ON COMBINING AMSU AND POLAR MM5 OUTPUTS

TO DETECT PRECIPITATING CLOUDS OVER ANTARCTICA

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Measurement of cloud IWC and precipitation over Antarctica from space

- *Satellite radiometry is successfully providing precipitation measurements at tropical and mid-latitudes, but the science necessary to facilitate the formation of remotely sensed precipitation measurement system over Antarctica is not enough consolidated.*

- *This is the reason why all satellite-based global precipitation products do not cover polar regions. On the other hand the complexity of the problem, and the lack of resources discourages most of scientists to devote time and efforts to the topic.*

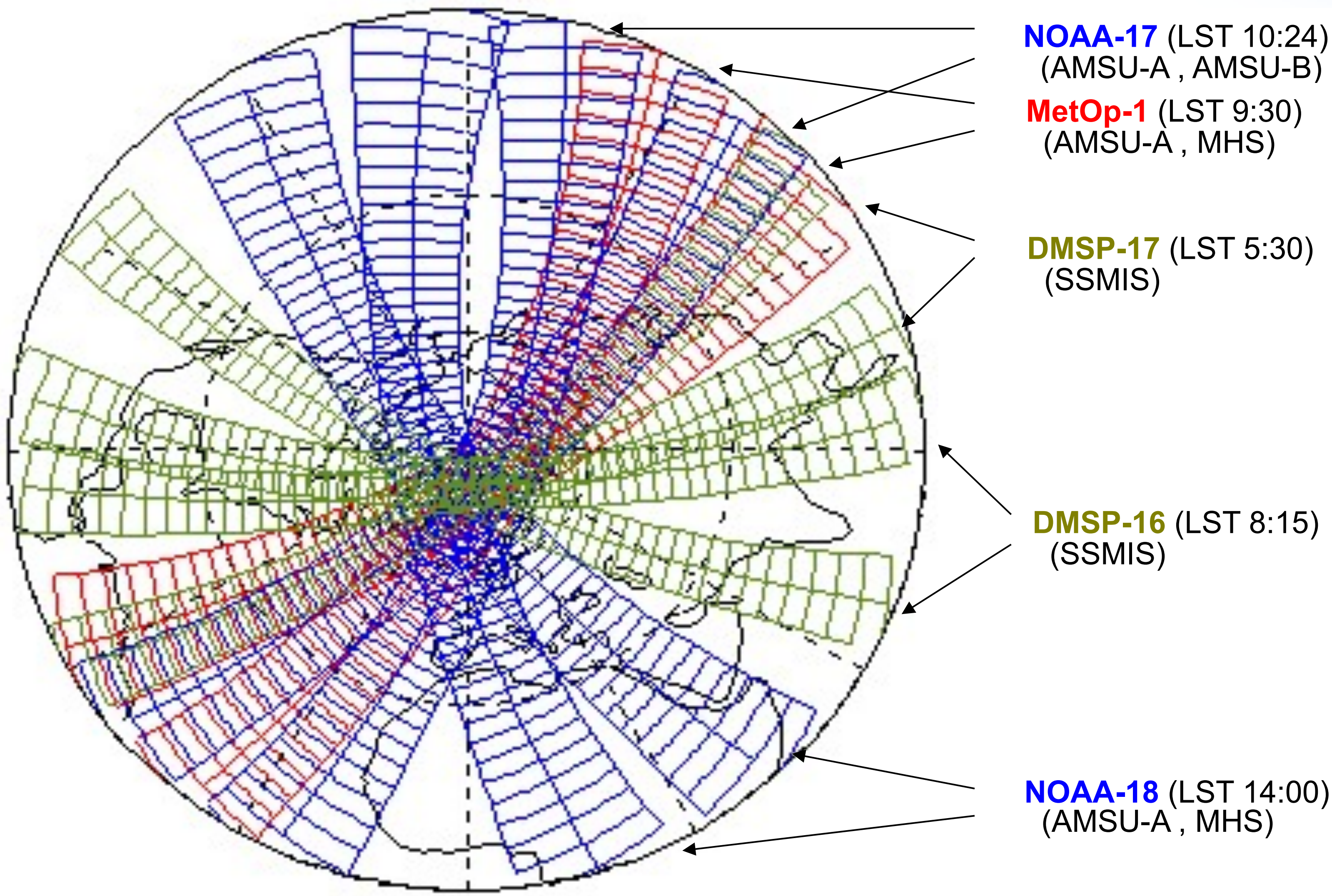
Considerations

- *Most promising global satellite-based approaches must be deeply revisited for Antarctic applications. (sensors, channels, cal-val strategies)*

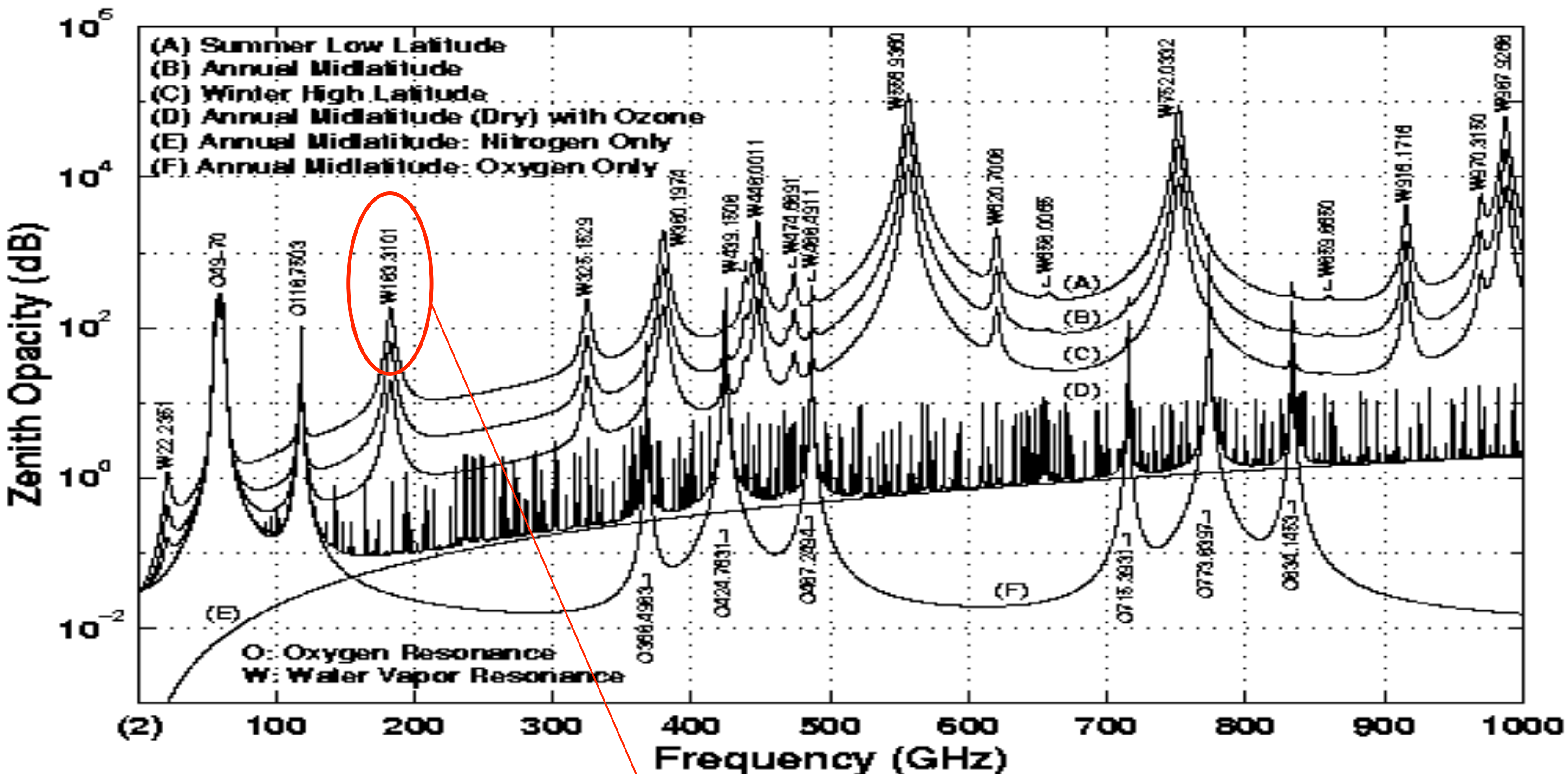
- *Satellite-based algorithms must use the well-established knowledge of high-latitude precipitating clouds as it is organized in available cloud models, focusing on microphysics.*

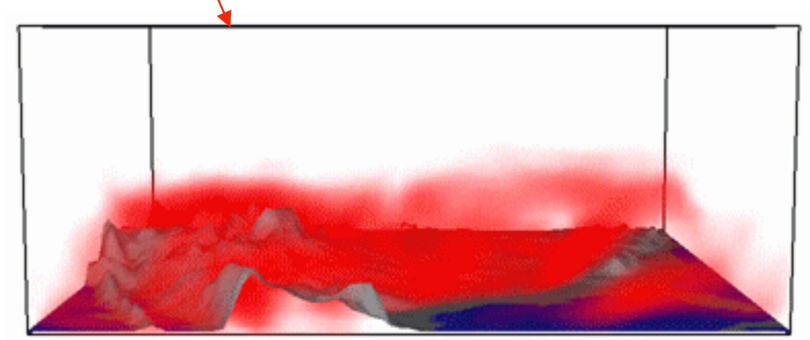
- *Few case studies represent particular occurrences, many of them better form the basis for a product.*

3-hr Coverage by Operational MW/LEO Satellites



MW window and sounding channels



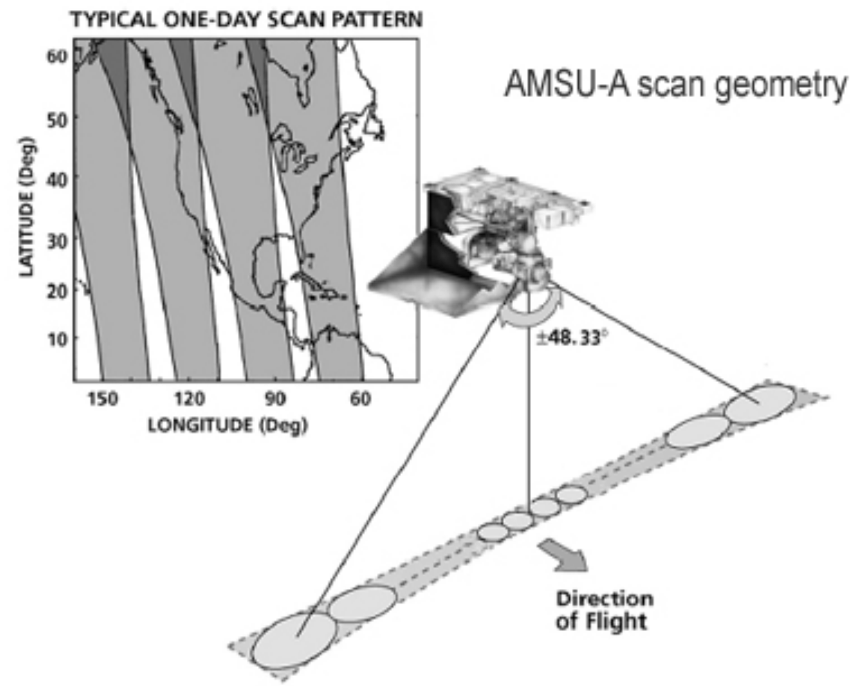


Advanced Microwave Sounding Unit (AMSU)

The Advanced Microwave Sounding Unit (AMSU) is derived from the Microwave Sounding Unit (MSU) which began service in 1978 on TIROS-N and continued on the NOAA 6 through 14 satellites.

