An Integrated Column Description of the Atmosphere

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ARM Atmospheric Radiation Measurement

Pacific Northwest National Laboratory

Credits to

- Ric Cederwall
- Xiquan Dong
- Chuck Long
- Jay Mace
- Mark Miller
- Robin Perez
- Dave Turner

and the rest of the ARM science team

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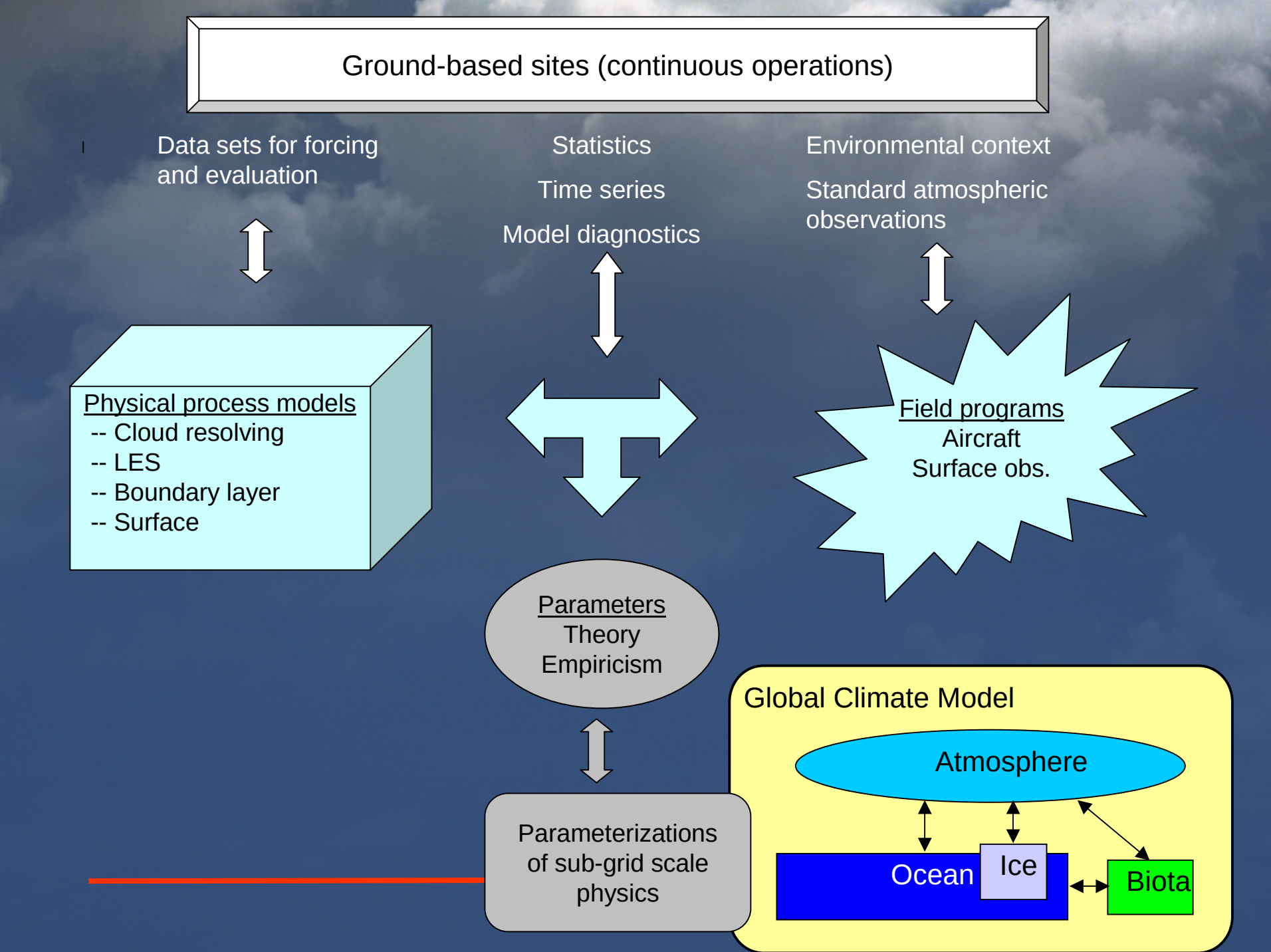
Atmospheric Radiation Measurement

Outline

- A little philosophy
- A short look at ARM
- A lot of snapshots of reality
- A commercial message


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 Cloud Parameterization Problem

Much of the difference in predictions of global warming by various climate models is attributable to the fact that each model represents these [cloud] processes in its own particular way. These uncertainties will remain until a more fundamental understanding of the processes that control atmospheric relative humidity and clouds is achieved.

"Climate Change Science: An Analysis of Some Key Questions", a report to the President from the Committee on the Science of Climate Change, National Research Council, June 2001

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ARM Questions

- ***If we can specify a cloud field, can we compute the radiative fluxes?***

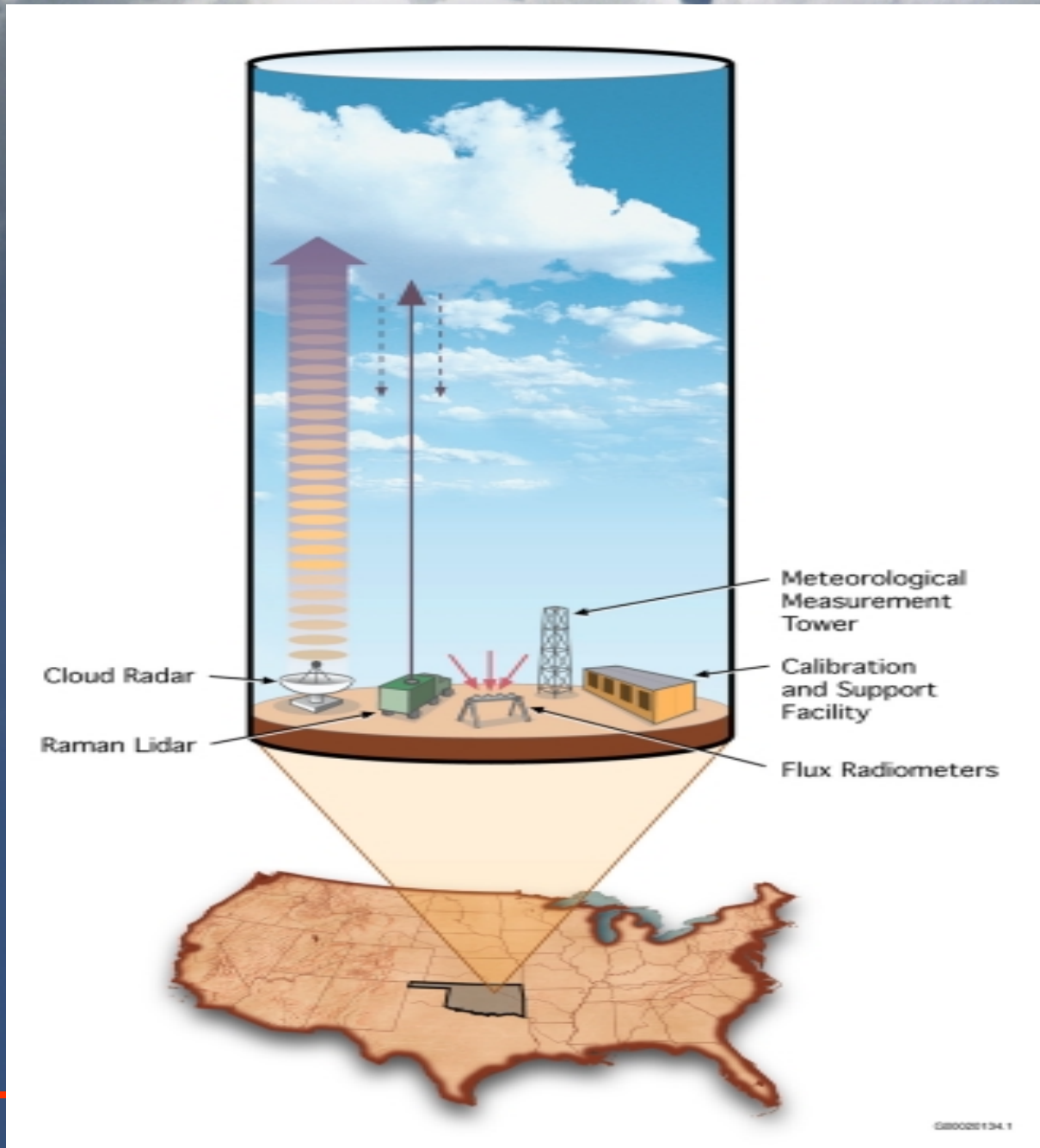
  => Requires knowledge of cloud properties

  (3D structure, water path, phase, size, etc.)

Need atmospheric observations to

-- test hypotheses in process model studies

-- analyze data for empirical relationships and statistical characteristics



ARM Questions

- ***If we can specify a cloud field, can we compute the radiative fluxes?***

  => Requires knowledge of cloud properties

  (3D structure, water path, phase, size, etc.)

- ***If we can specify the large-scale atmospheric fields, can we predict the cloud field properties?***

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

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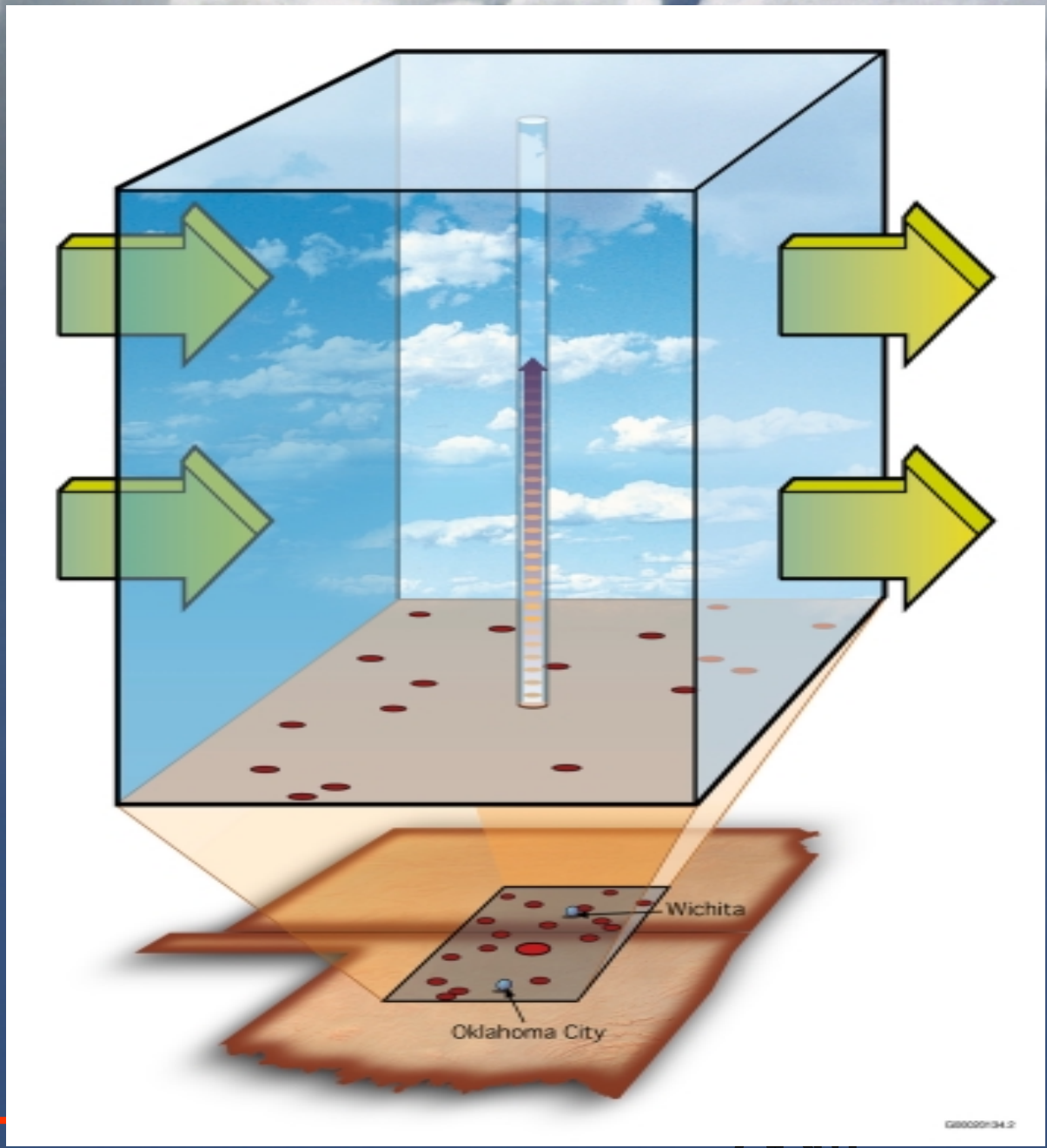
Need data sets that describe the large scale environment in which clouds form



Atmospheric Radiation Measurement

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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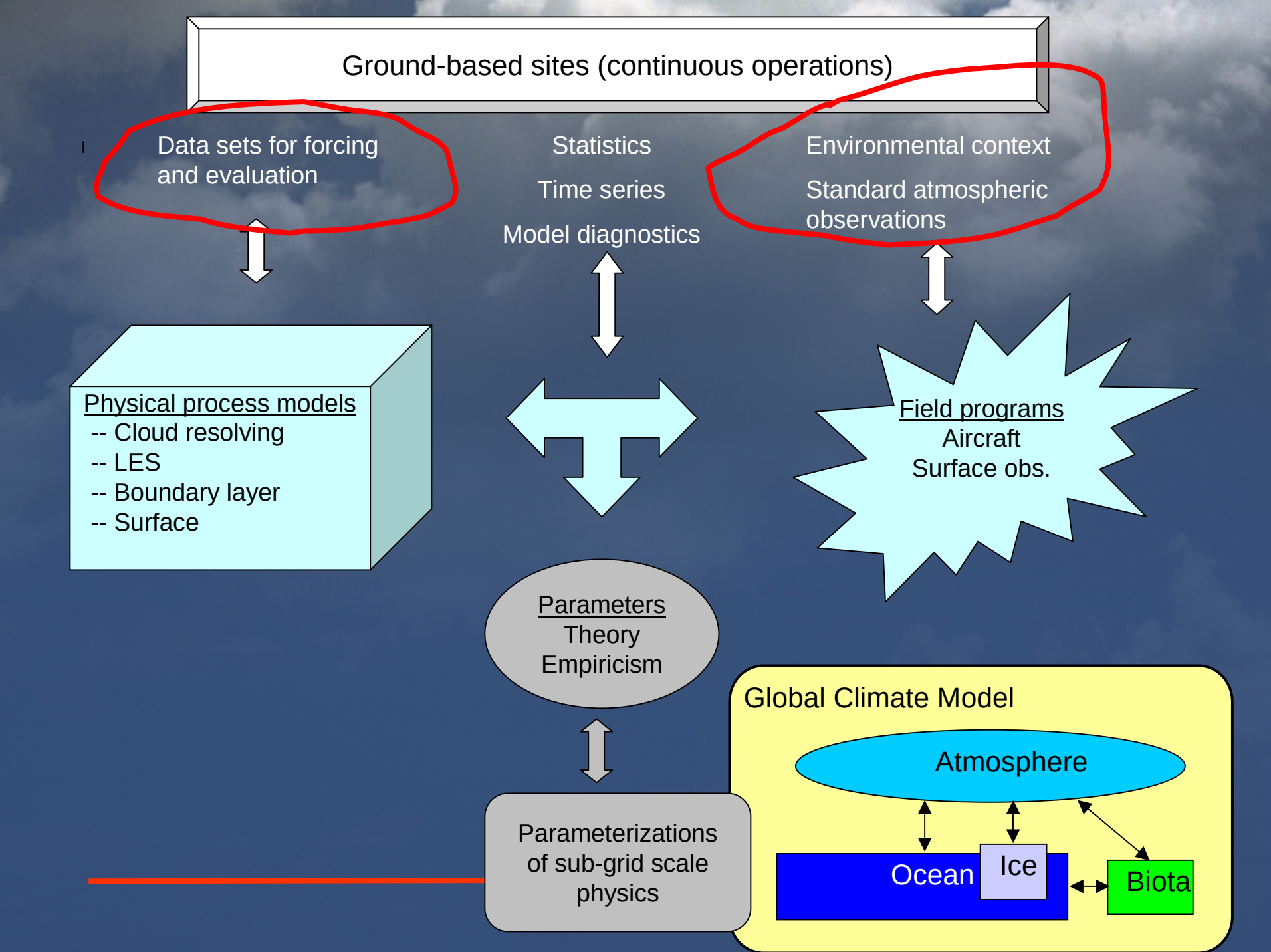
ARM Program Components

- 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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How well can we describe

- the state of the box?

- the radiatively active components?

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Data

- ARM Southern Great Plains Site
- March 2000
- 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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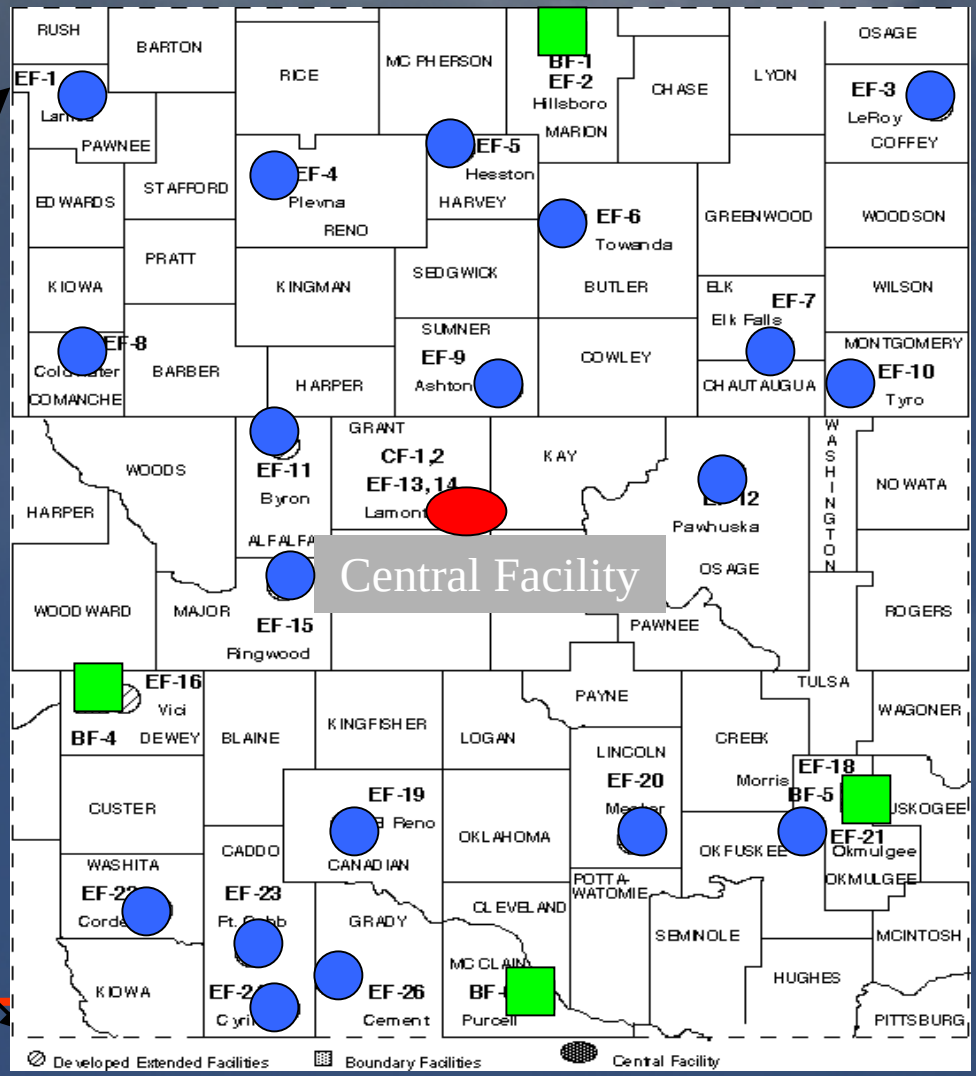
Southern Great Plains Site



Southern Great Plains Central Facility

Energy fluxes into the column

- GOES radiation fluxes at TOA
  - 10 W/m2 in IR
  - Potentially large errors in individual solar measurements due to BRDF
- Surface radiometer measurements
  - 10 W/m2 in individual measurements
  - Local albedo only
- Eddy correlation and Bowen flux measurements
  - Error?

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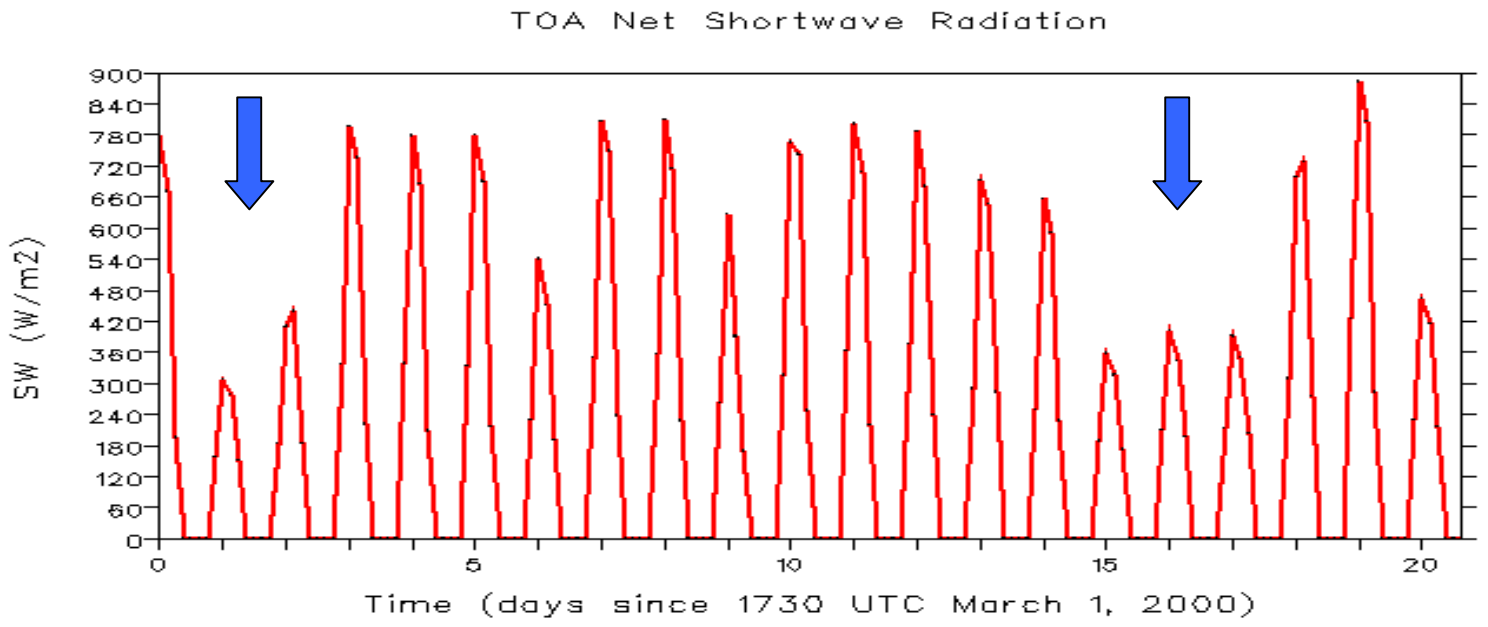
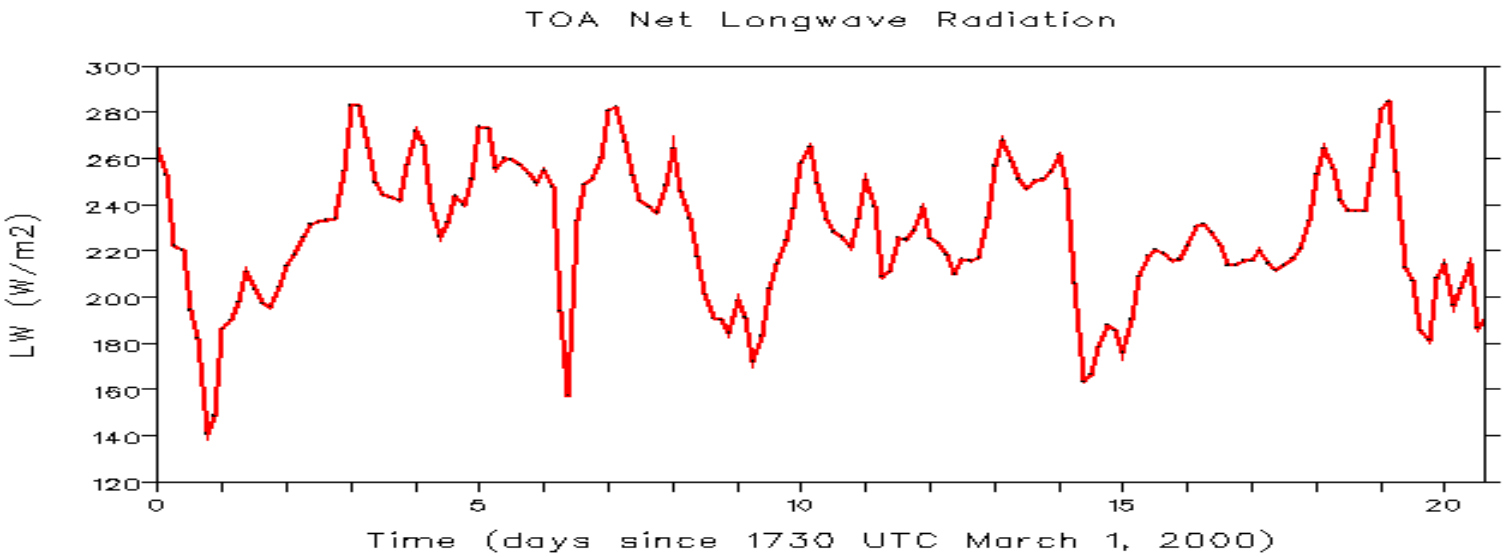
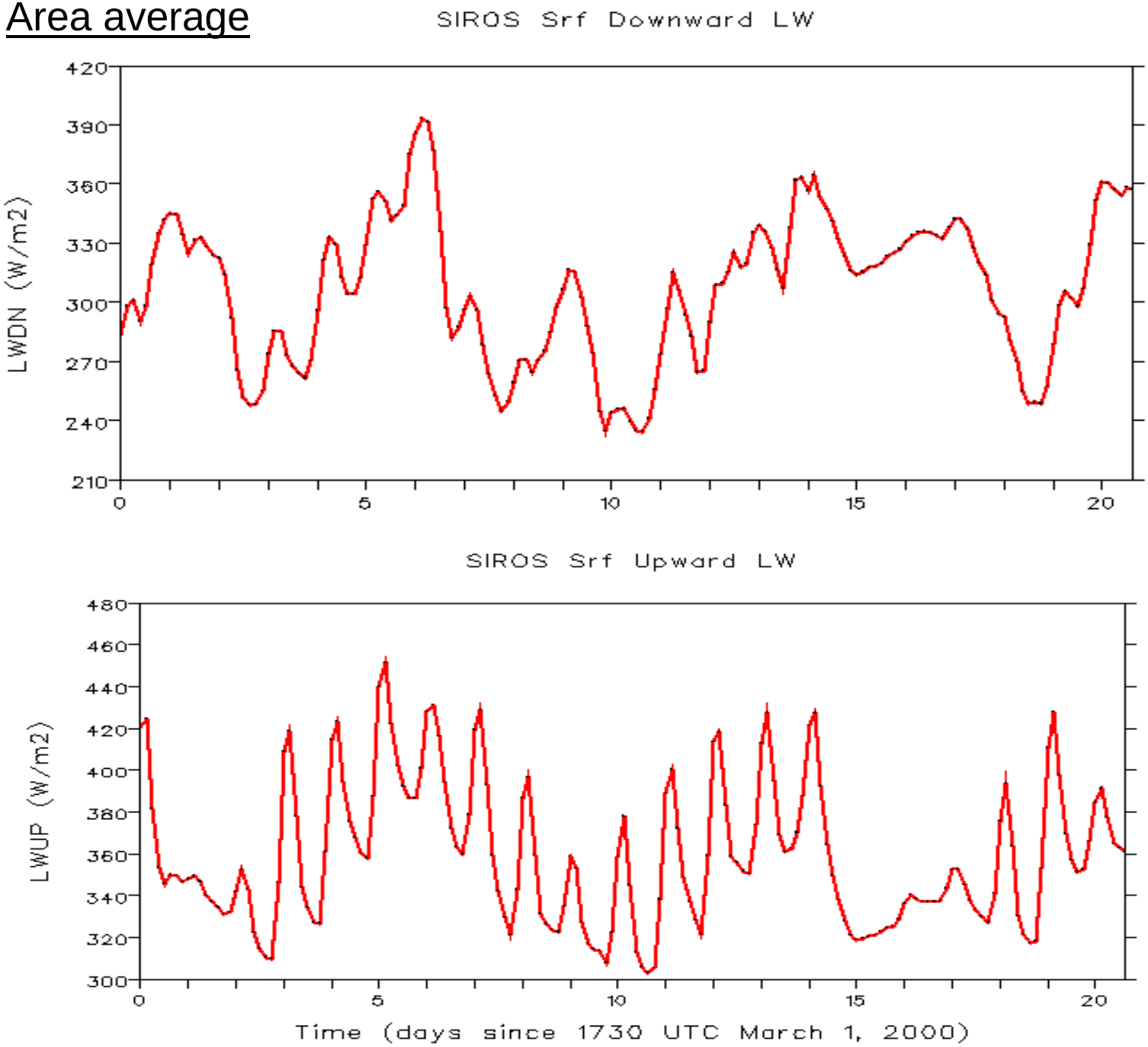


