Ocean Surface Topography Science Team Meeting (OSTST)

19-23 October, 2020
Virtual meeting

Integrating altimetry and coastal ocean observing systems for coastal circulation applications at multiple temporal and spatial scales

John Wilkin, Julia Levin and Javier-Zavala-Garay
Rutgers, The State University of New Jersey

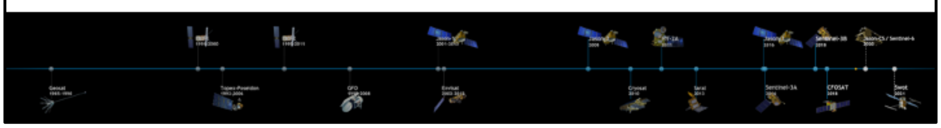
Douglas Vandemark, Hui Feng
University of New Hampshire

Multi-mission near-to-coast range corrected “coastal altimetry” SSH is merged with a high-resolution ocean circulation model (ROMS; Regional Ocean Modeling System) using 4-dimensional variational (4D-Var) methods for data assimilation (DA).

The system is implemented for the Gulf of Maine, Mid-Atlantic Bight and adjacent Slope Sea of the Northwest Atlantic Ocean.

The near-real-time DA model produces a 3-day forecast every day in support of U.S. IOOS. The impact of altimeter data in the system is evaluated using the Observation Impact analysis approach made possible by the ROMS 4D-Var design.

Altimeter based data products (including GlobCurrent analyses and Sentinel-3A SAR) are also evaluated for their ability to represent mean and variability of coastal currents in the Gulf of Maine and adjacent shelf waters.



Observation Impact Analysis: Evaluating the influence of individual observations on the data assimilation analysis:

$$\mathbf{x}_a = \mathbf{x}_\mathbf{b} + \tilde{\mathbf{K}}(\mathbf{y} - H(\mathbf{x}_\mathbf{b}))$$

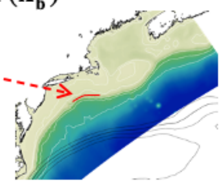
analysis = prior + gain times innovation

innovation **d** is model-data misfit

$$\mathbf{d} = \mathbf{y} - H(\mathbf{x}_\mathbf{b})$$

Define some scalar functional of model state $I(\mathbf{x})$ e.g. transport through a section:

$$I_1 = \frac{1}{\tau}\int_0^\tau \int_S \int_{-h}^{\zeta} u_n \, dz\, ds\, dt$$



Change due to having assimilated data is:

$$\Delta I = I(\mathbf{x}_\mathbf{a}) - I(\mathbf{x}_\mathbf{b})$$
$$= I(\mathbf{x}_\mathbf{b} + \tilde{\mathbf{K}}\mathbf{d}) - I(\mathbf{x}_\mathbf{b})$$
$$\simeq \mathbf{d}^T \tilde{\mathbf{K}}^T (\partial I / \partial \mathbf{x})|_{\mathbf{x}_\mathbf{b}}$$

from Taylor series expansion

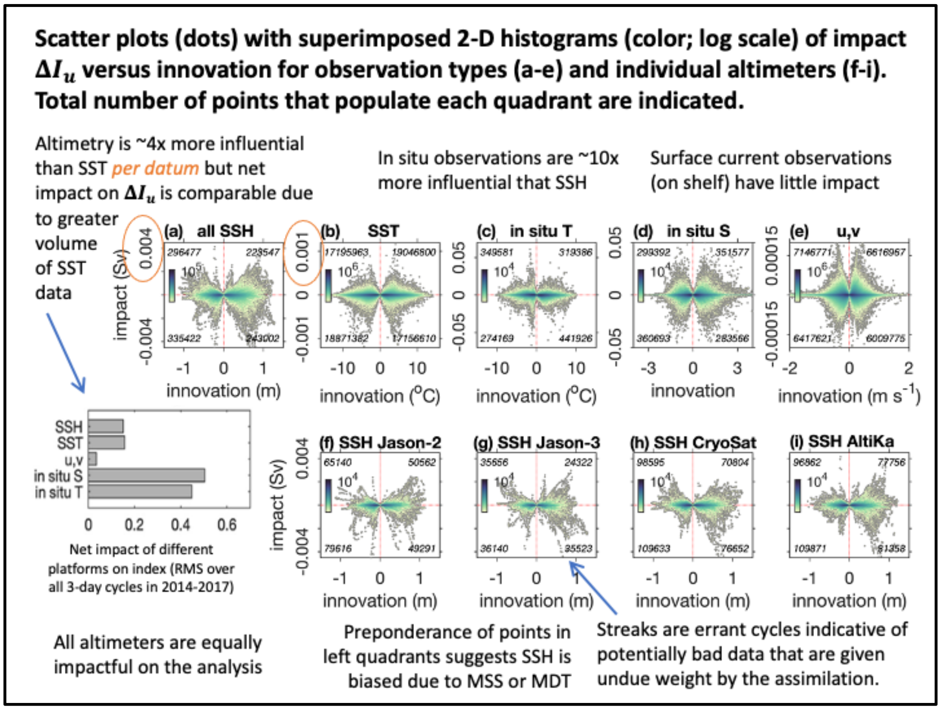
The vector of impacts $\mathbf{g}$ is computed from the practical gain matrix $\tilde{\mathbf{K}}$ reconstructed with the Adjoint model from saved Lanczos vectors of the 4D-Var conjugate gradient minimization

