Large Eddy Simulation of Stable Boundary Layer Turbulence in Complex Terrain

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Outline

- Objectives
- Motivation
- Method
- Expected Results

OBJECTIVES

- Determine the temporal and spatial scales. of turbulent instability processes in complex terrain flows.
- Examine the relationship between forcing (gravitational for slope flows, synoptic for basin flows) and SBL growth through entrainment.
- Examine the relative role of wave instabilities and SBL turbulent eddies in promoting changes in the SBL potential energy.

Mechanical Energy Budget

$$\frac{d}{dt}TKE = -\frac{\partial}{\partial x_j}\left(\frac{1}{\rho_o}\overline{pu_j} + \frac{1}{2}\overline{u_i^{\,2}u_j} - 2K_m\overline{u_i s_{ij}}\right) - \overline{u_i u_j}\frac{\partial U_i}{\partial x} + g\frac{\overline{w\rho'}}{\rho_o} - (2K_m\overline{s_{ij}s_{ij}})$$

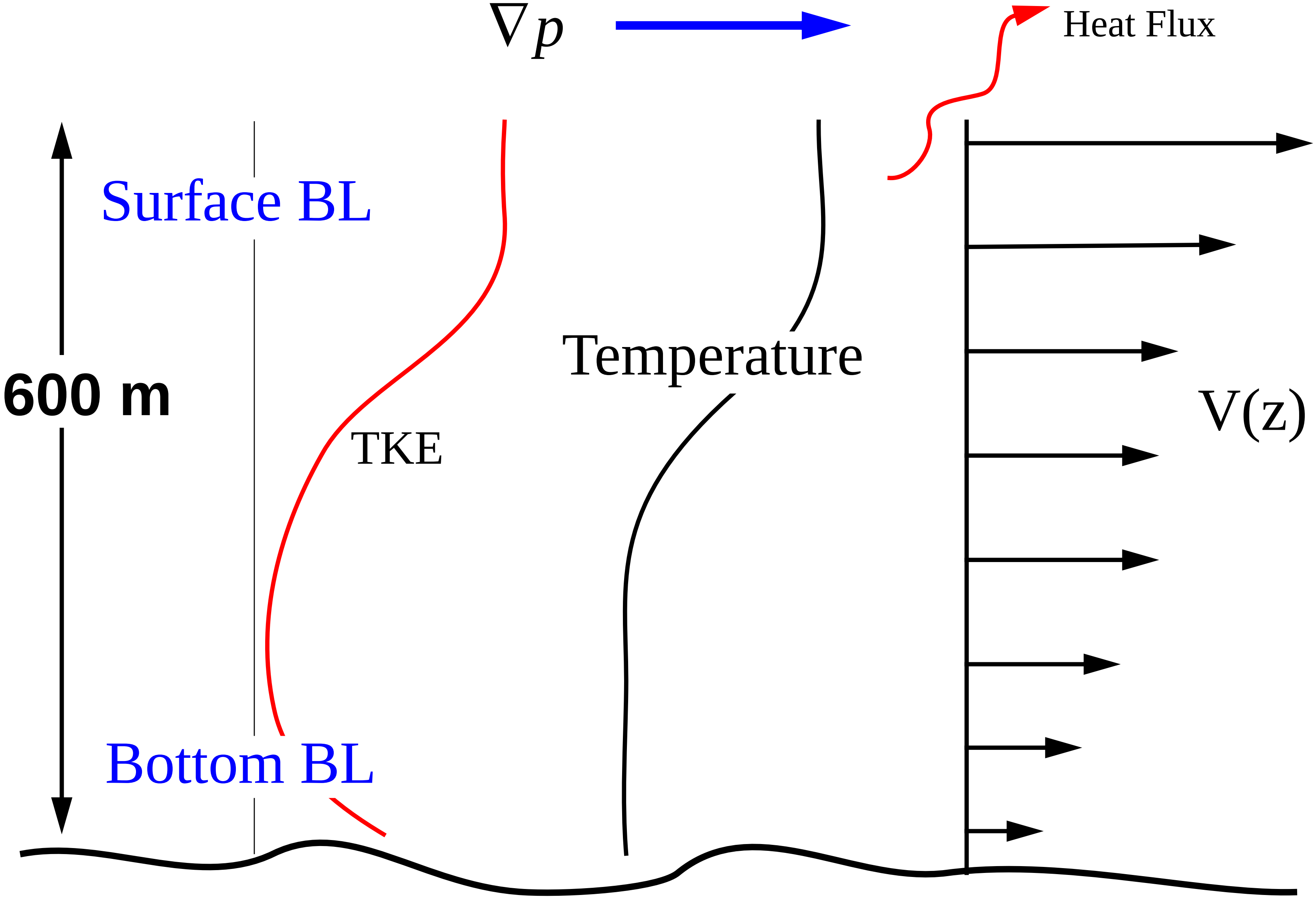
Transport Term | Shear Production | Buoyant Production | Dissipation

