Investigating Steric Sea Level Anomalies: Combining satellite altimetry, GRACE/GRACE-FO, and Argo.

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Closing the Sea Level Budget

Two ways of estimating SSL:

- Direct = Use Argo float data
- Indirect = Satellite Altimetry – Satellite Gravity

To close the SL budget: global direct = global indirect

Others often use grided products of altimetry, GRACE/GRACE-FO, and Argo temperature (T) and salinity (S)

We are individually integrating Argo profile data instead of starting with pre-made TS grids.

'First guess' of SSL by mapping Altimetry – GRACE & updating that map with Argo:

- First guess SSL = $\Delta SSL_{sat} = \langle \text{Altimetry} - \text{Grace} \rangle_{\text{Optimaly Interpolated}}$
- Updated SSL = $\langle \Delta SSL_{sat} \rangle_{\text{Optimaly Interpolated}} + \langle \Delta SSL_{Argo} - \Delta SSL_{sat} \rangle_{\text{Optimaly Interpolated}}$

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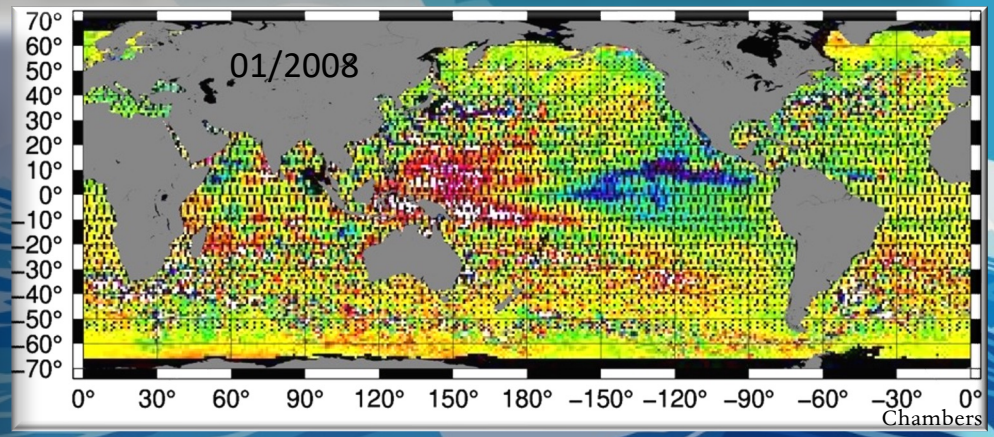
Start with satellite-derived steric sea level anomalies (altimetry – grace):

- **Altimetry**: 1-Hz Jason-1, Jason-2, Jason-3 along-track SSHA product produced by Beckley et al.
- **Gravity**: GRACE/GRACE-FO from JPL Release-06 Mascons

Altimetry – Grace (raw)



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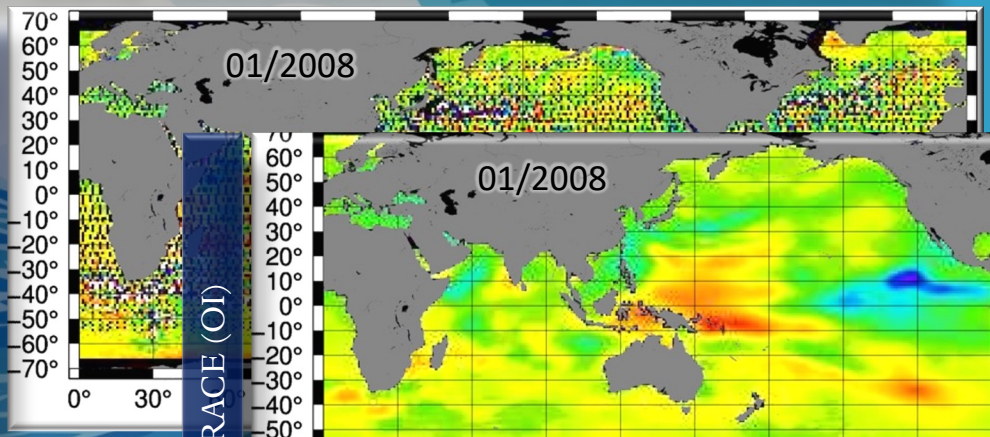
Spatial Covariance Function (best-fit to 2005-2010 covariance):

$$R_{signal}(r) = 25e^{-\left(\frac{r}{1675\ km}\right)^2}$$

$$R_{error}(r) = 82e^{-\left(\frac{r}{100\ km}\right)^2} + 25cm^2 \text{ random}$$

Altimetry – GRACE (raw)



Altimetry – GRACE (OI)

Optimal interpolation (OI) to extract long-wave signal.

