# Cloud Radiative Forcing in Central Greenland

Nathaniel Miller – University of Colorado (ATOC), CIRES
millernb@colorado.edu
Matthew Shupe (CIRES, NOAA), Jennifer Kay (CIRES, ATOC),
Christopher Cox (CIRES, NOAA), Ralf Bennartz (Vanderbilt University)

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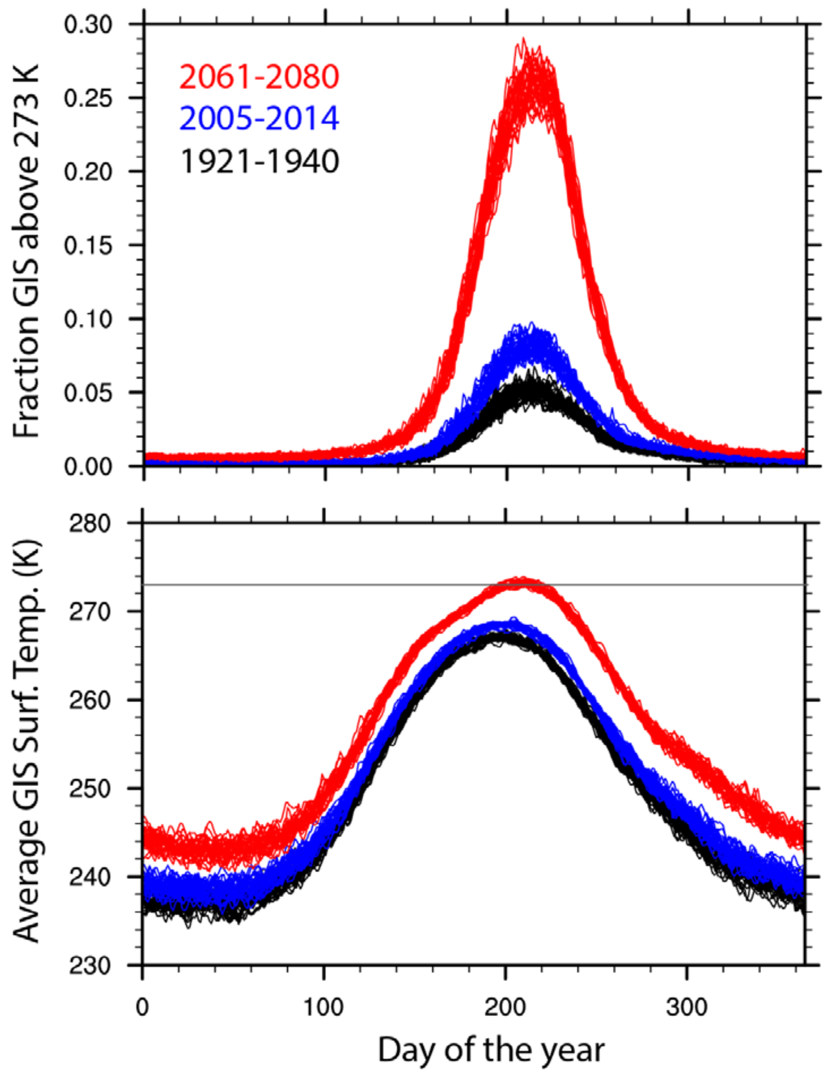
- Location
- Instrumentation
- Results
- CESM Validation
- Future Directions

# Greenland Ice Sheet

The GIS is over 3.2 km deep at Summit Station




CESM-LE, *J. Kay*

Observed increase in GIS melt rate and extent (*Mernild et. al. 2011, J. Glac.*) has global and regional impacts.

For surface temperatures close to 273K a small change in the surface energy budget can have substantial implications for the surface mass balance.

# ICECAPS

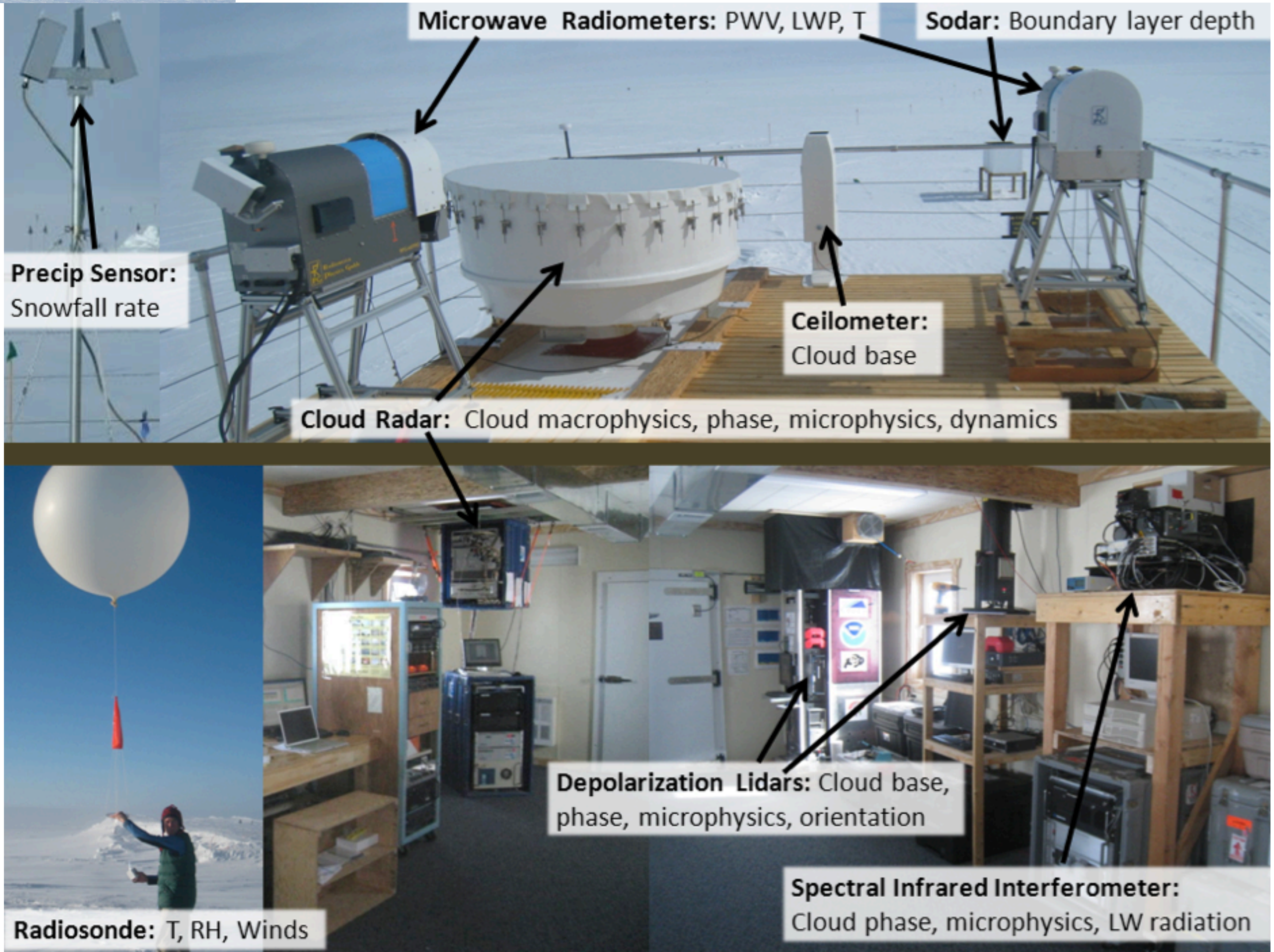
## Integrated Characterization of Energy, Clouds, Atmospheric State, and Precipitation at Summit, Greenland

- ***Atmospheric State*** **-** temperature and moisture profiles throughout the troposphere
- ***Cloud Macrophysics*** **-** cloud occurrence and vertical boundaries
- ***Cloud Microphysics*** **-** cloud phase, water content, optical depth, and particle size
- ***Precipitation*** **-** precipitation type and rate
- ***Cloud Radiative Forcing*** **-** impact of clouds on the surface radiation budget

