On the role of thermal fronts in setting up SST statistics

J. Isern-Fontanet

with contributions from

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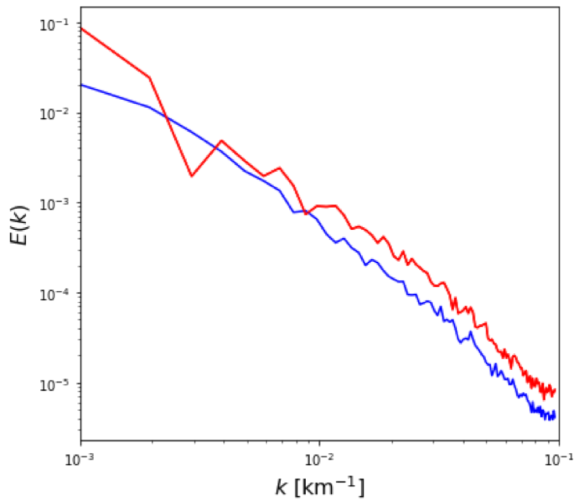
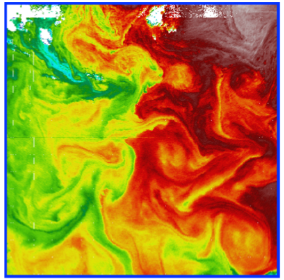
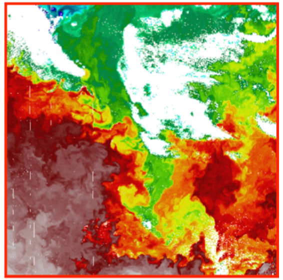
How do we characterize high resolutions SST products?

- High resolution SST images are full of fronts
  - Fronts are key pieces of ocean dynamics
- The variability of SST fronts should be mirrored by the variability of some SST statistics
- The use of spectral slopes have limitations
  - Changes in the properties of fronts may not change slopes







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Structure functions

- Structure functions are widely used to characterize the properties of turbulent variables such as SST

$$S_p(\ell) \equiv \langle |T(\vec{x}+\vec{\ell}) - T(\vec{x})|^p \rangle$$

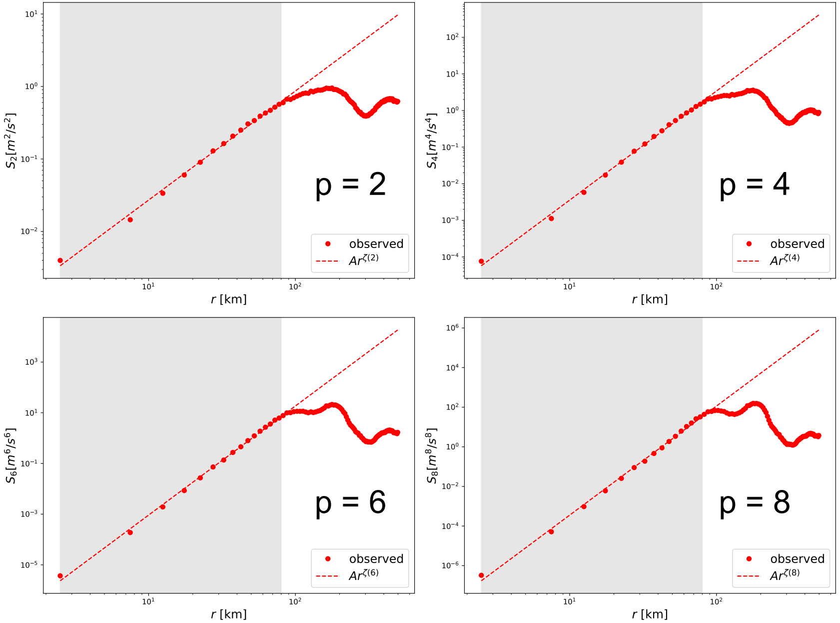
- Structure functions exhibit power laws

