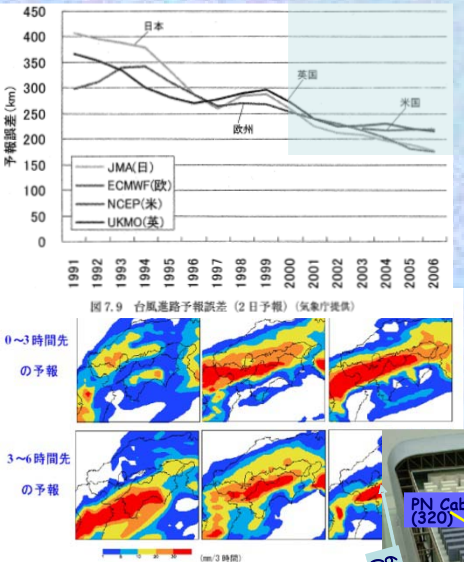
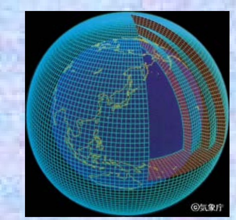
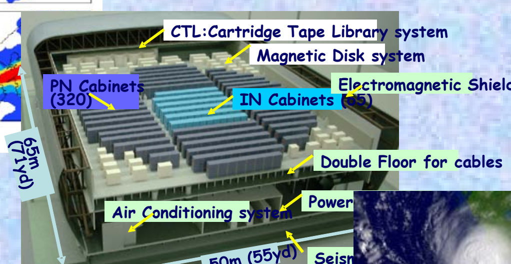
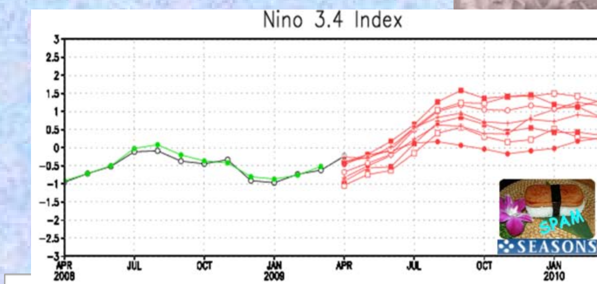
Expanding the horizon of seasonal prediction using state-of-the-art climate models

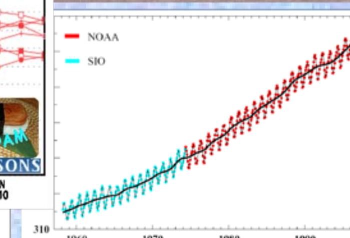
Masahide Kimoto
Atmosphere and Ocean Research Institute
University of Tokyo

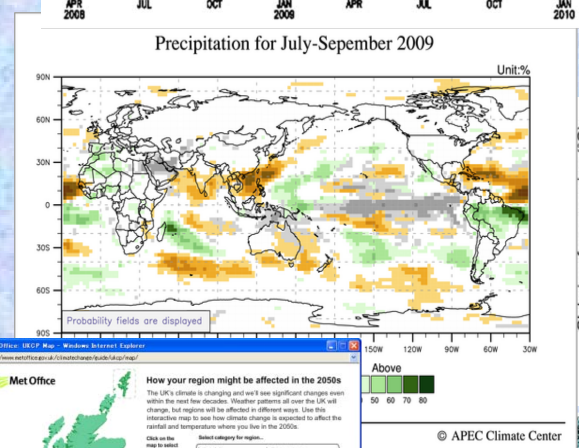


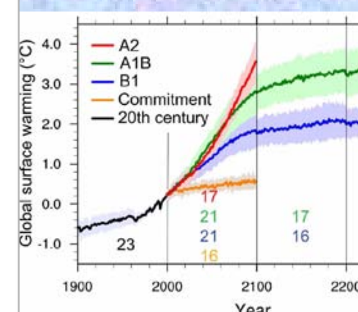


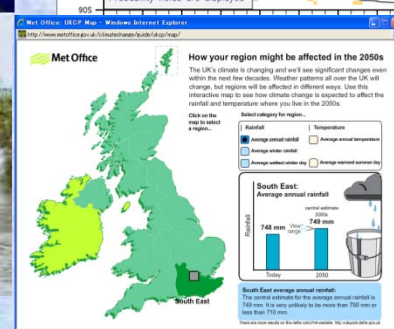


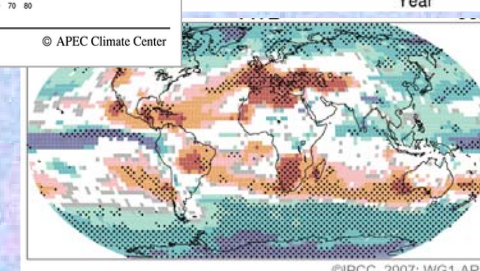








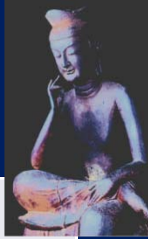




Topics

- Research and model development
- From seasonal to decadal prediction
- Earth system models and environmental prediction
- Better understanding and prediction with the help of process resolving models

Schemes in old/new MIROCs

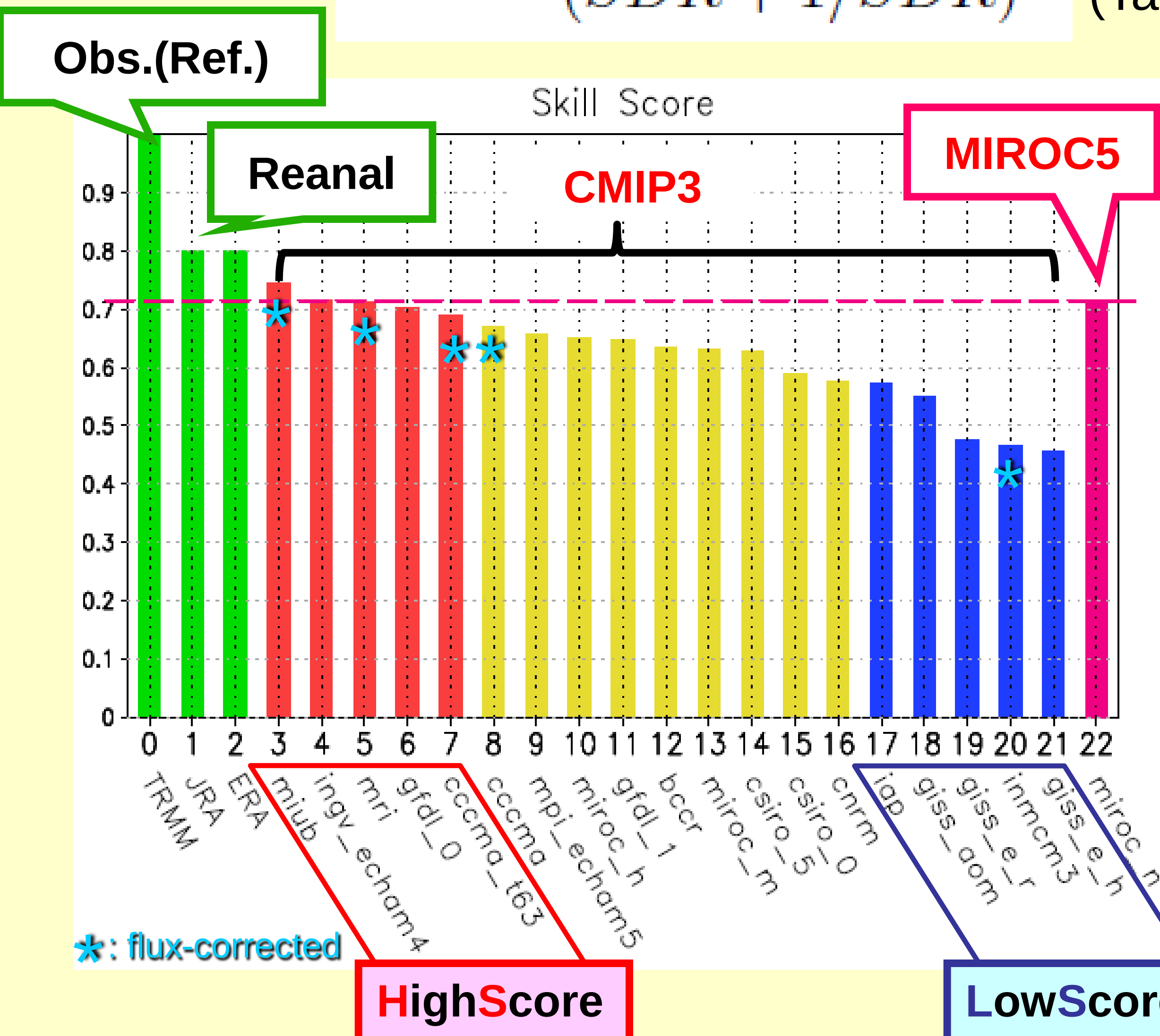


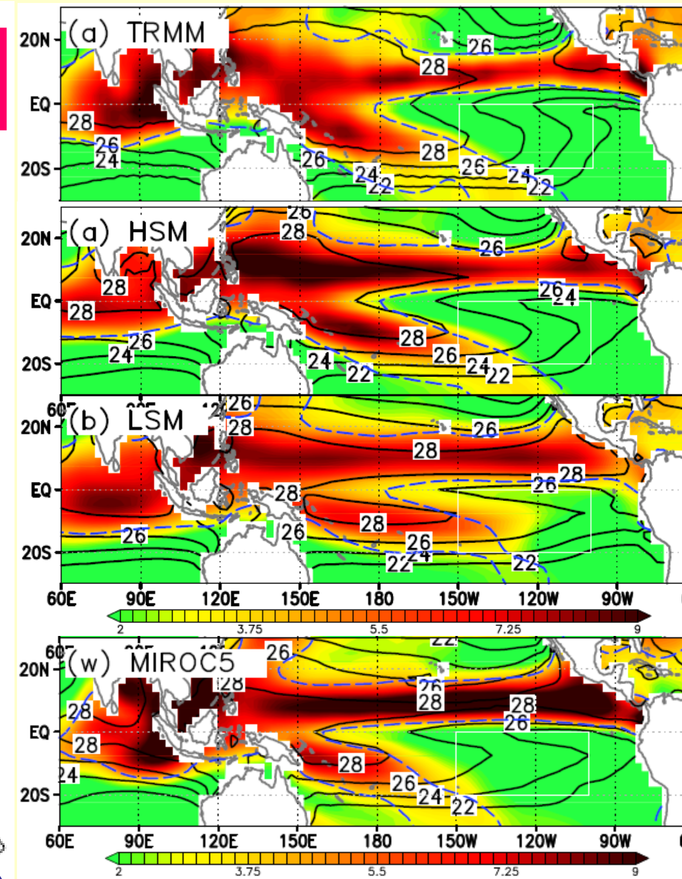
		MIROC3 (2004)	MIROC5 (2010)
Atmos.	**Dynamical core**	Spectral+semi-Lagrangian (Lin & Rood 1996)	Spectral+semi-Lagrangian (Lin & Rood 1996)
	V. Coordinate	Sigma	Eta (hybrid sigma-p)
	Radiation	2-stream DOM 37ch (Nakajima et al. 1986)	2-stream DOM 111ch (Sekiguchi et al. 2008)
	Cloud	Diagnostic (LeTreut & Li 1991) + Simple water/ice partition	Prognostic PDF (Watanabe et al. 2009) + Ice microphysics (Wilson & Ballard 1999; Ogura et al.)
	Turbulence	M-Y Level 2.0 (Mellor & Yamada 1982)	MYNN Level 2.5 (Nakanishi & Niino 2004)
	Convection	Prognostic A-S + critical RH (Pan & Randall 1998, Emori et al. 2001)	Prognostic AS-type, but original scheme (Chikira & Sugiyama 2010)
	Aerosols	simplified SPRINTARS (Takemura et al. 2002)	Full SPRINTARS + prognostic CCN (Takemura et al. 2005, 2009)
Land/ River		MATSIRO+fixed riv flow (Takata et al.; Oki et al.)	new MATSIRO+variable riv flow (Takata et al.; Oki et al.)
Ocean		COCO3.4 (lat-lon)	COCO4.4 (tripolar)
Sea-ice		Single-category EVP	Multi-category EVP

Tropical precip climatology

$$S \equiv \frac{4(1+R)^4}{(SDR + 1/SDR)^2}$$

(Taylor, 2001)





Hirota et al. (2010)

New convection scheme

Mixture of A-S and Gregory scheme

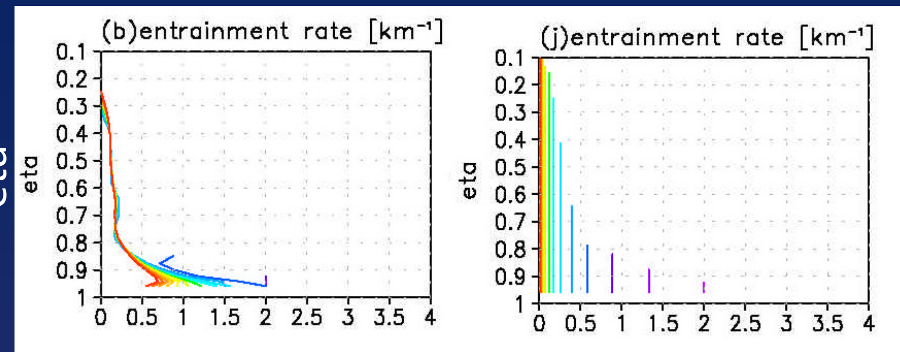
Entrainment rate (ε)

- Conventional A-S scheme:
  prescribed
- C-S scheme:
  dependent upon buoyancy and cloud-base mass flux

Vertical profiles of ε in a single column model

C-S A-S

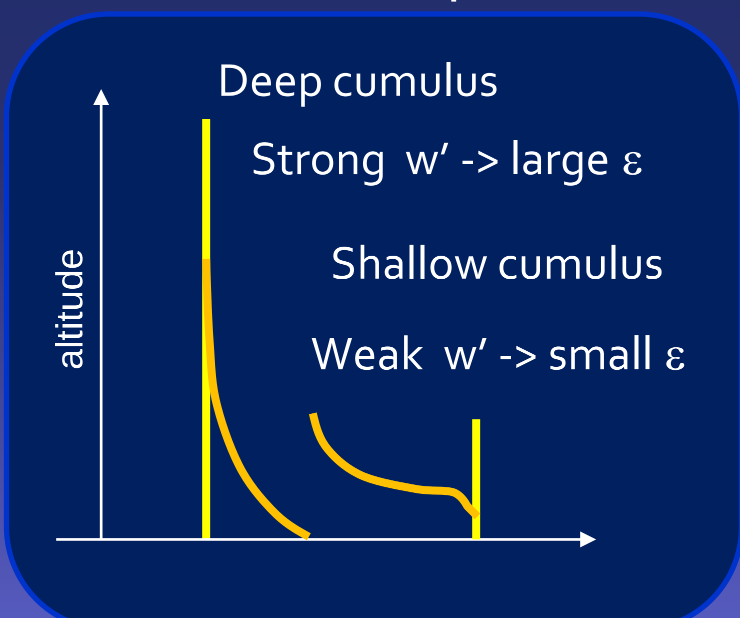
eta



Cloud type

Chikira and Sugiyama (2010)

