Observational Needs for Polar Atmospheric Science

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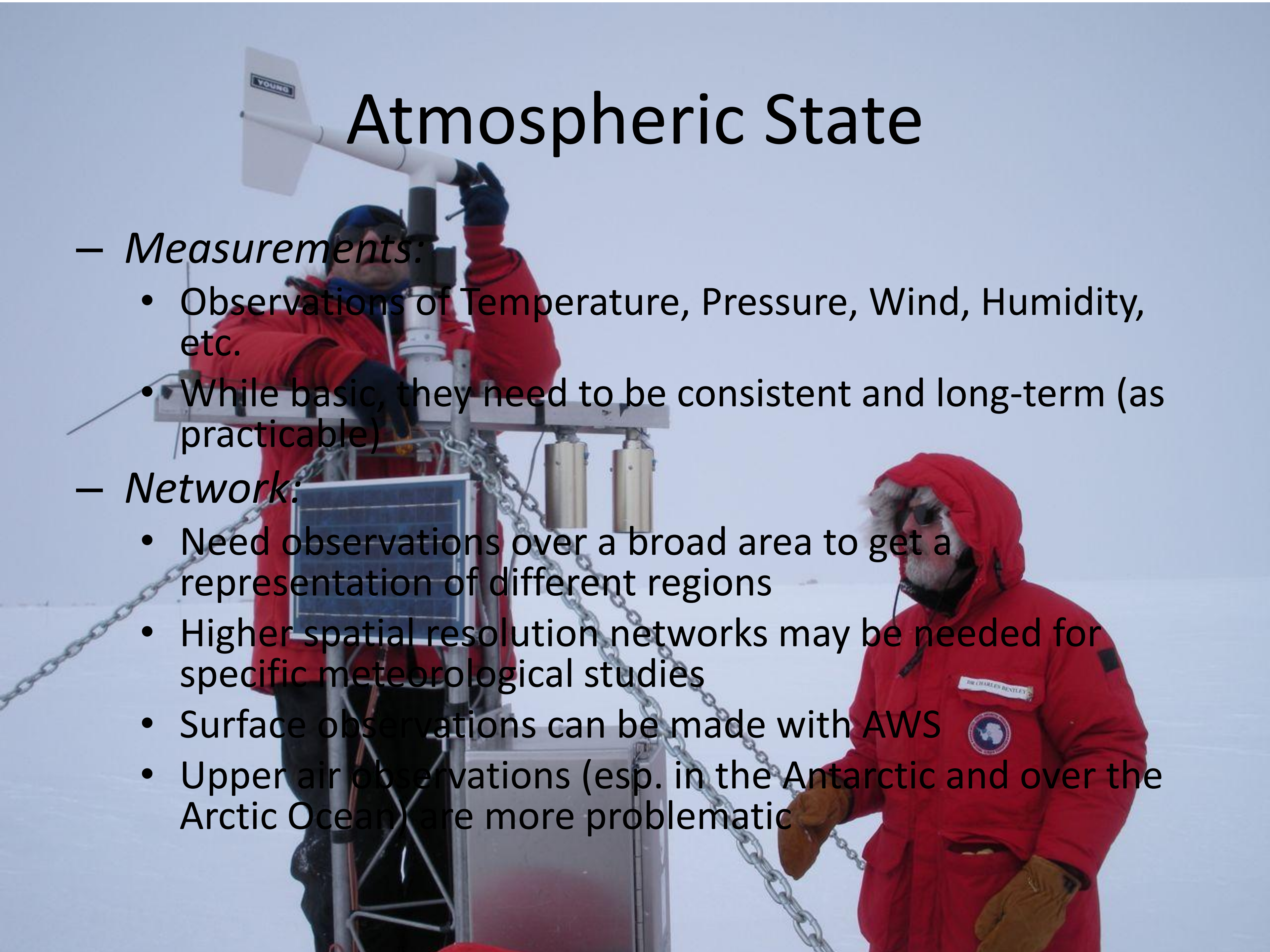
Scientific Motivation

- Climate monitoring
  - Ex. Climate change, teleconnections
- Atmospheric dynamics and physics
  - Ex. Cloud processes, radiative transfer, boundary layer and turbulence, topographically forced flows
- Coupling of atmosphere with other climate system components
  - Ex. Ice sheet surface mass balance, atmosphere-ocean-sea ice coupling
- Climate and NWP model evaluation

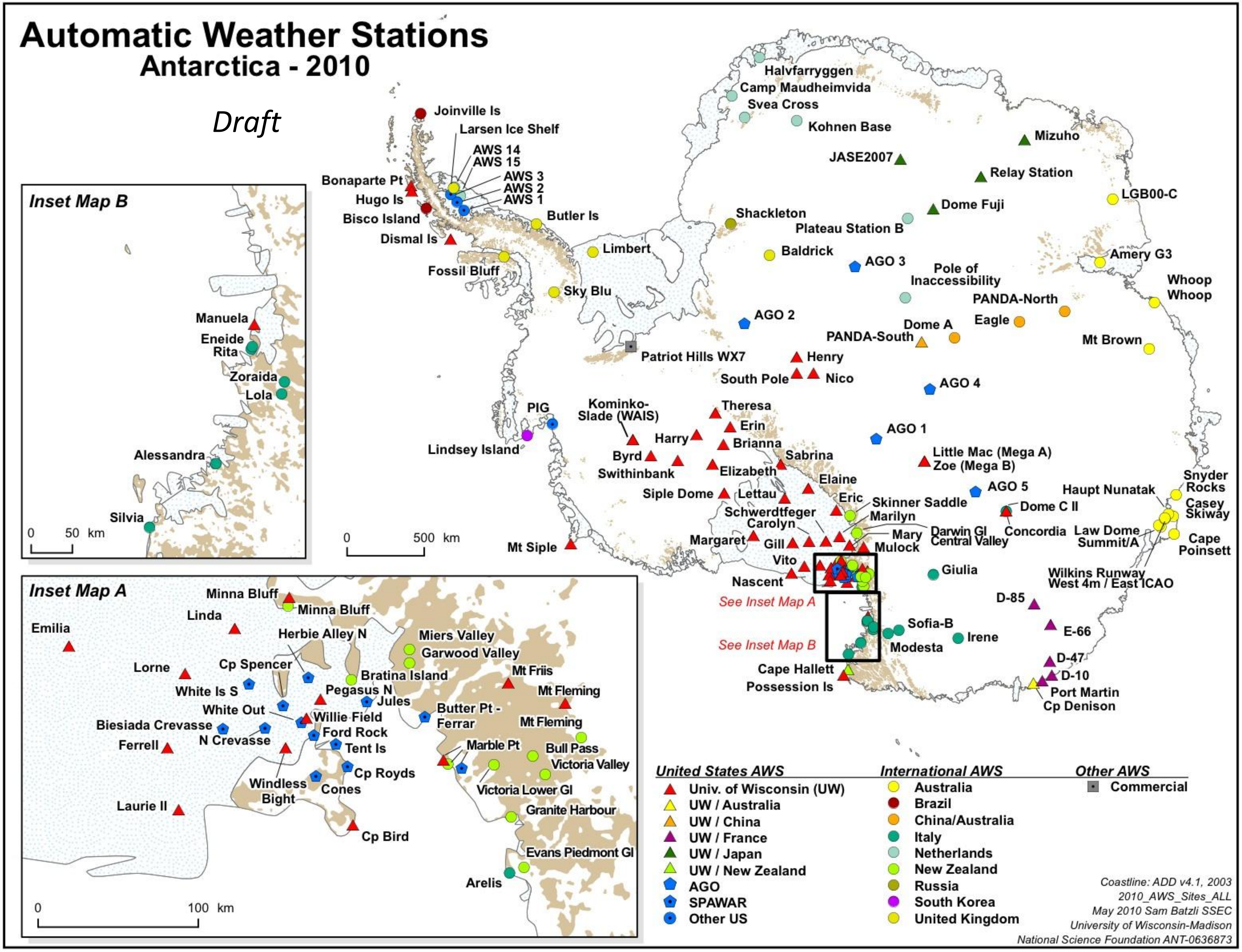
Needed Observations

- Atmospheric state
  - Surface and aloft
- Boundary layer properties and processes
- Clouds and precipitation
- Surface energy budget / Radiation
- Trace gases / Aerosols
- Non-atmospheric features
  - Sea ice, snow cover, etc.