Reduce sampling errors due to eddy-scale features. (important for Argo floats)

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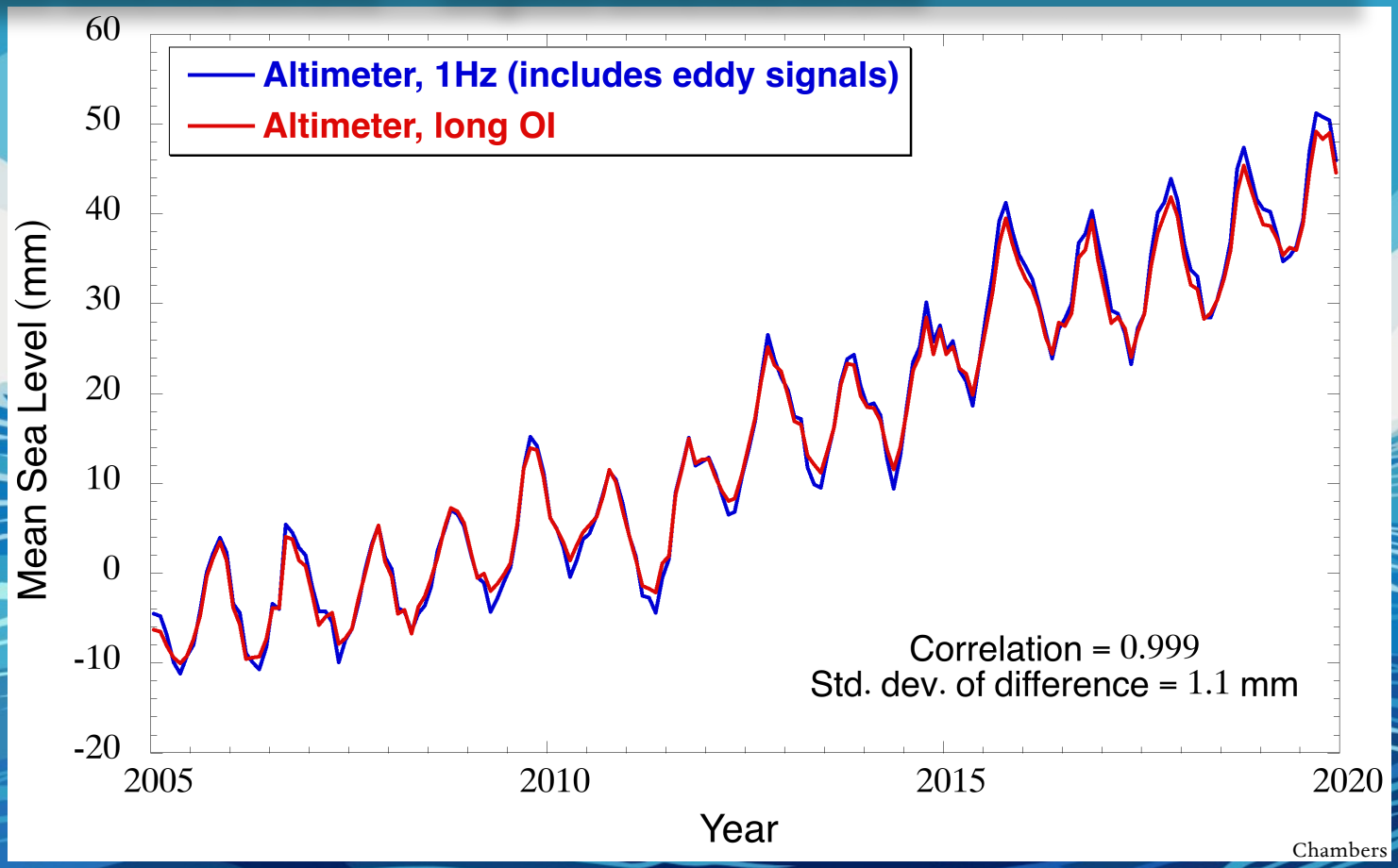
Raw Global Mean Sea Level and Long-wave Global Mean Sea Level:



Average long-wave GMSL variations from OI is about same as raw data.

∴ Long-wave SSLA maps sufficient for determining global SSLA.

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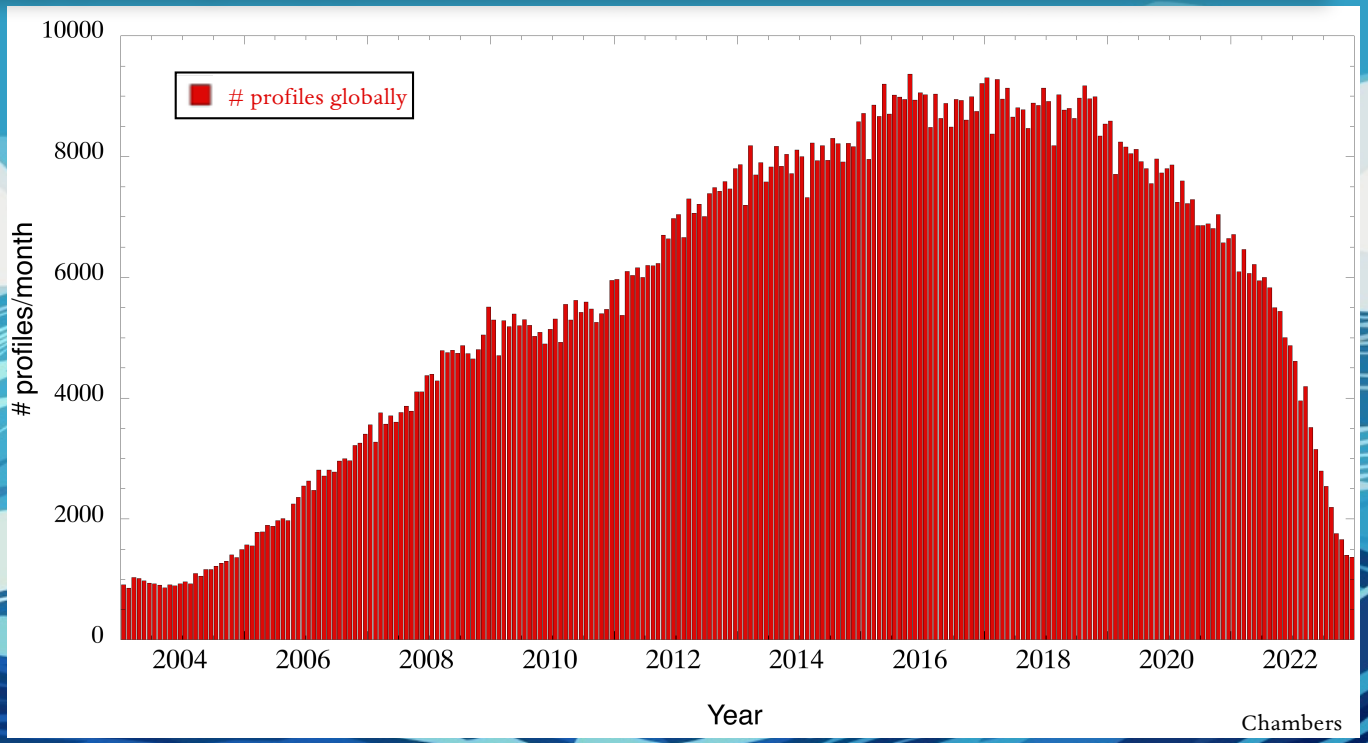
Updating the map with Argo