AMSU is a considerable advance over MSU:
• 20 channels versus 4 channels on MSU;
• Weighting functions better sample the atmosphere;
• 48 or 16 km resolution versus MSU's 110 km (at nadir);
• Designed to measure many atmospheric and surface parameters, not just temperature:

AMSU flies on the NOAA KLM satellites. A version of AMSU also flies on the NASA Aqua Earth science satellite.



Spacecraft	Orbit	Launch	MW instruments
NOAA-15 (K)	AM orbit (7:00)	May 13, 1998	AMSU-A AMSU-B
NOAA-16 (L)	PM orbit (14:00)	Sept. 21, 2000	AMSU-A AMSU-B
NOAA-17 (M)	AM orbit (10:00)	June 24, 2002	AMSU-A AMSU-B
NOAA-18 (N)	PM orbit (14:00)	May 20, 2005	AMSU-A MHS
Sun-synchronous circular, altitude = 833±19 km or 870±19 km, inclination = 98.7º (retrograde)			

AMSU-A data

Channel number	Channel Frequency [MHz]	Number of pass bands	Bandwidth [MHz]	Nominal Beamwidth [degrees]	NEΔT	
1	23,800	1	270	3.3	0.30	Vertical
2	31,400	1	180	3.3	0.30	Vertical
3	50,300	1	180	3.3	0.40	Vertical
4	52,800	1	400	3.3	0.25	Vertical
5	53,596±115	2	170	3.3	0.25	Horizontal
6	54,400	1	400	3.3	0.25	Horizontal
7	54,940	1	400	3.3	0.25	Vertical
8	55,500	1	330	3.3	0.25	Horizontal
9	f_0=57,290.344	1	330	3.3	0.25	Horizontal
10	f_0±217	2	78	3.3	0.40	Horizontal
11	f_0±322.2±48	4	36	3.3	0.40	Horizontal
12	f_0±322.2±22	4	16	3.3	0.60	Horizontal
13	f_0±322.2±10	4	8	3.3	0.80	Horizontal
14	f_0±322.2±4.5	4	3	3.3	1.20	Horizontal
15	89,000	1	<6,000	3.3	0.50	Vertical

AMSU-A data Characteristics

Spatial resolution at nadir: 48 km at 833 km altitude
Number of Earth samples per scan: 30 per channel
IFOV: 3.3 degrees (all channels)
Scan rate: 7.5 scans per minute

Cross track distance between sample centers at nadir: 48 km at 833 km altitude

Along track distance between sample centers at nadir: 52.7 km at 833 km altitude

Cross-track scan coverage: ± 48.33 degrees from nadir

Swath width: 2069.6 km at 833 km altitude

AMSU-B/MHS data

Channel number	Channel Frequency [GHz]	Number of pass bands	Bandwidth [MHz]	NEΔT	
16	89.0±0.9	2	1000	0.37	90-θ

* The polarization angle is defined as the angle from horizontal polarization (i.e., electric field vector parallel to satellite track) where θ

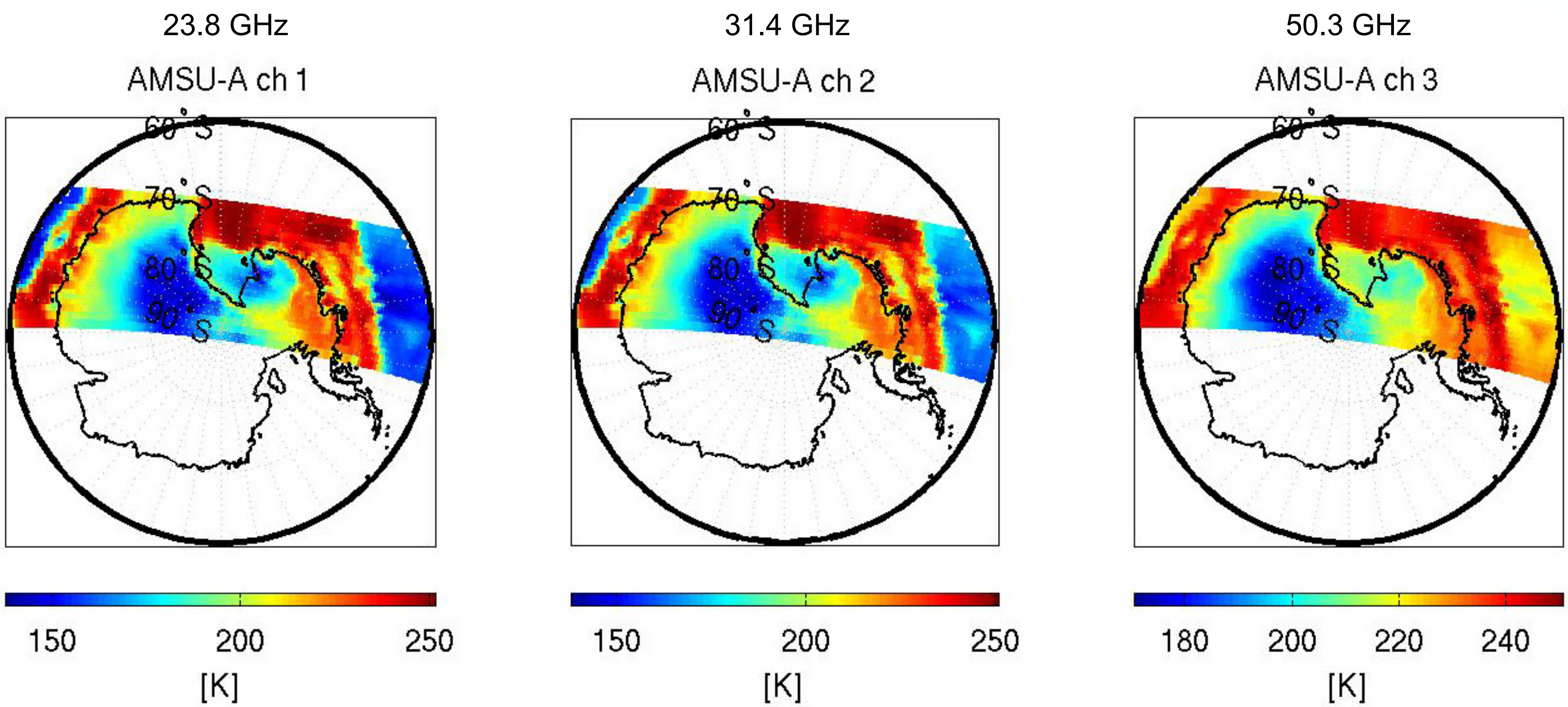
AMSU-B data Characteristics

Channel number	Channel Frequency [GHz]	Number of pass bands	Bandwidth [MHz]	NEΔT	
H1	89.0	1	2800	0.22	Vertical
H2	157.0	1	2800	0.34	Vertical
H3	183.311 ± 1.0	2	2 x 500	0.51	Horizontal
H4	183.311 ± 3.0	2	2 x 1000	0.40	Horizontal
H5	190.311	1	2200	0.46	Vertical

MHS data Characteristics

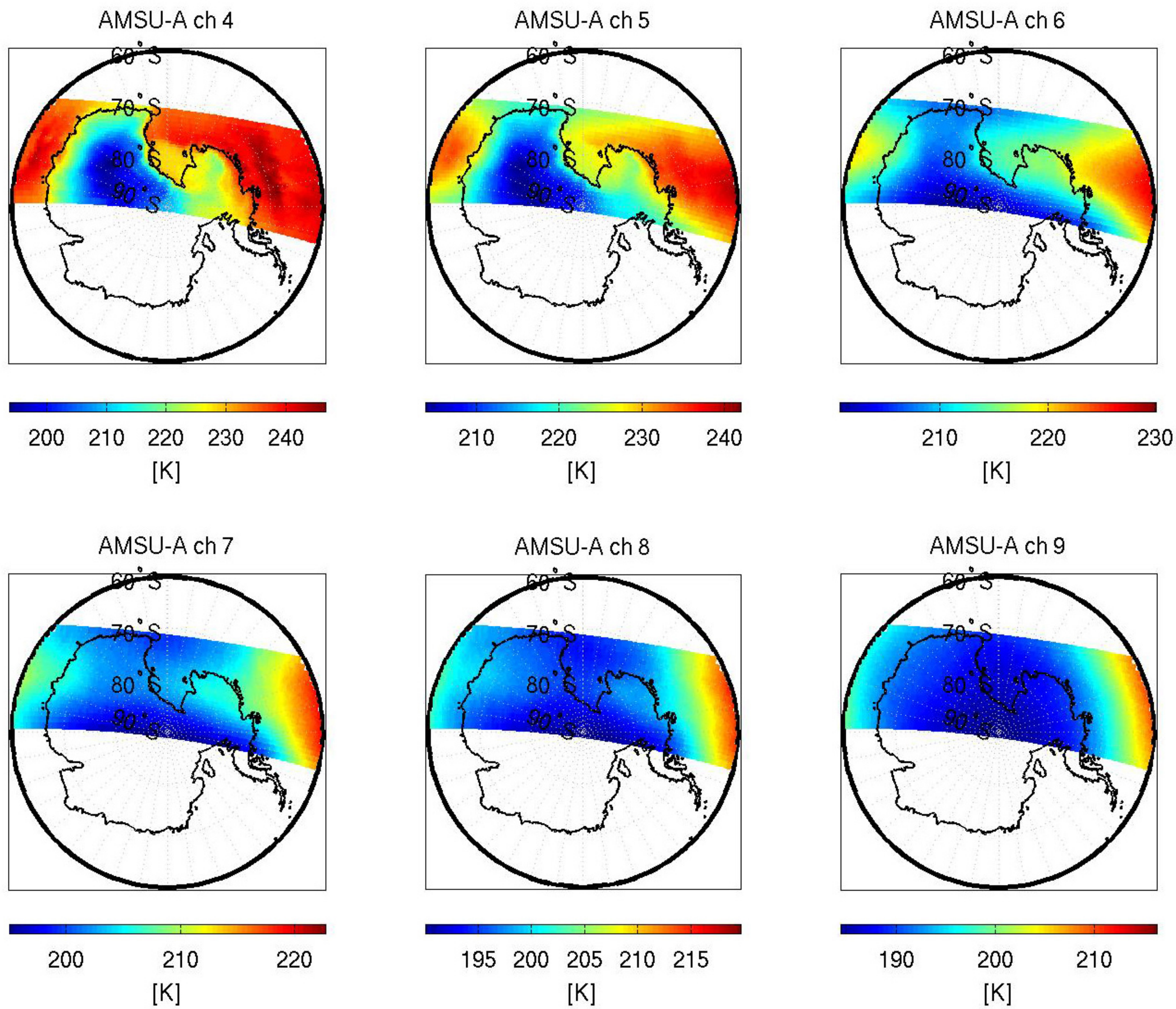
Spatial resolution at nadir: 16 km at 833 km altitude
Number of Earth samples per scan: 90 per channel
IFOV: 1.1 degrees (all channels)
Scan rate: 22.5 scans per minute
Cross track distance between sample centers at nadir: 16 km at 833 km altitude
Along track distance between sample centers at nadir: 17.6 km at 833 km altitude
Cross-track scan coverage: ± 48.95 degrees from nadir
Swath width: 2126.2 km at 833 km altitude

