Deeper Ocean Remote Sensing ***and*** *Deeper Ocean Response to Climate "Hiatus"*

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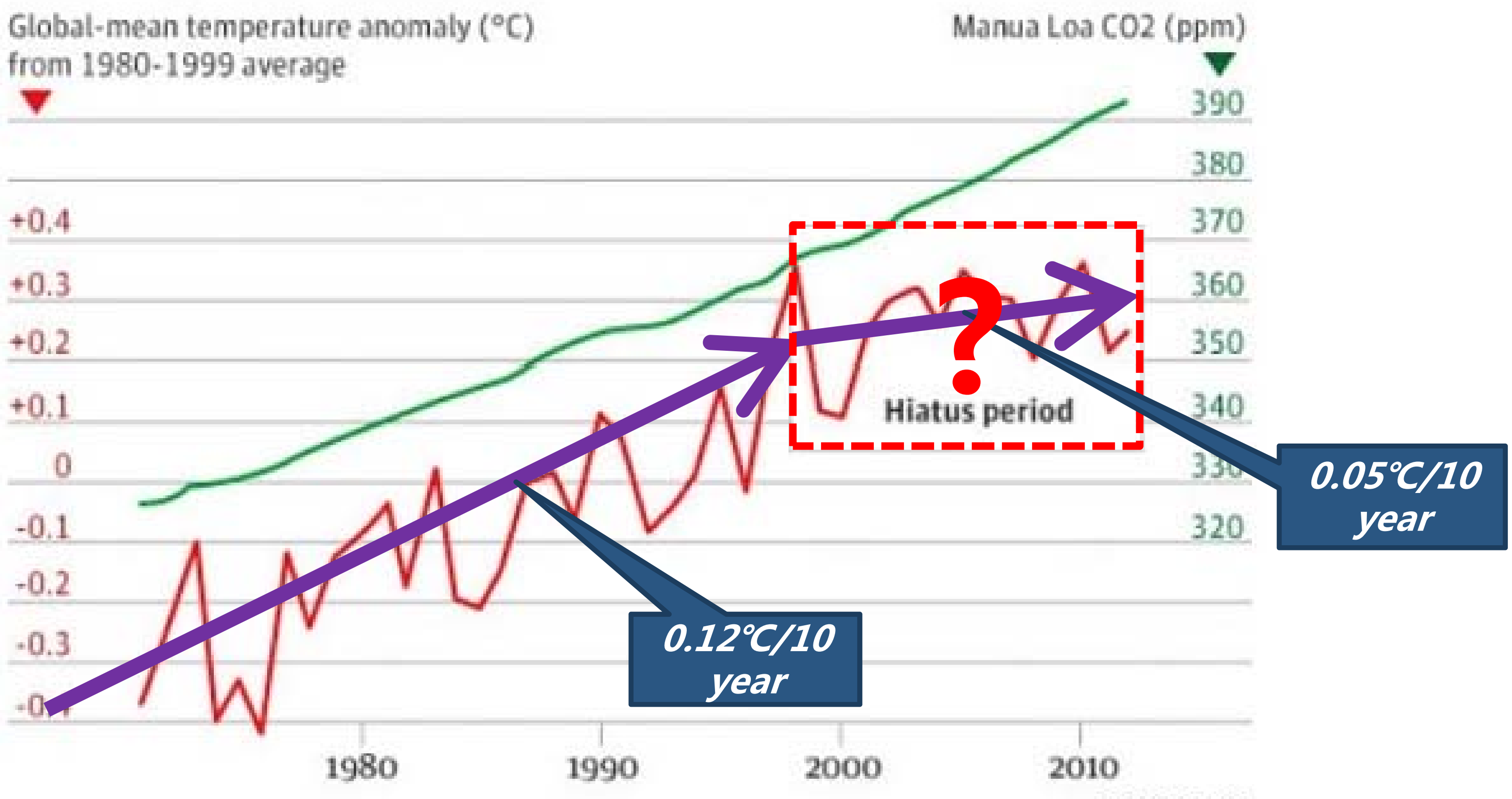
Climate (Global Warming) Hiatus

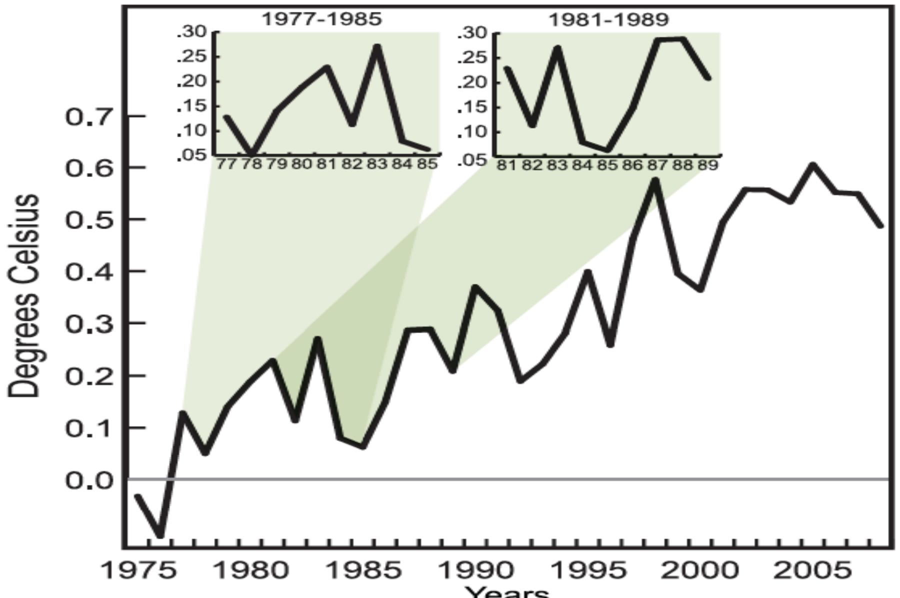


Mechanism? Many discussions, but still not certain yet.

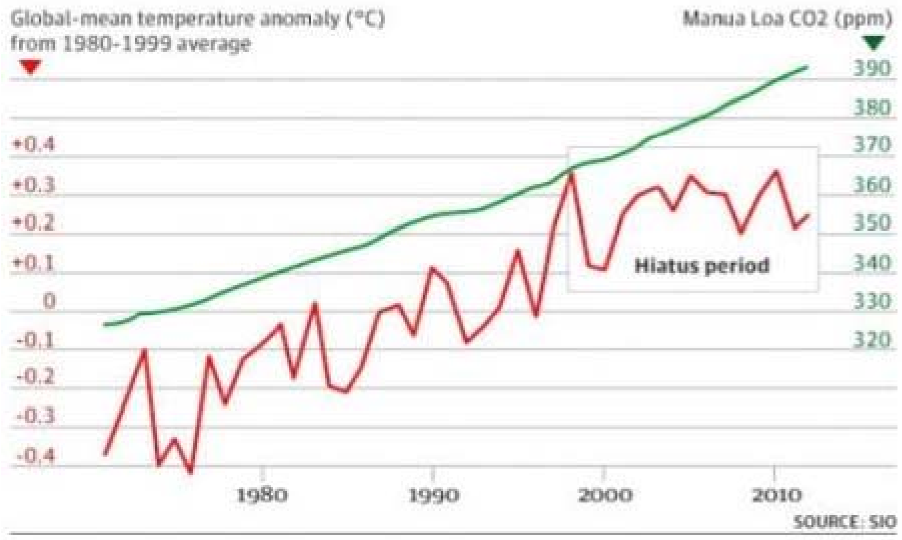
(Kosaka & Xie, 2013, Nature; IPCC, 2013)

