What forcing mechanisms affect interannual sea level co-variability between the Northeast and Southeast Coasts of the United States?

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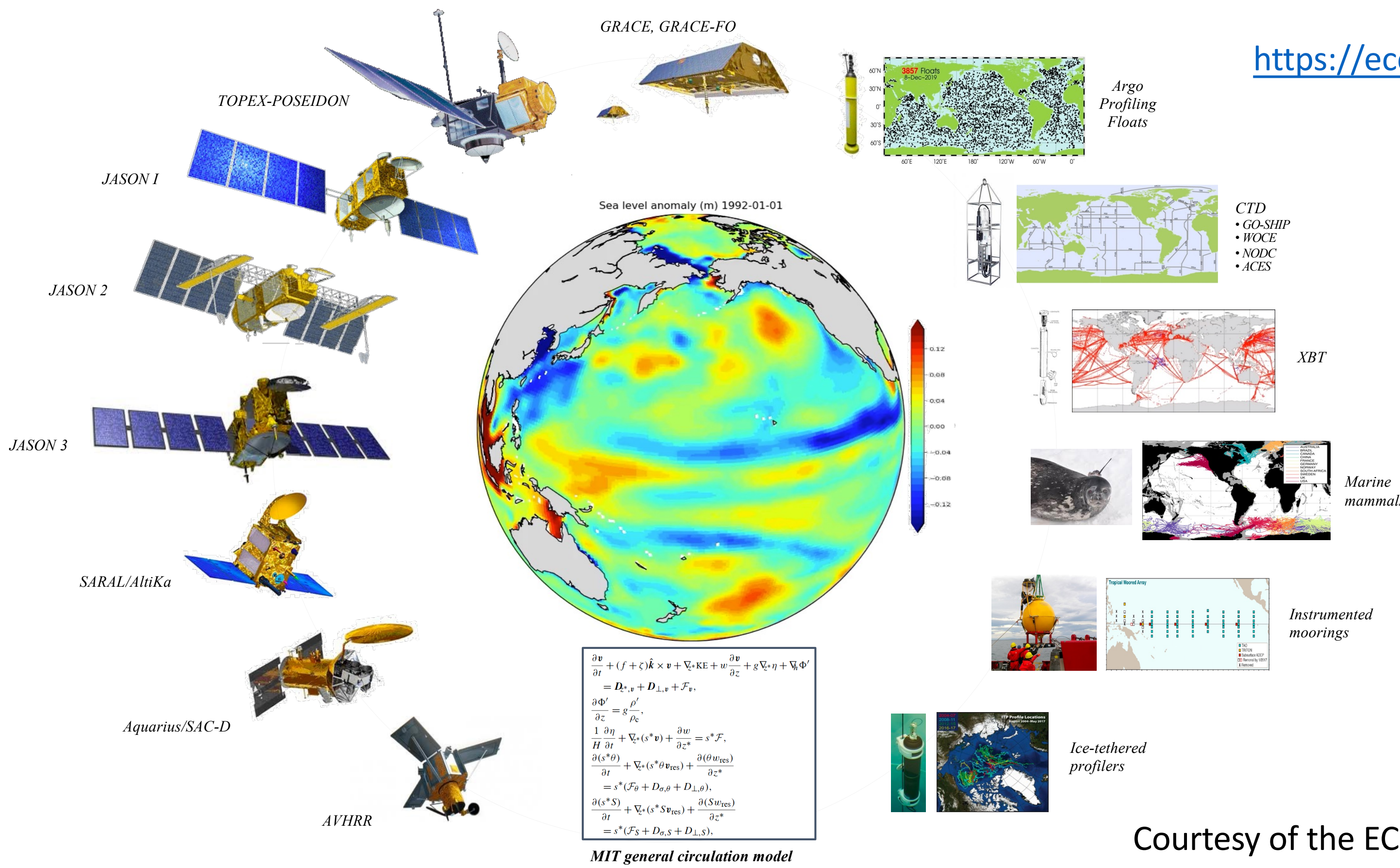
Motivation

- Sea level anomalies (SLA) in the northeast (**NE**) and southeast (**SE**) U.S. coasts co-vary within each sector, but not between the two sectors.
- The forcing mechanisms causing this behavior are not well understood.
- Here we use **ECCO** ocean state estimation and adjoint sensitivity analysis to investigate the causes, focusing on interannual time scales.
- Improving this understanding is important for sea level prediction and evaluation of climate models.

