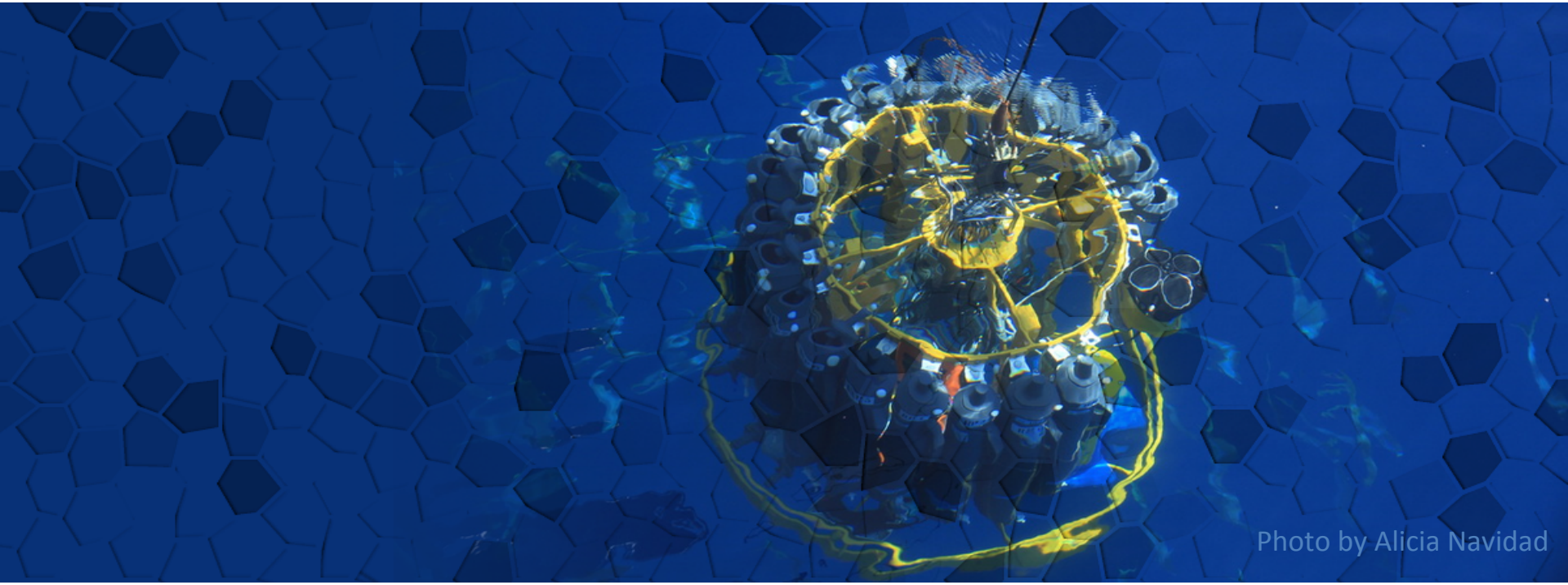
Global and spatio-temporal changes in upper-ocean thermal expansion



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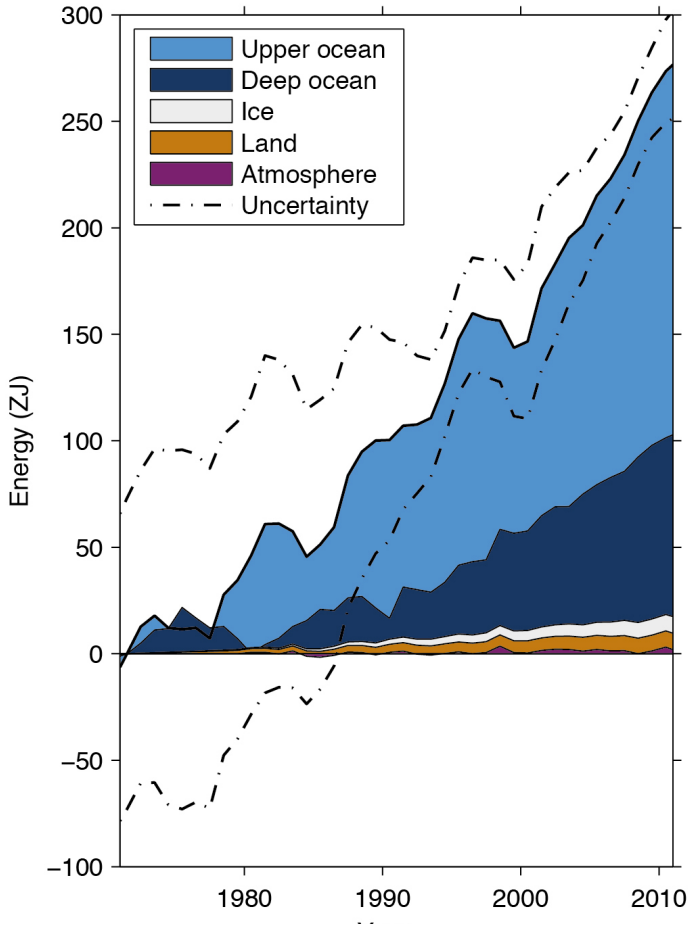
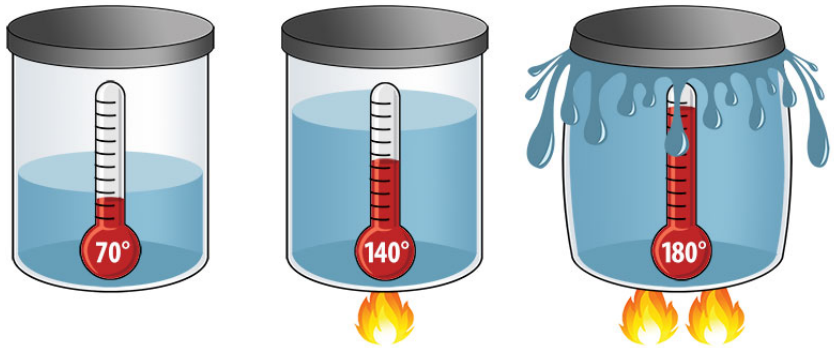
Rate of global warming: ocean heat uptake



