S2D: Frontiers in Earth System Prediction
Thu. 20 Sep.

ENSO prediction using an earth system model incorporating a high-resolution tropical ocean nesting model

Eddy resolving
(~0.1 degree)

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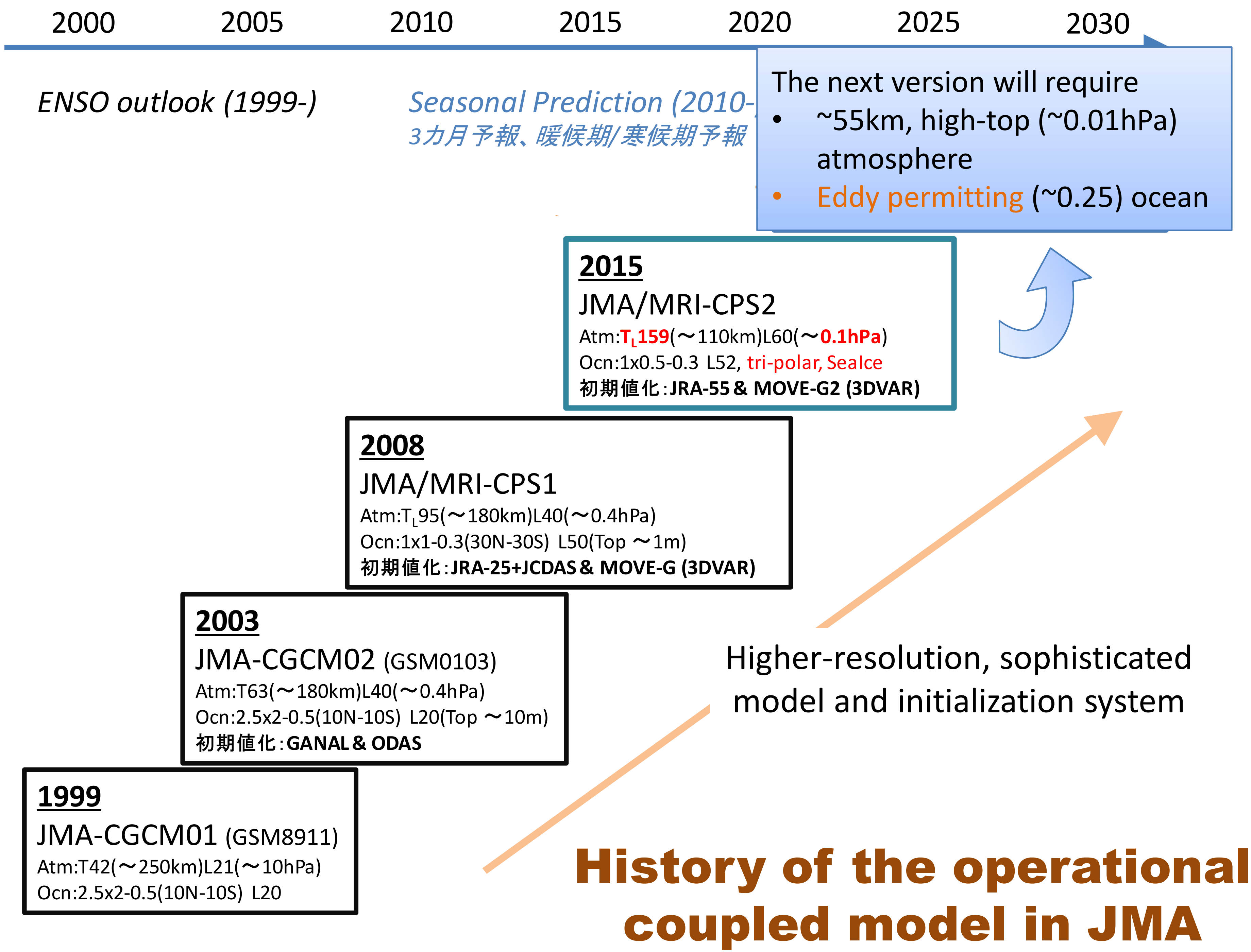
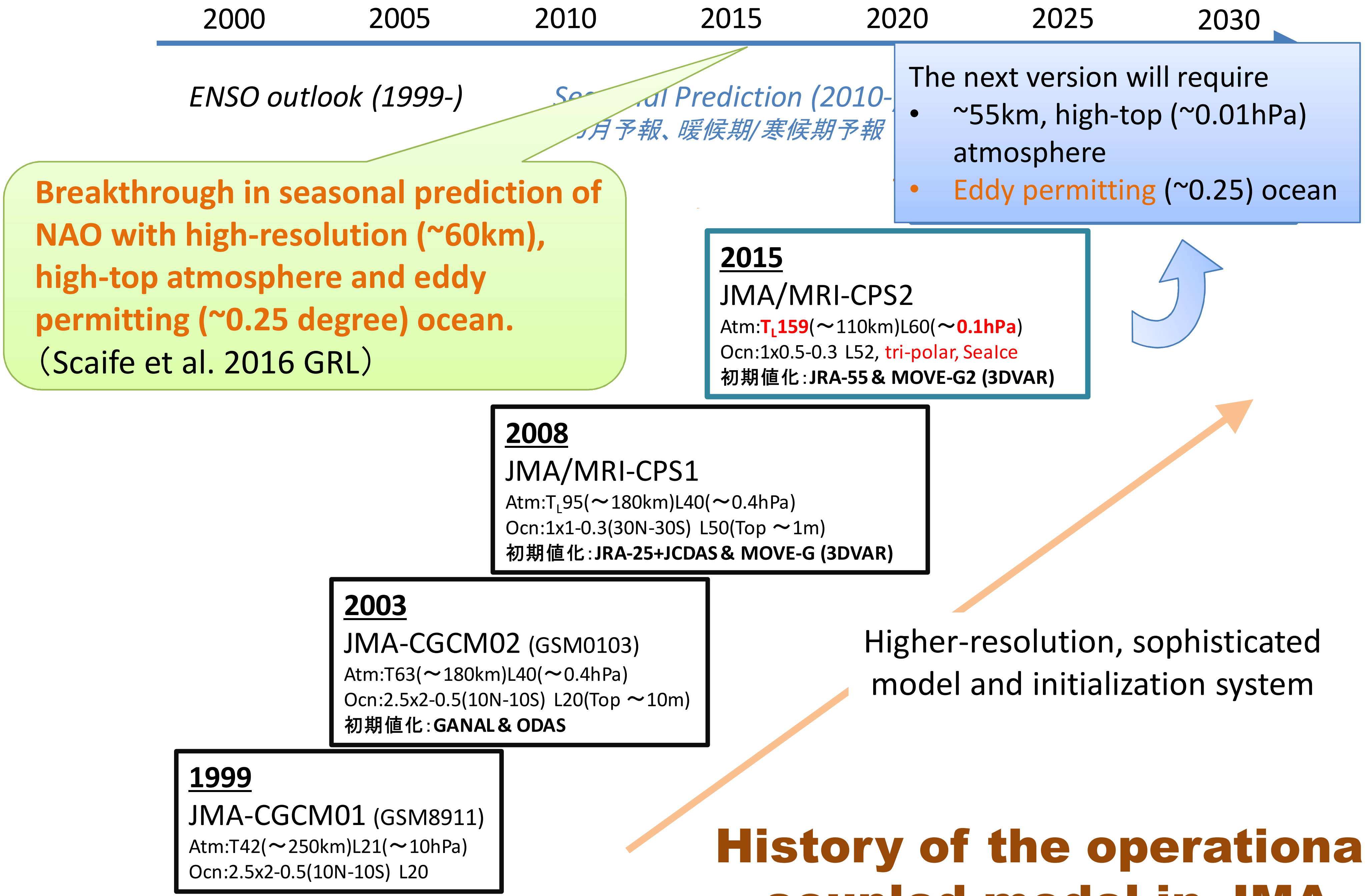
Japan Meteorological Agency


2000
2005
2010
2015
2020
2025
2030
ENSO outlook (1999-)
Seasonal Prediction (2010-)
3カ月予報、暖候期/寒候期予報
The next version will require
• ~55km, high-top (~0.01hPa) atmosphere
• Eddy permitting (~0.25) ocean
2015
JMA/MRI-CPS2
Atm:T$_L$159(〜110km)L60(〜0.1hPa)
Ocn:1x0.5-0.3 L52, tri-polar, SeaIce
初期値化:JRA-55 & MOVE-G2 (3DVAR)
2008
JMA/MRI-CPS1
Atm:T$_L$95(〜180km)L40(〜0.4hPa)
Ocn:1x1-0.3(30N-30S) L50(Top 〜1m)
初期値化:JRA-25+JCDAS & MOVE-G (3DVAR)
2003
JMA-CGCM02 (GSM0103)
Atm:T63(〜180km)L40(〜0.4hPa)
Ocn:2.5x2-0.5(10N-10S) L20(Top 〜10m)
初期値化:GANAL & ODAS
1999
JMA-CGCM01 (GSM8911)
Atm:T42(〜250km)L21(〜10hPa)
Ocn:2.5x2-0.5(10N-10S) L20
Higher-resolution, sophisticated model and initialization system
History of the operational coupled model in JMA



History of the operational coupled model in JMA

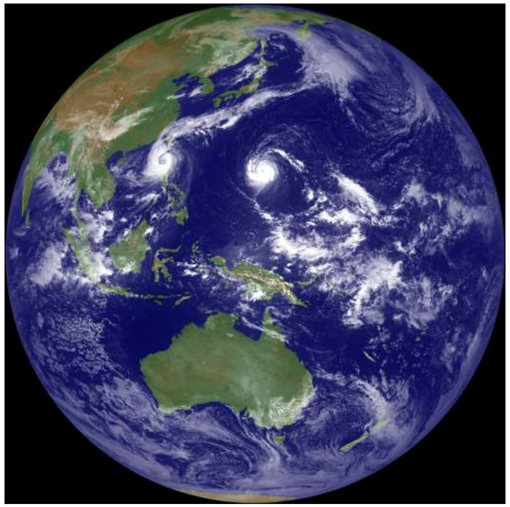
Purpose

Higher than eddy-permitting

- Can an eddy resolving (~0.1 degree) ocean model improve the skill of seasonal prediction?
- The problem is computational costs

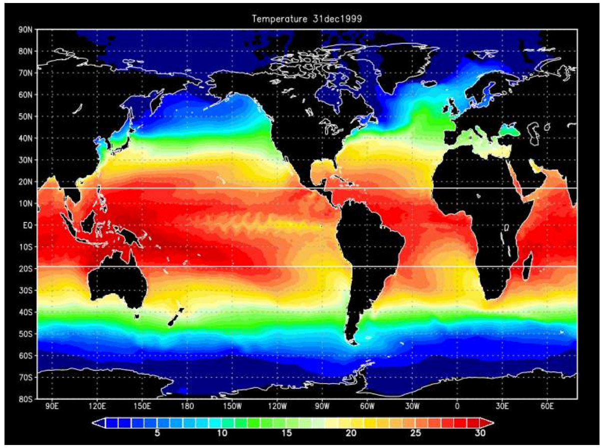
⇒ Ocean regional nesting model

Global earth system model
(TL159xL80; CMIP6 version)



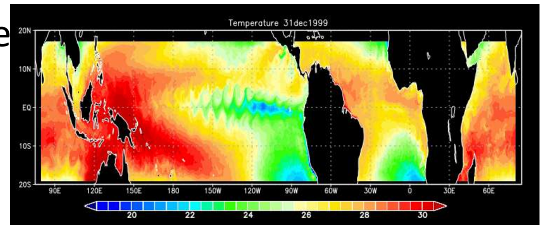
Coupling every 1hr

Global ocean model：GONDOLA_100
(1.0x0.5xL60bbl; CMIP6 version)



Every time step Interactive

Tropical Ocean model
(0.2x0.1xL60; 19°S-17°N)

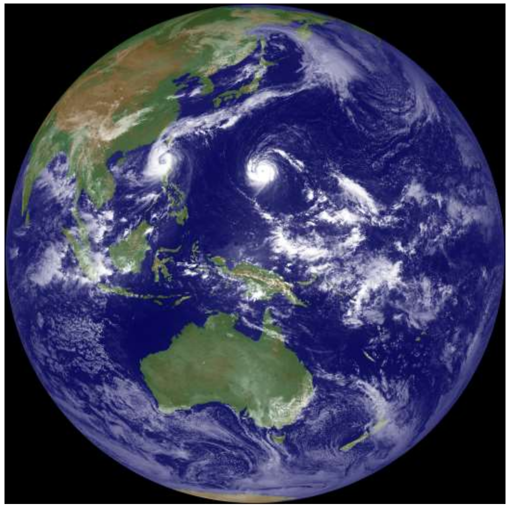


Experimental Design

- CMIP6-type historical experiment
  - All anthropogenic and natural external forcing are given
  - CTL: 1951-2010, Nesting: 1951-2010
  - Spinup: first 10 years
- Application to seasonal forecasting (CTL vs Nesting)
  - Initialization: SST nudging (MGDSST, τ=1day), 1985-2015
  - Hindcast experiments:

    Initial: 01 Jan, 1991-2015, Ensemble size: 3, 1year forecast

Global earth system model
(TL159xL80; CMIP6 version)



Coupling every 1hr

Global ocean model : GONDOLA_100
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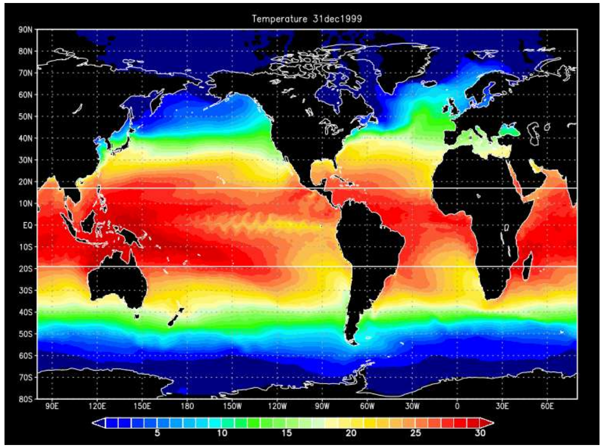

Every time step Interactive

Tropical Ocean model
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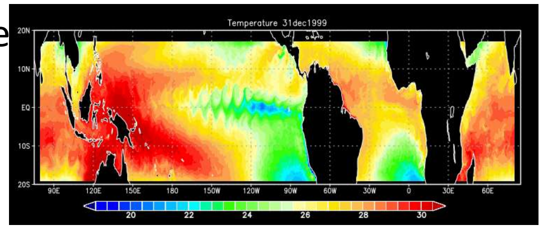


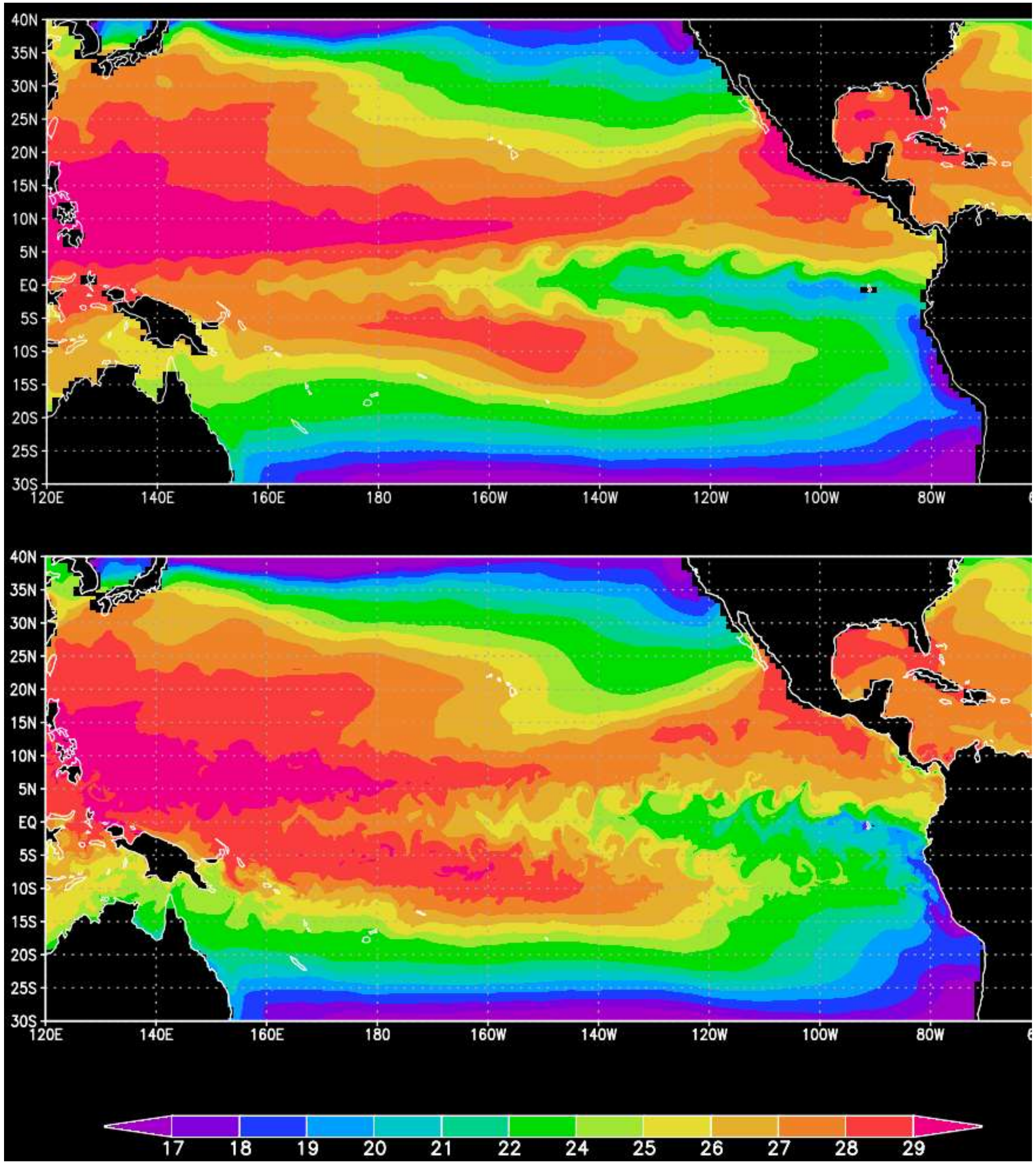
SST snapshot

CTL

1.0x0.5

Nesting

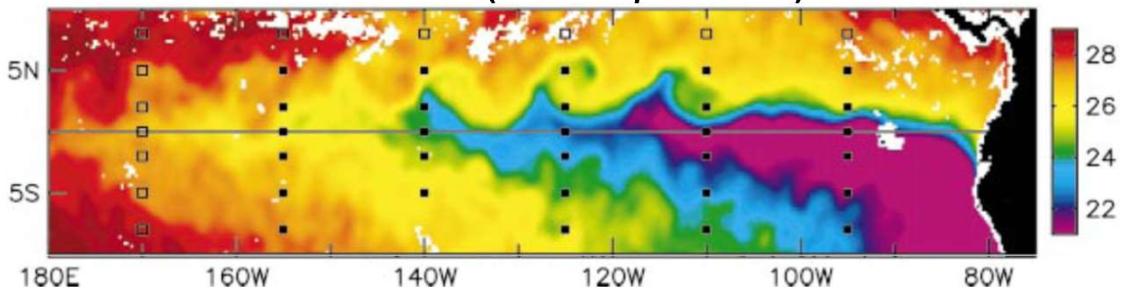
0.2x0.1xL60; 19^{o}S-17^{o}N



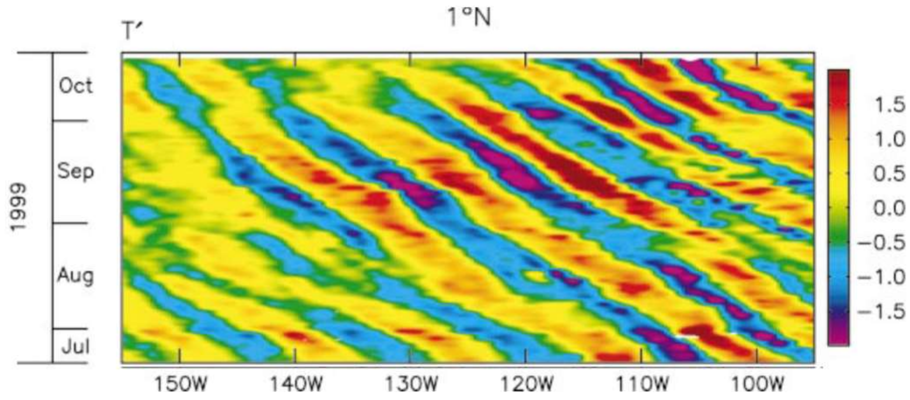
WHAT IS EXPECTED?

