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Scalewise Universal Relaxation to Isotropy of Inhomogeneous Atmospheric Boundary Layer Turbulence

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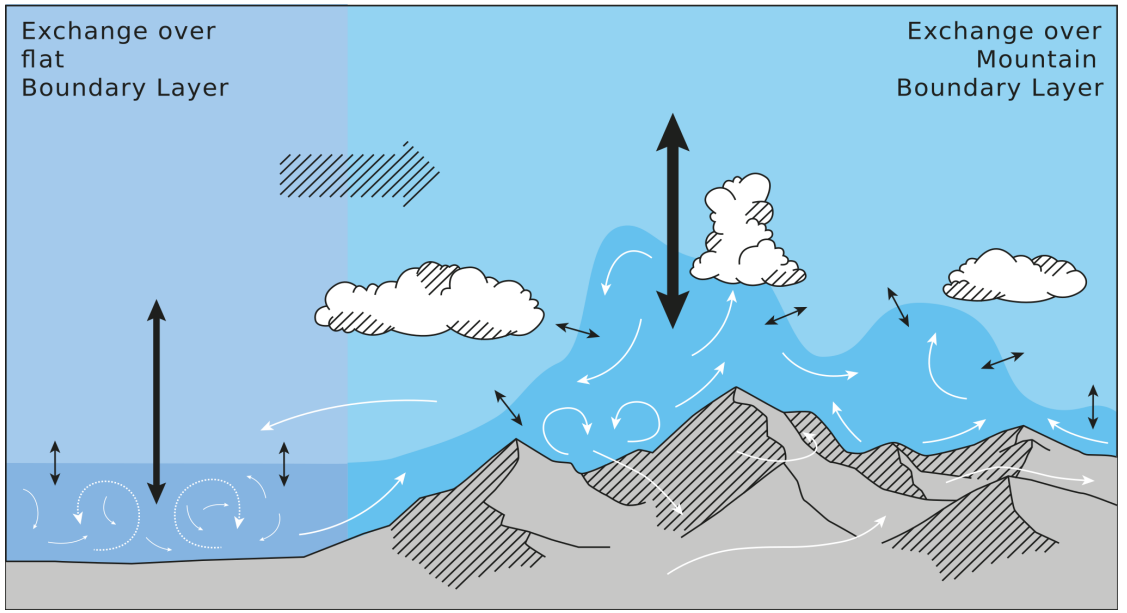
Motivation

Atmospheric turbulence:

- Re ~ 10^9
- wide inertial subrange (several decades)
- Tendency towards isotropy

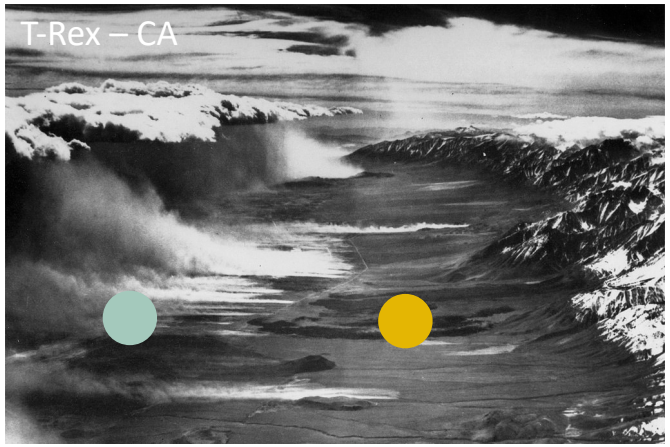
Production scales of turbulence are anisotropic:

