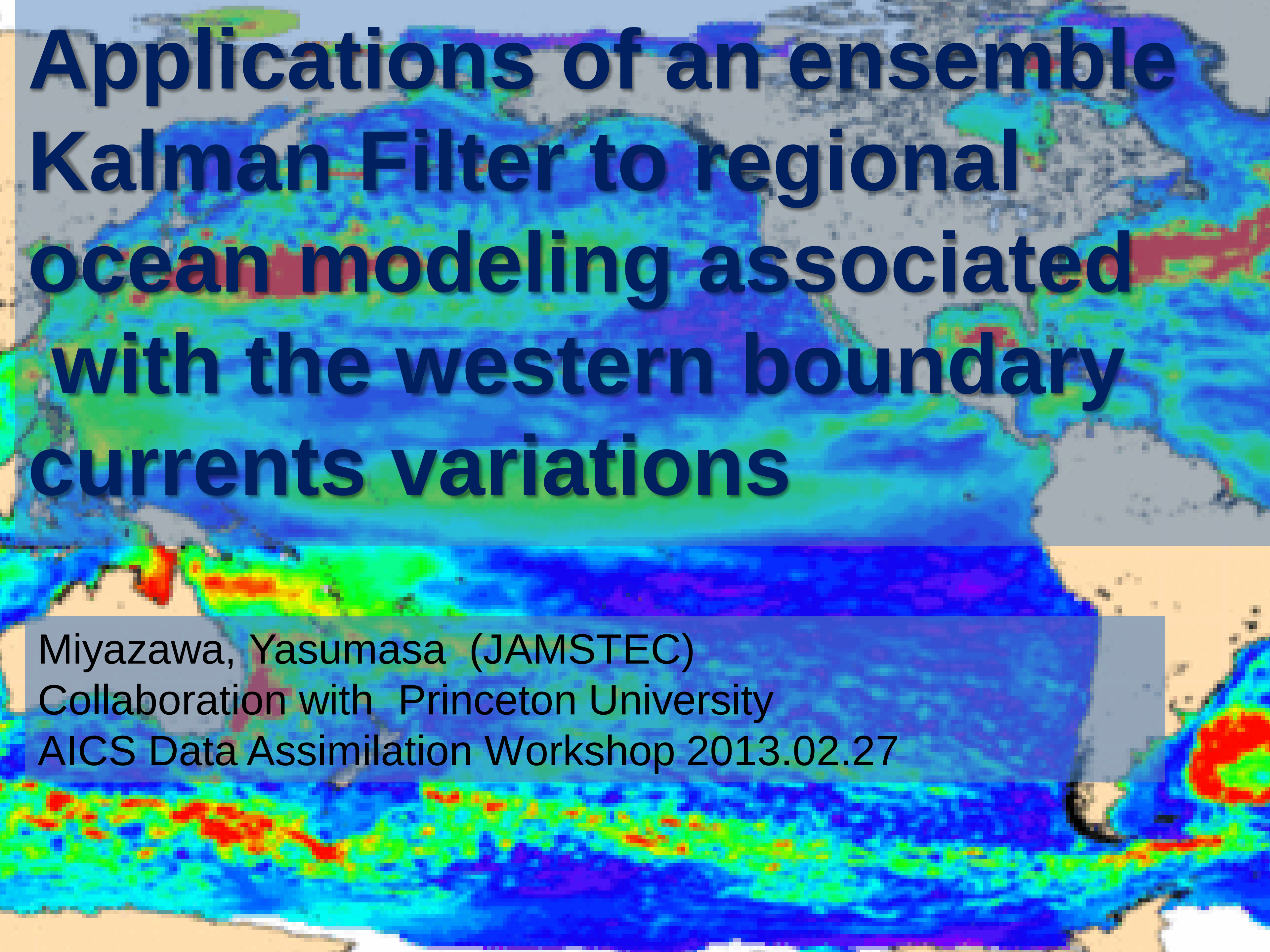
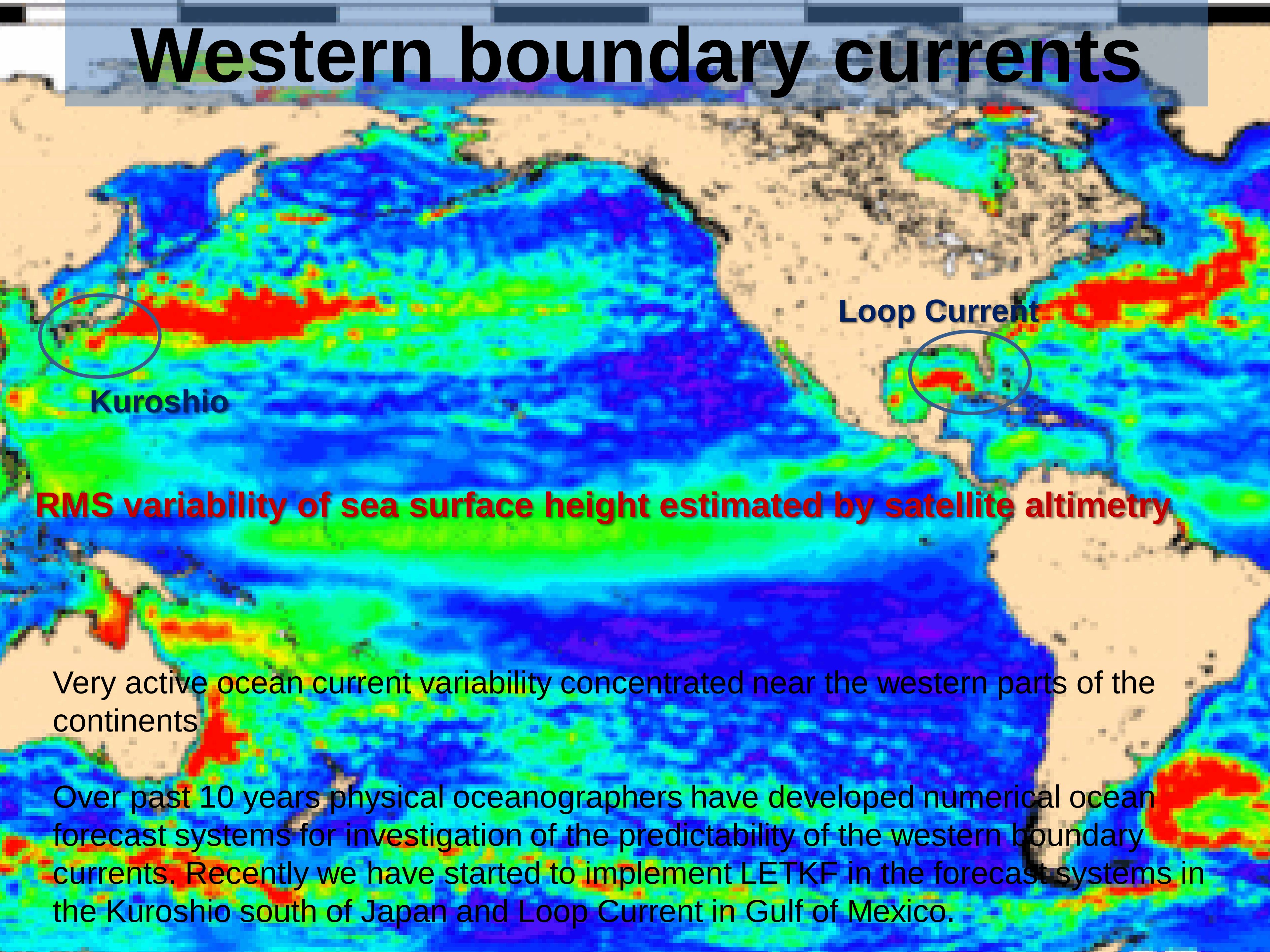


