Correlations across air-sea interface for variables without direct analogs

Santha Akella

Global Modeling and Assimilation Office (GMAO)
At NASA GSFC

State variables across air-sea interface

Atmosphere

- Wind: $(\vec{U}_a, \vec{V}_a)$
- Temperature (T_a)
- Humidity (Q)
- Pressure (P_s); 2d
- Skin SST (T_s); 2d

$$X_a = [U_a, V_a, T_a, Q, P_S, T_S]^T$$

Atmospheric Analysis

?

$$\mathbf{P} = \begin{bmatrix} \mathbf{P}_{\mathbf{a,a}} & \mathbf{P}_{\mathbf{a,o}} \\ \mathbf{P}_{\mathbf{o,a}} & \mathbf{P}_{\mathbf{o,o}} \end{bmatrix}$$

- Current $(\vec{U}_o, \vec{V}_o)$
- Temperature (T_o)
- Salinity (S)
- Sea Surface Height (η); 2d
- *Bottom pressure (P_b); 2d*

Ocean

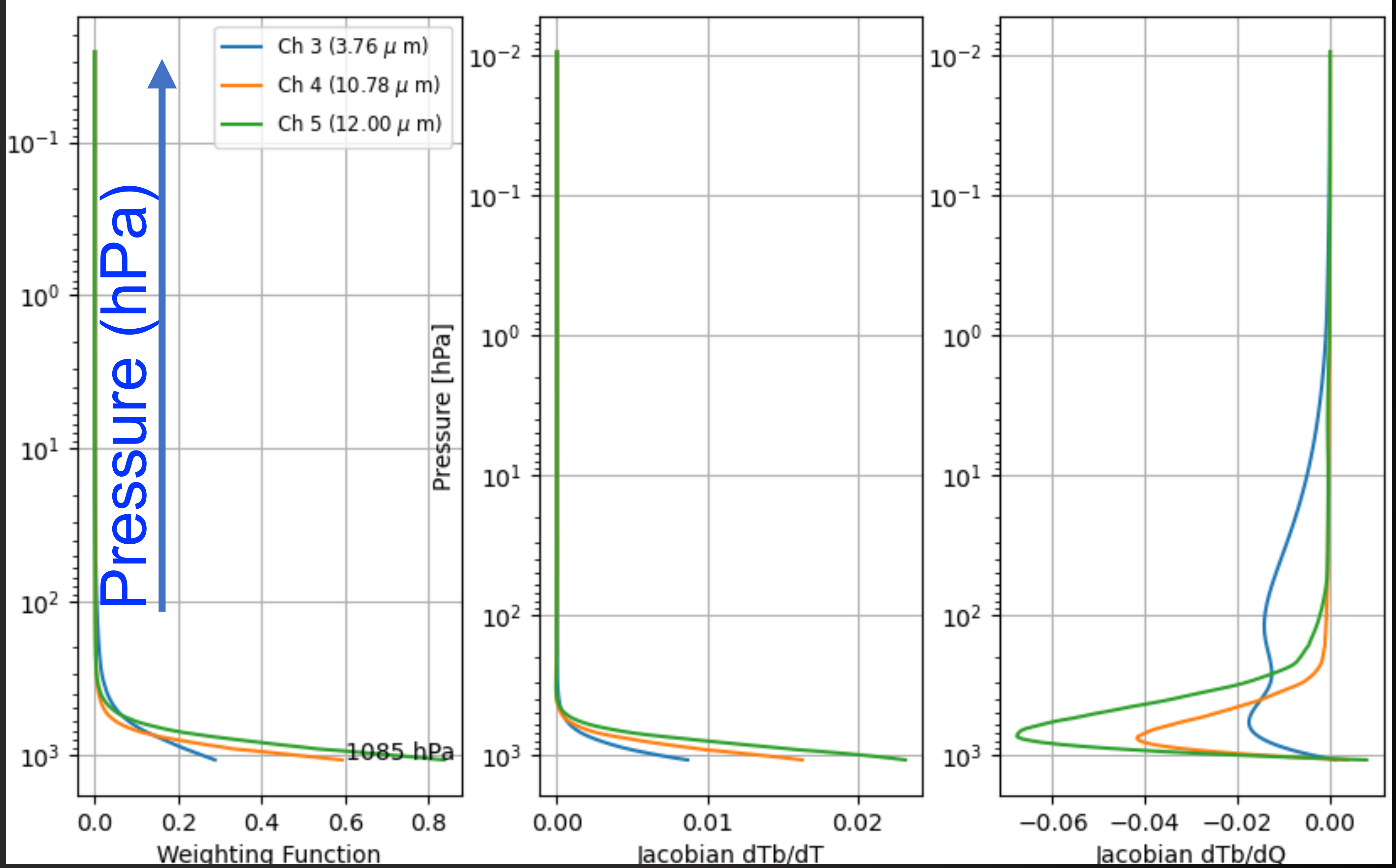
$$X_o = [U_o, V_o, T_o, S, \eta]^T$$

Oceanic Analysis

This consideration of **atmosphere-ocean only analysis is a much **simplified** case of a more **general earth system analysis**.

Cross-correlations: $\mathbf{P}_{\mathbf{a,o}}$

- If one ignores $\mathbf{P}_{\mathbf{a,o}}$, set $= \mathbf{0}$.
  - No cross-component impact: any observation of $y_i^o; i = a, o$ will not impact $X_i; i = o, a$.
  - I do not consider indirect cross-component correlations generated via (coupled) model integration.
  - Focus on what happens to analysis of coupled observations. Instead of entire data assimilation system (which includes model).
  - In Coupled Analysis: everything is "strong" - simplified terminology!



- Coupled observations: What are they? Why should you care?
  - Almost ALL satellite measurements: NOT retrievals, have sensitivity to both atmosphere (in certain wavelengths) and *surface* ocean.
  - Other examples include tropical moored array: atmosphere {winds, air temperature} and ocean {T, S}.
  - Assimilation of retrievals in the ocean (e.g., SST, SSS) and radiance (or brightness temperature) measurements in the atmosphere: amounts to trashing a % of observations! Introduces: Biases from retrievals, *Incomplete* satellite data impacts, etc.

What has been done so far to include $P_{a,o}$ in realistic cases?

National Aeronautics and Space Administration

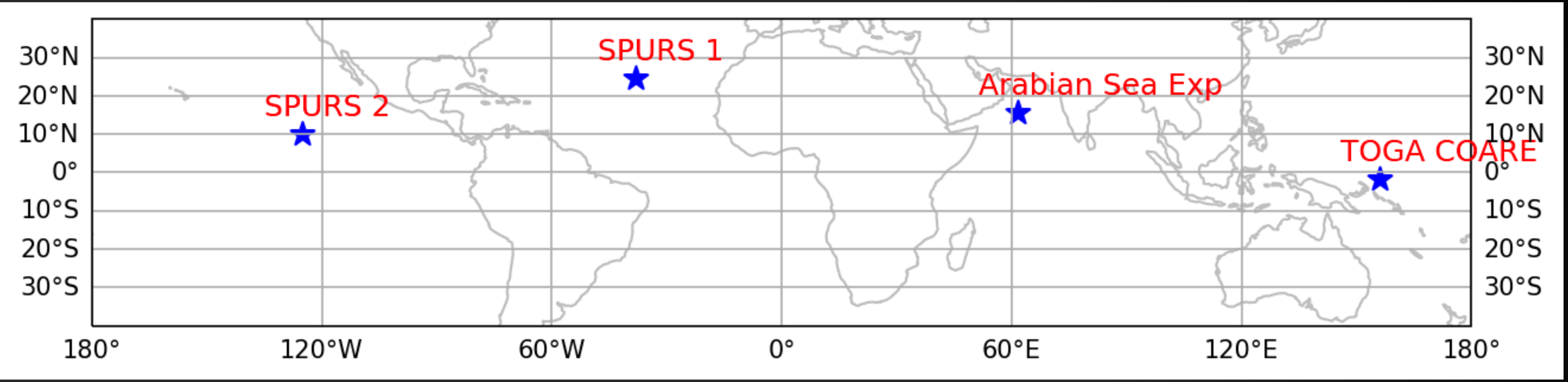
- Storto et al., 2018. “Strongly Coupled Data Assimilation Experiments with Linearized Ocean-Atmosphere Balance Relationships.”
  - Ocean model included an atmospheric boundary layer, as opposed to just typical usage of bulk flux formulae only: tighter coupling
  - An “air-sea balance operator” (K) that relates increments among atmosphere (T_a, Q) and ocean control variables (T_o, S): $[\delta T_a, \delta Q] = K\,[\delta T_o, \delta S]$
  - This balance operator (K) was derived:
    - Using linearized atmospheric boundary layer parameterization.
    - Statistically using EOFs.
- Smith et al., 2015, 2017, 2018, 2020. Coupled single column model configurations.
  - Ensembles were used to generate cross-correlations (they had to be *re-conditioned*).
  - Correlations vary with seasons and day/night.
- Yaremchuk et al., 2020. “Block iterative correction in strongly coupled data assimilation.”
  - Present a split of *full* P into coupled (off-drag) and uncoupled (diag) parts.
  - Iteratively obtain the effect of coupled correlations.

