Observations of radiative cooling and heating under clear sky and fog conditions:

Initial Results

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And updates of work by Matt Jeglum, Manuela Lehner and Dave Whiteman

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7-8 October 2015

Motivation

Fog forms when the near-surface air is cooled below its dew-point temperature and when enough cloud or ice condensation nuclei are available.

Condensation conditions can be reached by different mechanisms including local cooling and mixing processes of different air masses.

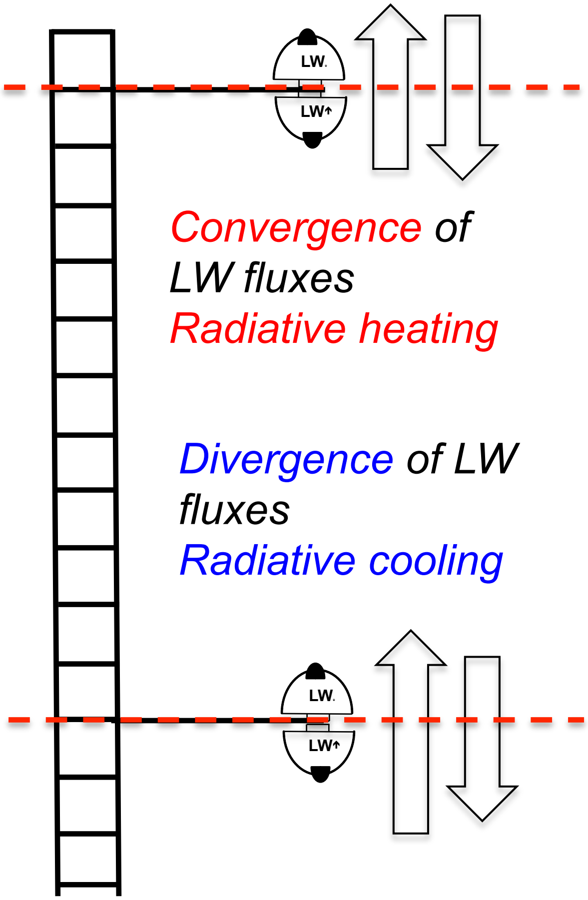
MATERHORN-FOG observations were designed to directly measure the cooling contributions.

$$\frac{\partial T}{\partial t} + \vec{v_h}\,\nabla_h T + w\frac{\partial T}{\partial z} = \nu_T \frac{\partial^2 T}{\partial z^2} - \frac{1}{\rho c_p}\left(\frac{\partial SW}{\partial z} \boxed{+ \frac{\partial LW}{\partial z}} + \frac{\partial H}{\partial z}\right).$$

This research investigated the **role of *clear-air radiative cooling*** or ***Radiative Flux Divergence (RFD)*** in the surface layer and its relative importance under different conditions.

Instrumentation and Methodology

- Small changes in LW fluxes need to be resolved.
- Kipp and Zonen CGR4 research-grade pyrgeometers – at two levels



Convergence of LW fluxes

Radiative heating

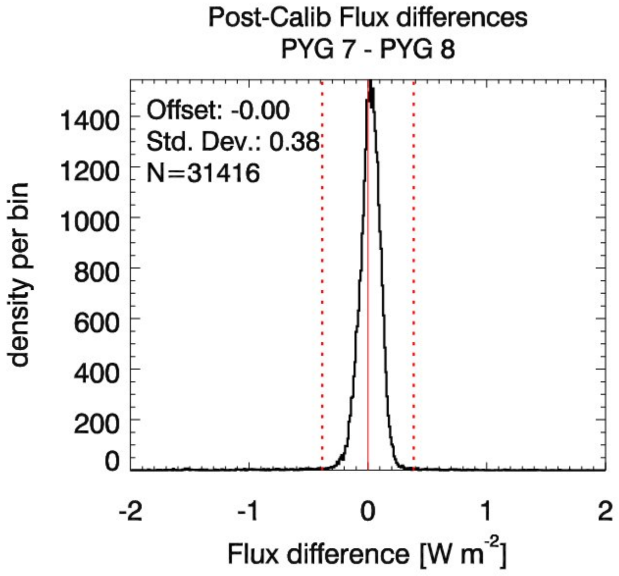
Divergence of LW fluxes

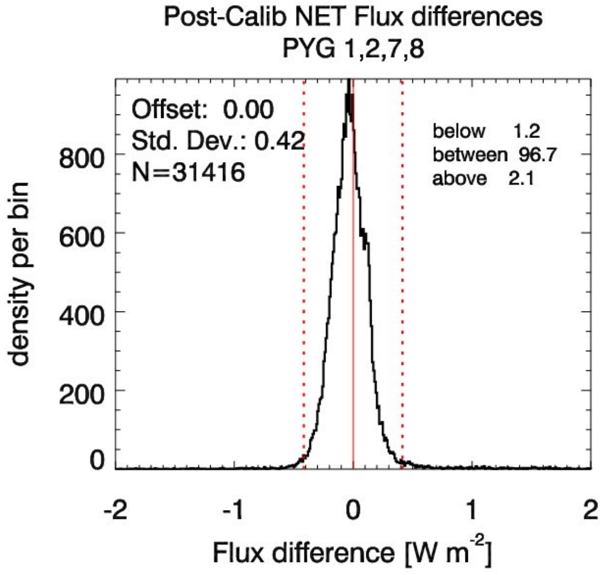
Radiative cooling

To maximize instrument accuracy, sensors are ventilated with heated air.

Careful ***Relative Calibration*** is necessary.

Relative Calibration - Results





Uncertainties	SLC	Heber
LW in	± 0.38 W m^{-2}	± 0.59 W m^{-2}
LW out	± 0.15 W m^{-2}	± 0.18 W m^{-2}
LW net	± 0.42 W m^{-2}	± 0.61 W m^{-2}
Radiative Heating Rate	± 5.5 K day^{-1}	± 6.5 K day^{-1}

Before relative calibration: flux difference as large as 5.5 ± 2.6 Wm^{-2} (PYG 8 vs 6)

Observational sites

Heber Valley (1697 m MSL)

Heber Valley, Jan. 8, 2015

Salt Lake City Basin (1289 m MSL)

Salt Lake City Basin, Jan. 8, 2015

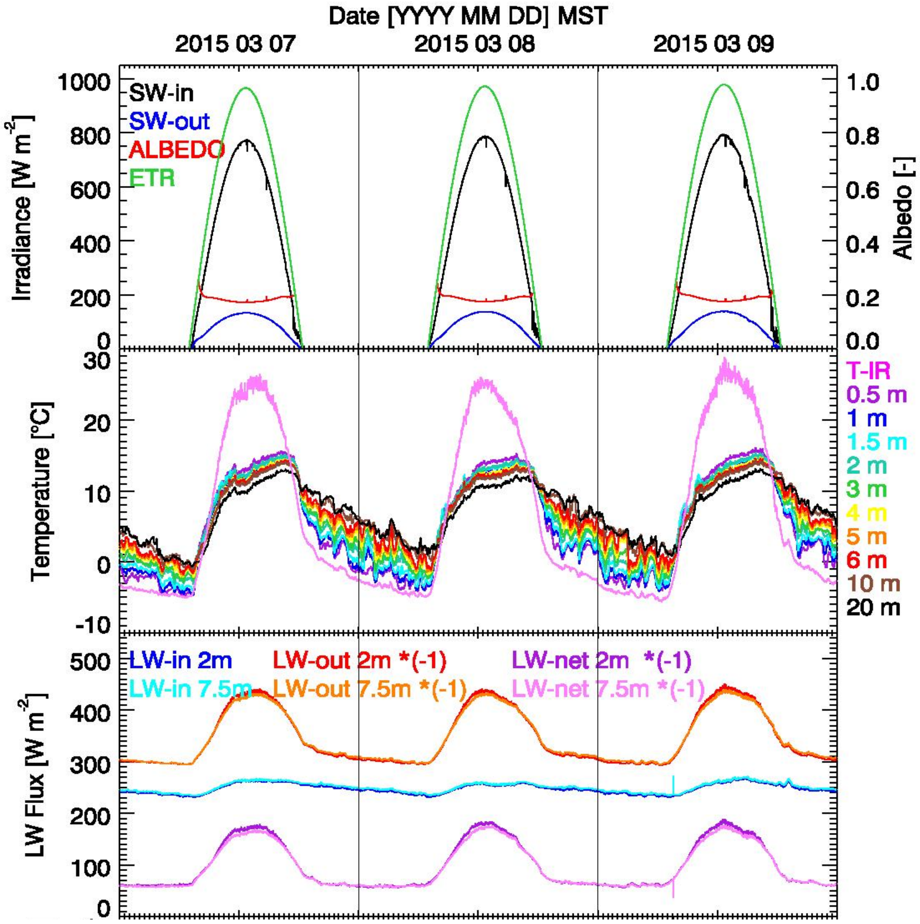
Radiative Flux Divergence (RFD) in the surface layer between 2 and ~7.5 m was investigated.