Since 1970: ~93% excess heat => ocean
Human-induced (increased confidence)

Ocean heat uptake: sea level rise



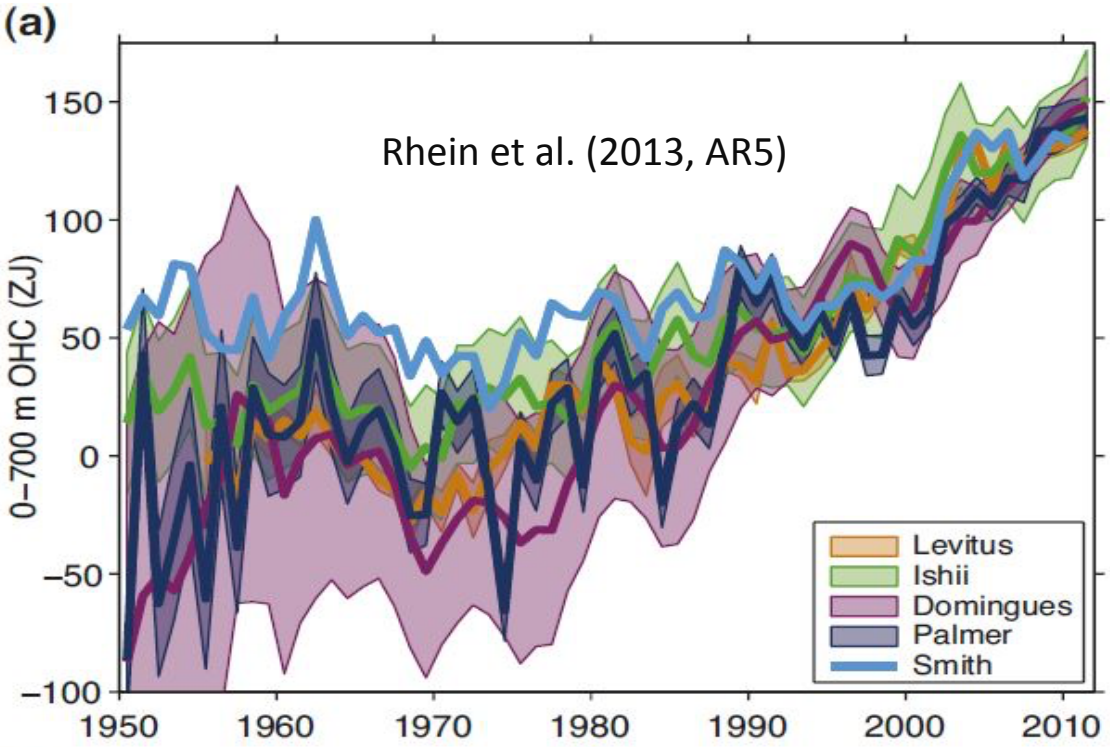
*Thermal expansion is **among the more serious of plumbing concerns**, but many homeowners know little about.*
https://www.plumbingsupply.com/thermal-expansion.html

Major contribution to global mean sea level (GMSL) rise and largely explains its regional patterns.

Rhein et al. Bindoff et al. Church et al. (2013, IPCC AR5)

Uncertainties: ocean heat content estimates

GLOBAL



- **Quality global temperature profile datasets?**
  (IQuOD.org; 17 nations/major data centres with support from SCOR/UNESCO-IOC-IODE/WCRP CLIVAR)
- **Instrumental (XBT) bias corrections? (10 XBT bias corrections since G&K, 2007)**
- **Climatologies?** (spatio-temporal coverage/period & length)
- **"Reconstruction" methods?** (in situ gaps)

Uncertainties: global ocean heat content estimates

- Lyman et al. (2010)
  Major uncertainty: instrumental (XBT) bias corrections
  ("Robust warming" 1993-2008)

- Boyer et al. (2016) – Coordinated/sensitivity study
  Major uncertainty: mapping ("reconstruction" method)

  - **Same input dataset versions:**
    7 groups/8 reconstructions
  - **6 XBT (representative) corrections**
  - **3 Climatologies**
    (2 Historical era; 1 Modern Argo era)
  - **1970-onwards**

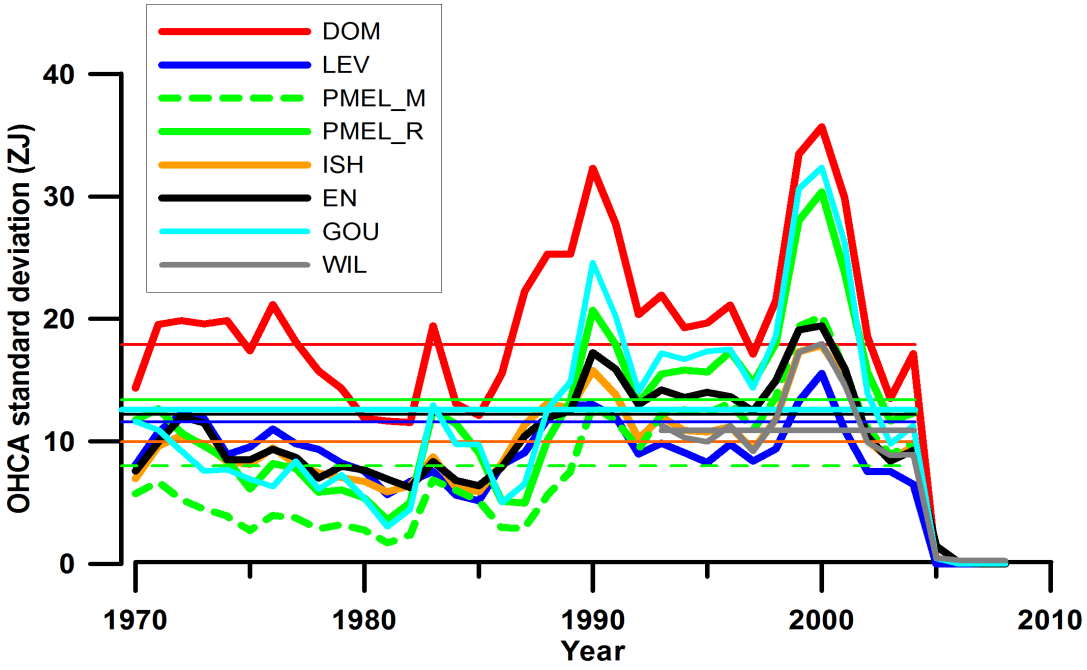
Summary table: GOHC sensitivity tests 1970-2008 (1993-2008)

