The Atmospheric Radiation Measurement (ARM) Program:

Observing the Atmosphere with Ground-Based Remote Sensing

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Chief Scientist

Pacific Northwest National Laboratory

ARM
Atmospheric Radiation Measurement

Pacific Northwest National Laboratory

Credits to

- Ric Cederwall
- Xiquan Dong
- Kuo-Nan Liou
- Chuck Long
- Jay Mace
- Mark Miller
- Dave Turner

and the rest of the ARM science team

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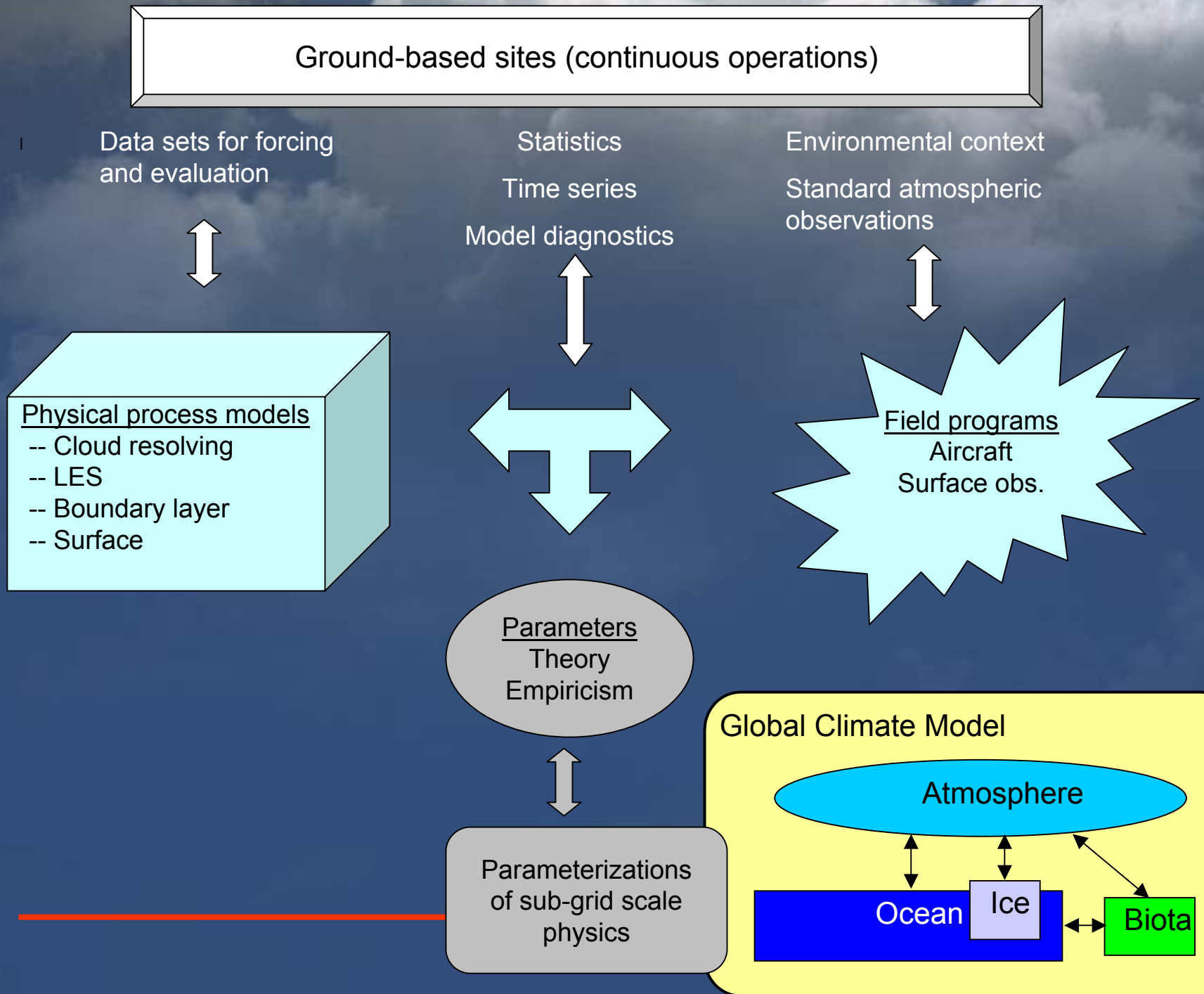
Ground-based sites (continuous operations)
Data sets for forcing and evaluation
Statistics
Time series
Model diagnostics
Environmental context
Standard atmospheric observations
Physical process models
-- Cloud resolving
-- LES
-- Boundary layer
-- Surface
Field programs
Aircraft
Surface obs.
Parameters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

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The Atmospheric Radiation Measurement (ARM) Program

Goal: Improve the representation of radiation and cloud physics in global climate models (the cloud parameterization problem)

Sponsored by the US Department of Energy

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Two Fundamental Questions

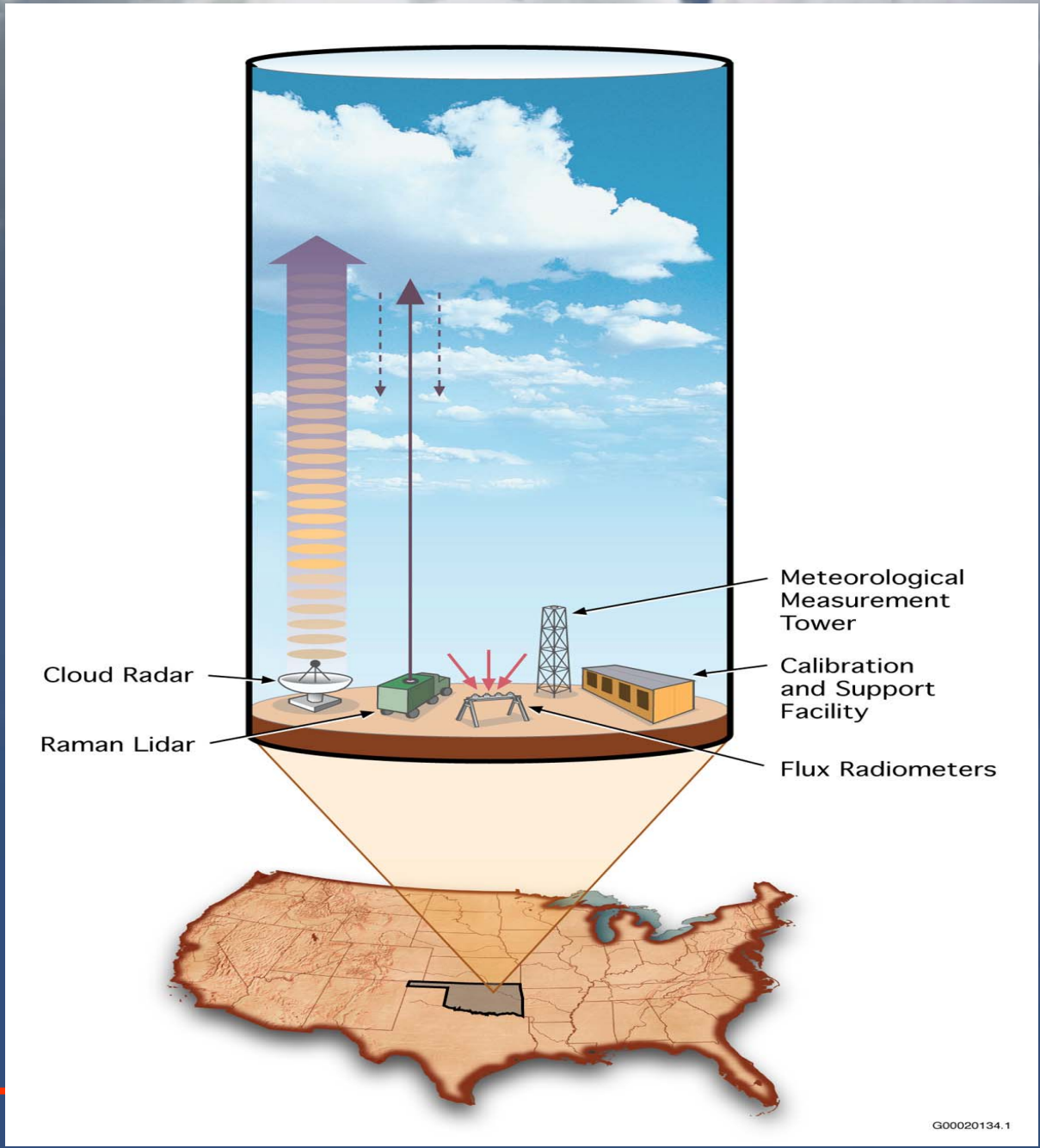
1. ***If we can specify all the properties of an atmospheric column, can we compute the radiative fluxes?***

   => 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

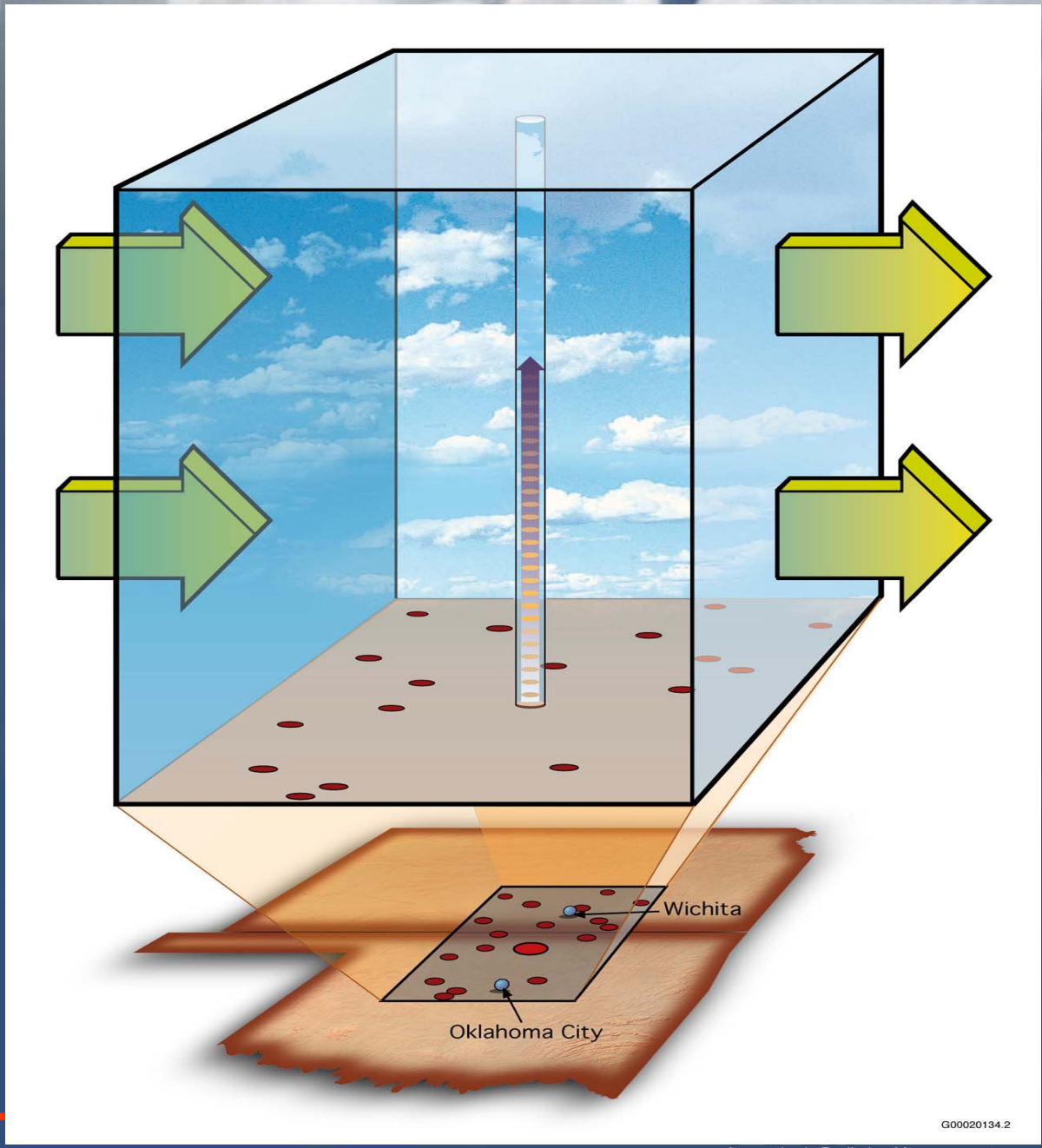


Two Fundamental Questions

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



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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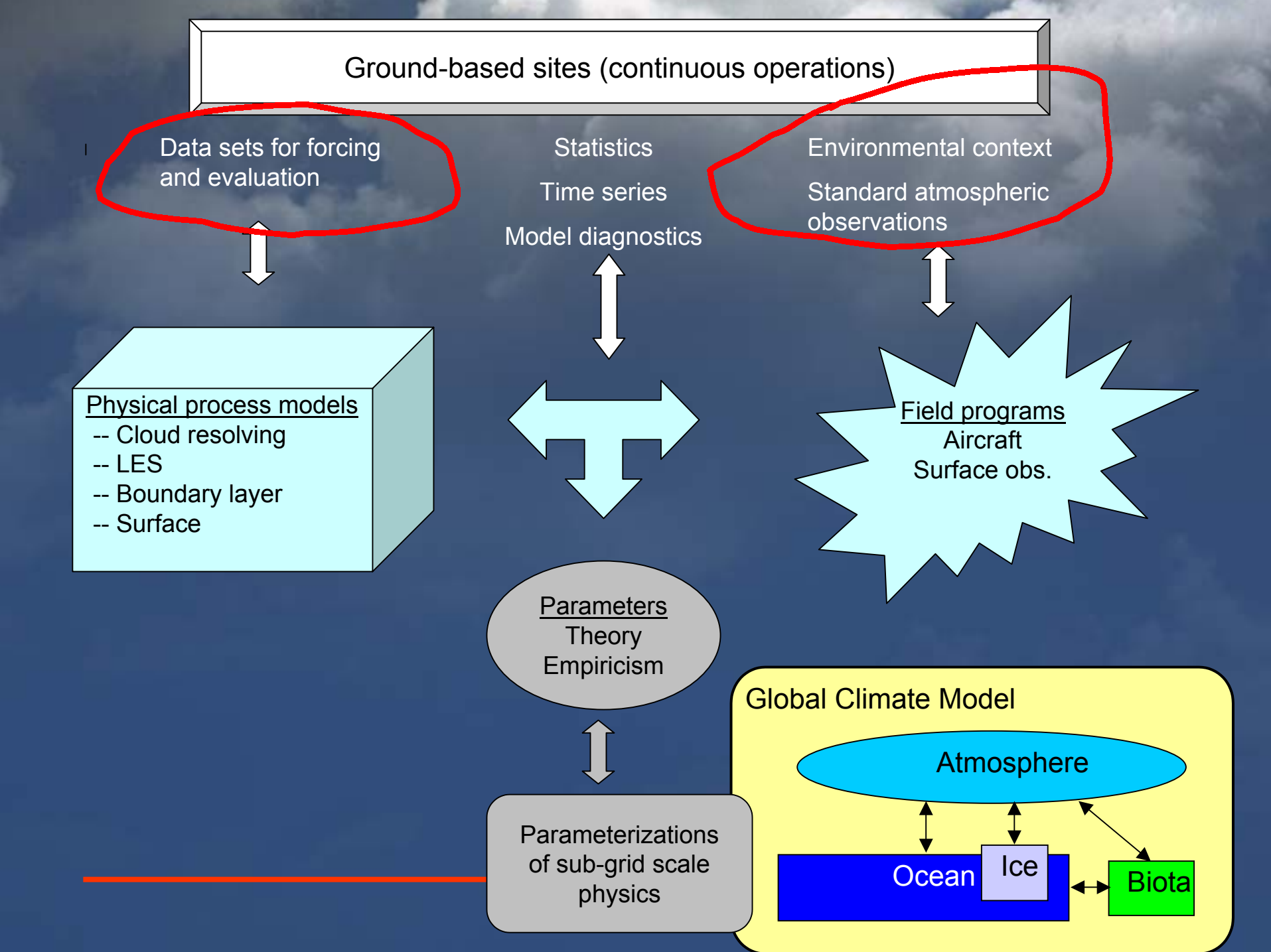
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How well can we describe

- the state of the box?

- the radiatively active components?

