The surface energy budget and the influence of clouds at Summit Greenland

Arctic Observing Open Science Meeting

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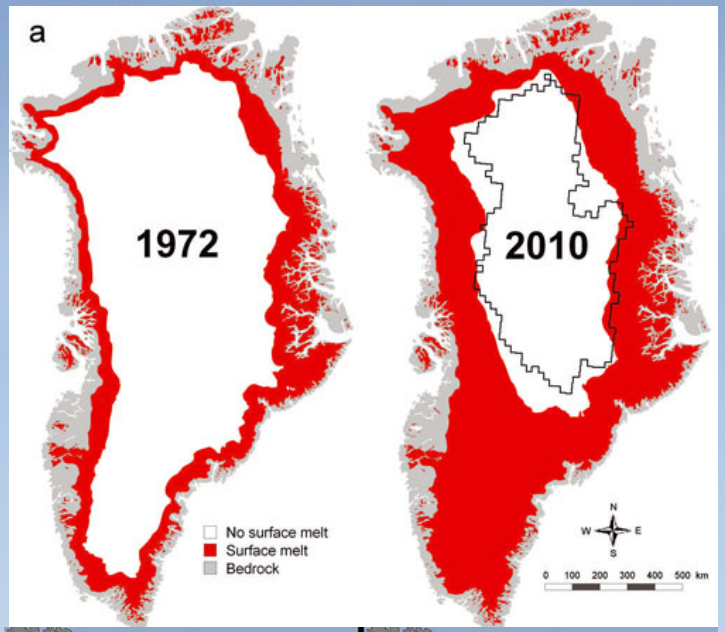
CIRES
Cooperative Institute for Research in Environmental Sciences

University of Colorado Boulder

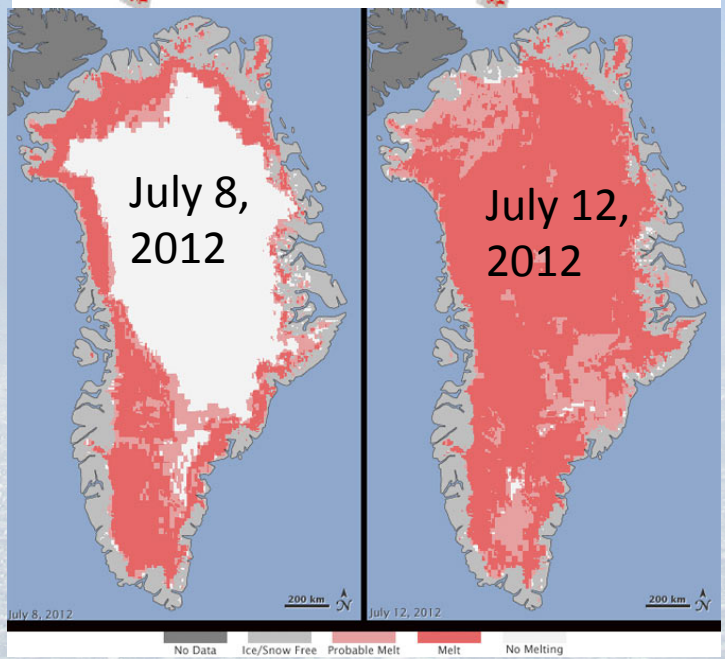
Greenland Ice Sheet

The GIS is over 3.2 km deep at Summit Station



Observed and simulated increases in melt extent impacts fresh water input to regional seas and has implications for global sea level rise.

Mernild et. al. 2011, J. Glac

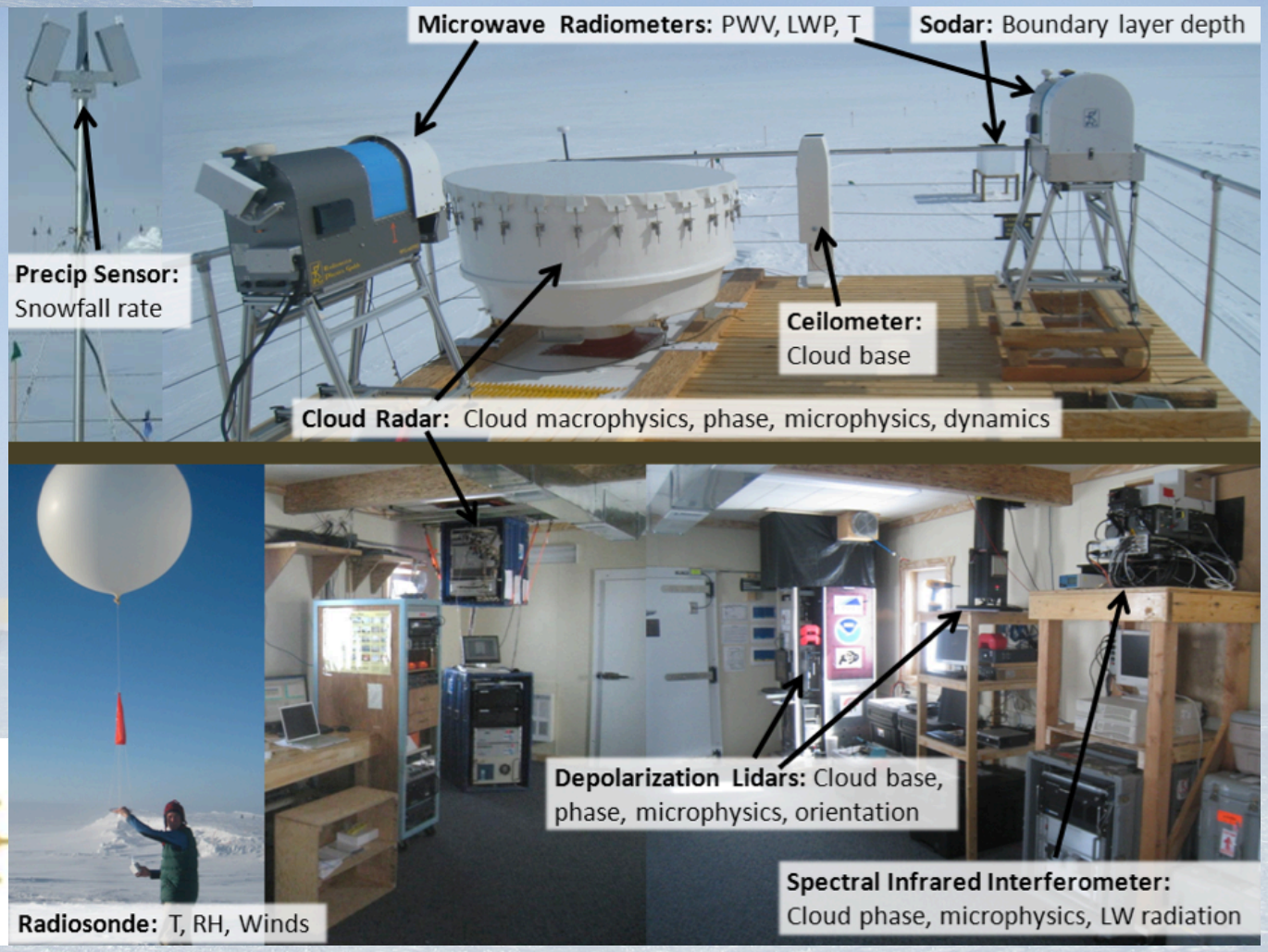


For surface temperatures close to 0°C a small change in the surface energy budget can have substantial implications for the melt extent of the GIS.