Entrainment profiles

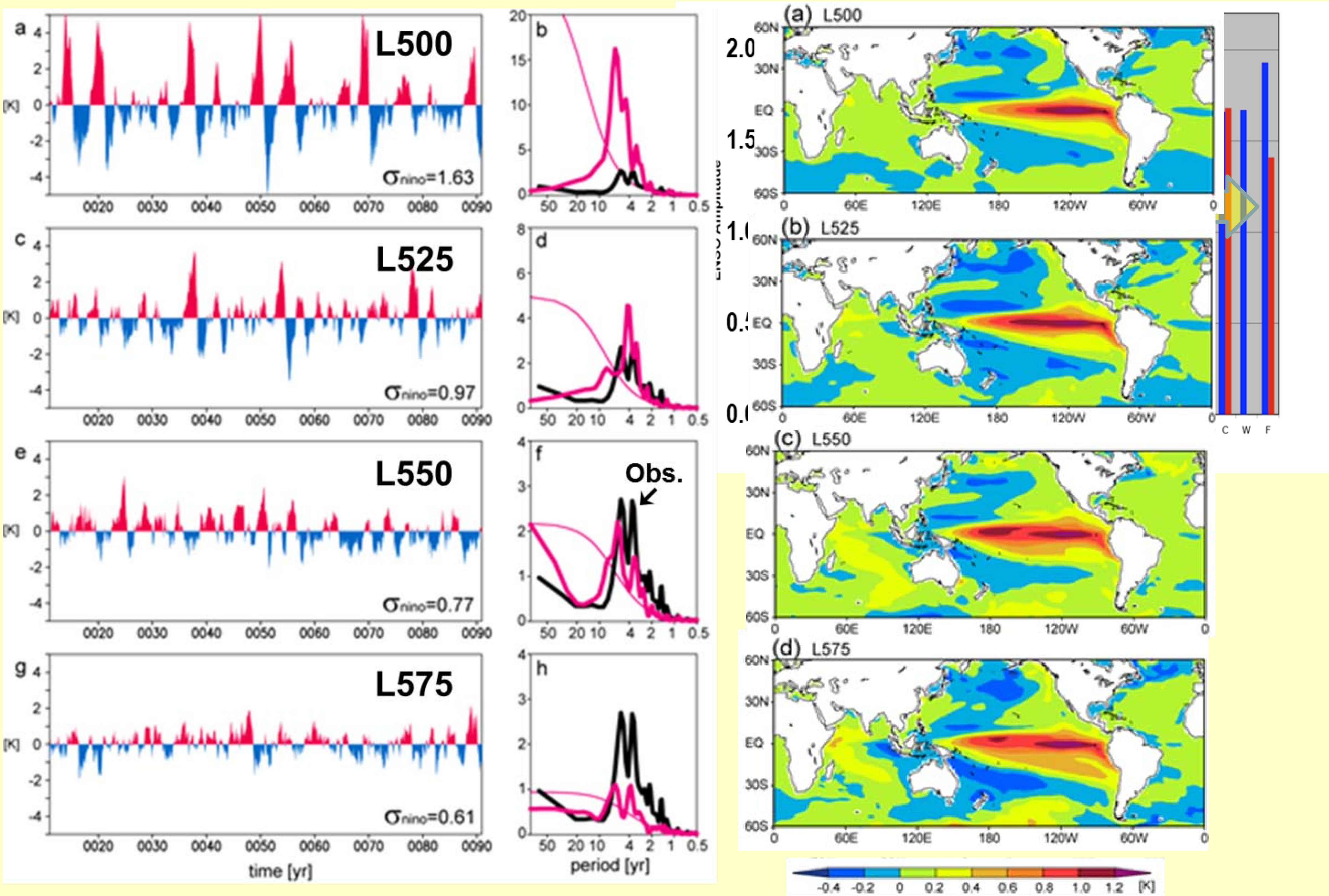


✓Both work to increase middle level cumulus that was less in A-S

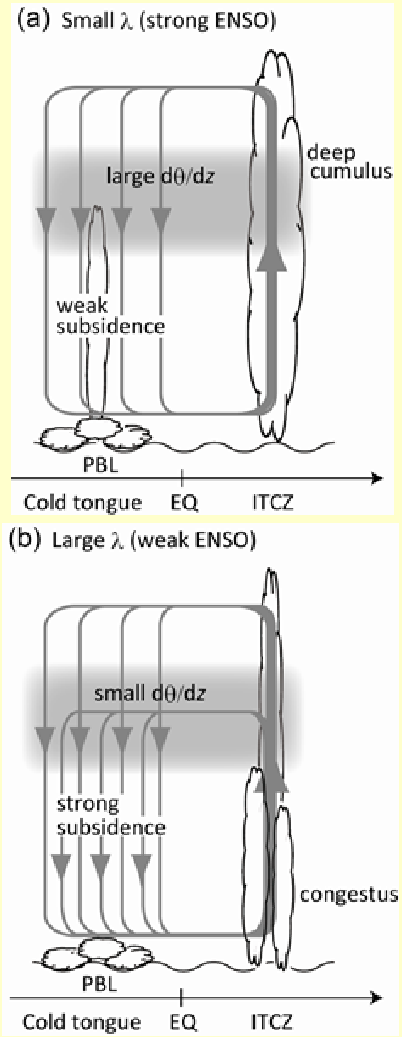
✓Not necessary to use empirical cumulus triggering function

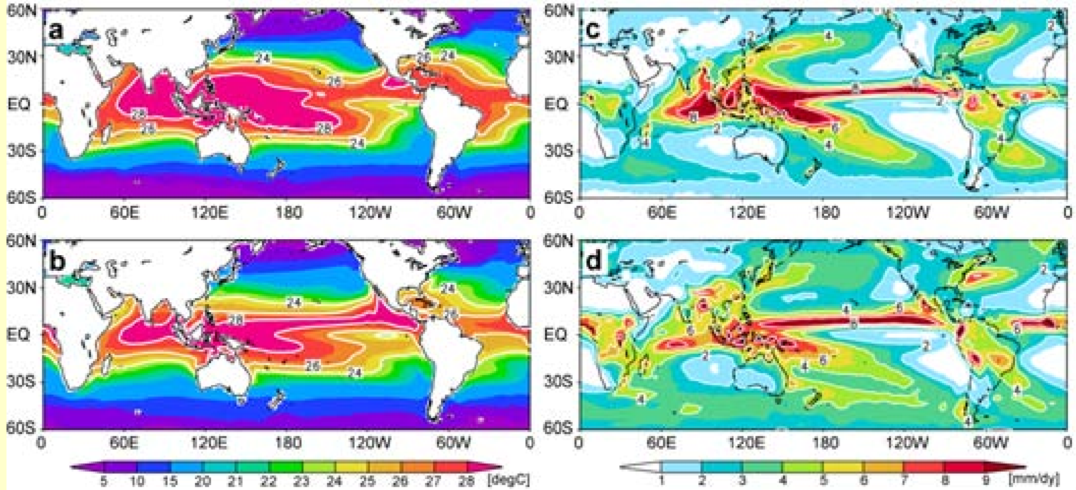
Convective control of ENSO

(Watanabe et al. 2010, J. Climate, in press)



Climatological mean state



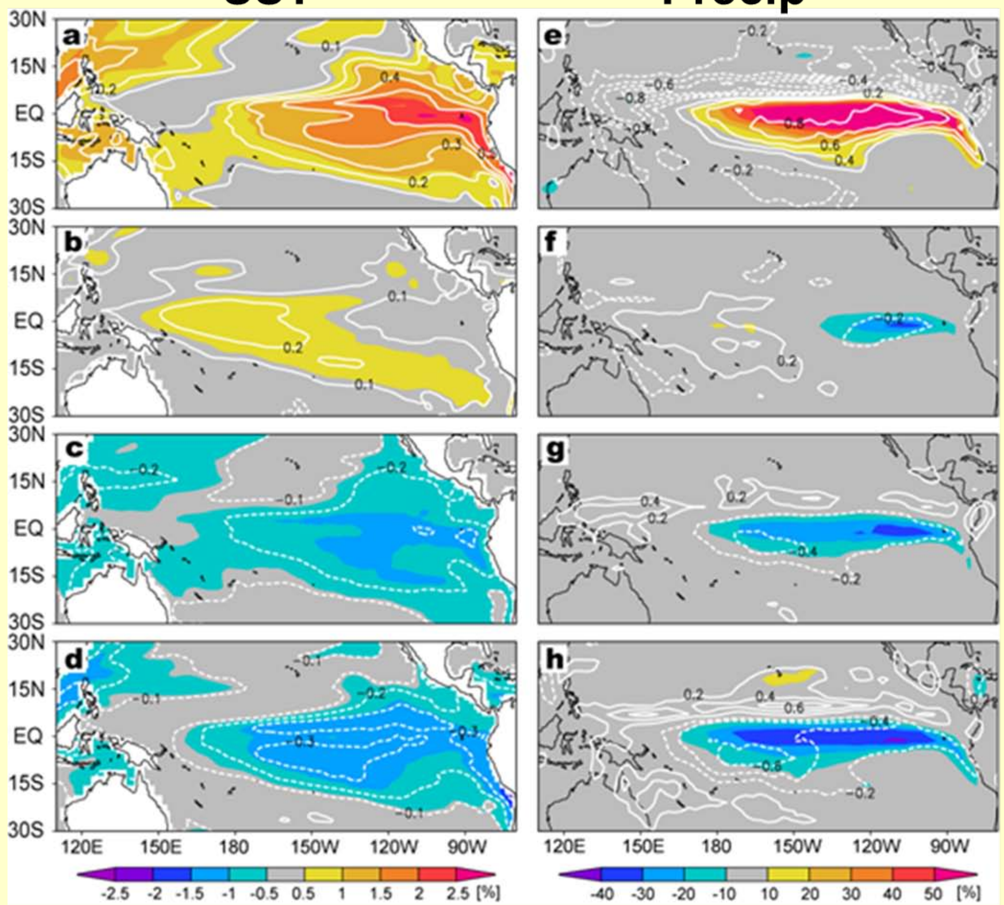


Obs.

Model (ens. mean)

SST

Precip



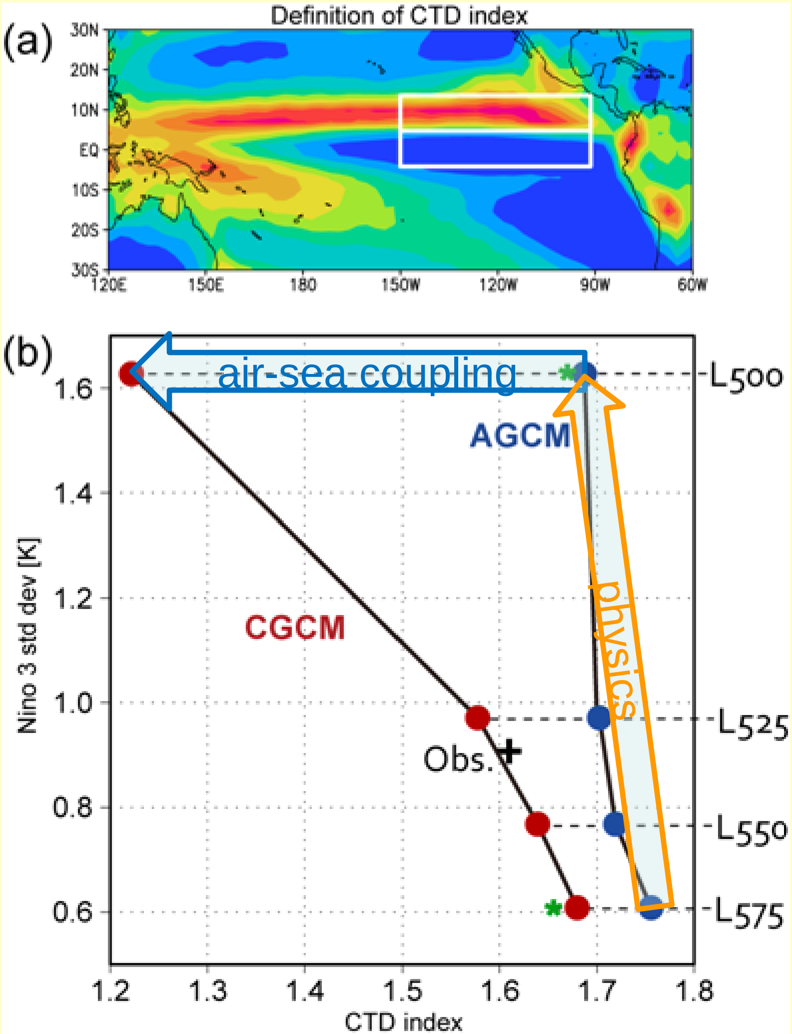
L500

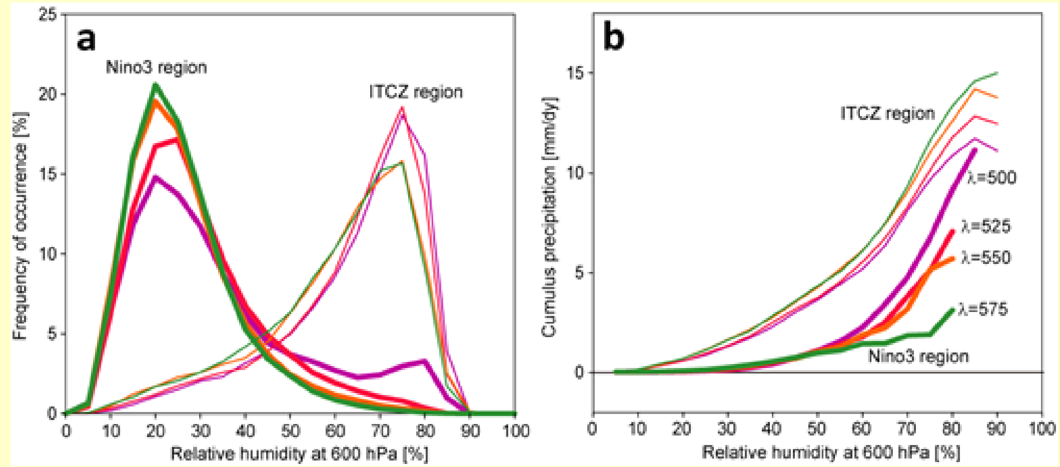
L525

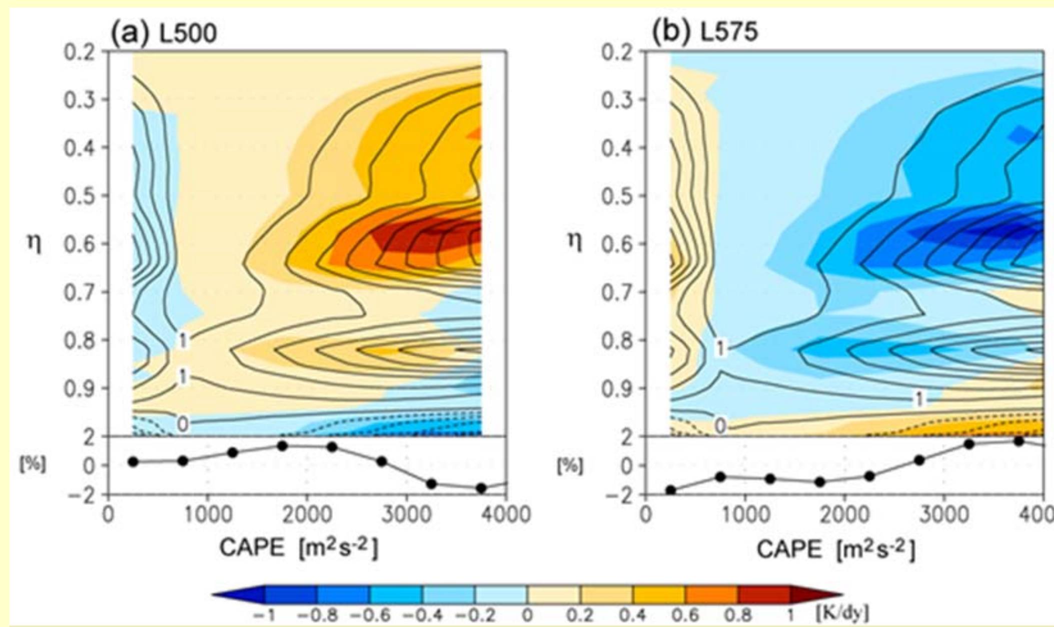
L550

L575

Watanabe et al. (2010)