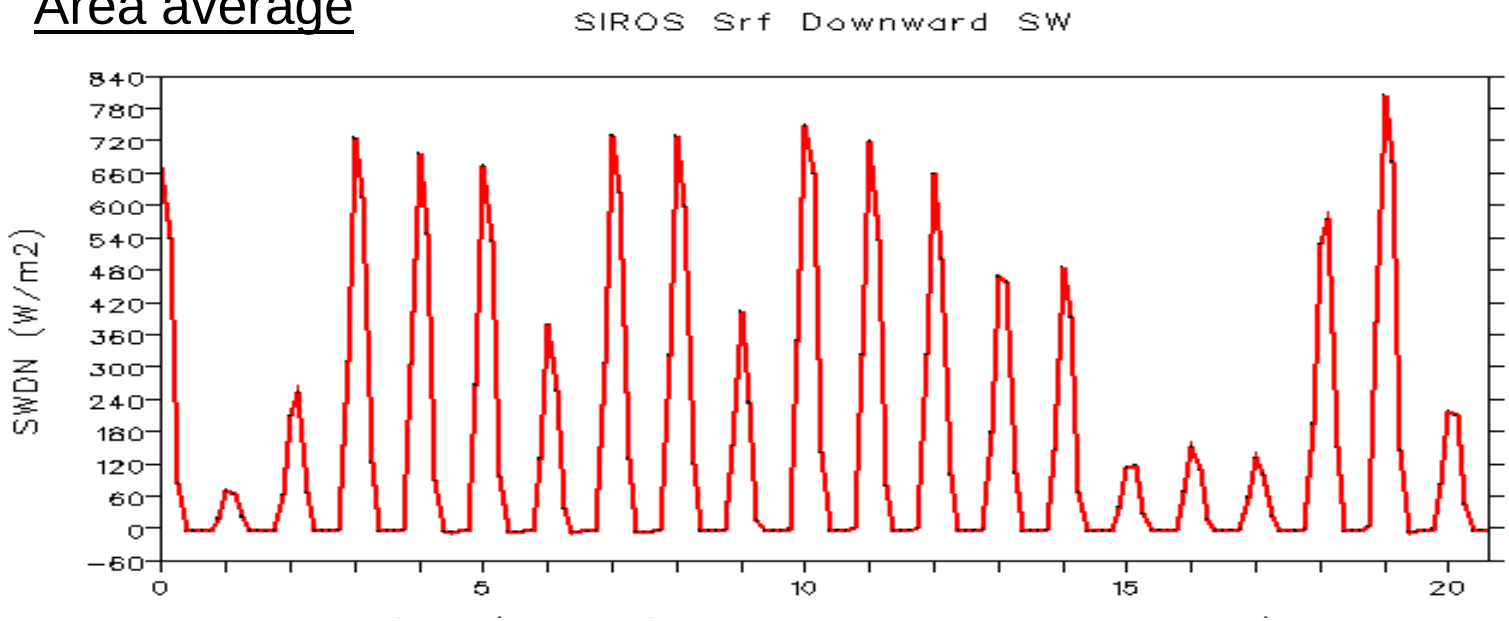


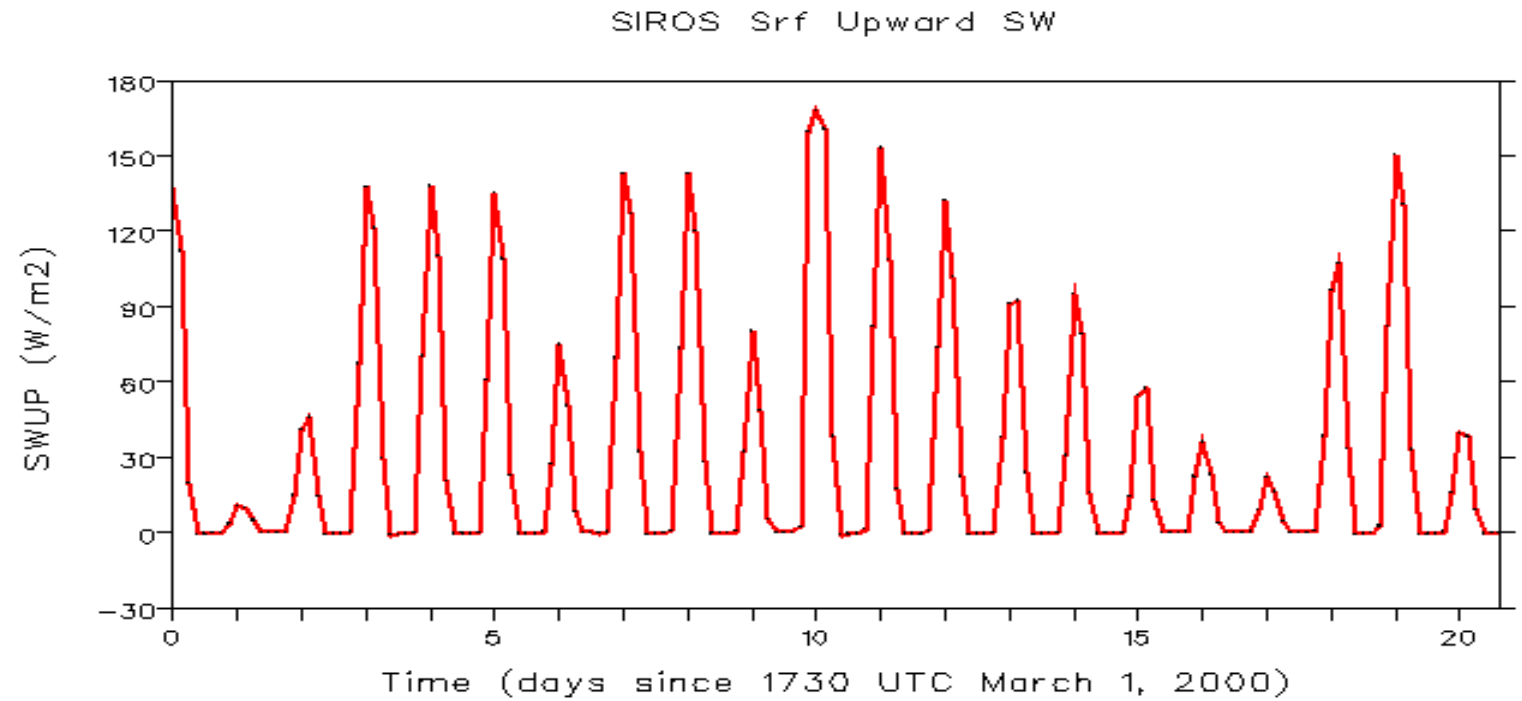
Measurement

Area average

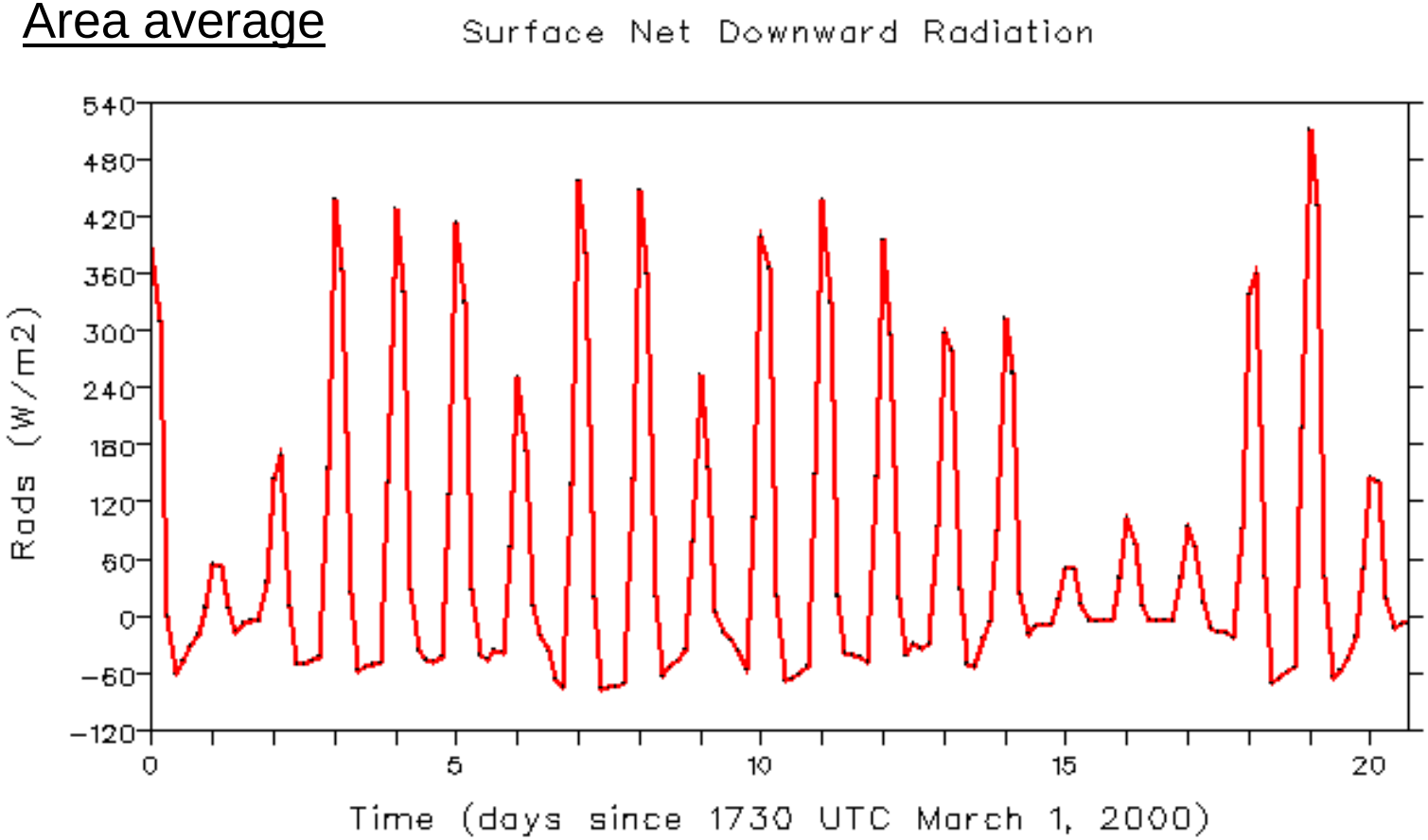


Area average





Area average



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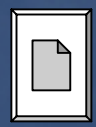
Domain averaged surface fluxes

- 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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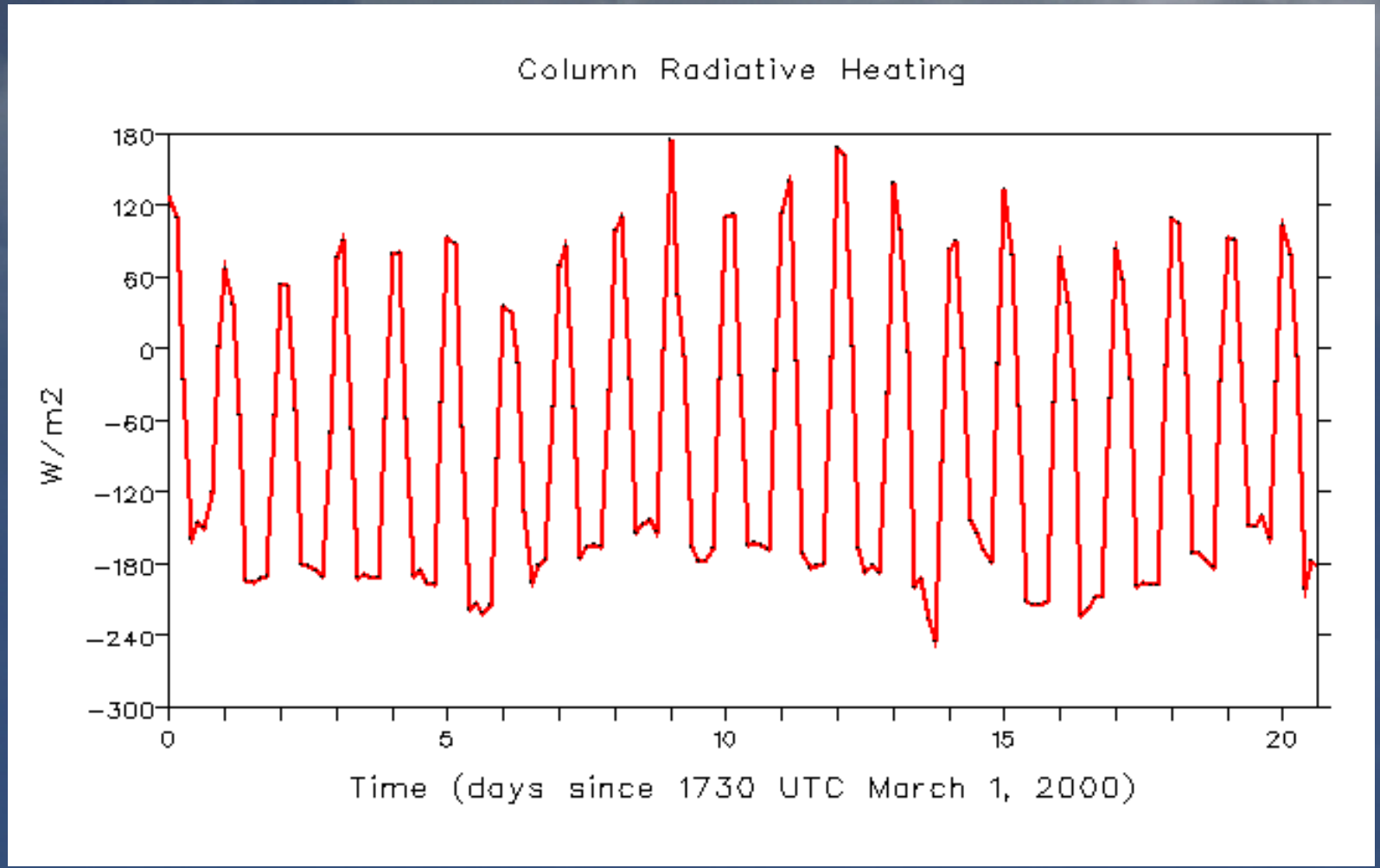
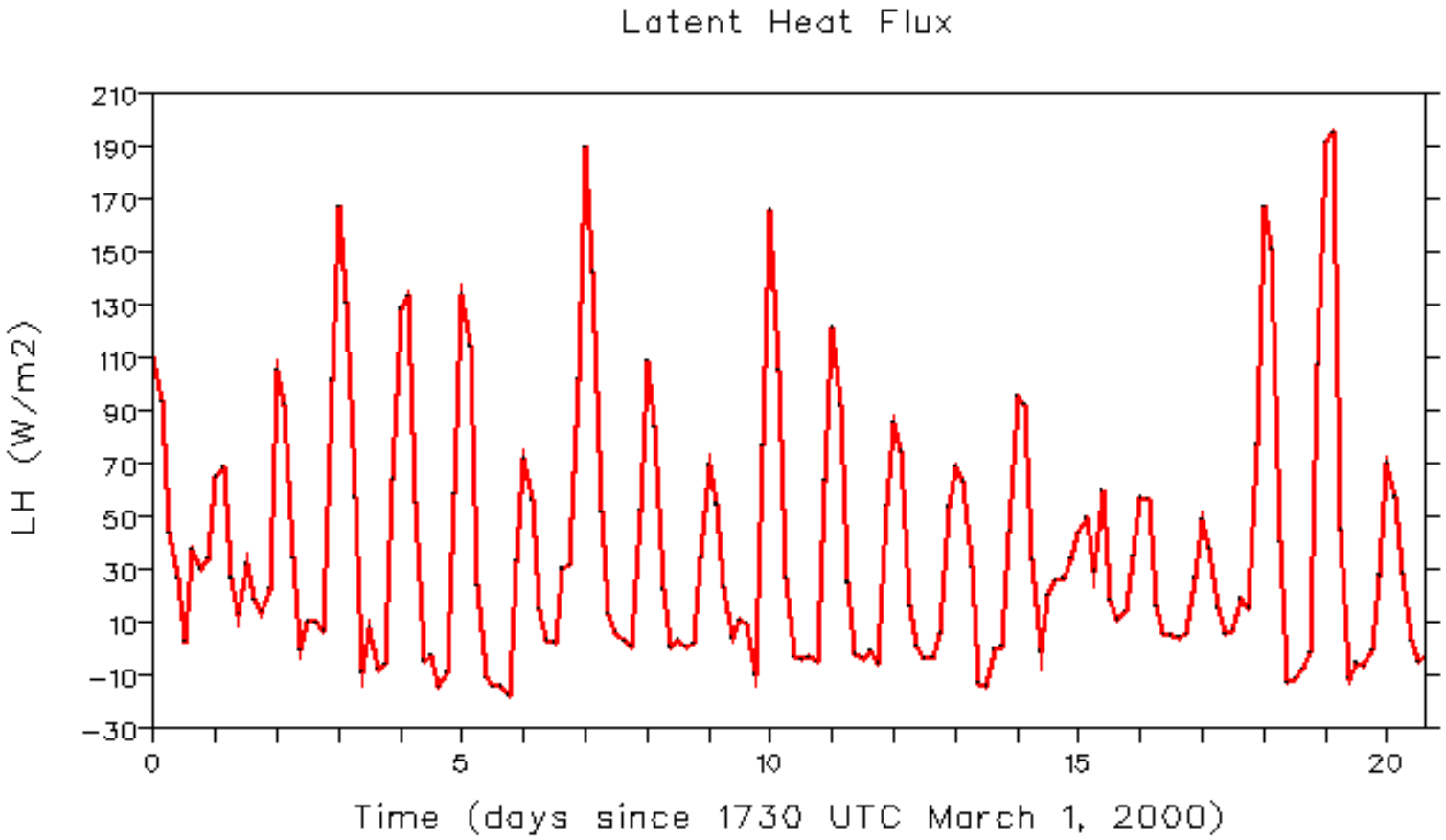

Column Radiative Heating
180
120
60
0
-60
-120
-180
-240
-300
W/m2
0
5
10
15
20
Time (days since 1730 UTC March 1, 2000)



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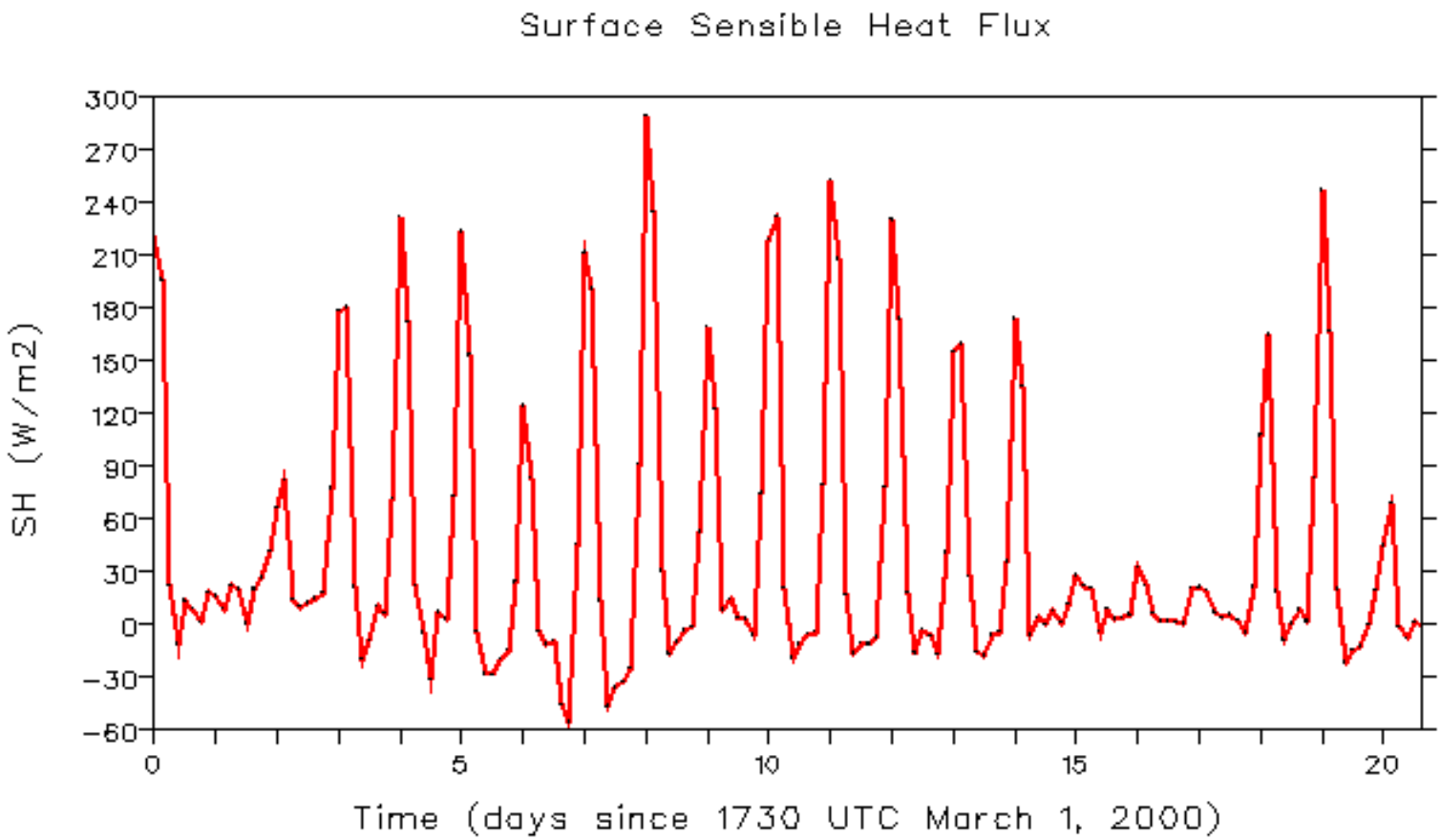

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Large-scale Forcing

- Start with assimilated mesoscale analysis (Rapid Update Cycle Model – NOAA)
- 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 domain average advection and convergence from integrated field
- Accuracy: uncertain