	Mapping Method	XBT bias correction	Baseline Climatology
DOM	16.5 (17.1) ZJ	17.9 (22.4) ZJ	5.2 (5.8) ZJ
LEV	16.5 (17.1) ZJ		2.7 (2.4) ZJ
PMEL_M	16.5 (17.1) ZJ	8.0 (13.4) ZJ	9.1 (10.3) ZJ
PMEL_R	16.5 (17.1) ZJ	12.5 (18.3) ZJ	4.3 (3.7) ZJ
ISH	16.5 (17.1) ZJ	10.0 (12.0) ZJ	4.7 (5.5) ZJ
EN	16.5 (17.1) ZJ	12.2 (12.6) ZJ	5.5 (6.9) ZJ
GOU	16.5 (17.1) ZJ	12.6 (19.1) ZJ	6.6 (5.0) ZJ
WIL*	*(17.1) ZJ	* (10.9) ZJ	* (1.4) ZJ
Average	16.5 (17.1) ZJ	12.1 (15.7) ZJ	5.4 (5.1) ZJ

Table 3. Time-mean standard deviations of global OHCA associated with variations in XBT bias corrections and baseline climatologies, for different mapping methods for 1970–2008 and 1993-2008 (in parentheses). * WIL method can only be calculated from 1993–2008.

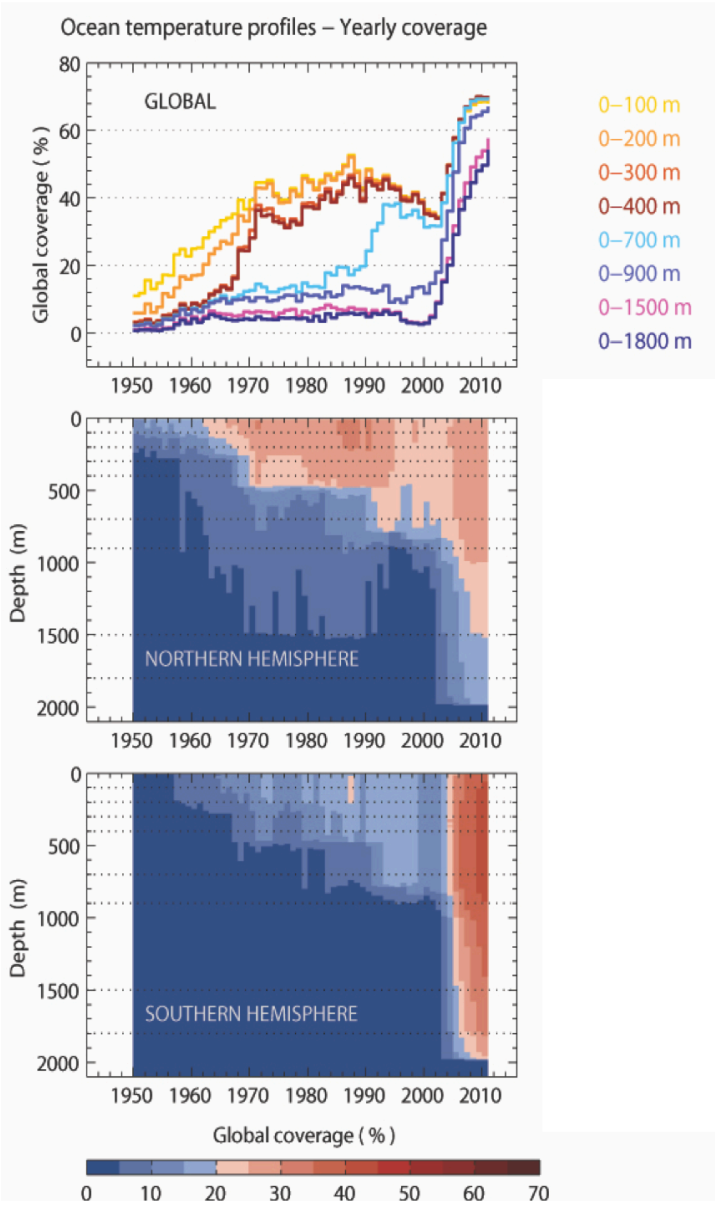
Boyer et al. (2016)

