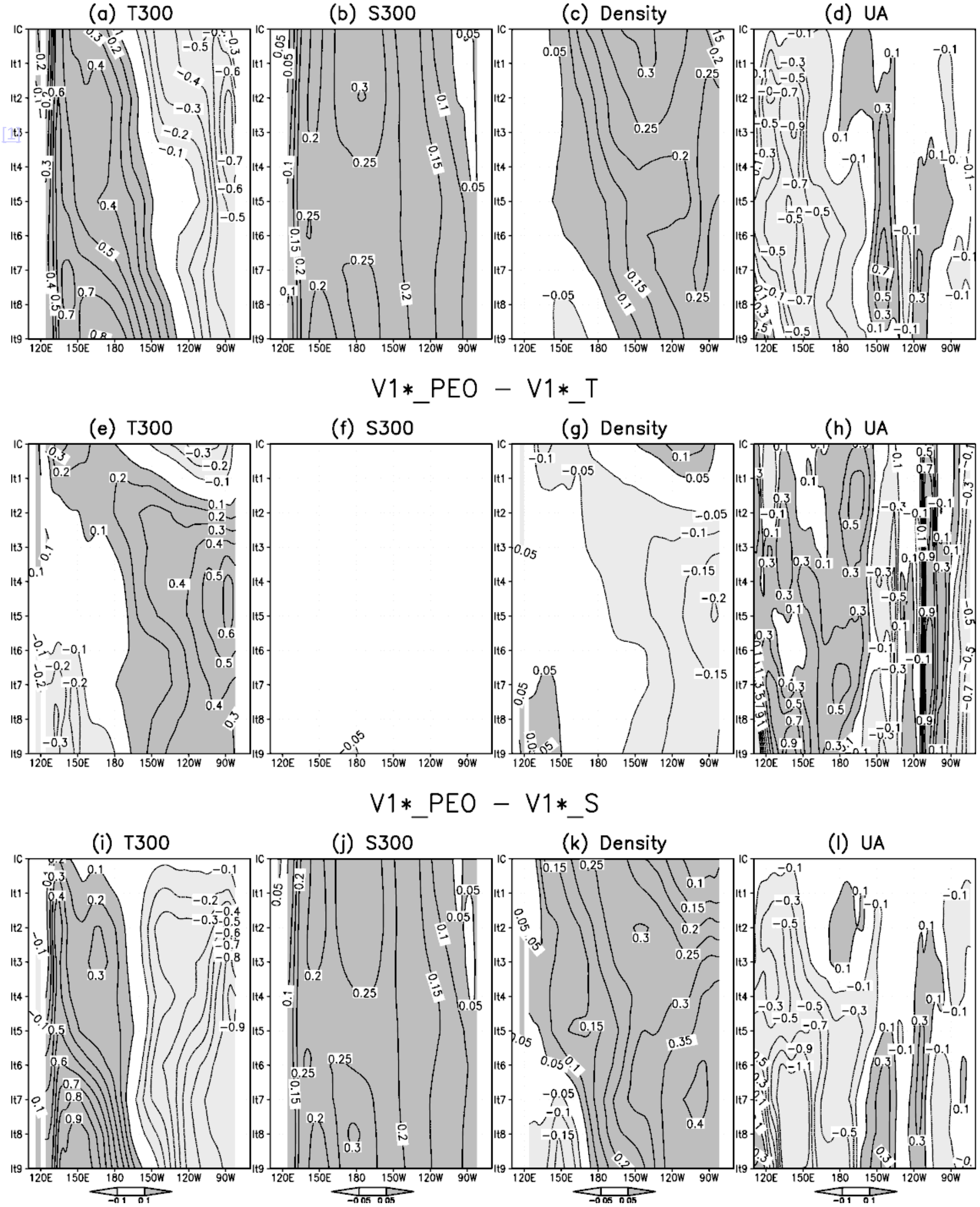
However, salinity is more important than first thought. Zhao et al MWR 2012 consider two analyses, one without salinity analysis and one with. The analysis differences in T are modest.



- 0.4 PSU= 1.1K

- Delta T ~ 0.3 int annual var
- Delta S ~5x int annual var in S


V1_PEO − V1_POI
(a) T300_mean
(b) S300_mean
(c) Density_mean
(d) UA_mean
(e) SST_mean
(f) SST_std
IC
It1
It2
It3
It4
It5
It6
It7
It8
It9
120E
150E
180
150W
120W
90W
−0.1
0.1
−0.05
0.05
−0.01
0.01
0.4
0.5
0.6
−0.3
−0.5
−0.7
−0.8
−0.6
−0.4
0.3
0.25
0.2
0.15
0.1
−0.05
−0.2
−0.1
0.05



Differences for the mean states for T300, S300, Density, and zonal wind (UA) along the equator between **V1*_PEO** and (a)-(d) **V1*_TSUV**, (e)-(h) **V1*_T**, and (i)-(l) **V1*_S** from the initial condition (IC) through to lead time 9 month for forecasts initialized on 1 January and 1 July 1990.

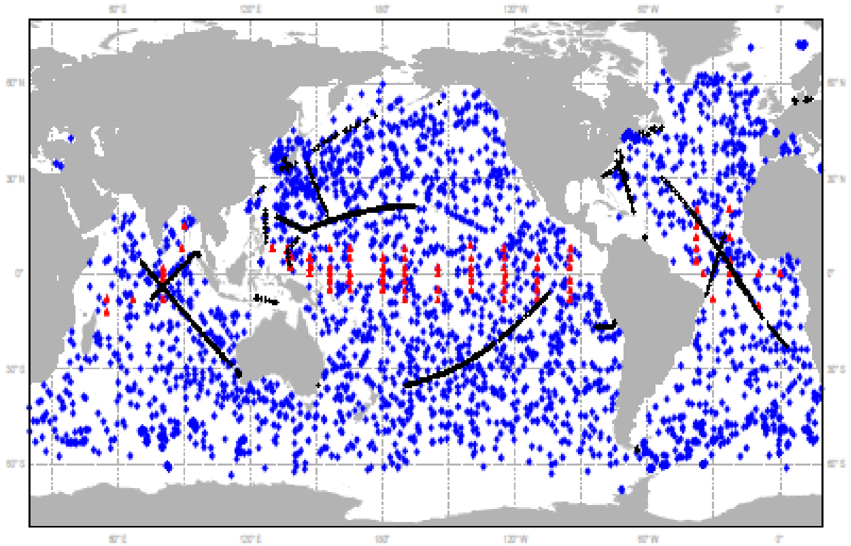
Temperature anomalies do not induce salinity anomalies and end up with opposite sign to panel a.