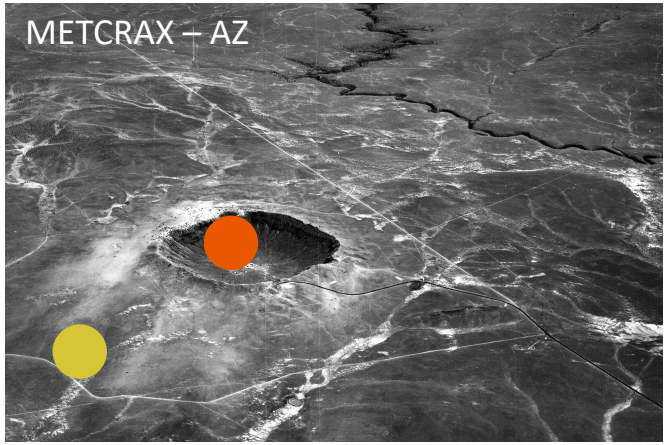
- Buoyancy
- Shear
- Terrain-induced pressure perturbations
- Streamline curvature
- Additional length scales (LLJ)



What is the effect of terrain and flow complexity on turbulence cascade?

Data from 20 turbulence towers: flat - mountain top





AHATS CASES-99 Cabauw IPAQs T-RexC i-Box0 i-Box1 FAR NEAR RIM T-RexW FLR i-Box10 i-Box27 SSW2 SSW4 i-BoxTop ImHint

Determining scalewise anisotropy

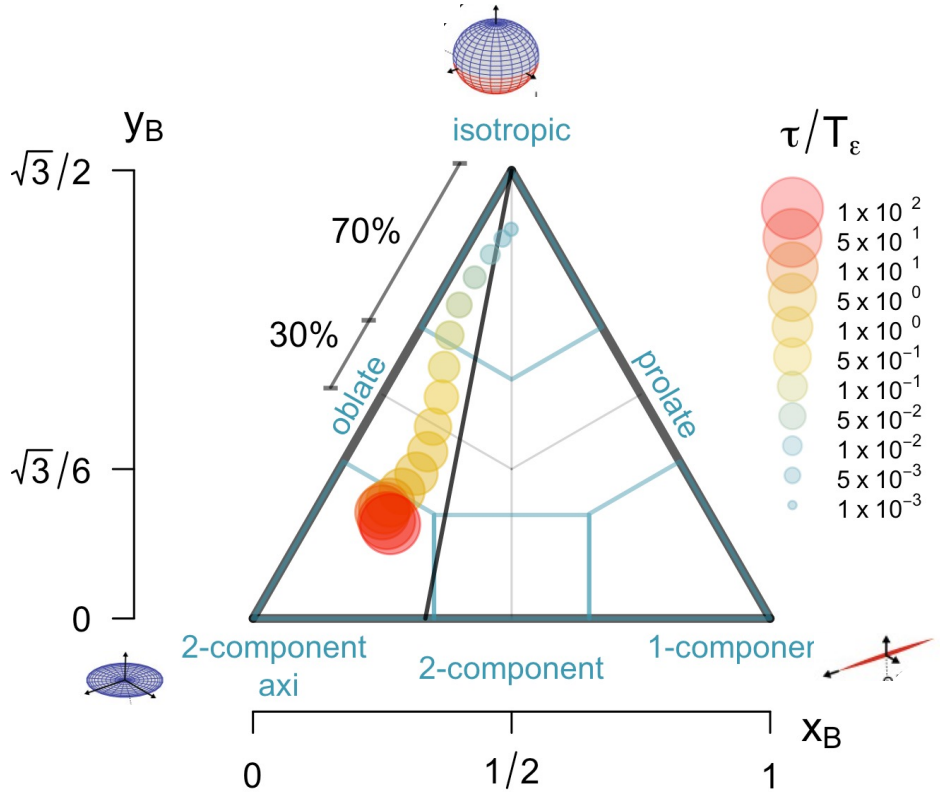
- Wavelet decomposition of Reynolds stress tensor

- At each scale:

→ Invariant analysis of the anisotropy tensor
(Lumley & Newmann 1977, Banerjee et al. 2007)

