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

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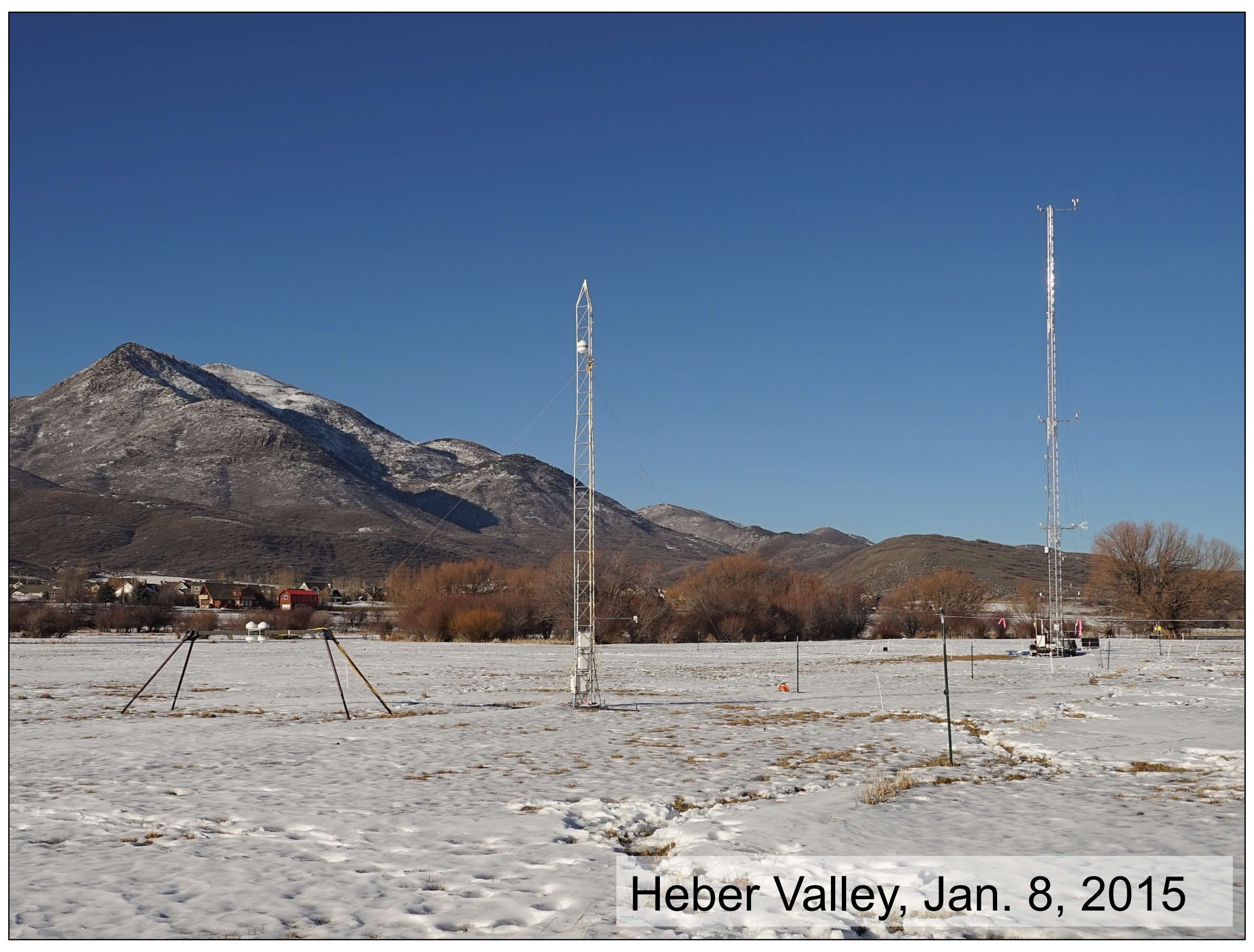
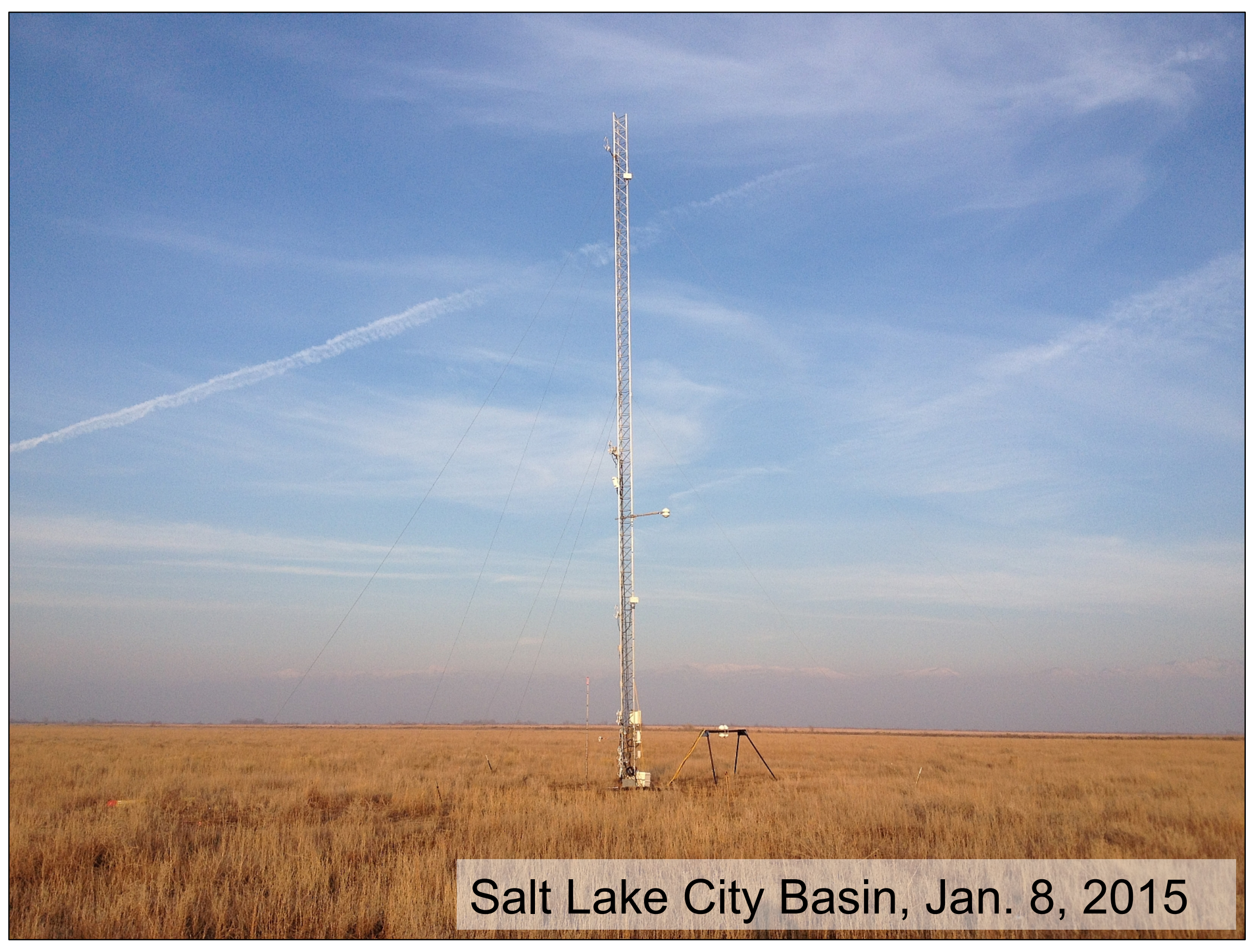
Introduction

