Impact of glider data assimilation on the predictability of the mesoscale circulation in the Gulf of Mexico

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Ocean 3D+1 workshop

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GHRSST (top) and model SST on 12 Jan 2012 (left) and 1 Apr 2012 (left)
Spray 50 trajectory for 12/27/11-1/12/12 (left) and 3/16/12-4/1/12 (right

SST 1/12/12 SST 4/1/12

OBS

Model

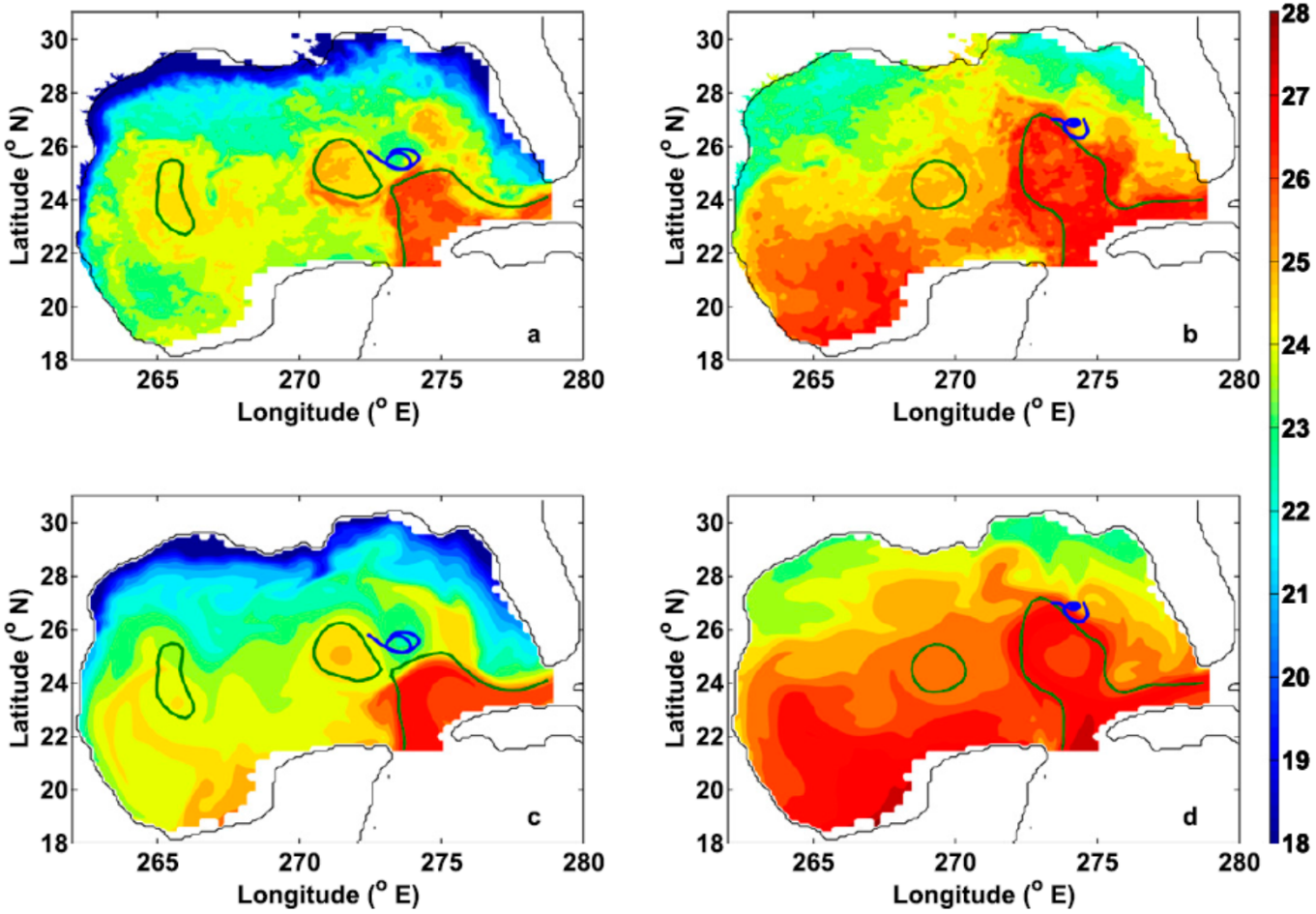

FIG. 4. SST measured by satellite and hindcast by model. GHRSST satellite SST on (a) 12 Jan 2012 and (b) 1 Apr 2012. (c),(d) Model hindcast SST is from experiment 2 on the same dates. The trajectory of Spray 50 (blue) is shown during the time periods in Fig. 3: (left) 27 Dec 2011–12 Jan 2012 and (right) 16 Mar–1 Apr 2012. The 17-cm contour of AVISO satellite sea surface height is shown for reference (green).

Science Goals

- Understand Loop Current system:
  - What controls LC growth?
  - What controls Eddy shedding?
- What is the predictability time for the LC?
  - How fast do errors grow?
  - Over how long can you make a good forecast?
  - How can the model(s) be improved?
  - What observations are needed, and where?

Words to live by

"Those who have knowledge don't predict.
Those who predict don't have knowledge."

Lao Tzu

For us prediction is not an operational goal, but a method for cross-validating the state estimate

Goal of this talk

- Describe our experiments using and withholding Spray glider data from the assimilation to see the impact on the forecast.
- Question: does the glider data improve the forecasts?
- Answer: Yes, most of the time, but there is a lot to learn about where and when to sample.
- Rudnick et al., 2015: Cyclonic Eddies in the Gulf of Mexico: Observations by Underwater Gliders and Simulations by Numerical Model (JPO)

Outline

- Introduction to model and method: 4DVAR
- Introduction to Spray gliders
- Show how well model matches glider before it is assimilated
- Show the effect of assimilating glider data on predictability
  - Apology: mostly using RMS SSH measures

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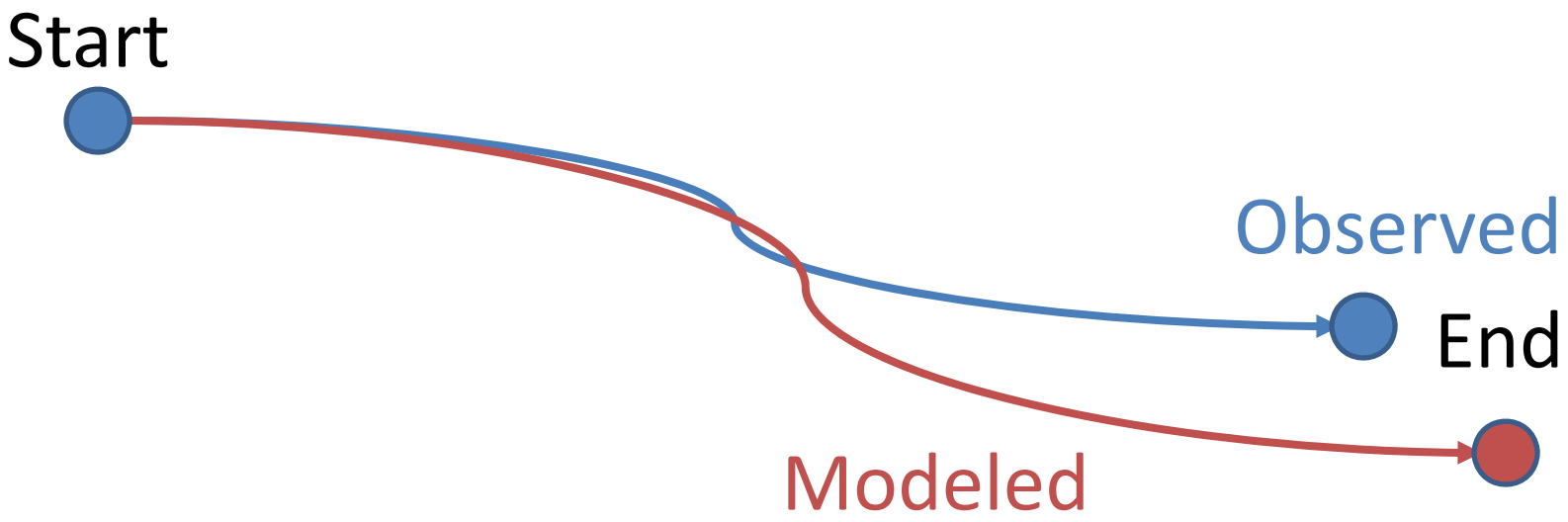
State Estimation

- Hindcast a dataset for hypothesis (and model) testing, dynamical analysis, and forecasting
  - "Generalized process experiments"
  - "Model-based data analysis"
- We use two related methods:
  - 4D Variational (4DVAR) which uses the adjoint model, but depends on weak nonlinearity
  - Ensemble Kalman Filter which does not need adjoint and can calculate uncertainty, but is limited to a small number of ensemble members

MITgcm – Inter-American Seas

- Regional 1/10 degree grid includes all IAS
  - Also enhanced 1/20 degree resolution in LC region
- 40 z-levels, ETOPO2 topog, partial cells
- Initial conditions and OBC from HYCOM
- NCEP forcing (atmospheric state)
- Use adjoint and assimilation tools from ECCO modified at SIO to include line integral data
- Long assimilation windows 1 or 2 months so can separate repeat altimeter anomalies from geoid

Trajectory data can be approximated as line integrals



Adjust modeled trajectory to end at observed spot by adjusting (u,v,w) velocity along track
Adjusting uniformly in time and space is simplest.
Then observation = integrated velocity along path

ECCO 4DVAR State Estimation

- “Hard constraint”: model dynamics are not changed. Adjust forcing, initial conditions, and boundary conditions to match observations. (4DVAR) (“adjoint”)
- No need for approximate mapping of observations
- Use Adjoint to make “reasonable” adjustments to forcing, boundary conditions, and initial conditions to make a forward run that fits the data “within error bars”.
- Generally used as a hindcast for scientific analysis or model testing. Really just a forward run with optimal tuning
- Natural for understanding prediction: each run is a prediction, we find the errors with the observations, and then apply controls to correct, so we know what matters.

