

# An Analysis of Tails



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## Introduction

Wind gradients calculated from scatterometer ocean vector winds are useful in identifying the footprint of Mesoscale Convective Systems (MCSs), the "seeds" of tropical cyclones, and where frontogenesis happens.

A recent study [1] of ASCAT winds in the Atlantic InterTropical Convergence Zone (ITCZ) found that wind derivative distributions had **heavy tails**. Events in those tails (called **extreme events**) were shown to correlate with nearby extreme (convective) rain. The interpretation was that the wind derivative extreme events were due to convective updrafts, downdrafts and gust fronts. We are thus motivated to carry out further work that focuses on the wind derivative "tail" — the events absent in global Numerical Weather Prediction (NWP) and climate models (e.g., Fig 1).

## Objective

Identify, document and develop methods to quantify and characterize the data in the tail of the wind derivative distribution, how it varies in space and evolves in time. Our goal is to yield new results useful for monitoring the climate, model downscaling and NWP code verification.

## Definitions

- $J = \|\nabla \mathbf{u}\|$  - wind gradient magnitude
- $P(J), P(J^2)$  - probability distributions
- $J^* \approx 2\sigma$  - threshold
- $\{\delta, s, \zeta\}$  - {divergence, strain, vorticity}

See **Notation** for further details.

## Bulk-Tail decomposition

Wind derivatives are classified as belong to the "bulk" or "tail":

- Bulk  $\in \{J \leq J^*\}$
- Tail  $\in \{J > J^*\}$

## Averaging

- Ensemble averages (calendar month).
- Latitude profiles (1 degree bins).

## Data

- 12.5 km ASCAT (partial swaths)
- Atlantic: 25°S - 25°N
- Winter: Dec 2012 - Feb 2013
- Summer: Jun - Aug 2013.