$$\frac{d}{dt}MKE = -\frac{\partial}{\partial x_j}(2K_m U_i S_{ij} - \overline{u_i u_j}U_i) - 2K_m S_{ij} + \overline{u_i u_j}\frac{\partial U_i}{\partial x_j}$$

Transport Term | Viscous Dissipation | Loss to Turbulence

where

$$S_{ij} = \frac{1}{2}\left(\frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i}\right), \qquad s_{ij} = \frac{1}{2}(u_{i,j} + u_{j,i}),$$


∇p
Heat Flux
Surface BL
600 m
TKE
Temperature
V(z)
Bottom BL

Why do it?

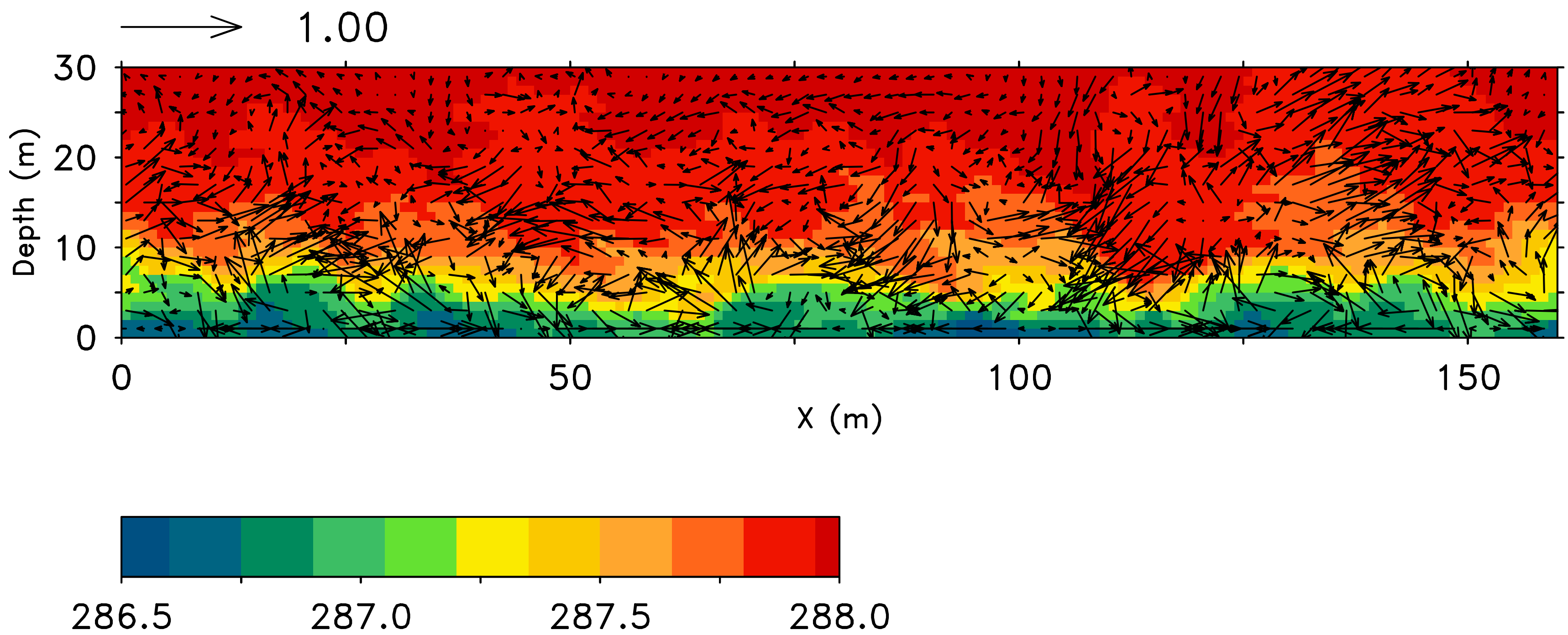
- Slope flow dynamics and turbulence entrainment are critical components in intermountain basin circulation.
- Mesoscale model parameterizations have problems with turbulence mixing processes in very shallow SBL and elevated shear layers.
- Combining turbulence measurements and LES results yields a more complete picture of turbulence. Provides a quantitative error estimate for vertical mixing parameterizations.