$$\Delta I = \mathbf{d}^\mathbf{T}\mathbf{g} = \sum_{i=1}^{N} d_i g_i$$

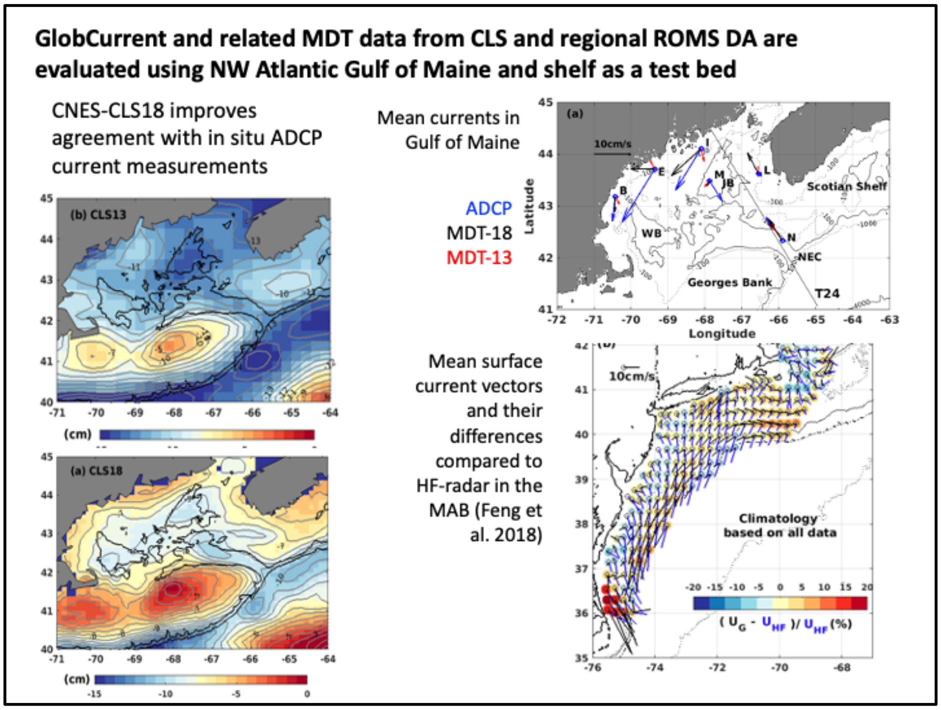
Each element of g is *uniquely* associated with a single observation.

We sum the impacts for subset $i=1,N$ of observation type and/or altimeter satellite to examine the respective net impacts

- We wish to explore how the act of assimilating data changes ocean state estimates, and which data have the greatest influence. We do this by defining a scalar *index* of a feature of the circulation and comparing that index evaluated from the forecast versus from analysis. The sensitivity of the change in the index to the data is the Observation Impact. It is effectively calculated by differentiating the change in index with respect to the vector of observations.
- ROMS 4D-Var minimizes a cost function using a Conjugate Gradient (CG) algorithm. This allows reconstruction of a reduced-rank approximation to the Kalman gain matrix using the (saved during 4D-Var analysis) normalized CG search directions from the *m* iterates (the Lanczos vectors). This approximation is readily inverted allowing the computation of the adjoint Kalman K^T gain highlighted in the slide.
- dI/dx is sensitivity of the index to the ocean state, x, in model space, and is an arithmetic function of the model variables on their grid. It sets the forcing to the adjoint model run. "Matrix" K^T projects from model space to the observation space such that $g = K^T$ dI/dx is a vector the size of the observation and gives the datum-by-datum contribution of each observation to the change in index I.
- We gather partial sums of the elements of *g* to aggregate the net impact of particular data types, or other subsets of assets/platforms in the observing network.

