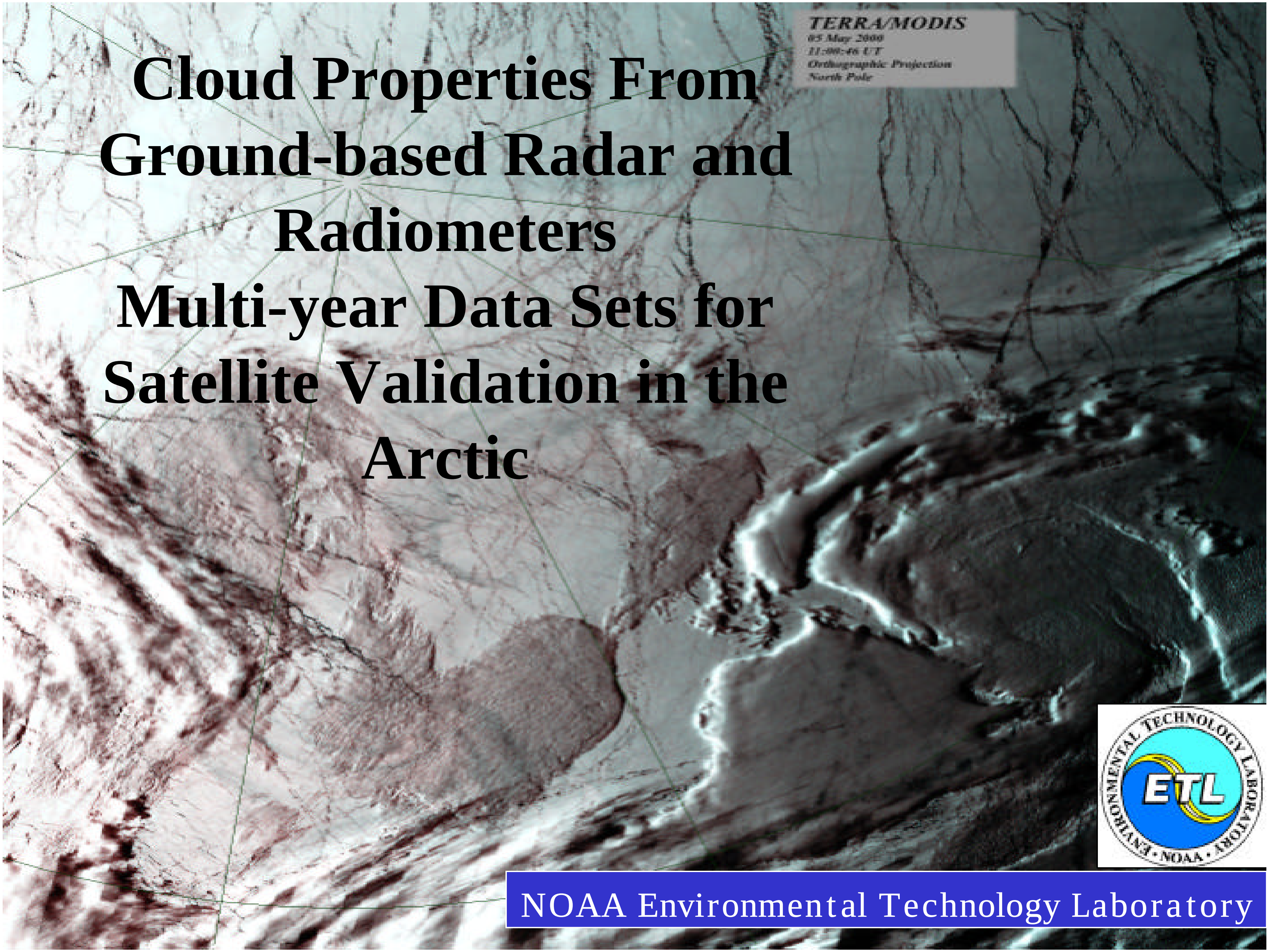
Cloud Properties From Ground-based Radar and Radiometers Multi-year Data Sets for Satellite Validation in the Arctic



NOAA Environmental Technology Laboratory

NOAA/ETL Arctic Research Group

Taneil Uttal, Matthew Shupe, Shelby Frisch, Paquita Zuidema, Ken Moran

Affiliates: Sergey Matrosov, Janet Intrieri

Why is the Arctic important?

From "Status of and Outlook for Large Scale Modeling of Atmosphere-Ice-Ocean Interactions in the Arctic" – Randall et al., 1998, BAMS, 197-219

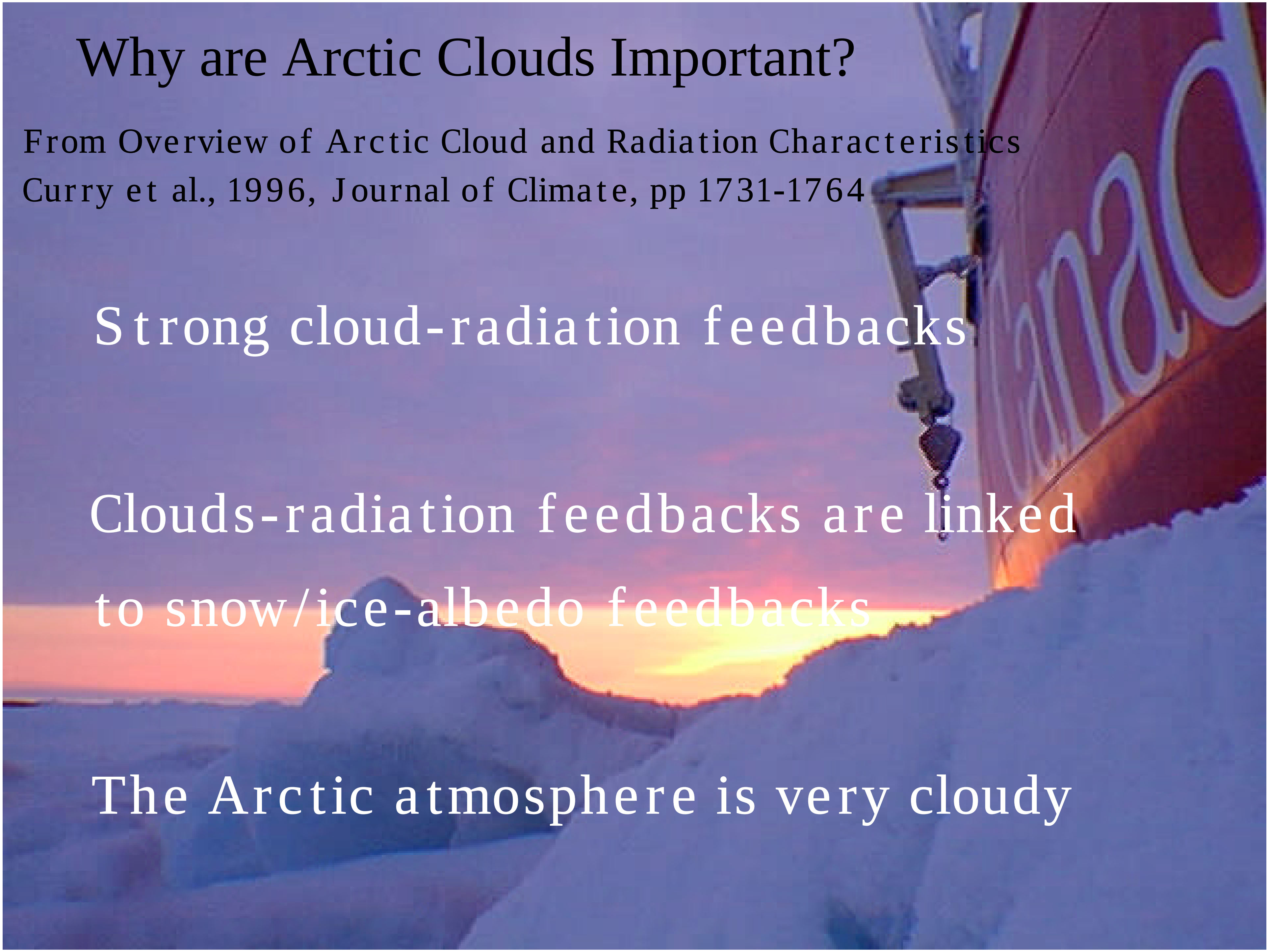
Coupled climate models show the largest disagreements in the polar regions

The North Atlantic thermohaline circulation exerts important controls on climate variability on scales ranging from years to millennia

CO_2 warming may be strongly amplified by retreat and thinning of sea ice

Why are Arctic Clouds Important?

From Overview of Arctic Cloud and Radiation Characteristics
Curry et al., 1996, Journal of Climate, pp 1731-1764



Strong cloud-radiation feedbacks

Clouds-radiation feedbacks are linked to snow/ice-albedo feedbacks

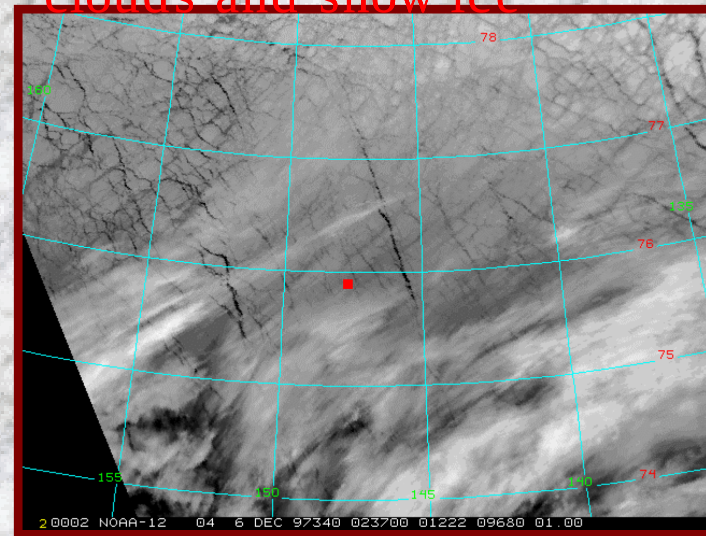
The Arctic atmosphere is very cloudy

Why are Arctic Clouds Hard?

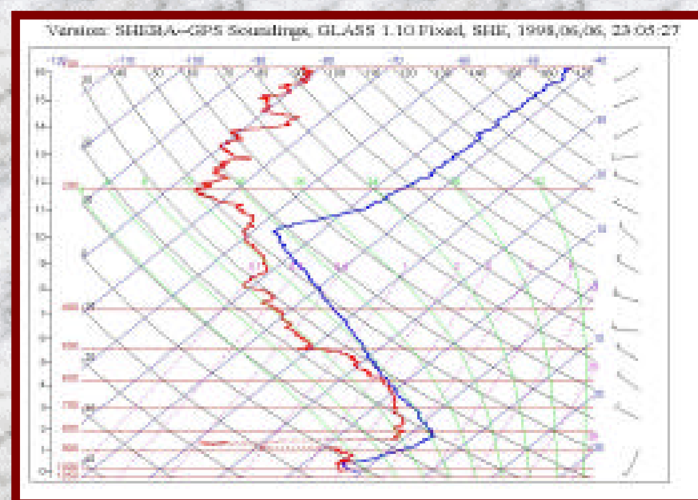
Polar Night – can't use shortwave

Cold – fieldwork difficult & few observations

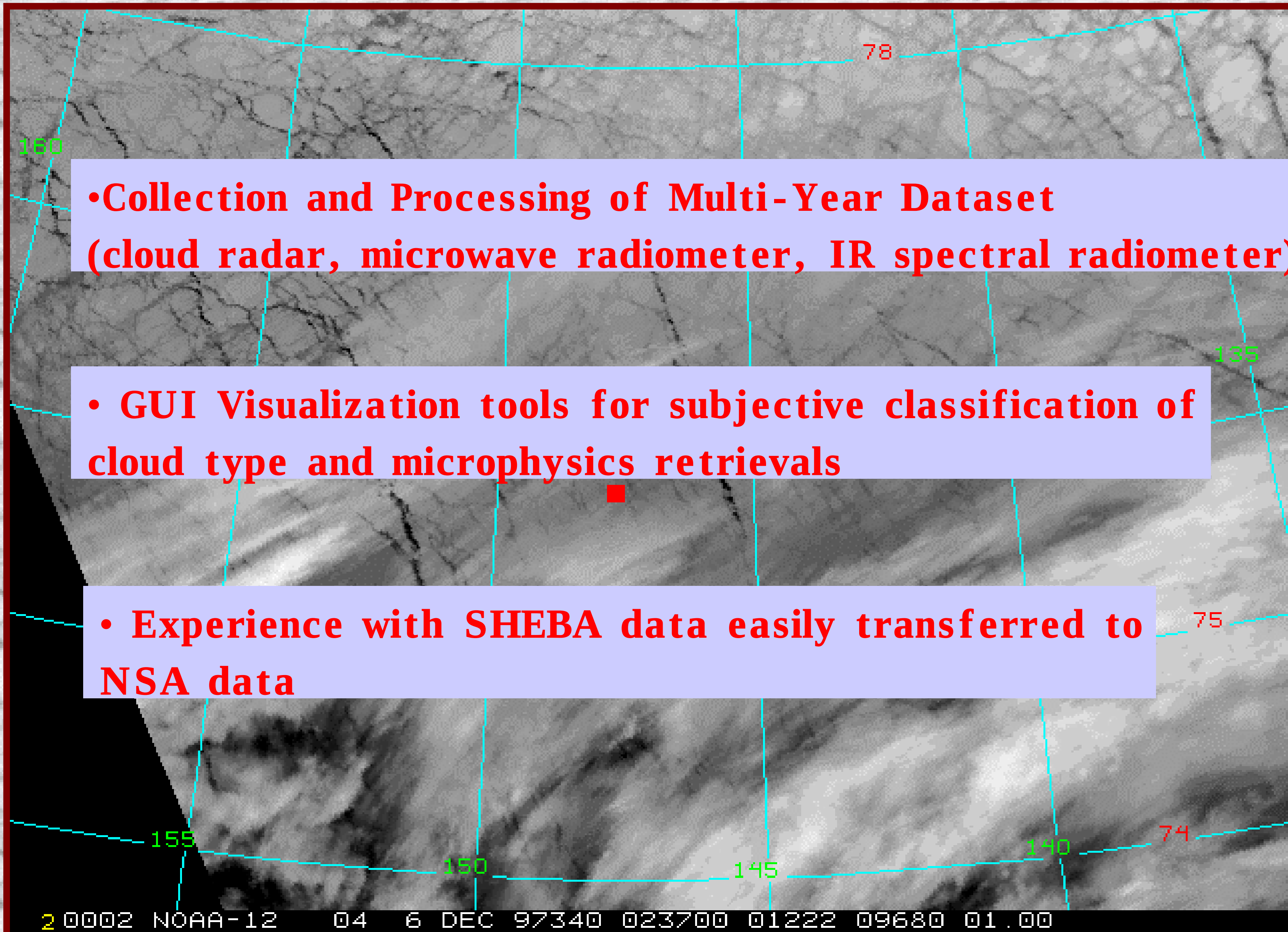
Low contrast between clouds and snow ice



Low Infrared contrast; Temperature-Humidity inversions



How can the ETL Arctic Research Group contribute ?



