Aerosol-Cloud-Precipitation and Atmospheric Circulation in the Arctic as revieled by CloudSat-CALIPSO during Winter

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CloudSat – CALIPSO – AURA Teams and PEARL / OPAL at Eureka, NU

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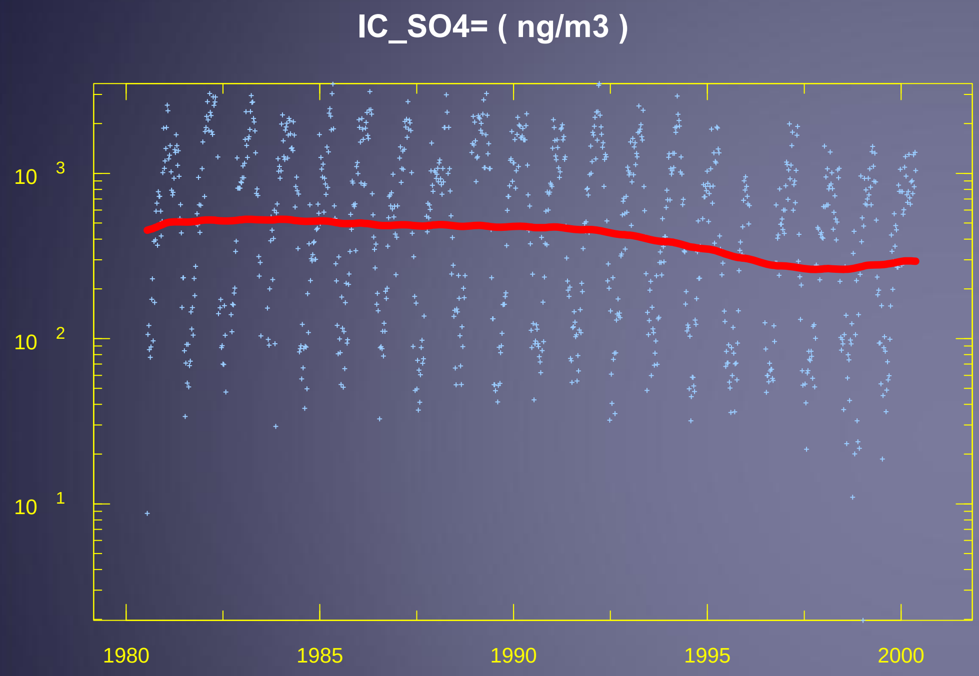
Madison. WI
JULY 28-31, 2009

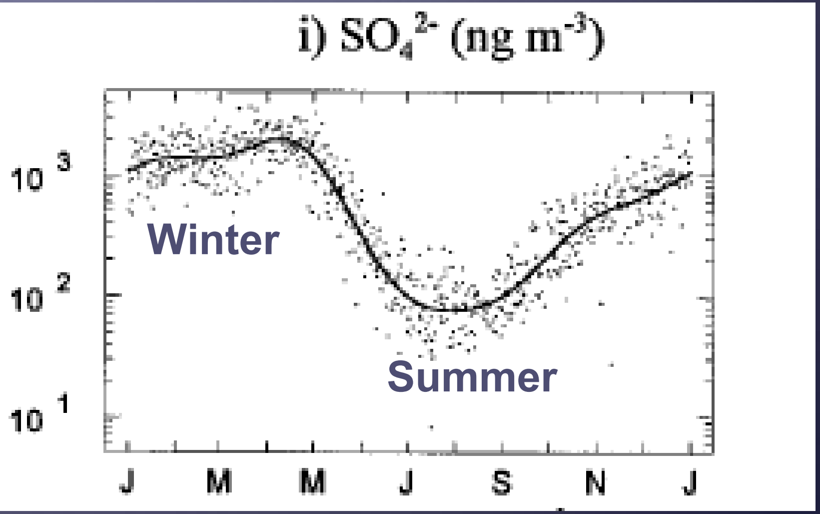
Partners

Funding Agencies

Sulfate Trend and Seasonal Variation

Alert, NU



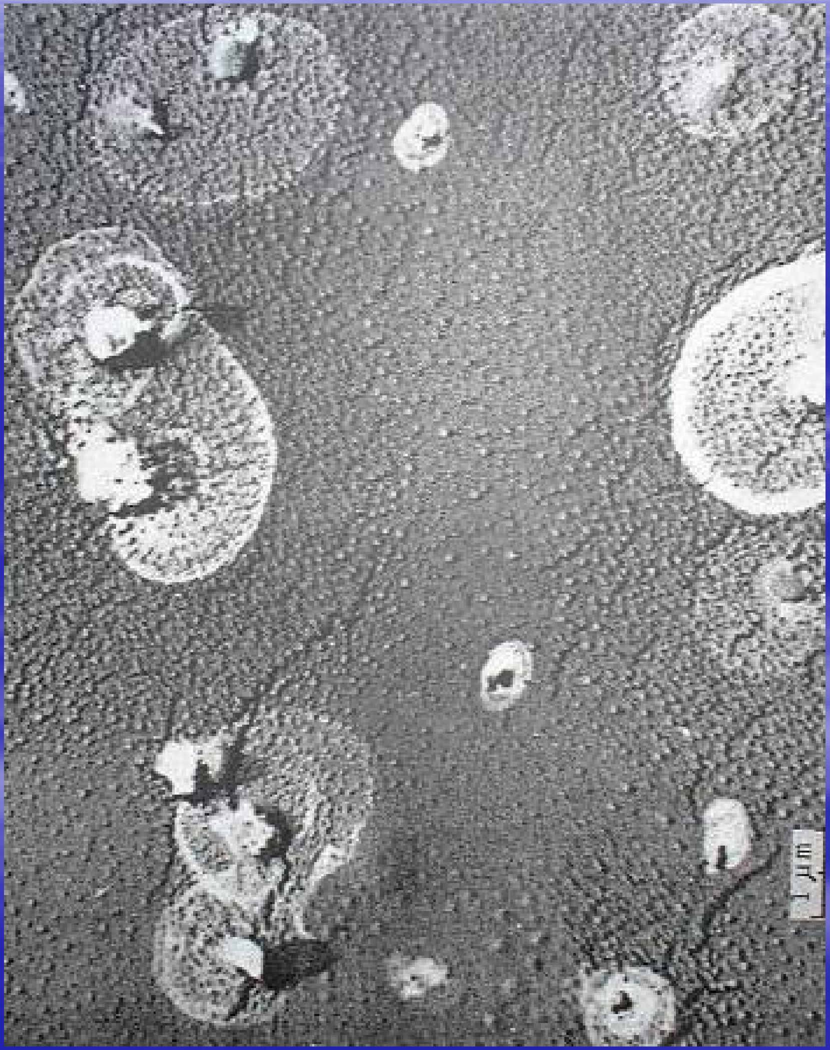


Ref. Gong, 2005

Evidences of aerosol alterations in the Arctic

- Bigg (1980) observed sulfuric acid coating on most other aerosol particles during winter
- Borys (1989) observed reduced ice nuclei activity by 10 to 1000 fold in crystal counts during anthropogenic Arctic haze event.

→ Blanchet-Girard (1994) Dehydration-Greenhouse Feedback (DGF)



Reaction on calcium fluoride

Ref.: Bigg, 1980

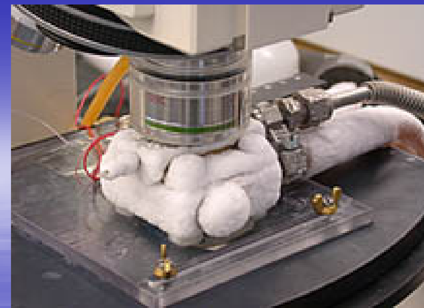
In Laboratory

Allan Bertram UBC

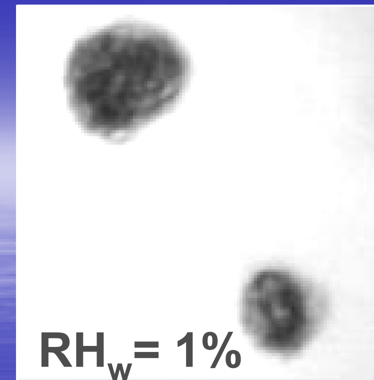
Acid Coated IFN

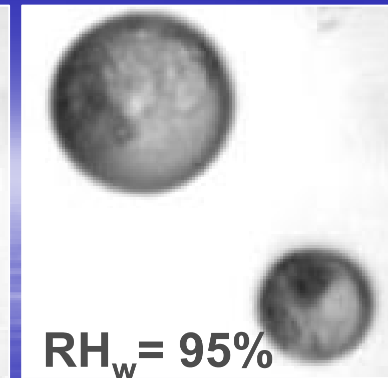
Ice Forming Nuclei

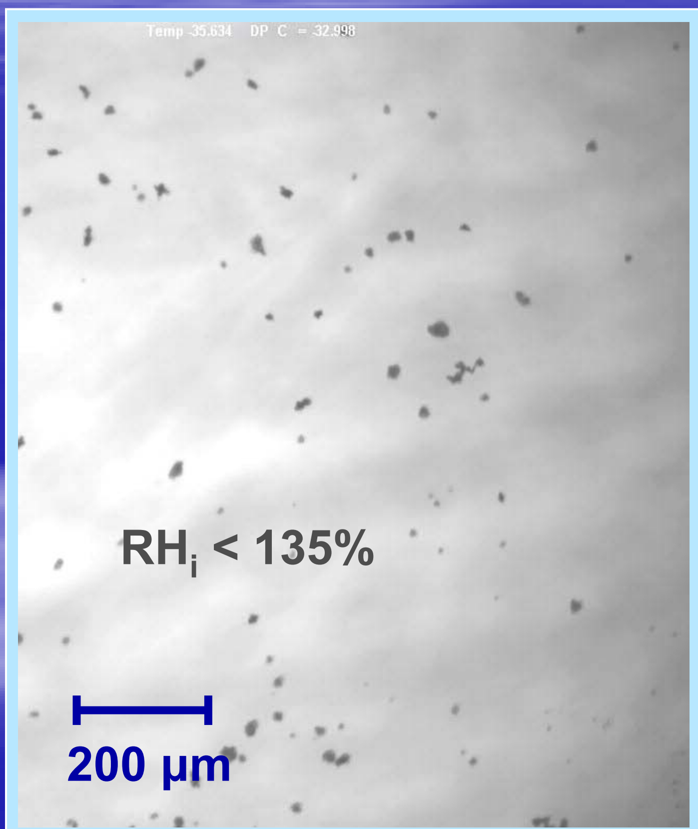
Sulfate Induced Freezing inhibtion (SIFI)



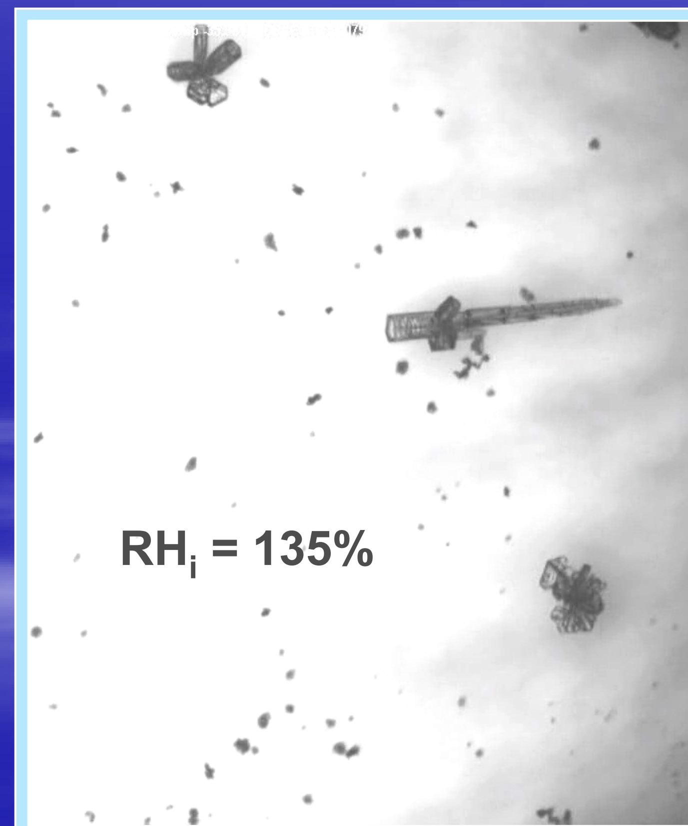
Flow cell coupled to microscope







Particles before ice nucleation



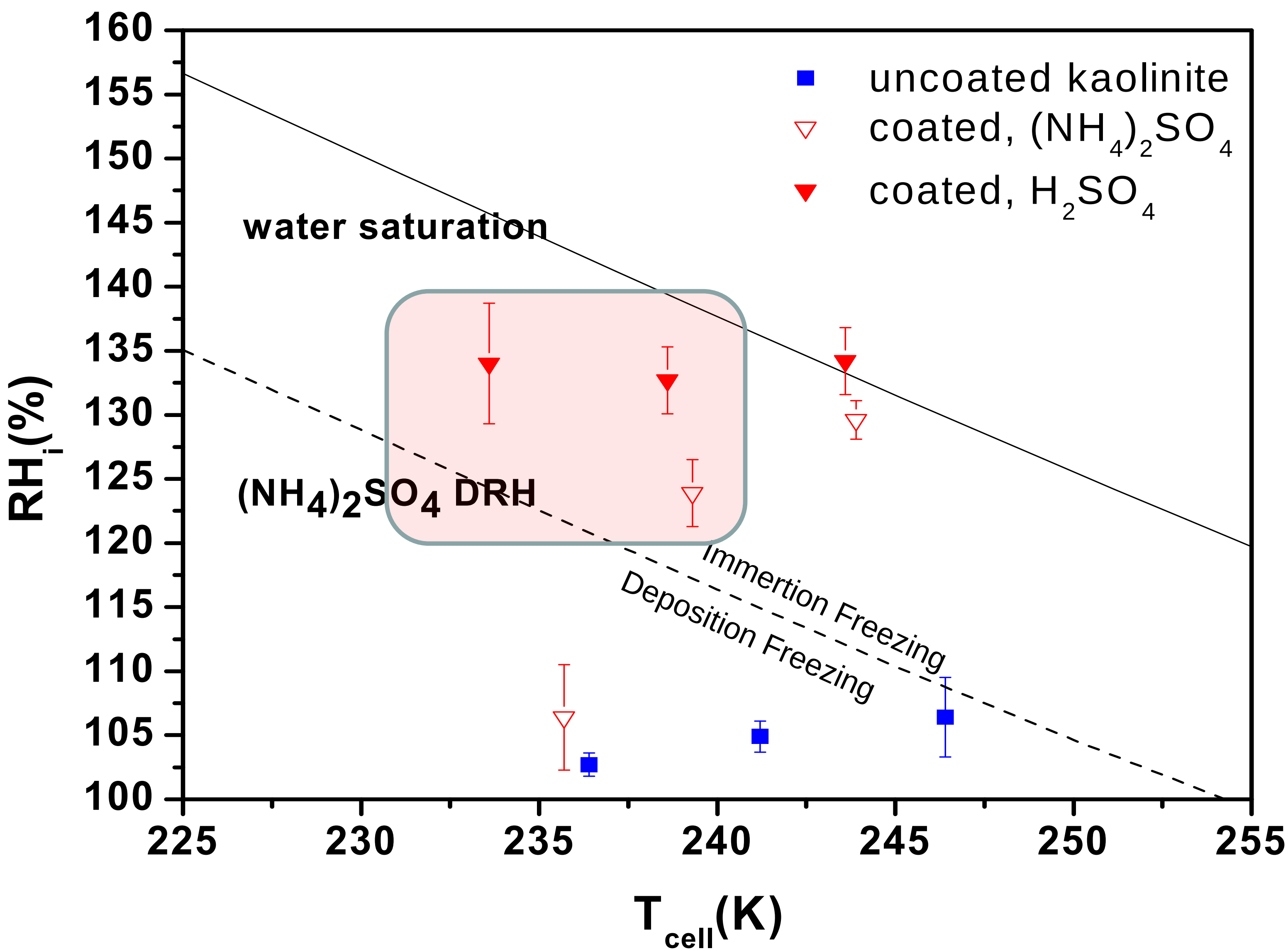
Particles after ice nucleation

(Ref.: Allan Bertram, UBC)

In Laboratory

Allan Bertram, UBC

Acid Coated IFN

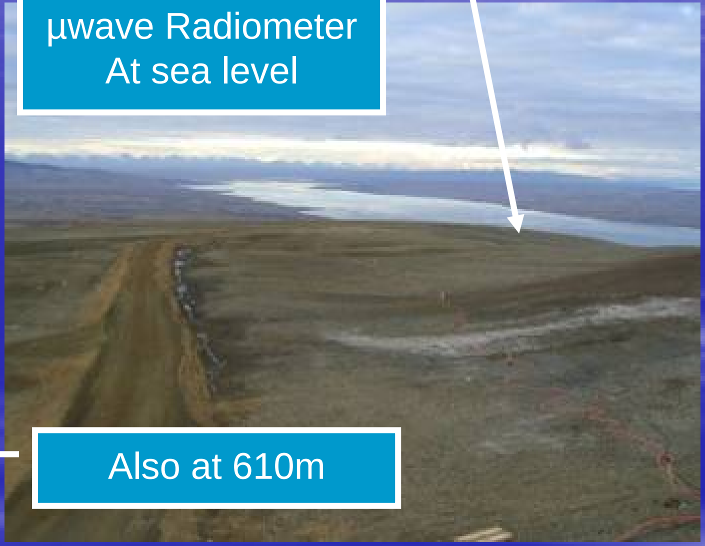


PEARLab (CANDAC) at Eureka on Ellesmere Island in the Canadian Arctic

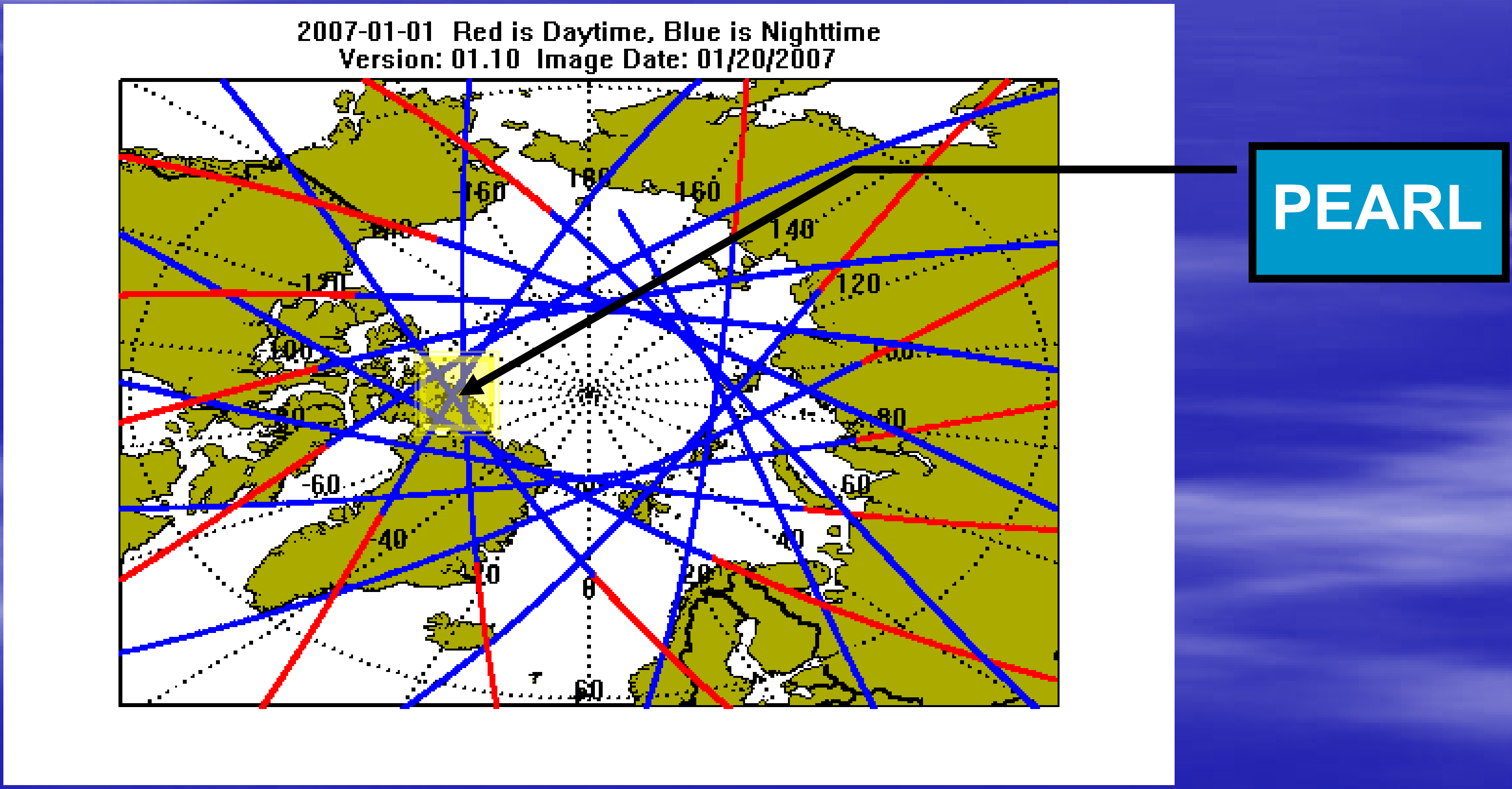
(80 deg N, 86 deg W, 610 meters)

