Industrial Era Global Ocean Heat Content Changes

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Talk outline

- Intro
- Observations and model simulations
- Comparisons of observed and simulated global OHC changes
  - All depths
  - Entire historical simulation period
- Global energy budget related conclusions

Much of this presentation is based on Gleckler et al., Nature Climate Change (2016) doi:10.1038/nclimate2915

Introduction

- More than 90% of the Earth system storage of excess heat since ~1970 is in the global ocean, which is a good proxy for changes in the Earth's energy budget
- OHC research emphasis has been on upper ocean (better obs, more warming)
- Little is known about OHC changes prior to 1970s

In this study we:

- Use a mixture of OHC change estimates and model results to examine the evolution of energy budget changes since the beginning of the industrial era
- Analyze the upper (0-700m), intermediate (700-2000m) and deep (>2000m) layers separately, based on available observations

Observationally-based estimates of global OHC changes

Upper and intermediate layers:

Mixed instrument estimates from 1970 to near present including Domingues et al. (2008), Ishii and Kimoto (2009), and Levitus et al. (2012)

"Argo only" estimates from 2006-2014 (Roemmich et al., 2014, Hosada et al., 2008, IPRC, 2015)

Challenger expedition comparison with Argo, 1870-2005 snapshot (Roemmich, 2012)

Deep ocean (> 2000 m):

1992-2005 linear change estimates based on repeat hydrographic transects with WOCE as baseline (Purkey and Johnson, 2010)

CMIP5 Simulations

Historically forced simulations end in 2005

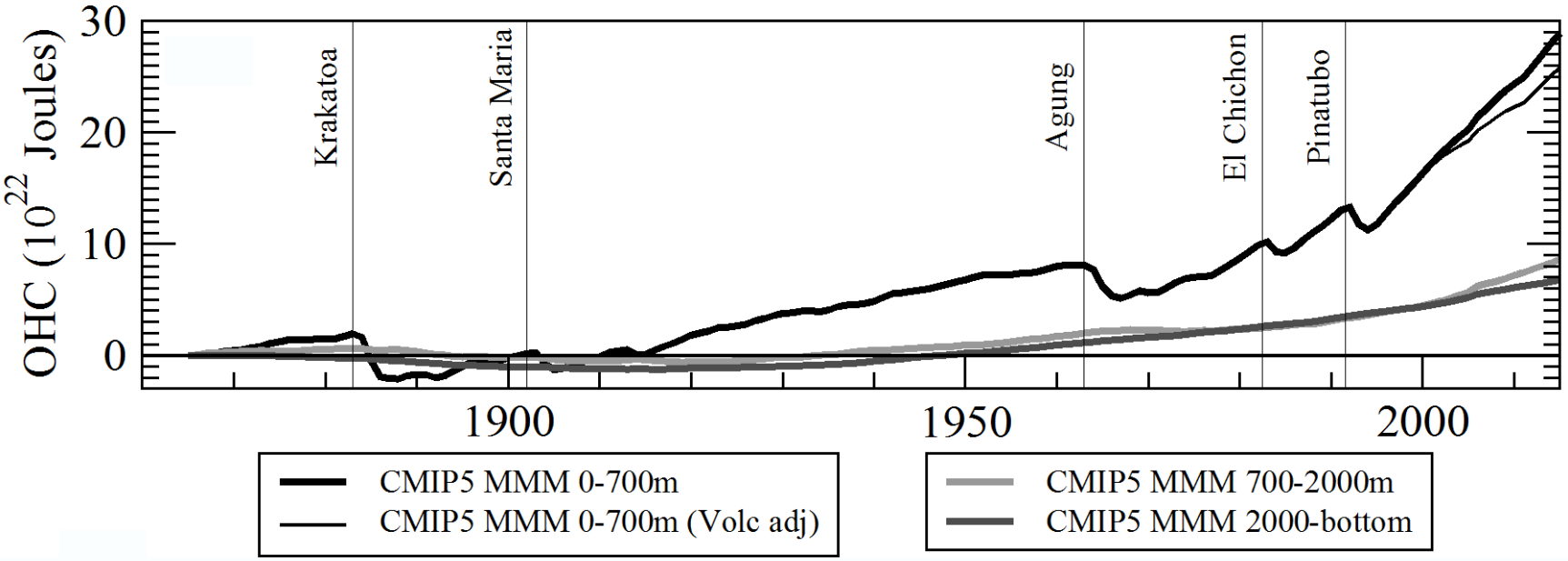
Combine historically forced + RCP8.5 (1865-2015)

Picontrol used to remove simulation drift in each layer and estimate variability

Only 15 models have been used due to metadata problems (e.g., “branch time”)