Estimating the Circulation & Climate of the Ocean (ECCO) ocean state estimates:

synthesis of global ocean data with MITgcm using an adjoint-based inverse estimation method, with the adjoint model providing sensitivities of ocean state to forcings

https://ecco.jpl.nasa.gov

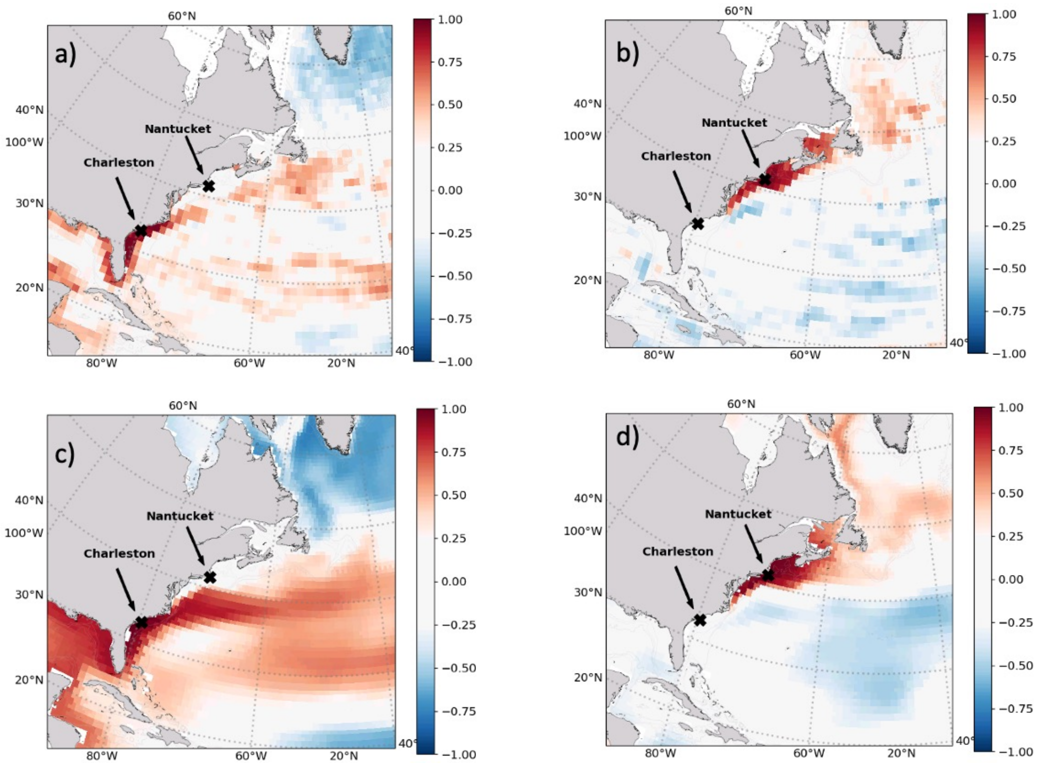


Courtesy of the ECCO team

SLA in the NE & SE U.S. coasts are well correlated within NE or SE, but not between NE & SE

Altimetry (**AVISO**)

ECCO



Co-variability of interannual SLA along the NE or SE US coasts, separated by Cape Hatteras

Correlation coefficients of **AVISO** SLA at Charleston (a) and Nantucket (b) with SLA elsewhere.
Correlation coefficients of **ECCO** SLA at Charleston (d) and Nantucket () with SLA elsewhere.

(A 13-month low-pass filter applied to the monthly mean SLAs after removing the global mean and the mean seasonal cycle)

Method

(for details: Wang, Lee, & Piecuch et al. 2022, Ferderikse; Lee, & Wang et al. 2022; Wang, Lee, & Frederikse et al. 2023)

- Compute sensitivities of Nantucket & Charleston SLA to atmospheric forcing (zonal & meridional wind stress, air-sea heat and freshwater fluxes) using ECCO adjoint model, as a function of forcing type, location, and forcing lead time (up to over 2 decades).

- Reconstruct ECCO estimation of Nantucket & Charleston SLA by "convolving" the SL sensitivity to atmospheric forcings with ECCO atmospheric forcing anomalies (success rate ~90%).

  Assuming SLA (J) responds to forcing anomalies (F) linearly, we expand J into a Taylor series:

  $$J(t) \approx \sum_i \sum_s \sum_{\Delta t} \frac{\partial J}{\partial F_i(s,\Delta t)} \delta F_i(s, t-\Delta t),$$

  where $\frac{\partial J}{\partial F_i(s,\Delta t)}$ is the adjoint sensitivity of SLA to forcing F_i at lead time Δt and location s; and $\delta F_i(s, t-\Delta t)$ is forcing F_i at some prior time $t-\Delta t$ (i.e., target time, t, minus lead time, Δt).

