Polar clouds and aerosol: Key results from CloudSat-CALIPSO

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ESCER Centre, Université du Québec à Montréal (UQAM)

CLALIPSO-CLOUDSAT
Ten year Progress Assessment and Path Forward

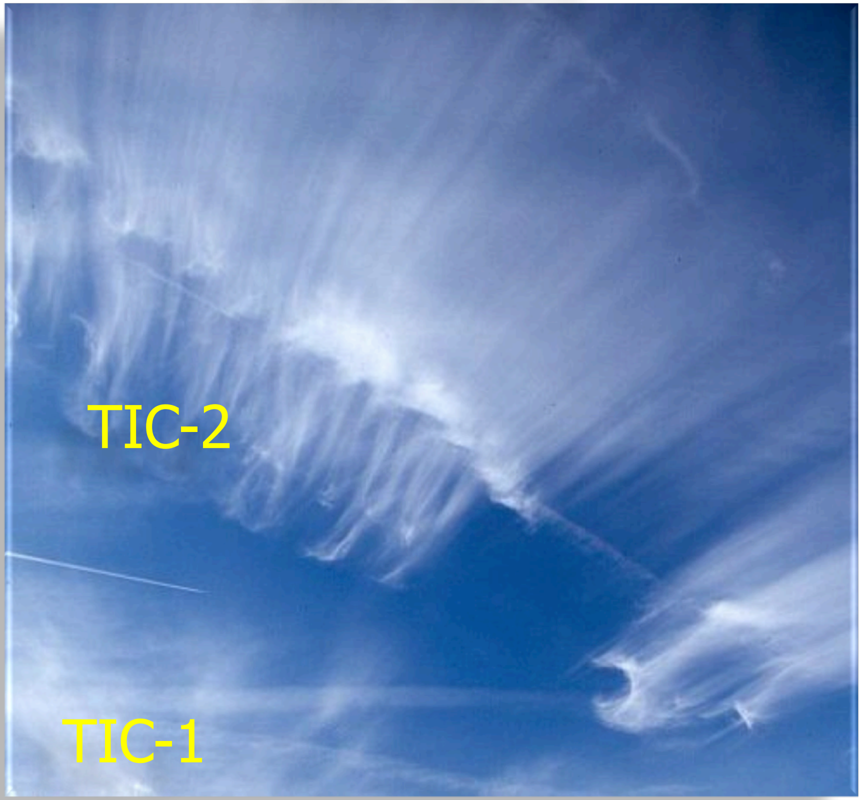
Paris, June 8 - 10, 2016

Plan: A focus on Polar Regions' atmosphere

- **Processes:** Aerosol – Clouds – Radiation – Precipitation – Circulation.
- **Observations:** Space, ground, aircraft and laboratory experiments.
- **Validation:** From ground-based, via *in-situ* aircraft to satellites.
- ~~**Model simulations:** Microphysics, radiation and climate models.~~
- **Data assimilation:** Operational forecast ~~and climate models~~.
- **Future missions:** Active – passive instruments.

Polar Thin Ice Clouds

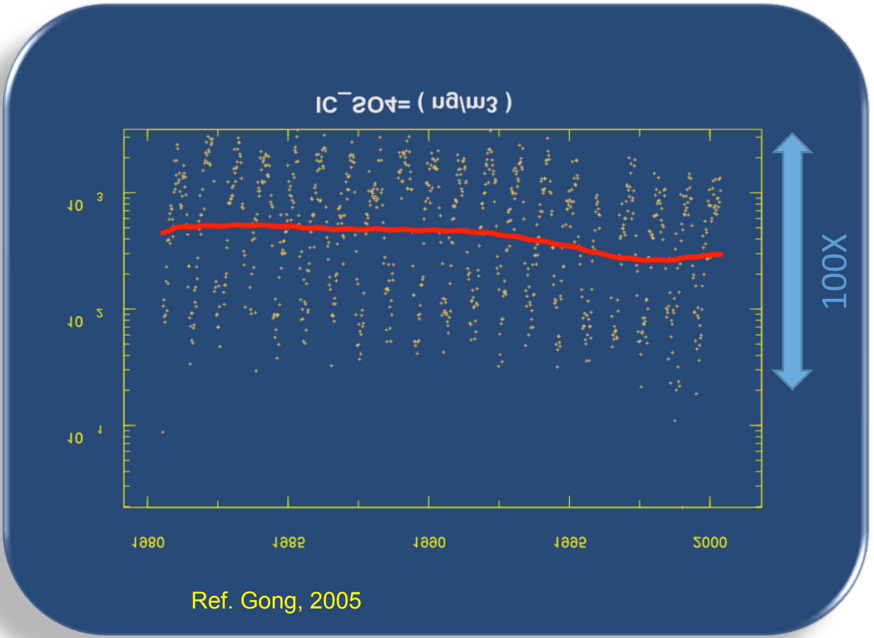
CIRRUS FIBRATUS



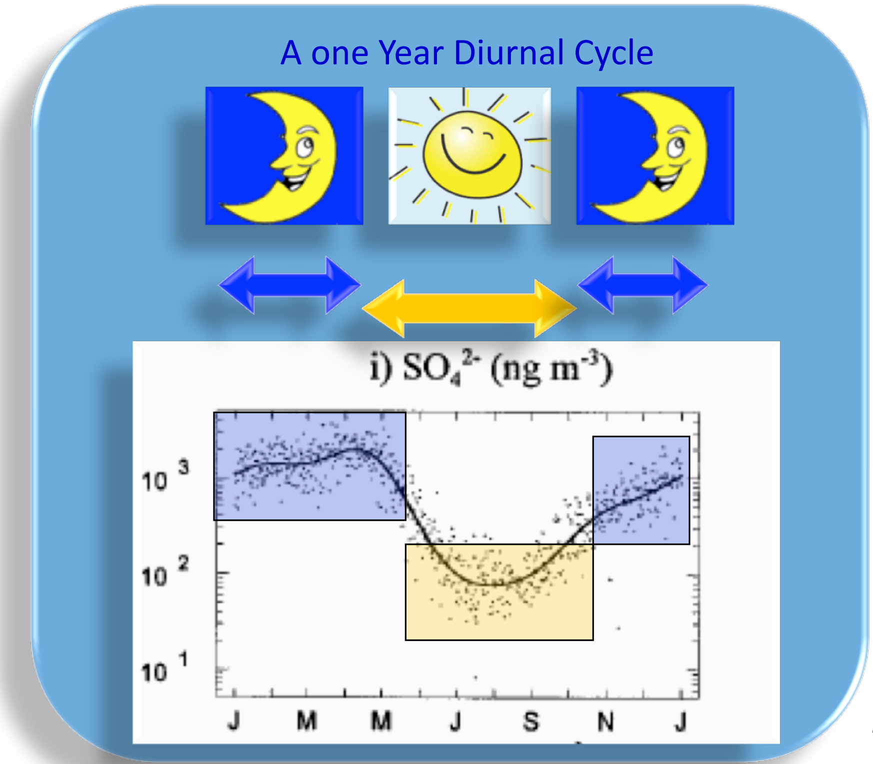
http://www.astrosurf.com/luxorion/meteo-nuages-images.htm

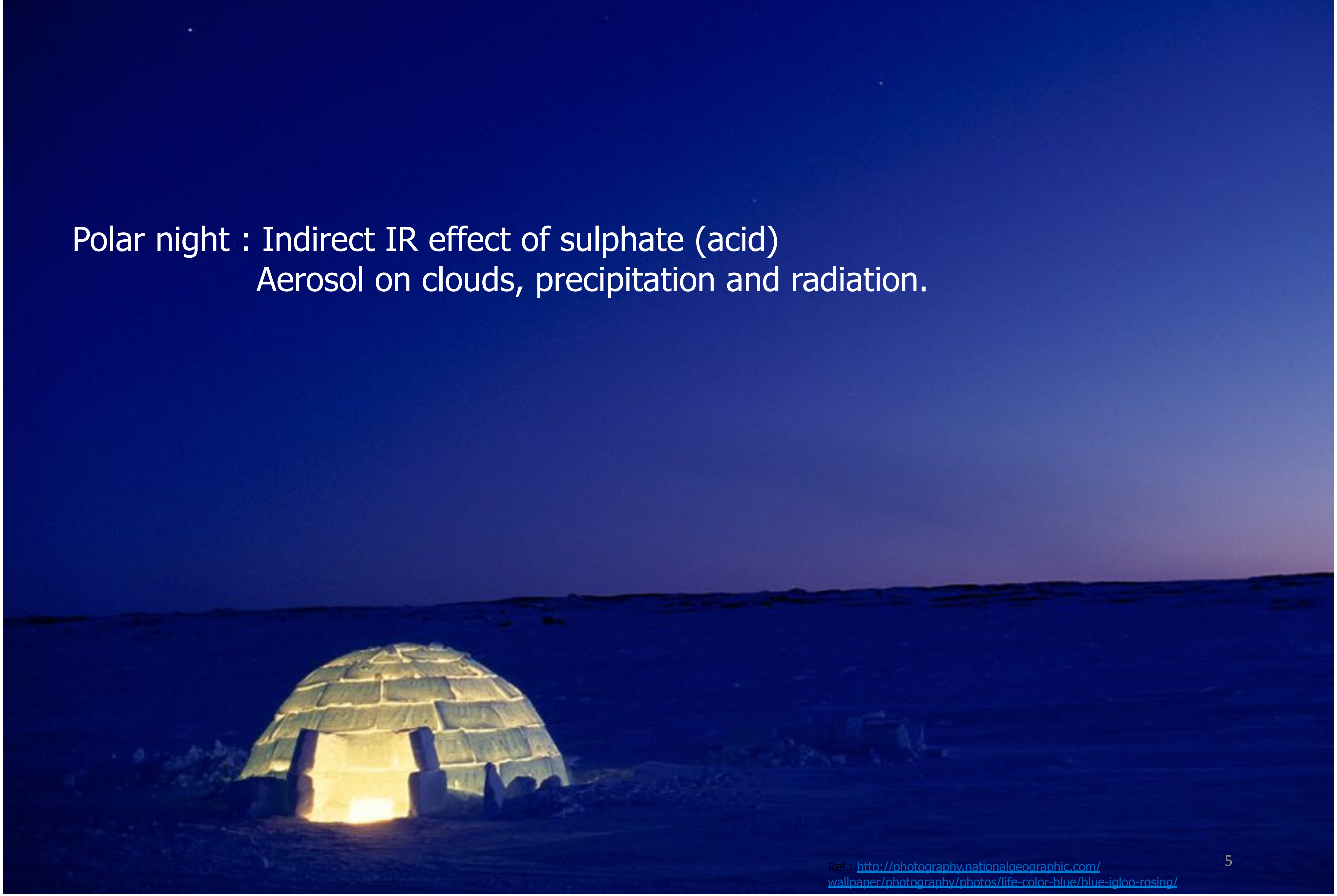
Sulphate Trend and Seasonal Variation

- Due to anthropogenic emission, sulphate concentration increases by about 50X during polar night with respect to the cleaner summer time.
- The associated sulfuric acid is responsible for TIC modulation and dehydration.
- The cooling process is predicted by model simulations and observed from satellites and ground stations.



Ref. Gong, 2005



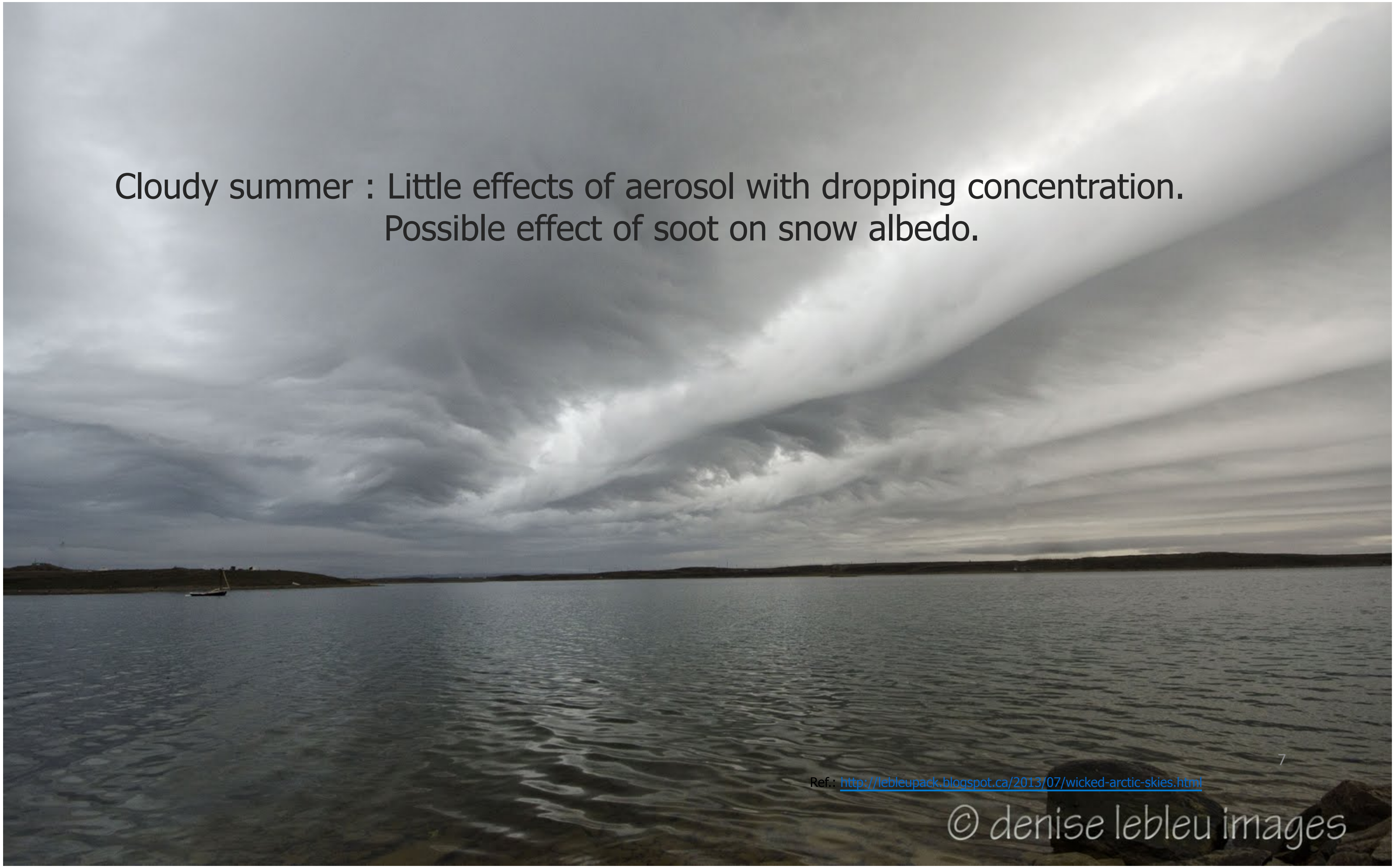


Polar night : Indirect IR effect of sulphate (acid)
Aerosol on clouds, precipitation and radiation.

Ref.: http://photography.nationalgeographic.com/wallpaper/photography/photos/life-color-blue/blue-igloo-rosing/

Clear skies spring : Direct solar effect of arctic haze
Sulphate and soot aerosols on solar radiation.

Ref.: http://johanna.wandel.ca/babbles/archives/000105.html


Cloudy summer : Little effects of aerosol with dropping concentration.
Possible effect of soot on snow albedo.
Ref.: http://lebleupack.blogspot.ca/2013/07/wicked-arctic-skies.html
© denise lebleu images
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CALIPSO – CloudSat revealed very extensive TIC associated to sulphate aerosol

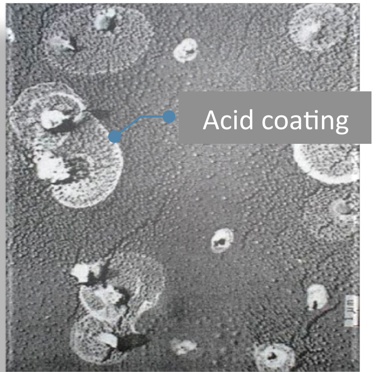
Ref.: http://www.touristmaker.com/climate/polar.html

Processes

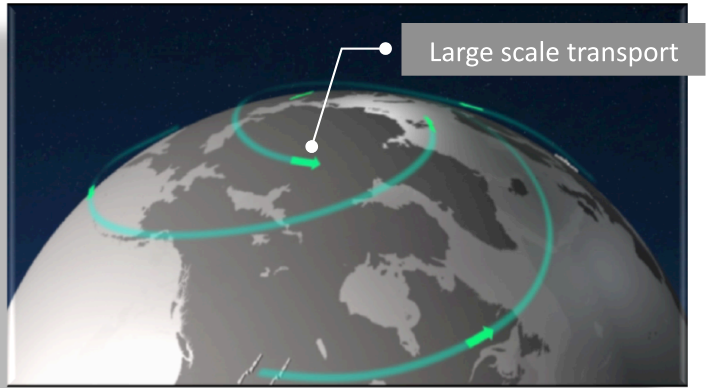
Aerosol – Clouds – Radiation – Precipitation – Circulation

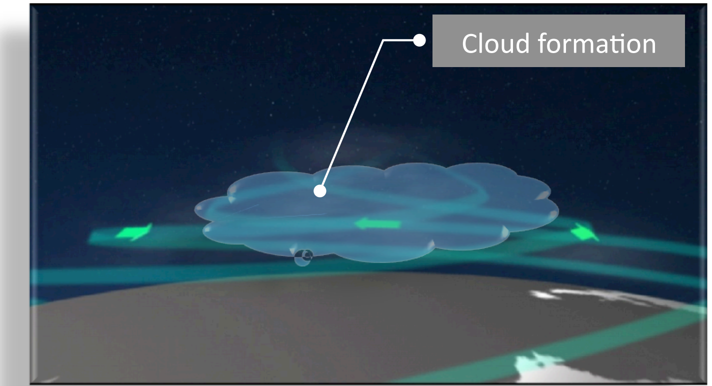
Background

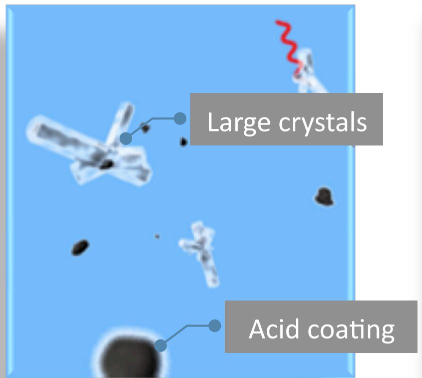
- Early DGF hypothesis (Blanchet & Girard, Nature, 1994)

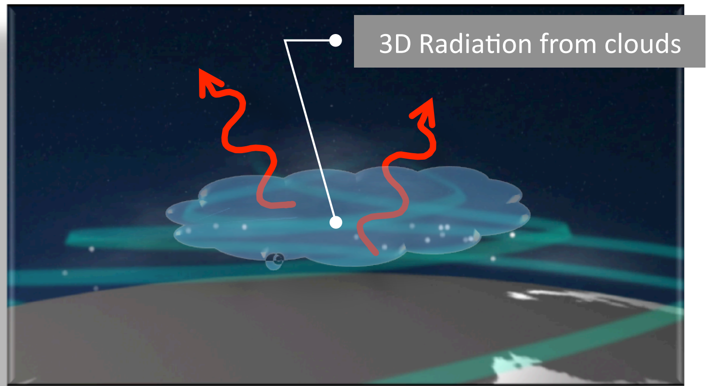


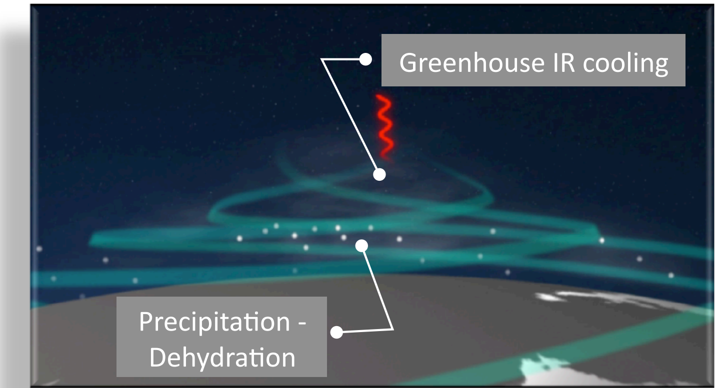
(Bigg, 1980)





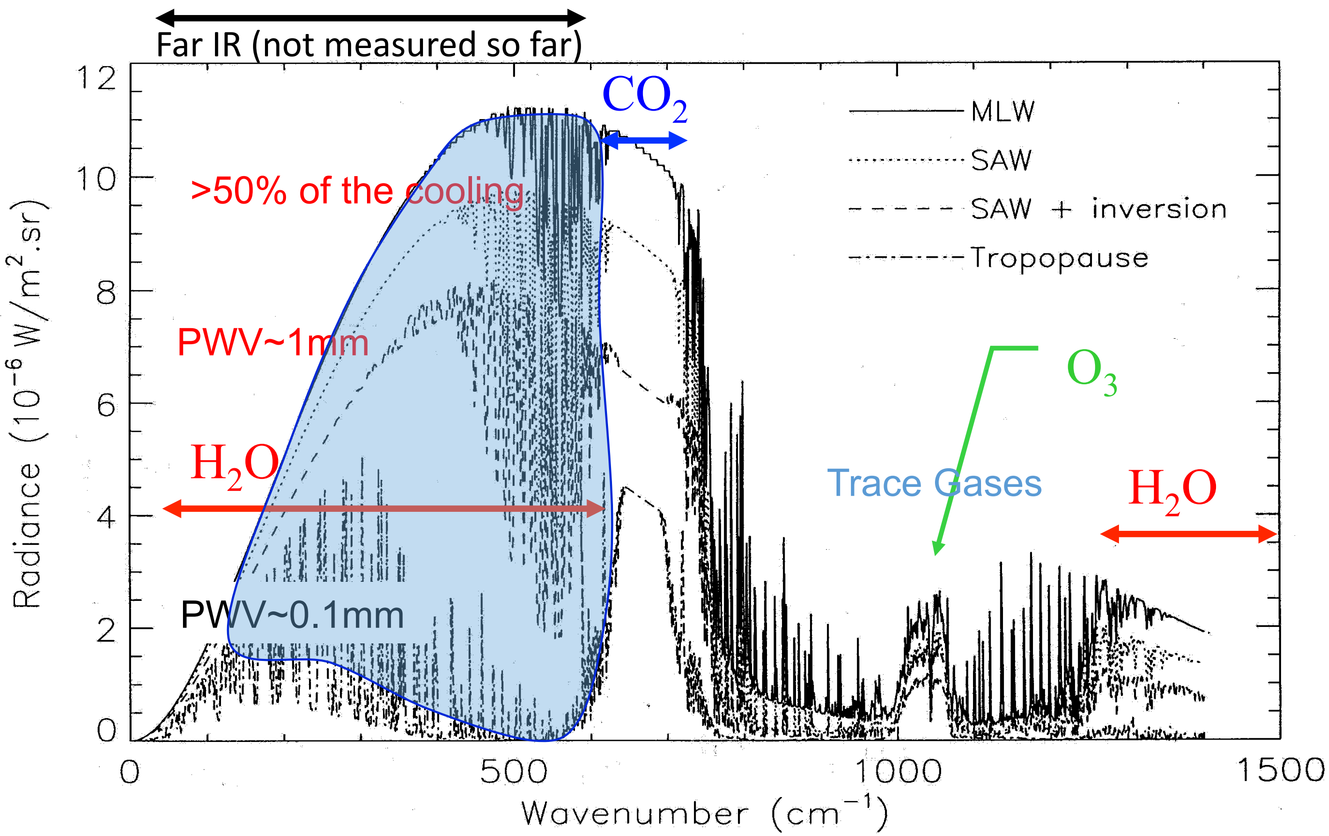






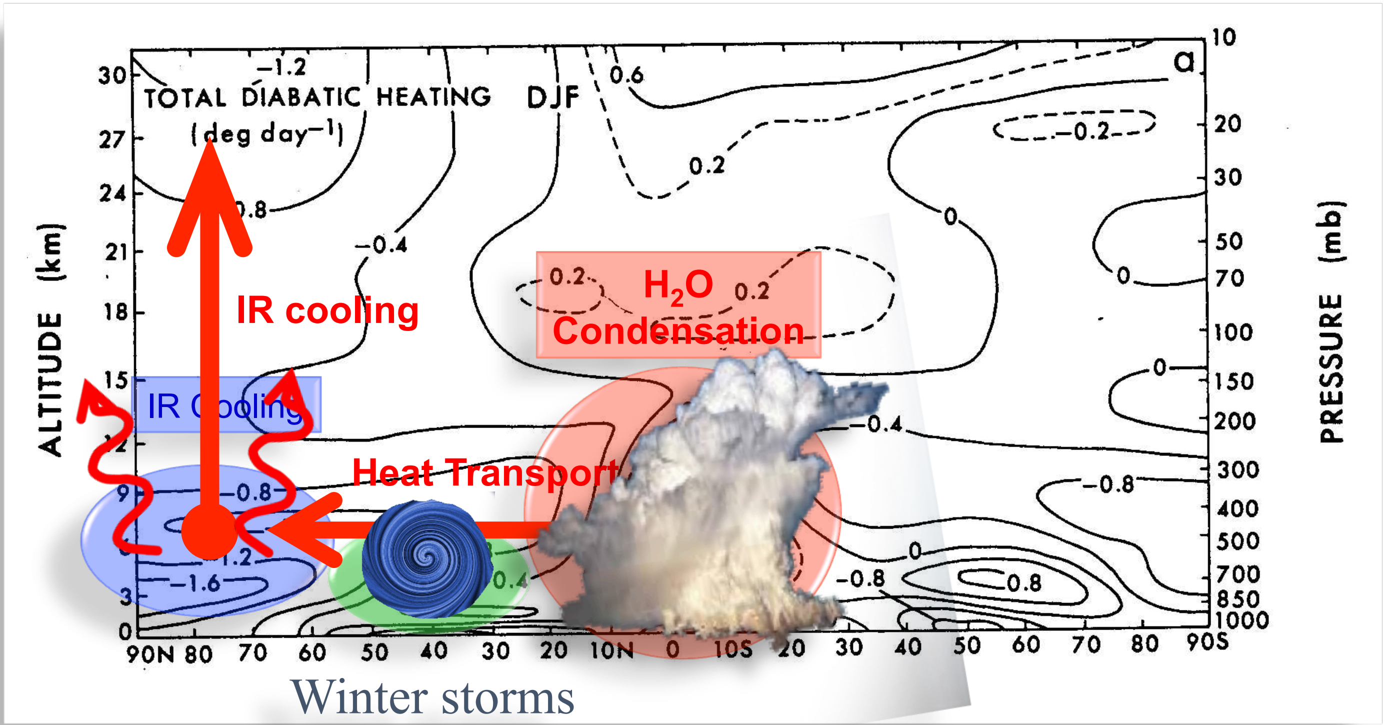
Greenhouse Atmospheric Radiation at the ground

- From enhanced precipitation/dehydration a vast spectral cooling window opens up in the far IR range, in the so called « dirty window ».



