Steep slope flow observations during the morning transition in a narrow alpine valley

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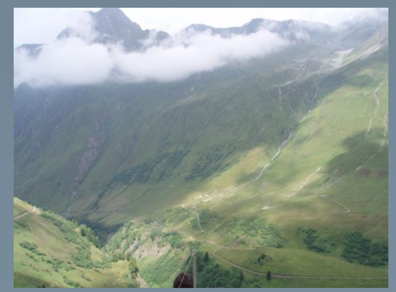
INTRODUCTION

Much of atmospheric boundary layer (ABL) theory holds for terrain that is: Flat • Uniform • Statistically homogeneous and for 'stationary' periods (day/night). For example:

- KANSAS 1968 and Minnesota 1973 Experiments
- Similarity theory: Monin-Obukhov, Willis and Deardorff, etc.

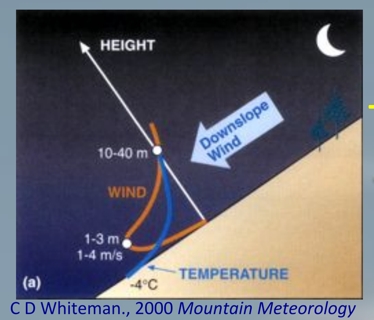
VS



In contrast, experiments during transitional periods (morning/evening) are underrepresented and the associated physics are less well understood especially in complex terrain. In addition, most numerical models perform poorly for steep terrain and during transitional periods.

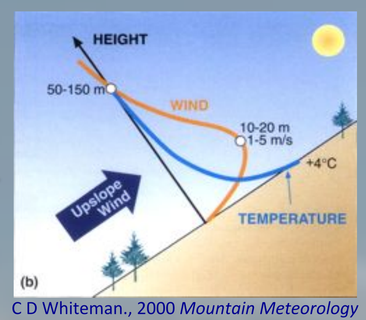
SLOPING TERRAIN

For sloping terrain, atmospheric flows under clear skies and weak synoptic forcing are thermally driven and characterized by upslope/up valley winds during the day and downslope/down valley winds at night. The turbulent mechanisms during the morning transition at the 10m flux tower from the on 21 Sept., a typical clear-sky day during the SELF-2011 field campaign, are examined herein.



C D Whiteman, 2000 Mountain Meteorology

Morning Transition



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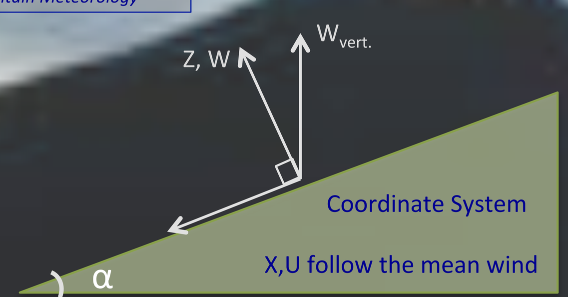
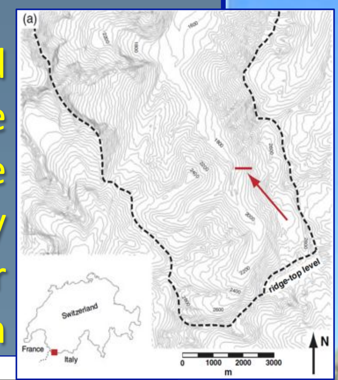
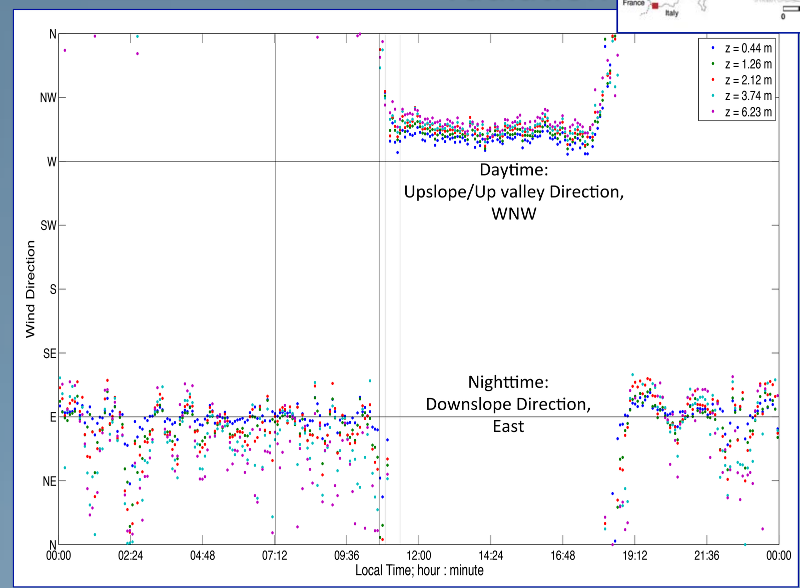


