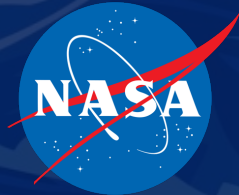


Investigating Steric Sea Level Anomalies: Combining satellite altimetry, GRACE/GRACE-FO, and Argo.

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College of Marine Science, University of South Florida



Contact: reinelt@usf.edu



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.

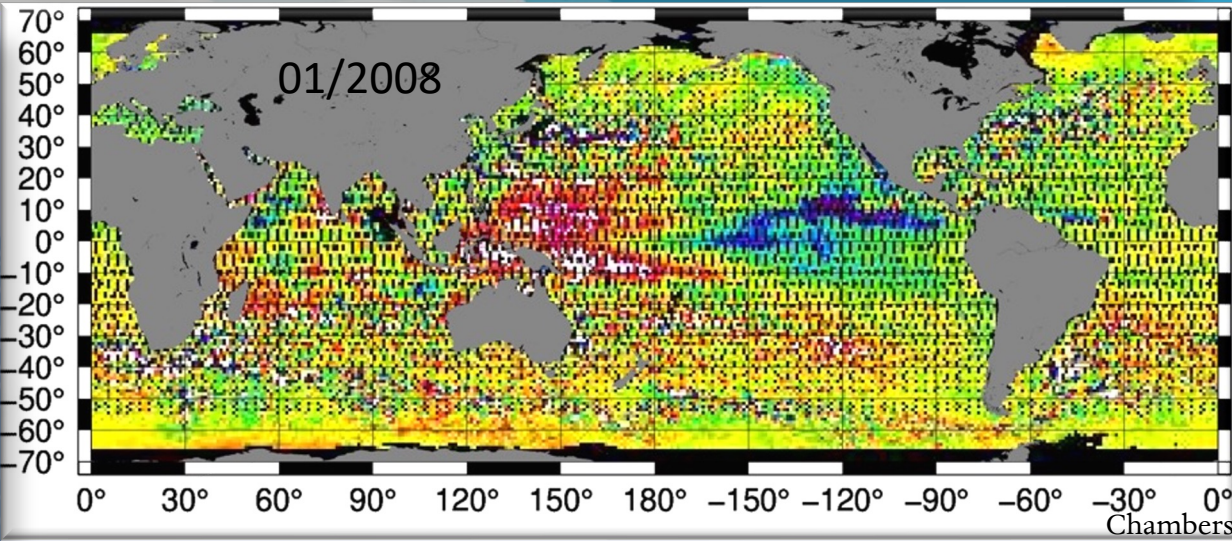
‘First guess’ of SSL by mapping Altimetry – GRACE & updating that map with Argo:

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

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)



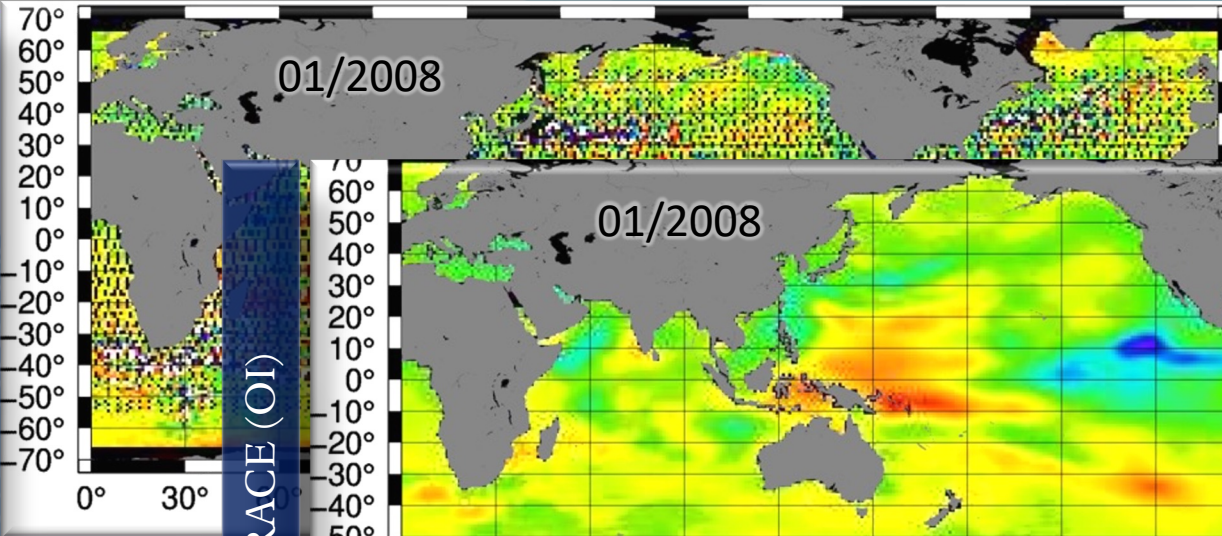
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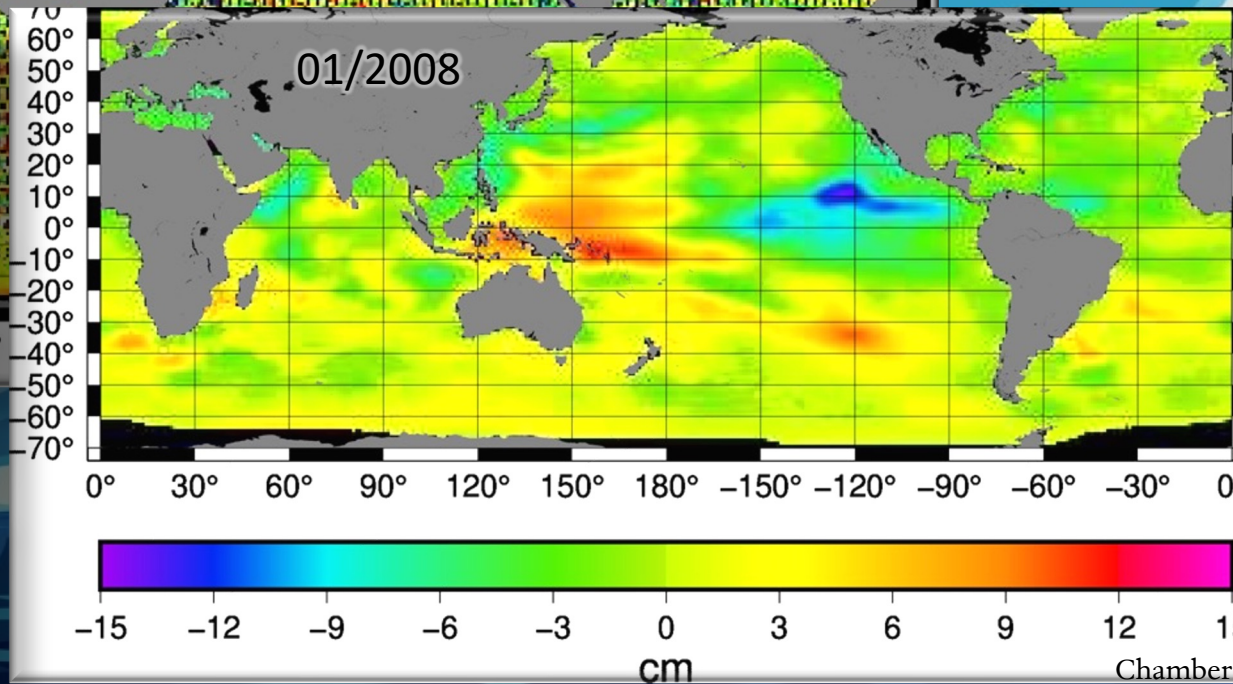
Spatial Covariance Function (best-fit to
2005-2010 covariance):

$$R_{signal}(r) = 25e^{-\left(\frac{r}{1675 \text{ km}}\right)^2}$$
$$R_{error}(r) = 82e^{-\left(\frac{r}{100 \text{ km}}\right)^2} + 25 \text{ cm}^2 \text{ random}$$