From these studies it is clear that any practical coupled analysis will be heavily reliant on existing uncoupled analyses.

That motivates a closer look at the spatial variation of cross-correlations.

Components of $\mathbf{P}_{o,o}$ and their variability

- Consider correlations in the tropics
- Spanning different years
- Use CMEMS daily, $\frac{1}{4}^{\circ}$ GREPV2
  - Variables: T, S, SSH
  - 4 ocean reanalyses:
    - ORAS5
    - FOAM
    - C-GLORS
    - GLORYS2V4
  - Time-averaged to compensate for sampling errors

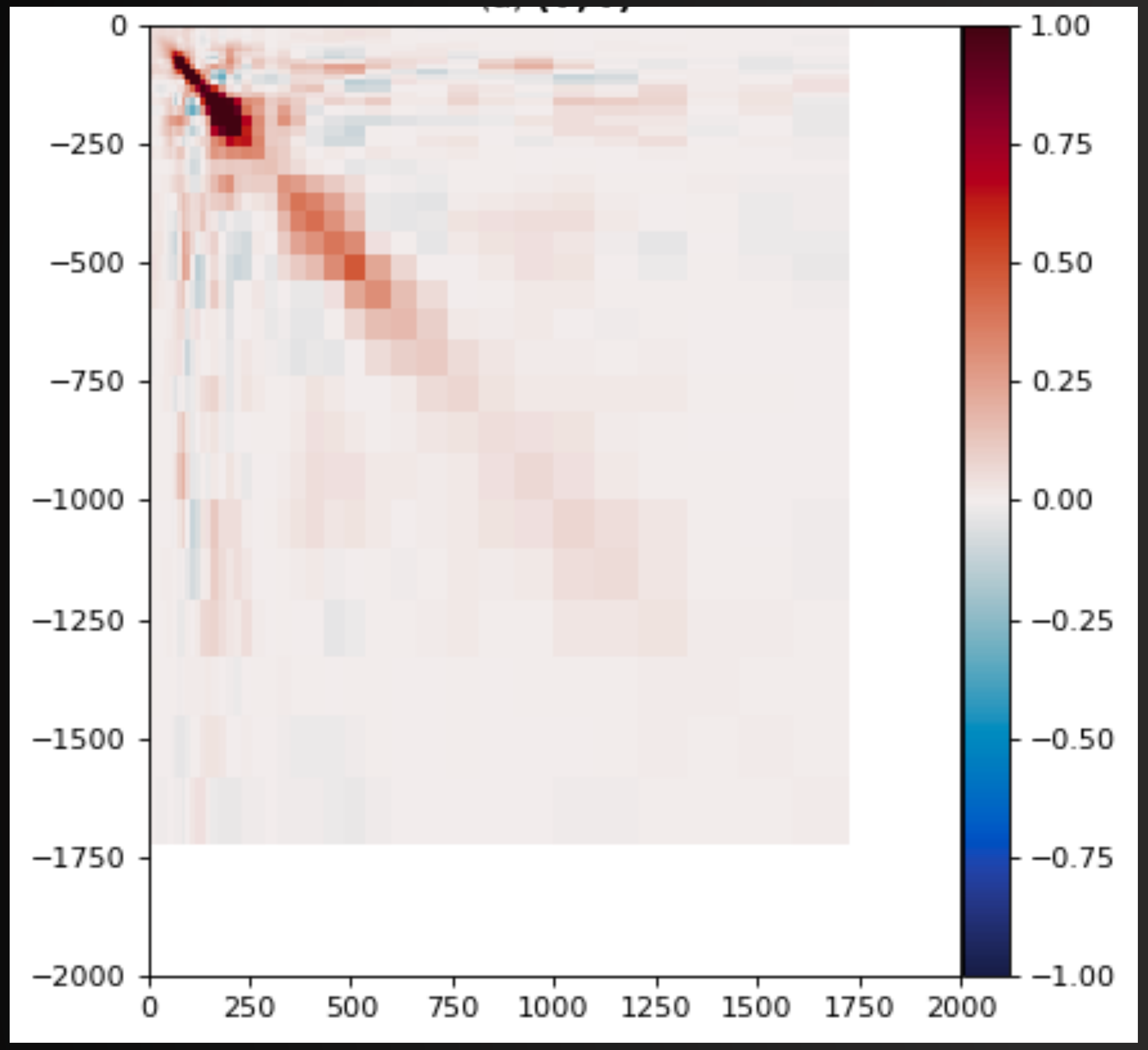


Name	Time (start - end)	Longitude	Latitude
TOGA COARE	1993/01/01 - 1993/03/04	156	-1.75
Arabian Sea Experiment	1994/10/16 - 1995/10/19	61.50	15.50
SPURS 1	2012/09/14 - 2013/09/30	-38	24.5
SPURS 2	2016/08/24 - 2017/11/06	-125	10

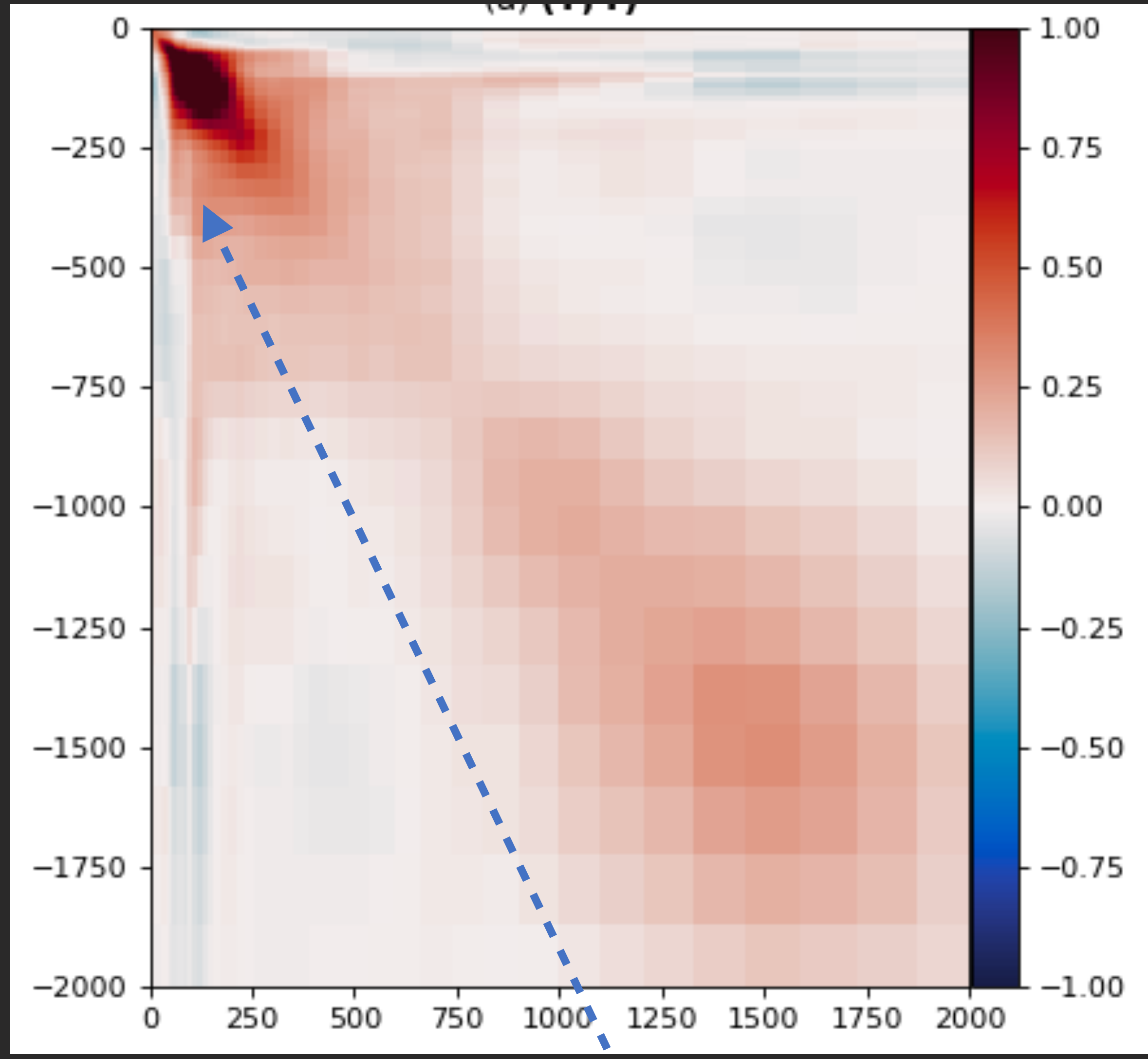
- How do cross-correlations vary in depth?
- $\mathbf{P}_{T_o,S}, \mathbf{P}_{T_o,\eta}, \mathbf{P}_{S_o,\eta}$