AMSU-A Brightness Temperatures



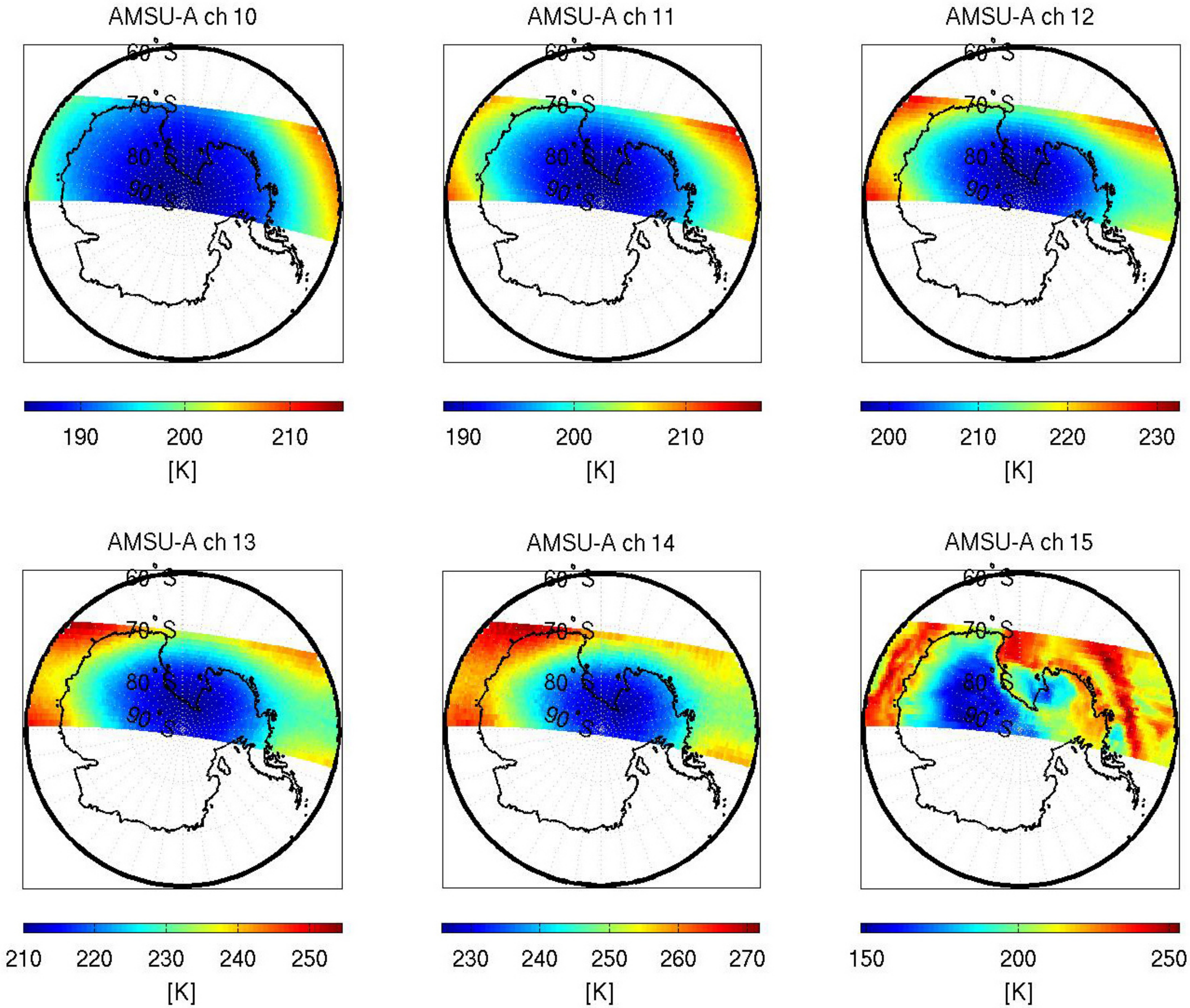
TB AMSU-A ch. 1-3 29/08/2006 07:12 UTC

AMSU-A Brightness Temperatures



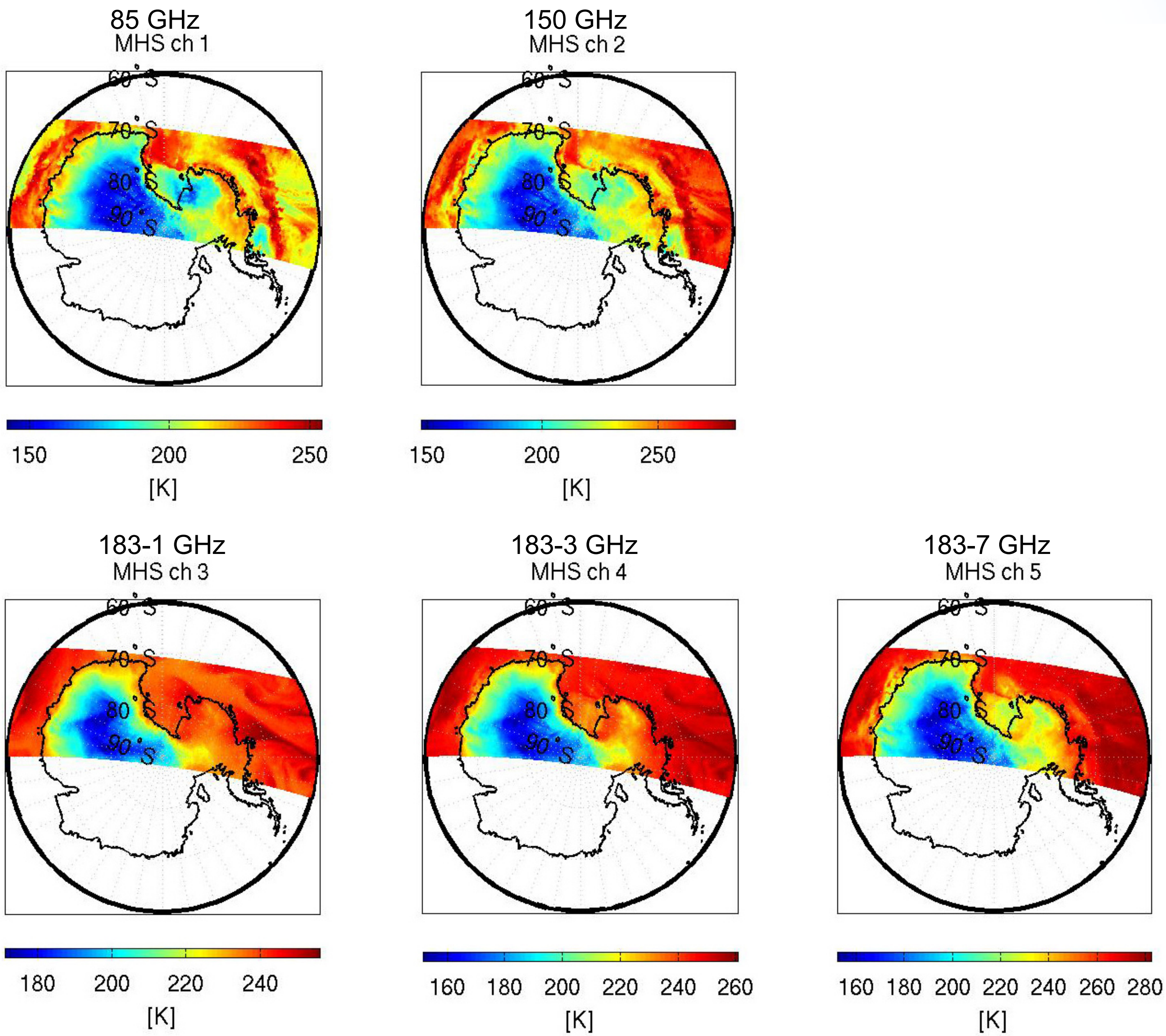
TB AMSU-A ch. 4-9 29/08/2006 07:12 UTC

AMSU-A Brightness Temperatures



TB AMSU-A ch. 10-15 29/08/2006 07:12 UTC

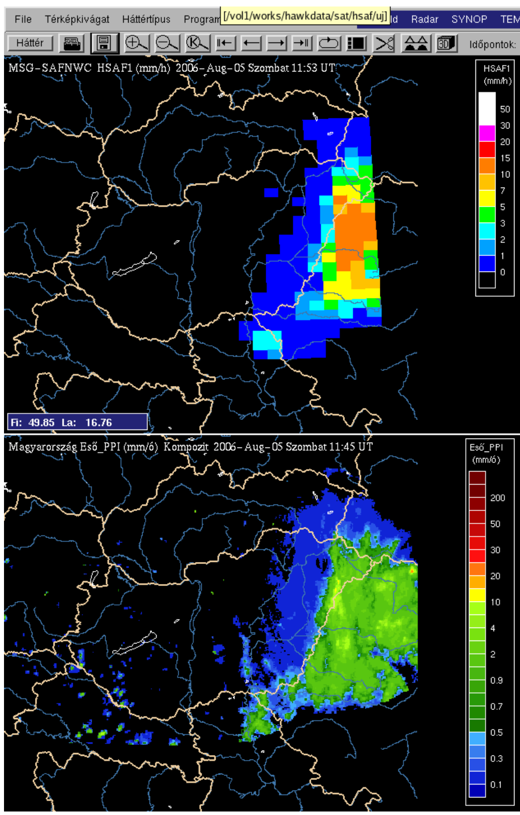
AMSU-B Brightness temperatures



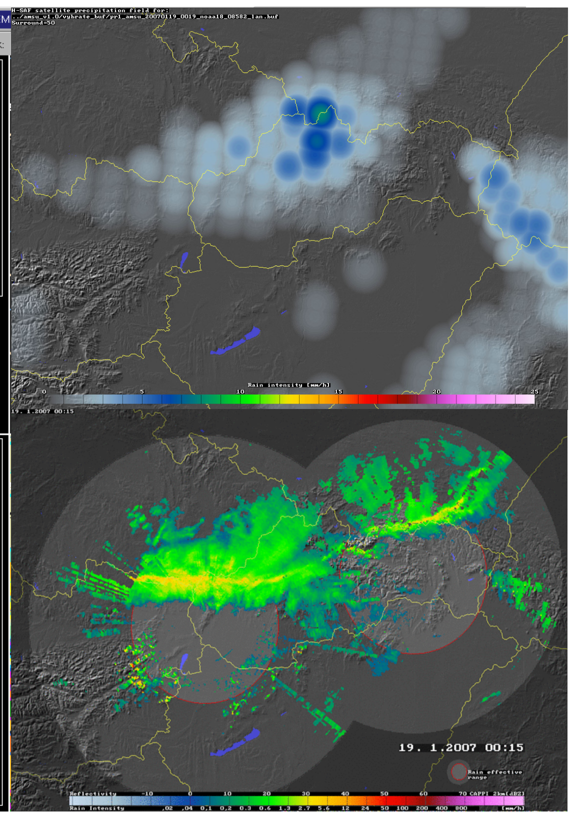
TB AMSU-B ch. 1-5 29/08/2006 07:12 UTC

Real time AMSU-based istantaneous precipitation measurement at middle-latitudes

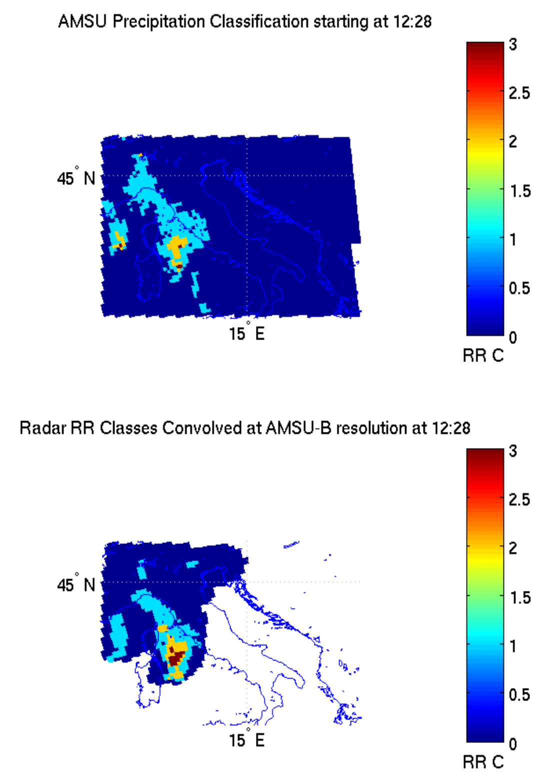
Since the relationship between precipitation and satellite brightness temperatures is nonlinear and imperfectly known, <u>especially with cross-track scanning</u>, the retrievals will employ <u>neural networks trained with tested physical models</u> (Chen and Staelin, 2002)



HMS, Hungary



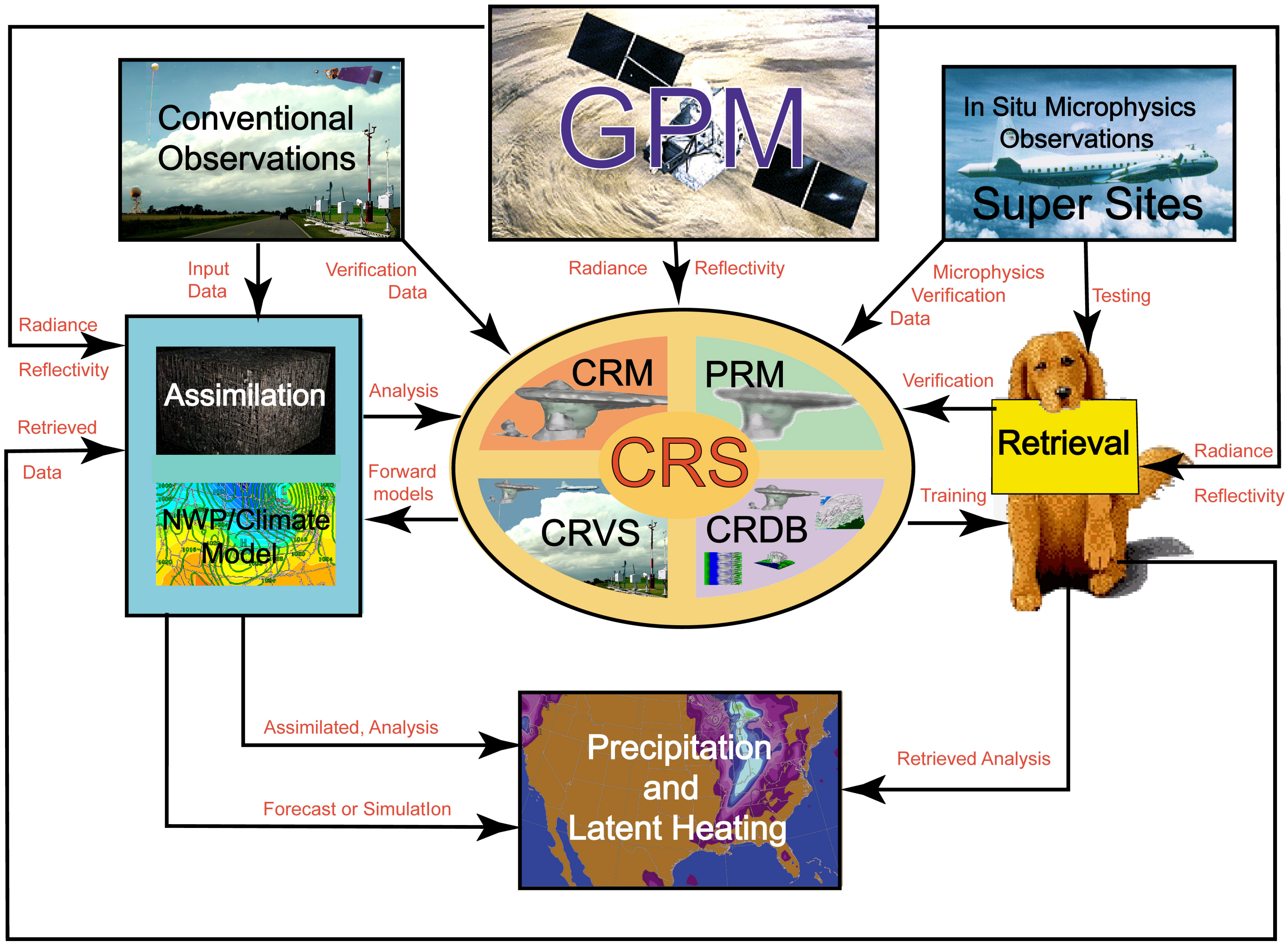
SHMI, Slovakia



DPCN. Italy