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A Sample of ARM Data

- ARM Southern Great Plains Site
- March 2000 (with one exception)
- Routine ARM data
- In addition
  - Enhanced soundings at central and boundary facilities
  - Aircraft data as part of Cloud Intensive Observing Period

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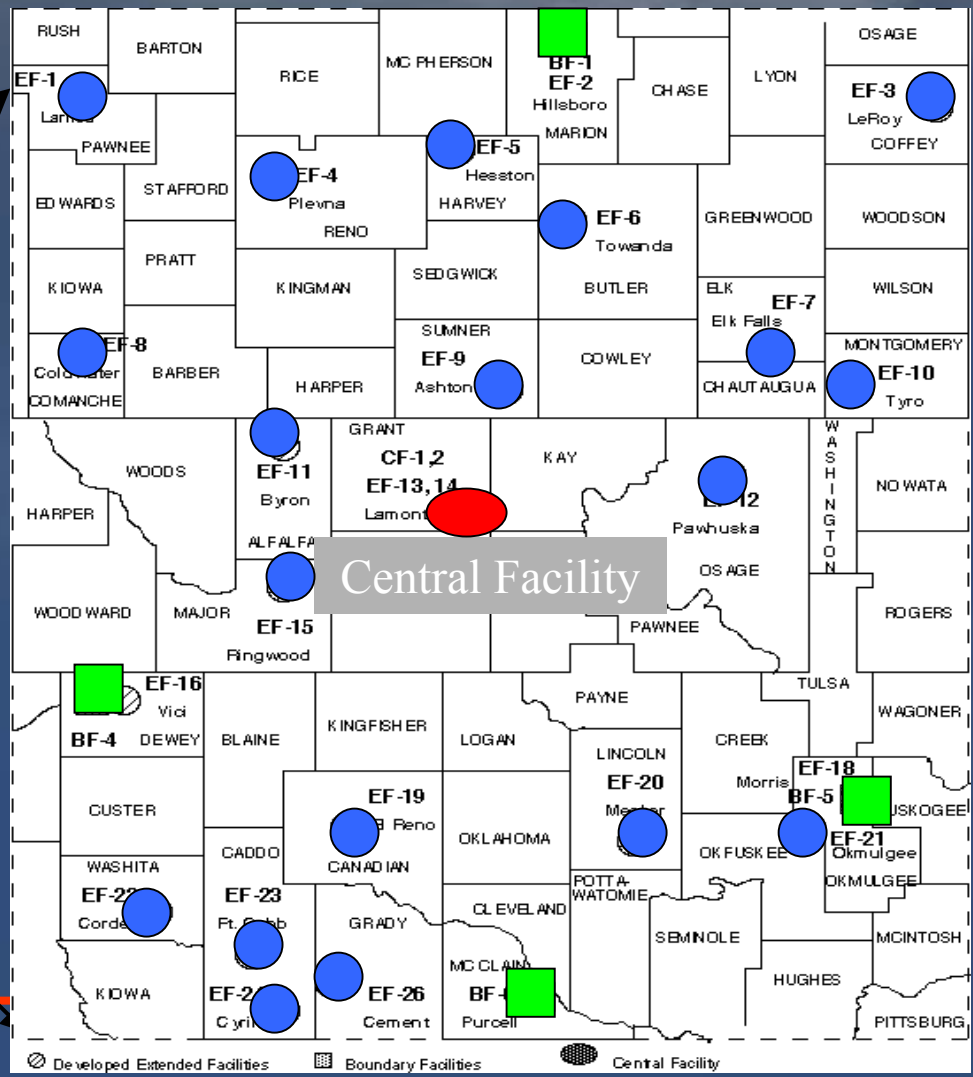
Southern Great Plains Site



Southern Great Plains Central Facility

Atmospheric state (local and domain-avg)

- Surface variables
- Temperature profiles
  - Analysis (sondes)
- Moisture profile
  - Analysis (sondes)
  - Raman lidar
  - Microwave radiometer
- Wind profiles
  - Radar wind profilers
  - Sondes

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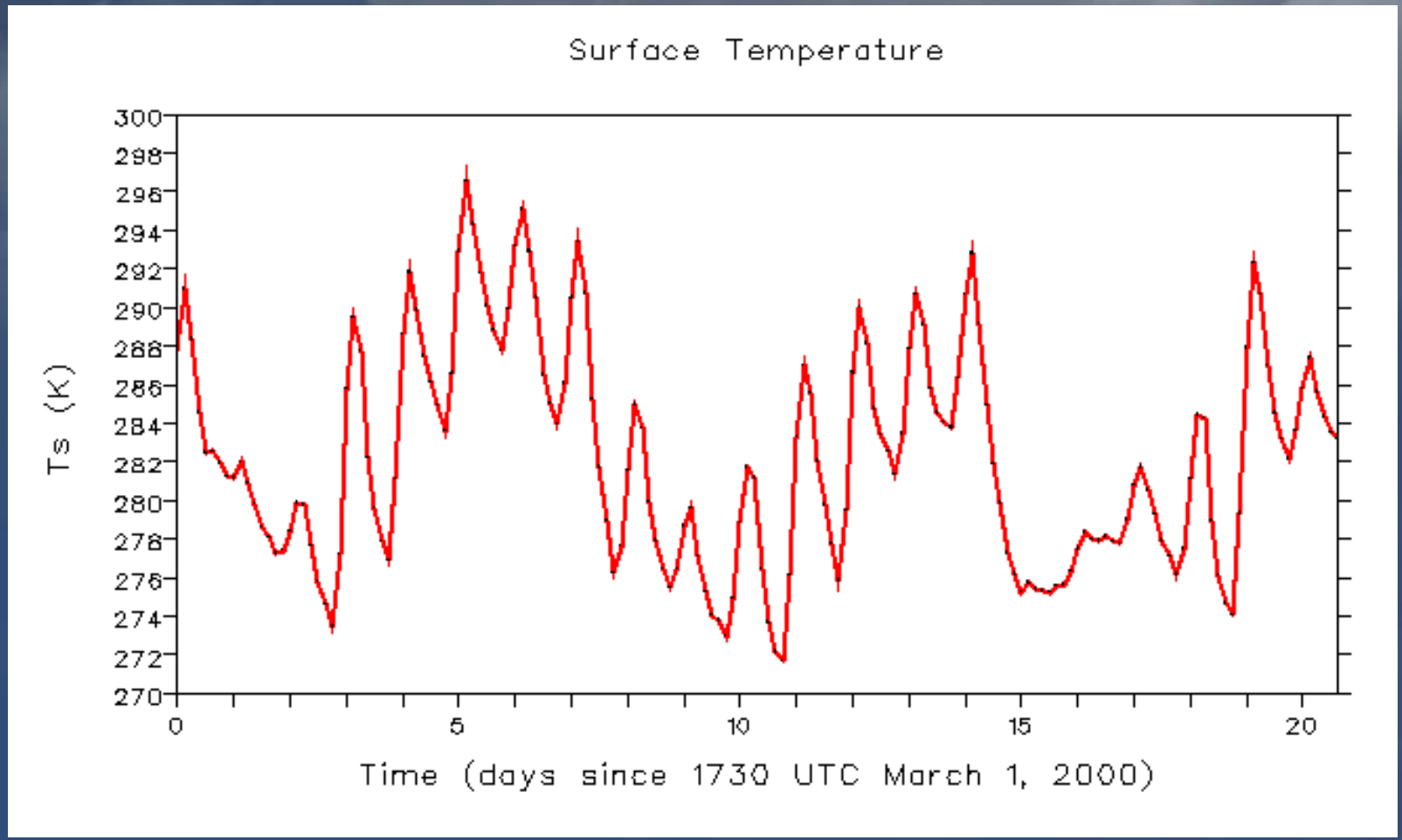
Large-scale Fields (and Boundary Forcing)

- Start with assimilated mesoscale analysis from US National Weather Service
- Add enhanced sondes (every three hours at 5 sites)
- Do data integration of sondes and other surface data using variational technique (M. Zhang et al.)
- Compute from integrated fields
  - domain average values of state variables
  - advection and convergence



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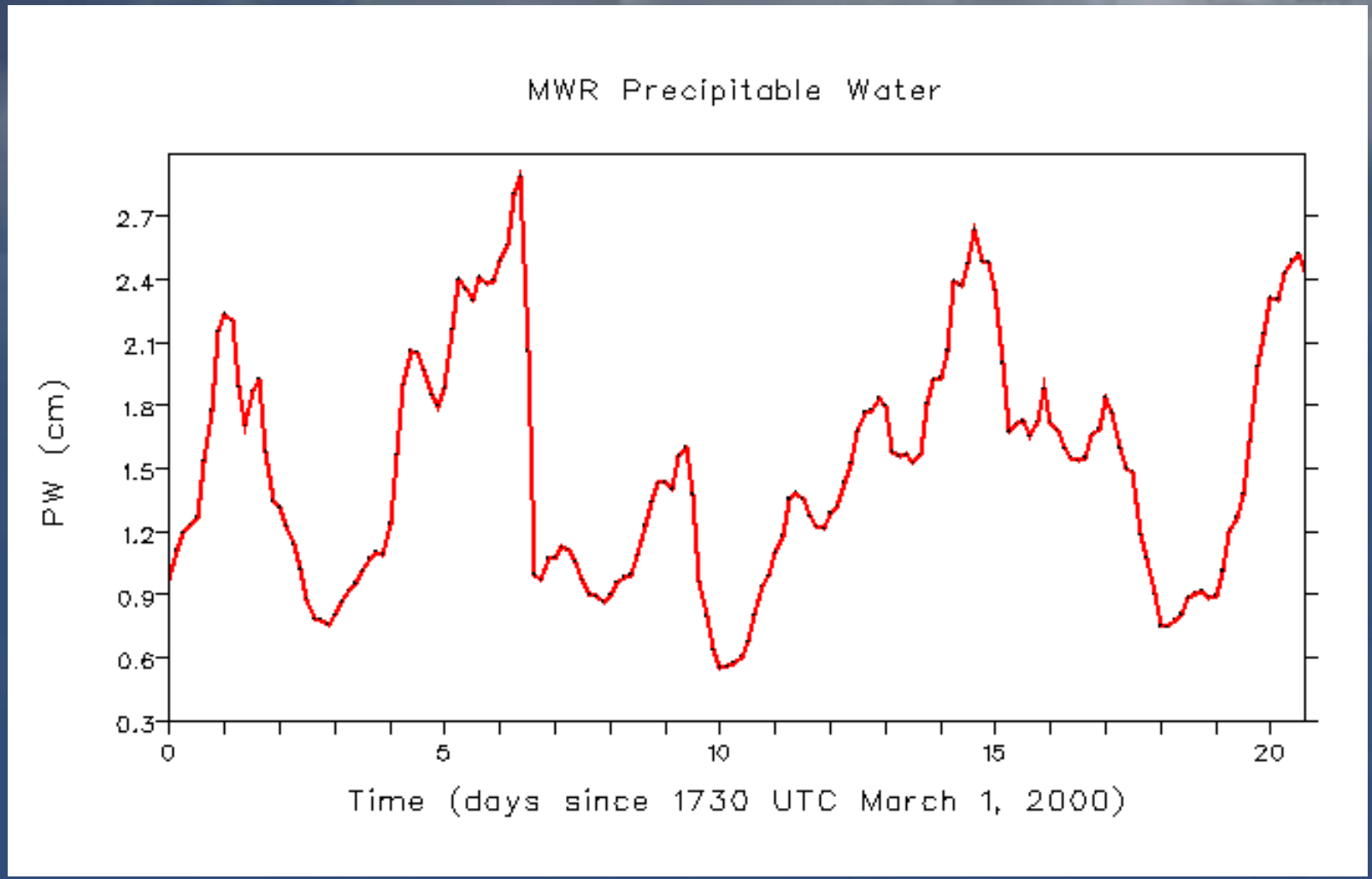

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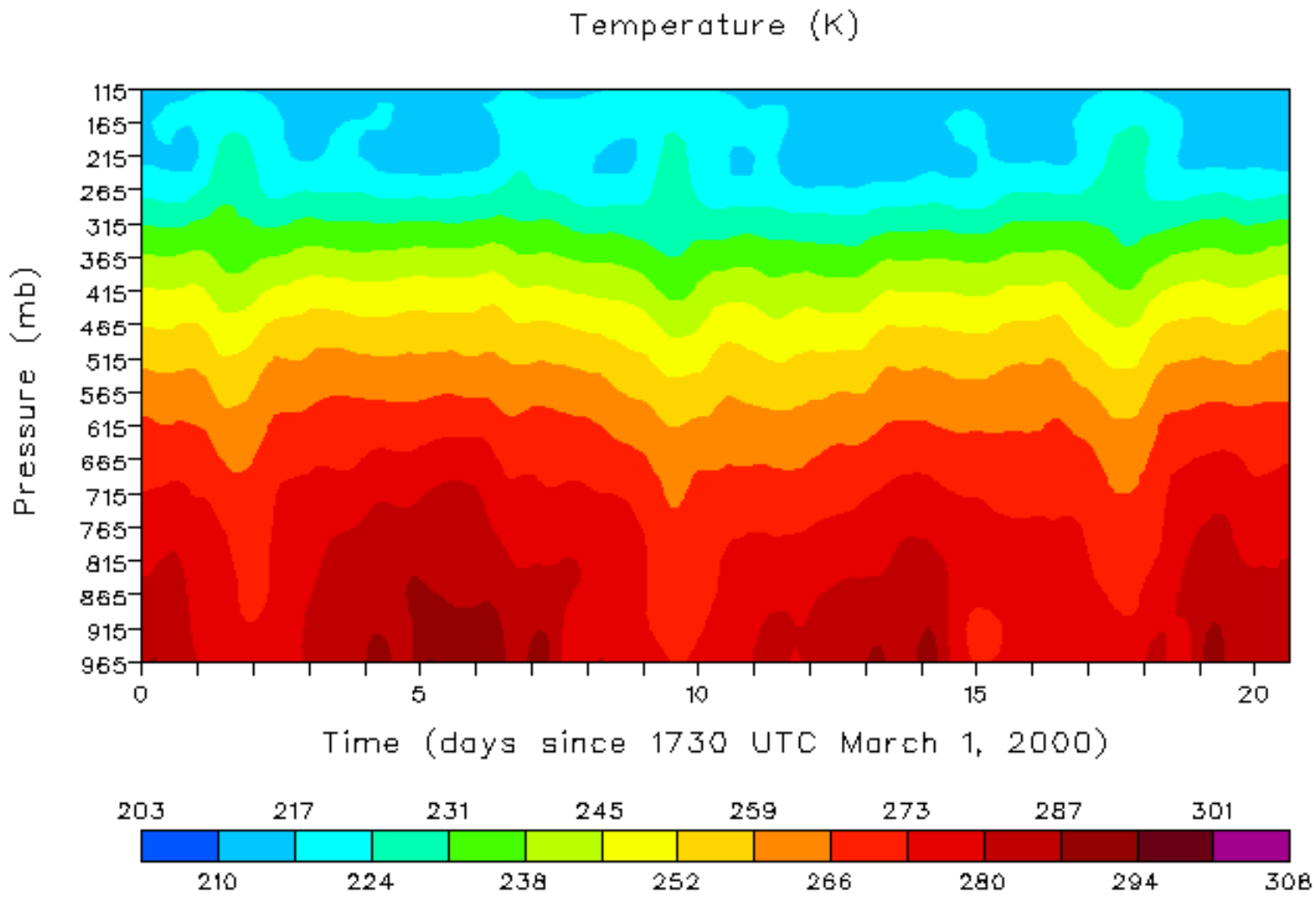

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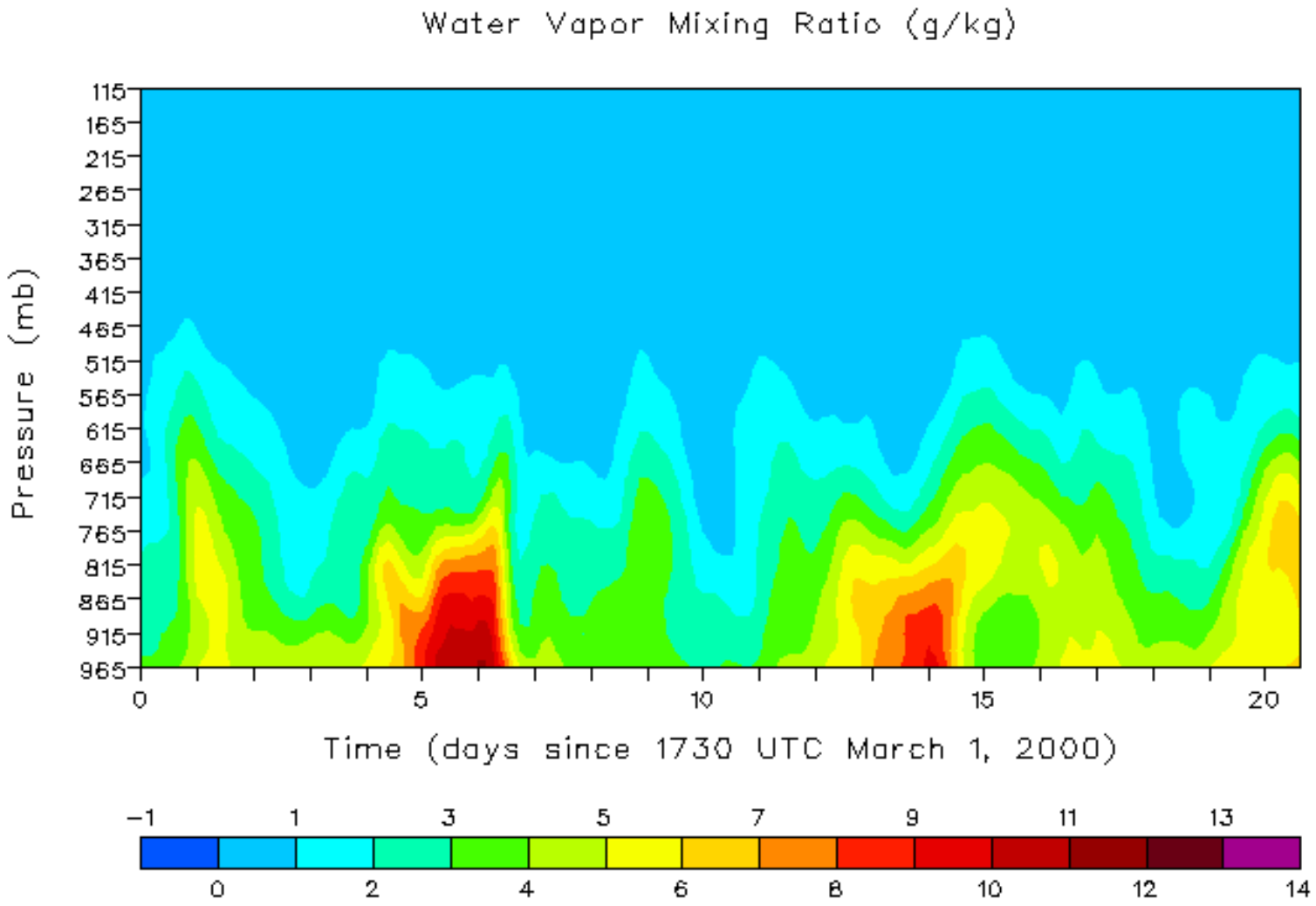