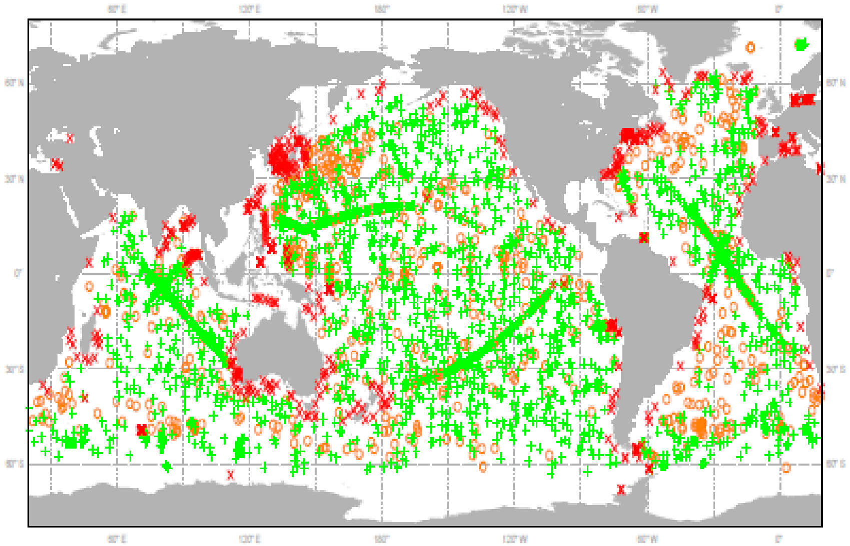
By contrast salinity anomalies reproduce most of the changes noted.

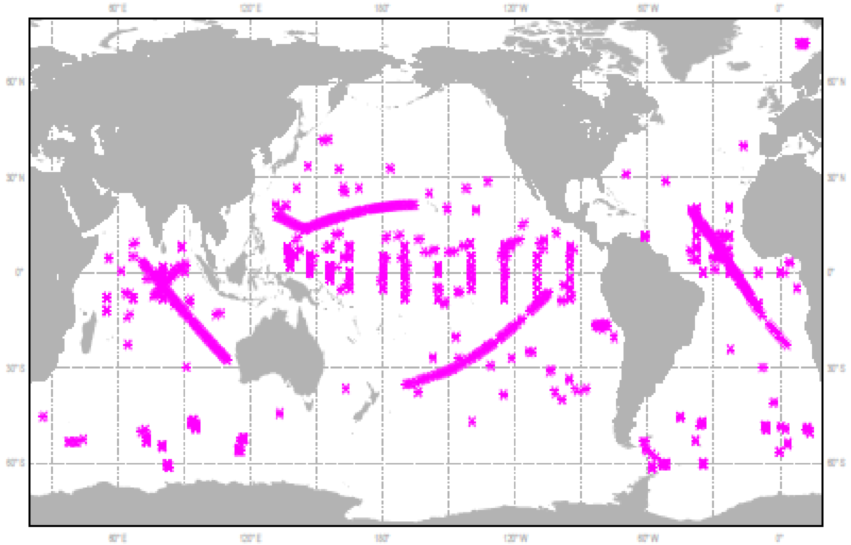
Temperature anomalies develop rapidly and persist.

Impact of Salinity Constraints on the Simulated Mean State and Variability in a Coupled Seasonal Forecast Model
Mei Zhao, Harry H. Hendon, Oscar Alves, Yonghong Yin, David Anderson Monthly Weather Rev 2012.

Typical receipt and use of observations in the ECMWF monthly and seasonal forecast systems







XBT probes: 813 profiles

Argo floats: 2877 profiles

Moorings: 962 profiles

Partially Accepted: 837 profiles

Fully Accepted: 3081 profiles

Fully Rejected: 734 profiles

SuperObs: 1989 profiles

(at least one per profile)

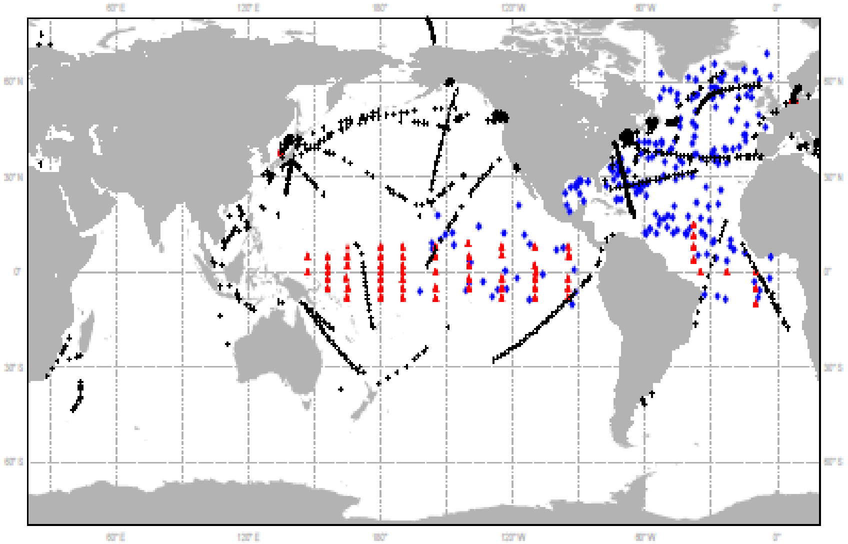
In situ observation

monitoring (temp)

