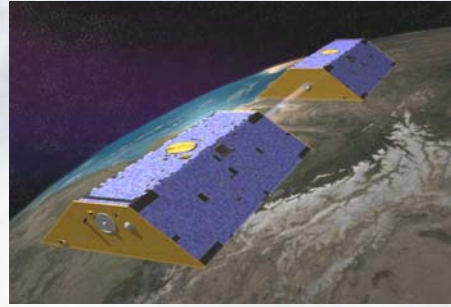




CAN A COMBINATION OF ALTIMETRY, ARGO, AND GRACE DETECT DEEP OCEAN WARMING?

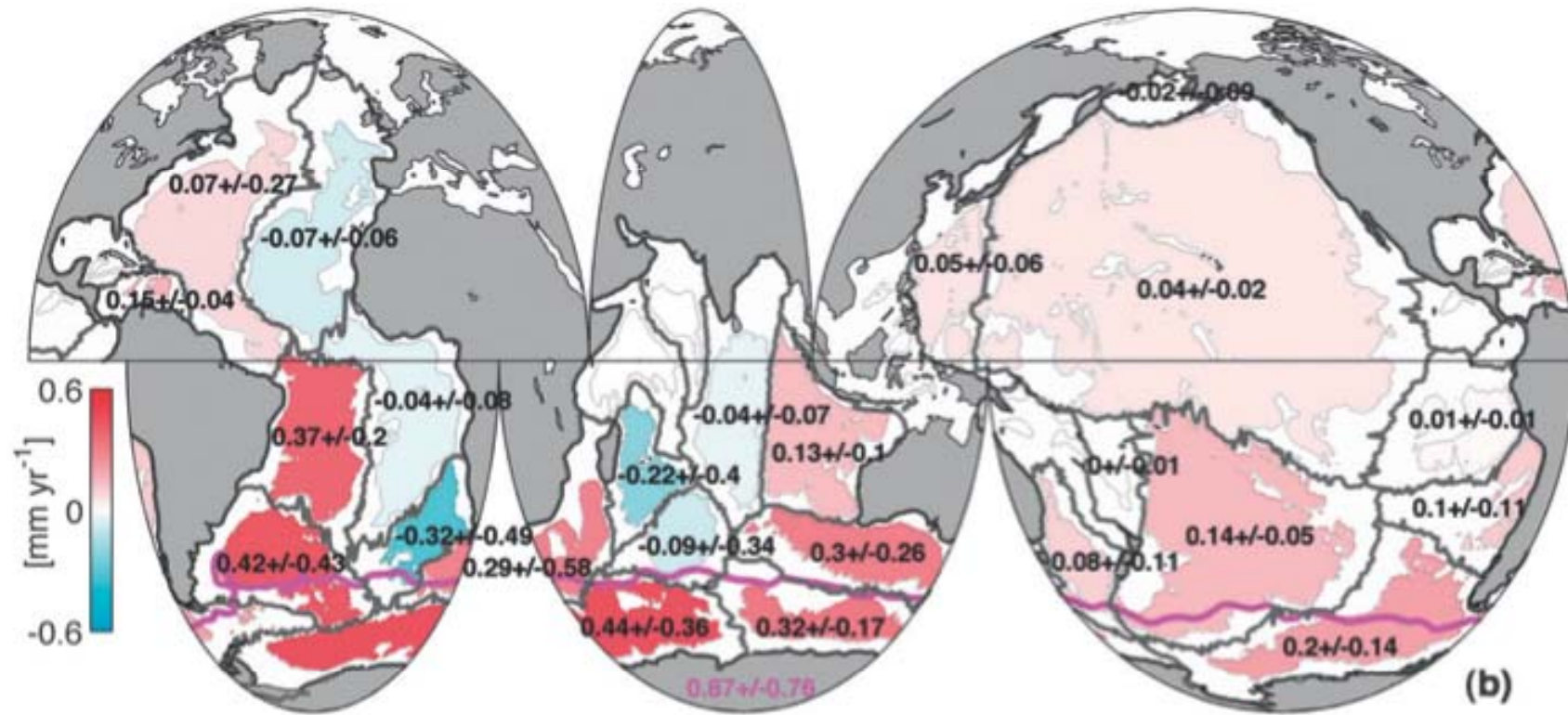
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Technology**