Examples of over land validation from EUMETSAT Satellite Application Facility on support to Operational Hydrology and Water Management (H-SAF), coordinated by CNMCA.

The model as the instrument to interpret MW



- **CRS – Cloud Radiation Simulation**
- **CRM – Cloud Resolving Model**
- **PRM – Passive Radiation Model**
- **CRVS – Cloud Radiation Verification Studies**
- **CRDB – Cloud Radiation Data Base**

The model as the instrument to interpret MW

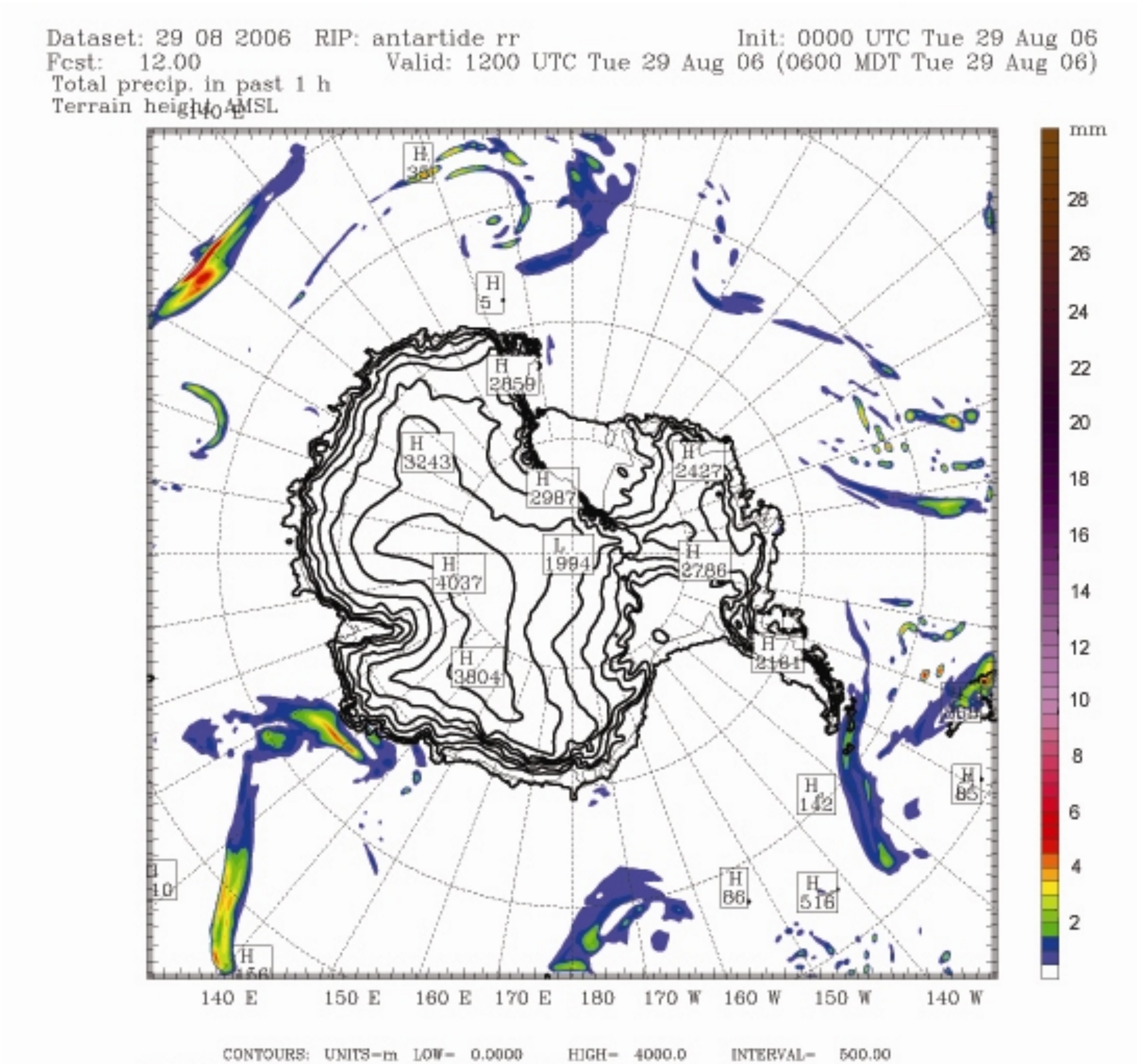
The estimates for surface precipitation rates and hydrometeor water-paths will be trained using a mesoscale numerical weather prediction (NWP) model (Polar MM5), a two-stream radiative transfer model (TBSCAT), and electromagnetic models for icy hydrometeors (F(λ)).

The Polar MM5 model, initialized with *National Center for Atmospheric Research* (NCEP), for many representative storms and their corresponding brightness temperatures simulated at AMSU frequencies will form the Antarctica cloud-radiation database.

