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Comparison of Two Global Ocean Reanalyses: NRL Global Ocean Forecast System (GOFS) and U. Maryland Simple Ocean Data Assimilation (SODA)

James Richman (Center for Ocean-Atmospheric Prediction Studiies, Florida State University, Tallahassee, FL U.S.A. Email: james.richman.ctr@nrlssc.navy.mil)

Jay F. Shriver, E. Joseph Metzger, Patrick Hogan (Ocean Dynamics & Prediction Branch, Code 7320, Naval Research Laboratory, Stennis Space Center, MS U.S.A.)

Ole Martin Smedstad (Vencore Services and Solutions, Inc.,, Stennis Space Center, MS U.S.A.)

NRL Global Ocean Forecast System (GOFS)

- The HYbrid Coordinate Ocean Model (HYCOM) is used as the ocean forecast model at NRL
- The model has:
  - 41 hybrid layers in the vertical
  - Tri-polar grid north of 47°N
  - 1/12.5° (~9 km at the Equator) horizontal resolution
  - K-Profile Parameterization (KPP) mixed layer model
- The ocean model is coupled to the Community ICE CodE (CICE v4.0)
- Navy Coupled Ocean Data Assimilation (NCODA) 3D Var is used to assimilate Sea Surface Temperature, Temperature/Salinity profiles and altimetric sea level anomalies via synthetic T/S profiles
- The system is forced with atmospheric output from the National Center for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR) to 2012 and CFSv2 after 2012 using COARE bulk flux parameterizations.
  - Wind stress is biased corrected using scatterometer winds
  - Sea Surface Salinity is relaxed to GDEM climatology with ~15 day relaxation time scale
    - No relaxation occurs in Western Boundary Currents or very large salinity differences

Taken from Shi, et al. (2017)

Simple Ocean Data Assimilation (SODA)

GFDL Modular Ocean Model (MOM5) is used as the ocean model for SODA. The model has
- 50 levels in the vertical
- Tri-polar grid in Northern Hemisphere
- 1/4°(~28 km at the Equator) horizontal resolution
- K-Profile Parameterization (KPP) mixed layer model

The ocean model is coupled to the Simple Ice System (SIS) ice model

The Optimal Interpolation filter for data assimilation of SST and T/S profiles has also been augmented with bias correction to reduce bias in estimates of long term trends of variables such as heat content.

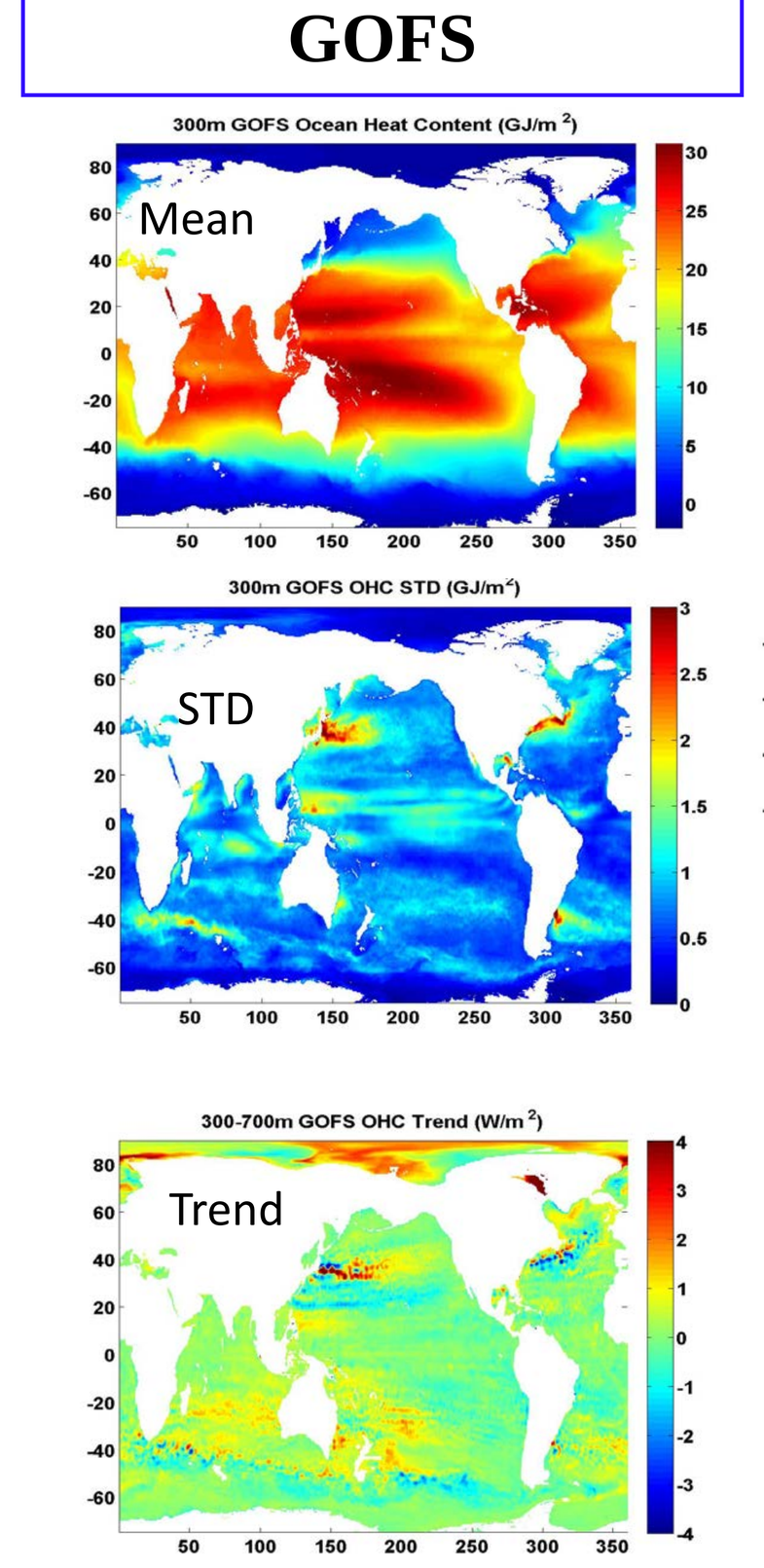
The system is forced by MERRA2 over the 36 year period 1980-2015, but only the 22 year span 1994-2015 will be used for the comparison.

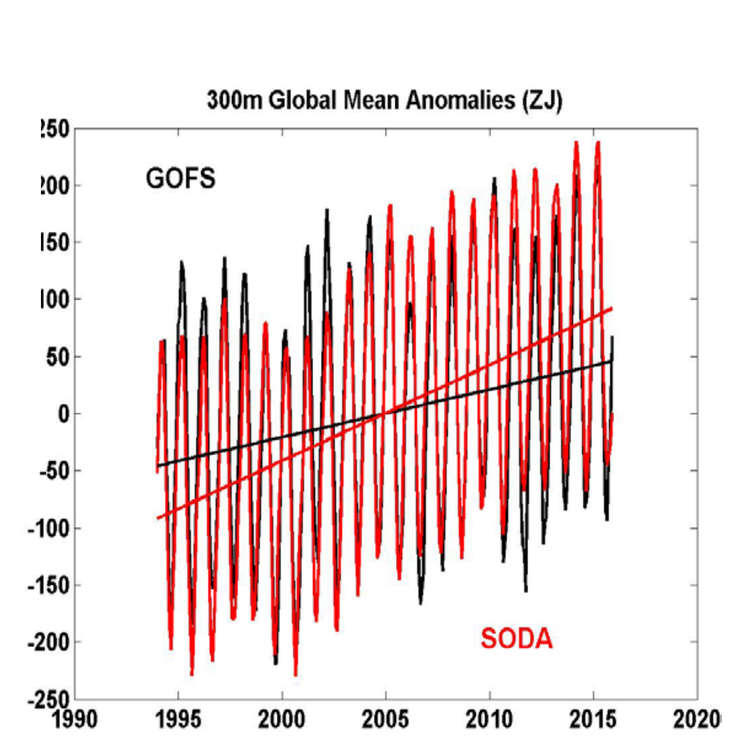
Ocean Heat Content

The ocean heat content is calculated by integrating the model temperature between fixed depths. The temporal mean, standard deviation and trends over the 22 years 1994-2015 and the spatial mean from 60S to 60N will be shown for the upper ocean 0-300m, upper thermocline 300-700 and lower thermocline 700-1500m