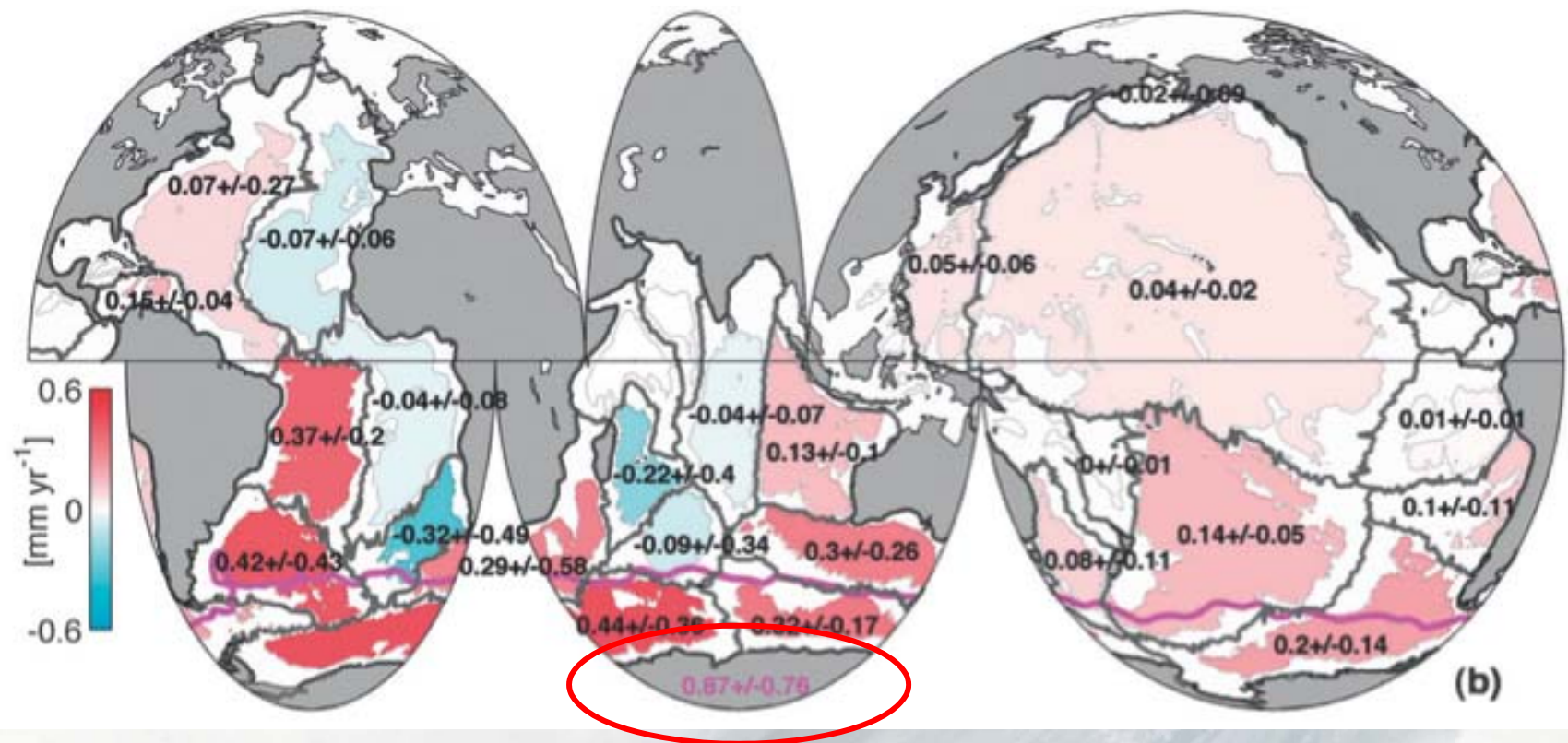
$$\Delta\eta_{total} = \Delta\eta_{mass} + \Delta\eta_{Steric}^{0-1000m} + \Delta\eta_{Steric}^{>1000m}$$

- **Several studies have examined sea level budget on global (e.g., Willis et al., 1998; Cazenave et al., 2009; Leuliette and Miller, 2009; Leuliette and Willis, 2011) and regional (Chambers and Willis, 2008; 2010) scales**
- **All have ignored deep steric signals as it is assumed small and very few observations**



