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Development of an Ensemble-Based Data Assimilation System with a Coupled Atmosphere–Ocean GCM

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Outline of Talk

- AFES–LETKF ensemble DA system
  - Atmospheric reanalysis: ALERA & ALERA2
- CFES–LETKF ensemble DA system
  - Preliminary results of CLERA-A
  - Ensemble simulations with OFES
- Summary

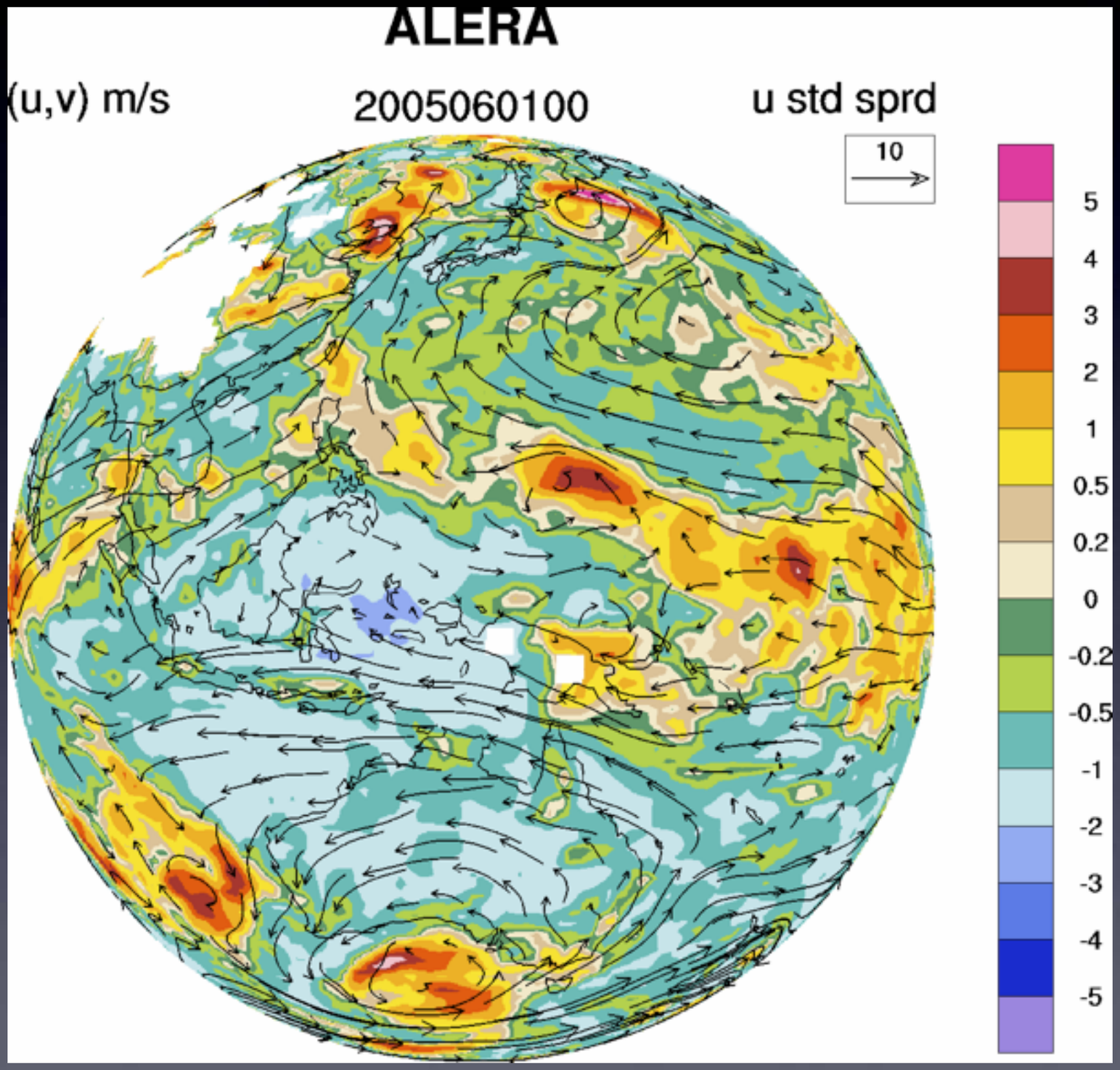
ALERA & ALERA2

ALERA

AFES–LETKF experimental ensemble reanalysis

- first application of LETKF to full AGCM
- provides analysis ensemble spread as error estimates
- a product of collaboration among JMA, JAMSTEC and CIS

850 (u,v) and standardized U850 spread

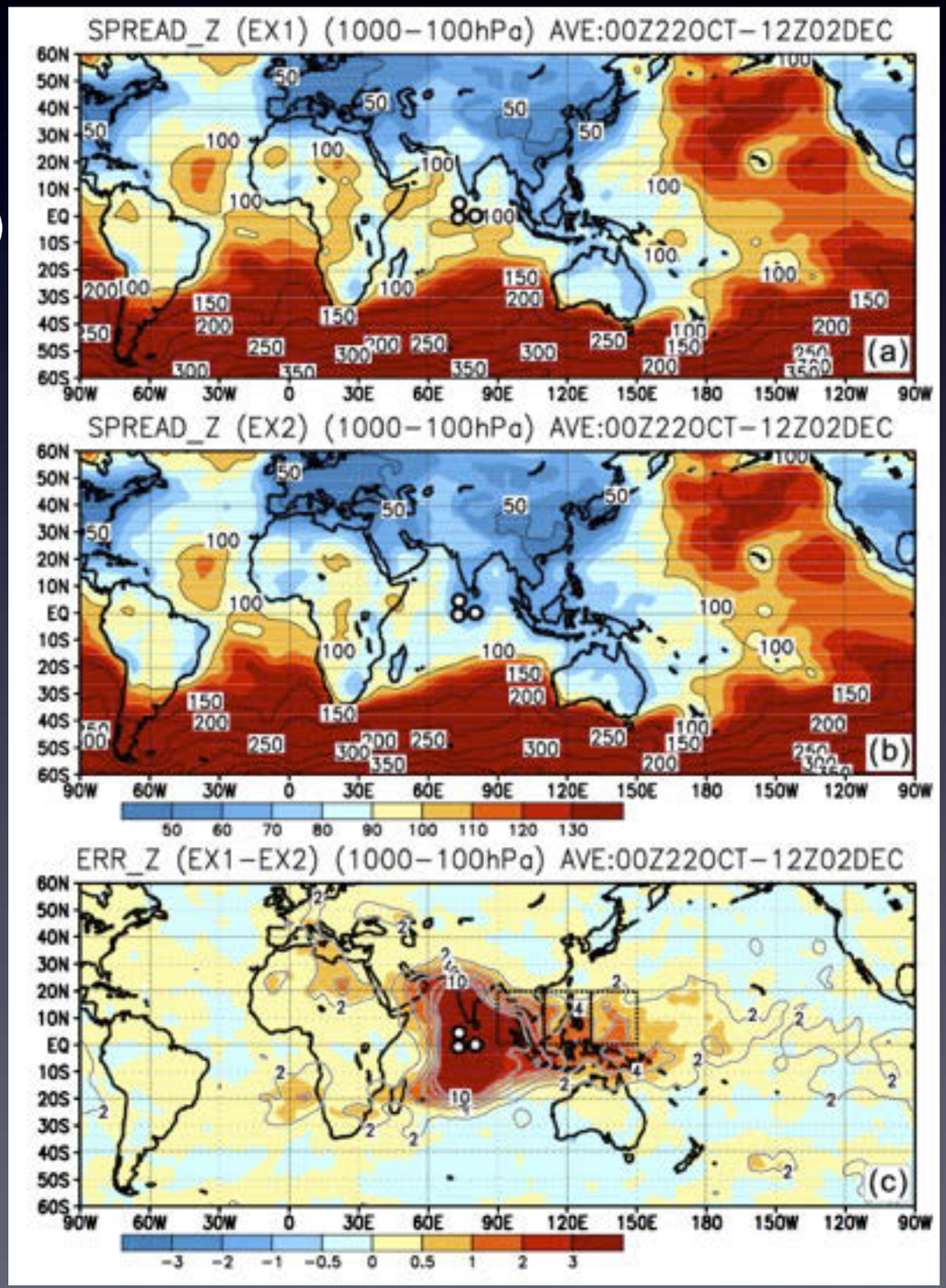


Influence of MISMO sondes

ALERA (w/o MISMO sondes)

with MISMO sondes

ALERA – with MISMO



MISMO Oct–Dec 2006
in the Indian Ocean

Influence on
typhoon genesis

Moteki et al. 2011 *QJRMS*

ALERA and ALERA2 compared

	ALERA	ALERA2
Resolution	T159L48	T119L48
Ensemble size	40	63+1
Boundary conditions	NOAA OISST weakly 1°	NOAA OISST daily 1/4°
Covariance localization	21x21x13	400 km/0.4 ln$p$
Spread inflation	0.1	
Obs compiled by	JMA	NCEP

ALERA2 streams

2003	2004	2005	2006	2007	2008	2009	2010	2011	2012

ALERA

PALAU 2005

MISMO

ALERA2

stream 2008

PALAU 2008

Mirai Arctic Ocean Cruise

T-PARC

Winter T-PARC

stream 2010

Mirai Arctic Ocean Cruise

VPREX 2010

CINDY 2011

Long-term Reanalysis

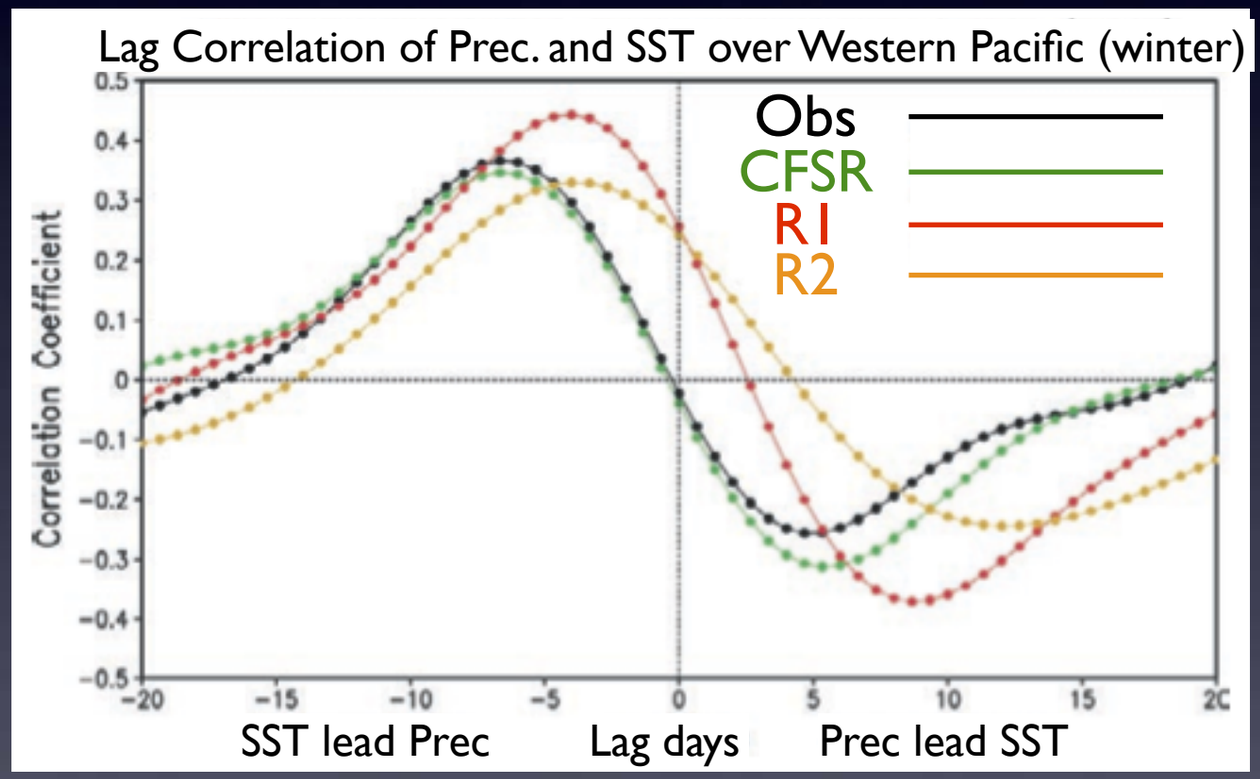
CFES–LETKF

Motivations

- Improve SST–precipitation correlation
- Remove underestimation of ensemble spread near the sea surface
- Evaluate observations including ocean buoys

