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Remote Sensing of Convective Storms:

A-Train Observations of Storm Tops

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Pao Wang, Jindřich Šťástka and Zdeněk Charvát

ECSS 2011, Palma de Mallorca, Spain, 3 - 7 October 2011

Observations of convective storms with the A-Train satellites

What and why?

Based on imagery from other satellites and instruments (AVHRR, GOES, MSG/SEVIRI, stand-alone MODIS), some of the important "well-known" convective storm-top features are still not sufficiently understood, and many open questions or ambiguities remain. Physical models or concepts of these can be improved if we manage to document such features by the A-Train satellites and their instruments …

This applies namely to the following:

- overshooting tops (general characteristics)
- embedded warm areas, cold-U/V (enhanced-V) and cold-ring features
- cloud-top microphysics and 3.5 – 4.0 µm reflectivity observations
- above-anvil ice plumes
- observations of positive BTD (brightness temperature difference) values of the WV and IR window bands above storm tops and their possible relationship to lower-stratospheric water vapor
- cloud-top definition and cloud-top height
- etc. …

Observations of convective storms with the A-Train satellites

What and why?

Besides the general scientific aspects (enhancing our understanding and concepts of storm-top processes), improved interpretation of the observed storm-top features will positively affect the following:

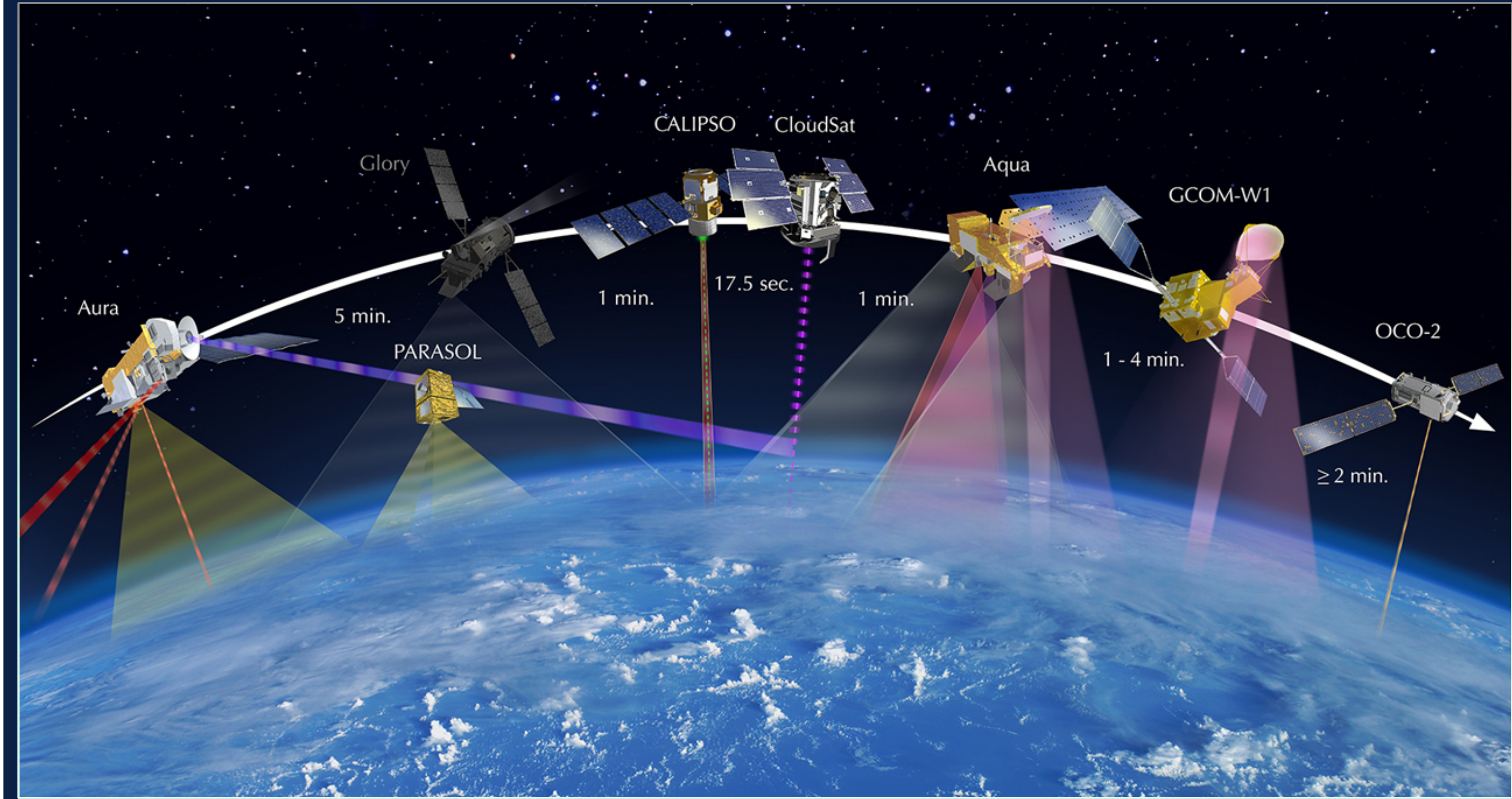
•subjective interpretation of real-time satellite imagery (enhanced IR-BT imagery, various multi-spectral RGB and "sandwich" image products, ...) when using these for nowcasting purposes (as a complementary or alternative data source to radar observations);