http://www.nasa.gov/topics/earth/features/greenland-melt.html

ICECAPS

Atmospheric State and Cloud Properties



Shupe et. al. 2013, BAMS

$$SEB = SW_{down} - SW_{up} + LW_{down} - LW_{up} + H_{sensible} + H_{latent} + G_{conductive}$$

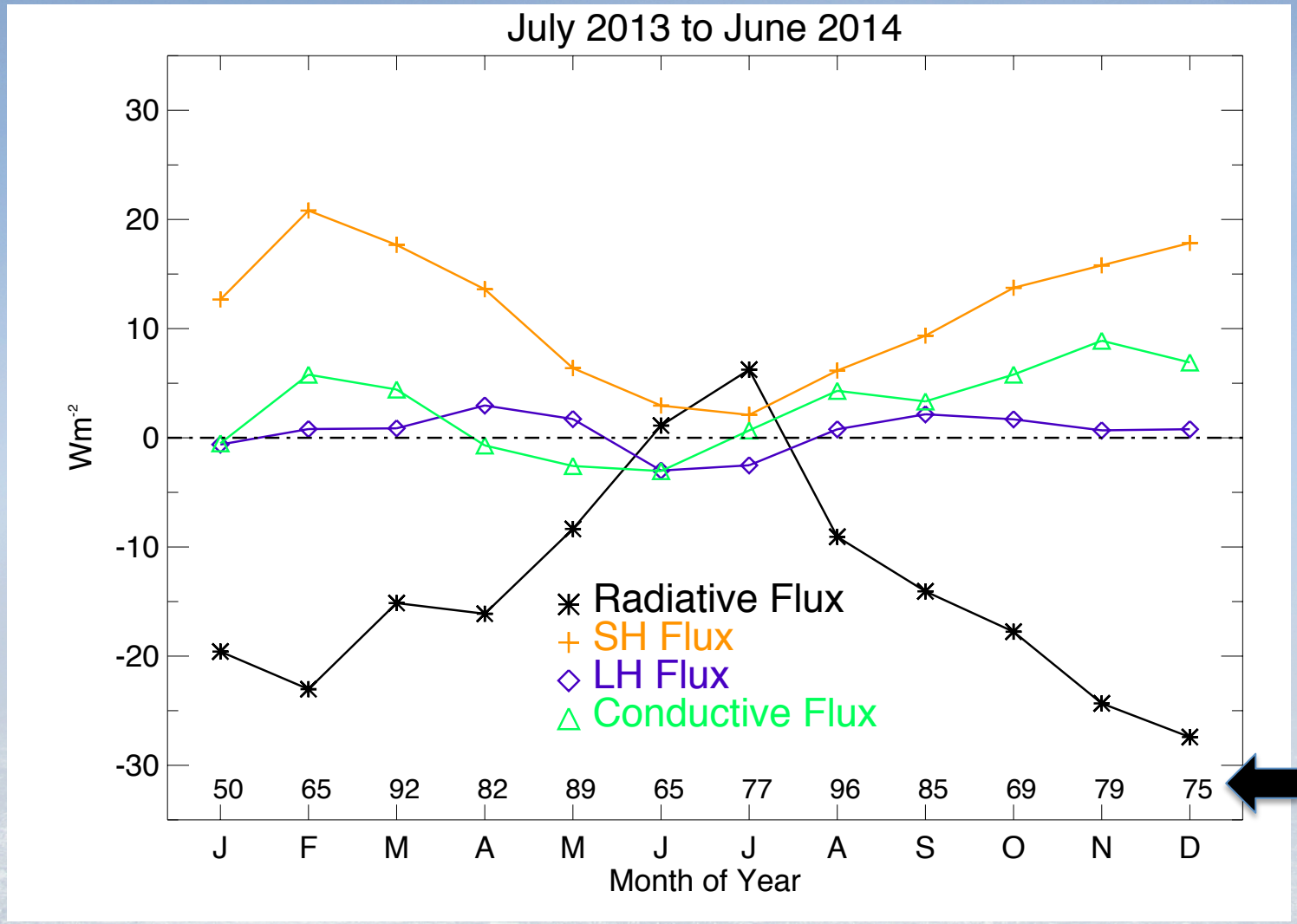
All components available for 1 year

July 2013 – June 2014

- Broadband Radiation - Swiss Federal Institute (ETH)
- Sensible heat Flux - Bulk Aerodynamic method (Persson et. al. 2002, JGR)
- Latent Heat Flux - Gradient 2-level method
- Conductive Heat Flux - Thermistor String

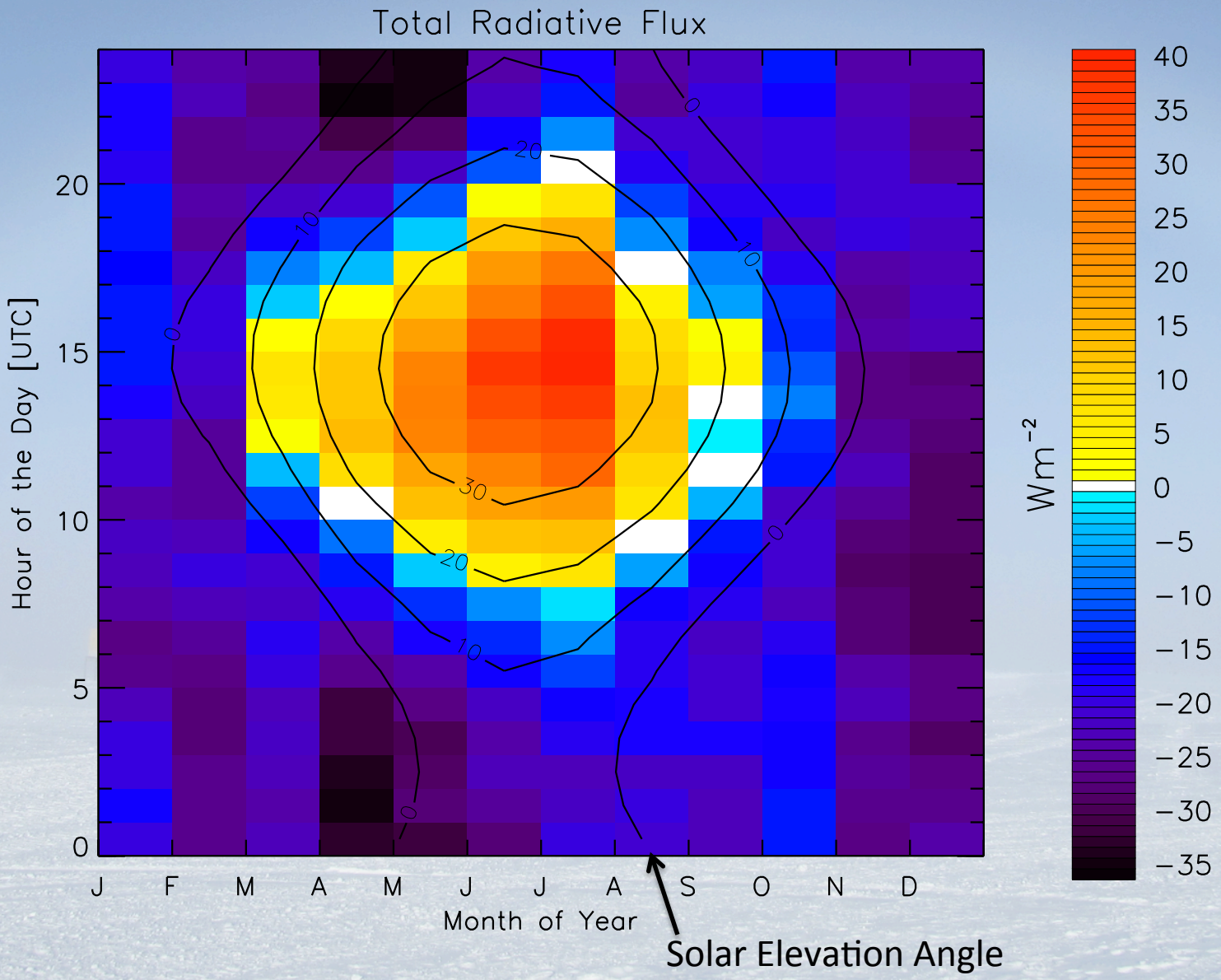
Define a positive flux as warming the surface