S3 ocean analysis

10 days period centered on 20090418

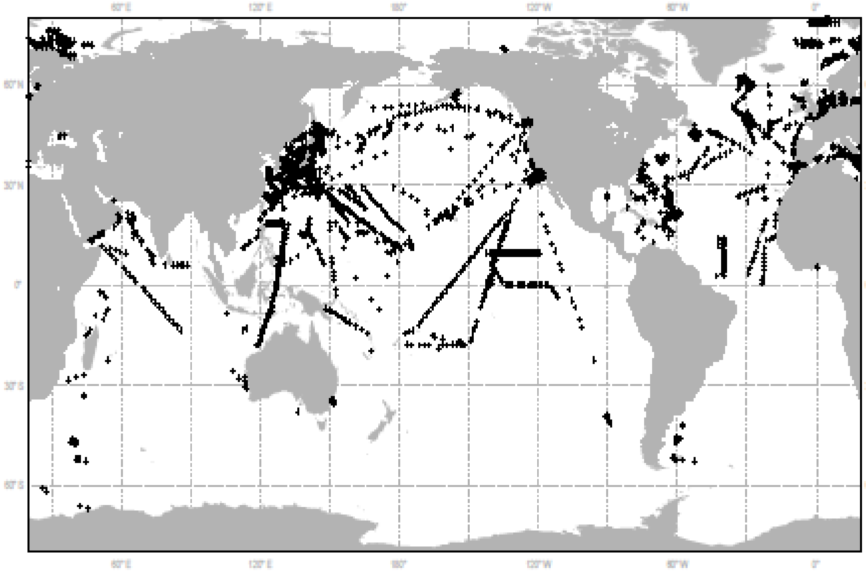
Coverage 1999



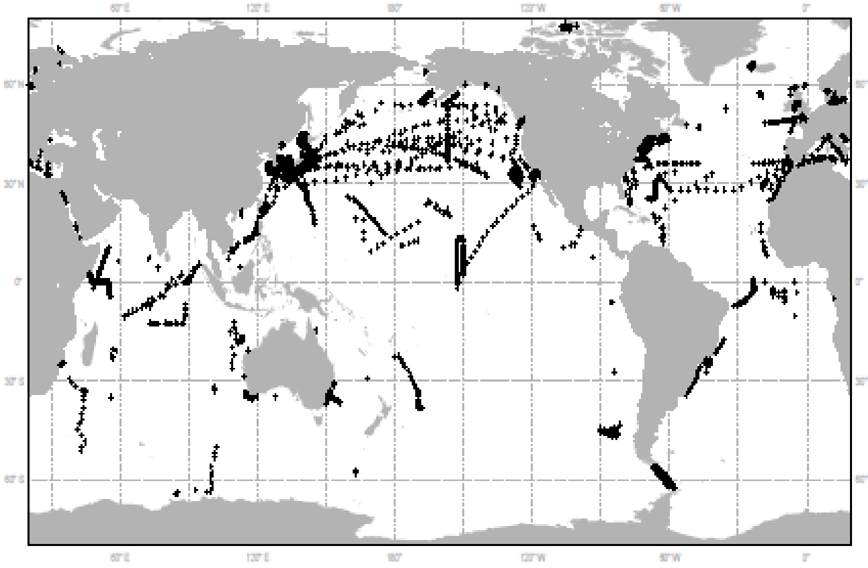
19990421

Note the TOGA TAO array. See McPhaden et al J Geophys Res TOGA review issue 1998, McPhaden, Busalacchi, Anderson Oceanography 2010, 23,86-103.