Upper Ocean 0-300m

GOFS



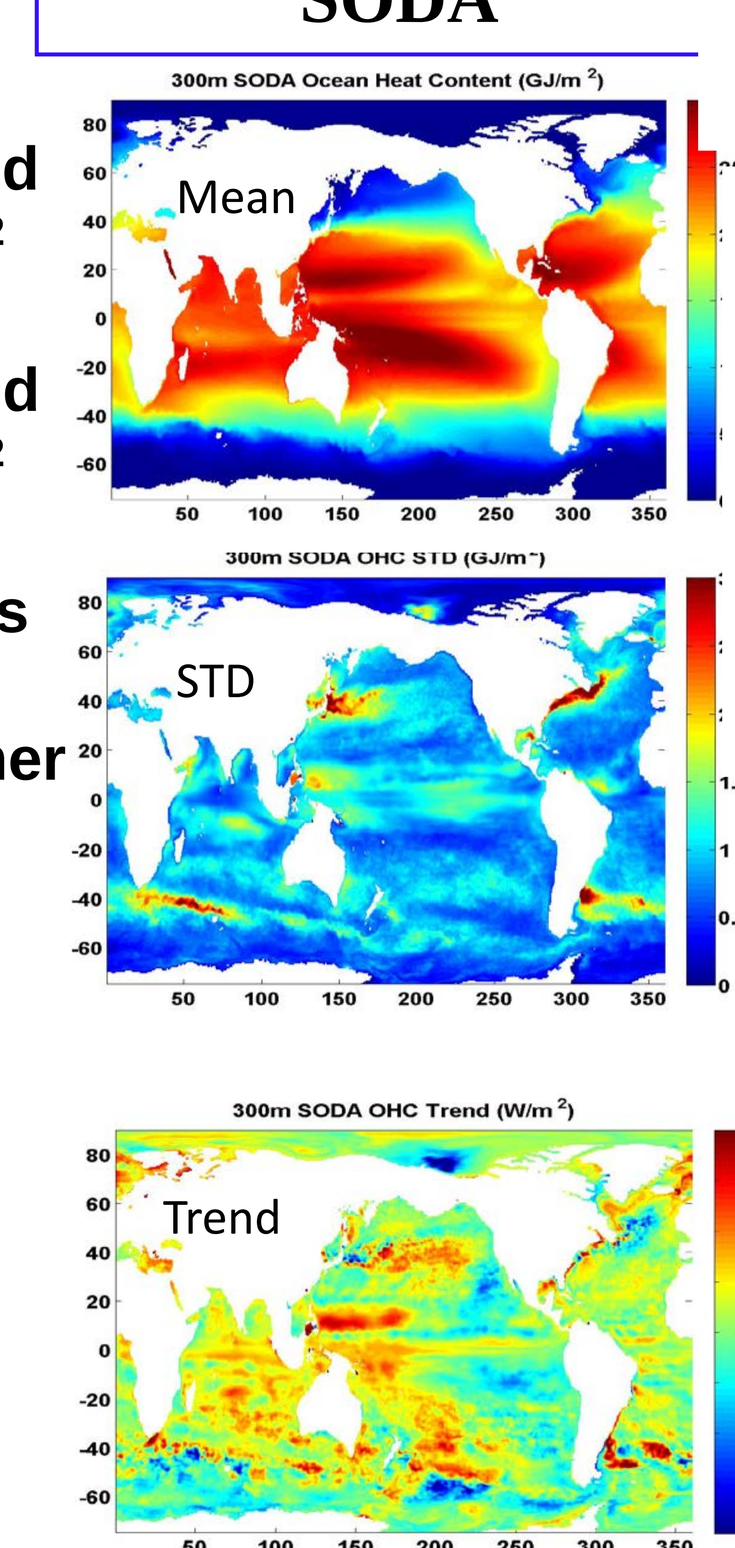


GOFS Trend 0.43 W/m²

SODA Trend 0.86 W/m²

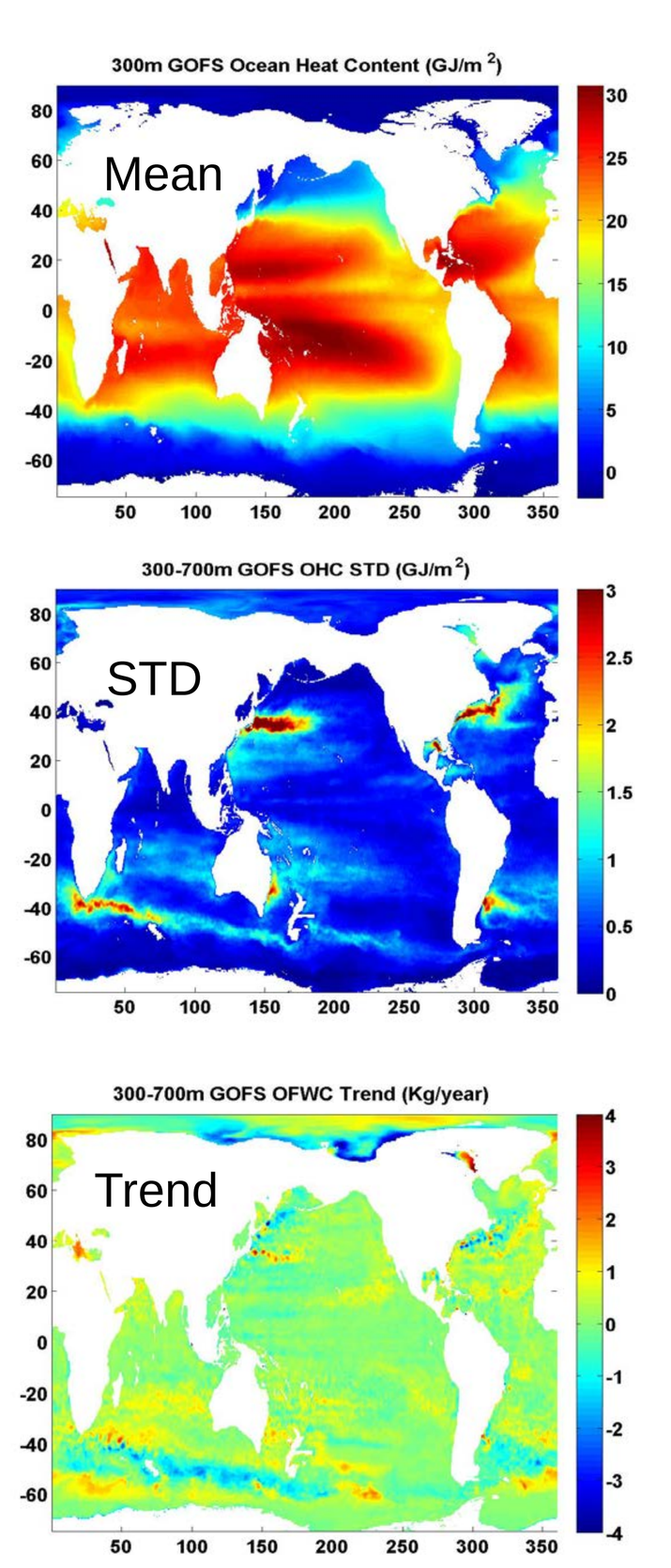
Global Bias 513 ZJ SODA warmer

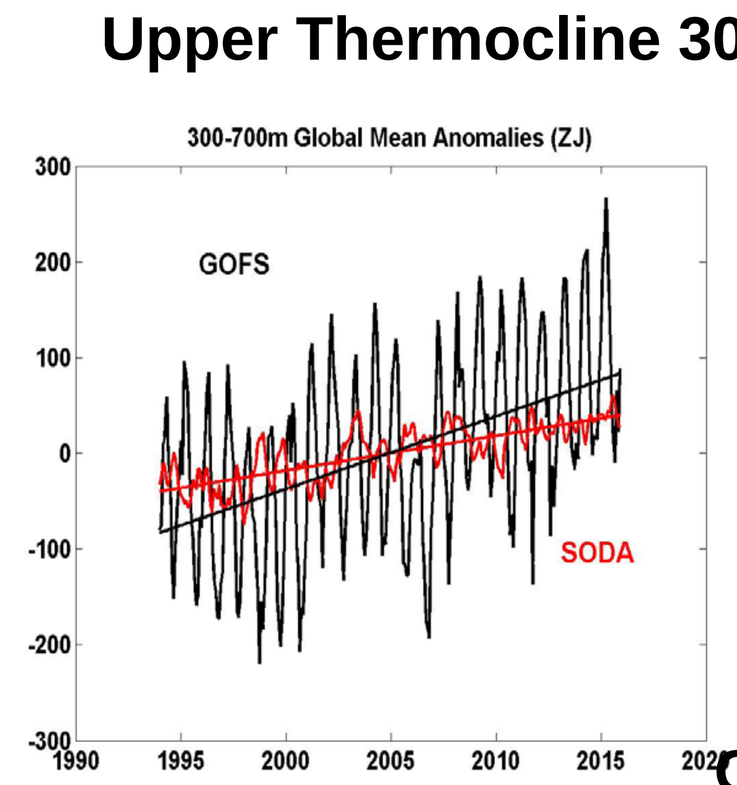
SODA



The spatial correlation and temporal correlation of the upper ocean heat content is high. SODA is warmer than GOFS. The monthly STD is dominated by the seasonal cycle. In the WBC regions SODA has a larger STD.
Both reanalyses show a warming trend over most of the globe with the SODA trend being twice the GOFS trend.
Pre-Argo era (prior to 2004), SODA is cooler than GOFS, while the reverse occurs after 2004