Methodology:

Compare Model Simulations to ground site measurements from Eureka, Alert, Spitsbergen, and Barrow and satellite data…

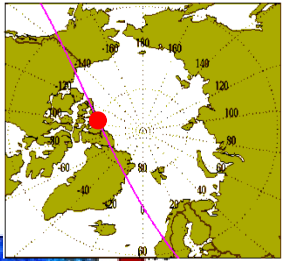


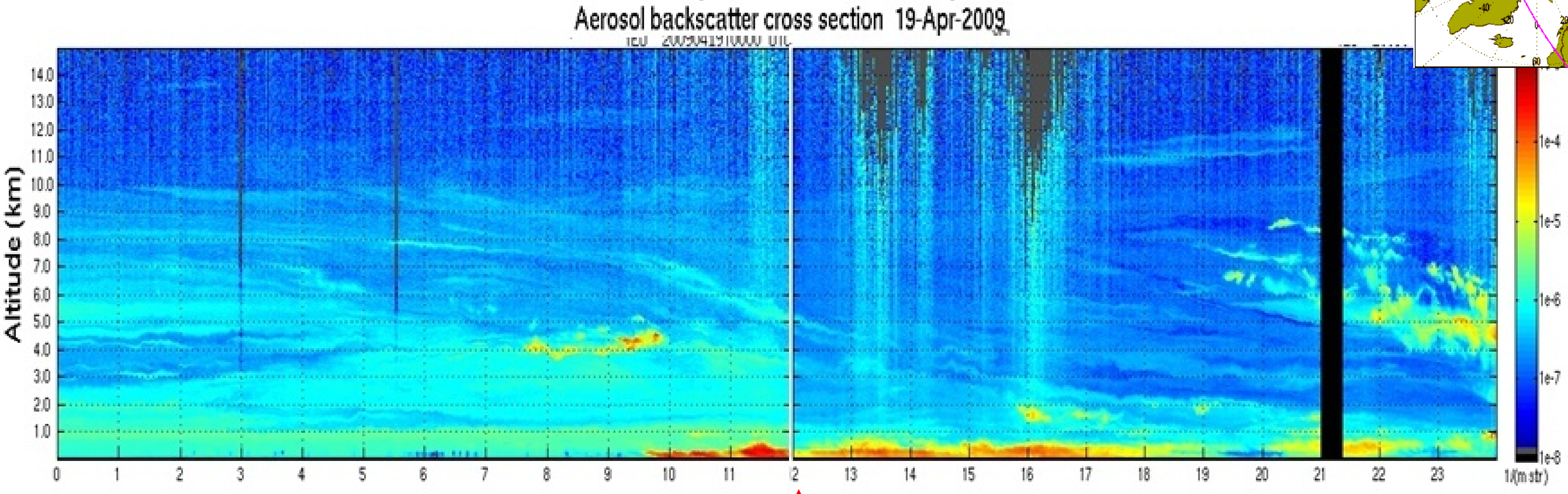
A-Train and PEARL Observations

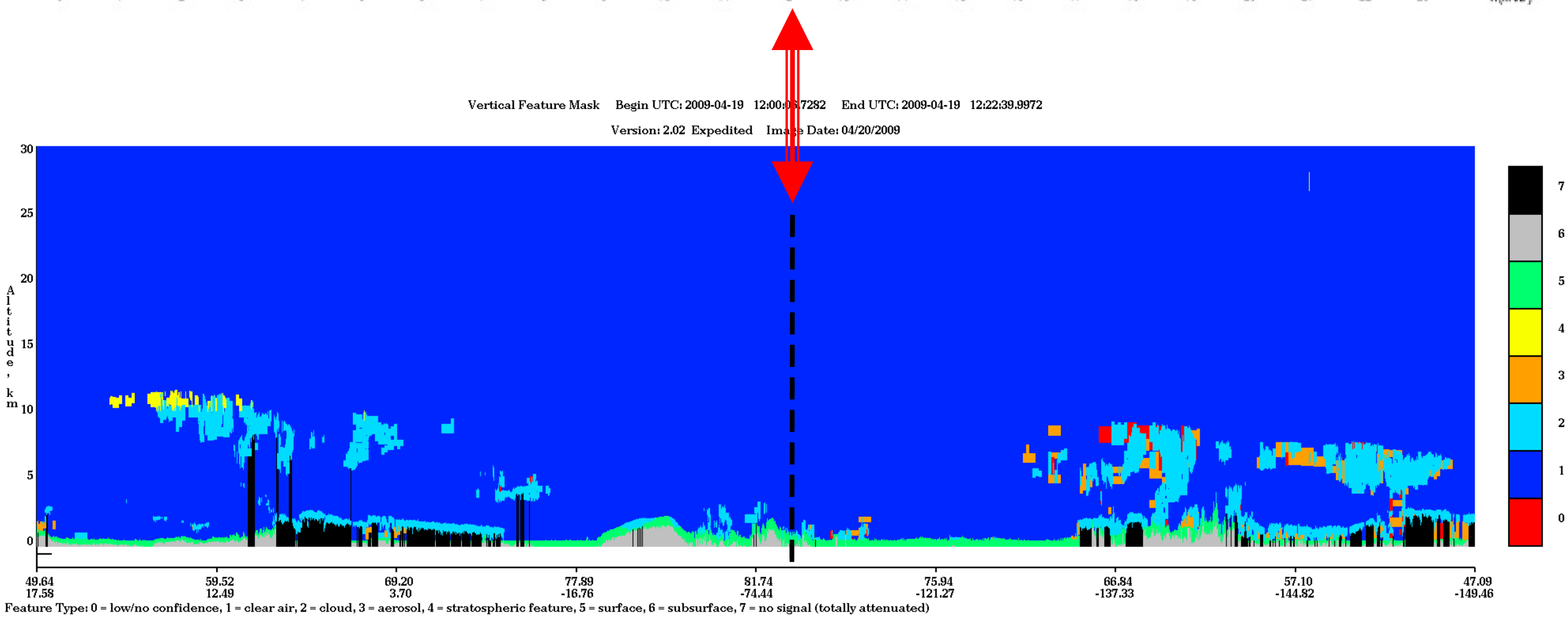


Comparison PEARL – CALIPSO

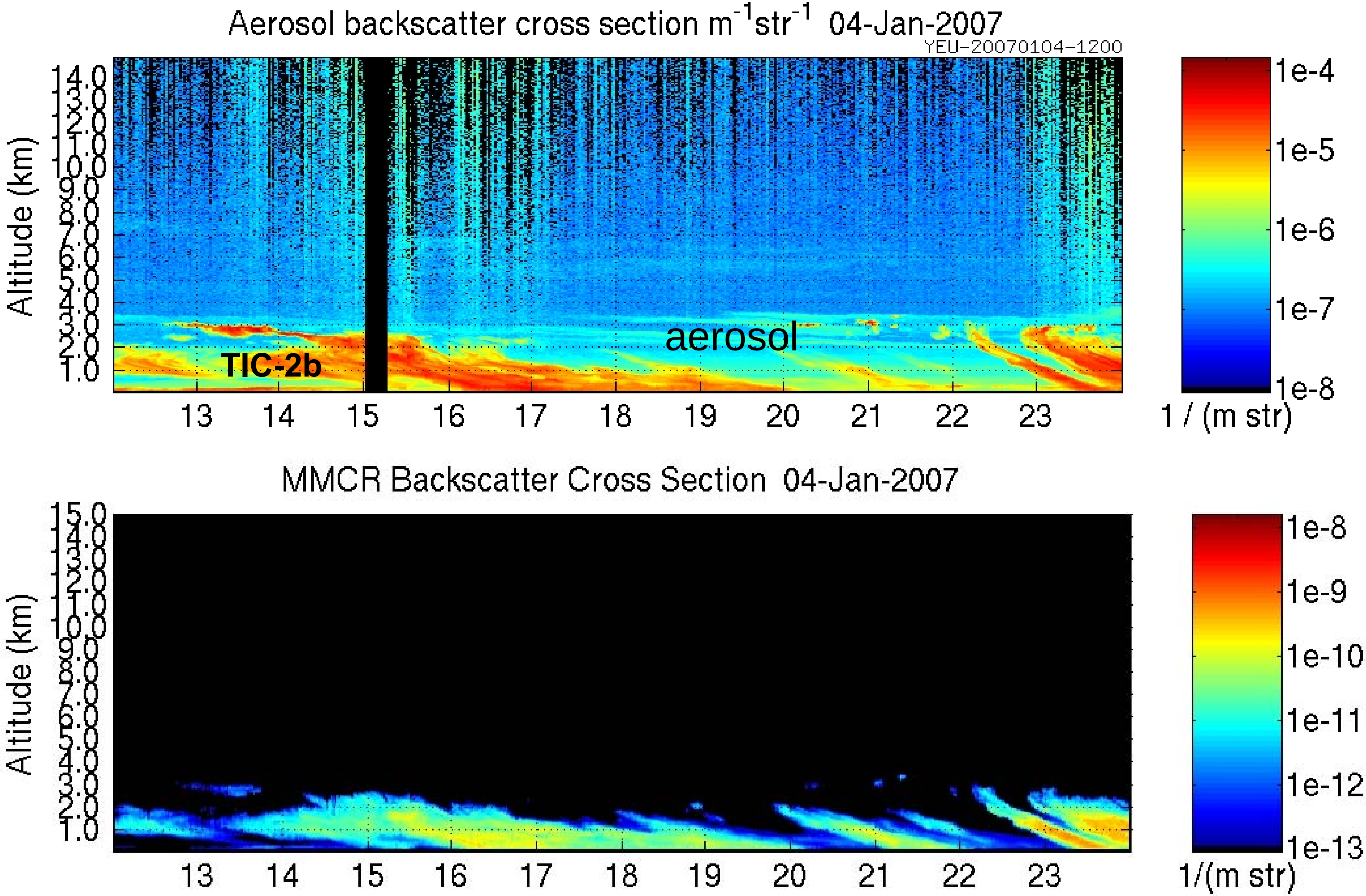
Ed Eloranta (U. Wisconsin)







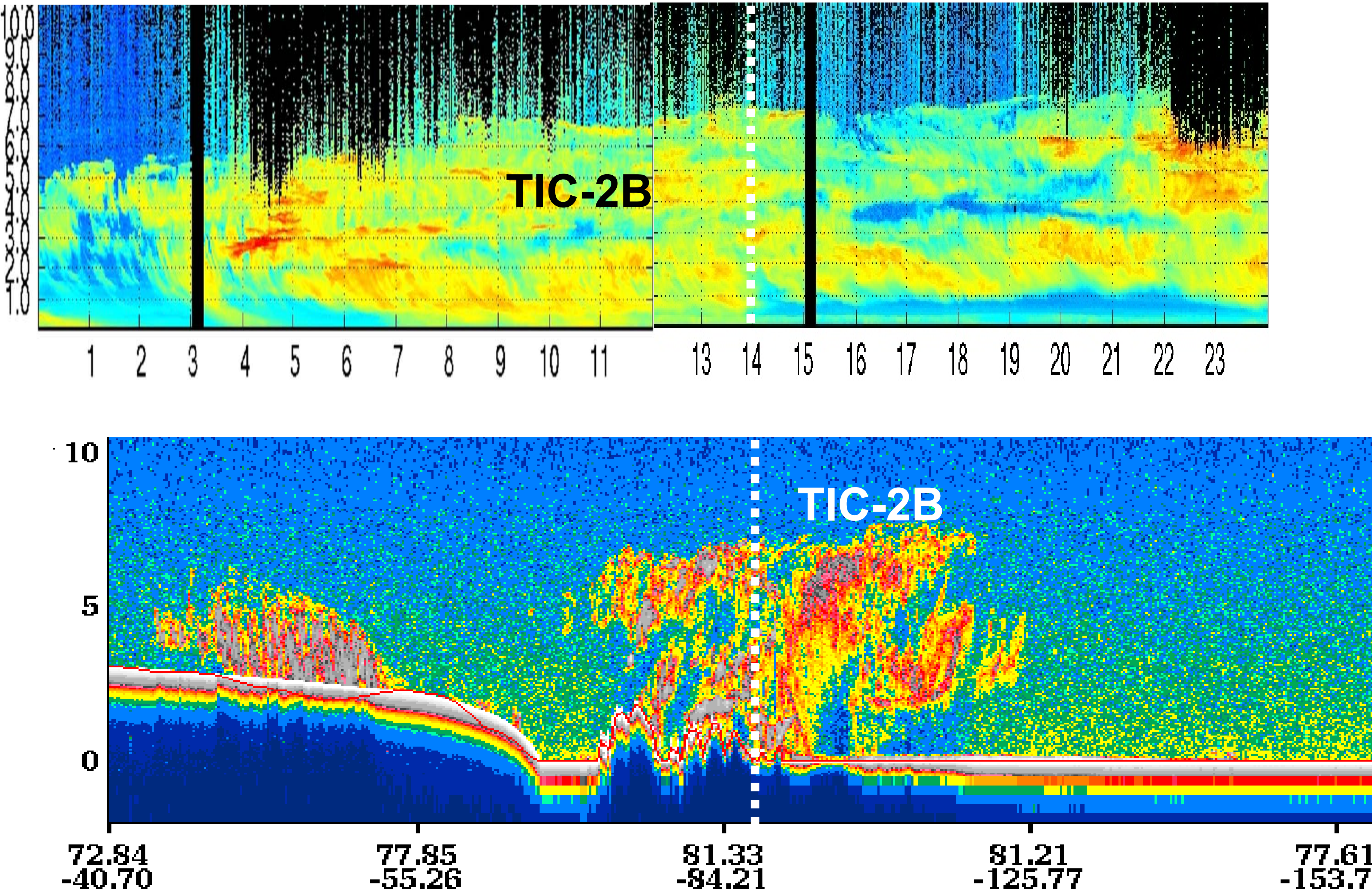
Example of TIC-2b form Aerosol – Clouds from Lidar – Radar Seen at OPAL (Ed Eloranta)

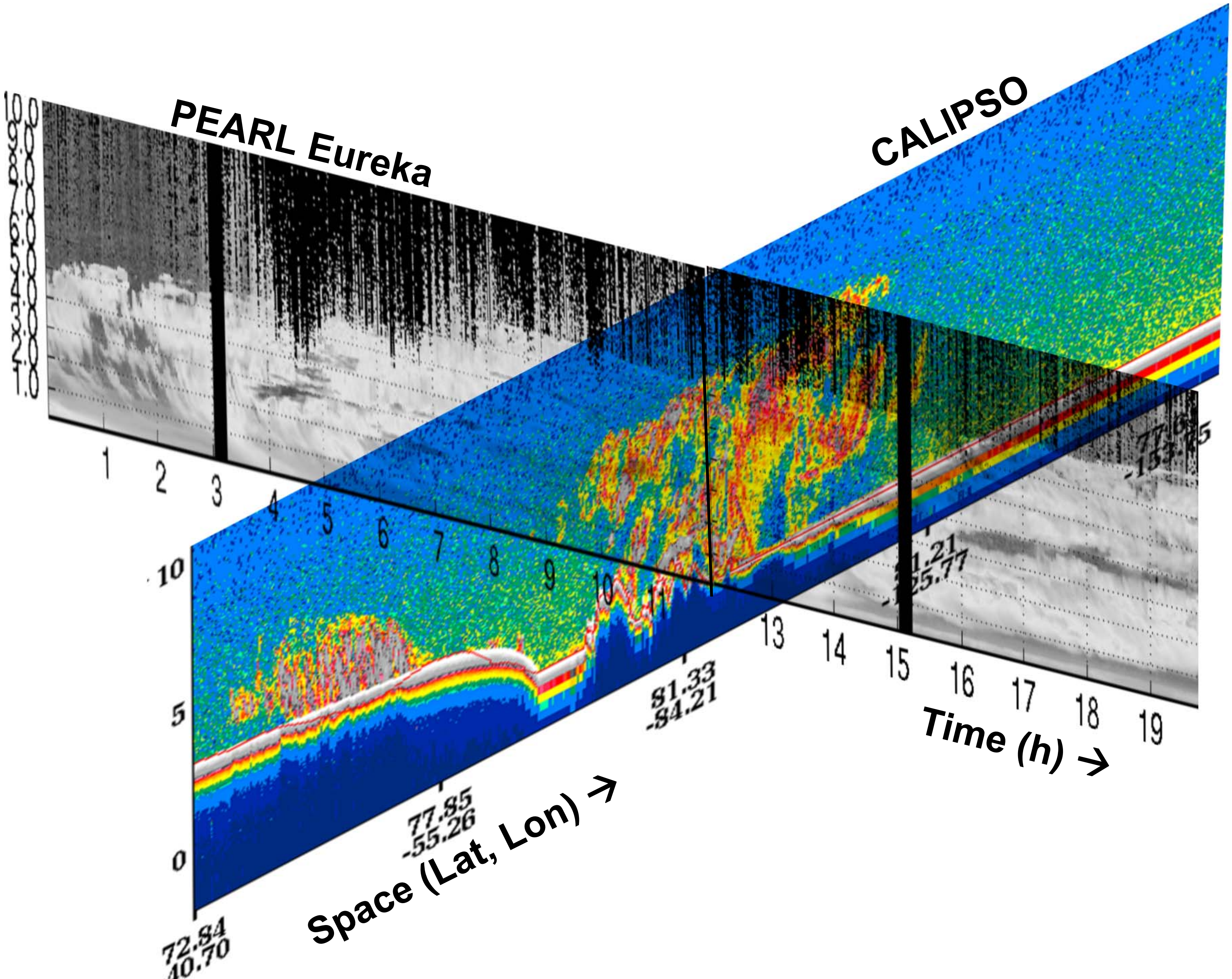


Ref.: eloranta@lidar.ssec.wisc.edu

TIC-2B from PEARL and CALIPSO Simultaneously

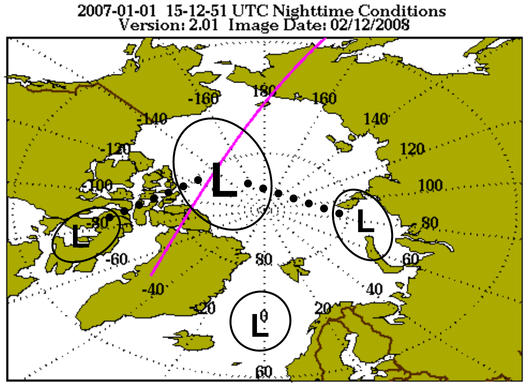
7 January 2007, 14h (Ref.: Ed Eloranta, OPAL at Eureka NU)



