The Atmospheric Radiation Measurement (ARM) Program

A Laboratory for the Study of Clouds and Atmospheric Radiation

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Why Study Clouds and Radiation?

- Clouds control the radiation balance of the planet – top of atmosphere (TOA) and surface
  - Solar reflectivity at TOA and surface transmission
  - Infrared loss at TOA and surface heating
- Cloud feedback processes (how cloud properties change in response to changes in climate forcing) are the most important and least understood component of climate change simulations

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Intergovernmental Panel on Climate Change (IPCC) Assessment Report 2001

Clouds

As has been the case since the first IPCC Assessment Report in 1990, probably the greatest uncertainty in future projections of climate arises from clouds and their interactions with radiation. Clouds can both absorb and reflect solar radiation (thereby cooling the surface) and absorb and emit long wave radiation (thereby warming the surface). The competition between these effects depends on cloud height, thickness and radiative properties. The radiative properties and evolution of clouds depend on the distribution of atmospheric water vapour, water drops, ice particles, atmospheric aerosols and cloud thickness.

Why Study Clouds and Radiation?

- Weather forecasting
  - Forecasts of more than a day require accurate radiation (cloud) specification (ECMWF)
- Regional hydrology
  - Improving forecasts of severe storms and floods requires improvements in representation of cloud microphysics, interactions with radiation, and precipitation formation

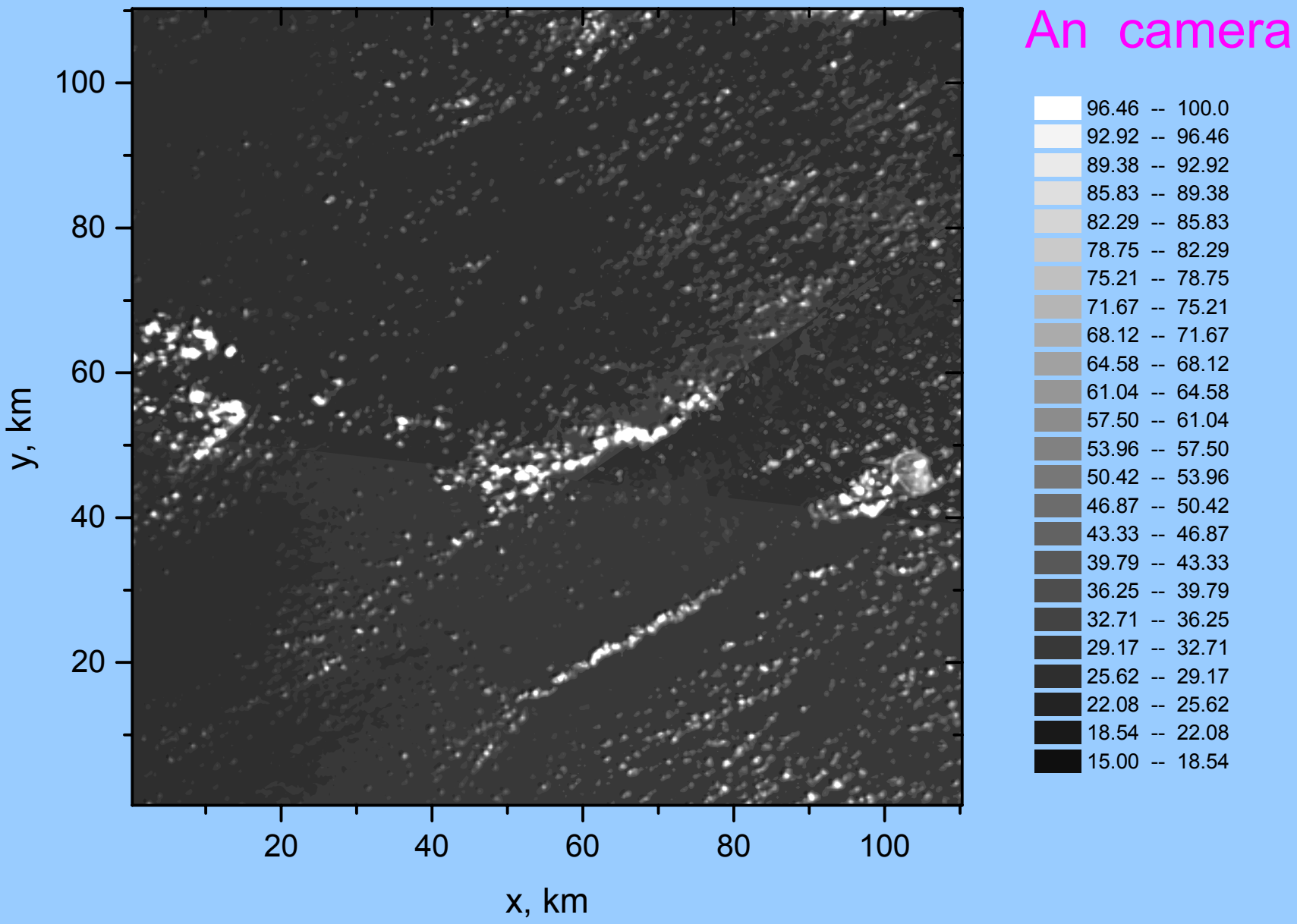
Why is the cloud problem so difficult?

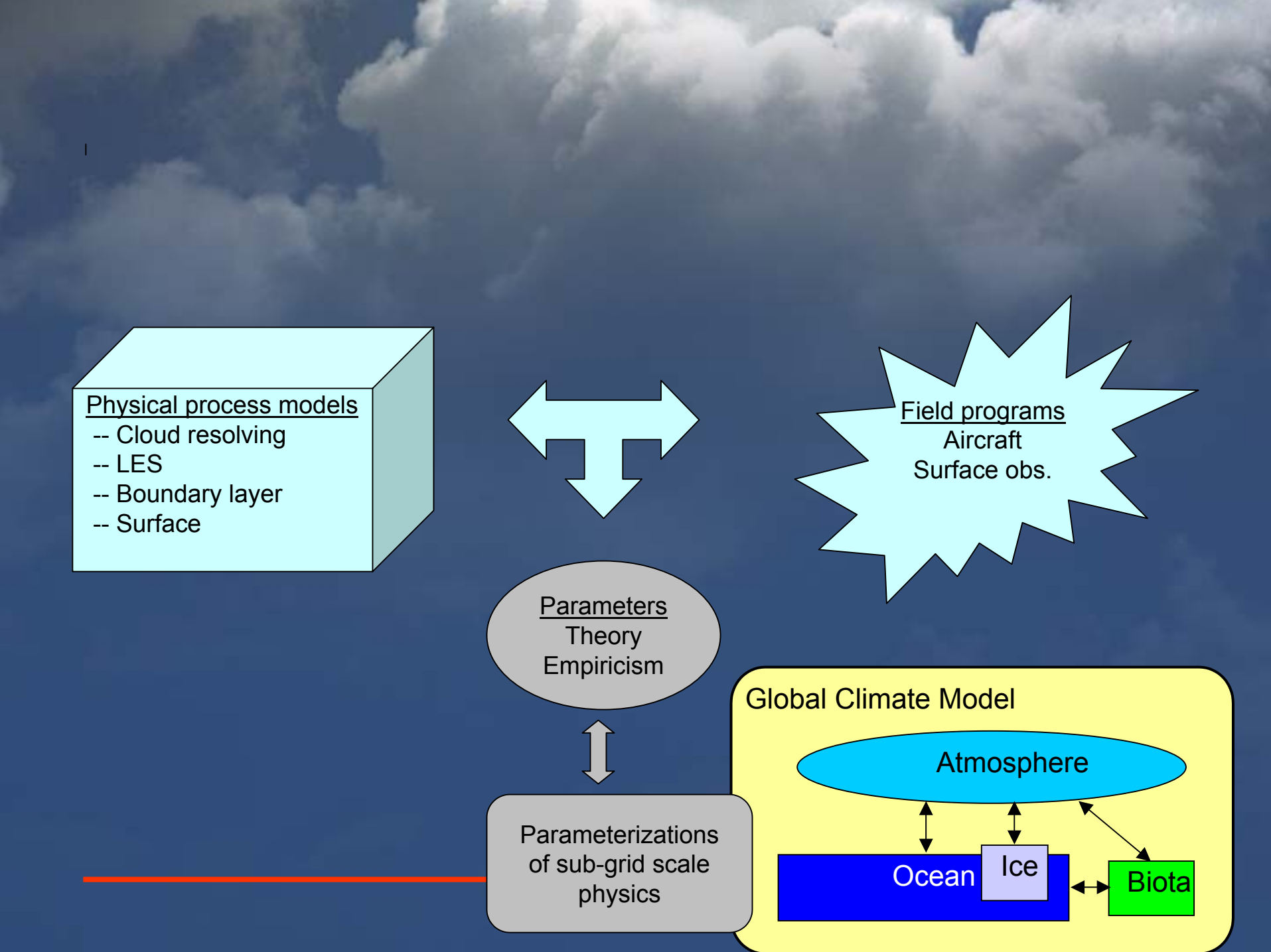
- Clouds are complicated
- Clouds are sub-grid scale in global models so they must be parameterized

Parameterization

In numerical models, the *approximate* representation, using a combination of theory and observations, of the relationship between a sub-grid scale process (clouds) and the large-scale computed model fields (temperature, humidity, winds).