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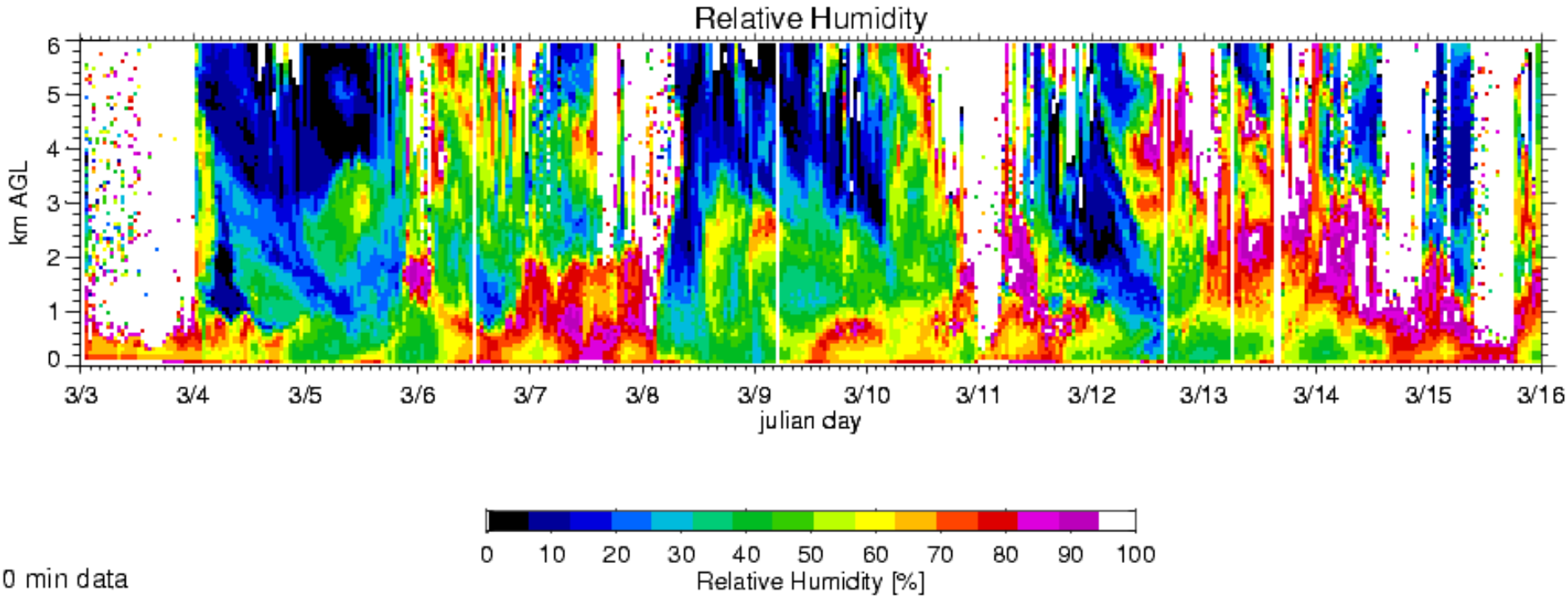
CART Raman Lidar Aerosol and Relative Humidity Data
3 March - 15 March 2000



10 min data

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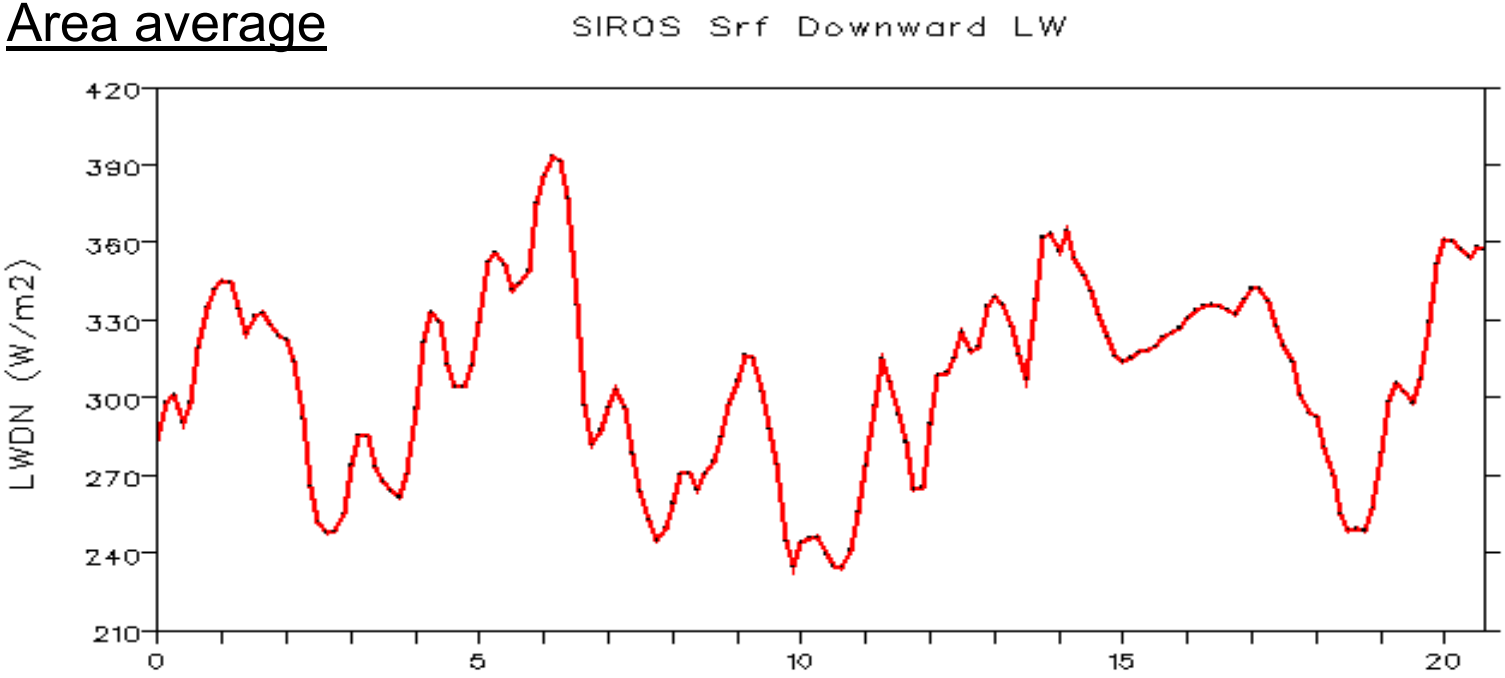
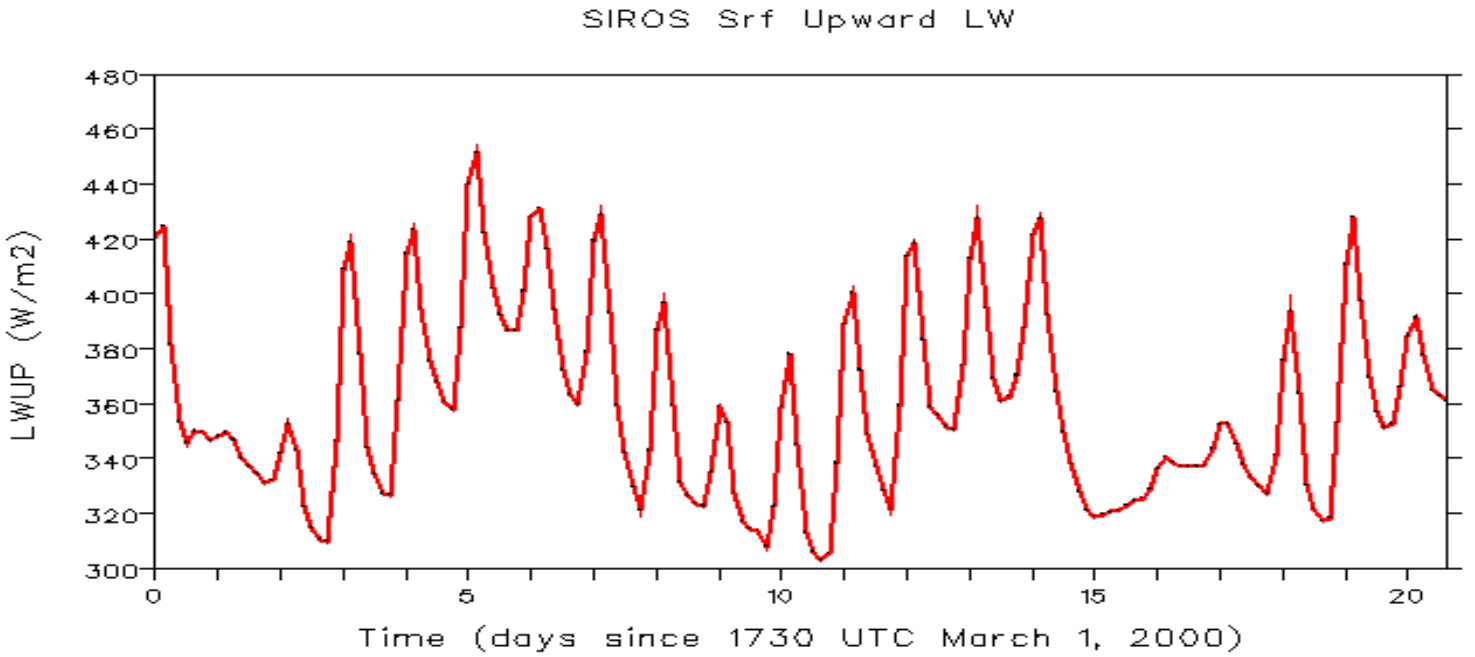
Energy fluxes into the column

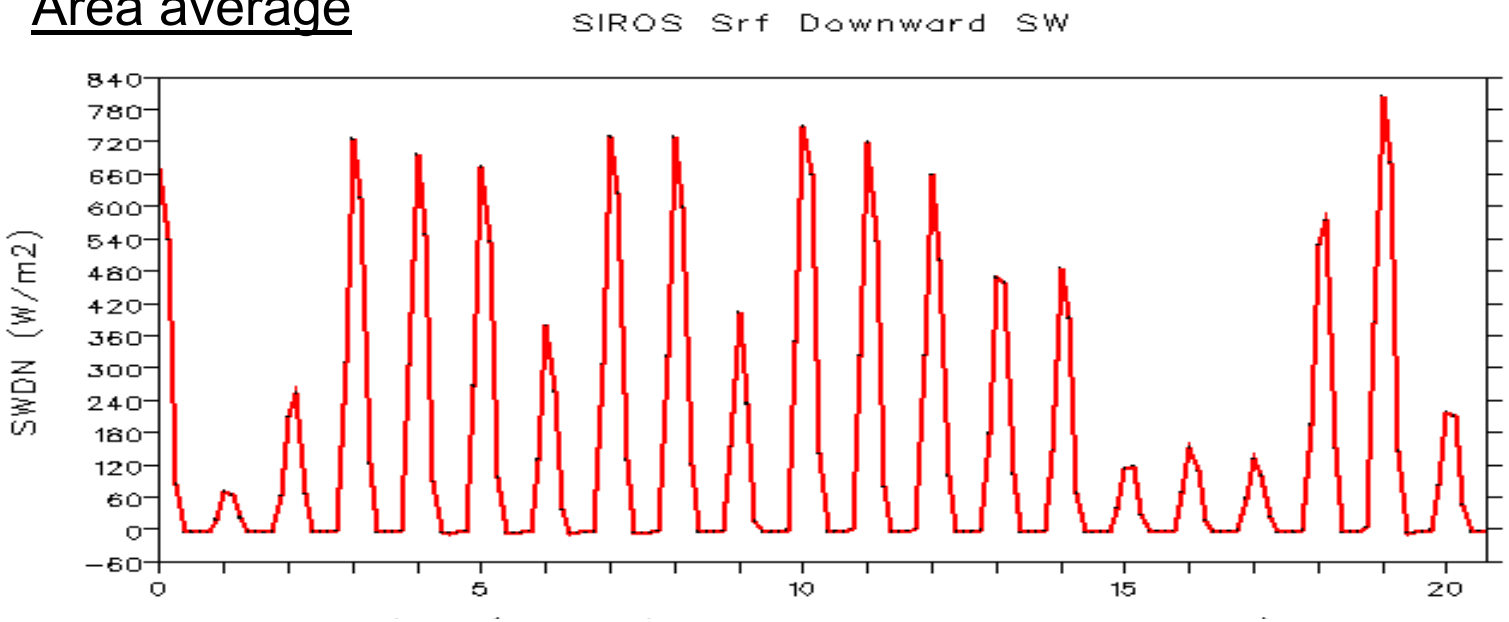
- GOES radiation fluxes at TOA
- Surface radiometer measurements
- Eddy correlation and Bowen flux measurements

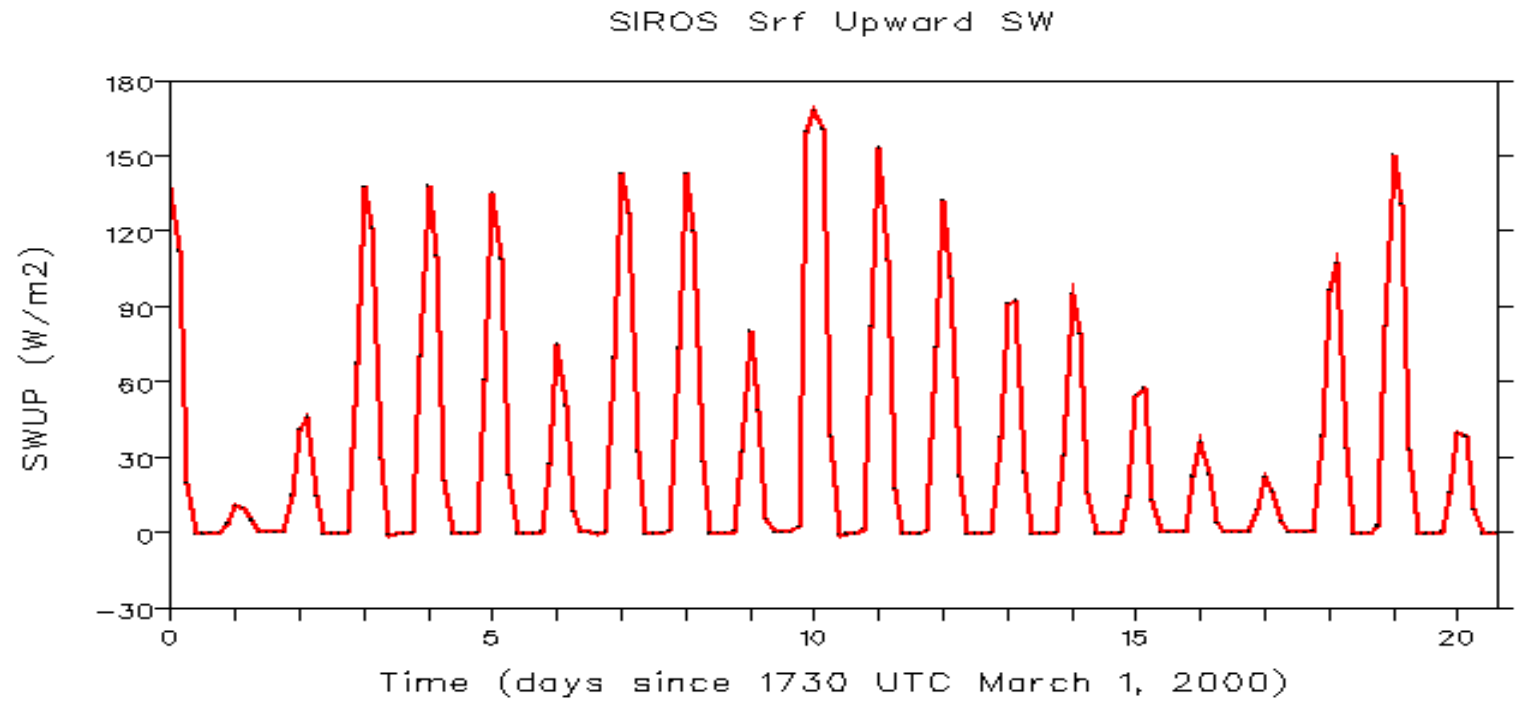
Area average





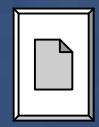
Area average

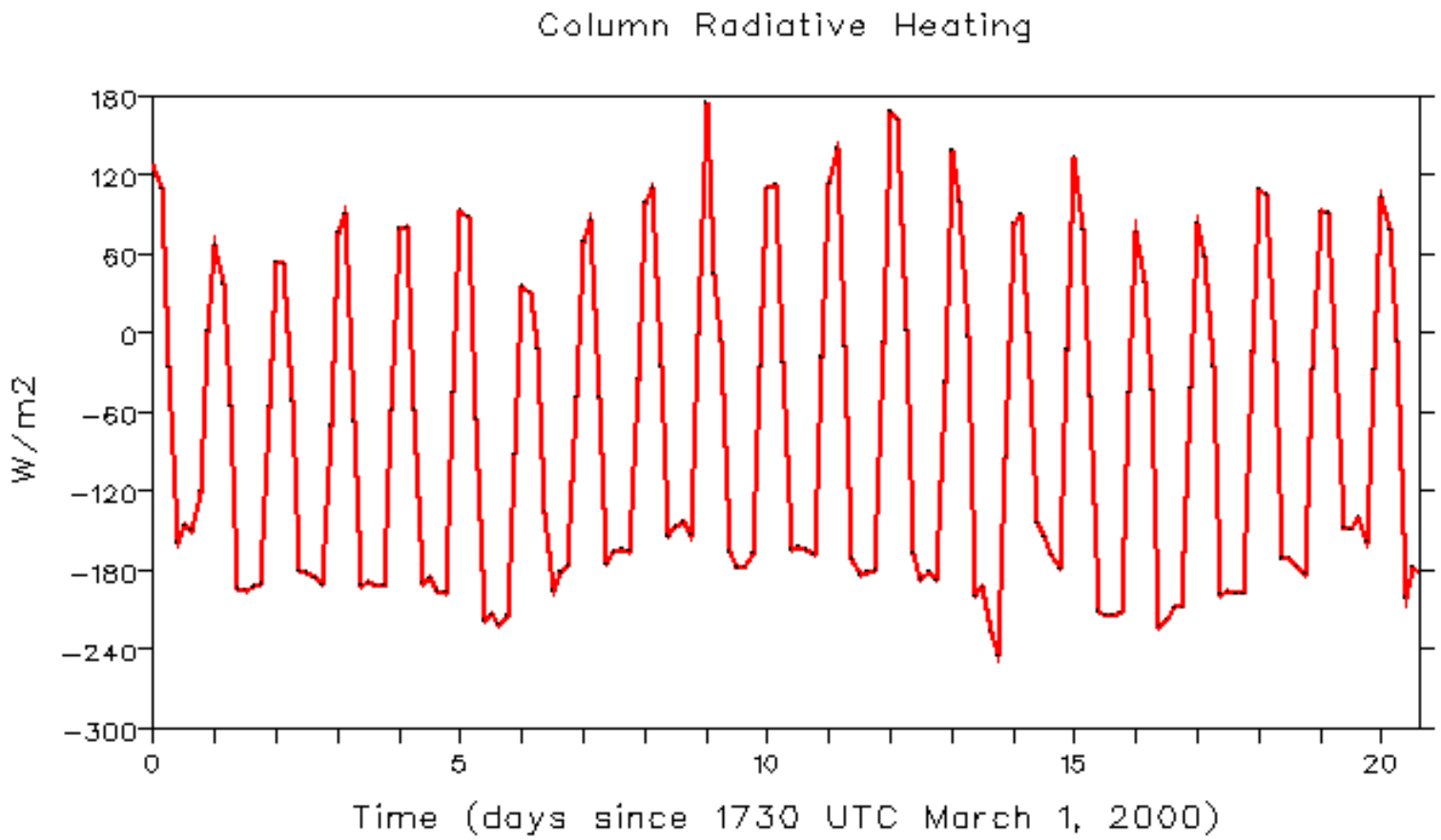




Domain averaged surface fluxes

- Based on spatially distributed radiometers
- Clear sky
  - Fit to hemispherically clear sky measurements
- Measured shortwave
  - Presented as ratio of measured to clear sky (1 = clear sky)