➡ Replace AFES with CFES

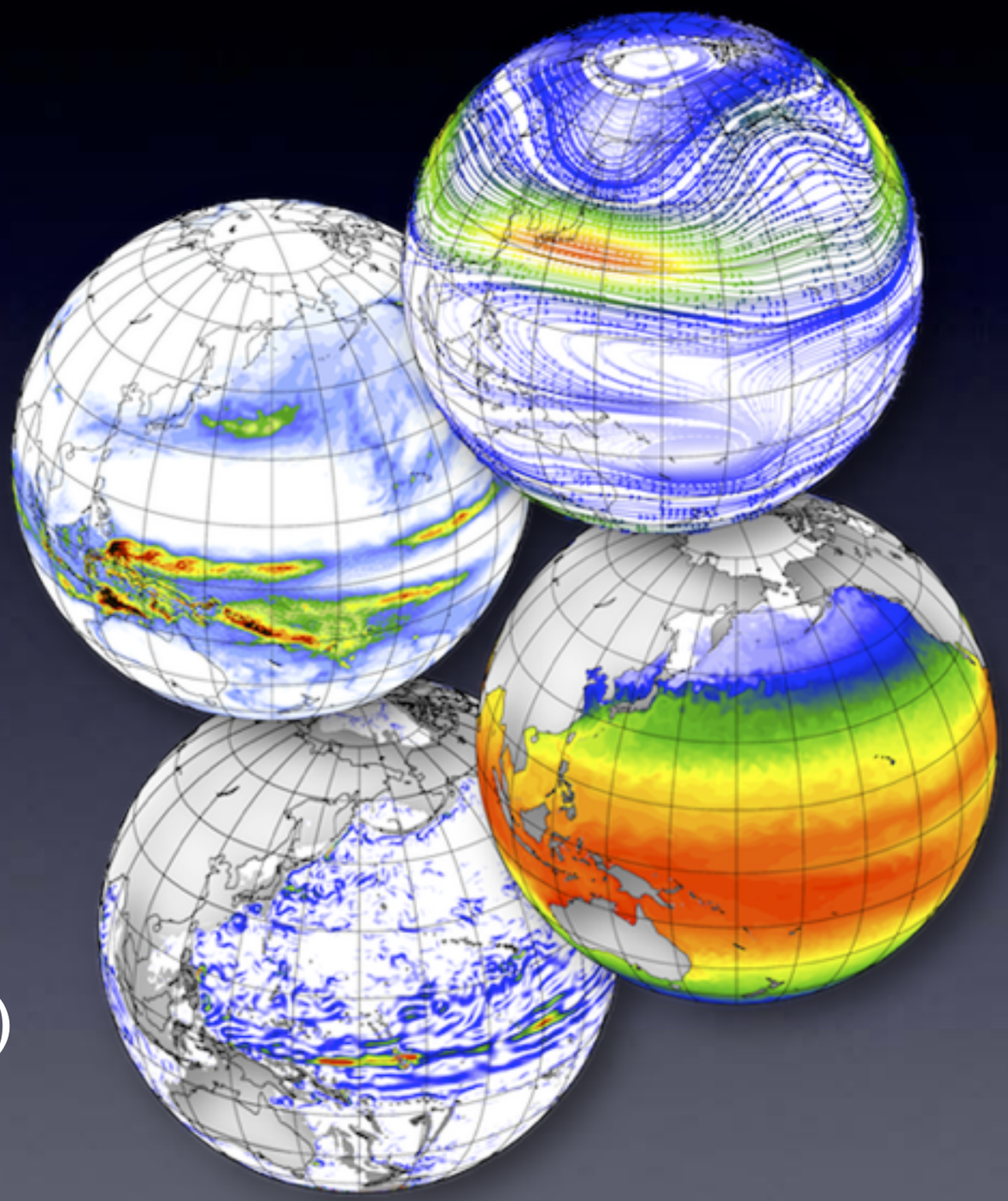
‣ Atmospheric DA only



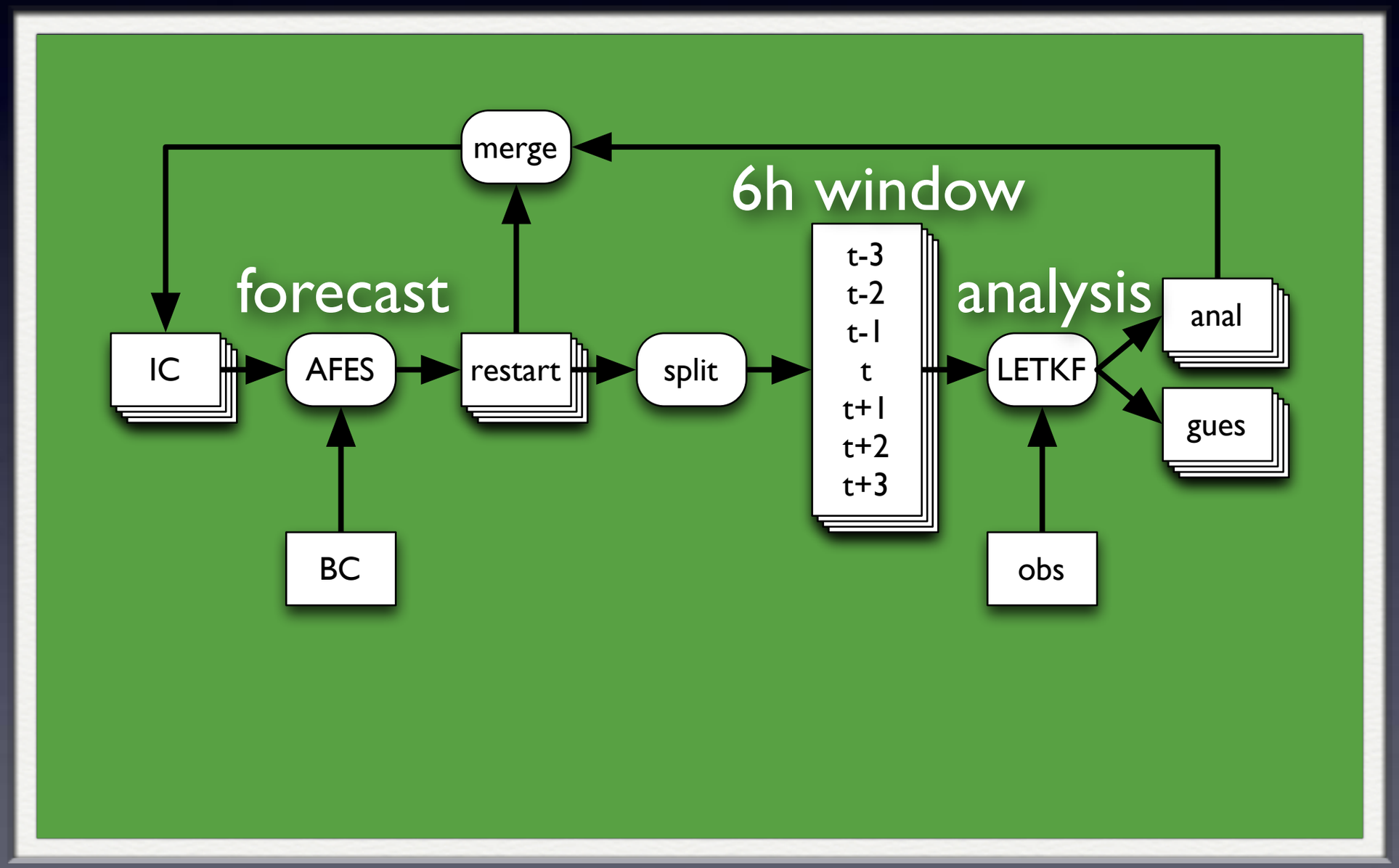
Saha et al. 2010

CFES

- Coupled GCM for the ES
  - AFES + OFES
  - Komori et al. (2008)
- CFES mini
  - AFES T119L48
  - OFES 0.5°x0.5° 54 lev.
  - Richter et al. (2010 *GRL*), Taguchi et al. (2012 *JC*), Bajish et al. (*SOLA* accepted)

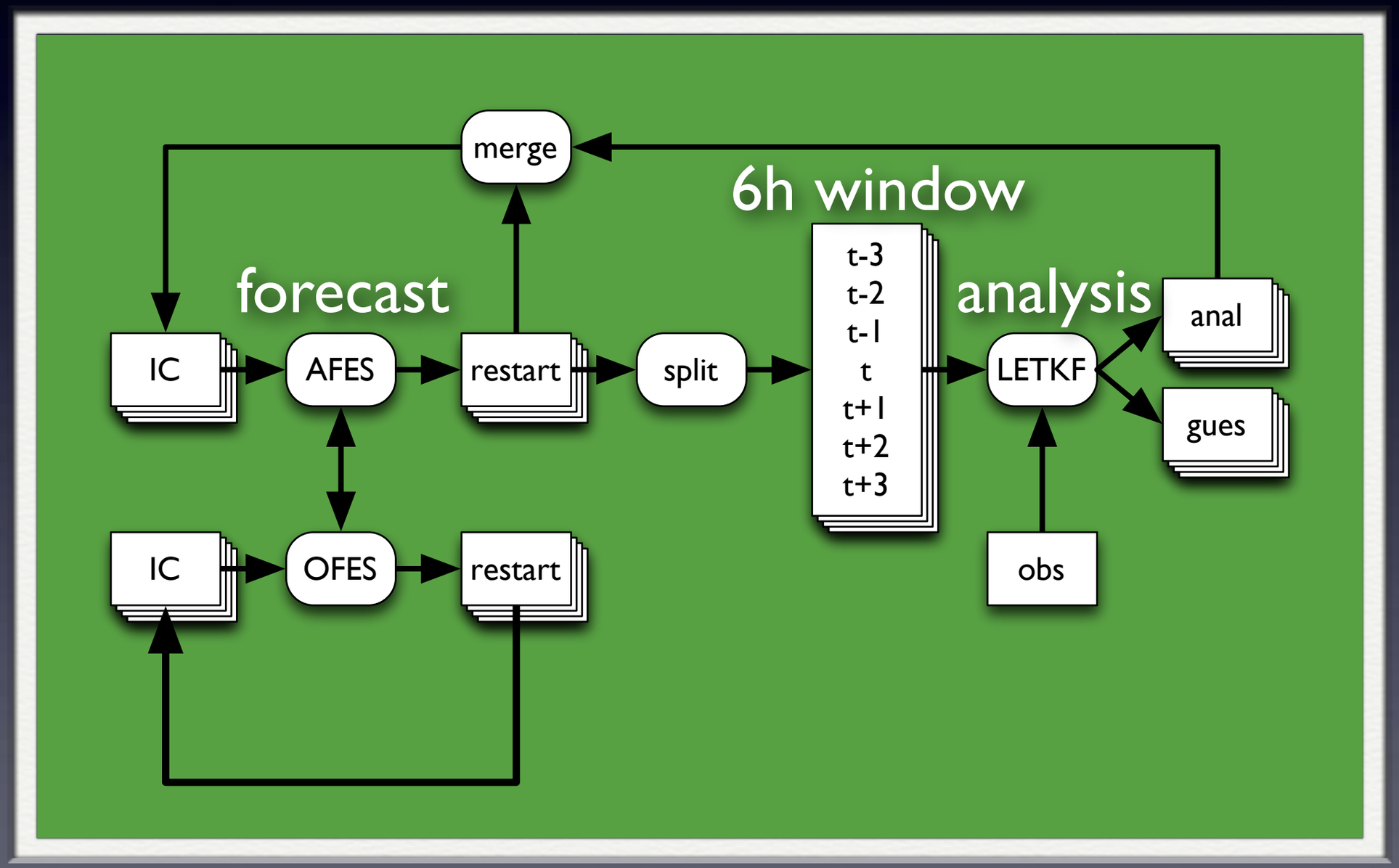


Forecast–Analysis Cycle



Hunt et al. 2007; Miyoshi and Yamane 2007

Forecast–Analysis Cycle



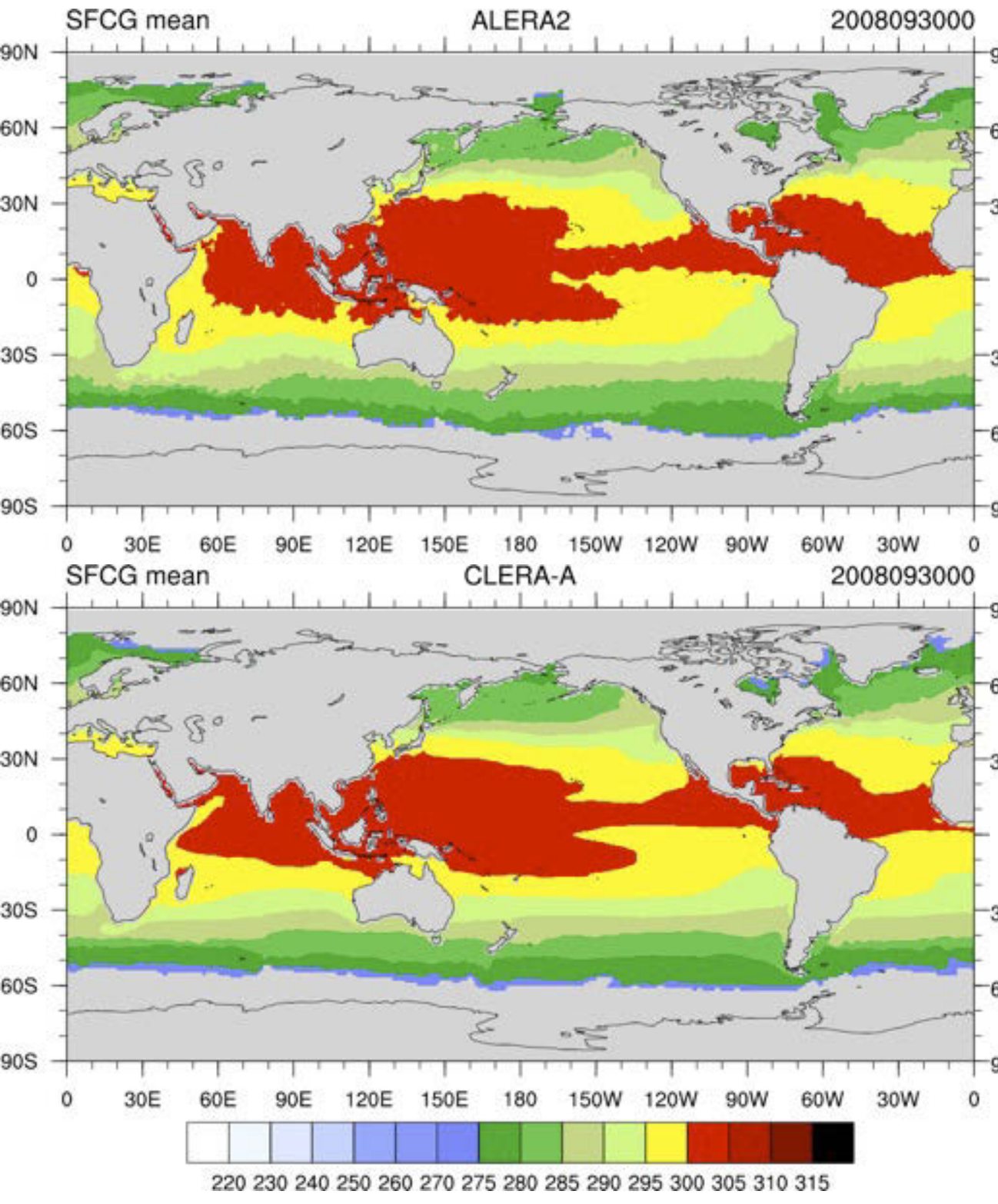
Enomoto et al. 2013, *in press*

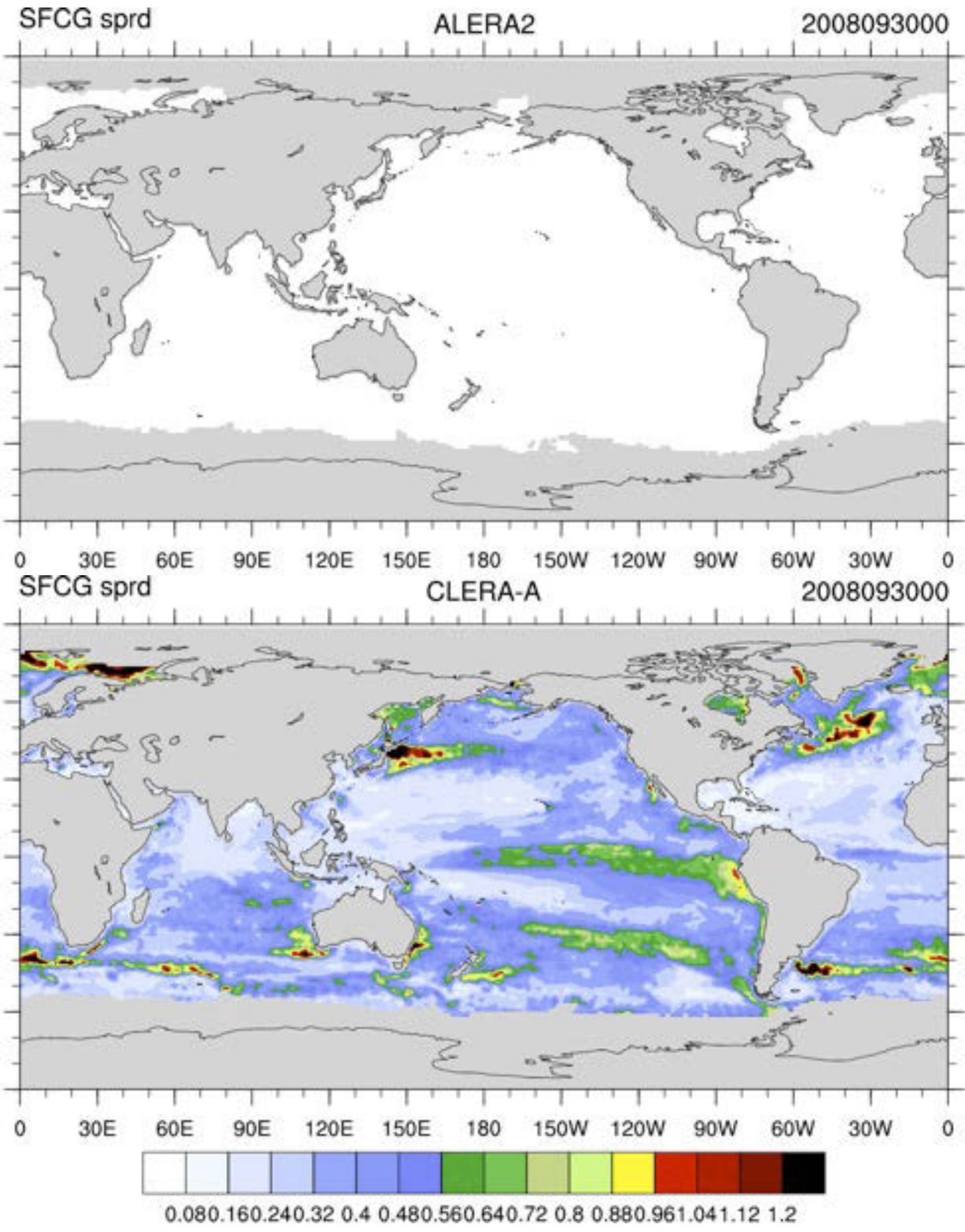
Experimental settings

- 39 members + control
- Atmospheric observation only
- Integration from 1 August to 30 September 2008
- Atmospheric IC from ALERA2
- Ocean IC from OFES mini
  - Exp. 1: 1 Aug from 1967 through 2006
  - Exp. 2: 1 Aug 2006 for all members

