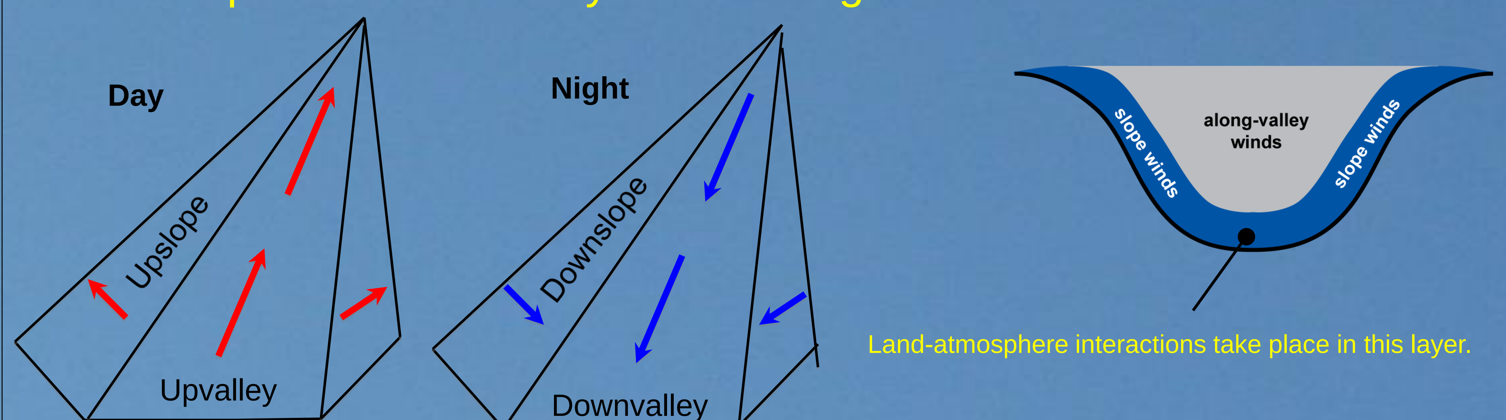
Thermal Circulation Patterns and Turbulent Fluxes along Steep Mountain Slopes

D. F. Nadeau[1], E. R. Pardyjak[2], C. Higgins[1], H. Huwald[1], F. Bärenbold[1] & M.B. Parlange[1]

Introduction:

Typical thermal circulations in mountainous terrain during clear sky conditions with surface heating/cooling and limited synoptic influence are characterized by upslope and upvalley winds during the day and downslope and downvalley winds at night.



Figures adapted from (Mountain Meteorology Whiteman, 2000)

Motivation:

What we know

- Basic atmospheric circulations in mountainous terrain are fairly well understood (Whiteman, 2000)
- Theory and literature mostly focused on gentle terrain and idealized slopes (Hunt et al., JFM, 2003)
- Some important field campaigns mountain winds
  - MAP experiment (Swiss Alps)
  - T-REX (California)
  - Mt. Hymettos (Greece)

Challenges

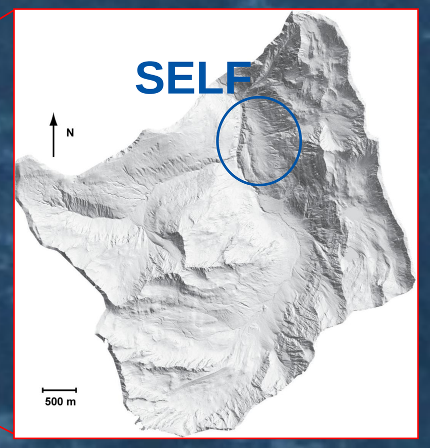
- **Transitory Behavior**
  - Thermal circulations are unsteady
  - Transition Periods – Theory & Understanding is incomplete
- Difficult to monitor meteorological processes over steep terrain

Open Questions Related to

- Turbulence processes – decay, multi-scale interaction
- Difficult to parameterize processes – transitional flow start, skin flows
- Time scales

