# Method Development to Decipher the Dissimilar Transport of Momentum, Heat, and Moisture in a Stably Stratified Flow

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## Motivation and Objective

Based on single-level measurements of turbulence over an alpine glacier, we explore the turbulent exchange in a stably stratified katabatic flow.

We are motivated to:

- develop a new method that is useful for analyzing eddy structures;
- address the dissimilar transport of momentum, heat, and moisture from the fresh perspective of anisotropic motions of turbulence.

Our objective is to:

- promote new understanding of boundary-layer turbulence anisotropy as one possible factor in dissimilar behaviors between momentum and scalar transport.

## Research Highlights

- A new method is developed for a scrutiny of turbulent transport, whereby quadrant analysis and cospectral analysis can be interconnected.
- In a stably stratified flow, dissimilar transport of momentum, sensible heat, and water vapor is associated with anisotropy properties of turbulence.
- Extending octant analysis to scalar turbulence identifies eddy structures that exhibit distinct behaviors indicative of the flux dissimilarity.

## Field Experiment

We made a field experiment over a melting valley glacier on the south-east Tibetan Plateau. Our fieldwork was made at 4,800 m above sea level and lasted from May 20 to September 9, 2009 at Palong-Zangbu No. 4 Glacier, which covers an area of about 12.8 km² and spans in altitude 4,650−5,800 m.

Atmospheric turbulence data were collected from:

- an eddy-covariance system using a CSAT3 three-dimensional sonic anemometer (Campbell Scientific Inc., Logan, Utah, USA) and a LI-7500 open-path gas analyzer (Li-Cor Inc., Lincoln, Nebraska, USA) – 10 Hz.