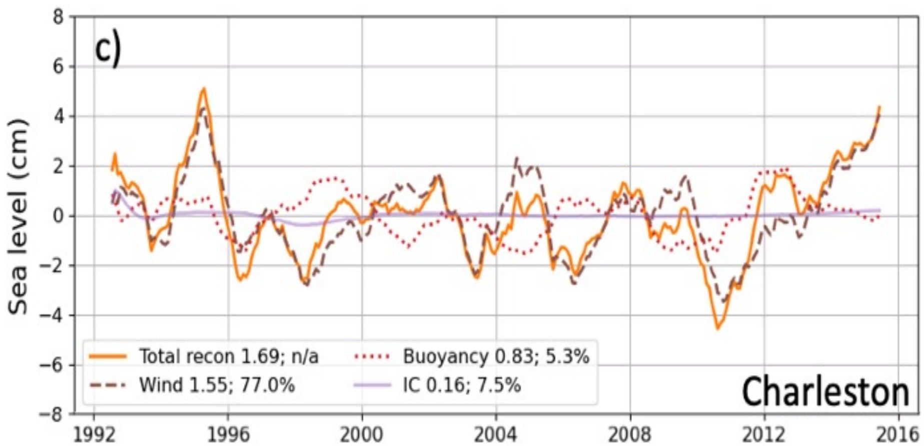
- Assess the relative contributions of wind stress & buoyancy forcing.

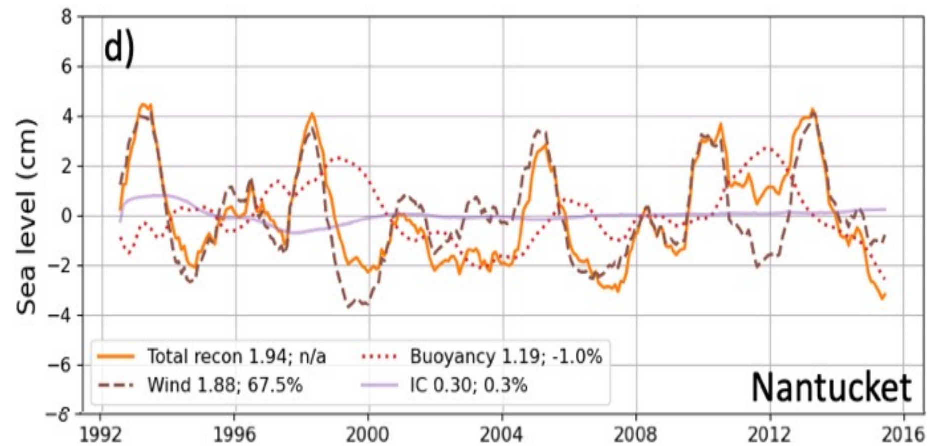
- Contrast regional atmospheric forcing contributions (e.g., using the so-called "Forcing Influence Maps").

- Quantify what regional forcings improve or degrade the co-variability of Nantucket & Charleston SLA.

Highlight of results: 1

Wind stress explain ~70% of the interannual SL variance both for Charleston and Nantucket