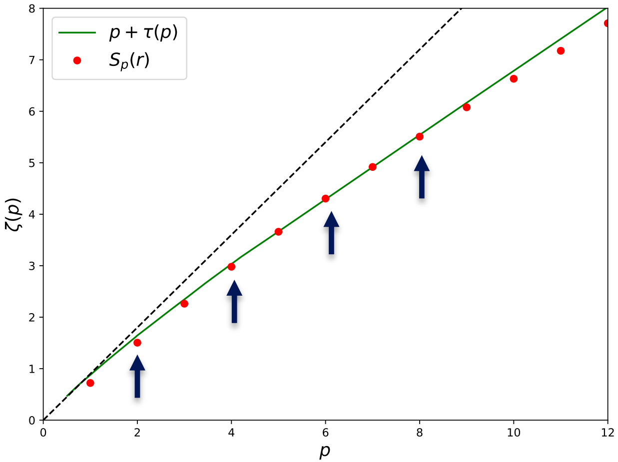
$$S_p(\ell) \sim \left(\frac{\ell}{\ell_0}\right)^{\zeta(p)}$$

- The structure function of 2nd order is related to the spectral slope of SST

$$E(k) \propto k^{-\zeta(2)-1}$$

An example of the scaling of the structure functions





- A characteristic of turbulent flows is the anomalous scaling, i.e. the departure from a straight line

Coarse-grained thermal gradients

- Coarse-grained thermal gradients are built as

$$\overline{|\nabla T|}_\ell(\vec{x}) \equiv \int_{\mathbb{R}^d} \ell^{-d} G(\ell^{-1}\vec{x}')|\nabla T|(\vec{x}+\vec{x}')d\vec{x}'$$

where $G(\vec{x})$ is a normalized, positive function that decays fast to zero

- In the limit of small scales $\ell/\ell_0 \to 0$, the behavior of coarse-grained gradients is characterized by scaling exponents

$$\overline{|\nabla T|}_\ell(\vec{x}) \sim \left(\frac{\ell}{\ell_0}\right)^{h(\vec{x})}$$

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Quantifying the intensity of fronts

- The scaling exponents of coarse-grained thermal gradients are known as singularity exponents

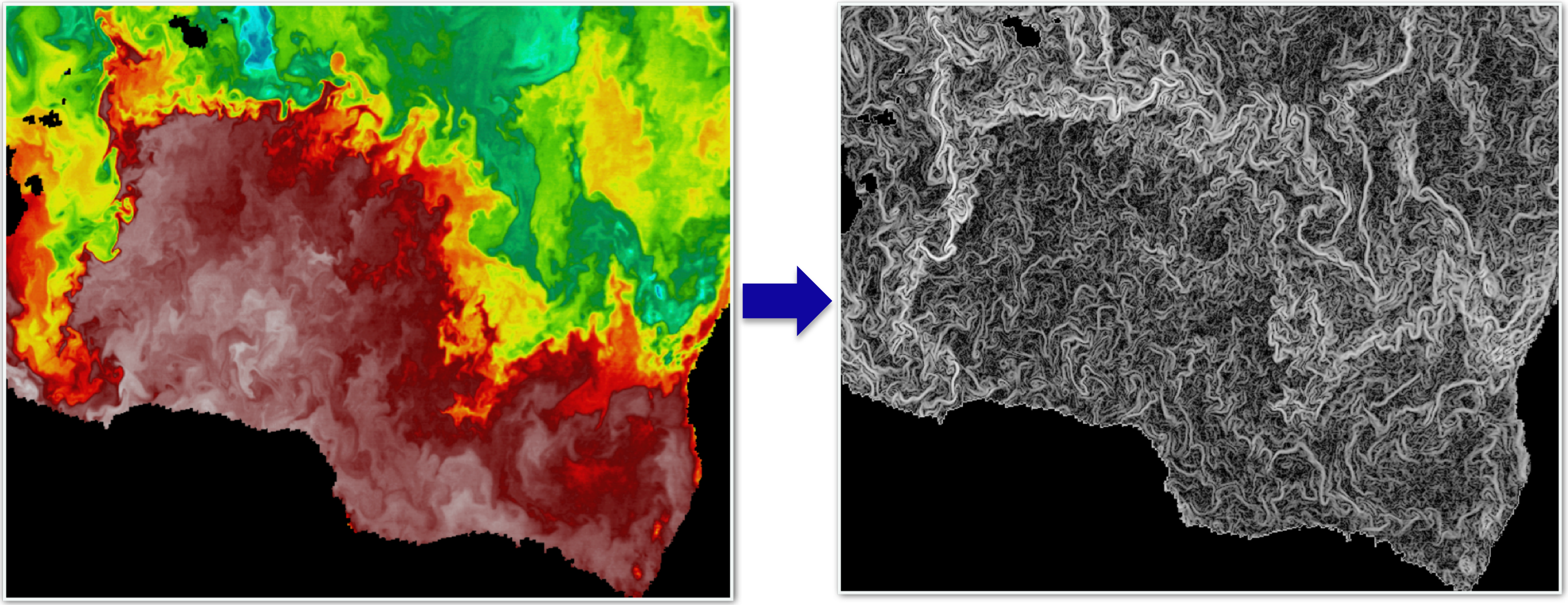
- These exponents quantify the degree of continuity of SST