Atmospheric State

- *Measurements:*
  - Observations of Temperature, Pressure, Wind, Humidity, etc.
  - While basic, they need to be consistent and long-term (as practicable)
- *Network:*
  - Need observations over a broad area to get a representation of different regions
  - Higher spatial resolution networks may be needed for specific meteorological studies
  - Surface observations can be made with AWS
  - Upper air observations (esp. in the Antarctic and over the Arctic Ocean) are more problematic

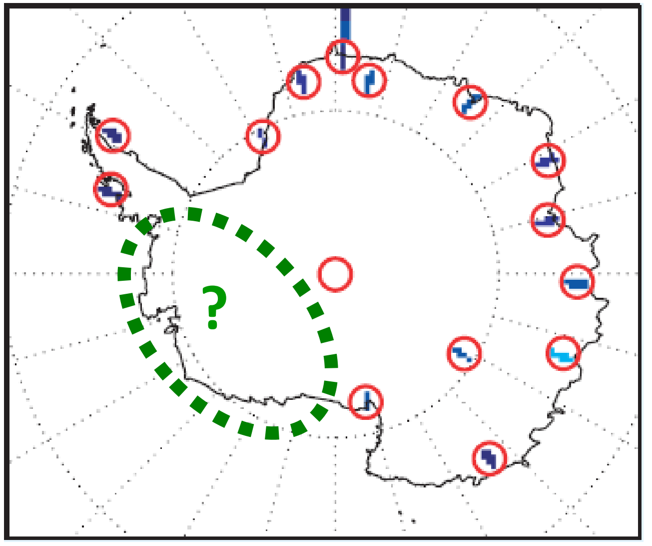


Automatic Weather Stations
Antarctica - 2010
Draft
Halvfarryggen
Camp Maudheimvida
Svea Cross
Kohnen Base
Mizuho
JASE2007
Relay Station
LGB00-C
Dome Fuji
Shackleton
Plateau Station B
Baldrick
AGO 3
Amery G3
Pole of Inaccessibility
Whoop Whoop
PANDA-North
AGO 2
Eagle
Dome A
PANDA-South
Mt Brown
Patriot Hills WX7
Henry
South Pole
Nico
AGO 4
Joinville Is
Larsen Ice Shelf
AWS 14
AWS 15
AWS 3
AWS 2
AWS 1
Bonaparte Pt
Hugo Is
Bisco Island
Butler Is
Dismal Is
Limbert
Fossil Bluff
Sky Blu
PIG
Lindsey Island
Kominko-Slade (WAIS)
Theresa
Erin
Harry
Brianna
Byrd
Swithinbank
Elizabeth
Sabrina
AGO 1
Little Mac (Mega A)
Zoe (Mega B)
Siple Dome
Lettau
Elaine
AGO 5
Haupt Nunatak
Snyder Rocks
Casey Skiway
Dome C II
Concordia
Eric
Skinner Saddle
Schwerdtfeger
Marilyn
Carolyn
Mary
Darwin Gl
Central Valley
Law Dome Summit/A
Cape Poinsett
Margaret
Gill
Mulock
Mt Siple
Vito
Nascent
Giulia
Wilkins Runway
West 4m / East ICAO
See Inset Map A
D-85
Sofia-B
E-66
Irene
See Inset Map B
Modesta
D-47
Cape Hallett
D-10
Possession Is
Port Martin
Cp Denison
0 500 km
Inset Map B
Manuela
Eneide
Rita
Zoraida
Lola
Alessandra
Silvia
0 50 km
Inset Map A
Minna Bluff
Minna Bluff
Linda
Emilia
Herbie Alley N
Miers Valley
Garwood Valley
Lorne
Cp Spencer
Bratina Island
Mt Friis
White Is S
Pegasus N
Mt Fleming
Jules
White Out
Willie Field
Butter Pt - Ferrar
Biesiada Crevasse
Ford Rock
Mt Fleming
N Crevasse
Ferrell
Tent Is
Marble Pt
Bull Pass
Victoria Valley
Cp Royds
Windless Bight
Cones
Victoria Lower Gl
Laurie II
Granite Harbour
Cp Bird
Evans Piedmont Gl
Arelis
0 100 km
United States AWS
Univ. of Wisconsin (UW)
UW / Australia
UW / China
UW / France
UW / Japan
UW / New Zealand
AGO
SPAWAR
Other US
International AWS
Australia
Brazil
China/Australia
Italy
Netherlands
New Zealand
Russia
South Korea
United Kingdom
Other AWS
Commercial
Coastline: ADD v4.1, 2003
2010_AWS_Sites_ALL
May 2010 Sam Batzli SSEC
University of Wisconsin-Madison
National Science Foundation ANT-0636873

Upper air observations: Issues

- Meteorological observations in Antarctica mostly confined to the near-surface
- Only 15 radiosondes provide daily upper-air observations
- Satellite temperature and moisture profile retrievals are not available over Antarctica because of cloud-clearing and surface emissivity issues.
- A repeated concern has been the lack of upper-air observations in West Antarctica

Antarctic radiosondes



[Andersson, 2007]

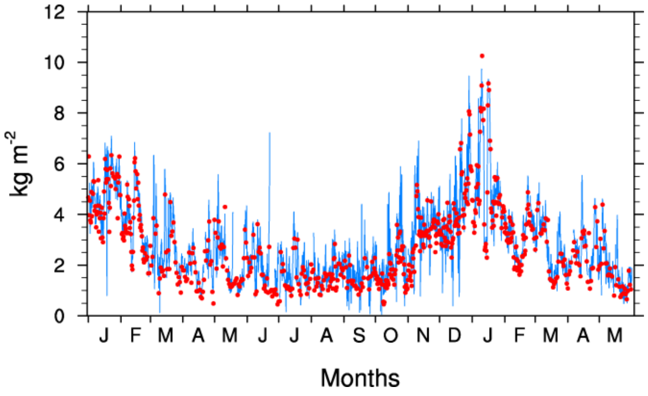
Upper Air Observations: New Data Sources

- Ground-based GPS
  - Used to give atmospheric total **precipitable water**
  - Compared to radiosondes: high temporal frequency but only vertically integrated measurements
- Other sounding measurements:

  Wind
  - Doppler sodar wind profilers

  Temperature
  - Lidar temperature profilers

'07-'08 PW data at McMurdo from radiosonde & GPS

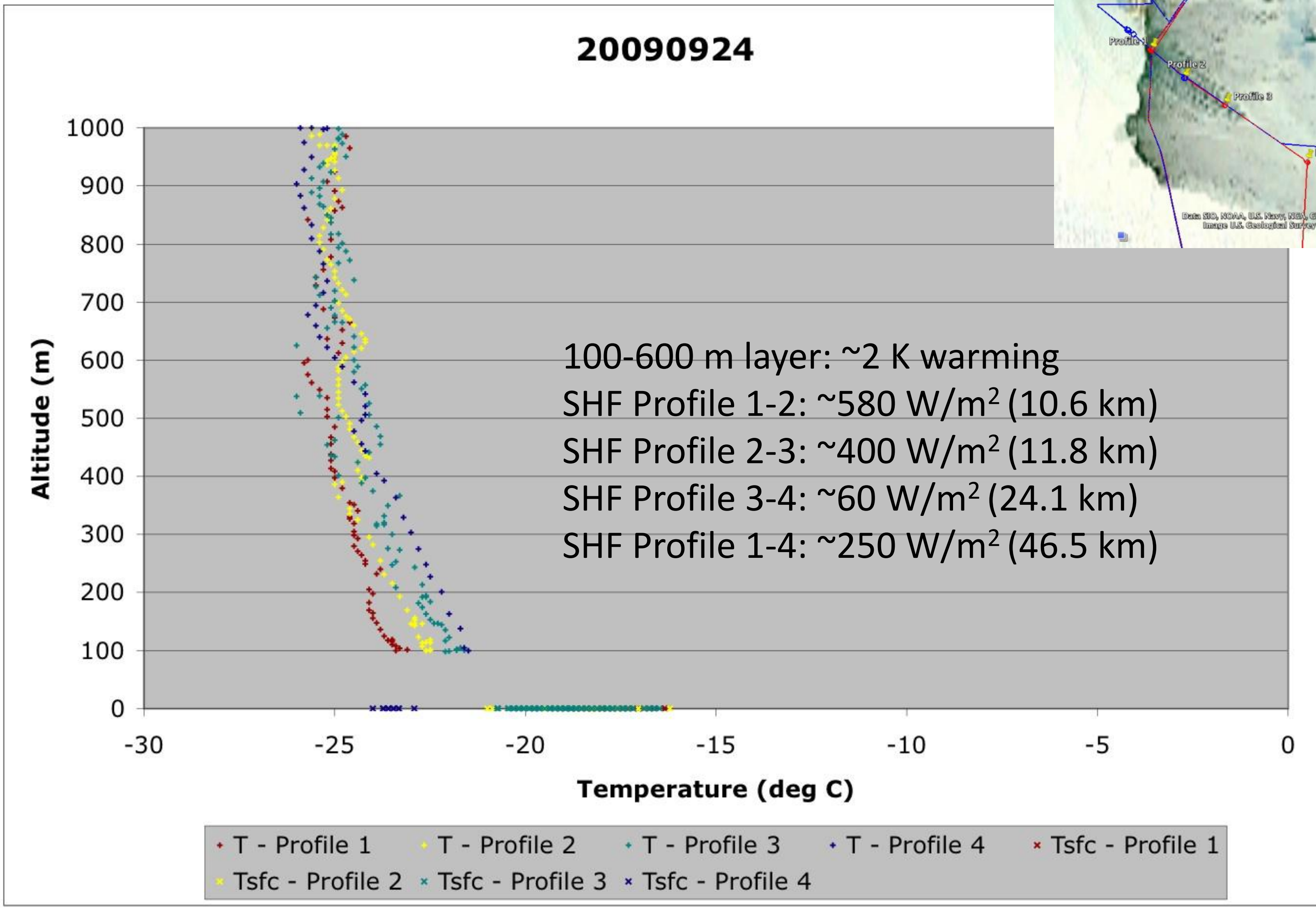


Boundary Layer Observations

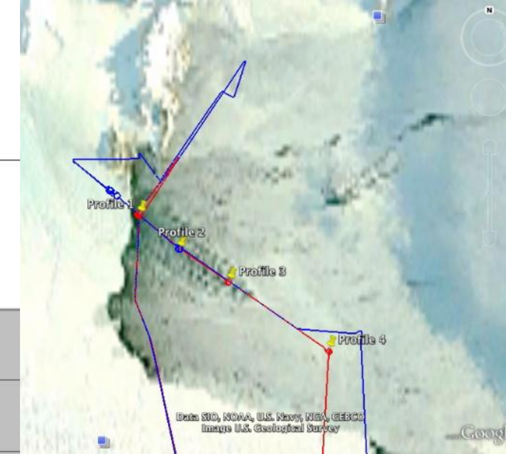
- The boundary layer is where the atmosphere interacts with the underlying components of the climate system
- Aside from surface observations routine boundary layer measurements are lacking

UAVs provide one option for detailed boundary layer measurements

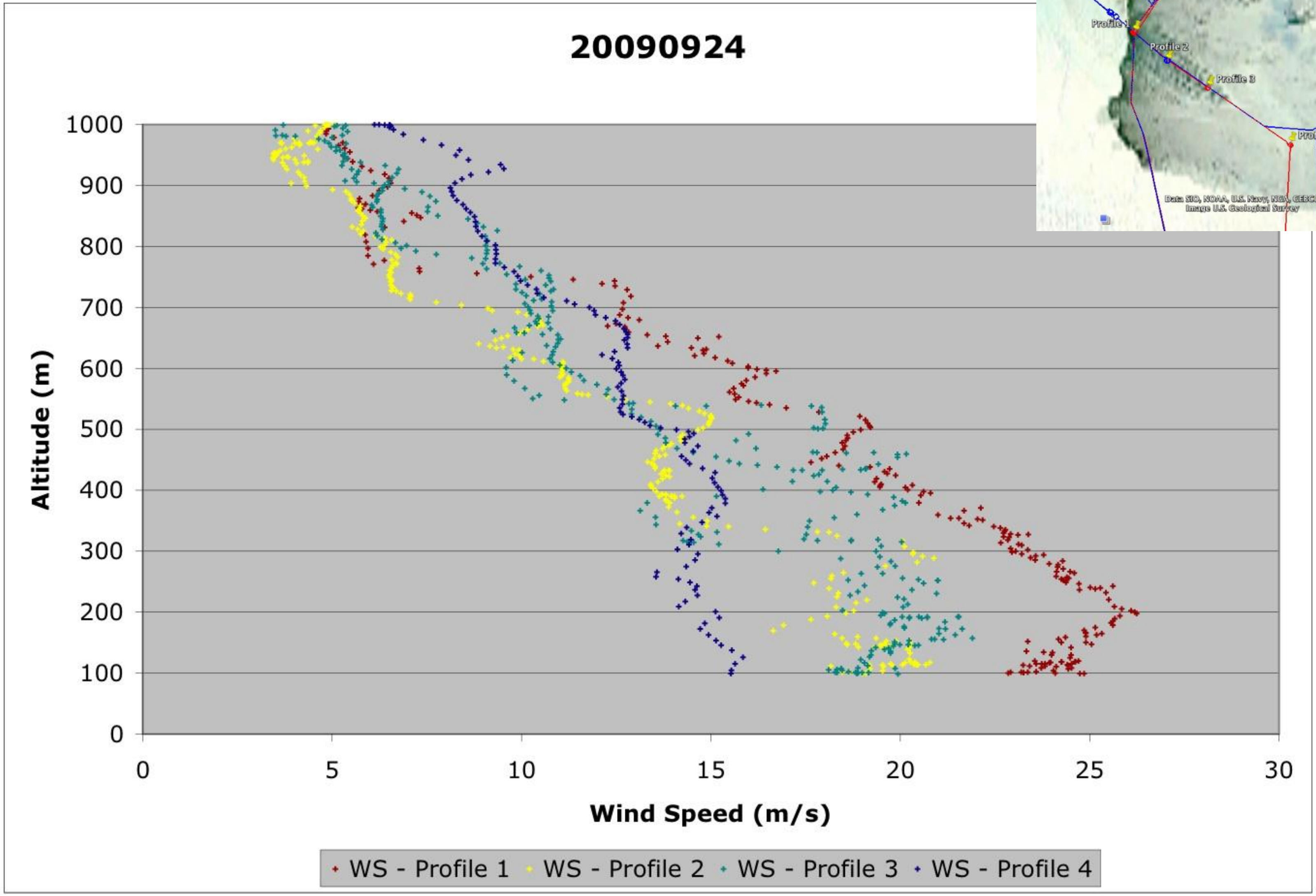
Temperature

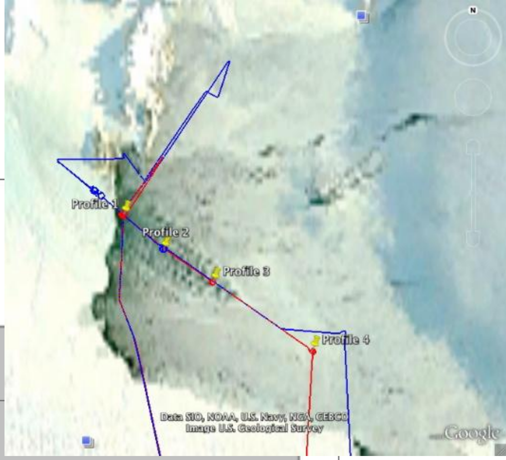


100-600 m layer: ~2 K warming
SHF Profile 1-2: ~580 W/m^2 (10.6 km)
SHF Profile 2-3: ~400 W/m^2 (11.8 km)
SHF Profile 3-4: ~60 W/m^2 (24.1 km)
SHF Profile 1-4: ~250 W/m^2 (46.5 km)



Wind Speed


20090924
Altitude (m)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
25
30
Wind Speed (m/s)
WS - Profile 1
WS - Profile 2
WS - Profile 3
WS - Profile 4


Profile 1
Profile 2
Profile 3
Profile 4
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image U.S. Geological Survey
Google

Why measure polar clouds?