Applications of an ensemble Kalman Filter to regional ocean modeling associated with the western boundary currents variations

Miyazawa, Yasumasa (JAMSTEC)
Collaboration with Princeton University
AICS Data Assimilation Workshop 2013.02.27

Western boundary currents



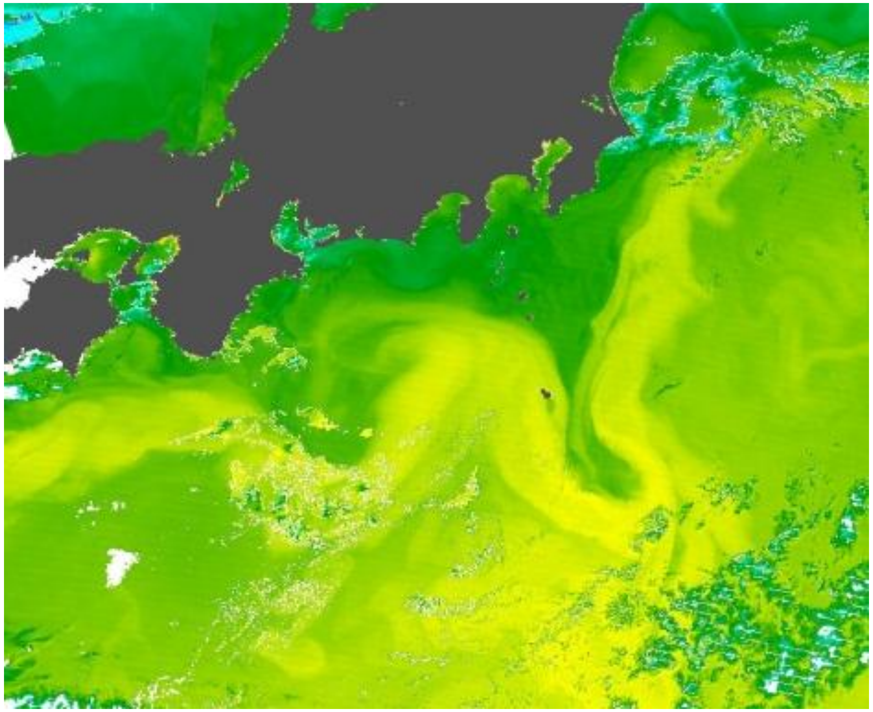
RMS variability of sea surface height estimated by satellite altimetry

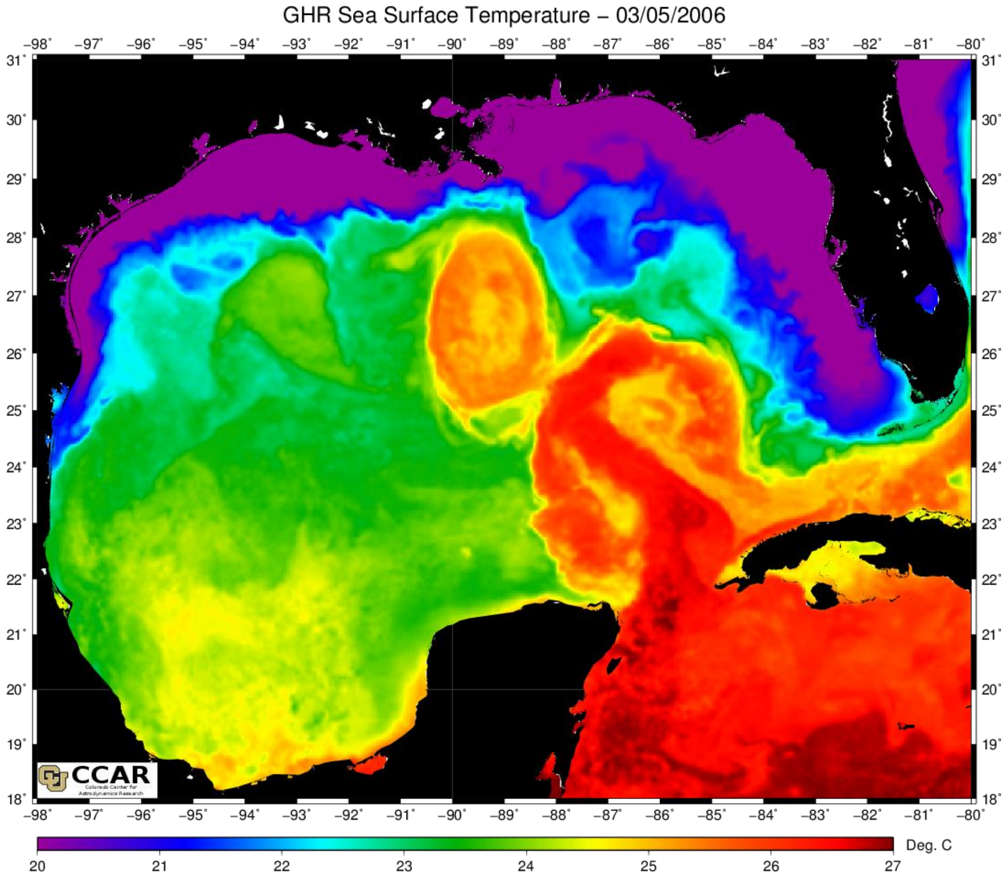
Very active ocean current variability concentrated near the western parts of the continents

Over past 10 years physical oceanographers have developed numerical ocean forecast systems for investigation of the predictability of the western boundary currents. Recently we have started to implement LETKF in the forecast systems in the Kuroshio south of Japan and Loop Current in Gulf of Mexico.

