Implementing glider observation strategies for Navy ocean observing systems

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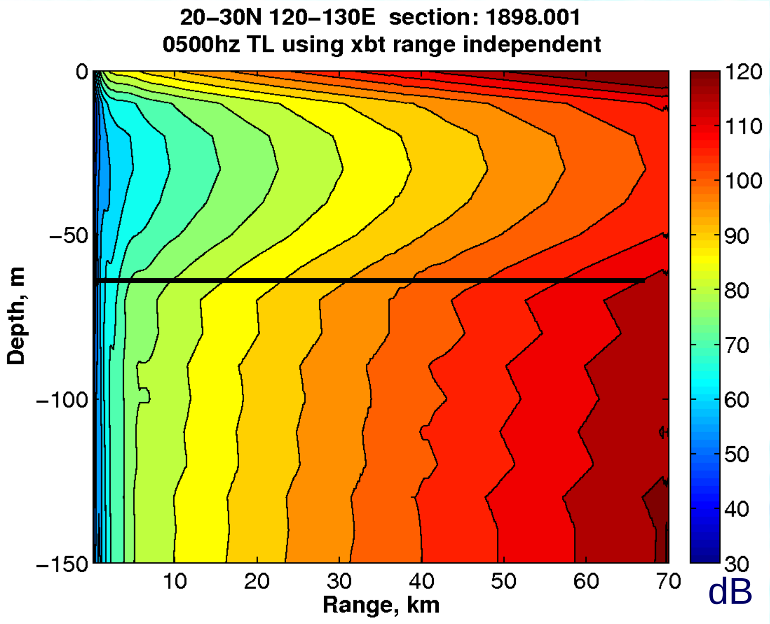
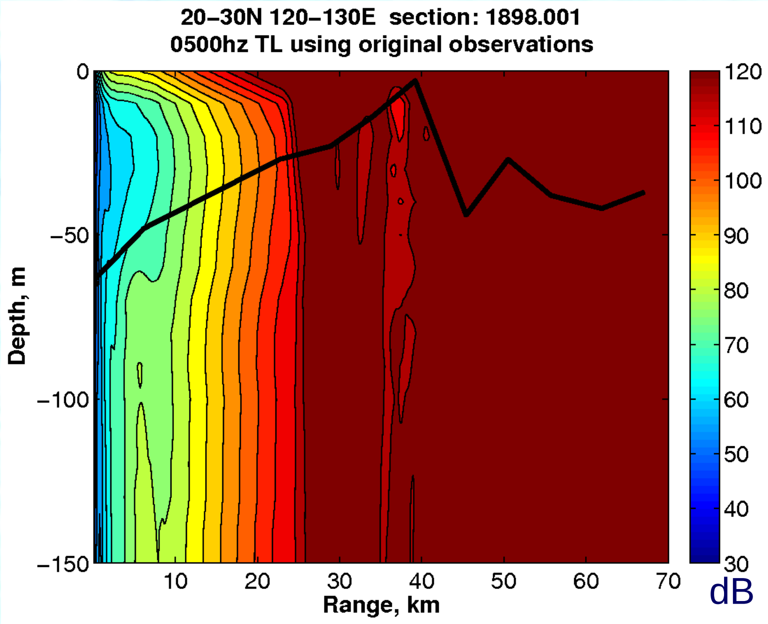
An ocean observation tells what the ocean is like nearby in time and space

A range-independent estimate from a single observation (left) may miss important changes in space (right) and time (next slide).



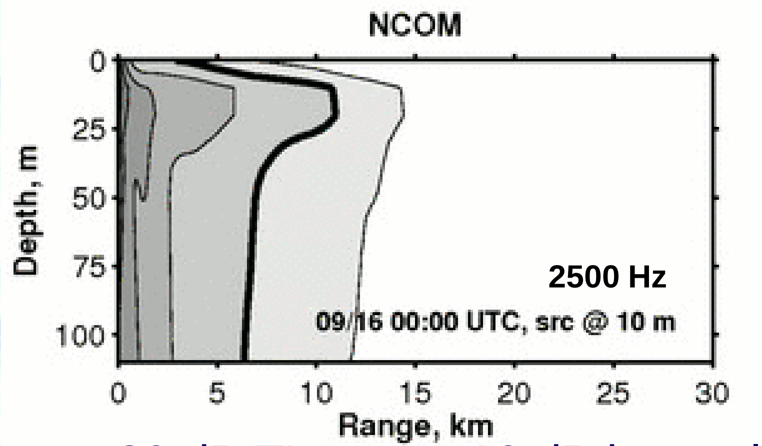
Range-independent environment



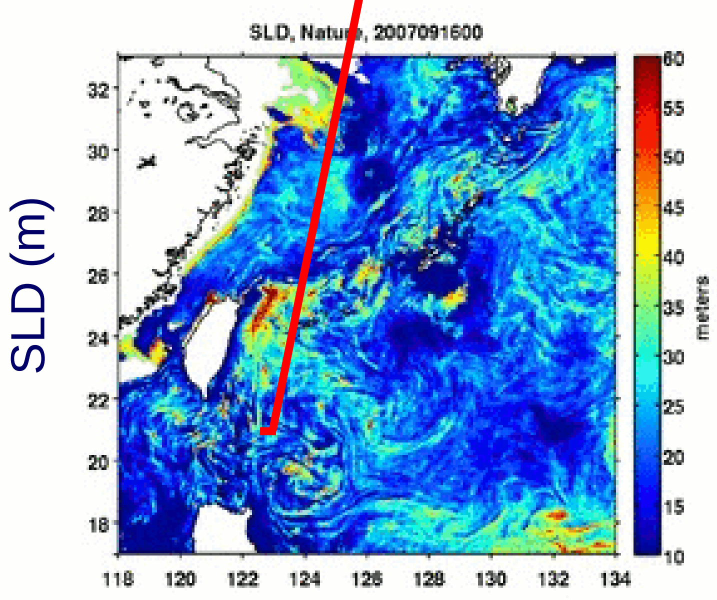
Range-dependent environment

Acoustic transmission loss (TL) in dB for a 500Hz source at 30 m calculated over a section east of Taiwan. Range-dependent changes are lead to ~15km (50% range errors) for a 90 dB FOM. The bold line shows the Sonic Layer Depth (SLD). These are determined by unclassified calculations using a flat, absorbing bottom.