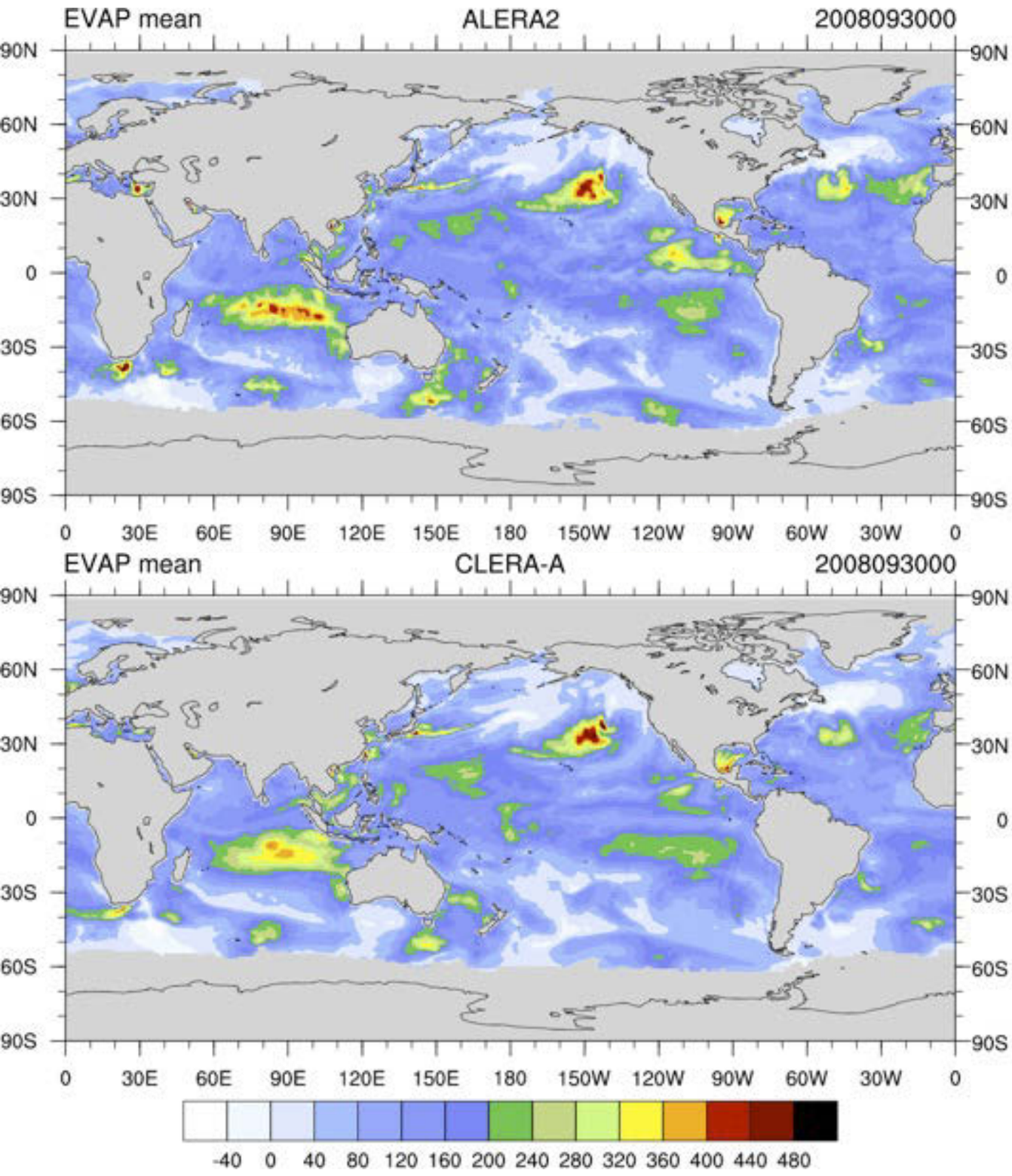
Results: Exp. 1

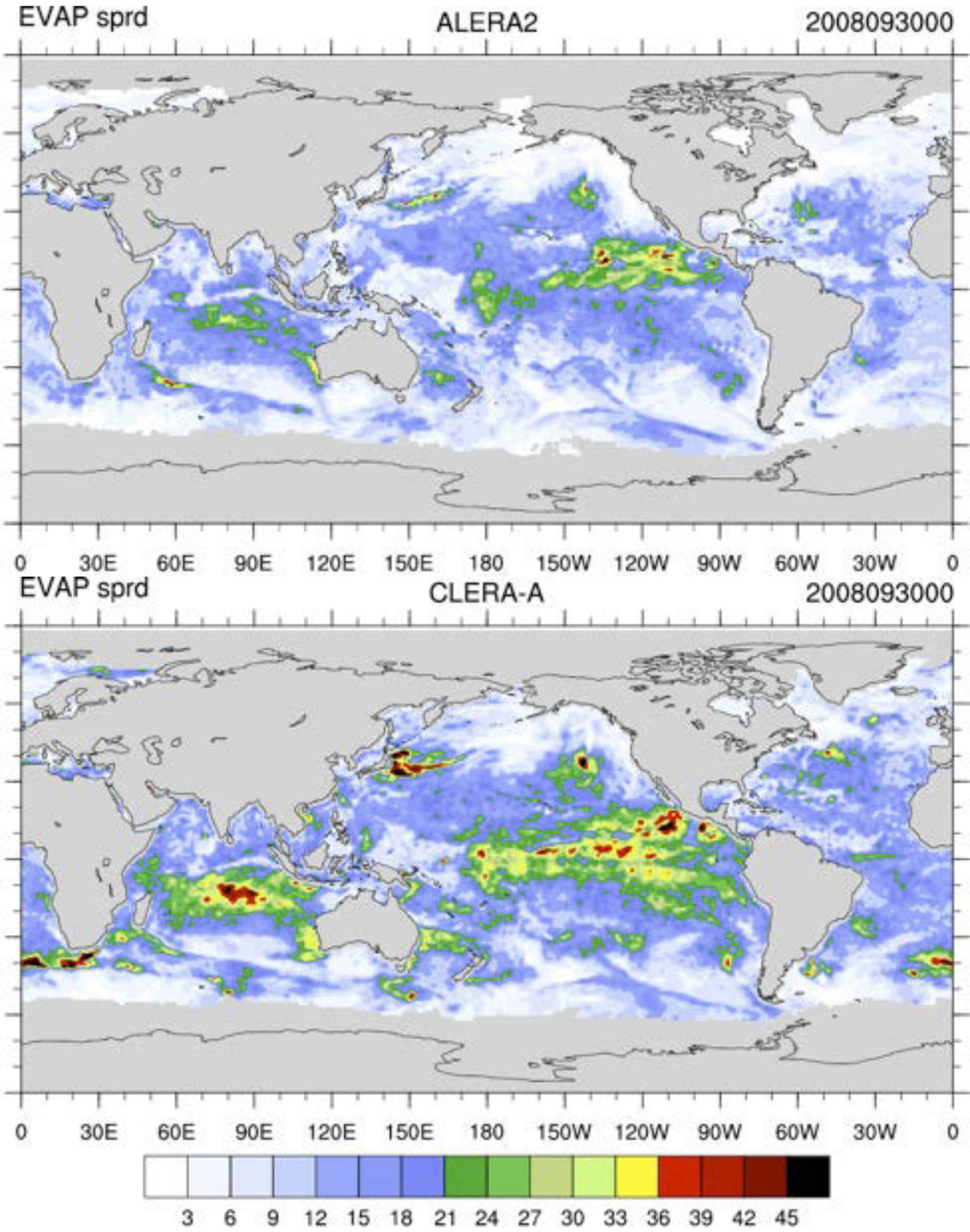
Surface temperature [K]





Latent heat flux [W/m^2]