Spread due to XBT bias corrections for each mapping method



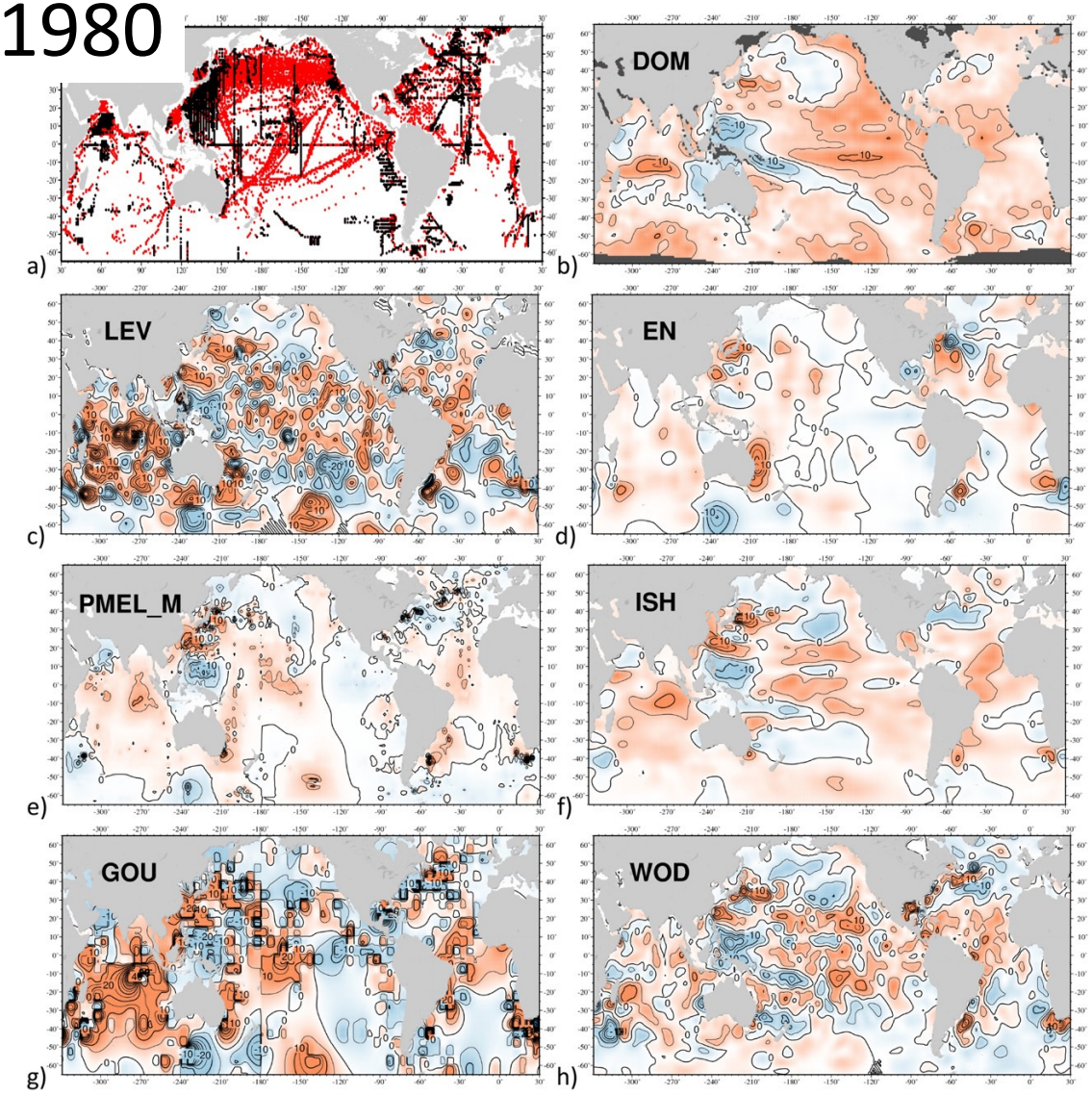
- Largest impact for **DOM estimates**
- Pre/Post 1990s (shallow/deep XBTs)
- Argo only (from 2005)

Boyer et al. (2016)



Abraham et al. (2013)