Results

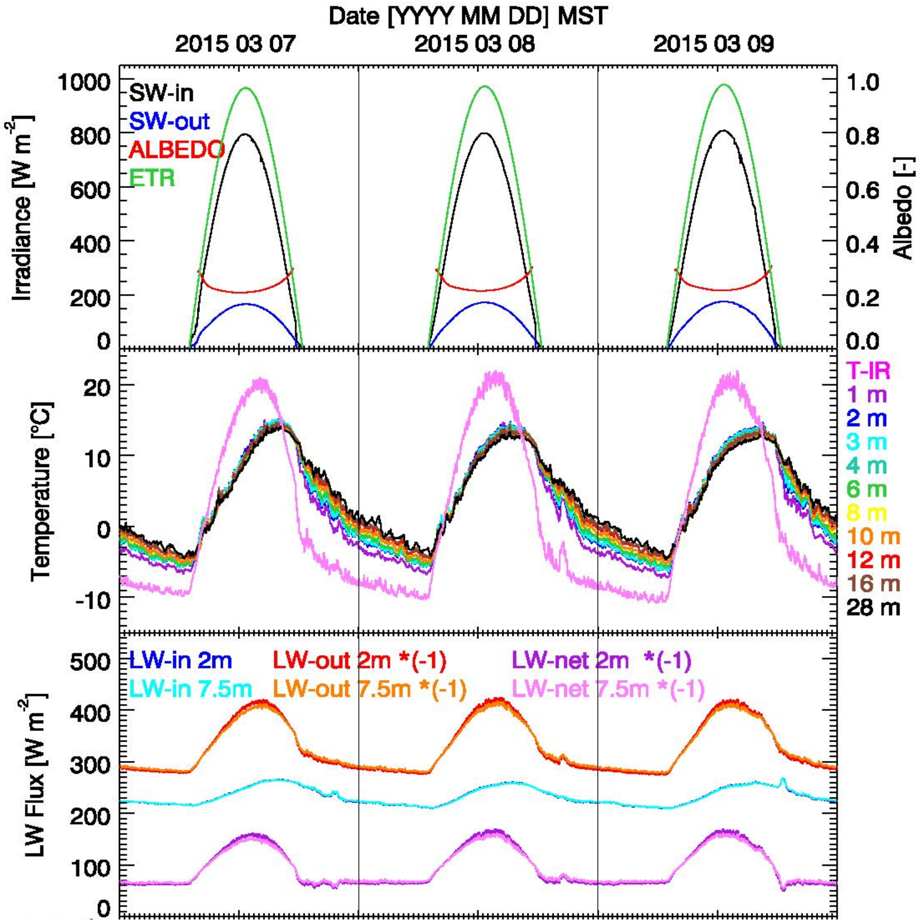
1. Clear Sky Conditions (7-9 March 2015)

Results – Radiative Fluxes – Clear Sky

SLC, clear sky, snow free

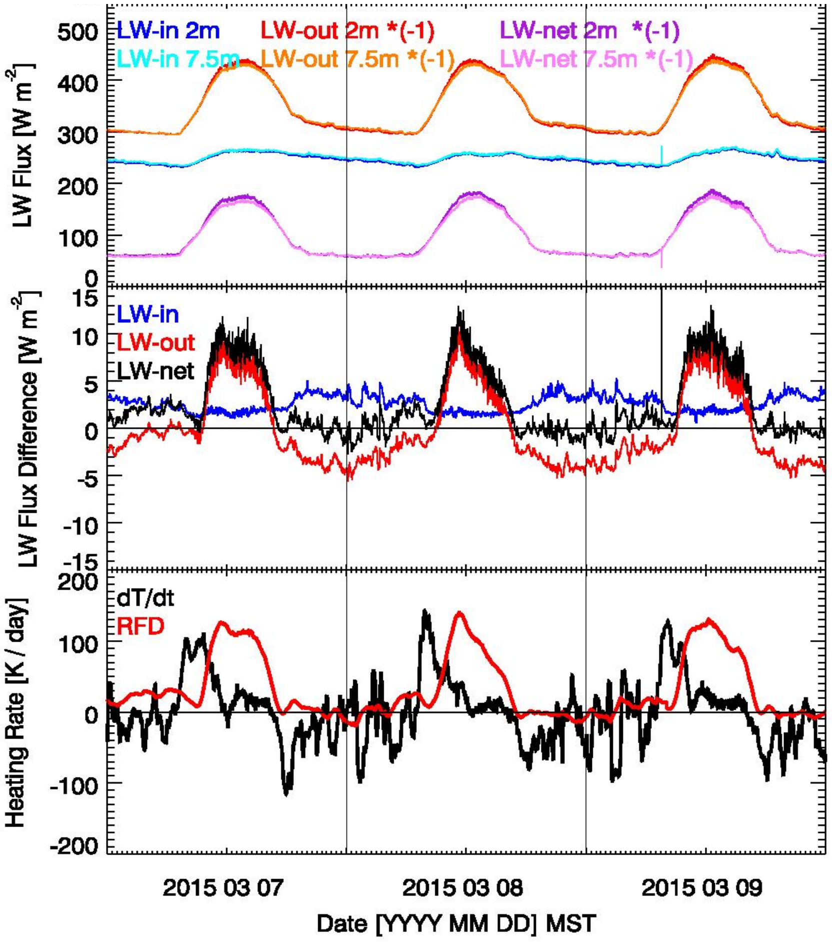


Heber, clear sky, snow free

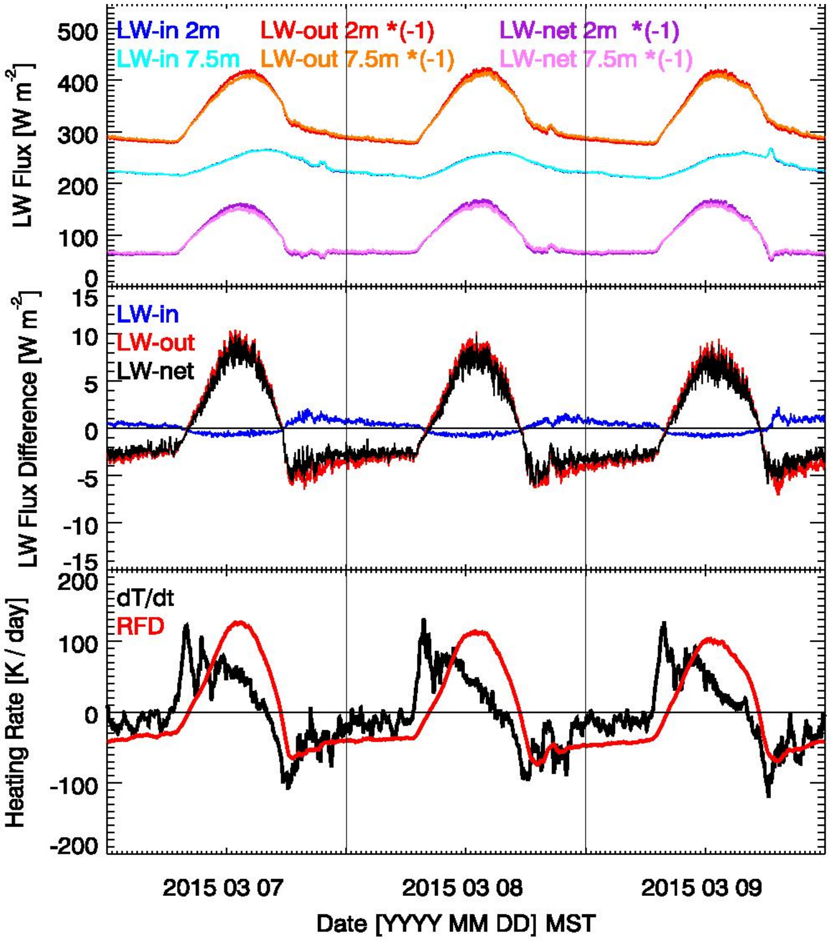


Results – Radiative Flux Divergence (RFD) – Clear Sky

SLC, clear sky, snow free



Heber, clear sky, snow free



Results – Clear Sky

- Significant differences in the incoming, outgoing, and net longwave radiative fluxes between 2 and ~8 m AGL can be resolved after a careful relative calibration of research-grade pyrgeometers.

- A daytime convergence of the net longwave flux typically leads to a daytime radiative heating rate of up to ~100 K day^{-1} (~4 K hr^{-1}). This magnitude corresponds to the temperature tendency observed in the morning hours. This illustrates the importance of clear-air longwave radiative heat exchange in the surface layer.

- The time lag between maximum observed heating and radiative heating indicates the important role of other processes.

- At night, under clear skies, the divergence of the outgoing flux is compensated by a convergence of the incoming flux. Zero to weak cooling results.

- Under clear-sky conditions, the divergence/convergence of the outgoing longwave flux component dominates net radiative cooling/heating.

