Ocean Heat Content Estimate an overview

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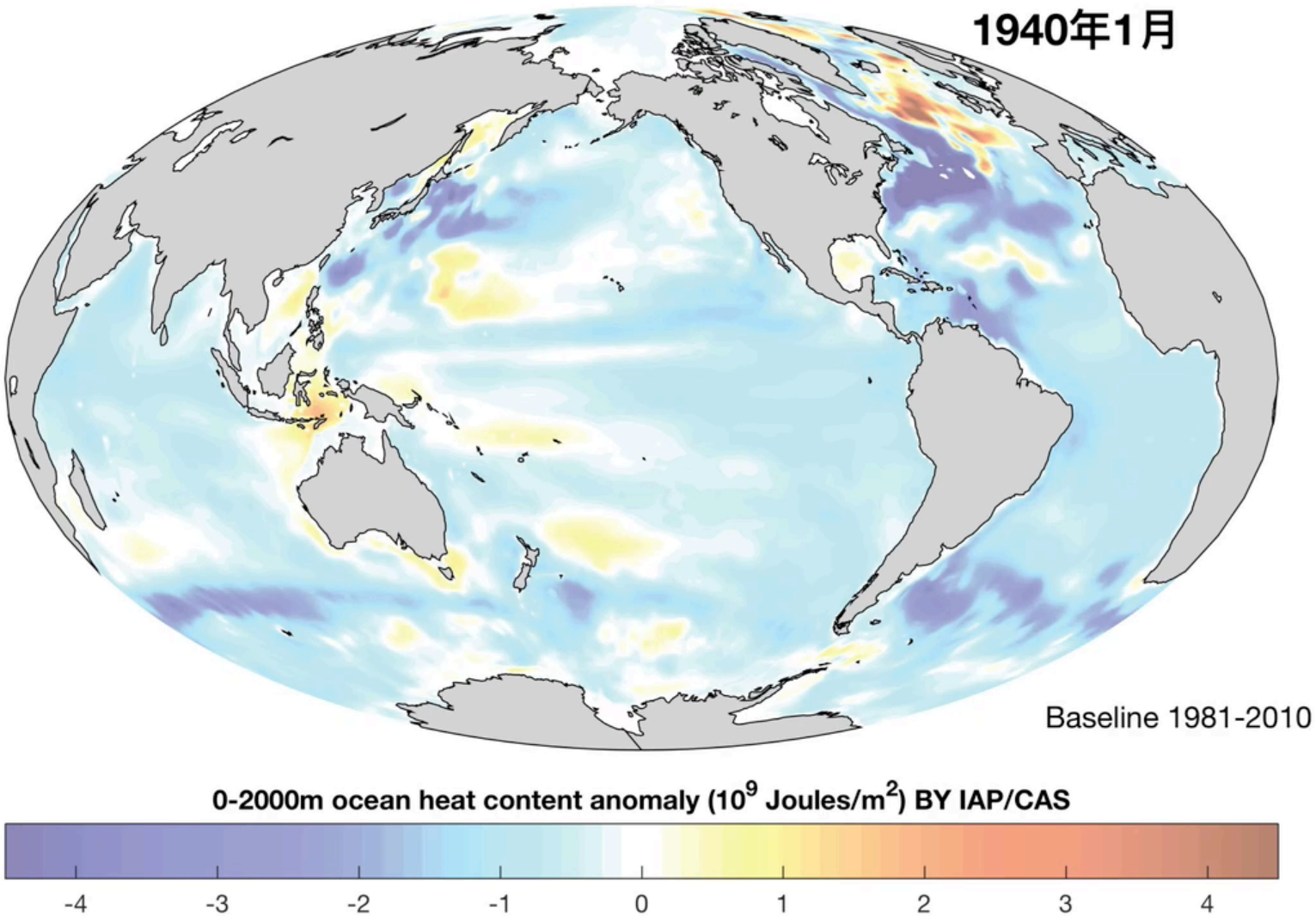
Ocean heat content

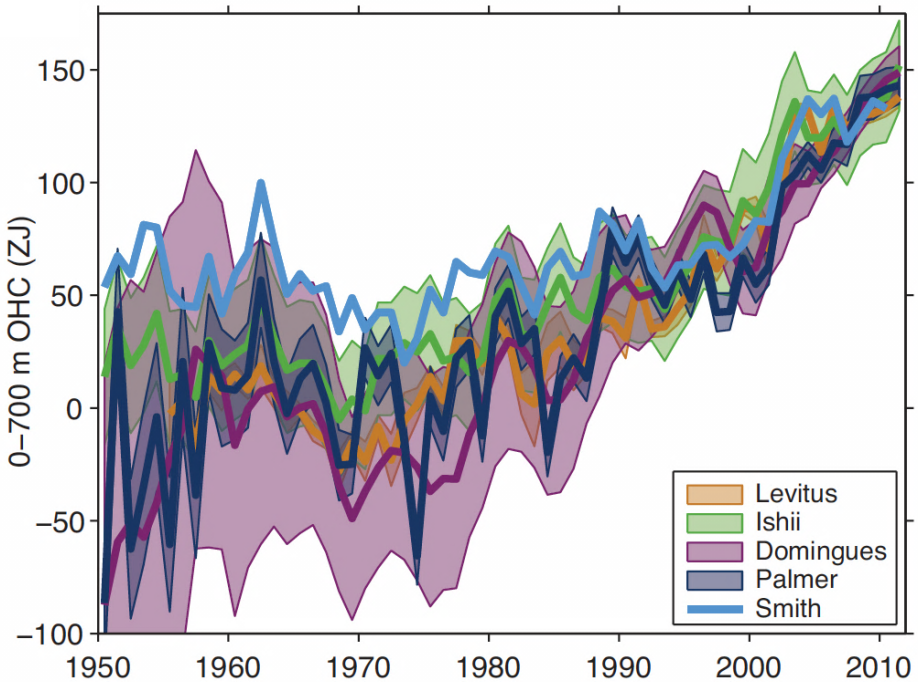
Ocean heat content: a key measure of Earth's energy imbalance



Ocean heat content

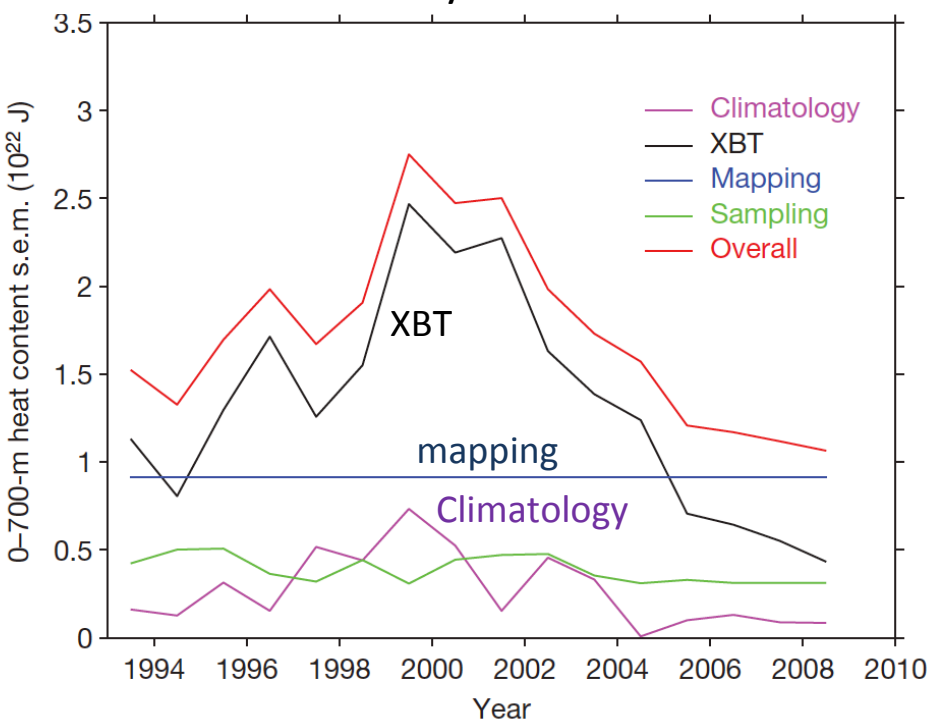
➢ **State of knowledge in IPCC-AR5**

0-700m OHC



IPCC-AR5 (2013)

Uncertainty in 0-700m OHC



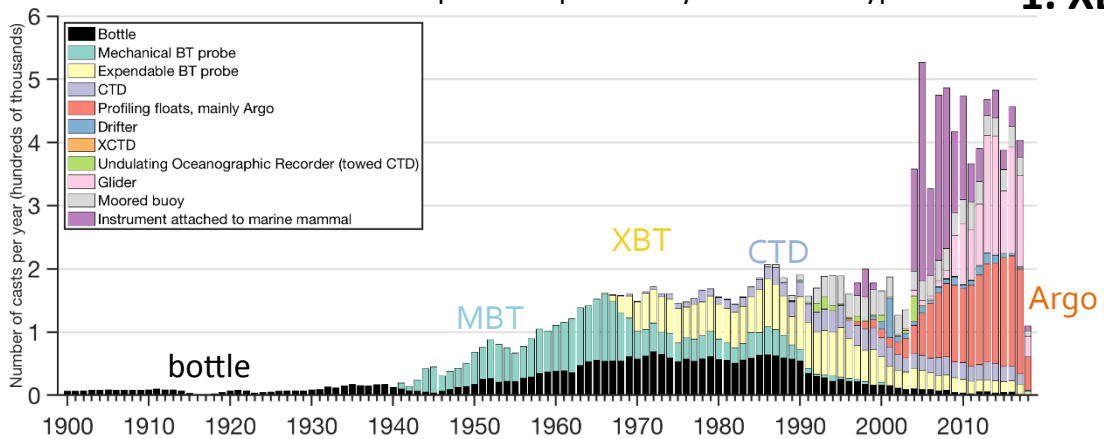
Lyman et al. 2010, Nature

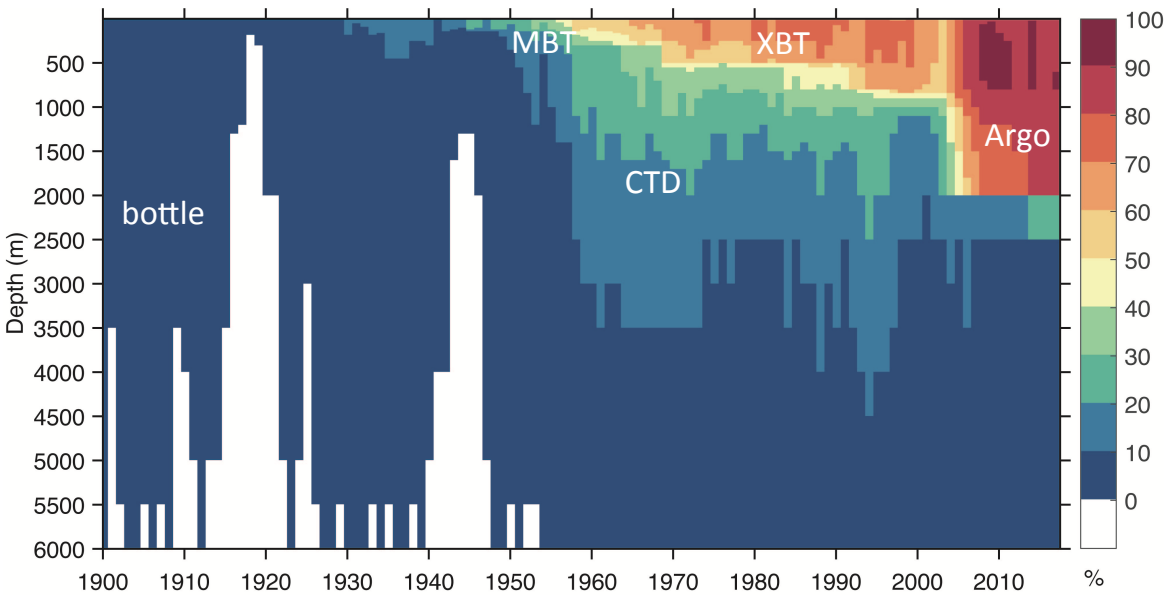
Progress after IPCC-AR5

Ocean heat content

How OHC calculated and why it is so uncertain?