The radiative heat exchange in the lowest atmospheric layers leads to "clear-air" radiative heating and cooling. During the third field campaign of the Mountain Terrain Atmospheric Modeling and Observations Program (MATERHORN), the contribution of the longwave radiative heating rate to the overall temperature tendency was directly measured in the near-surface layer between 2 and ~8 m above ground. Measurements were conducted at two sites: in the high alpine Heber Valley (1697 m MSL) and in the broad Salt Lake City (SLC) Basin (1289 m MSL).



Heber Valley, Jan. 8, 2015

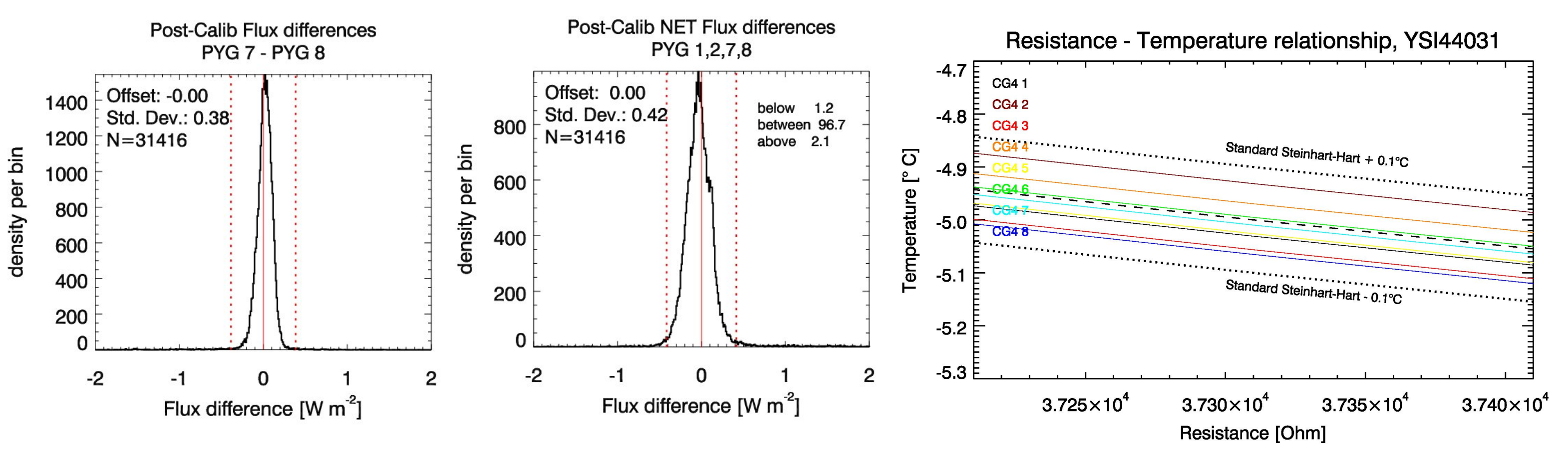


Salt Lake City Basin, Jan. 8, 2015

Relative Calibration

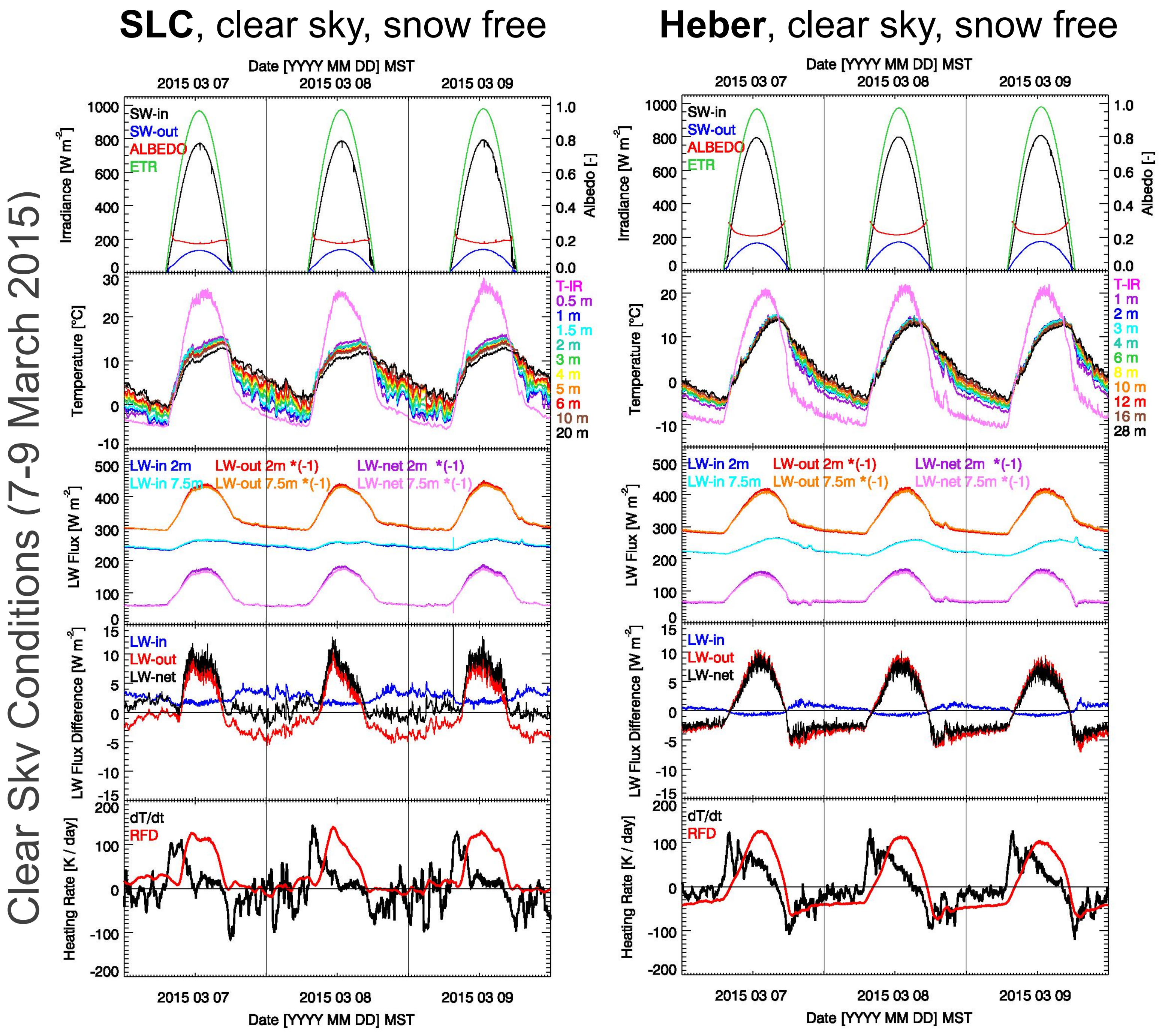
Kipp and Zonen CGR4 pyrgeometers were carefully calibrated at the SLC field site prior to deployment on meteorological masts. The *relative calibration* involves a regression allowing the calibration coefficient of the instruments and the thermistor coefficients to vary within their uncertainty ranges. It yielded an agreement of individual sensor pairs to between ±0.15 W m^{-2} and ±0.59 W m^{-2}. The uncertainties in the radiative heating rates determined for the bulk layer between the two measurement levels were below 7 K day^{-1} or 0.3 K hr^{-1}.

