Regional eddy-permitting state estimation of the circulation in the Northern Philippine Sea

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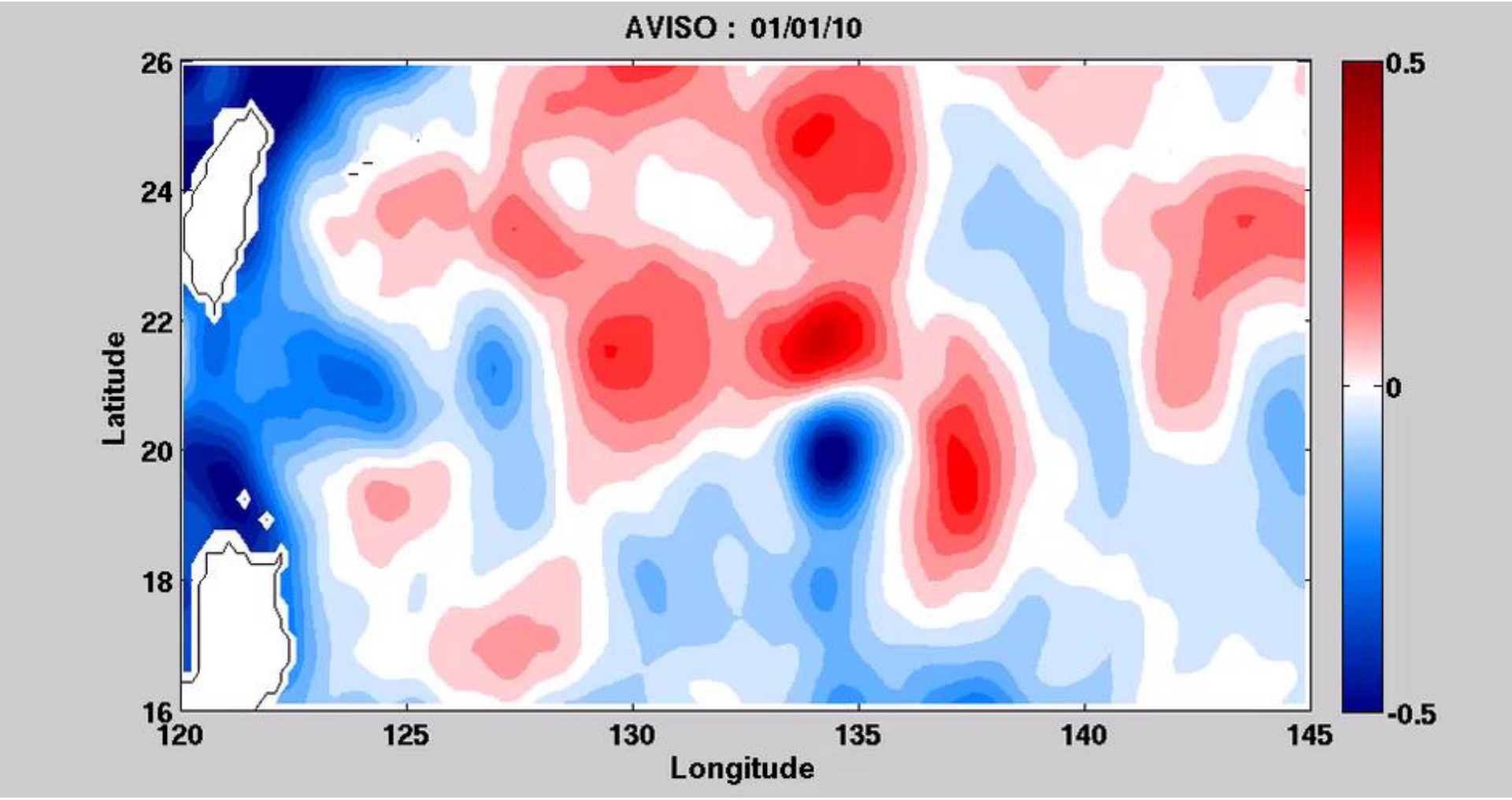
Main Points:

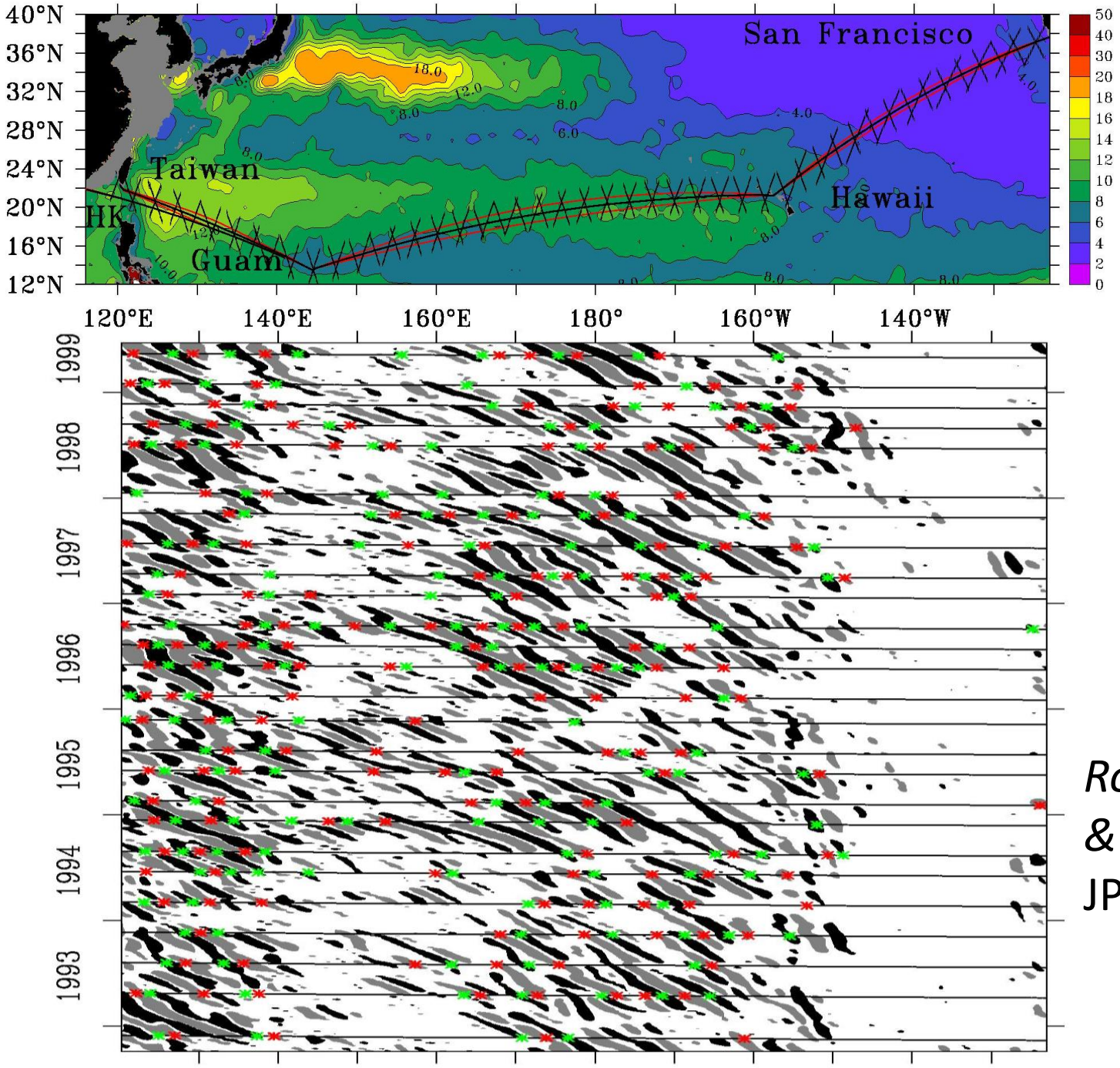
- Eddy-permitting 4DVAR succeeded with two month integrations in the very energetic Philippine Sea
- This was accomplished by filtering the adjoint using increased viscosity and is part of a multiscale approach.
- The estimate was cross-validated by independent observations and forecasts including acoustics
- The 4DVAR has been generalized to include line integrals along ray paths, including PIES.

