CISESS Science Meeting 2019

Seasonal Predictability of Tropical Atlantic Variability

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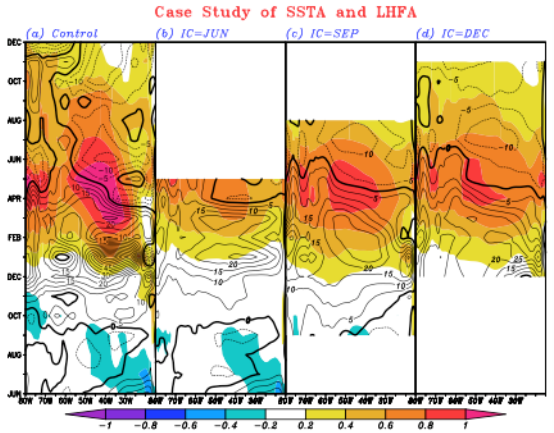
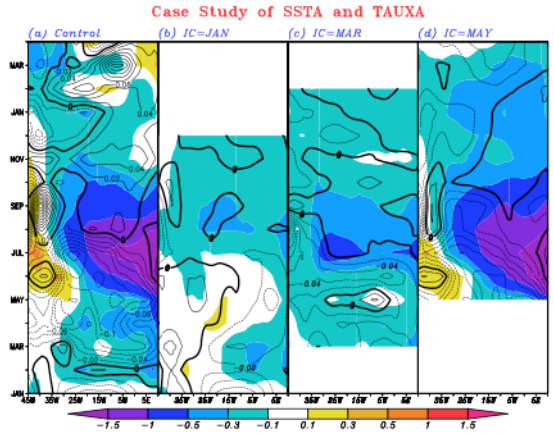
Outline

- **Background and Motivations**
- **Experiment design**
- **Results**
  - *Predictability of Northern Tropical Atlantic (NTA) pattern;*
  - *Predictability of Southern Tropical Atlantic (STA) pattern*
- **Summary**

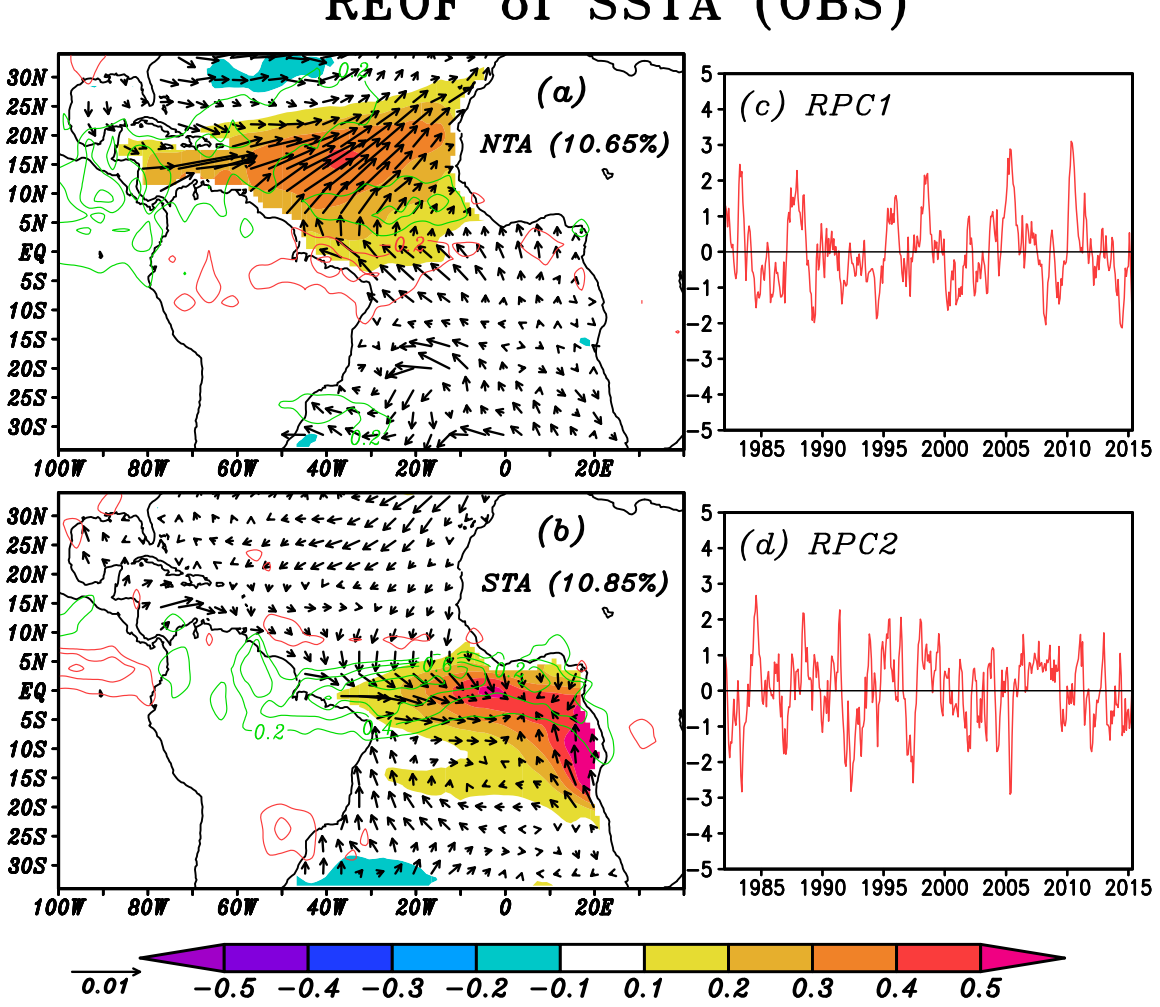




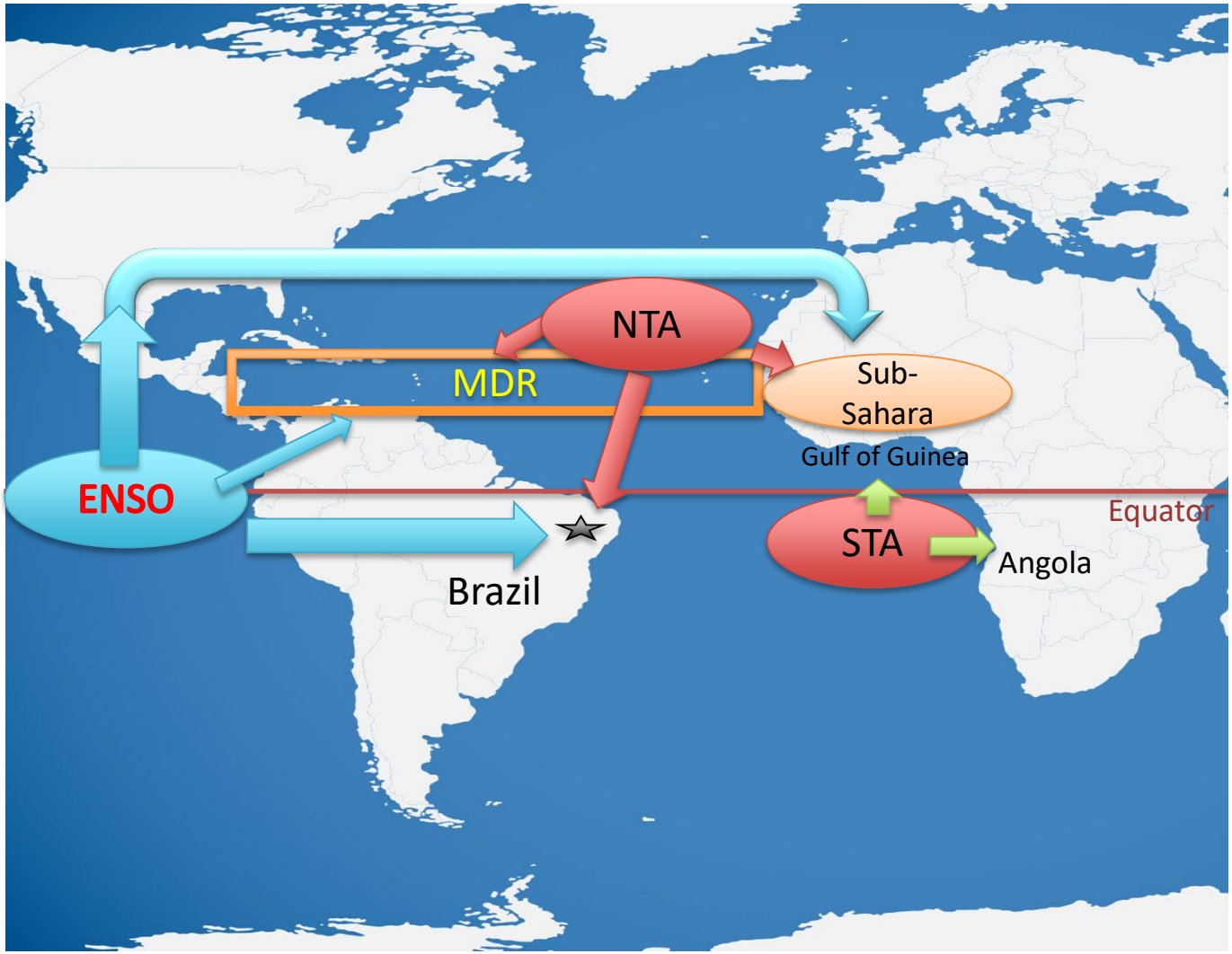
Interannual Variability: Tropical Atlantic Variability (TAV)

TAV is characterized by:

- Northern tropical Atlantic (NTA) pattern centered in the Open ocean of the northern tropical Atlantic;
- Southern tropical Atlantic (STA) pattern centered near the Angola coast, which extends toward the central equatorial ocean and the Gulf of Guinea;



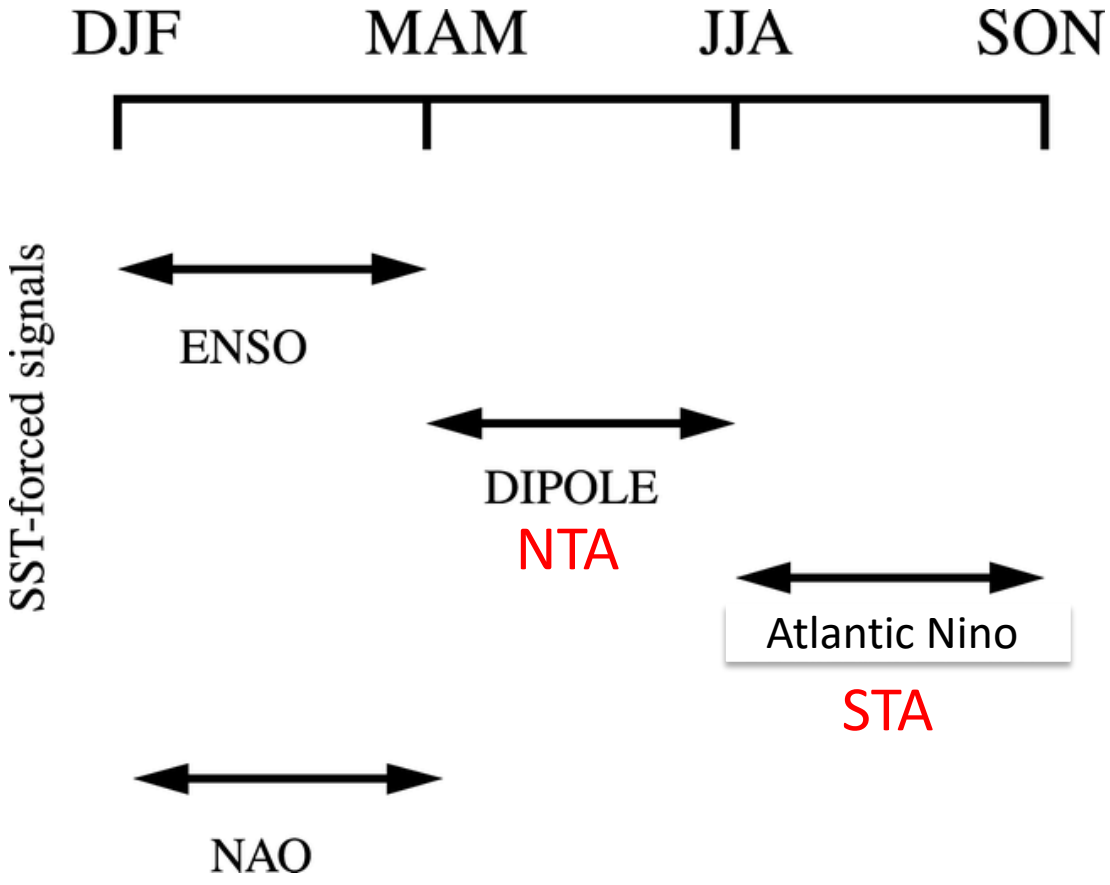
Why is TAV important?