Motivation One: Climate Hiatus/Deeper Warming

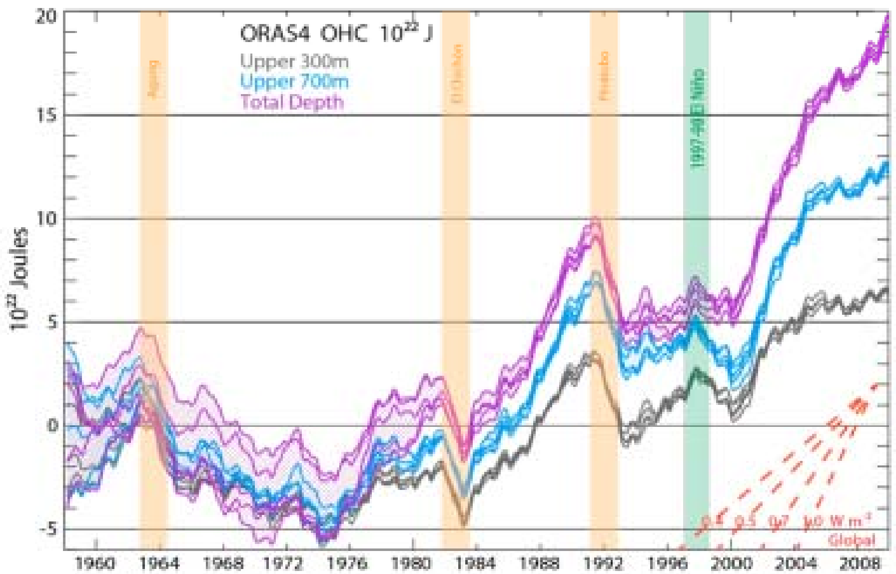
Meehl et al., 2011

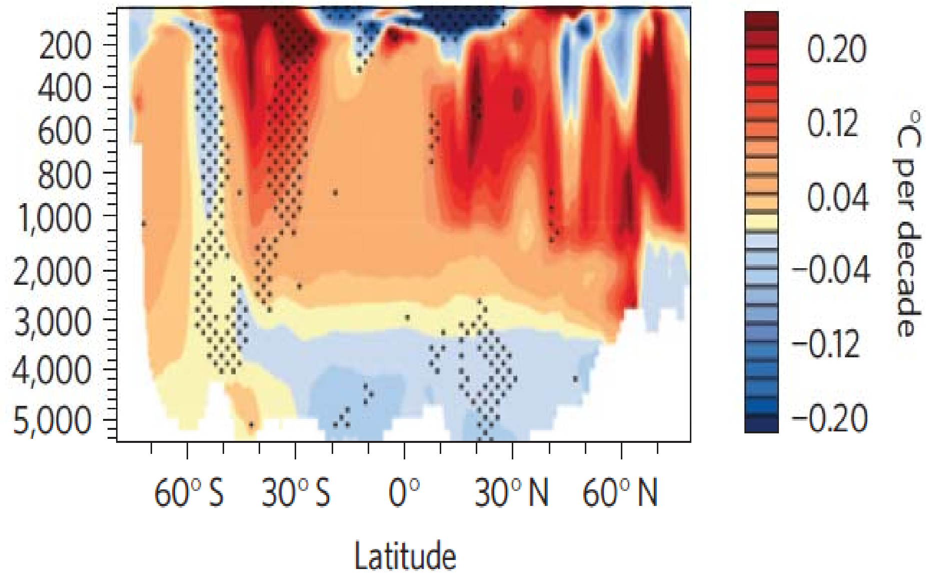


Easterling and Wehner, 2009

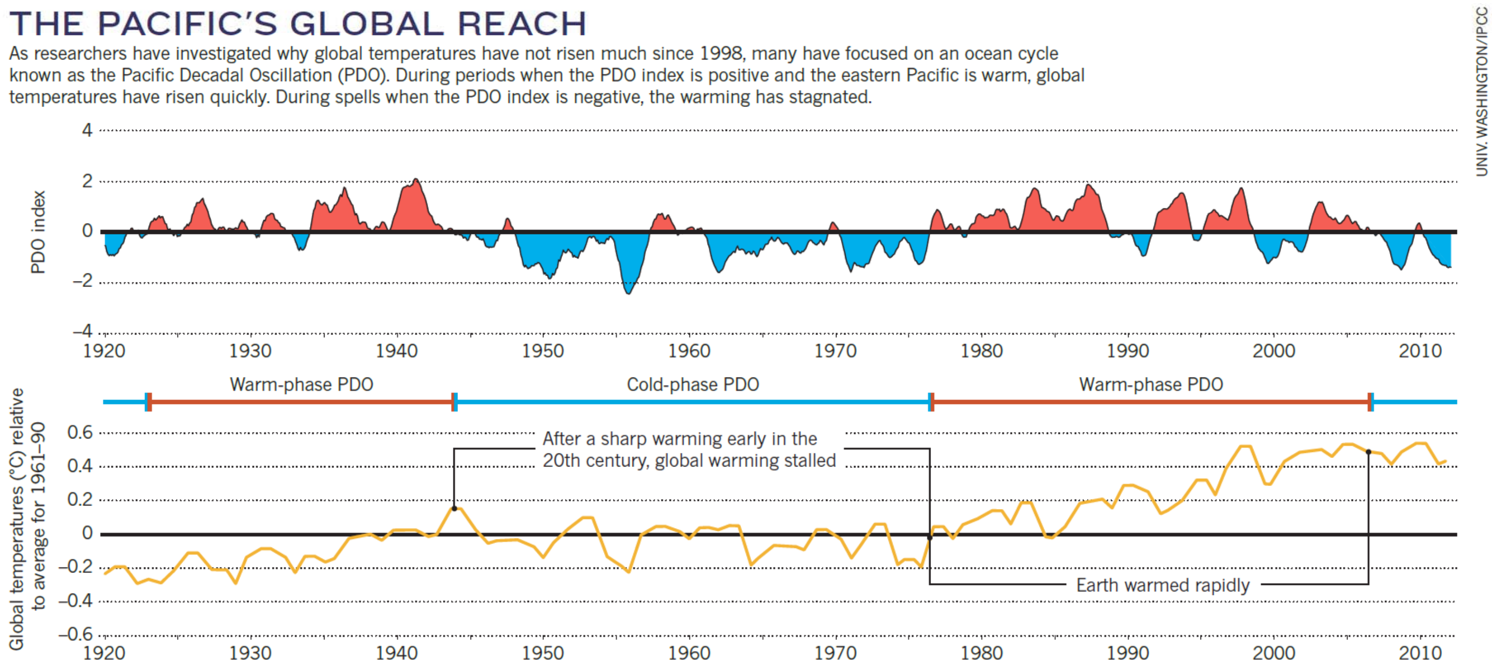


Global temperature rise Photograph: Guardian





PDO and hiatus

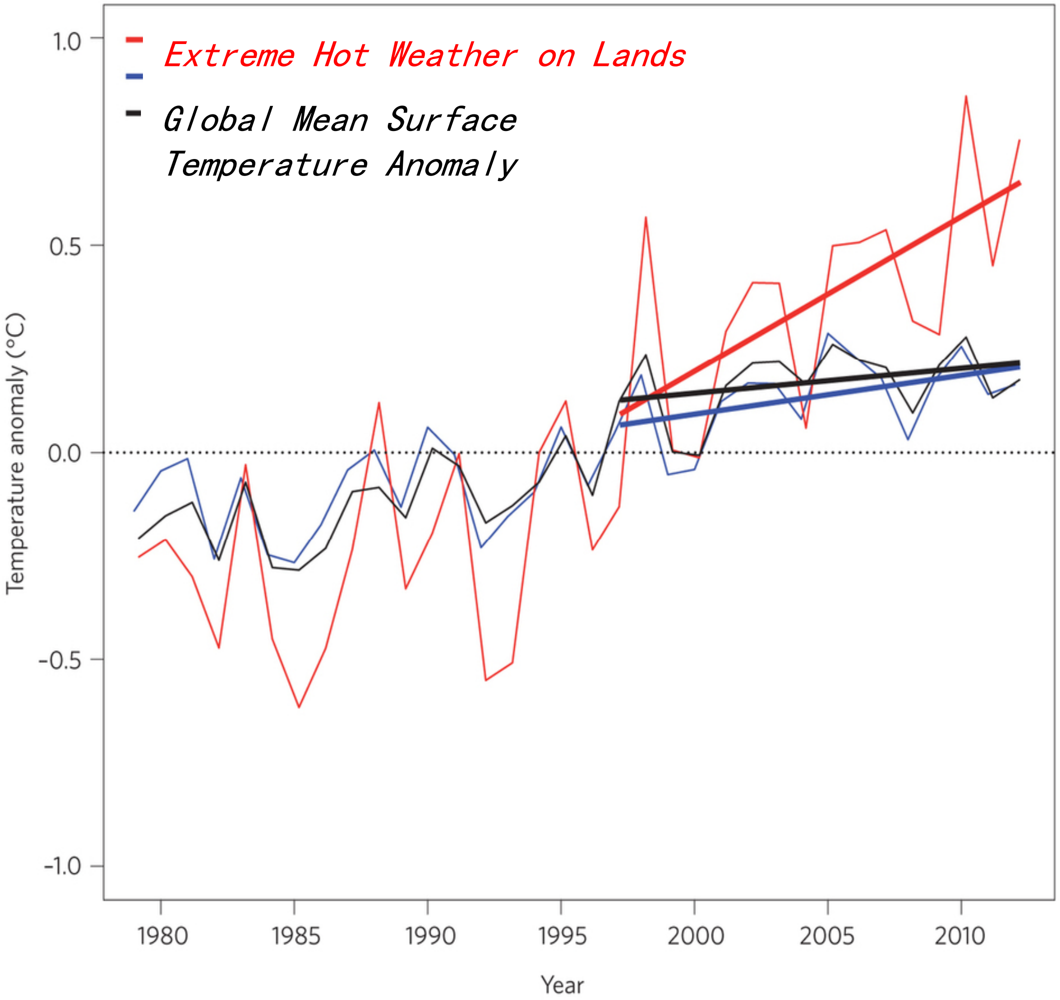


Trenberth & Fasullo, 2013

Is the hiatus real?

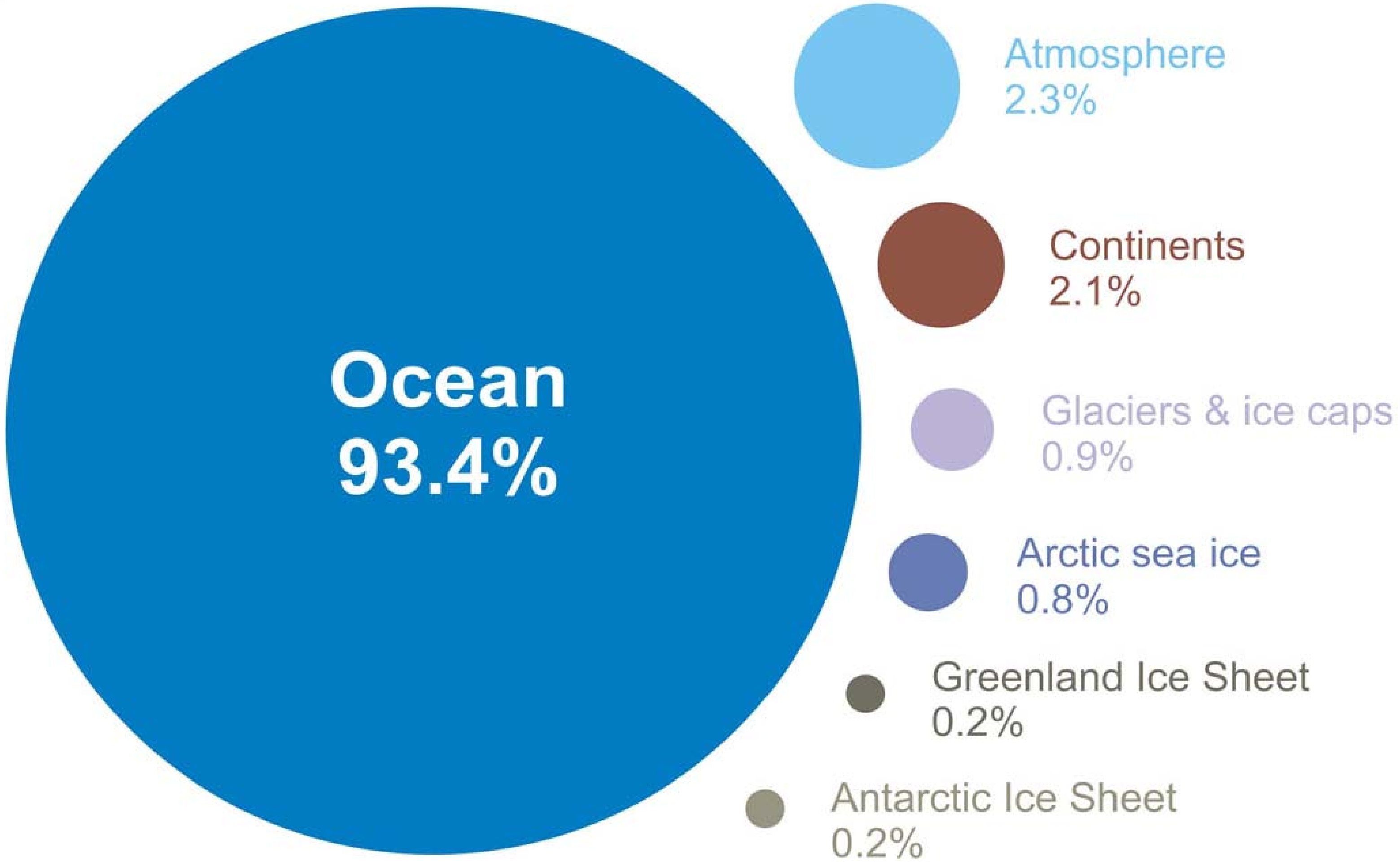
- A study found that by including polar region in the global mean temperature trend estimation, the trend will increase (Cowtan and Way, 2014), however, the global mean temperature trend after 2000 is still not as fast and steep as in the 1980s and 1990s.
- Trend estimation on the land surface temperature only (e.g. Ji et al. 2014) did not show hiatus feature, so the ocean may play an even larger role during the hiatus period.
- Atlantic Multi-decadal Oscillation (AMO) (e.g., Tung and Zhou, 2013), and changes in ocean uptake efficiency (e.g., Wanatabe et al., 2013).