GHRSST (top) and model SST on 12 Jan 2012 (left) and 1 Apr 2012 (left)
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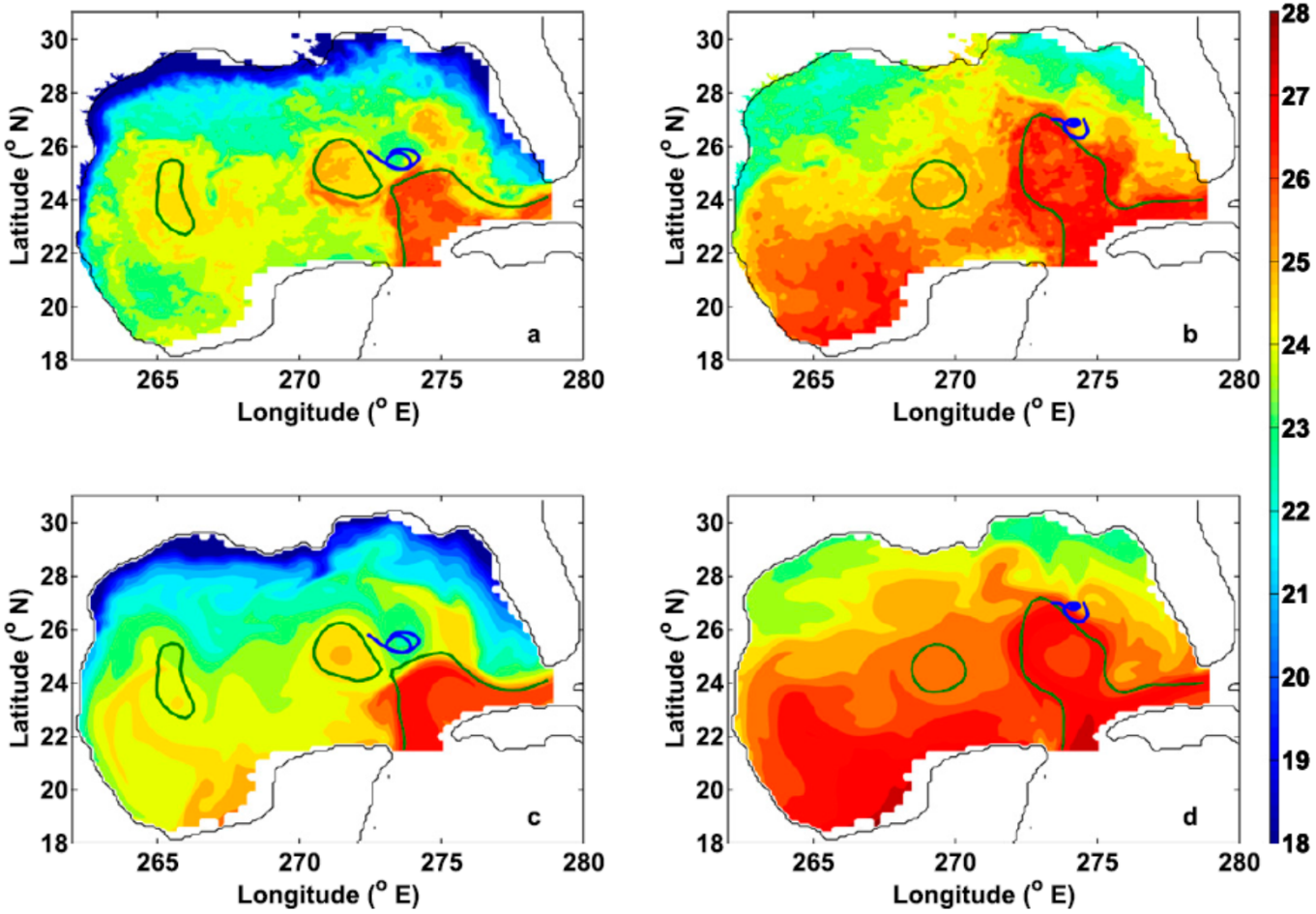

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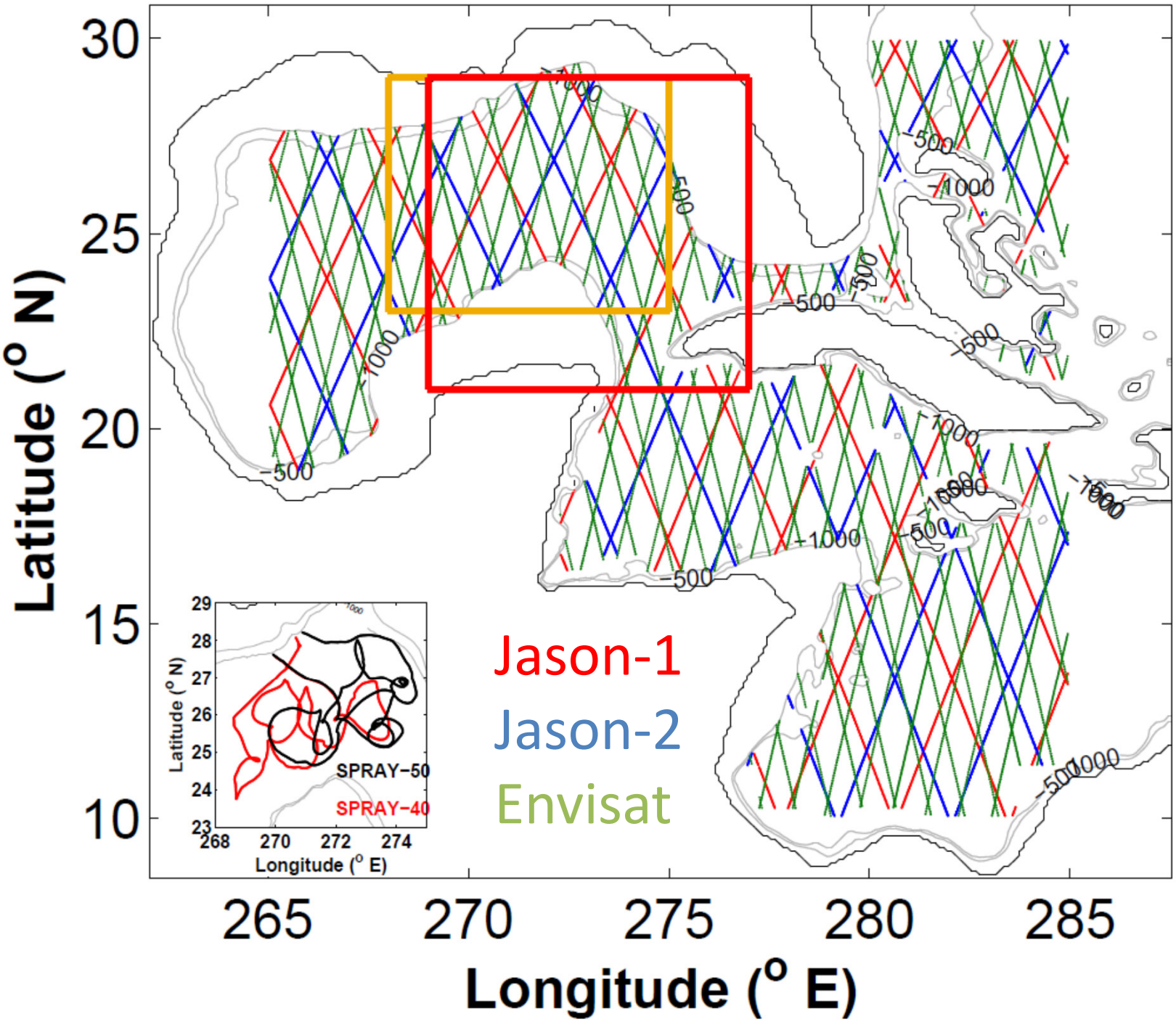
Latitude (° N)
Longitude (° E)
30
25
20
15
10
265
270
275
280
285
-500
-1000
Jason-1
Jason-2
Envisat
SPRAY-50
SPRAY-40
Latitude (° N)
Longitude (° E)
29
28
27
26
25
24
23
268
270
272
274