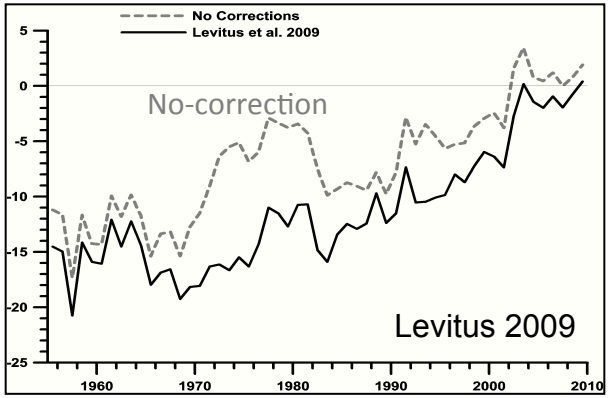
Annual number of temperature profiles by instrument type



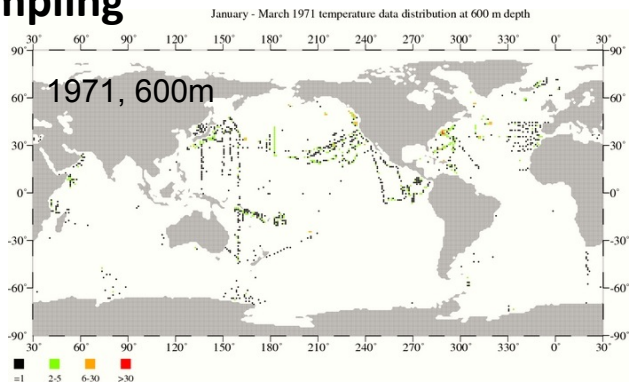


Ocean data coverage from sea surface to 6000m (3 by 3 degree resolution)

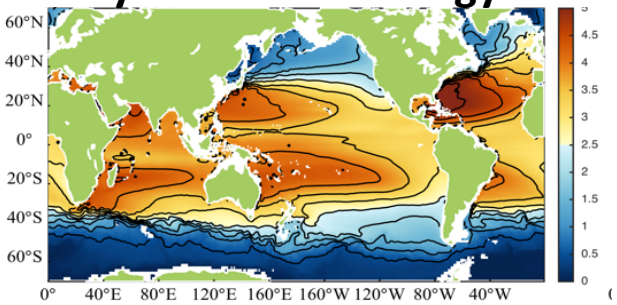
1. XBT bias



2. Sampling



3. Anomaly used: Climatology



Ocean heat content

Sources of uncertainties in OHC estimate (Boyer et al. 2016):

Using 8 mapping methods, 6 XBT correction schemes, 3 climatology.

① **Mapping method (gap-filling)**

② **XBT bias**

③ Choice of climatology (dependent on Mapping)

④ Data quality

Question: are these methods equally good???

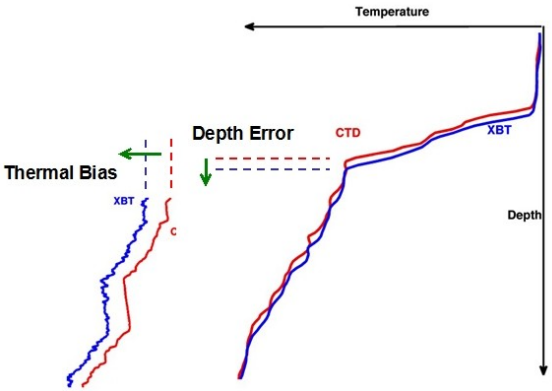
Improving OHC estimate: XBT

XBT bias: >10 correction schemes are proposed and used in the OHC estimate.

One correction scheme (CH14) has been identified and recommended by community.

CH14

Factors		Cheng et al. (2014)	Gouretski and Reseghetti (2010)	Levitus et al. (2009)	Gouretski (2012)	Hamon et al. (2012)	Good (2011)	Cowley et al. (2013)	Cowley et al. (2013) (CH)	Ishii and Kimoto (2009)	Wijffels et al. (2008)
Pure temperature bias	Pure temperature bias correction	✓	✓	✓	✓	✓		✓	✓		
	Time variable	✓	✓		✓	✓		✓	✓		
	Temperature dependency	✓	✓			☑ Cold and warm water					
Depth bias	Depth bias correction	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Time variable	✓	✓		✓	✓	✓	✓	✓	✓	✓
	Surface depth bias	✓	✓		✓	✓		✓	✓		
	Temperature dependency	✓	☑								
Probe type	Sippican	T7/DB; T4/T6; T5; T10	T4/T6; T7/DB		T10; T4/T6; T7/DB	Deep; shallow	T4; T7; T10	T4/T6; T7/DB	T4/T6; T7/DB	T7; T4; T6; T5; T10; FD	Deep; shallow
	TSK	T4/T6; T5; T7						TSK	TSK	T4; T6; T7	
	Unknown	Deep unknown; shallow unknown			Deep unknown; shallow unknown		Unknown				



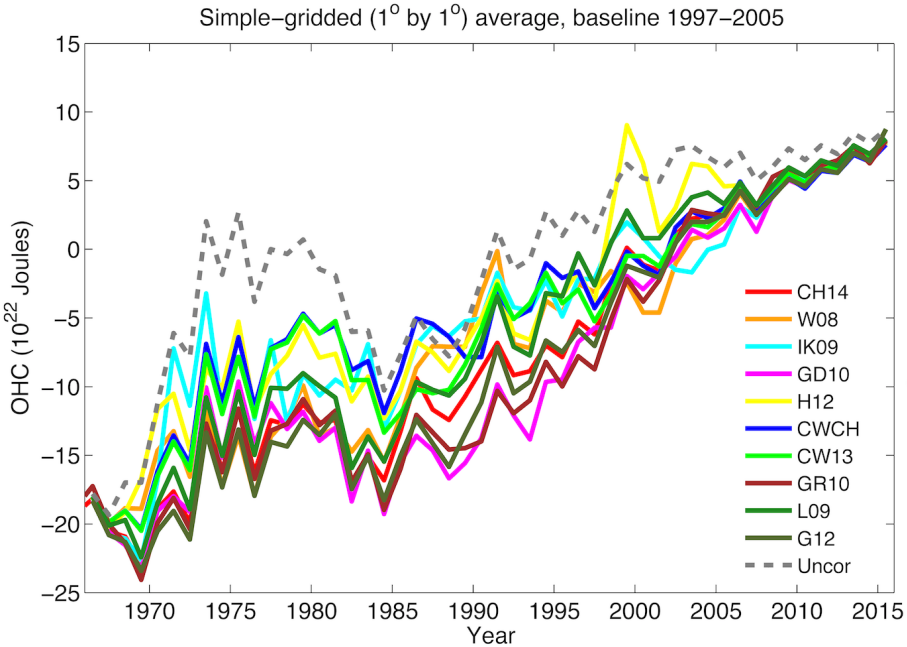
There are both Temperature and Depth errors, but only Z error is considered!

Cheng et al. 2016, BAMS

Used in OHCs in IPCC-AR5

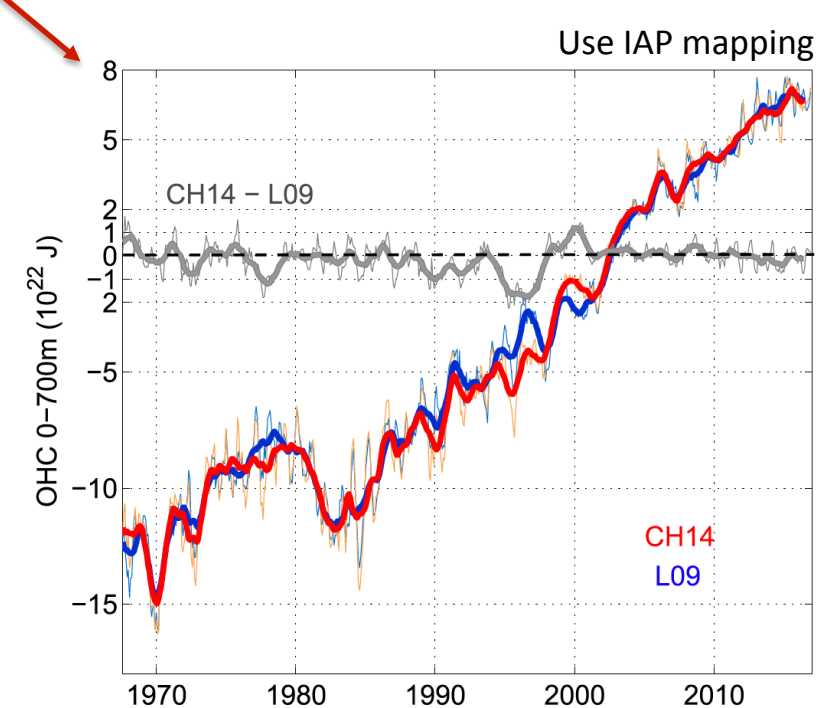
Improving OHC estimate: XBT

Correction schemes are thoroughly inter-compared (*Cheng et al. 2018, JAOT*)



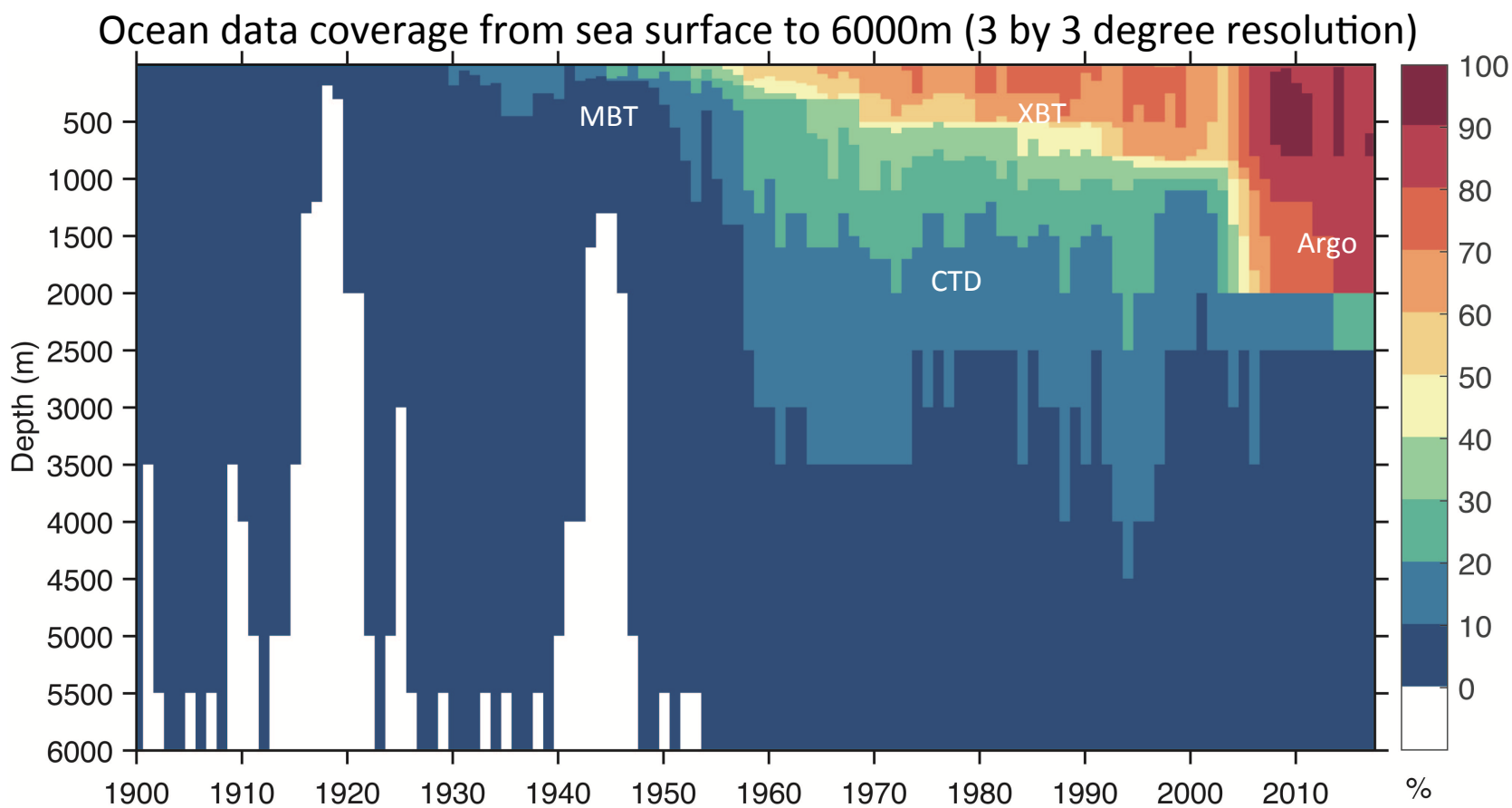
Use simple gridded average to get global mean OHC

Using the recommended method, or the best 2~3 methods could substantially reduce the XBT error.