In the hiatus period, extreme weather on lands intend increase



Seneviratne et. al.， 2014， Nature Climate Change

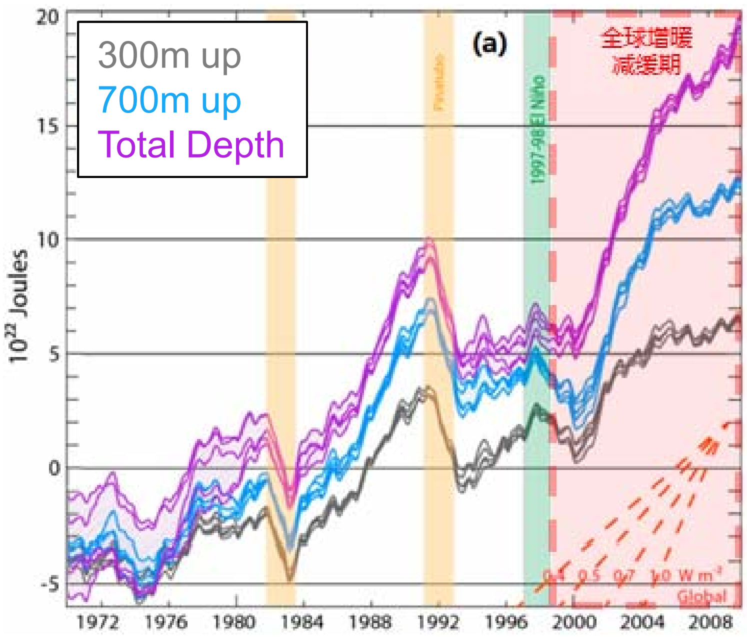
Thermal Energy Distributions



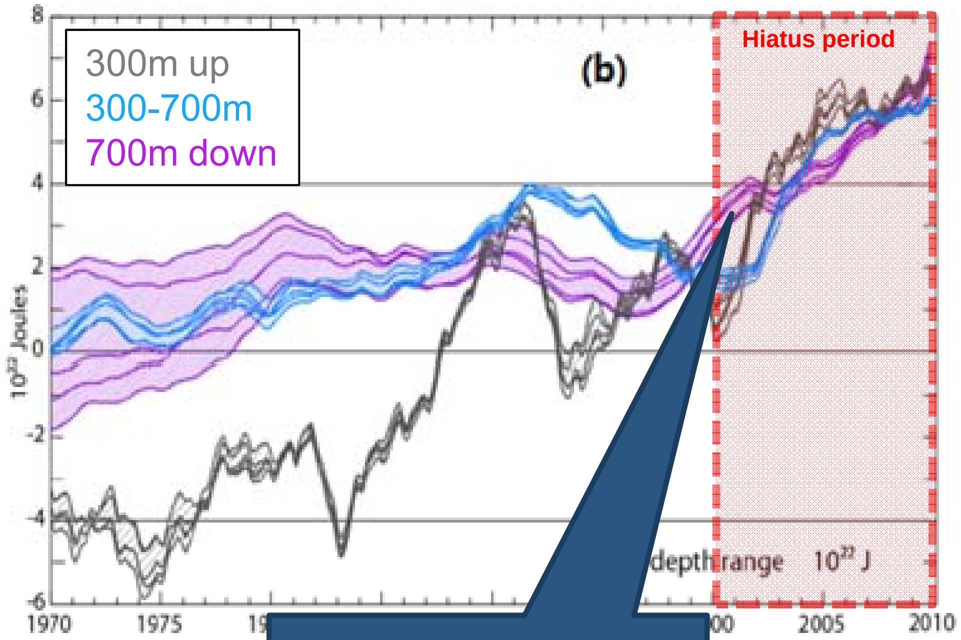
IPCC, 2013

Climate Hiatus and Deeper Warming

- **Deeper Ocean : 300~2000m**
- **Unclear: Mechanism?**
- **How about 300-700m?**



(Balmaseda et al., 2013)

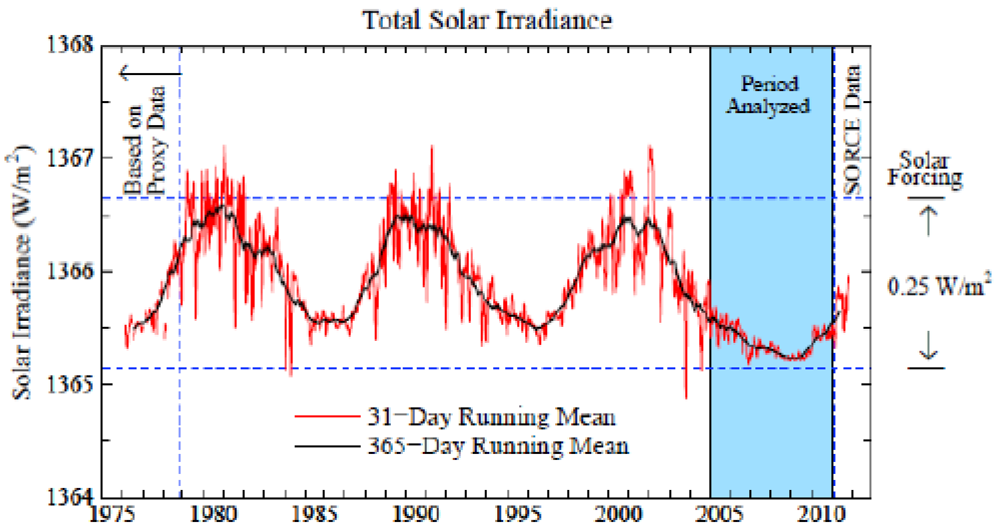


Hiatus : deeper warming before surface hiatus

Mechanisms (1)

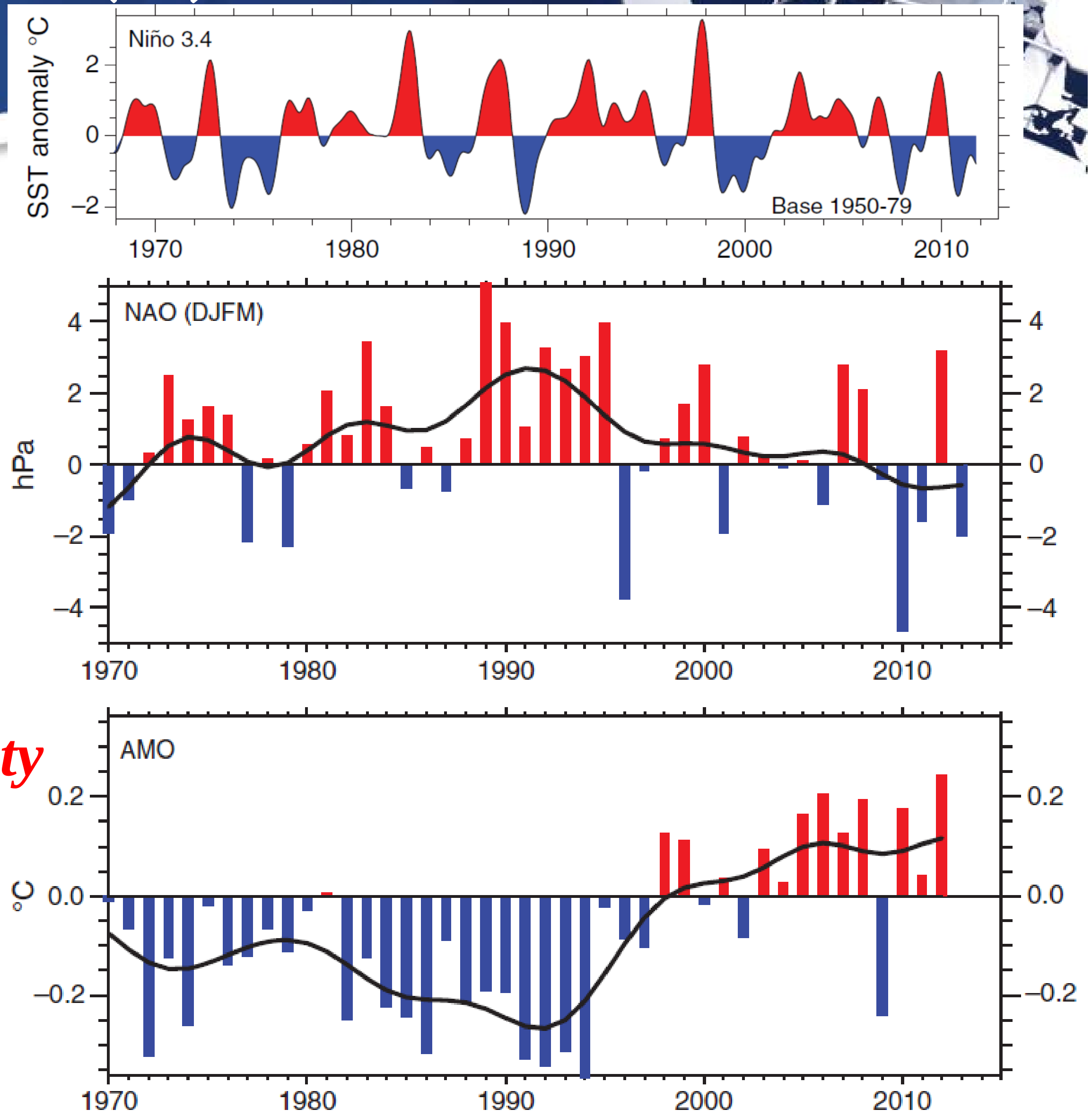
- **External Forcing**
  - Solar Activity
  - Volcanos
  - Aerosol

- ***Internal Natural Variability***
  - *PDO, NAO, AMO, etc*
  - *La Niñas*
  - *Deeper Ocean Warming*



Hansen et al., 2011

Mechanisms (2)



- **External Forcing**
  - Solar Activity
  - Volcanos
  - Aerosol

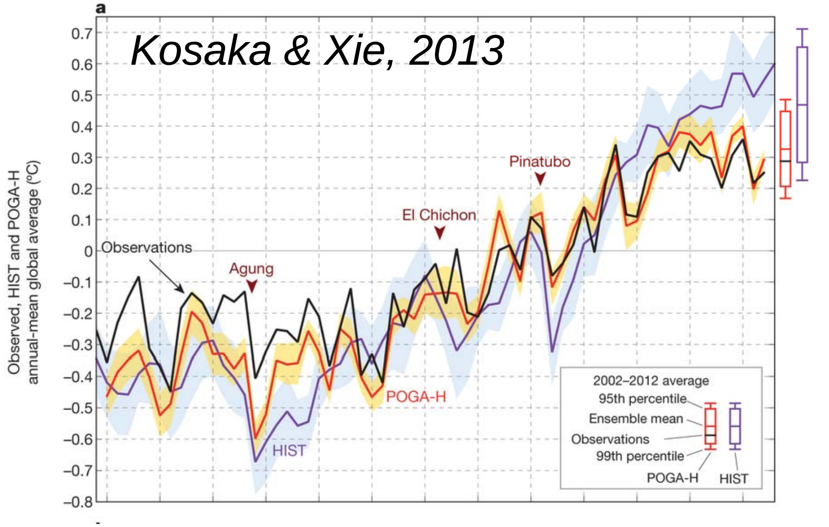
- ***Internal Natural Variability***
  - *PDO, NAO, AMO, etc*
  - *La Niñas*
  - *Deeper Ocean Warming*

