TEMPERATURE STATISTICS IN THE DEEP OCEAN

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Introduction

Mixing above slopes is an important contribution to the basin mean.

Scalar statistics provide:

- insights into turbulence intermittency,
- hints on mixing mechanisms,
- identification of different scaling regimes,

Statistics are well studied for:

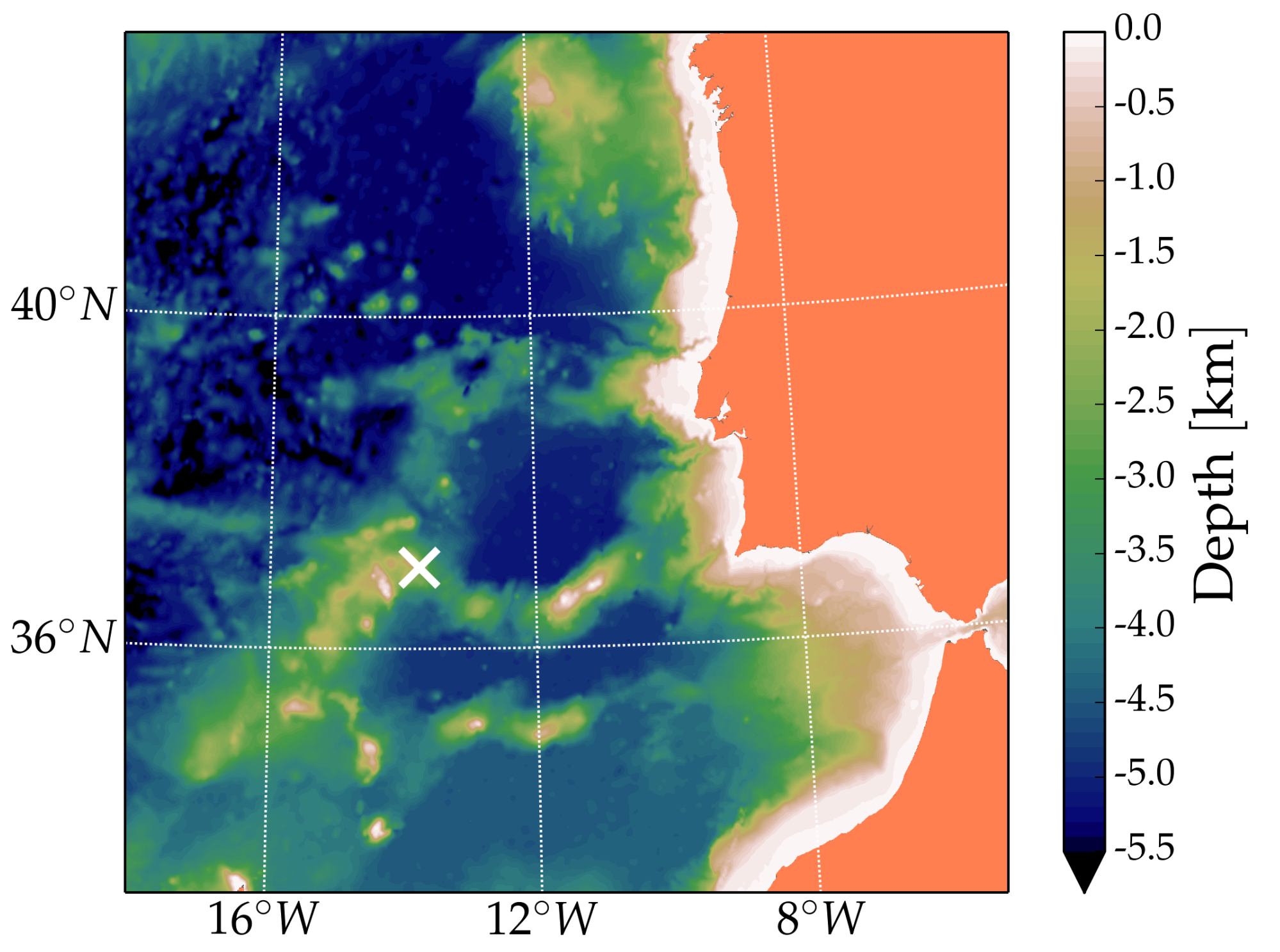
- passive scalars = shear turbulence (Warhaft 2000),
- active scalar = convective turbulence (Zhou and Xia 2002).
- *Scalars in stratified turbulent flow?*