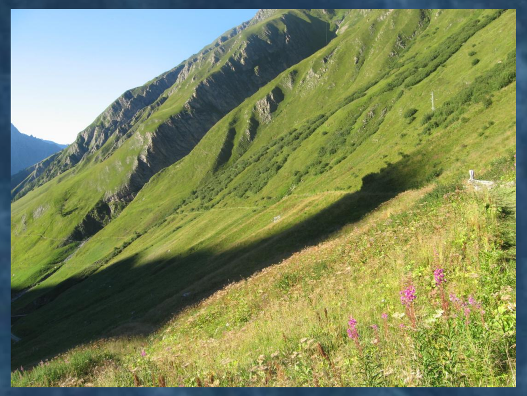
The Experimental Site: Slope Experiment at La Fouly (SELF)

Dranse de Ferret Alpine Catchment

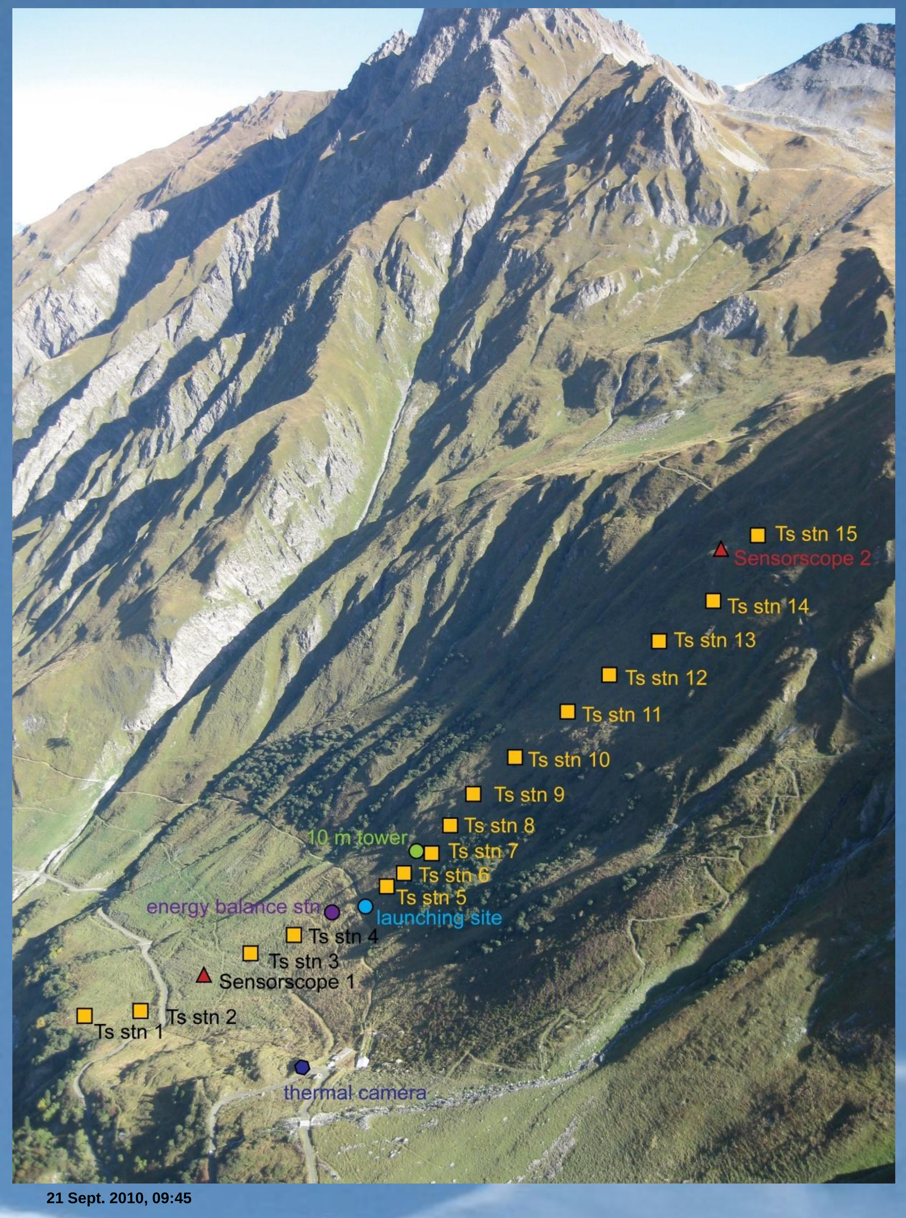


- Val Ferret, Swiss Alps
- 45.902°N, 7.123°E
- 7 July to 30 Sept. 2010
- West-facing slope
- Altitude range: 1800 to 2200 m ASL
- Slope range: ~25° to 45°

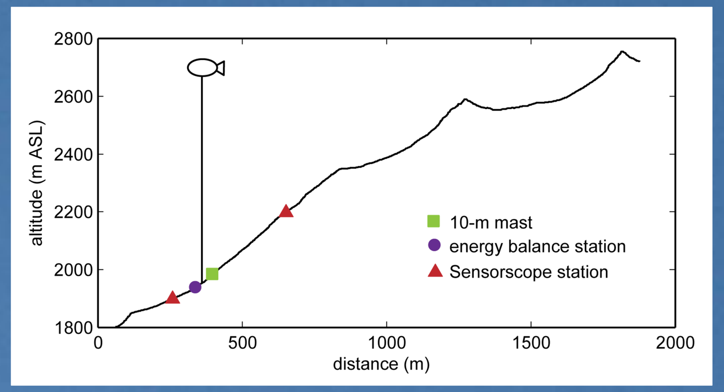
SELF Slope Site



The Experimental Setup:



A suite of instrumentation was deployed along a linear transect of the slope in an effort to capture the unsteady complex land-atmosphere interaction processes



Tethered Balloon System

- Deployed during 4 IOPs (clear skies)
- Measurements of WS, WD, RH, temperature
- profiles from 0 to 750 m above ground (1950 to 2700 m ASL)

Surface Temperature Stations