Tropical trade cumulus – MISR (250 m spatial resolution)




Physical process models
-- Cloud resolving
-- LES
-- Boundary layer
-- Surface
Field programs
Aircraft
Surface obs.
Parameters
Theory
Empiricism
Parameterizations
of sub-grid scale
physics
Global Climate Model
Atmosphere
Ocean
Ice
Biota

Atmospheric Radiation Measurement Program

Goal

Improve the treatment of cloud and radiation physics in global climate models in order to improve the climate simulation capabilities of these models

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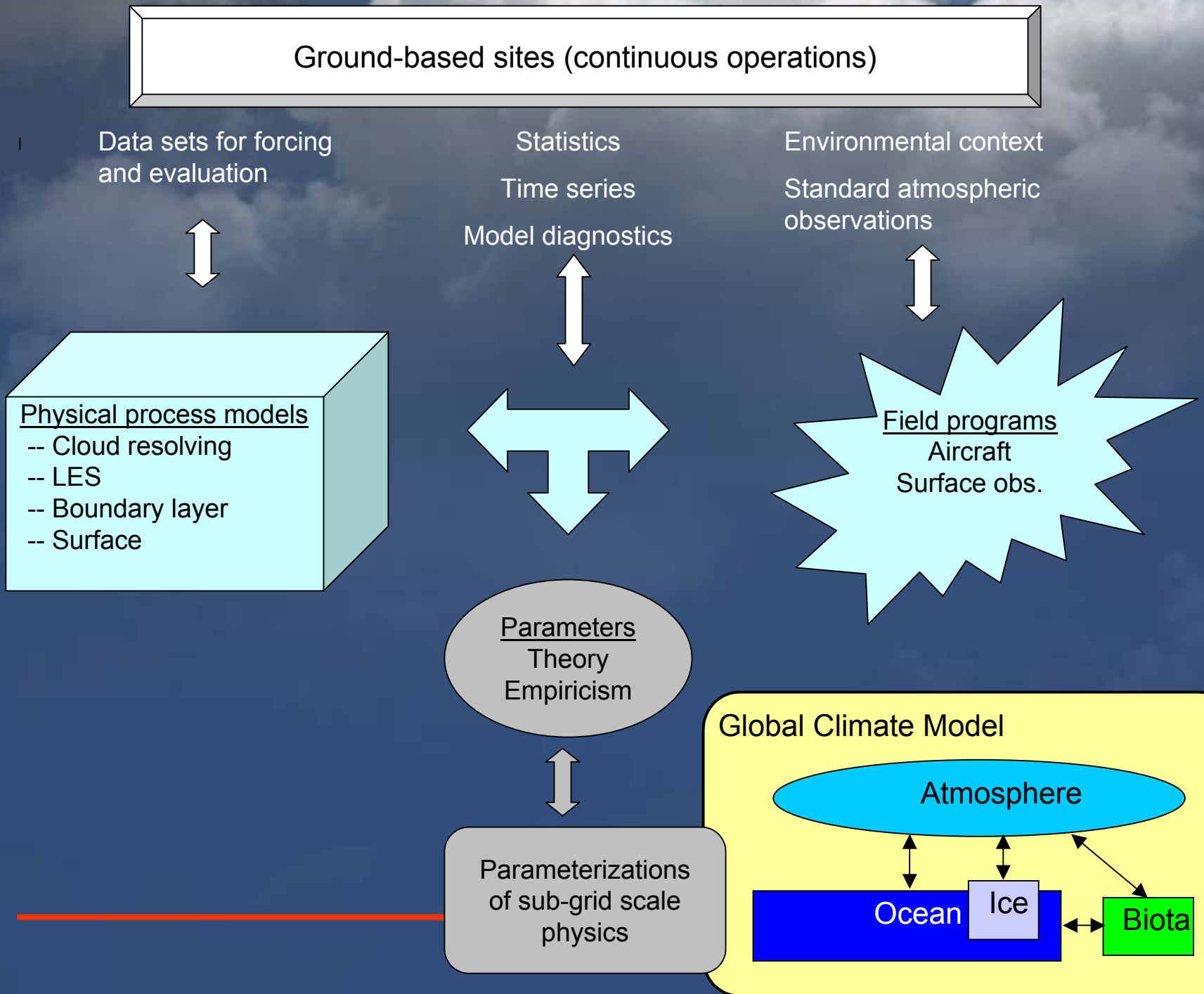
Ground-based sites (continuous operations)
Data sets for forcing and evaluation
Statistics
Time series
Model diagnostics
Environmental context
Standard atmospheric observations
Physical process models
-- Cloud resolving
-- LES
-- Boundary layer
-- Surface
Field programs
Aircraft
Surface obs.
Parameters
Theory
Empiricism
Parameterizations of sub-grid scale physics
Global Climate Model
Atmosphere
Ocean
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Biota

Desirable characteristics of ground-based data

- Continuous => temporal variability
- Comprehensive => cause and effect
- Useful to the broad science community
  - Of known and reliable accuracy
  - Easily available
- Spatially distributed
  - On the scale of model grid scales
  - Across climatic zones

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Two Fundamental Questions

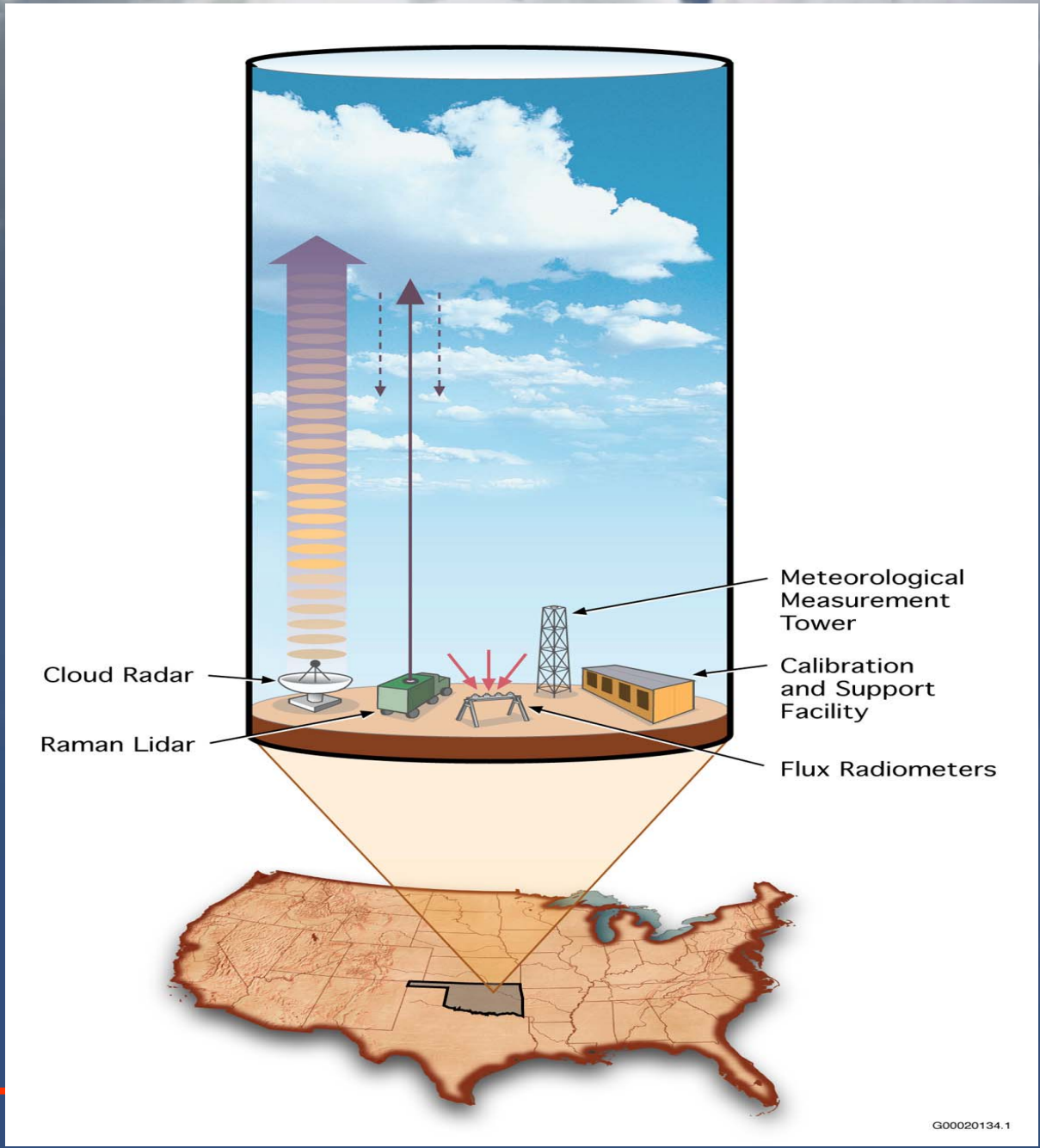
1. ***If we can specify all the properties of an atmospheric column, can we compute the radiative fluxes?***

   => Requires knowledge of atmosphere and cloud properties (water vapor, temperature, 3D cloud structure, water path, phase, size, etc.)