Elevation 3255 m
72°35′ N
38°25′ W

*Shupe et. al. BAMS 2013*

# Mobile Science Facility



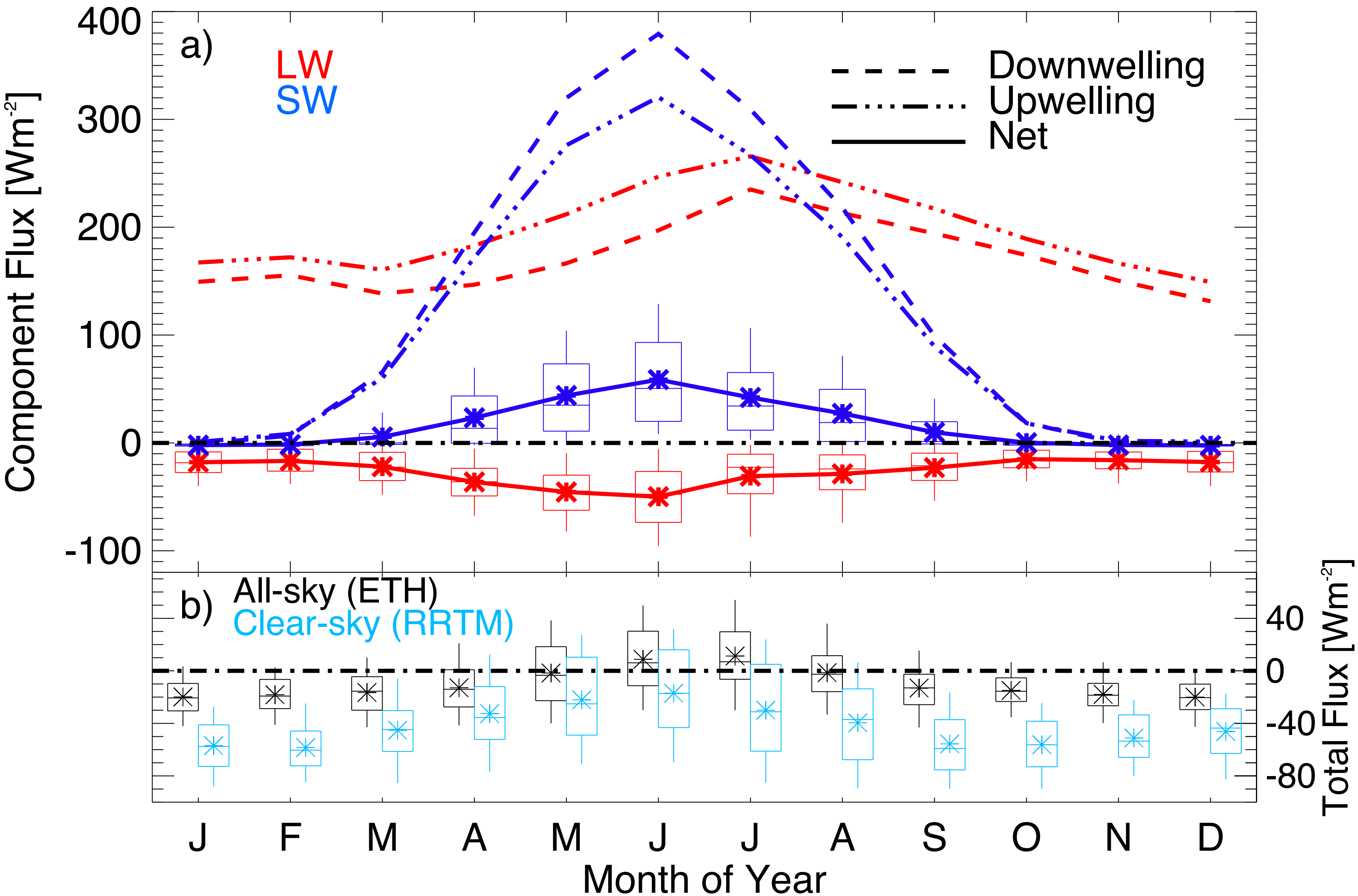

Photos (right):
M. Shupe,
M. Okrazewski

# Broadband Radiometers

Net = LW↓ - LW↑ + SW↓ - SW↑

ETH measurements –
courtesy of Dr. Konrad Steffen
– Swiss Federal Institute, Zürich
2004 - present