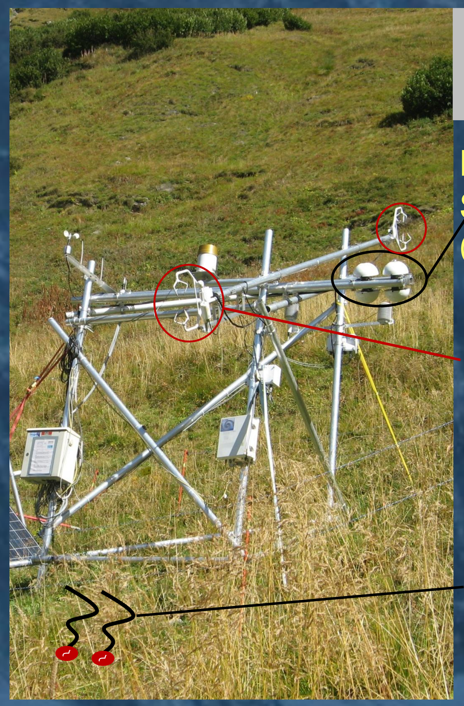
- Zytemp TN901 IR sensors with Arduino boards
- Low cost
- USB download
- 15 stations deployed (Ts stn 1-15)

Surface Temperature Field Measurements

- Deployed during 2 IOPs (clear-sky days)
- Infrared camera FLIR A320 16-bit (320 x 240) optical camera (752 x 480)
- Sampling frequency: 7 Hz

Sensorscope Stations

- Wireless network of weather stations
- Measurements of: WS, WDIR, RH, 2m air temp., surface temp., solar radiation, soil moisture & temp.
- 2 stations installed on the slope
- 15 stations in the entire catchment



Energy Balance Station (slope: 30°)

Radiometers (LW↑, LW↓, SW↑, SW↓) (mounted parallel to the slope)

1 open path LI-COR 7500 H_2O-CO_2 analyzer
2 sonic anemometers (axis normal to the slope)