Front variability in Kuroshio and Loop Current

The front variability in the western boundary currents is highly active



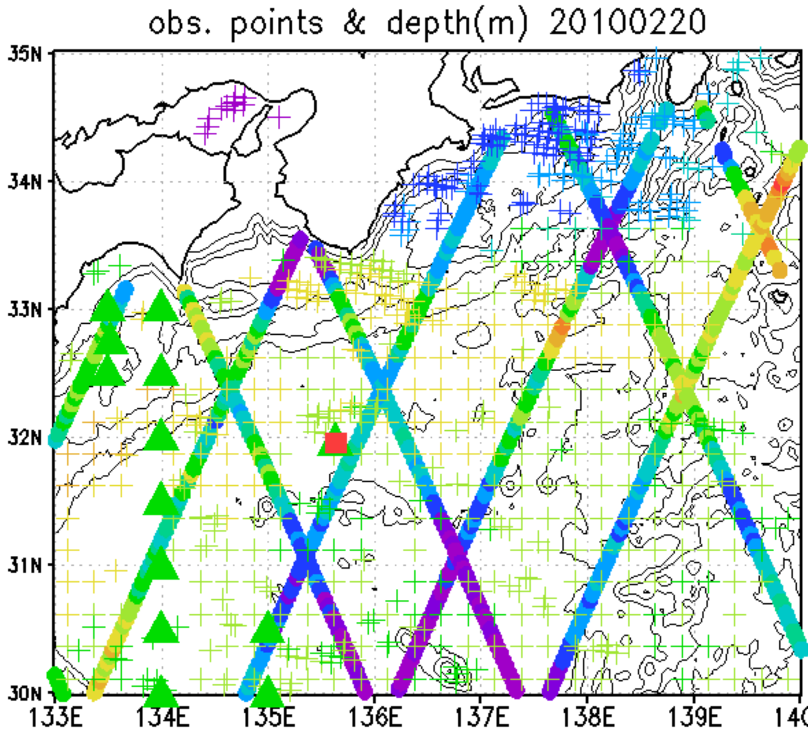

GHR Sea Surface Temperature – 03/05/2006

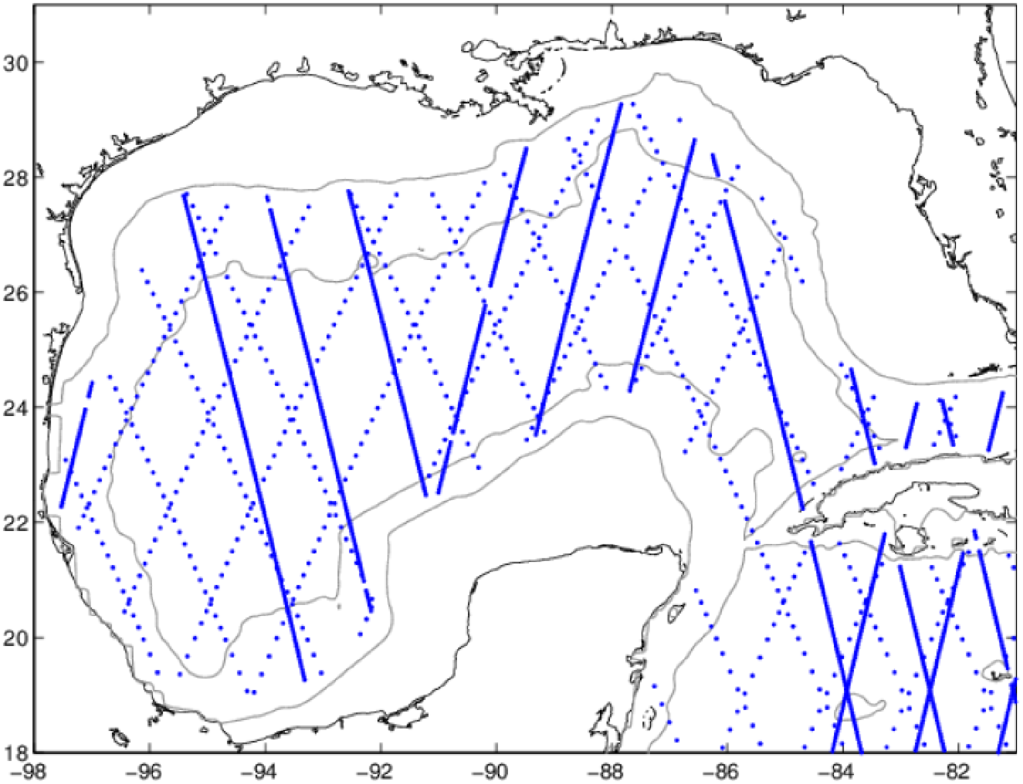
The Kuroshio south of Japan has meandering patterns with broad temporal and spatial scales. The complicated coastal and bottom topography significantly affects the meandering. In particular, the front variability considerably changes its scale from large one in open ocean down to small one inside of channels and bays.

The Loop Current in Gulf of Mexico is also quite energetic. The great meandering inside of the Gulf frequently ejects warm core rings, which further move westward. The behavior of the meandering and its associated eddies is highly variable.

Observations

Most important observation data for ocean forecasting are obtained by satellites.



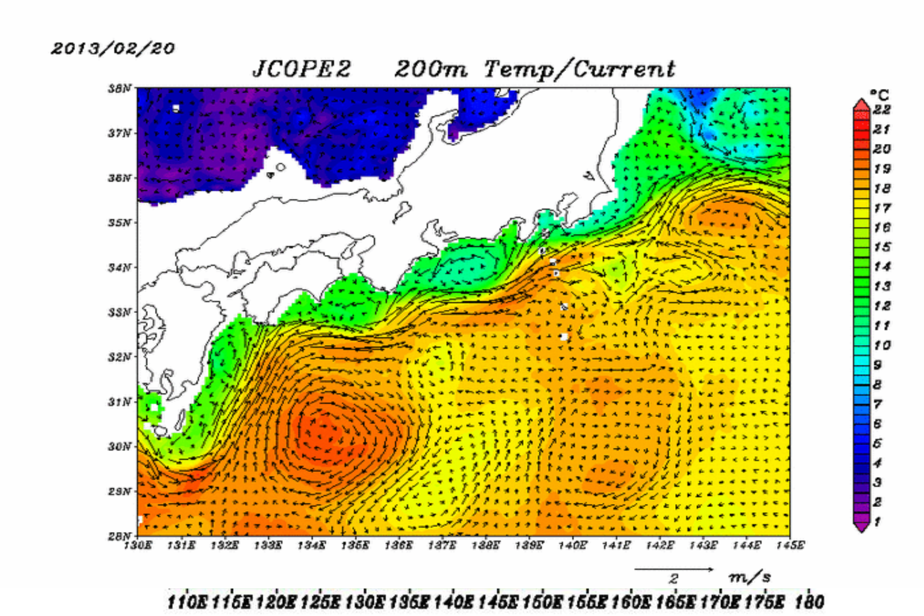


Satellite altimetry (SSH) is measured by micro wave penetrating into clouds and provides useful information about subsurface oceanic condition. Sea surface temperature measured by infrared sensors provides high-resolution data but it is easily contaminated by existence of clouds.