Ocean models forecast how the environment changes in space and time



80 dB TL 10 dB interval



Tactically significant changes in the ocean environment are best indicated by assimilative ocean models. While the relevant space and time scales and extent can not be resolved by observing systems alone, assimilation of the of the observations guides model forecasts toward the true ocean state.

(top) Acoustic transmission loss (TL) along a section east of Taiwan.

(bottom) Sonic layer depth (SLD) over the Okinawa Trough from Sep. 16-22, 2007.

Range from the source to the 80 dB TL figure of merit varies from less than 5 km to more than 30 km. Search tactics in the area should account for these variations.

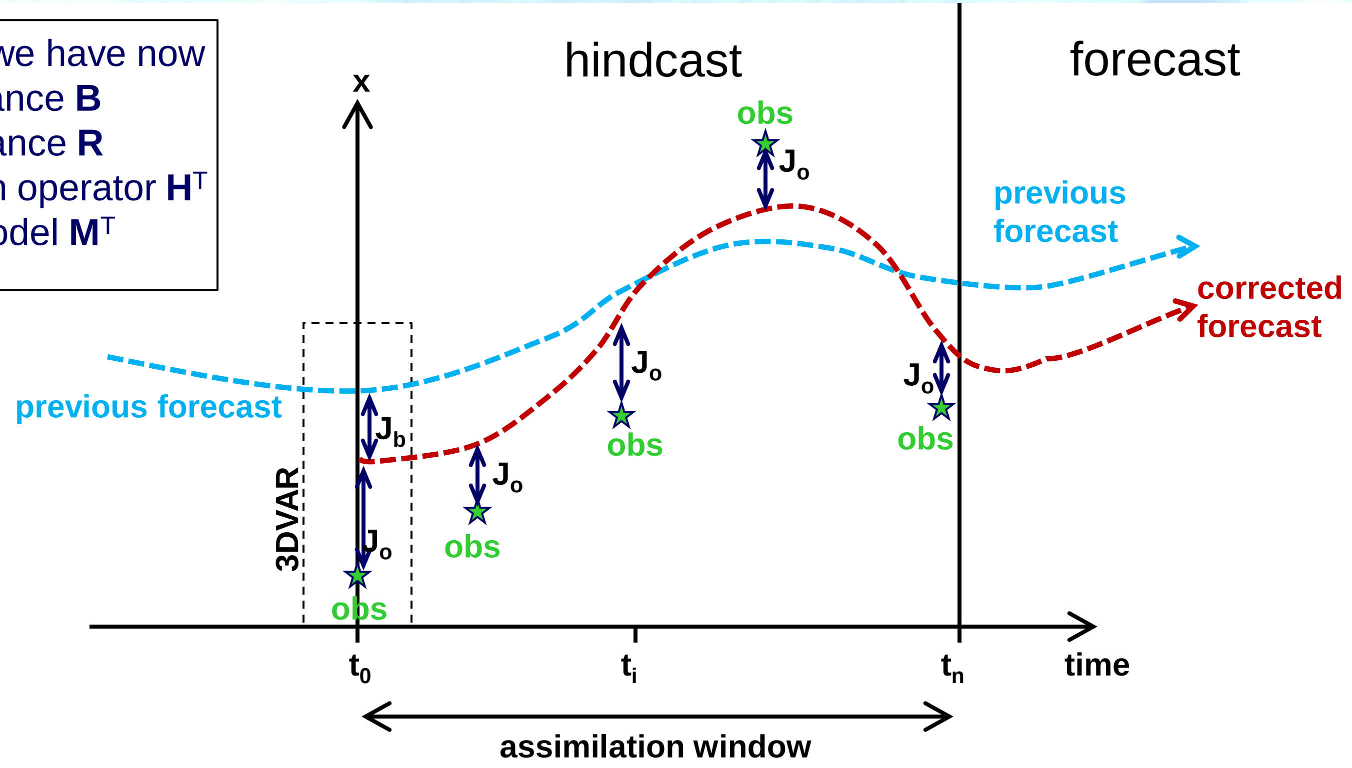
Data assimilation guides model forecasts from possible states toward actual conditions

What is the best estimate of the ocean state **x**? Variational assimilation finds it by balancing estimated errors to minimize a cost function *J*(**x**).

$$J(\mathbf{x}) = \underbrace{(\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_b)}_{J_b} + \underbrace{(\mathbf{Hx} - \mathbf{y})^T \mathbf{R}^{-1} (\mathbf{Hx} - \mathbf{y})}_{J_o}$$

ocean covariances, models we have now

- Background error covariance **B**
- Observation error covariance **R**
- Adjoint of the observation operator $\mathbf{H}^T$
- Adjoint of the forecast model $\mathbf{M}^T$