TAV Modes have strong seasonality

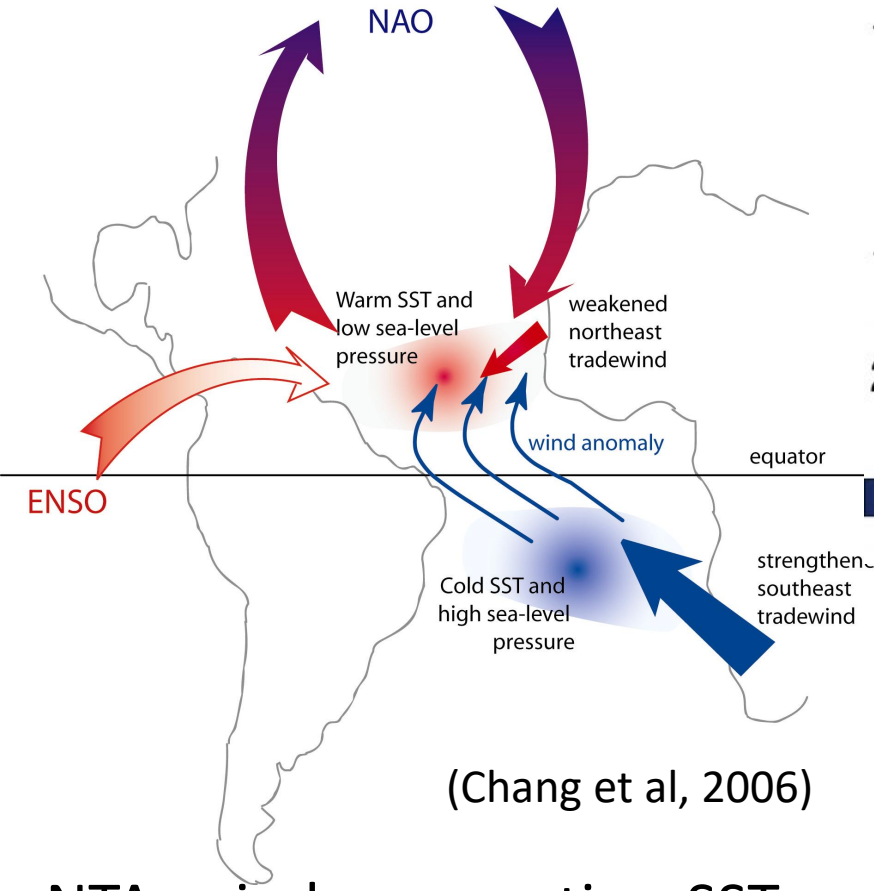
- NTA (Meridional mode, Dipole mode);
- STA (Zonal mode, Atlantic Nino);
- El Nino-Southern Oscillation (ENSO);
- North Atlantic Oscillation (NAO)

Strong seasonality of Tropical Atlantic Variability makes understanding and prediction of tropical Atlantic variability a challenge.

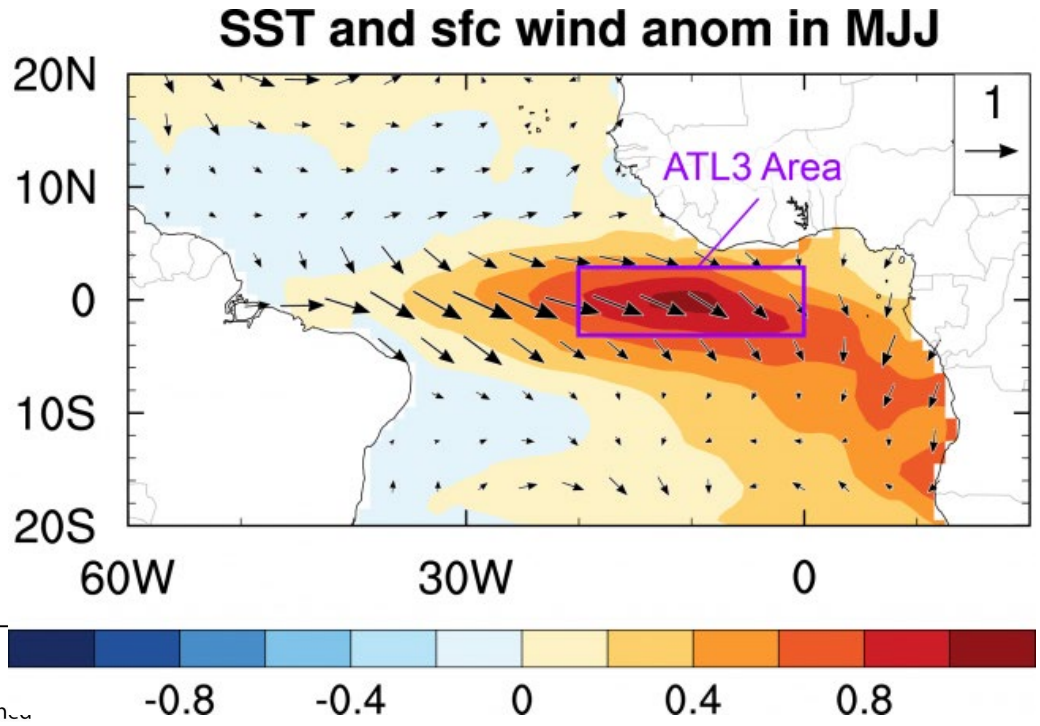


(Sutton et al, 2007)

Motivation: theoretically, the mechanisms of both NTA and STA modes are well known and they have high potential predictability (Kushnir et al 2006)



(Chang et al, 2006)

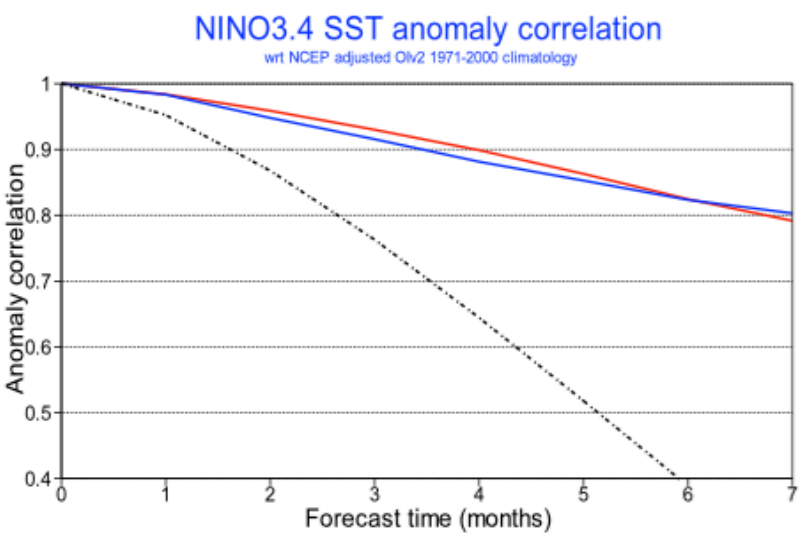


STA: Bjerknes feedback

NTA: wind-evaporation-SST positive (WES) feedback

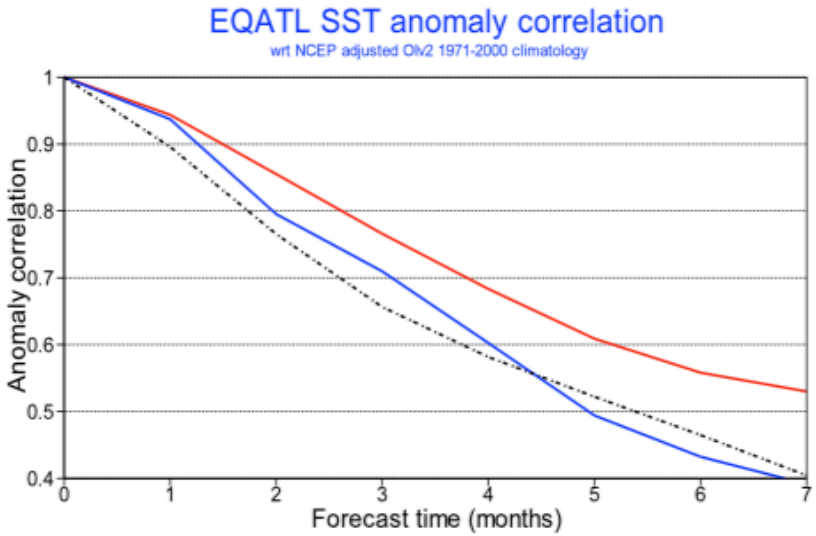
In reality, the skill of STA prediction is low

Tropical Pacific



S4 ACC
S3 ACC
Pers. ACC

Tropical Atlantic

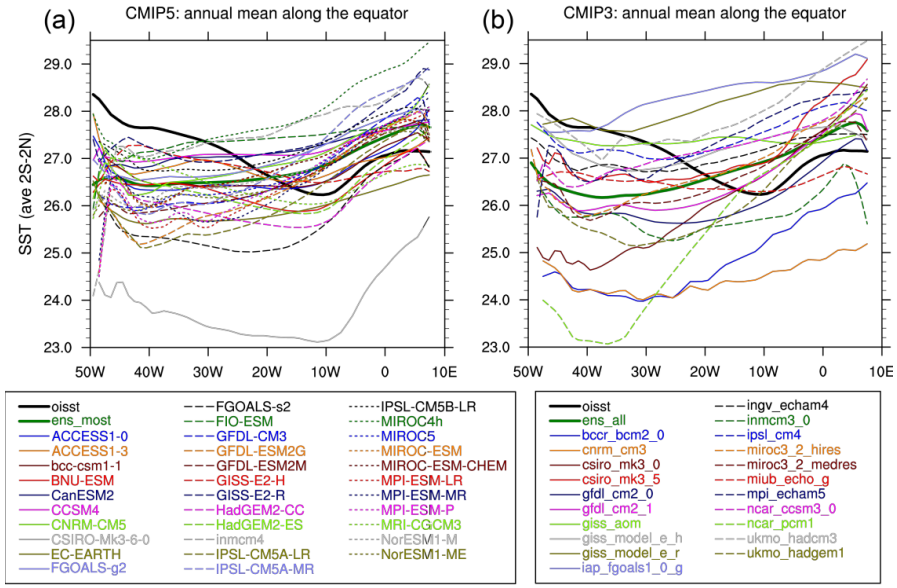


Forecast scores in ECMWF (ENSO vs. STA) (Molteni et al, 2011)

- S4 is newer version of S3 of ECMWF
- Persistence (black dash);
- In Month 6, ENSO: 0.8; STA: <0.5
- STA: S3 close to persistence; S4 improved but still low.

Why is Atlantic Nino harder to predict?

Hypothesis 1: Model bias;

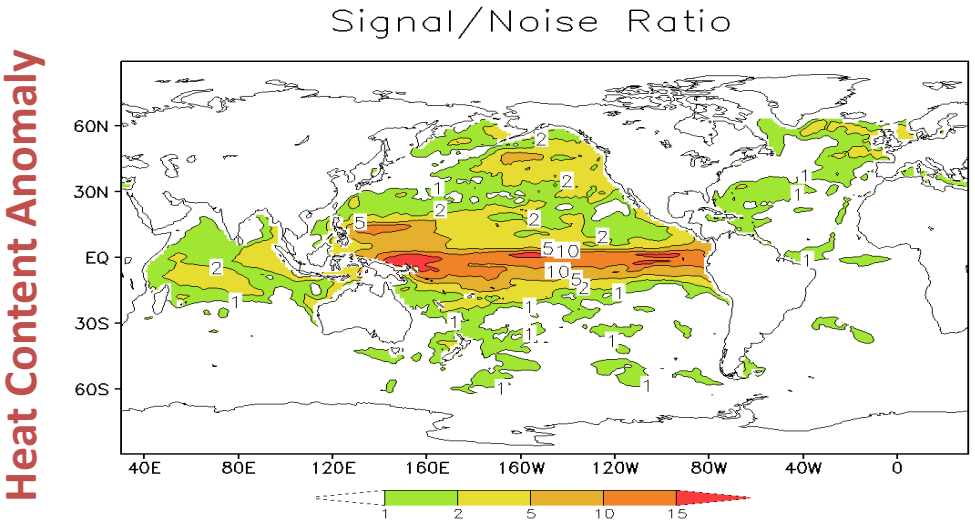


Predictions from realistic ICs will generate strong initial shock and climate drift

(Richter et al, 2012)

Hypothesis 2: Uncertainty of Initial conditions is large

Heat Content Uncertainty in Ocean Analyses (1979-2007)



$$Signal/Noise\ Ratio = \frac{Var(Ensemble\ Mean)}{Var(Intra\_Ensemble\ Deviation)}$$

DATA SOURCE

ECMWF:	ORA-S3, COMBINE-NV
NCEP:	GODAS, CFSR
UM/TAMU:	SODA
GFDL :	ECDA

Zhu et al. (*Clim. Dyn.*, 2012)

Hypothesis 3: Intrinsic limits of TAV predictability

Scientific Questions:

- What is the potential predictability of the TAV modes?
- What are the factors determining the potential predictability?

Predictability experiments of TAV events

- Control run using the state-of-the-art fully coupled model:
  - Model description: (Community Earth System Model, CESM1.1.2)
    - Atmosphere: CAM 5, 1° latitude/longitude, 30 vertical levels;
    - Ocean: POP2, 1° latitude × 1.25° longitude , 60 vertical levels;
  - Total 86 years in the control ("truth").
- Seasonal predictions of the selected TAV events:
  - Perfect model scenario;
  - Perfect oceanic initial state;
  - Small atmospheric random perturbation.