- Collection and Processing of Multi-Year Dataset (cloud radar, microwave radiometer, IR spectral radiometer)
- GUI Visualization tools for subjective classification of cloud type and microphysics retrievals
- Experience with SHEBA data easily transferred to NSA data

North Slope Of Alaska ARM CART Site

The SHEBA Ice Camp
Nov 1997-Nov 1998

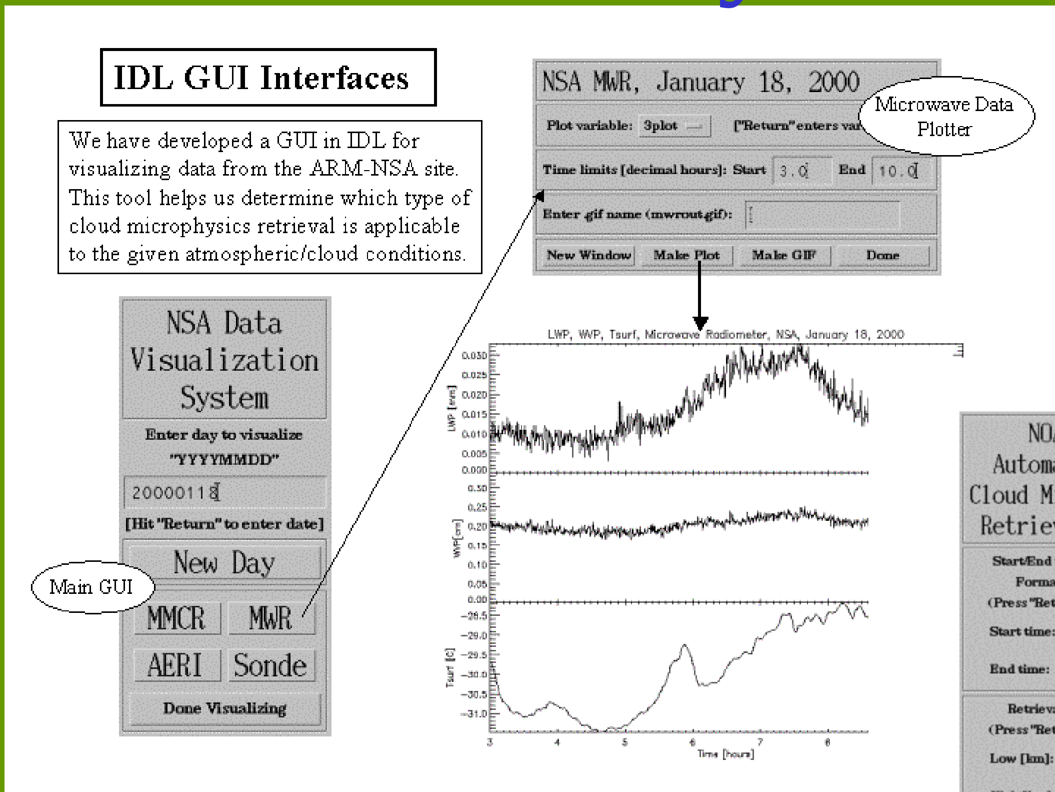
Instruments

8.66 millimeter-wavelength Cloud radar. Little contamination in the dry Arctic atmosphere

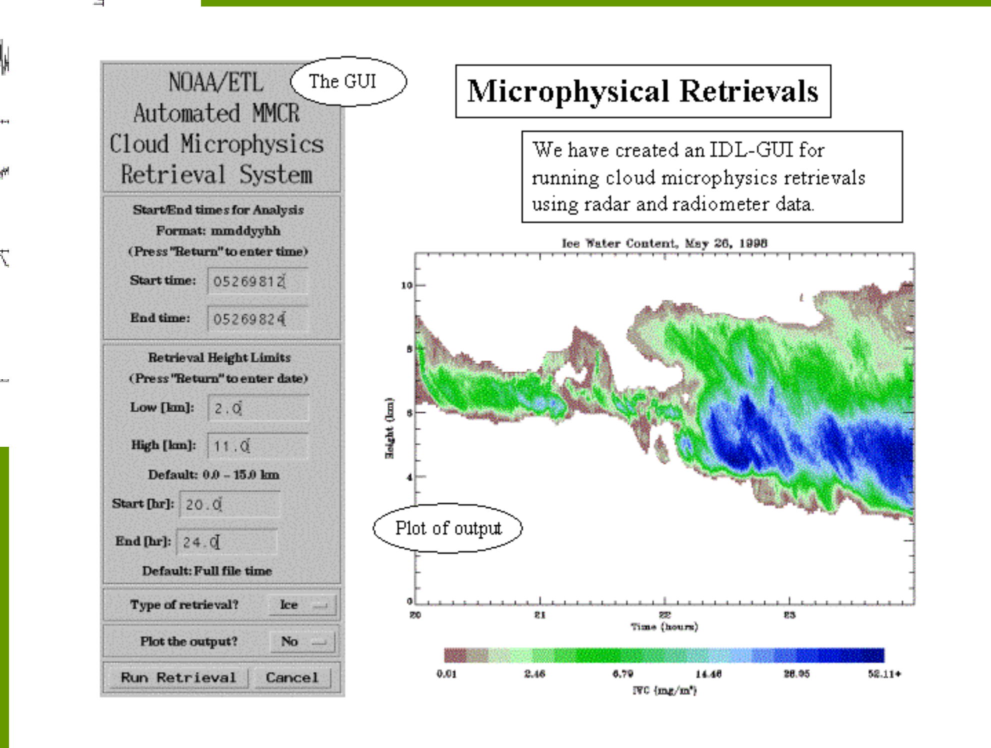
Microwave radiometer (23.8 & 31.4 GHz)

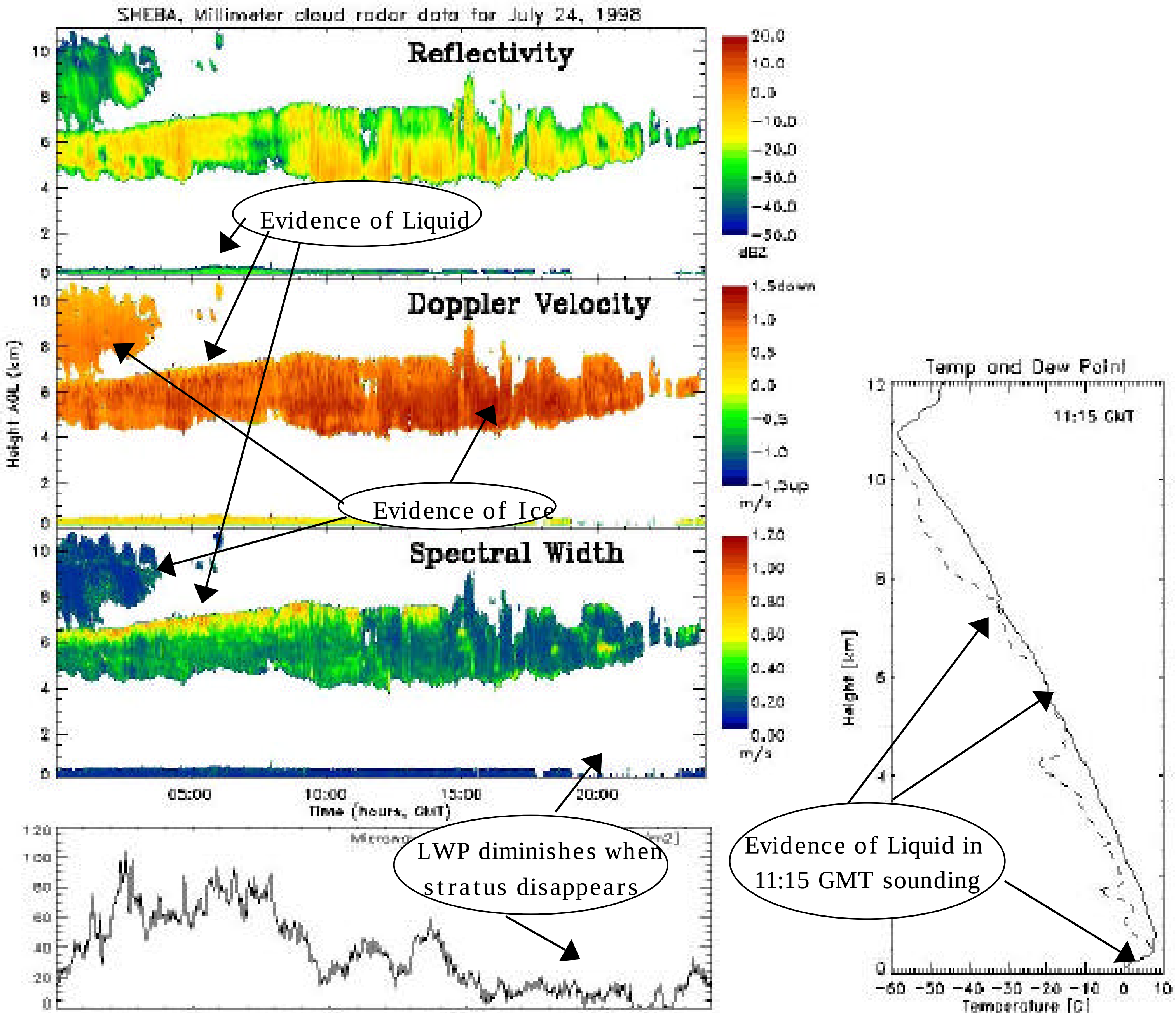
IR Spectral radiometer

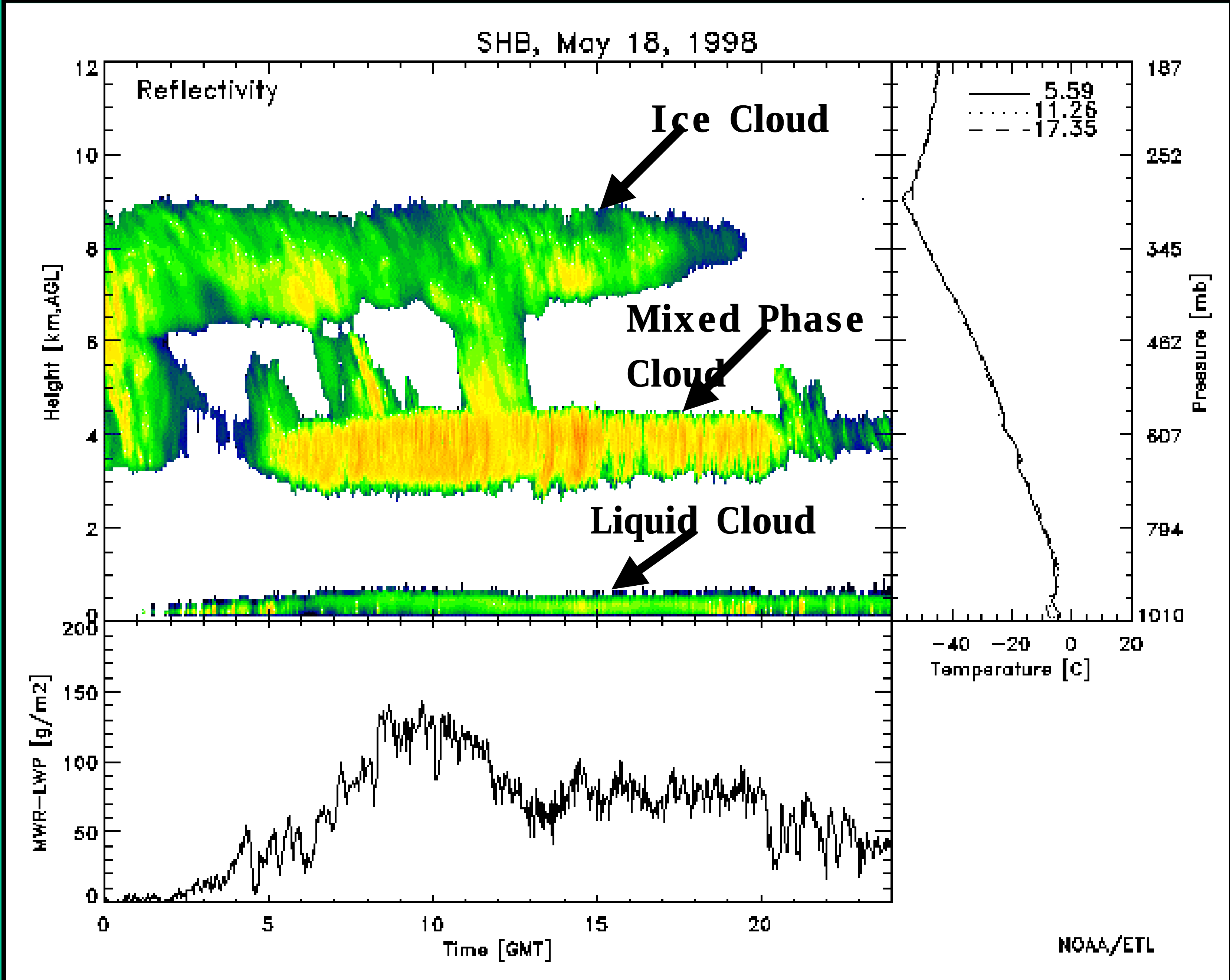
GUIs facilitate analysis of multi-year datasets

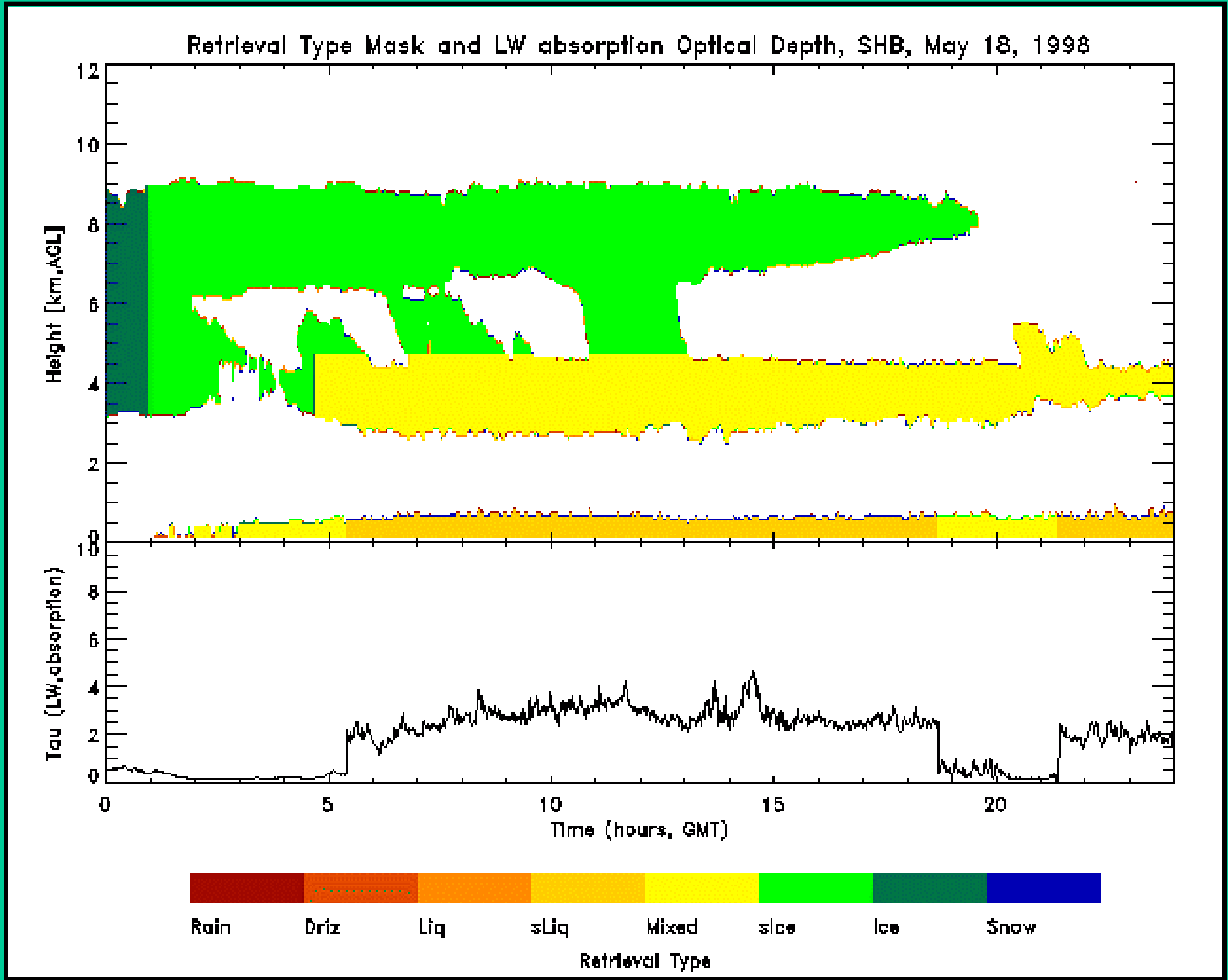


Subjective selection from a Suite of techniques to Produce retrievals




SHEBA, Millimeter cloud radar data for July 24, 1998
Reflectivity
Doppler Velocity
Spectral Width
Height AGL (km)
dBZ
m/s
Time (hours, GMT)
Evidence of Liquid
Evidence of Ice
LWP diminishes when stratus disappears
Temp and Dew Point
11:15 GMT
Height [km]
Temperature [C]
Evidence of Liquid in 11:15 GMT sounding