Need atmospheric observations to

-- test hypotheses in process model studies

-- analyze data for empirical relationships and statistical characteristics

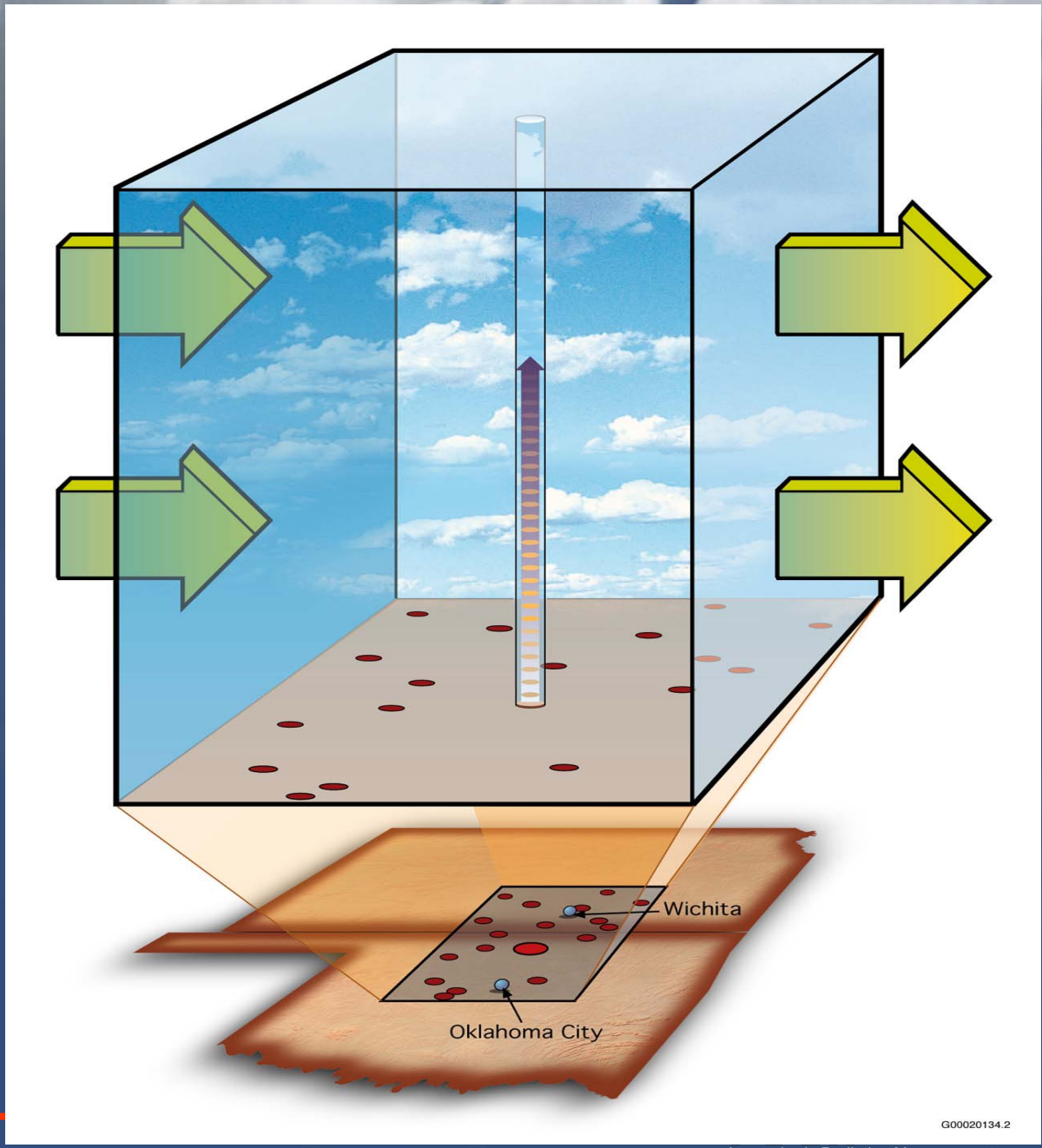


Two Fundamental Questions

2. ***If we can specify the large-scale atmospheric fields in some grid box, can we predict the cloud field properties associated with those properties?***

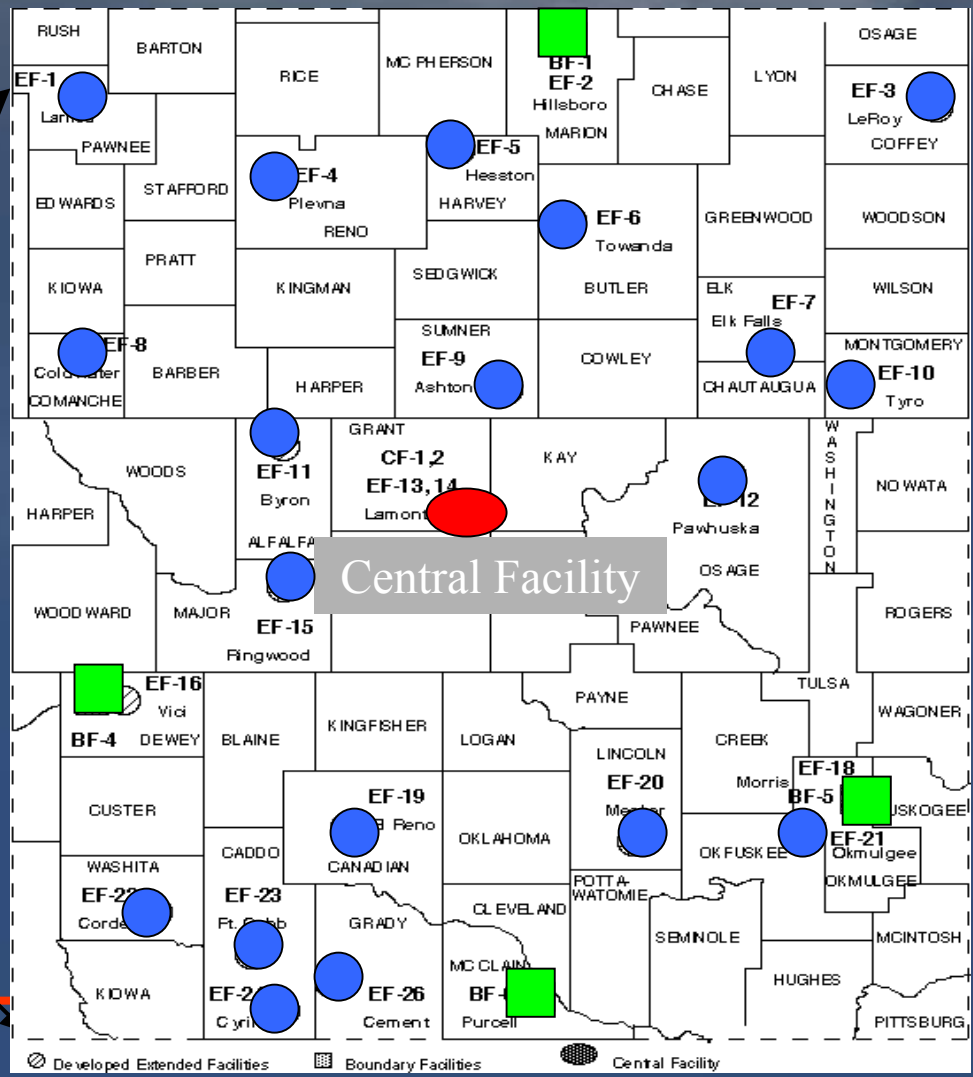
   => Requires 3D field of state properties *and* cloud field properties