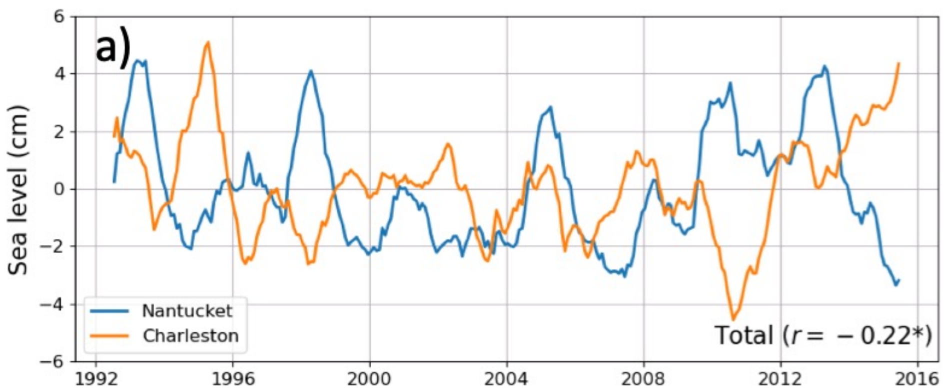


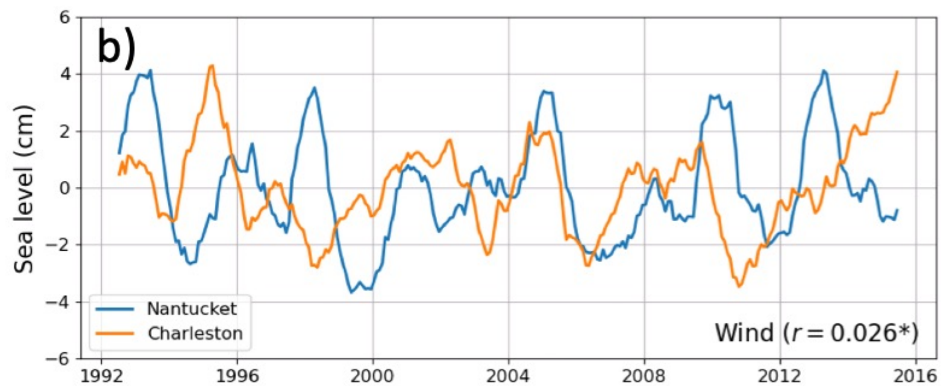


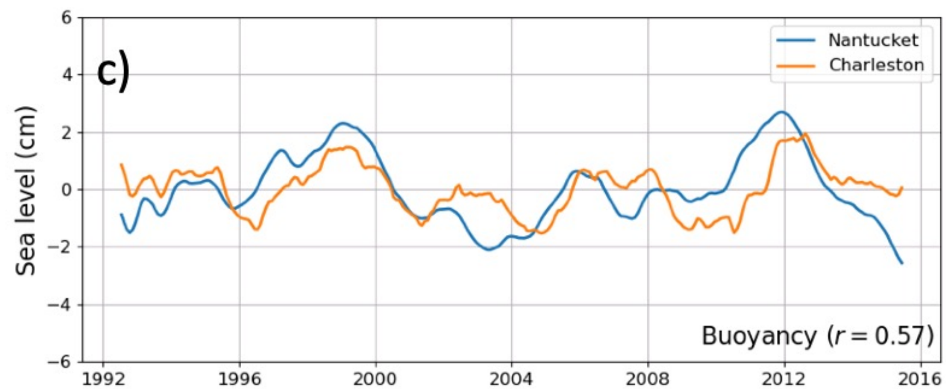
Panels (c) and (d) show decomposition of the total reconstruction of SLA into wind and buoyancy forcing contributions for (c) Charleston and (d) Nantucket. The two numbers in the legend are standard deviation (cm) and explained variance of the total reconstruction by each contribution.

Highlight of results: 2

- Wind stress tends to make Nantucket & Charleston interannual SLA less correlated.
- Buoyancy forcing tends to make Nantucket & Charleston interannual SLA more correlated.







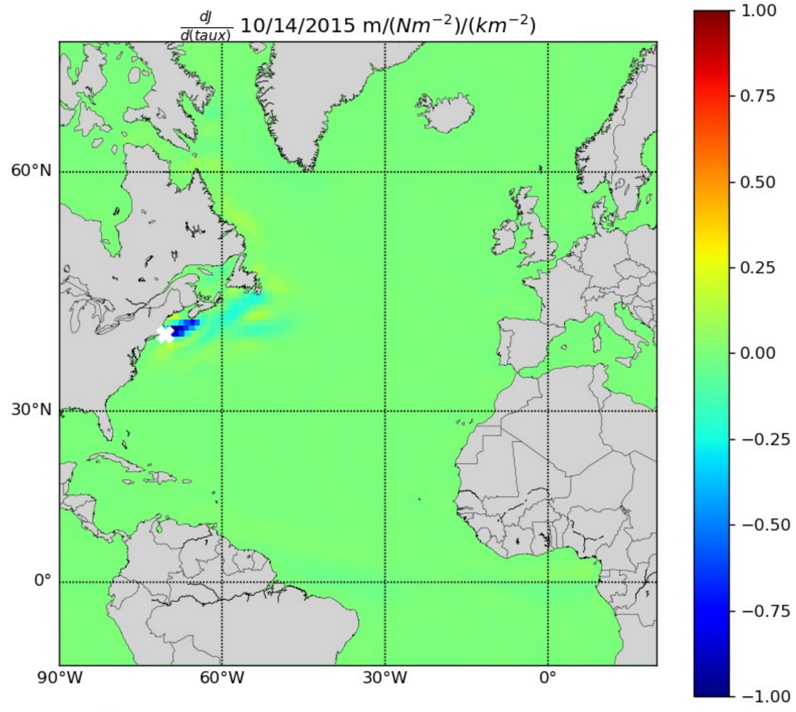
Comparison of SLAs (cm) between Charleston and Nantucket reconstructed using (a) all forcings, (b) wind stress, and (c) buoyancy forcing.