Altimetry – GRACE (raw)



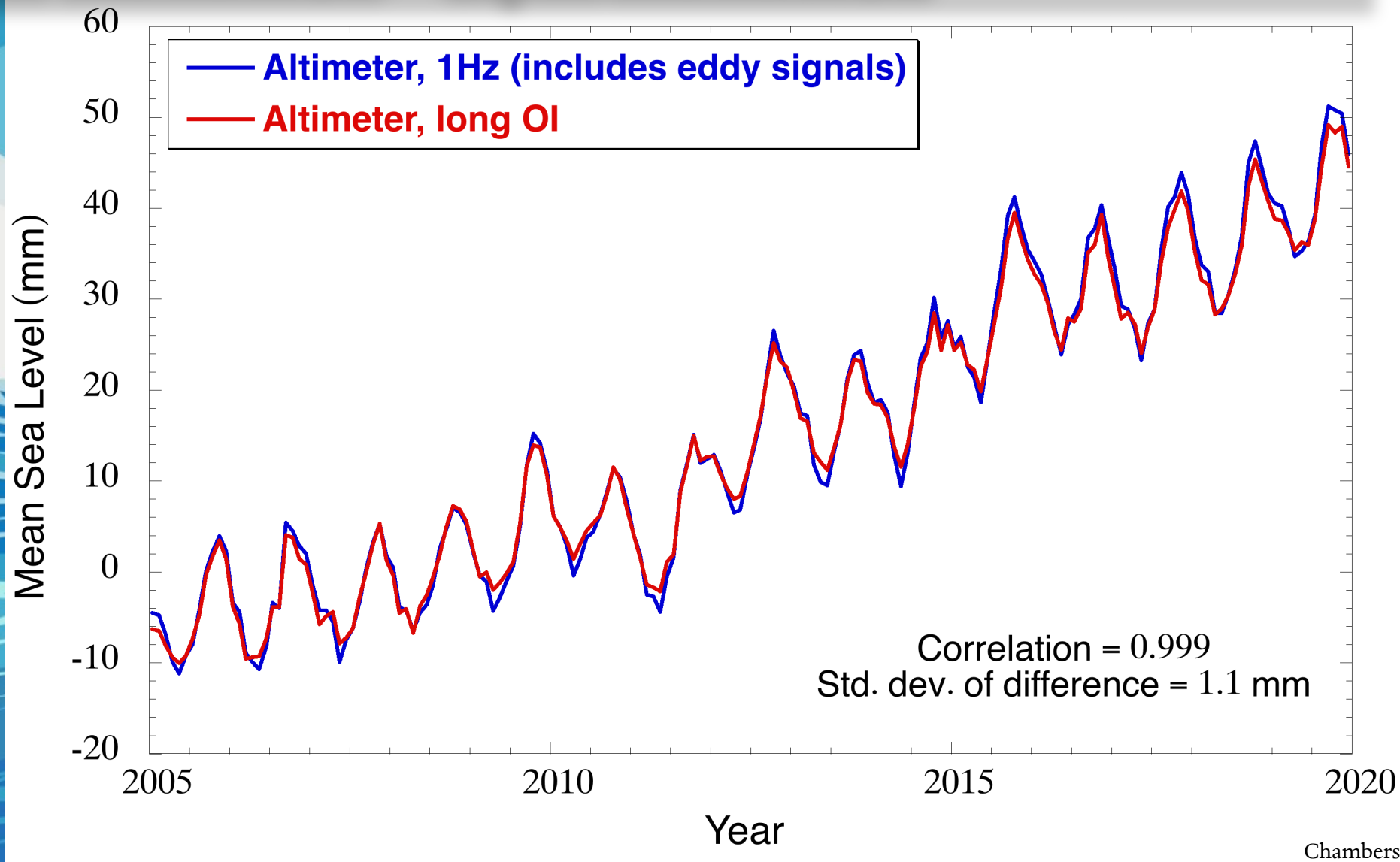
Altimetry – GRACE (OI)



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

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

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



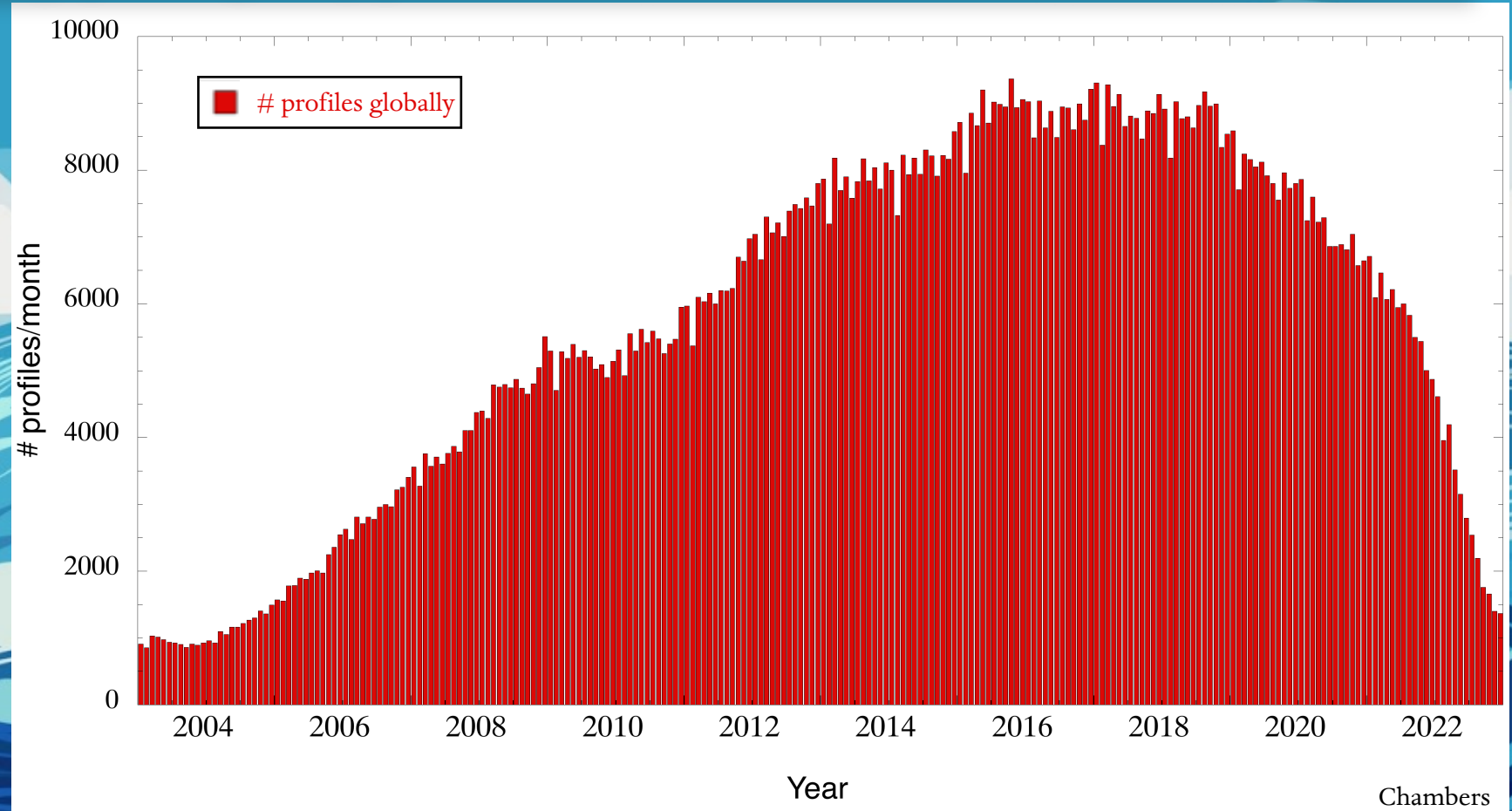
Average long-wave
GMSL variations
from **OI** is about
same as **raw data**.