  - If $h(\vec{x}) \in (n, n+1)$ with n being a positive integer, $\overline{|\nabla T|}_\ell(\vec{x})$ is derivable n times but not $n+1$ times

- We propose to use it as a proxy measure for the intensity of fronts

  - <u>The strongest fronts are those with the smallest singularity exponents</u>

An example of thermal fronts



- Robust algorithms for computing singularity exponents are available (Pont et al. IJCM 2013)

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How does ocean fronts contribute to such scaling?

- The singularity spectrum characterizes the ‘volume’ occupied by points of front intensity h'

$$D(h') \equiv d_F(\{\vec{x}|h(\vec{x} = h')\})$$

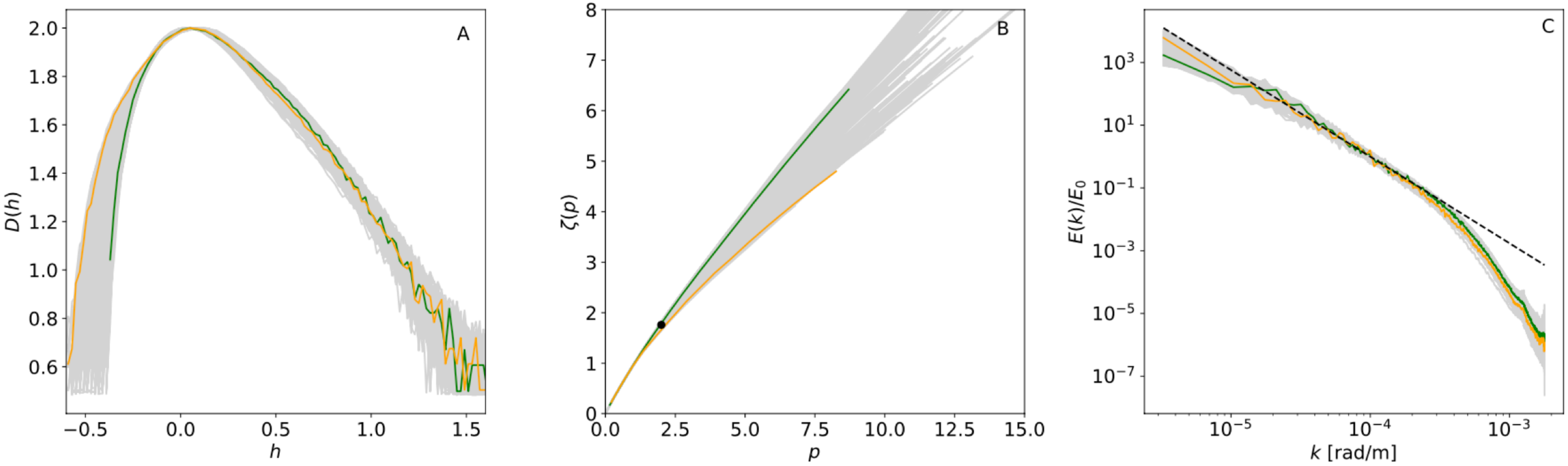
- The spatial distribution of fronts characterizes the scaling of the structure functions

$$\zeta(p) = p(h+1) + d - D(h)$$

$$p = \frac{dD}{dh}$$

(Parisi & Frisch 1985)