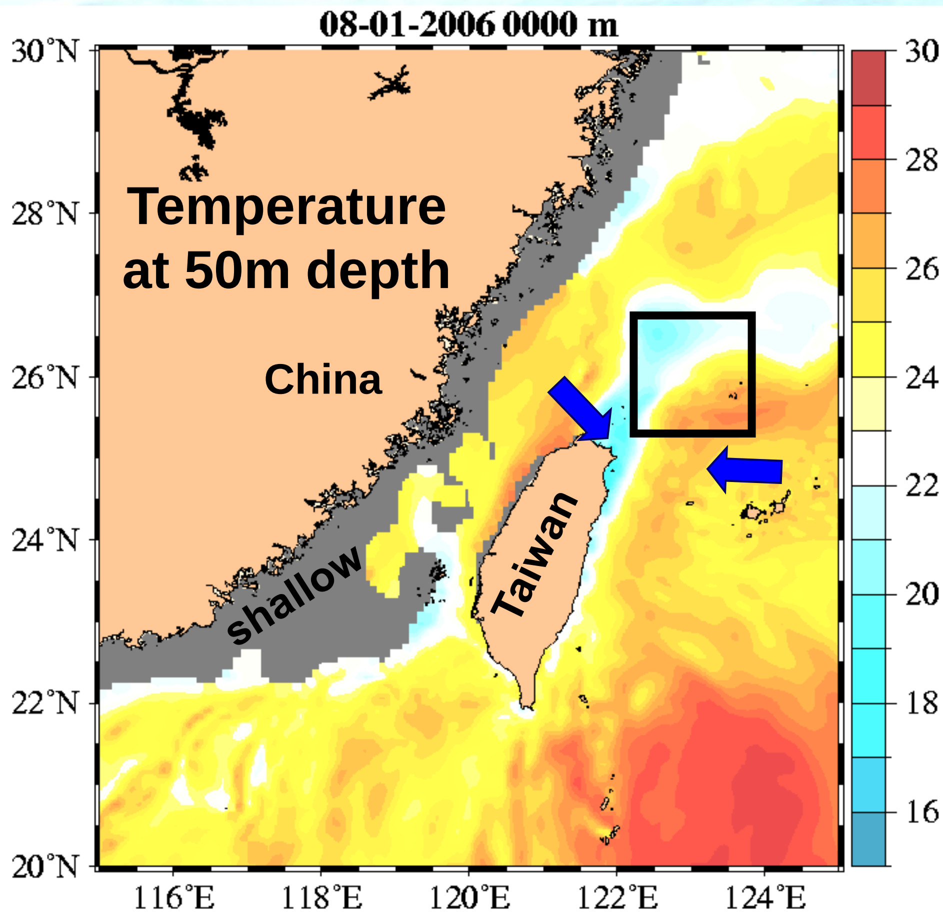


How does an ocean glider operate?

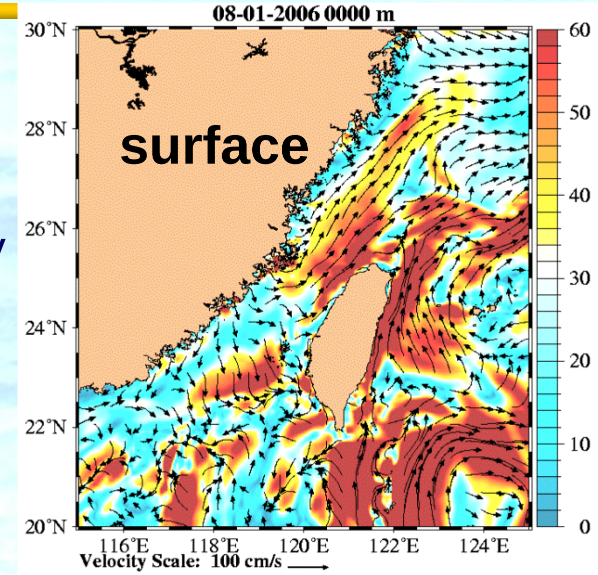
Ocean gliders are low power observing platforms that can continuously operate at sea for weeks to months. There is variation among characteristics from different manufacturers, but ocean gliders are typically ~2 m long and generate forward acceleration by compressing an internal bladder to change overall buoyancy. Gliders are slow, but there is some ability to increase glider speed by increasing compression, at an expense of increased power consumption. Mission duration can be several months. They are typically deployed and recovered from ships.

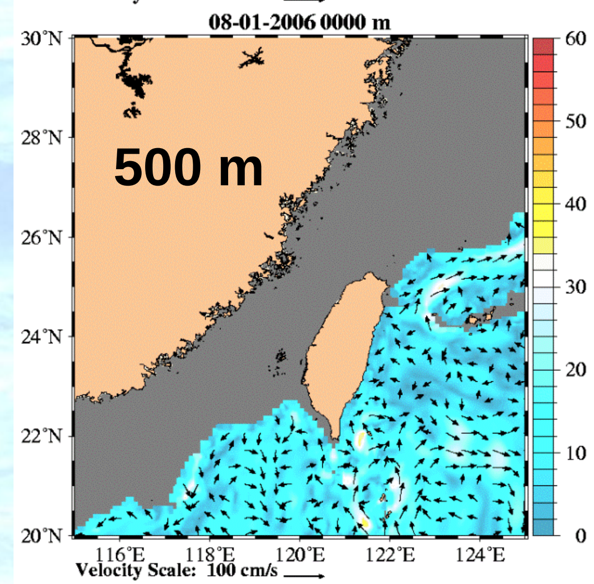
Sept. 2010 deployment from USNS Sioux.

How do we guide gliders to better support mission objectives?



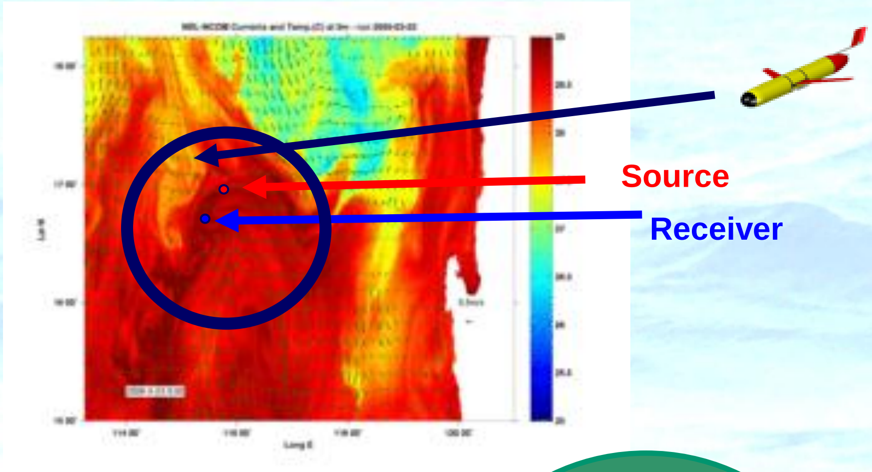
We use environmental forecasts to allocate, deploy and maneuver gliders such that these low-speed UUVs maintain coverage and provide data sufficient to meet mission objectives.