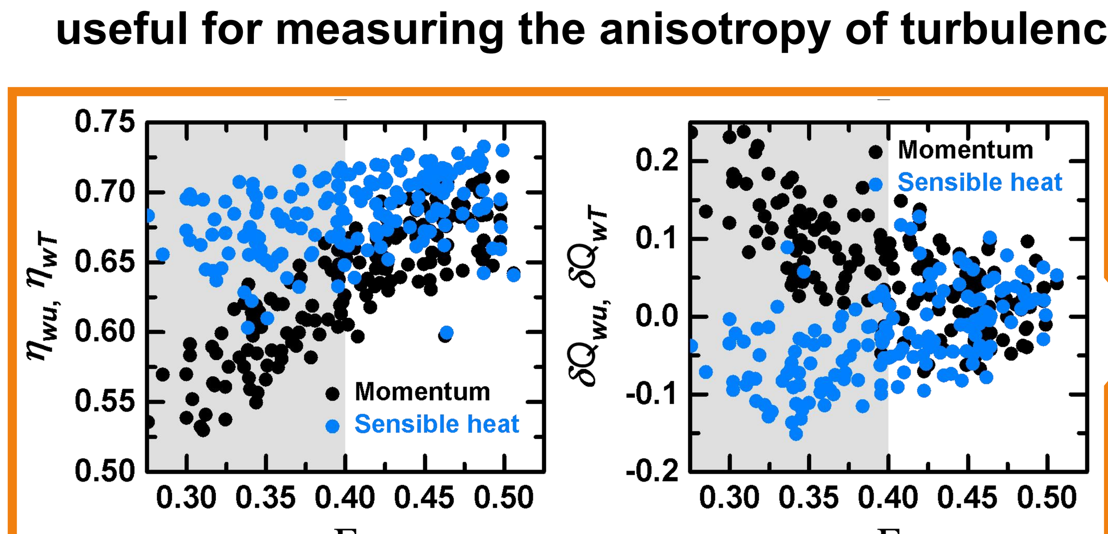
The valley glacier

Experimental set-up

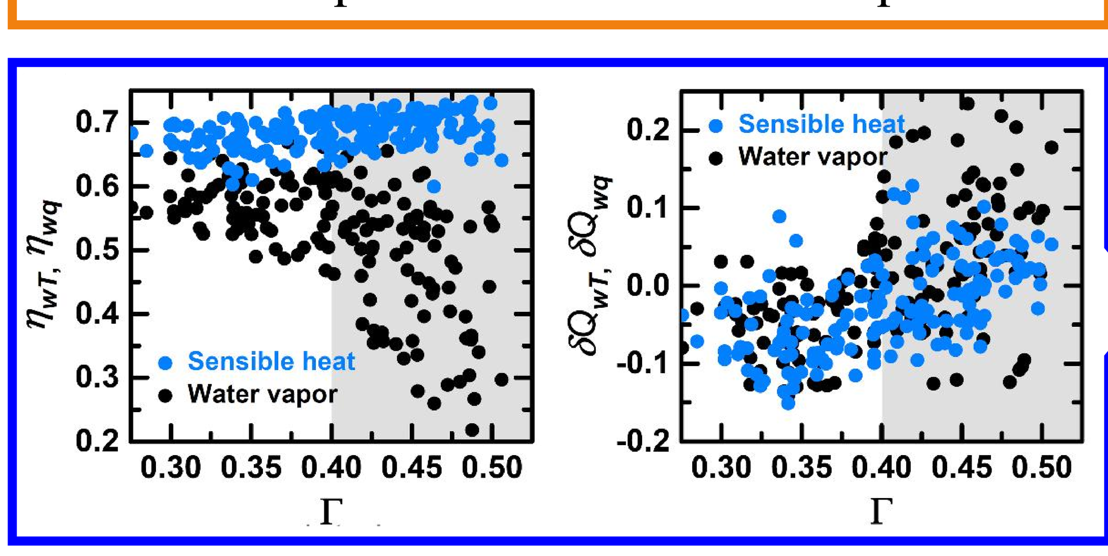
## Dissimilar Transport of Momentum and Scalars

- Based on the quadrant analysis technique, we characterize the dissimilar transport of momentum, heat, and moisture.
- Levels of flux similarity vary with the velocity aspect ratio (Γ), a parameter useful for measuring the anisotropy of turbulence.

$$\Gamma = \left(\frac{2\sigma_w^2}{\sigma_u^2+\sigma_v^2}\right)^{\frac{1}{2}}$$




- Higher degrees of turbulence anisotropy render lower levels of flux similarity of momentum and heat (see the range Γ <0.4).




- On the contrary, they render higher levels of flux similarity of heat and moisture (see the range Γ <0.4).