Advantage:

Eliminating the model climate drift and initial shock in real predictions.

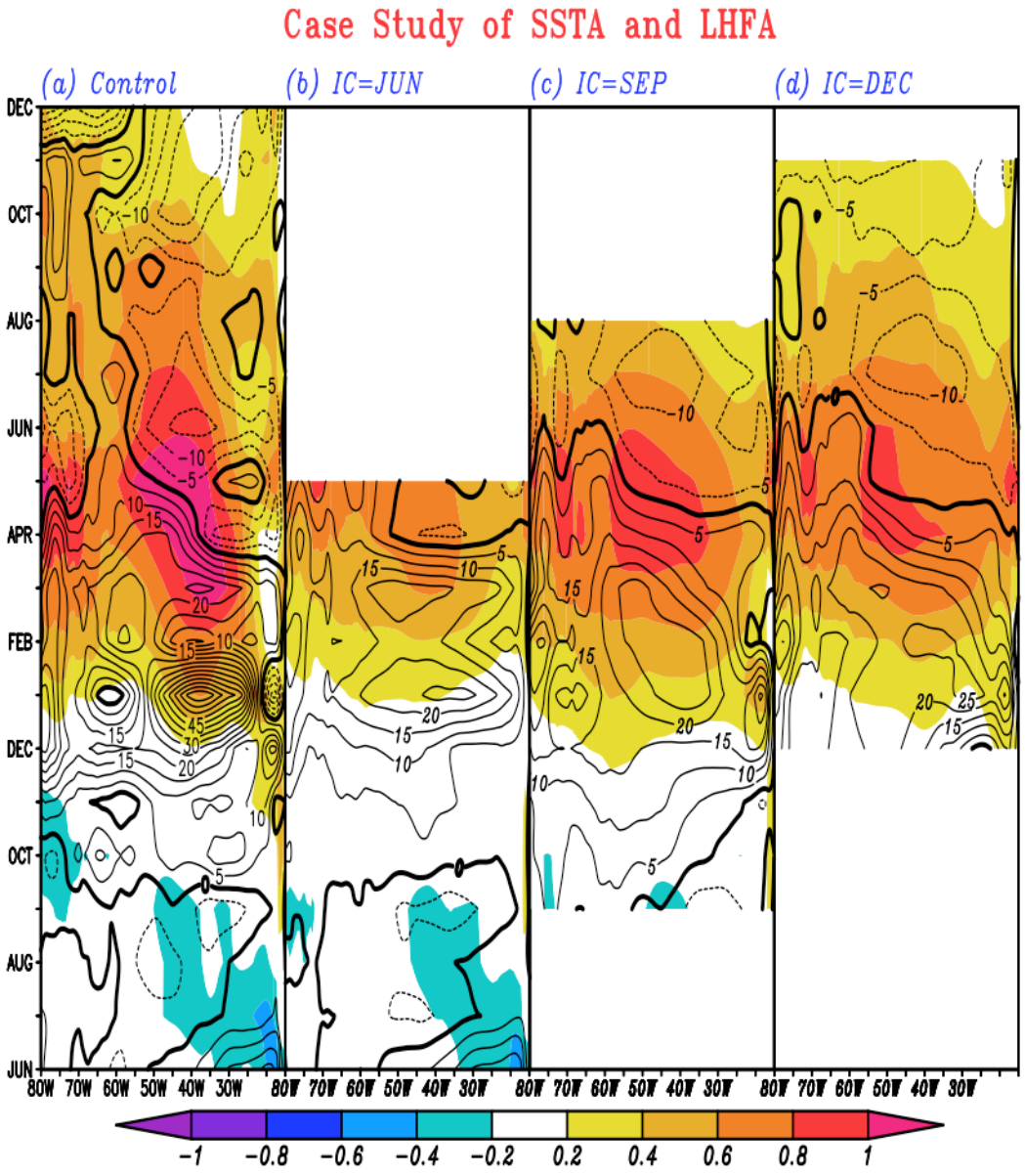
Potential Issue:

Model biases (different from observed and model climate) still exist;

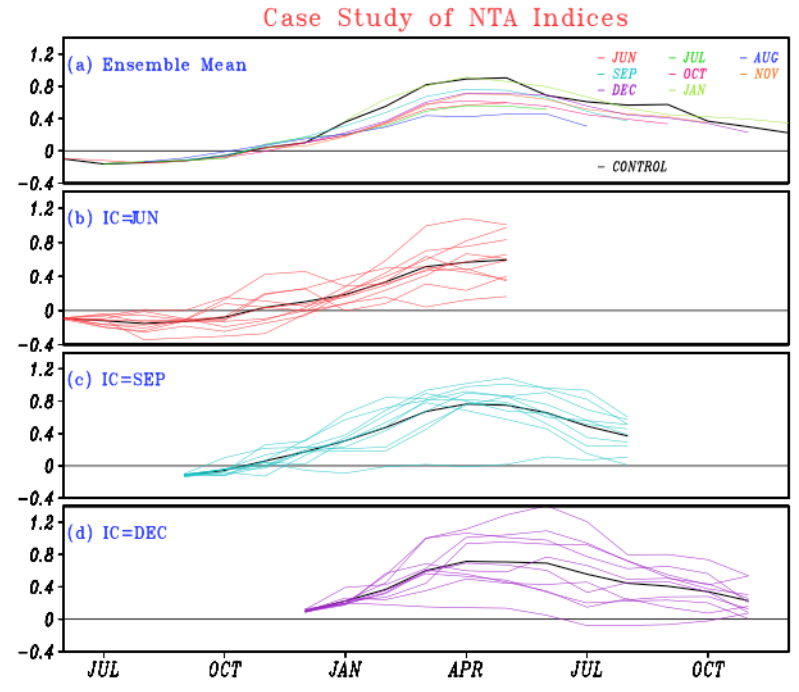
Results are model dependent.

Quality of the TAV simulation is critical to this study!

An example of NTA



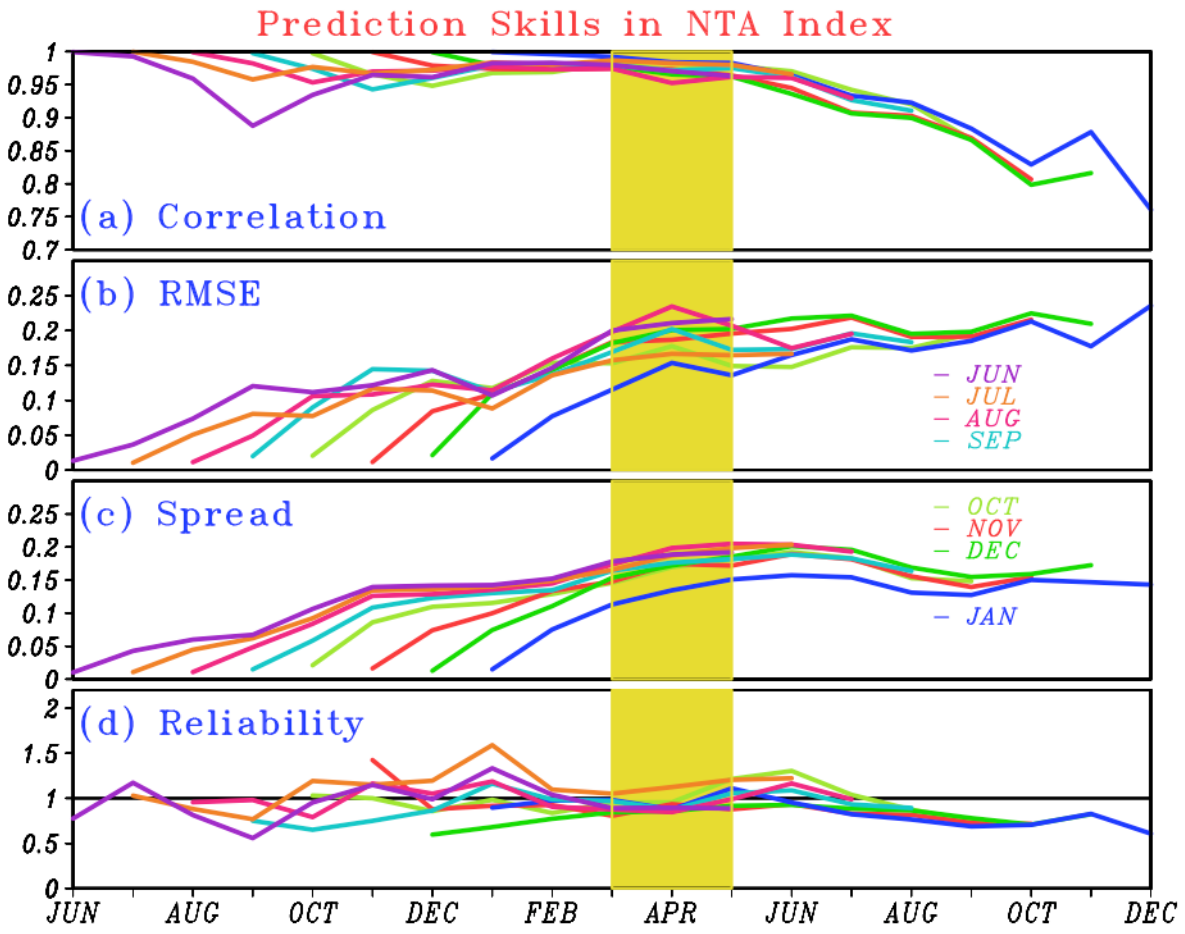
- Averaging between10N-20N
- SST anomalies generated by the surface latent heat flux anomalies 2 months ahead;
- Model is able to predict this NTA event skillfully with long leads



- All cases predict warm events;
- Uncertainty does not increase with lead time.

Prediction skill evaluation

- Deterministic metrics:
  - Correlation: 0.75-0.99 (0.95);
  - RMSE: 0.05-0.2 (0.2);
- Probabilistic metrics:
  - Spread: similar with RMSE;
  - Realiability: spread/RMSE~1, reliable.
- Predictability limit up to 9 months and even longer.