Framework for directing and using gliders

Ocean model (NCOM) surface currents and temperature in the northeastern Philippines Sea (Spring 09)



Where should this asset be deployed and directed to best support mission objectives?

Additional restrictions (speed limitations, restricted areas, …)

Instructions from glider pilot

Glider observations over dive sequence

Sampling strategy, automated waypoints

Adaptive sampling, prioritizing areas for observations

Present warfighter needs

Sensor QC, Data QC

Data assimilation

Numerical prediction

Warfighter relevant environment

Glider Observation Strategies 1.1 CONOPS

NAVOCEANO ocean modeling and prediction support three classes of missions:

1) tactical operations (specialized, most effort)
2) feature definition
3) sustained coverage

System requirements for its glider mission guidance:

- use standard operational products
- address standard classes of missions
- operate over a large number of platforms
- no operator inputs except change mission type
- guidance output indicates degree to which selected path is preferred over alternatives

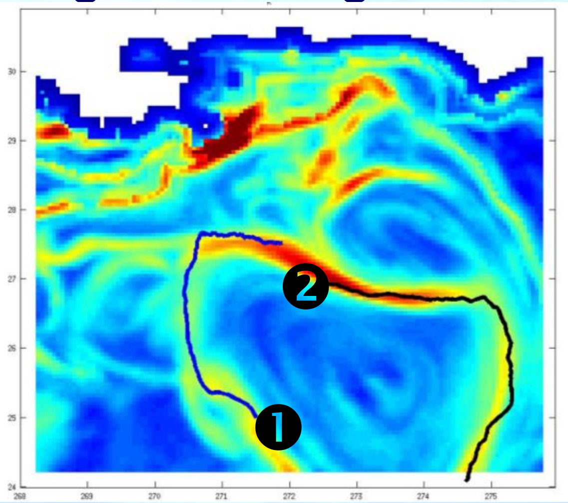
Mission Classes

Tactical Operations	Feature Definition	Sustained Coverage
Aim **to reduce uncertainty in forecast errors** in a user-specified area and time-horizon.	Designed to **sample areas of frontal position or rapid change**	aims for an even distribution of observations over an area to **maintain broader forecast performance** for an extended time period.
The cost functions for these missions are based on the adaptive sampling system.	The cost functions for these missions are based on temperature, salinity, and currents	GOST will seek to produce an even distribution and guarantee presence of observations over identified regions.
GOST provides waypoints that minimize the uncertainty within the specified target area and for the desired forecast ranges.	GOST emphasizes target observations to minimize uncertainty in feature boundaries.	This mission maintains a glider presence for future tactical or feature definition operations and would be the default choice for routine operations to maintain overall model forecast skill.
Validated in: MREA10 demo	Validated in: POMA11 demo	

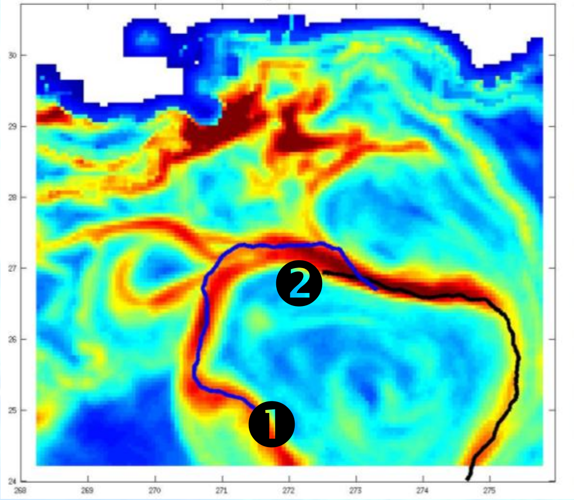
Each glider accomplishes its mission in concert with the other gliders in the local area.

Example: feature definition mission in the Gulf of Mexico

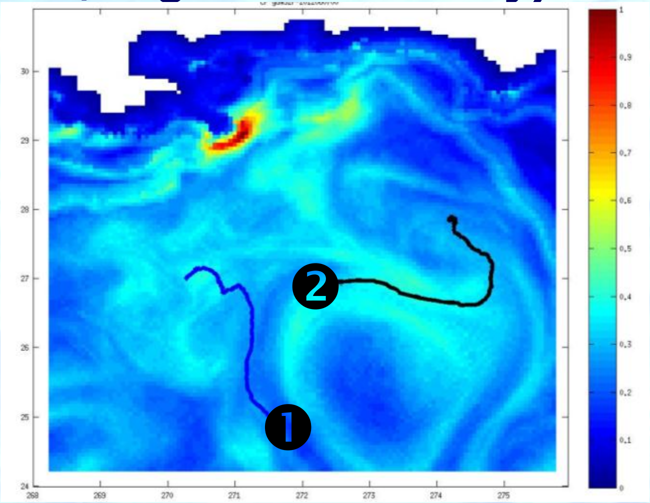
Feature definition mission cost functions from different real-time model forecasts in the northern central Gulf of Mexico on 7 June 2012. We have superimposed the 7-day paths for two gliders as determined by maximizing the daily cost function. Red areas indicate regions of higher cost function value (in this case, higher variability).



