Jet Propulsion Laboratory
California Institute of Technology

# The Relative Influence of Salinity and Temperature on Surface Density Gradient in the Tropical Pacific Ocean

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# INTRODUCTION

- Surface Salinity (SSS) and Temperature (SST) influence surface Density through the Equation of State :

$$\rho-\rho_0=\rho_{ref}\{-\alpha(T-T_0)+\beta(S-S_0)\}$$

- Density gradients in the tropical Pacific are mainly meridional and are associated with baroclinic instabilities

- Salinity fluctuations can regulate the baroclinic energy transfer (McPhaden et al. 1984, Grodsky et al. 2005, Lee et al., 2014)

- The new spaceborn SSS datasets give a new capability to enhance our knowledge of the density field and its variability as well as the contribution of SSS and SST

# DATA

SSS :

- **Aquarius/SAC-D** level-3 gridded dataset (V3.0 by the Aquarius Project via PO.DAAC) 1º spatial resolution from combined passes averaged over 7 day for August 2011-July 2014
- **SMOS** level-3 gridded dataset (v2013 CEC-LOCEAN) ¼º grid every 10 days for January 2010-July 2014
- **ISAS** in situ based optimal interpolation, 1º spatial resolution, monthly for 2010-July 2014 (Ifremer)

SST :

- **OSTIA** level-4 product (V1.0 by the UK Met Office), 0.054º grid at daily interval from 2006 to present
- **Reynolds** level-4 product (V2.0 by NCDC/NOAA) ¼º daily from 1981 till present
- **ISAS** as for SSS

Currents:

- **OSCAR** level-4 product (by ESR), 0.33º grid, every 5 days, 1992 to present

**All averaged on a 1º grid every 7 days over the Aquarius period**

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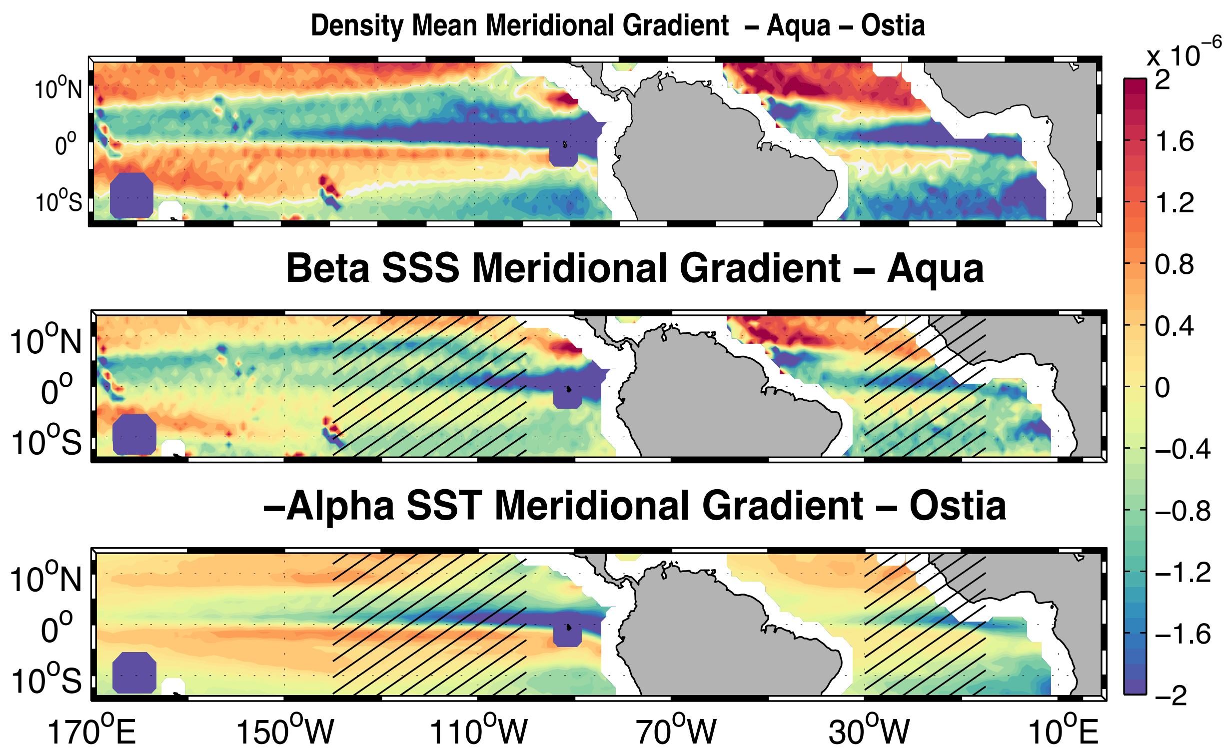
# Pacific Ocean Meridional gradient of surface ρ

Contributions of SSS (Aquarius v3) and SST (OSTIA)




- When looking in the **density space**, SSS and SST meridional gradients are of the same magnitude

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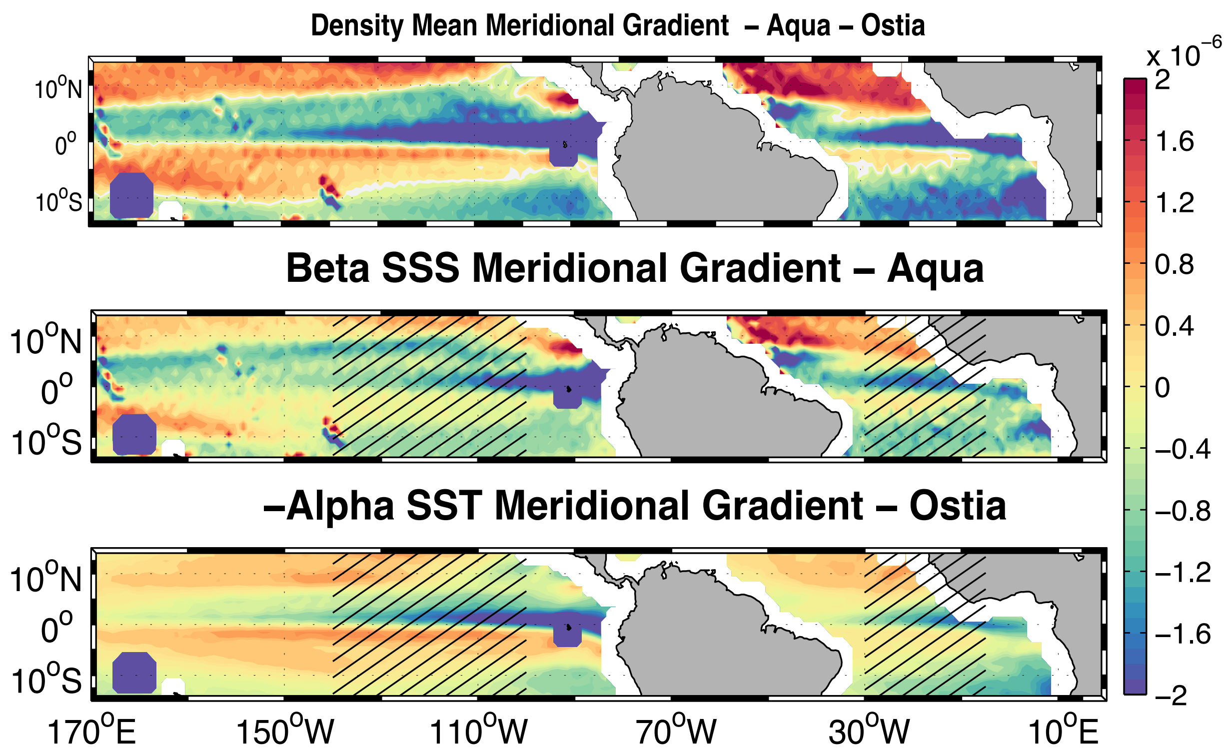


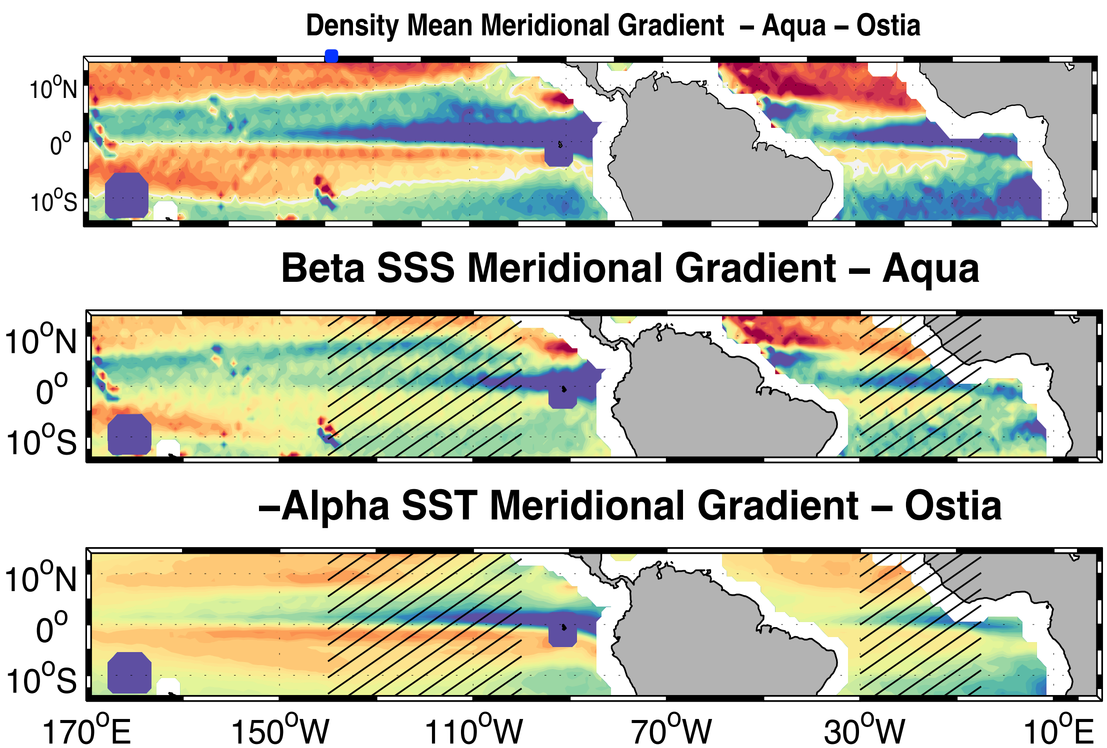

- When looking in the density space, SSS and SST meridional gradients are of the same magnitude
- SSS and SST both contribute around the equator