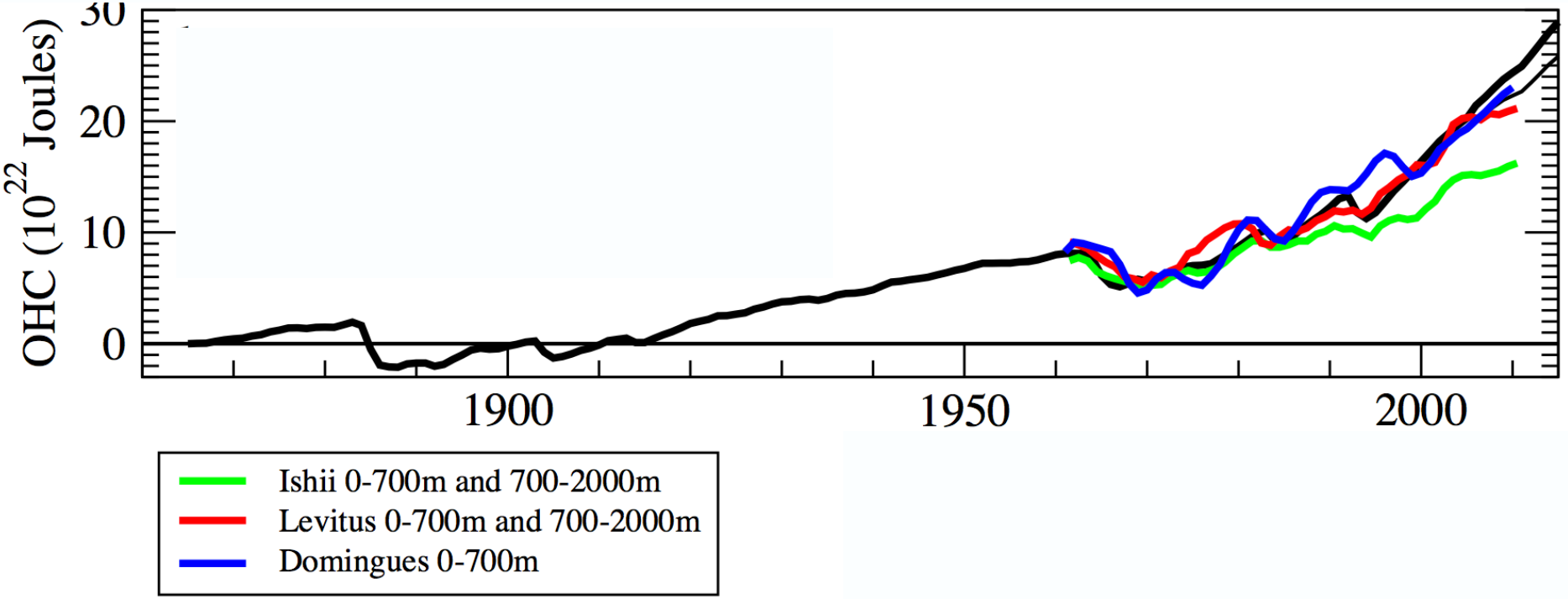
Emphasis is on Multi-Model Mean (MMM) although some results from individual models will be shown

Historical simulation of OHC
CMIP5 MMM (upper, intermediate and deep)



- Role of eruptions clear primarily in upper layer
- Simple adjustment to account for no 21st Century eruptions in CMIP5 (~.19 Wm^{-2} Ridley et al., 2014)

Observations and the CMIP5 MMM Upper Ocean (0-700m)



- MMM lies above observational estimates after about 2000
- Two estimates suggest slowdown in warming; one does not

Quantifying underestimates in upper ocean heat uptake

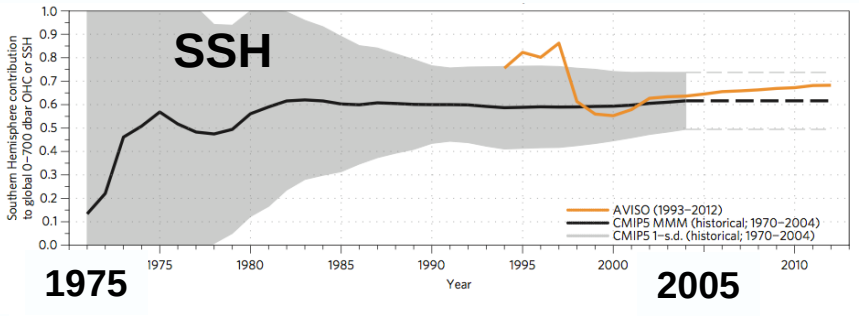
SSH hemispheric ratios in good agreement with altimetry

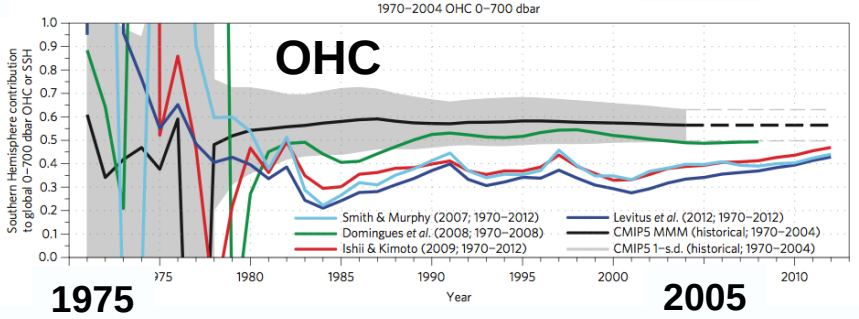
Contrasting OHU in the well-sampled NH to the poorly sampled SH. Data sparse regions set to climatological values, biasing trend estimates low

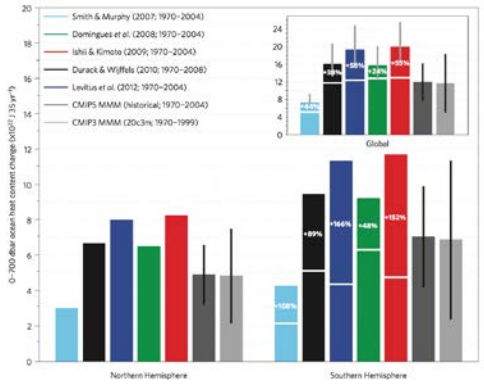
Conclusion: Altimetry and model results suggest estimates of OHU are biased low