•improvement of operational satellite-based derived products used in nowcasting (e.g. SAFNWC products) and better performance/efficiency of various automatic nowcasting algorithms;

•impacts on better understanding of the upper-troposphere/lower-stratosphere interactions (e.g. cross-tropopause transport of gases and aerosols);

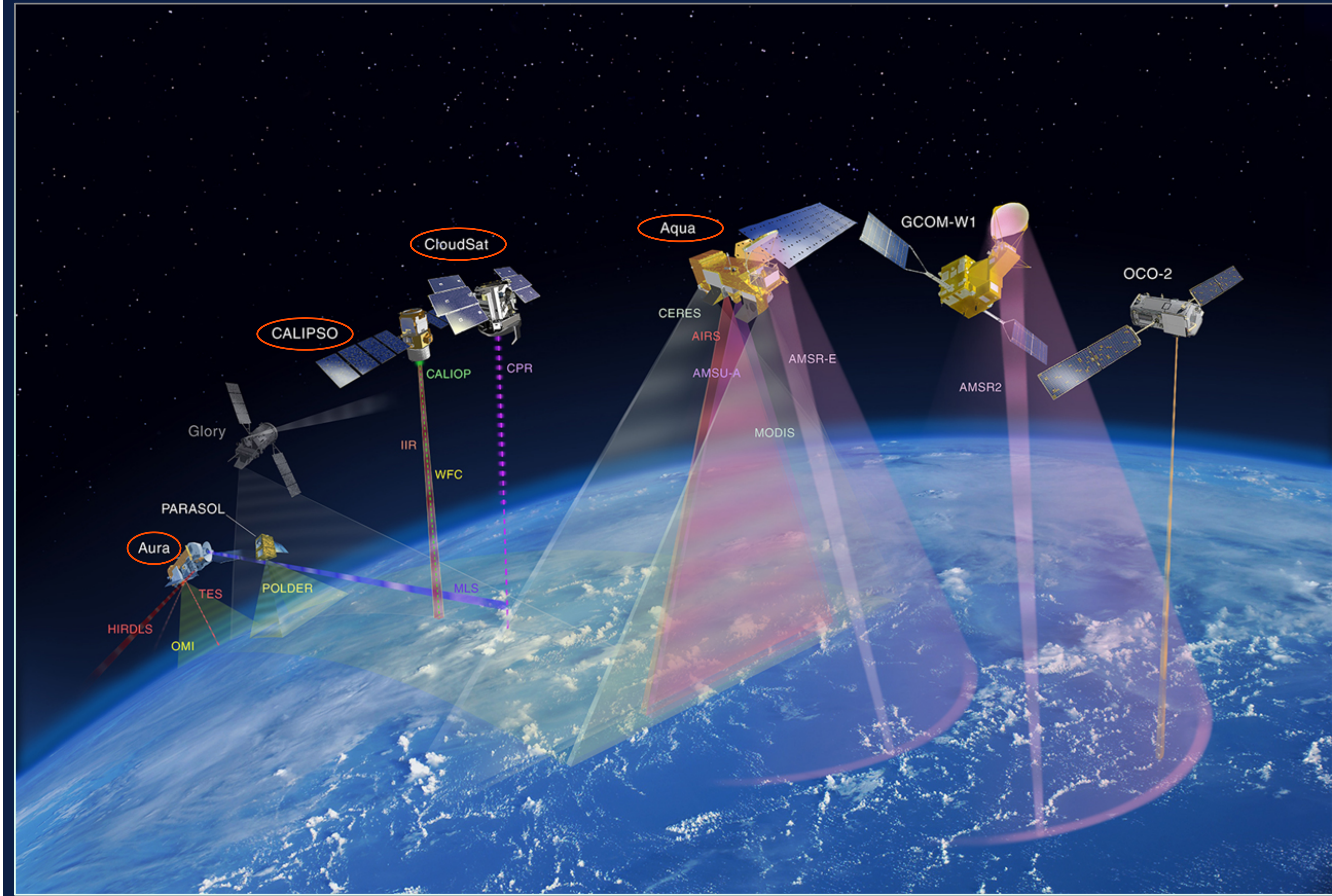
•impacts in climatology (e.g. moisturizing of the lower stratosphere by deep convection)