SHB, May 18, 1998
Reflectivity
Ice Cloud
Mixed Phase Cloud
Liquid Cloud
Height [km,AGL]
12
10
8
6
4
2
0
5.59
11.26
-17.35
187
252
345
462
607
794
1010
Pressure [mb]
-40 -20 0 20
Temperature [C]
MWR-LWP [g/m2]
200
150
100
50
0
0 5 10 15 20
Time [GMT]
NOAA/ETL



Retrieval Type Mask and LW absorption Optical Depth, SHB, May 18, 1998
Height [km,AGL]
12
10
8
6
4
2
0
Tau (LW,absorption)
10
8
6
4
2
0
0
5
10
15
20
Time (hours, GMT)
Rain
Driz
Liq
sLiq
Mixed
sIce
Ice
Snow
Retrieval Type

Liquid Cloud Retrievals

SHELBY FRISCH

Simple regressions between cloud parameters and radar reflectivity have the form:

$$LWC = a_1(N,\sigma)Z_e^{1/2} \qquad R_e = a_2(N,\sigma)Z_e^{1/6}$$

***Advantages*: Easy to apply, only used radar measurements.**

***Disadvantages*: If a fixed set of coefficients is used the retrieval uncertainty due to inter-cloud and regional variability between clouds is quite high (LWC ~ 50-100%).**

***Region Specific*: Can apply information on particle concentration (N) and width of the particle size distribution (σ) for a given geographic region to improve the coefficients. Using aircraft *in situ* FSSP measurements we have done this for the Arctic and SGP regions.**

Radar-radiometer technique With the addition of the LWP derived from the microwave radiometer, a constraint can be put on the liquid cloud retrieval, which improves the general retrieval agreement with aircraft (LWC ~ 30%).

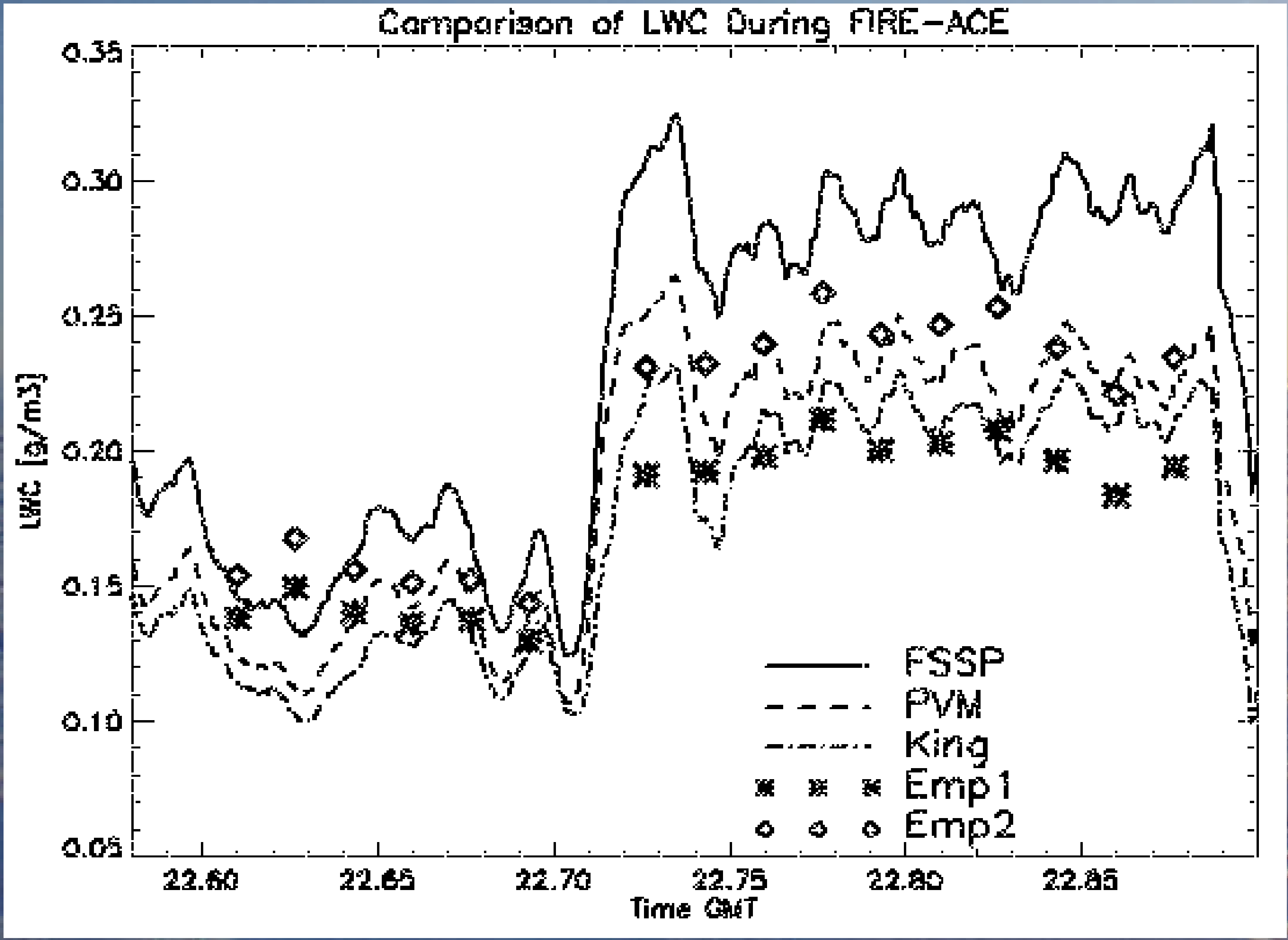
Requirements:

- **Cloud must contain only liquid water.**
- **All liquid in column must be in all-liquid layers.**
- **Cloud cannot contain drizzle or precipitation.**

$$LWC \propto LWP \frac{Z^{1/2}}{\sum_{clouddepth} Z^{1/2}}$$

Frisch et al., 1995 & 1998.

Technique assessment



Ice Cloud Retrievals

SERGEY MATROSOV

<u>Simple regressions</u> between cloud parameters and radar reflectivity have the form:

$$IWC = aZ^b \qquad D_{mean} \propto \left(\frac{Z}{IWC}\right)^{1/1.9}$$

Advantages: Easy to apply, only radar measurements used.

Disadvantages: Such general relationships do not account for inter-cloud and regional variability of coefficients which can lead to large retrieval uncertainties (IWC ~ 70-100%).

<u>Tuned Regression Technique</u> (Matrosov, 1999) Uses radiometer measurements of IR brightness temperature to effectively tune the "a" coefficient for a given cloud.

Advantages: Perhaps the most accurate ice cloud retrieval technique (IWC ~ 60% and Dmean ~ 30%) and a large improvement over any *a priori* empirical relationship.

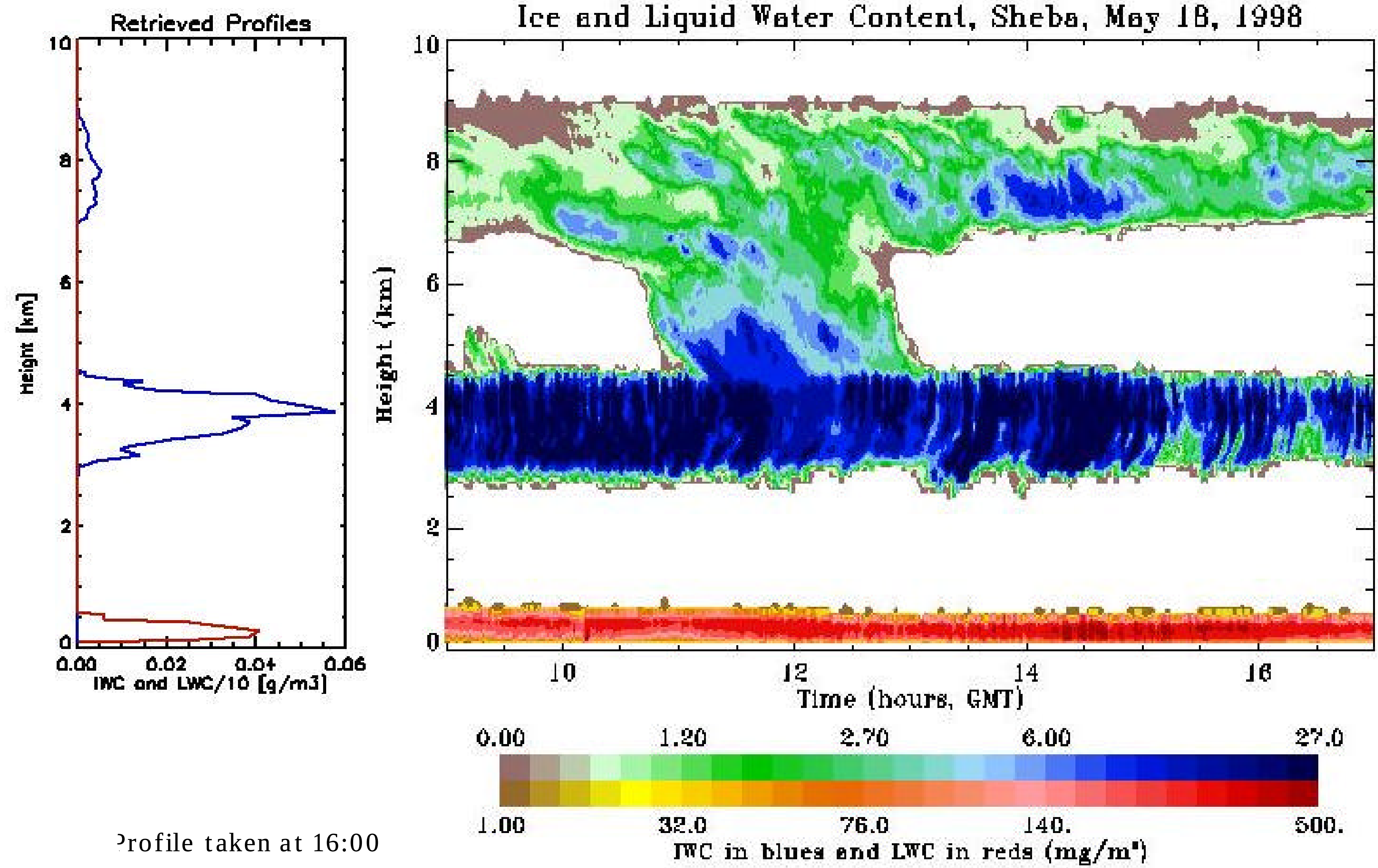
Disadvantages: Any multi-sensor technique suffers from differing viewed scenes.

Requirements: No liquid in the atmospheric column.

<u>Reflectivity-Velocity Technique</u> (Matrosov, in press) Uses only radar measurements of reflectivity and Doppler velocity.

Advantages: Uses measurements from only one instrument. Can retrieve the ice component of both ice and mixed-phase clouds. Preliminary comparisons show good agreement with the Tuned Regression technique.

Disadvantages: Must average radar parameters in time.



Profile taken at 16:00

http://www.etl.noaa.gov/nsa

NSA data partitioned into Satellite-friendly subsets

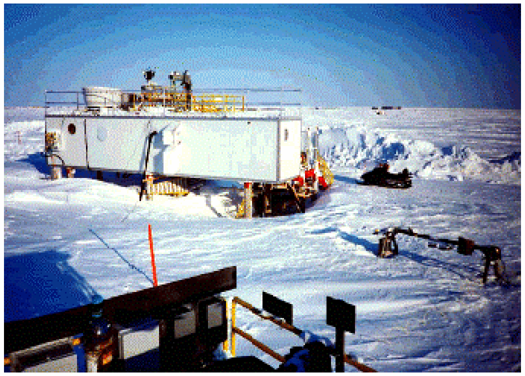
List of all-liquid, all-ice, Single-layer clouds

For each day,gif images of
- •Raw data
- •Cloud mask
- •Cloud water contents
- •Cloud particle sizes
  - -with Terra, NOAA Overpasses indicated