Need data sets that describe the large scale environment in which clouds form



Location of Current ARM Sites

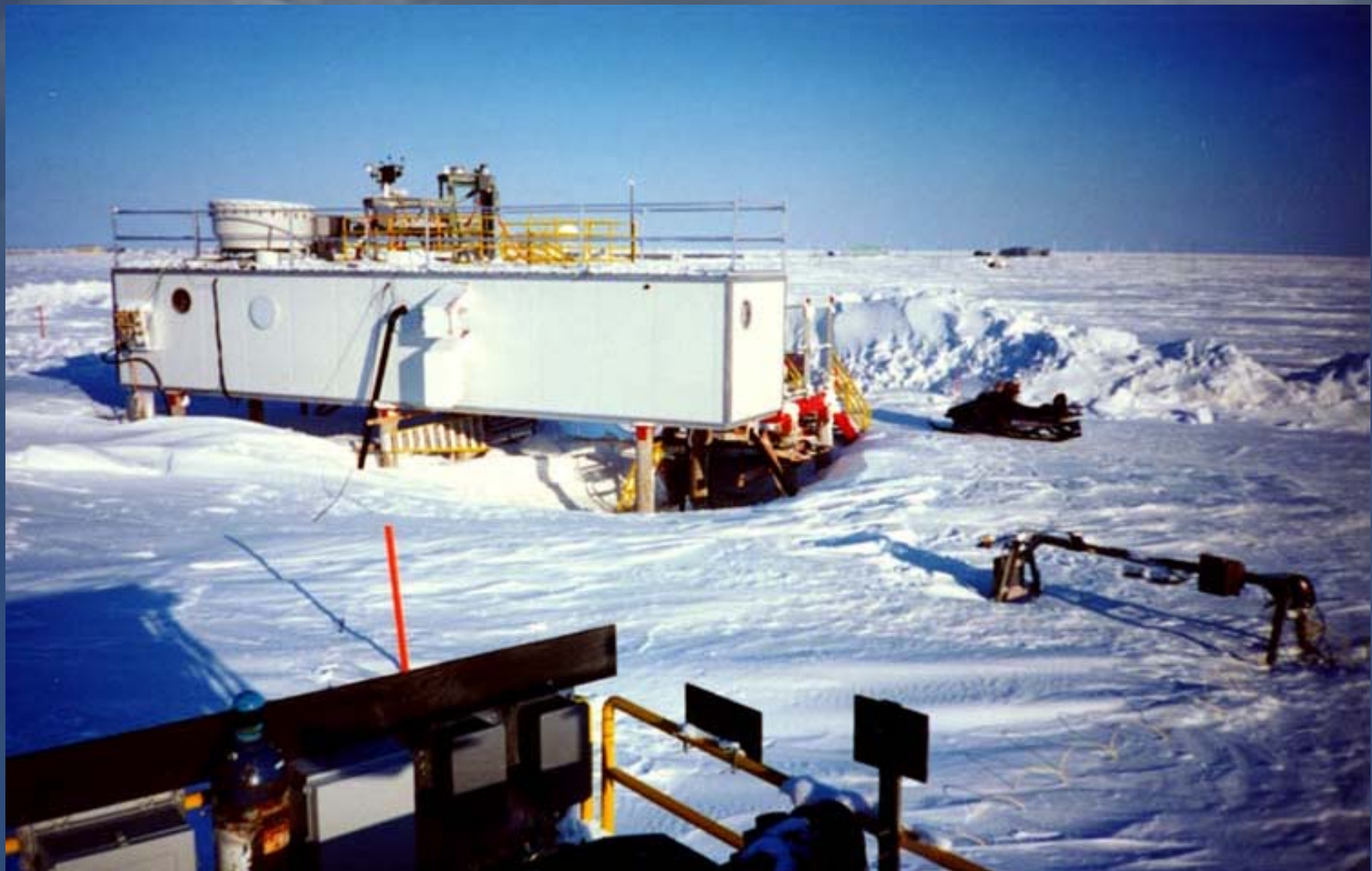
Southern Great Plains Site



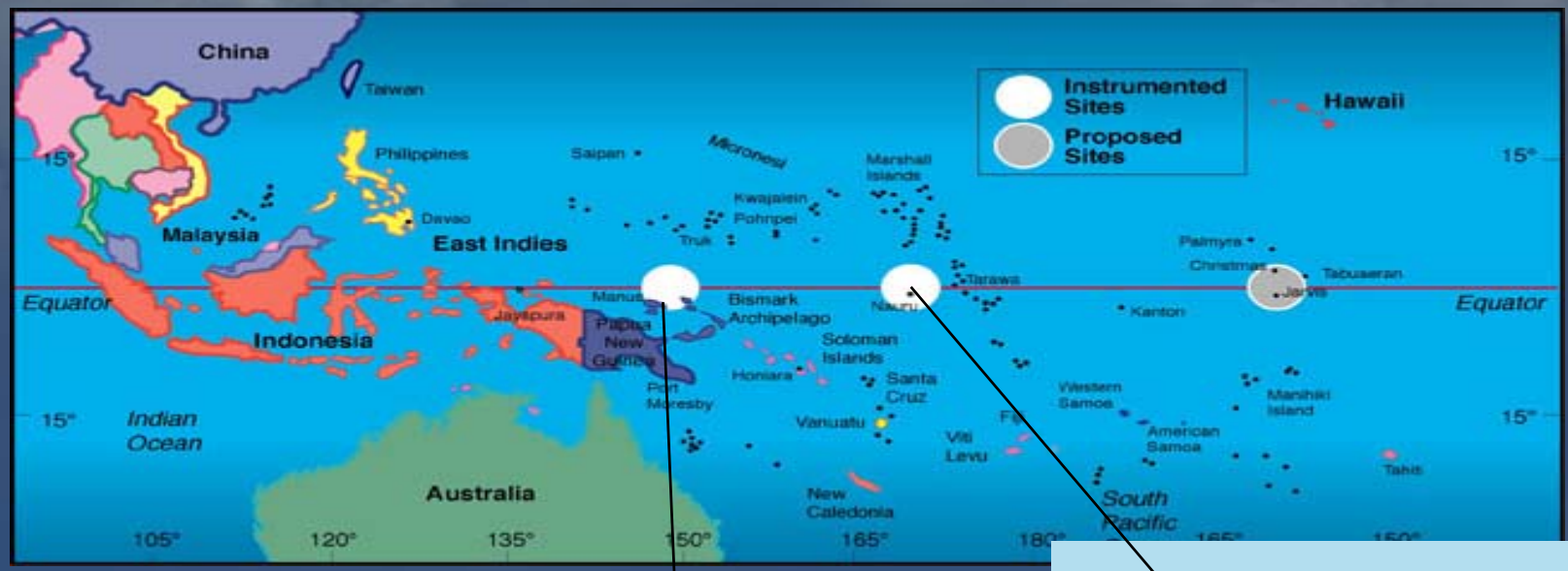
Southern Great Plains Central Facility

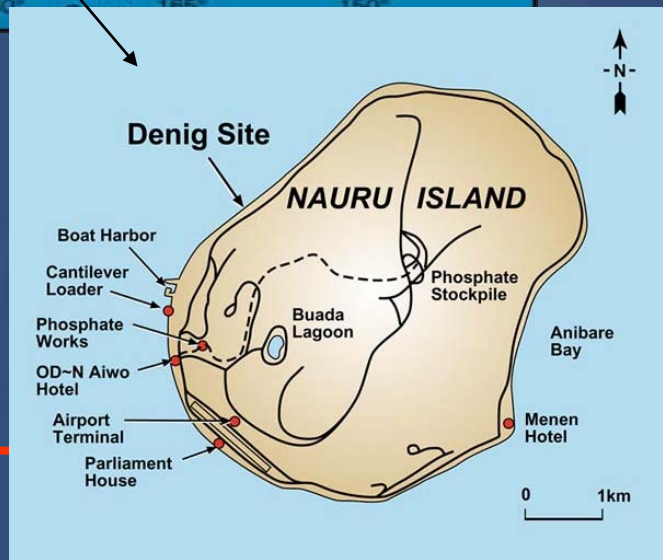
North Slope of Alaska Site

North Slope of Alaska Site



Tropical Western Pacific Site





Tropical Western Pacific Site

Nauru

Manus Island

Tropical Western Pacific Site -- Darwin

Ground-based Remote Sensing Instrumentation

- 35 GHz Radar (cloud properties)
- Lidar (pulsed laser; particle and thin cloud properties)
- Sky imagers (cloud cover)
- Broad-band and narrow-band radiometers (solar and infrared radiation)
- Microwave radiometer (water vapor and liquid water)
- Meteorology sensors (temp, humidity, winds)

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ARM Program Components

- Development and operation of ground-based remote sensing facilities
- Continuous data acquisition and archiving
- Data analysis
- Physical process modeling
- Parameterization development and testing

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ARM Science -- Some Examples*

- **Instrument development and data analysis**

- Radiation studies
- Cloud model studies
- Parameterization testing and development

* Lots of possible choices!

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Total Sky Imager -- Nauru

99-07-13 1150

99-07-13 1351

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ARM Raman Lidar

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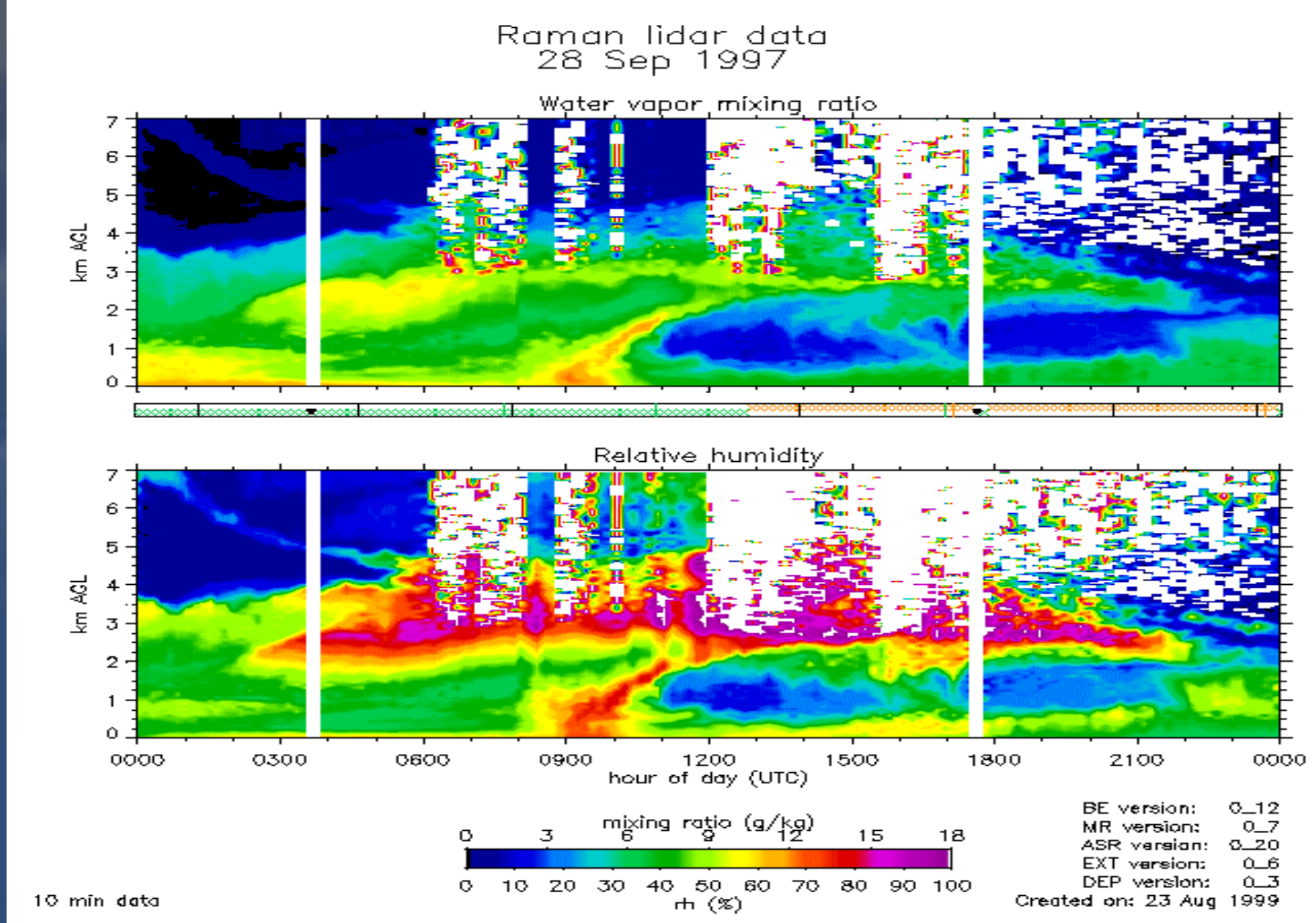

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ARM Millimeter Cloud Radar (MMCR)