Aims

- Detailed description of the statistics of temperature in a stratified environment.
- Exploit an observational data set above sloping topography,
  - at this location mixing is at least 2 orders of magnitude the value in the interior.
- Comparison between observed statistics and lab results,
  - consider both passive and active scalars.
- Provide a reference for studies of stratified turbulence in controlled environments.
- Provide estimates of the turbulent flux.

Data

Temperature data collected from a moored thermistors array.



The mooring location is marked by the white cross.

Latitude 36° 58.885′ N		Longitude 13° 45.523′ W
Max. depth 2205 m	Min. h.a.b. 5 m	Bottom slope 9.4° ($> \gamma_{crit}^{M_2}$)
Number of T-sens. 144	Vertical spacing 0.7 m	Array length 100.1 m
Deployment 13 Apr 2013	Recovery 12 Aug 2013	Sampling rate 1 Hz

NIOZ thermistors are described in (van Haren 2009)

M_2 tide is the dominant spectral peak.

Velocities are mainly aligned to isobaths, but a cross-isobath component is present.

Results

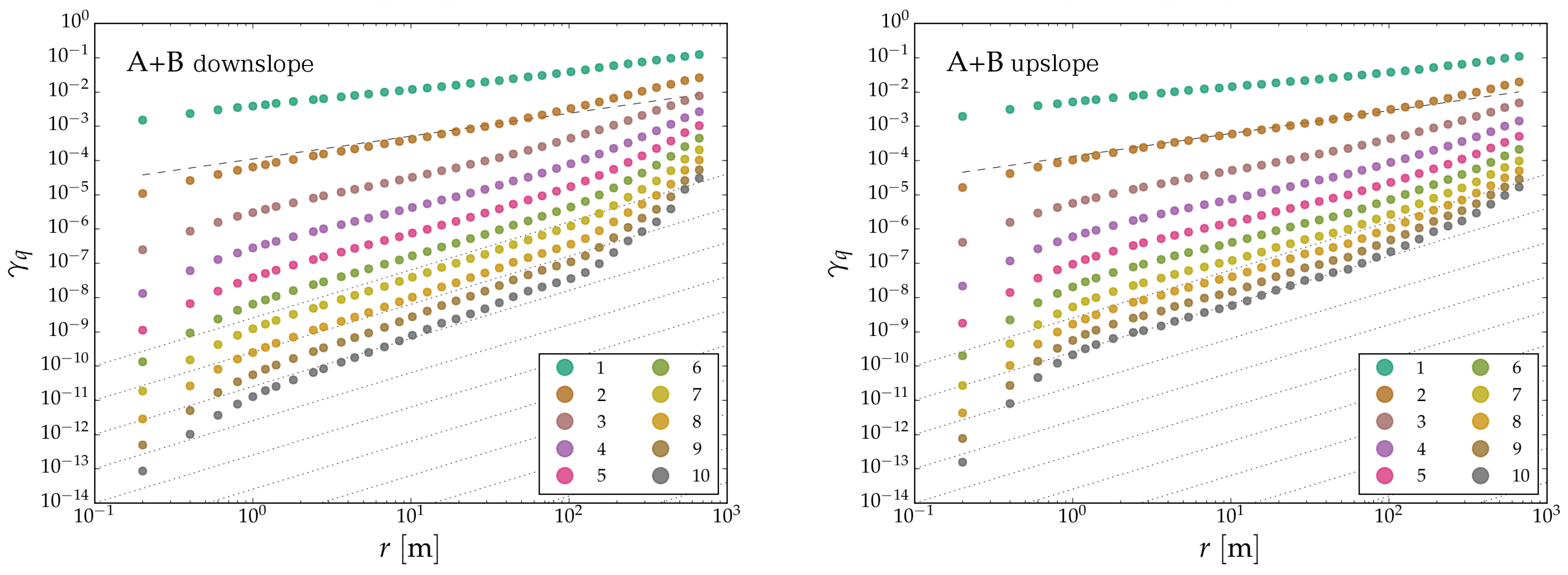
Generalised structure functions: $\gamma_q \equiv \gamma_q(r) = \langle|\Delta_r\theta|^q\rangle$, $\Delta_r\theta$: horizontal temperature increment at distance r. According to the non-intermittent (fully self similar) theory of Kolmogorov-Obukhov-Corrsin, $\gamma_q \sim r^{\zeta(q)}$, with $\zeta(q) = q/3$ for r within the inertial range and q the order of the function.