Motivation

- The Philippine Sea has strong westward-propagating eddies with surface currents >= 1 m/s
- Their meridional heat flux has been estimated at .09PW, about 15% of the total, but variable.
- The eddies merge with the Kuroshio affecting the western boundary current
- The state estimation was in support of an acoustic transmission experiment, which included a test of assimilation of acoustic observations.

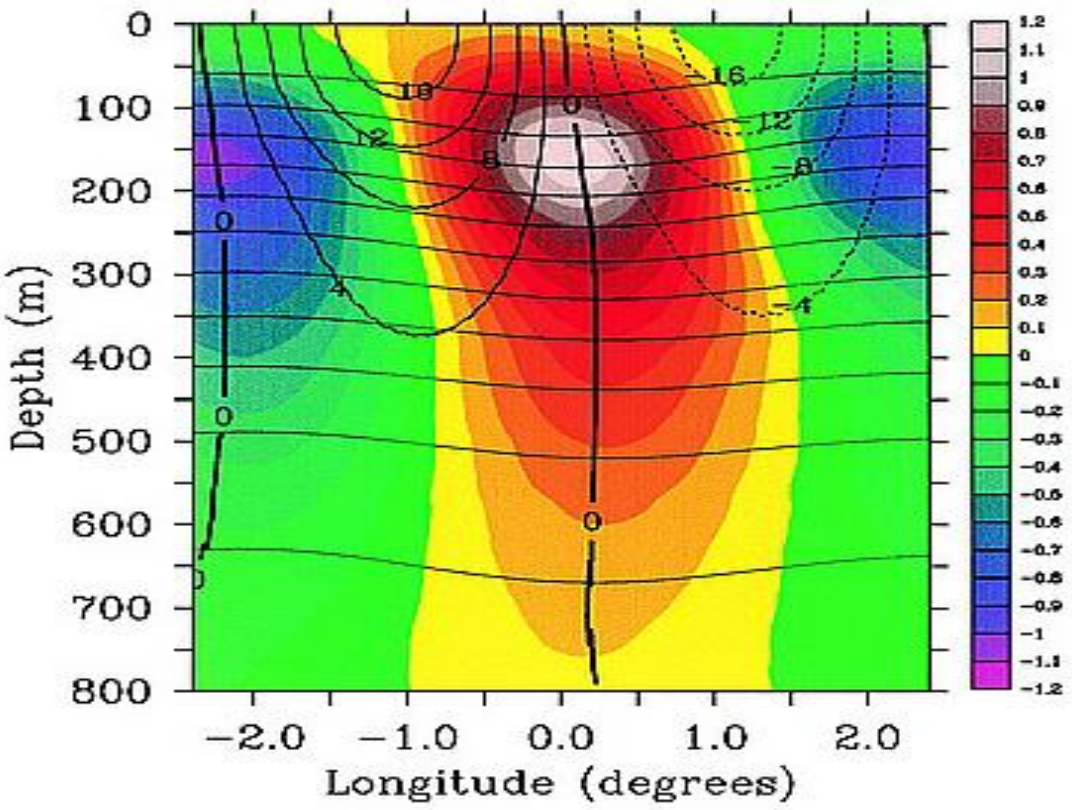
AVISO mapped SSH anomaly (m) weekly 1/1/2010-12/31/2011