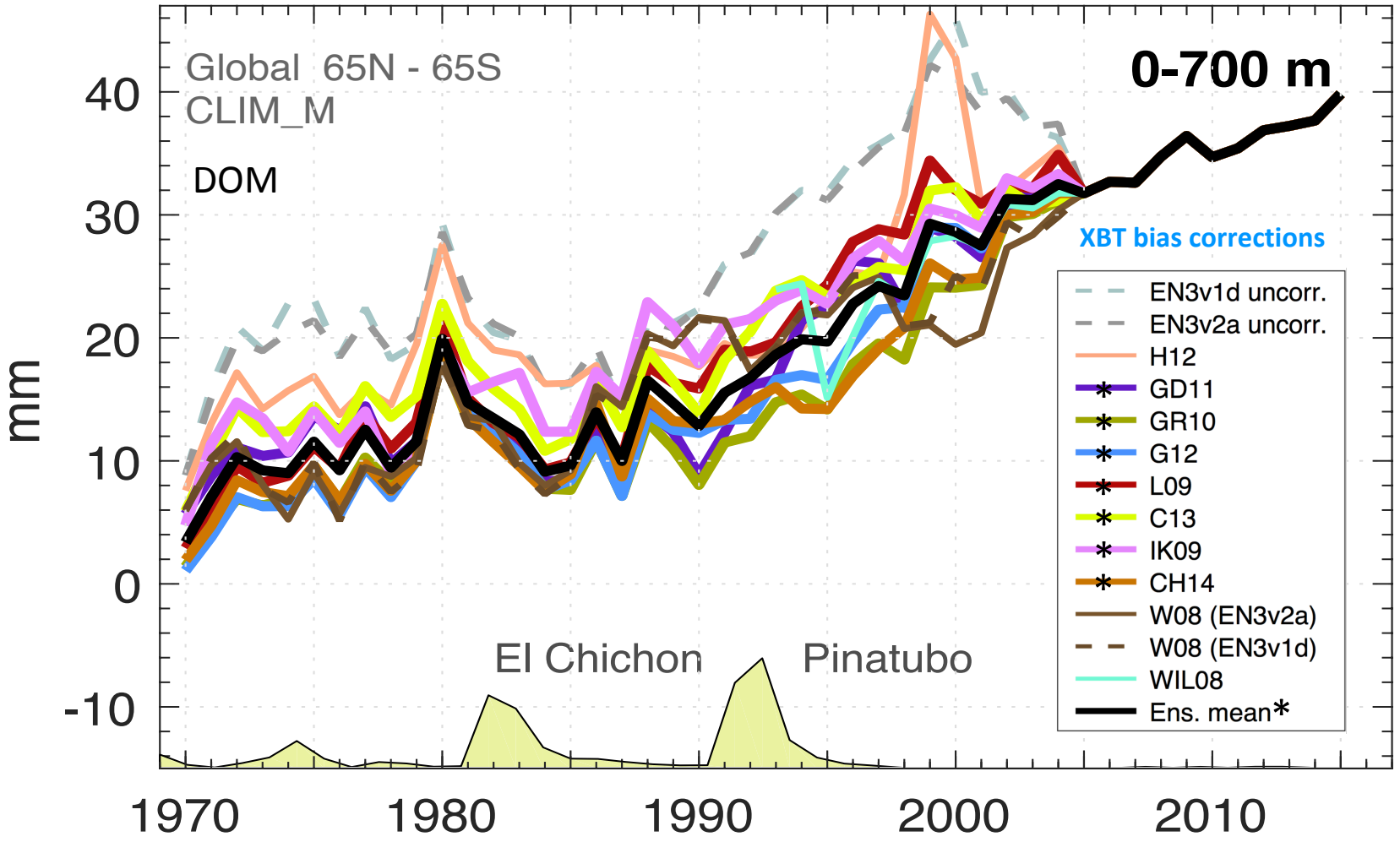
Regional OHC patterns: annual map 1980



Follow-up:
Abhishek Savita
CSIRO-UTAS QMS PhD student
June, 2017

- DOM = Australian team
- LEV = Levitus et al. NCEI/NOAA
- EN = Good et al./UK Met Office
- PMEL = PMEL/NOAA
- ISH = Ishii et al./MRI
- GOU = Gouretski/CLISAP
- WOD = NCEI/NOAA
  WIL = Willis et al.

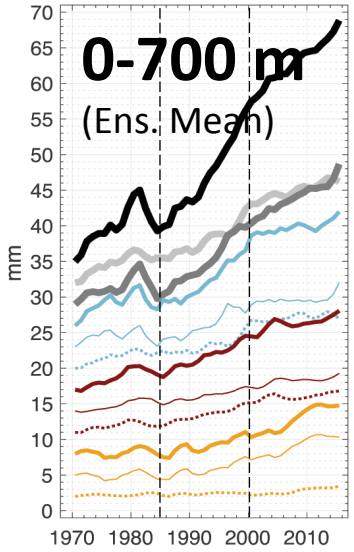
Global mean thermosteric sea level: 1970-2015



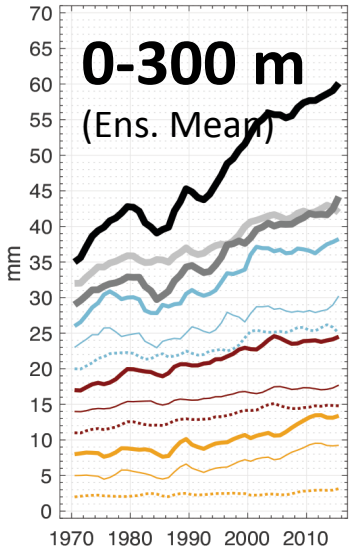
Nicholas Pittman
CSIRO-UTAS, ARCCSS, ACE CRC, Honours student, 2016 (in prep.)

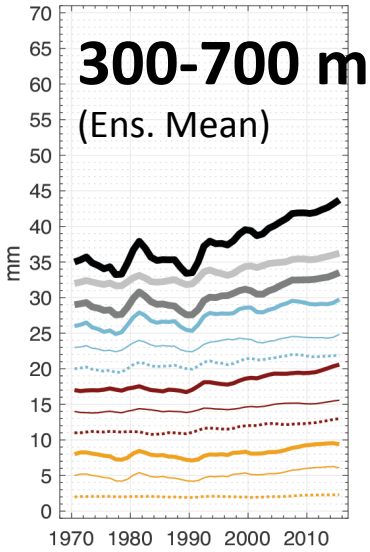
Ensemble mean: global, hemispheric, basins

- Global
- Northern Hem.
- Southern Hem.
- Pacific
- South Pacific
- North Pacific
- Atlantic
- South Atlantic
- North Atlantic
- Indian
- South Indian
- North Indian



- GThSL rise is quasi-linear
  1970-1985, 1985-2000, 2000-2015
- All ocean basins contribute to global rise