Tropical Instability Waves (TIWs)

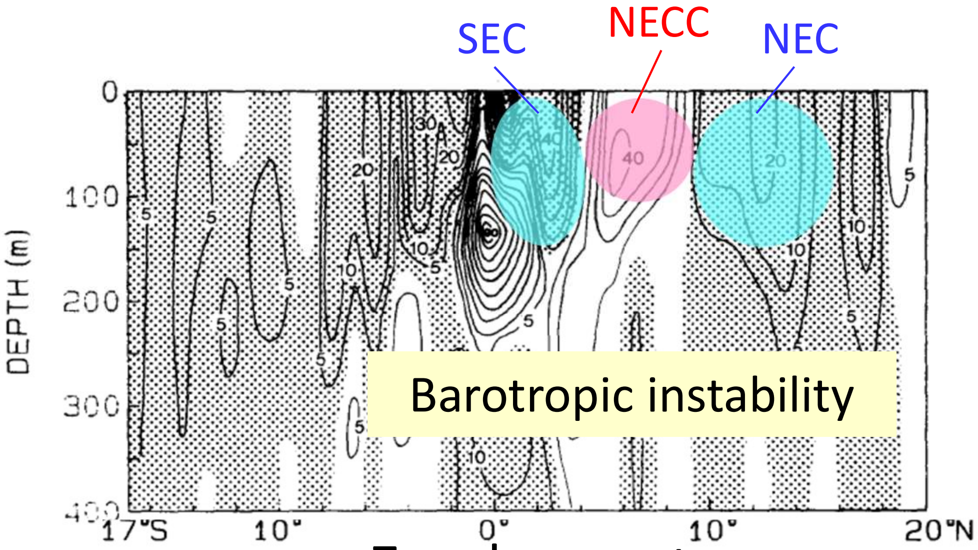
TMI SST (2-4 Sep. 1999)



- Period 20-40 days
- Wave length 1000—2000km
- Phase speed 0.4-0.6m/s westward
- Dominant during boreal summer and autumn

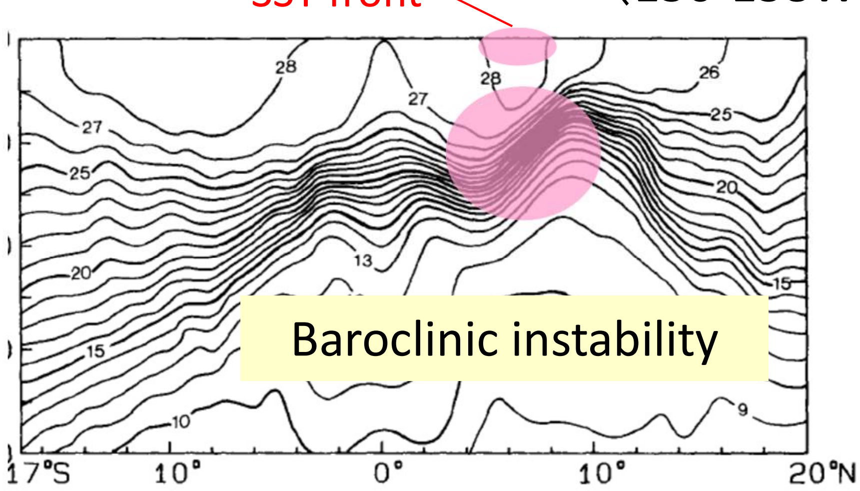


20° zonal wavelength high-pass filtering



Zonal current

(150-158W)



sea temperature

15 quasi-monthly cruises of the Hawaii-to-Tahiti Shuttle Experiment from Feb. 1979 to Jul. 1980

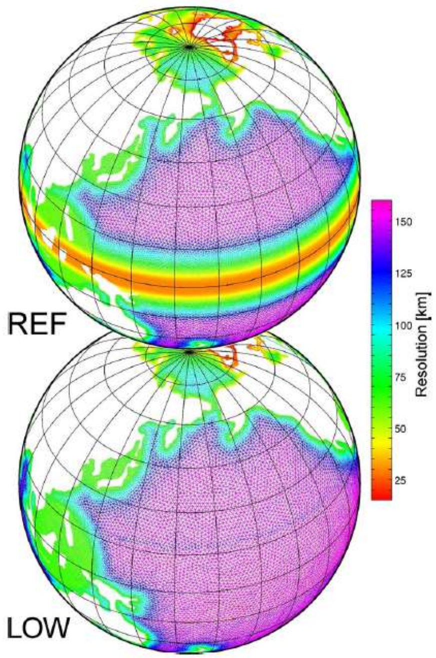
Previous Studies

- Roberts et al. 2009 (J. Climate)
  - Based on HadGEM1 resolution matrix
- Shidorenko et al. 2015, Rackow et al. 2016 (Clim. Dyn.)
  - ECHAM6-FESOM : (Atm: T63L47, top0.01hPa, Ocn: 150km～25km)
  - Comparison between default resolution and tropics-low-resolution (~1 deg) version

HadGEM1 resolution matrix

	N96: 1.5°	N144: 1.0°
1/3° ≈33 km	≈135 km Cross-resolution LoHi	≈90 km HiGEM1.1 HiHi
1°–1/3° ≈110 km	HadGEM1.1 LoLo	Cross-resolution HiLo

ECHAM6-FESOM

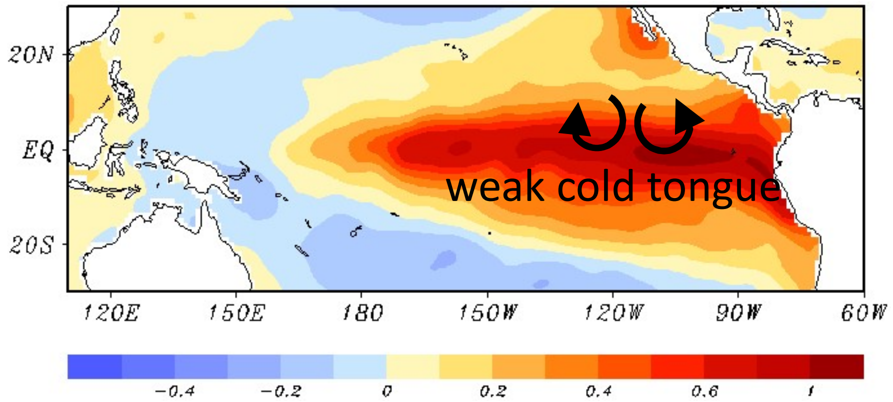


Improvement in

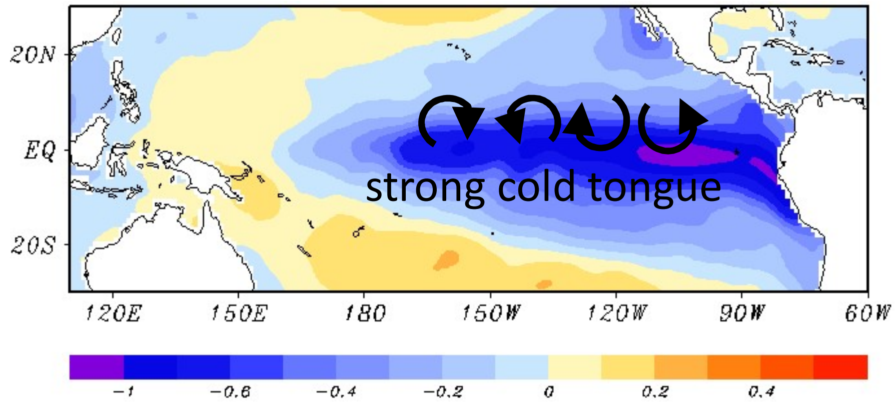
- ✓ **Eddy meridional heat flux due to TIWs -> reduce SST cold biases**
- ✓ Equatorial SST gradient
- ✓ Trade winds
- ✓ **Equatorial zonal currents**
- ✓ Thermocline structure
- ✓ **ENSO spatial distribution**
- ✓ Clearer ENSO peaks in power spectrum

Asymmetric relationship between TIWs and ENSO

El Niño



La Niña



Weakened mean SST gradient

Inactive TIWs

Weak El Niño damping

Enhanced mean SST gradient

Active TIWs

Strong La Niña damping

Induce ENSO skewness

An (2008, *J. Clim.*)
Imada et al. (2012, J. Clim)

Impacts of TIWs on ENSO skewness

- Imada and Kimoto (2012) J. Climate
  - Parameterization of eddy heat transport incorporated to the low-resolution CGCM MIROC3.

Skewness

$$\sqrt{b} = \frac{m_3}{m_2^{3/2}}$$

$$m_k = \overline{(x - \overline{x})^k}$$

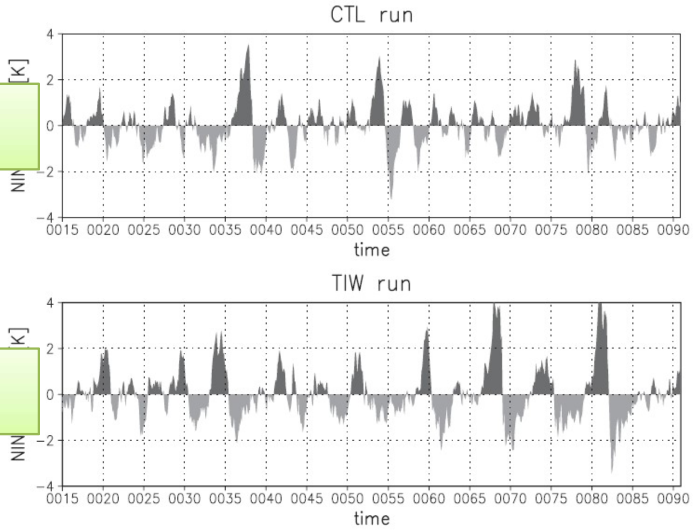
OBS（1950-97）

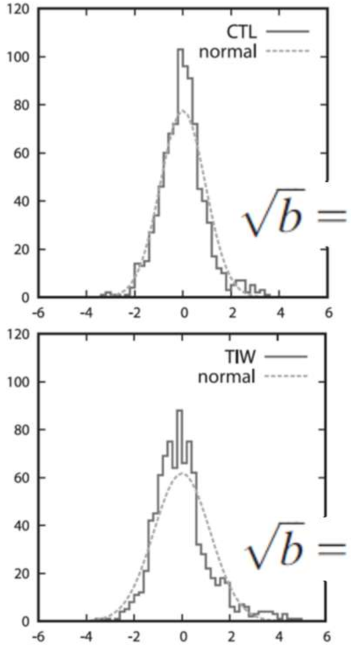
$$\sqrt{b} = 0.89$$

CTL

NINO3

TIW run

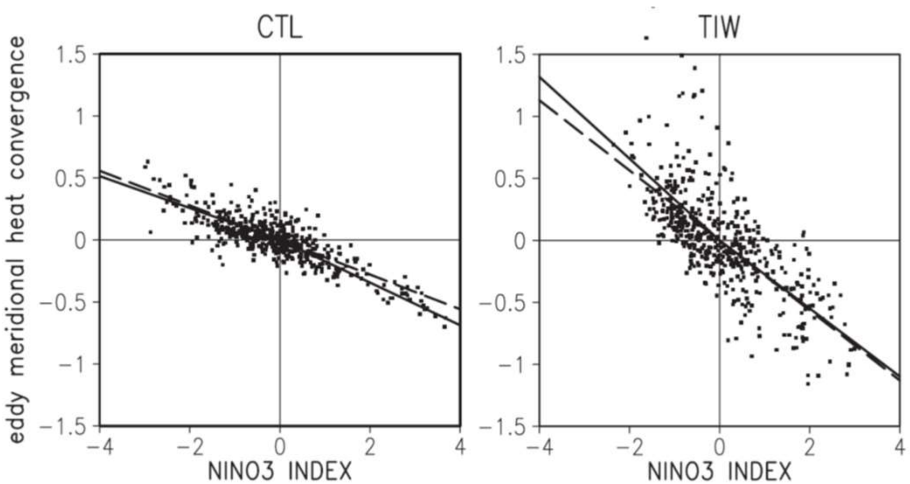


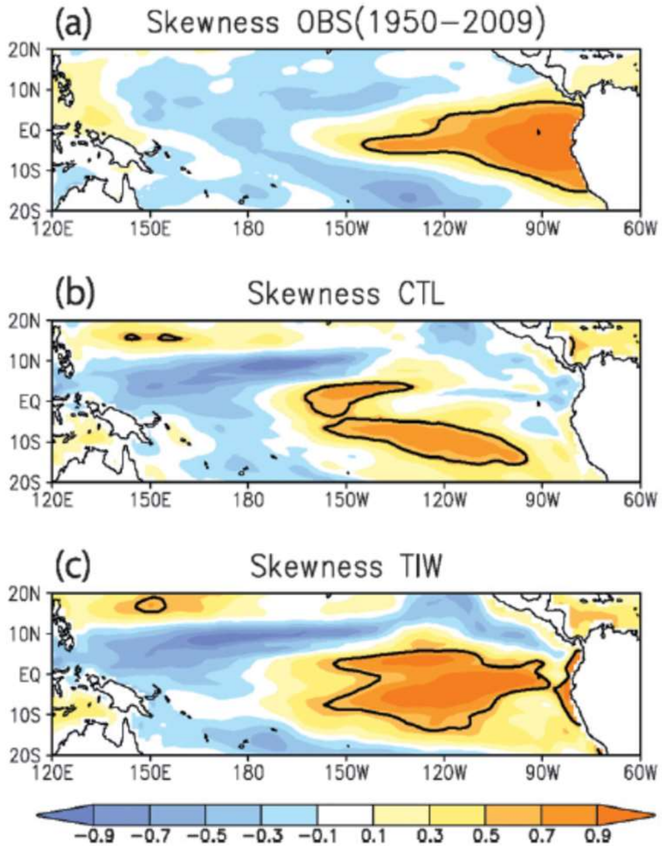


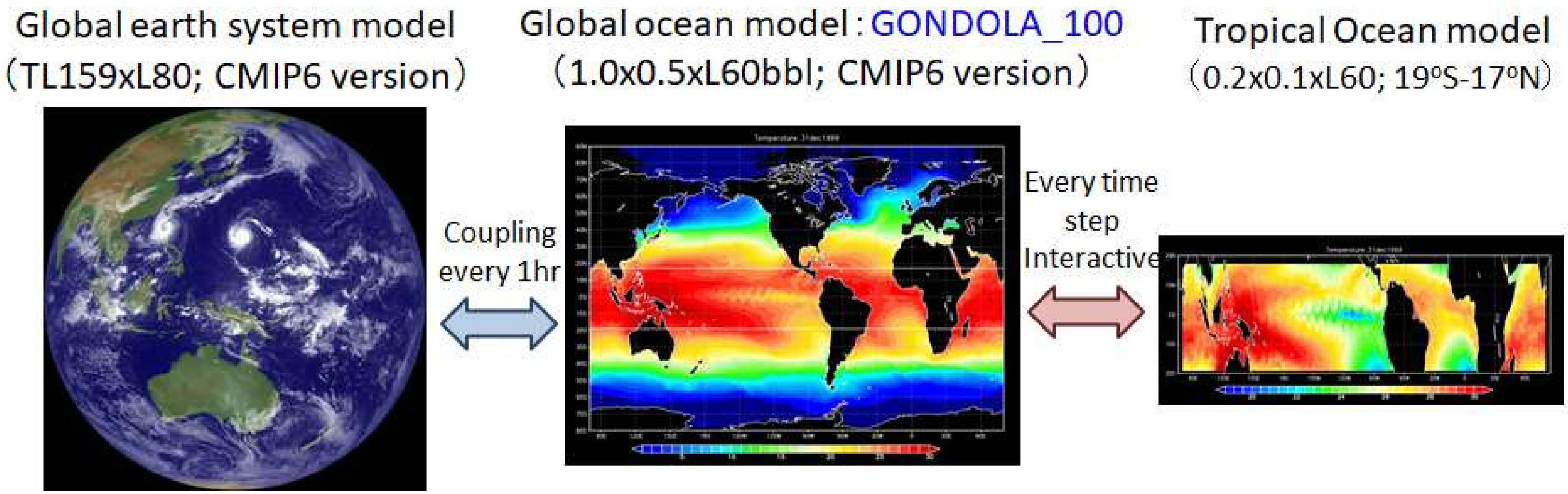
$$\sqrt{b} = 0.34$$

$$\sqrt{b} = 0.95$$

Nonlinear Dynamical Heating (NDH)