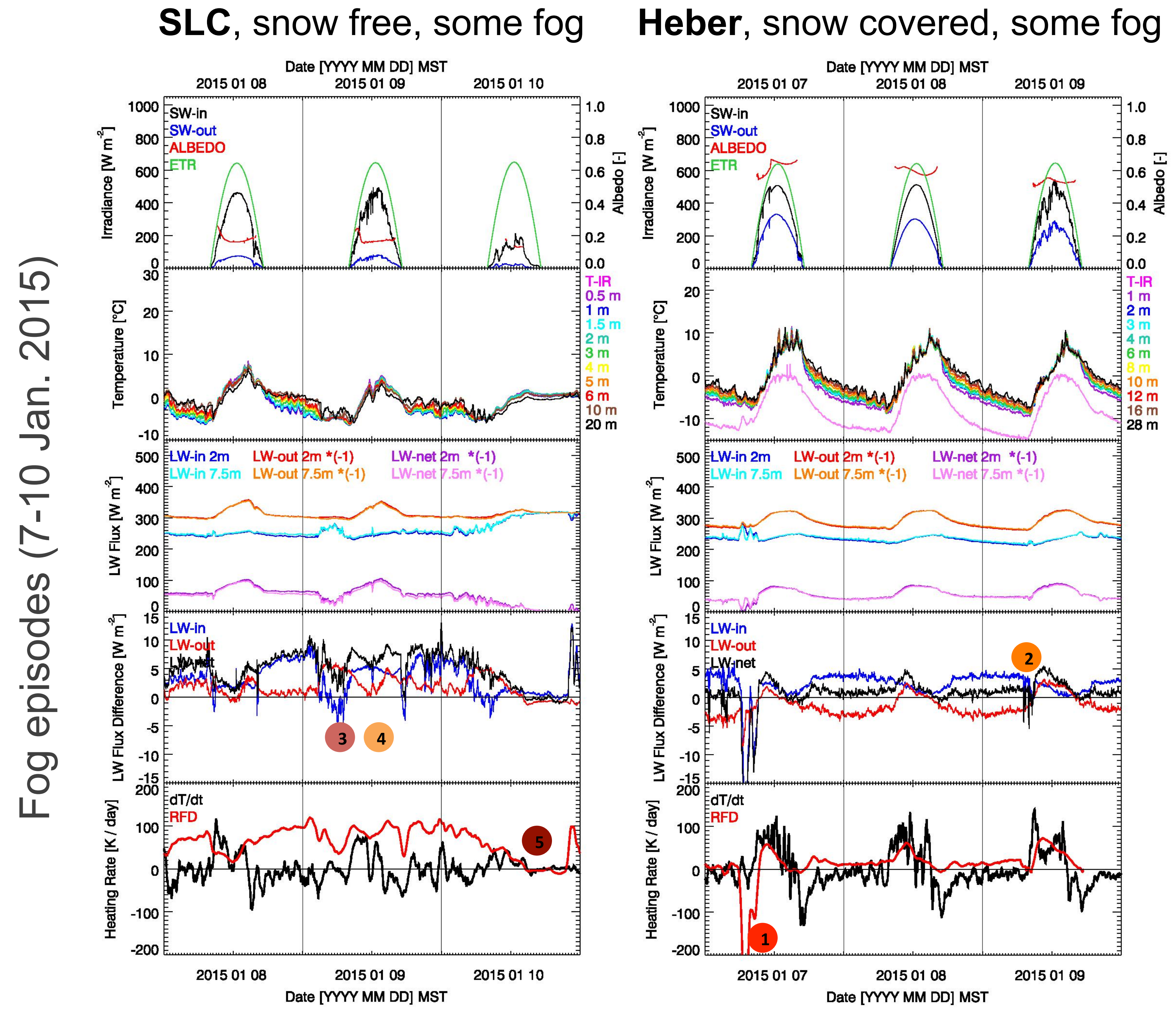
Uncertainties	SLC	Heber
LW in	± 0.38 W m^{-2}	± 0.59 W m^{-2}
LW out	± 0.15 W m^{-2}	± 0.18 W m^{-2}
LW net	± 0.42 W m^{-2}	± 0.61 W m^{-2}
Radiative Heating Rate	± 5.5 K day^{-1}	± 6.5 K day^{-1}