About a year on the web Site as of today

http://www.etl.noaa.gov/arctic

North Slope of Alaska Surface-Satellite Cloud Comparison Data Site



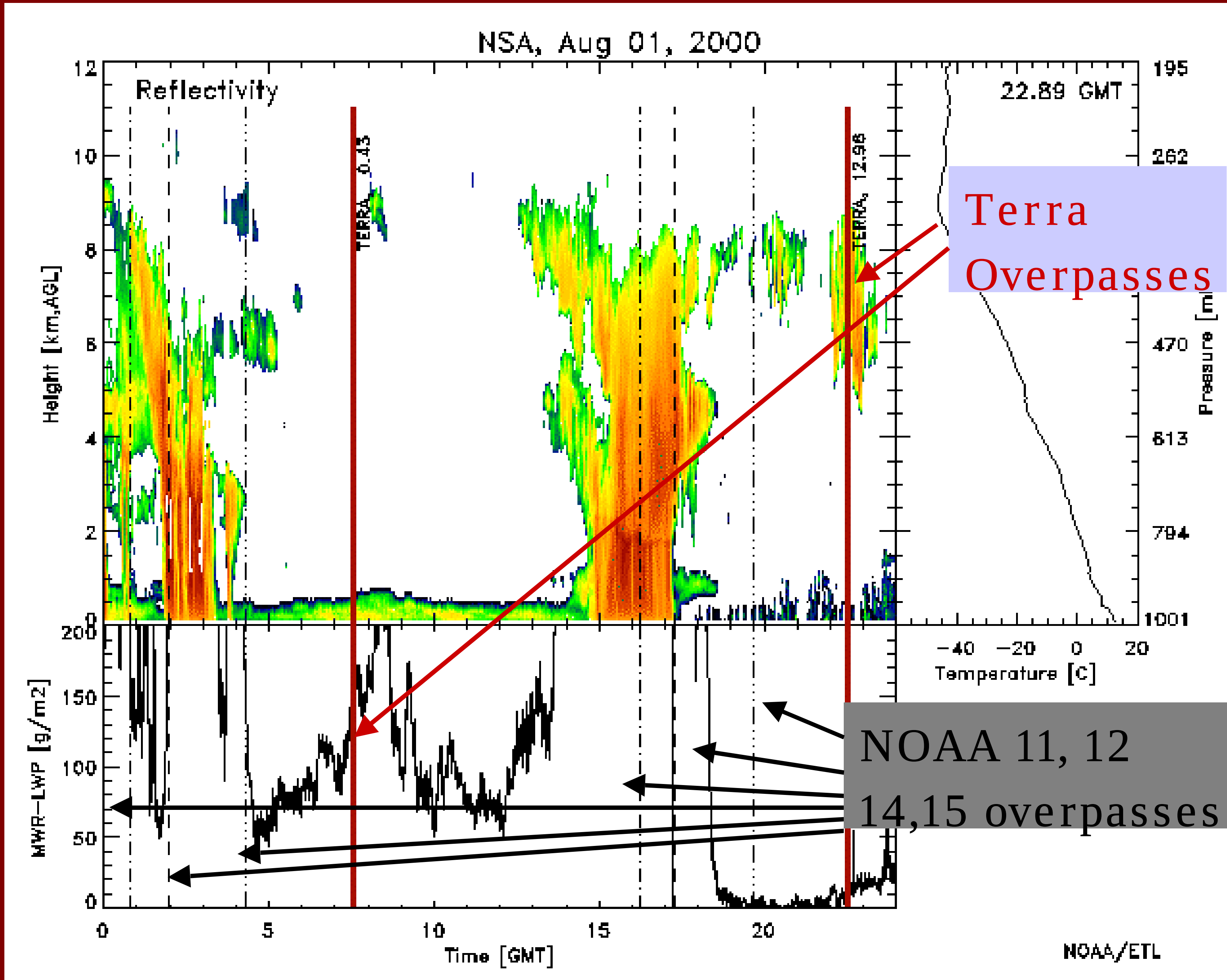
Background This site provides cloud microphysics data from a surface observing site (lat=71.17 lon=203.22) in Barrow, Alaska operated by the Department of Energy. The main purpose of this information is to provide a validation data set for satellite cloud sensors, particularly those on the TERRA satellite. Clouds observed with sensors operating at this ARM North Slope of Alaska CART site have been classified based on subjective (human) examination of data from radar, microwave and infrared radiometers, and rawinsonde data.
This site shows:

1. Composites of radar, microwave radiometer and rawinsonde data that is used to classify clouds as mixed phase, all-ice, all-liquid or precipitating
2. Resulting cloud classification masks
3. Water contents (mg/m3)
4. Ice particle or droplet sizes (um)\

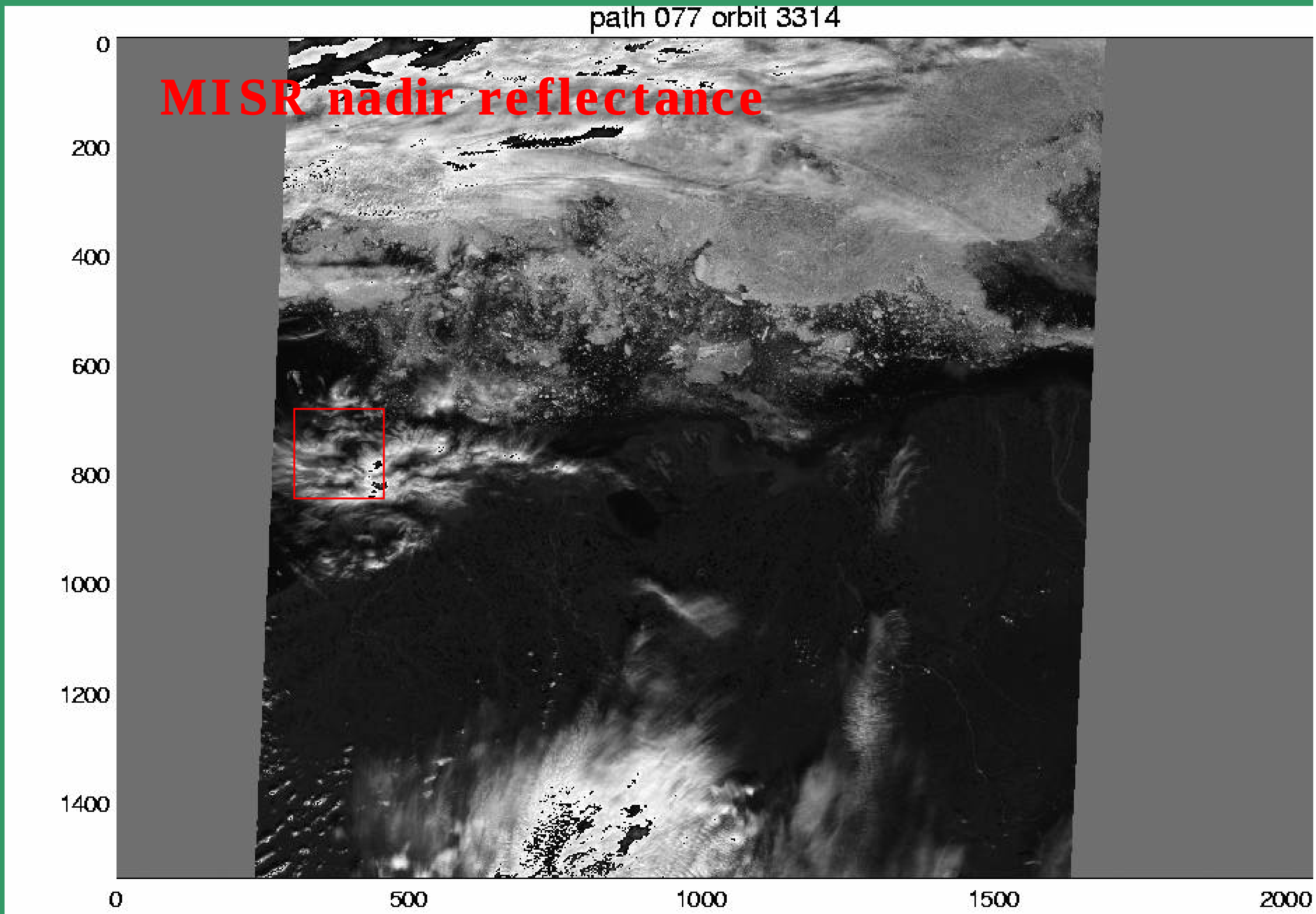
The overpass times for TERRA, NOAA-12, NOAA-14, NOAA-15, and NOAA-16 for which the viewing angle is less then 30 degrees is indicated on each plot. **The upper menu to the left allows selection of days which have been subsetted for TERRA overpasses into the following categories:**

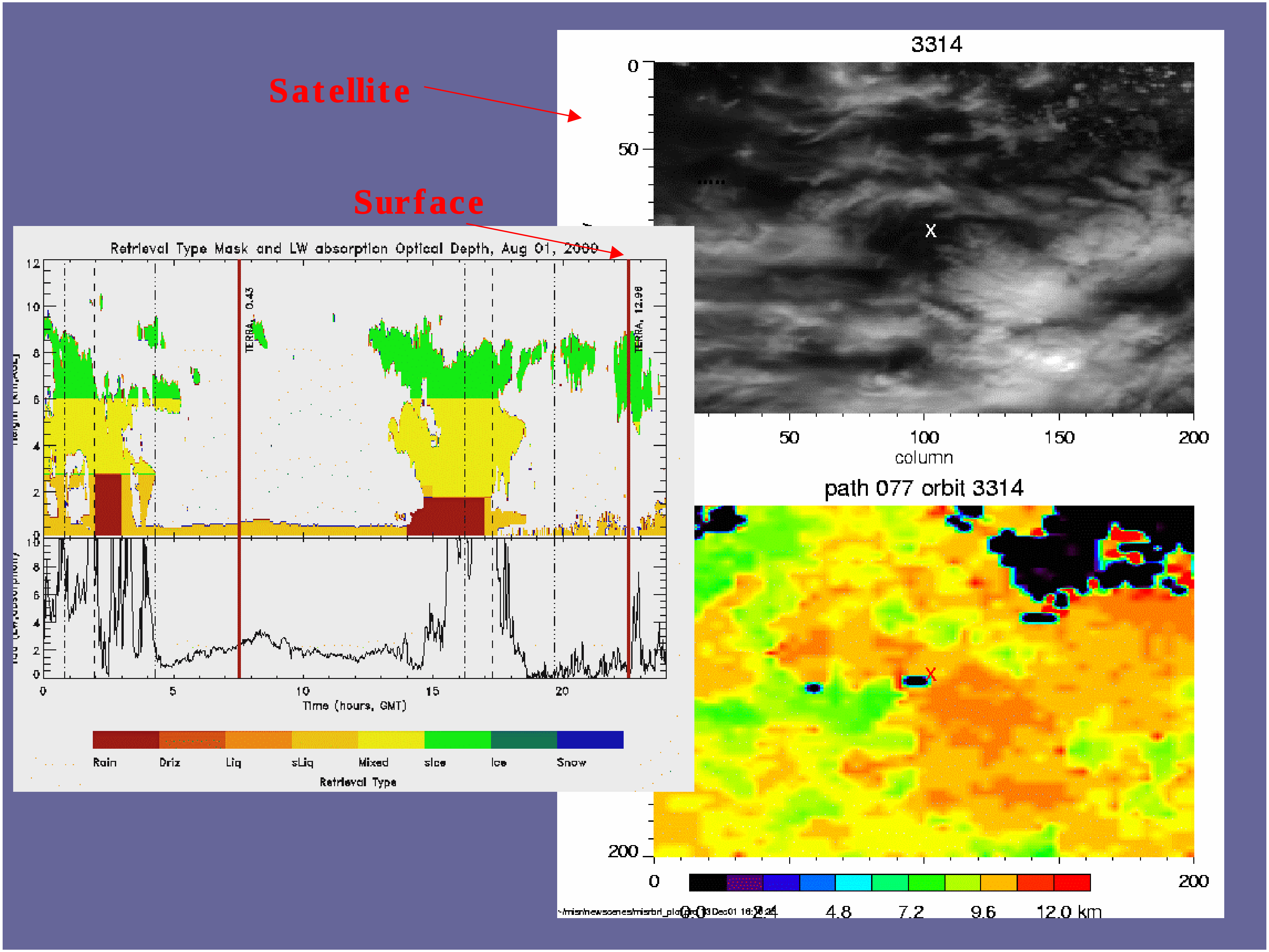
1. All overpasses
2. All-ice overpasses
3. All-liquid overpasses
4. Single-layer overpasses

The TERRA overpass is considered to be "all-ice", "all-liquid" or "single-layer" based on the criteria that the cloud(s) exhibits that characteristic for at least one hour preceeding and one hour following the overpass time. **The lower menu to the left allows selection of dates between March 1, 2000 and April 30 2000. As of June 22, 2001, these lists are being expanded backwards to when TERRA began collecting data on February 24, 2000, and forward to within 1 week of present.**



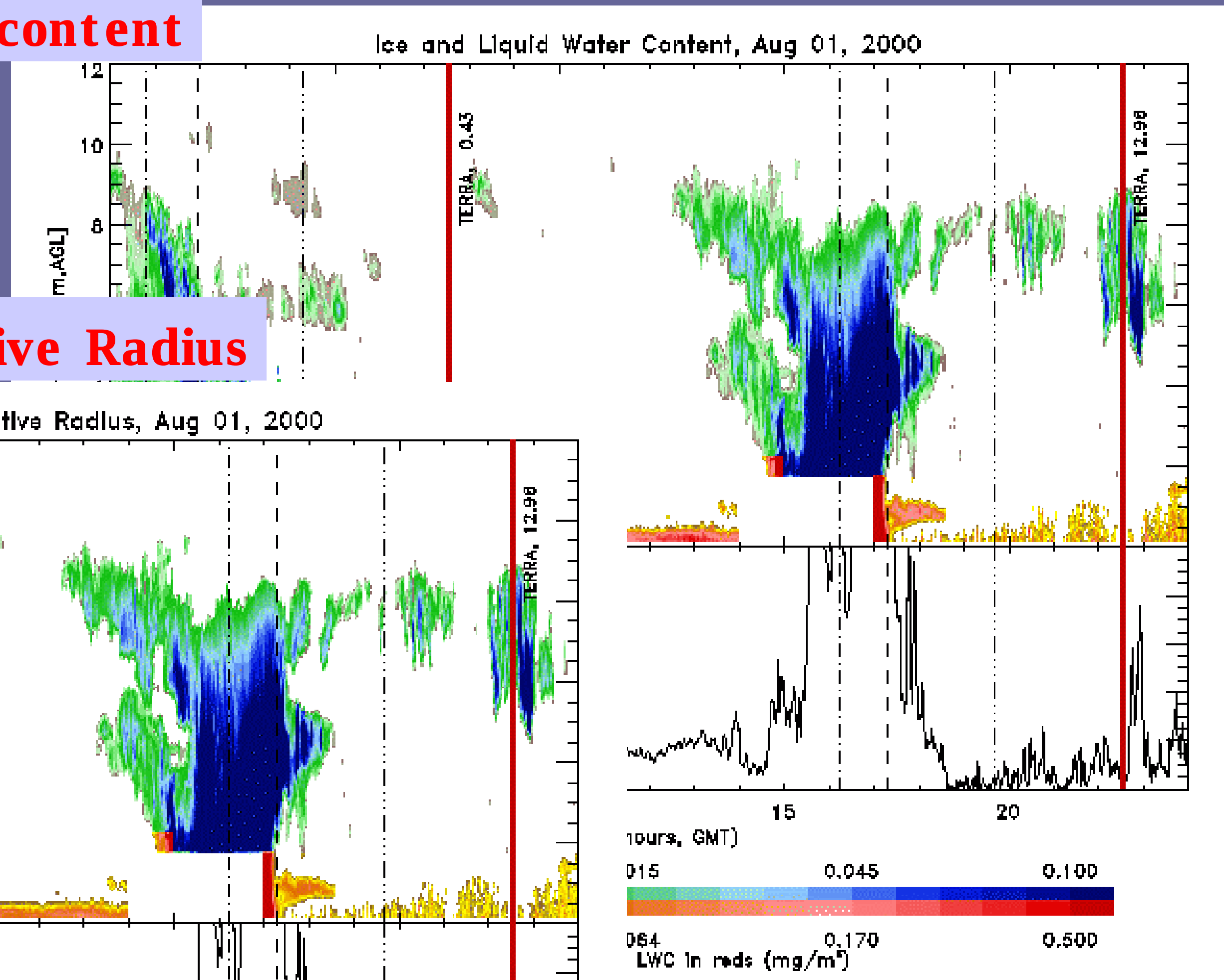
NSA, Aug 01, 2000
Reflectivity
22.89 GMT
TERRA, 0.43
TERRA, 12.98
Terra Overpasses
NOAA 11, 12
14,15 overpasses
Height [km,AGL]
Pressure [mb]
195
262
470
613
794
1001
-40 -20 0 20
Temperature [C]
MWR-LWP [g/m2]
Time [GMT]
NOAA/ETL


path 077 orbit 3314
MISR nadir reflectance
0
200
400
600
800
1000
1200
1400
0
500
1000
1500
2000