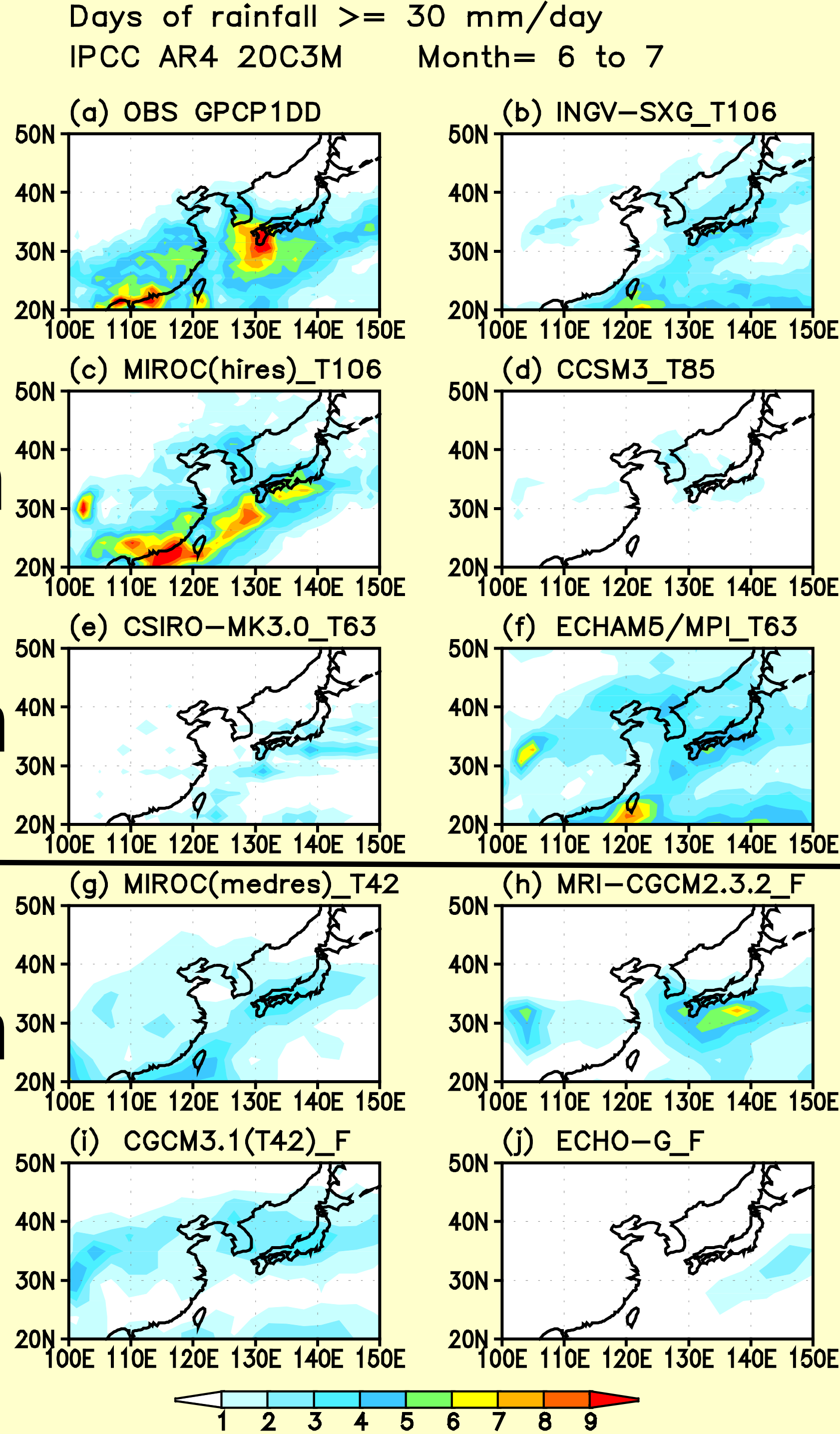
Cold Tongue Dryness (CTD) index
$$\equiv 2*(P_{ITCZ}-P_{NINO3})/(P_{ITCZ}+P_{NINO3})$$

Watanabe et al. (2010)

Resolution dependence of "heavy rain" reproducibility

of days w/ R>=30 mm/day

OBS



110km

110km

150km

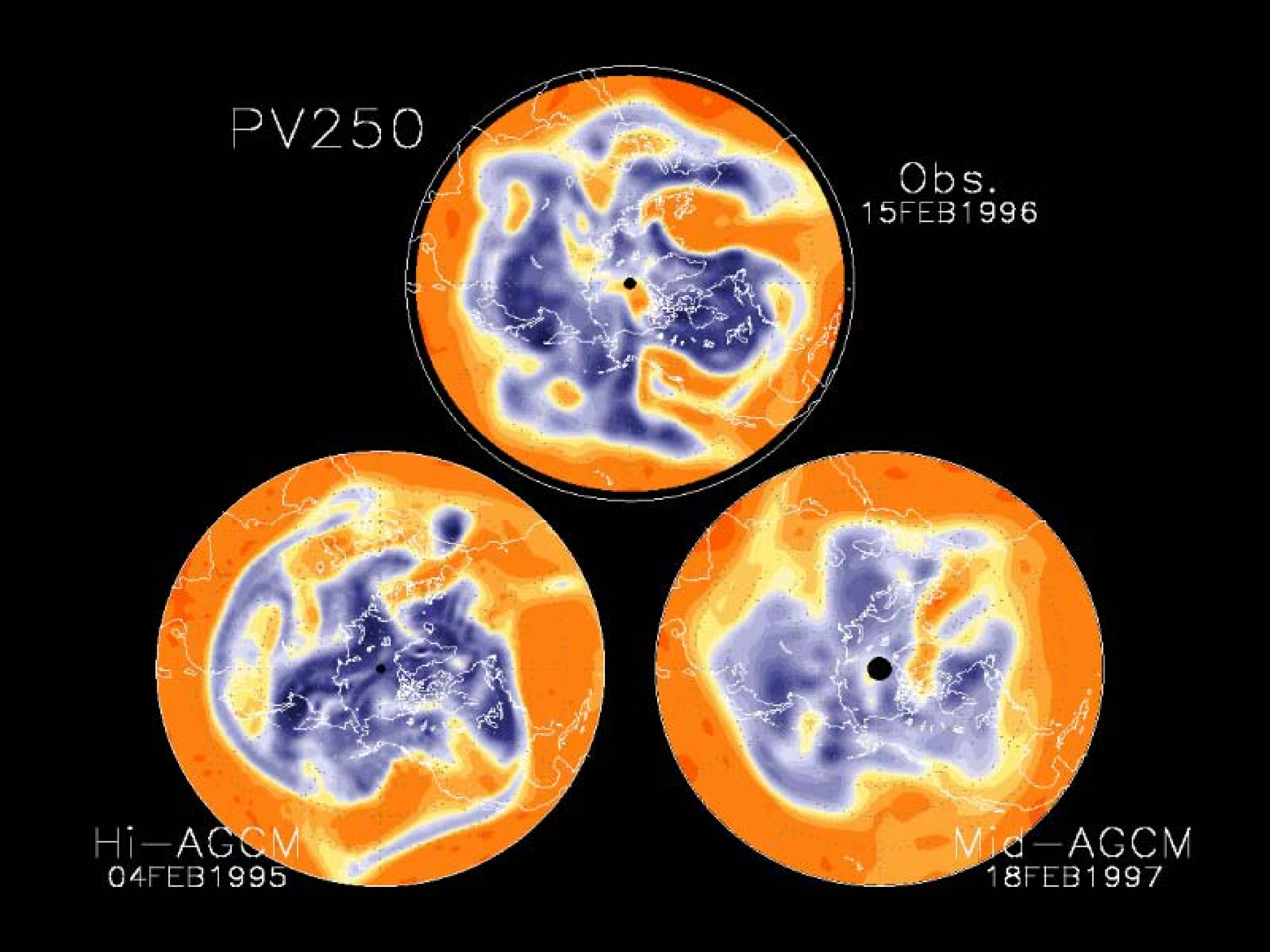
180km

180km

250km

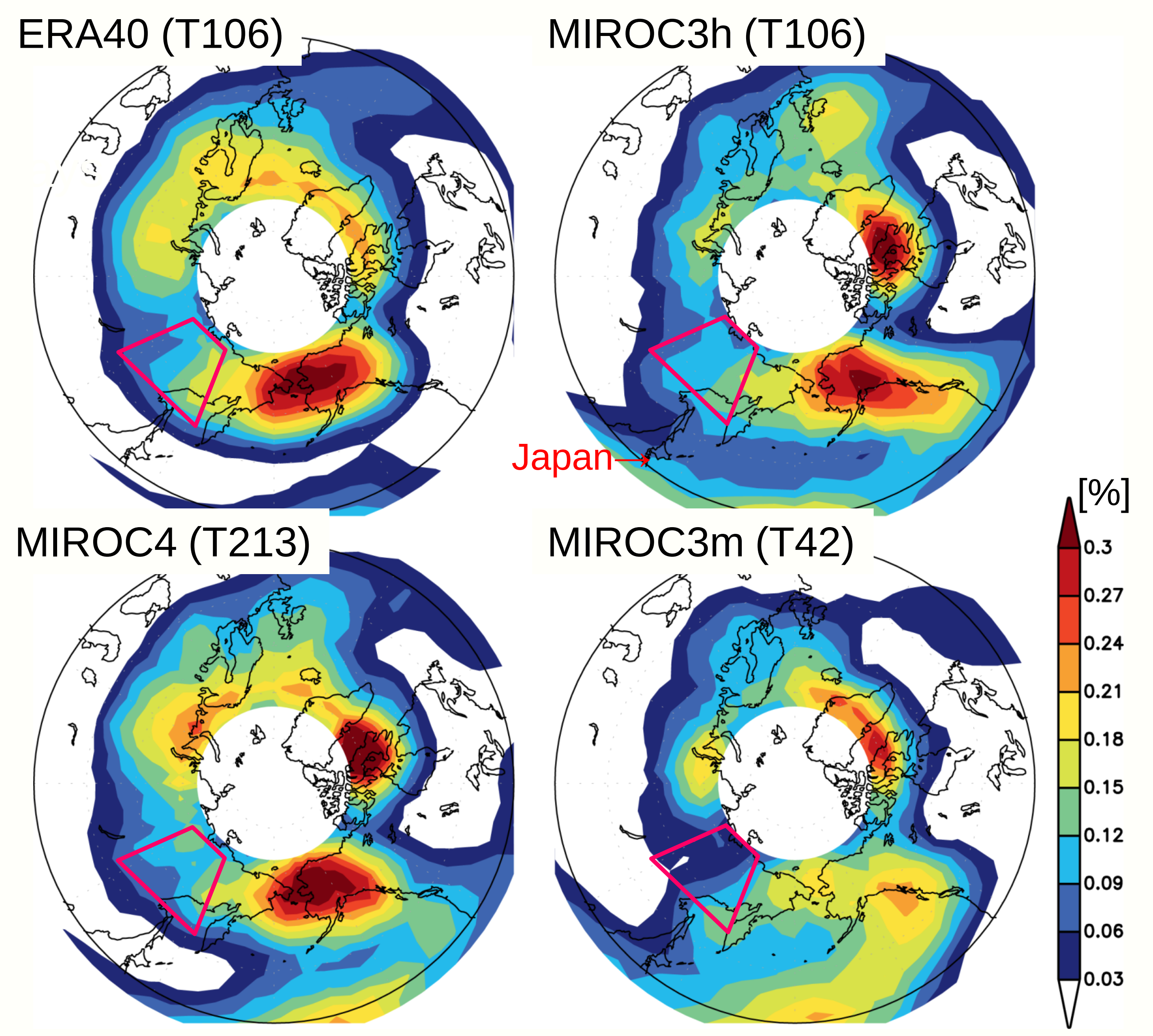
or coarser

Slide courtesy of Dr. Kusunoki (MRI)


