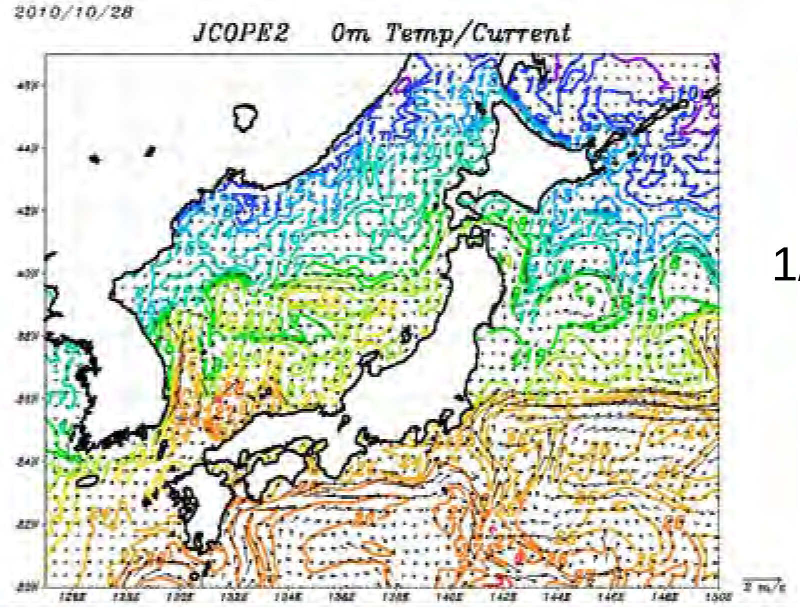
Application of the ensemble Kalman filter to the Kuroshio around the Kii Peninsula

Miyazawa, Miyama, Varlamov, Guo, Waseda (JAMSTEC)

Over past 10 years, we have established the operational ocean forecasting …

The present data assimilation scheme (3DVAR) was designed to detect typical mesoscale variations with O(10day) and O(100km).

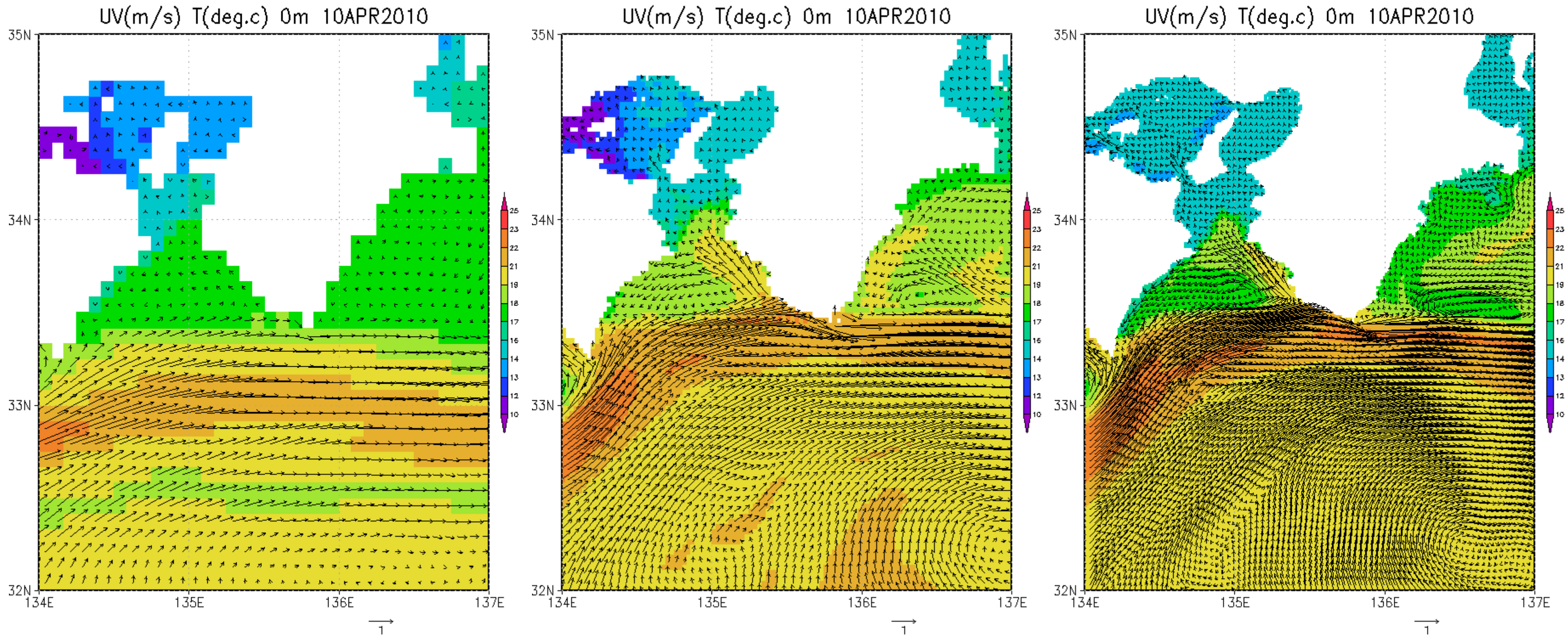
The present formulation of 3DVAR implicitly assumes the quasi geostrophic balance. It can not directly assimilate the ocean current information.



1/12 deg. (10km) grid

From typical mesoscale to smaller scales

10km (1/12deg.) grid　　3km (1/36 deg,) grid　　1km (1/108 deg.) grid



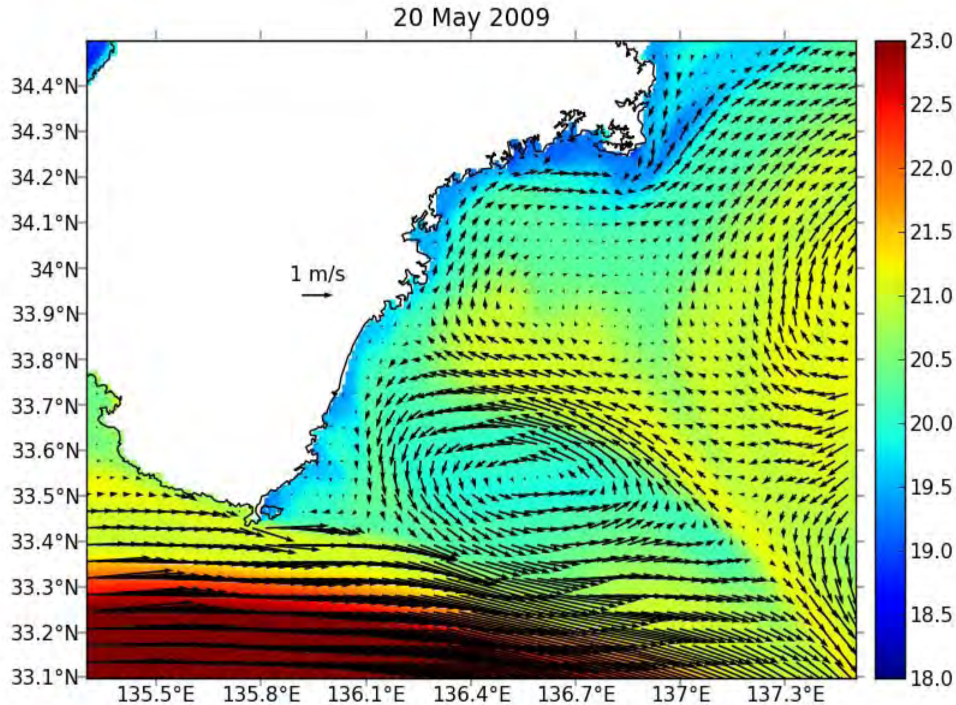
Now we are developing higher horizontal resolution models to study smaller scales phenomena and possible interactions between smaller scales and typical mesoscale phenomena..

The 10km grid is insufficient to resolve the smaller scales phenomena.