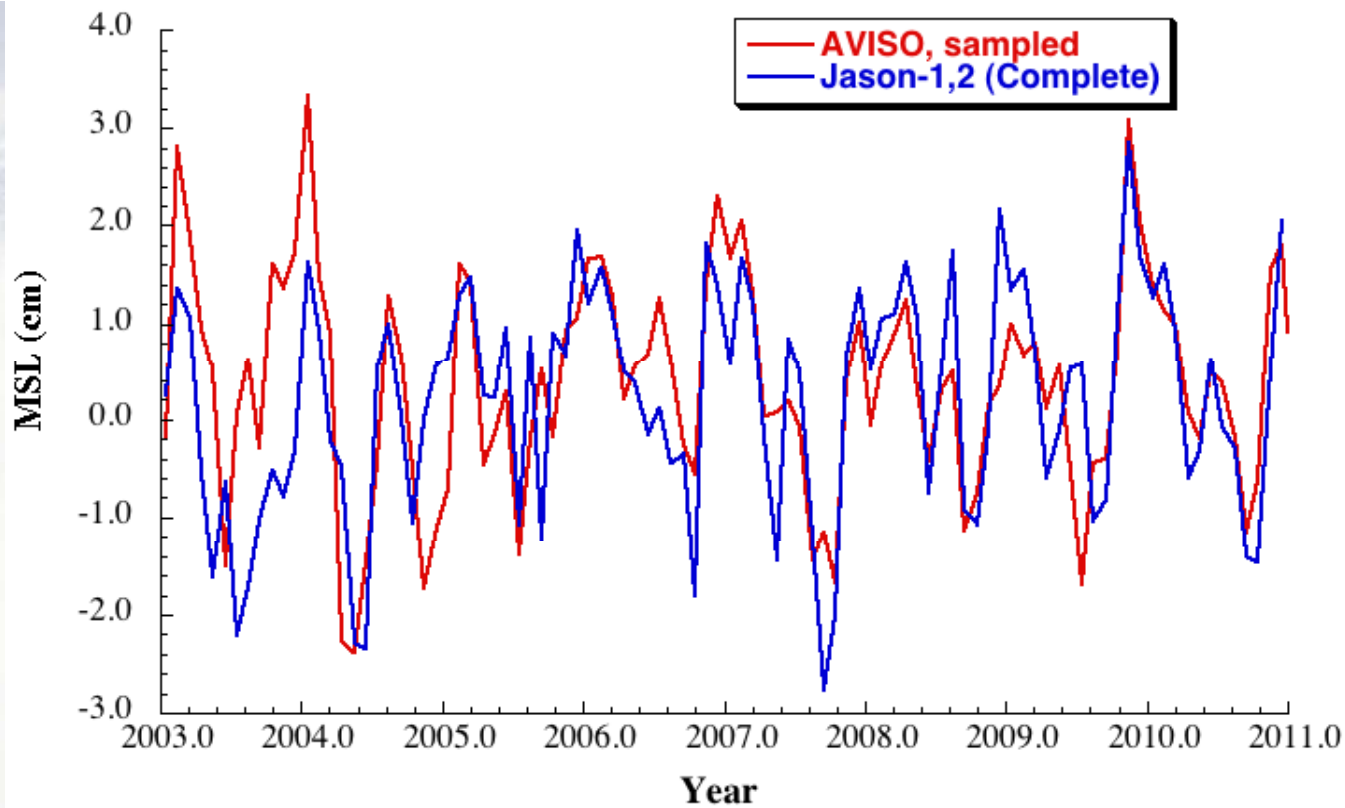
Purkey and Johnson, 2010

- Steric sea level trends from abyssal warming estimated from repeat hydrographic sections (~1995 – 2005)