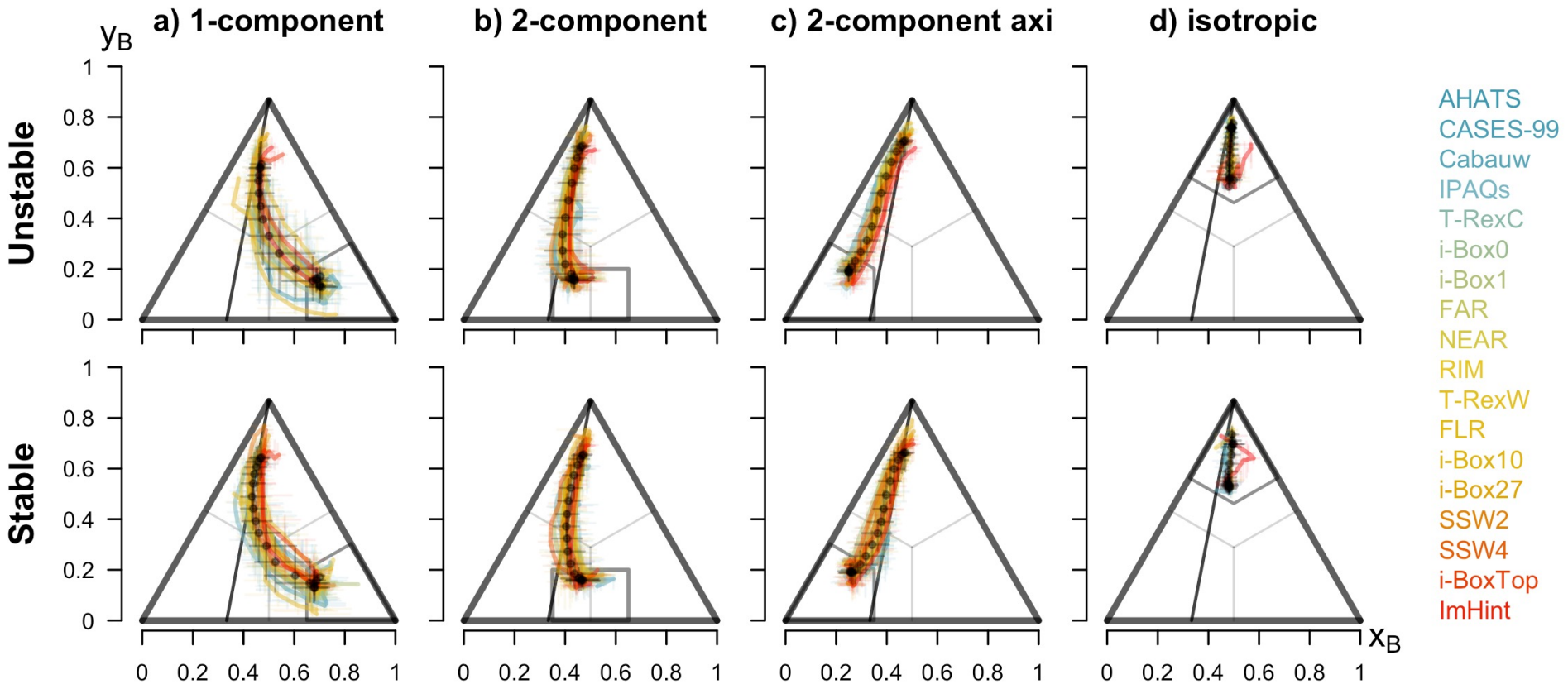
$$x_B = \lambda_1 - \lambda_2 + \frac{1}{2}(3\lambda_3 + 1)$$