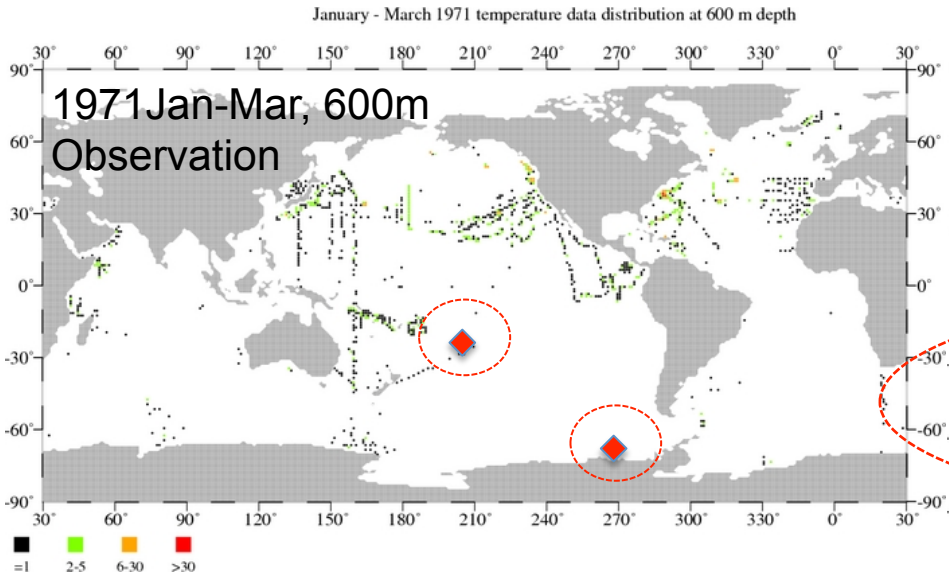
Improving OHC estimate: Mapping

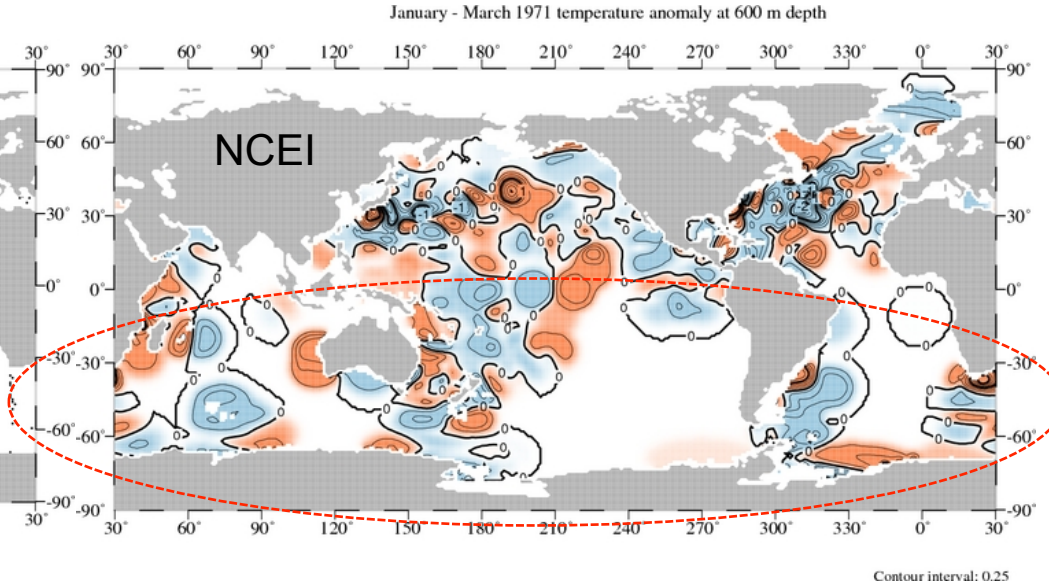
- **Mapping (Gap-filling): ocean data are not global**



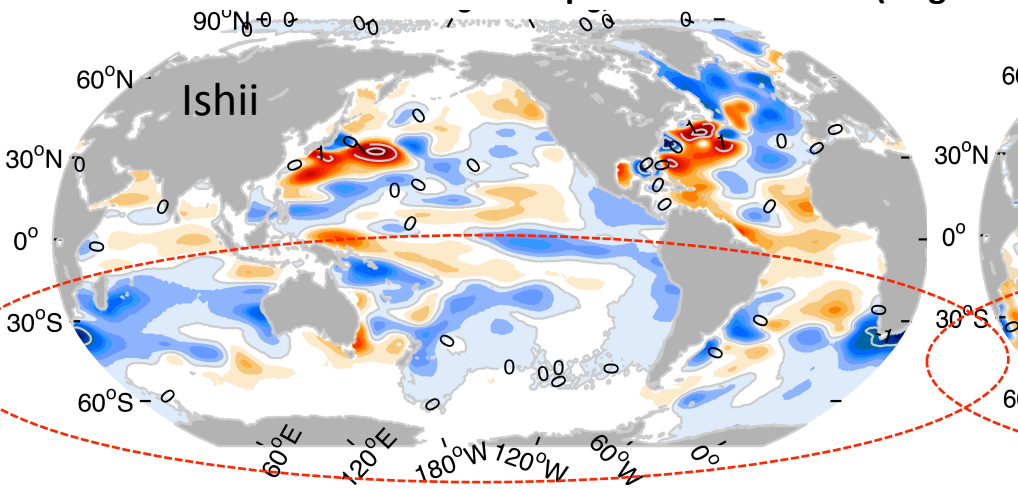
Improving OHC estimate: Mapping

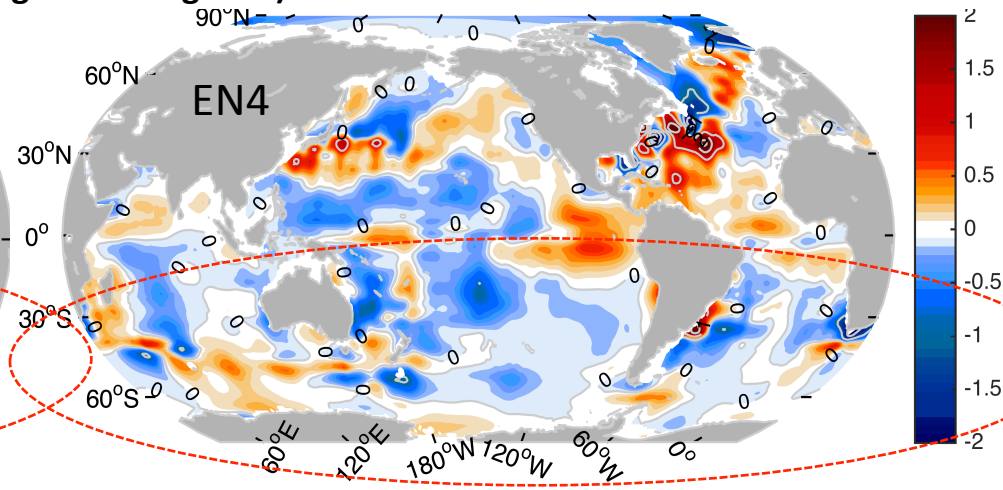
- **Conservative error** in traditional mapping method, leads to an underestimation of long-term warming trend





Temperature difference (Aug1992 – Aug1971) at 600m

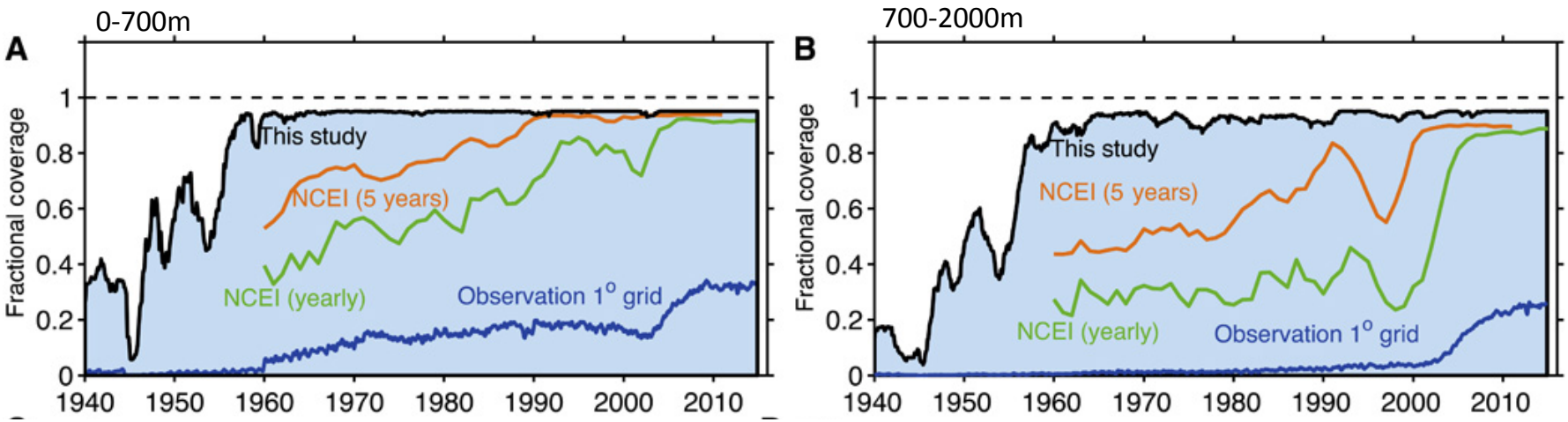




Improving OHC estimate: Mapping

A new mapping method (*Cheng&Zhu, 2016; Cheng et al. 2017*)

- **Larger localization radius (~25 degree)**
- **Better spatial covariance (CMIP5 models)**
- **EnOI framework**
- **Iterative runs (localization radius: 25-, 8-, 3- degree)**

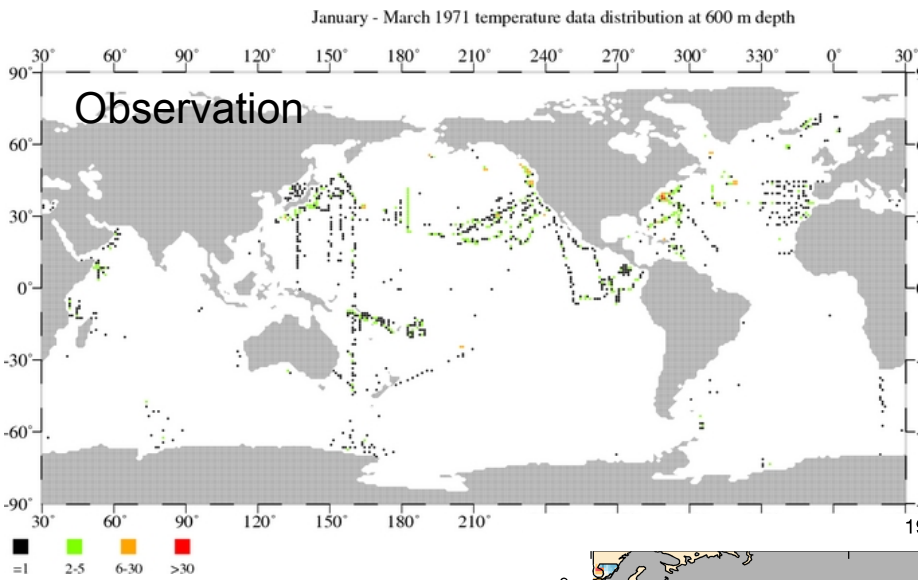


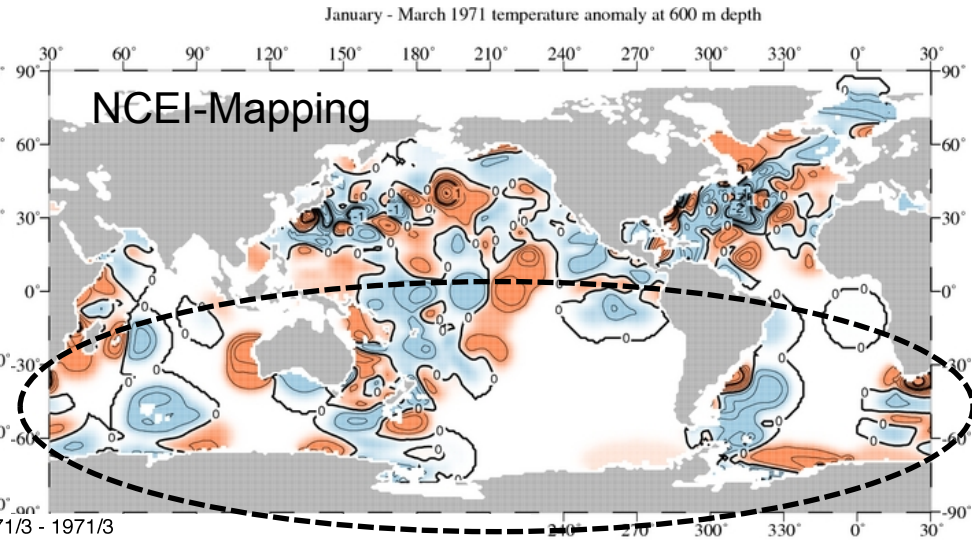
Fractional coverage of the mapping method used in IAP-mapping (Cheng et al. 2017)