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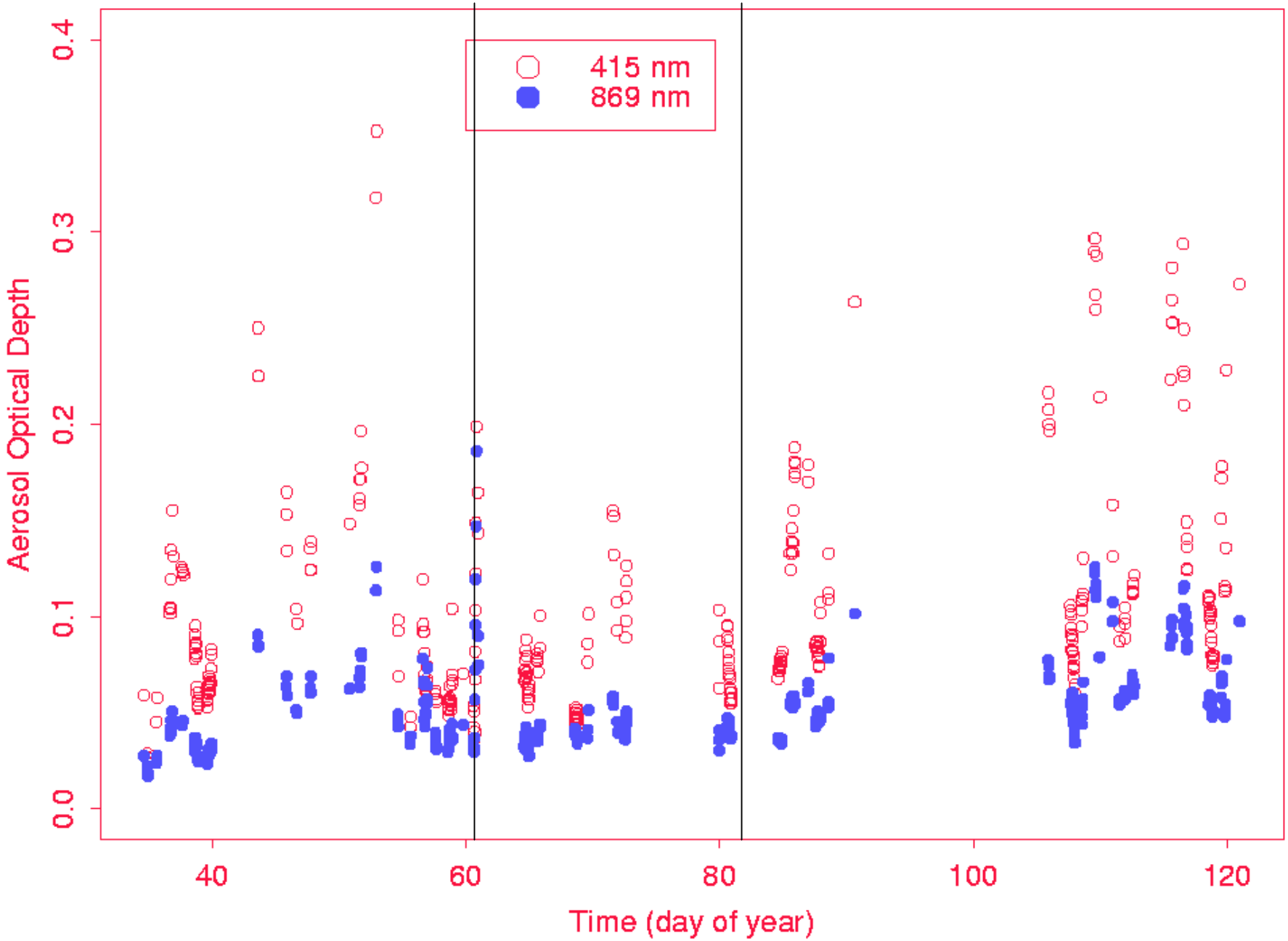
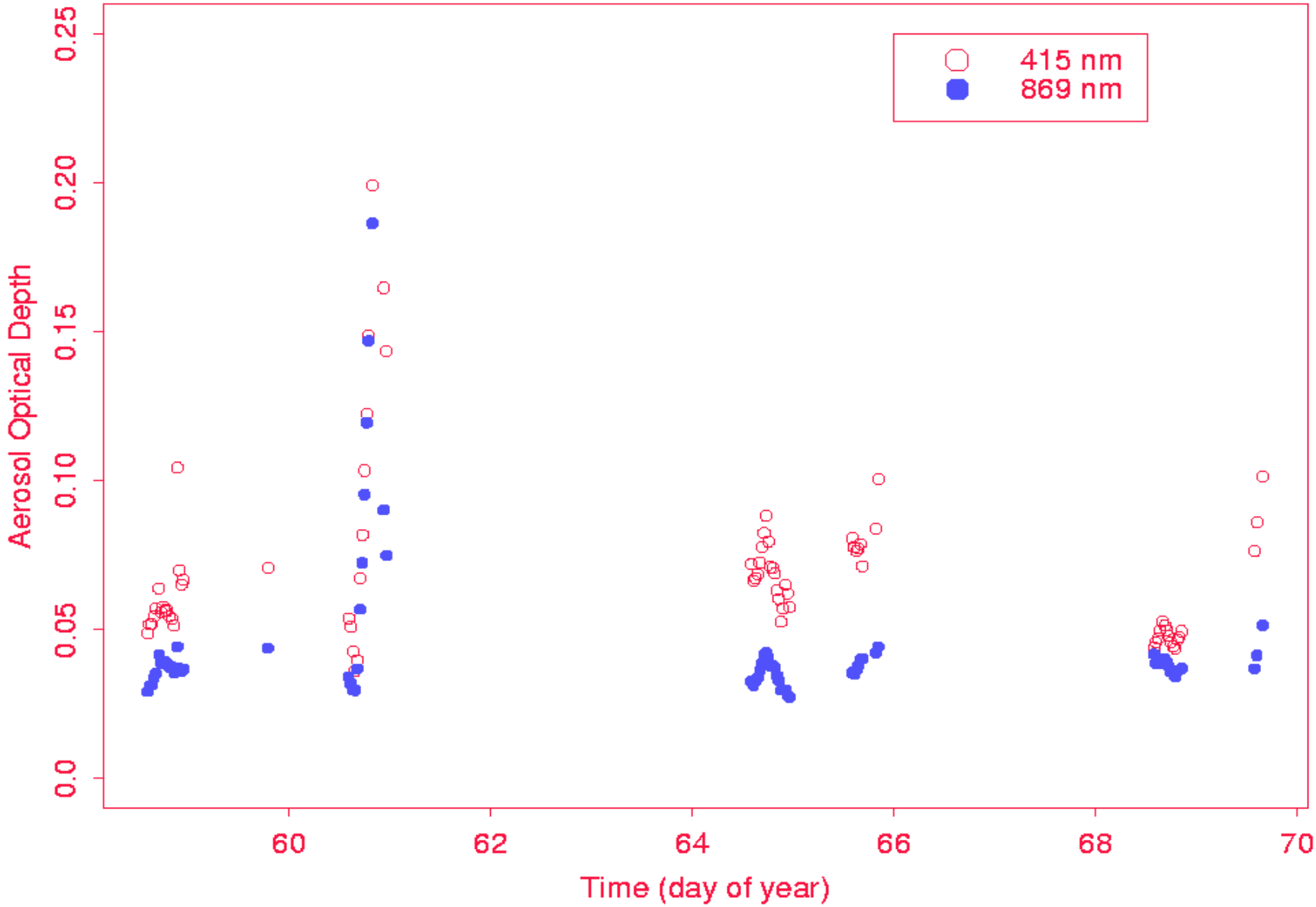
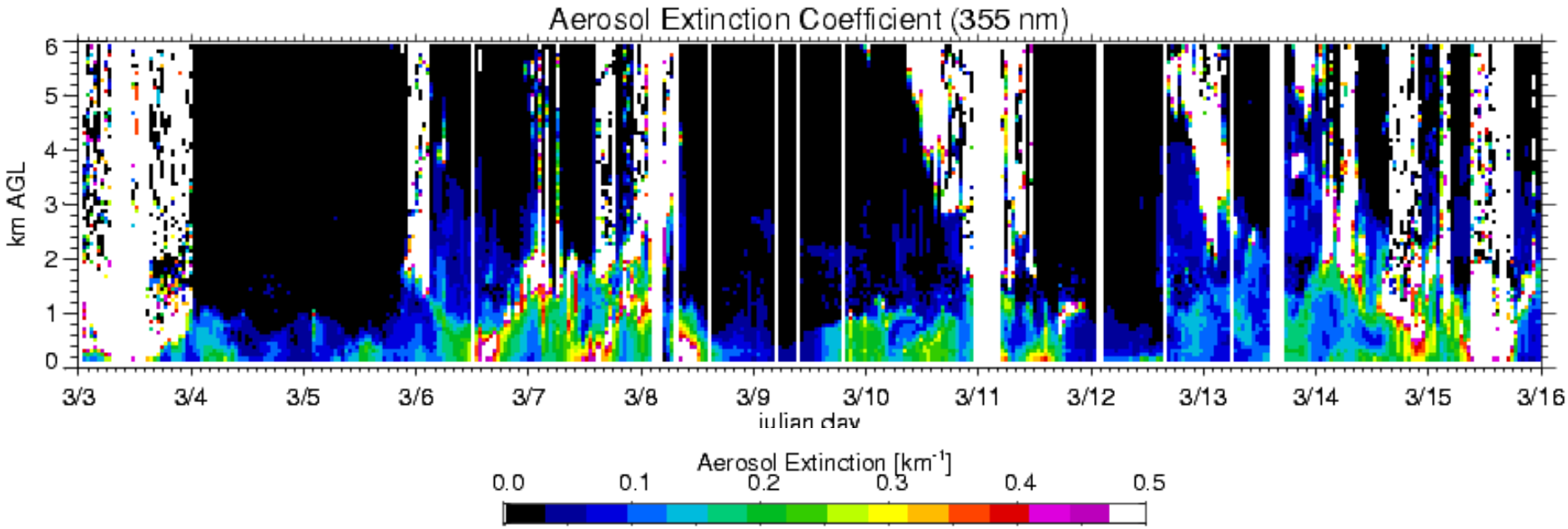
Aerosol

- Optical depth (clear only)
  - Sun photometry
  - Solar transmission
- Extinction coefficient profiles
  - Raman lidar
- Surface measurements (not shown)
  - Scattering and absorption coefficients
  - Size distribution


415 nm
869 nm
Aerosol Optical Depth
0.0
0.1
0.2
0.3
0.4
40
60
80
100
120
Time (day of year)


415 nm
869 nm
Aerosol Optical Depth
0.0
0.05
0.10
0.15
0.20
0.25
60
62
64
66
68
70
Time (day of year)

CART Raman Lidar Aerosol and Relative Humidity Data
3 March - 15 March 2000



10 min data

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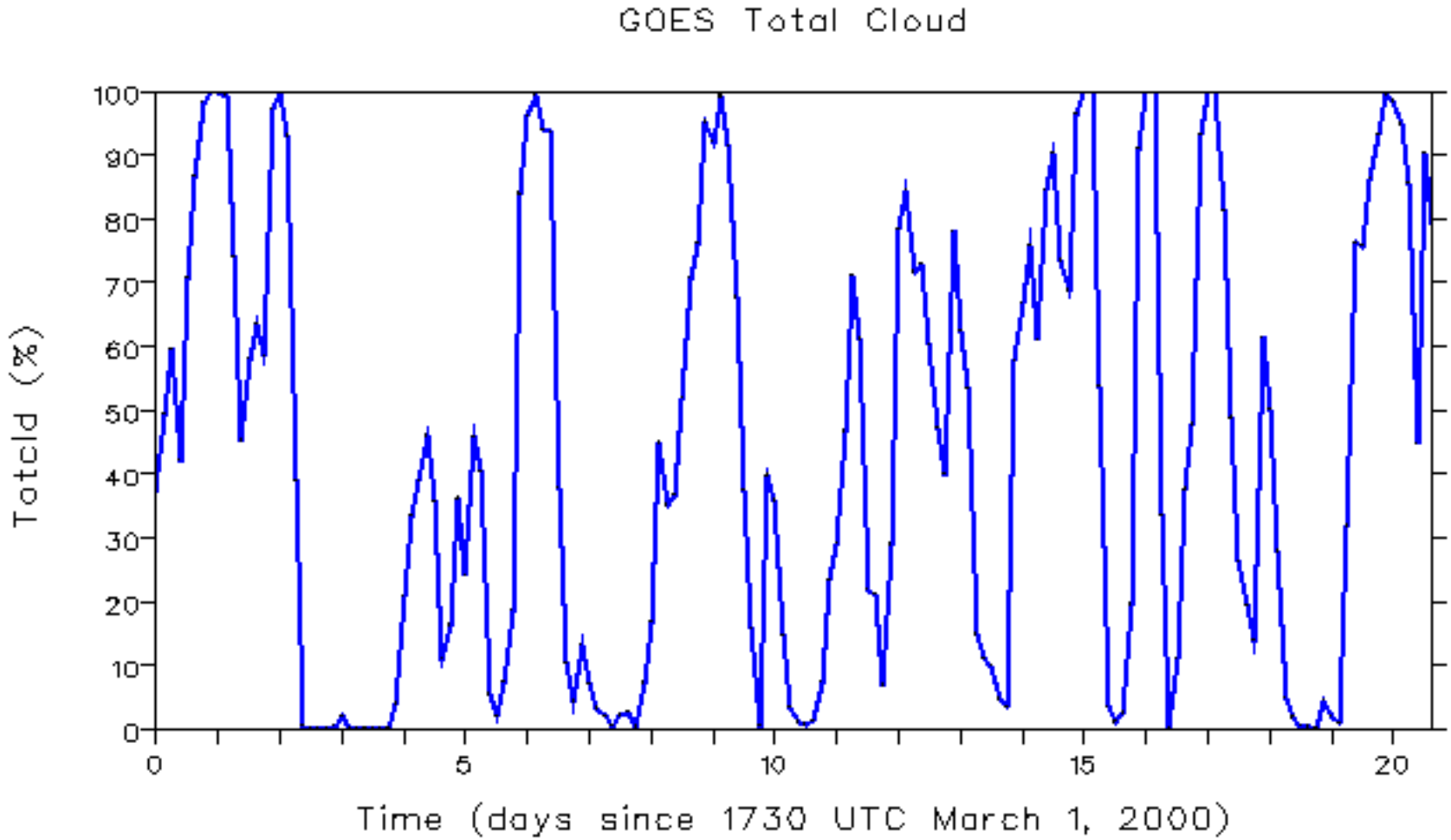
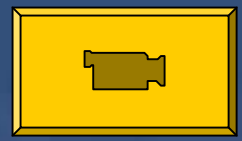
Cloud Macrophysics

- Cloud fraction (spatial)
  - GOES
  - Sky imagery
  - Diffuse/Total shortwave ratio
- Cloud vertical occurrence (local)
  - Cloud radar
  - Lidar

