Evolution of ocean heat content with ENSO

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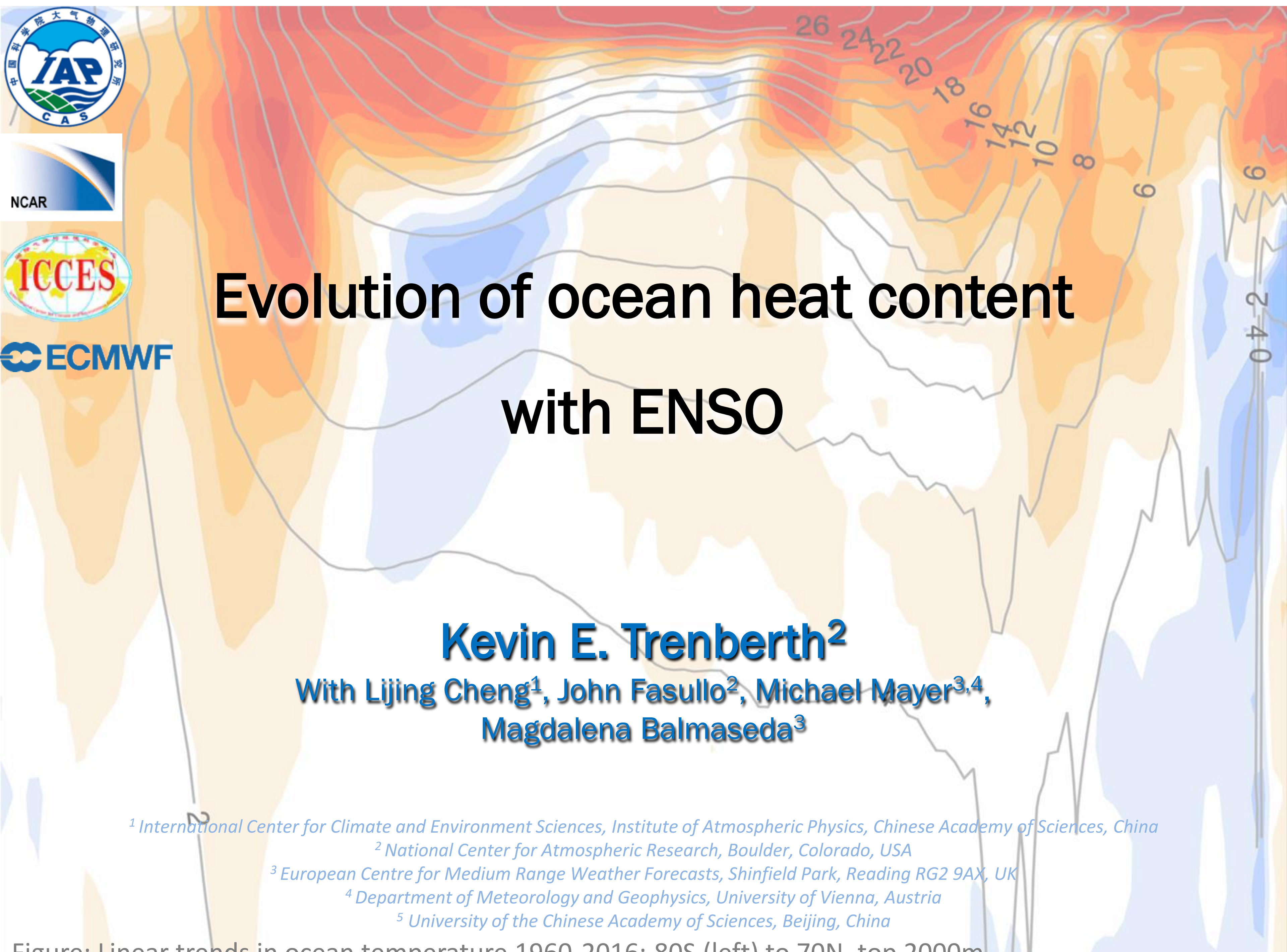


Figure: Linear trends in ocean temperature 1960-2016: 80S (left) to 70N, top 2000m

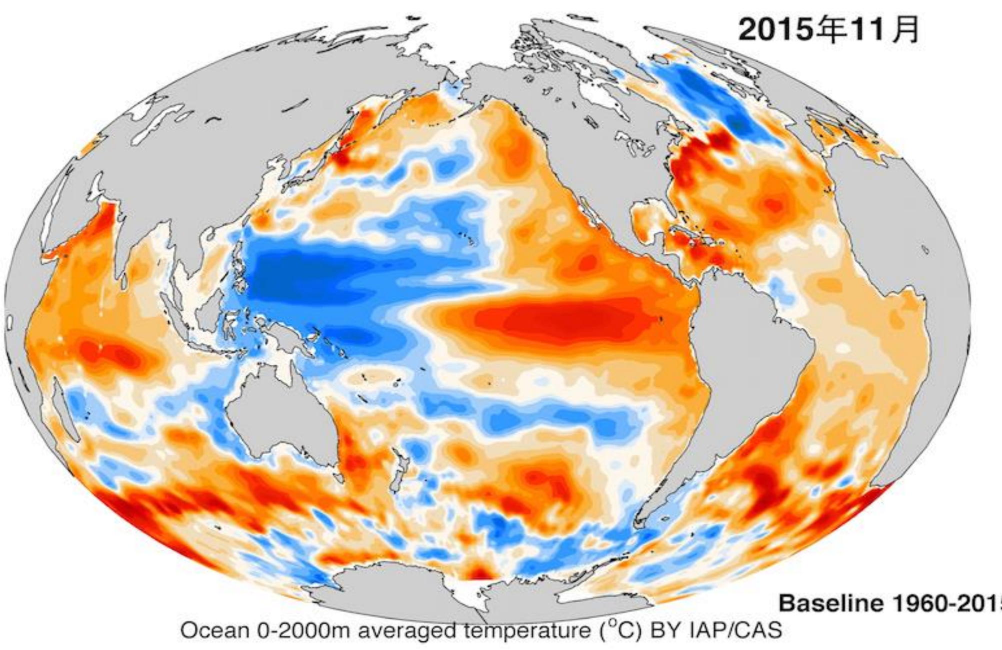
ENSO

The dominant mode of air-sea interaction in the climate system on inter-annual time scales.

During ENSO, the Ocean Heat Content (OHC) is radically changed and heat is moved around:

- **East-west**
- **North-south**
- **Vertically within ocean**
- **Ocean to/from atmosphere to space (diabatic)**

A snapshot of OHC 0-2000m in Nov.2015



1. Introduction

The movement of heat is confused in the literature owing to incomplete accounting of the domains:

How much is movement of heat vs how much is diabatic: discharge and recharge?

- **East vs west Pacific?**
- **Pacific vs Indian and Atlantic?**
- **Top 100m vs 300m vs 700m vs 2000m?**
- **Tropics vs extratropics?**
- **Ocean vs atmosphere?**
- **Land (water) and cryosphere?**

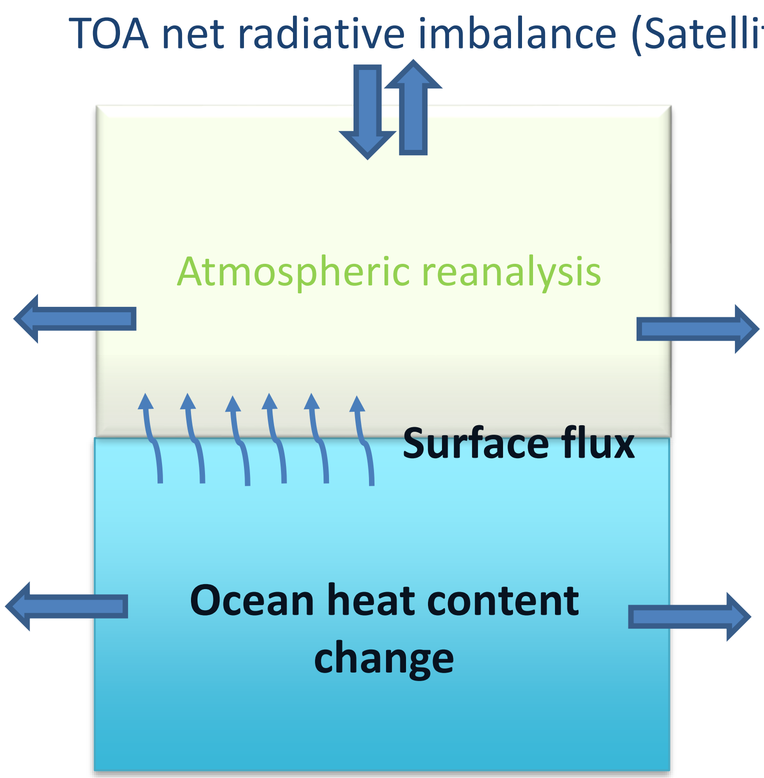
High pass filter applied to remove decadal and longer periods.
Also smoothed to remove <18 months.