Only storms with simulated morphologies that match simultaneous AMSU observations at 183 GHz sounding channels band are used. The nature of these storms used for training, it is supposed to overcome the scarcity of measurements.

The validity of these simulated storms is supported by their general agreement with histograms of concurrent AMSU observations.

Playing with Polar MM5



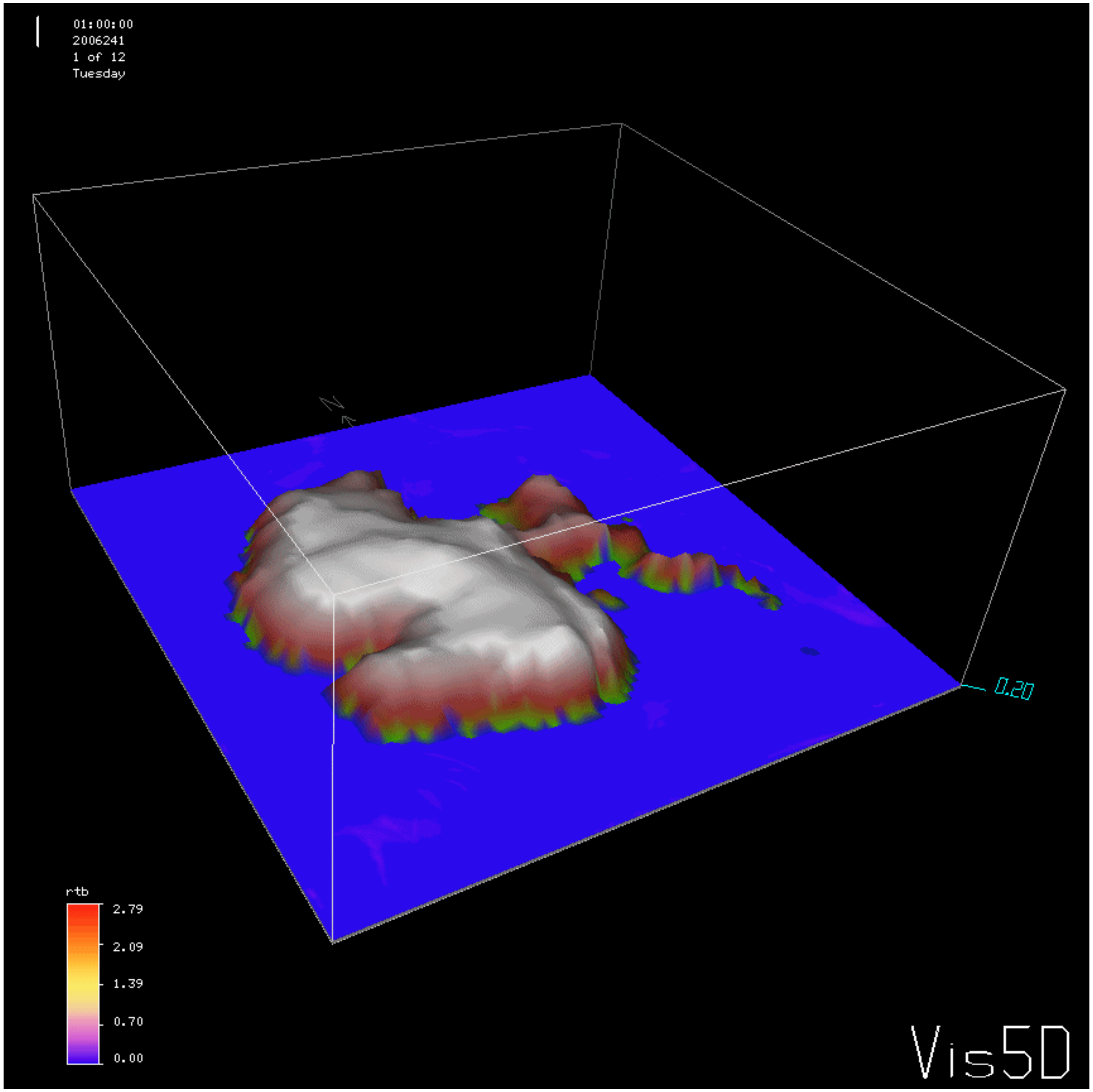
Hourly Precipitation – 29/08/2006 at 12:00 UTC

Polar MM5 (v. 3.7.4) running over the whole Antarctica at 16 km resolution grid; integration time 45”, Goddard explicit microphysics.

Initialization and boundary-condition from *National Centers for Environmental Prediction* (NCEP) at 1x1 deg every 6 hours.

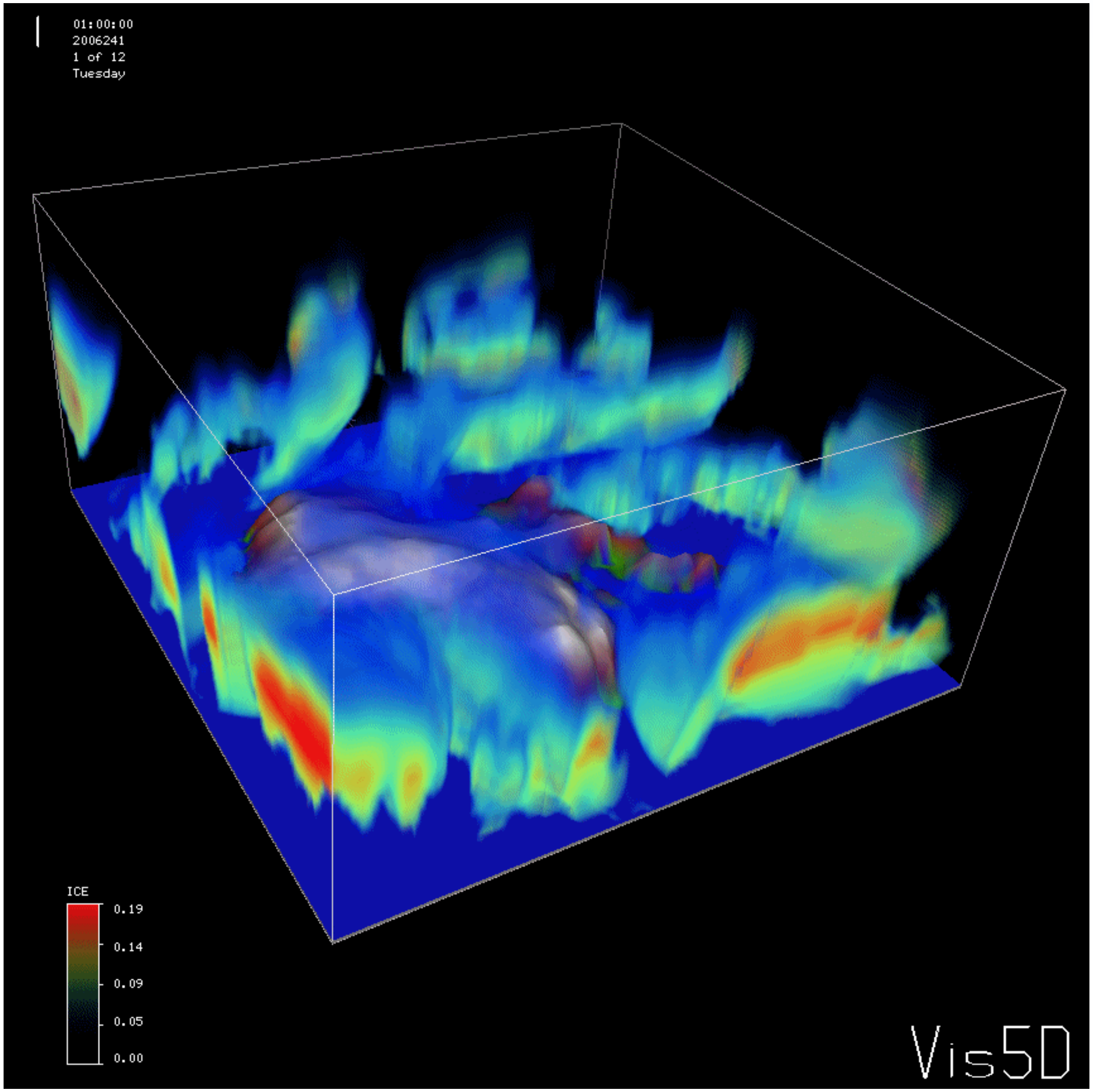
Each simulation starts 5 hours before the AMSU overpass

Polar MM5



Hourly precipitation (mm) – starting 29/08/2006 at 12:00 UTC

Polar MM5



Ice mixing ratio [g/kg] –starting 29/08/2006 at 12:00 UTC

Microphysics

Goddard microphysics includes a parameterized Kessler-type two-category liquid water scheme, including cloud water and rain, and parameterized three-category ice-phase schemes, including cloud ice, snow, and hail/graupel.

Hydrometeors are assumed in the Goddard model to have size distributions that are inverse-exponential functions of diameter (D) [cm] as

$$N(D) = N_0 \exp(-\lambda D)$$

where N(D) [cm^{-4}] is the number of drops per cubic centimeter, per centimeter of diameter D. The intercept values, N_0 = N(0), for rain, snow, and graupel are assumed to be 0.08, 0.04, and 0.04 cm^{-4}, respectively. By assumption the decay rate $\lambda = (\pi \rho N_0/\rho_0 q)^{0.25}$ [cm^{-1}] where ρ is the density for rain, snow, and graupel, and q is the mass mixing ratio given by MM5 for each species as a function of altitude; ρ_0 is the density of moist air. All cloud ice is assumed to have a single diameter D = 2×10^{-3} cm and a density of 0.917 $g\cdot cm^{-3}$.

This formula was used when computing brightness temperatures, but <u>ρ=F (λ) for snow and graupel</u>.

*) A. H. Shivola, “Self-consistency aspects of dielectric mixing theories,” *IEEE Trans. Geosci. Remote Sens.*, vol. 27, no. 4, pp. 403-415, Jul. 1989.

K. Karkainen, A. Sihvola, K. Nikoskinen, “Analysis of a three-dimensional dielectric mixture with finite difference method,” *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 5, pp. 1013-1018, May 2001.

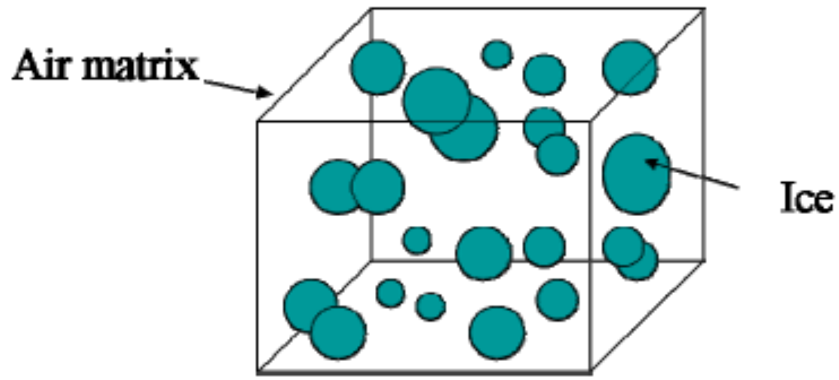
F(λ)

Snow and graupel are heterogeneous materials composed of ice and air. In an attempt to reproduce an approximate electromagnetic description of these materials, a F(λ) is used to compute the effective permittivity. The effective permittivity of a random medium, ε_{eff} , is defined as:

$$\bar{D} = \varepsilon_{eff}\bar{E}$$

where D = average displacement and E = average electric field with the limitation that the inhomogeneity has to be smaller scale than the wavelength.