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

Updating the map with Argo

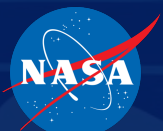
✓ Argo profiles (globally) per month (2003 – 2023):

- 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.



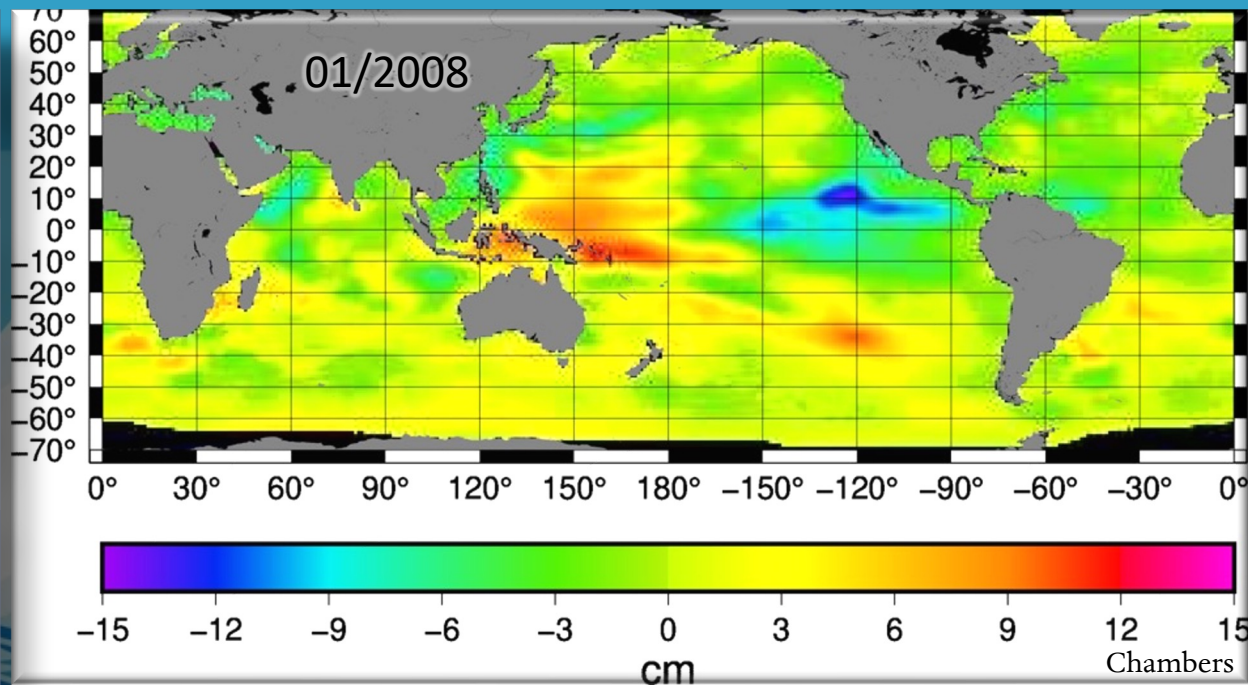
Updating the map with Argo

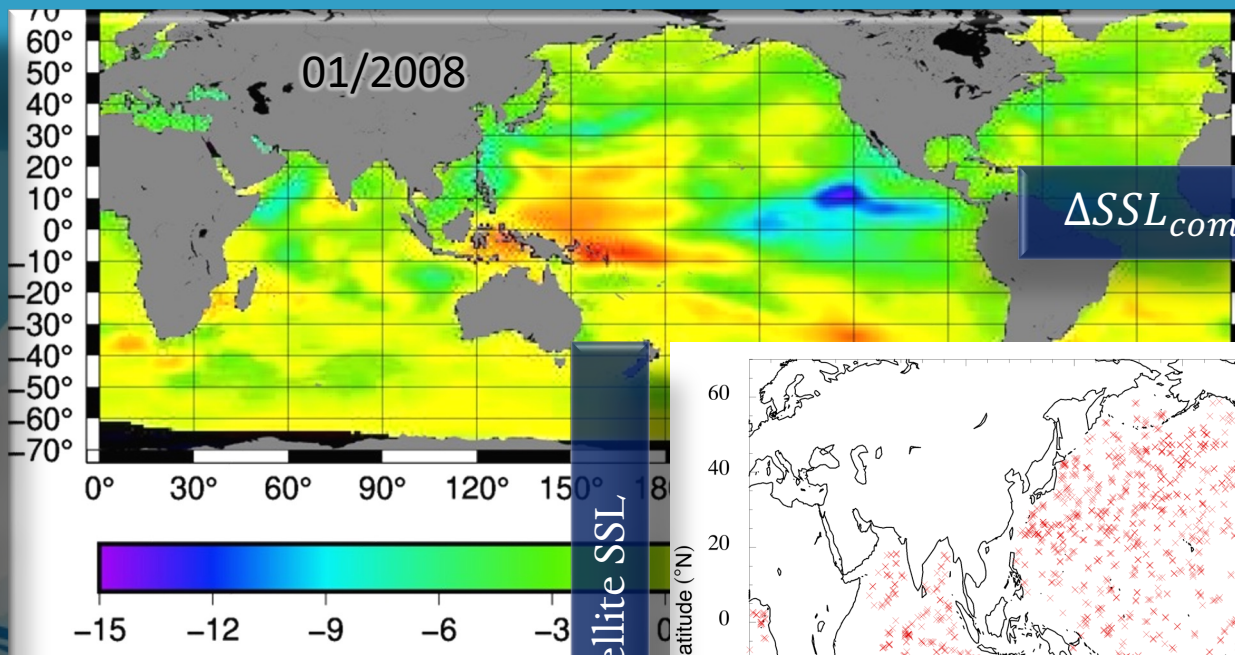
- Using Argo profiling floats (argo.ucsd.edu) to update satellite-derived sea level.
 - Only using delayed-time profiles with 'good' quality control flags.
 - Using only profiles with depths > 1000m.
- Argo profile locations matched with Roemmich & Gilson 2004-2015 Argo T & S climatology
 - Climatology 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.