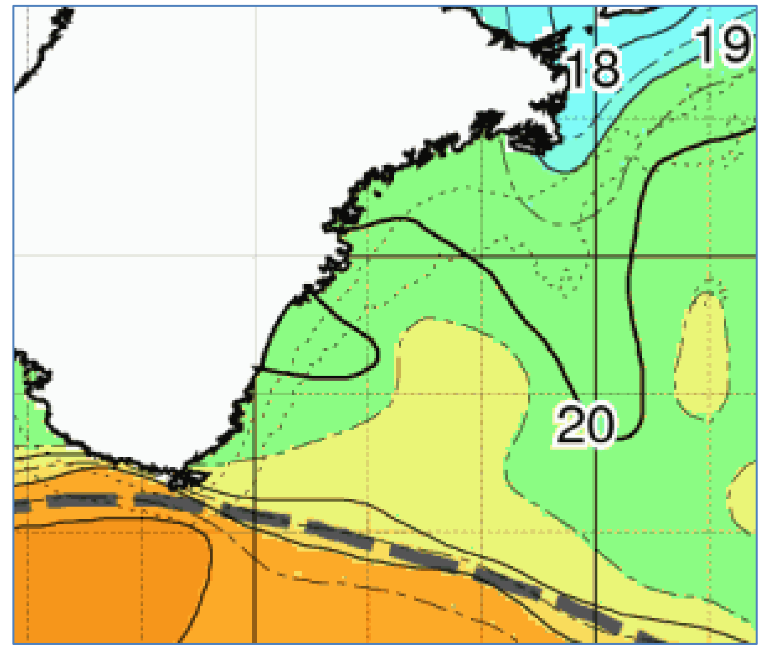
Also, the static assimilation methods may be insufficient to well detect them.

We need more dynamic data assimilation

Warm streamer simulated by 1km grid model



SST observation on the same day



(Created by the local fishery agencies)

Downscaled model can capture smaller scale phenomena. But it is still unclear how the observation constrains the model in the smaller spatial and temporal scales.

To well detect the small scale phenomena by data assimilation using limited numbers of observation data, dynamic estimate of background error covariance is required.

‘Dynamic’ means, for example, flow dependent and time variable estimate of error

Ensemble Kalman Filter (EnKF)

We are now developing an alternative assimilation method different from the present data assimilation method (3DVAR) used in our forecast system.

The Ensemble Kalman is a dynamic assimilation method allowing temporally and spatially variant forecast error covariance matrix, P.
Also, the Kalman Filter allows the direct assimilation of ocean current information

$$x^a = x^f + P^f H^T \left(HP^f H^T + R \right)^{-1} \left(y^o - Hx^f \right)$$

$$P_i^f \equiv (K-1)^{-1} \sum_{i=1}^{K} (x^{f(i)} - \overline{x}^f)(x^{f(i)} - \overline{x}^f)^T$$

The original formulation of the EnKF was proposed by Evensen in 1994; but the necessary ensemble size, K, is O(100), then computational resources are quite large.

Recently, Hunt et al. (2007) proposed more economical method that allows O(10) ensemble size: **the Local Ensemble Transformation Kalman Filter (LETKF).**

A regional model as test bed

We developed a regional model based on the parallelized Princeton Ocean Model.

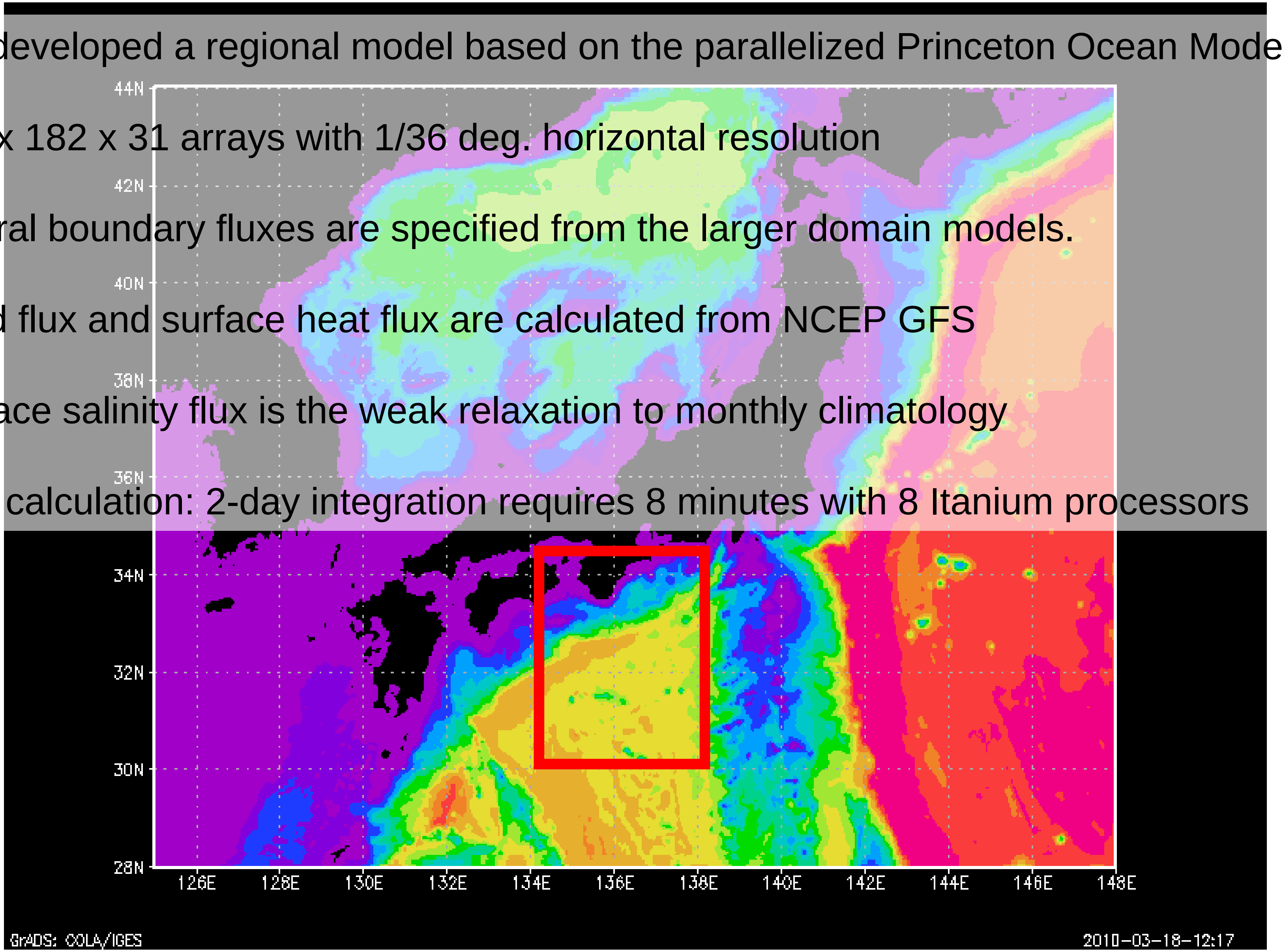
146 x 182 x 31 arrays with 1/36 deg. horizontal resolution

Lateral boundary fluxes are specified from the larger domain models.