(The *r* numbers are the correlation coefficients for each pair; * indicates insignificant correlation coefficient at the 95% confidence level)

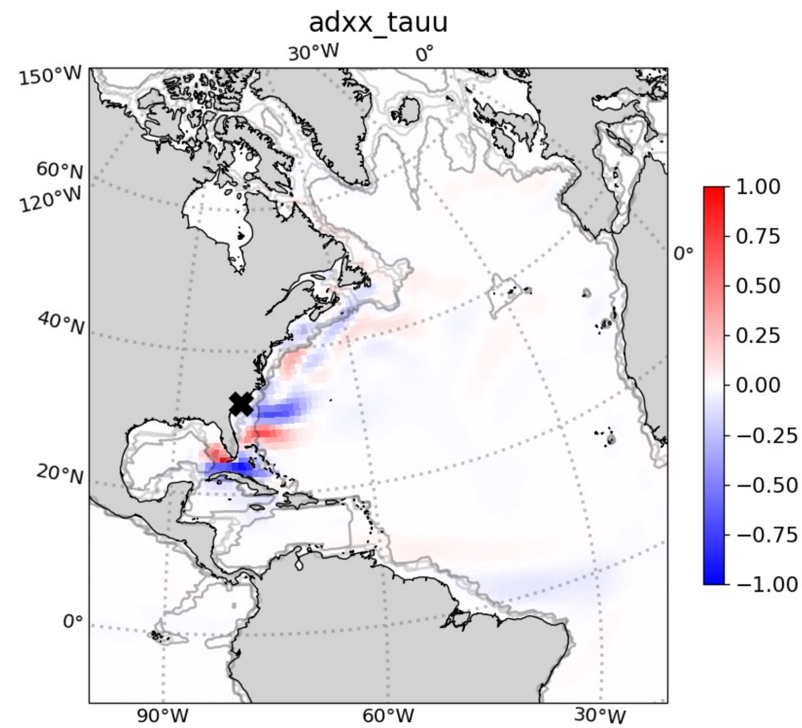
Highlight of results: 3

Examples of adjoint sensitivity maps

Sensitivity of **Nantucket** SL to zonal wind stress from 3 months before

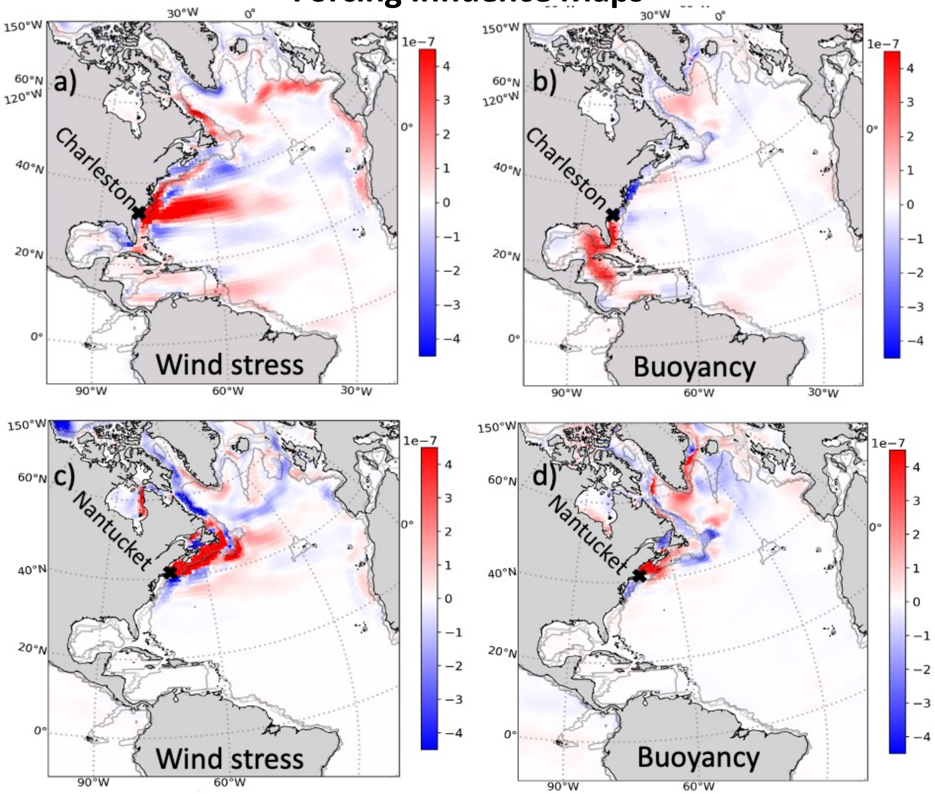


Sensitivity of **Charleston** SL to zonal wind stress from 3 months before



Key results

Forcing Influence Maps

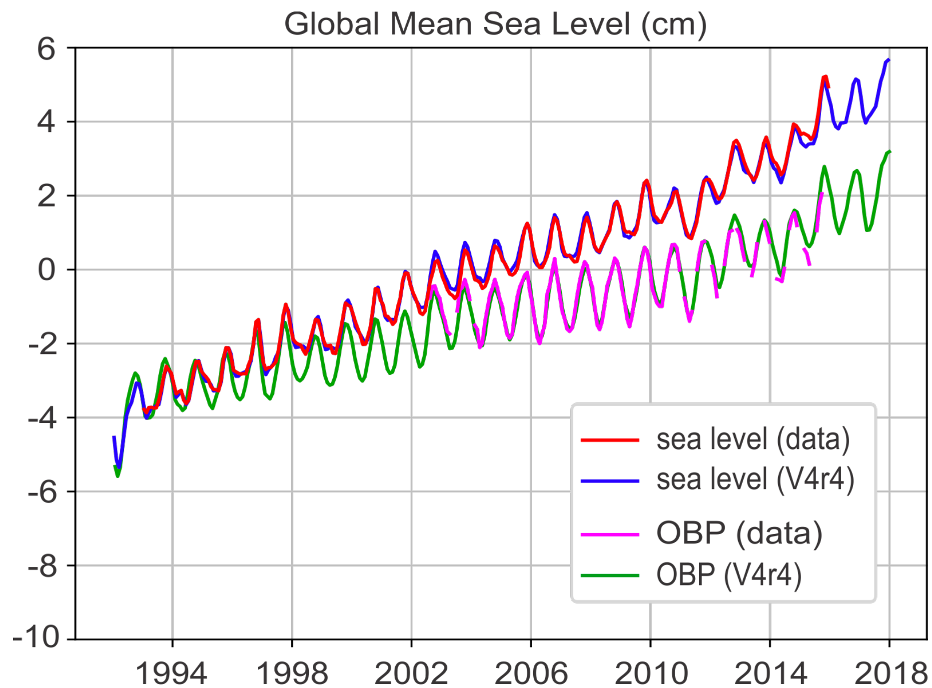


- Onshore winds north of Cape Hatteras & buoyancy forcing both cause Nantucket & Charleston SLA to co-vary.
- Offshore winds contribute much more to interannual SLA at Charleston than to that at Nantucket.
- **Offshore winds are the major factor causing incoherent interannual SLA between Nantucket and Charleston.**
    - **Open-ocean wind stress curl forces Rossby waves propagating slowly towards Charleston, in contrast to onshore winds that force coastal waves propagating down the coast rapidly.**
    - **Important info for ML-based SLA prediction.**

Forcing influence maps for Charleston SLAs due to a) wind stress and b) buoyancy forcing. Panels c) and d) are the same as a) and b) but for Nantucket. The values represent fractions per unit area (km^{-2}) of variance of total reconstructed interannual SLA variations at Charleston or Nantucket explained by reconstructed SLA using forcing at each location.

