Progress towards understanding and predicting turbulent heat fluxes in the Canadian Rockies

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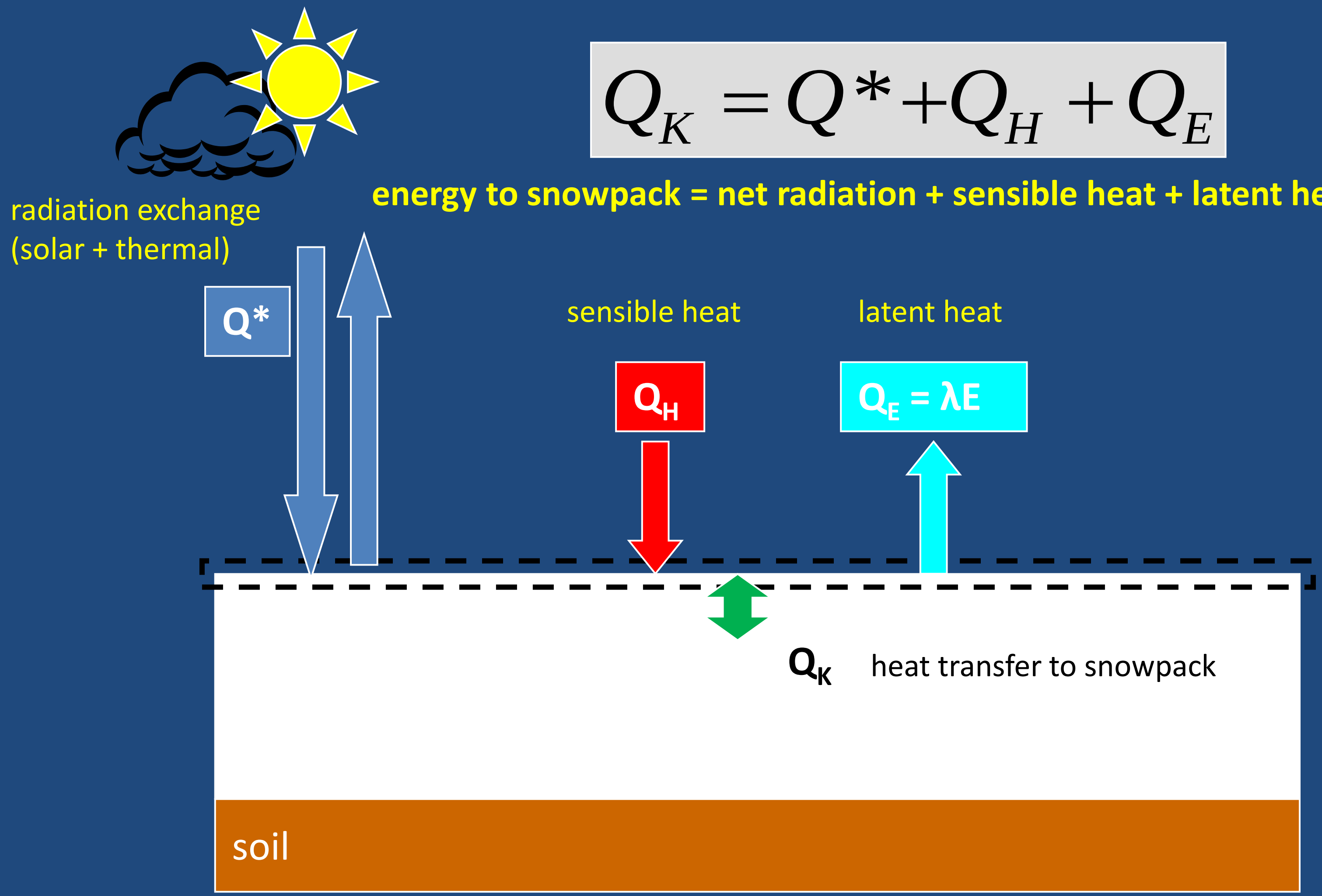
Background: Snow energy modeling

$$Q_K = Q^* + Q_H + Q_E$$

energy to snowpack = net radiation + sensible heat + latent heat

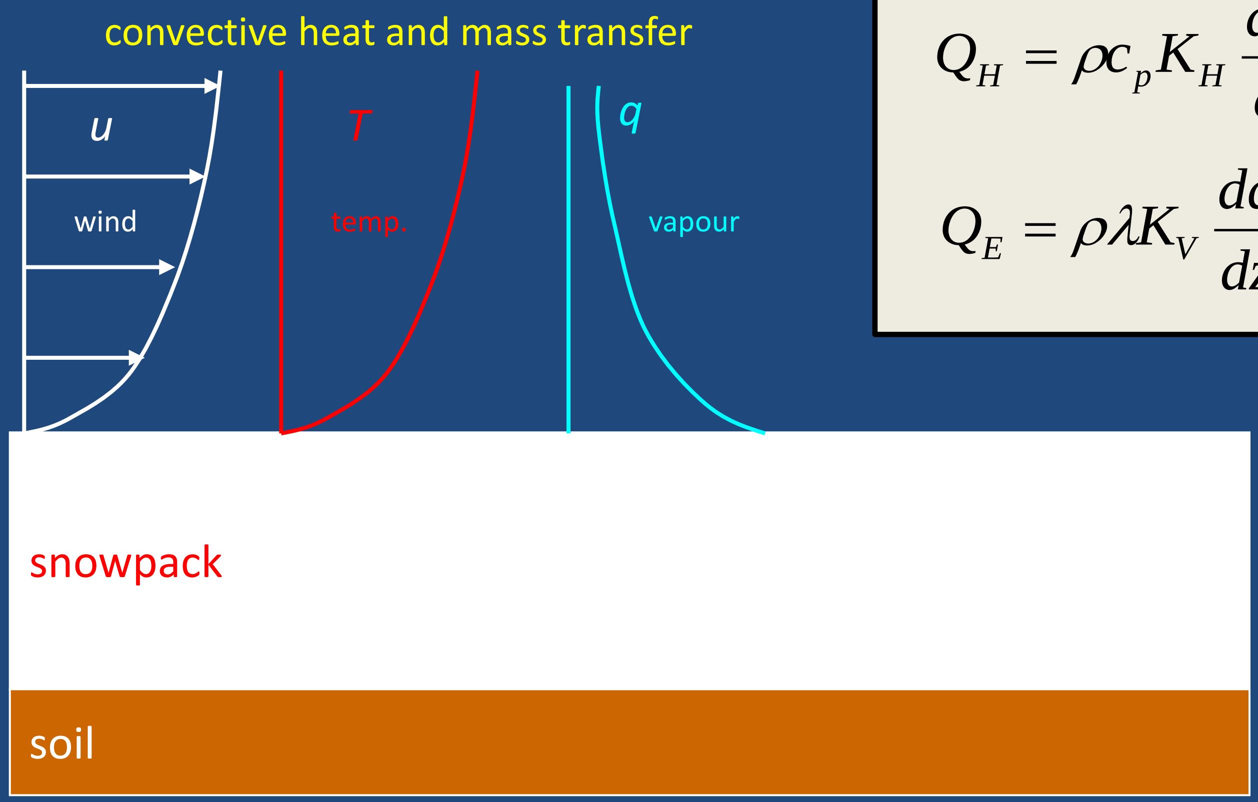


Background: Estimating turbulent transfer

$$\tau = \rho K_M \frac{du}{dz}$$

$$Q_H = \rho c_p K_H \frac{dT}{dz}$$

$$Q_E = \rho \lambda K_V \frac{dq}{dz}$$



Problems with flux estimation approaches?

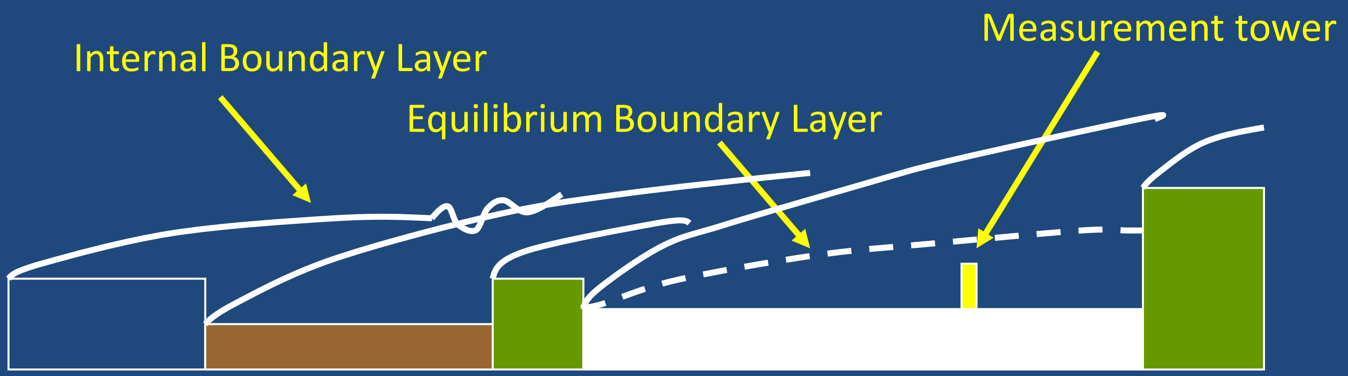
- 1st order flux estimation techniques are commonly employed in ***land-surface schemes***, ***hydrological models***, and ***snow physics models***
  - Assumptions:
    1. Fluxes are proportional to the vertical gradients of the mean concentration
    2. Production of turbulent energy is approximately equal to dissipation of energy
- There have been very few investigations of turbulent structure in mountain environment