A-Train satellites and instruments - a brief overview



A-Train = „The Afternoon Train" (1:30 p.m. equator crossing local time) or „Aqua Train" http://atrain.nasa.gov/

Aqua: 2002/05/04, **CloudSat**: 2006/04/28 - 2011/04/17, **CALIPSO**: 2006/04/28, **Aura**: 2004/07/15

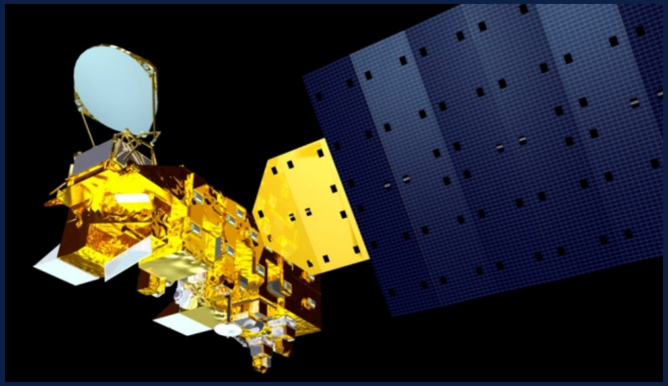


CloudSat
CALIPSO
Aqua
GCOM-W1
OCO-2
CERES
AIRS
AMSR-E
AMSU-A
AMSR2
CALIOP
CPR
Glory
IIR
WFC
MODIS
PARASOL
Aura
TES
POLDER
MLS
HIRDLS
OMI

Aqua / MODIS

Moderate Resolution Imaging Spectroradiometer

NASA EOS satellites Terra (1999) and Aqua (2002)



Reflected (backscattered) solar bands

Band	Bandwidth	Central Wavelength	Pixel Size
1	0.620 - 0.670 µm	0.6455 µm	250 m
2	0.841 - 0.876 µm	0.8565 µm	250 m
3	0.459 - 0.479 µm	0.4656 µm	500 m
4	0.545 - 0.565 µm	0.5536 µm	500 m
5	1.230 - 1.250 µm	1.2416 µm	500 m
6	1.628 - 1.652 µm	1.6291 µm	500 m
7	2.105 - 2.155 µm	2.1141 µm	500 m
8	0.405 - 0.420 µm	0.4113 µm	1000 m
9	0.438 - 0.448 µm	0.4420 µm	1000 m
10	0.483 - 0.493 µm	0.4869 µm	1000 m
11	0.526 - 0.536 µm	0.5296 µm	1000 m
12	0.546 - 0.556 µm	0.5468 µm	1000 m
13	0.662 - 0.672 µm	0.6655 µm	1000 m
14	0.673 - 0.683 µm	0.6768 µm	1000 m
15	0.743 - 0.753 µm	0.7464 µm	1000 m
16	0.862 - 0.877 µm	0.8662 µm	1000 m
17	0.890 - 0.920 µm	0.9040 µm	1000 m
18	0.931 - 0.941 µm	0.9355 µm	1000 m
19	0.915 - 0.965 µm	0.9352 µm	1000 m