- Using Argo profiling floats (argo.ucsd.edu) to update satellite-derived sea level.
- Only using delayed-time profiles with 'good' quality control flags.
- Using only profiles with depths > 1000m.

Argo profiles (globally) per month (2003 – 2023):



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- Argo profile locations matched with Roemmich & Gilson 2004-2015 Argo T & S climatology
- Climatology and Argo density values are computed using the TEOS-10 Gibbs-SeaWater Oceanographic Toolbox.
- Total Steric Sea Level (SSL) anomalies, Thermosteric Sea Level (TSL) anomalies, and Halosteric Sea Level (HSL) anomalies are calculated:
  - Directly integrated computed density from each Argo profile relative to computed climatology density.

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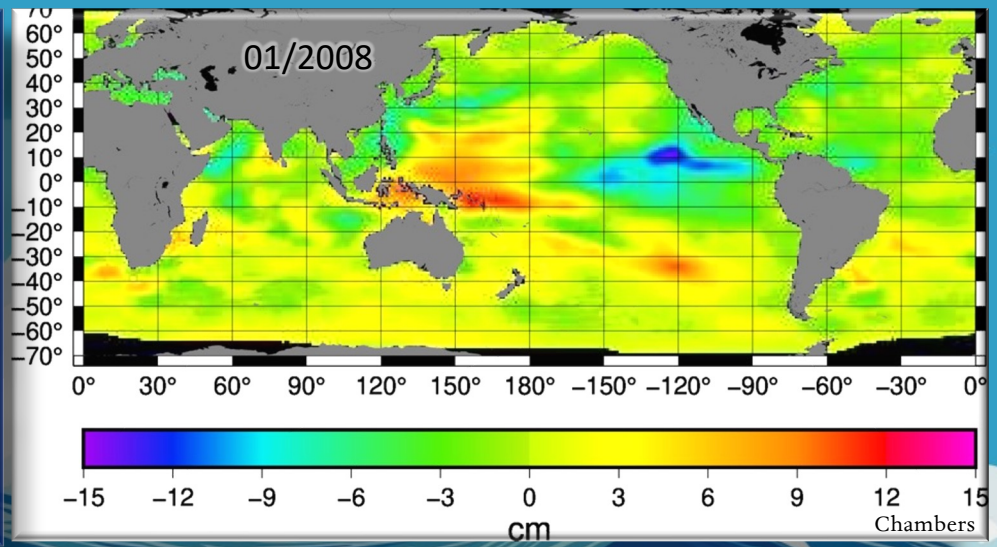
Altimetry – GRACE (OI)



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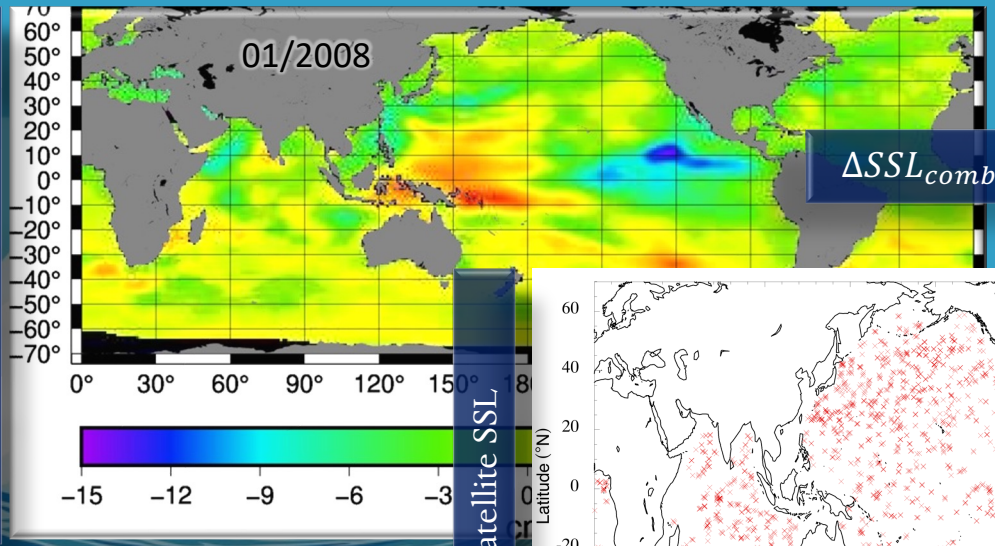
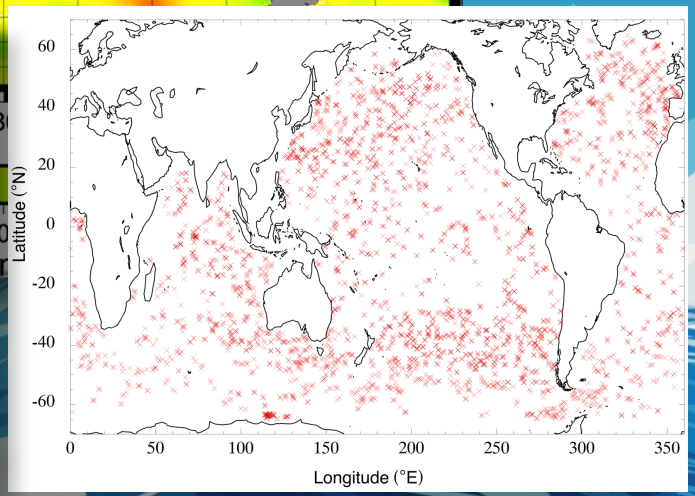
Altimetry – Grace (OI)



