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Why gliders appreciate good company: glider assimilation in a 4DVAR system with and without surface observations

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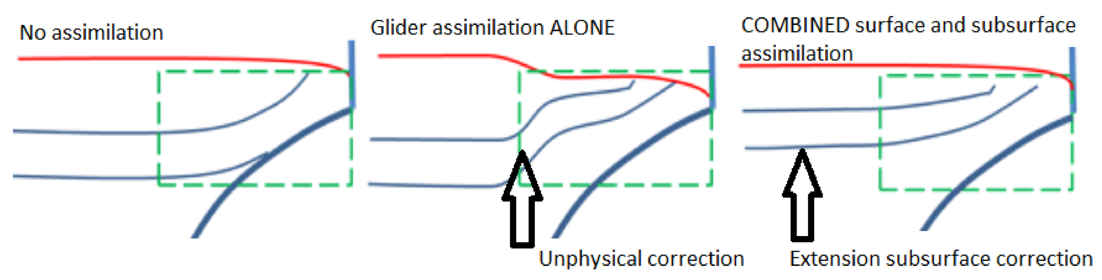
Hypotheses

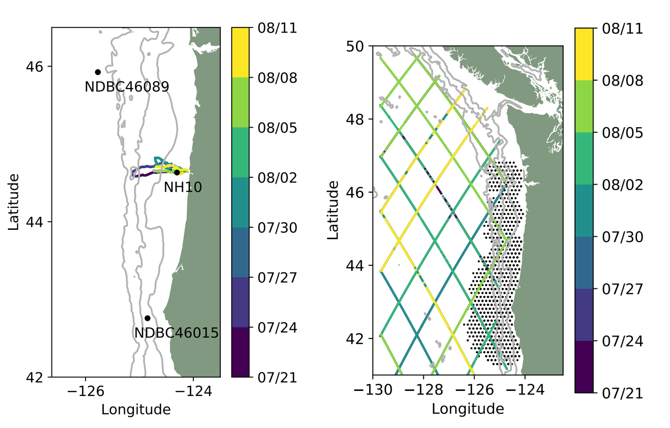
1. Assimilation of glider observations ALONE creates unphysical corrections, in particular spurious eddies, that can be suppressed by assimilating glider observations in combination with surface observations.
2. A 4DVAR data assimilation system that assimilates glider temperature and salinity observations generates forecasts that more accurately predict the subsurface structure than forecasts obtained from a 4DVAR system that only assimilates surface observations.
3. Combined assimilation of glider and surface observations results in corrections in the subsurface structure that extend beyond the region in which the subsurface is corrected when glider observations alone are assimilated.



Summary

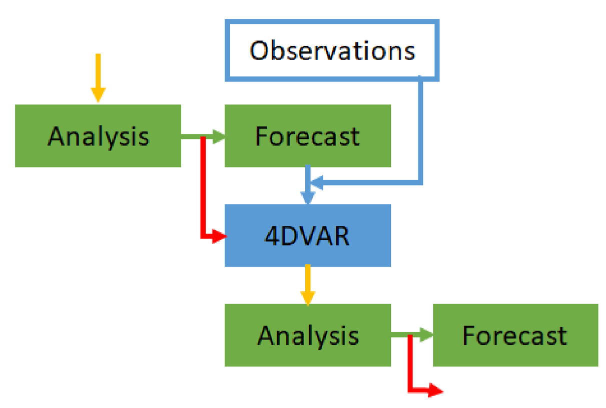
1. Assimilation of glider observations ALONE creates persistent eddies that are absent in the free model and the model using combined assimilation.
2. Comparison with buoy and glider observations shows that assimilation of glider observations can improve the accuracy of the forecasted subsurface temperature, but only when assimilated in combination with surface observations. Furthermore, comparison of the depth of the $26.5\,\mathrm{kgm^{-3}}$-isopycnal in the different experiments shows that the overall improvement in subsurface temperature does not necessarily result in a more accurate subsurface isopycnal depth density structure.
3. Corrections to the subsurface isopycnal structure extend beyond the direct vicinity of the glider transect when glider observations are assimilated. The change to the initial conditions south from the glider transect can be explained by coastally trapped waves.

