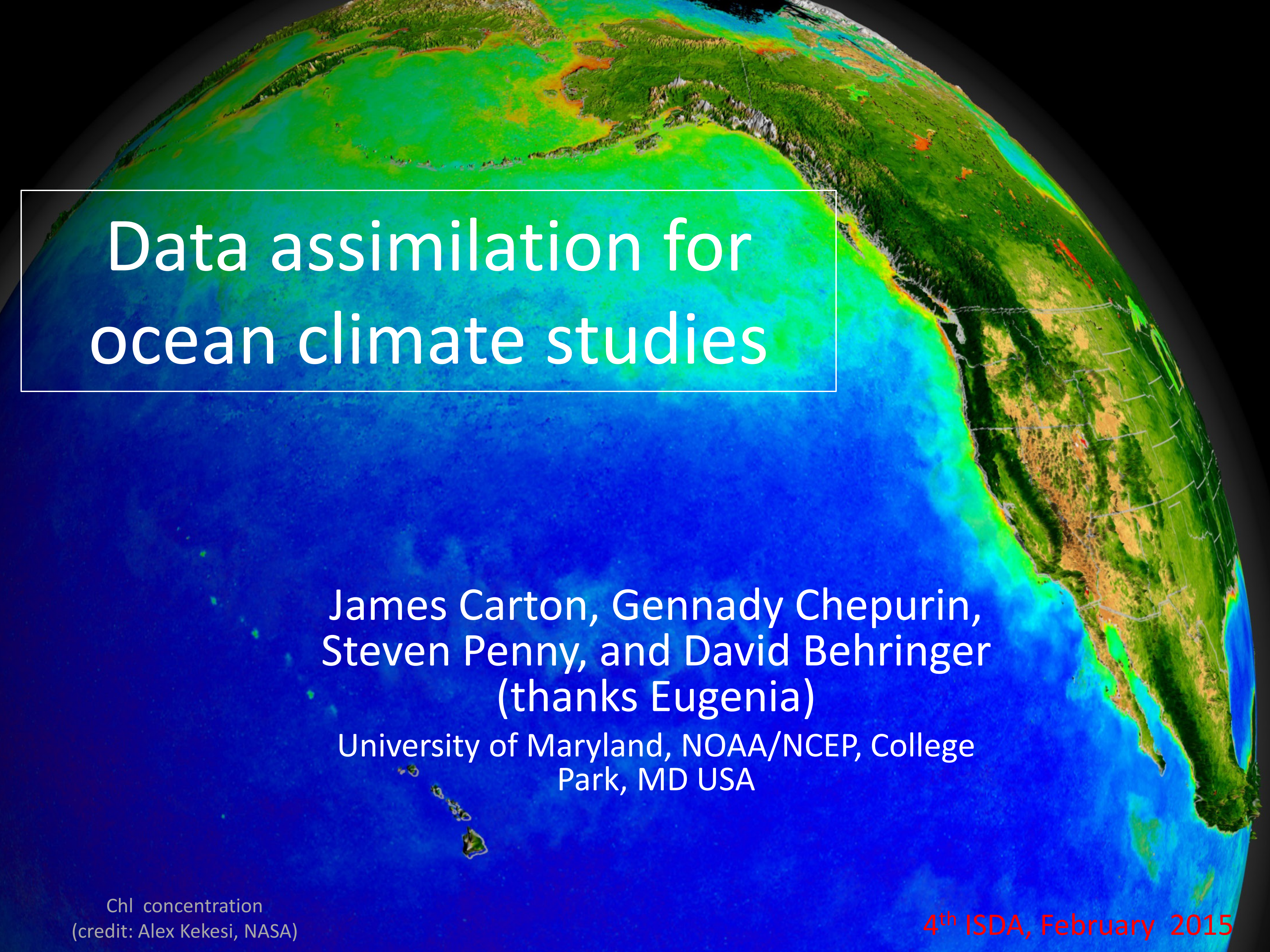
Data assimilation for ocean climate studies

James Carton, Gennady Chepurin, Steven Penny, and David Behringer
(thanks Eugenia)
University of Maryland, NOAA/NCEP, College Park, MD USA



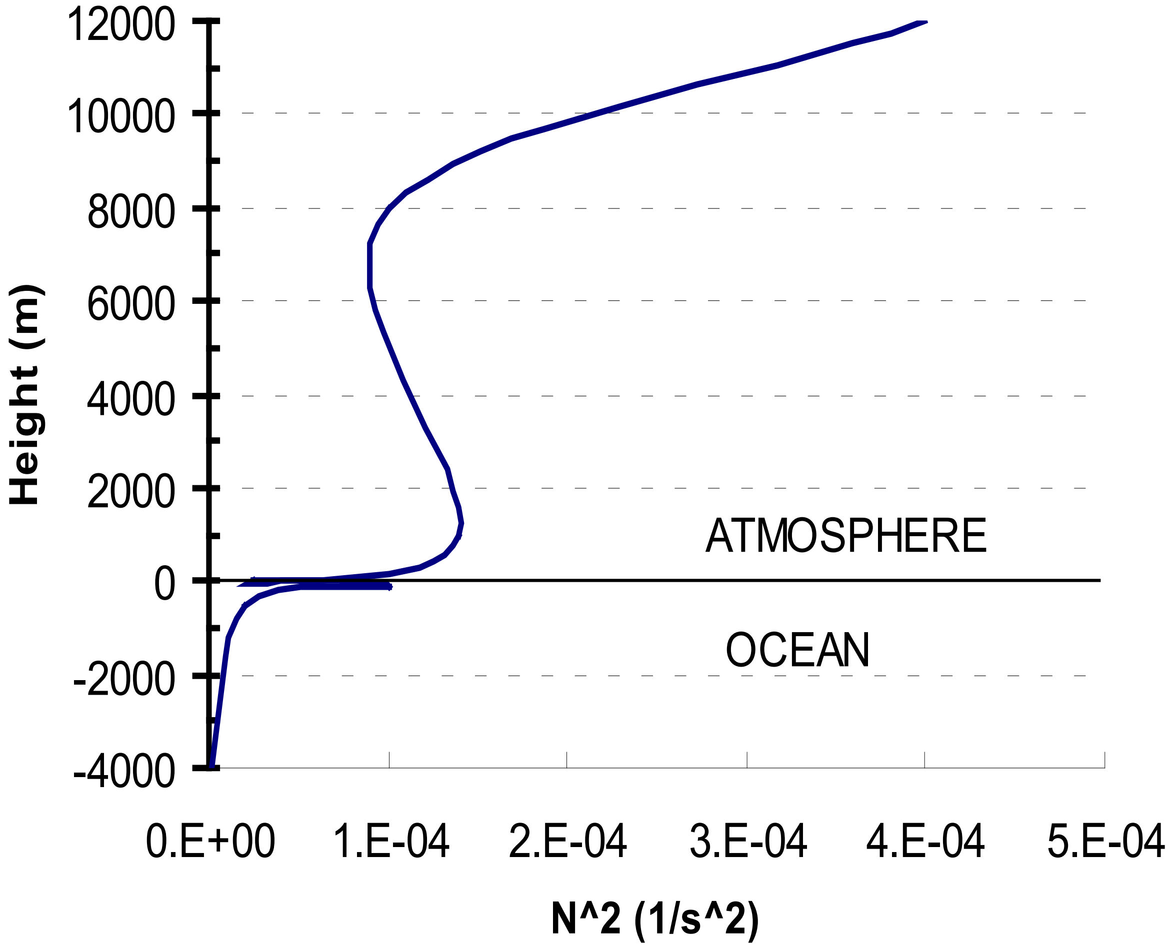
Chl concentration
(credit: Alex Kekesi, NASA)

4th ISDA, February 2015

Outline

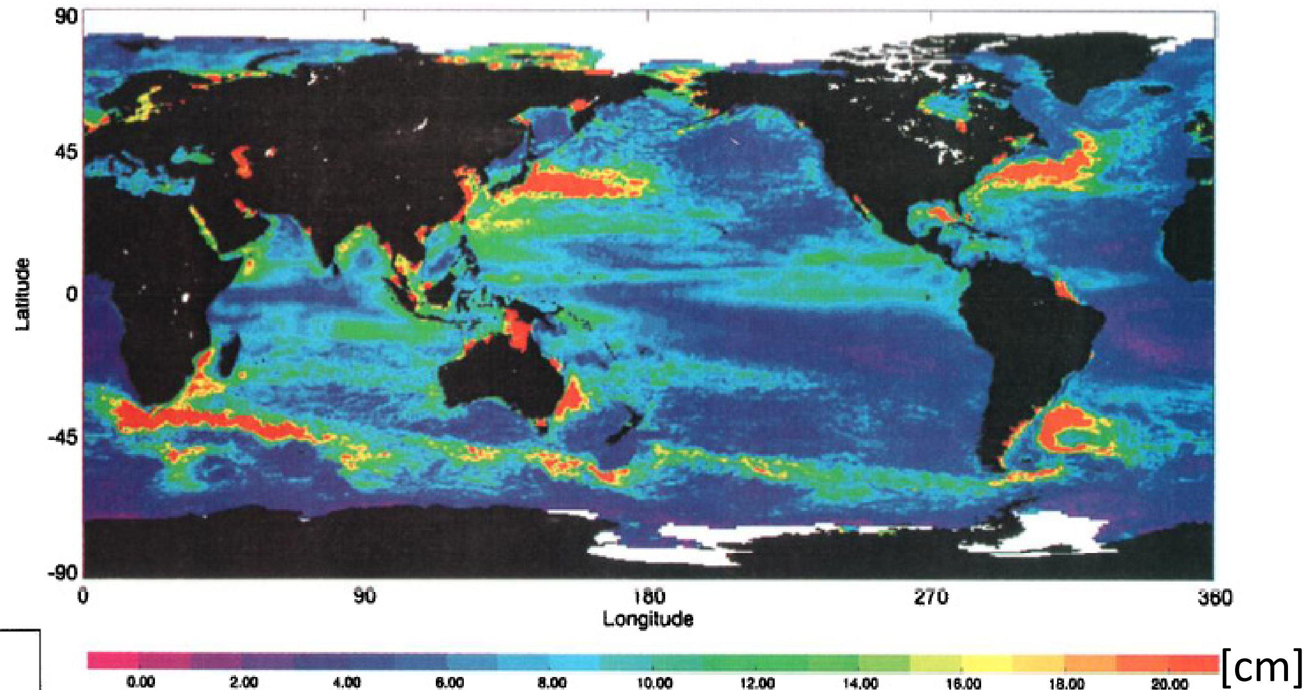
- Ocean dynamics
- Observational constraints
- Historical ocean reanalysis
  - SODA
  - Some upgrades
- Some comparisons
- Tropical cyclones and the ocean

Stratification



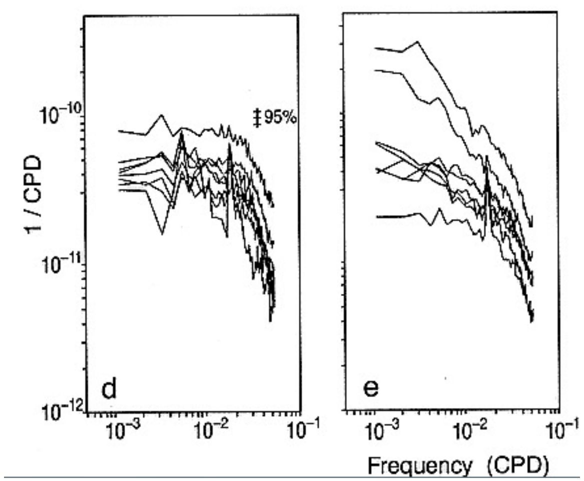
Inhomogeneous sea level variability

RMS monthly sea level variability



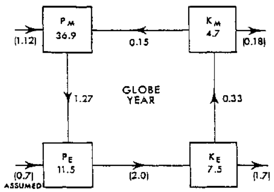
Ducet et al. (2000)