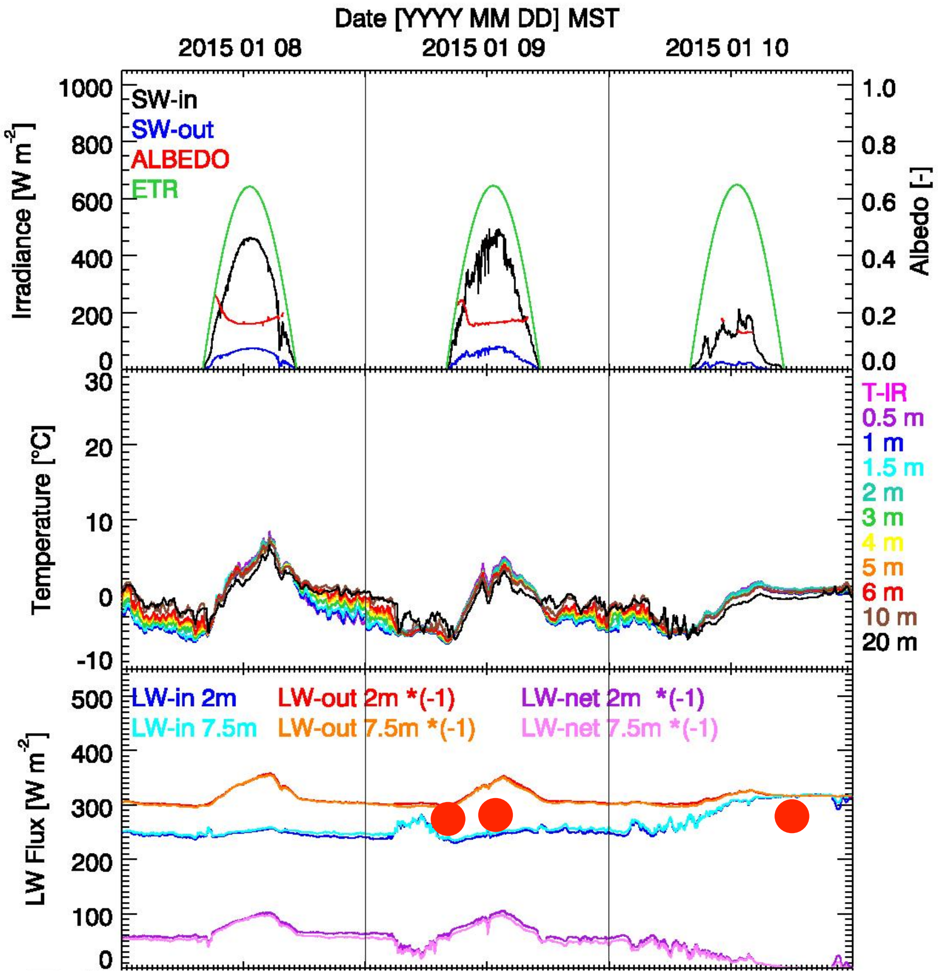
Results

2. Fog episodes (7-10 January 2015)

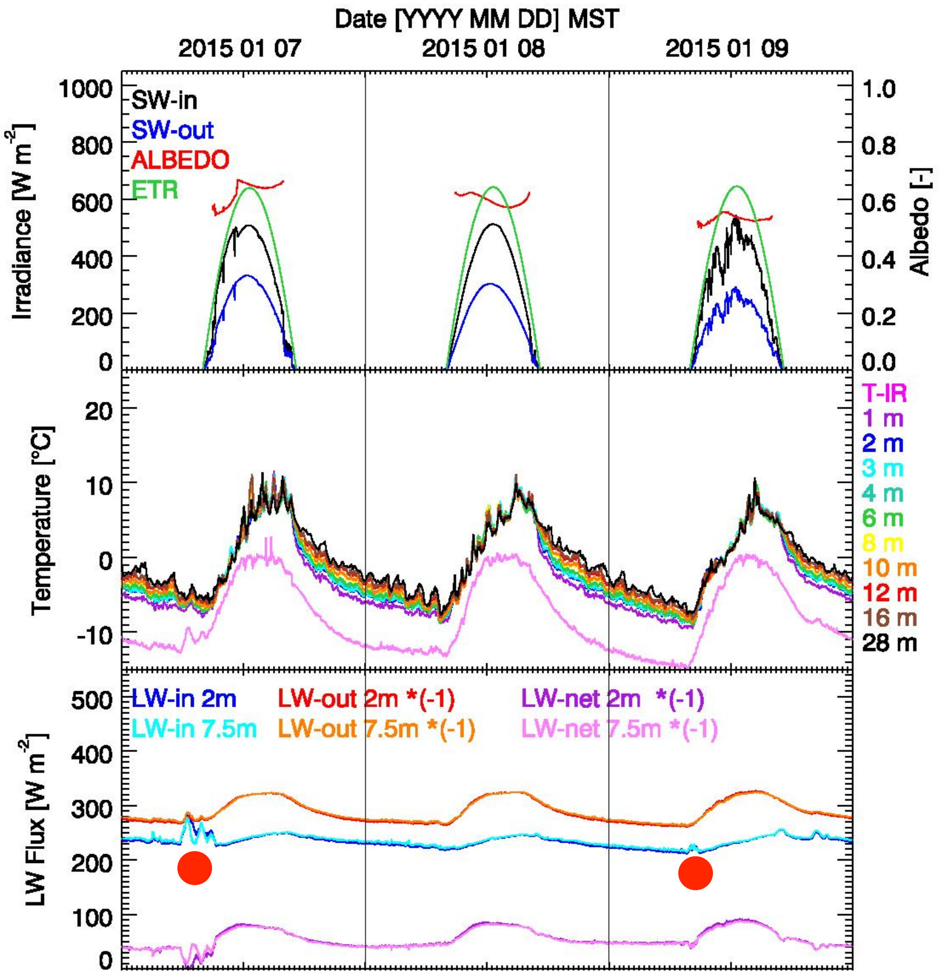
When ***fog droplets*** are introduced into the surface layer, radiative energy exchange changes dramatically. Radiative exchange is not limited anymore to water vapor and CO_2 spectral bands.

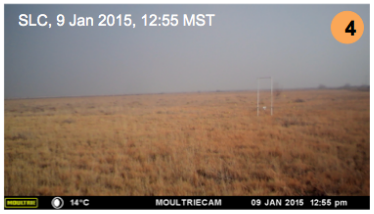
Results – Radiative Fluxes – with fog episodes