- The Arctic is warming faster than the rest of the globe
- Climate model predictions show the largest model to model variations in the polar regions
- Clouds are one of the largest source of uncertainty in the models
- Data for evaluating model simulated clouds is lacking, especially in polar regions where typical satellite cloud retrievals struggle

Polar Clouds: Science Questions

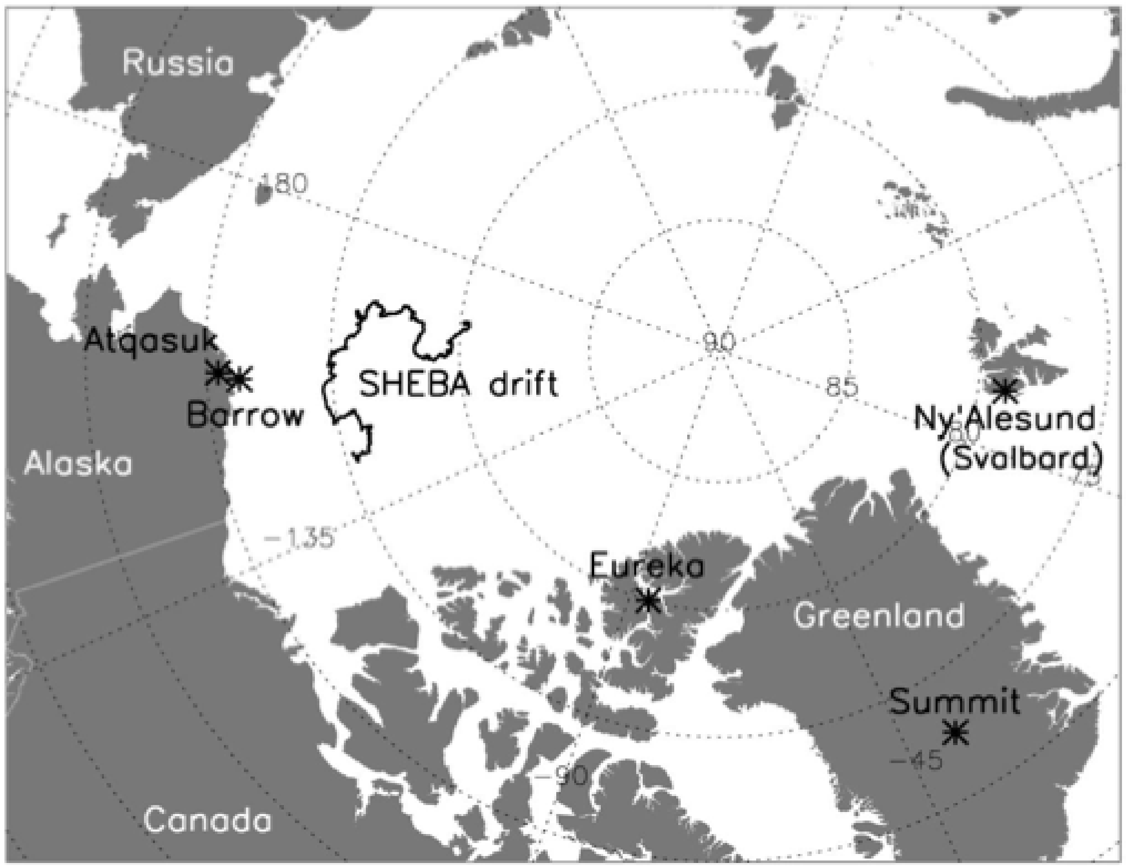
- How do the macro- and micro-physical properties of polar clouds vary seasonally in the polar regions?
- What are the conditions under which polar clouds form? What determines the phase of cloud particles?
- How are cloud properties influenced by local and regional meteorological variables?
- How do clouds influence radiative fluxes?
- How might parameterizations of polar clouds be improved in NWP and climate models?

Polar Clouds: Needed Observations

- Routine meteorological observations to complement cloud studies
  - Vertical profiles are especially important
  - Autonomous, ground-based network of meteorological and surface energy budget measurements
- Network of atmospheric observatories
  - Build upon "super sites" at Barrow, Eureka, Summit, Ny'Alesund, Tiksi, …
  - Permanent Arctic Ocean observatory
  - Antarctic observatory
- Network of precipitation and accumulation measurements

What are we doing now?

- Atmospheric "Super Sites"

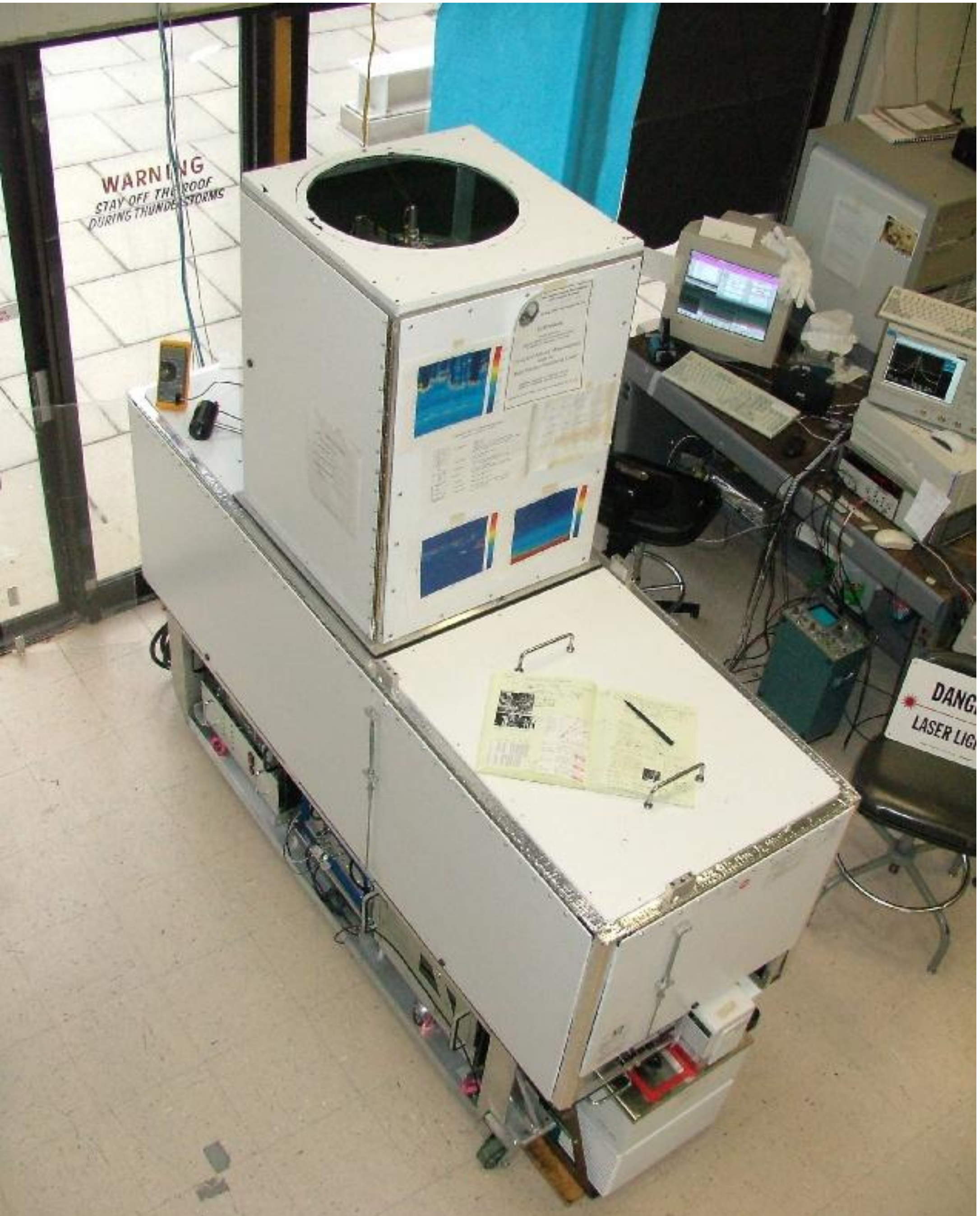


What are we doing now?