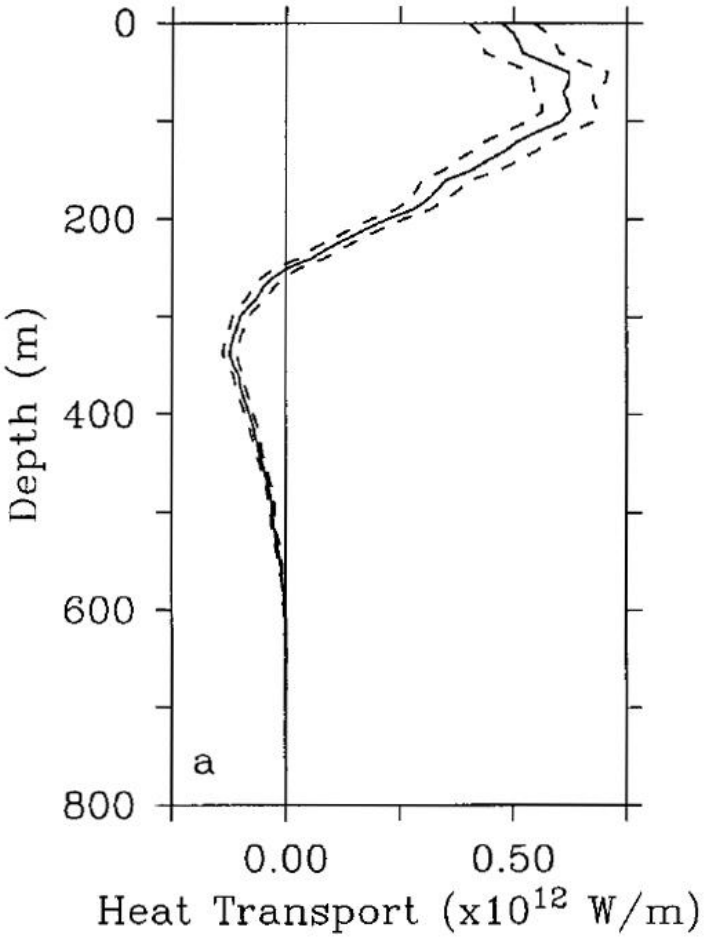


Roemmich & Gilson, JPO, 2001

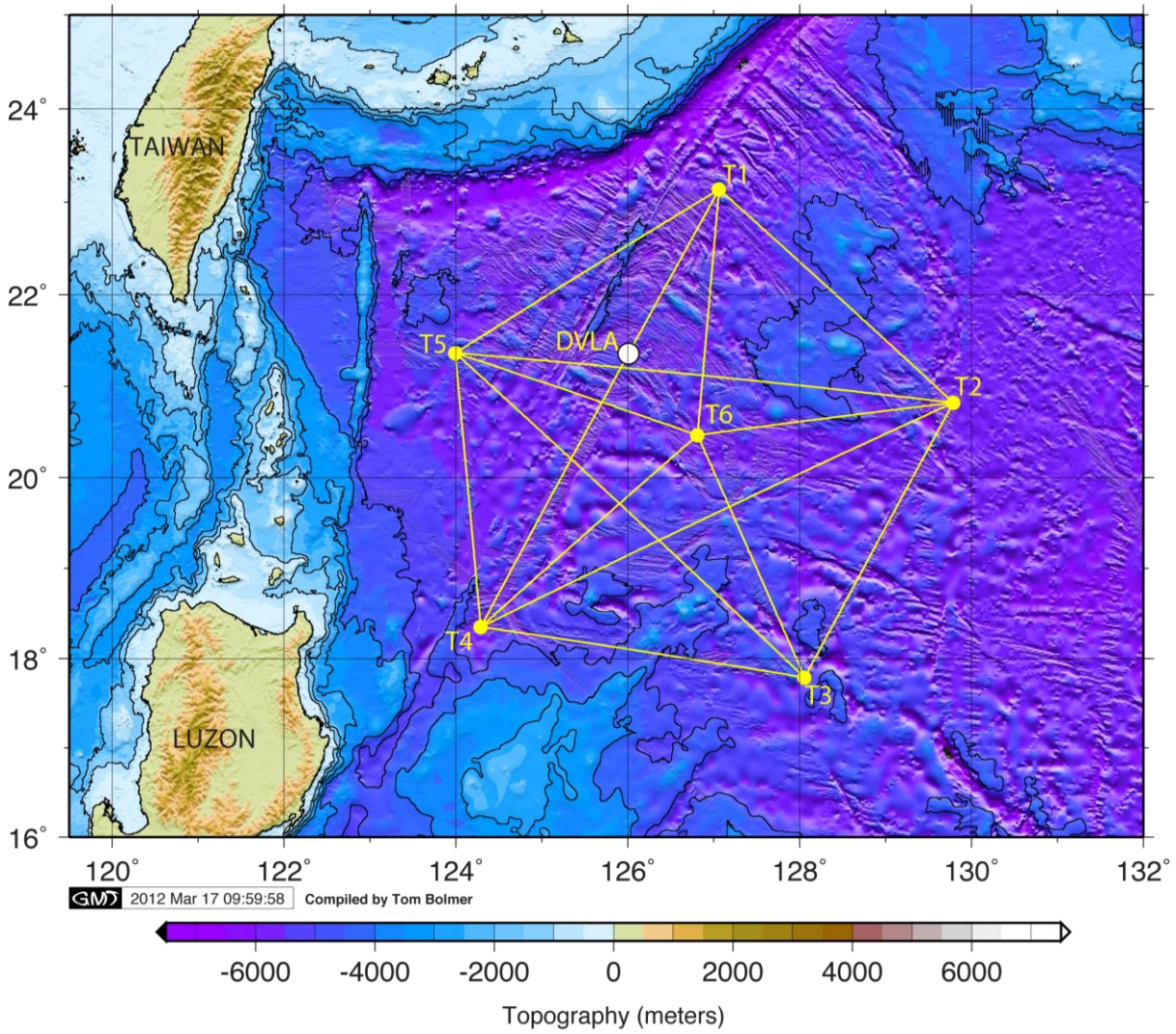
- Baroclinic structure associated with surface signature
- Composite eddy collected from superposing many observations
- Tilted eddy results in Northward eddy heat transport



Composite Eddy from N. Pacific XBT transect



2010–2011 NPAL Philippine Sea Experiment



- T1–T6: WRC transceivers
- 660 km diameter
- DVLA
- Moored oceanographic sensors
- CTD
- Acoustic Seagliders

Outline:

- Introduction to the modeling and state estimation
- Non-acoustic evaluation of the state estimates
- Acoustic evaluation of the state estimates
- Analysis of the tracked ray travel times
- State estimation using travel times

MITgcm configuration

1/6 degree regional: 115E-170E, 15S-30N

50 levels with 2.5m spacing in the upper ocean

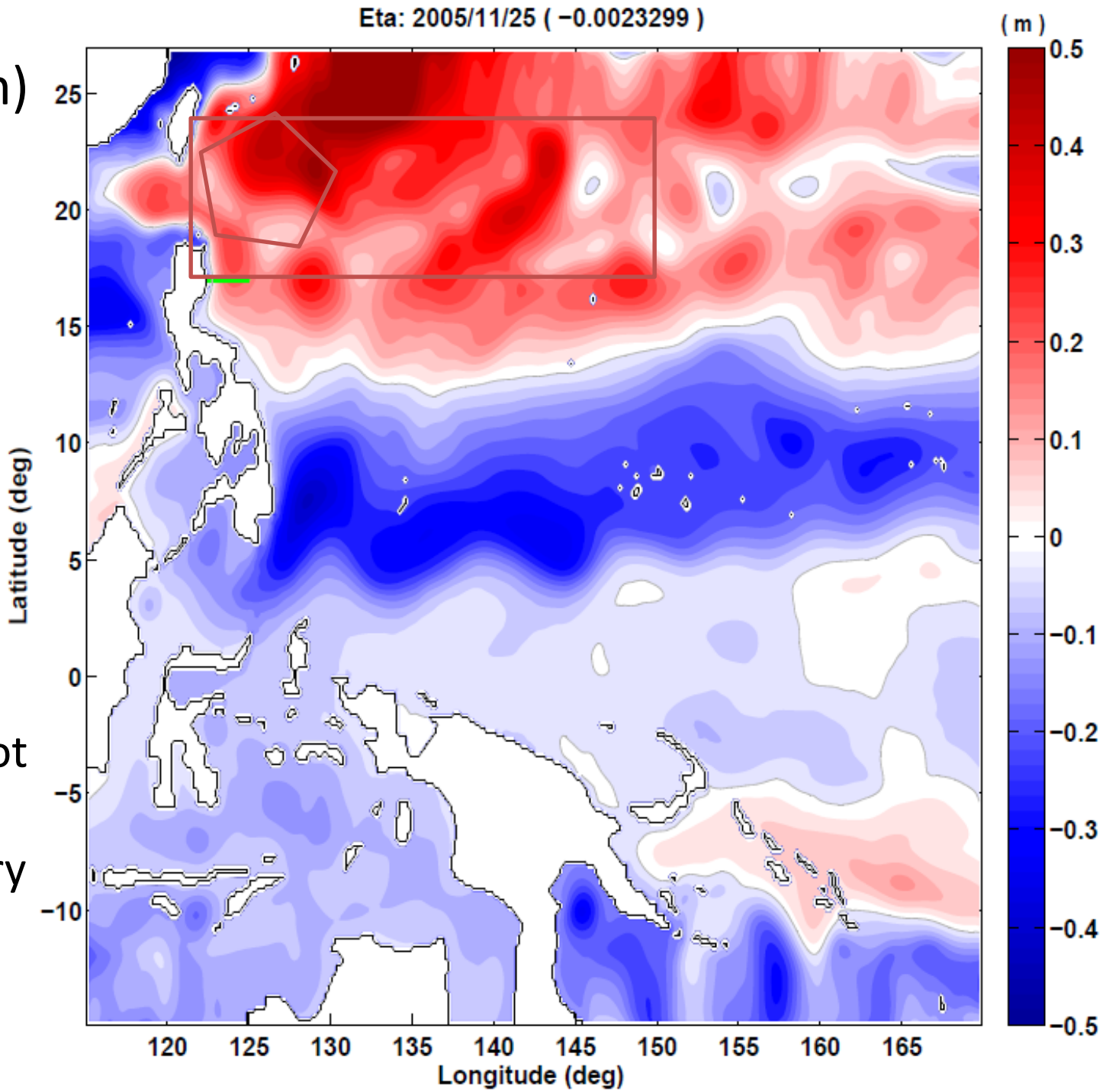
Surface forcing is derived from NCEP/NCAR Reanalysis (1 degree, daily averaged)

Initial and boundary conditions from global HYCOM-NCODA (excellent!)