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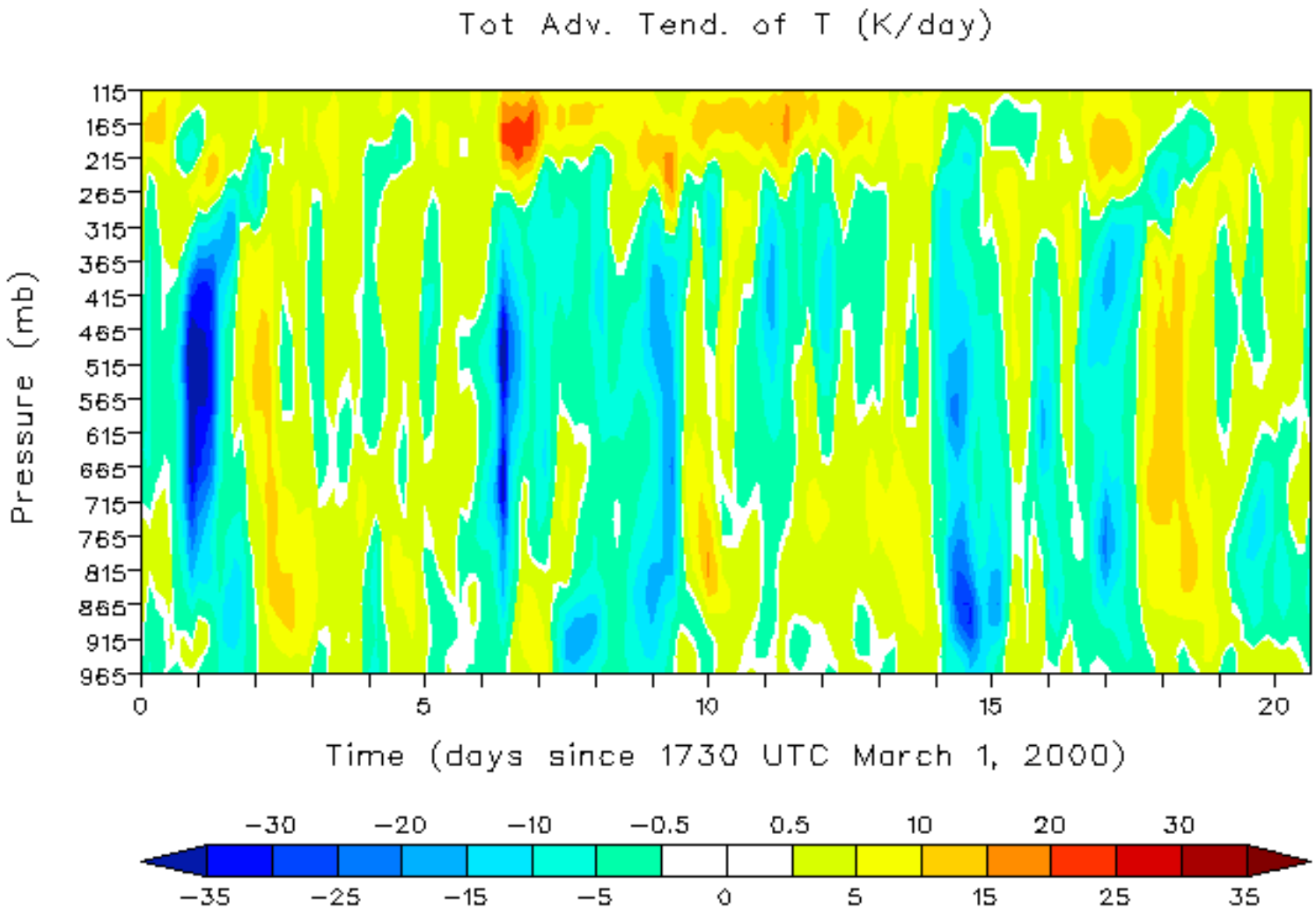

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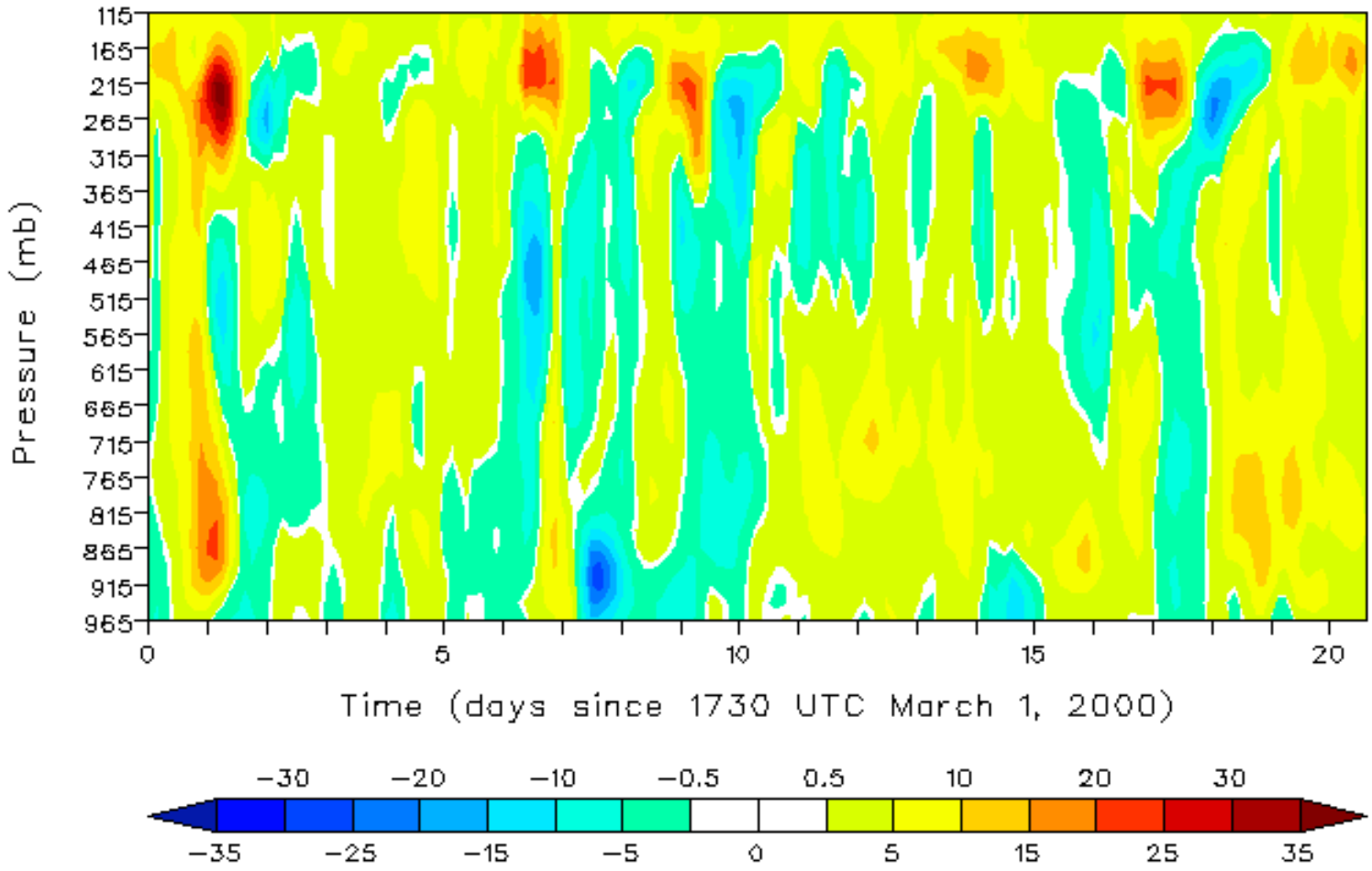

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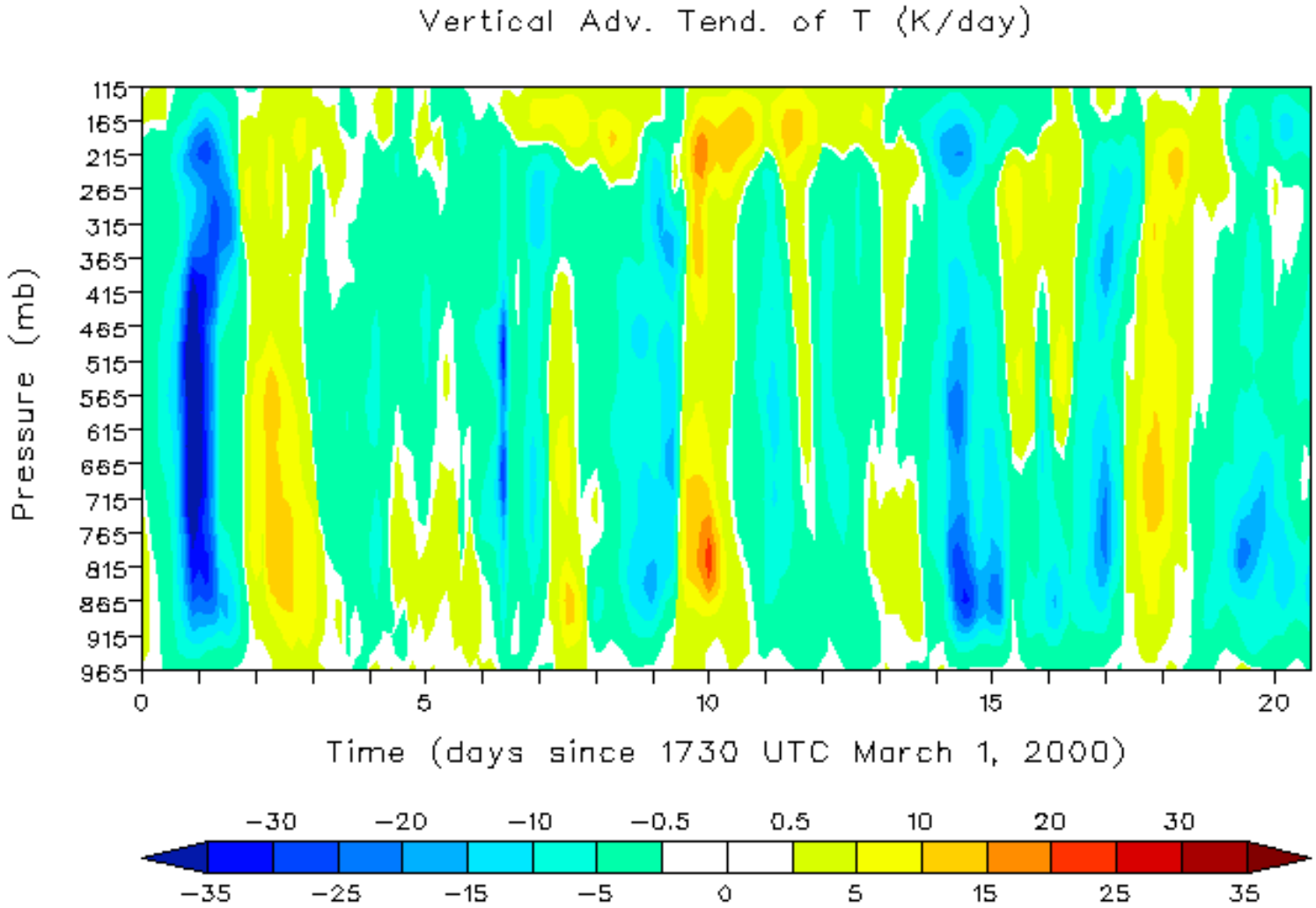

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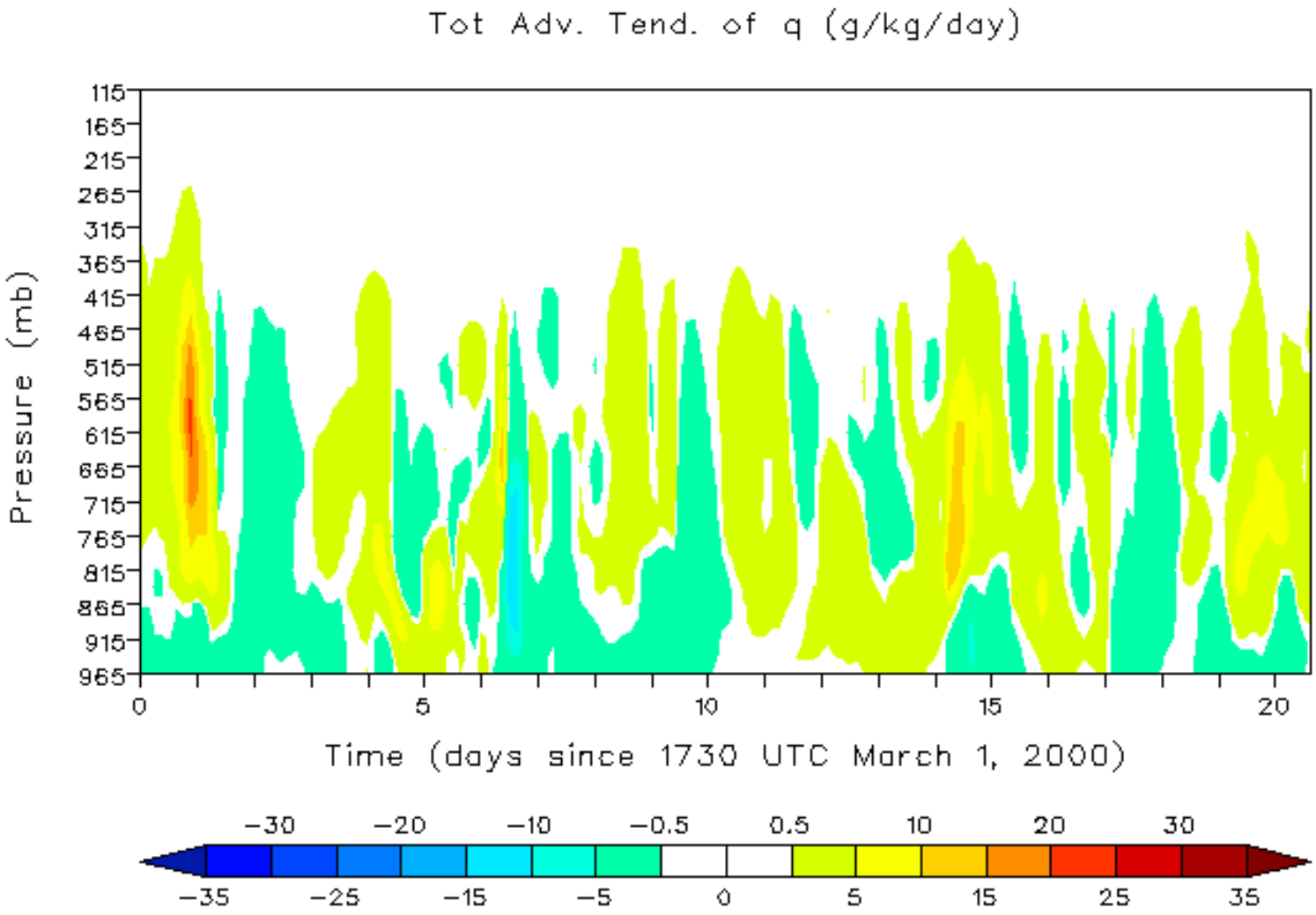

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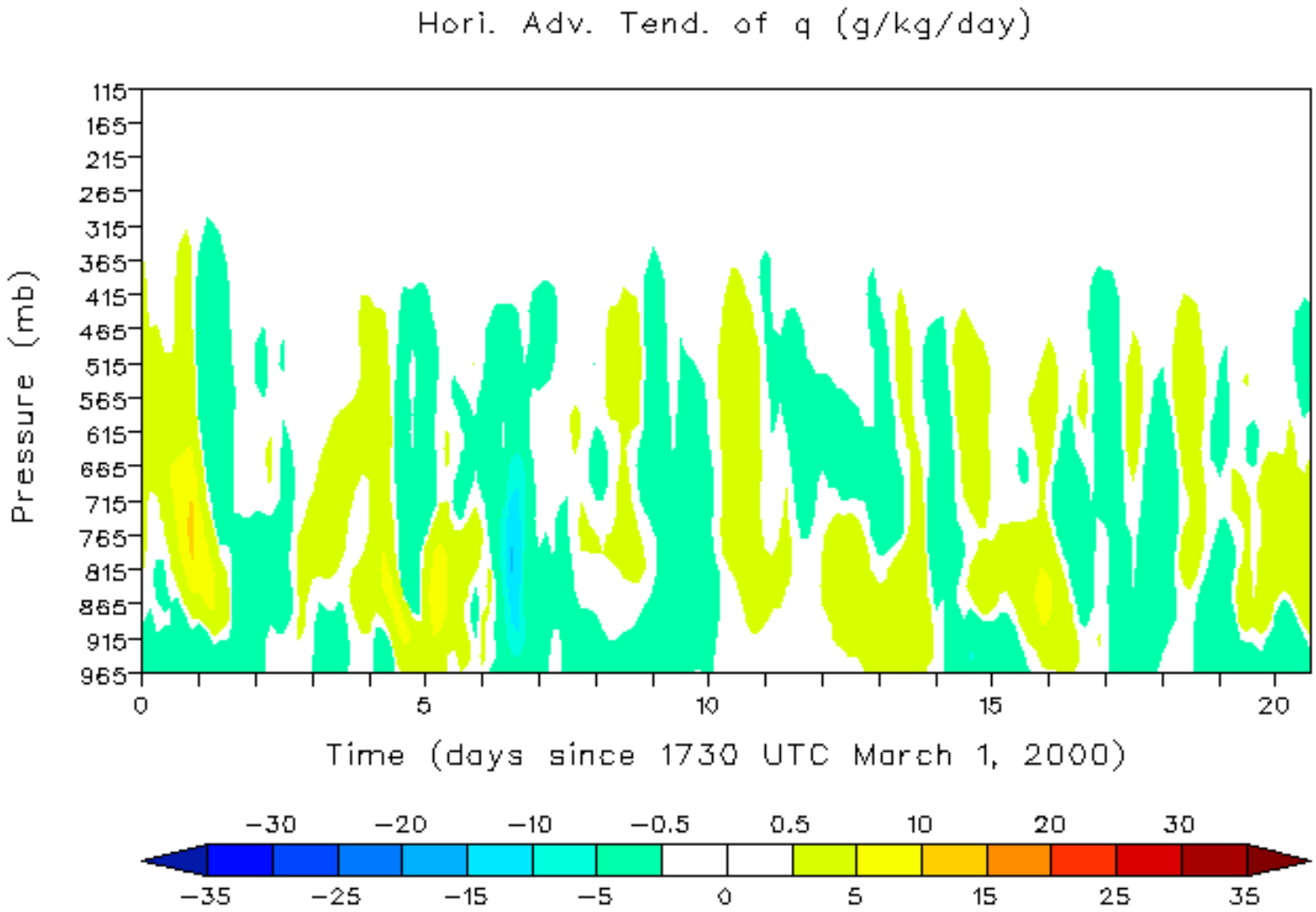

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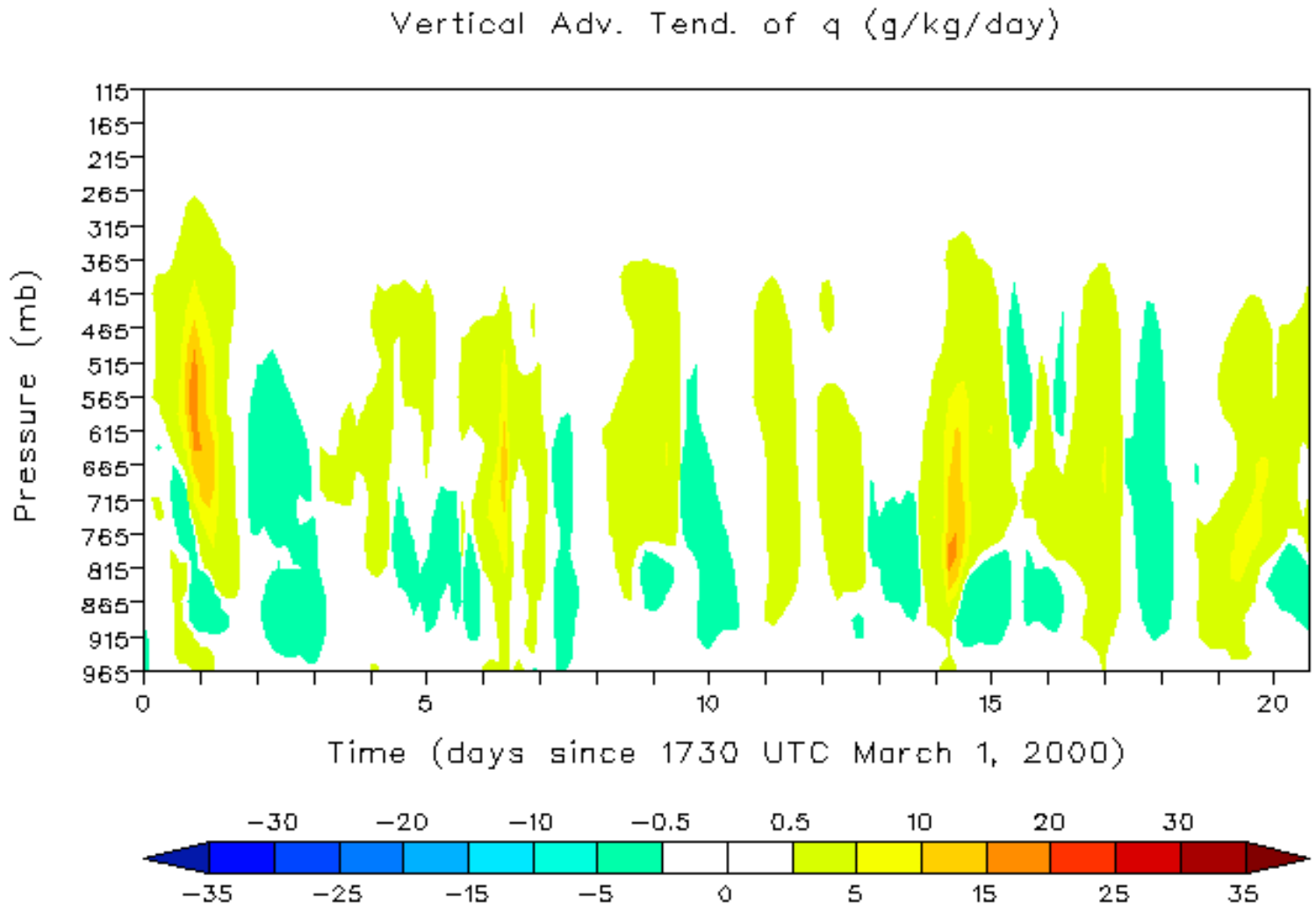

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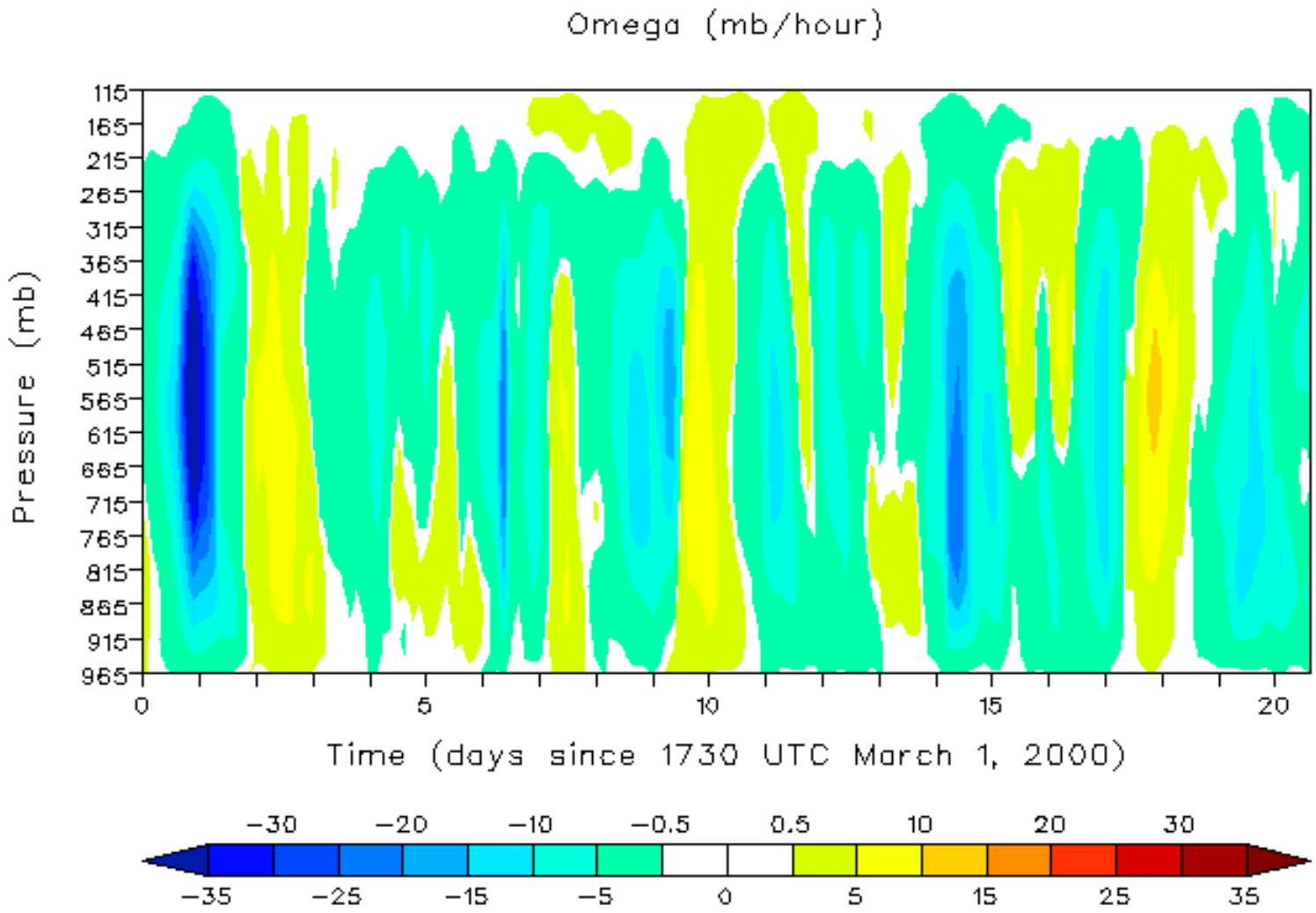

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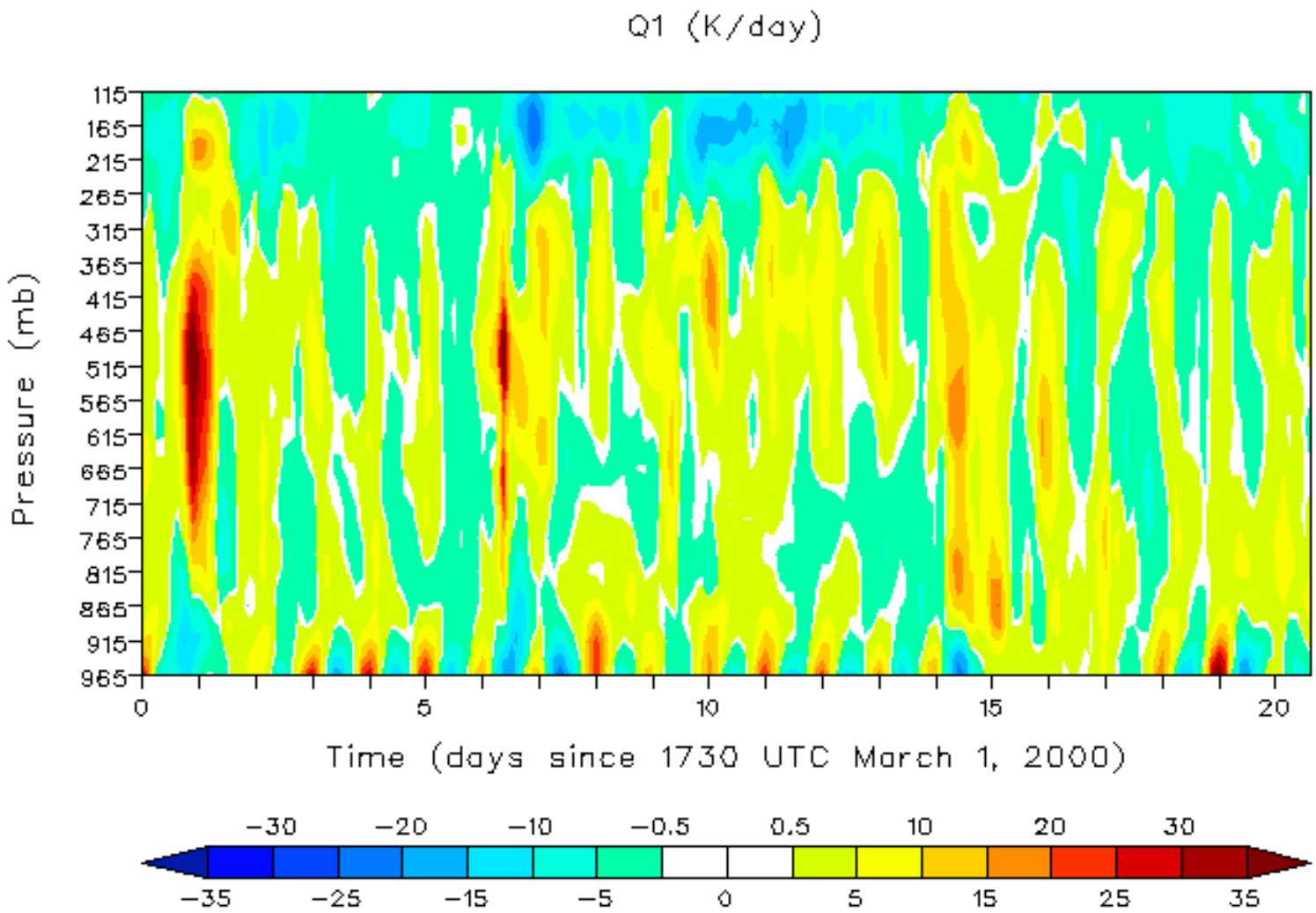