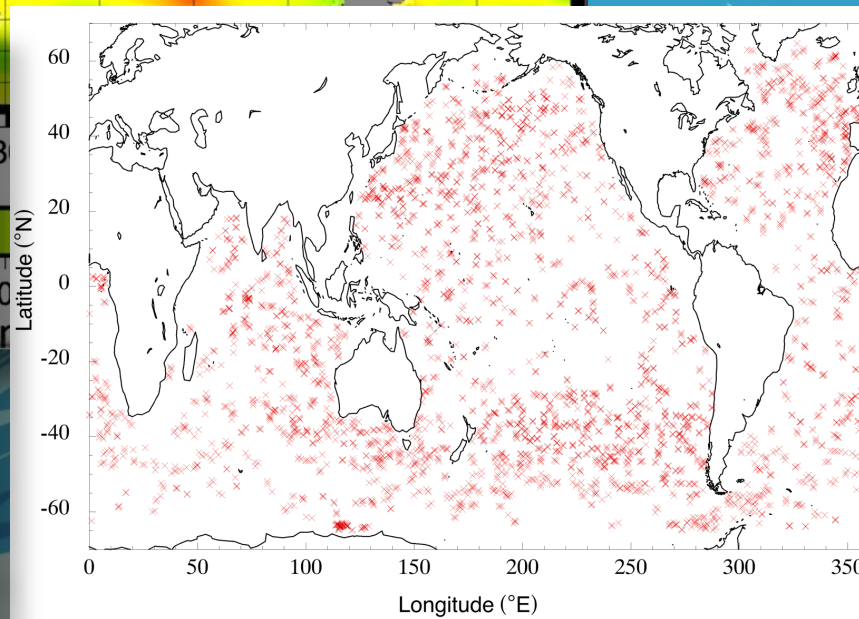
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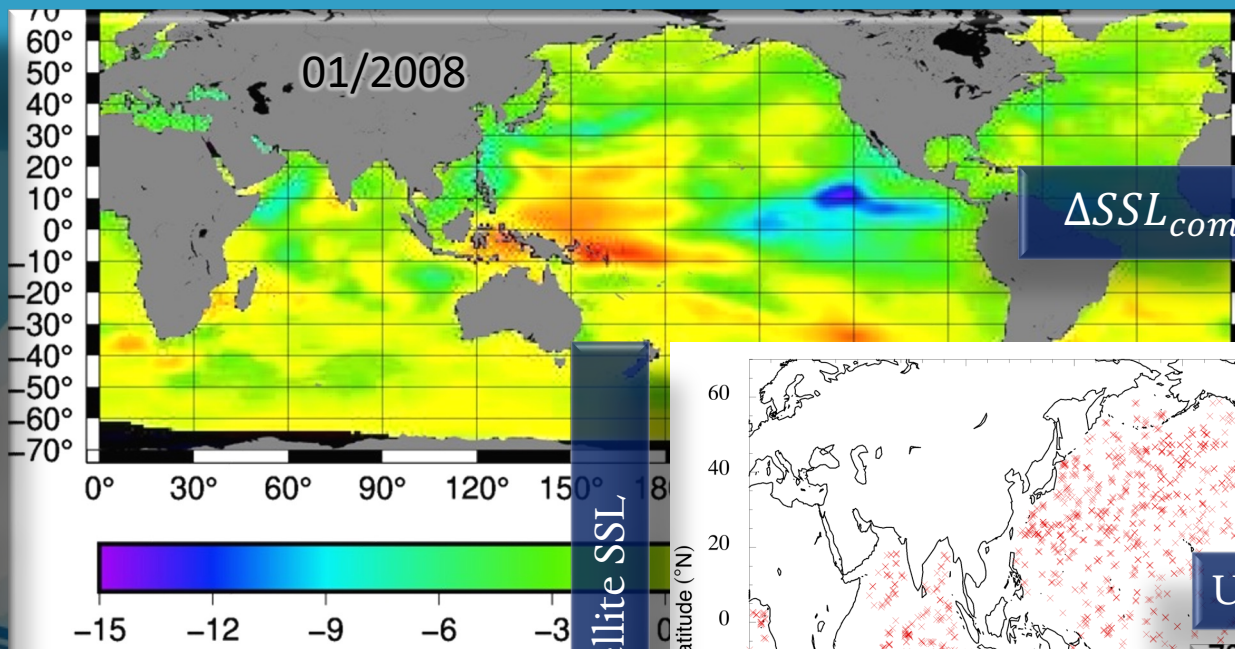




$$\Delta SSL_{combined}(\phi, \lambda, t) = \langle \Delta SSL_{Argo} - \Delta SSL_{sat} \rangle_{OI} + \langle \Delta SSL_{sat} \rangle_{OI}$$



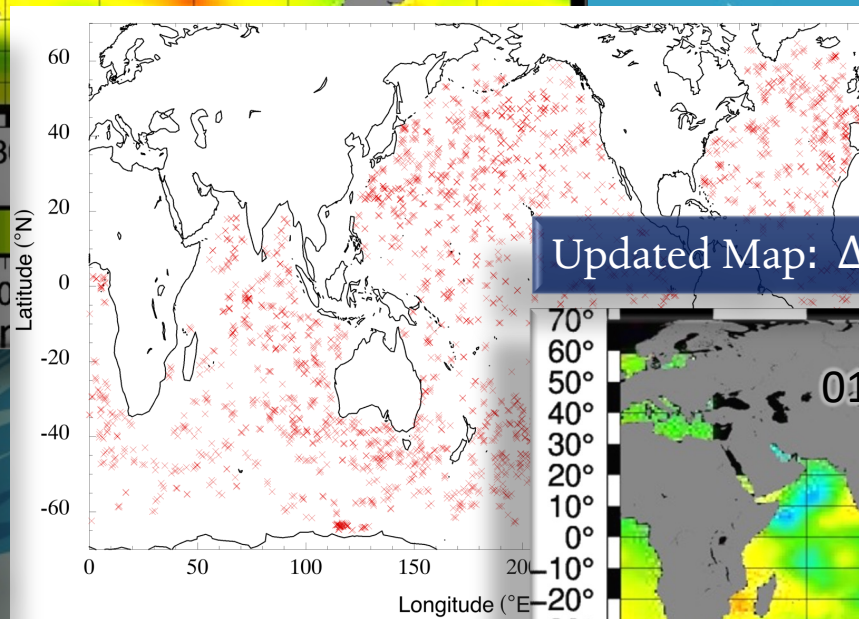
Map residuals with same OI function



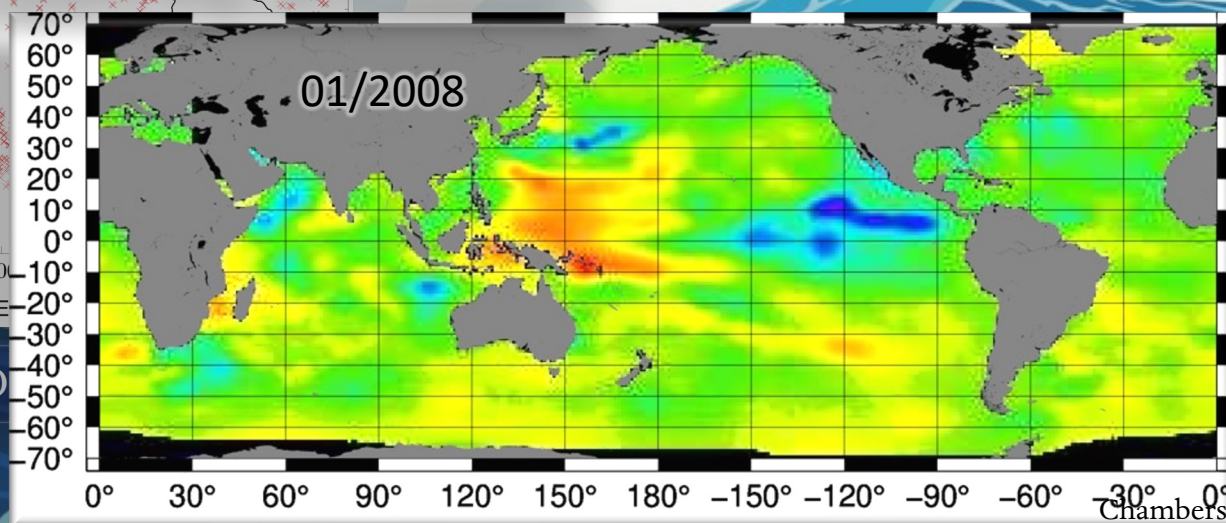
$$\Delta SSL_{combined}(\phi, \lambda, t) = \langle \Delta SSL_{Argo} - \Delta SSL_{sat} \rangle_{OI} + \langle \Delta SSL_{sat} \rangle_{OI}$$