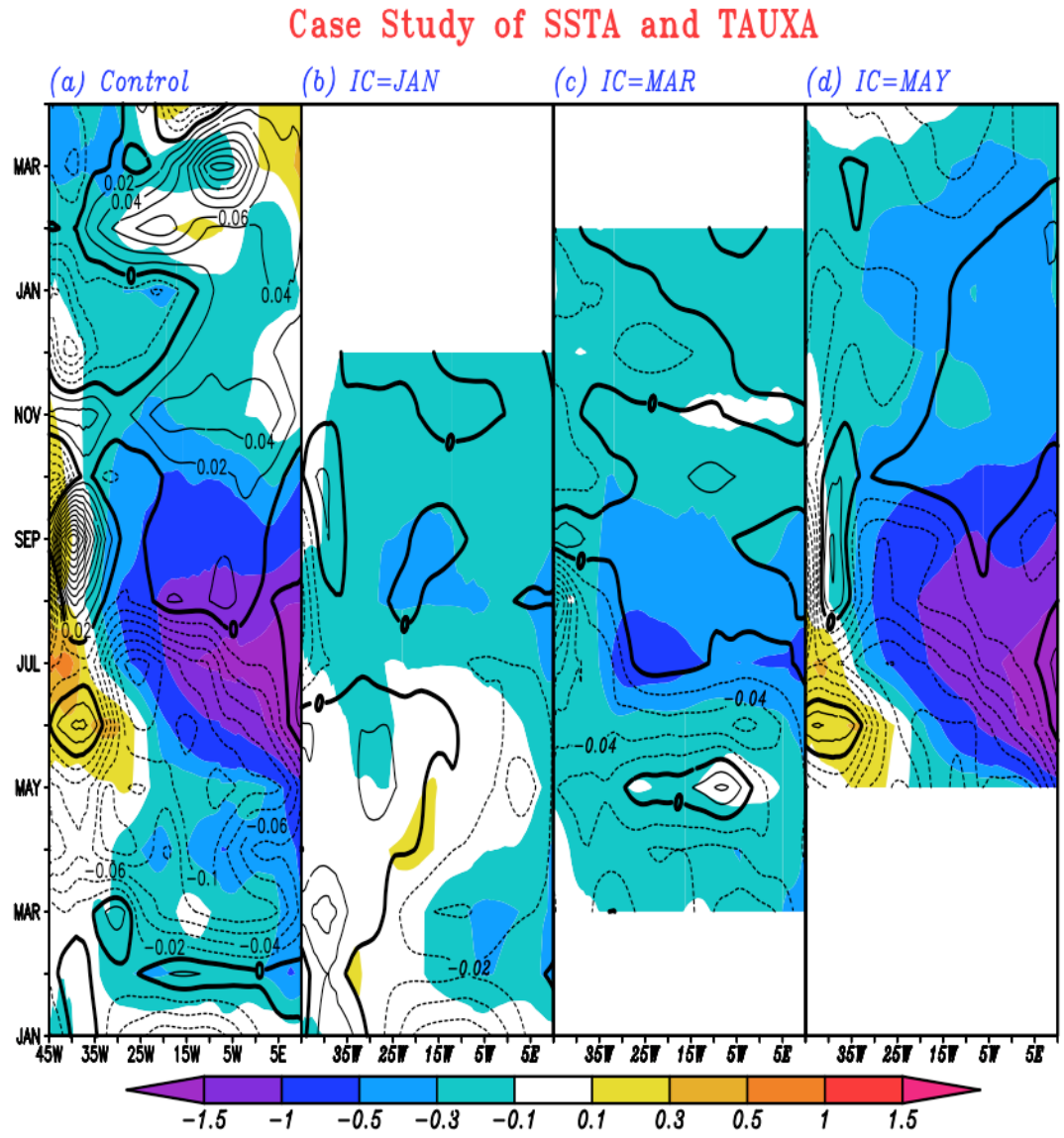


$$Spread = \sqrt{\frac{\sum_{i=1}^{n}(x_{ens,i} - \bar{x})^2}{n}}$$

$$Reliability = \frac{Spread}{RMSE}$$

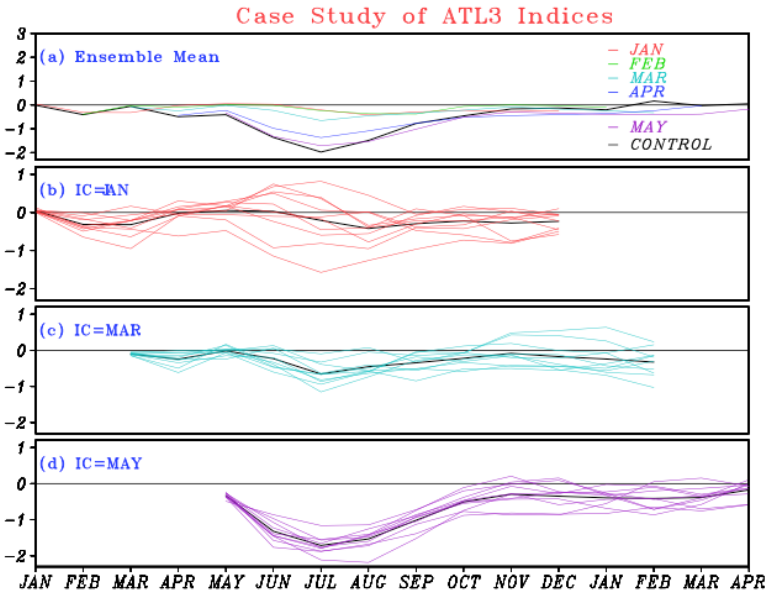
Where is the high predictability from?

STA predictability



- **Sensitive to lead time IC;**
- **With JAN IC, sign is predicted but magnitude is much lower;**
- **Whether Bjerknes feedback can be triggered in late spring is crucial.**

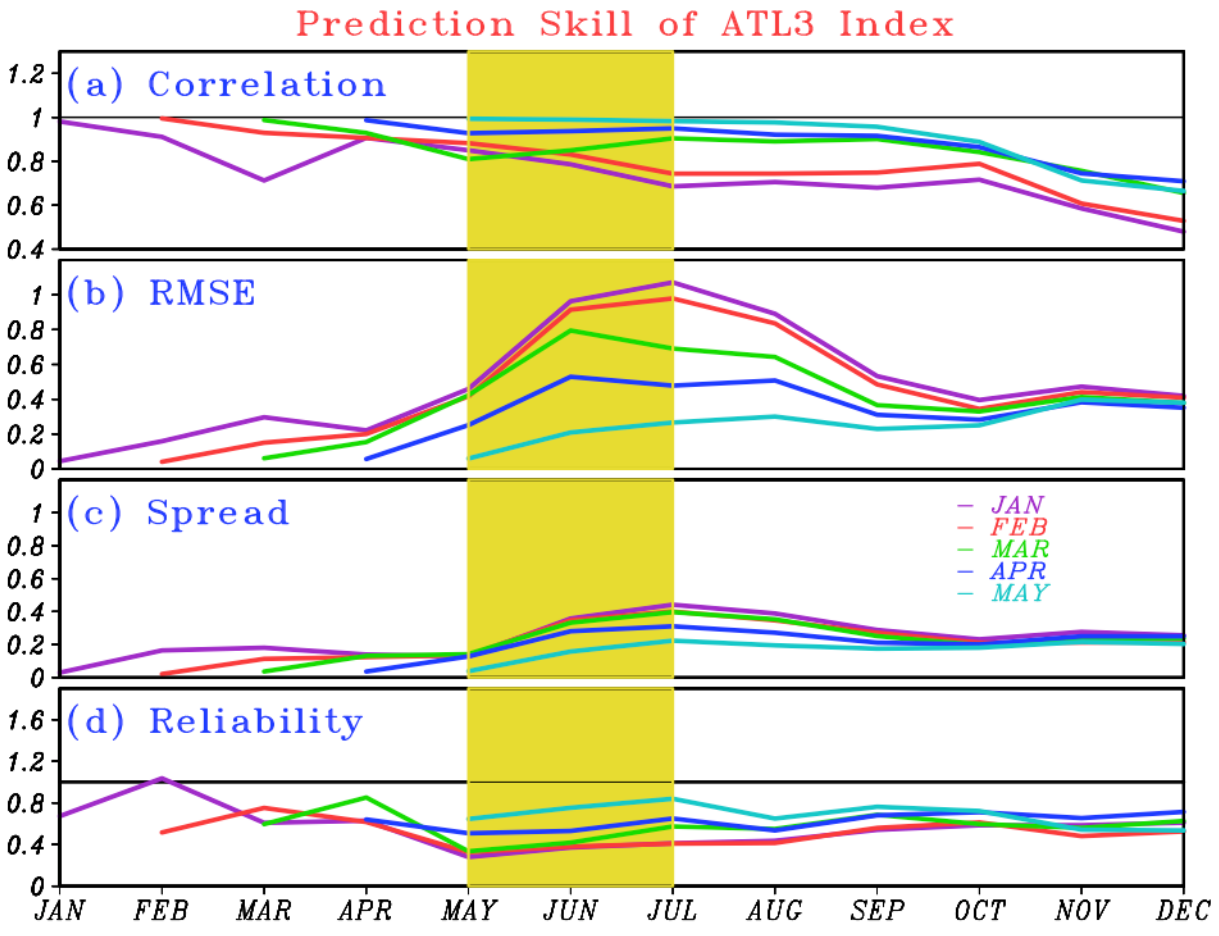
An example



- Ensemble mean depends on lead time;
- Uncertainty increases with lead-time (Spread largest in January case and smallest in May case)

Prediction skill evaluation

- Deterministic metrics
  - Correlation: 0.7-0.99 (0.8);
  - RMSE: 0.1-1.2 (0.8);
- Probabilistic metrics:
  - Spread: lower than RMSE;
  - Realiability: spread/RMSE<1, overconfident;
- Predictability limit up to 4 months.



Summary

- "Perfect" model approach is used to evaluate the predictability of two patterns of the leading modes in the tropical Atlantic;
- The NTA is predictable up to 9 months, and the source of the predictability comes from:
  - ✓ Positive WES feedback
  - ✓ ENSO predictability and tele-connection
- The STA has intrinsic prediction limit up to 4 months
  - ✓ Predictable with late-spring ICs;
  - ✓ Strength of Bjerknes Feedback is seasonal;
  - ✓ ENSO teleconnection is not critical.

Publications

- **Fang G.** and B. Huang, 2018: Seasonal Predictability of the Tropical Atlantic Variability: Northern Tropical Atlantic Pattern. *Clim Dyn*. https://doi.org/10.1007/s00382-018-4556-x
- **Fang G.** and B. Huang, 2018: Seasonal Predictability of the Tropical Atlantic Variability: Southern Tropical Atlantic Pattern, ready for submission.

Future Work

- Limitations of the experiment design:
  - ✓ Model dependence (what is the effect of model bias?);
  - ✓ Pre-selected events (can we predict the neutral states with skill?)
- Examining the TAV prediction skill in re-forecasts and operational prediction of the North American Multi-Model Ensemble (NMME):
  - ✧ Effect of model bias and drift;
  - ✧ Analyzing all situations of TAV;
  - ✧ Extra-tropical effects like NAO.
- Southern hemisphere influence: the southern subtropical Atlantic (SSA) mode.

Currently looking for a job!

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Thank you !

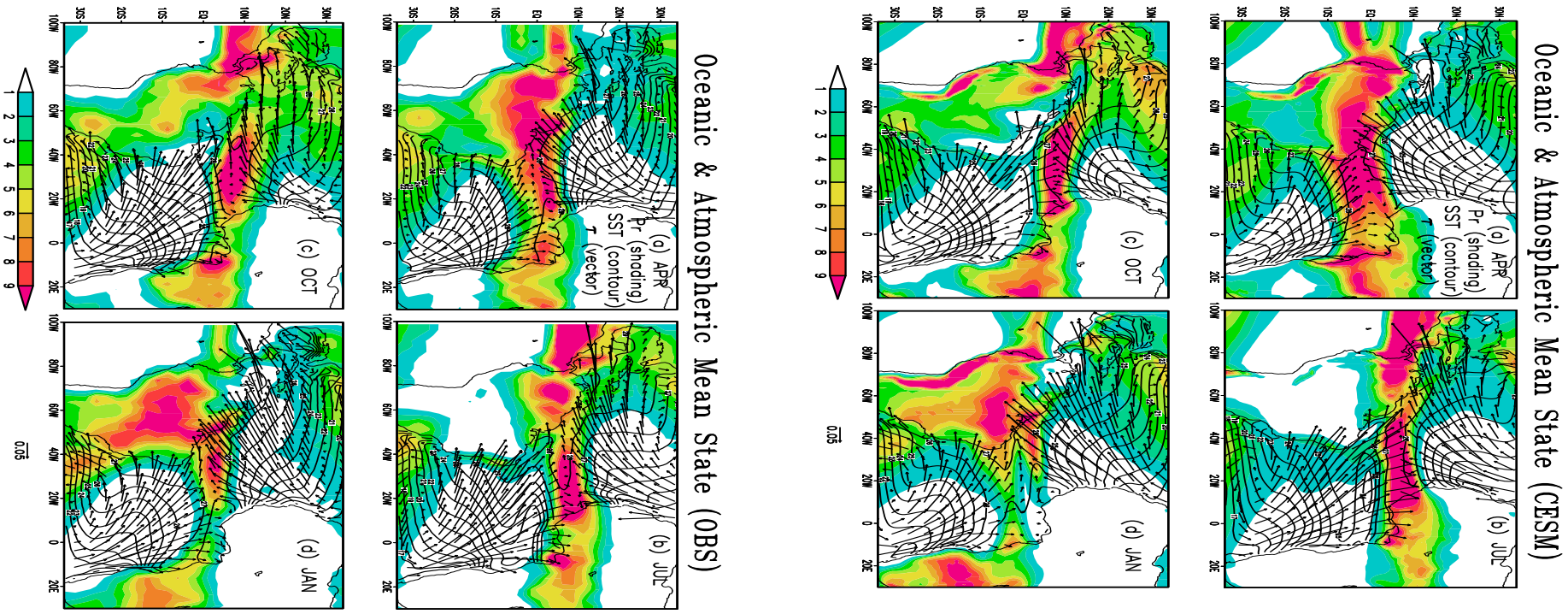
Recap of NTA

- Predictability of NTA is high (long lead);
- Sources of predictability:
  - ✧Air-sea WES feedback;
  - ✧ENSO forcing.
- Source of high NTA predictability (up to 9 months) comes from high ENSO predictability;

Recap of STA

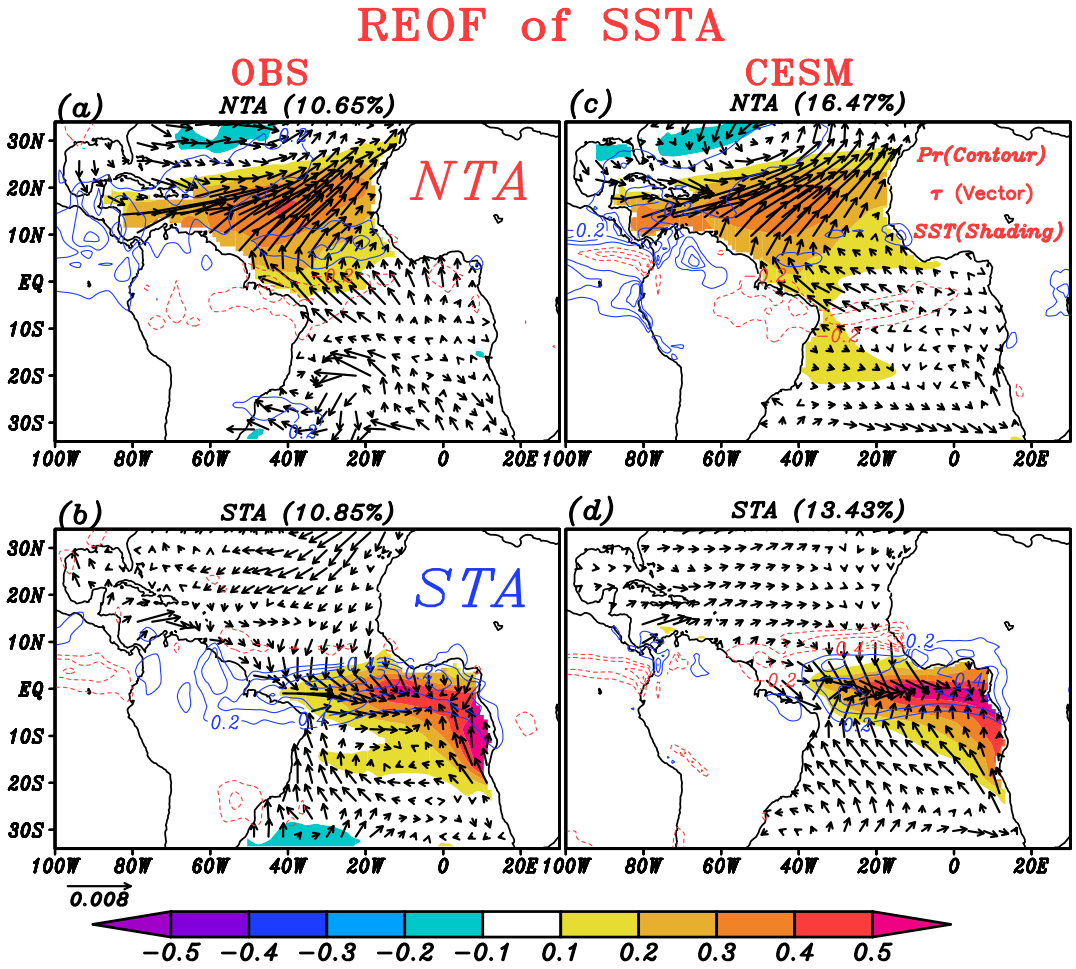
- Predictability of STA is limited by the initial condition in late spring (April and May);
- Source of predictability:
  - Bjerknes feedback;
    - ✧ The pre-condition of deepening of the thermocline in African coast is necessary but not suficient;
    - ✧Effective Bjerknes feedback in late spring or early summer is critical;
  - The role of ENSO teleconnection is secondary.