Solar (20-26) and emission (20-25) bands

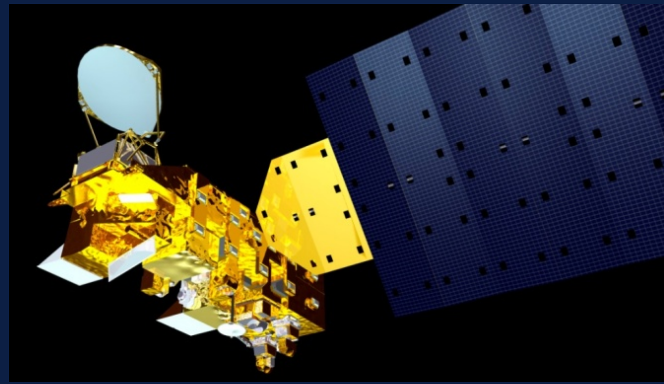
Band	Bandwidth	Central Wavelength	Pixel Size
20	3.660 - 3.840	3.785 µm	1000 m
21	3.930 - 3.989	3.960 µm	1000 m
22	3.930 - 3.989	3.960 µm	1000 m
23	4.020 - 4.080	4.056 µm	1000 m
24	4.433 - 4.498	4.472 µm	1000 m
25	4.482 - 4.549	4.545 µm	1000 m
26	1.360 - 1.390	1.383 µm	1000 m
27	6.535 - 6.895	6.752 µm	1000 m
28	7.175 - 7.475	7.334 µm	1000 m
29	8.400 - 8.700	8.518 µm	1000 m
30	9.580 - 9.880	9.737 µm	1000 m
31	10.780 - 11.280	11.017 µm	1000 m
32	11.770 - 12.270	12.032 µm	1000 m
33	13.185 - 13.485	13.359 µm	1000 m
34	13.485 - 13.785	13.675 µm	1000 m
35	13.785 - 14.085	13.907 µm	1000 m
36	14.085 - 14.385	14.192 µm	1000 m

Thermal emission only bands (27-36)