Hence we analyze 1.5 to 7 year fluctuations

2. Data & Methods

Energy Budget perspective

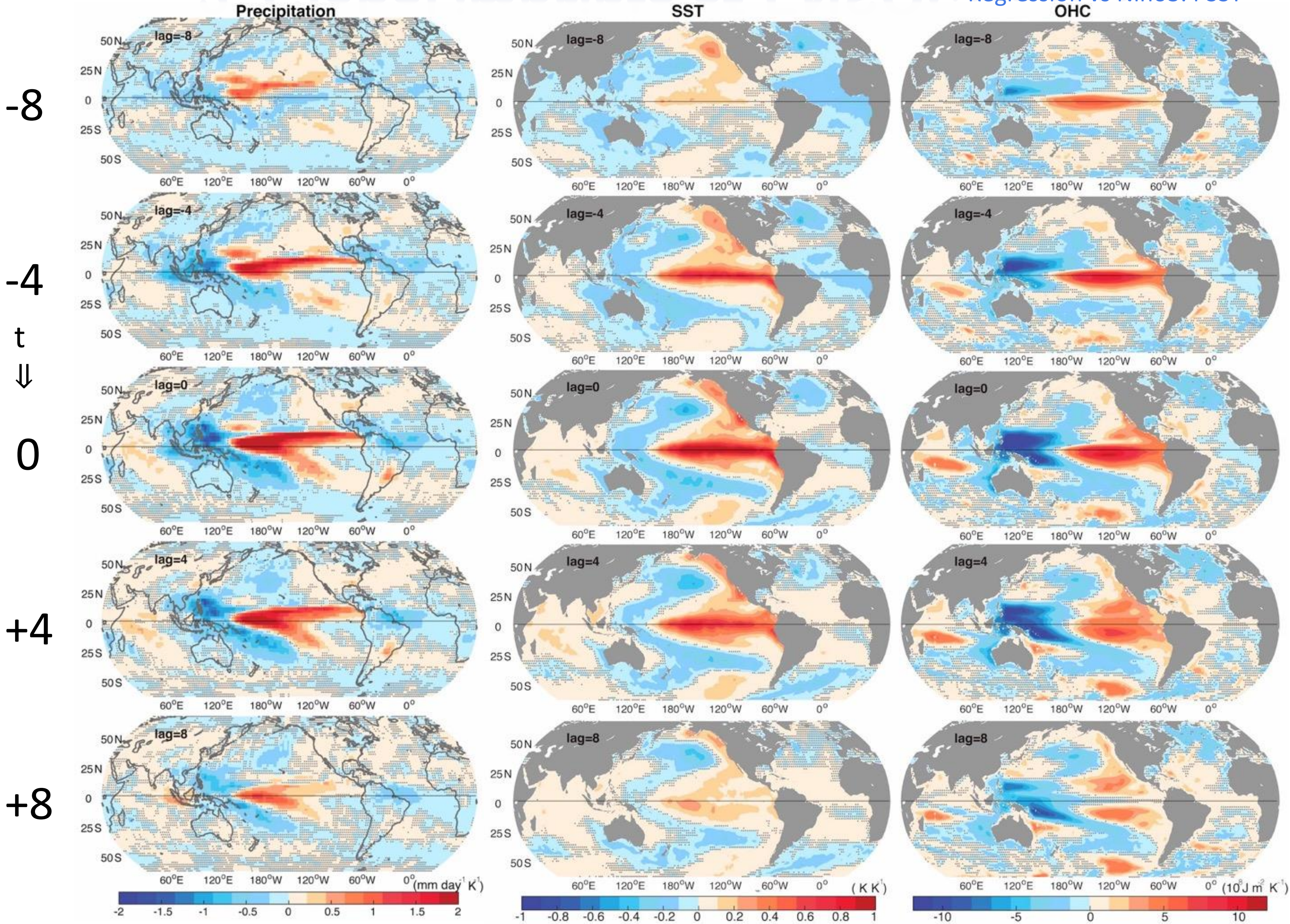
$$\text{OHC tendency} \approx \text{Surface flux (Q)} - \text{DIV.F}_O$$



- Ocean heat content 0-2000m
  (IAP ocean analysis; Reanalysis: ORAS5)
- Surface flux Q "Residual method",
  Trenberth & Fasullo data: TF;
  Deep-C Univ. Reading