$$\Delta SSL_{combined}(\phi,\lambda,t) = \langle \Delta SSL_{Argo} - \Delta SSL_{sat} \rangle_{OI} + \langle \Delta SSL_{sat} \rangle_{OI}$$

Argo SSL – Satellite SSL



Map residuals with same OI function

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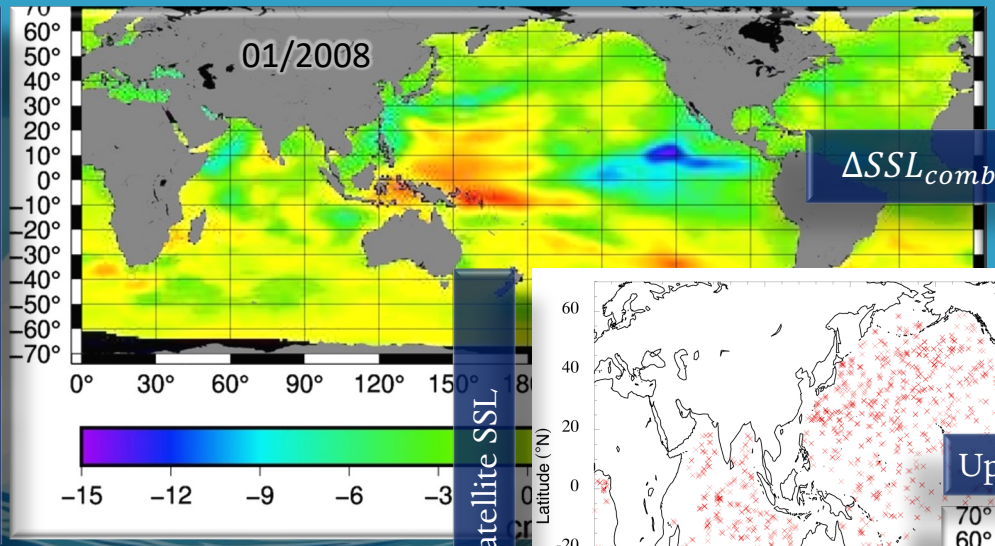
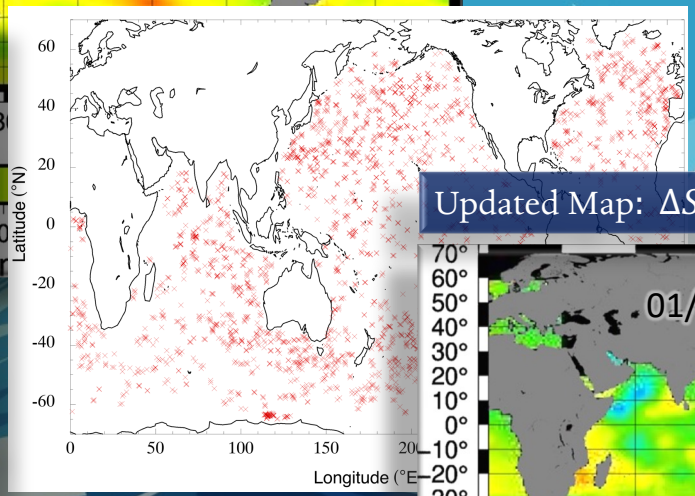
Altimetry – Grace (OI)