Red spectra



Atmosphere

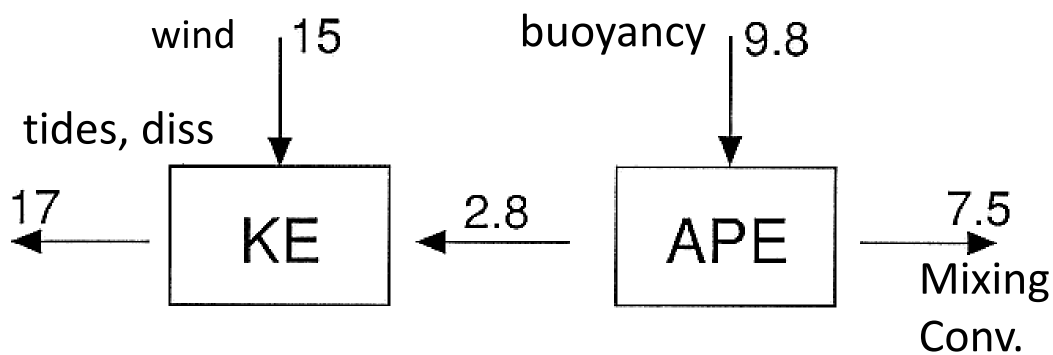
Energetics



Oort 1983 $W\,m^{-2}$

Ocean

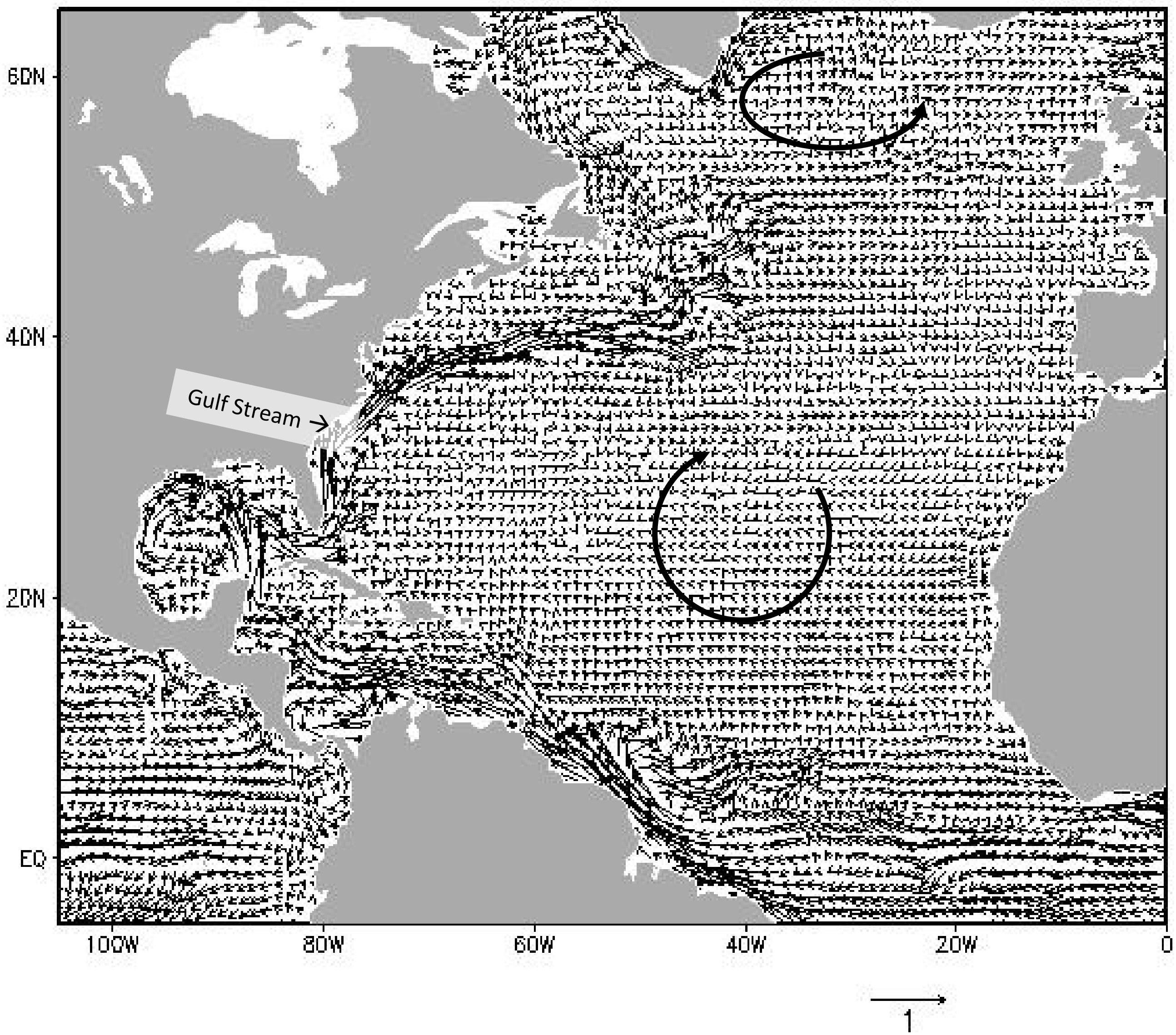
Oort, Anderson, & Peixoto (1994)



10^{-6} erg cm^{-3}/s

Atlantic surface currents

(based on surface drifter observations)



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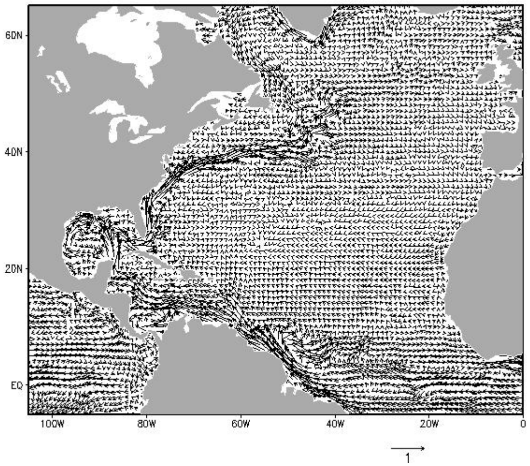
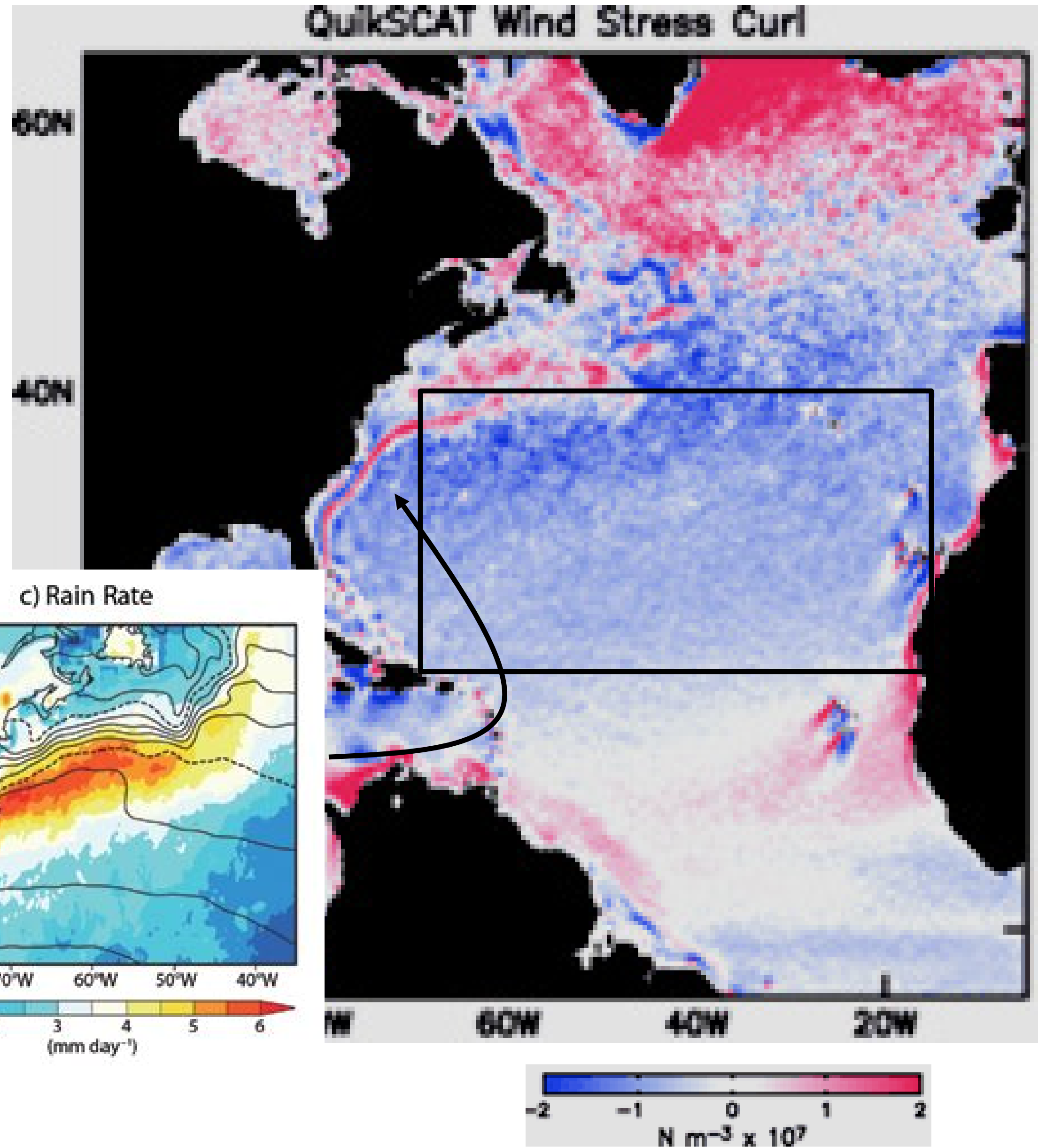
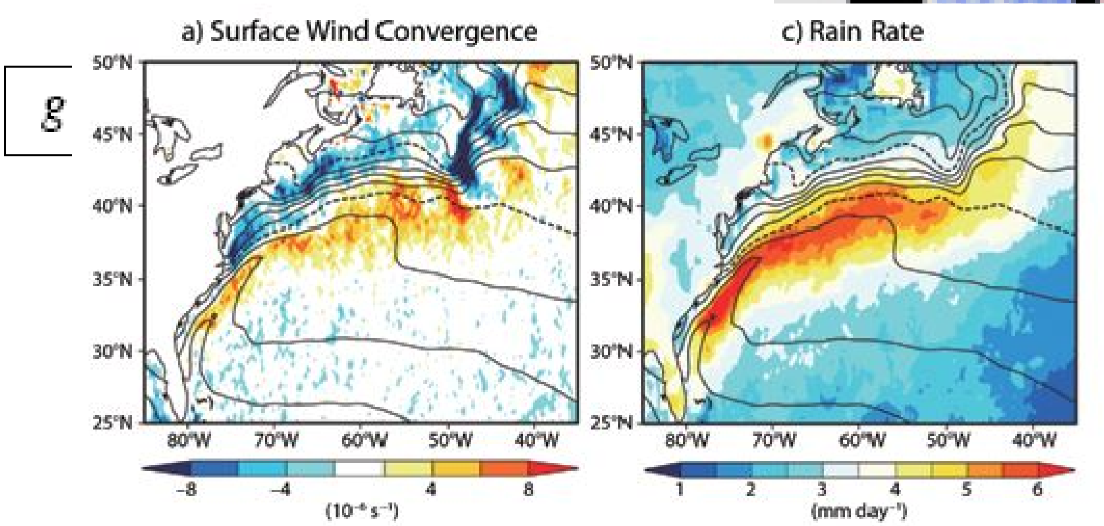
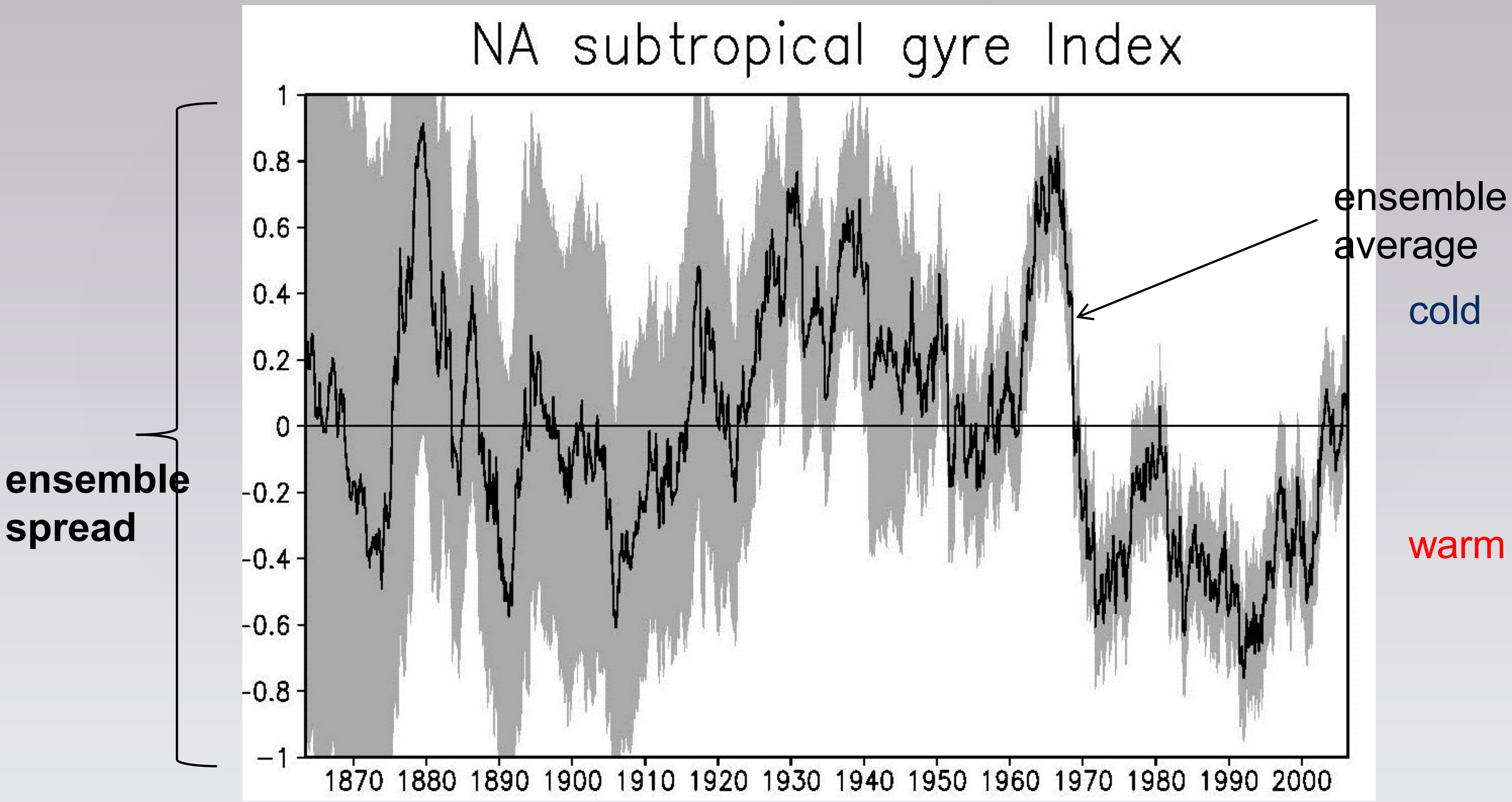