‘adjustments” to existing estimates

SHem/(Global) trends as a function of trend length





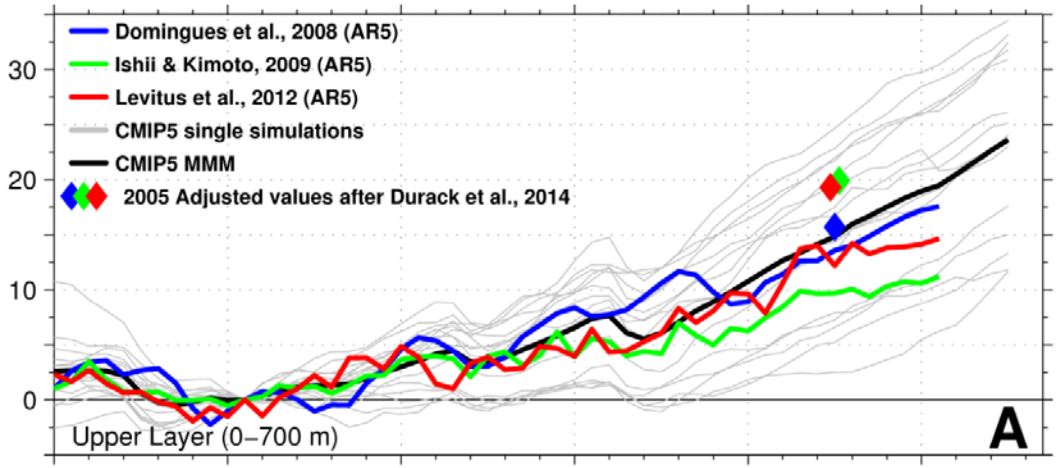


Durack et al. (*Nat.Clim.Change*, 2014)

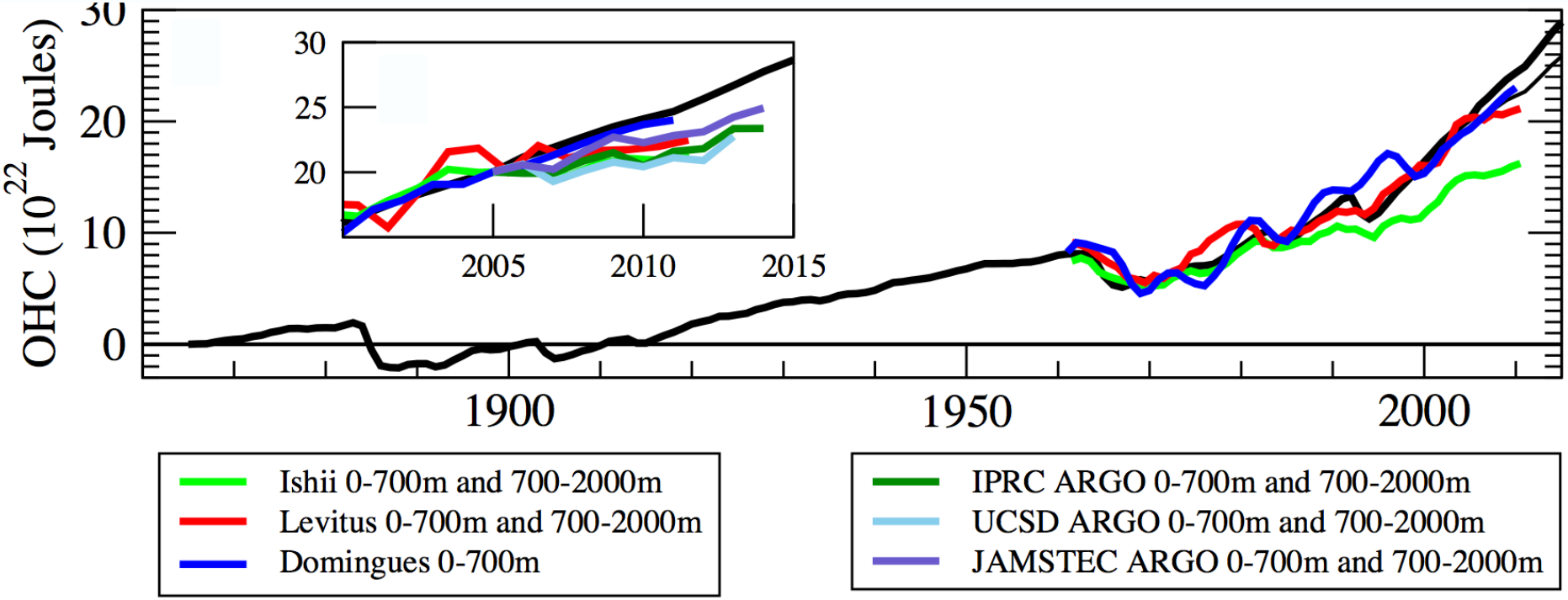
Revisiting observed and simulated upper OHC changes

Applying the Durack et al. (2014) adjustments to observationally-based estimates yields significantly higher values – Domingues et al. is closest to the CMIP5 MMM

If the lessons from our examination of hemispheric ratios are used by data experts, we expect newer versions of OHC estimates will have substantially larger heat uptake