Objectives:

1. Characterize the near-surface structure of the turbulent boundary layer within a mountain valley
2. Assess the suitability of 1st-order (flux-gradient) estimation techniques

Looking forward: Suggest future observational and modelling studies to address key knowledge gaps

Methodology: Internal Boundary Layer



Equilibrium boundary layer: (turbulence production = dissipation) flow is in 'equilibrium with local surface'

Strategy: make measurements in a locally homogeneous area

Compare turbulence statistics between measurement sites and with theory

Primary Study Location: Marmot Basin

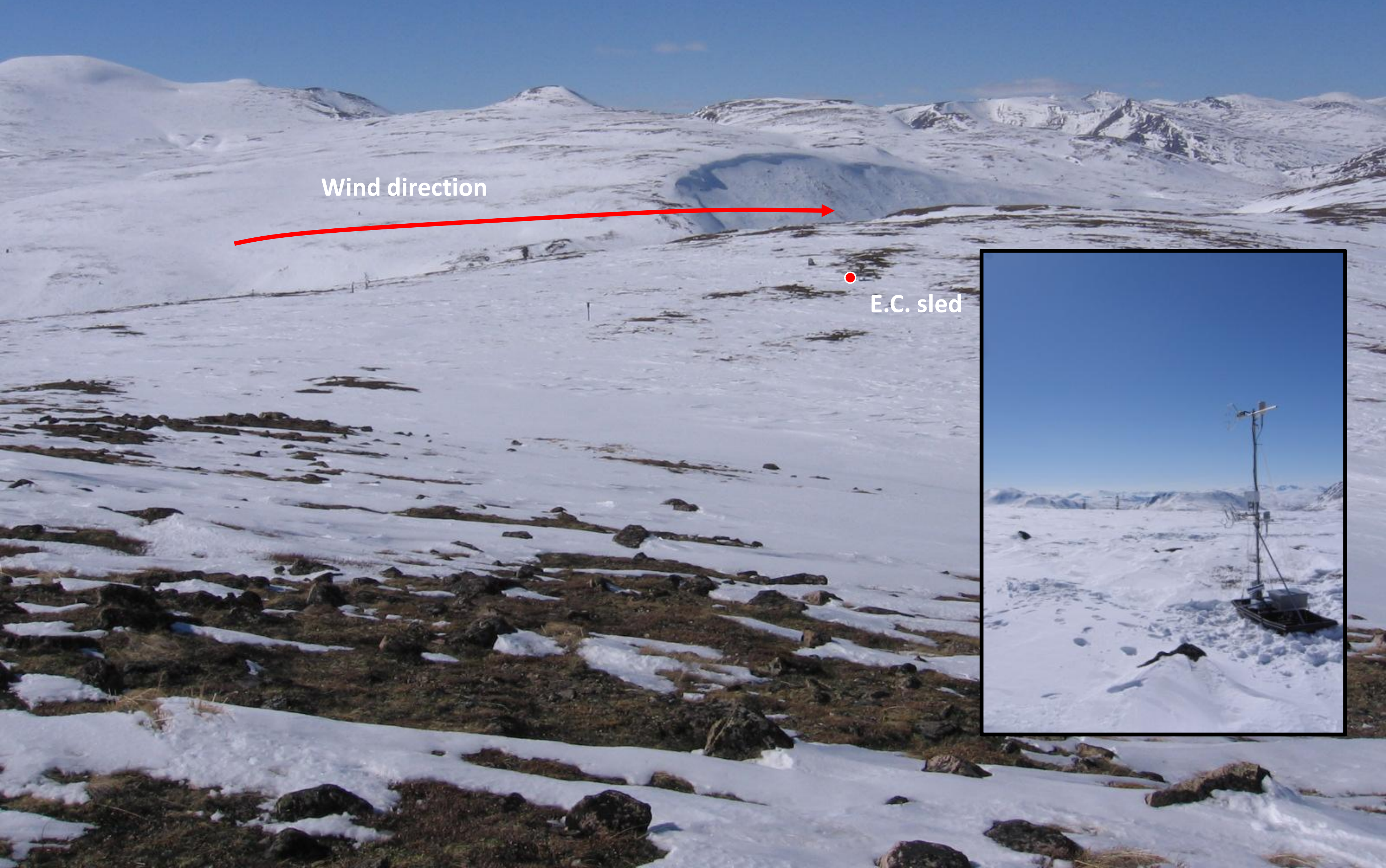
- Hay Meadow:
  - large, open clearing
  - local elevation: 1350m
  - surrounding mountains: 2700m
  - level topography
  - fetch: 100-200m