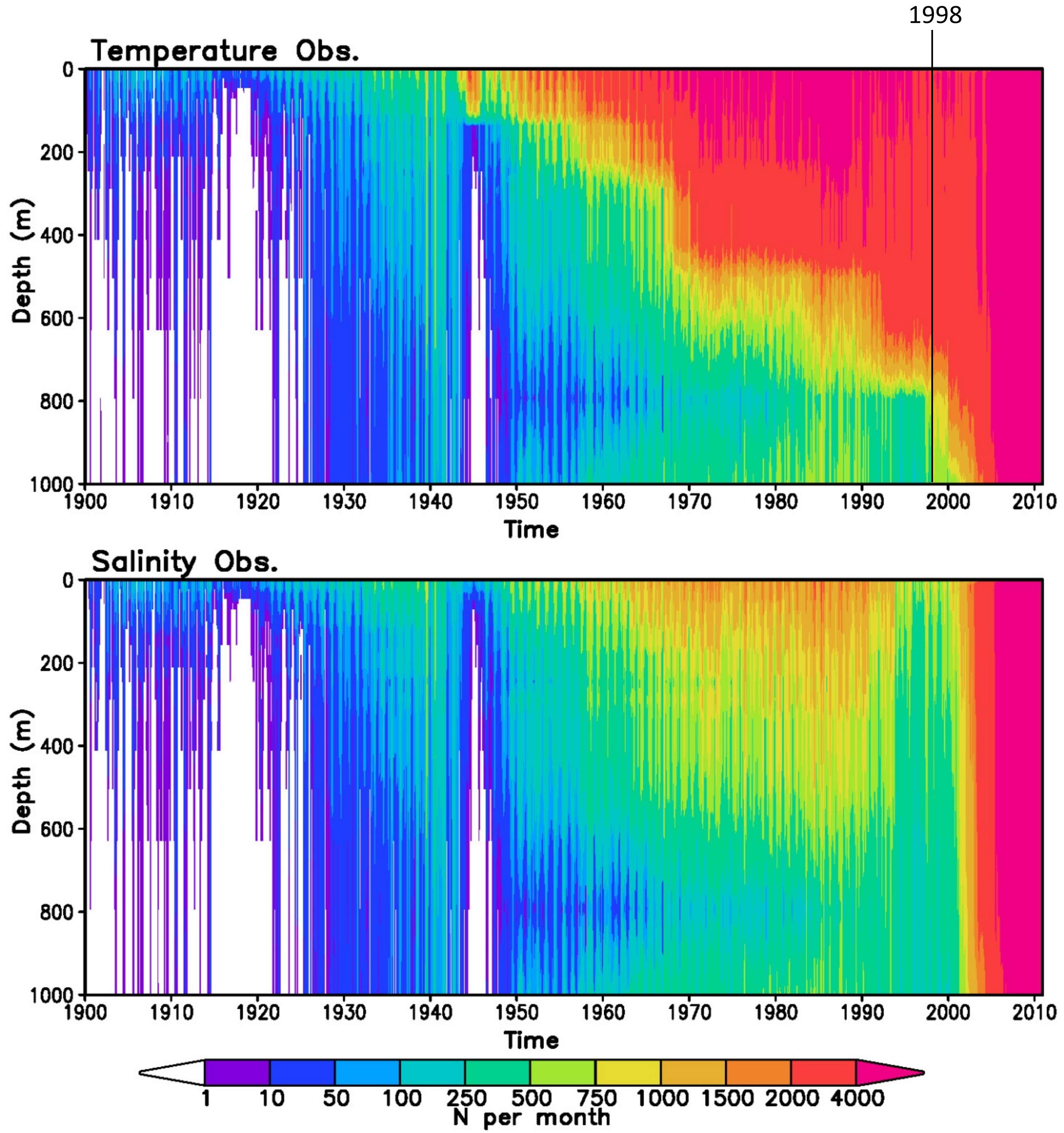


20CRv2 wind stress curl averaged in the subtropical box



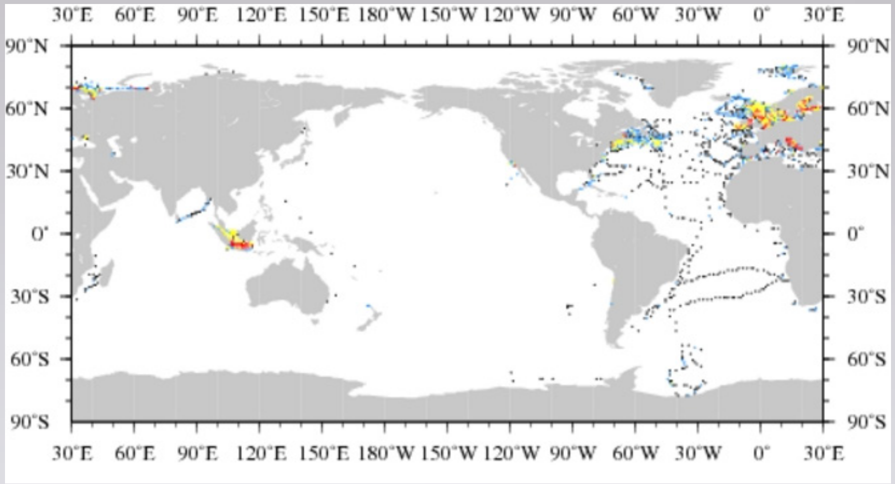
Time →

Number of profile observations

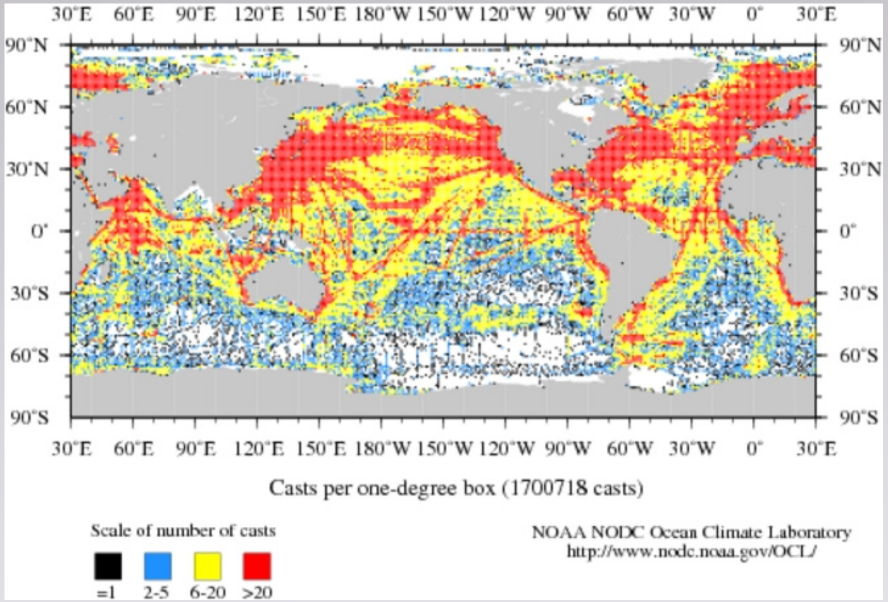


Observation distribution

1910-1919 (56,034 profiles)



1980-1989 (1.7M profiles)



Simple Ocean Data Assimilation

SODA 1,2

- Model: POP2.1 0.4^ox0.25^ox40lev resolution, no sea ice.
- Winds, heat, freshwater: ERA40, 20CRV2
- Observations: WOD2005, COADS
- Assimilation: OI with IAU and flow-dependent error covariances, Dee et al. bias correction

SODA3

- Model: MOM5 0.25^ox0.25^ox50lev, SIS sea ice
- Model: POP1.4 0.1^ox0.1^ox50lev, CICE sea ice
- Winds, heat, freshwater: 20CRV3, ERA20C
- Observations: WOD2013, COADS2, sea level
- Assimilation: OI with IAU and flow-dependent error covariances
- Assimilation: Hybrid Gain (*Penny, 2013*)

SODA3 <-> NOAA NCEP GODAS <-> GEOS5

Observing system simulation experiments

Carton et al. (2012)

How well can we resolve climate anomalies of the late 1990s if they had occurred earlier in the 20th century?

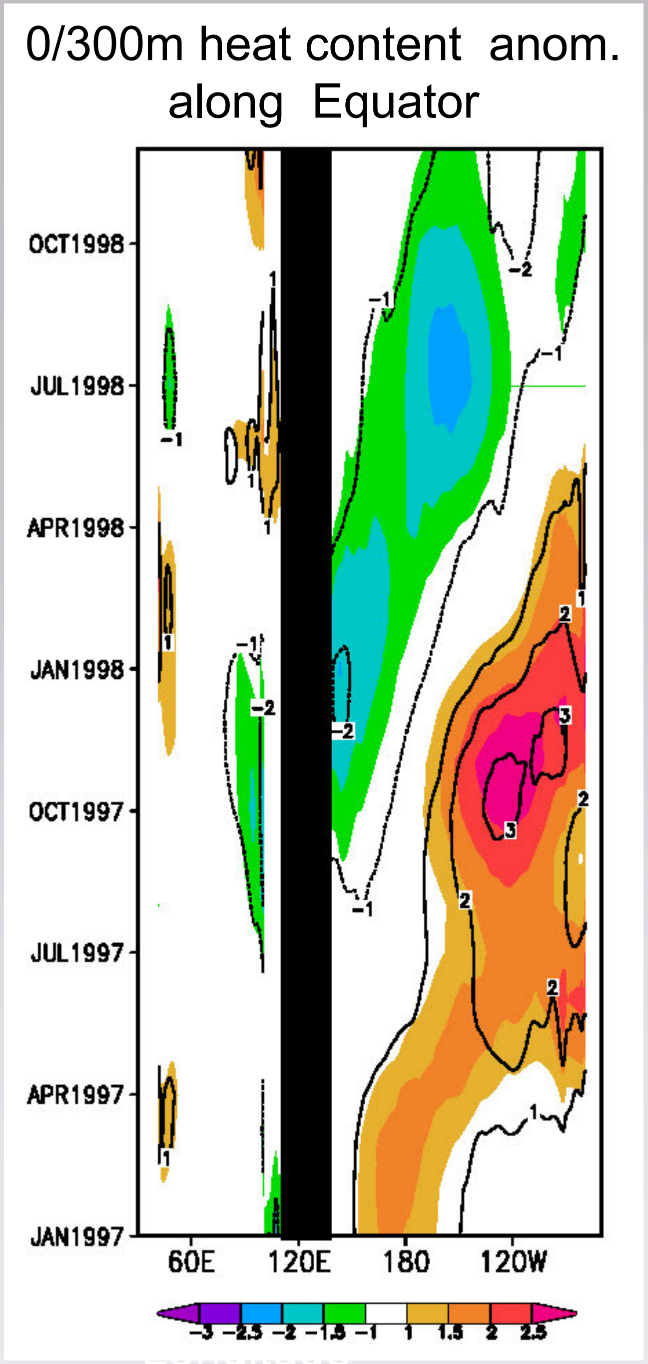
- Carry out simulation (Nature Run) forced by 20CRv2 ensemble mean surface forcing 1995-1999 (a period of strong variability)
- Sample Nature Run at the locations, depths, times, observations that actually exist in the historical archives shifting the dates of observations to the 1990s (1927->1997; 1947->1997; 1967->1997, etc)
- Assimilate observations into SODA, and use 'degraded' surface forcing
  - Climatological monthly forcing
  - Single 20CRv2 ensemble member

Nature Run

(and a comparison to observations)

Simulation using a $0.4^o x 0.25^o$ OGCM driven by 20CRv2 monthly surface fluxes.