GoM 3km



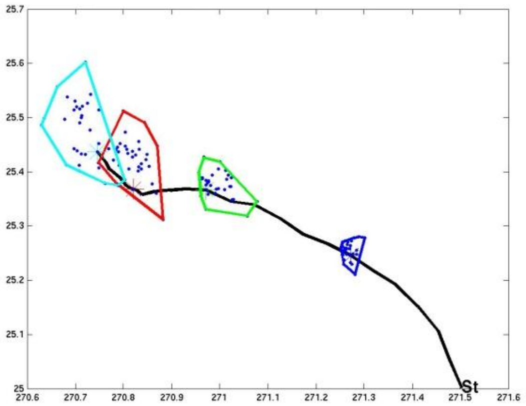
GoM 1km



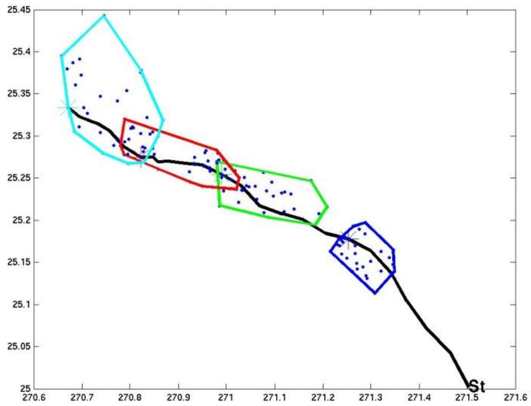
GoM 3km ensemble

Example: spread in path of glider 1

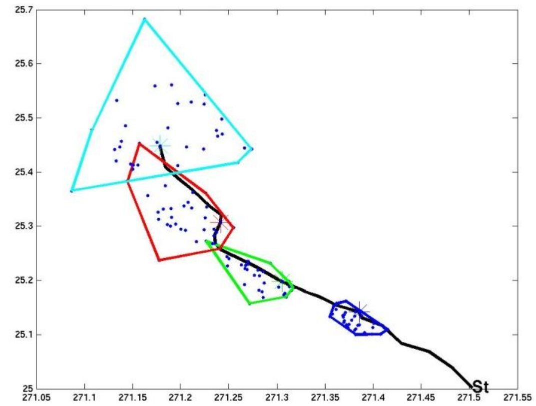
Glider 1 path for July 7 based on the different model forecast inputs for mission type 2. The spread every 6 hours shows waypoints from the top 20% of paths as evaluated by the genetic algorithm.