METHOD

- Large eddy simulation experiments will focus on slope flow growth and entrainment over stable basin boundary layers
- Perform LES experiments using observations as initial conditions and surface forcing.
- Compare model results with observations of the mean structure and turbulence measurements when available.

LES Cross Section (y = 31 m; 22 Minutes)

(Heat = -15 W m^{-2}, z_o = 10 cm, 20^o slope)



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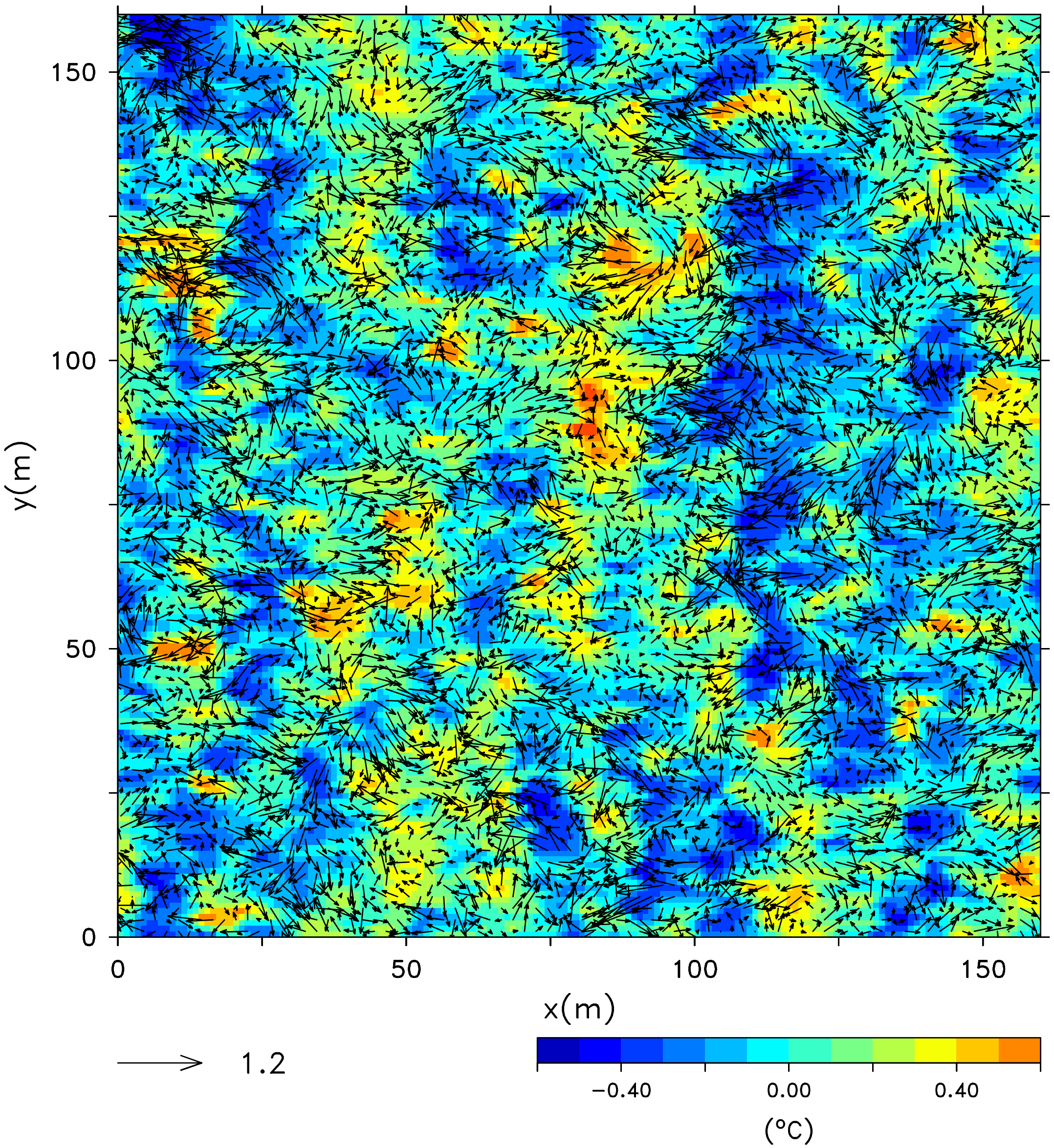
EXPECTED RESULTS