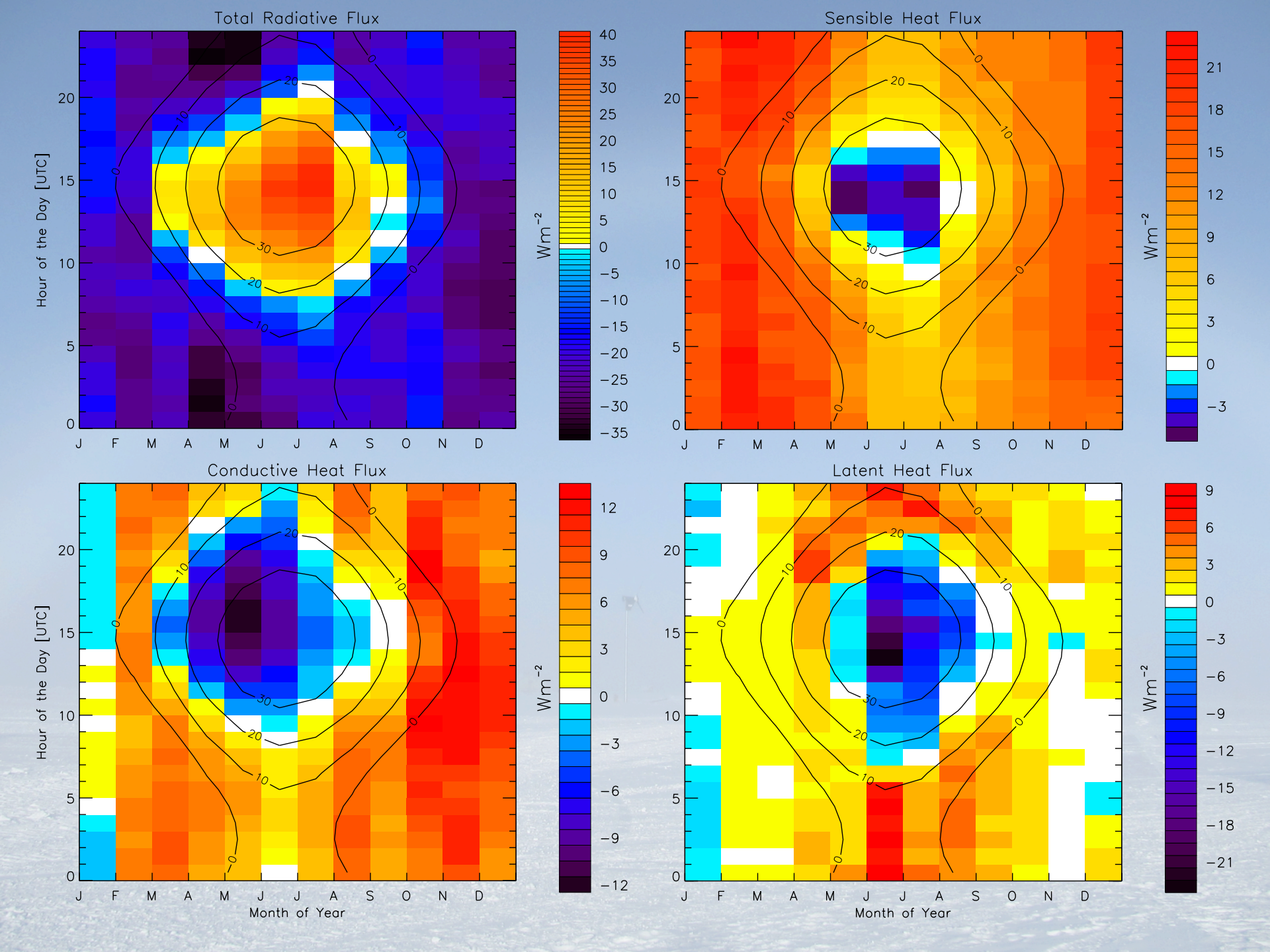
Monthly Mean SEB values



Percentage of all available 30 min data for a given month

Diurnal Cycle




Total Radiative Flux
Sensible Heat Flux
Conductive Heat Flux
Latent Heat Flux
Hour of the Day [UTC]
Month of Year
J F M A M J J A S O N D
Wm^{-2}

How do clouds effect the SEB?

Primarily through influencing the downwelling radiation.