The effective permittivity of a random medium, ε_{eff} , is characterized by <u>**the ice Factor F(λ)**, which is a fractional volume of ice in an air matrix</u>. Since the density of ice is ~1 [g cm^{-3}], ice factor is an inherent density of the heterogeneous mixture. For a given mass, it gives the volume of the mixture.



A mixture model for icy hydrometeors.

If $F(\lambda)$ = 0 means that the mixture is purely air without ice and ε_{eff} has to be equal to ε_0.

F(λ)/TBSCAT

AMSU-A and AMSU-B radiances are simulated by using a forward radiance program, TBSCAT, in its two-stream Mie-scattering approximation. TBSCAT was developed and provided by P. W. Rosenkranz (MIT).

To simulate brightness temperatures using TBSCAT, **all hydrometeors were assumed to be spherical and homogeneous with size distributions that are inverse-exponential functions of diameter, where F(λ) for each ice species was used in place of the density ρ.** Because F(λ) is generally not dependent upon hydrometeor diameters below 200 GHz, F(λ) was made independent of altitude or size distribution functions.

ICE FACTORS FOR SNOW, GRAUPEL, AND CLOUD ICE BASED ON DDSCAT

Ice Species	Ice Factors (F(λ)) (g cm^{-3})
Snow	$0.863 \cdot f_{THz} + 0.115$
Graupel	$0.815 \cdot f_{THz} + 0.0112$
Cloud ice	0.917

f_{THz} is frequency in units of THz.

The surface emissivity for ocean was computed using FASTEM, where the sea surface temperature and wind at 10 meters were provided by MM5. We are presently deciding the source for surface emissivity over glaciated surface.

Conclusions

- The work is in progress.

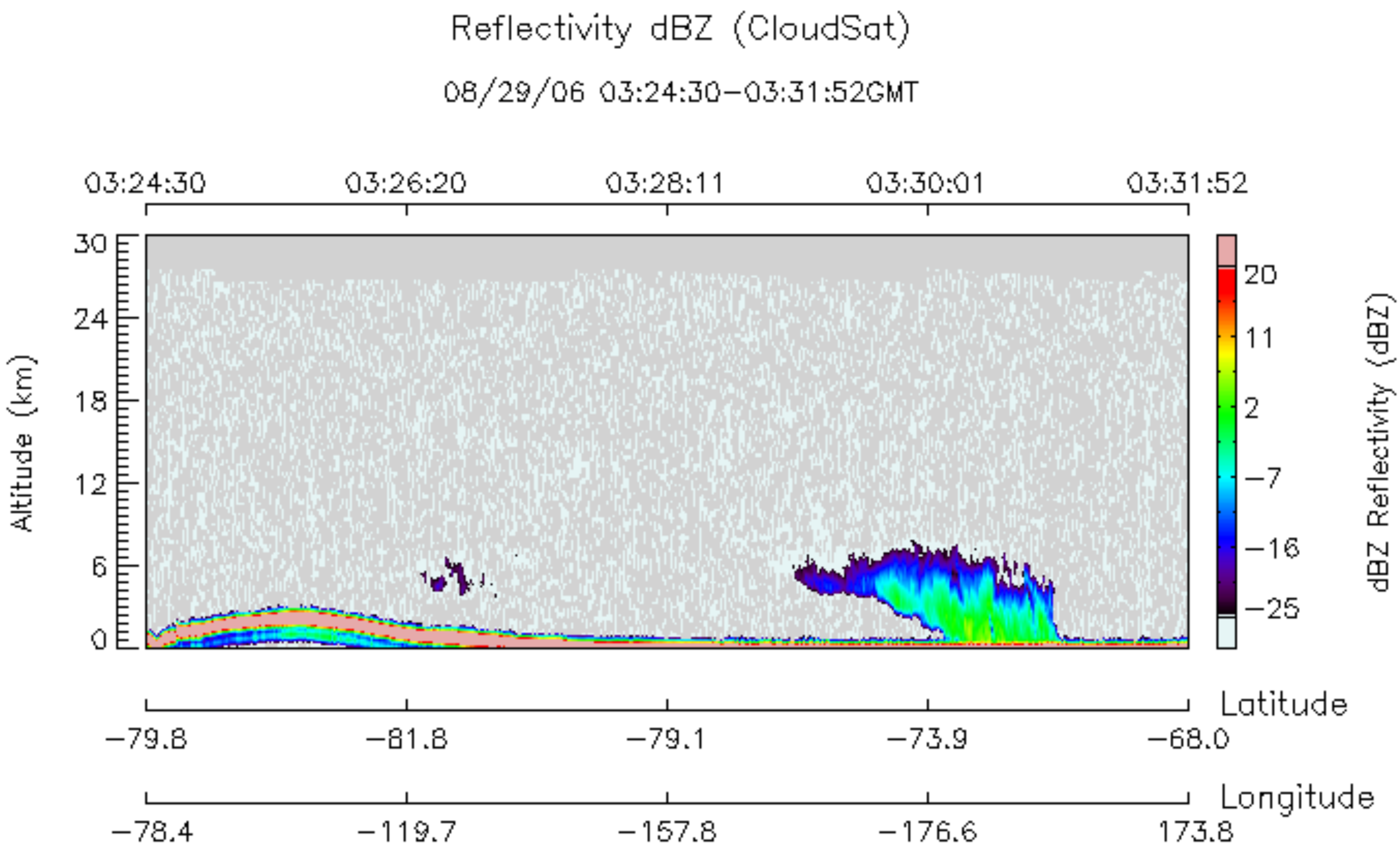
- The efforts Francesco Di Paola devoted to install and run the well documented "Polar MM5 tool", will be for sure useful also for other studies.

- The structure of the retrieval algorithm is based on the capability of the cloud model to generate reliable Antarctic microphysical profiles. The generation of such a cloud-radiation database (CRDB) represents the main research effort.

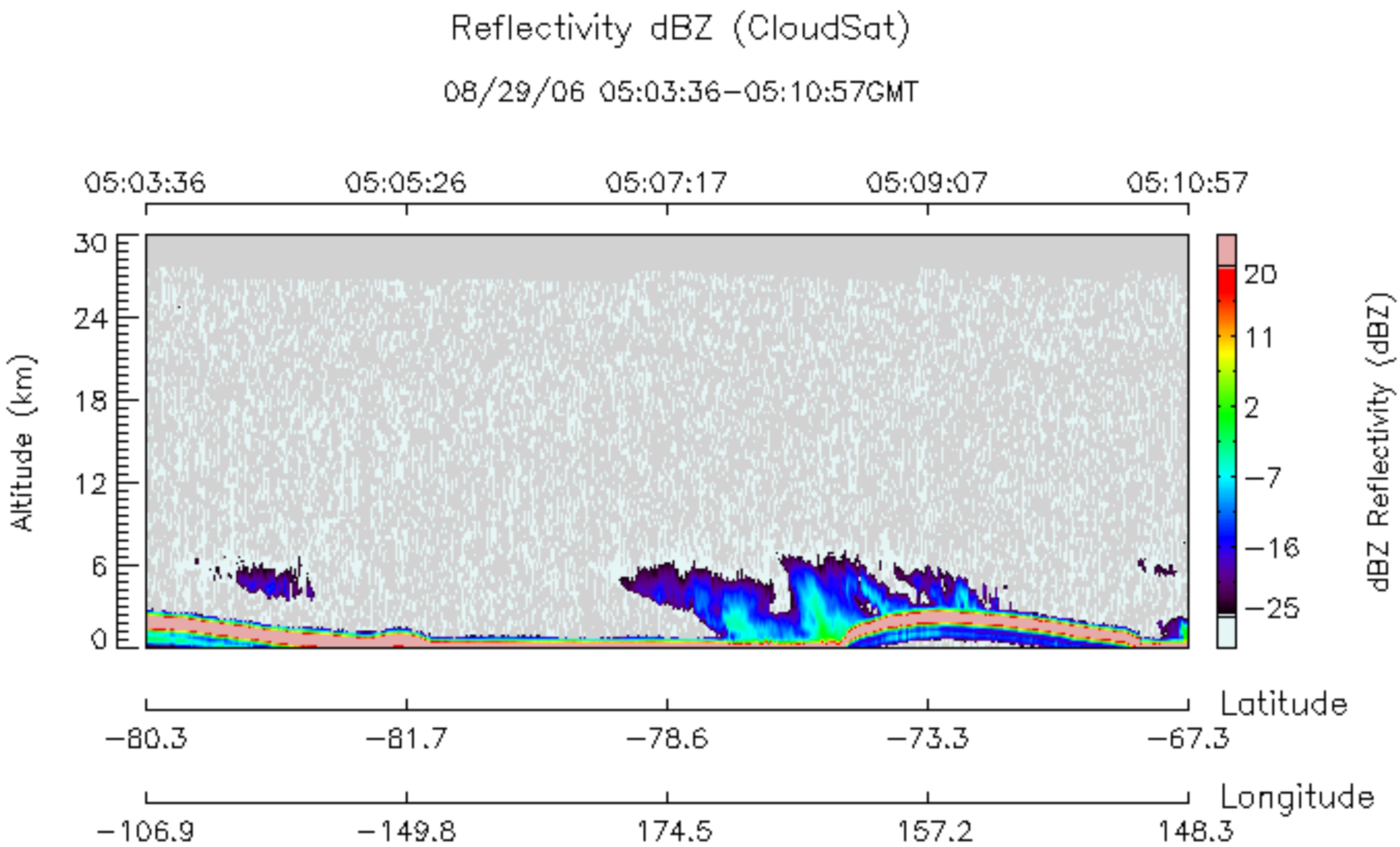
- Long lasting collaboration with Prof. Greg Tripoli (UW-NMS) will allow us to carry on sensitivity studies using different CRMs.

- It will be easy to enrich the CRDB including also the radiative part for different MW sensors and frequencies.