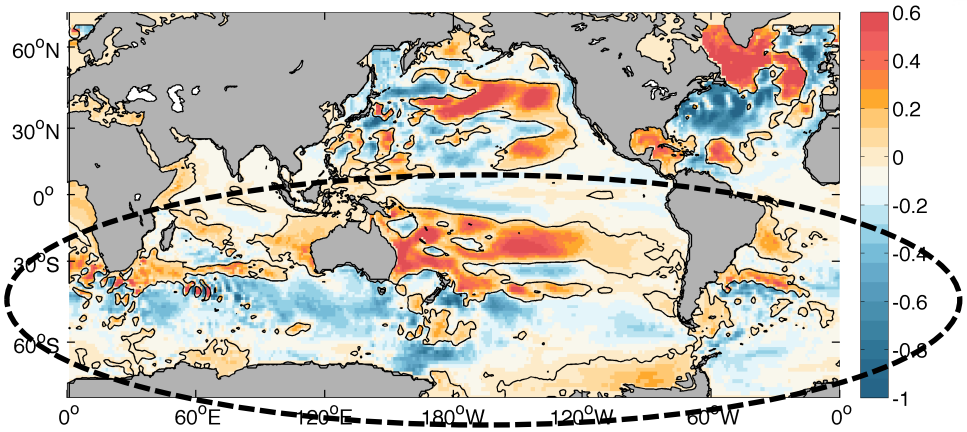
Improving OHC estimate: Mapping

A visual check:

Significant improvement by IAP-gap-filling method: looks more reasonable







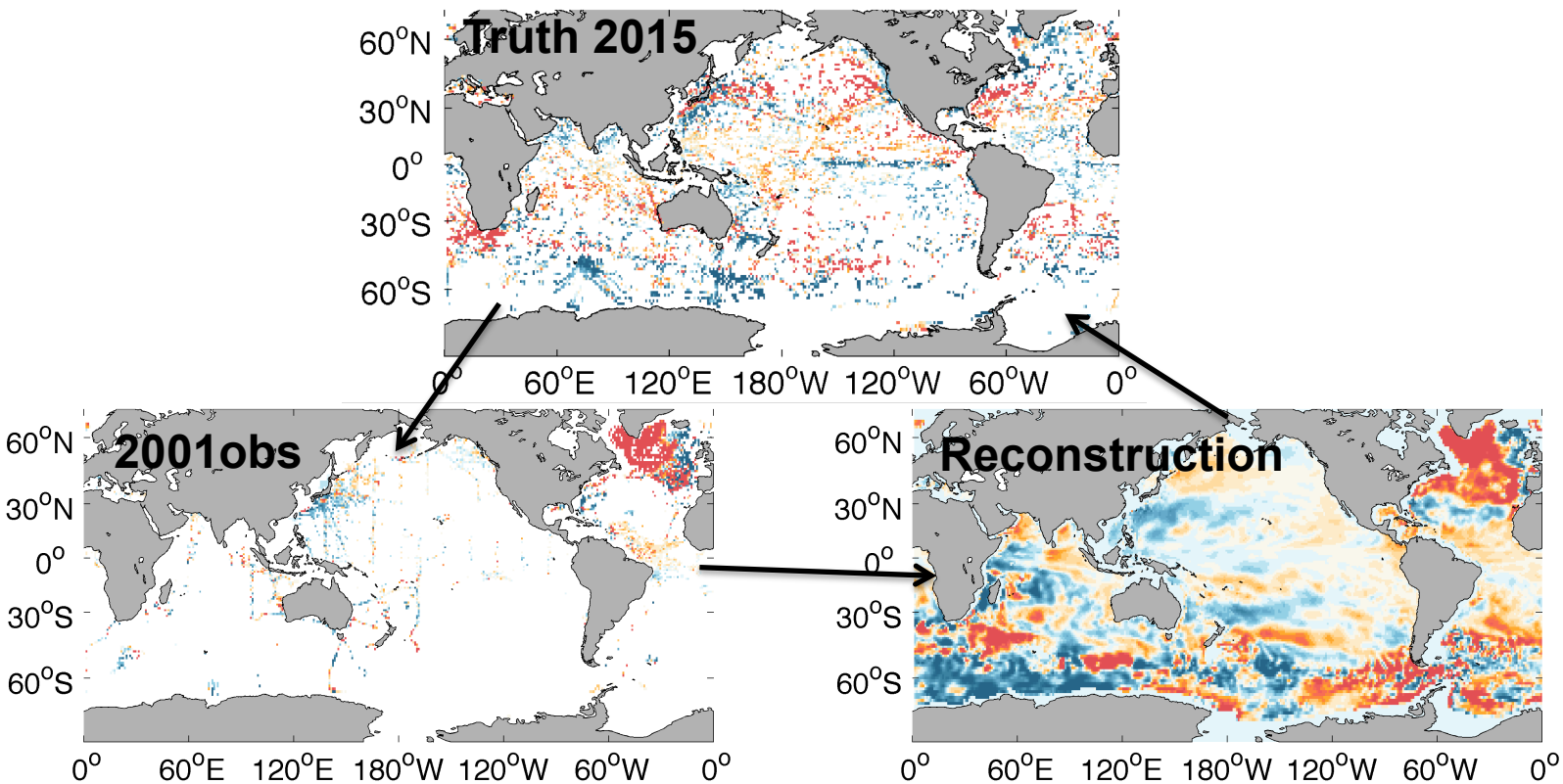
IAP mapping

Improving OHC estimate: Mapping

Evaluate the mapping method by a "Subsample test"

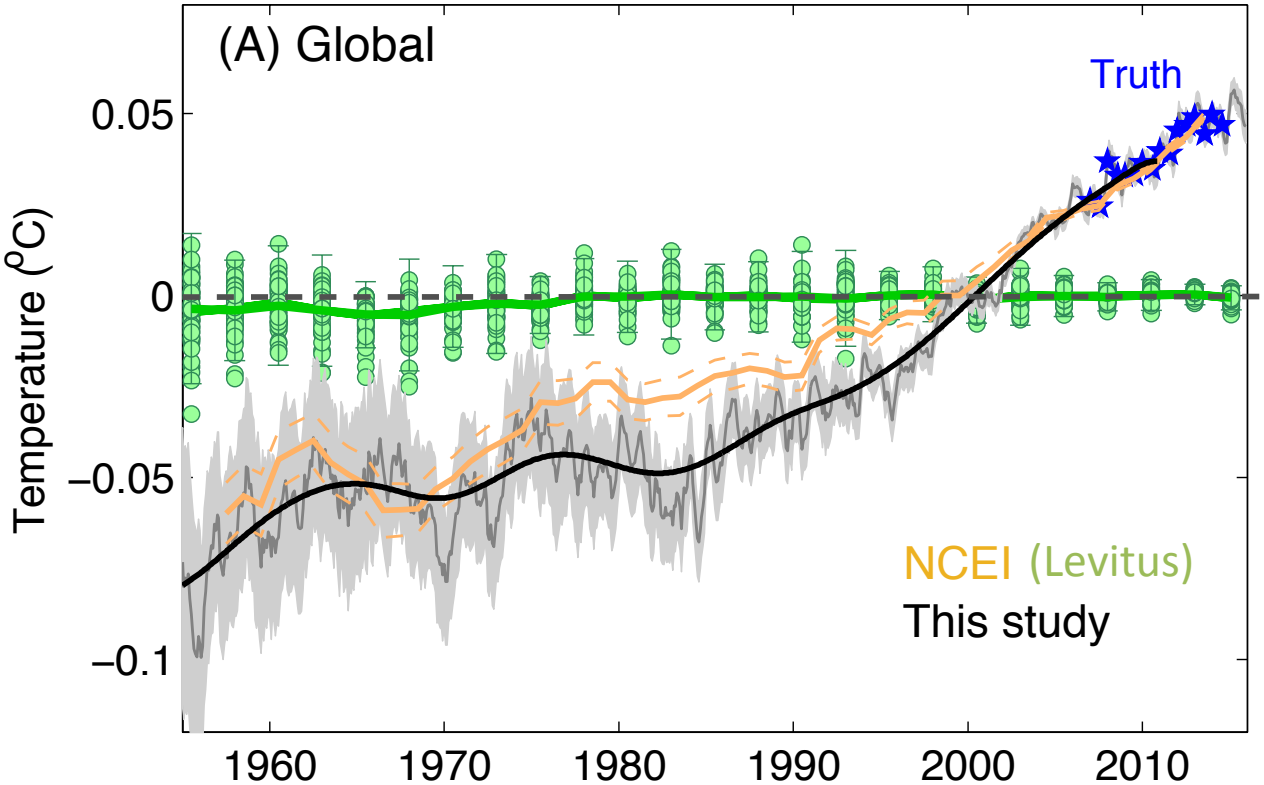
Sampling error = Reconstruction - Truth

Truth (full coverage): Argo data; Reanalysis data; High-resolution Model outputs



Mapping Evaluation

Global/0-2000m mean



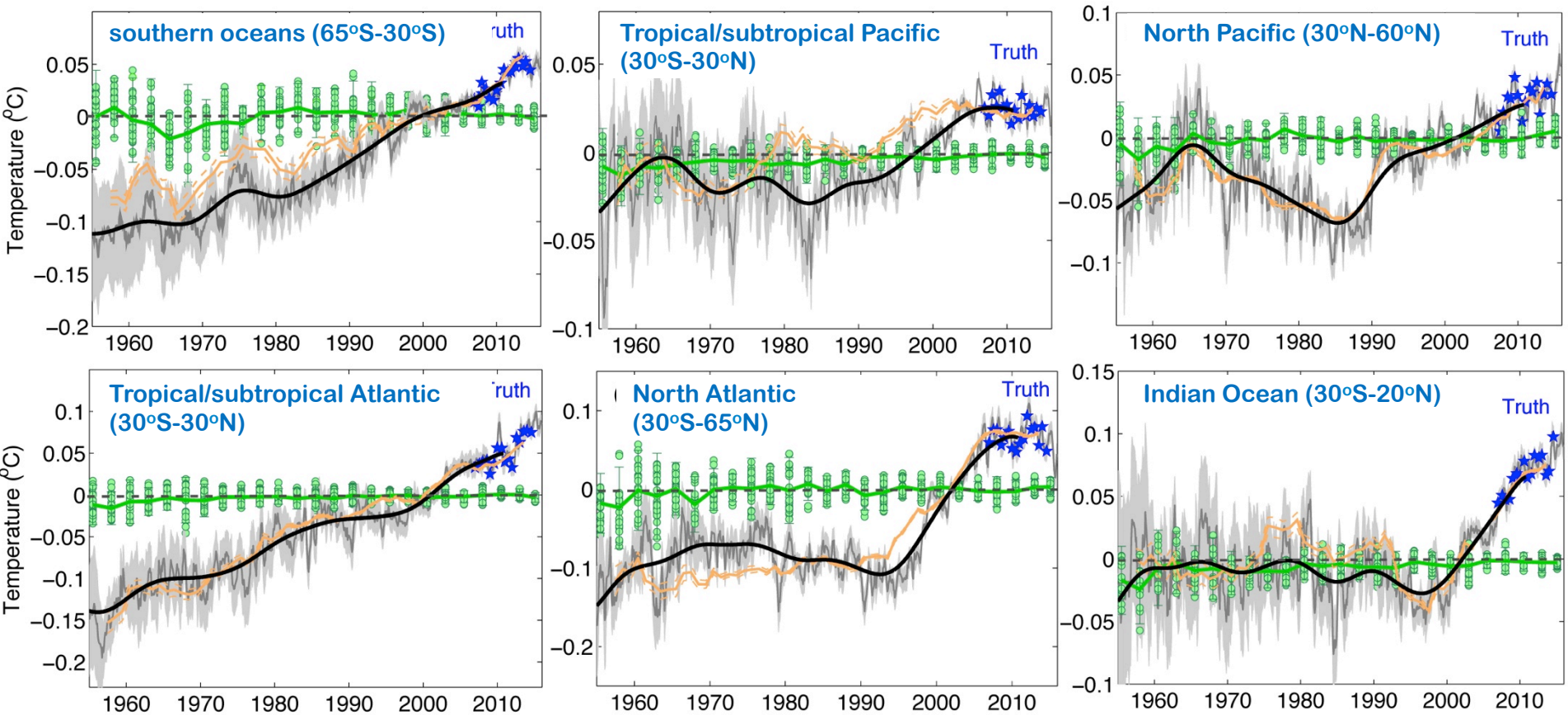
Reconstructed signals (0-2000m temperature time series)