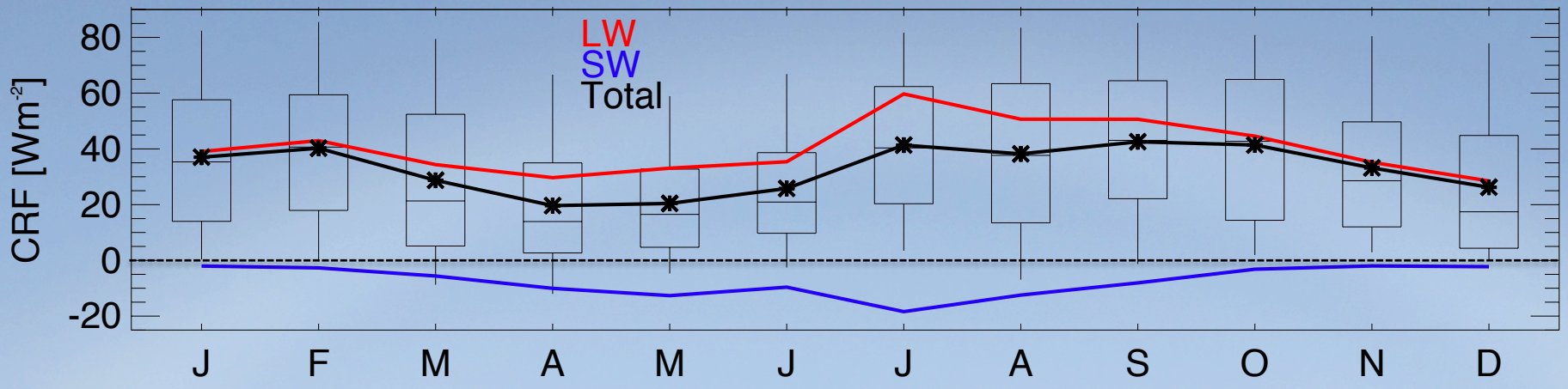
Cloud radiative forcing (CRF) is an estimation of a cloud's impact on the radiative flux at the surface.

$$CRF = Flux_{\text{all-sky, measured}} - Flux_{\text{clear-sky, modeled}}$$

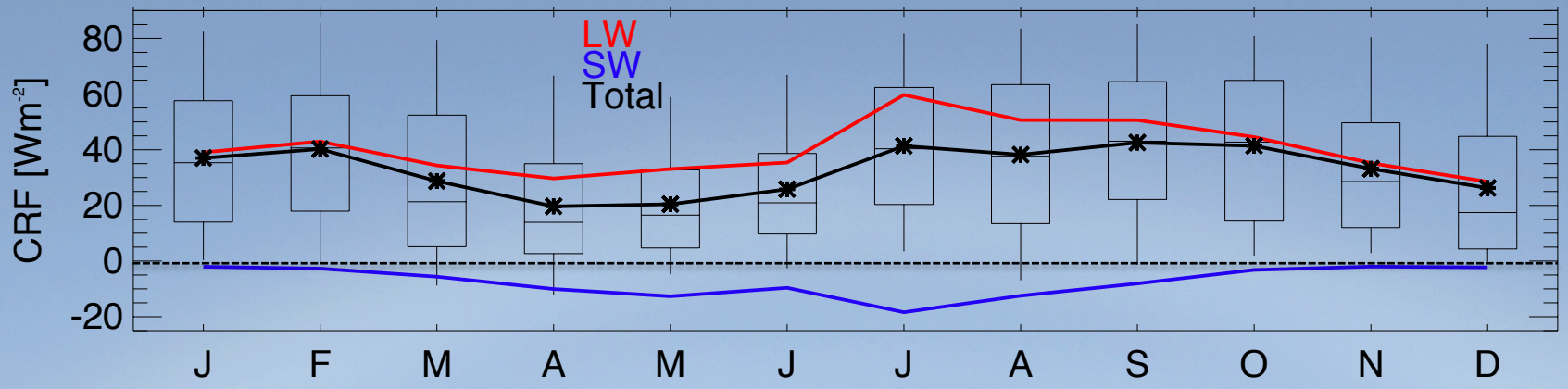
Best estimate atmospheric profiles

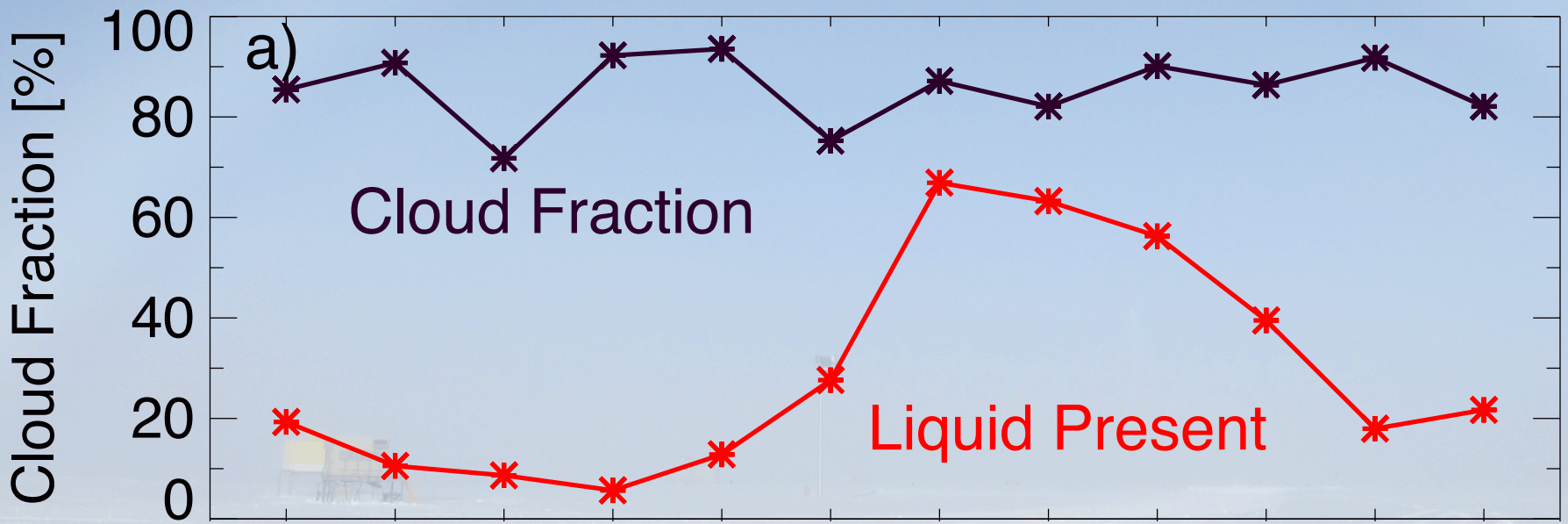
→ Rapid Radiative Transfer Model (RRTM)

January 2011 – October 2013 (Miller et. al. 2015, J. Climate)