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

Argo SSL – Satellite SSL



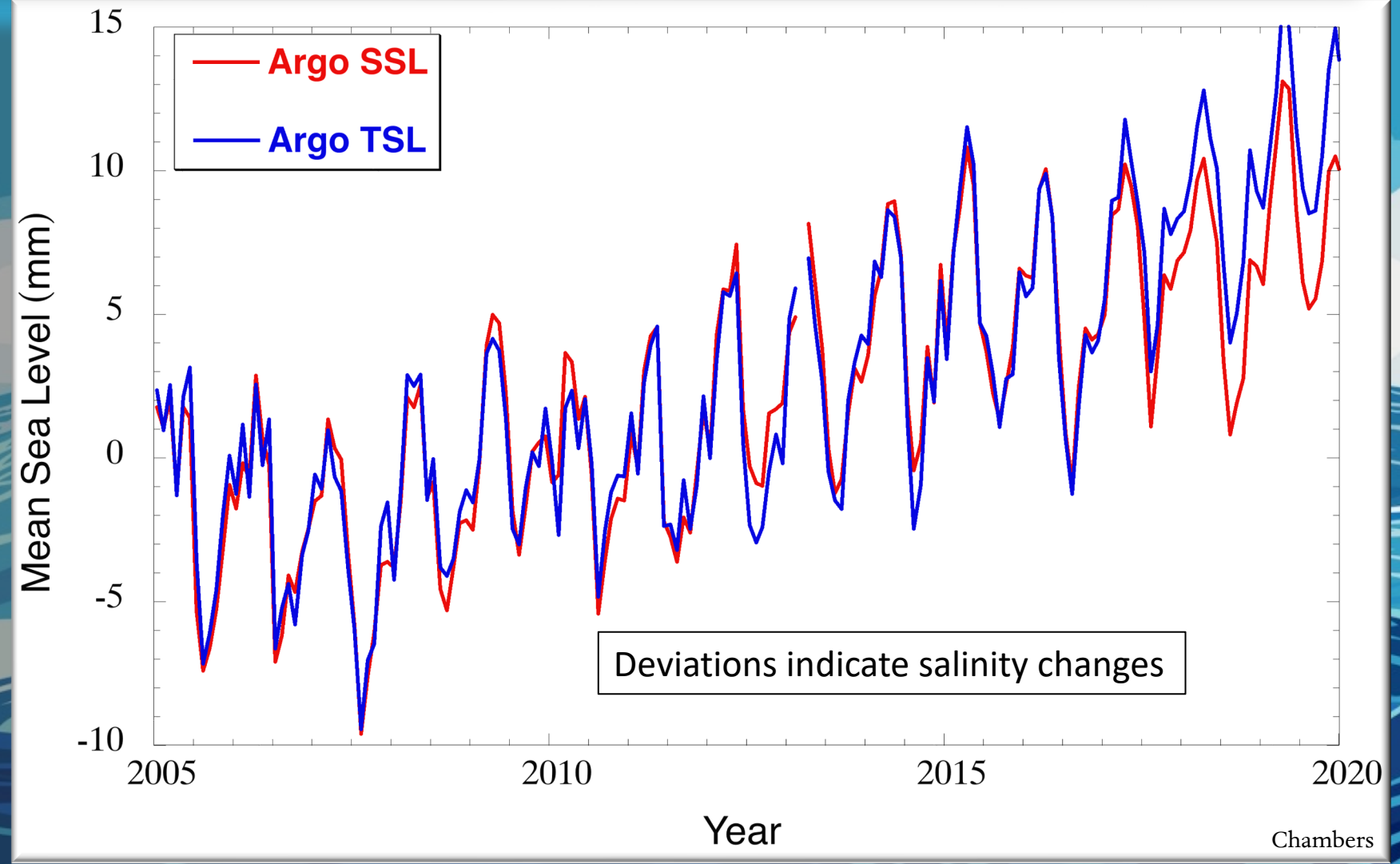
Map residuals with same O



Obstacles

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

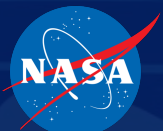
Global **Total Steric** and **Thermosteric** Sea Level Anomalies from Argo:



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 ($>1000\text{m}$) = very slow process

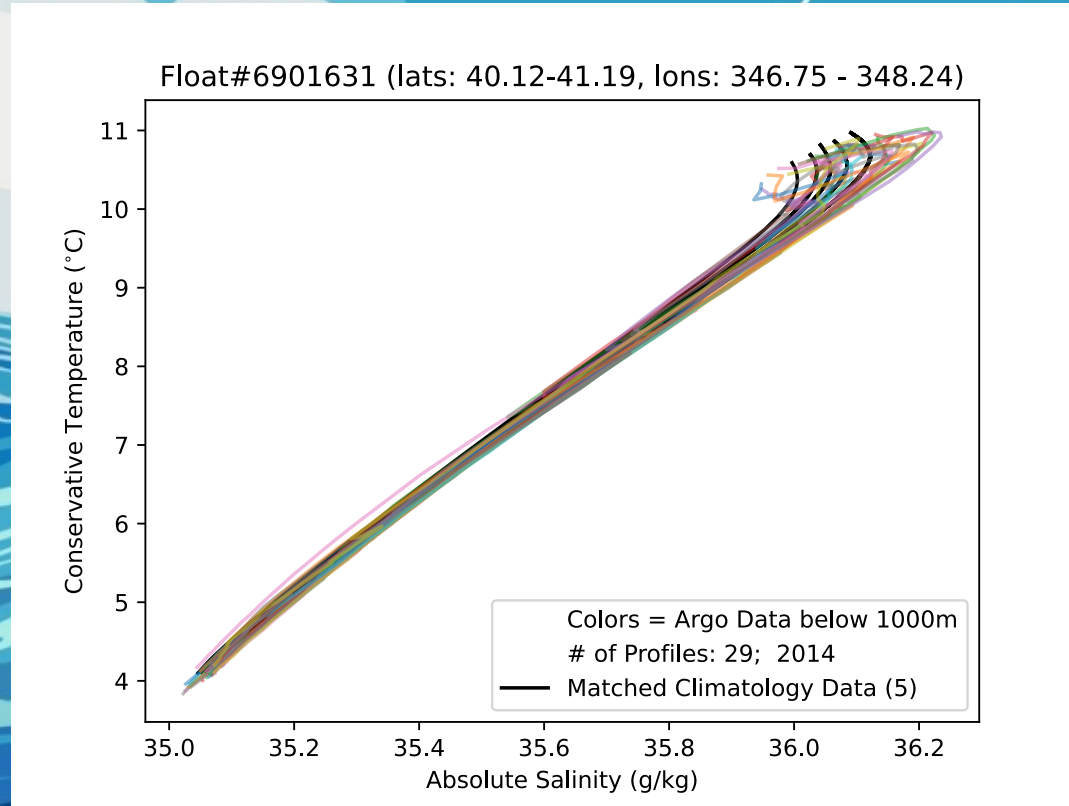


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Temperature-Salinity Diagrams