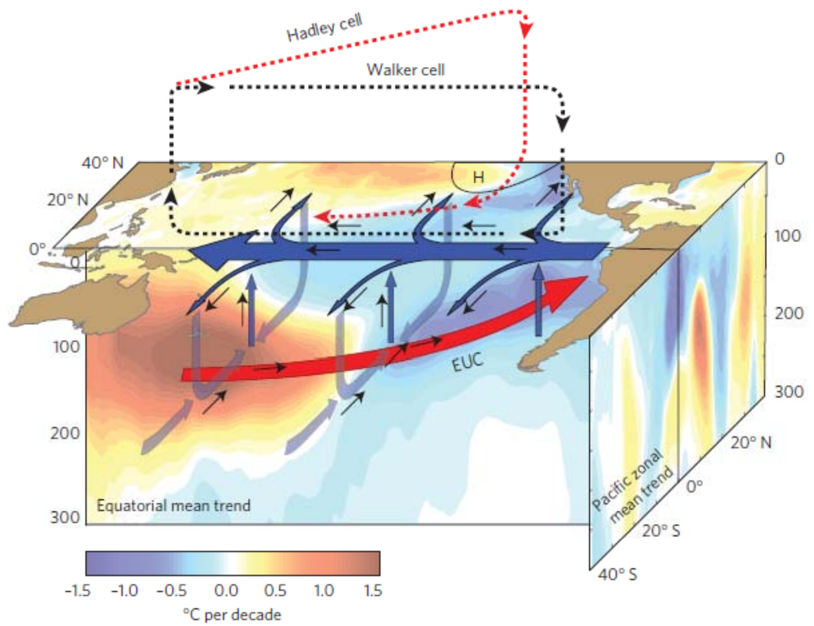
Trenberth et al., 2013

Mechanisms (3)

- **External Forcing**
  - Solar Activity
  - Volcanos
  - Aerosol

- ***Internal Natural Variability***
  - *PDO, NAO, AMO, etc*
  - *La Niñas*
  - *Deeper Ocean Warming*



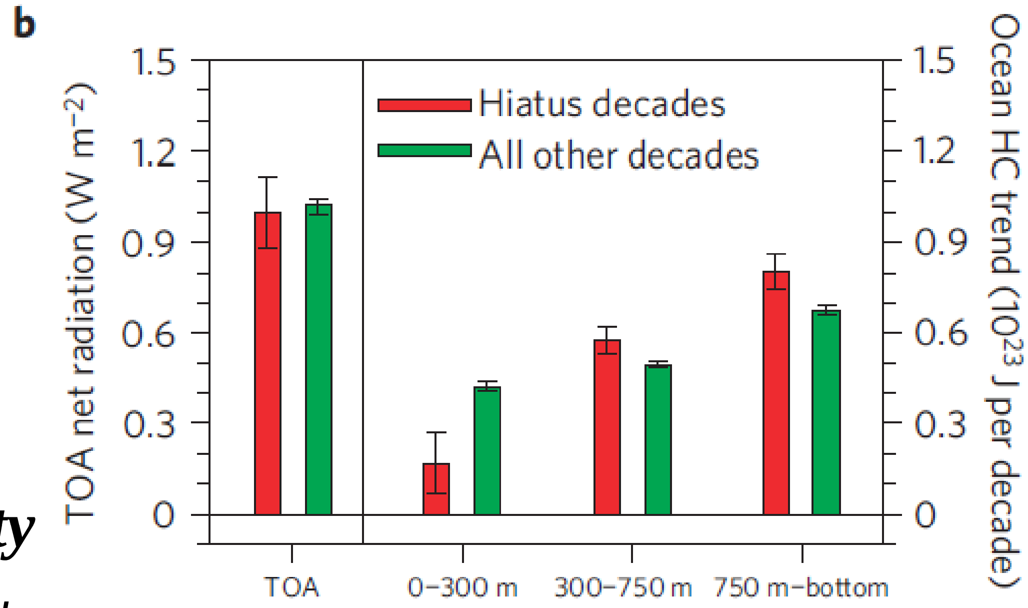


England et al., 2014

Mechanisms (4)

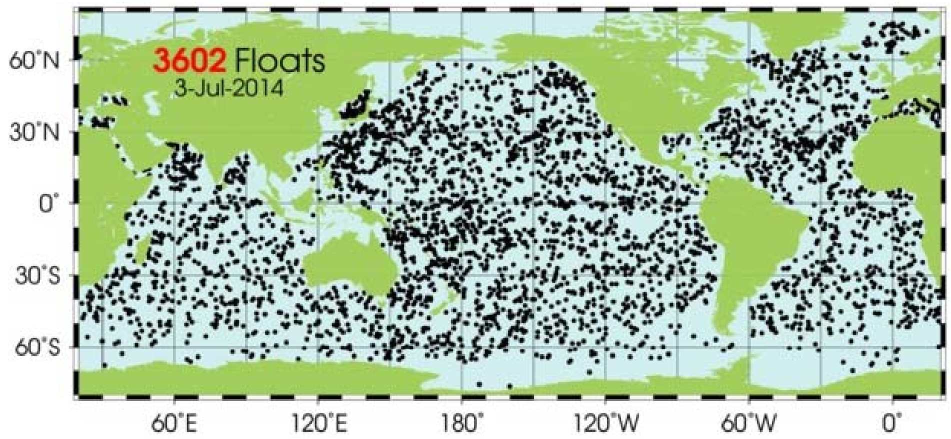
- **External Forcing**
  - Solar Activity
  - Volcanos
  - Aerosol

- ***Internal Natural Variability***
  - *PDO, NAO, AMO (Tung&Zhou, 2013), etc*
  - *La Niñas*
  - *Deeper Ocean Warming*
    (Meehl et al., 2011)



Lack of data prevent a thorough study of the deeper ocean and hiatus

- Deeper ocean remote sensing is necessary.
  - Super spatial and temporal coverage
  - Subsurface remote sensing data will improve data assimilation results



- Argo is great
- Coverage limit

(Spatial & Temp)

Subsurface and Deeper Ocean Remote Sensing

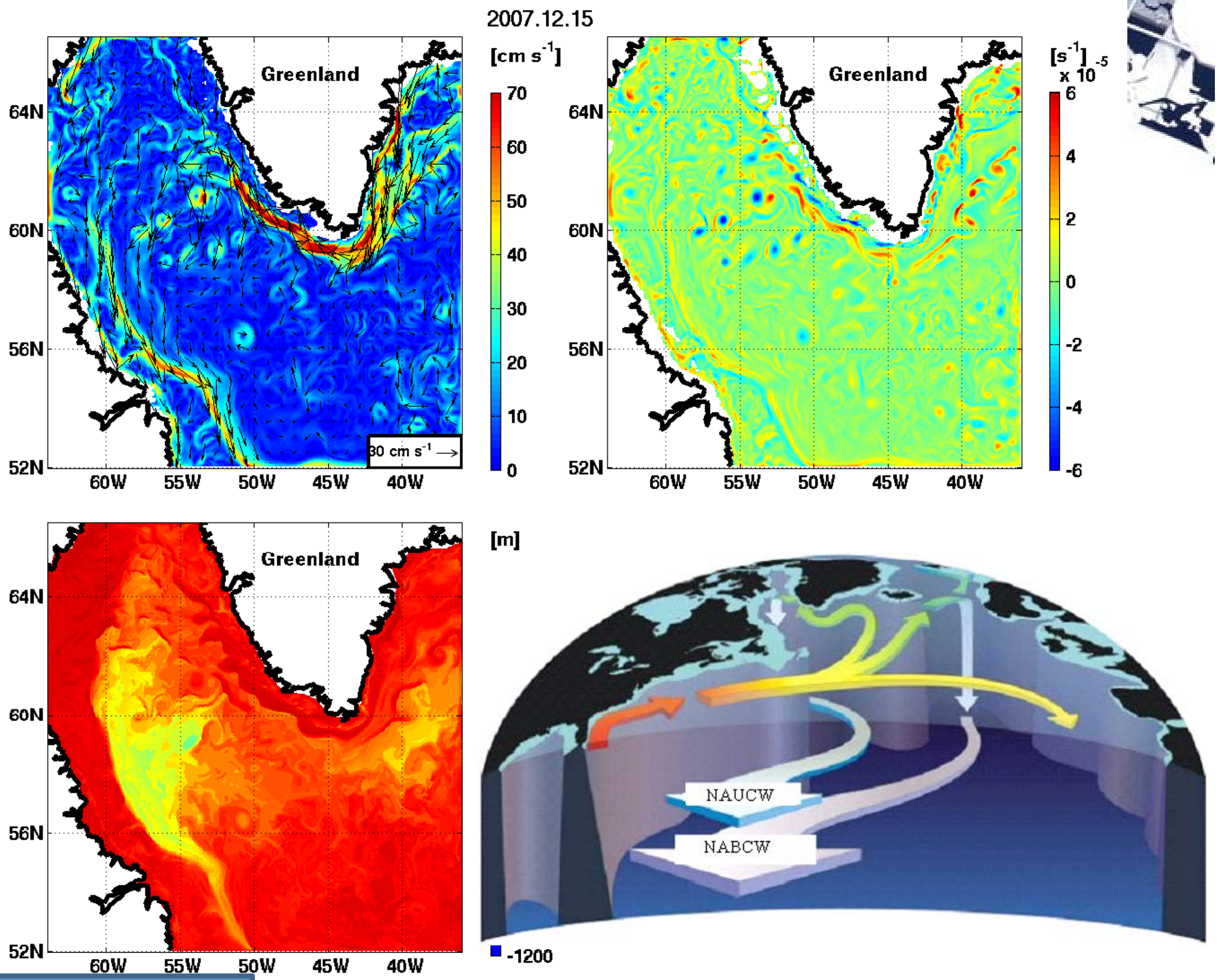
(klemas & Yan, a review paper in *Prog. Oceanography*, 2014,)

Generally, there are 3 methods:

- 1.Data Assimilations (AMOC/DOC)
- 2.Dynamic Analysis (Meddy/Cold Pool)
- 3.Statistic/Empirical (Subsurface Thermal Structure)

Method 1

Zhang & Yan,
JPO,2014

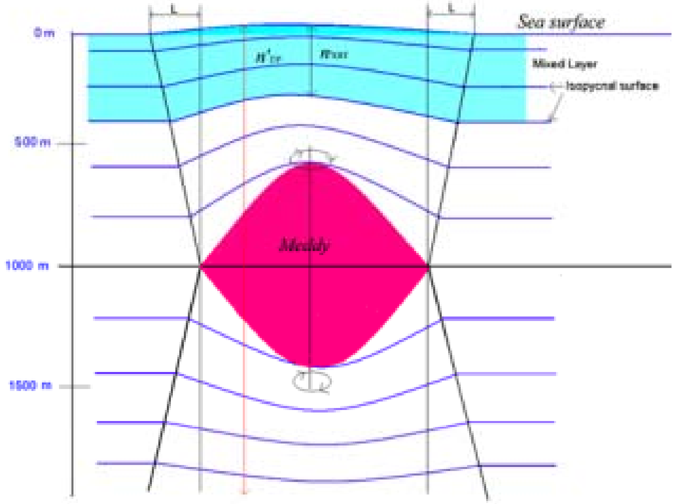


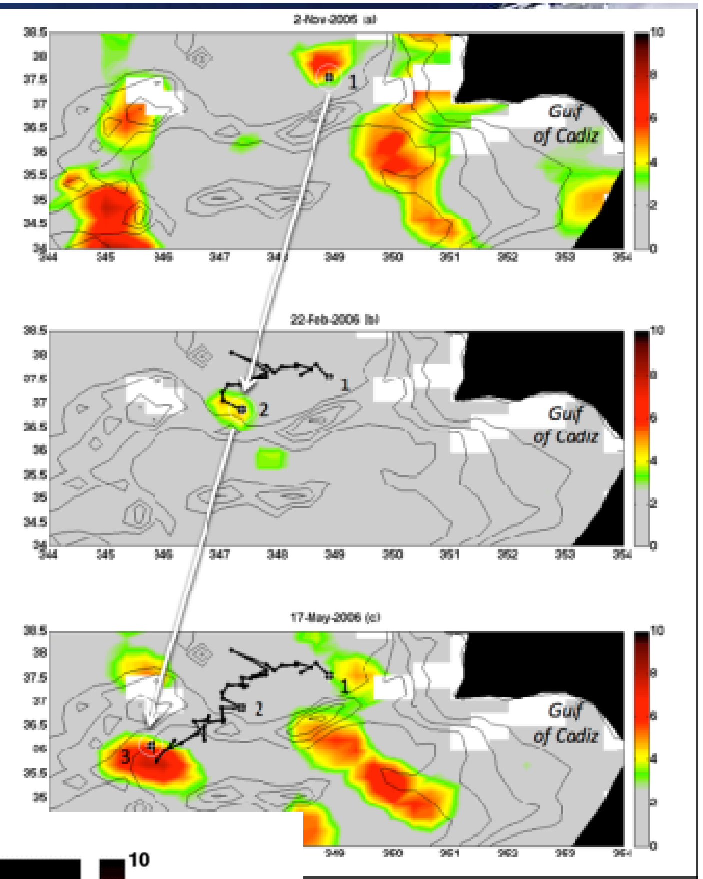
Re-Stratifications DOC slow-down → *AMOC/SPG Slow-down* → *Deep warming*