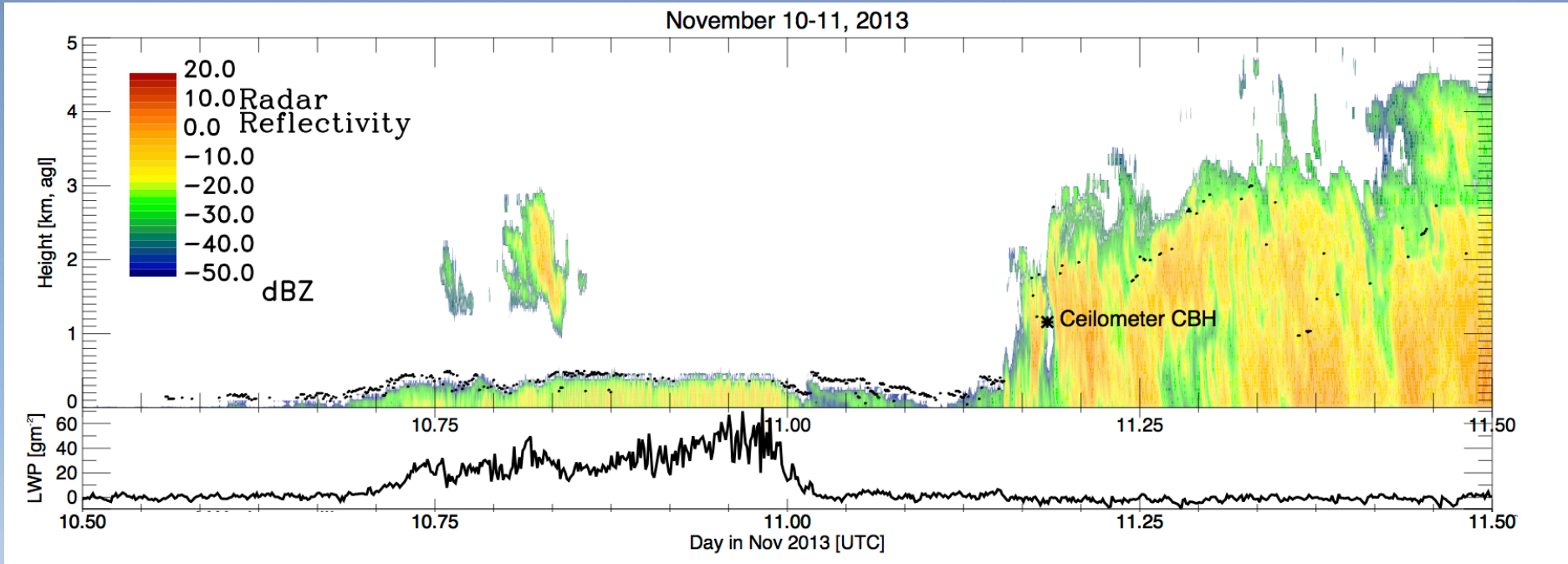


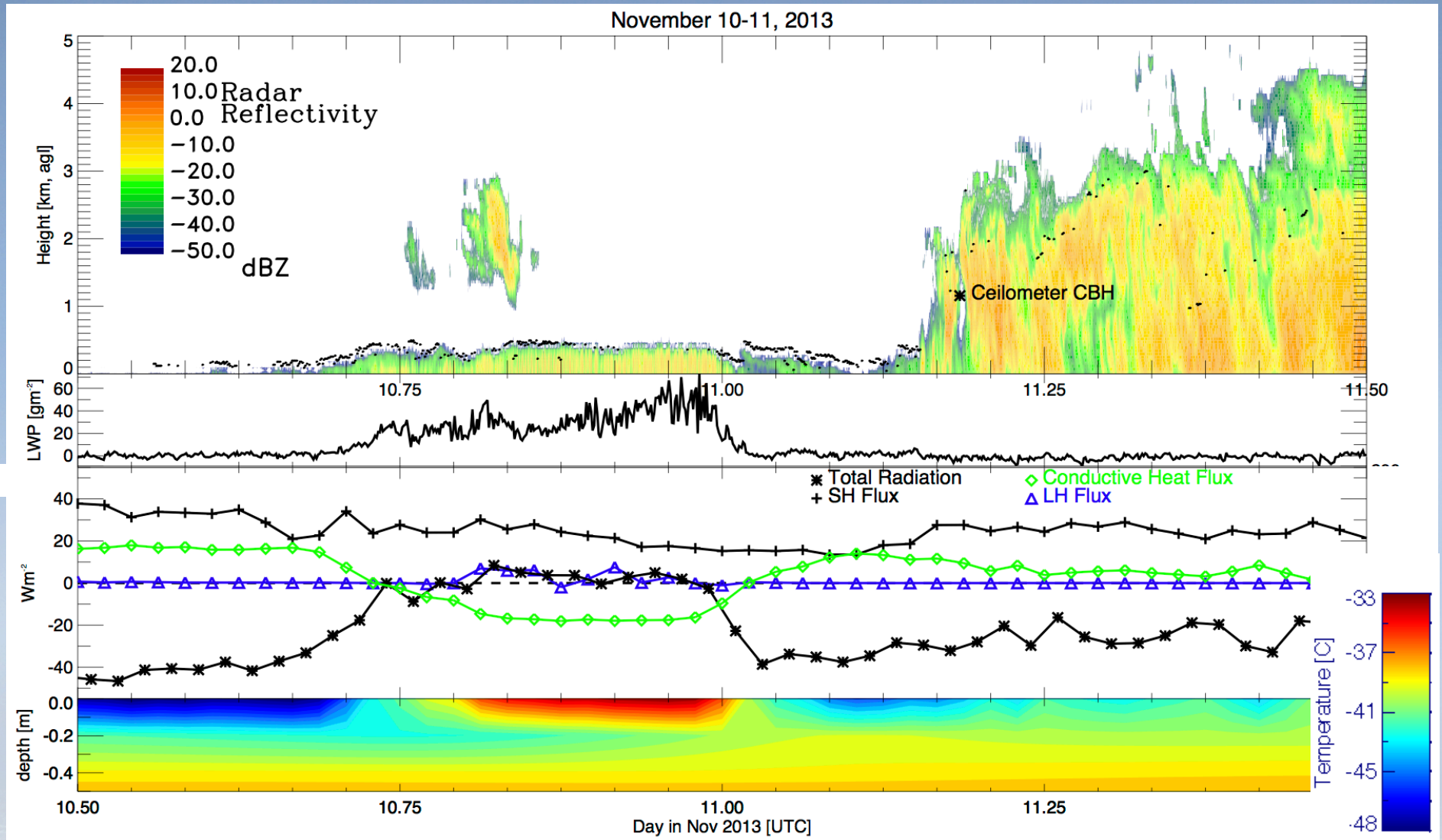
- Clouds act to radiatively warm the surface throughout the year
  - due to high surface albedo throughout the year





- Clouds are common at Summit. The annual average cloud fraction is 86%.
  - Ice-clouds are important to CRF
- LW CRF magnitude corresponds to the presence of liquid-bearing clouds