Structure of P_{T_o, T_o}

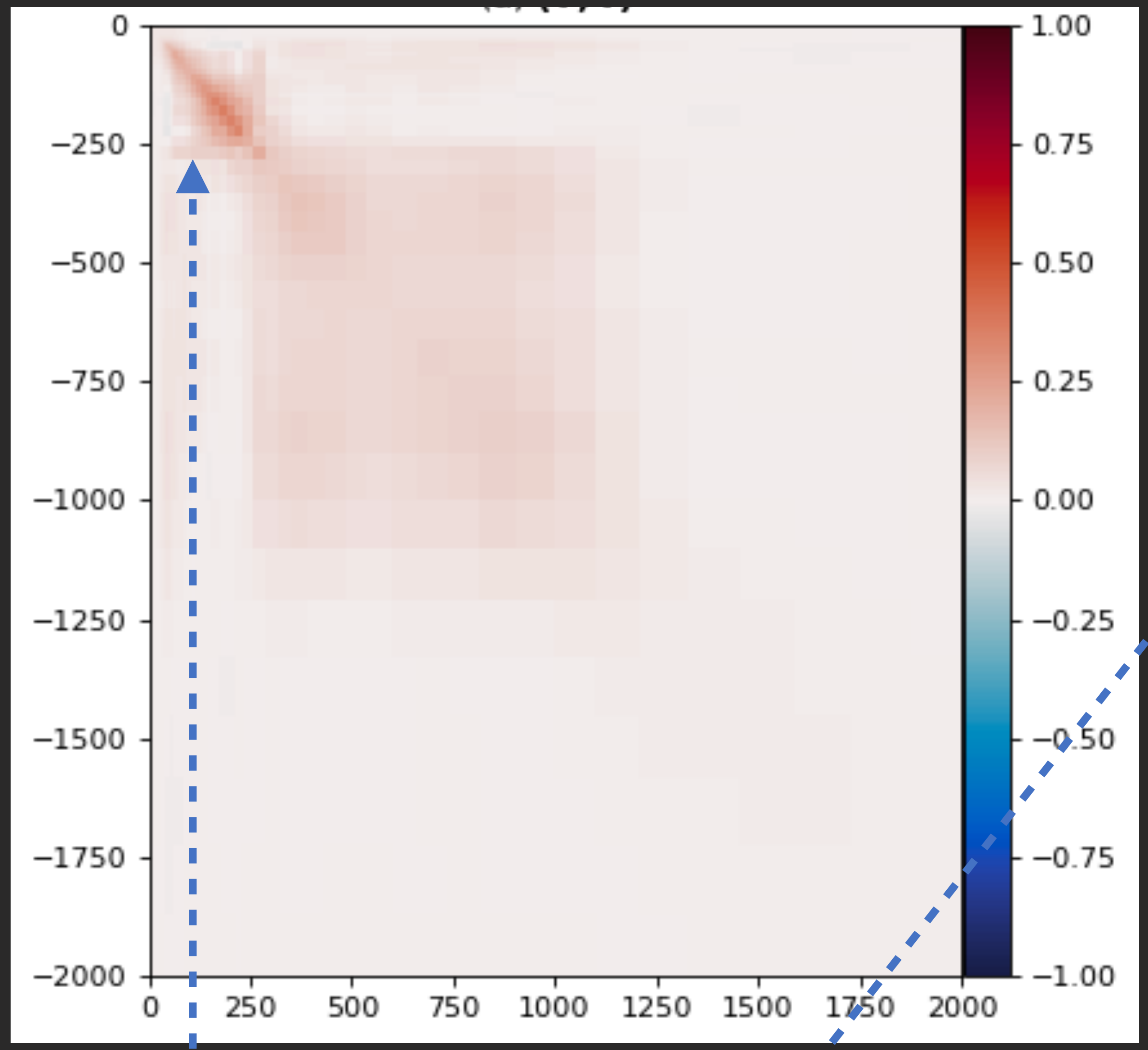
TOGA
COARE



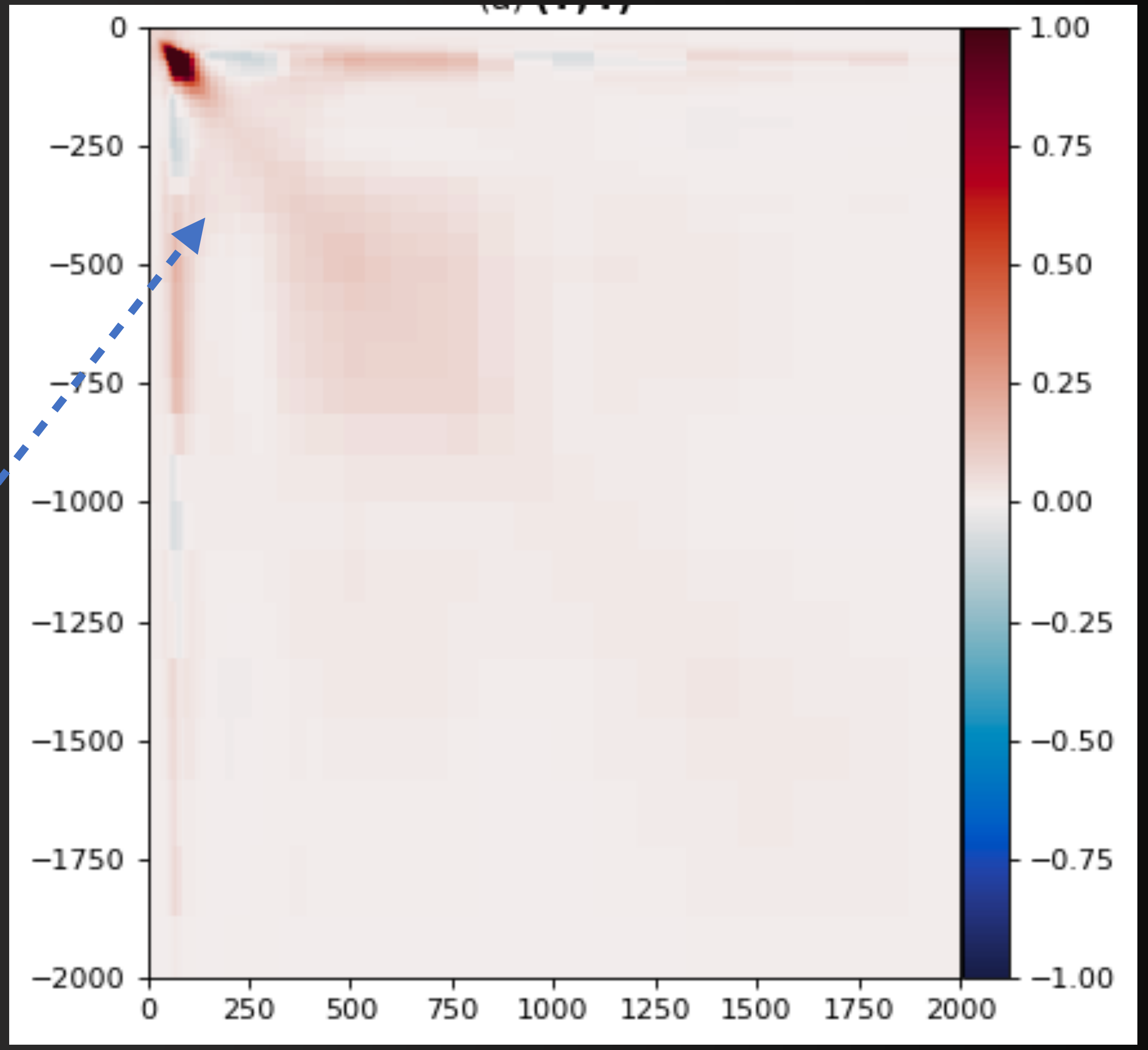
Arabian
Sea Experiment



SPURS 1



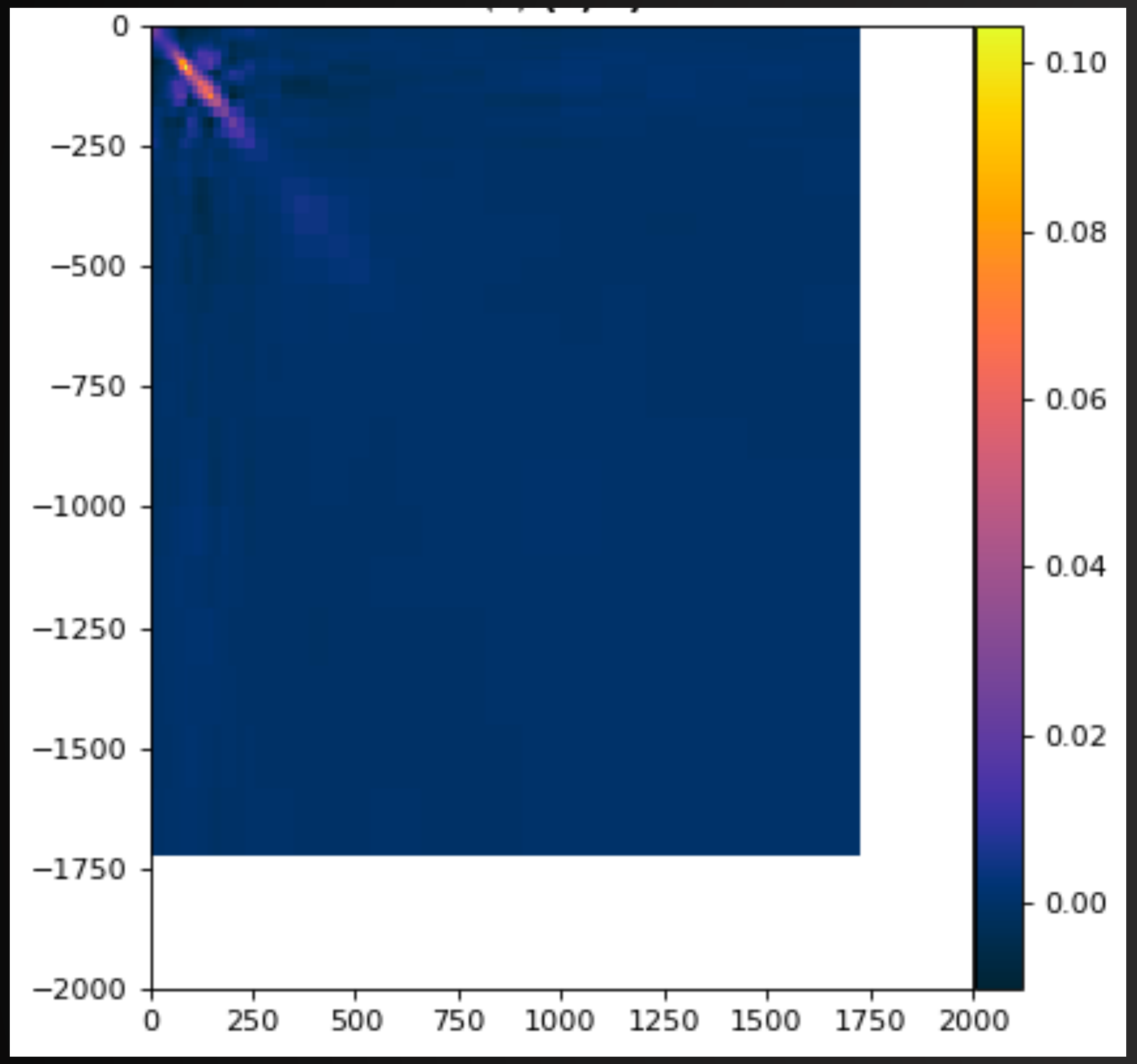
SPURS 2



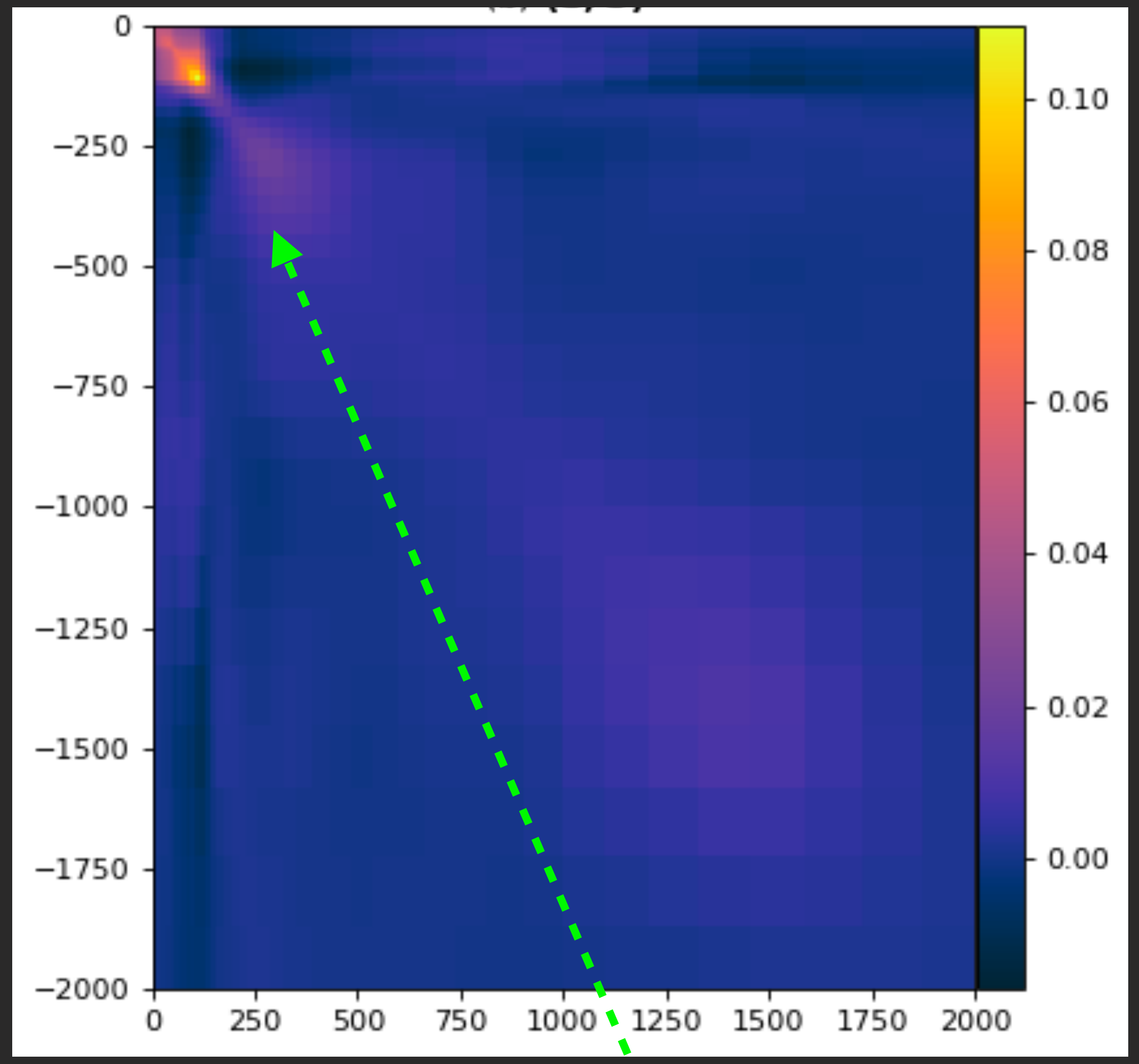