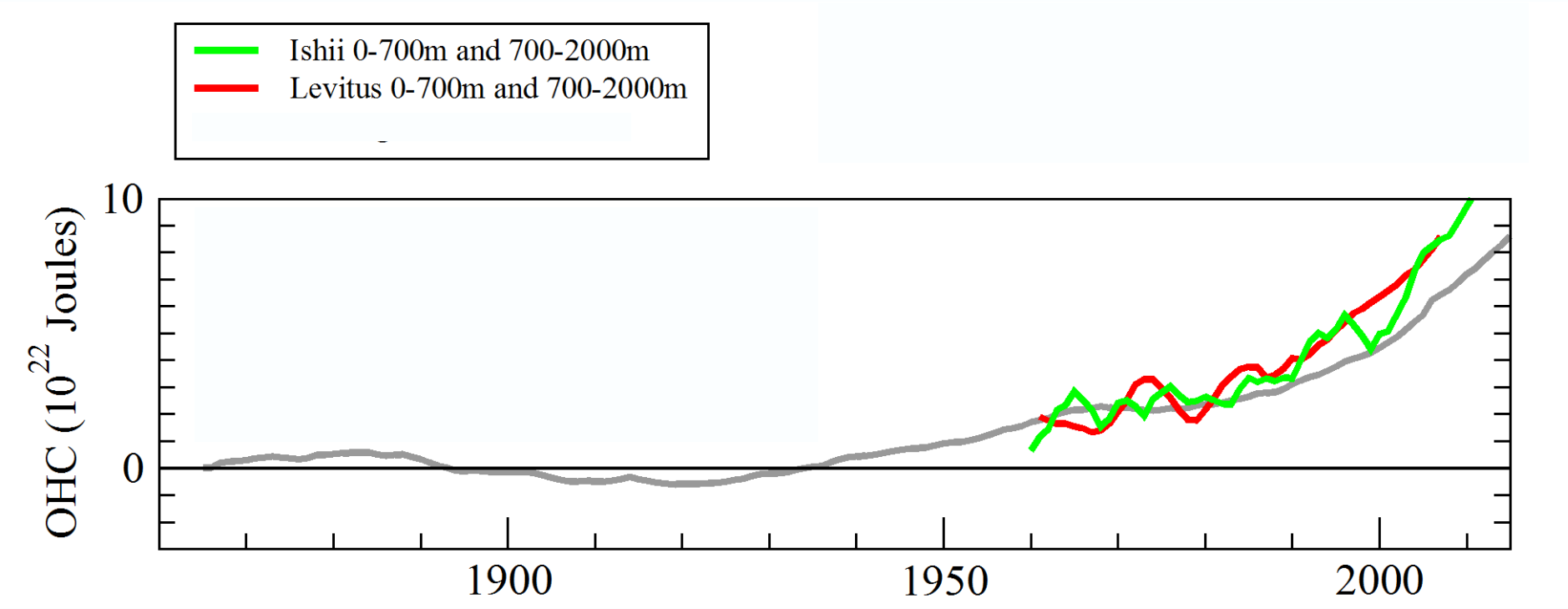


Observations and the CMIP5 MMM Upper Ocean (0-700m)



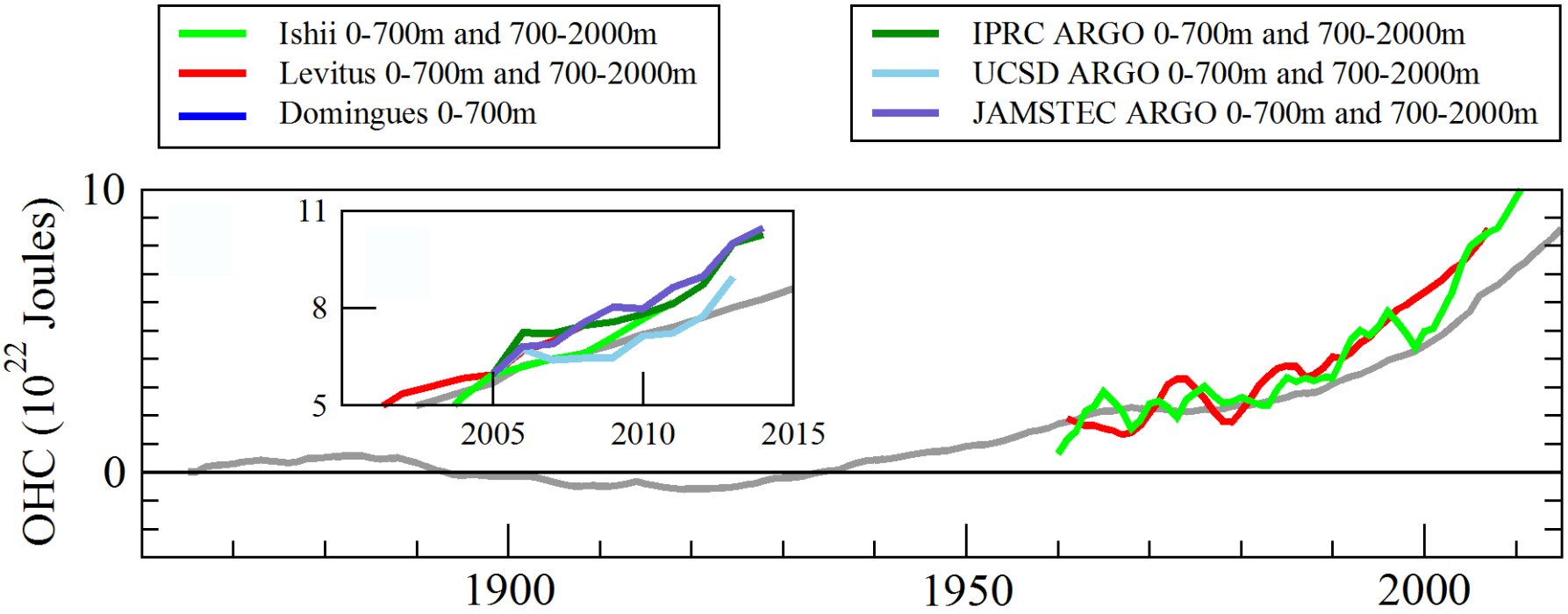
During Argo period the MMM is within range of estimates but on the high end

Observations and the CMIP5 MMM Intermediate Ocean (700–2000m)