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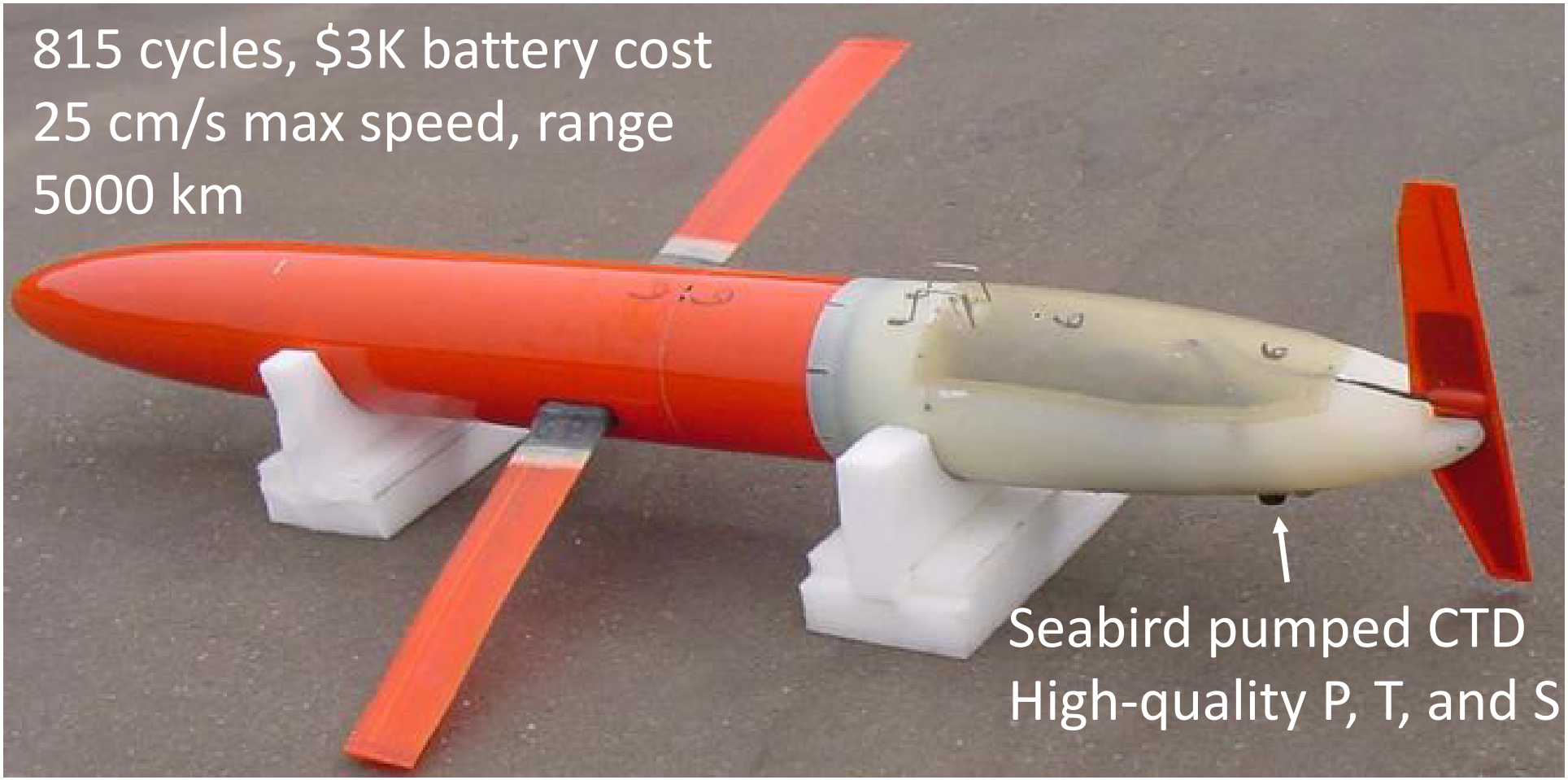
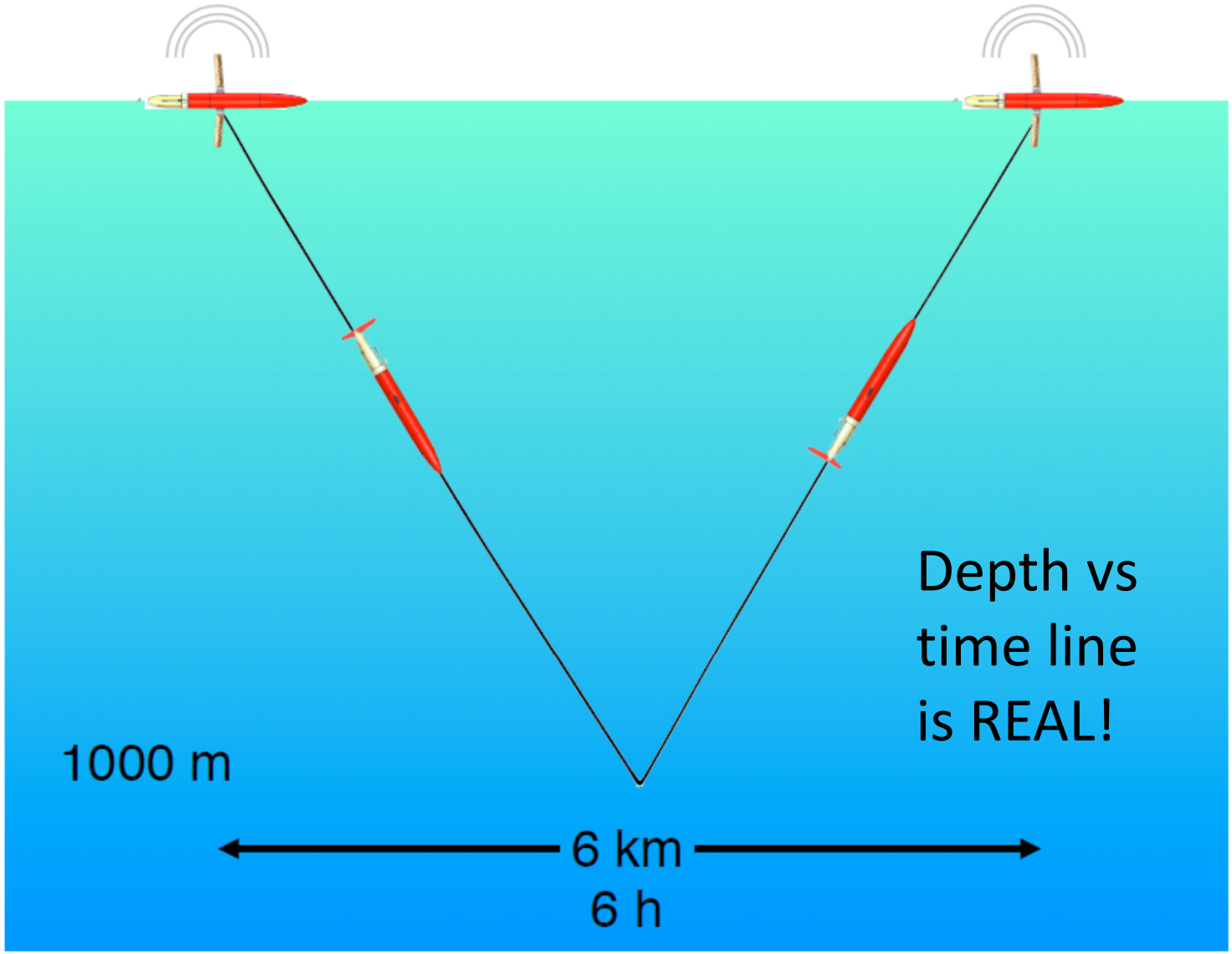
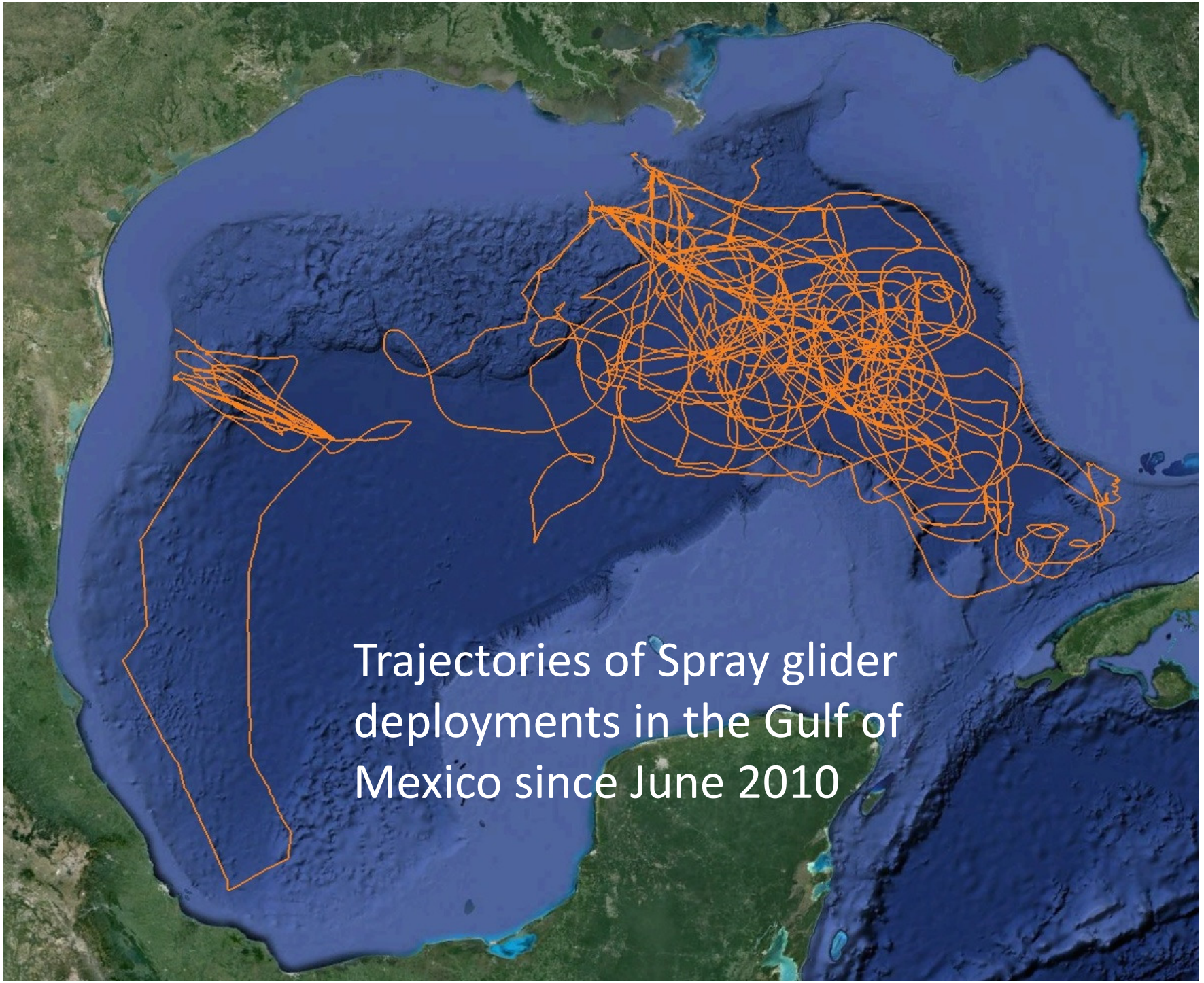
SIO Spray glider: 2m long, 20cm dia., 110cm wingspan, mass 52kg, 1500m max 6 hr dives to 1000m, 6km spacing



One dive cycle (6 hrs, 6 km)

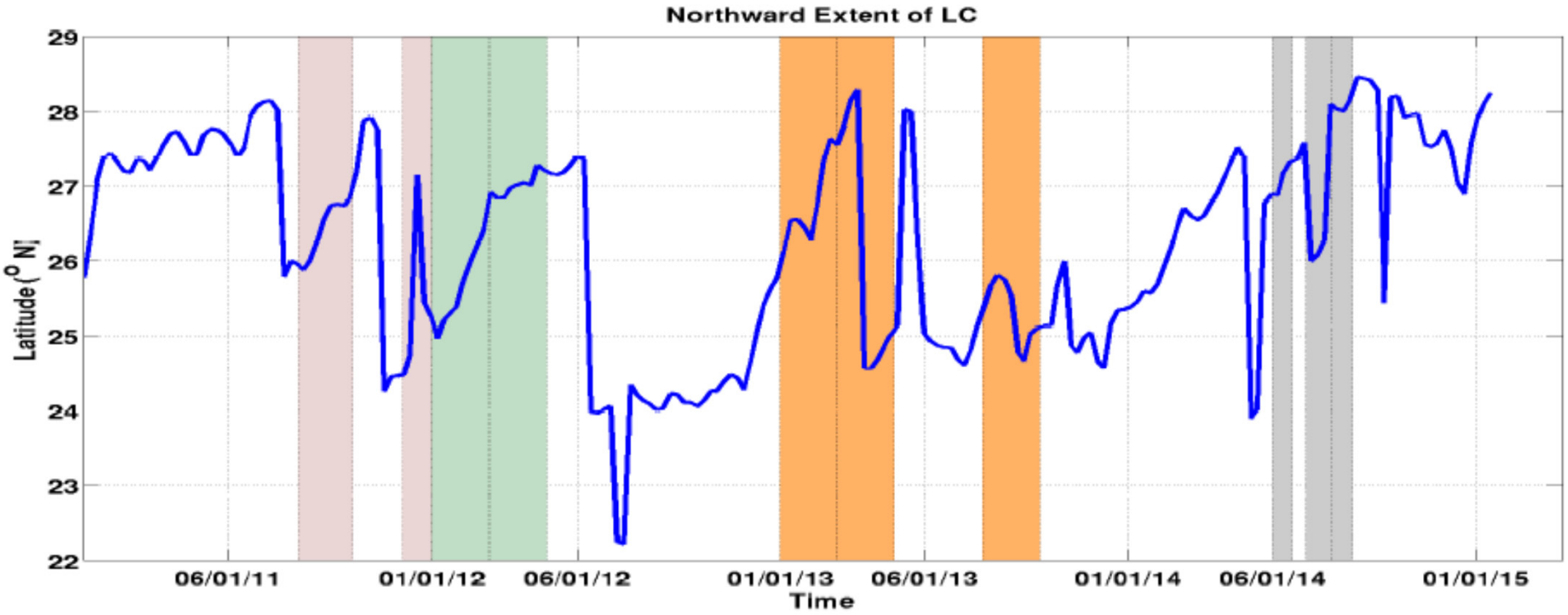



Trajectories of Spray glider deployments in the Gulf of Mexico since June 2010

Spray gliders in the Gulf

- 13 missions totaled 1679 glider-days, covered 44,287 km over ground and 38,849 km through water, and produced 8082 profiles.
- Started in 2009.
- Coverage was continuous from May 2011 through October 2014, with 1-3 gliders in the water at all times.