Due to slope aspect and topographic shading, the slope site is one of the final locations in the valley to receive direct solar radiation

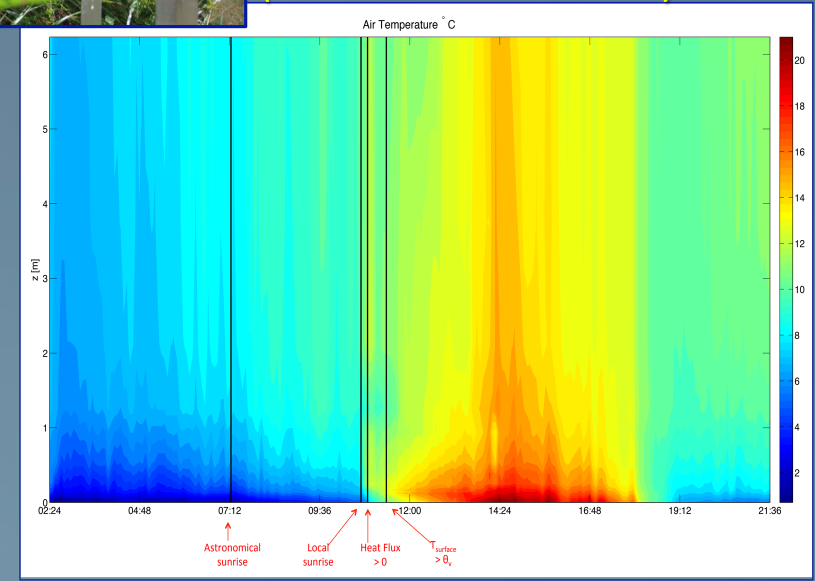




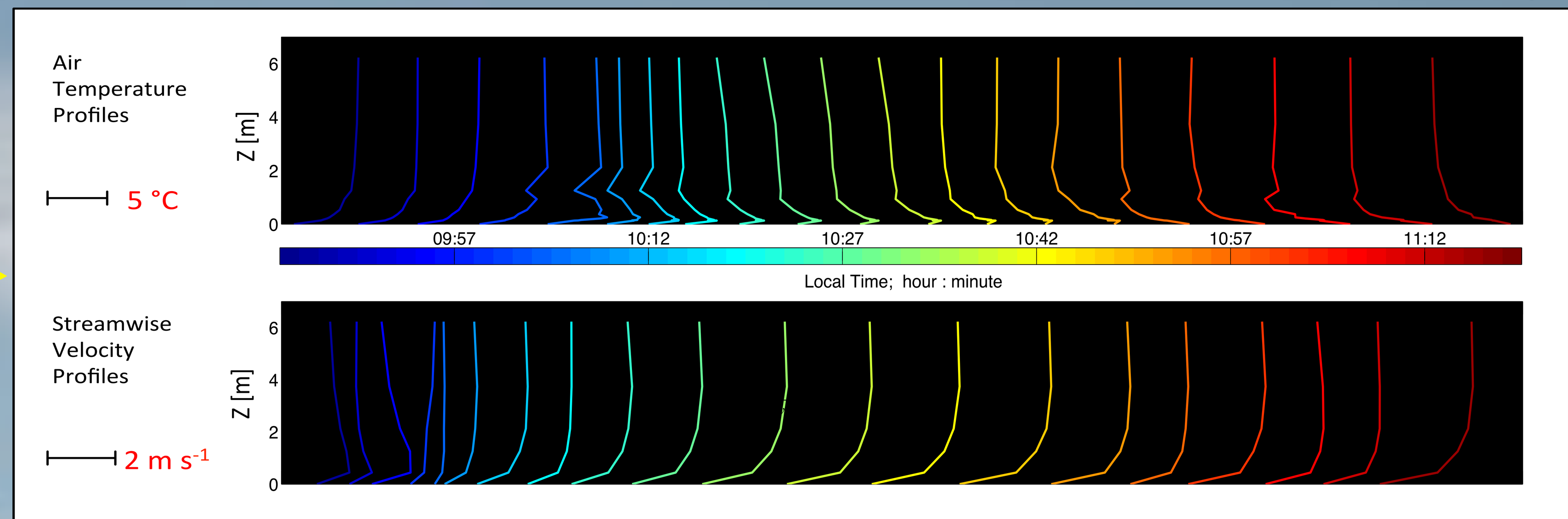
Typical diurnal slope flow patterns at the site.