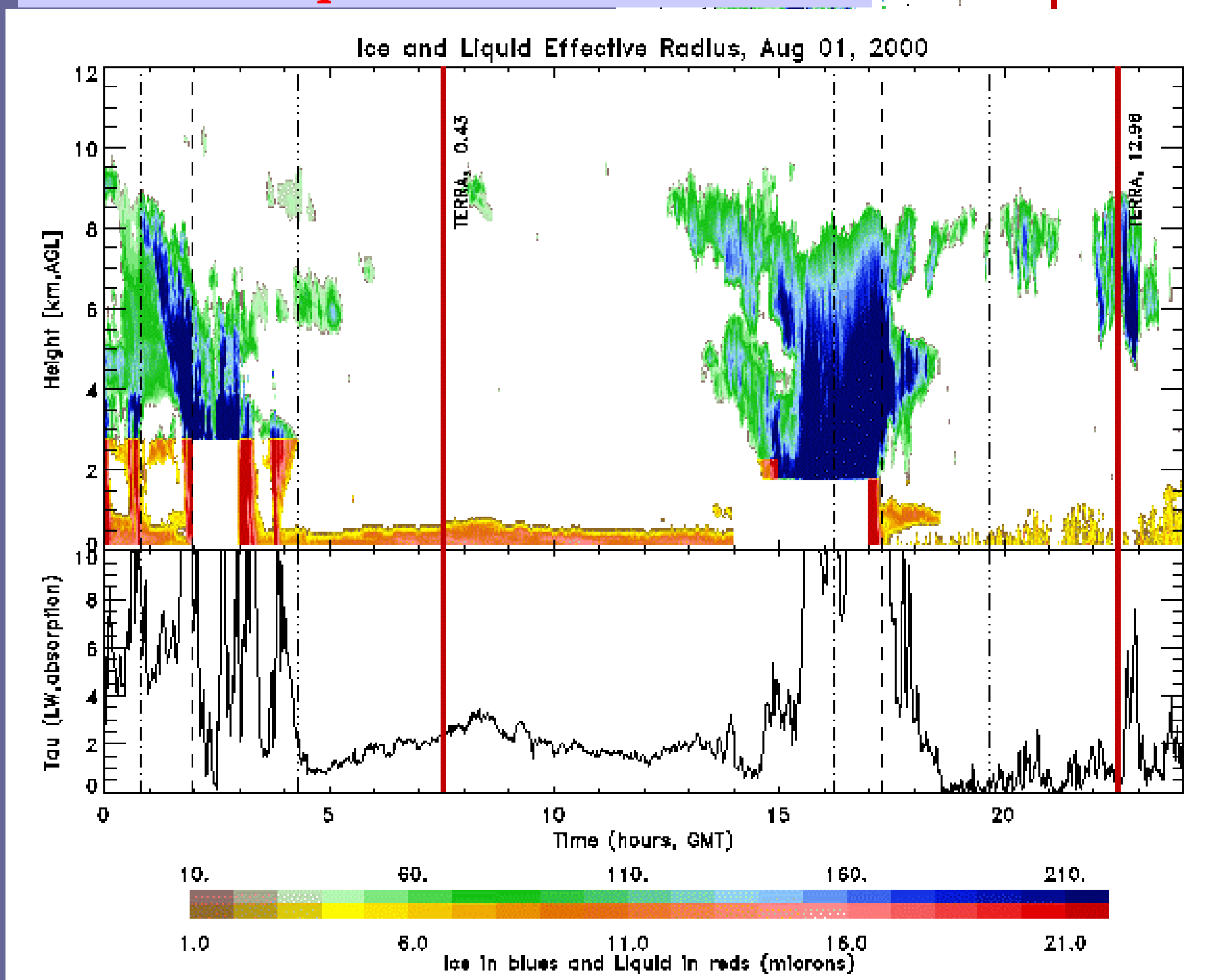


Satellite
Surface
Retrieval Type Mask and LW absorption Optical Depth, Aug 01, 2000
TERRA, 0.43
TERRA, 12.98
Time (hours, GMT)
Rain
Driz
Liq
sLiq
Mixed
sIce
Ice
Snow
Retrieval Type
3314
column
path 077 orbit 3314
0.0
2.4
4.8
7.2
9.6
12.0 km

Ice and liquid water content



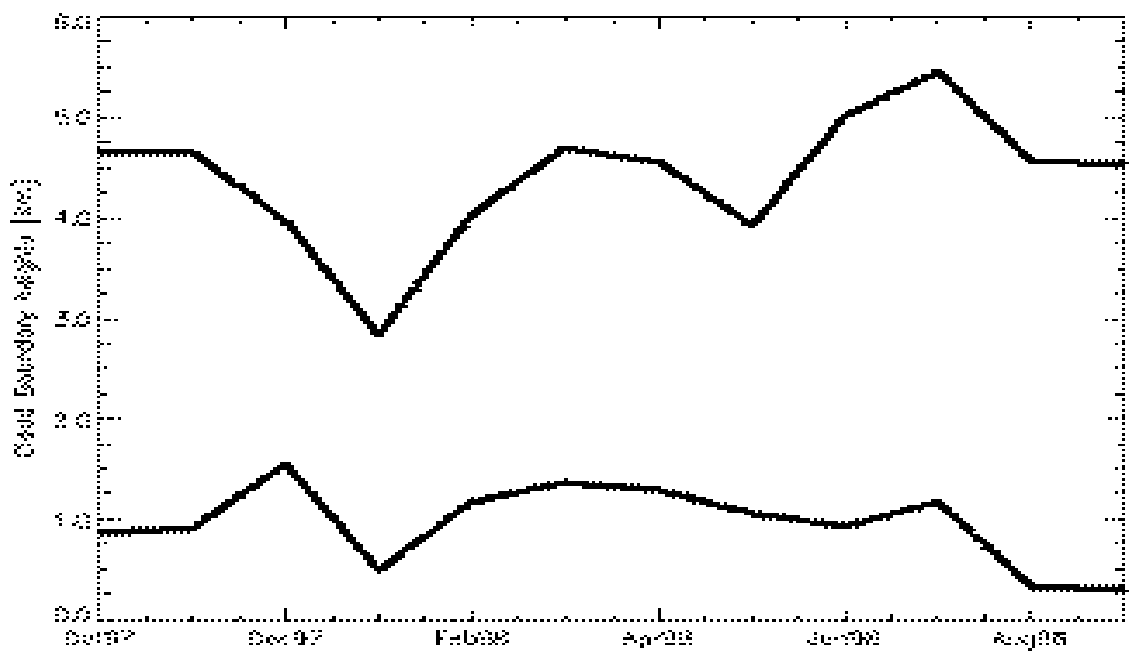
Ice and Liquid Effective Radius

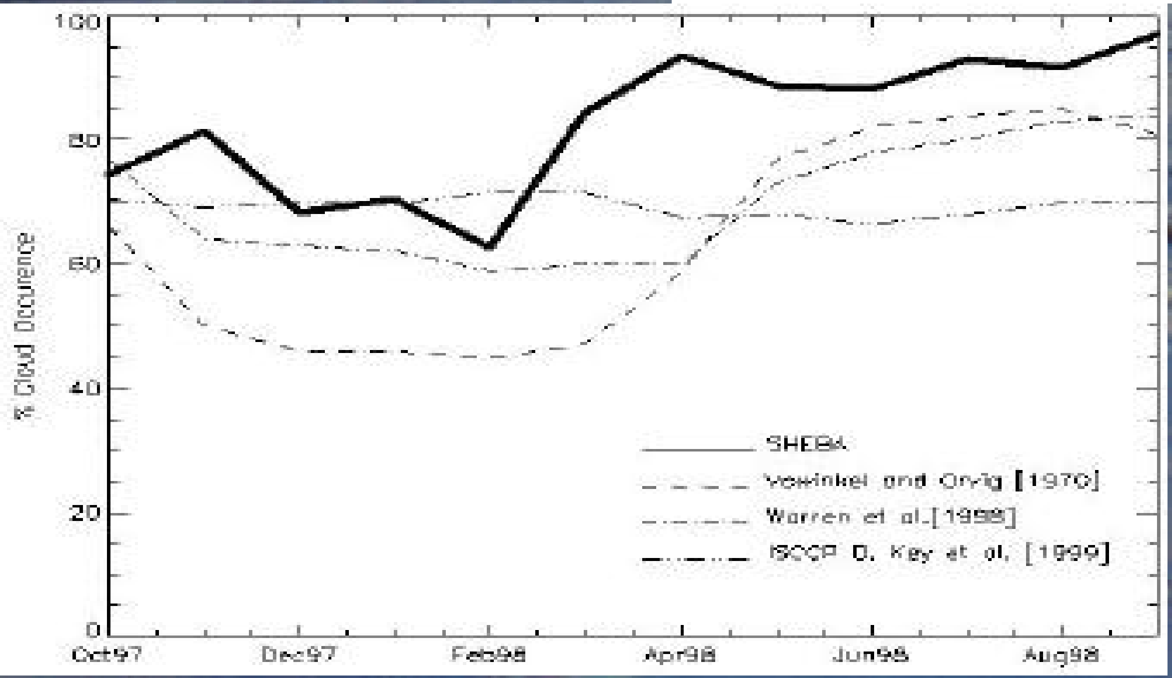


What have we learned about Arctic clouds so far ?

(SHEBA)

Physical cloud parameters

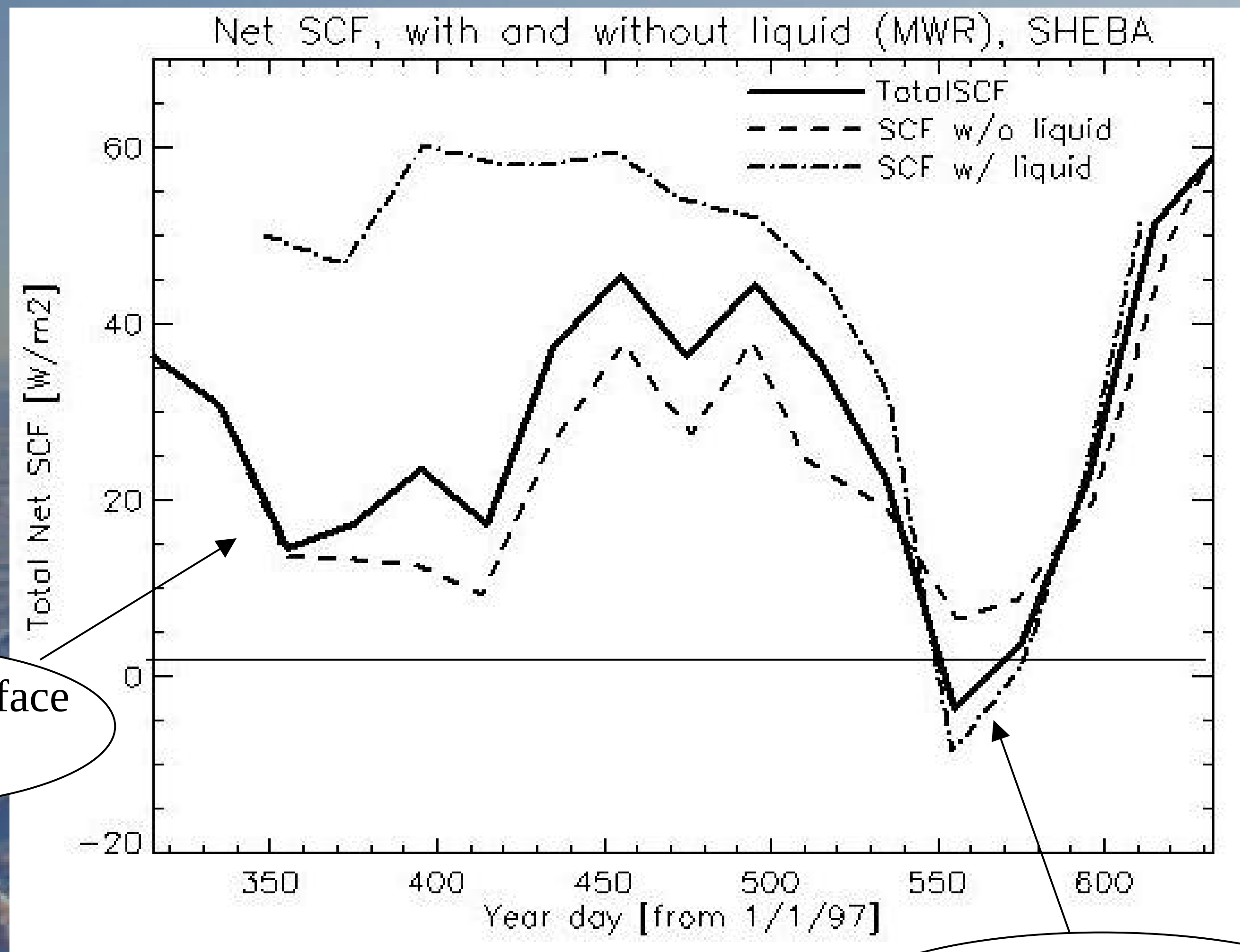




Intrieri et al., JGR, 2002

Radiative cloud properties

Surface Cloud Forcing (SCF) = NetRad(all sky) – NetRad(clear)