Hay Meadow, Kananaskis, AB

Mud Lake, Kananaskis, AB

Comparison Locations

Alpine site: Wolf Creek, YT



Prairie site: Saskatoon, SK

Turbulent Flux Measurement

Eddy Covariance Technique

- 20 hz. measurements

  u, v, w, T_s, q

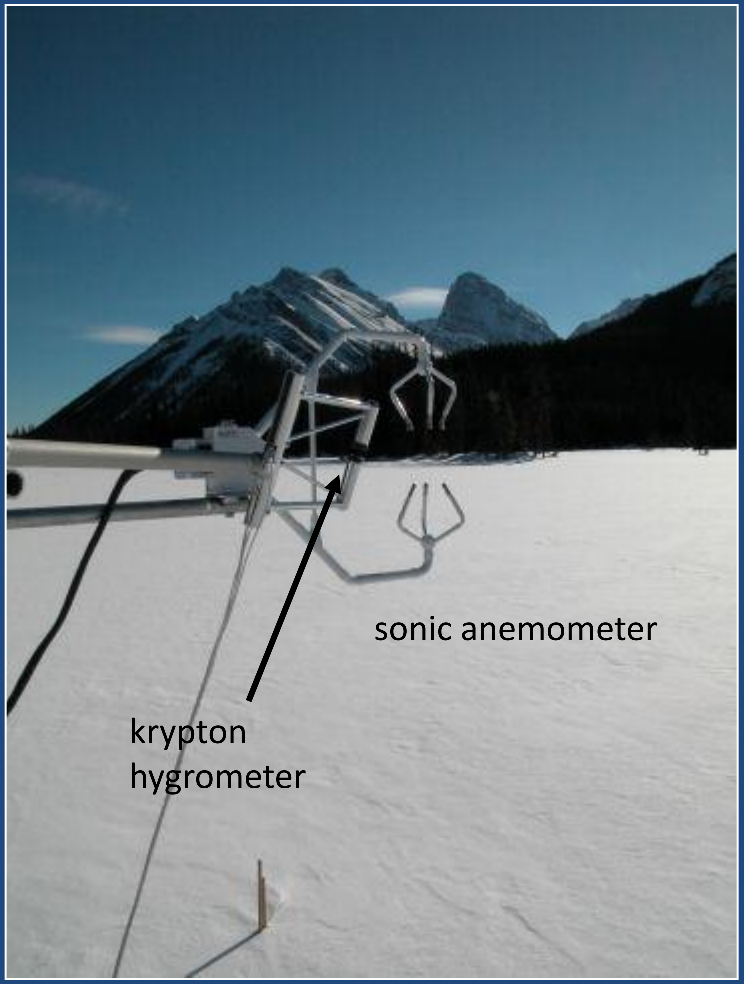
- 30 min. covariances

sensible heat flux $$Q_H = \rho c_p \overline{w'T'}$$

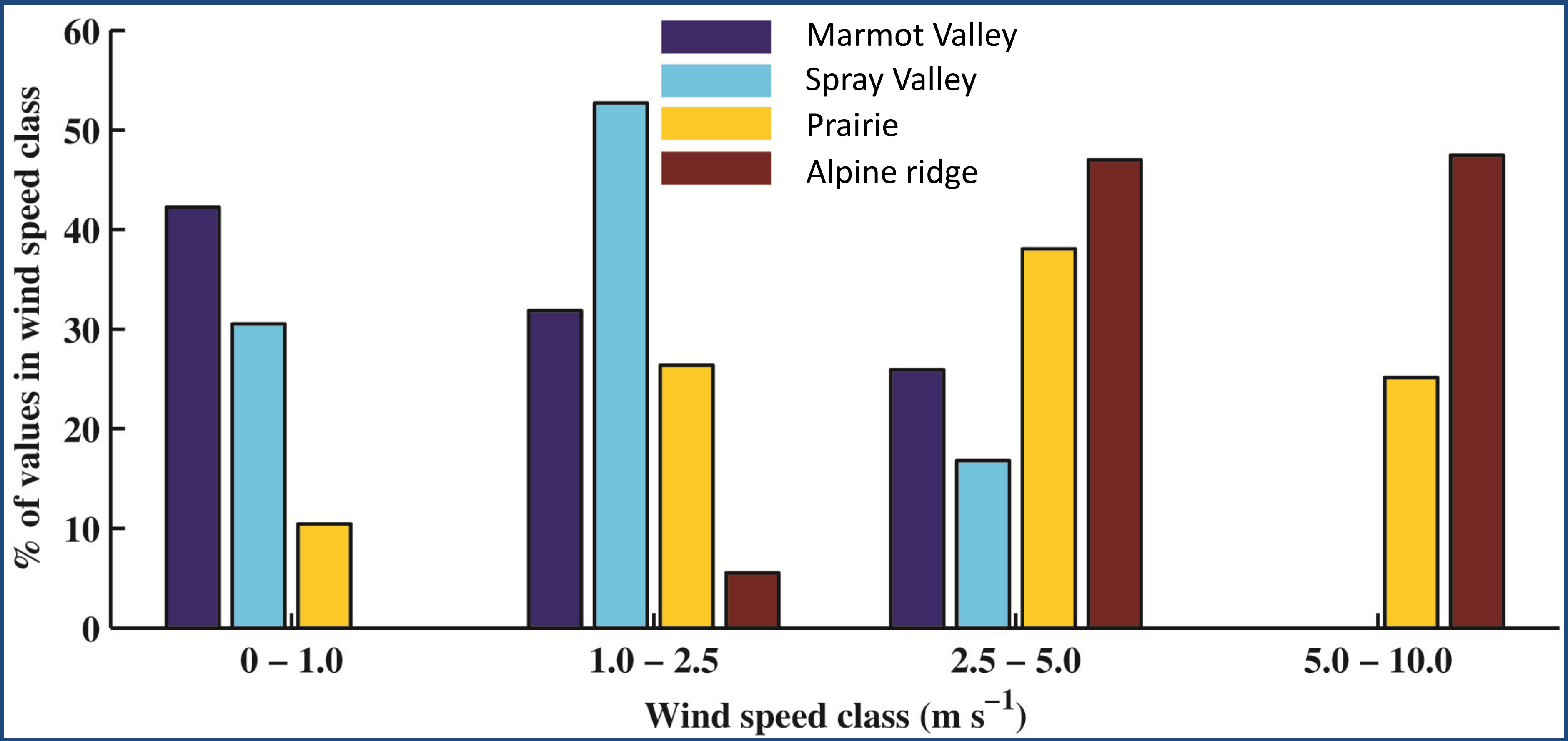
latent heat flux $$Q_E = \lambda_{sub} \rho \overline{w'q'}$$

momentum flux $$\tau = \rho \overline{u'w'}$$

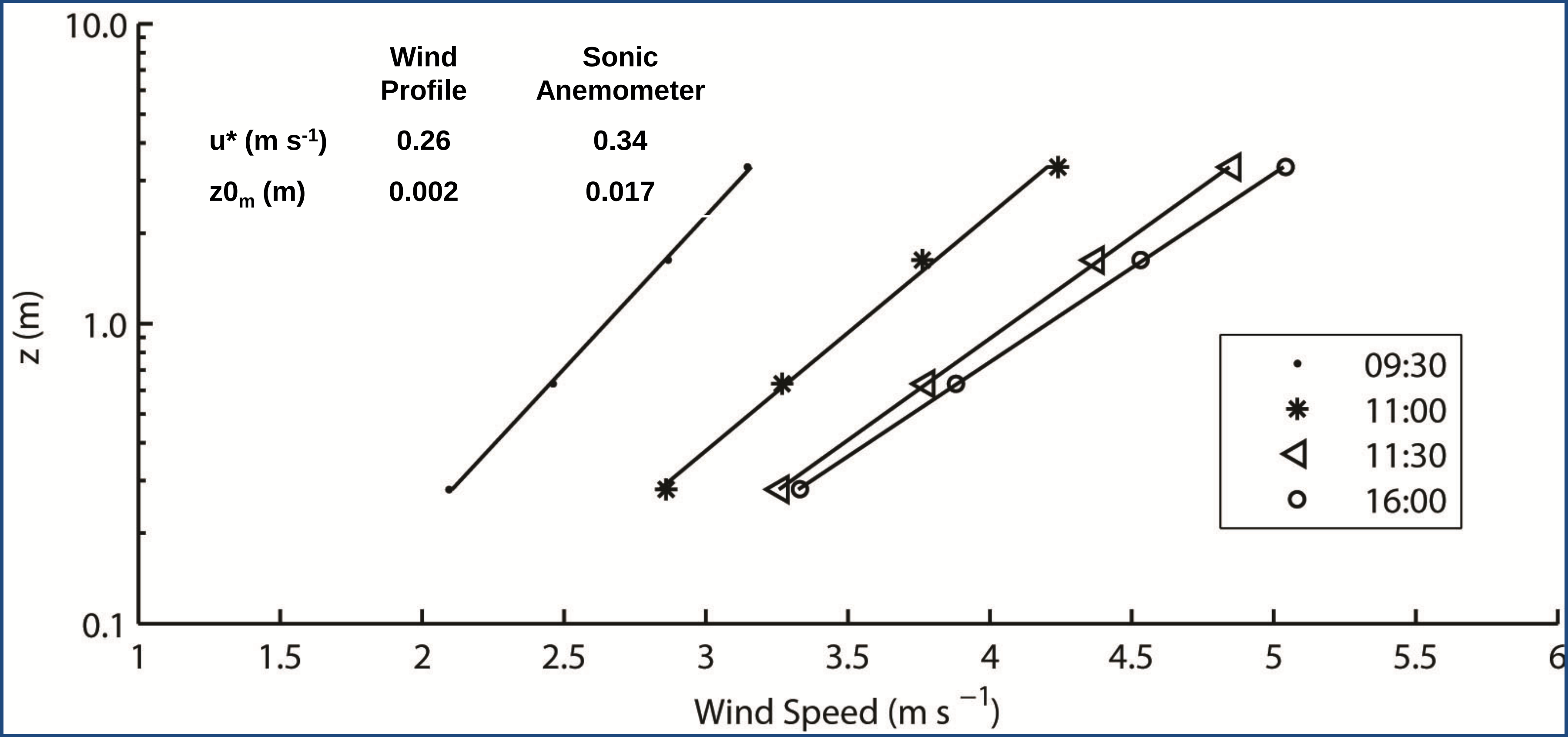
friction velocity $$u^* = \sqrt{\overline{u'w'}}$$