GoM 3km



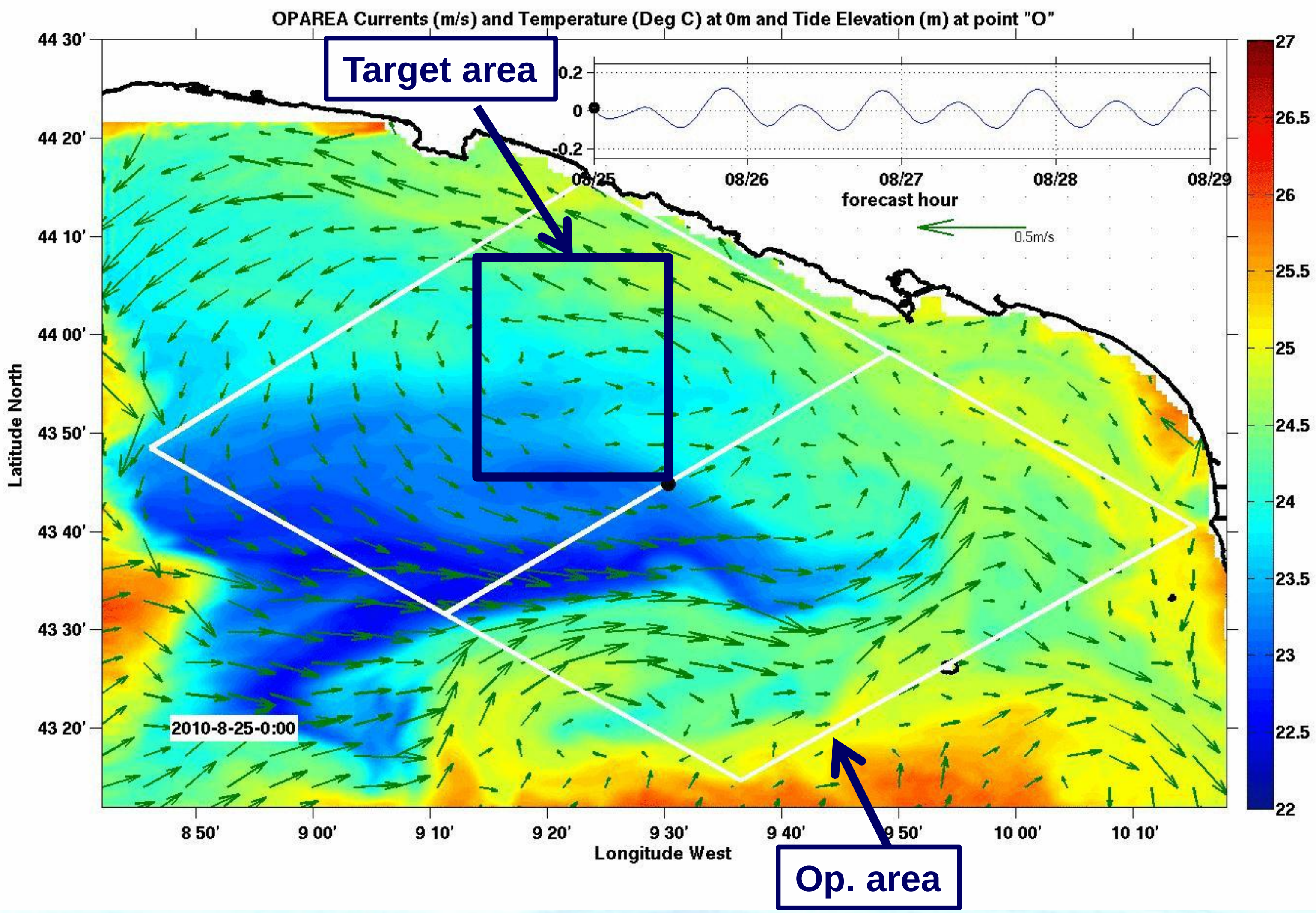
GoM 1km



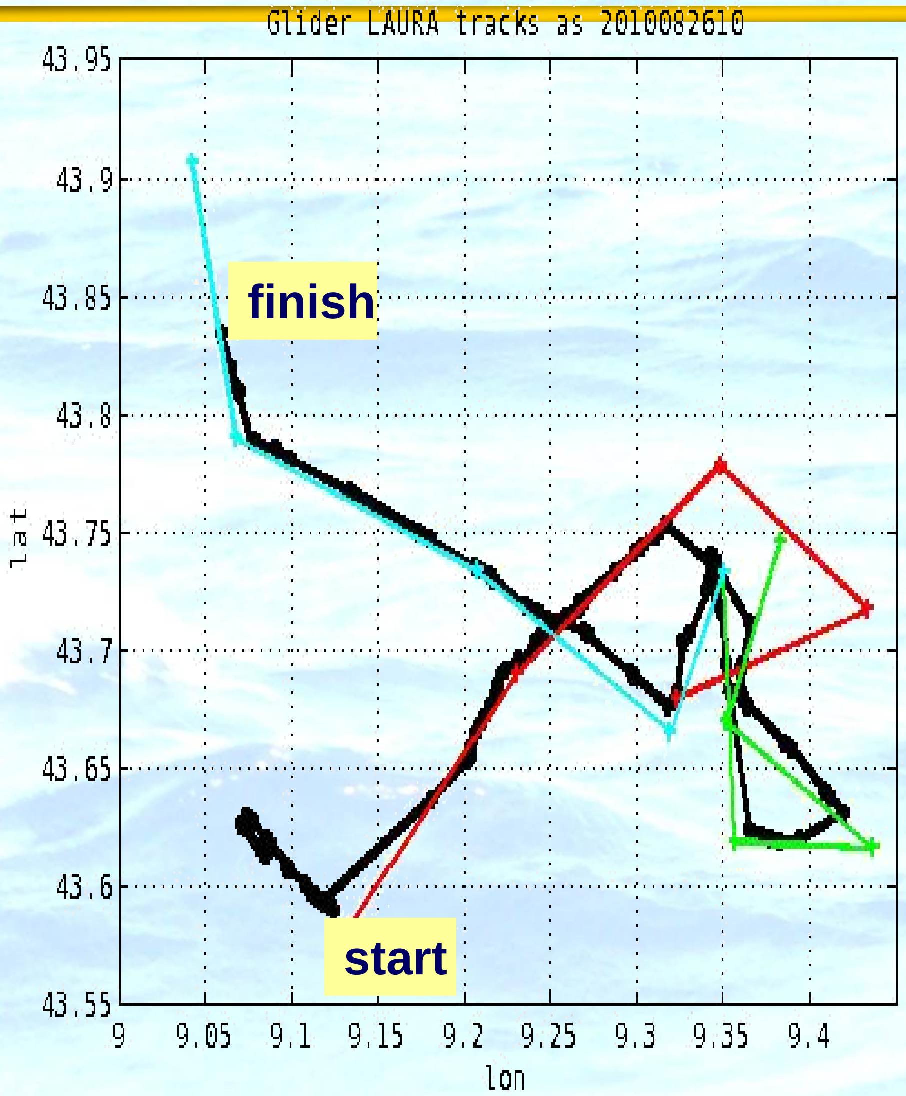
GoM 3km ensemble

This product gives the glider pilots as estimate of the tolerance and uncertainty in achieving optimum glider trajectories.

Example: tactical operation mission with target area – NATO MREA 10, Ligurian Sea



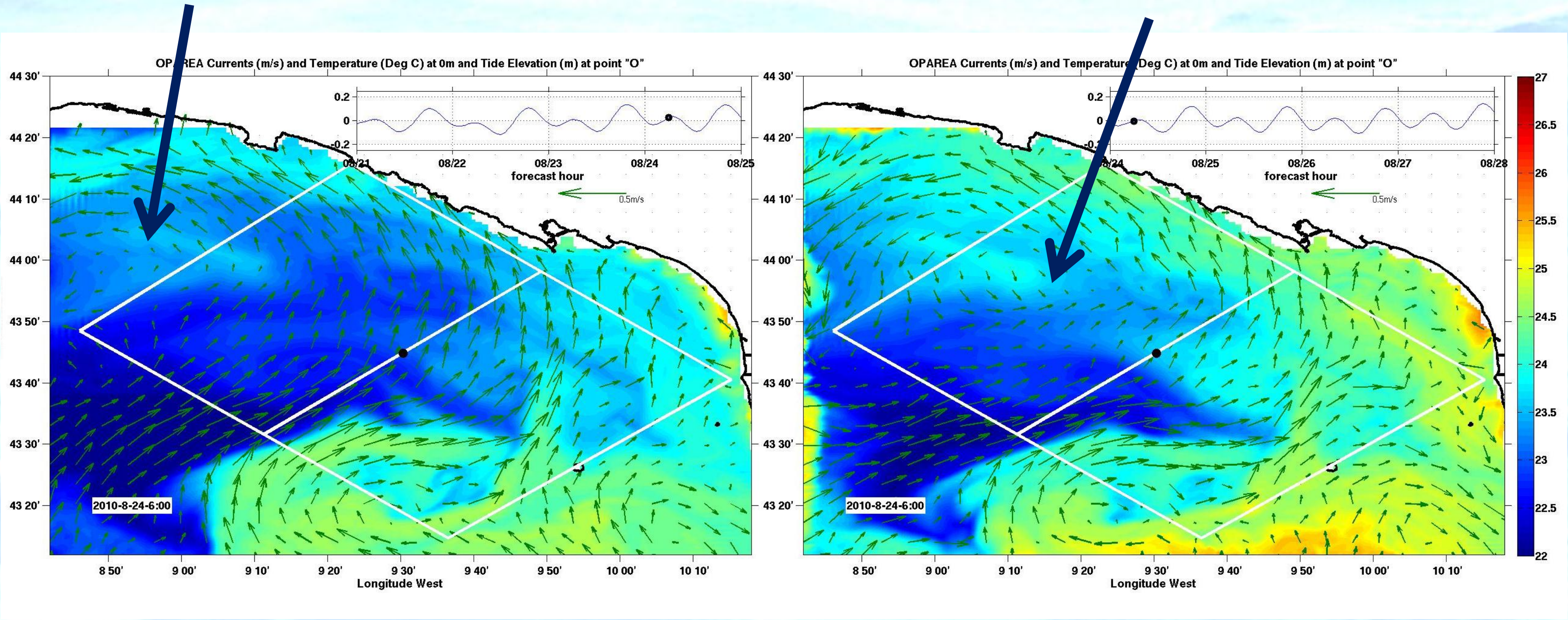
Example: tactical operation mission with target area – NATO MREA 10, Ligurian Sea