Time ->



Colors: Nature Run
Contours: SODA reanalysis

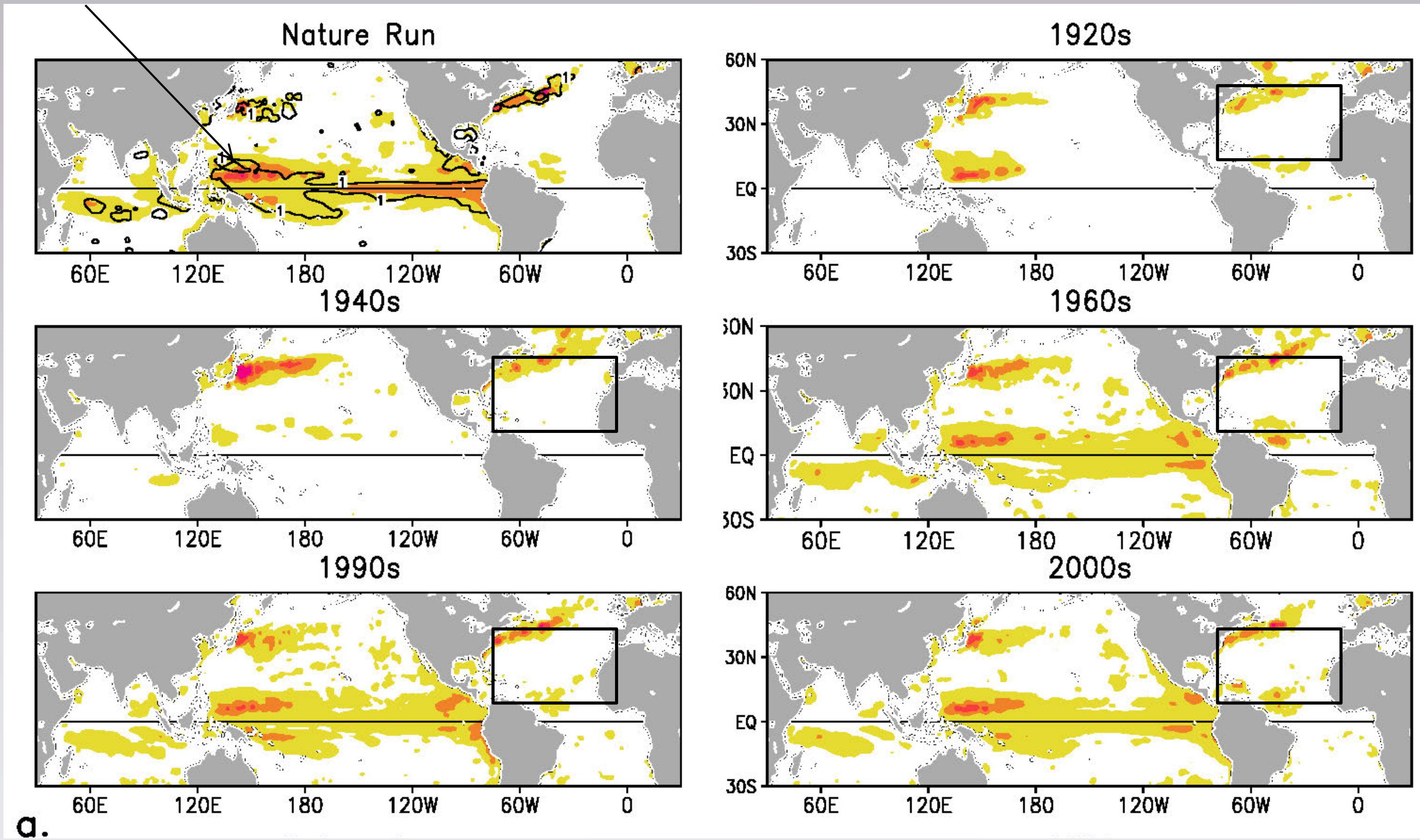
5 experiments:

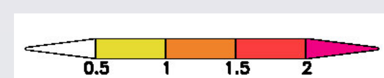
1920s
1940s
1960s
1990s
2000s

RMS HC' (0-300m) (1995-1999)

clim forcing

Observed



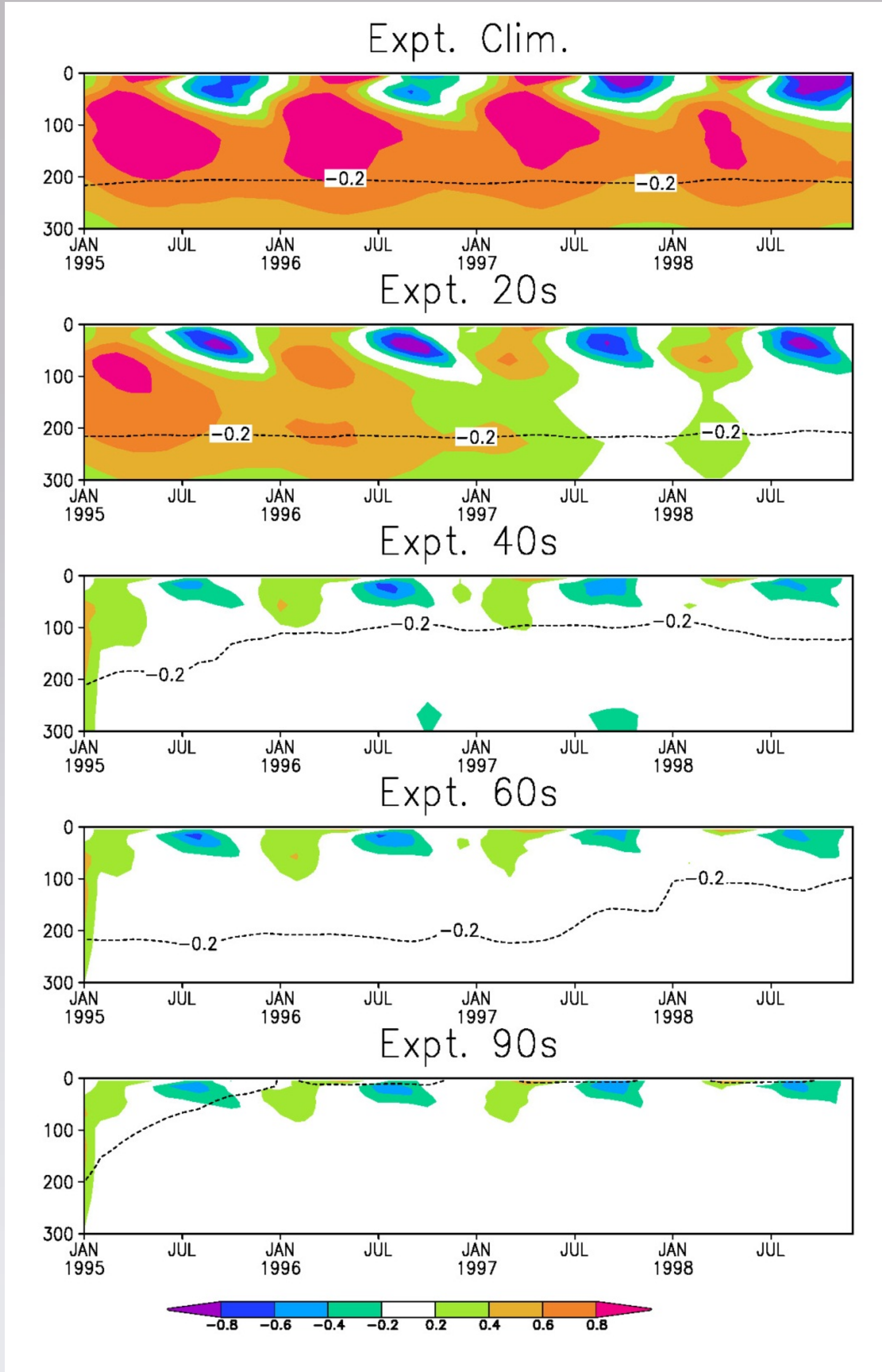


North Atlantic Temp/Sal <u>error</u>

(with depth and time)

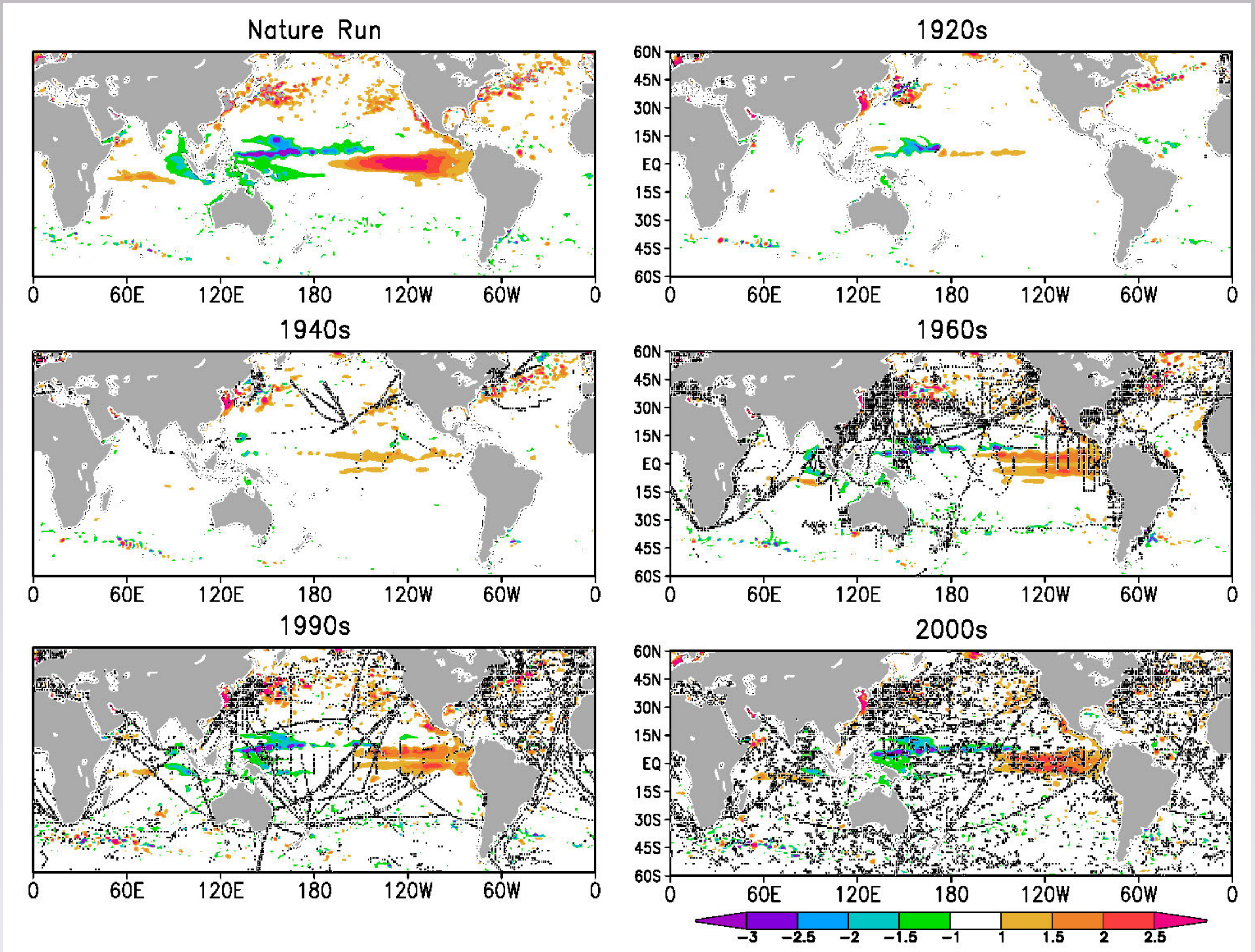
clim forcing

Experiment
Temp and sal bias



El Nino: HC' Sept.-Nov., 1997

clim
forcing



How good was the 1990s observing system?