Due to intermittency, above $q \approx 10$:
(Zhou and Xia 2002)

- Grid turbulence, shear driven → $\zeta(q) \approx 1.4$
- Convective turbulence, buoyancy driven → $\zeta(q) \approx 0.8$

Generalised structure function in the lower half of the mooring

Downslope phase — Upslope phase



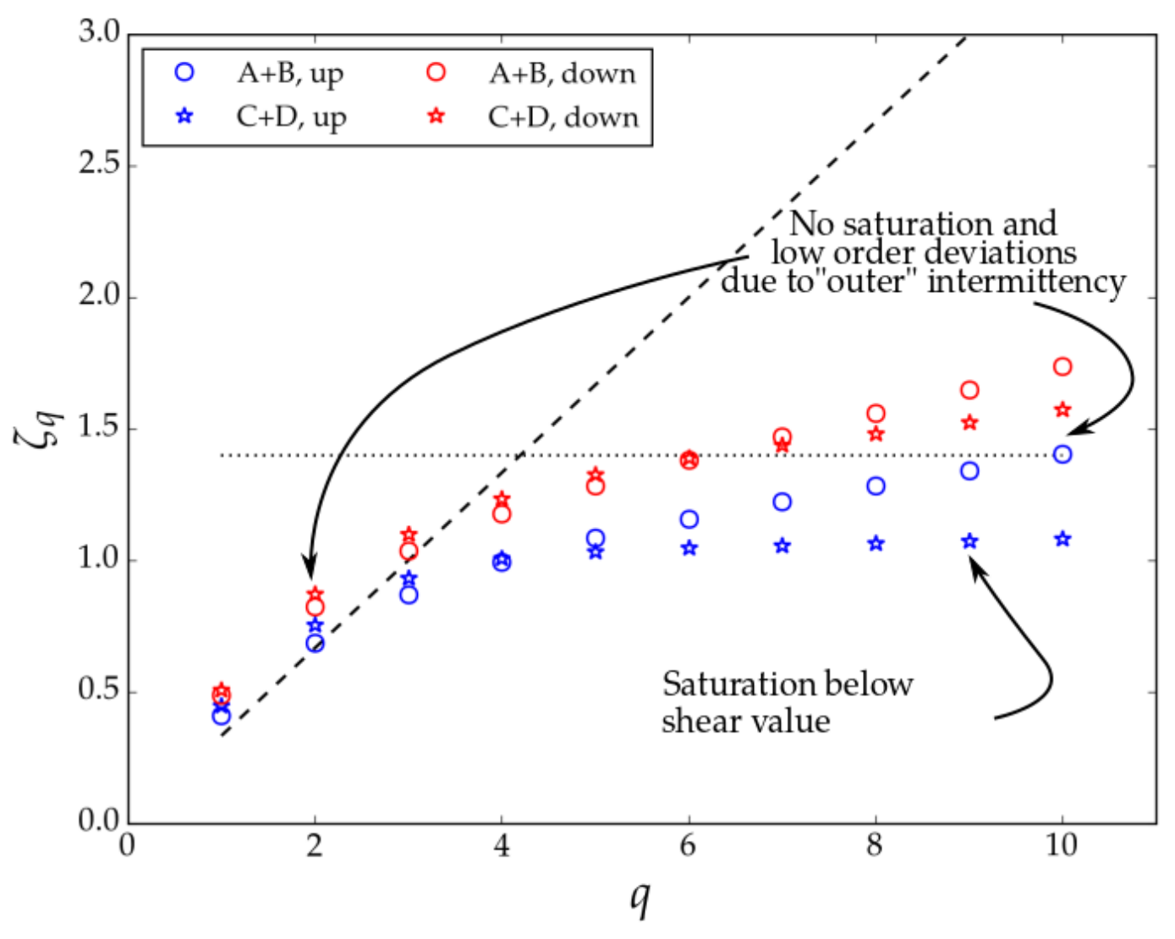
