False alarms in CFS ENSO Predictions

- Case analysis for 2012 prediction

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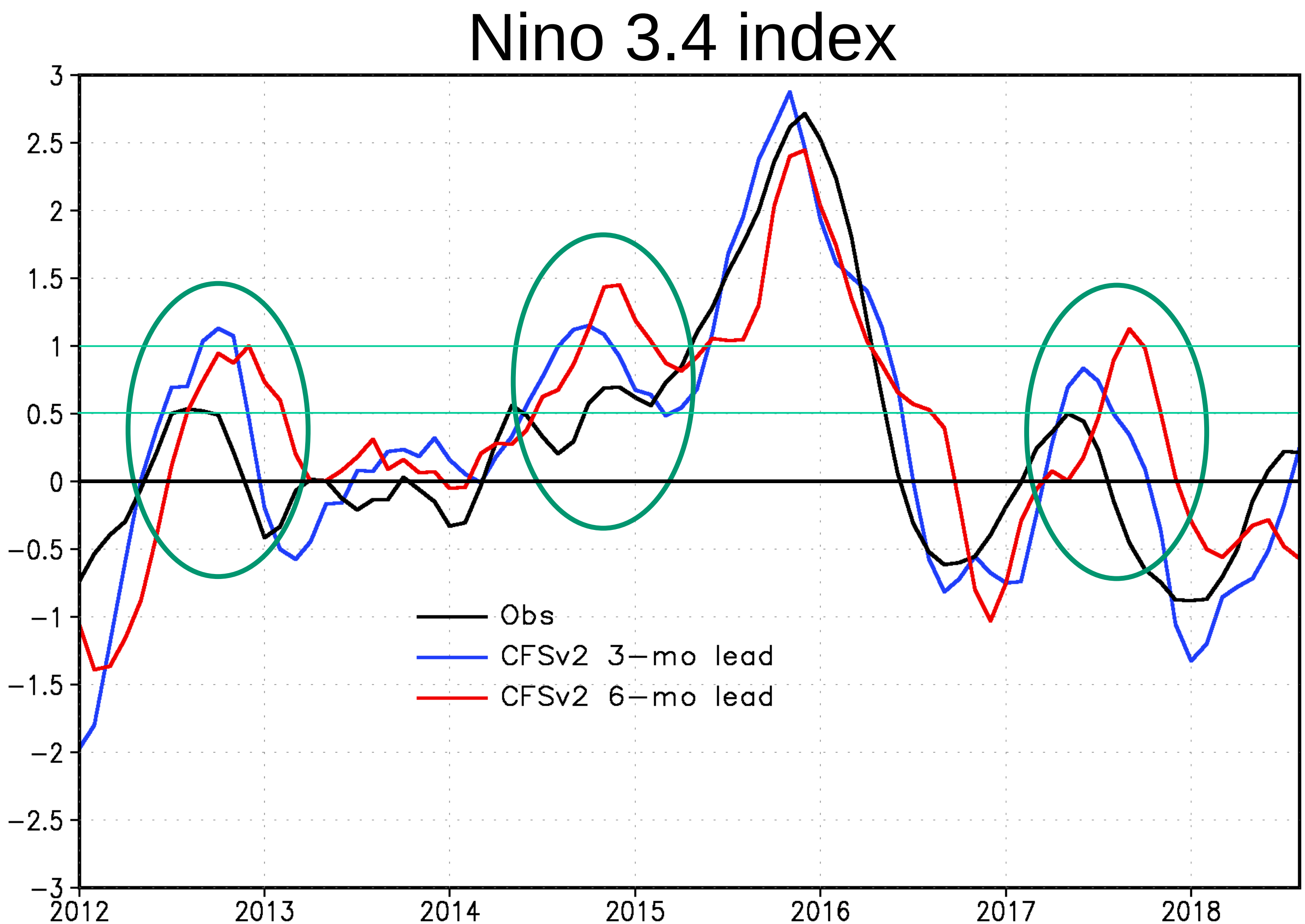
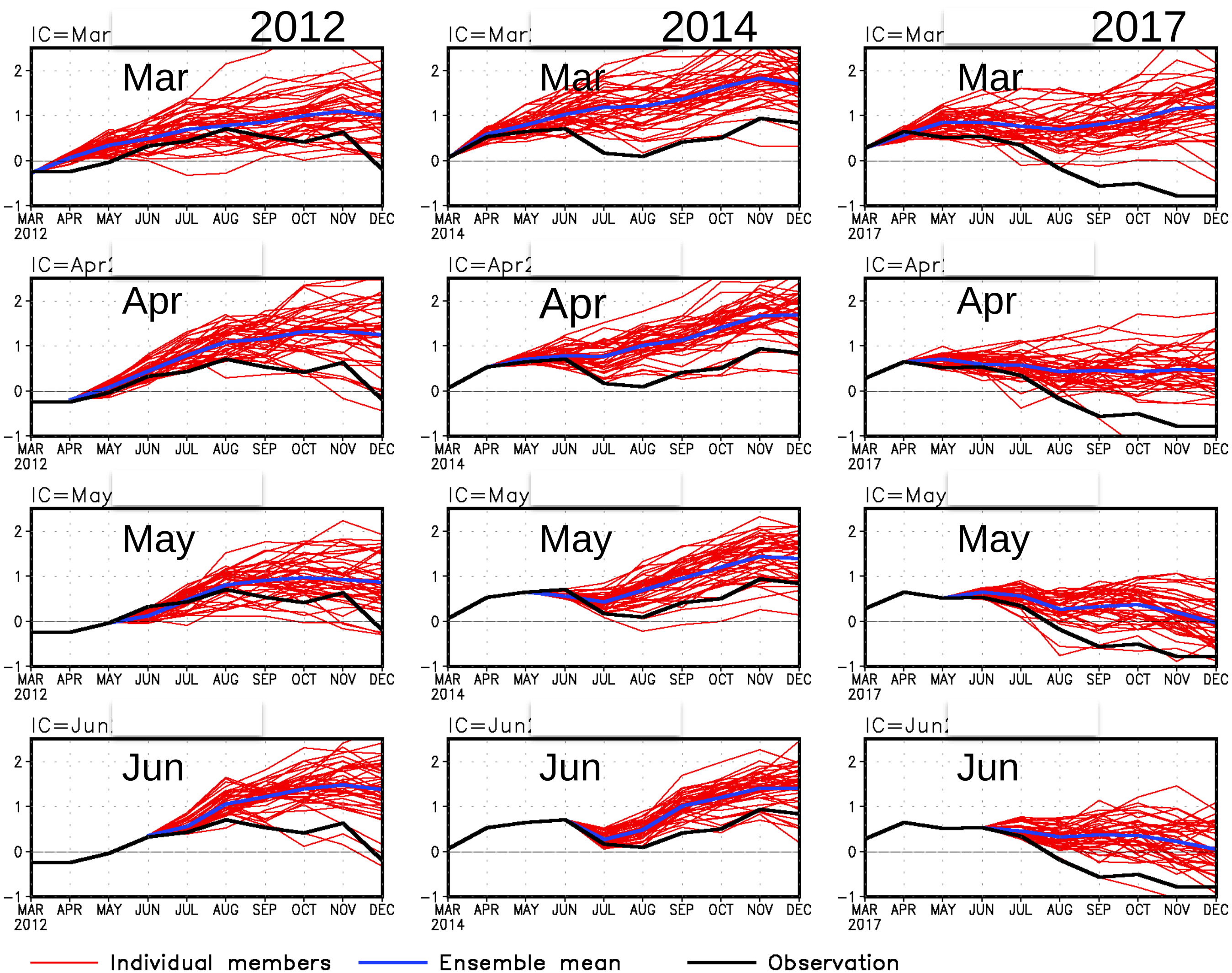
Taiwan Central Weather Bureau, August 2019

False alarms in CFSv2



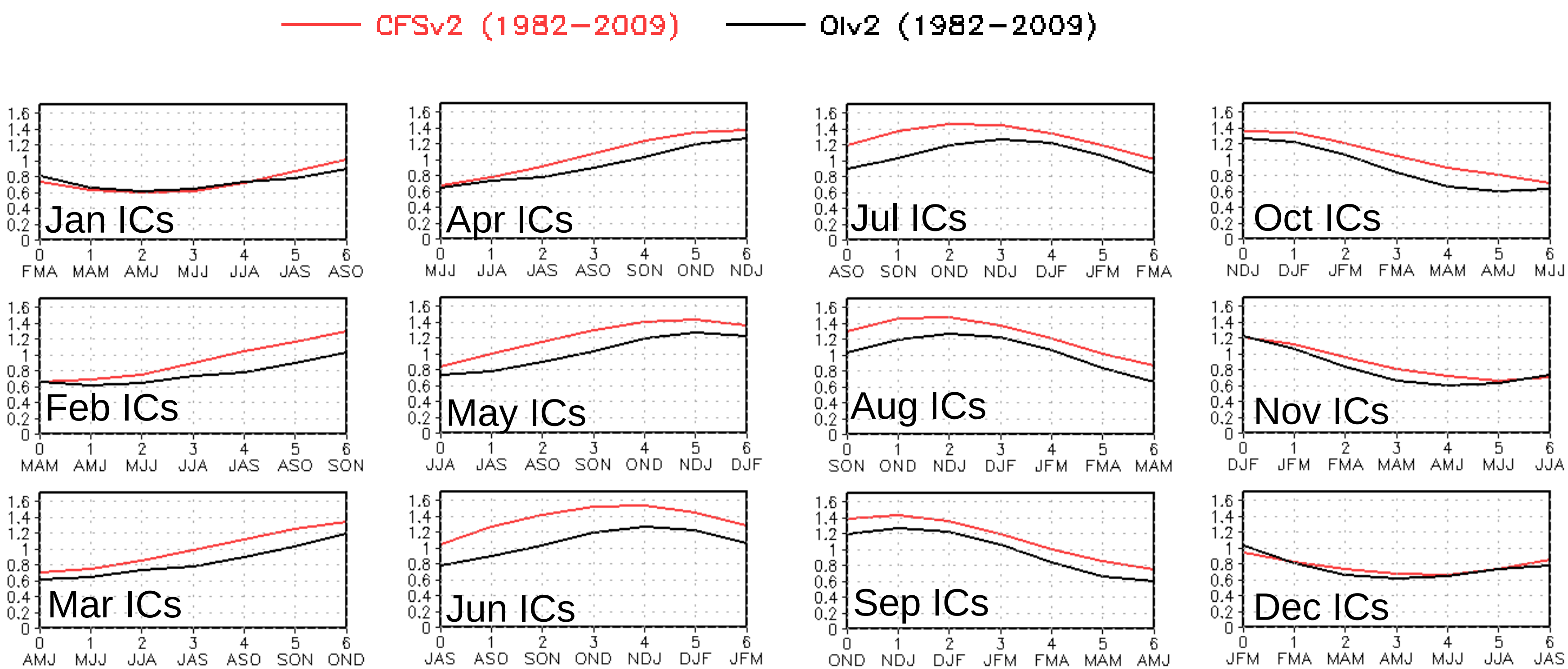
False alarms occurred in 2012, 2014, and 2017 in CFSv2 real-time forecasts.