PV250
Obs.
15FEB1996
Hi-AGCM
04FEB1995
Mid-AGCM
18FEB1997

Frequency of blocking

June-July
Persistent > 4

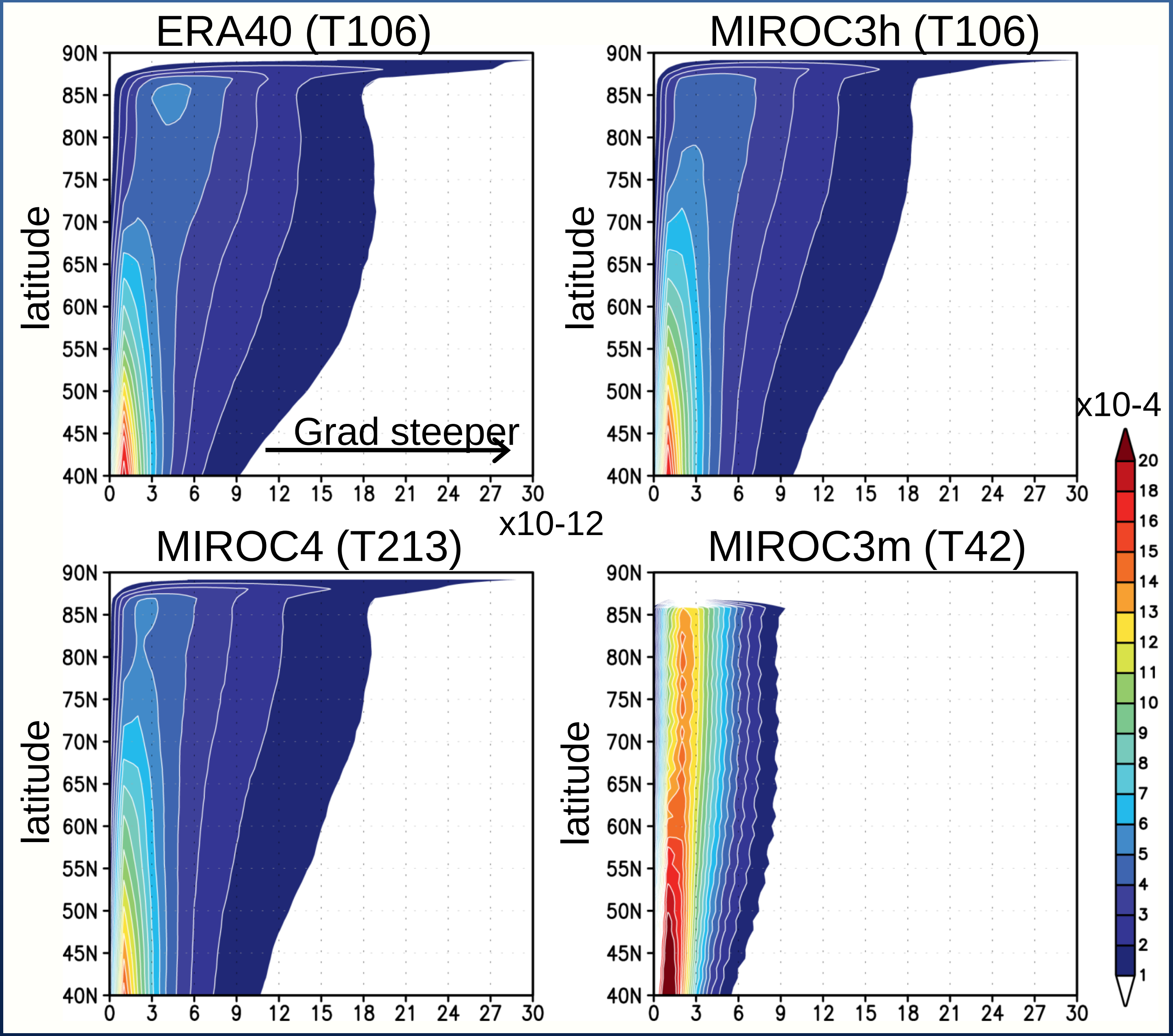


Slide courtesy of M. Mori

PDF of PV300 horizontal gradient

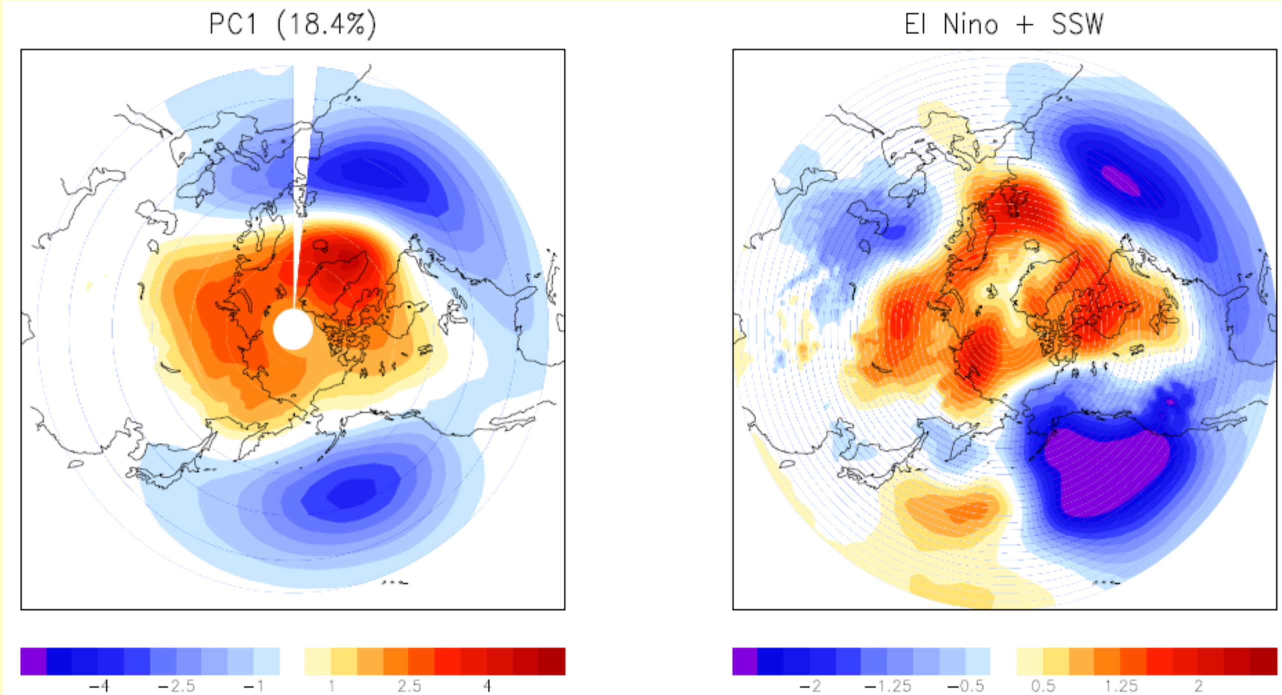
$$\Delta P_{300} = \left|\frac{\Delta P}{\Delta x}\right| + \left|\frac{\Delta P}{\Delta y}\right|$$

- 6 hourly
- On T106 grid



Slide courtesy of M. Mori

SLP
EOF1~AO

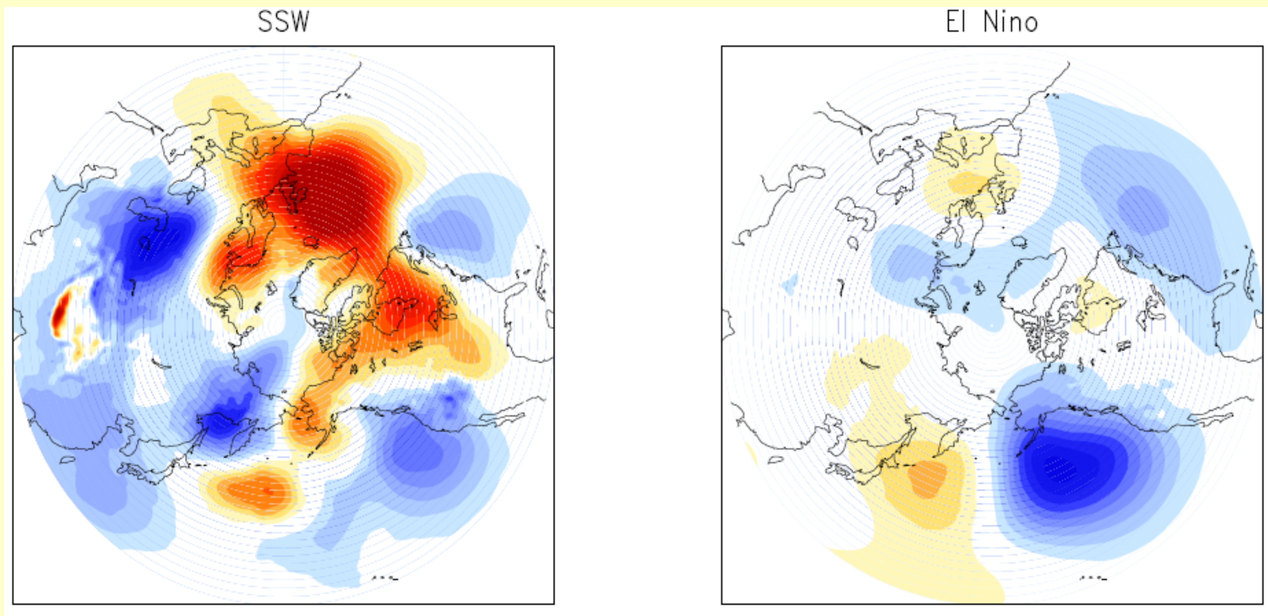


SLP
composite

ENSO
+
SSW

SLP
composite

SSW



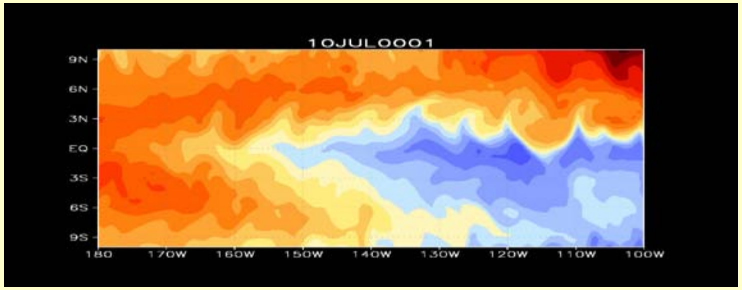
SLP
composite

ENSO

Cf. Ineson and Scaife (2009, NATURE GEOSCIENCE)

Imada & Kimoto (2010)

Tropical instability waves and their climatic impacts



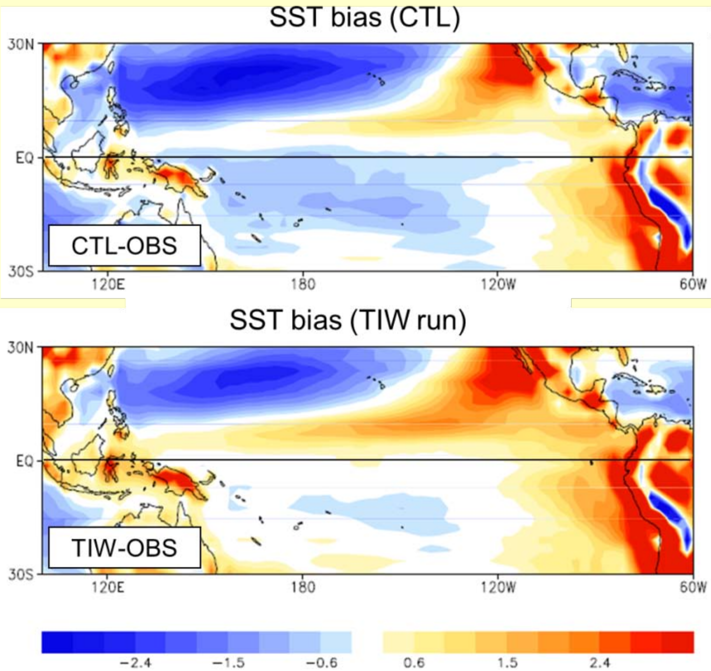
60km Atmos + 20-30km Ocean

Parameterization (Imada and Kimoto 2010)

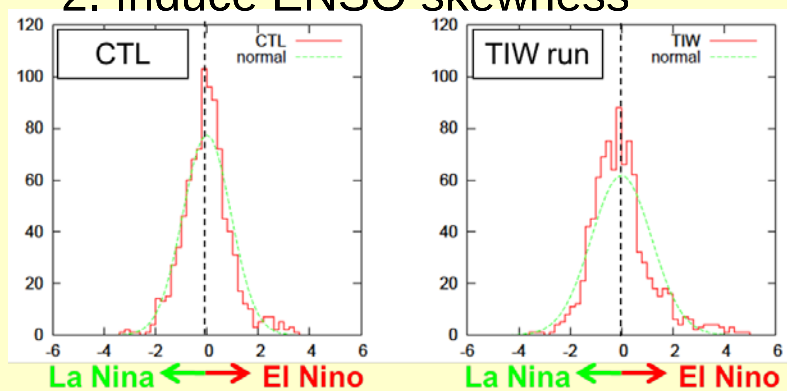
$$-\frac{\partial(v'T')}{\partial y} \sim -\frac{\partial}{\partial y^*} K_G \frac{\partial T}{\partial y^*},$$

$$\text{where } K_G = \alpha \frac{L^2}{T} = \alpha \frac{f}{\sqrt{Ri}} \frac{U}{\beta}$$

1. Reduce cold tongue bias



2. Induce ENSO skewness

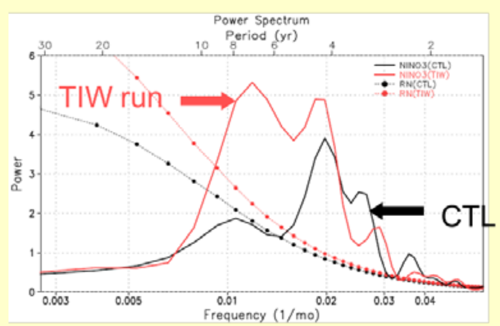


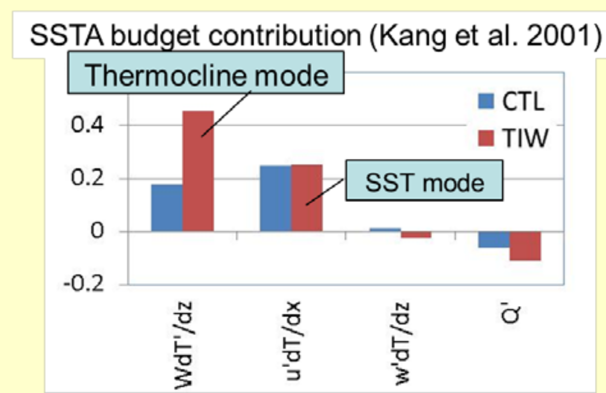
skewness: $\sqrt{b_1} = m_3 / m_2^{3/2}$

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

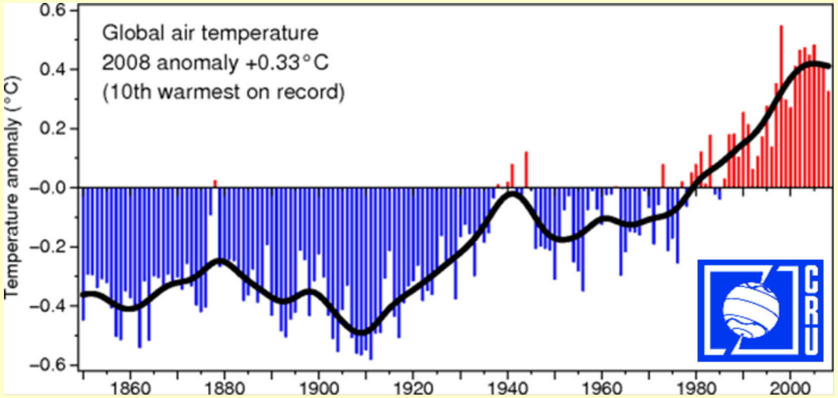
Hadisst (1950-1997)	0.89
CTL	**0.34**
TIW run	**0.95**