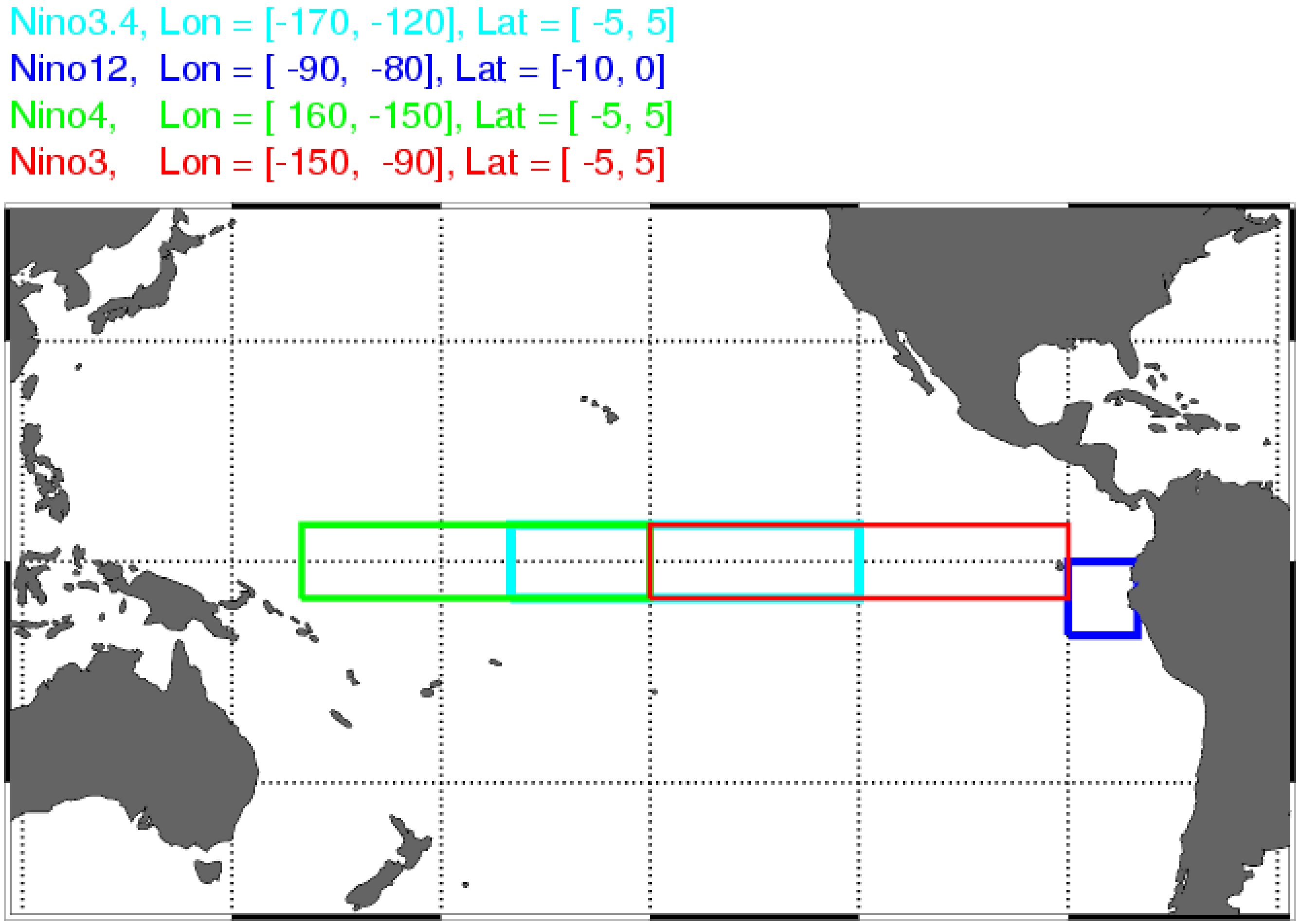
Coverage 1989, 1979



19890423



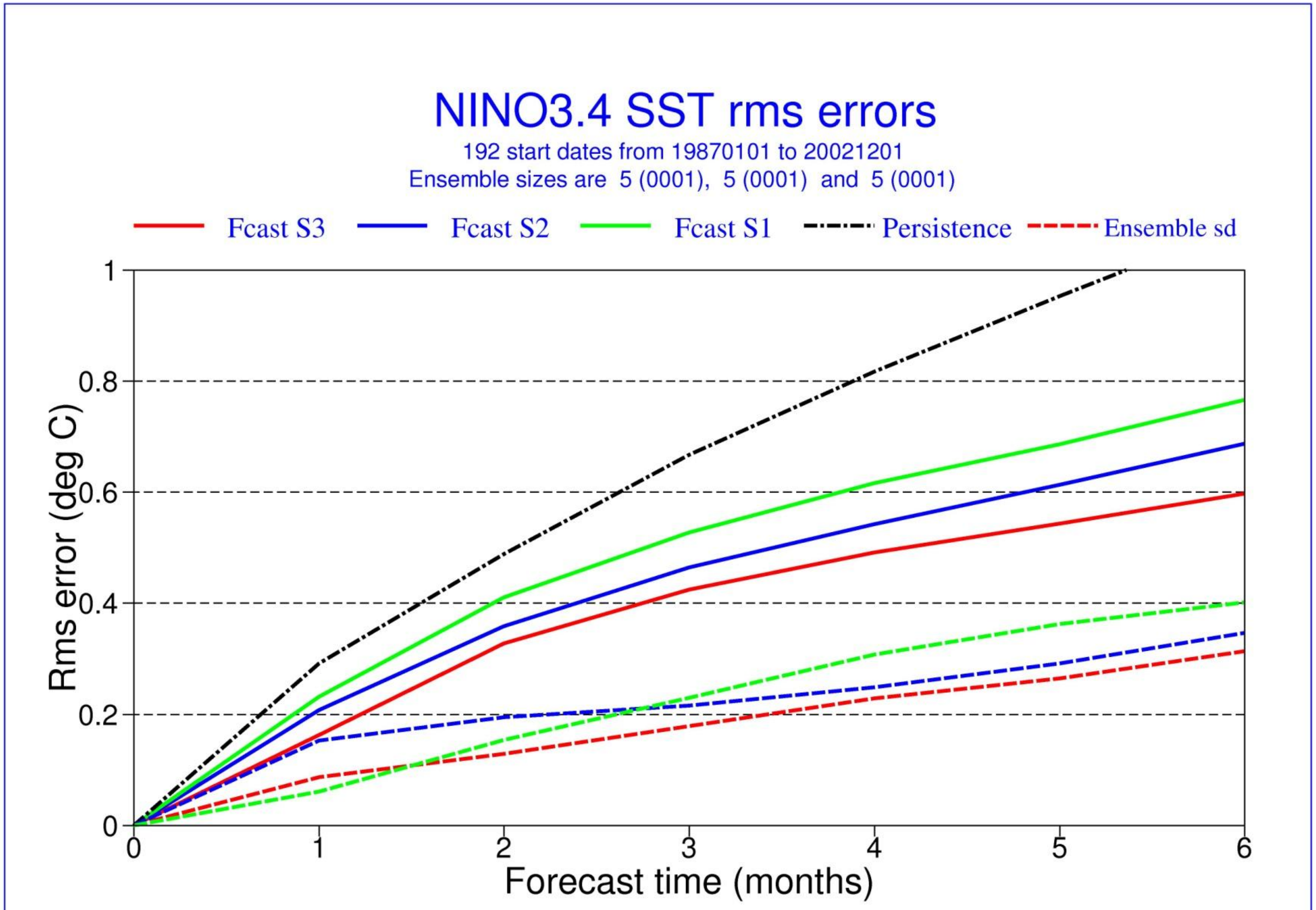
19790416

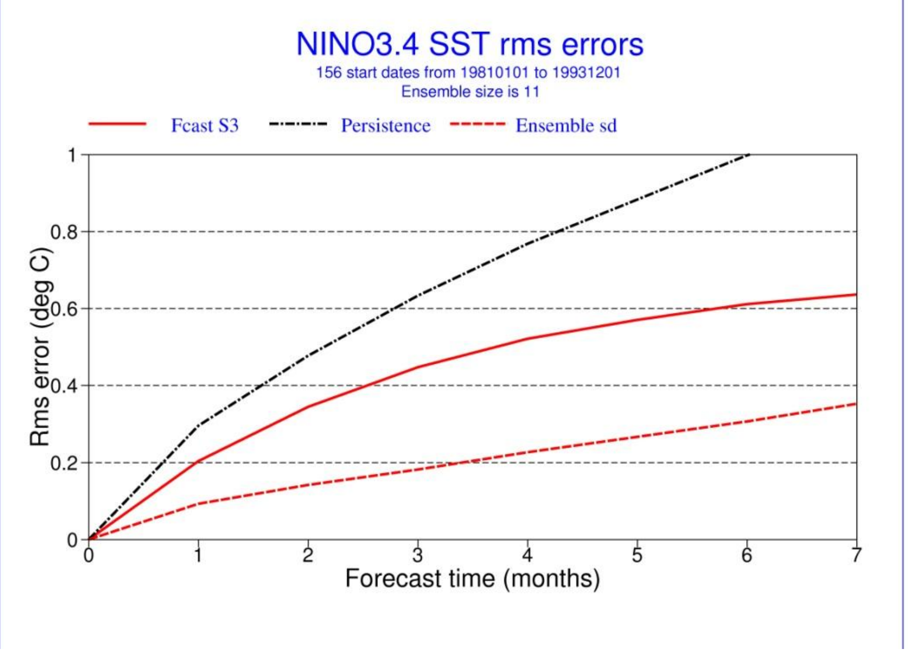


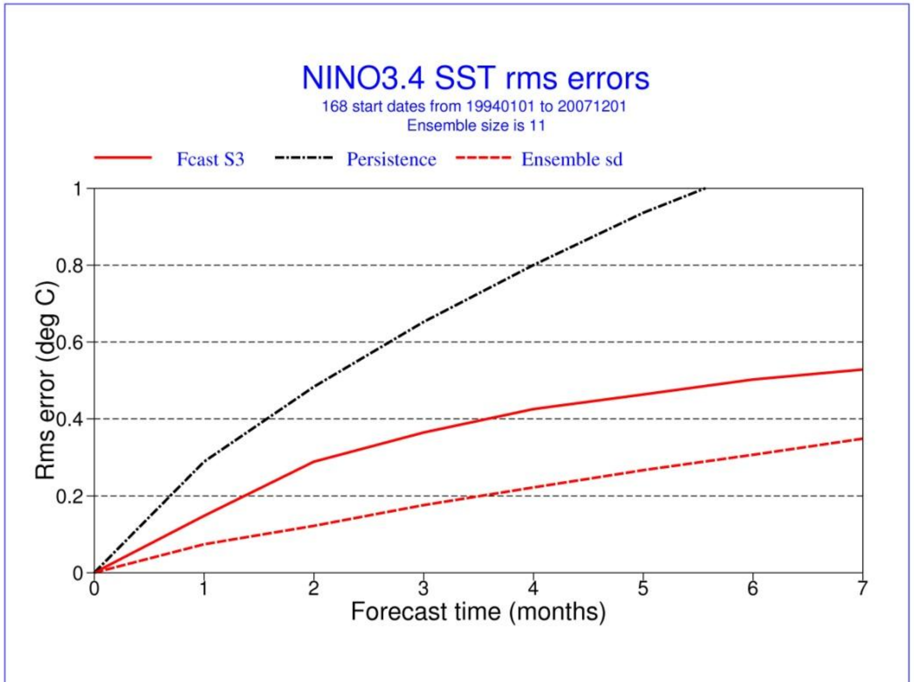
Frequently used regions for studying El Nino

Forecast improvement over the last 16 years, from better models, better data, better analyses.