Observations



- **Glider:** temperature and salinity measurements in $1\,\mathrm{km} \times 4\,\mathrm{m}$ bins for the top 200 m offshore from Newport, OR, (*Barth et al.*, 2011) approximately one one-way transect per 3-day assimilation window (colored dots left figure).
- **Surface currents (HFR):** surface high-frequency radar currents (HFR), daily-averaged, (u, v) mapped on a $6 \times 6\,\mathrm{km}$ grid (black dots right figure) (*Kosro*, 2011).
- **Sea-surface height (SSH):** Jason satellite alongtrack altimetry (colored dots right figure). Absolute dynamical topography minus mean along each track is assimilated.
- **Sea-surface temperature (SST):** GOES half-hourly, 6 km resolution, level 5 data (*Harris and Maturi*).

Data assimilation system



- **Nonlinear model:** ROMS (*Shchepetkin and McWilliams*, 2005) model (`www.myroms.org`) Oregon-Washington coast (40.7−50.0 N and 122.1−130 W), 2 km-resolution in the horizontal, 40 vertical layers.
- **Forcing:** NOAA NAM atmospheric model, Navy HYCOM boundary conditions, TPXO Tides (*Egbert and Erofeeva*, 2002).
- **4DVAR:** using home-made AVRORA tangent-linear and adjoint codes (*Kurapov et al.*, 2009, 2011; *Yu et al.*, 2012) gives more flexibility in the choice of the initial error covariance and cost functionals than standard ROMS 4DVAR.
- **Background error covariance:** model errors in temperature are assumed Gaussian, correlation length scale of 25 km in the horizontal and a depth varying vertical scale. Temperature error variance is $1.44\,{}^{\circ}\mathrm{C}^2$ at the surface and decreases exponentially with depth. Errors in salinity, velocities and sea-surface height are related to errors in temperature using the balance operator (*Weaver et al.*, 2005).

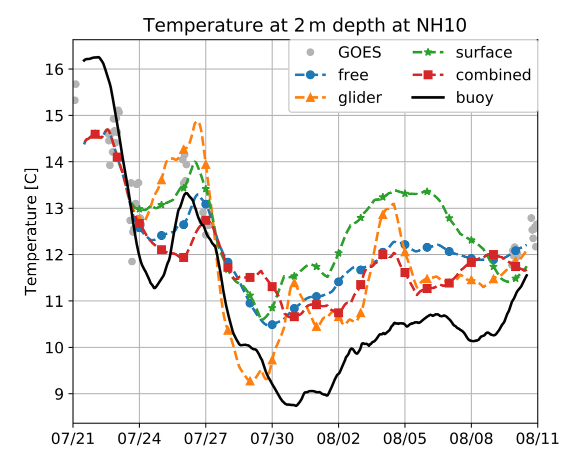
Analysis/Forecast evaluation

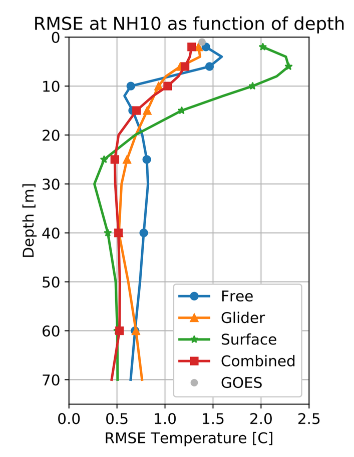
The model-observation RMSE in 4 different DA experiments, 21 July - 11 August:

Best model	Assimilation cases					Analysis			Forecast		
RMSE > RMSE free model	Free	Glider	Surface	Combined	Free	Glider	Surface	Combined	Glider	Surface	Combined
Glider temperature [°C]	no data assim.	x		x	1.02	0.62	1.12	0.46	1.02	1.09	0.85
Glider salinity [ppt]		x		x	0.41	0.37	0.42	0.37	0.46	0.42	0.43
HFR u [$10^{-2}\,\mathrm{ms}^{-1}$]			x	x	18.7	20.2	10.1	11.4	19.1	13.6	14.8
HFR v [$10^{-2}\,\mathrm{ms}^{-1}$]			x	x	18.0	23.3	9.7	11.0	21.0	13.4	14.7
SSH [$10^{-2}\,\mathrm{m}$]			x	x	6.0	6.3	3.4	3.5	6.2	5.2	5.4
SST [°C]			x	x	1.28	1.43	0.85	0.88	1.32	1.16	1.17

Assimilation of glider observations alone improves the fit to the glider data in the analysis, not in the forecast. Analysis/forecast RMSE with respect to other data worsens. Assimilation of surface observations alone yields the lowest RMSE in the surface data, but increases the RMSE with respect to the glider data. Combined assimilation yields an improvement in RMSE with respect to surface data compared to the free-run model. Furthermore, RMSE with respect to glider data is lower than in the case assimilating glider alone.

