International Workshop on Development of Atmosphere–Ocean Coupled Model towards Improvement of Long-Range Forecast
Japan Meteorological Agency, Tokyo, Japan, December 8–10, 2010

CFES: Coupled GCM for the Earth Simulator —Current status and future directions—

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CFES Project

CFES is developed to study *mechanisms* and *predictability* of high-impact phenomena especially in the *mid-latitudes* and their relation to global-scale circulations (rather than for global warming issues)

- The mid-latitude region
  - ... is affected from both the *tropical* and *polar* regions
  - ... has its own basin-scale and **local** air–sea interactions

➡Necessity of a **global**, **high-resolution**, coupled atmosphere–ocean model including land-surface and sea-ice processes

CFES will be used as a platform for *observing system (simulation) research* using ensemble-based data assimilation methods (rather than for operational prediction)

Outline of Talk

Model Development & Simulation Research

- Component Models of CFES
- Set Up for CFES
- Some Results
- Ongoing Efforts and Future Directions

Ensemble Data Assimilation & Observing System Research

- Current Status: AFES-LETKF
- Future Directions: CFES-LETKF

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Component Models of CFES

AFES (AGCM for the ES): Atmosphere & Land-Surface Component

- ... is adopted from **CCSR/NIES AGCM 5.4** and rewritten for the ES
- ... is improved for high-resolution and coupled simulations
- ... has better reproducibility of marine boundary-layer clouds
- In detail, see *Ohfuchi et al. (2004)*, *Enomoto et al. (2008)*, and *Kuwano-Yoshida et al. (2010)*, respectively.

OFES (OGCM for the ES): Ocean & Sea-Ice Component

- ... is based on **GFDL MOM 3.0** and optimized for the ES
- ... contains dynamic–thermodynamic sea-ice model
- In detail, see *Masumoto et al. (2004)* and *Komori et al. (2005).*

Atmosphere & Land-Surface Component

Horizontal Discretization: spherical harmonics

Vertical Coordinate: sigma-coordinate, Lorenz grid

Physical Processes

- radiation: mstrn-X (Sekiguchi and Nakajima, 2008)
- cumulus convection: Emanuel and Zivkovic-Rothman (1999)
- **grid-scale cloud**: use of joint-Gaussian PDF of liquid water potential temperature and total water content *(Kuwano-Yoshida et al., 2010)*

Ocean-Surface Processes

- **surface wind stress**: dependency on ocean surface currents

Land-Surface: MATSIRO (Takata et al., 2003)

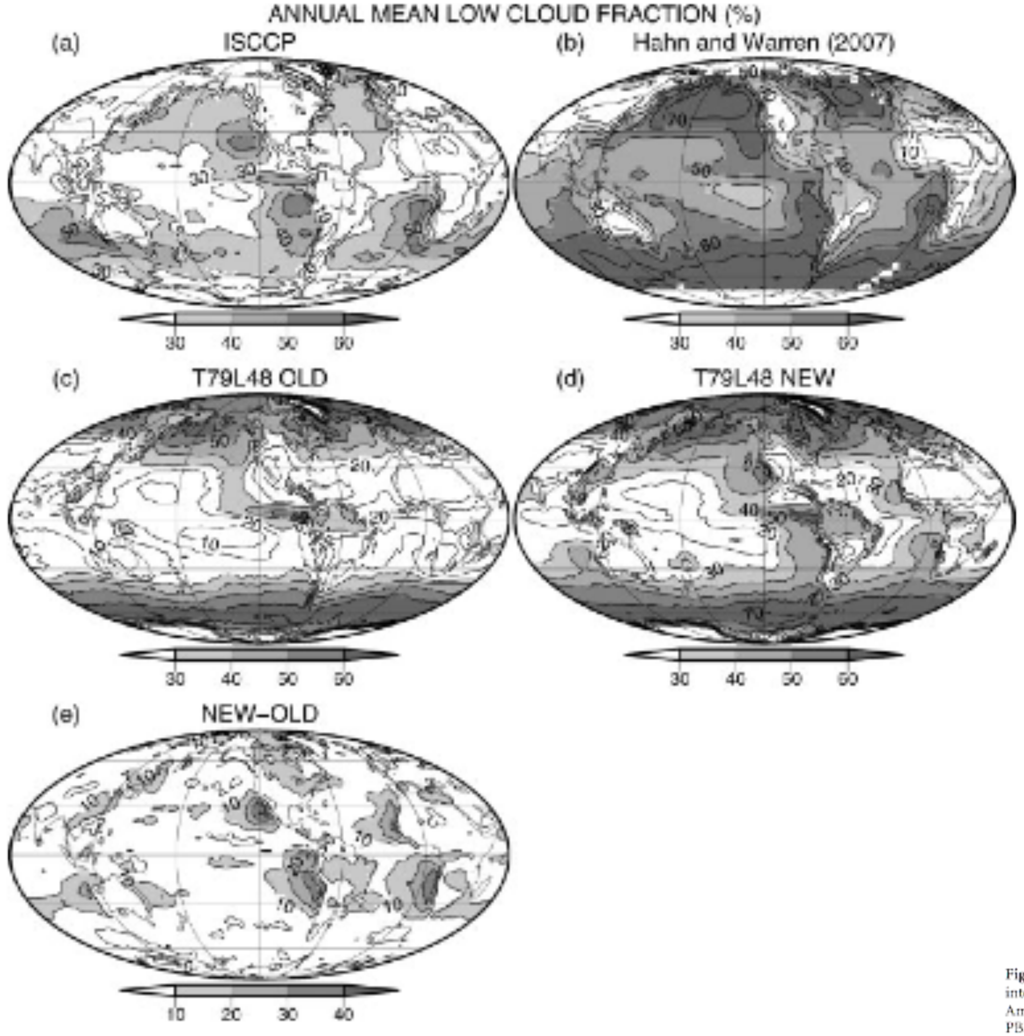


Figure 5. Annual mean low cloud fraction (%) for (a) ISCCP, (b) surface observation climatology by Hahn and Warren (2007), (c) T79L48 OLD, (d) T79L48 NEW, and (e) NEW-OLD, respectively.

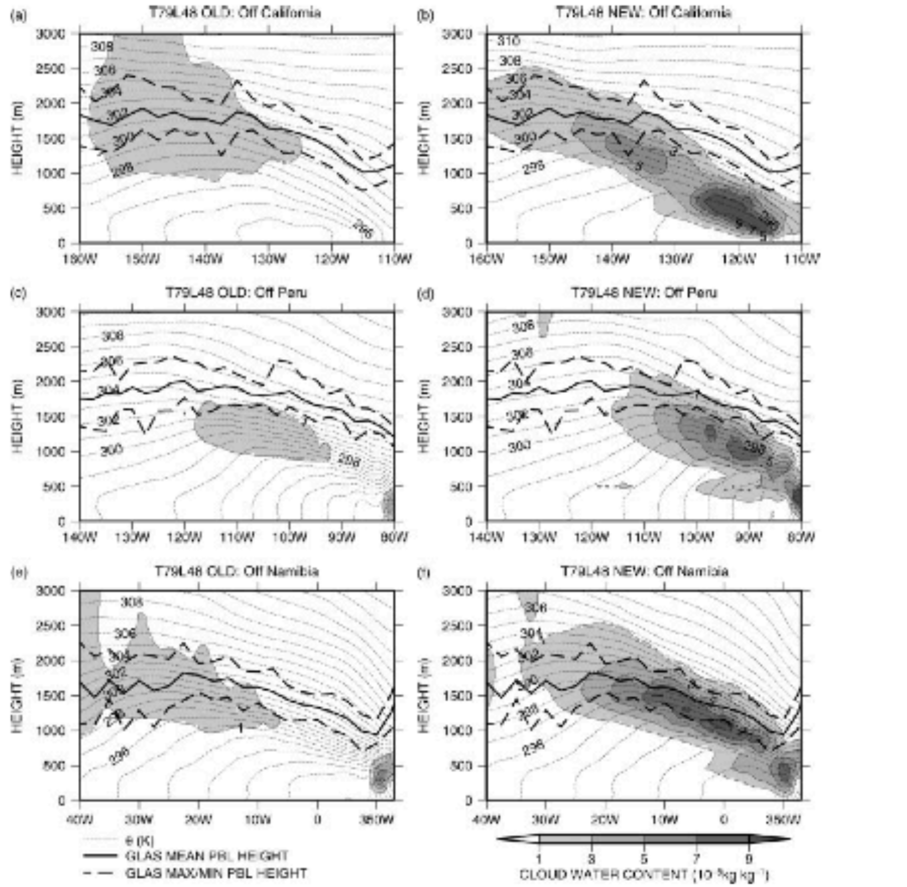


Figure 6. October–November mean vertical cross-section of cloud water content (shaded, 10^{-5} kg kg^{-1}), potential temperature (dotted line, K, contour interval is 1 K) for (left) T79L48 OLD and (right) T79L48 NEW averaged over (a) (b) 20–25°N (west of North America), (c) (d) 10–15°S (west of South America) and (e) (f) 17.5–22.5°S (west of South Africa). The bold lines show mean PBL height and the bold broken lines show maximum and minimum PBL height by GLAS averaged from 2003 and 2007.

Kuwano-Yoshida et al. [2010, QJRMS]

Ocean & Sea-Ice Component

Coordinate System

- horizontal: latitude-longitude, Arakawa's B-grid
- vertical: *z*-coordinate with partial bottom cell

Advection: 2nd-order central diff. (momentum); QUICKER (tracer)

Horizontal Mixing

- biharmonic (**CFES std.**)
- Laplacian + GM thickness diffusion (**CFES mini**)

Vertical Mixing: turbulent closure scheme (Noh & Kim, 1999)