Results will provide an important interpretation tool for field data analysis.

Analysis of energy budgets will allow us to assess the importance of slope flows and large scale forcing on vertical mixing and transport.

Understanding the dynamics of SBL instability processes will provide a physical basis for improved mixing parameterizations

22 Minutes LES Cross Section (z = 5 m)



Perturbation Temperature and Velocity
(every other point)

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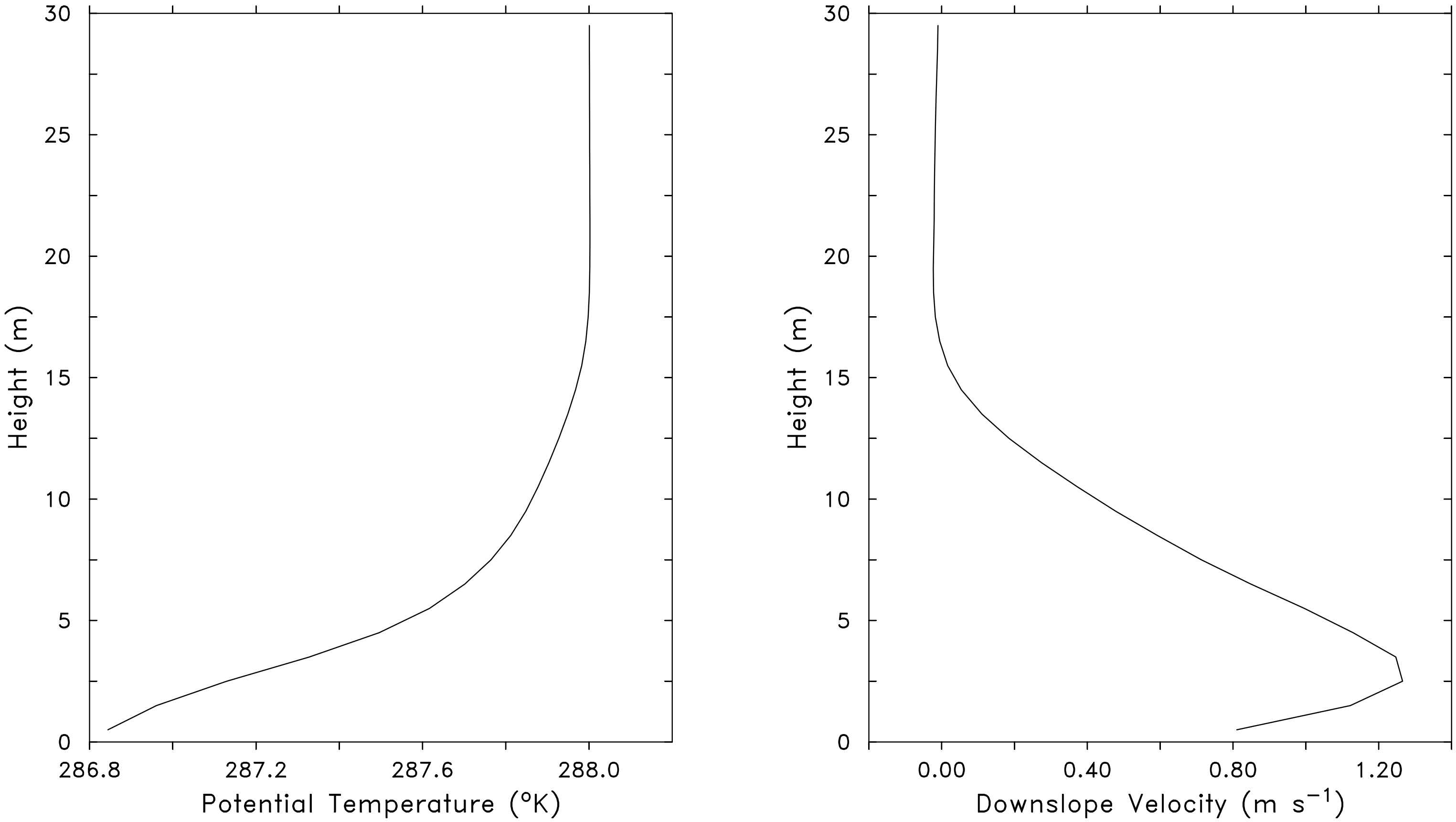
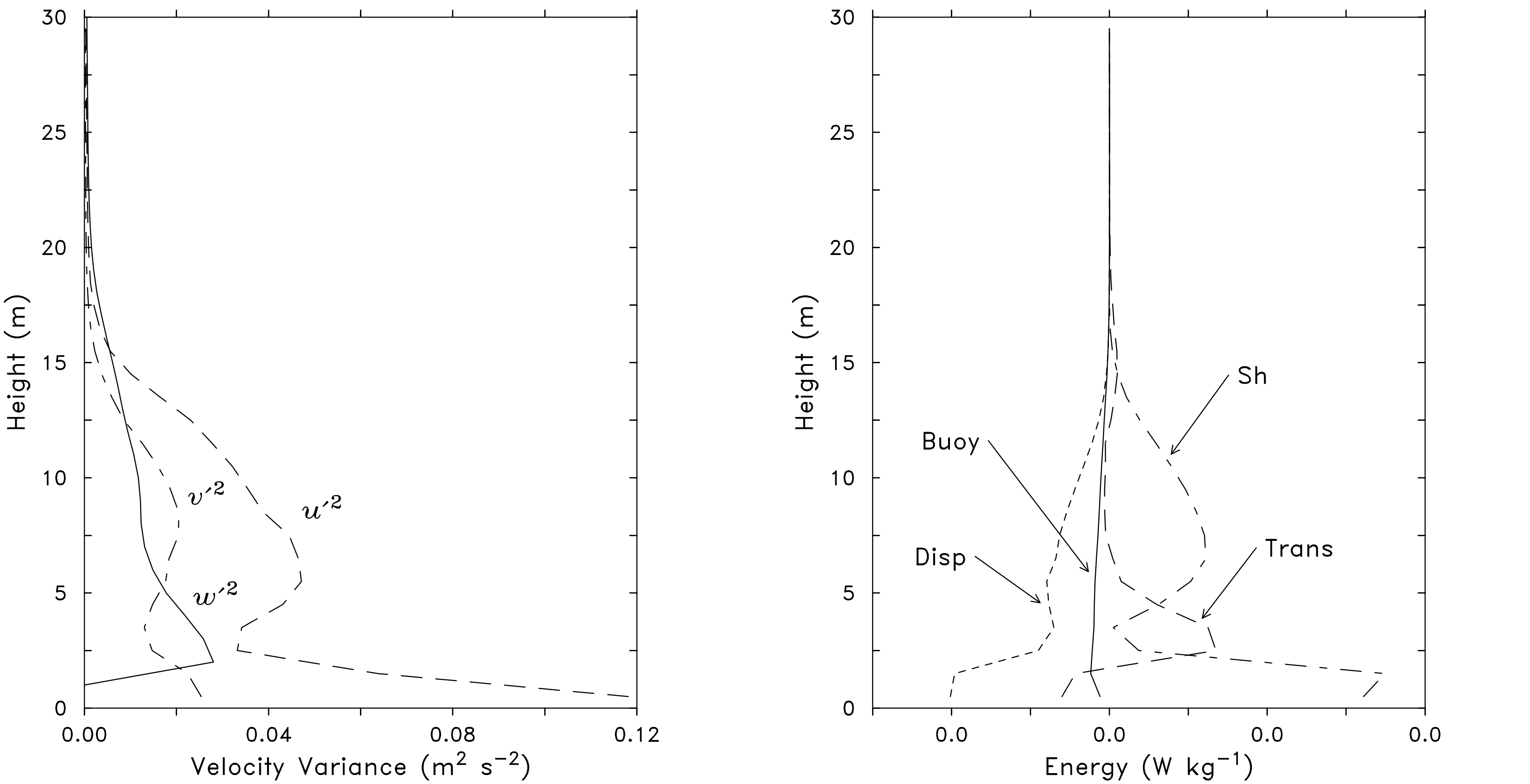
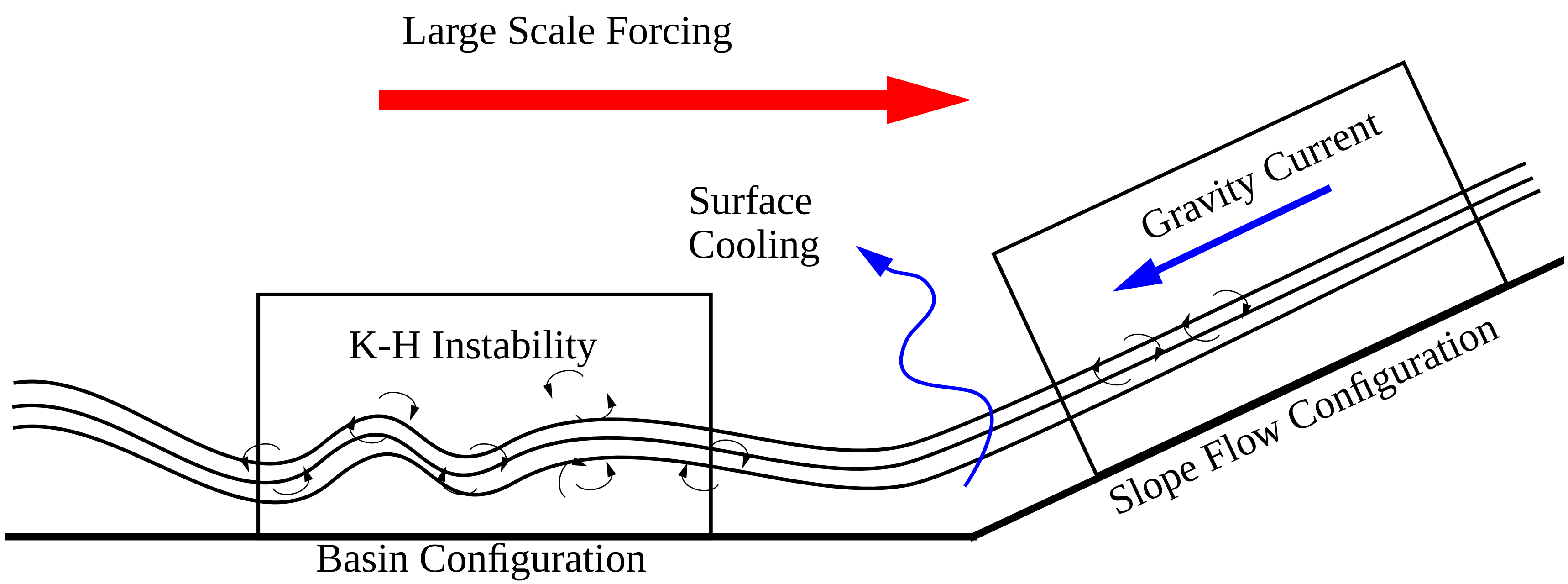


Vertical Profiles of Potential Temperature and Downslope Velocity at 15 minutes.



Vertical Profiles of Velocity Variances and TKE Budget Terms at 15 minutes.

Experimental Design



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LES Model Description

- Deardorff (1980) equation set.
- Ducros, et al. (1996) Filtered Structure Function subgrid model.
- Third-order Adams-Bashforth time differencing.
- Monotonic, conservative scalar advection scheme of Leveque (1996). Momentum uses Clark (1977) flux form.
- Durran and Klemp radiative upper boundary, periodic lateral boundaries, fluxes prescribed at the lower boundary using similarity functions.