Dashed line: $\zeta(2) = 2/3$ slope

A+B: lower half of the mooring

Dotted lines: "grid turbulence" slope

C+D: upper half of the mooring

Scaling exponent

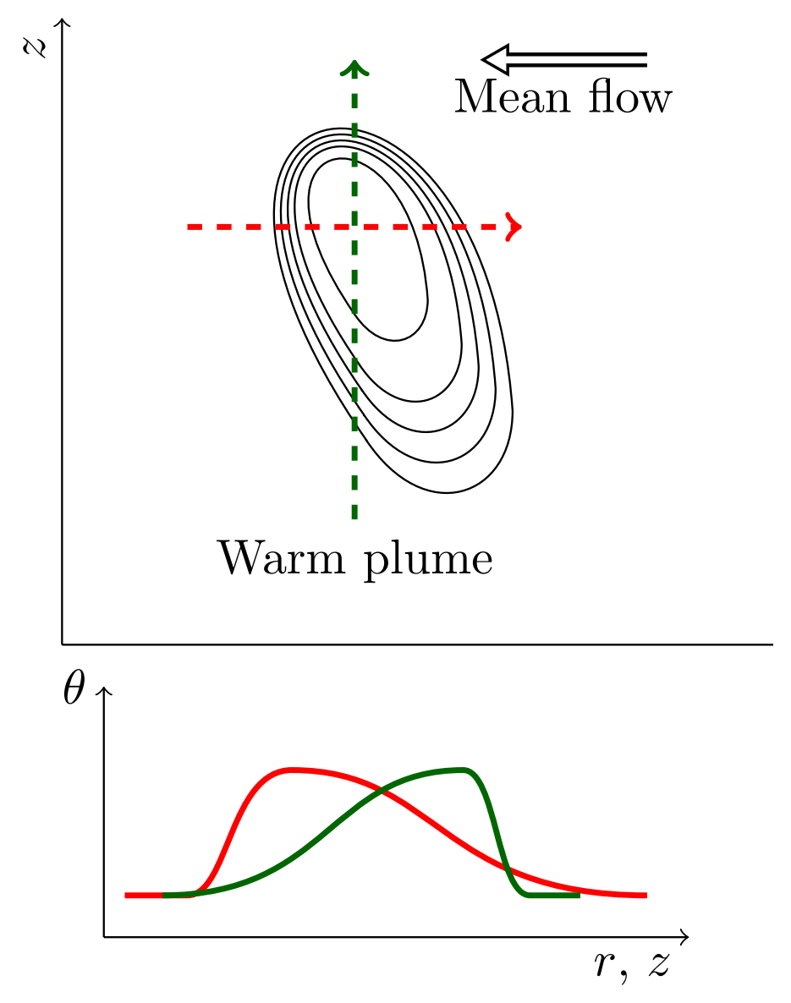


Dashed line: fully self similar

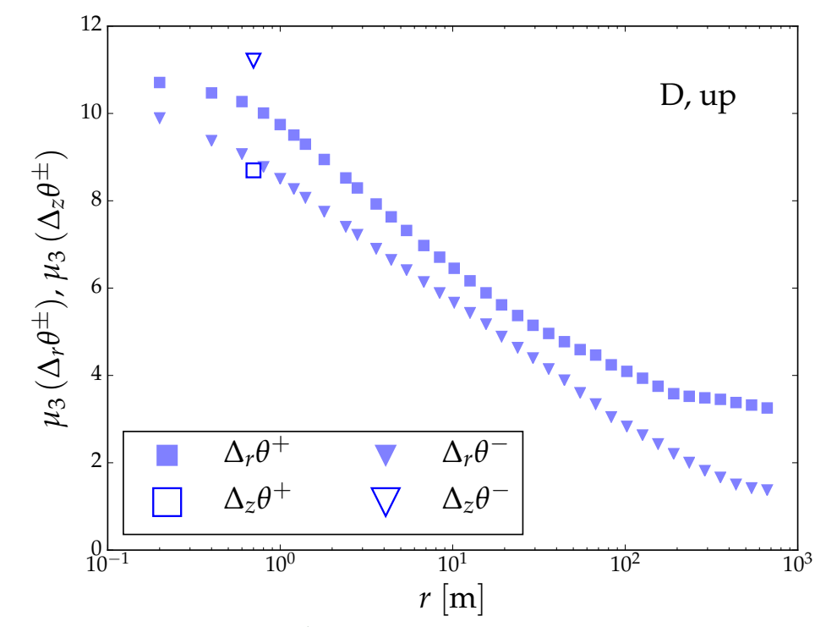
Dotted line: intermittency (shear)