From Stockdale et al Climate Dynamics 2011





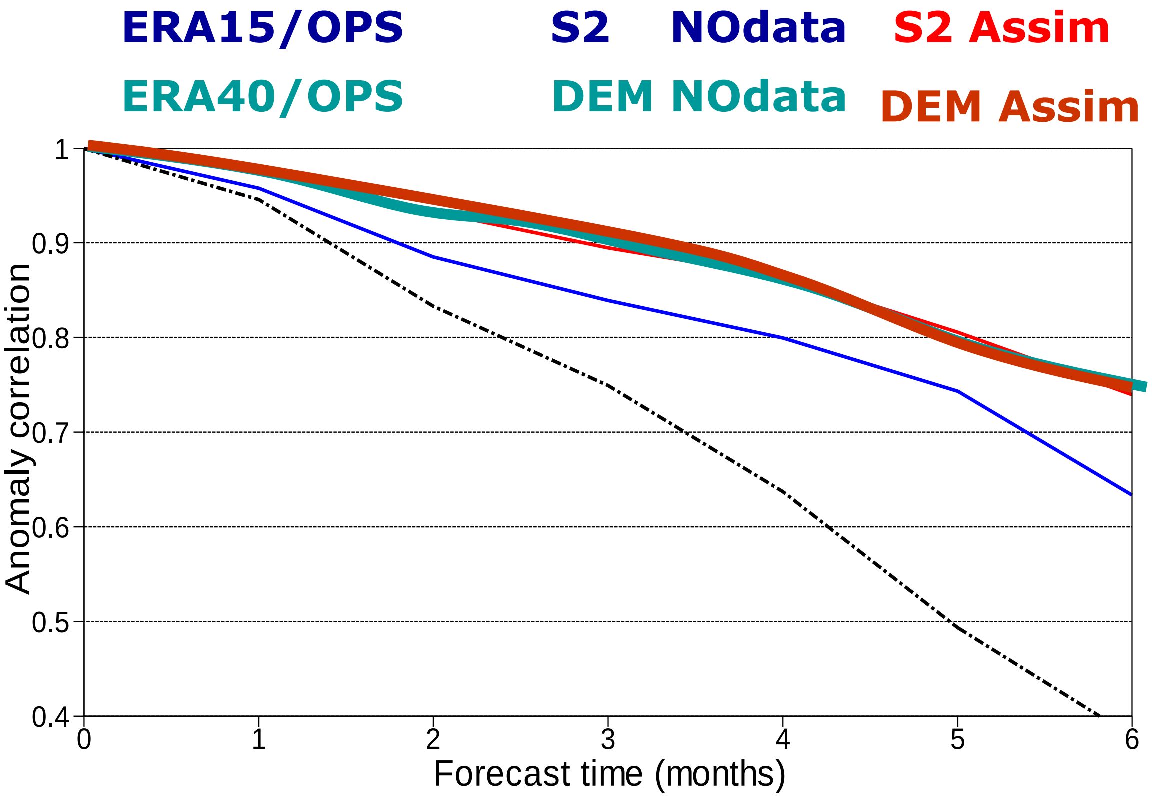


Pre/post 1993

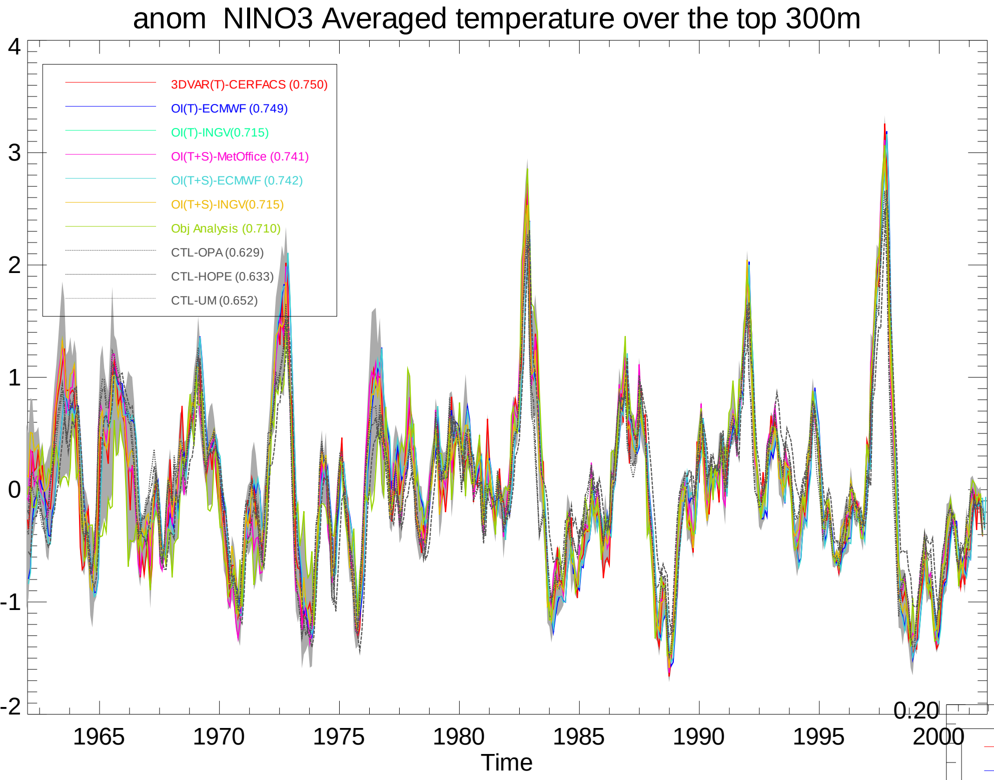
Note the rms error is lower in the more recent period, even though the skill of persistence and ensemble spread are about the same, suggesting the improved skill results from better analyses as a result of better data coverage.

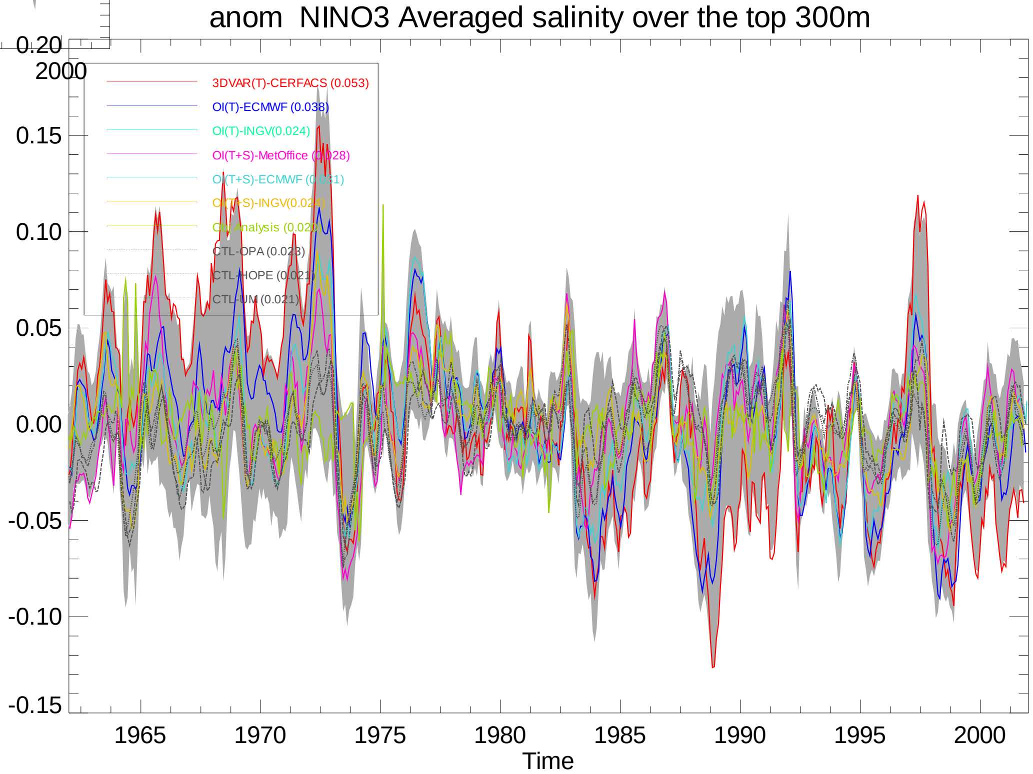
From Stockdale et al 2009, ECMWF Seasonal Forecasting System 3 and its prediction of SST. Climate Dynamics 2011

Progress also depends on the quality of the atmospheric analyses



Magdalena Balmaseda See also her talk on Wednesday





Temperature and salinity in the Nino3 region as analysed by several different models as part of ENACT.