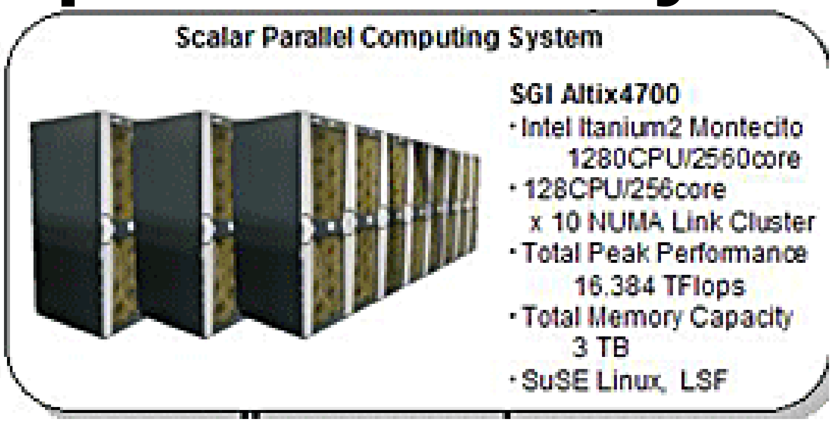
Wind flux and surface heat flux are calculated from NCEP GFS

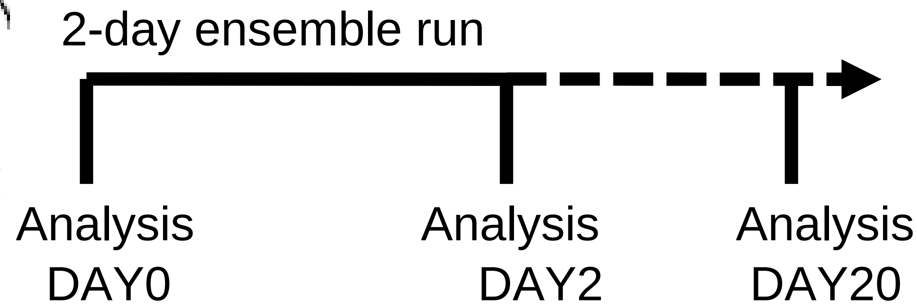
Surface salinity flux is the weak relaxation to monthly climatology

Fast calculation: 2-day integration requires 8 minutes with 8 Itanium processors



Parallel assimilation using parallelized OGCM on scalar parallel processors system





LETKF analysis is performed on 4 CPUS. (not time consuming)

4 ensemble member integrations on 8CPUs are independently performed.

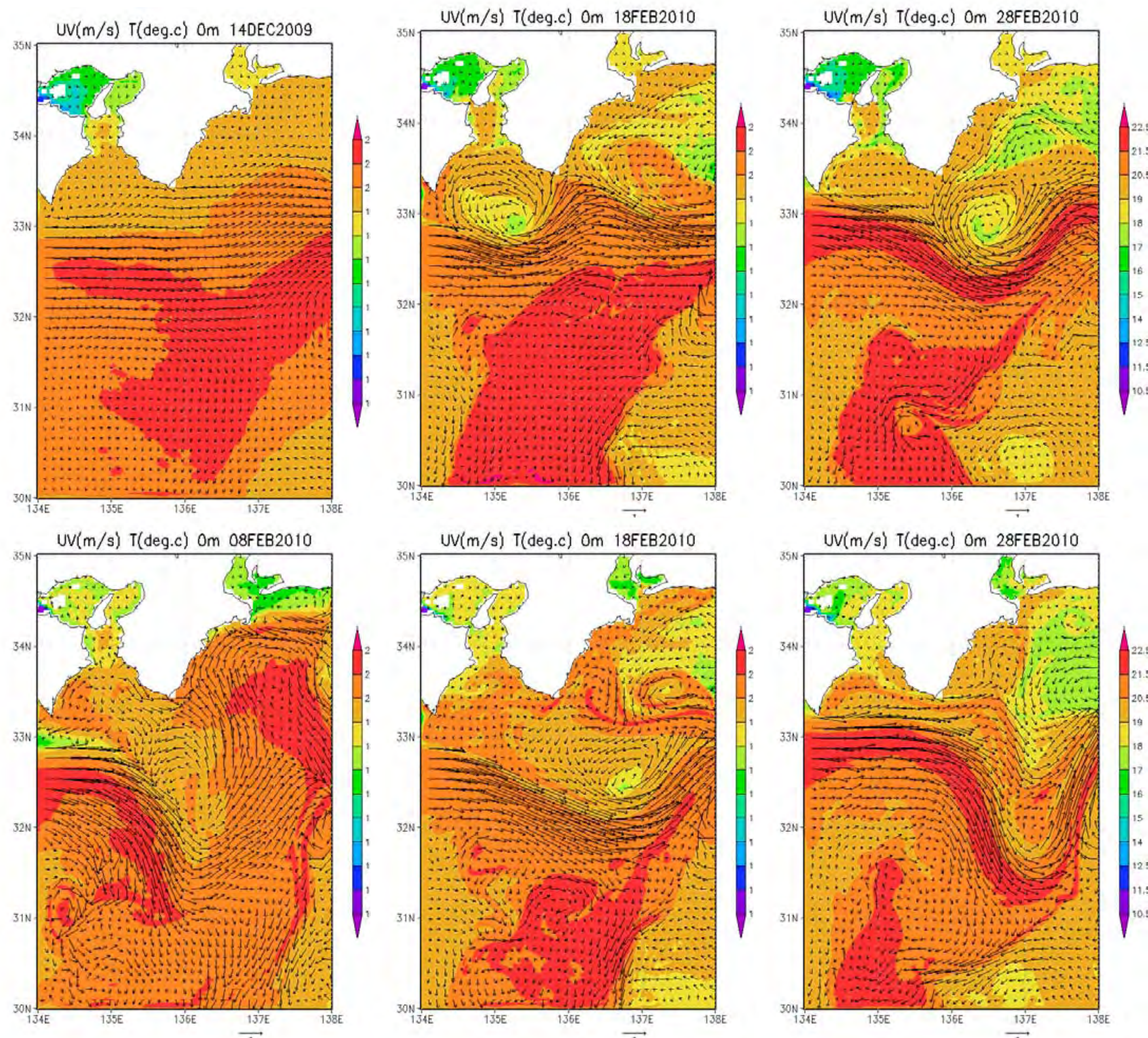
5 sequential runs are required to complete 20 member integrations.

Total 32 CPUs are occupied for the assimilation run

20 days assimilation with 2-day forecasts requires 7 hours elapsed time

Identical twin experiment

Free
Running
Forecast
(FRF)



'True'
Ocean

Only difference between two runs is the initial condition
→
Perfect model assumption

Observation System Simulation Experiments (OSSE)

1. Experiment <RON>

-- Feasibility of real observation network (RON)

-- Estimation of oceanic conditions using SSH, SST, in-situ temperature and salinity observations sampled on real positions.

2. Experiment <RON+ADCP>

-- Effects of ocean current information from the ADCP monitoring by local fishery agencies

-- Real observation network (RON) + Coastal ADCP

3. Experiment <RON+ADCP+DRIFT>

-- Effects of surface ocean current information from ship drift

-- Real observation network (RON) + Coastal ADCP + Ship drift

Real observation network (RON)

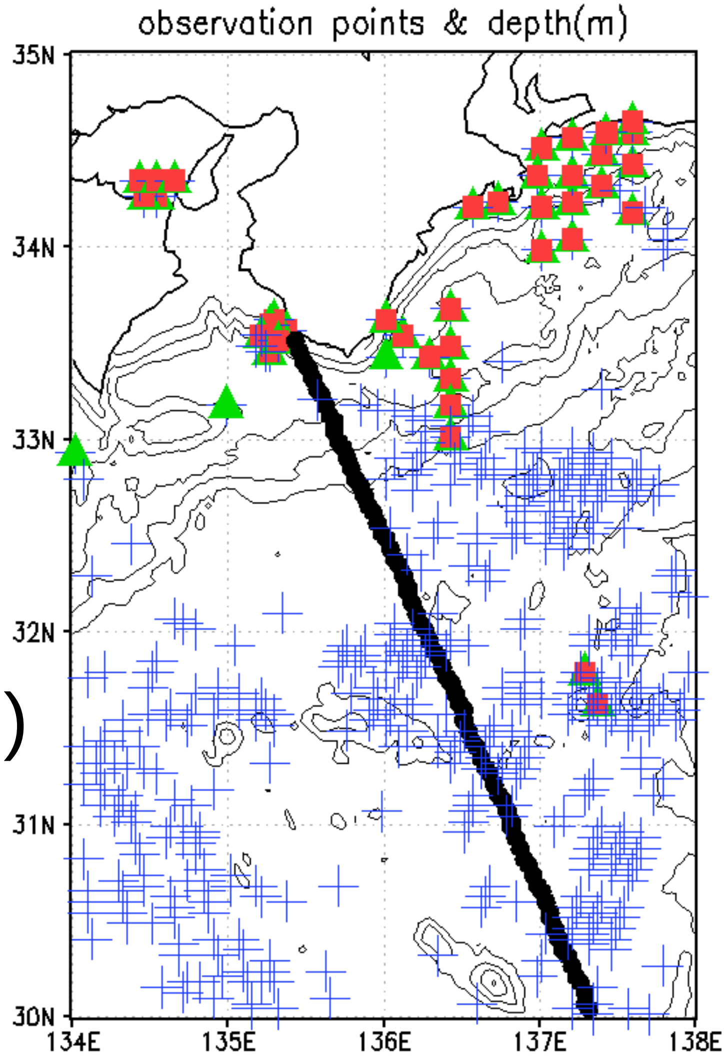
7-8 February 2010

● Satellite SSH (Jason-2)