2 soil heat flux plates

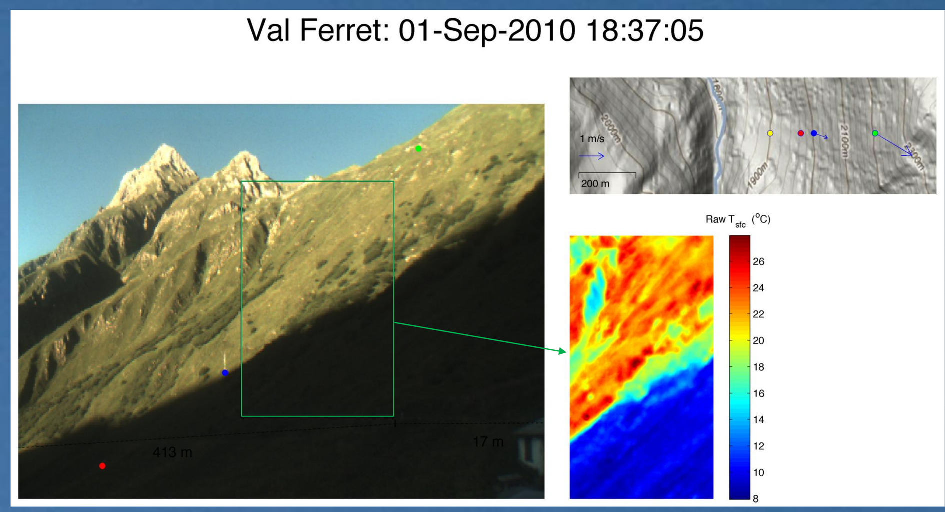
10-m Tower (slope: 42°)

4 sonic anemometers (axis normal to the slope)

2 Temp + RH sensors

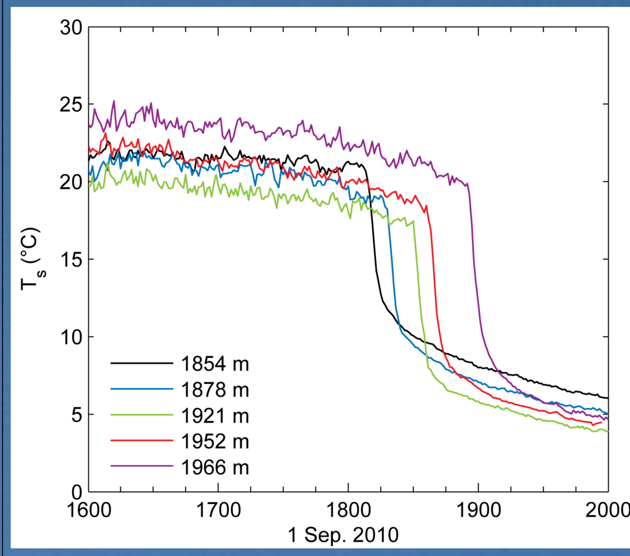
1 net radiometer (axis normal to the slope)

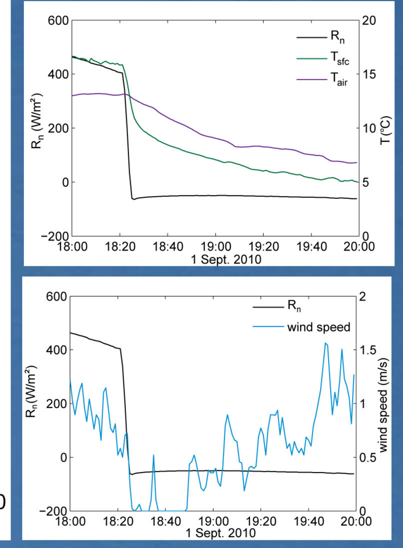
Results: Evening Transition



The FIR camera showed a very heterogeneous surface temperature (T_{sfc}) structure associated with local terain features.