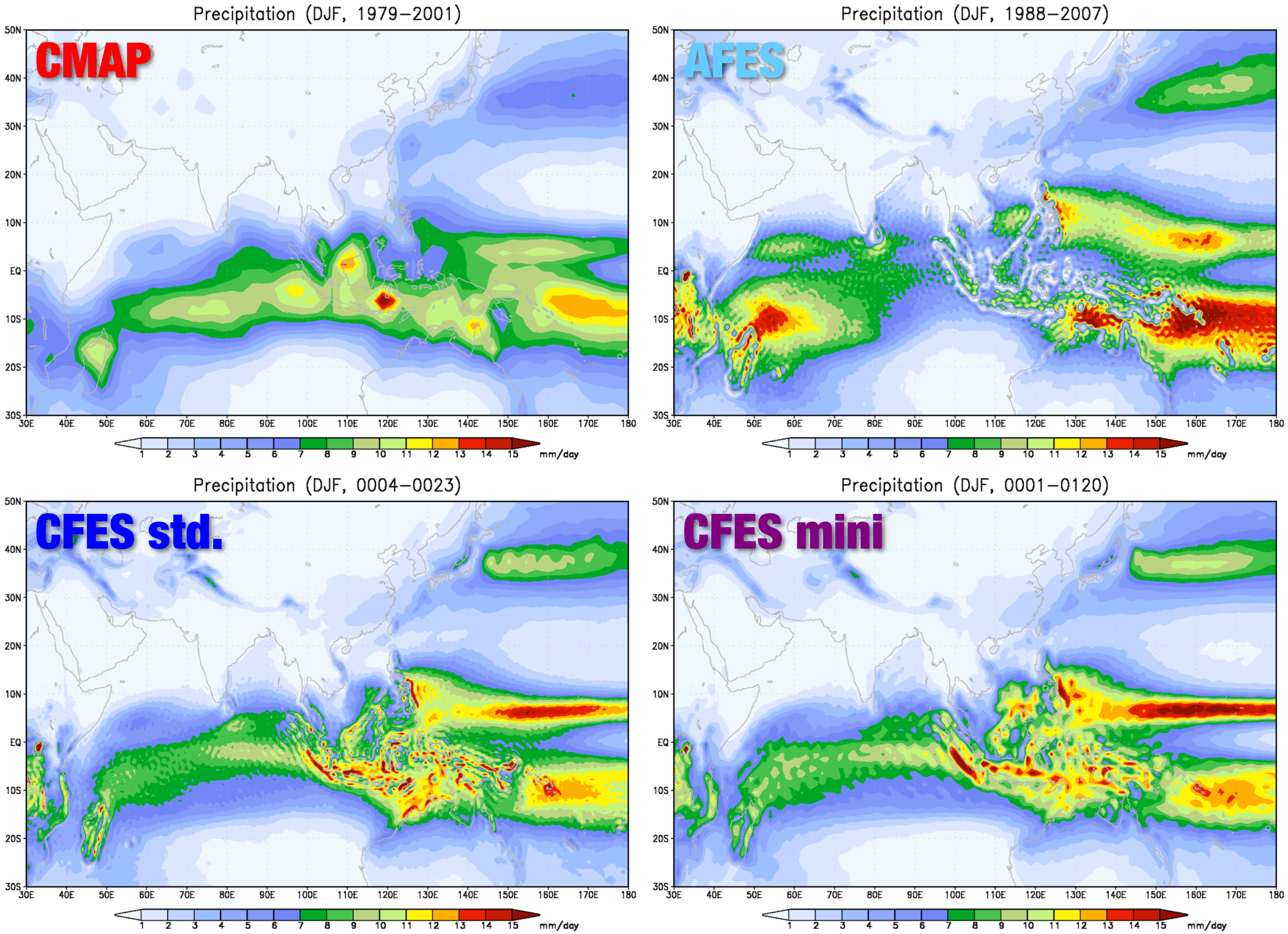
Shortwave Penetration: dependency on sea surface height

Sea-Ice: EVP rheology, 2-category, 0-layer thermodynamics (with snow)

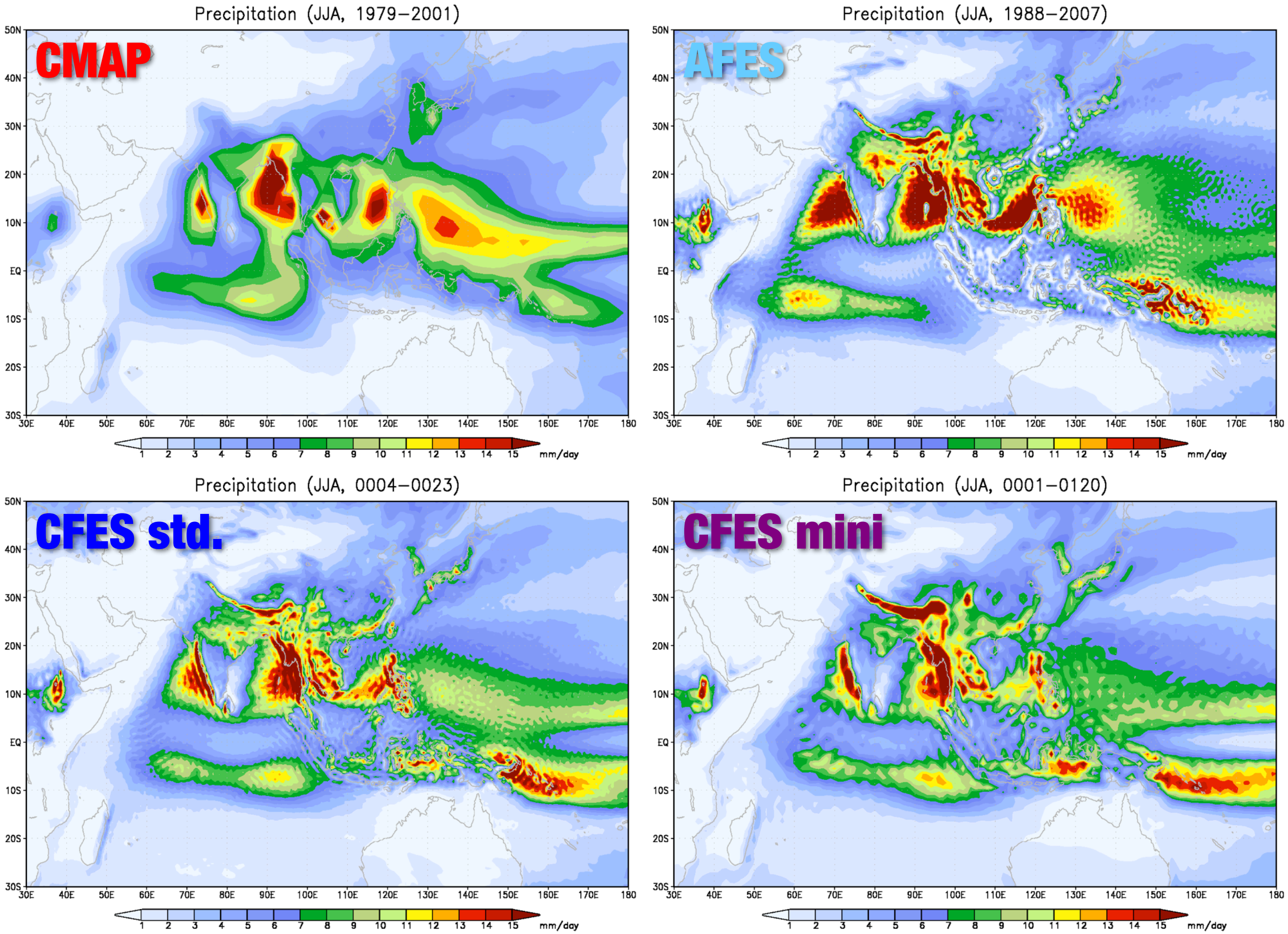
Set Up for CFES

	High-Res. Version (CFES std.)	Medium-Res. Version (CFES mini)
atmosphere	T239 L48	T119 L48
ocean	1/4º x 1/4º, 54 levels	1/2º x 1/2º, 54 levels
coupling interval	20 min	1 hour
integration period	23 years	> 150 years

Precipitation (DJF)



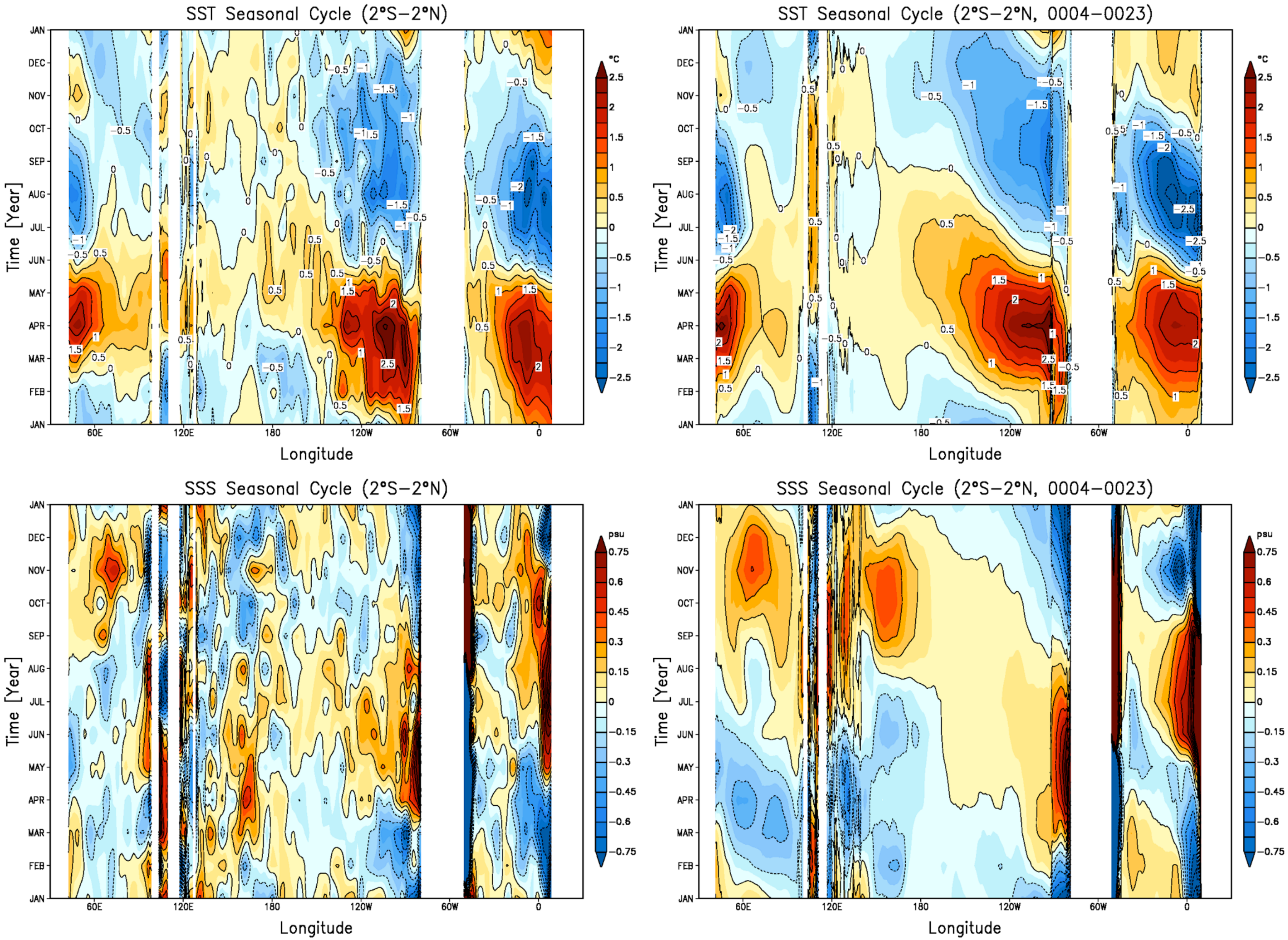
Precipitation (JJA)



