

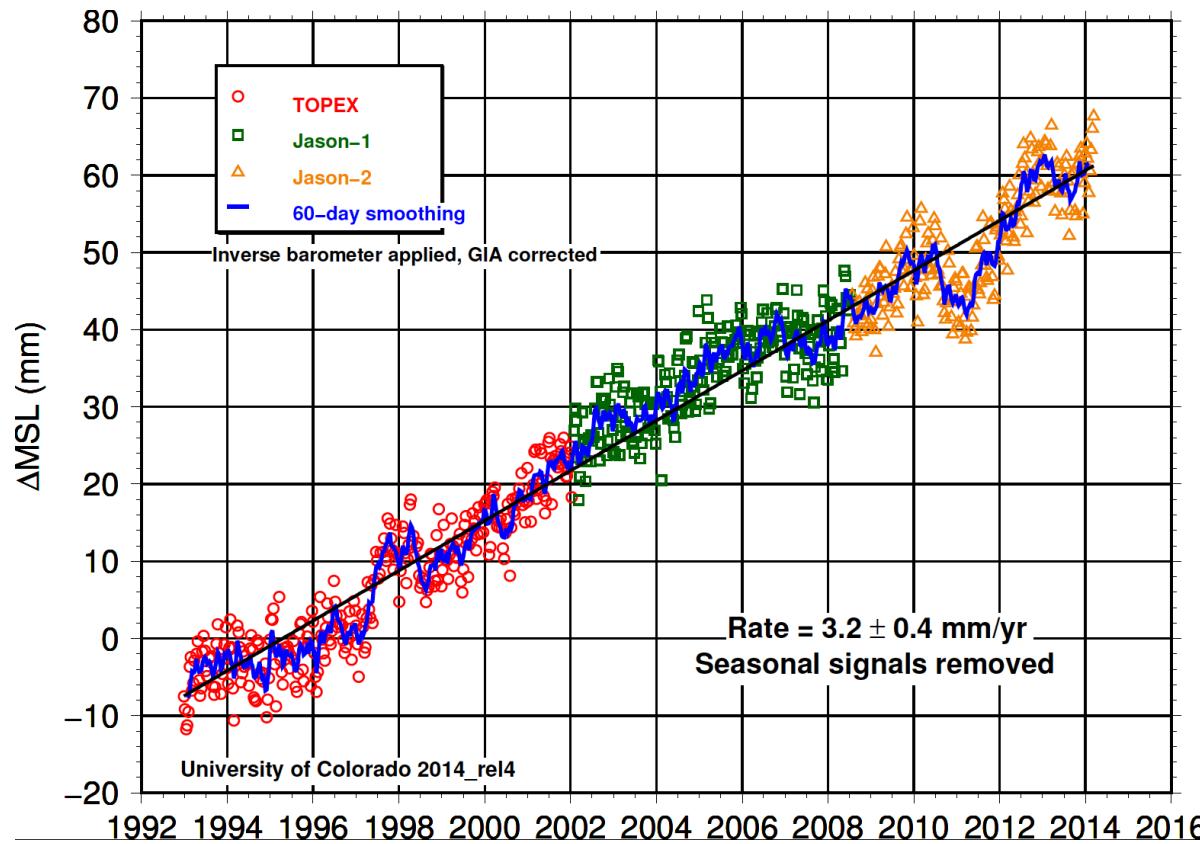
# **Deep-ocean contribution to sea level and energy budget not detectable over the past decade**

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# Global mean sea level over 1993-2013