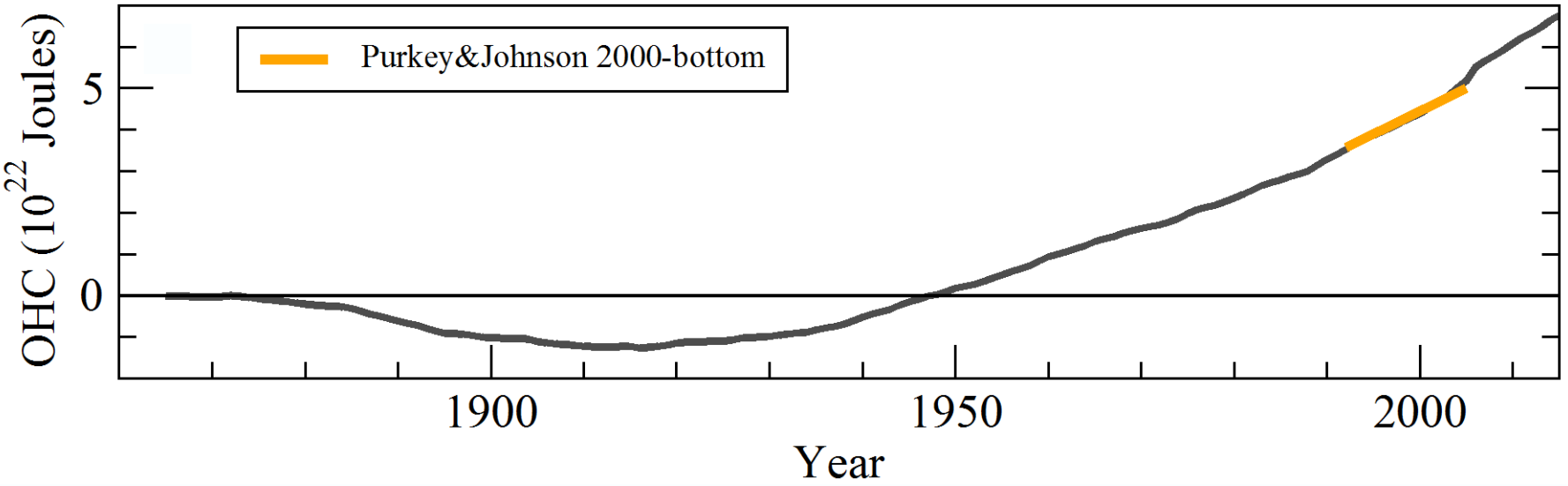
Measurement quality in intermediate layer is good but data coverage is poor compared to upper layer

Observations and the CMIP5 MMM Intermediate Ocean (700–2000m)



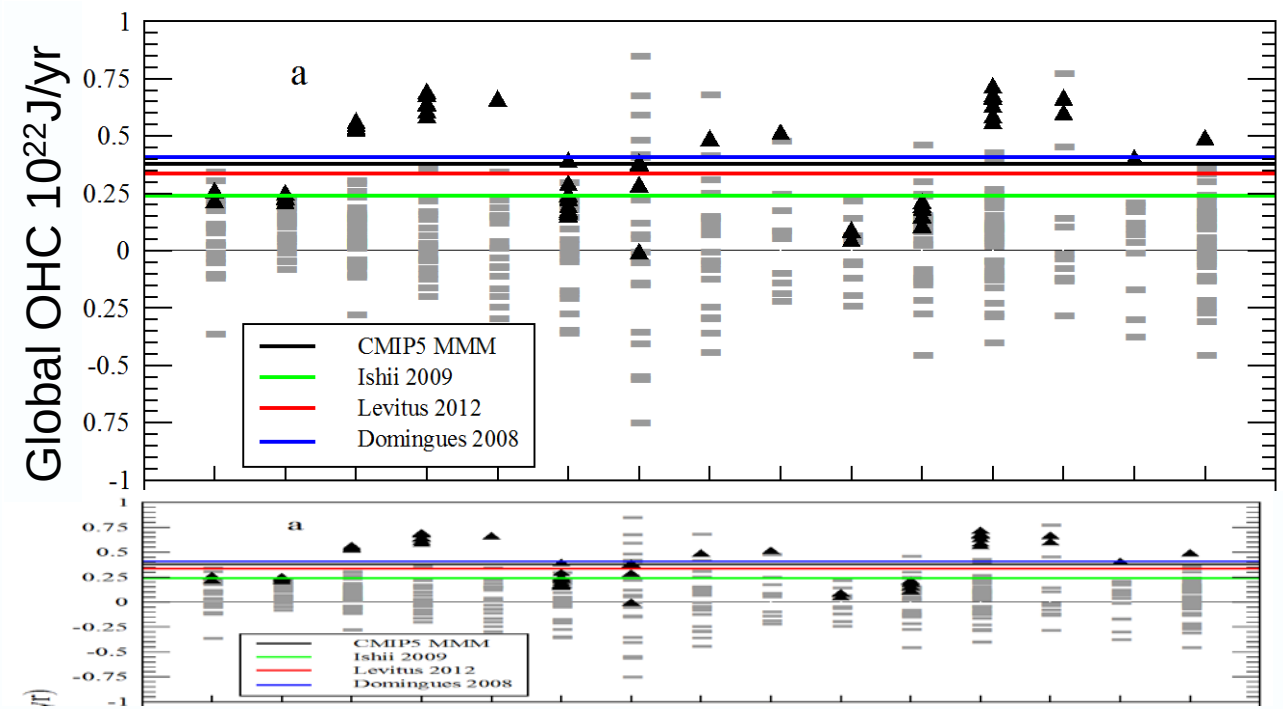
During Argo period the coverage is global and the MMM is within range of estimates but on the low end

Observations and the CMIP5 MMM
Deep Ocean (>2000m)



- Remarkably good agreement between MMM and deep ocean estimate
- Observational uncertainties are large but data is still invaluable

OHC trends (1971-2005): upper ocean Observed and simulated



OBS: colored lines

MMM: black line

Historical runs

PiCntrl 35yr distribution

- **Individual models straddle obs – no evidence of systematic warming bias**
- Historical warming distinct from natural variability
- Spread due to natural variability (multiple realizations) relatively small