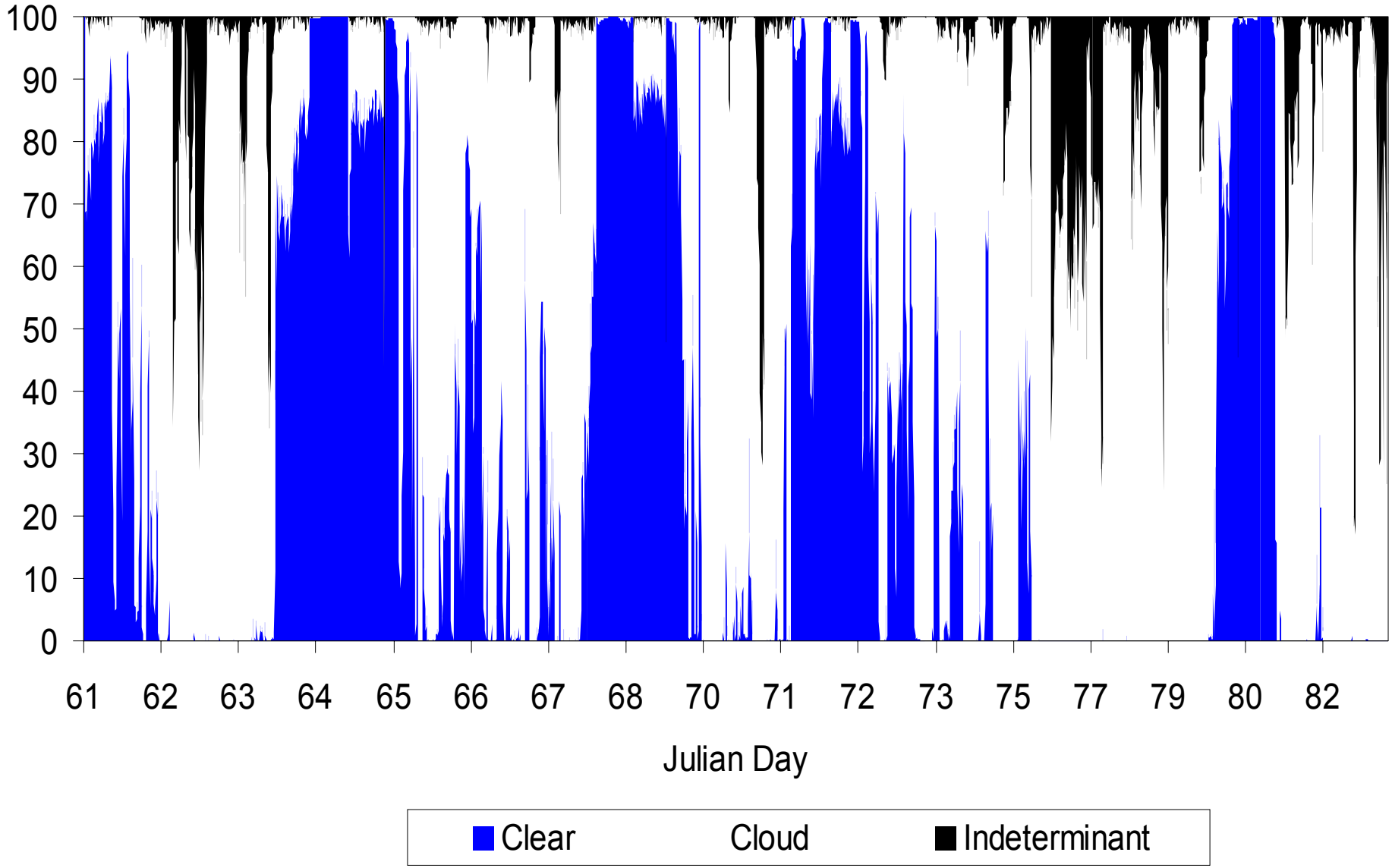

GOES Total Cloud
Totcld (%)
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
Time (days since 1730 UTC March 1, 2000)

Cloud fraction from sky imagery

- Line of sight cloud fraction
- Daytime at 1 to 10 minute intervals
- Nighttime using star trackers

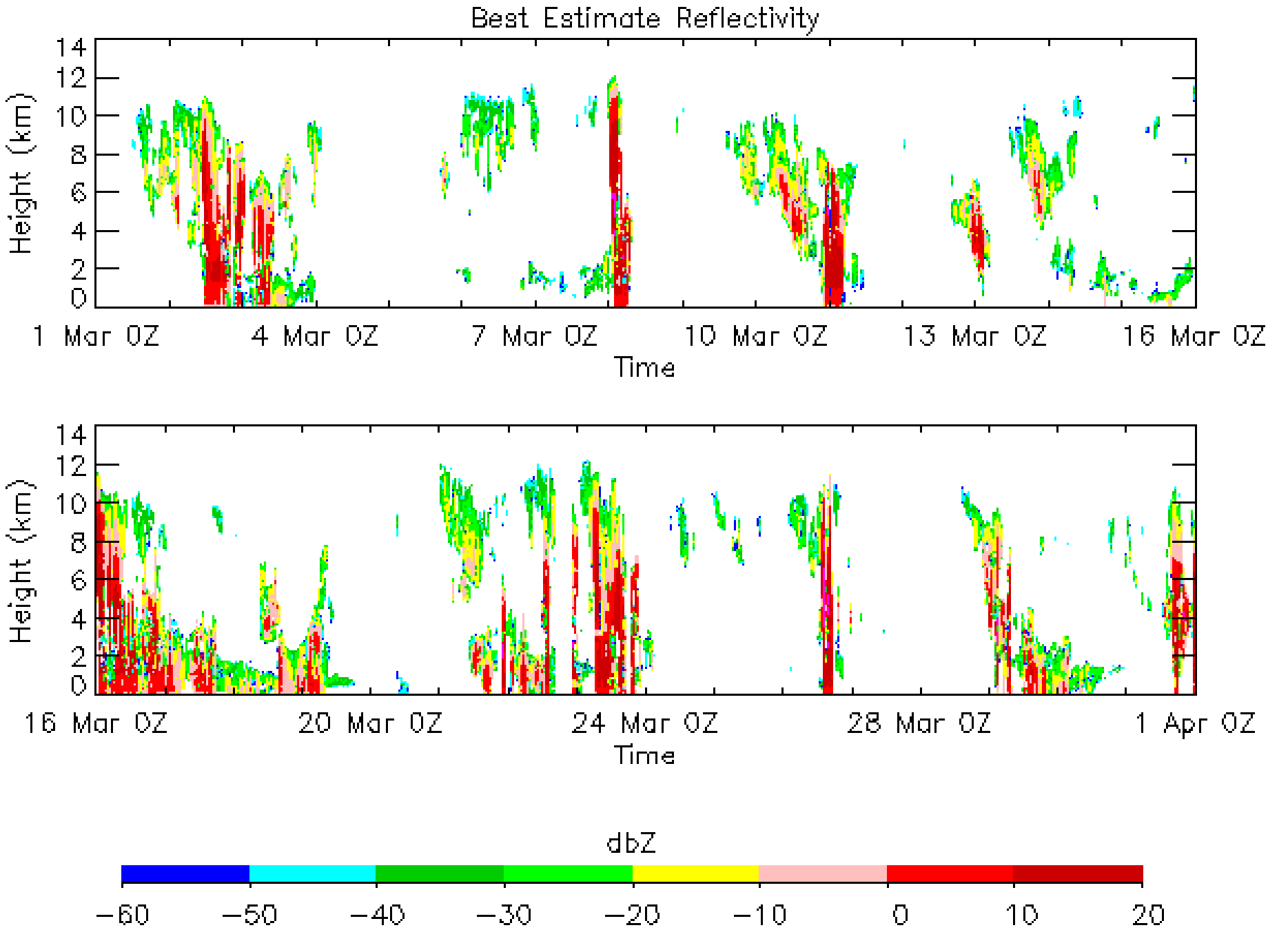


WSI Cloud Fraction (from March 1, 2000)



Cloud fraction from radiometry

- Line of sight cloud fraction
- Based on ratio of diffuse to total shortwave radiation (daytime only)
- Accuracy of 0.1 in cloud cover


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

Baseline Estimate Continuous Cloud Microphysics

- Provides a *continuous* estimate of microphysical structure.
- Based on simple reflectivity-based retrievals and parameterizations available in the literature.
- Ad-hoc temperature-reflectivity mixed-phase parameterization
- Will provide an “educated-guess” at microphysical structure when conditional retrievals cannot operate.

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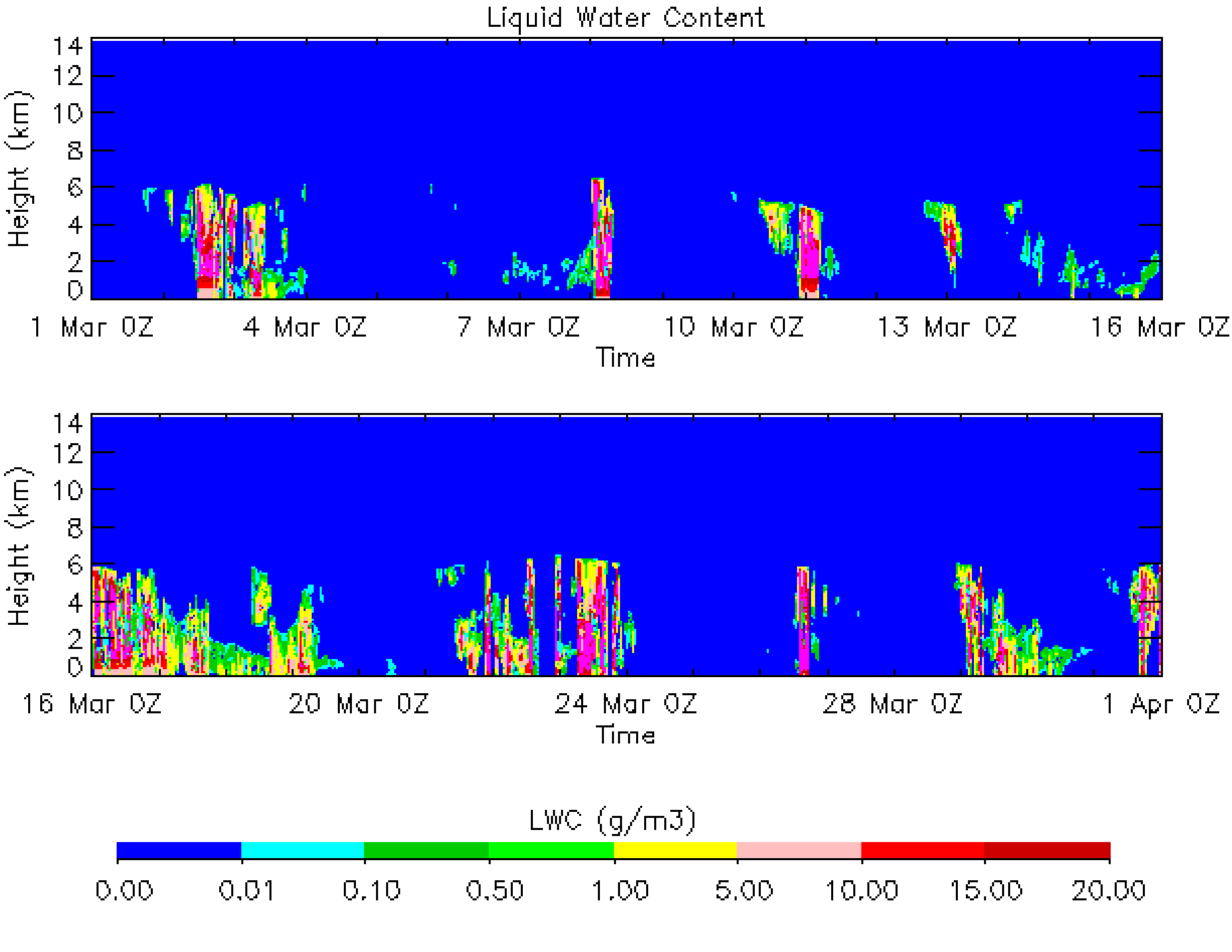
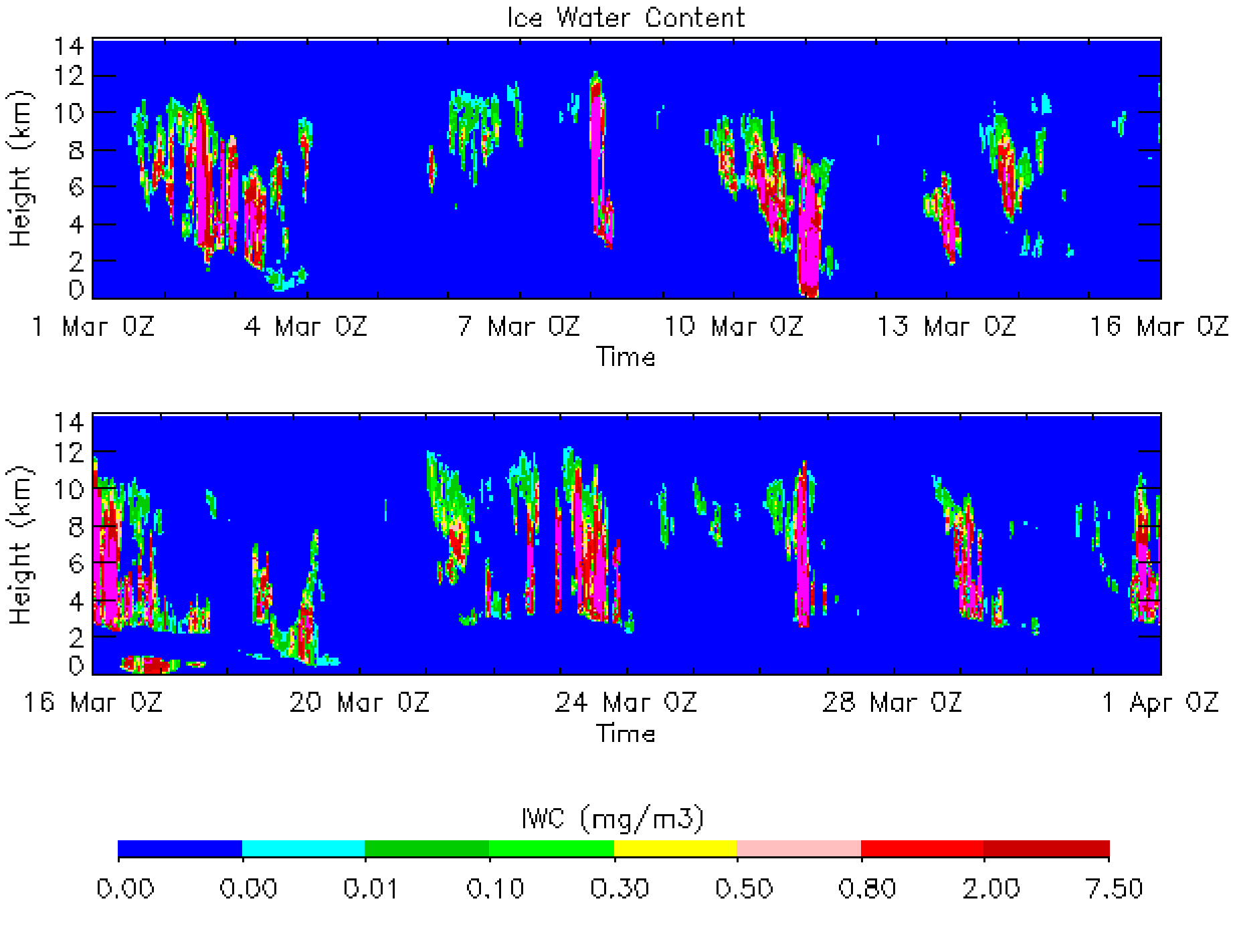
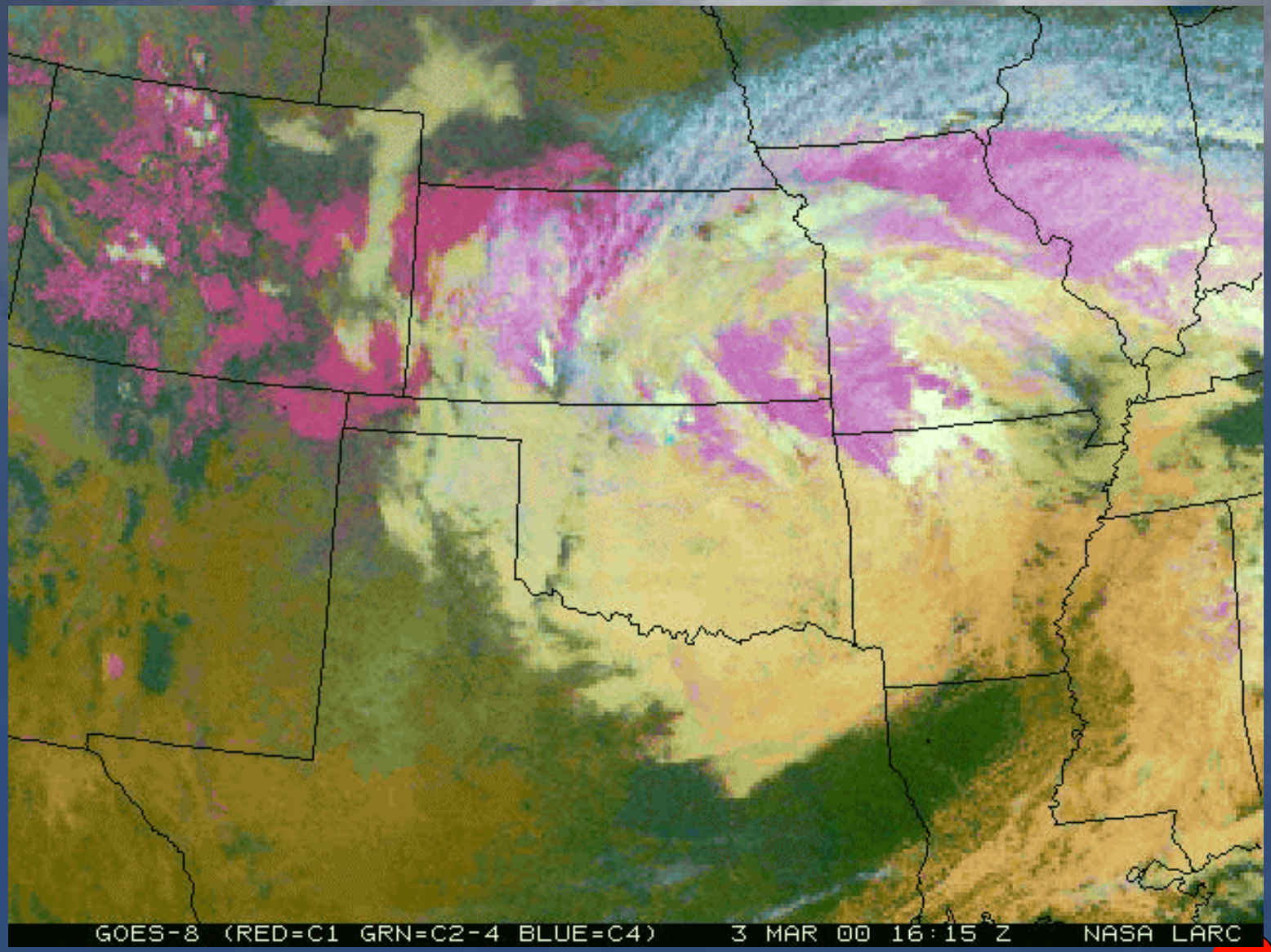