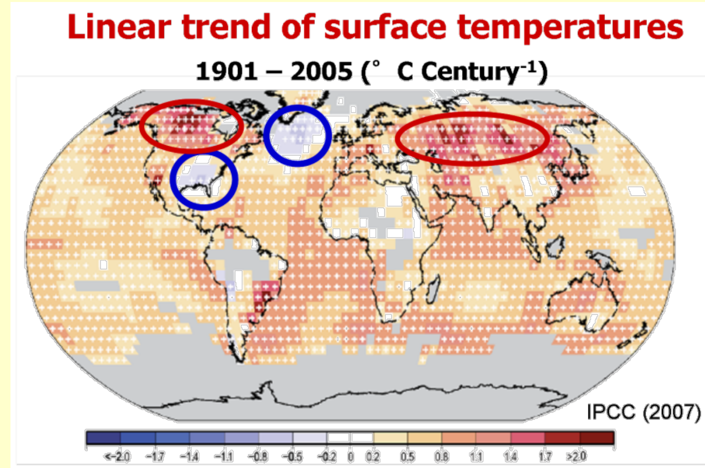
3. Affect ENSO regime



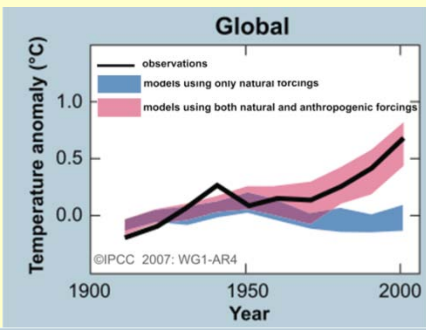


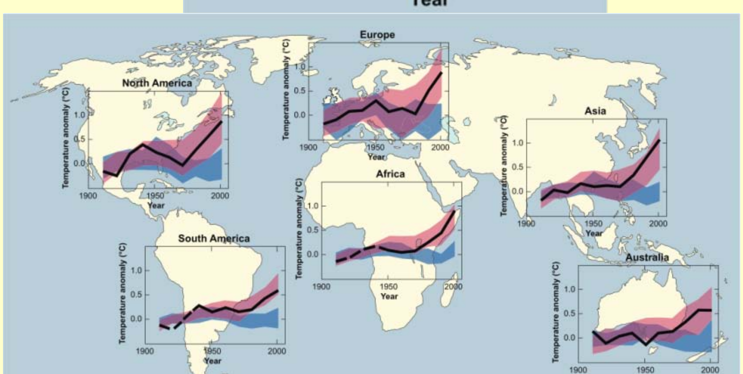
Forced + Natural Climate Change





Mixture of internal variability and forced climate change





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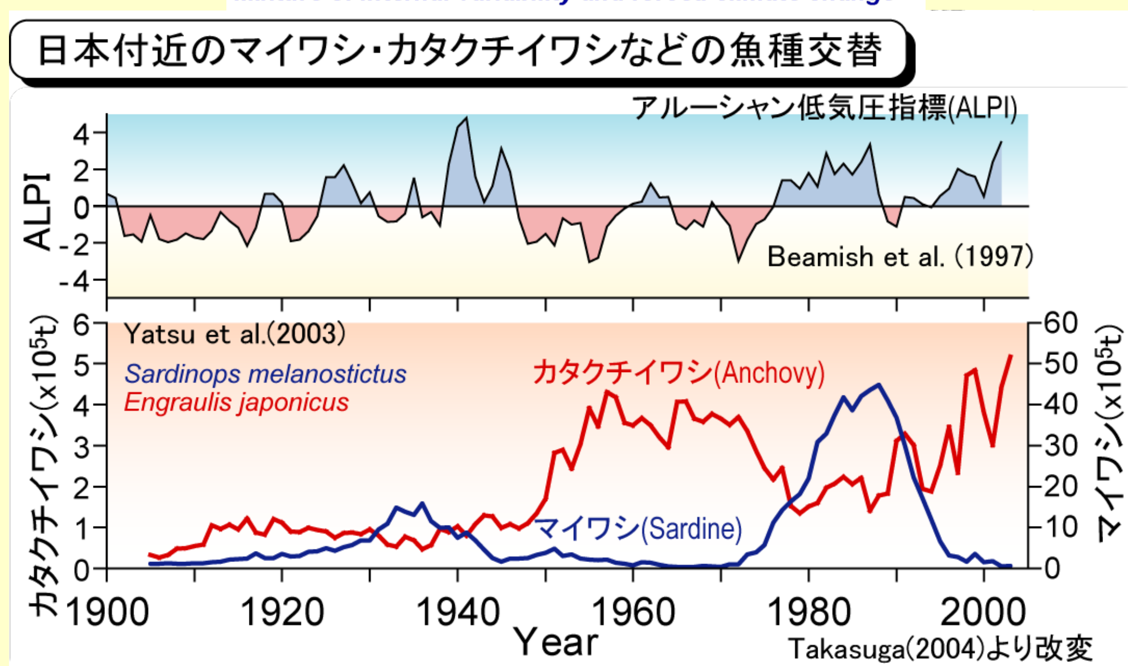
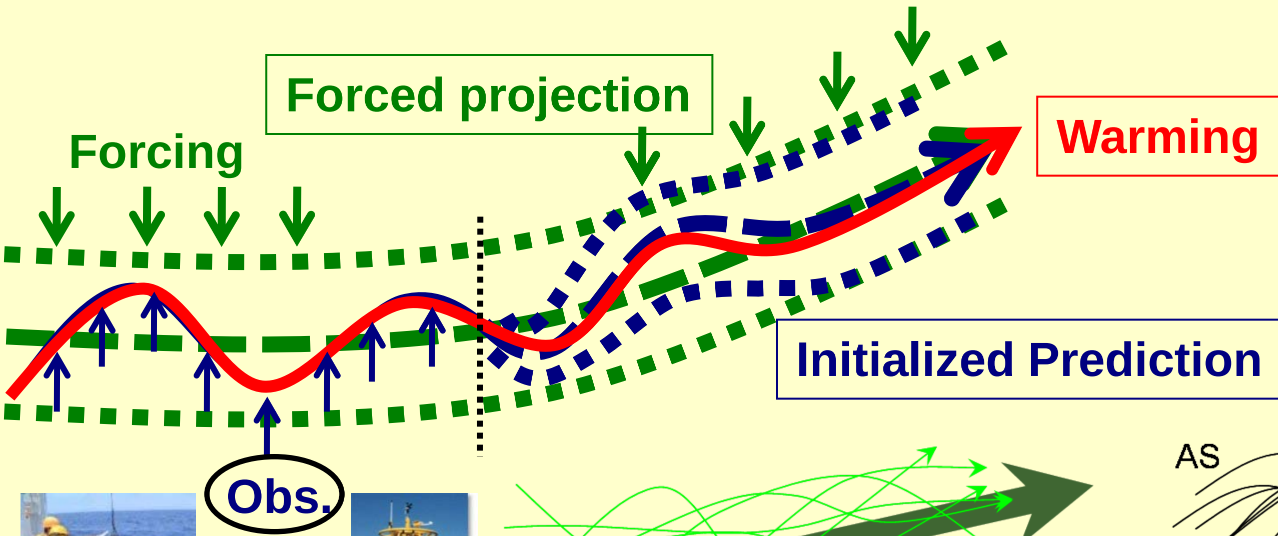
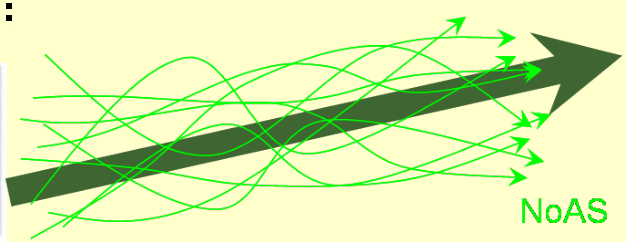
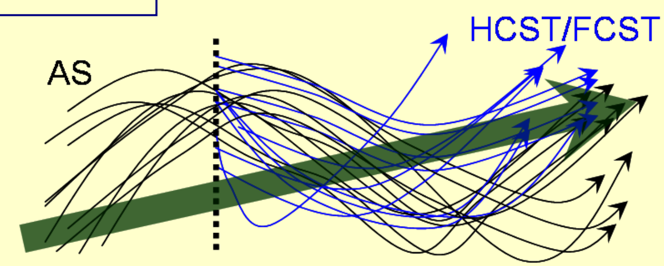
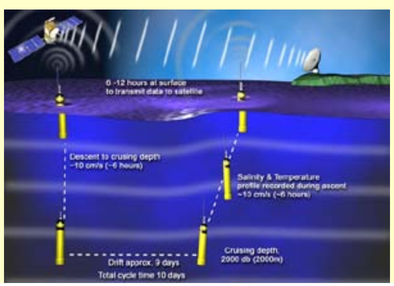


Decadal Prediction

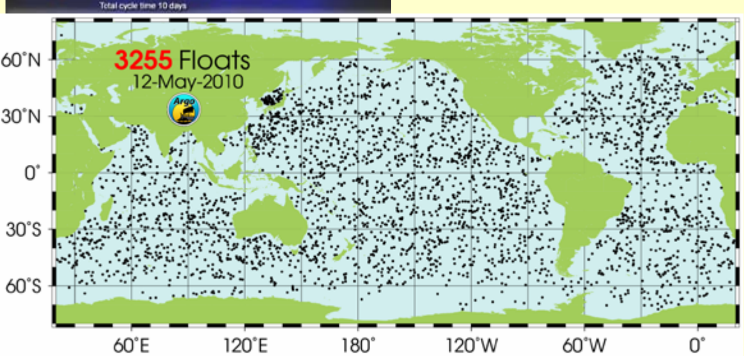


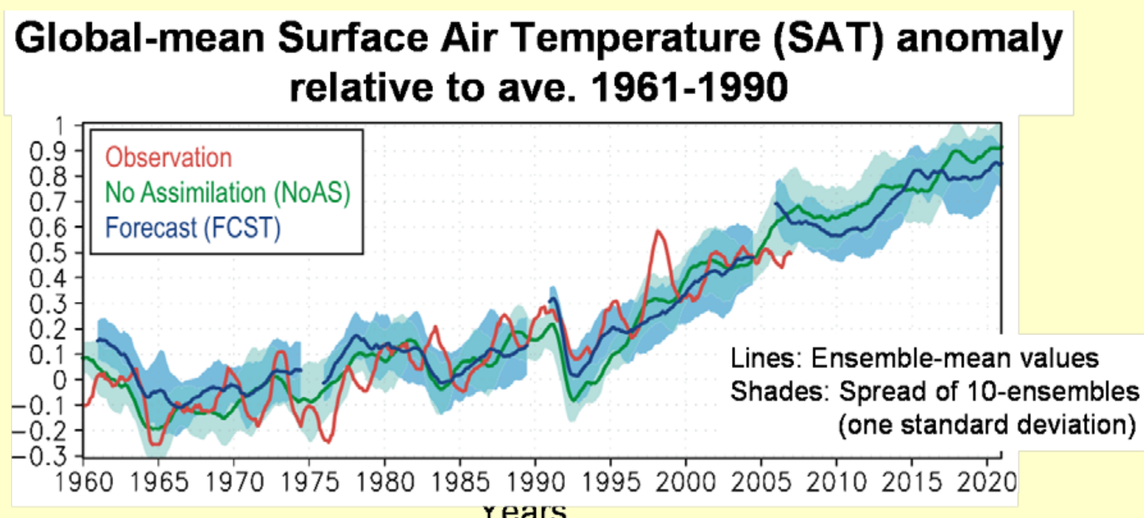






Argo subsurface ocean data network

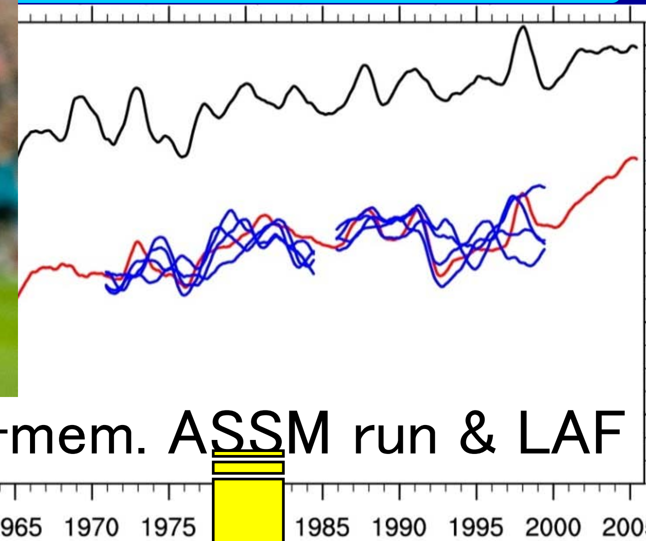




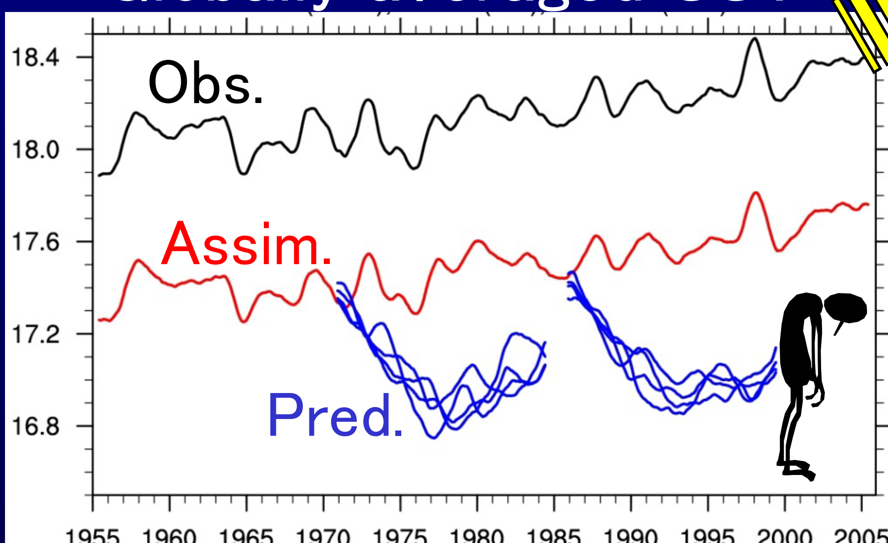
Mochizuki et al. (2010)

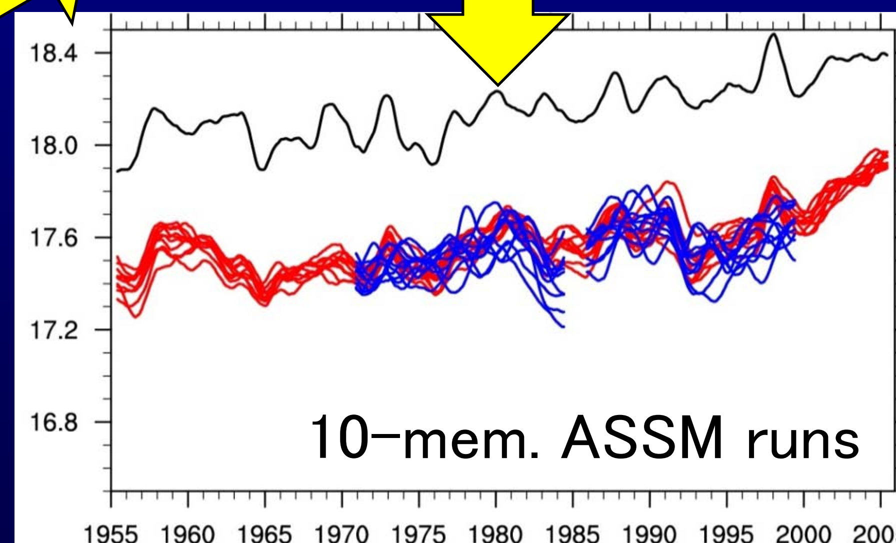
Preventing climate drift

- Anomalies of ocean temp. & sali. are assimilated into coupled model
- ~~Nudging~~ → IAU
- Weak assimilation



Globally averaged SST

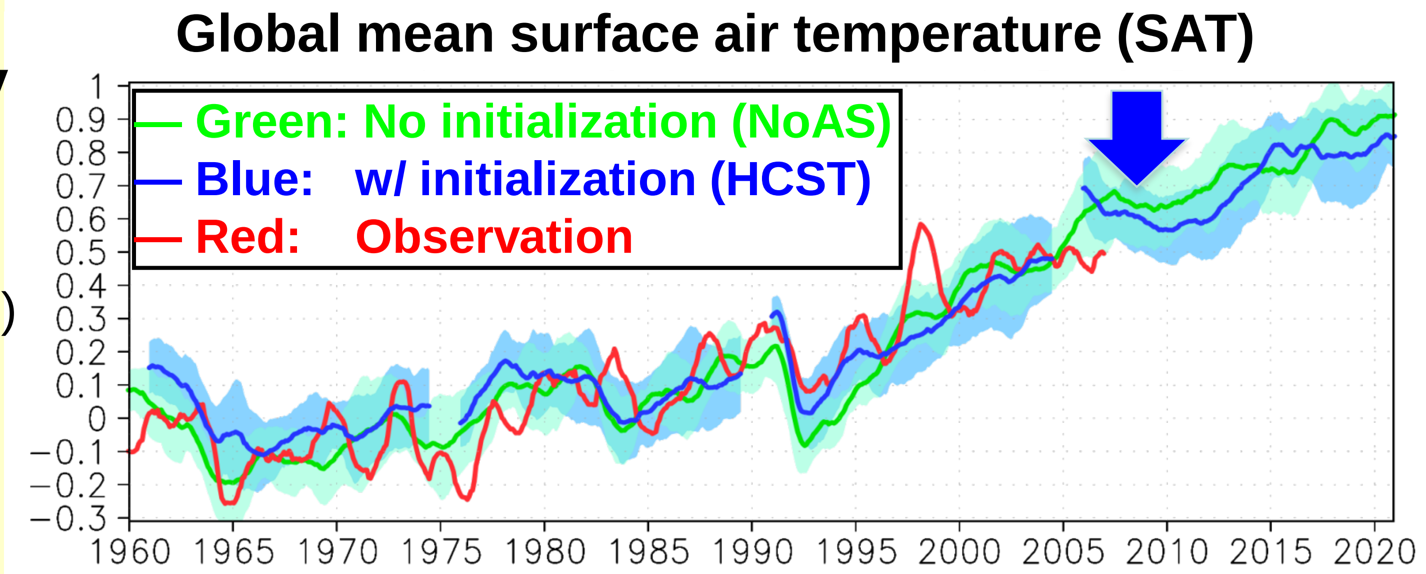




The anomaly assimilation: Smith et al. (2007), Keenlyside et al. (2008)

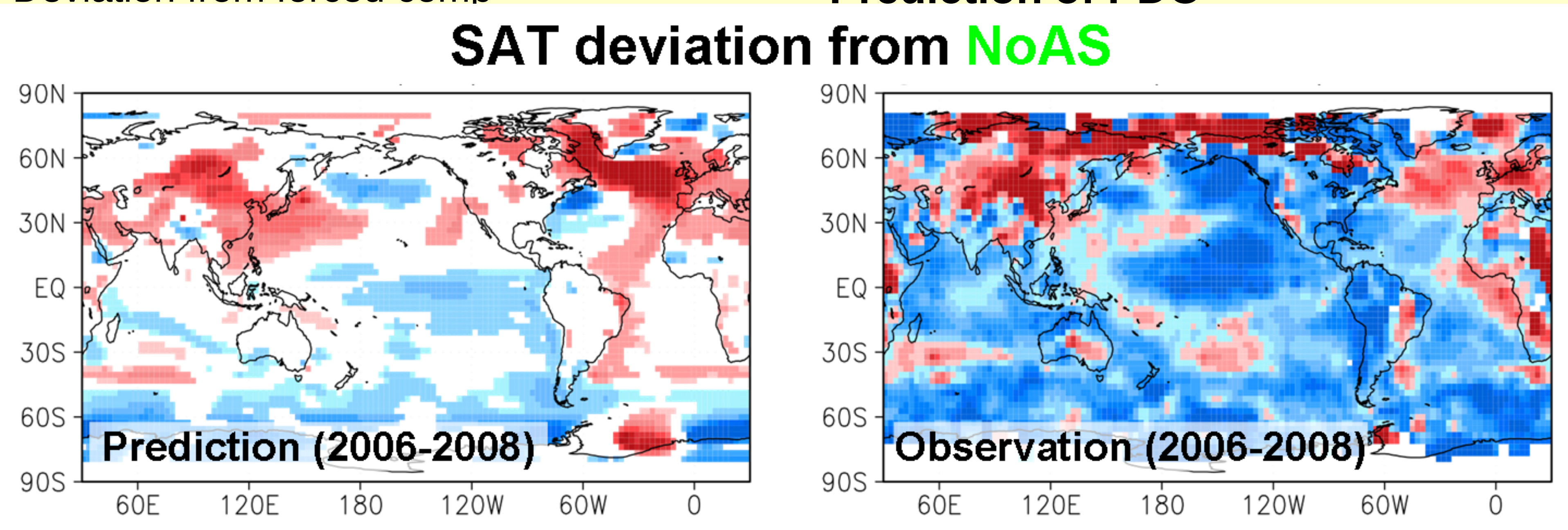
Predictability of PDO

Mochizuki et al. (2010)