Black – actual track
Colors –delivered paths

Forecast target waypoints for glider Laura were delivered every 48 hours. The actual trajectory of Laura over the week is shown in black.

Example: impact of glider assimilation – NATO MREA 10, Ligurian Sea



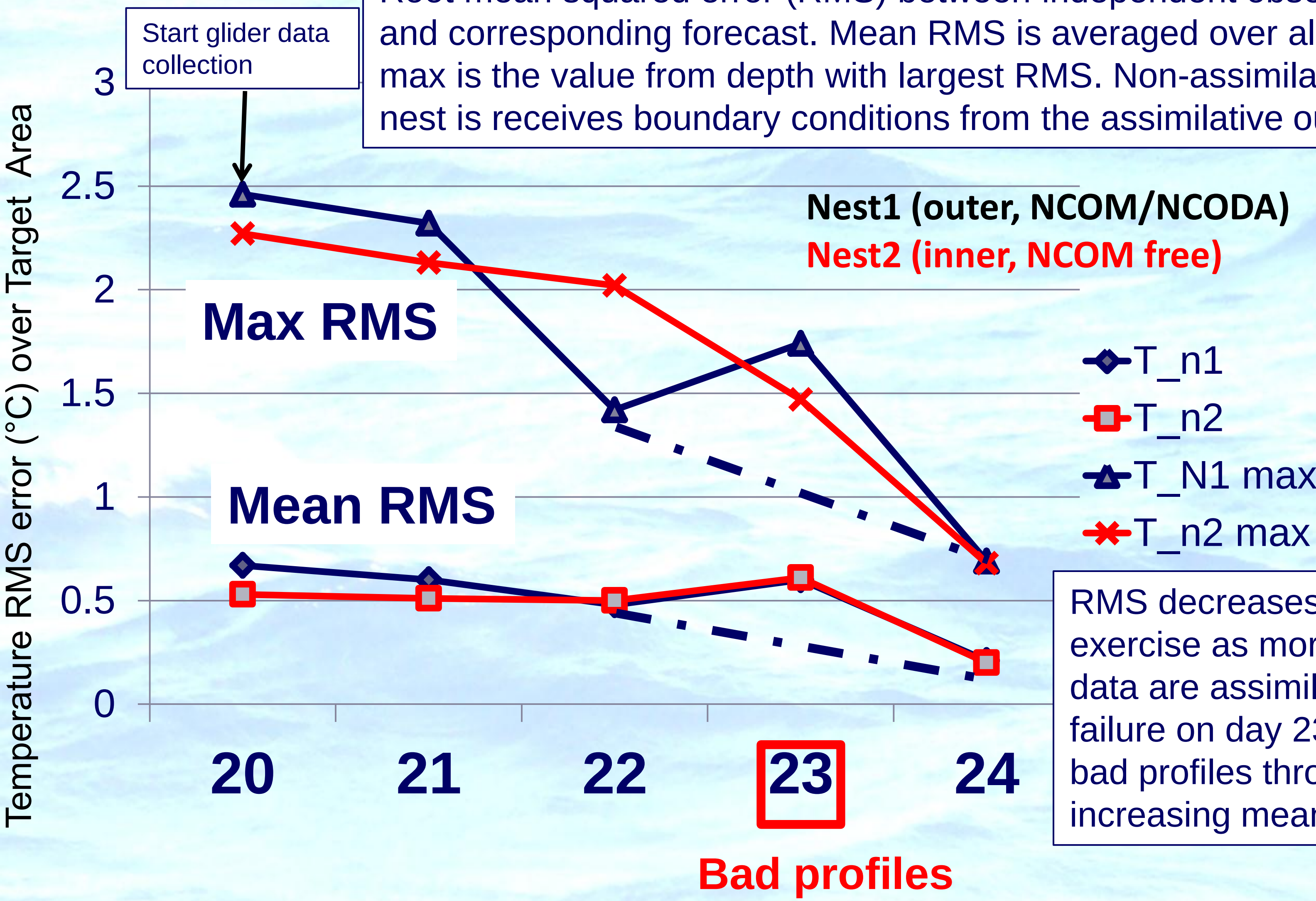
78hr forecast from 2010082100

6hr forecast from 2010082400

Based on the assimilation of data from glider Laura, the forecast location of the indicated eddy was corrected and shown to fall correctly within the target area, as confirmed by independent observations.