Generation of Available Potential Energy in the Atmosphere due to Latent Heat (tropics) and Radiative Cooling (Poles)

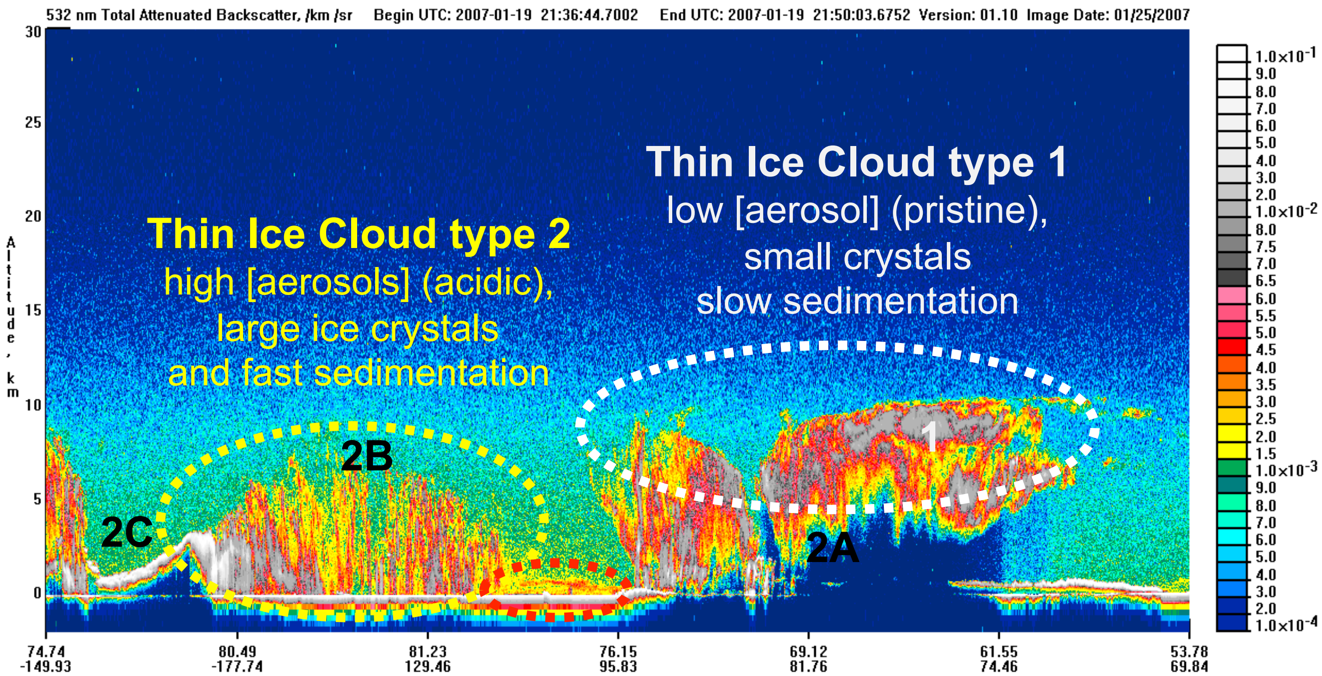
- Increasing cooling rates in the Arctic during winter, enhances the heat deficit
- Storm activities are strengthened to transport and fill the energy gap



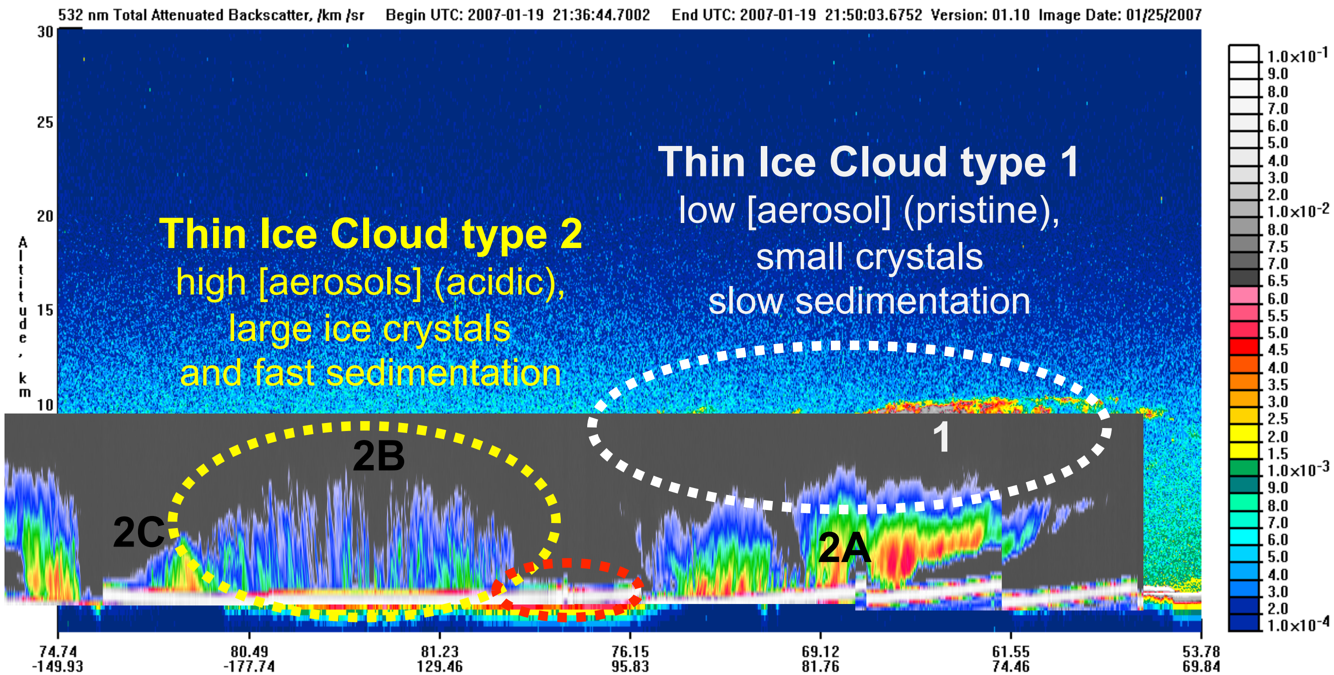
Atmospheric Heat Pump

Ref.: Newell, R.E., Kidson, J.W., Vincent, D.G., Boer, G.J.: The General Circulation of the Tropical. Atmosphere and Interactions with extratropical latitudes

Radar – Lidar Thin Ice Cloud Types (Definition)

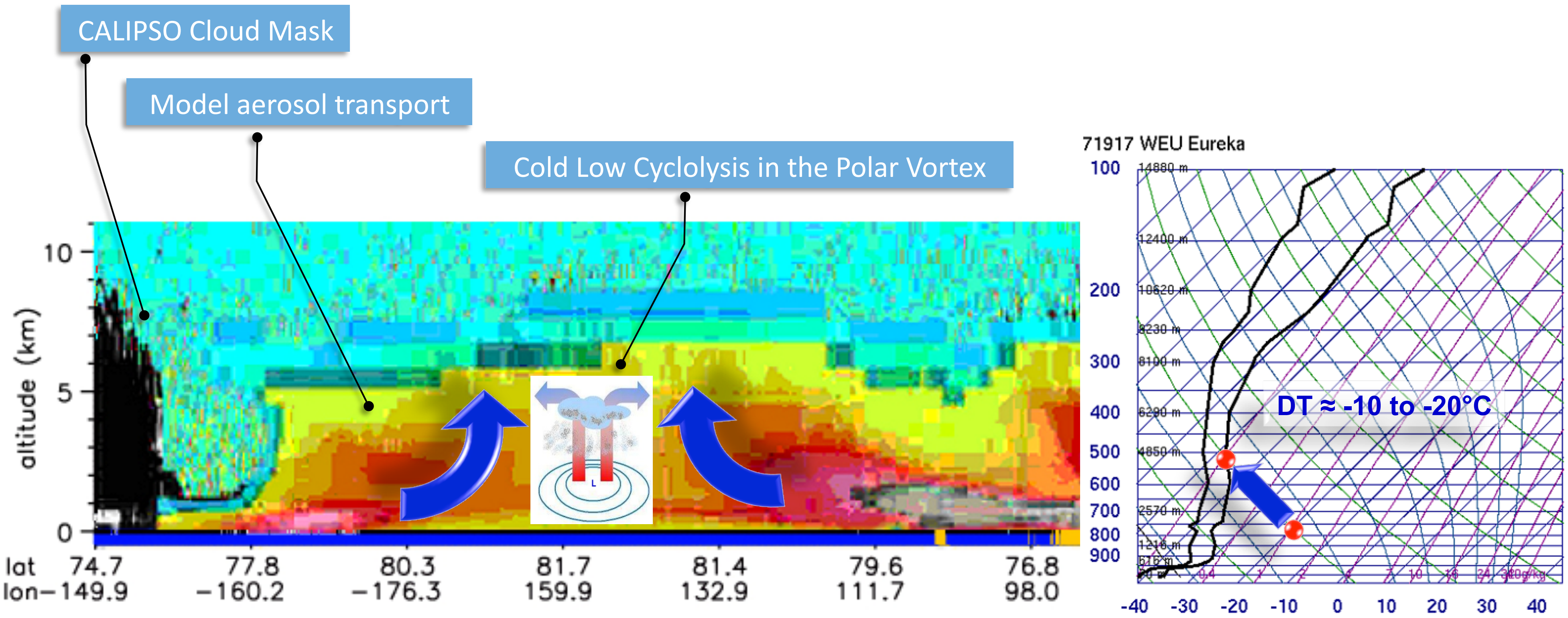


Radar – Lidar Thin Ice Cloud Types (Definition)



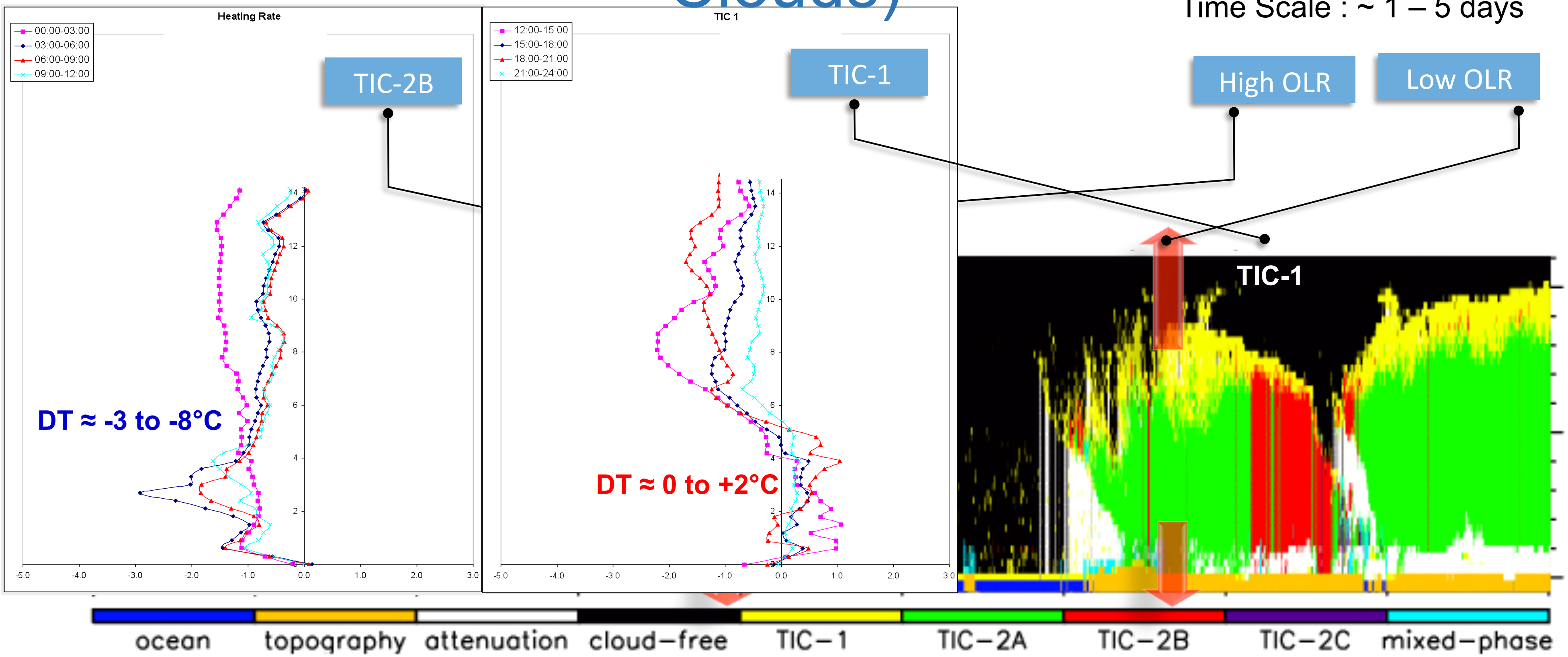
Process #1 – Adiabatic Cooling (Dynamics)

Time Scale : ~ 6 – 24 hours



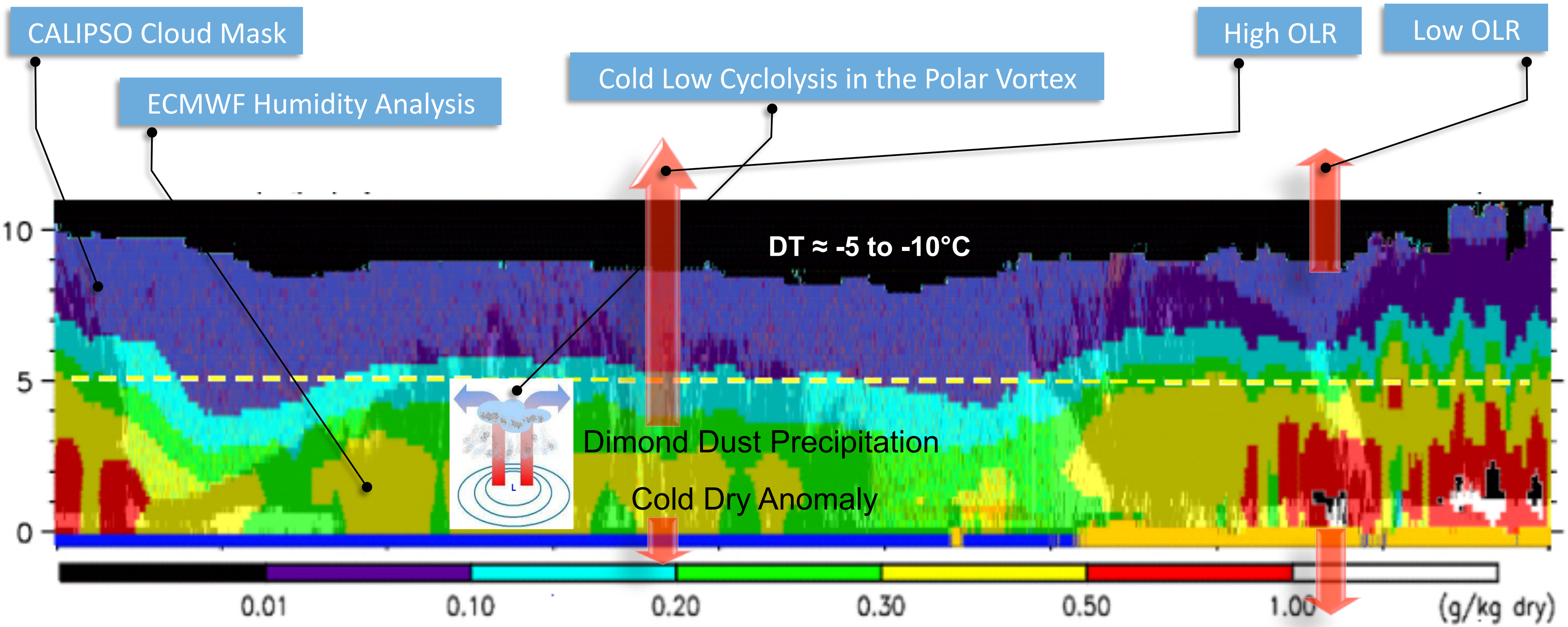
Process #2 – Direct IR Cooling (IR from Ice Clouds)

Time Scale : ~ 1 – 5 days



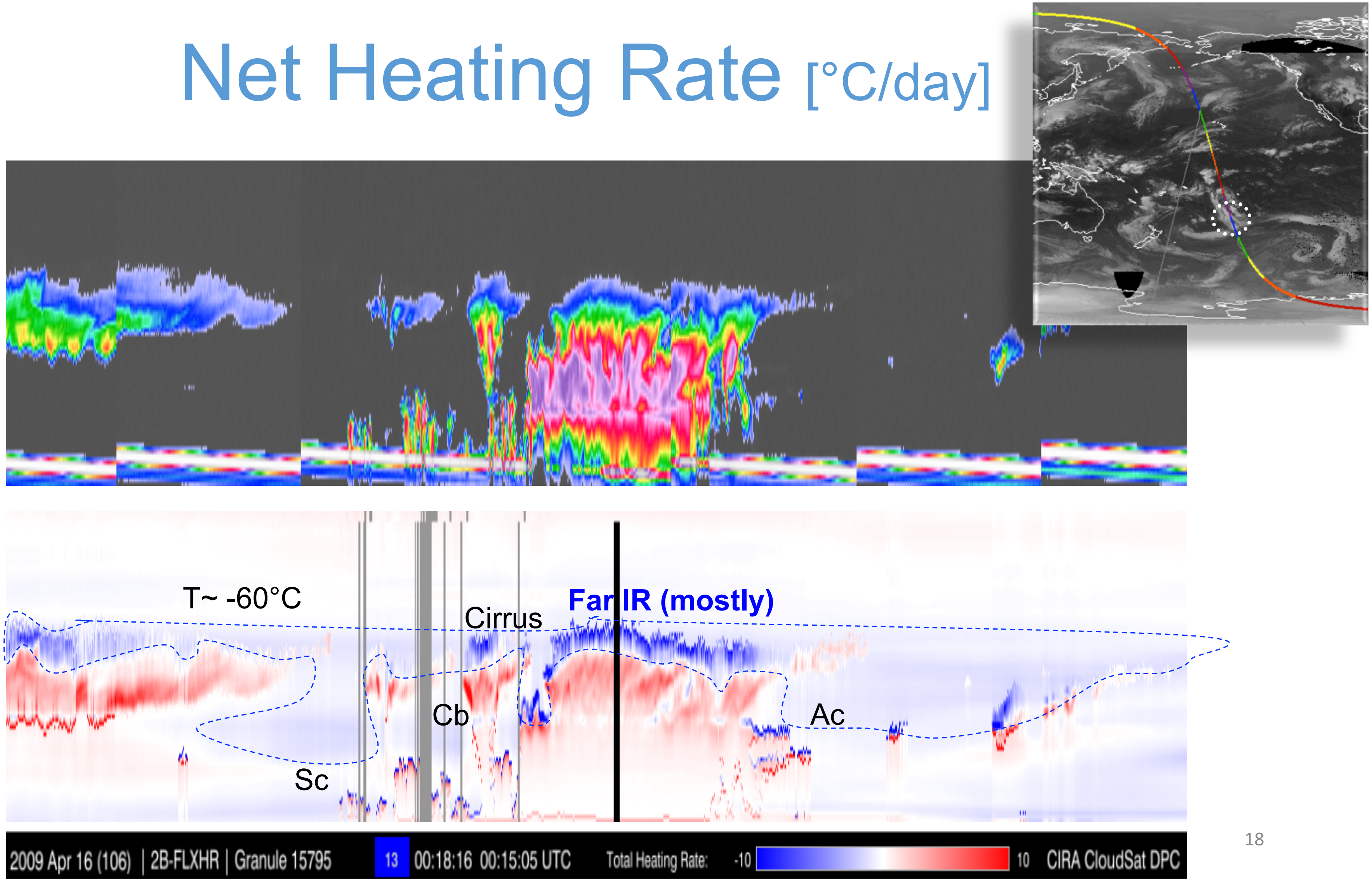
Process #3 – Indirect IR Cooling (Lost Water Vapor GHG)

Time Scale : ~ 1 – 2 weeks

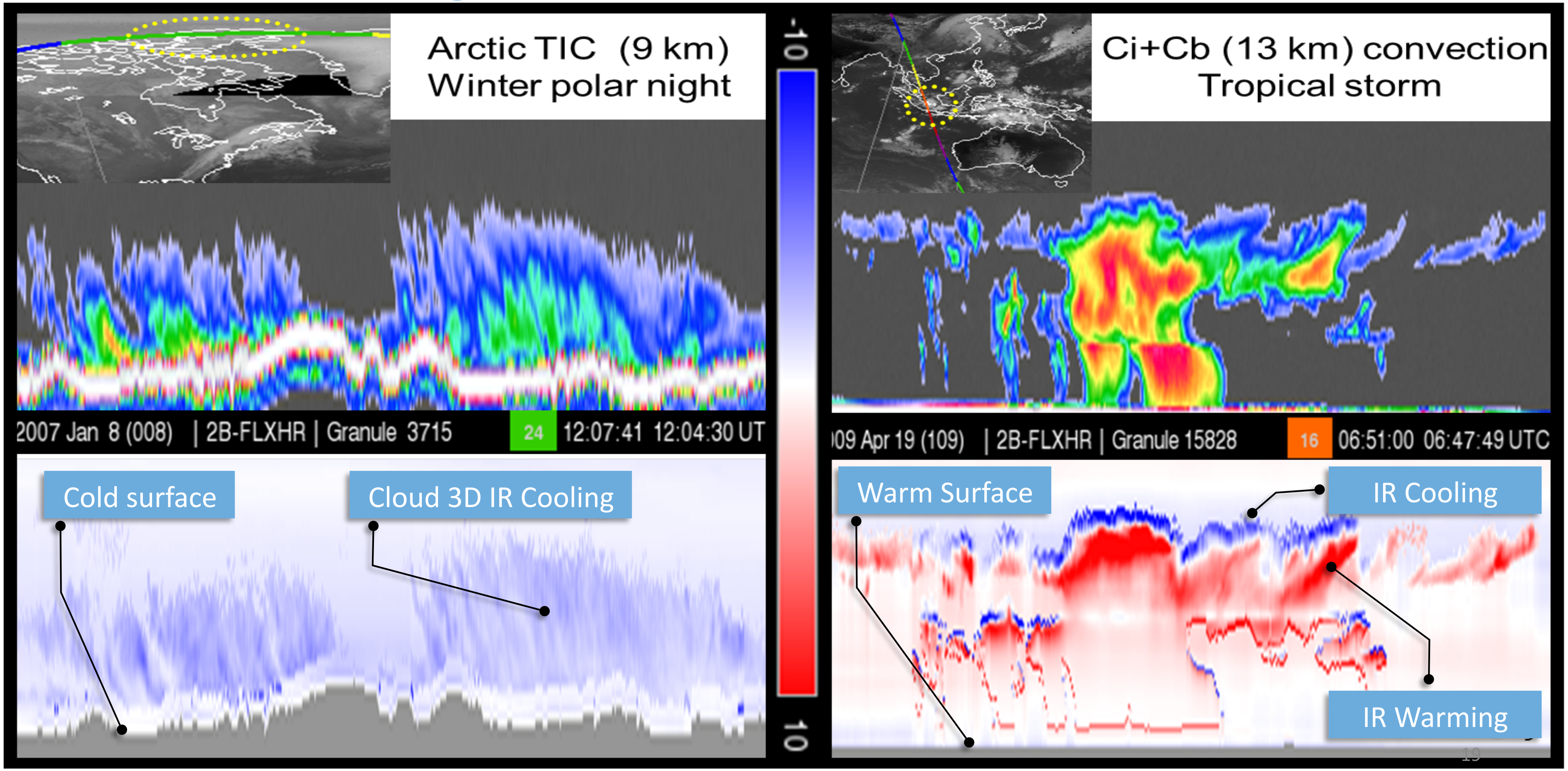


PCP-Water ~ 1 mm Model Bias + 0.3 mm (30%)

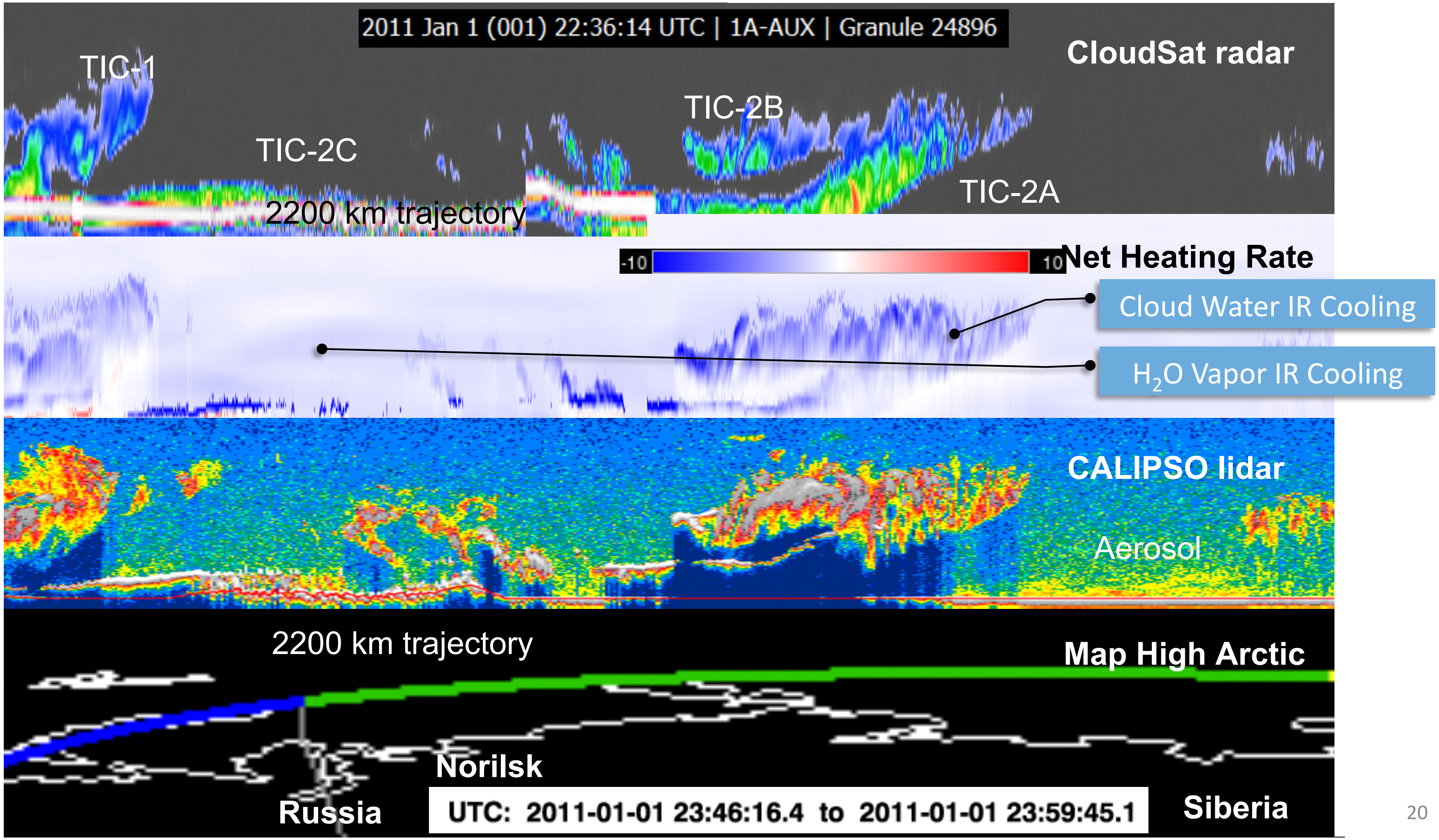
Net Heating Rate [°C/day]