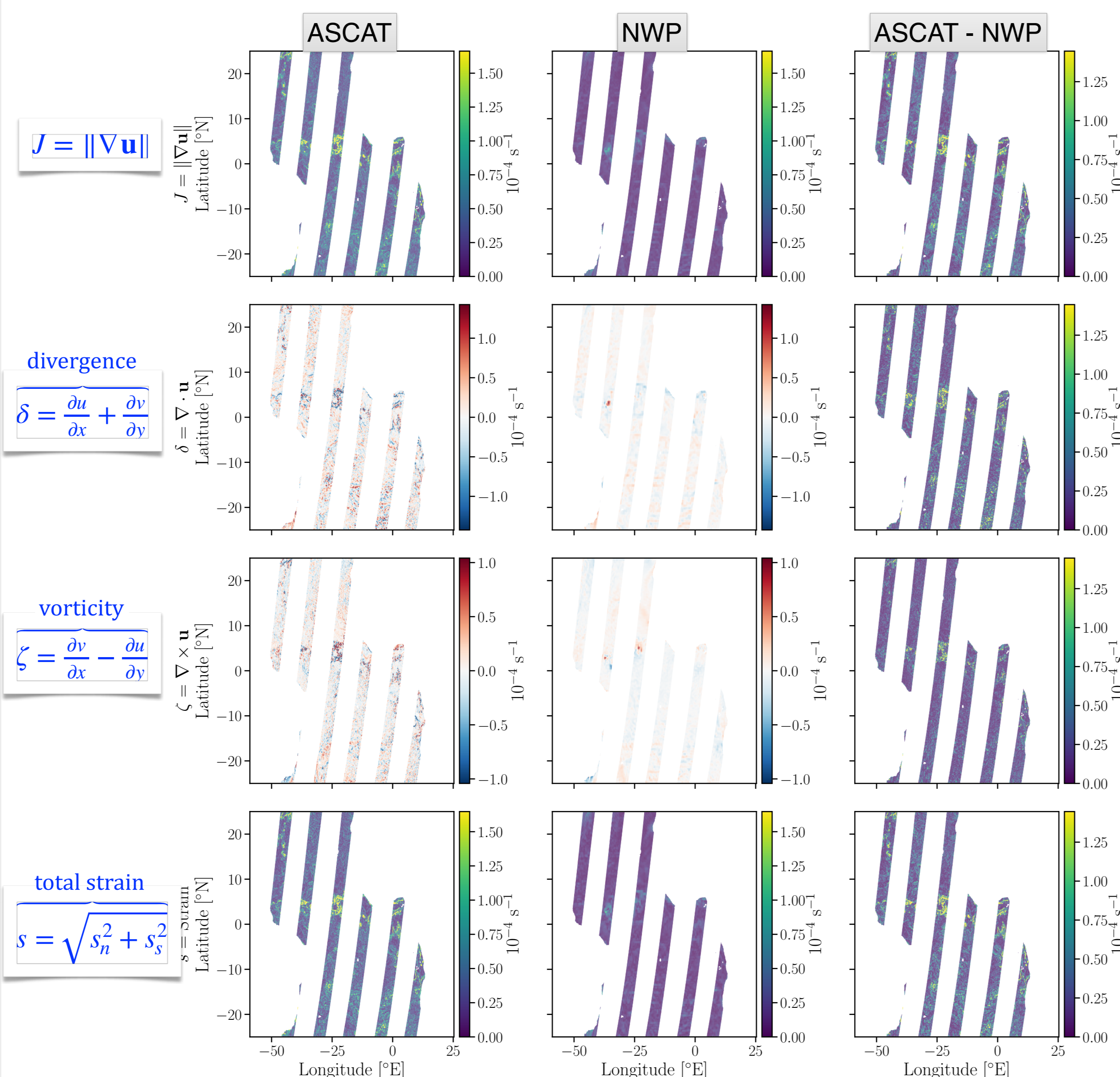
## Results

**Figure 1 : Comparison of ASCAT and NWP wind gradients.**

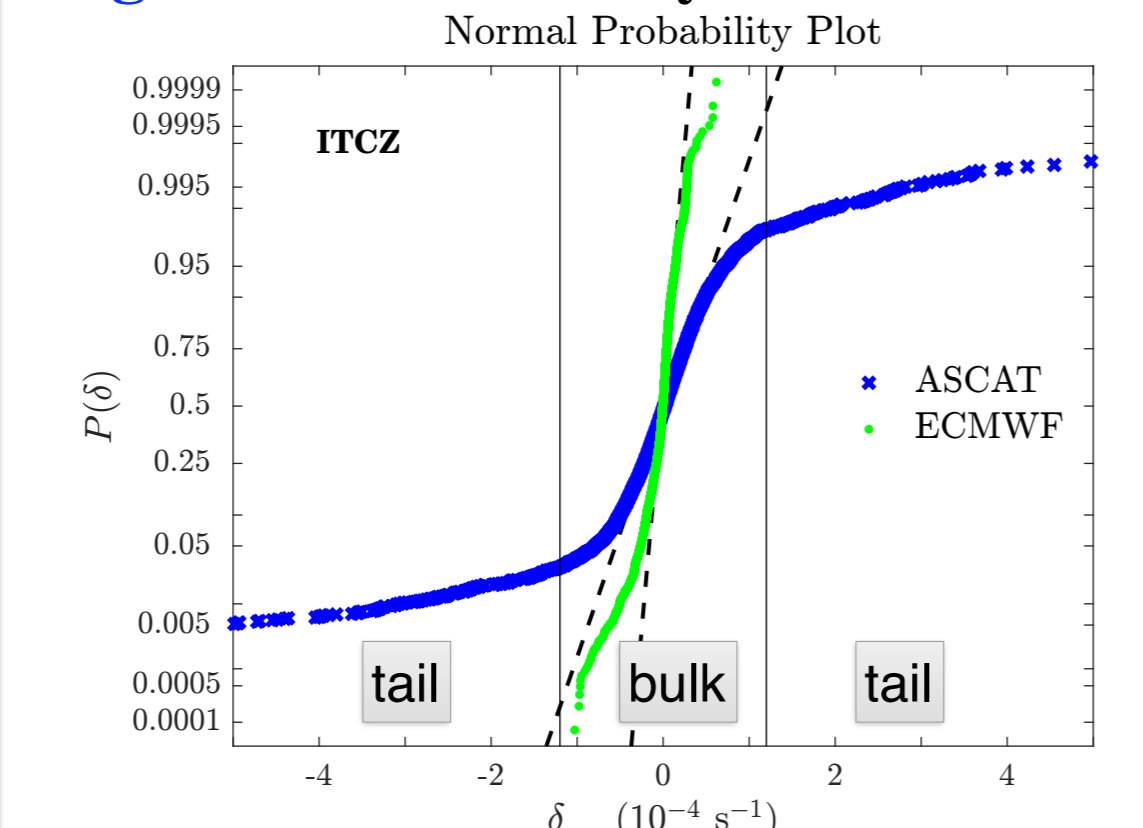
All fields in columns 1 and 2 are scaled according to the 98th percentile of the ASCAT observations.