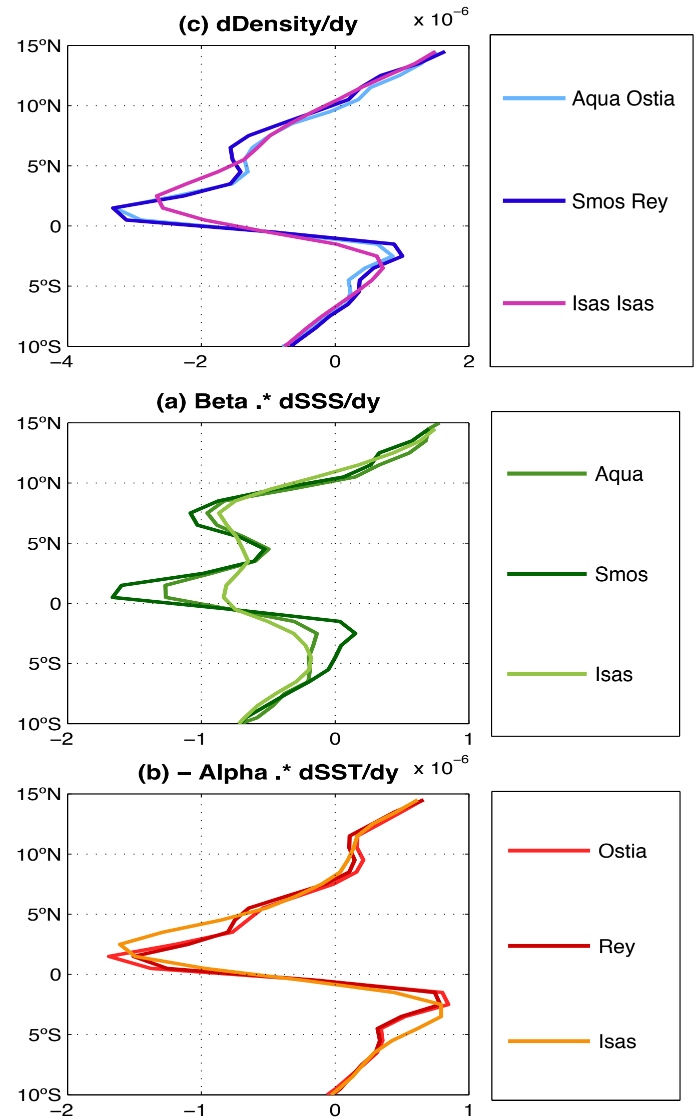
SSS dominates density where we observe strong regional gradients :

- in the upwelling zones
- near the ITCZ and SPCZ
- around the great estuaries (Amazon, Congo, Niger)

# Pacific Ocean Meridional gradient of surface ρ

## Contributions of SSS (Aquarius v3) and SST (OSTIA)




| | β*dS/dy | -α*dT/dy |
|---|---|---|
| 1ºN | -1.3 | -1.4 |
| Equator | -0.8 | -0.1 |
| 1ºS | -0.3 | 0.8 |

$*10^{-6}$

$\beta\, \partial S/\partial y$ is much larger than $-\alpha\, \partial T/\partial y$ at the equator

# Pacific Ocean Meridional gradient of surface ρ

Comparison of SSS and SST products

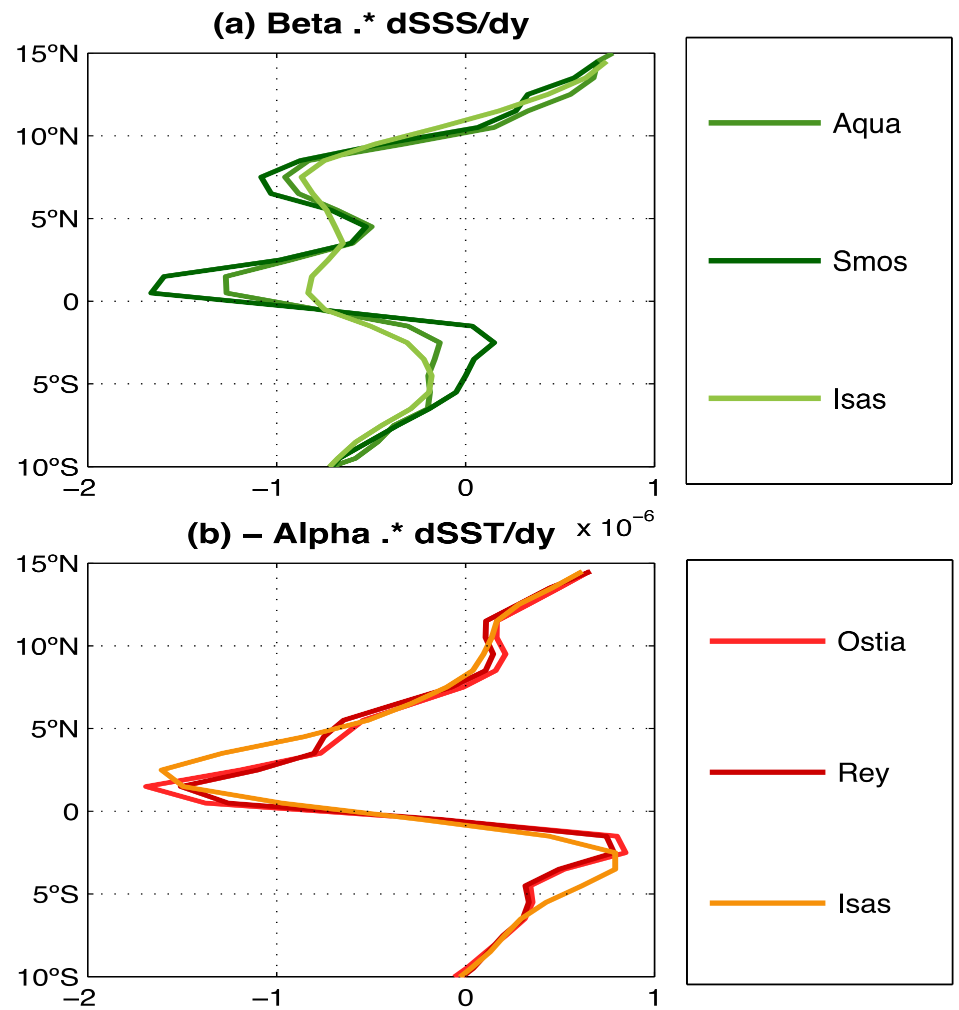
All SSS and SST products show consistent meridional profiles

SSS

- All SSS products show relative maxima at the same latitudes
- ISAS SSS fronts are weaker
- SMOS fronts are stronger

SST

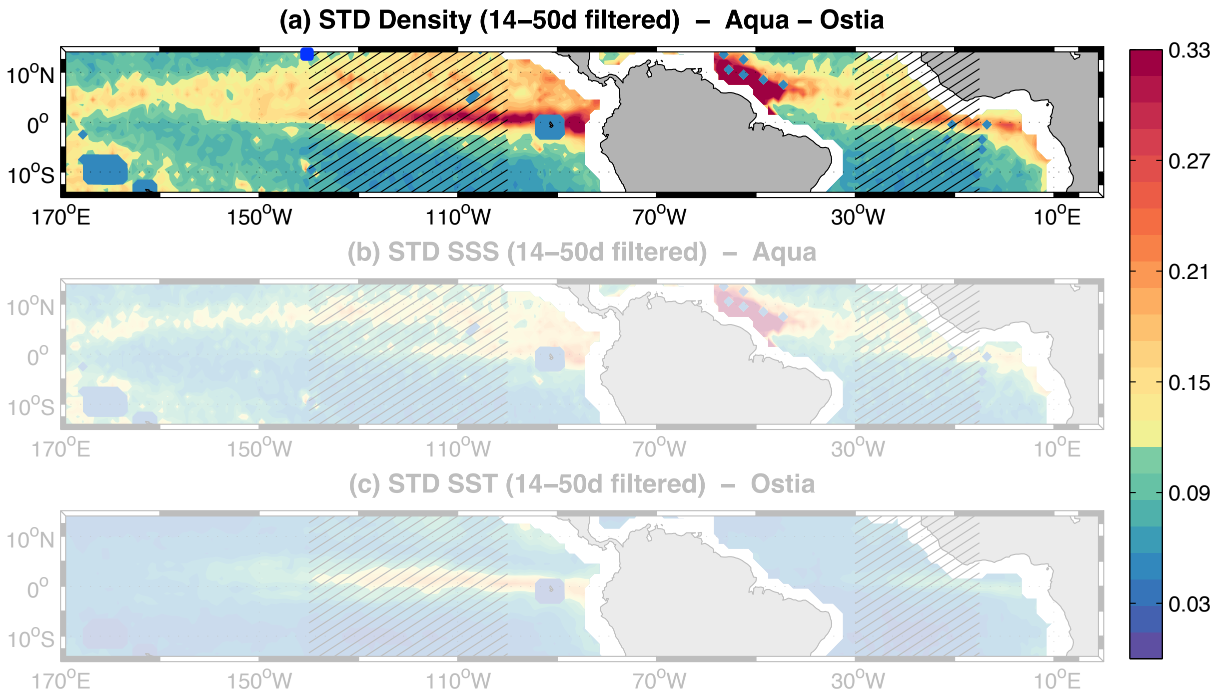
- All SST product show similar amplitude in the maxima
- ISAS SST maxima are shifted poleward and less narrow