Nino 3.4 index from CFSv2



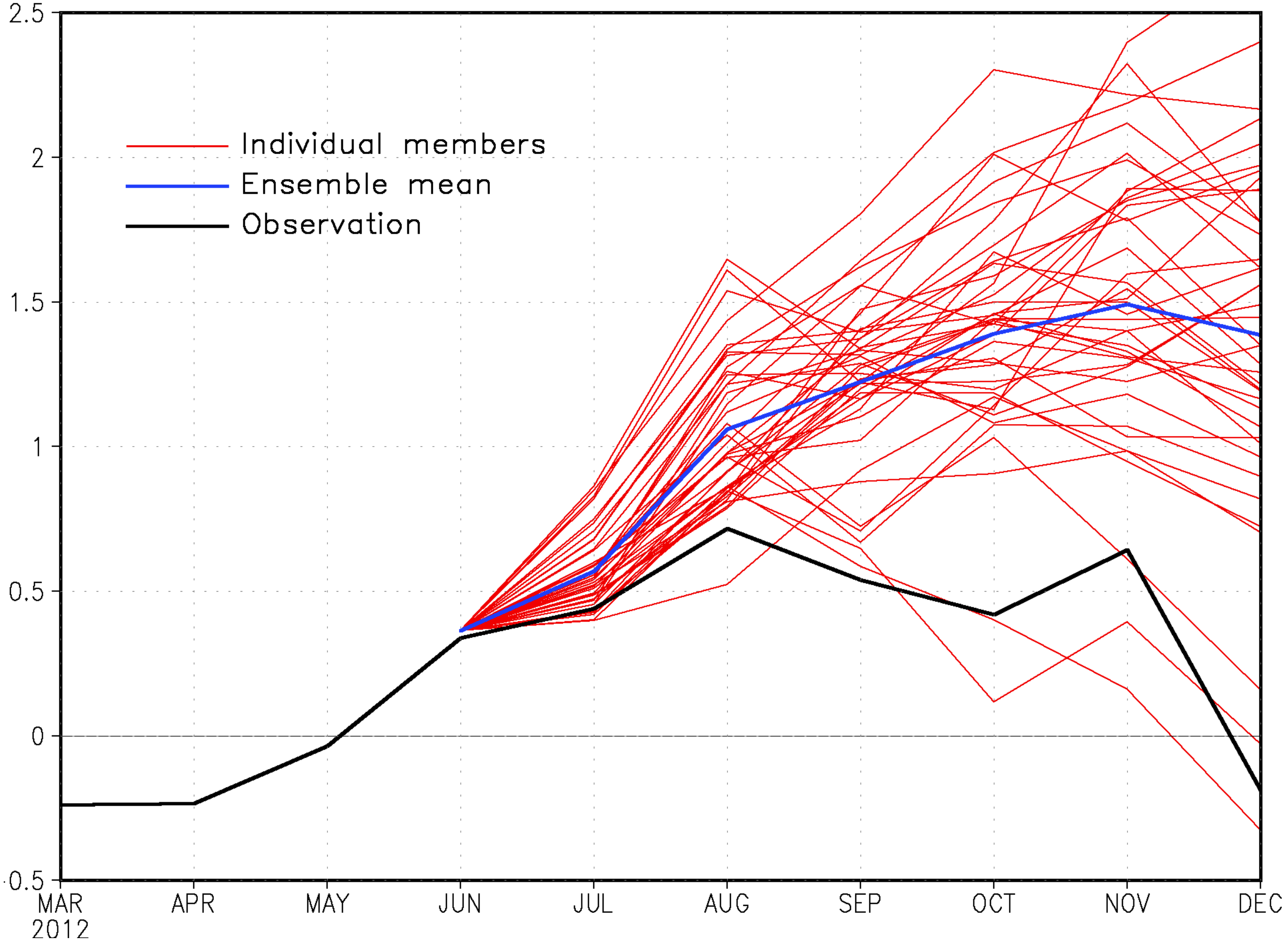
- False alarms may be from different months in different years.
- Will focus on Jun 2012 forecast.

Nino 3.4 standard deviation (K)



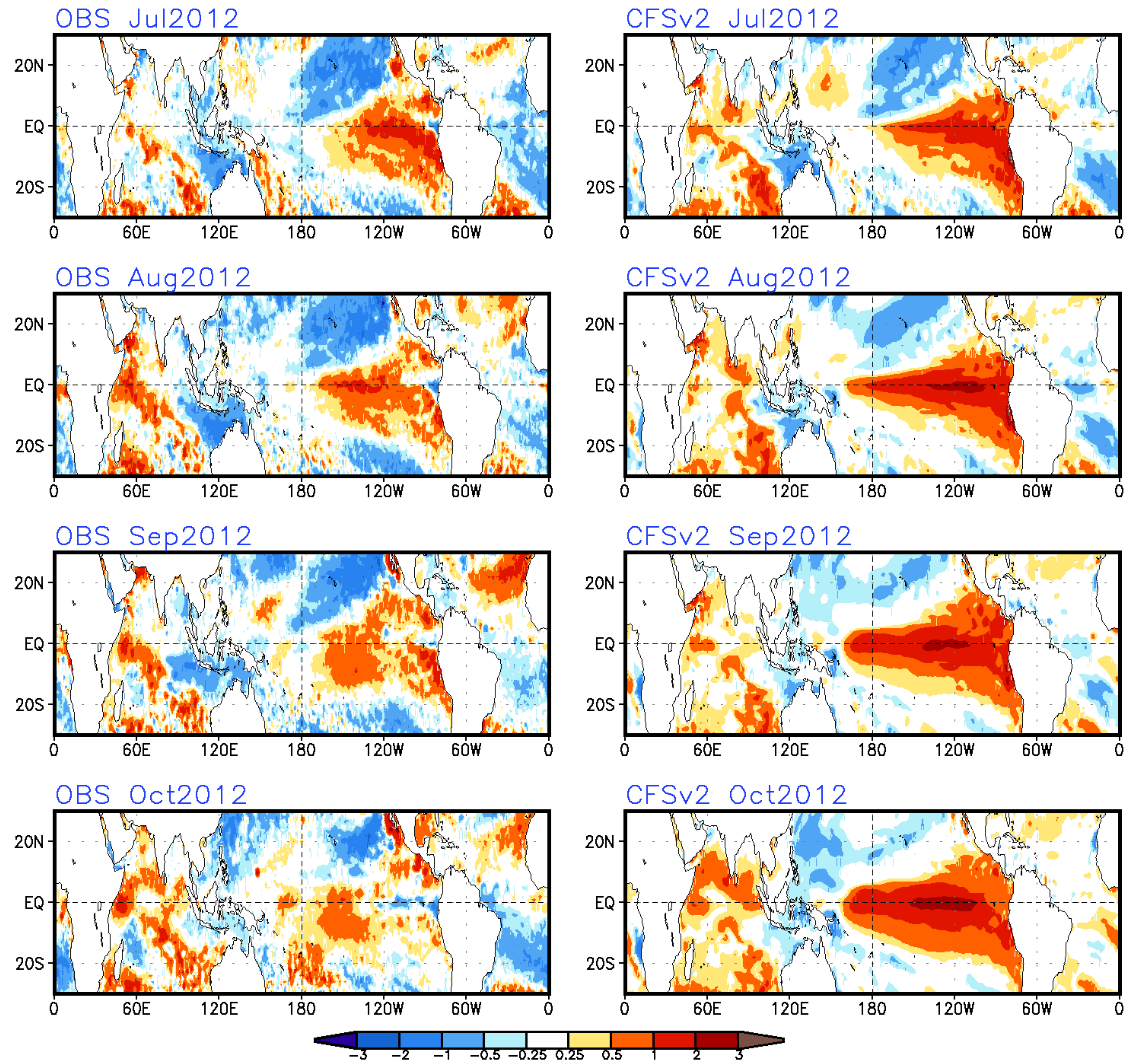
- CFS amplitude errors vary with initial month and target months.
- Amplitude in CFS is generally too large in JAS to NDJ in forecasts from spring and summer.

Nino 3.4 index from CFSv2



Jun 2012 forecast: After Sep, most runs were 0.5 warmer than obs.

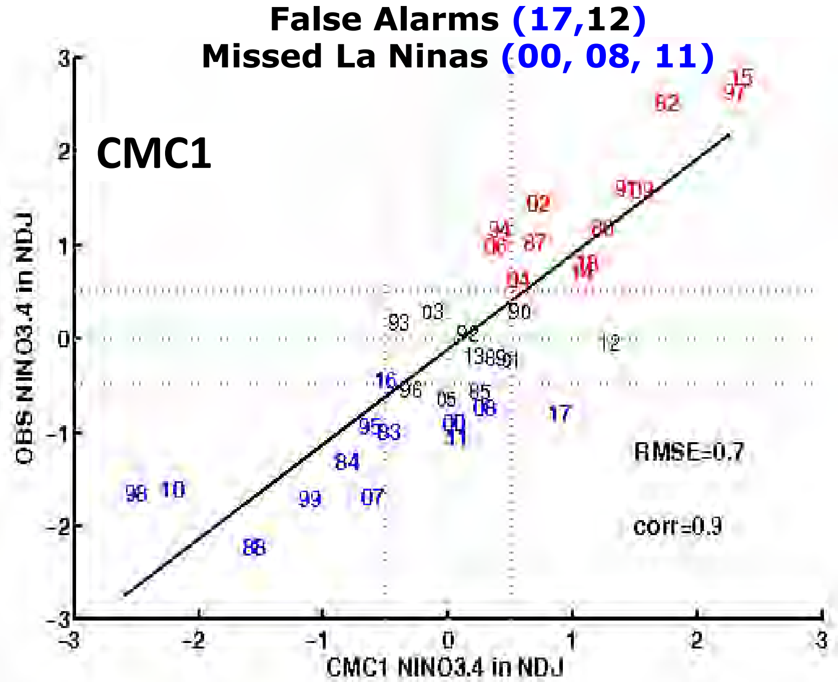
CFSv2 SST forecast from June 2012

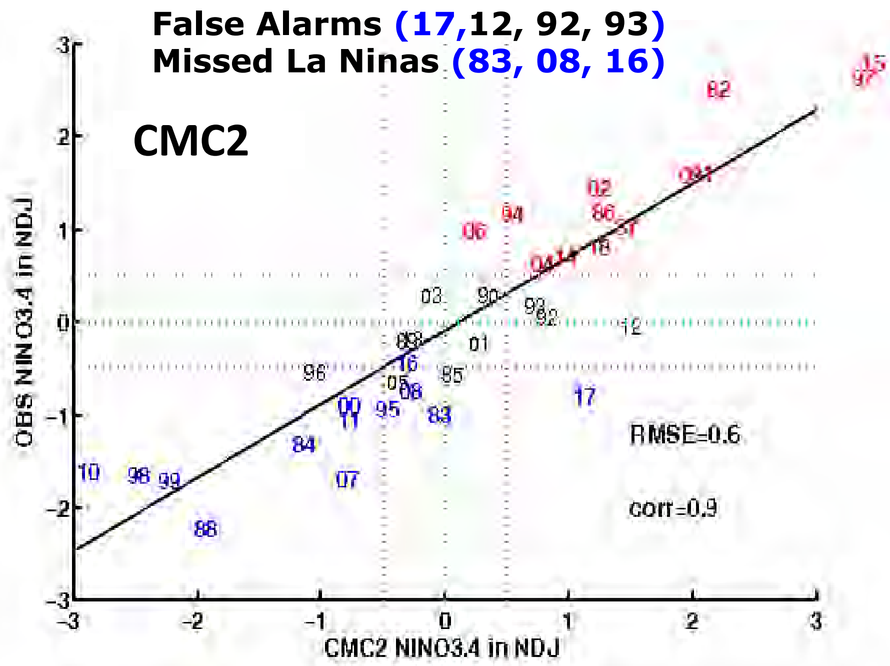


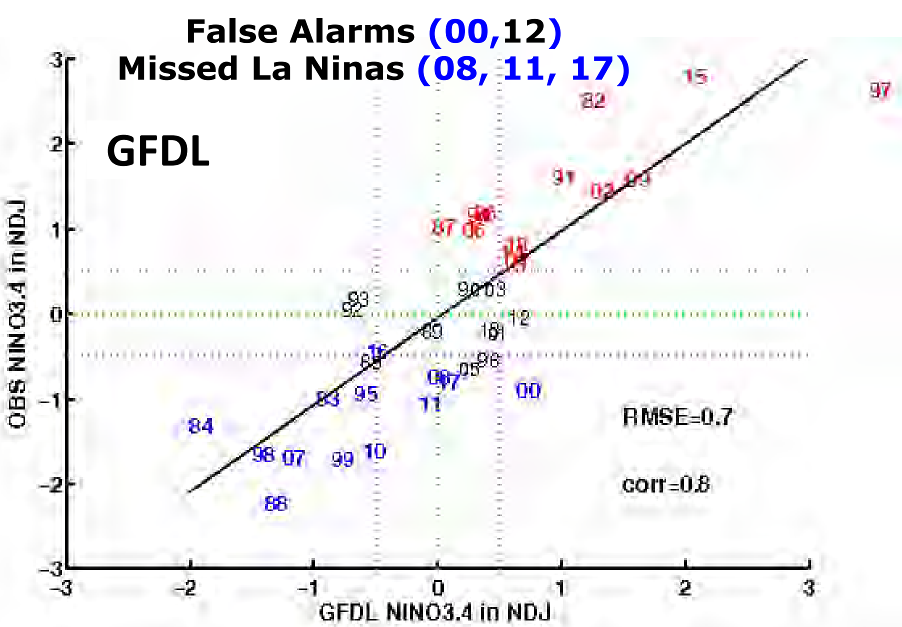
Initial anomalies decayed in the observation but enhanced in the forecast.