Valley sites are typically calm

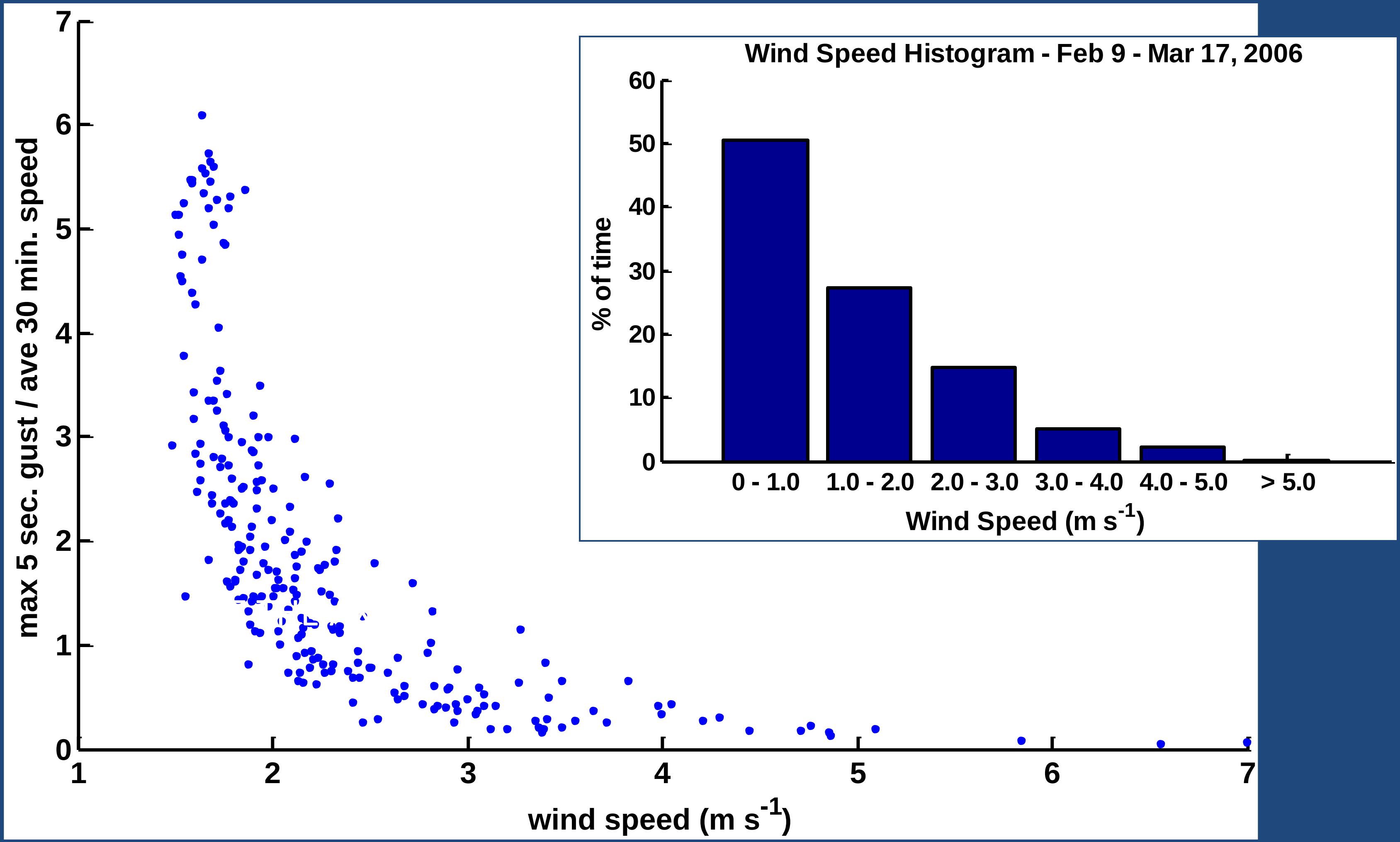


Log-linear profiles do exist, but...

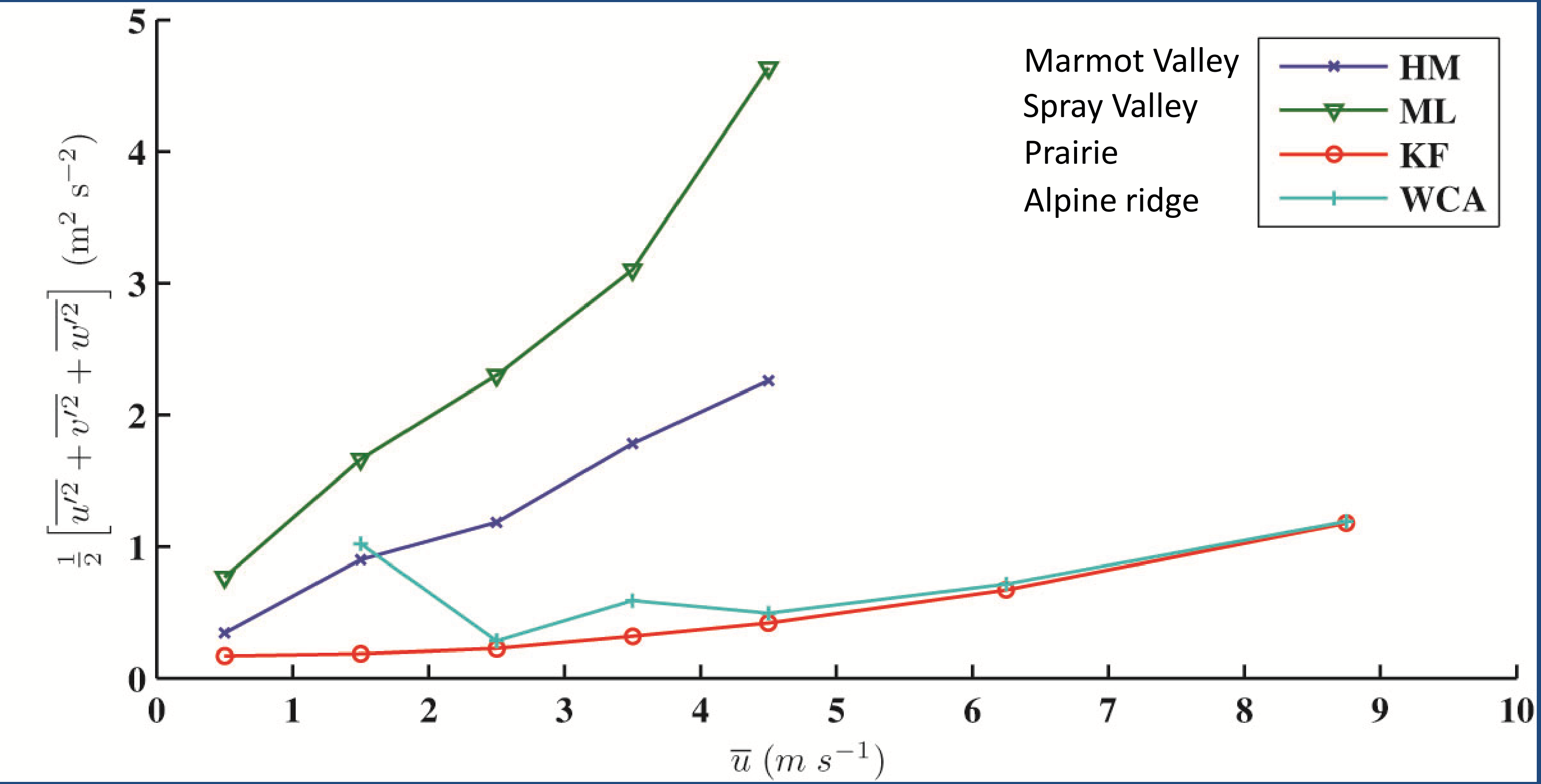


Measured fluxes do not agree with mean gradient predictions

Valley wind speeds are typically low, but often gusty



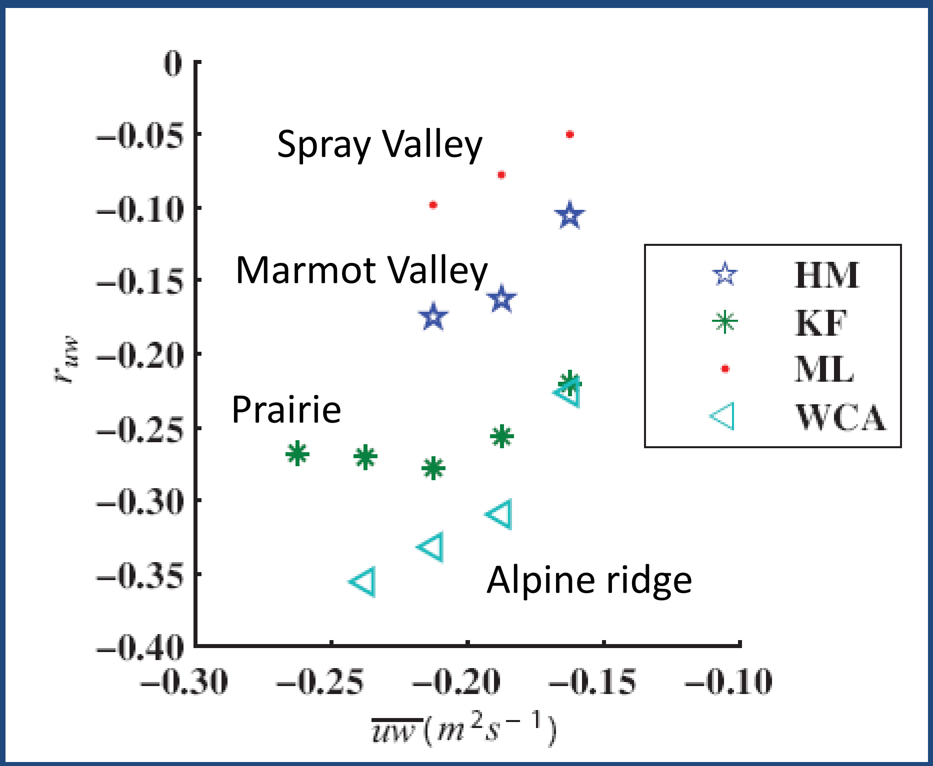
Valley sites have the highest intensity of turbulence



Turbulence Characteristics

- not all motions contribute to fluxes...

