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LETTERS

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Quantifying underestimates of long-term upper-ocean warming

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U.S. DEPARTMENT OF ENERGY | Office of Science

National Research FLAGSHIPS Wealth from Oceans

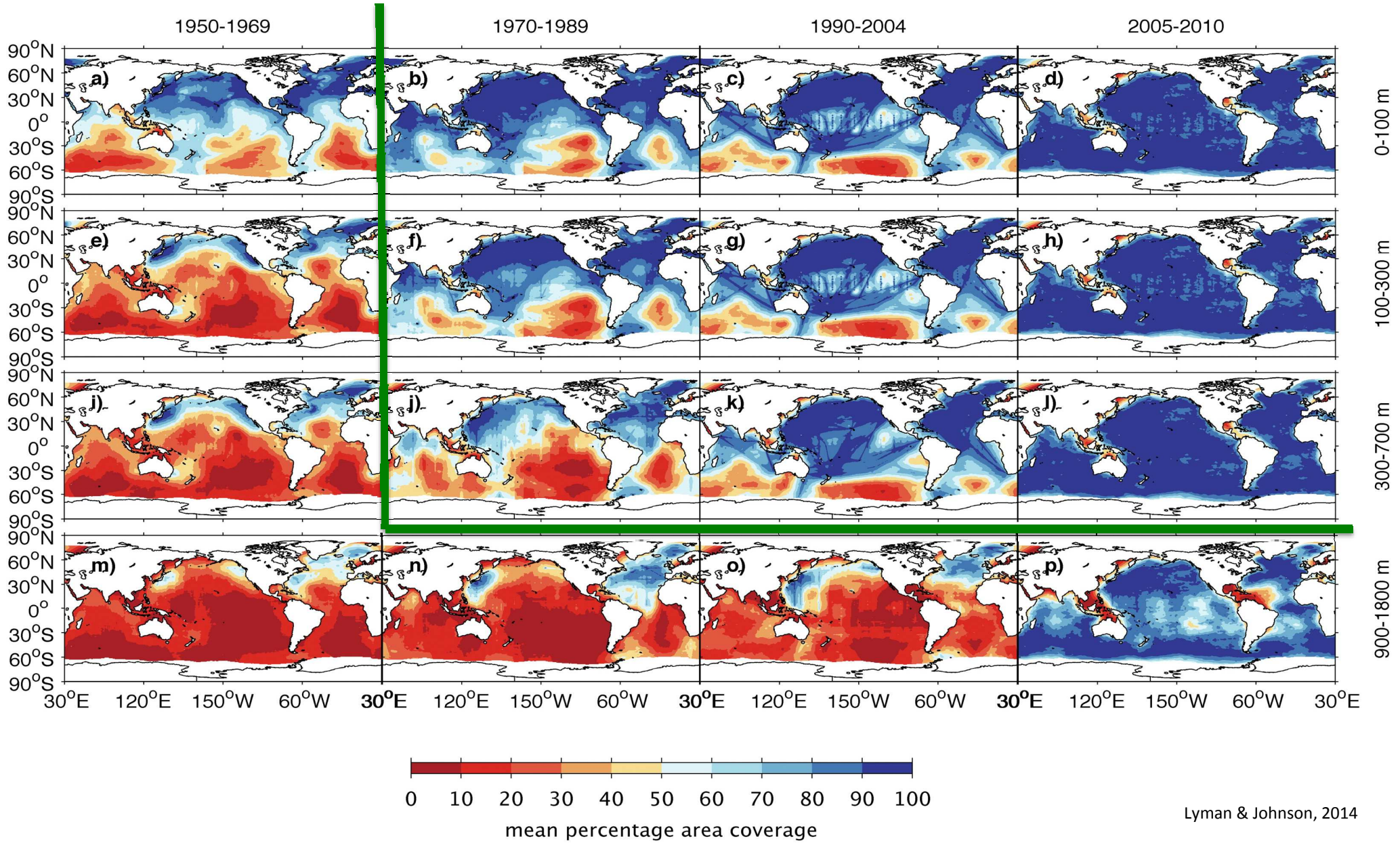
CSIRO

NASA JPL

Main points of this study:

- Southern hemisphere ocean significantly undersampled
- Temperature changes there are biased (typically: too low)
- Thus: net ocean heat gain underestimated
- So: how to quantify that?
  - use consistent **features/relationships** between satellite observations and climate models
- Our estimate: global ocean heat increase from 1970-2004 larger by 20-60% (!) than previous analyses

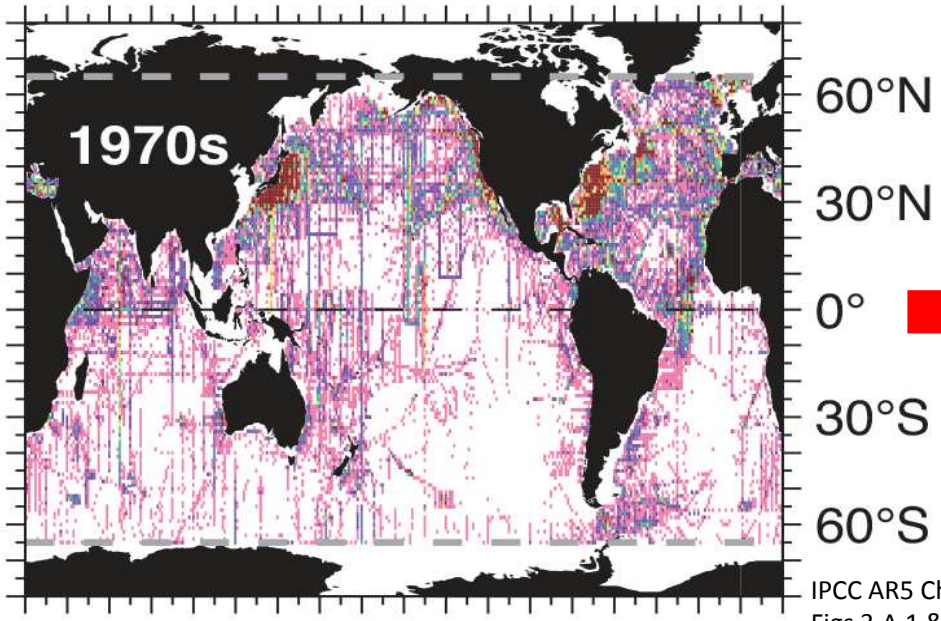
Evolution of ocean sampling:



Lyman & Johnson, 2014

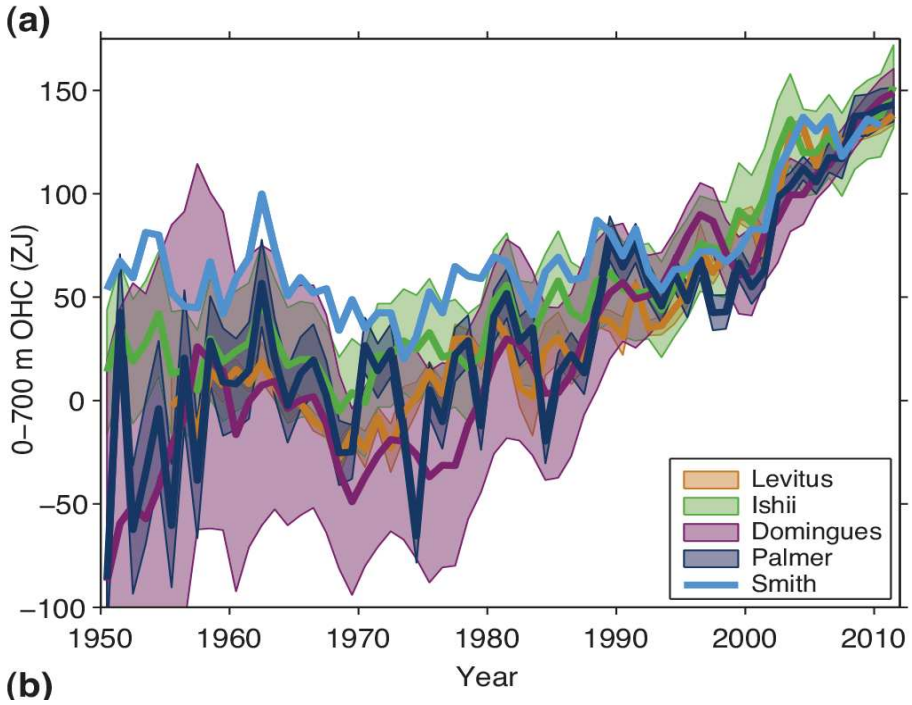
Estimating global upper-ocean temperature change is difficult..

From this …



IPCC AR5 Chap 3
Figs 3.A.1 & 3.A.2

To this?



Acknowledging these statements:

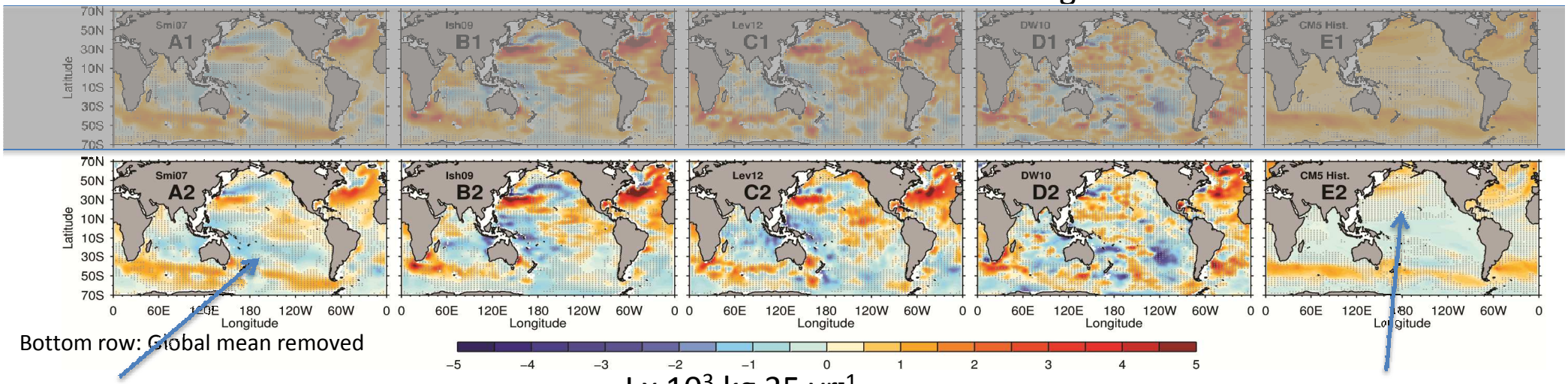
- Gille (2002): "…"
- Gregory *et al*. (2004): "…"
- Domingues *et al*. (2008): "…"
- Rhein *et al*. (2013): "…"
- Lyman & Johnson (2014): "…"