Q1 = Apparent heat sources

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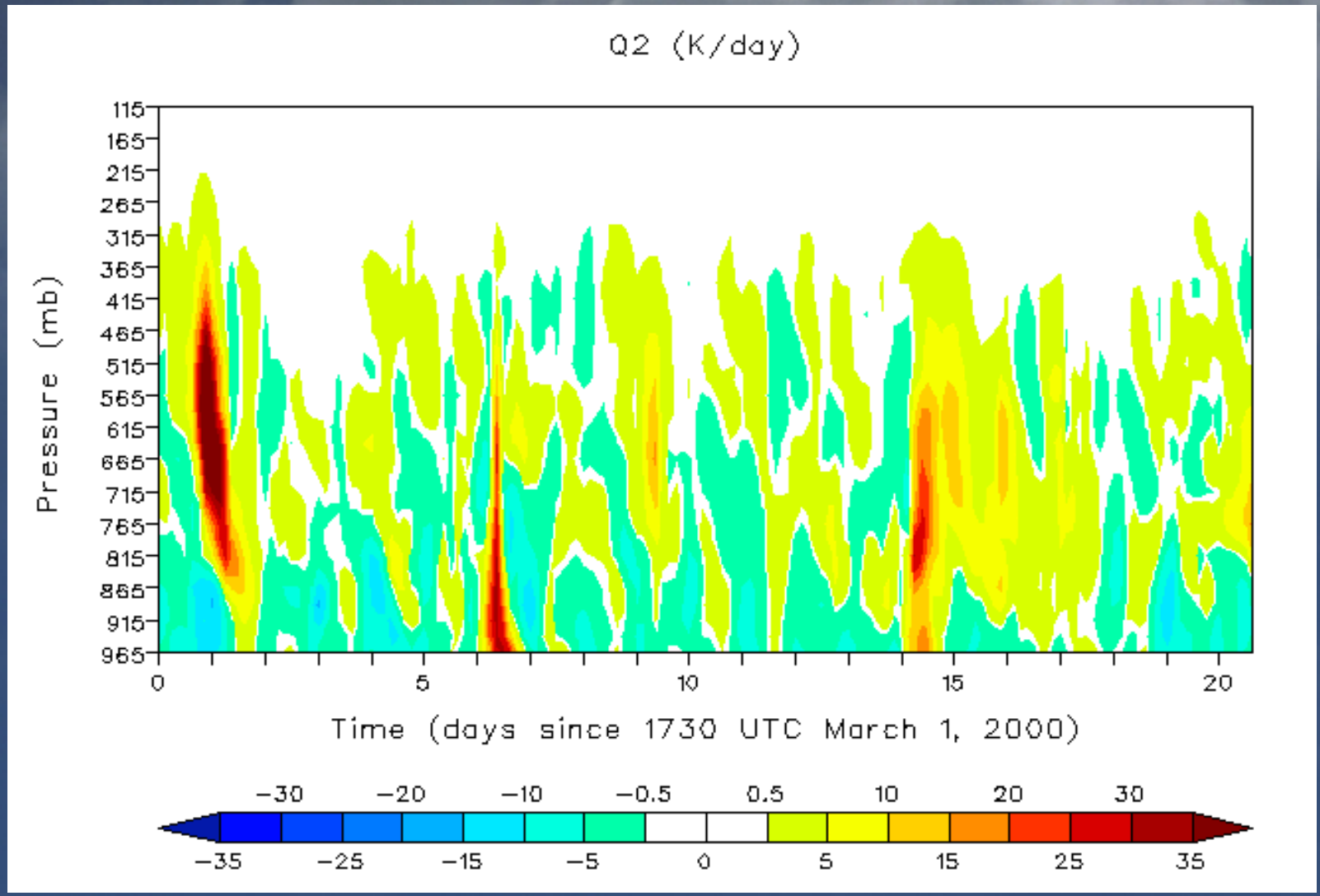

Q2 = Apparent moisture sink

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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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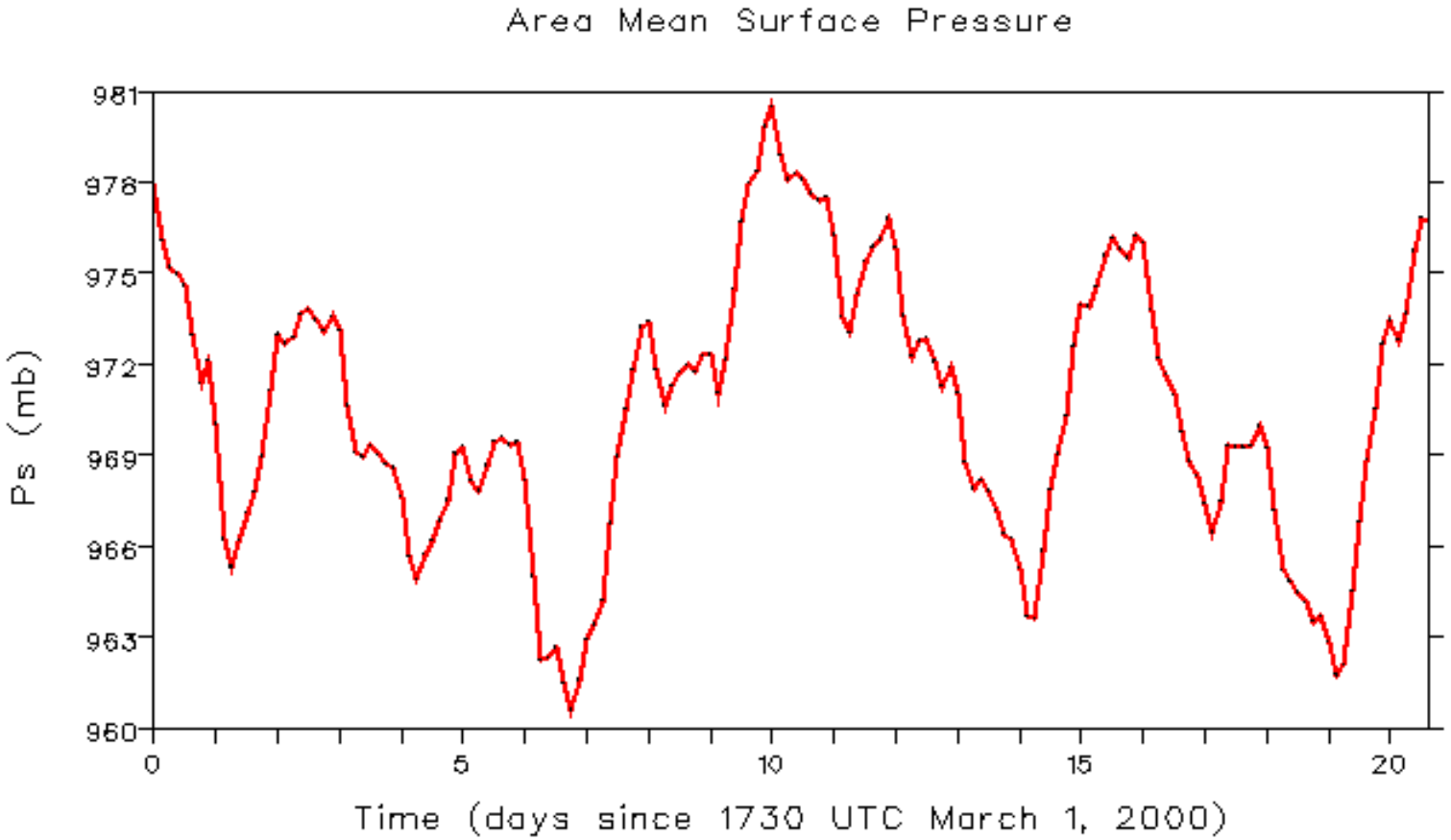
Atmospheric Radiation Measurement



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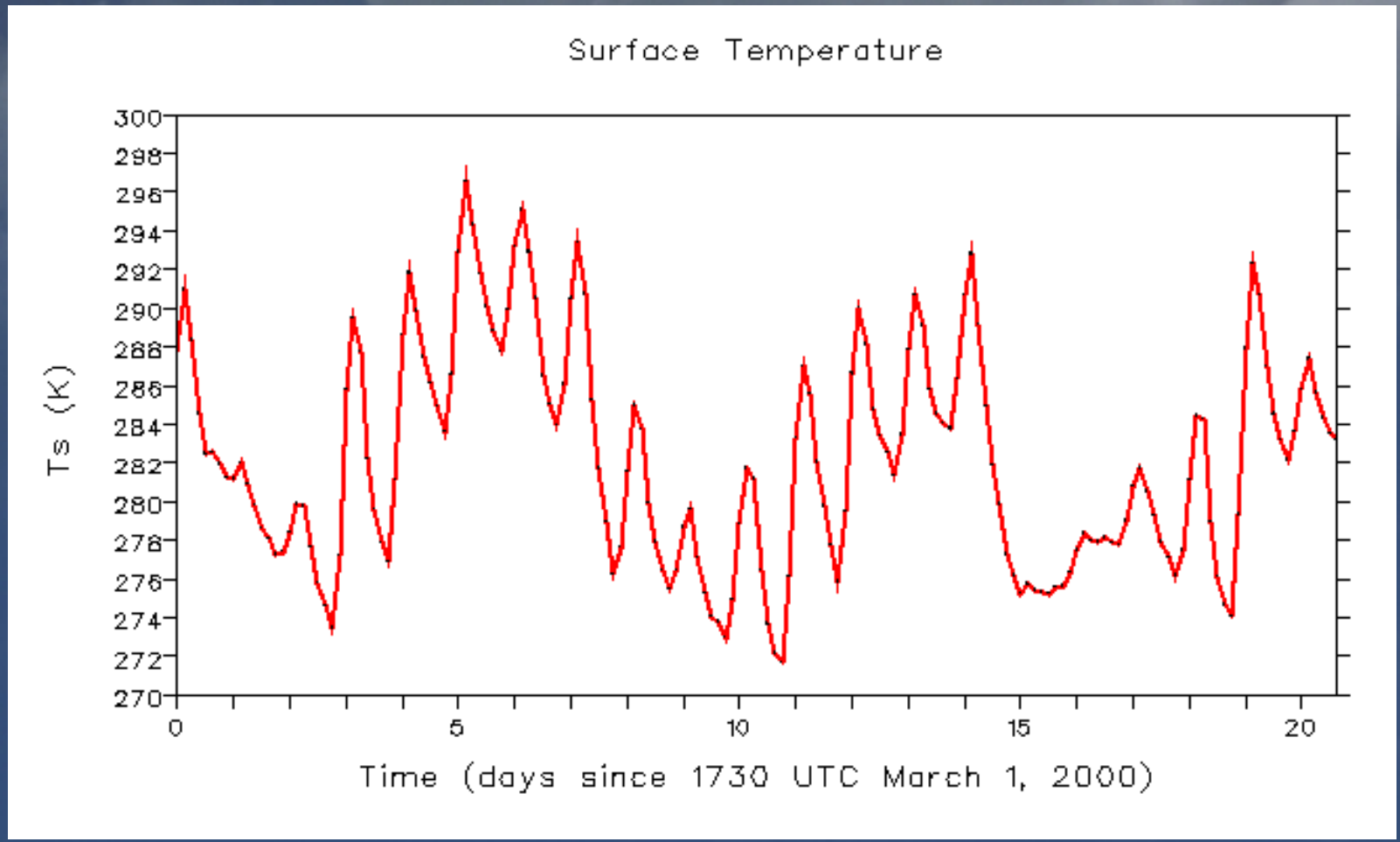

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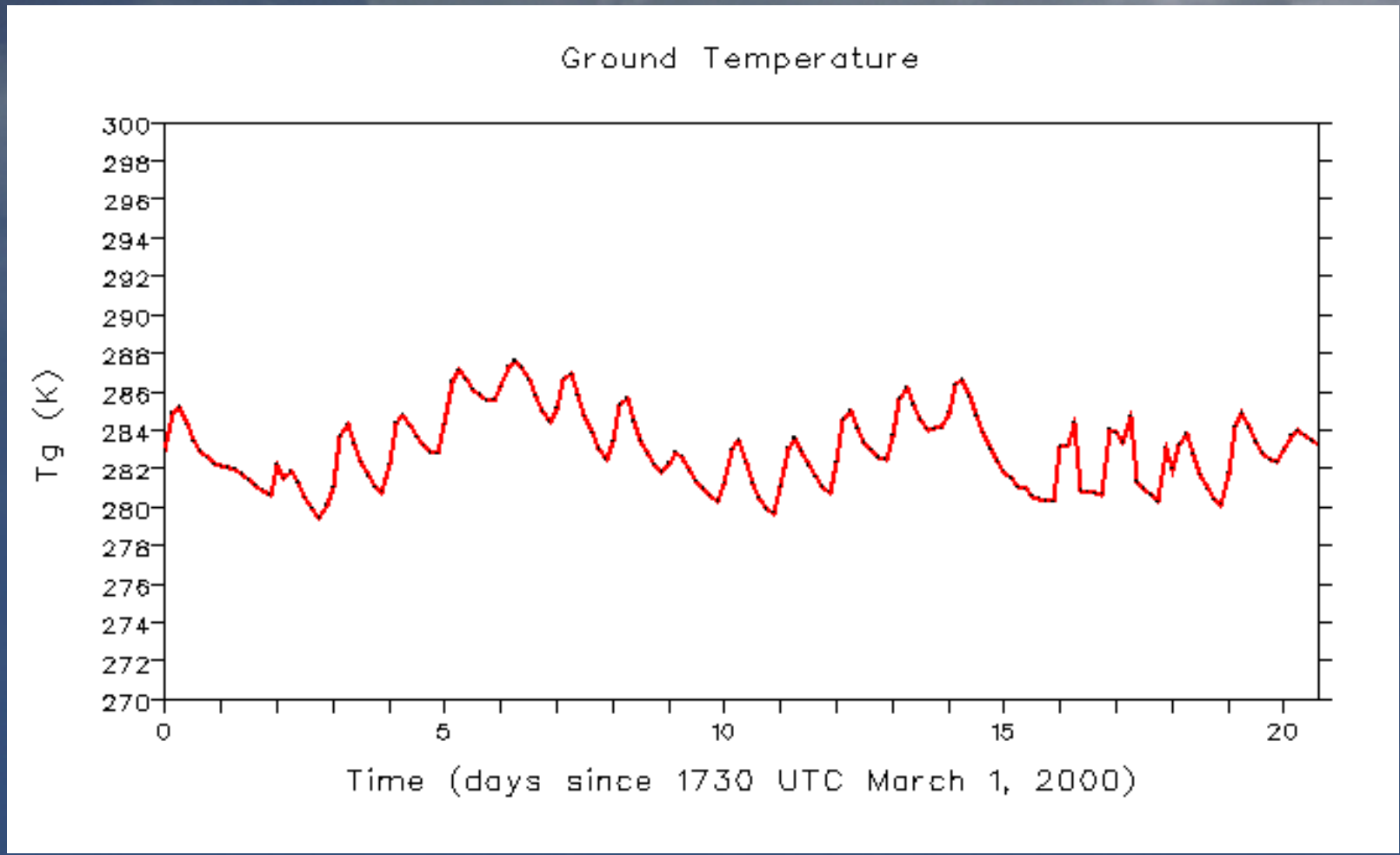

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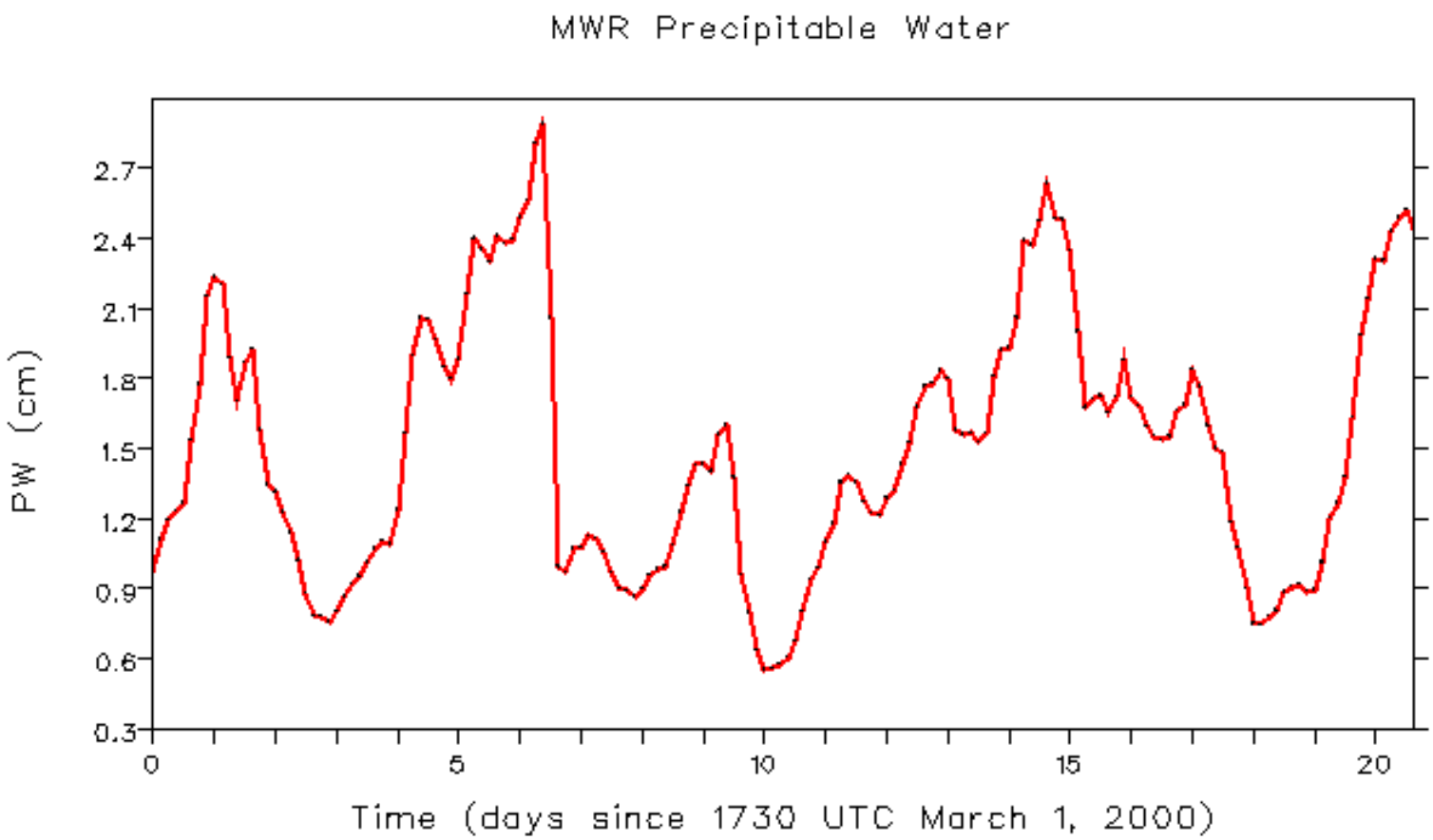

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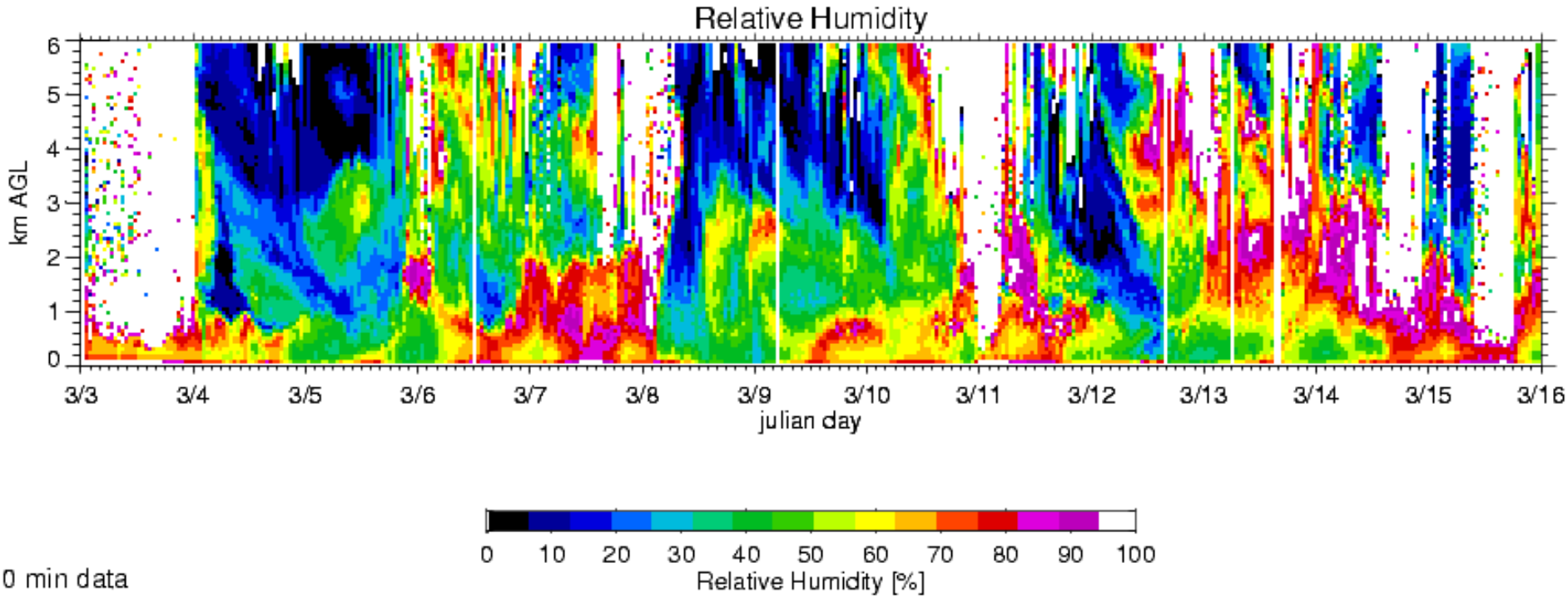
CART Raman Lidar Aerosol and Relative Humidity Data
3 March - 15 March 2000