- Significant off-diagonal values
- Pattern changes with location

Structure of $P_{S,S}$

TOGA COARE



Arabian Sea Experiment



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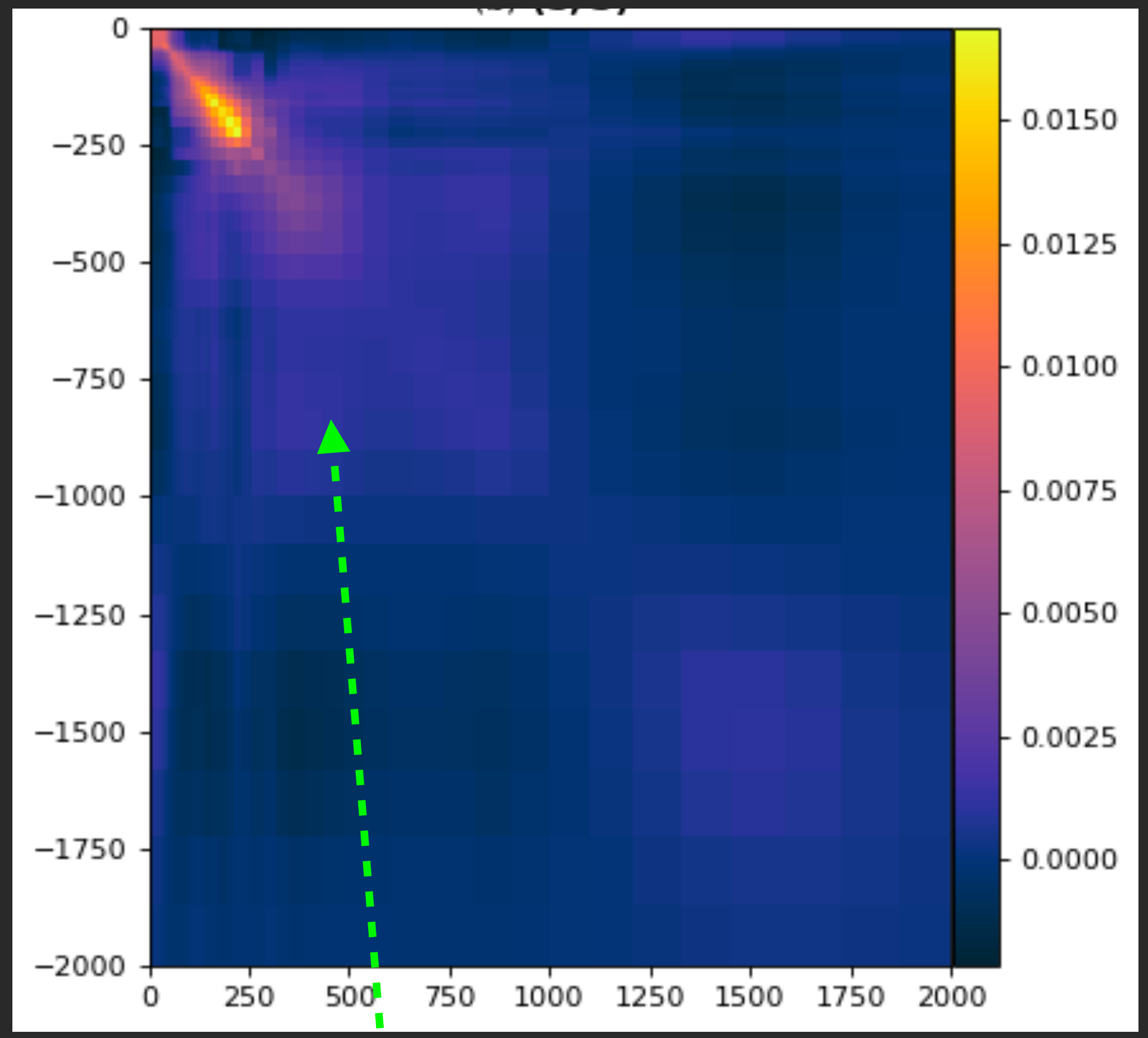