Aqua / MODIS

Moderate Resolution Imaging Spectroradiometer

Pixel size (nadir resolution): 250 m, 500 m and 1000 m;
swath width 2330 km

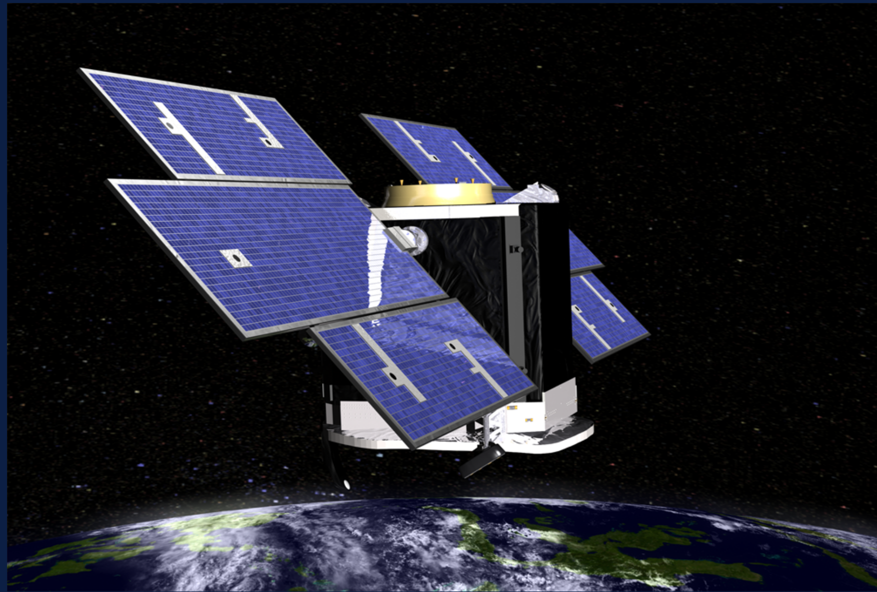


Corresponding MSG/SEVIRI bands

Band	Bandwidth	Central Wavelength	Pixel Size	MSG/SEVIRI
1	0.620 - 0.670 µm	0.6455 µm	250 m	VIS 0.6 HRV
2	0.841 - 0.876 µm	0.8565 µm	250 m	VIS 0.8
3	0.459 - 0.479 µm	0.4656 µm	500 m	
4	0.545 - 0.565 µm	0.5536 µm	500 m	
5	1.230 - 1.250 µm	1.2416 µm	500 m	
6	1.628 - 1.652 µm	1.6291 µm	500 m	NIR 1.6
7	2.105 - 2.155 µm	2.1141 µm	500 m	
8	0.405 - 0.420 µm	0.4113 µm	1000 m	
9	0.438 - 0.448 µm	0.4420 µm	1000 m	
10	0.483 - 0.493 µm	0.4869 µm	1000 m	
11	0.526 - 0.536 µm	0.5296 µm	1000 m	
12	0.546 - 0.556 µm	0.5468 µm	1000 m	
13	0.662 - 0.672 µm	0.6655 µm	1000 m	VIS 0.6
14	0.673 - 0.683 µm	0.6768 µm	1000 m	
15	0.743 - 0.753 µm	0.7464 µm	1000 m	
16	0.862 - 0.877 µm	0.8662 µm	1000 m	VIS 0.8
17	0.890 - 0.920 µm	0.9040 µm	1000 m	
18	0.931 - 0.941 µm	0.9355 µm	1000 m	
19	0.915 - 0.965 µm	0.9352 µm	1000 m	

Band	Bandwidth	Central Wavelength	Pixel Size	MSG/SEVIRI
20	3.660 - 3.840	3.785 µm	1000 m	
21	3.930 - 3.989	3.960 µm	1000 m	
22	3.930 - 3.989	3.960 µm	1000 m	IR 3.9
23	4.020 - 4.080	4.056 µm	1000 m	
24	4.433 - 4.498	4.472 µm	1000 m	
25	4.482 - 4.549	4.545 µm	1000 m	
26	1.360 - 1.390	1.383 µm	1000 m	
27	6.535 - 6.895	6.752 µm	1000 m	WV 6.2
28	7.175 - 7.475	7.334 µm	1000 m	WV 7.3
29	8.400 - 8.700	8.518 µm	1000 m	IR 8.7
30	9.580 - 9.880	9.737 µm	1000 m	IR 9.7
31	10.780 - 11.280	11.017 µm	1000 m	IR 10.8
32	11.770 - 12.270	12.032 µm	1000 m	IR 12.0
33	13.185 - 13.485	13.359 µm	1000 m	
34	13.485 - 13.785	13.675 µm	1000 m	IR 13.4
35	13.785 - 14.085	13.907 µm	1000 m	
36	14.085 - 14.385	14.192 µm	1000 m	XXX

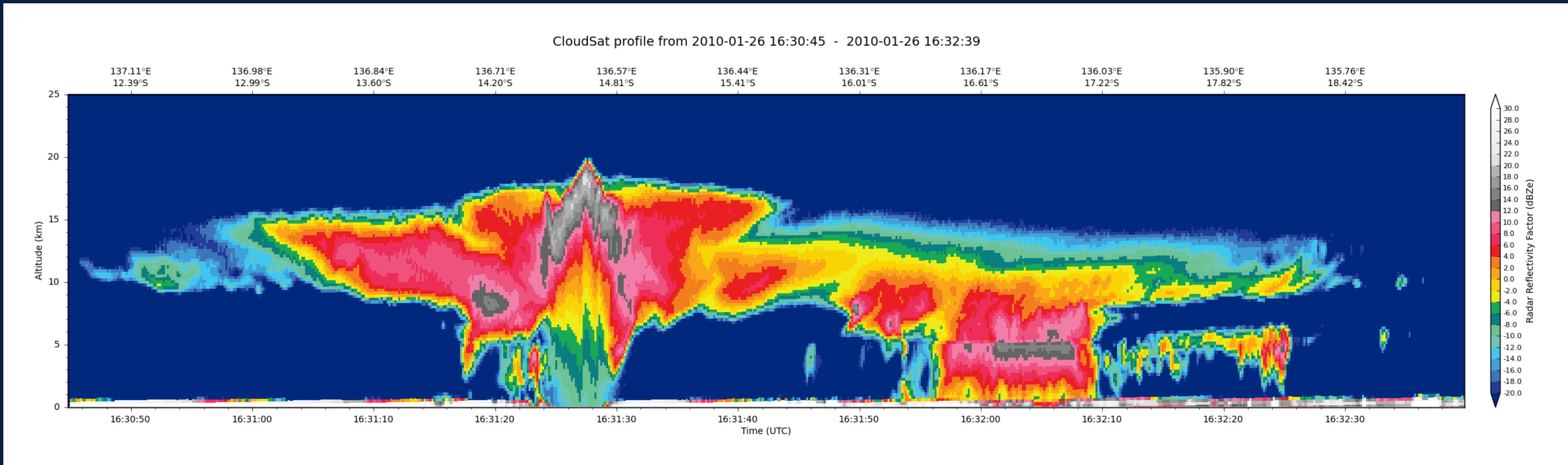
CloudSat



Cloud Profiling Radar (CPR)