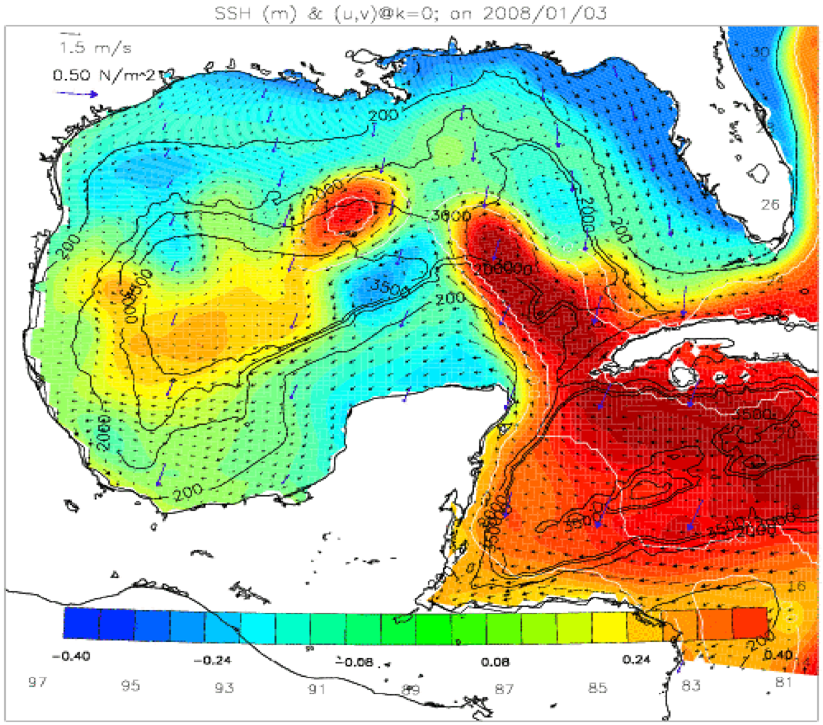
Temporal and spatial frequency of in-situ data is very law and then remote sensing data are most important for usual operations.

Operational ocean forecast systems

Japan Coastal Ocean Predictability Experiment (JCOPE)



Princeton regional Ocean Forecast System (PROFS)



By assimilating the available observation data into numerical ocean general circulation models, we have developed operational ocean forecast systems focusing on the predictability of the western boundary currents variability. Our group of JAMSTEC has developed the forecast system for the Western North Pacific ocean, called JCOPE. Our colleagues in Princeton University have also developed a similar forecast system, called PROFS, covering the Western North Atlantic ocean.

We are weekly updating 2-month lead forecast. Typical spatial scale of the meandering and eddies is O(100km). Temporal scale is O(10days). Predictability limit is maximum 2 months. Data assimilation methods of both systems are based on the static methods such as 3DVAR and optimum interpolation.

From static to dynamic assimilation in ocean forecasting

Present versions of our operational ocean forecast systems are using ‘static’ data assimilation methods（3DVAR/OI) based on an assumption of temporally constant and spatially isotropic forecast error covariance.

Recent developments of parallel computers systems (PC Clusters) and efficient EnKF algorithms (LETKF) motivated us to test EnKF for the predictability studies on the western boundary currents.

EnKF allows to represent spatiotemporally varying forecast error covariance that is crucial for skill improvements in the representation of highly variable western boundary currents.

We have actually implemented the LETKF code (Miyoshi et al. 2010) in both the forecast systems to investigate the impacts of EnKF on the reproducibility and predictability of the Kuroshio and Loop Current.

LETKF analysis for Kuroshio

Ocean General Circulation Model with 1/36 deg. grid driven by NCEP GFS base surface forcing
(Parallelized Princeton Ocean Model; Jordi and Wang, 2012)

20 numbers of ensemble forecasts

Each 2-day lead forecasts are updated with 2-day interval to provide the forecast error covariance.

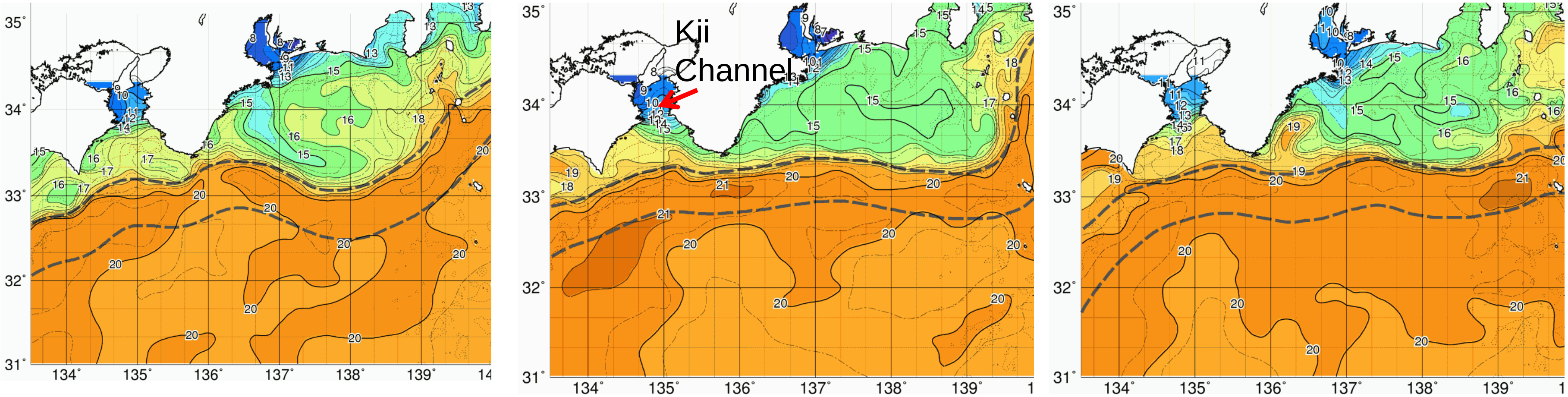
Test Period: 8 – 20 February 2010

Assimilation data: Satellite Sea Surface Height (SSH), Satellite Sea Surface Temperature (SST), In-situ temperature and salinity profiles

Examine the skill of the analysis products

Assimilation effects using the LETKF system developed for investigation of the Kuroshio variation south of Japan