$\langle \Delta SSL_{sat} \rangle_{OI}$

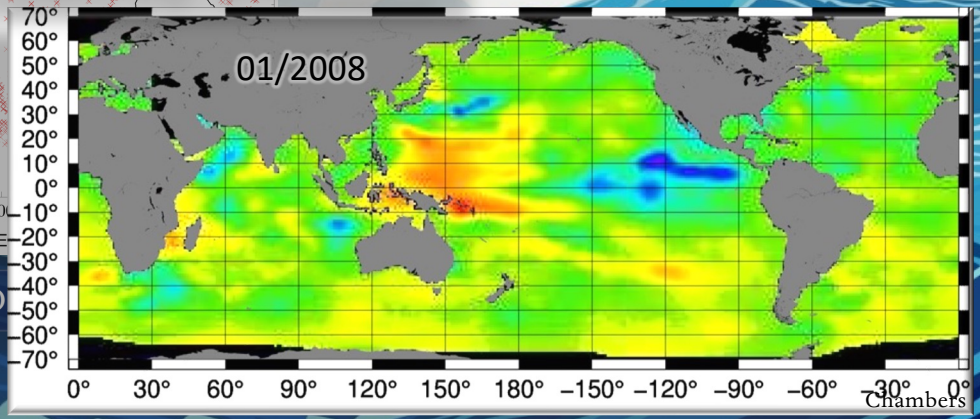
$$\Delta SSL_{combined}(\phi, \lambda, t) = \langle \Delta SSL_{Argo} - \Delta SSL_{sat} \rangle_{OI} + \langle \Delta SSL_{sat} \rangle_{OI}$$

Argo SSL – Satellite SSL



Map residuals with same O

Updated Map: $\Delta SSL_{combined}$:



Chambers

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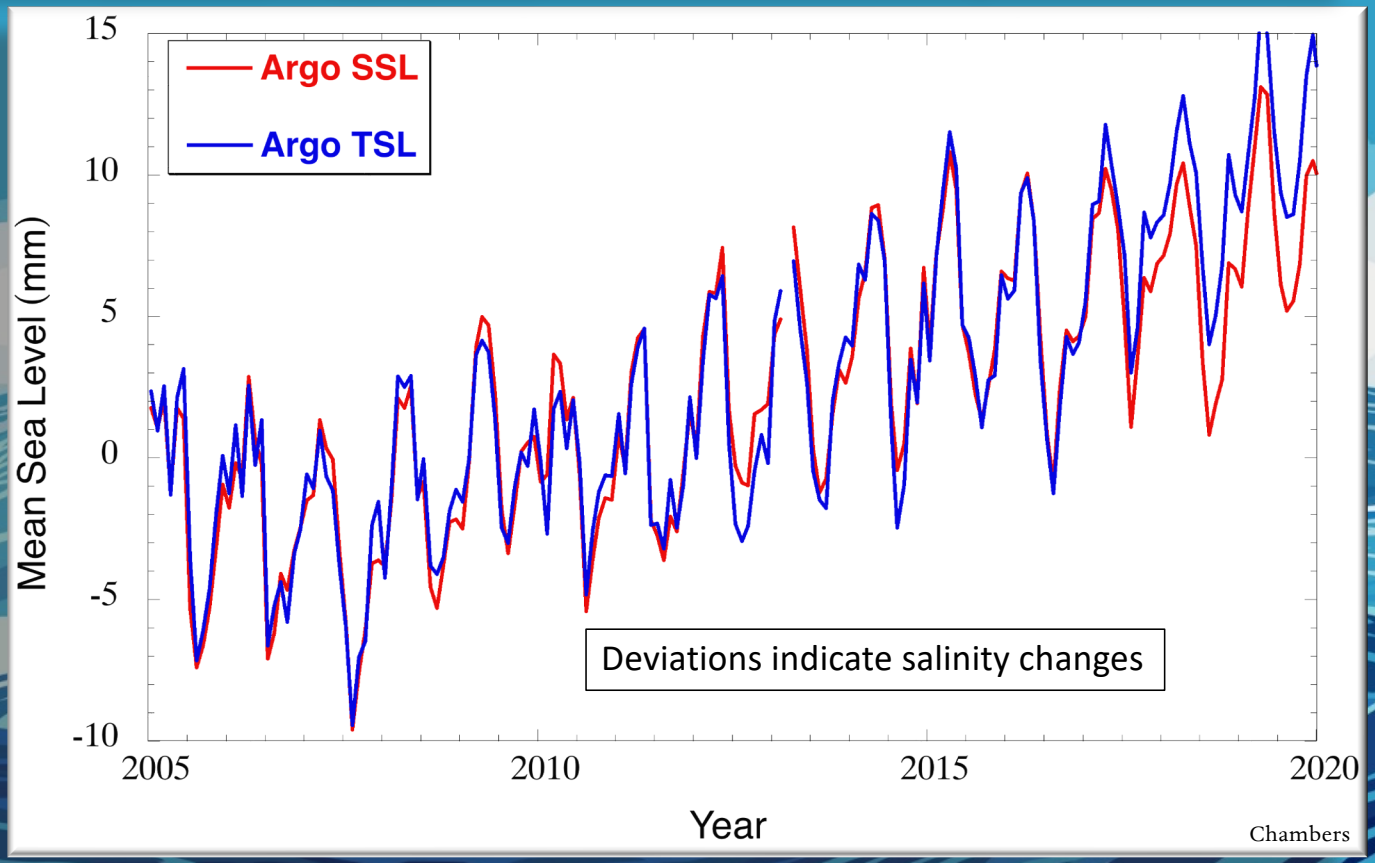
Obstacles

- This mapping method is working well overall.
- But still see a non-eddy-related salty-bias.
- Global salinity variations should be small, so SSL ≈ TSL.
- But SSL and TSL deviation ~2017!
- This indicates a saltier ocean, which makes no sense!