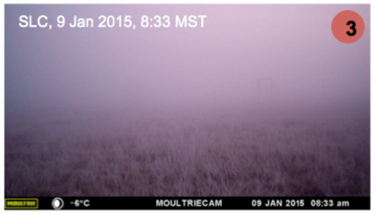
SLC, snow free, some fog

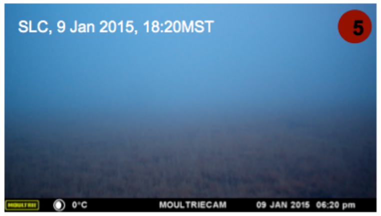


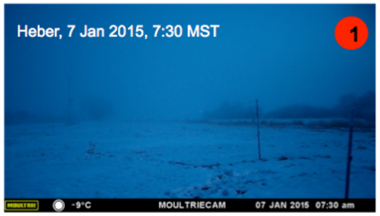
Heber, snow covered, some fog

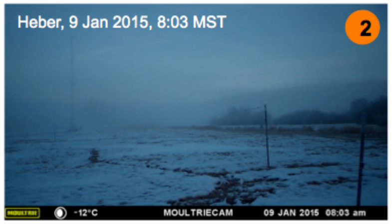






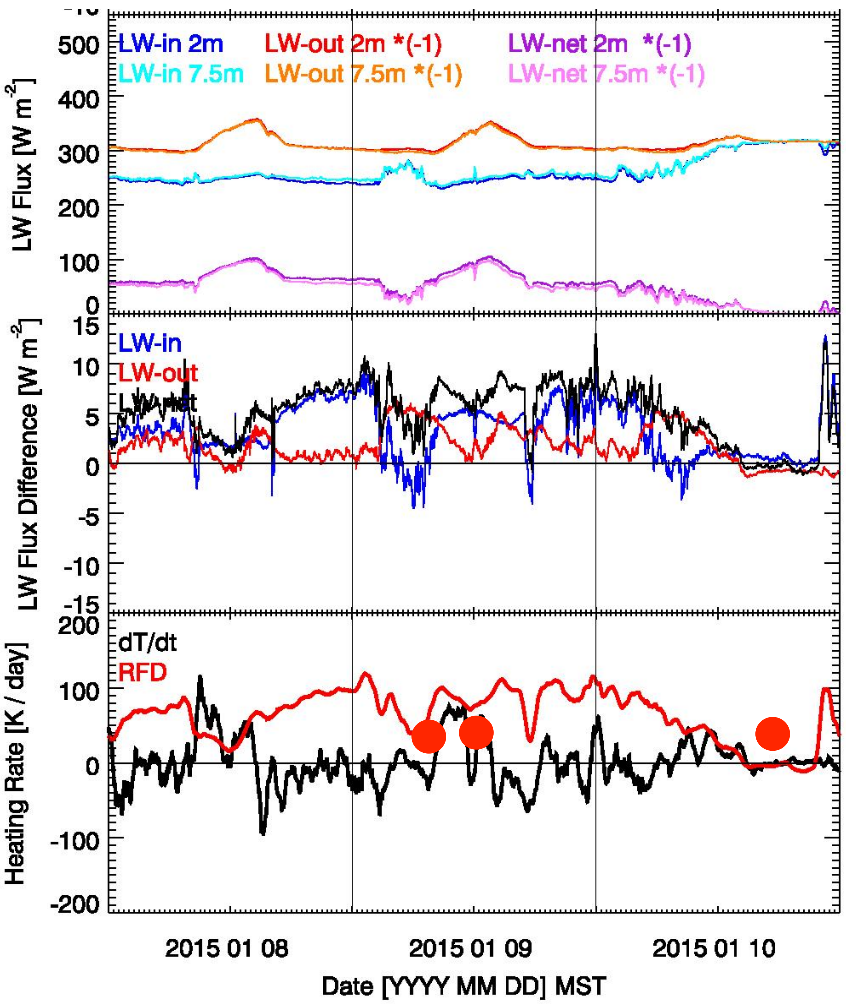




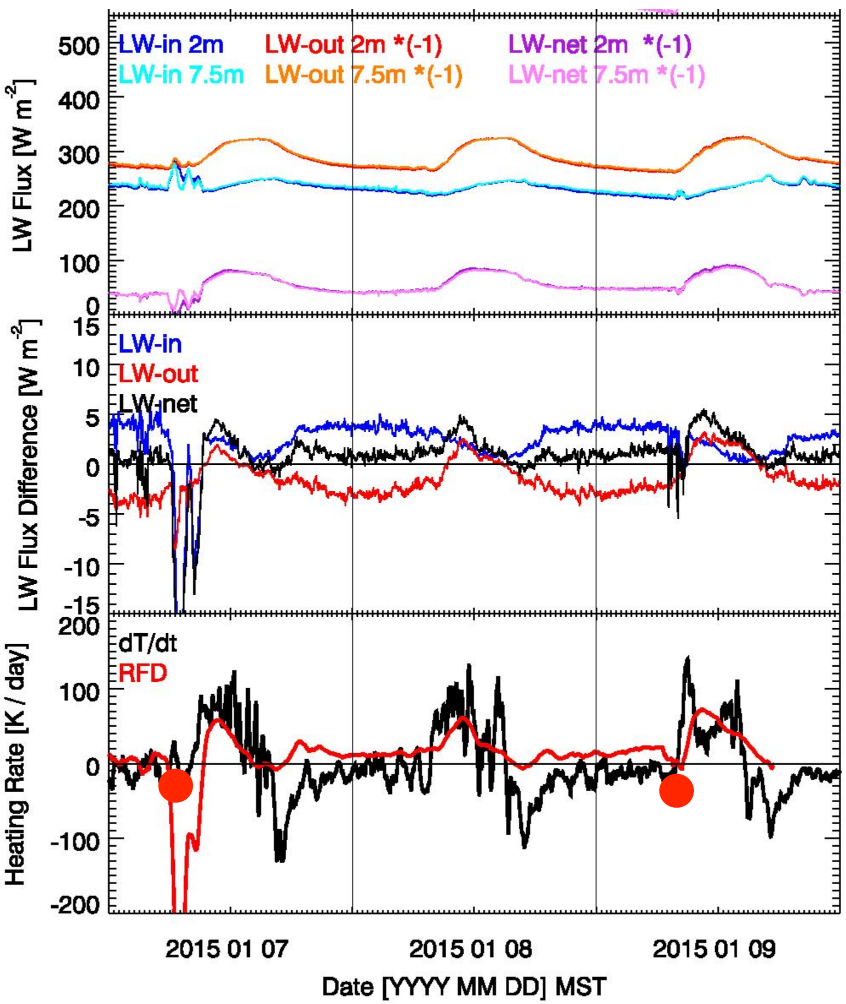


Results – Radiative Flux Divergence (RFD) – with fog

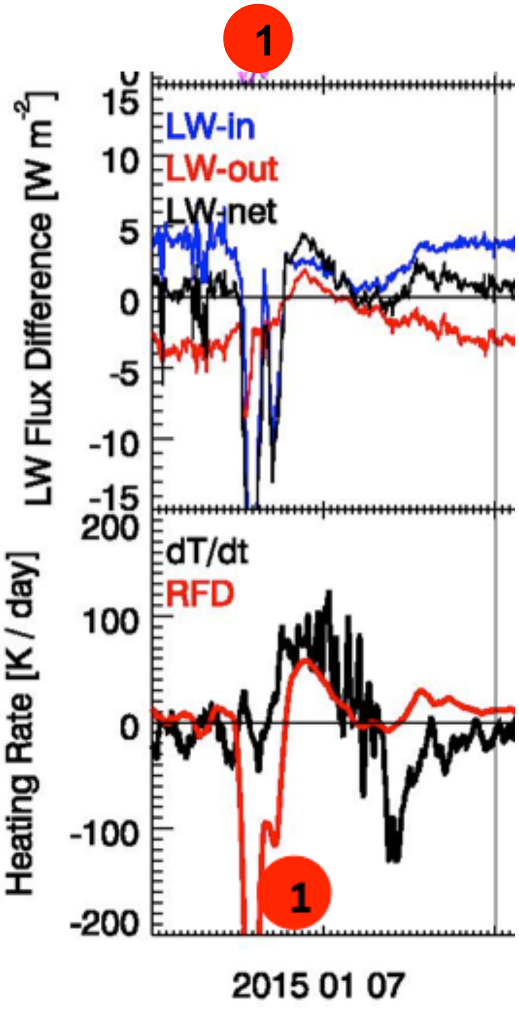
SLC, snow free, some fog

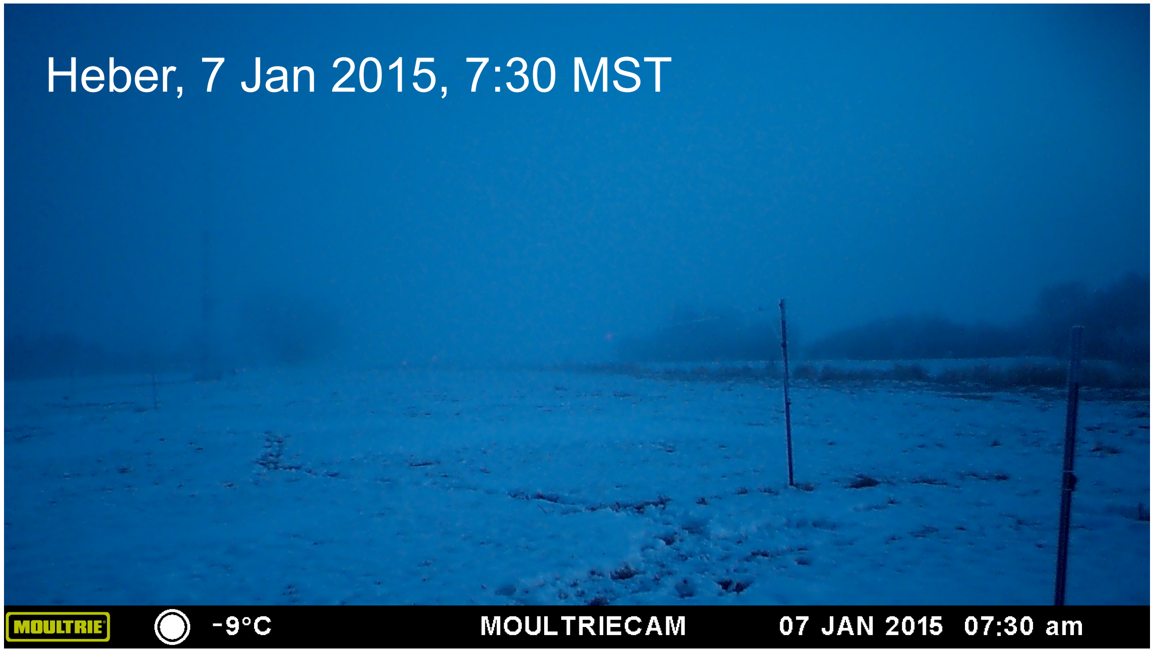


Heber, snow covered, some fog



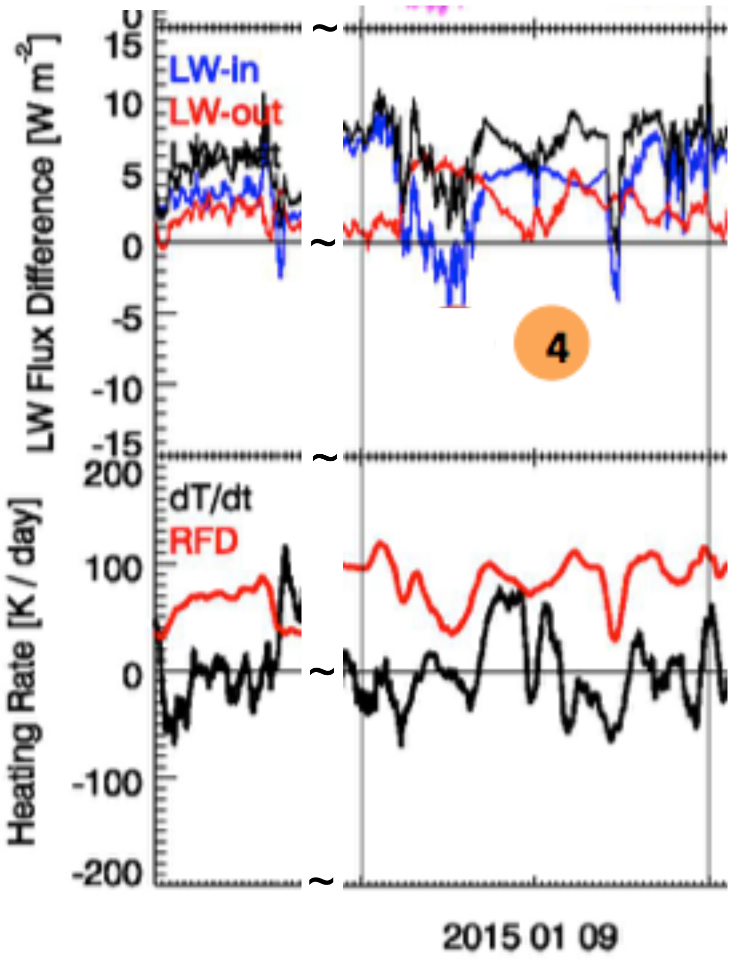
Initially, shallow fog leads to enhanced radiative cooling (Heber, 7 January). It is a strong divergence of the *downwelling* longwave flux that is responsible for the strong cooling.





Similar behavior has been reported in the Greenlandic Arctic (Hoch et al., 2007)