10 min data

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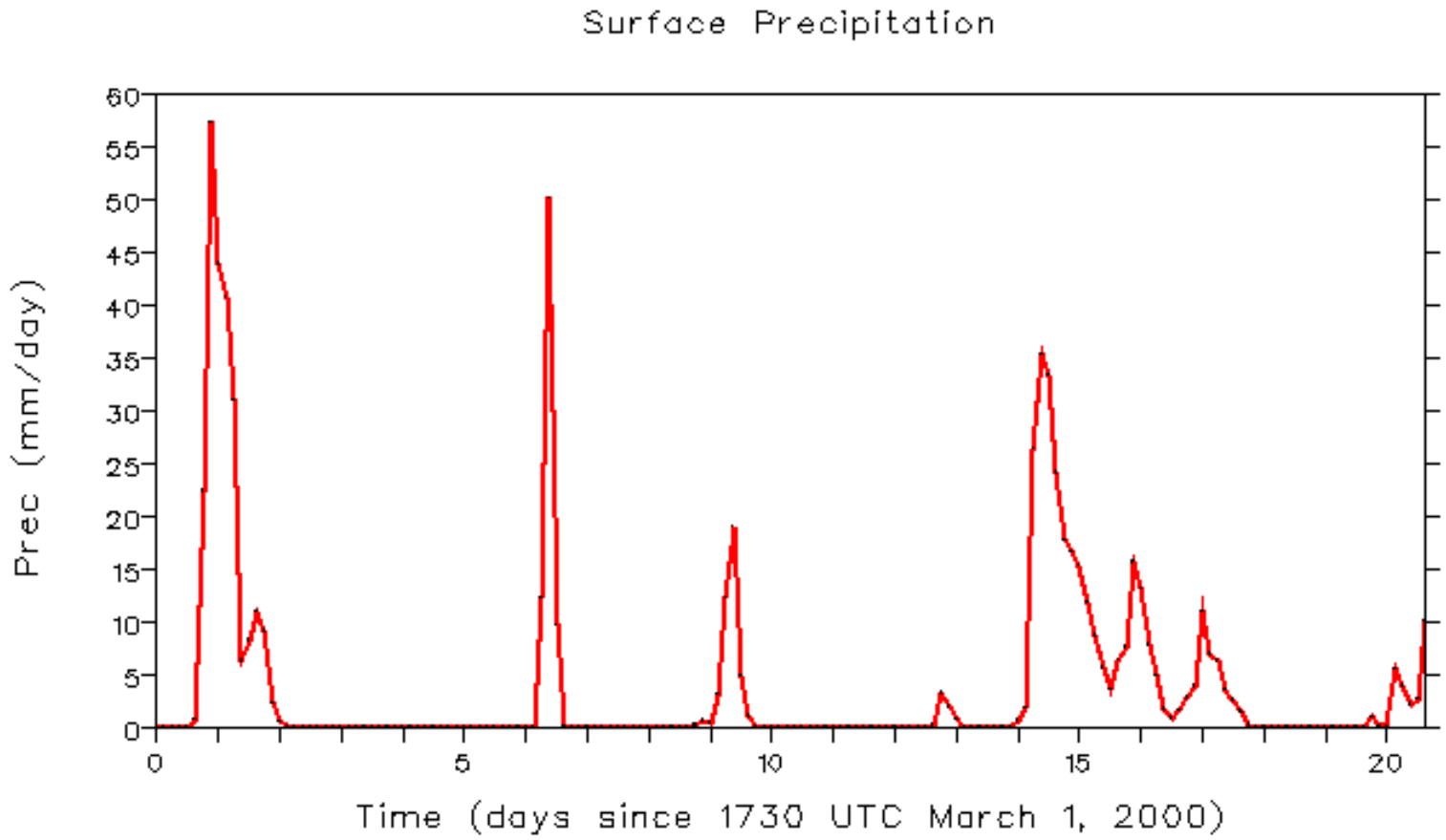
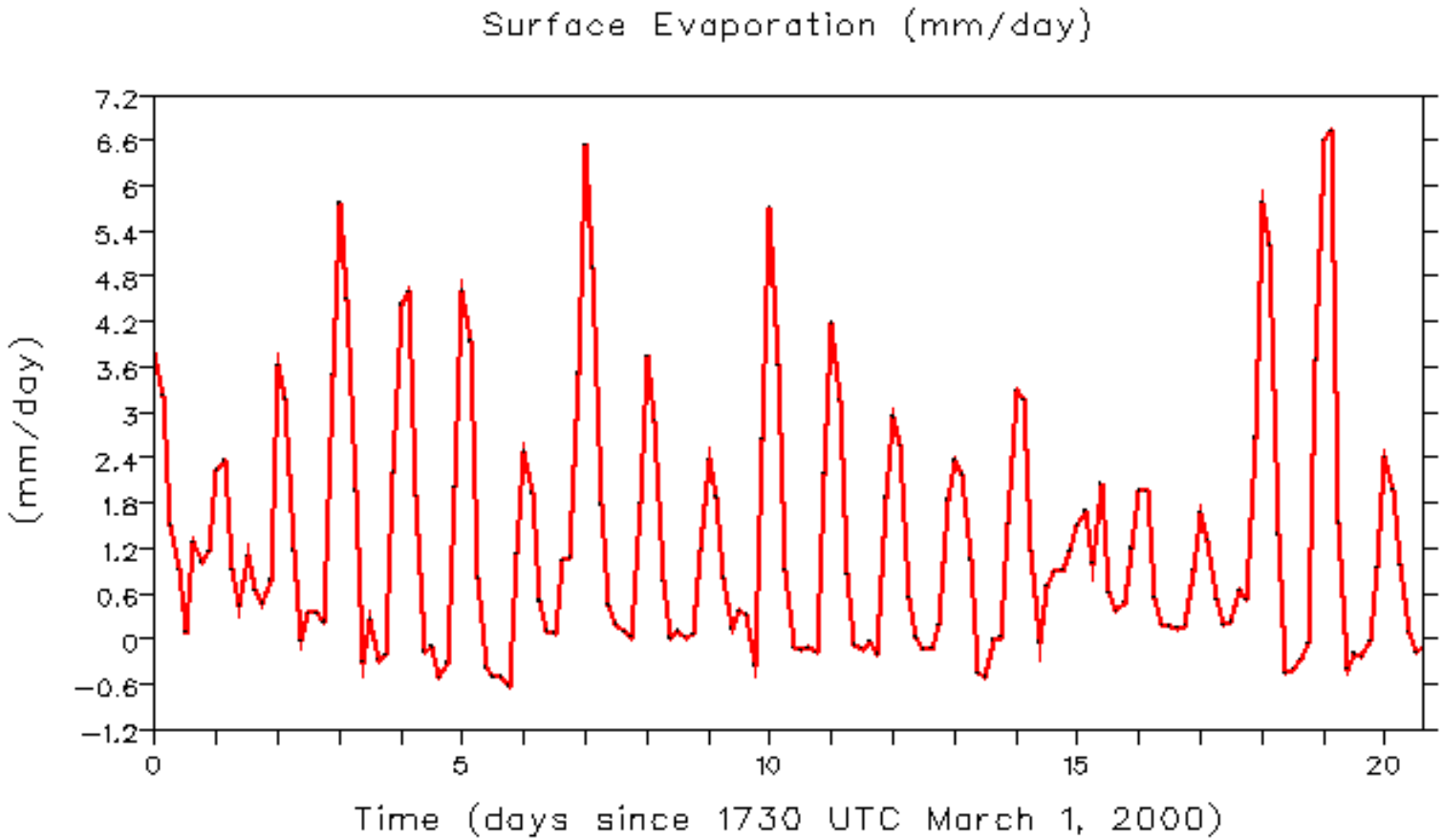

Surface Precipitation
Prec (mm/day)
60
55
50
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
Time (days since 1730 UTC March 1, 2000)



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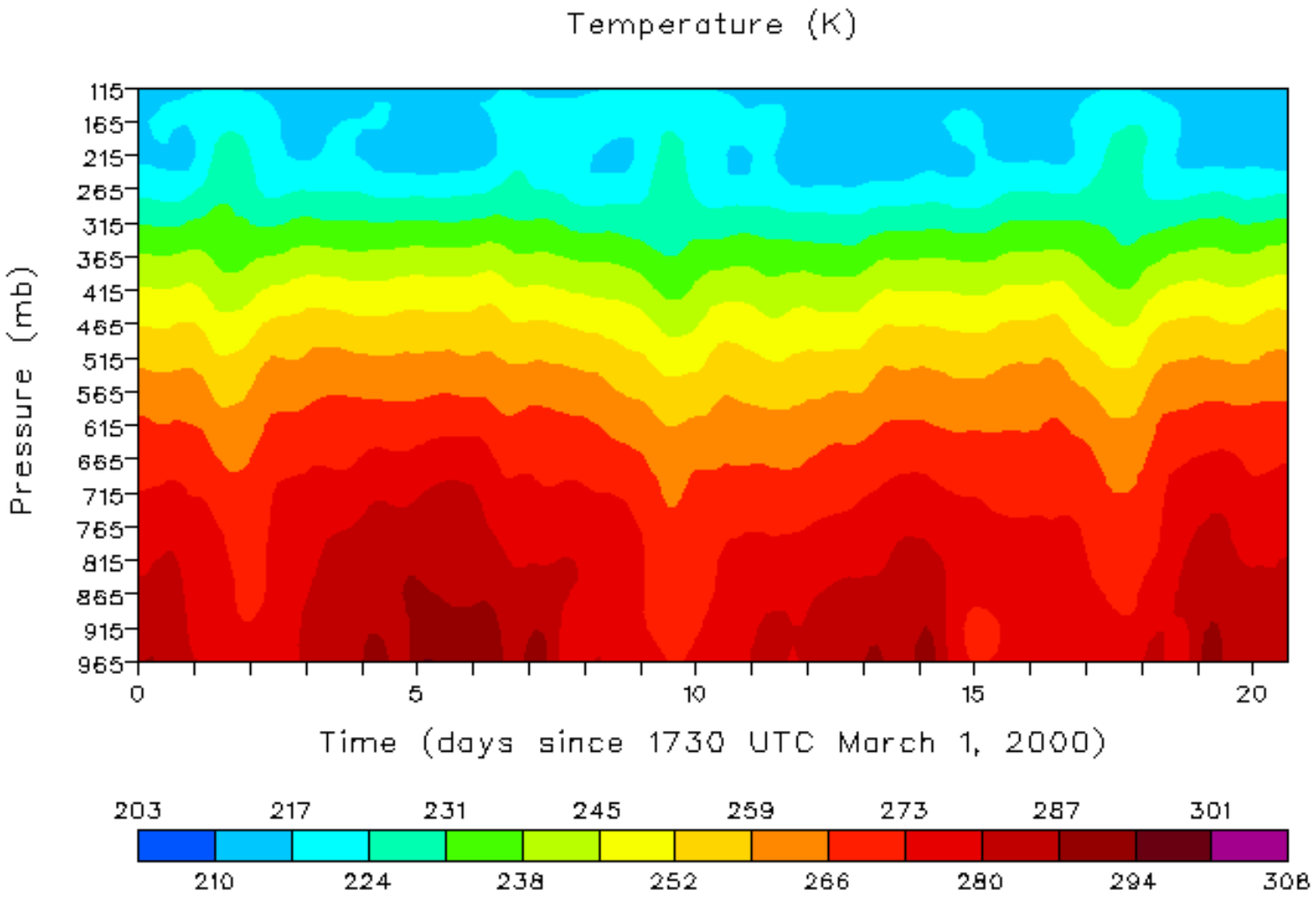

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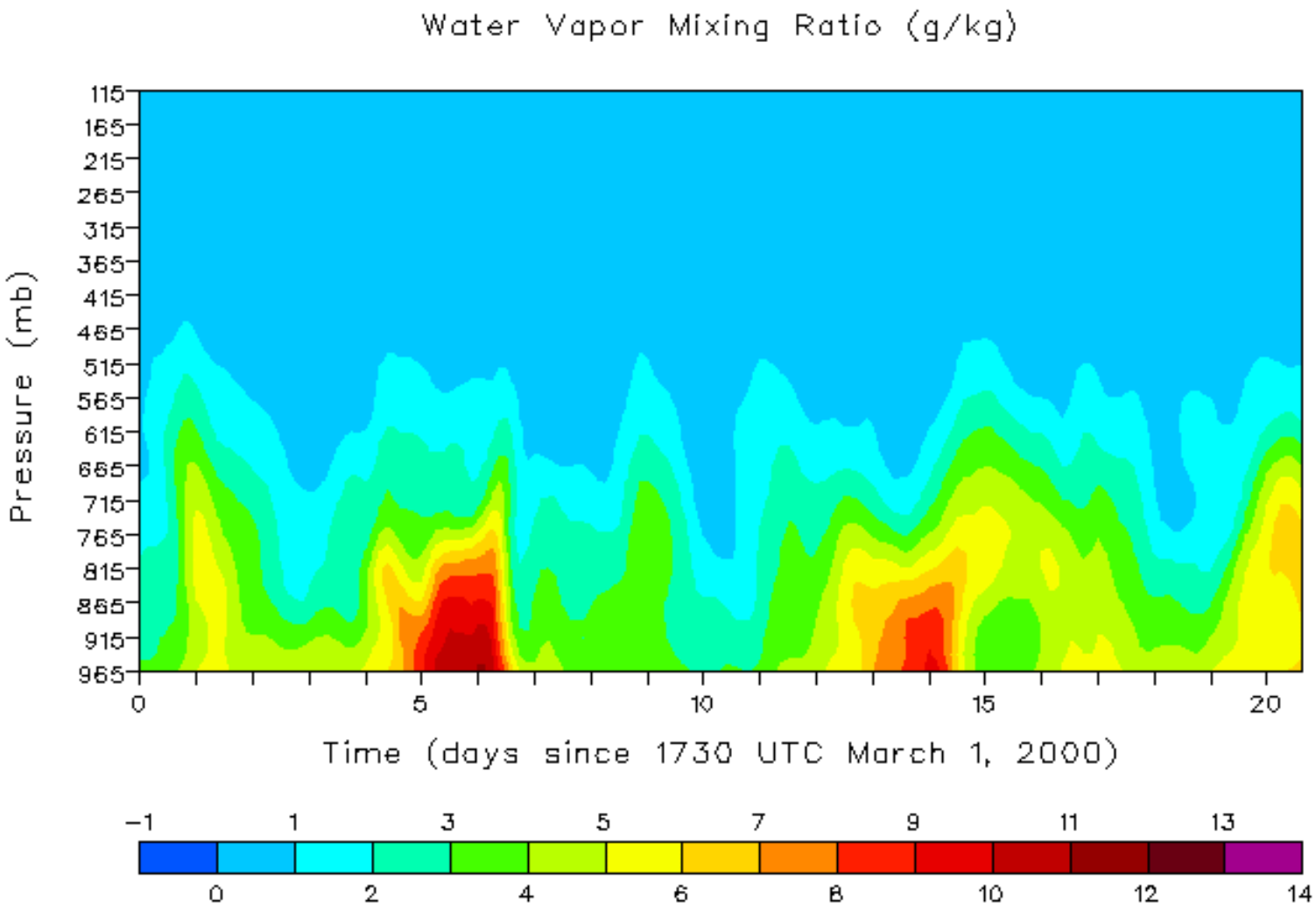

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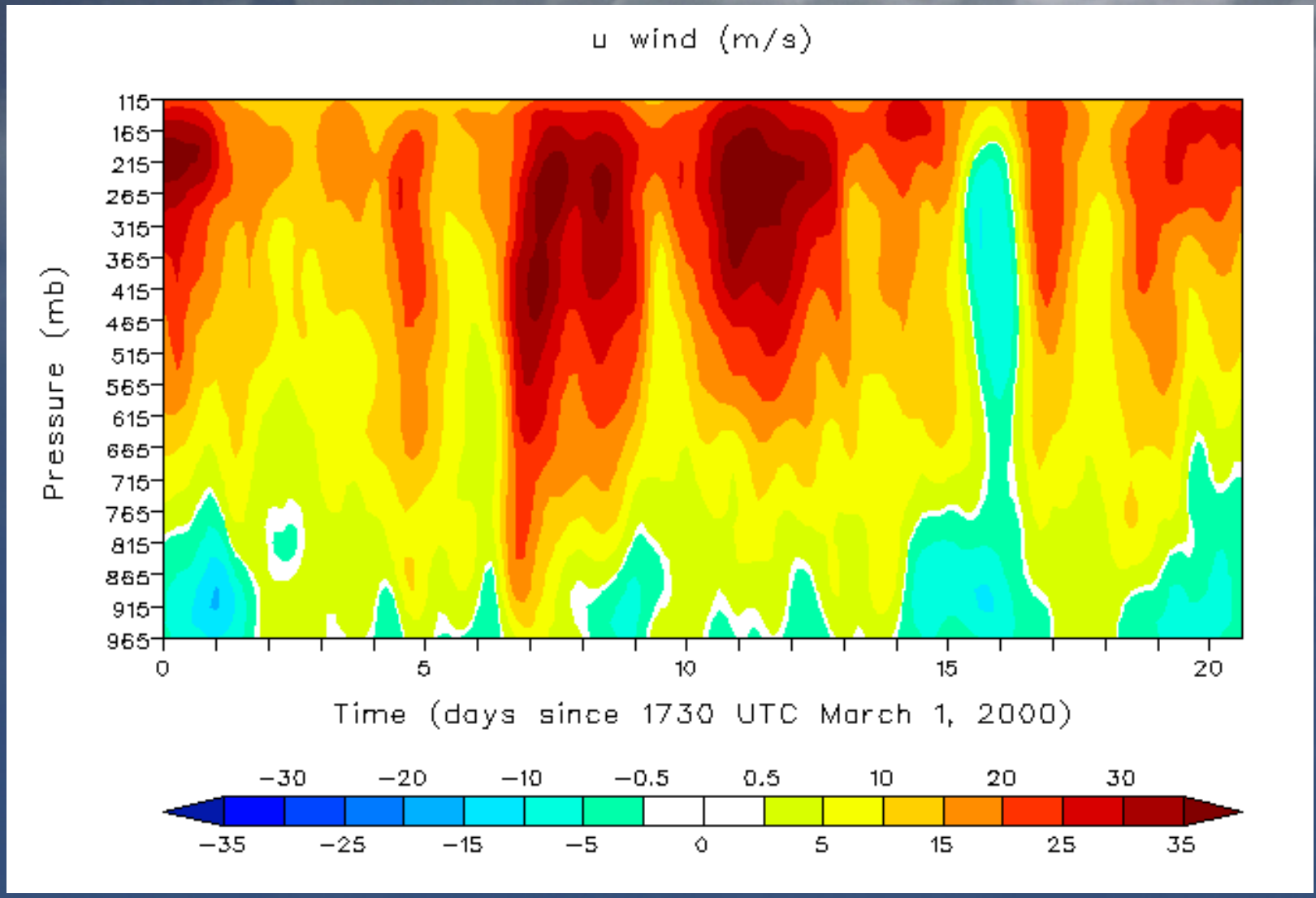

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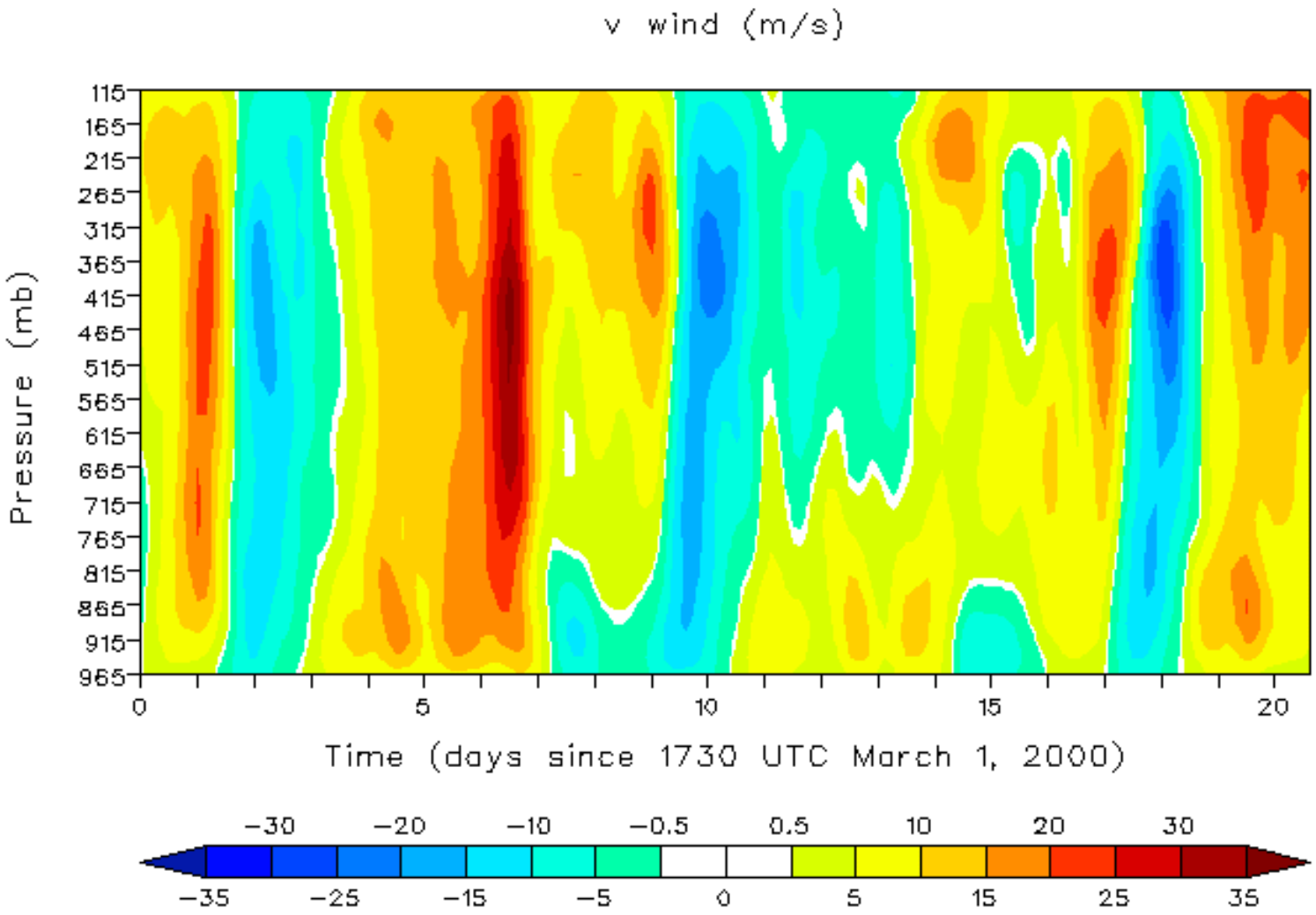

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Aerosol

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

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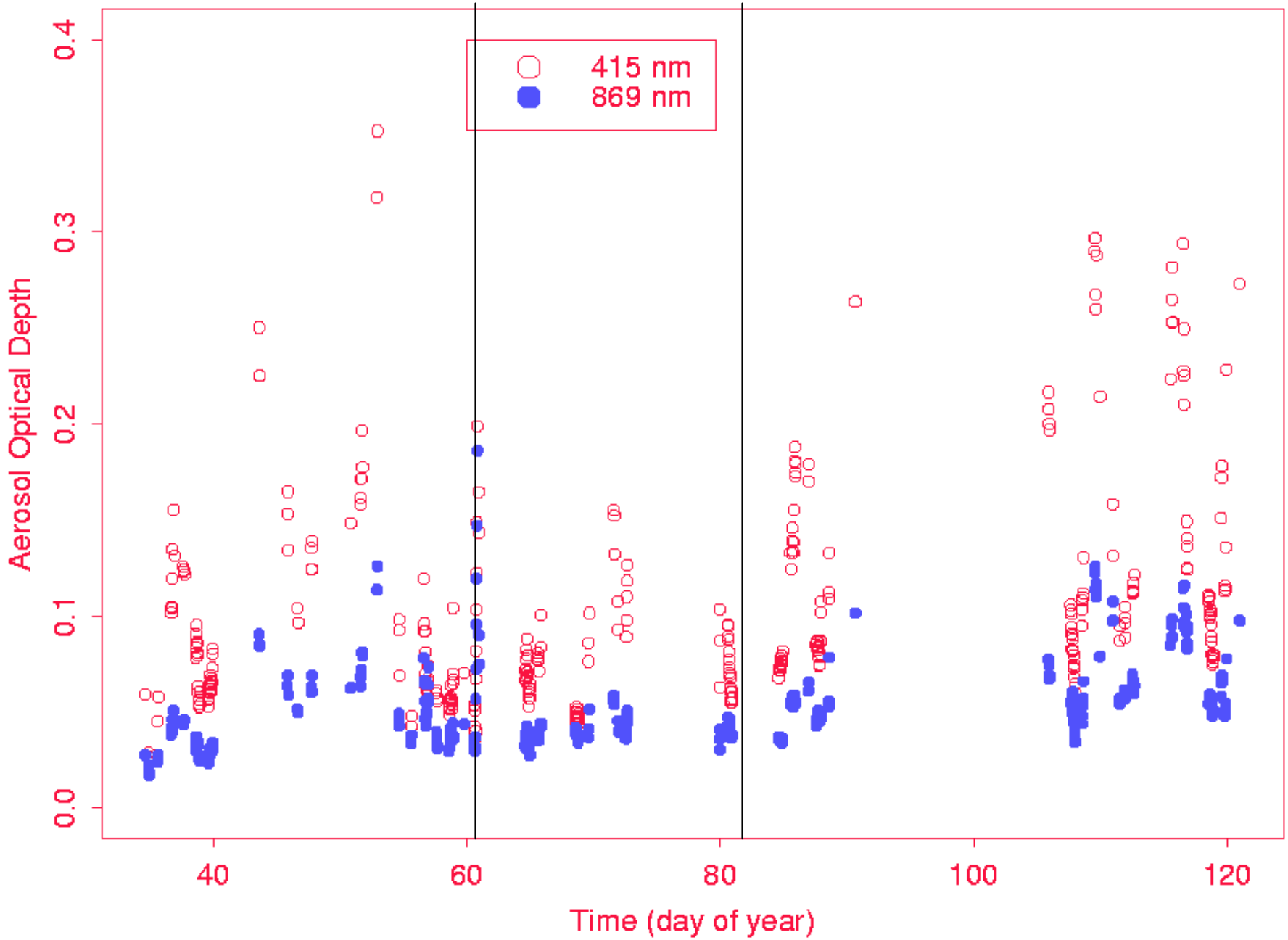
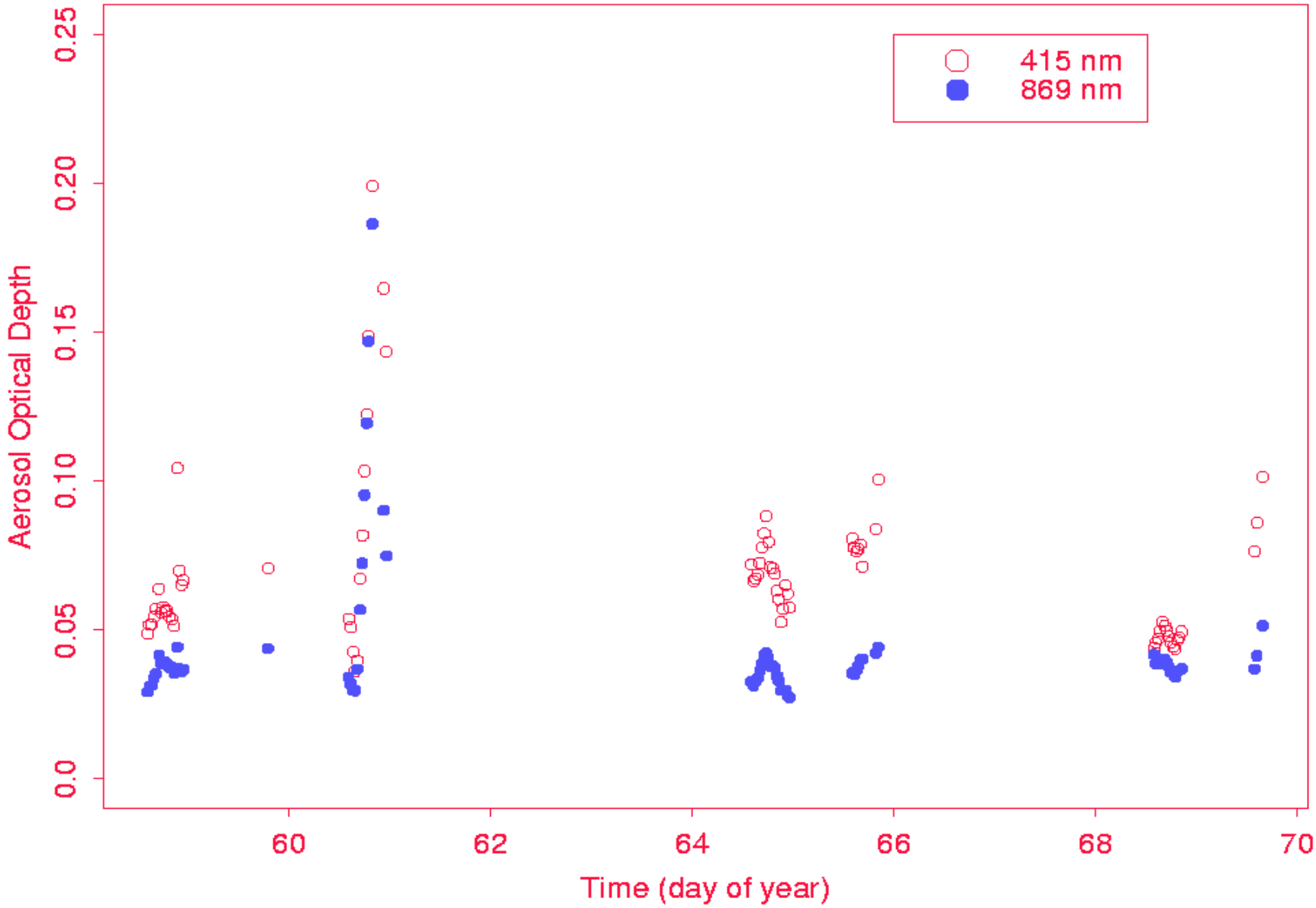
Atmospheric Radiation Measurement


