Separating the Steric and Eustatic Contributions to Global Sea-Level Rise

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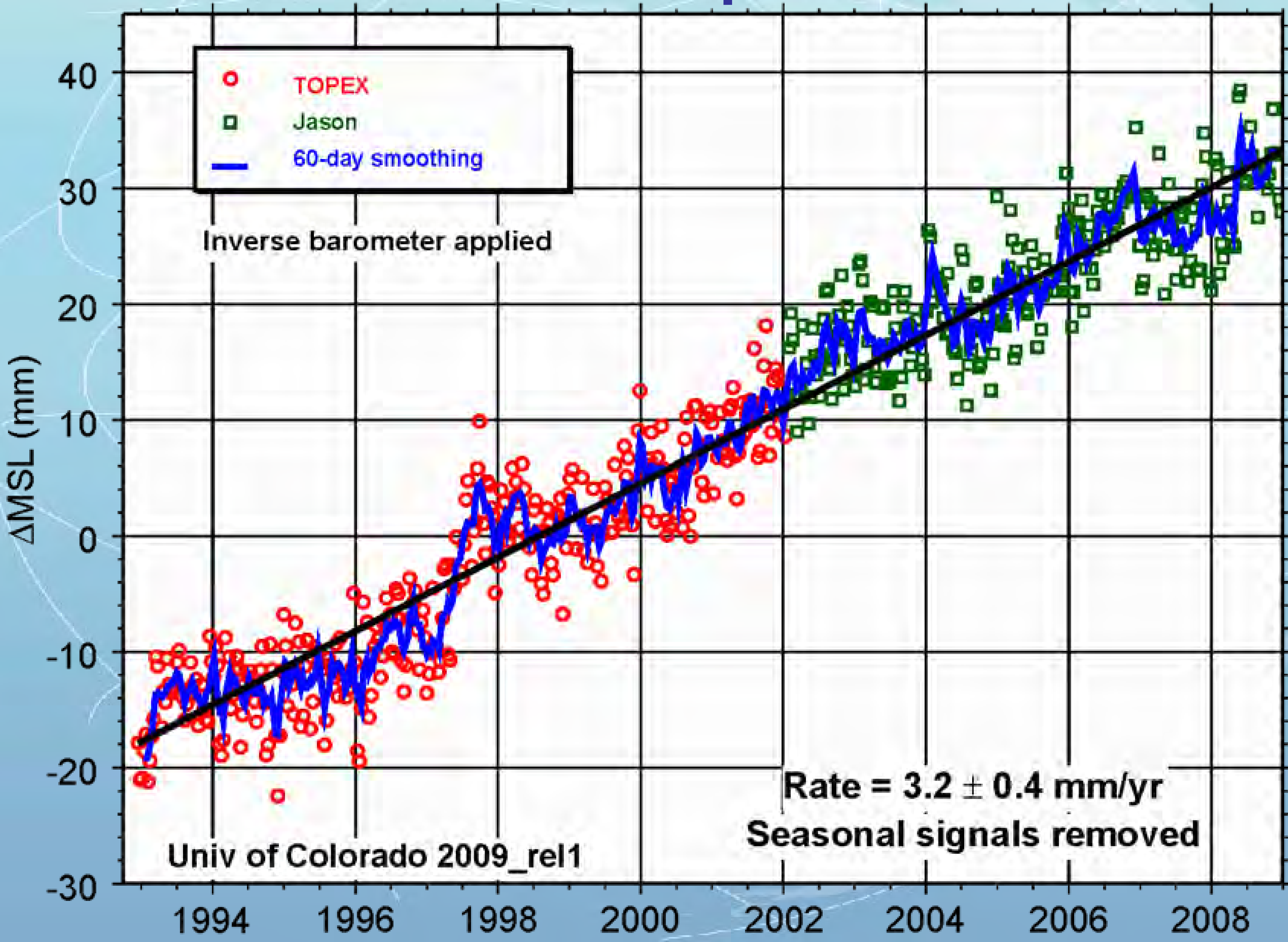
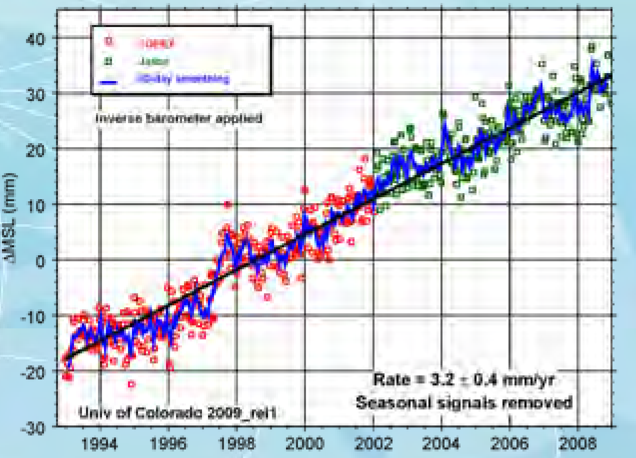
Fisheries and Oceans Pêches et Océans