Global Total Steric and Thermosteric Sea Level Anomalies from Argo:



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Temperature-Salinity Diagrams

- Enough suspicious Argo profile data to see this deviation between SSL and TSL anomalies.
- Currently working on objective method to identify suspicious Argo profiles:
  - Individual float TS diagrams in NA

- T and S = set at ocean surface from interaction with atm
- Below surface: Δ in T or S is due to mixing
- Δ in T or S below mixed layer depth (>1000m) = very slow process

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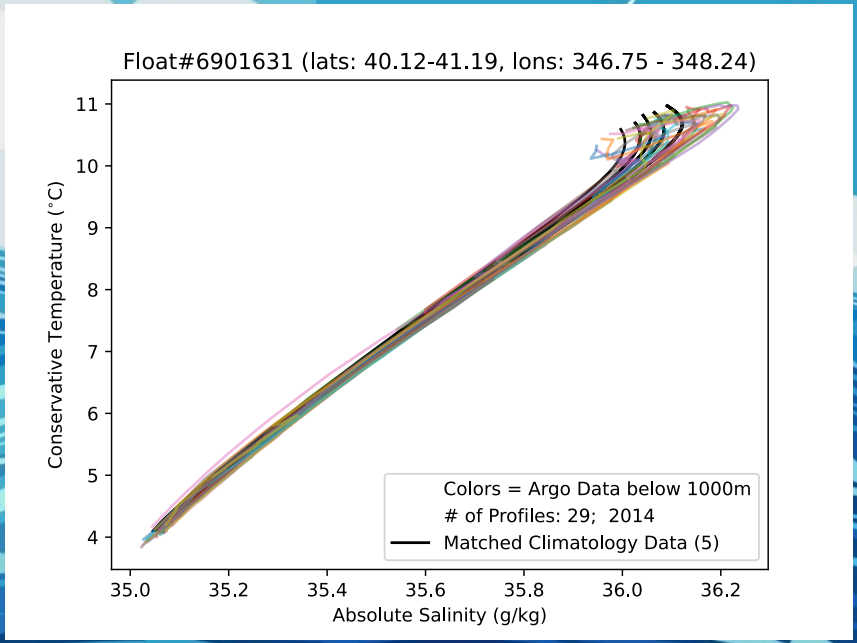
Temperature-Salinity Diagrams

TS plots of >1000m for Argo floats and matching climatology in the North Atlantic