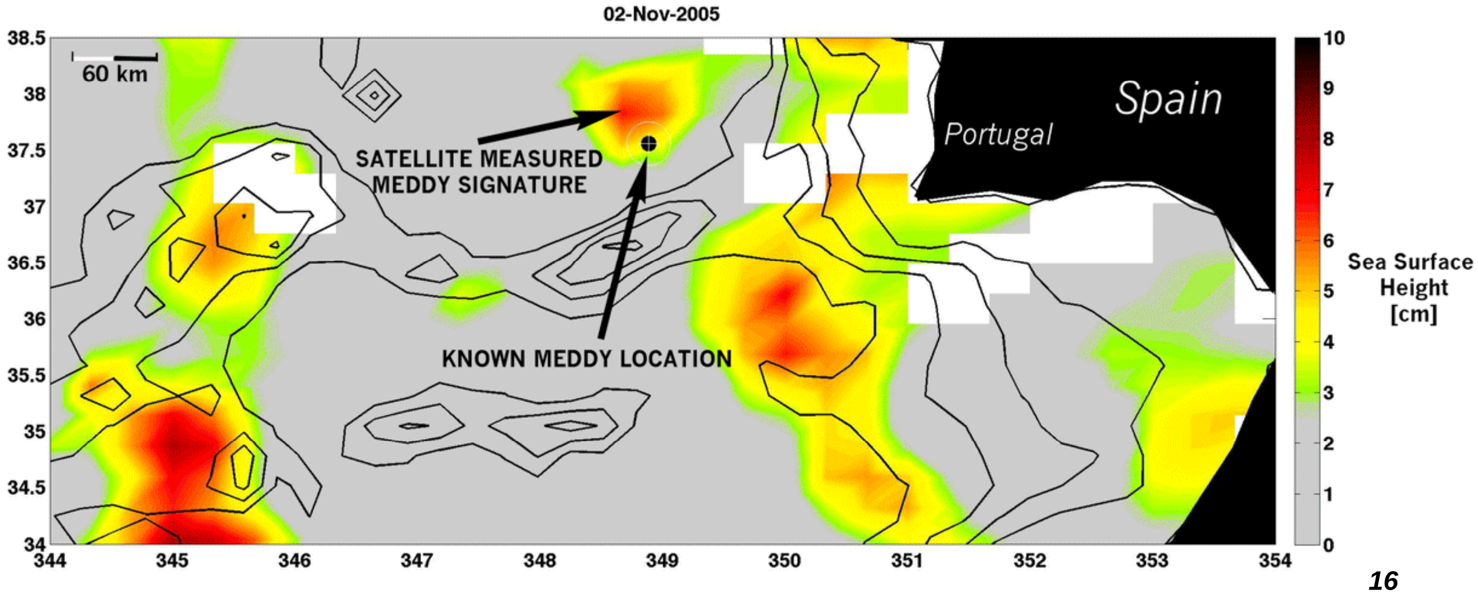
Meddy（Mediterranean Eddy）Remote Sensing (Tracking with XBT)

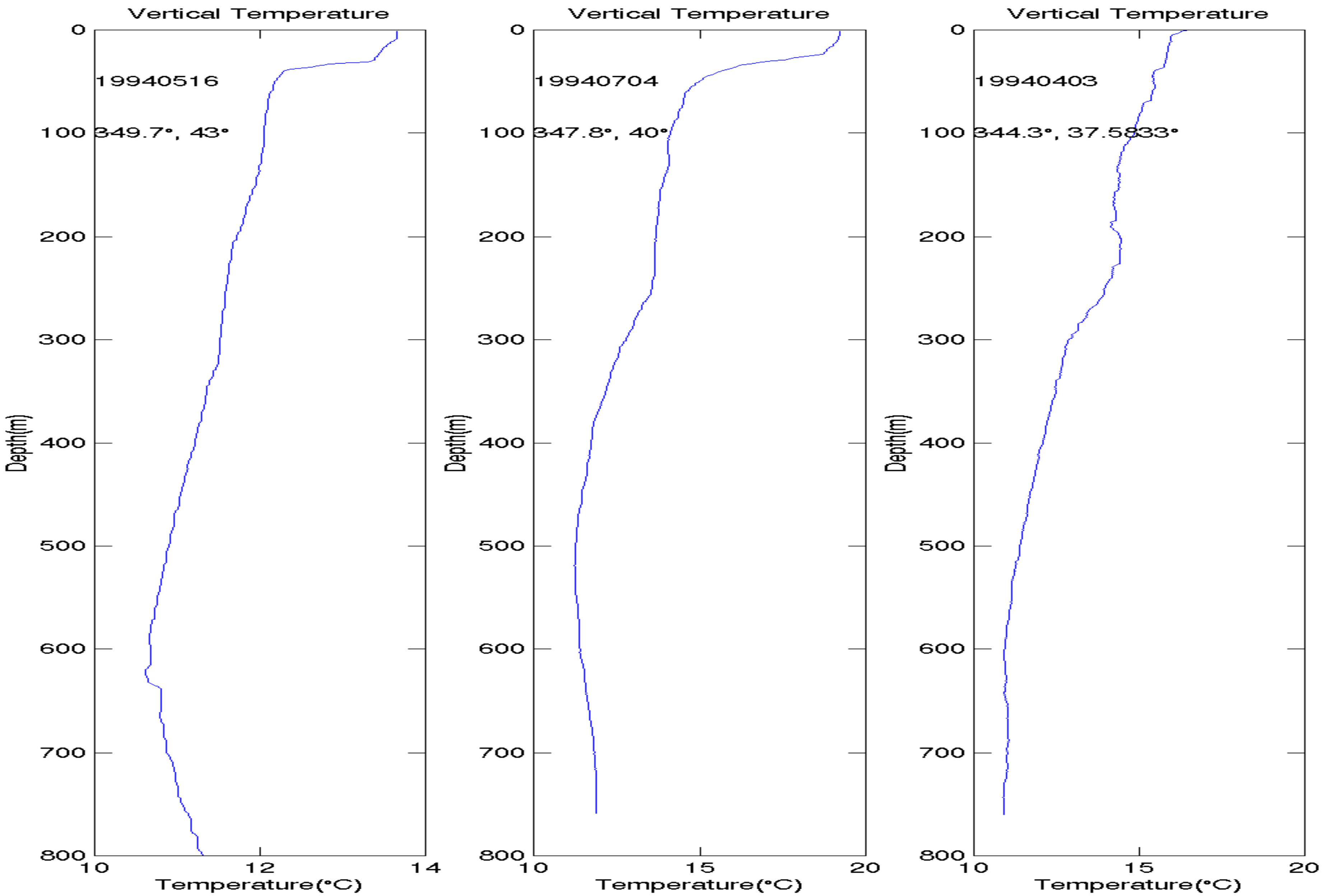
Method 2

Yan, et al., 2006, JPO; Ienna and Yan, 2014, J. A&O Tech.

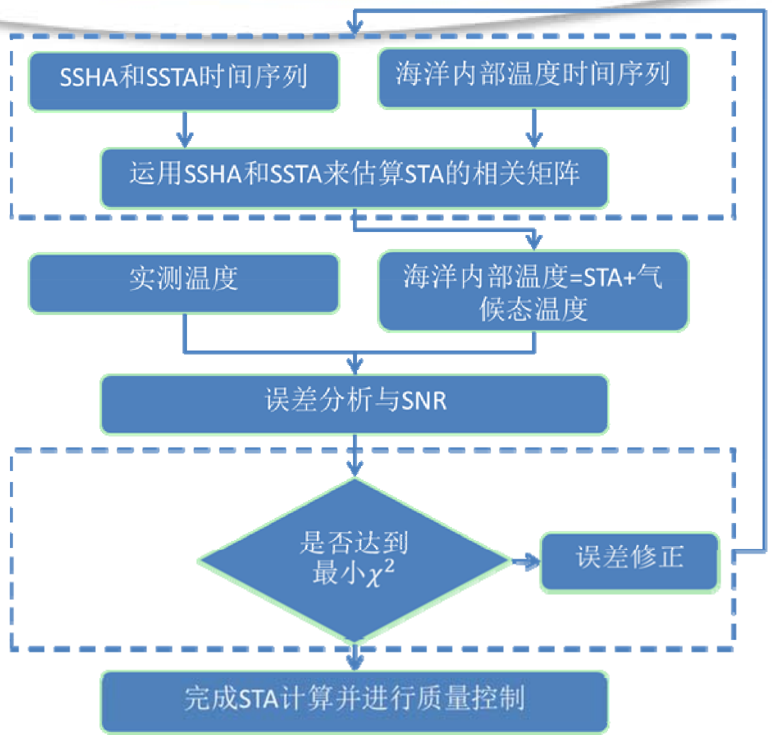


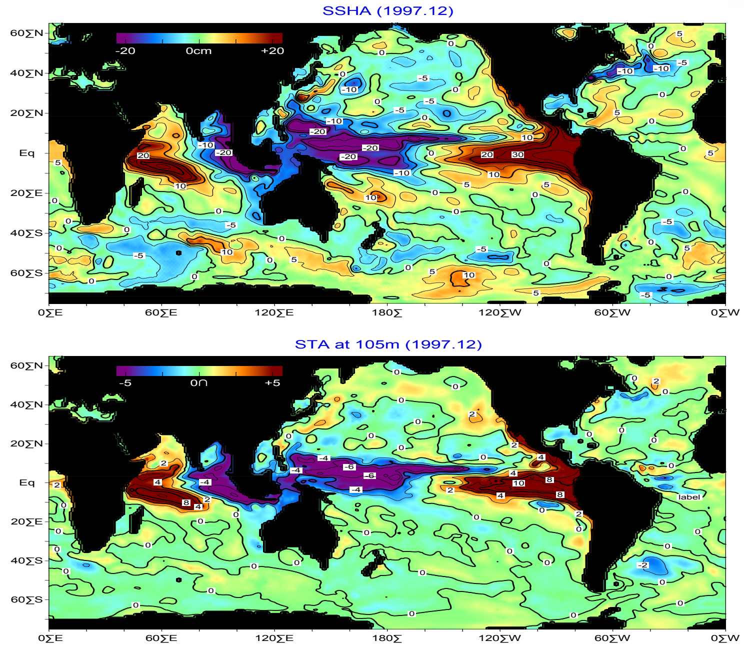


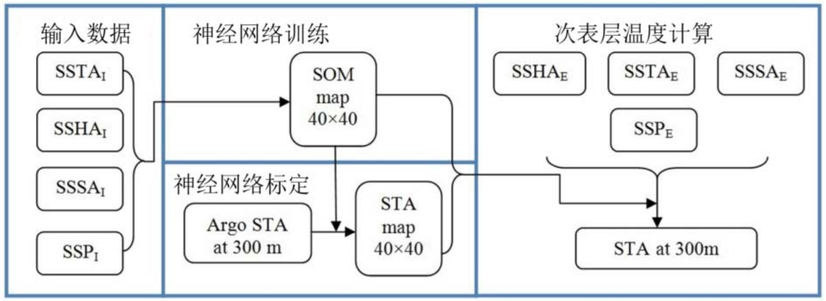



Vertical Temperature
19940516
349.7°, 43°
Depth(m)
Temperature(°C)
Vertical Temperature
19940704
347.8°, 40°
Depth(m)
Temperature(°C)
Vertical Temperature
19940403
344.3°, 37.5833°
Depth(m)
Temperature(°C)