Net Heating Rate [°C/day]: TIC vs ITCZ Ci+Cb



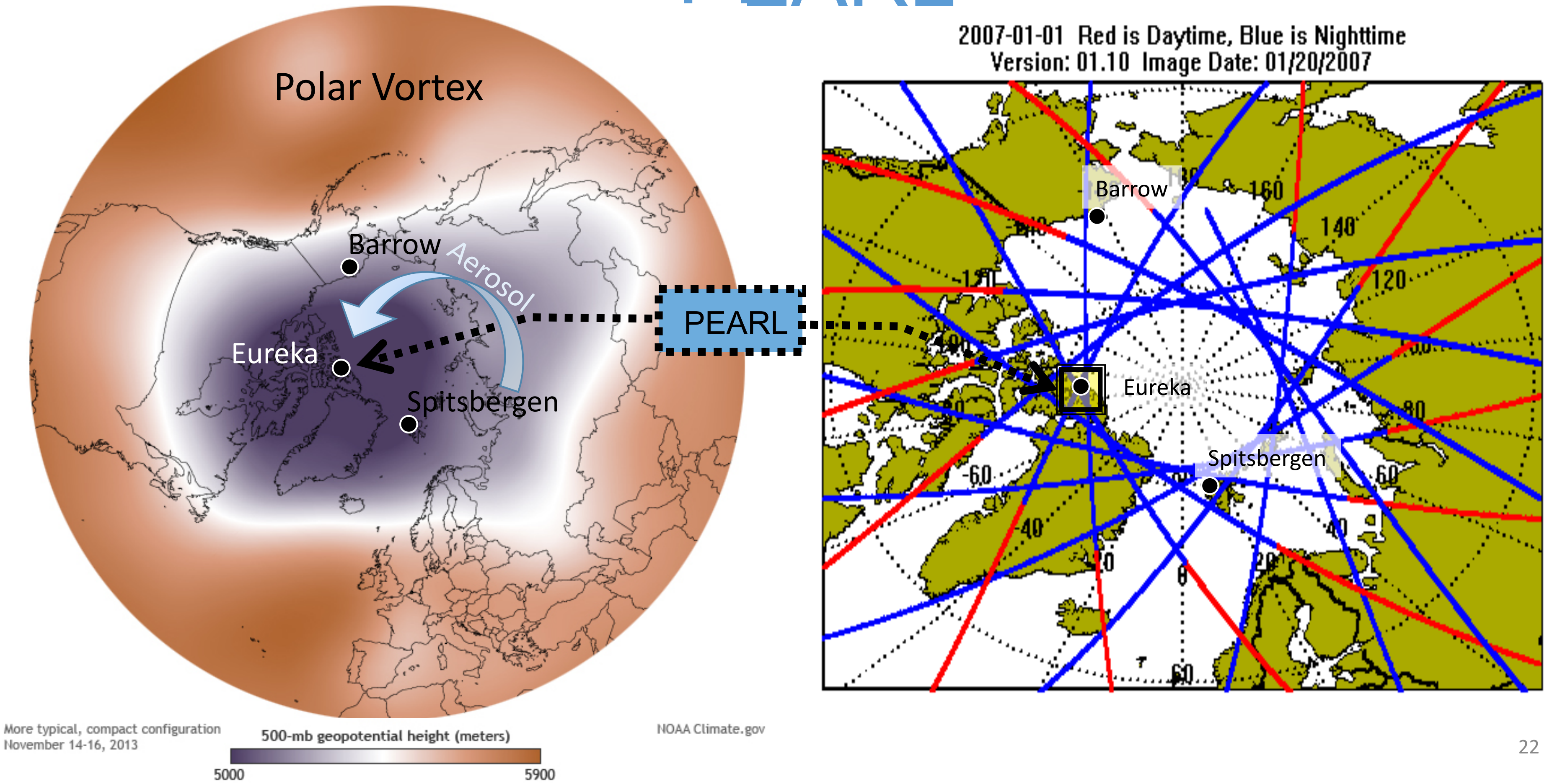
Arctic Clouds: TIC-1, TIC-2A, TIC-2B, TIC-2C

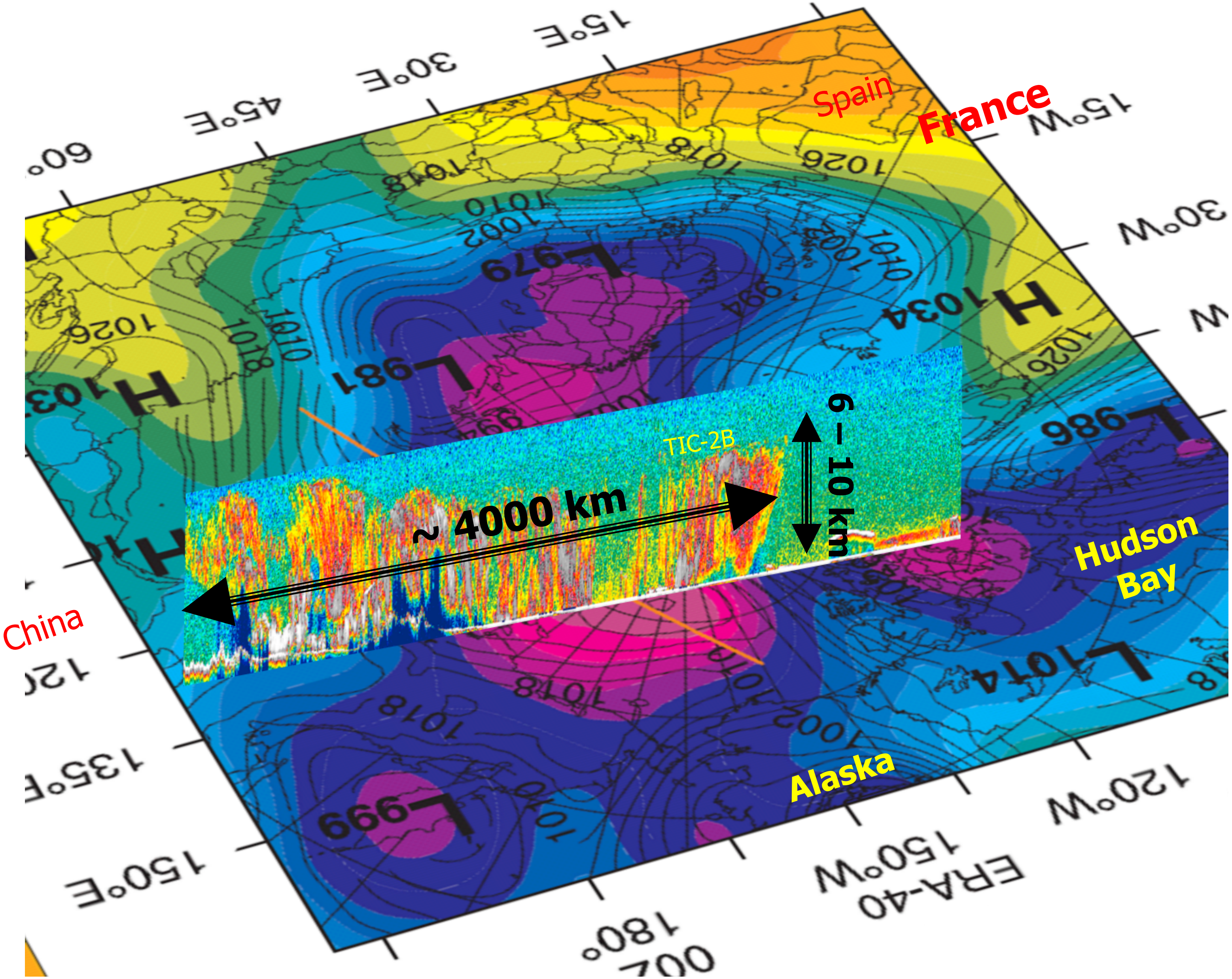


Observations

Space, ground, aircraft and laboratory experiments

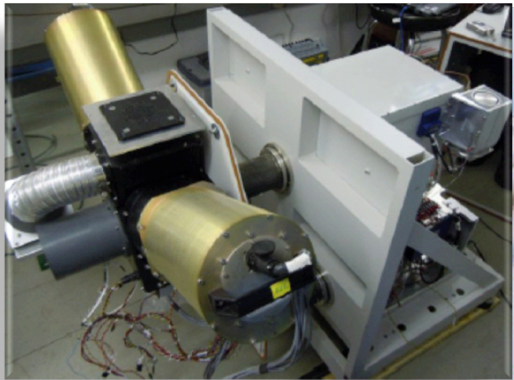
Polar Night Observations: A-Train and PEARL

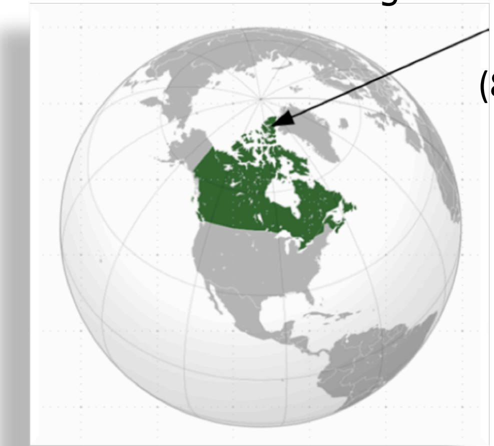



Spain
France
TIC-2B
~ 4000 km
6 – 10 km
Hudson Bay
China
Alaska

E-AERI & FIRR at PEARL 2015-16

In preparation for TICFIRE microsat mission, 3 campaigns are planed to test FIRR during winter



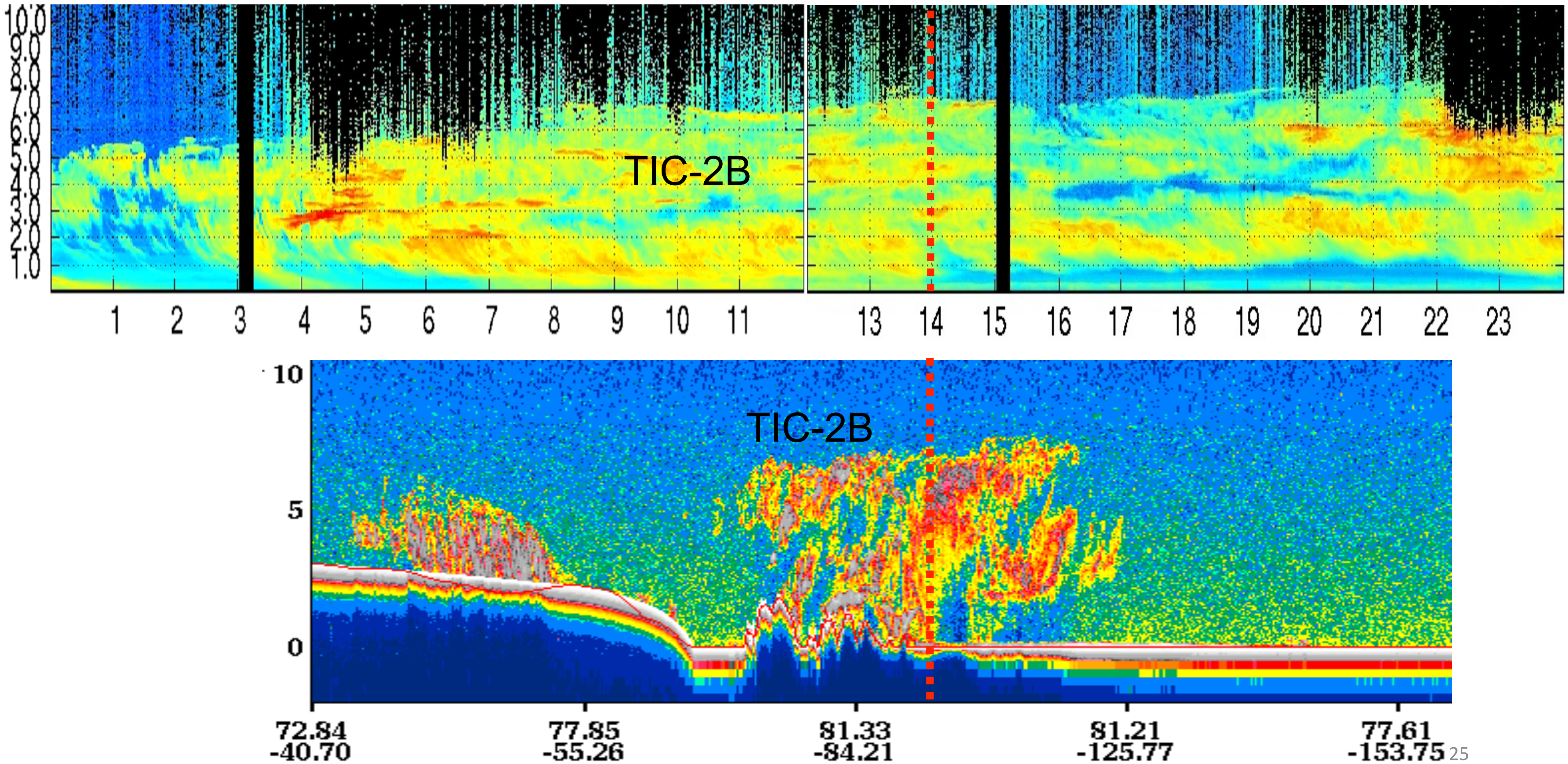


Eureka, NU
(80°N, 86°W)

TIC-2B from PEARL and CALIPSO Simultaneously

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

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

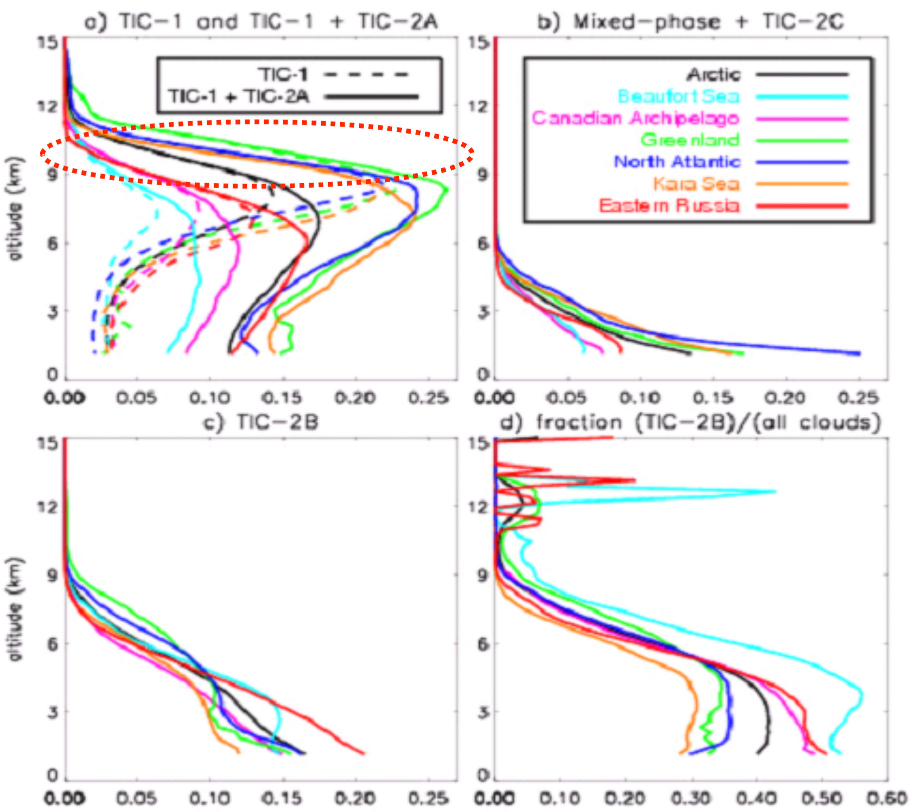


TIC Type Amount: CloudSat-CALIPSO vs PEARL

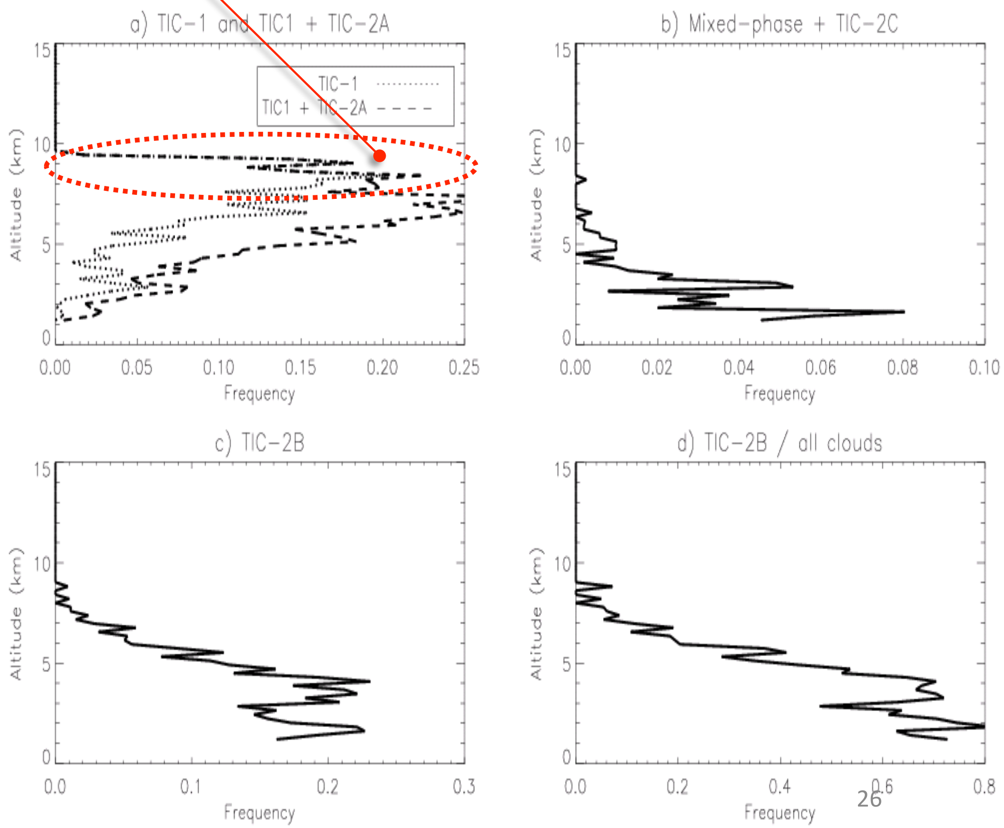
January 2007

TIC formation in the lower stratosphere

From Space: CALIPSO-CloudSat

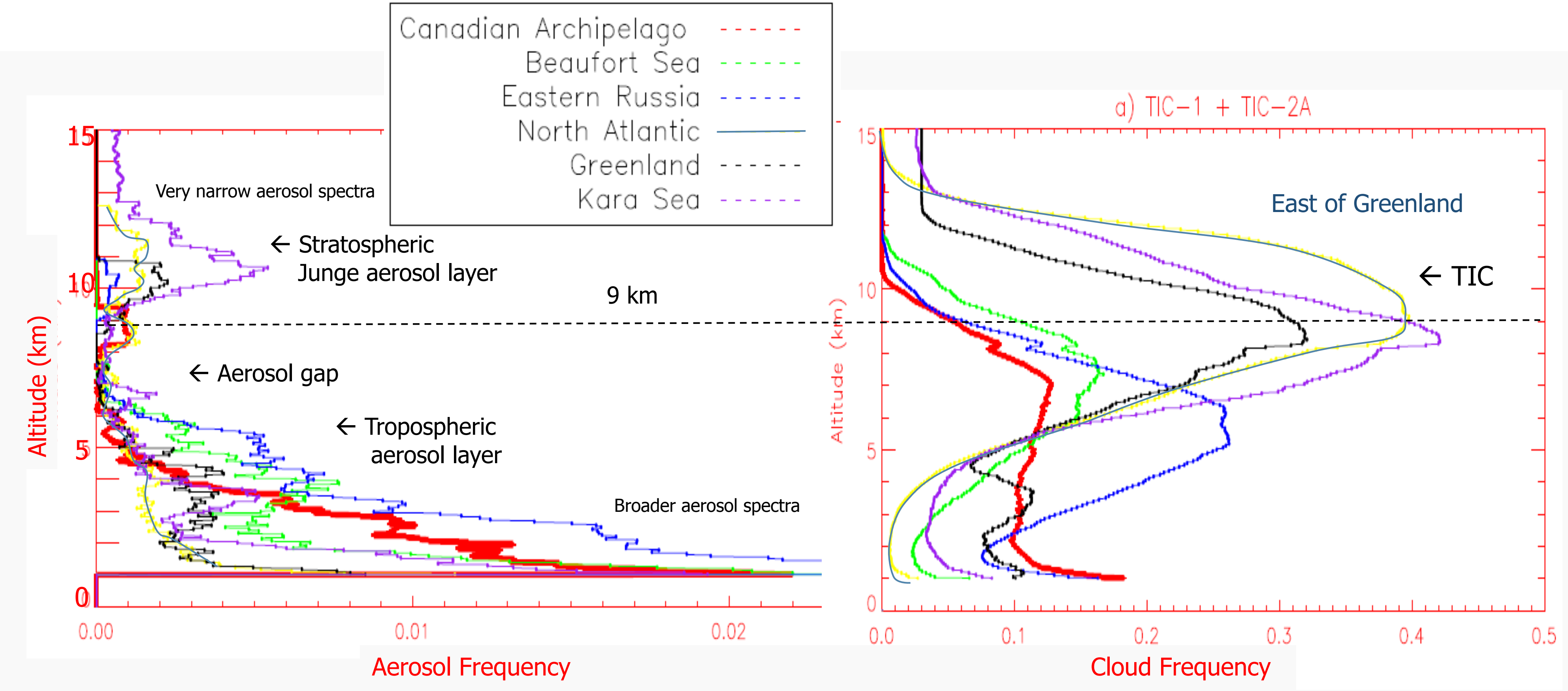


From Ground Base: Lidar-Radar @ Eureka



TIC Clouds and PRECIPITATION initiated in the UTLS region

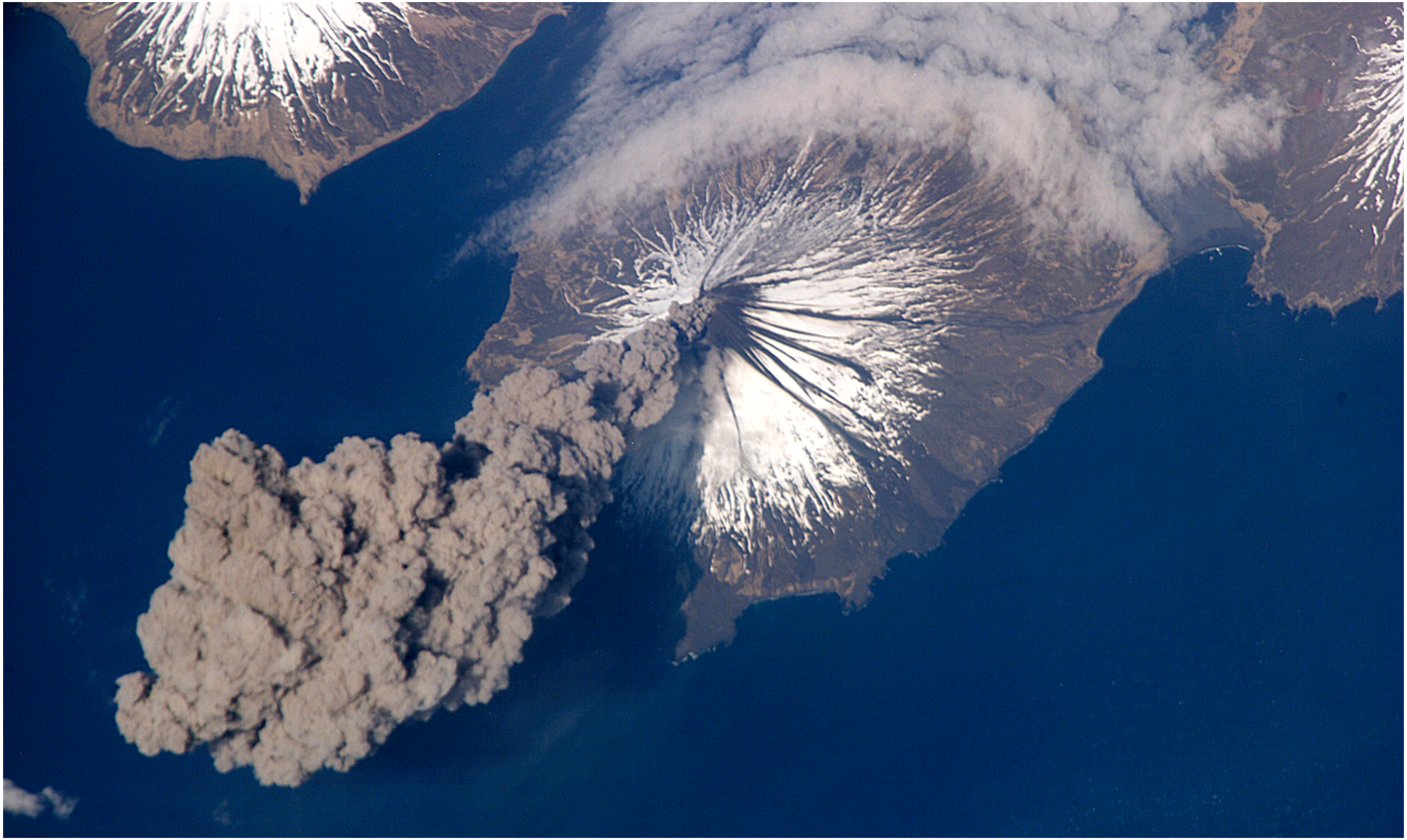
CALIPSO Dataset (Jan 2010)