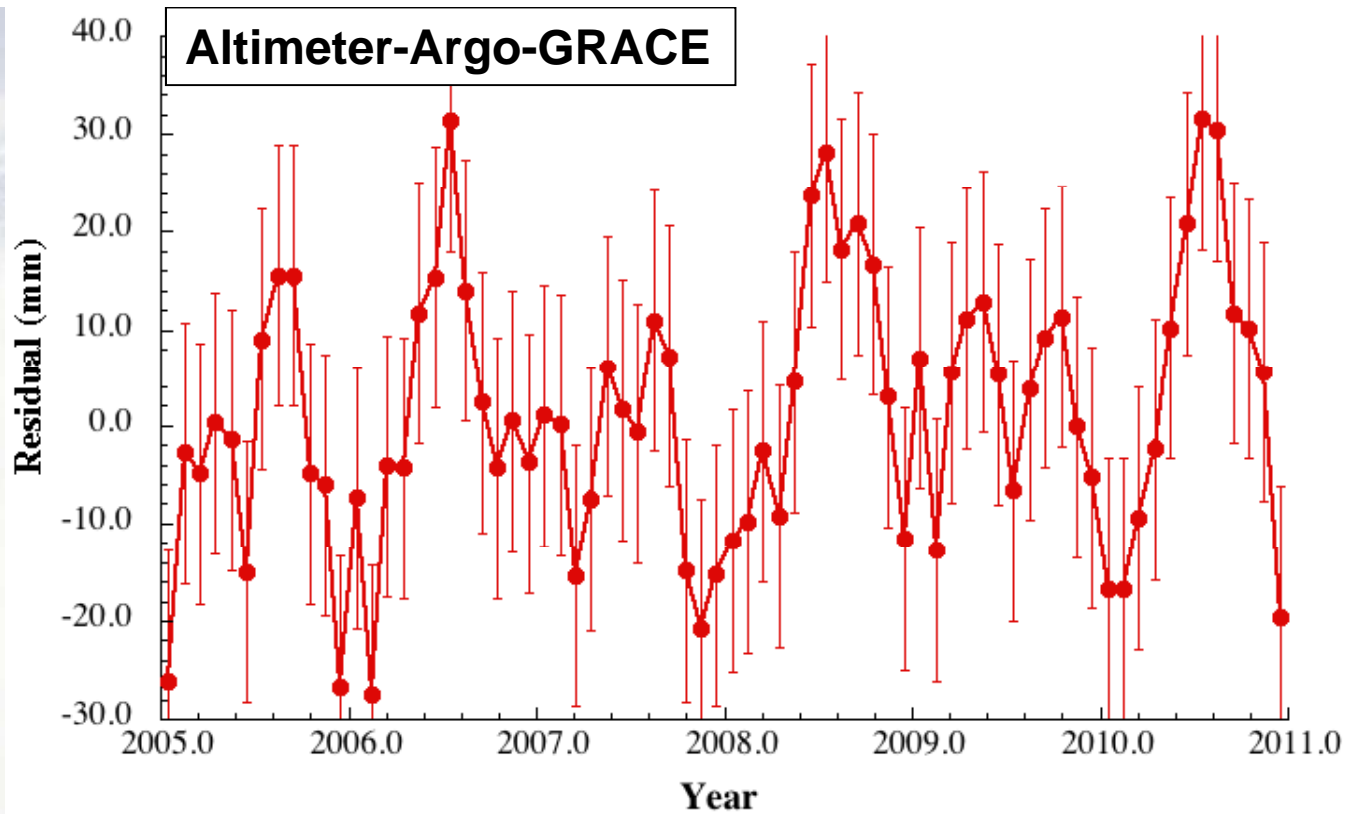


Purkey and Johnson, 2010

- Warming below 1000 m causes an average sea level trend south of Subantarctic Front of nearly 1 mm/year
- Large enough that analysis of residuals (Altimeter-Argo-GRACE) may be able to detect this