Sampling error by using different truth fields

- Sampling error ~ **0°C** from late 1950s to 2014.
- Reconstruction of historical temperature change is **reliable** by using the new mapping

Mapping Evaluation

6 major ocean basins/0-2000m mean

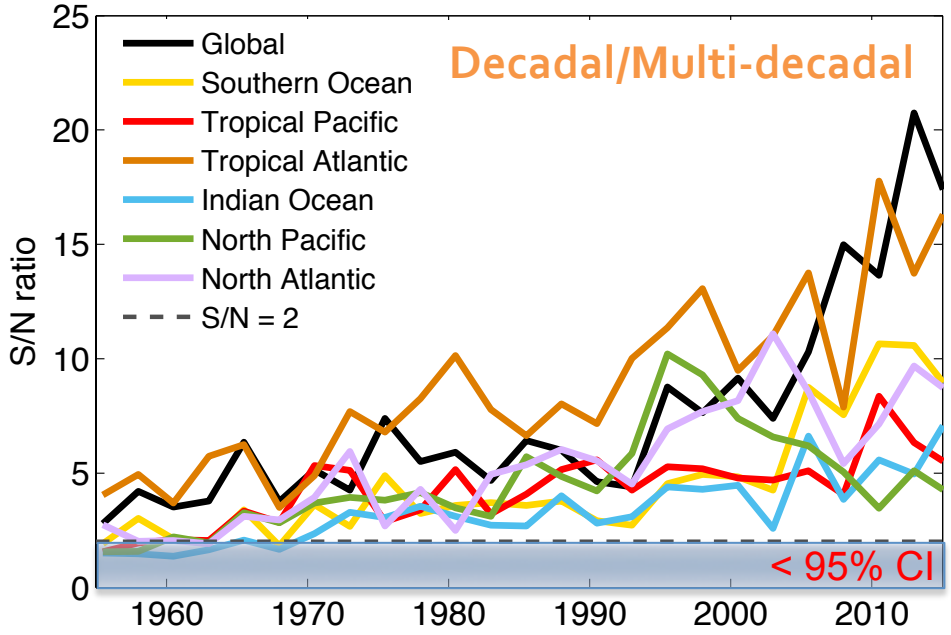


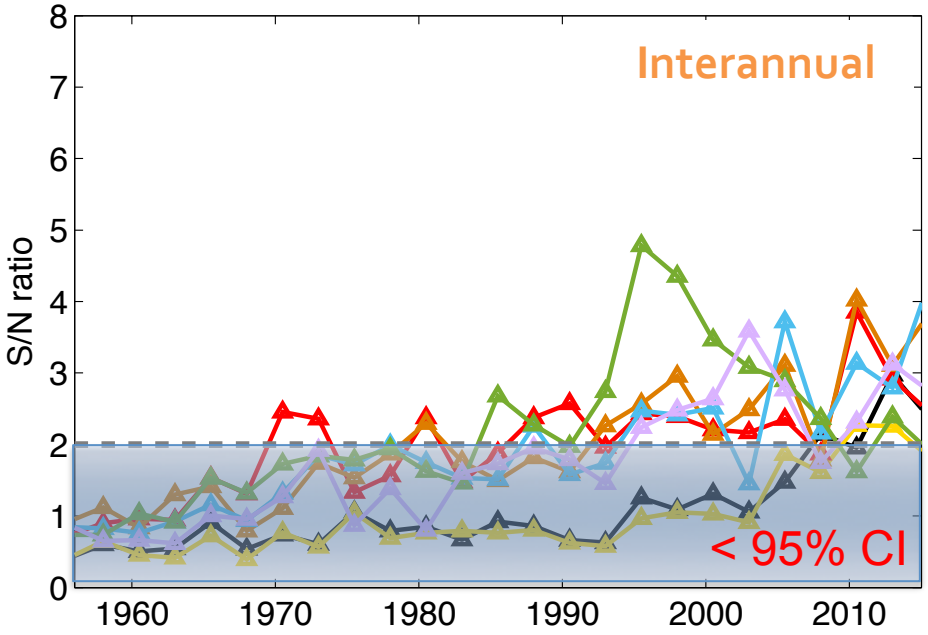
- Sampling error ~ 0°C from late 1950s to 2014.

Mapping Evaluation

Reliability of OHC estimate on different time scales

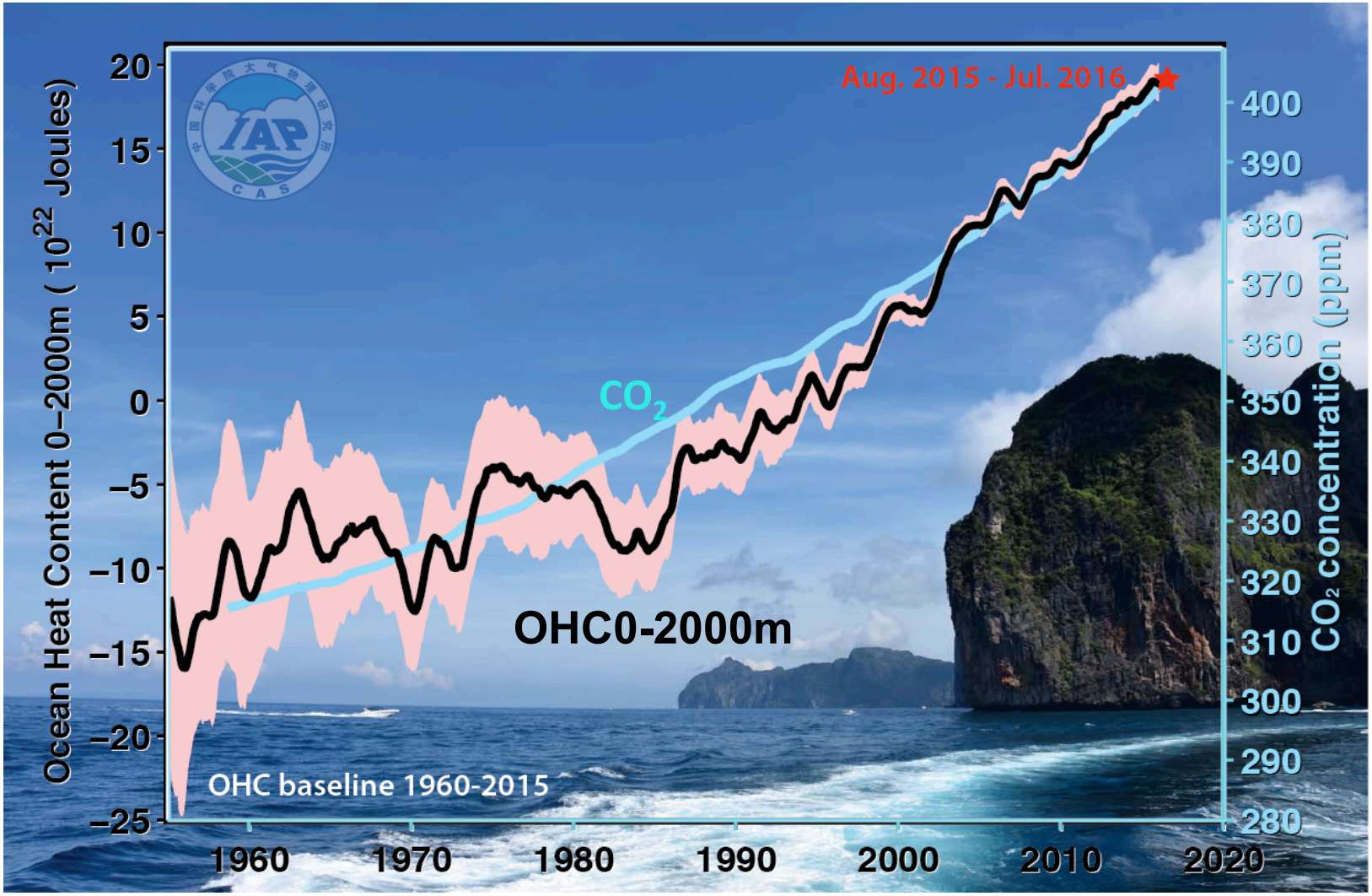
Signal/Noise ratio = Variance of temperature change / Sampling error





- The decadal/multi-decadal OHC change is reliable
- On inter-annual scale, the noise is comparable with signal before Argo era.

Improving OHC estimate

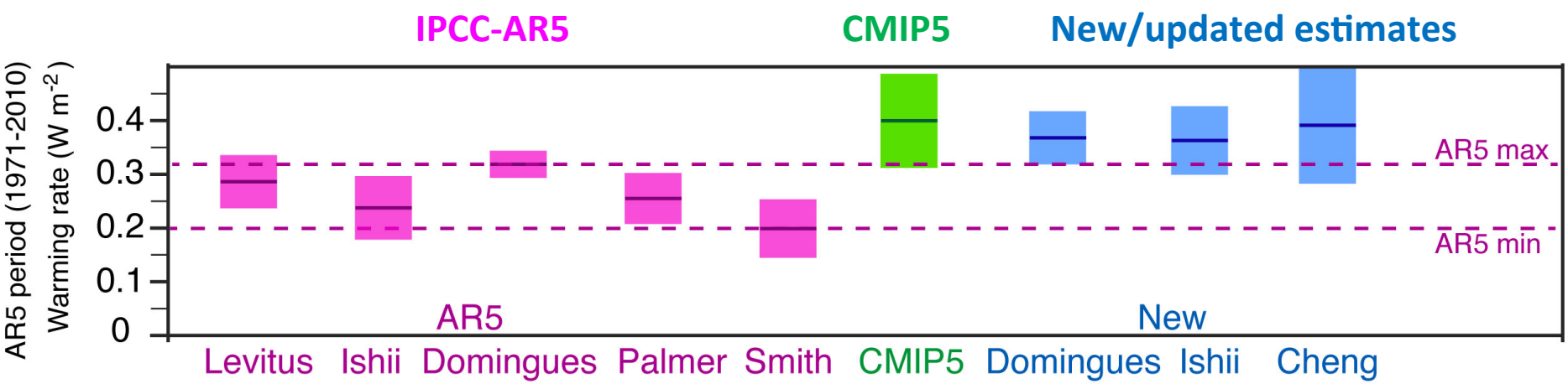


Cheng et al. 2018 *EOS*

Improving OHC estimate

Long-term ocean warming: quicker than IPCC-AR5

For the assessment period in IPCC-AR5: 1971-2010

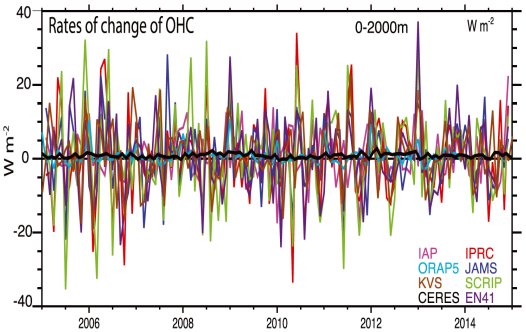


Ocean heat content

Ocean heat content: a key measure of Earth's energy imbalance

Ocean heat content

- Quasi-annual
- Inter-annual (i.e. ENSO)
- Decadal (i.e. PDO, AMO)
- Long-term (i.e anthropogenic forced)



Trenberth et al. 2016

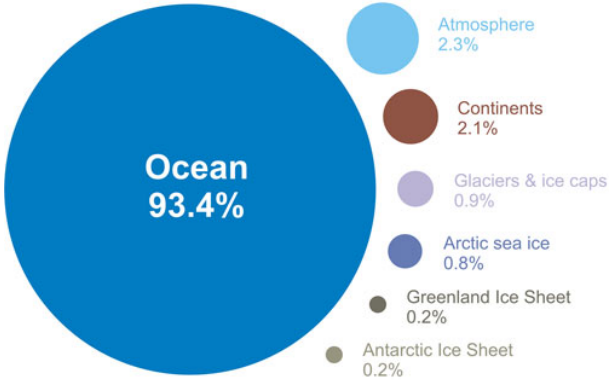
Not reliable

Some confusions

- A paper to be submitted

Less known

Where is global warming going?