Upper Thermocline 300-700m

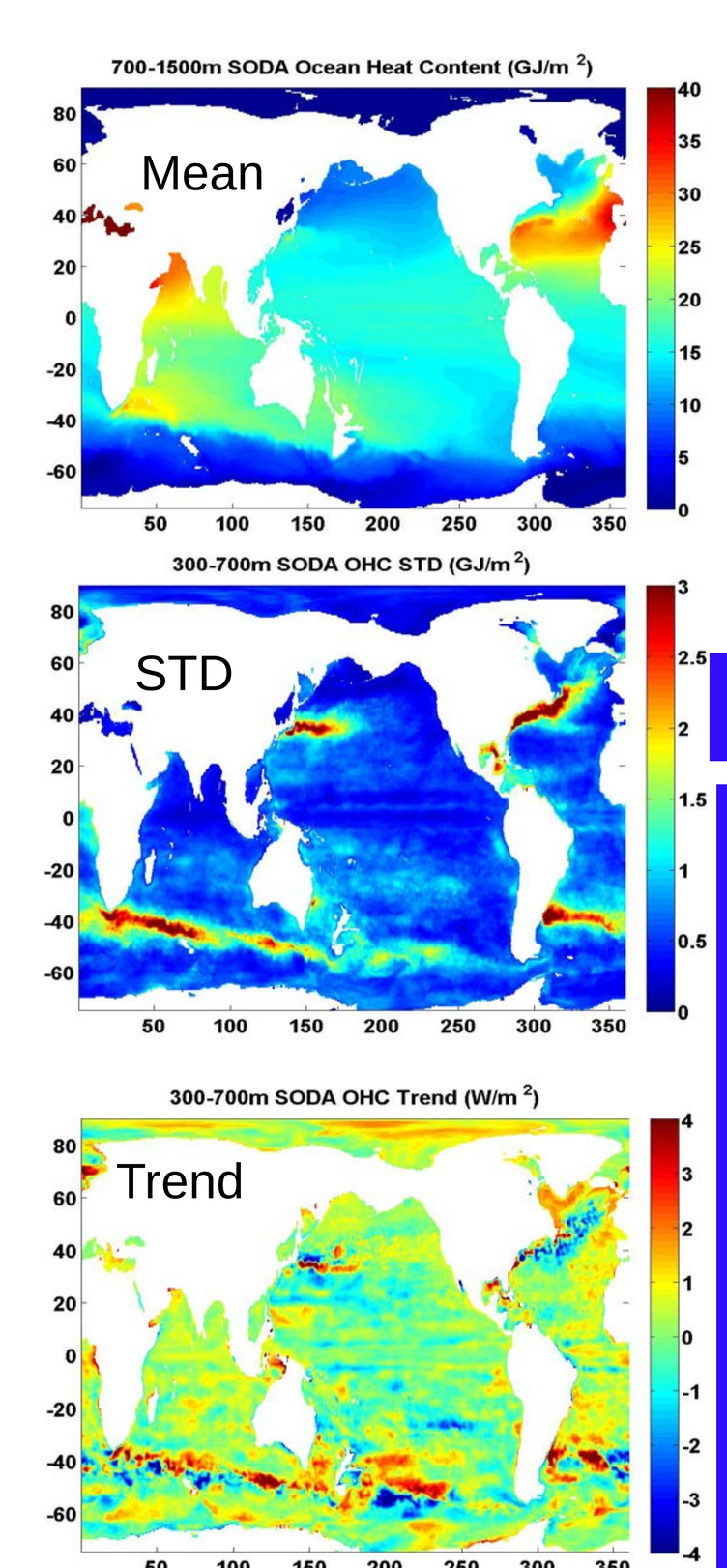




GOFS Trend 0.78 W/m²

SODA Trend 0.18 W/m²

Global Bias 20.9 YJ GOFS warmer

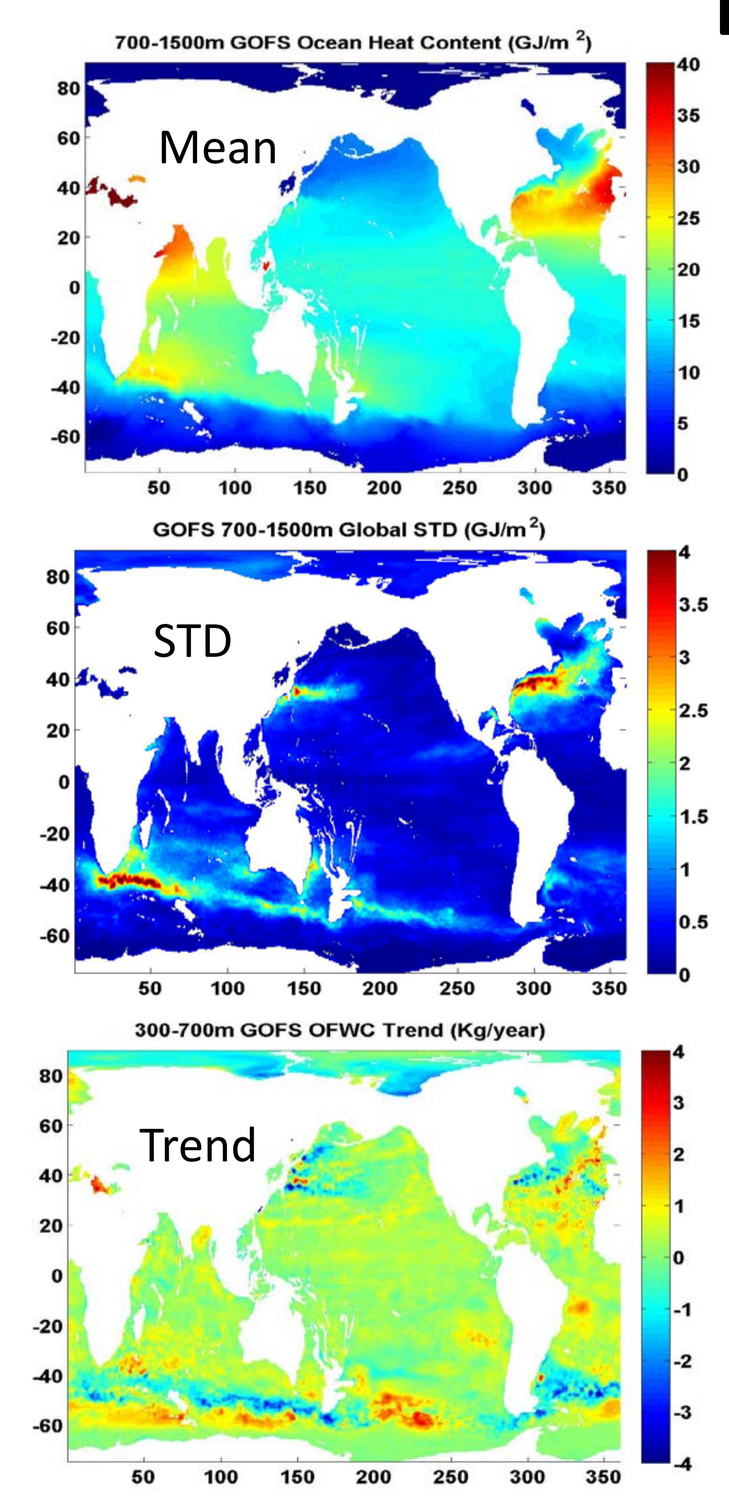


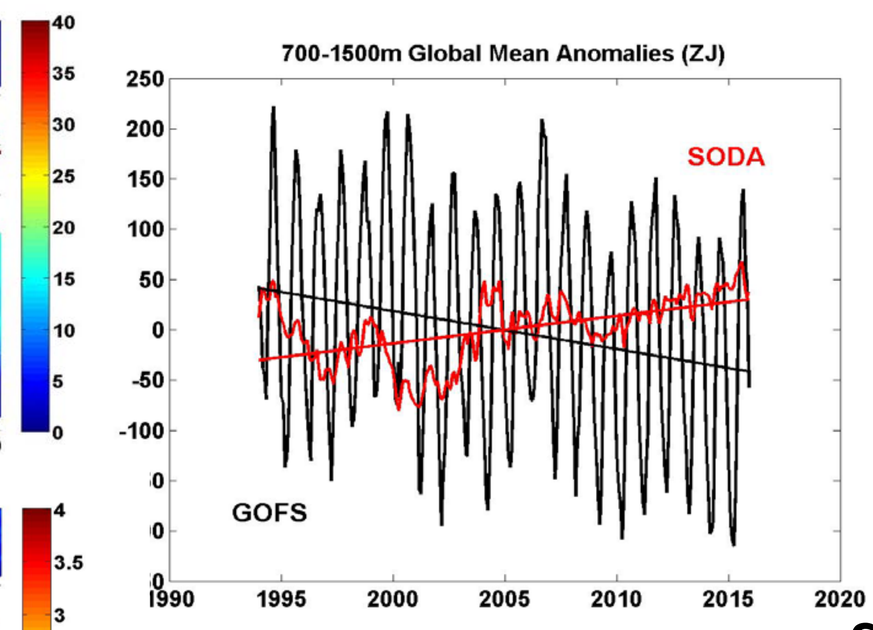
The differences between to two reanalyses are large for the upper thermocline. GOFS, which assimilates SSH as virtual T/S profiles using a variational correlation with climatology, has a much deeper thermocline than SODA which only assimilates actual T/S profiles. GOFS exhibits a large seasonal cycle in the heat content which is not found in SODA

GOFS with its deeper thermocline is warmer than SODA, which is the reverse of the upper ocean.

Ocean Heat Content

Lower Thermocline 700-1500m

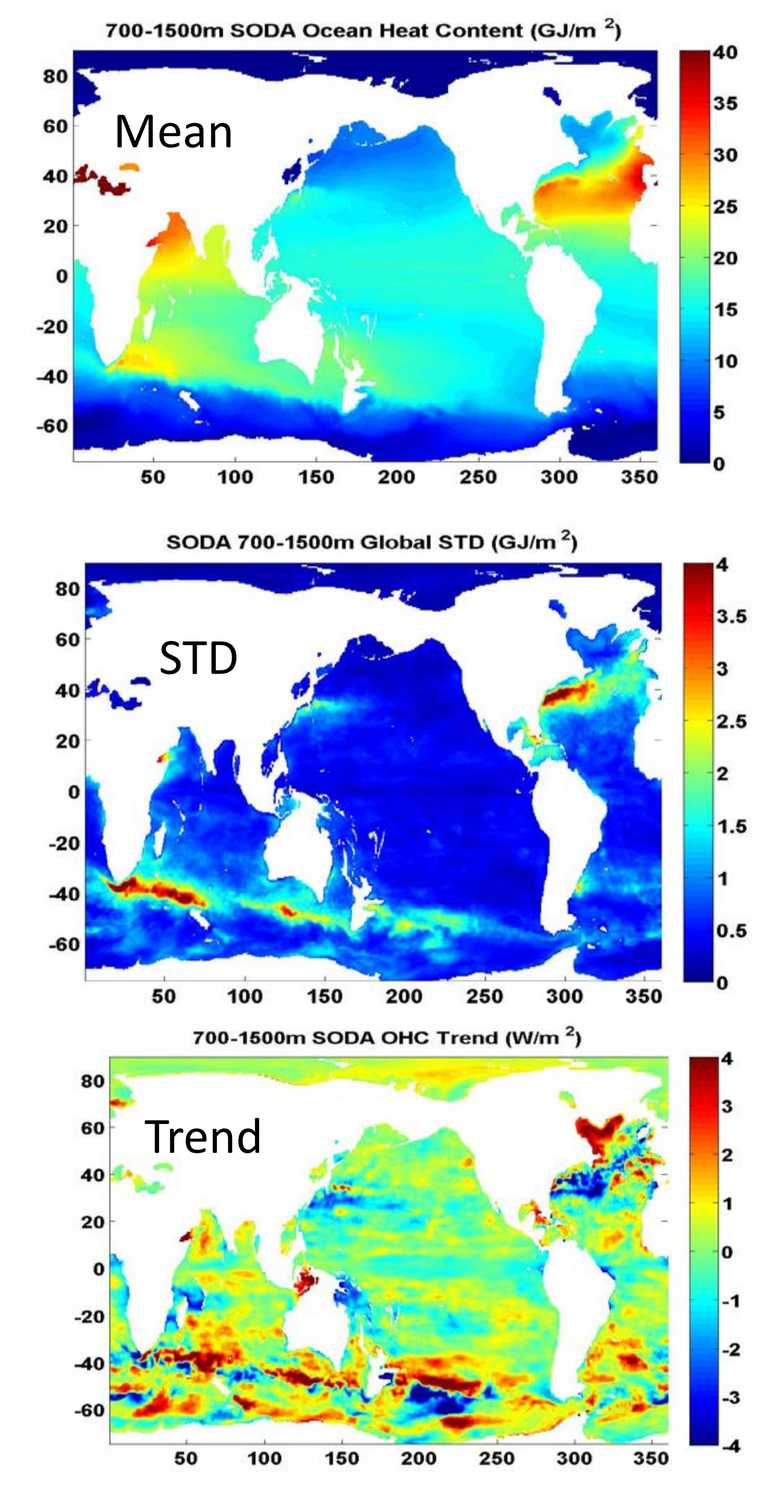




GOFS Trend -0.39 W/m²

SODA Trend 0.28 W/m²

Global Bias 22.0 YJ SODA warmer

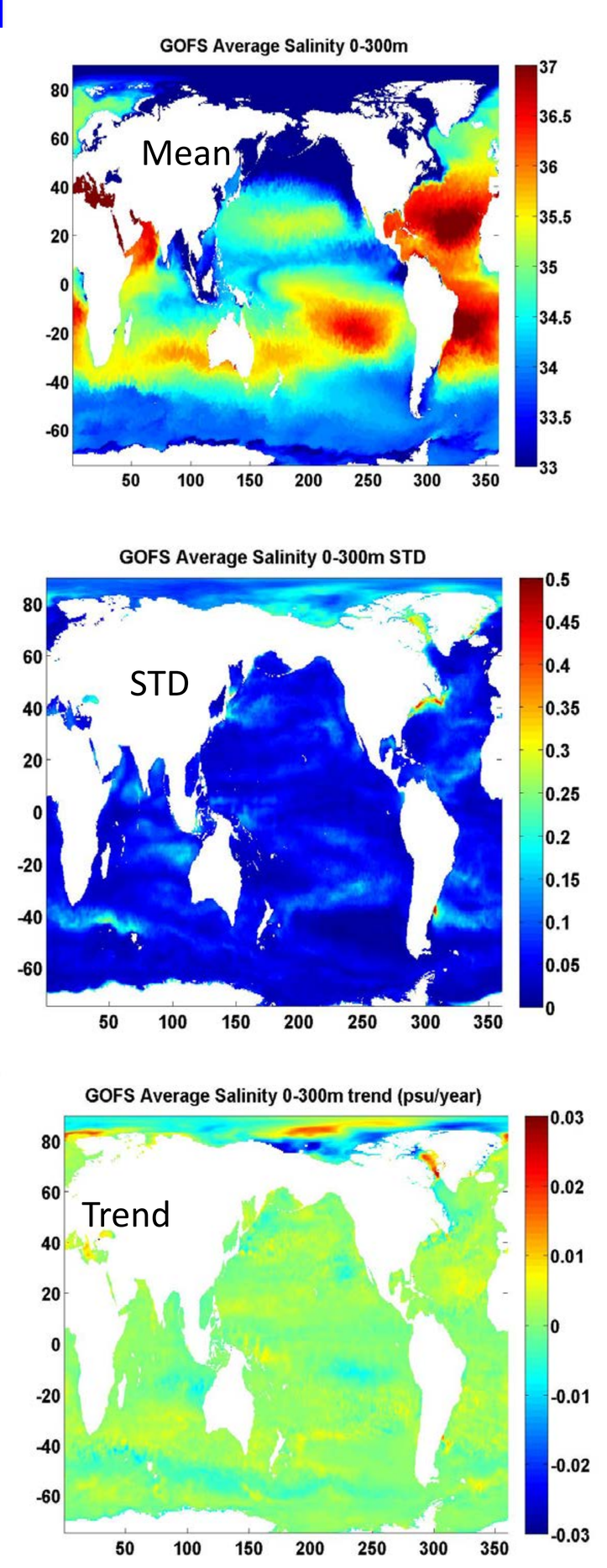


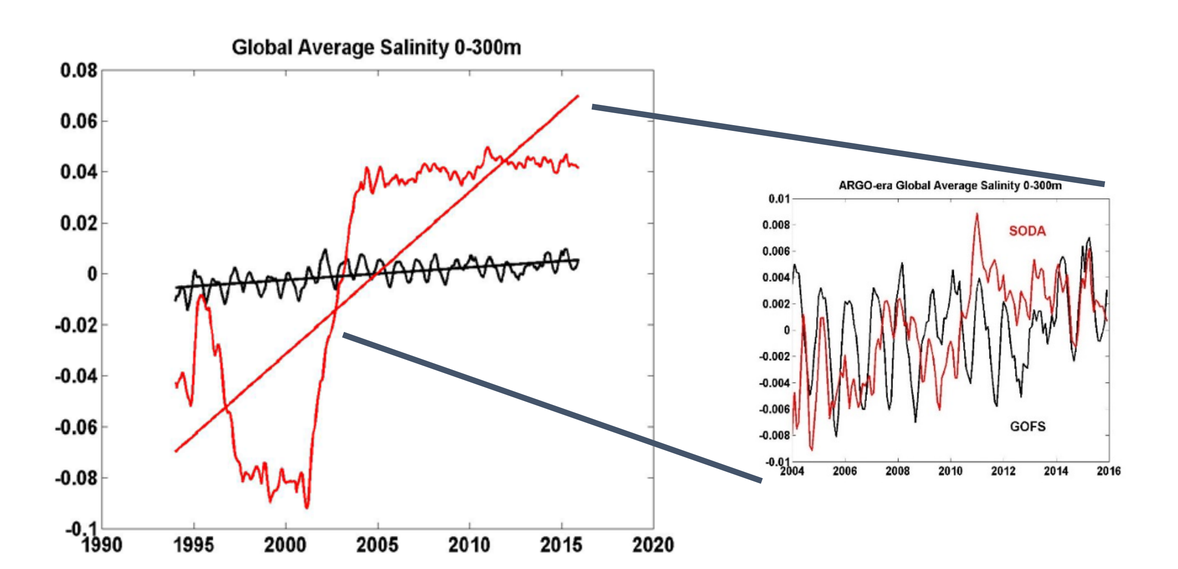
GOFS still exhibits a seasonal cycle in the thermocline heat content. For the lower thermocline, GOFS has a cooling trend compared to a warming trend for SODA.

The spatial patterns of the mean heat content are similar between the two reanalyses although SODA is warmer on average.