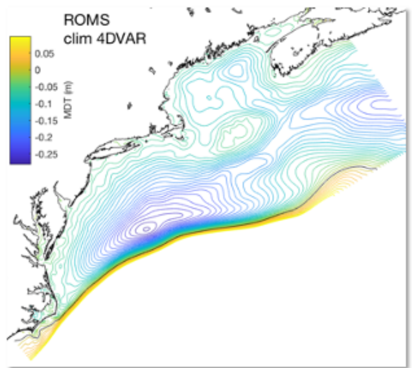


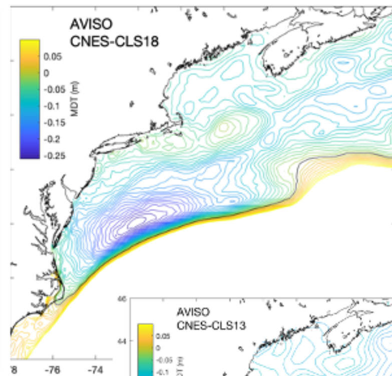
- "butterfly plots" of impact versus innovation (original model-data misfit prior to DA) is just *one* way of visualizing the impact. When innovation is small, impact is small (model and data agree). Impact grows as innovation grows and demands greater DA adjustment. Influence wanes at large innovation because the assimilation is less able to reconcile the model-data misfit with surrounding observations and the forecast which embodies the history of all prior data assimilated and the physics in the forecast model.
- per datum influence of altimetry is larger than SST, but given the larger volume of SST observations the net impact is comparable.
- In situ observations of T and S are extremely valuable for this metric (across-shelf volume transport). Satellite observations alone must be complemented by subsurface data in order to obtain skillful analyses of the 3-D coastal ocean.
- All altimeters assimilated in 2014-2017 (J-2, J-3, Cryosat and AltiKa) had comparable impact.
- Occasional streaks of high impact for small innovation emanate from the origin indicating undue weight, likely due to dynamically inconsistent (bad?) data.
- The preponderance of points in left two quadrants for SSH indicate observation bias – likely problems with MSS or MDT or both. It is plausible that the MDT is biased low, consistent with weaker along-shelf currents than in reality.

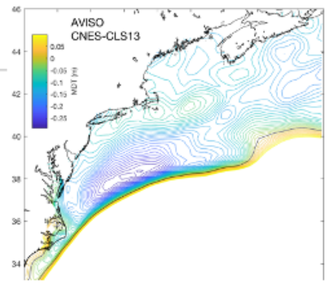


- We have undertaken several studies of the skill of the “L4” current products in comparison to moored ADCPs in the Gulf of Maine (shown above) and surface currents from HF-radar in the MAB (see Feng et al 2018).
- CNES-CLS18 improves agreement with in situ ADCP current measurements
- Improvements should translate to improved SSHA data that feed into regional data assimilative forecasts

Mean Dynamic Topography of the MAB and GoM

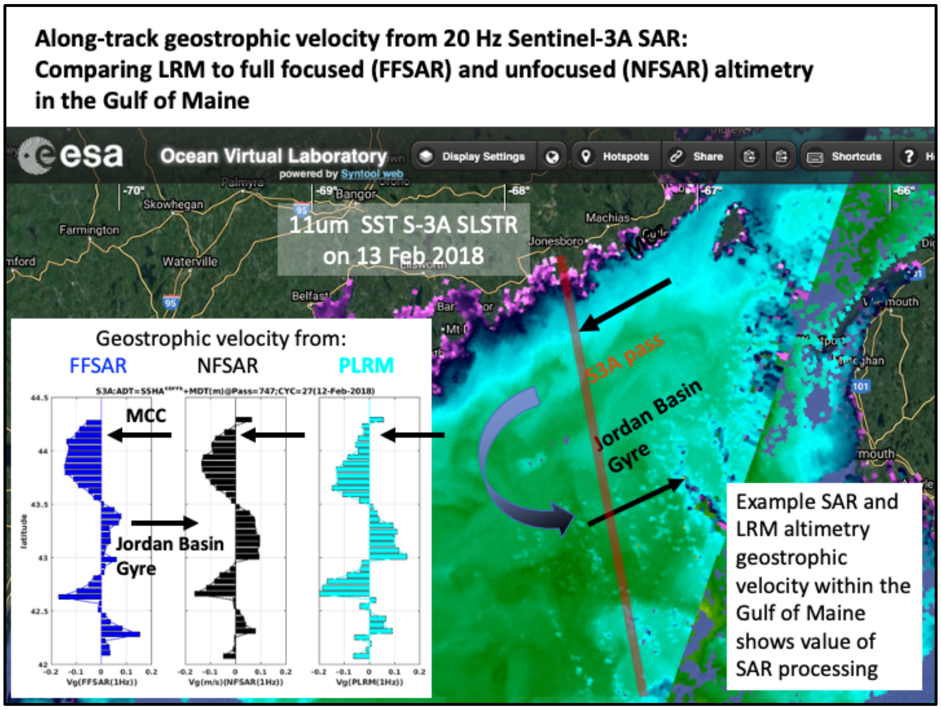






While CNES-CLS18 has improved representation of Gulf of Maine Coastal Current it still does not approach the intensity captured in ROMS DA analysis.