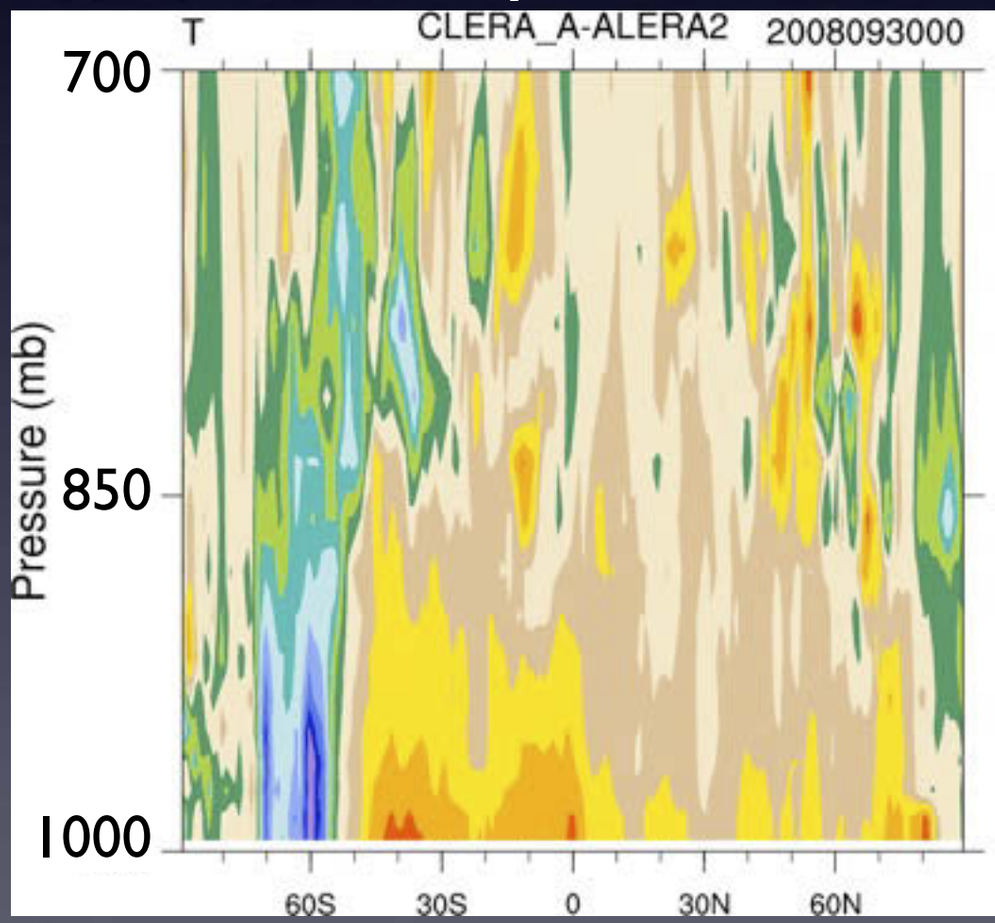




Difference in zonal mean spread

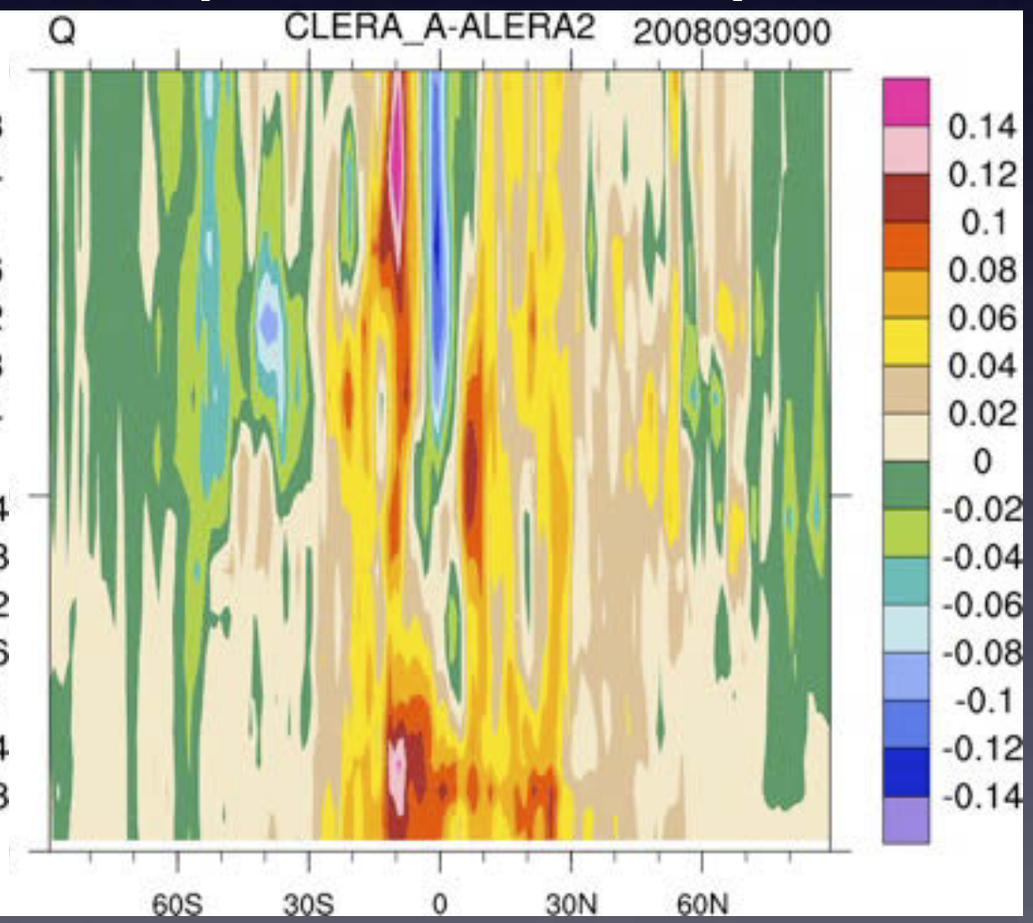
CLERA-A – ALERA2 2008093000

Temperature



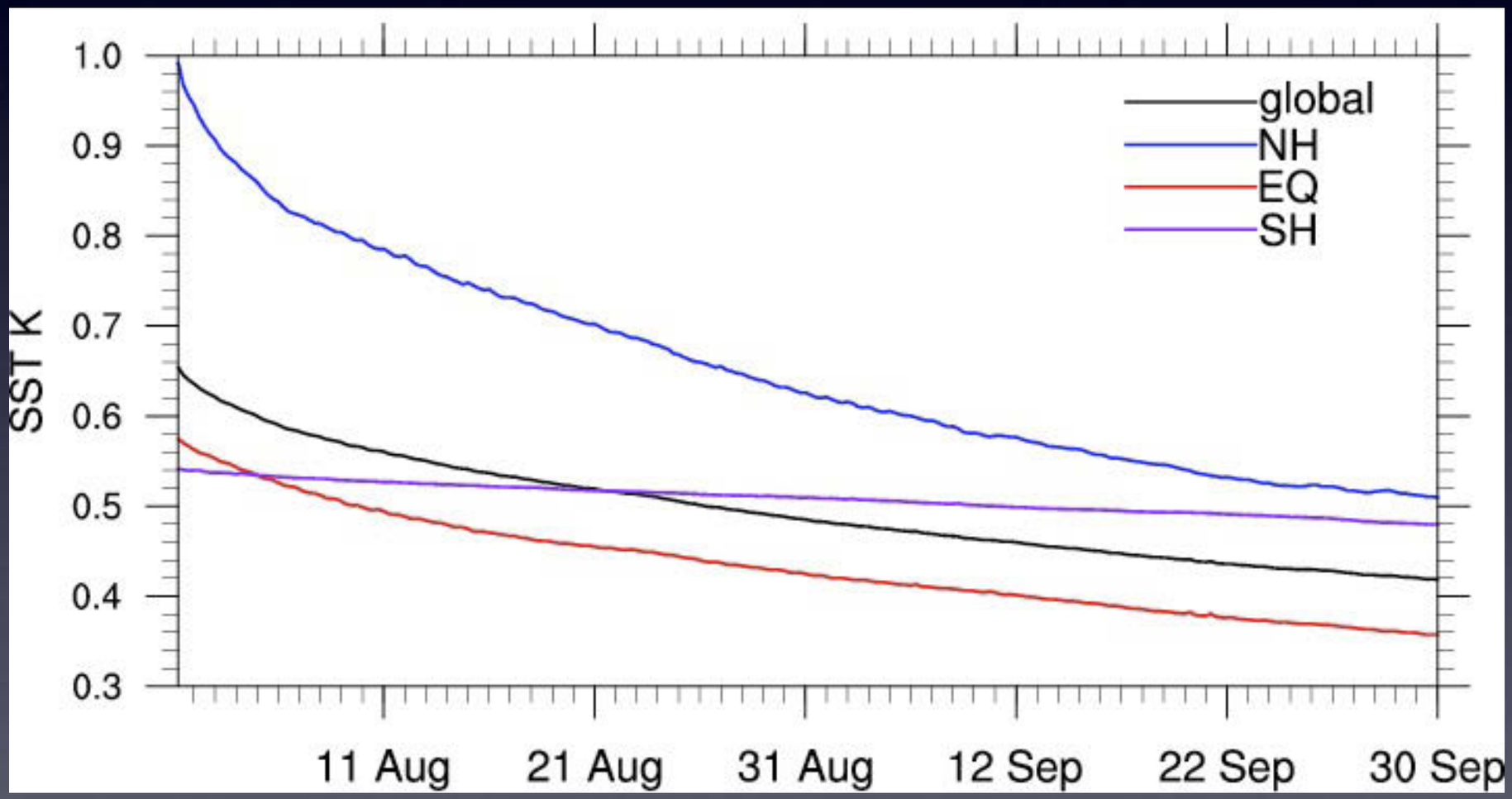
SP Eq NP

Specific humidity



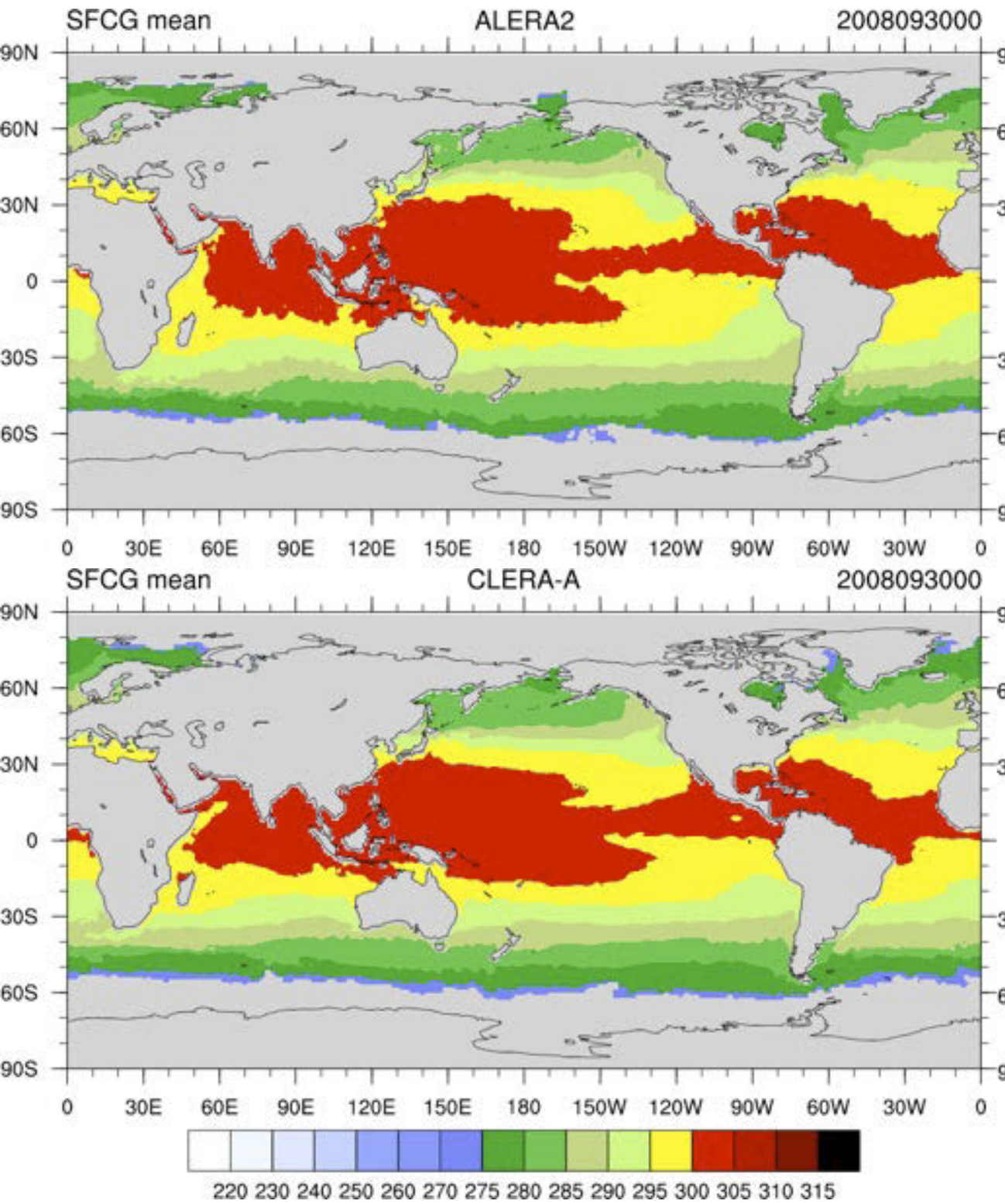
SP Eq NP

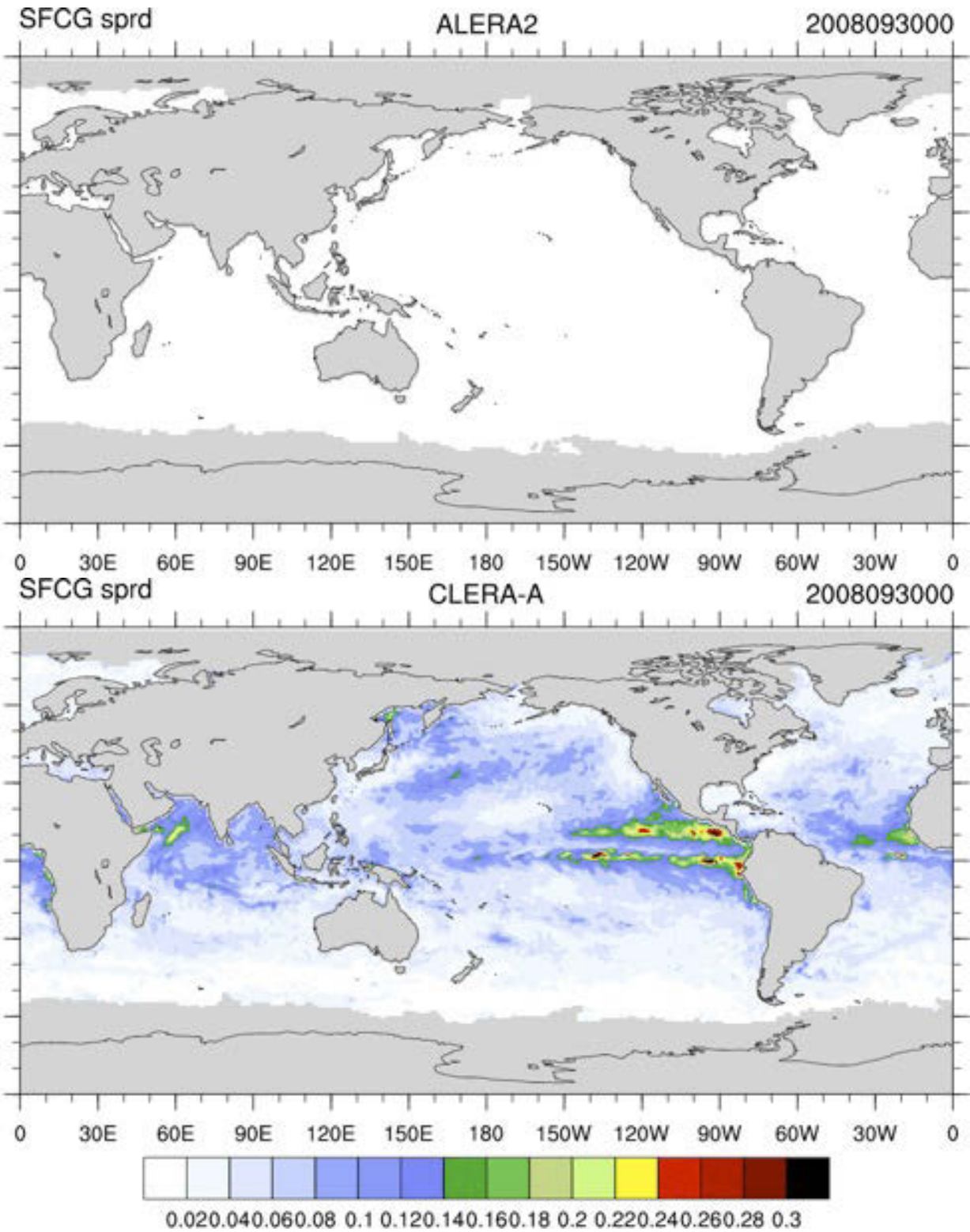
Time evolution of SST spread



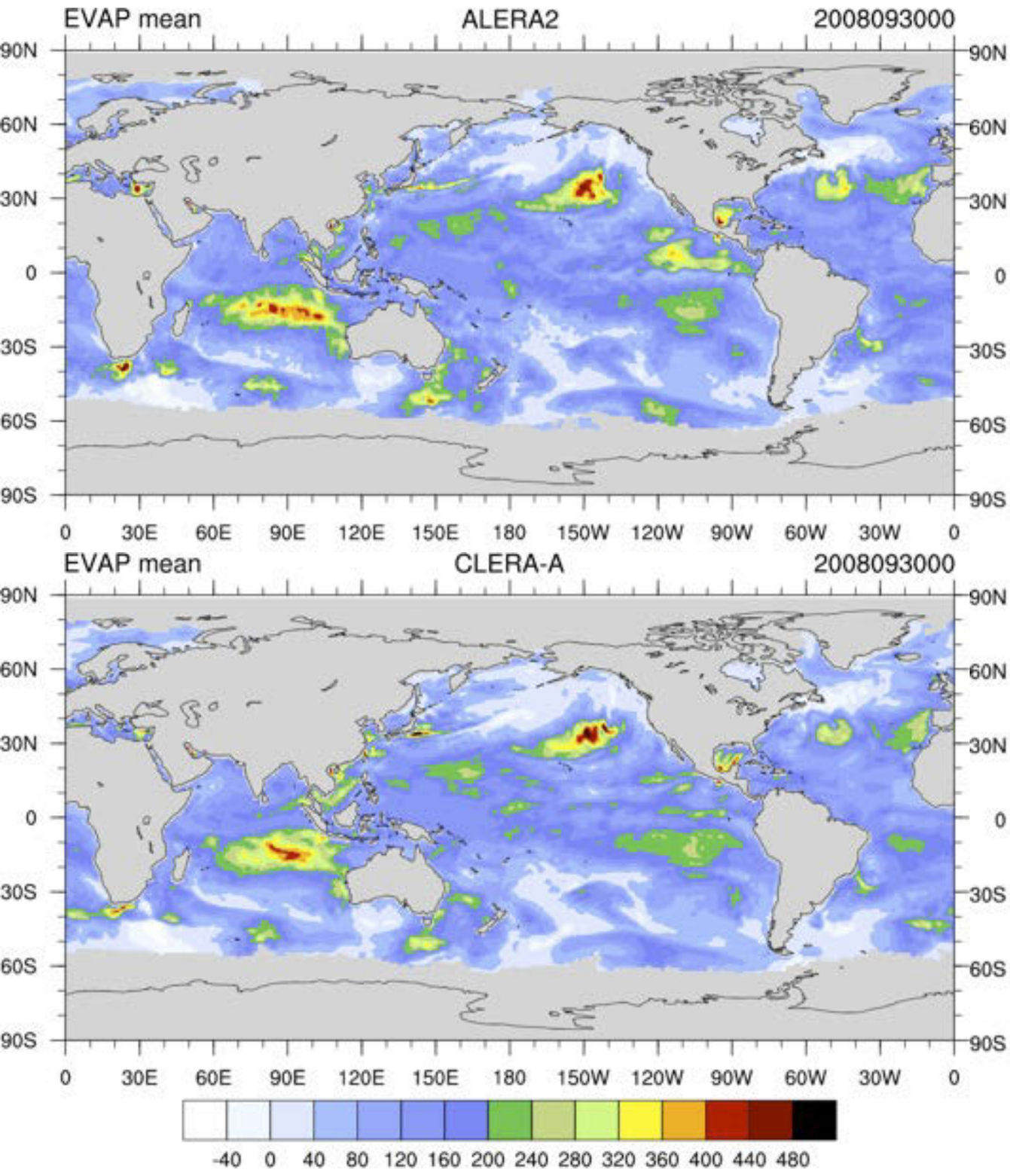
Results: Exp. 2

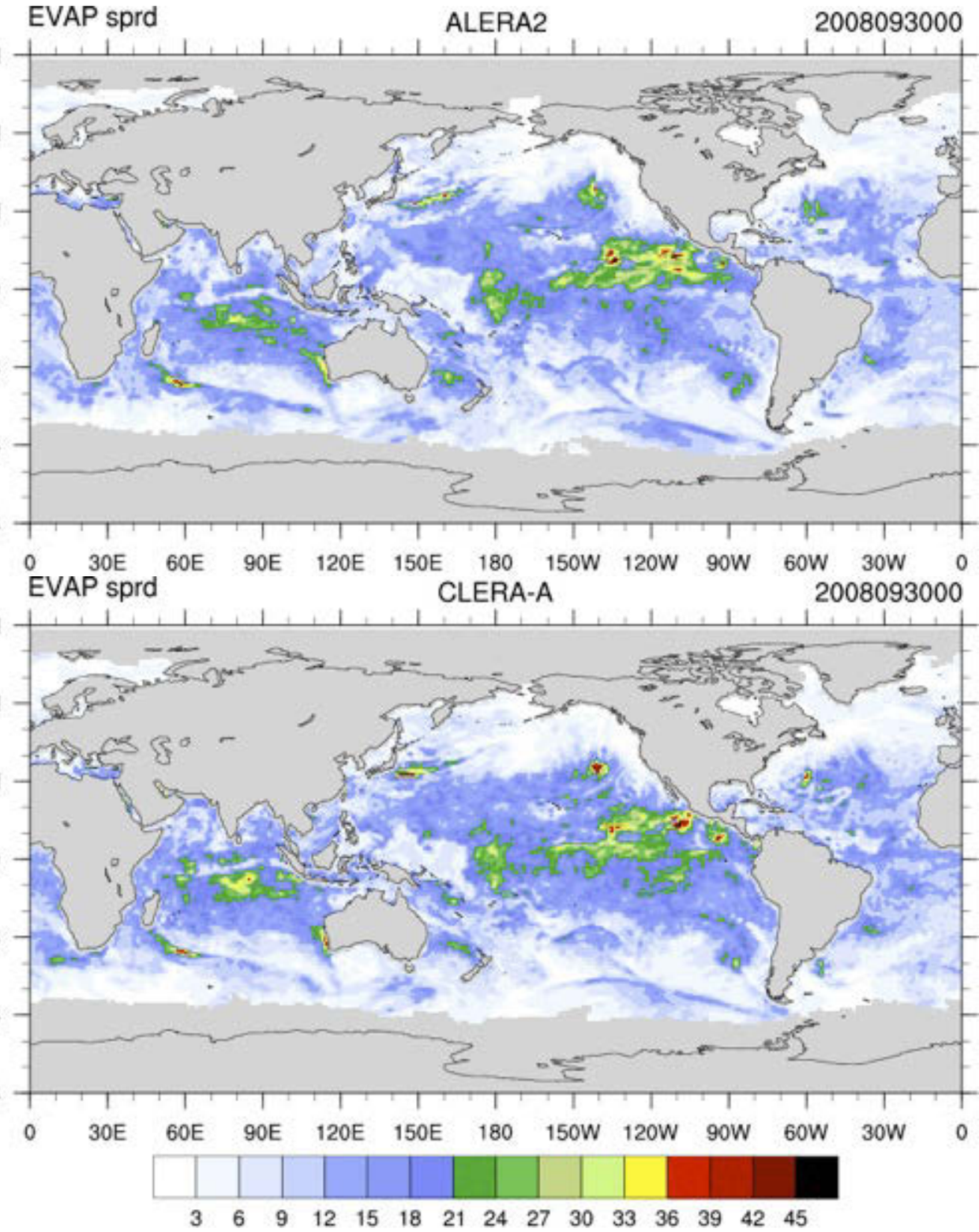
Surface temperature [K]





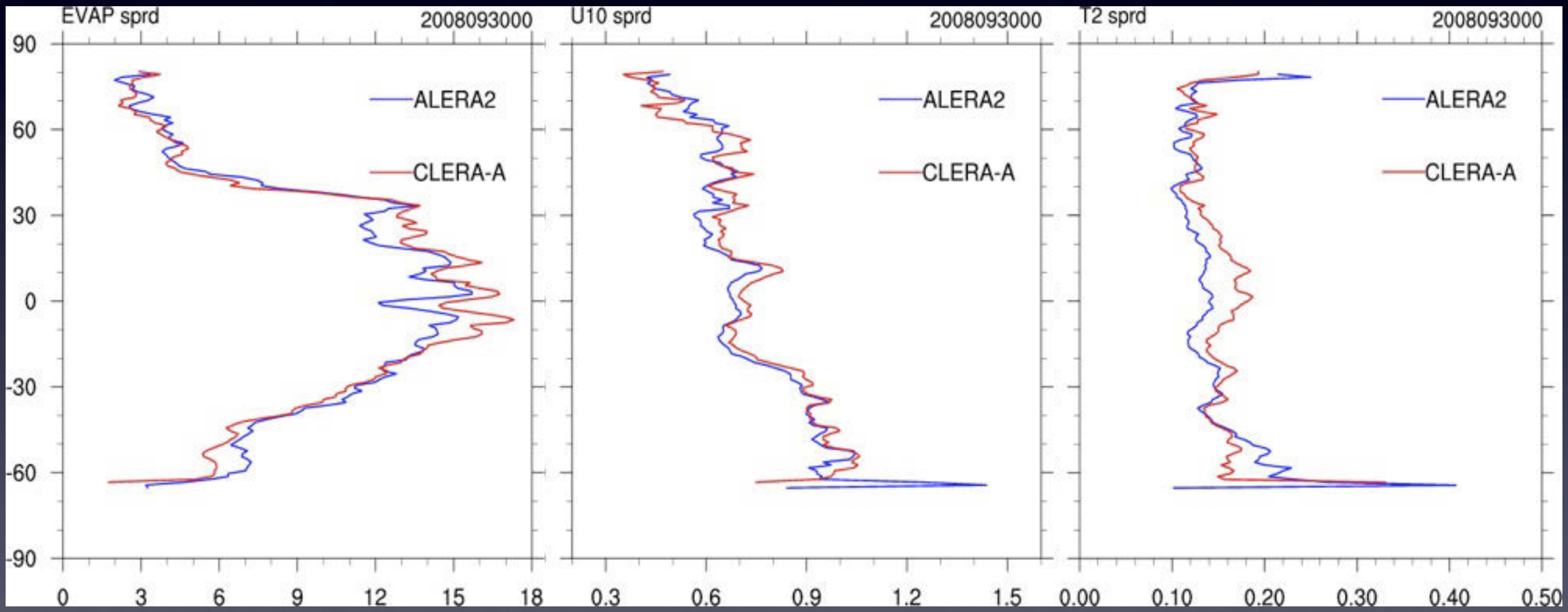
Latent heat flux [W/m^2]