Integrated 2004 -2012, compared to AVISO SSH

(no Ice or BGC, but Mazloff does Ocean-Ice-BGC assimilation in the Southern Ocean at 1/6 degree)

SSH
25 Nov 2005 (m)

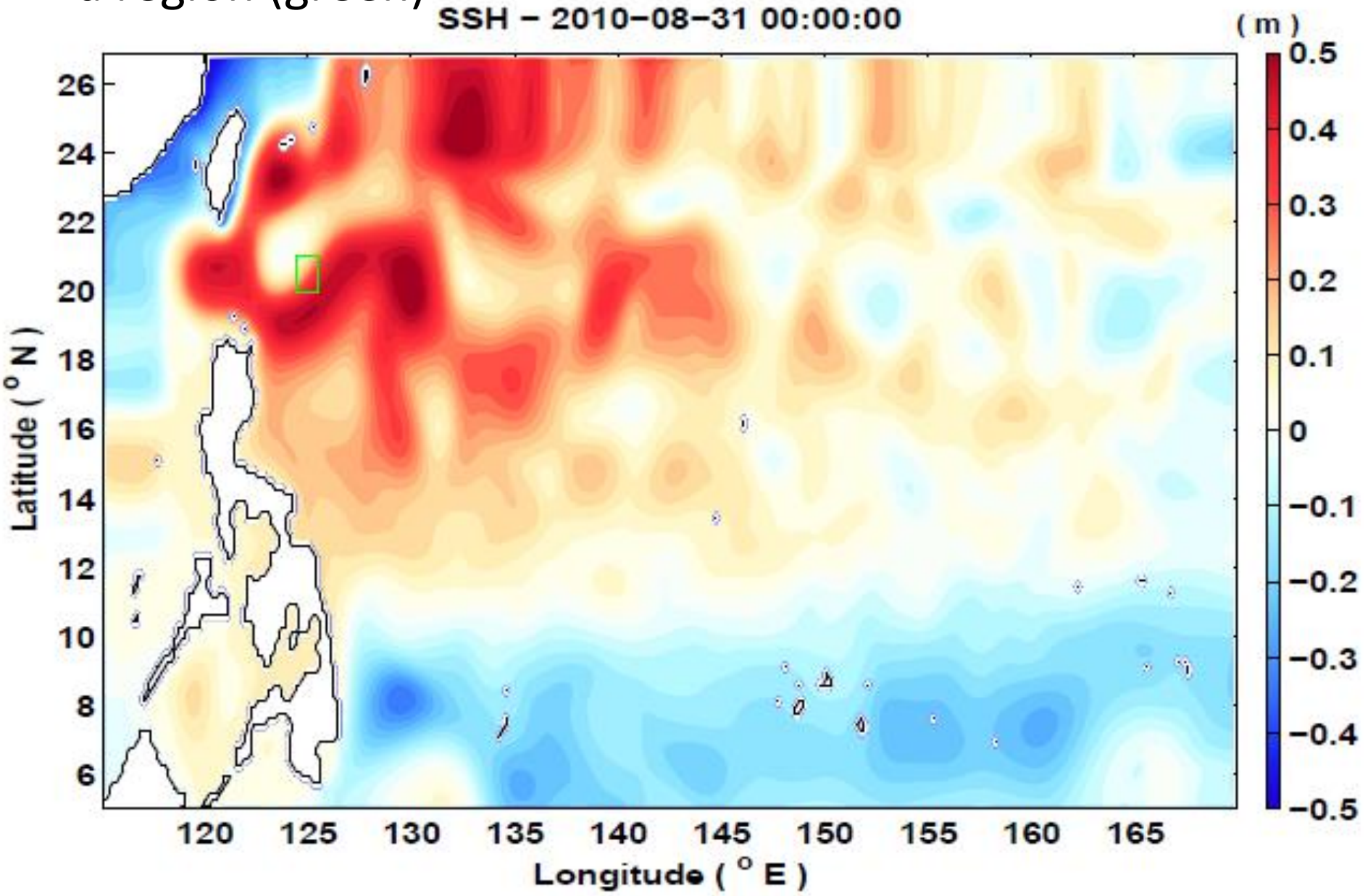


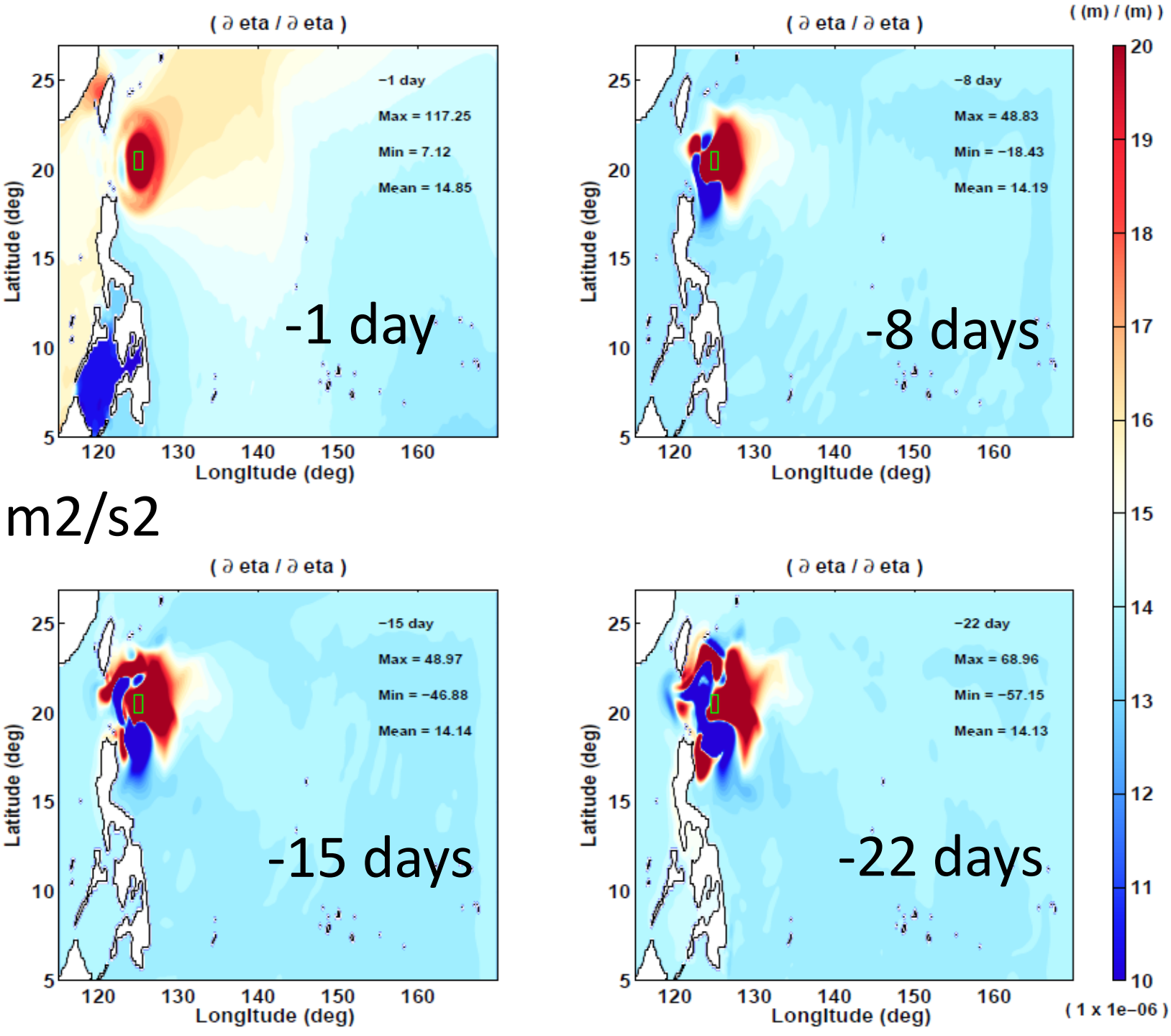
Example: snapshot
Of tropical Pacific
Western Boundary