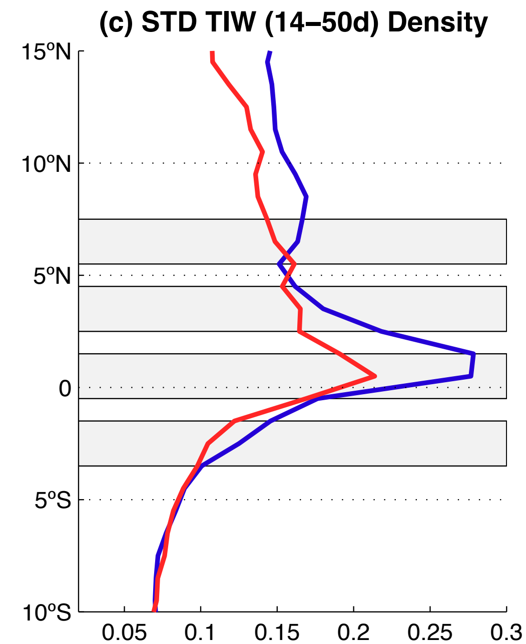


# Variability of ρ in the 14-50d band

Contributions of SSS (Aquarius v3) and SST (OSTIA)

- **Pacific**
- Atlantic




- In the Pacific Ocean, strongest variability found with 3ºN off the equator and around 7.5ºN
- Contribution of SSS in the 2 zones
- Contribution of SST only near equator

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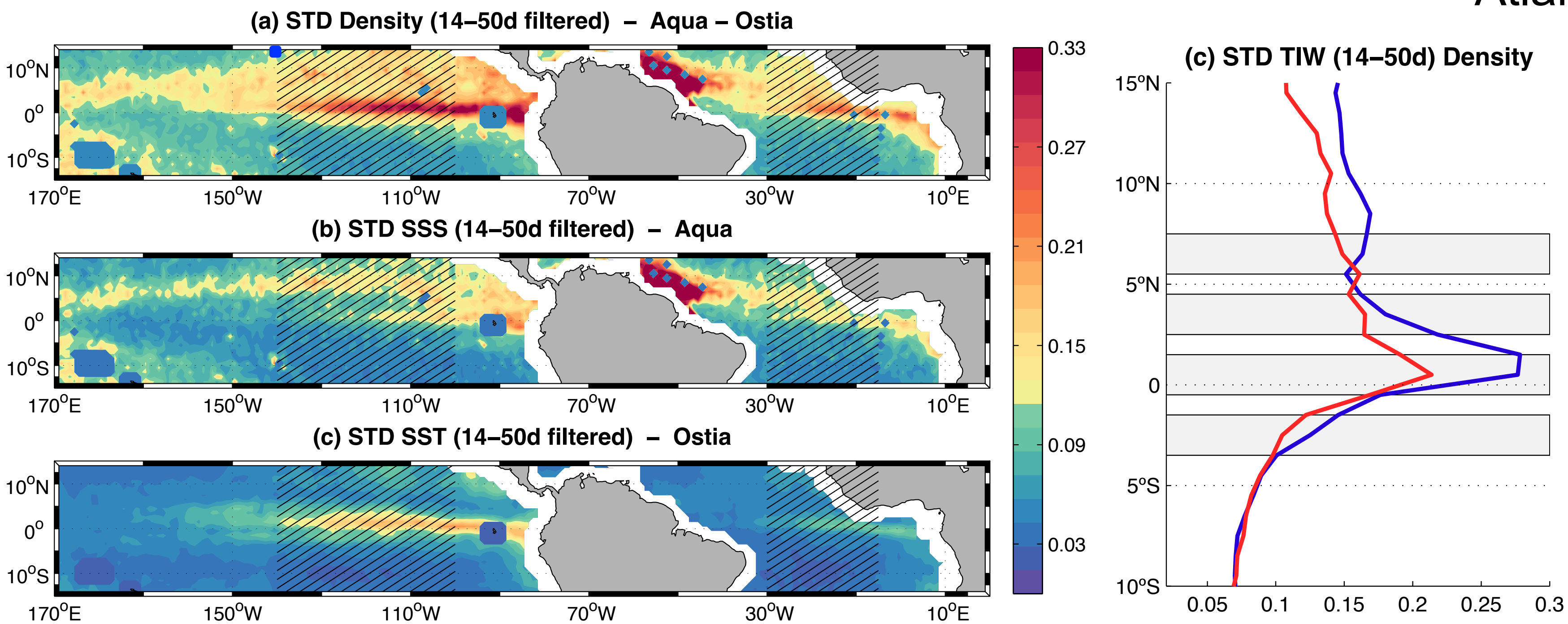


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# Sources of variability in the 14-50d band

From SSS (Aquarius v3) and SST (OSTIA)

- **Tropical Instability Waves** (TIWs) which extract energy through:
  - **Baroclinic conversion** between the background available potential energy and the perturbation potential energy (PPE)
  - **Barotropic conversion** between the background kinetic energy and the perturbation kinetic energy
  - We neglect the Kelvin-Helmholtz conversion (daily and shorter fluctuations)
- **Freshwater fluxes** mainly in the ITCZ and SPCZ

  - **Baroclinic instabilities** via the 50d low passed (LF) meridional density gradient (a)
  - **Barotropic instabilities** via the LF meridional gradient of zonal current (b)
  - **Freshwater fluxes** via Precipitation standard deviation (c)

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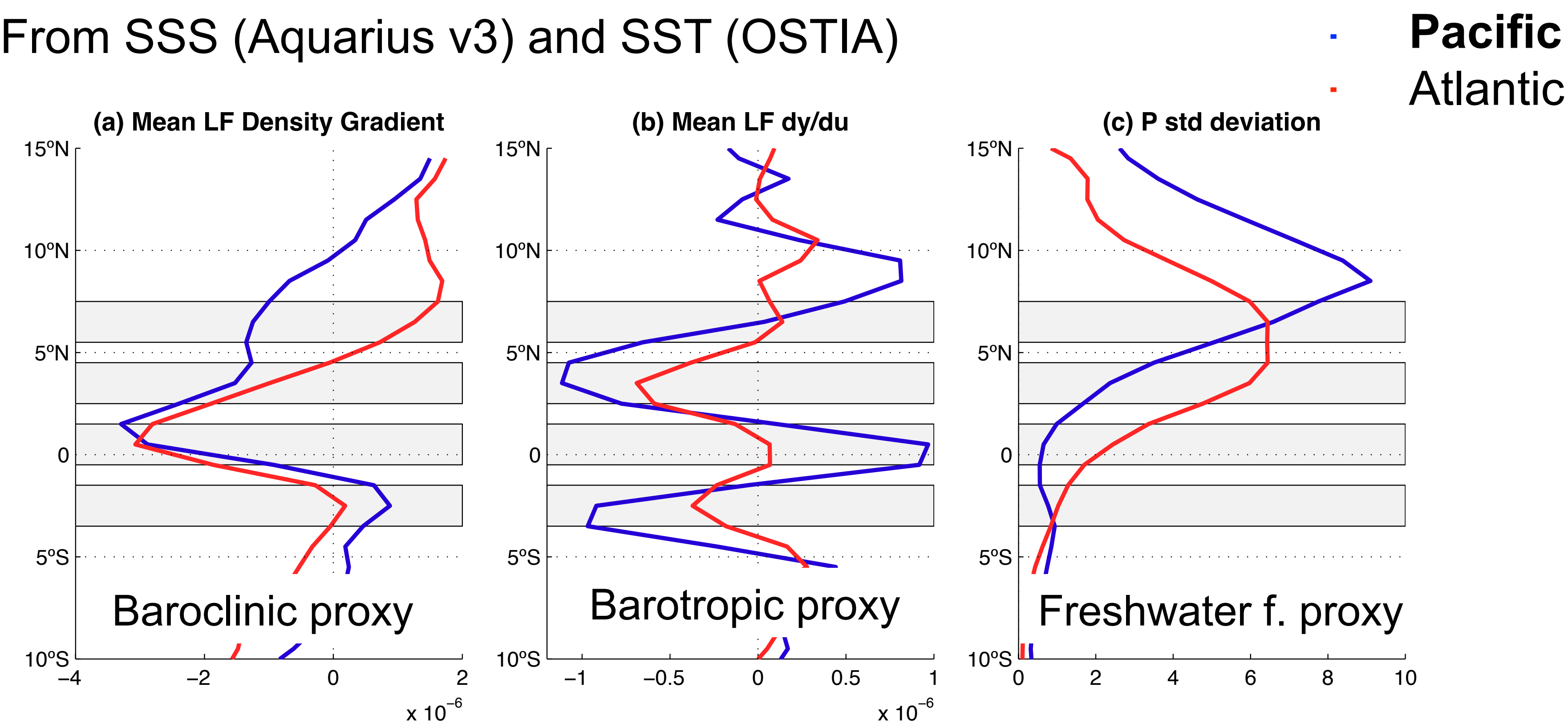