Method 3: Subsurface Thermal Structure Remote Sensing



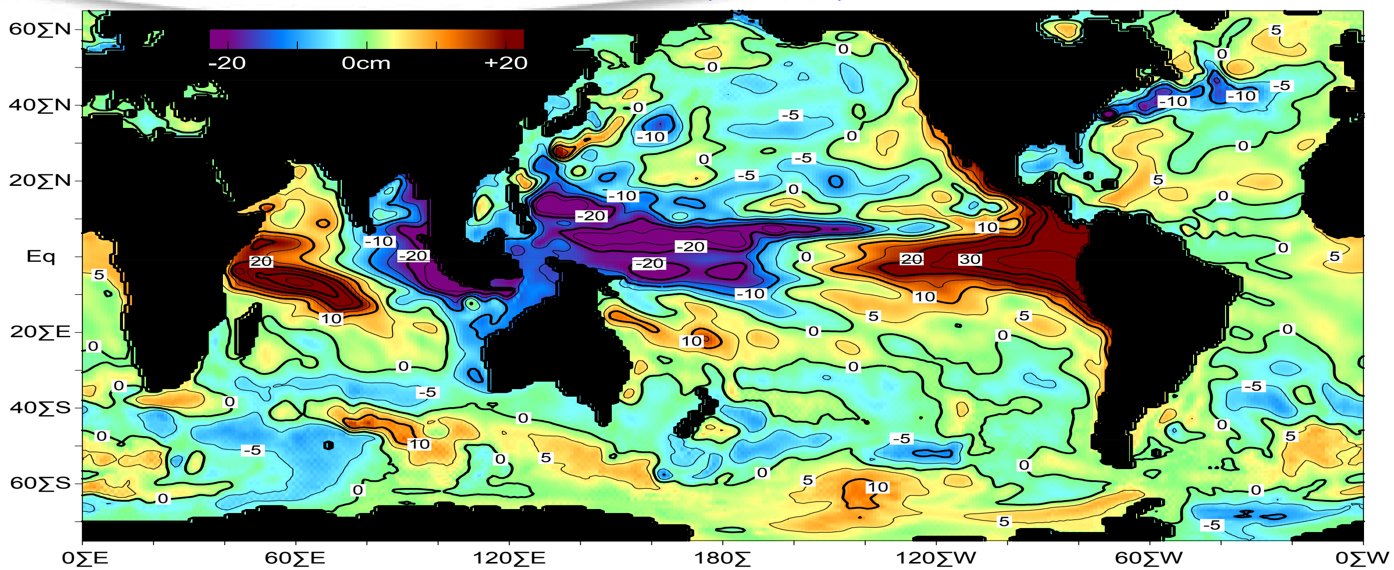




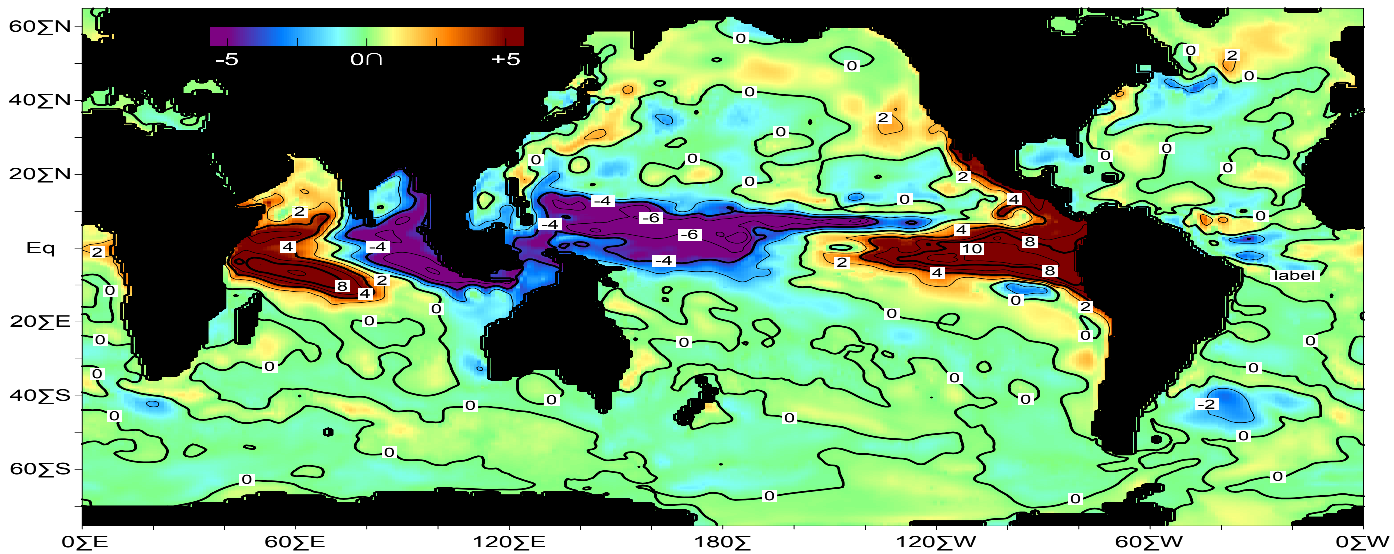
Using SSHA & SSTA to estimate Subsurface Thermal Structure（STA).
*a， **Bilinear Method** Kang&Yan，2012, US Patent, US8152366；*
*b，**NN Method,** Wu&Yan，2012）*

Similarities of SSHA and Subsurface temperature anomaly (STA) at 105m depth

SSHA (1997.12)



STA at 105m (1997.12)



Best spatial similarities between SSHA and STA

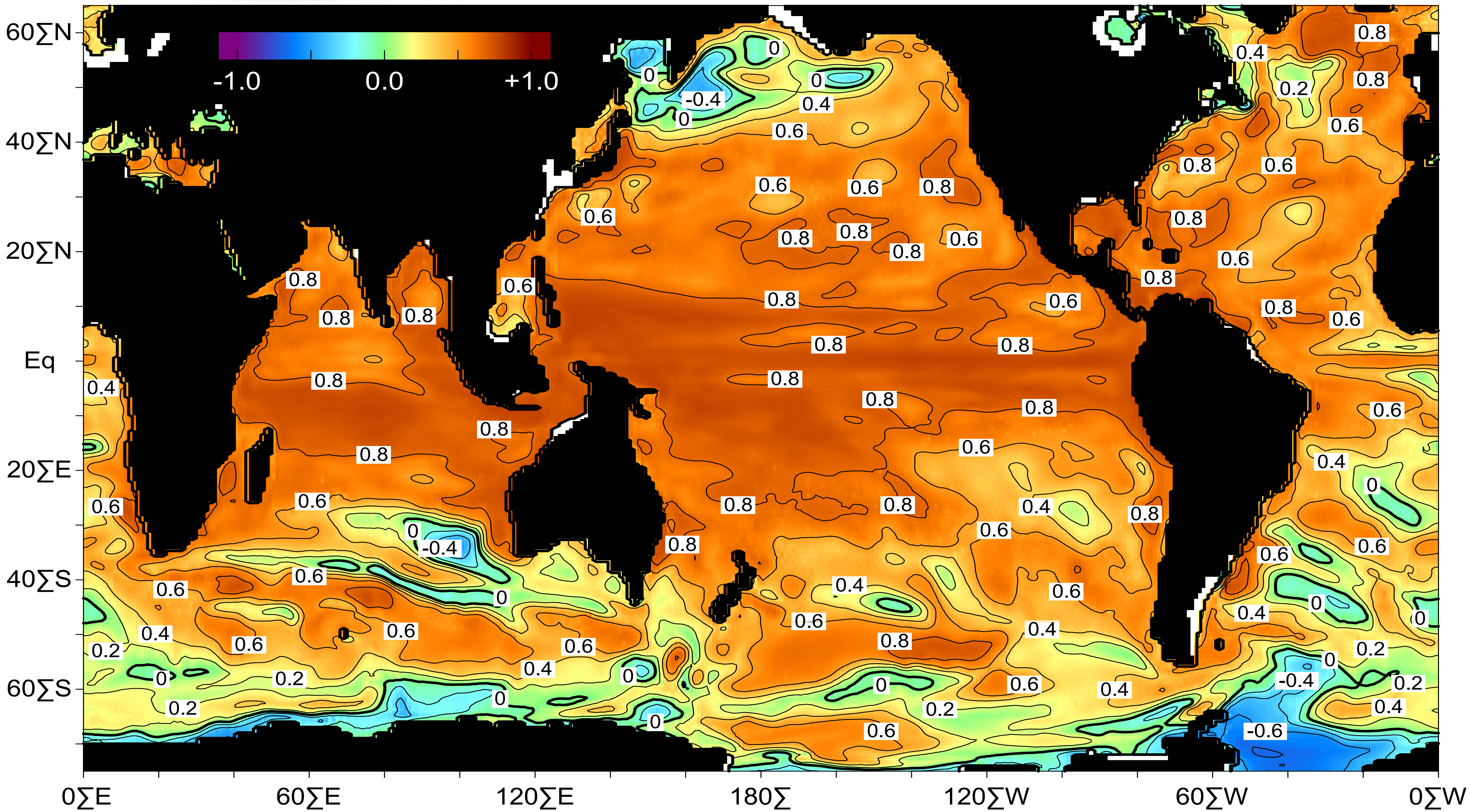
- Equators and Indian Ocean: STA at ~105m depth