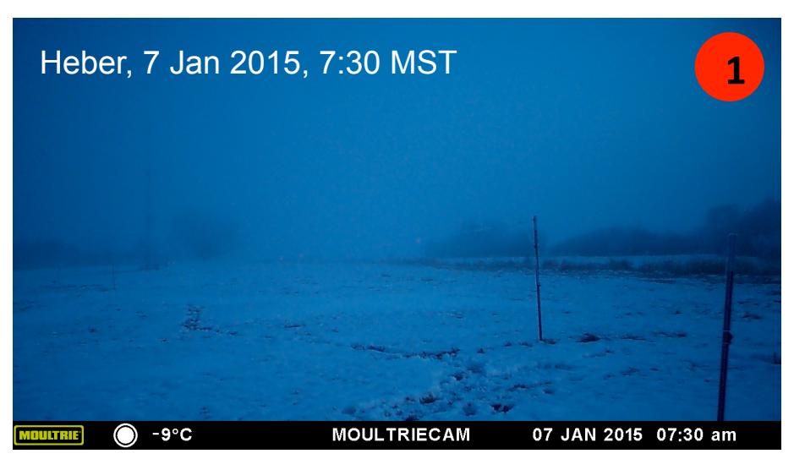


Data examples

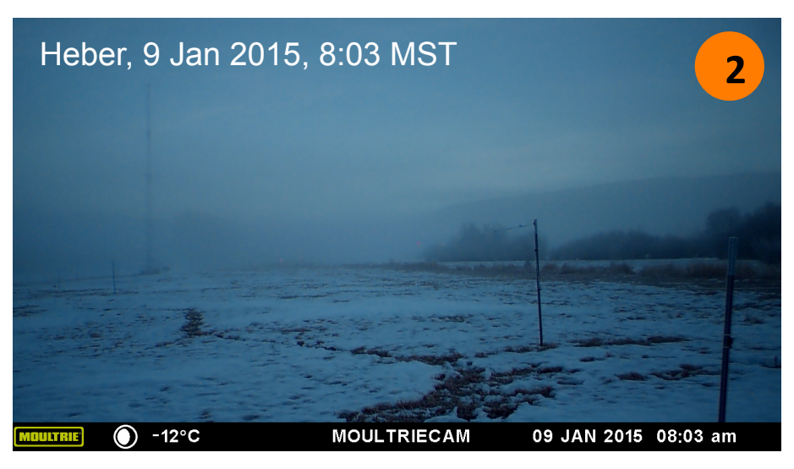
Time series of short- and longwave, in- and outgoing radiative fluxes, top-of-atmosphere radiation (ETR), albedo, temperatures, and inferred radiative heating rates are shown for a selected 3-day period of clear skies in March, and for 3-day periods in early January when fog formed at both the Salt Lake Basin and Heber Valley sites.