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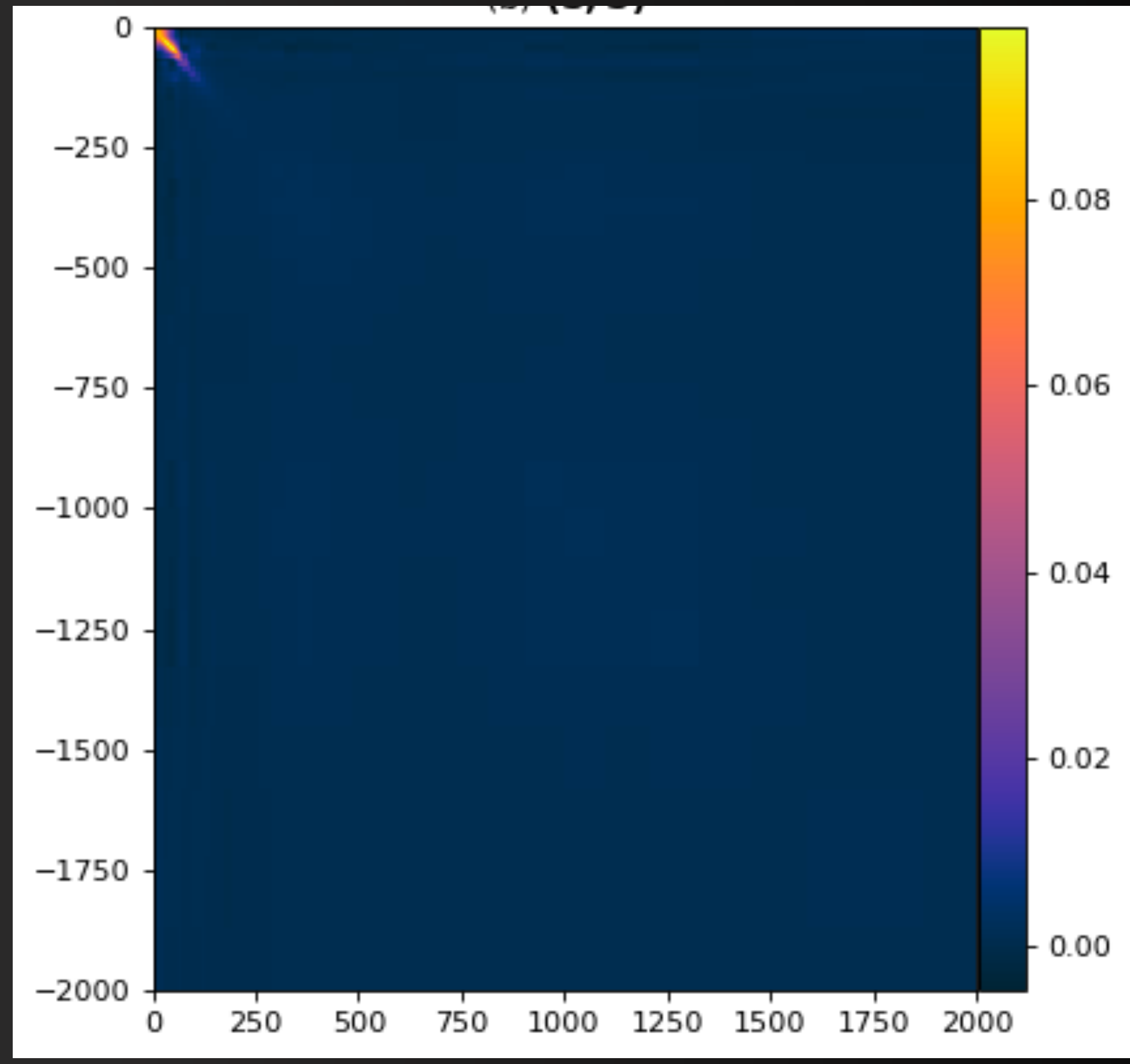
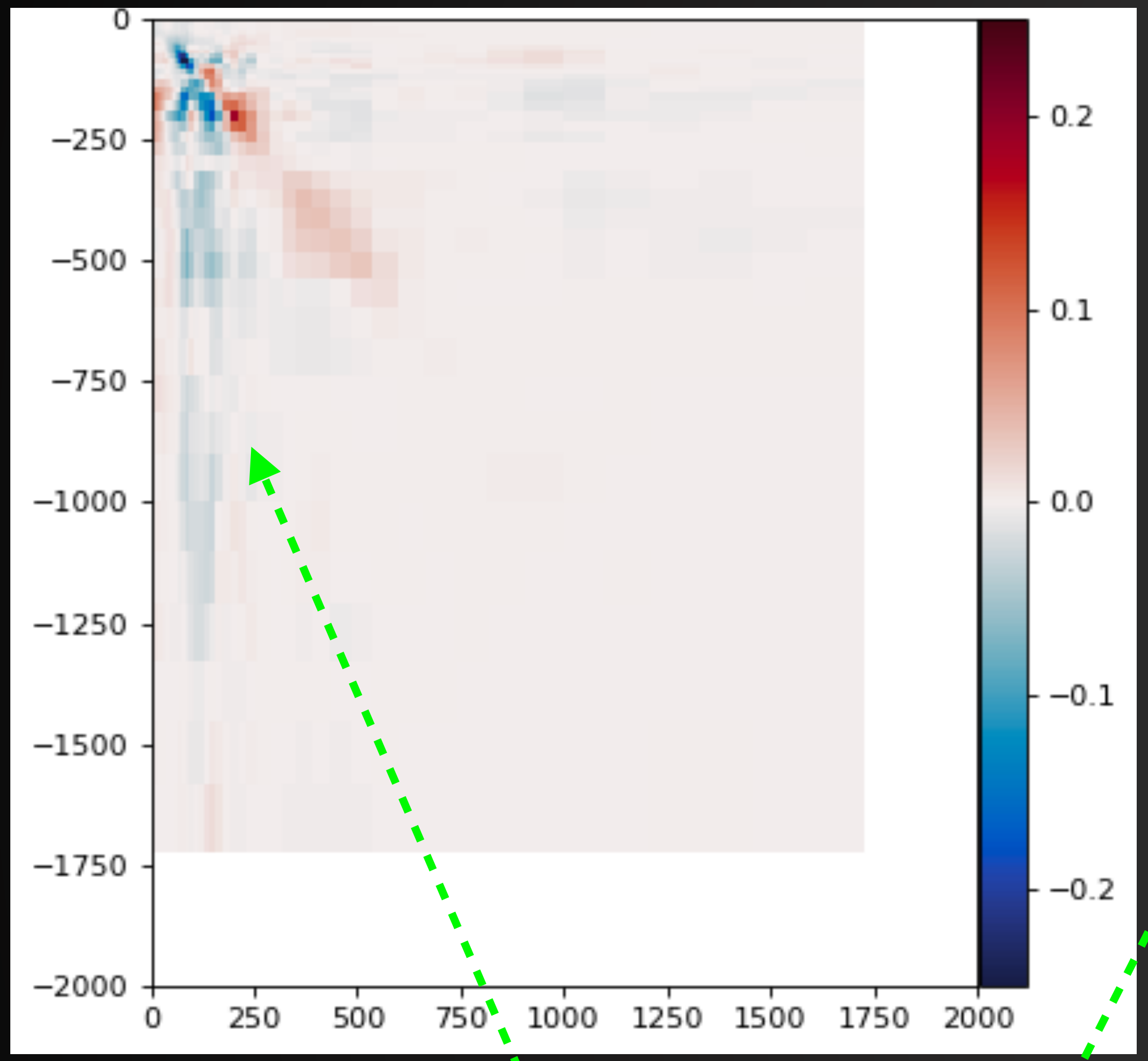