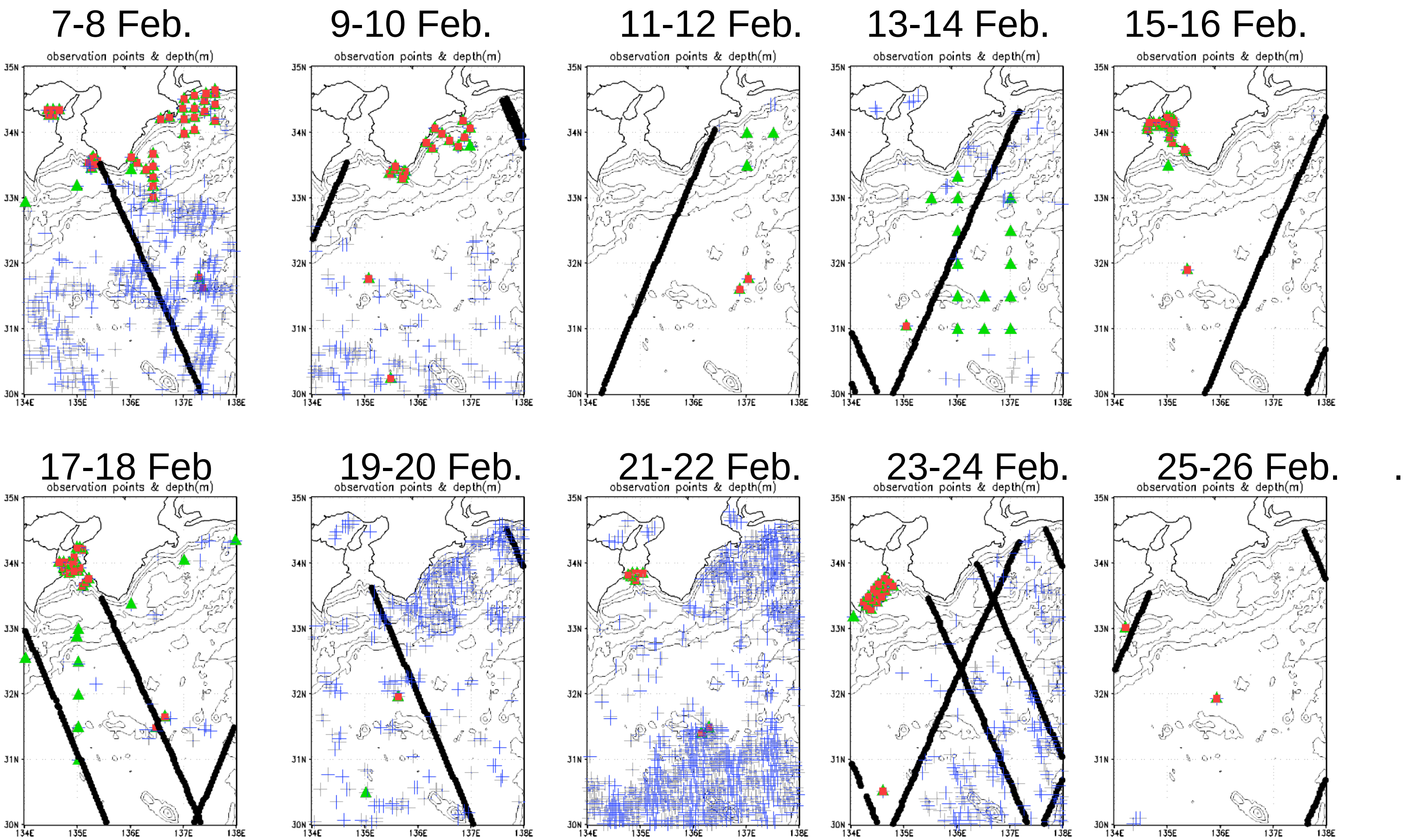
\+ Satellite SST (NOAA)

▲ In-situ temperature (GTSPP)

■ In-situ salinity (GTSPP)