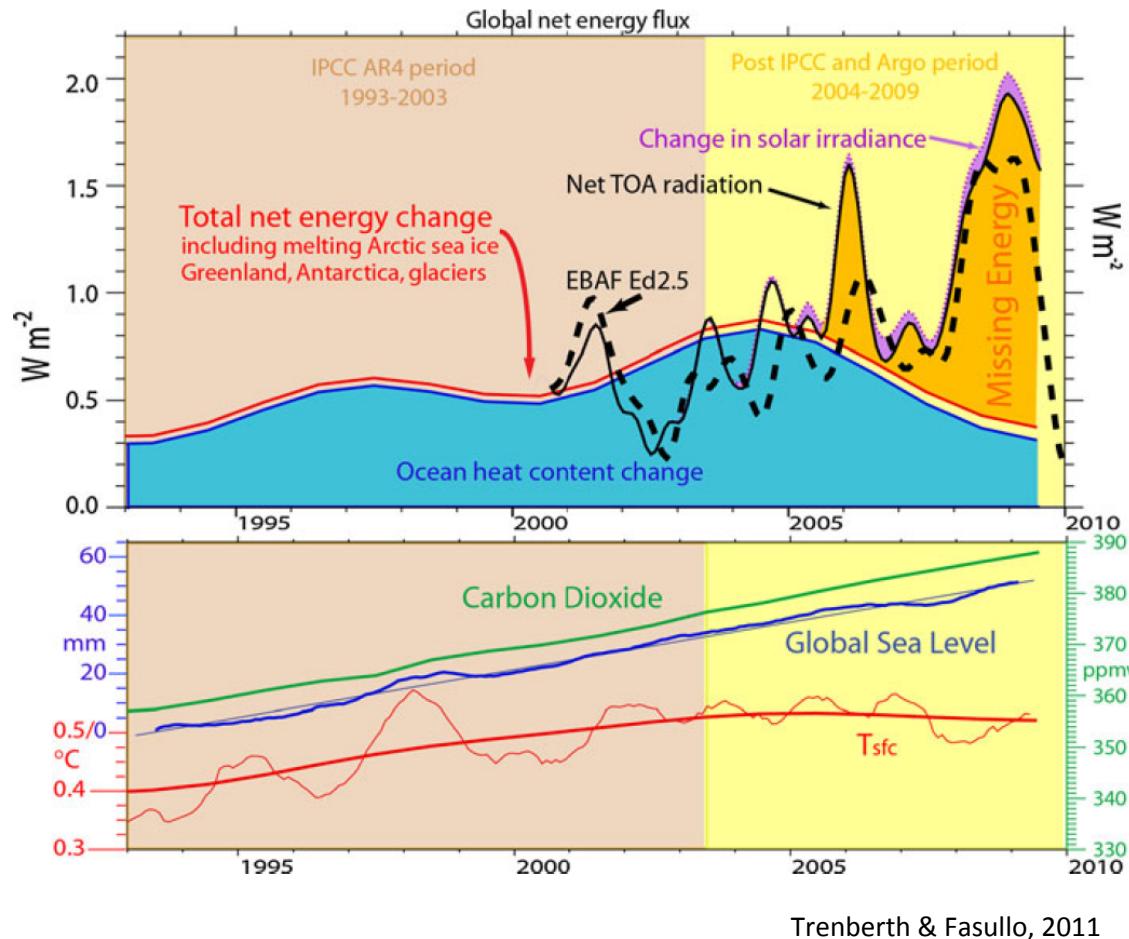
(Credit: U. of Colorado)

## IPCC-AR5 : Sea level budget over 1993-2010

- Steric sea level upper 700m depth :  $0.8 \pm 0.3$  mm/yr (updated from Domingues et al. 2008)
- Steric sea level trend (whole depth) :  $1.1 \pm 0.3$  mm/yr (Purkey and Johnson, 2010)

Temperature measurements for the deep ocean are sparse.

# The case for the ‘hiatus’ & ‘missing heat’



‘Missing Energy’ : Could it be in the ‘deep’ ocean?  
(below 700m depth)

Trenberth & Fasullo, 2011

- > IPCC-AR5 : 93% of Earth’s energy imbalance is stored by the oceans
- > Temperature measurements for the deep ocean are sparse.

## Outlines

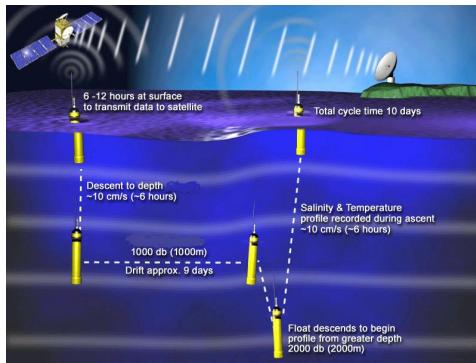
- Global mean sea level budget over 2005-2013
- Quantifying the different climate contributions to global mean sea level rise
- Heat content change and Earth's energy imbalance estimations