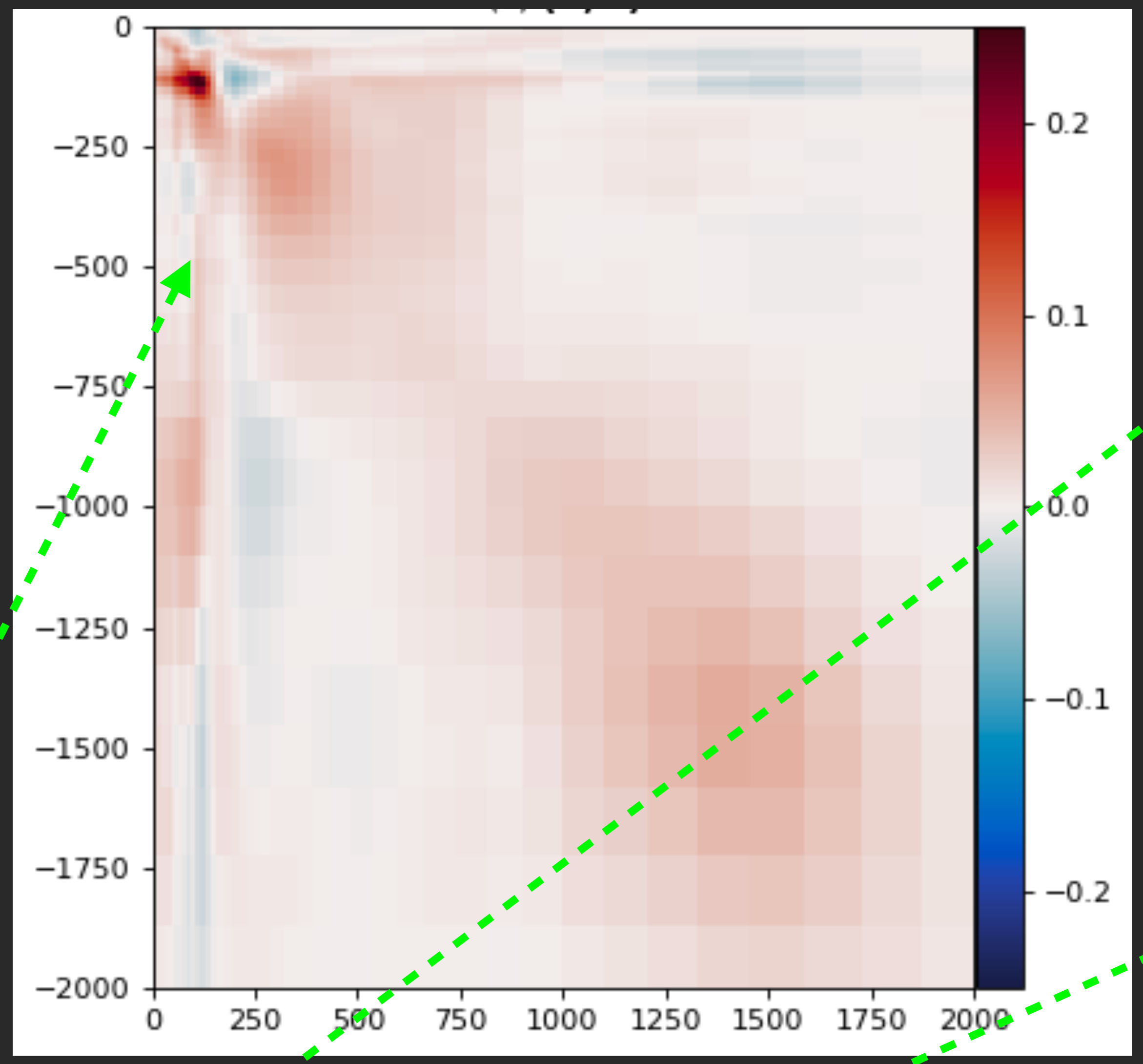
- Significant off-diagonal values
- As with T, pattern changes with location
- S is very localized in TOGA-COARE and SPURS 2 (rain)