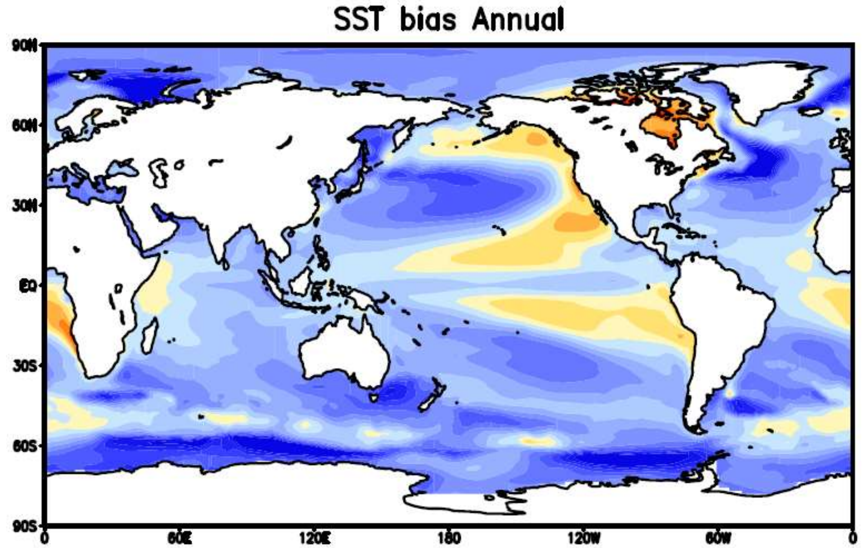




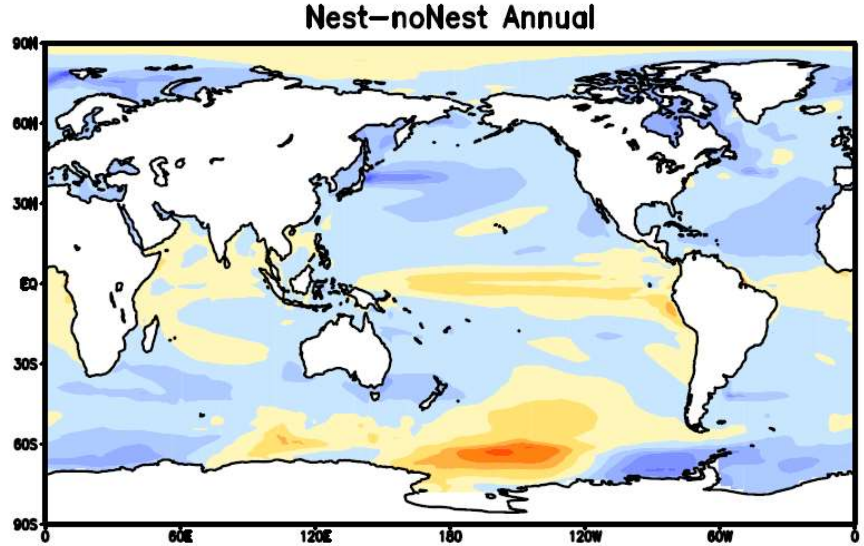
IMPACTS ON ENSO REPRESENTATION

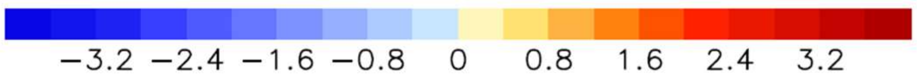
Impacts on ocean climatology

Original SST bias

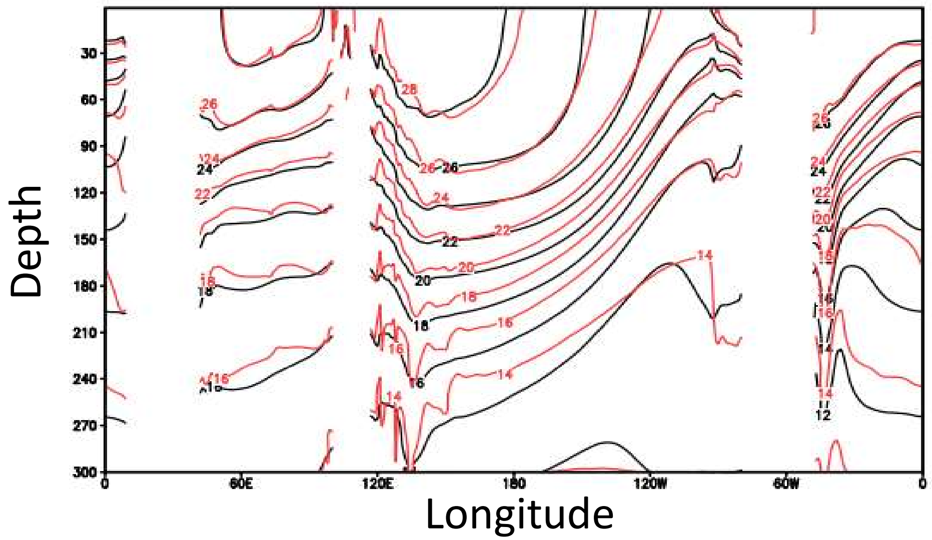


SST Nesting minus CTL

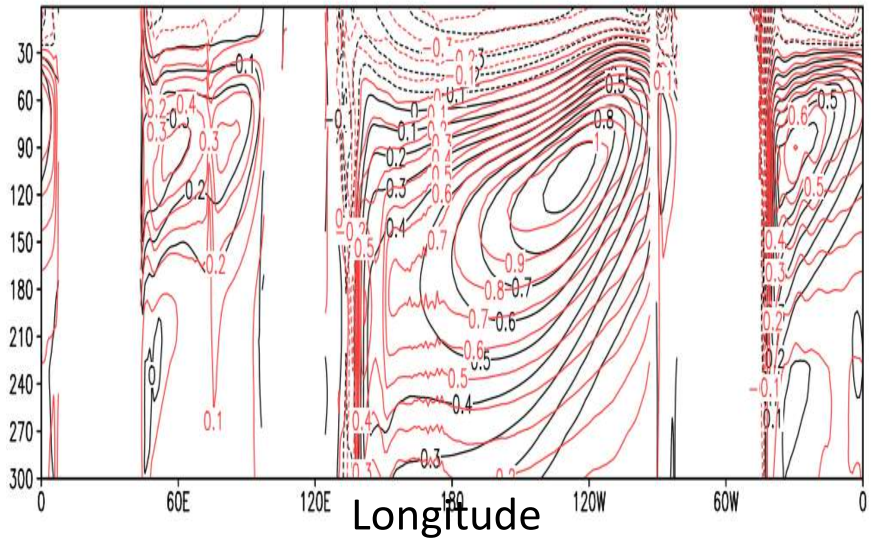




Ocean temperature @EQ



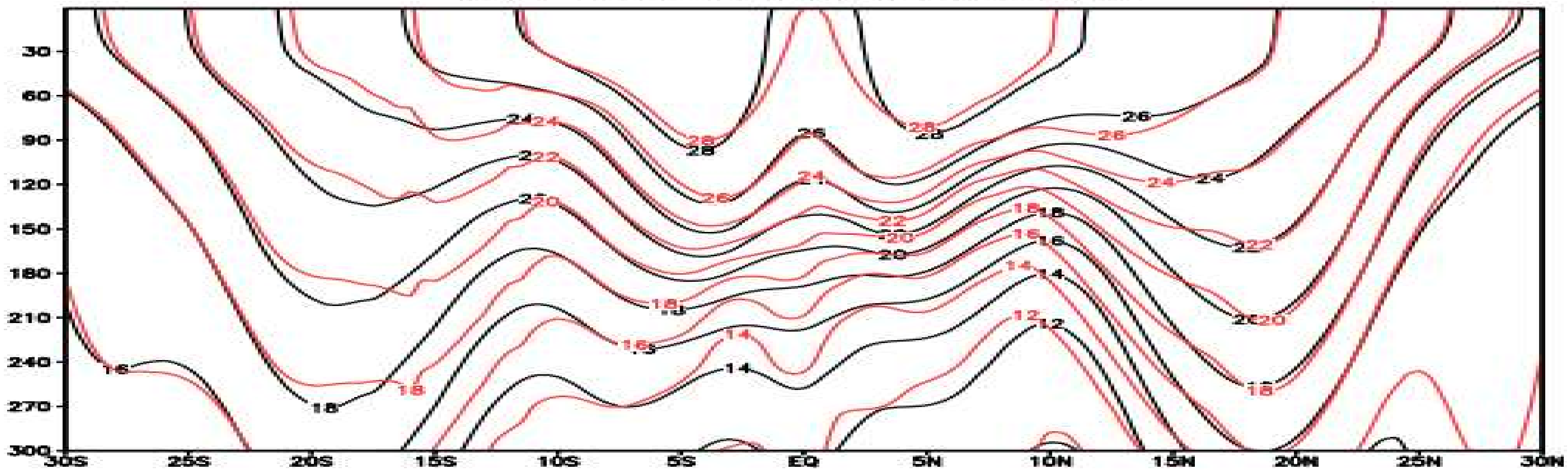
Zonal velocity @EQ



CTL
Nest

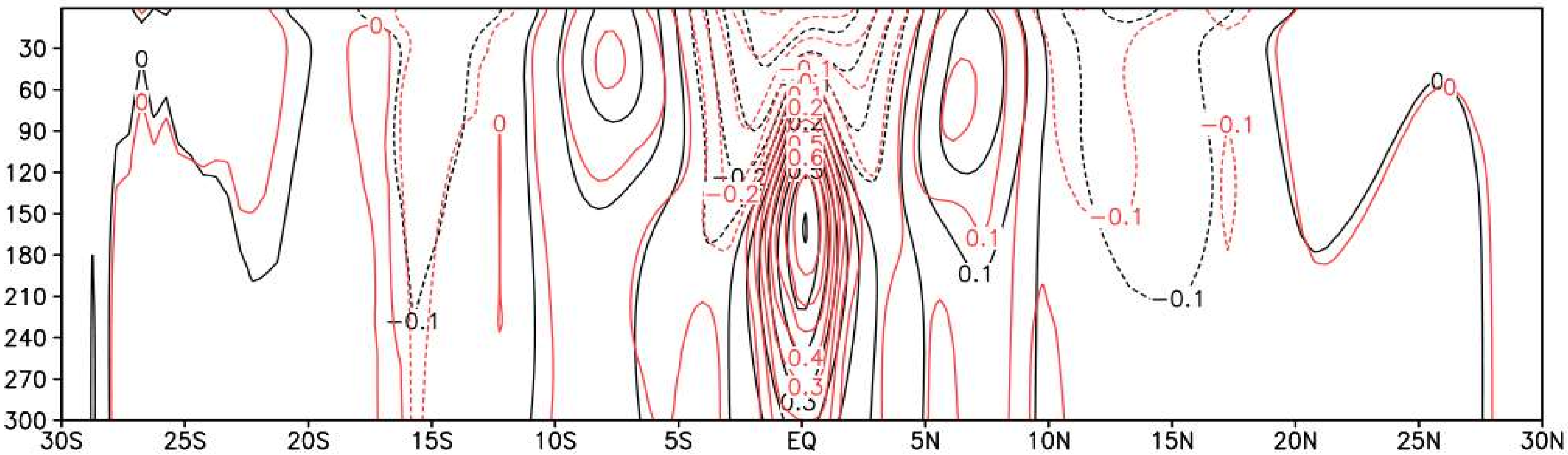
Impacts on ocean climatology

Ocean temperature @dateline



CTL
Nest

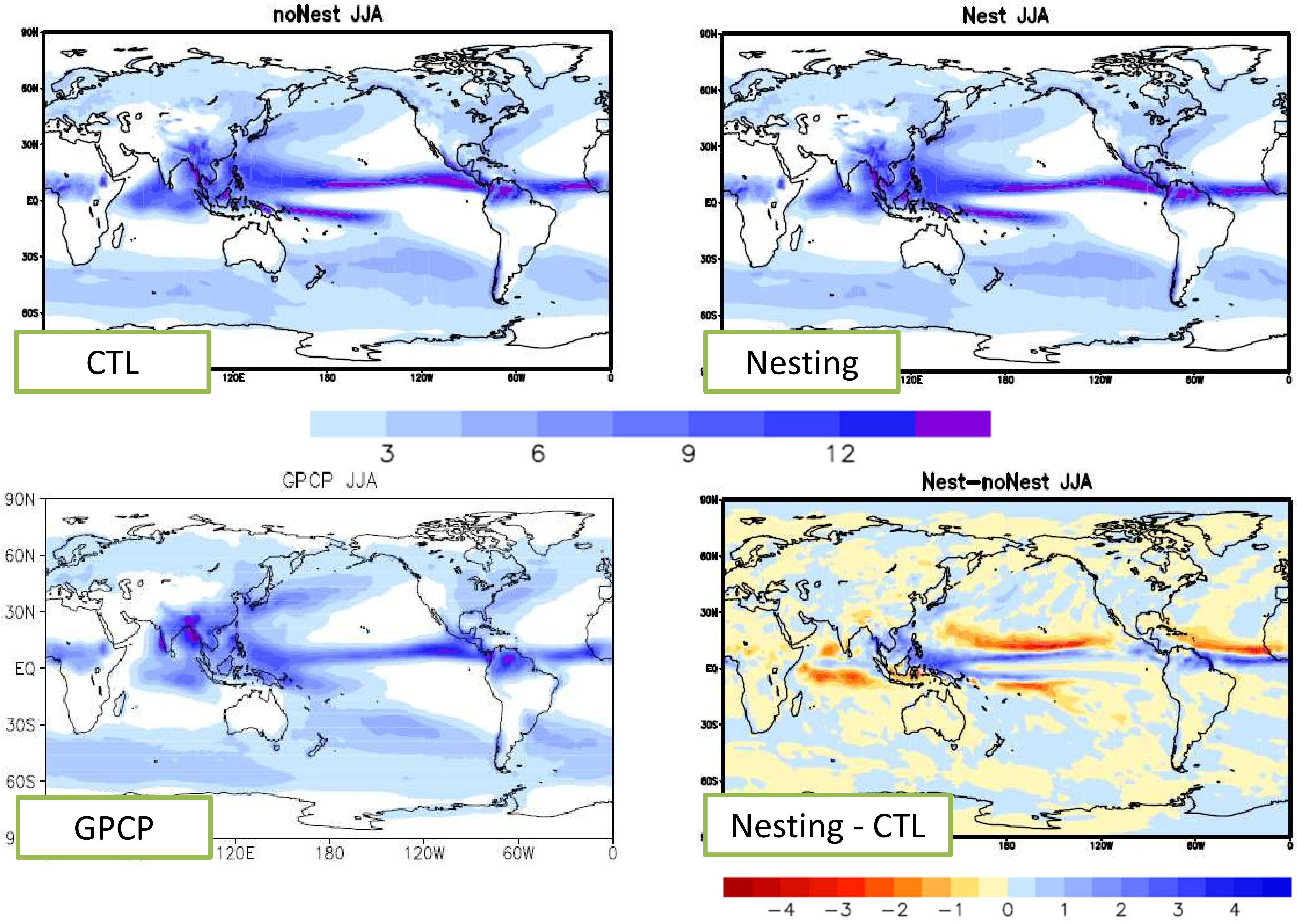
Zonal velocity @dateline



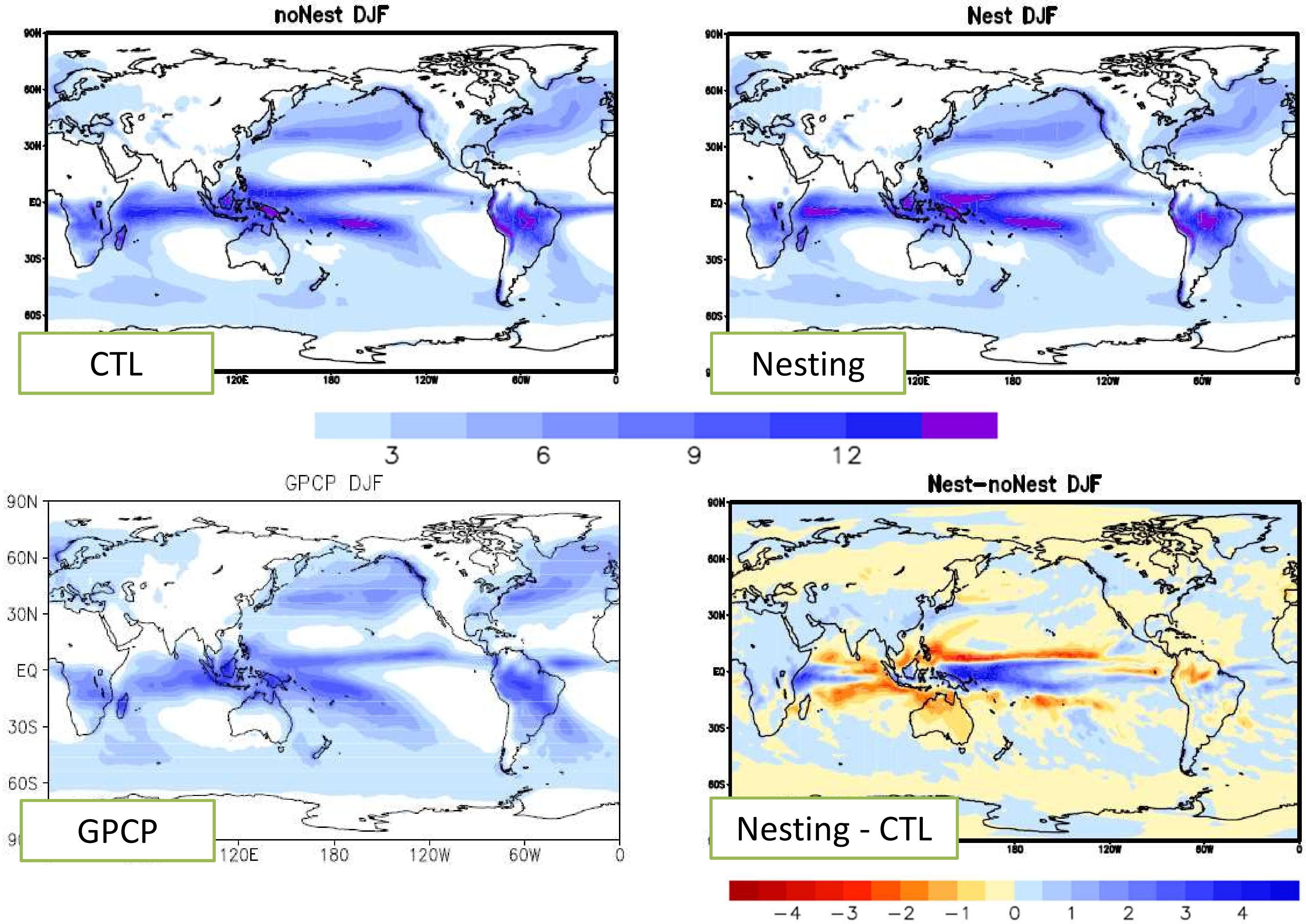
30S EQ 30N

Results from historical runs

Impacts on seasonal precipitation（JJA）

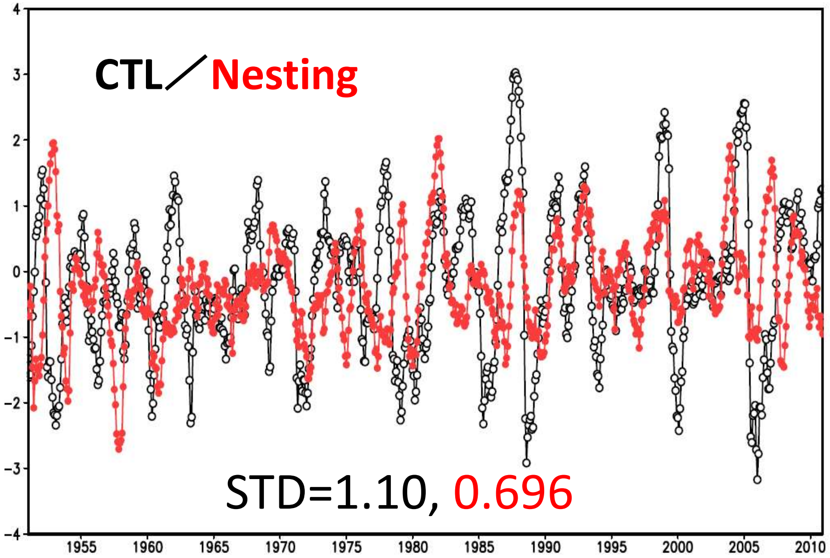


Impacts on seasonal precipitation（DJF）

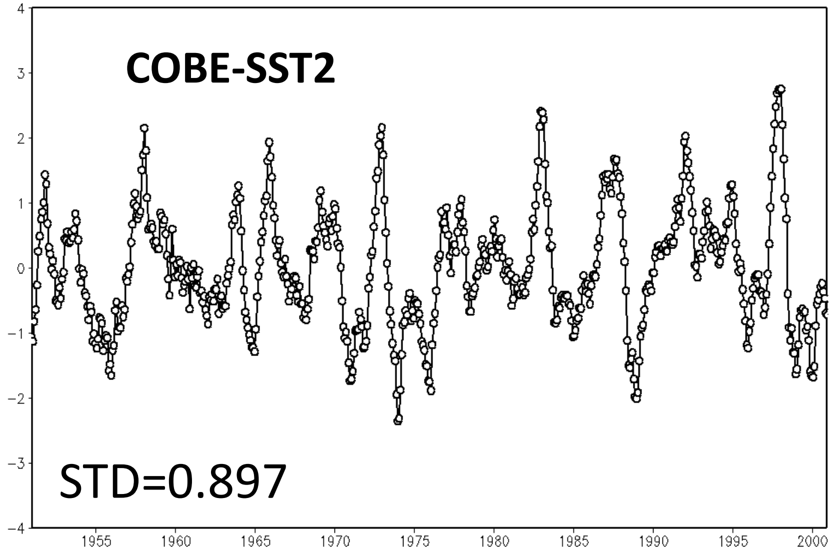


Results from historical runs

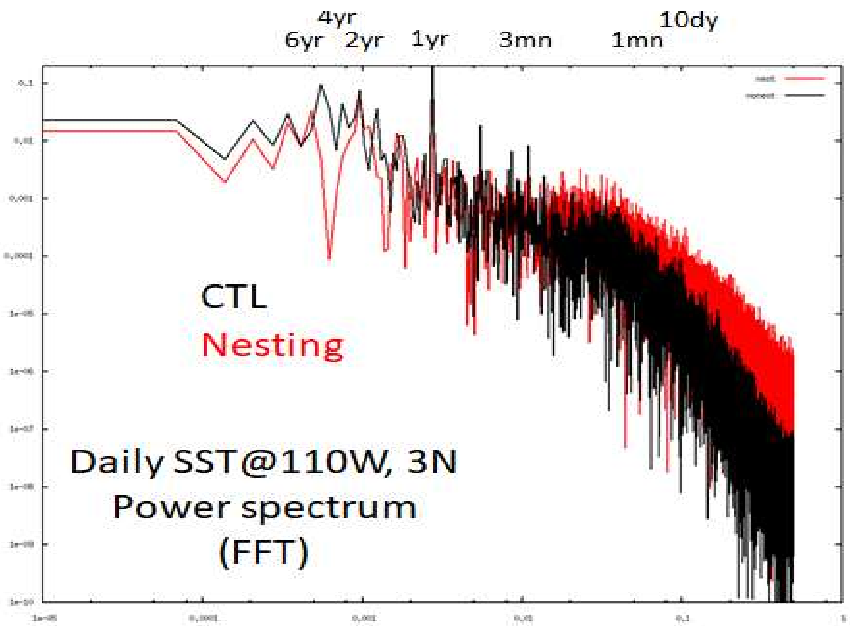
Impacts on ENSO characteristics



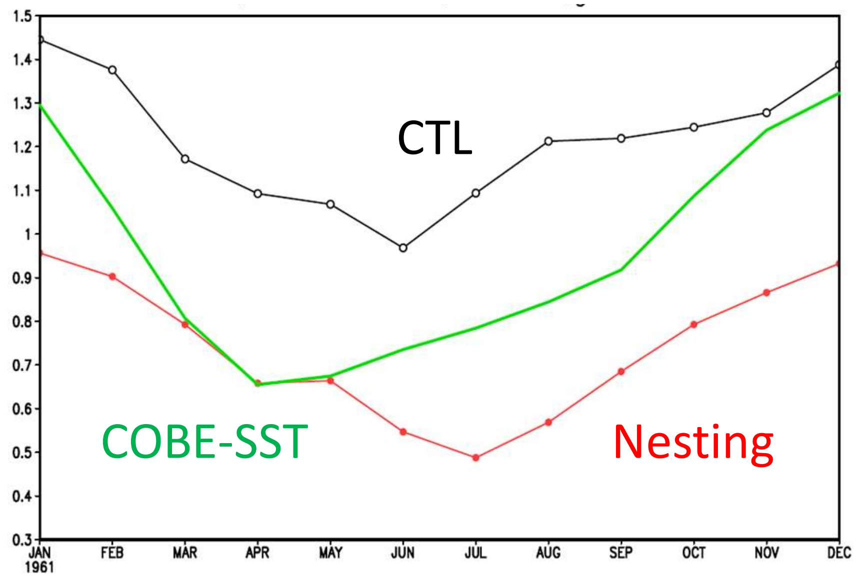
NINO3.4
※1961-2010



Power Spectrum for SST daily index at TIW active point



NINO3.4 seasonal phase lock
(monthly standard deviation)