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
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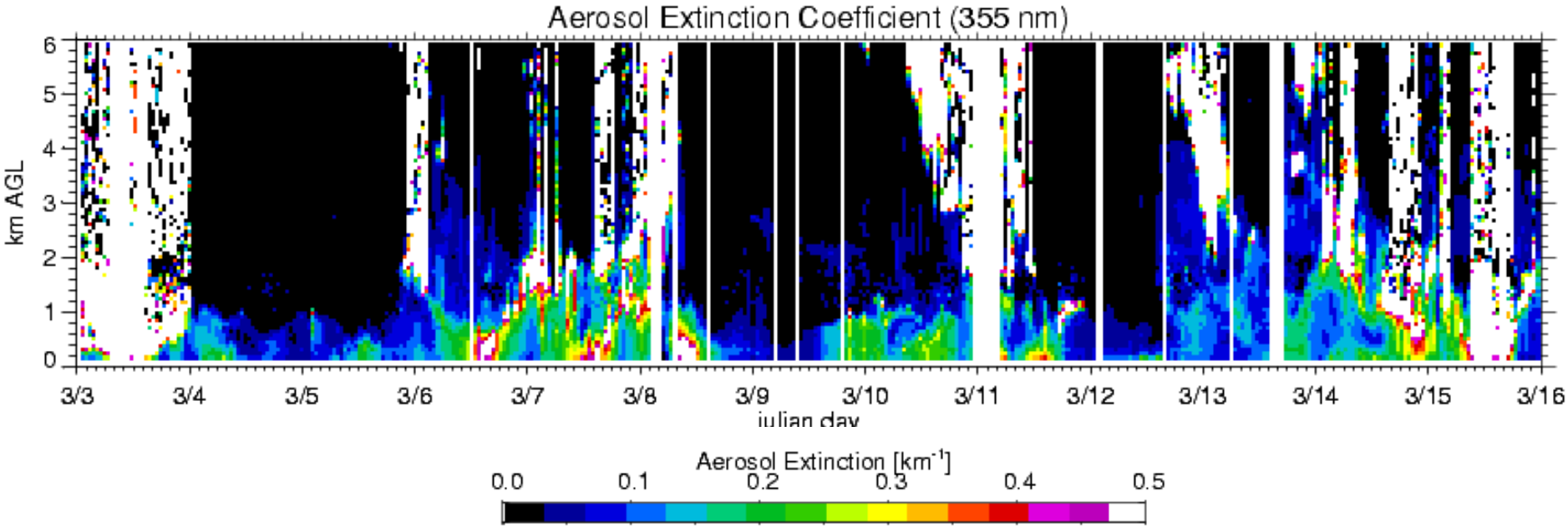

10 min data

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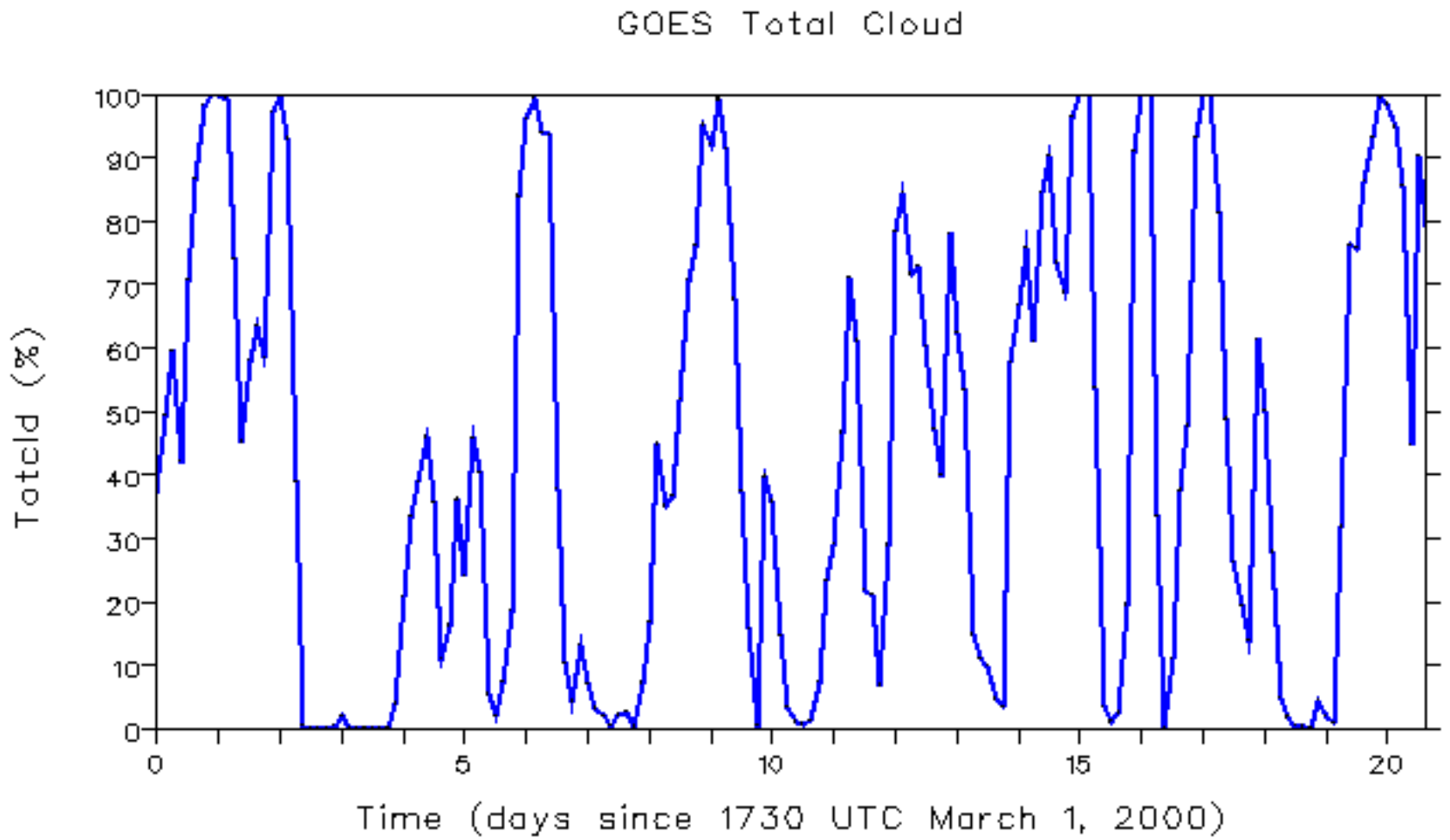
Cloud Macrophysics

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



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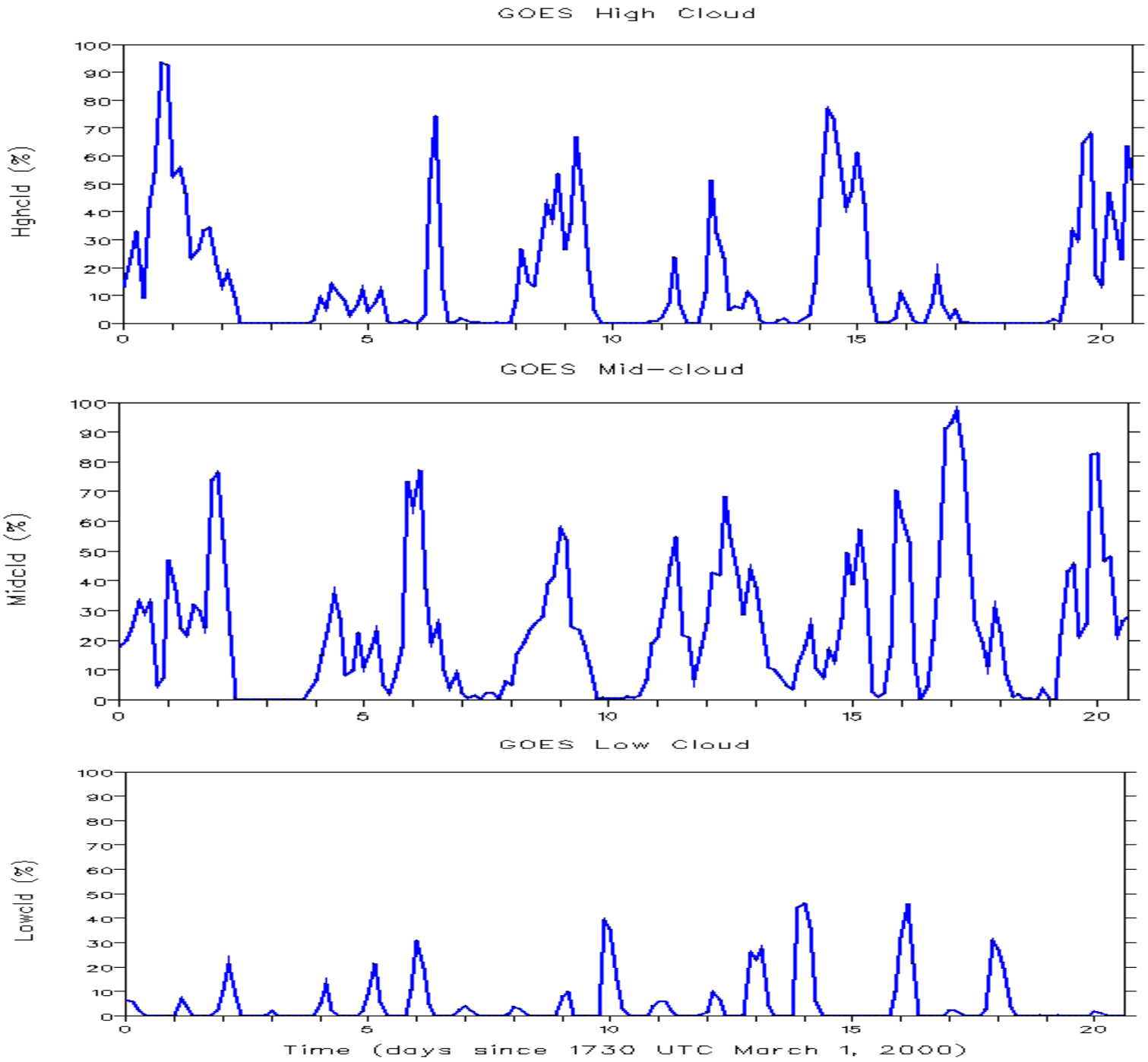
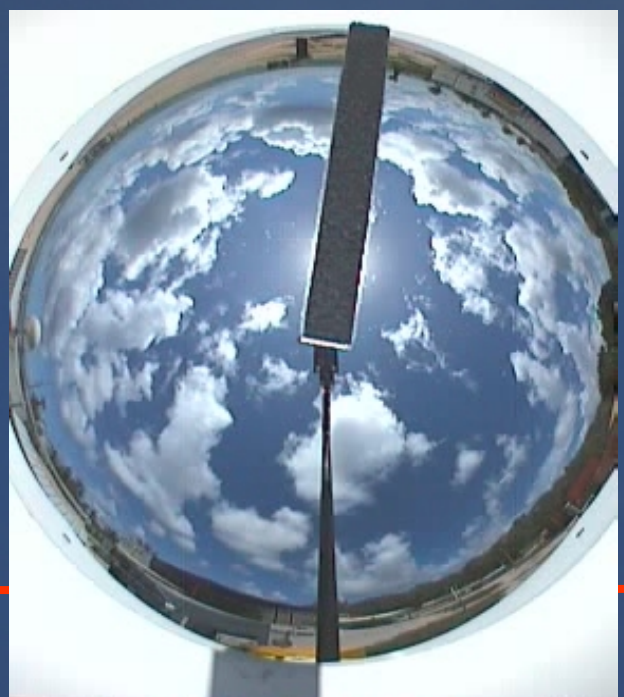

GOES High Cloud
Hghcld (%)
GOES Mid-cloud
Midcld (%)
GOES Low Cloud
Lowcld (%)
Time (days since 1730 UTC March 1, 2000)

Cloud fraction from sky imagery

- Line of sight cloud fraction
- Daytime at 1 to 10 minute intervals
- Nighttime for near-full moon

99-07-13 1150

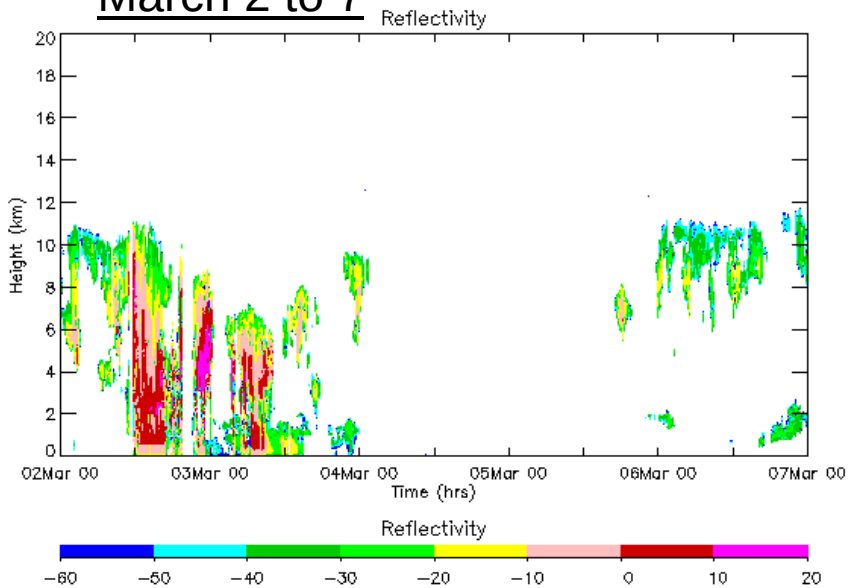


99-07-13 1351

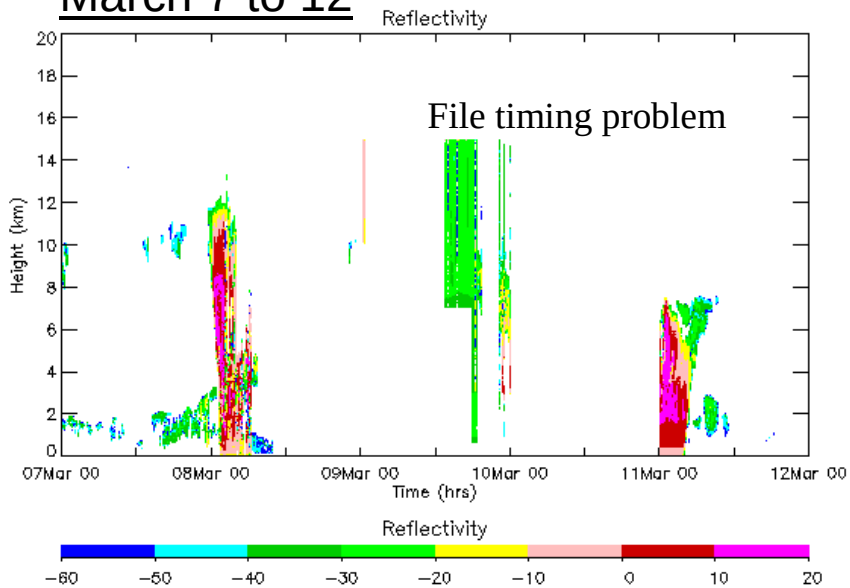
Cloud fraction from radiometry

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

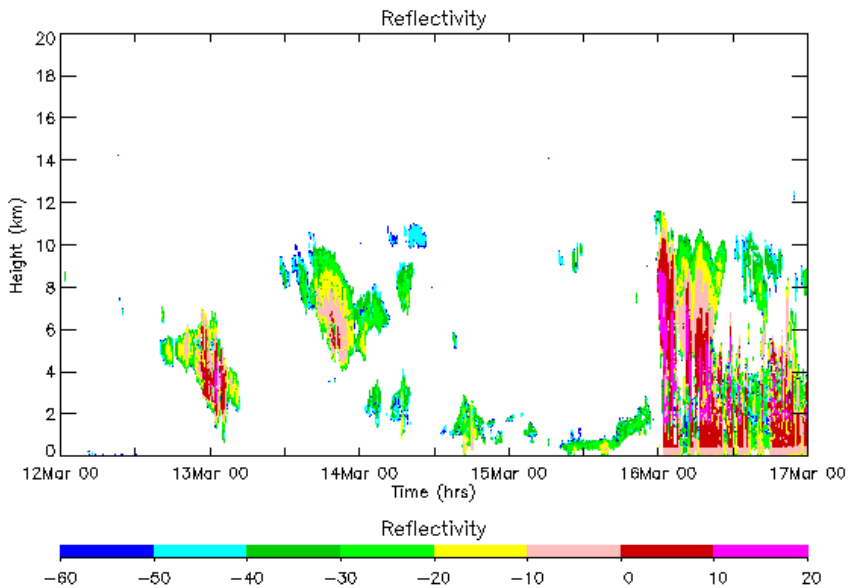
March 2 to 7



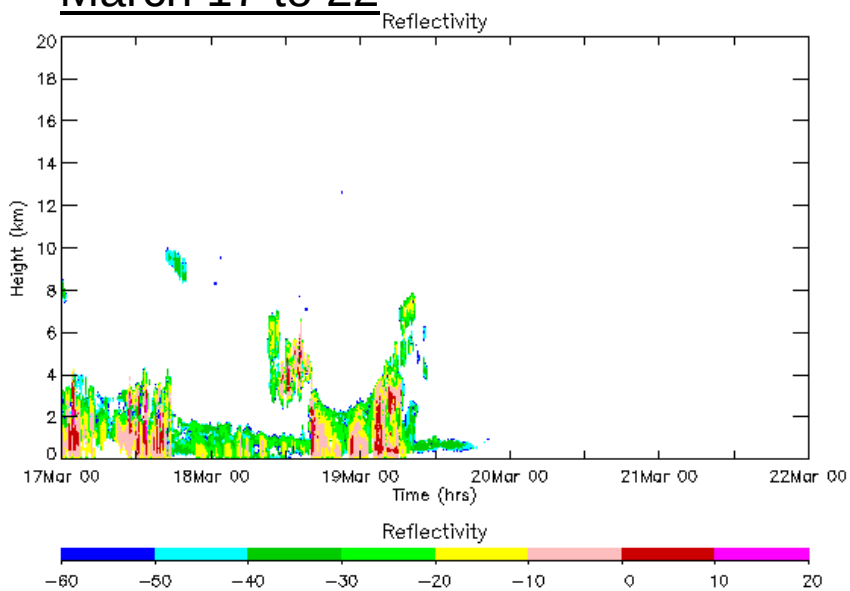
March 7 to 12



March 12 to 17



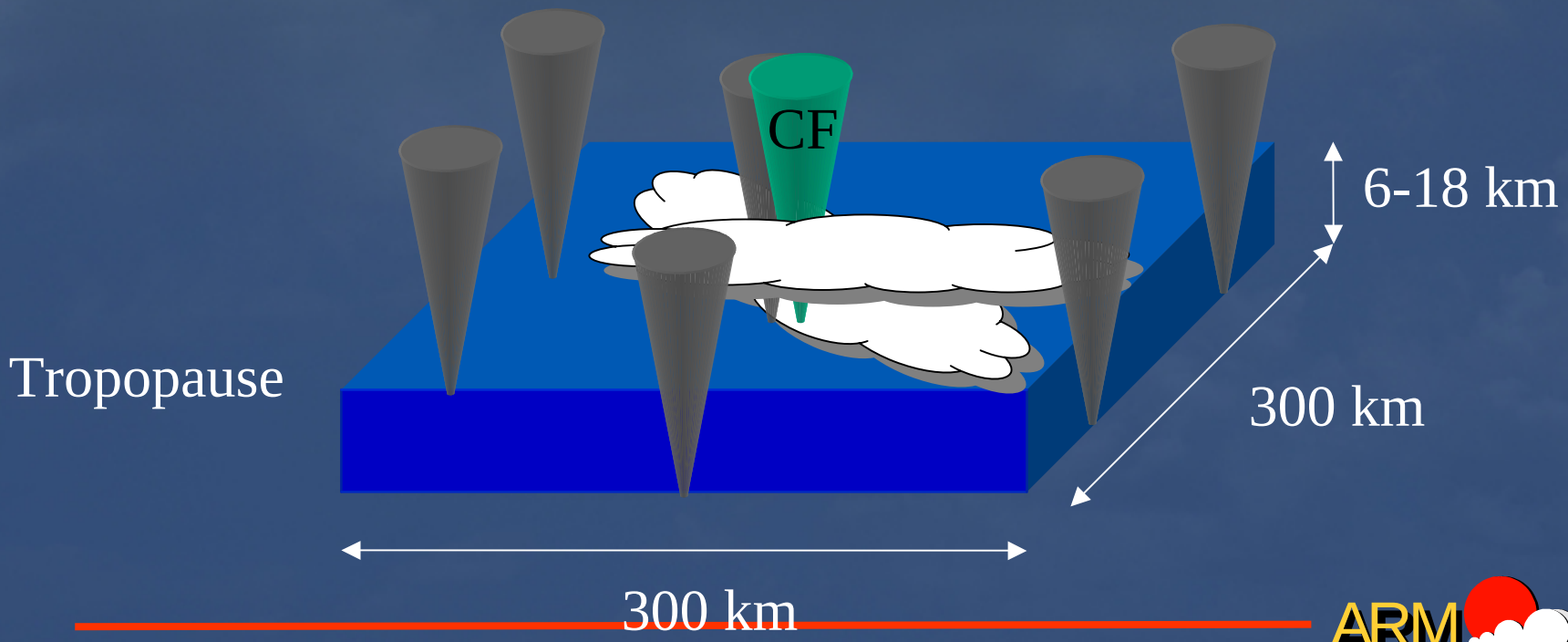
March 17 to 22



Cloud radar reflectivity in 5 day increments (0 to 20 km)

Southern Great Plains

- 7 NOAA 404-MHz Wind Profilers (0.75 m)
- Detailed cloud structural information-CF



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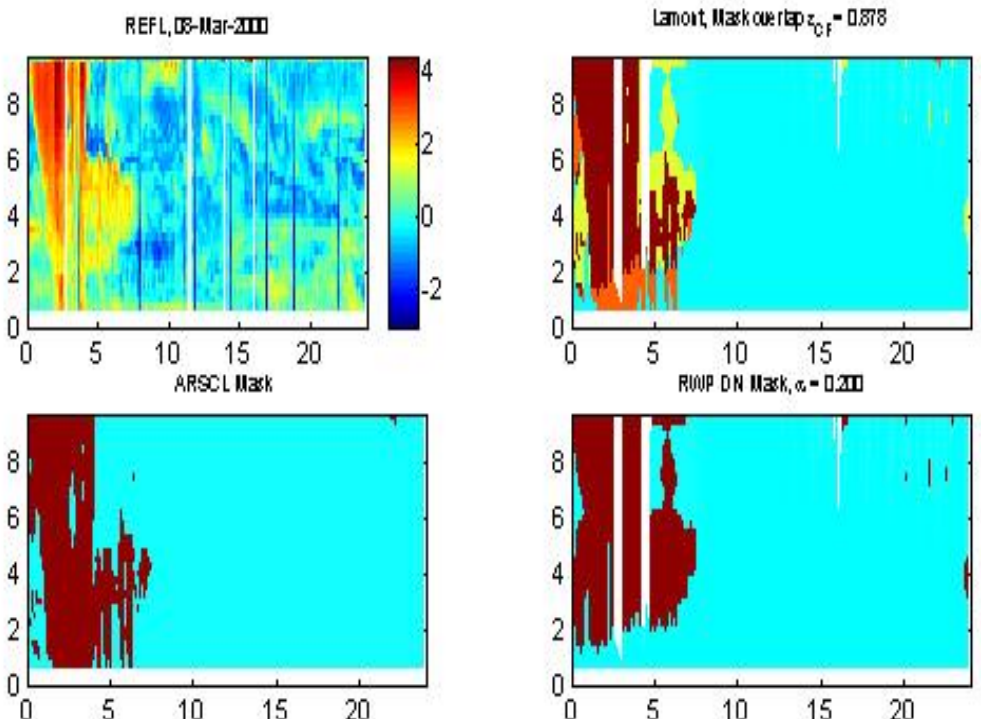
Clear-air Radars and Clouds

- Clear-air radar—refractive gradients
- Cloud boundaries —large refractive gradients
- Discrimination between clear-air echoes and cloudy echoes?
  - Condition dependent

CF Profiler Reflectivity

CF Cloud Mask (ARSCL)

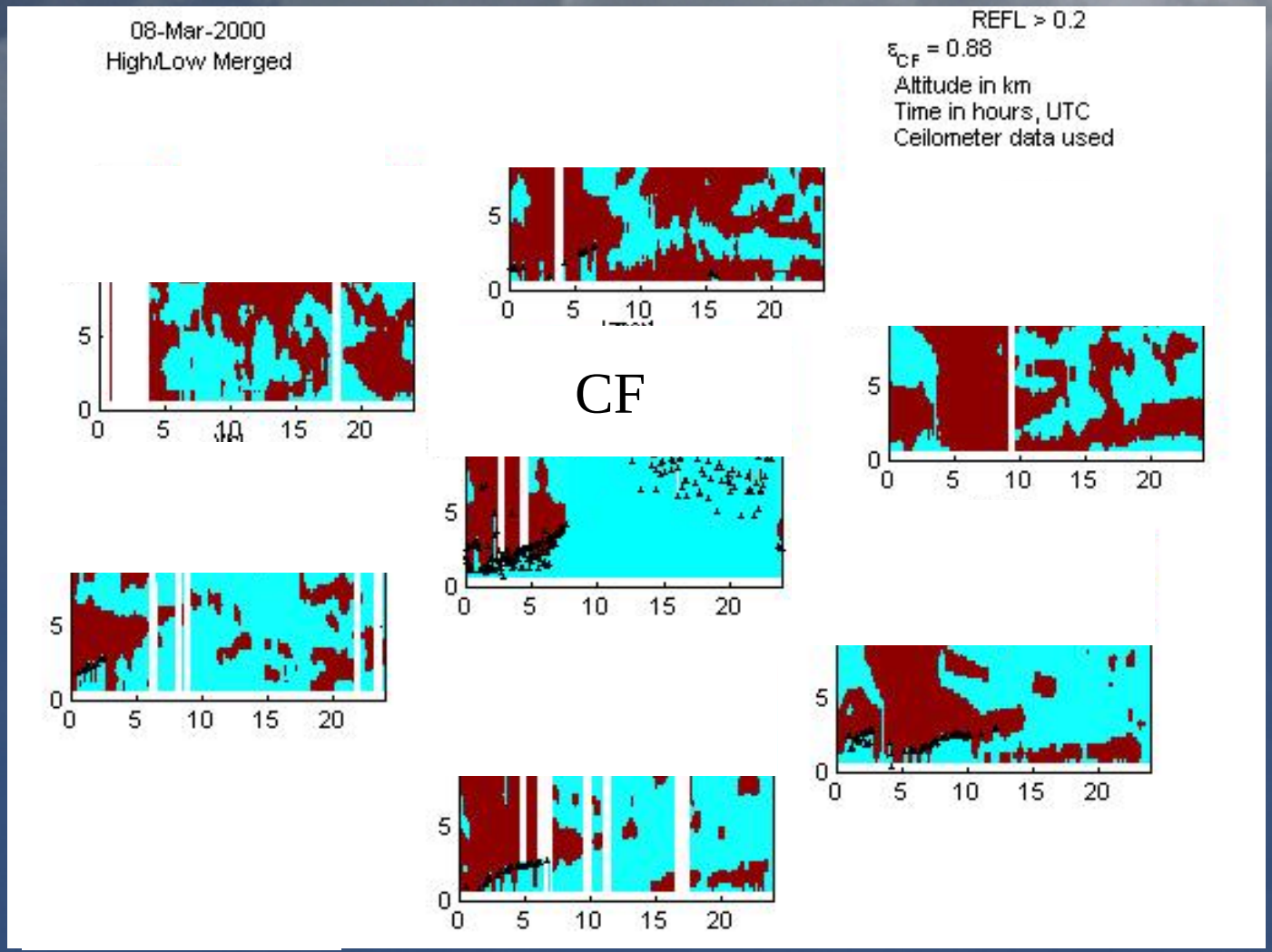


Tune profiler mask until the best match with MMCR mask is obtained and *record the values of the tuning parameters and the skill score.*