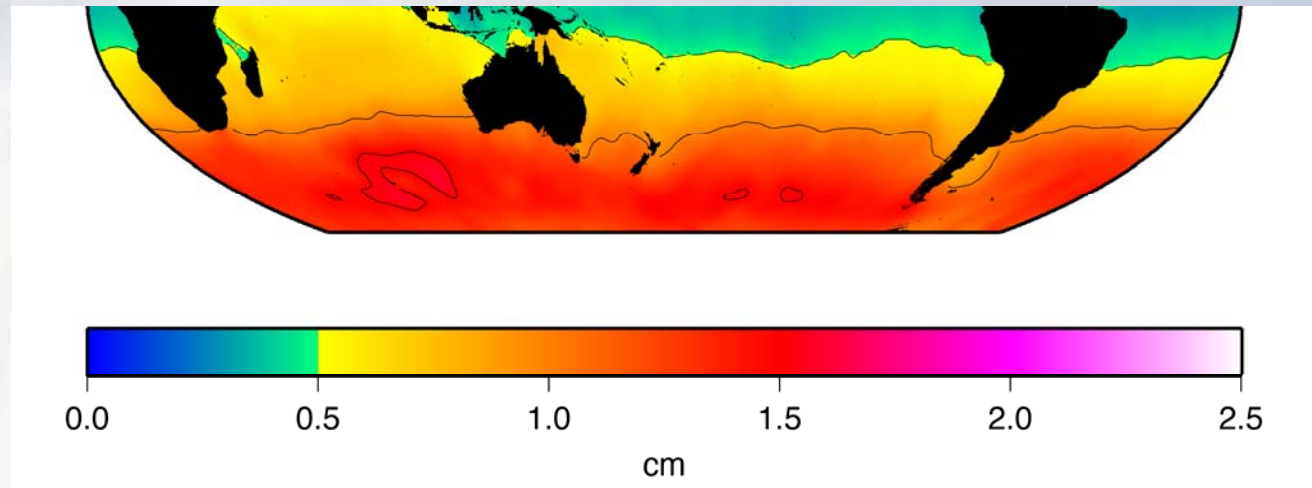


- **AVISO meso-scaled mapped sea level anomaly maps interpolated to Argo profile positions South of 50°S compared with average of all Jason-1 and 2 data in region**
- **Standard deviation of differences after 2005 = 0.8 cm; use this as sampling error for Argo data**