What is the problem?



What is the problem?

This diagram showing a global sea-level rise rate of 3.2 mm/year formed a substantial piece of the IPCC AR4, written by Bindoff et al.



Bindoff *et al* refer to work by numerous authors trying to estimate the two components of sea level rise, the steric contribution and the eustatic contribution. Balance is not achieved, but the cut-off date for material used in AR4 precluded the use of Argo data as a global resource, so can we do better now?

There is a minor flaw in the methods used.

Implicit in the discussions of Bindoff et al 2007 are the following equations:-

$$SLRise_{Total} = SLRise_{steric} + SLRise_{eustatic}$$

and

$$SLRise_{steric} = SLRise_{thermal} + SLRise_{haline}$$

In fact it is easily shown that neither of these equations is strictly correct. Both are close but an exact balance will **never** be possible.

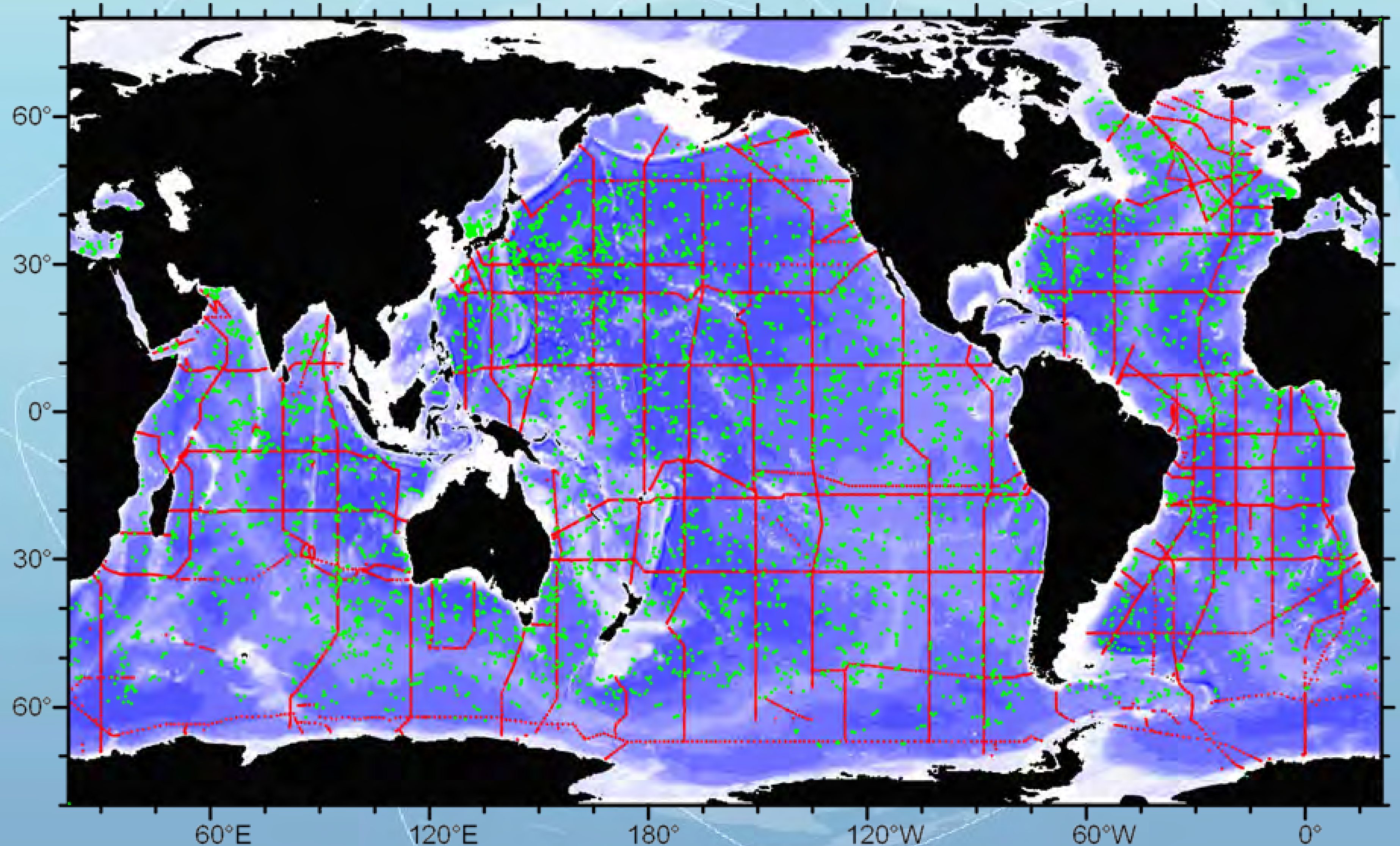
Here is one simple example……

A simple example…..

- Start with an isothermal and isohaline water column 700 metres high with T = 10.7°C and S = 35.2 psu
- Add a fresh water layer on top at 10.7°C and 1 mm thick.
- Clearly we have raised the sea level by 1 mm precisely.
- Now mix that water over the 700 metres water column and integrate to find the dynamic height of the surface relative to 700 metres.
- Delta-D = 1.026 mm.
- The difference is small, only 2.6%, but the difference is not zero.

Method

I will compare the global Argo dataset with the last high quality global survey we have on hand, WOCE, and use this to avoid computing a noisy annual cycle.



Method (continued)

- Scan the entire WHP Database one station at a time.
- For each WHP station there is associated with the vertical profile a Latitude, Longitude (φ, λ), Year, Month and day-of-the-month.
- Create an Argo version of the same profile using surrounding Argo profiles centred on (φ, λ) and centred on the month and day-of-the-month.
- Year is selected as one of three options:-

Run-1 – Select Argo data between 1st Jan. 2007 to 31st Dec. 2007

Run-2 – Select Argo data between 1st Aug. 2007 to 31st July 2008

Run-3 – Select Argo data between 1st Aug. 2006 to 31st July 2007

Run-4 – Select Argo data between 1st Jan. 2008 to 31st Dec. 2008

- Compute surface dynamic height relative to 700 decibars at both the target WHP station and the Argo simulation of the WHP station, also integrated salt content and heat content
- Plot Delta-H/Delta-time, note: Delta-time is always integral years.