-North Pacific: STA at ~50m depth

-North Atlantic: STA at ~200m depth

Correlation between SSHA and STA at 105m depth

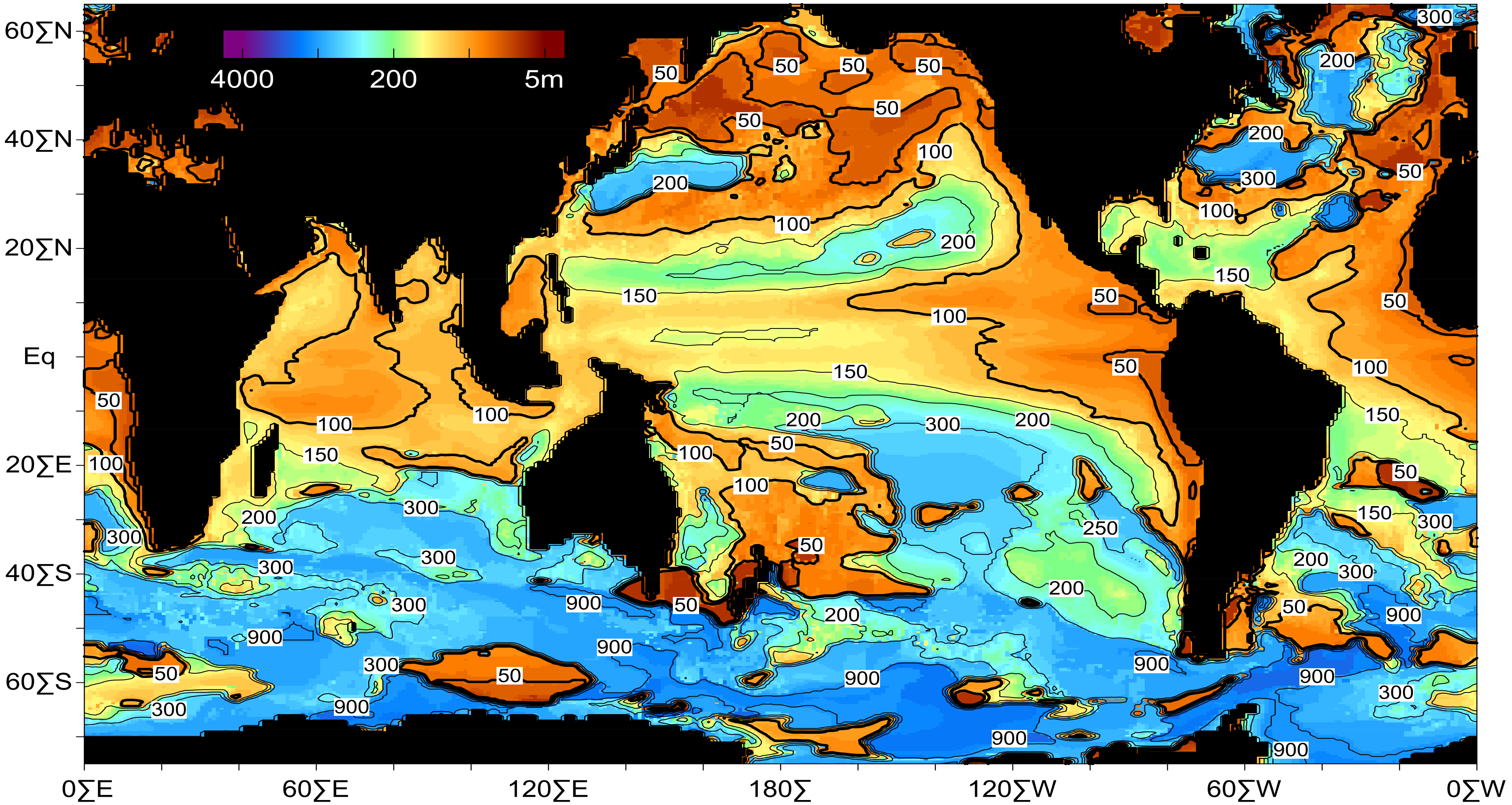
Cor (SSHA, STA105m)



Note: correlations depends on depths of STA

Depths for maximum correlation between SSHA and STA

Depth of Max COR】RMS of ST Anomaly



How to estimate STA from SSHA and SSTA

Suppose the STA is a linear combination of the SSHA and the SSTA,

$$STA(z,t) = a(z)SSHA(t) + b(z)SSTA(t) + c(z)$$

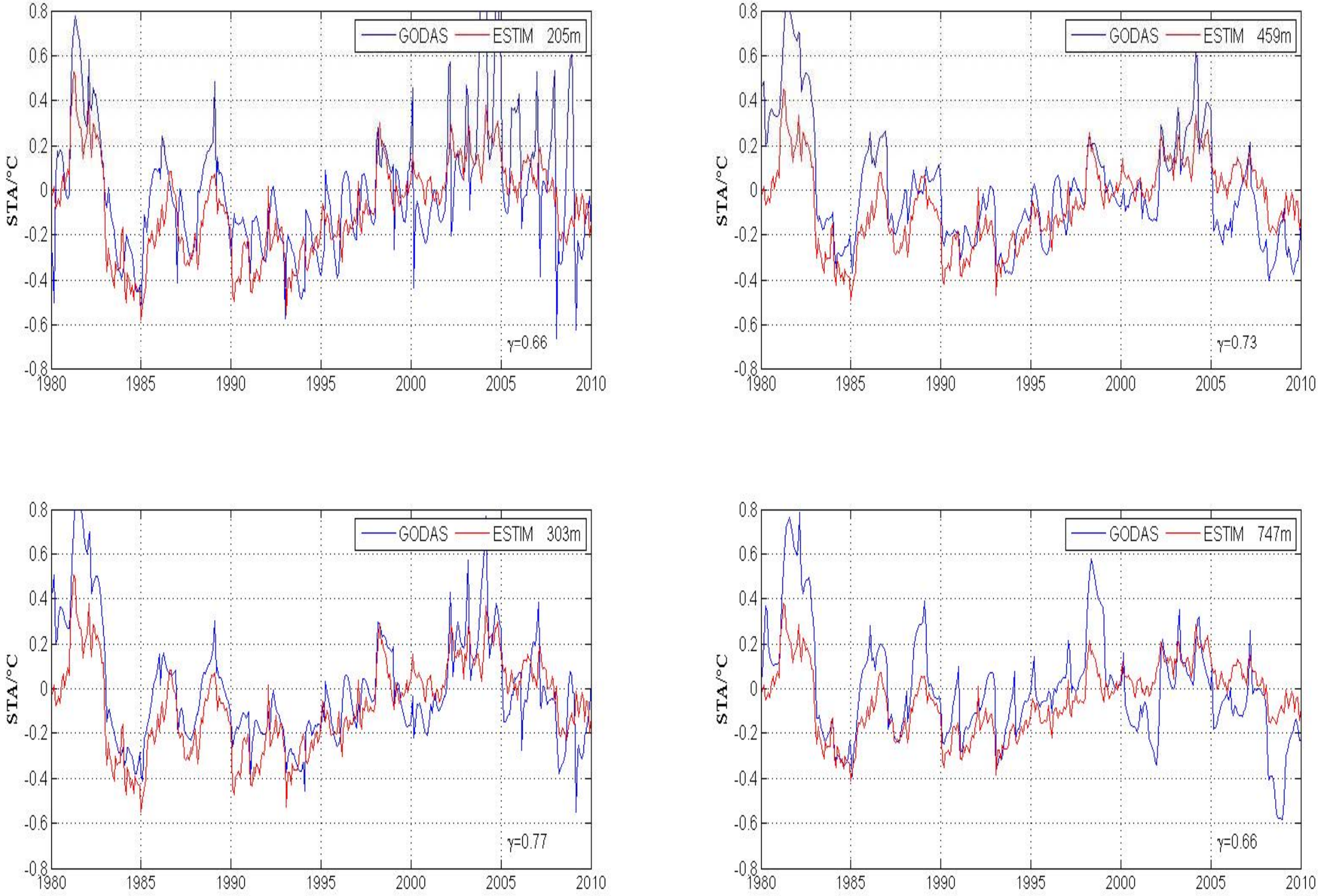
.

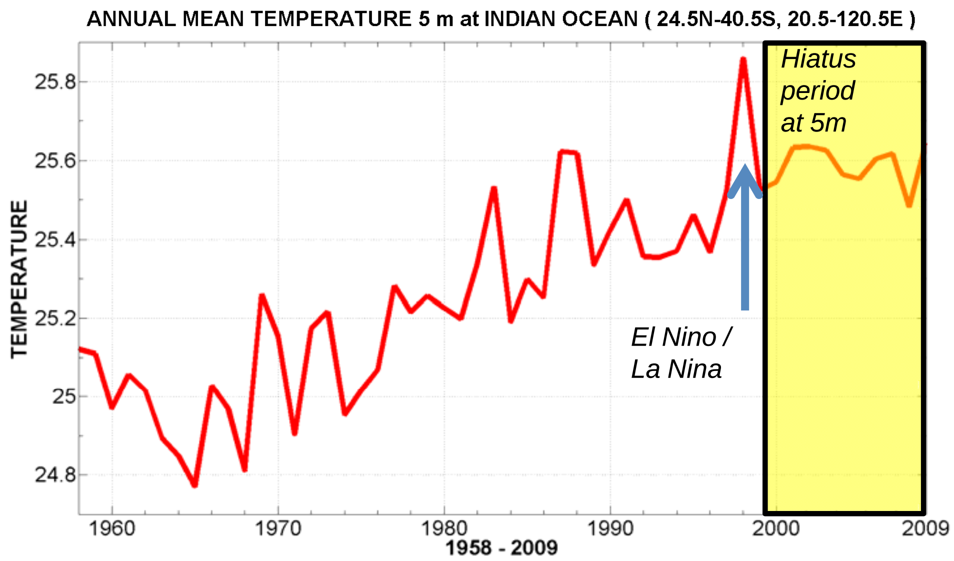
In order to determine unknown coefficients, *a*, *b*, and *c*, we can use the least square method (LSM) at each depth of a given location, i.e.,

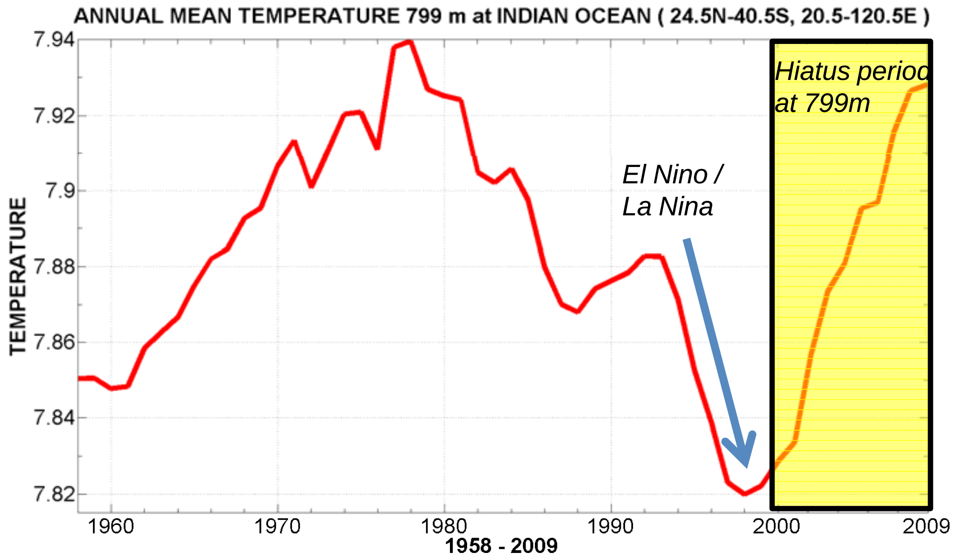
$$E(z) = \sum_{t=1}^{n} \left[a(z) * SSHA(t) + b(z) * SSTA(t) + c(z) - STA(z,t) \right]^2$$