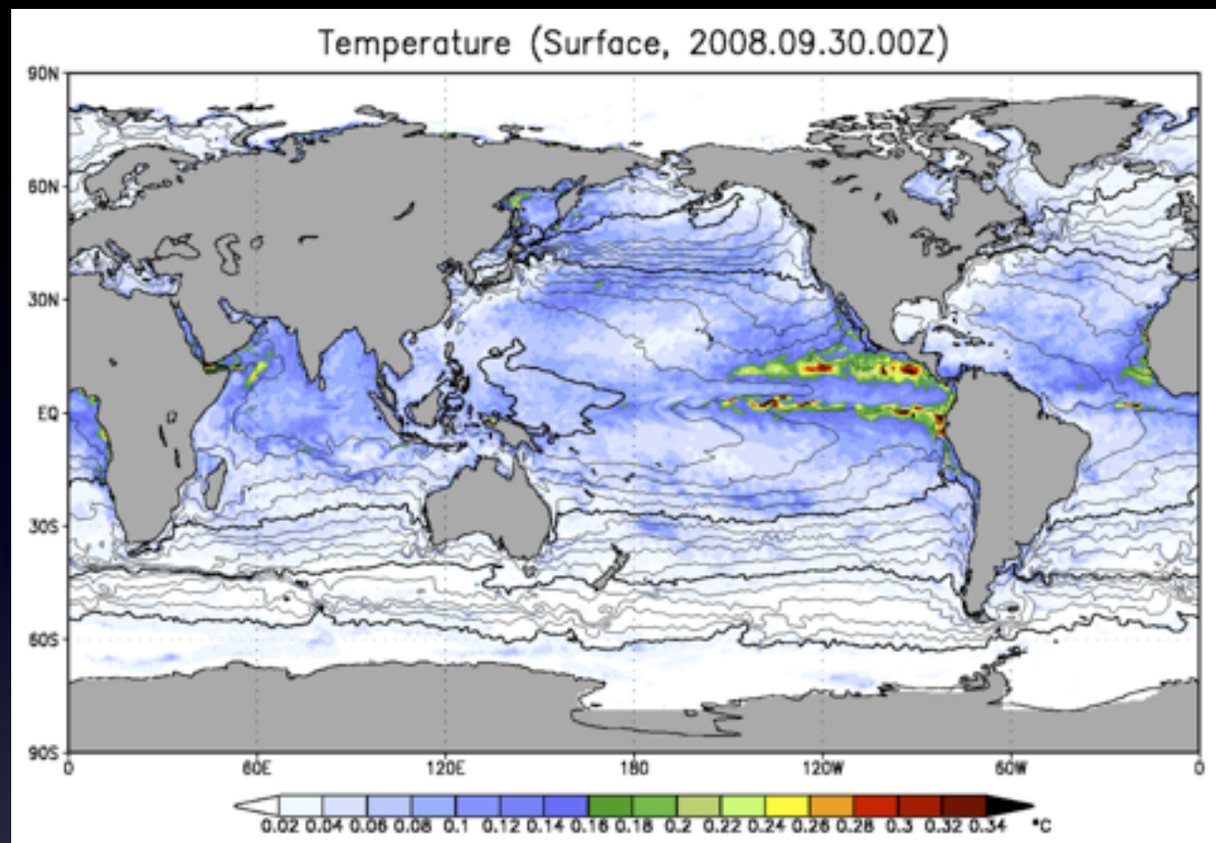


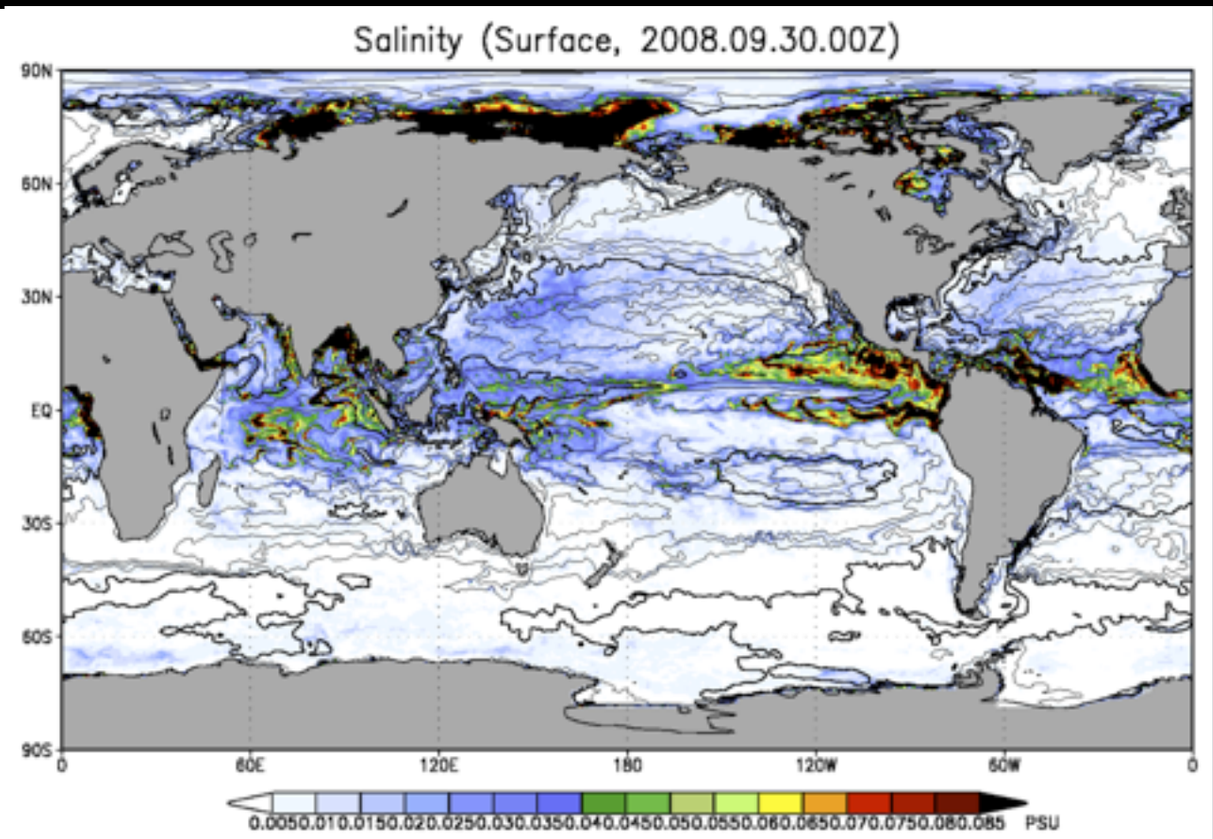


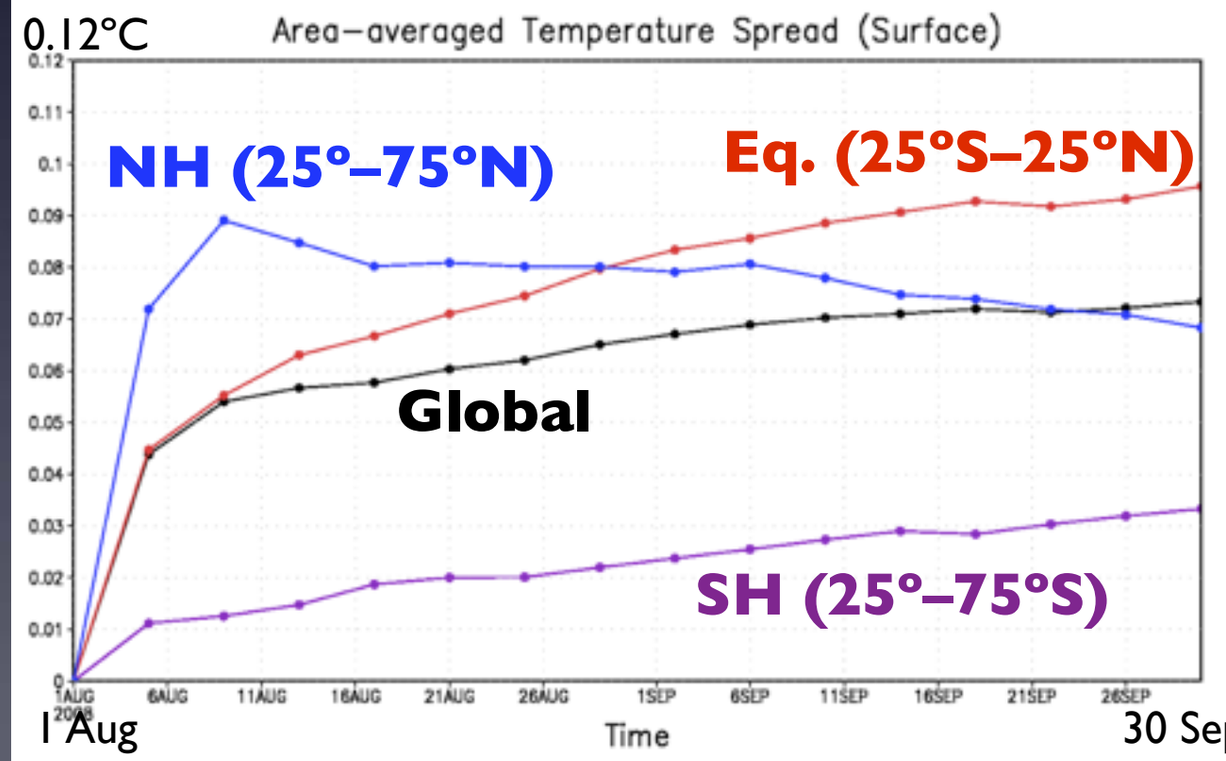
Zonal means

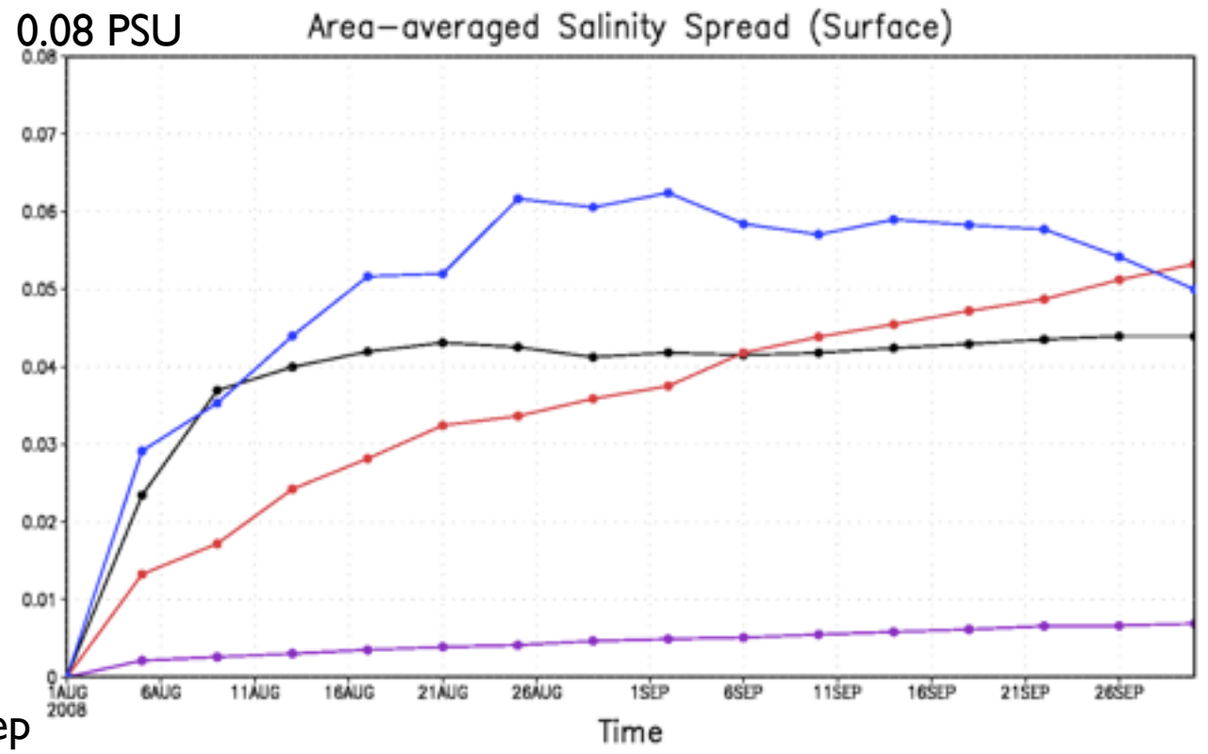
Latent heat flux [W/m^2] |U_{10m}| [m/s] T_{2m} [K]

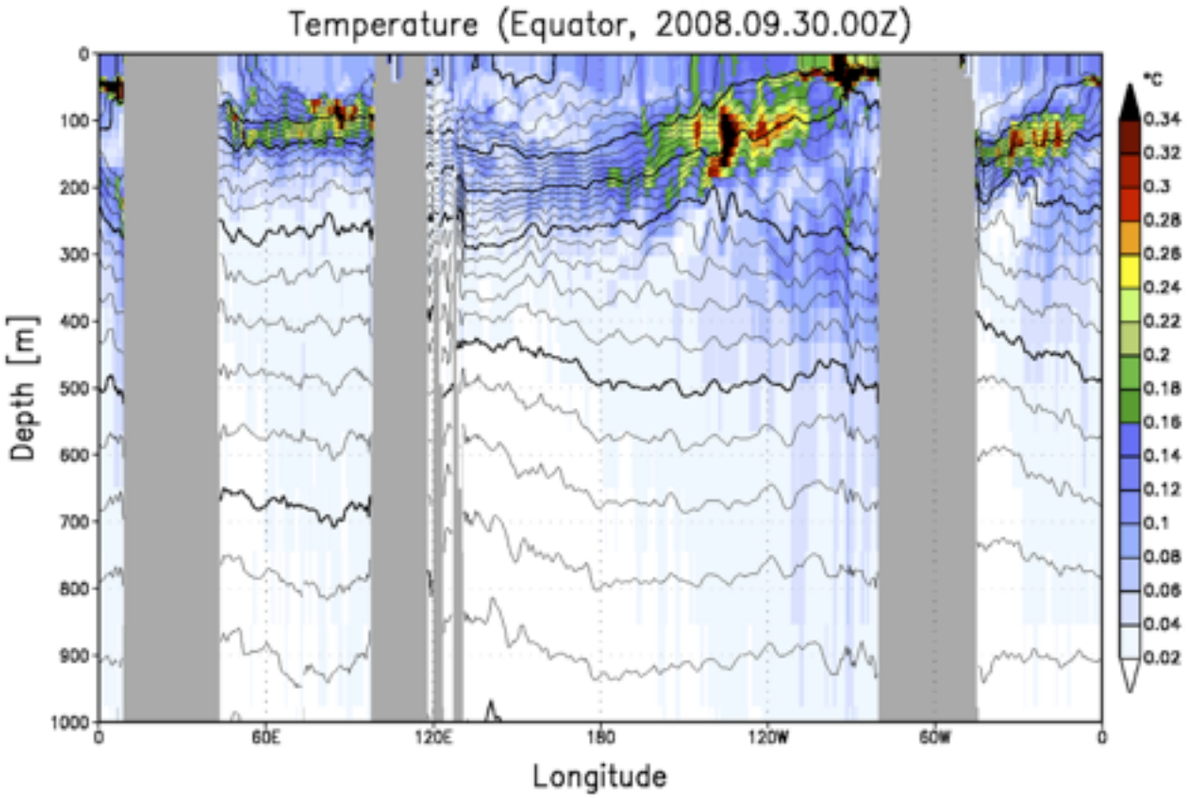


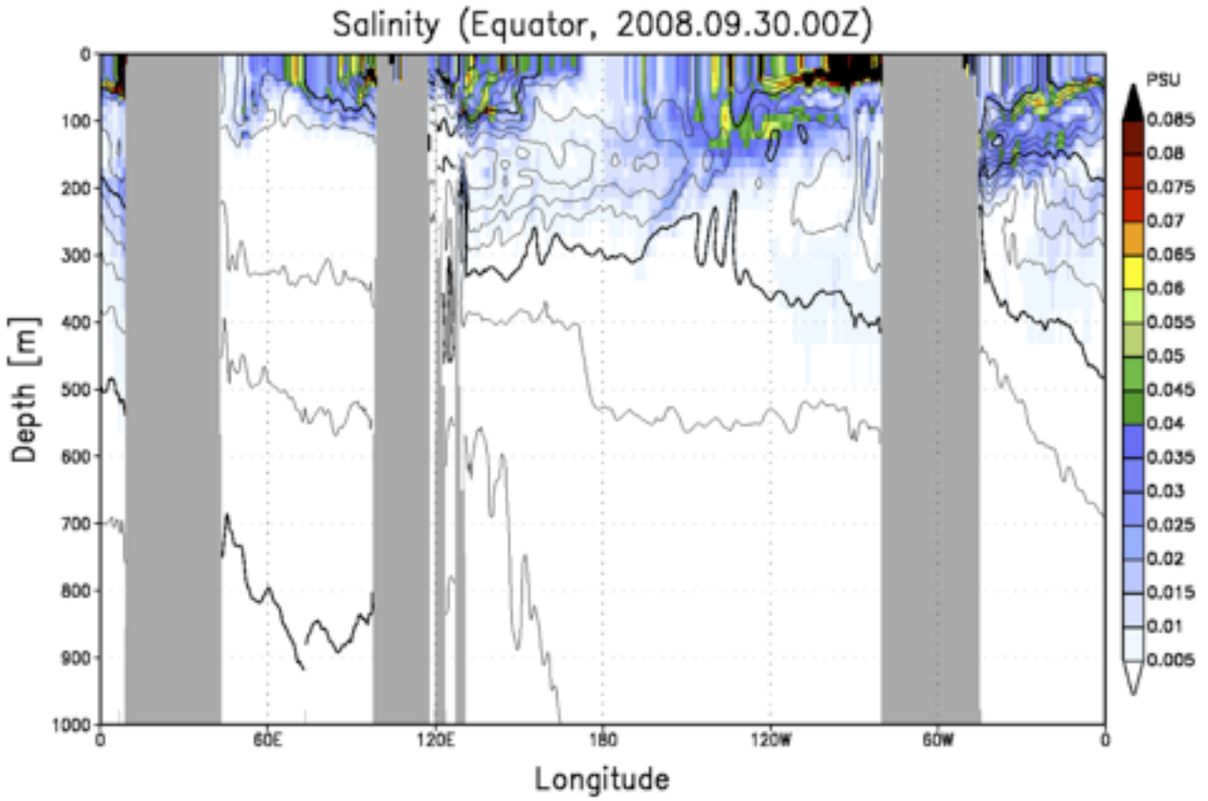

Temperature (Surface, 2008.09.30.00Z)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2 0.22 0.24 0.26 0.28 0.3 0.32 0.34 °C