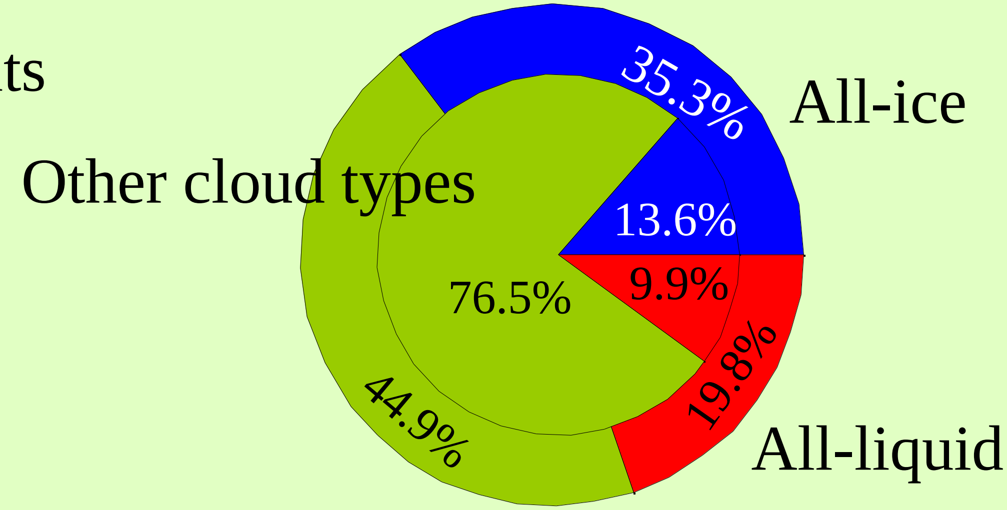


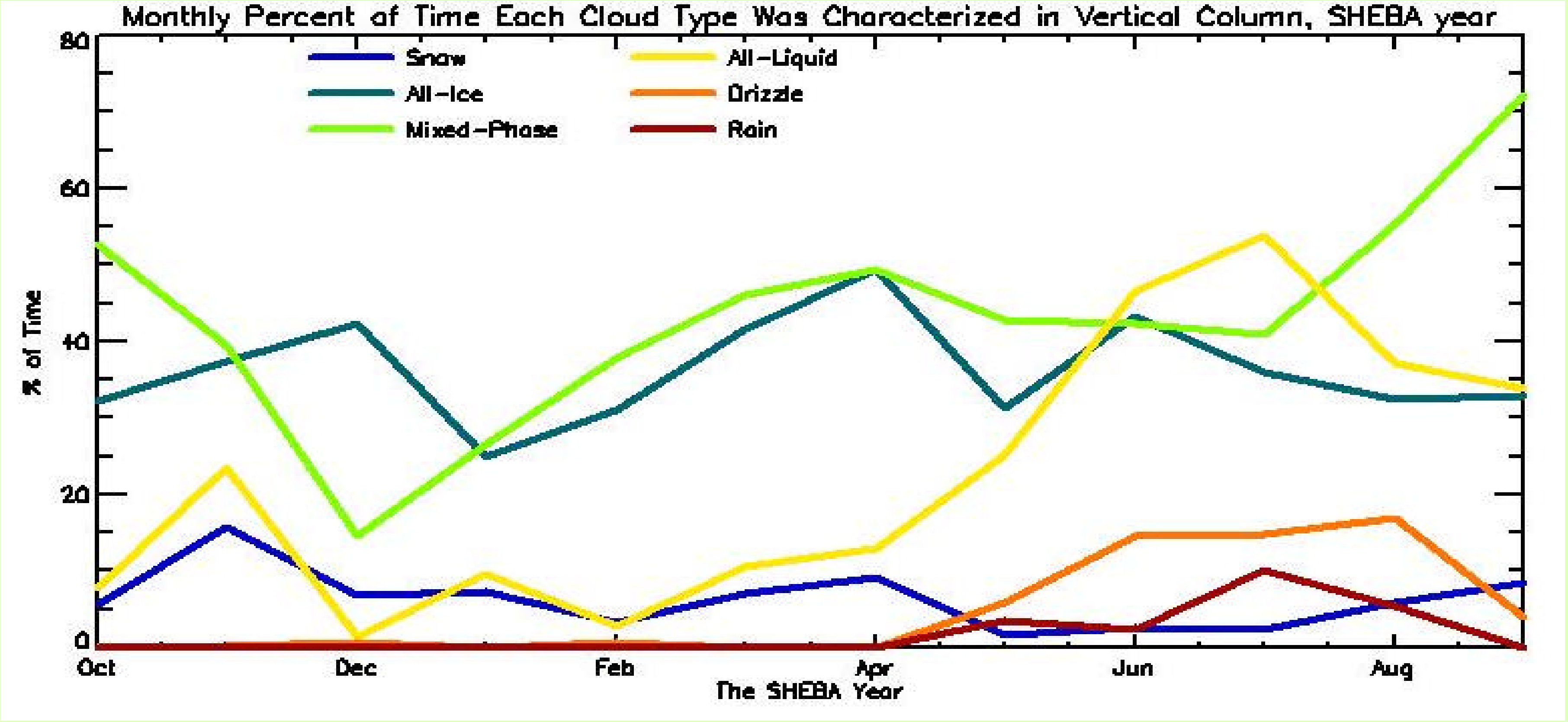
Clouds warm surface most of the year

Clouds cool surface for a few weeks in summer

Intrieri et al. 2002, Shupe et al. 2002

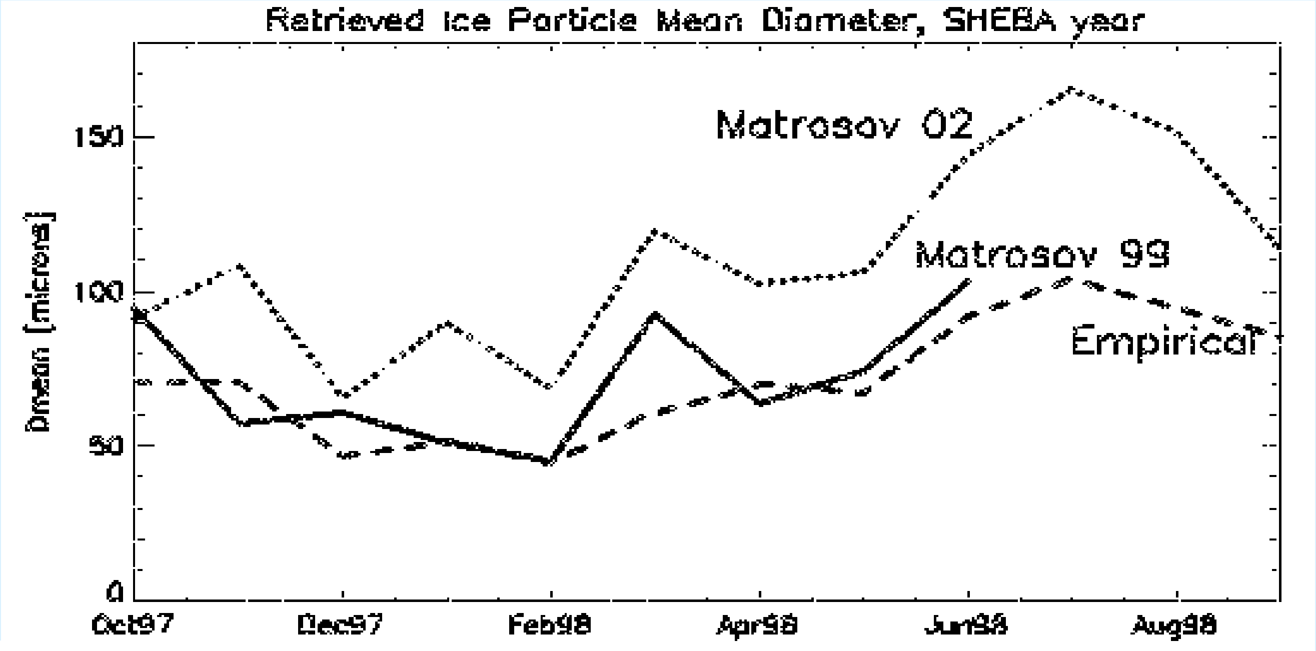
Cloud Classification Results

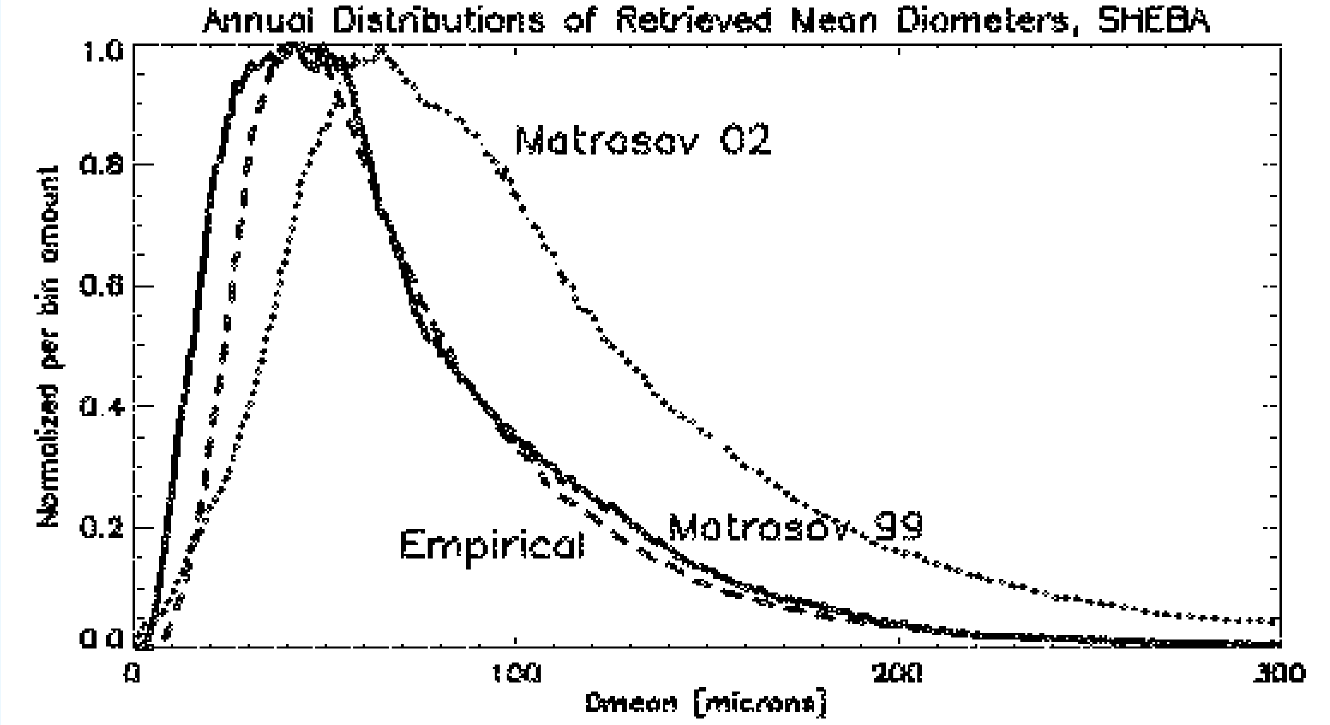




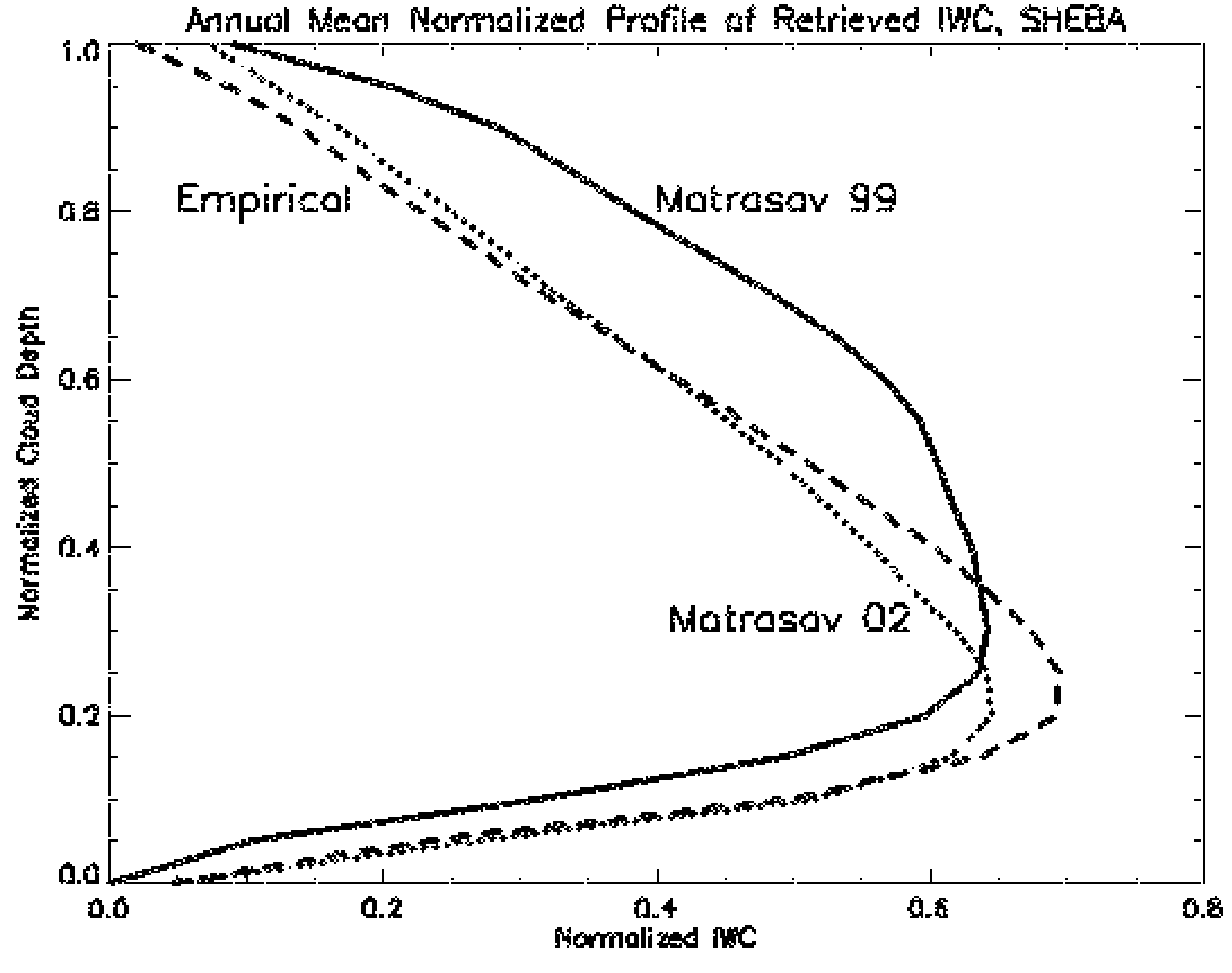
Ice Cloud Results

Reasonable averages:
•Dmean: 75-90 μm
•IWC: 7-10 mg/m^3
•IWP: 25-30 g/m^2
•Ni: 10-100 1/L