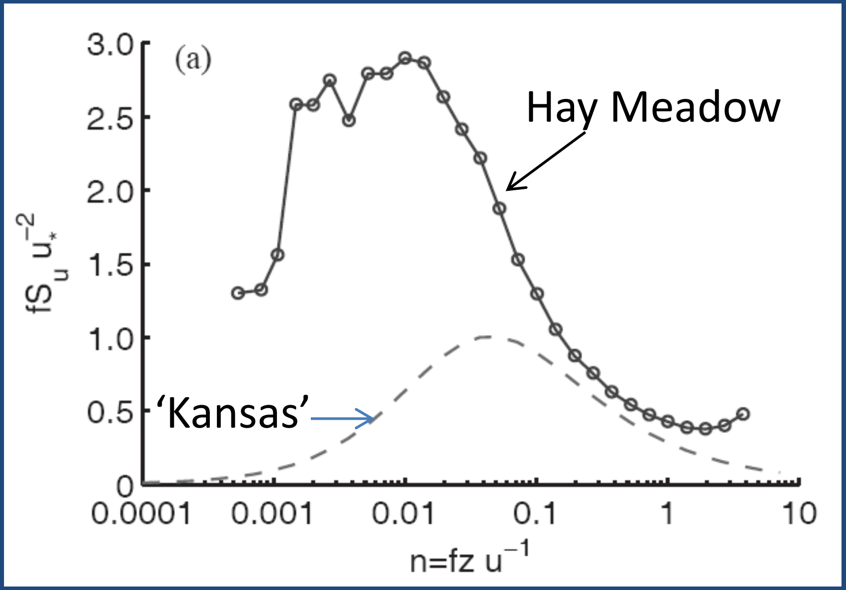
$$\overline{u'w'} = r_{uw}\left(\sigma_u \sigma_w\right)$$

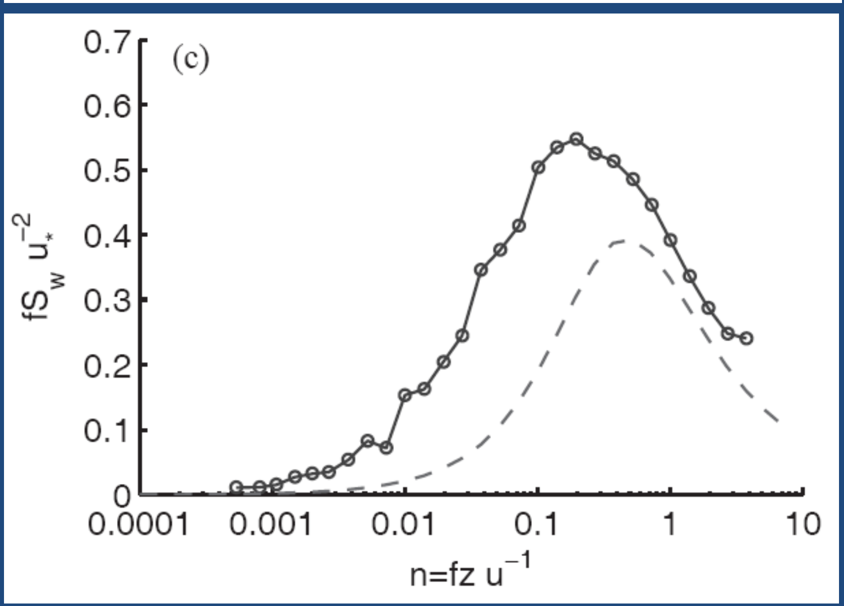


- mountain valleys have very low correlation between u, and w
- horizontal variance is larger than vertical (due to blocking)