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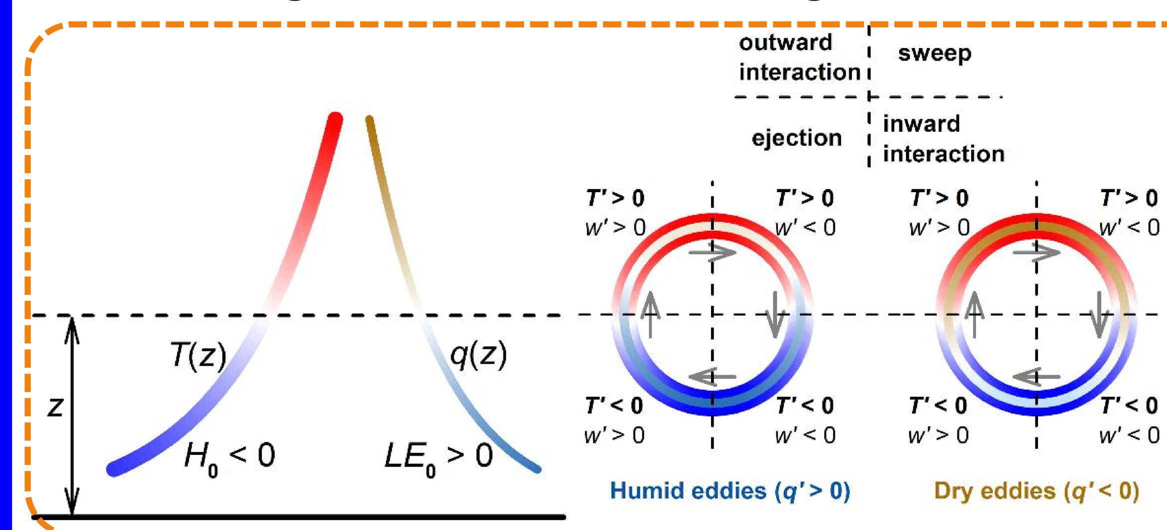
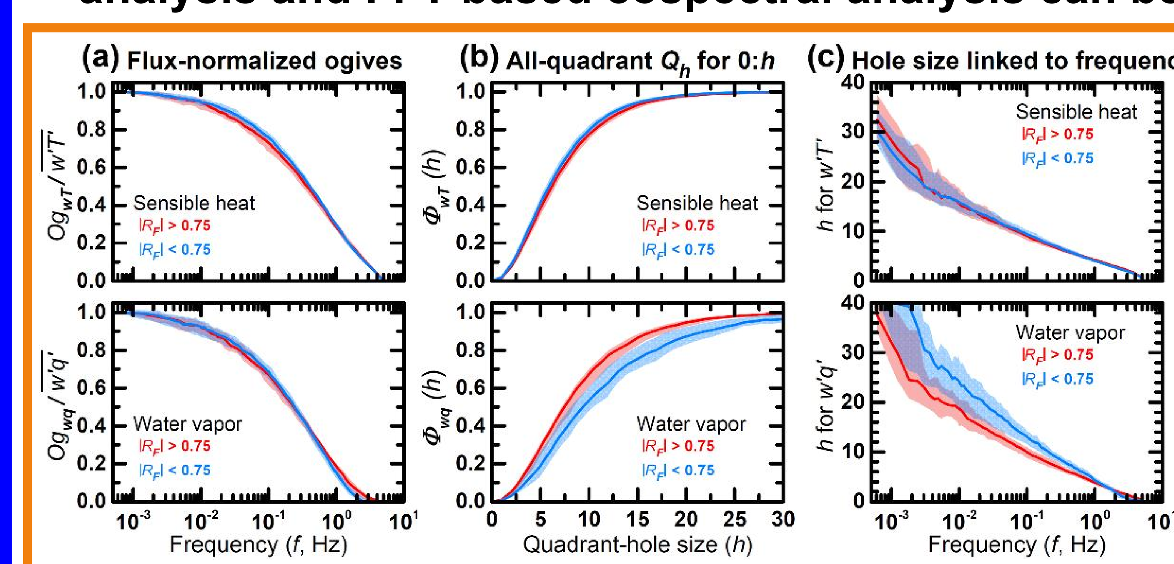
## Extending Octant Analysis to Scalar Turbulence

- Scalar-transporting eddy structures in relation to heat and moisture exchange can be organized into a total of eight octants in the $(w', T', q')$ space.




1. humid outward interaction
2. humid ejection
3. humid inward interaction
4. humid sweep
5. dry outward interaction
6. dry ejection
7. dry inward interaction
8. dry sweep

- A new method is developed for a scrutiny of scalar transport, whereby quadrant analysis and FFT-based cospectral analysis can be interconnected.