Ensemble winds

El Nino

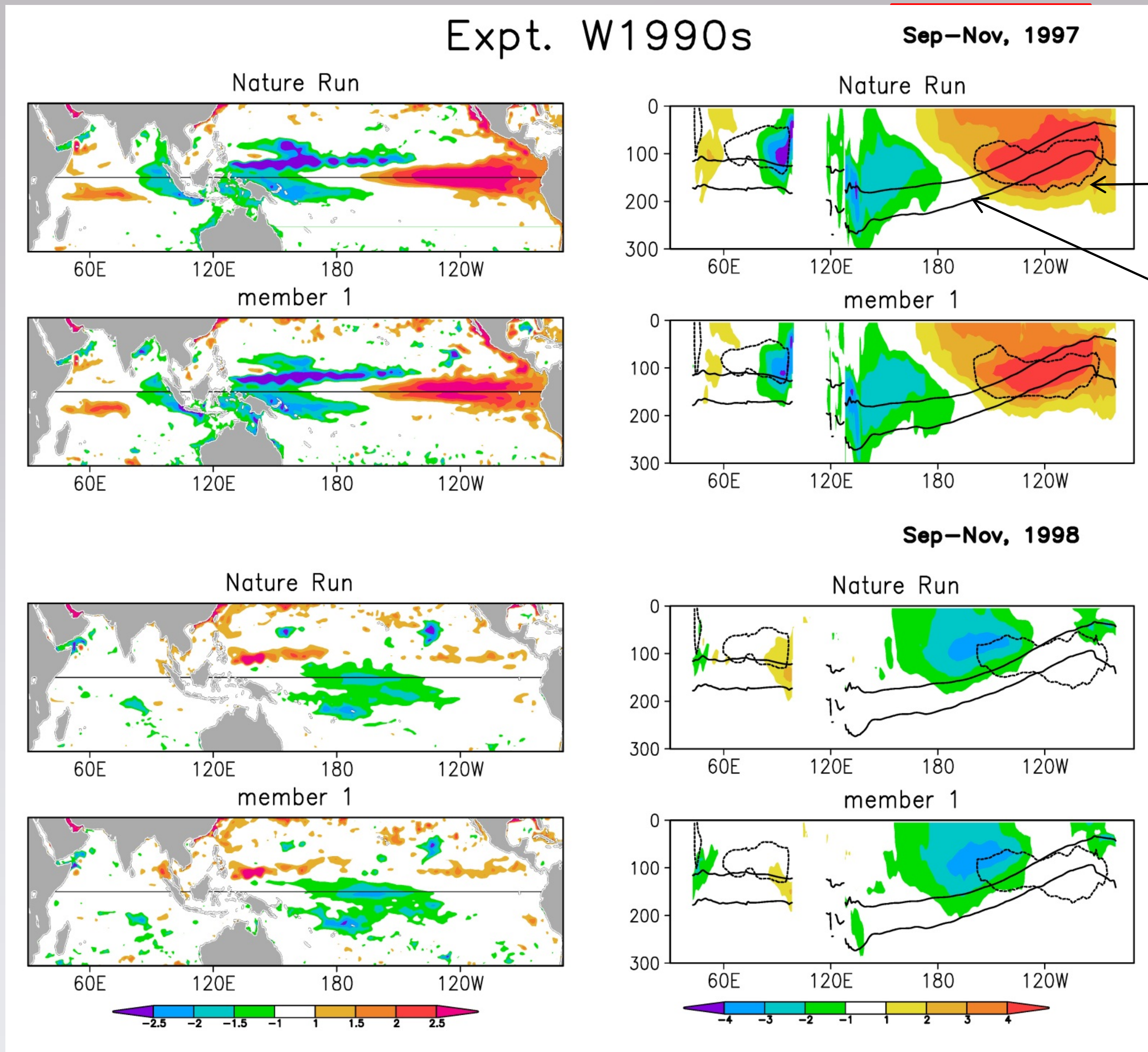
Truth

Our Estimate

La Nina

Truth

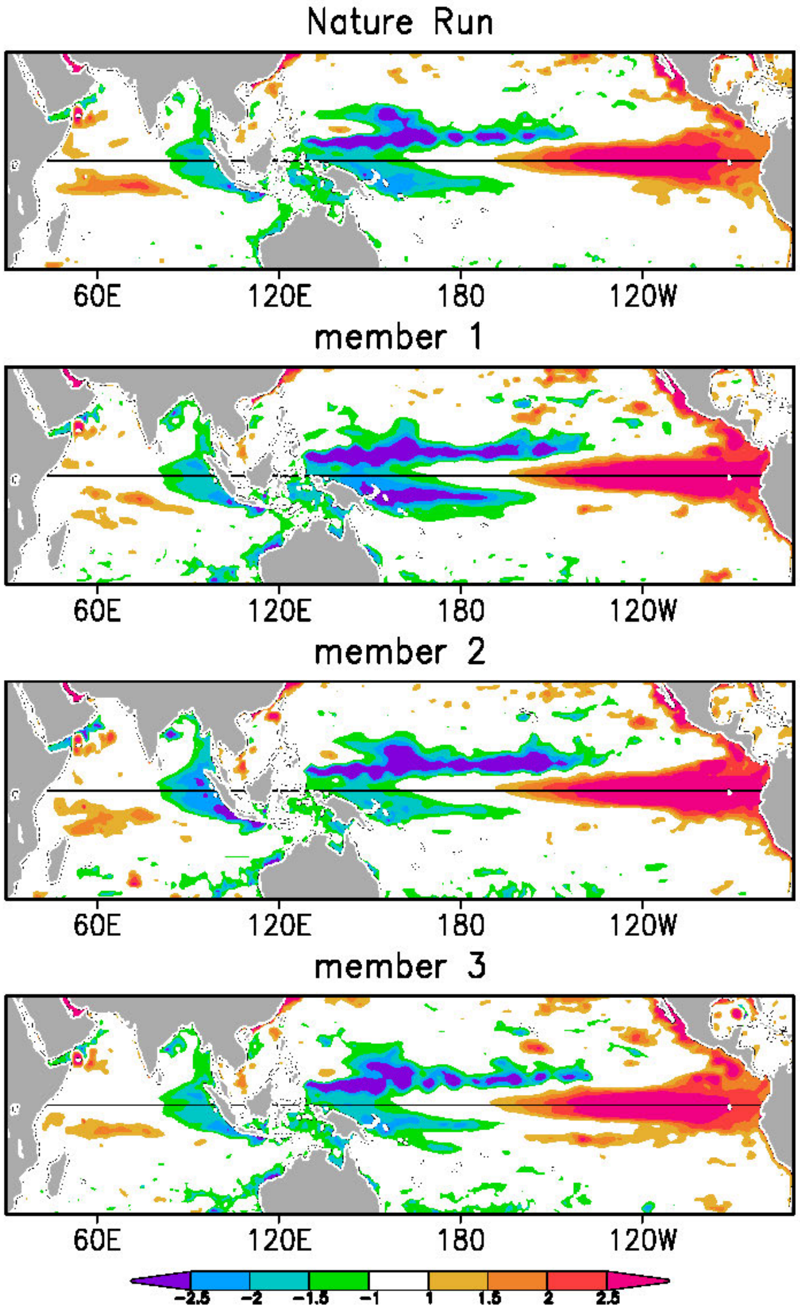
Our Estimate



50cm/s contour

15^{o}C

HC’ Sept.-Nov., 1997 for the 1920s experiment



2. Impact of improved data assimilation: 3DVar GODAS versus LETKF, *Penny (2013)* hybrid gain ENKF

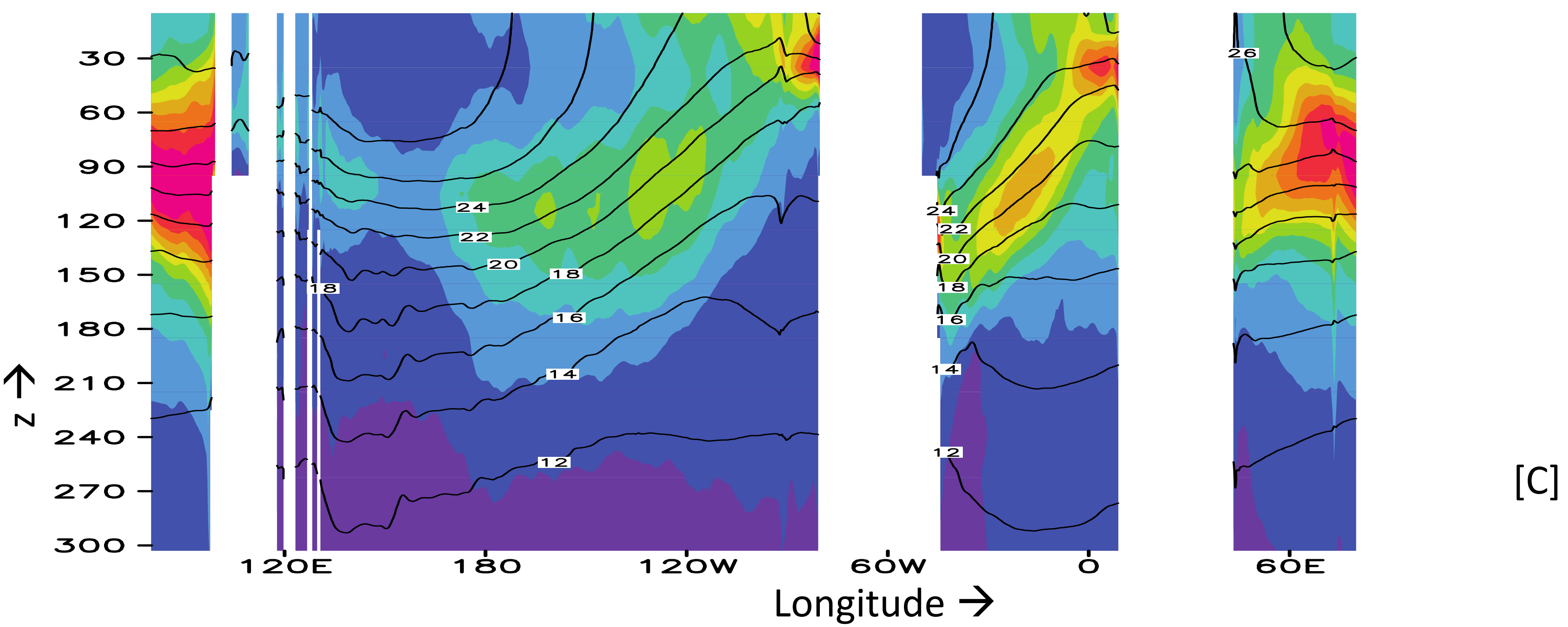
(Penny et al., 2015)

1) Carry out simulation (Nature Run) forced by 20CRv2 ensemble mean surface forcing 1991-1998
2) Sample Nature Run at the locations, depths, times, observations that actually exist in the archives during this period
3) Assimilate observations into GODAS, LETKF, and Hybrid GODAS , and use 'degraded' surface forcing: a single 20CRv2 ensemble member