$$y_B = \frac{\sqrt{3}}{2}(3\lambda_3 + 1)$$



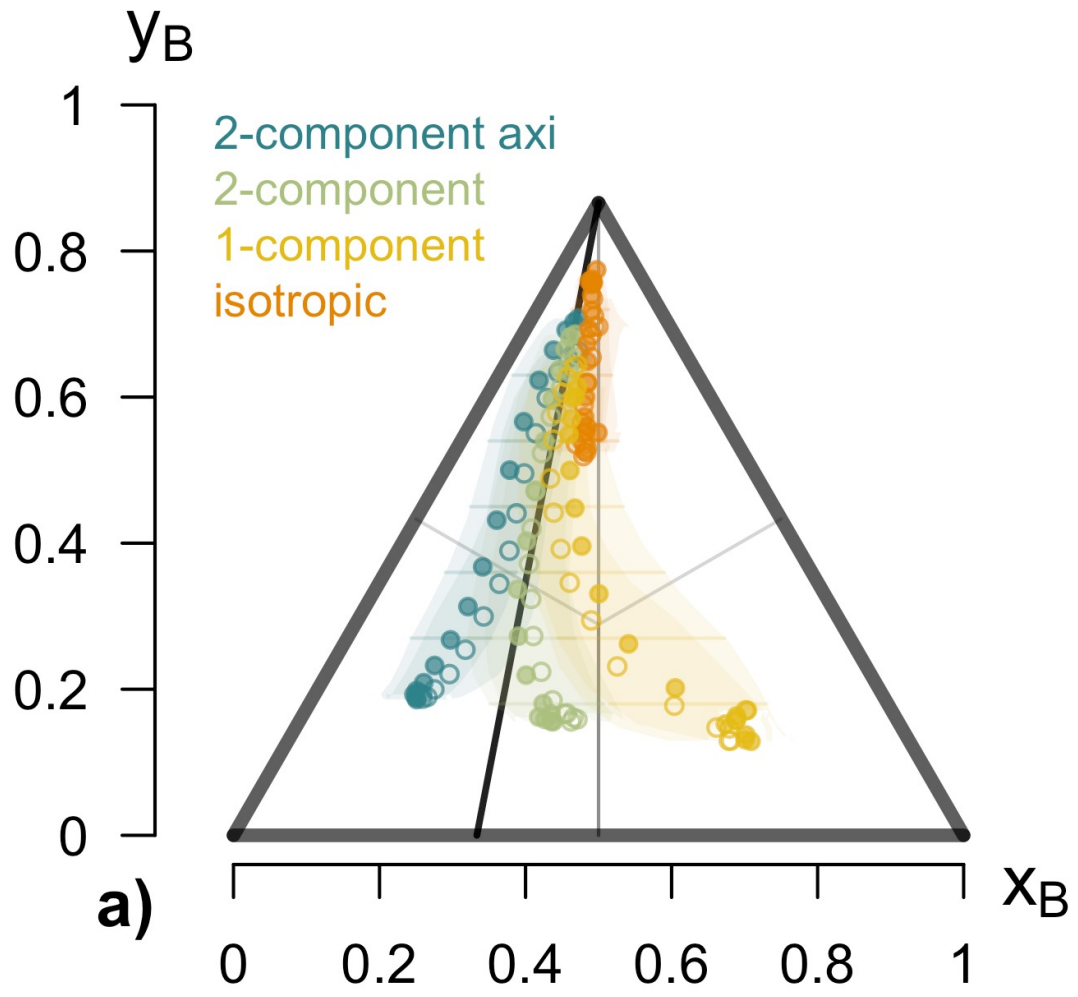
→ Cluster according to bulk anisotropy and stratification
→ Average trajectories for each dataset
→ Ensemble trajectories from all datasets