November 10-11, 2013
Radar Reflectivity
20.0
10.0
0.0
−10.0
−20.0
−30.0
−40.0
−50.0
dBZ
Height [km, agl]
Ceilometer CBH
LWP [gm-2]
10.50
10.75
11.00
11.25
11.50
Day in Nov 2013 [UTC]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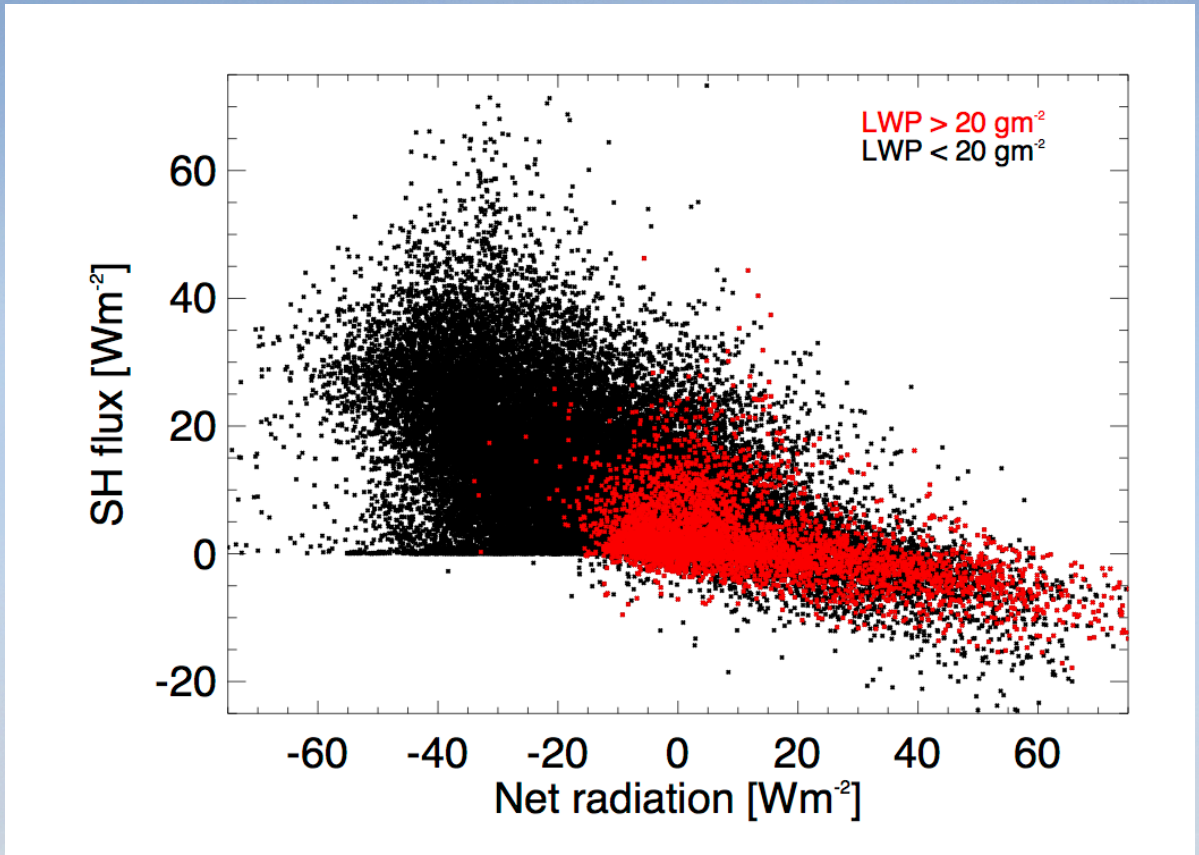
Response to Radiative Warming



For a 10 Wm^2 increase in net radiation

~ 3 Wm^2 decrease in Sensible Heat Flux

Summary

- Clouds act to warm the surface of central Greenland
  - Presence of liquid-bearing clouds control the magnitude
- An increase in Net Radiation leads to:
  - Cooling response of the sensible heat flux
  - Cooling response of the conductive heat flux
- A net positive total cloud forcing warms the surface, propagating heat into the Greenland Ice Sheet
  - or this energy contributes to melting snow/ice

Thank you

- This research is supported by the National Science Foundation under grants PLR1303879 and PLR1314156.

- The Swiss Federal Institute (ETH) provided the ETH broadband radiometer measurements.

- Additional broadband radiation measurements, ozonesonde soundings, CO_2 measurements, and near- surface meteorological tower data are provided by the National Oceanic and Atmospheric Administration's Global Monitoring Division.

- Thanks to Polar Field Services and the various science technicians for their excellent support of the field experiments at Summit Station.

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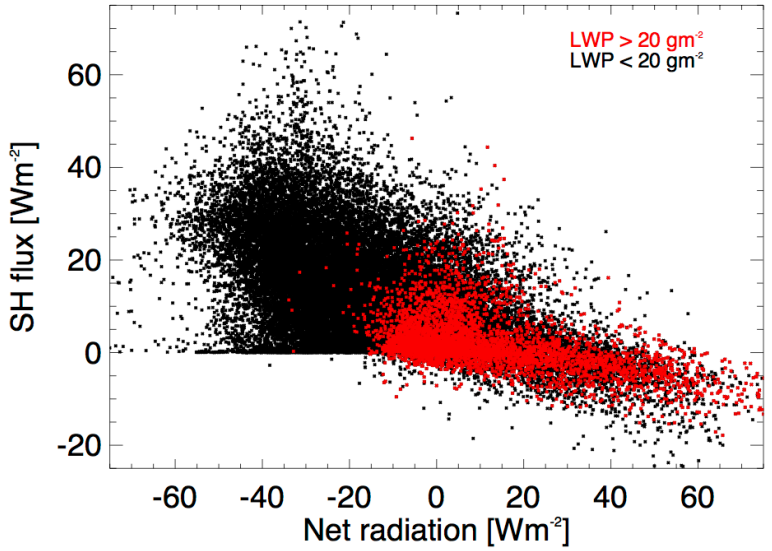

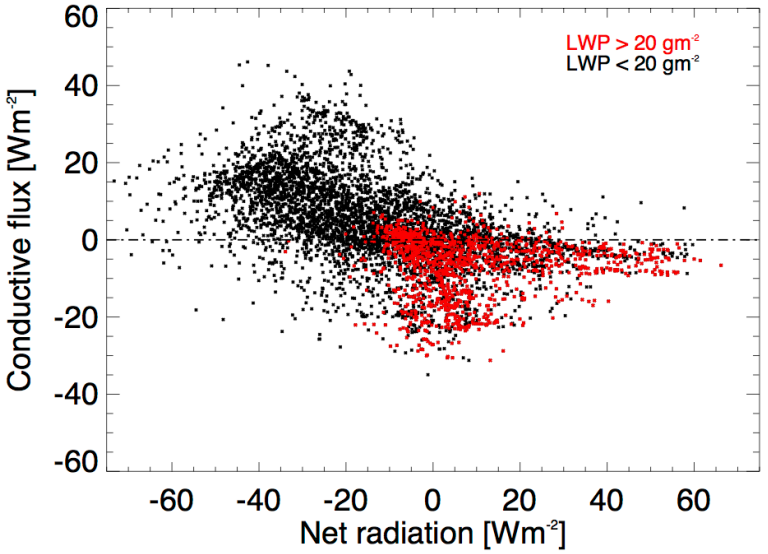

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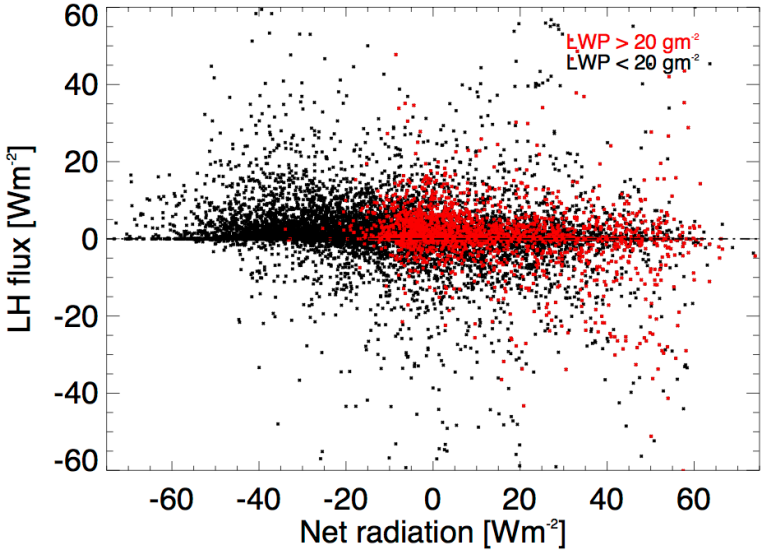