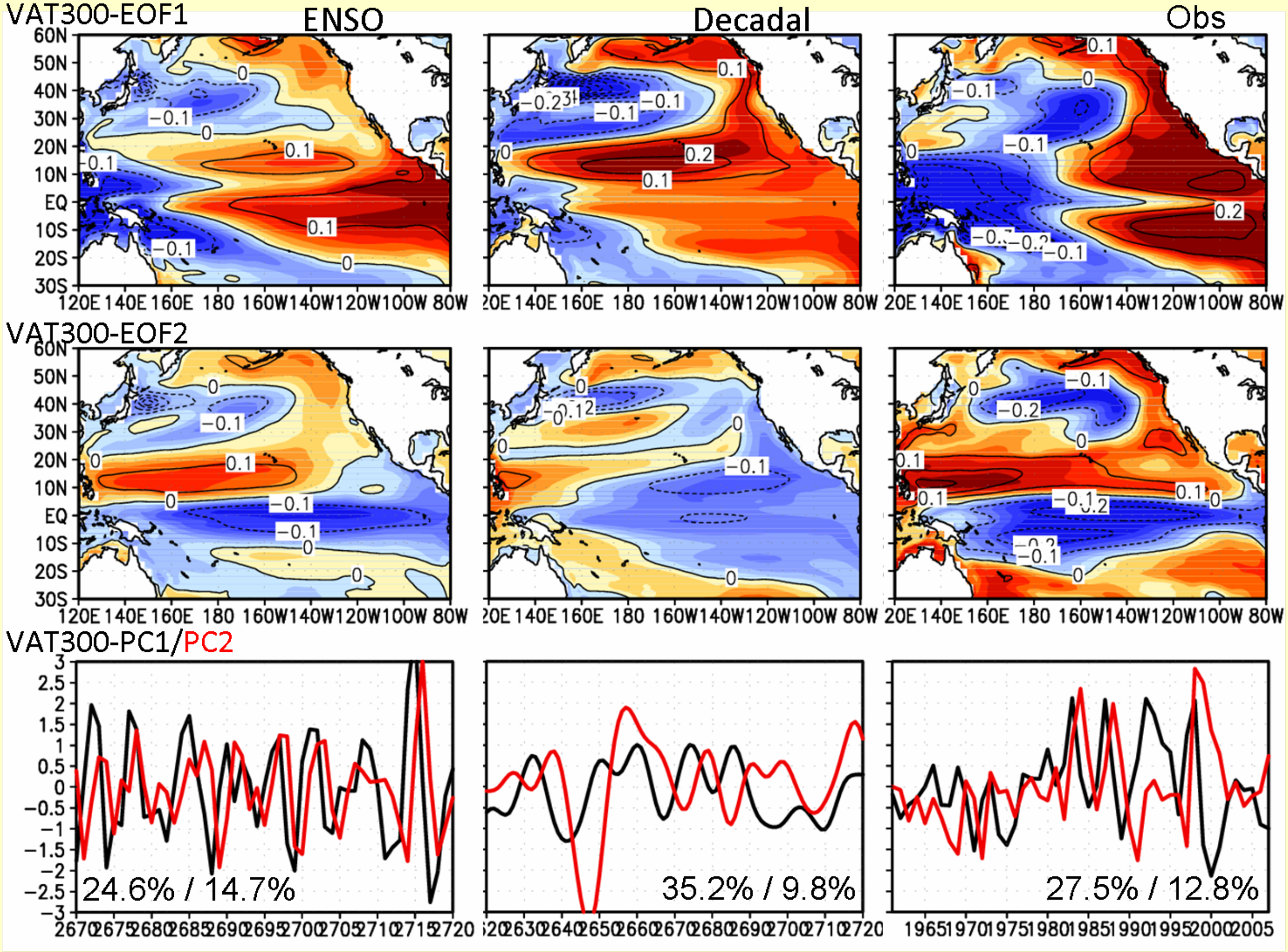
Deviation from forced comp

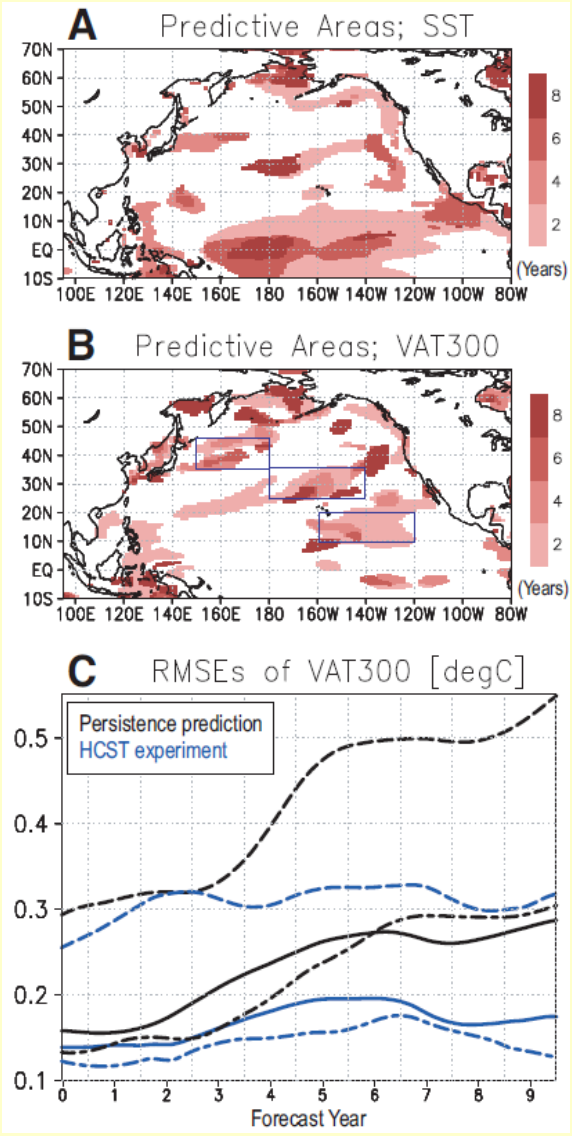
Prediction of PDO



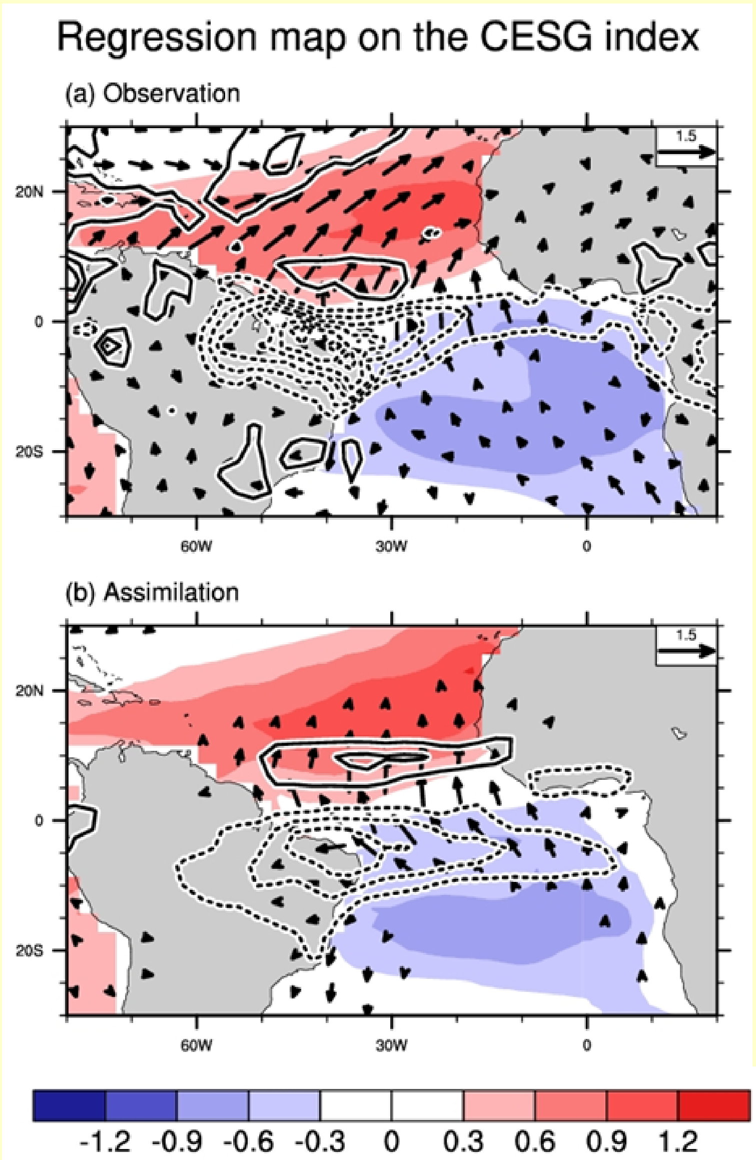
Lead time (yr)

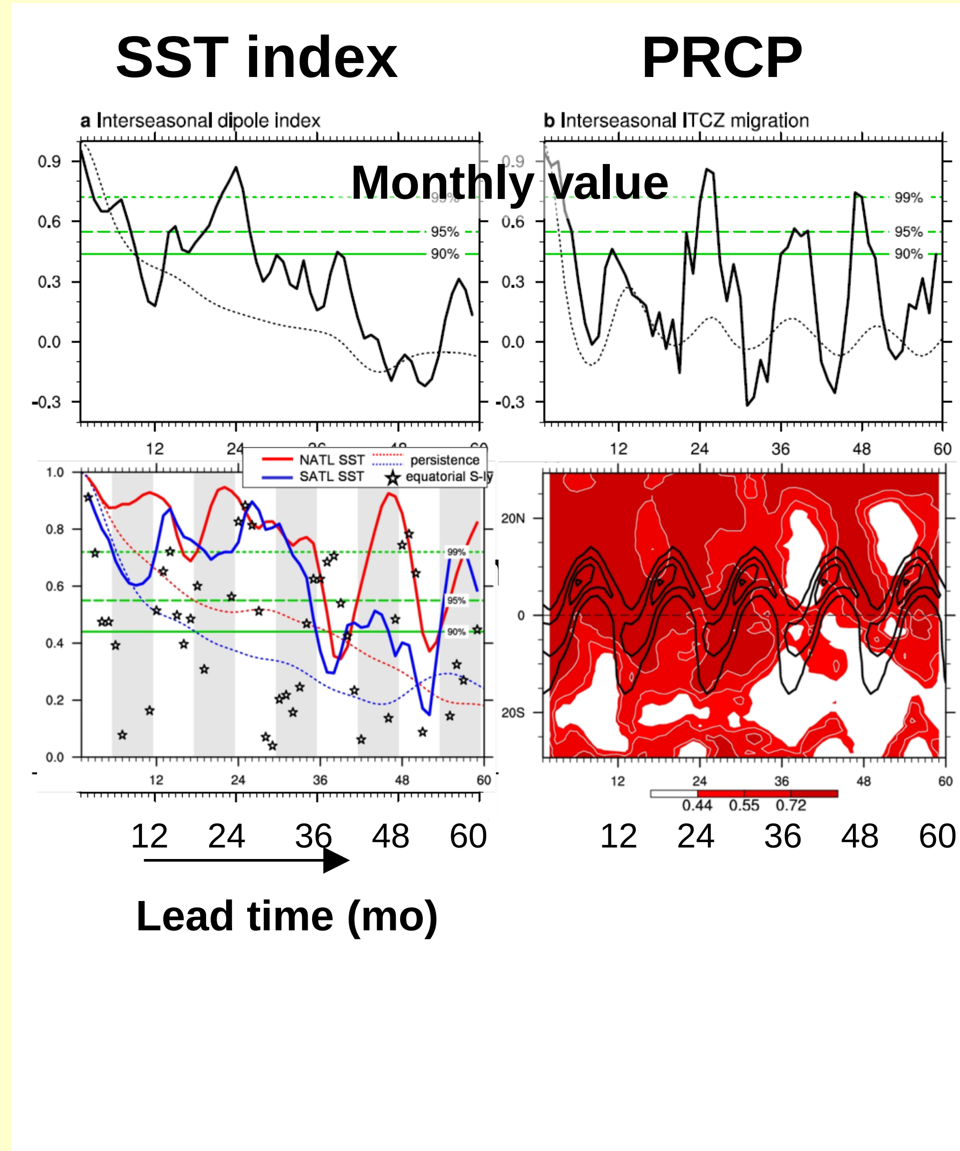
Subsurface memory





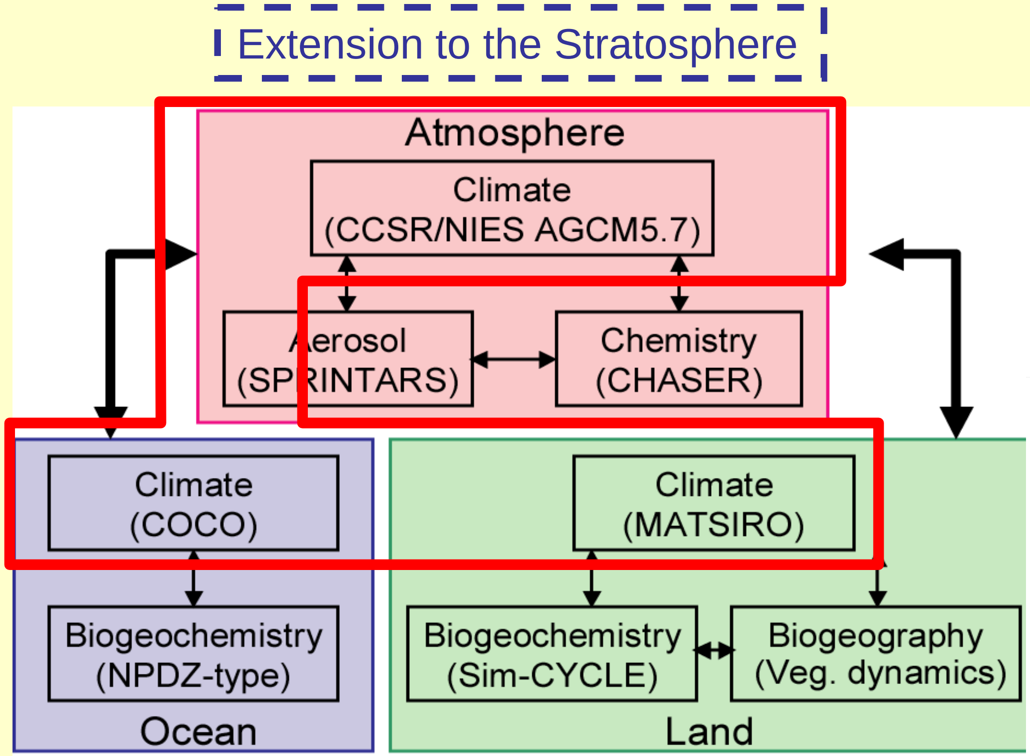
Tropical Atlantic dipolar mode

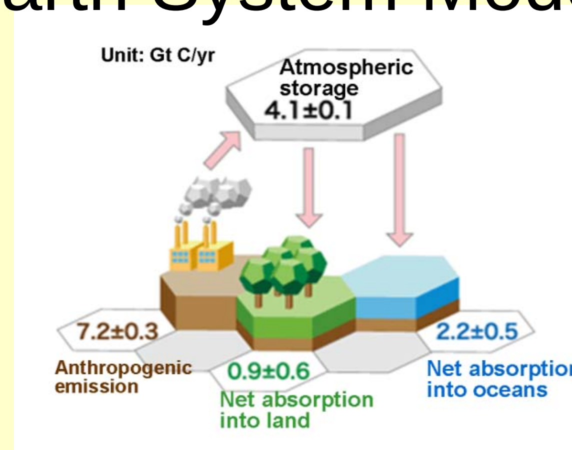




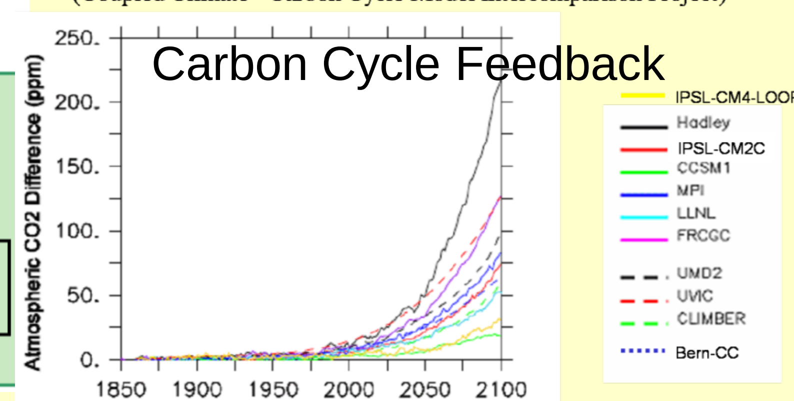
Chikamoto et al. (2010)