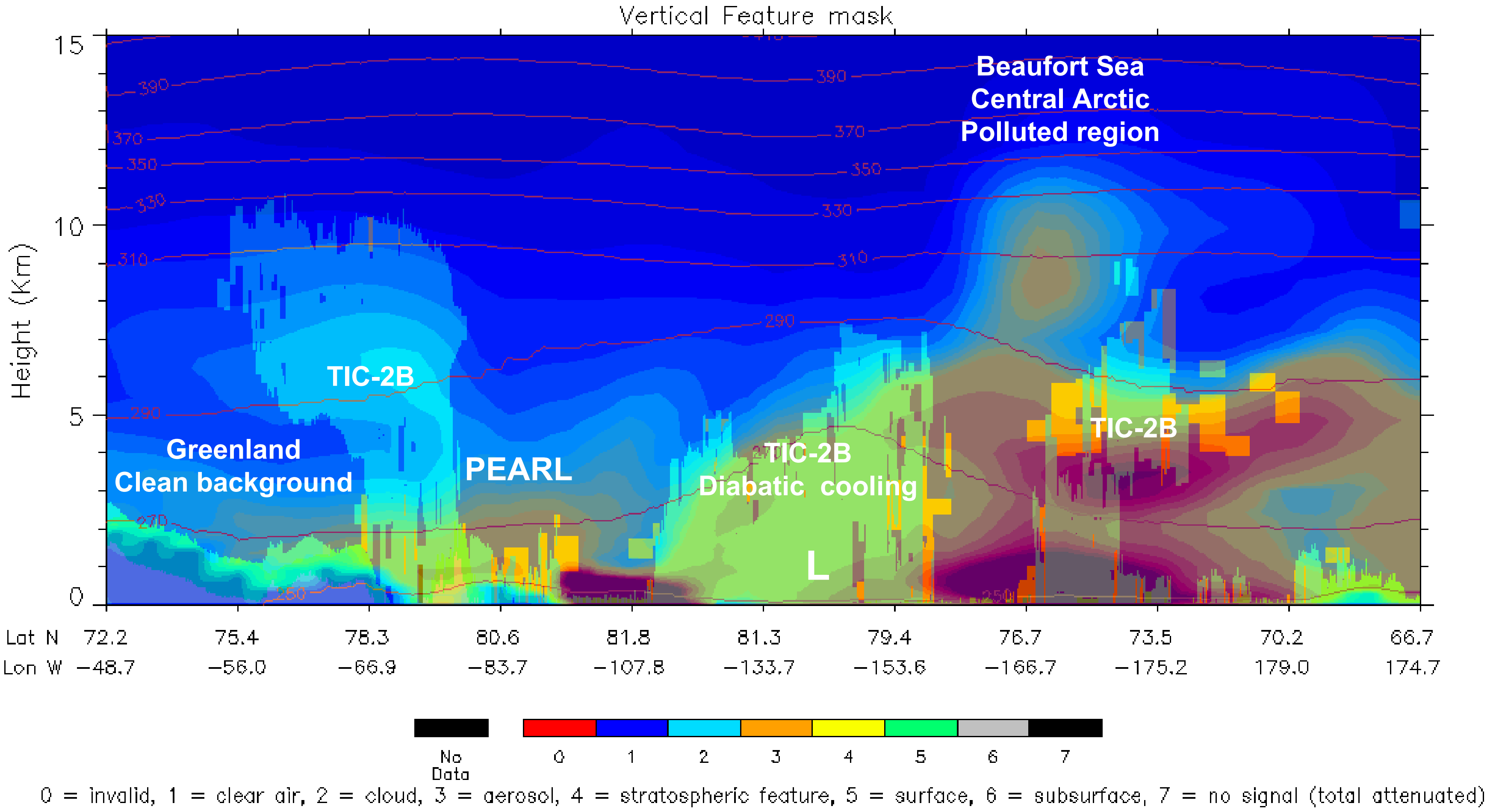


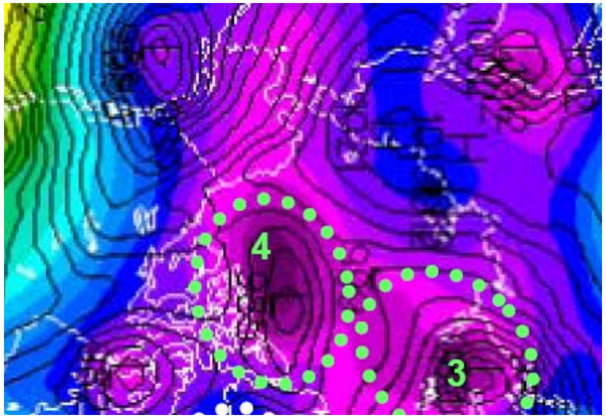
PEARL Eureka
CALIPSO
1
2
3
4
5
6
7
8
9
10
11
13
14
15
16
17
18
19
Time (h) →
10
5
0
72.84
-40.70
77.85
-55.26
81.33
-84.21
Space (Lat, Lon) →

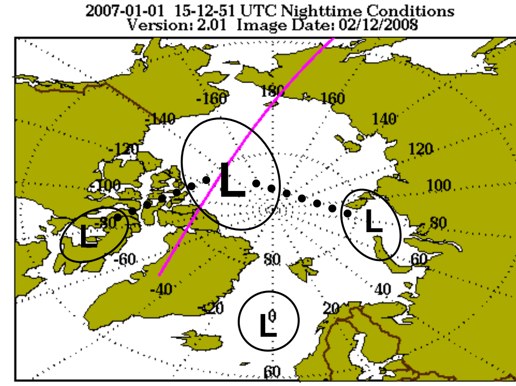
Observed and Simulated Aerosols



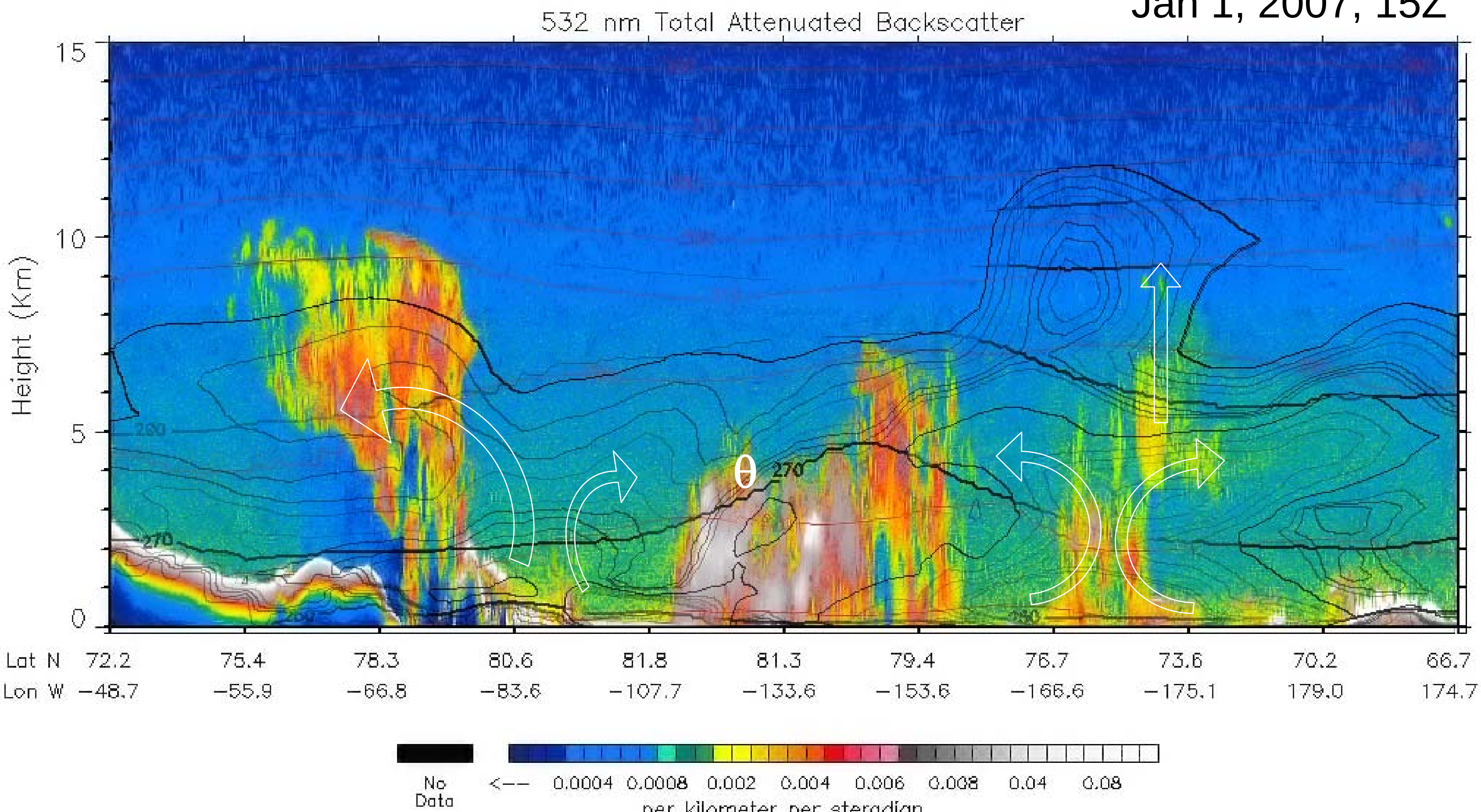
NARCM: 12 size bins [0.005 to 20 µm]
5 species (SO_4, soot, soil, seasalt, organics)
5 chemistry → aerosol







Jan 1, 2007, 15Z



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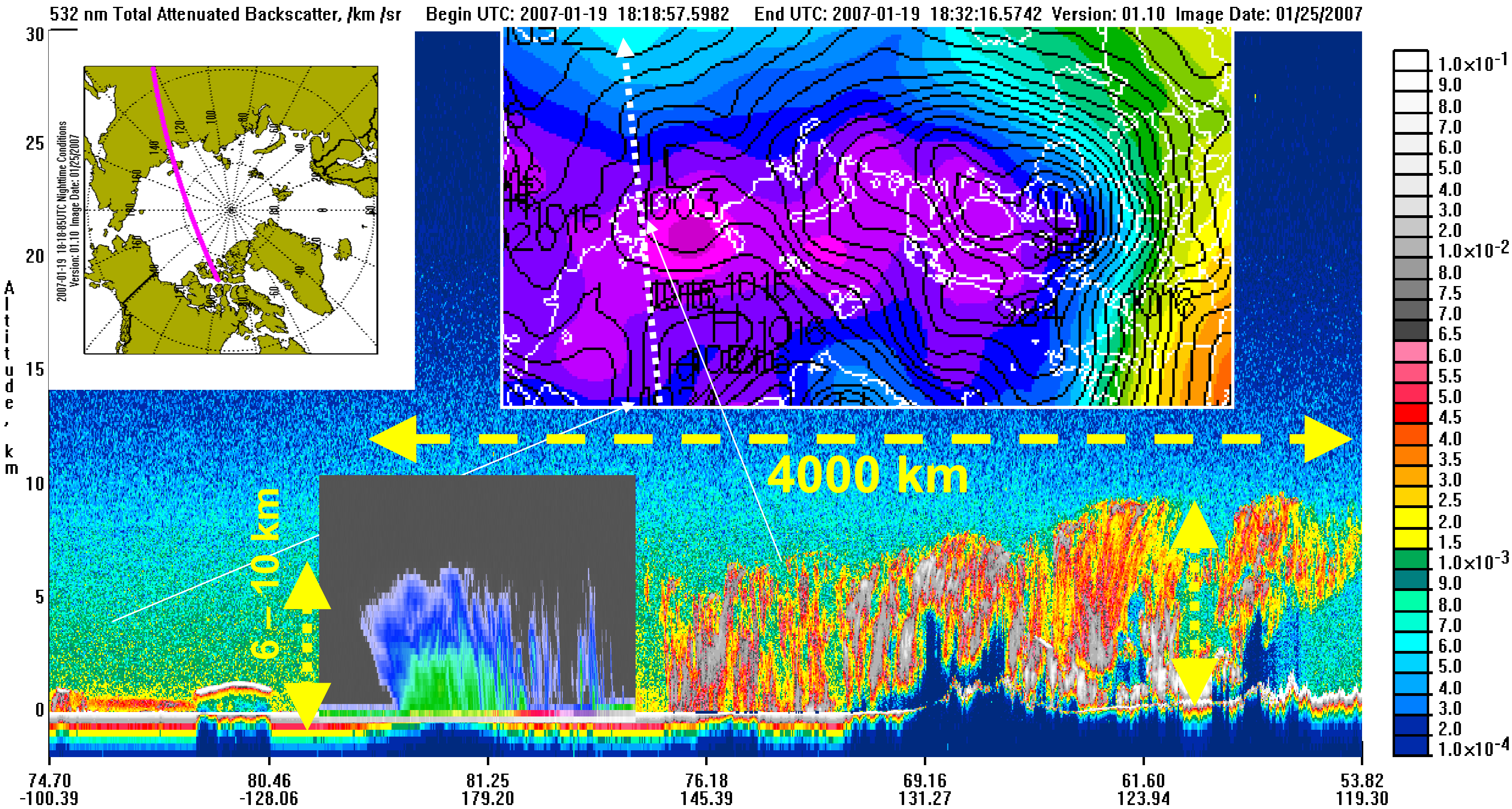
Methodology Thin Ice Cloud classification

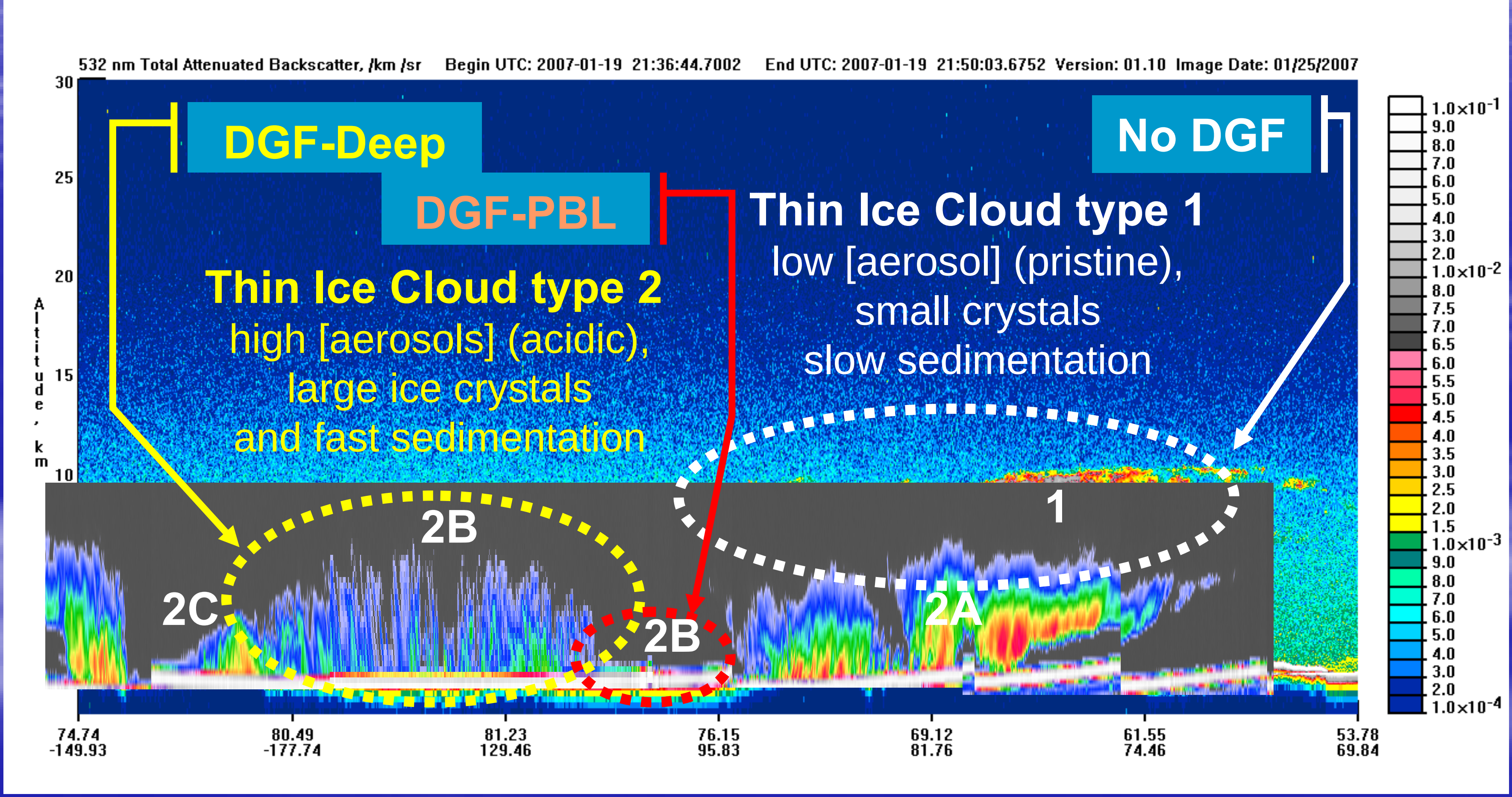
Cloud type	Physical characteristics	Identification method
Mixed-phase	**- sharp top** **- optically thick** **- small vertical extension** **- low levels**	**- strong backscattering gradient at top** **- a few bins thick**
TIC-1	**- Small crystals (< 30 μm)** **- No precipitation**	**- Radar invisible** **- strong lidar depolarization** **- color ratio ~ 1**
TIC-2	**- Big crystals (> 30 μm)** **- Light precipitation**	**- Radar visible**
2A	**Gradual growth from deposition and aggregation of small crystals in active systems**	**below TIC-1**
2B 	**Explosive growth right from the top of the clouds (3-7km) in cold-lows (barotropic)**	**no other clouds above**
2C	**Precipitate from mixed-phase layers**	**below mixed-phase clouds**

Radar – Lidar Comparison



Radar – Lidar DGF Signature

January 19, 2007

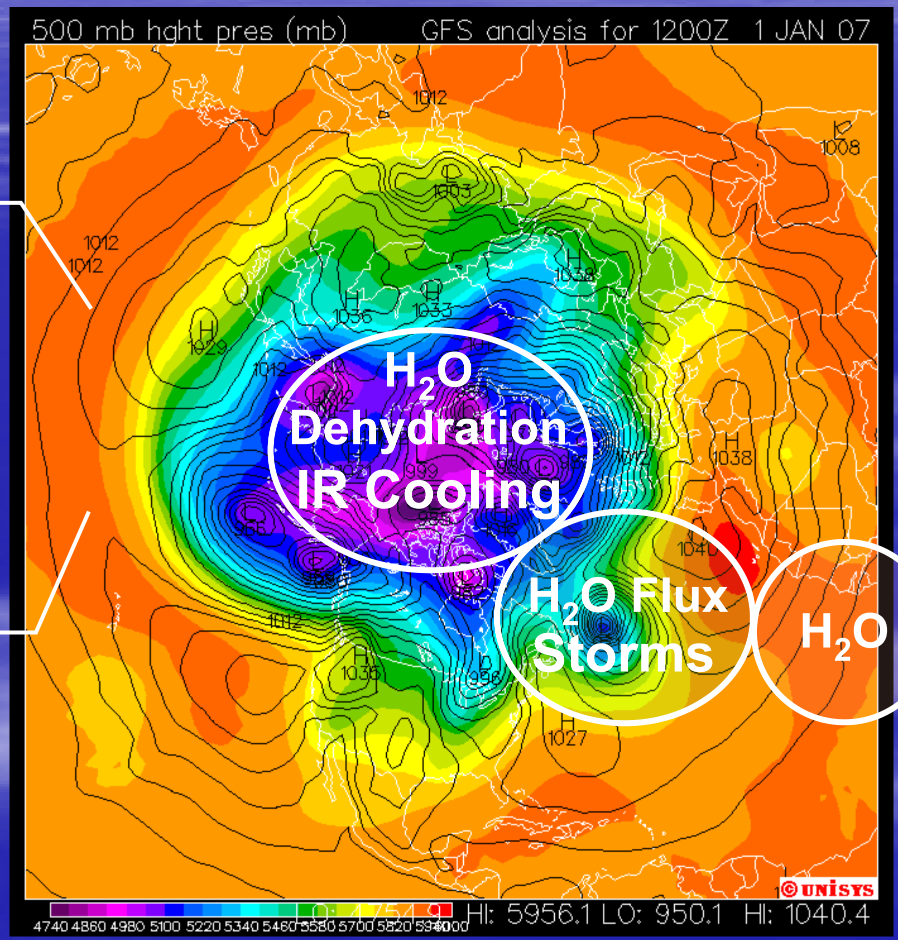


Surface Pressure & 500mb Height

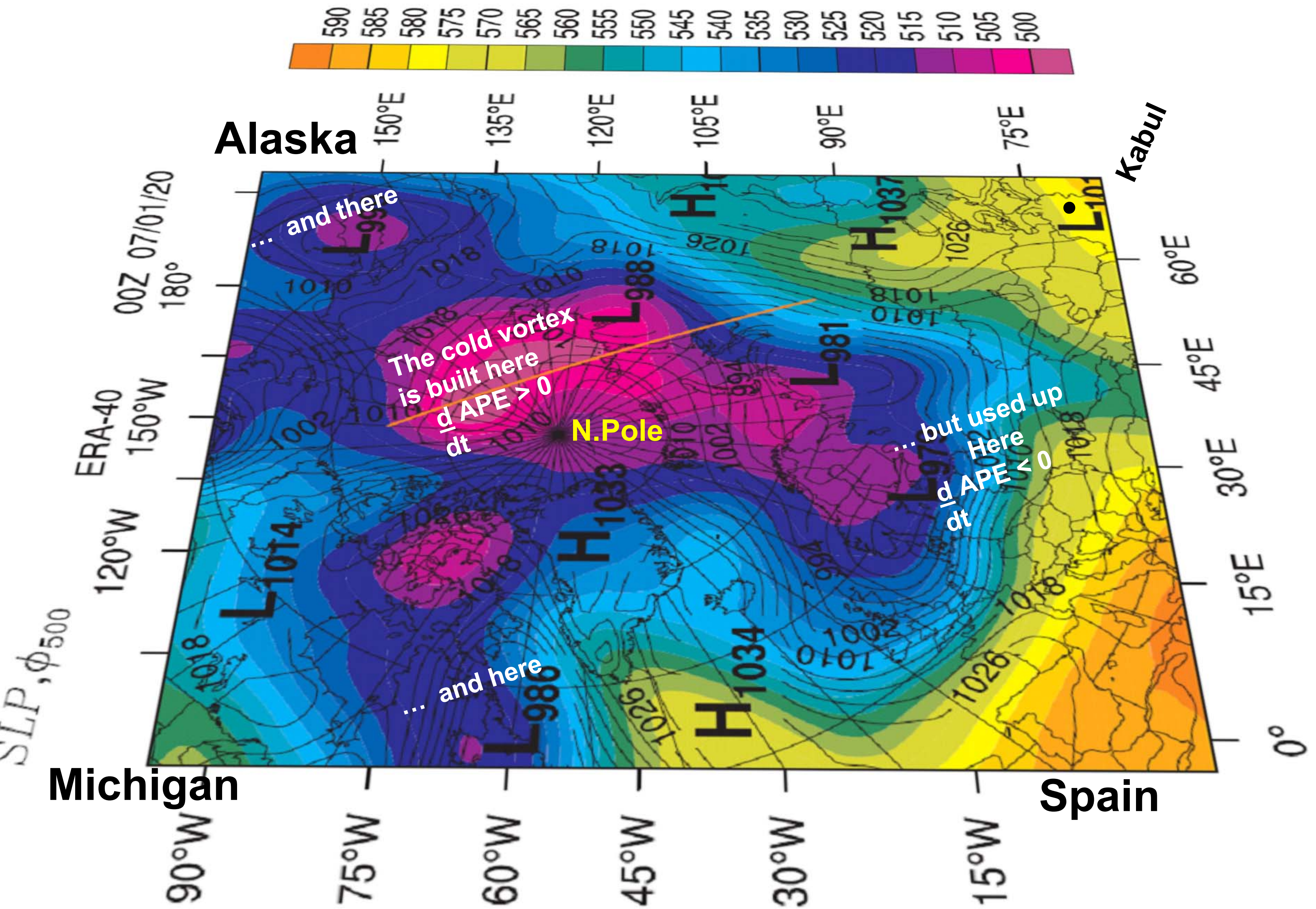
(~ Mean Temperature in lowest 5 km)