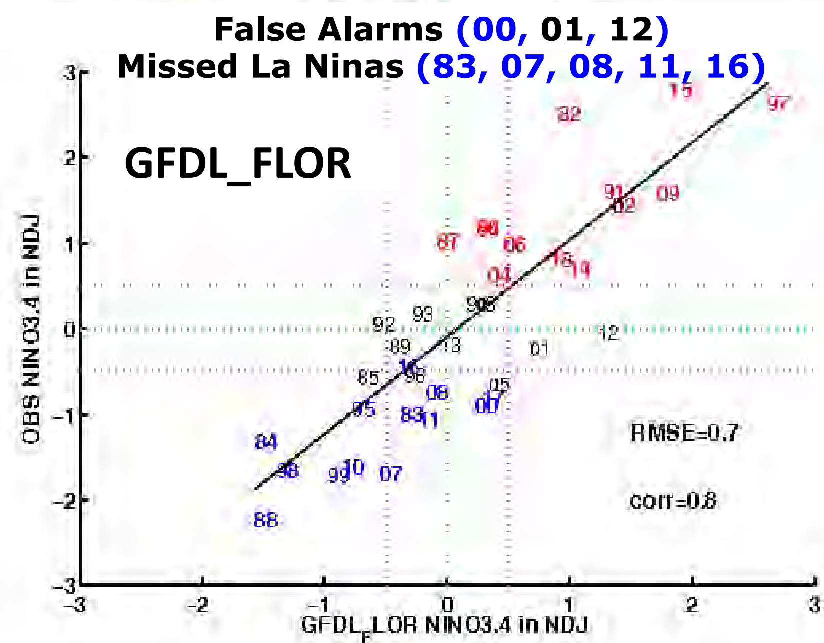
ENSO False Alarms in NMME

Courtesy of Yan Xue





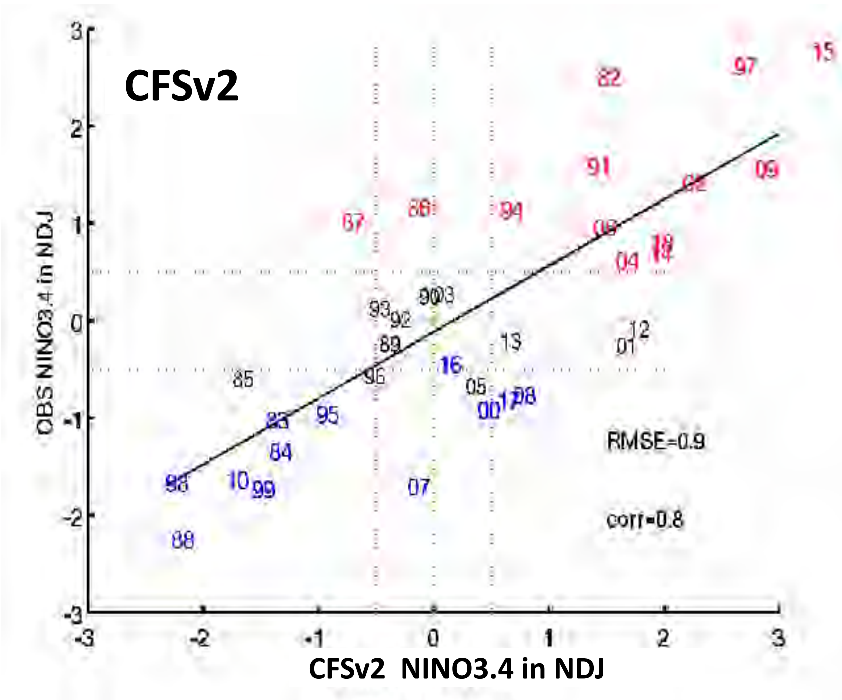




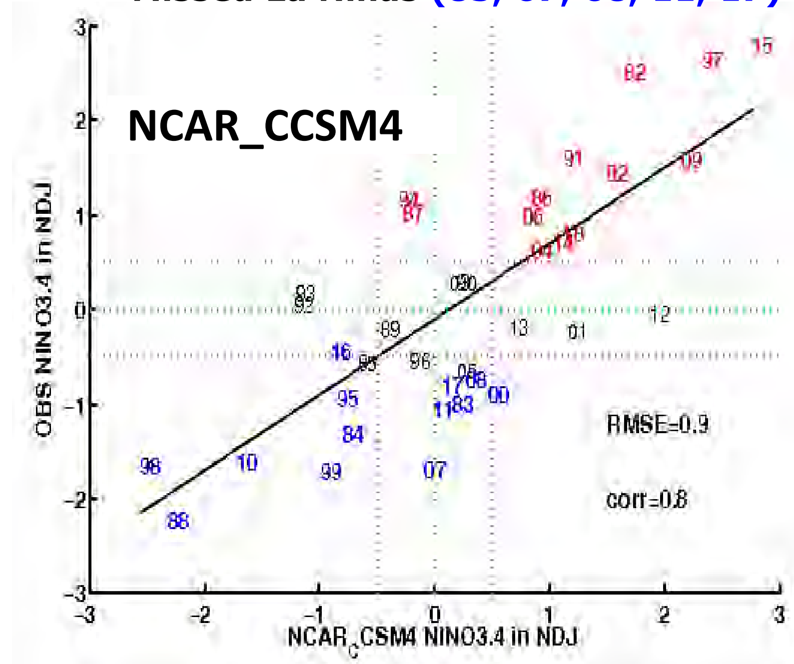
ENSO False Alarms in NMME

Courtesy of Yan Xue

False Alarms (00, 08, 17, 01, 12, 13)
Missed La Ninas (07, 11, 16)



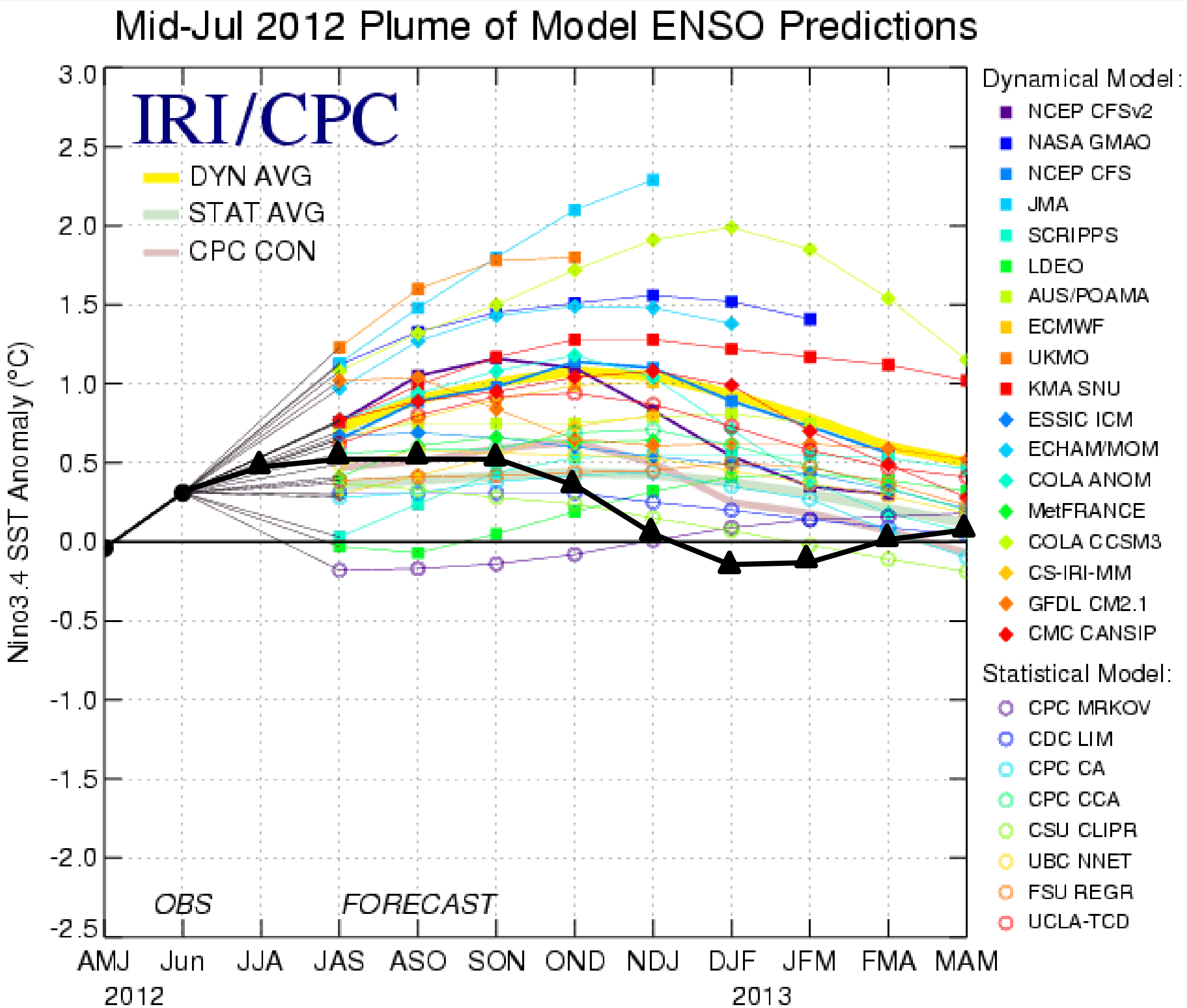
False Alarms (00, 01, 12, 13)
Missed La Ninas (83, 07, 08, 11, 17)



NCAR CCSM NINO3.4 in NDJ

- Different models produced false alarms in a few years
- All NMME models produced false alarm in 2012

IRI/CPC Nino 3.4 plume



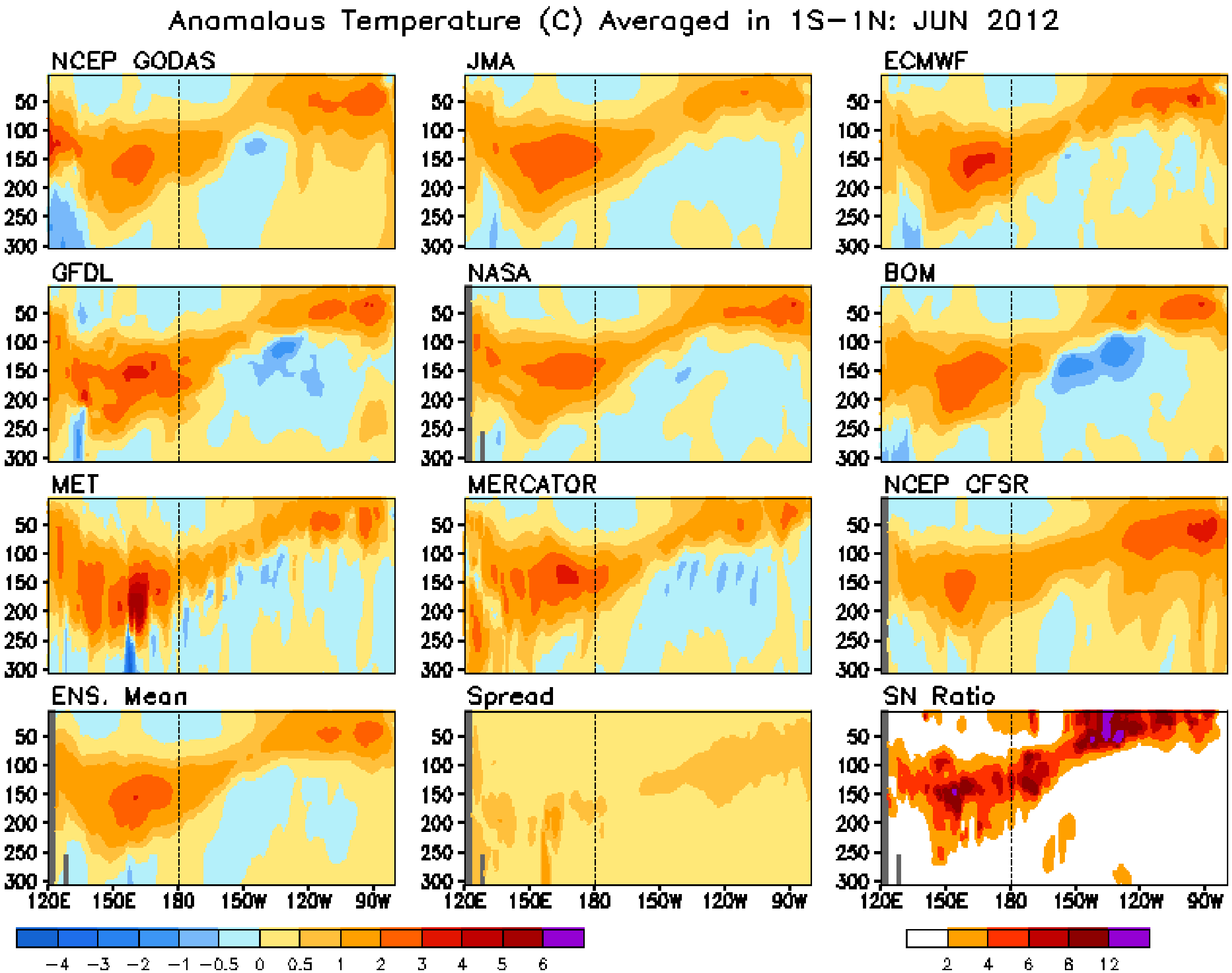
Almost all dynamical models produced a false alarm in Jul 2012 ENSO plume.