2. Global imprints of ENSO: 1985-2016

Regression vs Nino3.4 SST



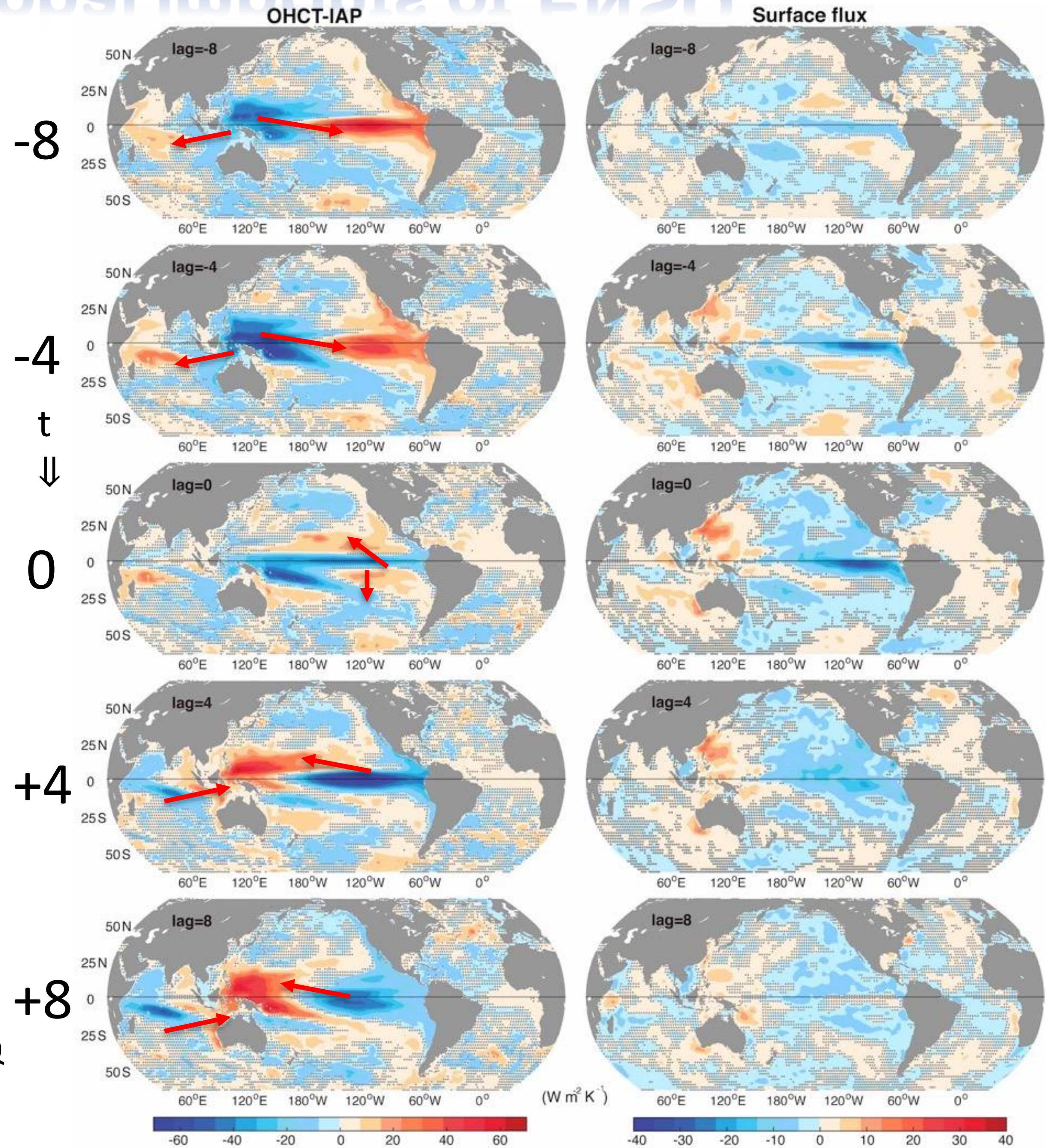
2. Global imprints of ENSO

Local OHC change: 1985-2016

OHC tendency ≈

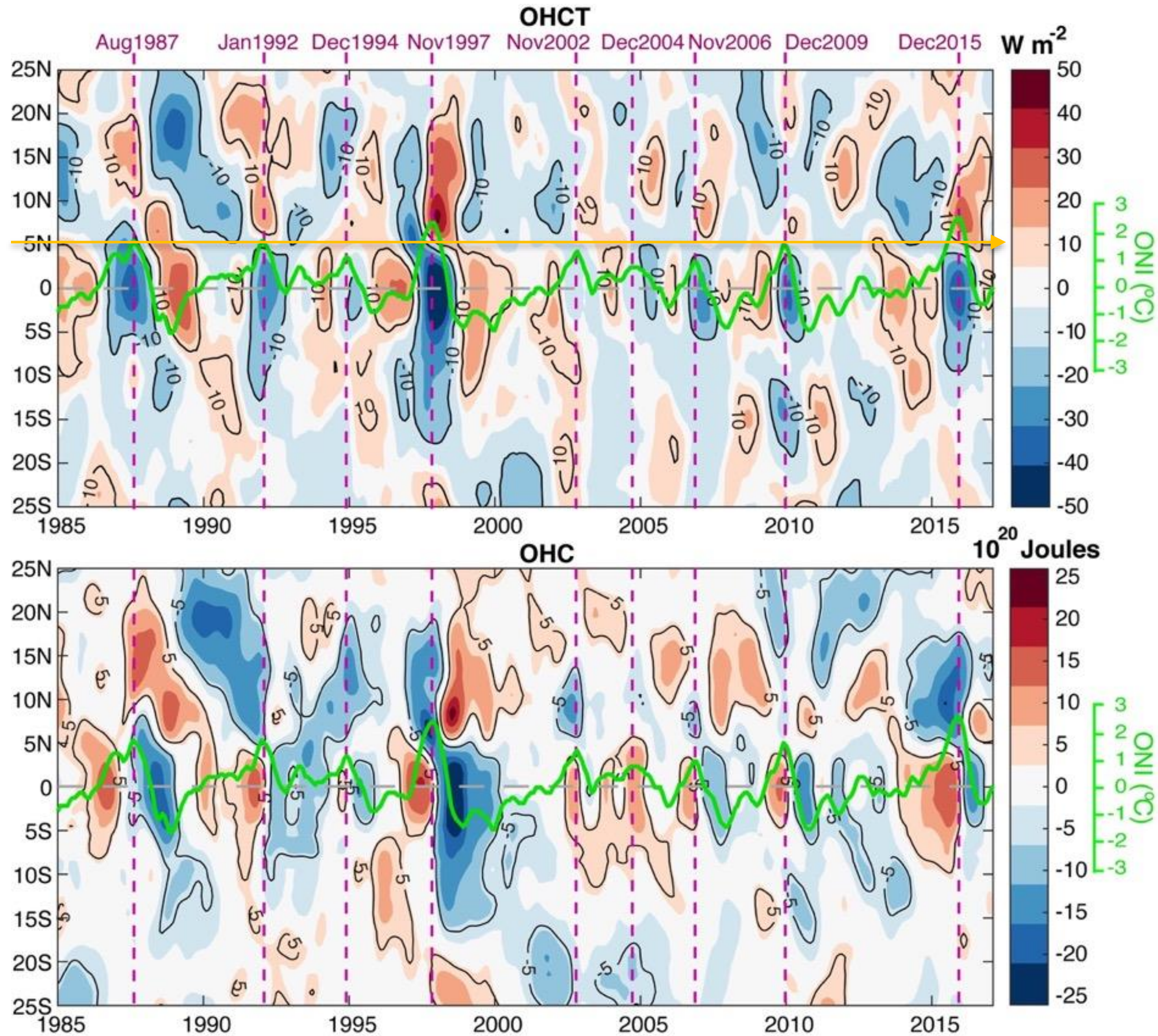
Surface flux (Q) – DIV.F_O

- Pattern of OHC change is dominated by local ocean heat transport (meridional & zonal)
- Surface flux determines the net changes



Linear regression of OHCT (left) and Q (right) against Nino3.4 SST

3. Meridional change



- Heat loss in the southern tropics during El Niño is discharged into the off-equatorial regions

- Striking divide near 5°N
- = ITCZ

Fig. Hovmöller diagram of the zonal mean OHCT (W m^{-2}) (upper) and OHC (10^{20} Joules) (bottom) in the tropical Pacific basin

3. Meridional change
Zonal means

Heat is transported and discharged from 20ºS-5ºN into off-equatorial regions within 5-20ºN during and after El Niño.

Ocean heat transport dominates the OHCT pattern

Surface flux anomalies result in ocean cooling in the tropical Indo-Pacific basin (within 10ºS~10ºN) during El Niño, coincident with the sea surface warming and P increase for the same zonal bands.

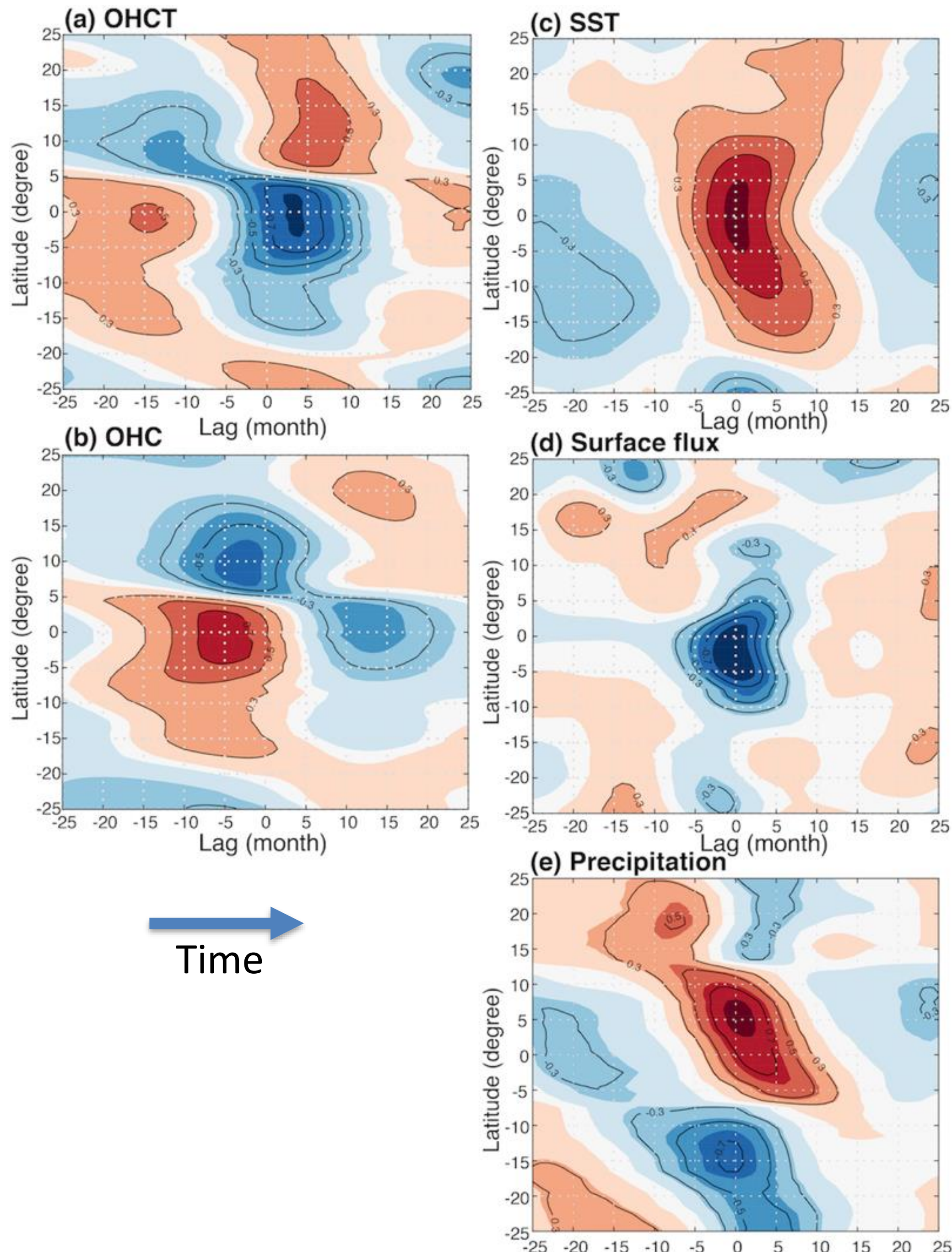


Fig. The lagged cross-correlations between ONI and a) OHCT, b) OHC, c), SST, d) Surface net flux, e) P