Model evaluation



- Main feature of ITCZ-cold tongue complex is realistic;
- Shortcomings:
  - Overestimated Precipitation;
  - Double ITCZ.

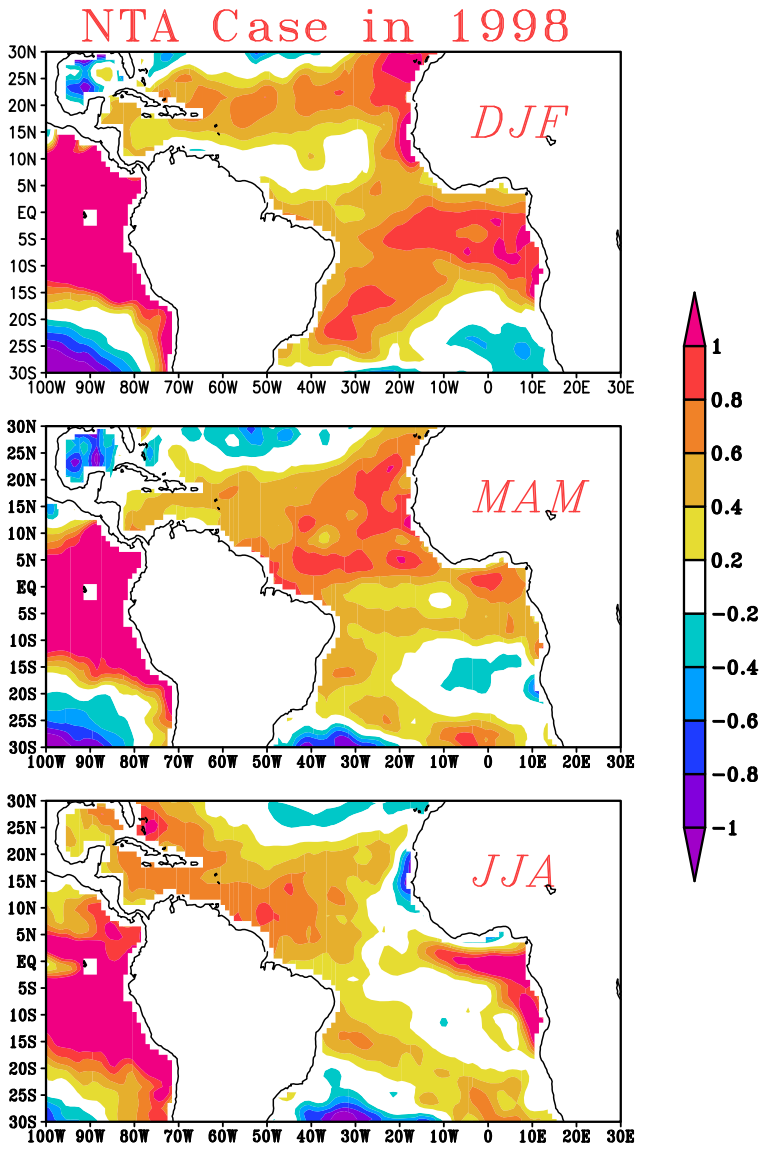
Interannual Variability

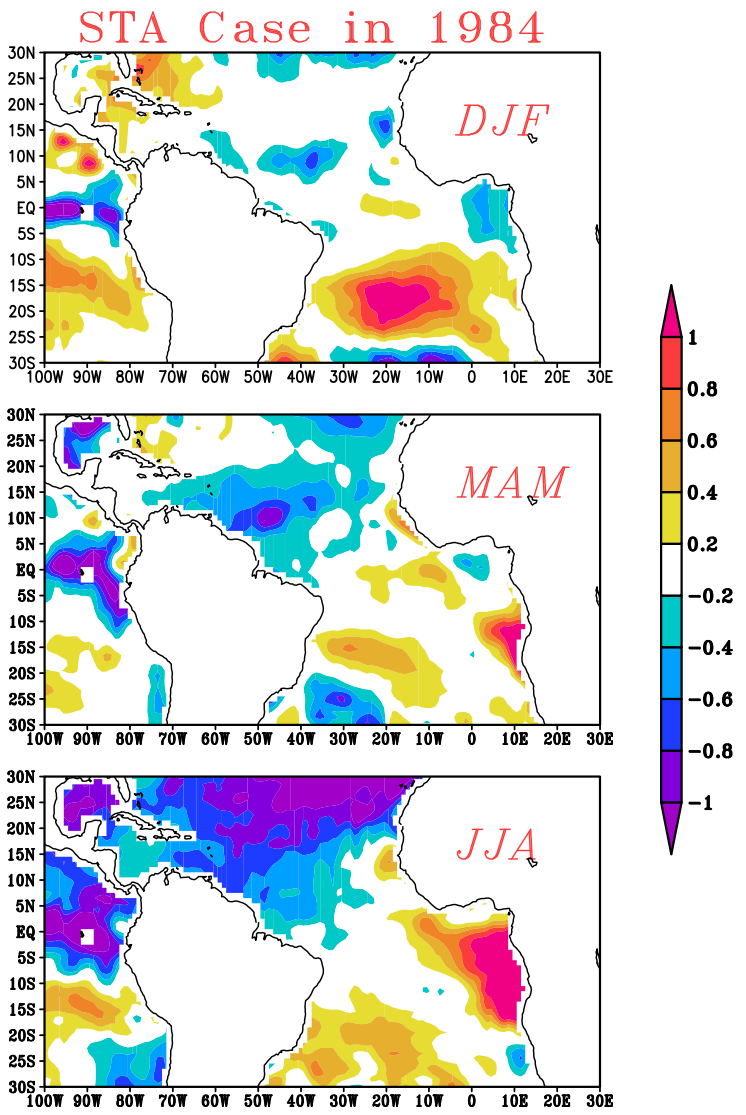


Simulated leading modes of TAV are realistic and adequate for conducting the predictability experiment.

Experiment design:

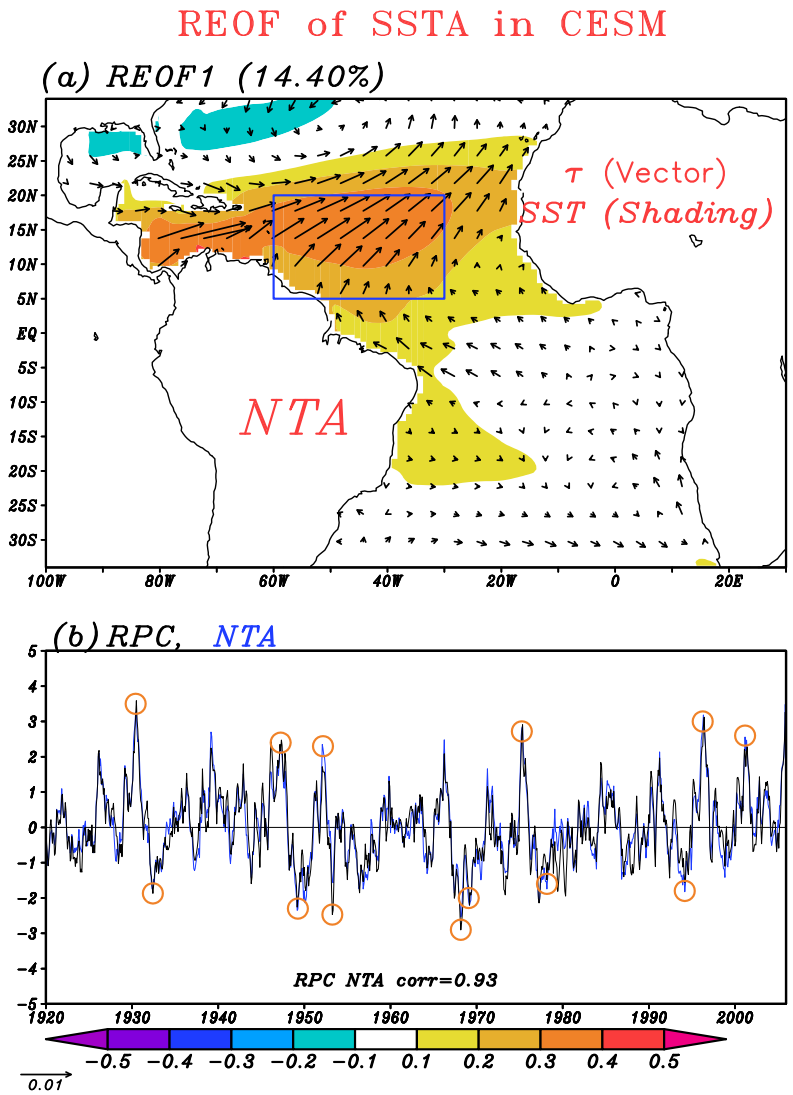
TAV prediction is to predict the occurrence of anomalous events.