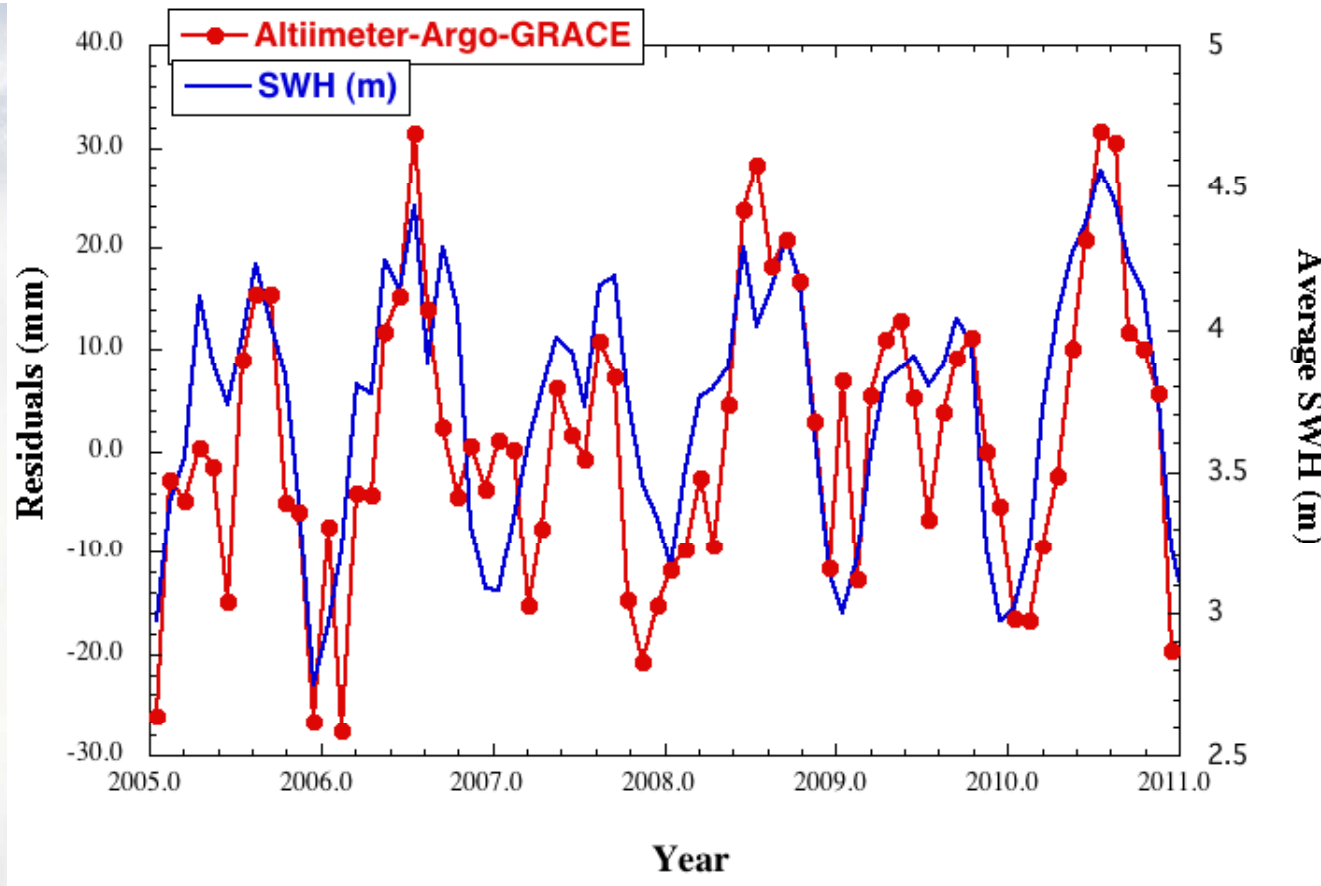


- **Uncertainty is $1-\sigma$ (14 mm), based on RSS of**
 - » **Argo sampling error ($1-\sigma= 8$ mm)**
 - » **Altimeter MSL error ($1-\sigma= 10$ mm, based on comparison between altimetry and tide gauges averaged over large regions)**
 - » **GRACE error ($1-\sigma= 6$ mm, based on difference between different solutions; propagation of error and leakage based on simulation)**

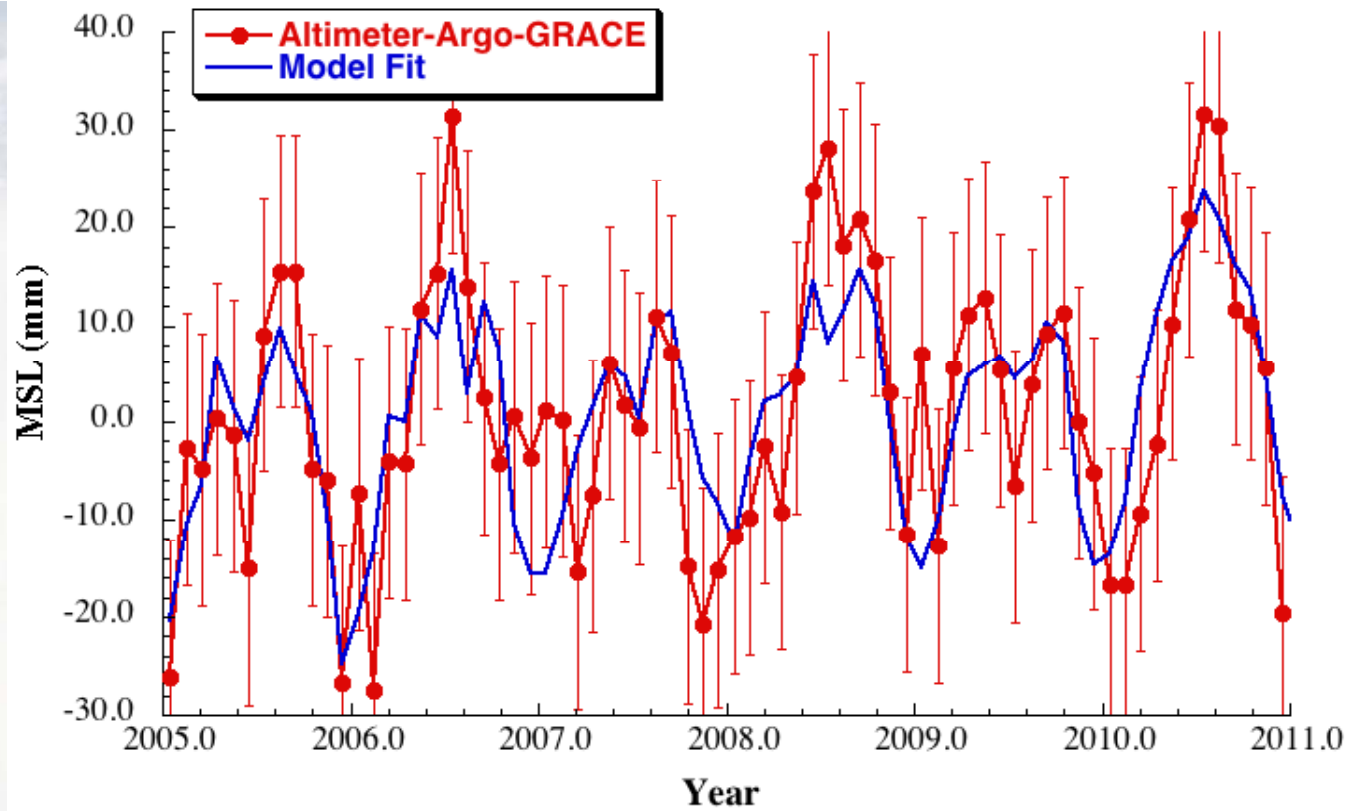
Potential size of SSB variable error, assuming ~ 1% SWH (after Chelton et al., 2001)