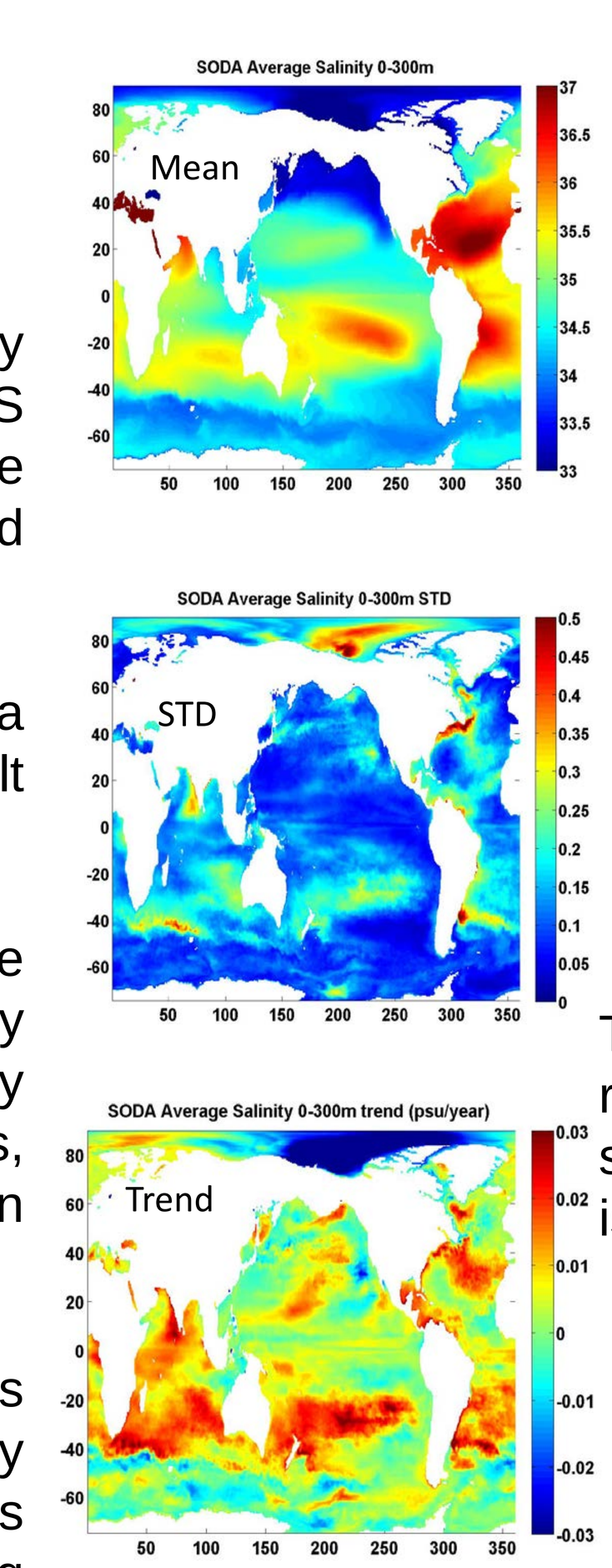
Salt Content (Average Salinity)

GOFS





SODA



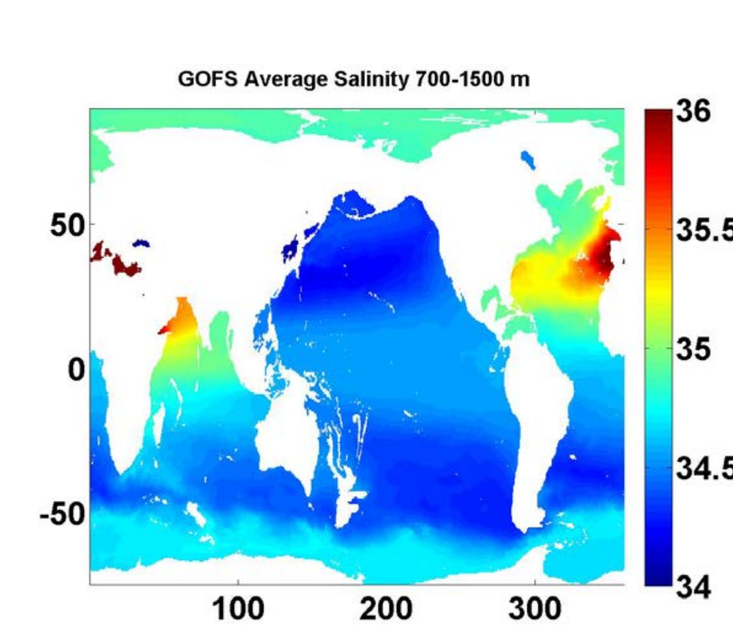
The spatial patterns of the mean salinity over the top 300m are very similar. GOFS is slightly salter over most in the subtropics, but fresher in the tropics and polar and subpolar regions.

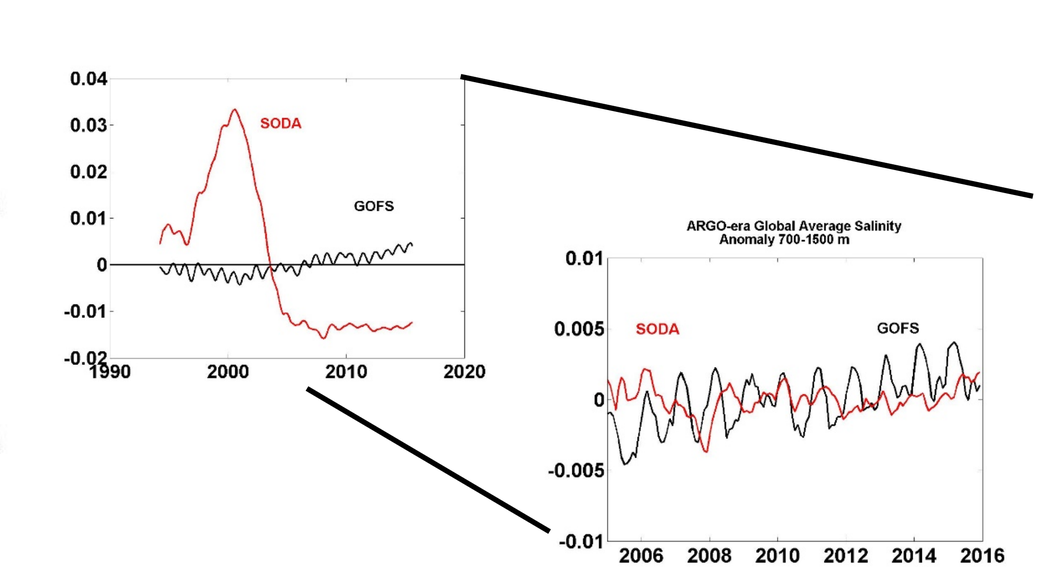
The effects of sampling and data assimilation are very apparent in the salt content.

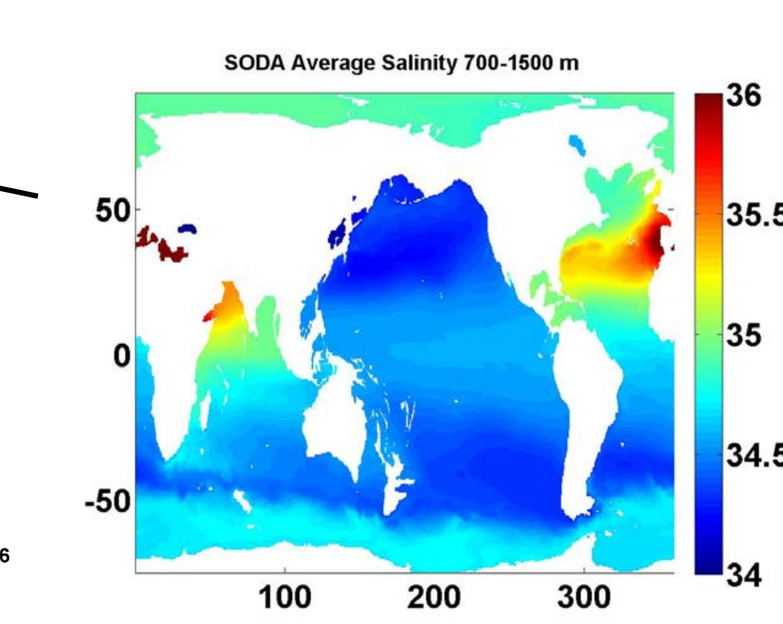
After 2004 when Argo profiles provide nearly global coverage on a monthly basis, GOFS and SODA have nearly identical patterns, variance and trends, although SODA remains slightly saltier on average.

Prior to 2004, GOFS assimilates SSH as virtual T/S profiles, while SODA only assimilates actual profiles. SODA has much larger variability with strong freshening over this period.