To give an idea on where sources of variability are important: 3 proxies

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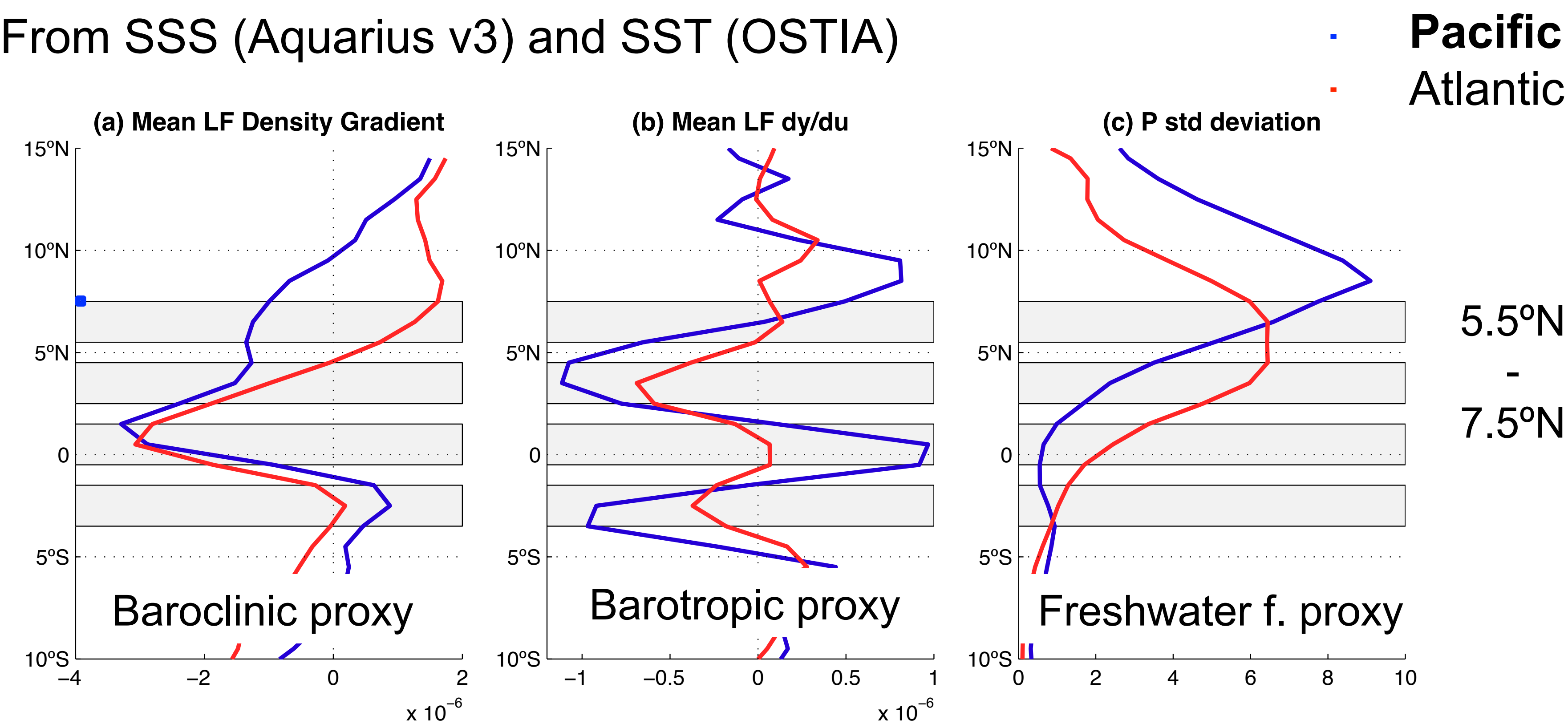


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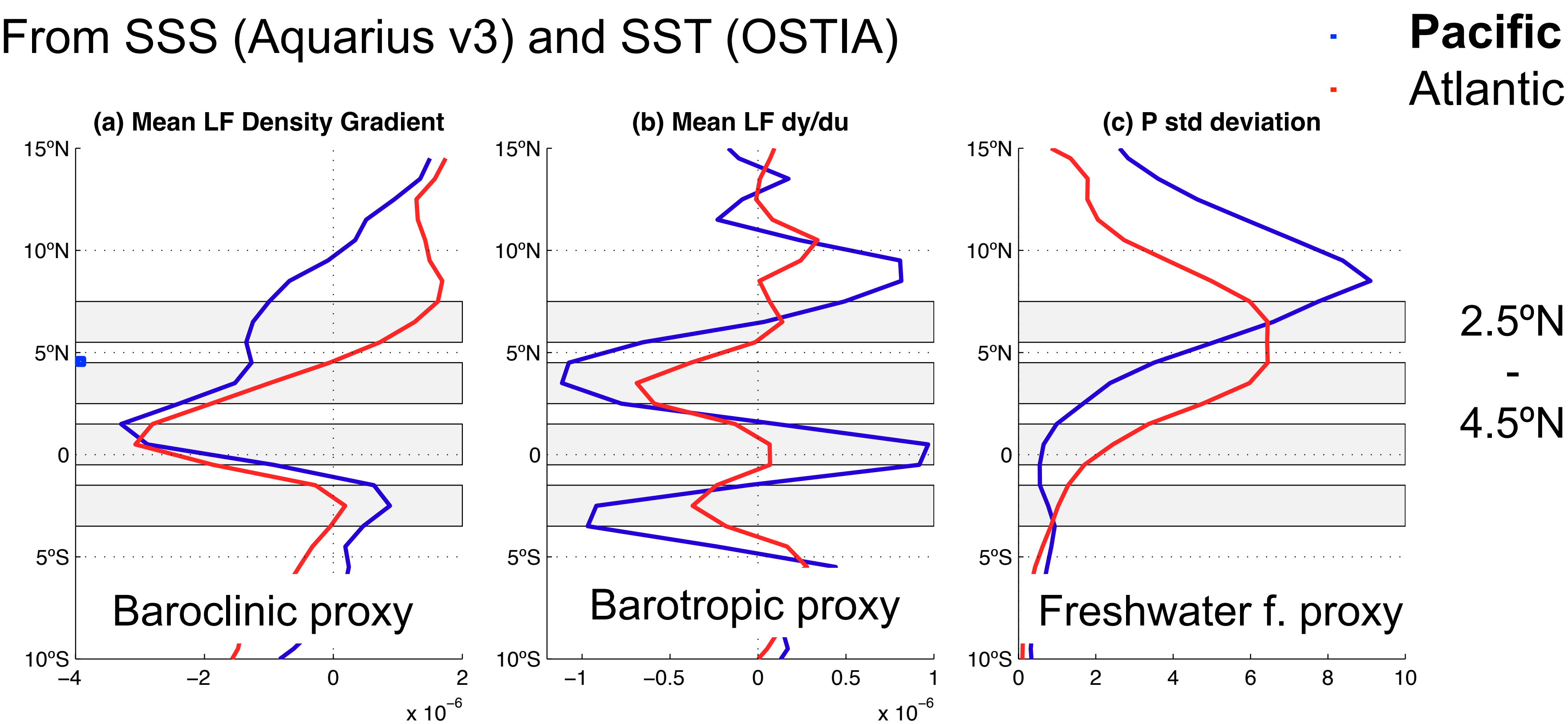