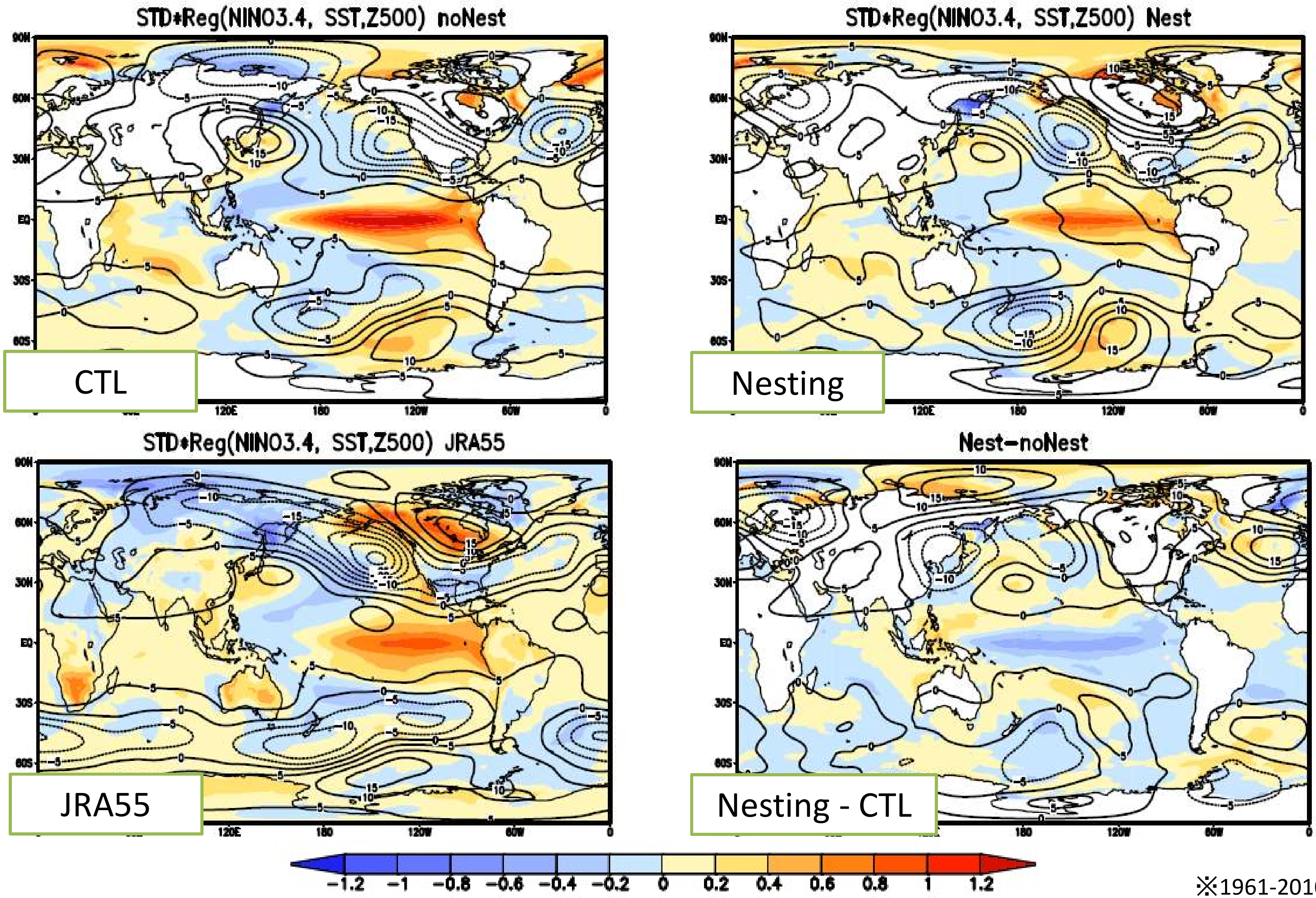


※1981-2010

Results from historical runs

ENSO teleconnection

SST and Z500 regressed onto NINO34 (DJF)



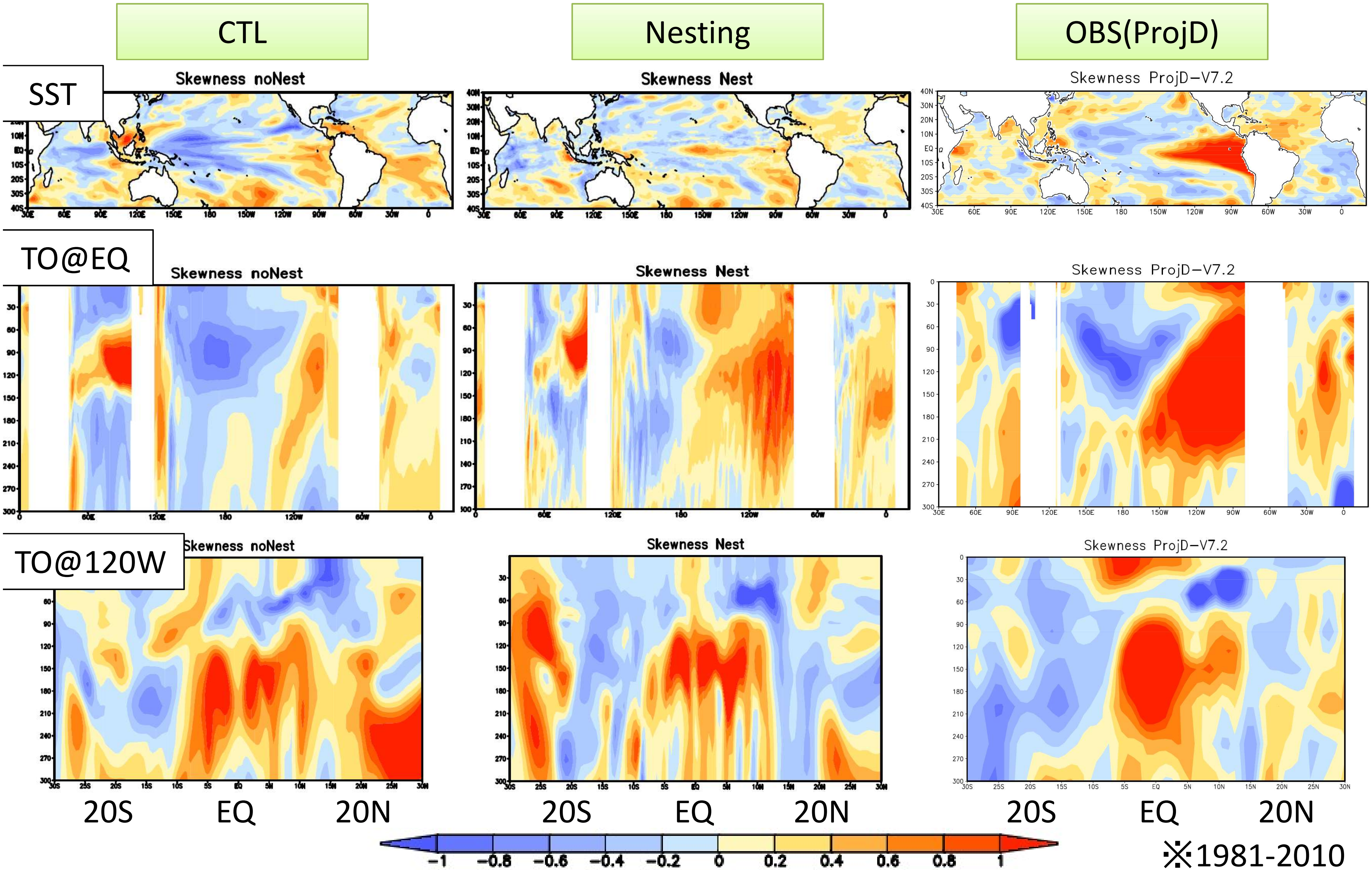
※1961-2010

Results from historical runs

Impact on ENSO skewness

Skewness: $\sqrt{b} = \frac{m_3}{m_2^{3/2}}$

$m_k = \overline{(x - \bar{x})^k}$

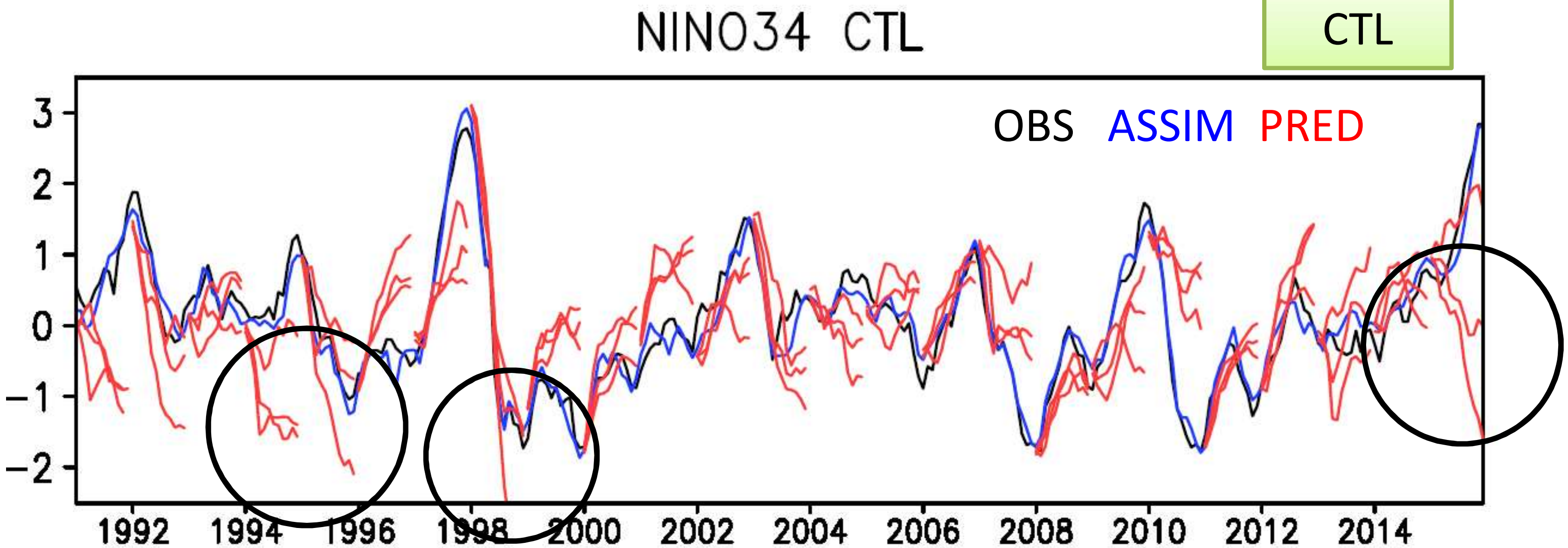


※1981-2010

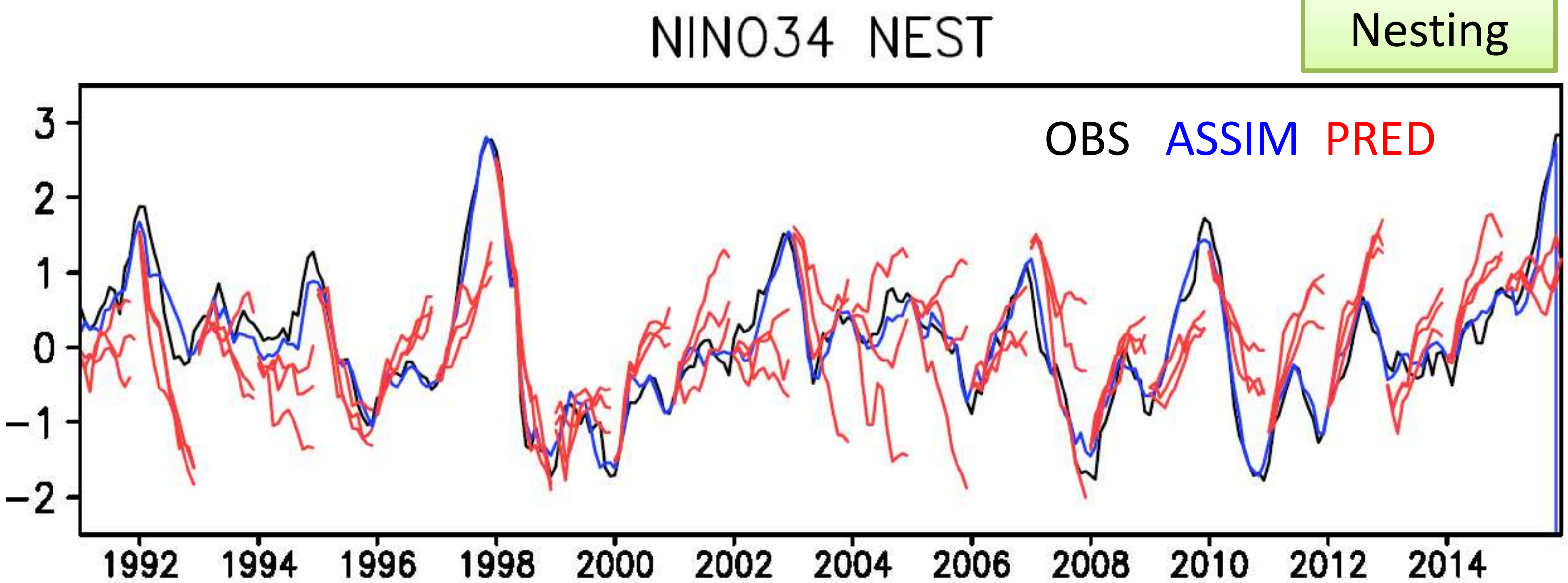
Results from Hindcasts

NINO3.4 hindcast

CTL

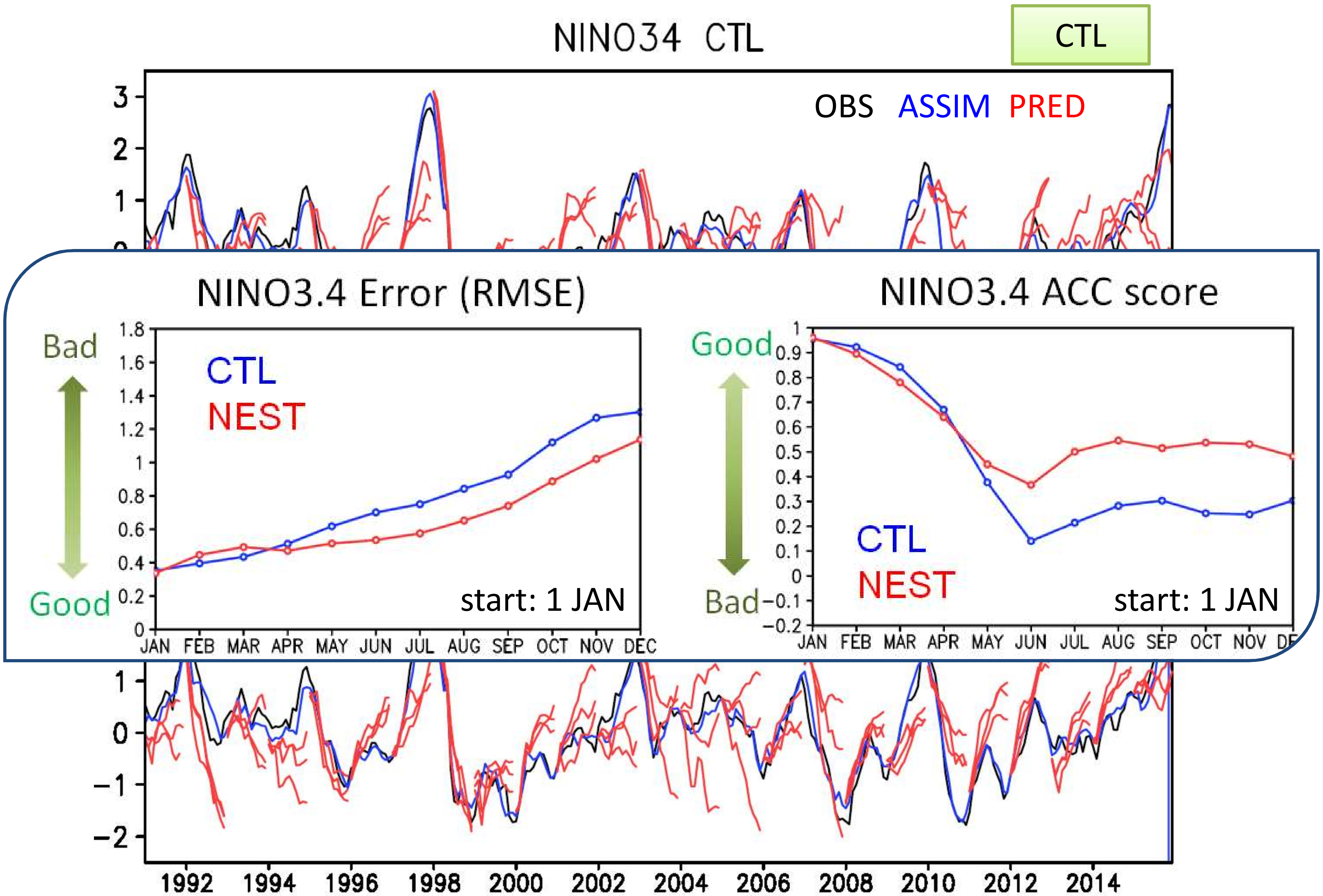


Nesting



Results from Hindcasts

NINO3.4 hindcast



Summary

- For the future JMA operational seasonal prediction system, we assessed the impacts of high-resolution (eddy-resolving) tropical ocean nesting, and found that:
  - TIWs were reasonably simulated.
  - SST cold biases in the tropical Pacific ocean/underestimation of zonal equatorial currents were reduced.
  - Double ITCZ bias was reduced.
  - ENSO anomaly patterns and associated teleconnection patterns were improved.
  - ENSO skewness was improved in the subsurface Pacific Ocean.
- The seasonal prediction skill improved after the spring season. One possible reason is the improved representation of ENSO asymmetricity.

Thank you for your kind attention

Your comments are welcome!

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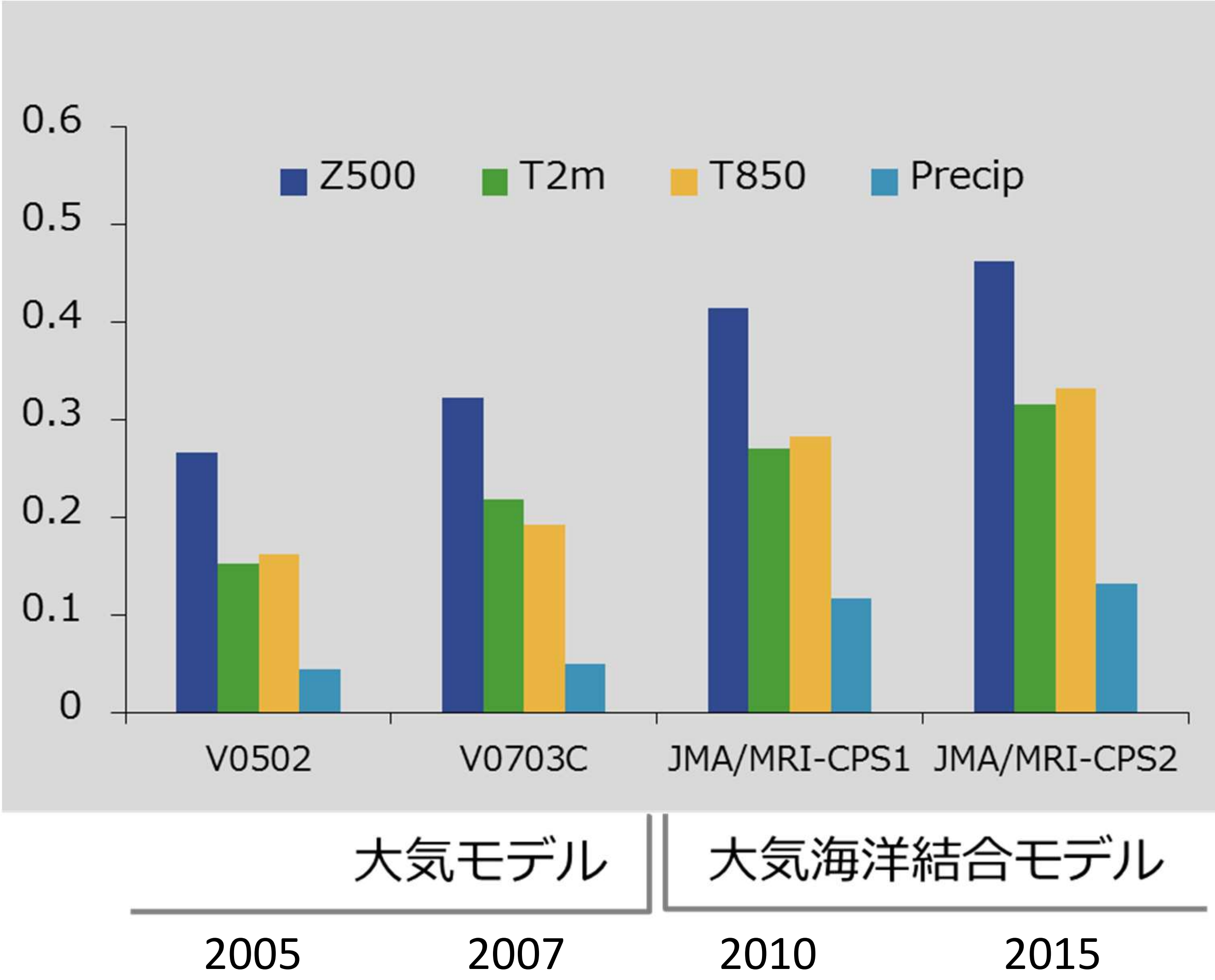
BACKUP