AVISO North loop current front Latitude
Shaded areas show hindcast and forecast experiments



Jan 2011 Jan 2012 Jan 2013 Jan 2014

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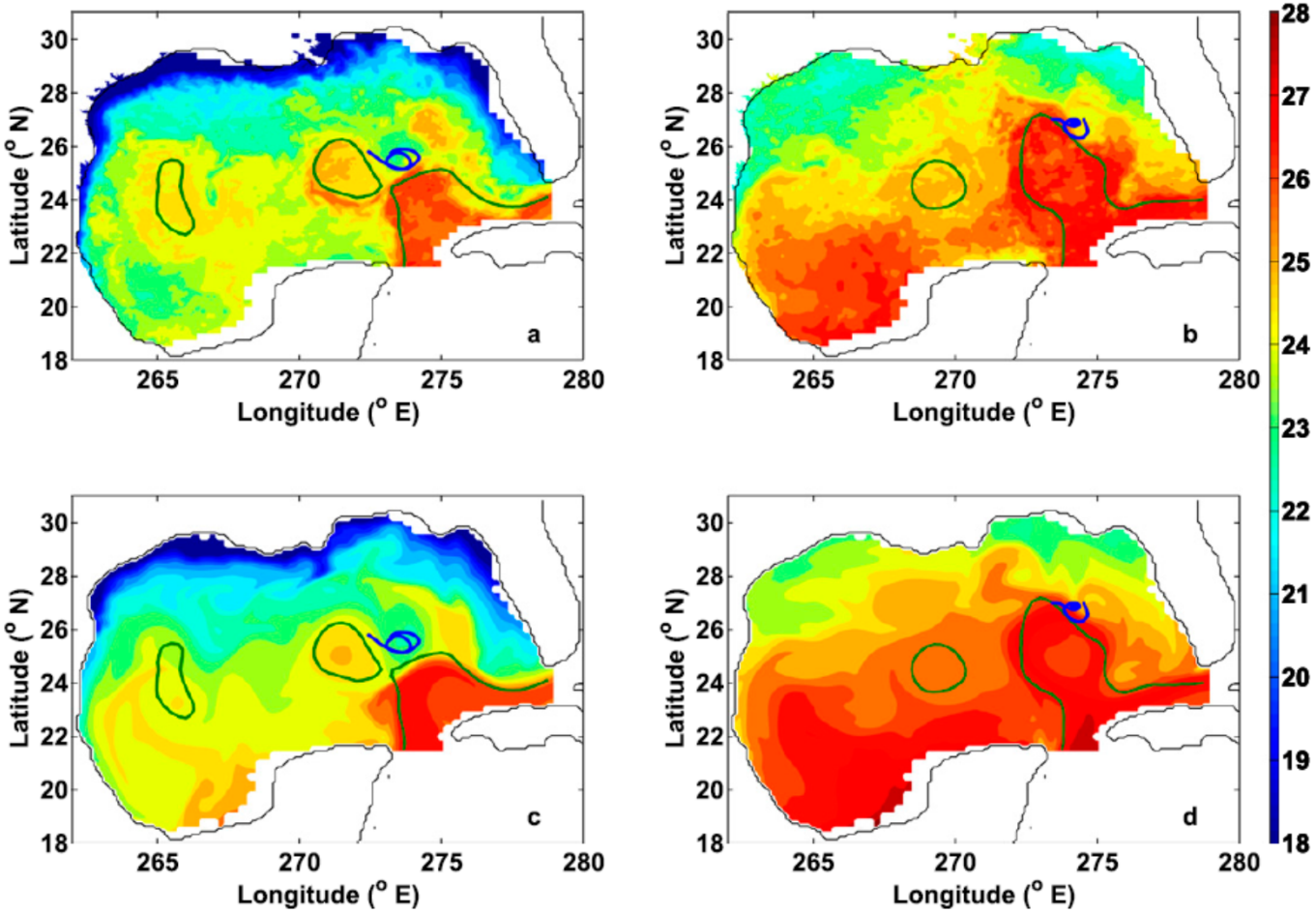

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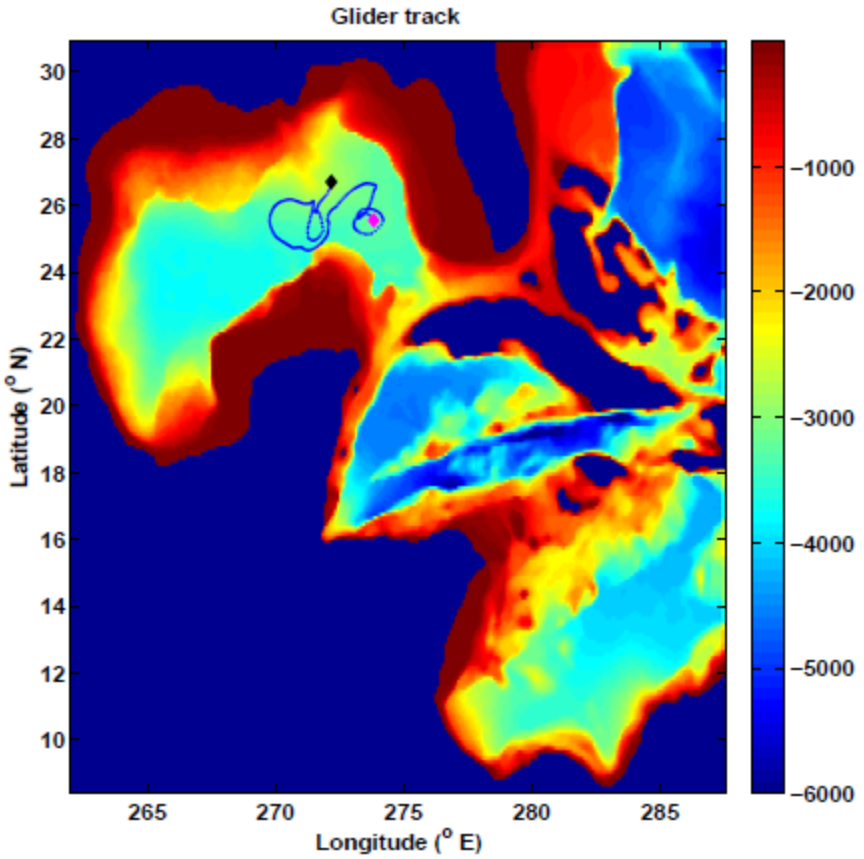
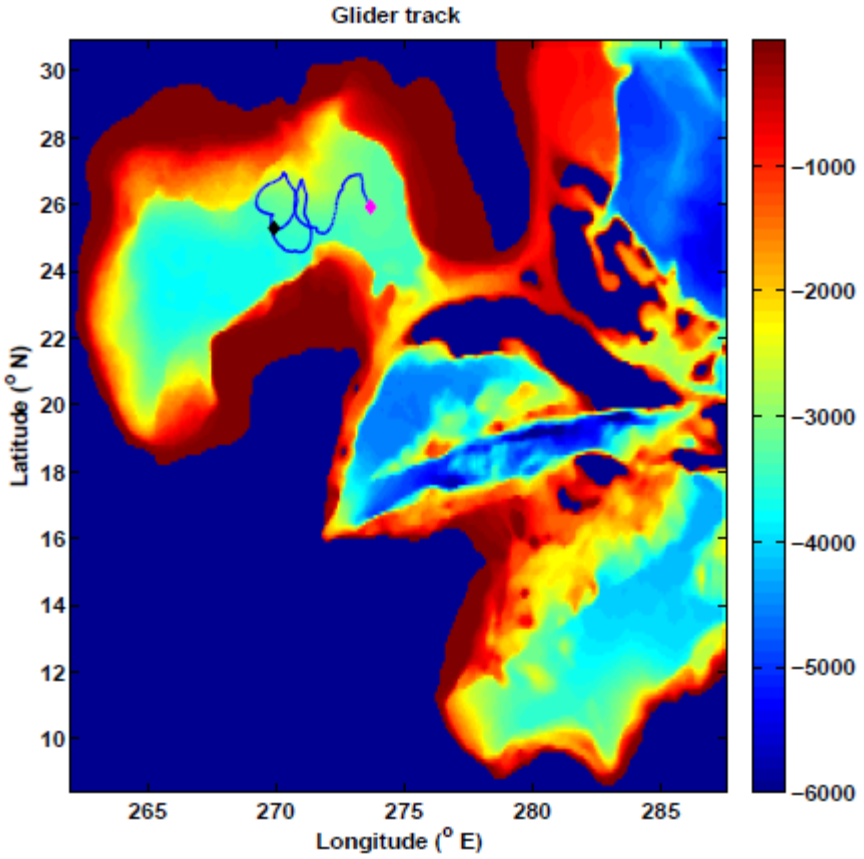
Hindcast Comparison: Glider track: 2012

SPRAY-1 (S/N 50)