Upper-ocean (0–700 dbar) heat content trends for 1970–2004

Top row: Global mean included

1970-2004 Observed and modeled OHC change

CMIP5 Historical MMM



Bottom row: Global mean removed

$J \times 10^3$ kg 35 yr^{-1}

stippling: the 4 different obs data sets *do not* agree in sign

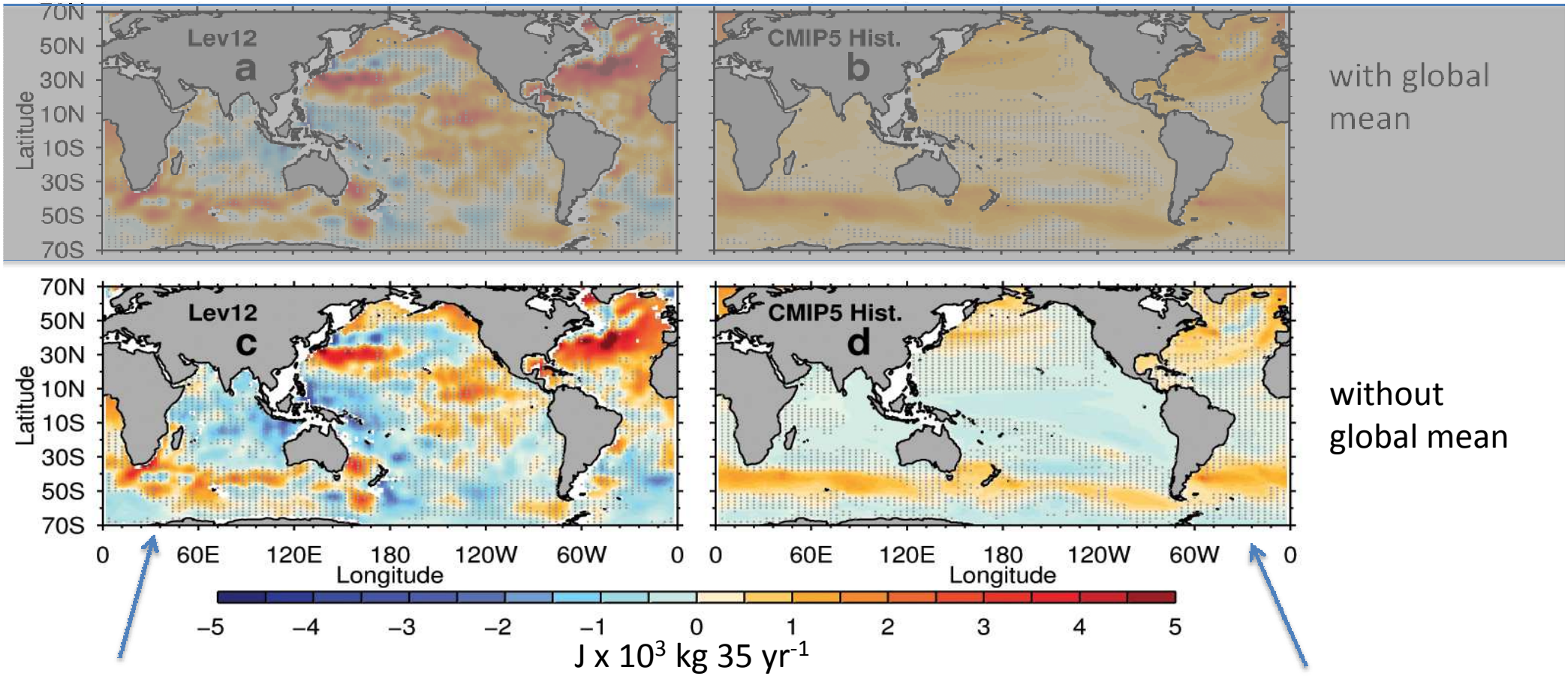
stippling: >25% of models *do not* agree in sign with multi-model mean

- Observational agreement is related to data coverage (Stippling)
  - Regional agreement exists, particularly in Northern Hemisphere (NH)
- Less agreement and muted change magnitudes in the SH, particularly the sparsely sampled South Pacific and South Atlantic Oceans

Upper-ocean (0–700 dbar) heat content trends for 1970–2004

Levitus data set (2012)