x-axis = Salinity
y-axis = temperature

Colors = Individual Argo float profiles
Black = matching climatology

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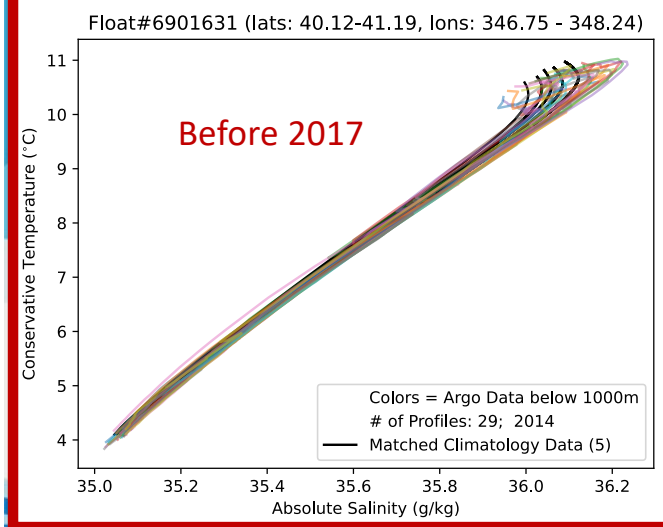
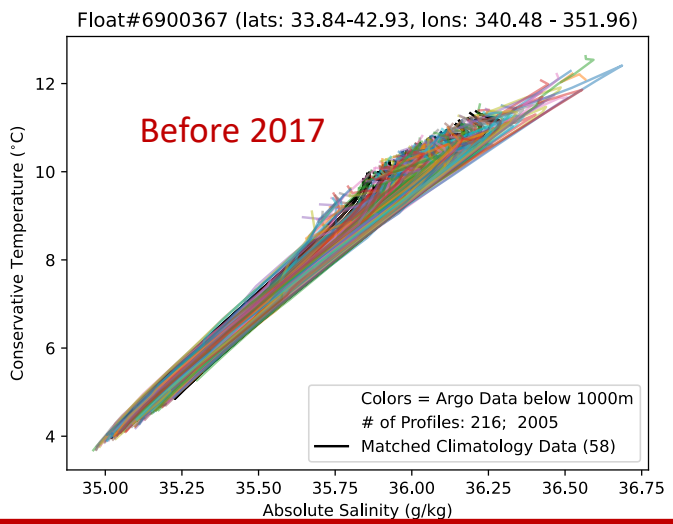
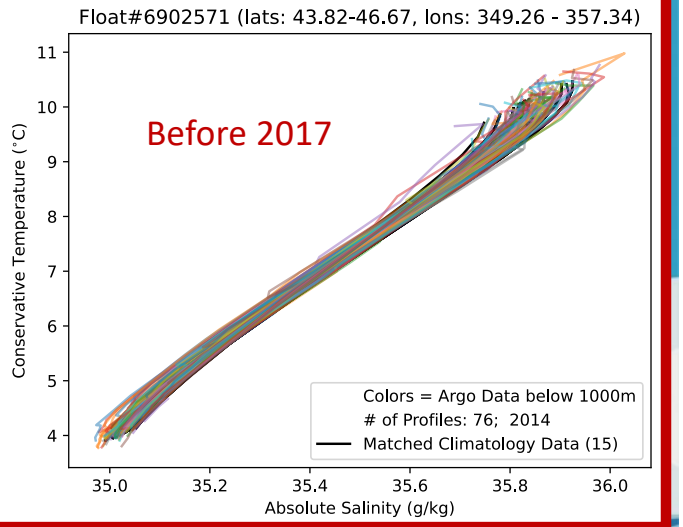
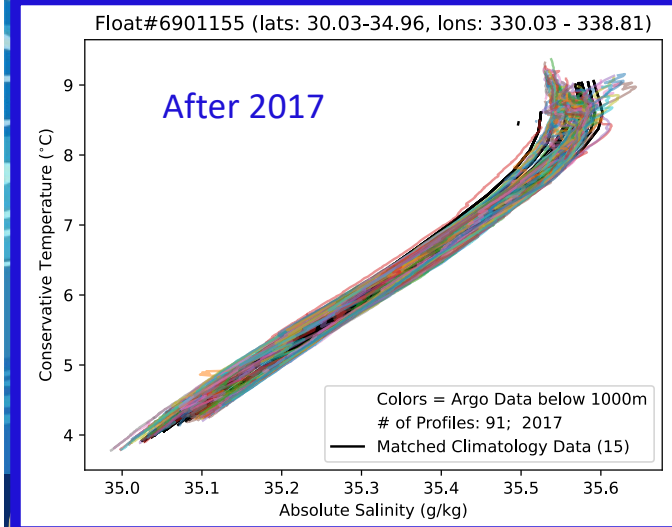
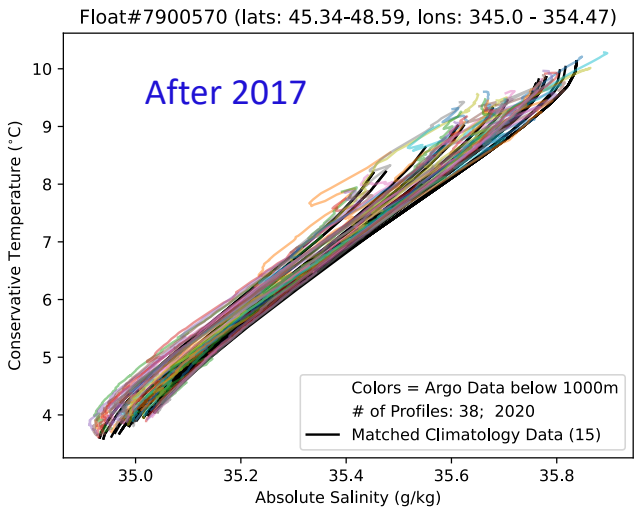
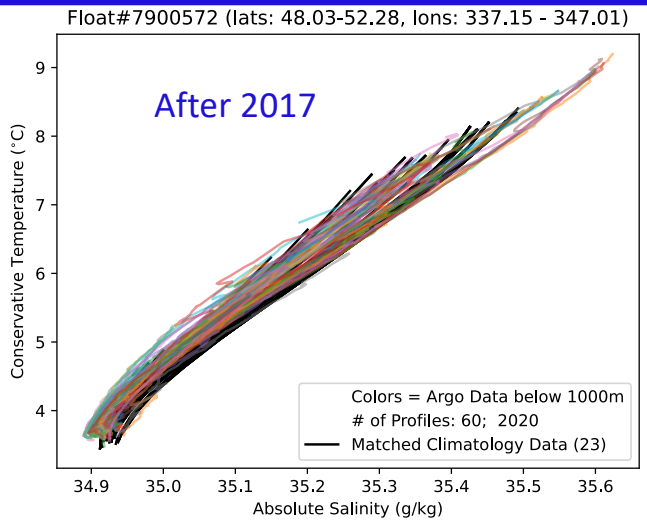