Quantify *spatial asymmetry* (plumes?) by computing the skewness of $\Delta_r\theta^{\pm} = (|\Delta_r\theta| \pm \Delta_r\theta)/2$, (similarly for the vertical increments $\Delta_z\theta$).

Sketch of an asymmetric temperature anomaly



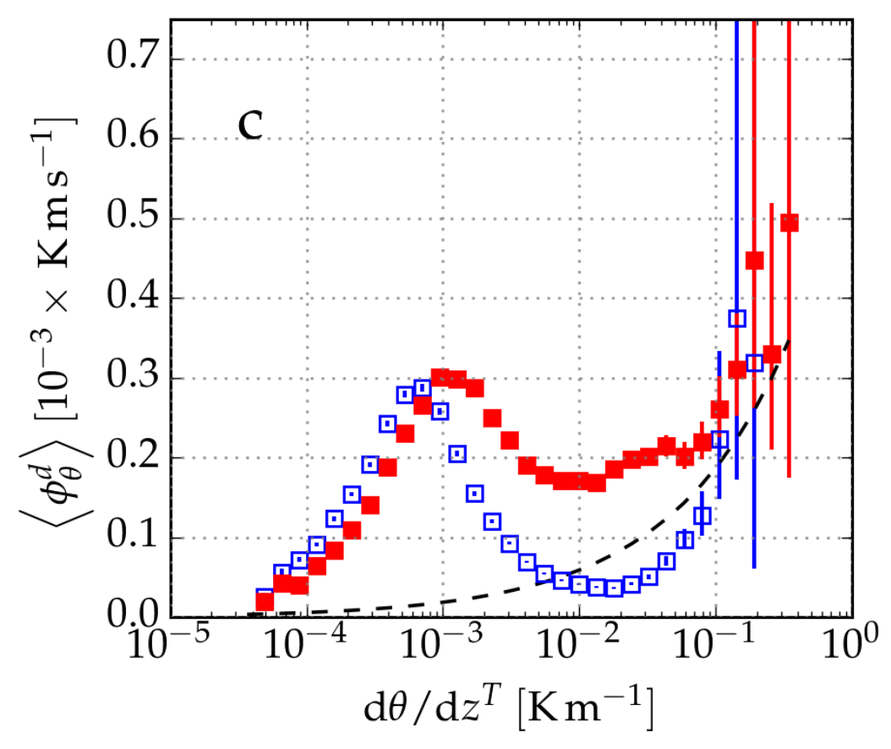
Skewness (μ_3) of plus/minus increments
Upslope phase, top of the mooring