4. Zonal change

Meridional means

- Strong zonal gradients in OHCT in the Pacific (cooling in the west and warming in the east) in the lead up to El Niño, with predominance for eastward propagating signals in the Pacific basin, and slower western propagating signals in the Indian Ocean

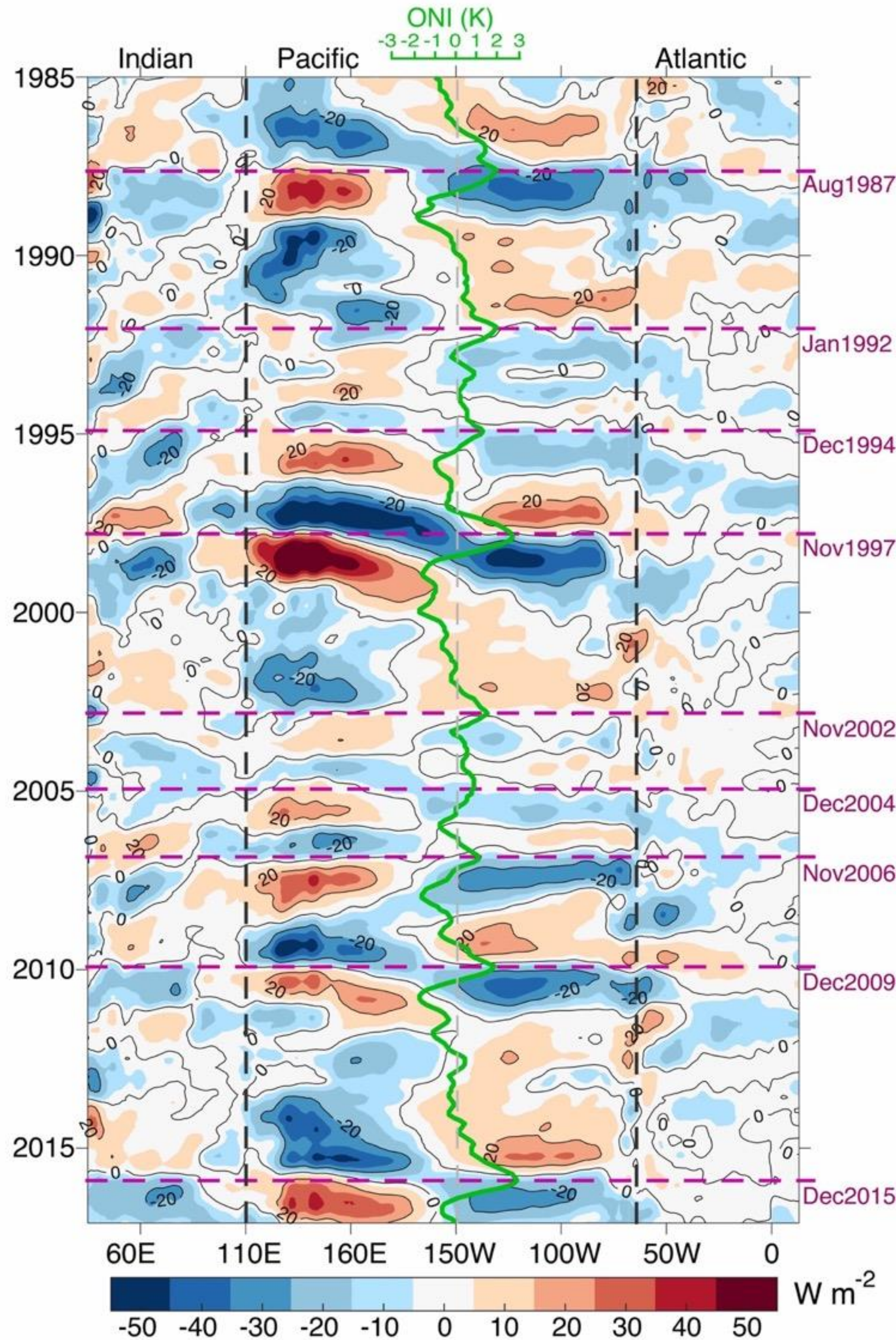


Fig. Hovmöller diagram of meridional mean OHCT in the tropics (20ºS-20ºN) from IAP data after 1985

4. Zonal changes

- OHCT is dominated by ocean heat transport.
- Sfc flux, Q relates to P (evaporation)
- **The consistency between SST, Q and P anomalies originates from the diabatic effects of ENSO:** higher SST in the central tropical Pacific and west Indian during El Niño, along with changed winds, drives higher **evaporation**, which cools the ocean, and this atmospheric moisture boosts convection and enhances **P.**