# Annual Cycle of Surface Flux




3-hour averages, Jan 2011-Oct 2013

*Miller et. al. J. Climate [submitted]*

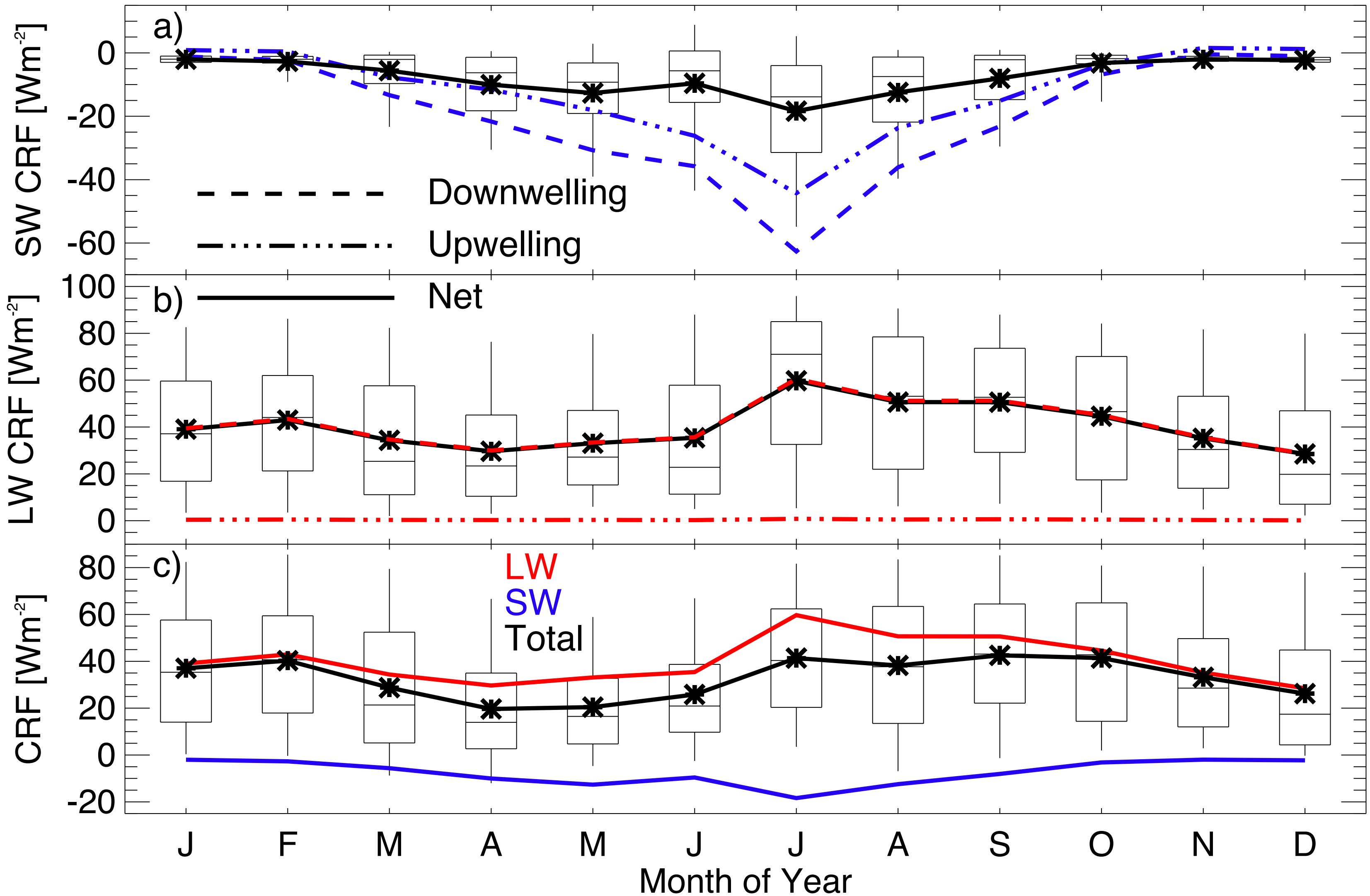
# CRF Defined

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

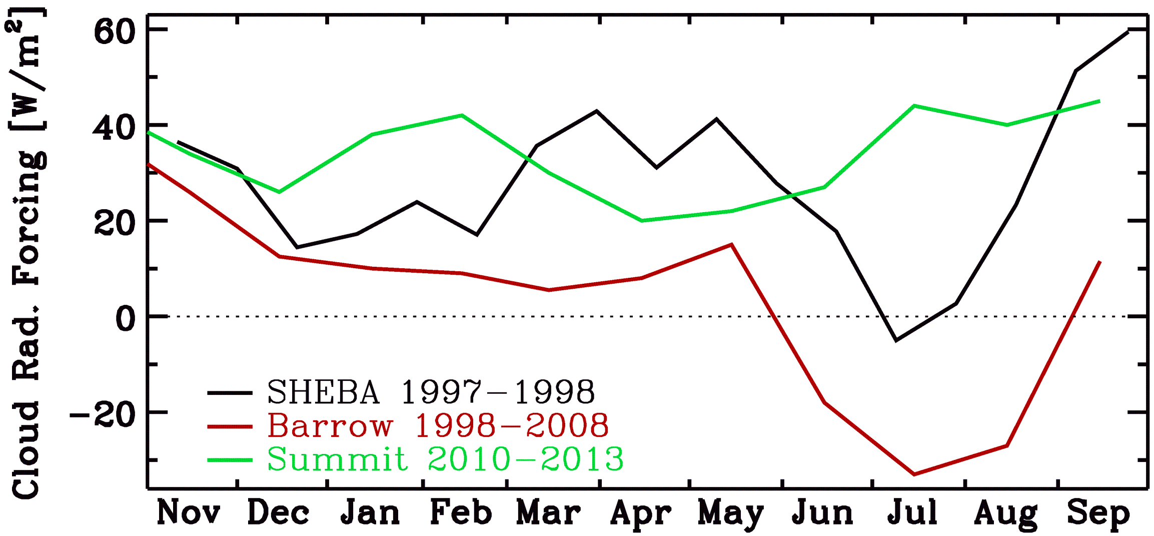
$$CRF = Flux_{\text{all-sky, measured}} – Flux_{\text{clear-sky, modeled}}$$

Rapid Radiative Transfer Model (RRTM)

# Annual Cycle of CRF



# Surface albedo important for CRF



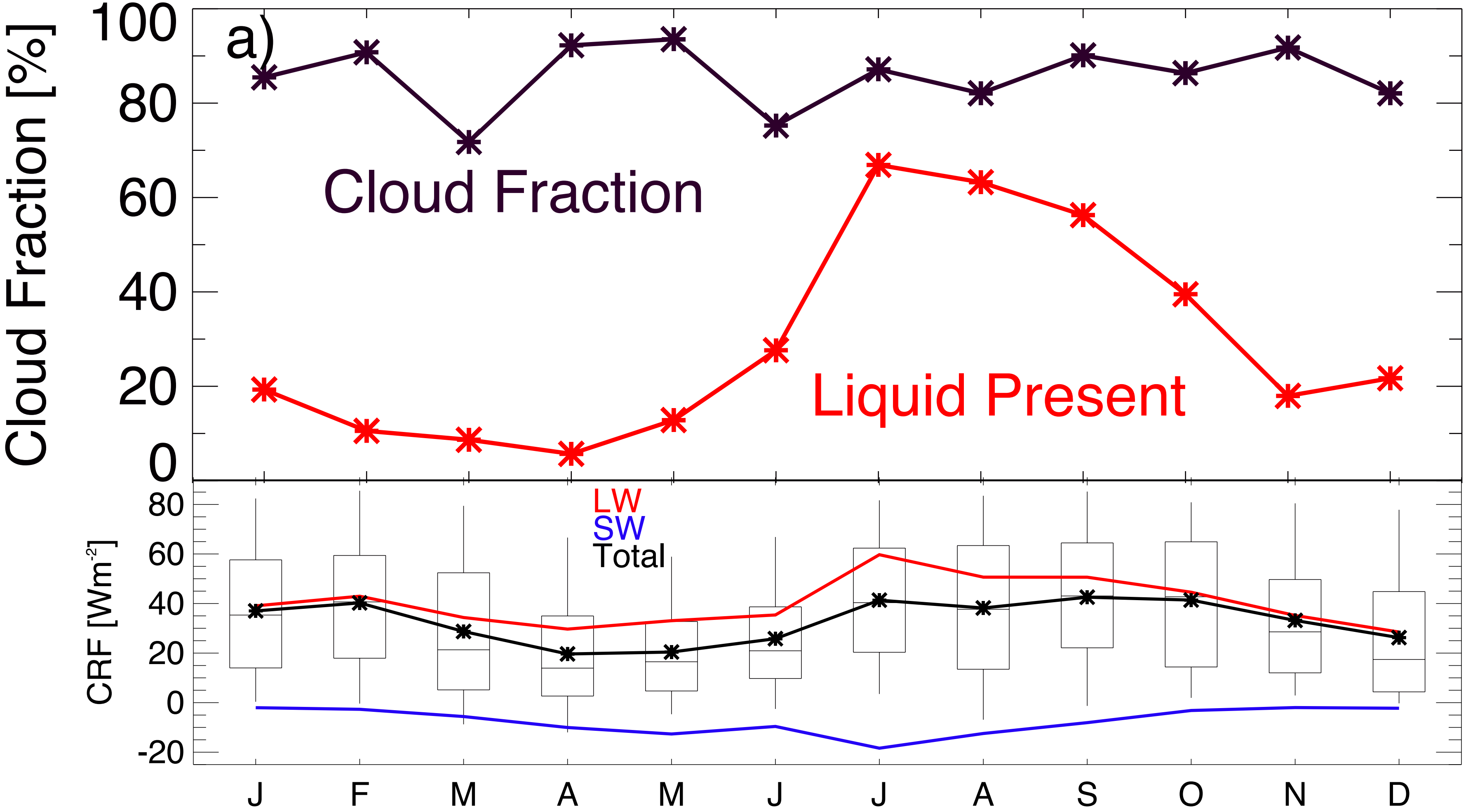

(*Shupe and Intrieri 2004, J. of Climate*)

(*Dong et. al. 2010, JGR*)

*M. Shupe*

- Central Greenland is a unique Arctic location

- High year round cloud fraction – 86%
- LW CRF magnitude corresponds to the presence of liquid-bearing clouds
- Changes in cloud frequency of occurrence or microphysical properties would change CRF magnitude.