- **Hausman and Zlotnicki (2010), using a model, showed that intrinsic correlations between SWH and wind-speed and real ocean variability can leak into SSB models**
- **SSB model errors will not necessarily be random, but will likely be systematic**



- **Correlation between average SWH and residuals is 0.8**
- **Residuals even track the higher SWH in 2006, 2008, and 2010**



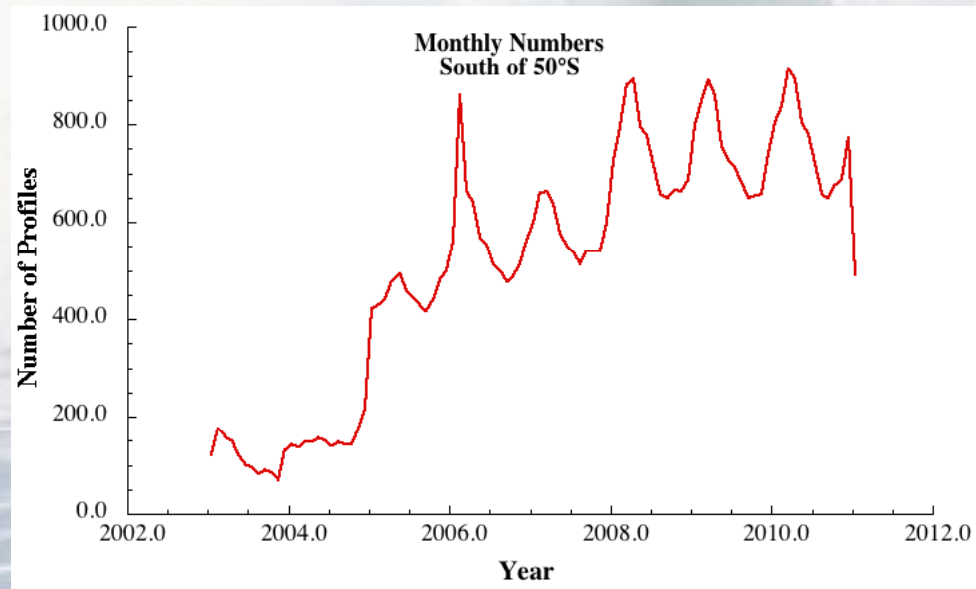
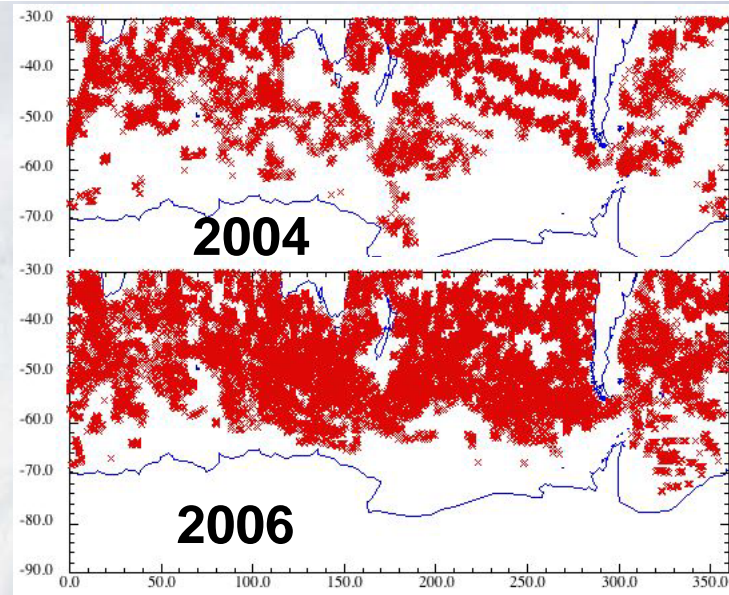
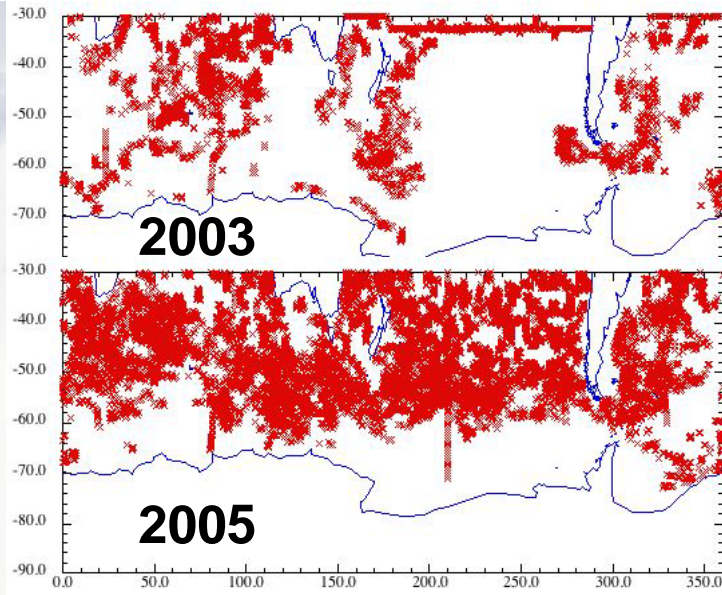
- $y = a_0 + a_1*(t-2003) + a_2*SWH$
- $a_1 = 1.2 \pm 1.0$ mm/year (95% confidence)
- $a_2 = 0.024 \pm 0.004$ (95% confidence), or 2.4%SWH error