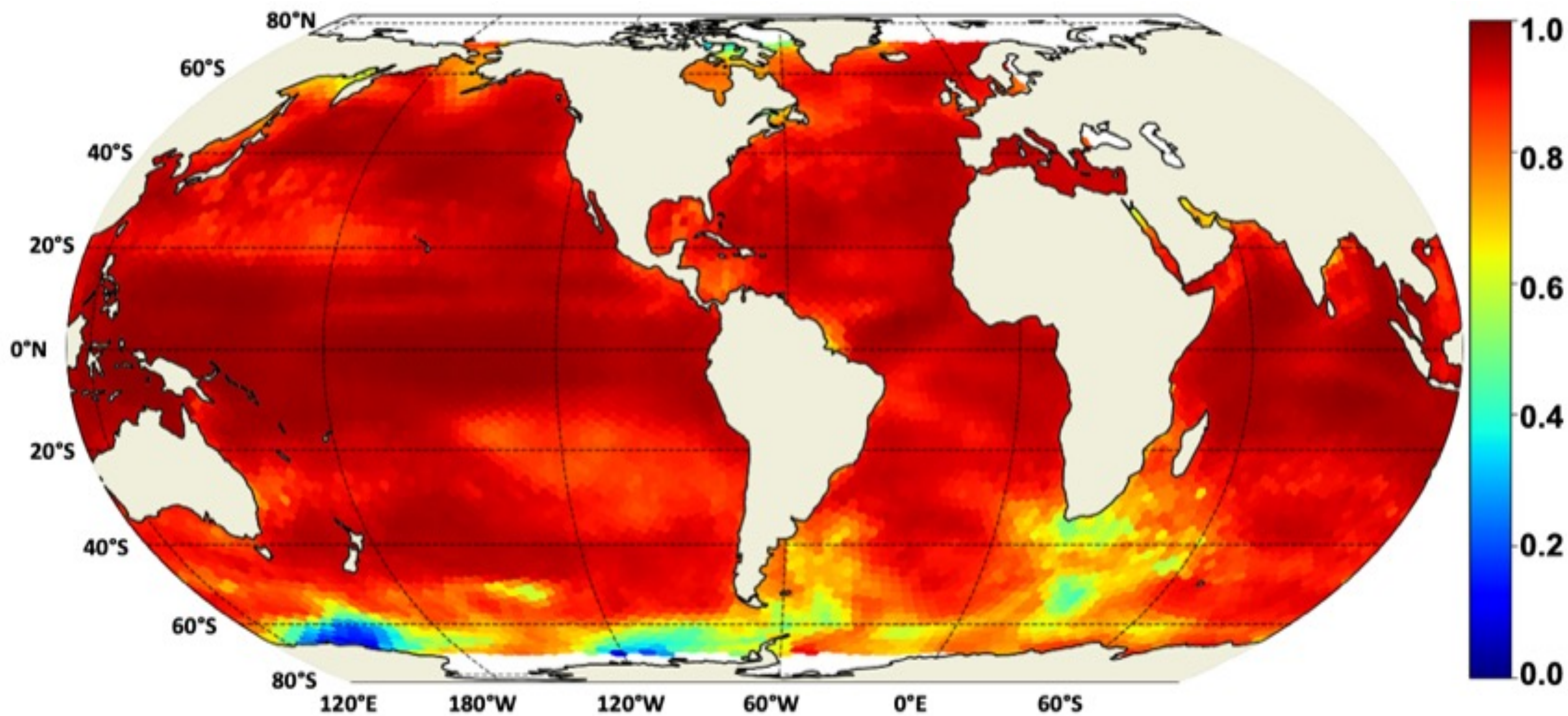
Backup slides

Fidelity of ECCO state estimates: comparison of global mean SL & ocean bottom pressure (OBP) between ECCOv4r4 and satellite data (assimilated)