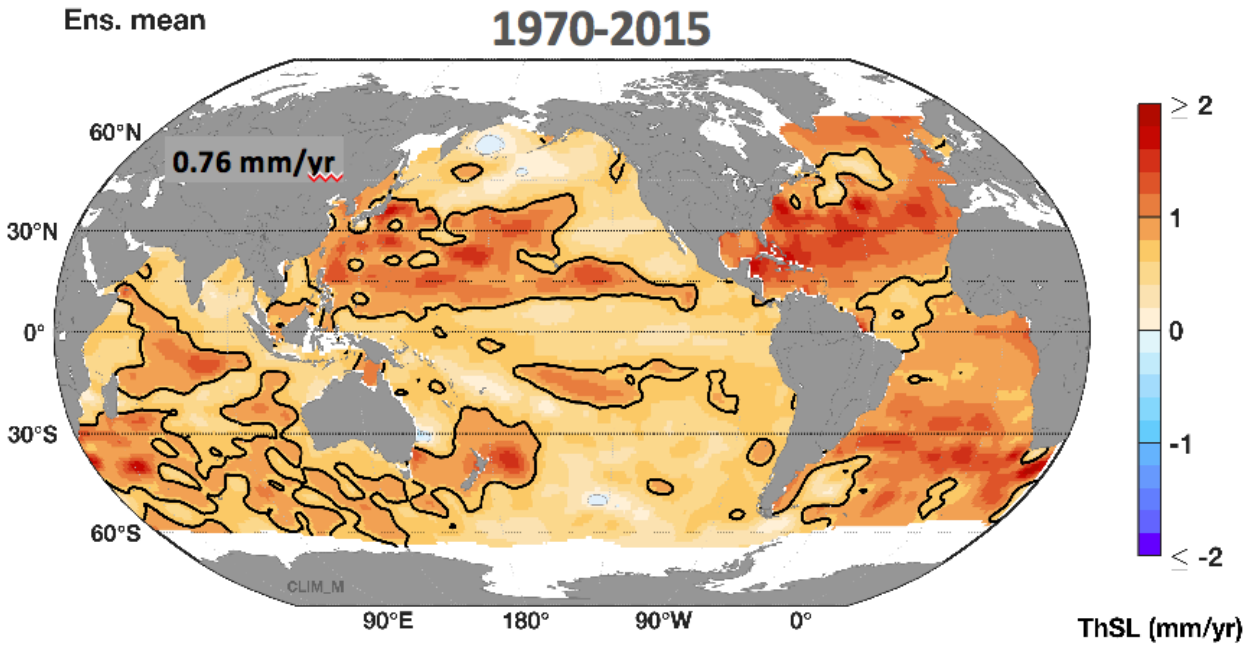




- Larger volume expansion in the upper 300 m (72% of the global rate) compared to 300-700 m

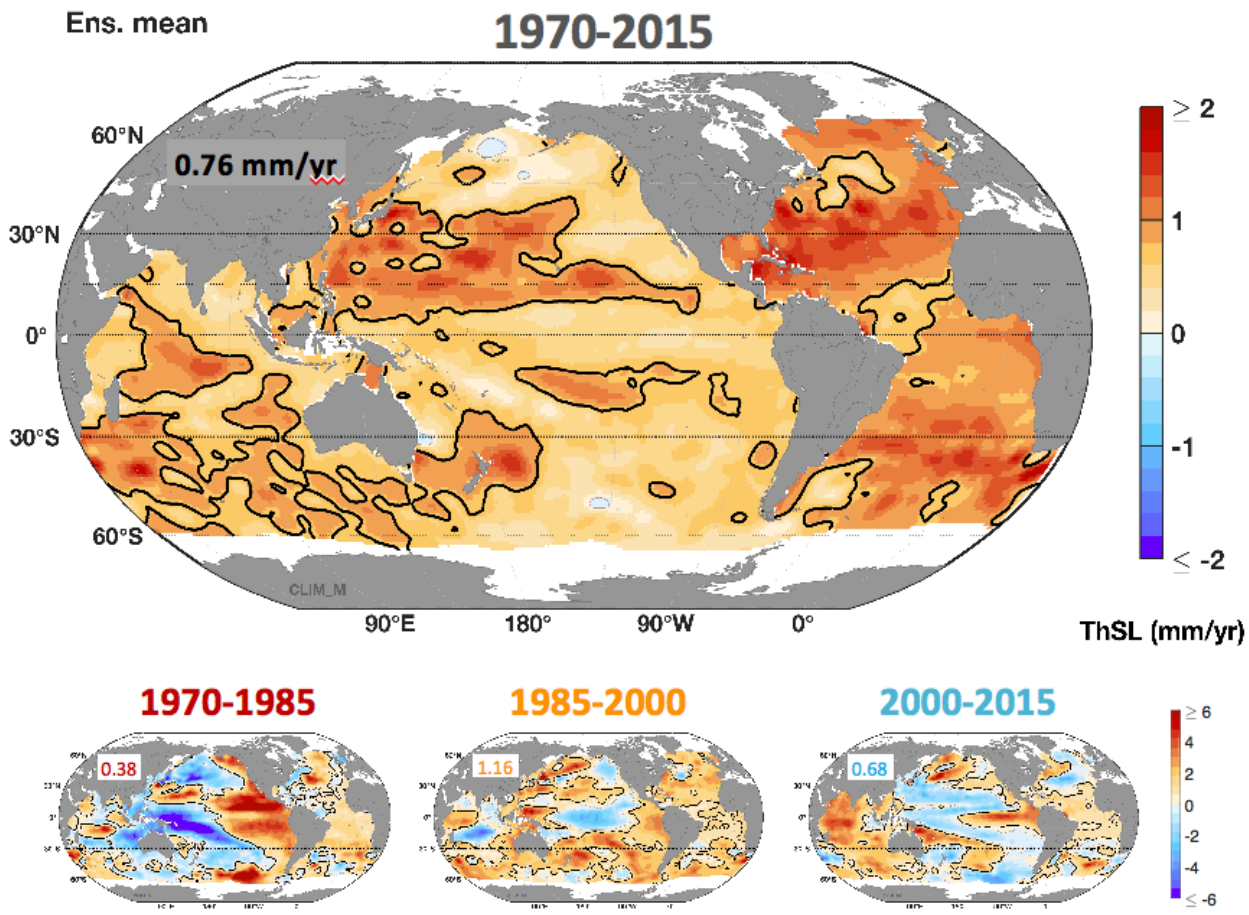
Pittman et al. (in prep.)