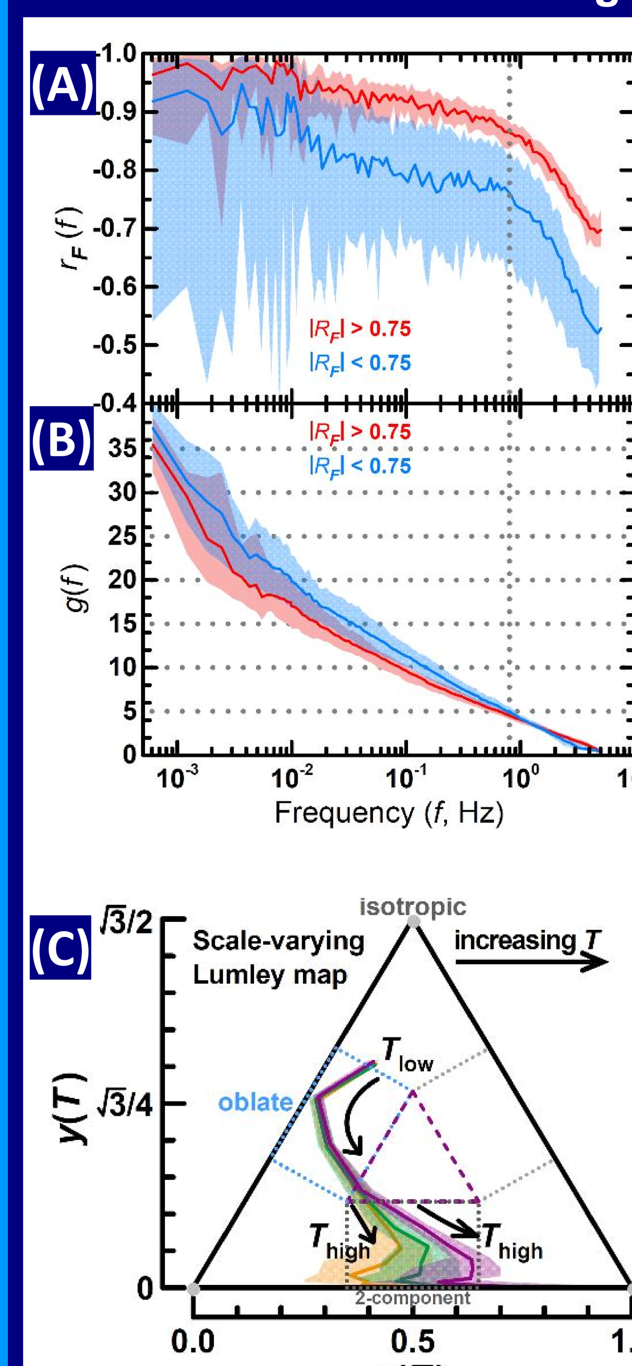

$$\frac{Og_{w\mu}(f)}{\overline{w'\mu'}} = \Phi_{w\mu}(h) = \varepsilon$$

- The hyperbolic quadrant-hole size ($h$) is coupled to the frequency ($f$) underlying the fast Fourier transform.