Synthetic observation SST maps provided by the local fishery agencies

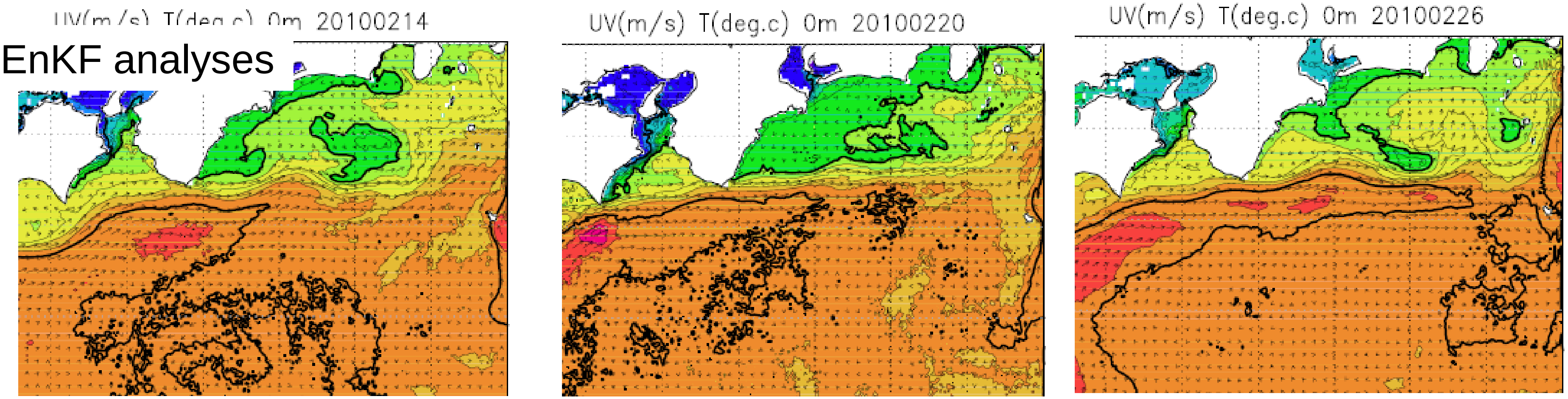


14 Feb. 2010

20 Feb. 2010

26 Feb. 2010

EnKF analyses

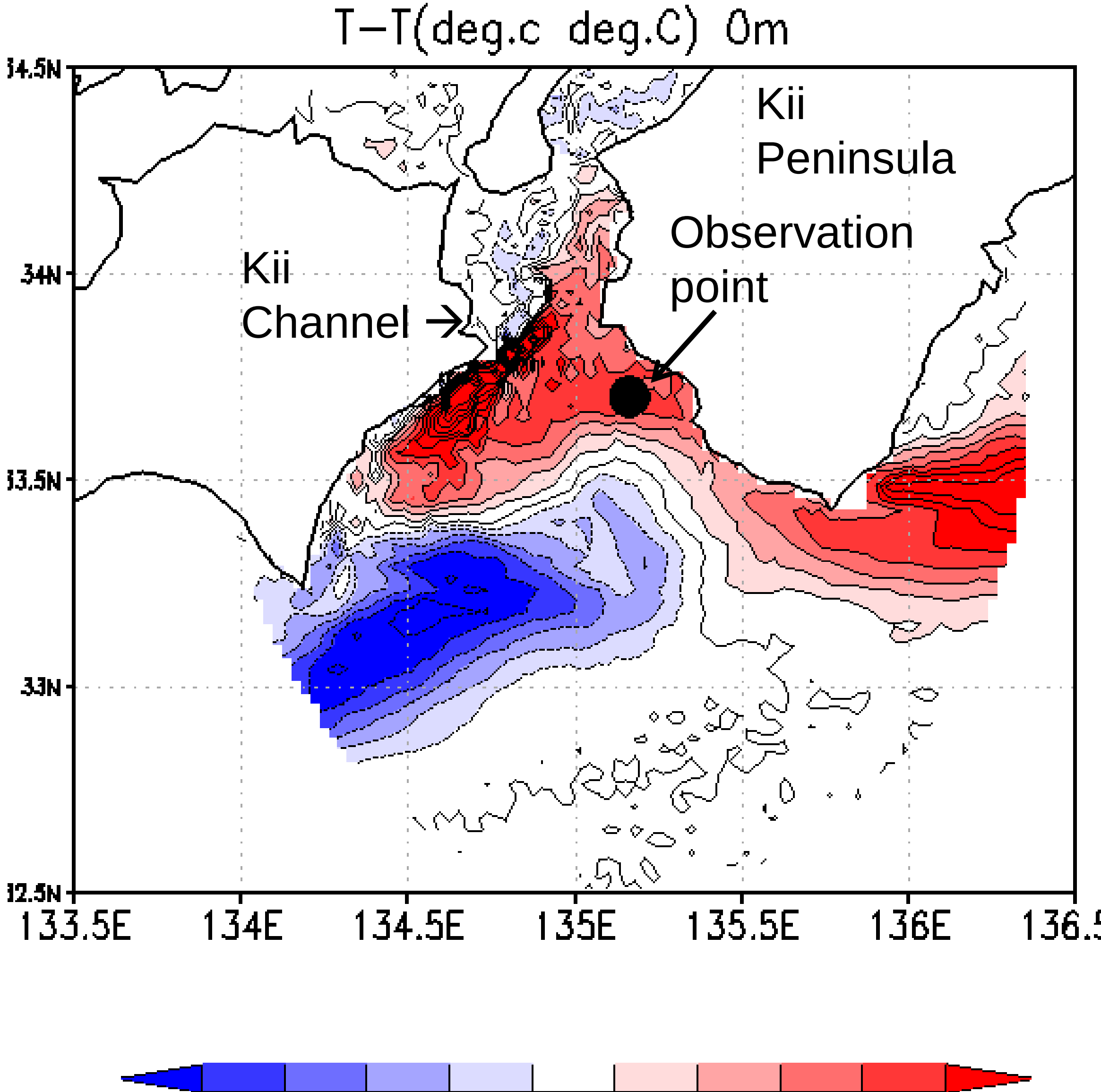

UV(m/s) T(deg.c) 0m 20100214

UV(m/s) T(deg.c) 0m 20100220

UV(m/s) T(deg.c) 0m 20100226

The small meander of the Kuroshio moved eastward during the period, and the variation of the Kii Channel Front was generally reproduced.

‘Flow-dependent’ forecast error covariance on 18 February 2010



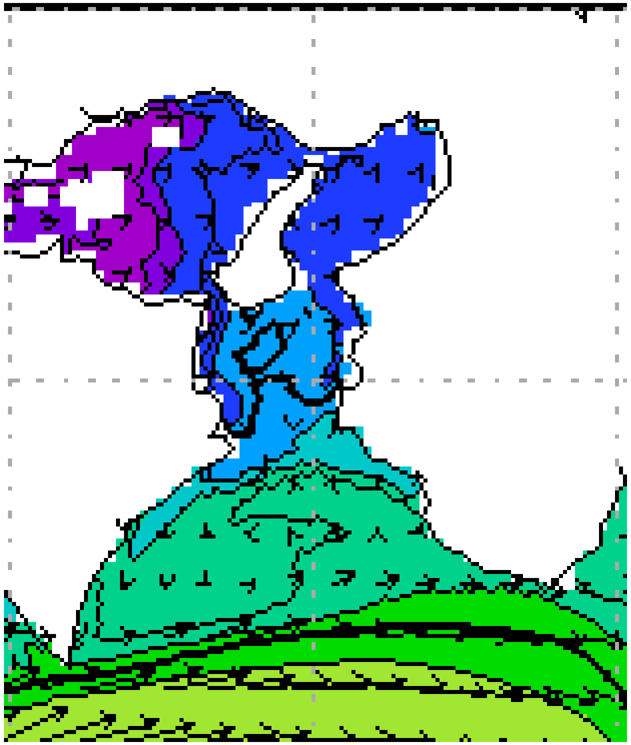
To confirm the effects of error covariance represented by EnKF, we visualized the forecast error covariance between the surface temperature observed near the western coast of the Kii Peninsula and surface temperature forecast around the observation point.