Deep, but thin fog/haze in cold air pools leads to a ***radiative warming*** dominated by the *convergence of the incoming longwave flux* (SLC, Jan 8 ~20:00 MST, Jan 9 ~13:00 MST)



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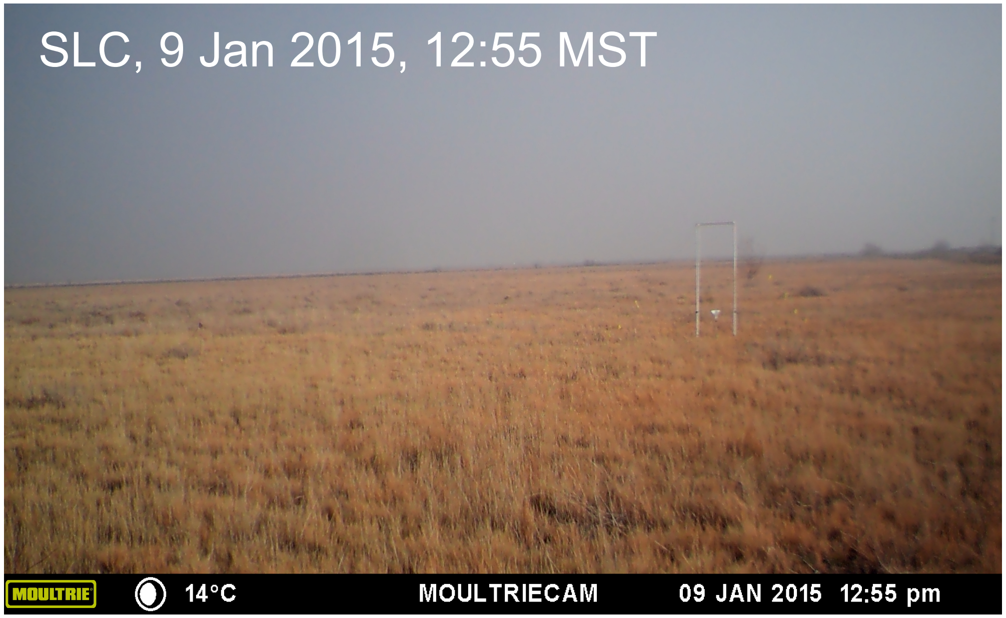
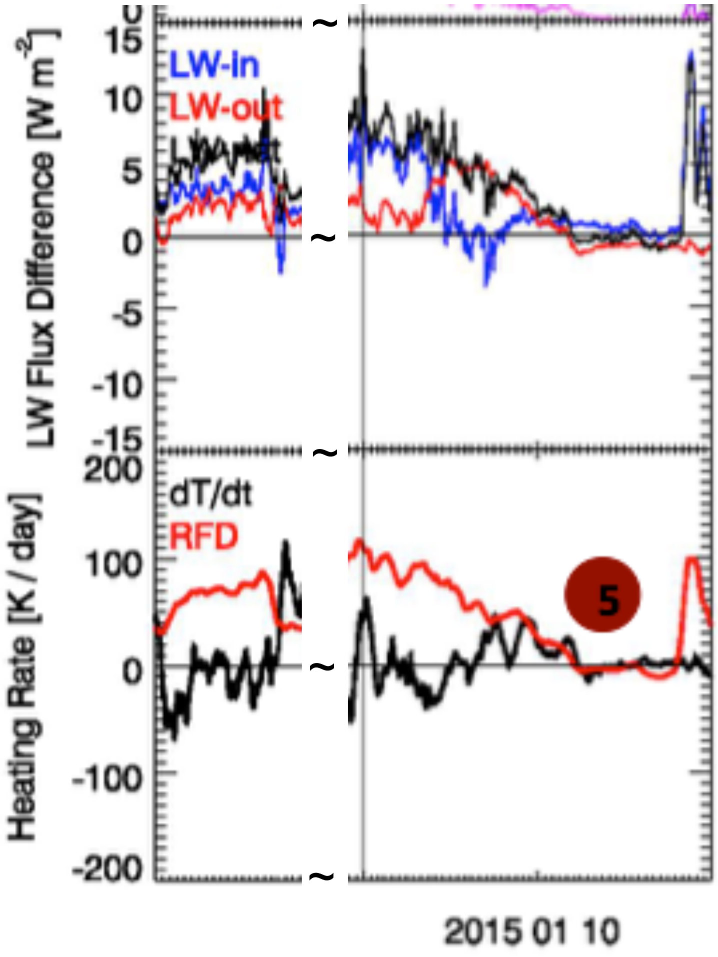


Very deep thick fog results in a ***zero radiative heating/cooling***.
(SLC, 9 January ~18:30 MST)



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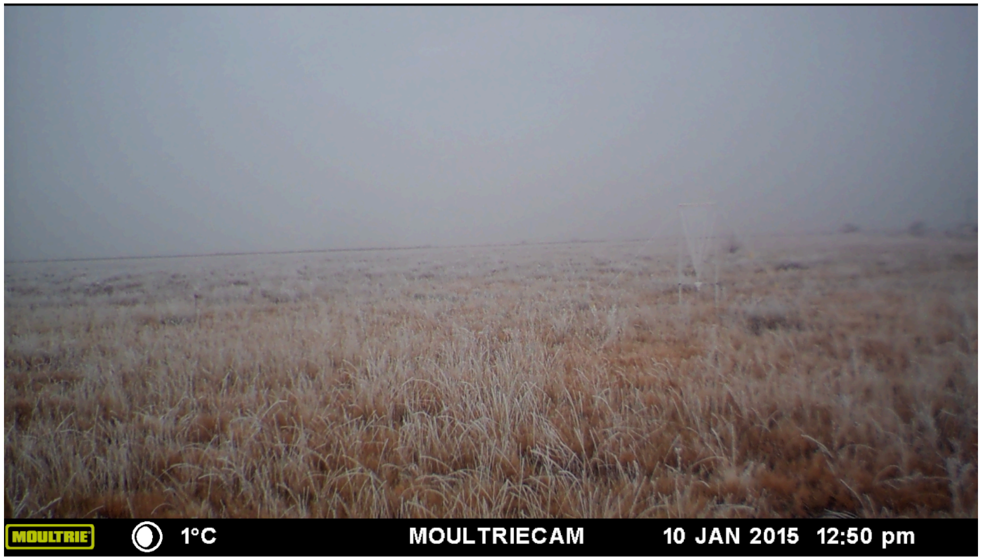

Future work

We presented preliminary and qualitative results highlighting the complex interaction between fog and radiative flux divergence.

A rich dataset is available from MATERHORN-FOG, for the first time combining direct observations of radiative flux divergence with detailed measurements of suspended hydrometeors (fog) and aerosols.

- Radiative transfer modeling
- Heat budget calculations (sensible heat flux divergence!)