History of operational seasonal prediction in JMA

3か月予測のアノマリー相関係数

夏季（6～8月）全球平均｜2月初期値

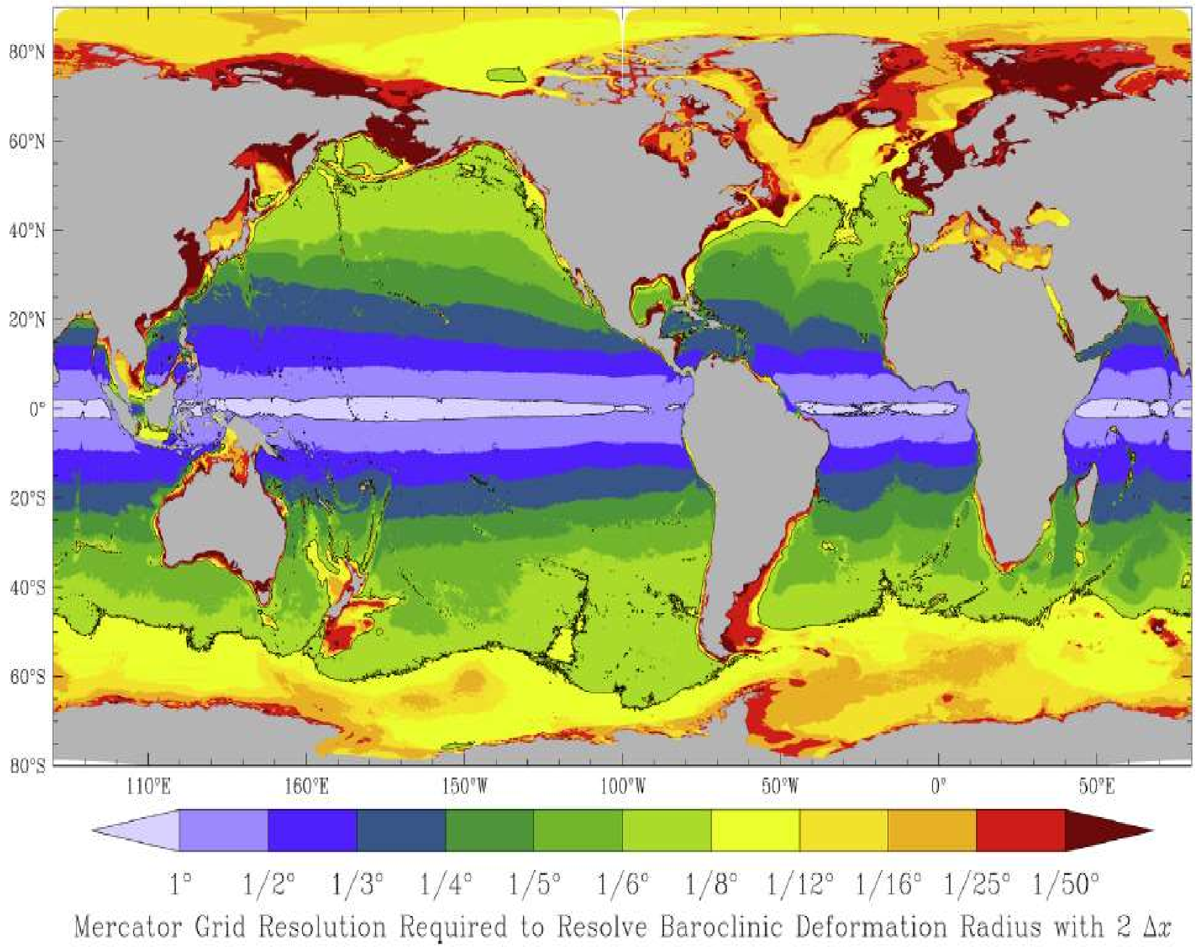
1984～2004年の20年間の予測実験により比較



Courtesy of 気象研山中さん

Eddy-resolving model

- 格子サイズ(Δ)が傾圧ロスビー変形半径(R)を解像可： 2Δ<R
- $R = \sqrt{c_g{}^2/(f^2 + 2\beta c_g)}$：緯度・成層・水深に依存
- Rを解像するには熱帯域でΔ～100km、高緯度沿岸域でΔ～2km以下が必要



- 0.25°モデル：
  南北30度より赤道側でRを解像
- 0.1°モデル：
  南北50度より赤道側でRを解像

Hallberg (2013)

Previous Studies

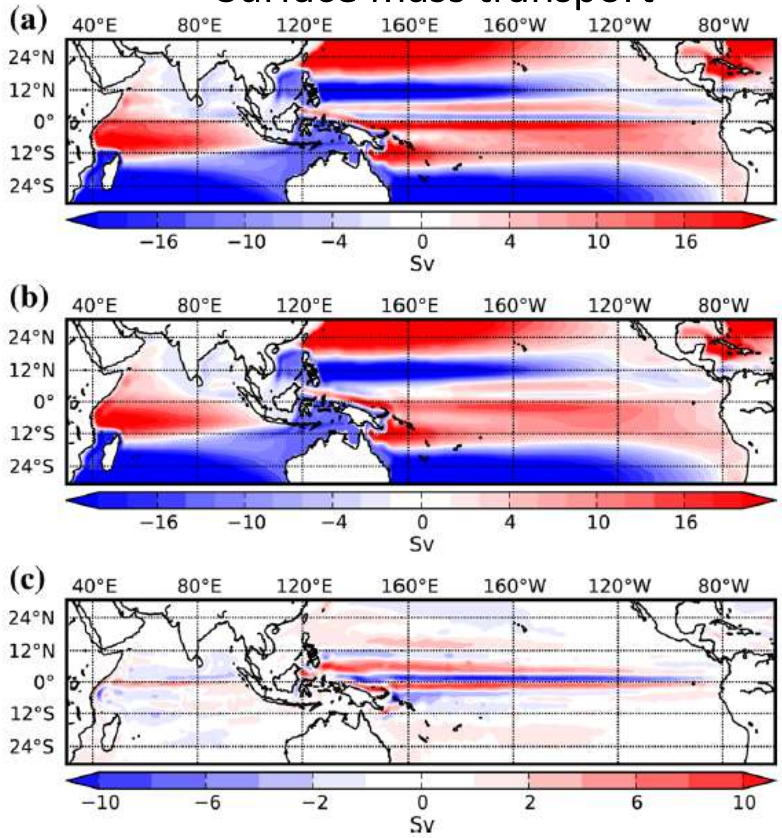
- Shidorenko et al. 2015, Rackow et al. 2016 (Clim. Dyn.)
  - ECHAM6-FESOM：
    - 大気T63L47(top0.01hPa)、海洋150km～25km
  - デフォルトモデルREFを、熱帯低解像度(～1度)版LOWと比較

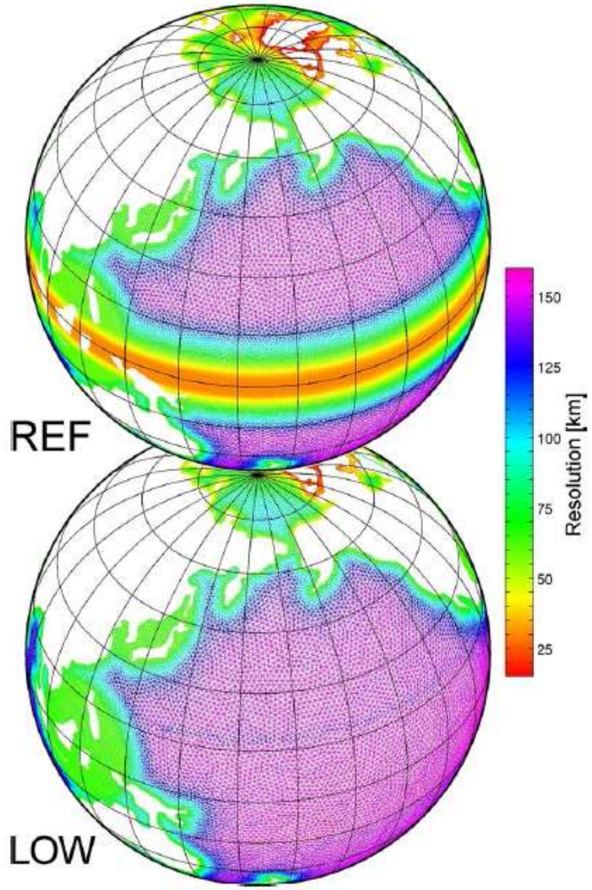
Surface mass transport

REF

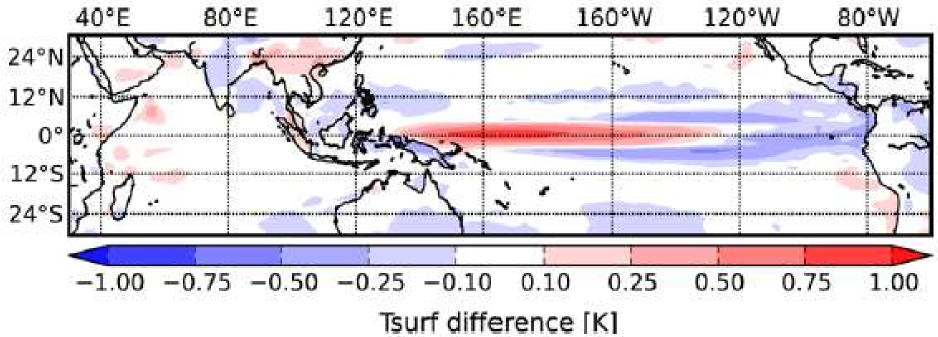
LOW

REF minus LOW





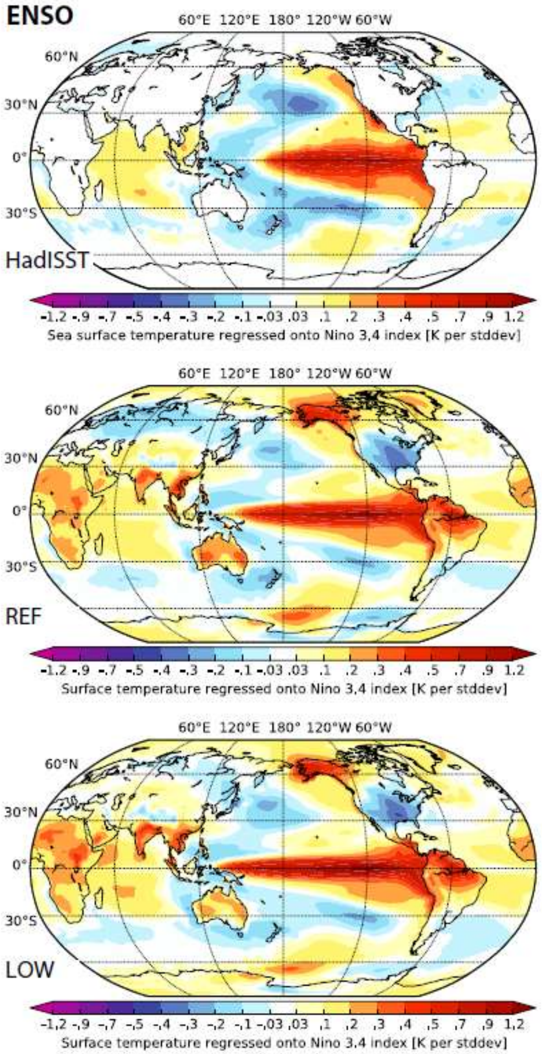
SST REF minus LOW



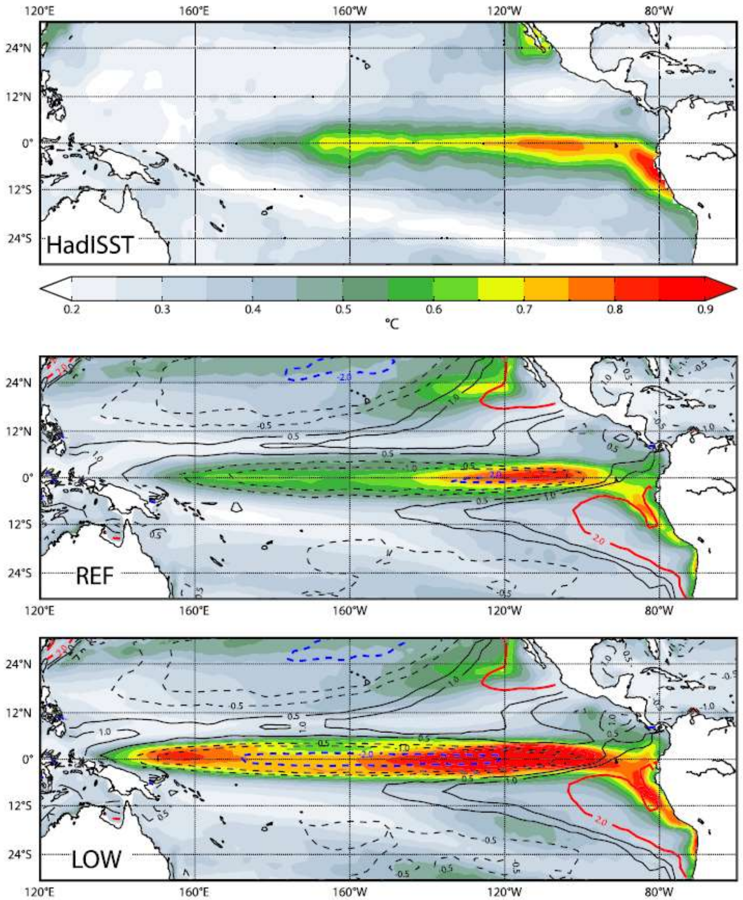
Previous Studies

- Shidorenko et al. 2015, Rackow et al. 2016 (Clim. Dyn.)
  - ECHAM6-FESOM：REFとLOWの比較

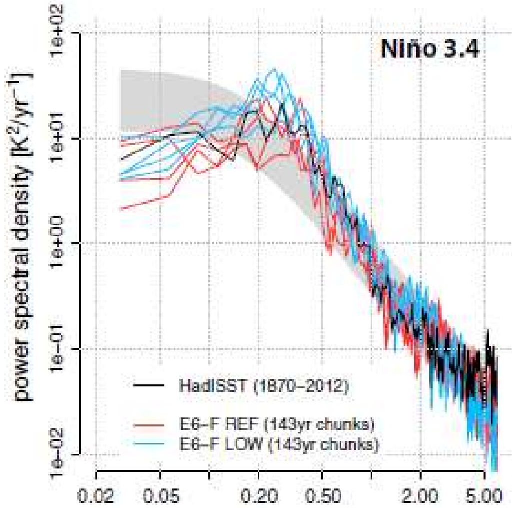
Reg(NINO3.4, SST)



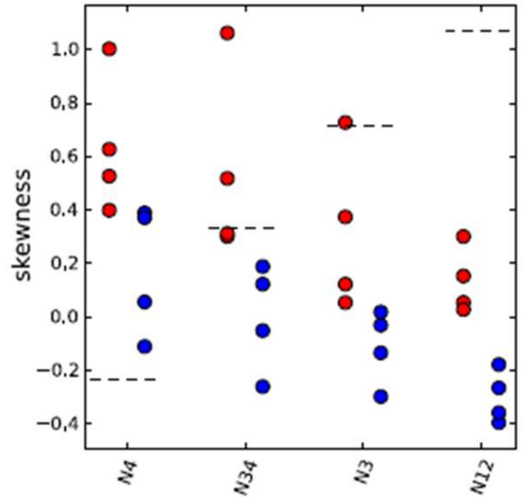
SSTバイアス（線）と標準偏差（色）



NINO3.4 Power Spectrum



NINO3.4 Skewness



Previous Studies

- Roberts et al. 2009 (J. Climate) -HadGEM1 resolution matrix

TABLE 1. UJCC model matrix showing resolutions of atmosphere (columns) and ocean (rows) models.

	N96: 1.5°	N144: 1.0°
	≈135 km	≈90 km
1/3° ≈33 km	Cross-resolution LoHi	HiGEM1.1 HiHi
1°−1/3° ≈110 km	HadGEM1.1 LoLo	Cross-resolution HiLo

海水温とTIW活動度

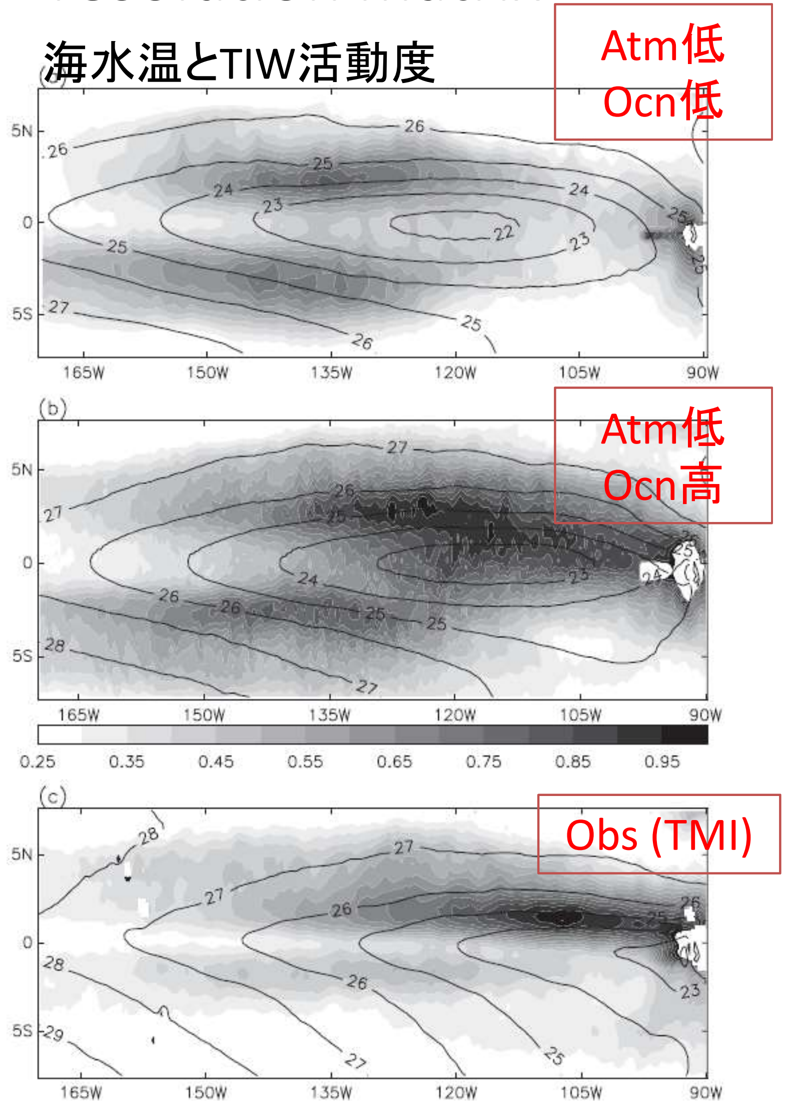
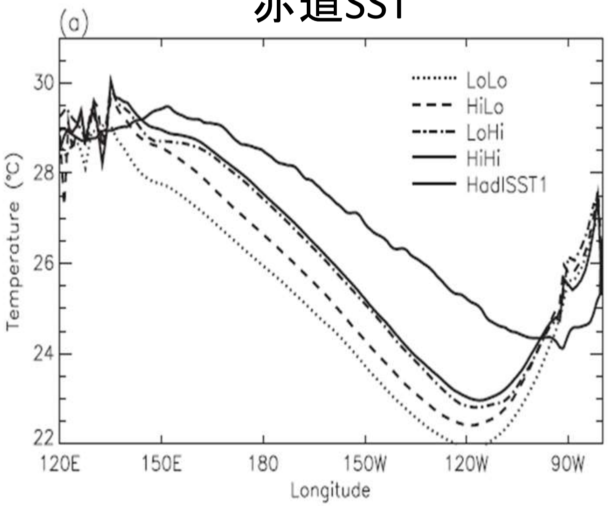
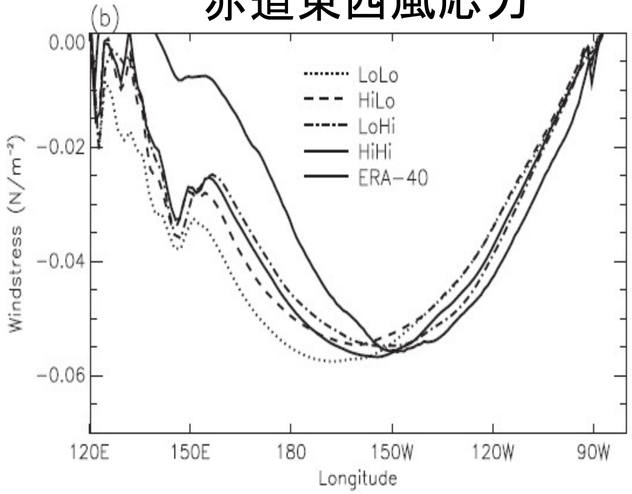


FIG. 6. Mean SST (contours) and std dev of zonally filtered 5-day SST for (a) LoLo and (b) LoHi, years 40–50. (c) Mean SST and std dev of zonally filtered daily SST from TMI (1999–2002), combined with TMI AMRS-E (2003–05)-observed SST.