The difference maps (column 3) are scaled to their own 98th percentile to highlight regions of maximum discrepancy.

Units for all panels are  $10^{-4} \text{ s}^{-1}$ .

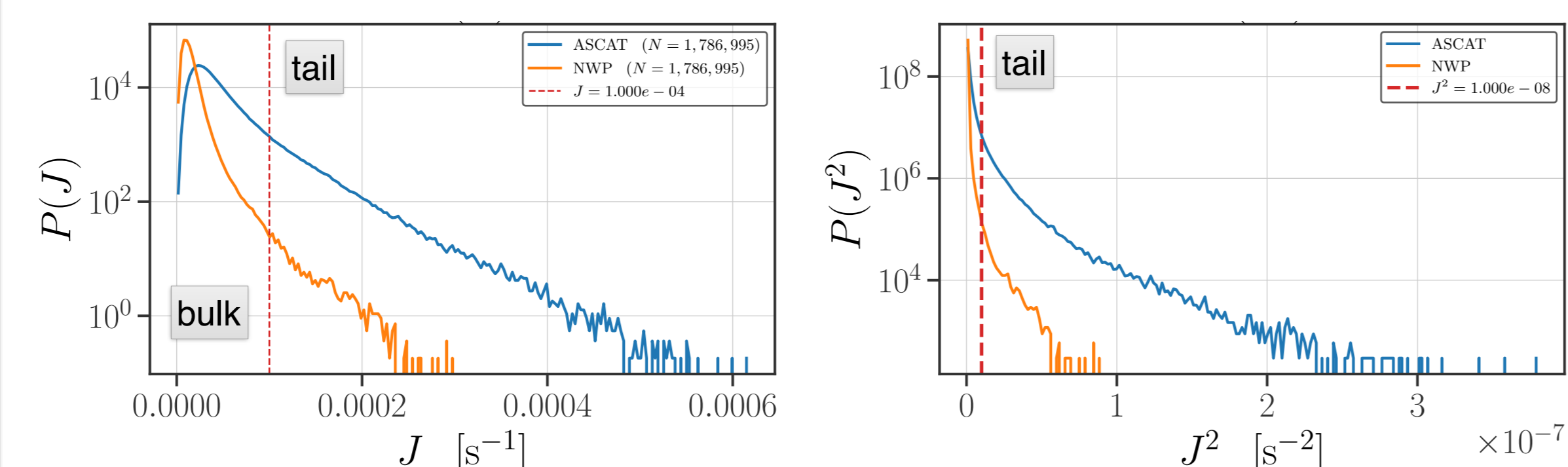


**Figure 2: Probability distributions**

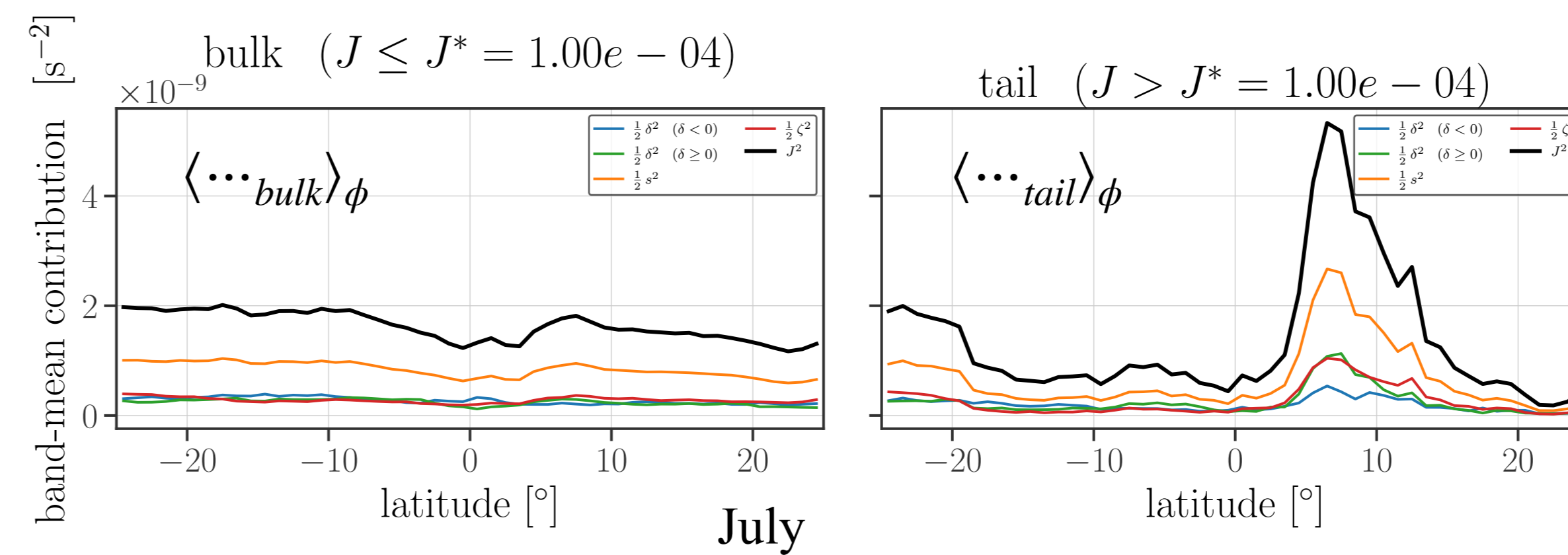


Heavy tails are emphasized in a **normal probability plot**. Gaussian distributions fall on a straight line. The ASCAT distribution follows a line in the