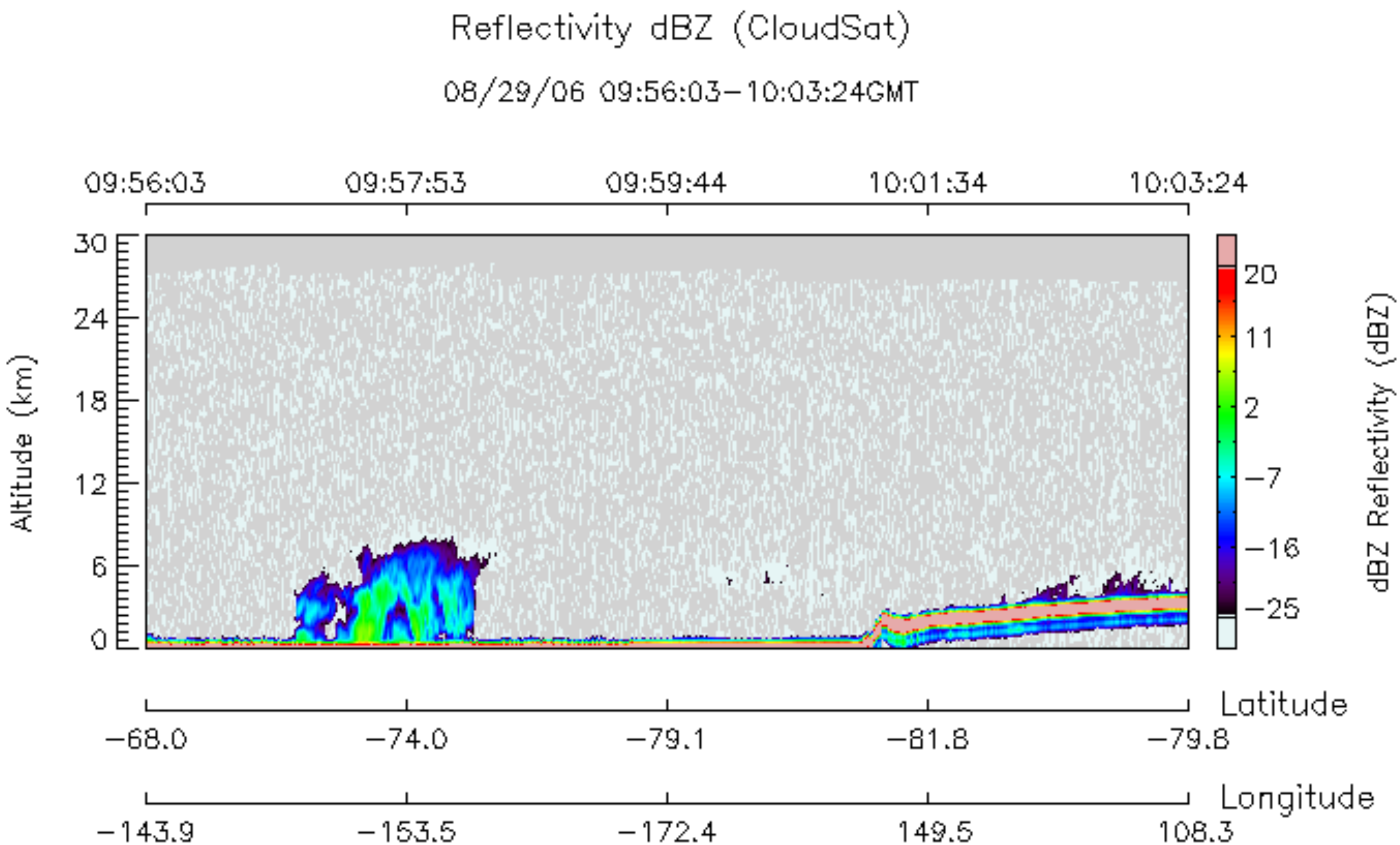
- A proposal concerning "*Cal/Val of precipitation monitoring technique over Antarctica*" has been recently submitted to the Italian Commission for the International Polar Year (IPY). We cross our fingers willing to participate to the *"Antarctic Climate and Atmospheric Circulation (ACSquared)".*



Reflectivity dBZ (CloudSat)
08/29/06 03:24:30–03:31:52GMT
03:24:30
03:26:20
03:28:11
03:30:01
03:31:52
Altitude (km)
30
24
18
12
6
0
20
11
2
−7
−16
−25
dBZ Reflectivity (dBZ)
Latitude
−79.8
−81.8
−79.1
−73.9
−68.0
Longitude
−78.4
−119.7
−157.8
−176.6
173.8



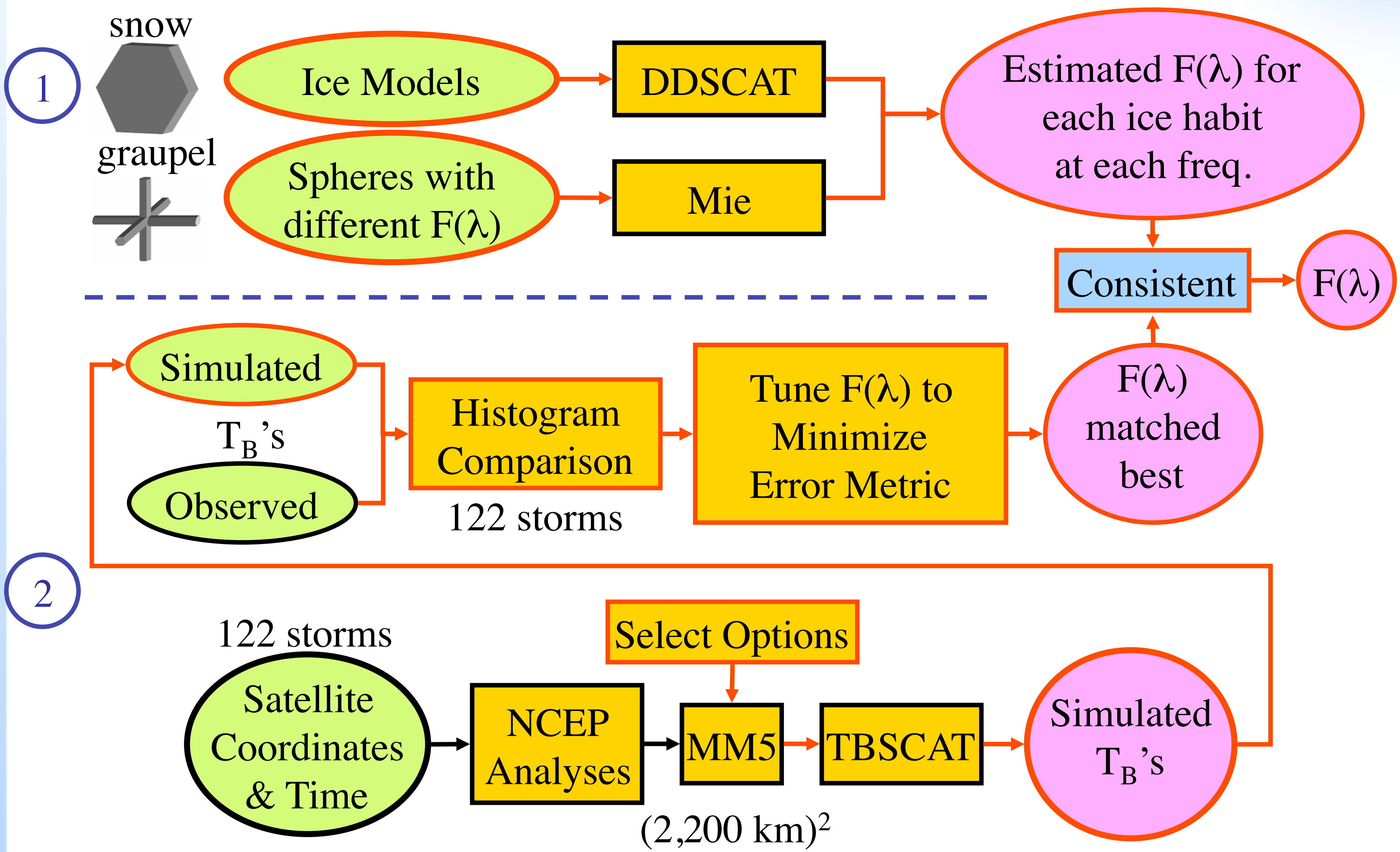
Reflectivity dBZ (CloudSat)
08/29/06 05:03:36–05:10:57GMT
05:03:36
05:05:26
05:07:17
05:09:07
05:10:57
Altitude (km)
30
24
18
12
6
0
20
11
2
–7
–16
–25
dBZ Reflectivity (dBZ)
Latitude
–80.3
–81.7
–78.6
–73.3
–67.3
Longitude
–106.9
–149.8
174.5
157.2
148.3



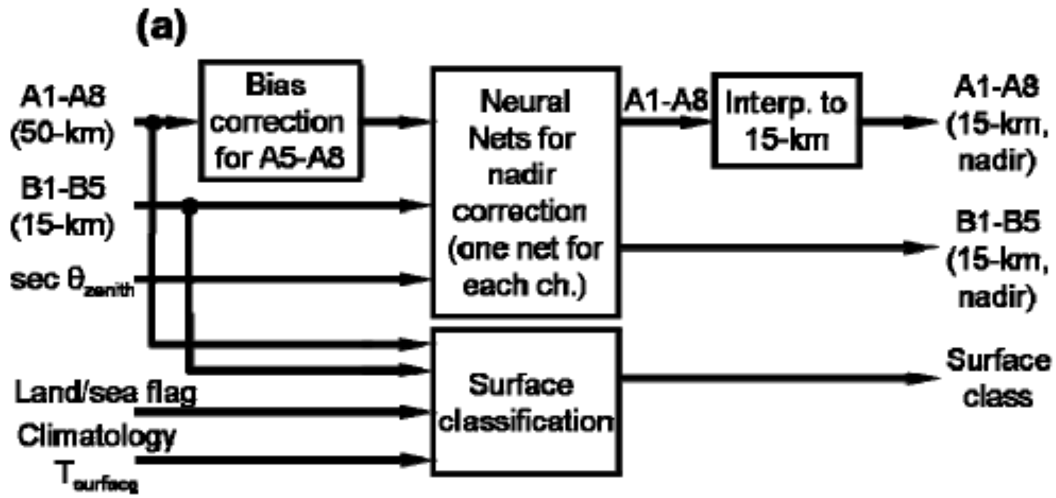
Reflectivity dBZ (CloudSat)
08/29/06 09:56:03–10:03:24GMT
09:56:03
09:57:53
09:59:44
10:01:34
10:03:24
30
24
18
12
6
0
Altitude (km)
20
11
2
–7
–16
–25
dBZ Reflectivity (dBZ)
Latitude
–68.0
–74.0
–79.1
–81.8
–79.8
Longitude
–143.9
–153.5
–172.4
149.5
108.3

Thank you!