Surface Pressure (mb)

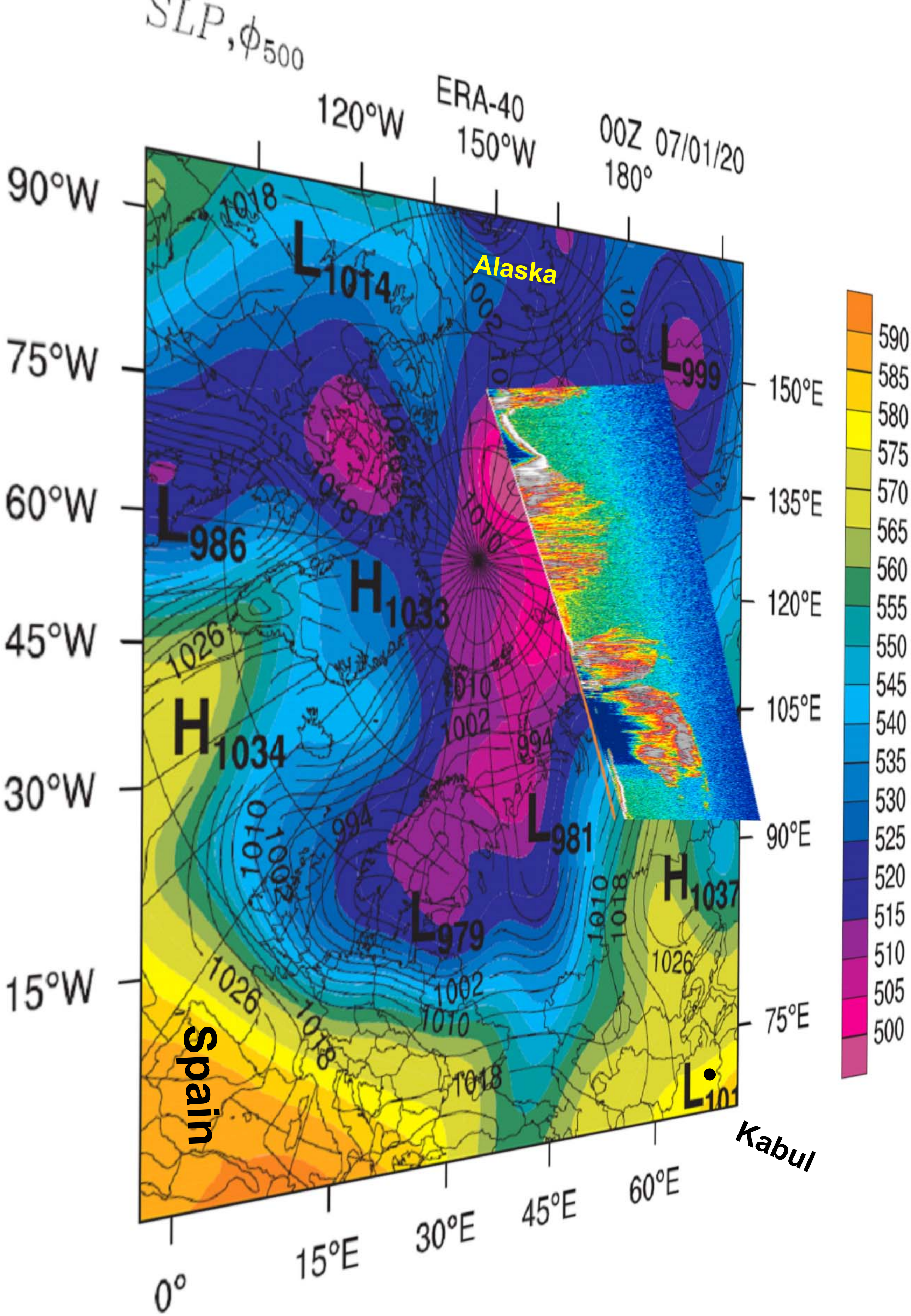
500 mb Geopotential Height (m)



Condensation + Radiation Heating



Alaska
Kabul
Michigan
Spain
N.Pole
… and there
The cold vortex
is built here
d APE > 0
dt
… but used up
Here
d APE < 0
dt
… and here
ERA-40
00Z 07/01/20
SLP, ϕ_{500}
590 585 580 575 570 565 560 555 550 545 540 535 530 525 520 515 510 505 500
150°E 135°E 120°E 105°E 90°E 75°E 60°E 45°E 30°E 15°E 0°
180° 150°W 120°W
90°W 75°W 60°W 45°W 30°W 15°W



SLP, ϕ_{500}
ERA-40
00Z 07/01/20
90°W
75°W
60°W
45°W
30°W
15°W
0°
120°W
150°W
180°
150°E
135°E
120°E
105°E
90°E
75°E
60°E
45°E
30°E
15°E
Alaska
Spain
Kabul
L 1014
L 999
L 986
H 1033
H 1034
L 981
L 979
H 1037
590
585
580
575
570
565
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555
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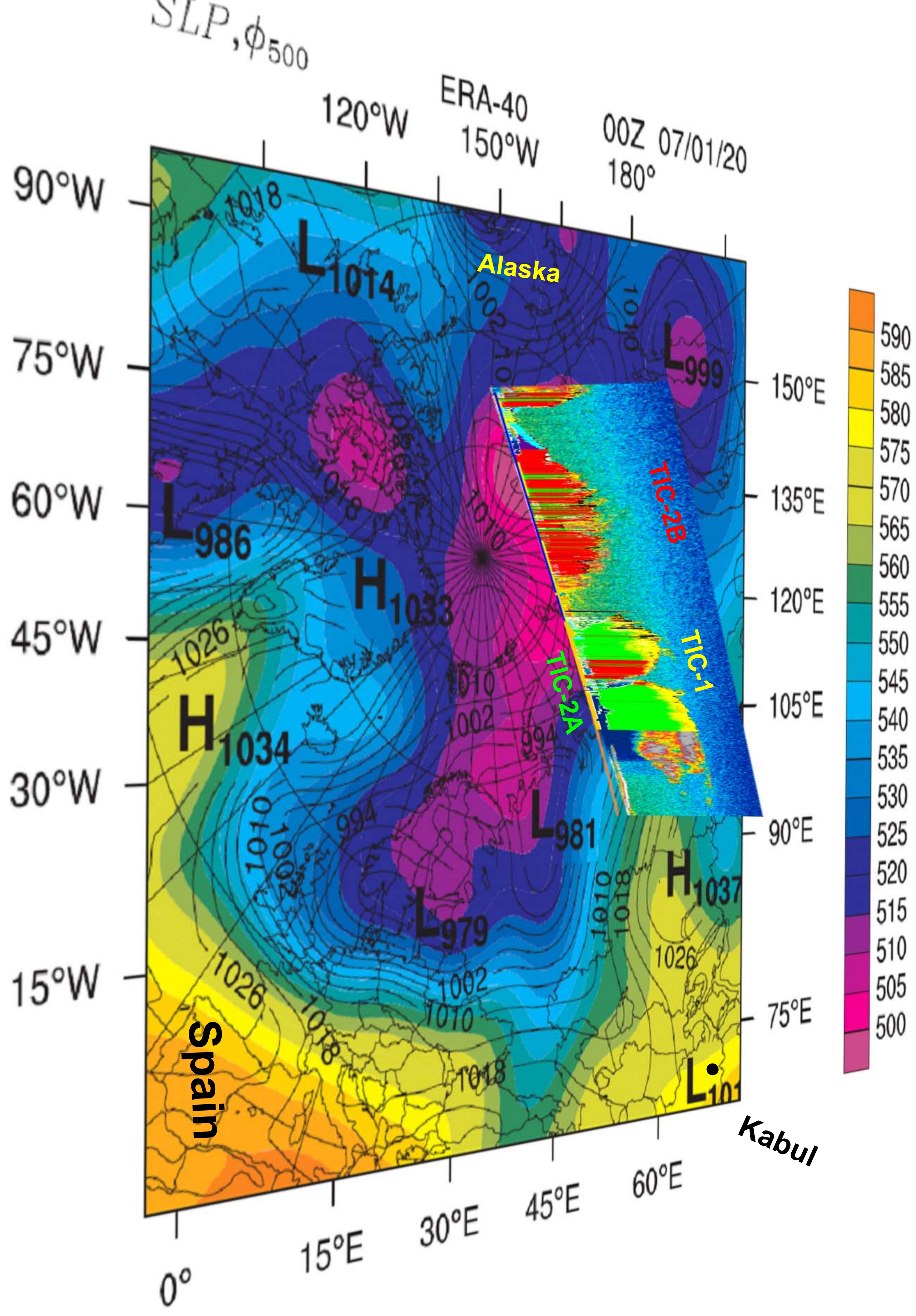
520
515
510
505
500



SLP, ϕ_{500}
ERA-40
00Z 07/01/20
120°W
150°W
180°
90°W
75°W
60°W
45°W
30°W
15°W
0°
15°E
30°E
45°E
60°E
75°E
90°E
105°E
120°E
135°E
150°E
Alaska
Spain
Kabul
TIC-2B
TIC-1
TIC-2A
L 1014
L 999
L 986
H 1033
H 1034
L 981
L 979
H 1037
590
585
580
575
570
565
560
555
550
545
540
535
530
525
520
515
510
505
500

Non-cloudy probed volumes are assigned an index (α).

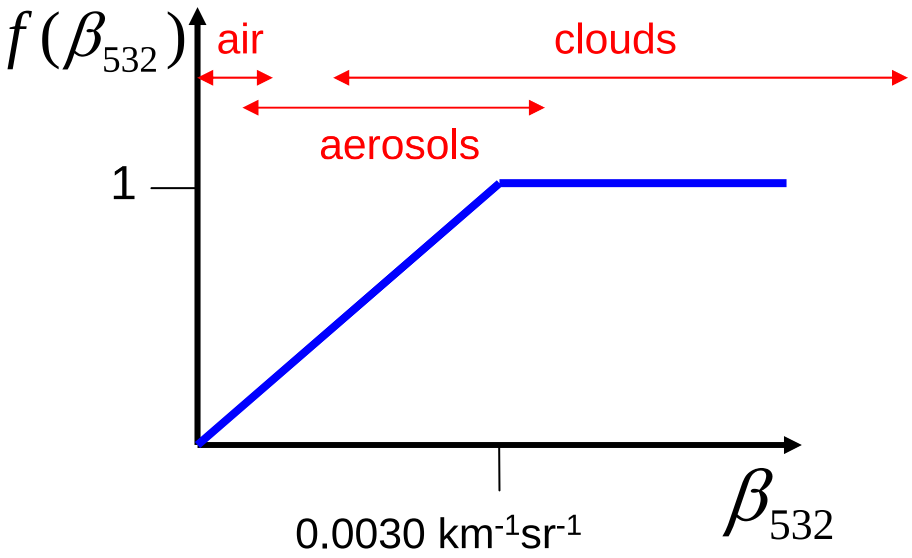
$$\alpha \equiv \frac{w_\beta \cdot f(\beta_{532}) + w_\chi \cdot g(\chi)}{w_\beta + w_\chi}$$

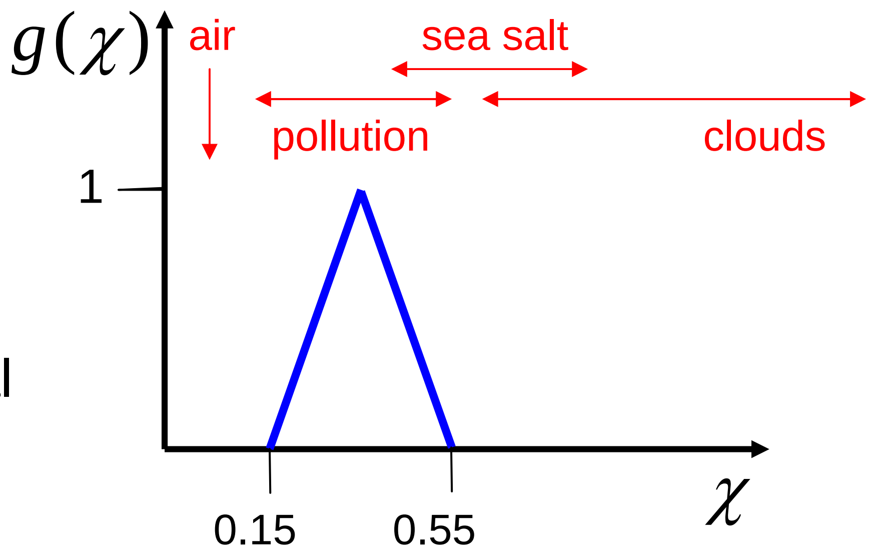
β_{532} : backscattering at 532 nm

χ : color ratio ($\equiv \beta_{1064}/\beta_{532}$)

w_β and w_χ : weigths (2:1)

Color term designed following theoretical considerations from **Liu et al. (2002)**.



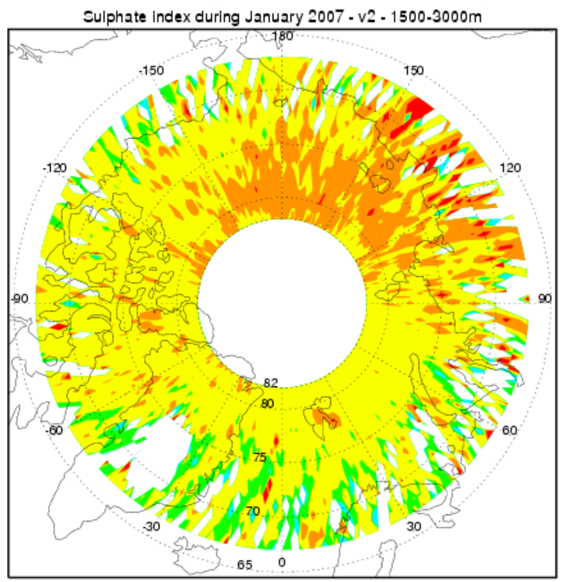


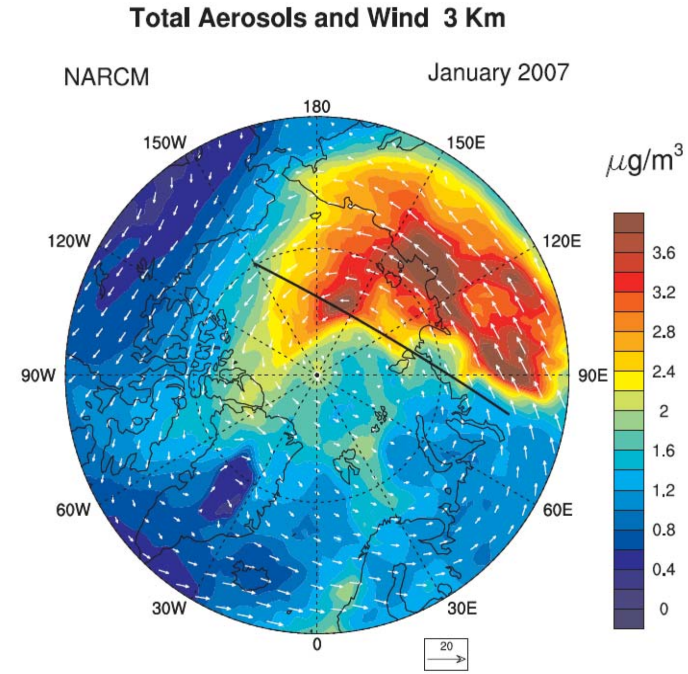
Monthly Mean Aerosol – Observed vs Simulated January 2007