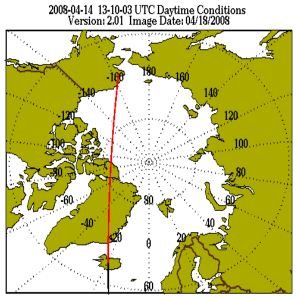


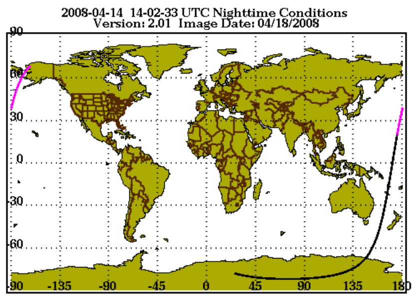
Ref.: Yacine Bouzid

Validation

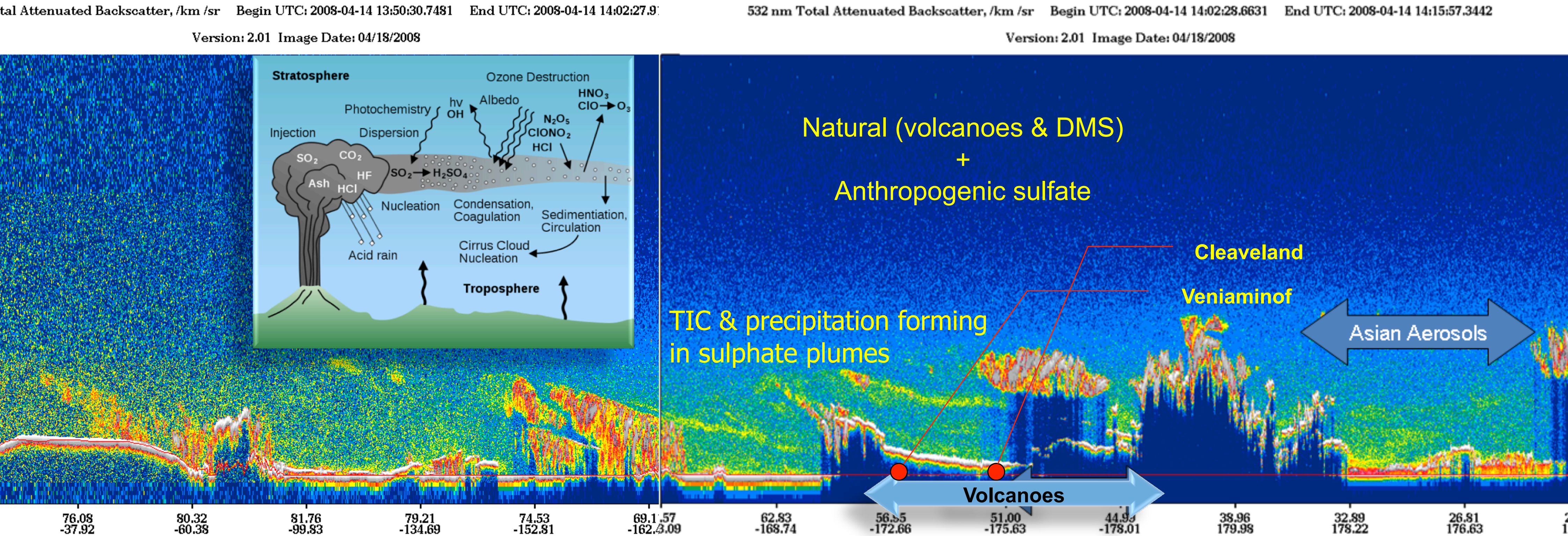
From ground-based, via *in-situ* aircraft to satellites





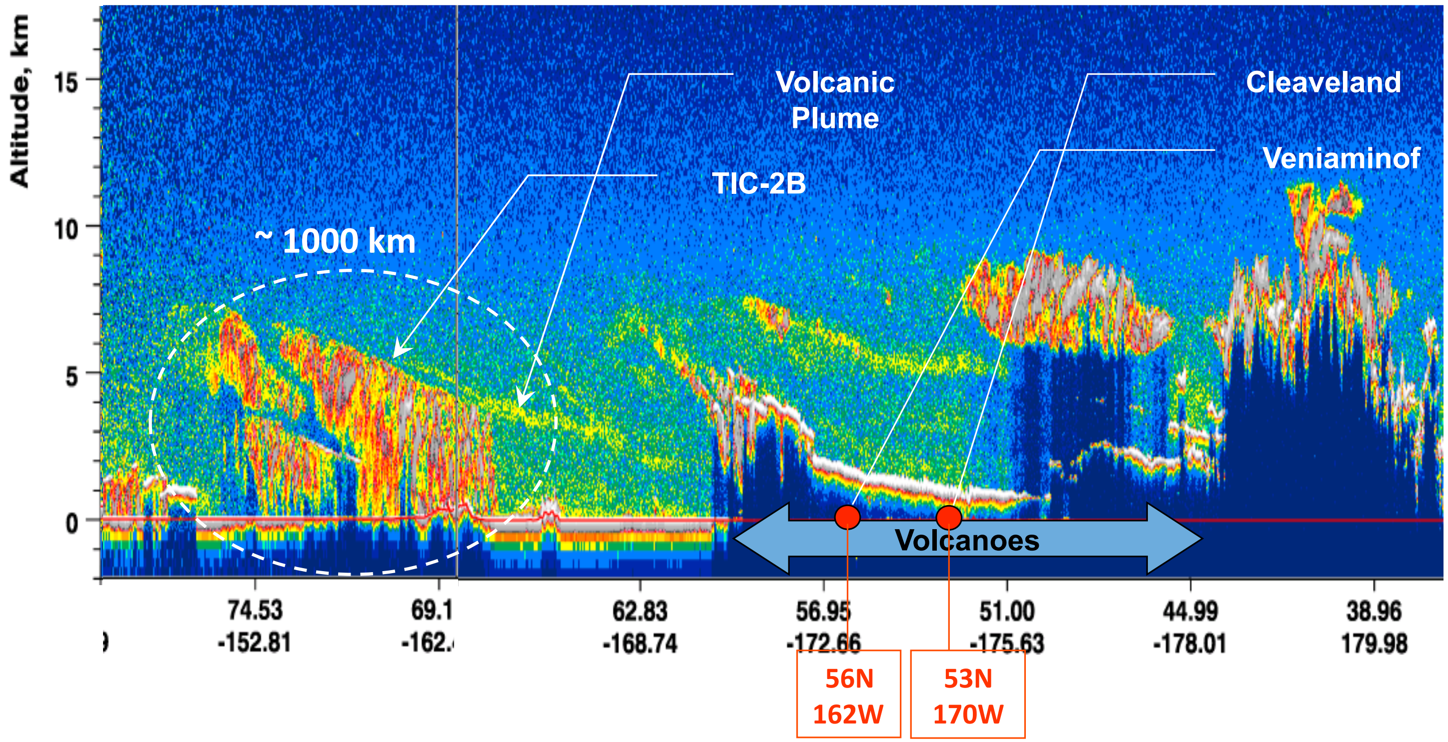


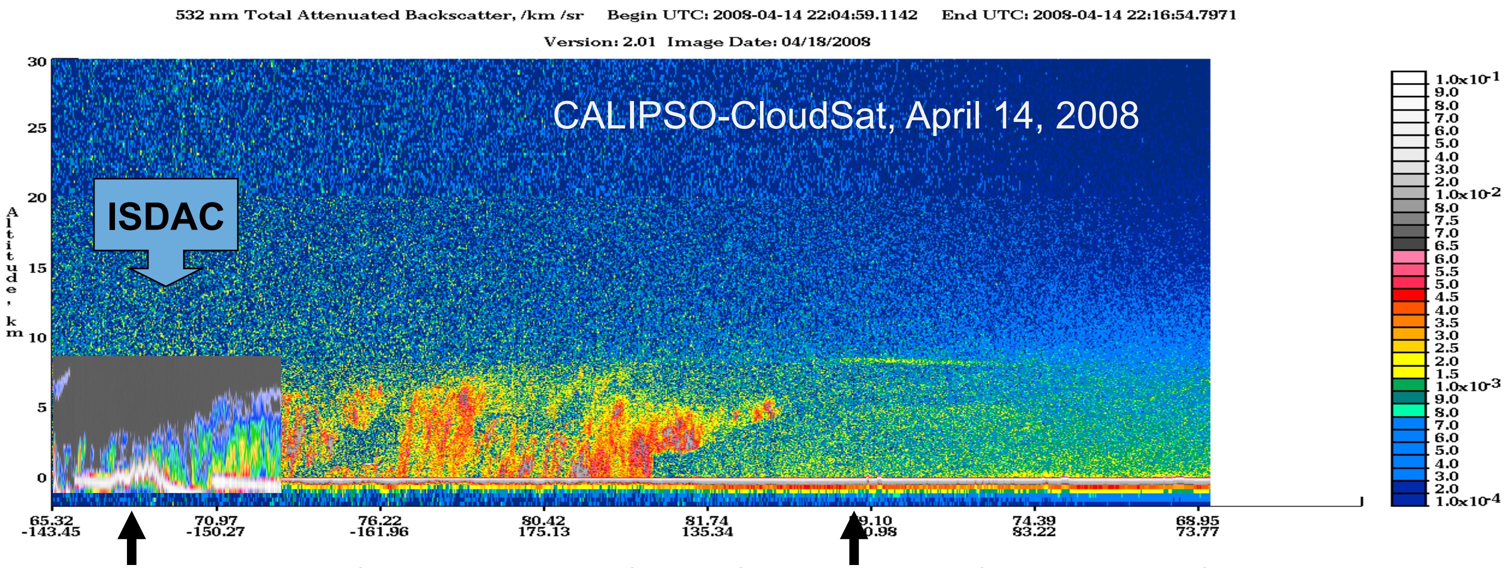
April 14, 2008
ISDAC Flight 20-21

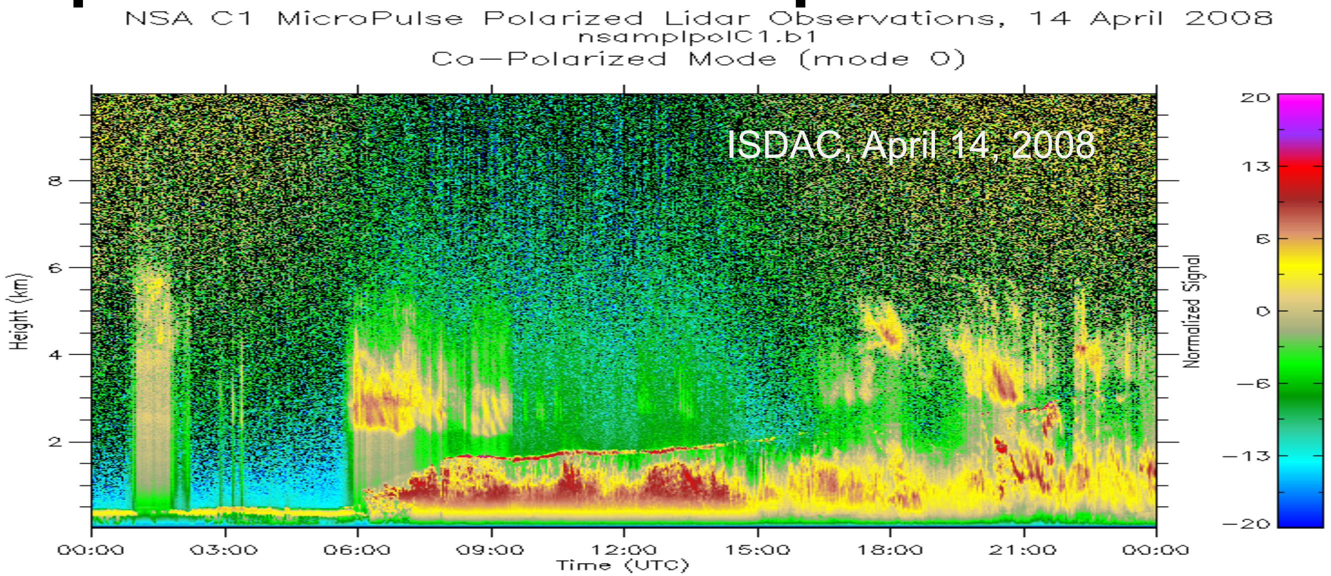


Evidence of Acid Aerosol – Cloud – Precipitation Interactions

From CALIPSO during ISDAC April 2008

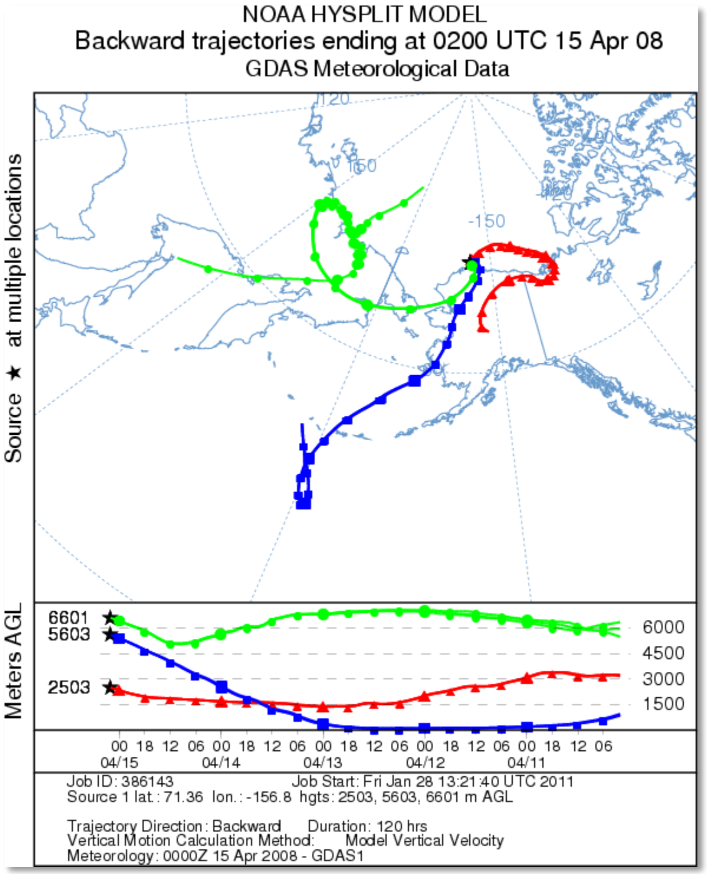



532 nm Total Attenuated Backscatter, /km /sr Begin UTC: 2008-04-14 22:04:59.1142 End UTC: 2008-04-14 22:16:54.7971
Version: 2.01 Image Date: 04/18/2008
CALIPSO-CloudSat, April 14, 2008
ISDAC
Altitude, km
30
25
20
15
10
5
0
65.32 -143.45
70.97 -150.27
76.22 -161.96
80.42 175.13
81.74 135.34
74.39 83.22
68.95 73.77
1.0x10-1
1.0x10-2
1.0x10-3
1.0x10-4

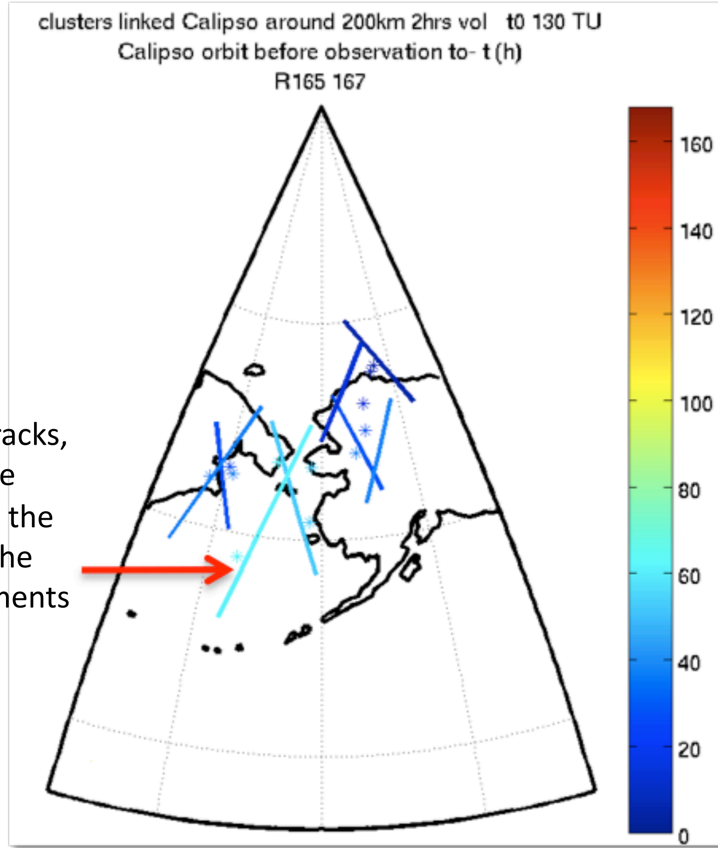

NSA C1 MicroPulse Polarized Lidar Observations, 14 April 2008
nsamplpolC1.b1
Co-Polarized Mode (mode 0)
ISDAC, April 14, 2008
Height (km)
8
6
4
2
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
Time (UTC)
Normalized Signal
20
13
6
0
−6
−13
−20

ISDAC Aircraft Campaign – March April 2008: Sources of IFN-SO_2

April 15, 2008 00:55:40 – 01:17:24



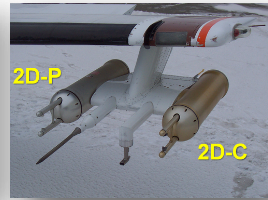
Examination of the CALIPSO satellite tracks, which intersects the back trajectories in the region away from the airborne measurements



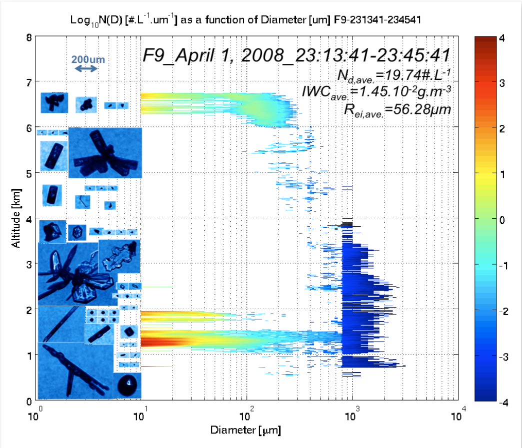
ISDAC Aircraft Campaign – March April 2008: Cloud Microphysics

ISDAC (April 2008)

- Ice and mixed-phase arctic clouds
- Barrow-Fairbanks (Alaska)
- Aircraft Convair-580 from NRC (Canada)
- **Probes :** 2-DS, 2-DC, 2-DP, Rosemount Icing Detector, PCASP …

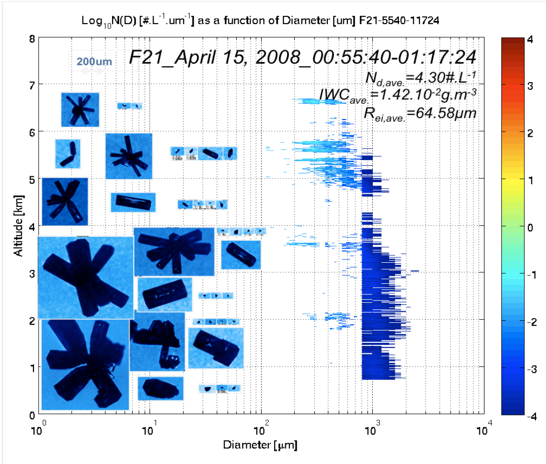


April 1, 2008 23:13:41 – 23:45:41

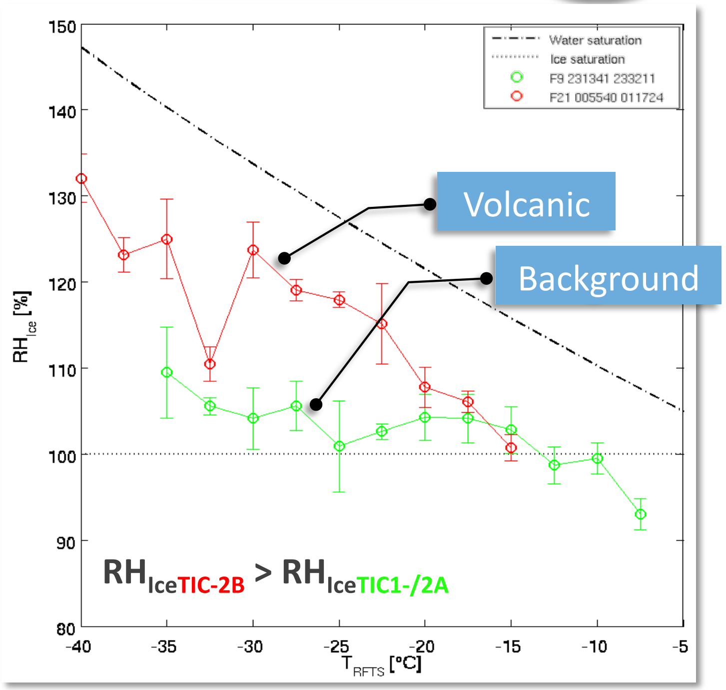


High [small ice crytsals]
looks like a TIC-1/2A

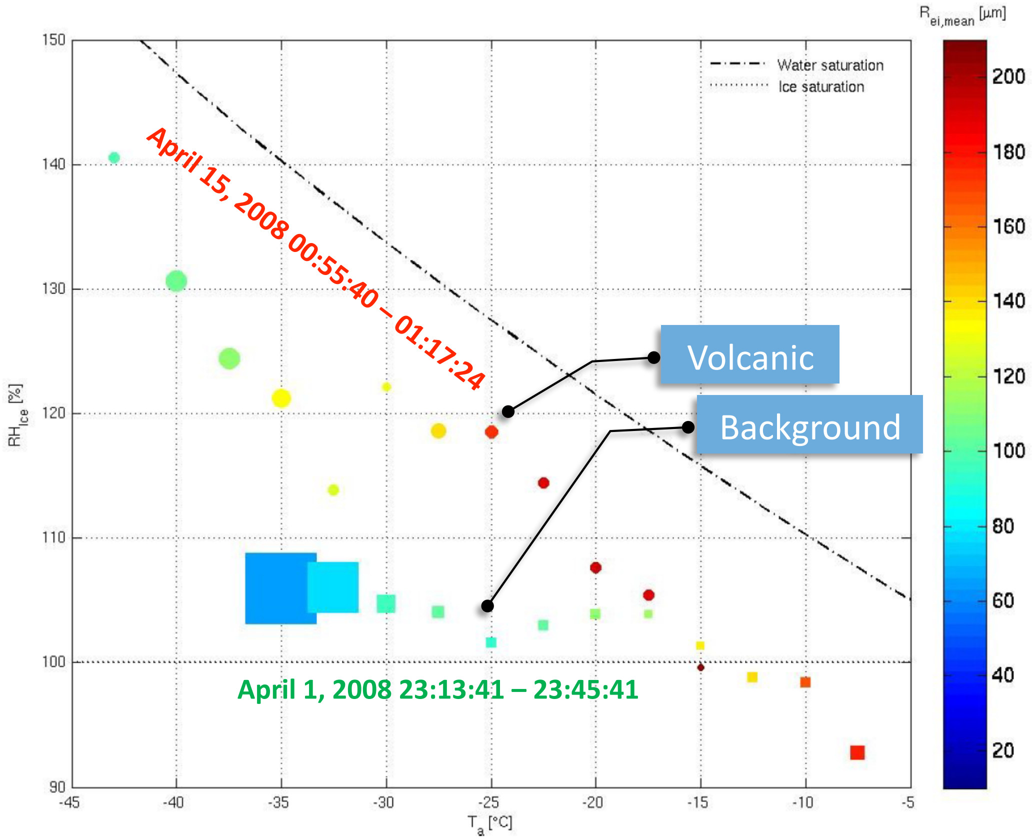
April 15, 2008 00:55:40 – 01:17:24



Low [large ice crystals]
looks like TIC-2B

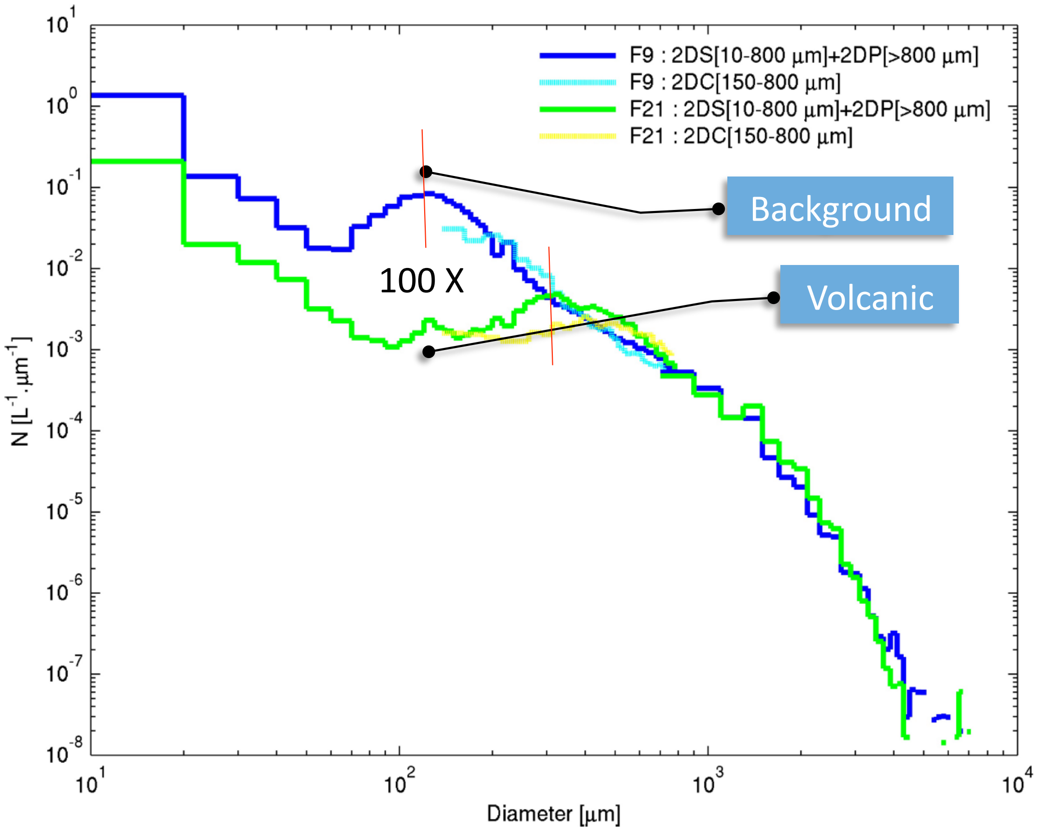


ISDAC Aircraft Campaign – March-April 2008: IFN-Size vs RH-T



Ref.: Jouan, C., Girard, E., Pelon, J., Gultepe, I., Delanoë, J. and Blanchet, J.P., 2012: Characterization of Arctic ice cloud properties observed during ISDAC. J. Geophy. Res.; DOI 2012JD017889.