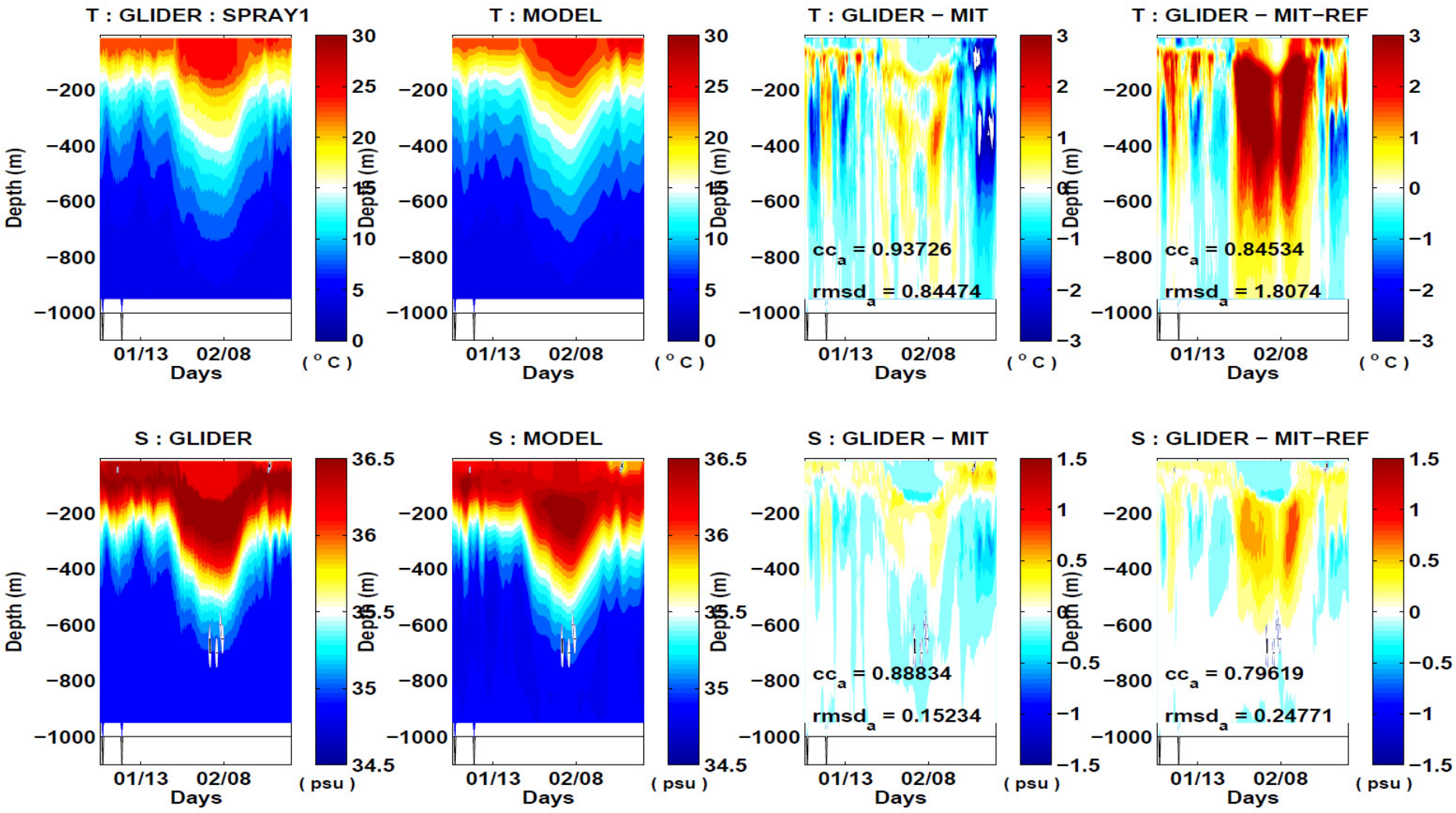


SPRAY-2 (S/N 40)



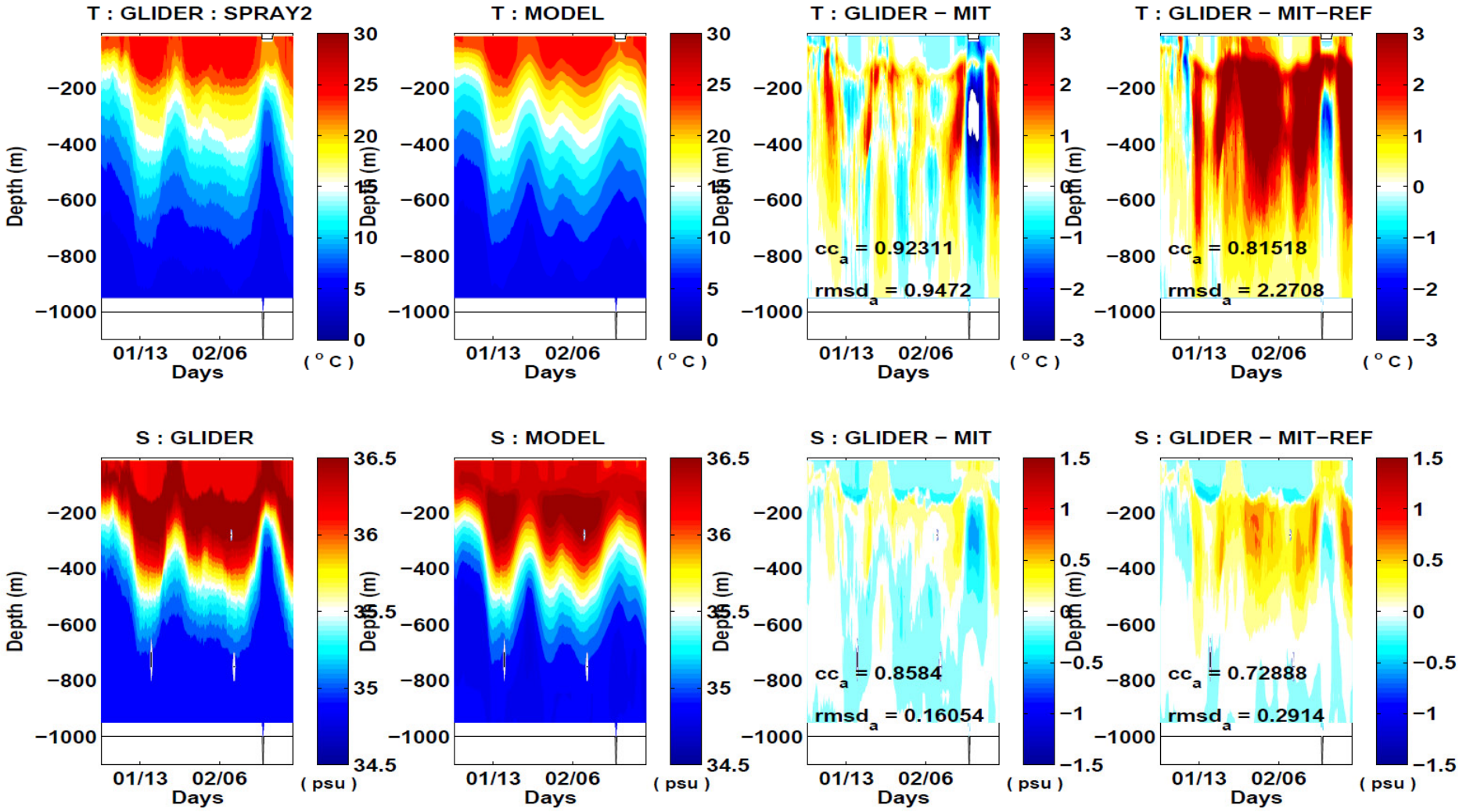
Jan thru Feb 2012

Compare to SPRAY-1 (No glider data used)



Glider Model Difference REF diff

Compare to SPRAY-2 (No glider data used)



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Dec 2011-April 2012 Glider Trajectories and depth-averaged velocities

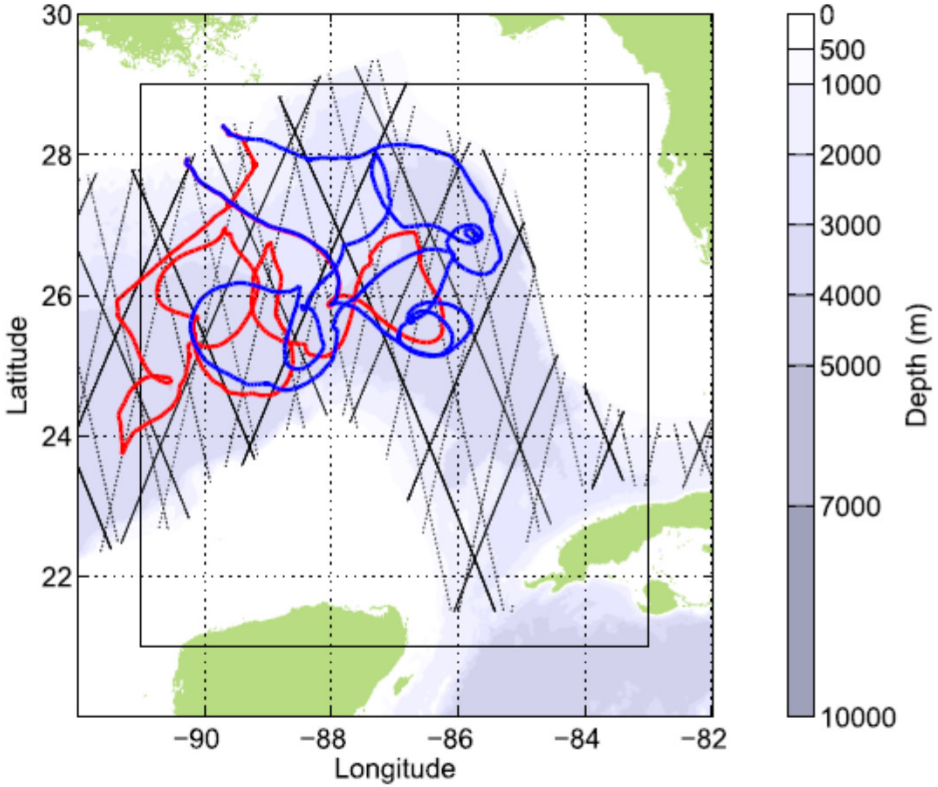

FIG. 1. Trajectories of Spray underwater gliders 40 (red) and 50

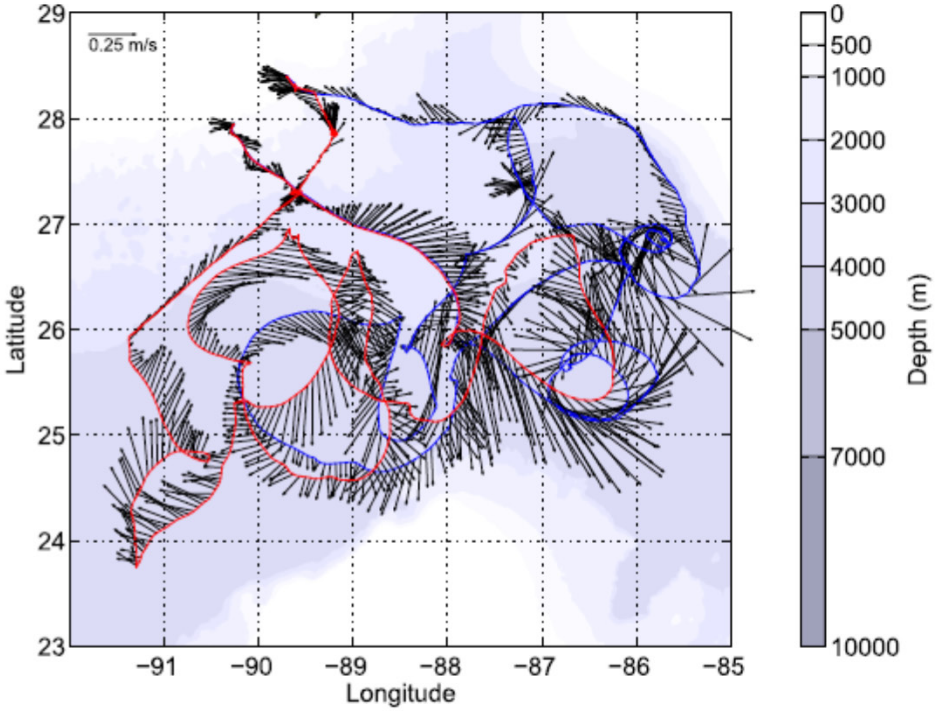

FIG. 2. Depth-averaged velocities measured by Sprays 40 (red trajectory) and 50 (blue trajectory). Velocity scale is in the upper-left hand corner.