core but lifts away as the  $2\sigma$  points (vertical lines) are approached. The NWP distribution stays close to a line and stays within the  $2\sigma$  points, indicating its distribution is close to a Gaussian.

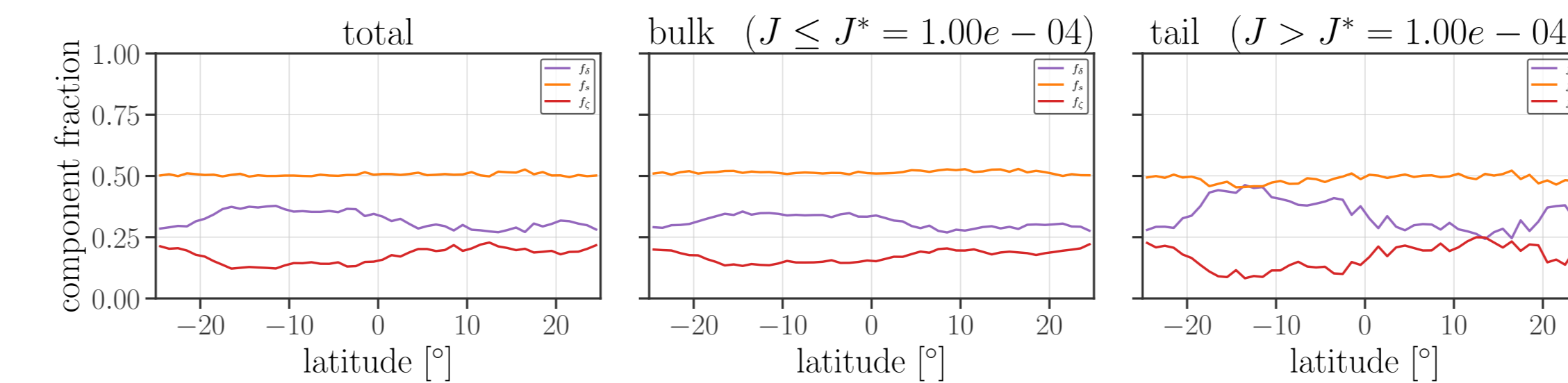
Below  $P(J)$  and  $P(J^2)$  distributions are plotted in more familiar form (semilog). The vertical line indicates the threshold  $J^*$  ( $J^{*2}$ ) that partitions events into bulk and tail.