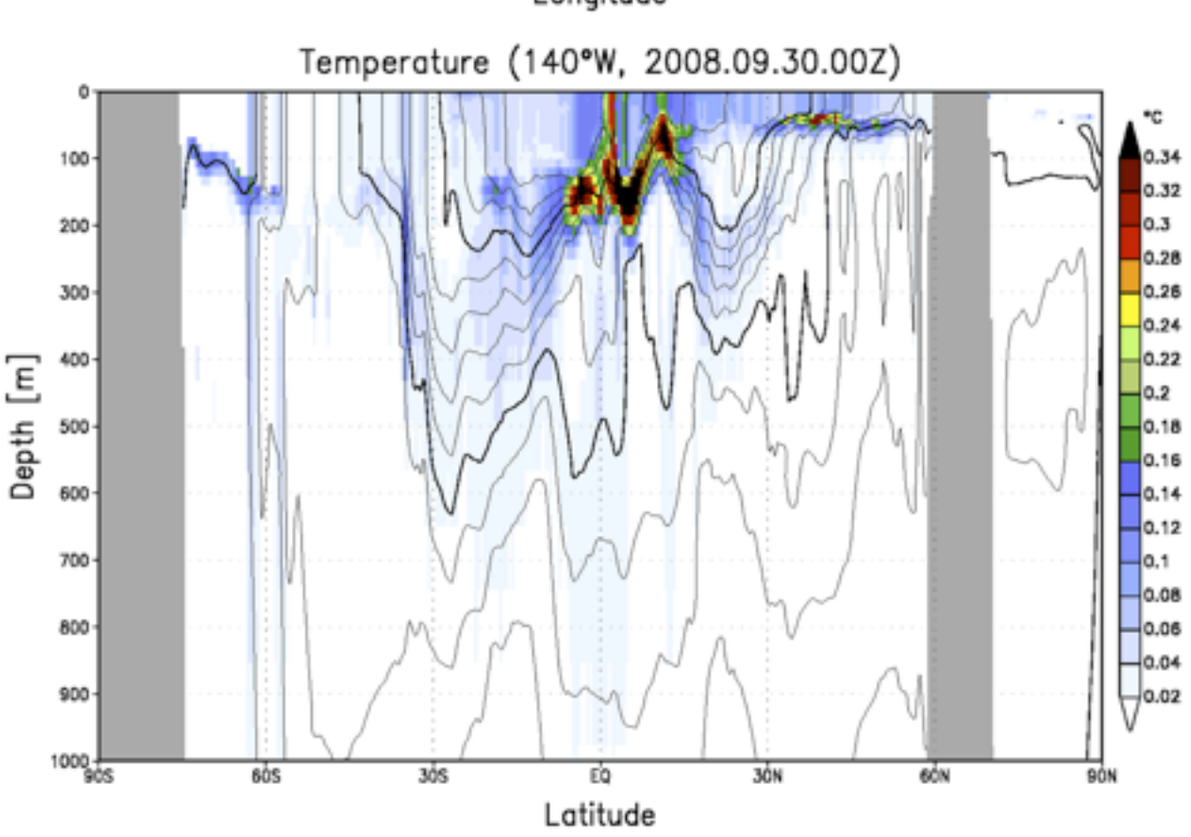

Salinity (Surface, 2008.09.30.00Z)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0.0050.010.0150.020.0250.030.0350.040.0450.050.0550.060.0650.070.0750.080.085 PSU

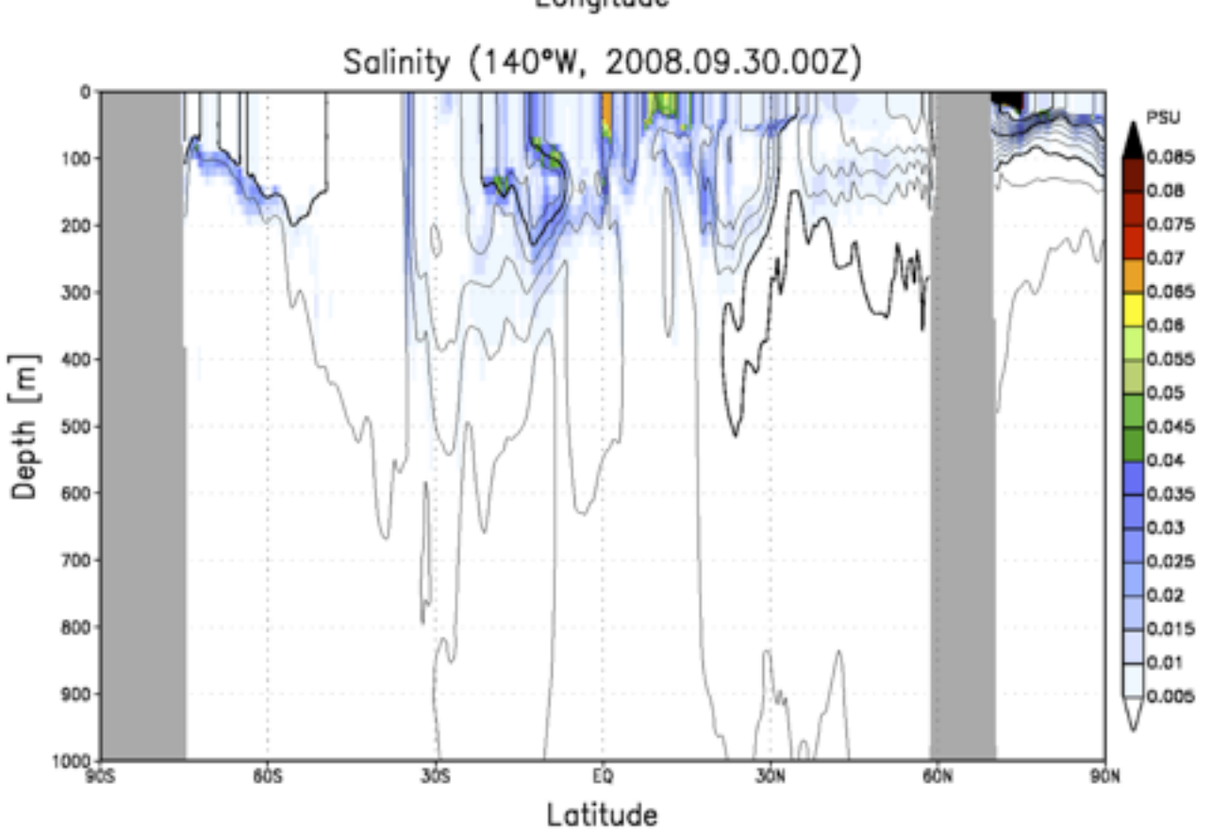

0.12°C
Area–averaged Temperature Spread (Surface)
NH (25°–75°N)
Eq. (25°S–25°N)
Global
SH (25°–75°S)
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1AUG 2008
6AUG
11AUG
16AUG
21AUG
26AUG
1SEP
6SEP
11SEP
16SEP
21SEP
26SEP
1 Aug
Time


0.08 PSU
Area–averaged Salinity Spread (Surface)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1AUG 2008
6AUG
11AUG
16AUG
21AUG
26AUG
1SEP
6SEP
11SEP
16SEP
21SEP
26SEP
30 Sep
Time

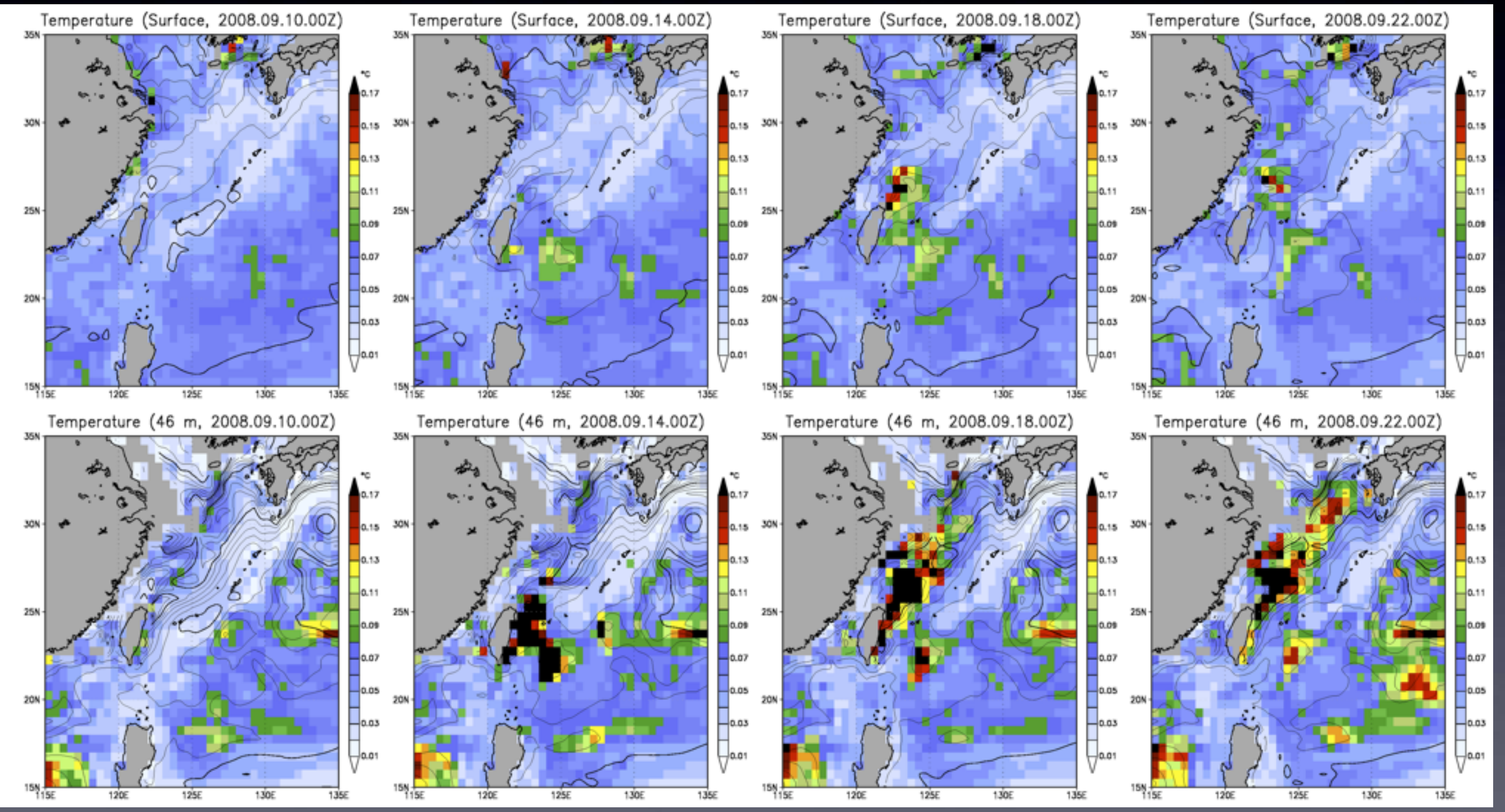

Temperature (Equator, 2008.09.30.00Z)
Depth [m]
Longitude
°C
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02


Salinity (Equator, 2008.09.30.00Z)
Depth [m]
Longitude
PSU
0.085
0.08
0.075
0.07
0.065
0.06
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005

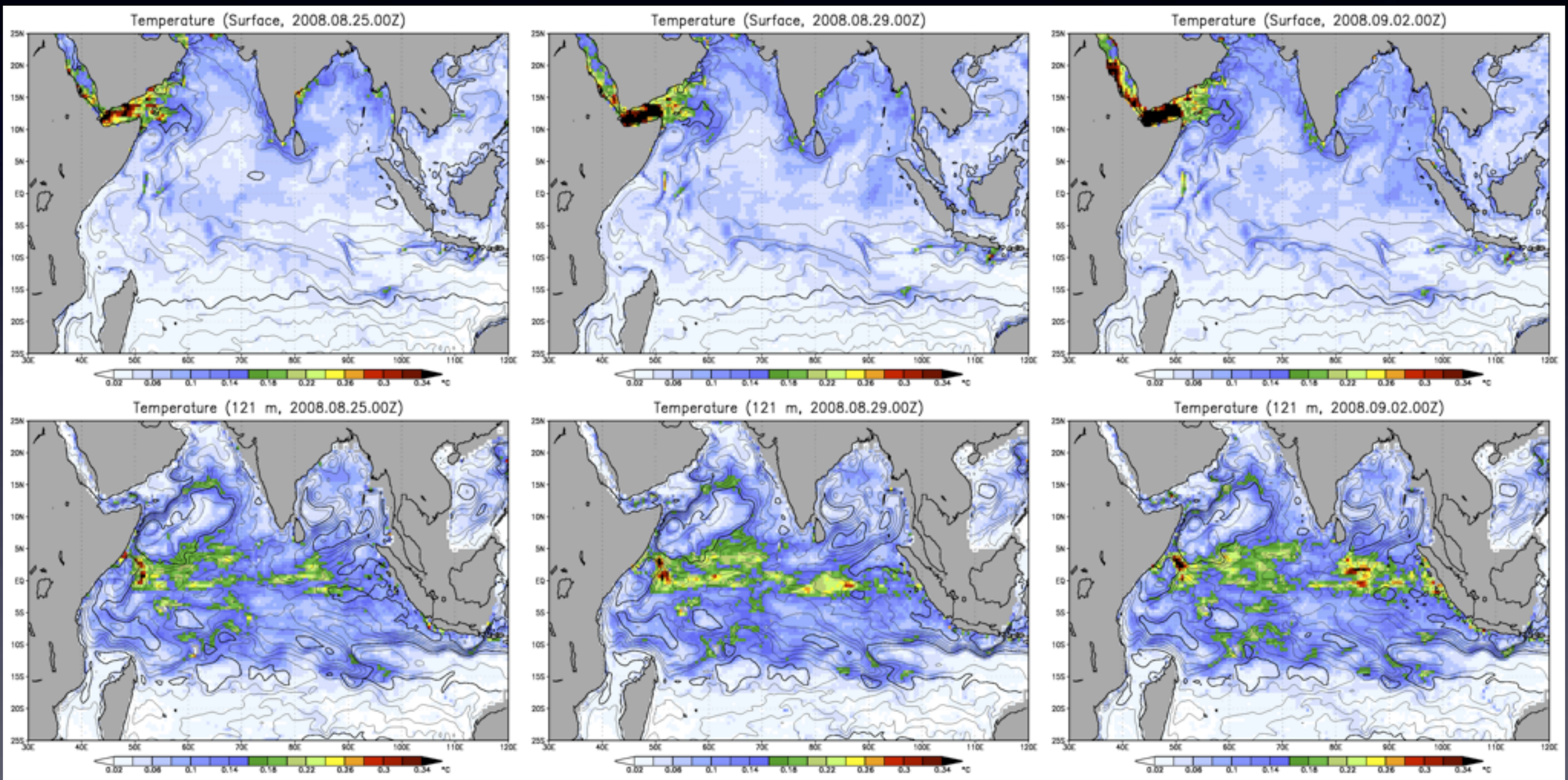

Temperature (140°W, 2008.09.30.00Z)
Depth [m]
Latitude
°C
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02


Salinity (140°W, 2008.09.30.00Z)
Depth [m]
Latitude
PSU
0.085
0.08
0.075
0.07
0.065
0.06
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005

Oceanic response to Typhoon Sinlaku



Oceanic response to MJO



Ensemble Ocean Simulations

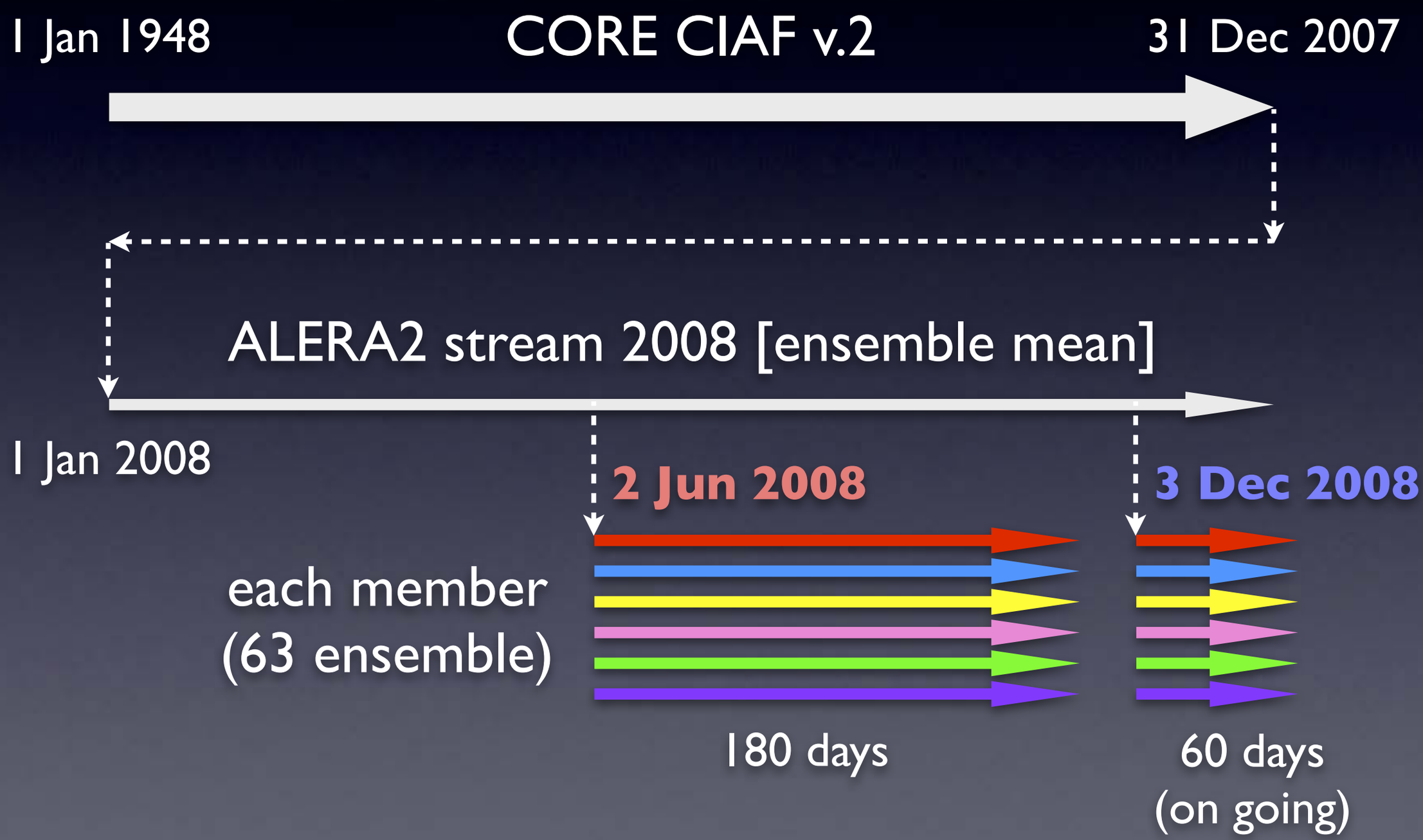
Objectives

- ensemble simulations using a global coupled ocean–sea-ice model (OFES) forced by 63-member outputs from ALERA2
- to investigate the uncertainty of the global coupled ocean–sea-ice system caused by external atmospheric forcing
- to design an ensemble-based data assimilation system with CFES assimilating both atmospheric *and* oceanic observational data