Real observation network

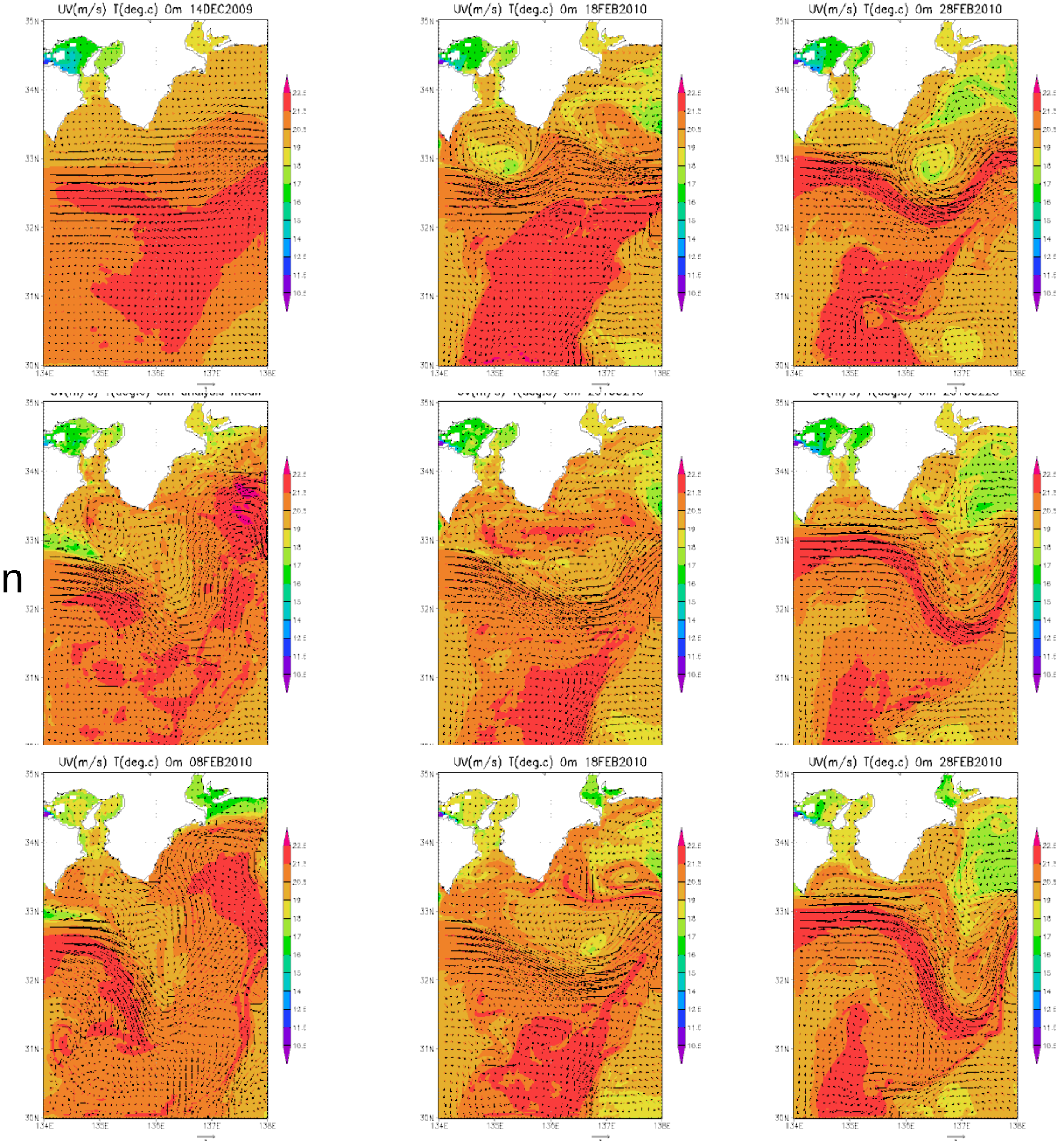


START 10DAYS 20DAYS

FRF

Real Observation Network

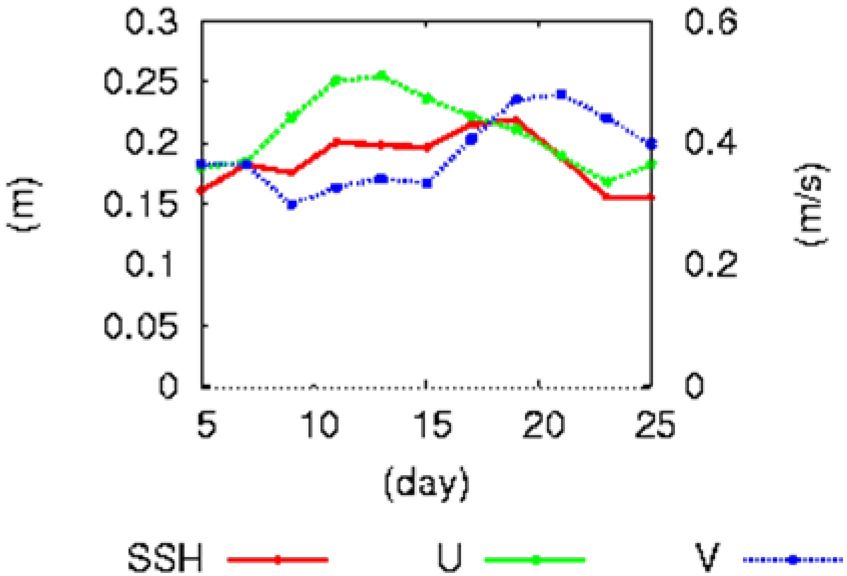
TRUE

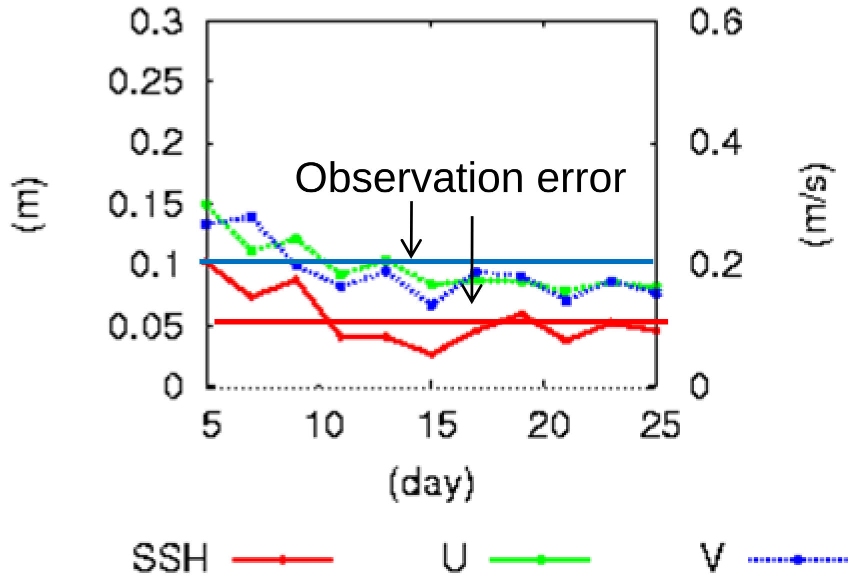


Errors over the model region

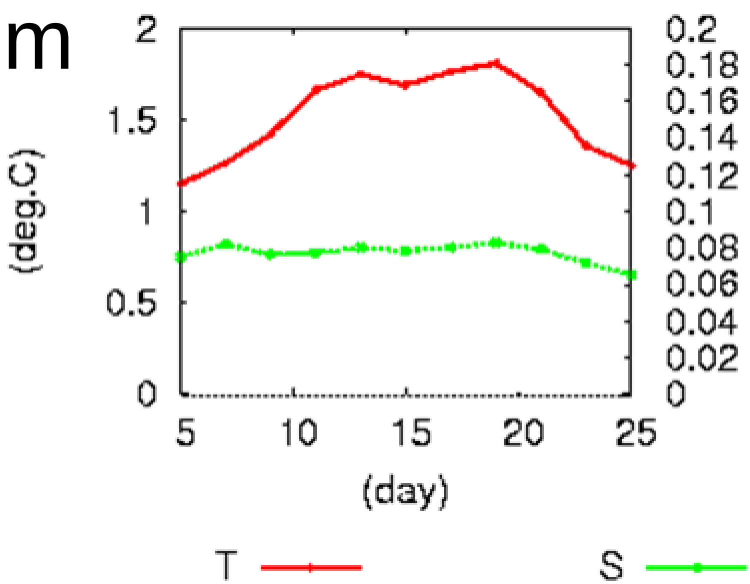
FRF RON

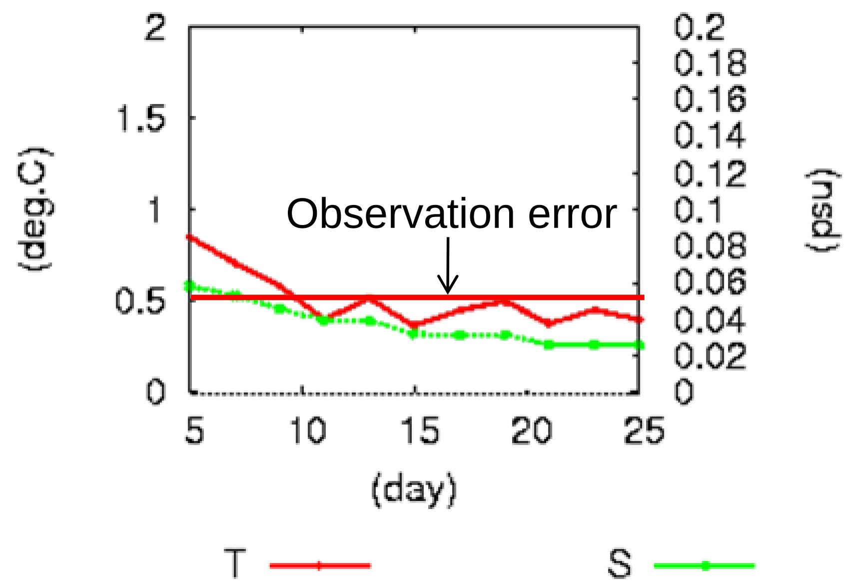