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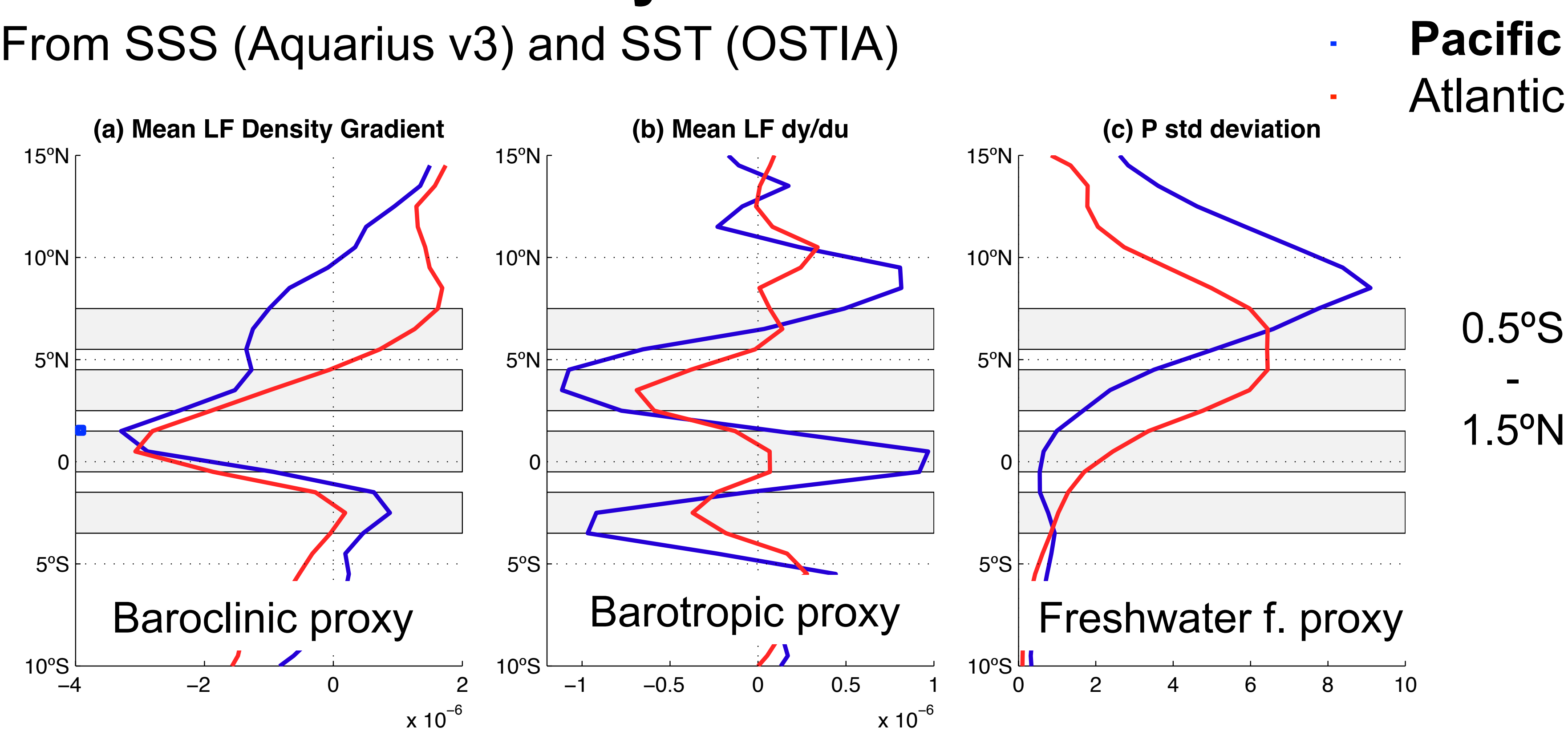


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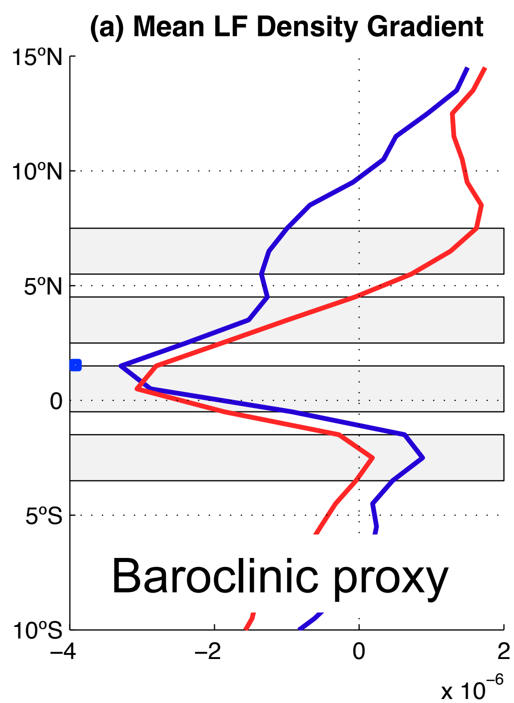
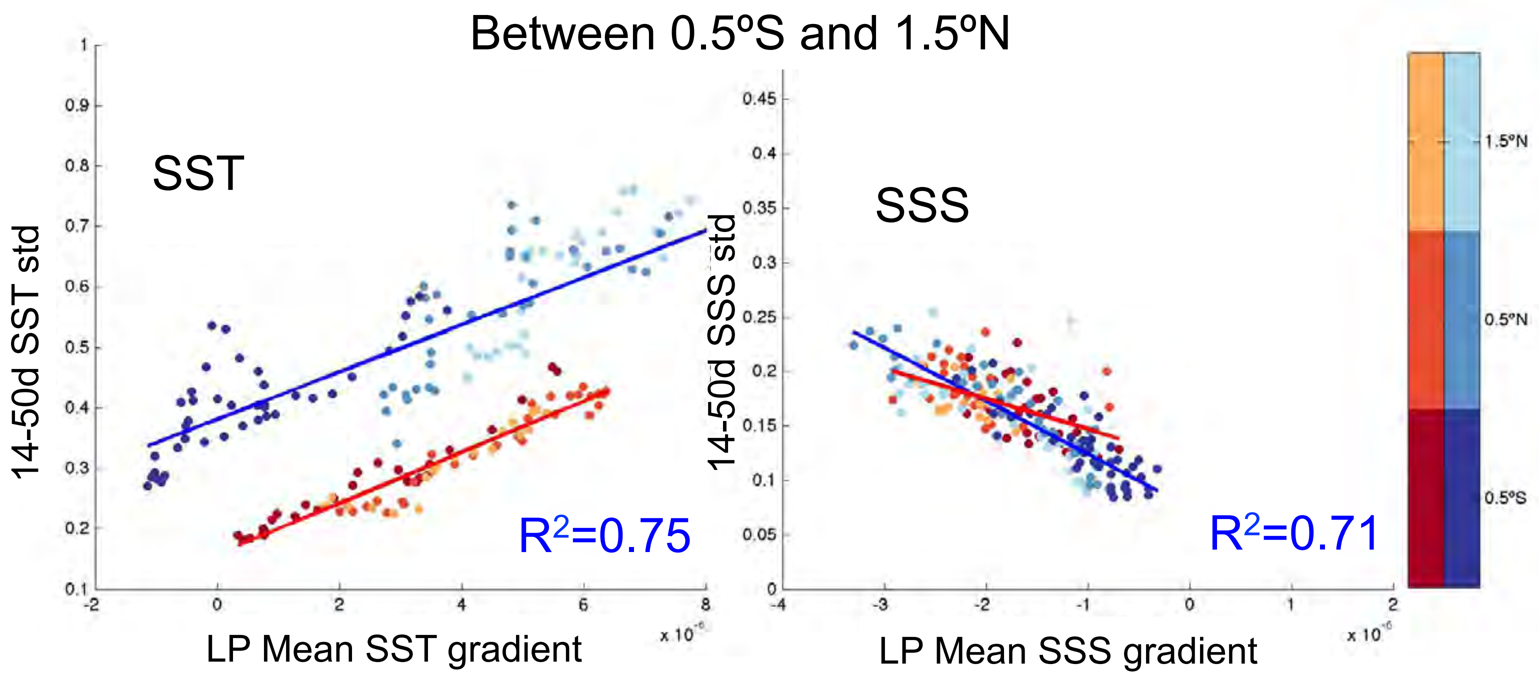



The recent SSS datasets give a **new insight to the Baroclinic Energy conversion** between the background available potential energy and the TIW induced Perturbation Potential Energy (PPE)

# Indication of Baroclinic conversion of energy

Contributions of SSS (Aquarius v3) and SST (OSTIA)