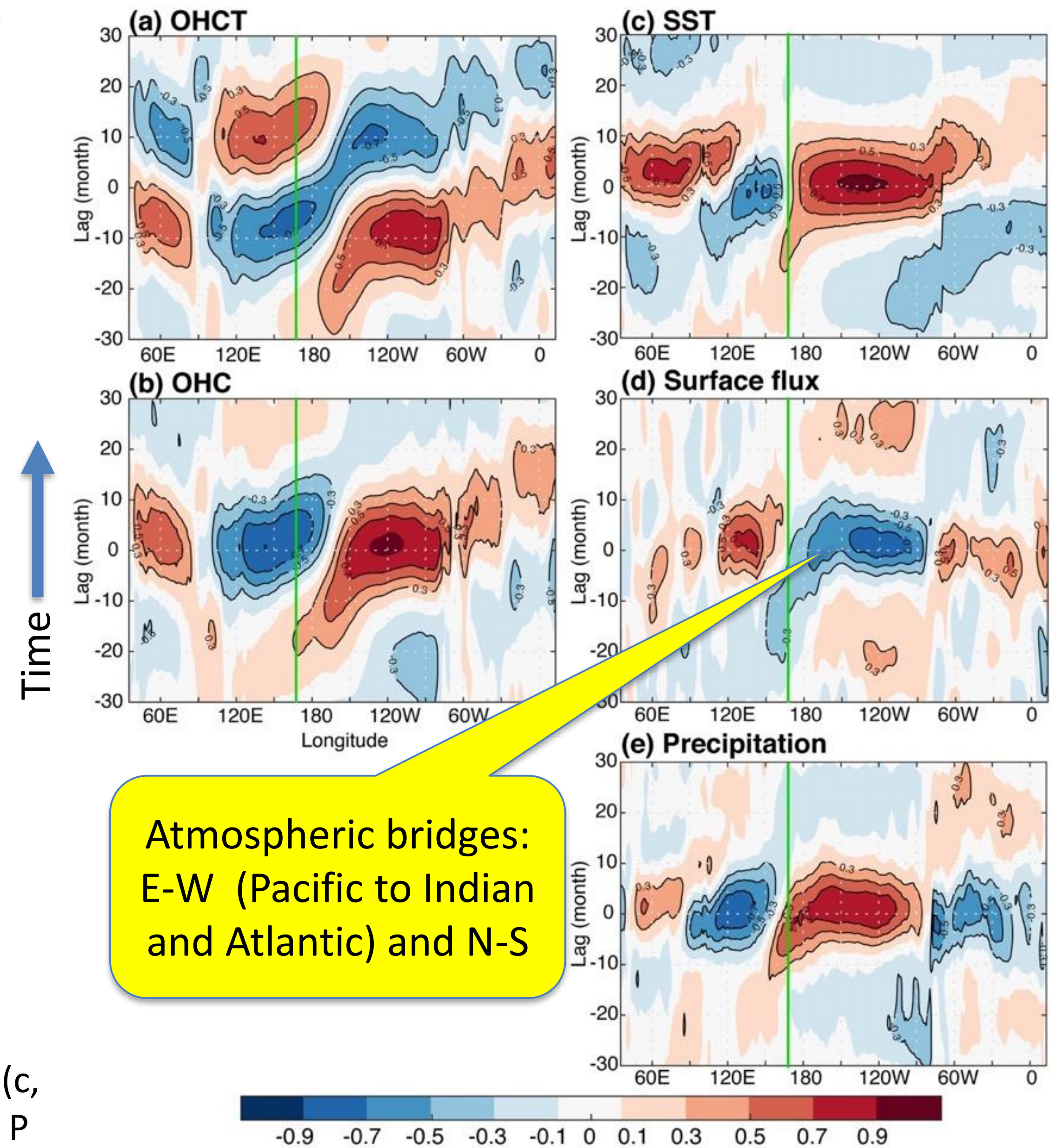
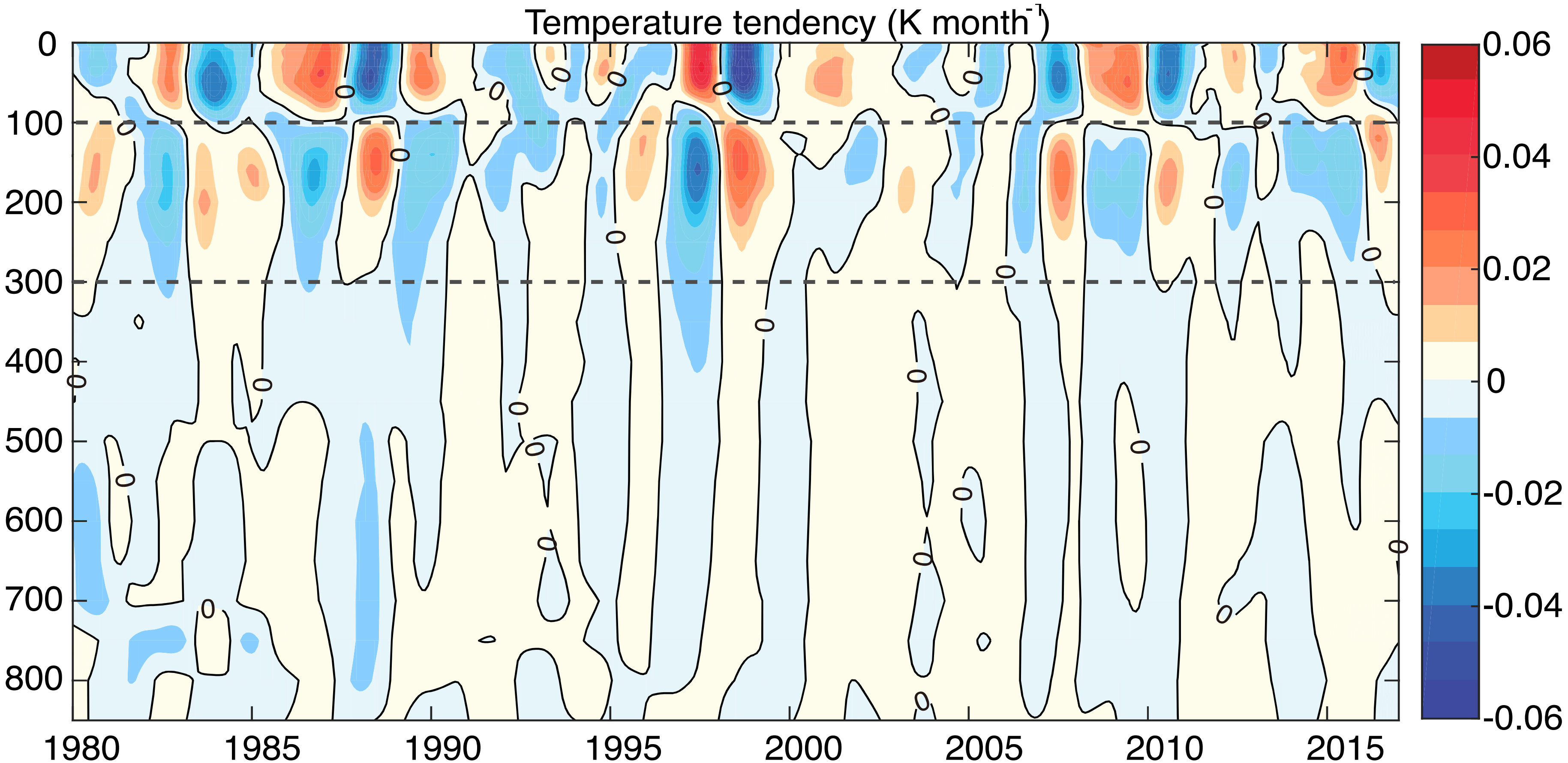


Fig. Lagged cross correlations of meridional mean OHCT (a, IAP data), OHC (b, IAP), SST (c, HadISST data), surface flux (d, DeepC data), P (e, GPCP) in tropics (20°S-20°N) as a function of longitudes.

5. Vertical heat redistribution

OHC changes in the tropics involve subsurface changes

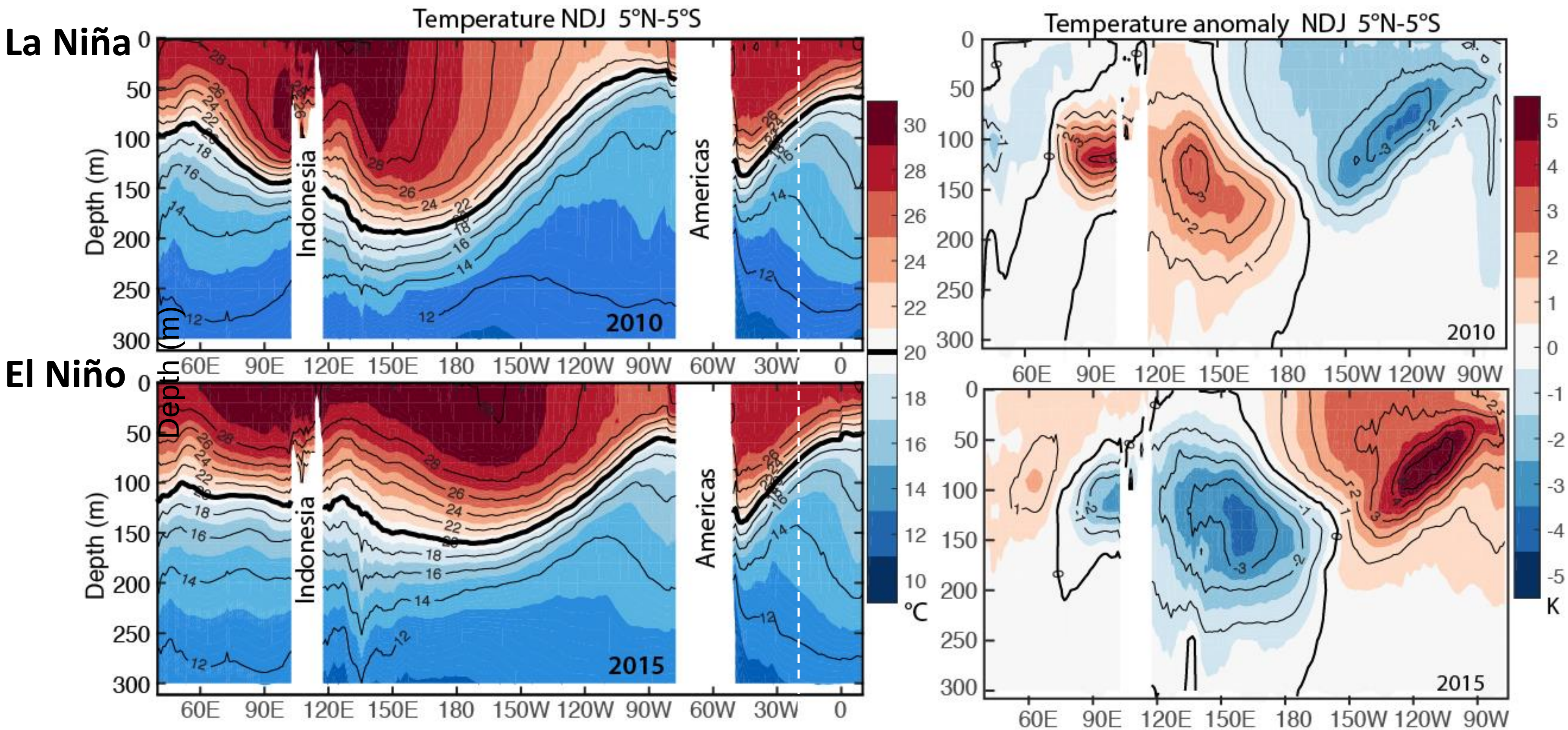
Adiabatic



- **temperature change within 100-300m is always opposite to the upper 100m change**