4D-Var State Estimation

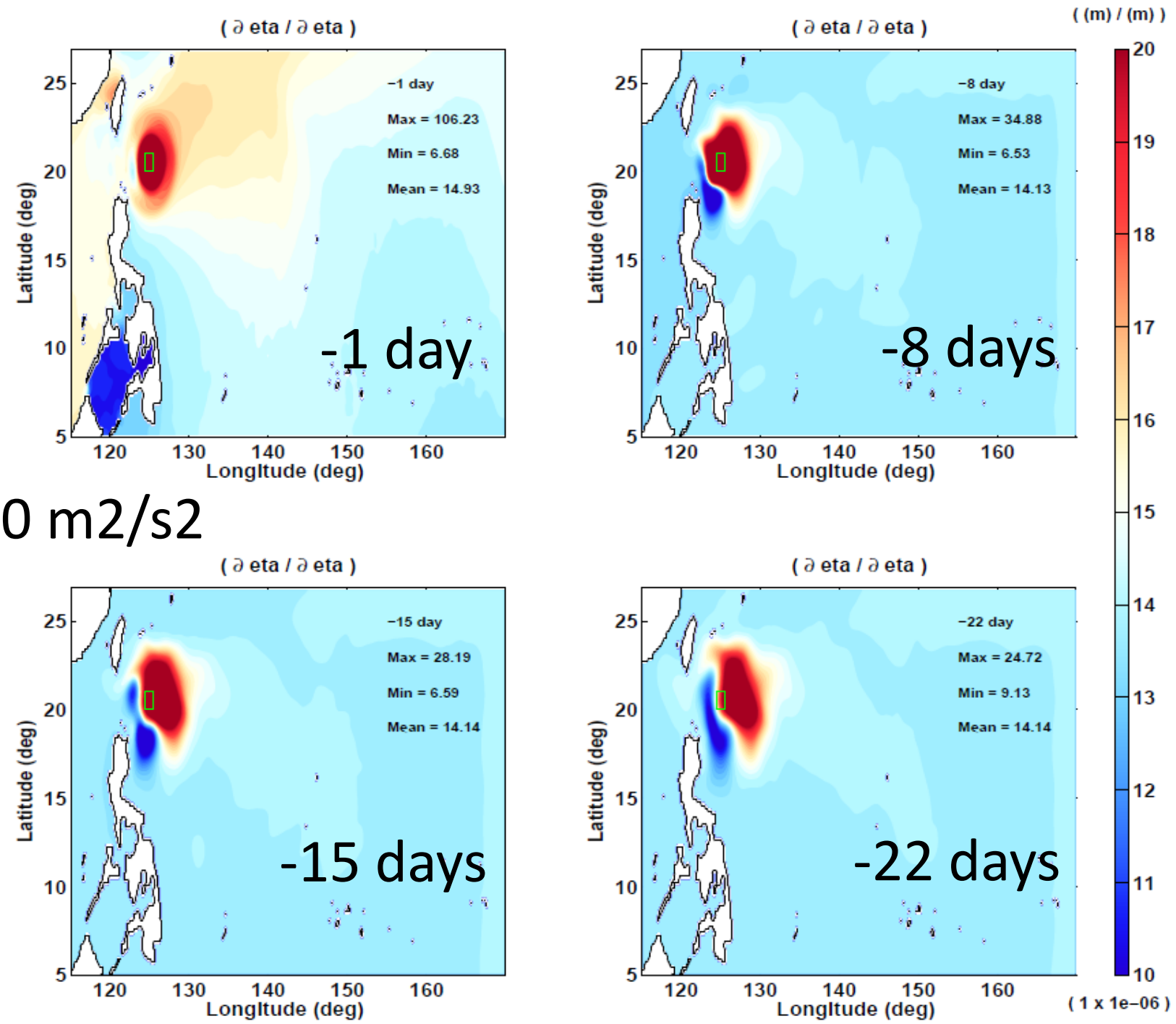
- Fit model to observations using 4D-Var (adjoint) (ECCO package for MITgcm)
- Adjust initial conditions, boundary conditions, and forcing (within error bars)
- Estimate is a free forward run of the model that should match the observations (within error bars)
- Is a dynamically-consistent reanalysis for research use, including sensitivities

Adjoint linearity tests. Cost function is average SSH in a region (green)