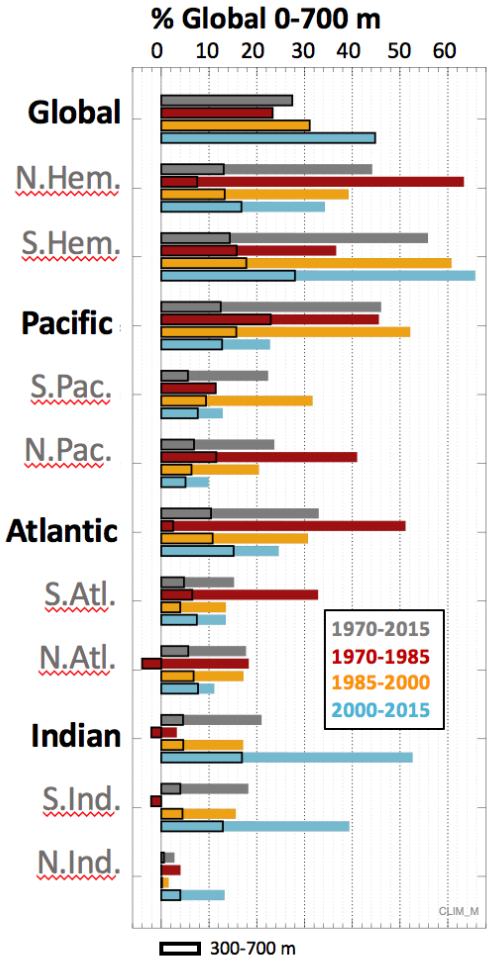
Regional/zonal rates & Basin contributions



Pittman et al. (in prep.)

Regional/zonal rates & Basin contributions

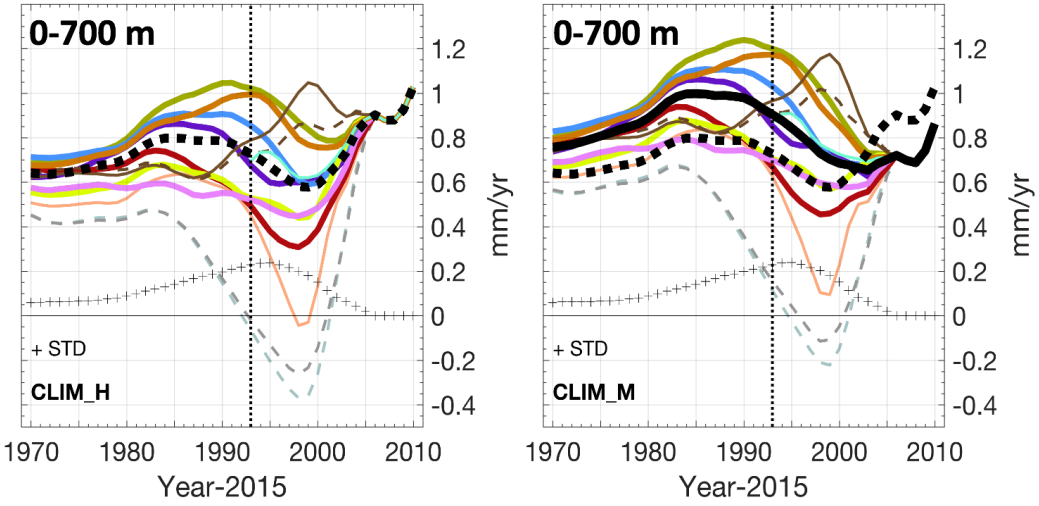




- SH 56% global, zonally-averaged maximum rate at 40°S, 2nd max. at 8°S
- Rates vary widely 15-year periods, from global to regional scales
- Major contributions: **Atlantic (51%)** **Pacific (52%)** **Indian (53%)**
- **ThSL 300-700 m** increase consistently: **23%, 31% and 45%.**

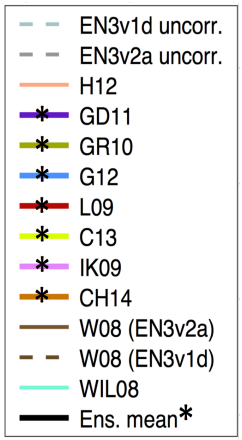
Pittman et al. (in prep.)

GThSL rates (XBTs/Climatologies)

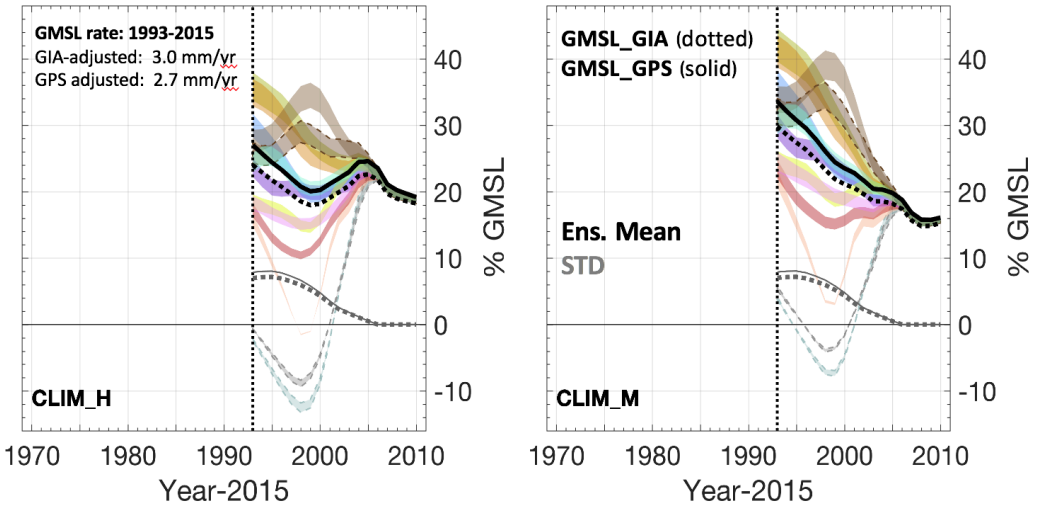


XBT bias corrections

H12	Hamon et al. (2012)
GD11	Good (2011)
GR10	Gouretski and Reseghetti (2010)
G12	Gouretski (2012)
L09	Levitus et al. (2009)
C13	Cowley et al. (2013)
IK09	Ishii and Kimoto (2009)
CH14	Cheng et al. 2014)
W08	Wijffels et al. (2008, Table 1)
WIL08	Wijffels et al. (2008, Table 2)