- **Pacific**
- Atlantic

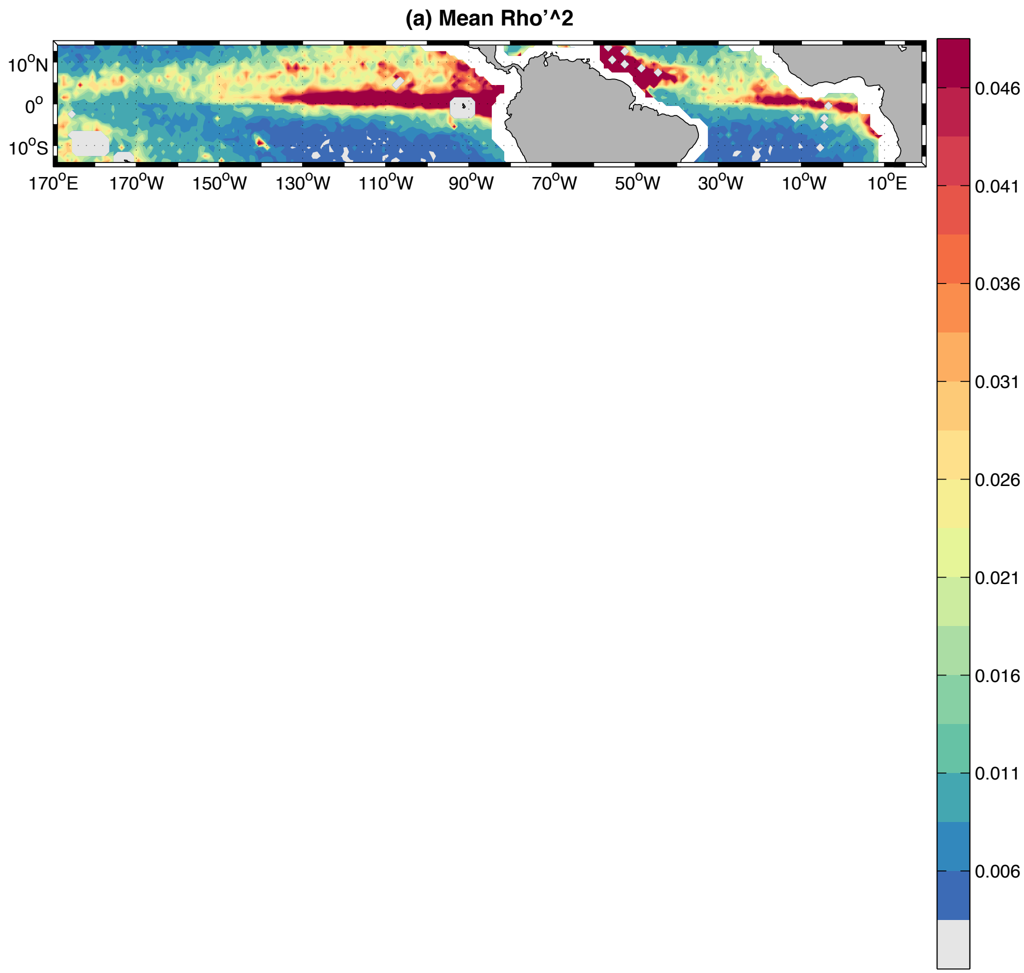



- High correlation in SST as found by Shelton et al. (2000) over 1998-99
- High correlation in SSS as well

Shows the **relation between the 14-50d variability and the low frequency meridional gradient**, reflecting baroclinic energy transfer between the TIW and background field

# Contribution of S and T to density variance

$\rho'^2$ as a proxy for the PPE and baroclinic conversion rate



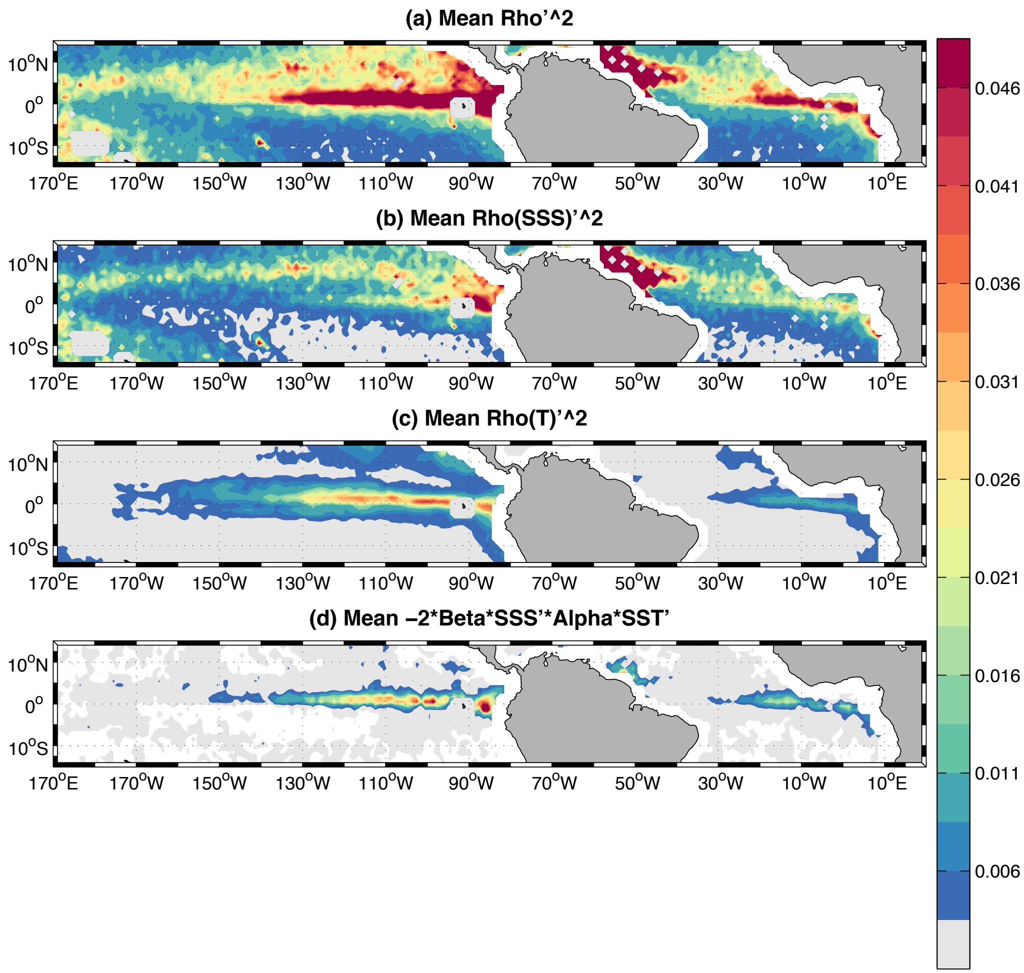

Perturbation Potential Energy (PPE) :

$$PPE = \frac{g\rho'^2}{2\rho_{0z}} = \frac{g{\rho_0}^2}{2\rho_{0z}}\{(\beta S')^2 + (-\alpha T')^2 - 2\alpha\beta T'S'\}$$

PPE is linked to Baroclinic conversion if no transfer from Kinetic to Potential Energy

# Contribution of S and T to density variance

ρ'[2] as a proxy for the PPE and baroclinic conversion rate




Perturbation Potential Energy (PPE)
Is proportional to :

$$\rho'^2 = \rho_0\{(\beta S')^2 + (-\alpha T')^2 - 2\alpha\beta T'S'\}$$

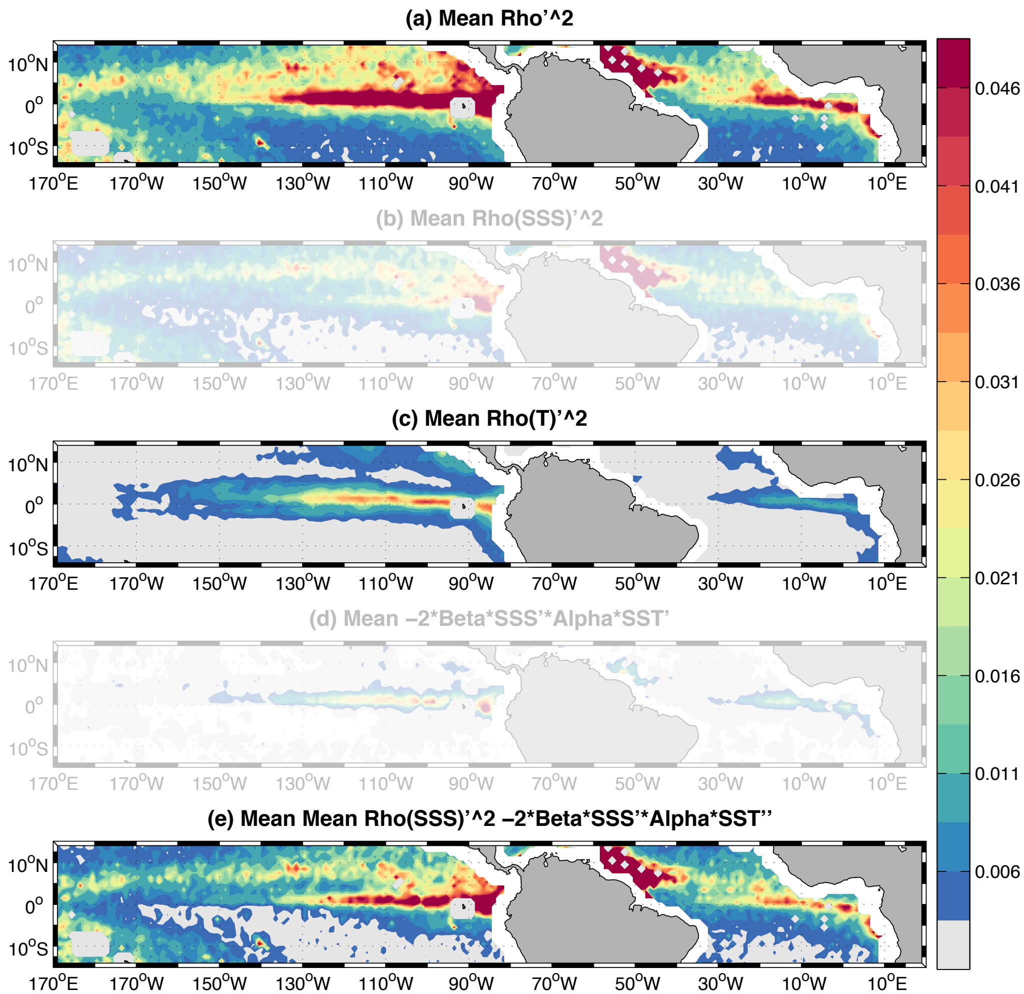
Direct contribution of SSS

Direct contribution of SST

Contribution of the SSS and SST covariance

# Contribution of S and T to density variance

$\rho'^2$ as a proxy for the PPE and baroclinic conversion rate




Perturbation Potential Energy (PPE)

Is proportional to :