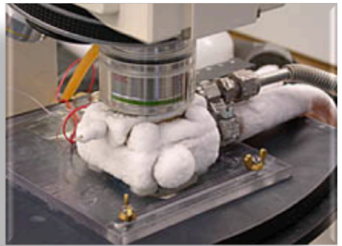
ISDAC Aircraft Campaign – March-April 2008: Size Distribution



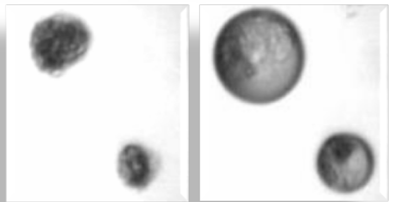
Ref.: Jouan, C., Girard, E., Pelon, J., Gultepe, I., Delanoë, J. and Blanchet, J.P., 2012: Characterization of Arctic ice cloud properties observed during ISDAC. J. Geophy. Res.; DOI 2012JD017889.

In Laboratory Allan Bertram UBC

Acid Coated IFN
Ice Forming Nuclei

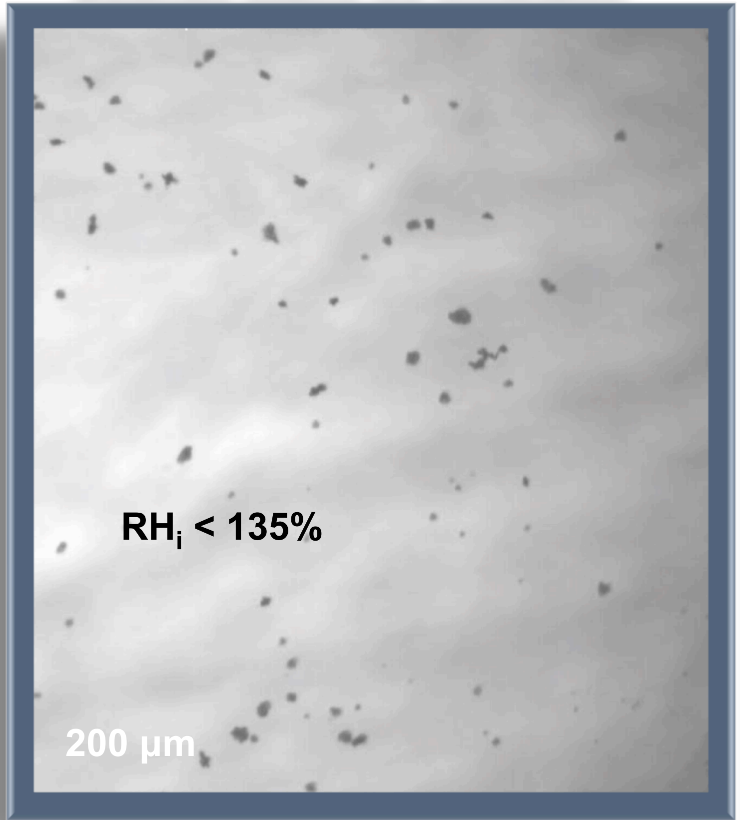


Flow cell coupled to microscope



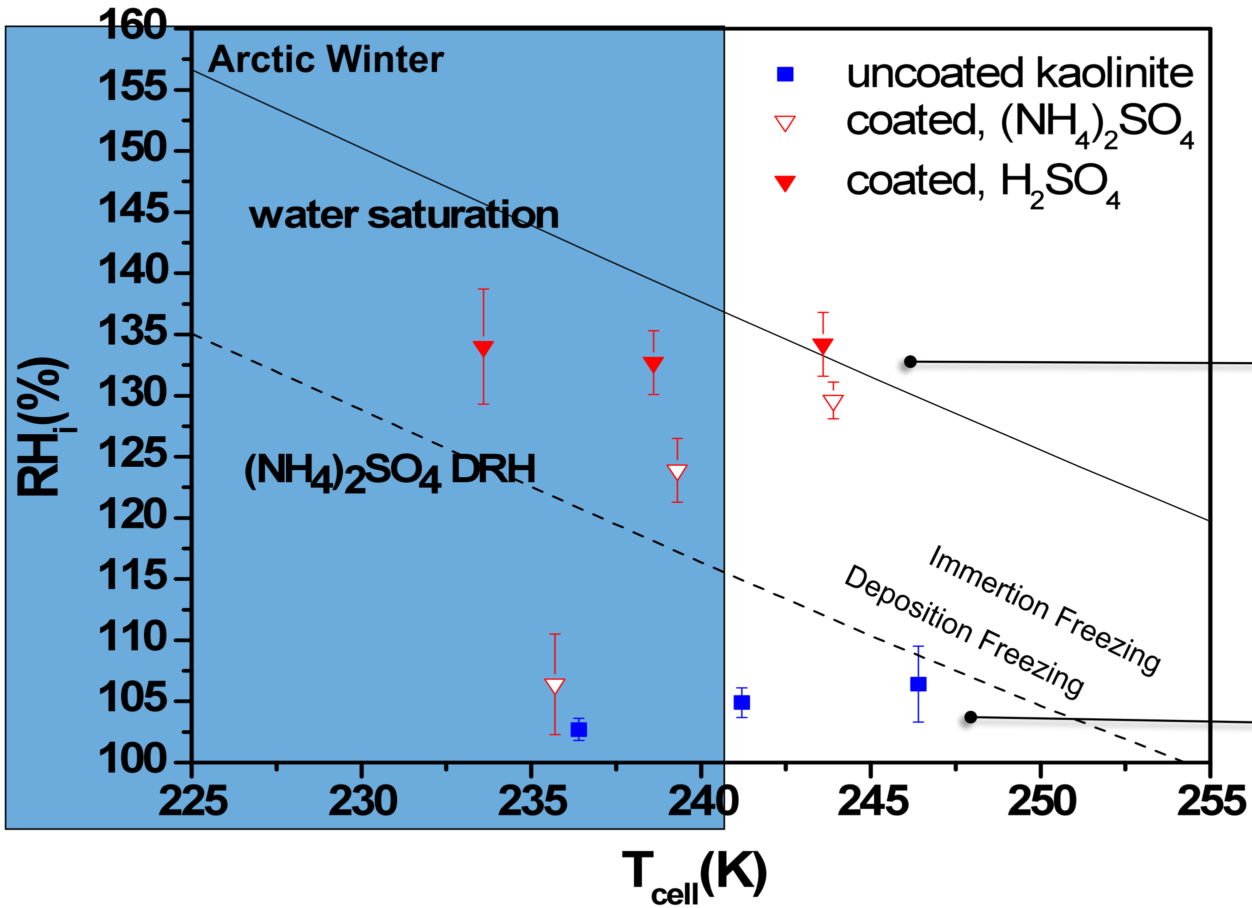
RH_w= 1% RH_w= 95%

Particles before ice nucleation



Particles after ice nucleation

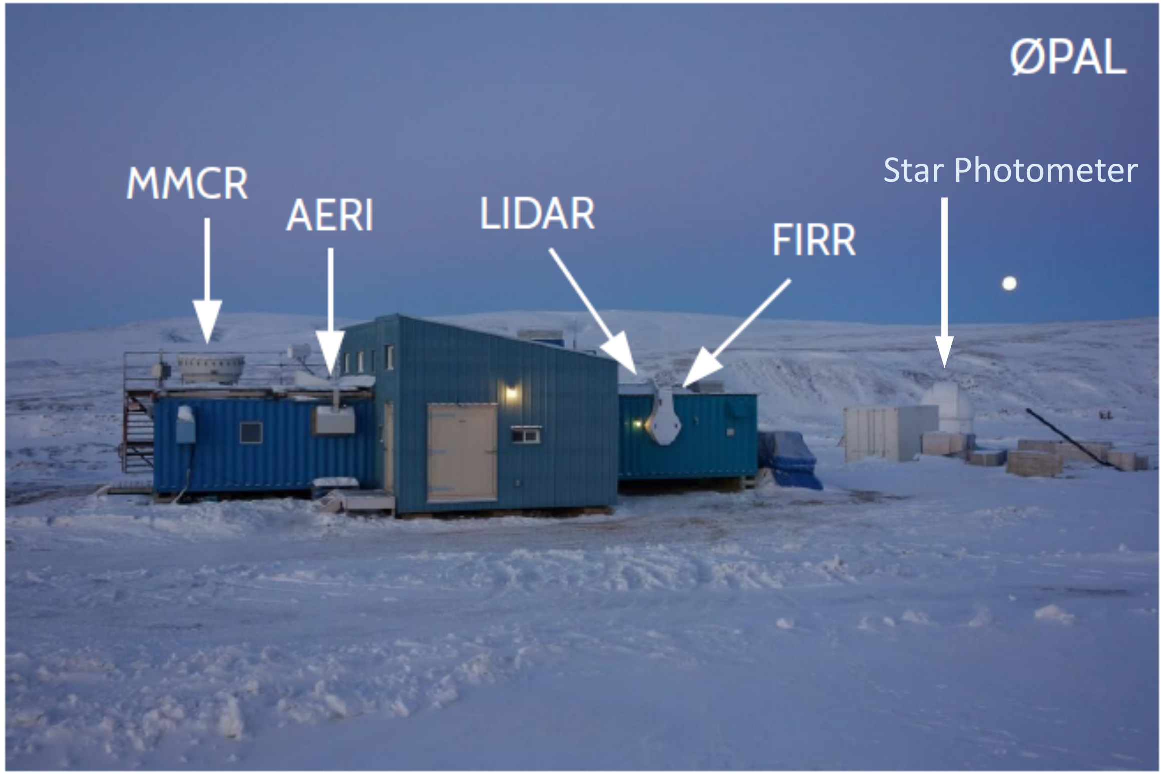
In Laboratory Allan Bertram UBC



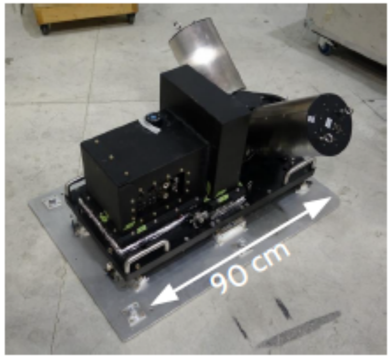
High Supersaturation
Low nucleation rate
Explosive growth
Few Ice Crystals
Easy Precipitation

Low Supersaturation
High nucleation rate
Slow growth
Many Ice Crystals
Low Precipitation

Ground Campaign, Eureka – Winter 2015-16

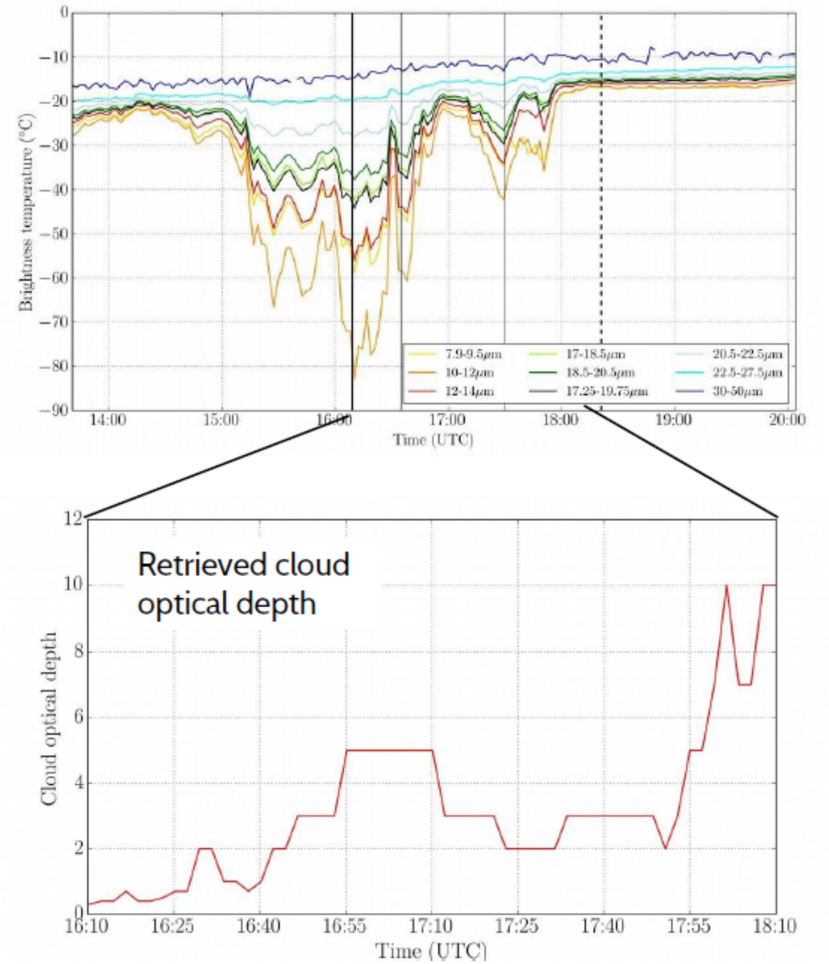


Far IR Spectral Radiometer (FIRR)



Optomechanical device

Filter wheel to explore the range 8-50 µm

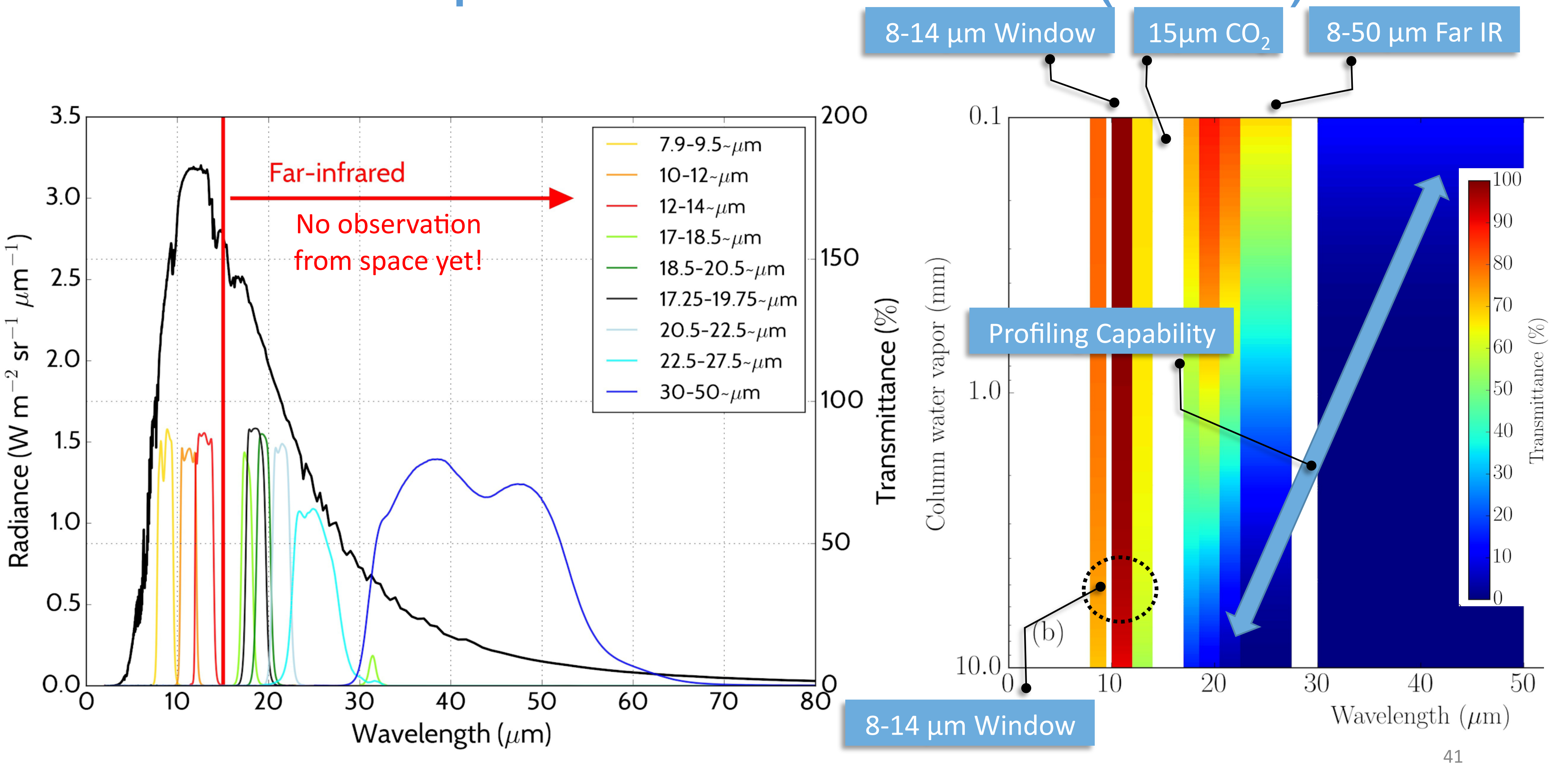


Ground measurements

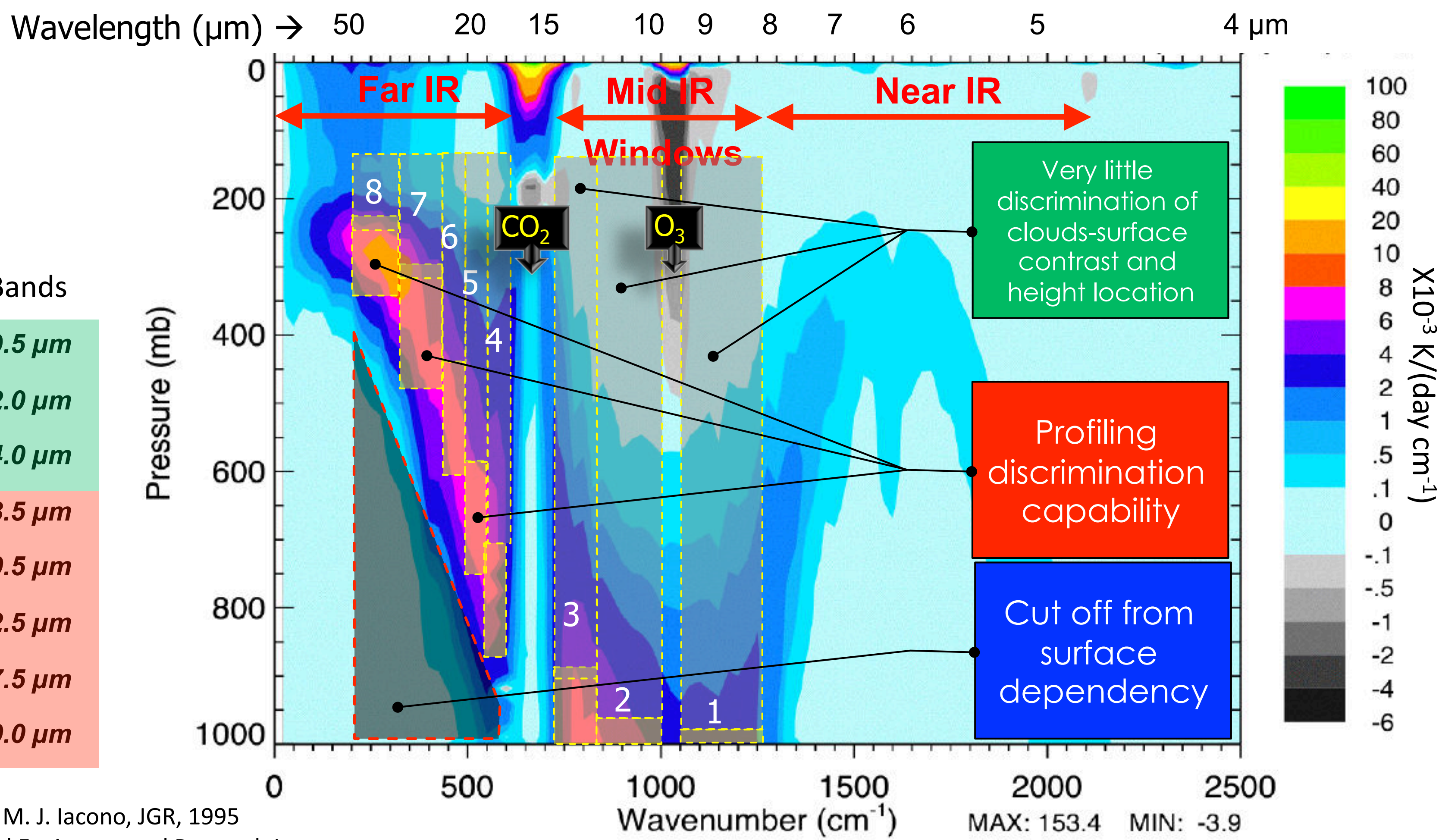
Airborne measurements

Far IR Spectral Radiometer (FIRR)

INO
UQÀM



Mid & Far IR Radiative Spectral Cooling Rates Profile (MLS)



FIRR Spectral Bands

B1: 7.9 μm to 9.5 μm
B2: 10.0 μm to 12.0 μm
B3: 12.0 μm to 14.0 μm
B4: 17.0 μm to 18.5 μm
B5: 18.5 μm to 20.5 μm
B6: 20.5 μm to 22.5 μm
B7: 22.5 μm to 27.5 μm
B8: 30.0 μm to 50.0 μm

Ref.: S.A. Clough and M. J. Iacono, JGR, 1995
Atmospheric and Environmental Research Inc

Shepard A. Clough, and Michael J. Iacono, JGR, 1995.
Atmospheric and Environmental Research, Inc.