An example of singularity spectrum



- Singularity spectrum connects the geometrical/statistical properties of fronts with some SST statistics

- Further insight can be obtained from the properties of singularity spectra

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How does ocean fronts contribute to such scaling?

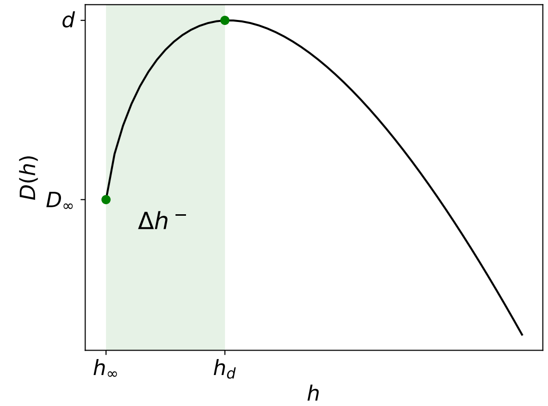
- The Legendre transform imply that the singularity spectrum is connected to the slope of the scaling function

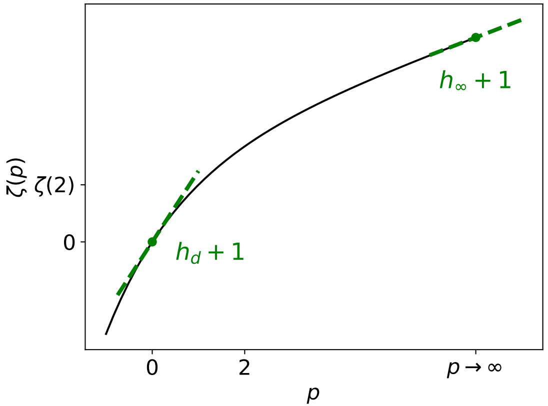
$$h + 1 = \frac{d\zeta}{dp}$$

- Anomalous scaling can be quantified as

$$\Delta h^{-} \equiv h_d - h_\infty = \left.\frac{d\zeta}{dp}\right|_{p=0} - \left.\frac{d\zeta}{dp}\right|_{p\to\infty}$$

- It has been compared to h_∞





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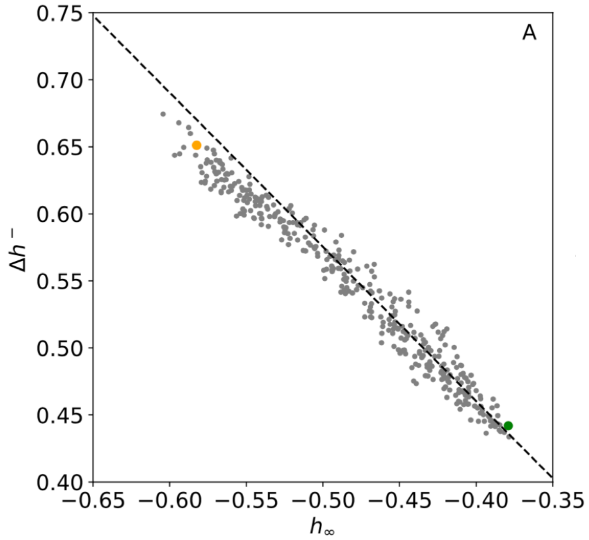
A key result

- We've found that the anomalous scaling (the amplitude of the singularity spectrum) is proportional the intensity of the strongest front

$$\left.\frac{d\zeta}{dp}\right|_{p=0} - \left.\frac{d\zeta}{dp}\right|_{p\to\infty} \propto h_\infty$$