Observed

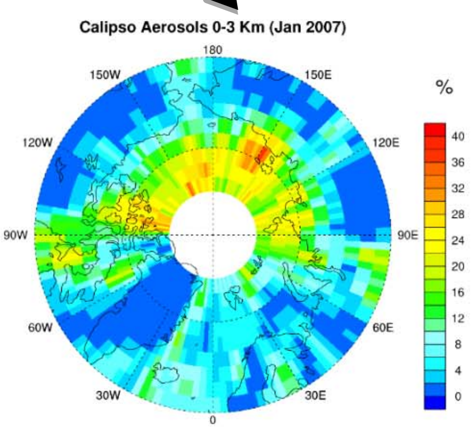
Simulated

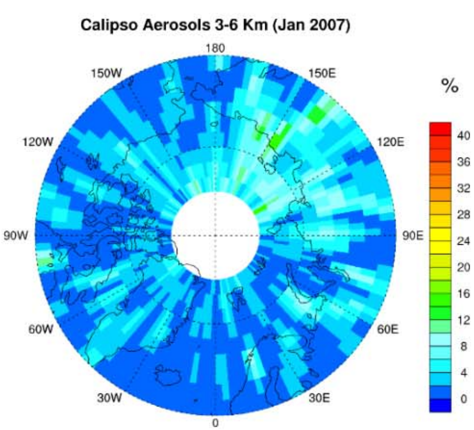
Amount → Our index

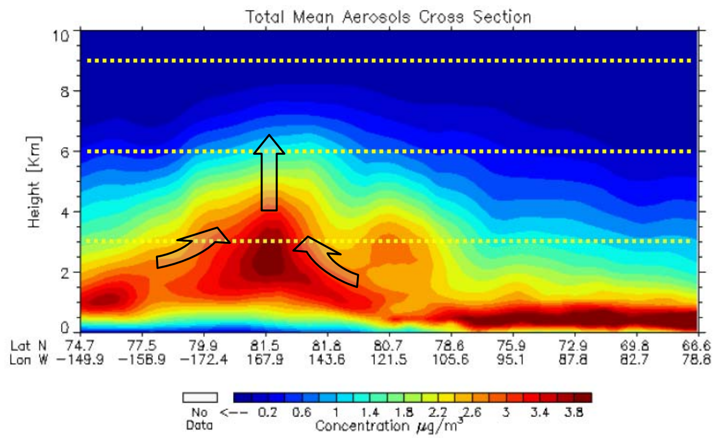




Occurrence CALIPSO Level 2

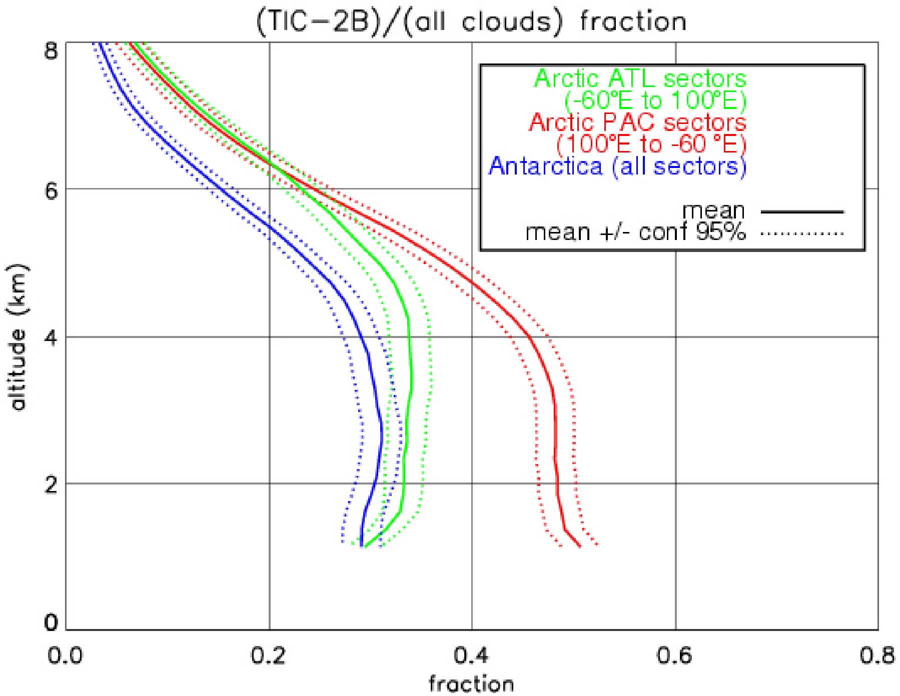


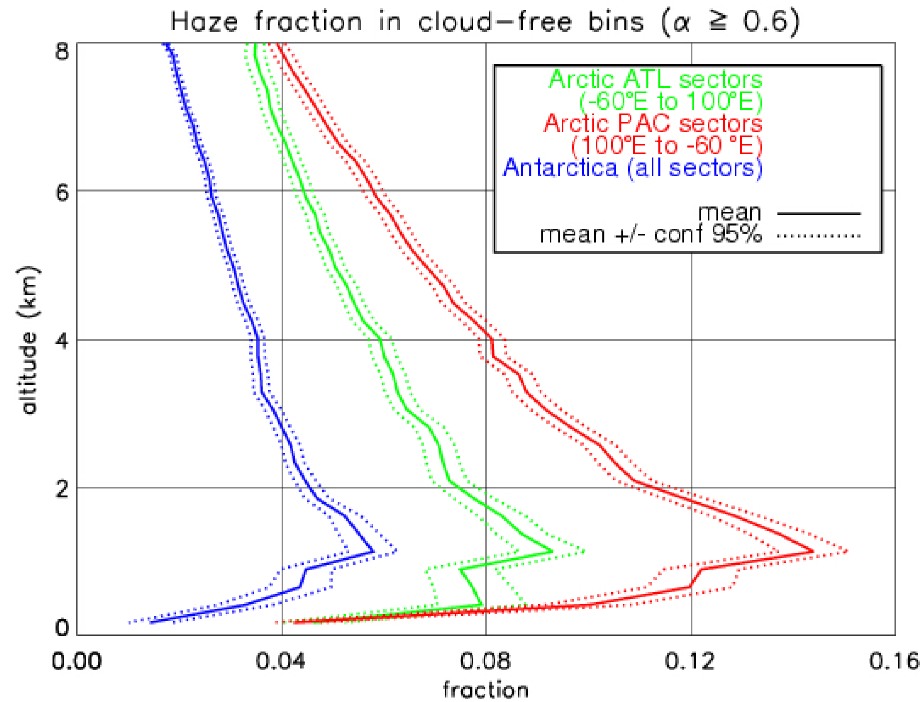


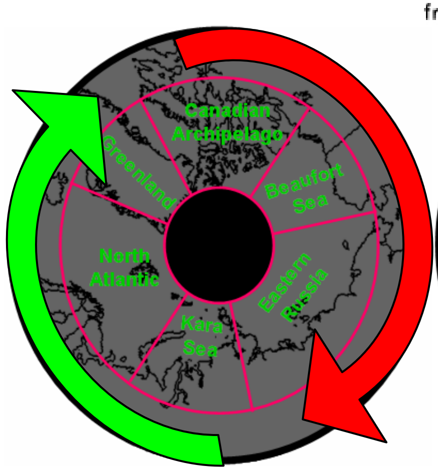


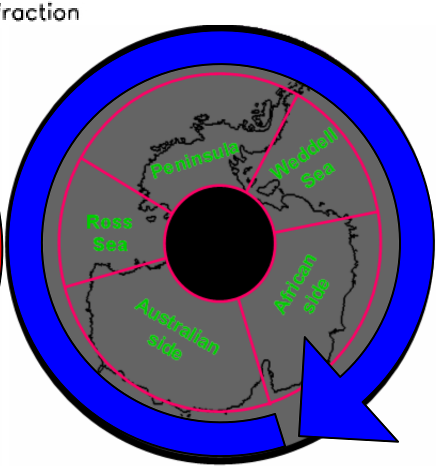
Statistics for TIC – Aerosols

January & July 2007



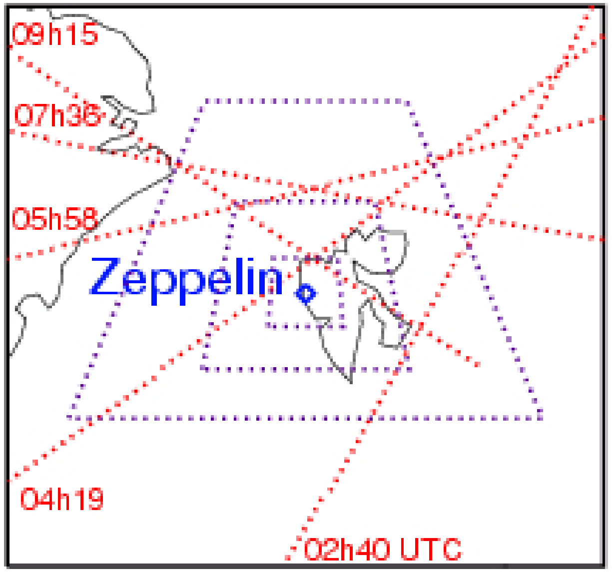


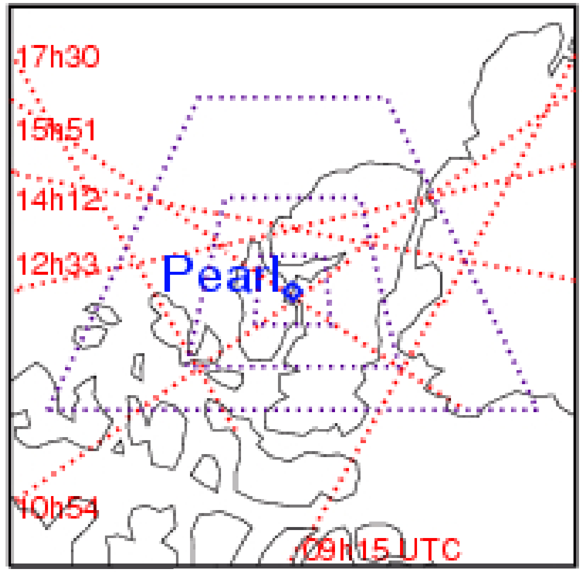




Ref.: Grenier, Blanchet and Munoz-Alpizar (JGR, 2009)

January 27th, 2007





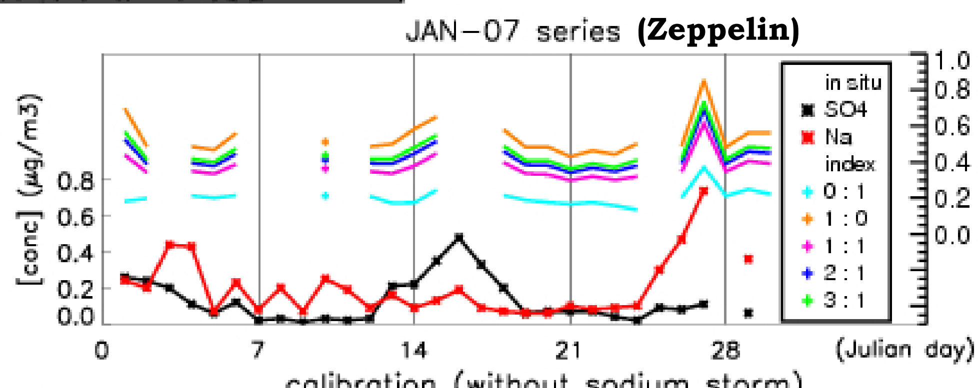
Index used as a sulphate concentration proxy.

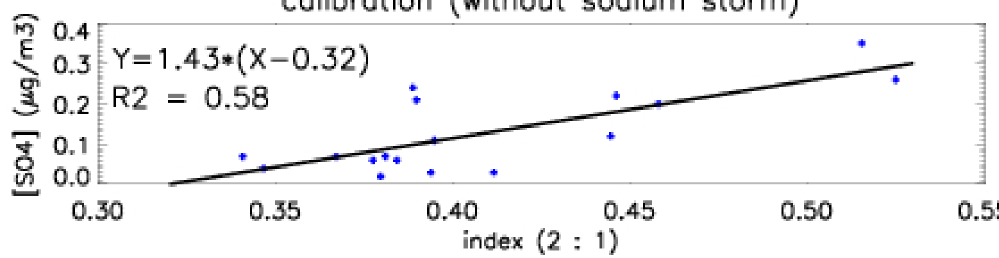
Calibrated on (in situ) Zeppelin (Norway) and Pearl (Canada) observations.

Correlation of the index with in situ [SO_4] is significant.

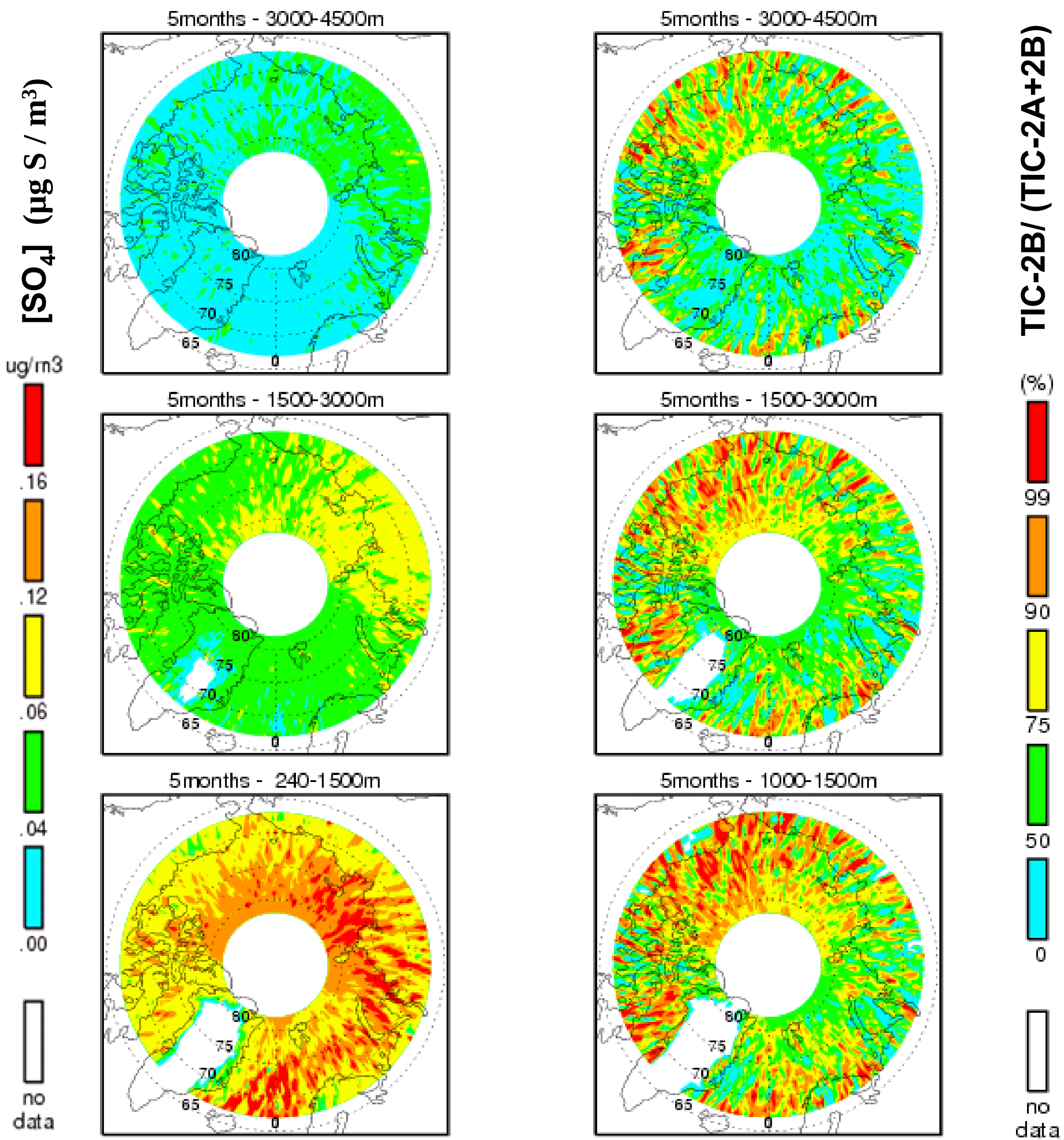
Caveat: [Na] strongly correlates with the color term.

Sodium storm events must be rejected before performing the calibration.





Results — $[SO_4]$ and TIC-2B fraction



Stats from 5 winter months so far
(1787 overpasses)
(~ 6.5 million profiles)

DEC-06 | JAN-07 | FEB-07
DEC-07 | **JAN-08 | FEB-08**
DEC-08 | JAN-09 | FEB-09

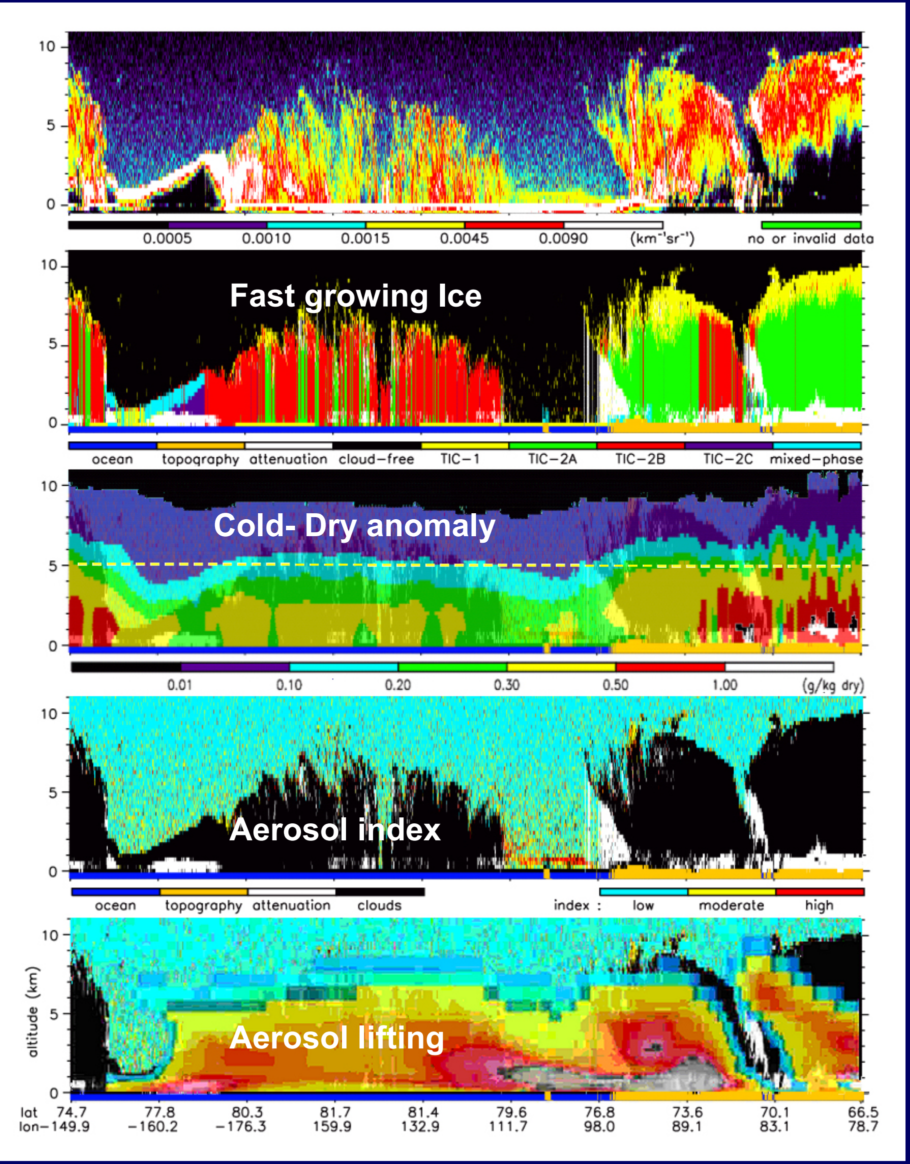
Averages over the period

$1^o x 1^o$ grid cells

TIC-2B higher fractions shifted downwind the prevalent winter circulation compared to $[SO_4]$ higher values, especially northward of 75^oN and above 1500 m.