typical atmospheric value: -0.35

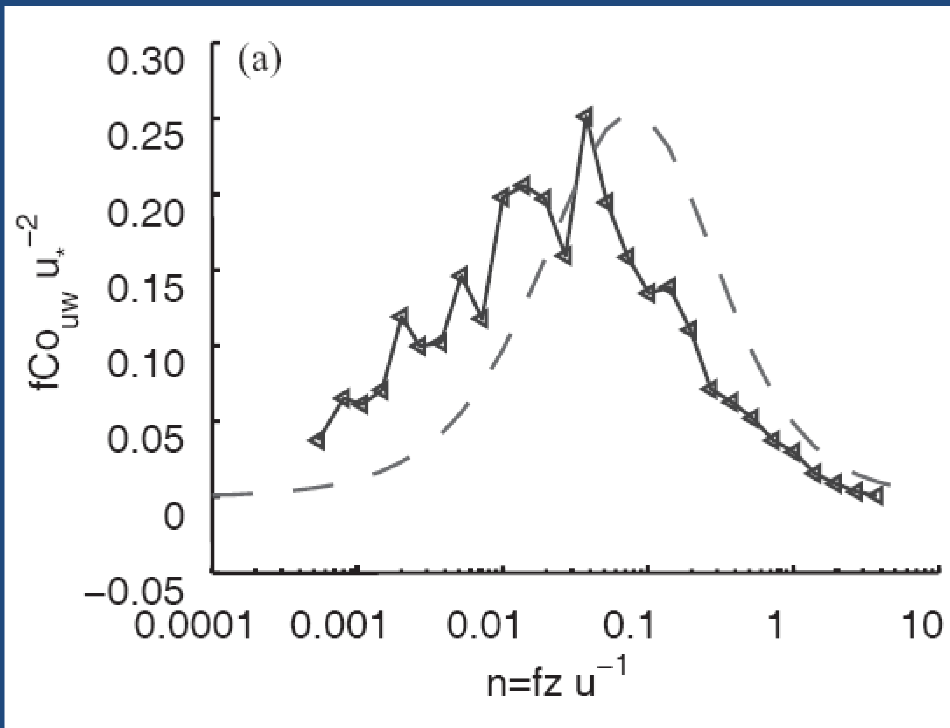
Spectra –wind velocity components

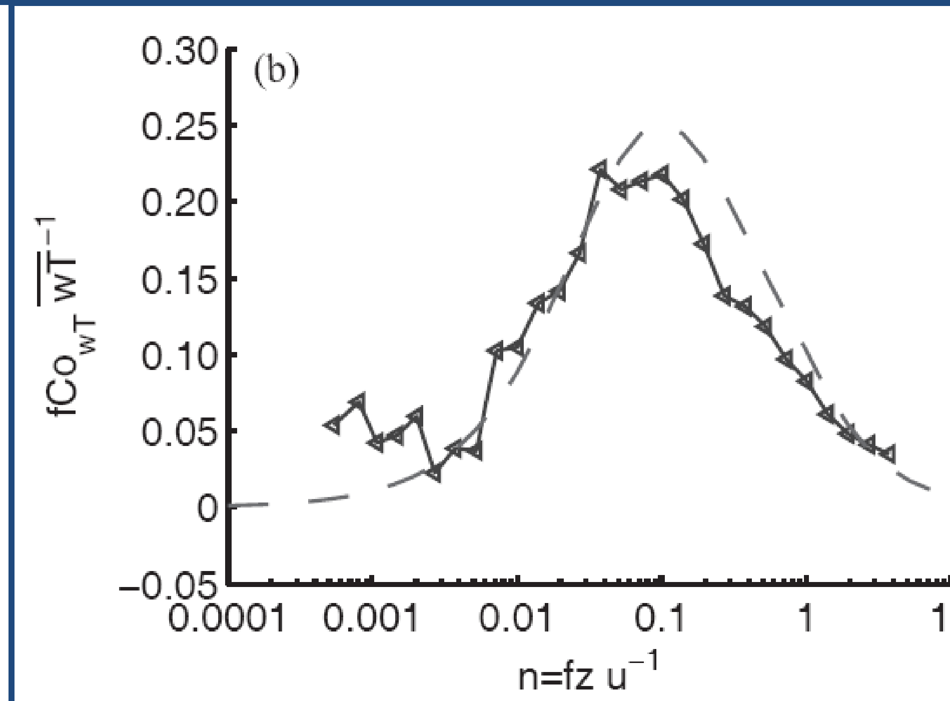




Both horizontal and vertical spectra exhibit enhanced energy at low frequencies

Cospectra – momentum and heat flux

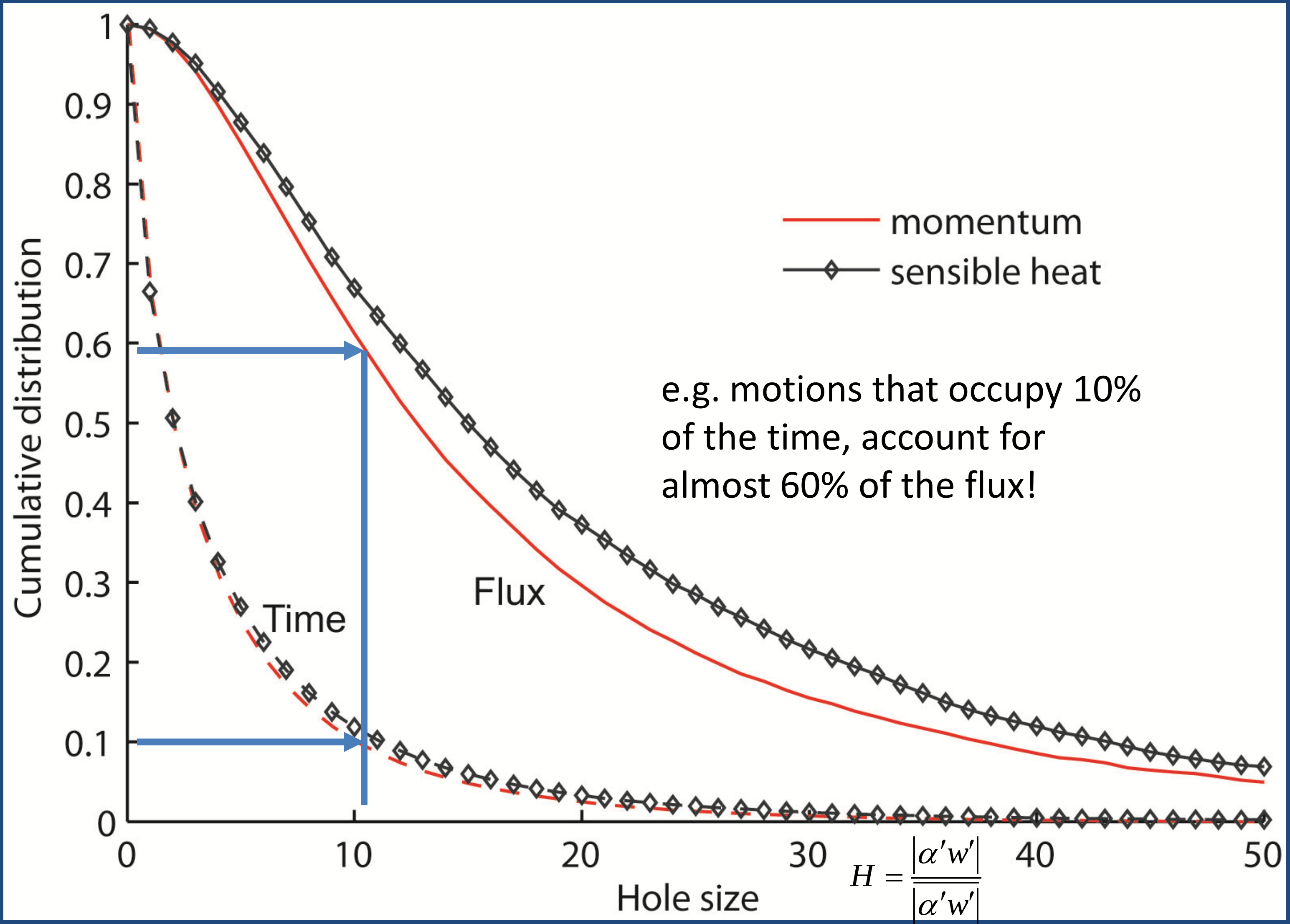




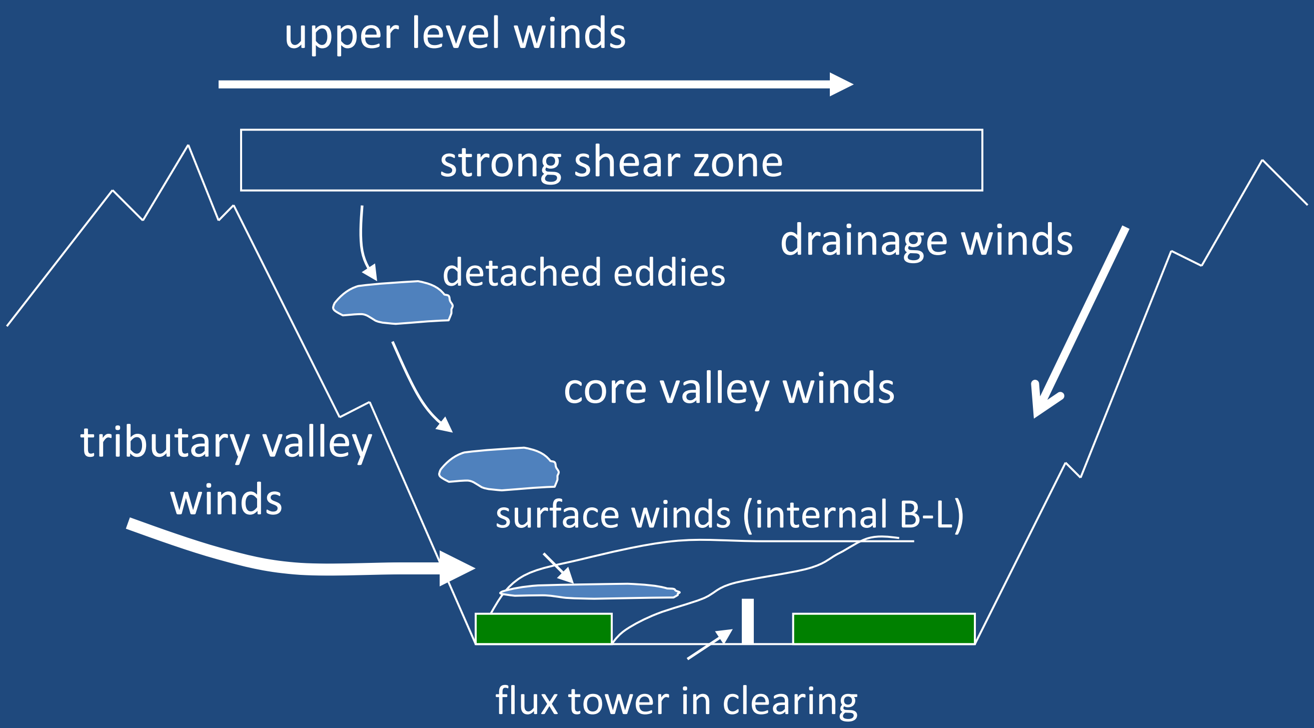
co-spectra peak at lower frequencies

wind gusts cannot be considered 'inactive' turbulence

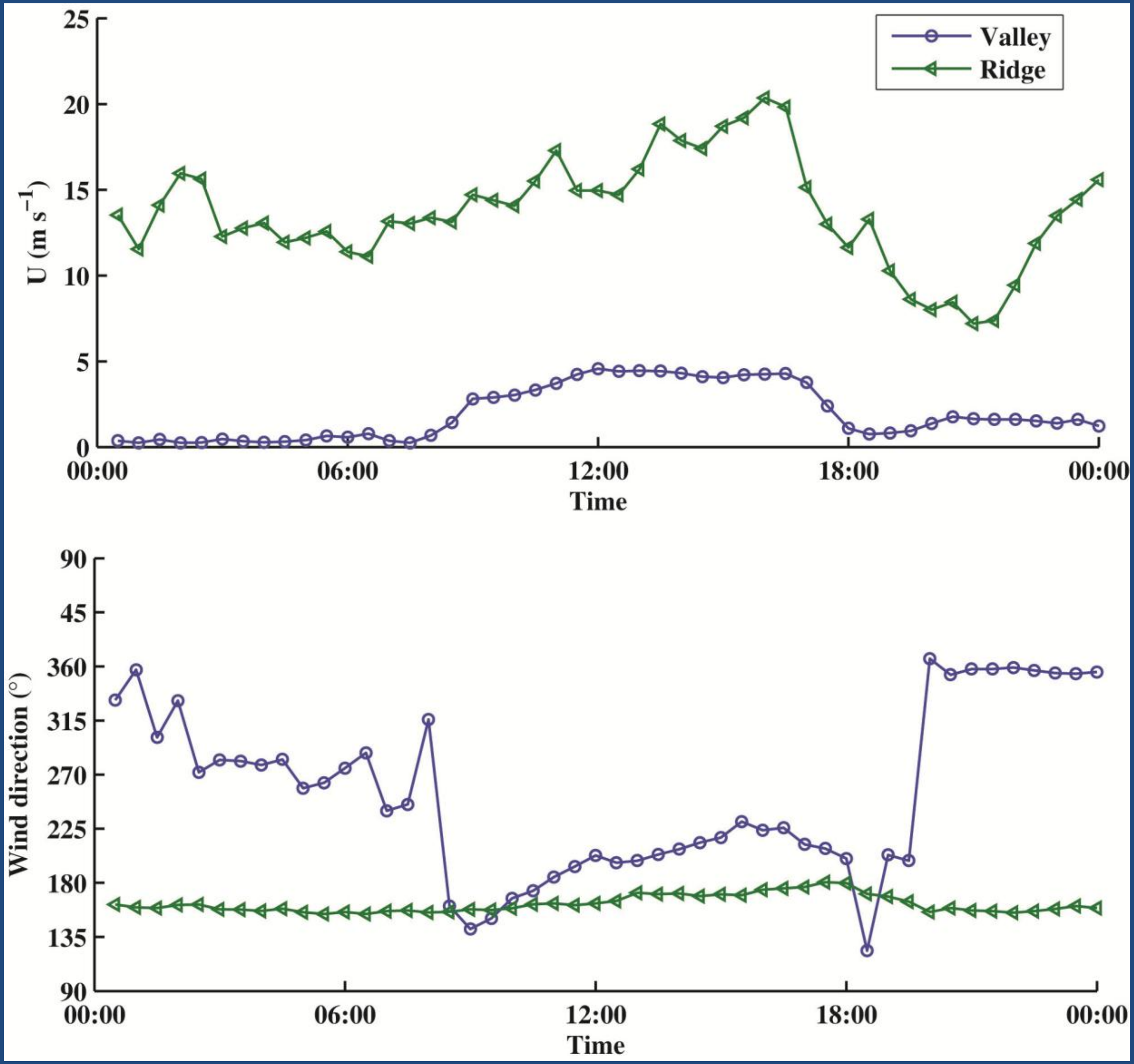
Much of the flux contributed by gusts



Conceptual model

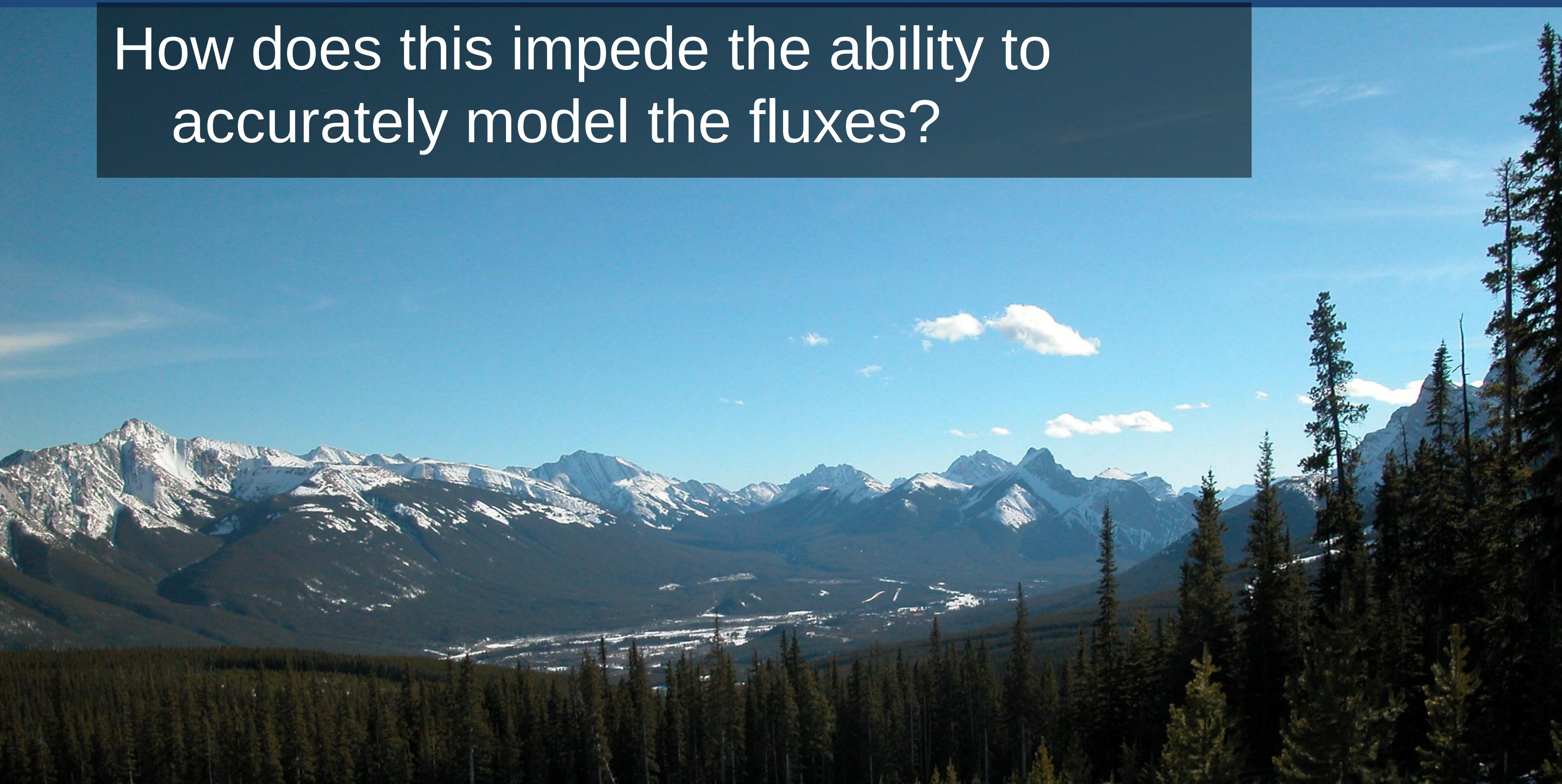


Valley wind system independent of overlying flow

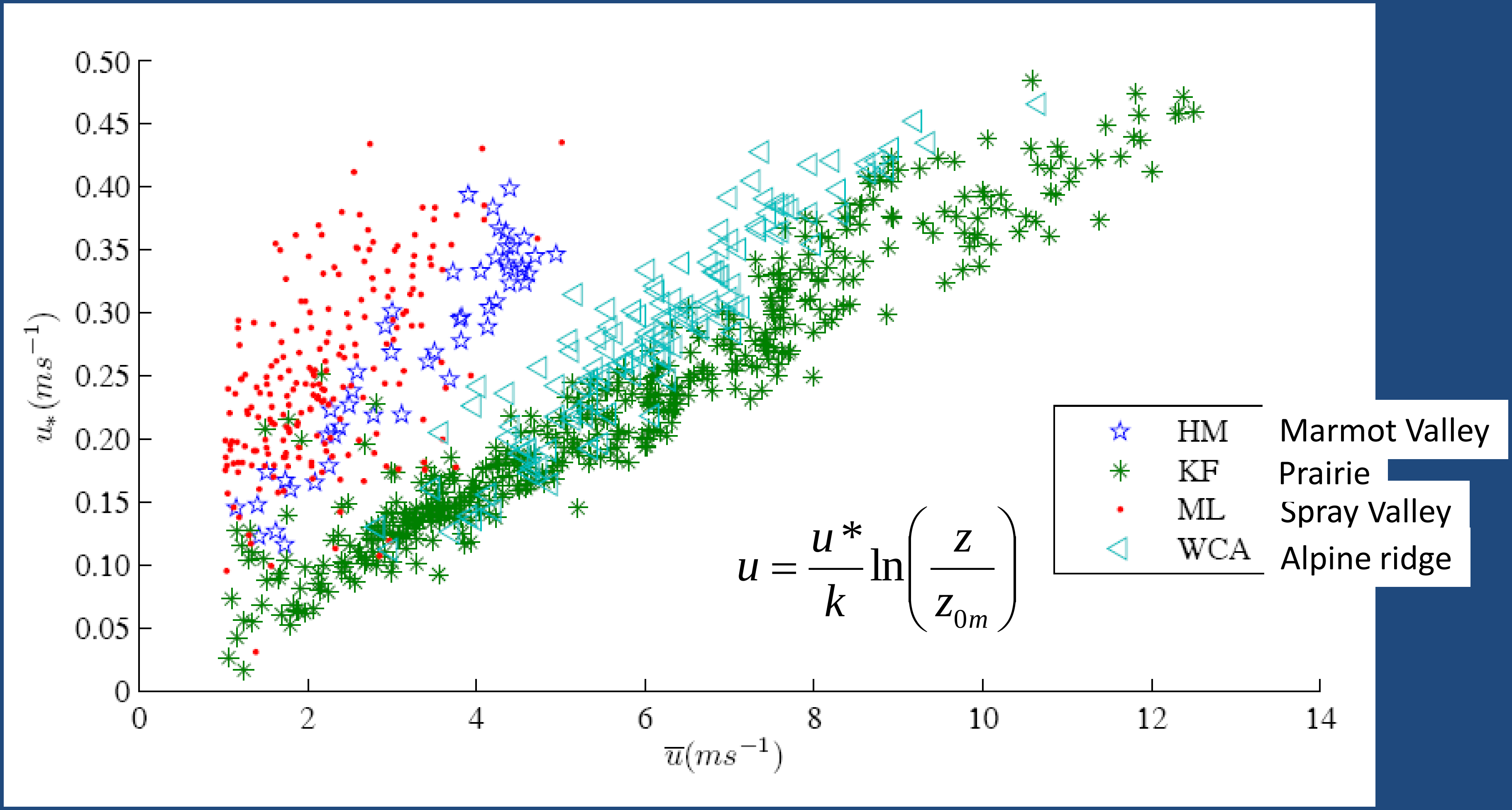


Fluxes in mountain valley sites are strongly influenced by non-local processes

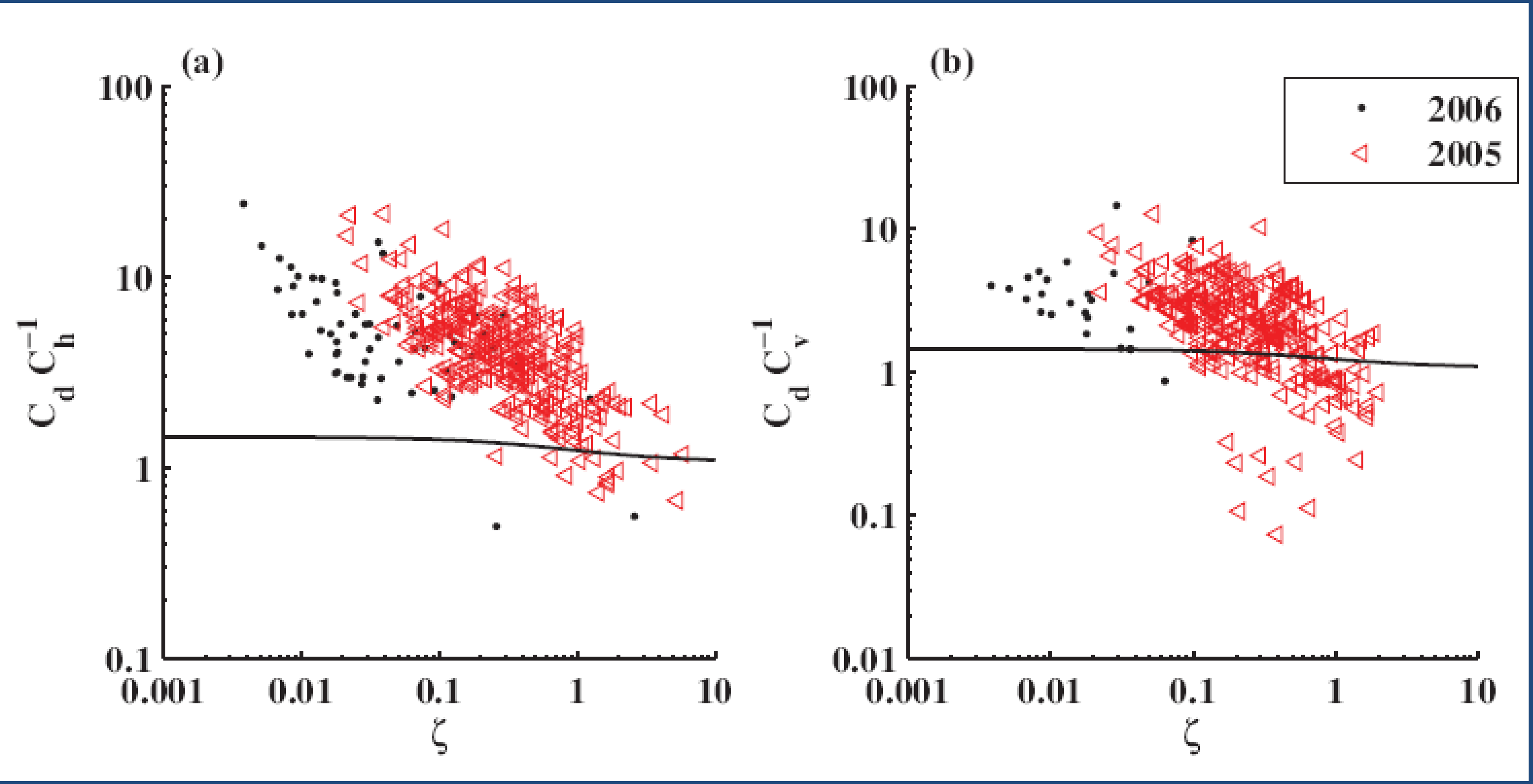