- See Balmaseda, Clivar GSOP, Reading 2006 for more examples

Summary

- There has been substantial progress over the years in seasonal climate prediction, some of it coming from model development, some from better use of the data and some from greater observation coverage.

- Meteorological experience suggests that, as models and data assimilation systems improve, greater information can be extracted from past observations. But if key observations are not made, we can not go back to recreate them. Better to have some redundancy than a deficit.

- Ocean analyses are currently 'all over the place' with respect to some variables, such as salinity, at least in part because there are insufficient data to constrain the analysis sufficiently. If the region or variable isn't key, then that is not necessarily a problem but if it is, then it is a big concern. Ignorance is still a major challenge.

- Improvements in ocean analyses are linked to improvements in atmospheric analyses. There might be merit in coupled analyses, but this is very much in its infancy.

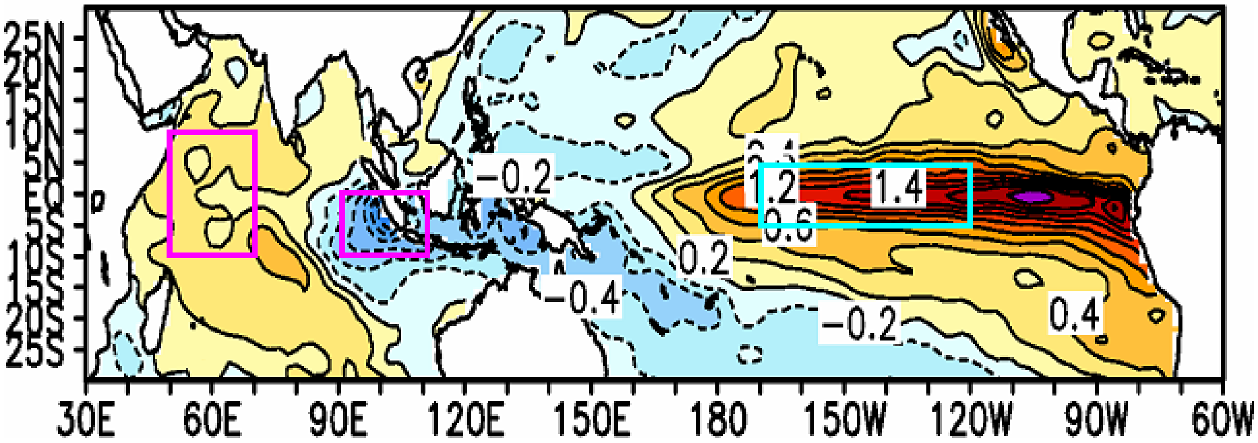
Summary

- Pre TOGA, the 1982/3 El Nino was not well predicted. In fact, the opposite a non El Nino was predicted, reflecting a lack of understanding and a shortage of observations.
- Improvements in observation coverage as a result of TOGA and CLIVAR and improvements in models have lead to better analyses and more reliable forecasts.
- Improved meteorological reanalyses can lead to improved ocean analyses and forecasts.
- There is a large scatter in ocean analyses, partly because of analysis deficiencies but partly because of lack of observations.
- There is skill in predicting the Indian ocean as well as the Pacific, but there is less skill in predicting the evolution of SST in the tropical Atlantic

How to validate forecasts

- Should validation be over all events or concentrated on big events.
- Do not want a lot of false alarms.
- The 1982/3 and 1996/7 El Ninos were not that well forecast, (but see Mason talk tomorrow and Palmer and Stockdale talks on Thursday).
- How about the 2010 La Nina.

Composite OBS IOD (SON)



Li, Hendon, Alves, Luo, Balmaseda, Anderson MWR 2012 in press.
How Predictable is the Indian Ocean Dipole?