<u>Instrumentation at "Super Sites"; Barrow, Eureka, and Summit</u>

- **Millimeter Cloud Radar (MMCR)**
  - NOAA CIRES
- **Cloud Lidars**
  - HSRL (Eloranta), CAPABL (Neely), MPL and ceilometer (DOE)
- **Polar Atmospheric Emitted Radiance Interferometer**
  - PAERI measures spectral infrared radiance from 3 to 20 μm (1 cm^{-1})
- **Microwave Radiometer (MWR)** - total column water vapor
  - NOAA, SSEC
- **Radiosondes** (from Barrow, Eureka Weather Office, now from Summit)
- **Precipitation Occurrence Sensor System**
- Others
  - NOAA (gases, ozonesondes), NOAA Sodar, 50-m Swiss tower (Sonic anemometers),

University of Wisconsin Arctic High Spectral Resolution Lidar

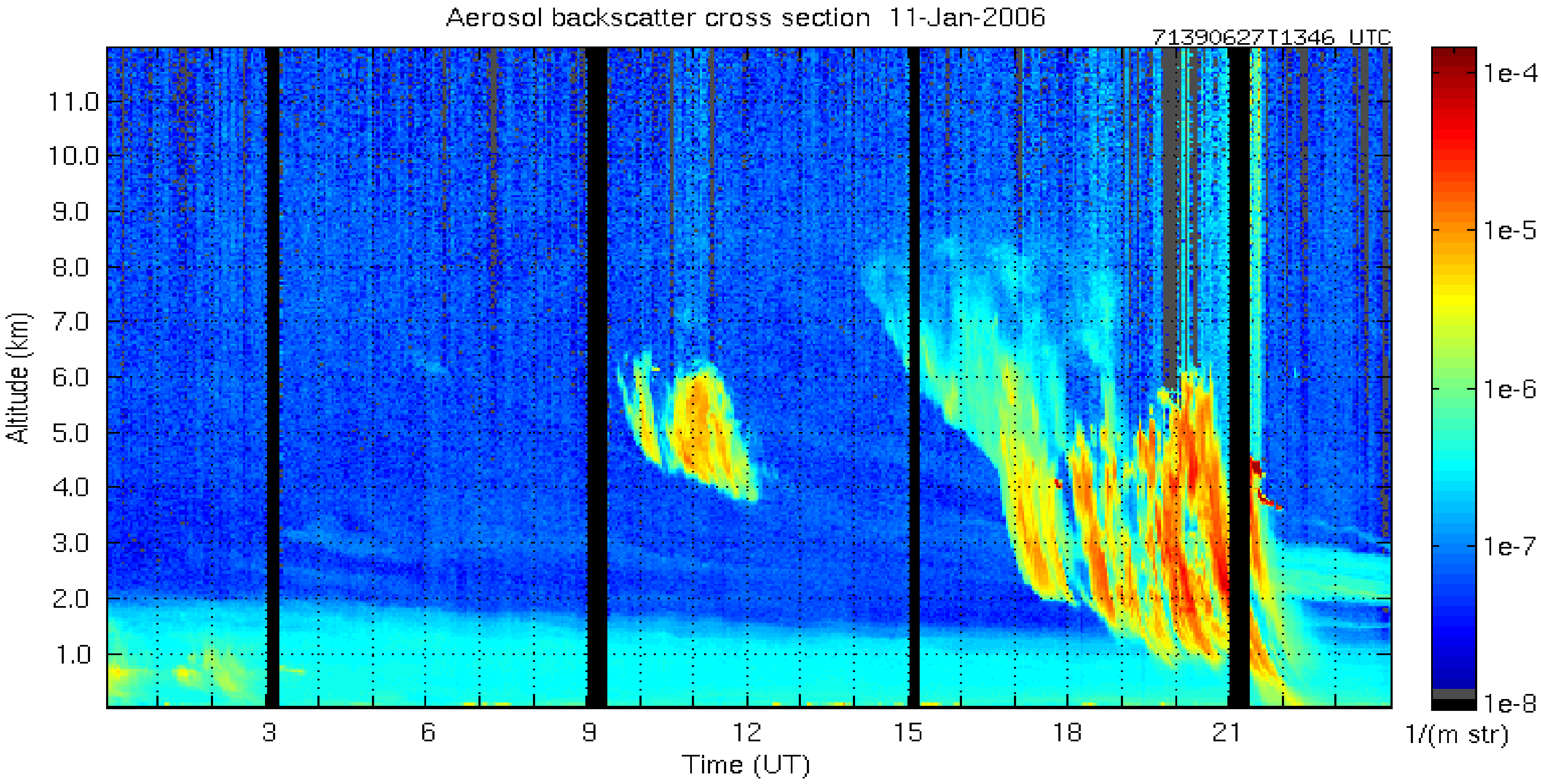


Has operated since Sept 2004 at Eureka, Nunavut.

Provides calibrated measurements of cloud and aerosol backscatter cross sections, optical depth and depolarization.

Vertical resolution 7.5 m
Temporal resolution 2.5 s
Altitudes 100m → 30 km

Ed Eloranta
University of Wisconsin
http://lidar.ssec.wisc.edu



Aerosol backscatter cross section 11-Jan-2006
71390627T1346 UTC
Altitude (km)
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
3
6
9
12
15
18
21
Time (UT)
1e-4
1e-5
1e-6
1e-7
1e-8
1/(m str)

Surface Radiation Budget

- This is a critical climate parameter
- Reflects integrated changes in overlying atmosphere
- Critical for evaluation of model simulations
- Autonomous radiation observations are challenging