0m





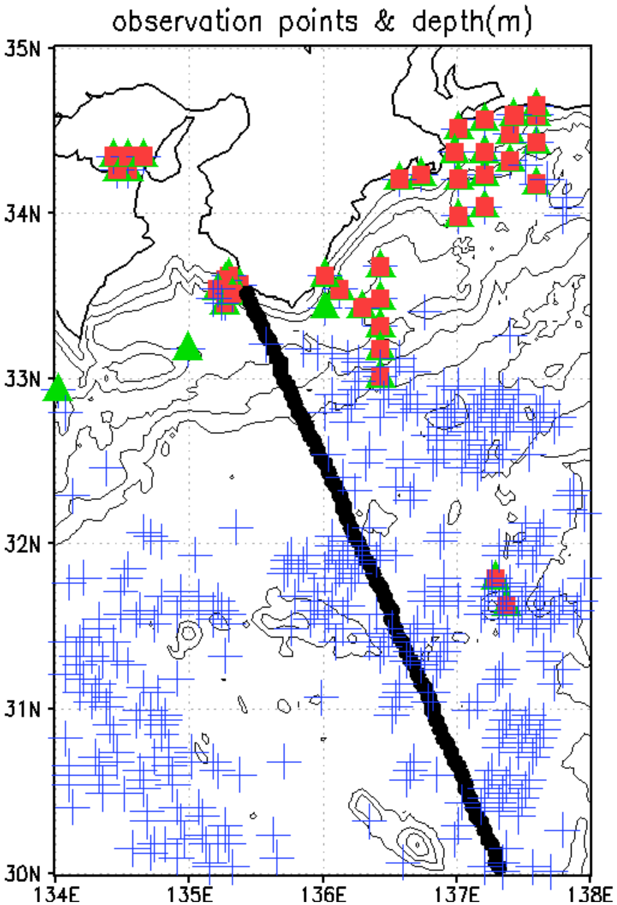
200m



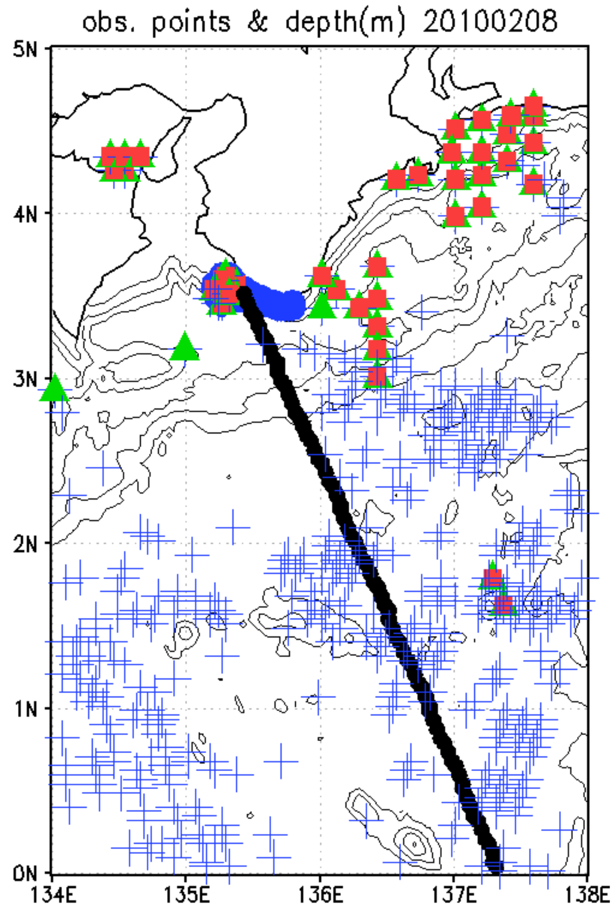


Effects of ocean current observations

RON(SSH+SST+TS)

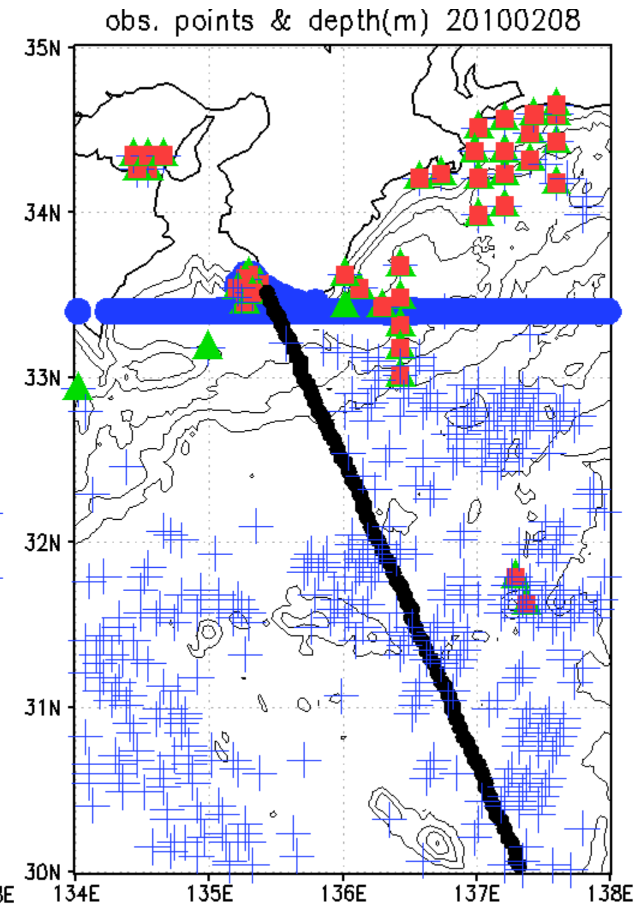


+ Coastal ADCP



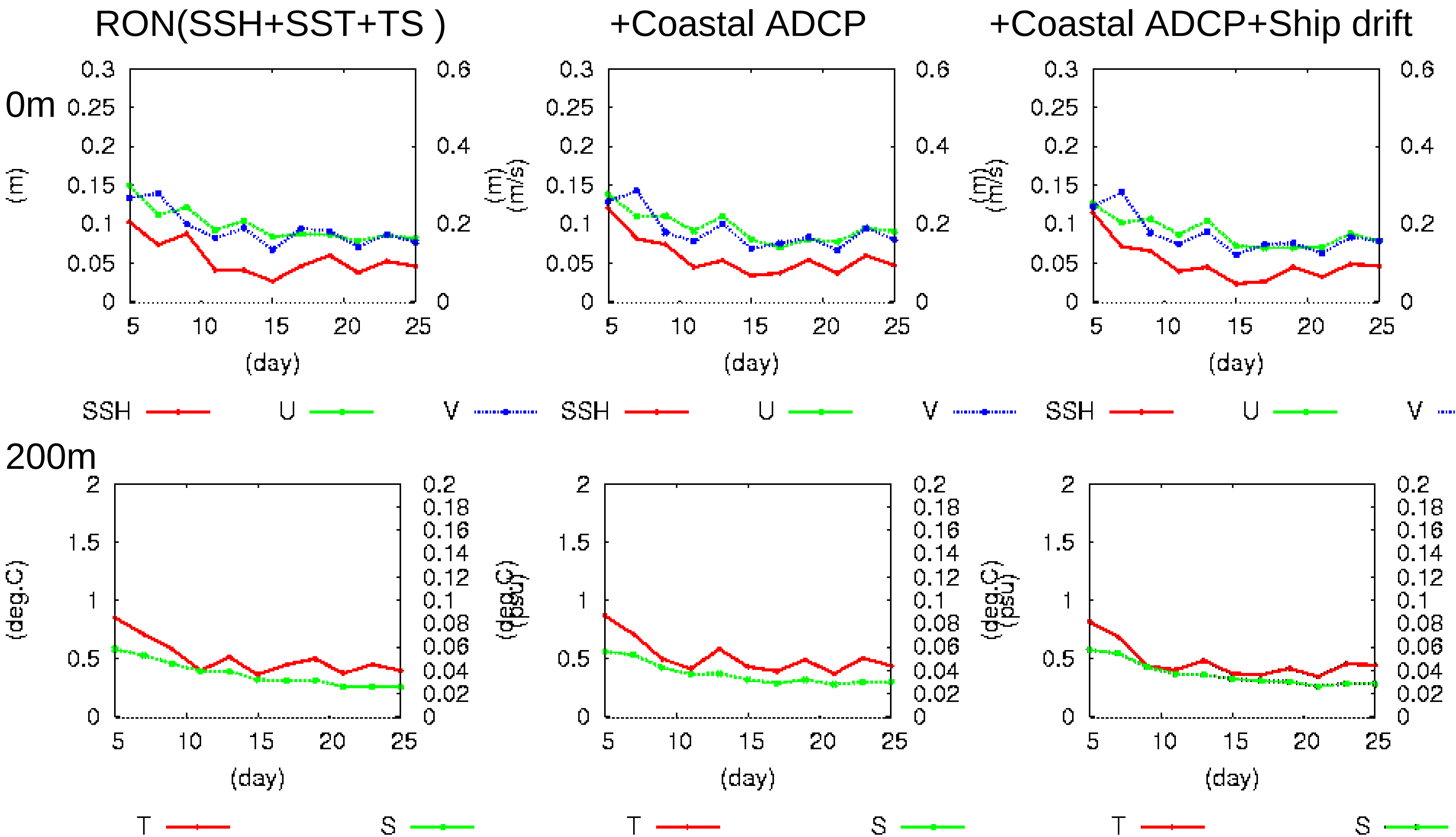
+0-200m depth ADCP
3 times in the 20-day period