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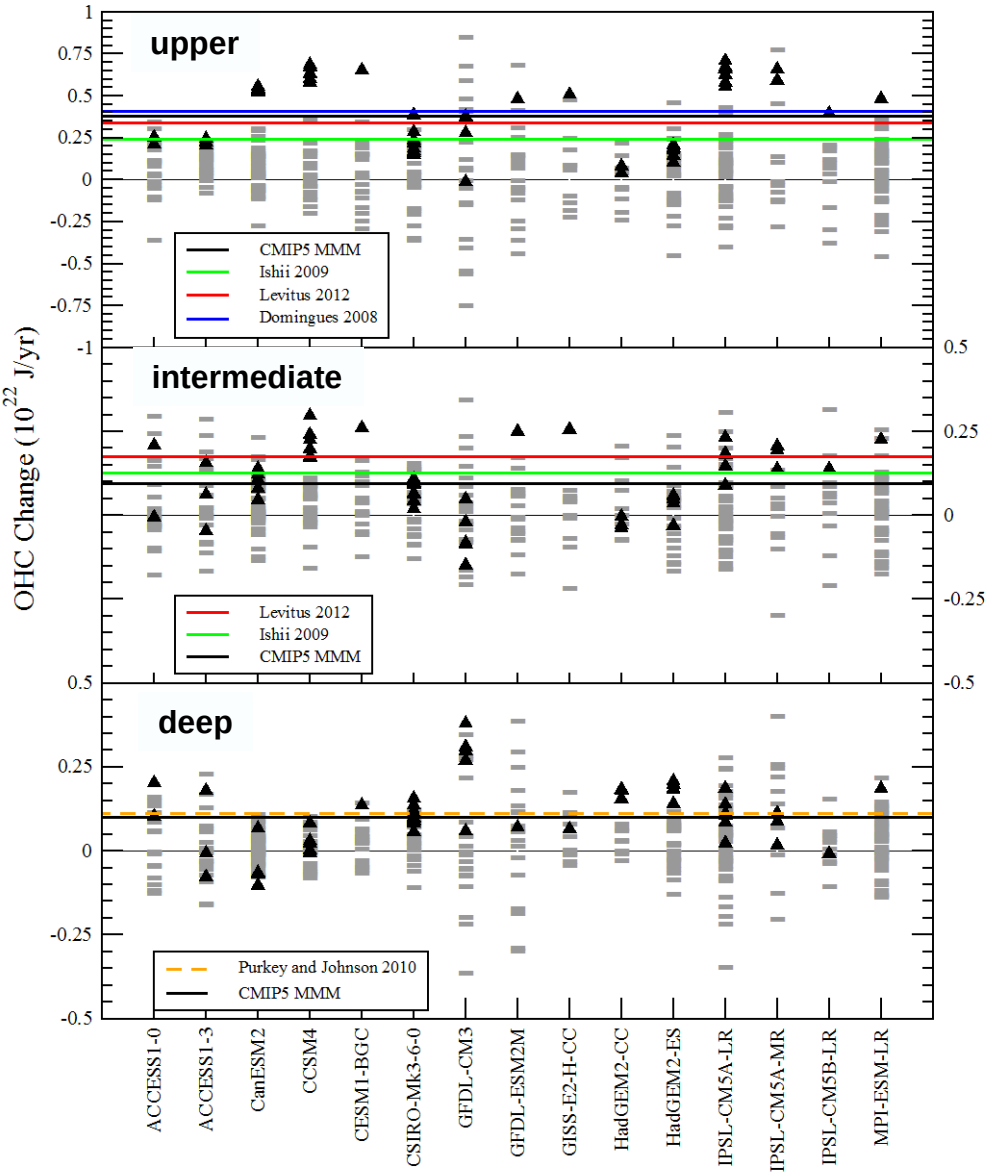
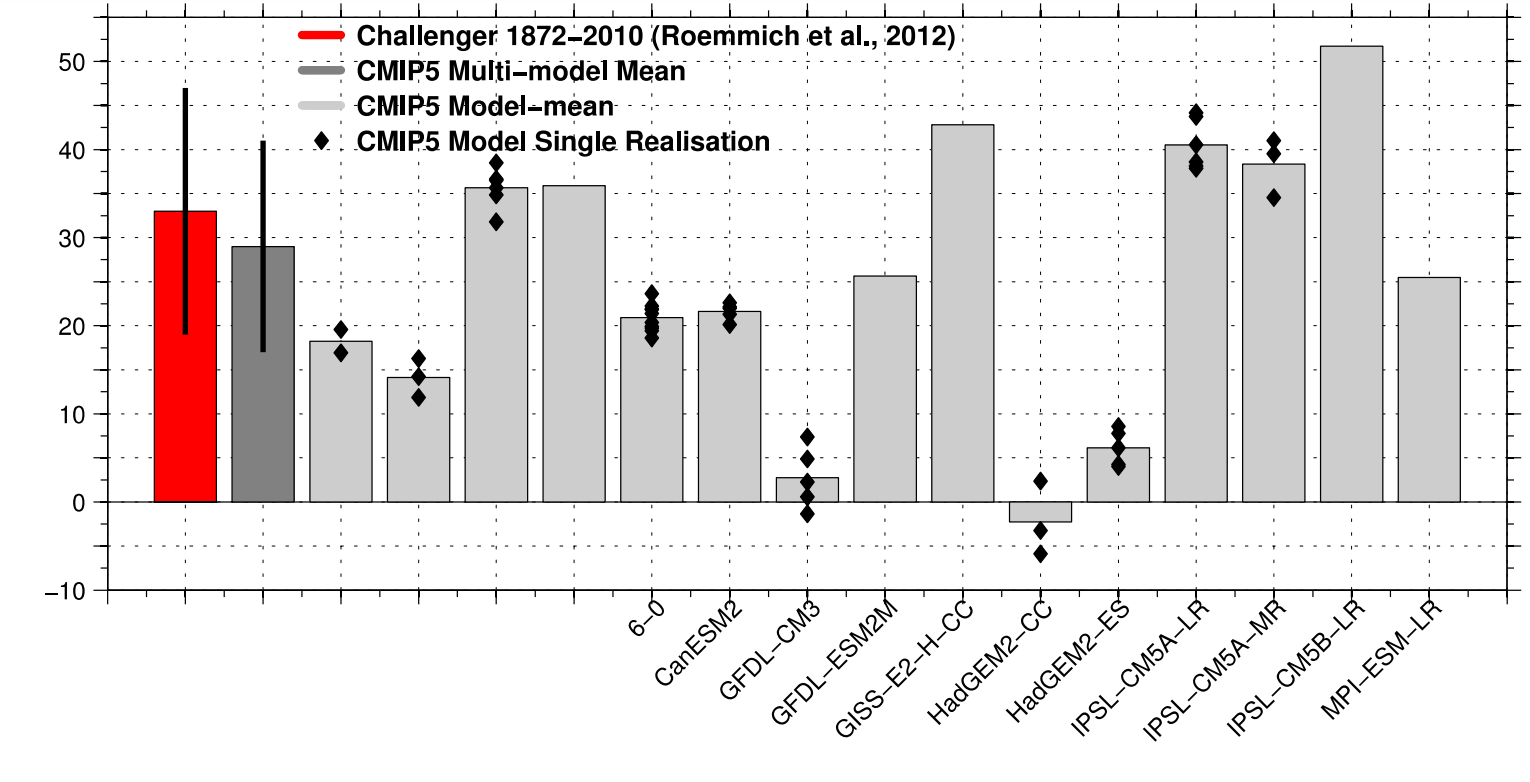
OHC trends (1971-2005)
Observed and simulated