MIROC-ESM: MIROC-based Earth System Model

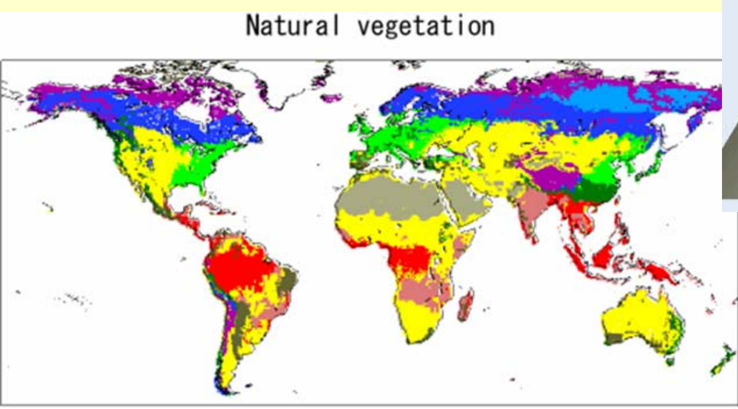




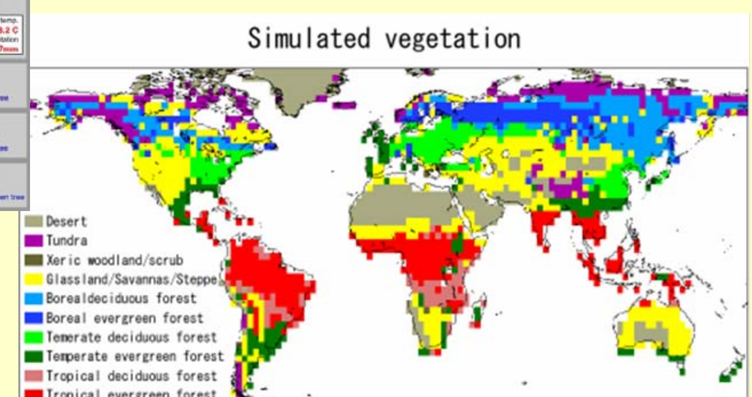
(Coupled Climate - Carbon Cycle Model Intercomparison Project)

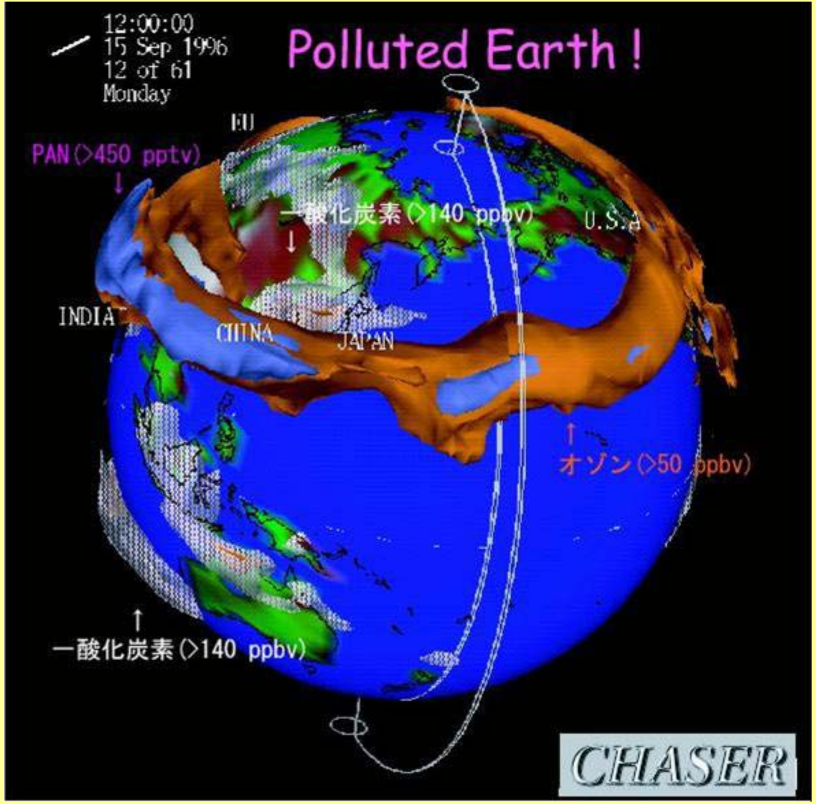


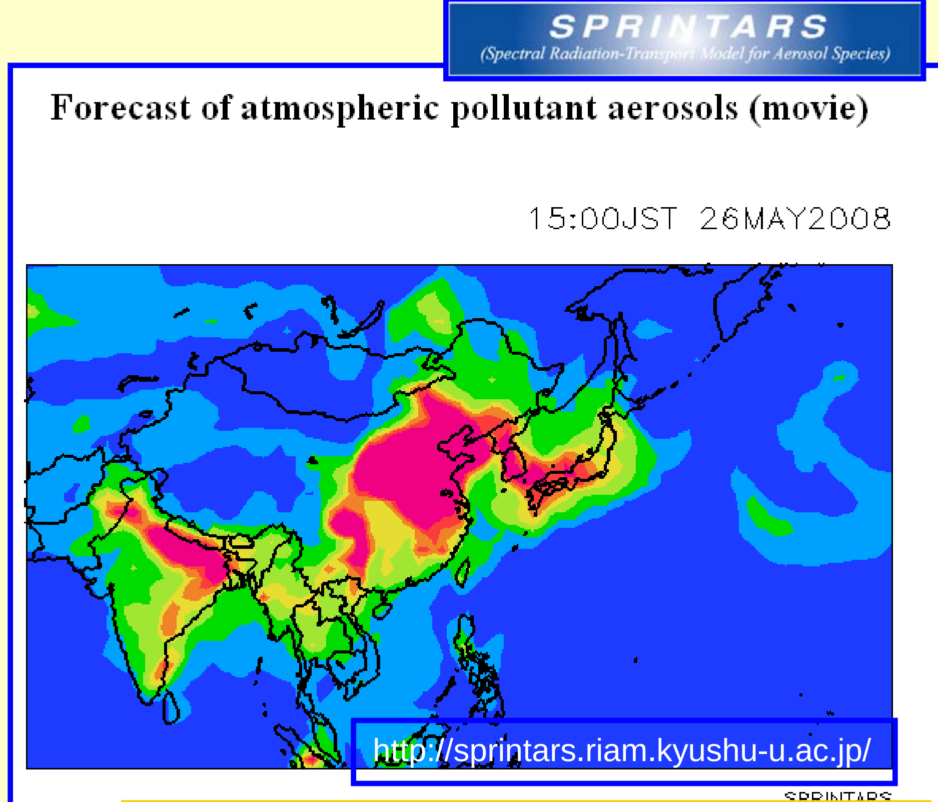
Friedlingstein et al. (2005, JC, in press)

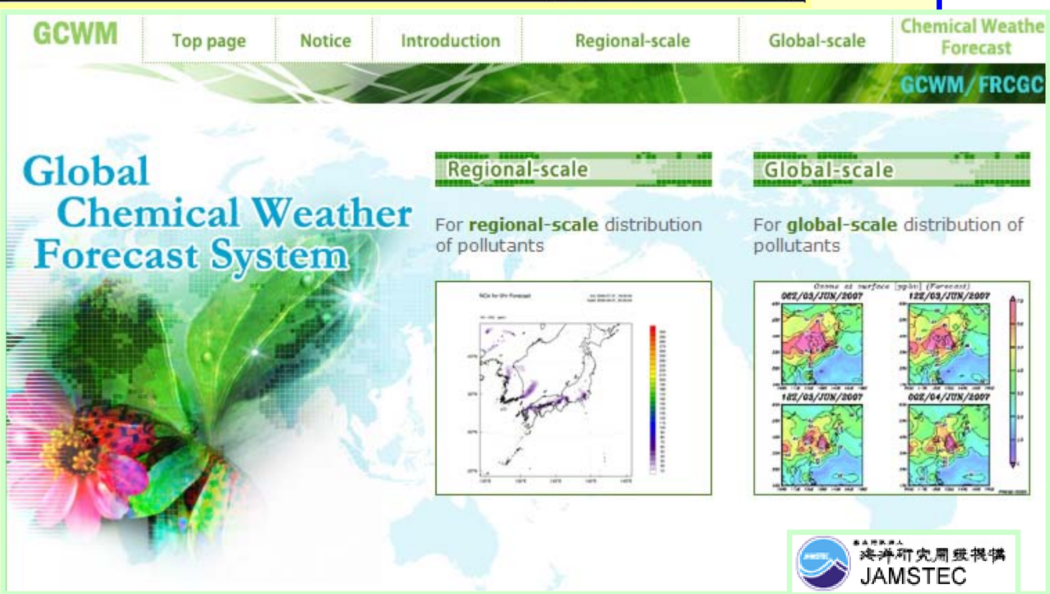


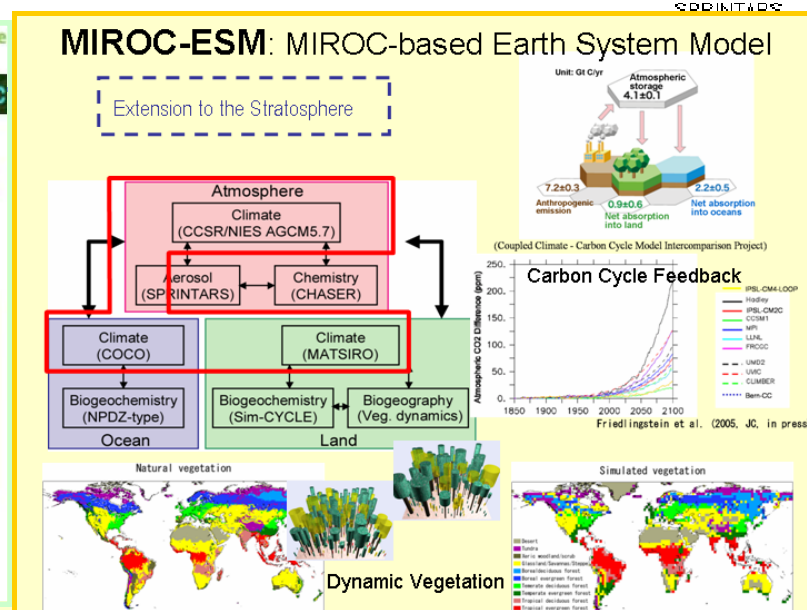
Dynamic Vegetation




12:00:00
15 Sep 1996
12 of 61
Monday
Polluted Earth !
EU
PAN (>450 pptv)
一酸化炭素 (>140 ppbv)
U.S.A
INDIA
CHINA
JAPAN
オゾン (>50 ppbv)
一酸化炭素 (>140 ppbv)
CHASER

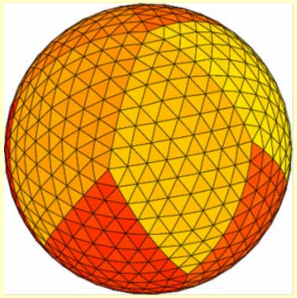

SPRINTARS
(Spectral Radiation-Transport Model for Aerosol Species)
Forecast of atmospheric pollutant aerosols (movie)
15:00JST 26MAY2008
http://sprintars.riam.kyushu-u.ac.jp/


GCWM
Top page
Notice
Introduction
Regional-scale
Global-scale
Chemical Weather Forecast
GCWM/FRCGC
Global Chemical Weather Forecast System
Regional-scale
For regional-scale distribution of pollutants
Global-scale
For global-scale distribution of pollutants
JAMSTEC

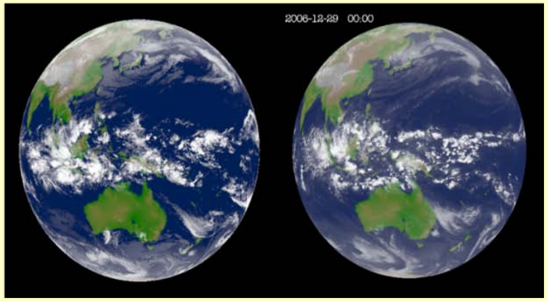

MIROC-ESM: MIROC-based Earth System Model
Extension to the Stratosphere
Atmosphere
Climate (CCSR/NIES AGCM5.7)
Aerosol (SPRINTARS)
Chemistry (CHASER)
Climate (COCO)
Biogeochemistry (NPDZ-type)
Ocean
Climate (MATSIRO)
Biogeochemistry (Sim-CYCLE)
Biogeography (Veg. dynamics)
Land
Unit: Gt C/yr
Atmospheric storage 4.1±0.1
7.2±0.3
Anthropogenic emission
0.9±0.6
Net absorption into land
2.2±0.5
Net absorption into oceans
(Coupled Climate - Carbon Cycle Model Intercomparison Project)
Carbon Cycle Feedback
Atmospheric CO2 Difference (ppm)
Friedlingstein et al. (2005, JC, in press)
Natural vegetation
Simulated vegetation
Dynamic Vegetation

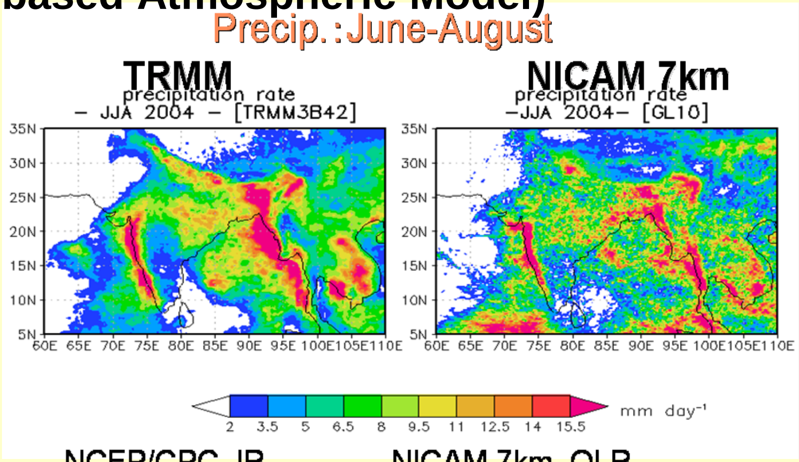
A Global Cloud System Resolving Model

NICAM (Non-hydrostatic ICosahederal grid-based Atmospheric Model)