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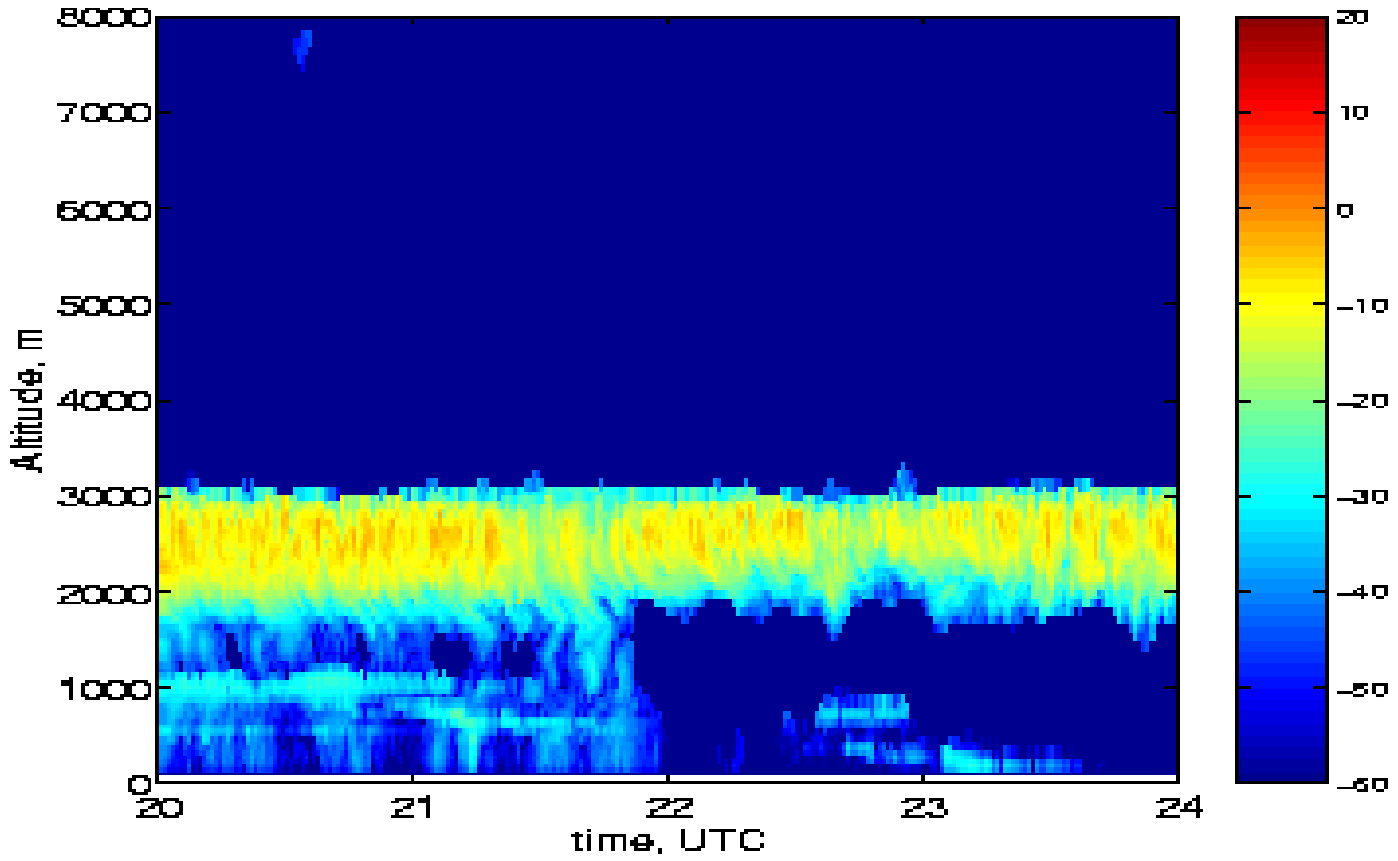
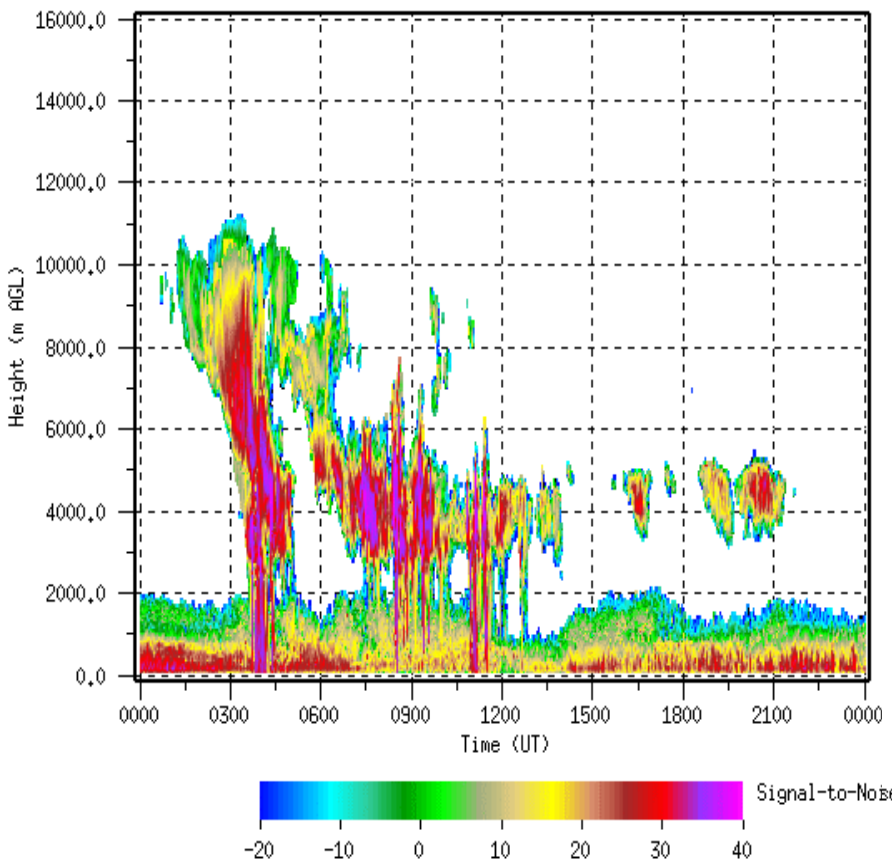
35 GHz Radar Reflectivity (Arctic)

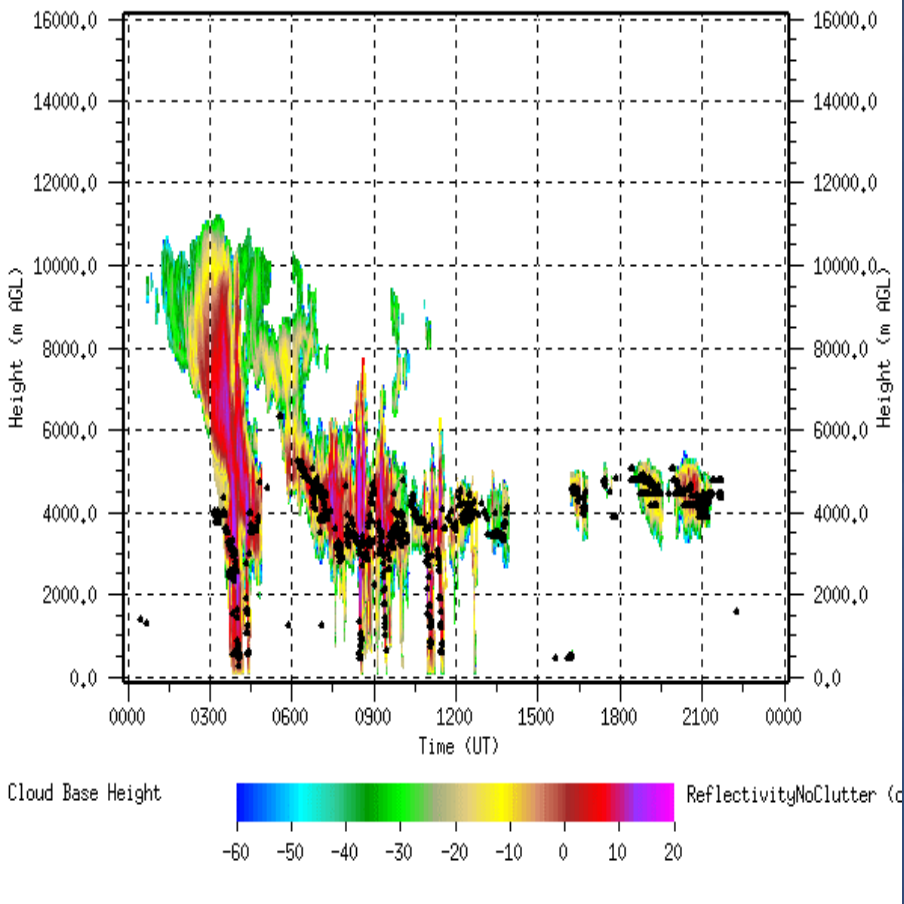


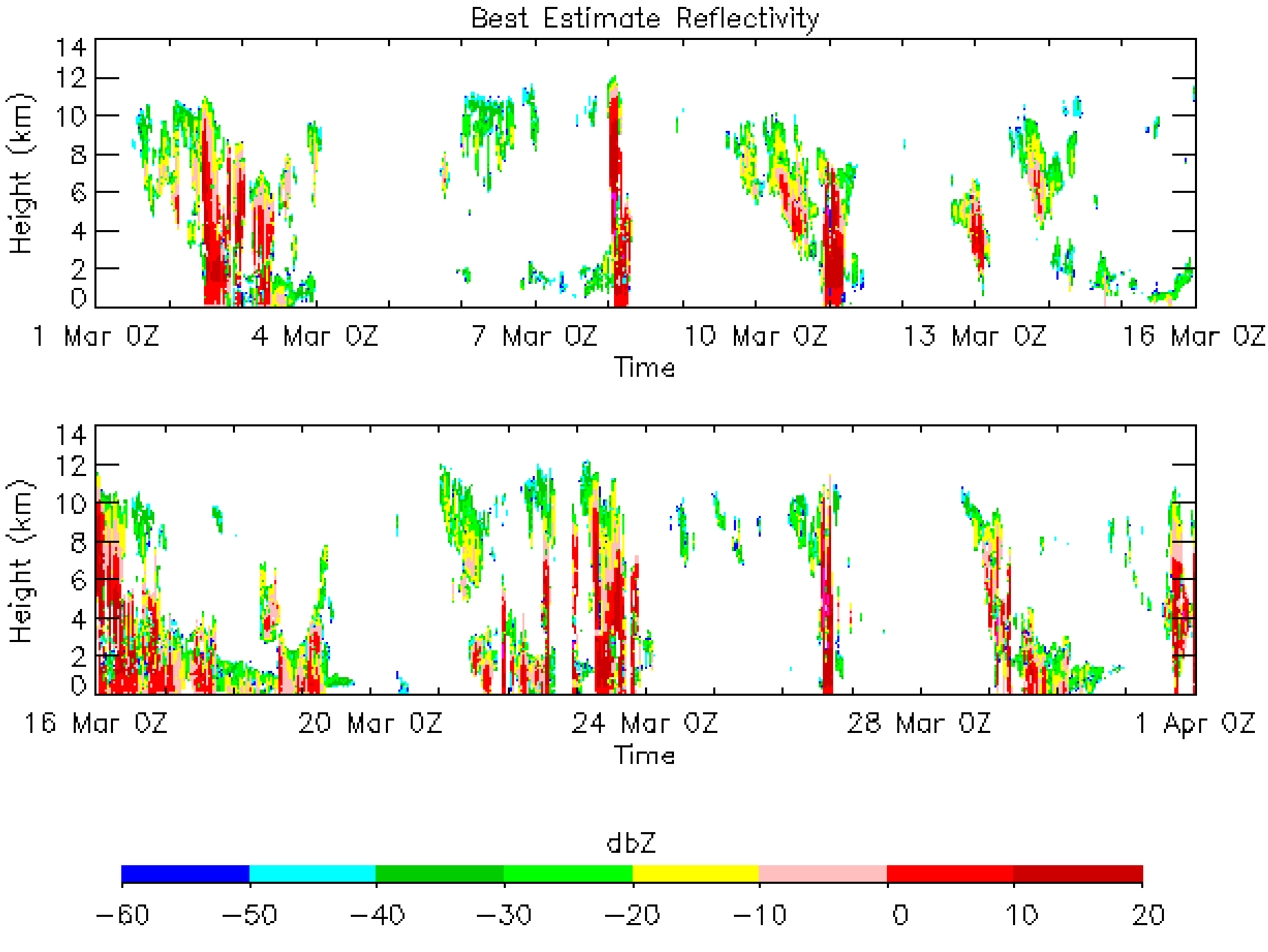
Cloud Boundary Product

Radar only

Radar & lidars






Best Estimate Reflectivity
Height (km)
0
2
4
6
8
10
12
14
1 Mar 0Z
4 Mar 0Z
7 Mar 0Z
10 Mar 0Z
13 Mar 0Z
16 Mar 0Z
Time
Height (km)
0
2
4
6
8
10
12
14
16 Mar 0Z
20 Mar 0Z
24 Mar 0Z
28 Mar 0Z
1 Apr 0Z
Time
dbZ
−60
−50
−40
−30
−20
−10
0
10
20