Glider 50 (blue line) sampled cyclonic eddies

Does that matter?

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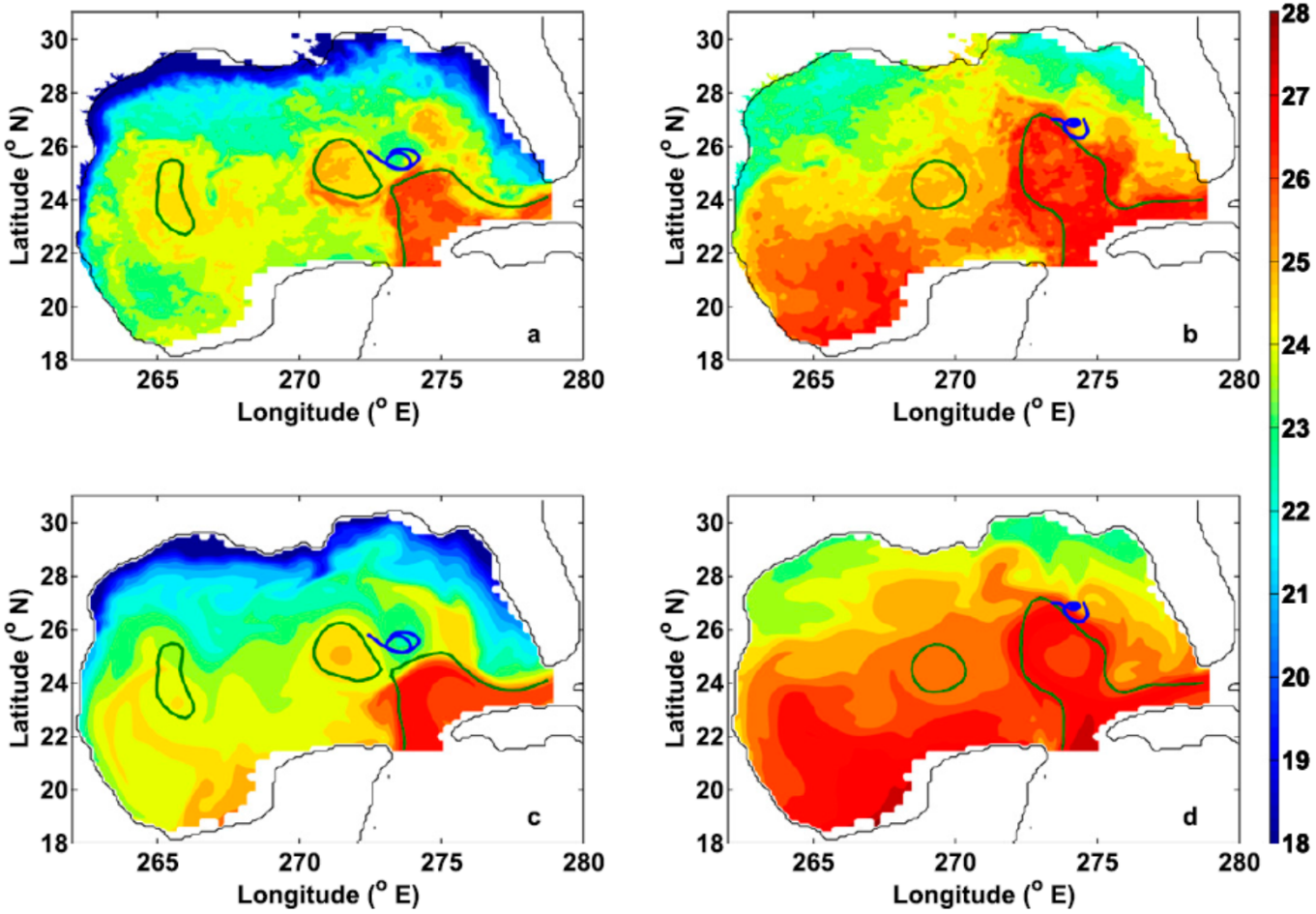