Slope Experiment near La Fouly (SELF-2011)

10 Thermocouple array: Measures near-surface air temperature. (10 TCs between 0-1m)

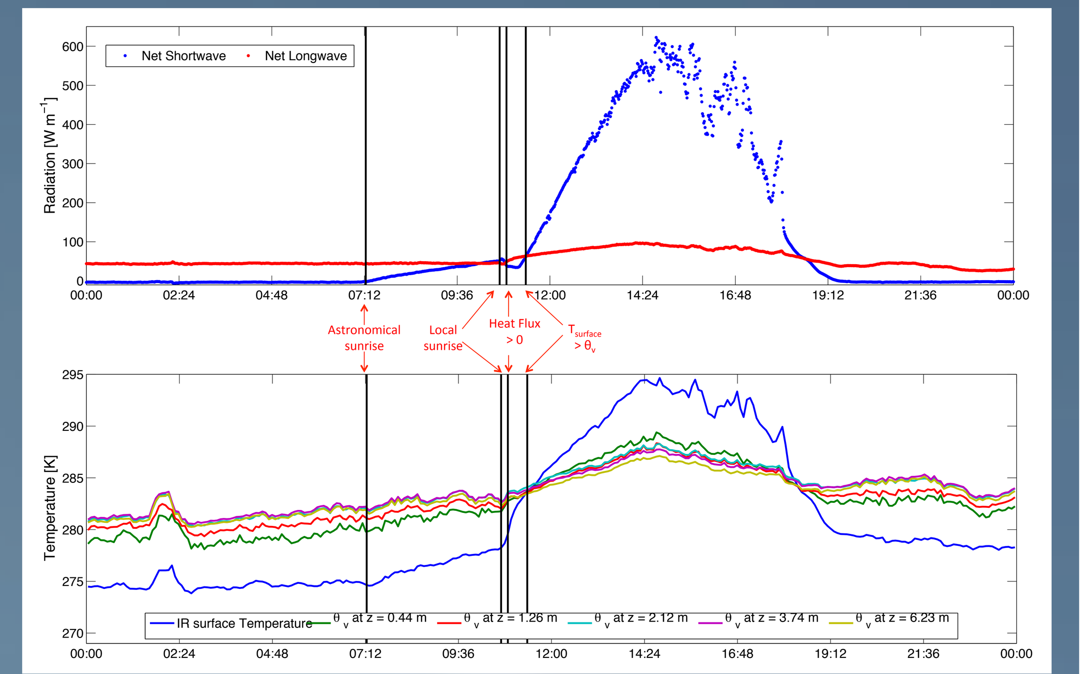


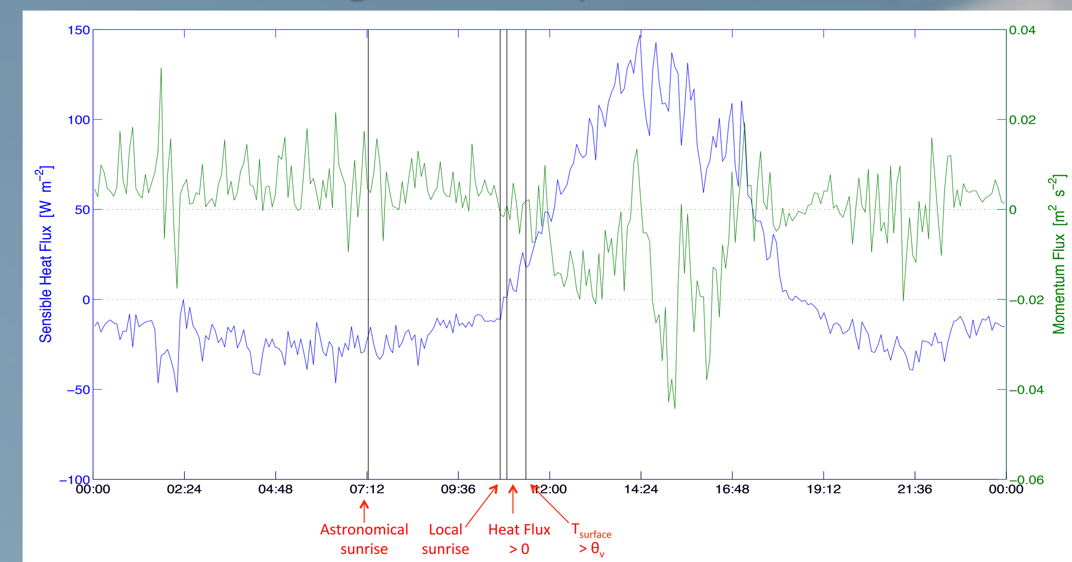
Nighttime air temperature inversion breaks up from above due to heating in the valley.



EVENT TIMING

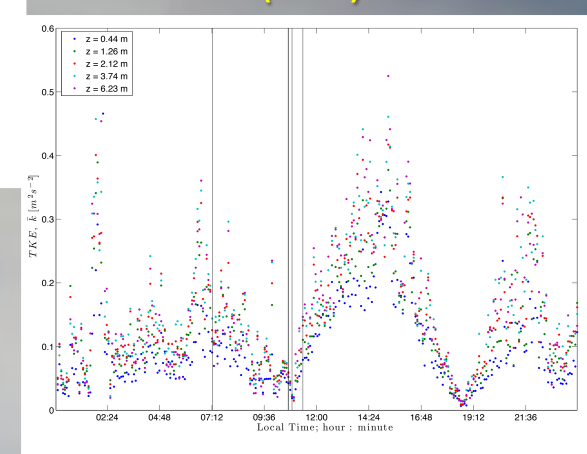
- Astronomical sunrise: 07:14
- Local sunrise (slope site receives direct solar radiation): 10:42
- Sensible heat flux, H, becomes positive $(\rho C_p \overline{w'\theta'} > 0)$: 10:52
- Surface temperature overtakes virtual temperature $(T_{surf} > \theta_v)$: 11:22