The positive region inside of the Kii Channel indicates warming of the warmer side of the Kii Channel Front. The effect of the temperature data assimilation on this point completely disappeared within the colder part of the Kii Channel Front.

Comparison between 3DVAR and LETKF

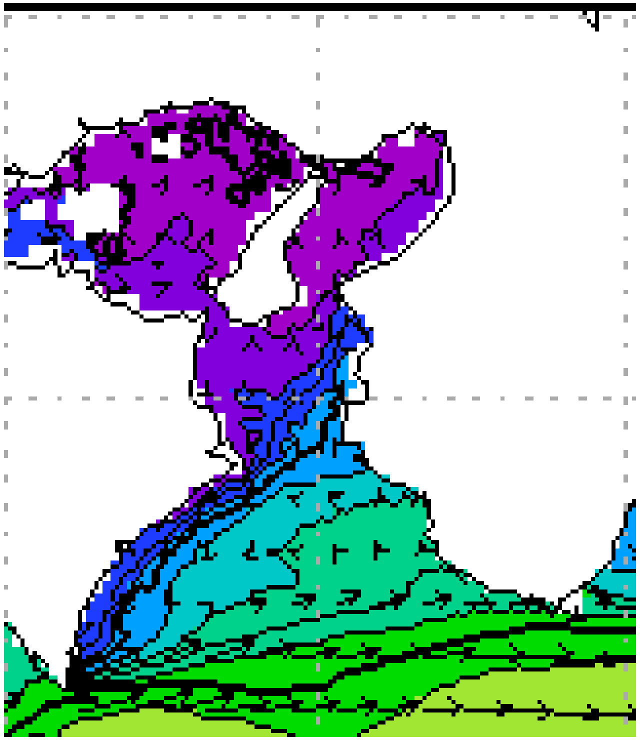
SST and surface flow analyses

3DVAR (Miyazawa et al. 2009)



200km scale isotropic
static error covariance

LETKF



un-isotropic
time dependent error covariance

Isotropic and time constant error covariance smoothed the horizontal gradient of the front

Flow dependent error covariance represented by EnKF was responsible for the representation of the steep Kii Channel Front

LETKF forecasts for Loop Current

The LETKF data assimilation is initialized on April 22, 2010, with 20 ensemble members.

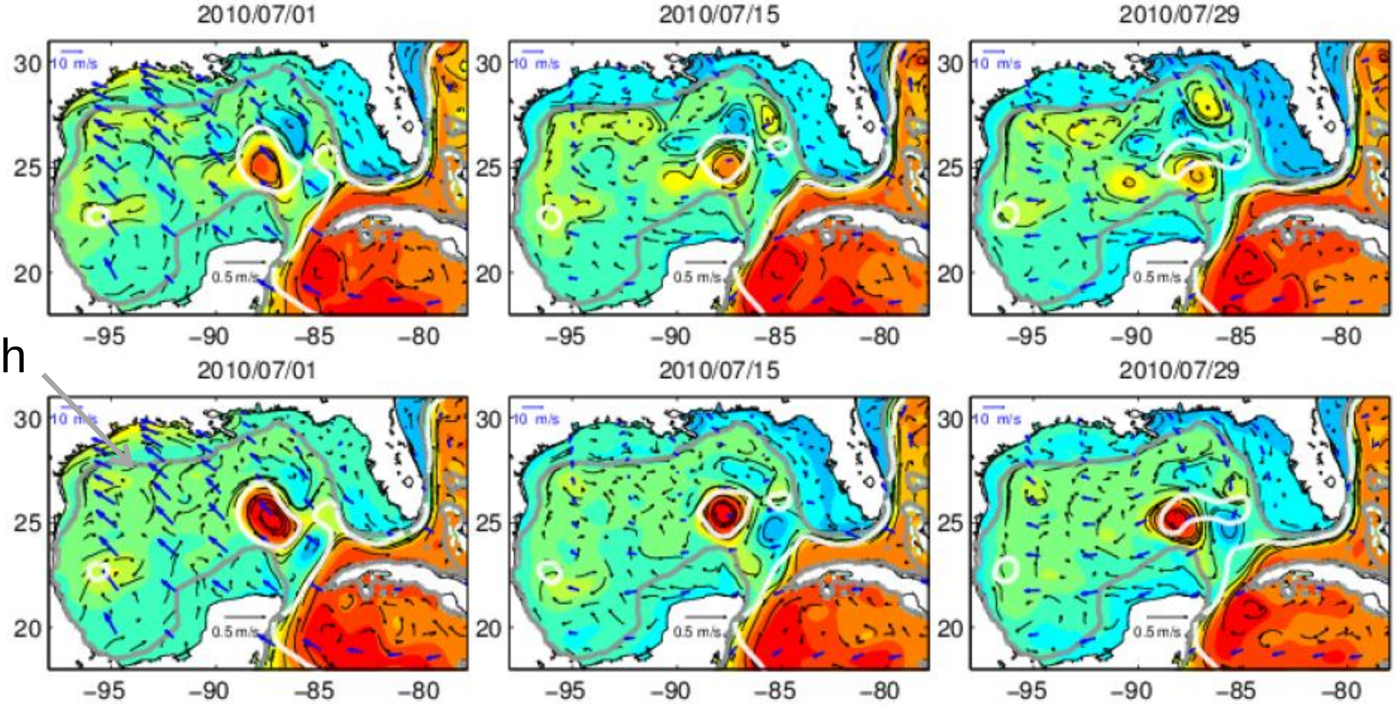
These initial members are sampled from the outputs of PROFS OI assimilative analyses during the period April 12th to May 2nd, 2010.

The time interval for LETKF analysis is 2 days.

We conduct 2-month lead forecasts starting from Jul/01/2010 to test the forecast skill, initialized from restart files produced by OI and LETKFs.

In all cases, the forecast code and boundary conditions etc. are the same, and all are also forced by the same GFS winds.