Possible causes for the ENSO alarms

1. Errors in initial conditions

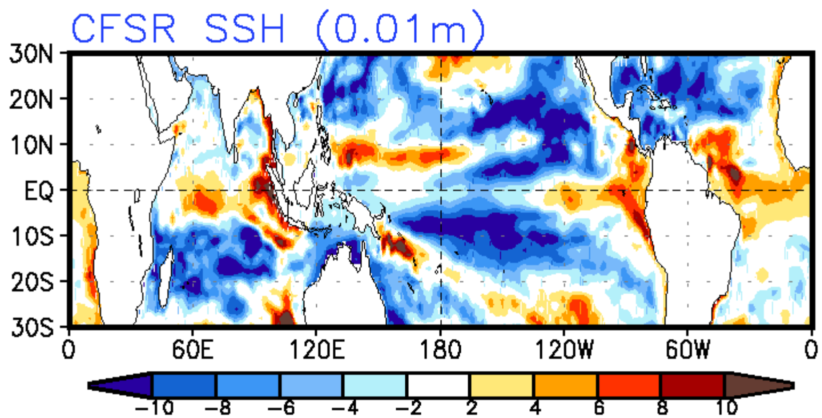
2. Errors in the model

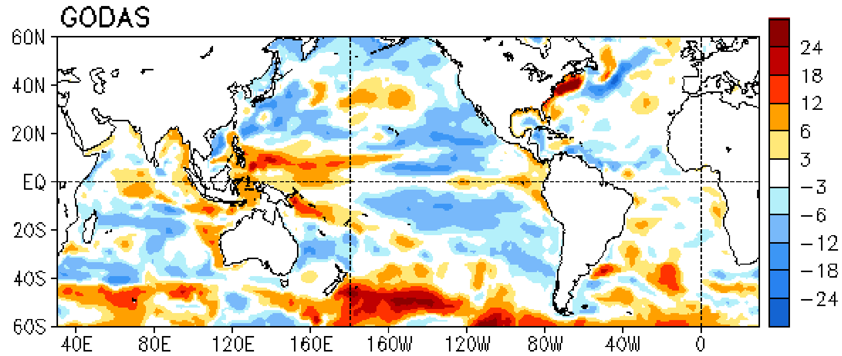
Jun 2012 oceanic state



- Some uncertainties among ocean analyses.
- CFSR subserface was not significantly warmer than others.

Jun 2012 oceanic state





Off equator condition in June 2012 did not favor an ENSO development.

CPC Ocean Briefing

Possible causes for the ENSO alarms

1. Errors in initial conditions

2. Errors in the model

Outline of this analysis

1. Analyze processes that may contribute to the CFS 2012 false alarm <u>focusing on air-sea interactions</u>

2. Experiment impact of model physics in CFS on ENSO prediction <u>focusing on dependencies on convection schemes</u>

Outline of this analysis

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Feedbacks contributing ENSO development

I. Dynamic (Momentum flux related)
- Zonal advective (positive)
- Thermocline (positive)
- Ekman (positive)
- Advections by mean-currents (negative)

II. Thermodynamic (Heat flux related)
- Solar radiation flux (negative)
- Latent heat flux (negative)

While the SST evolution results from dynamic and thermodynamic balance within the ocean, errors in momentum and heat fluxes are likely the primary sources that are translated into the dynamic and thermodynamic processes.

Possible factors leading to the false alarms (overshooting) in CFSv2?

(1) Too strong dynamical (BJ; SST-wind) feedback?

(2) Too weak thermodynamical damping?

(3) IC bias?

(4) Unpredictable components/noises interruption?

…

Aspects to analyze

1. How are the air-sea interactions compared with observational estimates <u>in general</u>?

2. How are responses of surface fluxes to SST anomalies compared to observational estimates in 2012 <u>in particular</u>?

Variables and observations to use

Variables:

• SST	(Sea surface temperature)
• OLR	(proxy for precipitation)
• LH	(Latent heat flux)
• SW	(Solar radiation)
• Taux	(Zonal momentum flux)

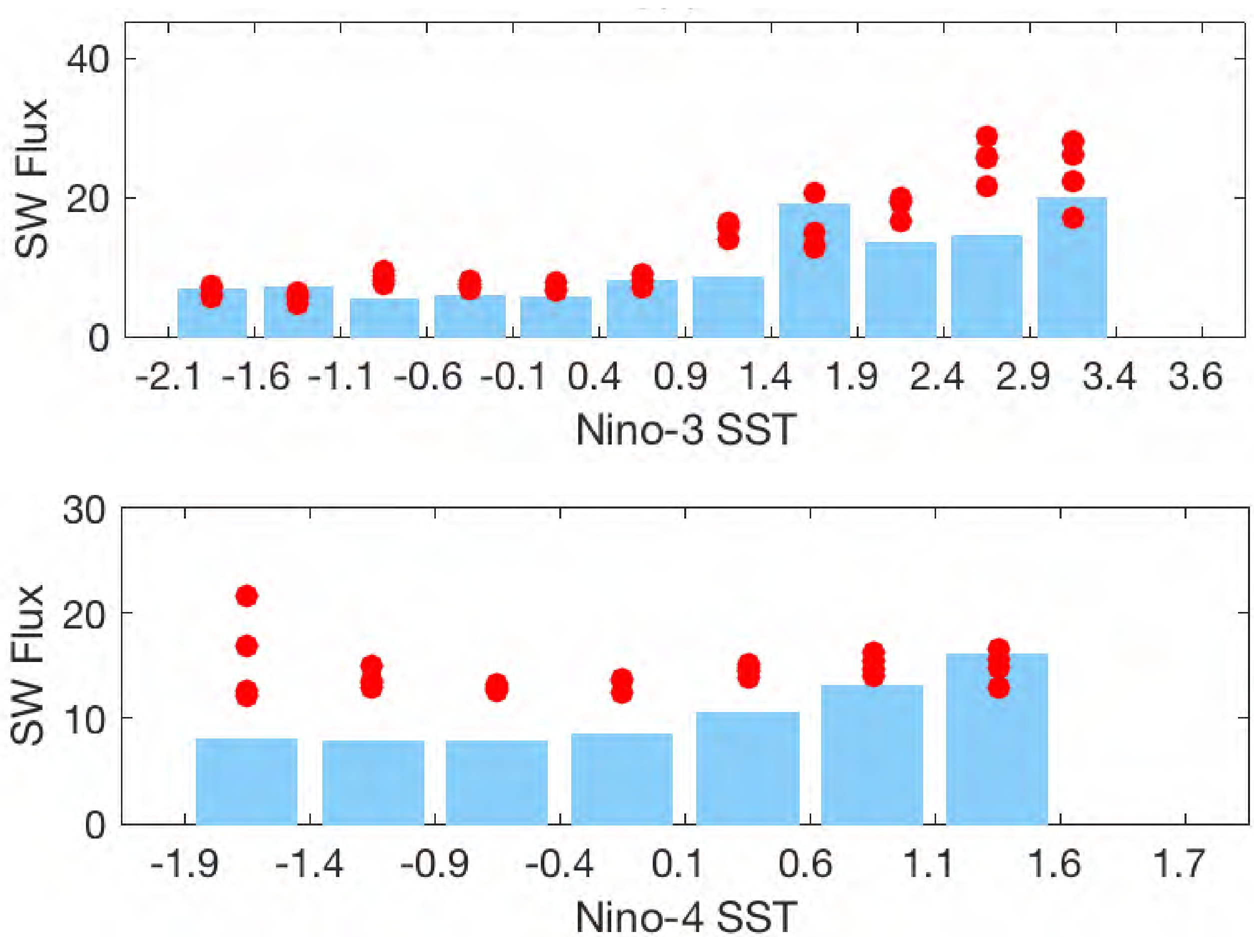
Observations

• OLR:	NOAA
• SST:	OIv2 (NCEI)
• LH:	ERA-I, OAflux
• SW:	CERES, ISCCP, ERA-I
• Taux:	ERA-I, CFSR, R1, R2

Air-sea interactions compared with observational estimates in general

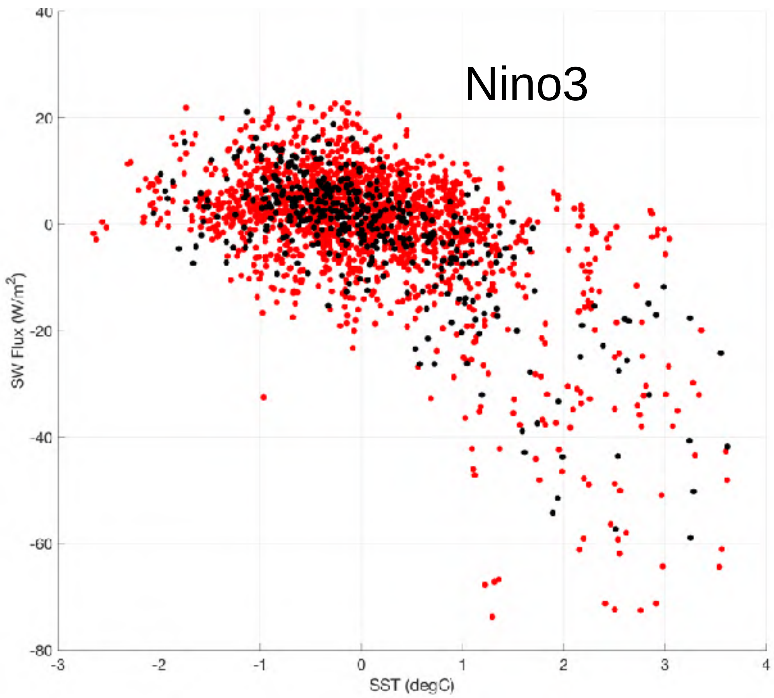
- Variance of surface fluxes
- Regression of surface fluxes against SST

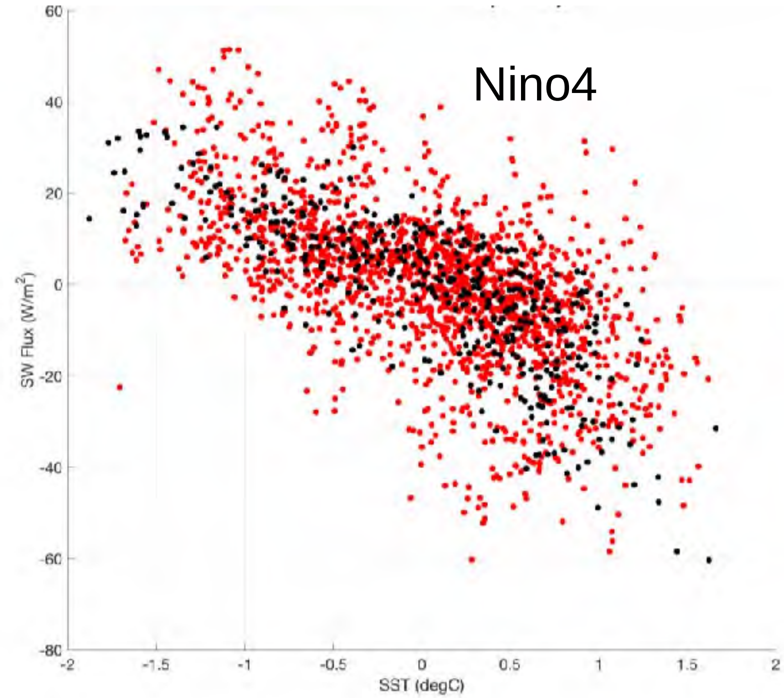
0-month lead SW STDV vs SST



- Nino3: CFS tends to produce stronger SW variability when SST is warmer than 0.9 K. (Observed value for 1.4-1.9 range may have a sampling issue)
- Nino4: CFS tends to produce stronger SW variability when SST is below normal or weakly above normal.