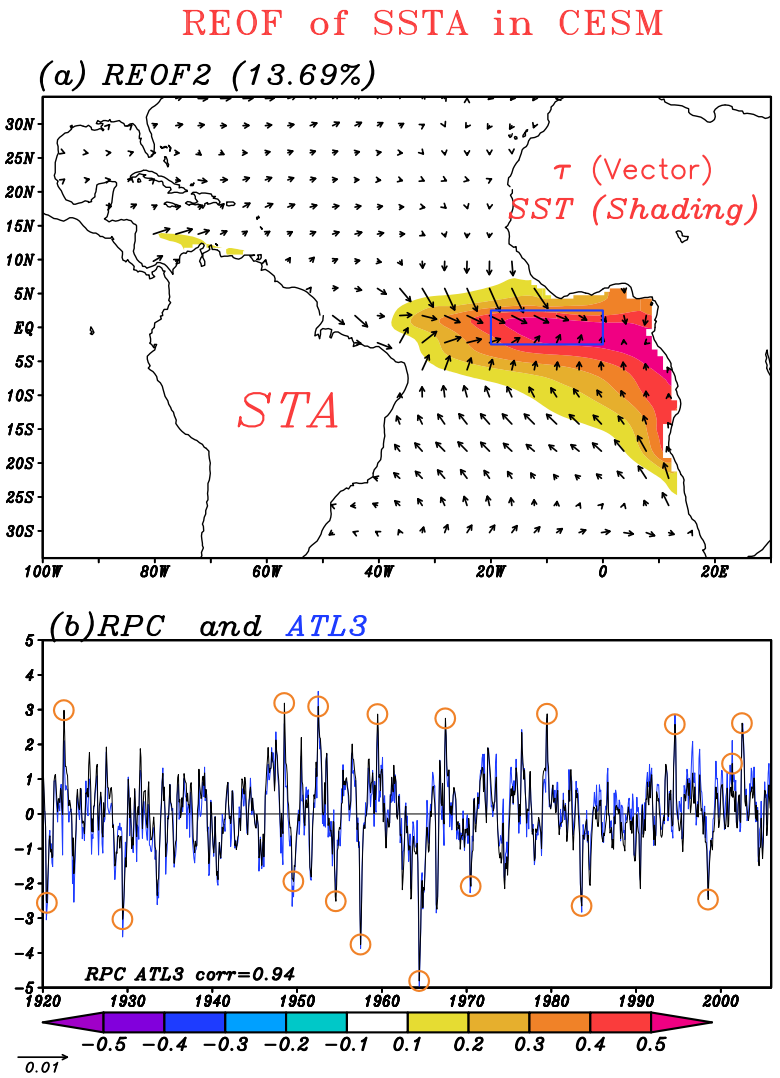


Anomalous events in observations

Experiment design: Anomalous events selection



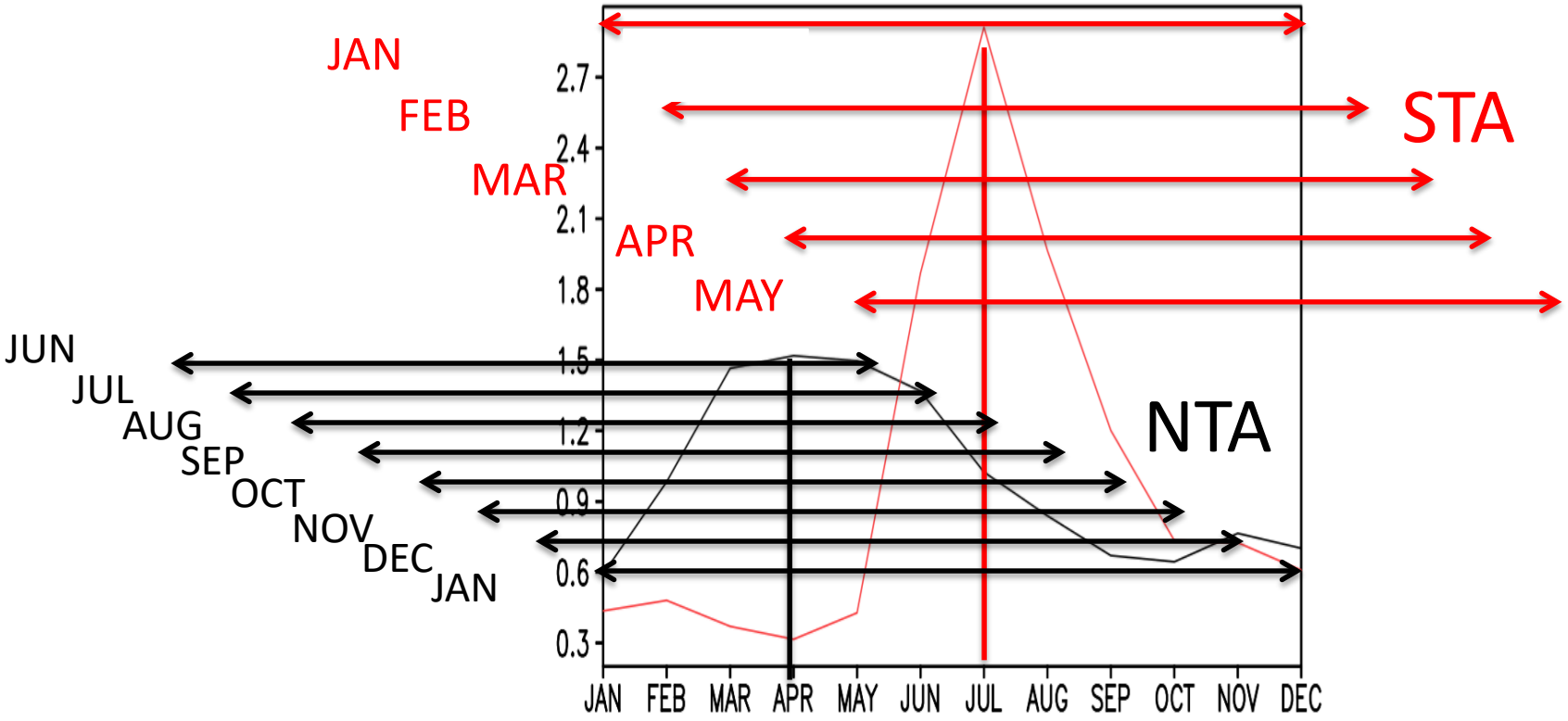
- 13 anomalous event chosen: 6 positive and 7 negative.



- 18 anomalous event chosen: 9 positive and 9 negative.

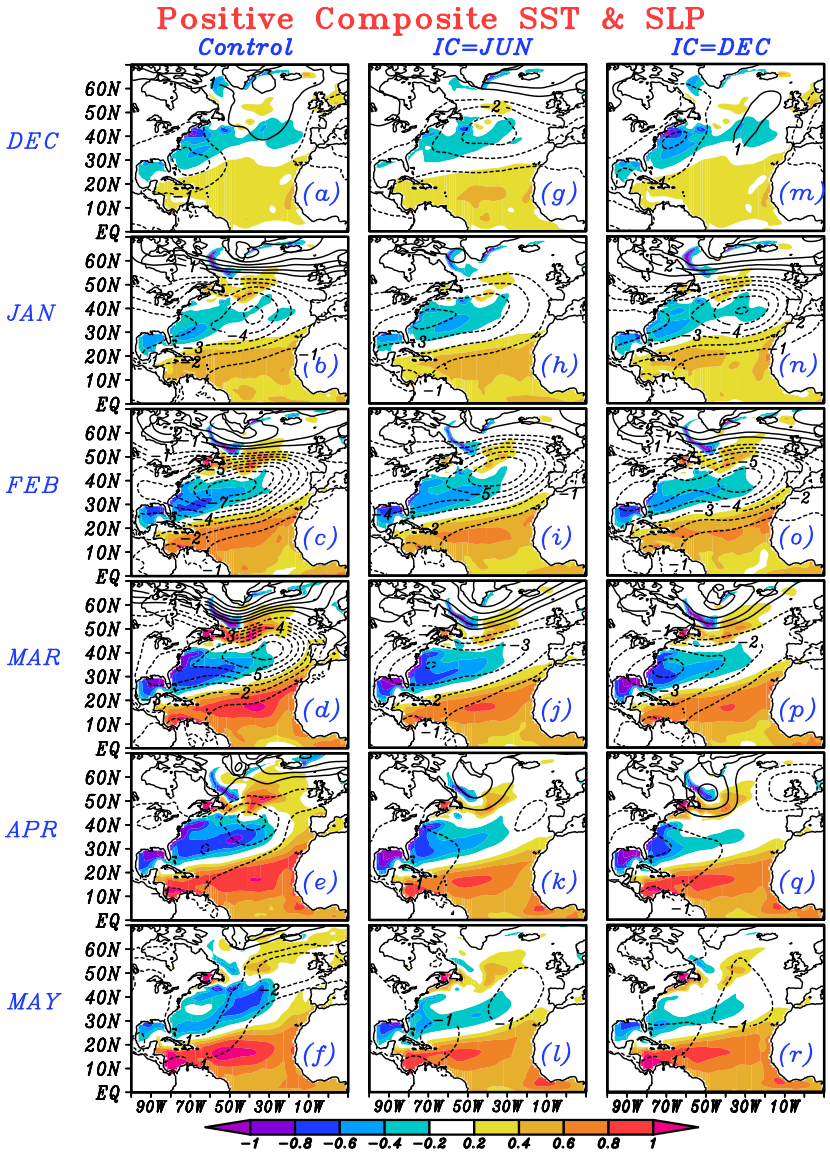
Lead months

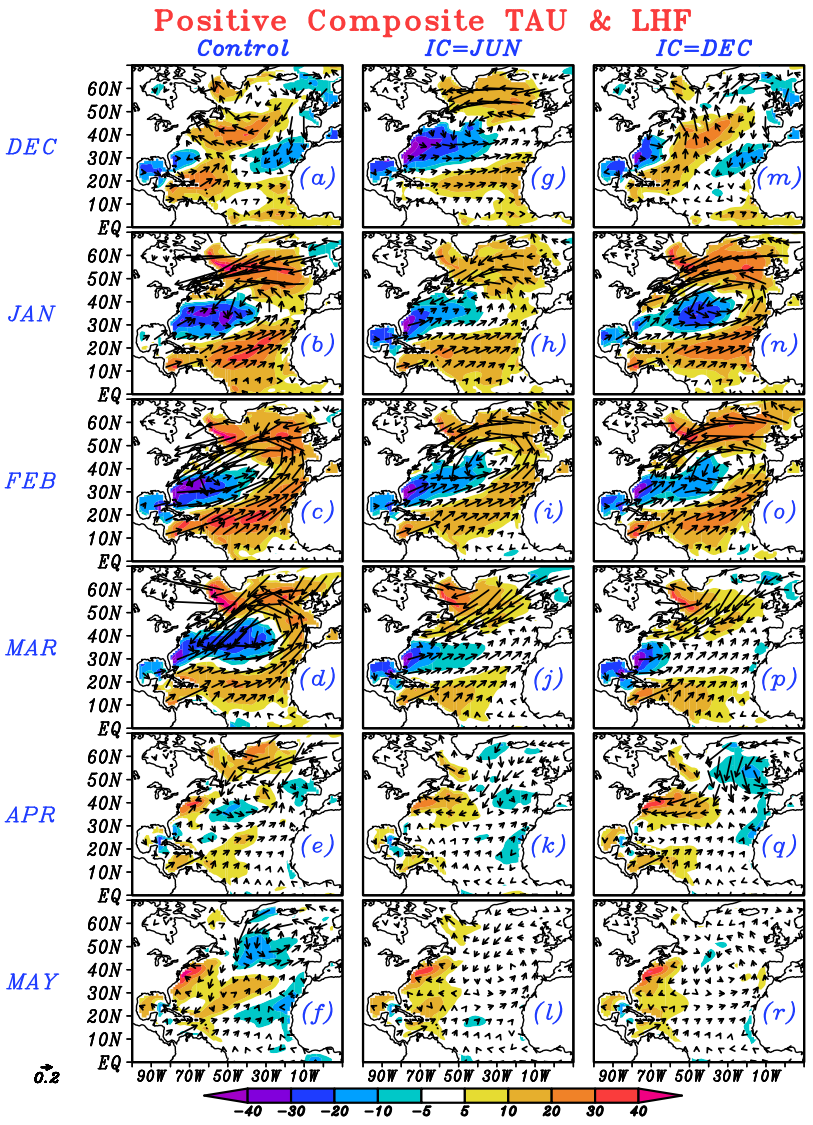
Experiment design:



- NTA and STA events have strong seasonal phase-lock;
- NTA peaks in April and STA peaks in July;
- Different starting dates for each forecast due to its seasonality.

Source of Predictability: WES feedback



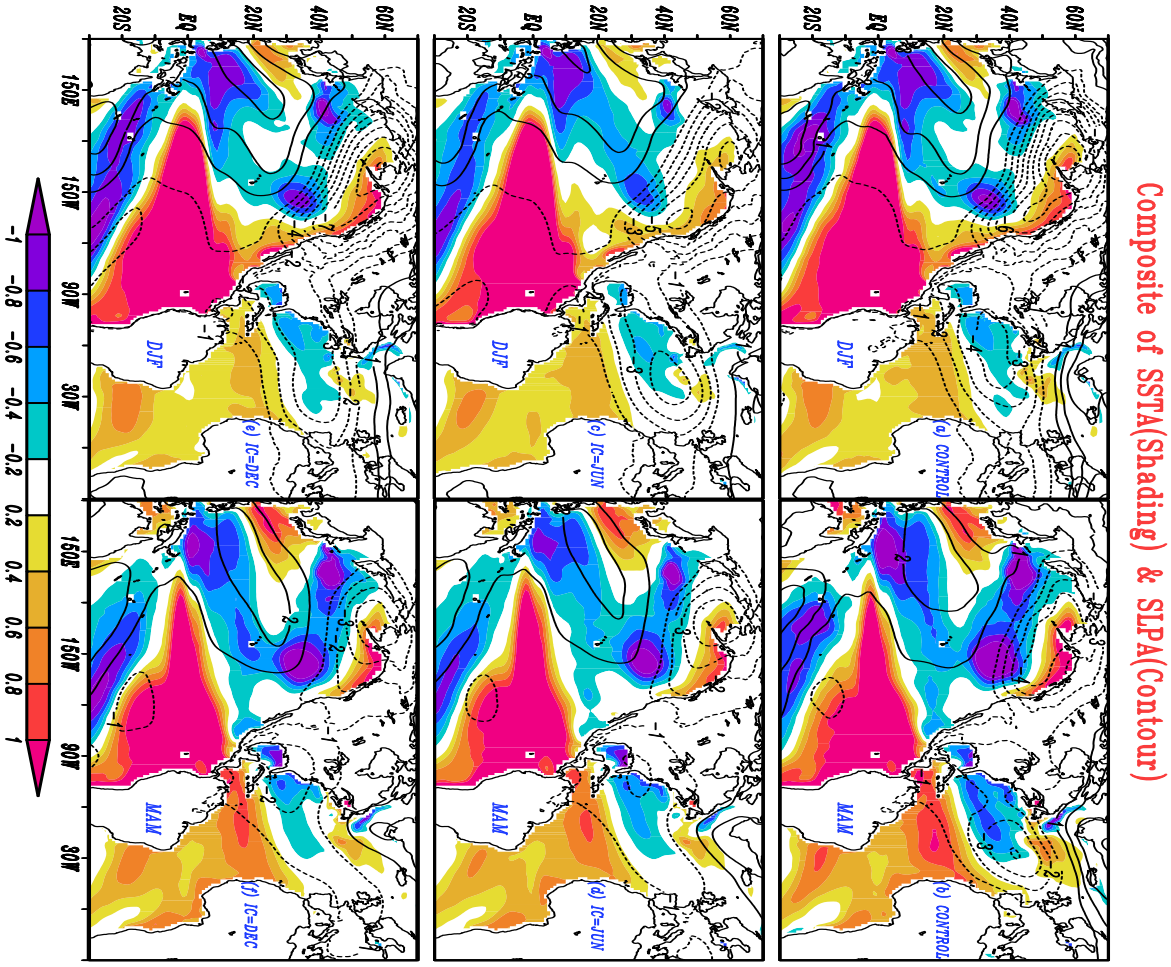


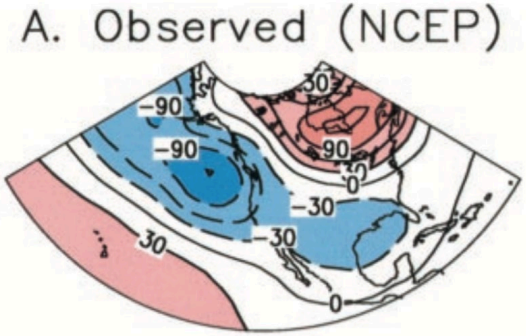
- Not very sensitive to lead time of IC;
- The key feature is the cyclonic anomaly in sub-tropic.