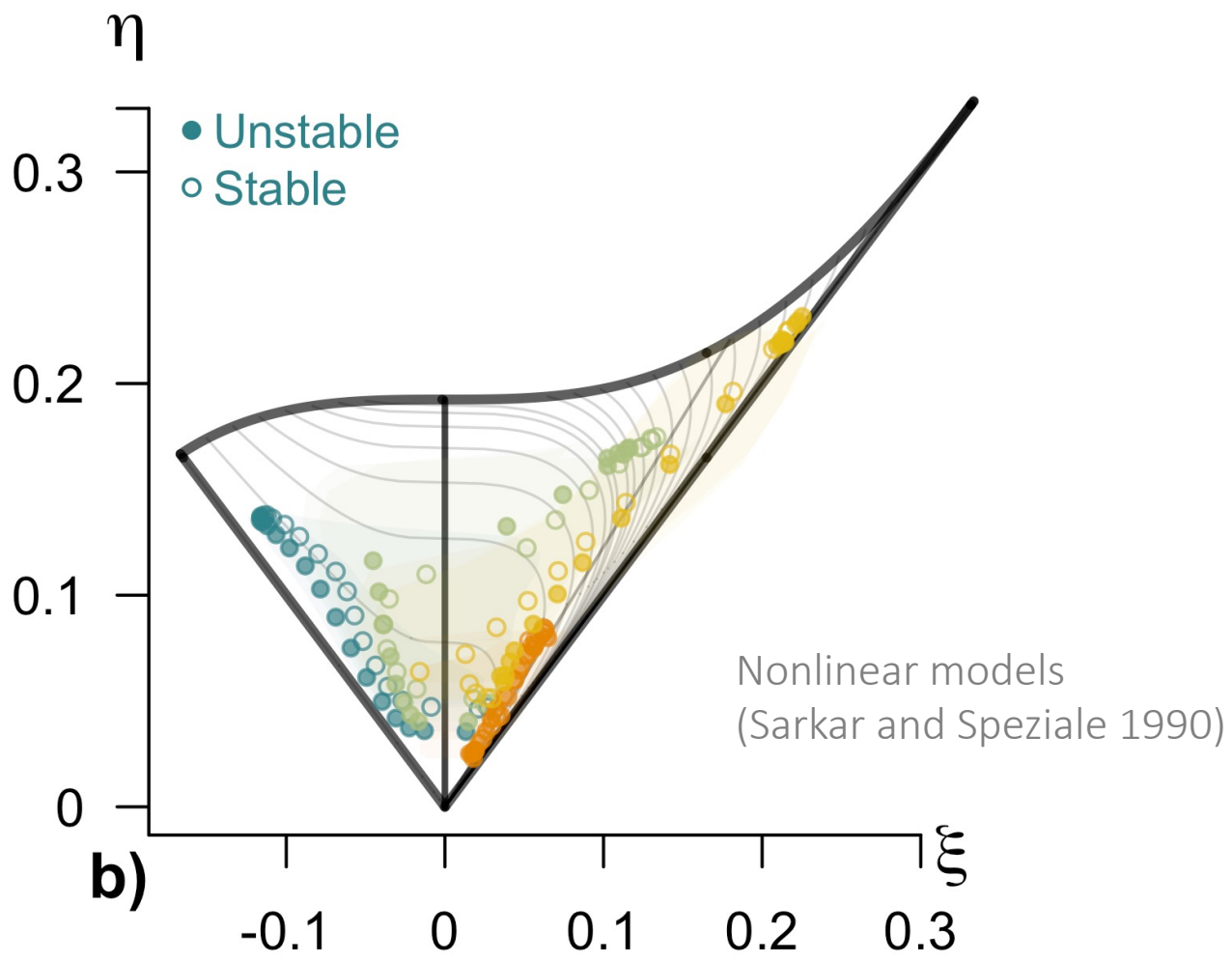
Relaxation to isotropy: does not depend on terrain complexity



- Same shape of trajectories in each cluster
- Minimal variation between data sets