SST & SSS Seasonal Cycle

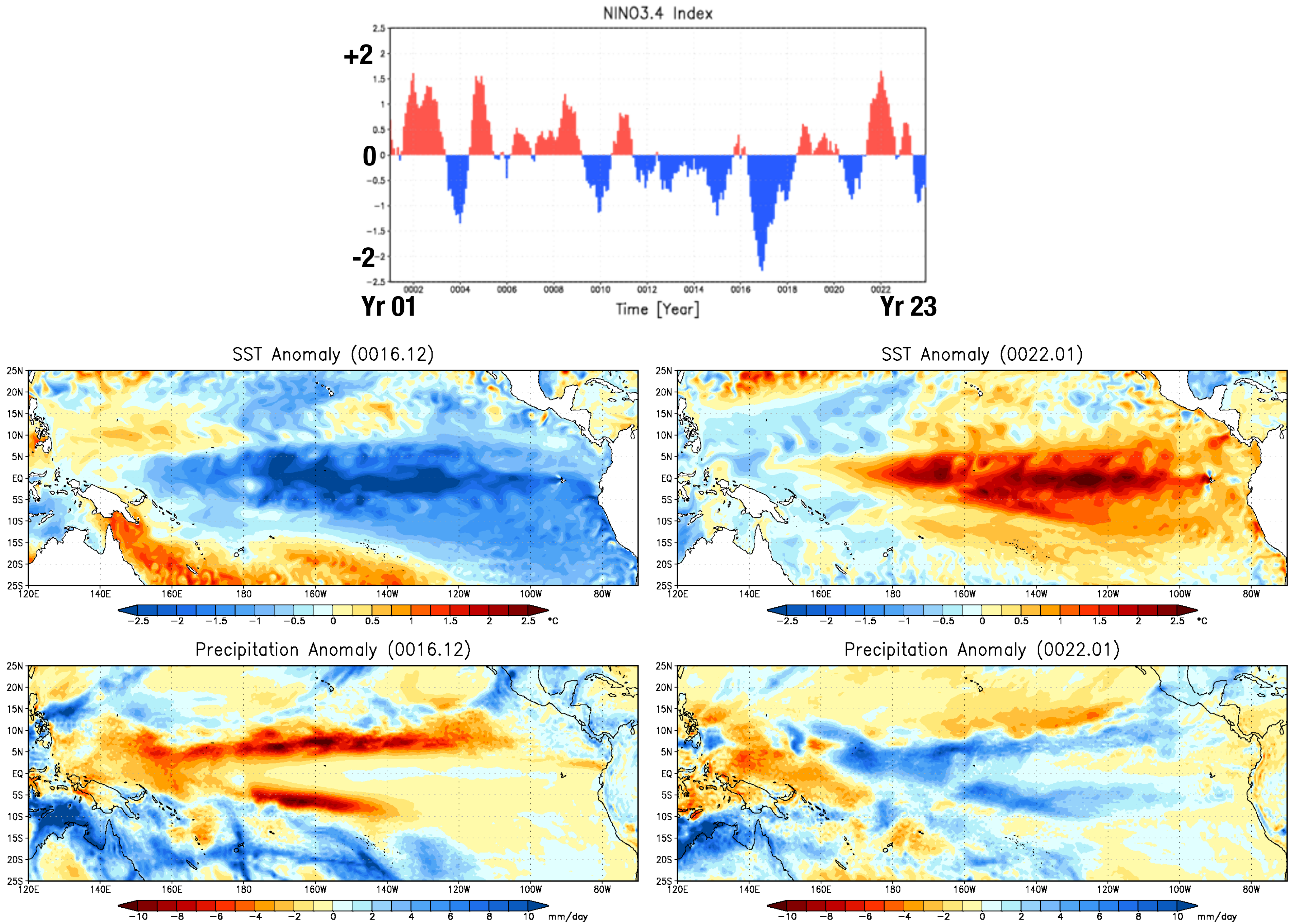
SST

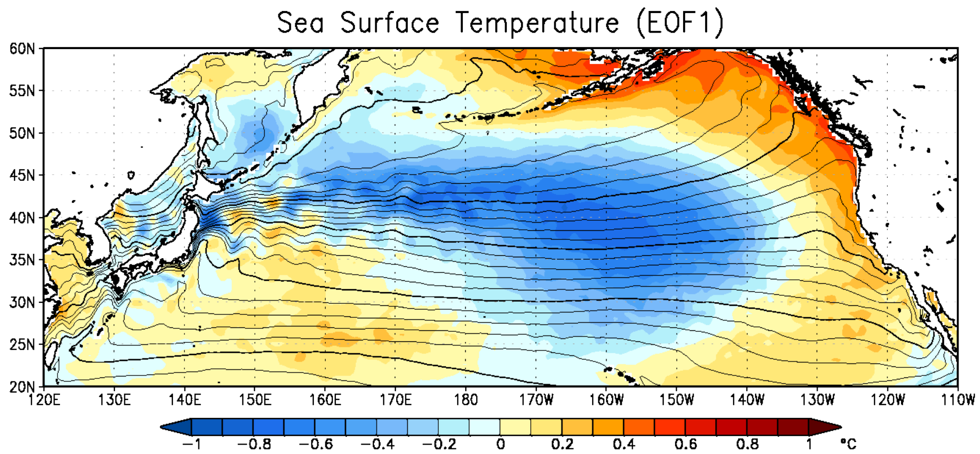
SSS

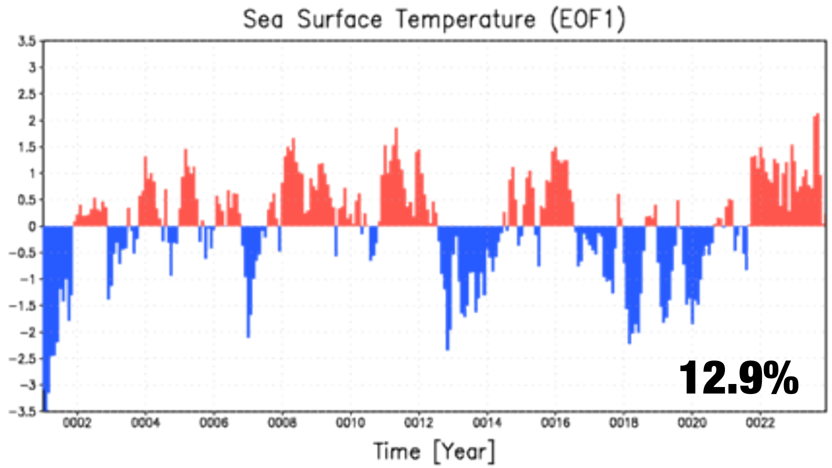


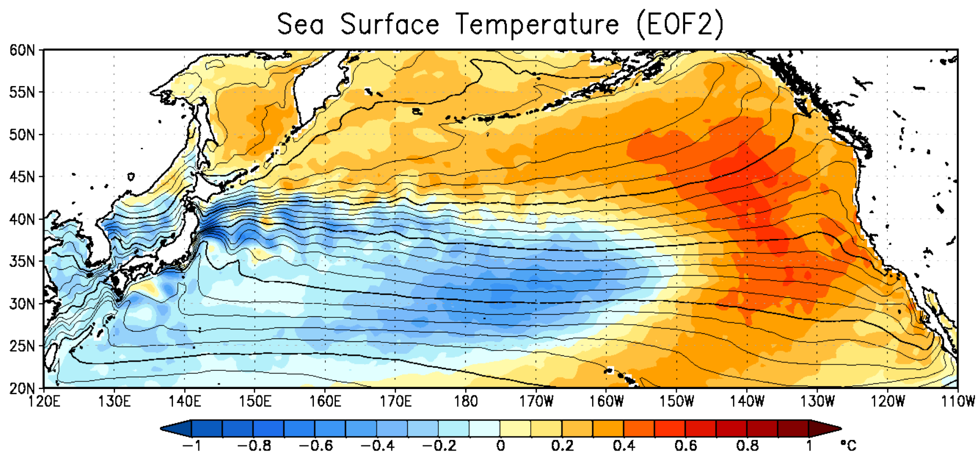
WOA98

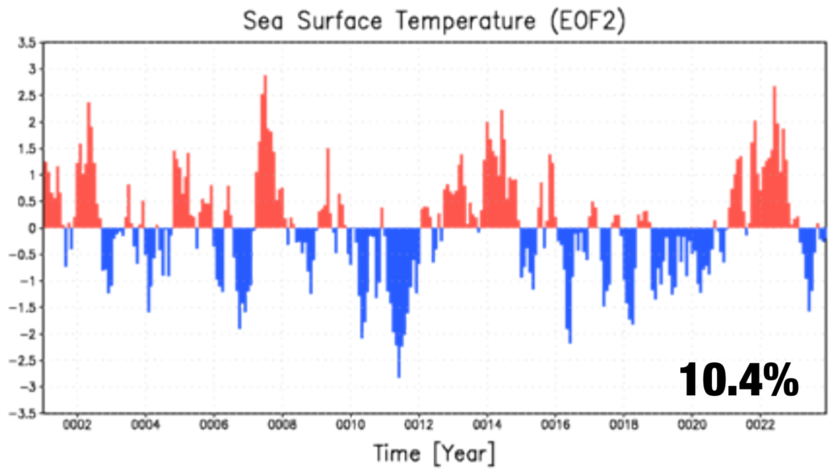
CFES std.


NINO3.4 Index
+2
0
-2
Yr 01
Yr 23
Time [Year]
SST Anomaly (0016.12)
SST Anomaly (0022.01)
°C
Precipitation Anomaly (0016.12)
Precipitation Anomaly (0022.01)
mm/day


Sea Surface Temperature (EOF1)
60N
55N
50N
45N
40N
35N
30N
25N
20N
120E 130E 140E 150E 160E 170E 180 170W 160W 150W 140W 130W 120W 110W
−1 −0.8 −0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1 °C


Sea Surface Temperature (EOF1)
3.5 3 2.5 2 1.5 1 0.5 0 -0.5 -1 -1.5 -2 -2.5 -3 -3.5
0002 0004 0006 0008 0010 0012 0014 0016 0018 0020 0022
Time [Year]
12.9%