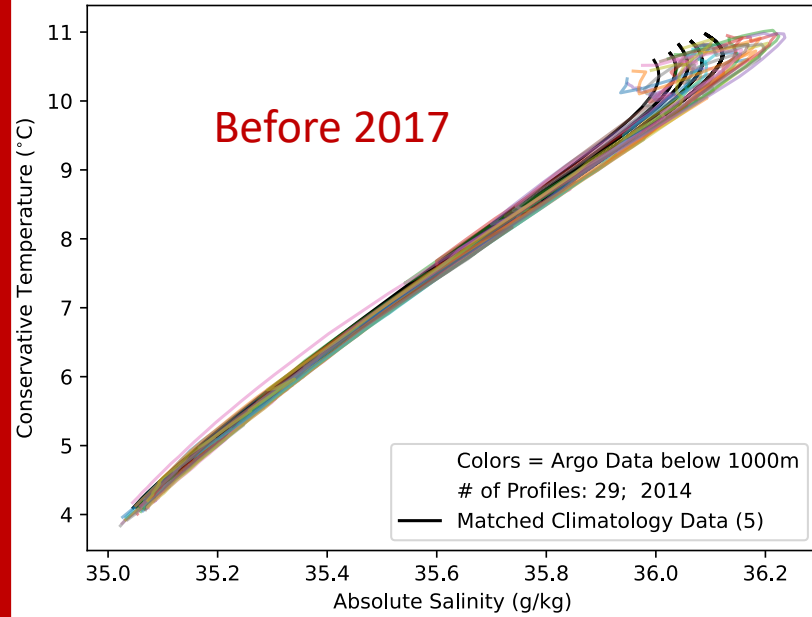
TS plots of >1000m for Argo floats and matching climatology in the North Atlantic



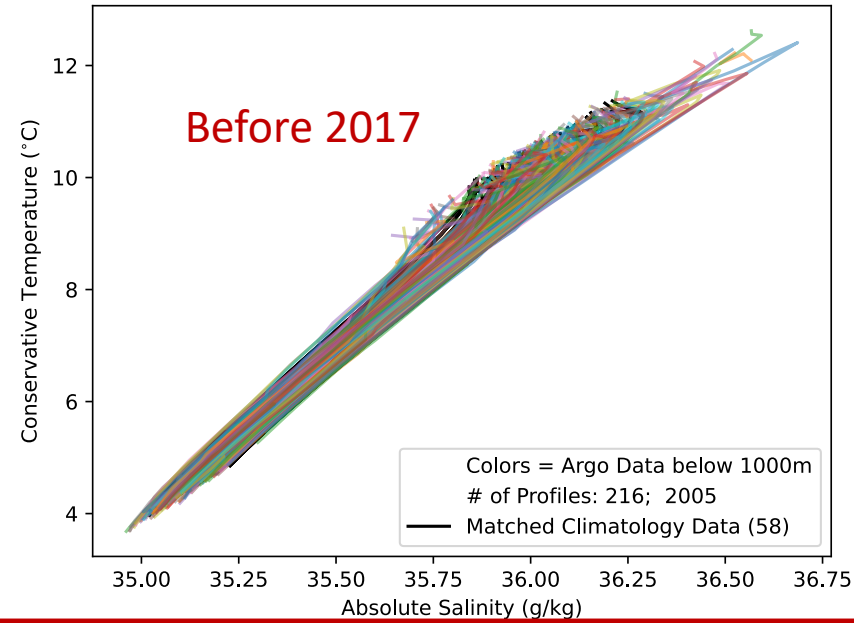
x-axis = Salinity
y-axis = temperature

Colors = Individual Argo float profiles
Black = matching climatology

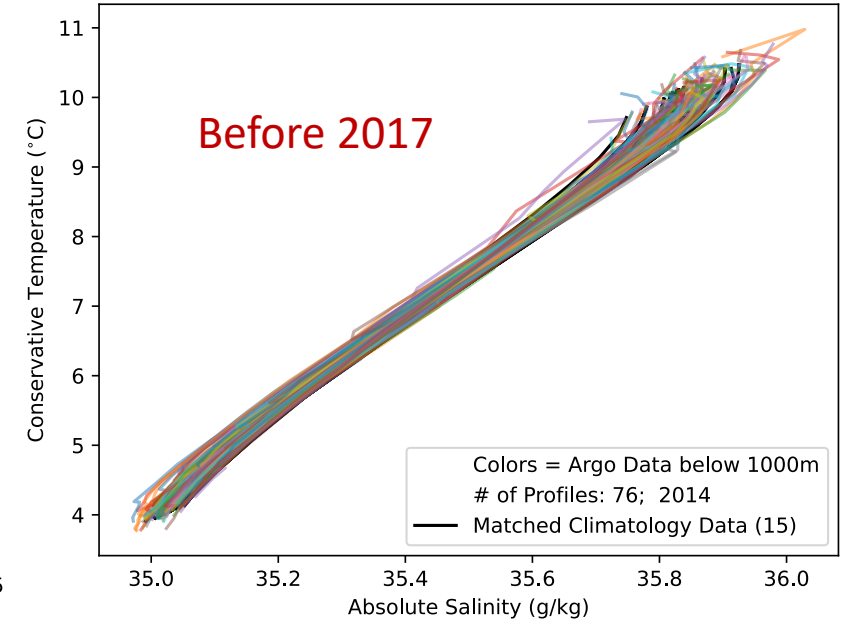
Float#6901631 (lats: 40.12-41.19, lons: 346.75 - 348.24)



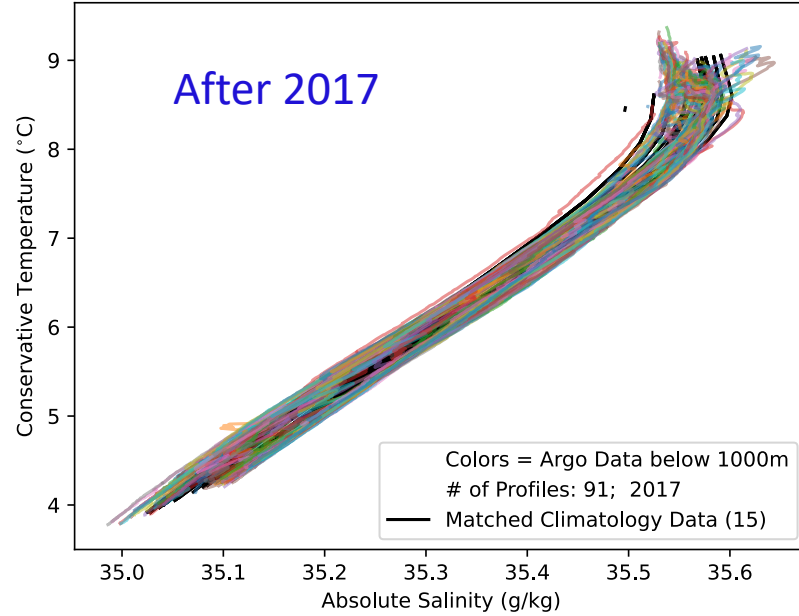
Float#6900367 (lats: 33.84-42.93, lons: 340.48 - 351.96)