Riming Example – SHEBA Radiometers

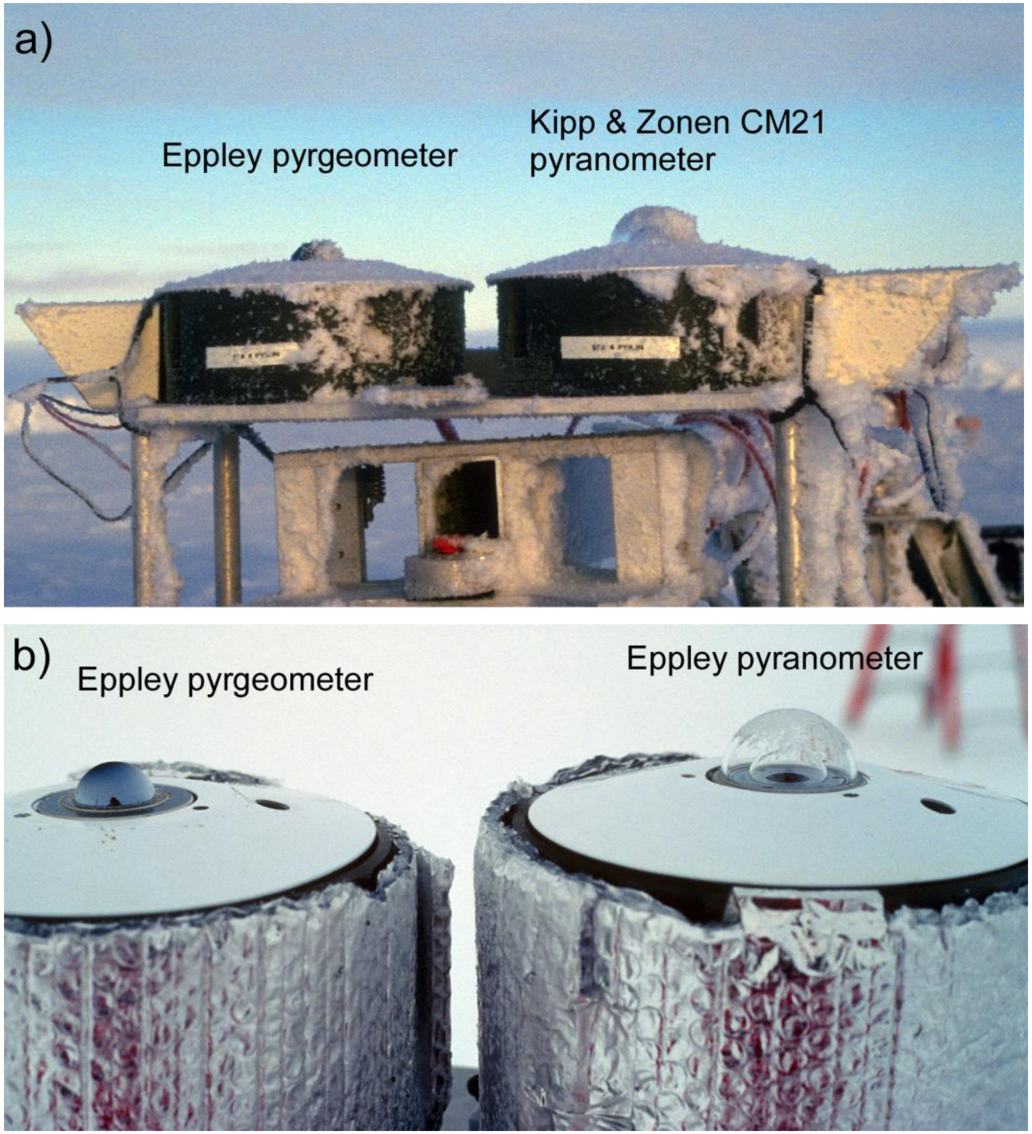


Fig. 2: a) Rimed pyrgeometer and pyranometer on Cleveland PAM station at SHEBA on 980404 at 1805 UTC (~0805 solar time). The radiometers are ventilated with DC power. b) Rimed pyranometer and unrimed pyrgeometer on ASFG mast at 1750 UTC 980408. These radiometers are ventilated (and heated) by AC fans. Logbook indicates this riming on ASFG domes is similar to or slightly less than that on the ASFG domes at time of photo in a). (photos: O. Persson)

Polar Night Riming on Up-looking DC-ventilated Pyrgeometers

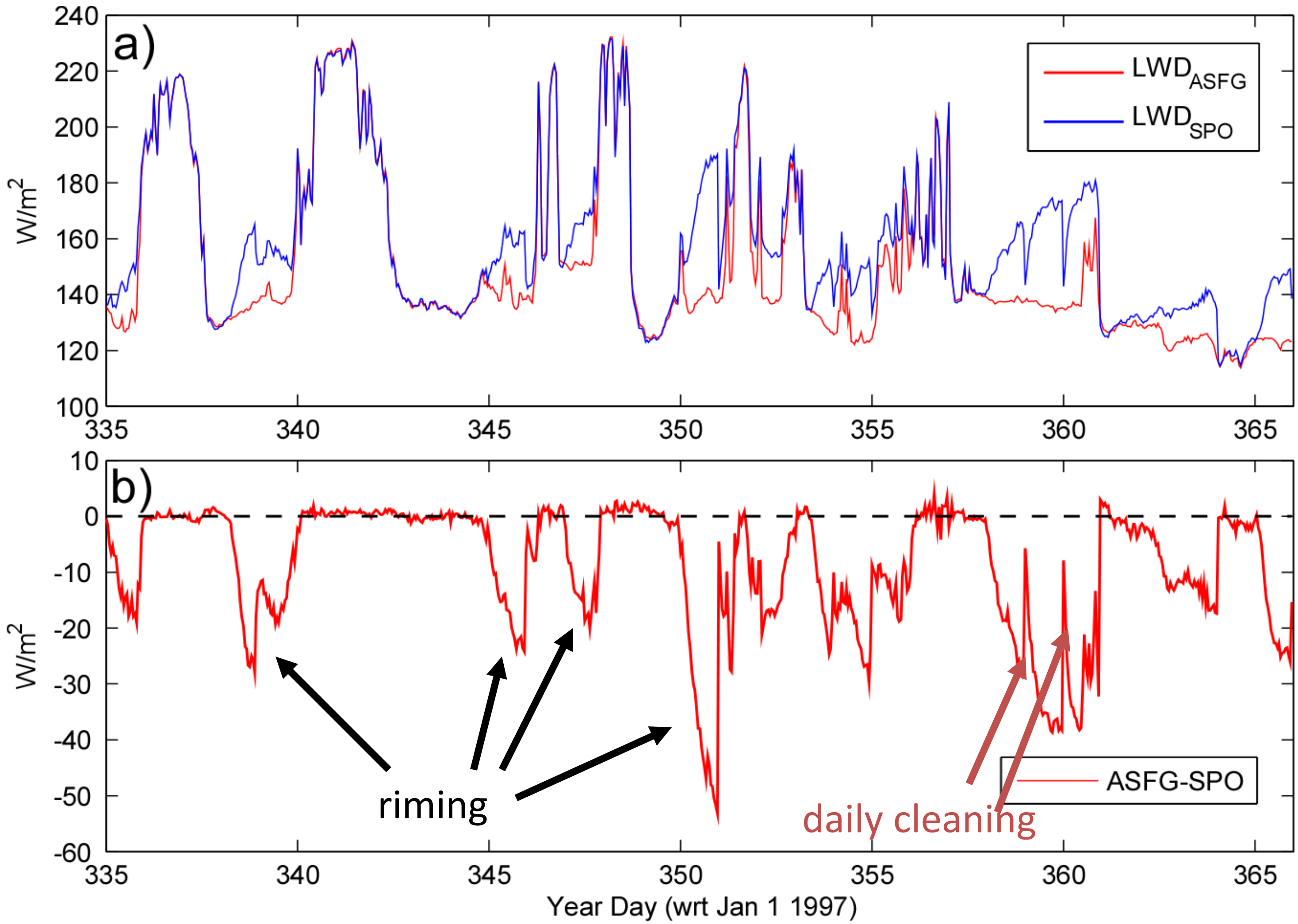
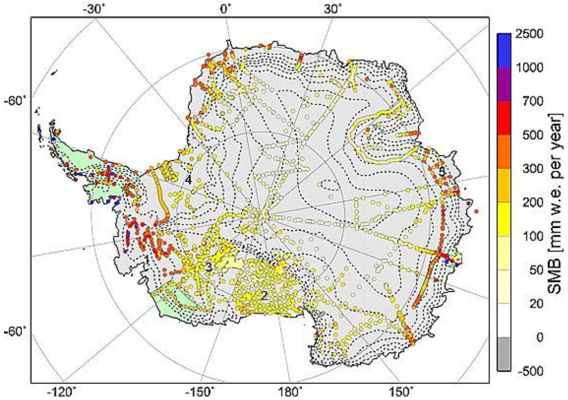


Fig. 3: Time series of a) LW_d at the ASFG tower(red) and the SPO site (blue) at SHEBA for the month of December 1997and b) the difference LW_d (ASFG) -LW_d (SPO). The dashed line in b) is 0 W m^{-2}.