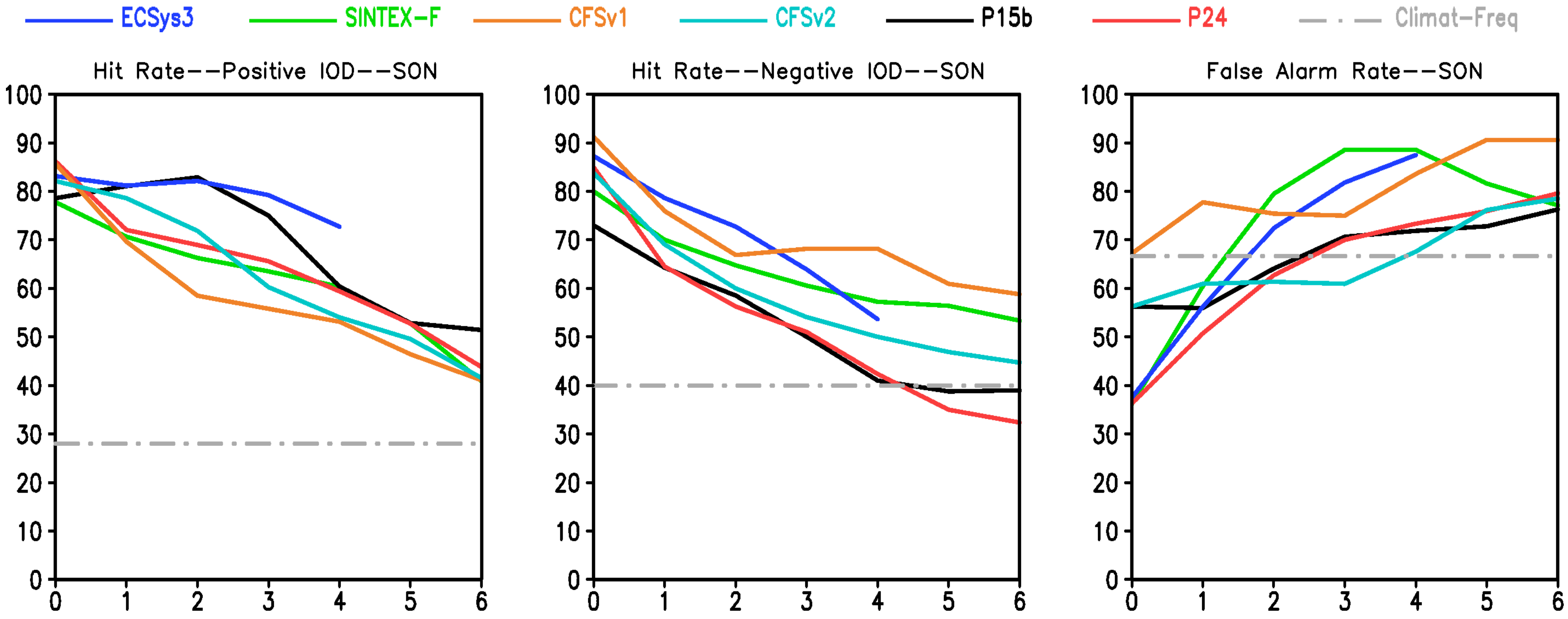
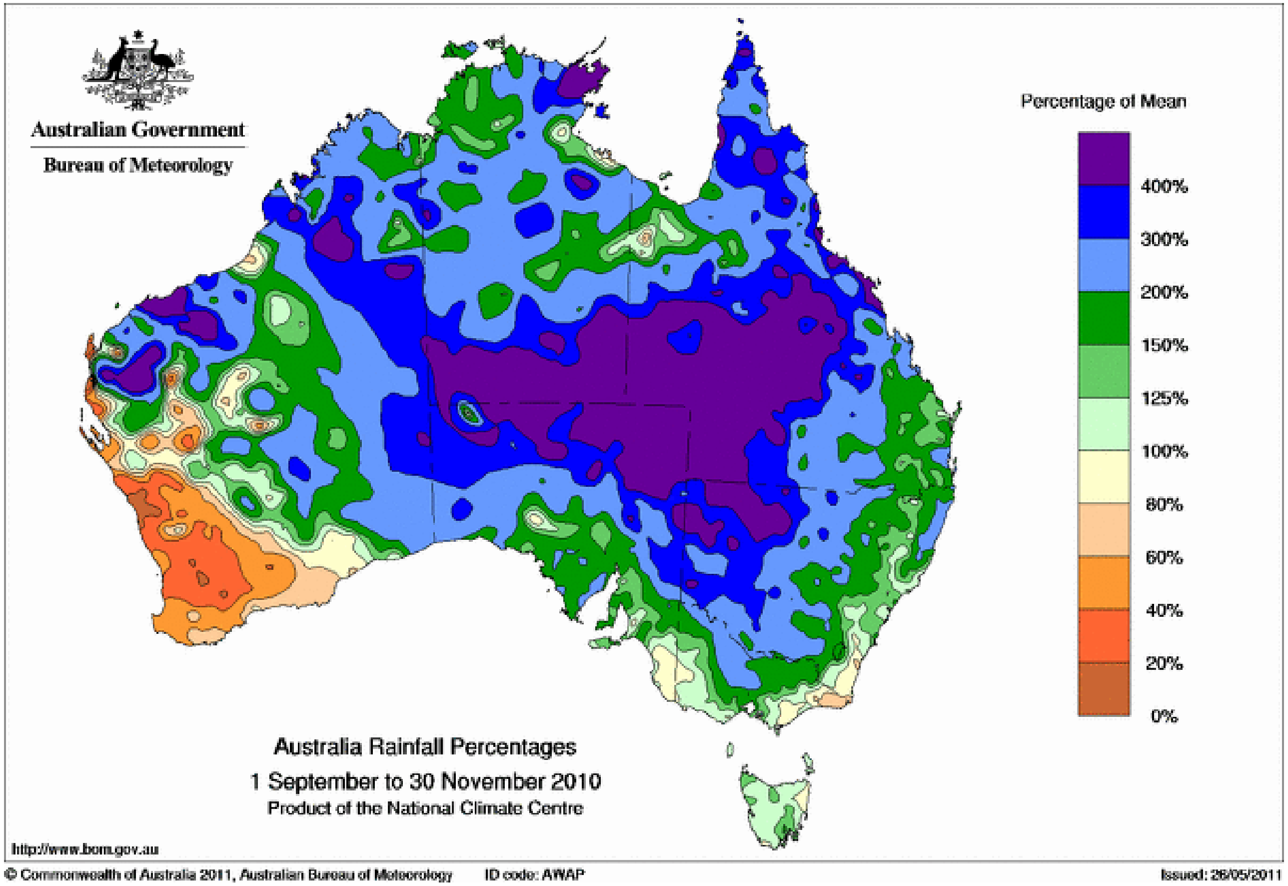


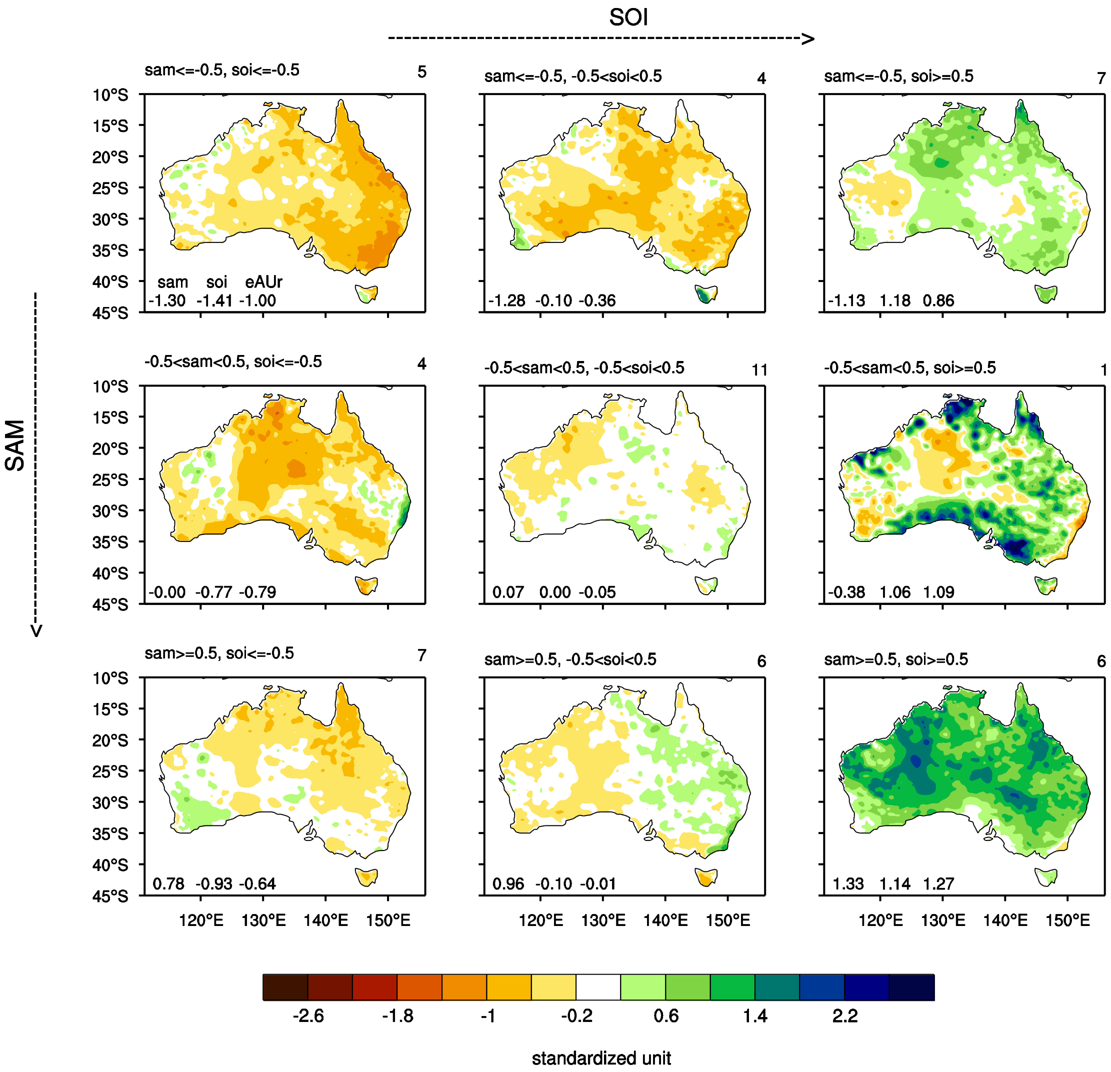
Figure 8: Hit rate for prediction of (a) positive IOD events ,(b) negative IOD events, and (c) false alarm rate for both positive and negative events in the SON that exceed 1/2 observed standard deviation. Abscissa is lead time in months and ordinate is percentage.
Dashed lines in (a)-(c) are estimated climatological rates of occurrence (see text). A 1-2-1 filter across lead time was applied to the hit rate and false alarm rate prior to plotting.