Update – Manuela Lehner

Research Assistant Prof. UU

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SPECIAL
MATERHORN
COLLECTION

A Case Study of the Nocturnal Boundary Layer Evolution on a Slope at the Foot of a Desert Mountain

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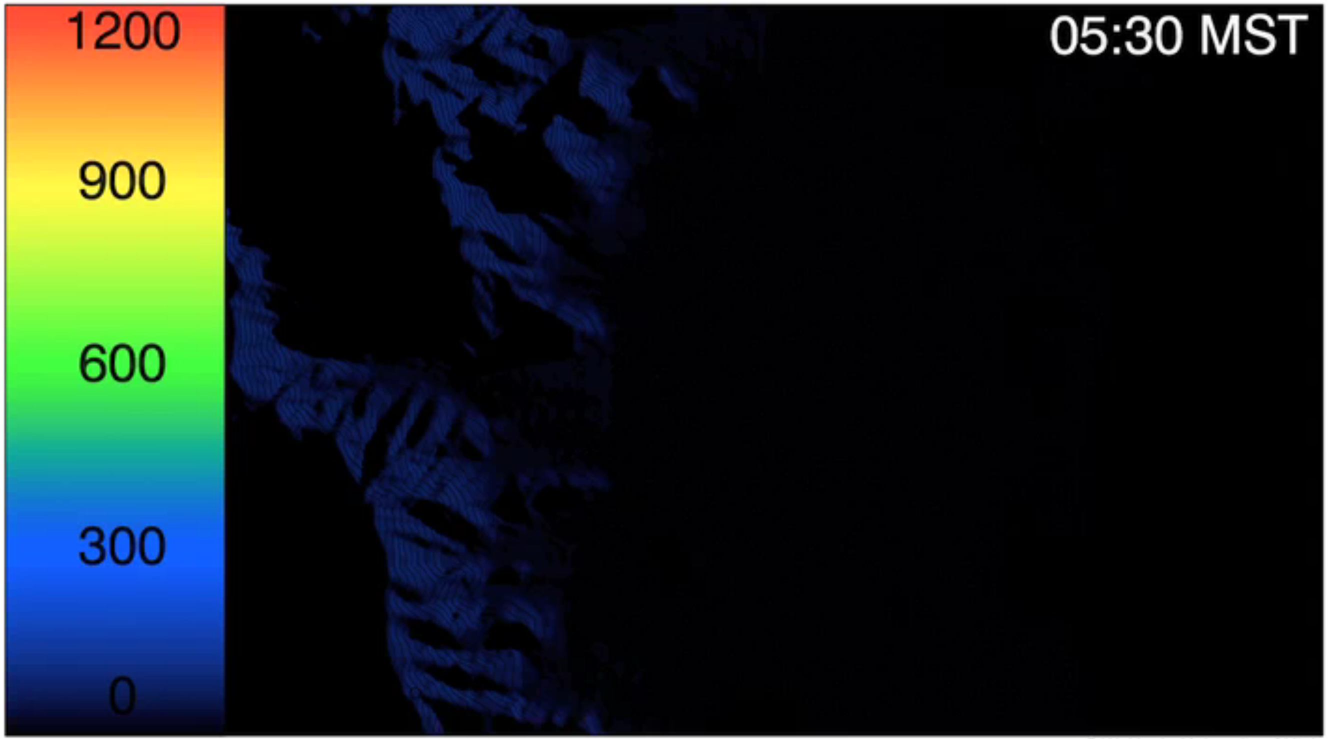
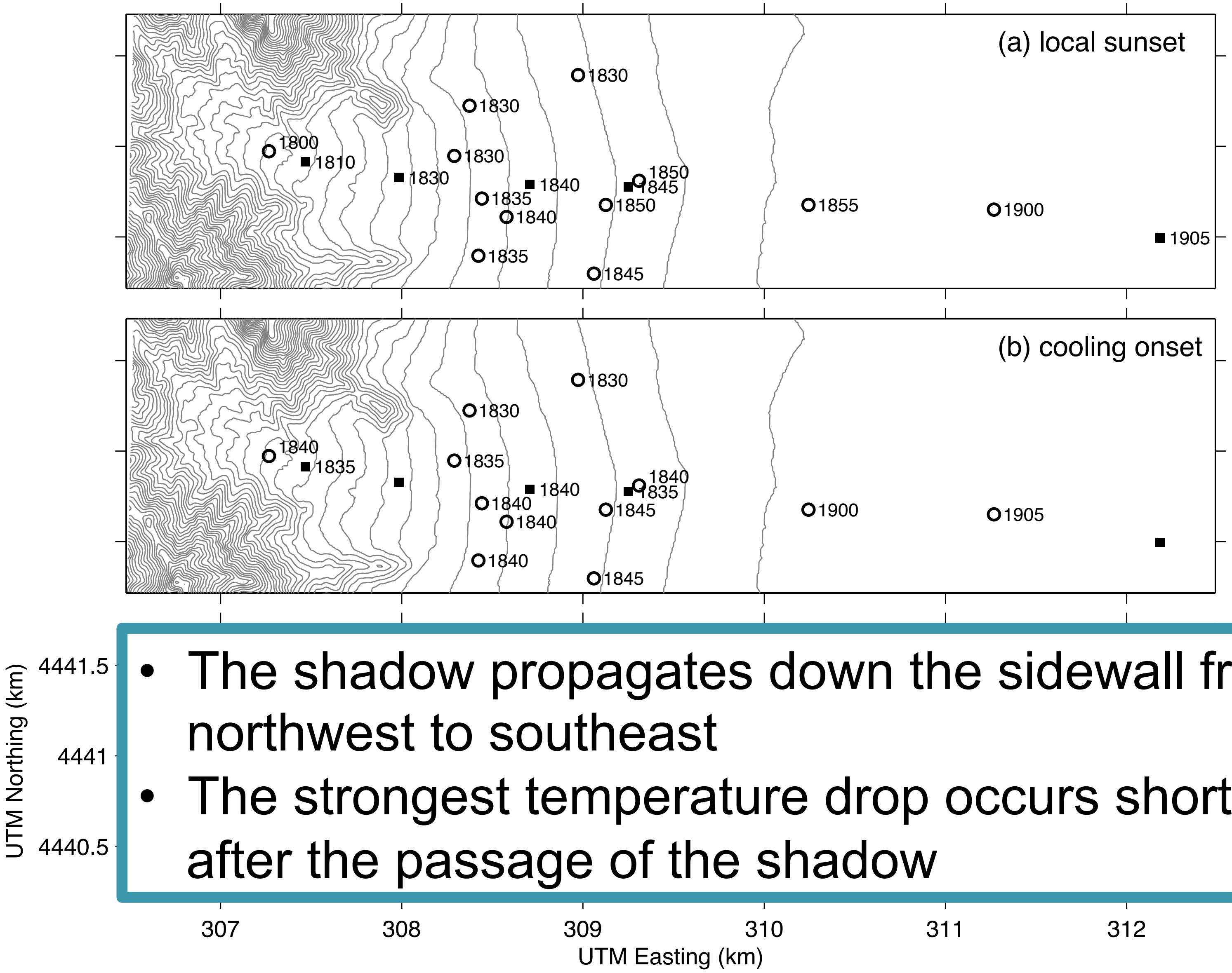
GLOBAL RADIATION, PARAMETERIZED, [W m^{-2}]



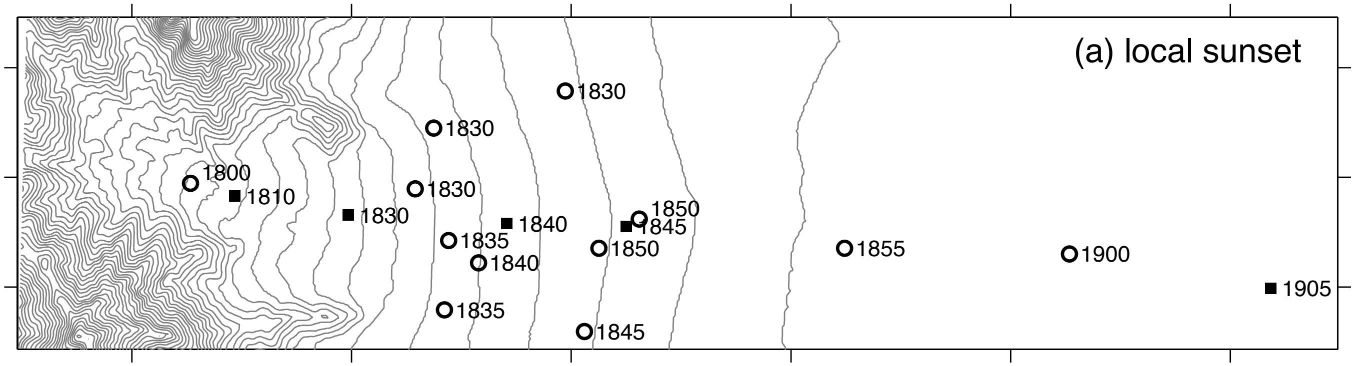
S.W. Hoch, University of Utah

Evening flow transition on the east slope (11/12 May 2013, IOP 4)