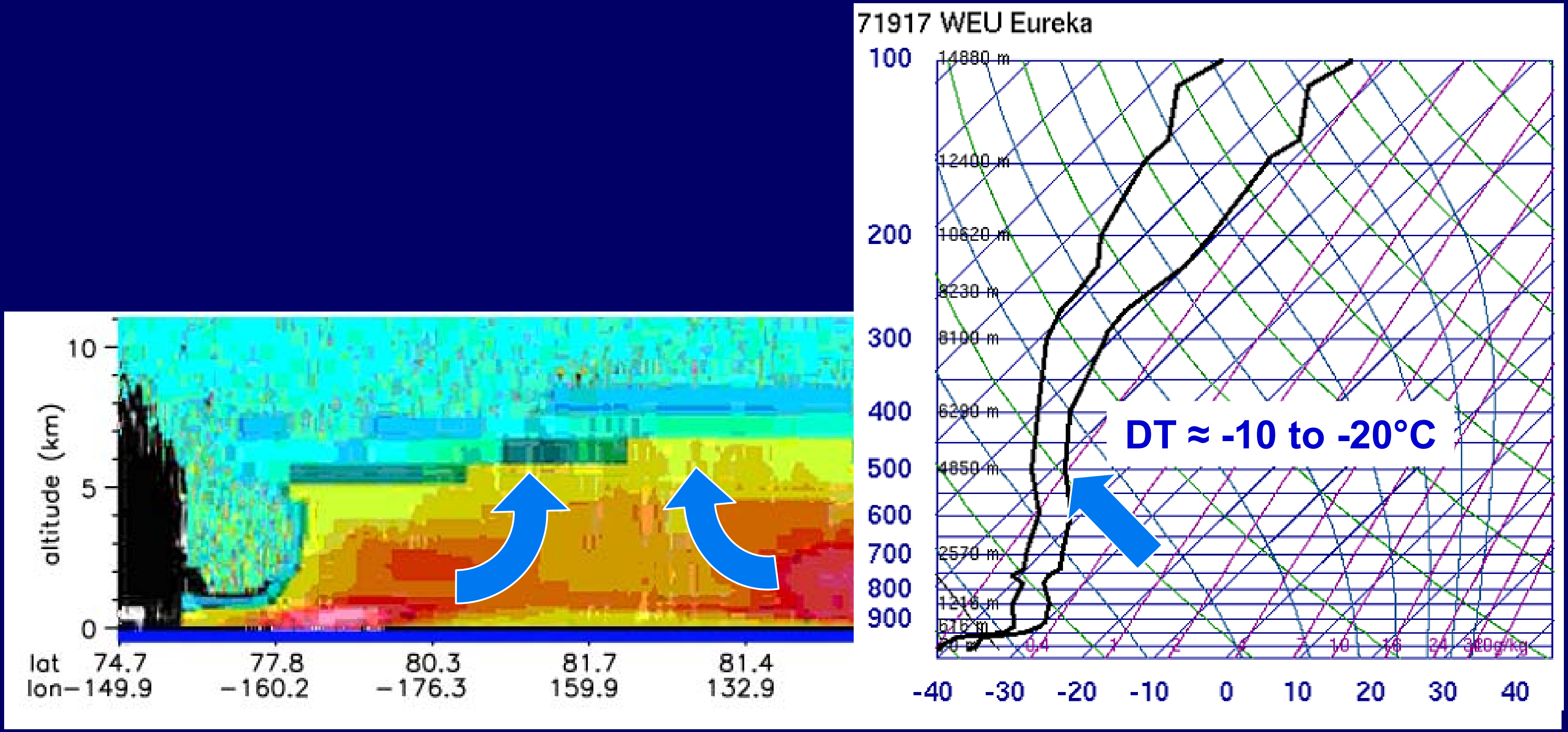
Processes : Vertical Loop

Dynamics – Radiation – Precipitation



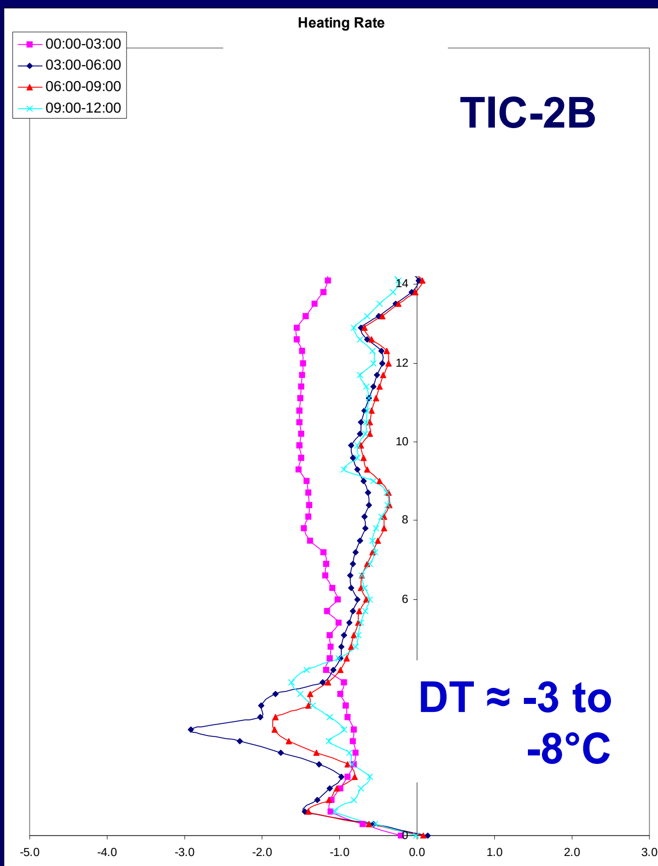
Fast growing Ice
Cold- Dry anomaly
Aerosol index
Aerosol lifting
0.0005 0.0010 0.0015 0.0045 0.0090 (km⁻¹sr⁻¹)
no or invalid data
ocean topography attenuation cloud−free TIC−1 TIC−2A TIC−2B TIC−2C mixed−phase
0.01 0.10 0.20 0.30 0.50 1.00 (g/kg dry)
ocean topography attenuation clouds
index : low moderate high
altitude (km)
lat 74.7 77.8 80.3 81.7 81.4 79.6 76.8 73.6 70.1 66.5
lon −149.9 −160.2 −176.3 159.9 132.9 111.7 98.0 89.1 83.1 78.7

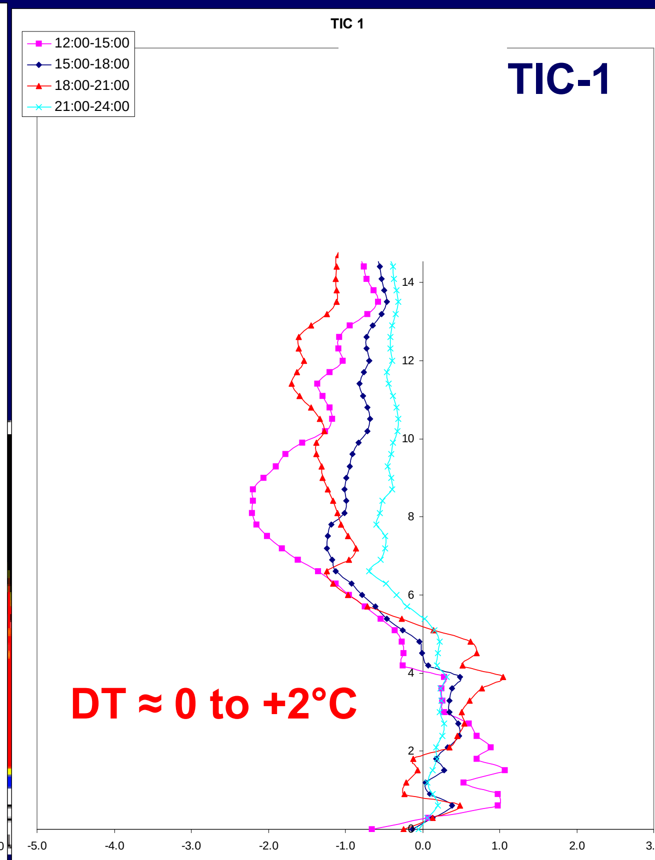
Process #1 – Adiabatic Cooling Dynamics

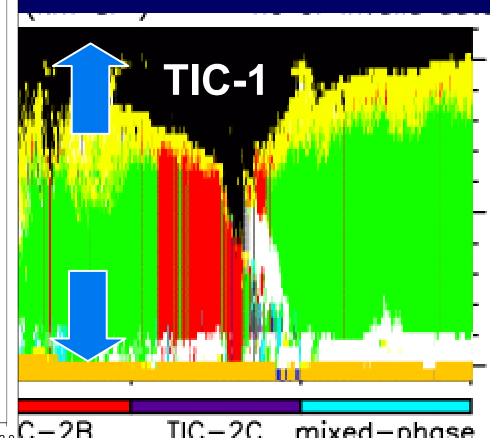


Time Scale : ~ 6 – 24 hours

Process #2 – Direct IR Cooling Emission from Ice Clouds





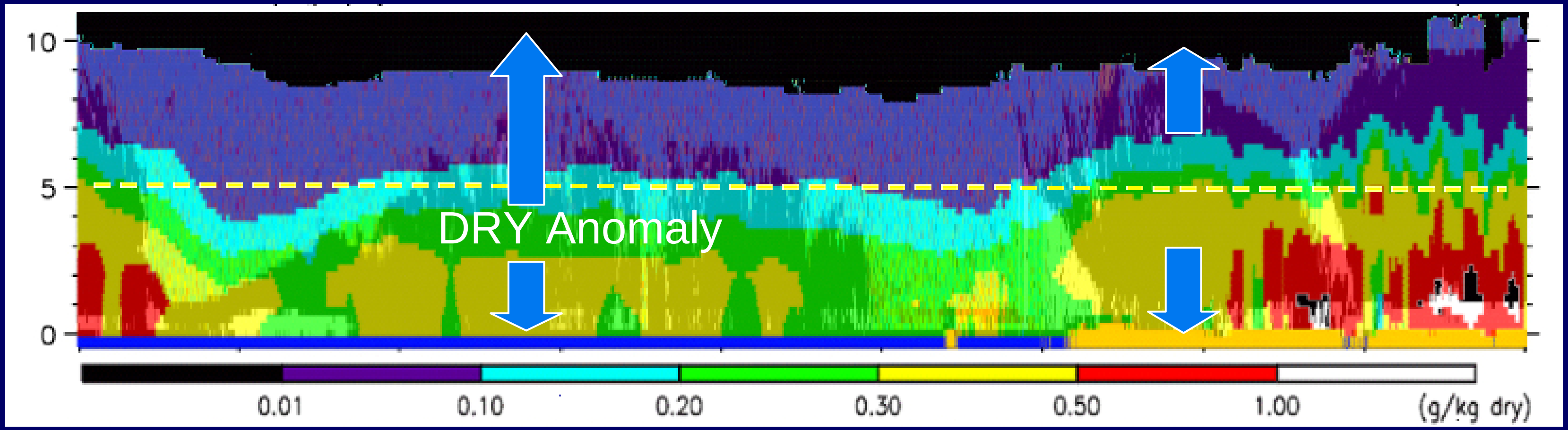


Time Scale : ~ 1 – 5 days

Process #3 – Indirect IR Cooling Emission due to Lost Water Vapour

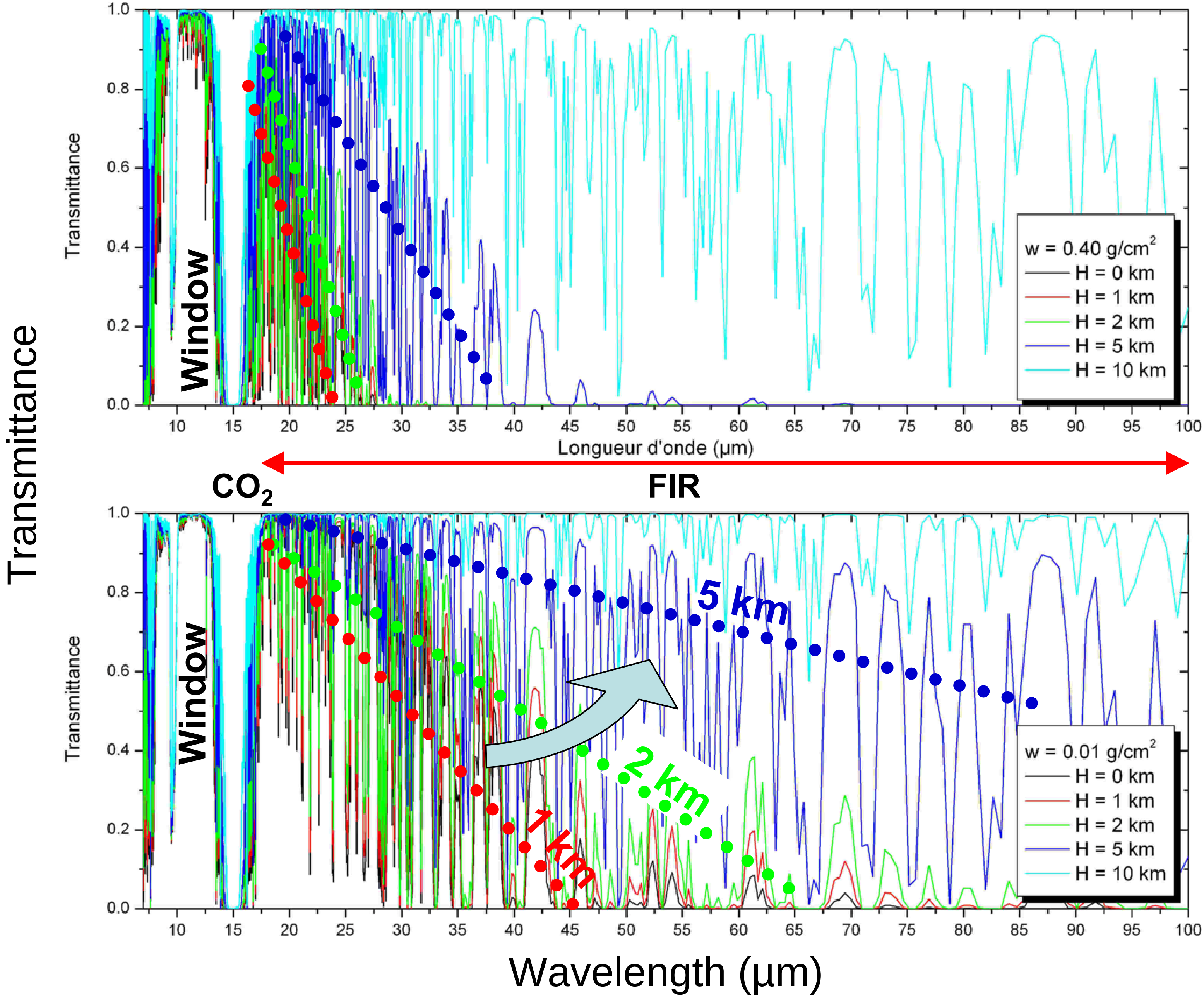
PCP-Water ~ 1 mm Model Bias + 0.3 mm

DT ≈ -5 to -10°C

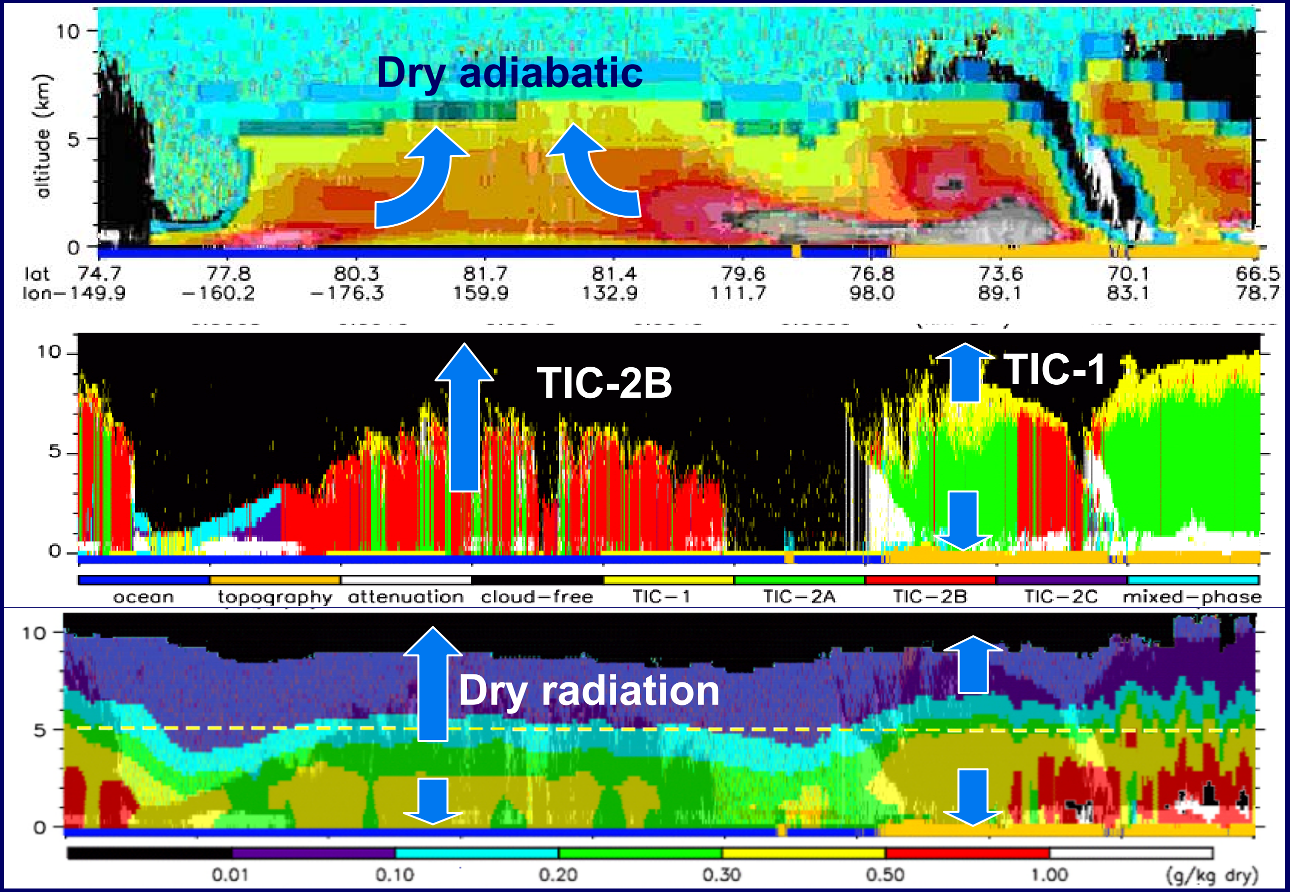


Time Scale : ~ 1 – 2 weeks

Sensitivity of the FIR to Water Vapour Concentration for Arctic Air



Net Effect of all 3 Processes



Process #1: Dynamics

6 – 24 hr

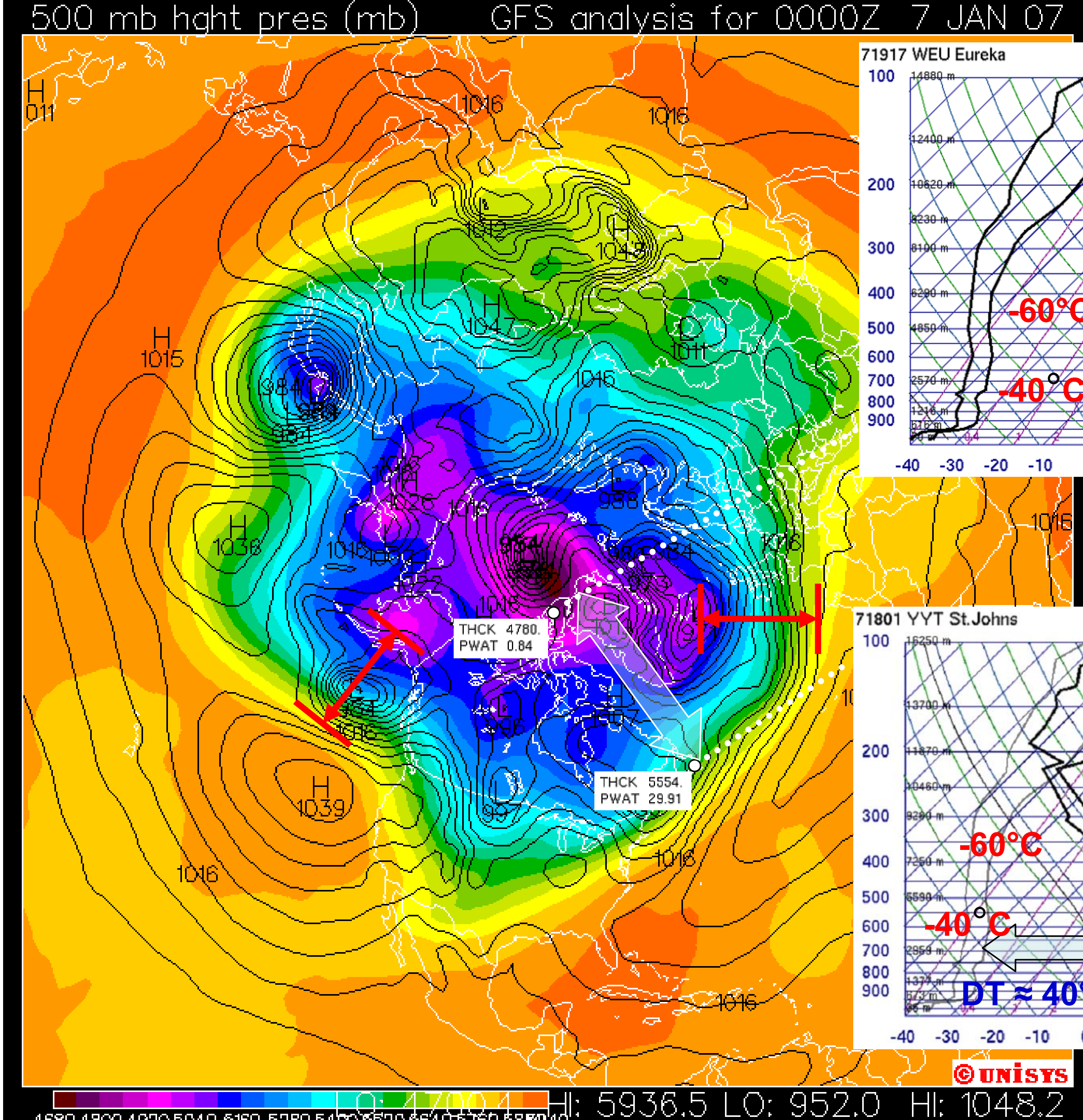
Process #2: Direct IR

1 – 5 days

Process #3: Indirect IR

1 – 2 weeks

Total Cooling ≈ -30 to -40°C



500 mb hght pres (mb) GFS analysis for 0000Z 7 JAN 07
71917 WEU Eureka
-60°C
-40°C
71801 YYT St.Johns
-60°C
-40°C
+10°C
DT ≈ 40°C
THCK 4780.
PWAT 0.84
THCK 5554.
PWAT 29.91
HI: 5936.5 LO: 952.0 HI: 1048.2
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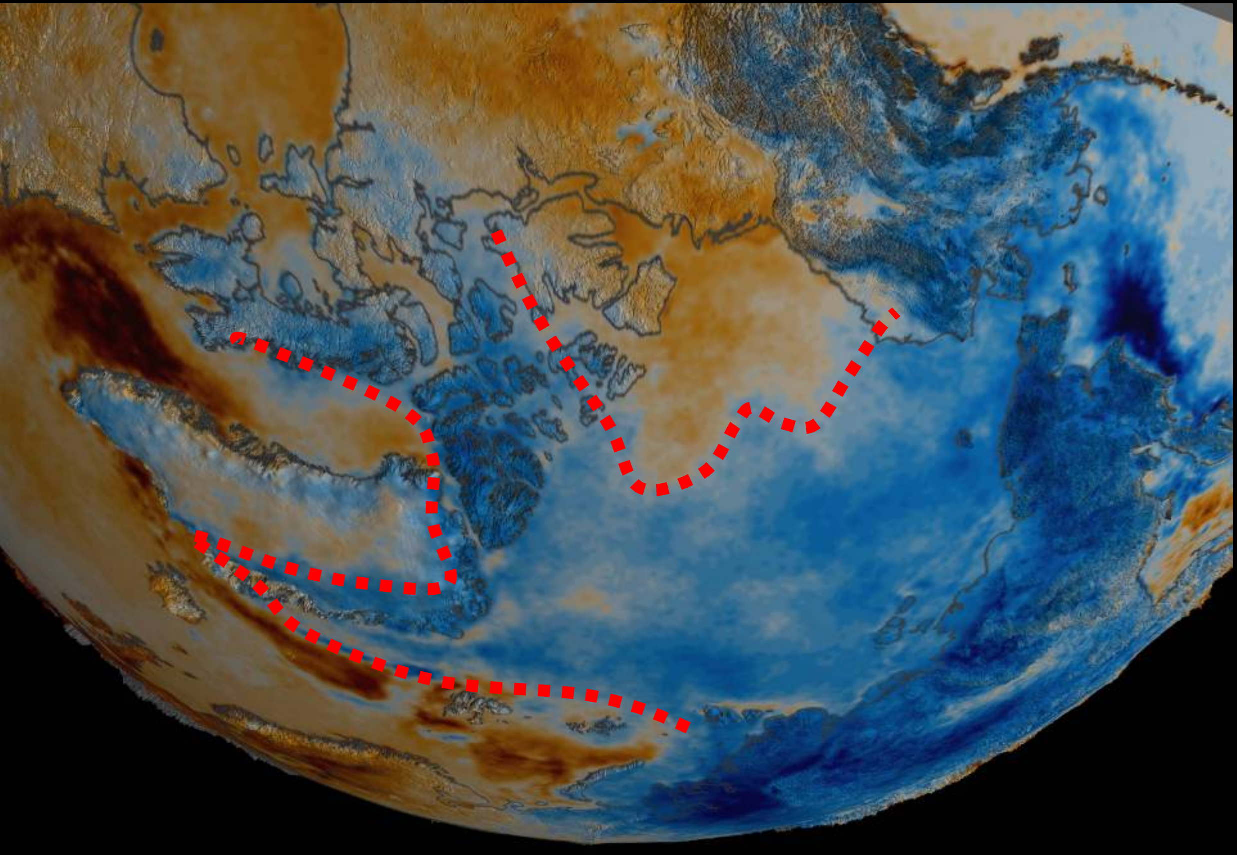
Sulphur Sources and AVHRR Temperature Trend