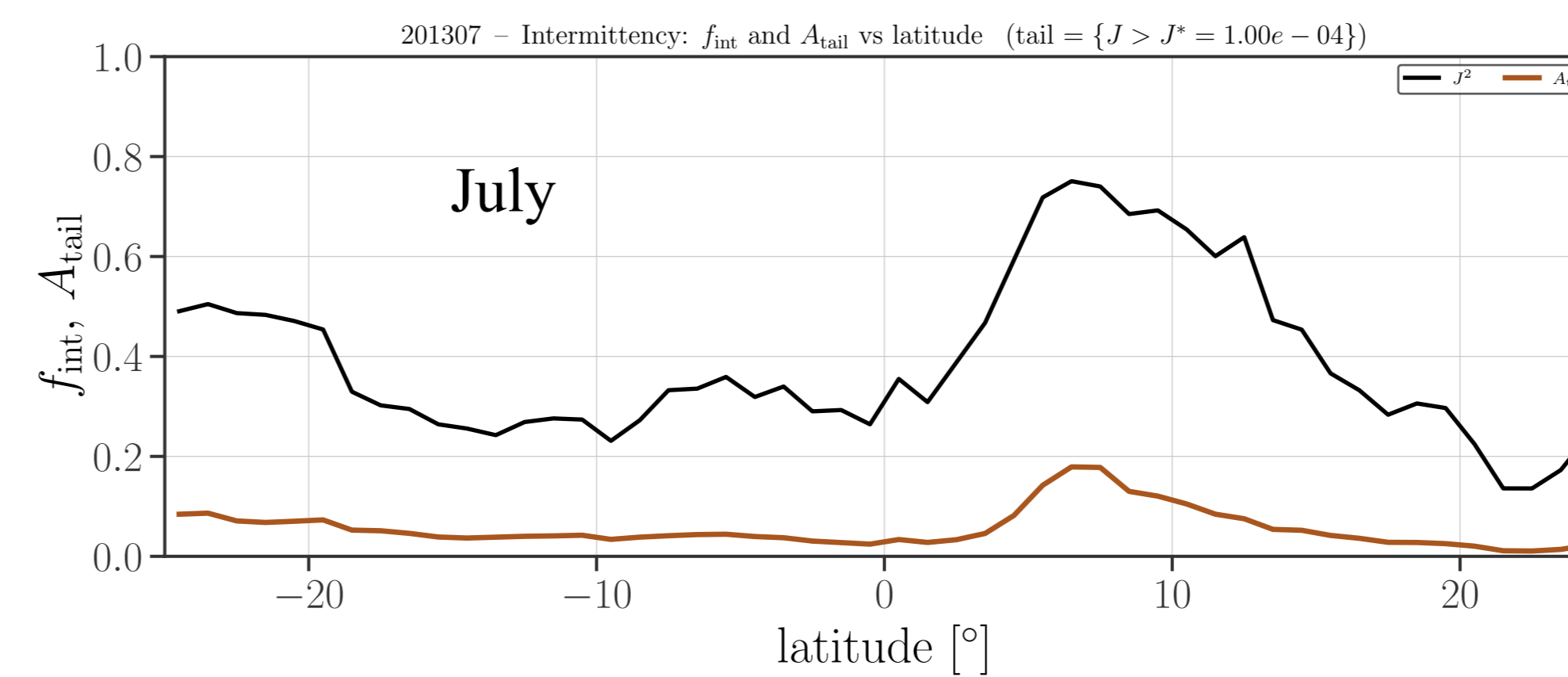
**Figure 3: Latitude profiles** of bulk and tail  $J^2$  and components:  $\frac{1}{2}\delta^2$  (convergence and pure divergence),  $\frac{1}{2}s^2$ , and  $\frac{1}{2}\zeta^2$ . The signature of the ITCZ can be clearly seen.