赤道SST



赤道東西風応力



Previous Studies

- <u>Roberts et al. 2009 (J. Climate)</u> -HadGEM1 resolution matrix

海水温（赤道）

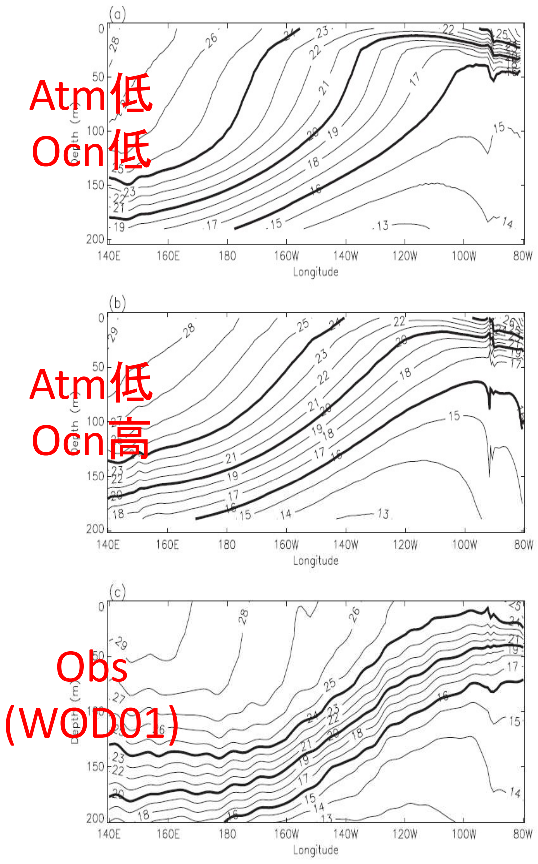


FIG. 3. Temperature cross section at the equator for the (a) LoLo, (b) LoHi, and (c) WOD01 climatology. Model mean years 30–50.

海水温（130W）

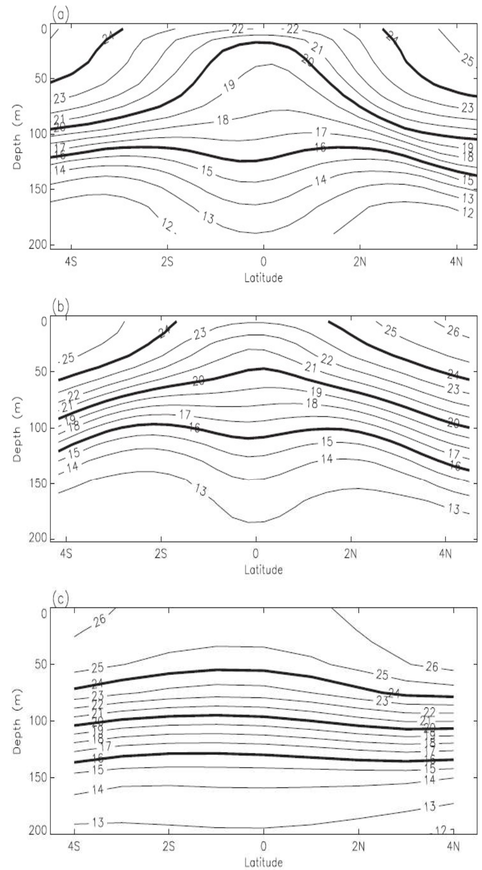
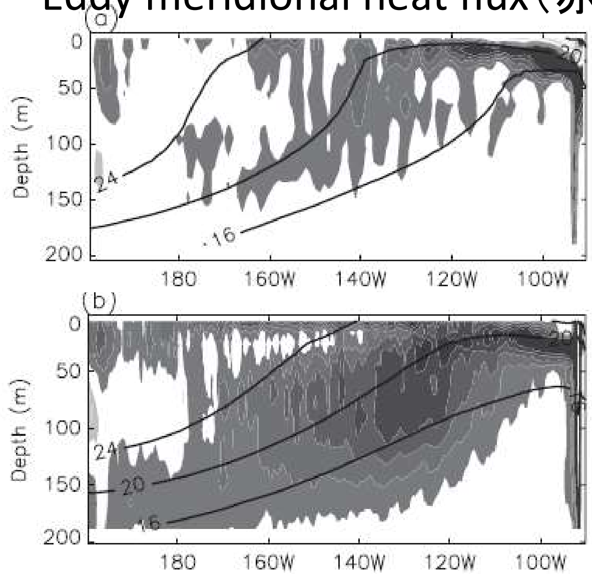
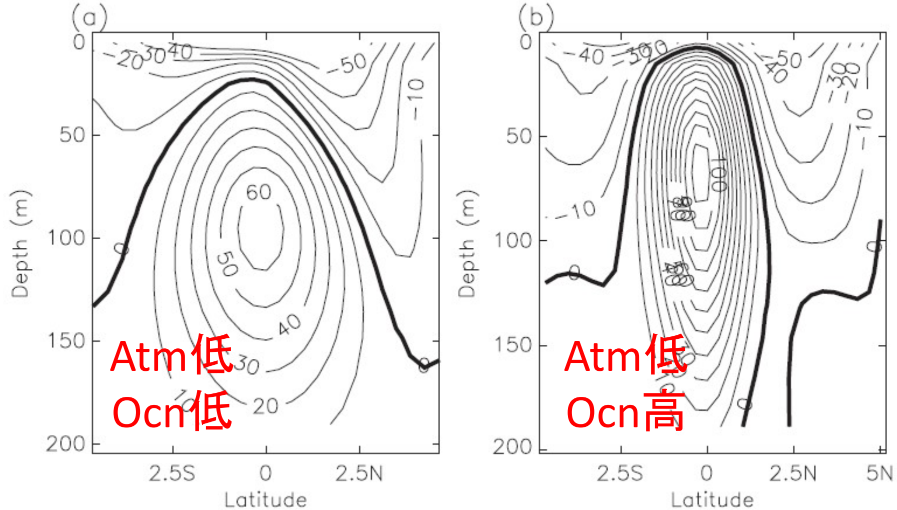


FIG. 4. Temperature cross section at 130°W for (a) LoLo, (b) LoHi, and (c) WOD01 climatology. Model mean years 30–50.

Eddy meridional heat flux（赤道）



東西流速（140-110W）



Previous Studies

- Roberts et al. 2009 (J. Climate) -HadGEM1 resolution matrix

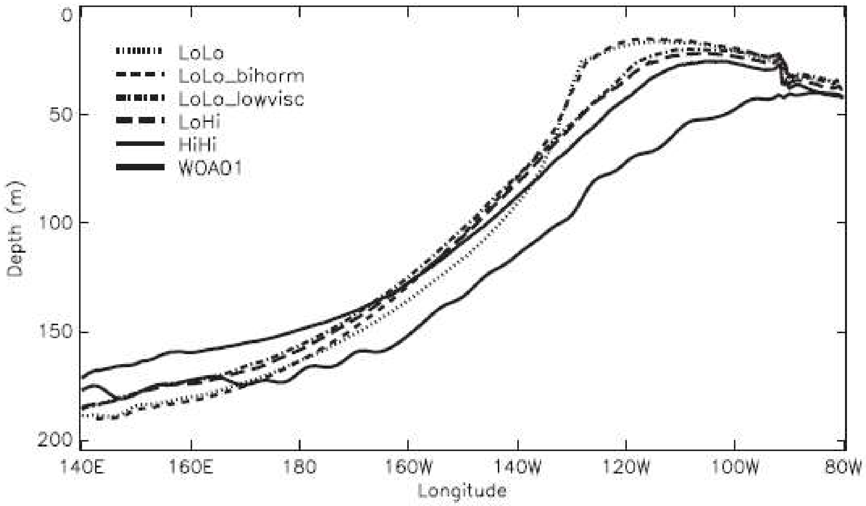


FIG. 13. Depth of the 20° isotherm in the ocean along the equator for LoLo (dotted), LoLo-biharm (short dashed), LoLo-lowvisc (short dash–dot), LoHi (long dashed), HiHi (dash–three dot), and WOA01 observations (solid). Model mean years 5–10.

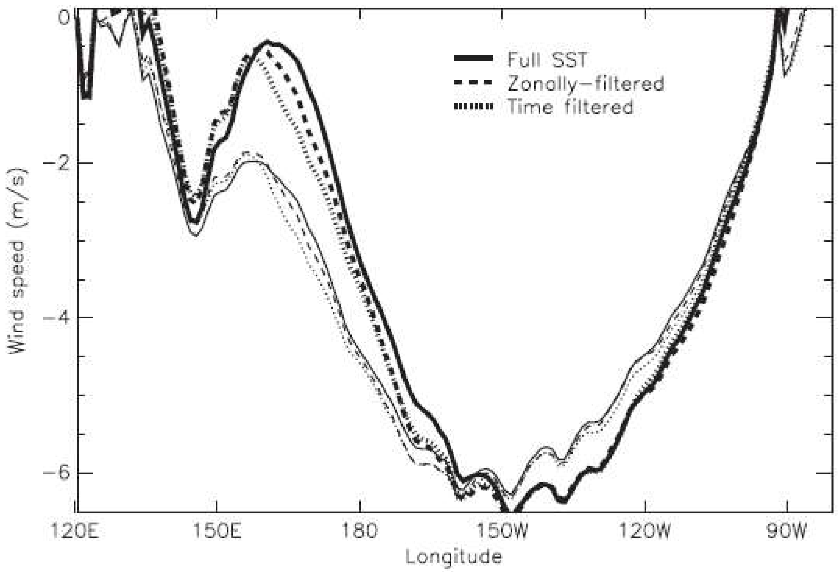
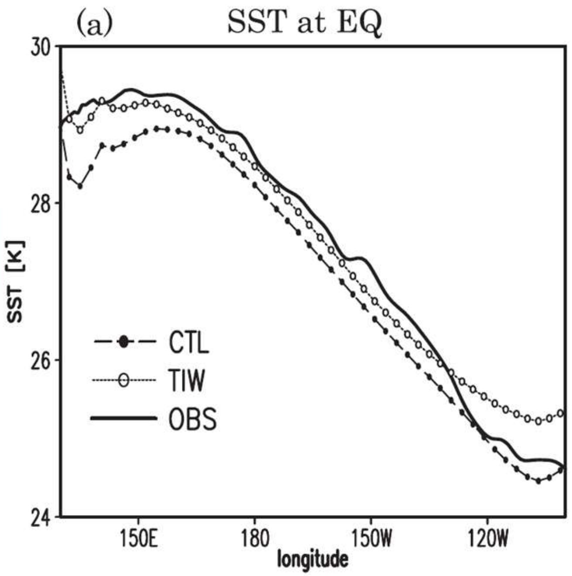


FIG. 14. 10-m winds from atmosphere models forced by SSTs diagnosed from the HiHi-coupled model, averaged between 2°S and 2°N. The thick lines correspond to averages between August and December, and the thin lines to annual means, both averaged over 5 yr.