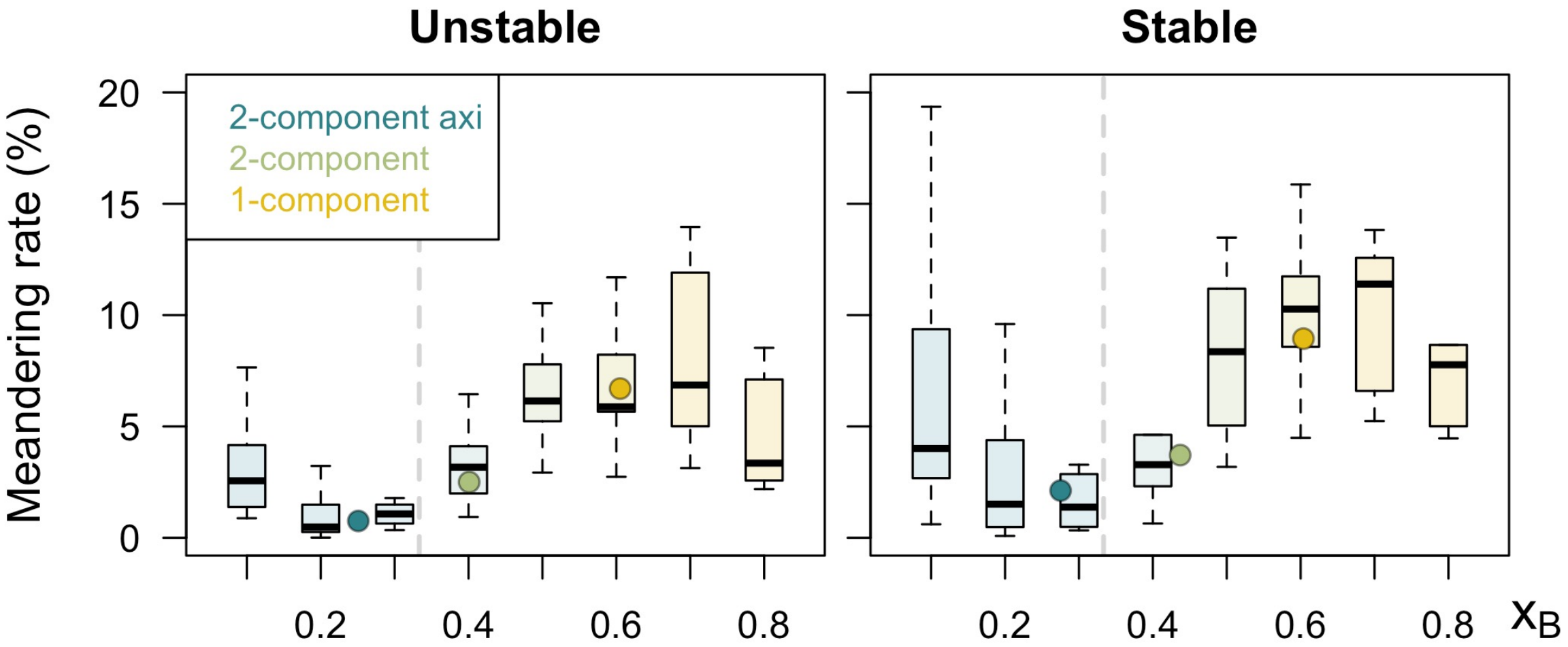
Relaxation to isotropy: weakly depends on stratification





Nonlinear models
(Sarkar and Speziale 1990)