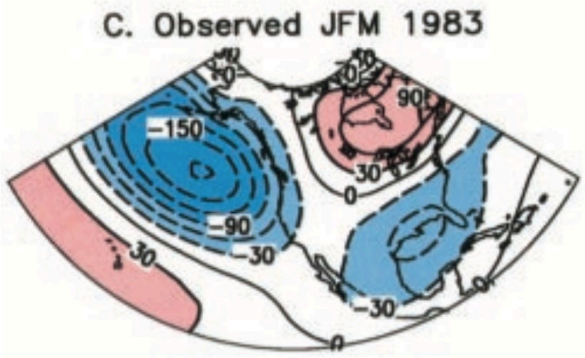
Why predicted well? Wind >Latent heat flux >SST anomalies

Where does the cyclone come from?

Source of Predictability: ENSO teleconnection



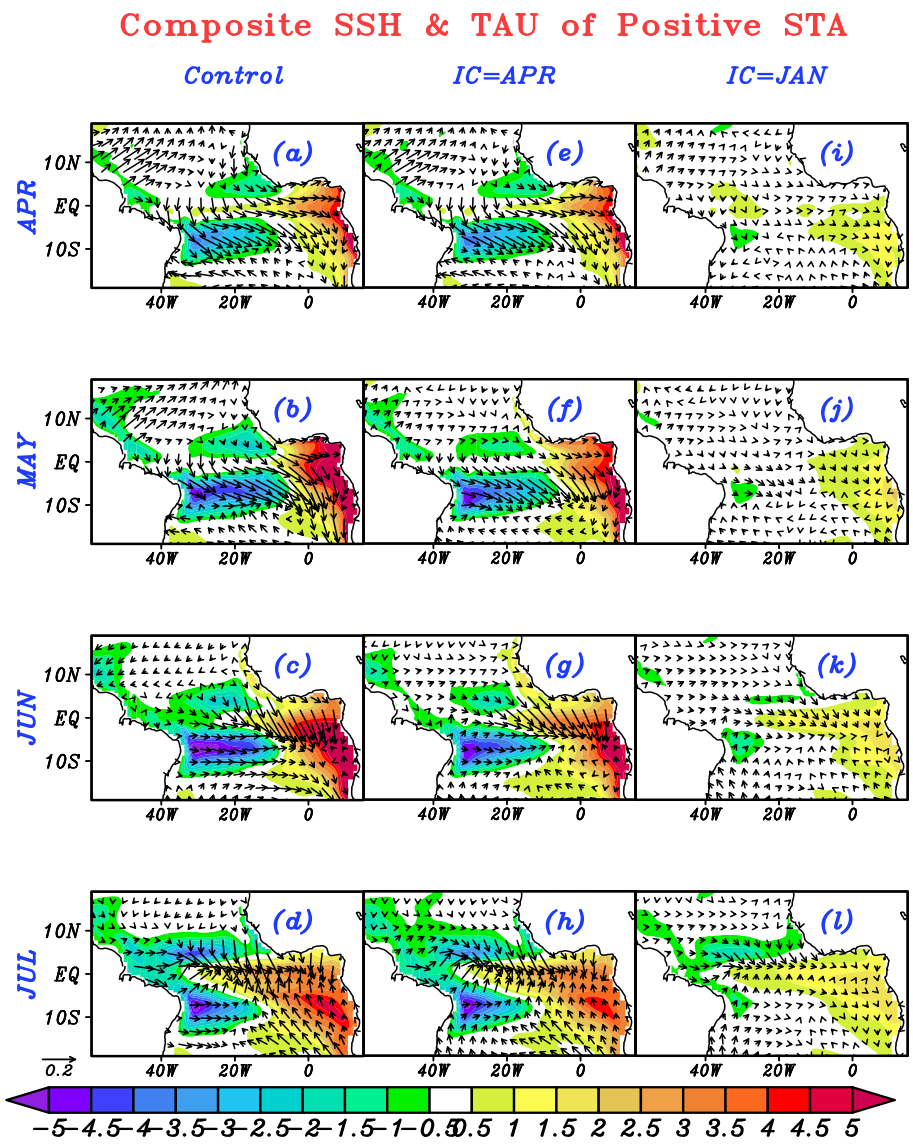


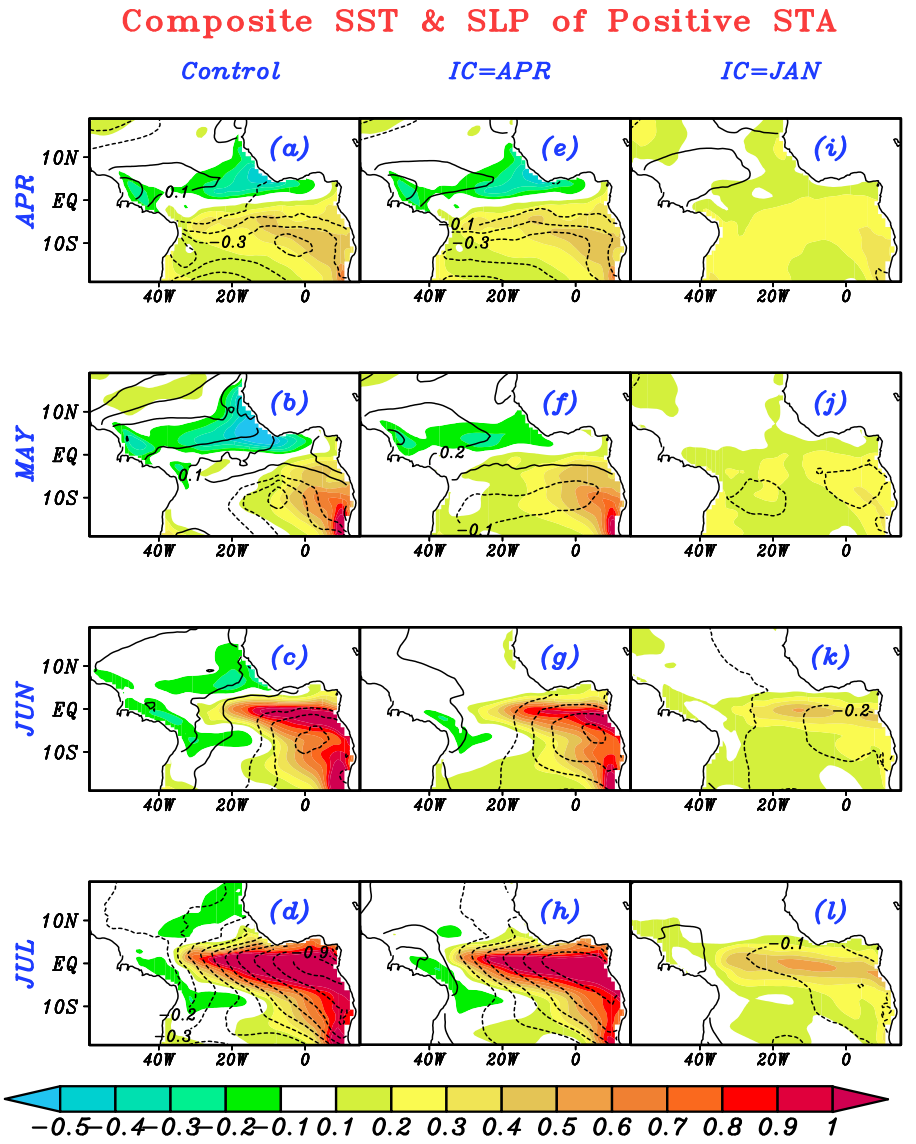


Averaging 500 mb height anomaly (m) for JFM 1998 and 1983 from NCEP (Shukla, 1998)

- **Remote forcing from winter to spring;**
- **Cyclone comes from ENSO response by Pacific/North American (PNA) pattern;**
- **Successful prediction of El Nino > cyclonic SLPA > warming in NTA region.**