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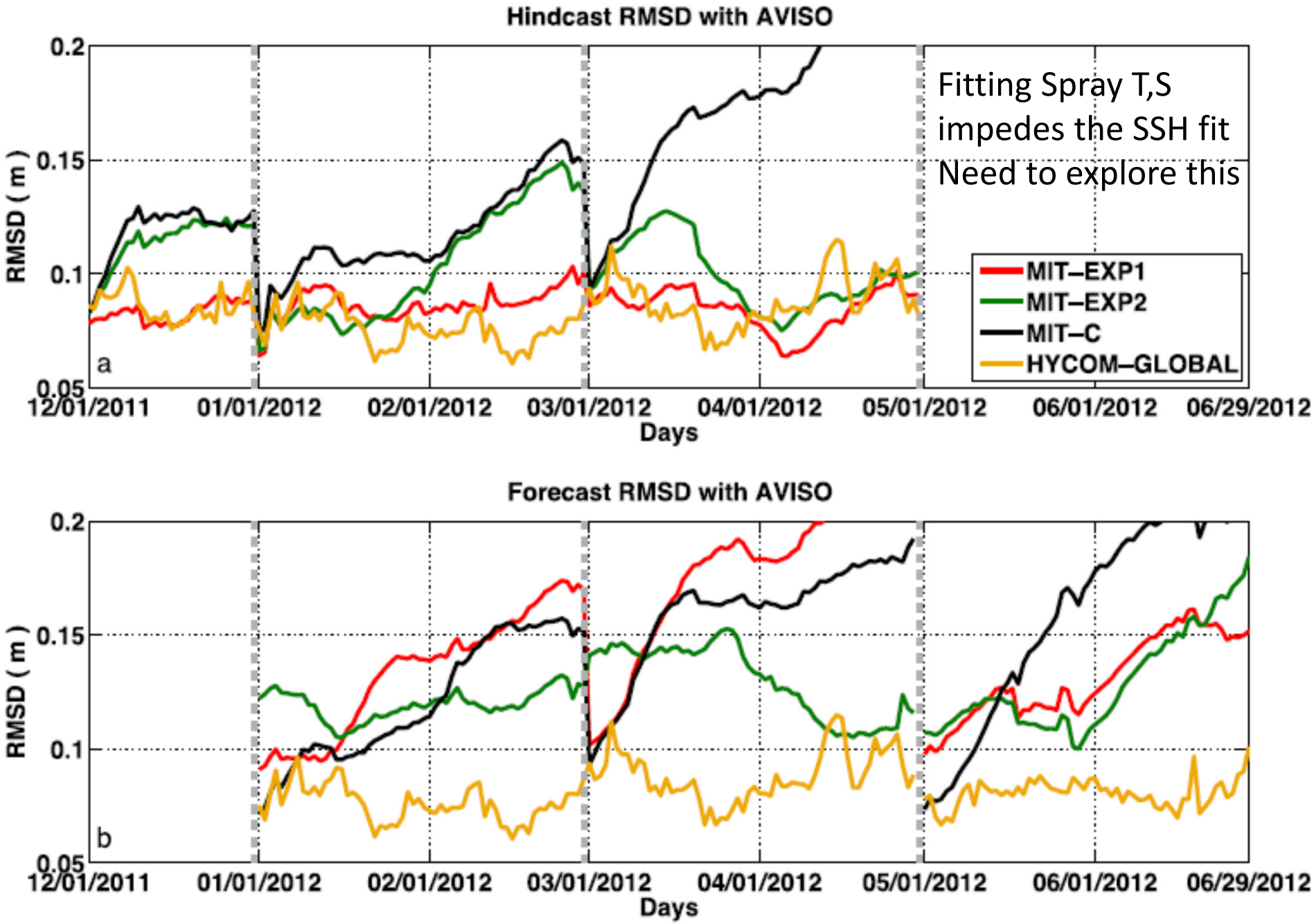
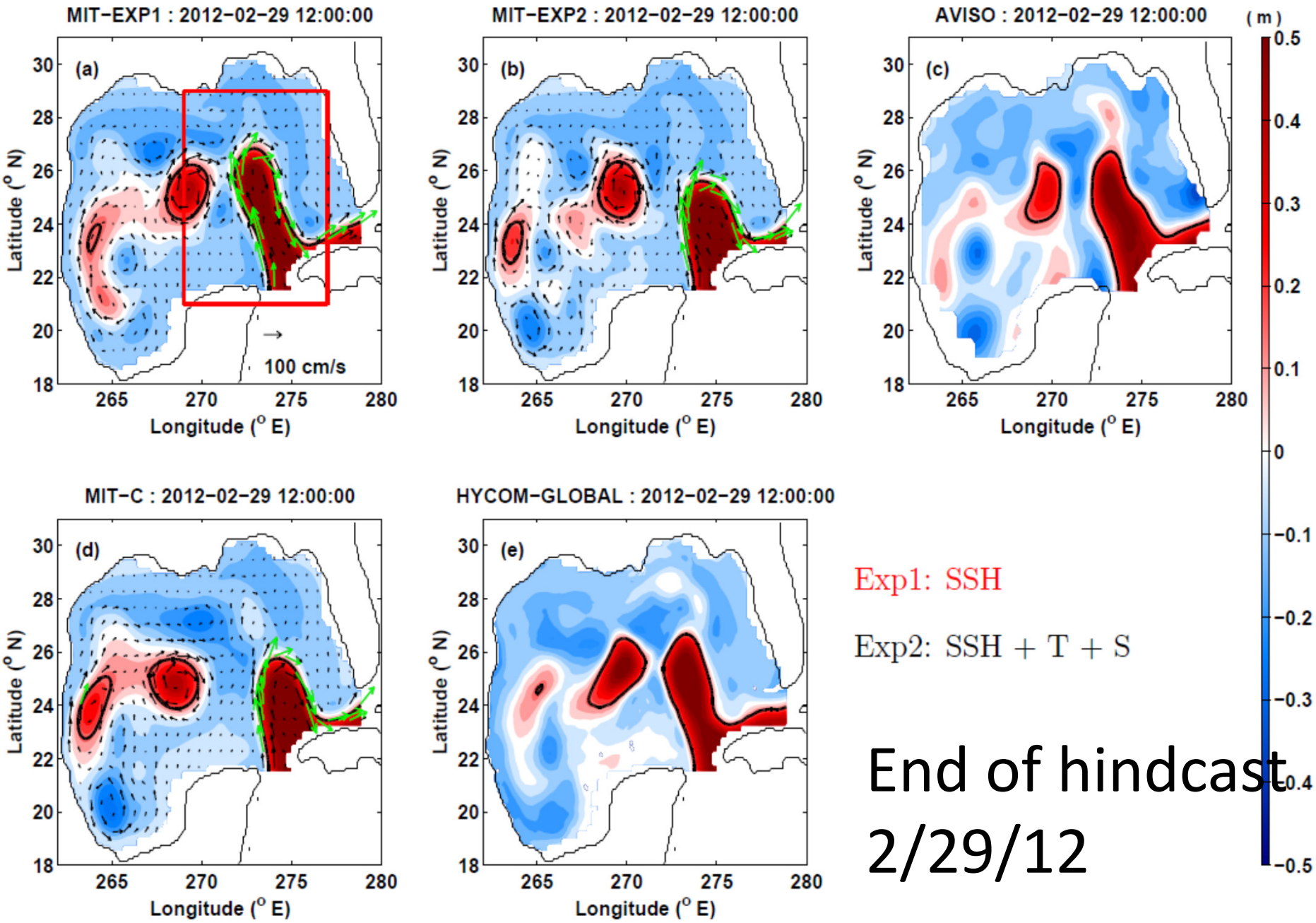
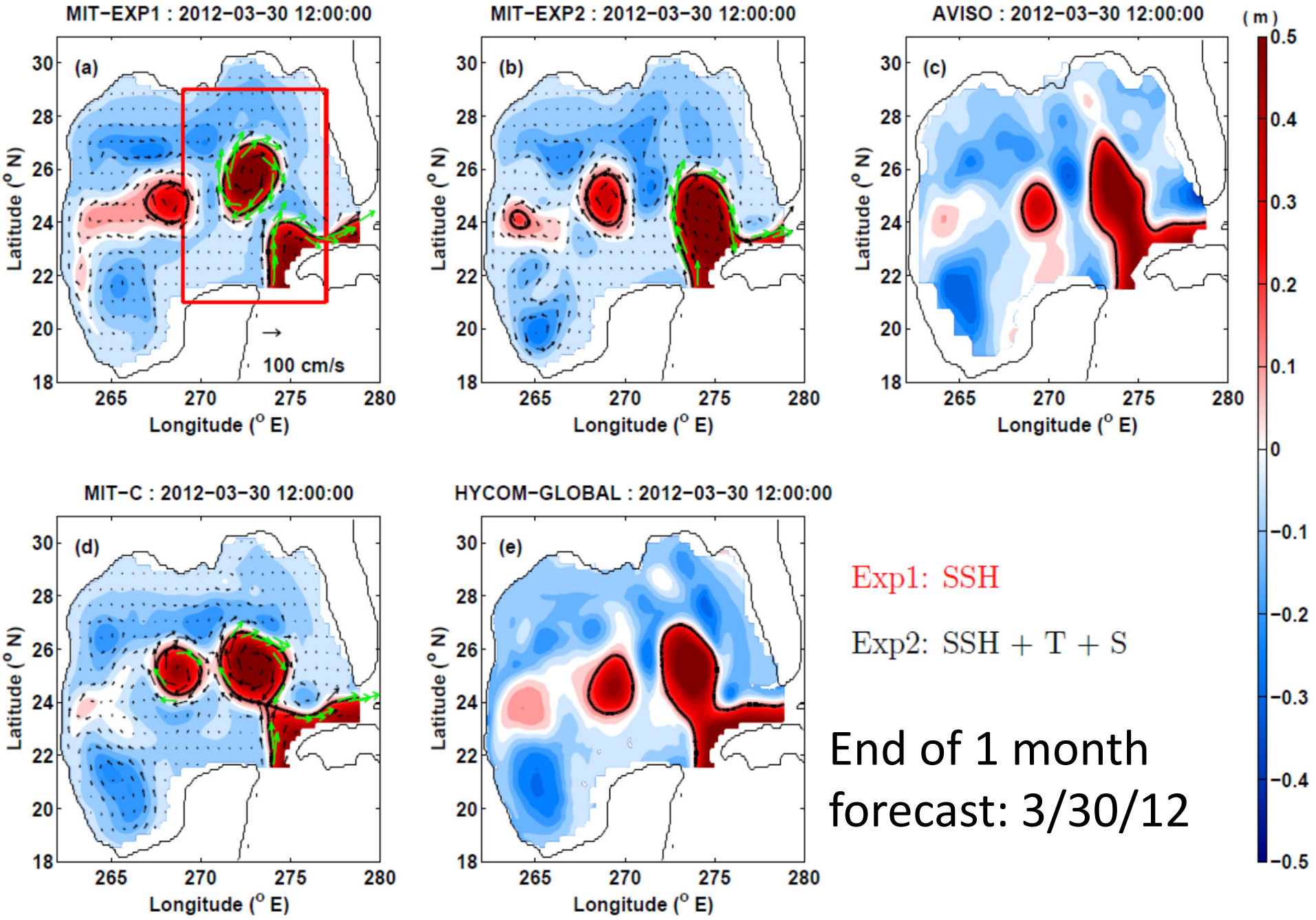
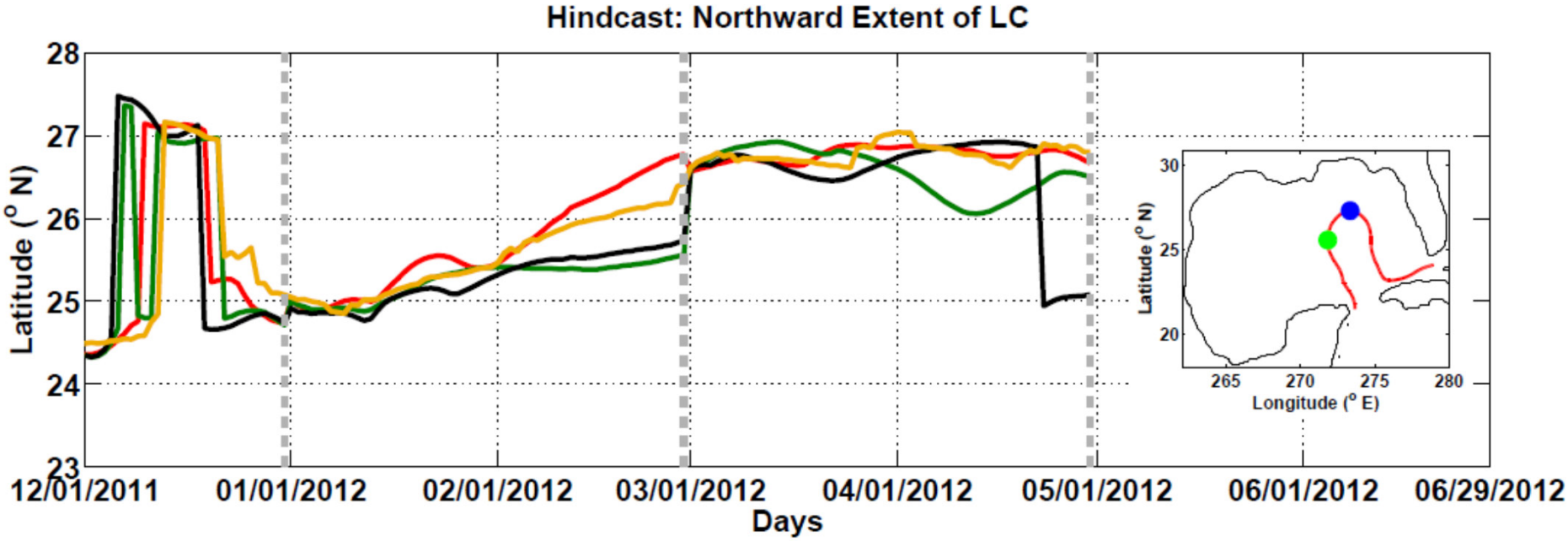
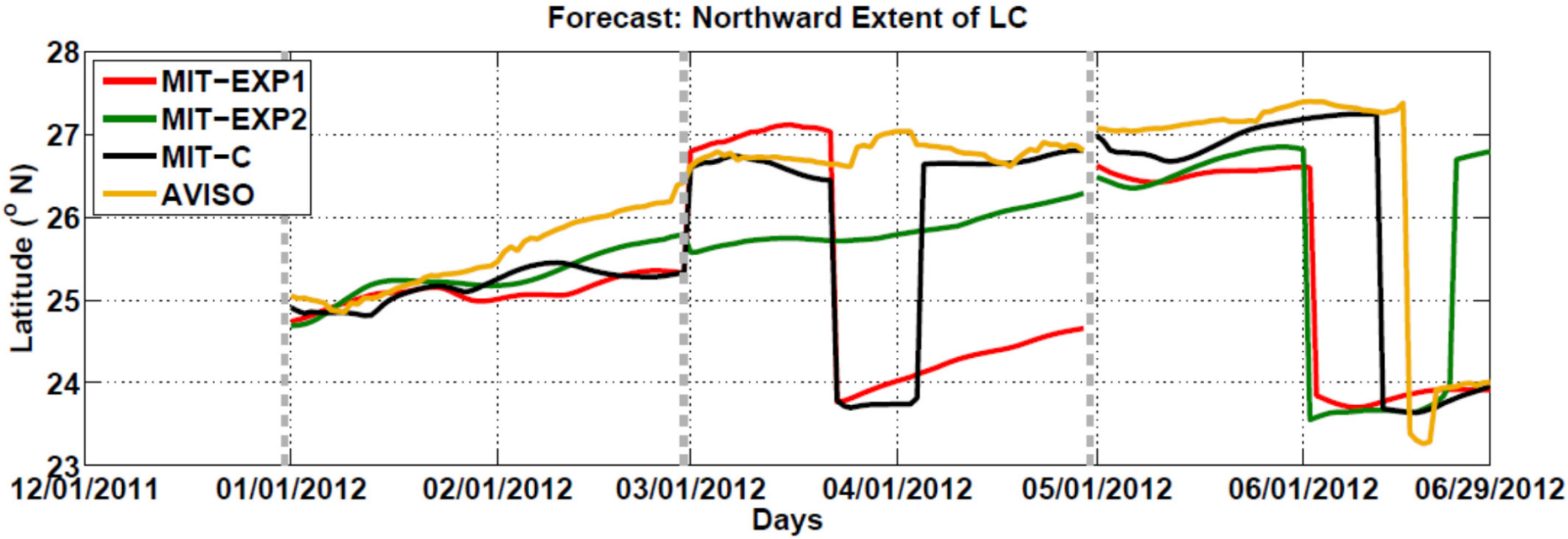
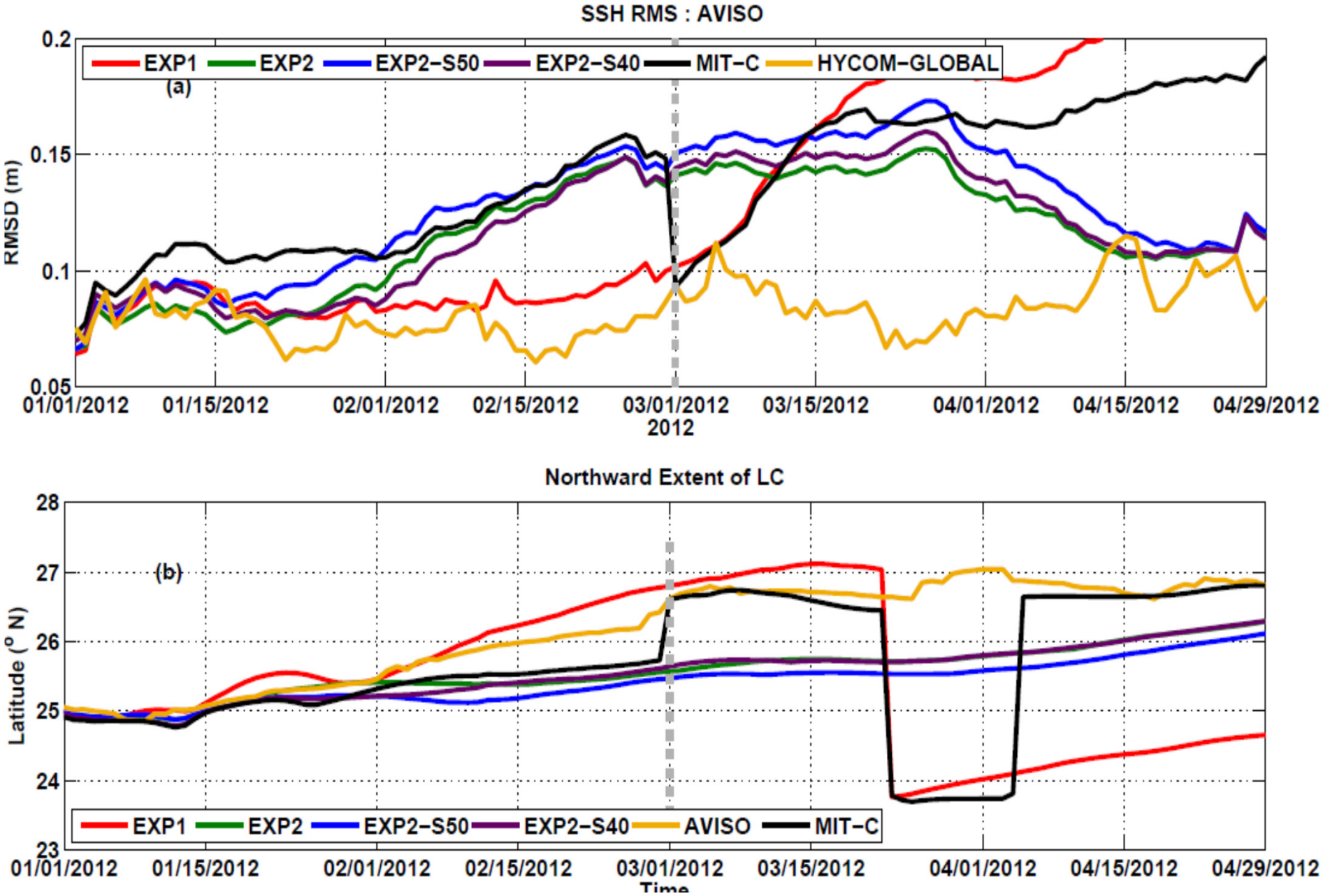