5. Vertical heat redistribution

OHC changes in the tropics involve subsurface changes (thermocline variations)

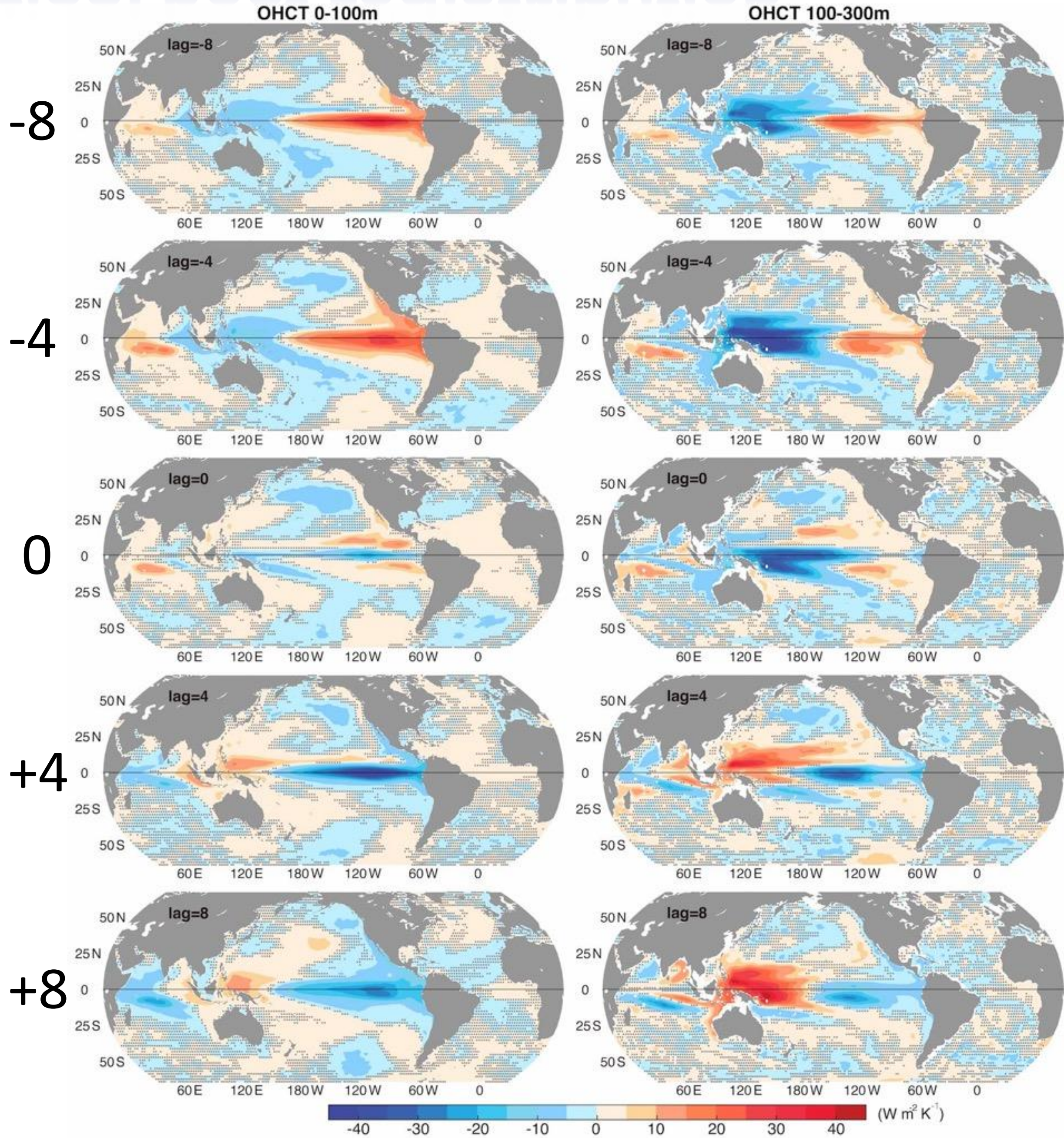


- **Zonal heat redistribution is related to the thermocline change**

5. Vertical heat redistribution

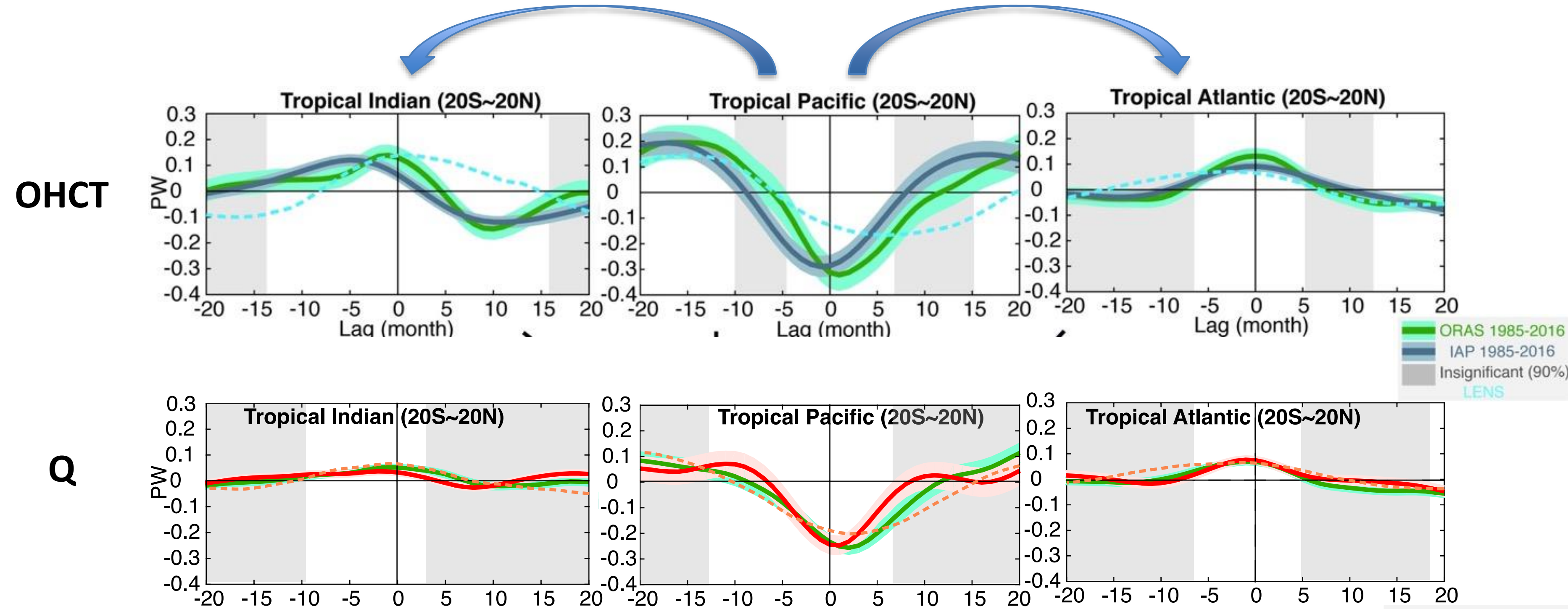
OHC change within 0-100m and 100-300m

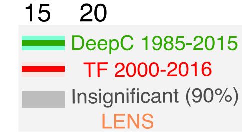
- Spatially, the vertical heat redistribution is dominated by tropical Pacific Ocean
- **Upper 100m**: Broad area of ocean warming in the **east Pacific** dominates the tropical/global OHCT
- **100-300m**: Broader cooling in the **west Pacific** dominates the tropical/global OHCT