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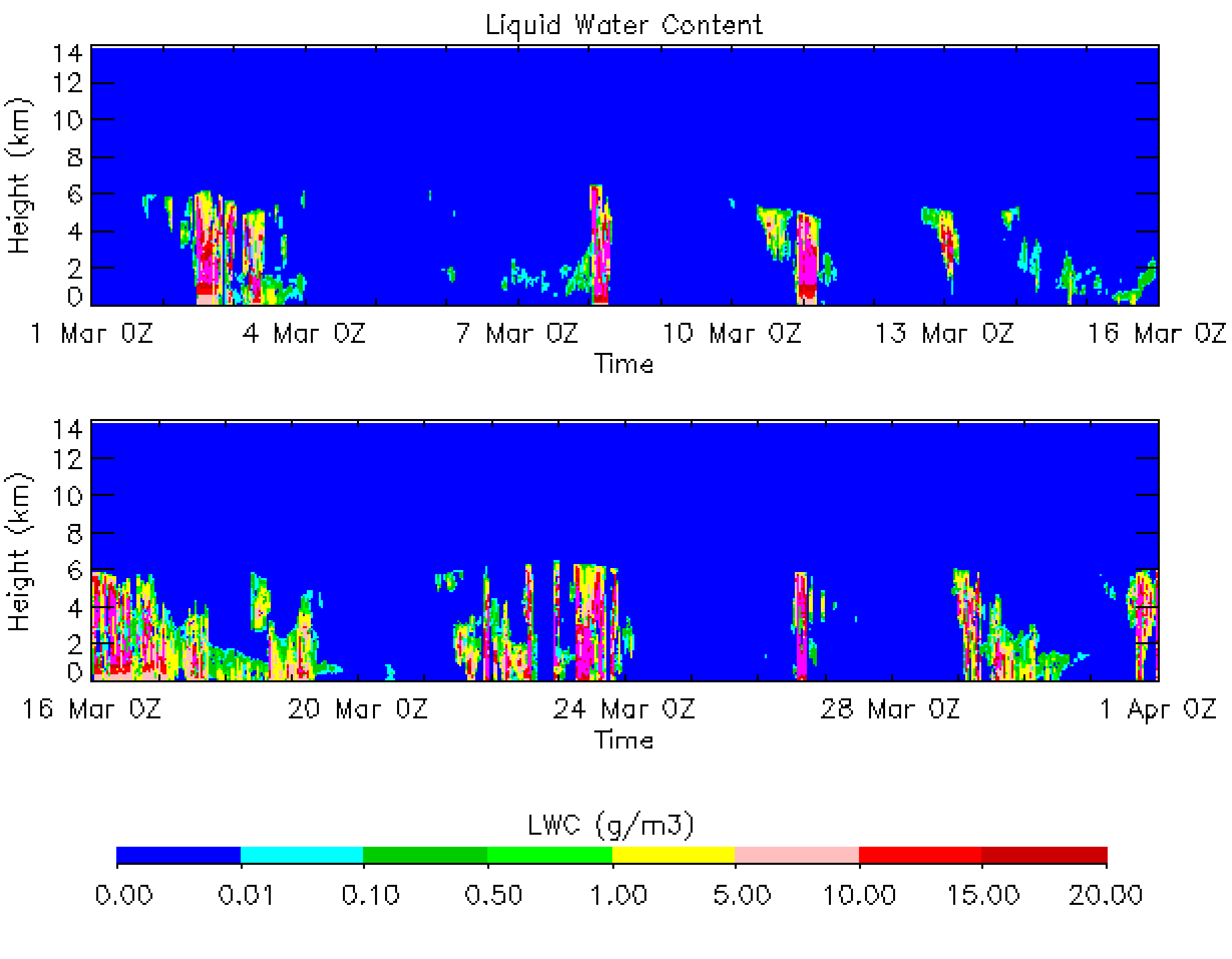
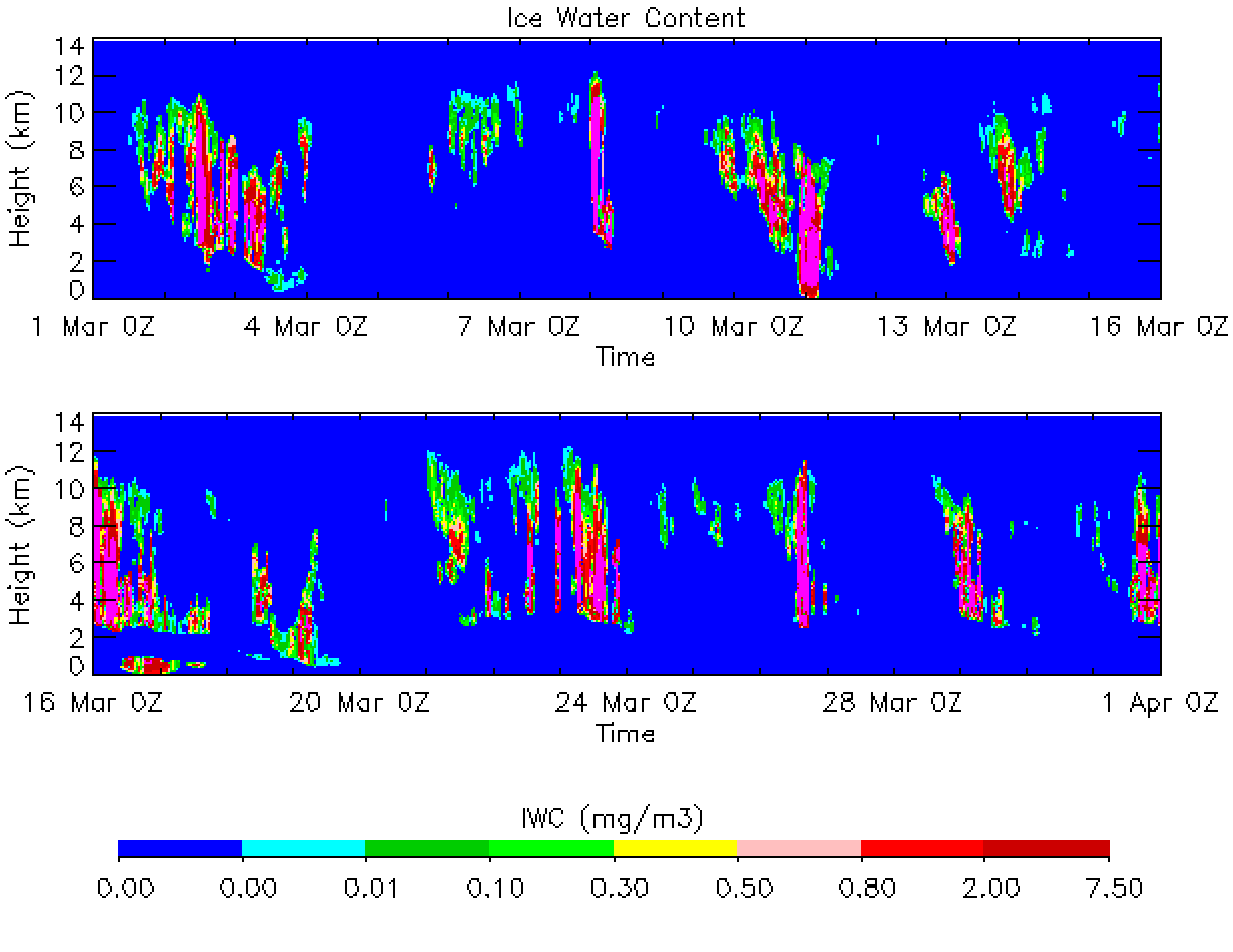
From Reflectivity to Cloud Properties

- Radar reflectivity and other instrumental data provide opportunity to retrieve cloud properties
  - Cloud vertical structure from radar and lidar
  - Cloud microphysics (size and condensed water amount) from combined instrument retrievals
  - Simple reflectivity-based retrievals and parameterizations available in the literature.