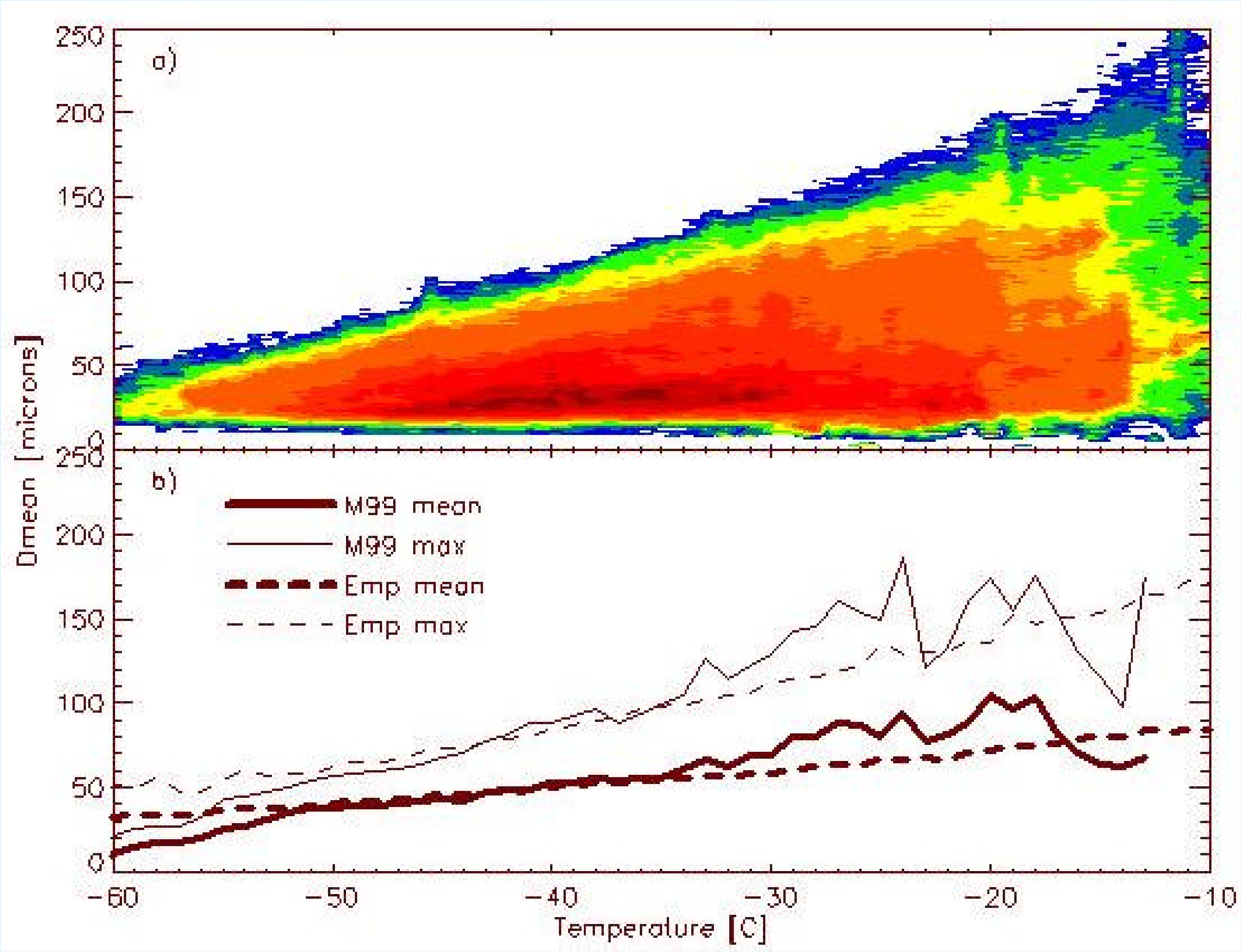




Ice Cloud Results

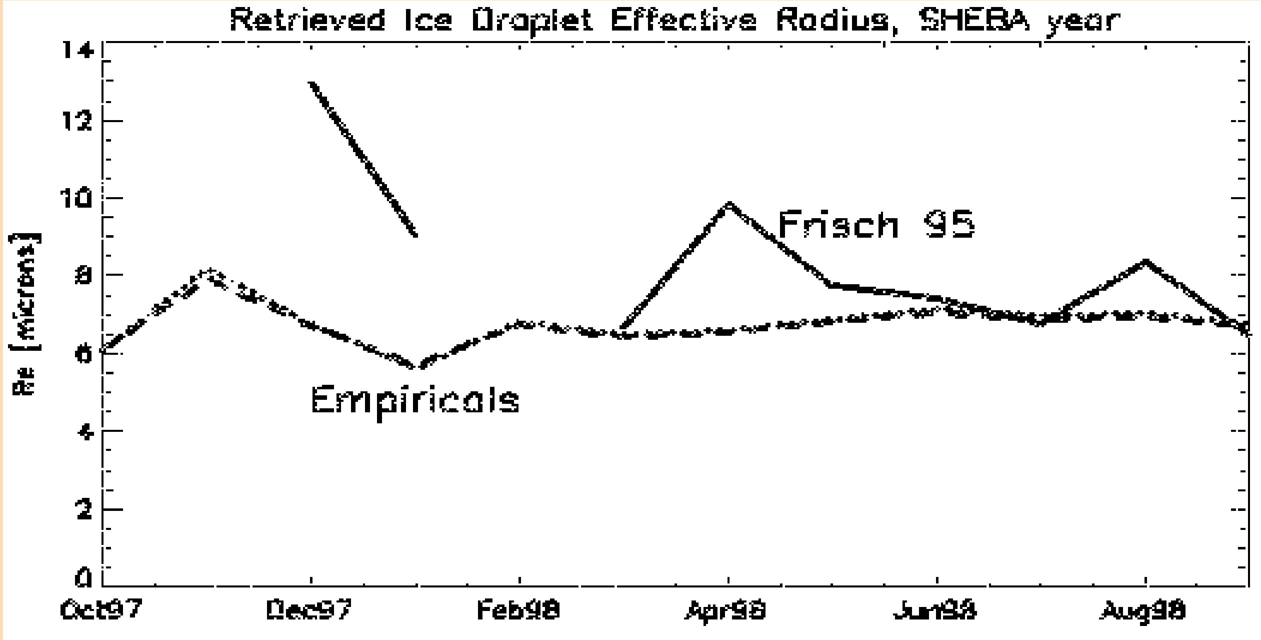


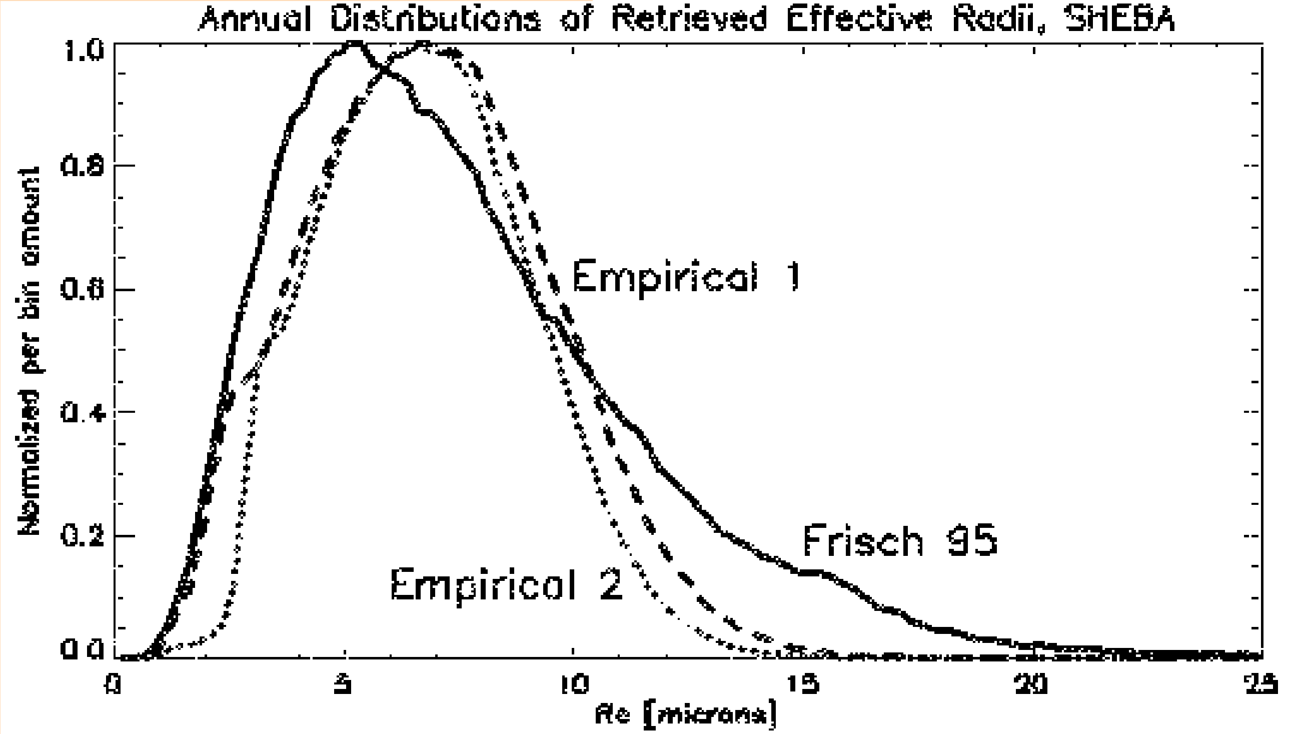
Ice Cloud Results

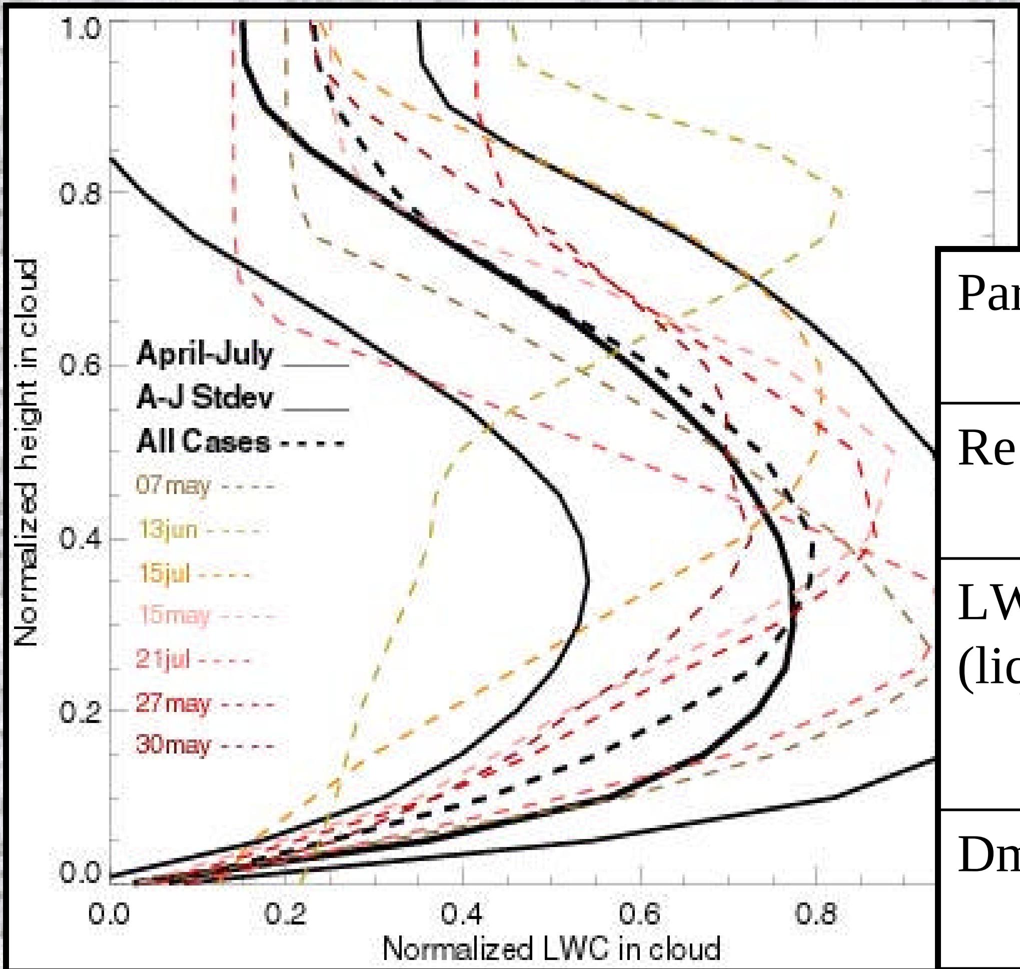


Liquid Cloud Results

Reasonable averages:
- •Re: 7.3 µm
- •LWC: 0.085 g/m^3
- •LWP: 30-40 g/m^2
- •Nl: 50 1/cm^3



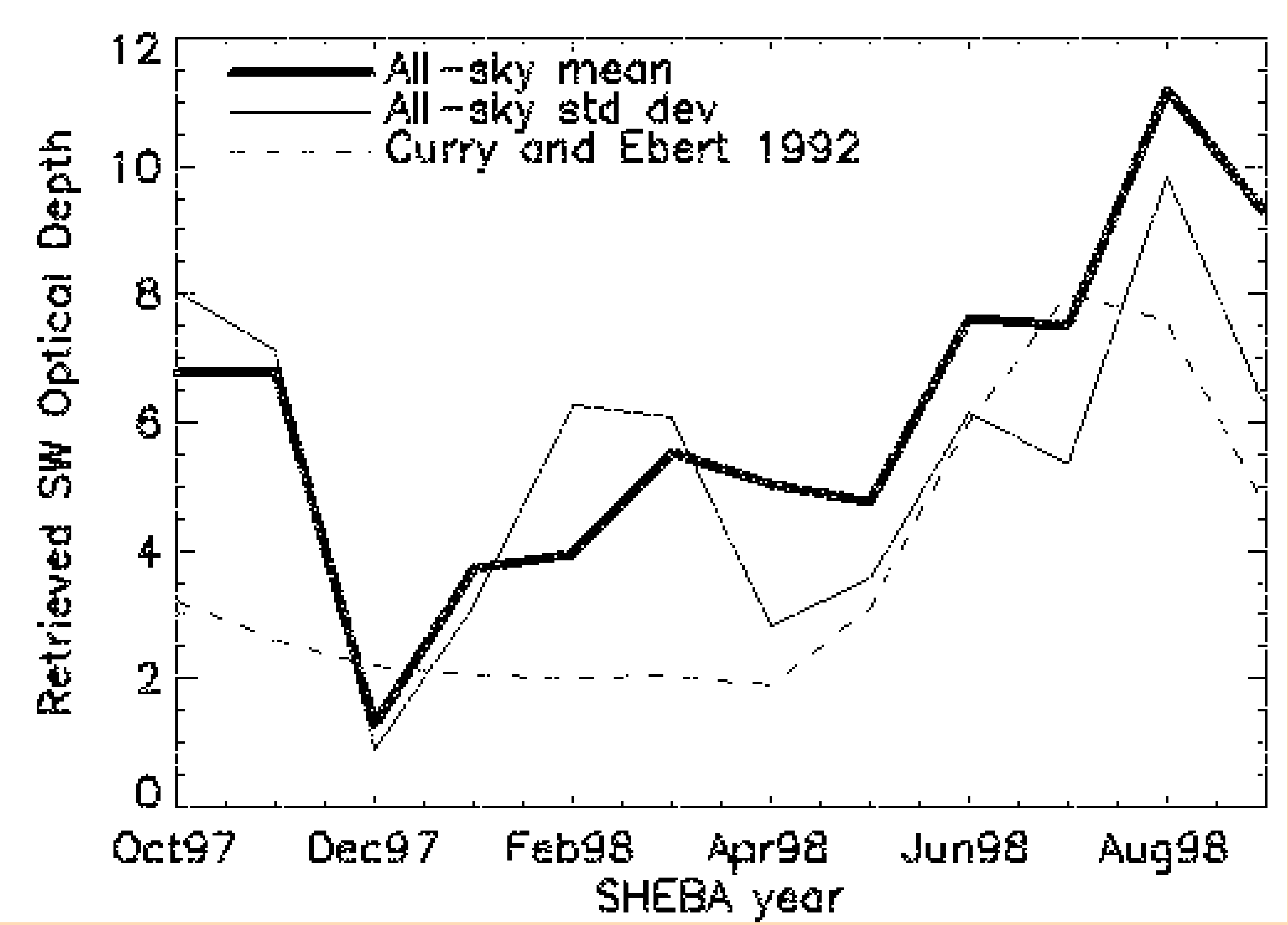




Parameter	Range	Mean	Median
Re (liquid)	2-33 um	7.7 um	6.um
LWC (liquid)	0-0.6 g/m3	0.073 g/m3	0.04 g/m3
Dmean	8-230 um	55.1 um	4.6 um
IWC (Ice)	0-0.1 g/m3	0.0048 g/m3	0.001 g/m3