# Global mean sea level : 2005-2013

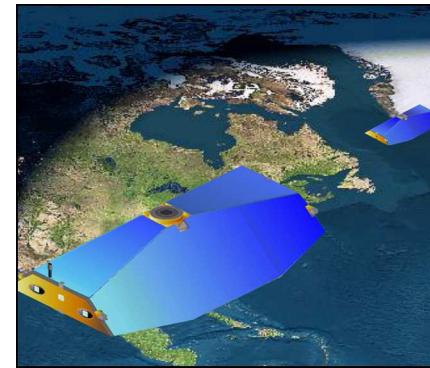
$$\Delta H_{\text{SeaLevel}} = \Delta H_{\text{steric}} + \Delta H_{\text{mass}}$$



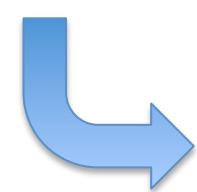
Jason-1&2 (2001-2013  
et 2008-... )



Argo (~2005)

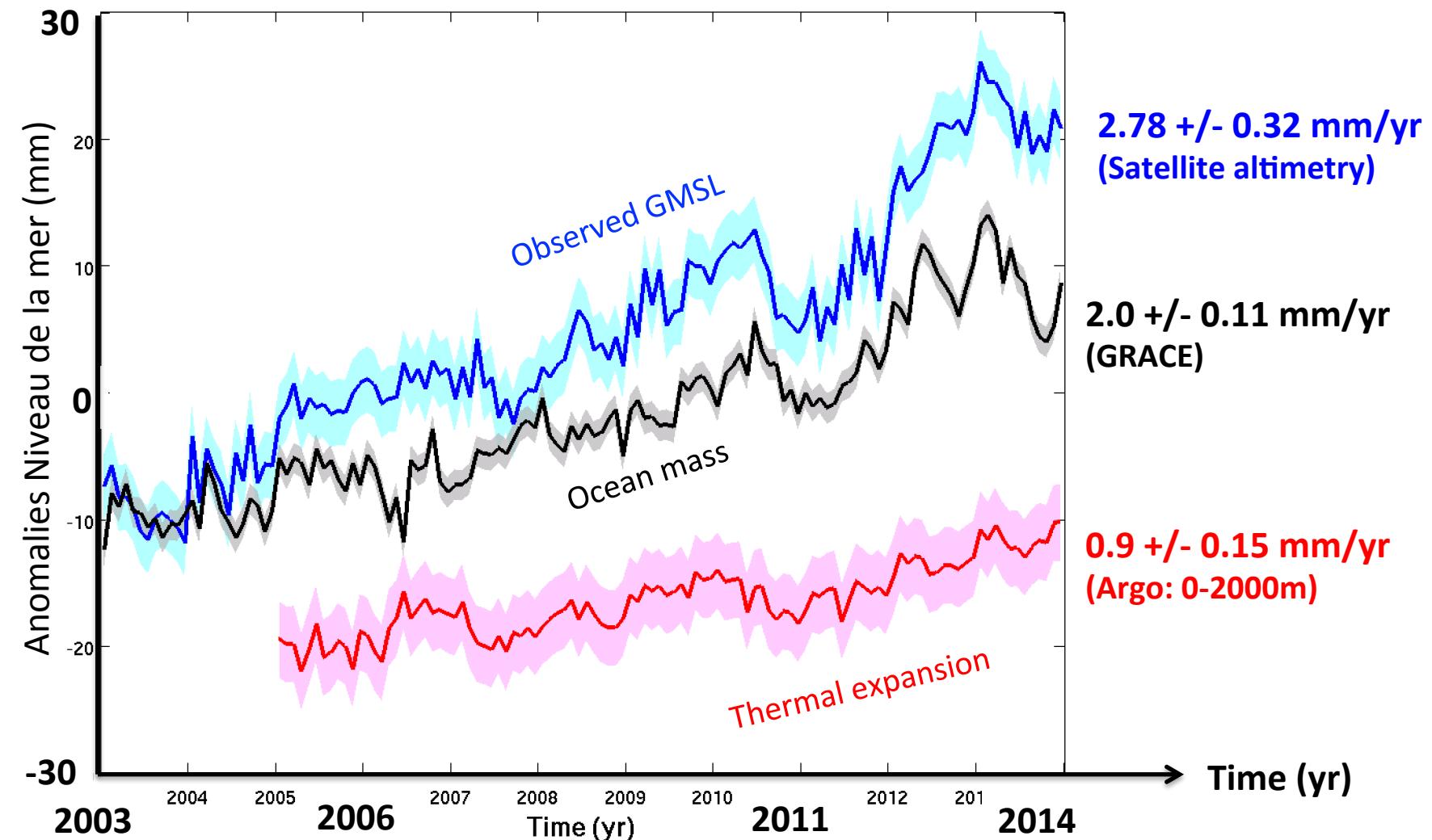


GRACE (2002-... )