Hindcast RMSD with AVISO
RMSD (m)
0.2
0.15
0.1
0.05
a
12/01/2011
01/01/2012
02/01/2012
03/01/2012
04/01/2012
05/01/2012
06/01/2012
06/29/2012
Days
Fitting Spray T,S
impedes the SSH fit
Need to explore this
MIT–EXP1
MIT–EXP2
MIT–C
HYCOM–GLOBAL
Forecast RMSD with AVISO
RMSD (m)
0.2
0.15
0.1
0.05
b
12/01/2011
01/01/2012
02/01/2012
03/01/2012
04/01/2012
05/01/2012
06/01/2012
06/29/2012
Days


MIT−EXP1 : 2012−02−29 12:00:00
MIT−EXP2 : 2012−02−29 12:00:00
AVISO : 2012−02−29 12:00:00
MIT−C : 2012−02−29 12:00:00
HYCOM−GLOBAL : 2012−02−29 12:00:00
(a)
(b)
(c)
(d)
(e)
100 cm/s
Latitude (° N)
Longitude (° E)
(m)
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
Exp1: SSH
Exp2: SSH + T + S
End of hindcast
2/29/12


MIT−EXP1 : 2012−03−30 12:00:00
MIT−EXP2 : 2012−03−30 12:00:00
AVISO : 2012−03−30 12:00:00
MIT−C : 2012−03−30 12:00:00
HYCOM−GLOBAL : 2012−03−30 12:00:00
(a)
(b)
(c)
(d)
(e)
100 cm/s
Latitude (° N)
Longitude (° E)
(m)
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
−0.4
−0.5
Exp1: SSH
Exp2: SSH + T + S
End of 1 month forecast: 3/30/12


Hindcast: Northward Extent of LC
Latitude (° N)
28
27
26
25
24
23
12/01/2011
01/01/2012
02/01/2012
03/01/2012
04/01/2012
05/01/2012
06/01/2012
06/29/2012
Days
30
25
20
265
270
275
280
Latitude (° N)
Longitude (° E)

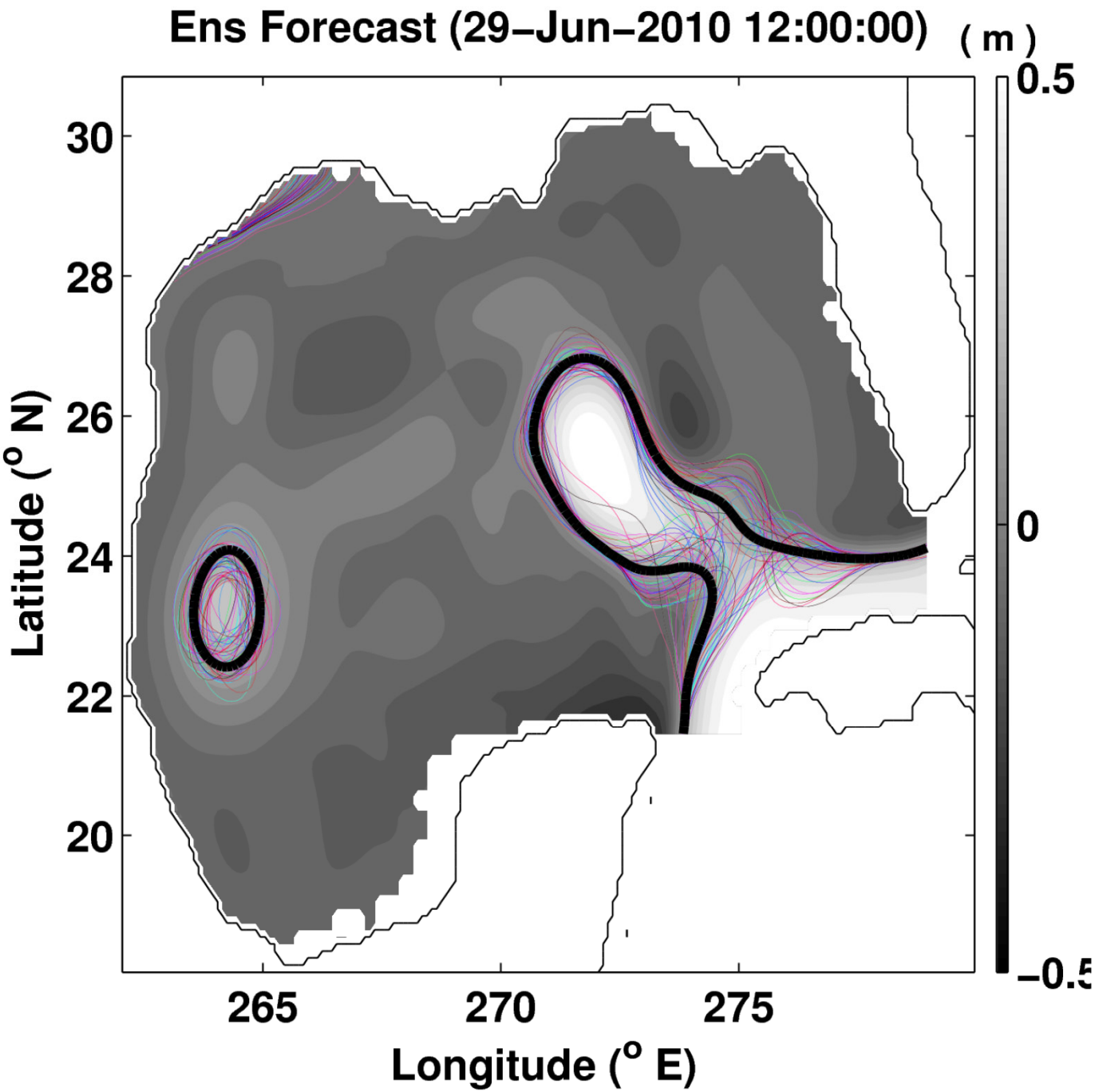

Forecast: Northward Extent of LC
MIT−EXP1
MIT−EXP2
MIT−C
AVISO
Latitude (° N)
28
27
26
25
24
23
12/01/2011
01/01/2012
02/01/2012
03/01/2012
04/01/2012
05/01/2012
06/01/2012
06/29/2012
Days


SSH RMS : AVISO
EXP1
EXP2
EXP2−S50
EXP2−S40
MIT−C
HYCOM−GLOBAL
(a)
RMSD (m)
0.2
0.15
0.1
0.05
01/01/2012
01/15/2012
02/01/2012
02/15/2012
03/01/2012
03/15/2012
04/01/2012
04/15/2012
04/29/2012
2012
Northward Extent of LC
(b)
Latitude (° N)
28
27
26
25
24
23
EXP1
EXP2
EXP2−S50
EXP2−S40
AVISO
MIT−C
01/01/2012
01/15/2012
02/01/2012
02/15/2012
03/01/2012
03/15/2012
04/01/2012
04/15/2012
04/29/2012
Time

Conclusions

- In this and other cases, gliders improve the forecast more than not.
- This is not definitive, since we need more realizations and to understand what is needed better.
- In one case, sampling a CE had more effect than sampling the LC
- Optional slide: illustration of different regimes


THANK YOU for listening!
- Any Questions?


Ens Forecast (29–Jun–2010 12:00:00)
(m)
0.5
0
–0.5
30
28
26
24
22
20
Latitude (° N)
265
270
275
Longitude (° E)