0-month lead SW STDV vs SST

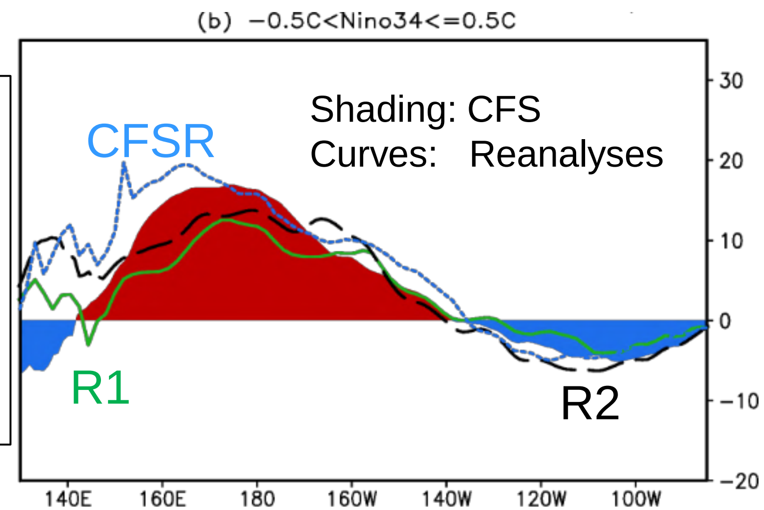


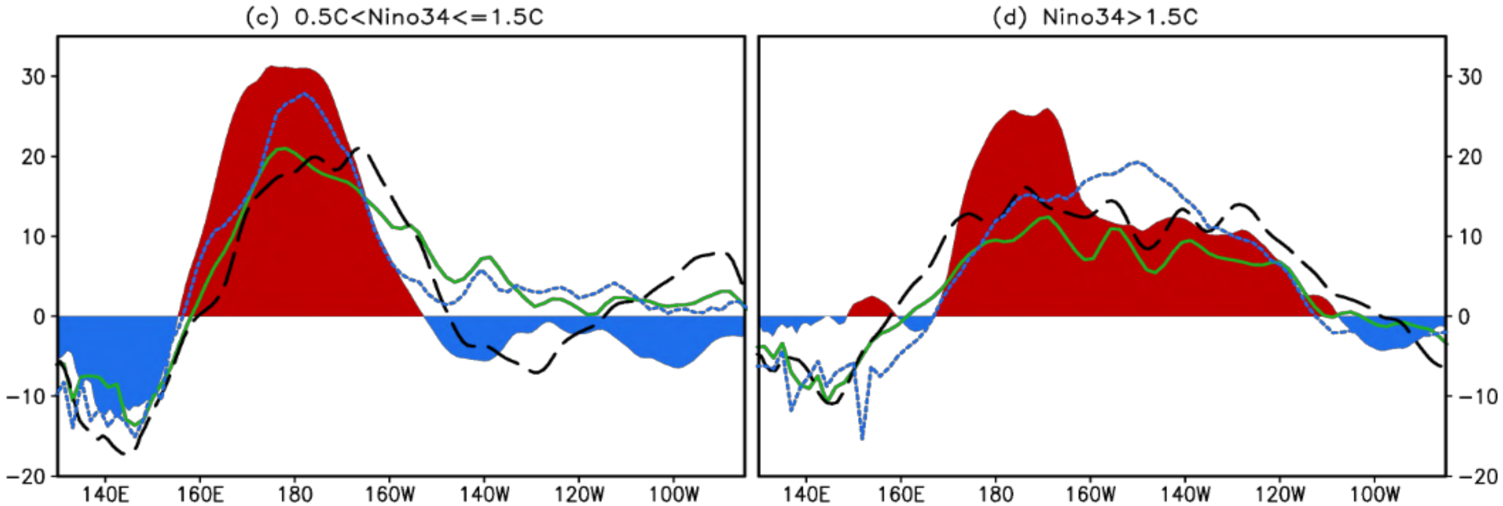


- CFS SST varies beyond the observed range, especially for Nino4

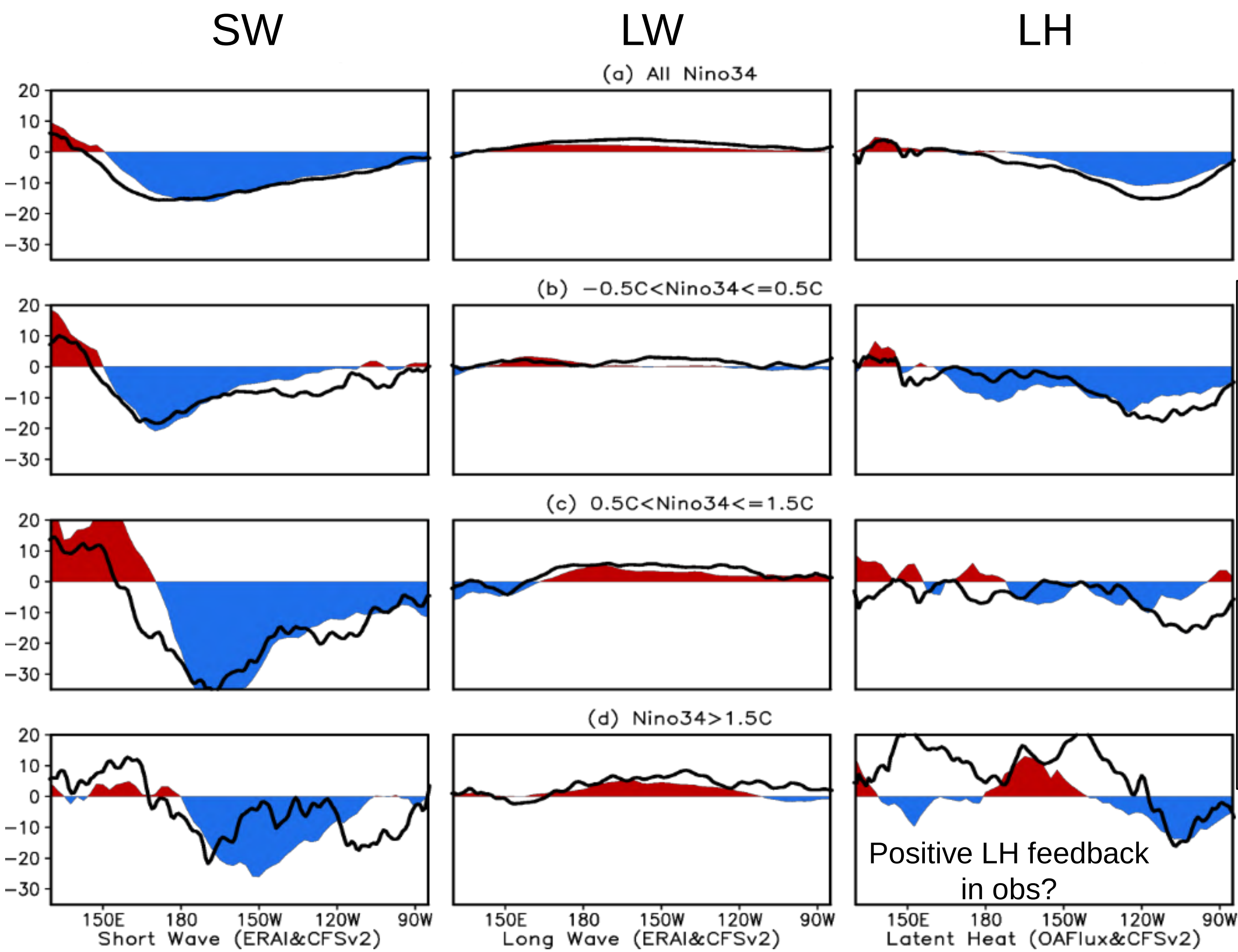
Regression of 5S-5N Taux against Nino34 SST index

- There exist some uncertainties in observational analyses
- CFS produces stronger wind-stress when Nino34 SST is moderately warm or very warm in the central Pacific.





Regression of 5S-5N Hflx against Nino34 SST index

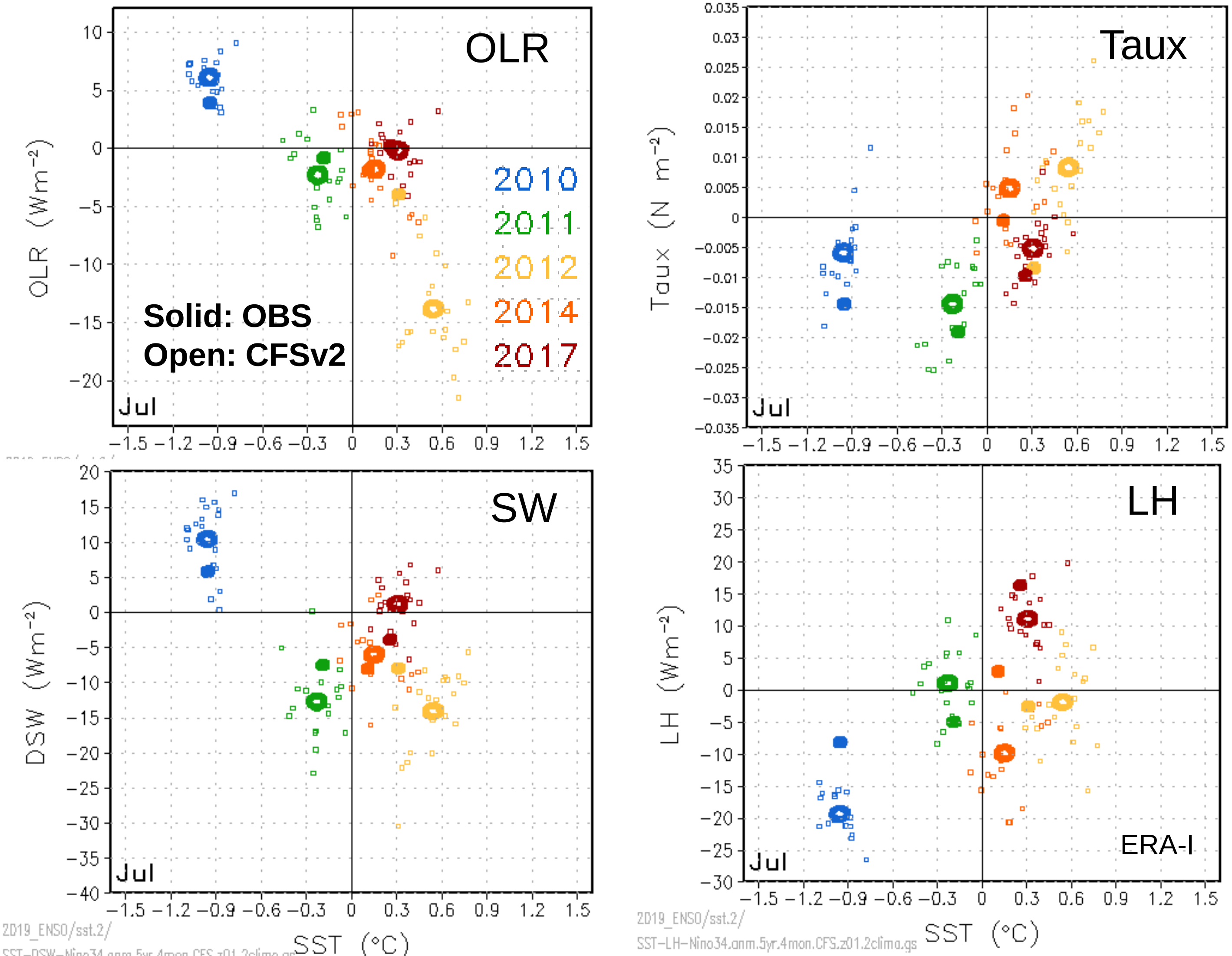


Shading: CFS
Curves: ERAI/OAflux

- Comparable negative feedback amplitude in heat flux regressions between CFS and observation
- Contribution from LW is much smaller than that from SW and LH

Responses of surface fluxes to SST anomalies compared to observational estimates in 2012

July 2012
Relationships among variables



- Stronger convection response to SST anomaly
- Stronger Taux associated with convection
- Larger SST anomalies due to stronger Taux.
- Larger negative SW in CFS corresponding to stronger convection, but the ratio (ΔSW/ΔSST) is similar to the observed
- Difference in LH is small

Summary from CFSv2 analysis

- CFS historical forecasts generally produce stronger Taux response to SST than the observation, when Nino34 SST is moderately or very warm (>0.5K)
- SW and LH feedbacks to SST in CFS are comparable to that in observations
- The 0-month lead forecast for July 2012 produced stronger interactions among SST, convection, and Taux, consistent with the general relationships among these variables in historical forecasts. SW and LH feedbacks do not appear to be the reason for 2012 false alarm.
- This analysis suggests CFS 2012 false alarm is due to too strong SST-convection-wind feedback
  - Convection developed too quickly or too strongly in response to weak SST anomalies
  - The resulting convection induced or enhanced eastward wind which amplified the existing warm SST through zonal advection, thermocline, and Ekman feedbacks.
  - SW and LH feedbacks were comparable to observational estimate and may not the reason for the false alarm in CFS