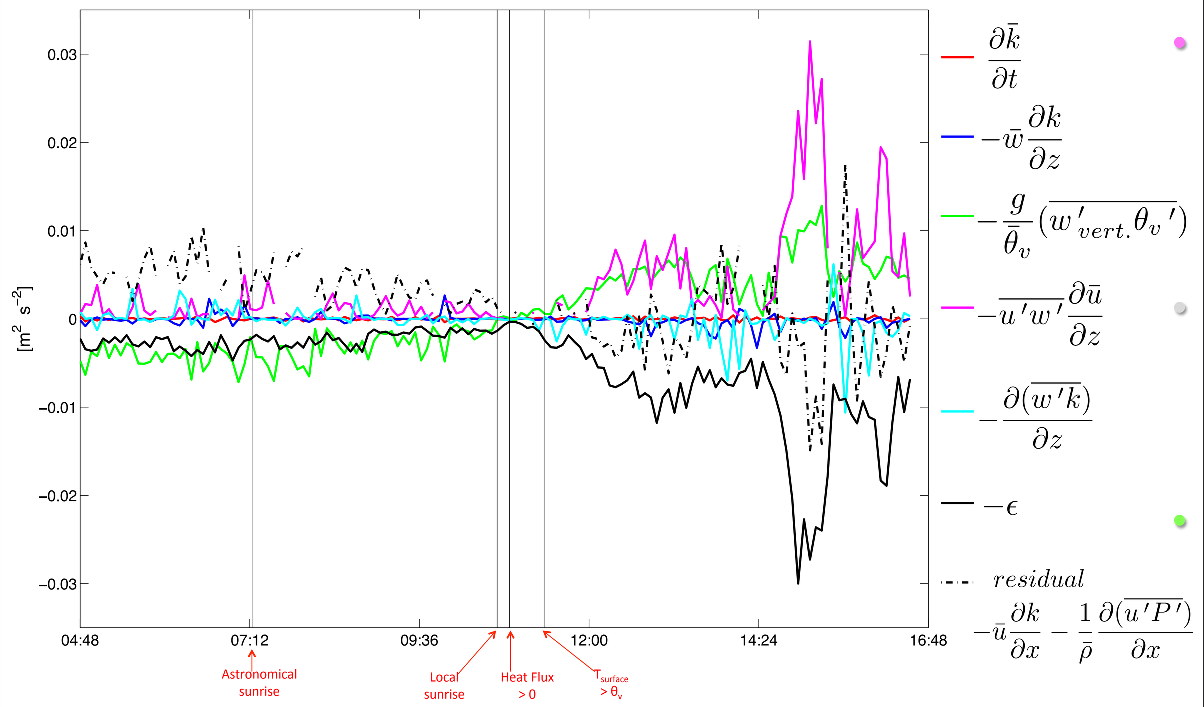
Heat and momentum fluxes at z = 1.26 m

Turbulence Kinetic Energy (TKE)



TKE Budget at z = 1.26 m

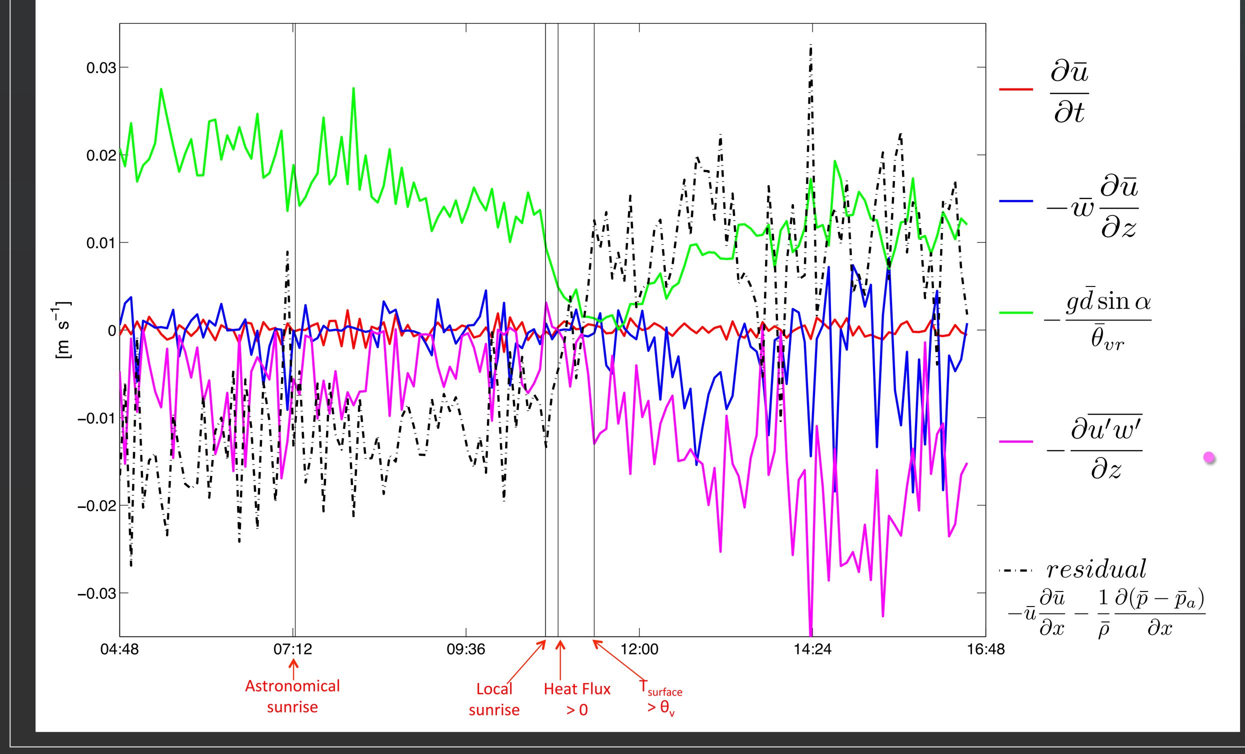
$$\underbrace{\frac{\partial \bar{k}}{\partial t}}_{I} = -\underbrace{\bar{u}\frac{\partial k}{\partial x}}_{II} - \underbrace{\bar{w}\frac{\partial k}{\partial z}}_{III} + \underbrace{\frac{g}{\bar{\theta}_v}(\overline{w'_{vert.}\theta_v{}'})}_{IV} - \underbrace{\overline{u'w'}\frac{\partial \bar{u}}{\partial z}}_{V} - \underbrace{\frac{\partial(\overline{w'k})}{\partial z}}_{VI} - \underbrace{\frac{1}{\bar{\rho}}\frac{\partial(\overline{u'P'})}{\partial x}}_{VII} - \underbrace{\epsilon}_{VIII}$$