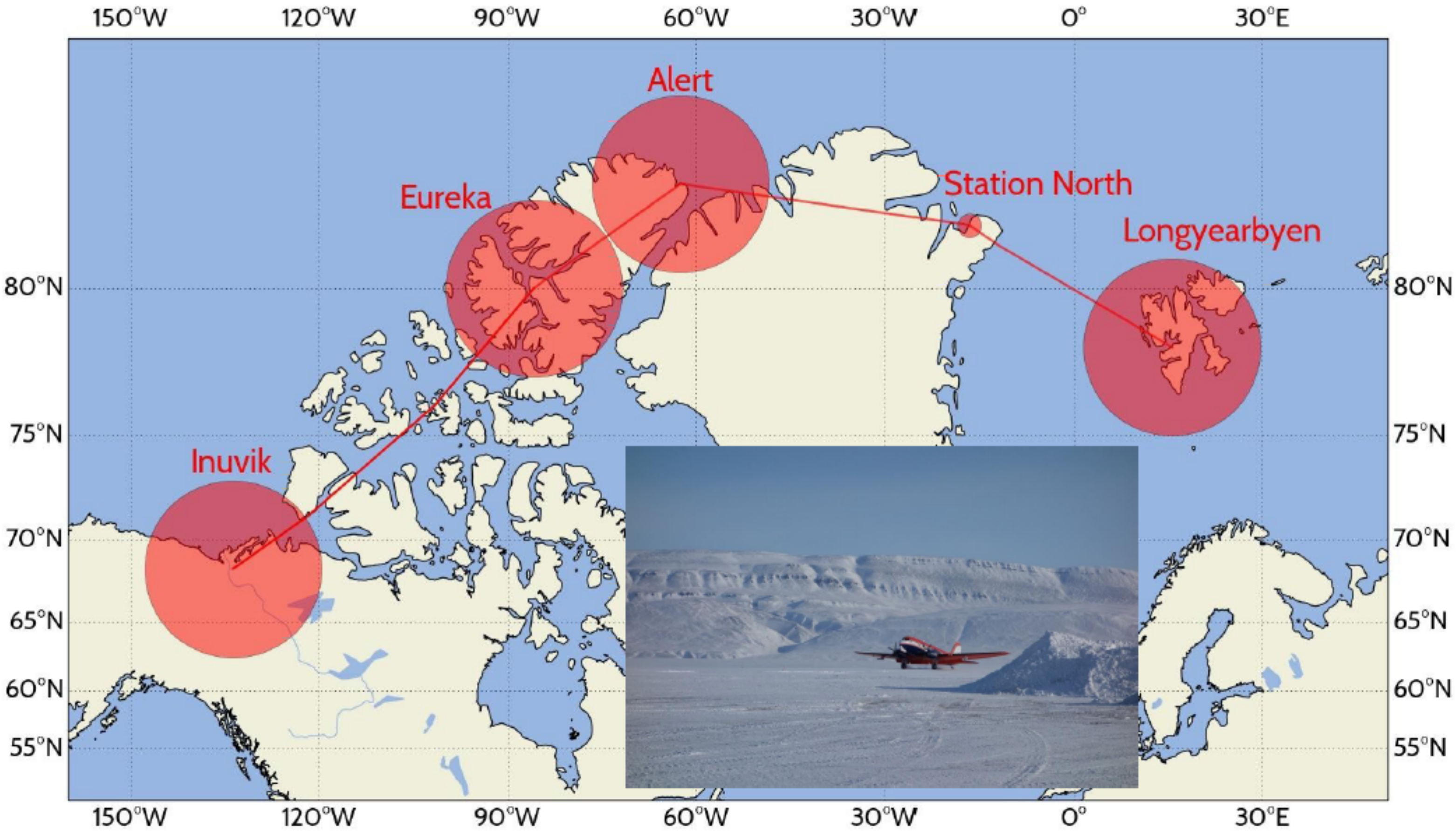
Scale: $x10^{-3}$ K/(day cm^{-1})

April 2015

Liviu Ivanescu

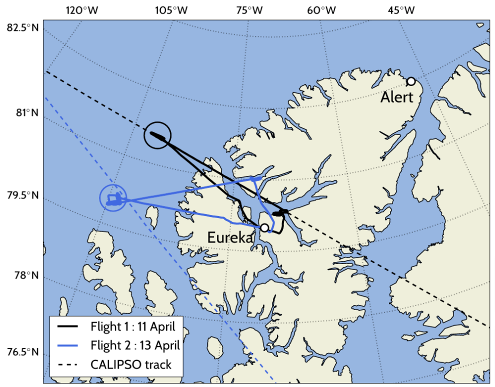
Quentin Libois

NETCARE Campaign – April 2015



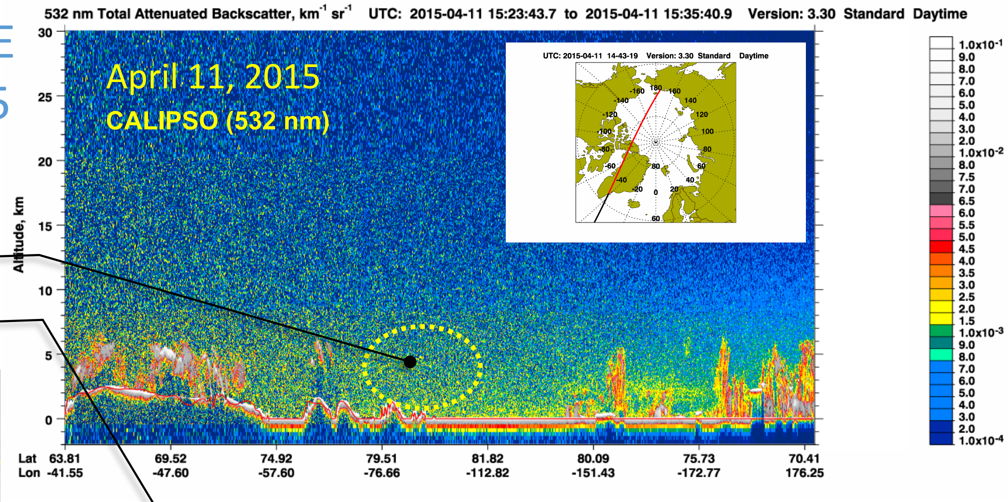
NETCARE Campaign – April 2015

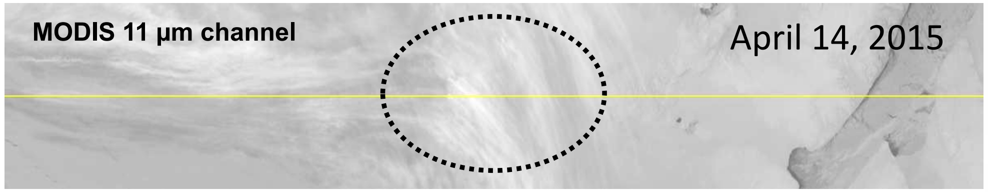
NETCARE/FIRR/TICFIRE Campaign – April 2015

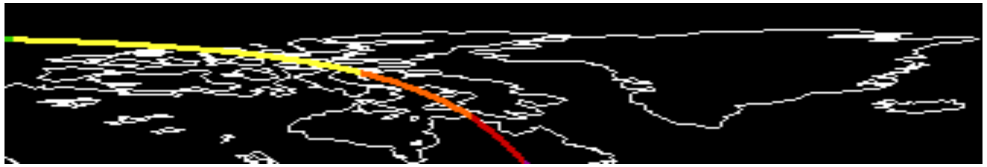


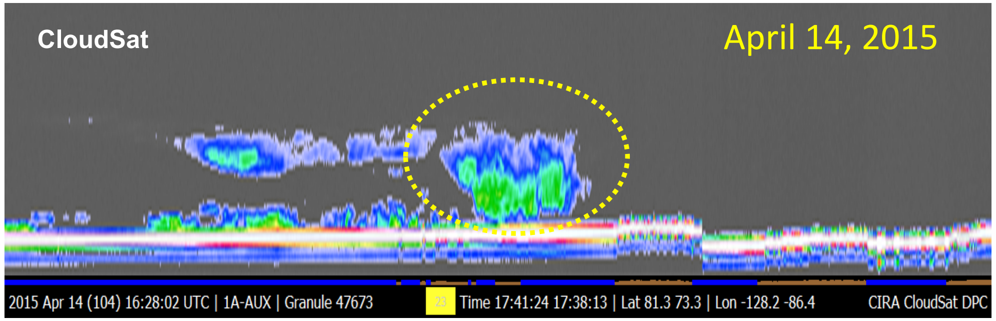
Clear Sky April 11, 2015

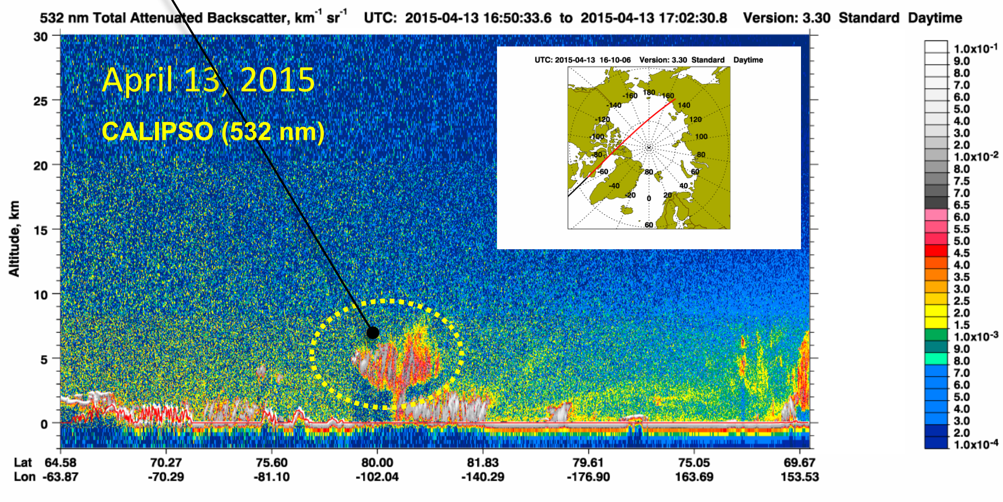
Cloudy Sky April 13, 2015





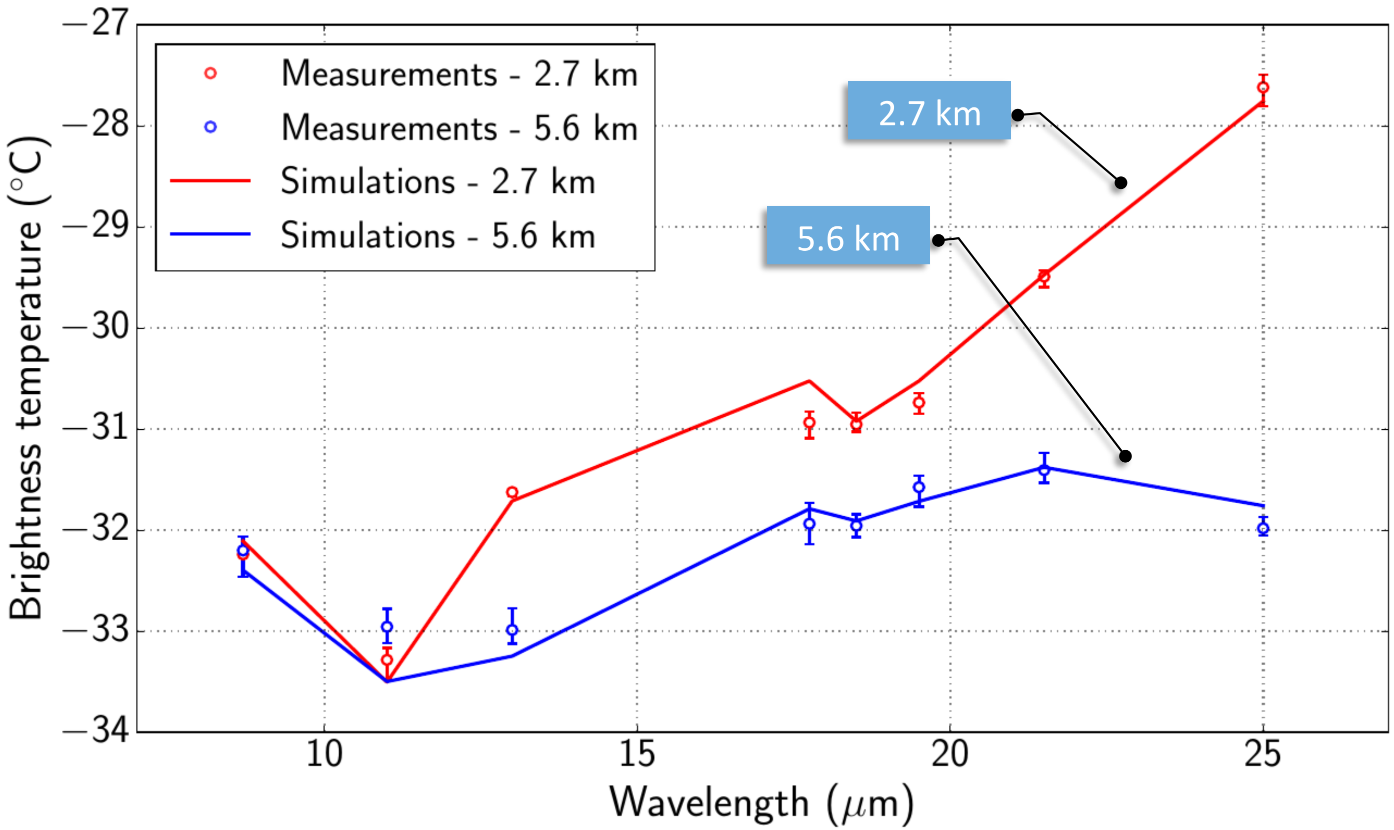






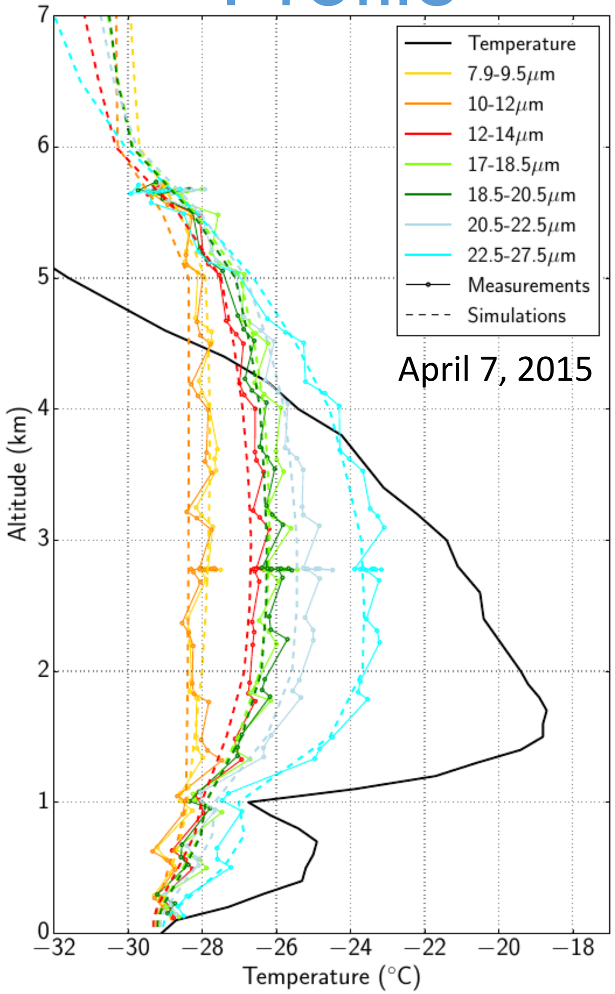
Spectral Radiance vs Simulations: Clear Sky

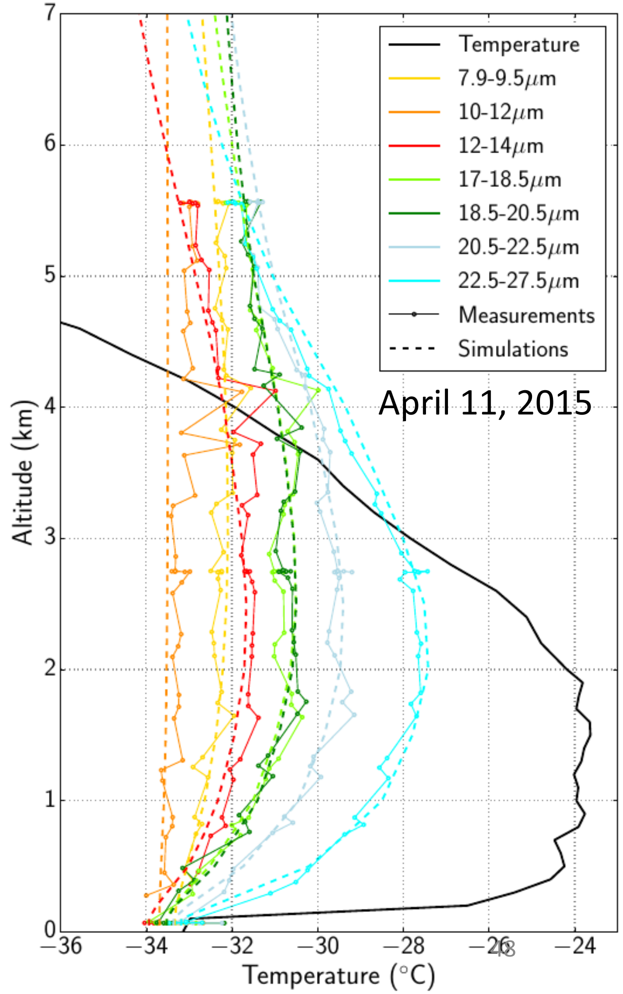
- MODTRAN V5.4
- Clear sky
- April 11, 2015
- Two altitudes



Clear Skies Measured vs Simulated Radiance Profile

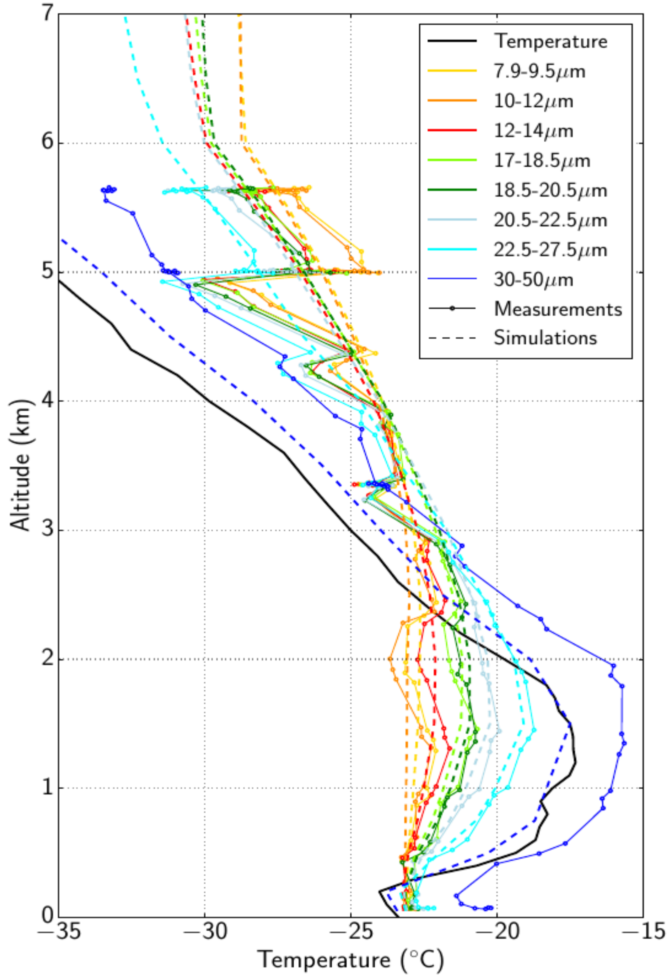
- Spectral radiance profiles in cold atmosphere regions
- April 7, 2015 (left)
- April 11, 2015 (right)

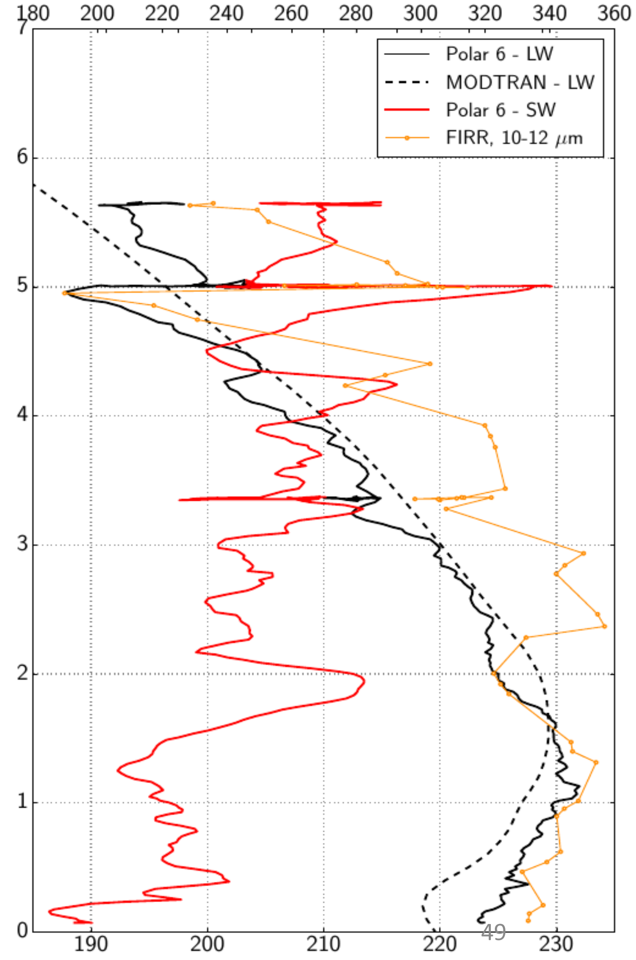




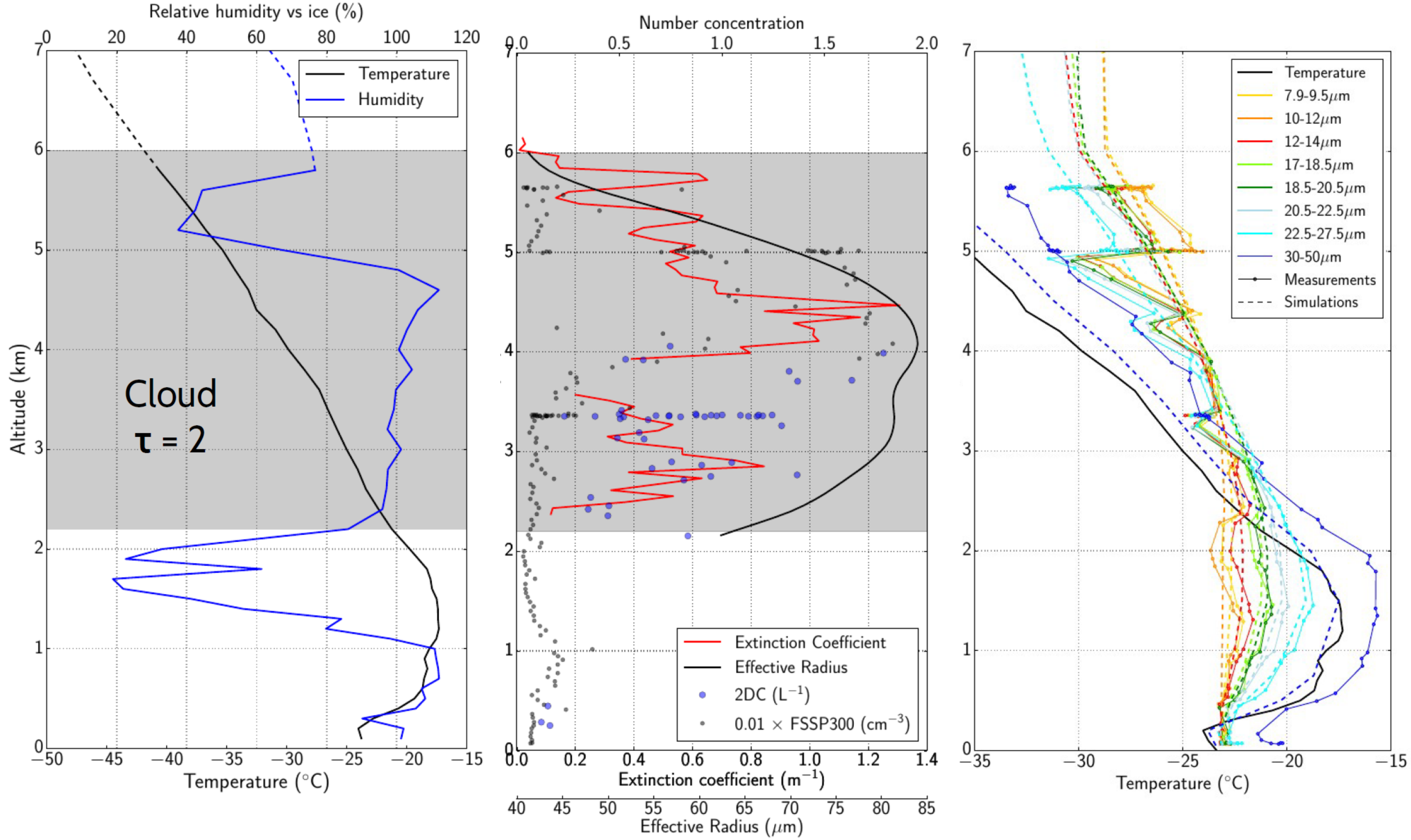
Cloudy Skies Measured vs Simulated Radiance Profile

- Complex profile
- Short wave and longwave features correlate
- Spectrally resolved





Cloud-Radiation Closure Experiments



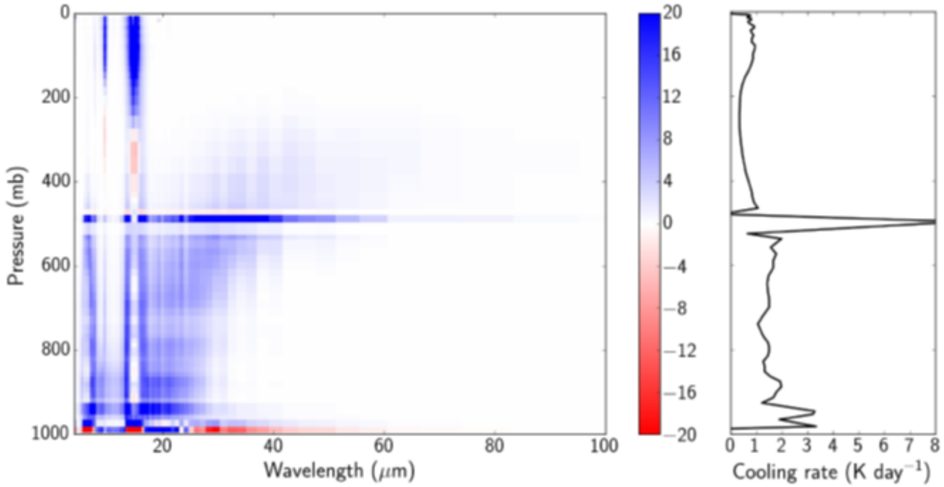
Quentin Libois

Validation of IR Cooling Rates

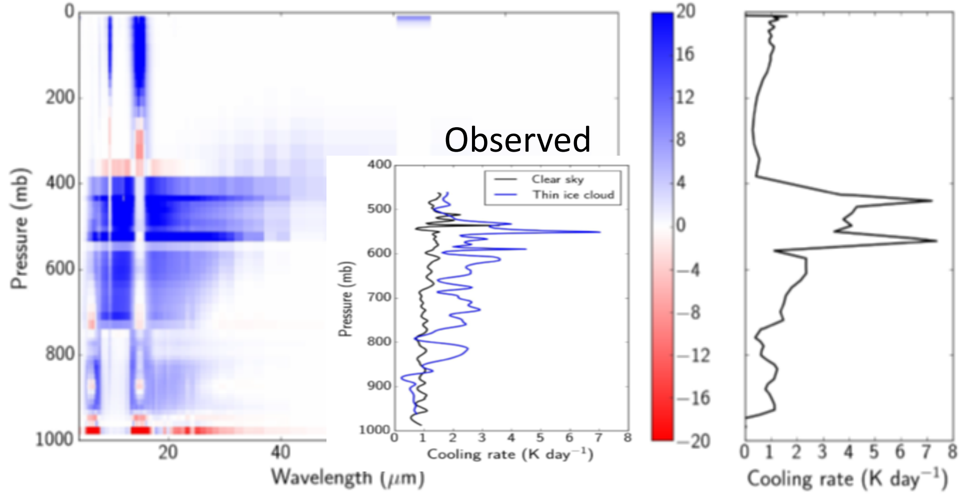
Quentin Libois

Simulated by MODTRAN V5.4

Clear Sky: April 11, 2015



Cloudy Sky: April 13, 2015



Ground Campaign, Eureka – Winter 2015-16

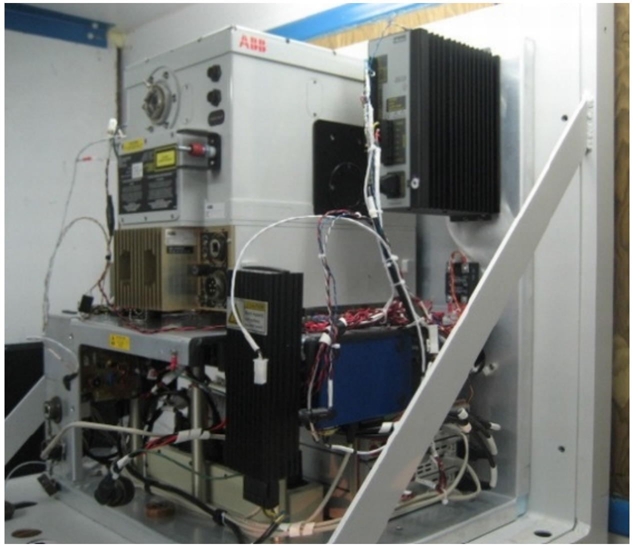
Ground Campaign, Eureka – Winter 2015-16