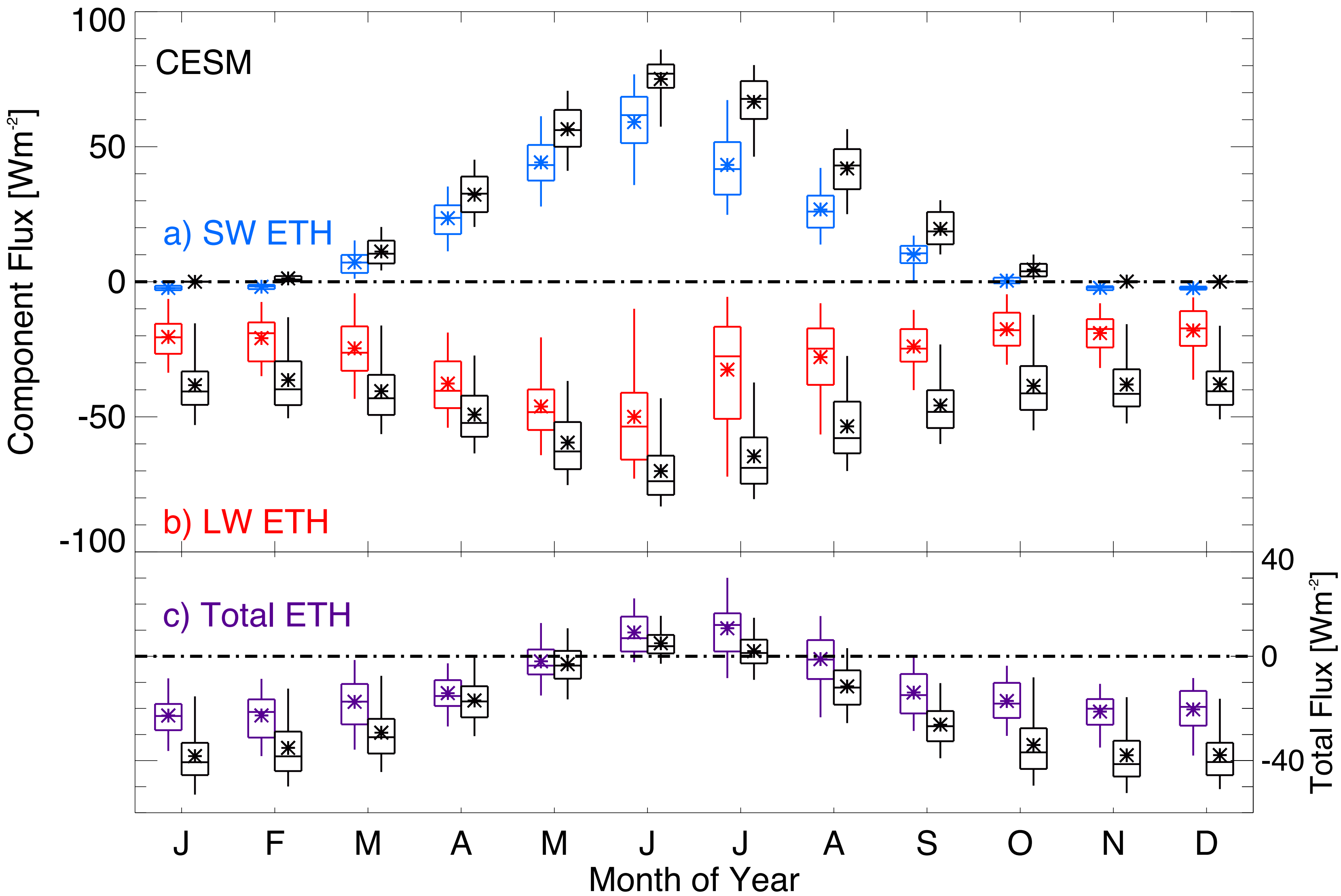


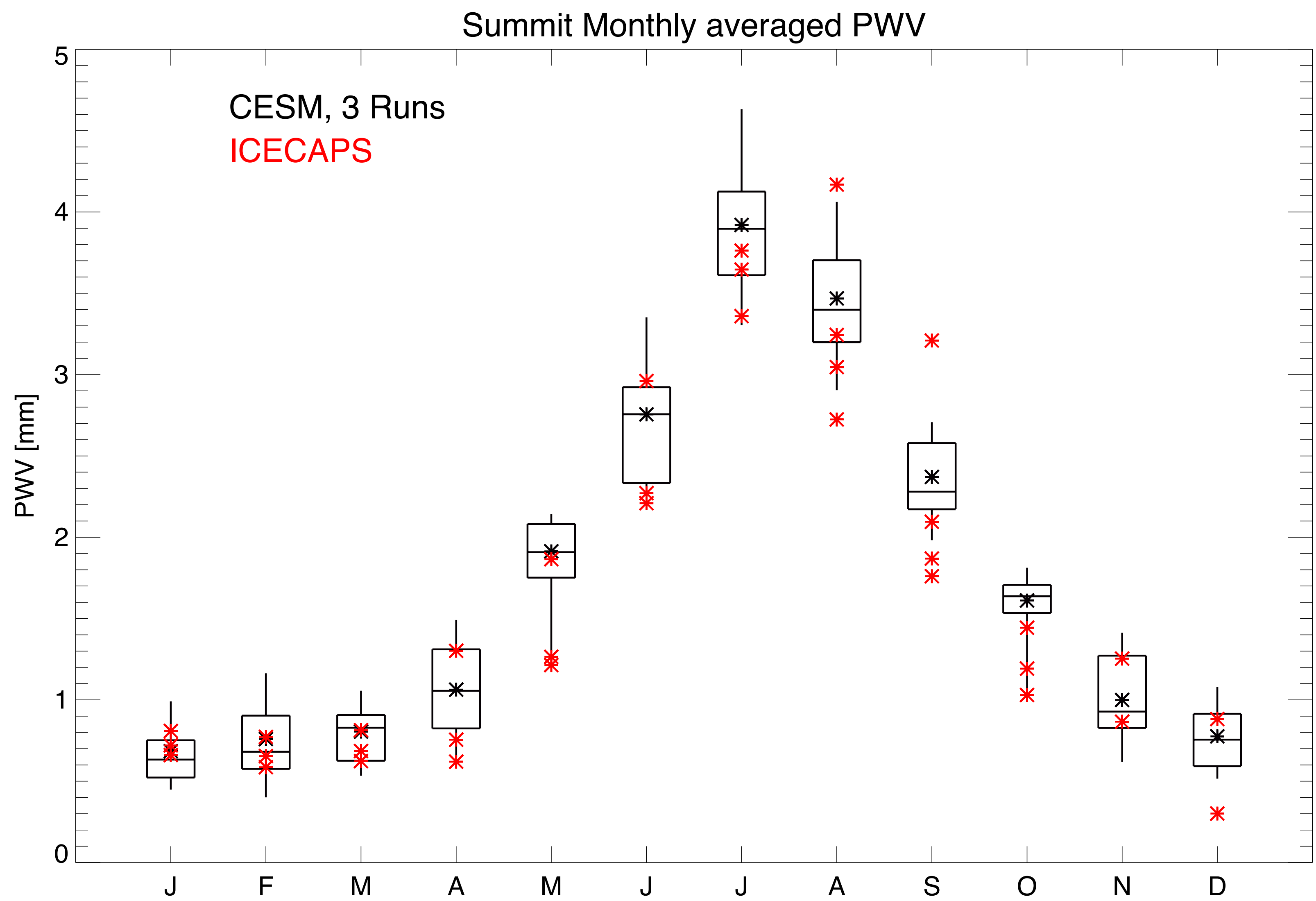
# Community Earth System Model

CESM validation

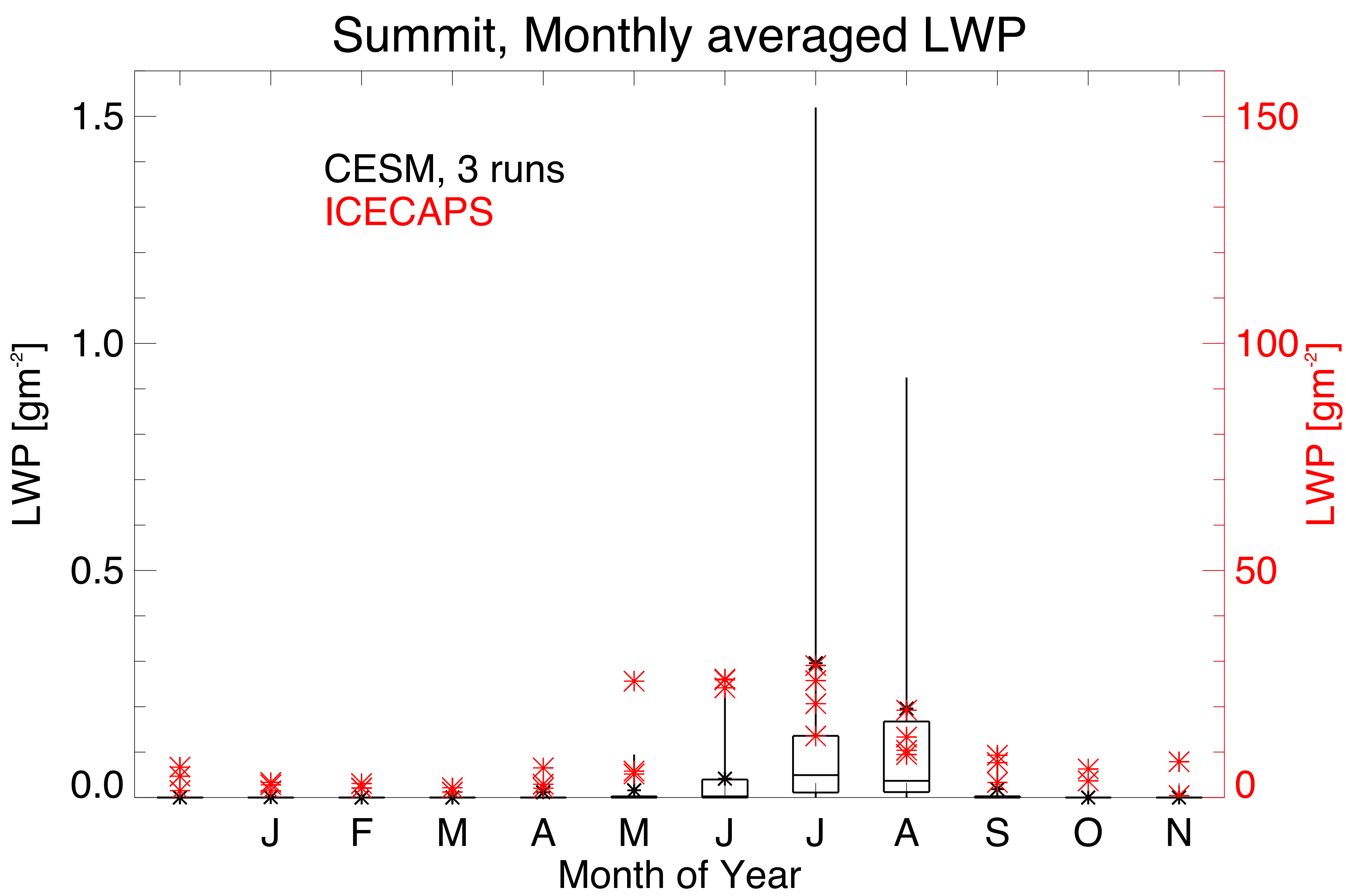
- Radiative Fluxes (daily averages)
- Precipitable water vapor (monthly averages)
- Liquid water path (monthly averages)
- Cloud radiative forcing (daily averages)
- Near-surface air temperatures (daily values)