- All terms ~0 for 10 min. after local sunrise.
- Mechanical production (termV) dominates production of TKE
- Viscous dissipation (termVII) dominates destruction of TKE
- Buoyancy (termIV) destroys at night and produces TKE during the day.

U Momentum Budget z = 1.26 m

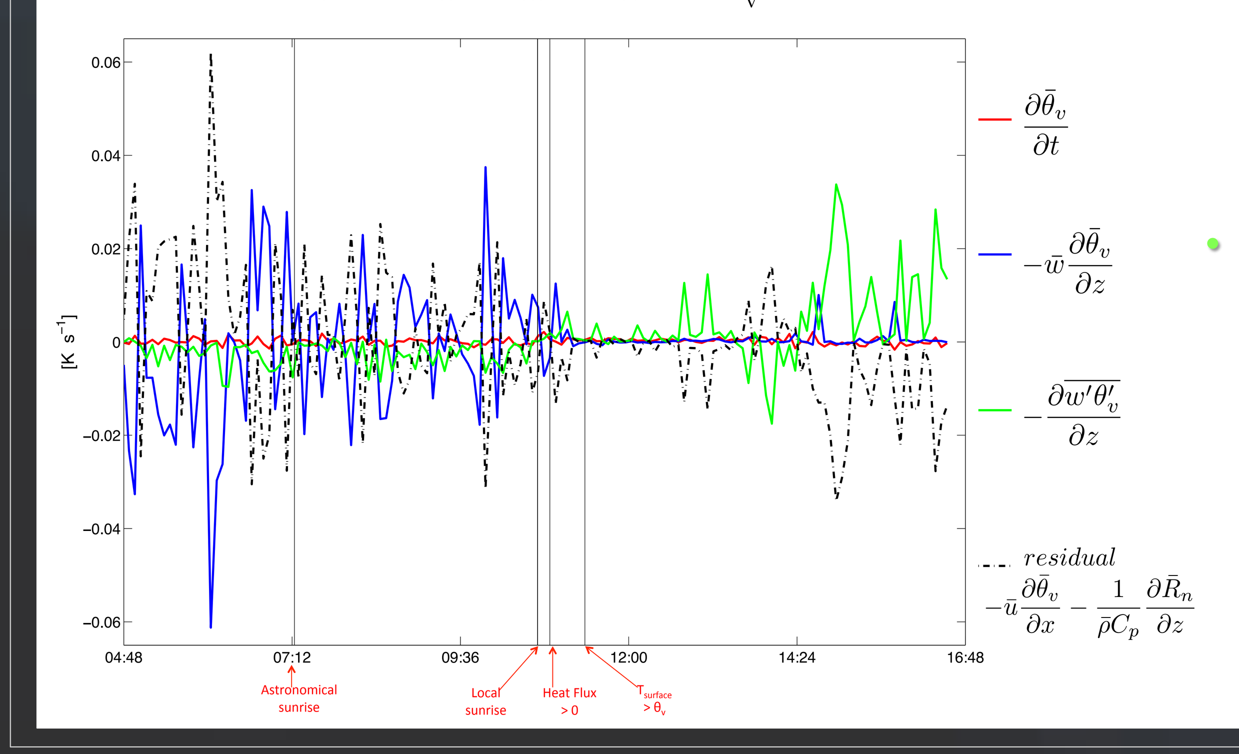
$$\underbrace{\frac{\partial \bar{u}}{\partial t}}_{I} = -\underbrace{\bar{u}\frac{\partial \bar{u}}{\partial x}}_{II} - \underbrace{\bar{w}\frac{\partial \bar{u}}{\partial z}}_{III} - \underbrace{\frac{g\bar{d}\sin\alpha}{\bar{\theta}_{vr}}}_{IV} - \underbrace{\frac{\partial \overline{u'w'}}{\partial z}}_{V} - \underbrace{\frac{1}{\bar{\rho}}\frac{\partial(\bar{p}-\bar{p}_a)}{\partial x}}_{VI} \qquad -\bar{d} = |\theta_v - \theta_{va}|$$