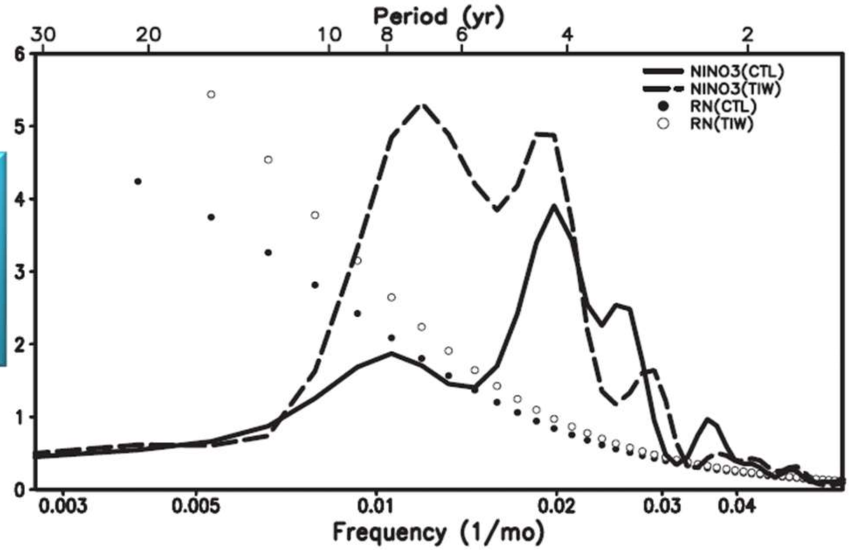
Impacts of TIWs on ENSO

- Imada and Kimoto (2012) J. Climate
  - Parameterization of eddy heat transport

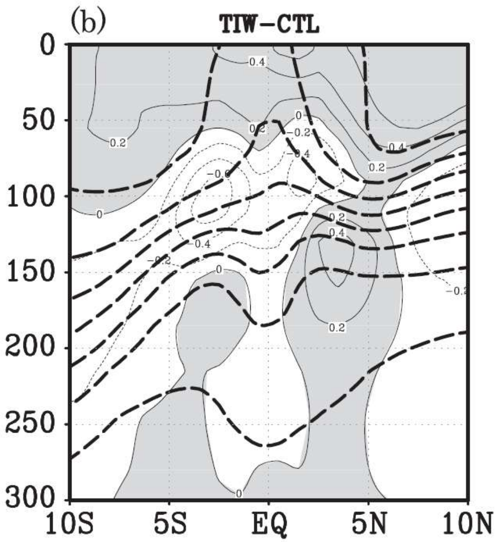
SST



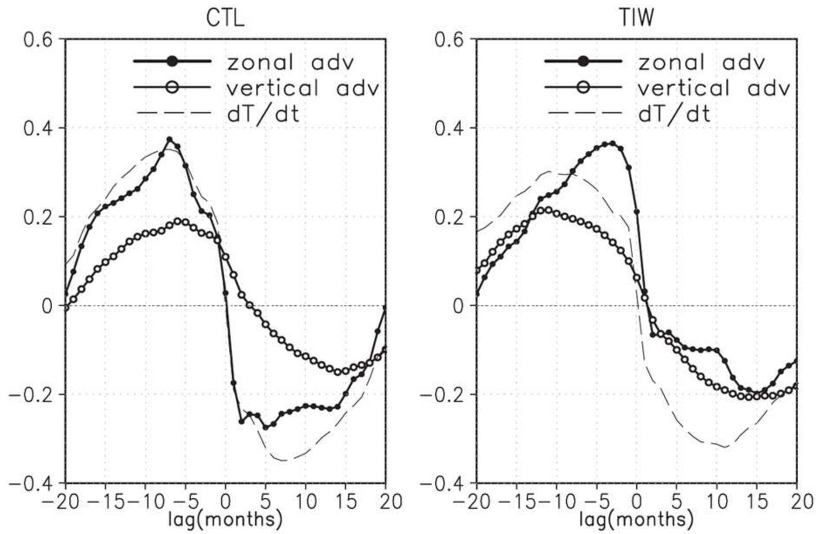
Nino3 Power Spectrum



海水温の変化 @120W

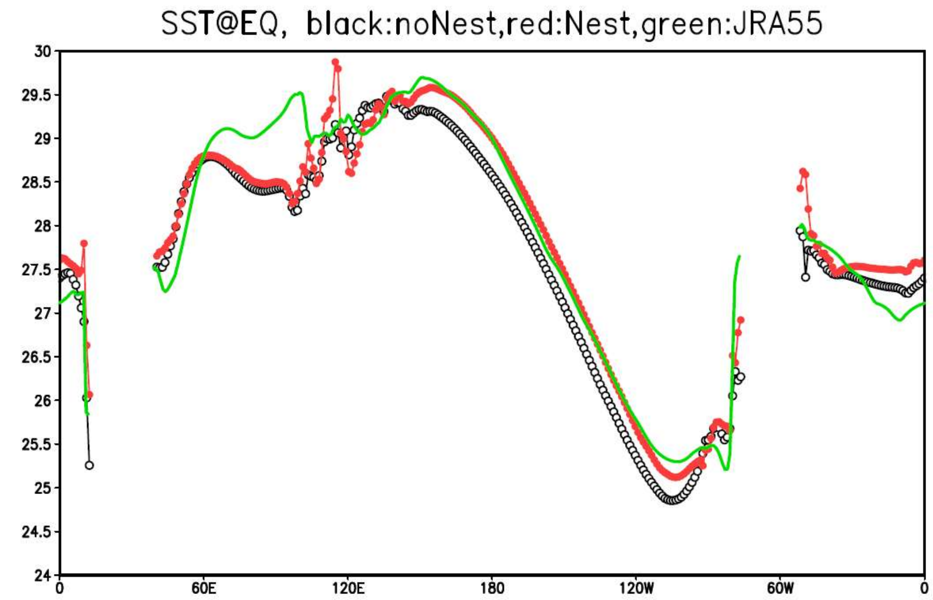


Nino3 budget analysis

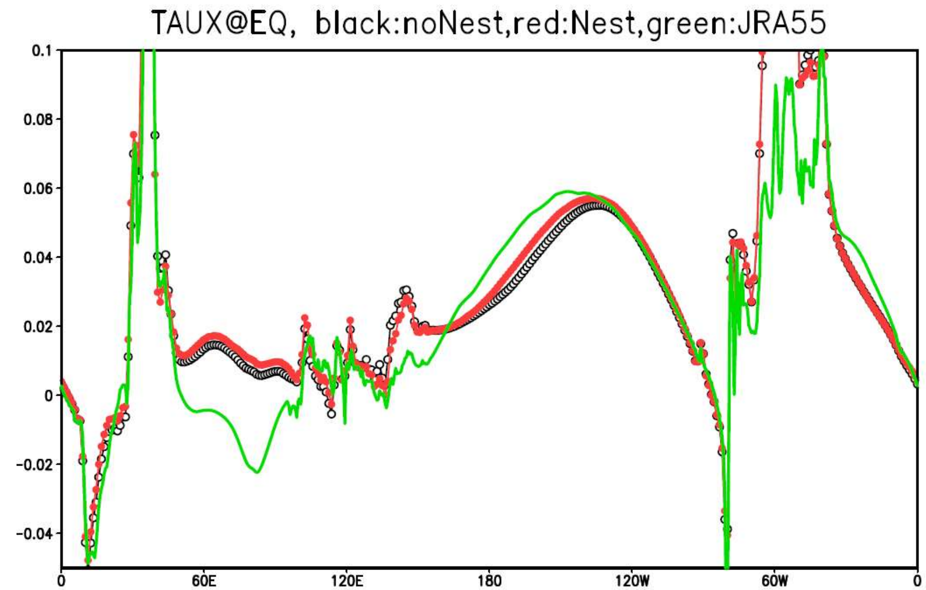


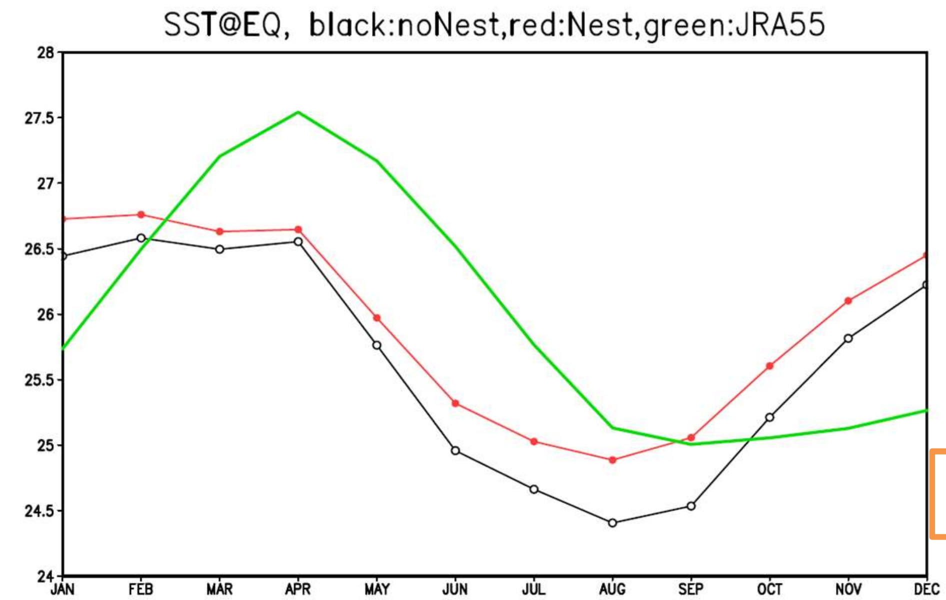
Impacts on equatorial climatology

SST@EQ



Zonal wind stress@EQ





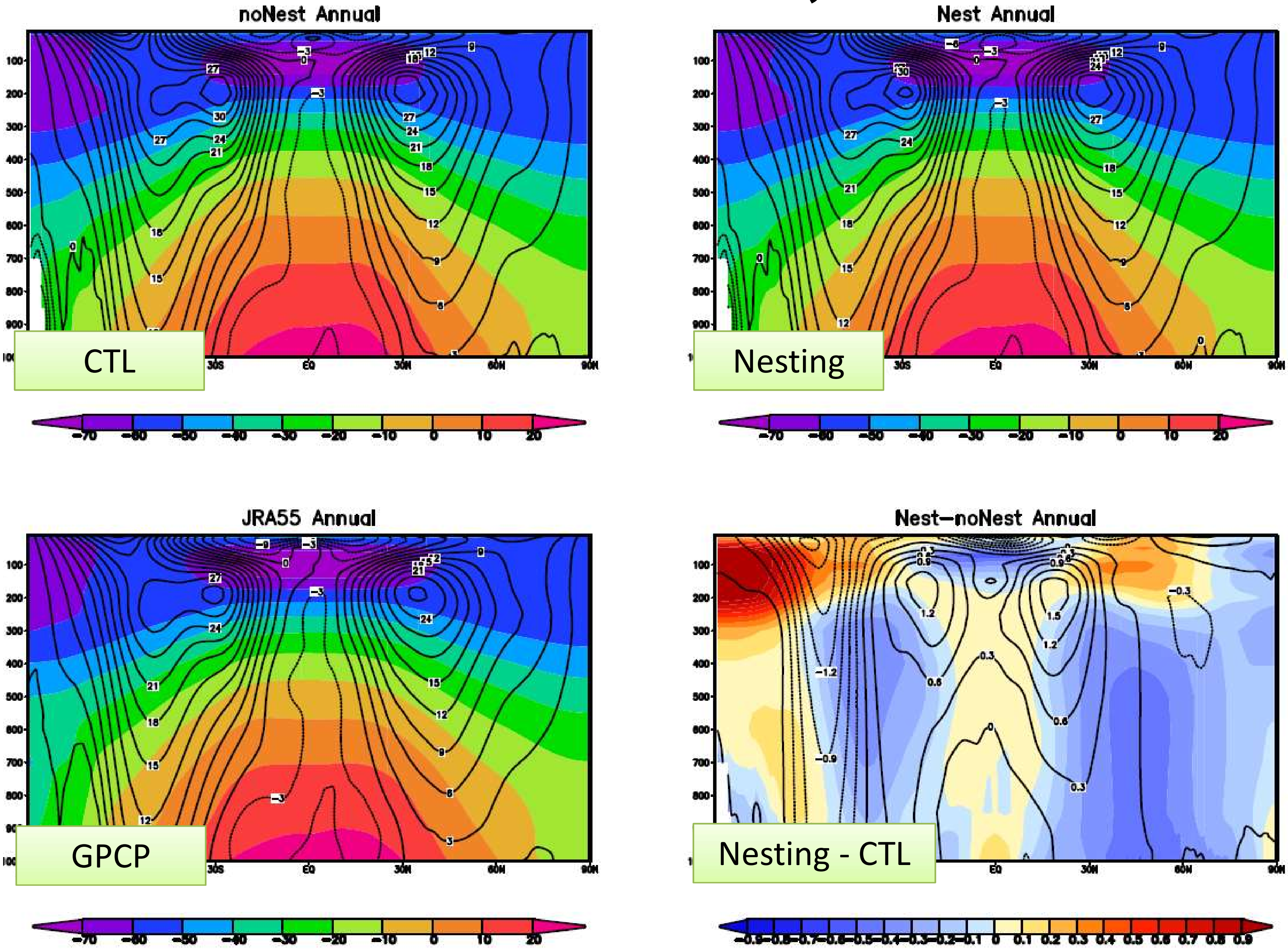
COBE-SST/JRA55

CTL

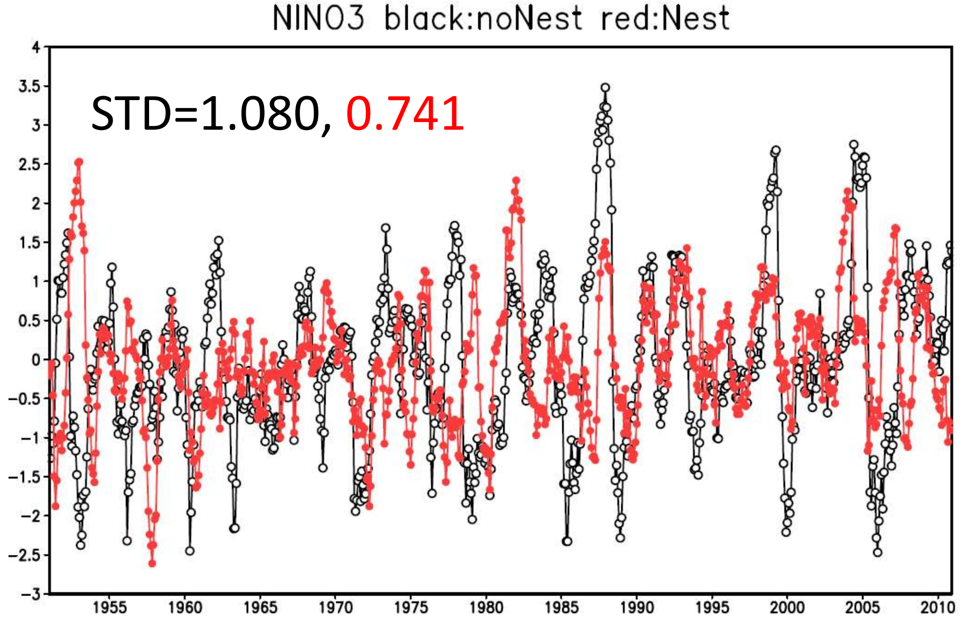
Nesting

←SST monthly climatology @NINO3

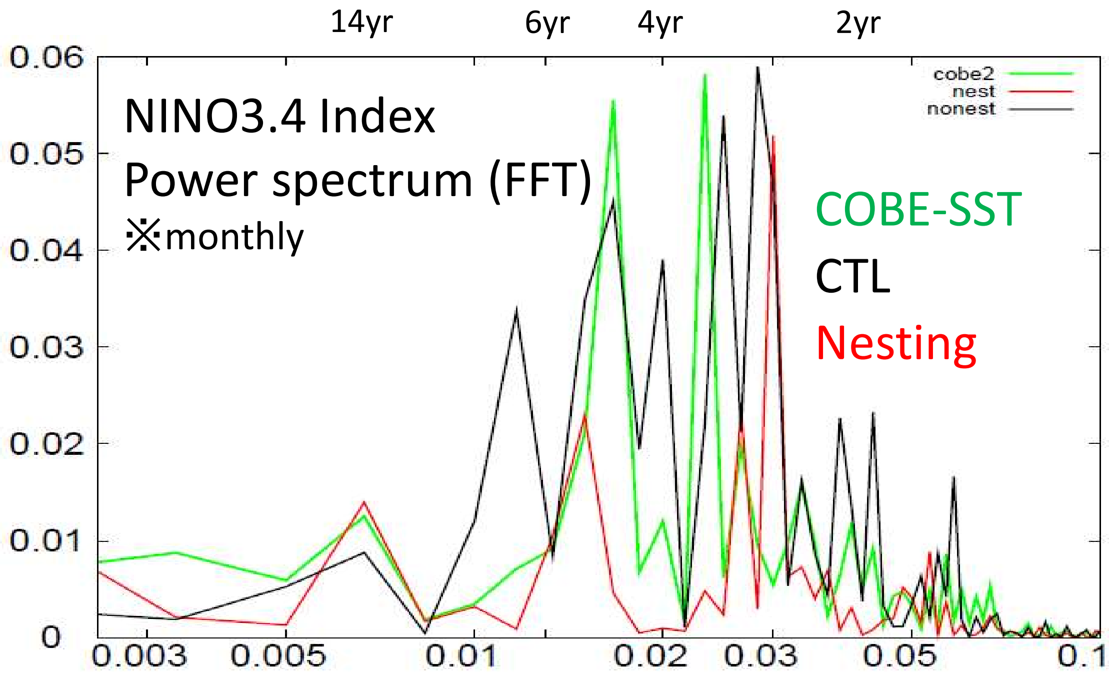
Impacts on atmospheric meridional circulation
（zonal mean T, U）



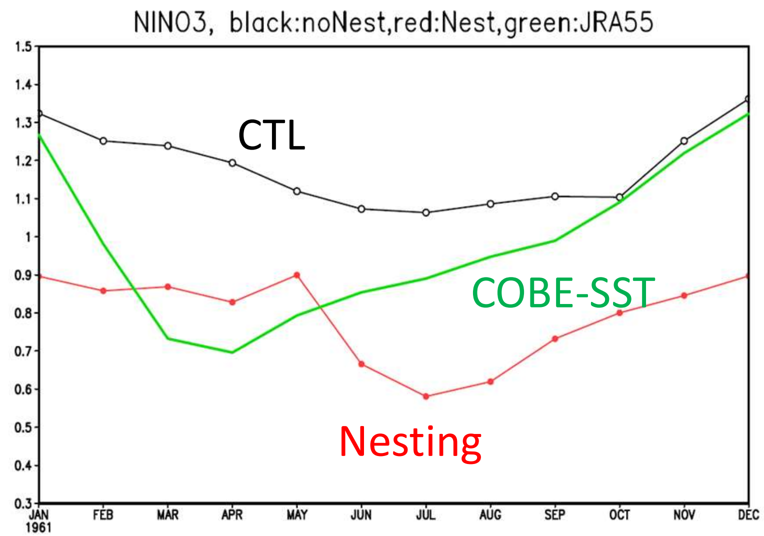
（NINO3）　※1961-2010



※COBE-SST2:　STD=0.908

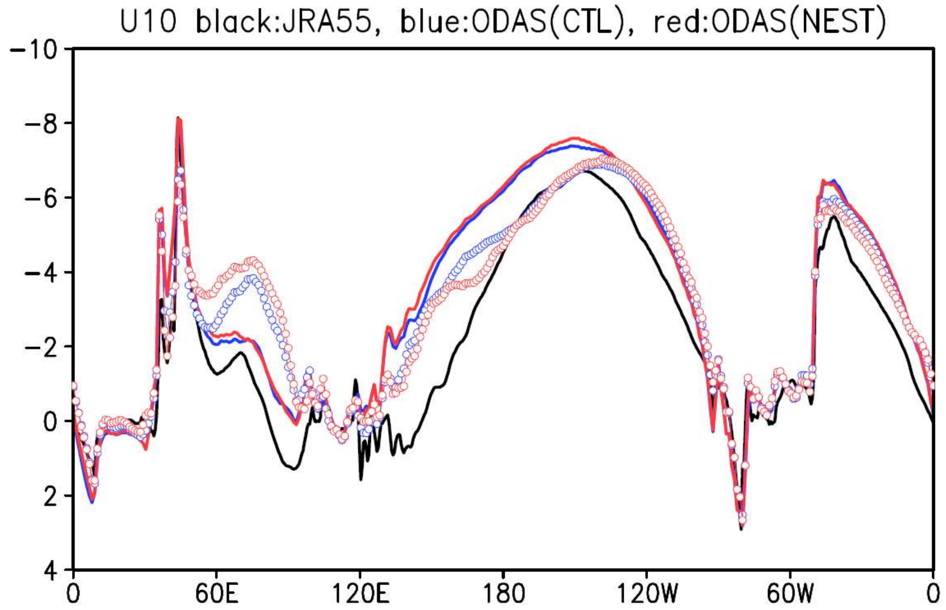


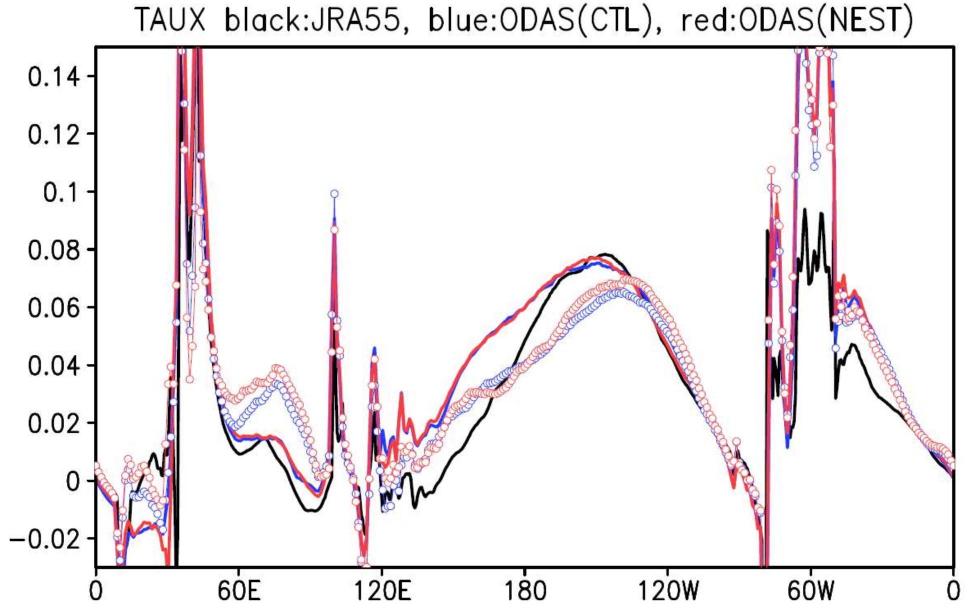
※1961-2010



※1981-2010

U10, TAUX @EQ (HIST and ODAS)