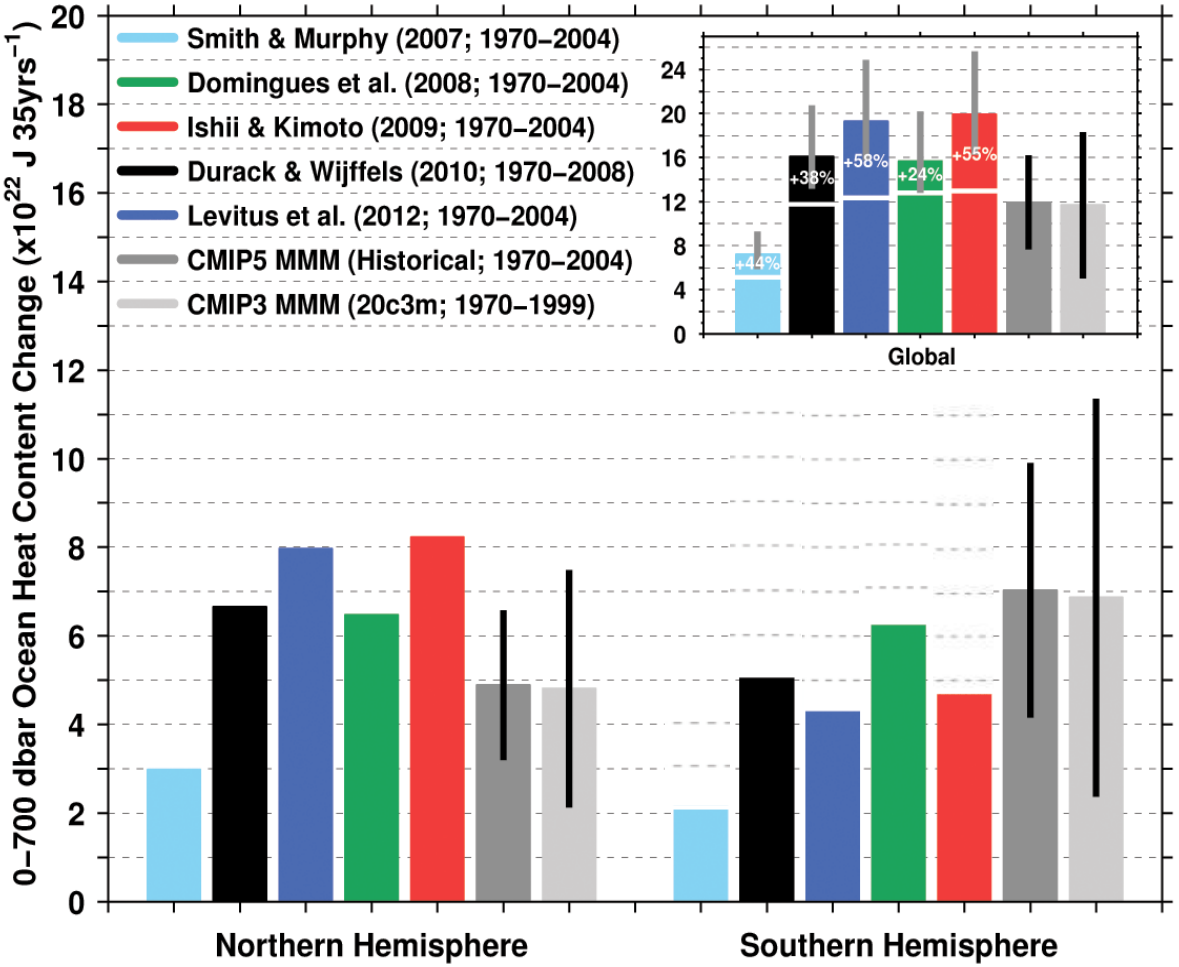
CMIP5 ensemble (166 realizations)



stippling: 4 different obs data sets *do not* agree in sign

stippling: >25% of models *do not* agree in sign with multi-model mean

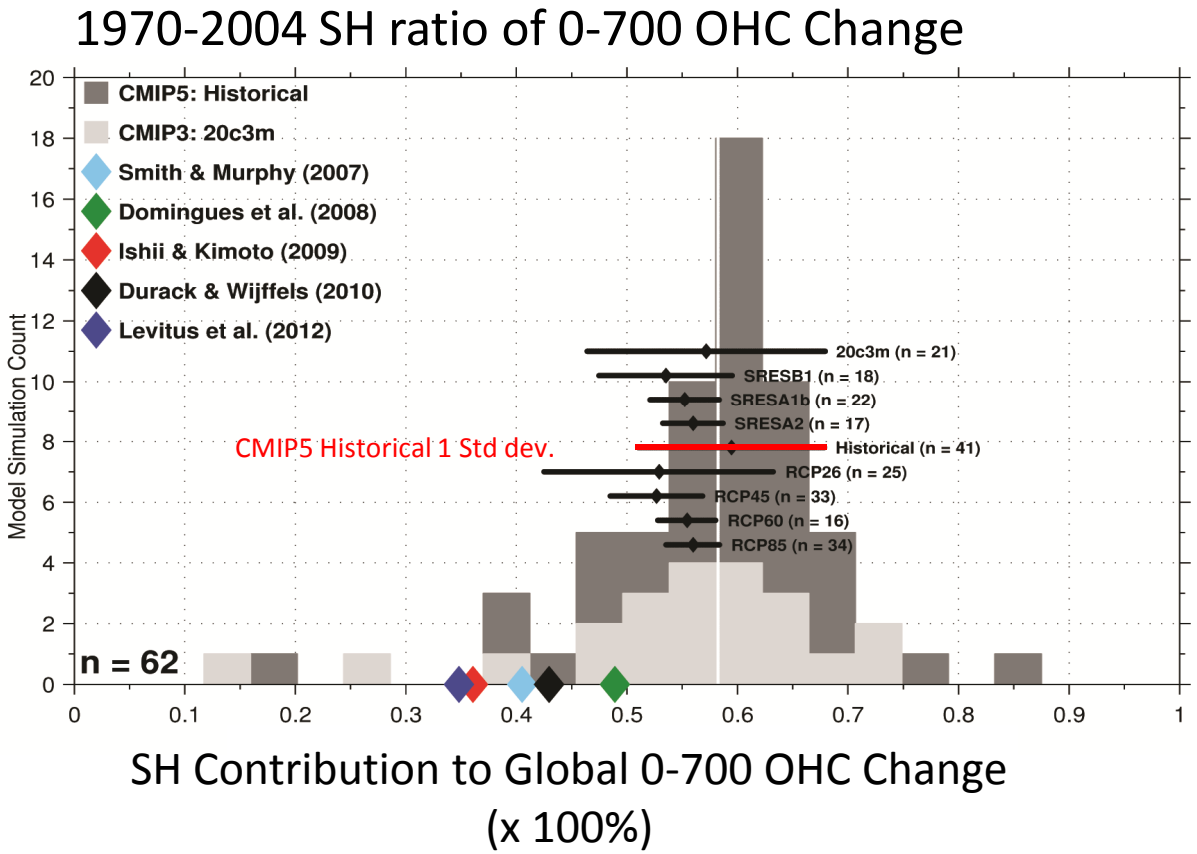
Southern *vs.* Northern Hemisphere Ocean Volume & OHC changes 1970-2004