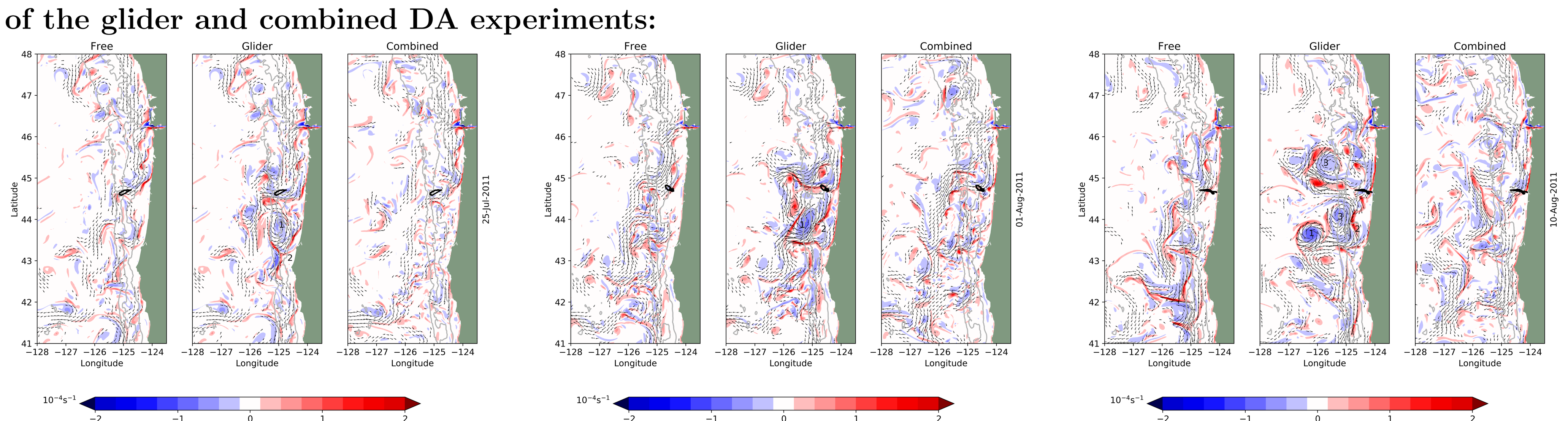
Center: Comparison against unassimilated temperature observations at the NH10 buoy location (*Levine et al.*, 2011) shows that neither the free model nor the forecasts are able to reproduce fully the decrease in temperature caused by coastal upwelling during the period 21-30 July 2011
Right: a large temperature RMSE for the surface DA experiment in the top of the water column due to absence of GOES data in the vicinity of NH10 on 2-11 Aug. Forecasts from the glider DA experiment have RMSE similar to those in the combined DA experiment. Below 20 m the RMSE with data assimilation is smaller than in the free model.