6. Net ocean heat change in the tropics

OHC tendency ≈ Surface flux (Q) – DIV.F$_O$





Linear regression of OHCT (upper) and Q (bottom) against Nino3.4 SST

- **Strong tropical Pacific Ocean cooling driven by air-sea flux is responsible for the global mean cooling**
- **Large compensation among three tropical basins (atmospheric bridge: Walker circulation change)**
- **Indian Ocean also has the impact of ocean transport (ITF?)**

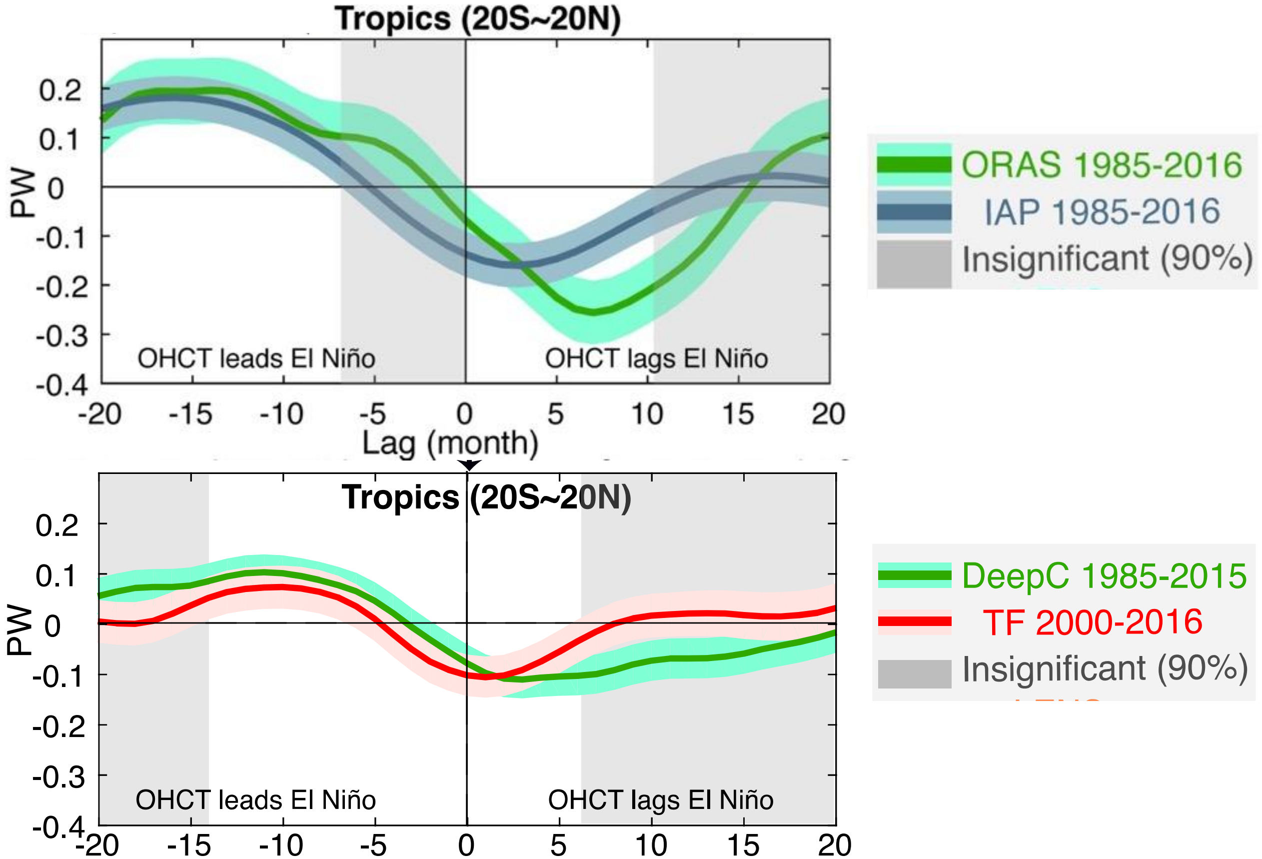
6. Net ocean heat change in the tropics
Pacific combined with Atlantic and Indian

- Dominated by Pacific

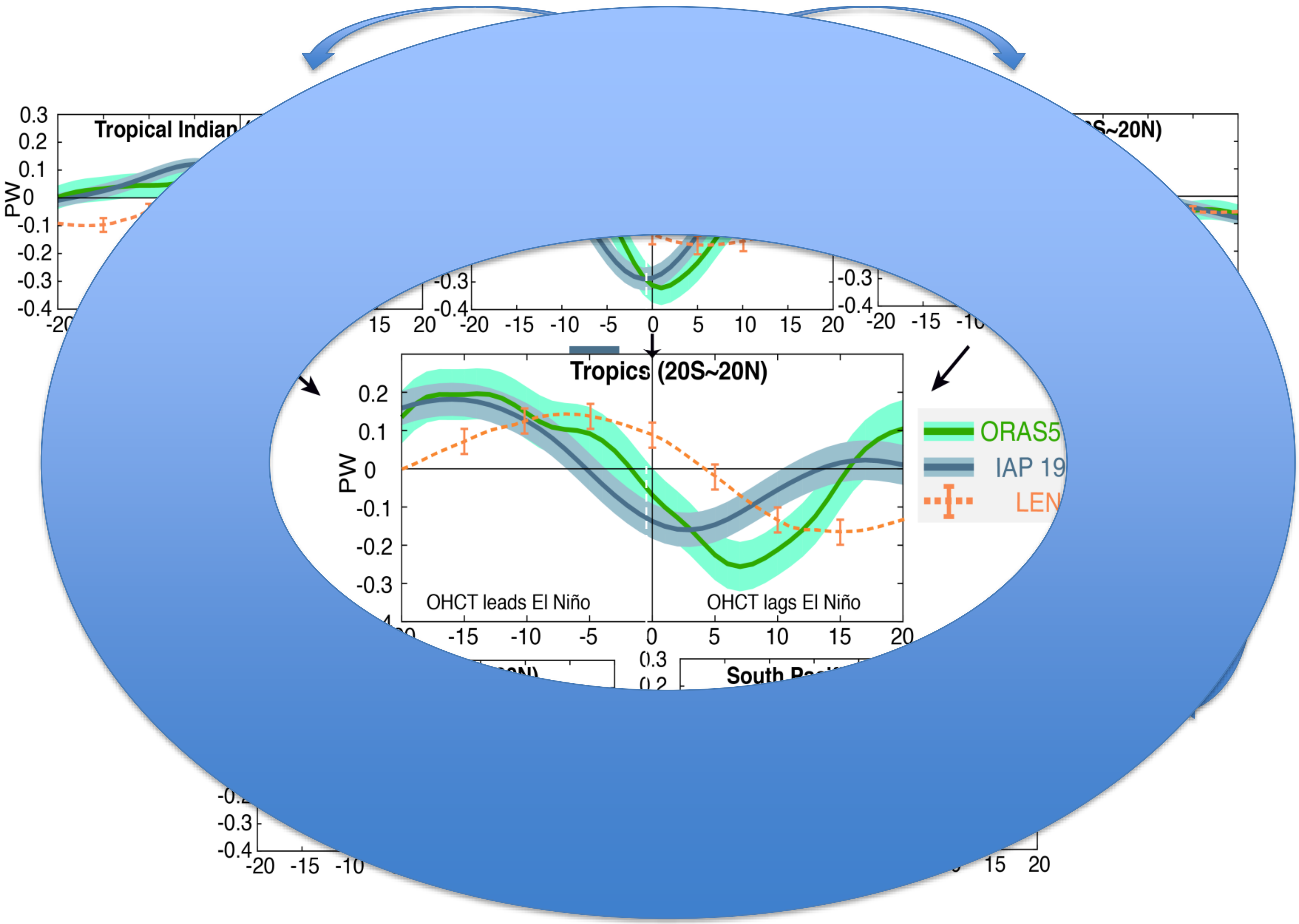
OHC tendency ≈ Surface flux (Q) – DIV.F$_O$