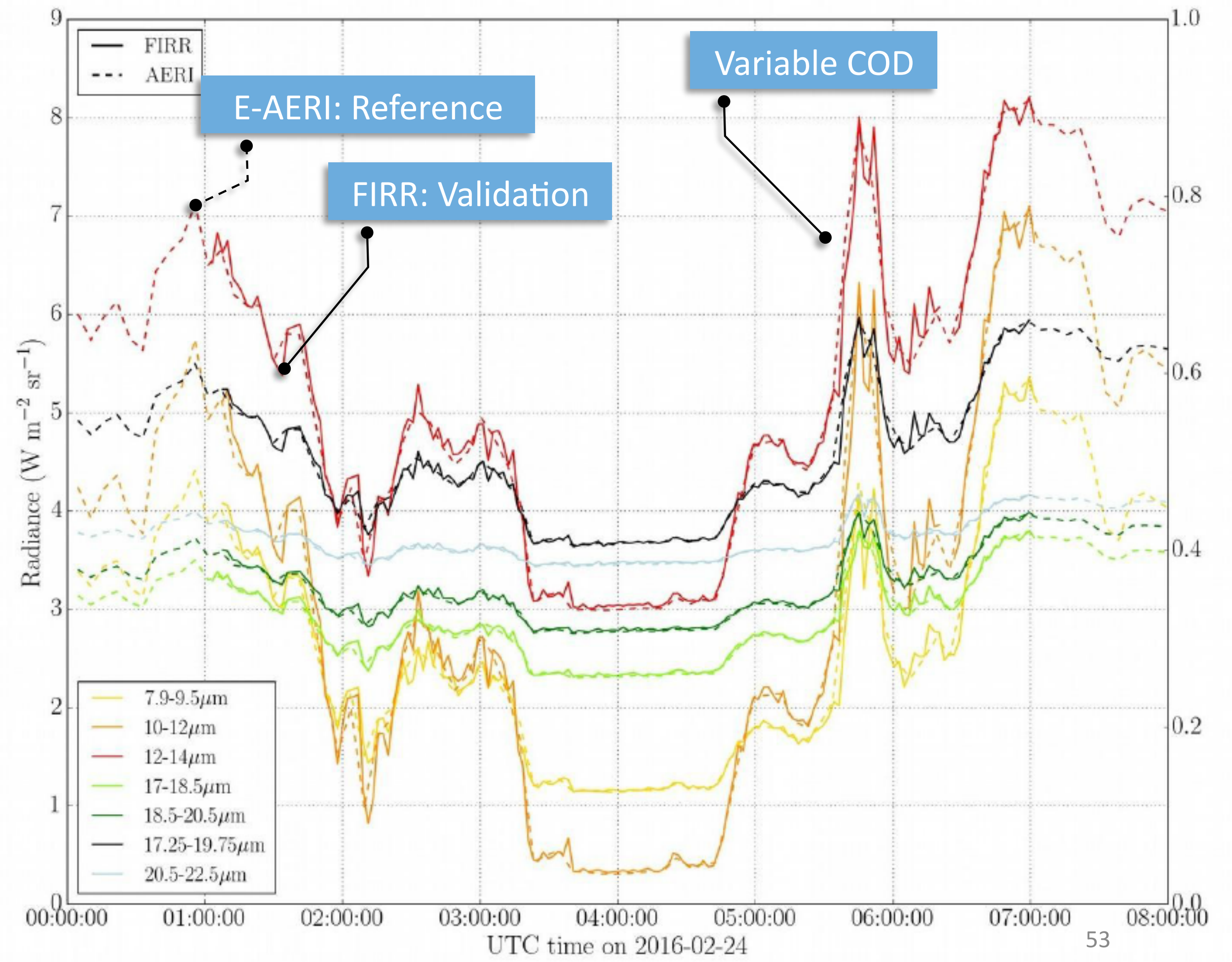

Sophie Tran (UofT)


Ludovick S. Pelletier

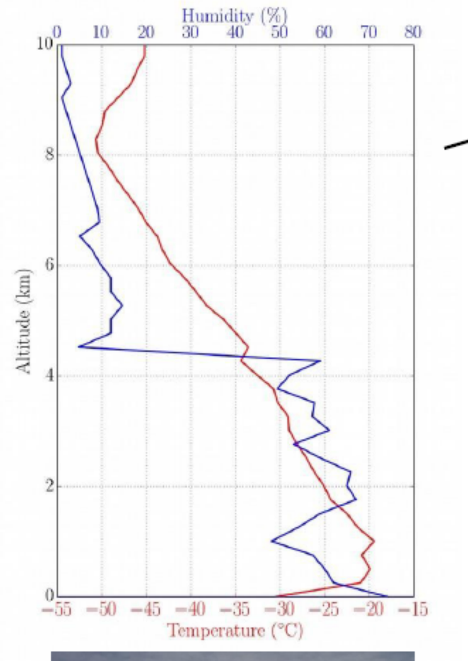

Kim Strong (UofT)

Validation against reference
E-AERI at PEARL, Eureka



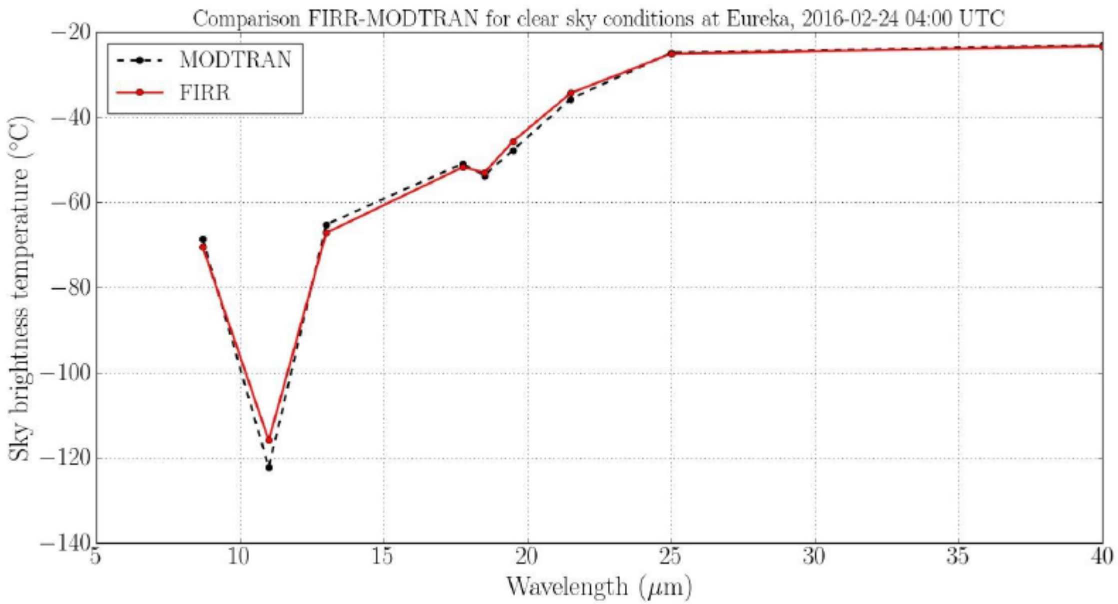


Clear Sky Observed FIRR vs Simulation



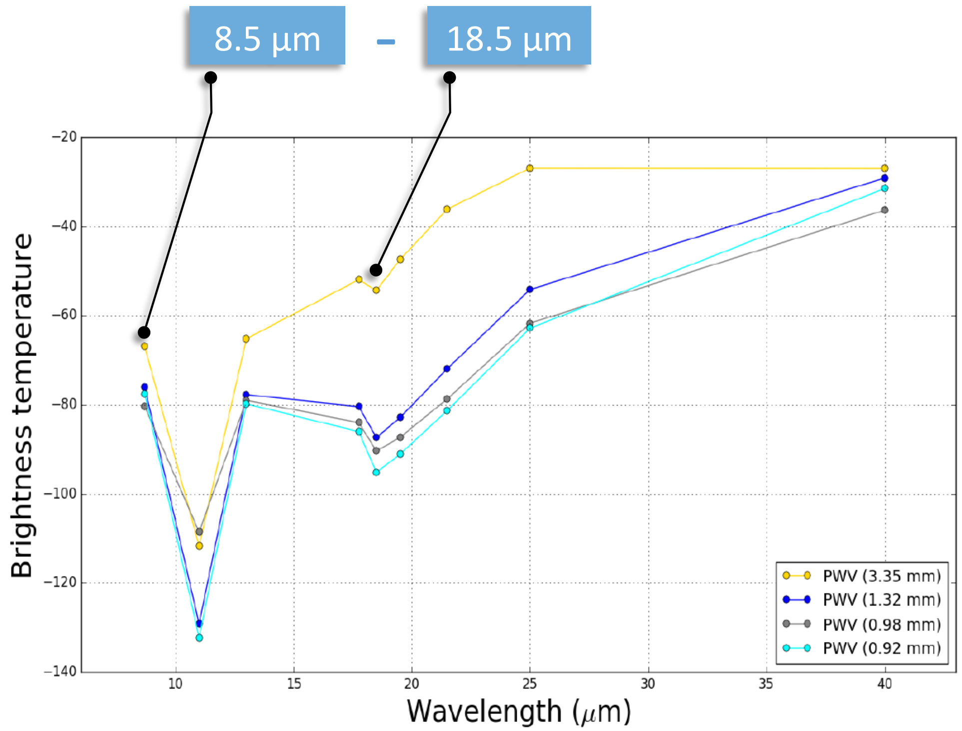
MODTRAN

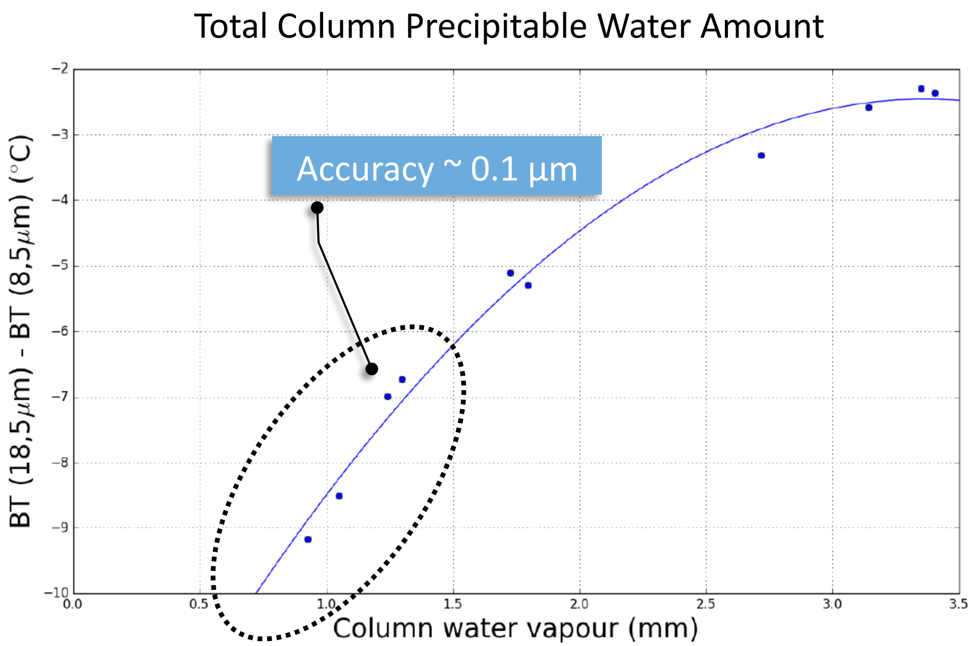

Ludovick S. Pelletier

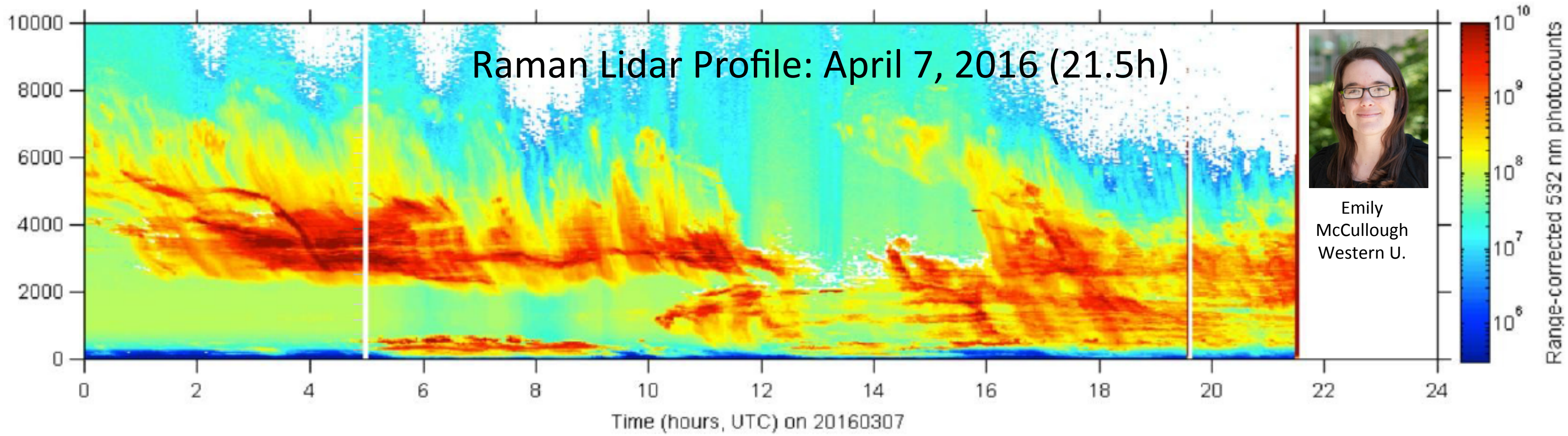


Validation against a radiative transfer model : MODTRAN

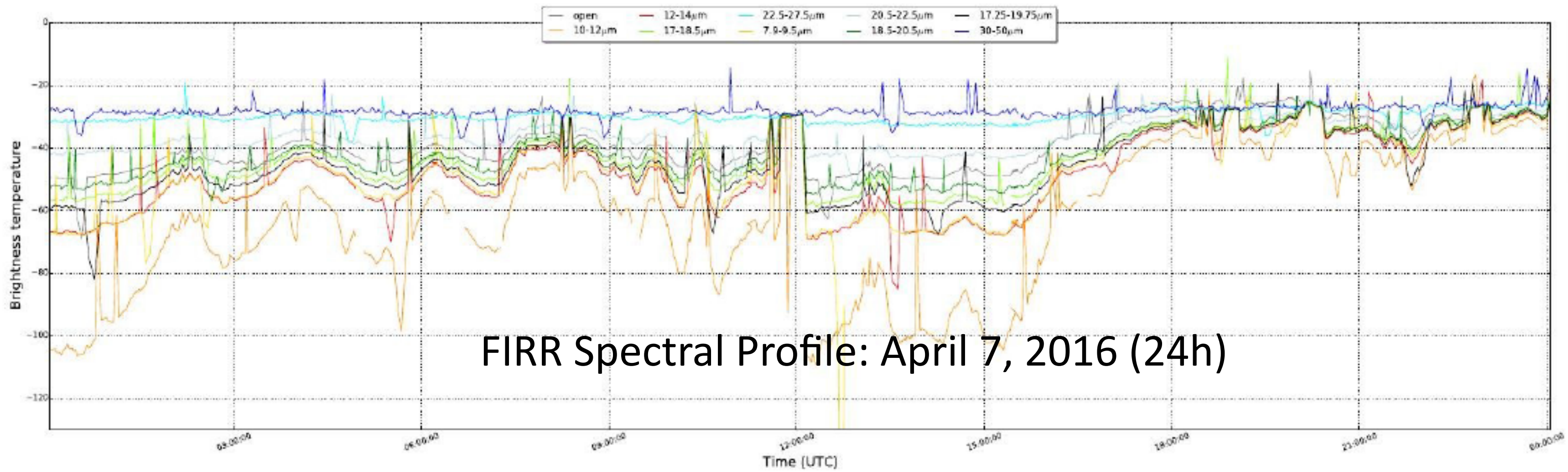
Retrieved Total Precipitable Water





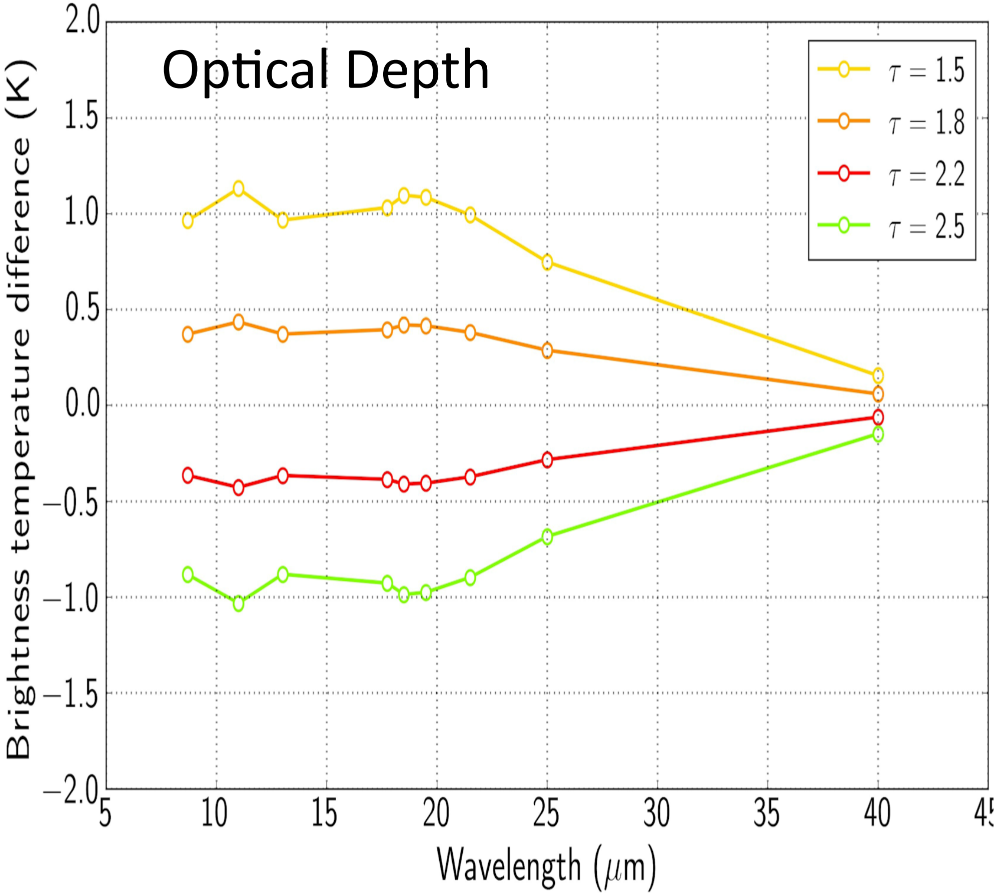


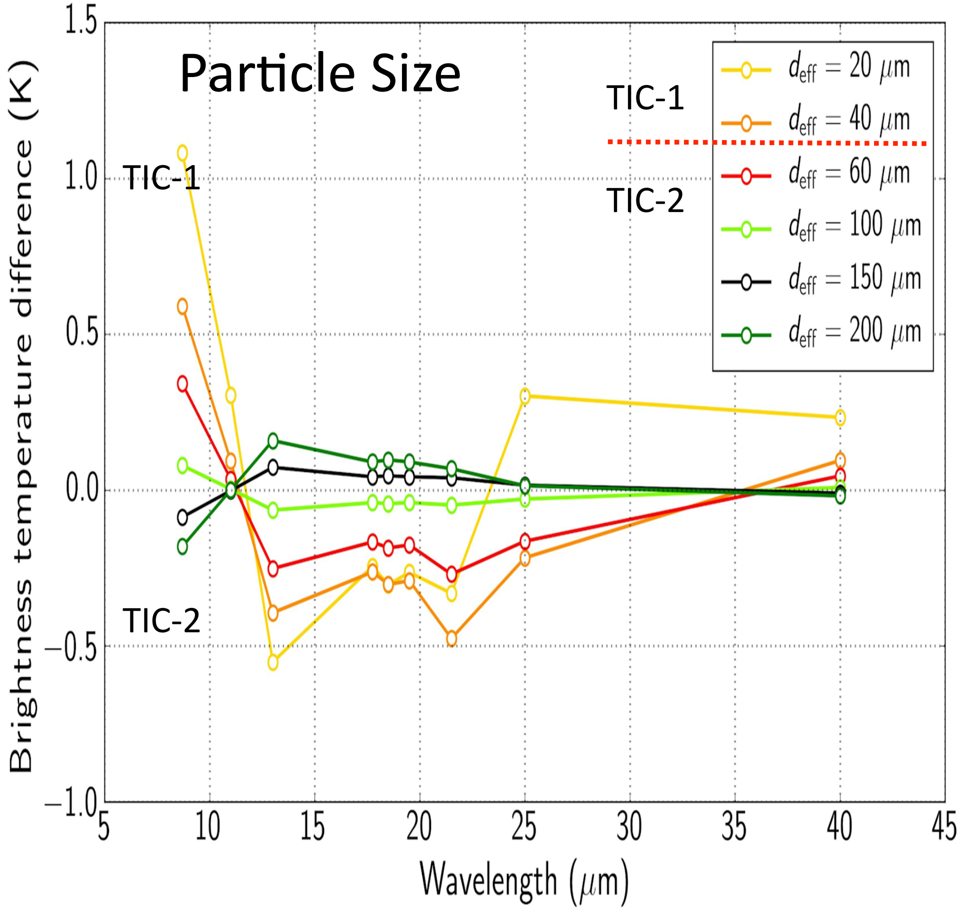
Emily
McCullough
Western U.



Ludovick
Pelletier
UQAM

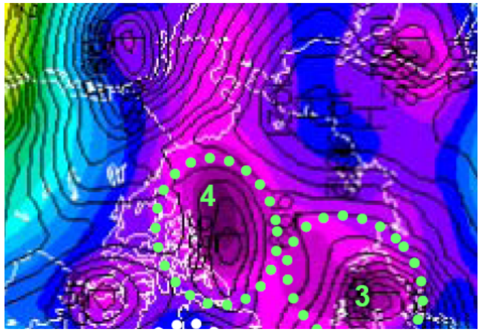
FIRR Sensitivity to Cloud Microphysics



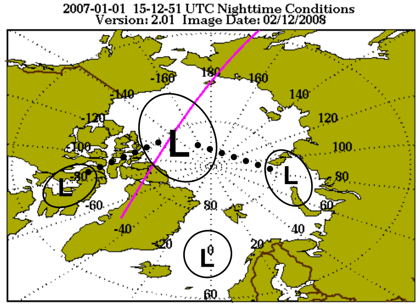


Model simulations

Microphysics, radiation and climate models



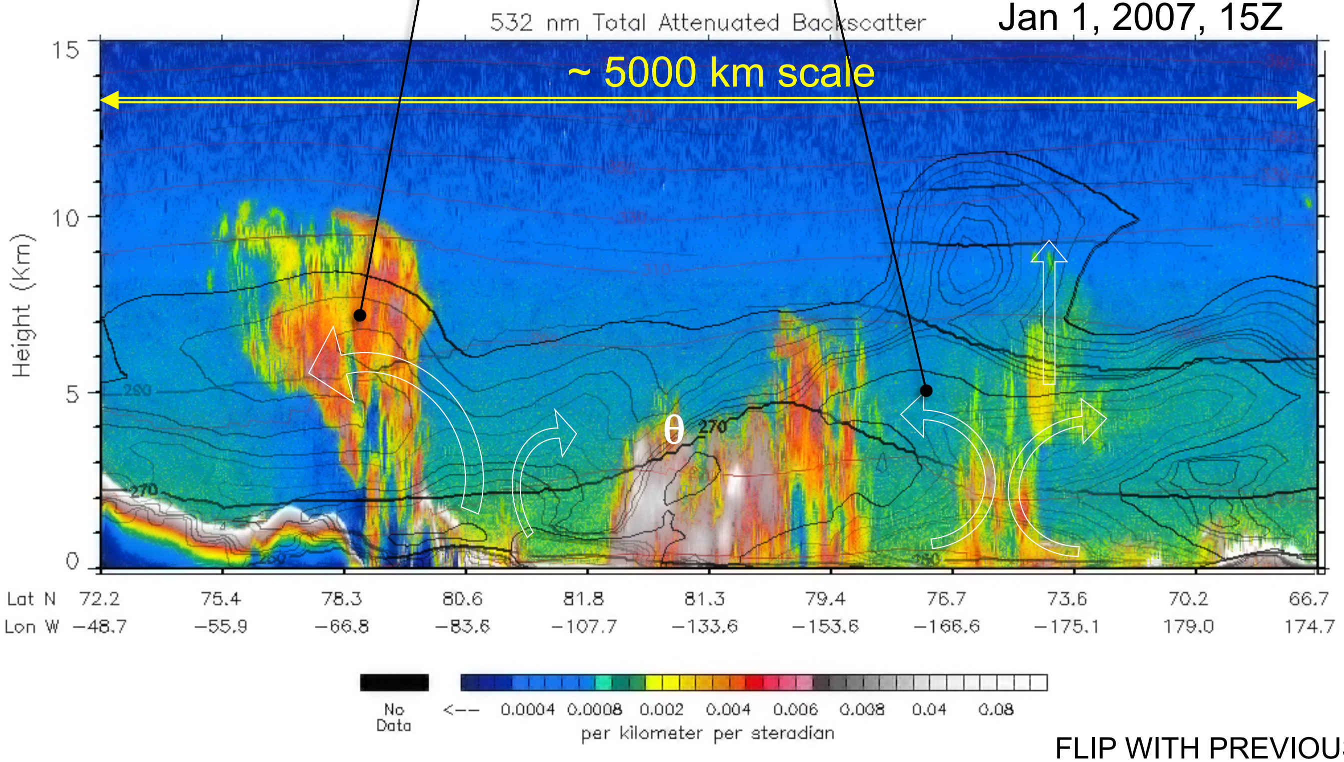
Observed and Simulated Aerosols



CALIPSO Features

Model Aerosol

Jan 1, 2007, 15Z



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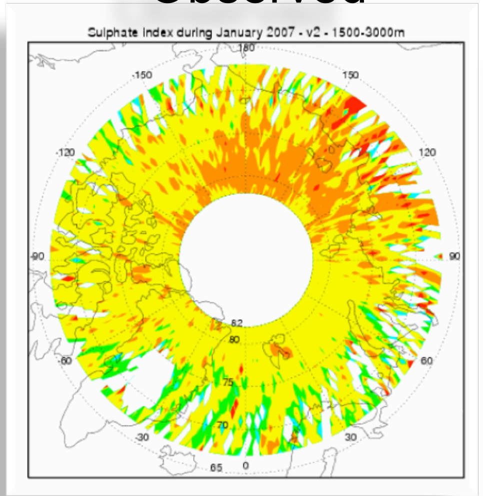
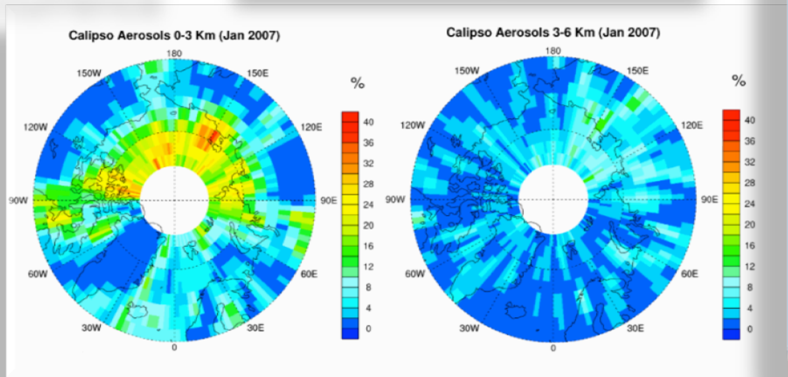
Monthly Mean Aerosol – Observed vs Simulated