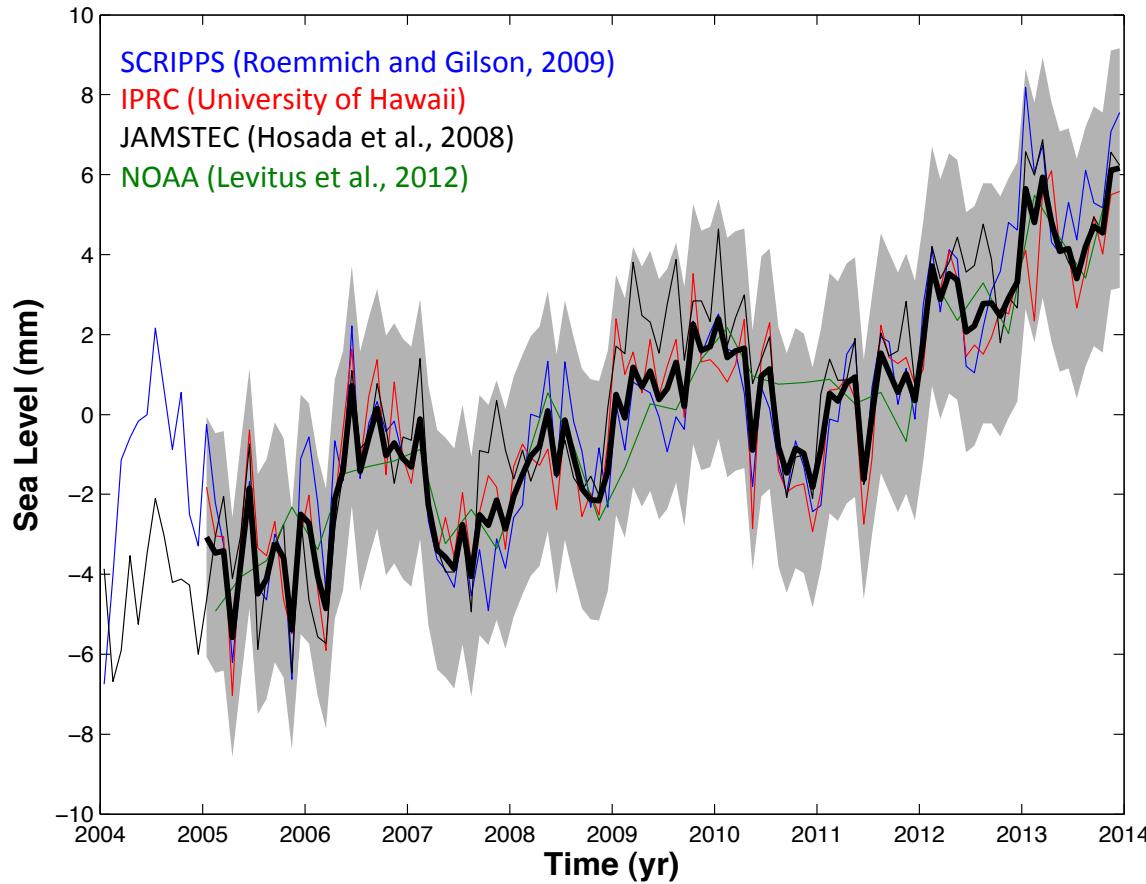


$$\Delta H_{\text{SeaLevel}} = \Delta h_{\text{steric}(0-2000m)} + \Delta h_{\text{mass}} \\ + \Delta h_{\text{steric}(2000m-bottom)} + \text{Err}$$