Liquid Water Content
Height (km)
14
12
10
8
6
4
2
0
1 Mar 0Z
4 Mar 0Z
7 Mar 0Z
10 Mar 0Z
13 Mar 0Z
16 Mar 0Z
Time
Height (km)
16 Mar 0Z
20 Mar 0Z
24 Mar 0Z
28 Mar 0Z
1 Apr 0Z
Time
LWC (g/m3)
0.00
0.01
0.10
0.50
1.00
5.00
10.00
15.00
20.00


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

Cloud Microphysics

- Ground-based retrievals
  - Stratus – based on MWR and solar transmission
  - Cirrus – based on cloud radar and IR emissivity
- Aircraft data from Citation (U. of North Dakota)



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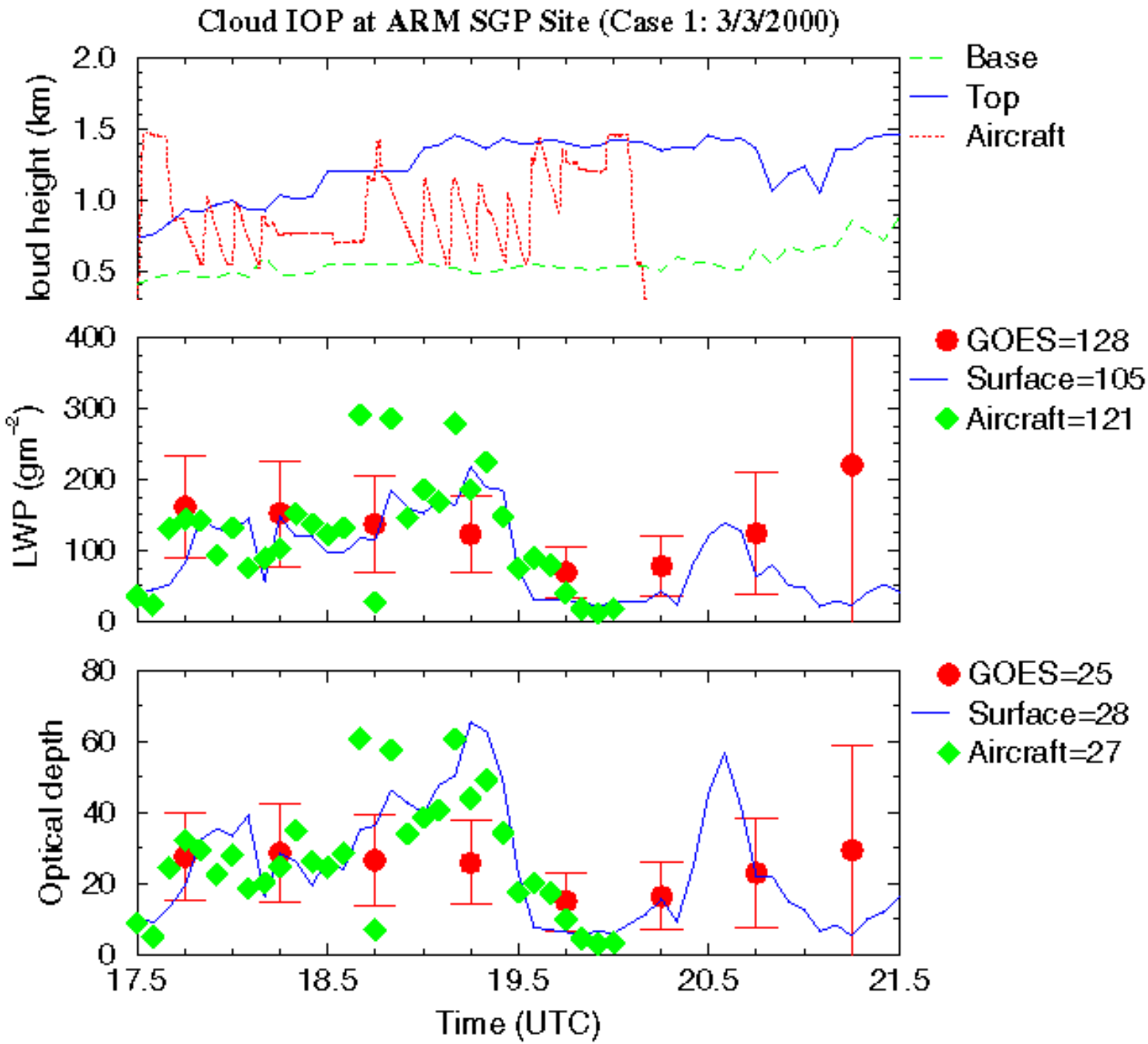
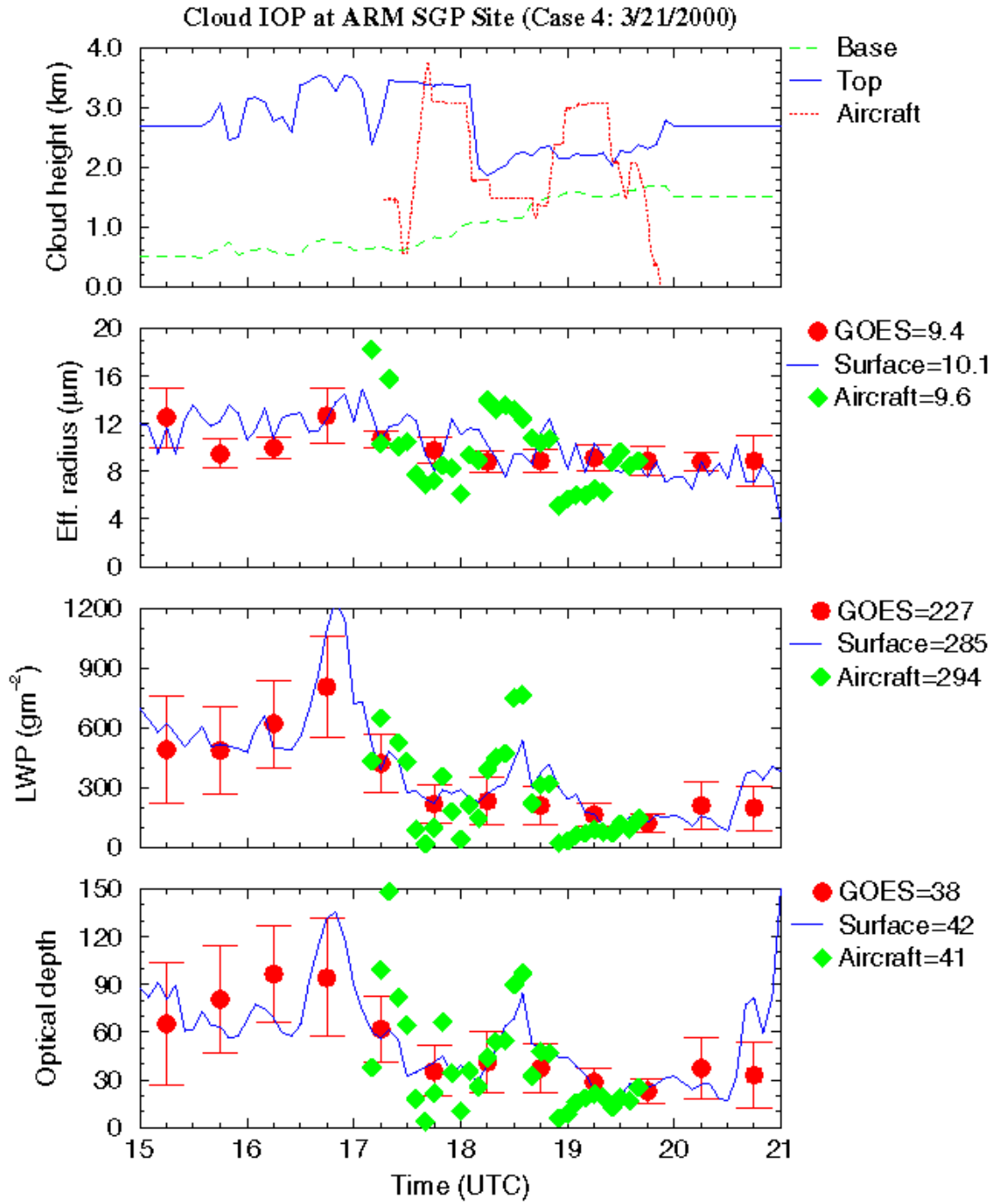

Cloud IOP at ARM SGP Site (Case 1: 3/3/2000)
loud height (km)
2.0
1.5
1.0
0.5
Base
Top
Aircraft
LWP (gm^{-2})
400
300
200
100
0
GOES=128
Surface=105
Aircraft=121
Optical depth
80
60
40
20
0
GOES=25
Surface=28
Aircraft=27
17.5
18.5
19.5
20.5
21.5
Time (UTC)



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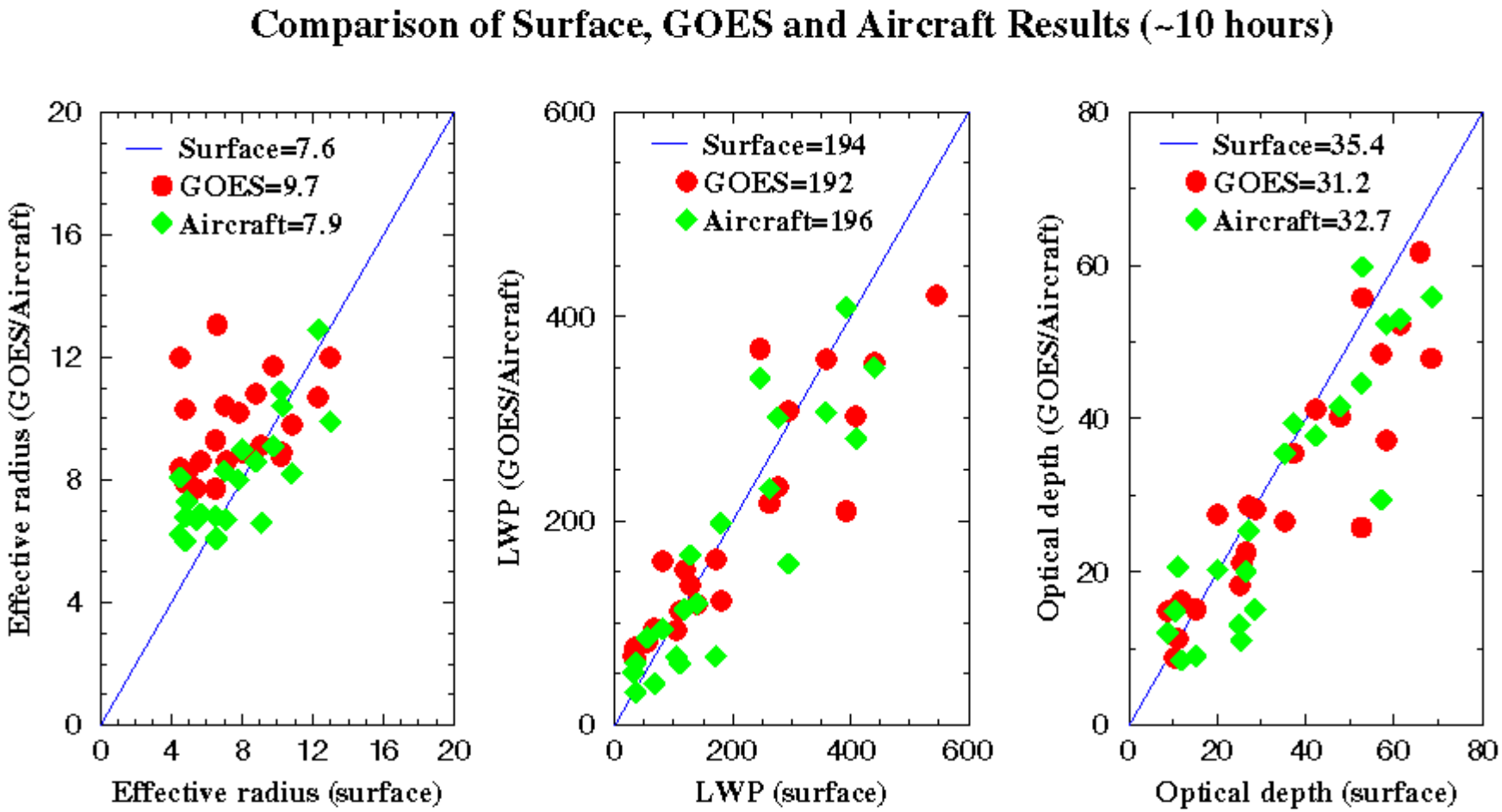


Fig. 8. Comparison of three datasets during 10–hour time period from 4 cases in 30–min temporal resolution.

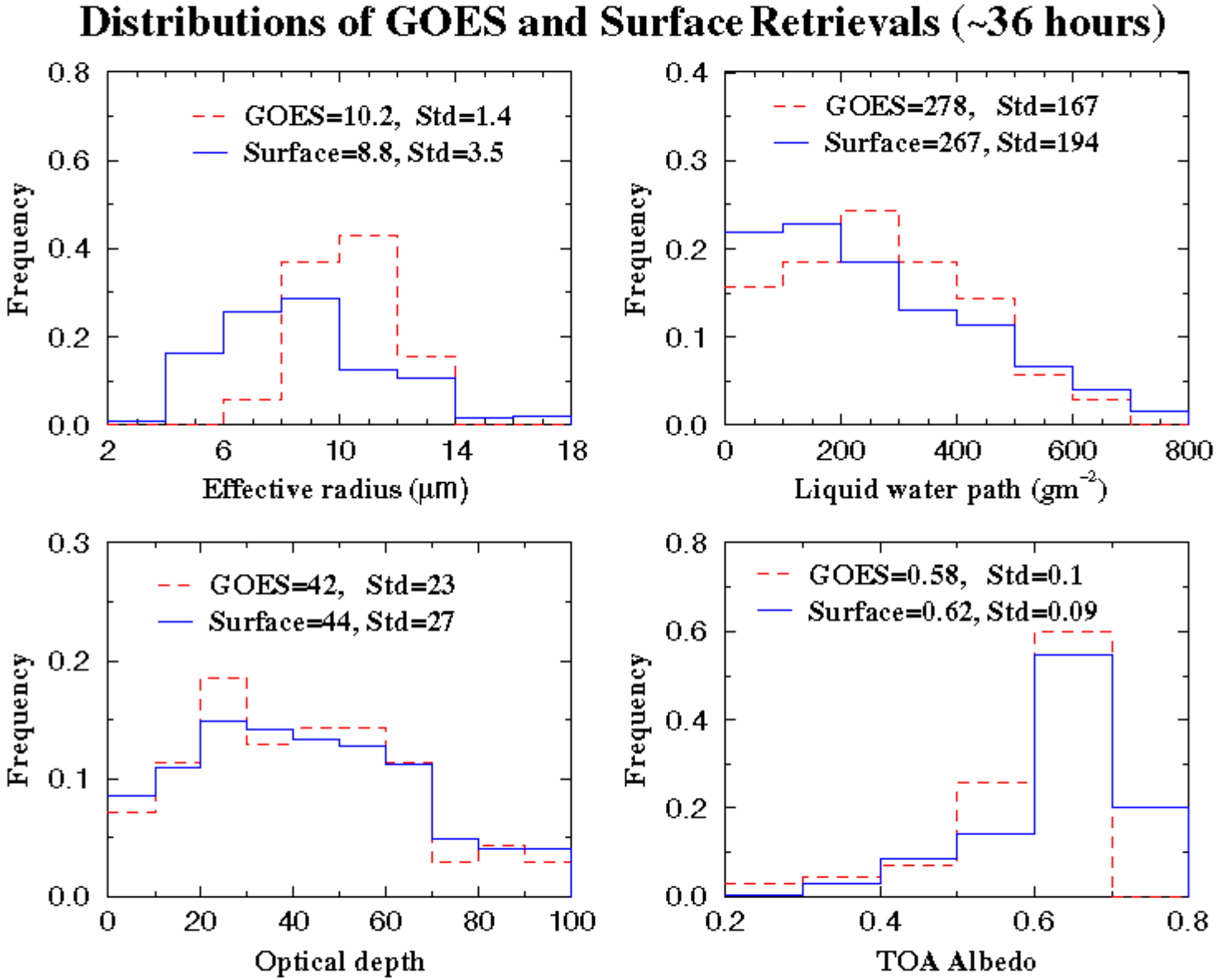
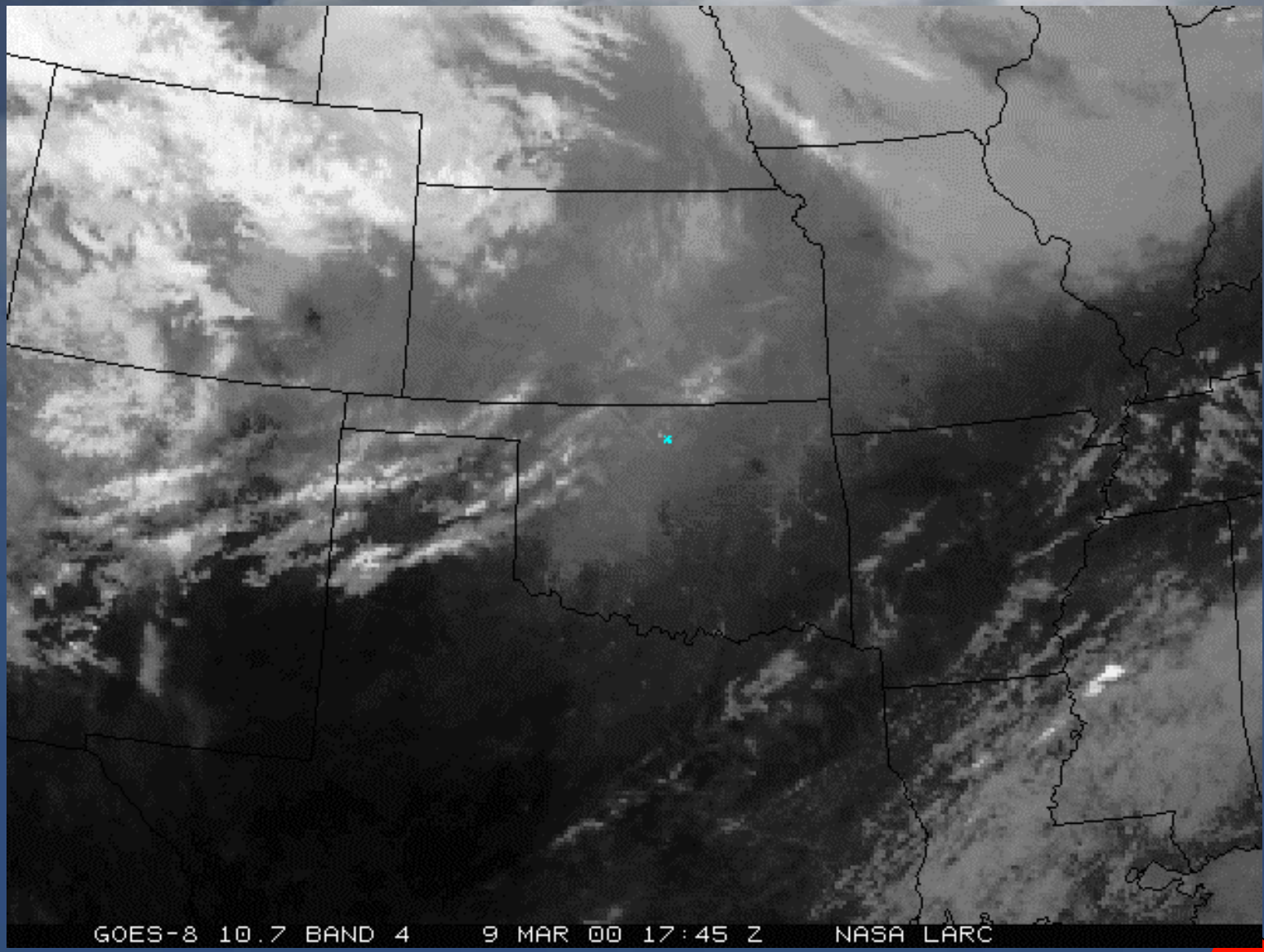


Fig. 12. Total 36 hours of surface (5–min) and GOES (30–min) data from 7 cases during the IOP.