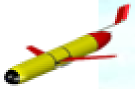
Example: impact of glider assimilation – NATO MREA 10, Ligurian Sea

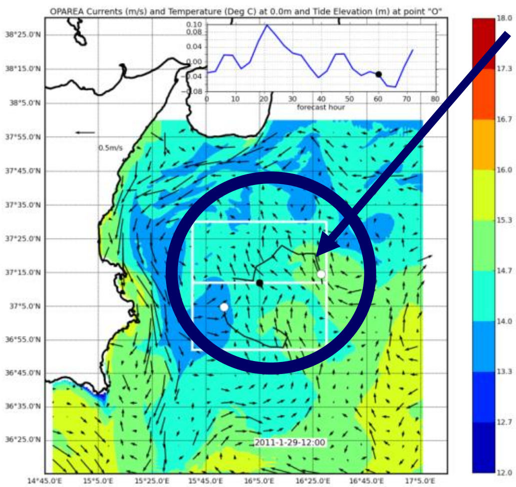
Root mean squared error (RMS) between independent observations and corresponding forecast. Mean RMS is averaged over all depths; max is the value from depth with largest RMS. Non-assimilative inner nest is receives boundary conditions from the assimilative outer nest.



RMS decreases over the exercise as more glider data are assimilated; QC failure on day 23 allows bad profiles through, increasing mean RMS.

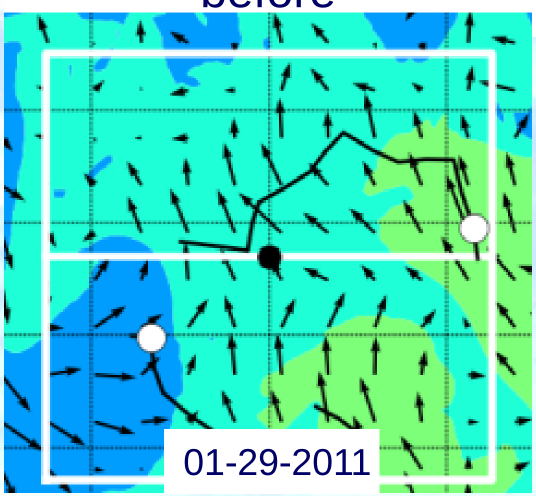
Example: impact of glider assimilation – NATO POMA 11, east coast of Sicily



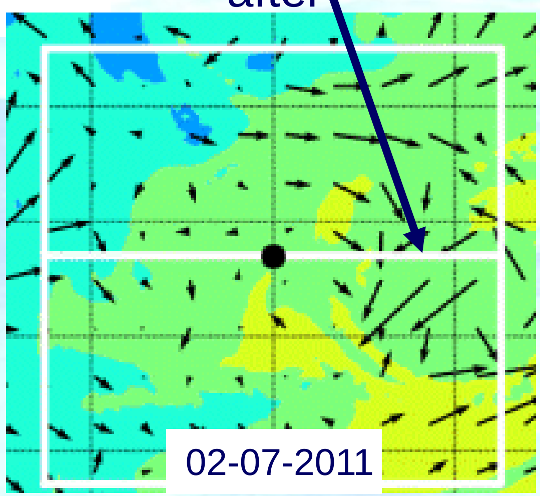


Example of a feature definition mission: Currents and temperature at 25m before and after assimilation of observations from the GOST-directed glider. The glider identified a **cold-core ring** that significantly modifies the op area.

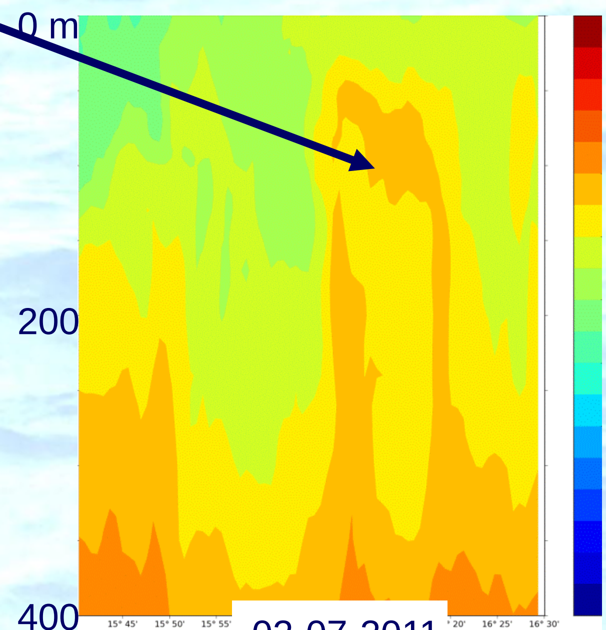
before



after



Sound speed (m/s) across op area (37.2°N)



Summary: Implementing glider observation strategies for Navy ocean observing systems

- Gliders are slow, energy-efficient autonomous underwater vehicles that can be deployed as a flexible, low-cost, persistent observing system

- Optimizing algorithms identify preferred waypoints that enable glider networks to more effectively achieve mission objectives

- Under such guidance, gliders can discover or confirm environmental conditions that have significant impact on Navy ocean model forecasts

Abstract

Glider Observation Strategies (GOST) is an autonomous system to guide ocean glider networks such that their observations are optimized for a specified mission class: tactical operations, feature definition, or sustained coverage. Forecasts of the ocean state, its variability, and its uncertainty are used to develop mission-specific cost functions indicating the relative benefit of combinations of observations at different times and locations. GOST combines these cost functions with forecasts of ocean currents to develop preferred deployment and navigation plans for glider networks. Glider pilots are provided with a time series of waypoints and their uncertainties as guidance for glider navigation over the next 24-72 hours. Examples from prior deployments show the impact of the glider observing systems on ocean forecasts.