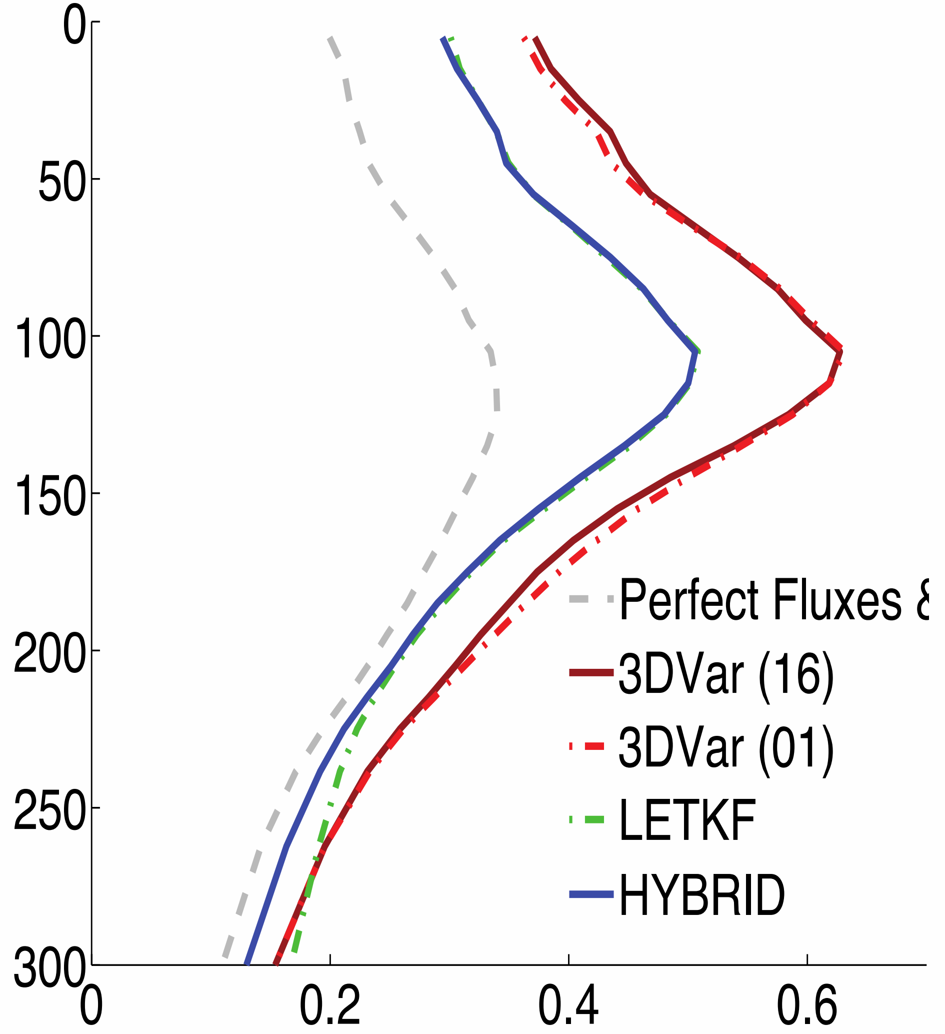
- Model: GFDL MOM4p1, 1/2º-1/4º, 40-vertical level (CFSv2/CFSR Operational Model)
- Surface forcing:
  Hybrid: **28-member 20th Century Reanalysis** (20CRv2: *Compo et al. 2011*)**;**
  members 1-28 are selected **after** re-centering 56 members at R2 (adds slight bias)
  3DVar: (a) Randomly selected from ensemble of surface forcing (1-28) used by Hybrid
  (b) Reference "Perfect Forcing" run, using the NCEP R2 (like nature run)
- Inflation: none
- Horizontal Localization: Latitude dependent: 720km at Eq. down to 200km at poles
- Vertical Localization: none (=> more accurate, faster, & facilitates future use of satellite data)
- Initialization: **6-year spinup from Jan 1st 1985 CFSR ocean state (same for all 56 members), forced by 56-member 20CRv2 re-centered to NCEP R2**

Impact of improved data assimilation: 3DVar GODAS versus LETKF, *Penny (2014)* hybrid gain ENKF

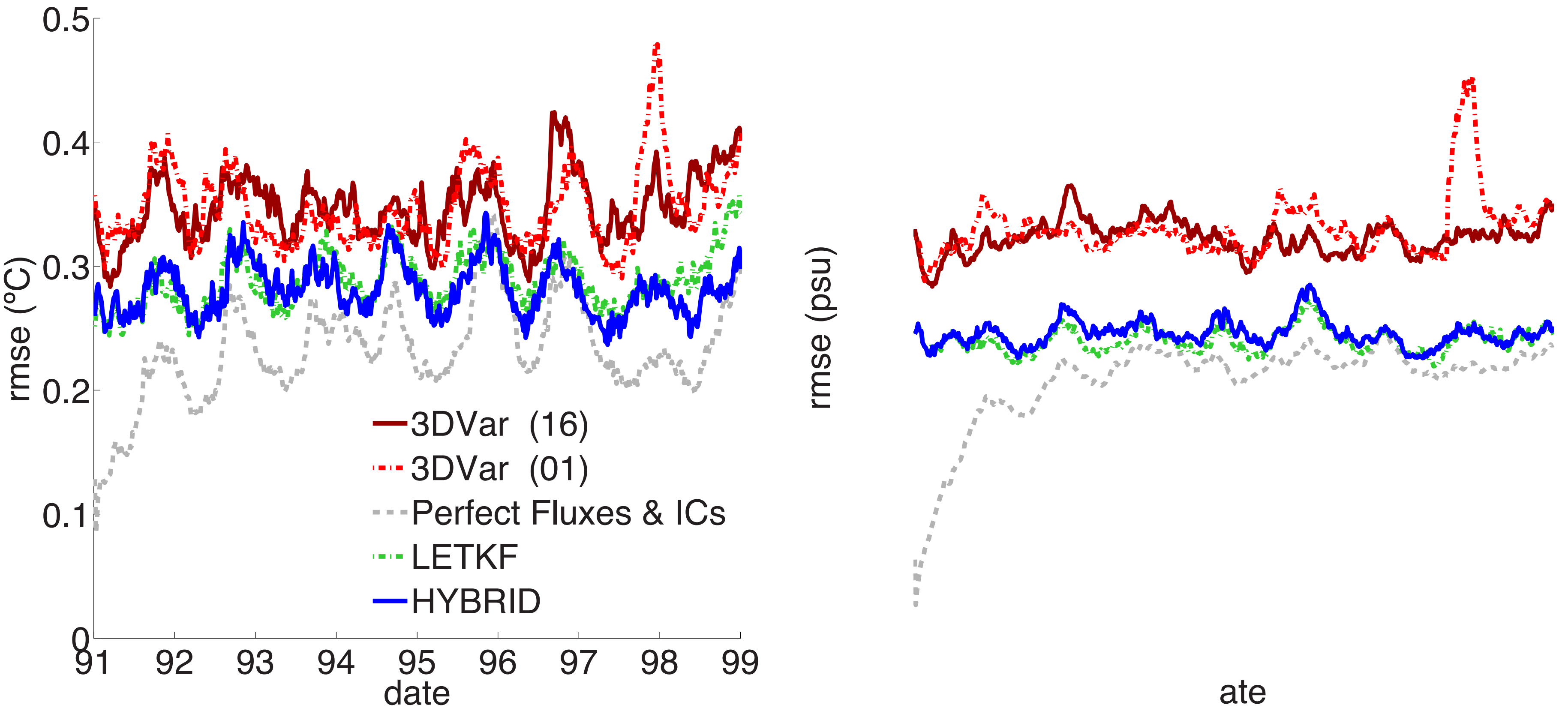
Hybrid GODAS ensemble spread of temperature along equator



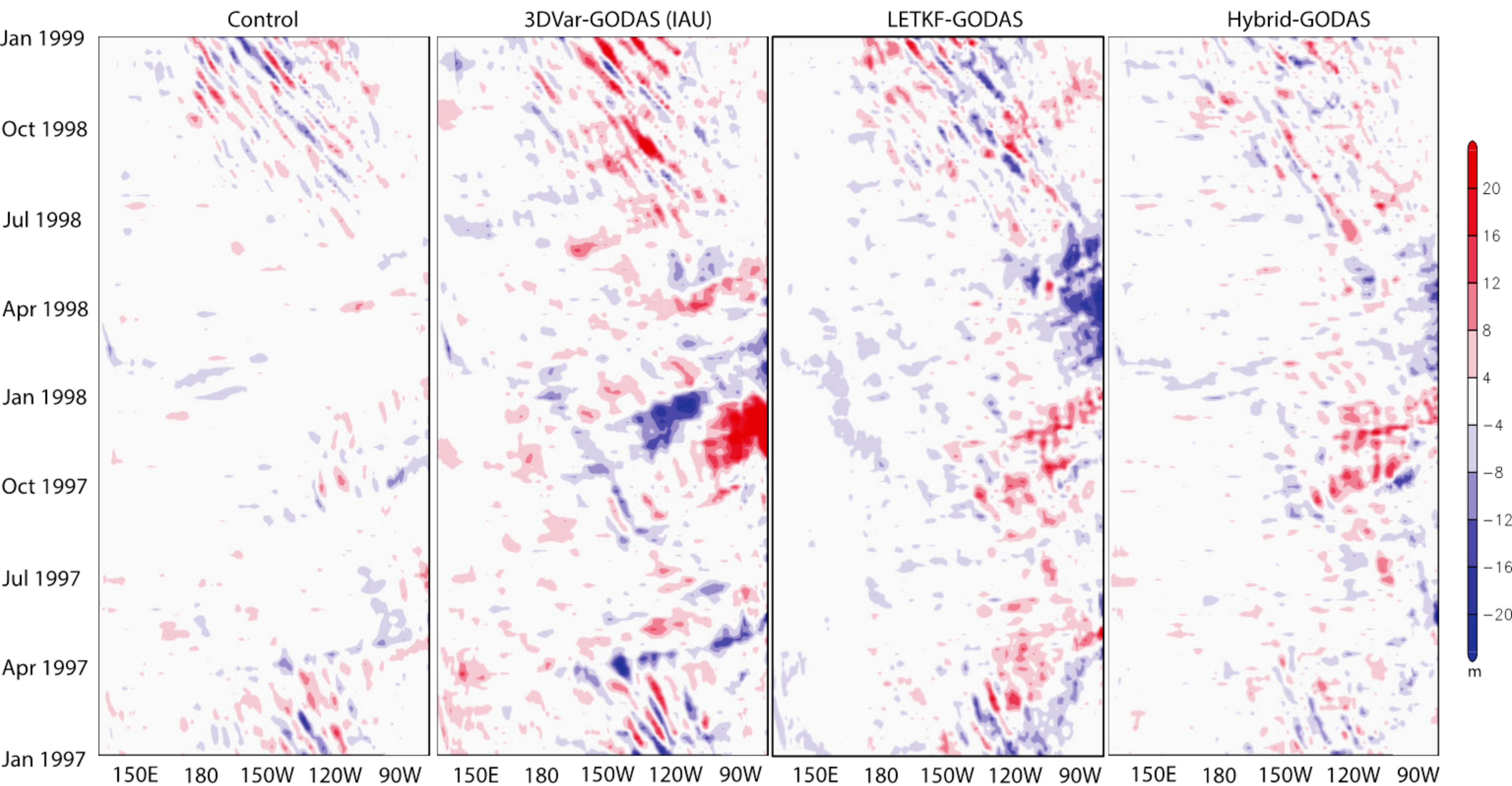
Temperature error (1991-1998) with depth in tropics



Global error (0-700m)



20C isotherm error averaged 5S-5N (Analysis – Nature)