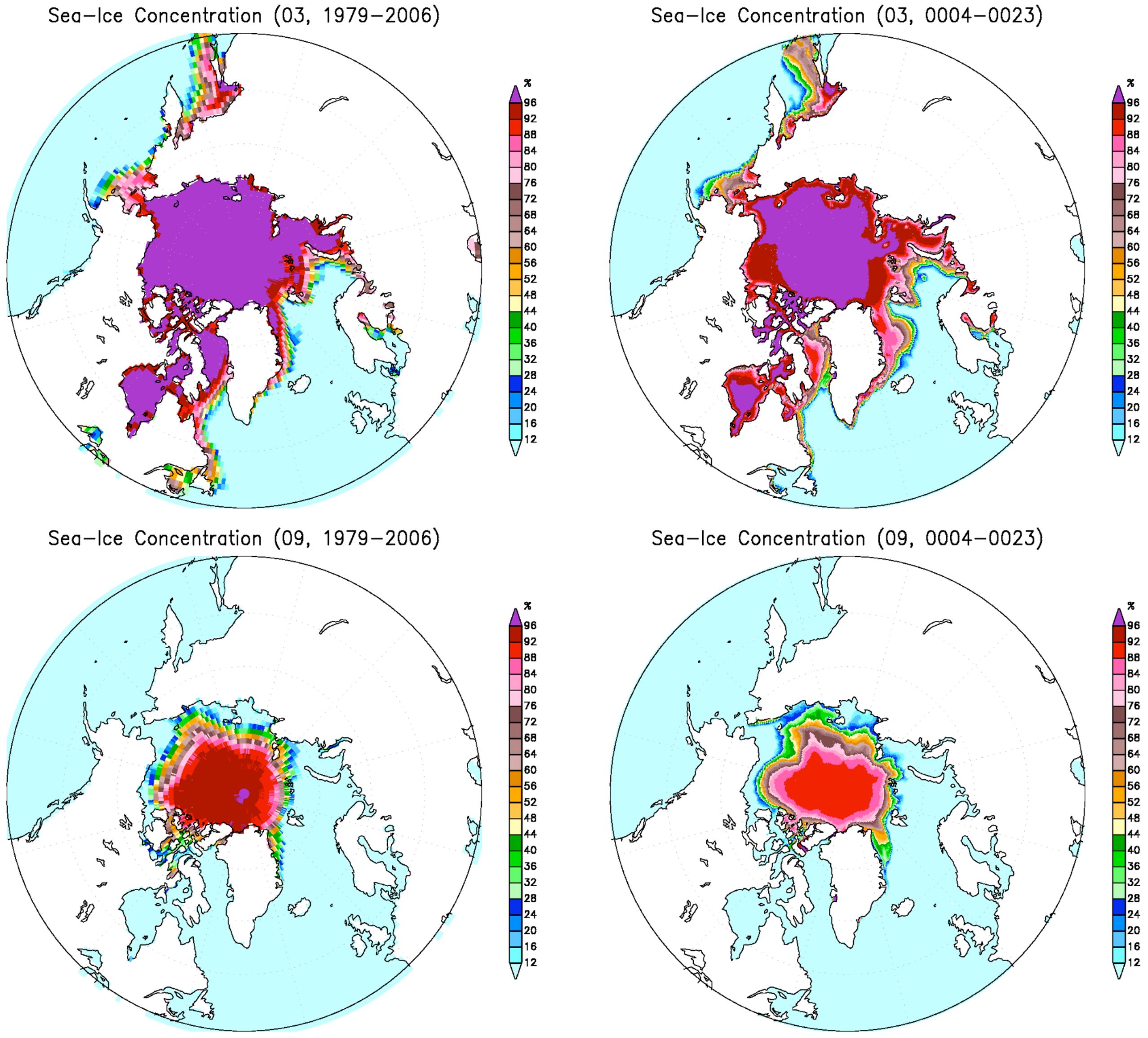

Sea Surface Temperature (EOF2)
60N
55N
50N
45N
40N
35N
30N
25N
20N
120E 130E 140E 150E 160E 170E 180 170W 160W 150W 140W 130W 120W 110W
−1 −0.8 −0.6 −0.4 −0.2 0 0.2 0.4 0.6 0.8 1 °C


Sea Surface Temperature (EOF2)
3.5 3 2.5 2 1.5 1 0.5 0 -0.5 -1 -1.5 -2 -2.5 -3 -3.5
0002 0004 0006 0008 0010 0012 0014 0016 0018 0020 0022
Time [Year]
10.4%

Sea-Ice Concentration

March

September



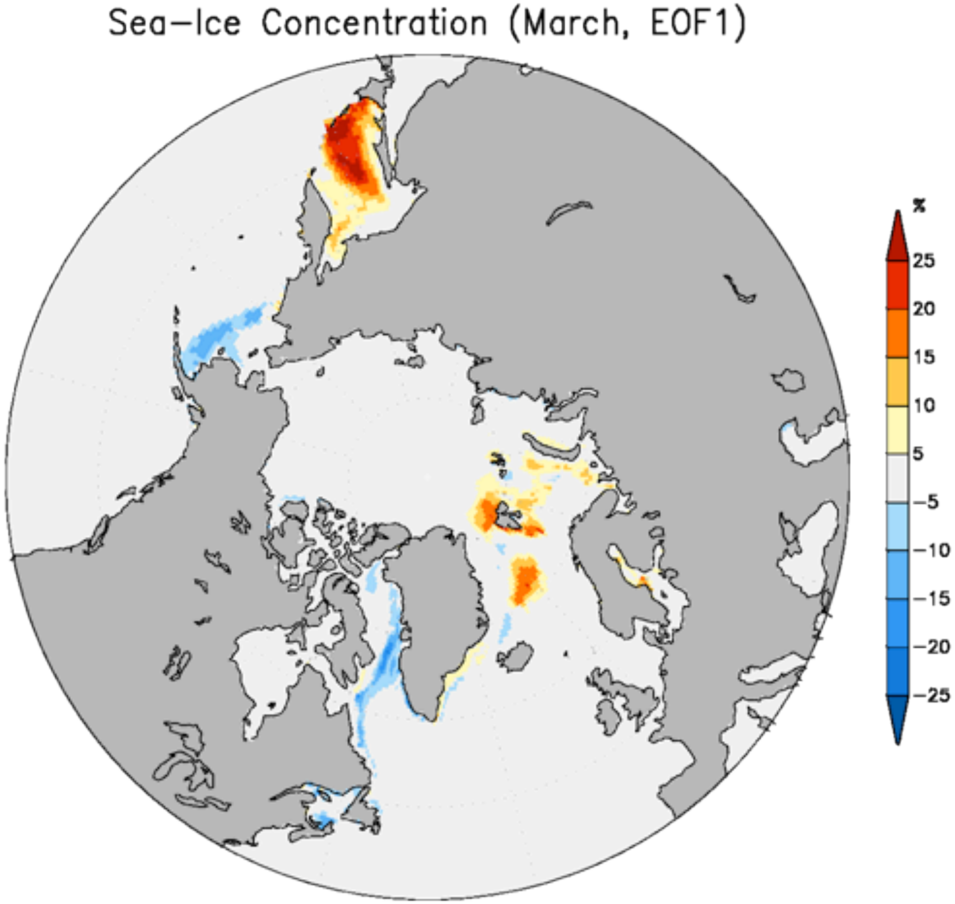
HadISST

CFES std.

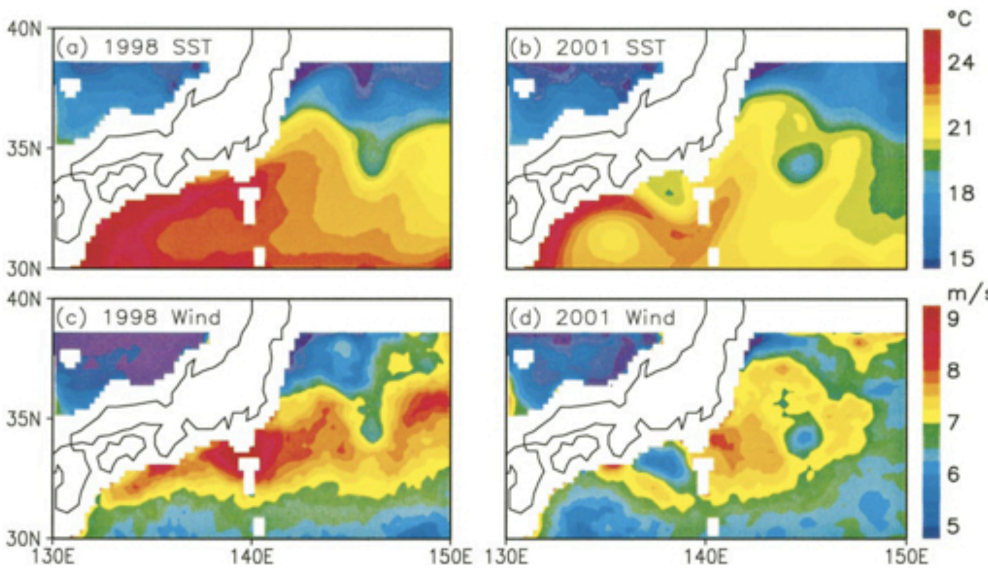
Satellite

Yamamoto et al. (2006, GRL)

CFES

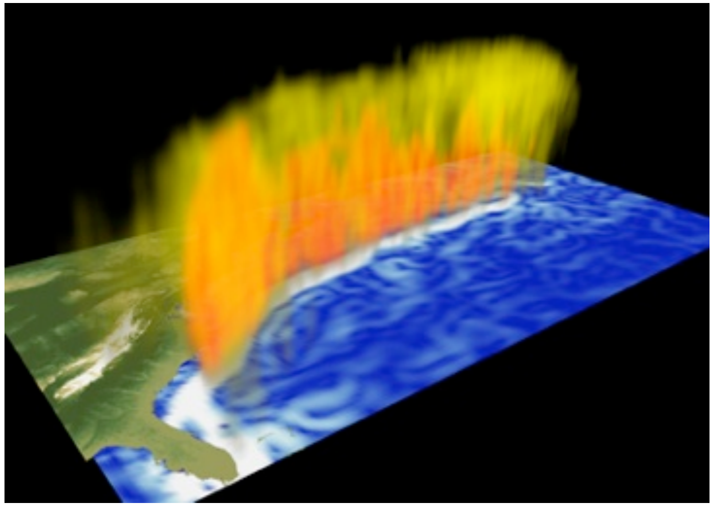


Covariations of SST and wind over the Kuroshio



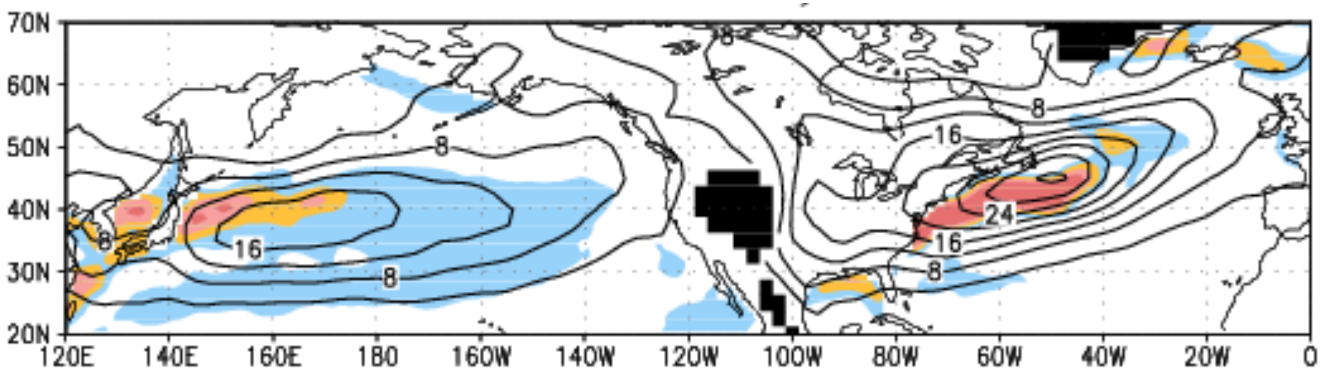
Nonaka & Xie (2003, J. Climate)