# Global mean sea level : 2005-2013



# Global mean sea level : thermal expansion (2005-2013)

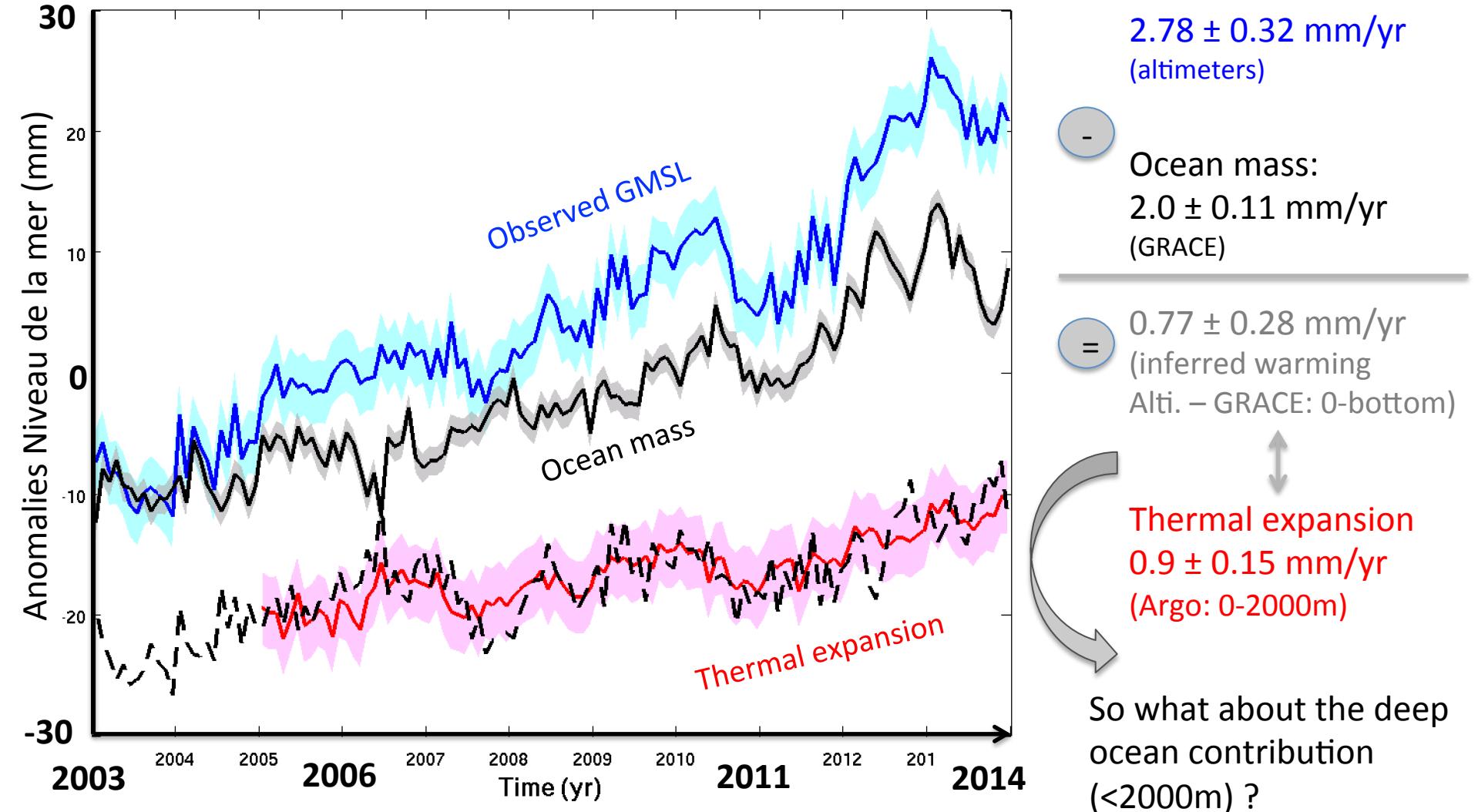


Sea level (mm/yr)	0-2000m	0-700m	700-2000m
SCRIPPS	$0.93 \pm 0.21$	$0.51 \pm 0.17$	$0.42 \pm 0.07$
IPRC	$0.80 \pm 0.19$	$0.50 \pm 0.15$	$0.31 \pm 0.07$
JAMSTEC	$0.96 \pm 0.19$	$0.65 \pm 0.16$	$0.34 \pm 0.06$
NOAA	$0.93 \pm 0.12$	$0.48 \pm 0.10$	$0.45 \pm 0.05$
Mean	$0.90 \pm 0.15$	$0.53 \pm 0.13$	$0.38 \pm 0.05$