OFES

- Ocean GCM for the Earth Simulator
  - based on GFDL MOM3 and optimized for the ES (Masumoto et al., 2004)
  - coupled with a sea-ice model (Komori et al., 2005)
- OFES mini
  - almost identical to the ocean comp. of CFES mini
    - resolution (0.5°x0.5° 54 lev.), schemes, parameters, ...
    - a polar filter north of 85°N

Ensemble simulations

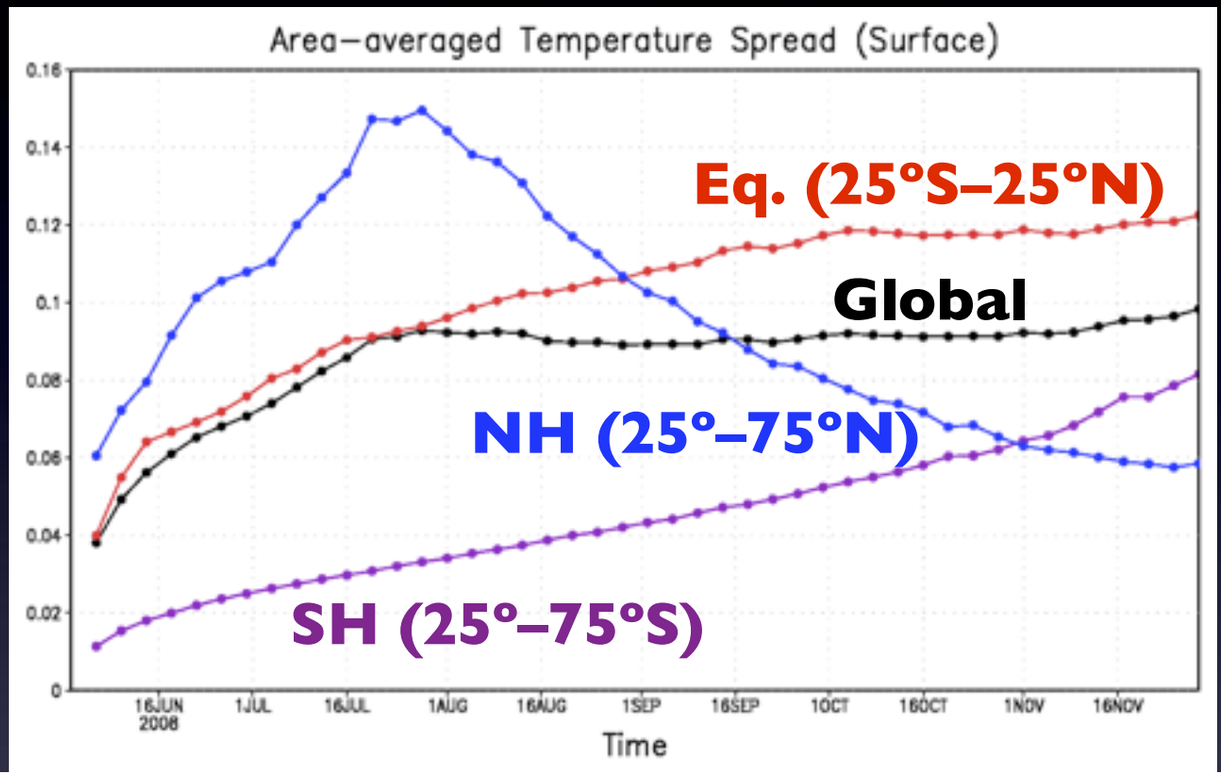


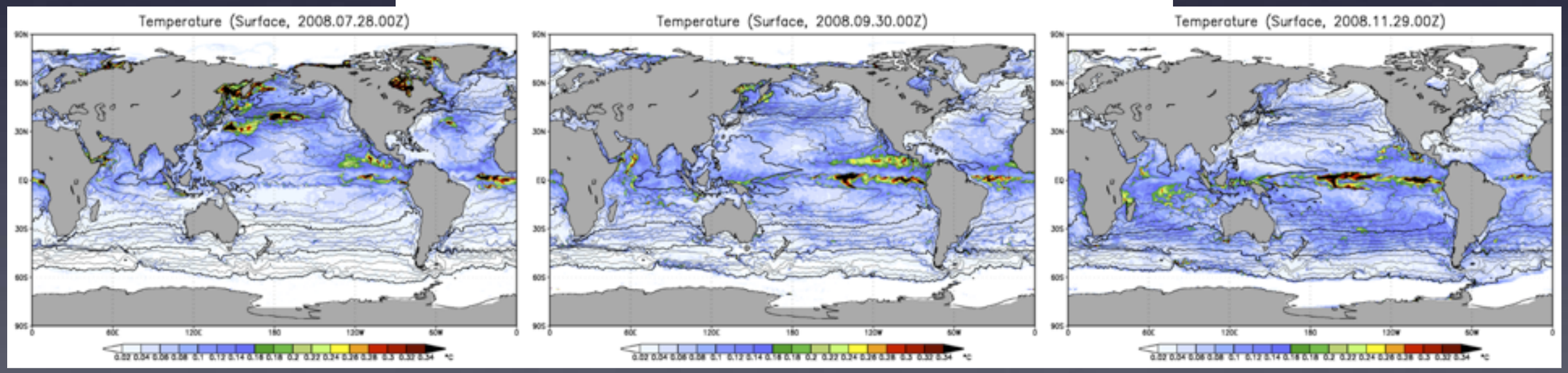
Temperature (Surface, 2008.06.06.00Z)

90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0

0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18 0.2 0.22 0.24 0.26 0.28 0.3 0.32 0.34 °C