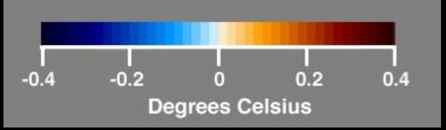
The RHS figure shows the temperature change due to sulfuric acid coating on IFN for the run with high acid concentration minus no acid cases during January. Our model simulations (right) of the Dehydration-Greenhouse Feedback (DGF) process show a similar signature (pattern and strength) over land and sea-ice than observed in the AVHRR 20 year temperature trend.

J-P Blanchet

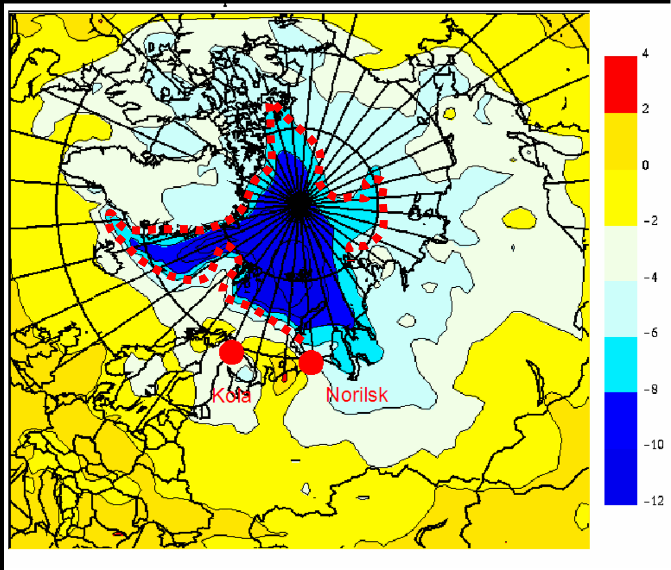
20-Year Arctic Winter Seasonal Surface Temperature Trend



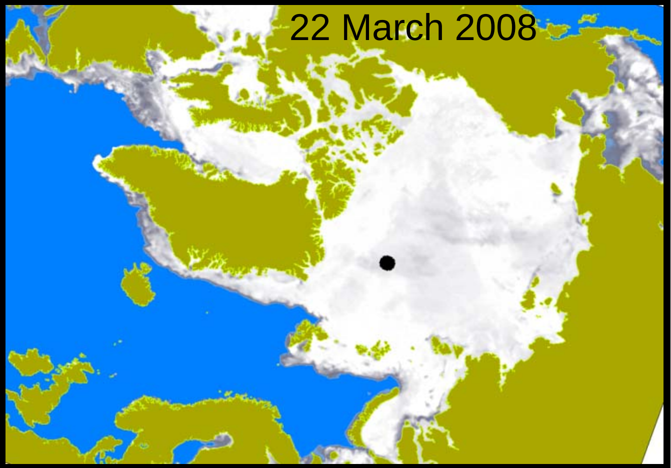
http://svs.gsfc.nasa.gov/search/Keyword/Arctic.html



Mean Annual Trend °C / yr



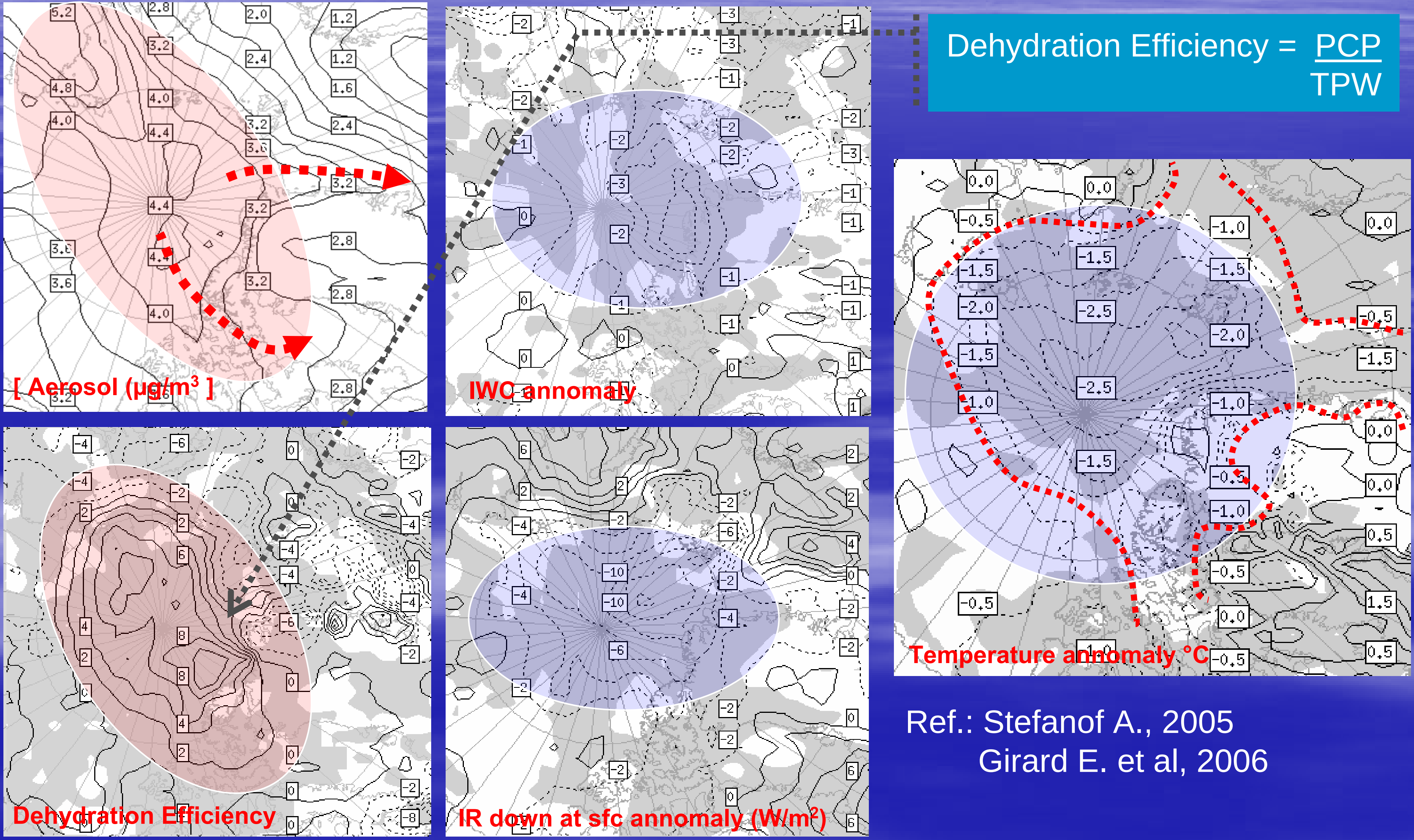
Pavlovic and Blanchet using NARCM



http://www.socc.ca/seaice/seaice_current_e.cfm

Example: ensemble of 12 Months January

Simulations (perturbed – reference)



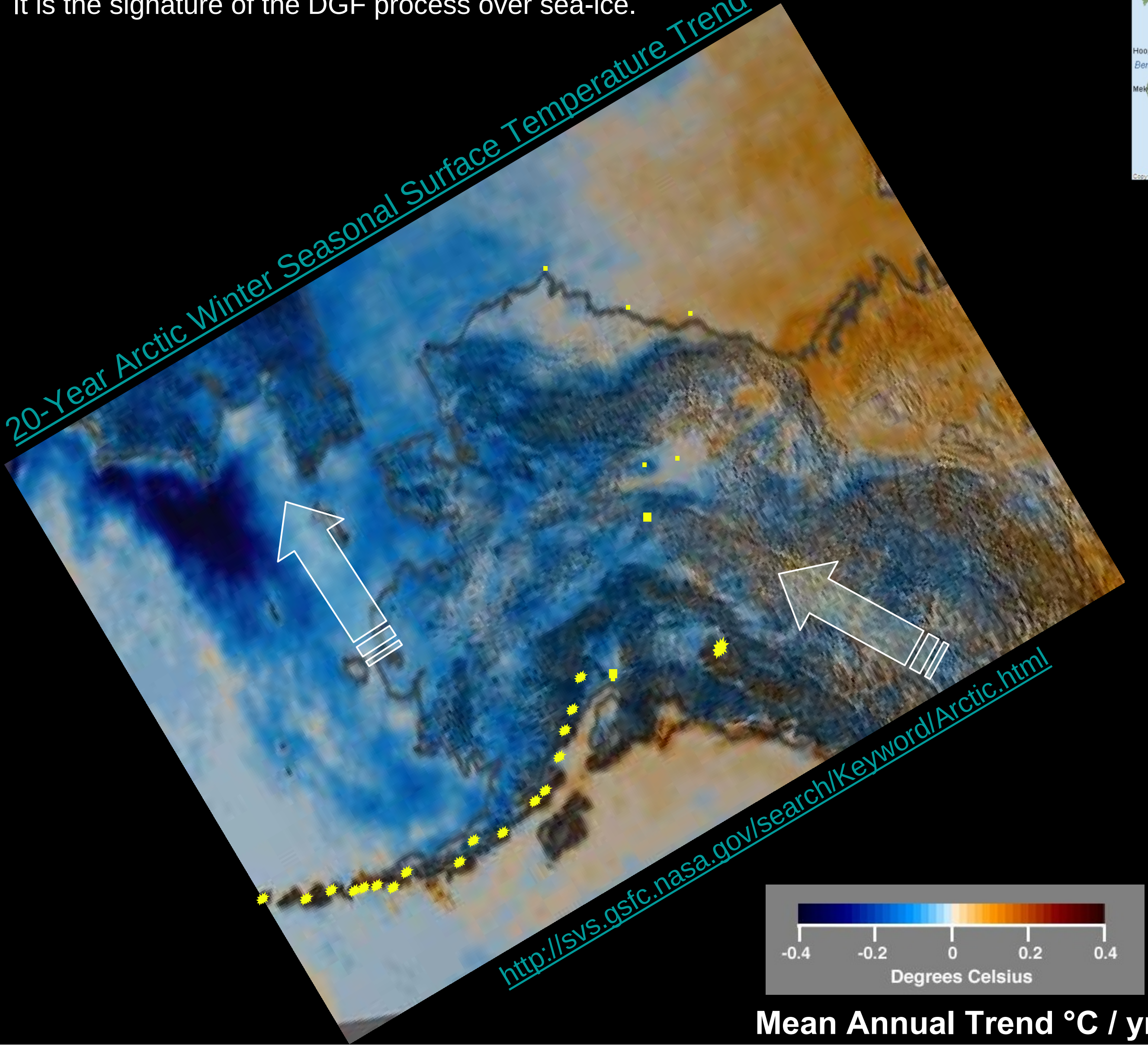
Dehydration Efficiency = $\frac{PCP}{TPW}$

Ref.: Stefanof A., 2005
Girard E. et al, 2006

Sulphur Sources and AVHRR Temperature Trend

Active Aleutian volcanoes emit large amount of sulphur in the lower troposphere.
This is a strong indication that SO_2 – SO_4 sources are affecting surface temperatures trends shown in AVHRR.
It is the signature of the DGF process over sea-ice.

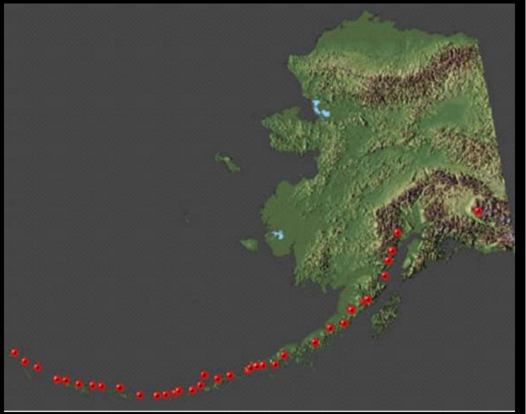
20-Year Arctic Winter Seasonal Surface Temperature Trend



http://svs.gsfc.nasa.gov/search/Keyword/Arctic.html

Mean Annual Trend °C / yr

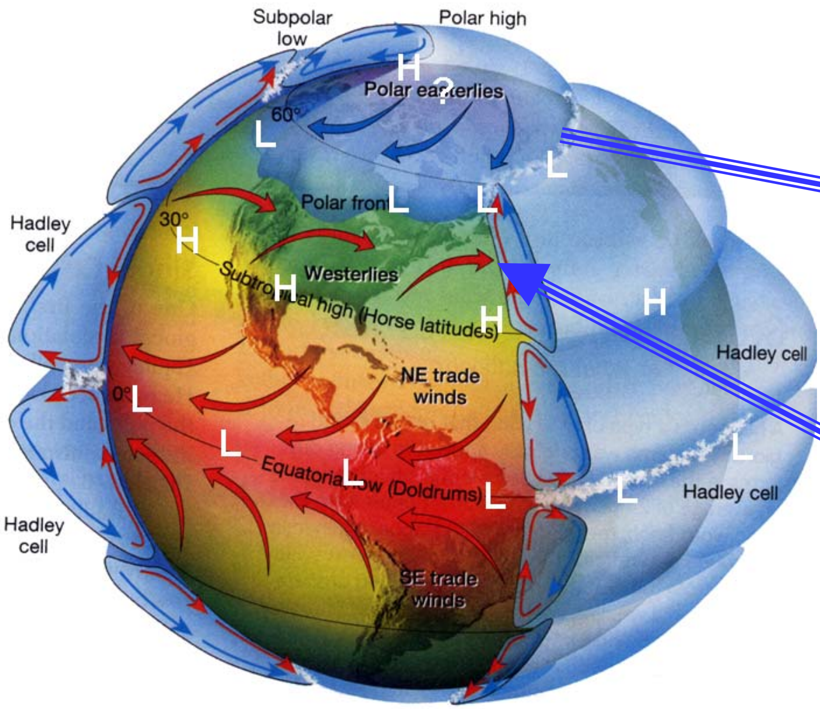
http://www.socc.ca/seaice/seaice_current_e.cfm



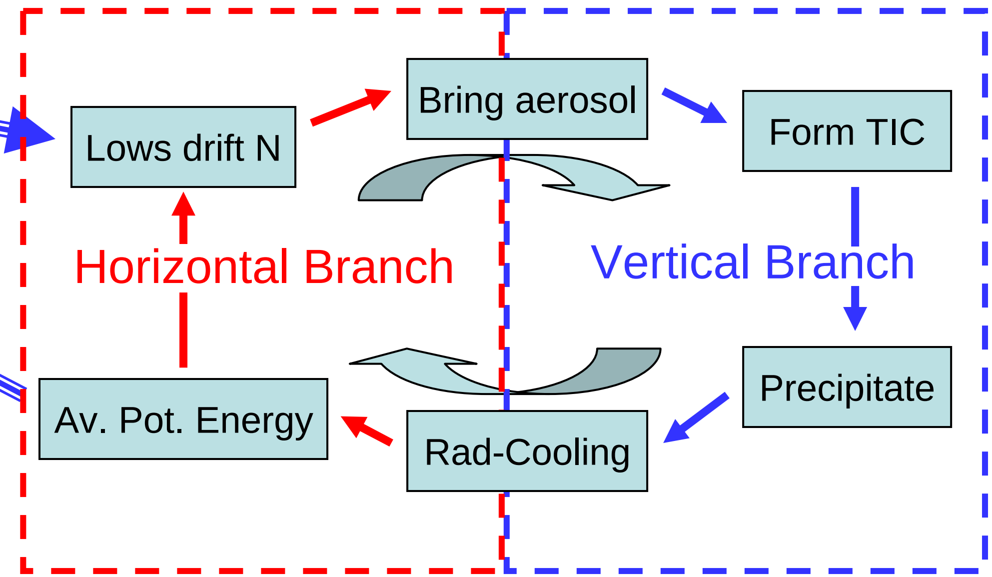
http://nationalatlas.gov/dynamic/dyn_vol-ak.html

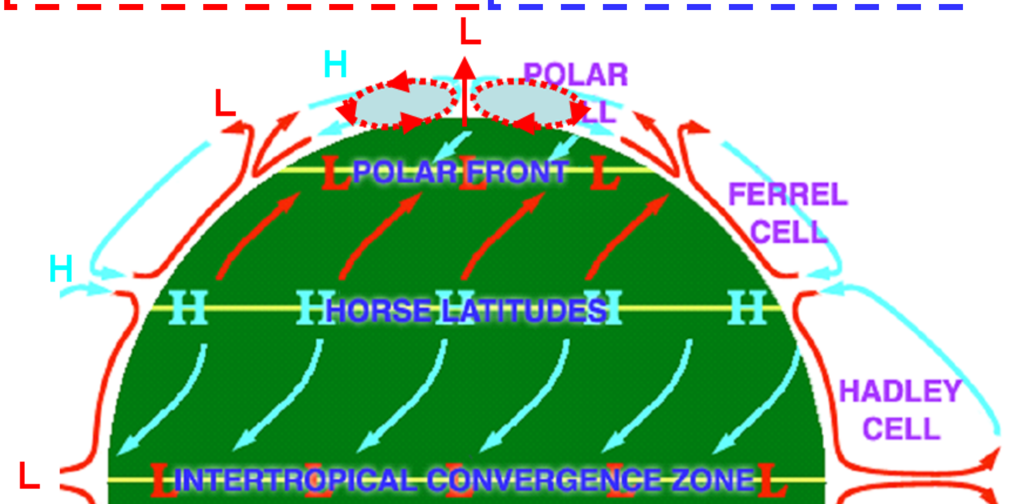
A dynamics-aerosol-clouds-precipitation-radiation Interaction on planetary scale