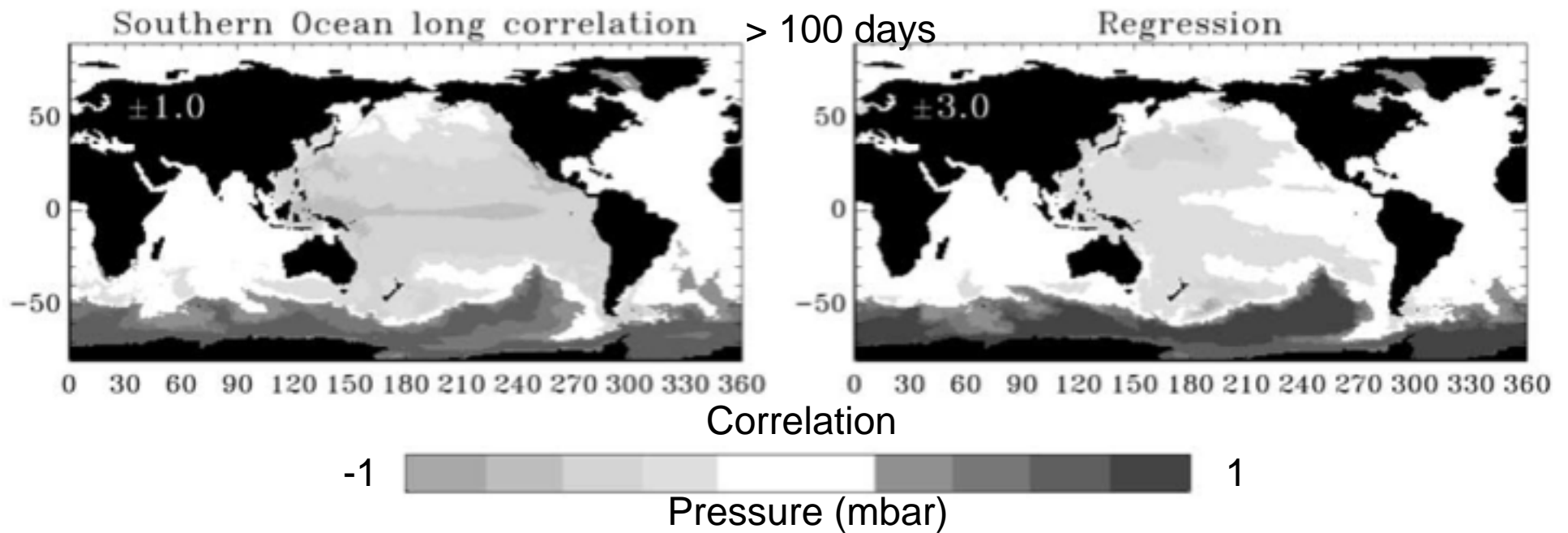
Conclusions

- **Altimeter-Argo-GRACE residuals show a trend south of 50°S consistent with the rate of warming observed below 1000m by Purkey and Johnson (2010)**
- **Still highly uncertain**
- **Appears to be a significant error in SSB model in region**
 - **Suggest improving by using coincident SSH**
 - **(Argo+ GRACE) in SSB modeling**

Thank you







Stepanov and Hughes, 2010

- **Significant low-frequency fluctuation in mass into/out of Southern Ocean with amplitude of ~ 1 cm of sea level**
- **Having GRACE estimate is important, not just to remove mean ocean mass variation**