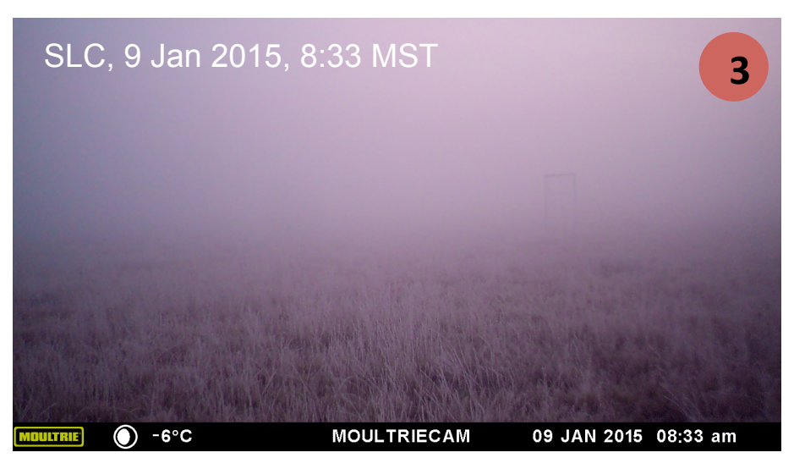




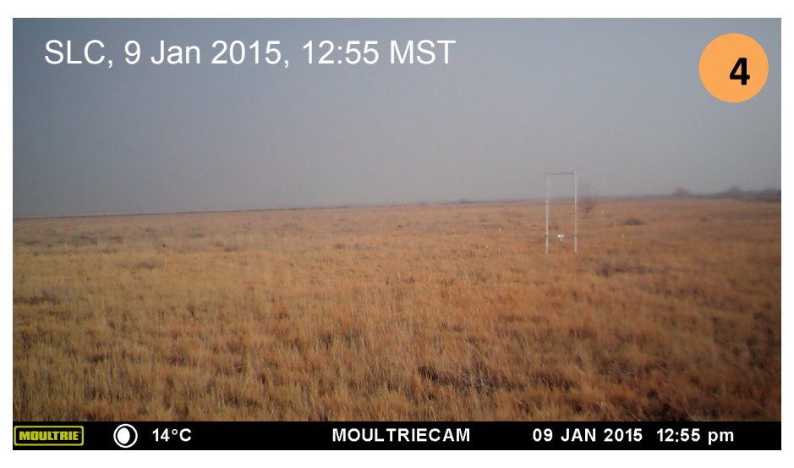
Heber, 7 Jan 2015, 7:30 MST ①



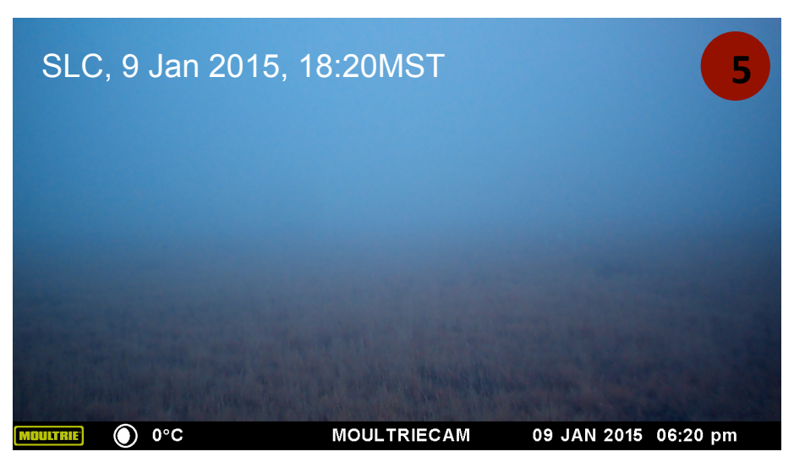
Heber, 9 Jan 2015, 8:03 MST ②



SLC, 9 Jan 2015, 8:33 MST ③



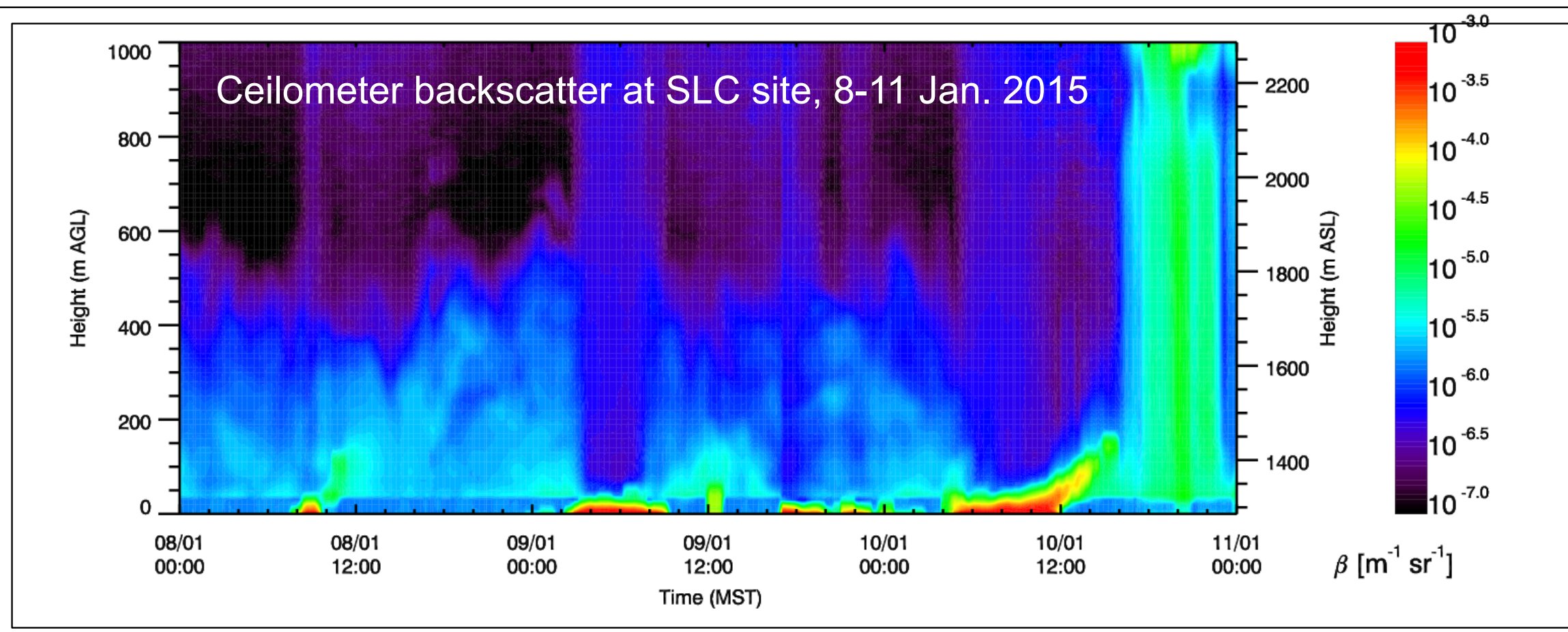
SLC, 9 Jan 2015, 12:55 MST ④



SLC, 9 Jan 2015, 18:20MST ⑤

Initial Results

- 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.
- When **fog** droplets are introduced in the surface layer, radiative energy exchange changes dramatically. Initially, shallow fog leads to enhanced radiative cooling (Heber, 7 Jan. ①); persistent deep, but thin fog/haze in cold air pools leads to a radiative warming dominated by the convergence of the incoming flux (SLC, Jan 8 ~20:00 MST, Jan 9 ~13:00 MST④); very deep thick fog results in a zero radiative heating/cooling (SLC, 9 Jan ~18:30 MST ⑤).