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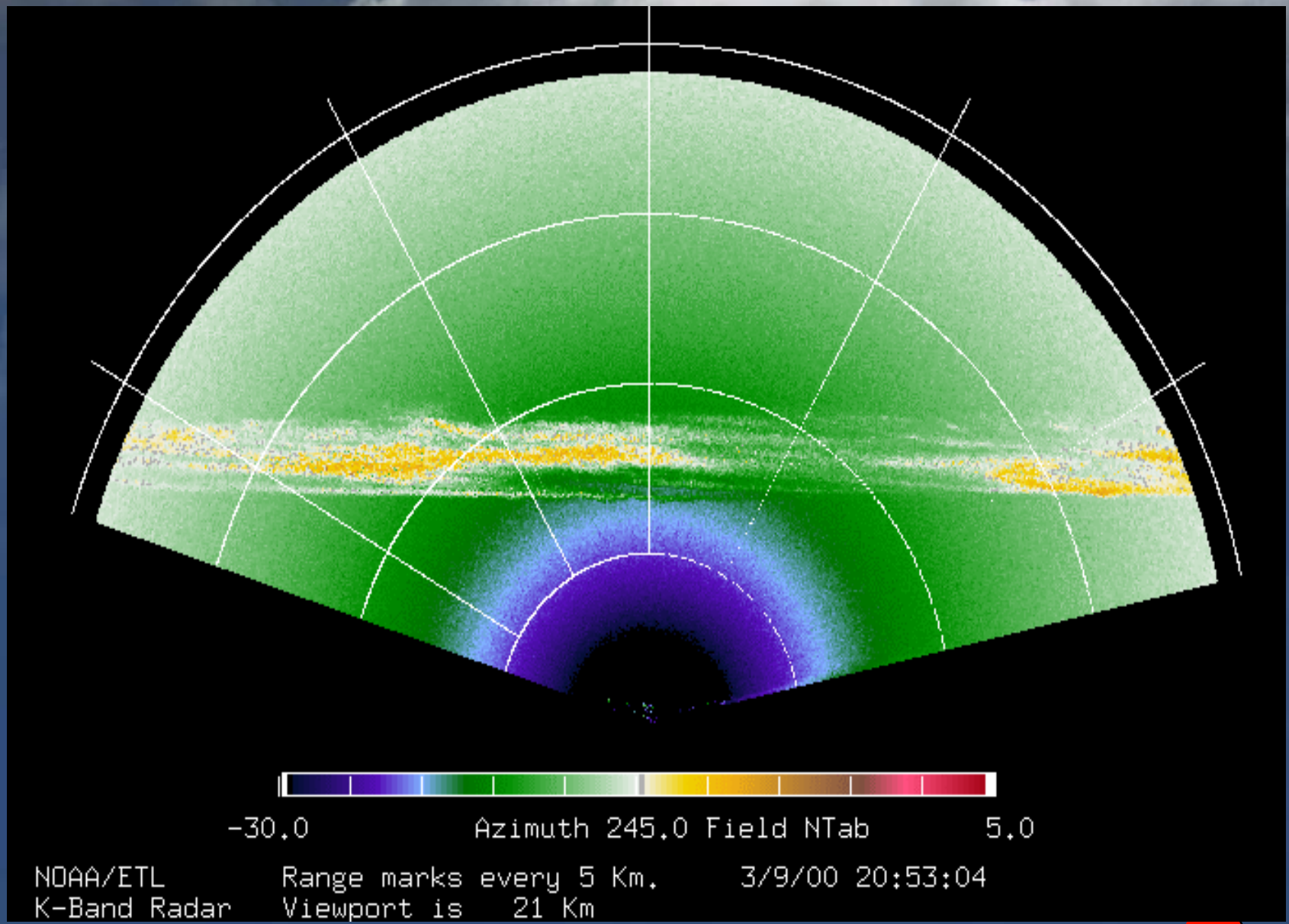

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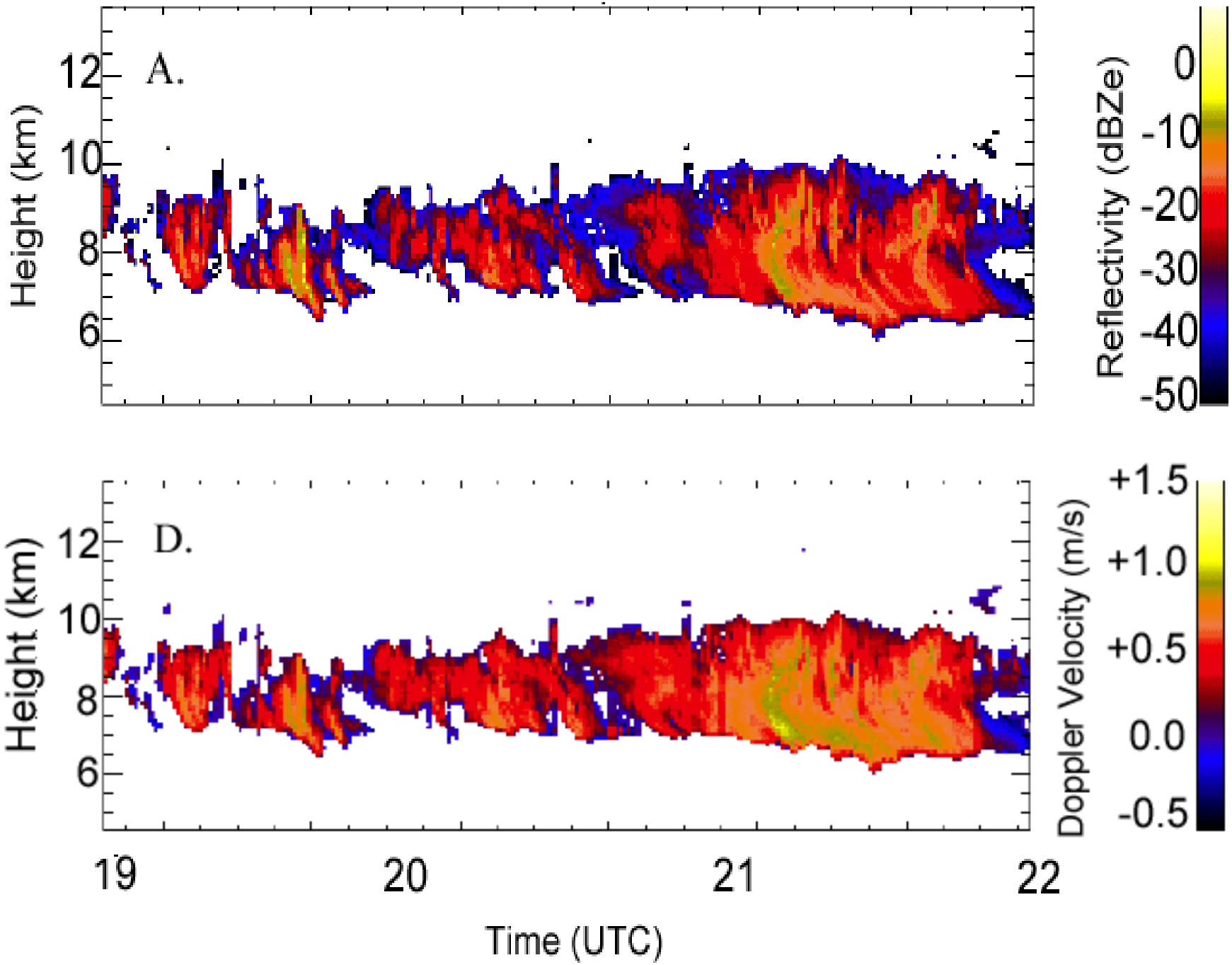
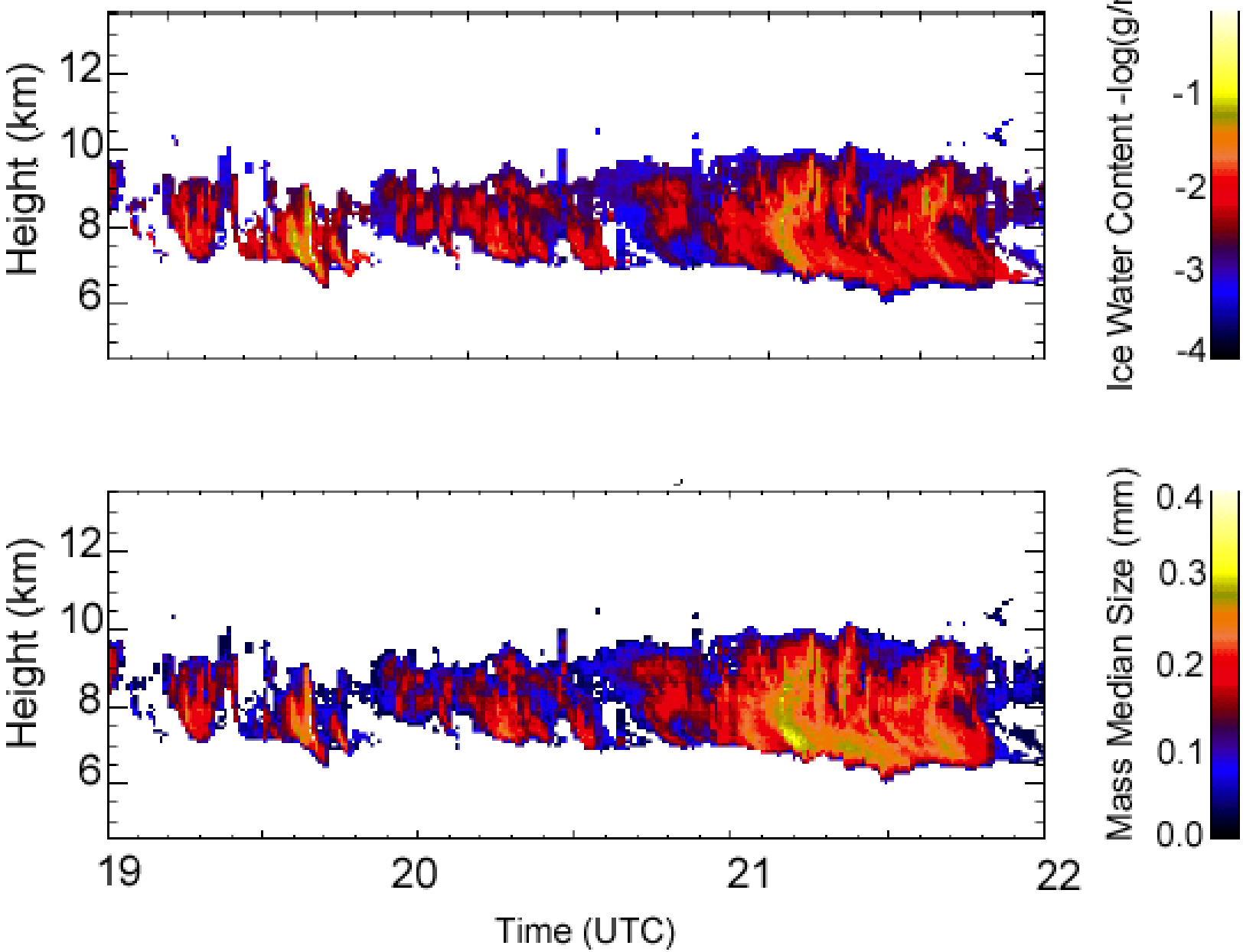
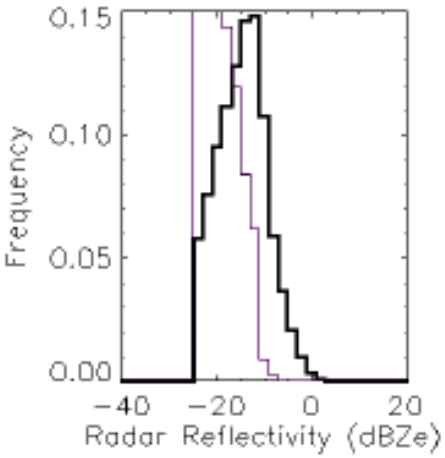
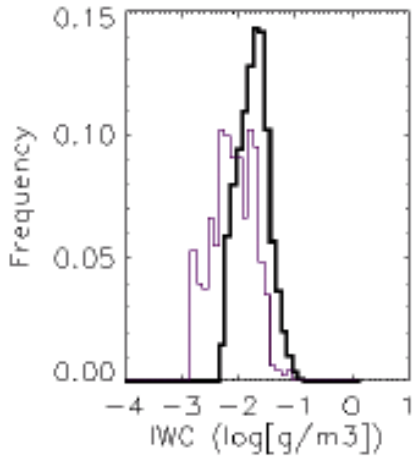
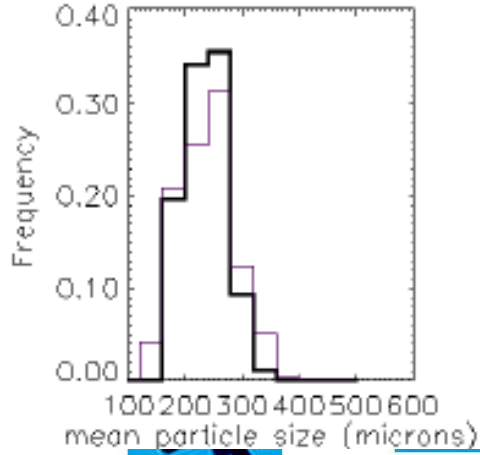
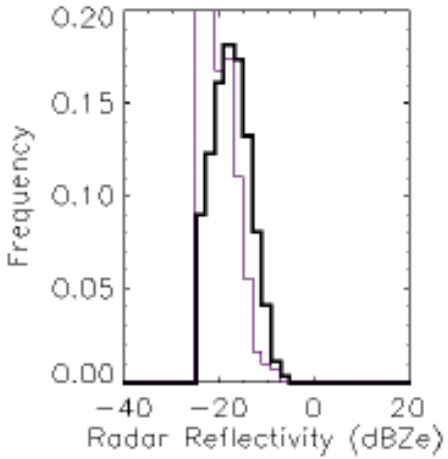

A.
D.
Height (km)
12
10
8
6
Reflectivity (dBZe)
0
-10
-20
-30
-40
-50
Doppler Velocity (m/s)
+1.5
+1.0
+0.5
0.0
-0.5
19
20
21
22
Time (UTC)

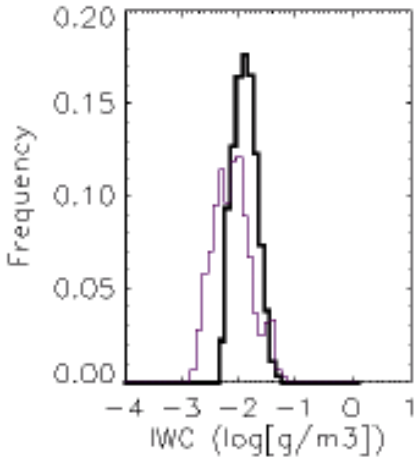

Height (km)
12
10
8
6
Ice Water Content -log(g/m3)
-1
-2
-3
-4
Height (km)
12
10
8
6
Mass Median Size (mm)
0.4
0.3
0.2
0.1
0.0
19
20
21
22
Time (UTC)