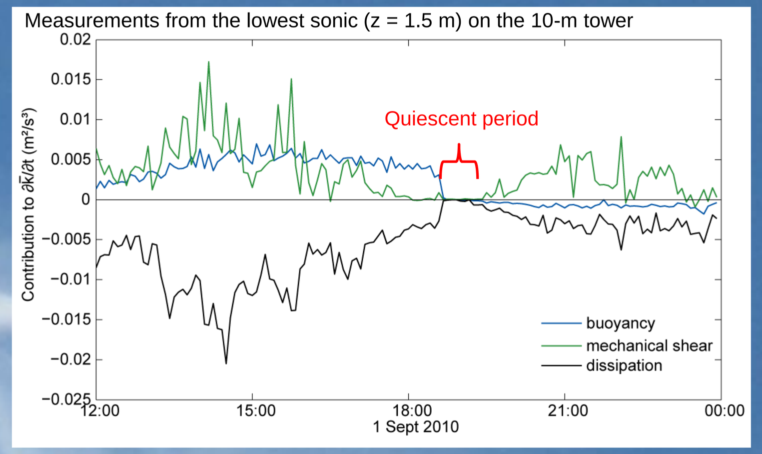
During the evening transition, the local topography caused highly non-uniform shading and rapid decreases in net radiation (R_n) and T_{sfc}.





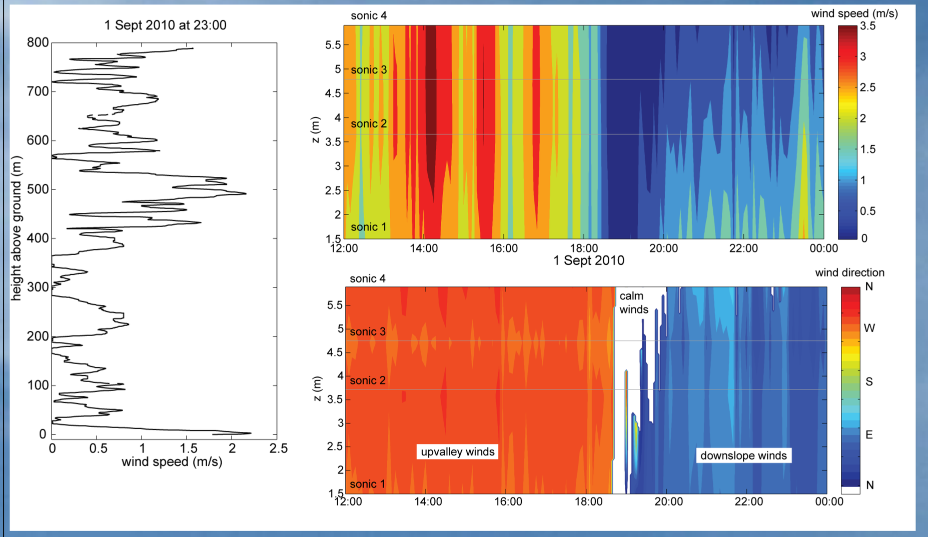
As a result of local terrain shading, the surface cooled like a front moving from the bottom of the valley up-slope.

The wind direction changed from up-slope to down-slope following this front, however the wind speed measurements indicate a 30 minute period of extremely light winds.



Quiescent Period

The light wind period is associated with a rapid decay of turbulence to extremely low levels. Buoyancy production, mechanical shear production and dissipation all drop to almost zero before the down-slope winds start the nocturnal circulation.



Skin Flow

Preliminary observations indicate the existence of a thin layer near the slope surface where winds are substantially higher than those at higher levels.

Conclusions:

- The evening transition appears to proceed as follows:
  - The surface temperature (T_{sfc}) reacts quickly in response to the rapid decrease in net radiation (R_n)
  - Turbulence near the surface is quiescent for 30 min. during the transition
  - Build-up of stratification leads to very shallow down-slope winds (skin flows)

Corresponding author address: Daniel F. Nadeau, EPFL, Switzerland
E-mail: *daniel.nadeau@epfl.ch*

[1]École Polytechnique Fédérale de Lausanne, Switzerland; [2] University of Utah, Salt Lake City, UT, USA