Structure of $P_{T_o,S}$

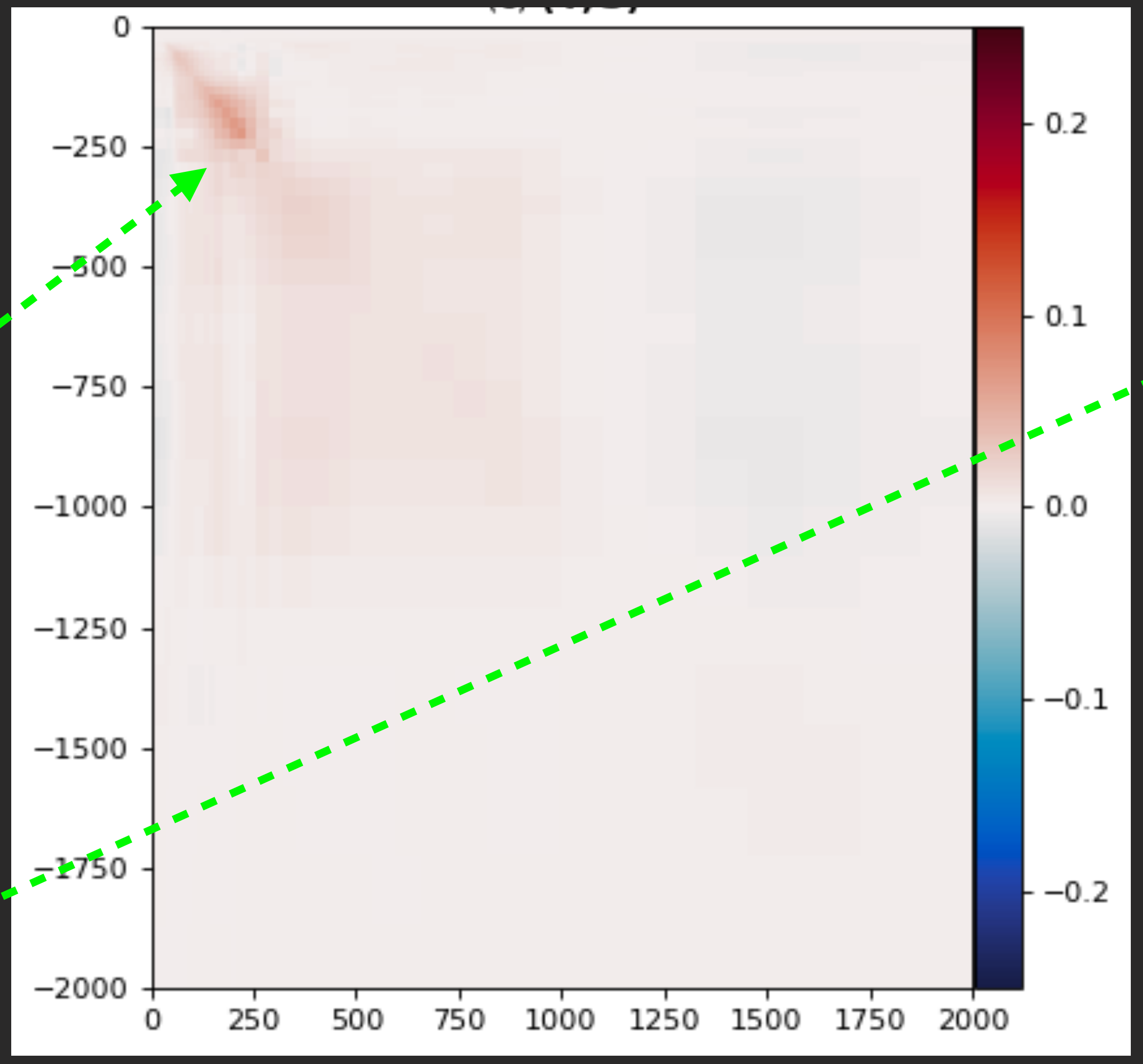
TOGA COARE



Arabian Sea Experiment



SPURS 1



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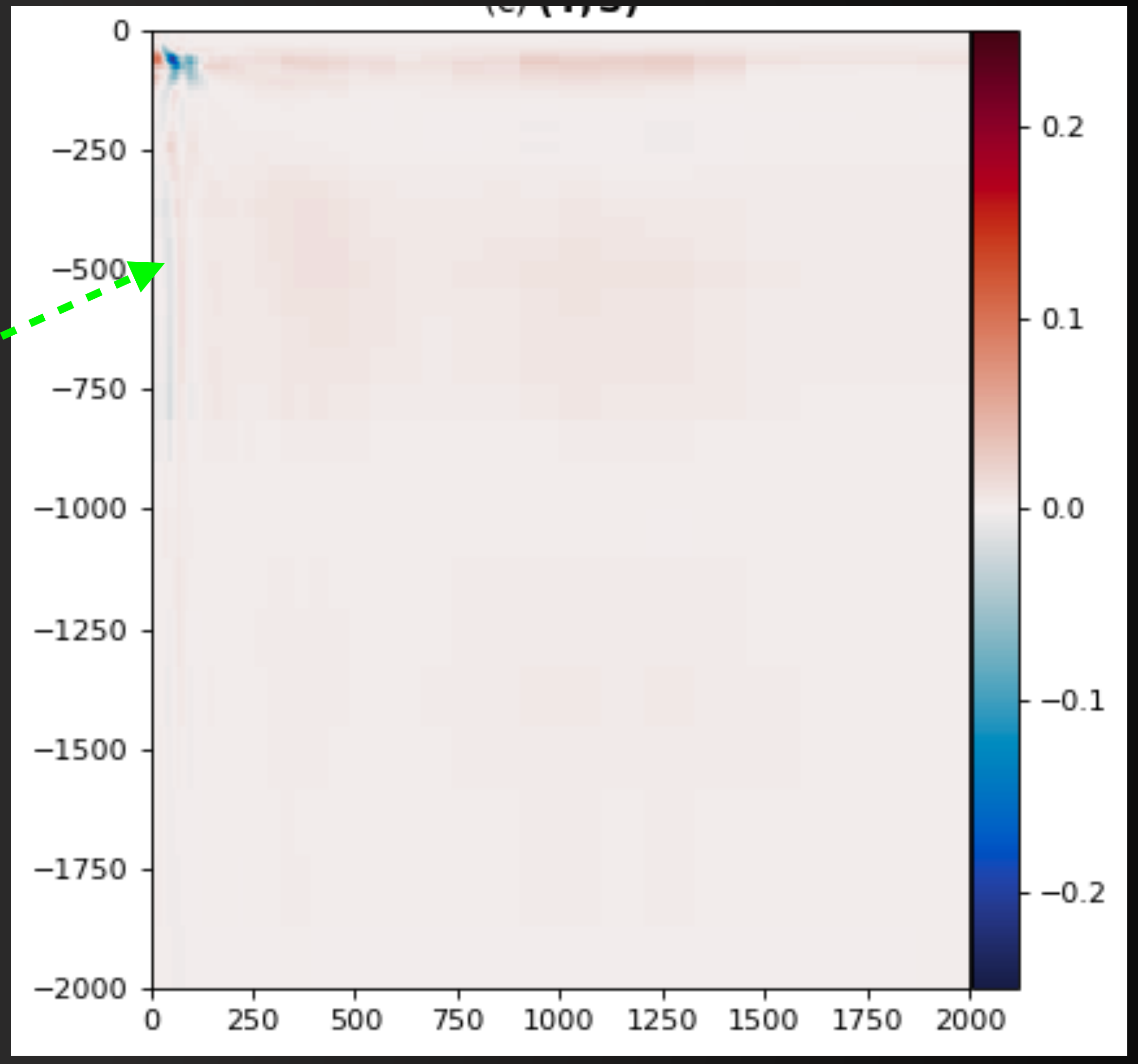
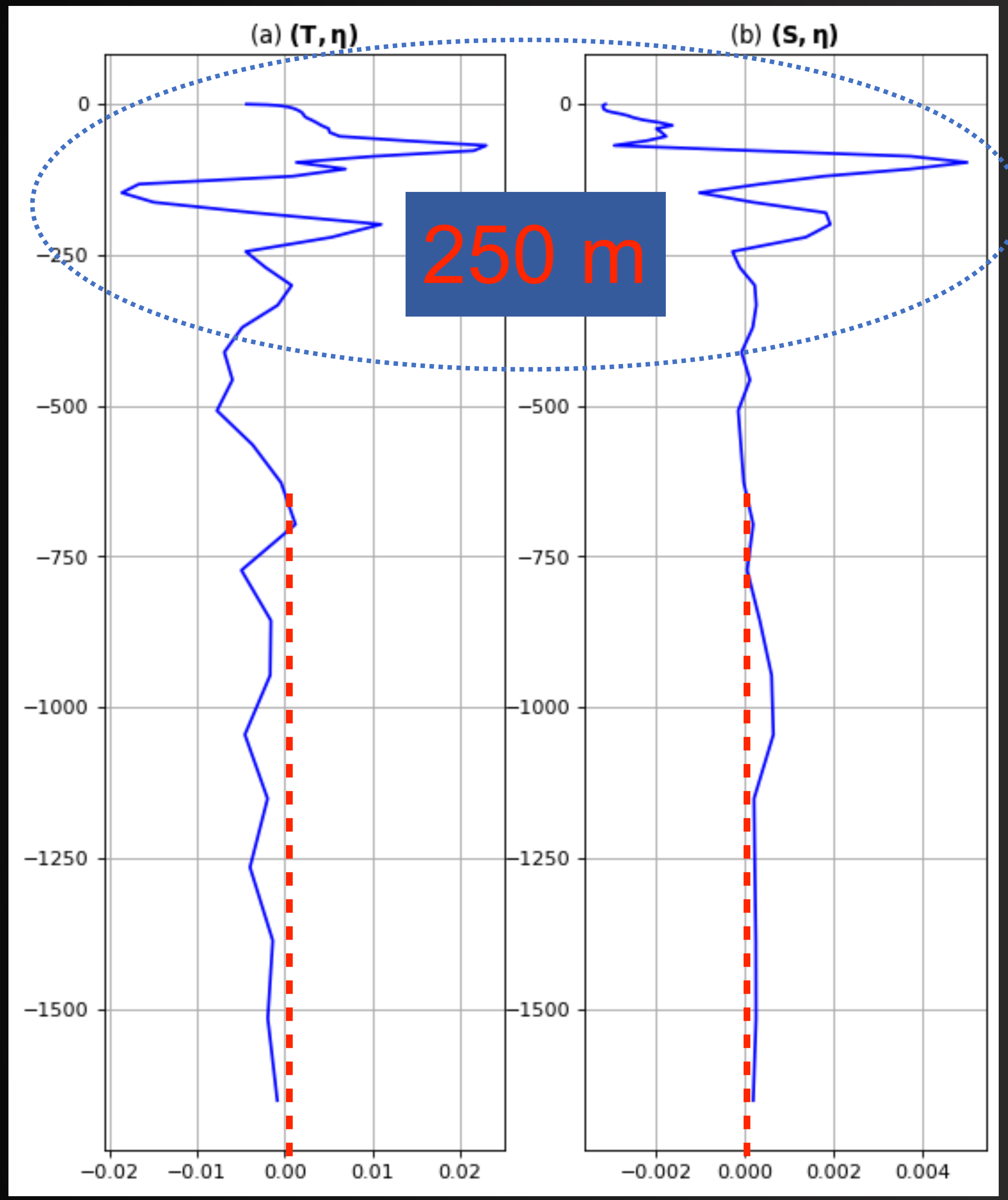


Re-think localization

Structure of $P_{T_o,\eta}$ and $P_{S,\eta}$

TOGA COARE



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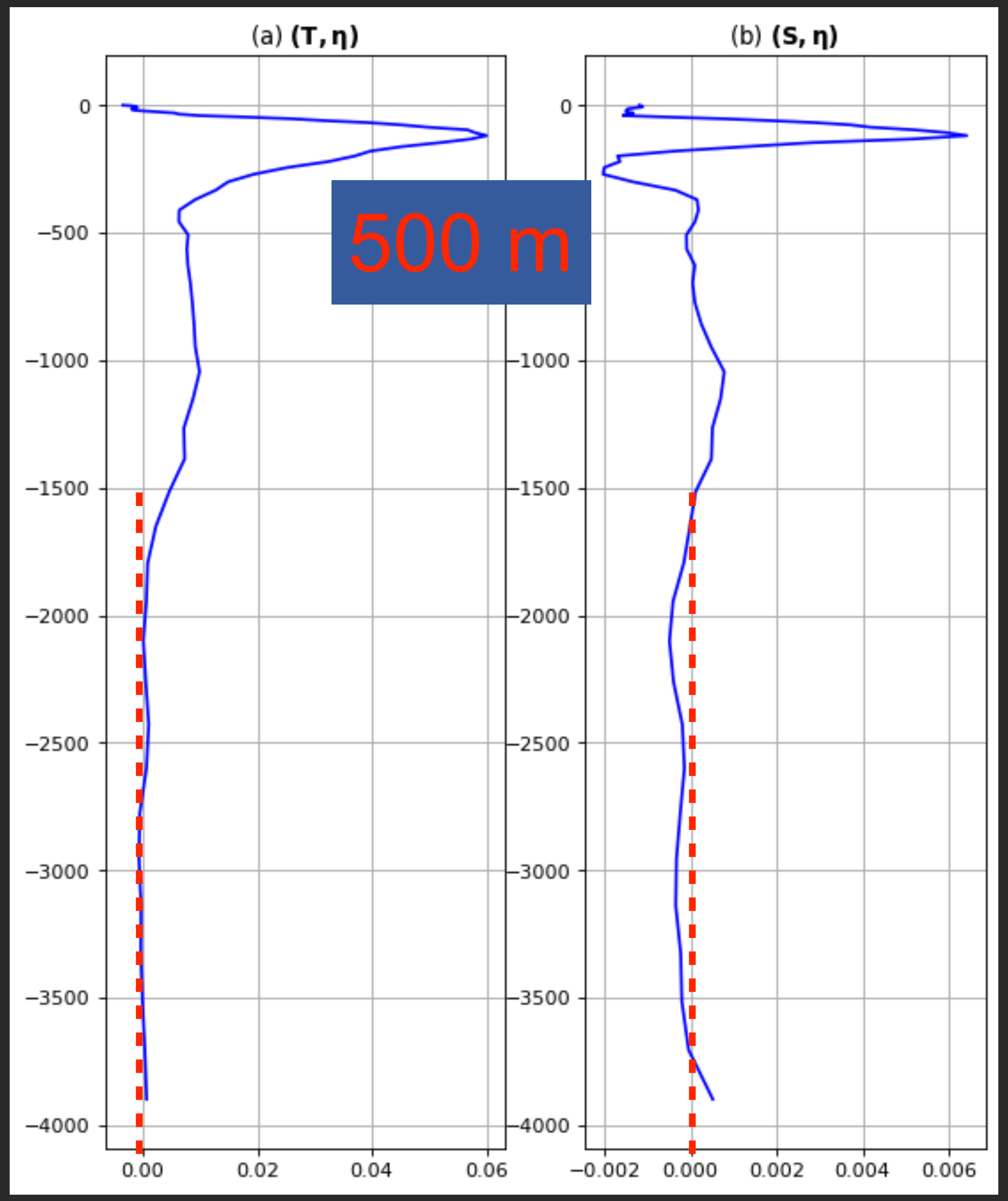
Arabian Sea Experiment