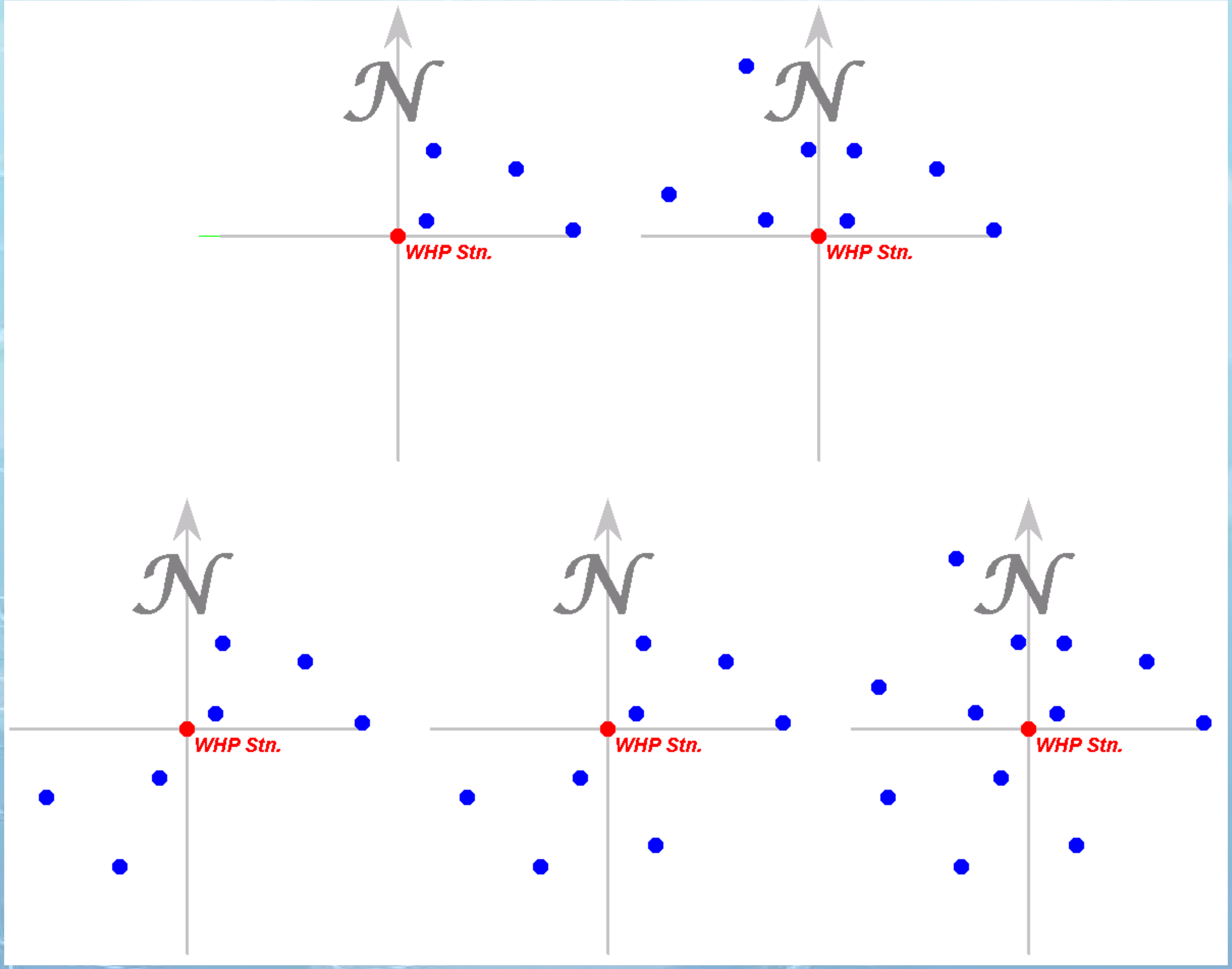
Caveats….

- WHP stations were rejected if the shallowest sampling was deeper than 8 decibars.
- A few WHP stations are flagged as doubtful, these were rejected.
- For WHP stations that passed those tests Argo profiles were used to simulate them subject to some tests….
- Argo profiles were used that lay within 1000 km of the target WHP station and within ±8 days.
- Only data with QC flag of 1 were used.
- If more than 10% of the data in a profile failed the QC test then the profile was rejected.
- If the shallowest sample is deeper than 8 decibars the profile is rejected.
- A quadrant check was used to ensure that only extrapolation outside the Argo array was disallowed.