Example: tuned profiler mask has 87% agreement with ARSCL at CF

FINAL Profiler Mask

ARM Atmospheric Radiation Measurement



Tuning parameters from CF applied to all profilers in the domain

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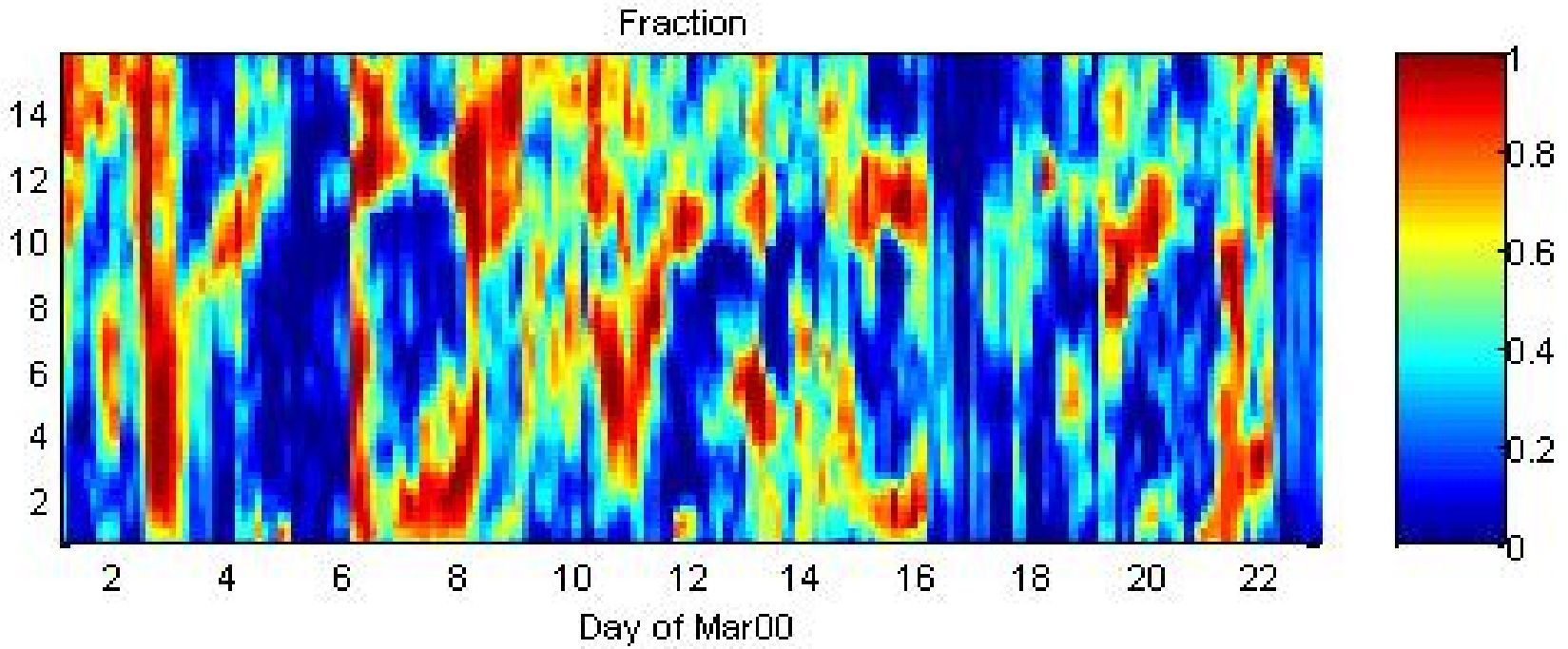
Atmospheric Radiation Measurement

Spatial Cloud Product

- **Use profiler masks to estimate cloud fraction over the SGP domain *as a function of time and height***
- **Example:**
  - **At a given height and time, if five of seven profilers test positive for cloud, Cloud Fraction=5/7=0.71**

Cloud Fraction
over *entire* SGP CART Site



Skill scores can be low on some days.

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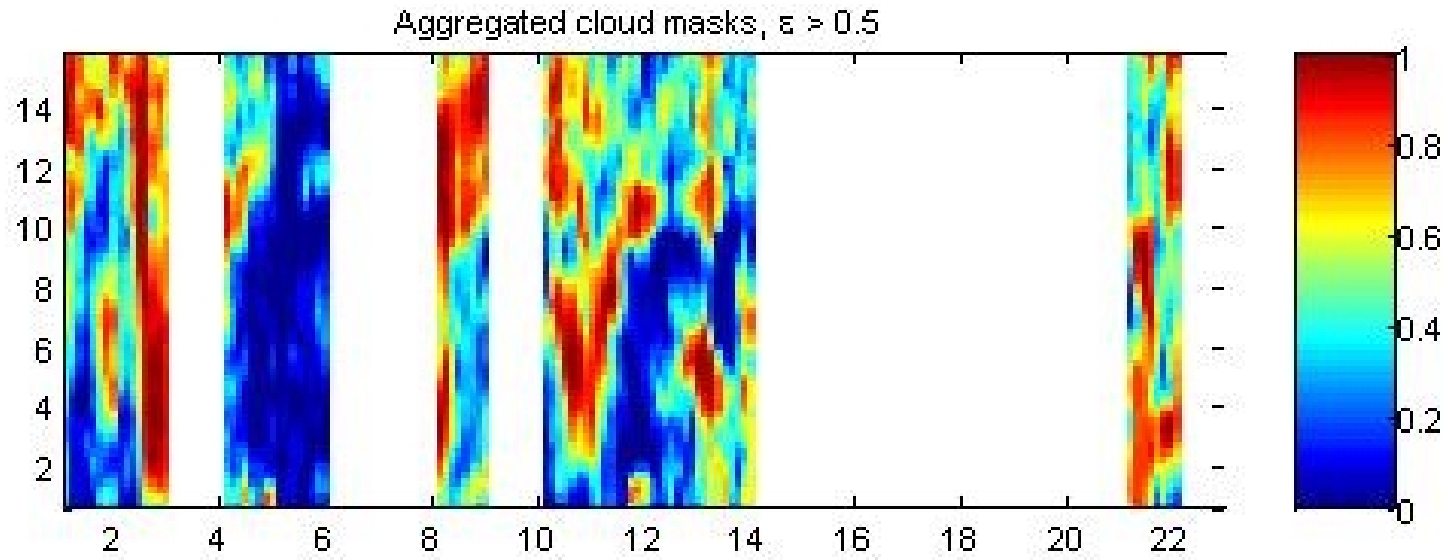
Cloud Fraction over *entire* SGP CART Site



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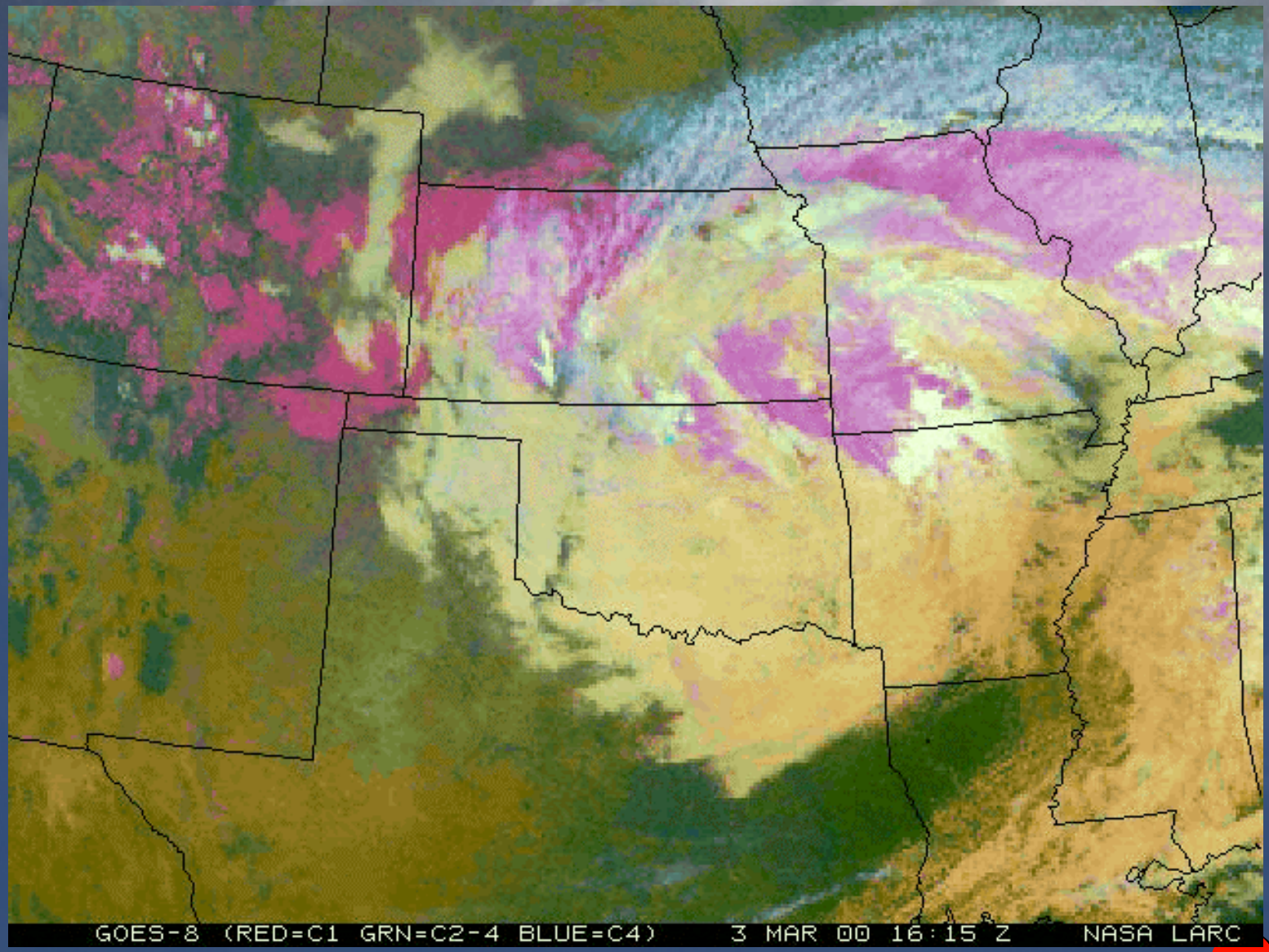
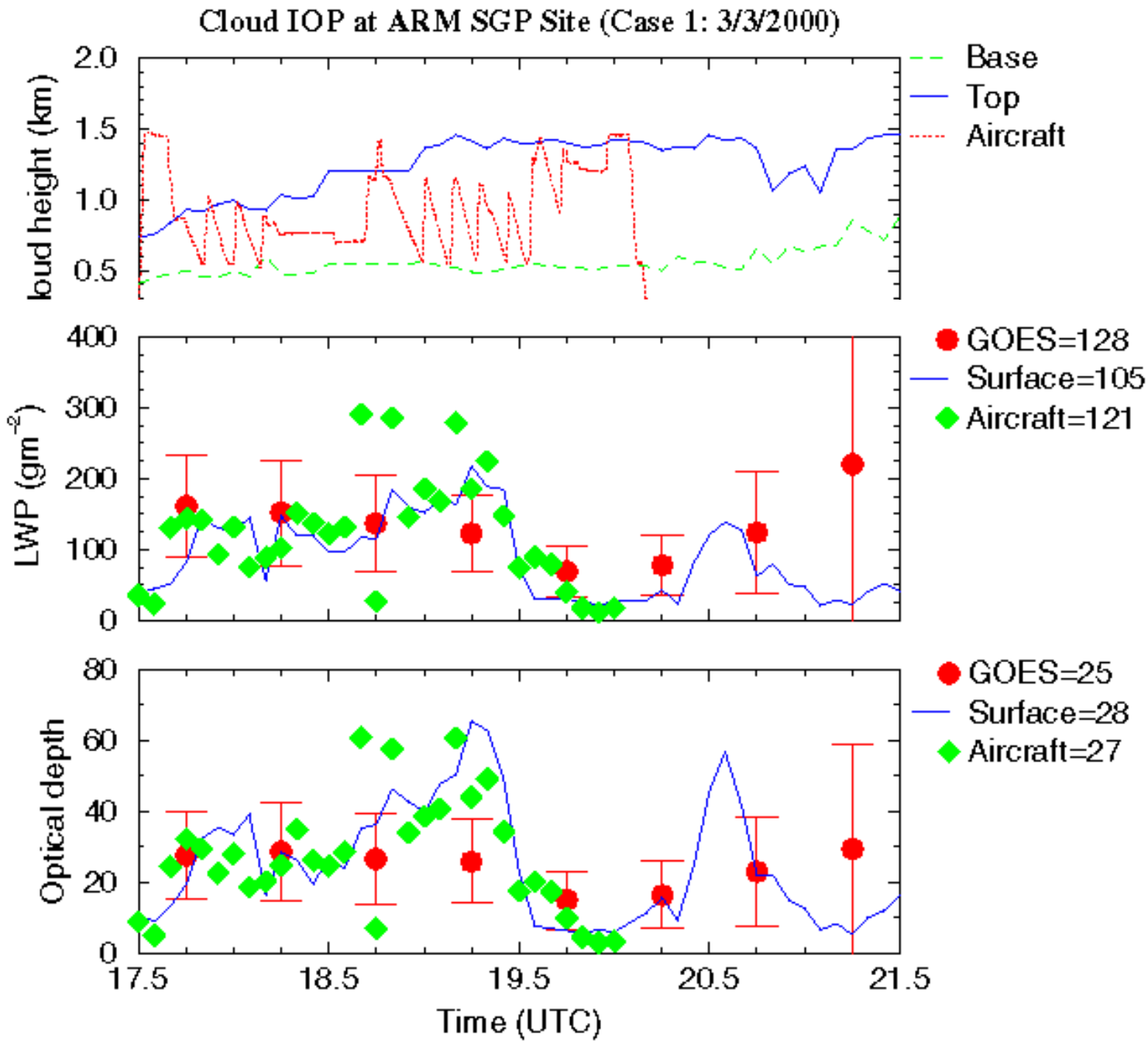
Atmospheric Radiation Measurement

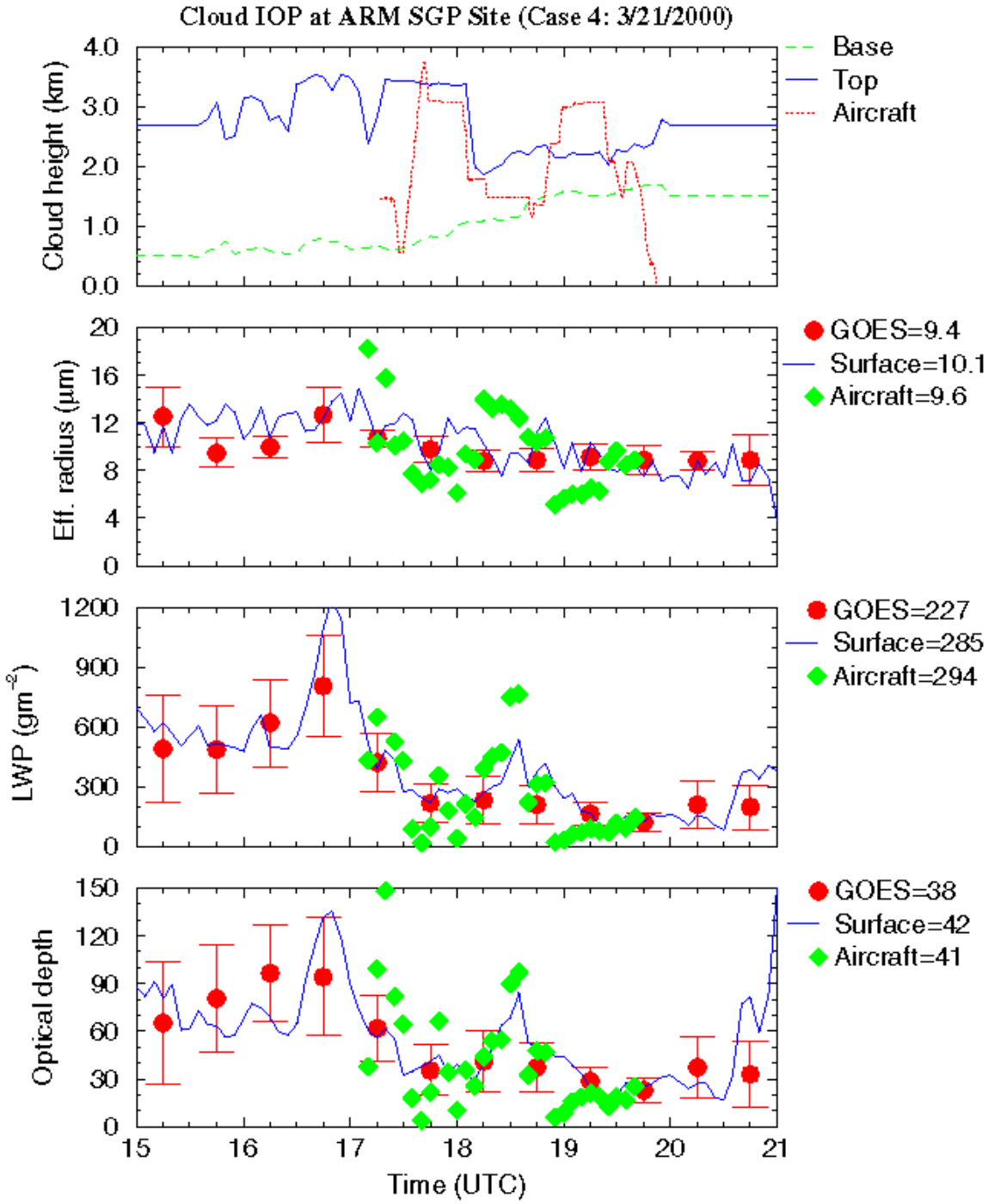
Cloud Microphysics

- 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)



ARM
Atmospheric Radiation Measurement


Cloud IOP at ARM SGP Site (Case 1: 3/3/2000)
Cloud 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)



ARM
Atmospheric Radiation Measurement

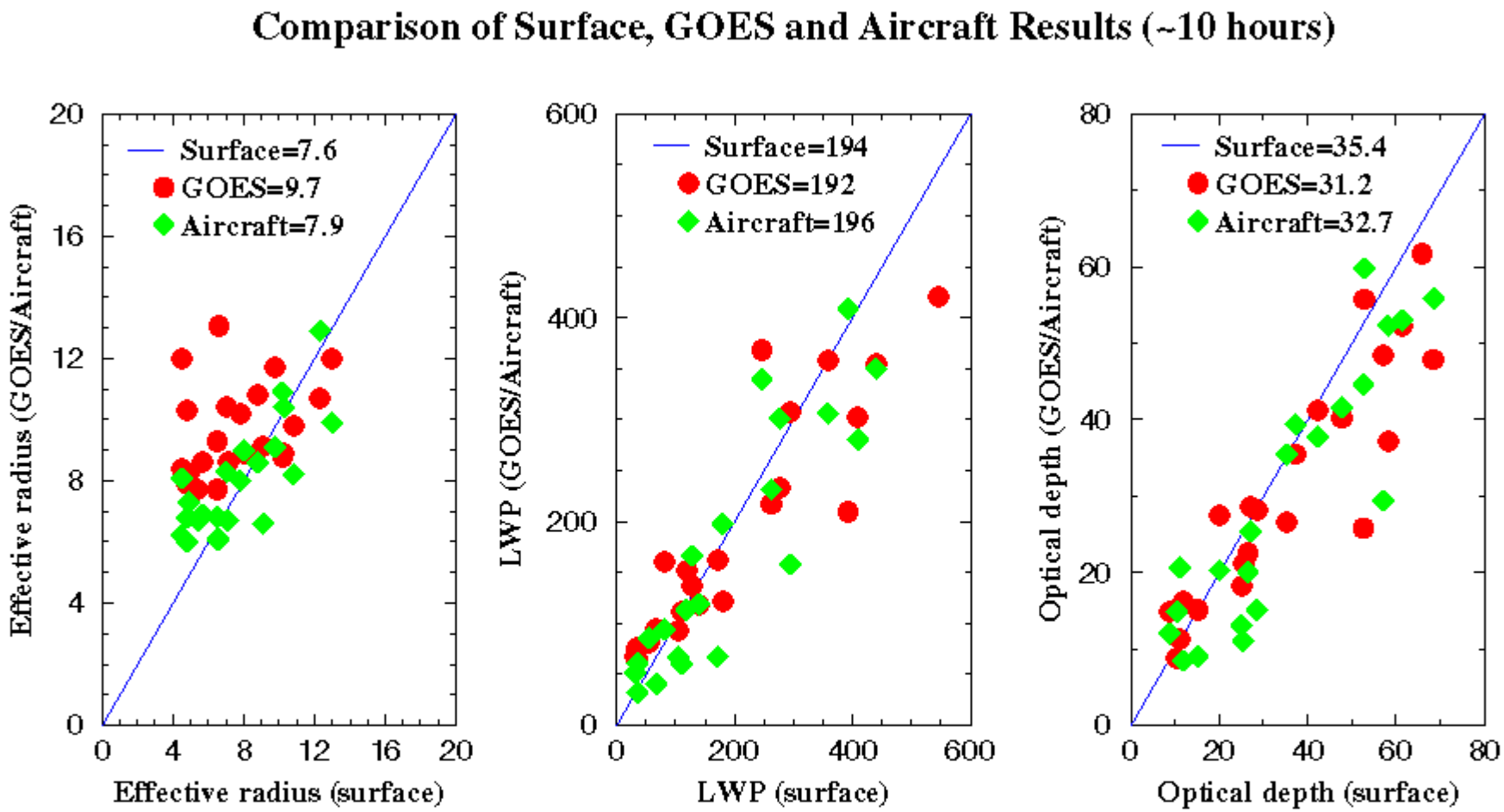


Fig. 8. Comparison of three datasets during 10–hour time period from 4 cases in 30–min temporal resolution.