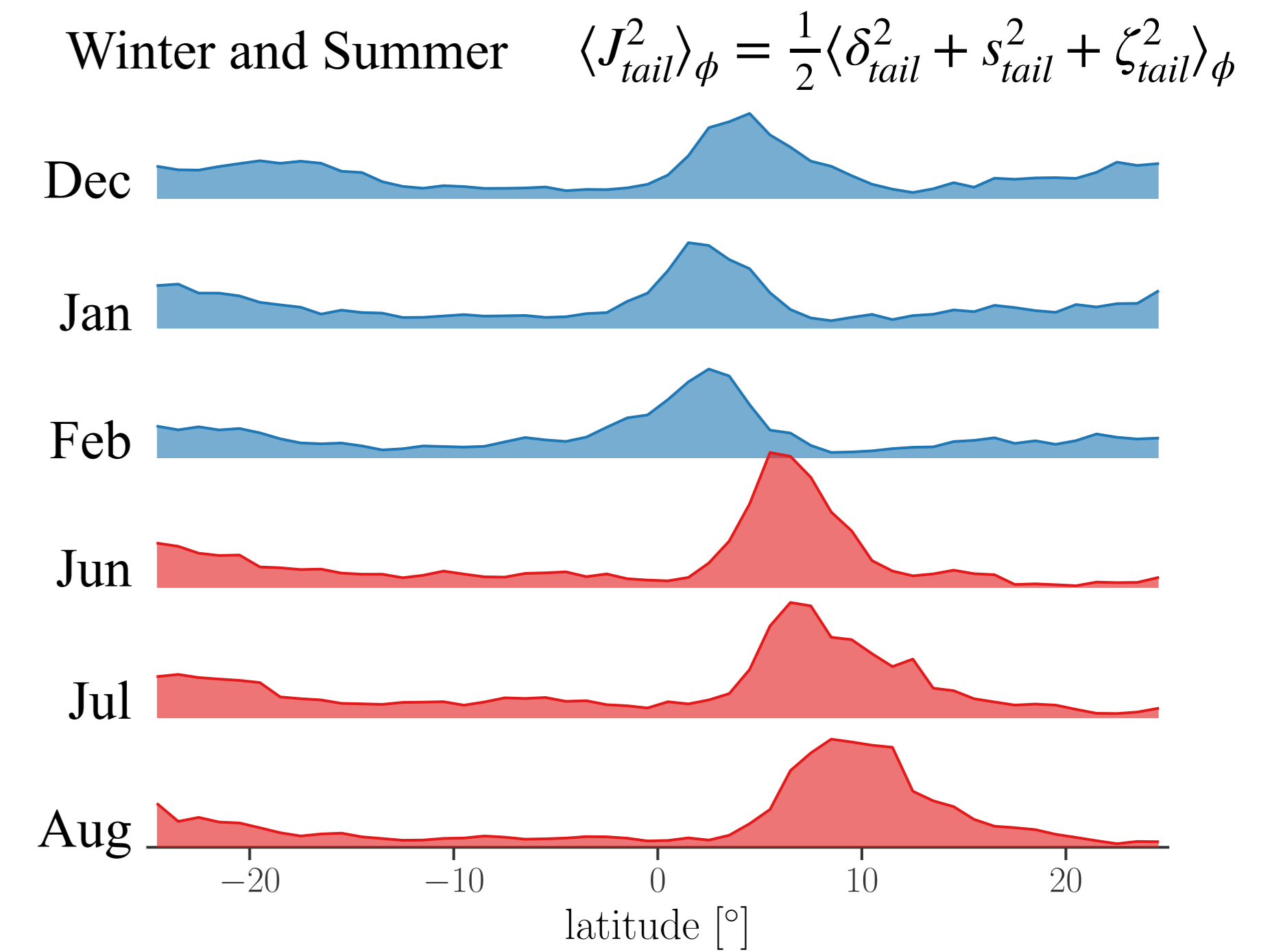
**Figure 4: Latitude profiles of component fractions.** This figure shows which component dominates at each latitude. The most dramatic shift is in the tail components for divergence (convergence and divergence combined) and vorticity. Results are for July.



**Figure 5: Latitude profiles** of the intermittency fraction  $f_{int}$  (top) and filling fraction  $A_{tail}$  (bottom).  $f_{int}$  is the fraction of all events that are in the tail at each latitude.  $A_{tail}$  measures the fraction of the total spatial area (within the latitude bin) that is occupied by tail events.  $f_{int}$  is a measure of the ITCZ intensity at each latitude, and  $A_{tail}$  measures the width of the ITCZ.



**Figure 6: As in Fig 3, but for all months:** Winter (blue) and Summer (red). The signature of the ITCZ can be clearly seen.



## Conclusions and Future Work

We have demonstrated the bulk-tail decomposition and used the tail information to measure ITCZ intensity, width and seasonal evolution.

In future work we aim to carry out a structure analysis to identify strong vortices, updrafts, downdrafts and fronts. We will also intend to carry out a multifractal analysis — firstly, because it is part of turbulence research and secondly, because it offers a more interesting way to determine a threshold to make the bulk-tail decomposition.

**Notation**  $J = \|\nabla \mathbf{u}\|$   $J^2 = \|\nabla \mathbf{u}\|^2$

### Wind Gradient Tensor

$$\nabla \mathbf{u} = \begin{pmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{pmatrix} \quad \|\nabla \mathbf{u}\| = \sqrt{\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2}$$

$$\|\nabla \mathbf{u}\|^2 = \frac{1}{2}(\delta^2 + s^2) + \frac{1}{2}\zeta^2$$

$$s = \sqrt{s_n^2 + s_s^2} \quad \text{normal strain } s_n = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \quad \text{shear strain } s_s = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$$

## References:

- [1] King, G.P., M. Portabella, W. Lin and A. Stoffelen (2022): Correlating Extremes in Wind Divergence with Extremes in Rain over the Tropical Atlantic. *Remote Sensing* 14(5), 1147. <https://doi.org/10.3390/rs14051147>.