How do we get regional dynamical model-based information into global MDT products?



- Results from Sentinel-3A SAR altimeter assessments indicate that more precise resolution of SSHA is obtained from both fully-focused (FFSAR) and unfocused (NFSAR) leading to derived geostrophic currents that differ from previous LRM altimeter measurements.
- We observe this both inside the Gulf of Maine and along the coastline of Nova Scotia. The Gulf of Maine SST image shown here is coincident with S3 altimeter data collection on 13 Feb. 2018. Cold water in the north coincides with the Maine Coastal Current (MCC), a persistent narrow along-coast current that we have been unable to resolve using the long-term LRM mission data. The figure at left shows that we see a much better depiction on this single track when using the SAR altimeter data (left two panels).
- Another feature that is now resolvable using SAR altimetry is a cyclonic gyre just south of the MCC. This Jordan Basin gyre is a fundamental circulation whose presence and strength changes with season and with intermittent and ecologically important shelf-slope water mass exchanges. We are comparing these derived geostrophic velocities to both in situ ADCP observations and to a regional ocean model in ongoing study of these exchanges. For further detail, see also the presentation of Feng et al. in this meeting under the coastal splinter session.

Project publications

Rio, M.-H., S. Mulet, H. Etienne, C. Artana, M. Cancet, G. Dibarboure, H. Feng, N. Picot, C. Provost, P.T. Strub, The new CNES-CLS18 Global Mean Dynamic Topography , in preparation.

Levin, J., H. Arango, B. Laughlin, E. Hunter, J. Wilkin and A. Moore, (2020a), Observation Impacts on the Mid-Atlantic Bight Front and Cross-Shelf Transport in 4D-Var Ocean State Estimates, Part I – Multiplatform Analysis, Ocean Modelling, revised https://www.myroms.org/Papers/Levin_etal_2020a_OM.pdf

Levin, J., H. Arango, B. Laughlin, E. Hunter, J. Wilkin and A. Moore, (2020b), Observation Impacts on the Mid-Atlantic Bight Front and Cross-Shelf Transport in 4D-Var Ocean State Estimates, Part II – The Pioneer Array, Ocean Modelling, revised https://www.myroms.org/Papers/Levin_etal_2020b_OM.pdf

Lopez, A., J. Wilkin and J. Levin, (2020), Doppio – a ROMS (v3.6)-based circulation model for the Mid-Atlantic Bight and Gulf of Maine: configuration and comparison to integrated coastal observing network observations, Geosci. Mod. Devel. 13, 3709-3729, https://doi.org/10.5194/gmd-13-3709-2020

Levin, J., H. G. Arango, B. Laughlin, J. Wilkin and A. M. Moore, (2019), The Impact of Remote Sensing Observations on Cross-Shelf Transport Estimates from 4D-Var Analyses of the Mid-Atlantic Bight, Advances in Space Research, https://doi.org/10.1016/j.asr.2019.09.012

Feng, H., D. Vandemark, and J. Wilkin, (2018) Examining the accuracy of GlobCurrent upper ocean velocity data products on the Northwestern Atlantic shelf, Rem. Sens., (10) 1205, doi:10.3390/rs10081205

Wilkin, J., J. Levin, A. Lopez, E. Hunter, J. Zavala-Garay, and H. Arango, (2018), A coastal ocean forecast system for the U.S. Mid-Atlantic Bight and Gulf of Maine, In: New Frontiers in Operational Oceanography, E. Chassignet, A. Pascual, J. Tintoré and J. Verron (Eds.), GODAE OceanView, 593-624, doi: 10.17125/gov2018.ch21

Levin, J., J. Wilkin, N. Fleming and J. Zavala-Garay, (2018), Mean circulation of the Mid-Atlantic Bight from a climatological data assimilative model, Ocean Modelling, 128, 1-14, doi:10.1016/j.ocemod.2018.05.003

Cipollini, P., J. Benveniste, F. Birol, M. J. Fernandes, E. Obligis, M. Passaro, P. T. Strub, G. Valladeau, S. Vignudelli and J. Wilkin, (2017), Satellite Altimetry in Coastal Regions, in: Satellite Altimetry over Oceans and Land Surfaces, Eds. D. Stammer and A. Cazenave, CRC Press, Boca Raton, pp. 343-380.

Feng, H., D. Vandemark, and J. Wilkin, (2016), Gulf of Maine salinity variation and its correlation with upstream Scotian Shelf currents at seasonal and interannual time scales, J. Geophys. Res., 121, 8585–8607