58%

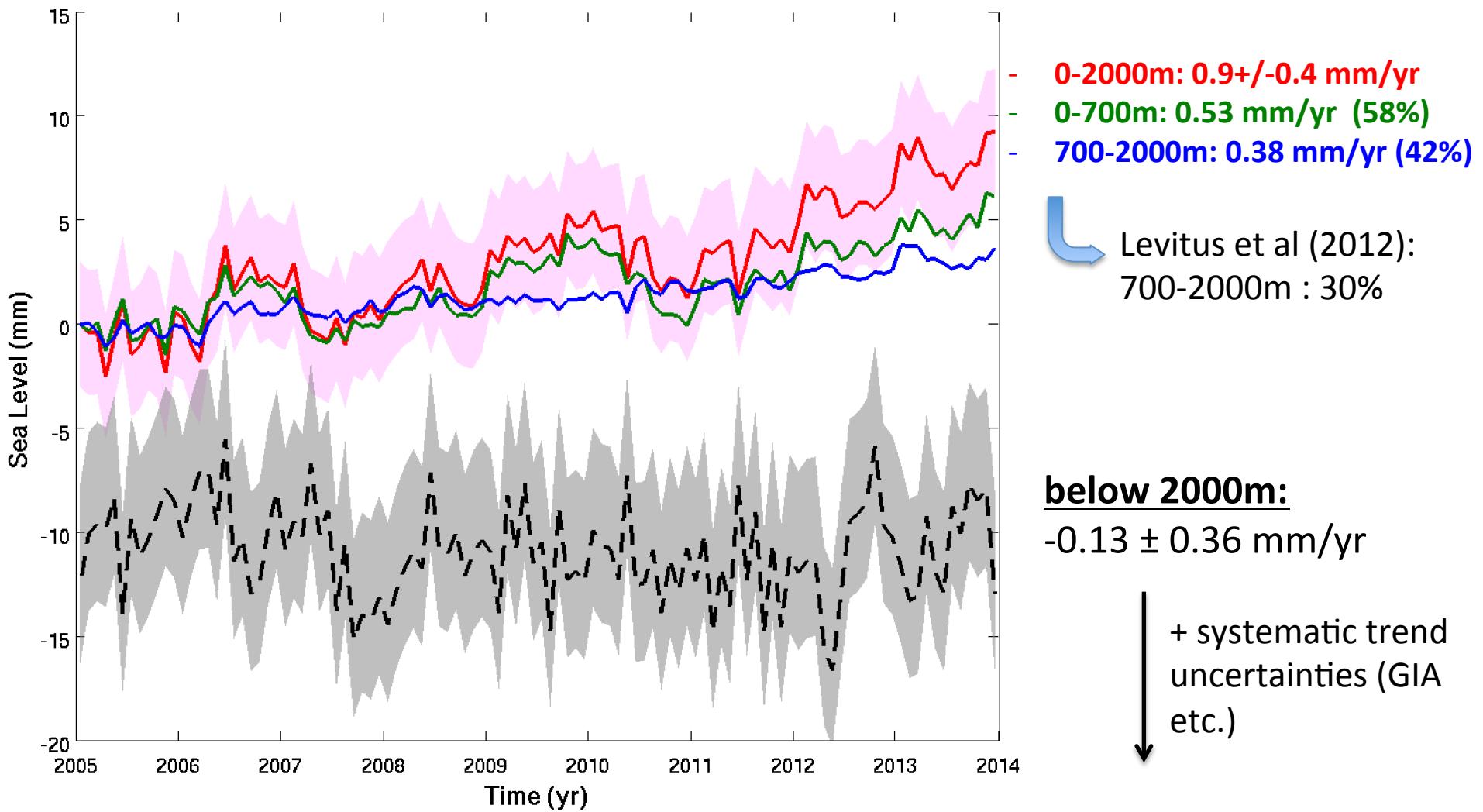
42%

# Global mean sea level: 2005-2013



# Global mean sea level: 2005-2013

## Thermal expansion as a function of depth



**below 2000m:**

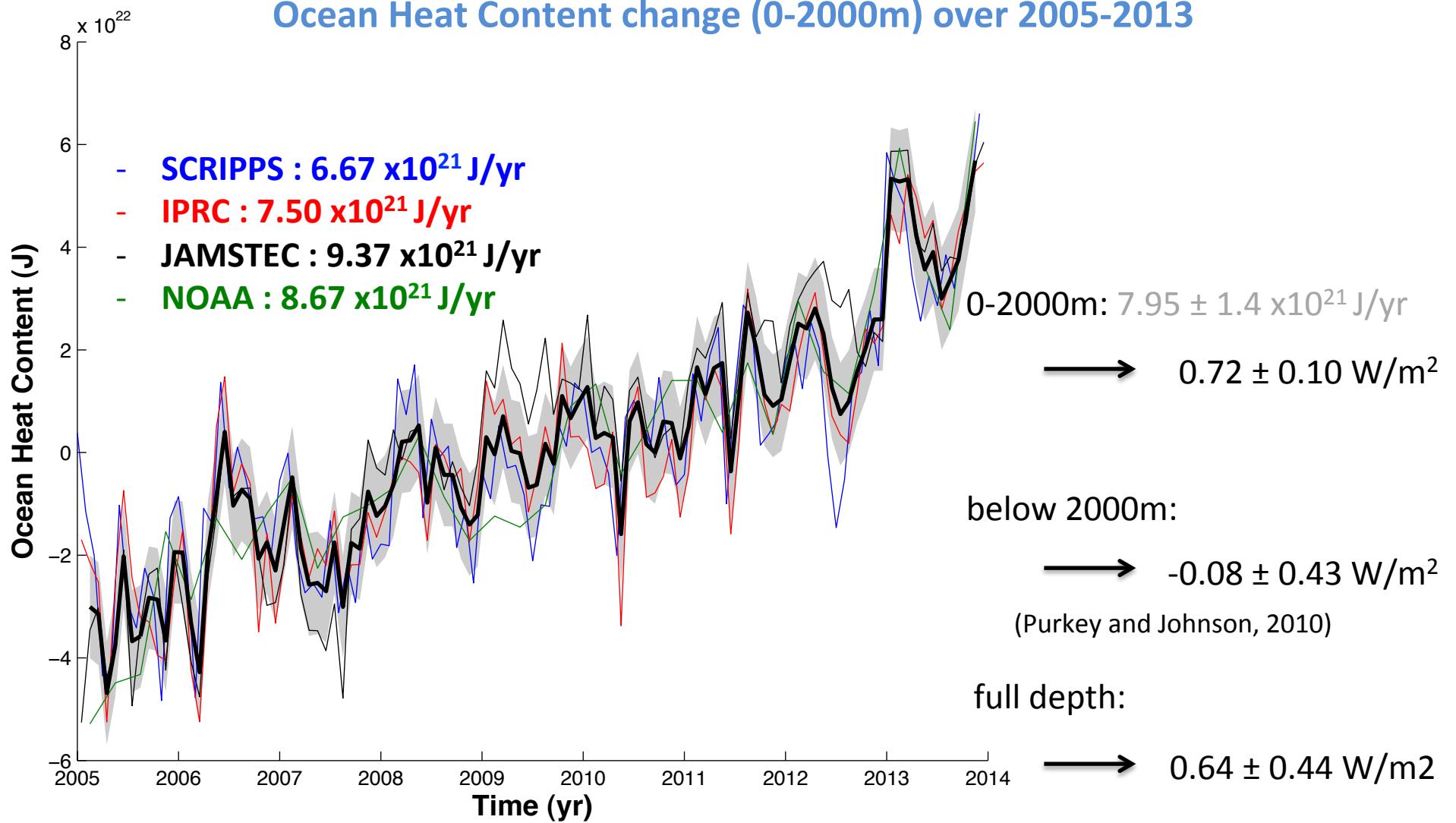
$-0.13 \pm 0.36 \text{ mm/yr}$

+ systematic trend  
uncertainties (GIA  
etc.)

$-0.13 \pm 0.72 \text{ mm/yr}$

=> Upper limit  $0.59 \text{ mm/yr}$

# Ocean Heat Content change (0-2000m) over 2005-2013



Consistent with Loeb et al (2012)



## Conclusions

1. Closure of sea level budget over 2005-2013
2. 0-2000m = 0.9 mm/yr (32%) of the observed GMSL trend of 2.8 mm/yr
3. 0-700m = 58% and 700-2000m = 42% (higher estimate than Levitus et al., 2012)
4. Heat content change : 0-2000m  $\rightarrow 0.72+/-0.1 \text{ W/m}^2$
5. 0-bottom :  $0.64+/-0.44 \text{ W/m}^2$  in agreement with Loeb et al. (2012). Missing energy by Trenberth and Fasullo (2010) ?
6. Observing systems are complementary
7. Need to obtain more deep in situ measurements for the deep ocean