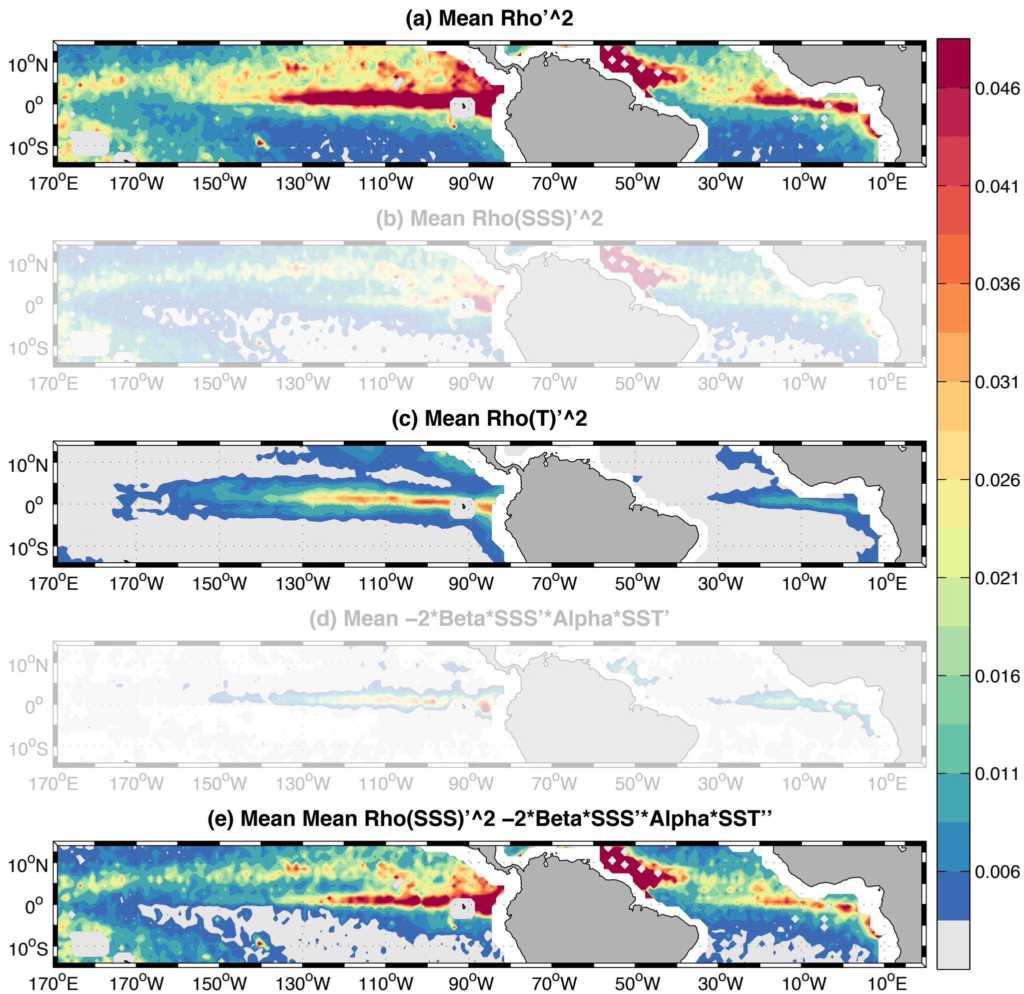
$$\rho'^2 = \rho_0\{(\beta S')^2 + (-\alpha T')^2 - 2\alpha\beta T'S'\}$$

Direct contribution of SST

Direct and indirect contribution of SSS

# Contribution of S and T to density variance

ρ'² as a proxy for the PPE and baroclinic conversion rate




Perturbation Potential Energy (PPE)
Is proportional to :

$$\rho'^2 = \rho_0\{(\beta S')^2 + (-\alpha T')^2 - 2\alpha\beta T'S'\}$$

Omitting SSS to the PPE computation lead to an underestimation of

- **72%** in the entire domain
- **66%** in the northern edge of the CT
- **84%** in the ITCZ

consistent with Grodsky et al. (2005) and Lee et al. (2014) findings in the Atlantic Ocean.

# CONCLUSIONS

- Satellite measurements of SSS has enabled the studies of the **relative contribution of SST and SSS** on the **mean meridional density gradient** as well as the **TIW-related density variability** on basin scale.

- **Salinity has a substantial effect** on meridional gradient and thus TIW-related **baroclinic energy conversion**, both in the Pacific and the Atlantic.

- All SSS and SST products are consistent. **Spaceborn data captures sharp gradients and variability** not seen in gridded observations.

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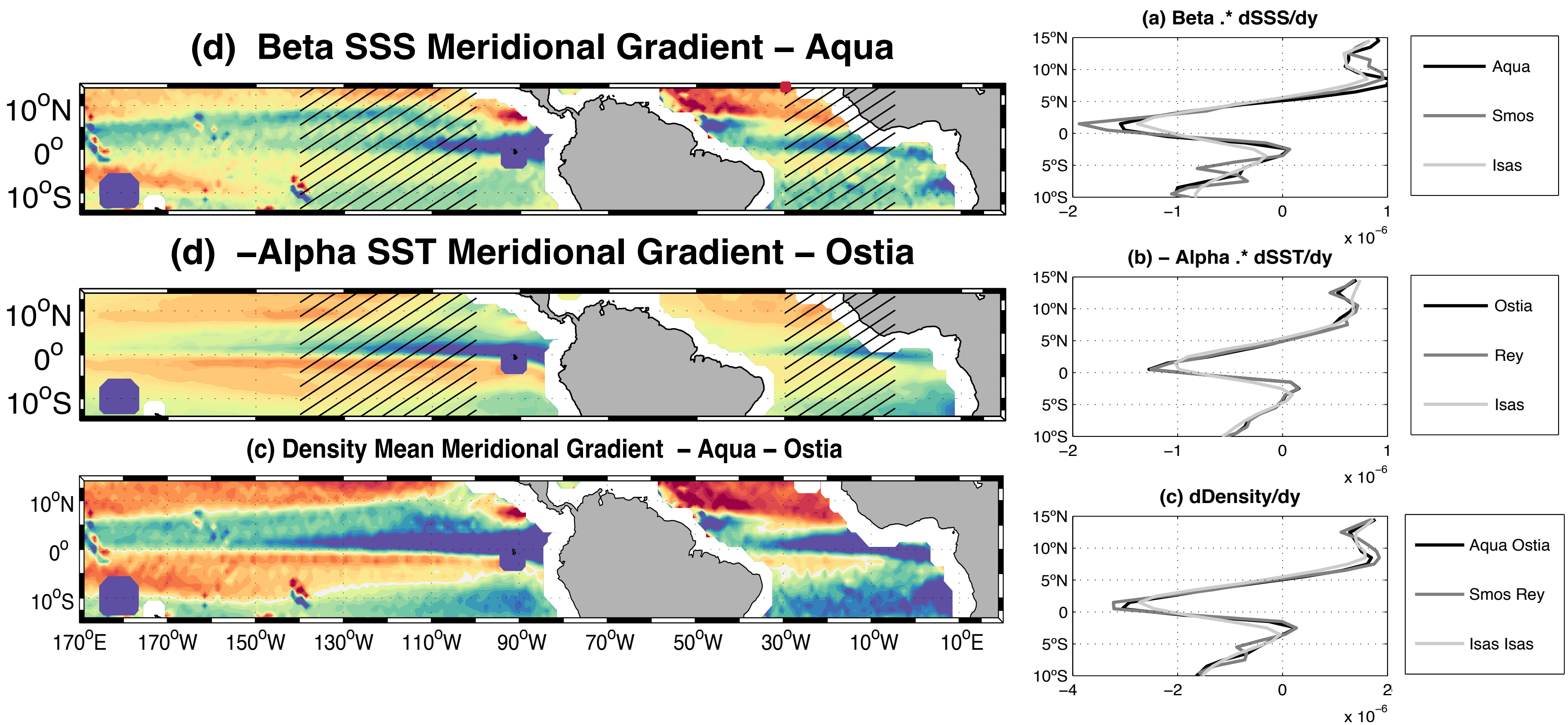
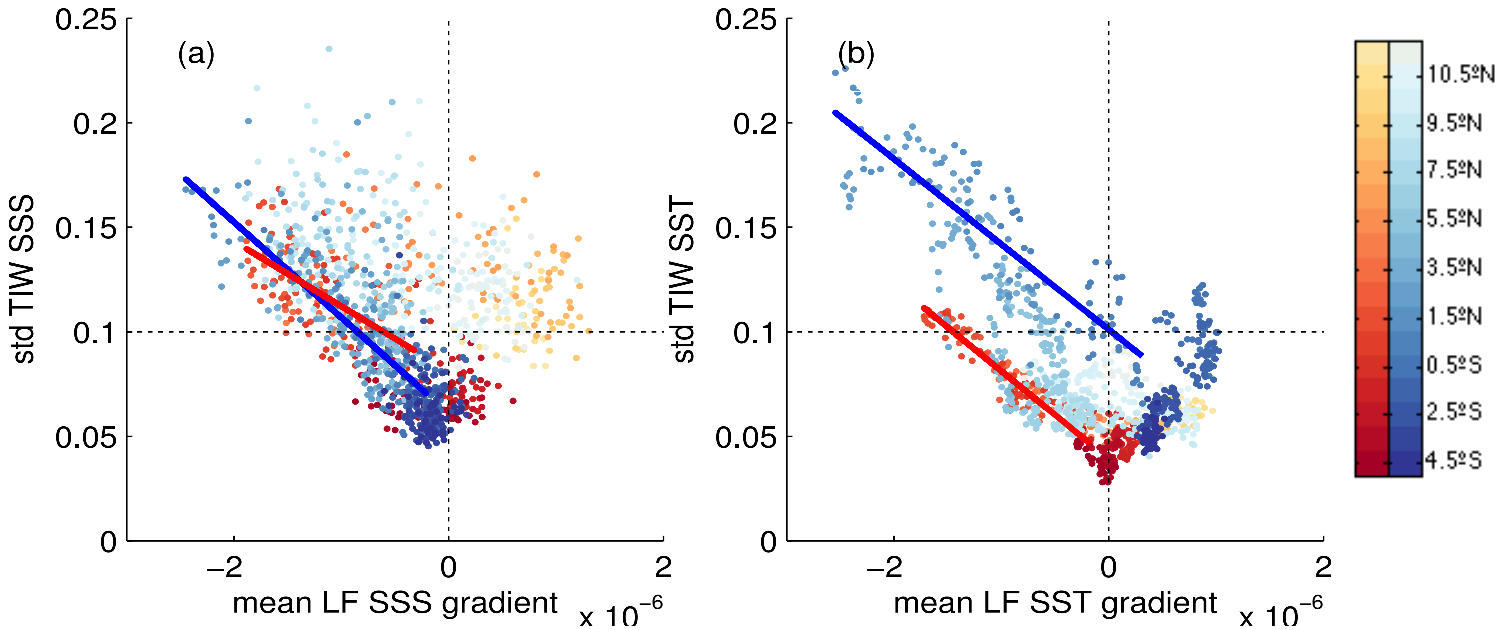