Precipitation: Snow accumulation

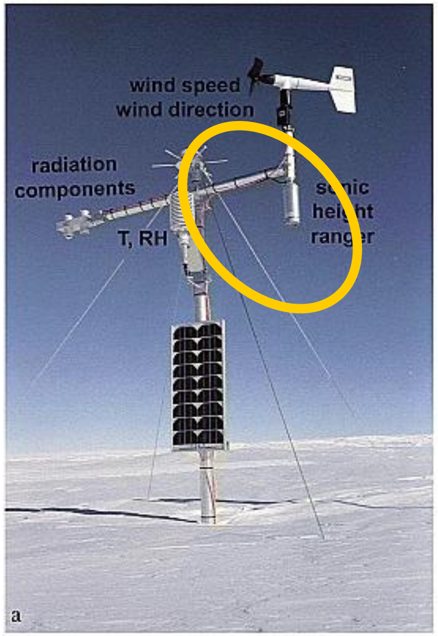
- Measurement of polar precipitation is very challenging
  - Sparse observations
  - Blowing snow
- As a result knowledge of polar precipitation relies heavily on reanalyses and models
- Evaluation of model simulated precipitation is difficult because:
  - Uncertainties in long-term accumulation maps
  - Limited data for model validation on short time scales
  - Difficult to partition “new” precipitation from wind blown precipitation

SMB in-situ observations



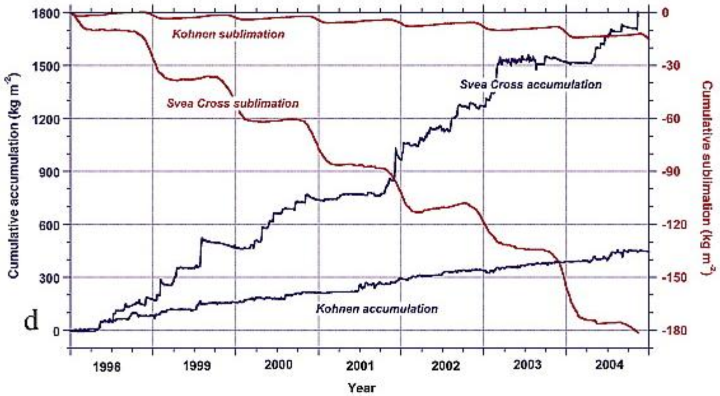
[Van de Berg et al., 2006]

Precipitation Observations



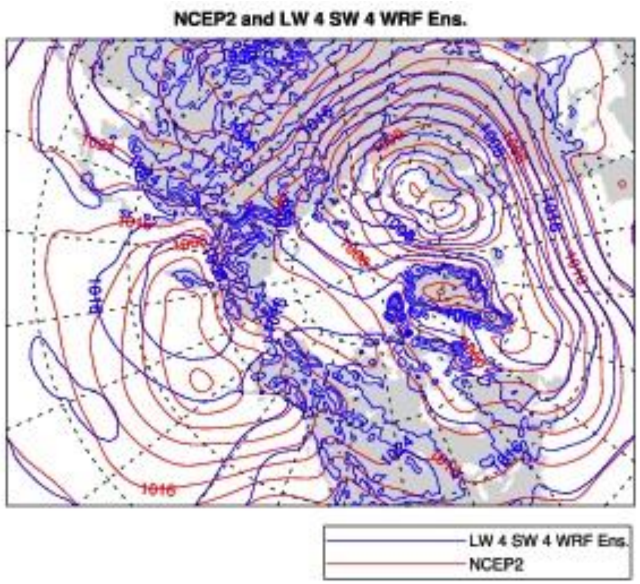
- Ultrasonic height rangers
  - Measure surface height changes with high temporal frequency (minutes)
  - Challenges
    - Because of high spatial variability of precipitation, deployment of multiple sensors within a limited area ("farms") is necessary
    - Conversion height → mass changes depends upon accurate estimation of snow density
    - Servicing requirements
    - Problems in high-accumulation areas because of sensor rapidly buried.

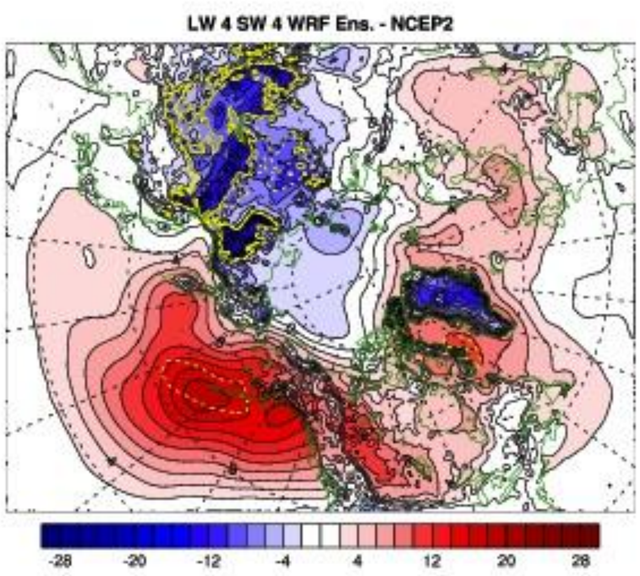
SMB Time series in Dronning Maud Land from ultrasonic rangers



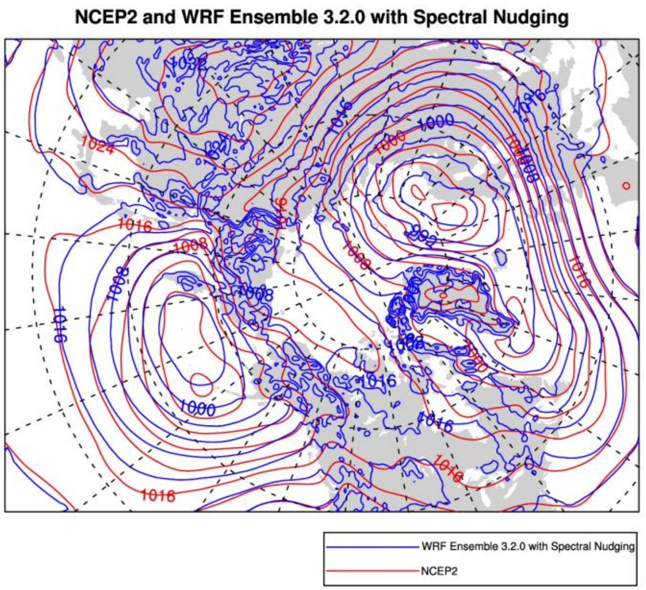
[Eisen et al., 2008]