Influence of the Gulf Stream on the troposphere

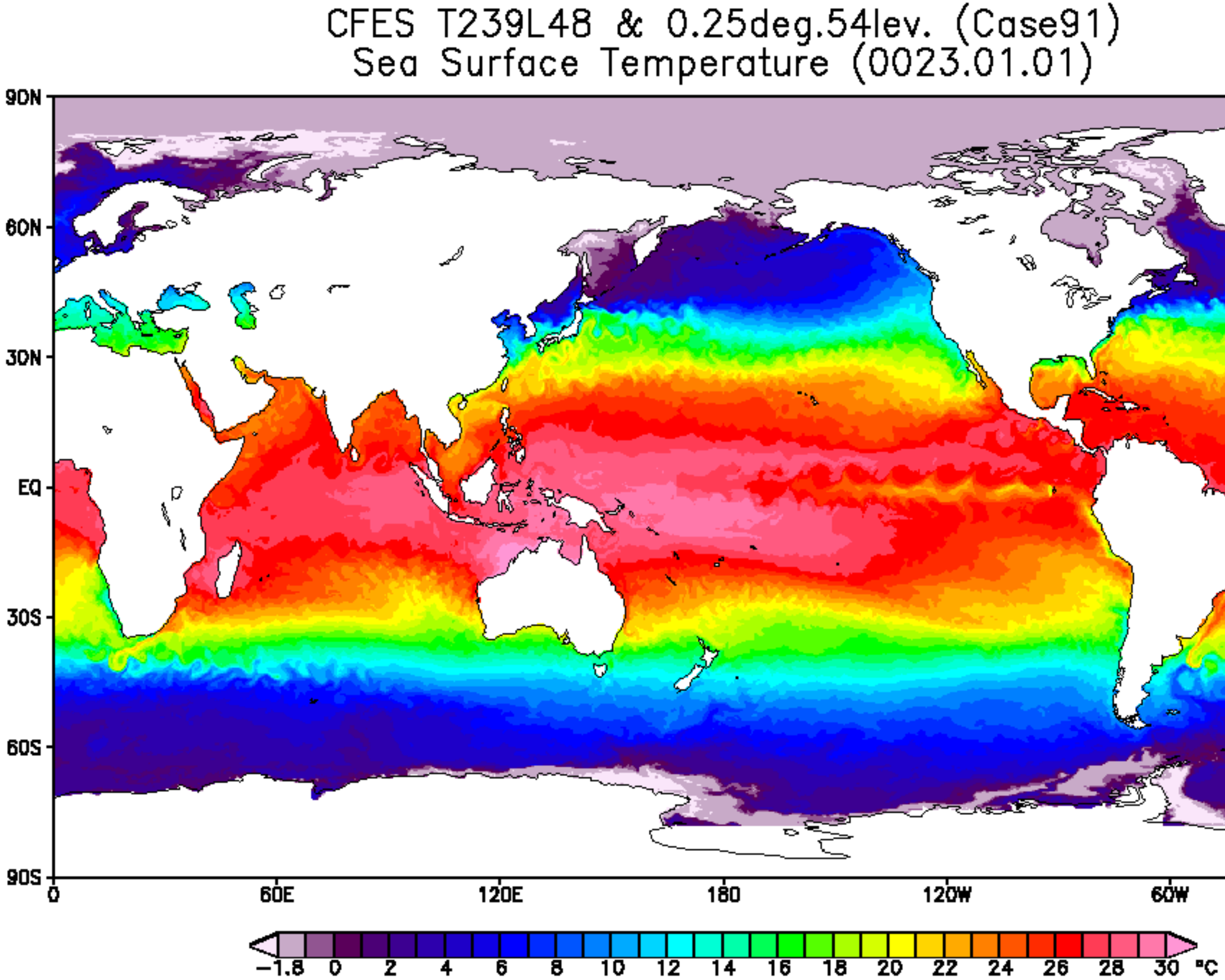


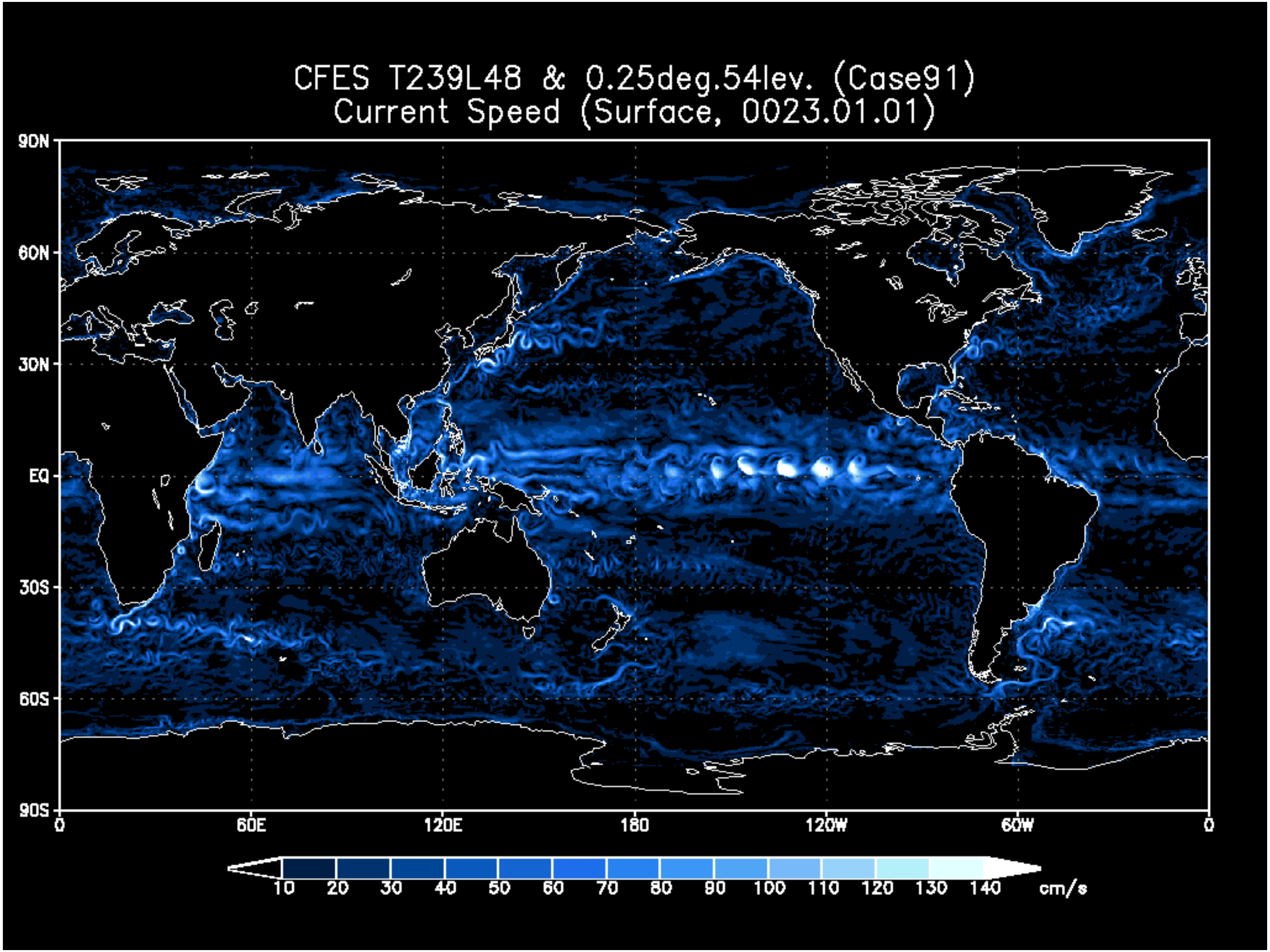
Minobe et al. (2008, Nature)

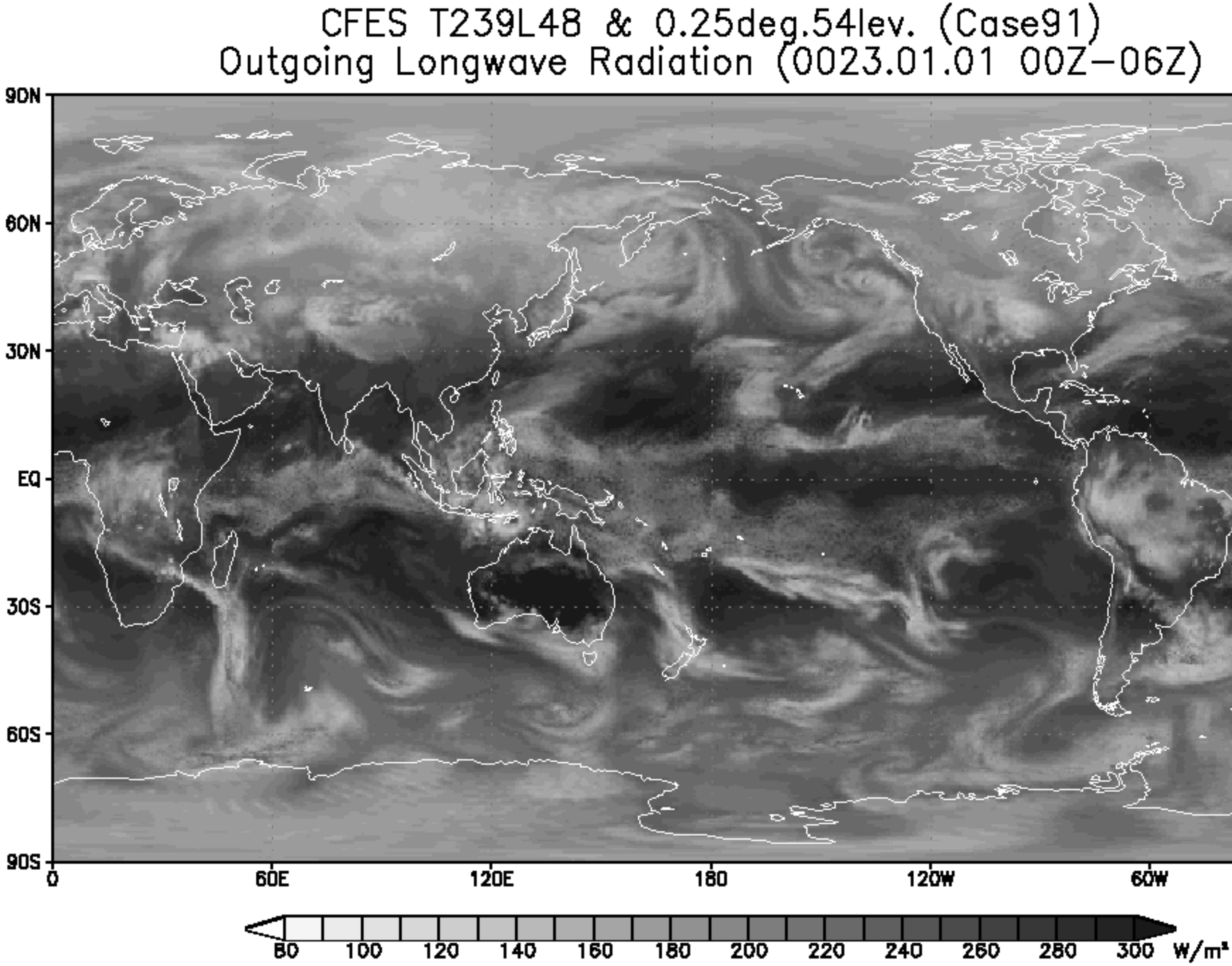
Associations among storm tracks, jet streams, and midlatitude oceanic fronts



Nakamura et al. (2004, AGU monogr.)