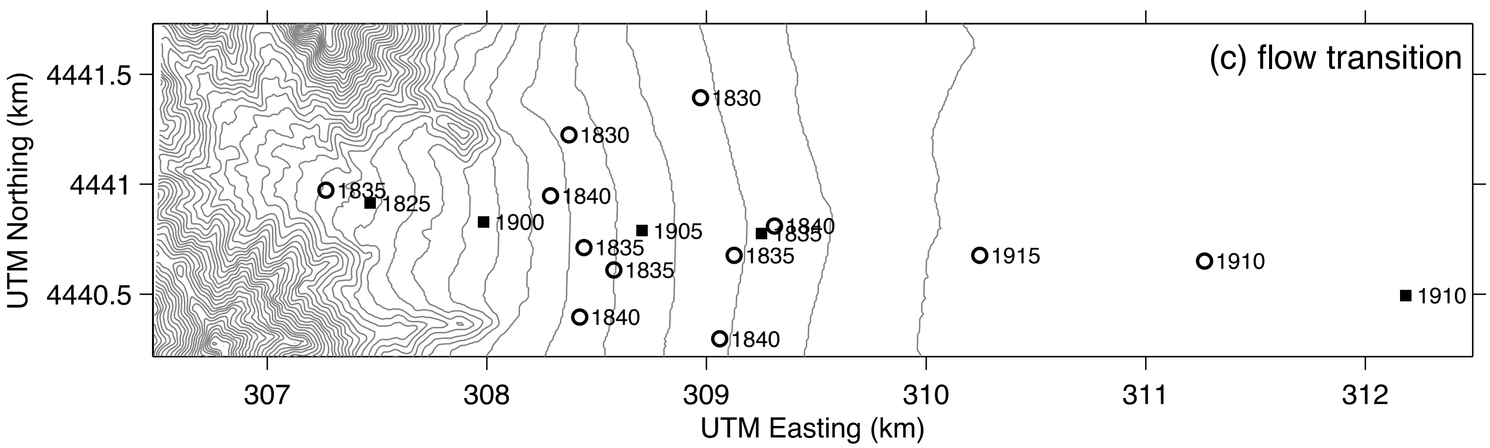


- The shadow propagates down the sidewall from northwest to southeast
- The strongest temperature drop occurs shortly after the passage of the shadow

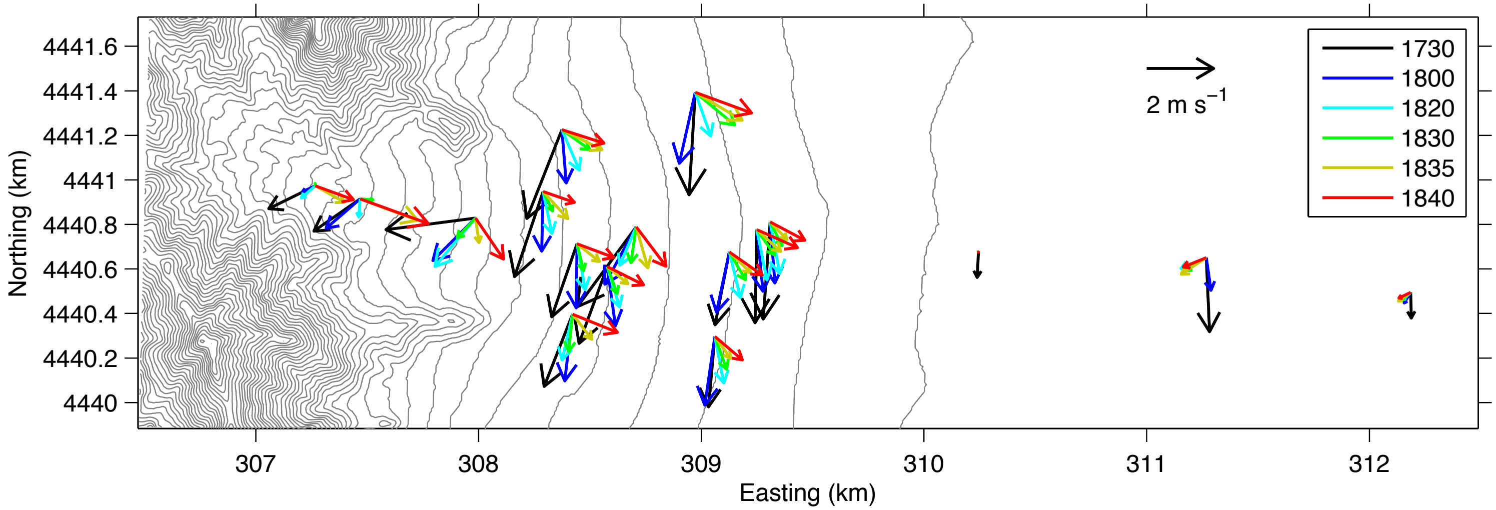
Evening flow transition on the east slope (11/12 May 2013, IOP 4)



- The transition from upslope to downslope flows follows the passage of the shadow down the slope



Evening flow transition on the east slope (11/12 May 2013, IOP 4)



- **Upper part of the slope:** Weakening and stagnation of the upslope flows before the onset and increase of downslope flows
- **Lower part of the slope:** Gradual counter-clockwise turning and weakening of the flow

Update – Matt Jeglum

PhD candidate UU

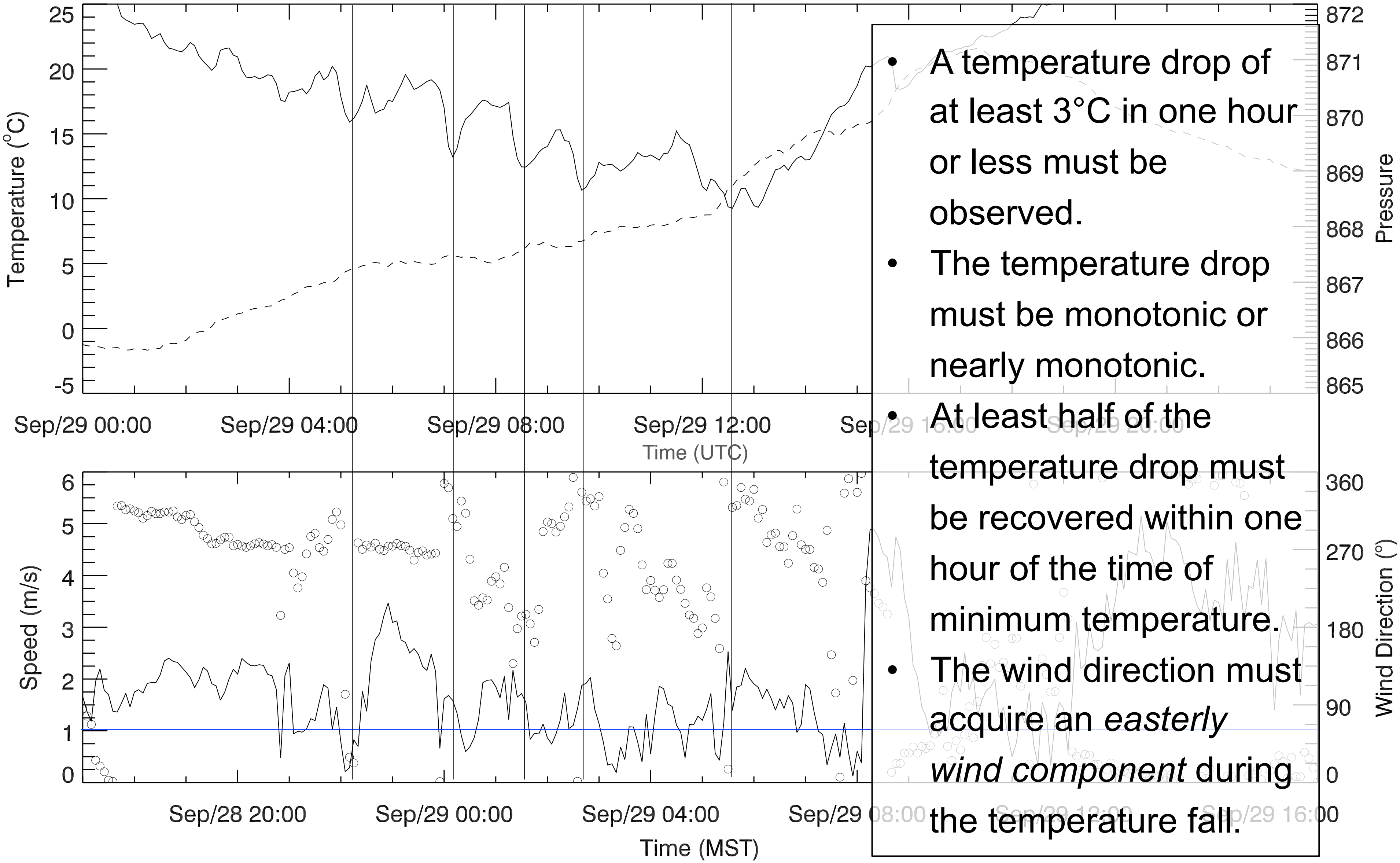
“Multiscale Forcings of Surface Winds in Complex Terrain”

Journal article to be submitted to JAMC

Cold-Pool displacements in the Dugway basin

AGU 2015

CAP Displacement Identification Criteria & Algorithm



- A temperature drop of at least 3°C in one hour or less must be observed.
- The temperature drop must be monotonic or nearly monotonic.
- At least half of the temperature drop must be recovered within one hour of the time of minimum temperature.
- The wind direction must acquire an *easterly wind component* during the temperature fall.