+ Coastal ADCP + Ship drift



+ Surface ship drift
every 2 days

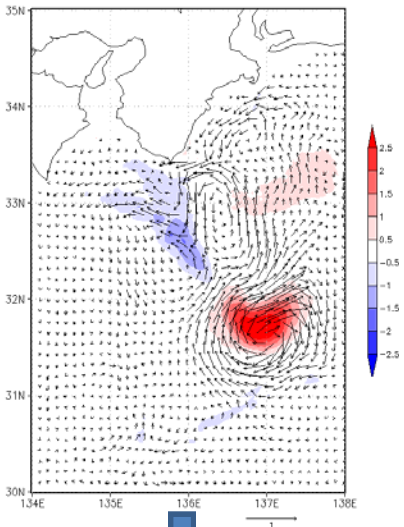
Errors


RON(SSH+SST+TS)
+Coastal ADCP
+Coastal ADCP+Ship drift
0m
200m
(m)
(m/s)
(day)
(deg.C)
(psu)
SSH
U
V
T
S

Flow dependent covariance

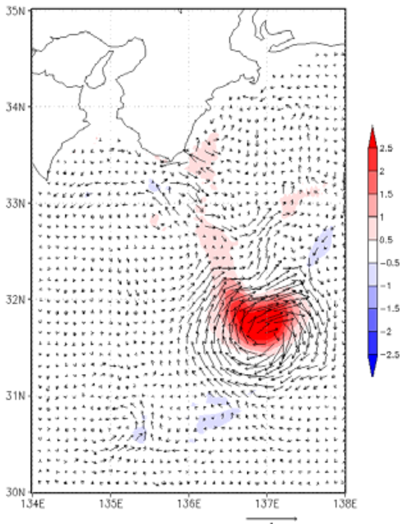
Temperature errors at 200m

2/26



+ ocean current assimilation

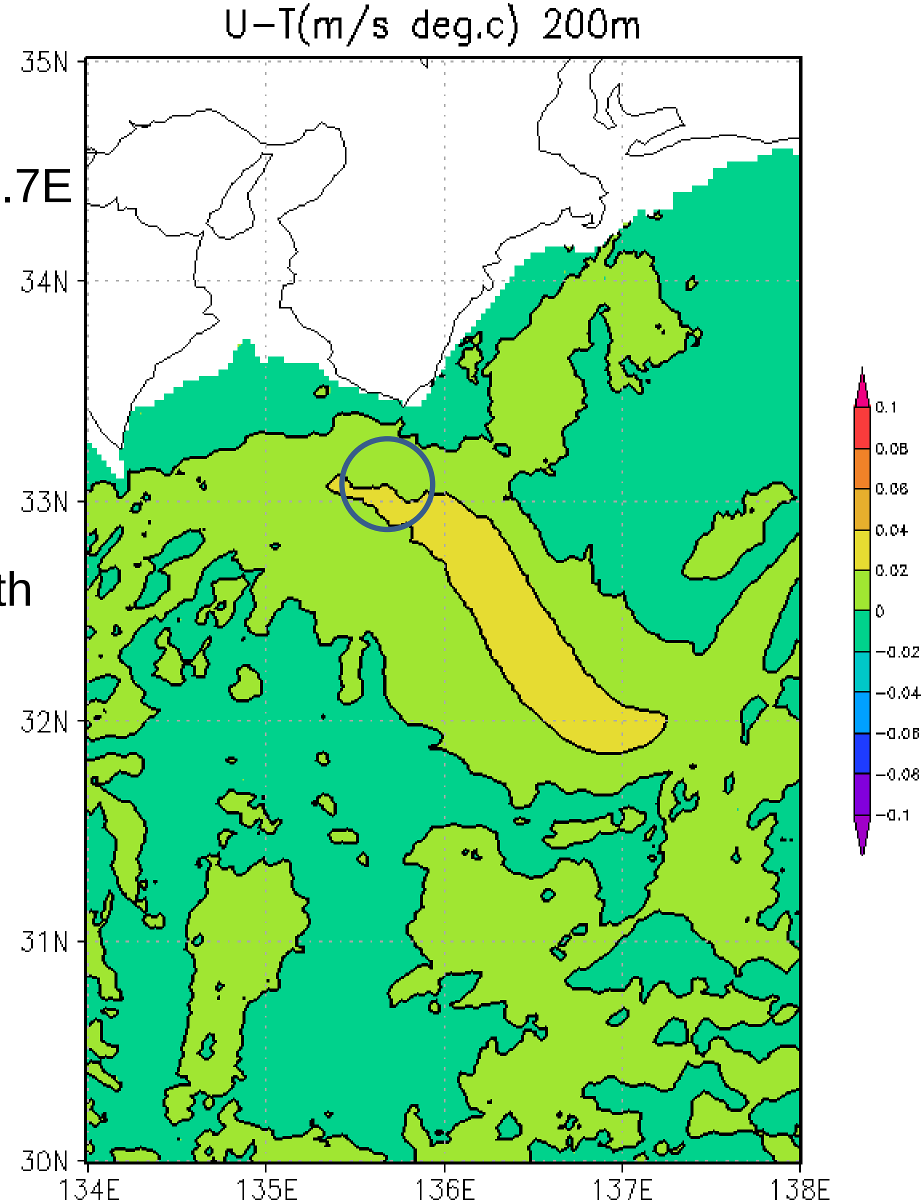
2/26



Surface U Observation at 33.4N,135.7E

and

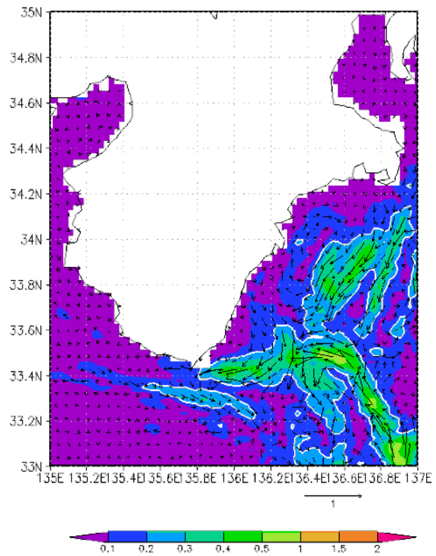
Subsurface temperature on all grids at 200m depth