OI v.s. LETKFs forecasts



Initial state

2-week later

4-week later

OI
SSH
SST

200m
isobath

LETKF
SSH
SST

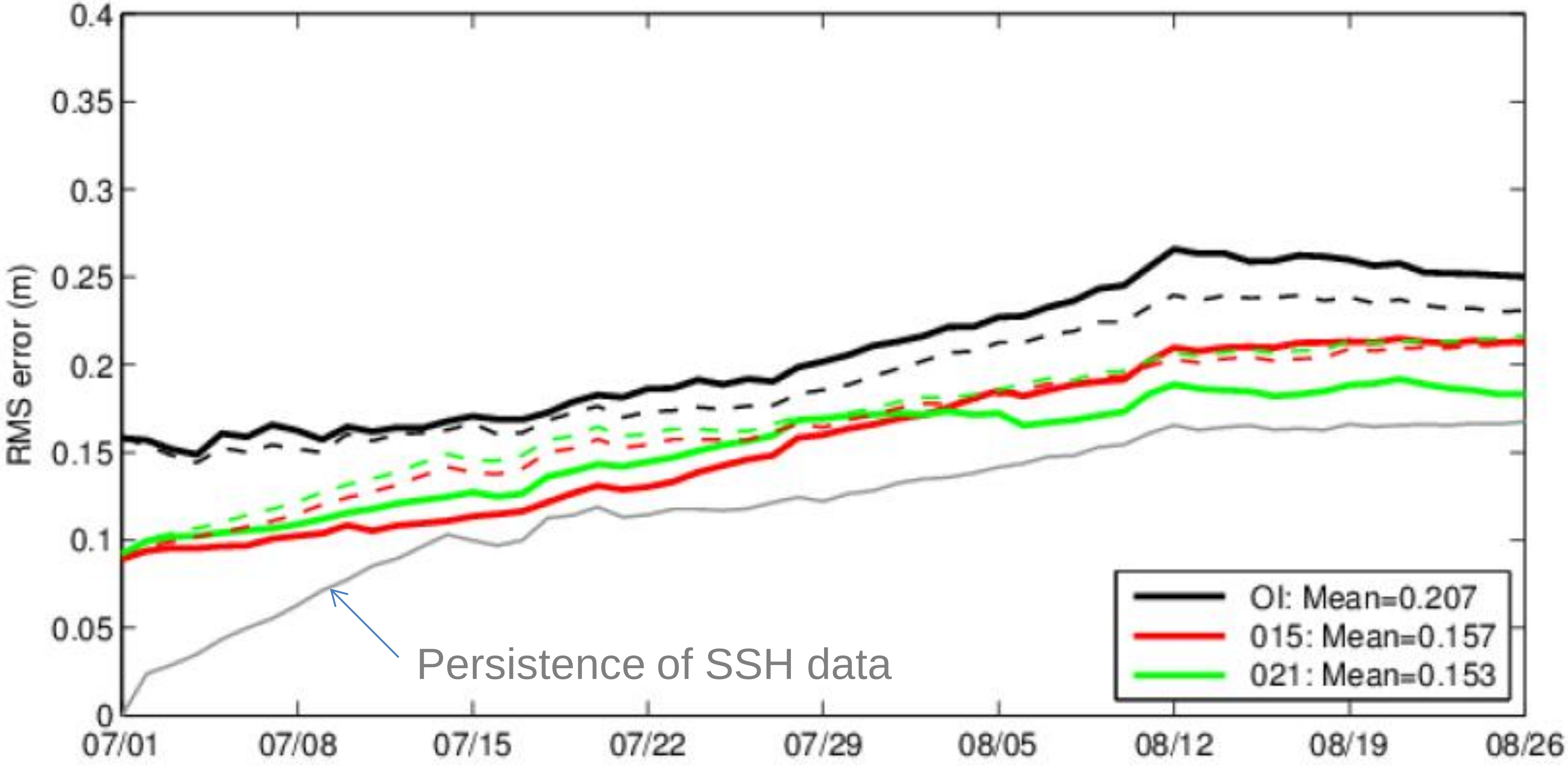
On July 1st, an eddy separated from the LC and began to (very slowly) propagate westward. At this initial time, the eddy and the LC match quite well the observed positions from the SSH product.

Two weeks later (07/15), the separated eddy of the OI-forecast propagated faster than observed, and a small warm ring separated from the model Loop Current and moved northeastward along the 200m isobath contour, which was not observed. In comparison, the LETKF forecast simulates well the LC eddy position and the small warm eddy near the 200m isobath.

On Jul/29, the forecast from the LETKF case to simulate fairly well the almost stationary eddy.

Skill comparison (OI vs LETKF forecasts)

RMS errors between models and observation Sea Surface Height

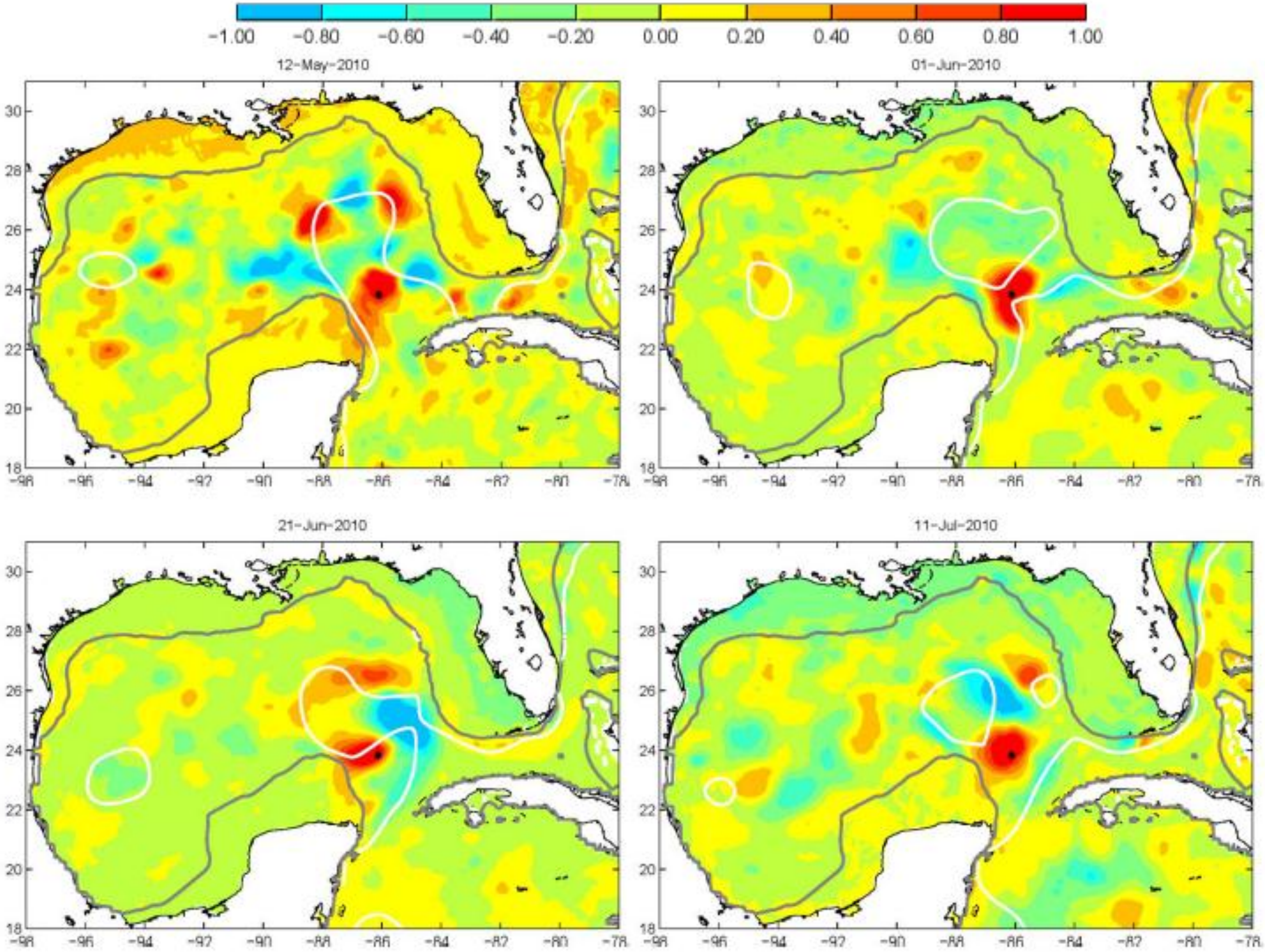


Persistence of SSH data

The forecasts from some LETKF cases have 25% smaller RMS errors than the OI forecast.