Southern Hemisphere Ocean volume:
-> about 60% of total

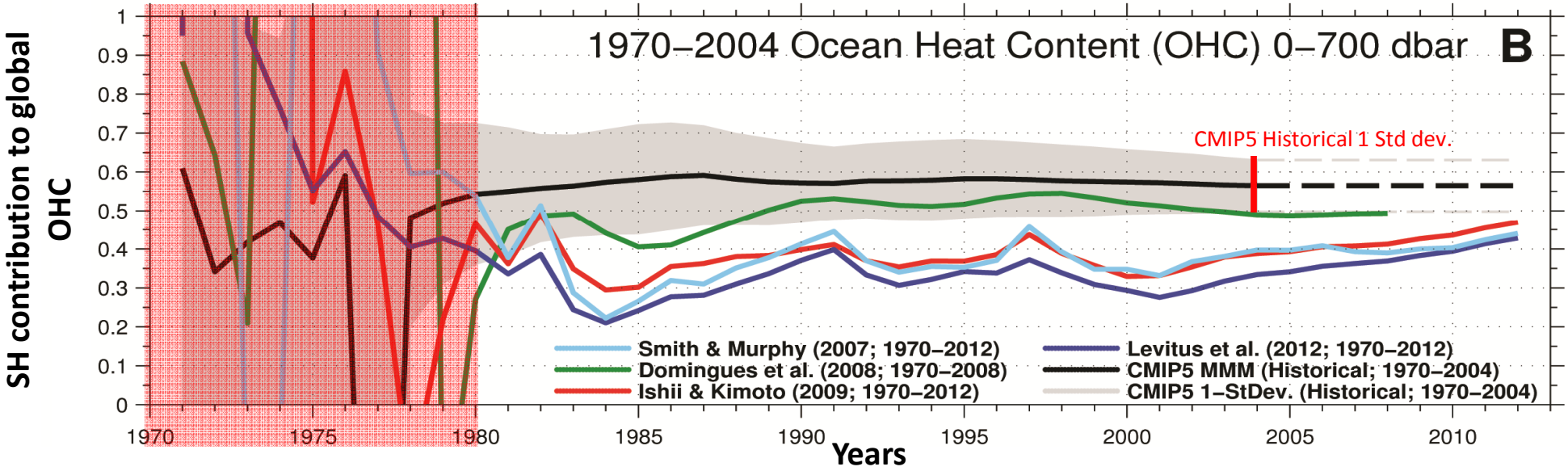
Southern Hemisphere Warming:
-> less than 40% of total in obs! -> a

Histogram of observed *vs.* simulated Southern Hemisphere contribution to global OHC trends for 1970–2004



- Histogram of modeled hemispheric trend ratios; ratio = SoH/Global
- SH comprises 60% of global ocean volume
- All observed estimates underestimate the SH warming compared to the CMIP multi-model mean