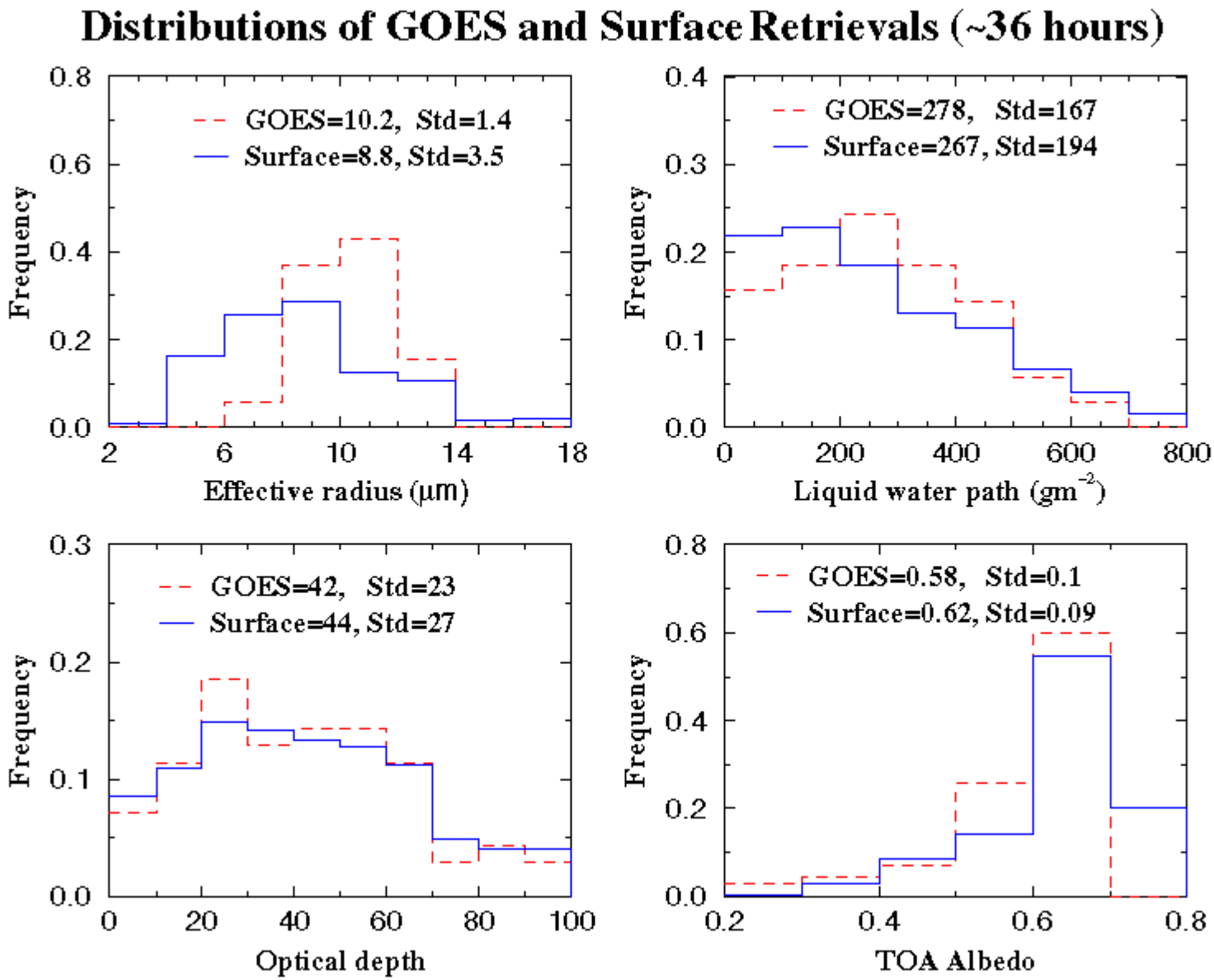
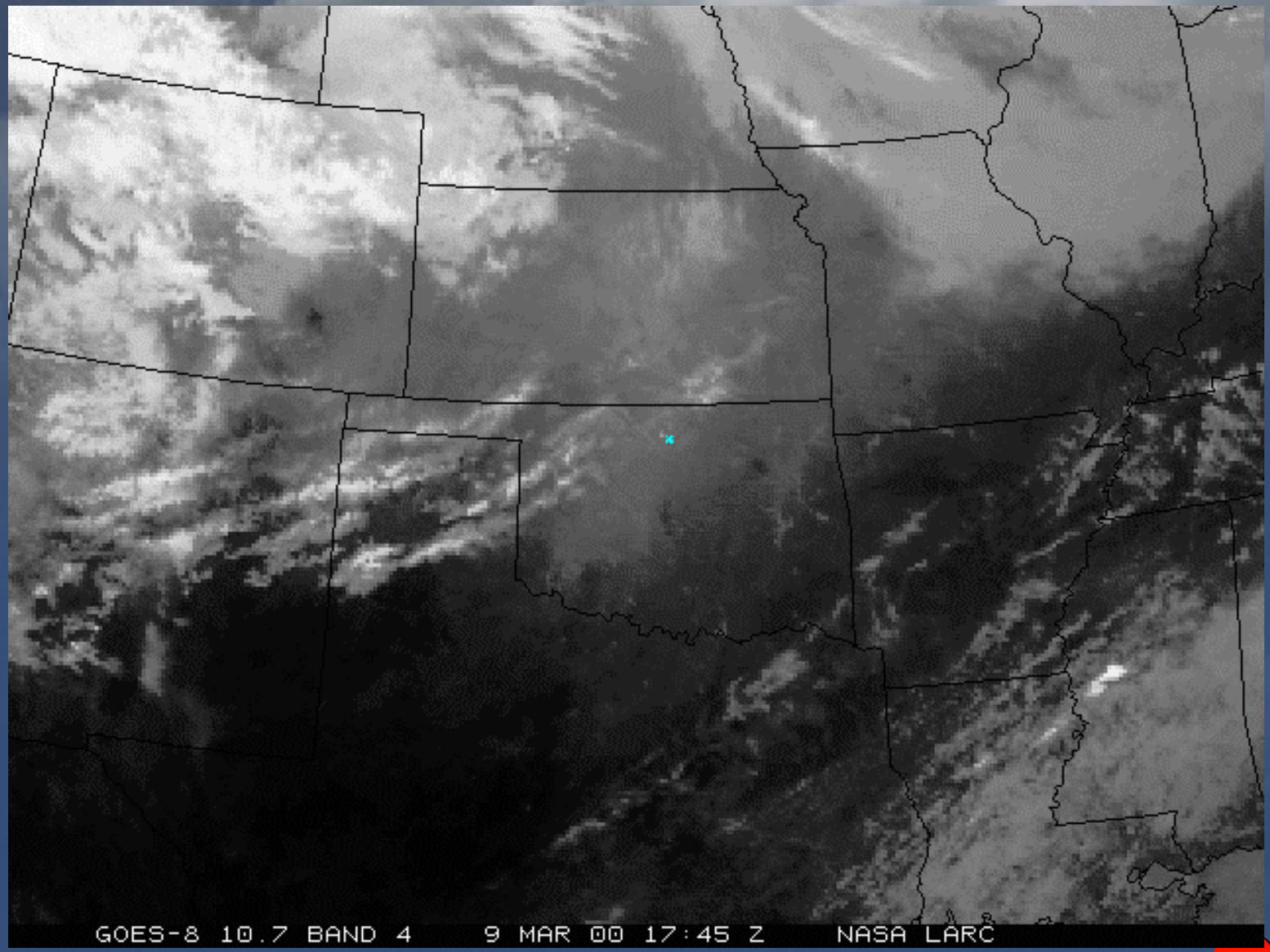
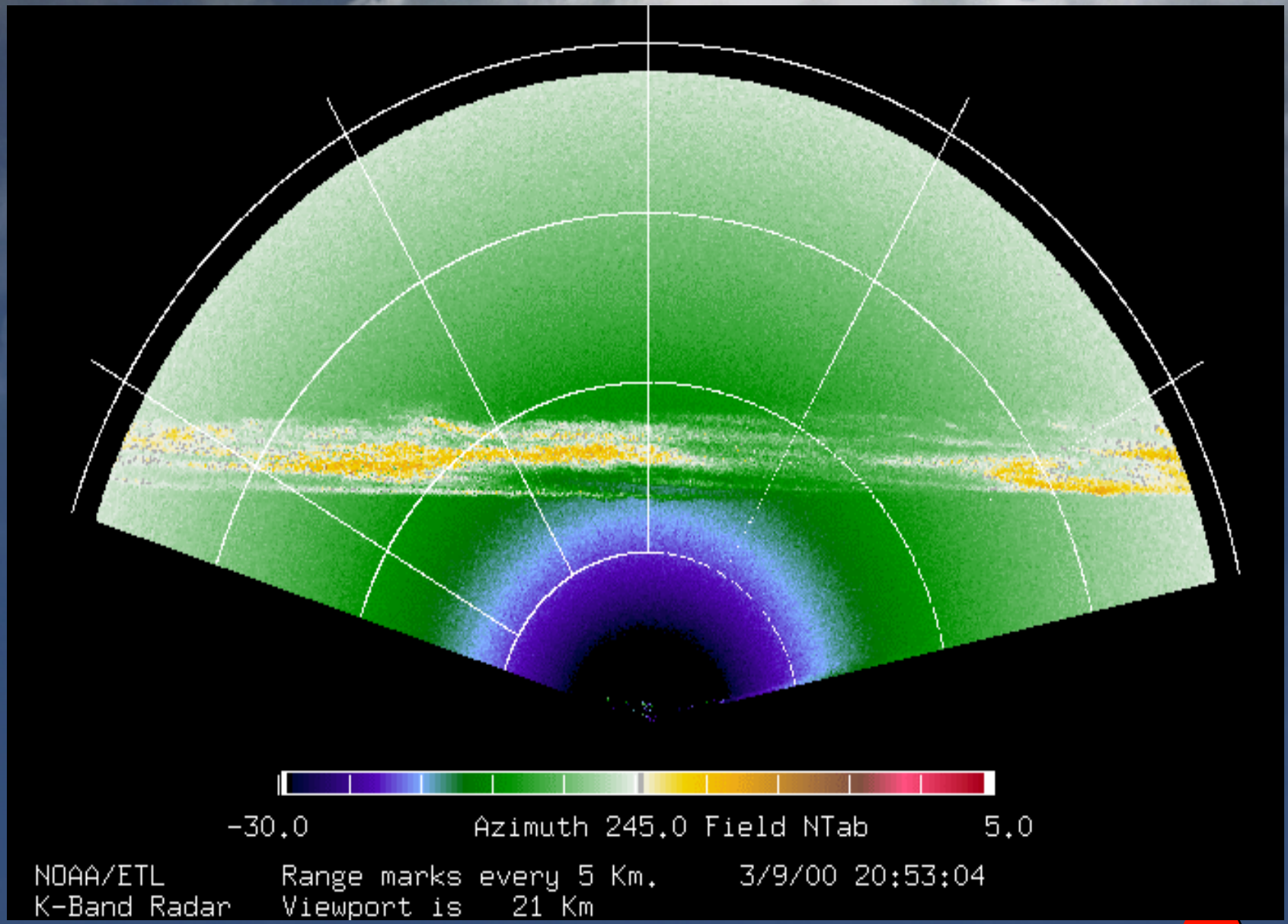


Fig. 12. Total 36 hours of surface (5–min) and GOES (30–min) data from 7 cases during the IOP.



ARM
Atmospheric Radiation Measurement



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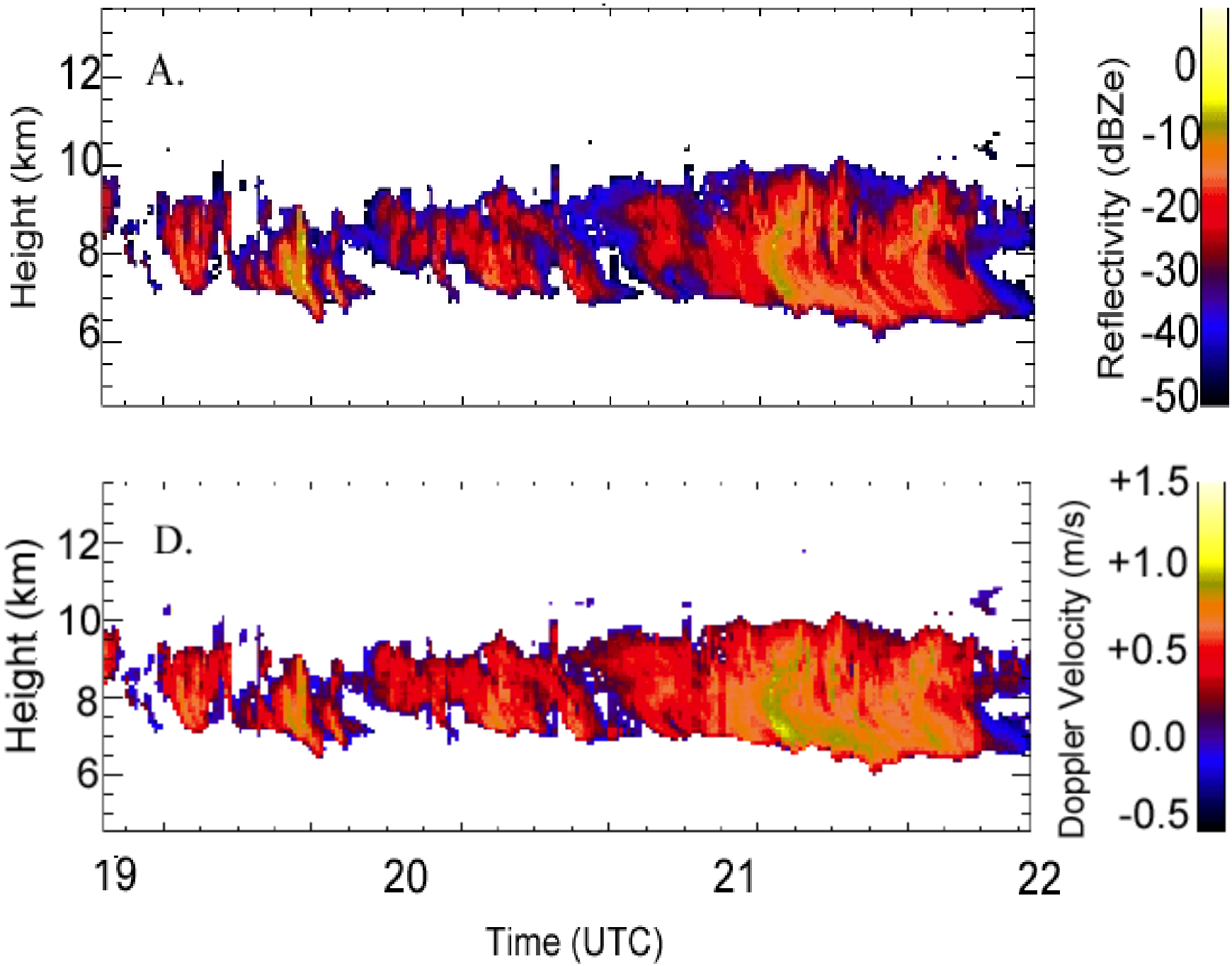
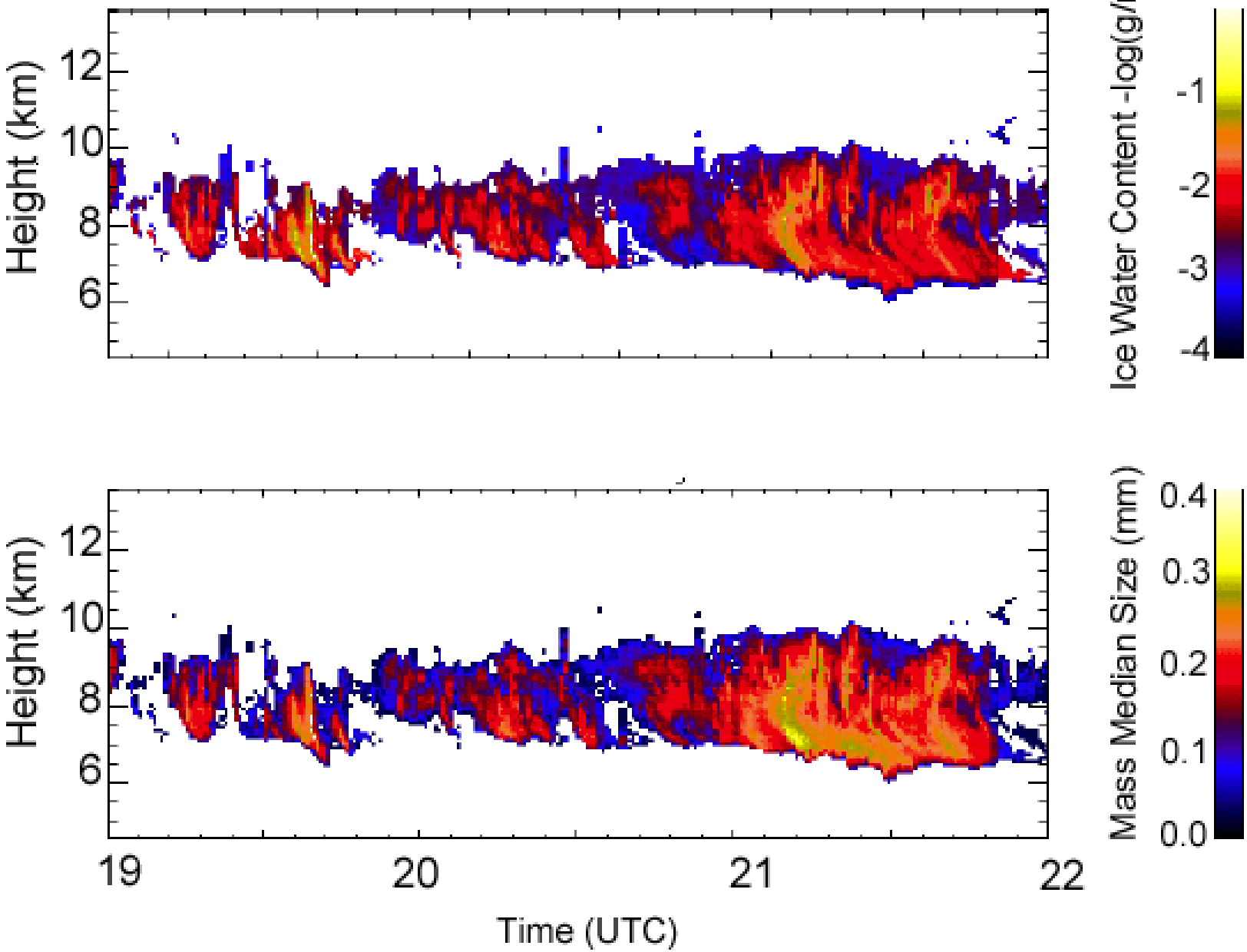
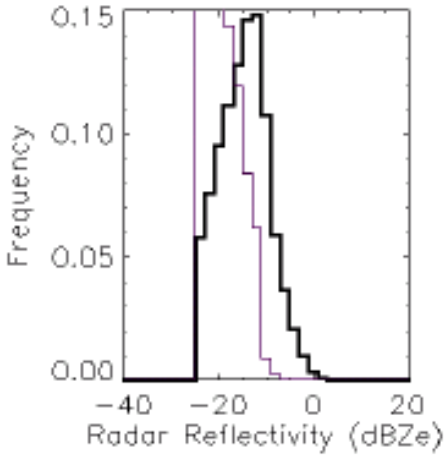
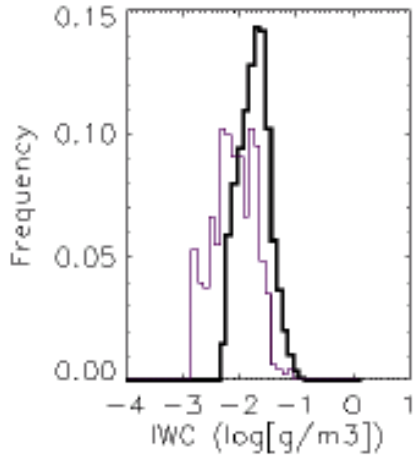
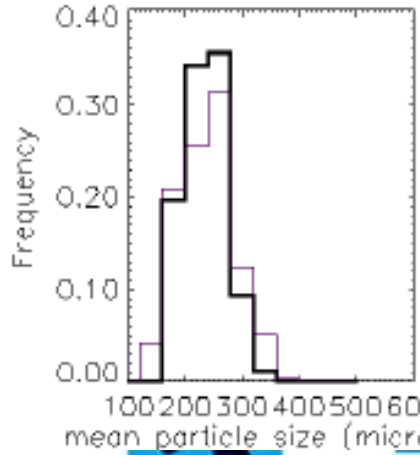
Atmospheric Radiation Measurement

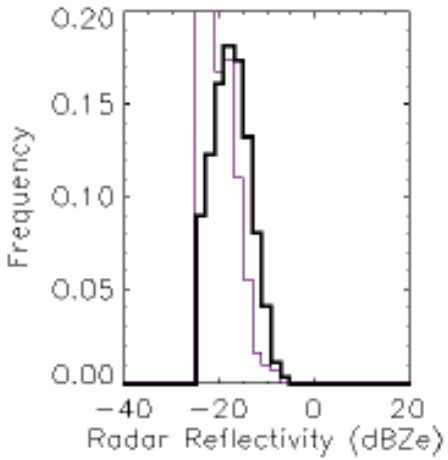

A.
D.
Height (km)
12
10
8
6
Reflectivity (dBZe)
0
-10
-20
-30
-40
-50
Doppler Velocity (m/s)
+1.5
+1.0
+0.5
0.0
-0.5
19
20
21
22
Time (UTC)

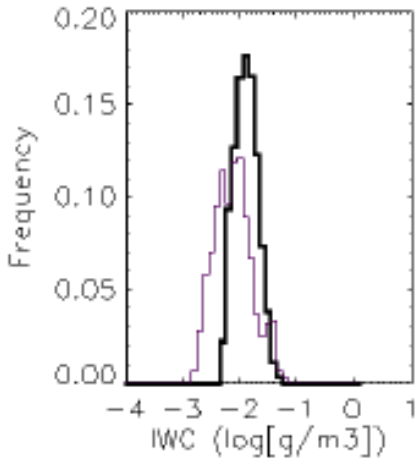

Height (km)
12
10
8
6
Ice Water Content -log(g/m3)
-1
-2
-3
-4
Height (km)
12
10
8
6
Mass Median Size (mm)
0.4
0.3
0.2
0.1
0.0
19
20
21
22
Time (UTC)











Heavy line = scanning radar
Light line = aircraft horizontal leg

How well do we do?

- Surface energy budget – very good
- Large scale forcing – fair to good
  - Need to find way around extra sondes
  - What about remote sites?
- Atmospheric mean state
  - Central point – very good
  - Domain average – good (water vapor)

How well do we do?

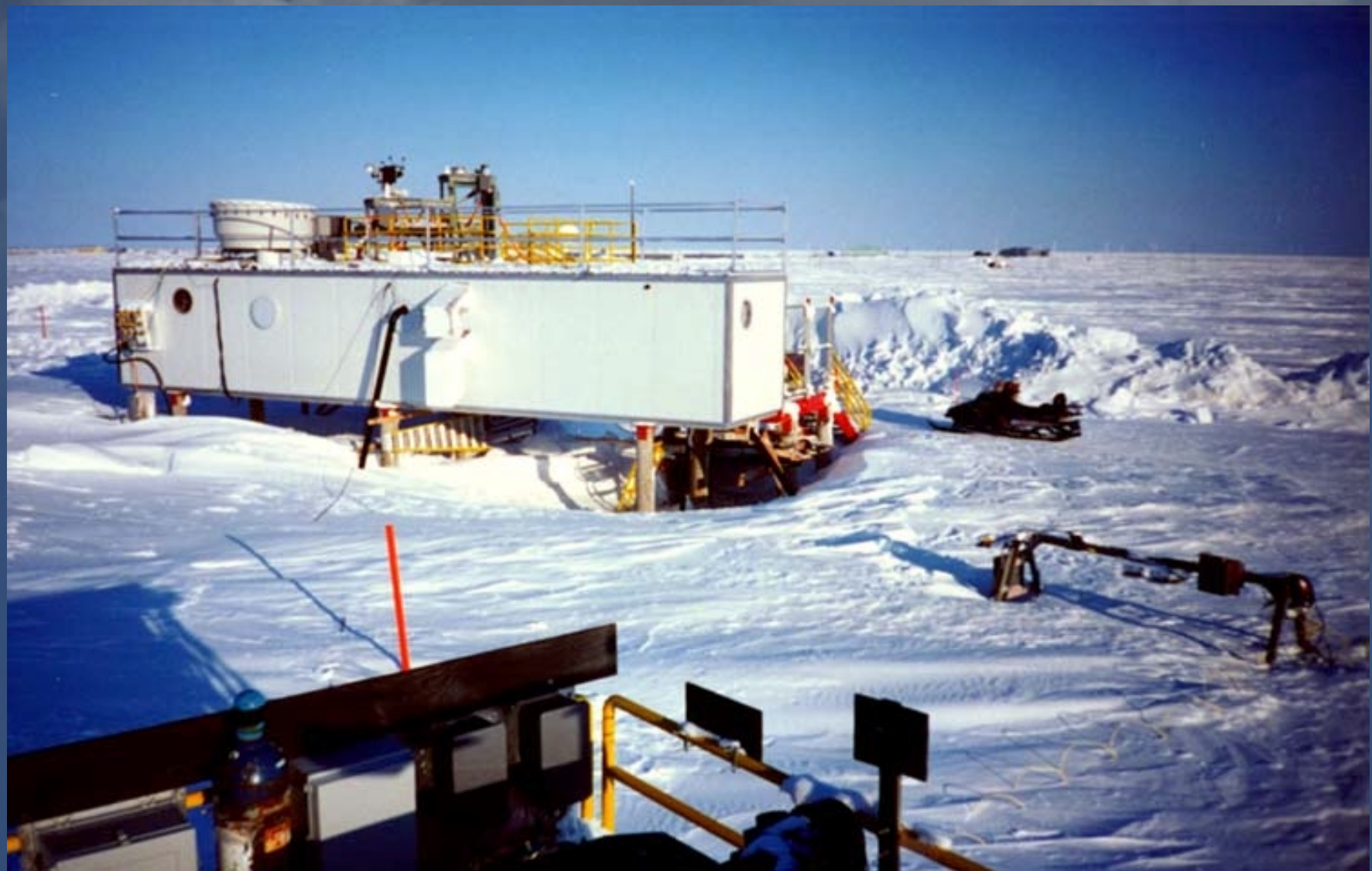
- Aerosol – fair to good (chemistry)
- Cloud macrophysics
  - Central point – very good
  - Domain average – fair to good
  - Advection – poor
- Cloud microphysics – fair

Where to?

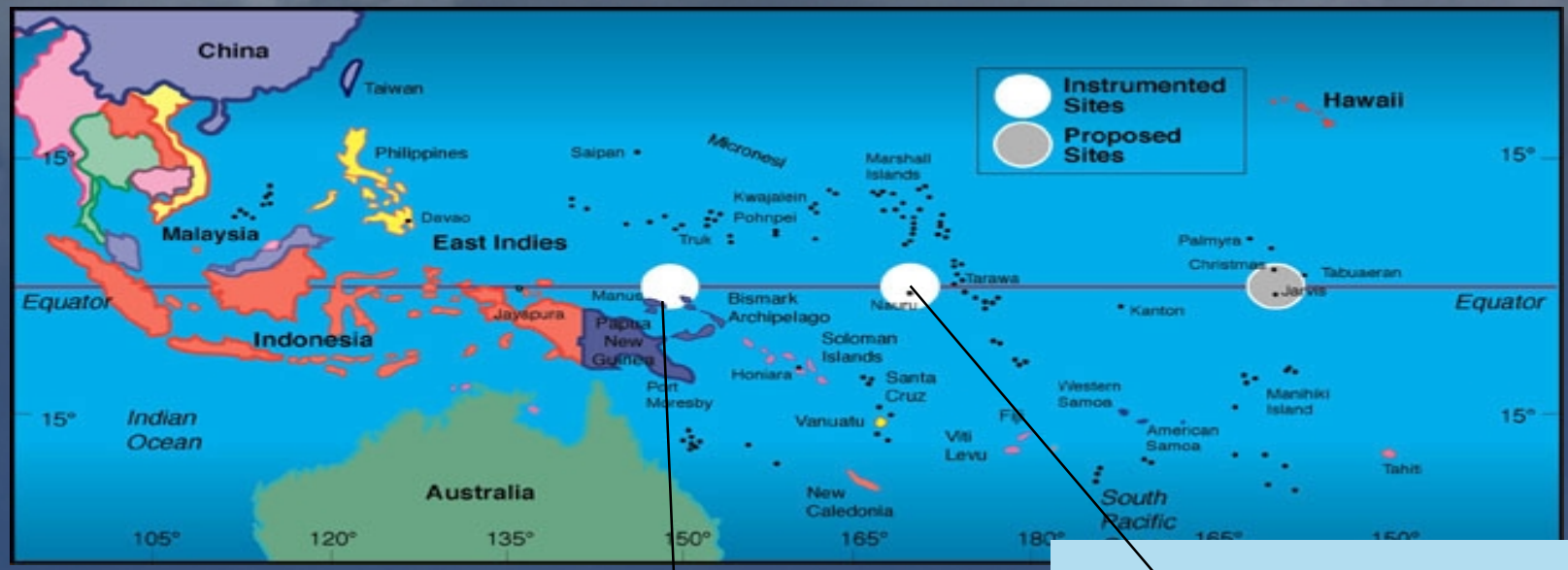
- SGP site
  - Continuous forcing fields
  - Domain average water vapor and cloud
  - Cloud advection
  - Integrated products
- Remote sites

North Slope of Alaska Site

North Slope of Alaska Site



Tropical Western Pacific Site



Tropical Western Pacific Site

Manus Island

Nauru

Where to?

- European sites
  - Cabauw – the Netherlands
  - Chilbolten – United Kingdom
  - Palaiseau – France
  - Lindenberg – Germany?
- Joint Australia / ARM site
  - Darwin

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Commercial Message

ARM data: freely available at www.arm.gov

Post-doc positions available in data analysis and cloud modeling


Thanks for your attention!