(d) Beta SSS Meridional Gradient – Aqua
(d) –Alpha SST Meridional Gradient – Ostia
(c) Density Mean Meridional Gradient – Aqua – Ostia
10°N
0°
10°S
170°E
170°W
150°W
130°W
110°W
90°W
70°W
50°W
30°W
10°W
10°E
(a) Beta .* dSSS/dy
Aqua
Smos
Isas
(b) – Alpha .* dSST/dy
Ostia
Rey
Isas
(c) dDensity/dy
Aqua Ostia
Smos Rey
Isas Isas
15°N
10°N
5°N
0
5°S
10°S
x 10⁻⁶

- Pacific
- Atlantic

# Baroclinic conversion of energy

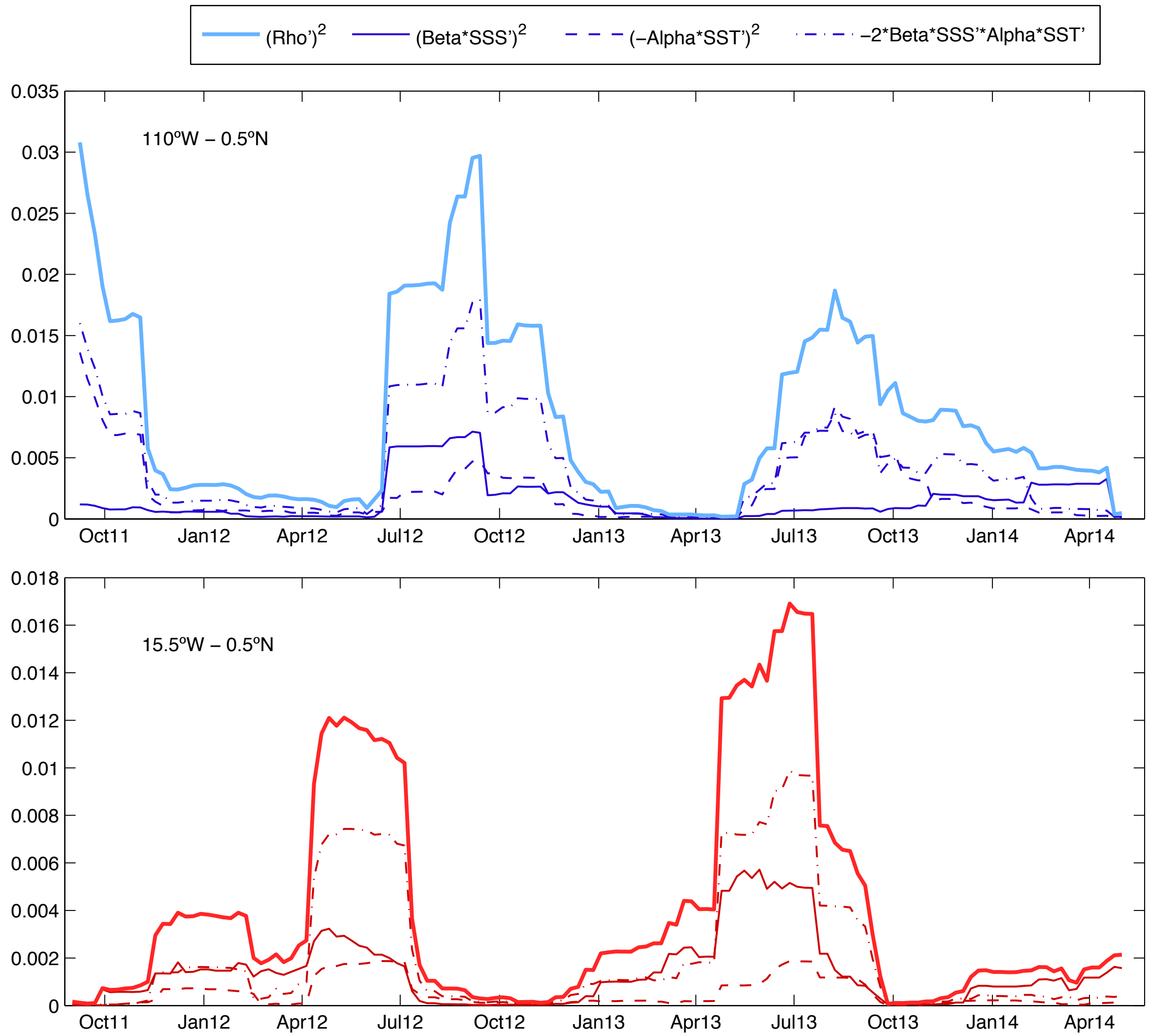
## Contributions of SSS (Aquarius v3) and SST (OSTIA)

Pacific (blue) and Atlantic Oceans (red) between –5.5–11.5ºN



# Seasonality of the baroclinic conversion rate

## Contribution of SSS and SST



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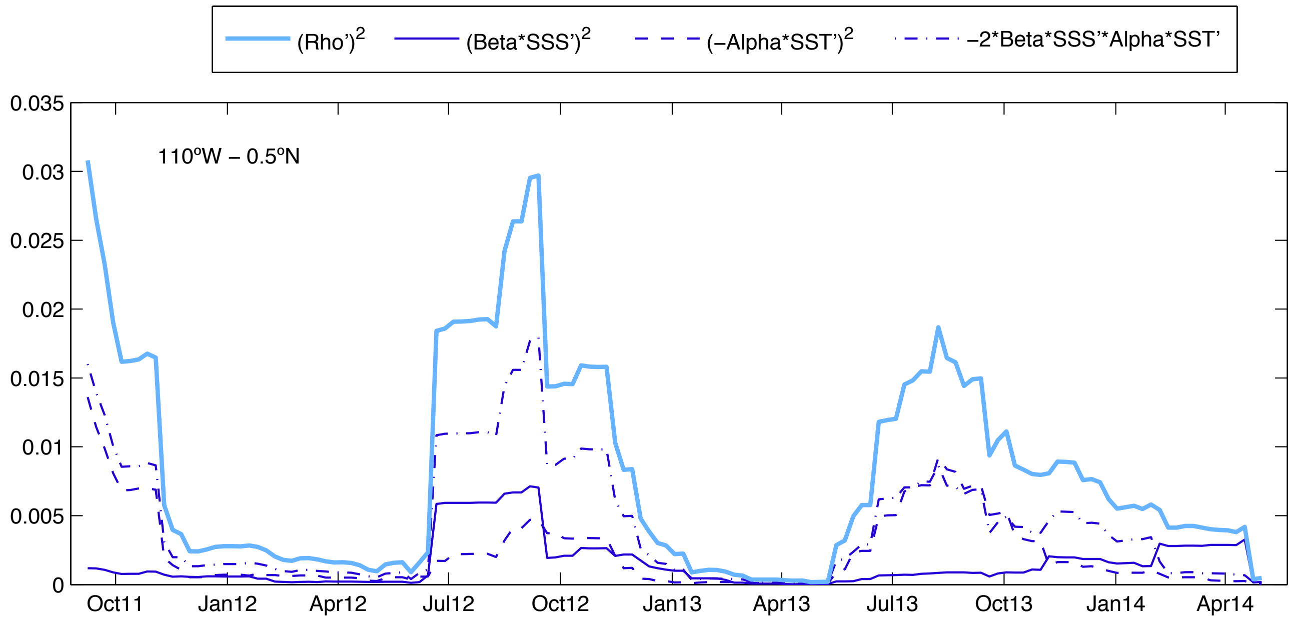


Seasonal cycle in the proxy for PPE

- Maximum from July to January – consistent with TIW activity cycle
- Contribution from SST following the cycle
- Contribution from SSS has a strong interannual variability