Making sense of hemispheric-scale OHC change estimates

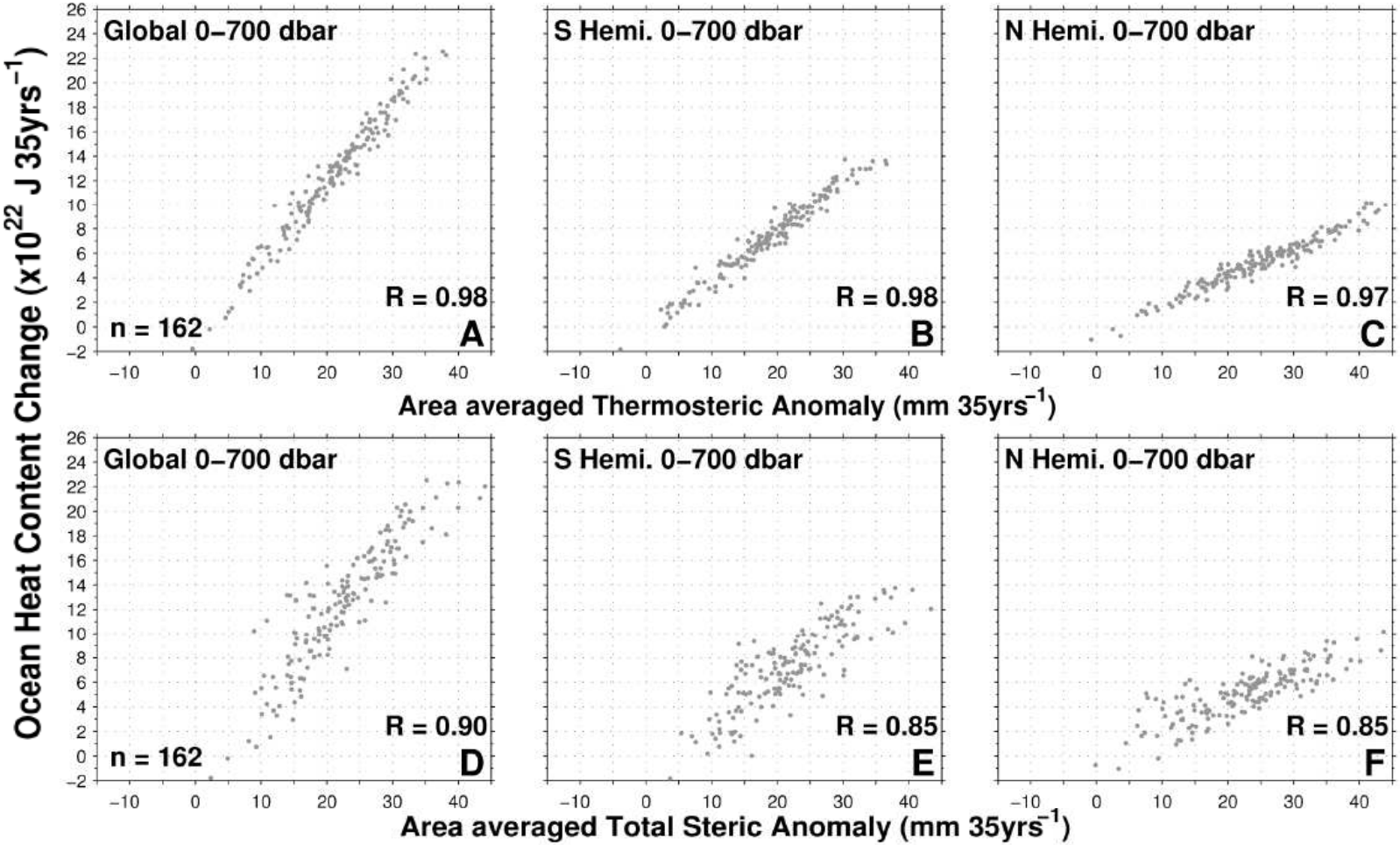


Plotted is ratio SH/(SH+NH) as a function of trend length - all trends start in 1971 (1 yr), 1972 (2 yrs), … 2004 (35yrs)

-> Inter-model spread (grey cloud) from CMIP5 model distribution

- Observed and modeled SH ratios disagree – observed SH estimates low?
- Are there other independent observations that provide insights into long-term ocean temperature changes?