CFES T239L48 & 0.25deg.54lev. (Case91)
Sea Surface Temperature (0023.01.01)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
-1.8 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 °C


CFES T239L48 & 0.25deg.54lev. (Case91)
Current Speed (Surface, 0023.01.01)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
cm/s

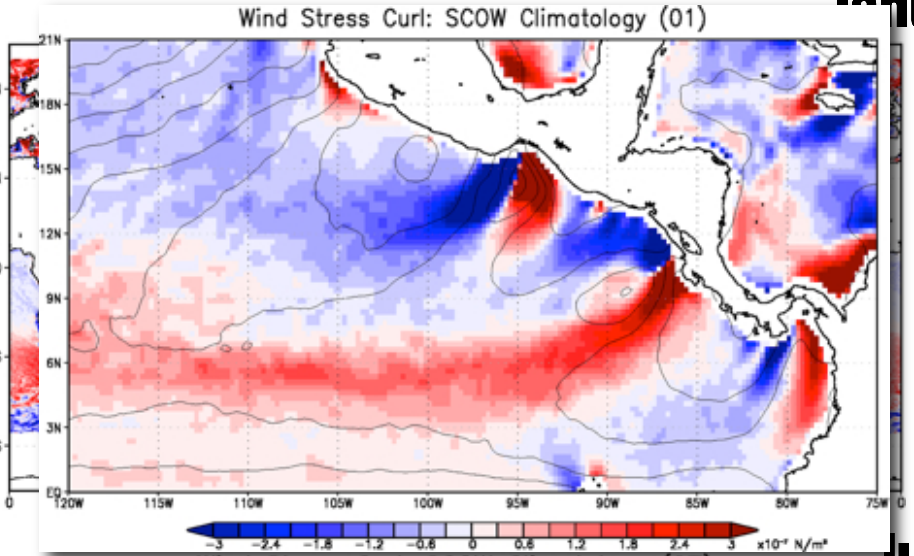

CFES T239L48 & 0.25deg.54lev. (Case91)
Outgoing Longwave Radiation (0023.01.01 00Z-06Z)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
80
100
120
140
160
180
200
220
240
260
280
300
W/m²