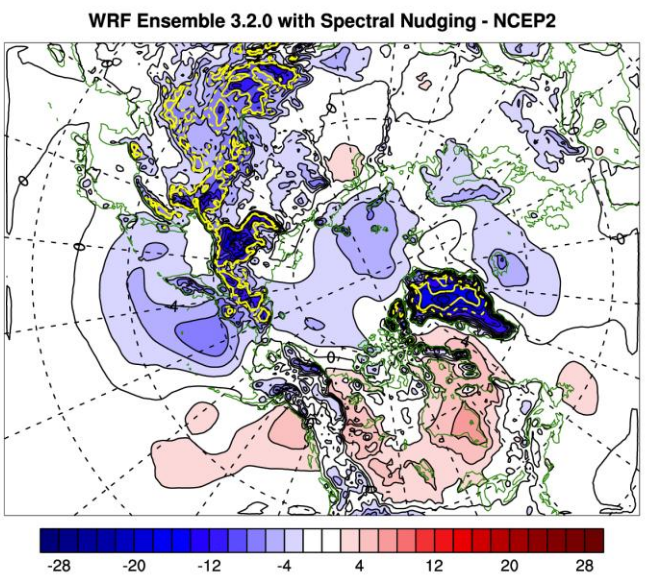
Model evaluation

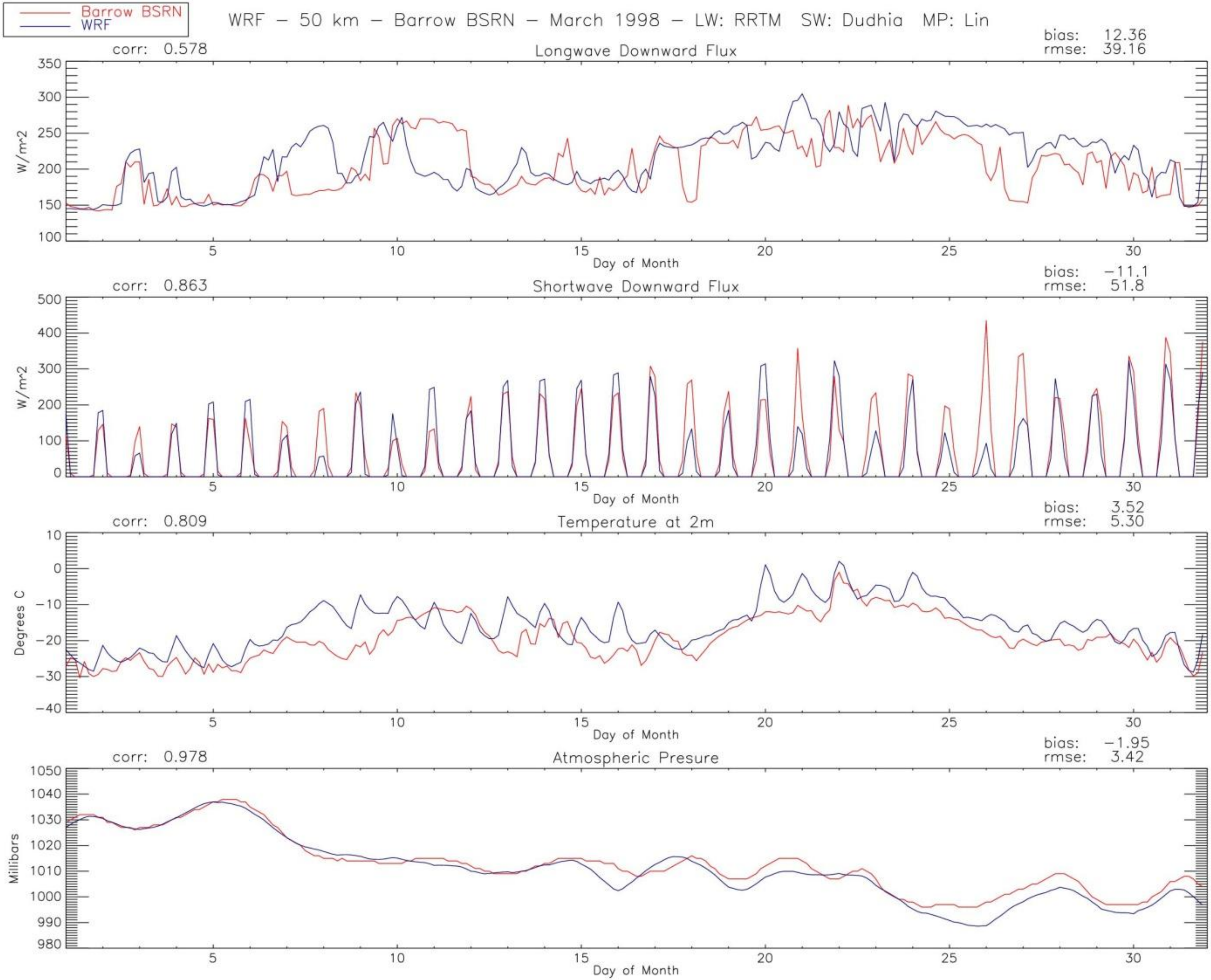




- Need to evaluate models on several scales
    - At largest scales need to compare model to reanalyses
    - At smaller scales can compare model to point observations

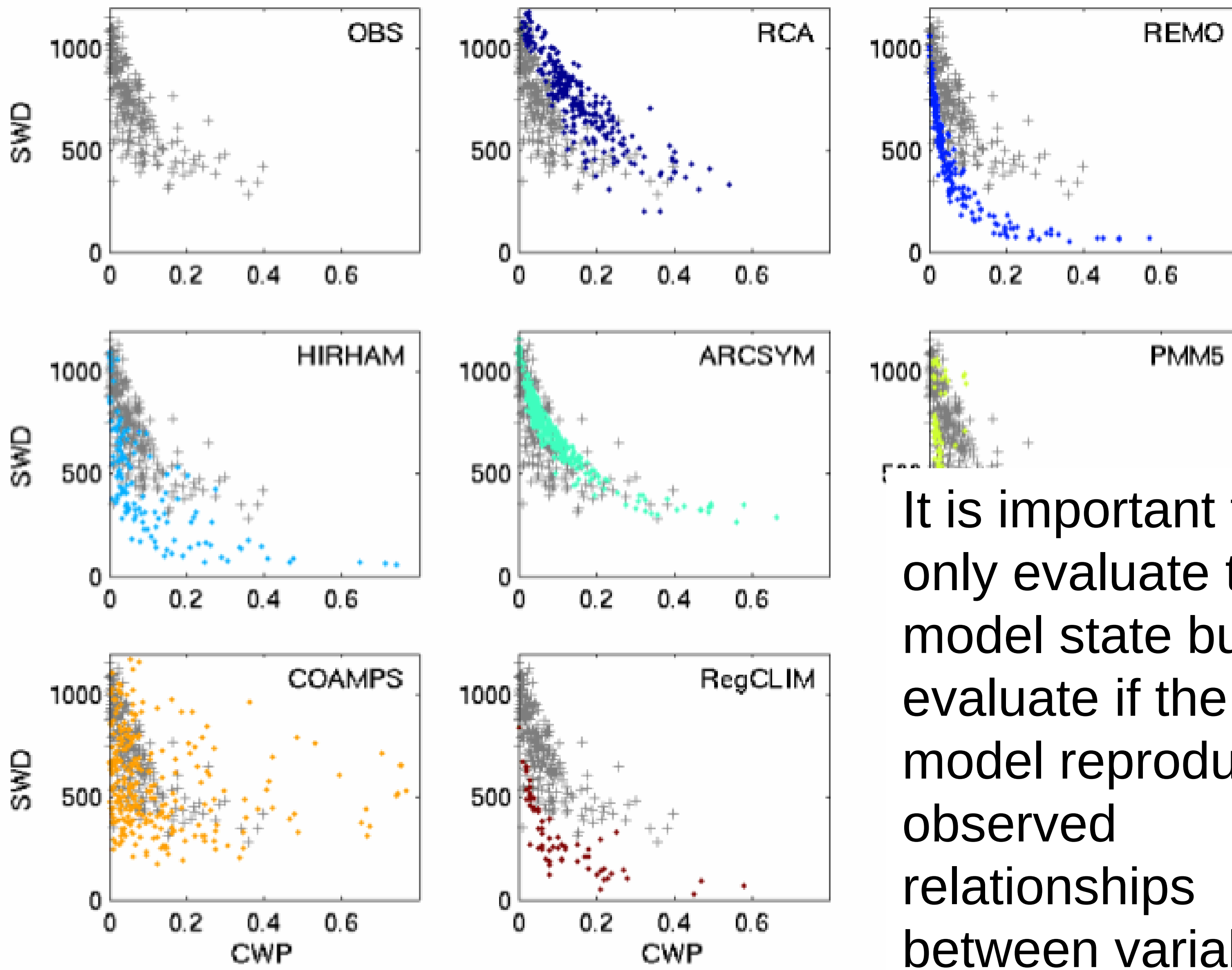






Barrow BSRN
WRF
WRF – 50 km – Barrow BSRN – March 1998 – LW: RRTM SW: Dudhia MP: Lin
corr: 0.578
Longwave Downward Flux
bias: 12.36
rmse: 39.16
W/m^2
Day of Month
corr: 0.863
Shortwave Downward Flux
bias: −11.1
rmse: 51.8
W/m^2
Day of Month
corr: 0.809
Temperature at 2m
bias: 3.52
rmse: 5.30
Degrees C
Day of Month
corr: 0.978
Atmospheric Presure
bias: −1.95
rmse: 3.42
Milibars
Day of Month

Model Evaluation: Physical Processes



It is important to not only evaluate the model state but to evaluate if the model reproduces observed relationships between variables