- Bouyant acceleration (termIV) drives both up and down slope flow. It drops after local sunrise and rises again almost 2hrs later.
- Momentum flux divergence (termV) partially balances acceleration.

Thermal Energy Budget at z = 1.26 m

$$\underbrace{\frac{\partial \bar{\theta}_v}{\partial t}}_{I} = -\bar{u}\underbrace{\frac{\partial \bar{\theta}_v}{\partial x}}_{II} - \underbrace{\bar{w}\frac{\partial \bar{\theta}_v}{\partial z}}_{III} - \underbrace{\frac{\partial \overline{w'\theta'_v}}{\partial z}}_{IV} - \underbrace{\frac{1}{\bar{\rho}C_p}\frac{\partial \bar{R}_n}{\partial z}}_{V}$$



- Advection of heat normal to the surface (termIII) damps out after the heat flux crossover time.
- Heat flux divergence (termIV) is negative and steady, but weak at night. After it becomes >0, it does not strengthen until afternoon.

CONCLUSIONS:

Residual terms in the budget equations are generally significant which indicates the missing terms are potentially significant. Since the night time temperature inversion breaks up from above, horizontal advection most likely plays a significant role that is not accounted for in the budget analyses. Future studies should attempt to measure horizontal advection of TKE, momentum and heat