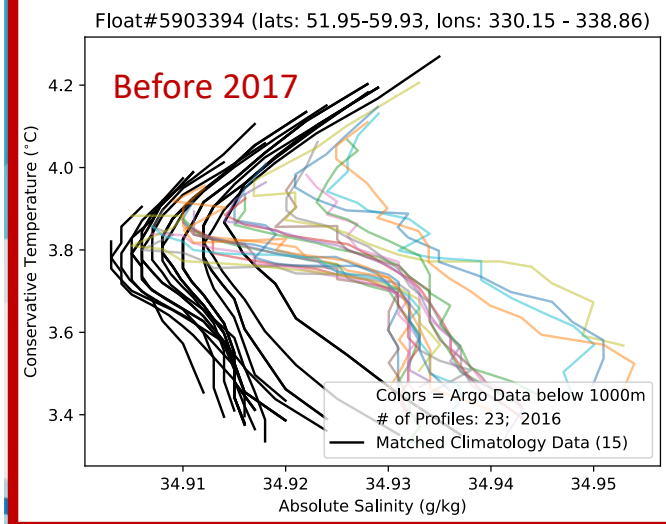


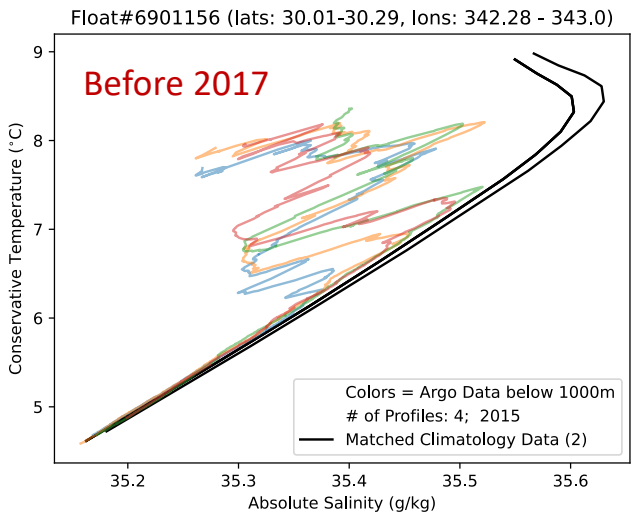


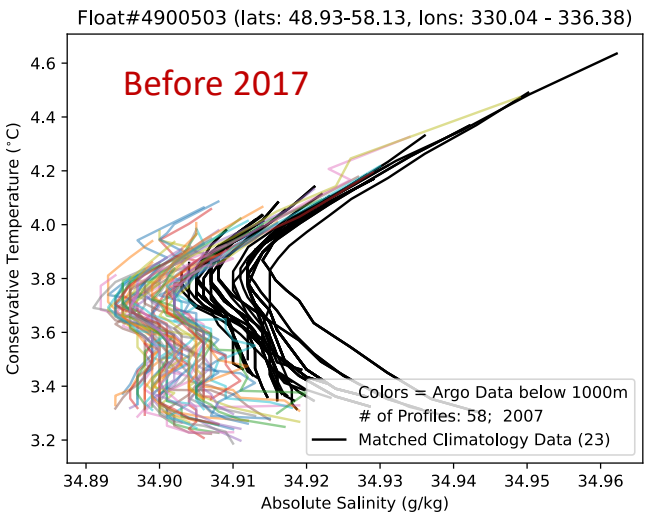


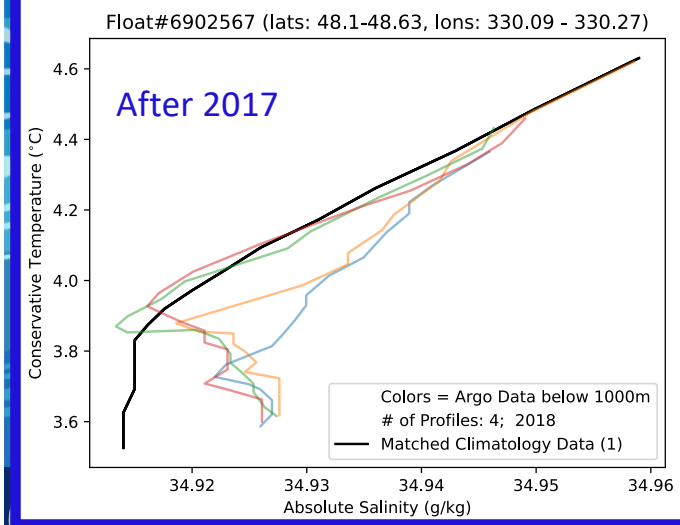


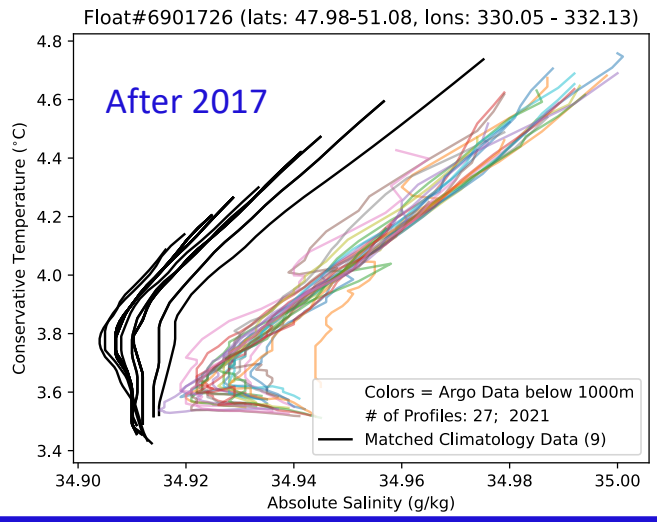
GRACE/GRACE-FO, and Argo.

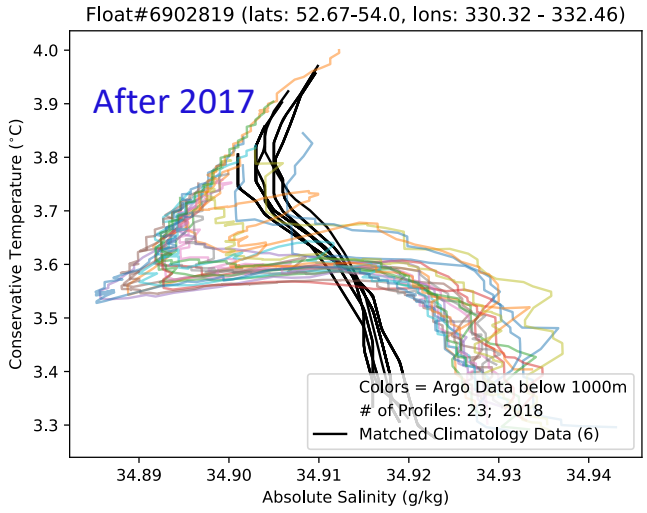












GRACE/GRACE-FO, and Argo.

Future Work

Hoping to identify biased Argo floats and remove from SSL calculations.

Commonalities amongst Argo floats with 'bad' data?

- Same sensor type?
- Same deployment group?
- Other factors?

Questions?

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