OHCT

Q



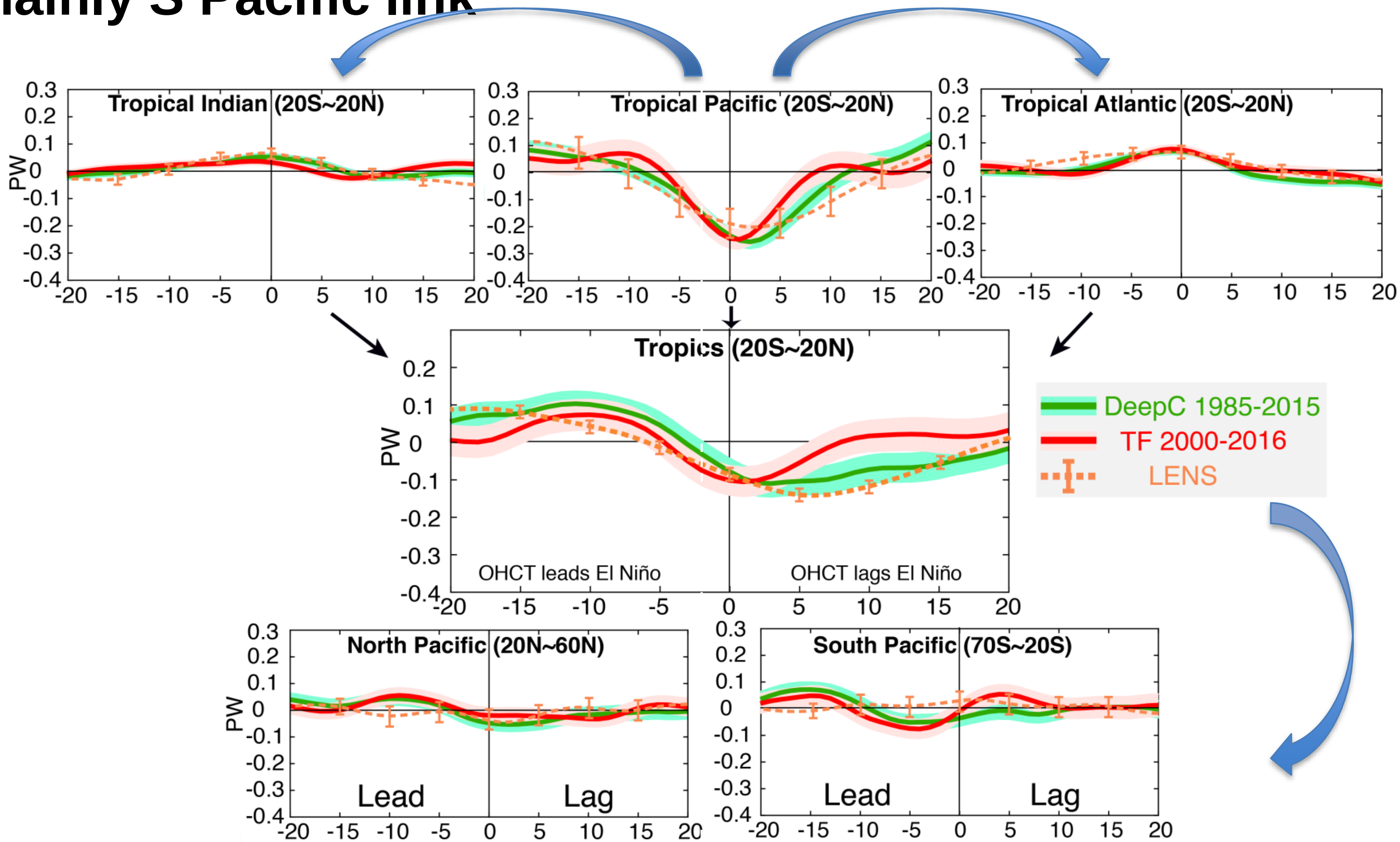
8. Ocean heat change regionally
OHC



8. Ocean heat change outside of the tropics

Surface fluxes

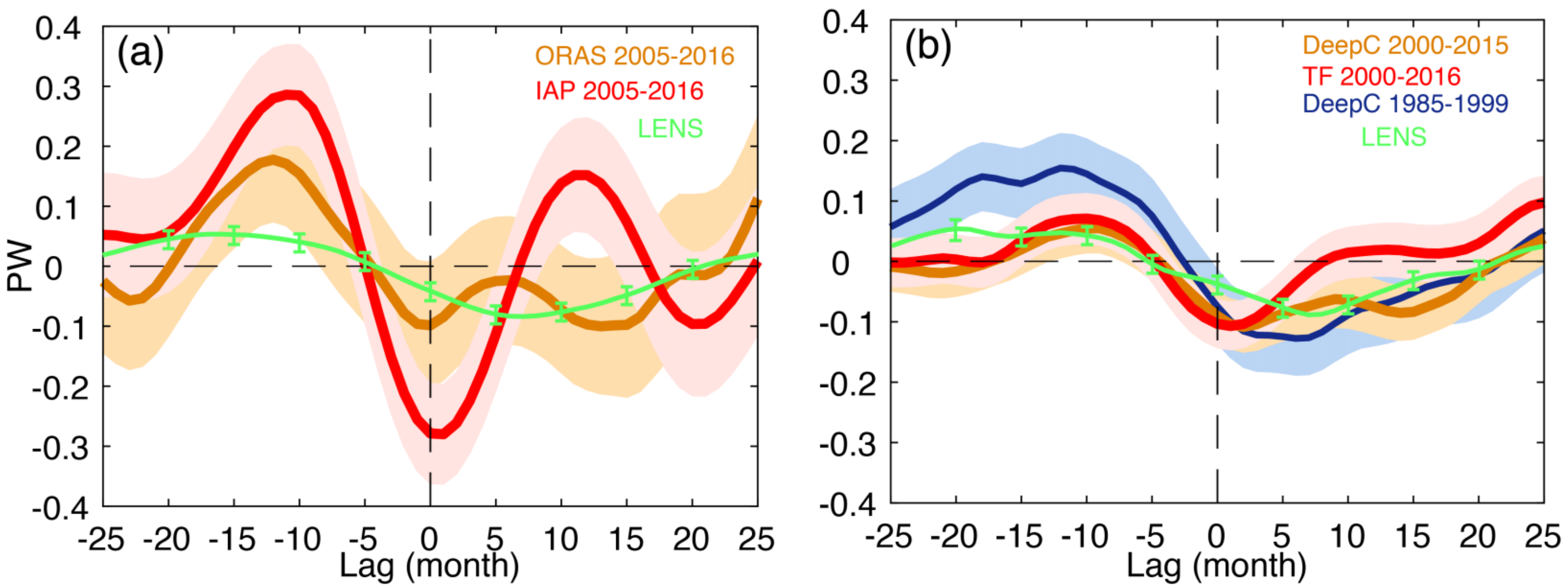
-mainly S Pacific link



10. Global OHC change

Global mean OHCT change (OHC: 0-2000m)

Globally, OHC tendency ≈ Surface flux (Q)



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(Submitted)

Linear regression of OHCT (a) and Q (b) against Nino3.4 SST

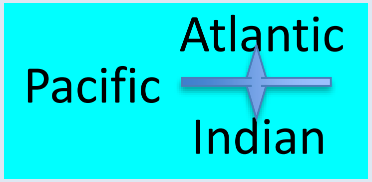
- **Robust global ocean cooling during El Niño due to air-sea exchange (revealed by three independent data: surface flux, and observational OHC)**
- **0.1 PW => 0.2 W m^{-2} globally**

Summary

- Net global ocean cooling during El Niño is reflected in the surface flux
  - Evaporative cooling of ocean
  - Latent heating of atmosphere
  - Net loss of heat to space

} OCEAN HEAT DISCHARGE

- Compensation of heat change in tropical Pacific (↓), Atlantic (↑); Indian (↑); and South Pacific (↑) oceans, but
- Pacific Ocean cooling dominates global changes
- Ocean moves heat laterally and vertically during ENSO
- Atmospheric bridges also redistribute energy
- GMST rises as ocean loses heat



A number of previous studies have incorrect answers because they failed to include all domains and processes.