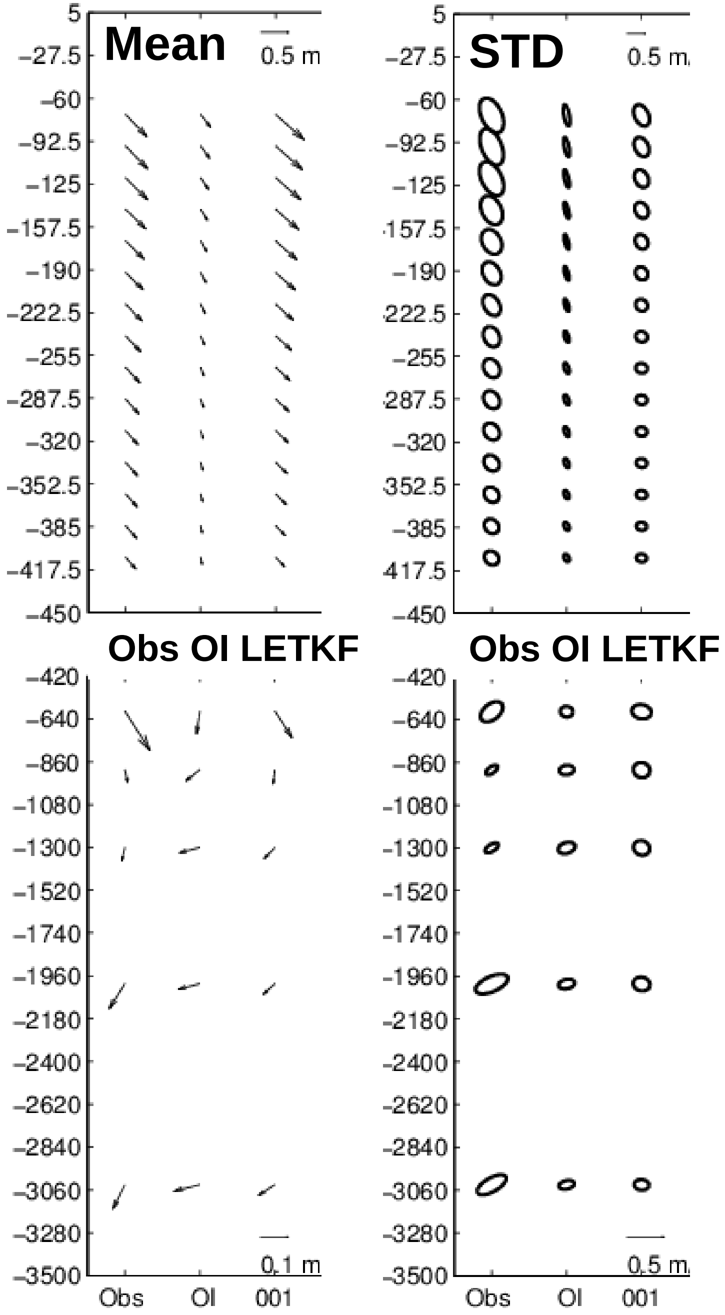
At all time during the forecast period, the LETKF forecasts have higher skills than the OI forecast.

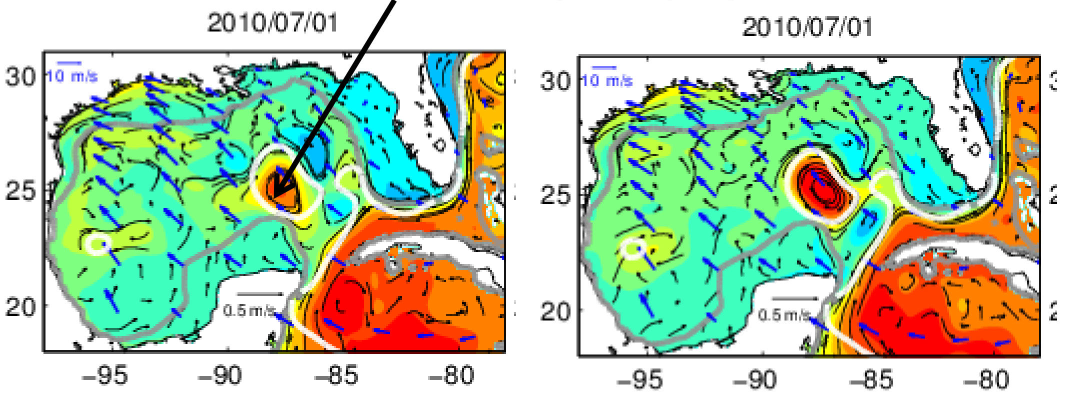
Spatiotemporally varying error covariance



The error covariance represented by LETKF is highly variable in time and space and clearly evolves with the flow field, suggesting the positive role of the error covariance in the representation of the complicated eddy-shedding process.

SSH/SST assimilation effects on current





Ocean current observation (ADCP), Apr.2009-Nov.2011

(←This observation data are not assimilated into the model)

LETKF produce larger mean and variance in better agreement with observation. The shedding eddy has strong nonlinearity, thus its movement was governed by the flow of the eddy itself.

Better forecast skill of LETKF on the eddy movement is due to the better representation of the flows from subsurface to deep levels, caused by the better representation of the error covariance between the assimilated variables and model current.

Summary

LETKF is applied to the parallelized version of the Princeton Ocean Model to investigate variations of the western boundary currents including the Kuroshio south of Japan and Loop Current in Gulf of Mexico.

The coastal and open seas interactions such as the channel front variation in the Kuroshio region, and eddy-shedding from the Loop Current in Gulf of Mexico are well captured by LETKF.

LETKF is effective for detection of the open and coastal seas interactions because of its ‘seamless’ representation of the forecast error covariance from larger (open ocean) to smaller (coastal) scales.

LETKF has better ability to extract the information required for well representation of ocean current from the satellite observation of Sea Surface Height and Sea Surface Temperature than OI, and leads to better forecast skill on the movement of shedding eddy.

(Miyazawa et al. 2012, **Ocean Dynamics**; Miyazawa et al. 2013, **remote sensing**)
(Xu et al. 2013, **Ocean Modelling**)