Liquid Water Content
Height (km)
14
12
10
8
6
4
2
0
1 Mar 0Z
4 Mar 0Z
7 Mar 0Z
10 Mar 0Z
13 Mar 0Z
16 Mar 0Z
Time
Height (km)
16 Mar 0Z
20 Mar 0Z
24 Mar 0Z
28 Mar 0Z
1 Apr 0Z
Time
LWC (g/m3)
0.00
0.01
0.10
0.50
1.00
5.00
10.00
15.00
20.00

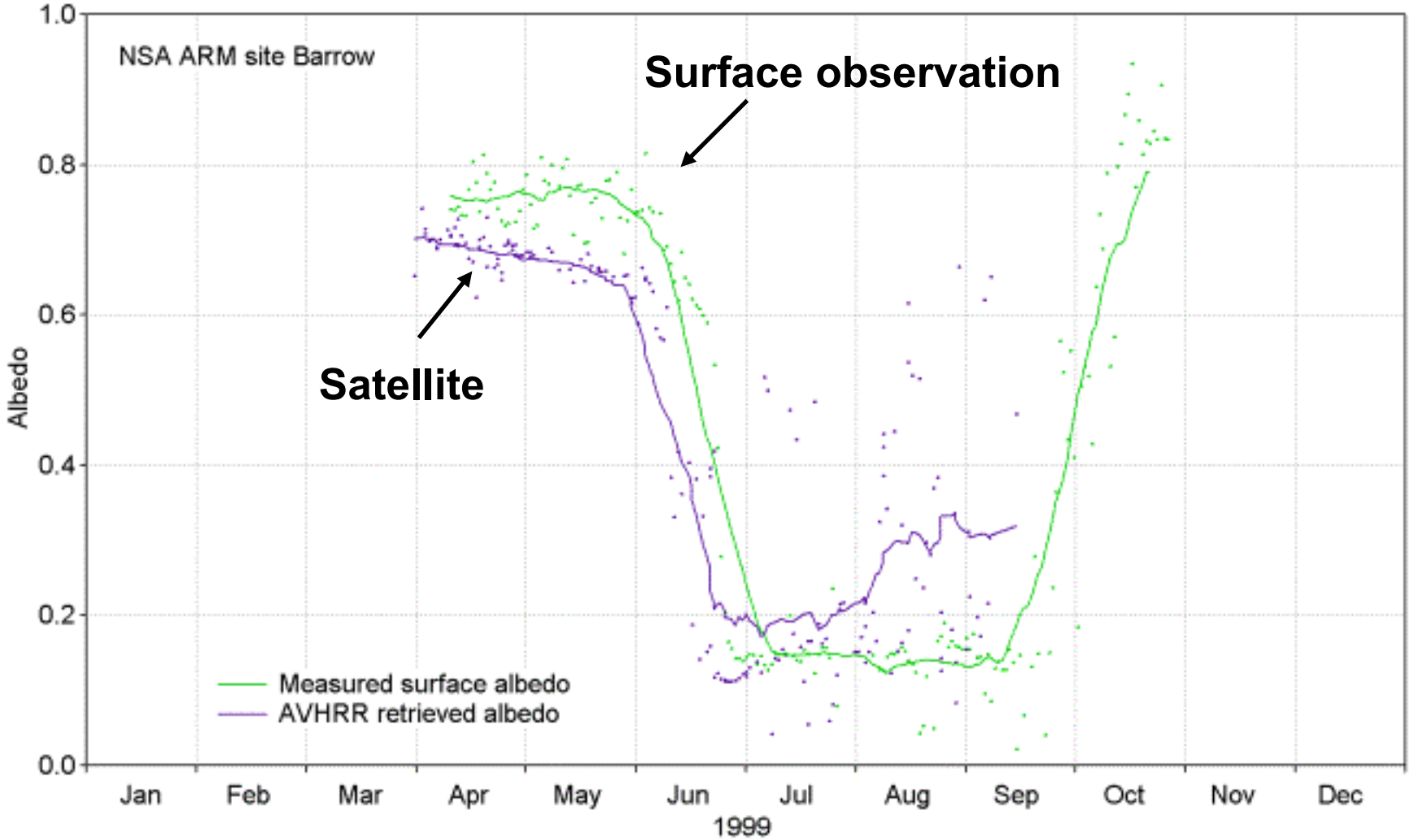

Ice Water Content
Height (km)
14
12
10
8
6
4
2
0
1 Mar 0Z
4 Mar 0Z
7 Mar 0Z
10 Mar 0Z
13 Mar 0Z
16 Mar 0Z
Time
Height (km)
14
12
10
8
6
4
2
0
16 Mar 0Z
20 Mar 0Z
24 Mar 0Z
28 Mar 0Z
1 Apr 0Z
Time
IWC (mg/m3)
0.00
0.00
0.01
0.10
0.30
0.50
0.80
2.00
7.50

ARM Science -- Some Examples

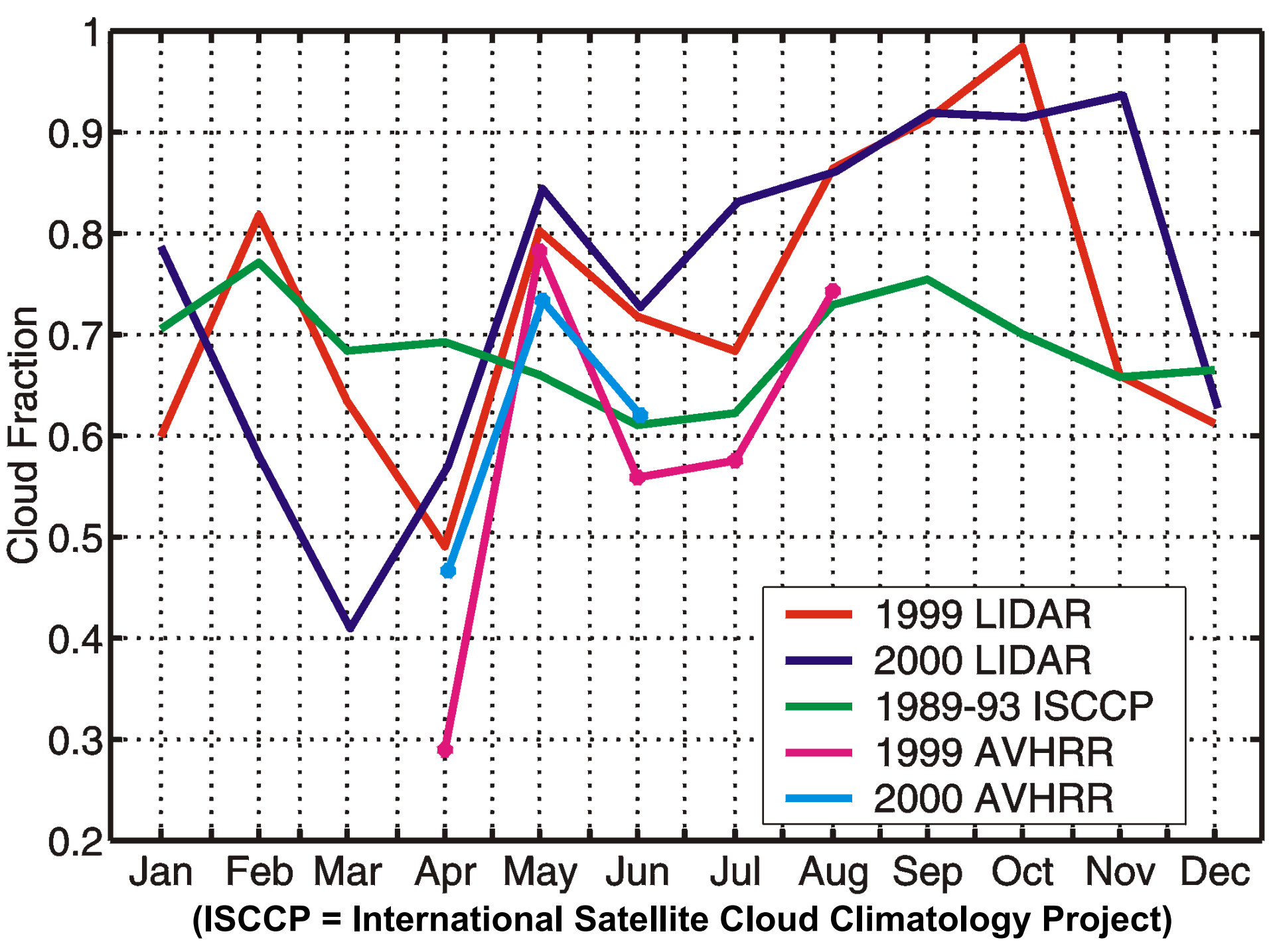
- Instrument development and data analysis
- Radiation studies – Satellite validation
- Cloud model studies
- Parameterization testing and development