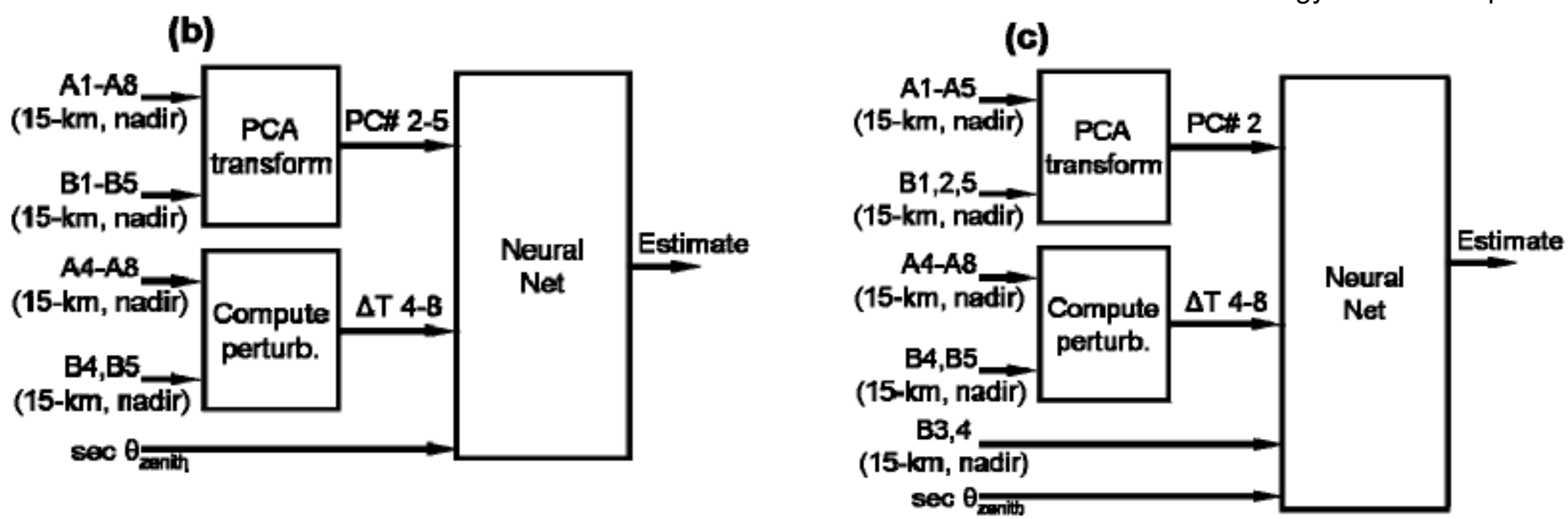
Validate NCEP/MM5/TBSCAT/F(λ) against AMSU observations



AMSU V2.0 block diagram



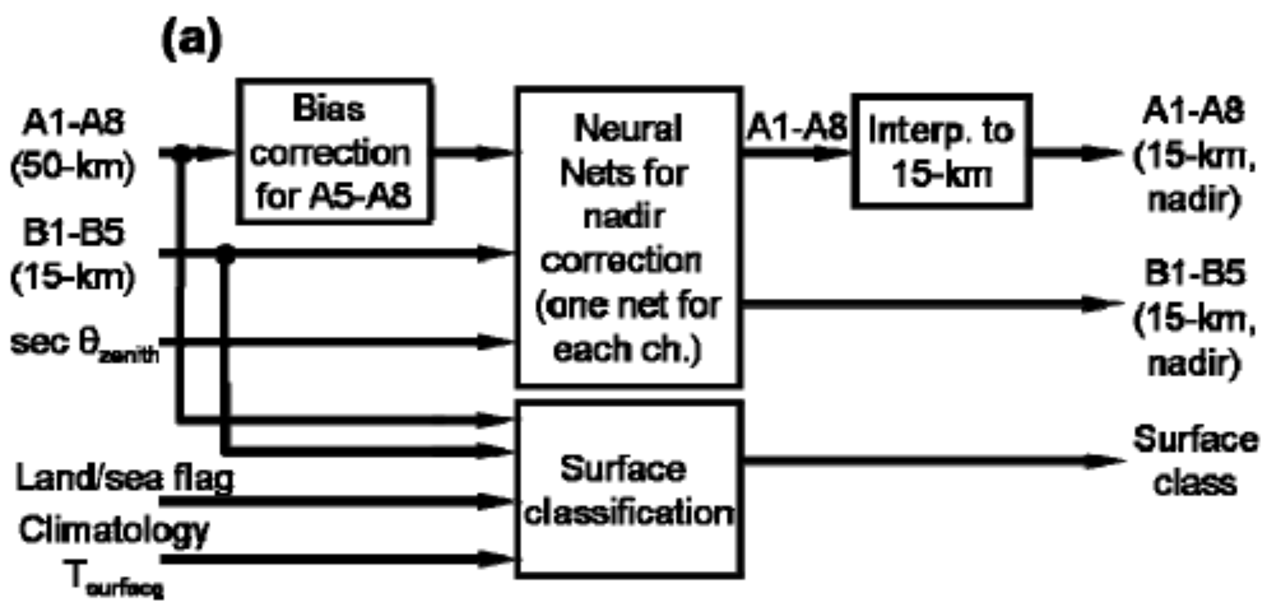
(a) Architecture for surface classification and for estimation of brightness temperatures that would have been seen at nadir.
Block diagrams for retrieval algorithms for (b) ocean and (c) land.
A1 and B1 signify channel 1 for AMSU-A and AMSU-B, respectively. ΔT4 is the spatially local perturbation in AMSU-A channel 4 brightness due to precipitation. PC's are principal components, θzenith is the zenith angle, and $T_{surface}$ is the climatology surface temperature



All neural networks have three layers with 10, 5, and 1 neuron, respectively, where the first two layers employ tangent sigmoid operators, and the final layer is linear.

Corrections of angle-dependent brightness temperatures to nadir

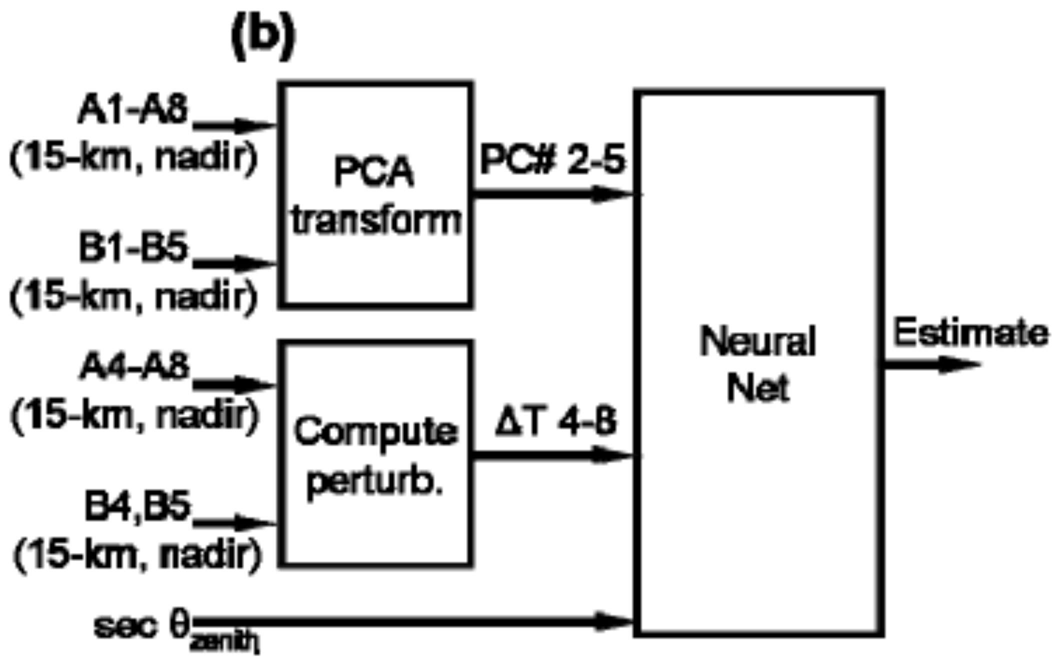
To estimate brightness temperatures at nadir for AMSU-A, the inputs to the neural networks were the secant of the satellite zenith angle and the MM5-simulated brightness temperatures for AMSU-A channels 1-8 (50.2 - 55.5GHz). To estimate brightness temperatures at nadir for AMSU-B, the inputs to the neural networks were MM5-simulated brightness temperatures for AMSU-B channels 1-5, and the secant of the satellite zenith angle. In both cases, <u>the target was the MM5-simulated brightness temperature at nadir</u> for the same pixel.



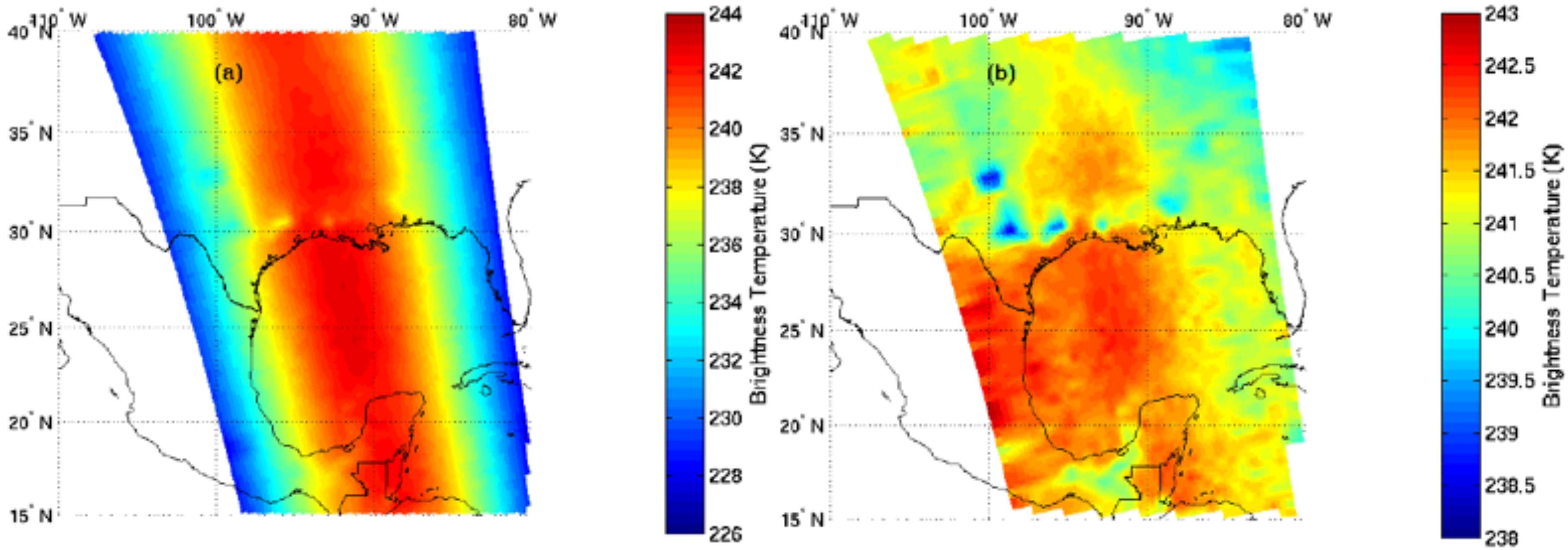
Precipitation retrieval algorithm for ocean

To reduce any residual dependence of brightness temperatures upon viewing angle, and dependence upon surface properties, only those principal components of the brightness temperature spectrum that exhibited the least dependence were preserved.

The principal components were computed for the estimated nadir brightness temperature spectra of all AMSU-B channels and AMSU-A channels 1-8 that were classified as ice-free ocean



Limb and surface correction



NOAA-15 AMSU-A 54.4-GHz brightness temperatures for a northbound track on 13 Sept 2000. (a) Uncorrected, and (b) Limb-and-surface corrected