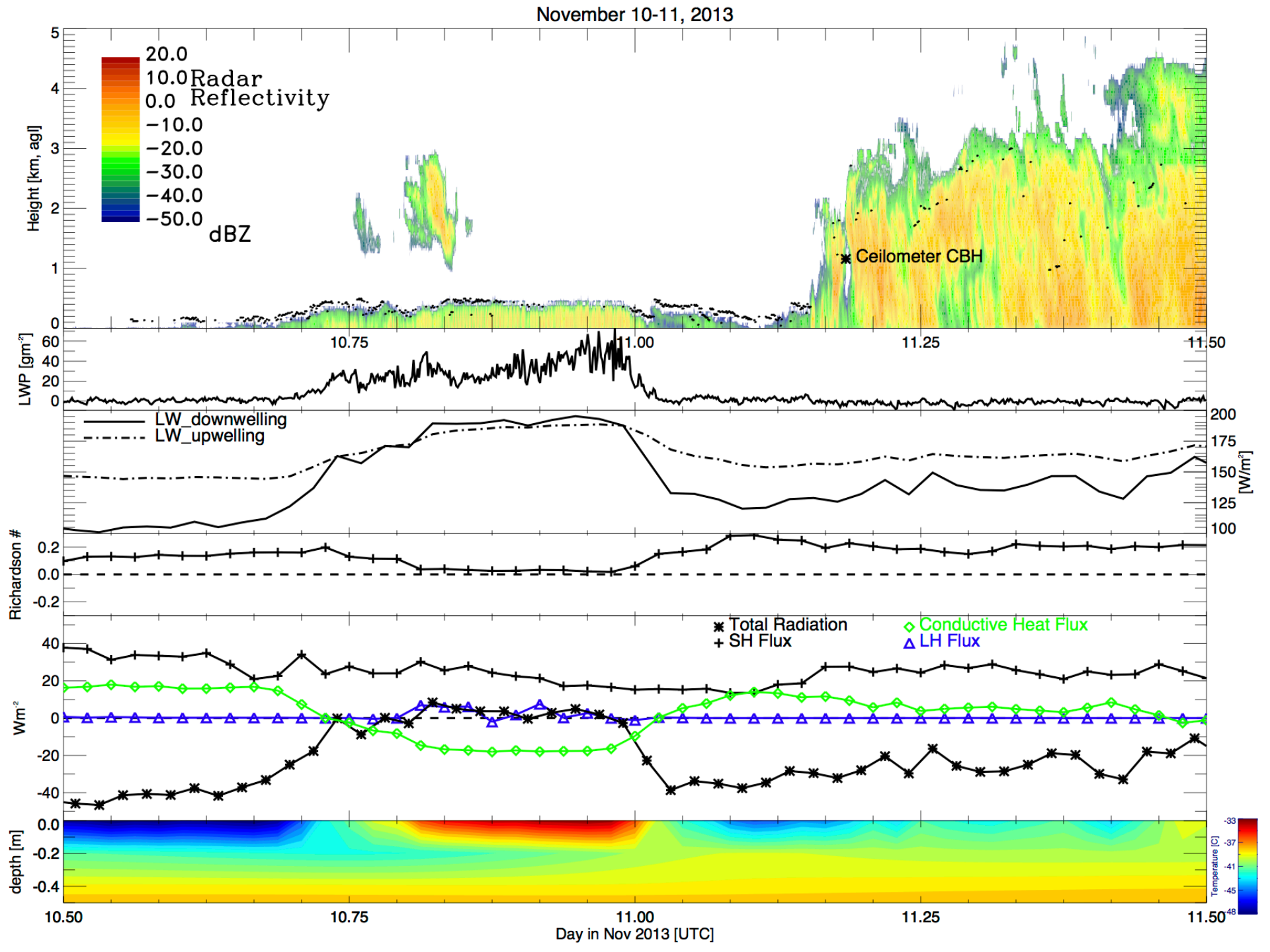
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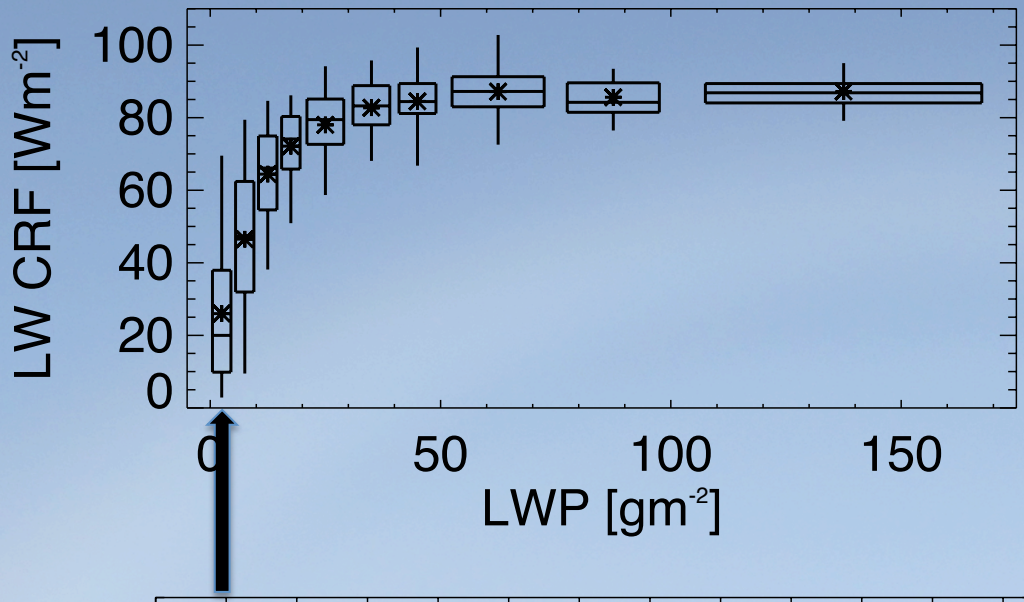
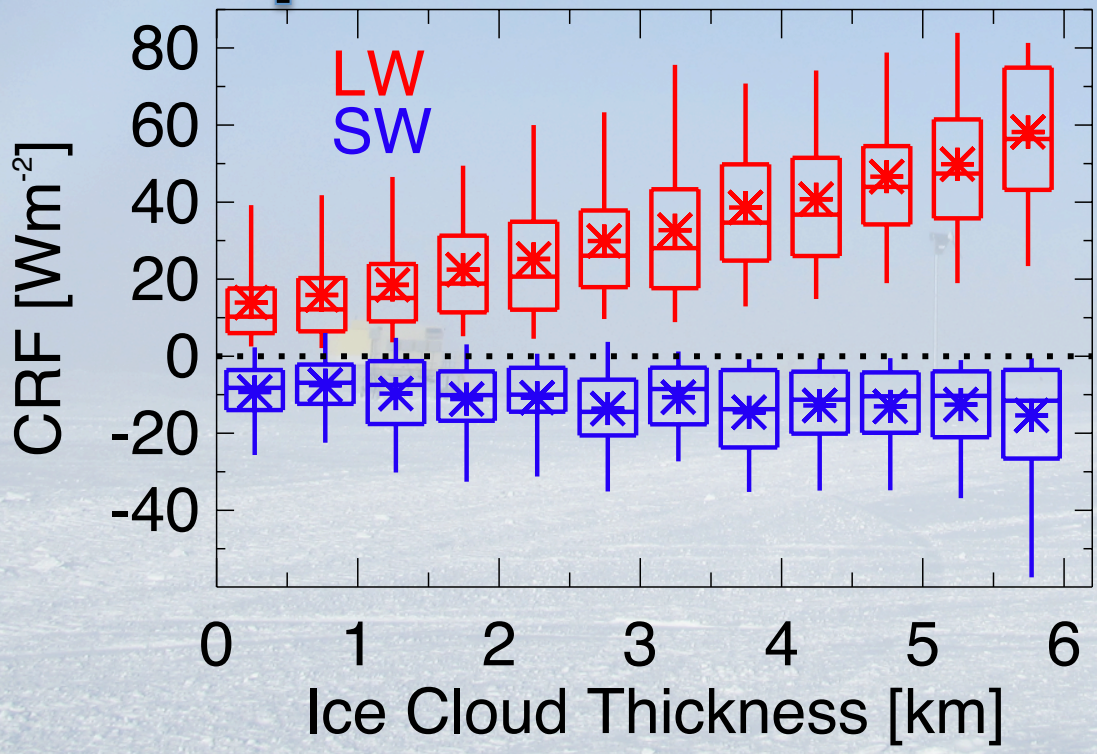
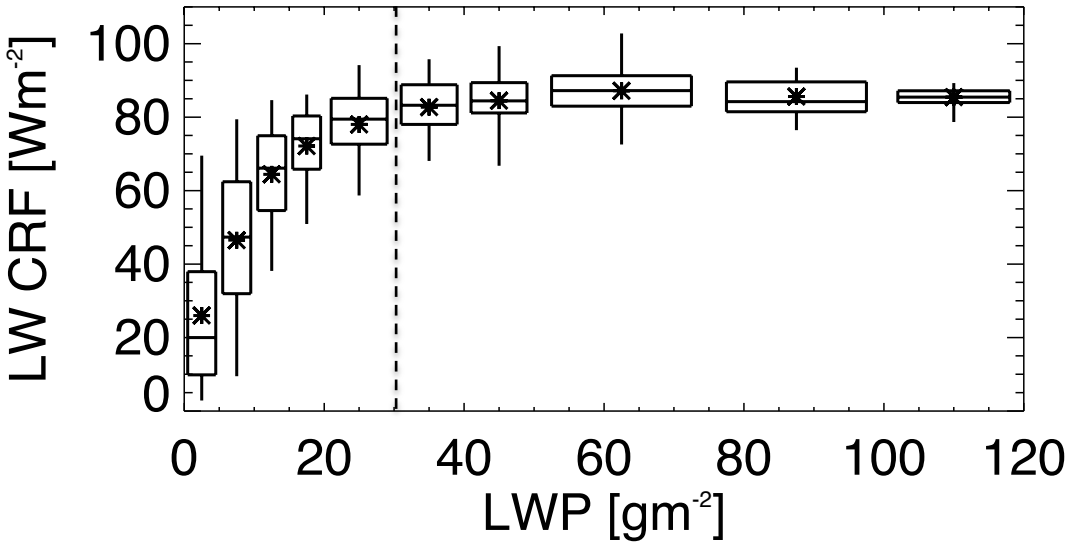