Meteogram from PWIDS 82 (middle of the east slope)

Some numbers from **PWIDS 82**…

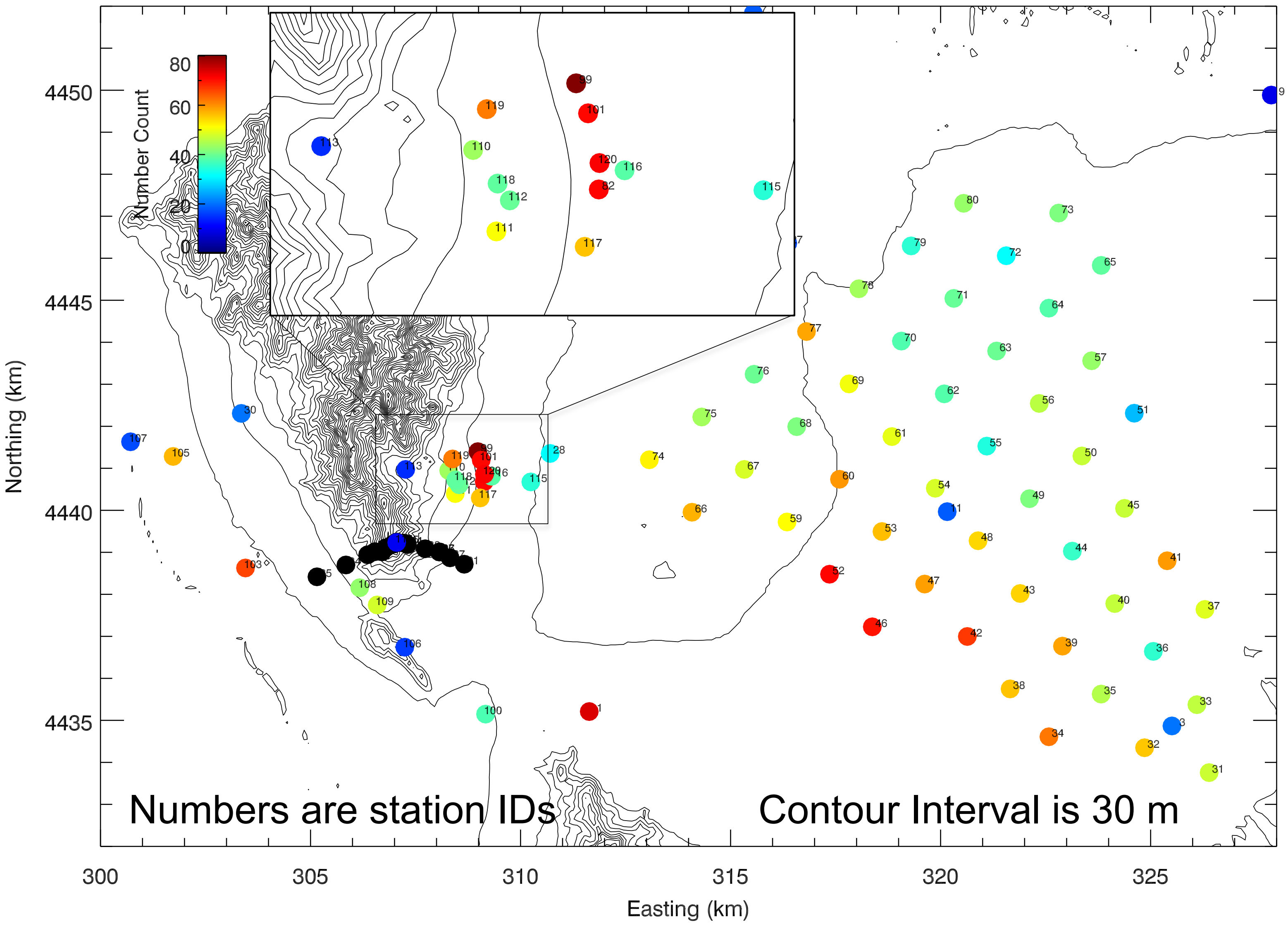
Different Criteria

ΔT (°C)?	Monotonic?	Recovery of 0.5ΔT?	Wind from east half?	Wind from east at least 1m/s?	Overall per day count
0.5	N	N	N	N	15
2	N	N	N	N	7.2
3	N	N	N	N	4.6
3	Y	N	N	N	3.4
3	Y	Y	N	N	2
3	Y	Y	Y	N	1.6
3	Y	Y	Y	Y	0.9

YELLOW ROW

- 63 total displacement events were observed.
- Average of 1.6 displacement events per night
- One displacement event on 29 of 40 nights (Fall campaign)
- Maximum: 5 per night.

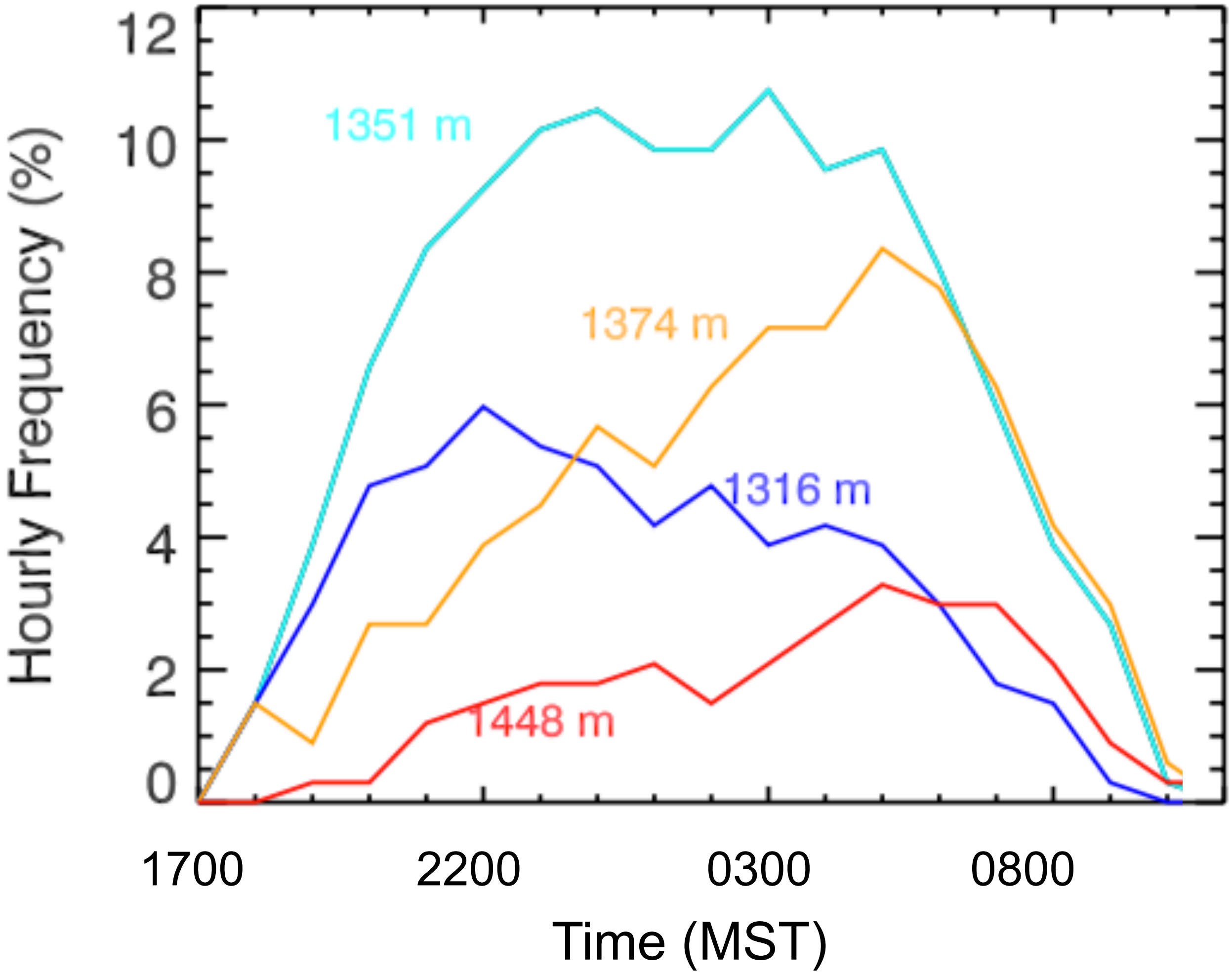
Standardized Number Count of Displacement Events– Fall Campaign



Numbers are station IDs

Contour Interval is 30 m

Hourly Distribution of CAP Displacement Events – Fall Campaign



- Flow interactions with Granite Peak appear to influence the advection processes that lead to cold pool displacements in the Dugway Basin.
- Cold Pool Displacements are relatively common on days that would be called “transitional”, i.e. when synoptic forcing is relatively strong but variable in time and strength.
- Advection of cold air eastward and southward, advection of warm air northward and westward or turbulent mixing in the vertical all appear to be important during displacements.
- Composite data of cold air displacements point to east-west displacements early in the night, and north-south displacements later in the night.
- No cold air displacements are observed when winds are strong all night (> 10 m/s) or under significant cloud cover with precipitation. (No cold pools form.)

Work is ongoing – focusing on processes forcing the displacements. An update will be given by Matt at AGU.

Acknowledgements

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- All MATERHORN participants and volunteers!