Where *n* and z are the measurement period and depths, respectively. The coefficients are determined at the minimum *E.*

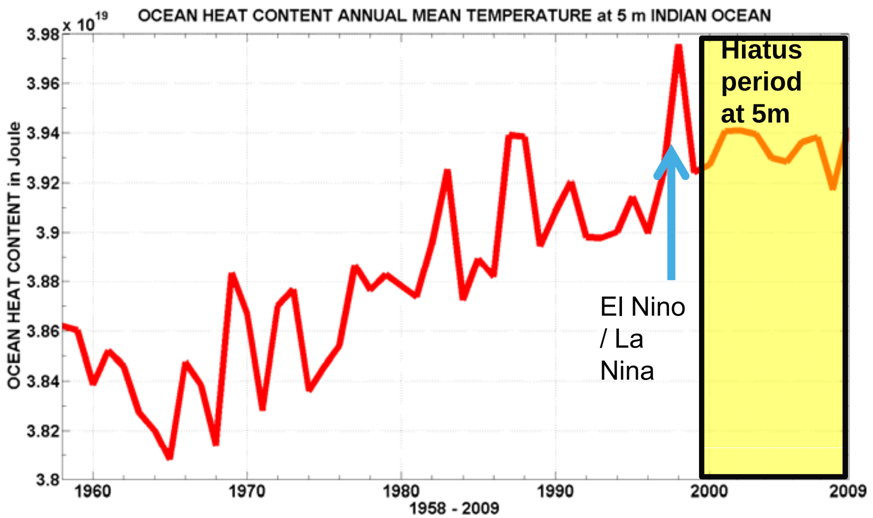
Comparisons between estimated and GODAS measurements

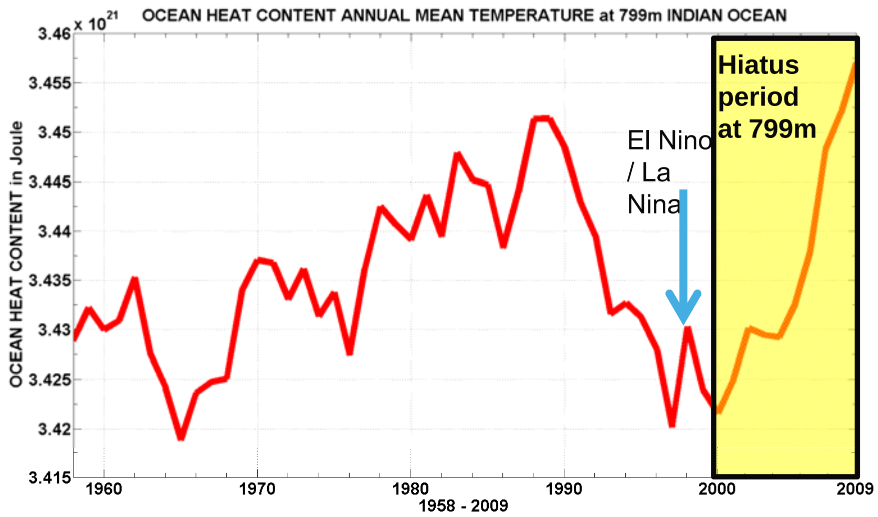


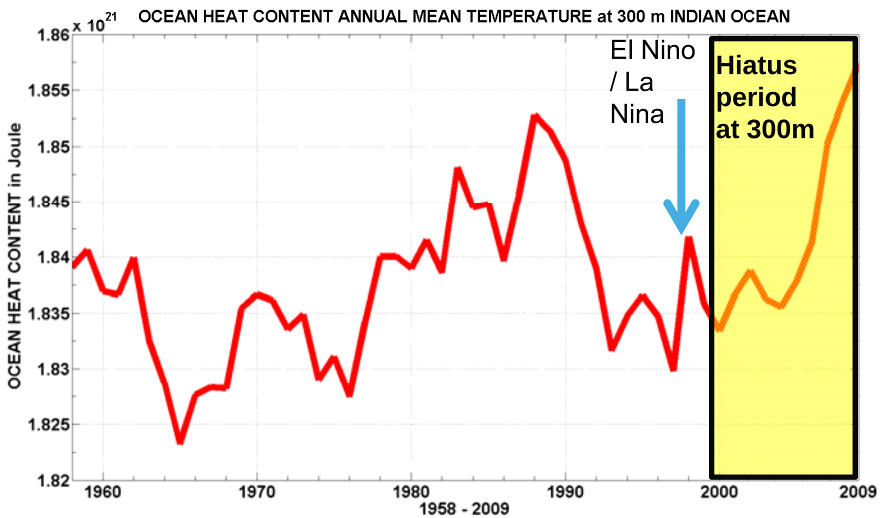


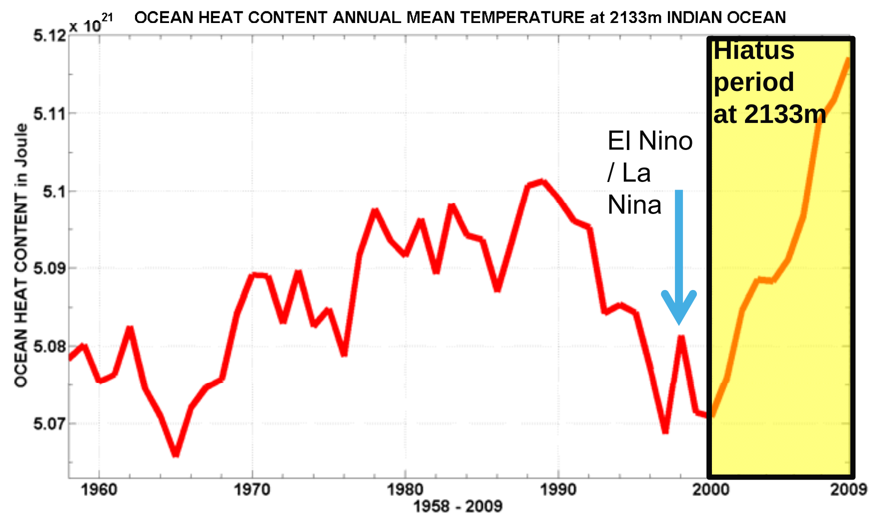


(Makarim & Yan, 2014)

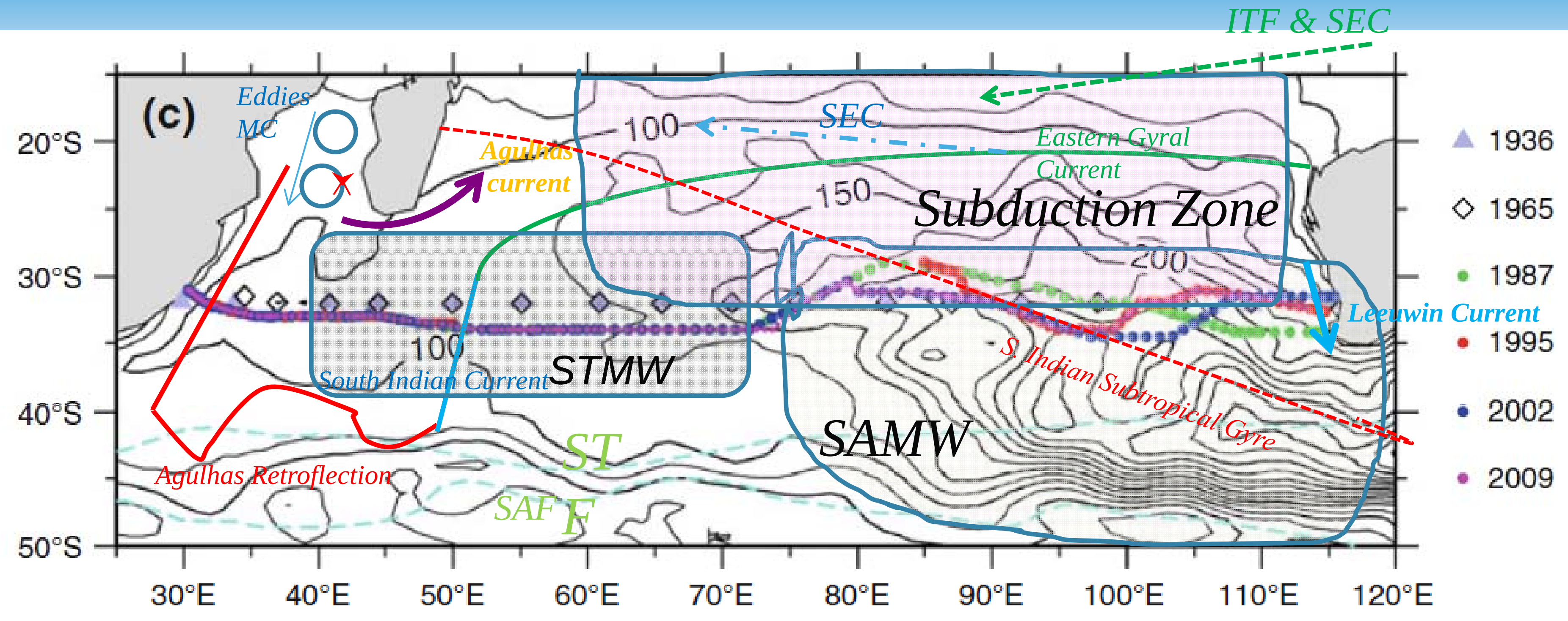








(Makarim & Yan, 2014)



STMW = Sub Tropical Mode Water (0-300m)
SAMW = Sub Antartic Mode Water (0-700m)
STF = Sub Tropical Front
SAF = Sub Antartic Front
Agulhas Current (up to 2000 m)
Agulhas Retroflection (up to 2000 m)
Eddies Mozambique Channel (up to 1500 m)

Agulhas&retroflection&Eddies MC, (ref : Will de Ruijter et. Al, 2002,2010,2012)

SEC = South Equatorial Current low salinity in subduction zone (800-1200m)
ITF = Indonesian Throughflow (0-500 m)
Subduction Zone (0-1000 m)
Eastern Gyral Current (200 m)
South Indian Current
South Indian Subtropical Gyre at 200 m
Leeuwin Current (0-150 m,Talley et.al, 2011) and (0-300m, Koch-Larrouy et al,2010)
AAIW (Antartic Intermediate Water), 500-1200 m

Conclusions:

1. *Deeper ocean warming up contributed significantly in recent global warming hiatus, and in the paradox of accelerating Arctic sea ice melting despite the slow-down in the global warming trend during the recent climate hiatus.*
2. *Deeper ocean remote sensing is do-able and can help in studying the climate change & hiatus. Subsurface and deeper ocean remote sensing is difficult, but important and do-able and need to be further developing and emphasizing.*
3. *With help of Argo, field work, (30 N, Indian Ocean, WPWP, etc.), CMIP5, re-analysis data, modeling, and deeper ocean remote sensing, we should be able to do more.*

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Frontiers of Ocean Remote Sensing

1. *Deeper Ocean Remote Sensing*
2. *High Resolution/All Weather Remote Sensing-SAR, Real Time Disaster and Environment Monitoring*
3. *Coupling of Physical/Biological/Chemical Oceanography/Interdisciplinary Research*
4. *Global Change-Climate Change Research*
5. *Multi-Sensor Remote Sensing*
6. *New Sensors, e.g., Salinity, etc.*
7. *Coastal Remote Sensing/Arctic-Polar RS*