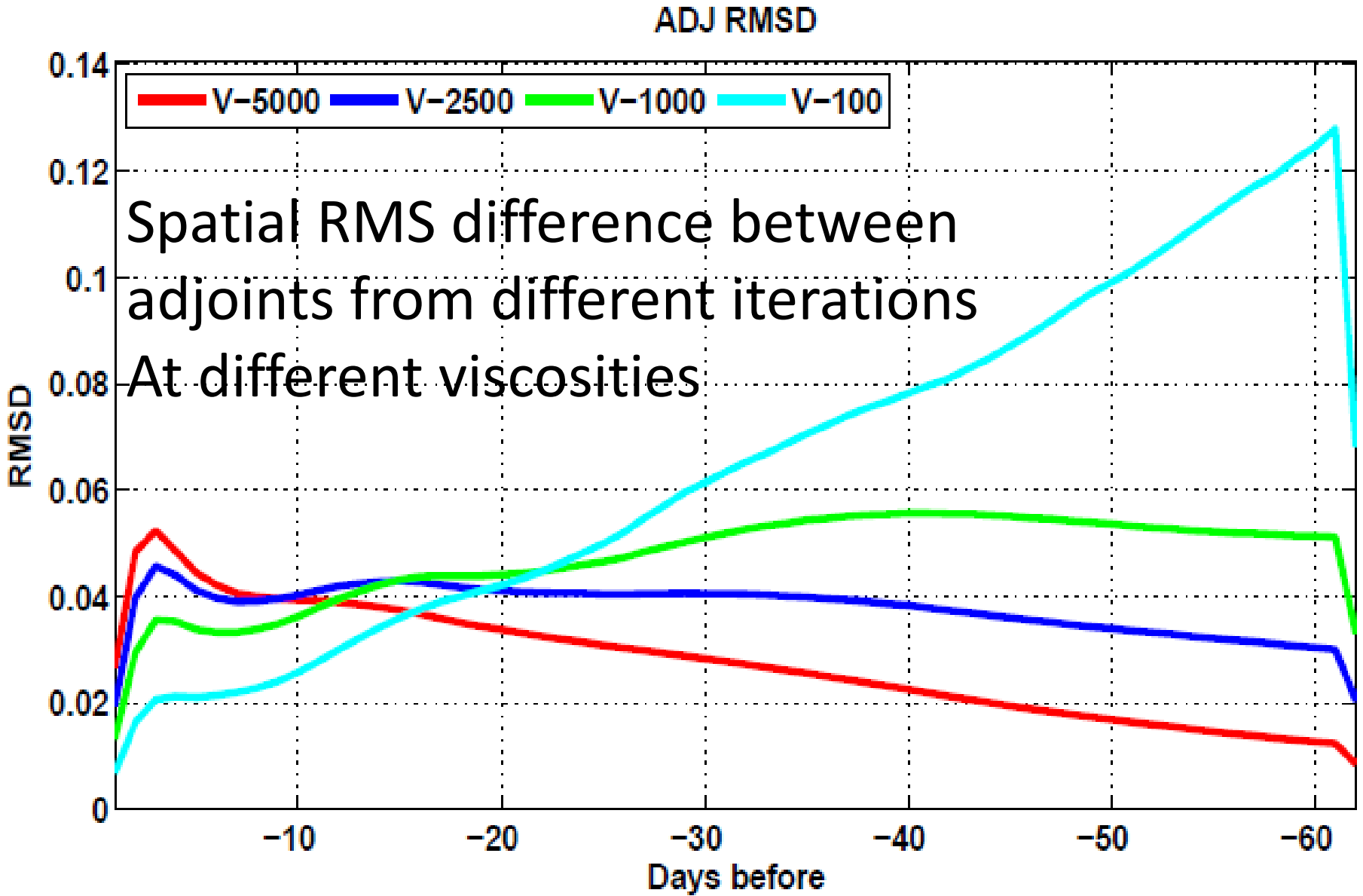



(∂ eta / ∂ eta)
−1 day
Max = 117.25
Min = 7.12
Mean = 14.85
-1 day
(∂ eta / ∂ eta)
−8 day
Max = 48.83
Min = −18.43
Mean = 14.19
-8 days
((m) / (m))
(∂ eta / ∂ eta)
−15 day
Max = 48.97
Min = −46.88
Mean = 14.14
-15 days
(∂ eta / ∂ eta)
−22 day
Max = 68.96
Min = −57.15
Mean = 14.13
-22 days
Latitude (deg)
Longitude (deg)
(1 x 1e−06)

100 m2/s2


(∂ eta / ∂ eta)
−1 day
Max = 106.23
Min = 6.68
Mean = 14.93
-1 day
(∂ eta / ∂ eta)
−8 day
Max = 34.88
Min = 6.53
Mean = 14.13
-8 days
((m) / (m))
20
19
18
17
16
15
14
13
12
11
10
(1 x 1e−06)
5000 m2/s2
(∂ eta / ∂ eta)
−15 day
Max = 28.19
Min = 6.59
Mean = 14.14
-15 days
(∂ eta / ∂ eta)
−22 day
Max = 24.72
Min = 9.13
Mean = 14.14
-22 days
Latitude (deg)
Longitude (deg)
5
10
15
20
25
120
130
140
150
160

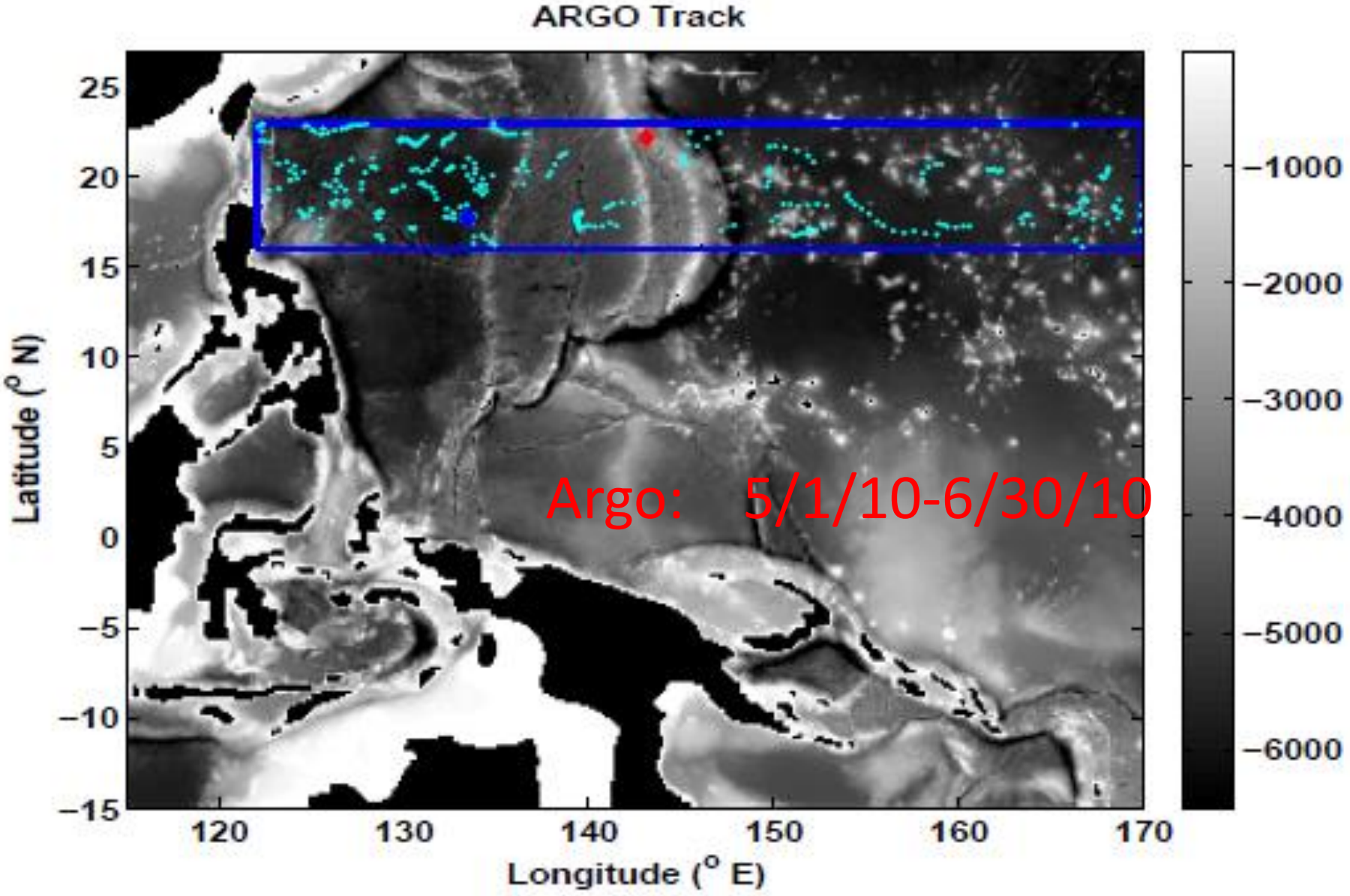
Filtered adjoint is less sensitive to model state (less nonlinear)