% GMSLR rate (altimeter era)



CLIM_H: Historical climatology
CLIM_M: Modern climatology

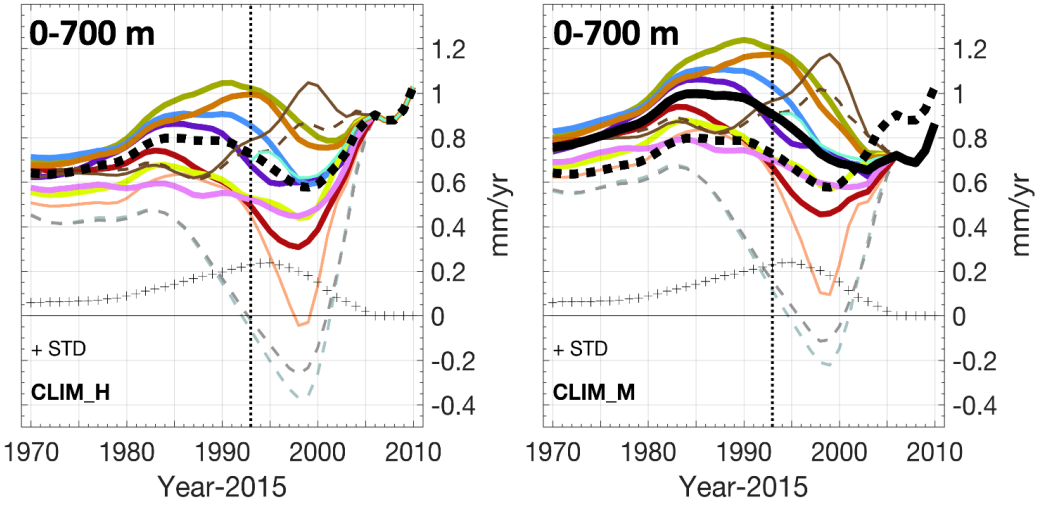
GIA: Glacial Isostatic Adjustment
GPS: Global Position System

GThSL 0-700 m contribution to the GMSL rate is dependent on:

- XBT-bias corrections
- Climatology(3)
- Altimeter sea level adjustments (GIA/GPS, lower/upper bound of envelope respectively)

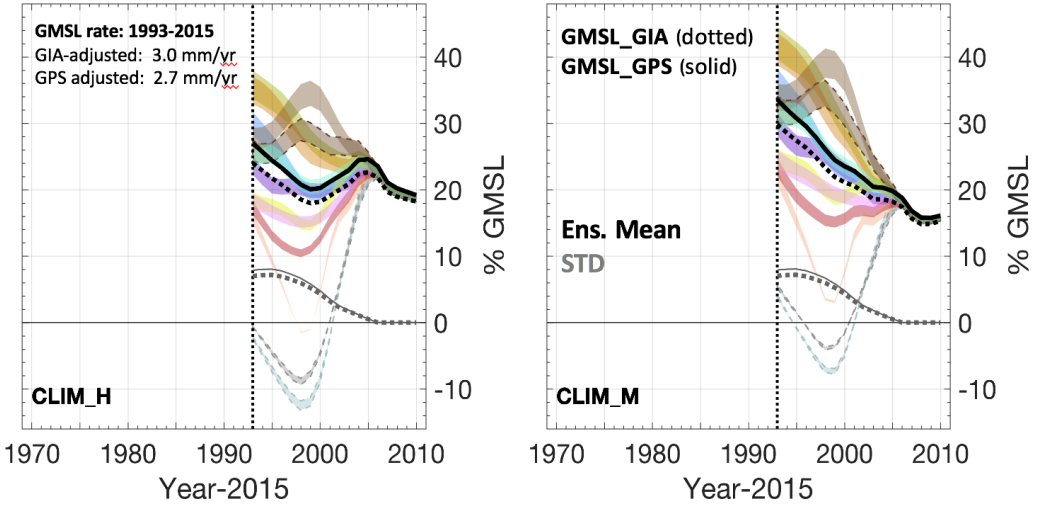
Pittman et al. (in prep.)

GThSL rates (XBTs/Climatologies)



For the ensemble mean and relative to the modern climatology[3], ThSL 0-700 m accounts for ~34% of the GMSL rate over 1993-2015.

% GMSLR rate (altimeter era)



CLIM_H: Historical climatology
CLIM_M: Modern climatology

GIA: Glacial Isostatic Adjustment
GPS: Global Position System

Individual ThSL contributions range from 24% for L09 to 42% for GR10.

The two estimates (GR10, CH14) with all recommended XBT bias factors corrected[4] lie in the upper range (~40%).

Pittman et al. (in prep.)

Recent progress: internationally-coordinated activities:

- **Internationally Quality-controlled Ocean Database**
  (CLIVAR GSOP/SCOR/IODE/GODAE,www.iquod.org)
- **Refinement of XBT bias corrections**
  (XBT Science Team, Cheng et al. 2016)
- **Understanding and quantifying uncertainties in direct estimates**
  (reanalyses/CLIVAR GSOP)
- **Evaluation of mapping methods (to be undertaken)**
  (Palmer et al.)
- **Refinement of mapping methods**
  (McDougall et al., STATMOS)
- **CLIVAR RF CONCEPT-HEAT**
  (von Schuckmann et al.)
- **In situ observing system: development/implementation of under seasonal sea ice and deep Argo floats (> 2000 m; operational in about 10 years)**

Gap: no sustained in situ monitoring system for <2000 m.

Oceanos'19 white papers; WCRP GCSL, GOOS/OOPC, etc.

THANK YOU