Relaxation to isotropy: is non-linear



Relaxation to isotropy: speed depends on initial anisotropy

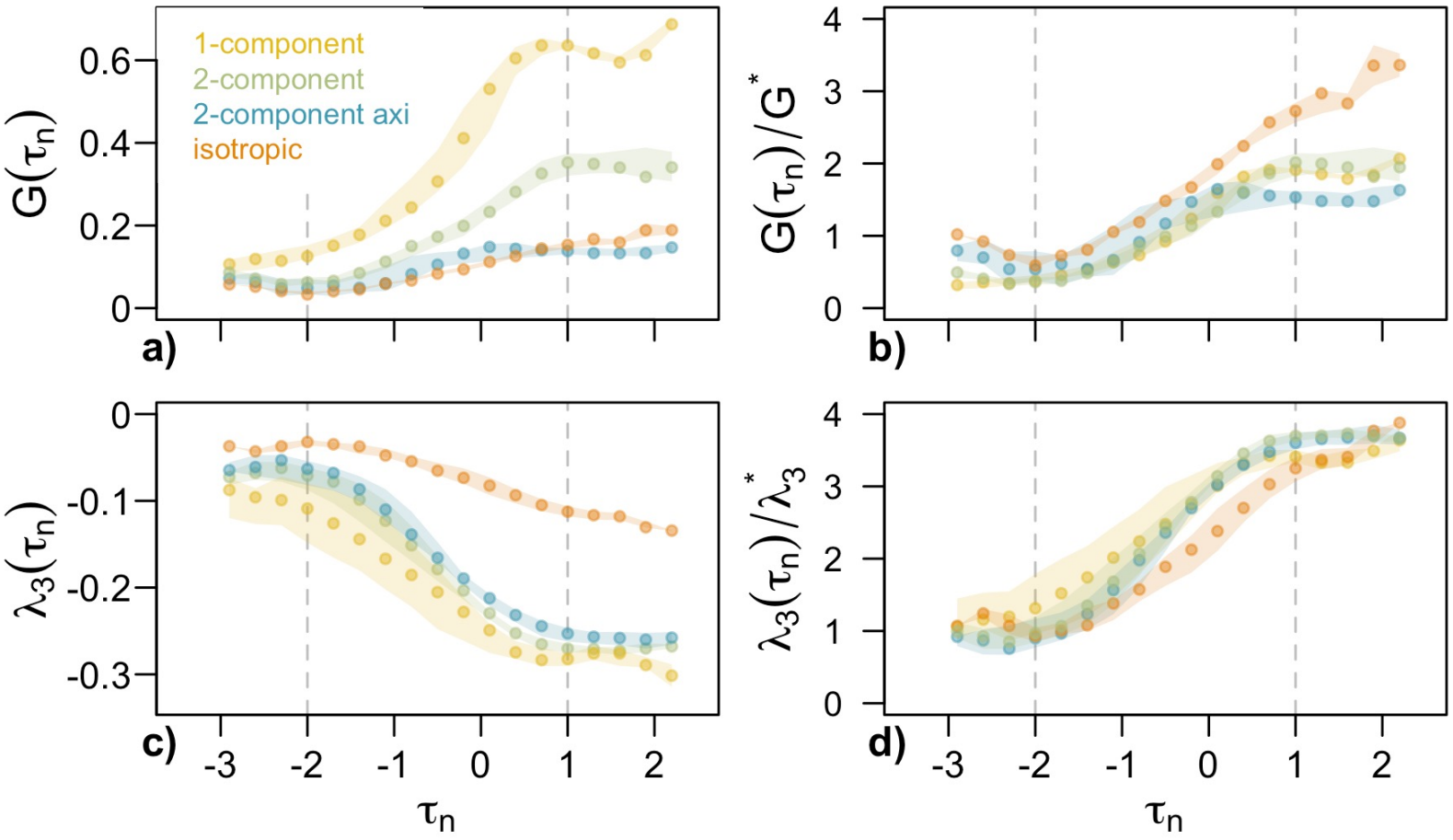
$$x_B = G + \frac{1}{2}(3\lambda_3 + 1)$$

$$y_B = \frac{\sqrt{3}}{2}(3\lambda_3 + 1)$$

We can develop a scaling for speed of trajectories

$G^* \sim \lambda_1$

$\lambda_3{}^* \sim \lambda_3$



Conclusions

- Bulk anisotropy sets a universal path towards isotropy at smallest scales
- Anisotropy encodes all relevant information on complexity: both stratification, and terrain and flow complexity
- Anisotropy invariant map imposes controls on trajectories
- Outlook: inclusion of anisotropy can improve Monin-Obukhov similarity scaling

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