Isern-Fontanet et al. GRL 2022

- This result is robust
  - Observed for different areas and variables
  - It can be theoretically predicted (Isern-Fontanet & Turiel JPO 2021)

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Seasonal changes

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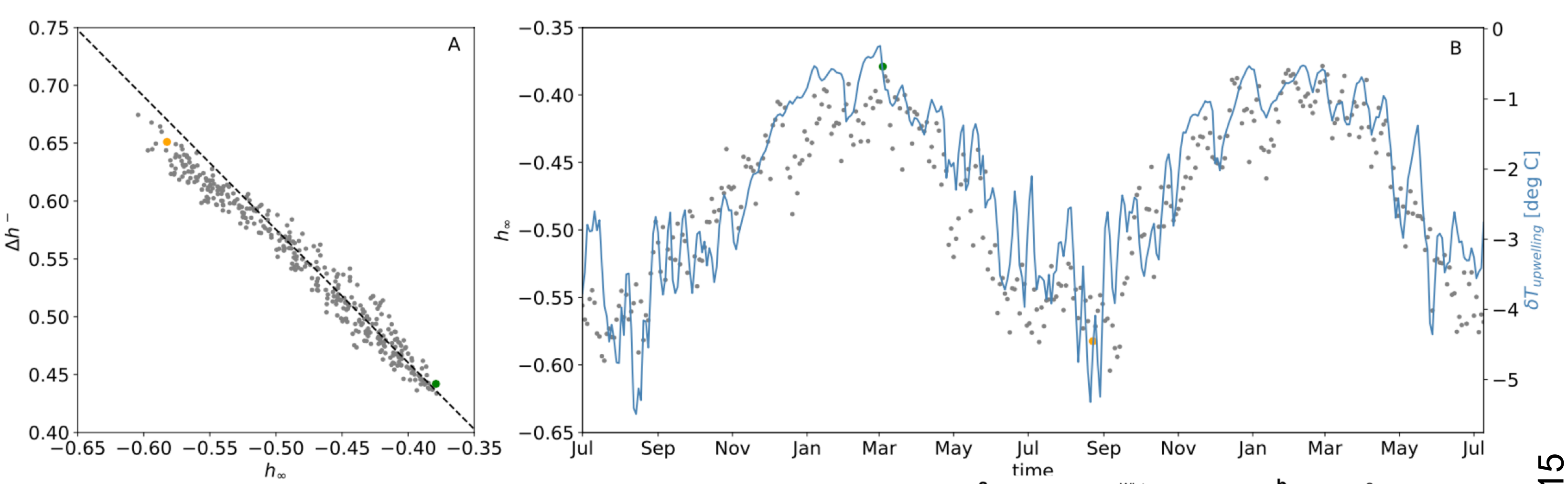
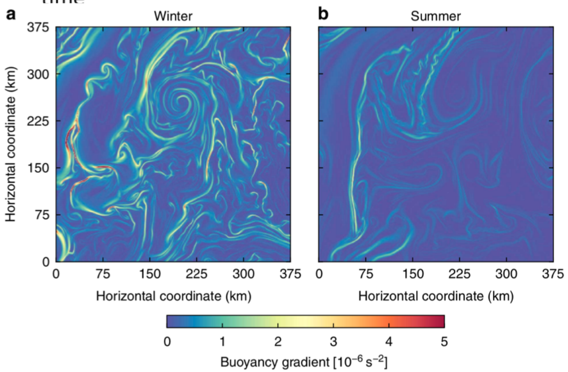
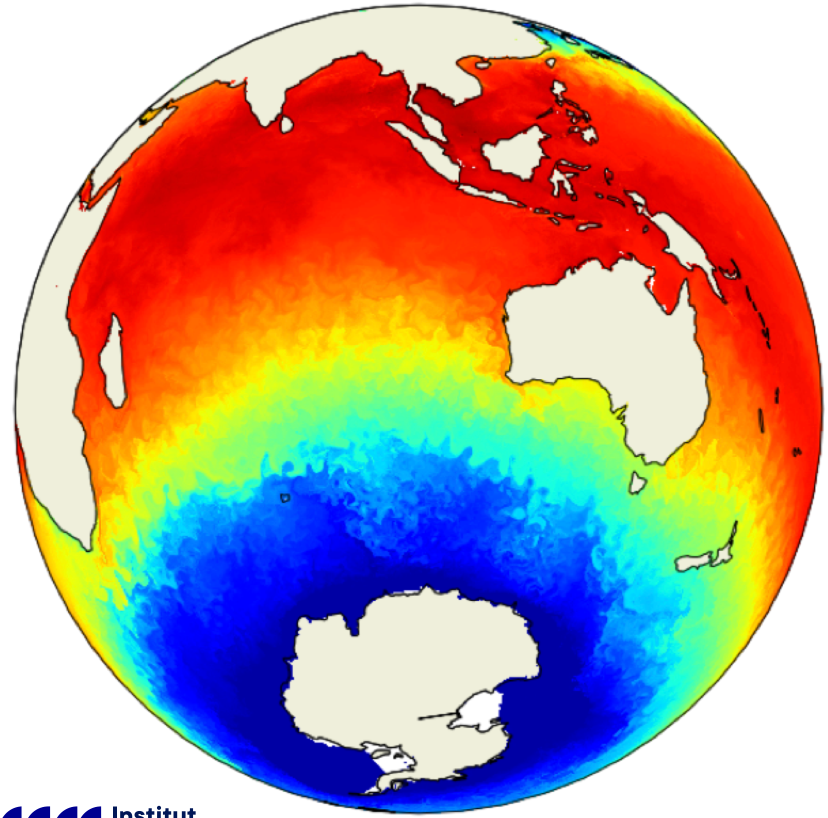
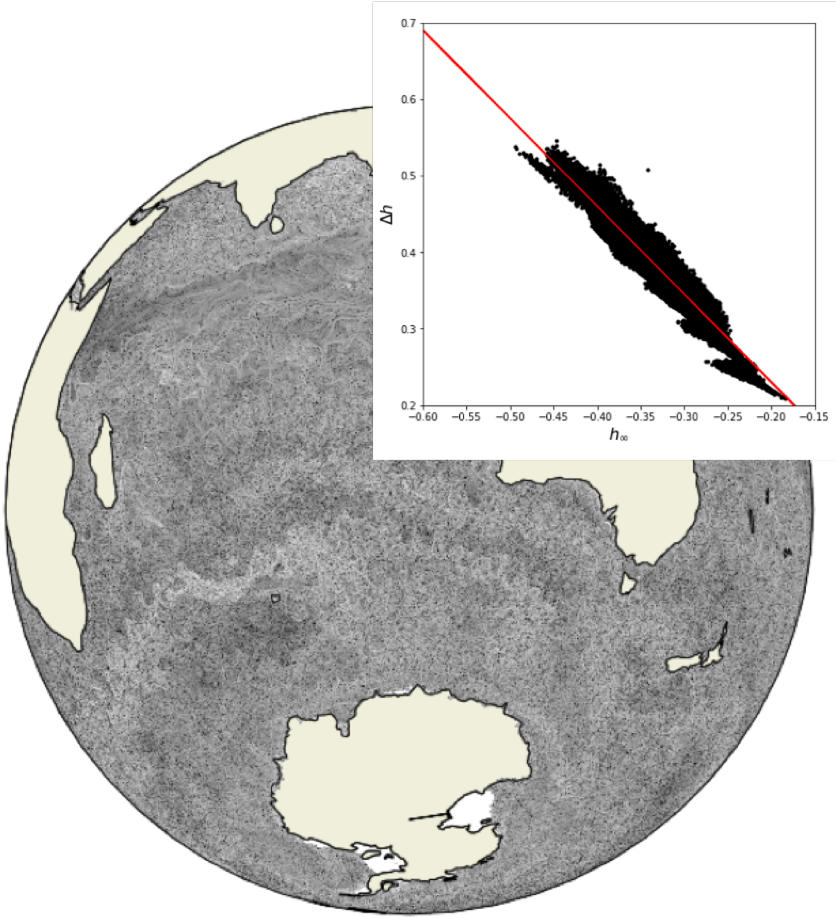