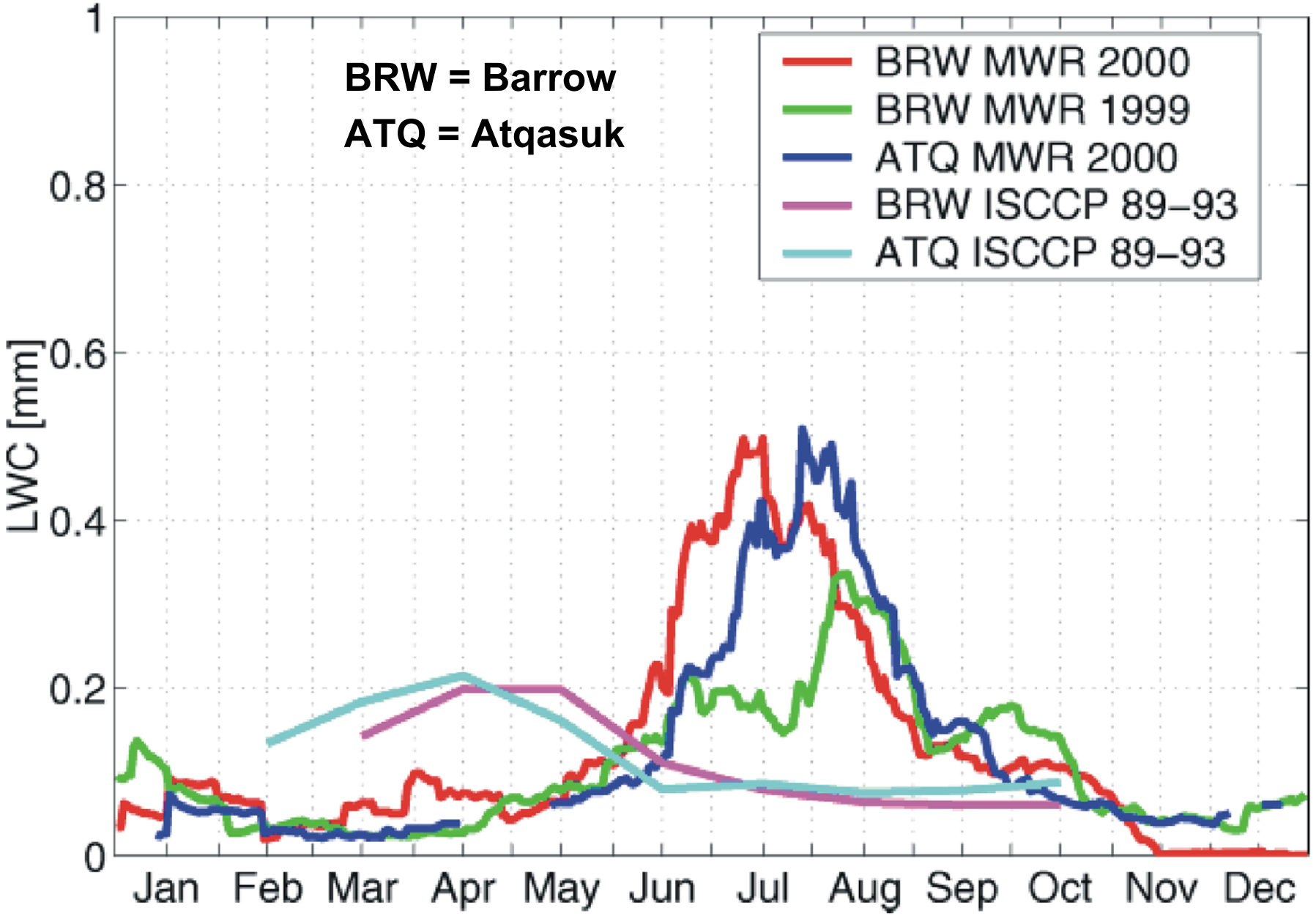
Satellite Validation Studies

- Surface radiation balance
  - Clear and cloudy sky
  - Surface albedo and SST
- Cloud fraction
- Cloud height
- Cloud microphysics (mean particle size)



Comparison between surface and satellite determined albedo: The 10% lower satellite derived albedo in spring and during the melt period can be explained with the large AVHRR grid size, which also includes icy ponds and windblown ridges. Errors in the AVHRR albedo seems to increase in the second part of the summer. This might be due to the fact that a almost permanent stratoform cloud layer during this time prevents the measurement of the necessary amount of clear-sky pixels.


Cloud Fraction
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1999 LIDAR
2000 LIDAR
1989-93 ISCCP
1999 AVHRR
2000 AVHRR
(ISCCP = International Satellite Cloud Climatology Project)



Daily-averaged liquid water path over the ARM NSA sites in

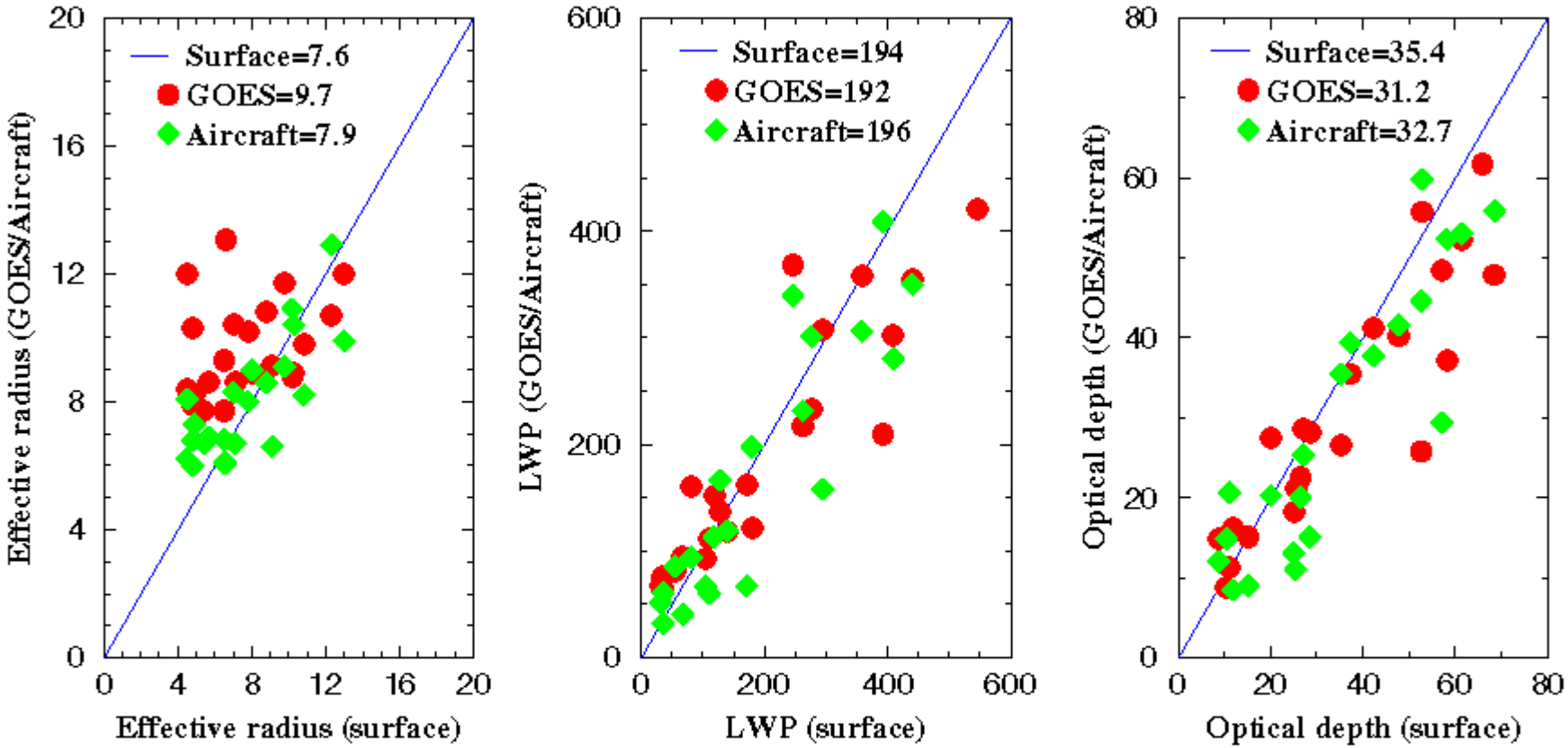


Fig. 8. Comparison of three datasets during 10–hour time period from 4 cases in 30–min temporal resolution.

Courtesy of Xiquan Dong

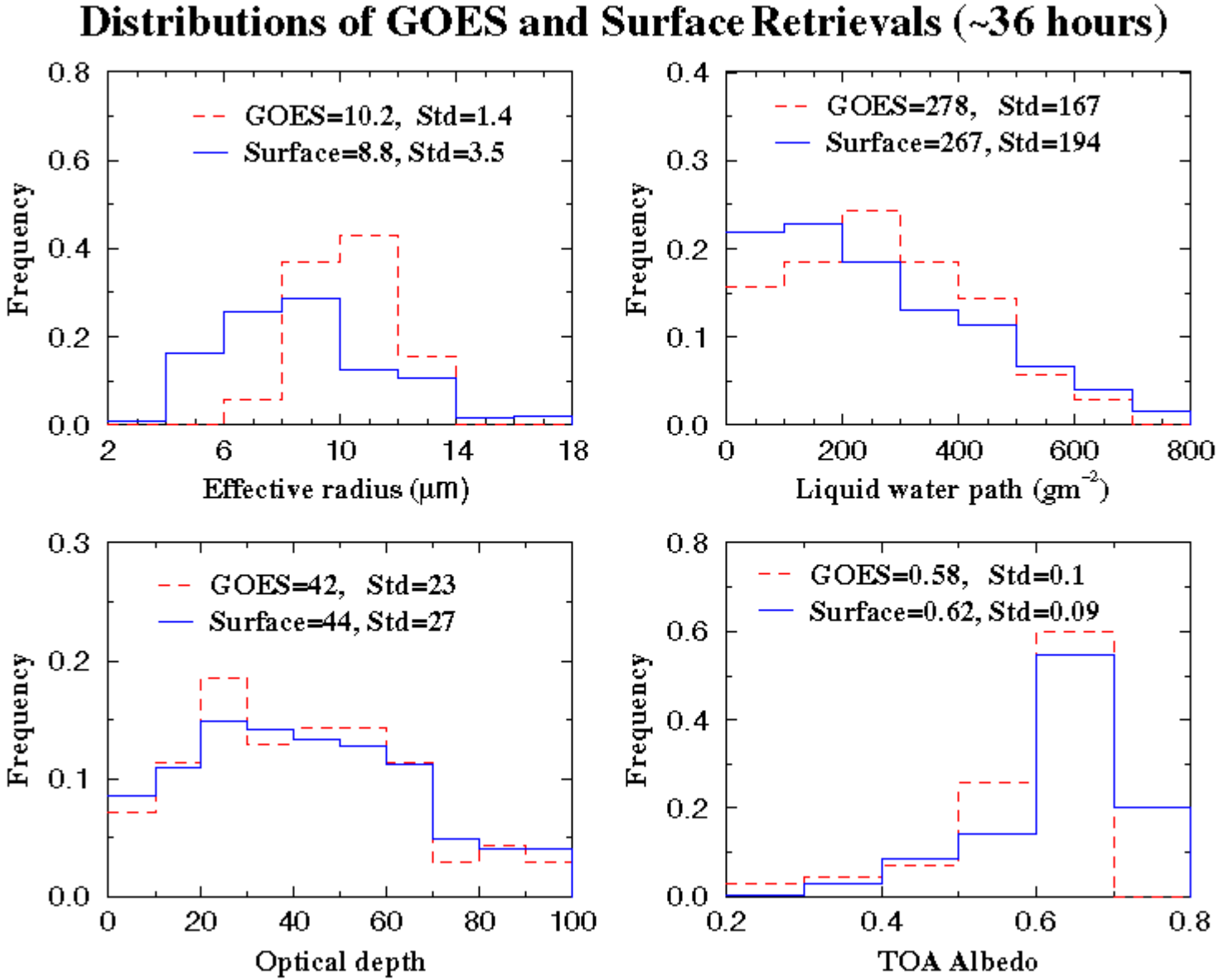


Fig. 12. Total 36 hours of surface (5–min) and GOES (30–min) data from 7 cases during the IOP.