The 3-quadrant rule

Reject these

Accept these



Method (continued)

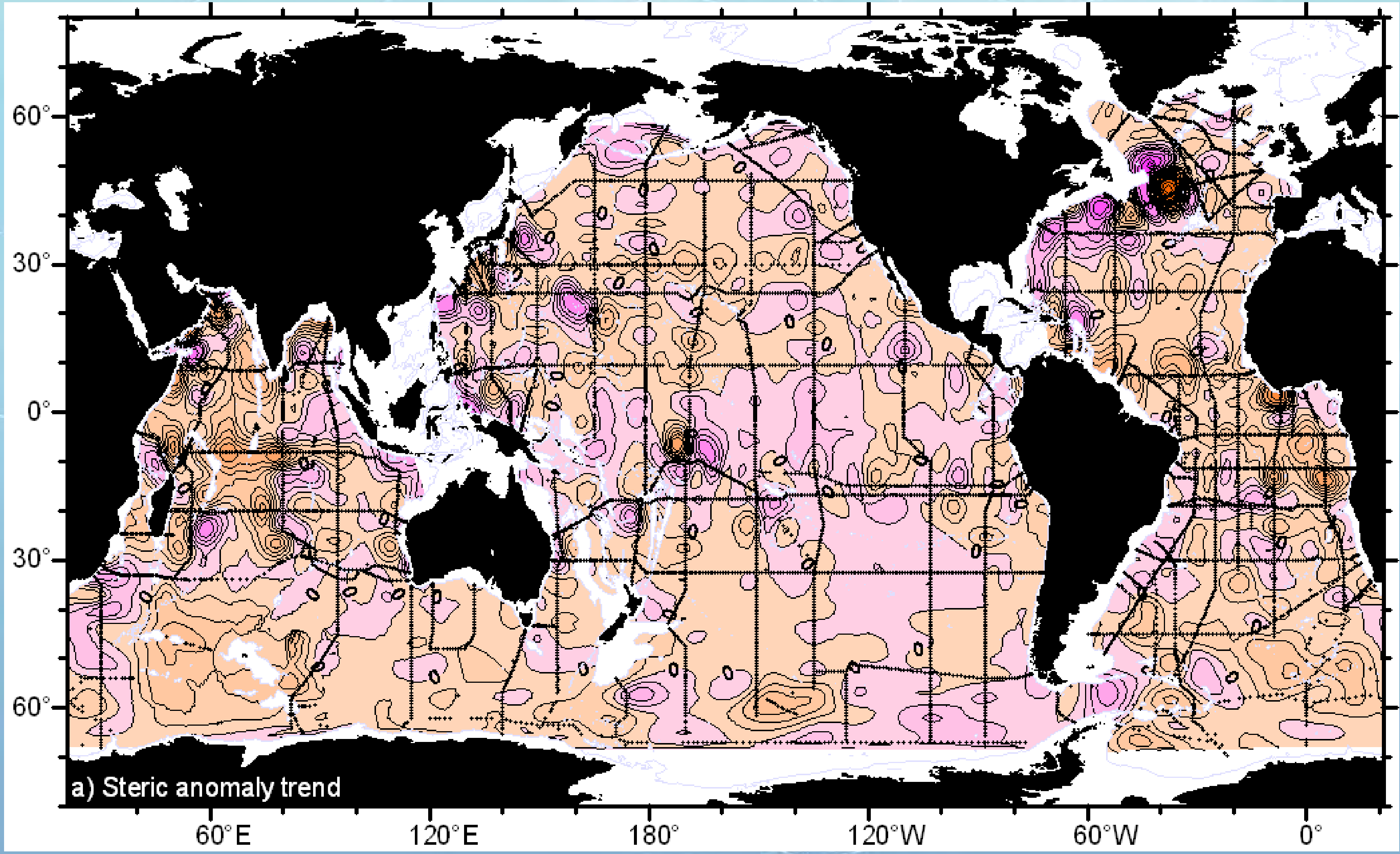
From the heat, salt and height differences versus latitude and longitude interpolate onto the regular 1° x 1° grids, one for each run.