Source of Predictability: Regional feedback

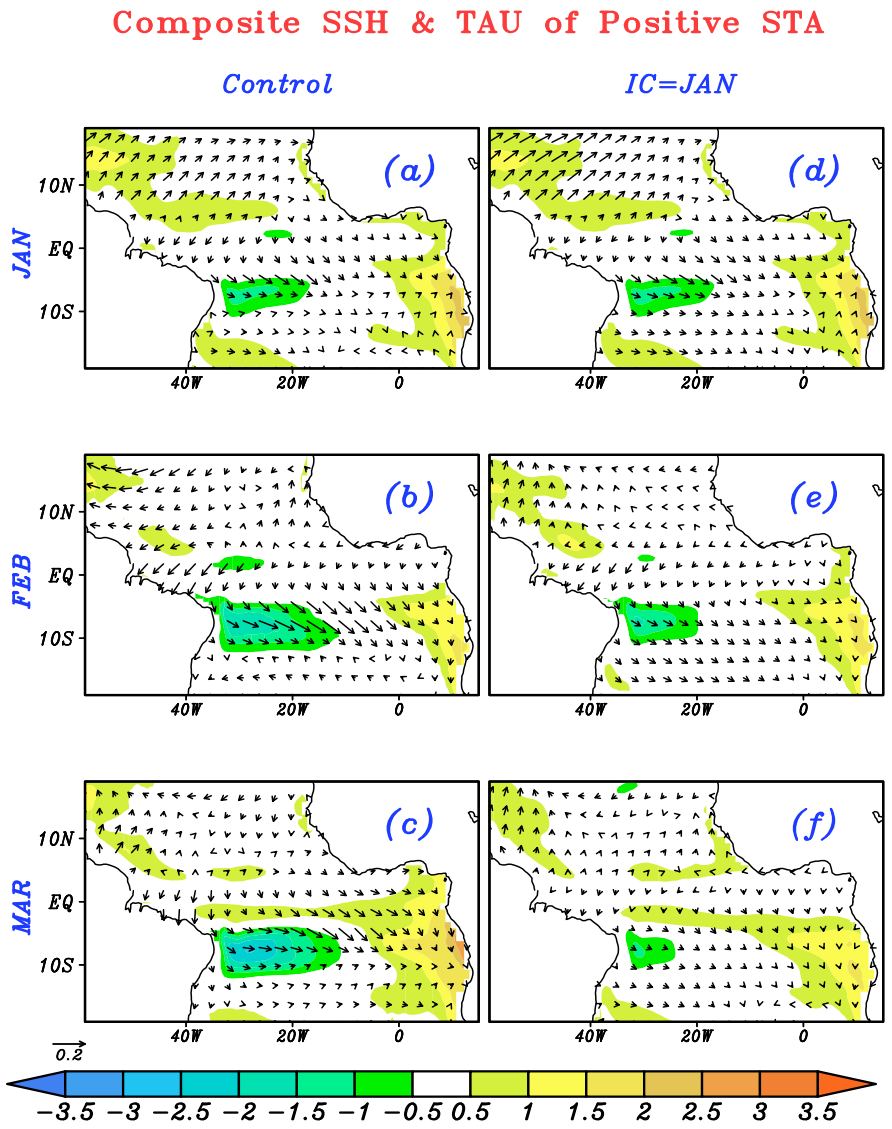




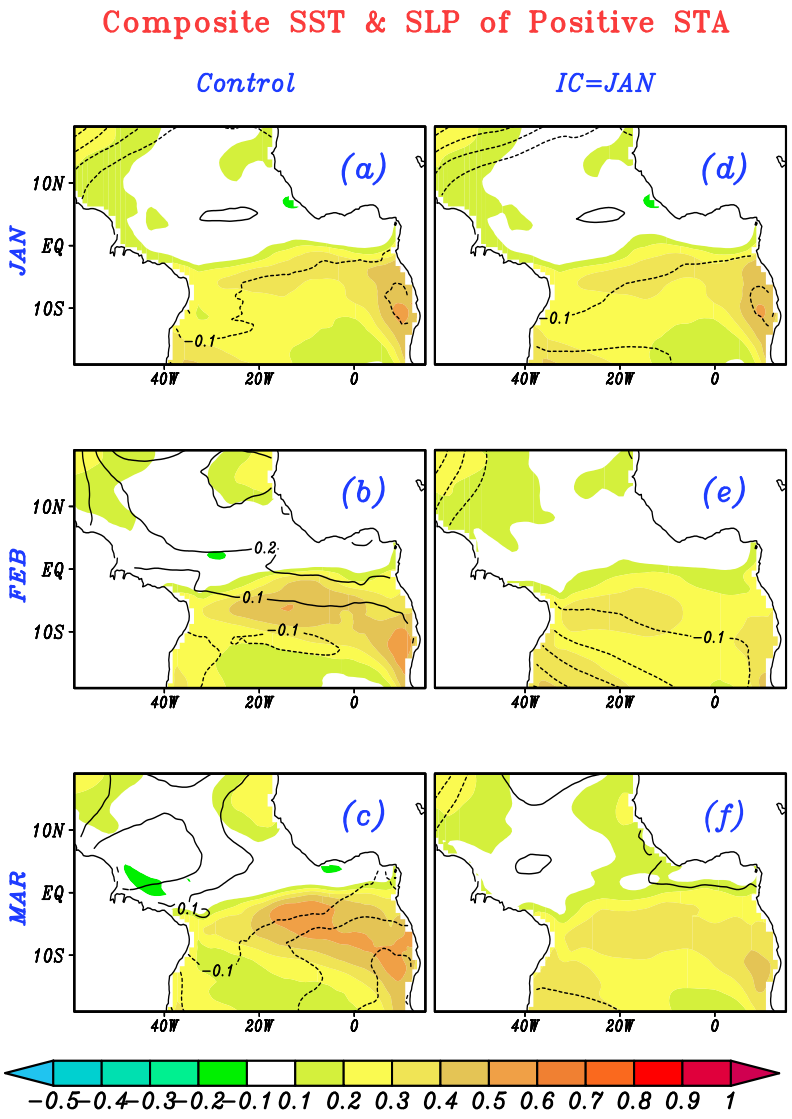
Bjerknes feedback: **North wind anomalies increasing > easterly trade winds depressing > deepening thermocline > upwelling suppressing > SST increasing > wind converging to warm water > westerly anomalies increasing**

- Low pressure center > warm anomalies;
- For January case: no low pressure center.

Source of Predictability

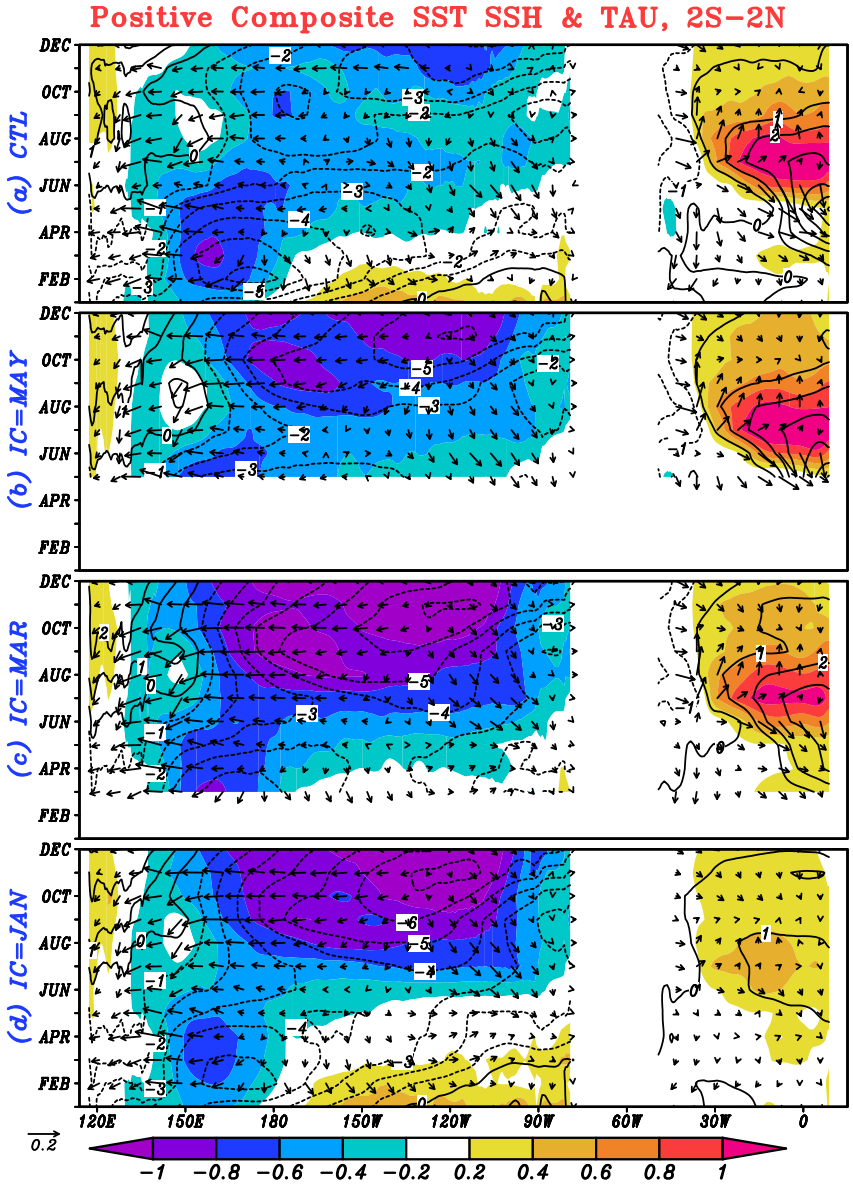


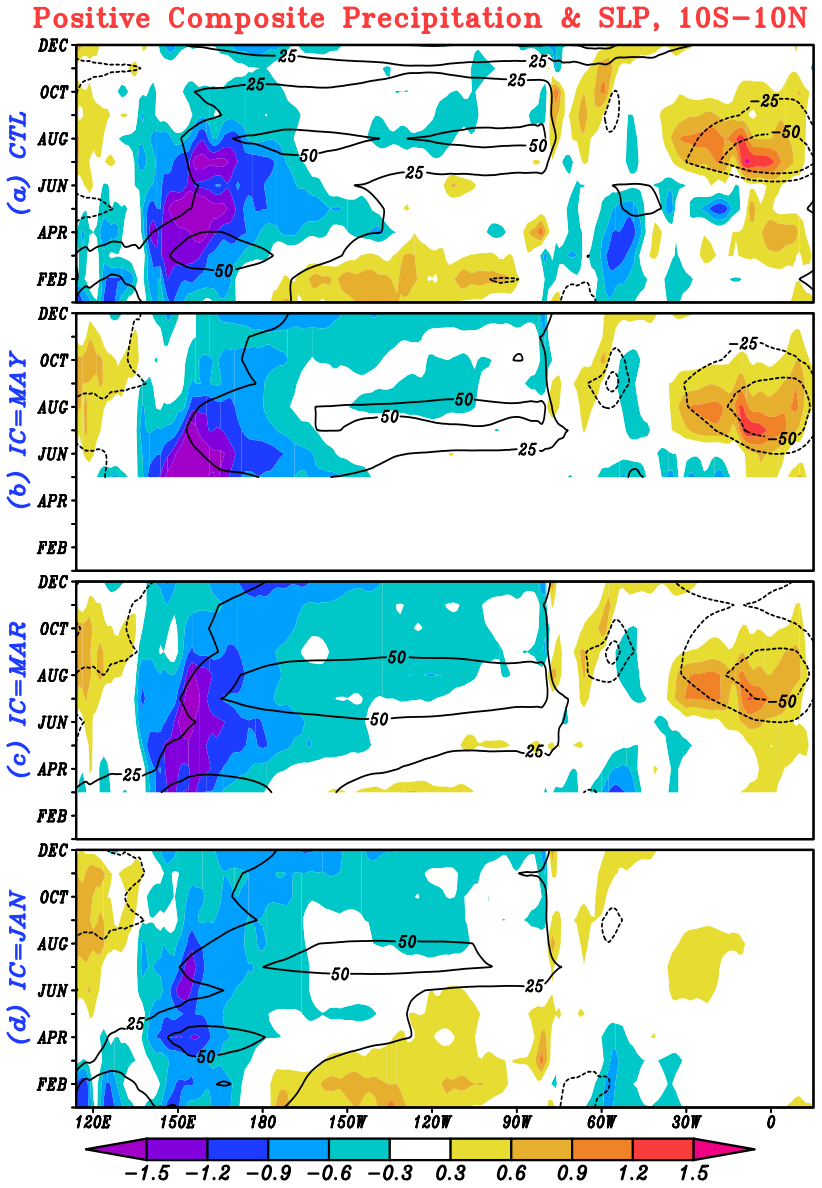
- SSH & TAU decaying in model;
- No air-sea feedback in January forecast



- SST & SLP decaying in model;
- Ocean memory existing but not persistent;
- No air-sea feedback in prediction

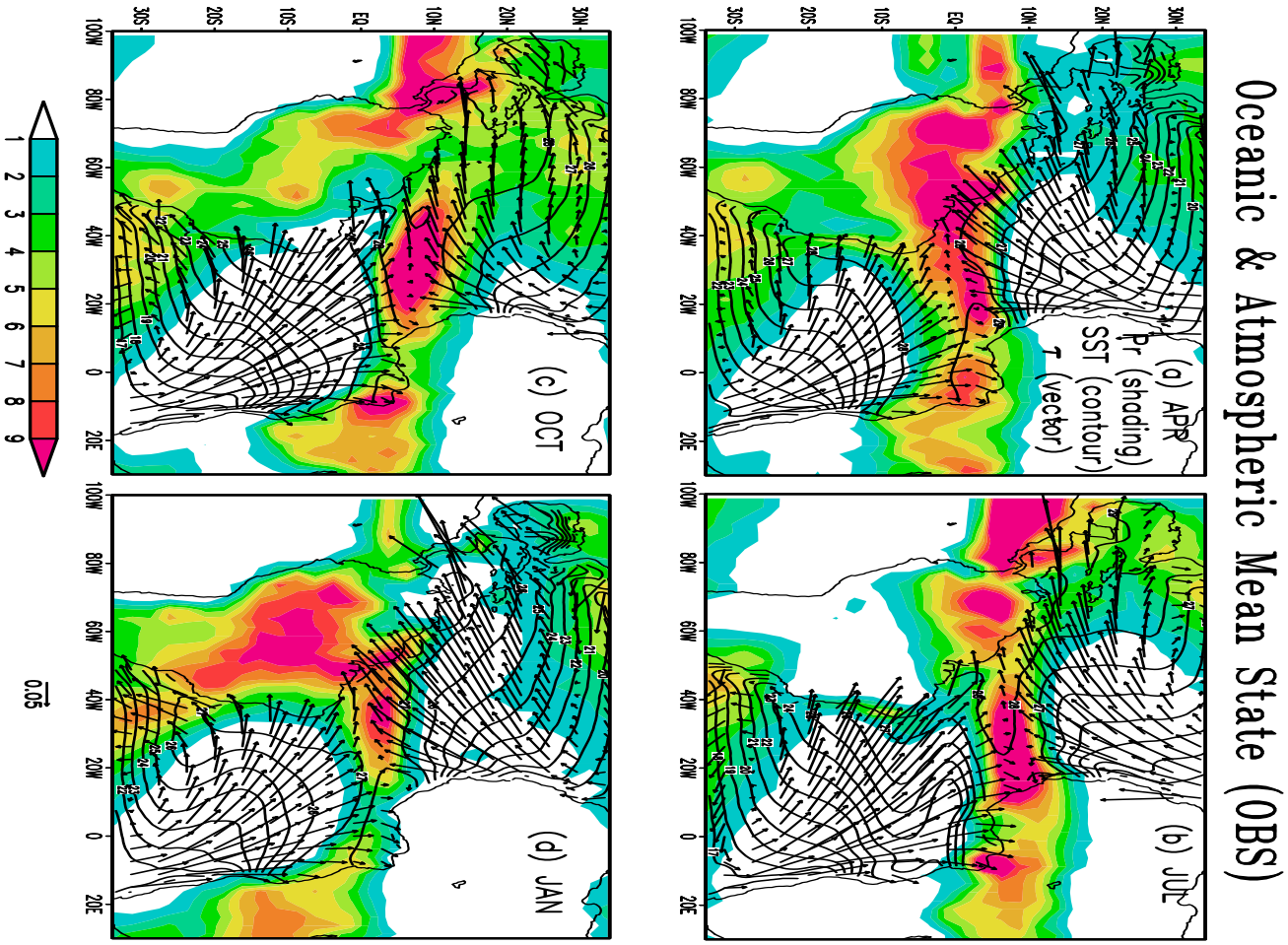
Does ENSO teleconnection play a role?





- **STA occurring in ENSO transition period, but not related to the strength of ENSO;**
- **In January case, no STA developing although ENSO is stronger than other cases;**
- Pr & SLP not predicted in the January case;
- Warm low SLP anomaly center is the key!

Annual cycle is the dominant variability in the tropical Atlantic domain



Associated with the covariation of the intertropical convergence zone (ITCZ)-cold tongue complex;

Seasonal cycle has significant climate influence.