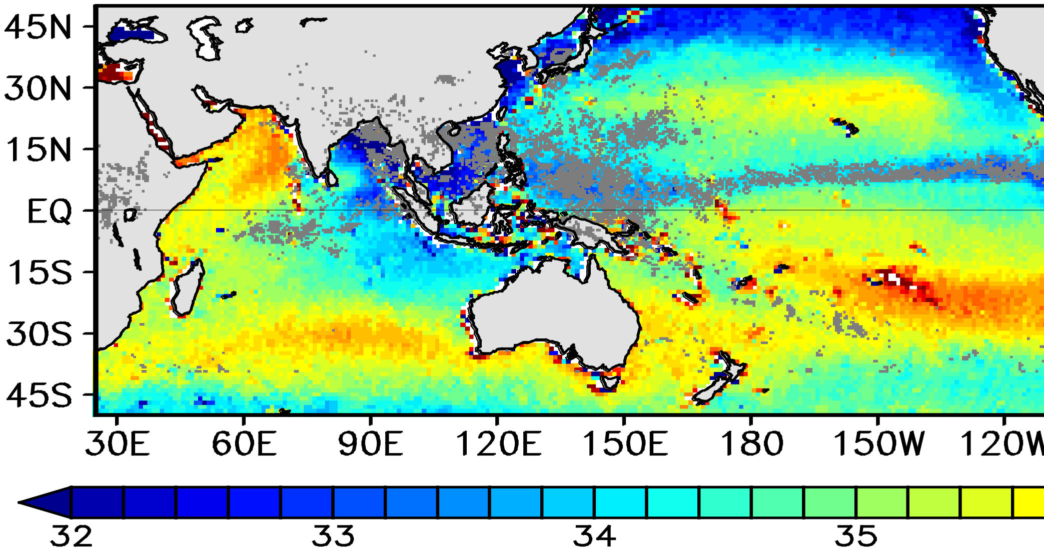


Real data comparison among current 14 ocean assimilation systems

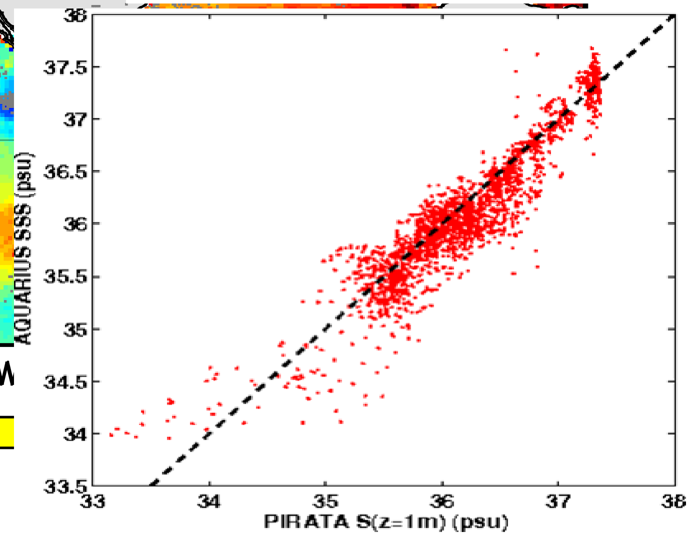
1. ARMOR3D*	CLS	1/3° no model	OI (T/S/SST)
2. CFSR	NOAA NCEP	1/2° MOM4 coupled	3DVAR (T)
3. ECCO-NRT	JPL/NASA	1° MITgcm	KF-KS (SLA/T)
4. EN3 v2a*	UK Met Office	1° no model	OI (T/S)
5. GECCO2	U. Hamburg	1×1/3° MITgcm	4DVAR (SLA/SSH/T/S/SST)
6. GMAO	GSFC/NASA		
7. ECDA	GFDL/NOAA	1/3° MOM4 coupled	EnKF (T/S/SST)
8. GloSea5	UK Met Office	1/4° NEMO3.2	3DVAR (SLA/T/S/SST/ice)
9. GODAS	NOAA NCEP	1×1/3° MOM3	3DVAR (SLA/T)
10. GLORYS2V1	Mercator Océan		
11. NODC	NODC/NOAA	1° no model	OI (T/S)
12. ORAS4	ECMWF	1° NEMO3	3DVAR (SLA/T/S/SST)
13. MOVE-C	MRI/JMA	0.3-1° MRI.COM2 coupled	3DVAR (SLA/T/S/SST)
14. MOVE-G2	MRI/JMA	0.3-1° MRI.COM3	3DVAR (SLA/T/S/SST)
15. MOVE-CORE	MRI/JMA	0.3-1° MRI.COM3	3DVAR (T/S/SST)
16. SODA	UMD/TAMU	0.4×1/4° POP2.1	OI (T/S/SST)
17. UR025.4	University of Reading	1/4° NEMO3.2	OI (SLA/T/S/SST)