Correlation: OHC *vs* Steric Sea Level

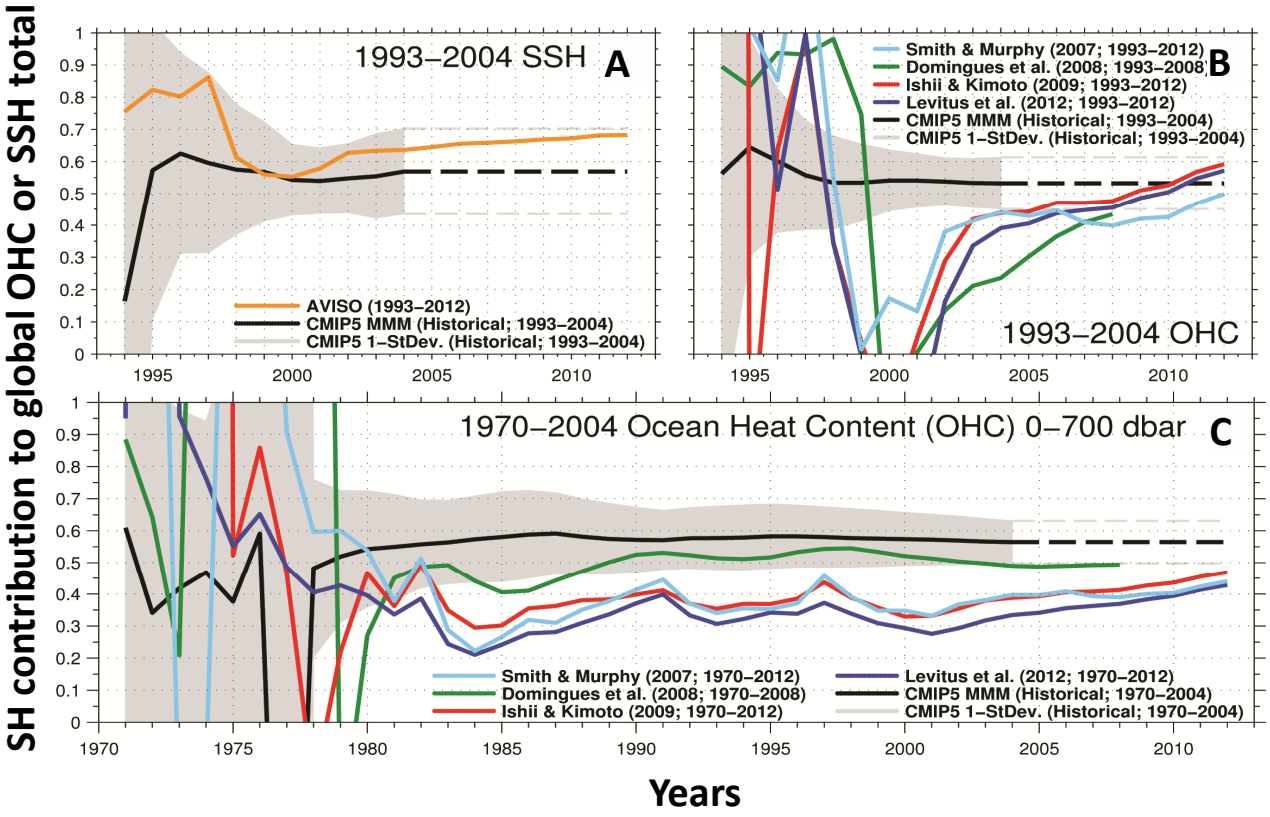


Heat uptake ratio:
SH / Global ≈ 0.6

consistent with approx. hemispheric volume partitioning
…

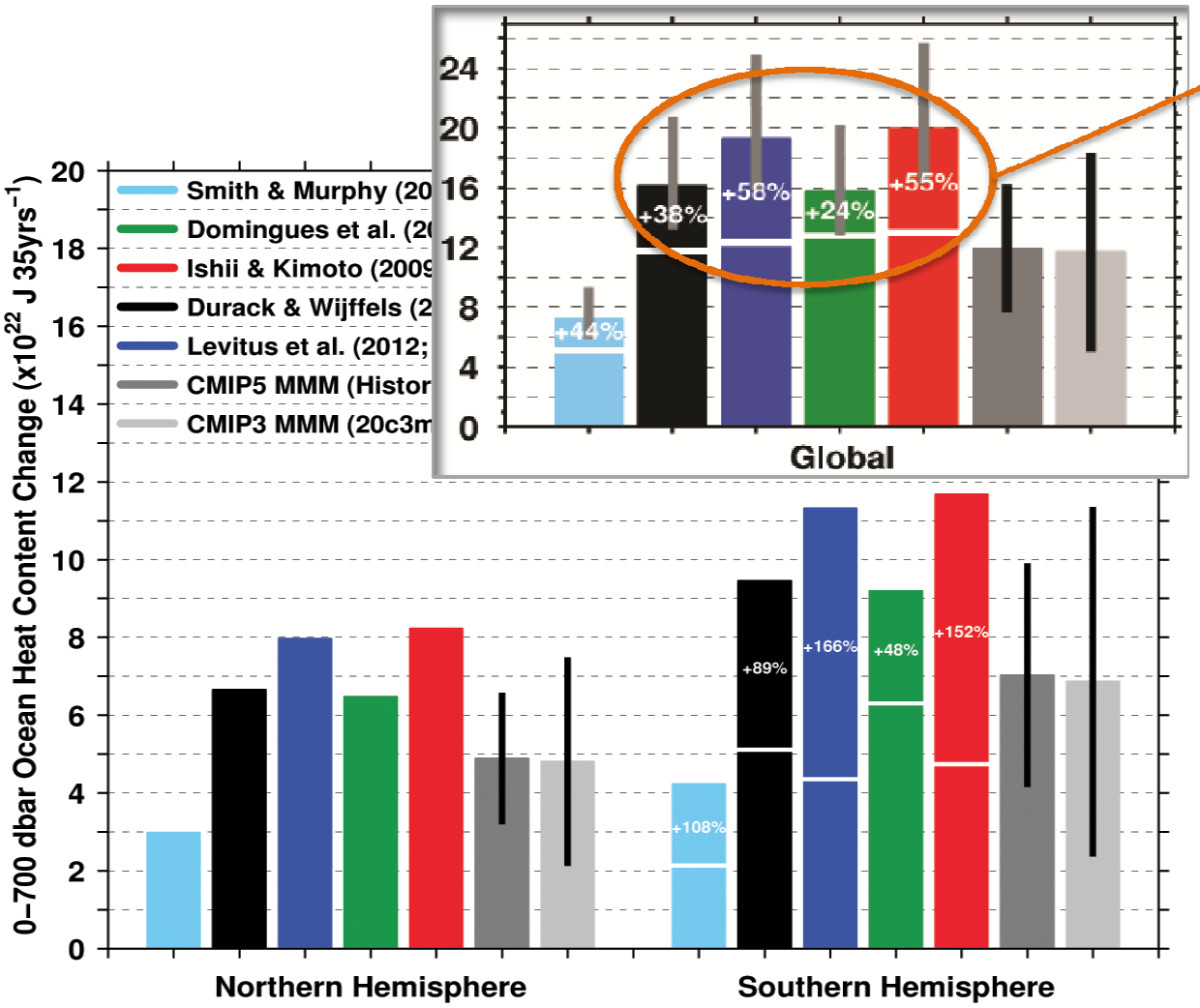
Data points: CMIP5 trends (1970-2004) from 162 multi-model runs

Southern Hemisphere fractional contributions to global upper-OHC or global SSH anomaly for varying trend lengths (1–35 years)



- On shorter (and longer) timescales, SSH hemispheric ratio appears consistent with modeled estimates (A)
- If the more modern period is considered observed and modeled OHC estimates converge (B) – (includes Argo and provides near global coverage)
- Long-term observed OHC appears largely inconsistent with modeled estimates (C)