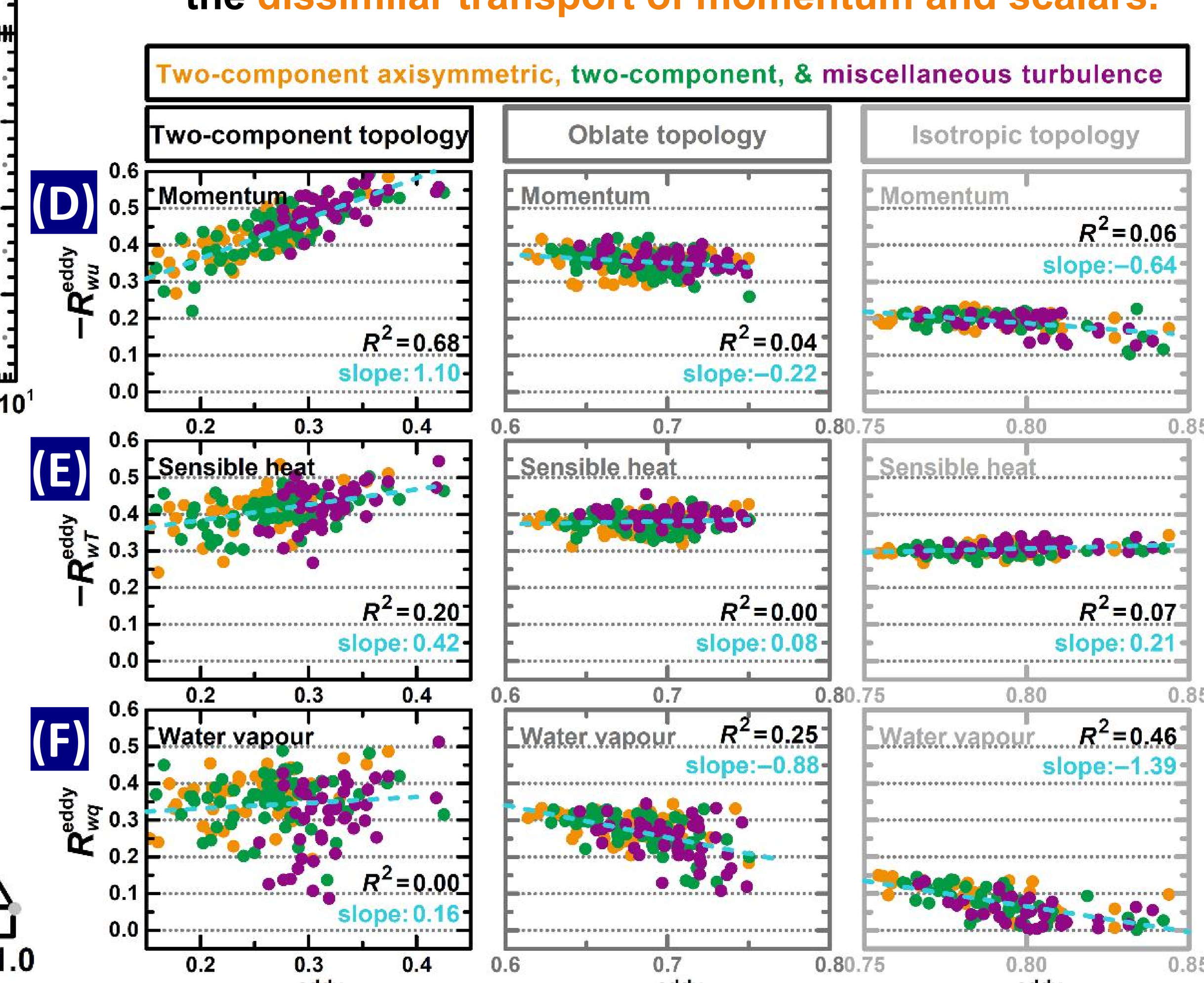
$$Og_{w\mu}(f) = \int_f^{f_N} Cs_{w\mu}(F)\, dF$$

$$\Phi(h) = 1 - \sum_{J=1}^{4} Q_{J,h}$$

## Illuminating the Dissimilar Transport of Scalars




(A, B) Levels of the heat-moisture flux correlation vary with the eddy scale, as is linked to the frequency.
(C) Turbulent eddies at different time scales ($T$) bear a diversity of topological structures.
(D, E, F) A change in eddy scale-wise topology illuminates the dissimilar transport of momentum and scalars.




## Publications

- Guo X, Yang W, Gao Z, Wang L, *et al.* (2022) Katabatic flow structures indicative of the flux dissimilarity for stable stratification. *Boundary-Layer Meteorology*, *182*, 379−415.
- Guo X, Yang W, Hong J, Wang L, Gao Z, Zhou D (2023) Turbulence behaviors underlying the sensible heat and water vapor flux dissimilarity in a stably stratified flow. *Environmental Fluid Mechanics*, https://doi.org/10.1007/s10652-023-09940-2.
- Guo X, Yang W, Zhou D (2023) Eddy scale-wise topology underlying turbulence anisotropy illuminates the dissimilar transport of momentum, heat, and moisture in a stably stratified katabatic flow. *Boundary-Layer Meteorology*. (major revision requested)

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