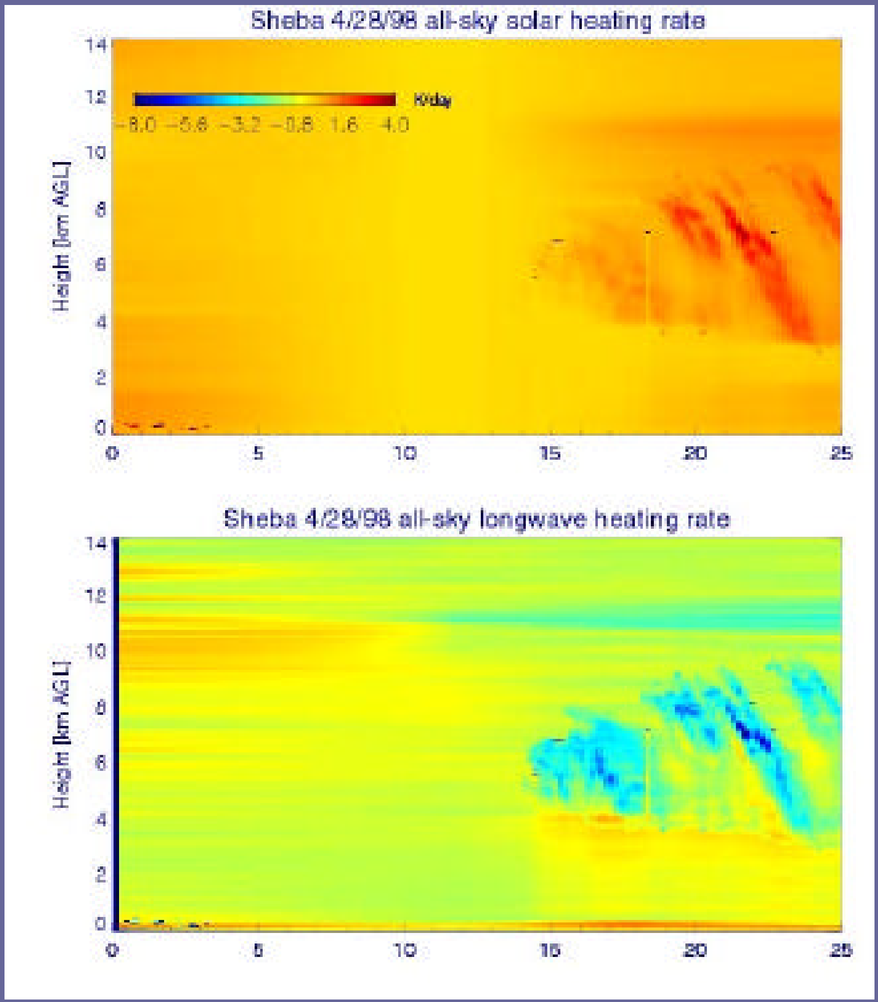
Shupe, M.D., T. Uttal, S.Y. Matrosov, A.S. Frisch, 2000: Cloud water contents and hydrometeor sizes during the FIRE-Arctic Clouds Experiment. *J. Geophys. Res.*

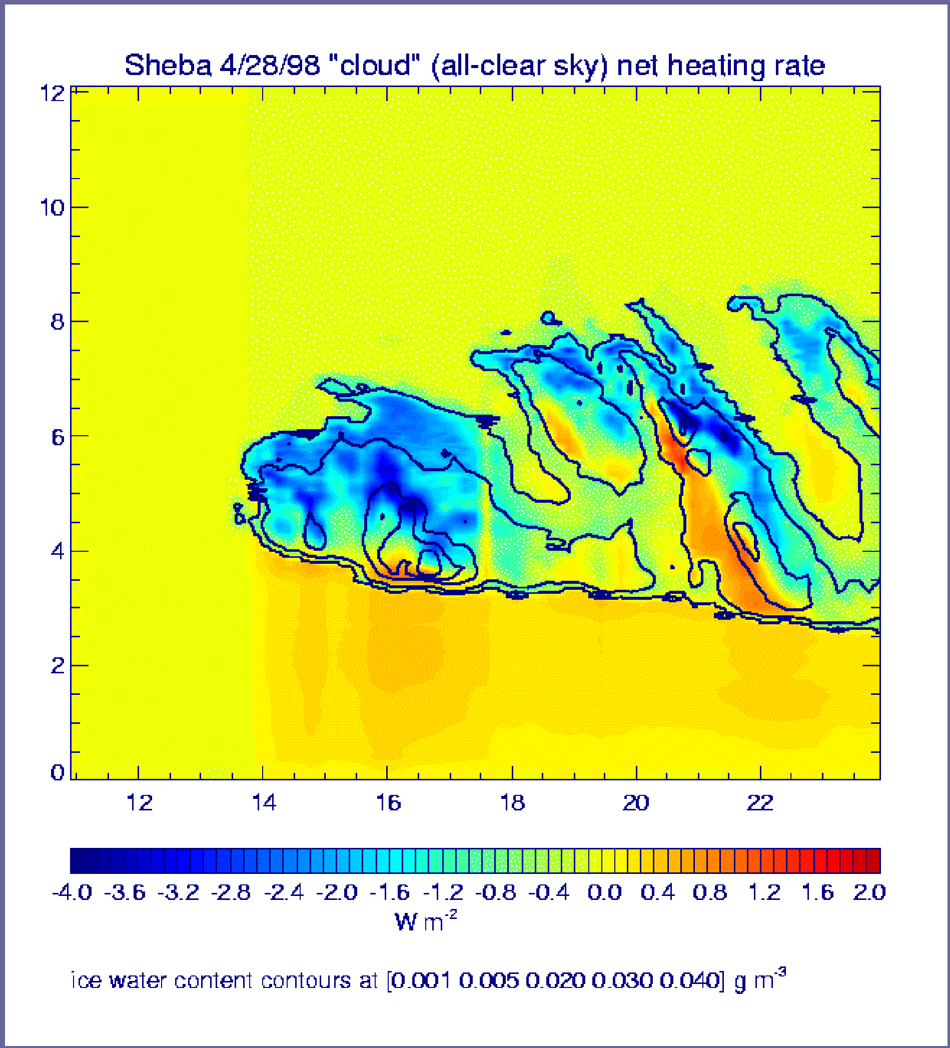
Optical Depth Results



Some current work -

Radiative Transfer Modeling using explicit microphysics

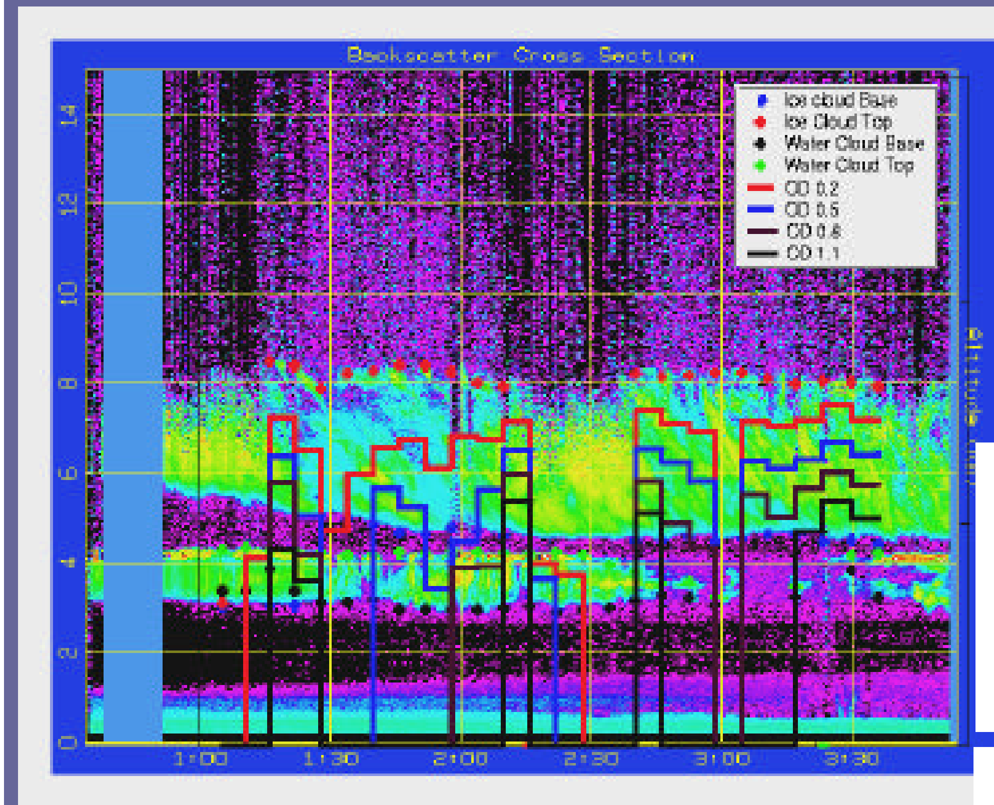




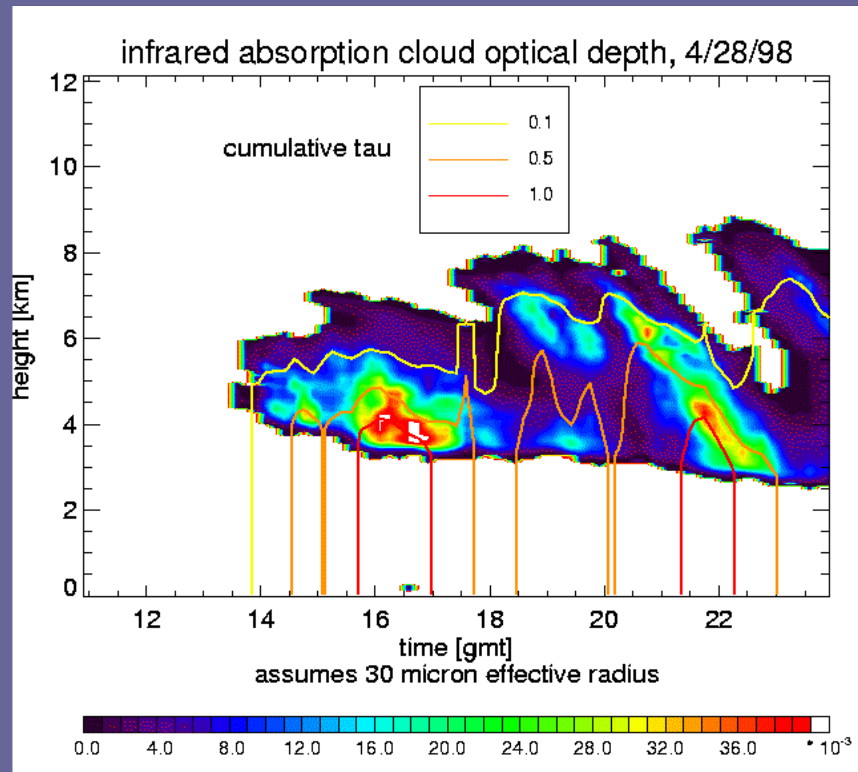
Ed Eloranta,

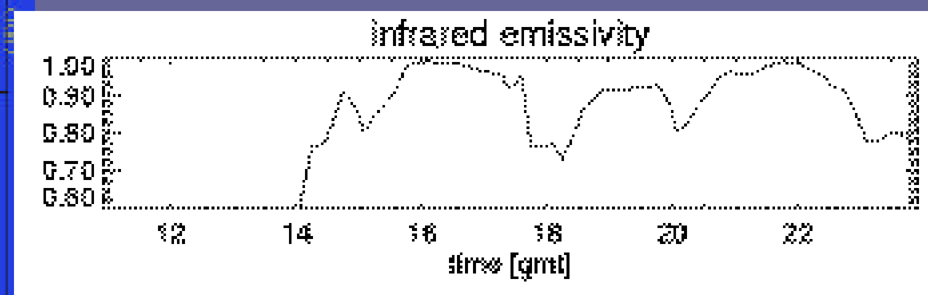
High Spectral Resolution Lidar

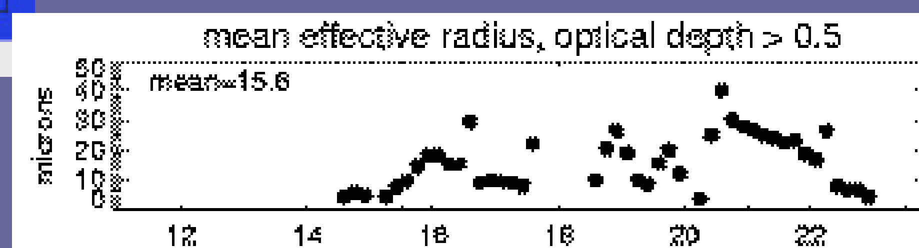
Lidar backscatter cross-section w/ cumulative optical depth from top down to better correlate w/ satellite

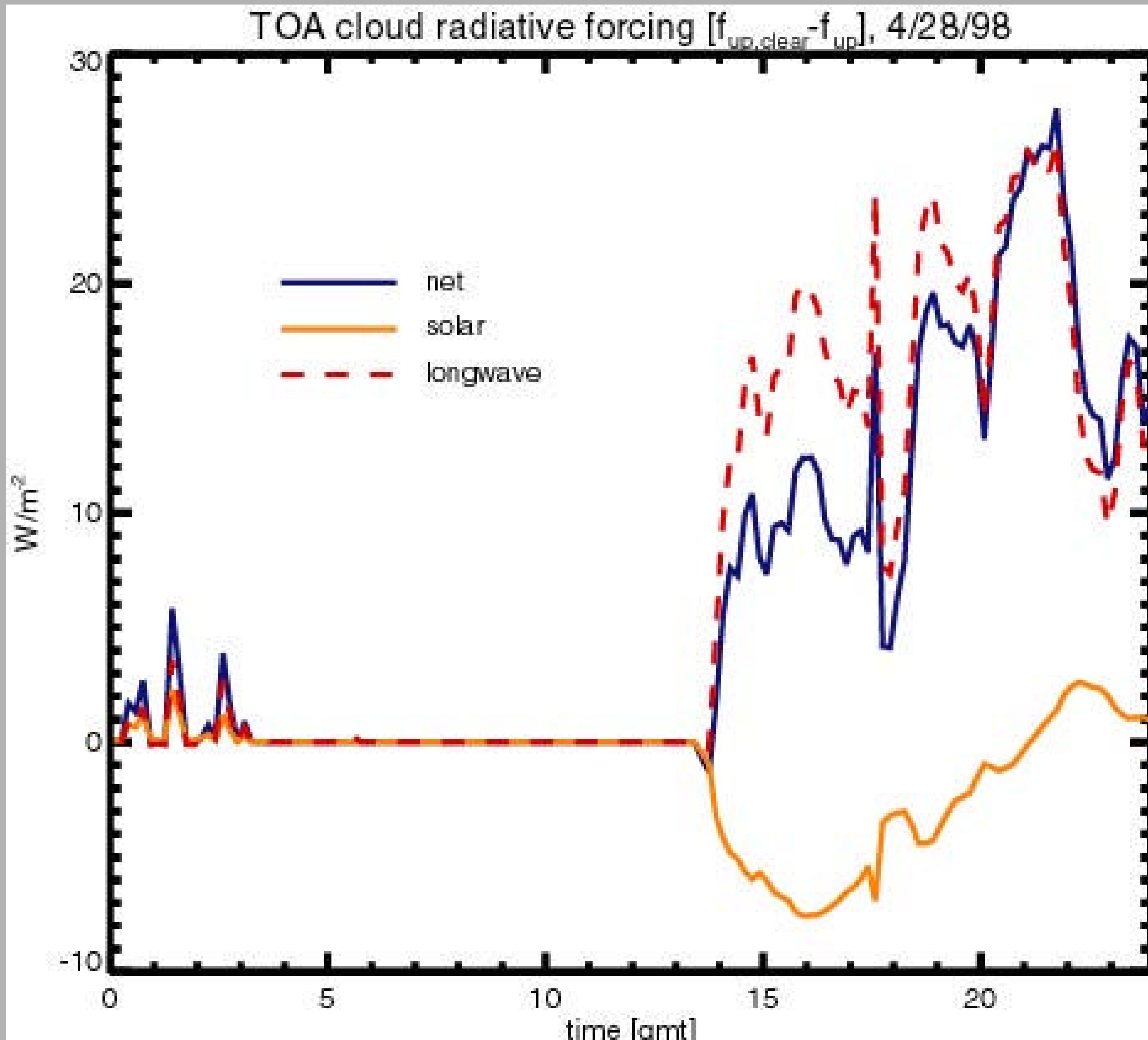


Radar proxy








TOA cloud radiative forcing [f_up,clear-f_up], 4/28/98
net
solar
longwave
W/m^2
30
20
10
0
-10
0
5
10
15
20
time [gmt]

To Do List

Get NetCDF files on website

Compare to U of Utah

Expand to SGP and TWP

Validate with Aircraft

Develop More Cloud Property Statistics

Radiative Transfer Modeling Using explicit microphysics

Compare to Satellites (case studies and statistical)