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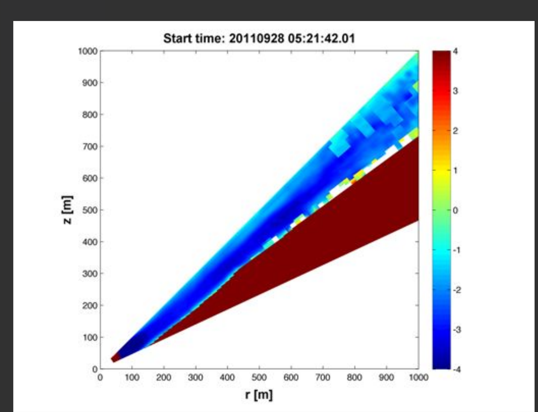
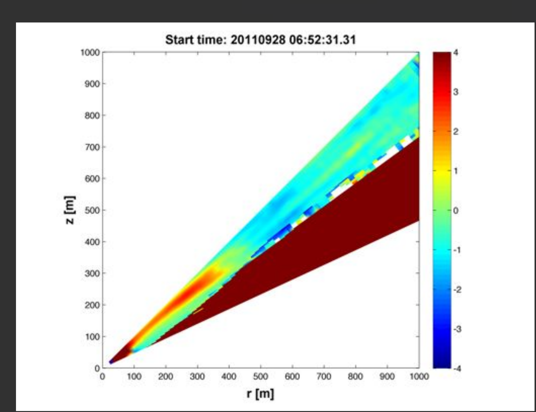
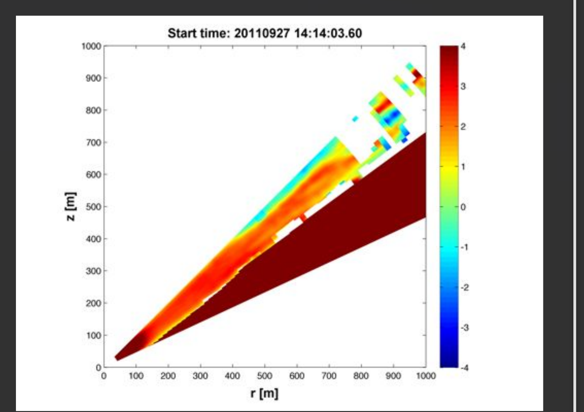
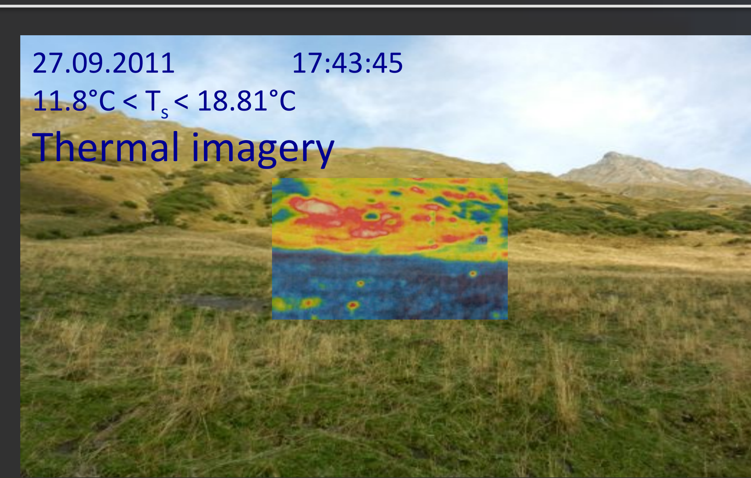
Future work: Connect the local physics to the valley scale flows using the balloon soundings, Doppler lidars, and sensorscope (distributed sensor network in the catchment)

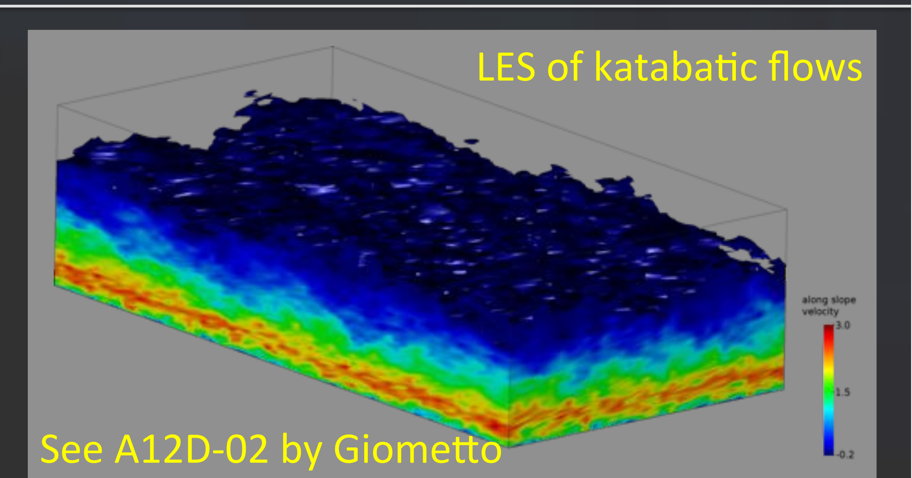






Future work: Compare with LES and try to improve modeling. Learn more about the physics from LES test cases. Sensitivities to slope angle, surface temperature patches, roughness patches, etc.





See A12D-02 by Giometto