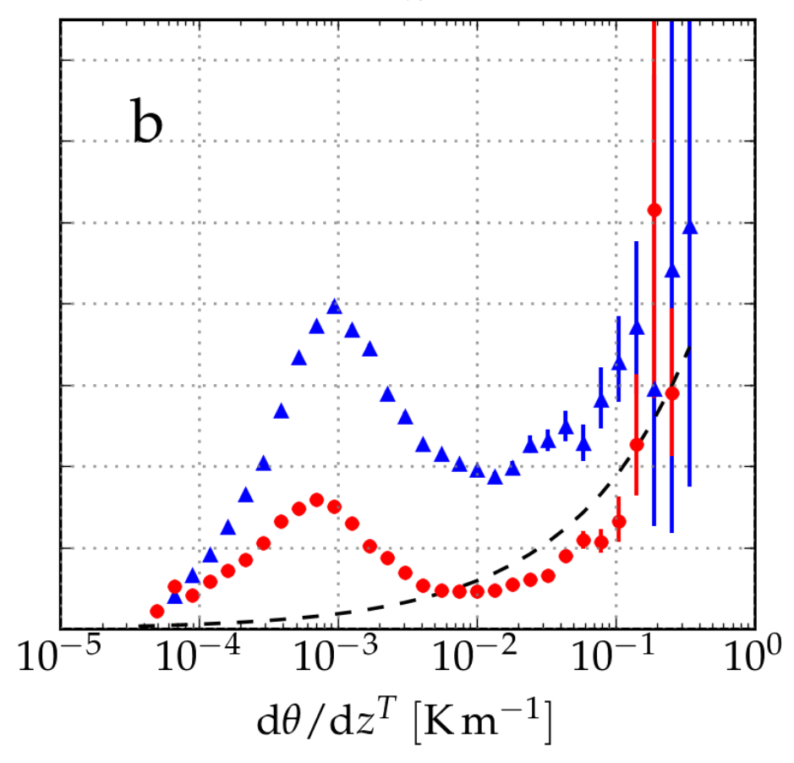
$$\mu_3\left(\Delta_z\theta^+\right) < \mu_3\left(\Delta_z\theta^-\right)$$

$$\mu_3\left(\Delta_r\theta^+\right) > \mu_3\left(\Delta_r\theta^-\right)$$

Flux-gradient function estimate: $\frac{\partial\theta}{\partial t} = \frac{\partial\phi}{\partial z} = \frac{\mathrm{d}\phi(\theta_z)}{\mathrm{d}\theta_z}\theta_{zz}$, instability for $\frac{\mathrm{d}\phi(\theta_z)}{\mathrm{d}\theta_z} < 0$ (Balmfort 1998)



lower 1/2 of mooring — upper 1/2 of mooring



warming tidal phase — cooling tidal phase

Conclusions

- Sharp scaling break between turbulence and waves at $r = \mathcal{O}(100\,\mathrm{m})$ (kink in γ_q).
- Outer intermittency (no saturation, large ζ_q).
- Smooth, "classical" $\mathcal{N}$-shaped flux-gradient relation.

Downslope (warming) phase	Upslope (cooling) phase
Weaker heat flux	Stronger heat flux
Skewness of $\Delta_r\theta^{\pm}$: cold convective "plumes"	Upper half of the mooring: temperature ≈ active scalar (warm "plumes")
High-order γ_q: ≈ passive scalar?	Lower half of the mooring: temperature ≈ passive scalar

References

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