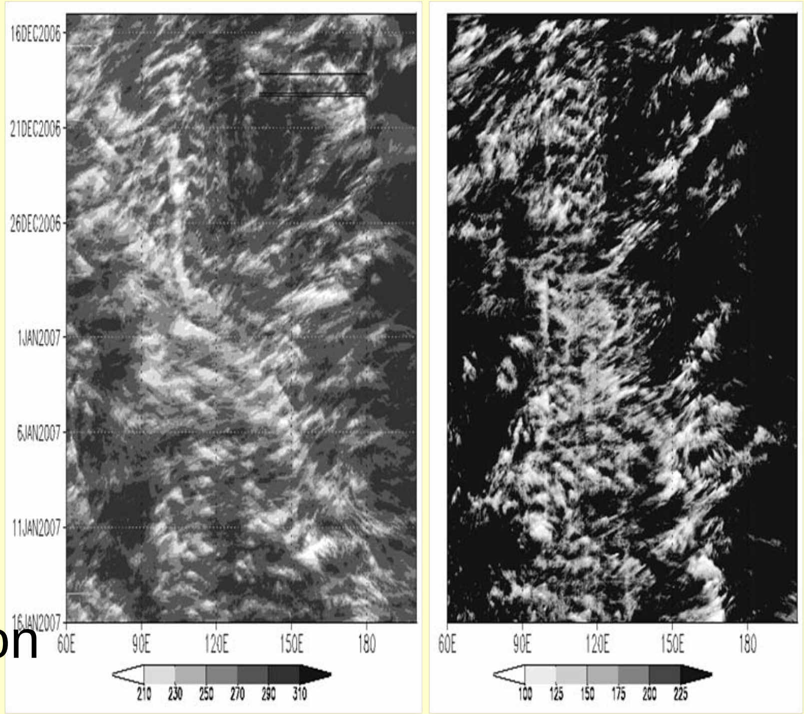


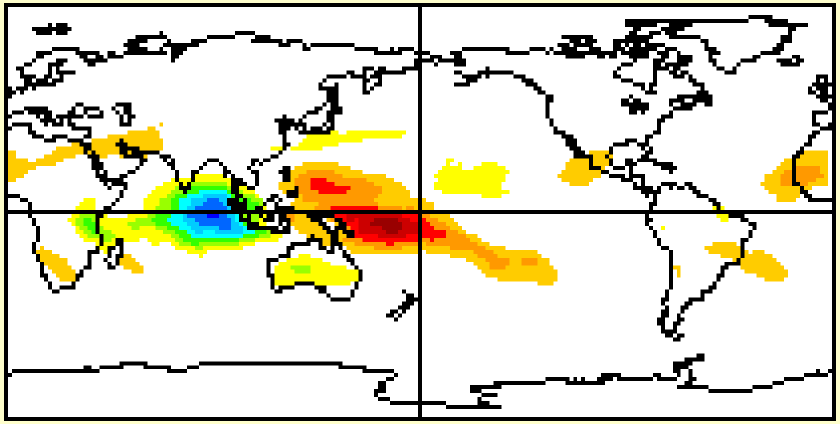
MTSAT-1R, IR NICAM 3.5km, OLR





NCEP/CPC IR NICAM 7km, OLR



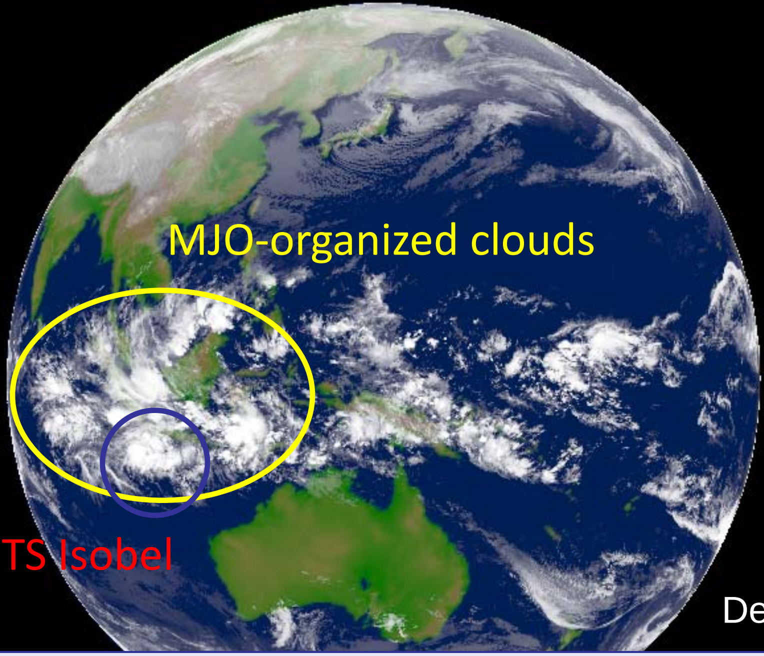


MJO simulation

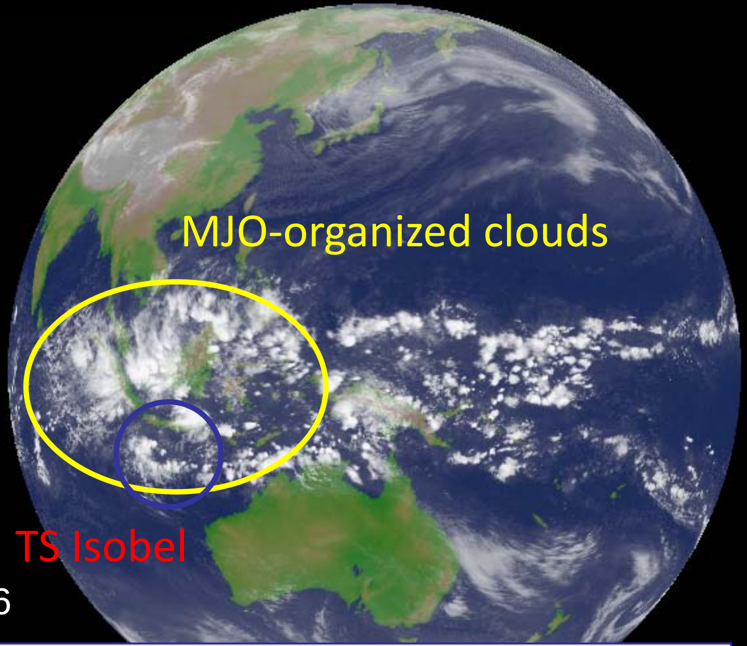
Miura et al. (2007,Science), Nasuno et al. (2009,JMSJ), Fudeyasu et al. (2009, GRL), Liu et al. (2009, MWR)

2-week forecast of TC genesis?

MTSAT-1R

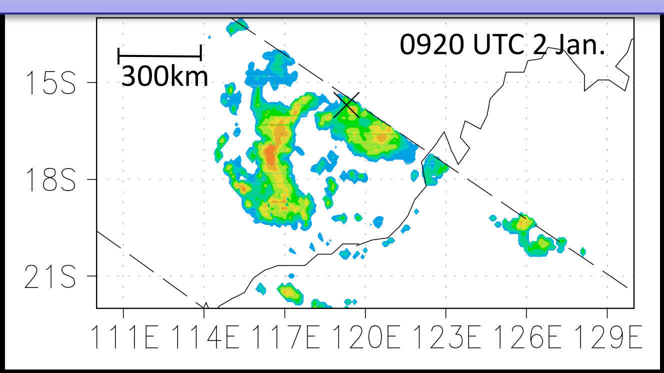


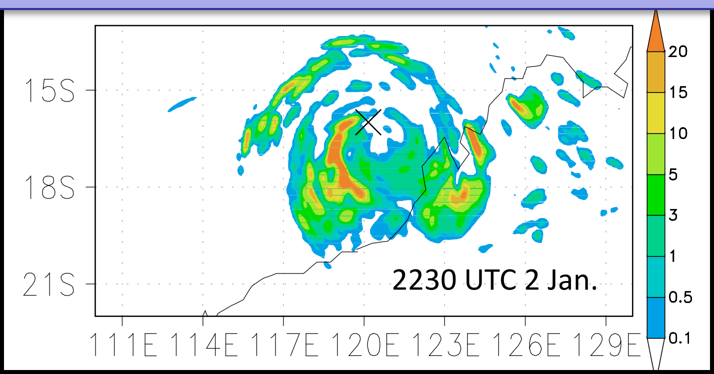
NICAM



Dec. 29 2006

NICAM reasonably produced not only the large-scale circulation, such as the MJO, but also the embedded mesoscale features, such as TC rainbands.

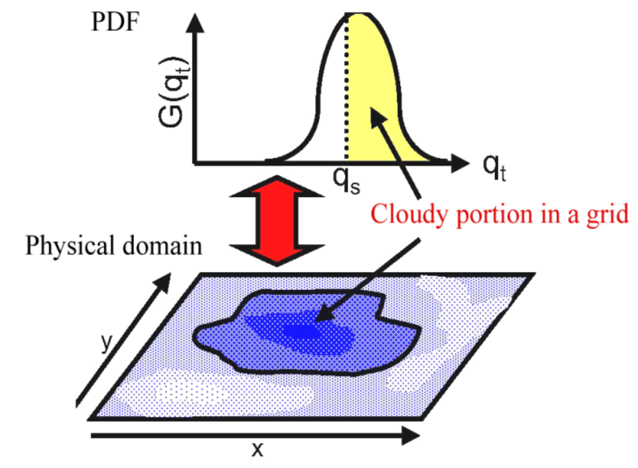




New LSC scheme

- ✓ Assume a subgrid-scale distribution of q_t' or $s=a_L(q_t'-\alpha_L T_l')$?
- ✓ Predict condensate amount and cloud?

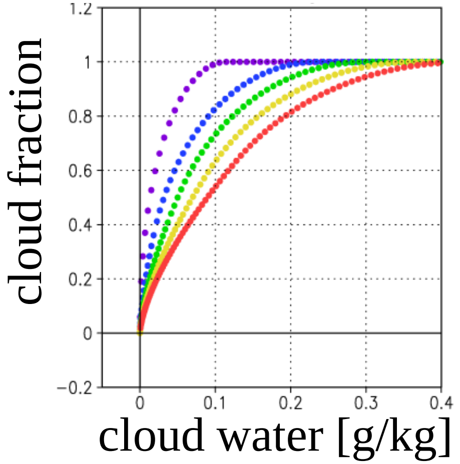
$$C=\int_{-Q_c}^{\infty} G(s)ds \ , \quad q_c=\int_{-Q_c}^{\infty}(Q_c+s)G(s)ds \ , \quad Q_c=a_l\left\{\bar{q}_t-q_s(\bar{T}_l,\bar{p})\right\}$$



Tompkins (2005)

- ✓ Prognostic equations for PDF variance & skewness
- ✓ Quasi-reversible operator between grid quantities & PDF

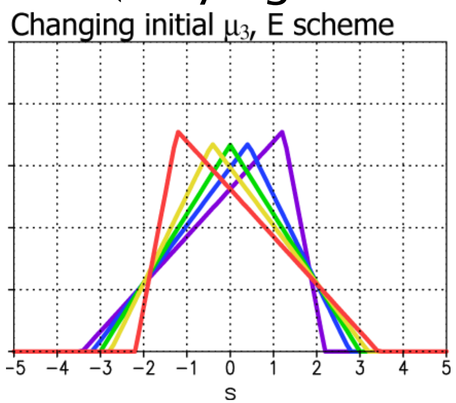
C–q_c relationship



$$C, q_c \leftrightarrows \mathcal{V}, S$$

Similar approach:
Tompkins (2002, JAS)
Wilson & Gregory (2003, QJ)

Basis PDF (varying skewness)

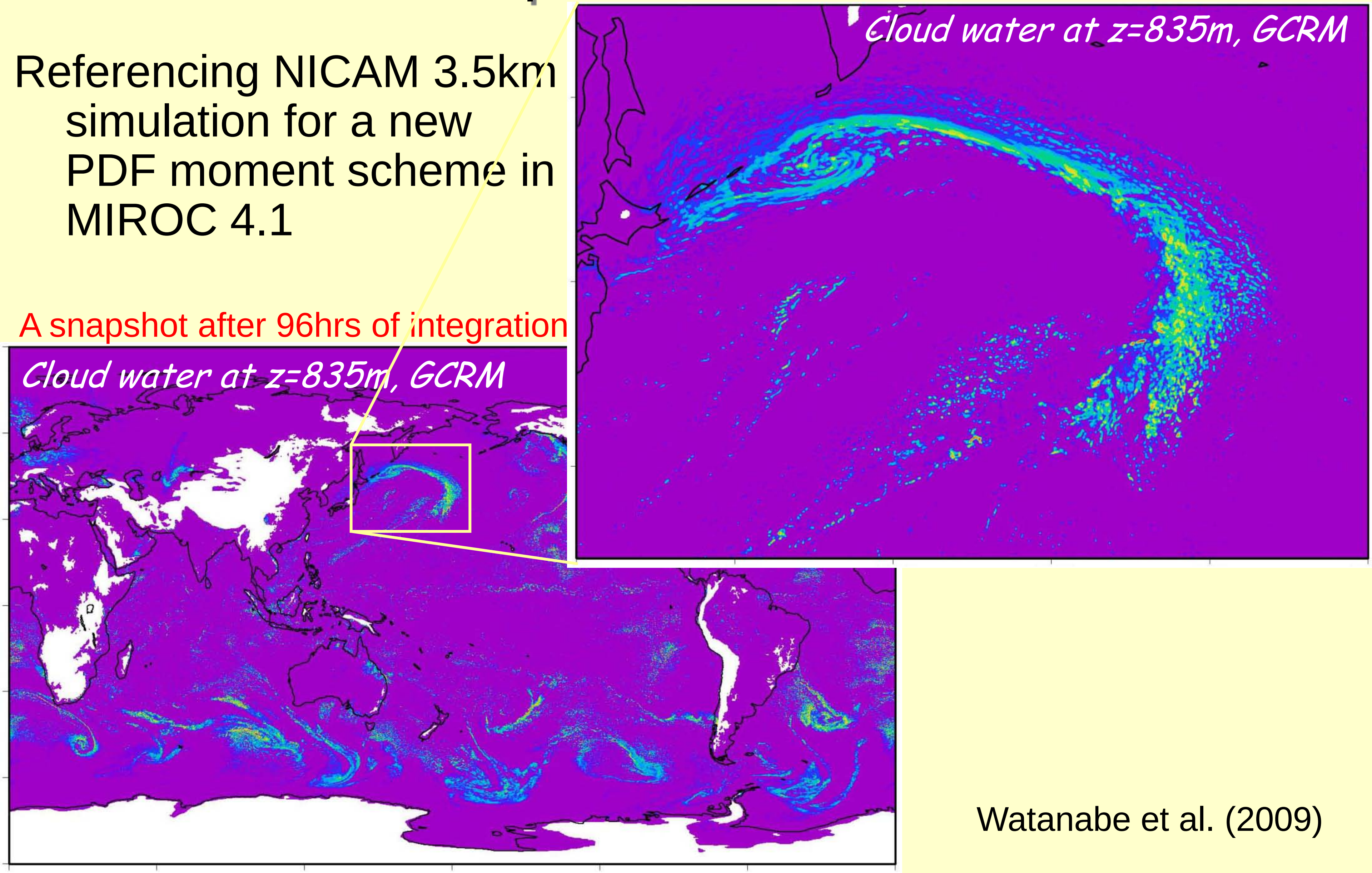


Watanabe et al. (2009)

Cloud system resolving model guiding new GCM parameterizations

Referencing NICAM 3.5km simulation for a new PDF moment scheme in MIROC 4.1

A snapshot after 96hrs of integration



Watanabe et al. (2009)