Observations

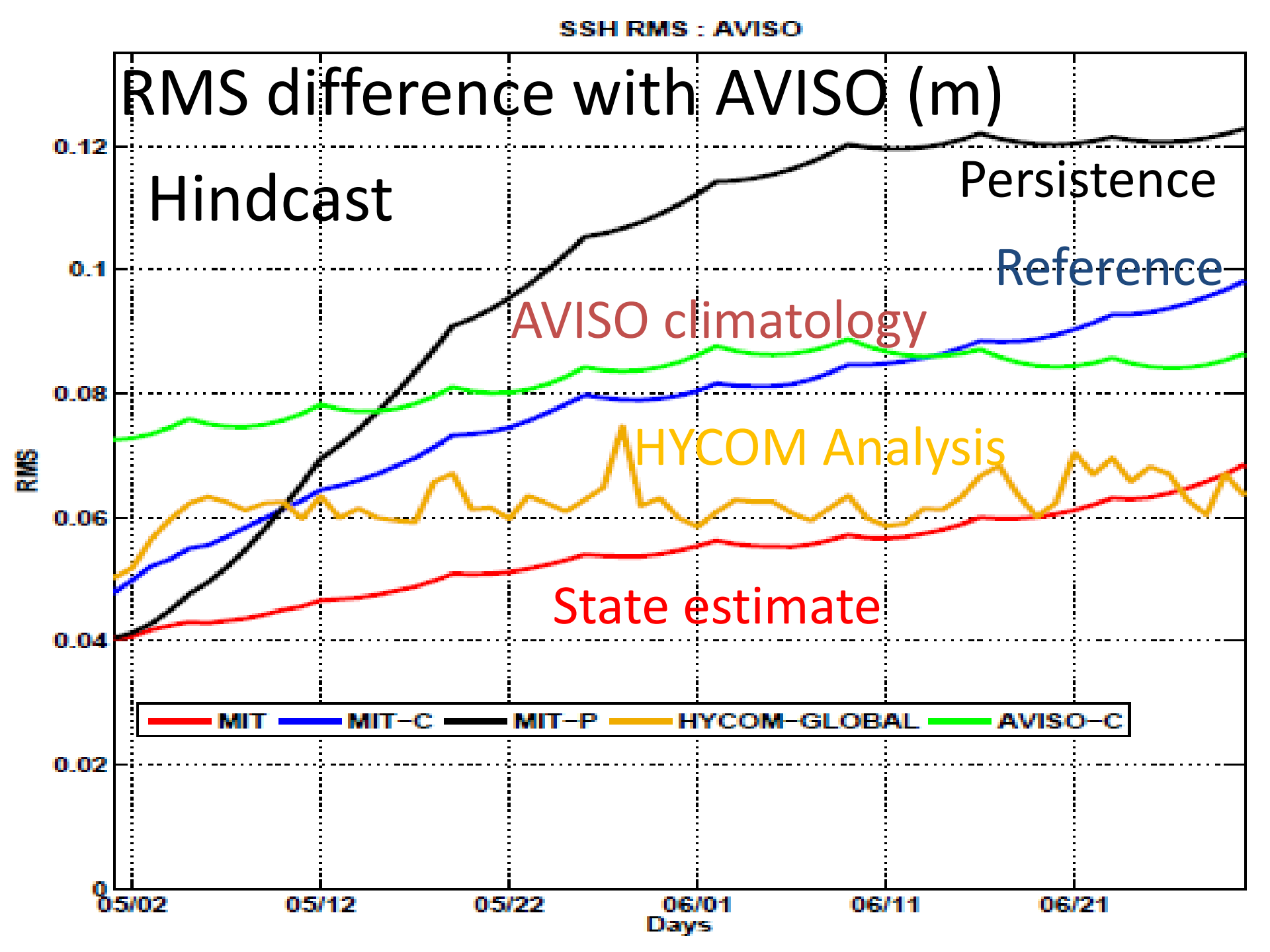
- Along-track altimeter sea surface height
- Temperature and salinity profiles from Argo
- Geoid constraints from GRACE (“HMEAN”)
- SST from TMI and AMSR-E (microwave)
- CTDs, XBTs, and other profiles
- Using 2 month windows, observations only in sub-region. How long is best? (Model error)
- Analysis and forecasts start April 1 2010
- Comparison to obs: Hindcast, Forecast

Bathymetry (m) (+ Argo locs)