How does this impede the ability to accurately model the fluxes?



Momentum transfer is significantly enhanced, but still proportional to the wind speed gradient

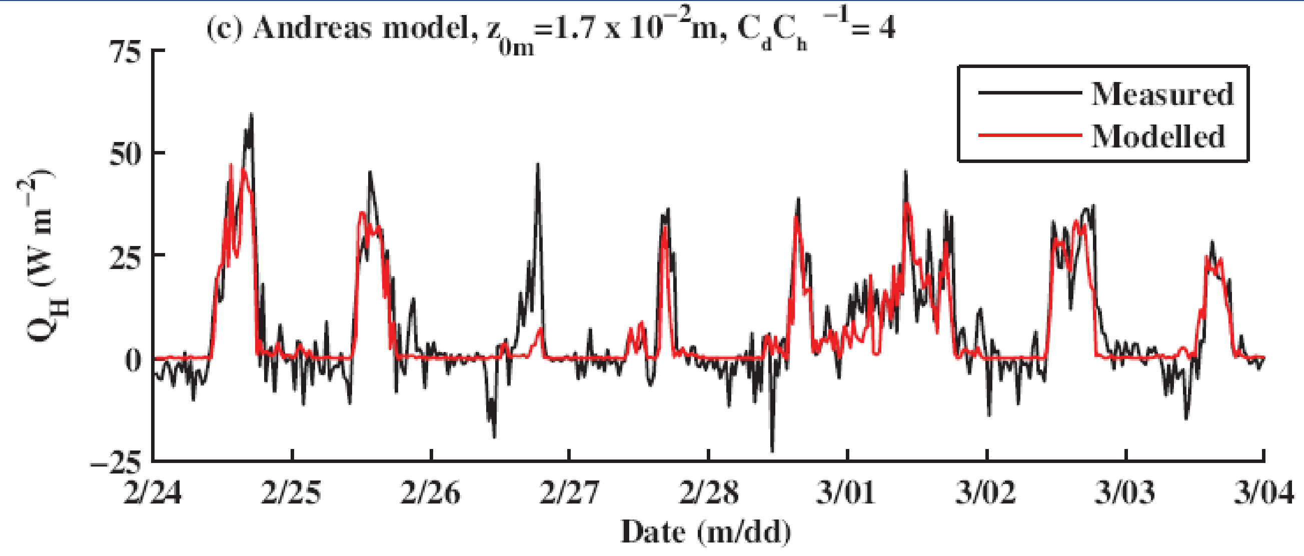


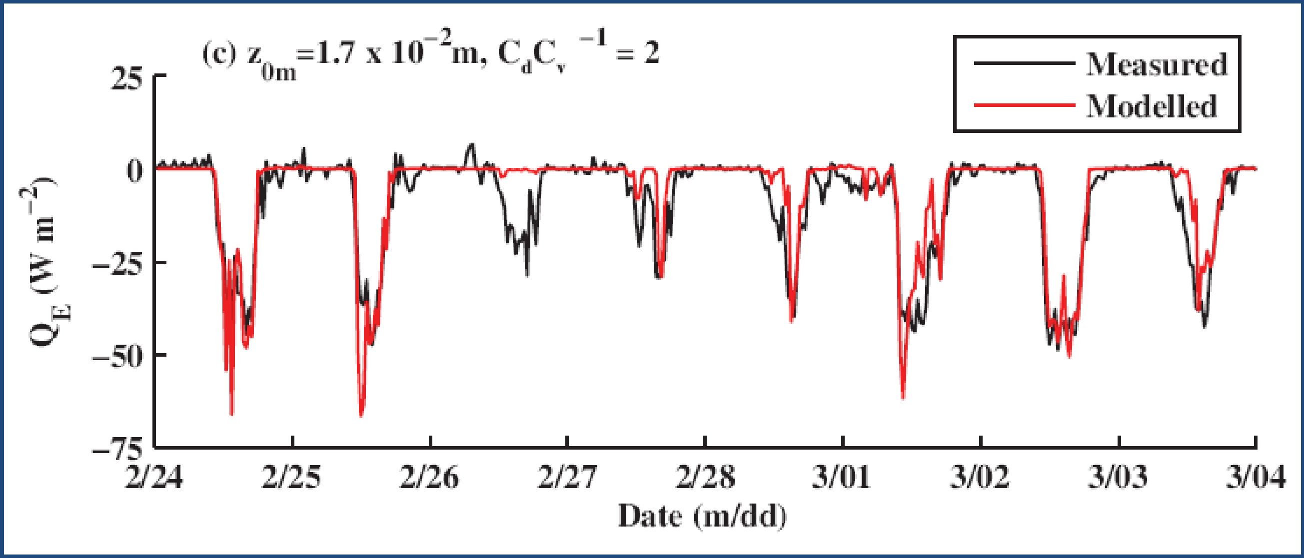
Heat and mass transfer coefficients are poorly estimated from momentum transfer



$$Q_H = \rho c_p U C_H (T - T_0)$$

Modeling the mountain valley fluxes required environment-specific parameters





Summary of Observations

1. wind gusts are a source of turbulent energy that don't scale on local processes.
2. boundary layer is not in equilibrium
3. 1st order flux estimation not valid

   ... but can be made to work with empirical factors

These results are not unique to this basin!

Future Directions

- Develop flux estimation techniques that incorporate non-local contributions (empirically, statistically, or physically based)
- Need to understand turbulent wind structure at multiple scales
  - regional synoptic forcing
  - mountain valley climate system
  - local winds (drainage, land cover)
  - turbulent scales (emphasis on larger eddies containing the energy)

Combined observation / modelling

- surface winds: micrometeorological equipment
- vertical structure: SODAR w / windRASS
- windflow patterns: mesoscale model (WRF, meso-NH, etc.)
- fine scale turbulence: large eddy simulation nested (2-way) within mesoscale model

Future Plans:

- Fall 2013 - resume turbulence observations; mesoscale weather model setup
- Summer 2014 - intensive field campaign
- Fall 2014 - detailed modelling (Nested LES)


QUESTIONS?
COMMENTS?