JRA55

フル同化（ネストなし）

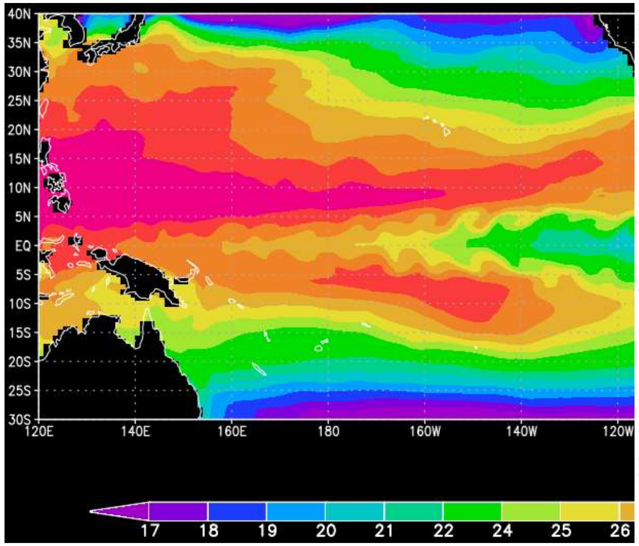
フル同化（ネストあり）

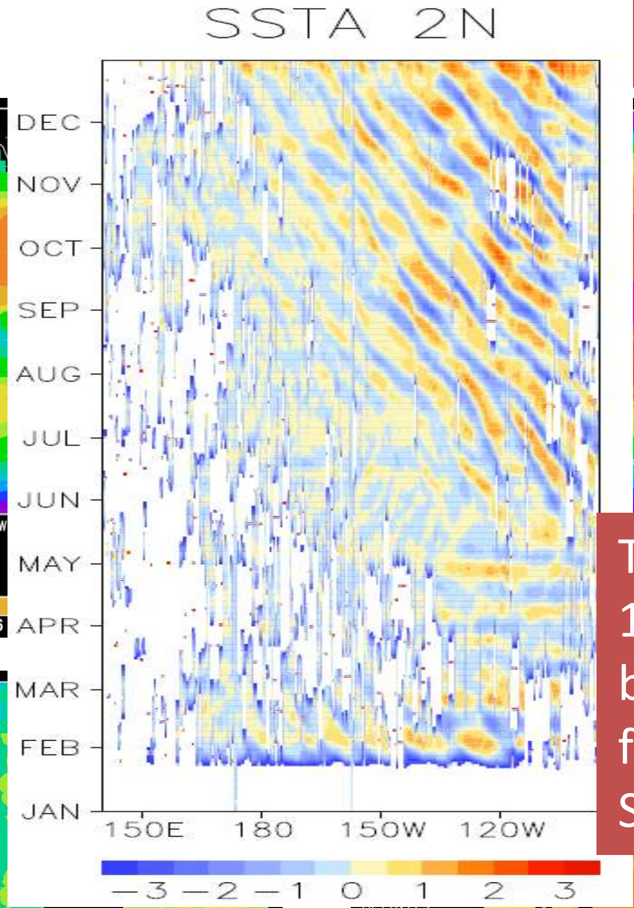
historical（ネストなし）

historical（ネストあり）

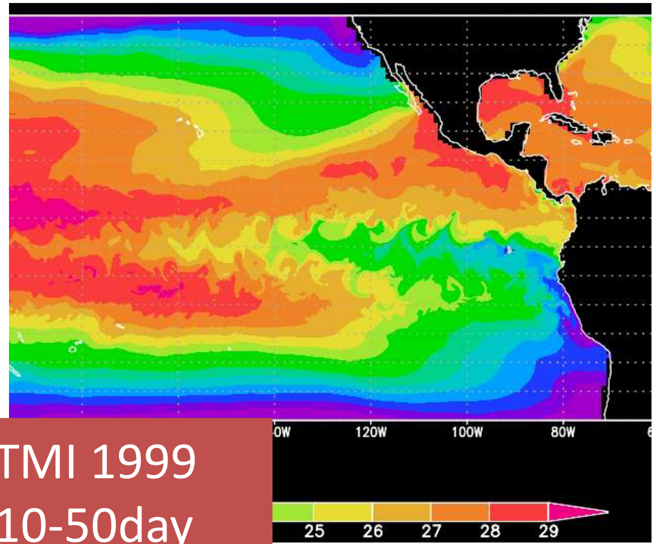
TIWs

CTL

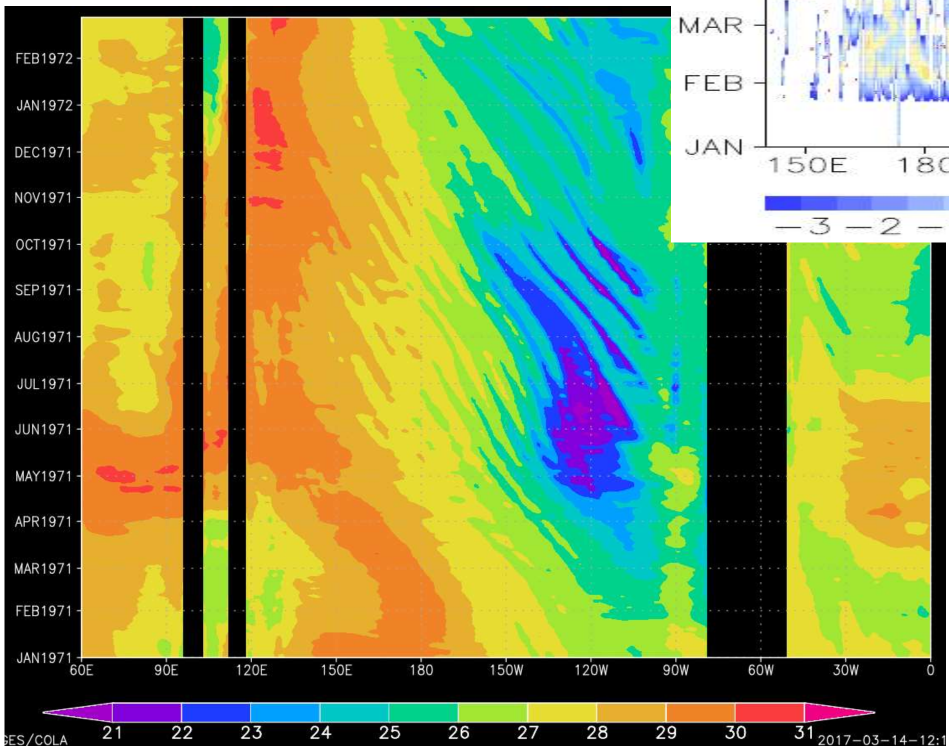


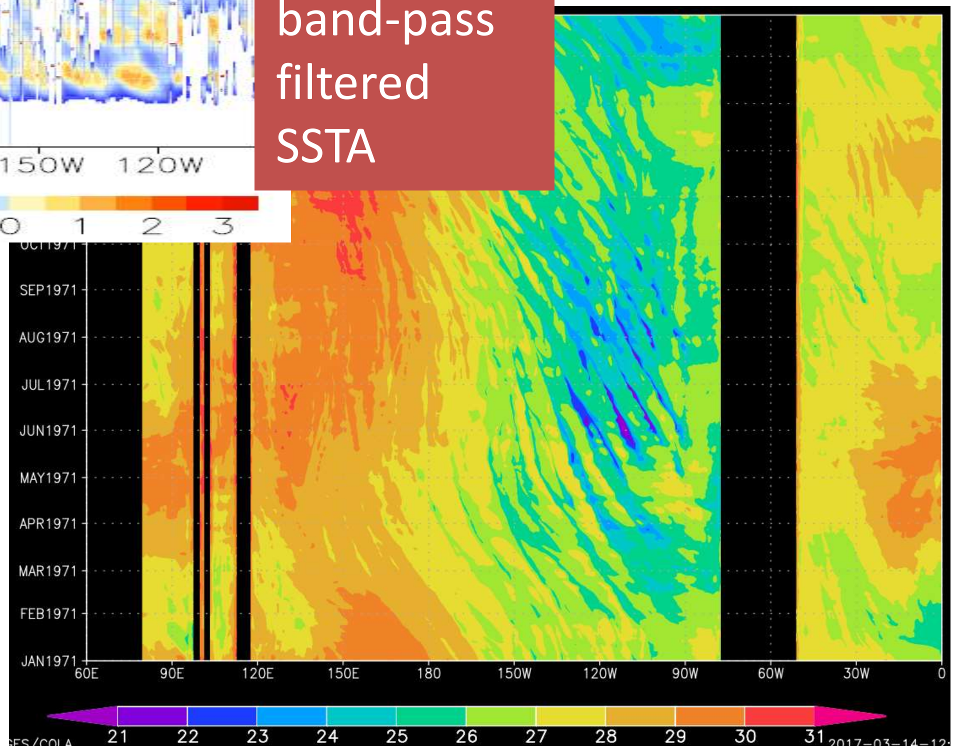


Nesting



TMI 1999
10-50day
band-pass
filtered
SSTA



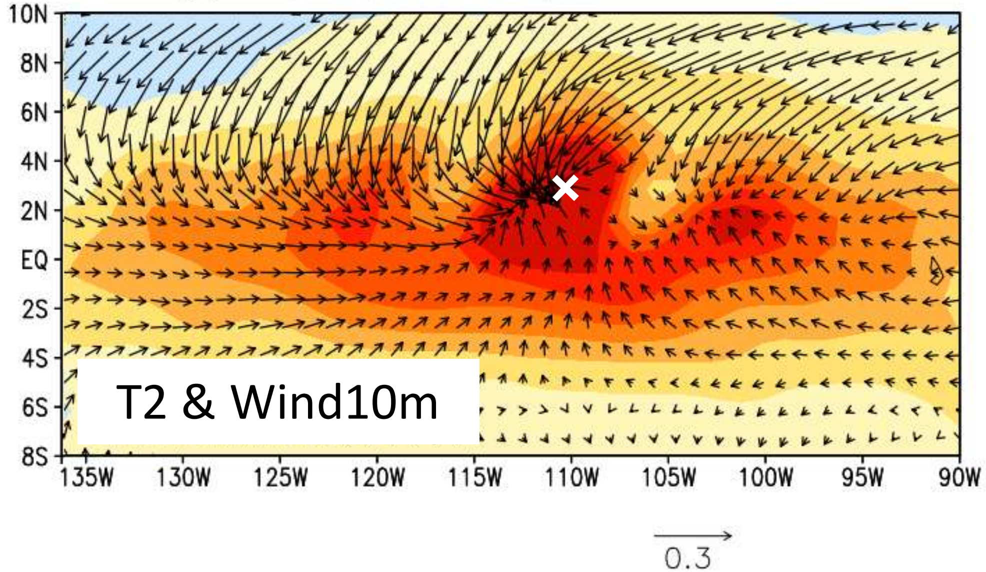


TIWs-scale atmospheric anomalies

Regression onto high-path filtered SST@110W, 3N

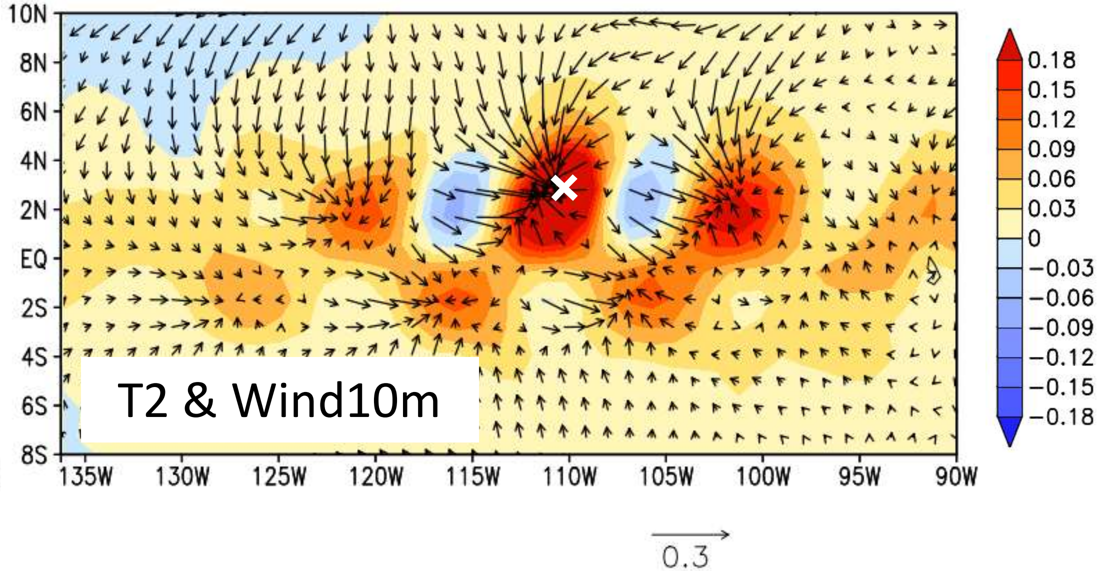
CTL

STD*Reg(idx,T2,Wind10) noNest



Nesting

STD*Reg(idx,T2,Wind10) Nest



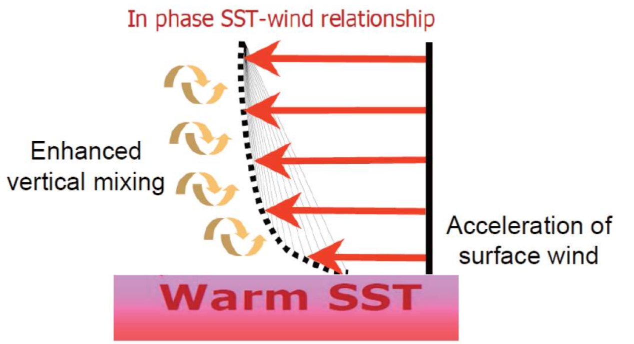
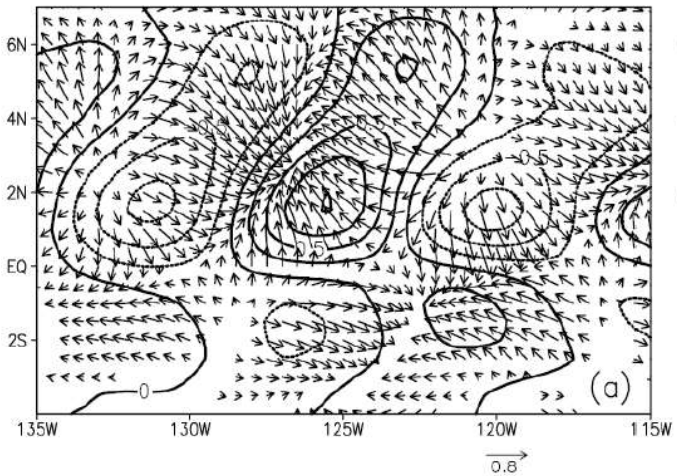
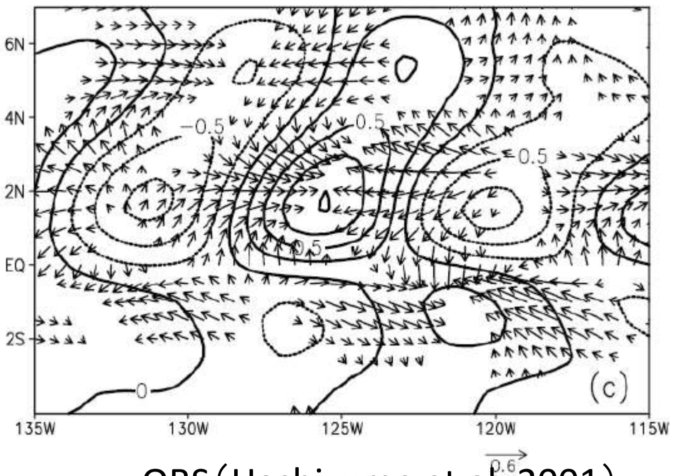


Figure 1.5: Schematic representation of the vertical mixing mechanism.

Regression (OBS)



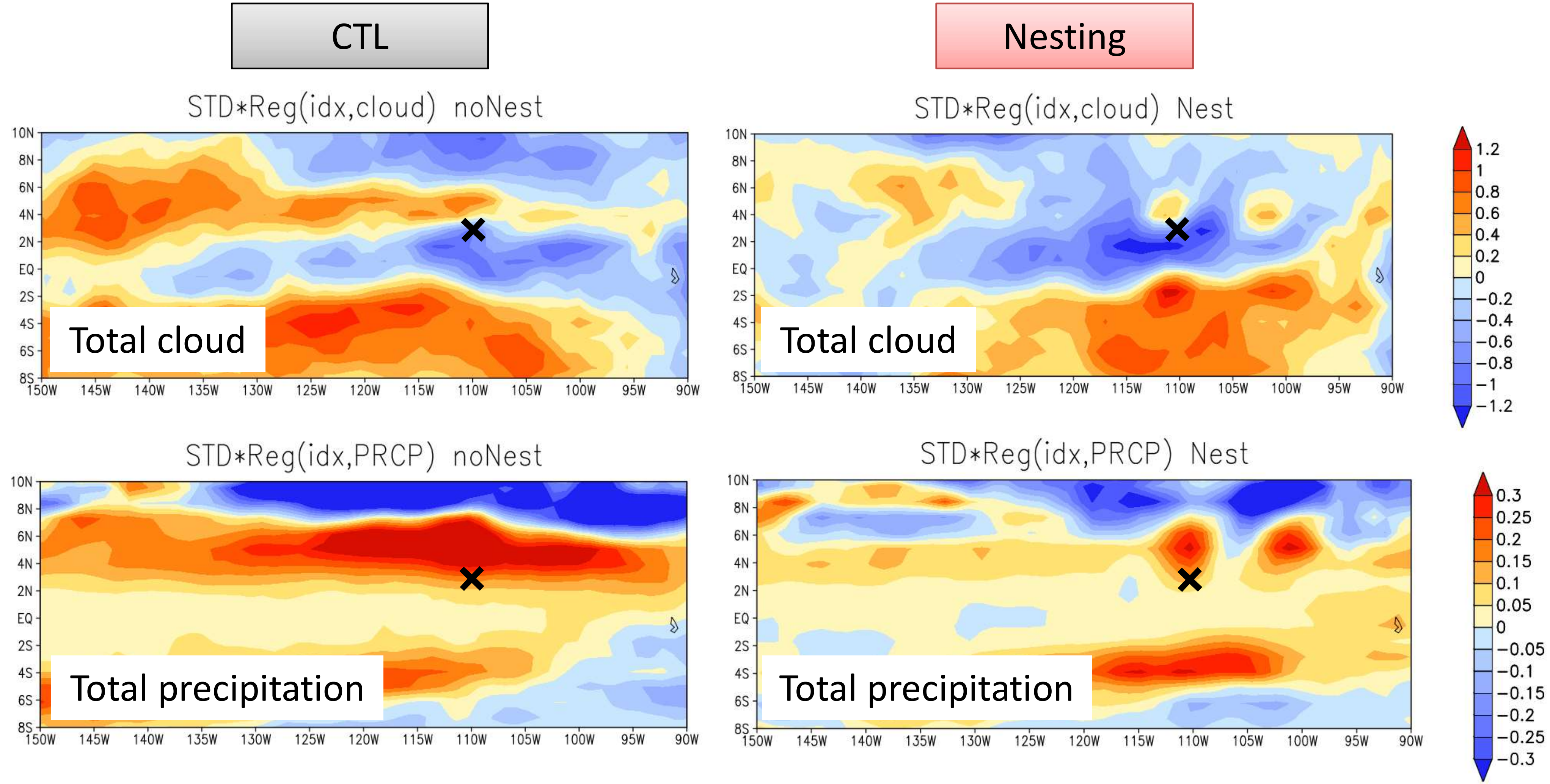
SLP-driven



OBS（Hashizume et al. 2001）

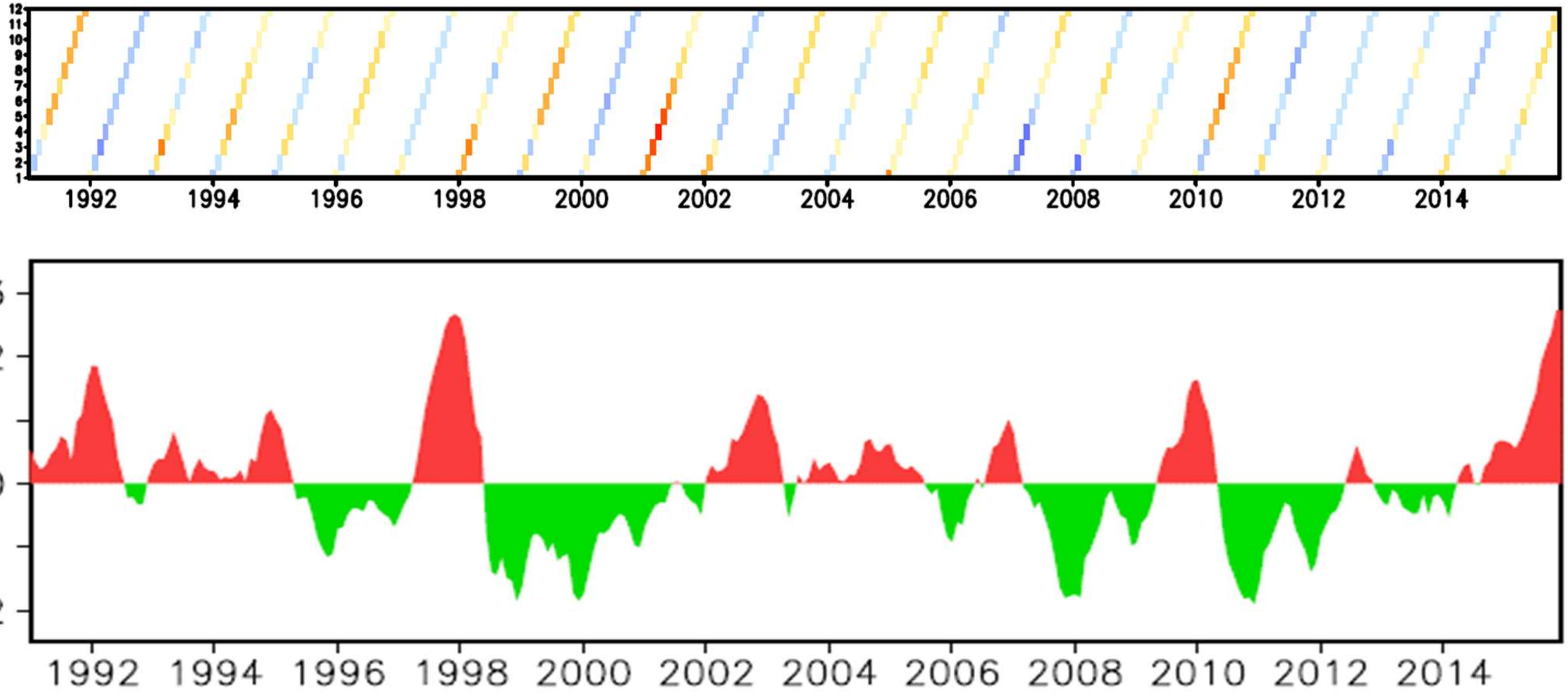
TIWs-scale atmospheric anomalies

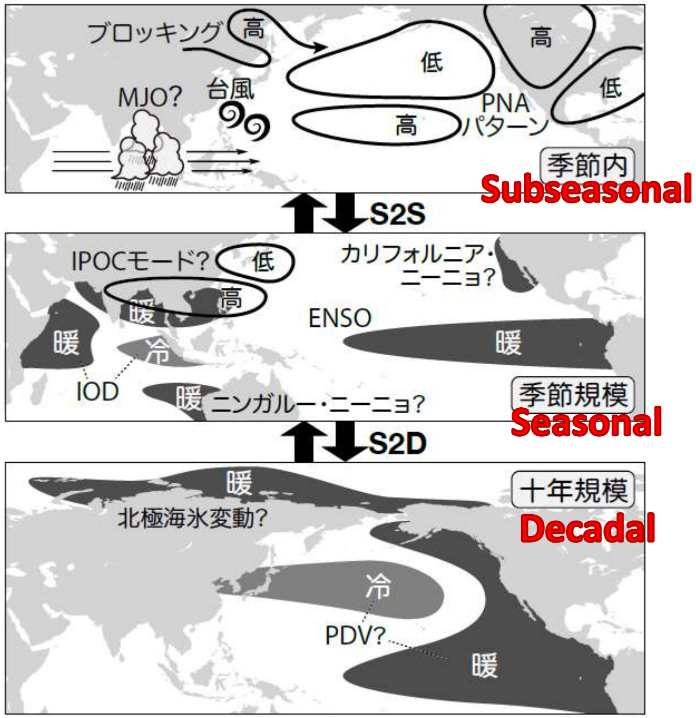
Regression onto high-path filtered SST@110W, 3N



Low-level cloud responses to TIWs (Deser et al. 1993)

Rate of improvement





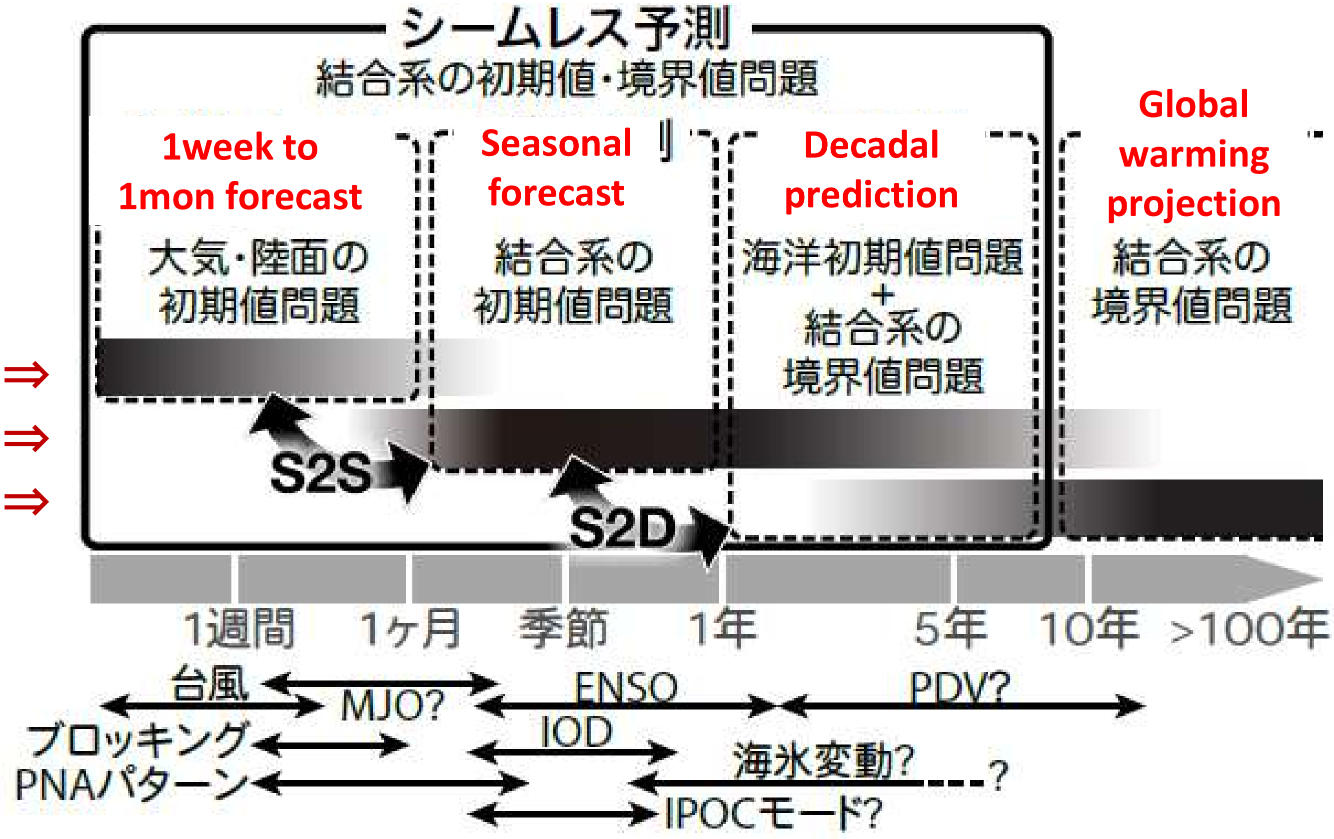
JMA Forecasts:

- Short-term Forecasts
- Daily Forecasts
- One-week Forecasts
- One-month Forecasts
- Three-month Forecasts
- El Nino prompt report（エルニーニョ監視速報）
- Warm/Clold Seasonal Forecasts（暖候期・寒候期予報）

Global coupled model
is needed

Key of predictability

Atmosphere/land initial condition⇒
Ocean initial condition⇒
External forcing⇒



大気と海洋の空間スケールの違い

大気の典型的なパラメータ:

$H \sim 10km$, $U \sim 10ms^{-1}$, $N \sim 10^{-2}s^{-1}$

○ロスビー変形半径:

$L_d = NH/f \approx 10^{-2}10^{4}/10^{-4} \approx 1000$ km

○Eady問題での最も傾圧不安定な空間スケール:

$L_{max} \approx 3.9\ L_d \approx 4000$ km

○成長率:

$\sigma \approx 0.3\ U/L_d \approx 0.3 \times 10 / 10^{6}\ s^{-1} \approx 0.26\ day^{-1}$

海洋の典型的なパラメータ:

$H \sim 1km$, $U \approx 0.1ms^{-1}$, $N \sim 10^{-2}s^{-1}$

○ロスビー変形半径:

$L_d = NH/f \approx 10^{-2}10^{3}/10^{-4} \approx 100$ km

○Eady問題での最も傾圧不安定な空間スケール:

$L_{max} \approx 3.9\ L_d \approx 400$ km

○成長率:

$\sigma \approx 0.3\ U/L_d \approx 0.3 \times 0.1 / 10^{5}\ s^{-1} \approx 0.026\ day^{-1}$

Vallis (2006)より

ロスビー変形半径を考えると、例えば格子間隔60kmの大気モデルの解像度は、格子間隔6kmの海洋モデルの解像度と同等