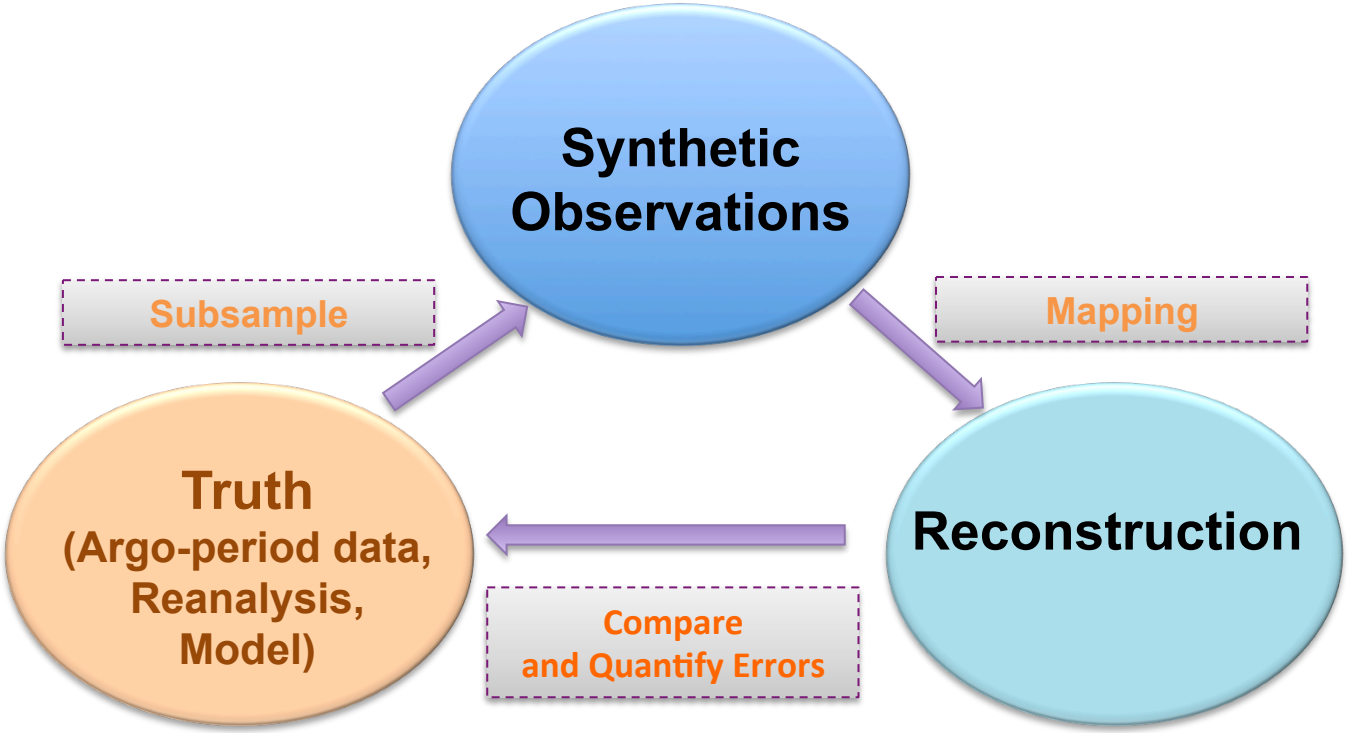


Larger rate of change than AR5

An ongoing effort

Mapping

- How reliable is OHC on different temporal/spatial scales?
- Can we further identify problems in mapping and then improve?

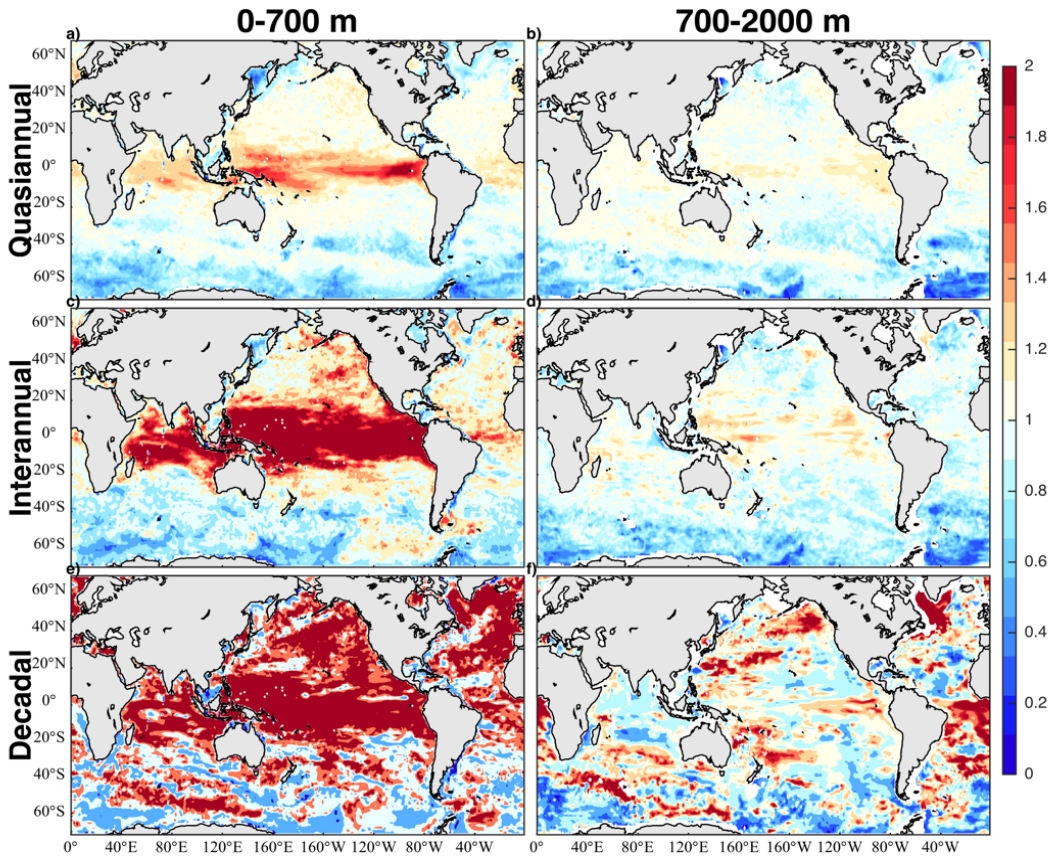


An ongoing effort

Now we use **1/4° reanalyses (C-GLORSv5)** to uncertainty the errors (Subsample test)

Signal-to-noise ratio of OHCT on three different time scales

1980-2015



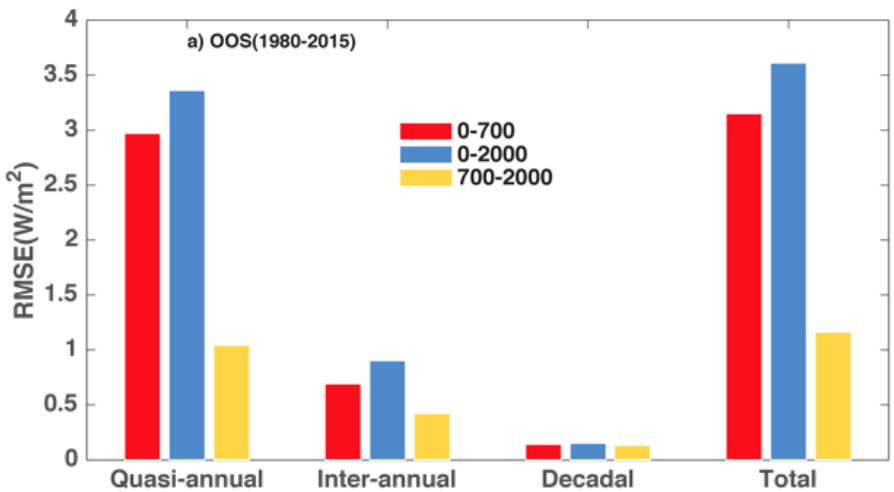
Wang et al. submitted

Quasi-annual: <18 month
Inter-annual: 18 month ~ 8 years
Decadal: >8 years

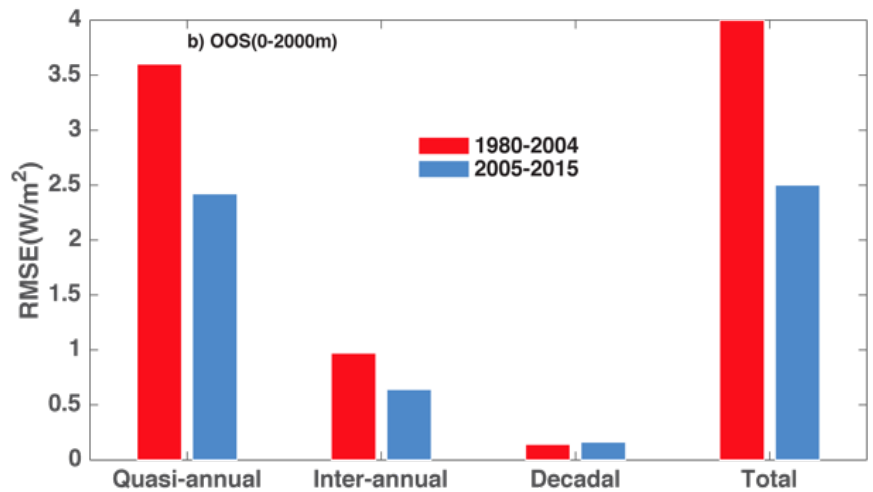
An ongoing effort

Now we use **1/4° reanalyses (C-GLORSv5)** to uncertainty the errors (Subsample test)

RMSE for OHCT on three different time scales



RMSE for OHCT before and after 2005



Wang et al. submitted

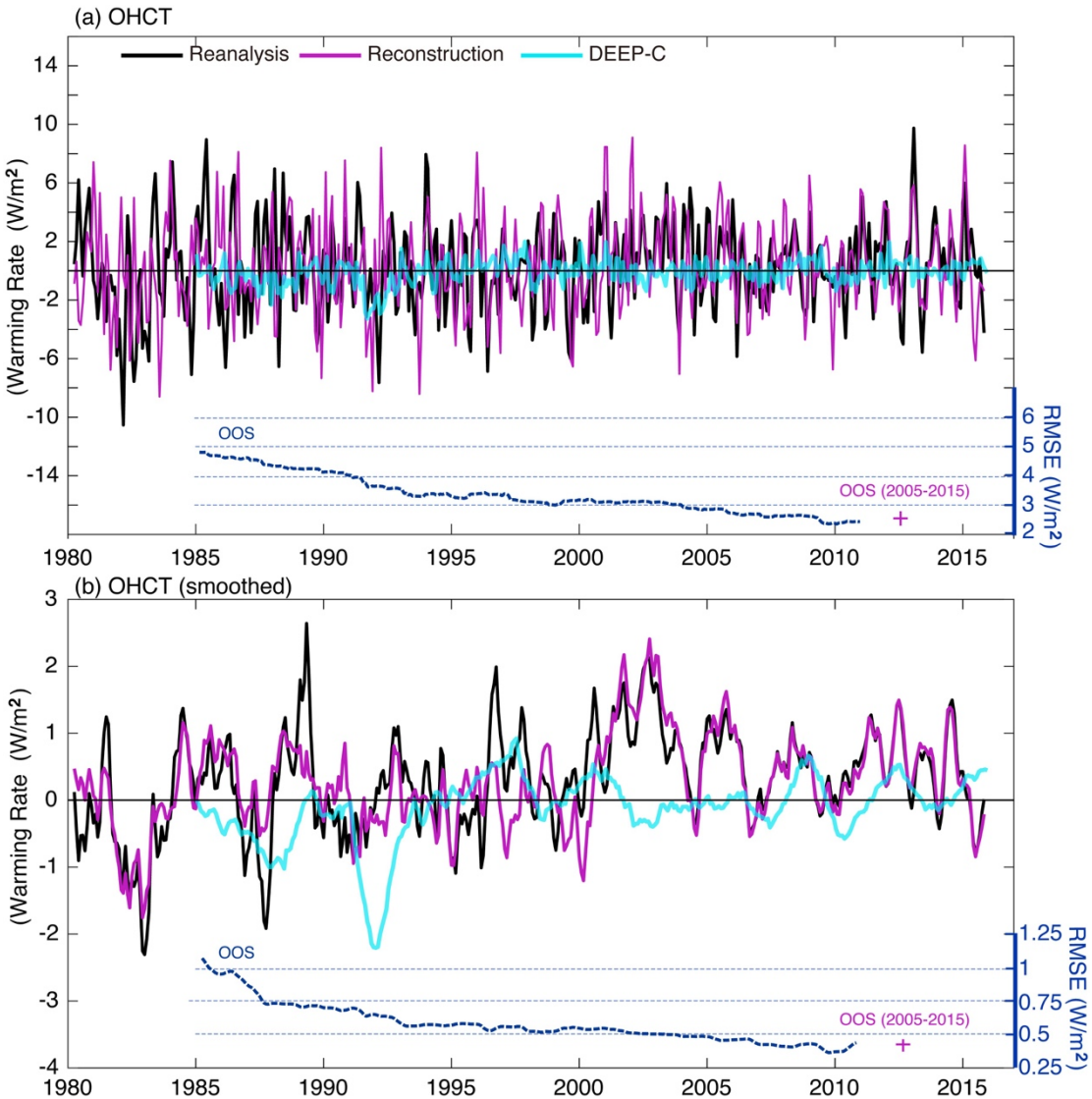
Quasi-annual: <18 month
Inter-annual: 18 month ~ 8 years
Decadal: >8 years

Thanks !