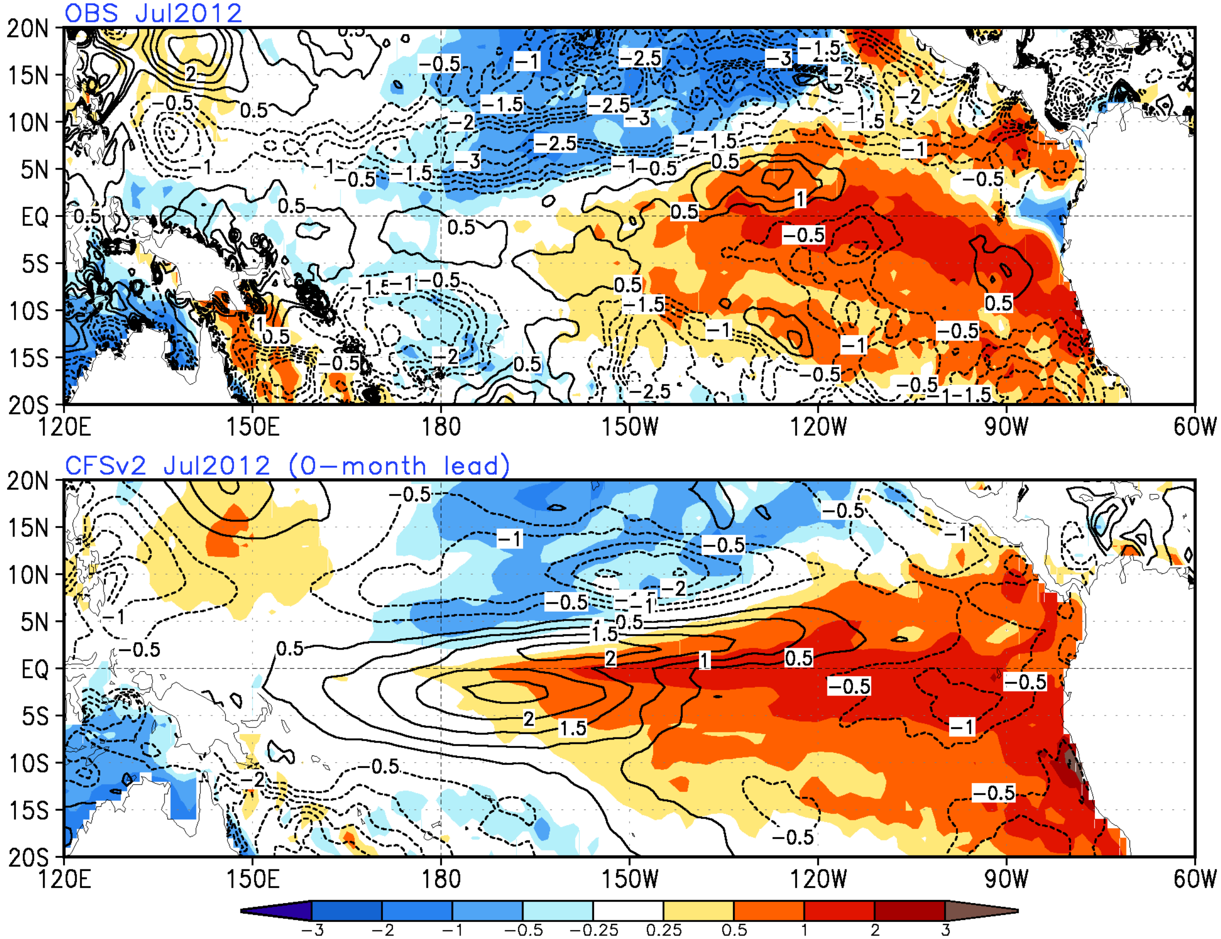
Outline of this analysis

1. Analyze processes that may contribute to the CFS 2012 false alarm focusing on air-sea interactions
2. Experiment impact of model physics in CFS on ENSO prediction focusing on dependencies on convection schemes

July 2012 SST (shading) and Taux (contour)

Obs

CFSv2 0-m lead



Forecast errors in the first month:	(i) Stronger westerly Taux in central Pacific; (ii) SST started to become warmer

Hypothesis

1. CFSv2 El Nino false-alarm is due to unrealistic representation of air-sea interaction with too strong wind-stress/SST feedback.

2. Convection parameterization in the model is a cause for the unrealistic air-sea interaction.

Numerical Experiments

1) AMIP Simulations of atmospheric response to observed SST anomalies using three convection schemes

2) Oceanic response to atmospheric forcing from AMIP simulations

3) Initialized forecasts with a coupled model from 30 June 2012

Convection schemes

(1) SAS (Simplified Arakawa–Schubert cumulus convection). The SAS is used in NCEP Climate Forecast System (CFS). The SAS scheme (Pan and Wu 1995) is based on Arakawa and Schubert (AS, 1974) and simplified by Grell (1993) to consider only one cloud instead of a spectrum of clouds. Convection occurs when the cloud work function exceeds a certain threshold. A simple trigger is employed, which requires the level of free convection must exist and must be within the distance of 150 hPa of the parcel starting level.

(2) RAS (Relaxed Arakawa–Schubert cumulus convection). The RAS is used in many climate models. The RAS scheme (Moorthi and Suarez 1992, 1999) simplifies the entrainment relation and assumes that the normalized mass flux is a linear function of height rather than being exponential as in the original AS scheme. In addition, rather than requiring that 'quasi equilibrium' of the cloud ensemble be achieved each time, the scheme only relaxes the ambient atmospheric state toward equilibrium.

(3) SAS2 (Simplified Arakawa–Schubert version 2). SAS2 was used in operational GFS from 28 Jul 2010 to 18 Jul 2017. The SAS2 scheme (Han and Pan 2011) is modified from its earlier version (SAS). Instead of using a fixed distance of 150 hPa, the convection trigger in SAS2 uses a distance range of 120–180 hPa in proportion to the large-scale vertical velocity. Unlike the old SAS scheme, the revised SAS scheme specifies finite entrainment and detrainment rates for heat, moisture, and momentum above the cloud base following Bechtold et al. (2008).

1). **Atmospheric response to observed SST anomalies**

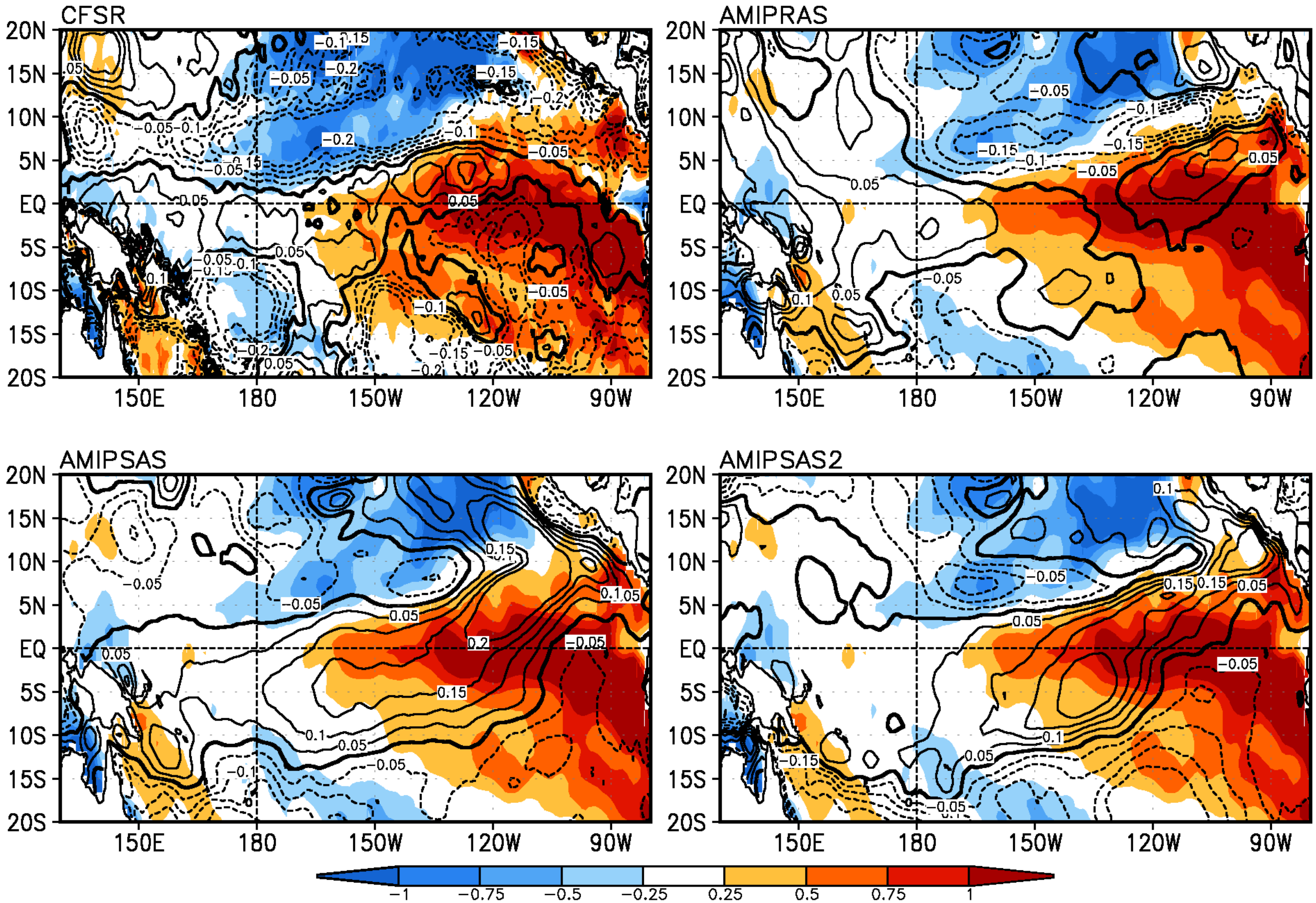
- Model

    GFS: Atmospheric component of CFSv2

- AMIP runs
  - Daily SST from NCEI analysis
  - 1999 to Dec 2010
    - ✓ One member
    - ✓ To establish climatology
  - Jan 2012 to Jul 2012
    - ✓ 18 members
    - ✓ To derive anomalous response in 2012
  - Three convection schemes
    - ✓ AMIPSAS (Simplified Arakawa-Schubert)
    - ✓ AMIPRAS (Relaxed Arakawa-Schubert)
    - ✓ AMIPSAS2 (Simplified Arakawa-Schubert v2)

1). **Atmospheric response to observed SST anomalies**

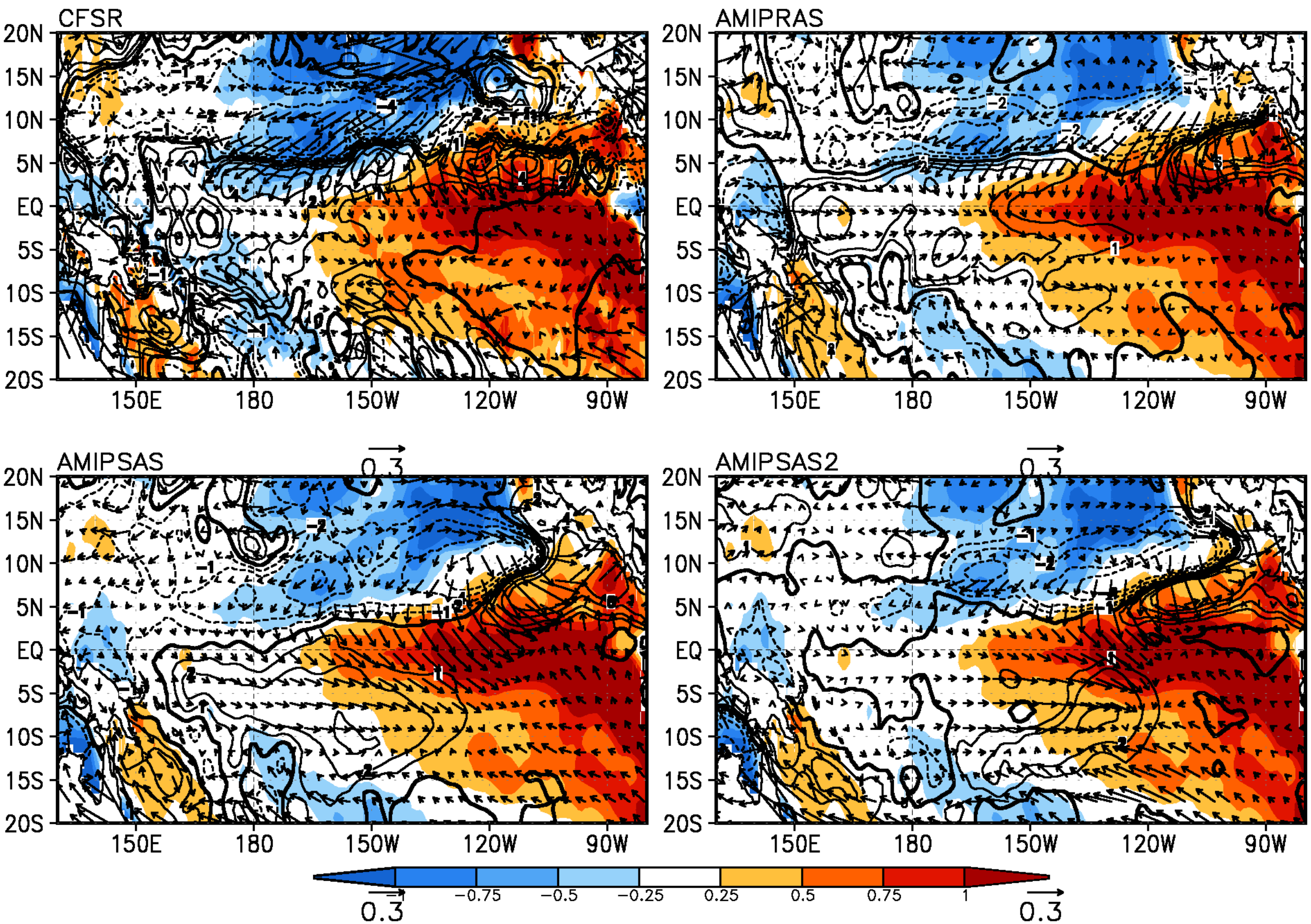
July 2012 SST (shading), Taux (contour)