Lower Thermocline 700-1500m



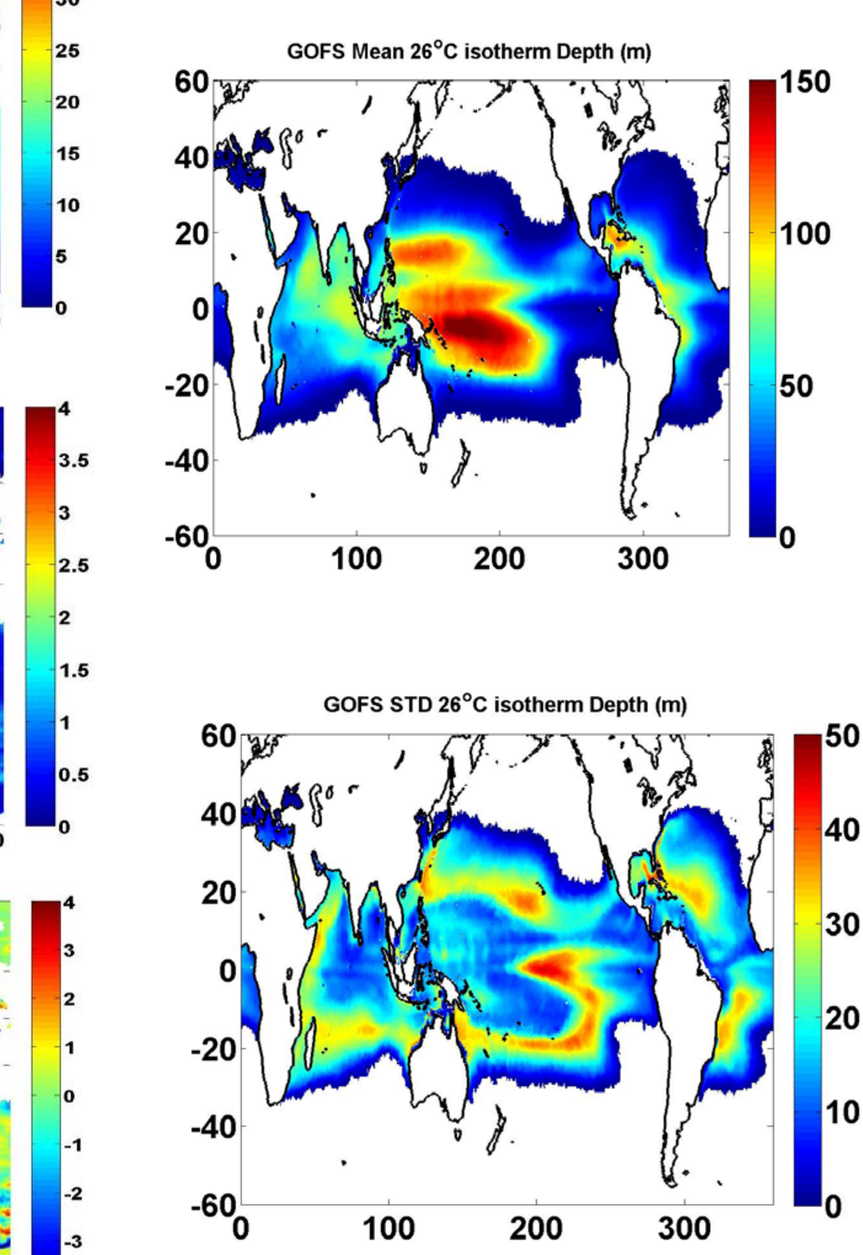


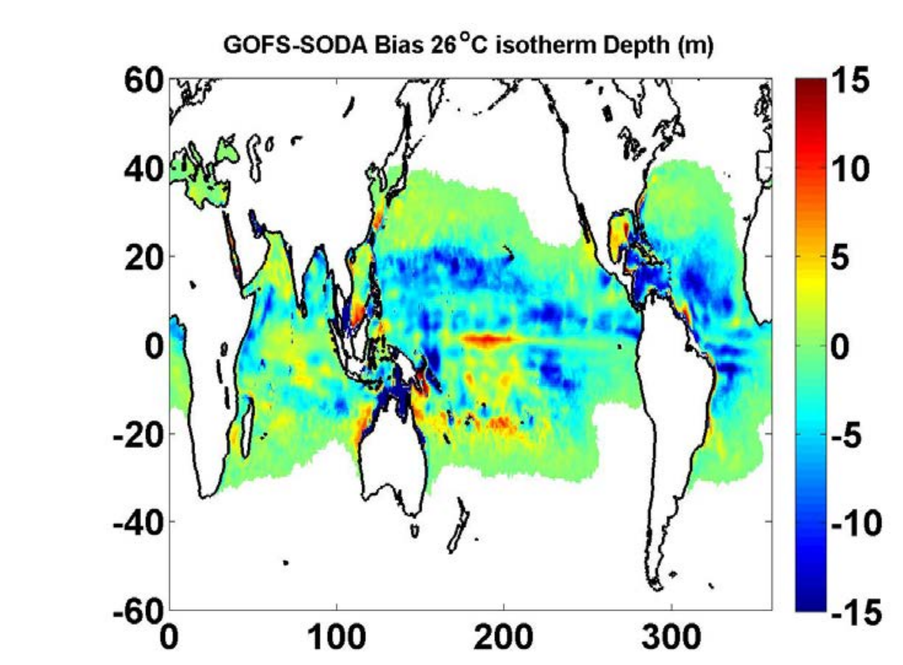


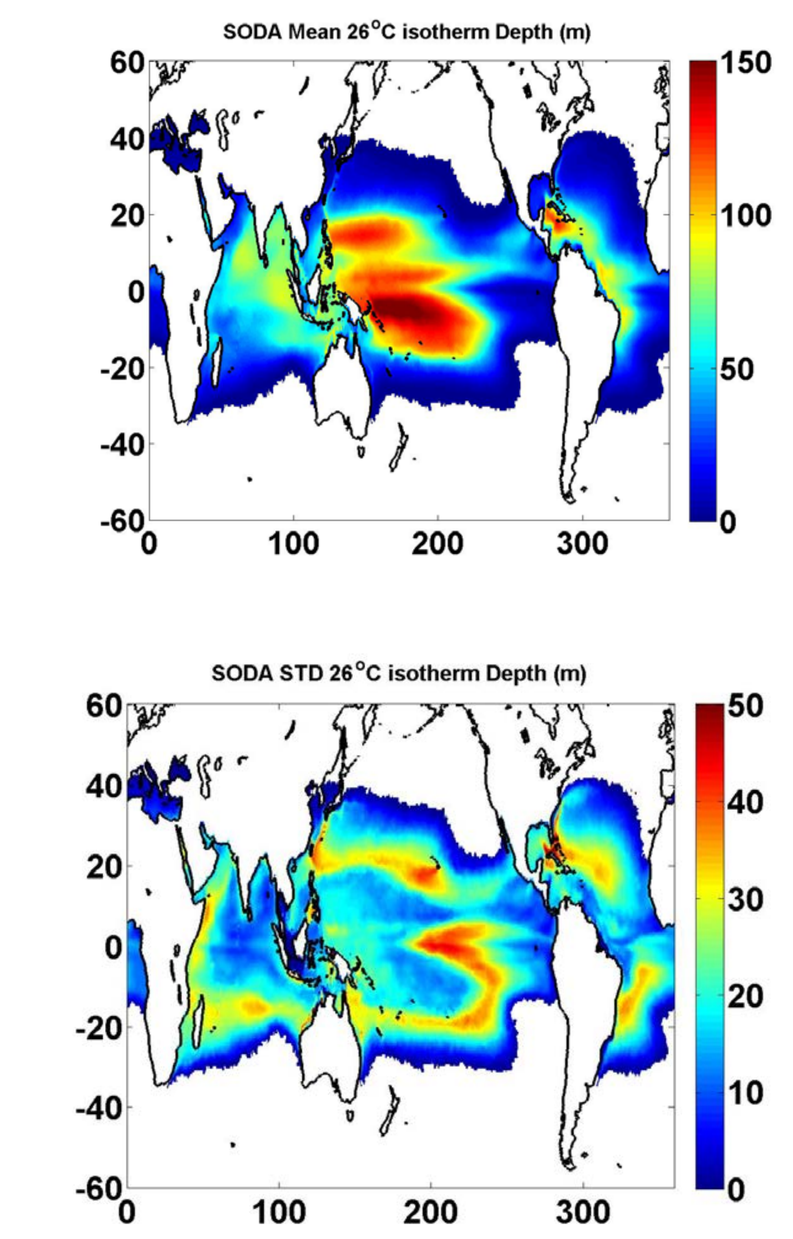
Similar to the upper ocean, the spatial patterns of the mean salinity over the lower thermocline are very similar. GOFS is slightly fresher over most in the subtropics, but saltier in the tropics and polar and subpolar regions.
The effects of sampling and data assimilation are very apparent in the salt content. After 2004 when Argo profiles provide nearly global coverage on a monthly basis, GOFS and SODA have nearly identical patterns, variance and trends, although SODA remains slightly saltier on average and GOFS has a weak salty trend. Prior to 2004, GOFS assimilates SSH as virtual T/S profiles, while SODA only assimilates actual profiles. SODA has much larger variability with strong freshening over this period.

Isotherm Depths

GOFS | 26^oC Isotherm | SODA

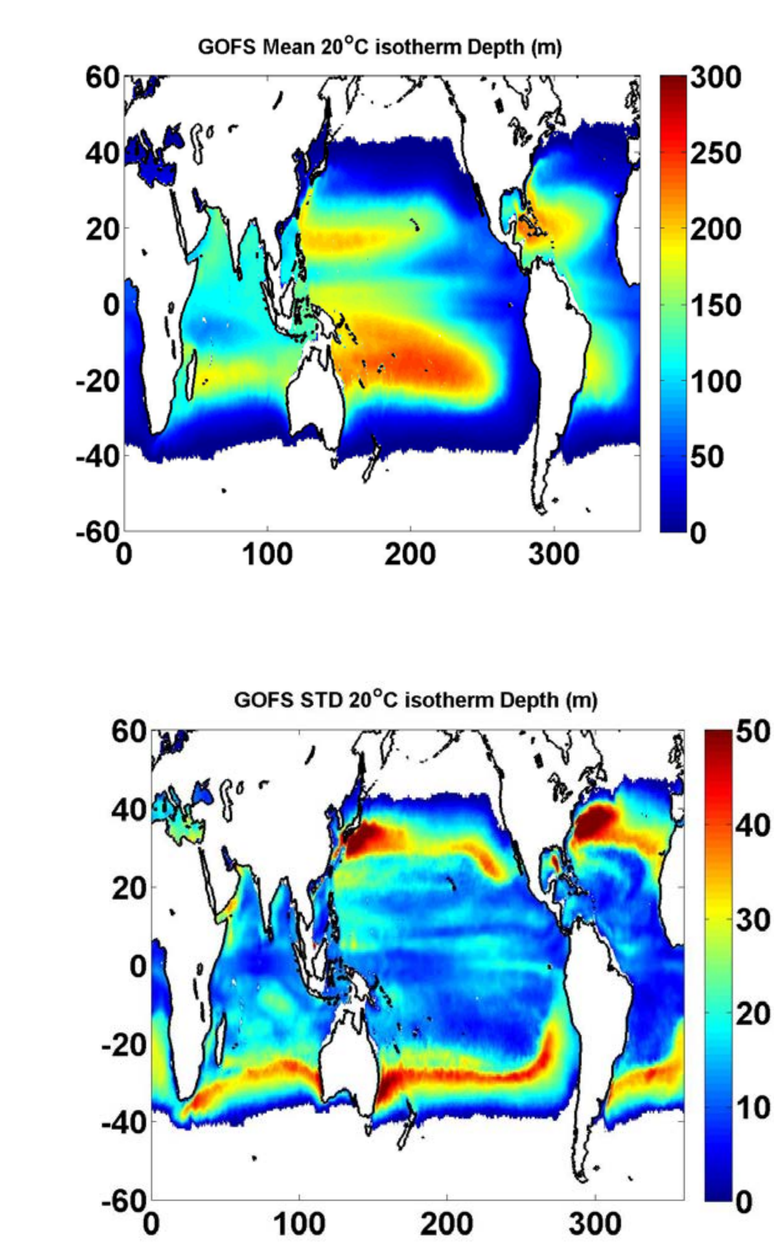


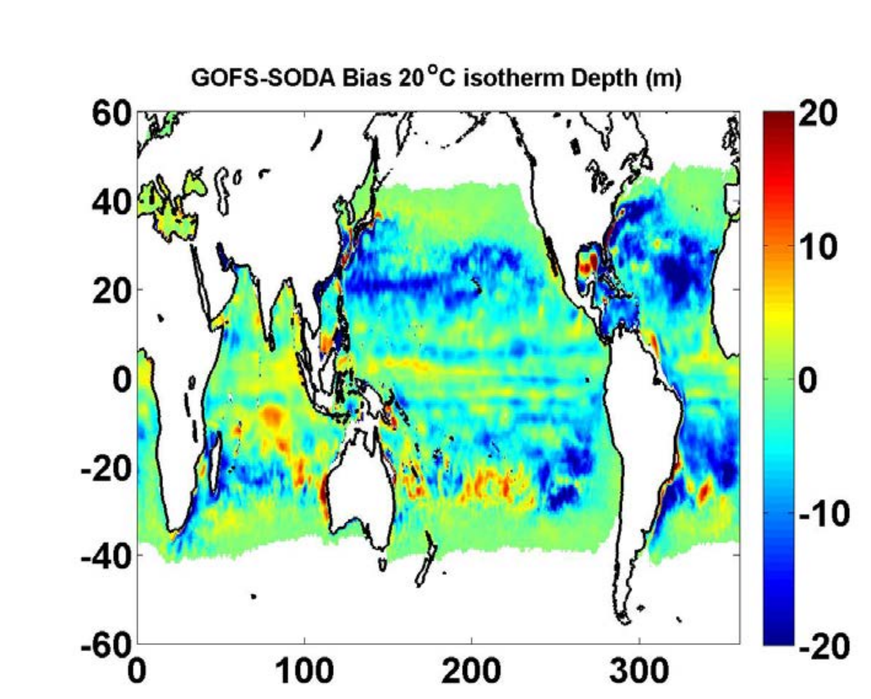


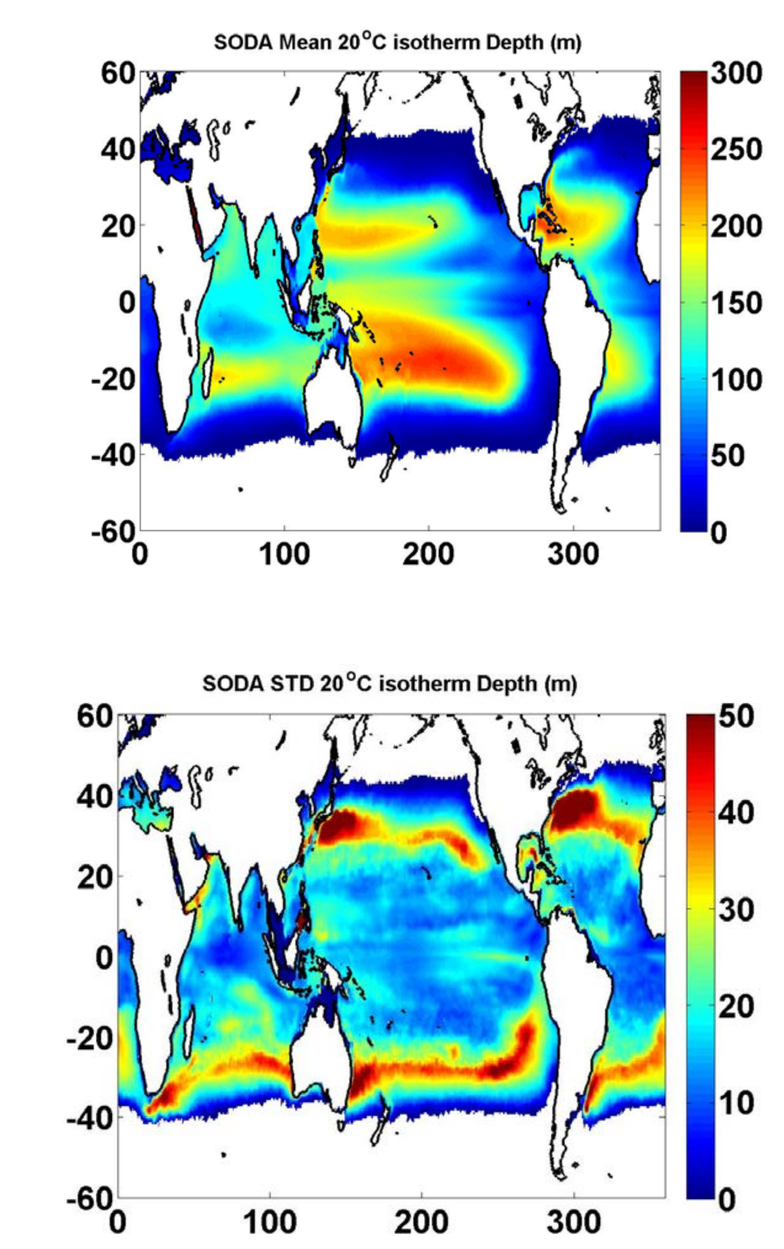


The spatial pattern of the depth of the 26ºC isotherm is similar between the two reanalyses. SODA is deeper in the tropics, while GOFS is deeper in the central equatorial Pacific and subtropics. The standard deviation and seasonal cycle (not shown) for this shallow isotherm are very similar. GOFS has a slightly larger standard deviation in the central equatorial Pacific.