Temporal evolution of spread

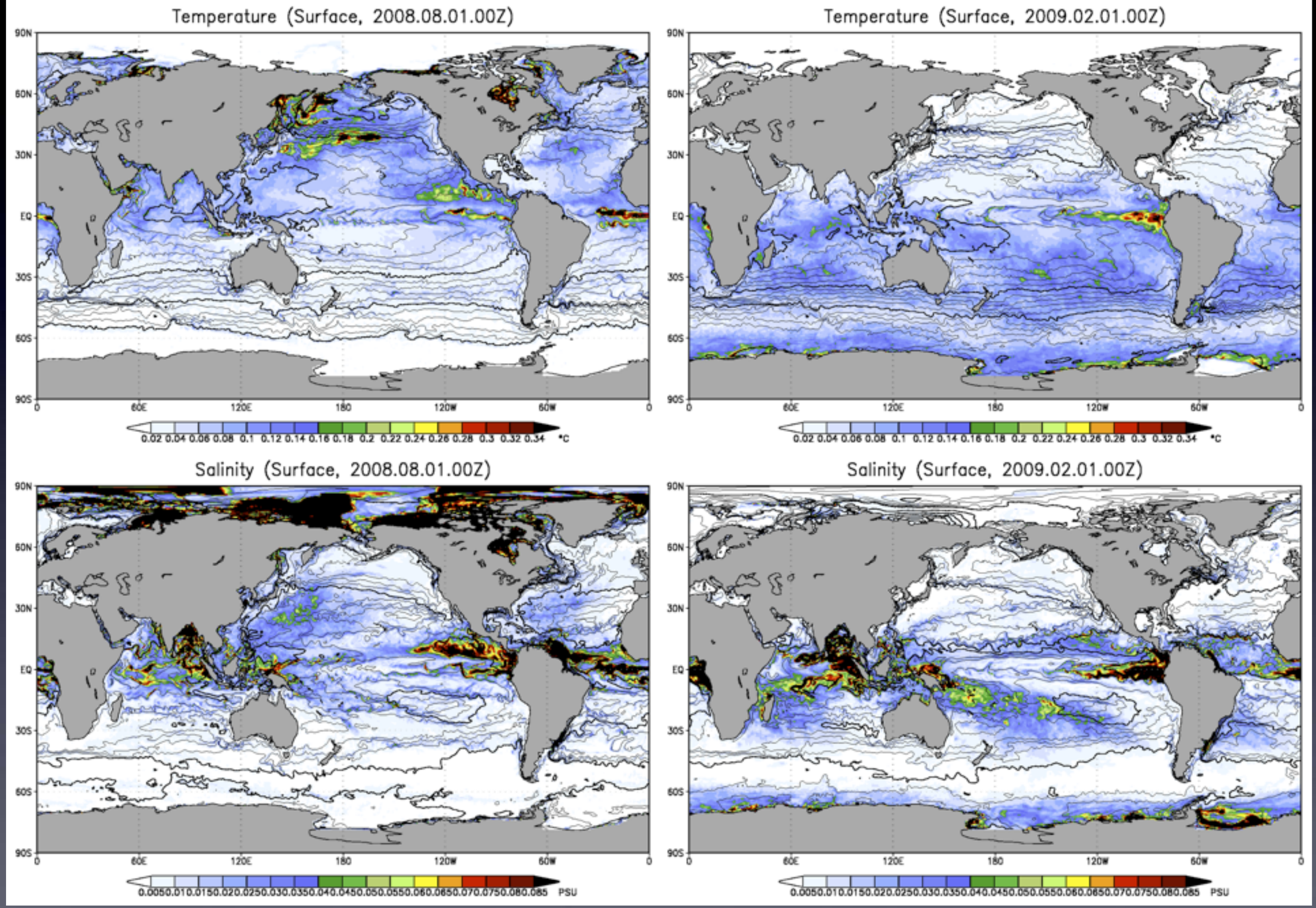




28 Jul 2008 | 30 Sep 2008 | 29 Nov 2008

1 Aug 2008

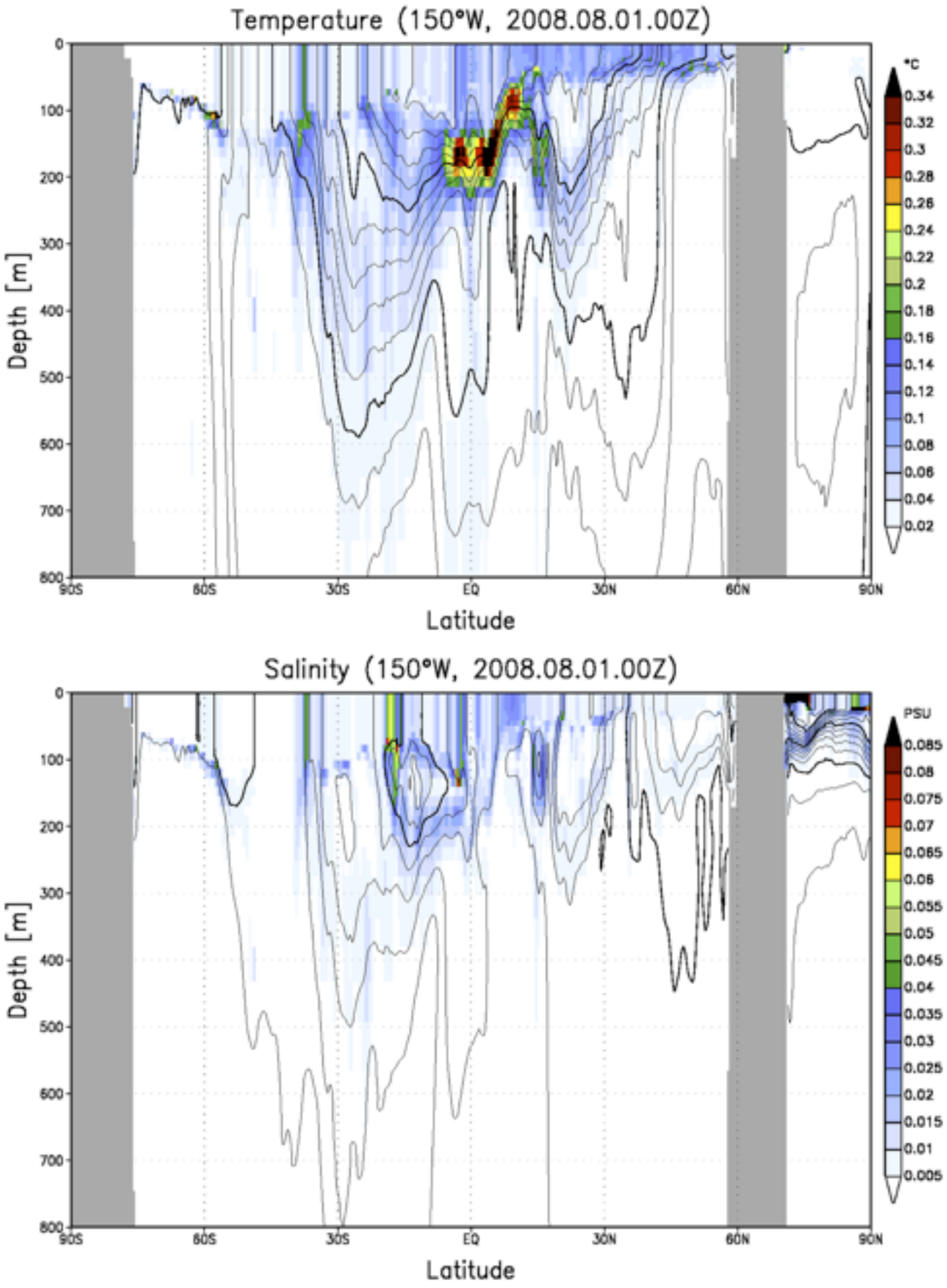
1 Feb 2009

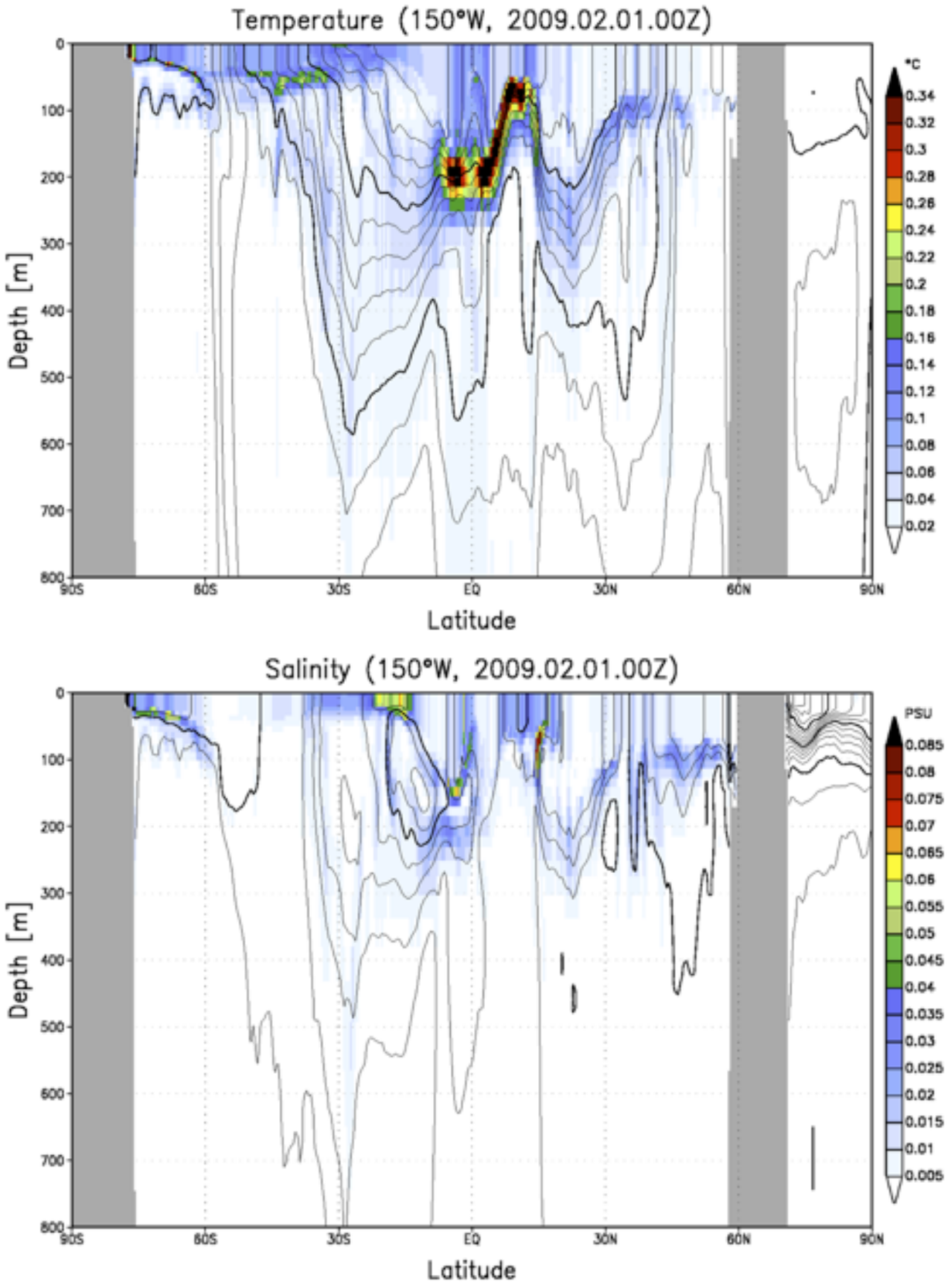


60 days after IC

1 Aug 2008

1 Feb 2009

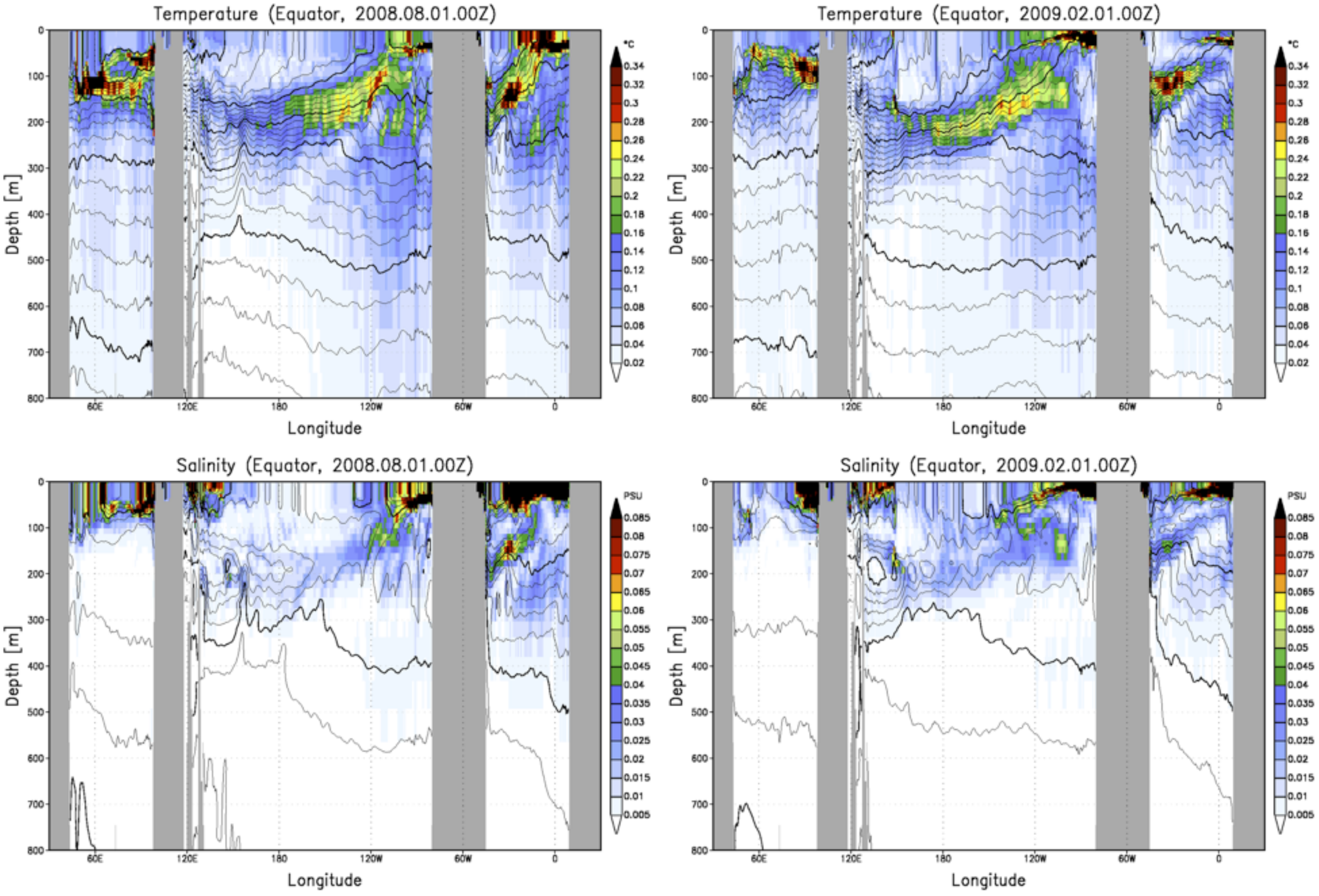




60 days after IC

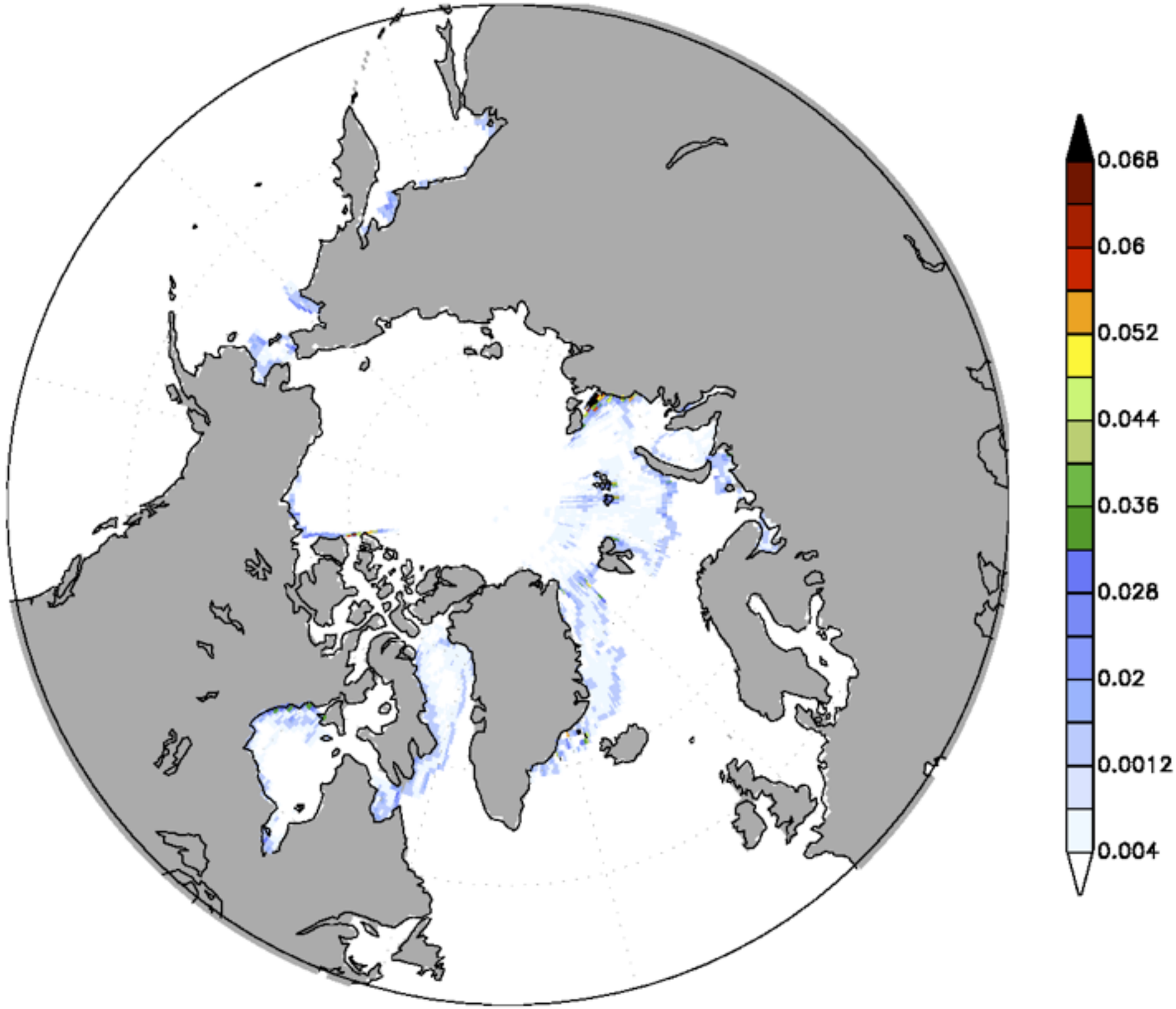
1 Aug 2008

1 Feb 2009

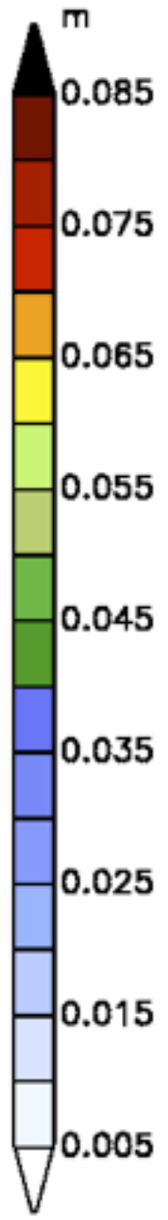


60 days after IC

Sea–Ice Concentration (2008.06.06.00Z)



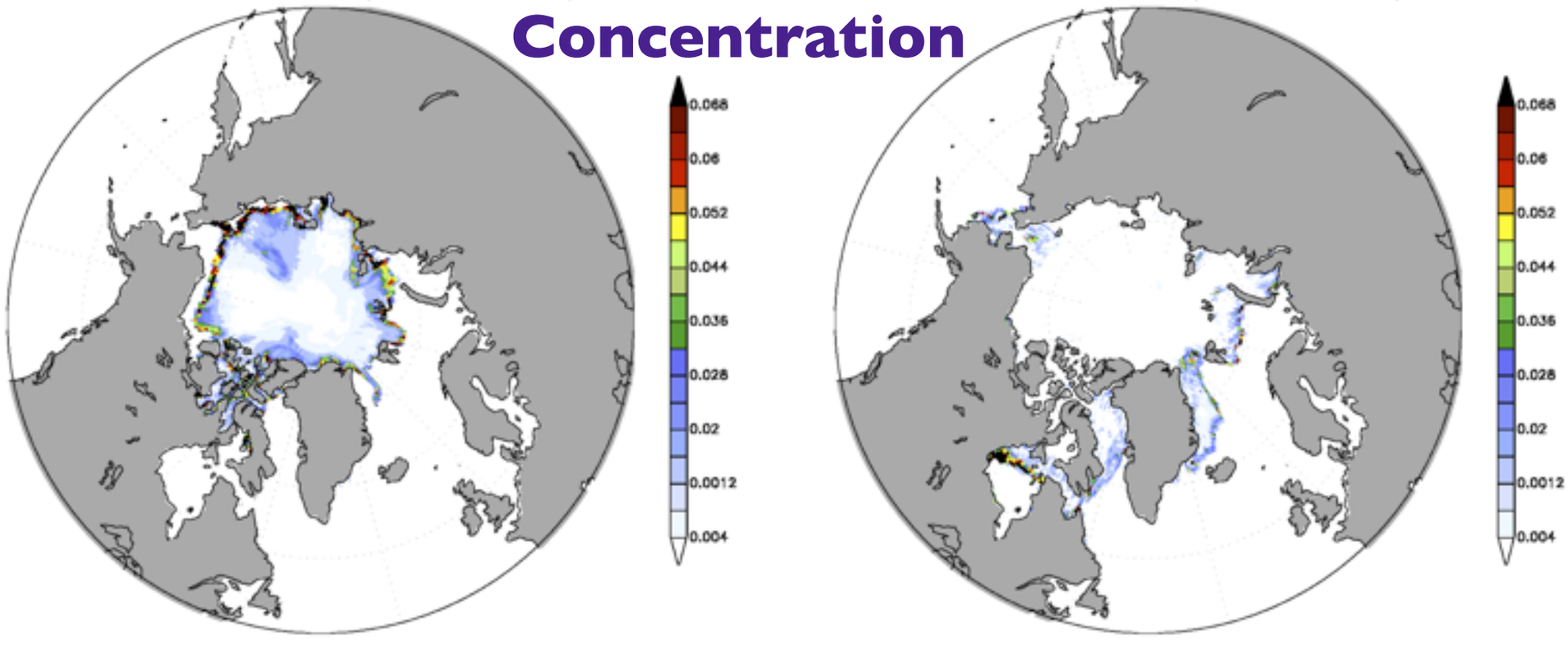
Effective Sea-Ice Thickness (2008.06.06.00Z)



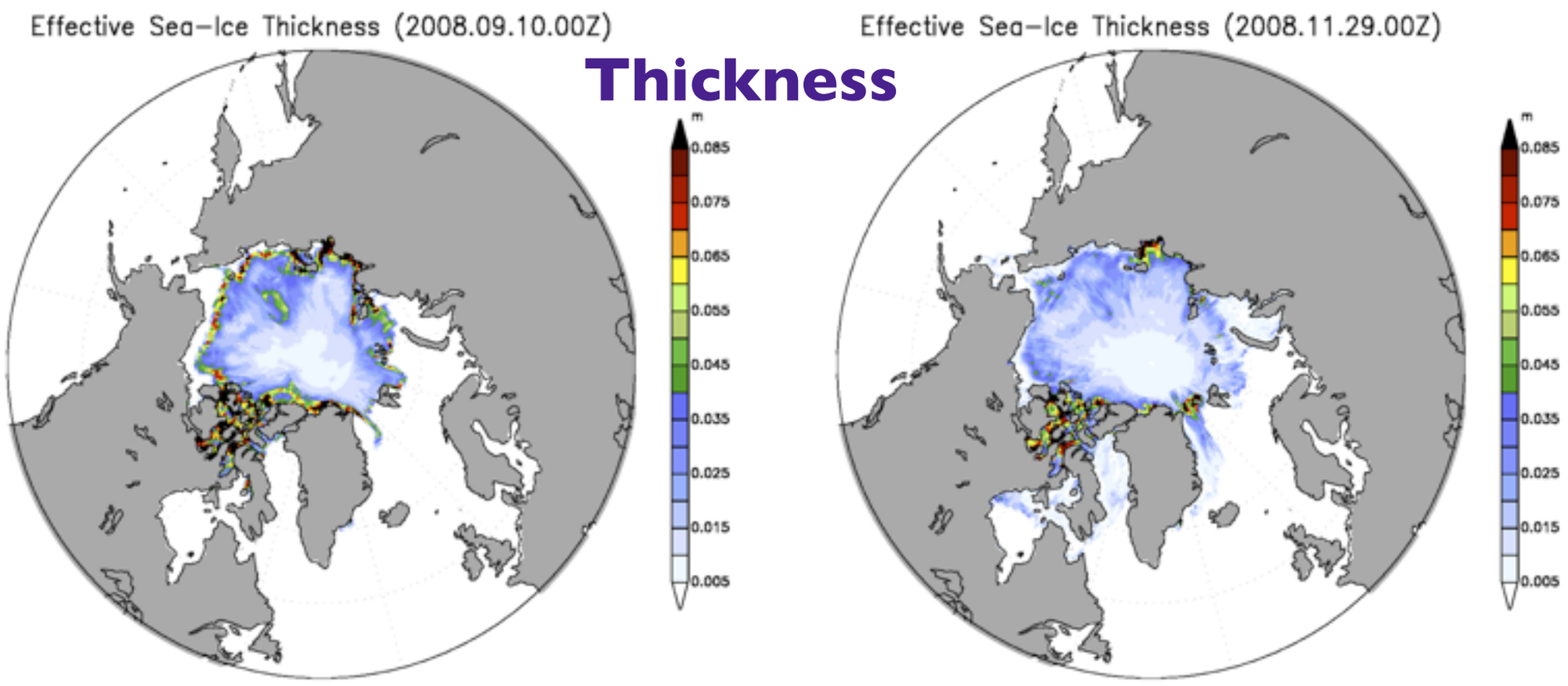
10 Sep 2008

29 Nov 2008

Concentration



Thickness



Summary (CLERA-A)

- The CFES–LETKF ensemble DA system has been constructed.
  - Ocean ensemble creates perturbed surface BC.
    - Oceanic response along the thermocline
    - Asymmetry in oceanic response between summer and winter hemispheres
- Needs to handle oceanic biases and drift for a longer run and atmospheric analysis.

Summary (EnOFES)

- Two sets of ensemble simulations using OFES are carried out: (i) from 2 Jun 2008, (ii) from 3 Dec 2008.
  - large ensemble spread around the depth of thermocline and the bottom of the mixed layer
  - asymmetry between the summer and winter hemispheres
  - different *memories* between ensemble spreads of sea-ice concentration and sea-ice thickness

Future Plans

- development of the improved version of CFES–LETKF DA system assimilating both atmospheric *and* oceanic observational data
  - need of special attention to the treatment of ensemble for the polar region (e.g., non-Gaussian statistics)
- application to atmosphere–ocean interaction studies
  - co-variability between atmospheric and oceanic variables

Thank You!