IAP data, OHC : http://159.226.119.60/cheng/

An ongoing effort

Now we use **1/4° reanalyses (C-GLORSv5)** to uncertainty the errors (Subsample test)

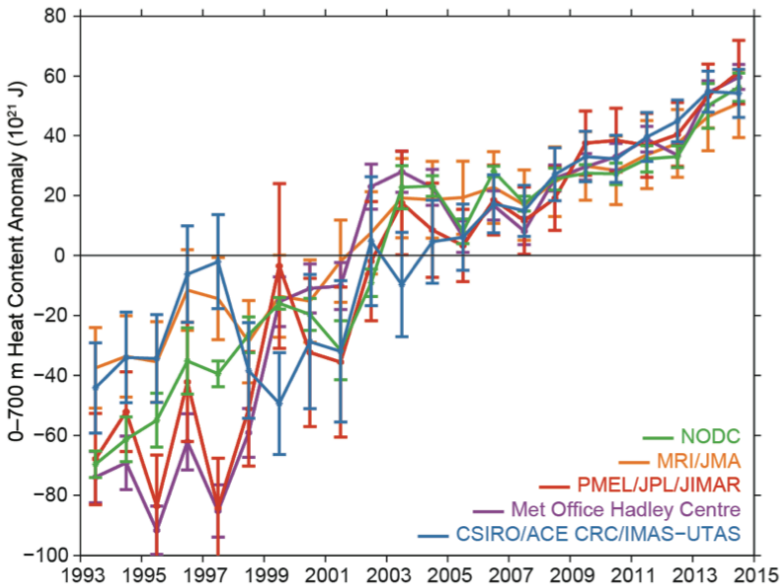


- OHCT: Larger variability for both reanalysis and reconstruction than net EEI at TOA.
- Decreasing error with time
- Much smaller error after smoothing (18-month running mean)

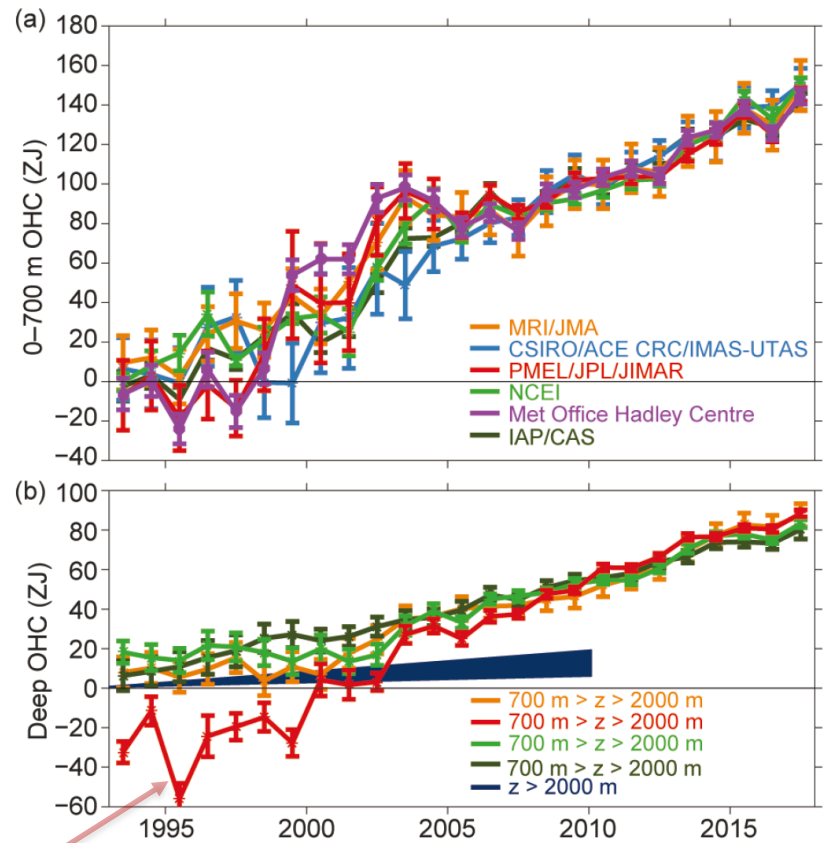
Wang et al. submitted

Improving OHC estimate

Long-term ocean warming: more consistency among groups



BAMS state-of-climate 2014

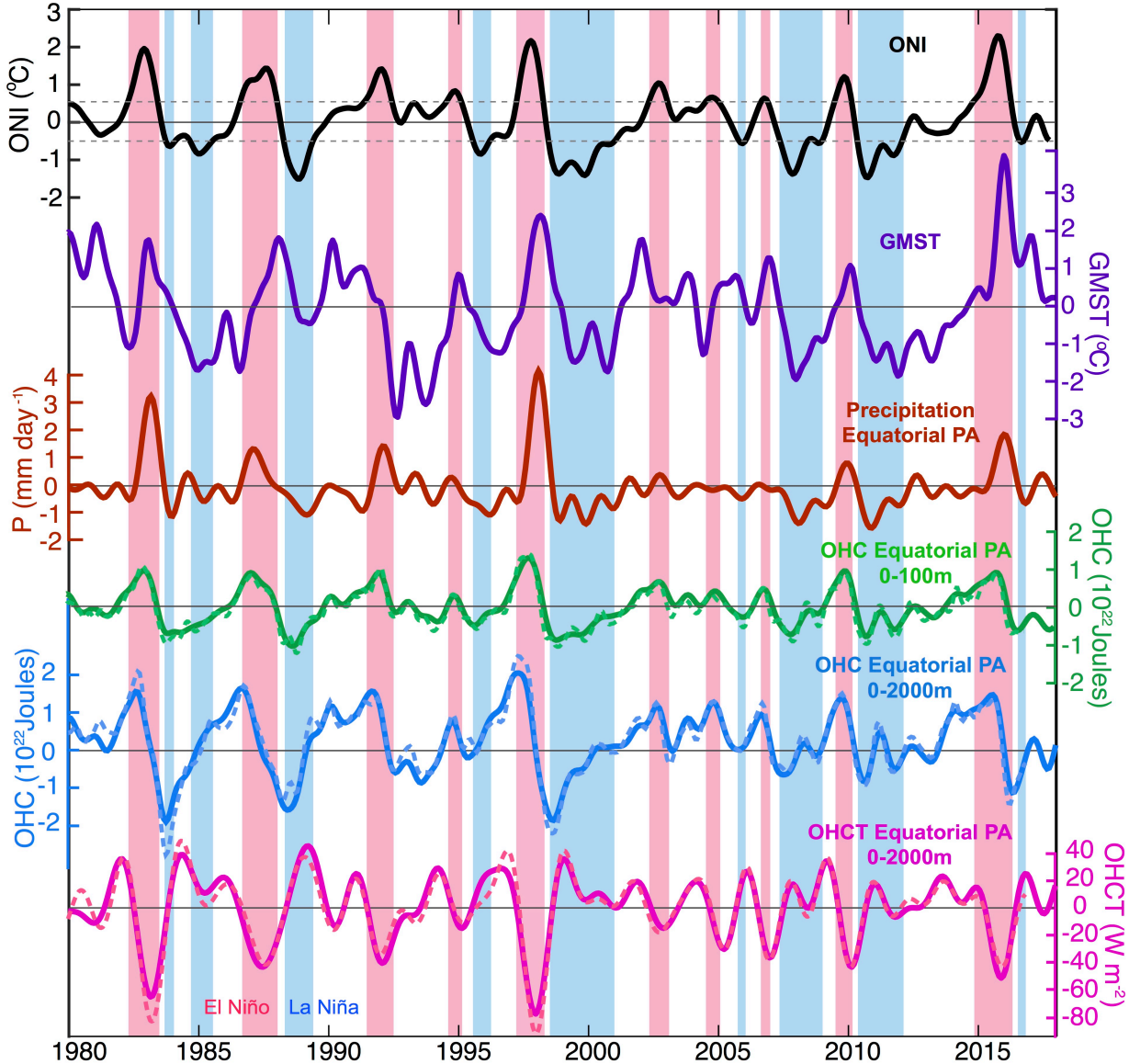


BAMS state-of-climate 2017

Simple gridded average, less stable

OHC variability

Inter-annual scale variability (ENSO, 5°S~5°N)