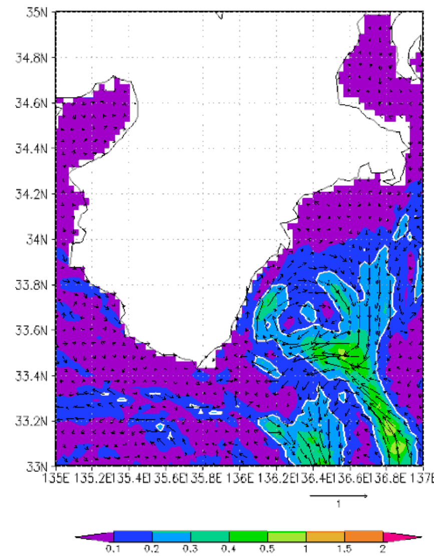


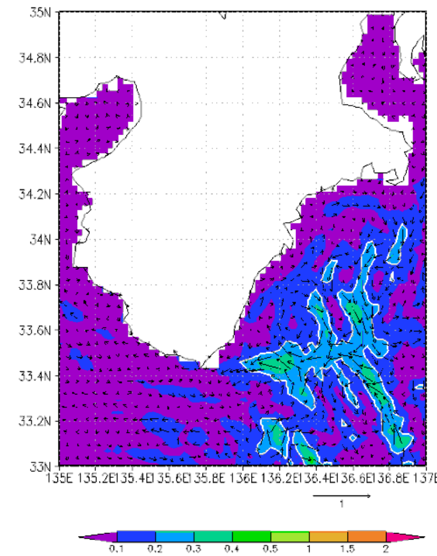
Errors: after 20 days

RON(SSH+SST+TS) | RON +ADCP | RON +ADCP + Ship drift

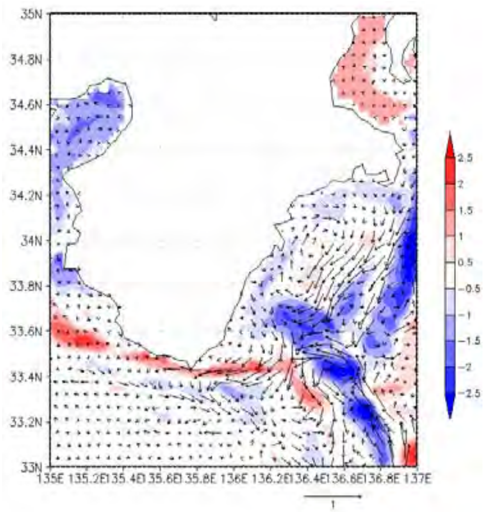
0m
UV

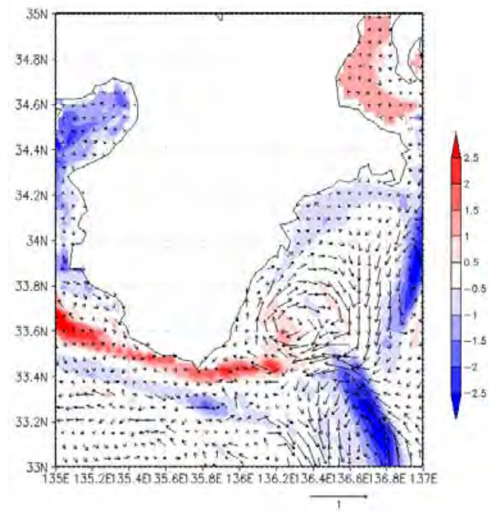


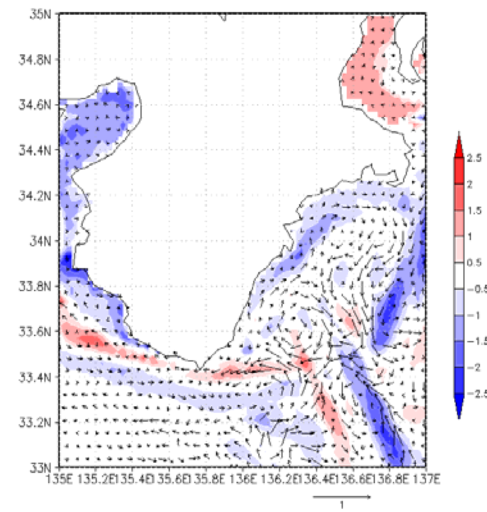




0m
UV
T

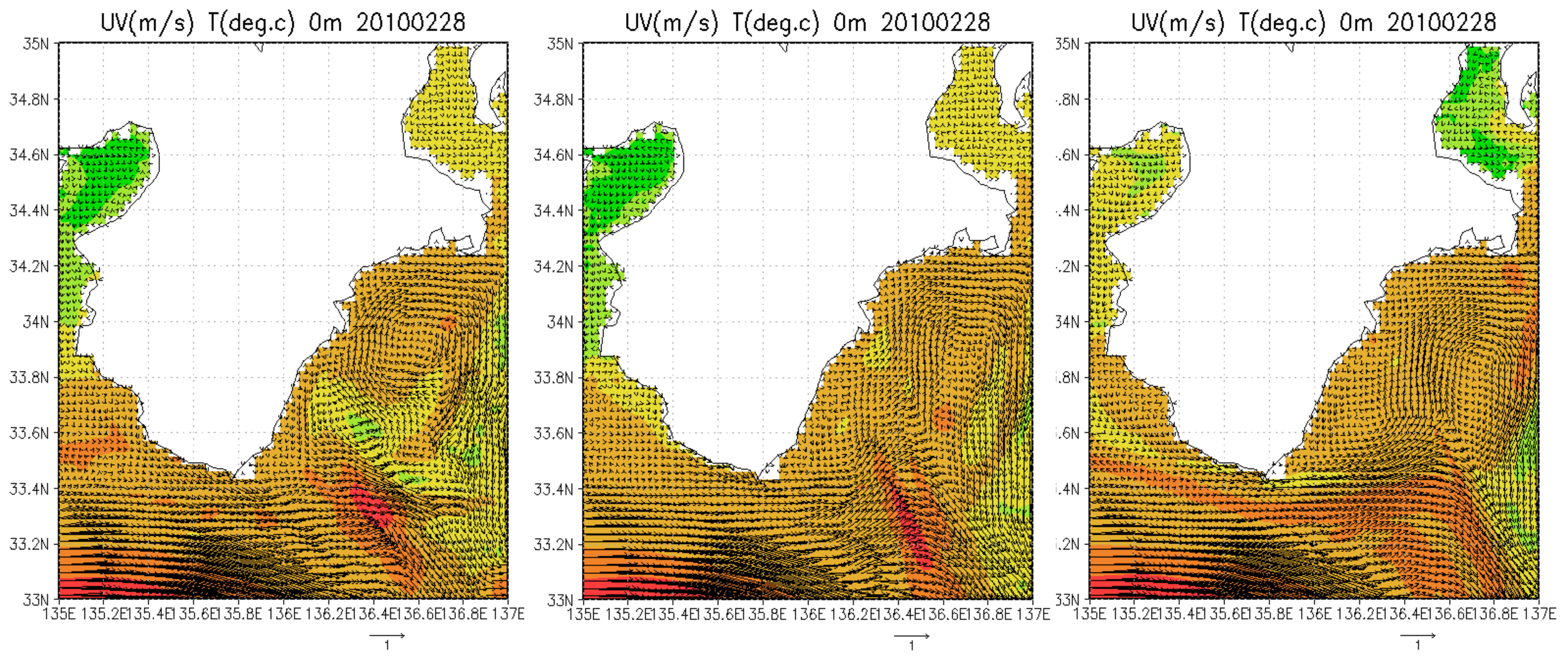






Impacts on small scale phenomena after 20 days

RON(SSH+SST+TS) | RON+ Coastal ADCP +Ship drift | TRUE



Summary

The ensemble Kalman filter system using POM (POM-LETKF) was implemented on the SGI-Altix super computer system.

We have checked the performance of POM-LETKF based on the perfect model assumption.

We have conducted the POM-LETKF runs for the 20-day period, including the 2-day forecasts of 20 ensemble members. .

We have performed the sensitivity experiments to confirm that …

1. Feasibility of real observation network
   → possible; the flow dependent covariance was important to utilize the non-regu
   grids of the real observations.

2. Effects of the ocean current observation
   → positive impacts; the smaller scales phenomena near the coast was well
   detected by the assimilation of coastal ADCP and ship drift.

We will try to exmaine the feasibility of the real observation data for the detection o the real phenomena, and to facilitate collaborations between the real observation network and ocean modelers.