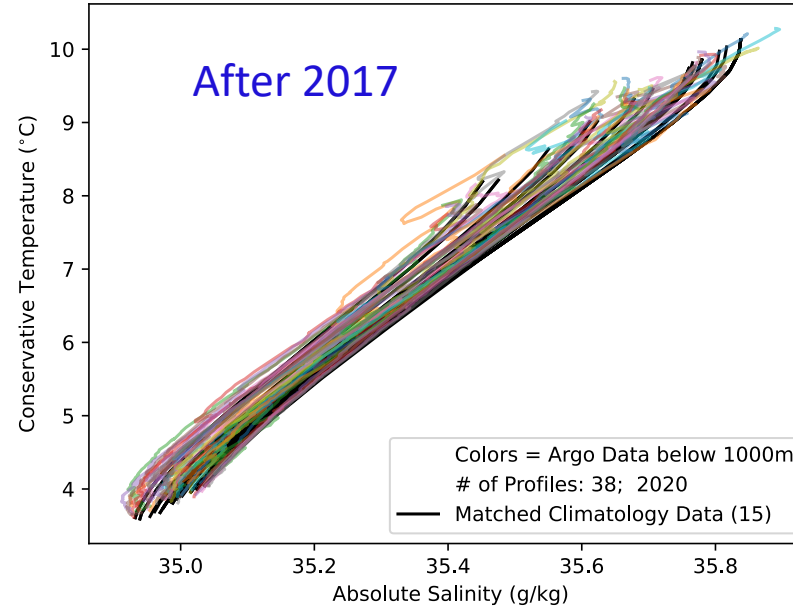
Float#6902571 (lats: 43.82-46.67, lons: 349.26 - 357.34)



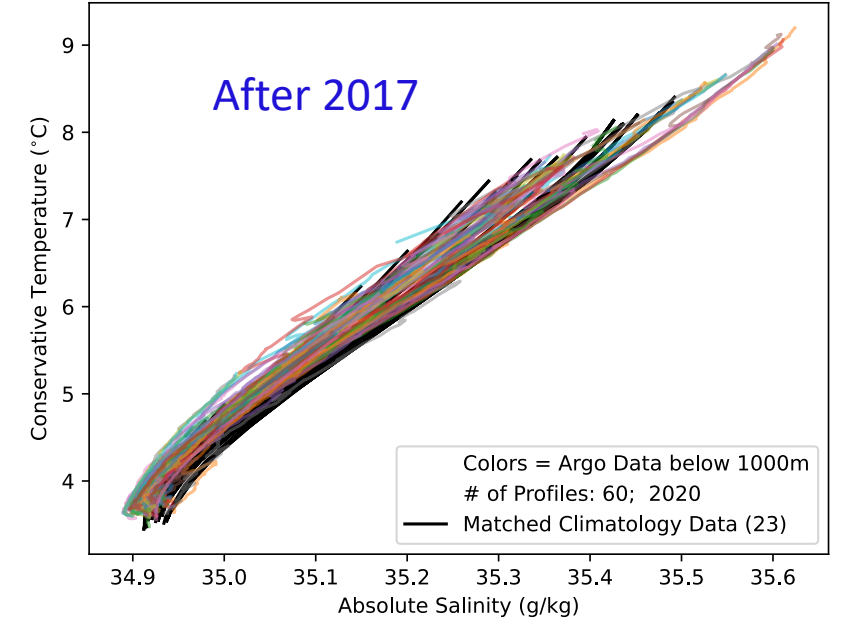
Float#6901155 (lats: 30.03-34.96, lons: 330.03 - 338.81)



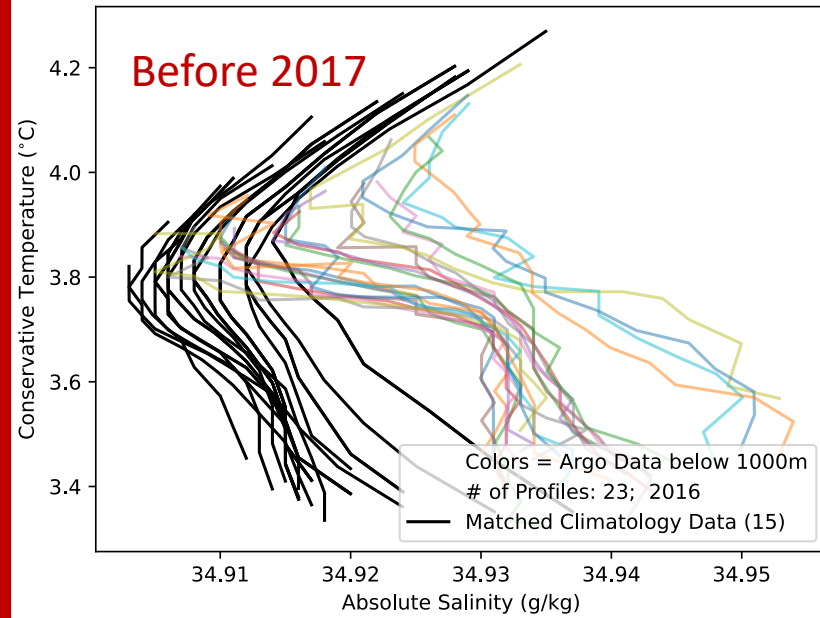
Float#7900570 (lats: 45.34-48.59, lons: 345.0 - 354.47)



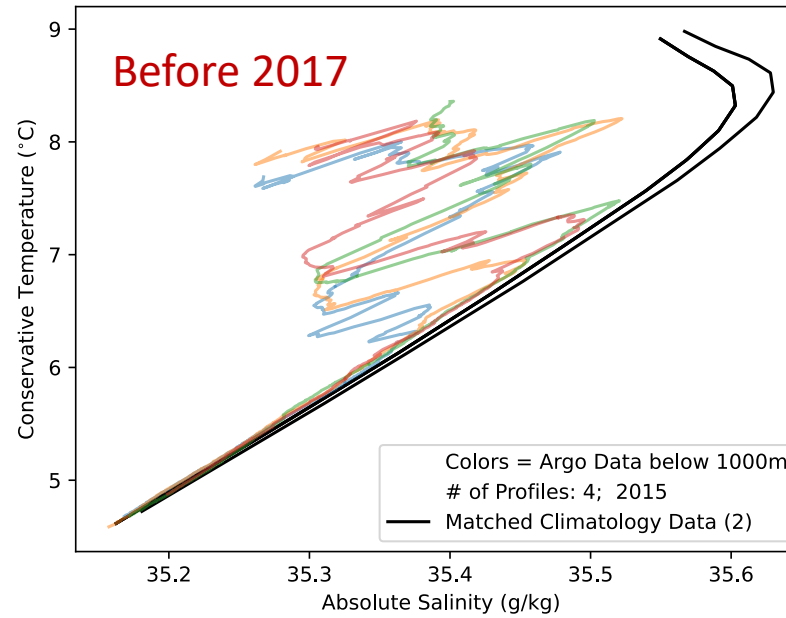
Float#7900572 (lats: 48.03-52.28, lons: 337.15 - 347.01)