1) Weak Taux anomalies in CFSR
2) Too strong Taux in central-eastern Pac with SAS and SAS2
3) More reasonable Taux with RAS

1). **Atmospheric response to observed SST anomalies**

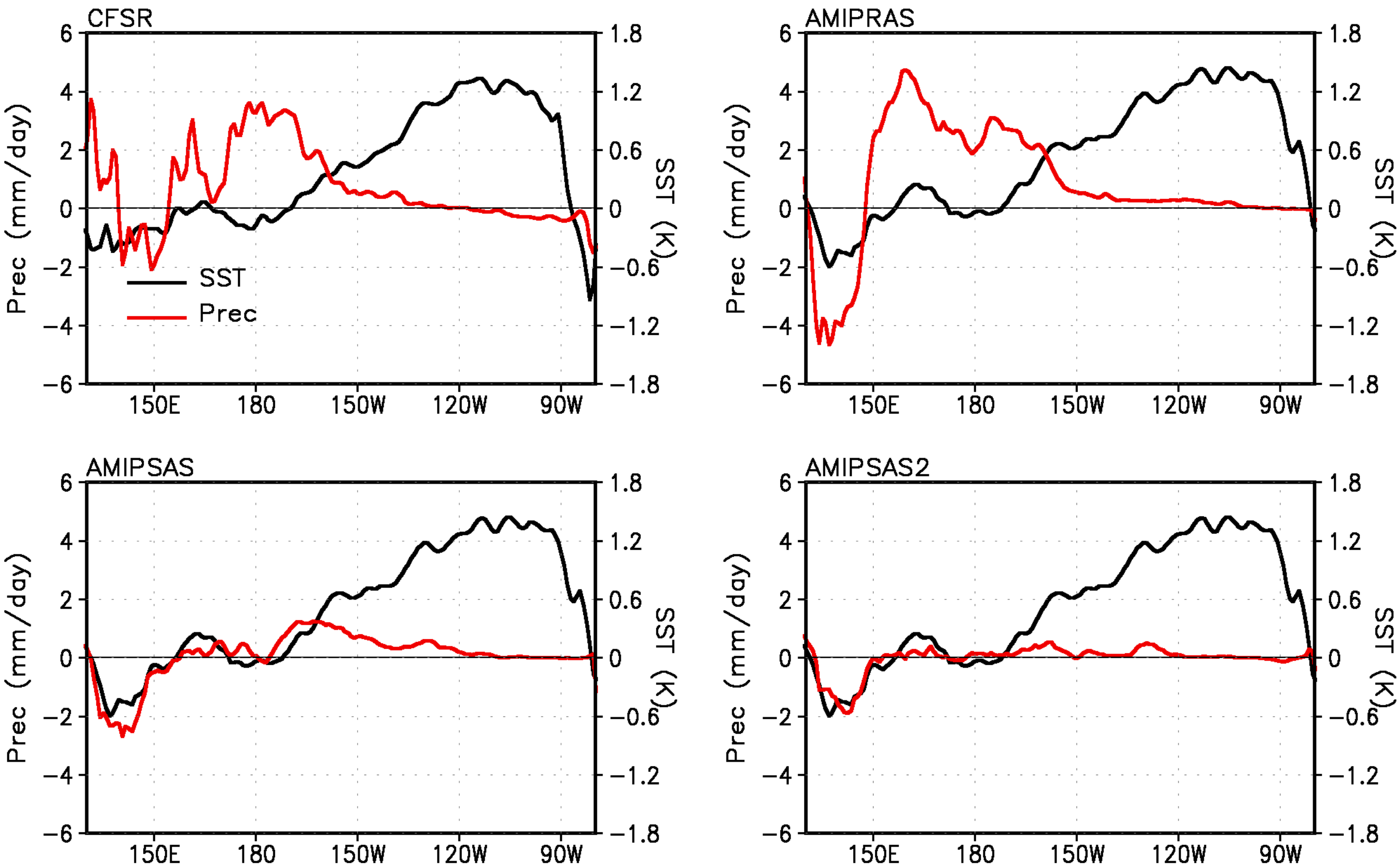
July 2012 SST (shading), rainfall (contour), Tau (vector)



- Unrealistic rainfall with SAS & SAS2, corresponding to too strong Tau in equatorial central-eastern Pacific
- More reasonable rainfall and Tau anomalies with RAS

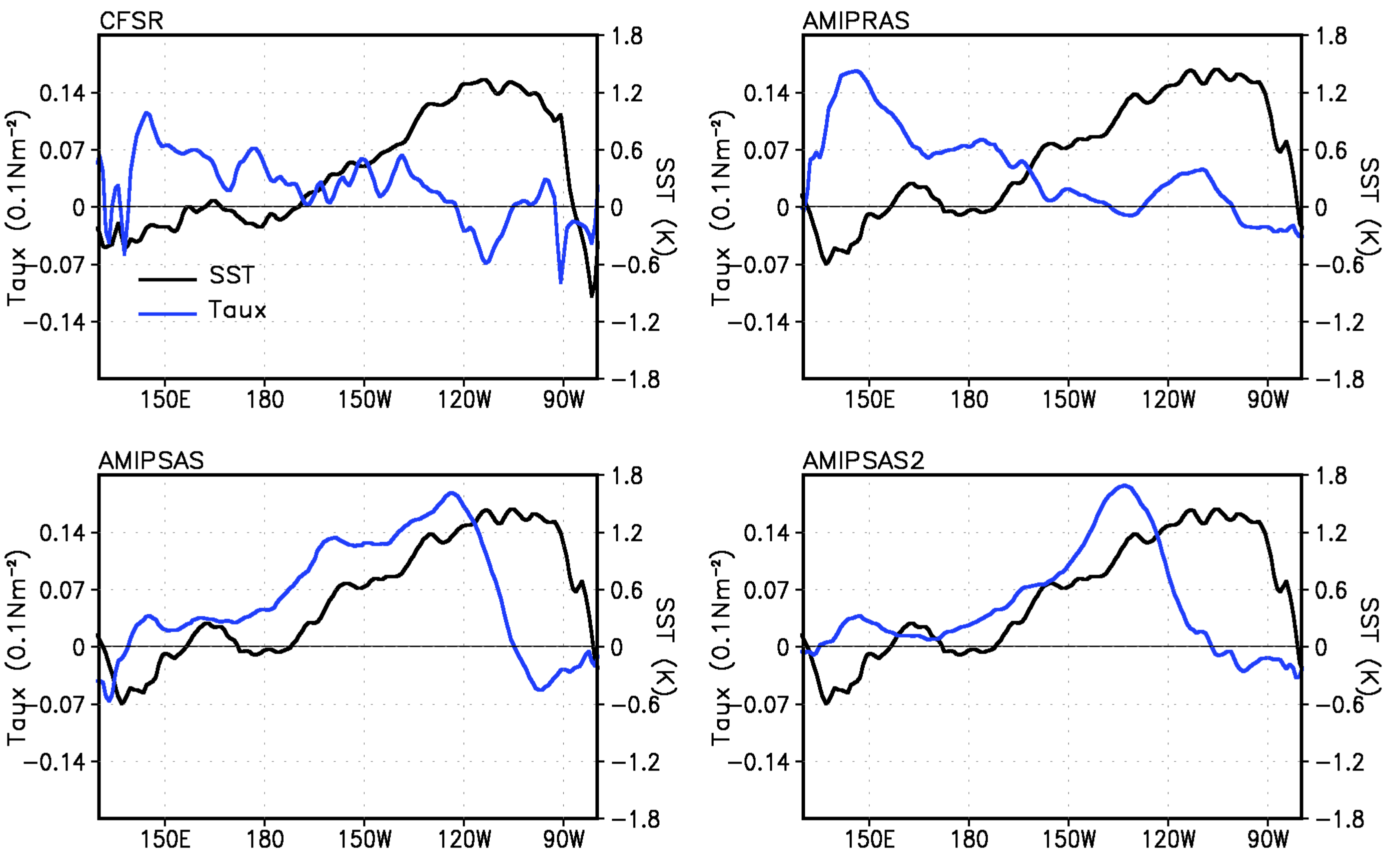
1). **Atmospheric response to observed SST anomalies**

July 2012 SST, Prec (2S-2N average)



1). **Atmospheric response to observed SST anomalies**

July 2012 SST and Taux (2S-2N average)

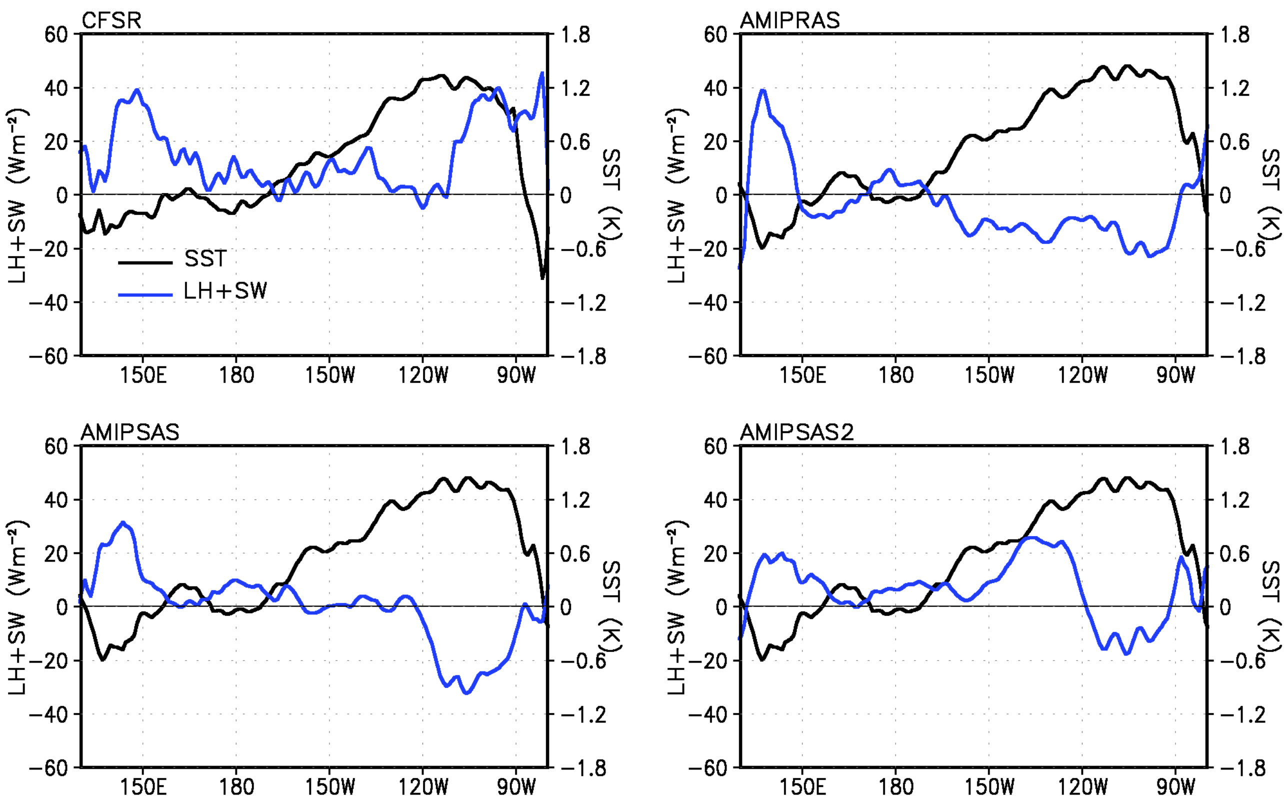


1) Weak Taux anomalies in CFSR
2) Too strong Taux in central-eastern Pac with SAS and SAS2
3) More reasonable Taux with RAS

How sensitive is the SST to the differences in Taux if used to force an ocean model?