Callies et al. NC 2015

The LLC4320 experiment





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Summary & conclusions

- We propose the use of singularity exponents as a proxy measure for the intensity of fronts
- Ocean fronts determine the scaling properties of the structure functions
  - We’ve found that the most intense fronts control the anomalous scaling of the structure functions
- Practical use: validation of SST products
  - See C. González-Haro et al. Evaluation and intercomparison of GHRSST products at global scale (S2-35 poster)

More information in …

AUGUST 2021 JOURNAL OF PHYSICAL OCEANOGRAPHY 2639

On the Connection between Intermittency and Dissipation in Ocean Turbulence: A Multifractal Approach

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ABSTRACT: The multifractal theory of turbulence is used to investigate the energy cascade in the northwestern Atlantic Ocean. The statistics of singularity exponents of horizontal velocity gradients computed from in situ measurements at 2-km resolution are used to characterize the anomalous scaling of the velocity structure functions at depths between 50 and 500 m. Here, we show that the degree of anomalous scaling can be quantified using singularity exponents. Observations reveal, on one side, that the anomalous scaling has a linear dependence on the exponent characterizing the strongest velocity gradient and, on the other side, that the slope of this linear dependence decreases with depth. Since the observed distribution of exponents is asymmetric about the mode at all depths, we use an infinitely divisible asymmetric model of the energy cascade, the log–Poisson model, to derive the functional dependence of the anomalous scaling with the exponent of the strongest velocity gradient, as well as the dependence with dissipation. Using this model we can interpret the vertical change of the linear slope between the anomalous scaling and the exponents of the strongest velocity gradients as a change in the energy cascade. This interpretation assumes the validity of the multifractal theory of turbulence, which has been assessed in previous studies.

KEYWORDS: Atlantic Ocean; Mesoscale processes; Turbulence; In situ oceanic observations

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RESEARCH LETTER
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On the Seasonal Cycle of the Statistical Properties of Sea Surface Temperature

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Key Points:

- The intensity of Sea Surface Temperature (SST) fronts is quantified using singularity exponents, which measure the continuity of the field
- Anomalous scaling of SST structure functions is correlated to the the intensity of the strongest fronts
- The variability of the strongest fronts depends on the seasonal variability of the coastal upwelling in the area of study

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Abstract The contribution of ocean fronts to the properties and temporal evolution of Sea Surface Temperature (SST) structure functions have been investigated using a numerical model of the California Current system. First, the intensity of fronts have been quantified by using singularity exponents. Then, leaning on the multifractal theory of turbulence, we show that the departure of the scaling of the structure functions from a straight line, known as anomalous scaling, depends on the intensity of the strongest fronts. These fronts, at their turn, are closely related to the seasonal change of intensity of the coastal upwelling characteristics of this area. Our study points to the need to correctly reproduce the intensity of the strongest fronts and, consequently, properly model processes such as coastal upwelling in order to reproduce SST statistics in ocean models.

Plain Language Summary Forecasting the evolution of the Earth's climate requires to predict the evolution of the statistical characteristics of essential climate variables such as the Sea Surface Temperature. In this study, it has been found that some of such statistical properties depend on the intensity of the strongest fronts in the ocean. This implies that those ocean, or climate, models that fail to correctly predict their intensity will not be able to correctly reproduce the statistical characteristics of key variables such as temperature. The area analyzed in this study is the California Current system, where the strongest fronts are modulated by the seasonal evolution of the upwelling. Therefore, our results imply that such a system has to be correctly modeled, or parametrized, in order to properly reproduce the statistics of ocean temperatures.

… and in the in-person event on Tuesday 28 at 9:30 AM

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Moltes gràcies!
&
Welcome to Barcelona

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