Observed

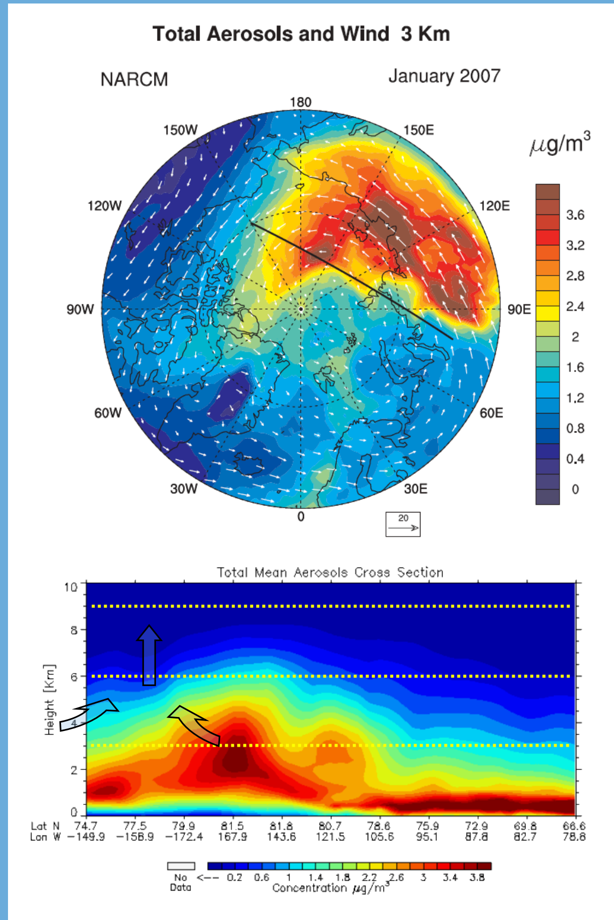
Amount →



Occurrence



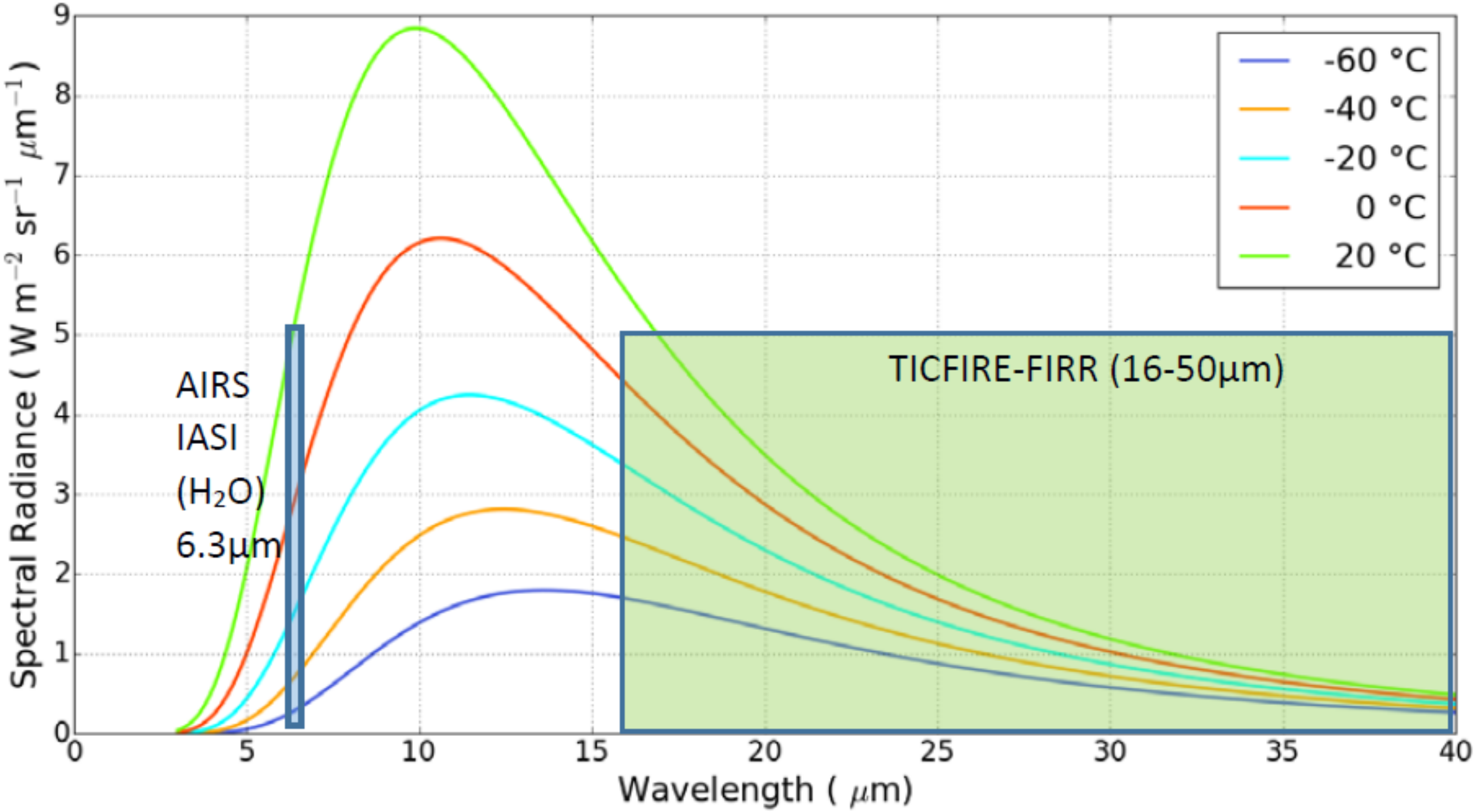
Simulated



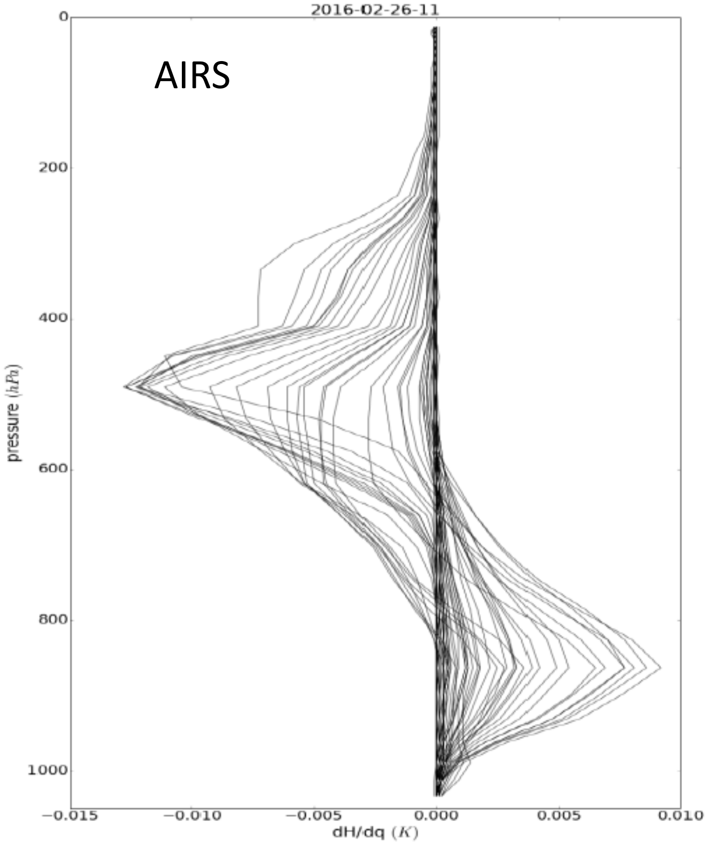
Data assimilation

Operational forecast and climate models

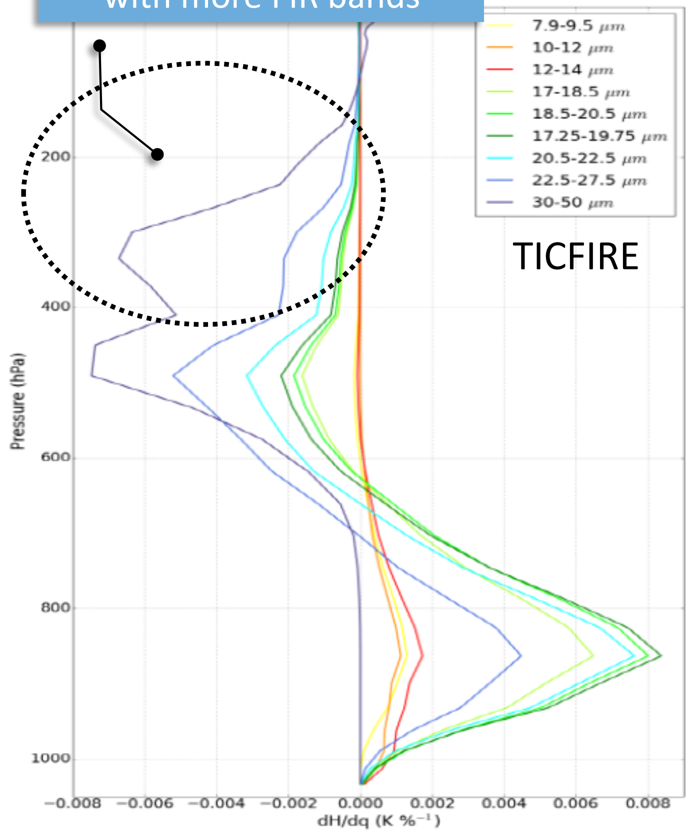
Planck Function and Channel Ranges



Jacobian AIRS and FIRR/TICFIRE - Humidity



Room for improvement with more FIR bands



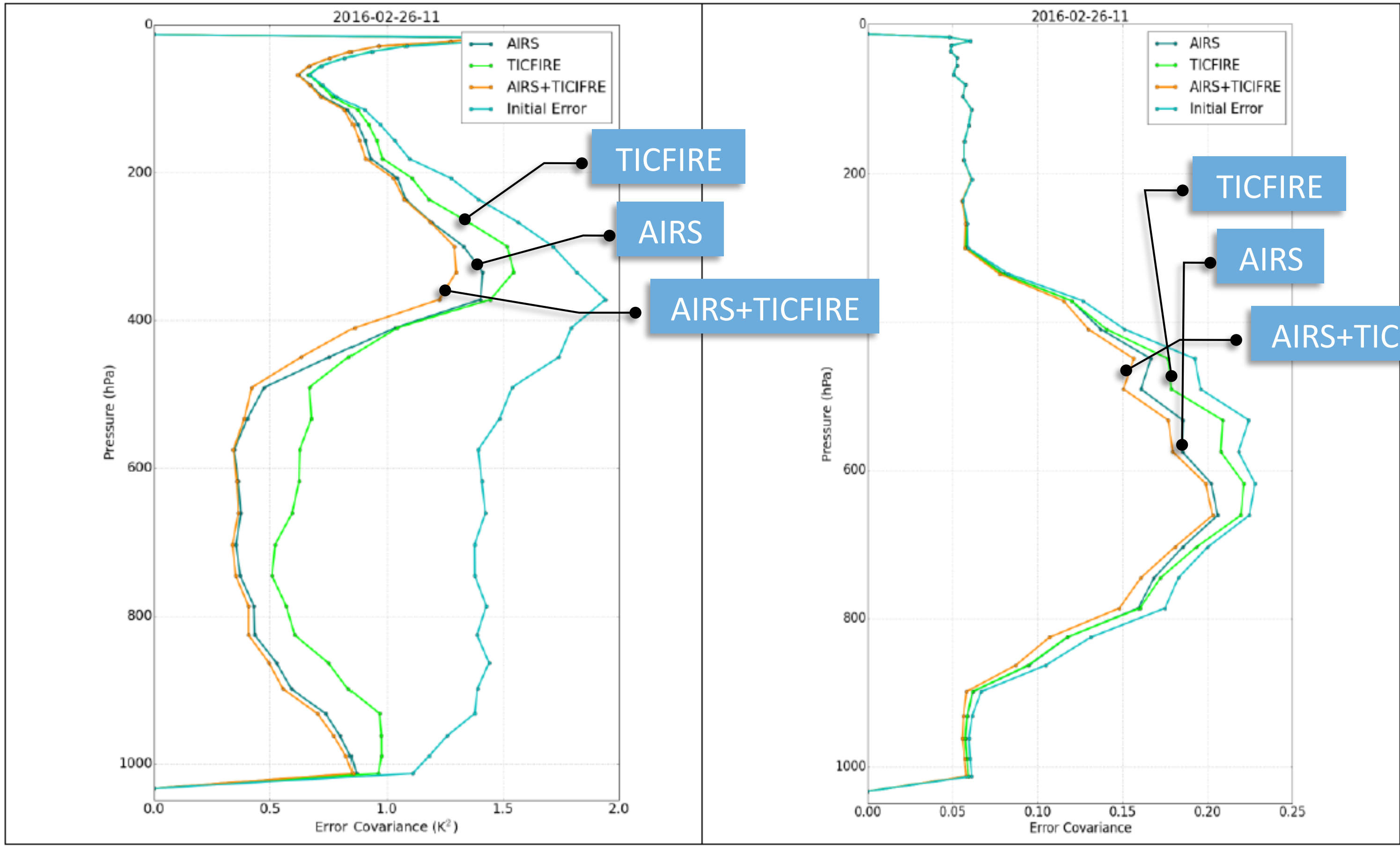
Laurence Coursol

Pierre Gauthier

Analysis Error Variance – AIRS vs FIRR/ TICFIRE

Temperature

Moisture



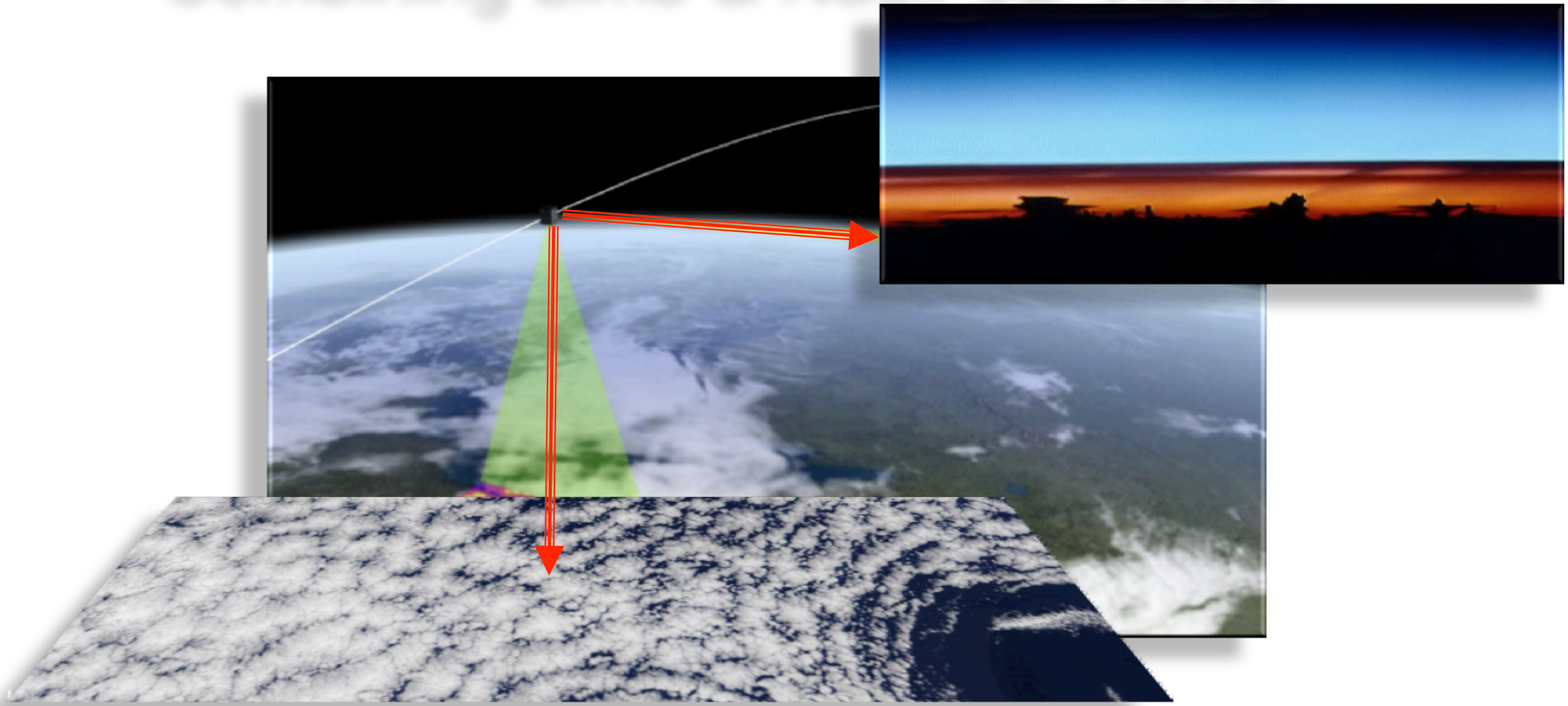
Laurence Coursol

Pierre Gauthier

Future missions

Active – passive instruments

Combining Limb & Nadir 3D Views



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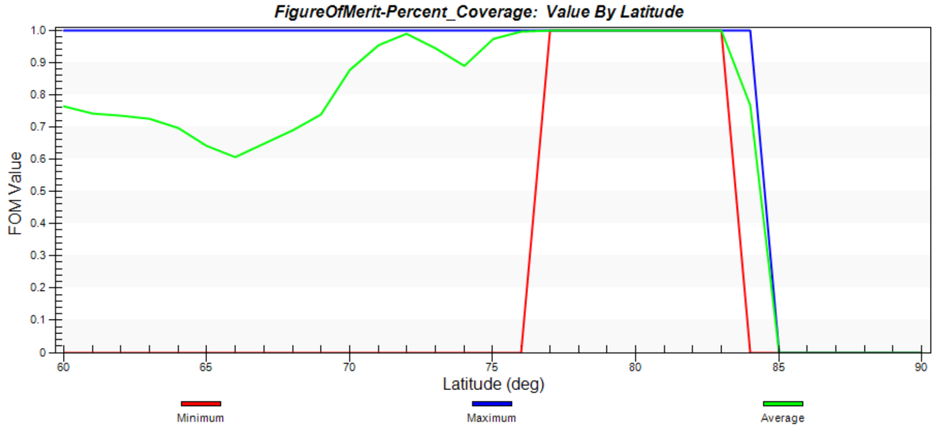
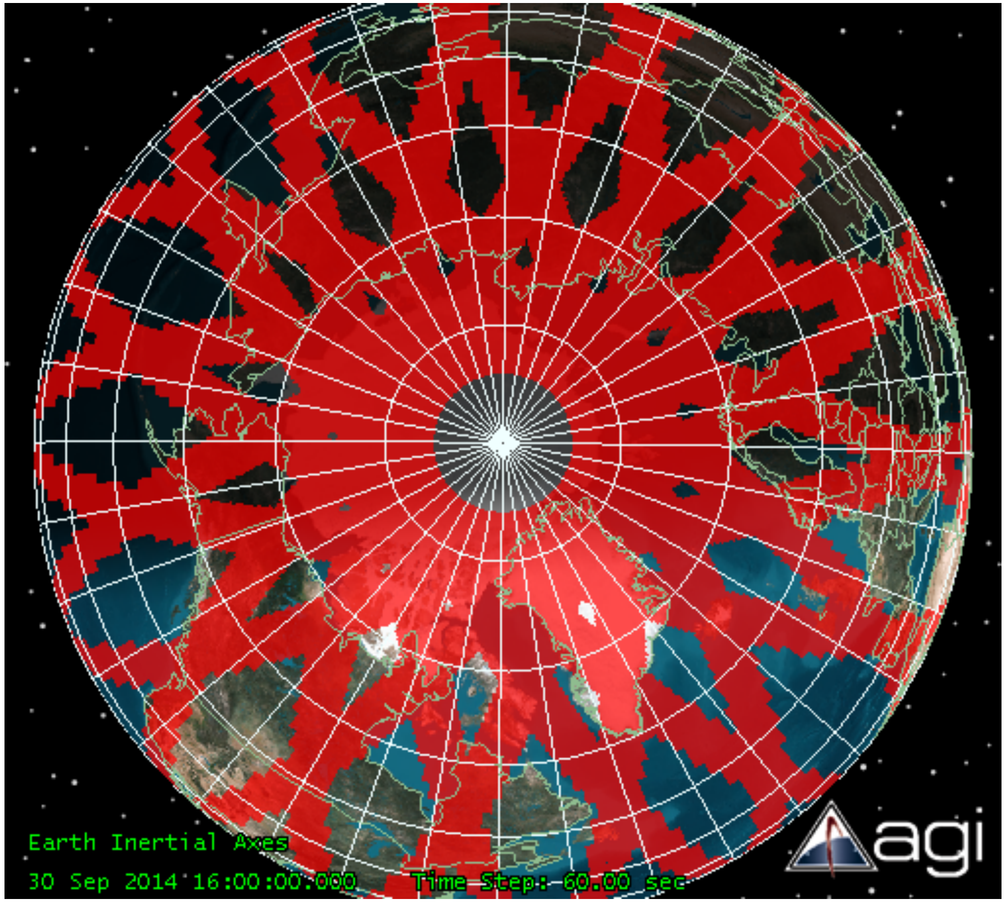
66

Coverage Analysis – Orbit Altitude, 650 km



Daily coverage, based on 20º half-angle:

- 70% coverage from 60º to 70º lat
- 90% coverage from 70º to 76º lat
- 100% coverage from 76º to 84º lat
- (~40% coverage of P3 region)



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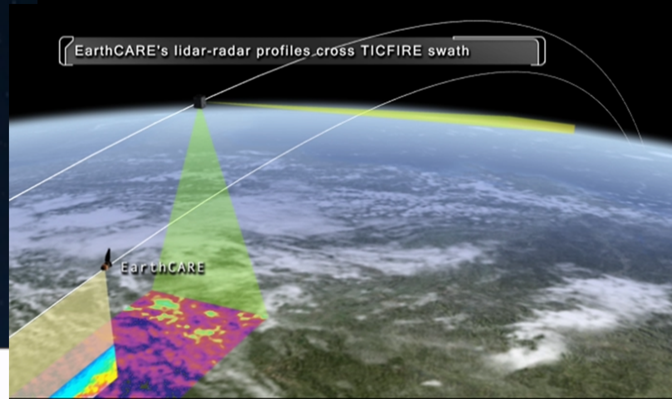
TICFIRE

Thin Ice Cloud in Far IR Experiment

- To monitor TIC, atmospheric water and cold anomalies formation a new microsatellite is being developed



Conclusion

- Spectral Radiance is a fundamental quantity to constrain models.
- Sidetracking via "evaluation" of aerosols and cloud microphysics add uncontrollable errors and model biases (R_{eff}, N, types… do not exists!).
- Direct and accurate measurement of radiation energy everywhere and all the time is the ultimate and least biased constrain.
- It can be directly assimilated into forecast models.
- The combination of active and passive instruments is the way to go!

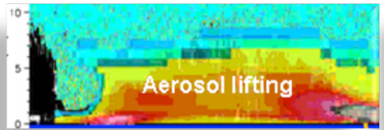
Summary

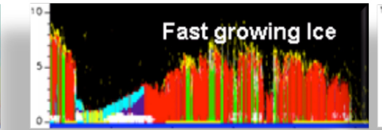
- Coordinated observations from space, ground and aircraft are essential.
- CloudSat and CALIPSO have permitted to close many of the gaps in the complex interaction between aerosol, clouds, precipitation and radiation in the Arctic during the polar night.
- The involved feedback processes are powerful modulators of the atmospheric circulation and regional climate.
- Future mission should involve active instruments together with radiometric measurements, especially in the far IR and sub-mm range.

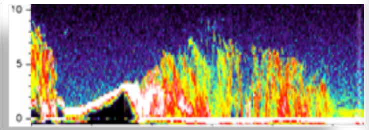

Thanks!

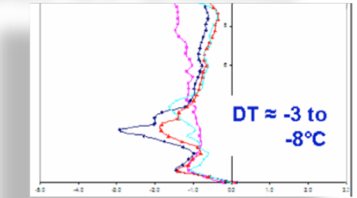
Two Coupled Planetary Scales Feedback Loops

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



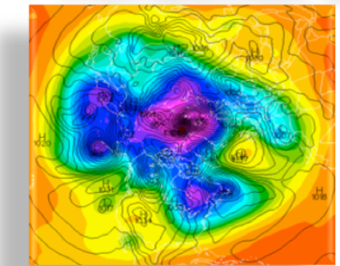


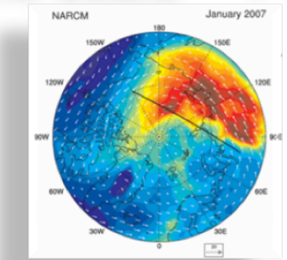


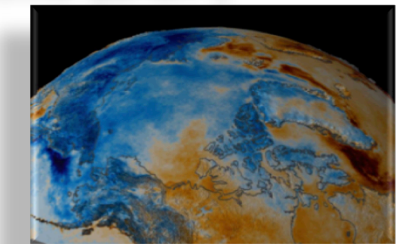


Aerosol → Cloud → Precipitation → Radiation

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







Circulation → Aerosol transport → Radiation