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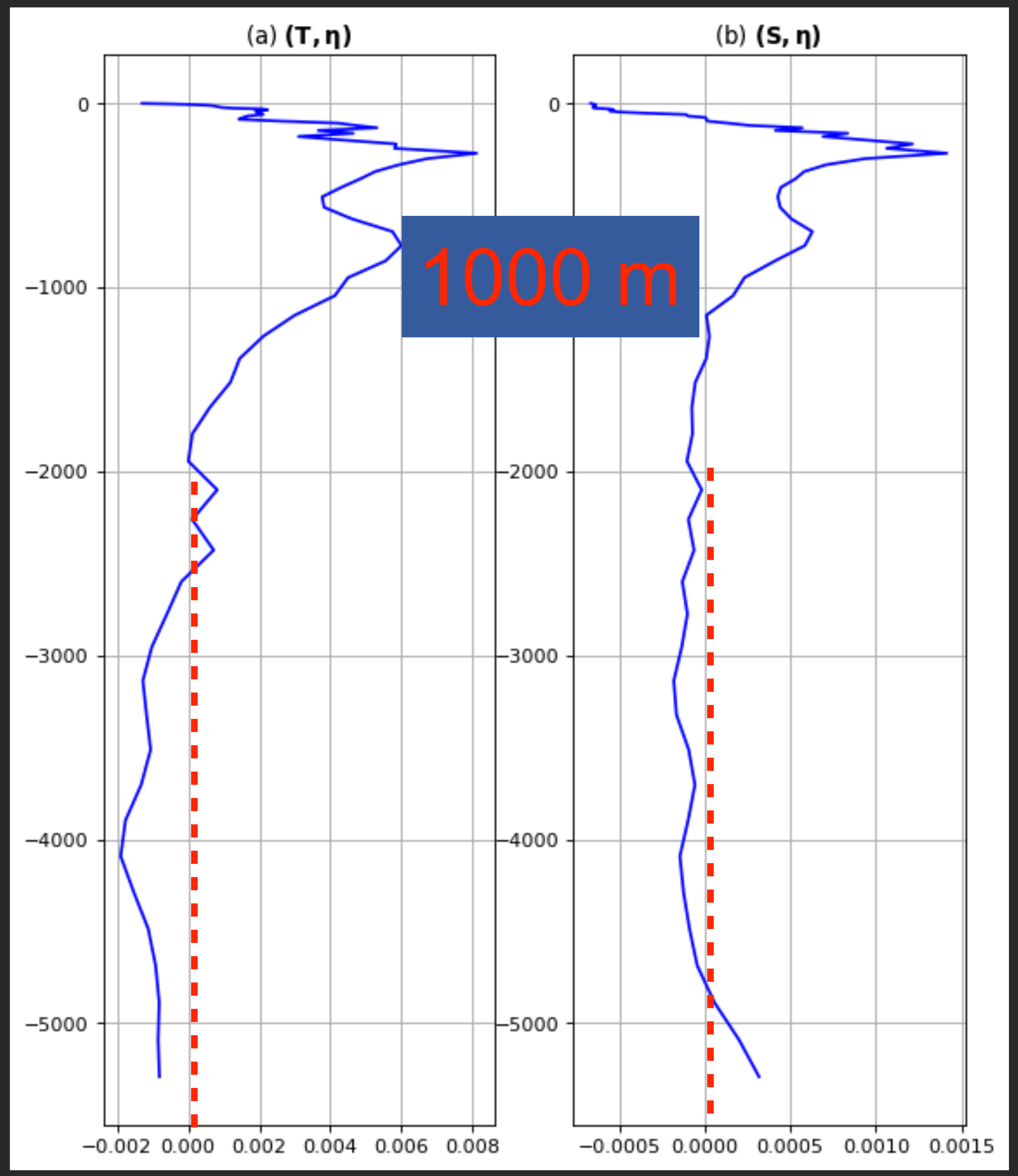
SPURS 1



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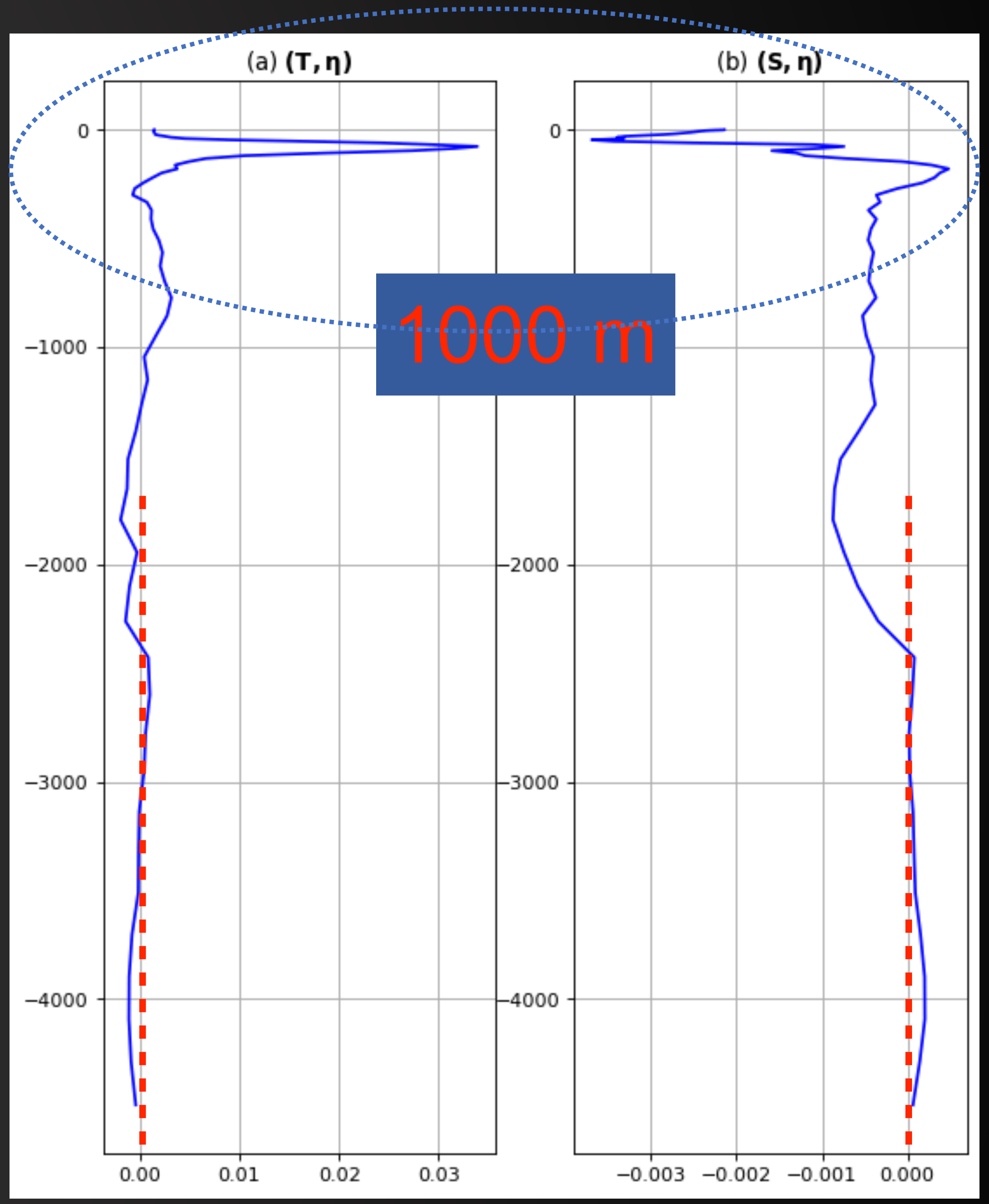
SPURS 2



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- $\{T_o, \eta\}$ about an order (or two) of magnitude larger than $\{S_o, \eta\}$
- Important to focus on the upper ocean

Take home message

- Near-surface impacts deeper ocean/atmosphere aloft.
- Consider tighter coupling across boundary (ocean and atmosphere) layers.
  - Spatial refinement: vertical is cheaper than horizontal.
- Uptake measurements that help observe across air-sea interface.
- Cross-correlations are not necessary the same everywhere.
  - Significantly differ.
- Distance based localization may not always work.

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Thanks for your attention!