1). **Atmospheric response to observed SST anomalies**

July 2012 SST and SW+LH (2S-2N average)



- Weak thermal feedback in Nino34 (190-240E) region in CFSR, SAS and RAS
- Positive feedback around 230E in SAS2
- All simulations failed to capture the CFSR positive feedback in far eastern (250-280E) Pacific

Thermal feedback does not appear to be the main reason for the false El Nino forecast. Similar anomalies from other observational analyses (e.g., ERA-I and CERES)

2). **Oceanic response to AMIP forcing**

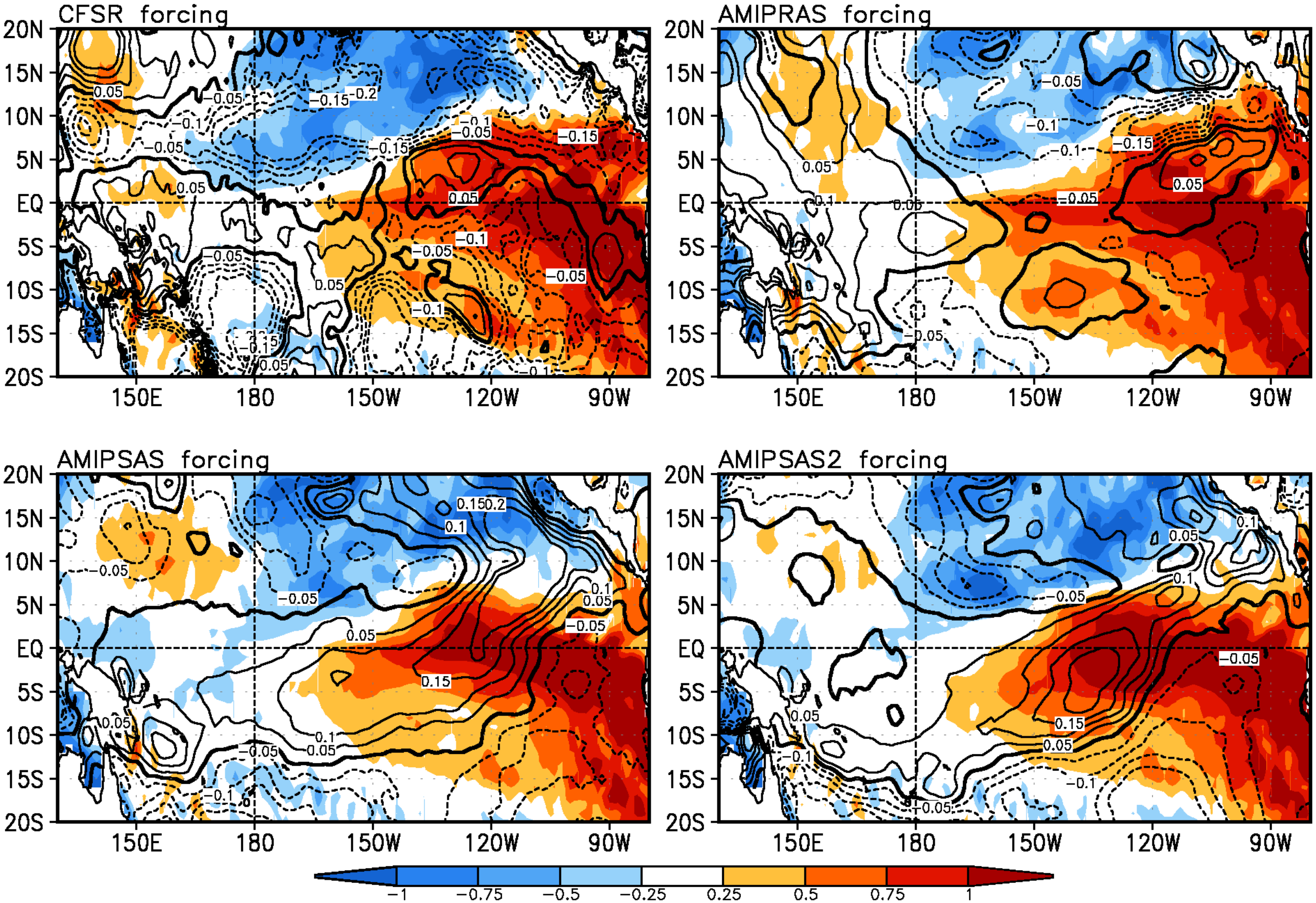
- Model

  MOM5: GFDL Modular Ocean Model v5

- MOM5 runs
  - Daily surface forcing from AMIP runs
  - 1999 to Dec 2010
    - ✓ One member
    - ✓ To establish climatology
  - July 2012
    - ✓ 18 members
    - ✓ To derive anomalous response in July 2012
  - Forcing from three AMIP runs
    - ✓ AMIPSAS forcing
    - ✓ AMIPRAS forcing
    - ✓ AMIPSAS2 forcing

2). **Oceanic response to AMIP forcing**

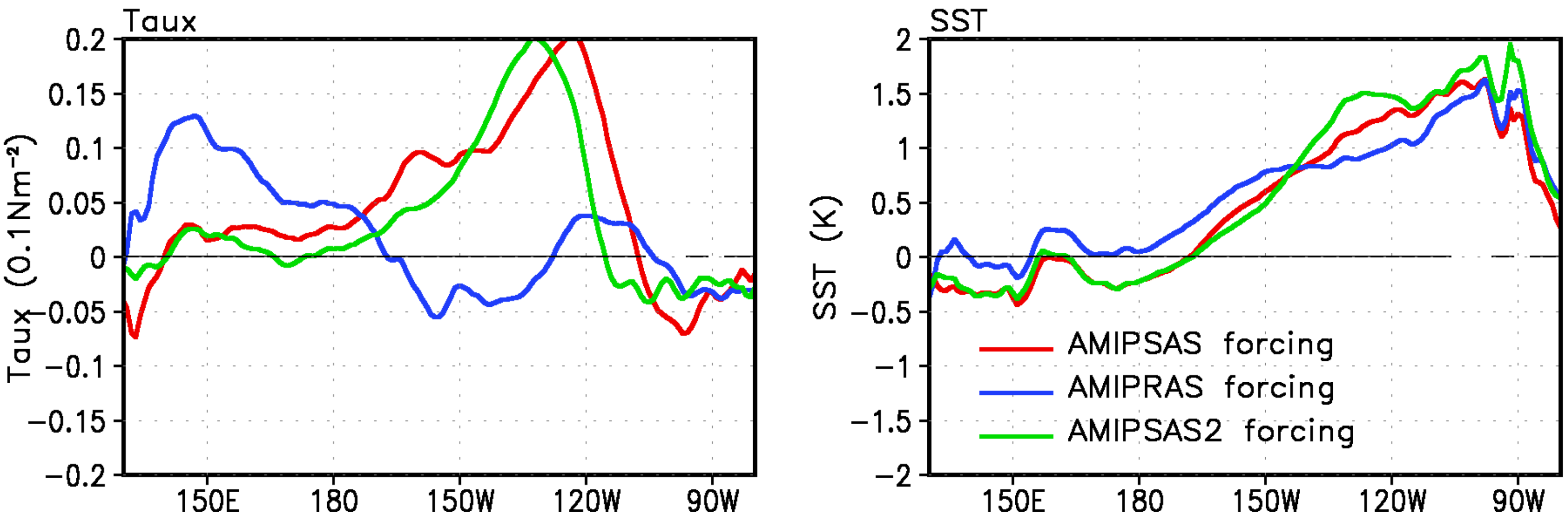
July 2012 SST (shading) and Taux (contour)



- SST consistent with Taux forcing.
- AMIPSAS and AMIPSAS2 result in warmer SSTs in eastern Pacific, especially for AMIPSAS2.

2). **Oceanic response to AMIP forcing**

July 2012 SST and Taux (1S-1N average)



- SST anomalies consistent to Taux forcing.
- AMIPSAS and AMIPSAS2 result in warmer SSTs in eastern Pacific, especially for AMIPSAS2.

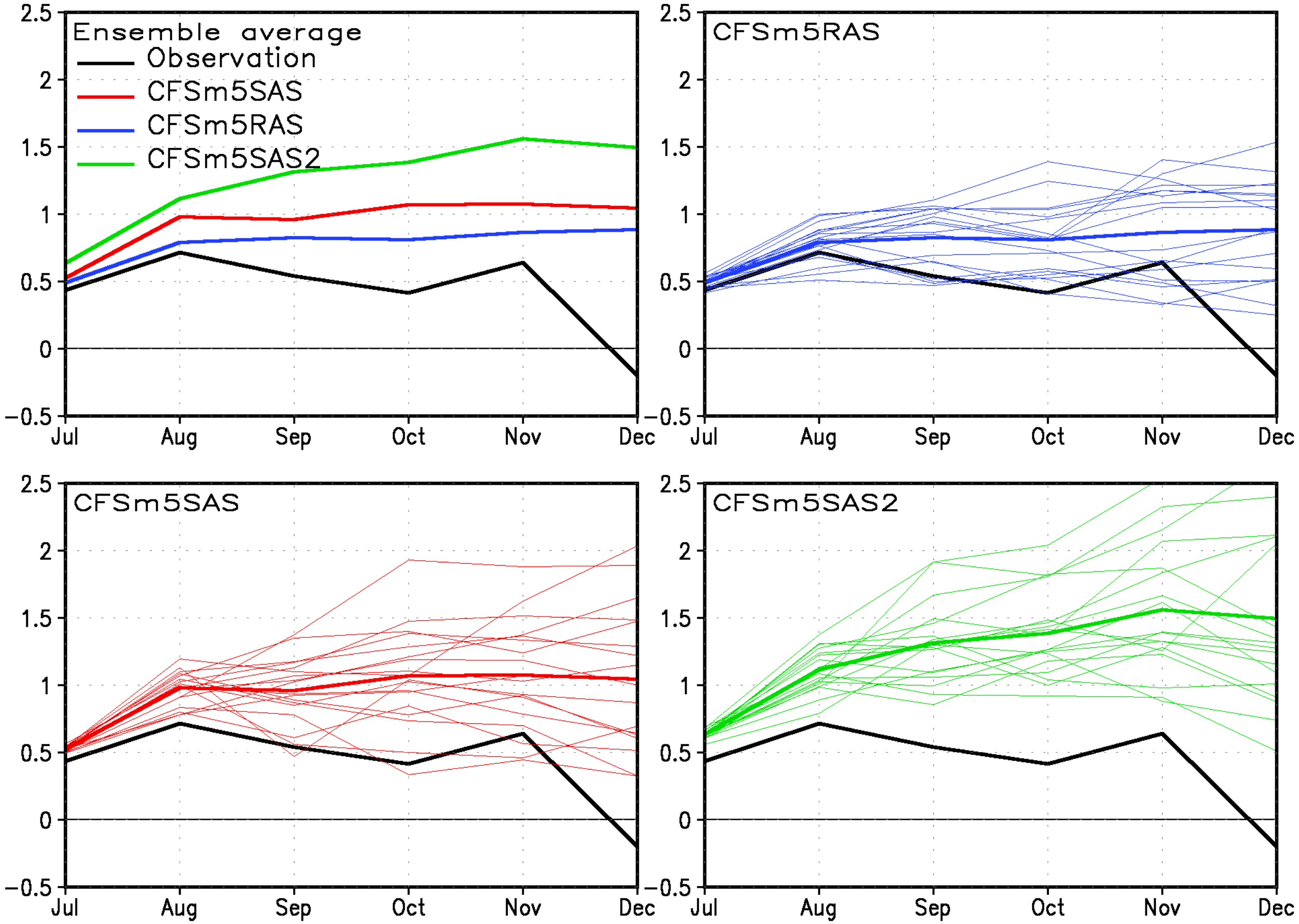
3). Coupled forecast runs

- Model

  CFSm5: GFS coupled with MOM5

- Coupled forecast runs
  - Initial date: June 30; Target: July-December
  - 1999 to Dec 2010
    - ✓ One member
    - ✓ To establish climatology
  - 2012
    - ✓ 18 members
    - ✓ Monthly mean anomalies for July-December 2012
  - Three convection schemes
    - ✓ CFSm5SAS
    - ✓ CFSm5RAS
    - ✓ CFSm5SAS2

3). Coupled forecast runs



- Ensemble mean Nino3.4 warmest with SAS2 and least warm with RAS.
- Obs is more contained in CFSm5RAS
- All three convection schemes tend to produce warmer forecasts than that observed.

Summary from numerical experiments

- Cumulus convection scheme is a possible cause for ENSO false alarms predictions in CFS.

- The convection scheme used in CFSv2 produces too strong westerly surface wind in response to moderate SST initial anomalies in the eastern Pacific, resulting in unrealistic positive wind-stress/SST feedback.

- An effective way to test convection scheme for its suitability for ENSO prediction is through AMIP runs to examine the surface wind response to observed moderate SST anomalies.

謝謝　！