# Annual Cycle of Surface Flux



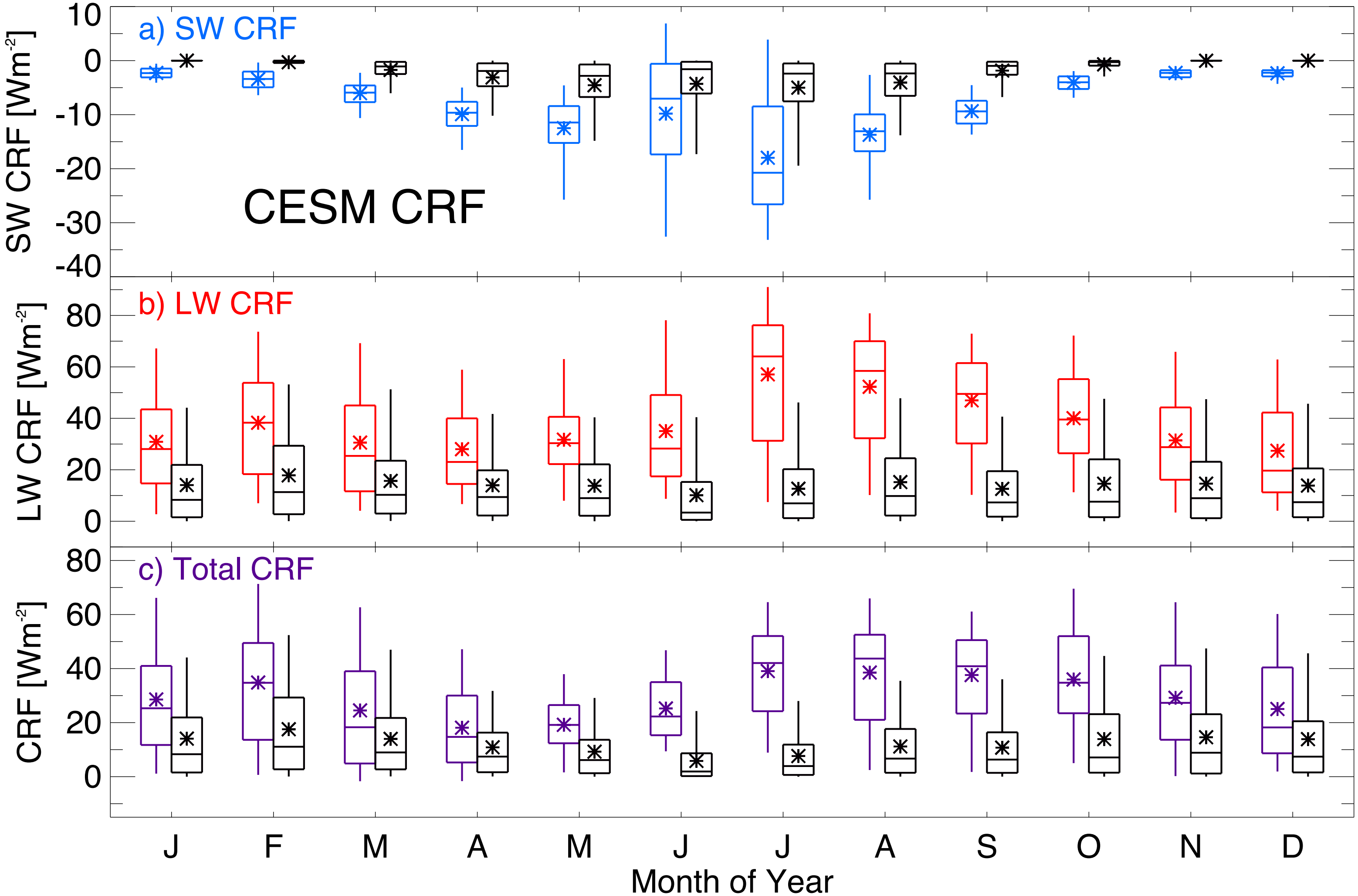


Summit Monthly averaged PWV
CESM, 3 Runs
ICECAPS
PWV [mm]
0
1
2
3
4
5
J
F
M
A
M
J
J
A
S
O
N
D



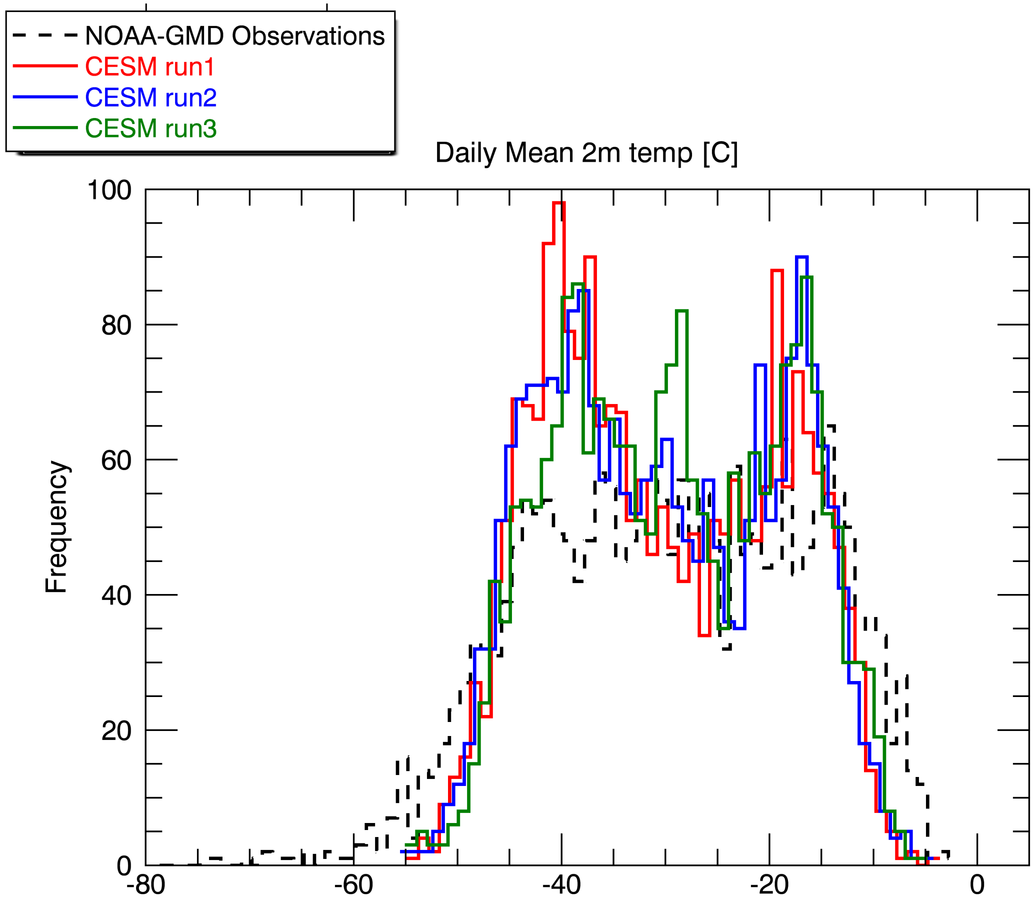
Summit, Monthly averaged LWP
CESM, 3 runs
ICECAPS
LWP [gm-2]
LWP [gm-2]
1.5
1.0
0.5
0.0
150
100
50
0
J
F
M
A
M
J
J
A
S
O
N
Month of Year