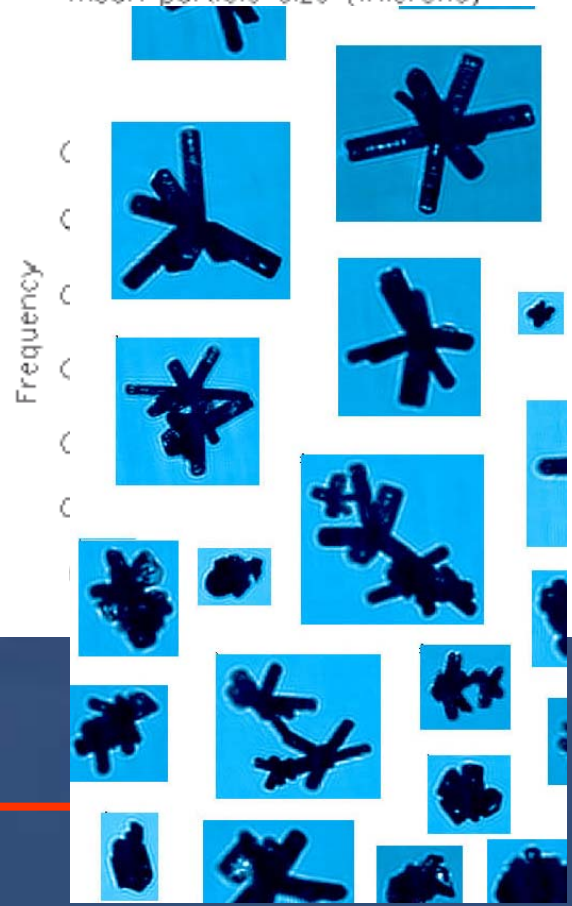












Heavy line = scanning radar
Light line = aircraft horizontal leg

3D Cloud Mapping in a Mesoscale Grid

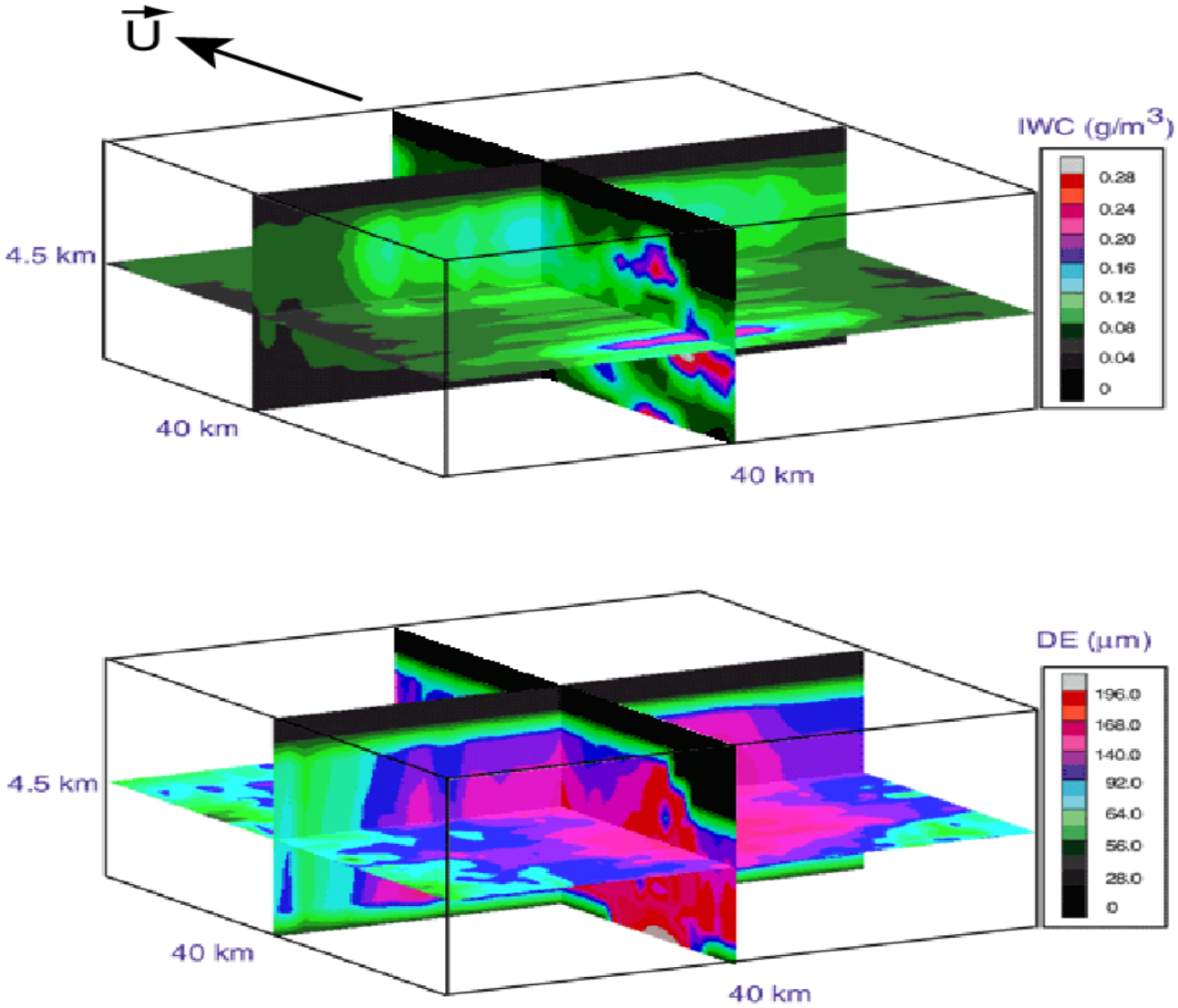


Fig. 1 Three-dimensional ice water content (IWC, g/m^3) and mean effective ice crystal size (DE, µm) determined from a unification of the optical depth and DE retrieval from the 0.63 and 3.7 µm AVHRR channels abroad the NOAA-14 satellite and the IWC and DE retrieved from the 35 GHz cloud radar over the ARM-SGP CART site at 2023 UTC on April 18, 1997. The 3D IWC and DE results are presented in *xy*, *yz*, and *xz* planes over a 40 km × 40 km × 4.5 km domain (Liou et al., 2002; *Geophy. Res. Lett.*, in press).

3D Radiative Heating Rate in a Mesoscale Grid

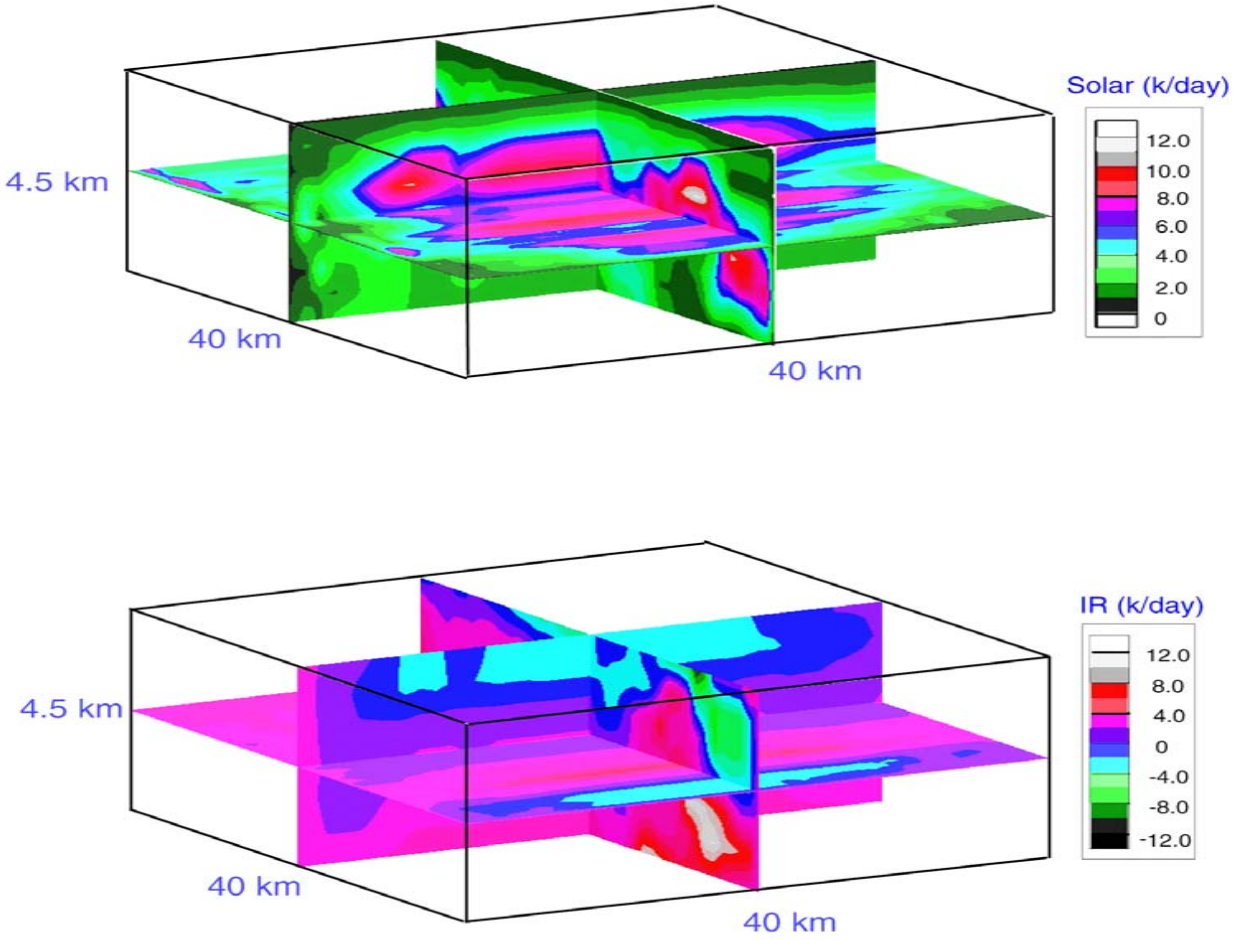


Fig. 2 Three-dimensional solar heating and IR heating/cooling rates in a mesoscale grid, presented in the xy, yz, xz planes. The input cloud IWC and DE fields were from those presented in Fig. 1. The solar constant and solar zenith angle used were 1366 W/m^2 and 60^o, respectively. The Standard atmospheric profiles were employed in the calculations.

Where to?

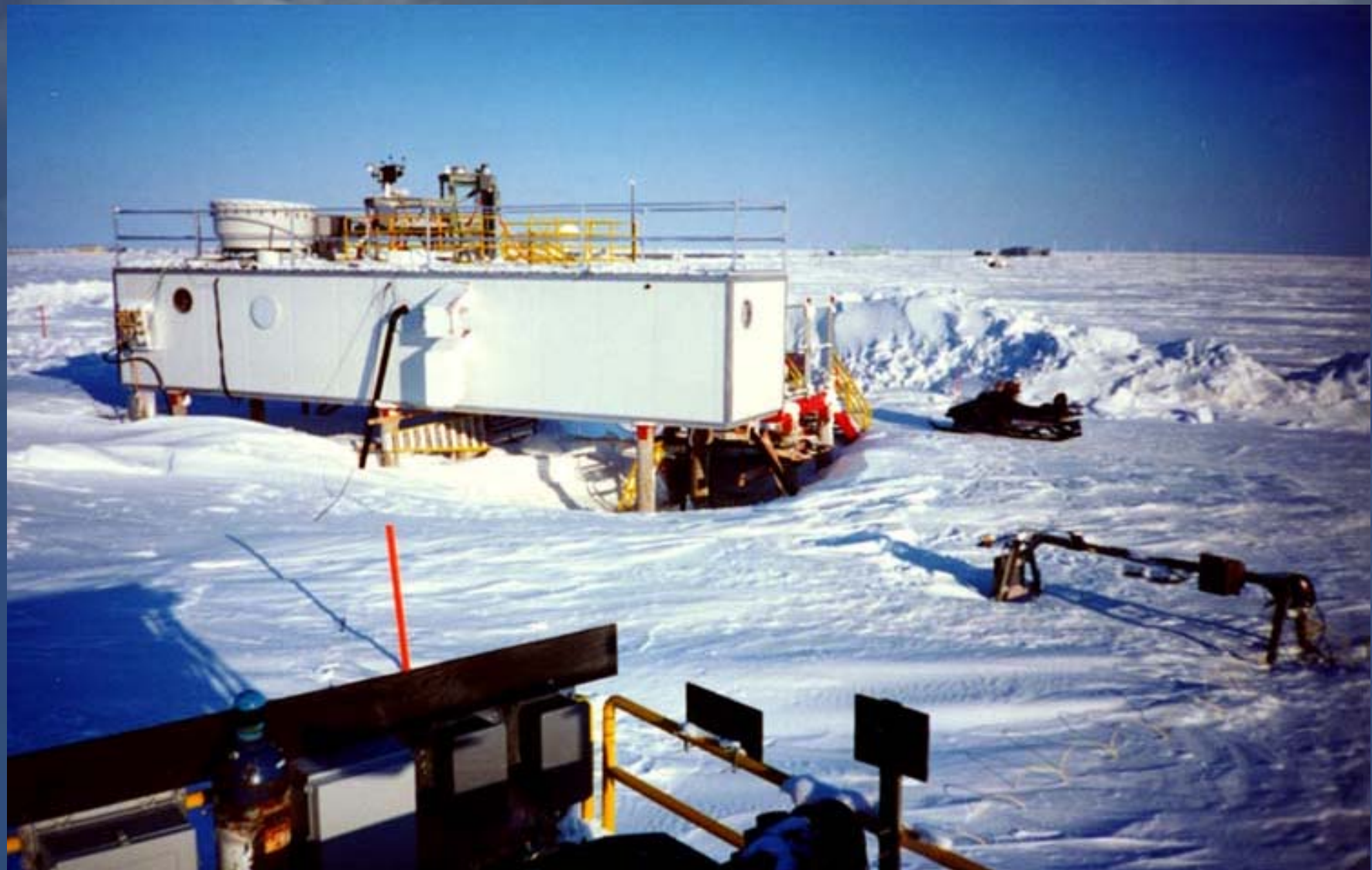
- SGP site
  - Continuous forcing fields
  - Domain average water vapor and cloud
  - Cloud advection
  - Integrated products
- Remote sites

Remote Sites

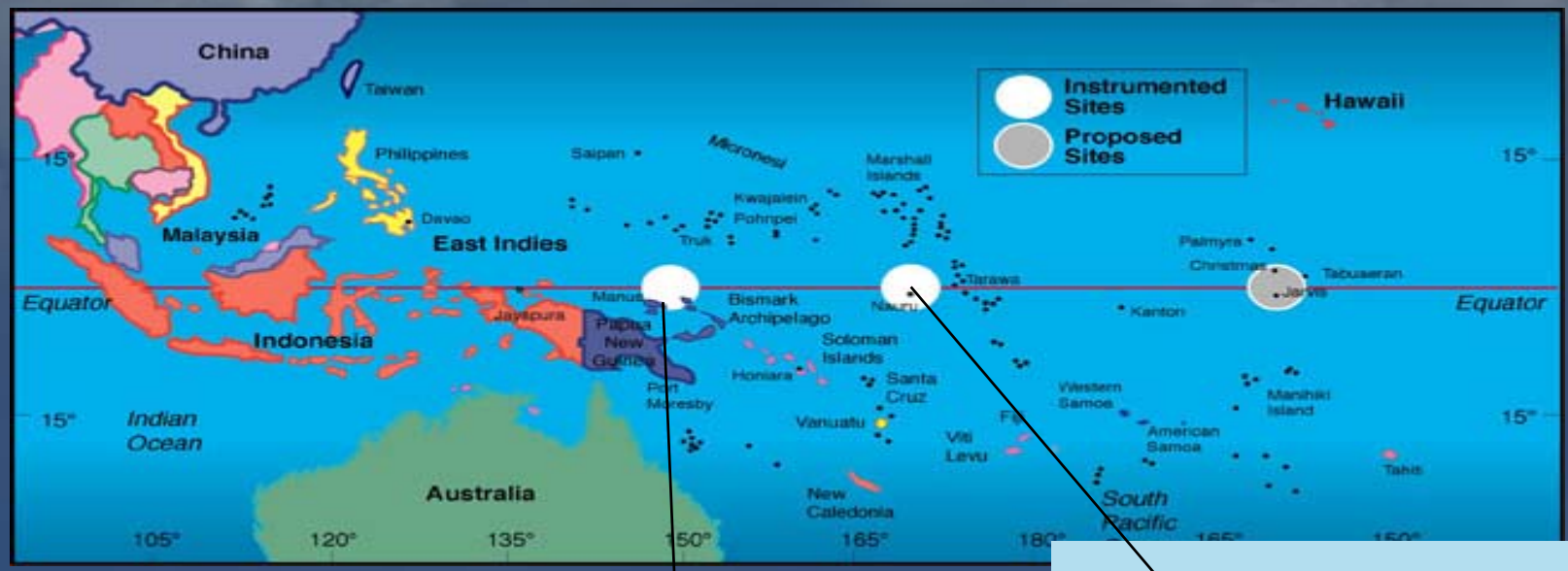
ARM
Atmospheric Radiation Measurement

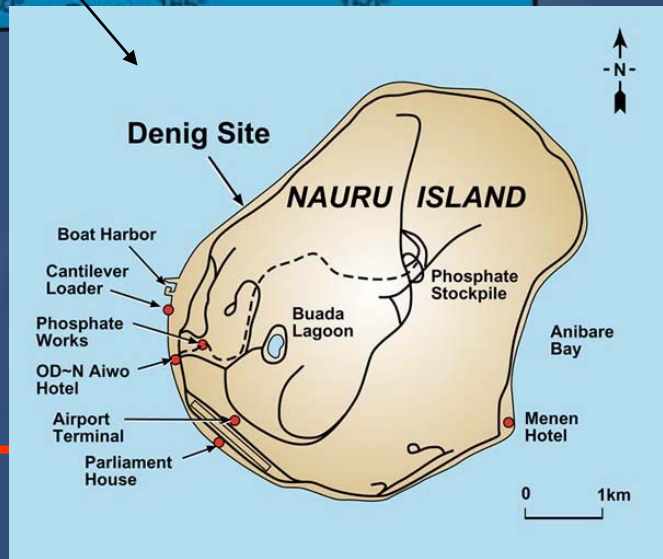
North Slope of Alaska Site

North Slope of Alaska Site



Tropical Western Pacific Site





Tropical Western Pacific Site

Manus Island

Nauru

Tropical Western Pacific Site -- Darwin

Other Sites

- European sites
  - Cabauw – the Netherlands
  - Chilbolten – United Kingdom
  - Palaiseau – France
  - Lindenberg – Germany
- Asian sites?

Commercial Message

ARM data: freely available at www.arm.gov


Thanks for your attention!