Liquid-bearing clouds become opaque to LW radiation ~ 30 gm^{-2}



The physical depth of ice clouds influences the magnitude of CRF

Liquid-bearing clouds change the boundary-layer structure



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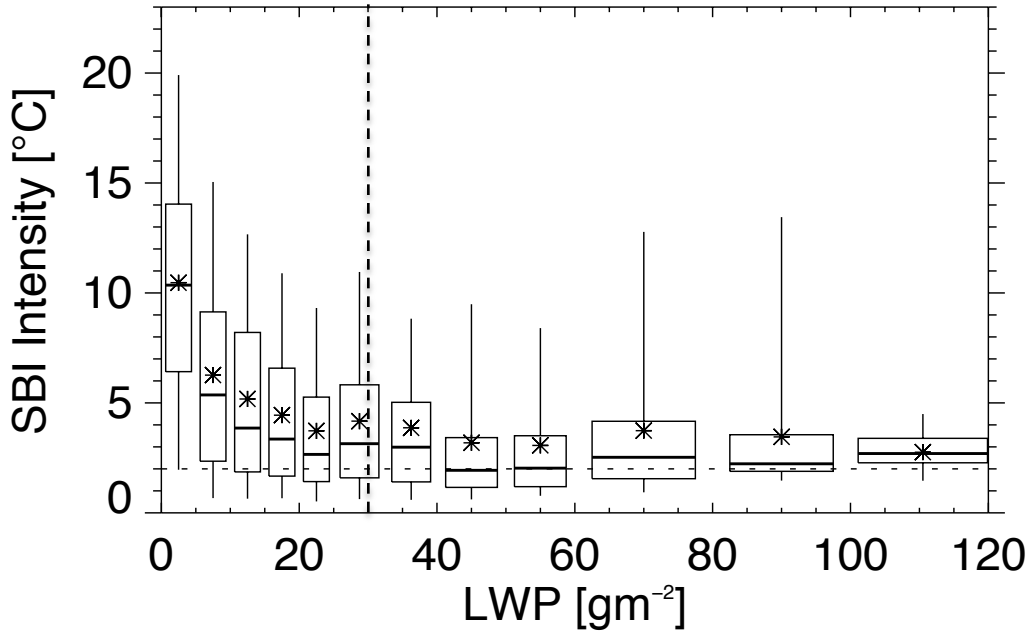

Surface-based inversion (SBI) intensity decreases in the presence of liquid-bearing clouds