20ºC Isotherm

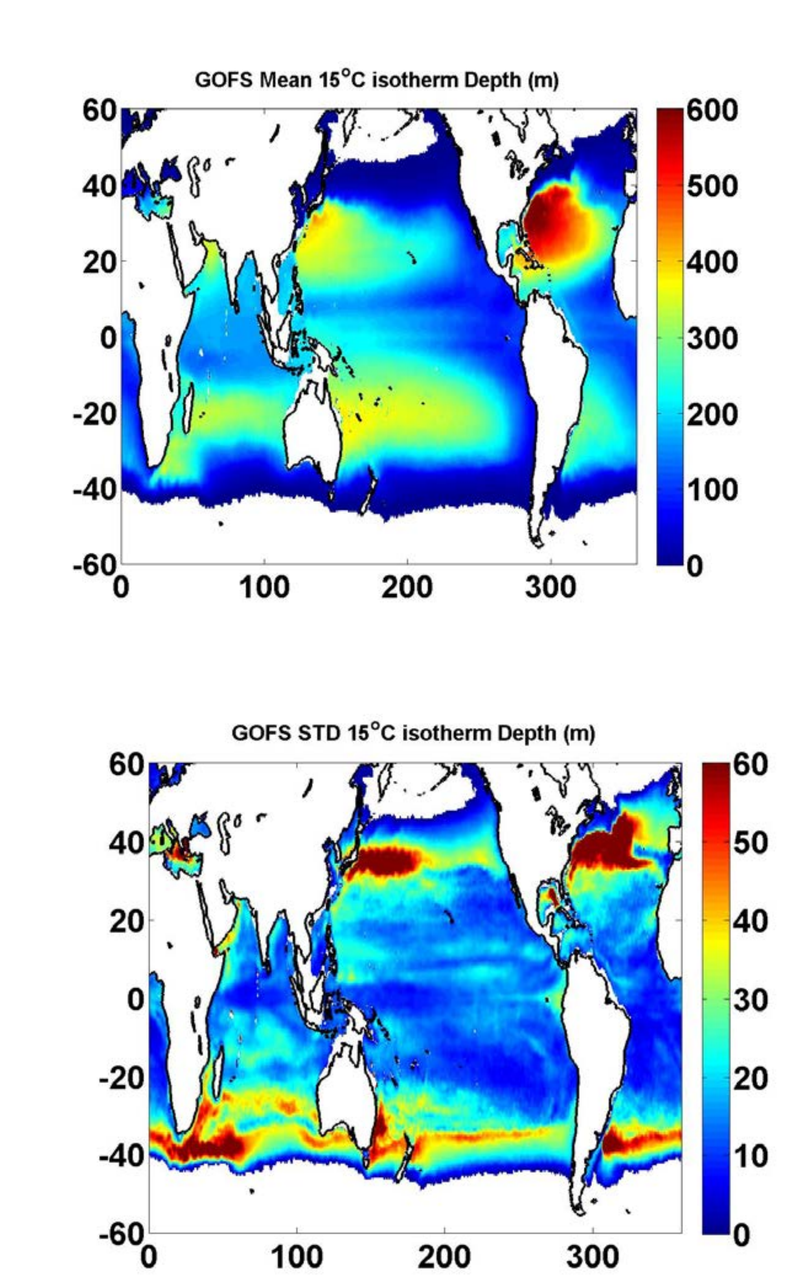


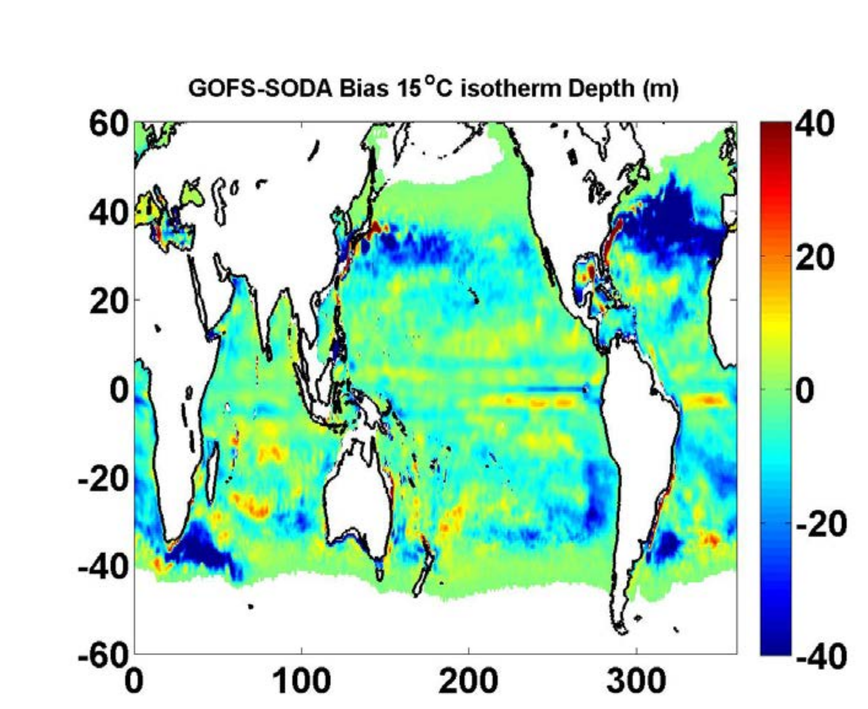


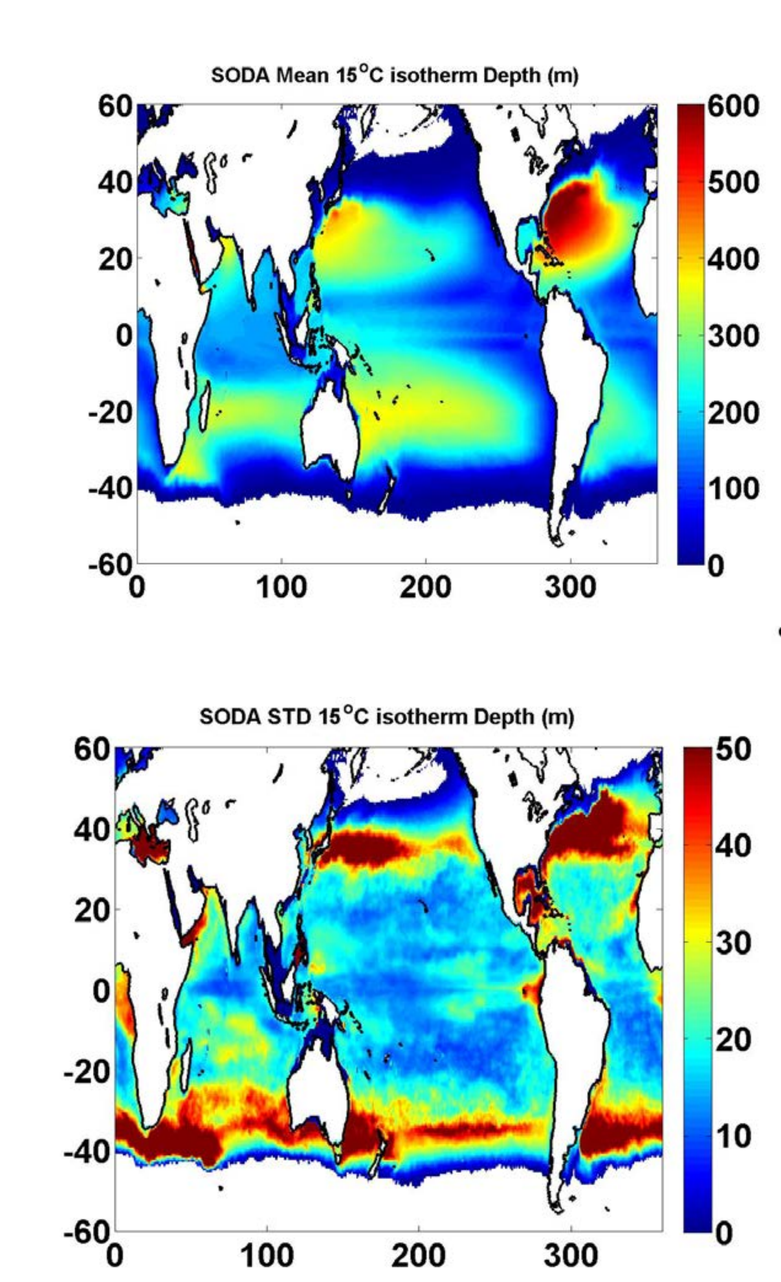


The spatial pattern of the depth of the 20ºC isotherm is similar between the two reanalyses. SODA is deeper in the tropics, while GOFS along the equator and subtropics. The standard deviation and seasonal cycle (not shown) for this shallow isotherm are very similar. GOFS has a smaller standard deviation in the tropics.

15ºC Isotherm





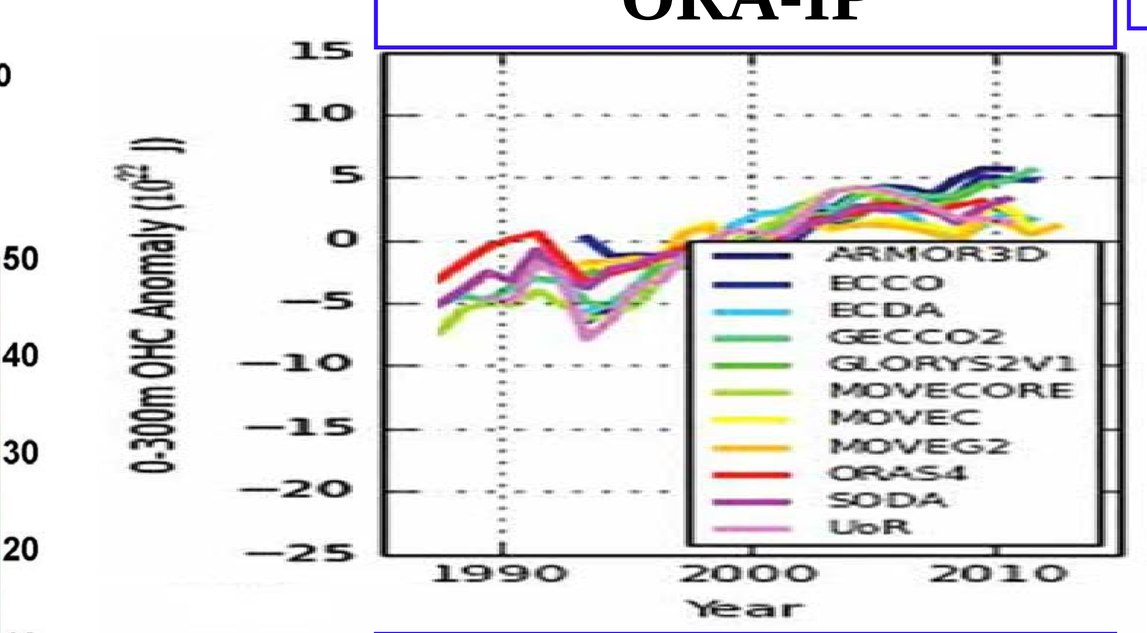


The spatial patterns of the 15ºC isotherm are very similar for the two reanalyses. GOFS is slightly shallower in the tropics and .near the outcropping latitudes. SODA is deeper in the western boundary currents and subtropics