Hit rate is good but the false alarm rate is high, making the forecasts of strong IODs unreliable beyond a month or two. Webster et al., Saji et al Nature 1999

- In Austral spring (and summer) there was a lot of rain and several floods over a large part of Australia (after a prolonged drought of a decade in parts).
- Eastern Australia received its highest rainfall since 1900.
- Based on a very large la Nina and associated warm SST anomalies in the eastern Indian Ocean and to the north of Australia and in the west Pacific, this was very favourable to excessive rainfall.

Austral Spring Rainfall percentiles- highest on record in 2010

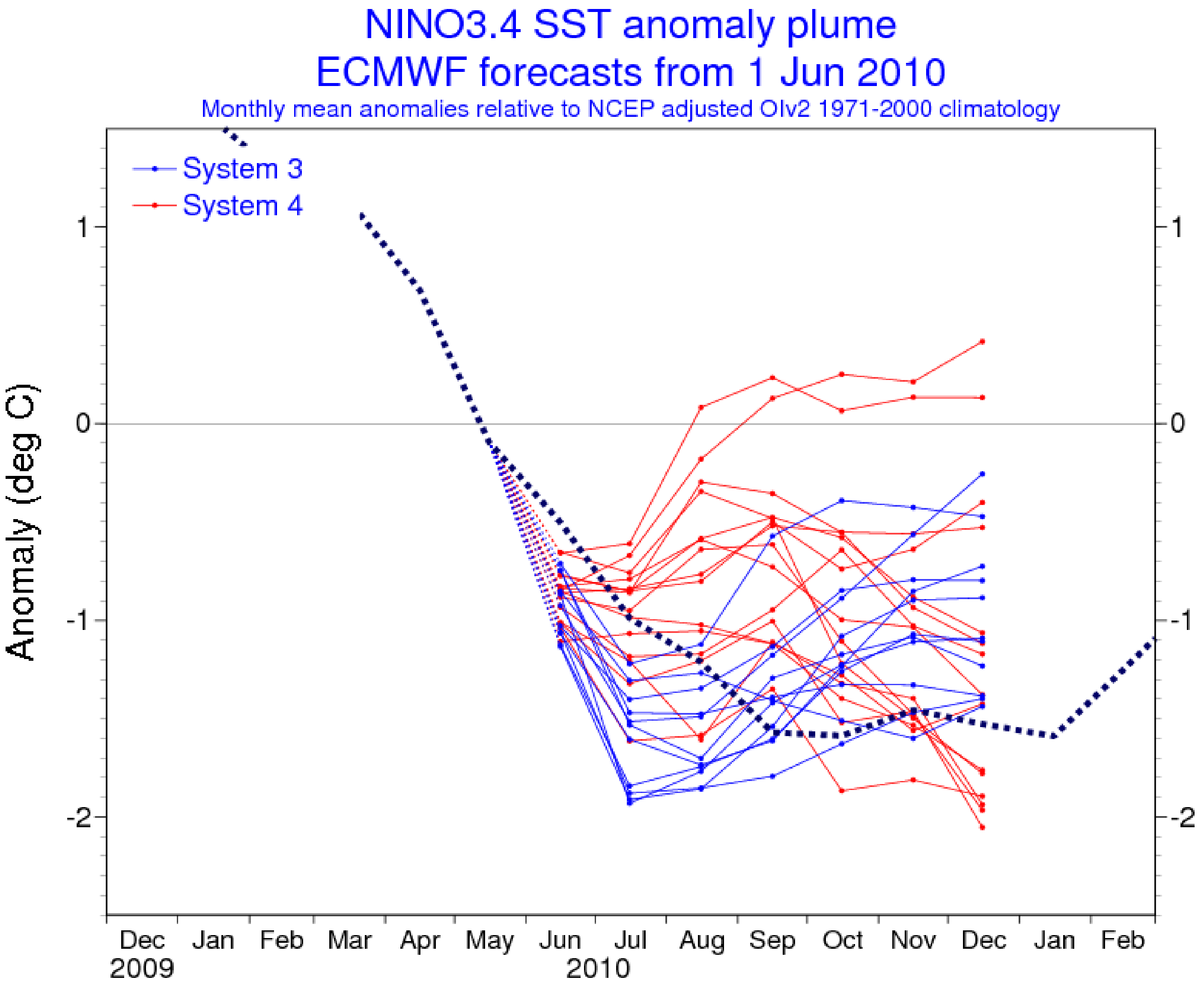




Composites of standardized rainfall anomalies for negative (<=-0.5σ), neutral (-0.5 σ <   < 0.5 σ) and positive (>=0.5 σ) events of SOI and SAM. Rainfall anomalies are from the AWAP analyses for 1960-2010. Color shading indicates rainfall anomalies with 0.4 shading interval. The number of samples in each category is shown in the upper right of each map. The mean amplitudes of standardized SAM, SOI and eastern Australia area averaged rainfall for each category are displayed at the bottom left in each map.

- A large positive swing of the Southern Annular Mode (SAM), appears to have accounted for up to 40% of the rainfall in places.
- To the degree that SAM is unpredictable, the associated rainfall would be unpredictable. But could a large La Nina have induced a large SAM.
- Hendon et al 2012: Causes and predictability of the record wet spring, Australia 2010.

How well was the La Nina predicted? I don’t know how well SAM was predicted.



- There are various ‘modes’ of variability that can ‘upset’ a forecast.
- MJO (Madden Julian Oscillation)
- Indian Ocean Dipole (Webster et al Saji et al)
- Southern (and northern) annular mode.
- They can have higher frequency than eg ENSO but might be tied in part to it. How well can they be predicted.