ONI

GMST

Precipitation

OHC0-100m

OHC0-2000m

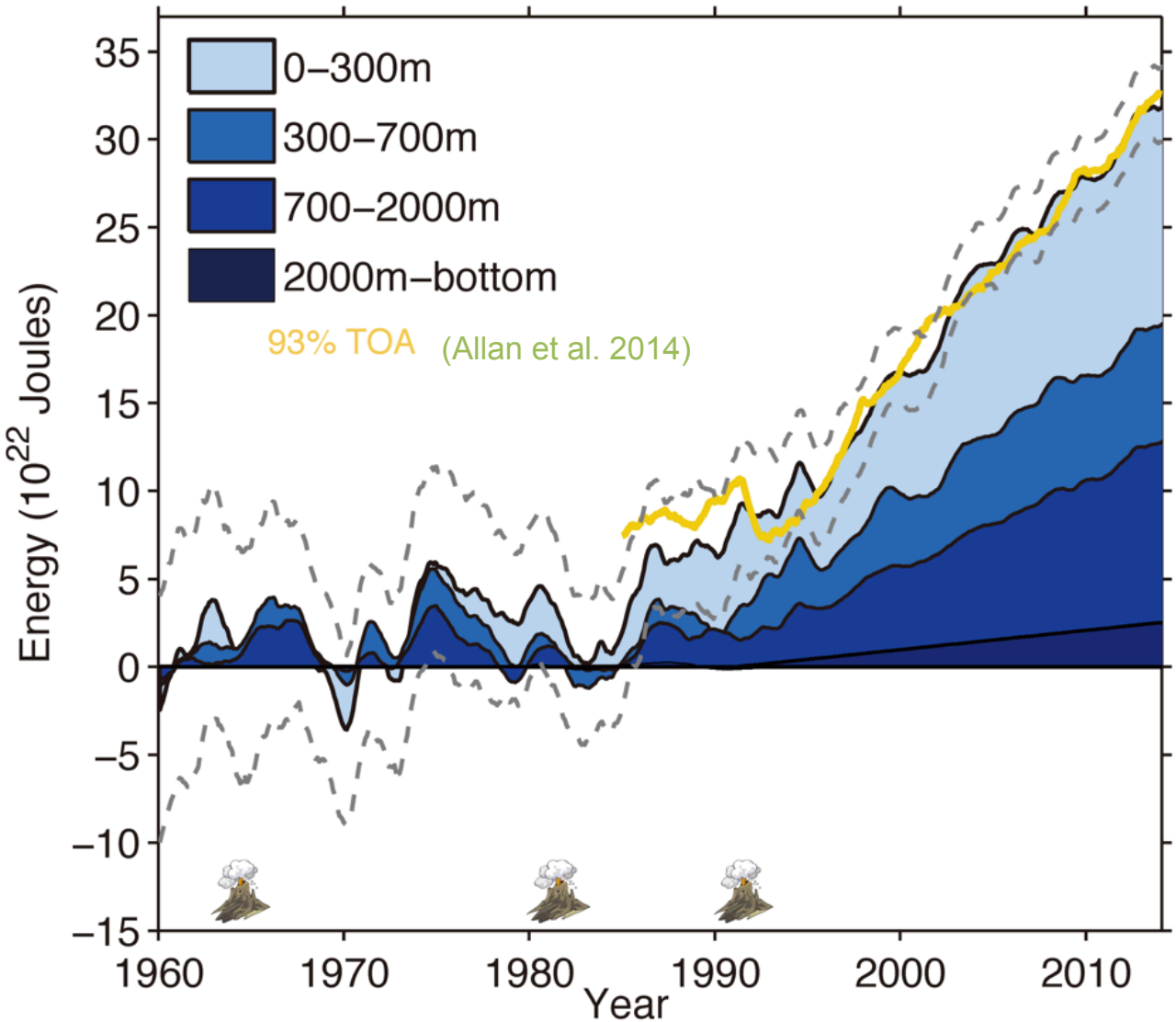
OHCT 0-2000m

Dashed: ORAS5

Solid: observation

Ocean energy budget

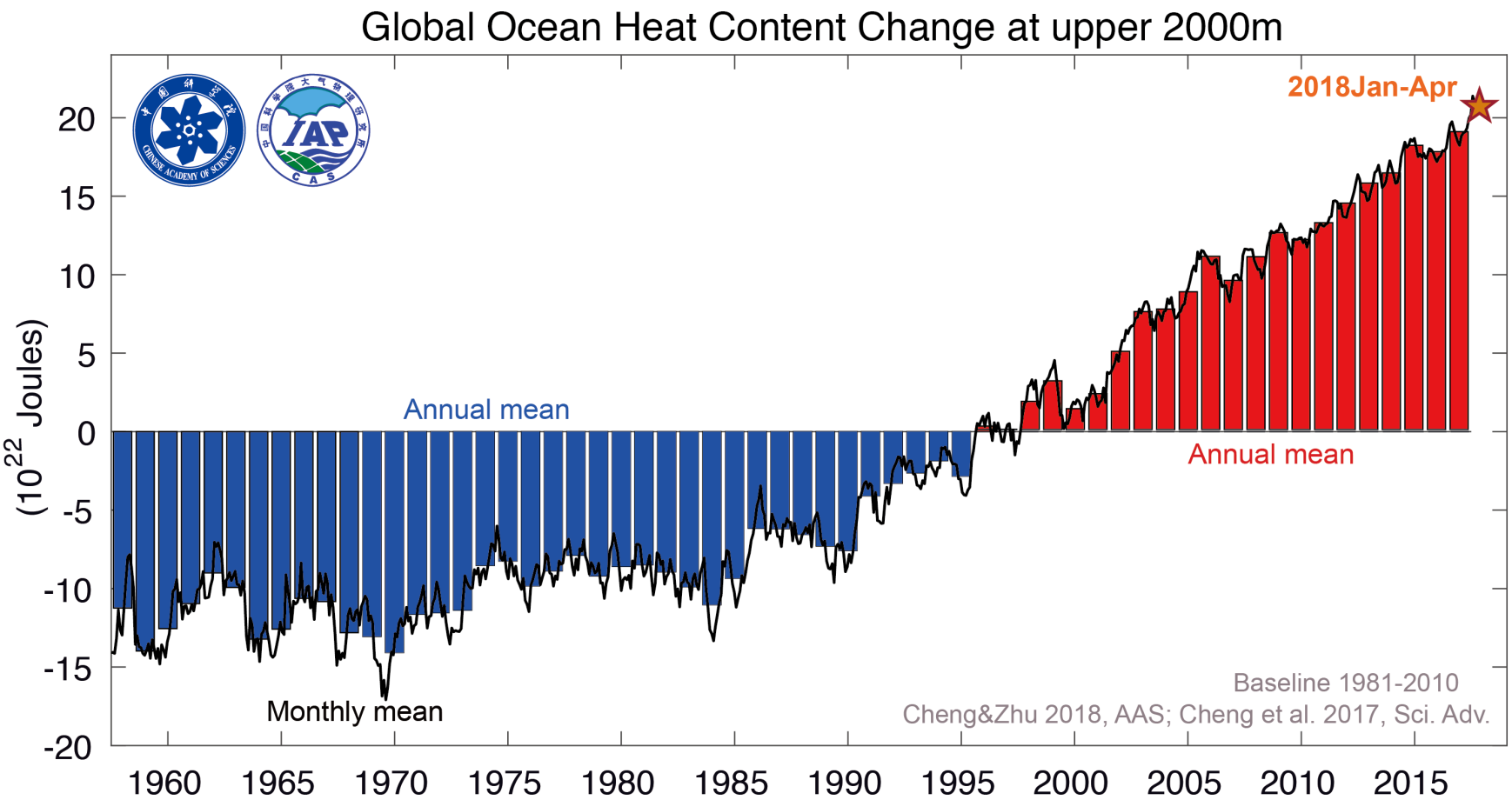
Ocean energy budget (referred to 1960)



- **Consistency** between observational OHC and TOA observations.
- **No** missing heat: Improved OHC estimate
- **Robust** global warming

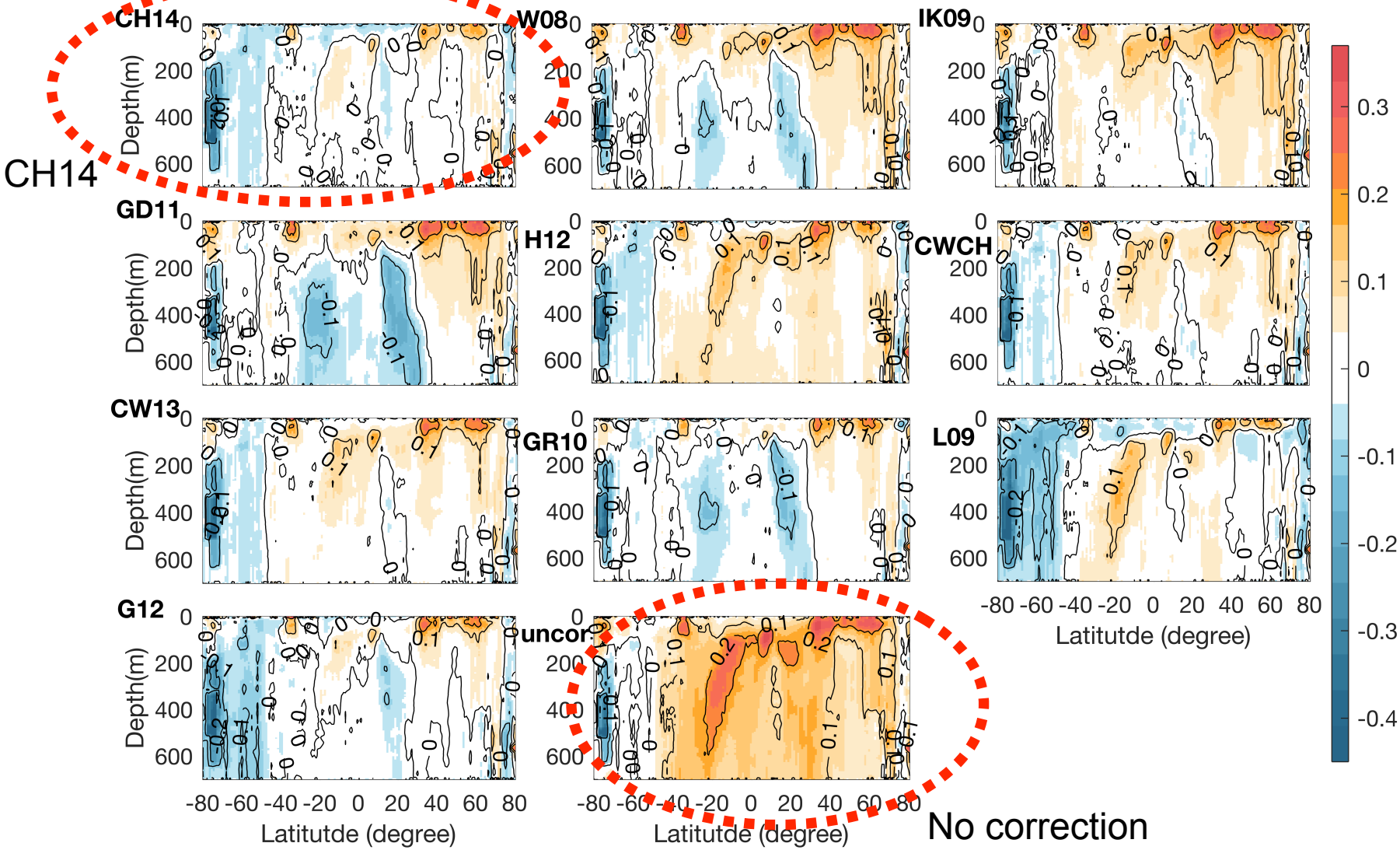
Global ocean heat content

2017 was the warmest year on record for global ocean



XBT bias

- Reduce the geographical variation of XBT bias (CH14)

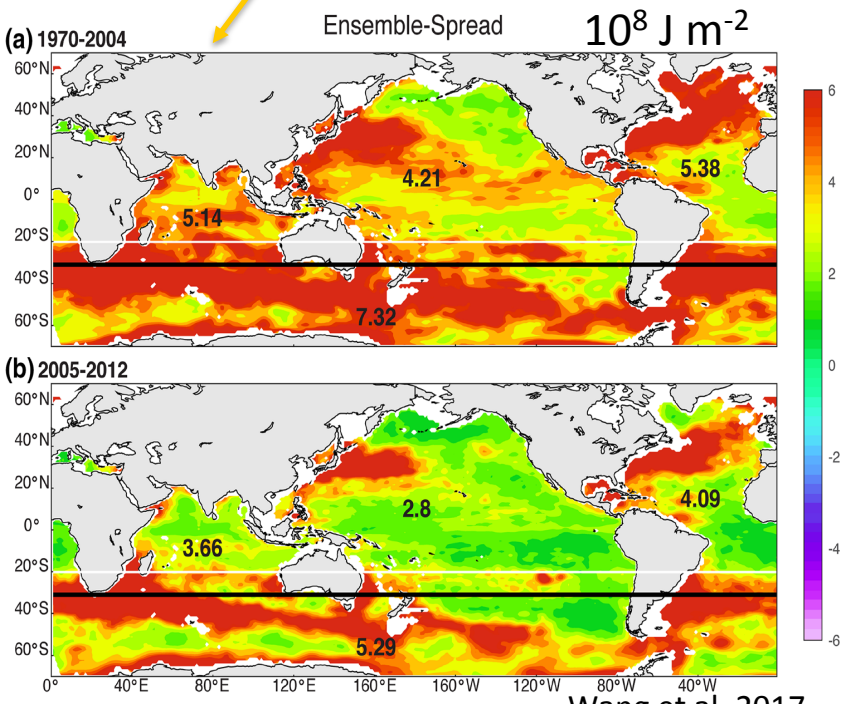
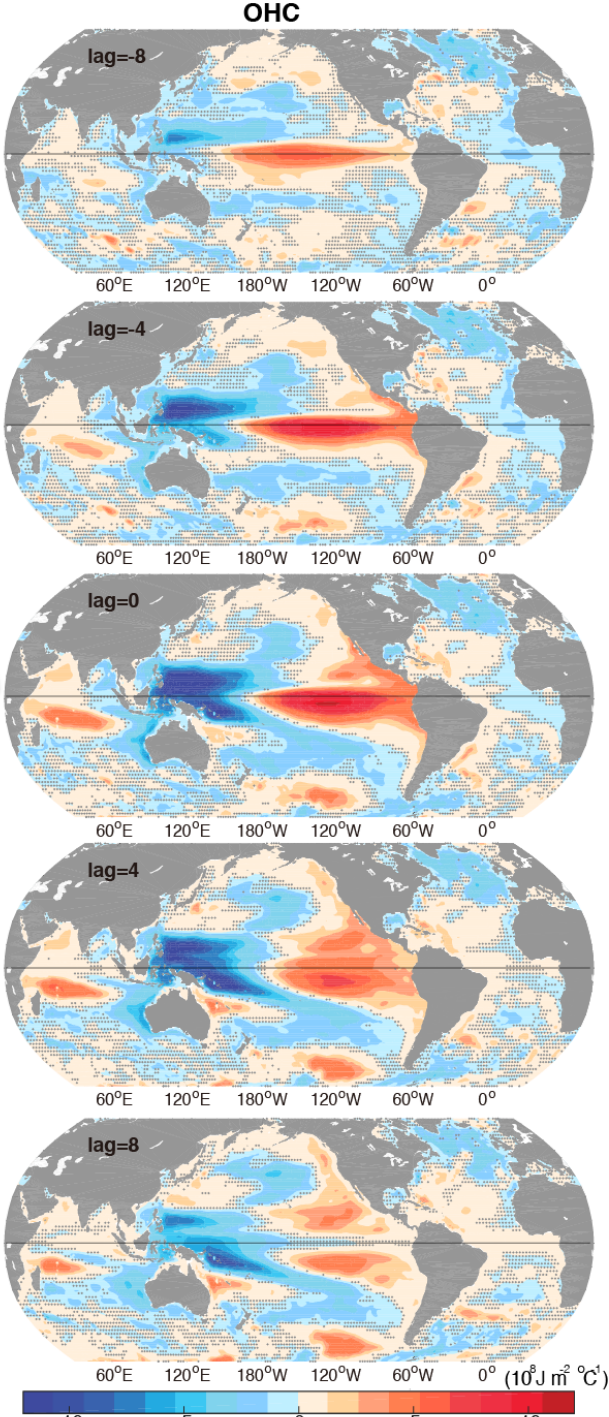


OHC variability

Inter-annual scale variability: regional e.g. ENSO

Signal
(OHC regressed onto ONI)

Noise
(Spread among three observational datasets)



Wang et al. 2017