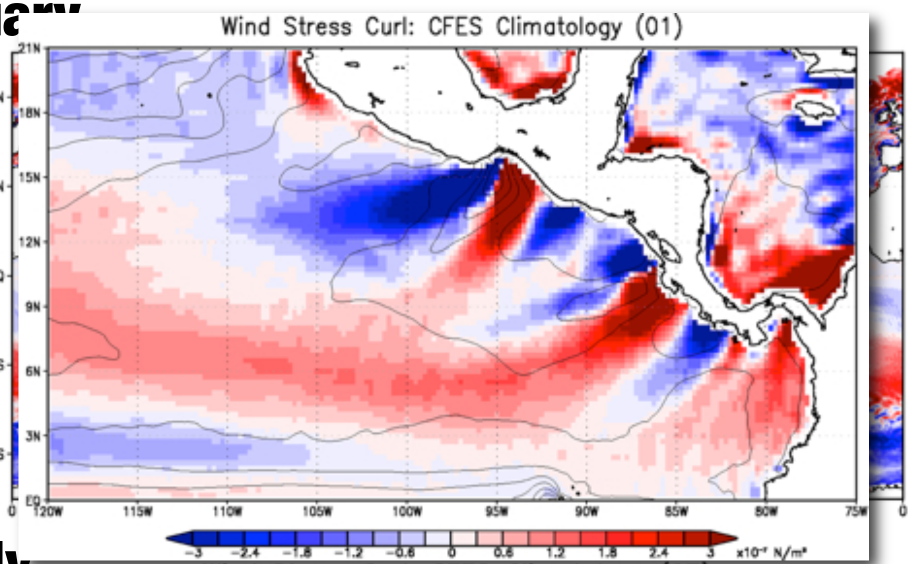
Wind Stress Curl

Satellite

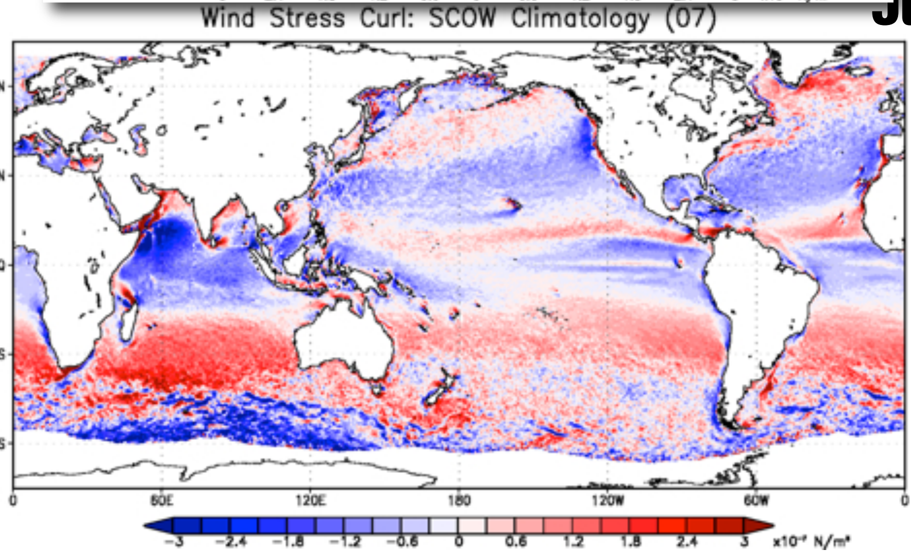
CFES

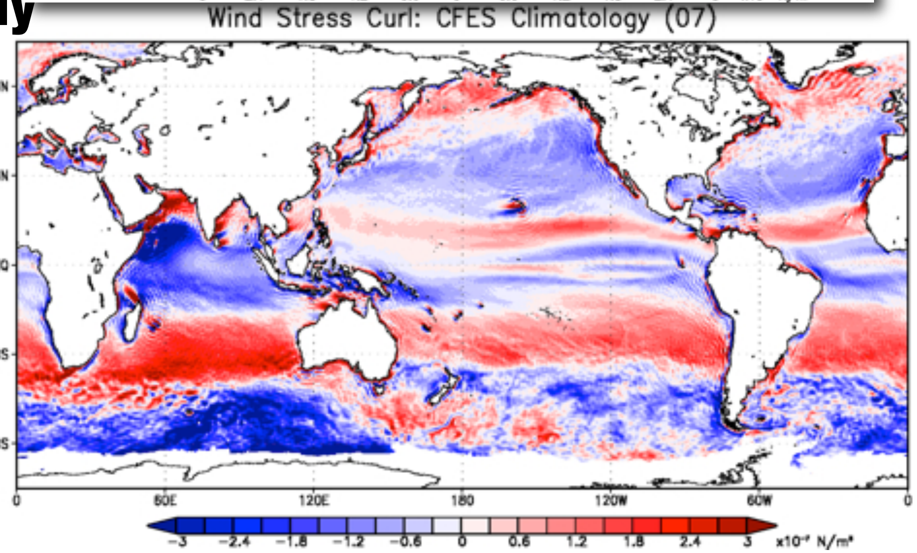
January





July



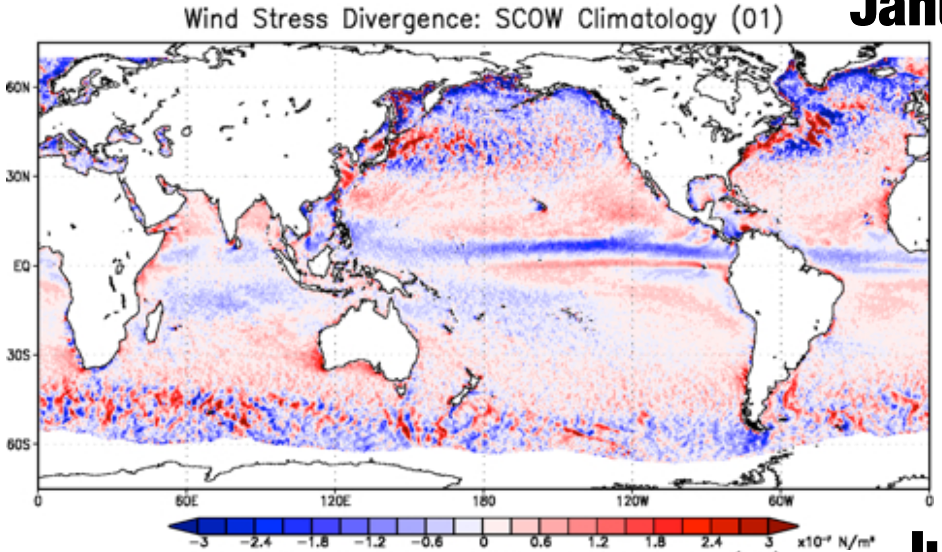


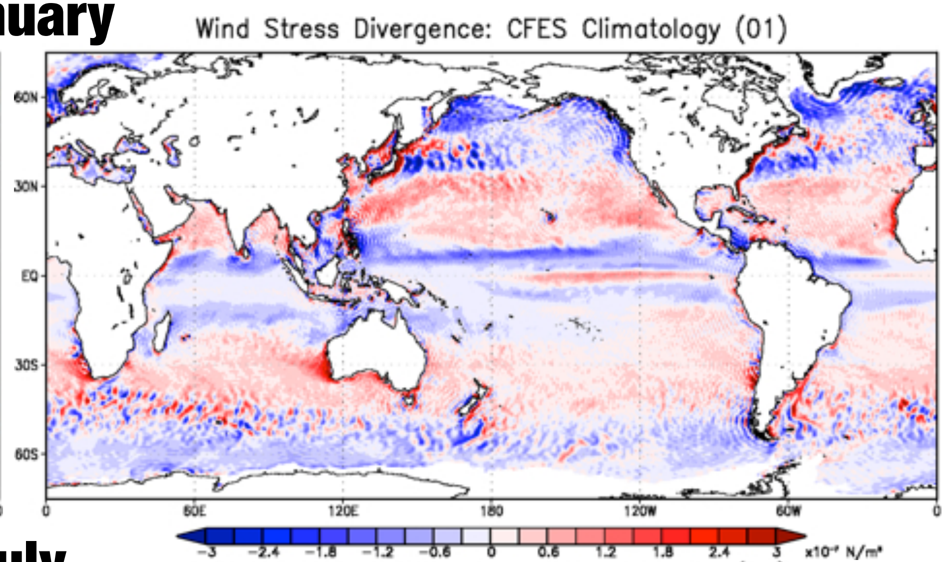
Wind Stress Divergence

Satellite

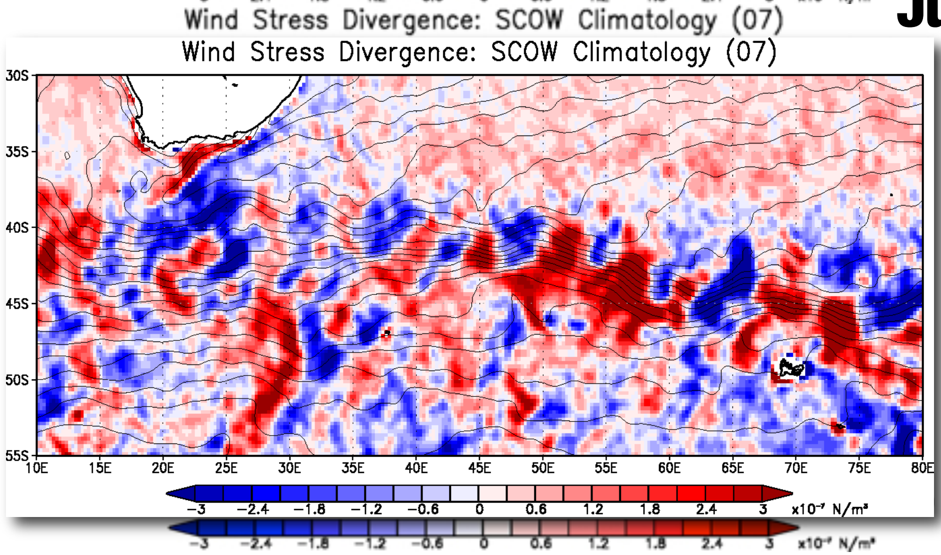
CFES

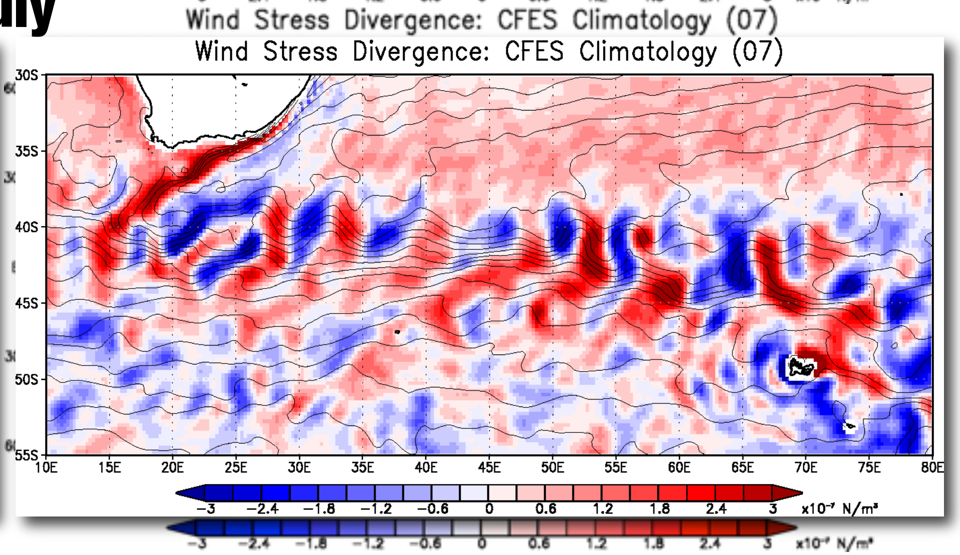
January





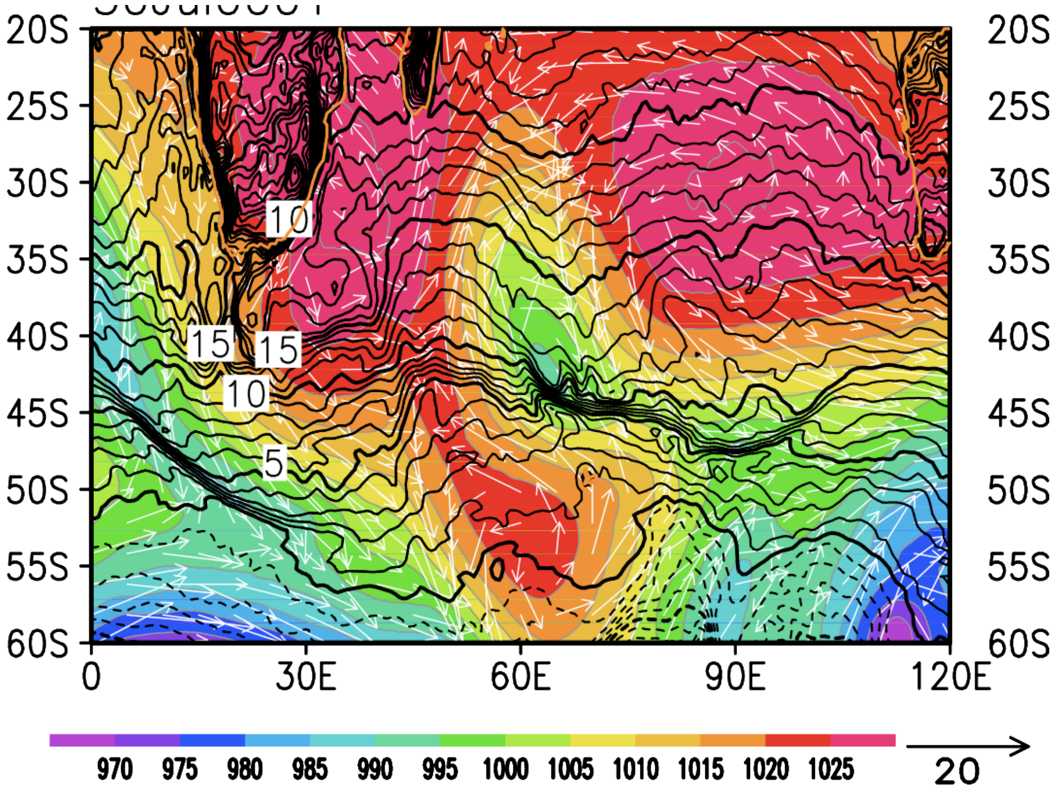
July



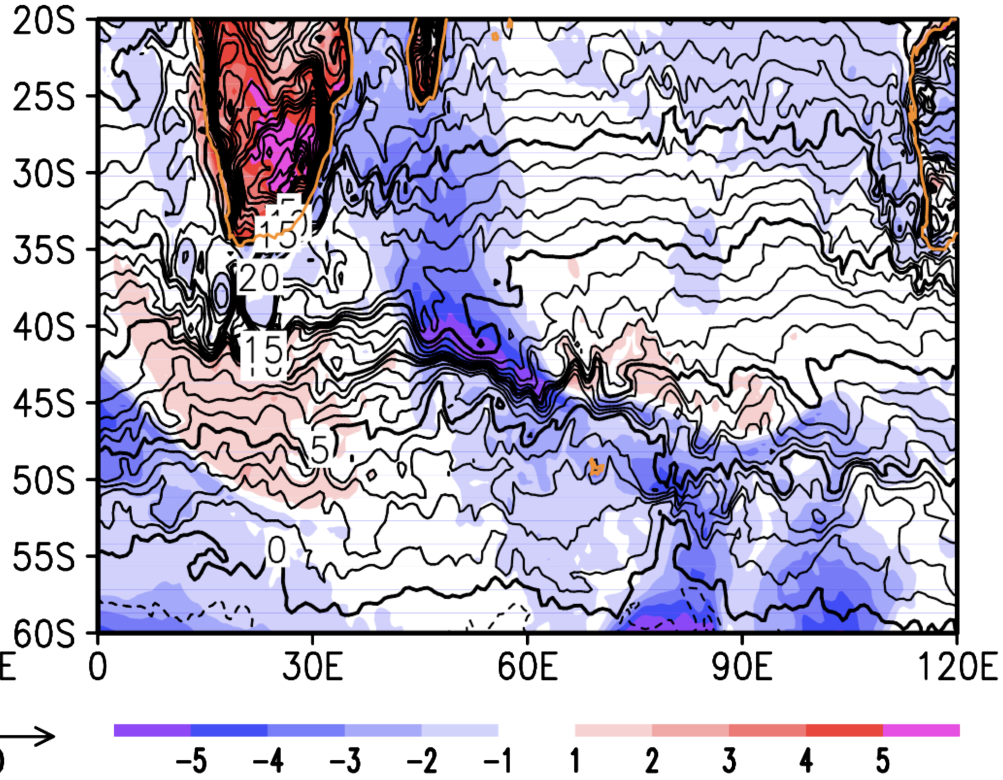


Impacts of a SST Front on Distributions of Surface Heat Flux and Air Temperature

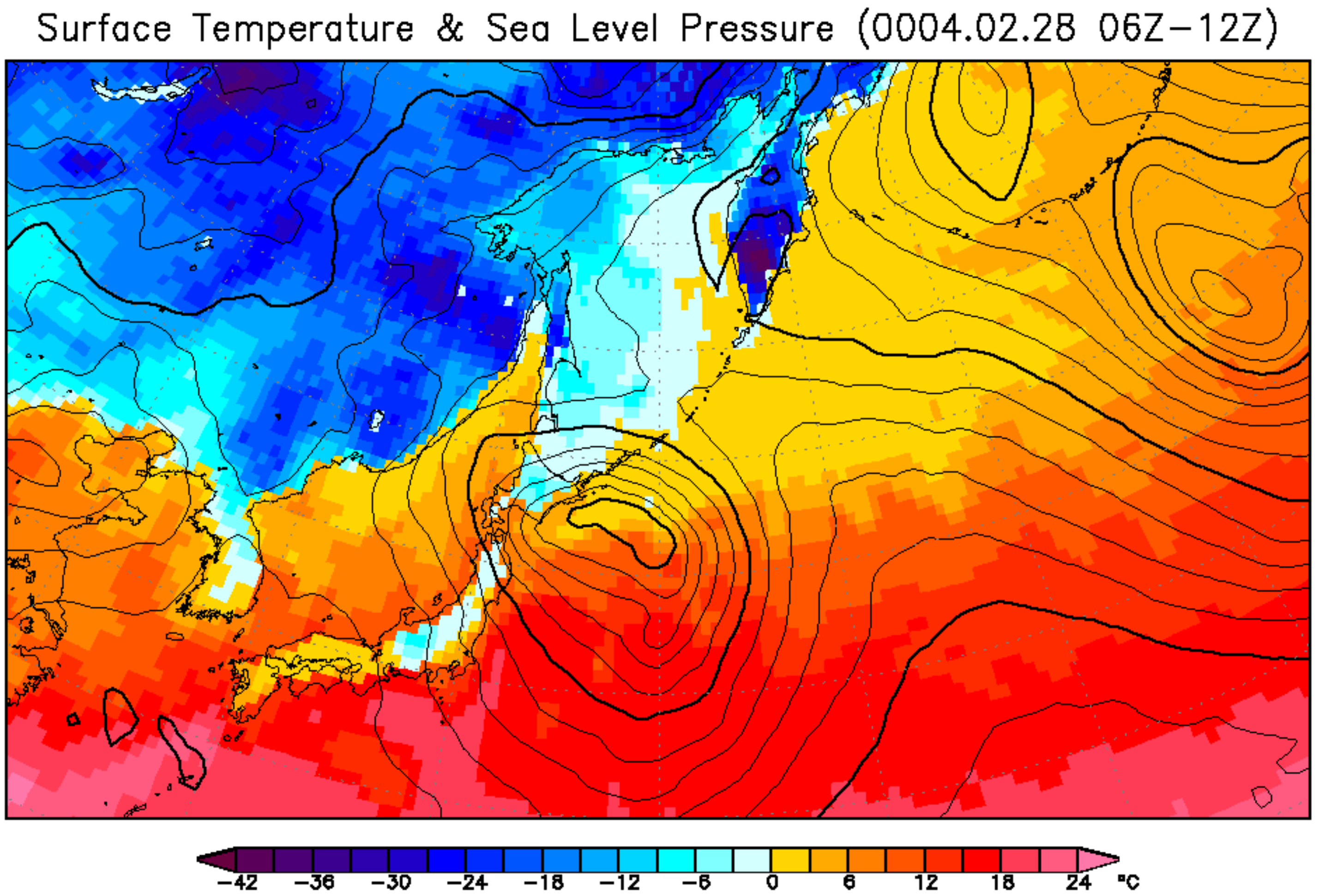
Color: SLP, Contour: SAT, Vector: Surface Winds



Color: SAT-SST, Contour: SST



Nonaka et al., [2009, J. Climate]


Surface Temperature & Sea Level Pressure (0004.02.28 06Z–12Z)
–42 –36 –30 –24 –18 –12 –6 0 6 12 18 24 °C

CFES Papers

High-Resolution (but Earlier) Version

- Komori et al. (2008): Deep ocean inertia-gravity waves simulated in a high-resolution global coupled atmosphere–ocean GCM. *Geophys. Res. Lett.*, **35**, L04610.
- Nonaka et al. (2009): Air–sea heat exchanges characteristic of a prominent midlatitude oceanic front in the South Indian Ocean as simulated in a high-resolution coupled GCM. *J. Climate*, **22** (24), 6515–6535.