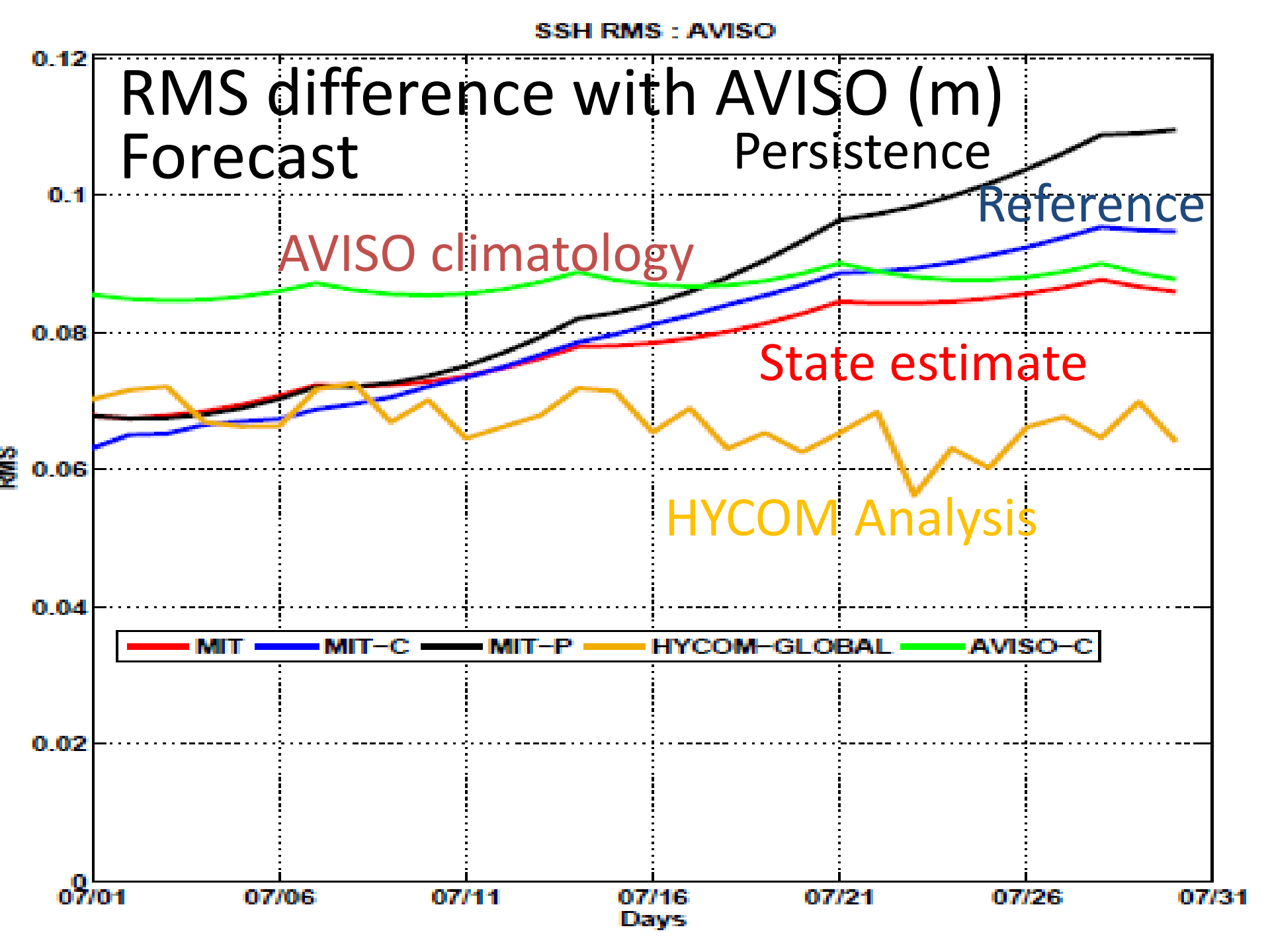
Non-Acoustic State estimate results

- Reduces misfit variance 30% from HYCOM
- Fits SSH best, also Argo T and S
- Controlled by initial T, S primarily


SSH RMS : AVISO
RMS difference with AVISO (m)
Hindcast
Persistence
Reference
AVISO climatology
HYCOM Analysis
State estimate
MIT
MIT−C
MIT−P
HYCOM−GLOBAL
AVISO−C
RMS
0.12
0.1
0.08
0.06
0.04
0.02
0
05/02
05/12
05/22
06/01
06/11
06/21
Days

State estimate evaluation

- Smoother than HYCOM starting point, but may not fit as well at any one time.
- Test against future data (forecast, cross-validation) shows improvement due to the optimization.
- Also compare to T, S, acoustics…


SSH RMS : AVISO
RMS difference with AVISO (m)
Forecast
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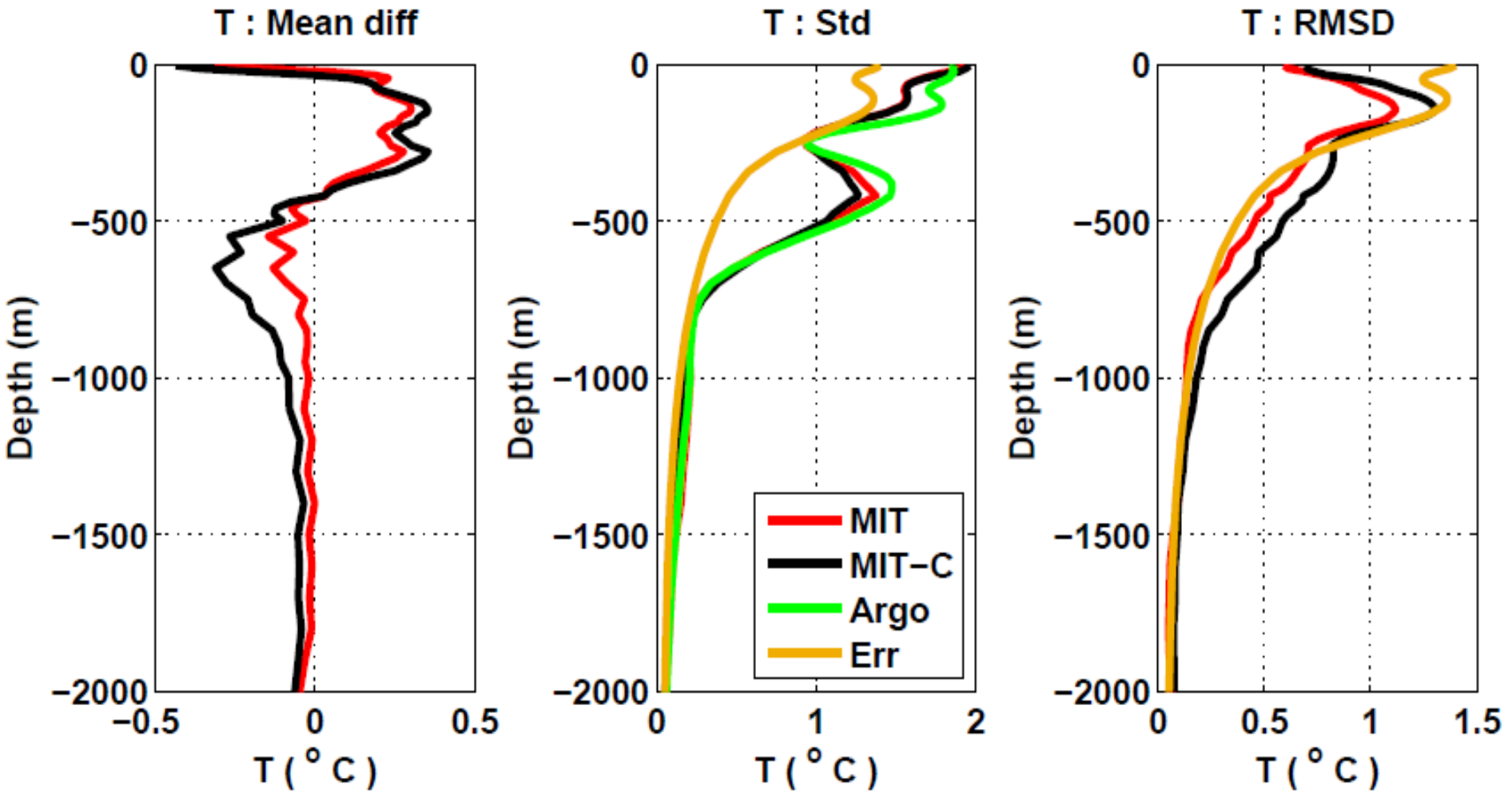
AVISO climatology
State estimate
HYCOM Analysis
MIT
MIT−C
MIT−P
HYCOM−GLOBAL
AVISO−C
RMS
Days
0.12
0.1
0.08
0.06
0.04
0.02
0
07/01
07/06
07/11
07/16
07/21
07/26
07/31

Comparison against independent T observations on the DVLA
Black = Before, Red = After, Gold = assumed obs. error



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- This was accomplished by filtering the adjoint using increased viscosity and is part of a multiscale approach.
- The estimate was cross-validated by independent observations and forecasts including acoustics
- Same eddy tilt and heat flux as Roemmich and Gilson; also calculated salt flux

Extra Slides