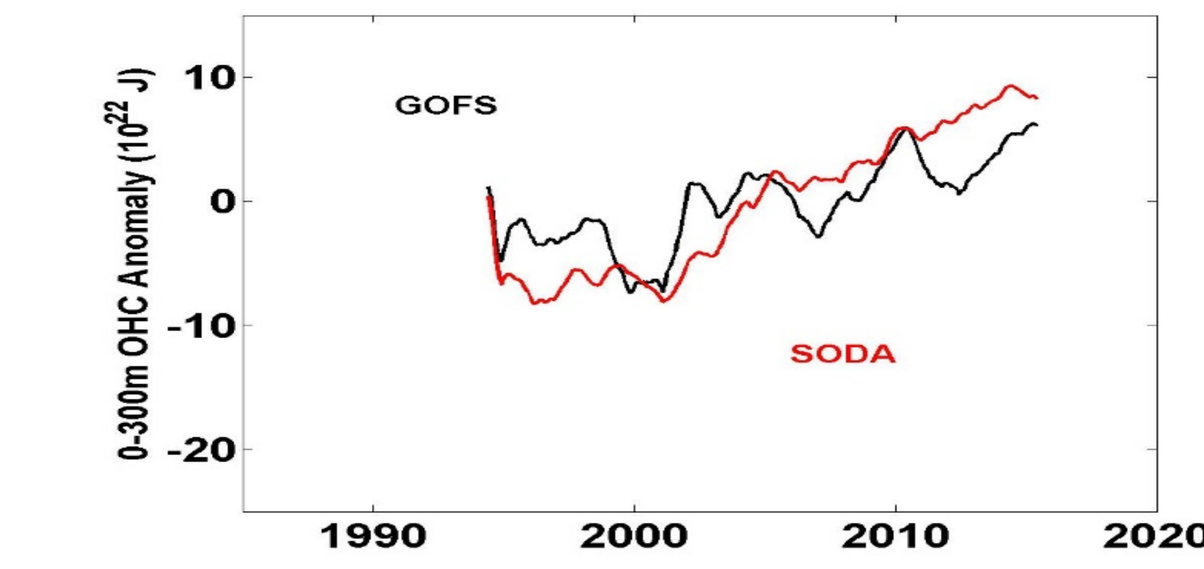
Comparison with Ocean Reanalyses Intercomparison Project (ORA-IP)

The Ocean Reanalysis Intercomparison Project (ORA-IP) evaluated an ensemble of approximately 14 different ocean reanalysis for ocean state estimation. The models differed in their dynamical cores, resolution and forcing. Most of the models had either coarse (1°) or eddy-permitting (1/2° or ¼°) horizontal resolution. For the current analysis, GOFS has an eddy resolving resolution of 1/12.5°, while SODA has an eddy permitting resolution of ¼°.