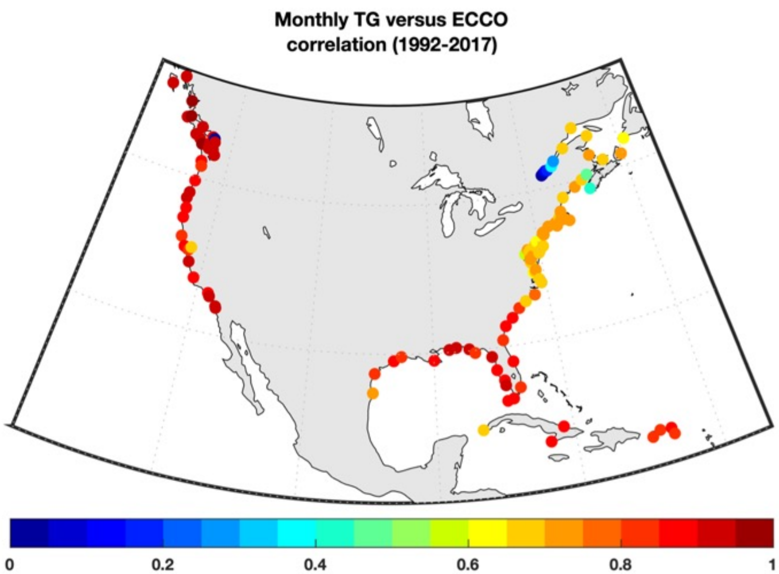


Courtesy of the ECCO team

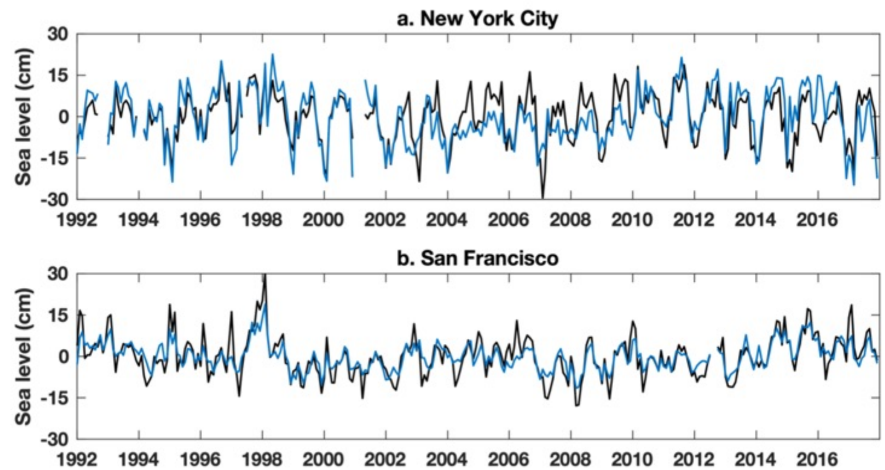
Correlation of monthly ECCO-v4 & altimeter SLA



Fidelity of ECCO state estimates:
comparison of regional SL between ECCOv4r4 & tide gauge (TG) data (independent)



Correlation of monthly SLA between ECCOv4r4 and TG data around the North American coasts.



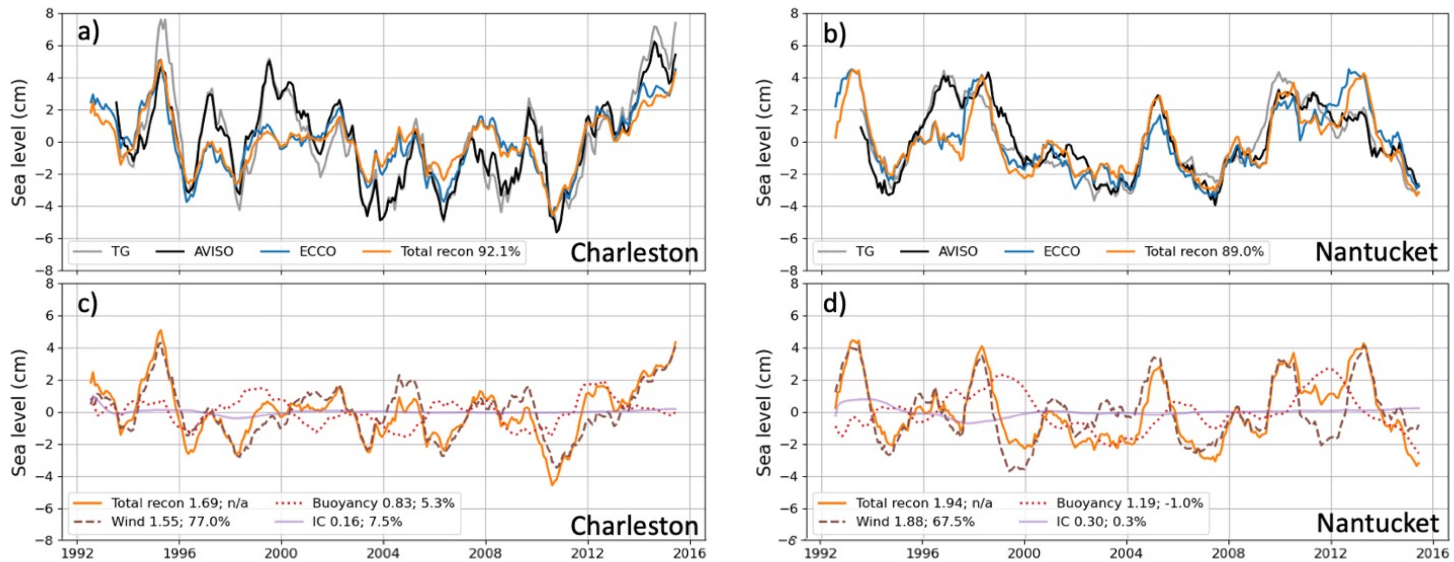
SLA time series off New York City and San Francisco (Blue-ECCO, Black: TG).

Because VLM affects long-term trends of tide gauge data, the linear trends during the 1992-2017 period were removed from all time series. Atmospheric pressure effects were included in all time series.

Courtesy of Chris Piecuch

SLA comparison: tide gauge, Altimetry/AVISO, ECCO estimate, and adjoint-based reconstruction

Relative contribution of wind stress and buoyancy forcing to SLA reconstruction (13-month low-pass)



SLA (cm) from tide gauge (gray), AVISO (black), ECCO (blue), and total reconstruction (orange) from all contributions for (a) Charleston and (b) Nantucket. Panels (c) and (d) show decomposition of the total reconstruction into various contributions for (c) Charleston and (d) Nantucket. The two numbers in the legend are standard deviation (cm) and explained variance of the total reconstruction by each contribution.