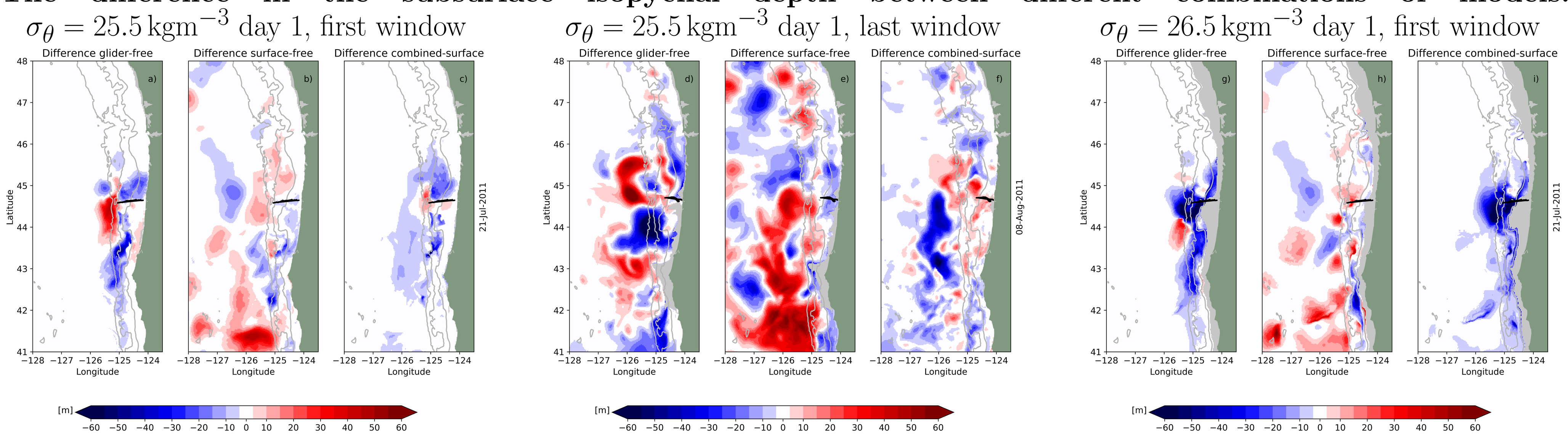
Assimilation impact

Surface daily-averaged current stronger than $0.2\,\mathrm{ms}^{-1}$ and relative vorticity for the free model and the analyses of the glider and combined DA experiments:



Assimilation of glider observations alone (black dots) intensifies the separating coastal jets (2) and creates eddies south of the glider transect (1). The vorticity in these eddies and separated coastal jets gets advected to the west (center and right figure) energizing the coastal transition zone (3). These eddies and separated coastal jets are absent in both the free model and in the analysis results from the combined DA experiment.

The difference in the subsurface isopycnal depth between different combinations of models:
$\sigma_\theta = 25.5\,\mathrm{kgm^{-3}}$ day 1, first window $\sigma_\theta = 25.5\,\mathrm{kgm^{-3}}$ day 1, last window $\sigma_\theta = 26.5\,\mathrm{kgm^{-3}}$ day 1, first window



On both isopycnals assimilation of glider observations alone (black dots) creates corrections to the south along the coastal slope (gray contours), as the effect of coastal trapped waves in the adjoint model. Over time corrections spread further west and south, as an effect of advection and eddy interactions.

Acknowledgements

References

Barth, J., A. Erofeev, R. Shearman, and P. Welch, Slocum gliders (1km x 4m) gridded data plots, http://gliderfs2.coas.oregonstate.edu/gliderweb/links.php, 2011.
Egbert, G. D., and S. Y. Erofeeva, Efficient inverse modeling of barotropic ocean tides, *Journal of Atmospheric and Oceanic Technology*, *19*(2), 183–204, 2002.
Harris, A., and Maturi, NOAA/NESDIS/STAR, pers. comm.
Kosro, P., Mapping Oregon coastal ocean currents, http://bragg.coas.oregonstate.edu, 2011.
Kurapov, A., G. Egbert, J. Allen, and R. Miller, Representer-based analyses in the coastal upwelling system, *Dynamics of Atmospheres and Oceans*, *48*(1), 198–218, 2009.
Kurapov, A., D. Foley, P. Strub, G. Egbert, and J. Allen, Variational assimilation of satellite observations in a coastal ocean model off oregon, *Journal of Geophysical Research: Oceans*, *116*(C5), 2011.
Levine, L., P. Kosro, C. Risien, and W. Waldorf, NH-10 conductivity and temperature observations, http://ona.coas.oregonstate.edu:8080/thredds/catalog/NANOOS/NH10, 2011.
Shchepetkin, A. F., and J. C. McWilliams, The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model, *Ocean Modelling*, *9*(4), 347–404, doi:10.1016/j.ocemod.2004.08.002, 2005.
Weaver, A. T., C. Deltel, E. Machu, S. Ricci, and N. Daget, A multivariate balance operator for variational ocean data assimilation, *Q.J.R. Meteorol. Soc.*, *131*(613), 3605–3625, doi:10.1256/qj.05.119, 2005.
Yu, P., A. L. Kurapov, G. D. Egbert, J. S. Allen, and P. M. Kosro, Variational assimilation of hf radar surface currents in a coastal ocean model off oregon, *Ocean Modelling*, *49*, 86–104, 2012.

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