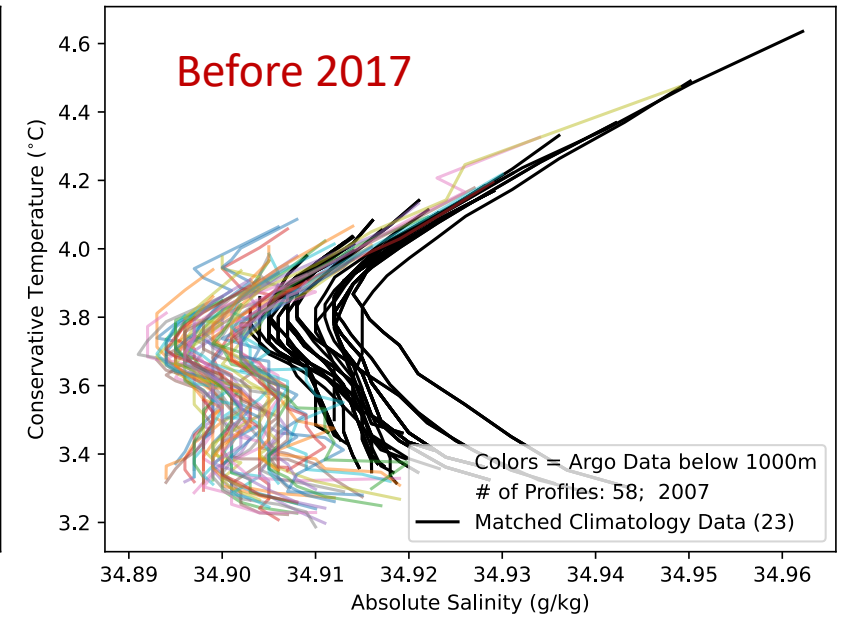
Float#5903394 (lats: 51.95-59.93, lons: 330.15 - 338.86)



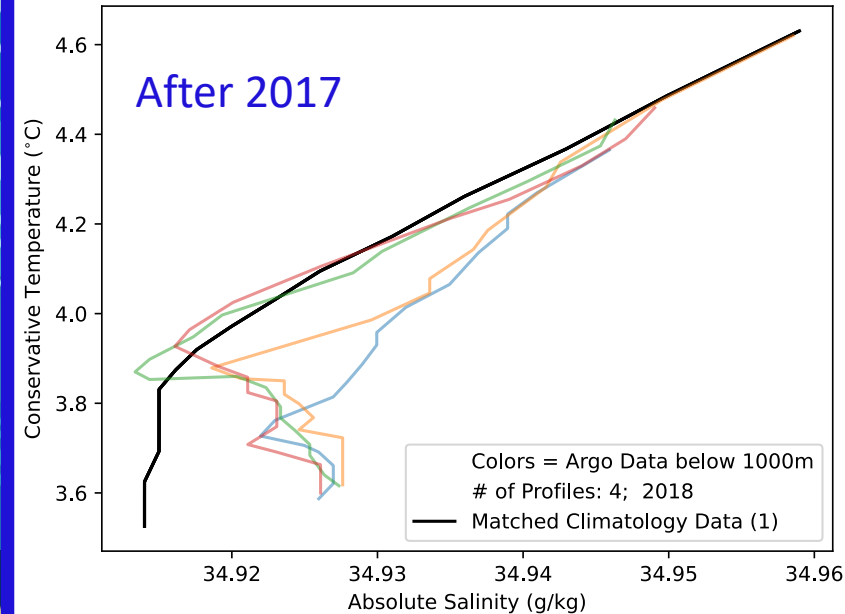
Float#6901156 (lats: 30.01-30.29, lons: 342.28 - 343.0)



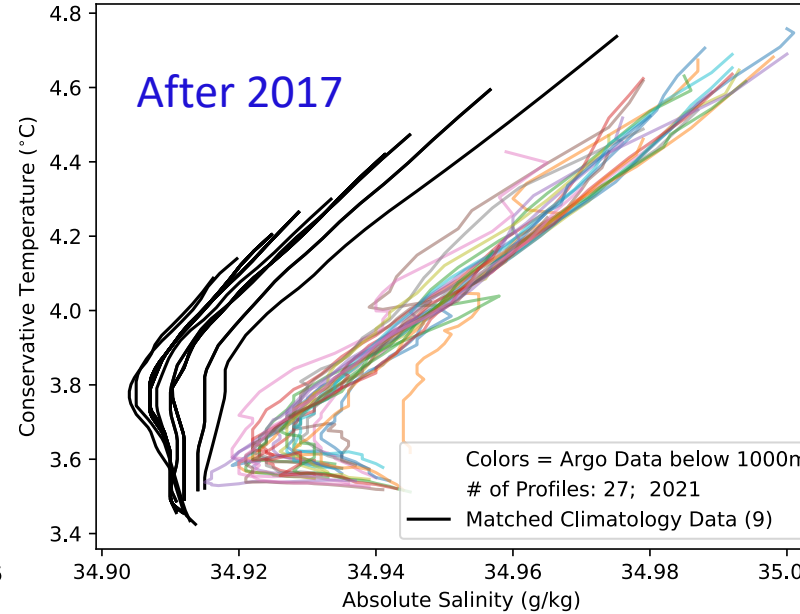
Float#4900503 (lats: 48.93-58.13, lons: 330.04 - 336.38)



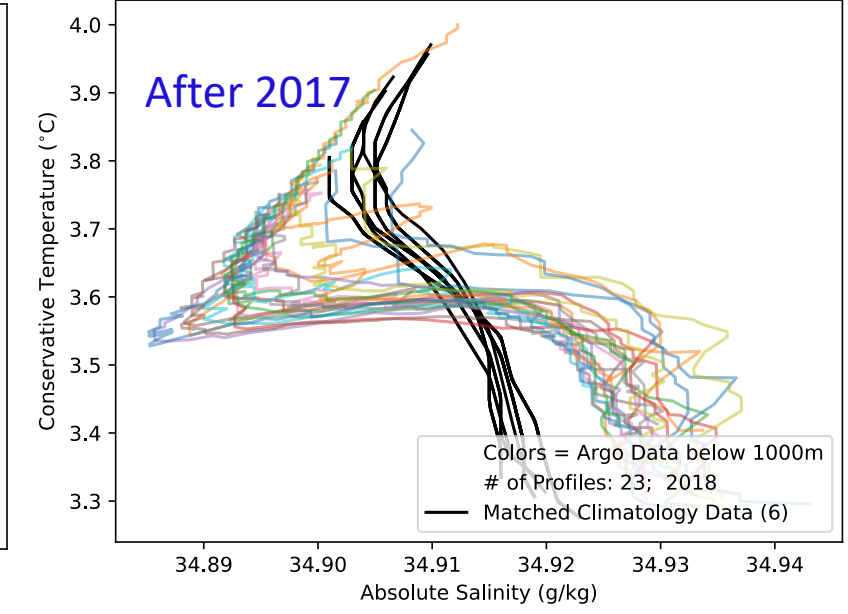
Float#6902567 (lats: 48.1-48.63, lons: 330.09 - 330.27)



Float#6901726 (lats: 47.98-51.08, lons: 330.05 - 332.13)



Float#6902819 (lats: 52.67-54.0, lons: 330.32 - 332.46)



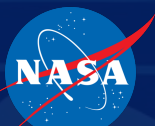
Future Work

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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