No evidence of systematic bias in OHC changes in the upper, intermediate and deep ocean

Industrial Era Global Ocean Heat Uptake (~1875 to ~2005) Observed and simulated



- **MMM in good agreement "Argo-Challenger" estimate**
- Large spread across individual models; natural variability contribution is small

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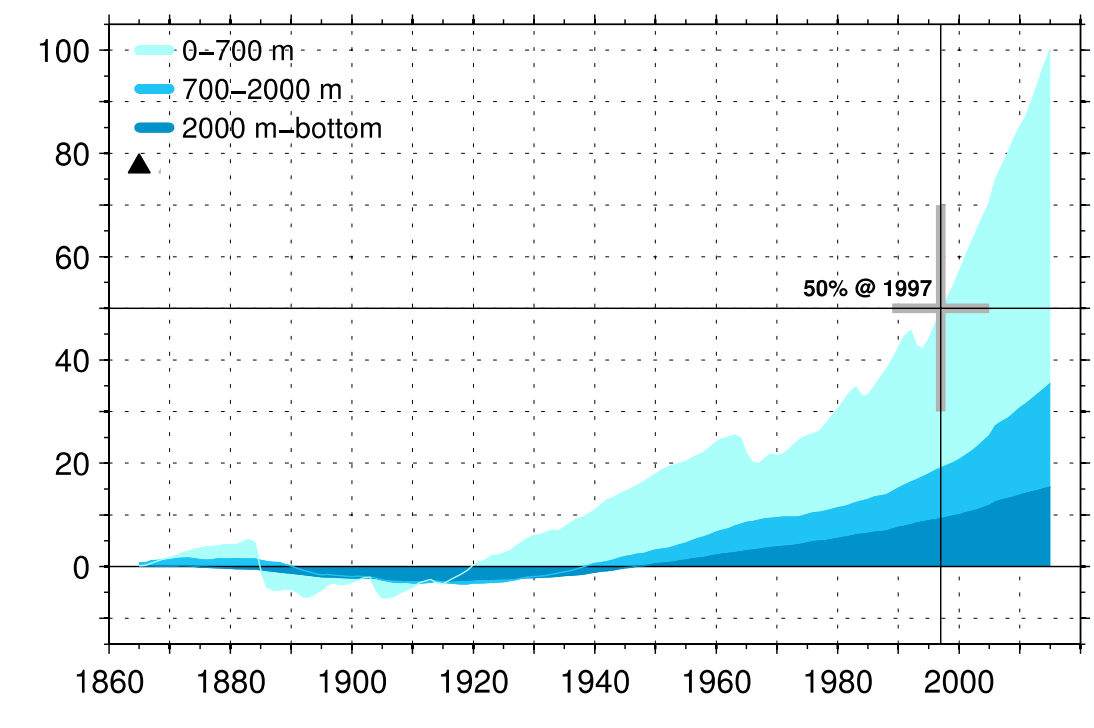
Cumulative fraction of total (1865-2015) heat uptake CMIP5 MMM



- Deeper (>700m) contribution is 35% and steadily increasing
- 50% of total heat uptake has occurred since 1997
- Accounting for missing 21st century volcanic forcing has only small effect of “50% date”