The Big Picture



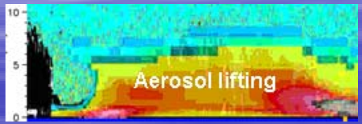
Ref: The Atmosphere, Lutgens F. and E. J. Tarbuck, 2007 Prentice Hall. 520pp

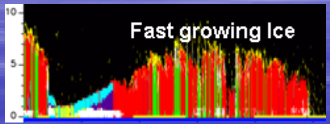


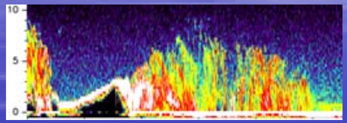


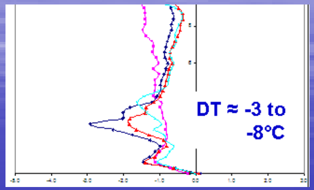
Two Coupled Planetary Scales Feedback Loops

Vertical Branch : Time scale ~ 1 – 5 days (indirect IR-Cloud)



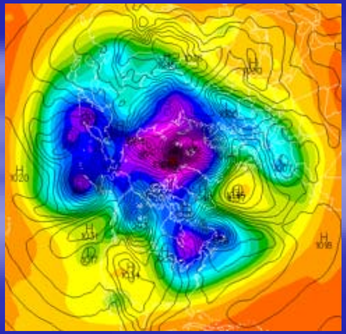


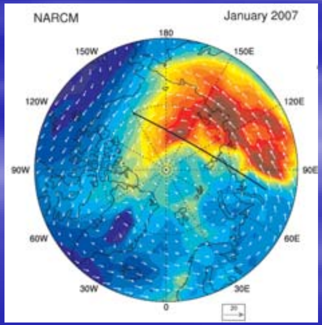


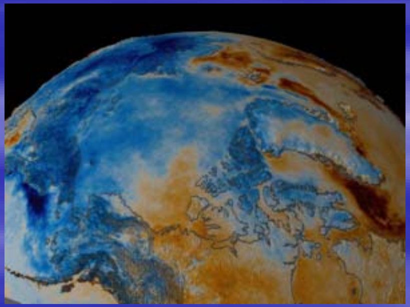


Aerosol ⇨ Cloud ⇨ Precipitation ⇨ Radiation

Horizontal Branch : Time scale ~ 1 – 2 weeks (DGF)







Circulation ⇨ Aerosol transport ⇨ Radiation

Summary

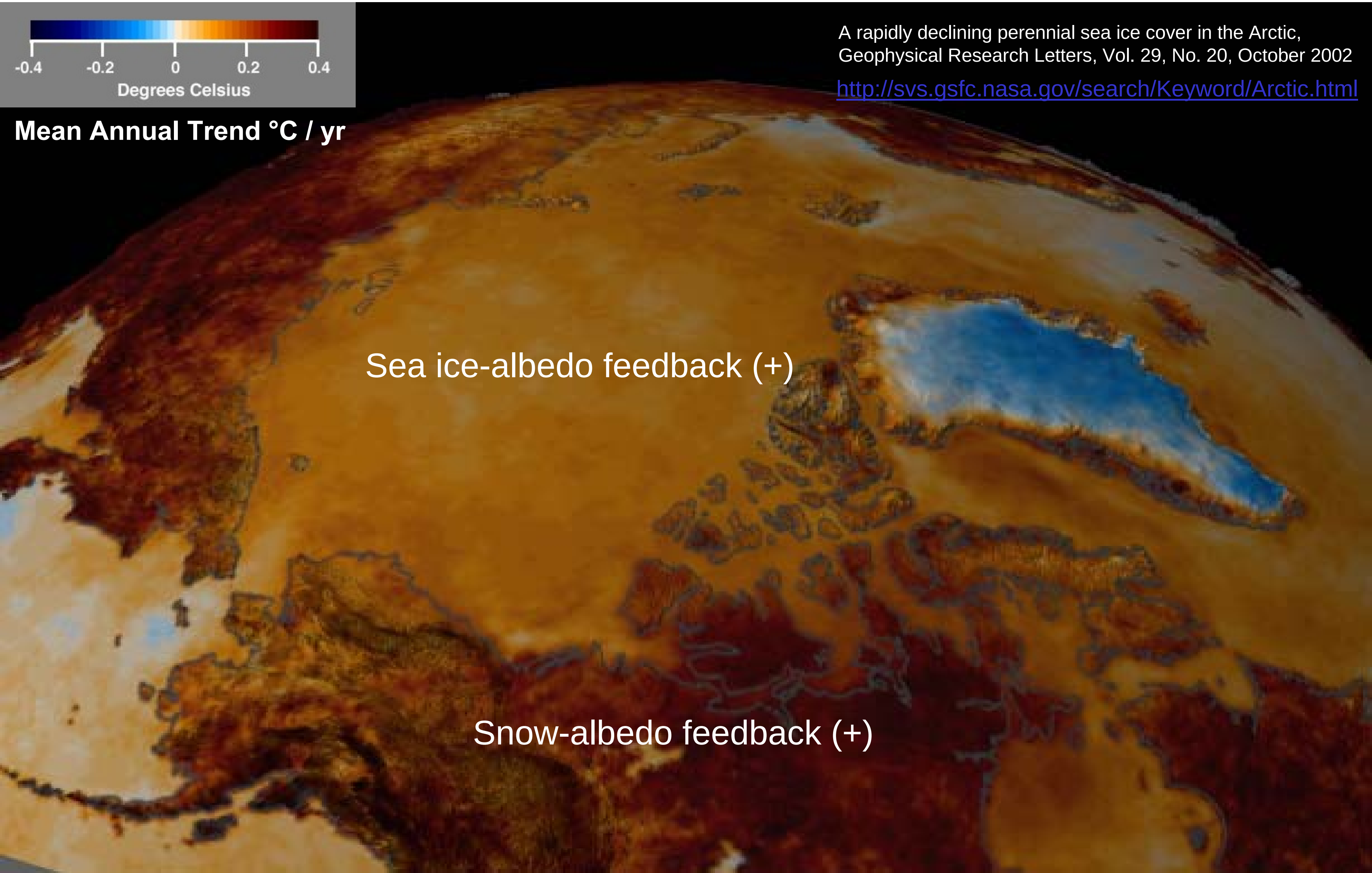
- In Arctic cold low pressure systems aerosols are long-range transported and mixed deeply in the troposphere.
- We have indications that acidic aerosols interact with fast growing TIC-2B to enhance light precipitation on very large scales during Arctic winter with potential effects on weather and climate.
- Three processes lead the generation of potential energy in the Arctic, controlling the hemispheric circulation: one, dynamic-adiabatic, is internal and two diabatic processes, cloud-precipitation (TIC-2B) and low water vapour (DGF) can be altered by anthropogenic acid production.
- Two branches (vertical and horizontal) of a large scale feedback can lead to cold anomalies and enhanced winter storms in the mid-latitudes.
- CloudSat, CALIPSO, Eureka combined to lab experiments and model simulation are determinant in study this key climate process.

AVHRR T 20 yr Summer Temperature Trend

NASA/Goddard Space Flight Center

Scientific Visualization Studio, Larry Stock, Robert Gersten

based on data analysis by Joey Comiso (NASA)



A rapidly declining perennial sea ice cover in the Arctic, Geophysical Research Letters, Vol. 29, No. 20, October 2002

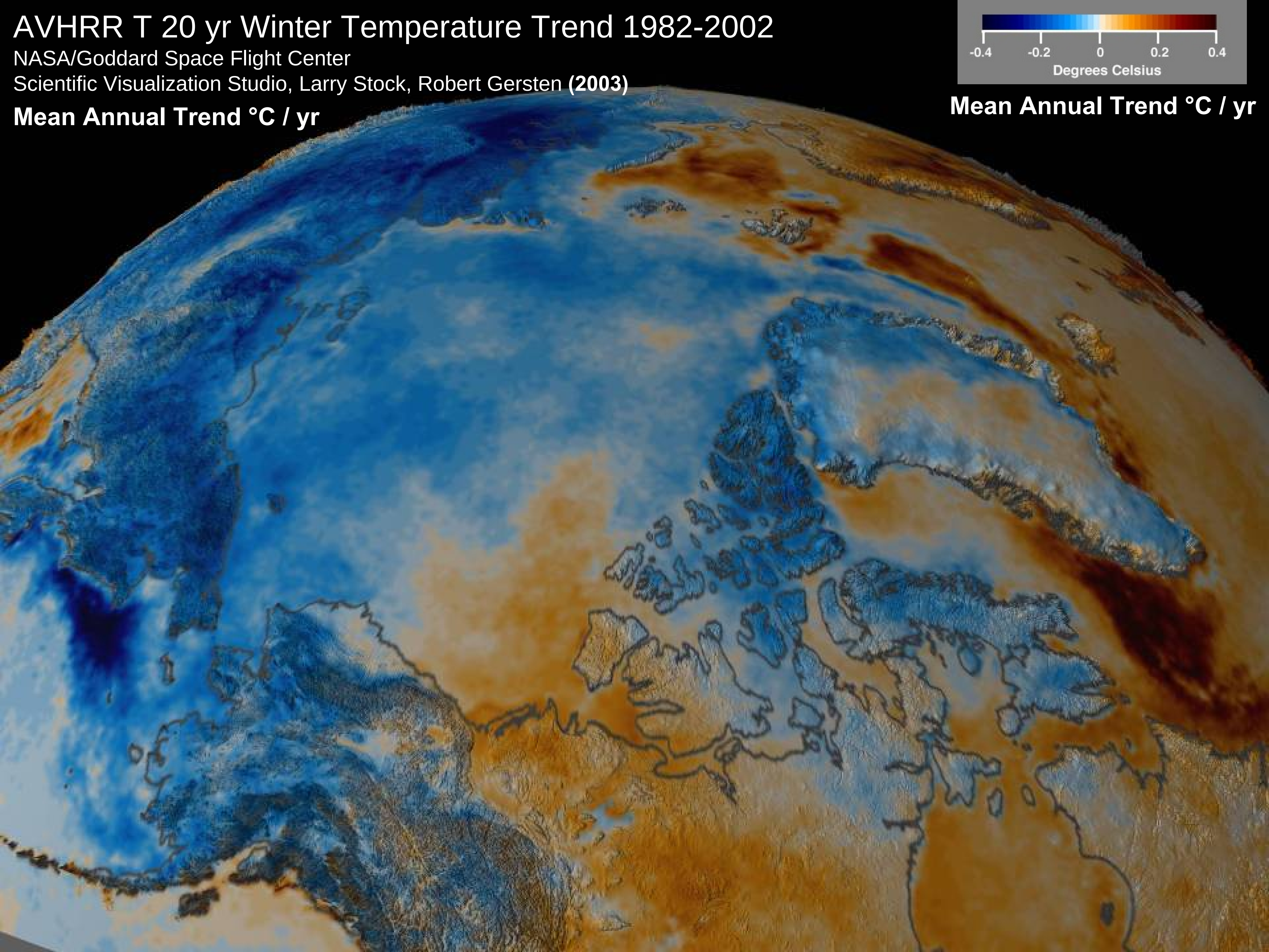
http://svs.gsfc.nasa.gov/search/Keyword/Arctic.html

AVHRR T 20 yr Winter Temperature Trend 1982-2002

NASA/Goddard Space Flight Center

Scientific Visualization Studio, Larry Stock, Robert Gersten **(2003)**

Mean Annual Trend °C / yr

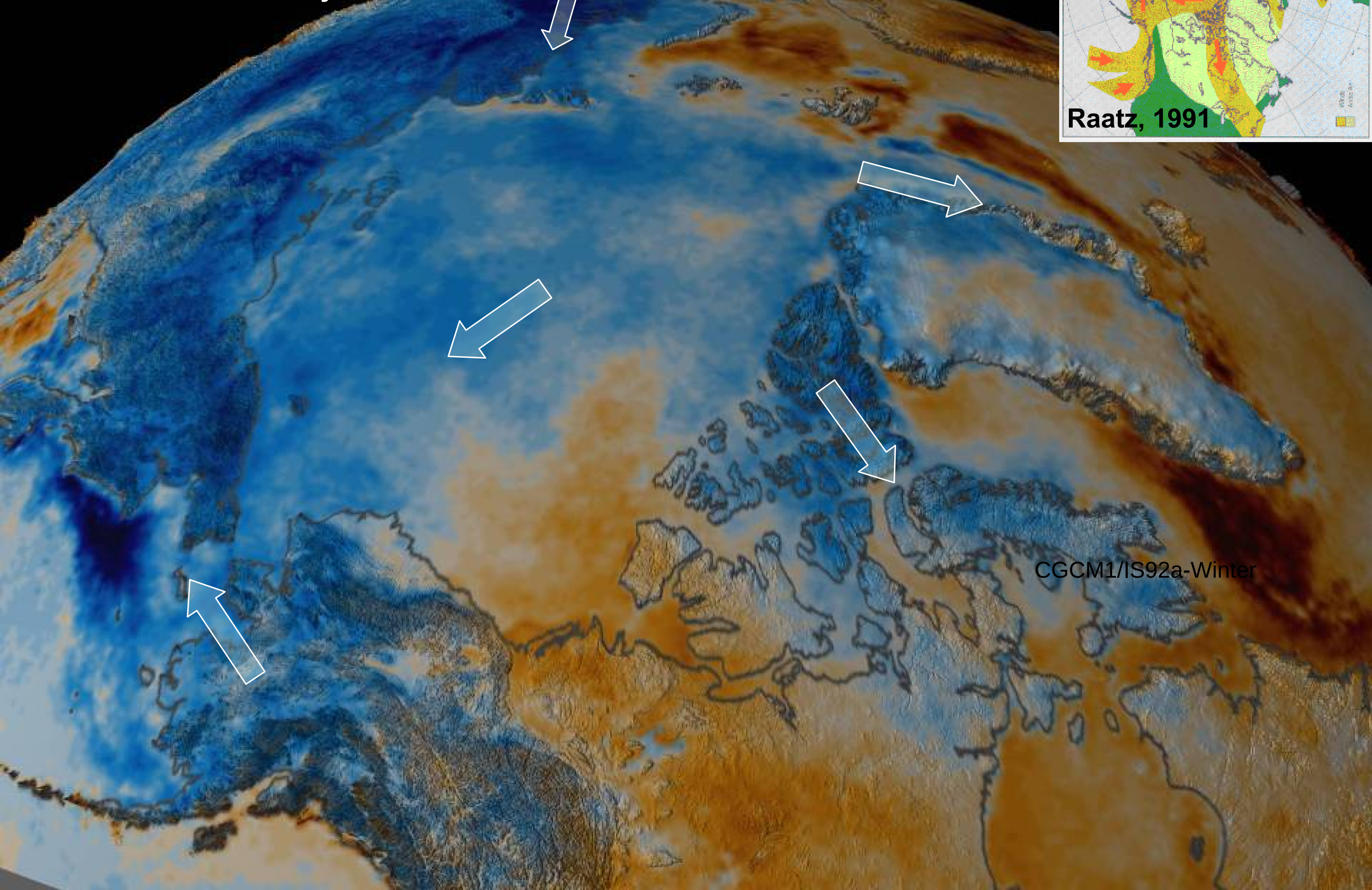


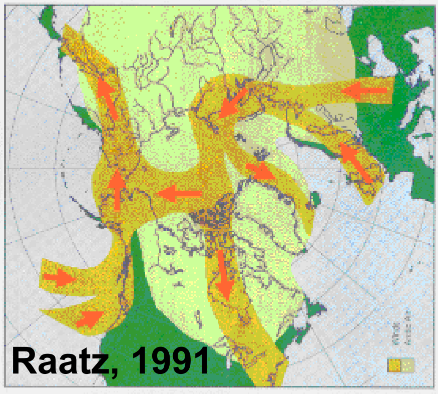
AVHRR T 20 yr Winter Temperature Trend 1982-2002

NASA/Goddard Space Flight Center

Scientific Visualization Studio, Larry Stock, Robert Gersten **(2003)**

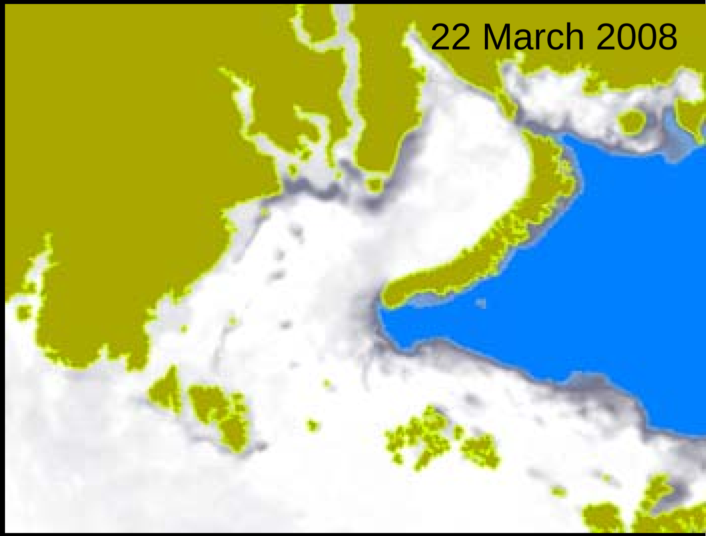
Mean Annual Trend °C / yr





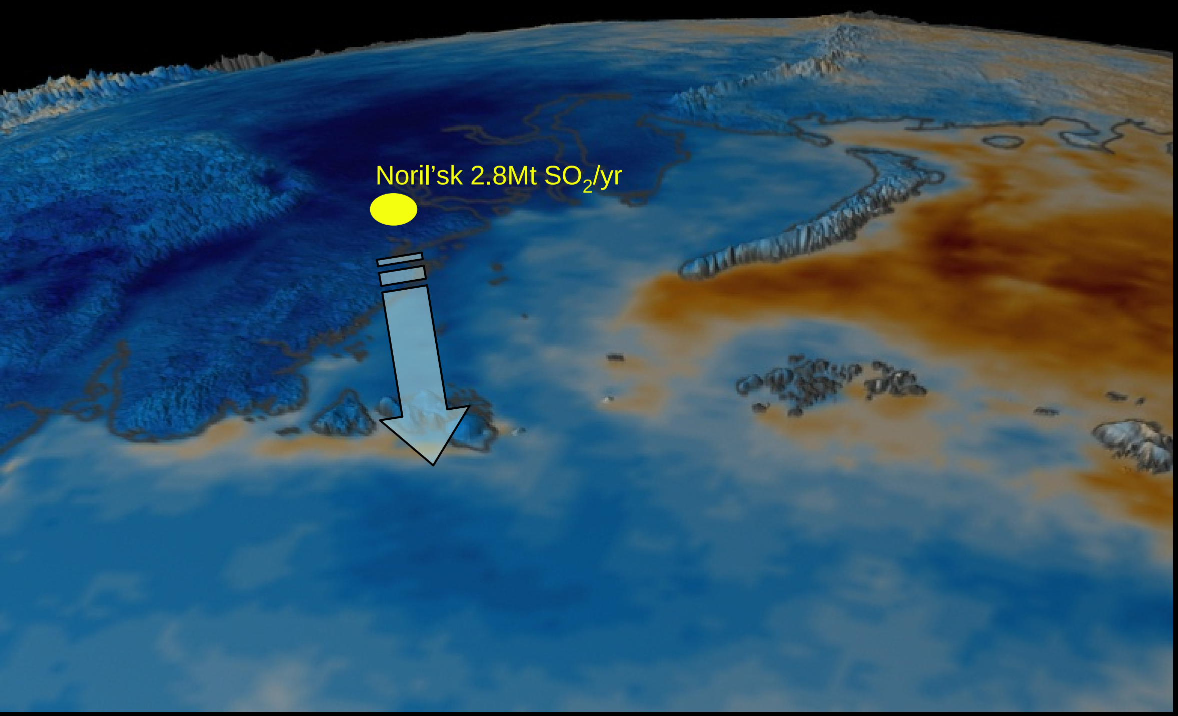
Sulphur Sources and AVHRR Temperature Trend

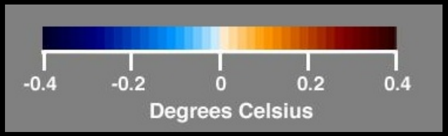
The city of Noril'sk in Russia emits 2.8 million tons of SO_2 per year.
This is another indication that SO_2 – SO_4 sources are affecting surface temperatures trends, here shown in AVHRR at a mean rate of 0.4C/year (8C in 20 years).
It is the signature of the DGF process over land and sea-ice.



http://www.socc.ca/seaice/seaice_current_e.cfm

20-Year Arctic Winter Seasonal Surface Temperature Trend





Mean Annual Trend °C / yr

http://svs.gsfc.nasa.gov/search/Keyword/Arctic.html