All interpolations are done using objective analysis using a Gaussian correlation function and an imposed noise level of 10% of total variance. The data mapped are the anomalies after a local plane is fitted.

Results will be shown for each of the three runs and for a composite run computed via an EOF analysis on the three original runs.

The gridded differences supply summary changes, correlation structure along WHP lines supplies confidence levels.

Results –steric anomaly



Results

	Run-1	Run-2	Run-3	Run-4	EOF-1
Steric height $\pm$95% (mm/year)	2.24$\pm$1.17	2.27$\pm$0.87	2.27$\pm$1.24	2.10$\pm$0.76	2.24
Temperature$\pm$95% (°C/century)	1.06$\pm$0.72	1.34$\pm$0.67	0.77$\pm$0.65	1.29$\pm$0.59	1.11
Salinity $\pm$ 95% (psu/century)	-.10$\pm$0.15	-.11$\pm$0.14	-.15$\pm$0.16	-.11$\pm$0.12	-.13

$SLRise_{thermal} + SLRise_{haline} = 1.38 + 0.67 = 2.05$ mm/year

Note on 95% confidence intervals

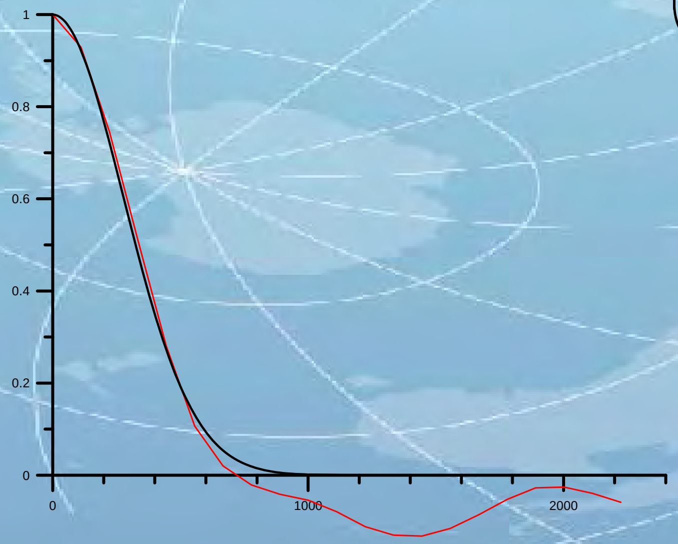
1) Examine differences (Argo minus WOCE) for each variable, dynamic height, temperature and find a best-fit Gaussian correlation function R = 390 km.

2) Integral scale = $\int_0^\infty \exp(-y^2/R^2)dy = \sqrt{\pi}R$

3) WOCE sampling was typically ½° latitude = Δy

4) 95% confidence interval = $\dfrac{1.96\sigma}{\sqrt{n^*}}$

5) Effective number of degrees of freedom = $n^* = n \Big/ \left(\dfrac{2\sqrt{\pi}R}{\Delta y}\right) = n/12.6$



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Conclusion

The sea-level rise rate we observe is larger than any of the figures quoted in the IPCC report and with recent estimates of mass loss from ice-sheets brings us much closer to a closed budget for the total sea-level rise rate.

Wishes and Concerns

- The salinity decline rate in each run is not systematically different from zero, but each run individually does show a decline. This is a concern as they are all too large. Nobody suggests that we are adding that much freshwater to the oceans. I do not know why this is occurring, but it could be random.
- I would have greater confidence if DMQC were being completed more expeditiously.
- There are problems completing the interpolations in some areas of the ocean where Argo does not have adequate density.