Medium-Resolution Version

- Richter et al. (2010): On the triggering of Benguela Niños: Remote equatorial versus local influences. *Geophys. Res. Lett.*, **37**, L20604.

Ongoing Efforts and Future Directions

Ongoing Efforts

Improvement and extension of CFES

- modification of **Emanuel's convective parameterization**
- coupling with an **NPZD-type marine ecosystem model**

Sensitivity experiments (**CFES mini**)

- e.g., Atlantic Niño, Indian summer monsoon, Baiu-front

New reference simulations using the improved version of CFES

- **CFES mini**: several centuries
- **CFES std.**: several decades

Data assimilation system using **CFES mini** (**CFES-LETKF**)

Development of **eddy-resolving** version of CFES (???)

Future Directions

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AFES-LETKF

Data assimilation system combining **AFES** with **local ensemble transform Kalman filter** *(Miyoshi and Yamane, 2007)*

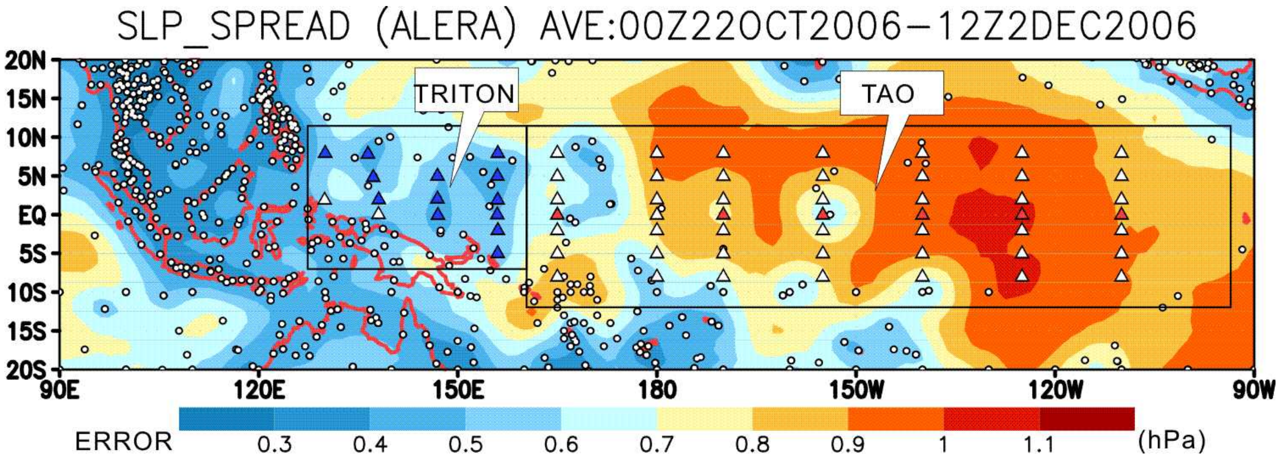
ALERA: AFES-LETKF Experimental Ensemble Reanalysis *(Miyoshi, Yamane, and Enomoto, 2007)*

- collaborative research among JMA, JAMSTEC, and Chiba Inst. Sci.
- data are available from **http://www.jamstec.go.jp/esc/afes/**
- **observing system researches** based on ALERA
  - impact of observations from Arctic drifting buoys *(Inoue et al., 2009)*
  - precursory signals in ensemble spread *(Enomoto et al., 2010)*

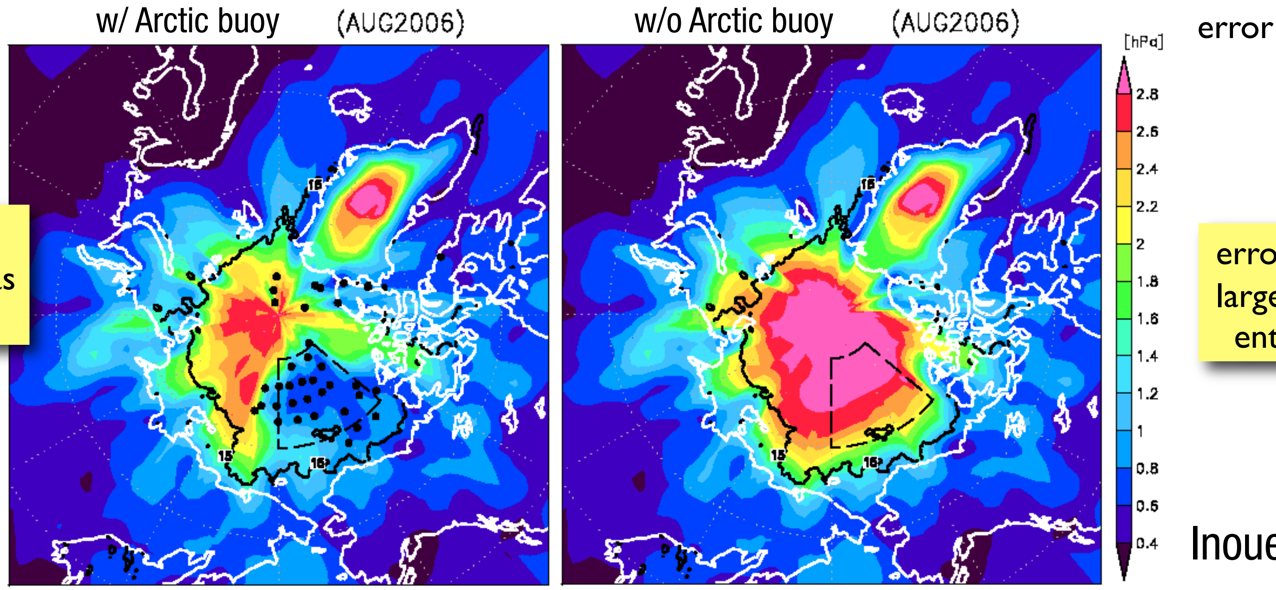
ALERA 2 is now running on the Earth Simulator 2.

Application to Observing System Design

Evaluation of Pressure Measurement by Tropical Buoys



Evaluation of Pressure Measurement by Arctic Buoys



accuracy in the region w/ Arctic buoys (●) is as high as in the mid-latitudes

error becomes larger over the entire Arctic

Inoue et al. (2009)

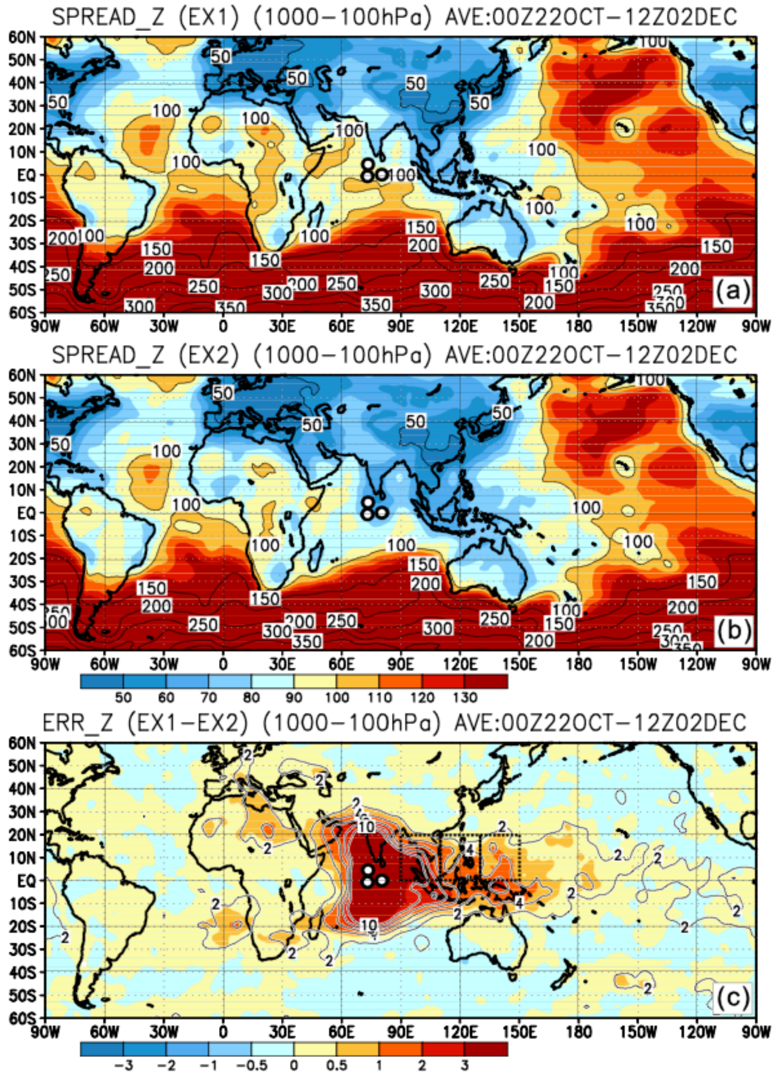
Impact of Sonde Observations manifested as "Matsuno-Gill" Pattern

MISMO 2006/10–12
Indian Ocean

w/o MISMO sonde

ALERA (w/ MISMO sonde)

w/o MISMO sonde – ALERA



affects reproducibility of typhoon generation

Moteki et al. [*QJRMS*, in revision]

ALERA vs. ALERA 2

	ALERA	ALERA 2
resolution	**T159** L48	T119 L48
ensemble member	40	**63 + 1**
localization	21 x 21 x 13	**400 km/0.4 lnp**
spread inflation	0.1	
observational data	JMA	NCEP
boundary condition	NOAA OISST weekly 1º	NOAA OISST **daily 1/4º**

CFES-LETKF

Extension of **AFES-LETKF** data assimilation system to **CFES**

- at the beginning phase, only atmospheric observational data will be assimilated into a coupled atmosphere–ocean model

Need to develop data assimilation methods for precipitation, land-surface (soil moisture, snow), and sea-ice processes

- common difficulties
  - phase change »»» *non-linear* system
  - non-negative value »»» *non-Gaussian* error statistics
- new satellite data will be available in future (SMOS, CryoSat, ICESat)


NEC
Thank You!