# Annual Cycle of CRF




| | Annual CRF | Summer CRF |
|---|---|---|
| Observations | 30 $Wm^{-2}$ | 34 $Wm^{-2}$ |
| CESM | 12 $Wm^{-2}$ | 8 $Wm^{-2}$ |

# Daily Mean 2m temperature

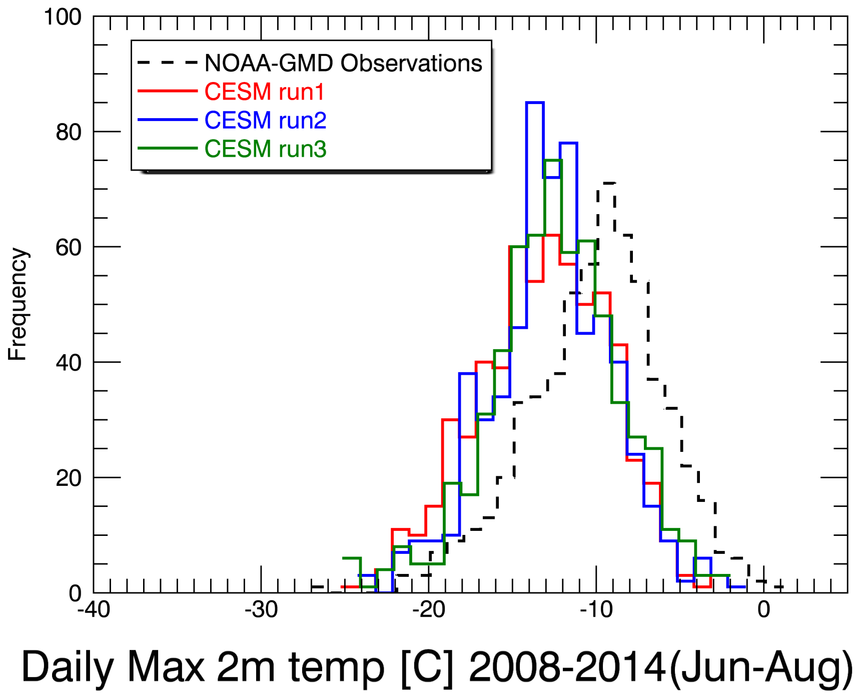



2008-2014

Modeled values are bimodal.

Observed extremes not captured by CESM.

# Summer Daily Maximum Temperatures




- **In order to accurately represent surface temperatures → need to capture the presence and phase of clouds above the GIS**
- Summer maximum temperatures are critical to represent because they have the greatest impact on melt extent
- At Summit, clouds can force surface temperatures to the melting point of snow (i.e. *Bennartz et. al. Nature 2013*).
- If 26 $Wm^{-2}$ (summer CRF residual) was added to the surface energy budget then, -13C → -7C
- Of course it is more complicated - turbulent flux response and heat conduction into the snowpack.

# Future CESM fields to investigate

- LW↓, LW↑ , SW↓, SW↑
- Albedo
- IWP
- Cloud Fraction
- Latent Heat Flux
- Sensible Heat Flux
- Skin temperature
- Surface Pressure
- Temperature and humidity profiles
  - Stability of the boundary layer
  - Inversion Strength

# Thank you


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

- Thanks to Dr. Konrad Steffen for providing the ETH broadband radiometer measurements.

- National Oceanic and Atmospheric Administration's Global Monitoring Division

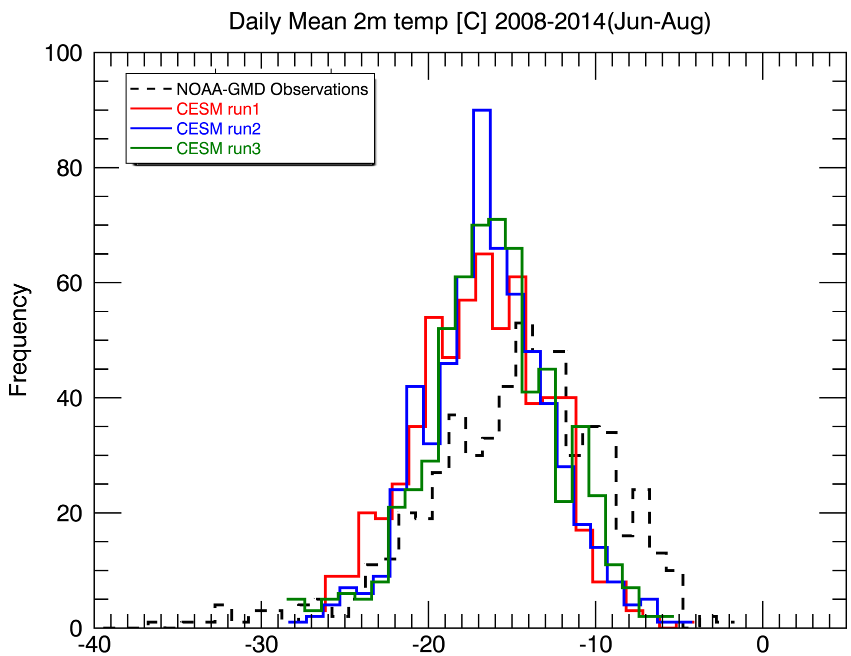
- European Centre for Medium-Range Weather Forecasts

- Professor Kay for providing the CESM data.

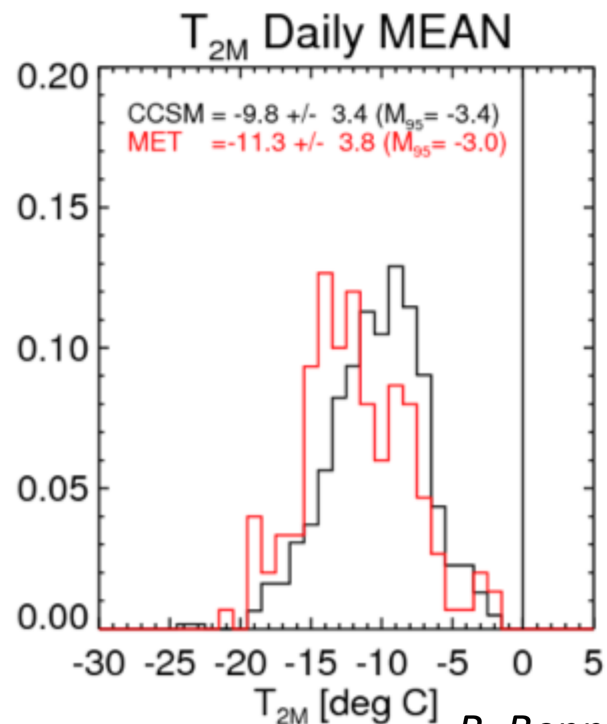
CESM average daily summer temperatures are:

- too cold (CAM5)
- too warm (CAM4)