Satellite salinity

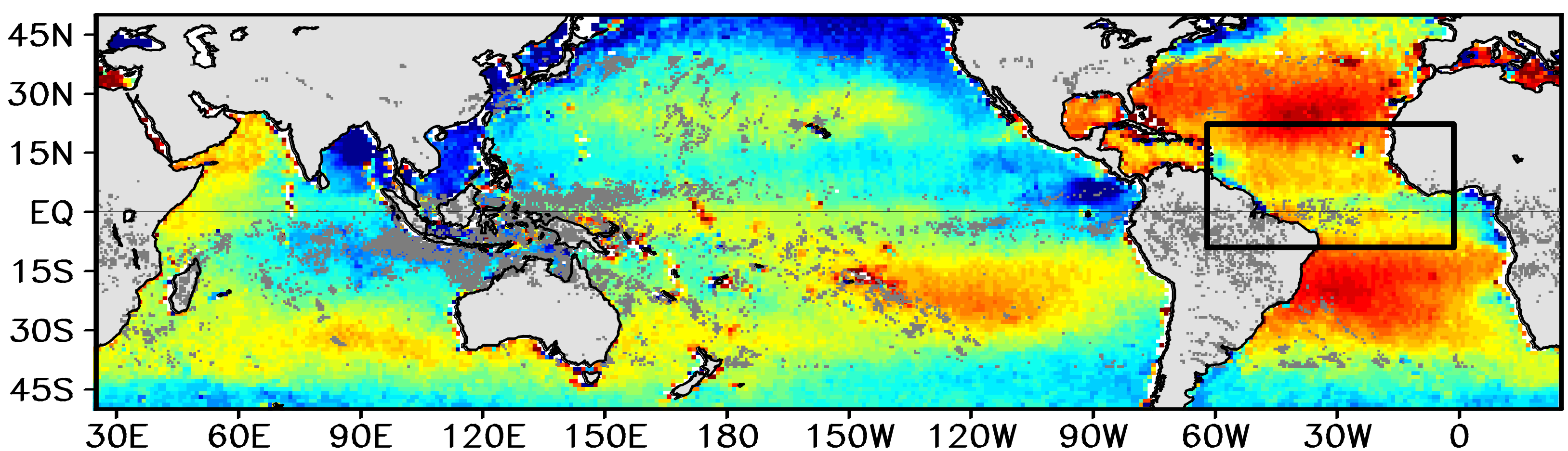
SEP2011



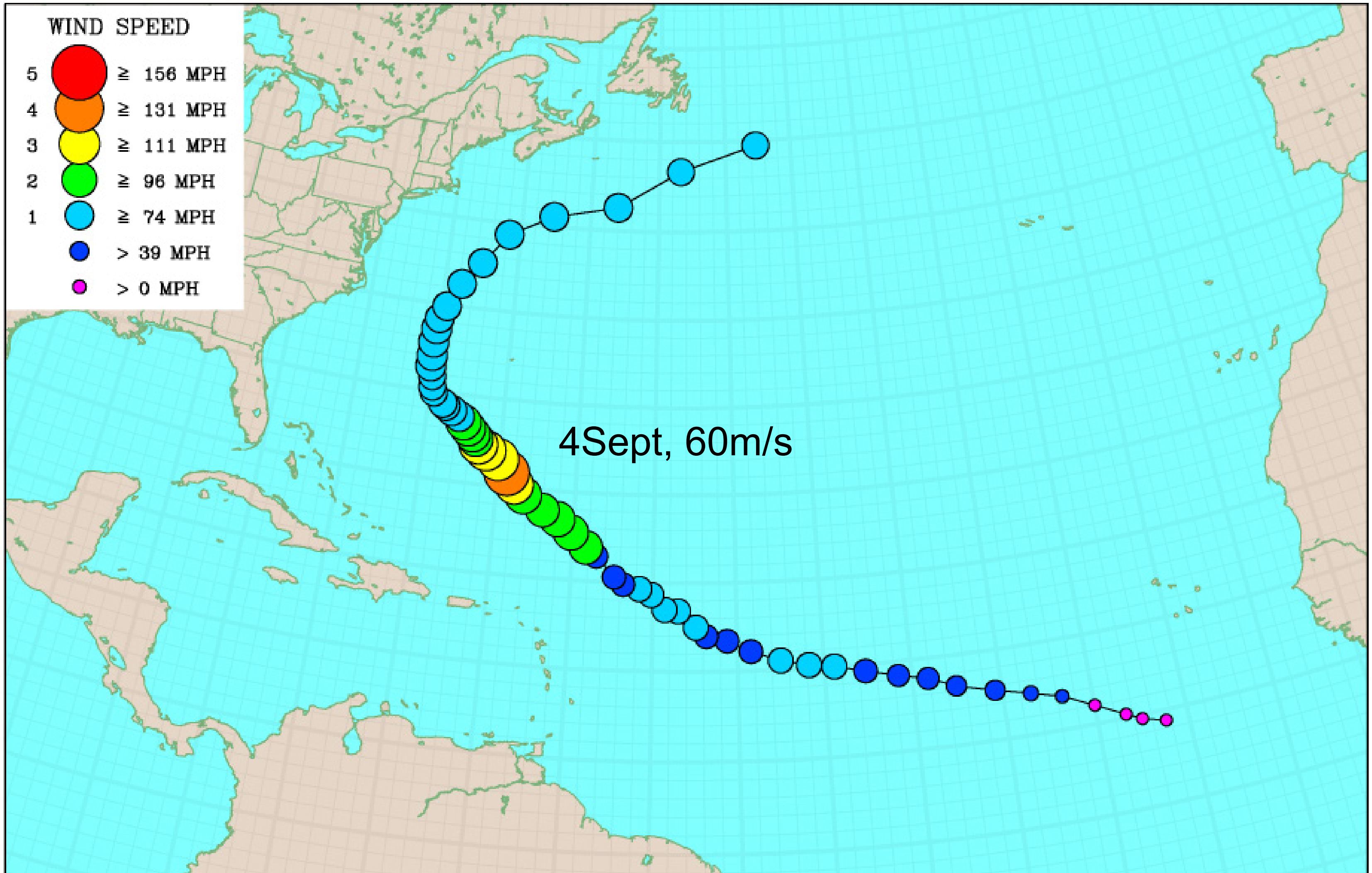
Uncertainty of SSS



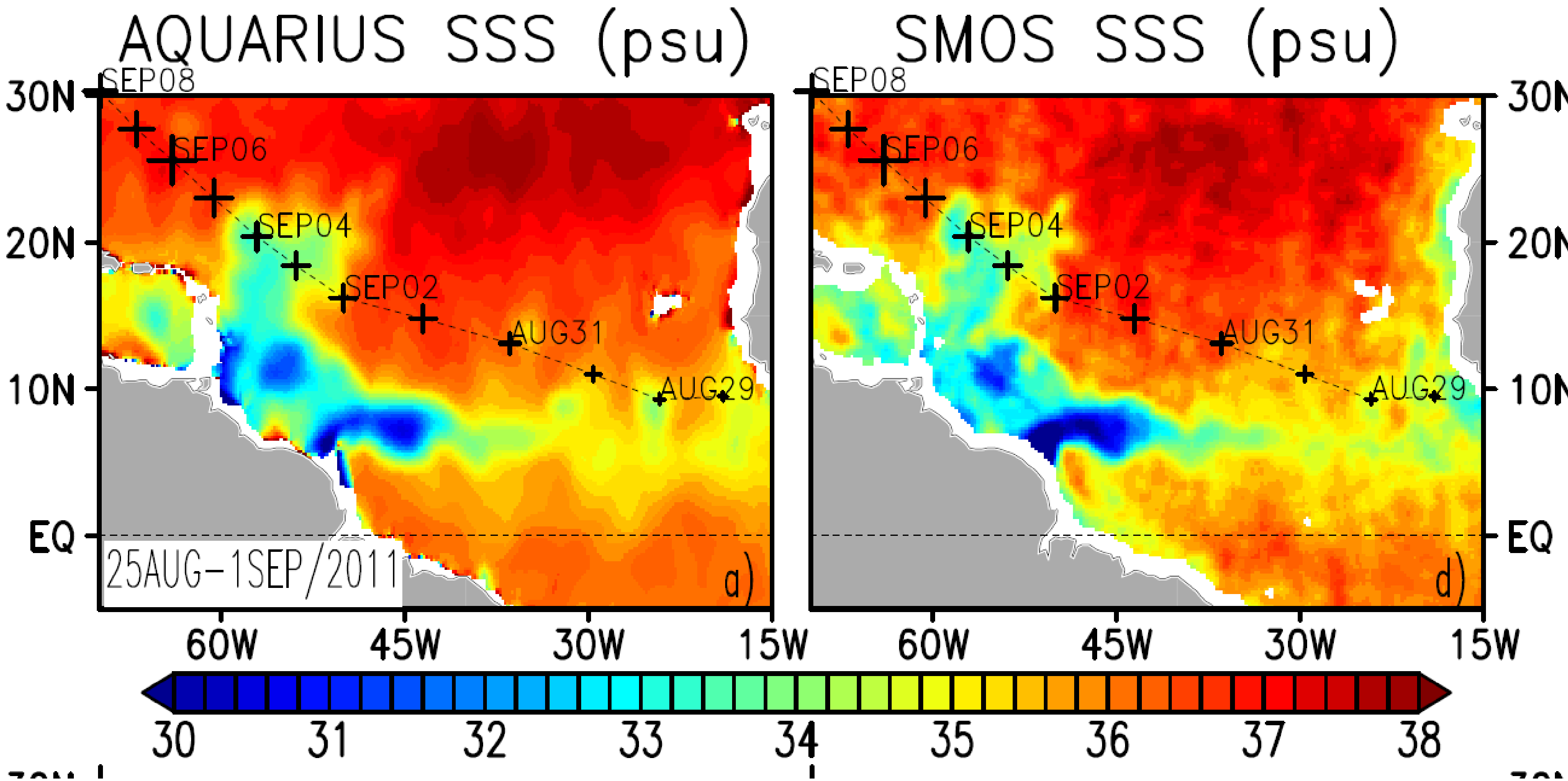
MAR2012



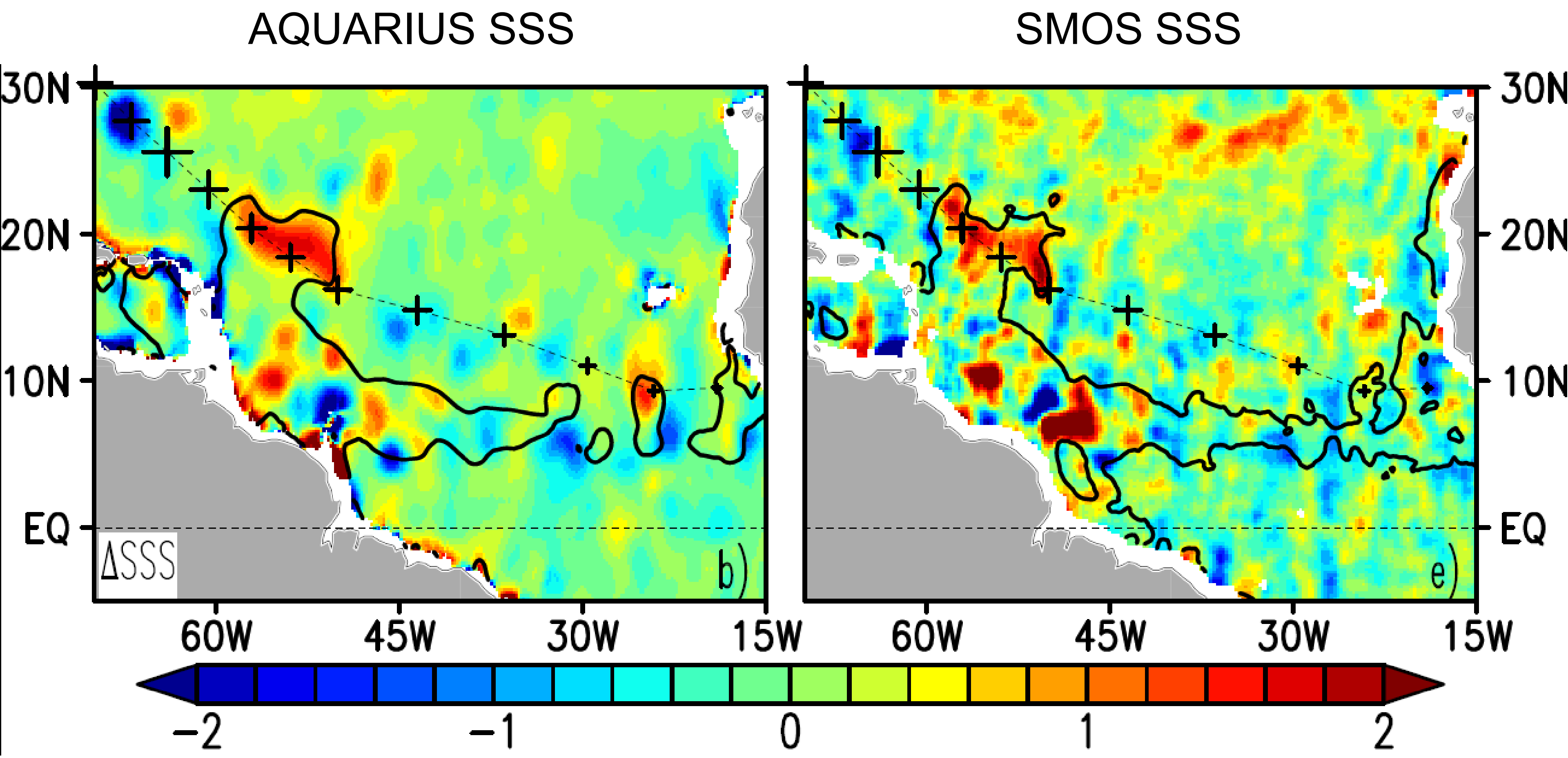
Hurricane Katia
(29Aug-10Sept, 2011)



Amazon/Orinoco fresh pool

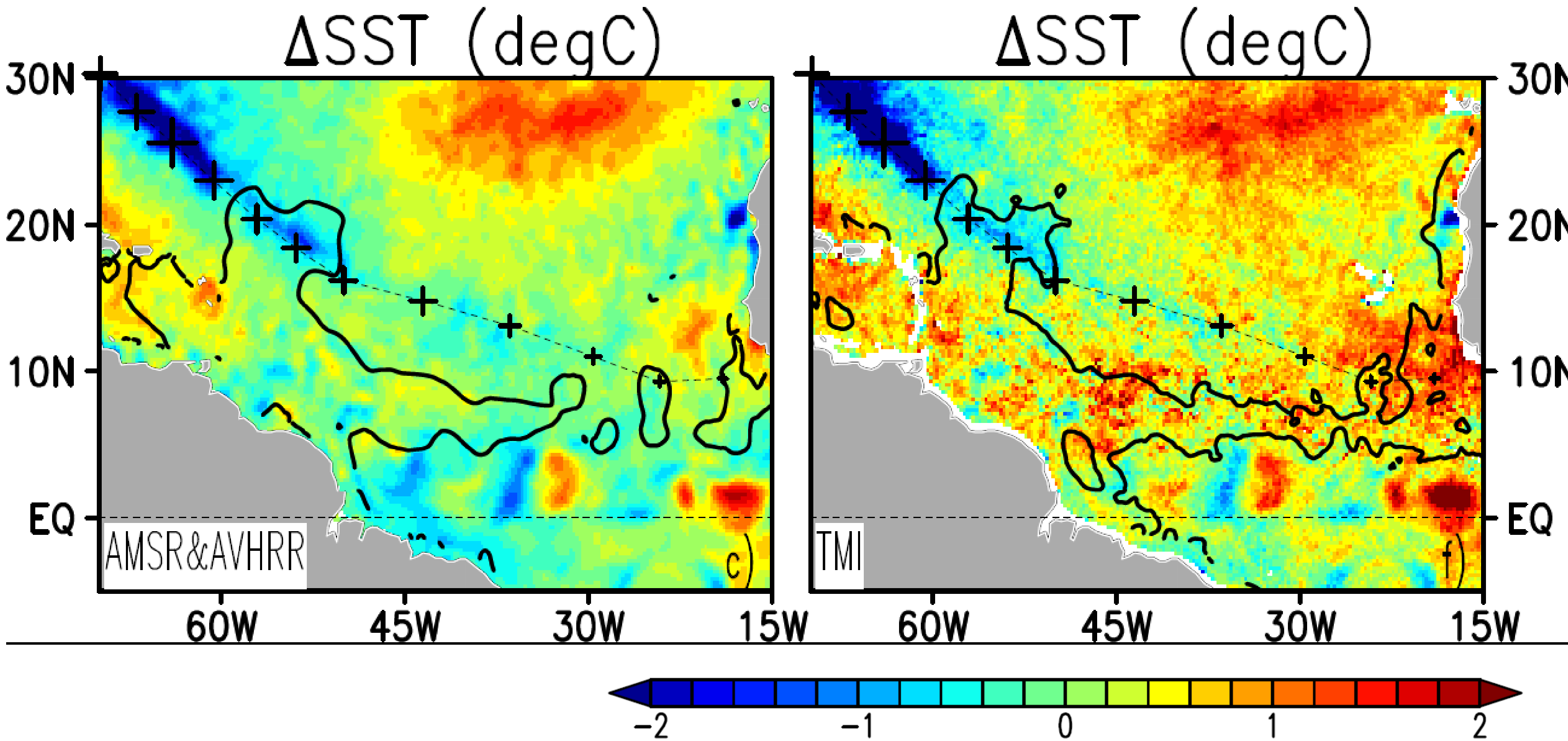


SSS change

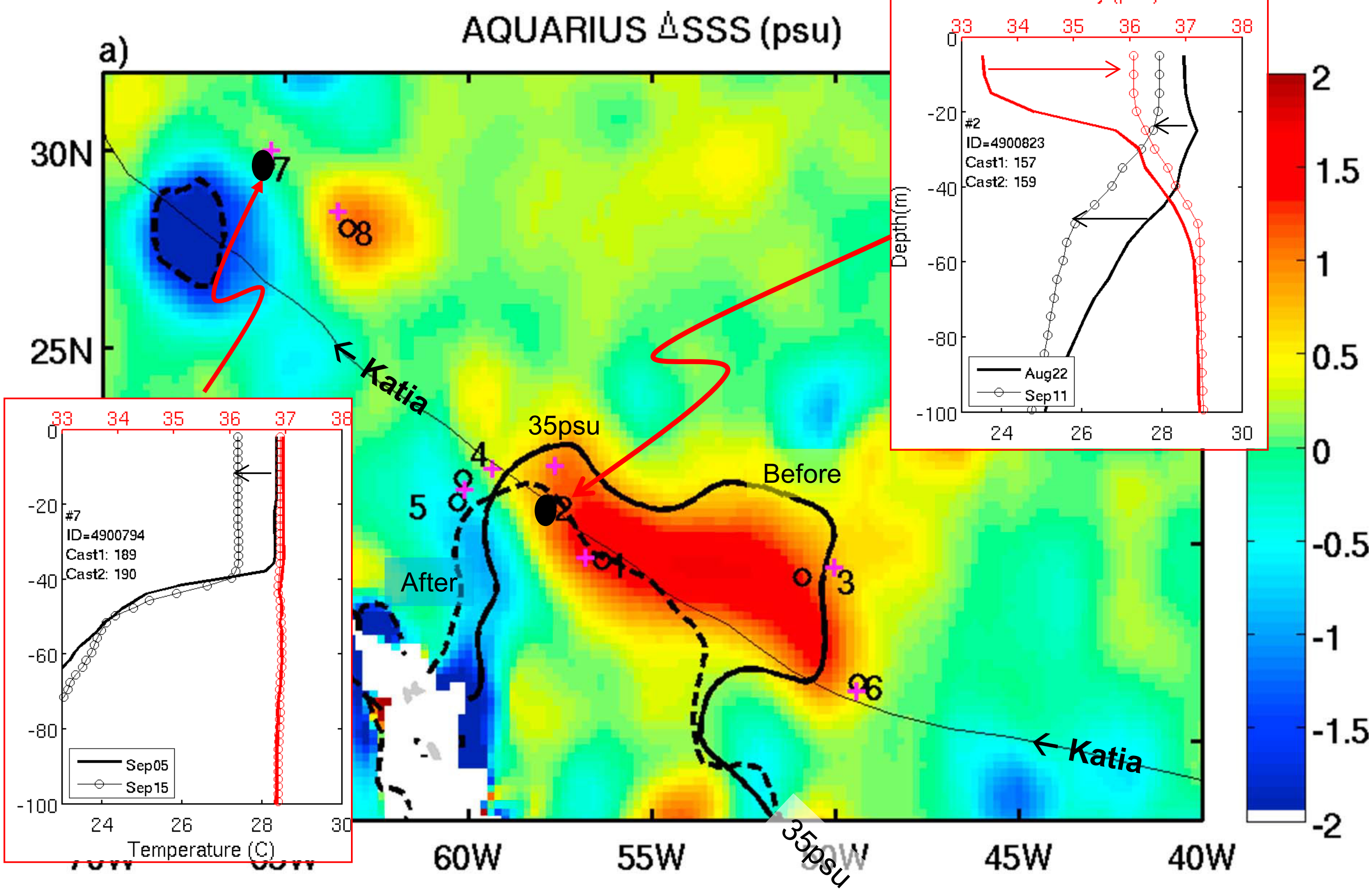


AQUARIUS SSS
SMOS SSS
30N
20N
10N
EQ
60W
45W
30W
15W
ΔSSS
b)
e)
−2
−1
0
1
2

SST difference after-before Katia



SSS change



AQUARIUS ΔSSS (psu)
a)
30N
25N
60W
55W
45W
40W
Katia
Katia
35psu
35psu
Before
After
Salinity (psu)
Depth(m)
#2
ID=4900823
Cast1: 157
Cast2: 159
Aug22
Sep11
#7
ID=4900794
Cast1: 189
Cast2: 190
Sep05
Sep15
Temperature (C)

Comments

Still plenty of room for improvement

- Surface forcing and a reasonable estimate of uncertainty are key.
- Biases remain important. A major cause of bias is insufficient resolution in ocean models which are unable to resolve the key space and timescales.
  - Minimum resolution: 0.25^{o}, but $1/12^{o}$ is more reasonable
- Need to implement updated assimilation algorithms (but expensive given the need for resolution!)
- Proper representation of sea ice is a continuing problem and leads to bias. Positive feedbacks for sea ice make this a sensitive system.