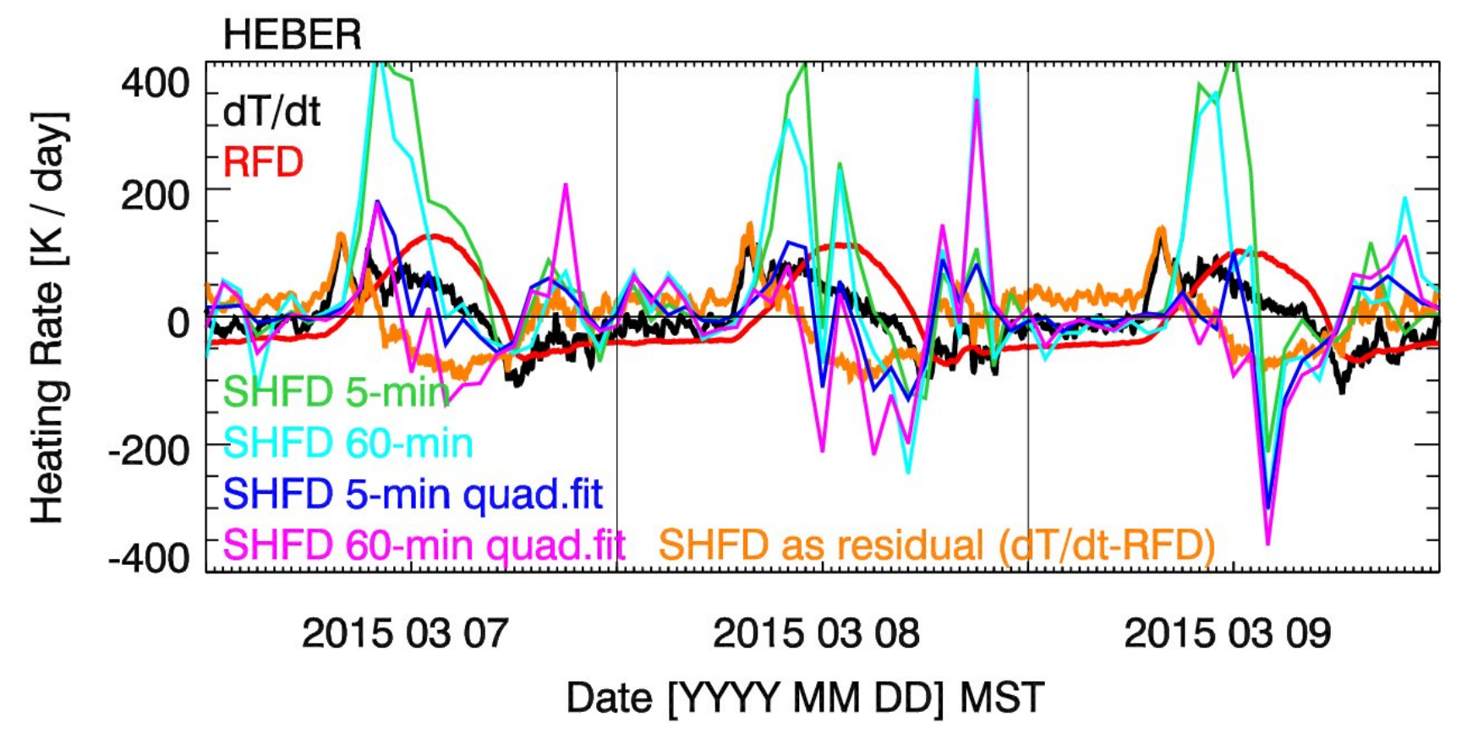


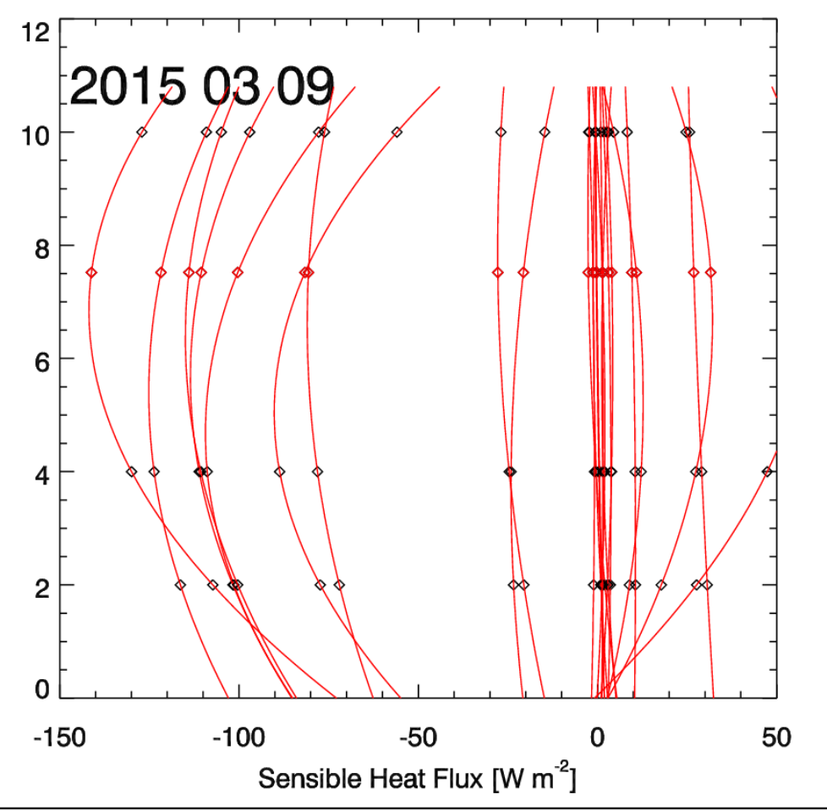
Heat budget calculations

Future work will involve estimating the other terms in the heat budget besides the radiative flux divergence (*RFD*) term:

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

Especially the derivation of ***sensible heat flux divergence*** *(SHFD)* is of interest. Key questions relative to the SHFD calculation methodology include averaging times for flux calculations, interpolation of fluxes to different levels, etc.





Radiative Transfer Modeling

Spectrally-resolved radiative transfer modeling using observed temperature and humidity profiles and measured aerosol concentrations and size distributions will be necessary to fully understand the radiative energy exchange.

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