Individual model results normalized by their heat uptake at year 2015

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Summary

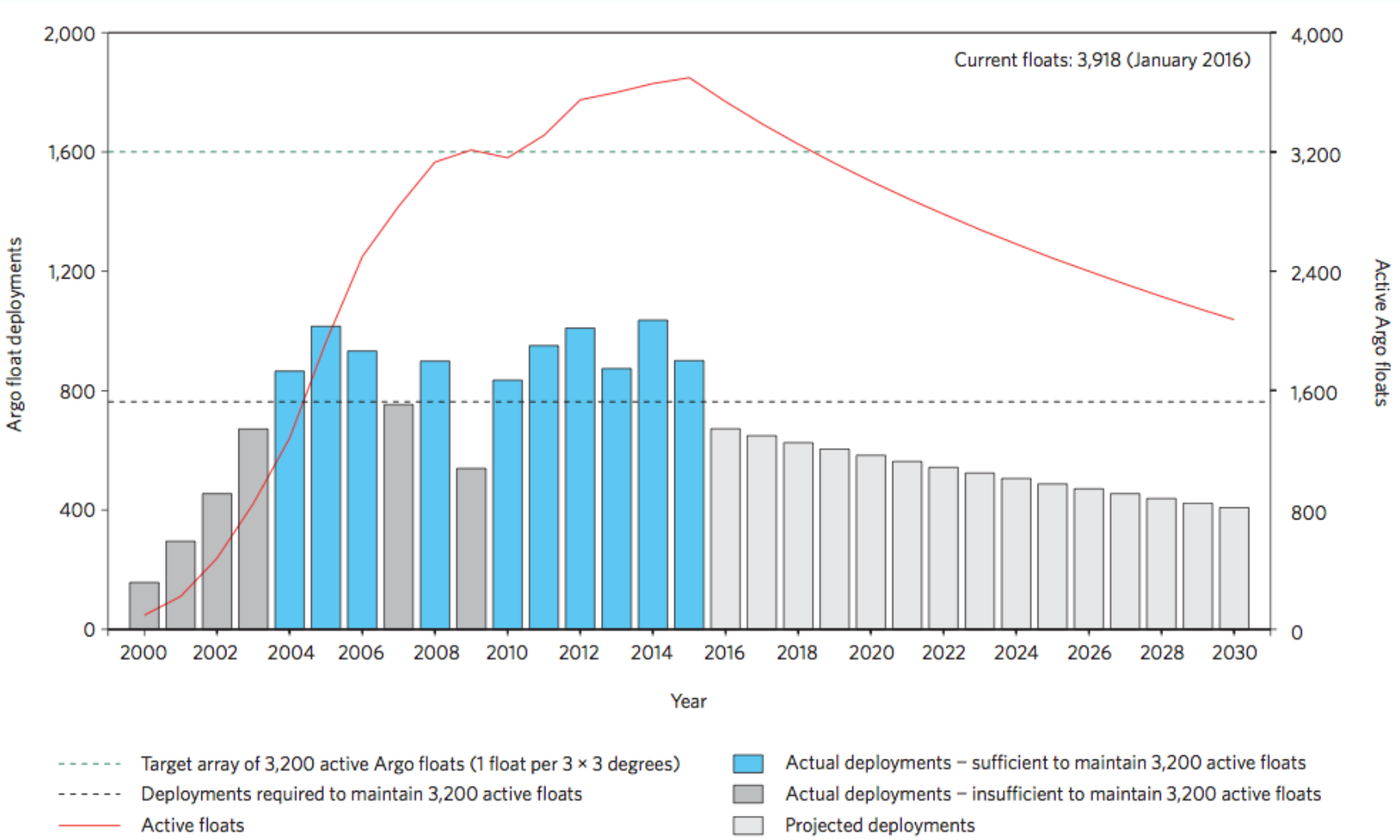
- There are complex observational uncertainties and substantial spread in model based estimates of ocean heat uptake. However, we find no evidence of a systematic bias in the CMIP5 MMM, and

- The CMIP5 MMM is consistent with a broad range of observationally-based estimates of OHC changes

- The MMM indicates half of the global ocean heat uptake has occurred in recent decades with an increasing contribution from the deeper ocean (currently ~35%)

- Our results reinforce the crucial importance of Argo, deep Argo and the GO-SHIP program for understanding the global energy budget

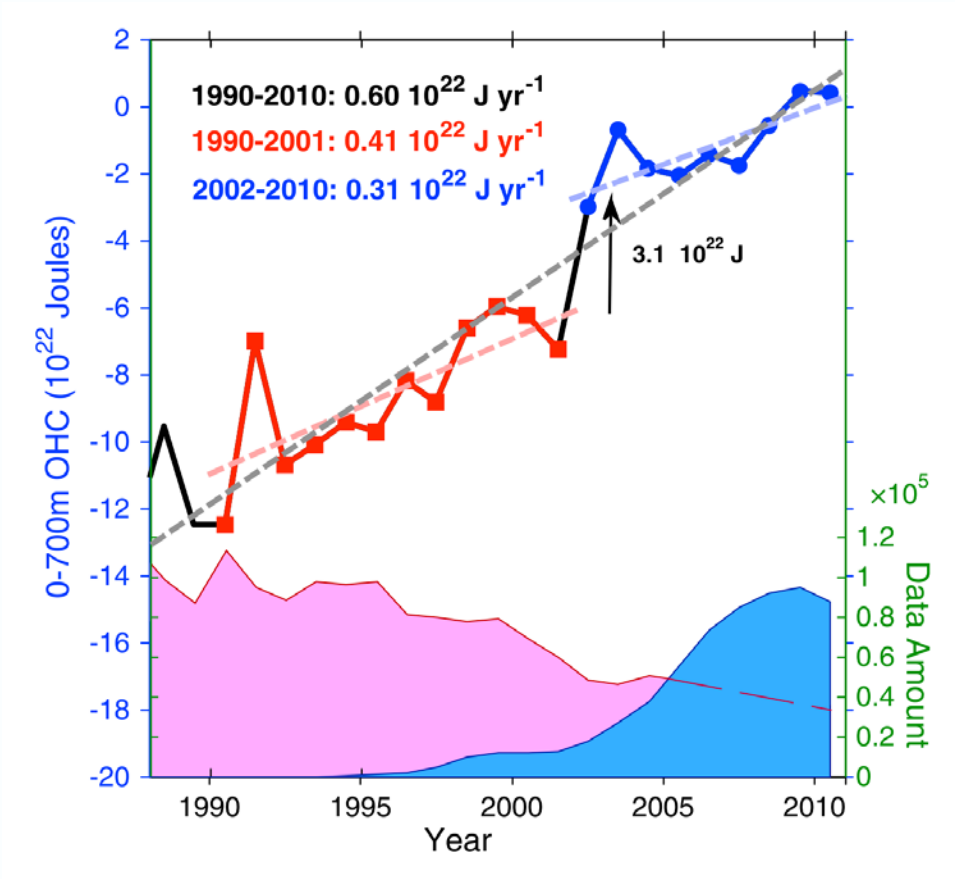
Argo's global coverage at risk



Durack et al. commentary (*Nat.Clim.Change*, in press)

Extras

Transition to global coverage with Argo



Role of Argo transition (2000-2005) is poorly understood

Fig. 1 of Cheng and Zhu, GRL, 2014