Bottom Line of model + observation analysis: Adjusted OHC trends 1970-2004



global OHC are biased low with likely magnitudes of **20-60%**

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

W. Llovel, J. K. Willis, F. W. Landerer and I. Fukumori

- Llovel et al. (2014) 2005 – 2010: **0.6 Wm^{-2}**

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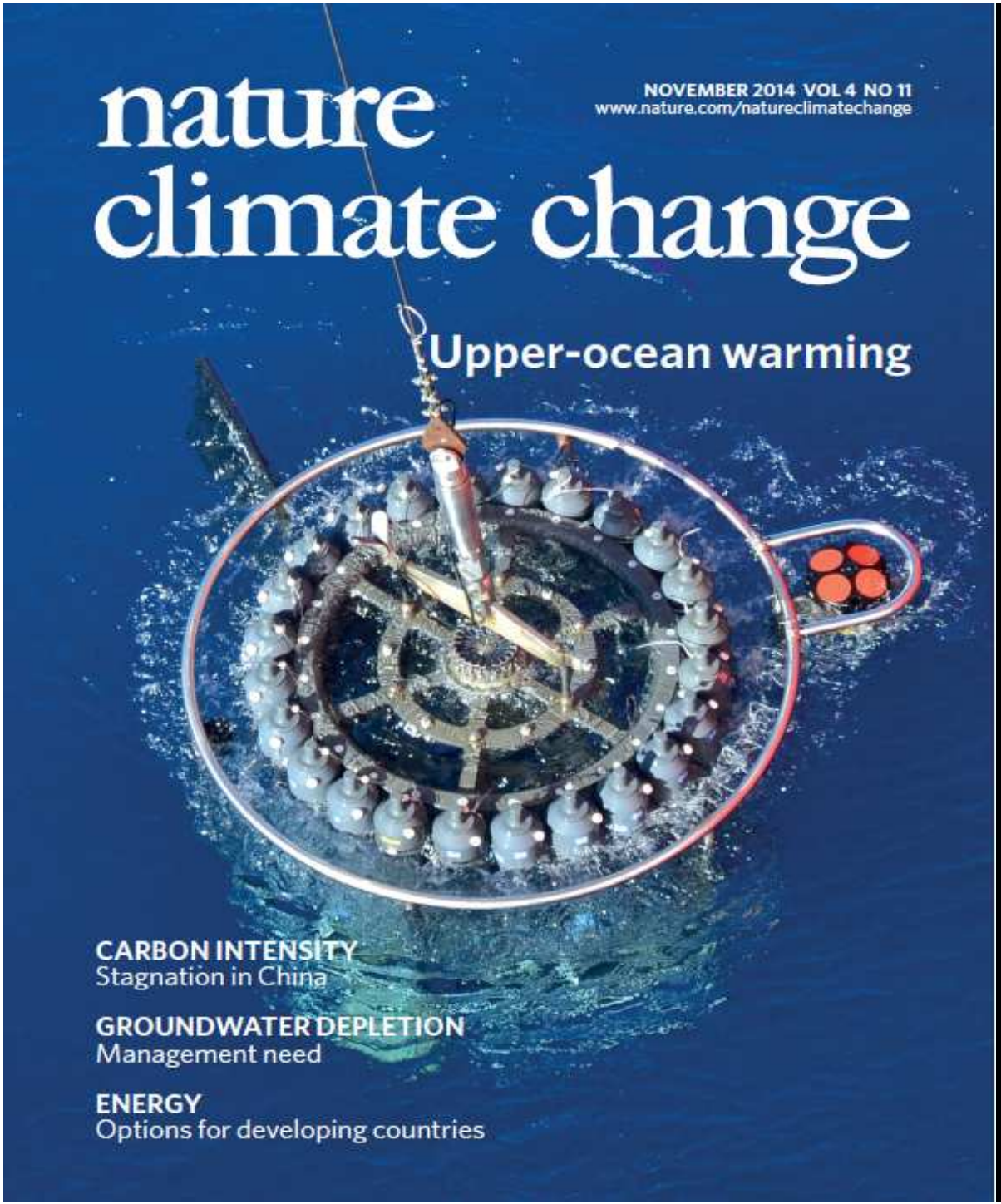
- Durack et al. (2014) 1970 – 2004: **0.3 Wm^{-2}**

Key Points

- Long-term in-situ based observations are underestimating the SH (Southern Hemisphere) contribution to global OHC change
- Observed and modeled estimates of SSH suggest ocean steric changes have occurred at equivalent rates in each hemisphere – agreement gives confidence in assessing modeled OHC estimates
- Considering model spread, all but one uncorrected observed estimate is incompatible with the modeled hemispheric ratios
- If SH observed estimates are adjusted to give the same hemispheric ratio as the multi-model mean, this yields SH upper-OHC increases of 40-160% and global increases of 20-60%
- Work in progress: Implications for sea level budget over last 35 years …



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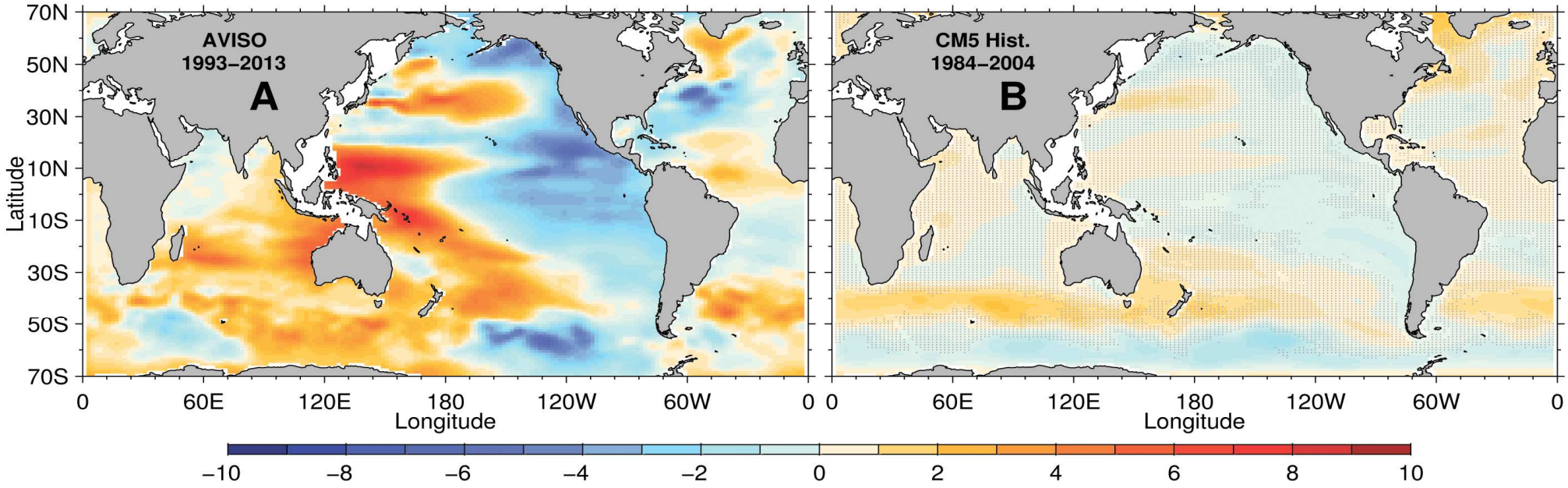
backup

20-year SSH trends: observations *vs.* CMIP5 mean



mm / year
(global mean removed)