CAM 5

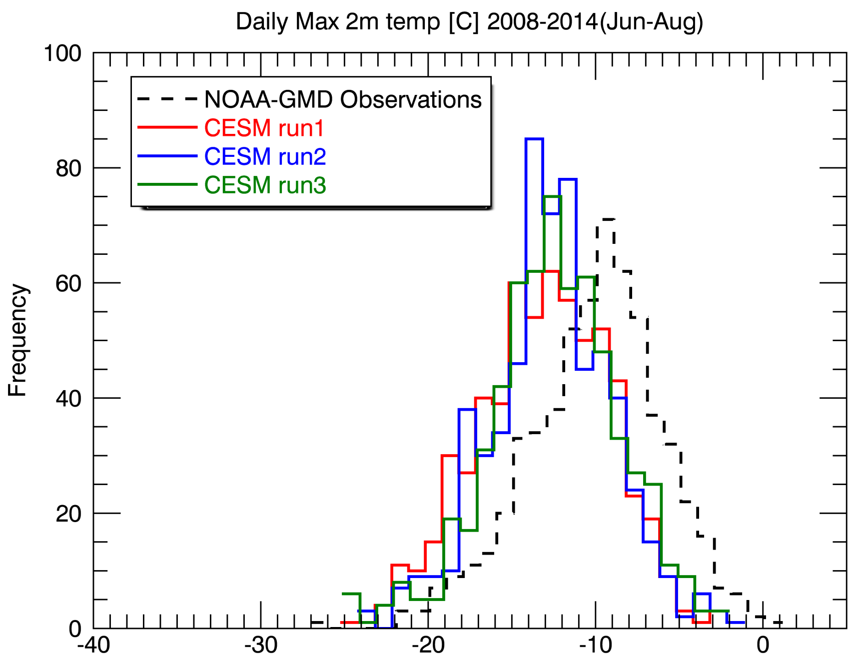



CAM 4

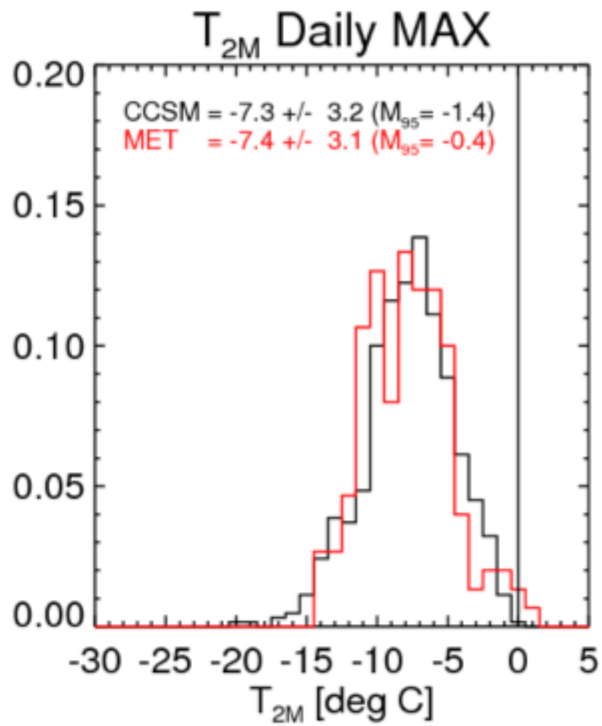



*R. Bennartz*

CAM 5


Daily Max 2m temp [C] 2008-2014(Jun-Aug)
NOAA-GMD Observations
CESM run1
CESM run2
CESM run3
Frequency
100
80
60
40
20
0
-40
-30
-20
-10
0

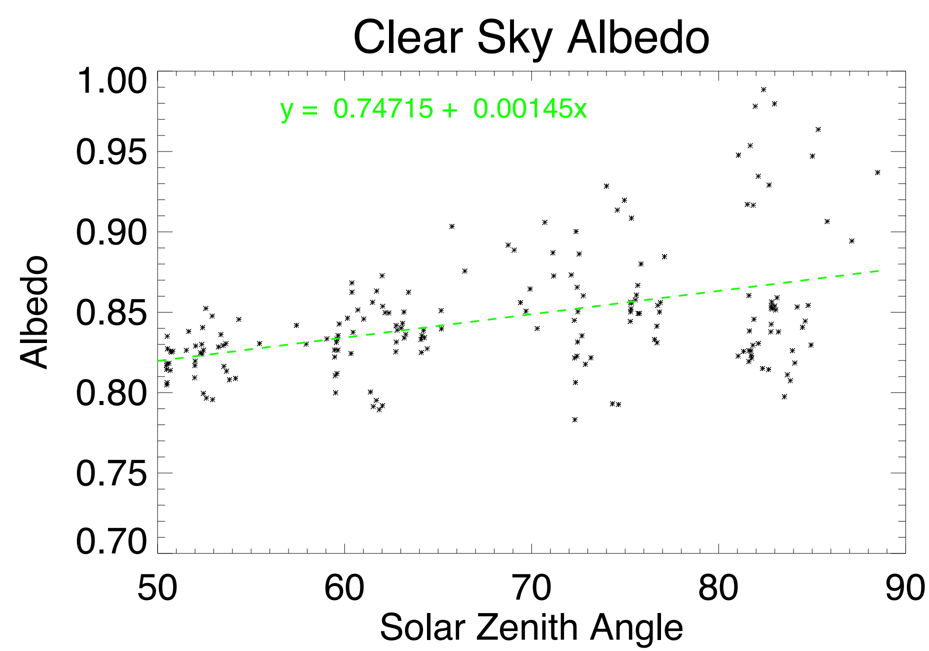
CAM 4

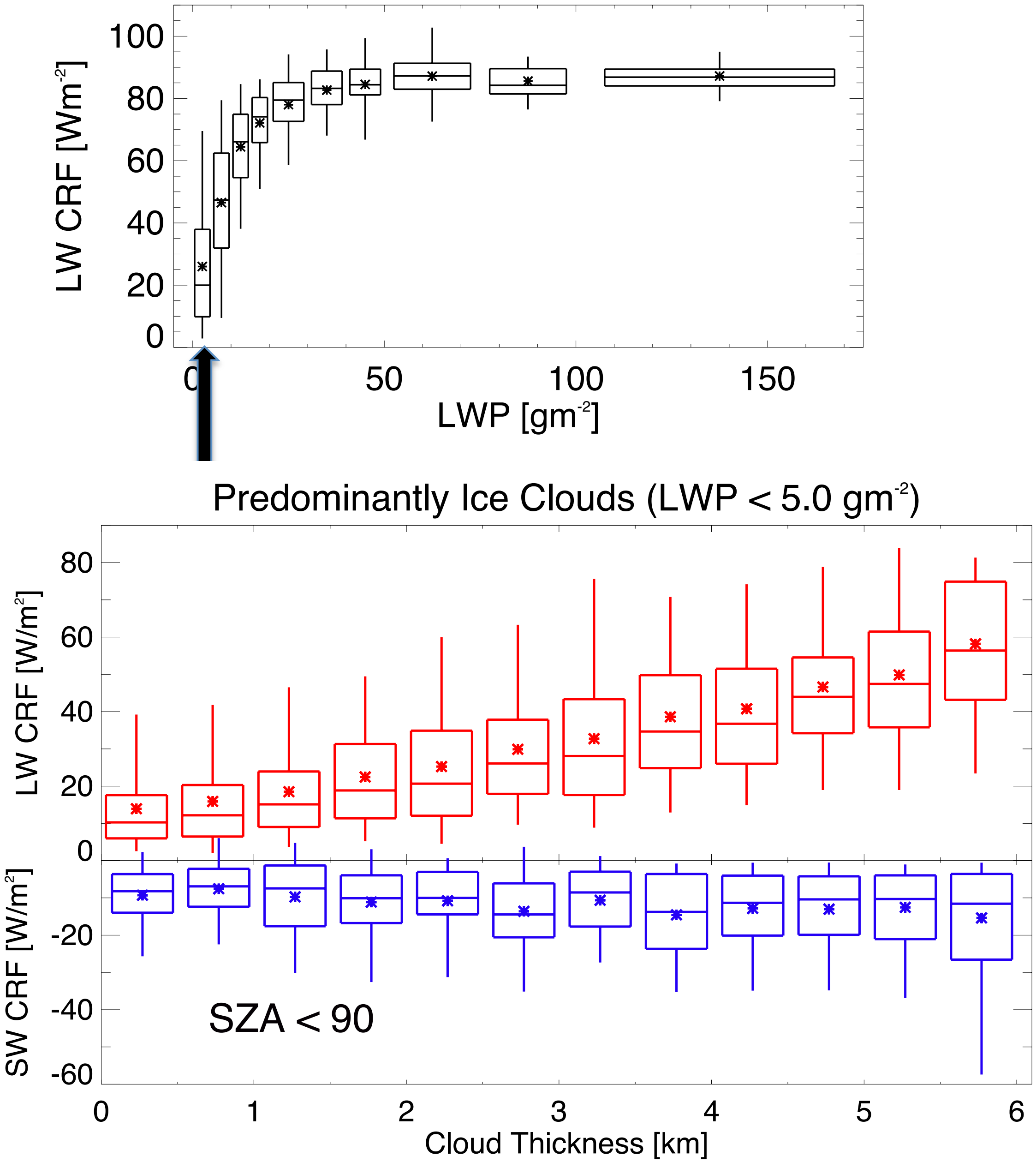

T2M Daily MAX
CCSM = -7.3 +/- 3.2 (M95= -1.4)
MET = -7.4 +/- 3.1 (M95= -0.4)
0.20
0.15
0.10
0.05
0.00
-30 -25 -20 -15 -10 -5 0 5
T2M [deg C]