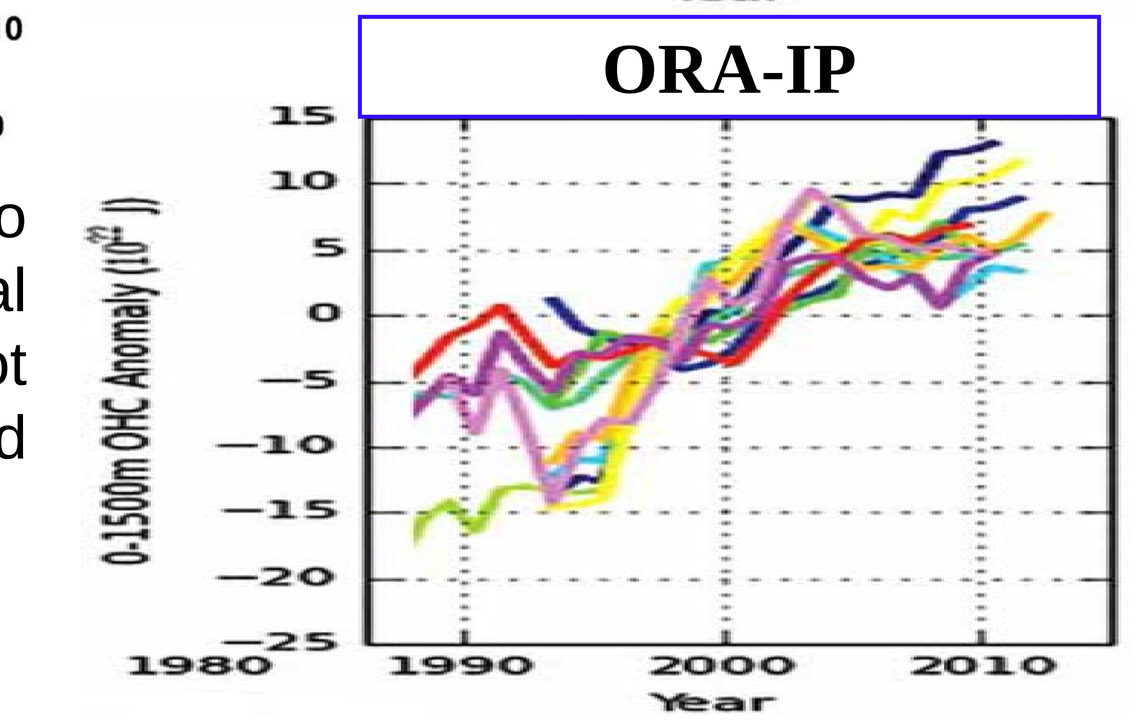
ORA-IP

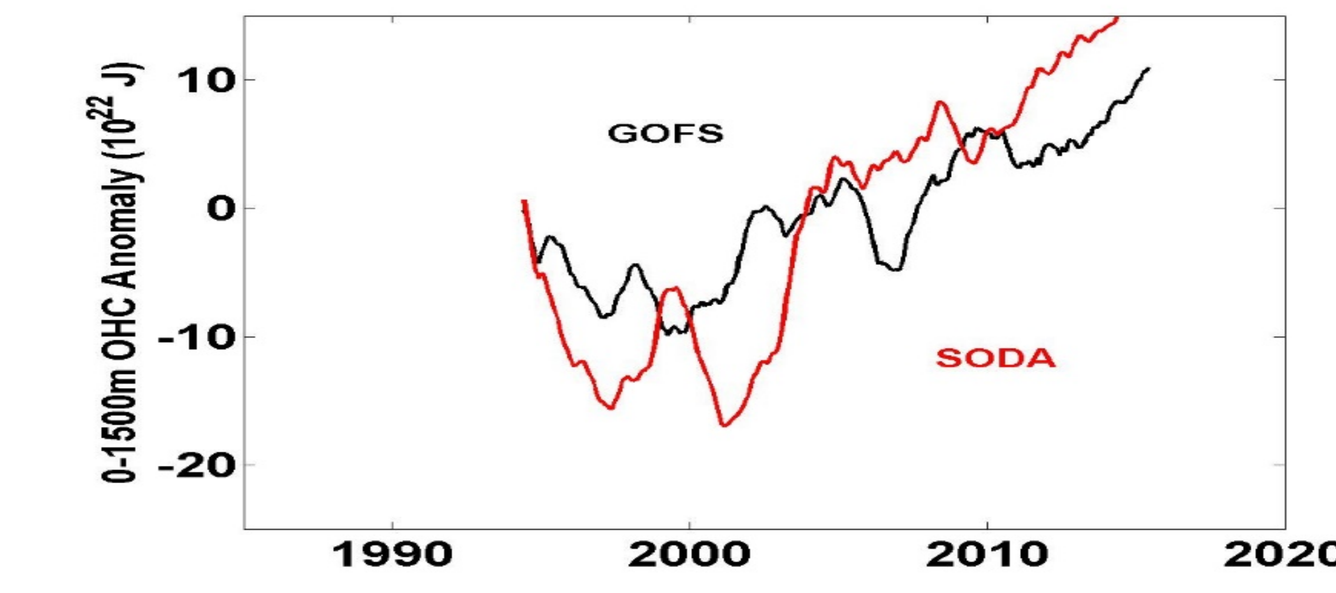


GOFS & SODA

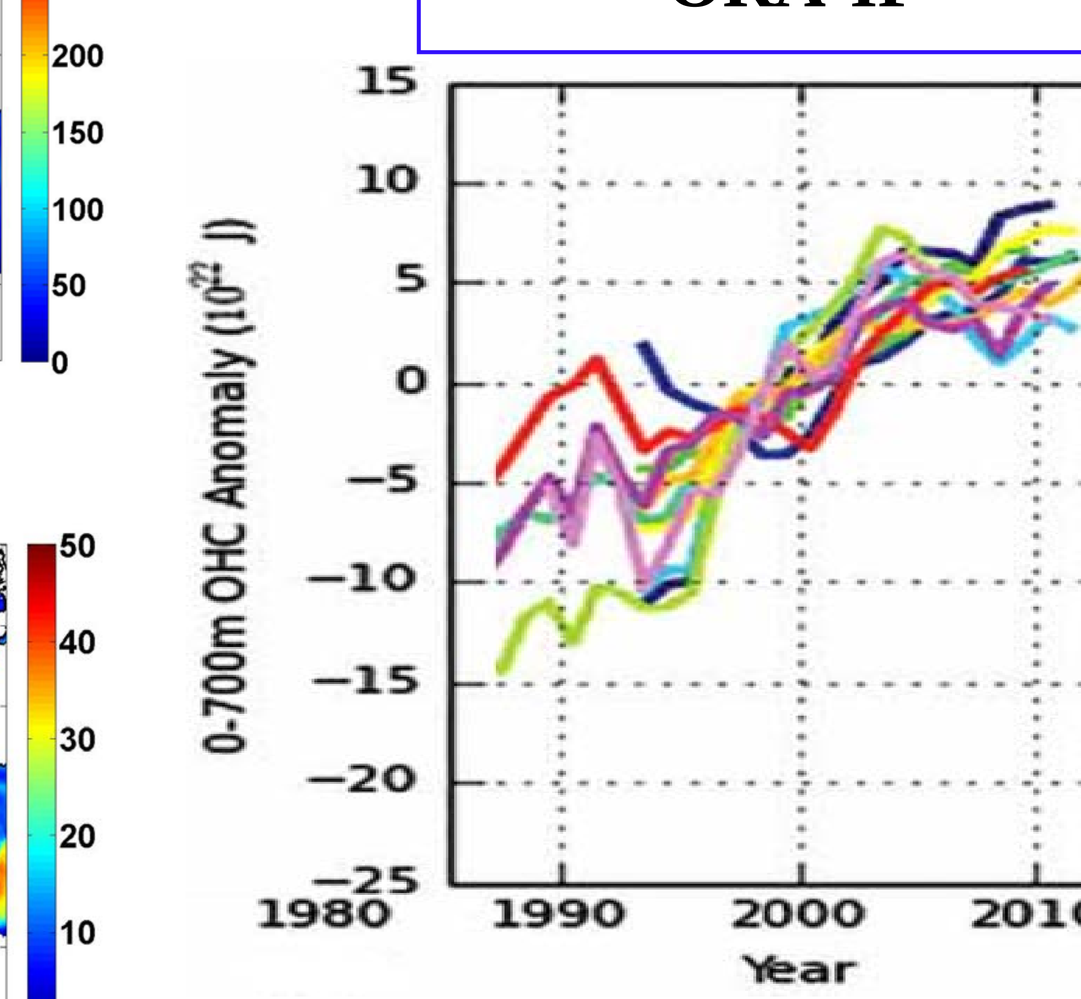


ORA-IP

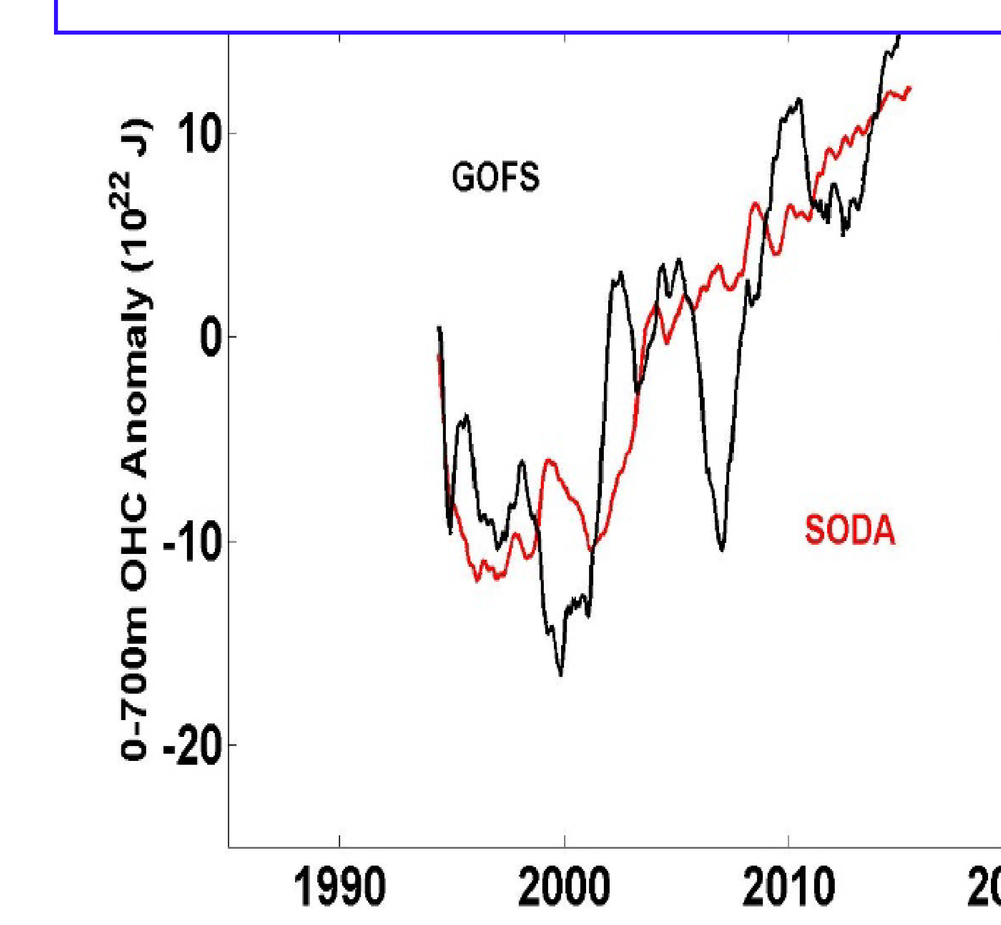




ORA-IP



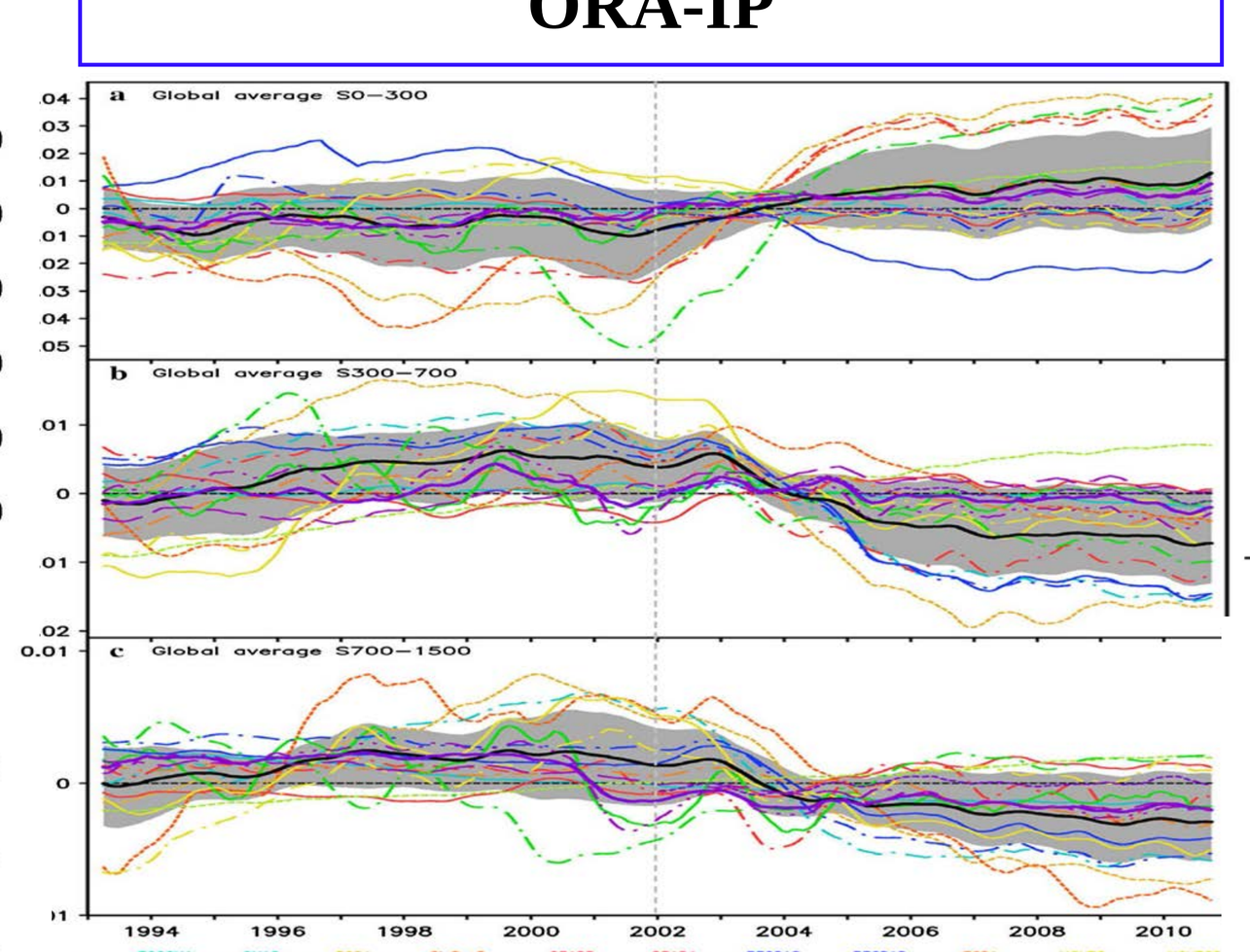
GOFS & SODA



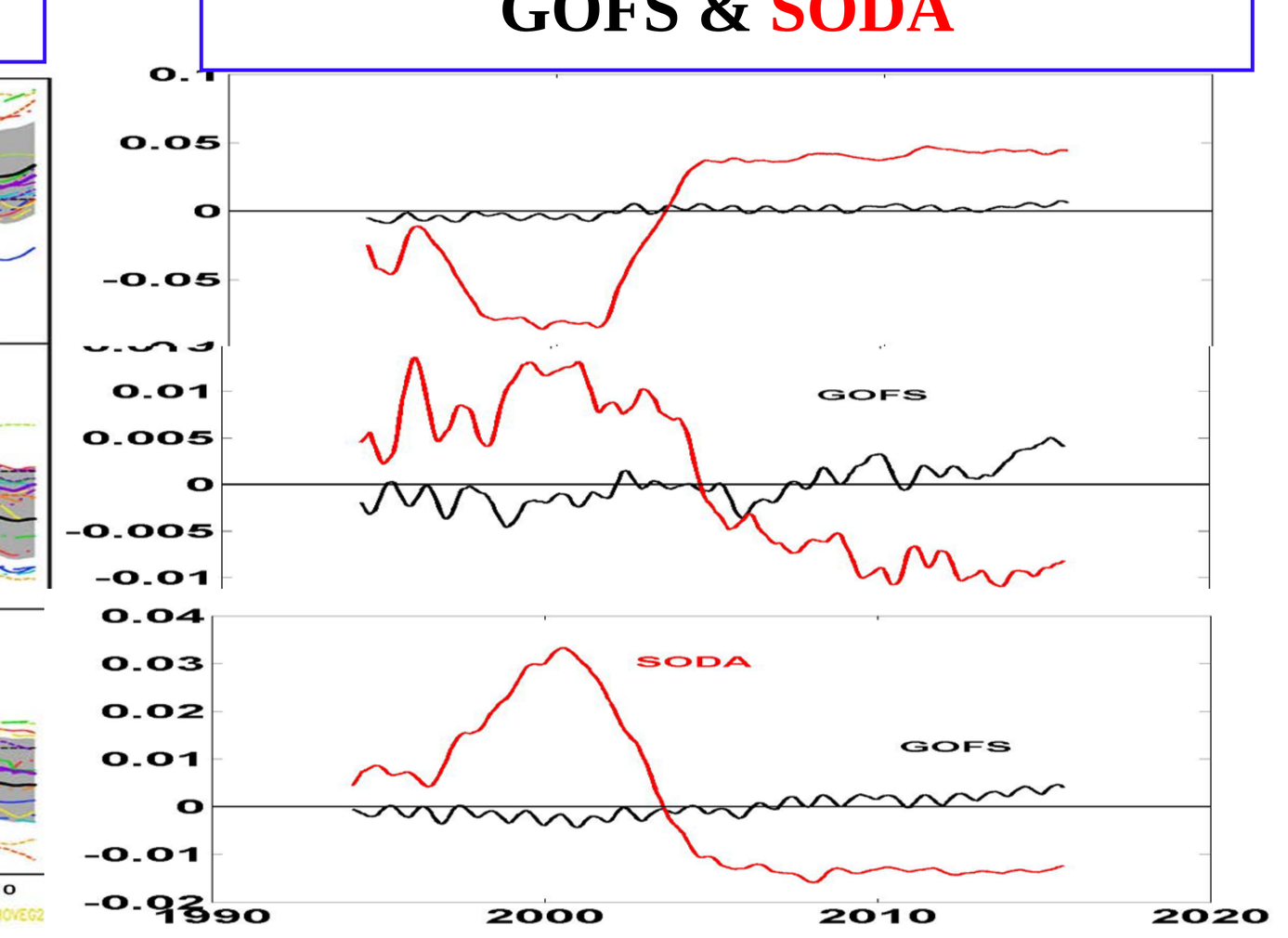
Taken from Balmaseda, et al. (2015)

In general, the later GOFS and SODA reanalysis heat content fall within the ensemble spread of ORA-IP. The recent reanalyses continue the warming trend of ~0.75 W/m² observed in the upper ocean with SODA have a larger warming trend. GOFS has a cooling event in 2008. The largest differences outside of this cooling event occur in the pre-Argo era (prior to 2004).

ORA-IP



GOFS & SODA



Taken from Shi, et al. (2017)

ORA-IP ensemble has significant spread around the ensemble mean salinity (dark black line on plots). For the upper ocean 0-300m, GOFS lies close to the ensemble mean showing a slight trend towards increasing salinity. In the thermocline, GOFS continues to show an increase in salinity, while the ensemble shows a freshening trend. However, GOFS still falls within the spread of the ensemble. SODA tends to have much greater variability than the ensemble mean and spread. For the upper ocean, SODA is too fresh prior to 2004 and too salty after 2004. In the thermocline, SODA is too salty prior to 2004 and too fresh after 2004.

Conclusions

- The ocean heat content and salt content for an eddy-resolving (1/12º) ocean reanalysis (The Navy Global Ocean Forecast System (GOFS) and an eddy-permitting (1/4º) ocean reanalysis (Simple Ocean Data Assimilation (SODA)) have been compared on a monthly mean, reduced uniform horizontal grid 1/2º) and identical interpolated vertical grid for the 22 year period of 1994-2015.

- Differences due to sampling and data assimilation are apparent between the two reanalyses
  - GOFS assimilates SSH as virtual profiles of temperature and salinity using regionally and seasonally climatological covariations to generate synthetic profiles. Prior to the full implementation of Argo in 2004, the synthetic profiles dominate the assimilated data below the surface.
  - SODA only assimilates actual profiles using an optimal interpolation filter. Thus, prior to 2004, deep ocean profile data is limited, especially in salinity.
  - Large differences occur between the two reanalyses prior to 2004, particularly in salinity. The differences after 2004 are smaller, but still occur.
  - The seasonal cycle in the ocean heat content and average salinity penetrats too deeply in GOFS.

- In general, the spatial patterns of the mean heat and salt content for the 22 years are very similar
  - GOFS tends to be warmer and saltier than SODA
  - In the upper ocean the heat content is highly correlated with similar amplitude seasonal cycle, although SODA is cooler prior to 2004 and warmer after 2004. Both reanalyses have a warming trend of ~0.75 W/m², which is consistent with the ORA-IP ensemble.
  - In the thermocline, the differences between the two reanalyses are greater, The thermocline in GOFS is too deep and seasonality of the heat content penetrates into the thermocline.
  - For salinity, GOFS has a negligible trend over the 22 years and falls within the spread of ORA-IP at all depth. SODA tends to fall outside the ORA-IP spread with the largest differences prior to 2004.

References

- Balmesada, et al., The Ocean Reanalysis Intercomparison Project (ORA-IP), *J. Operational Ocean.*, **8**, s80-s97, 2015
- Palmer, et al., Ocean heat content variability and change in an ensemble of ocean reanalyses, *Clim. Dyn.*, **49(3),** 909-930, 2017.
- Shi, et al., Ocean heat content variability and change in an ensemble of ocean reanalyses, *Clim. Dyn.*, **49(3),** 1009-1029, 2017.