# Rapid radiative transfer model (RRTM)

## Inputs:

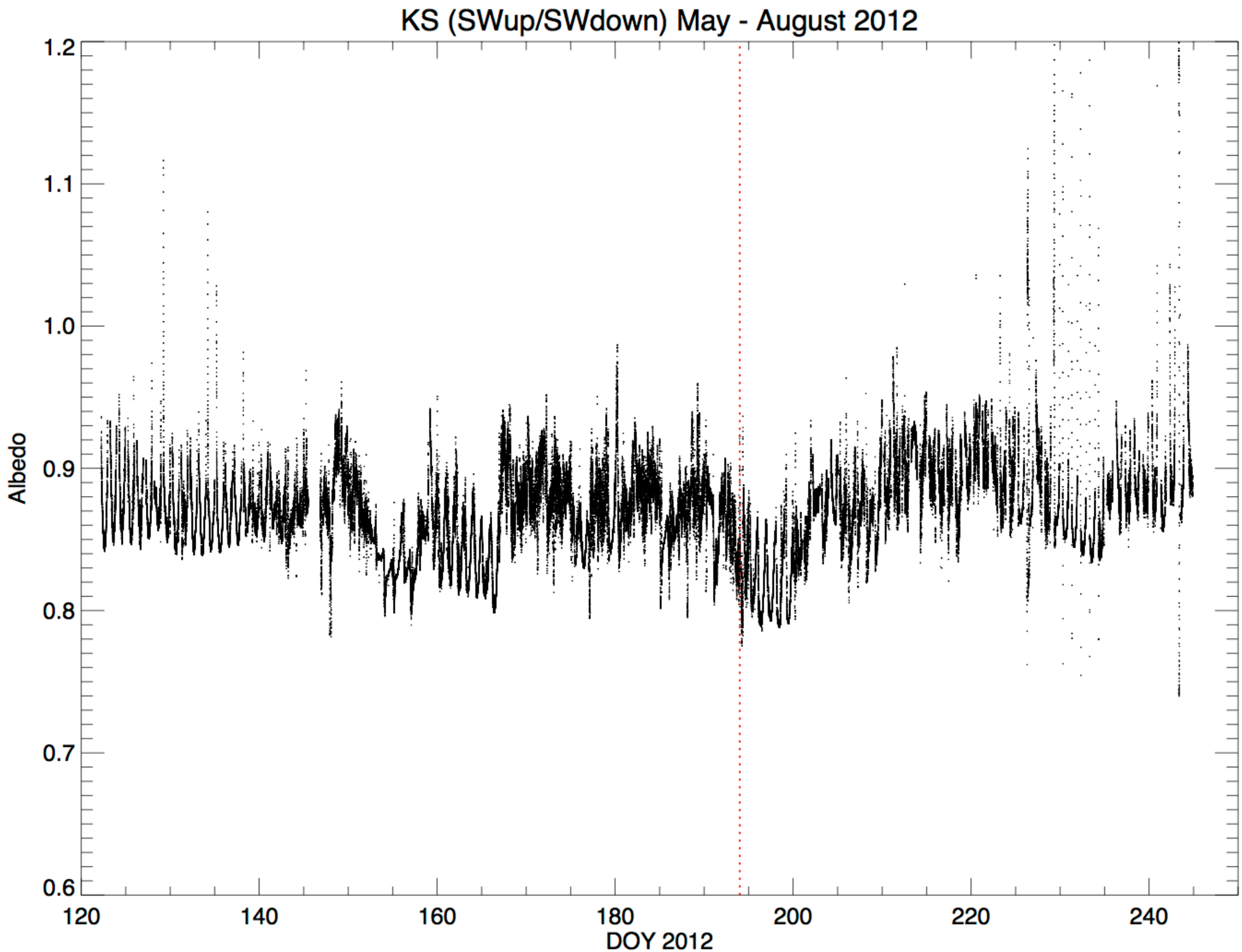
- Merged temperature profiles
  - ECMWF, twice daily radiosondes, MWR derived boundary layer profiles
- Merged moisture profiles
  - ECMWF, twice daily radiosondes, scaled by MWR derived PWV
- Snow emissivity = 0.985
- Clear-sky snow albedo →
- $CO_2$ mixing ratio
- Standard subarctic winter
  - $N_2O$, CO, $CH_4$ and $O_2$
- Ozonesonde profile
- Surface temperature
  - derived from LW measurements



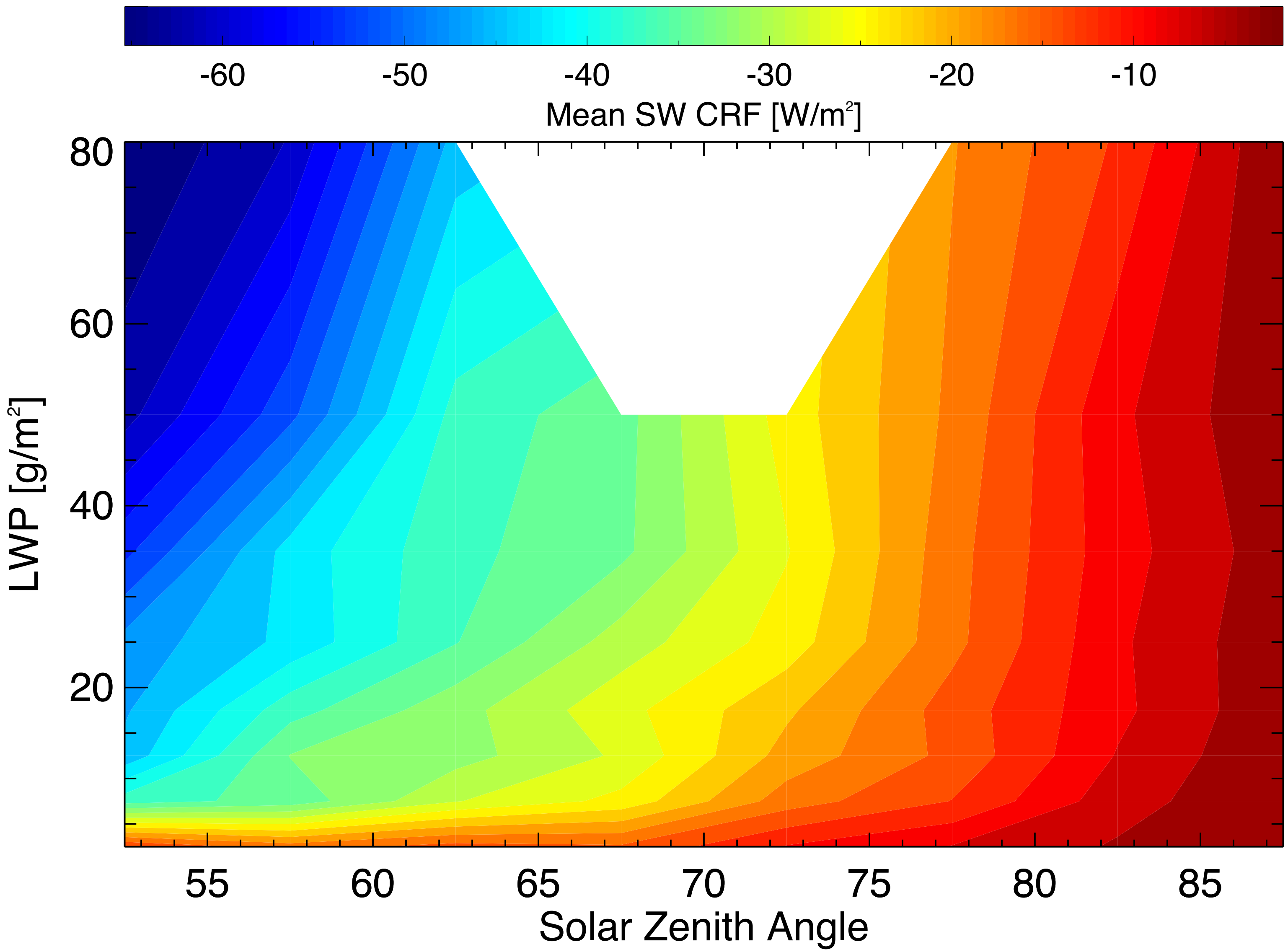



The physical depth of an ice-cloud influences the optical depth

Linear relationship between cloud thickness and LW CRF


KS (SWup/SWdown) May - August 2012
Albedo
DOY 2012
1.2
1.1
1.0
0.9
0.8
0.7
0.6
120
140
160
180
200
220
240

# SW CRF is sensitive to changes in sun angle and LWP



# Maximum Total CRF for optically thin clouds with low LWP