94 GHz (~ 3 mm) cloud profiling radar

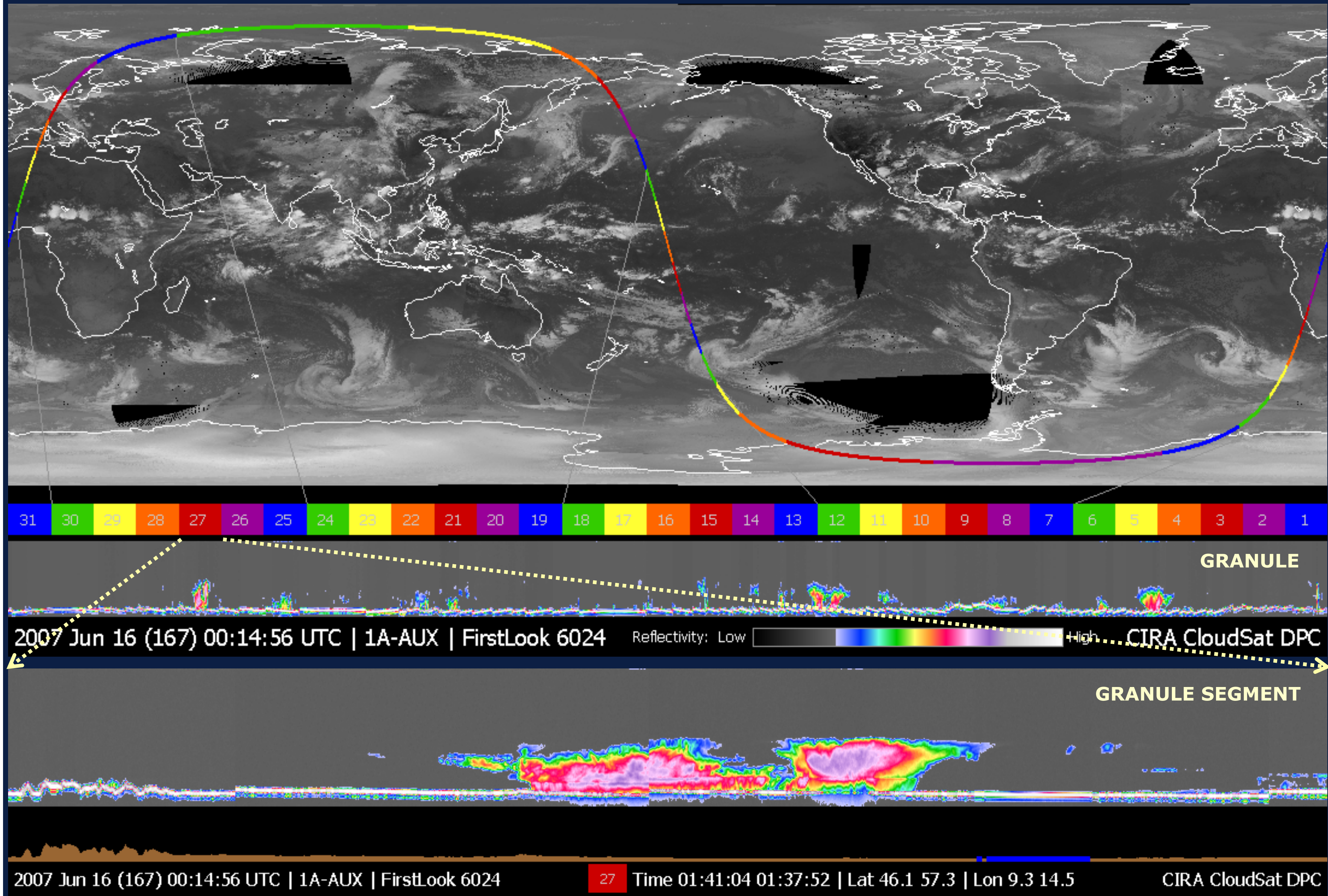
- approx. 1.4 km FOV
- 500 m vertical resolution
- from surface to 30 km



Visualization of data: ***ccplot*** - CloudSat and CALIPSO plotting tool, *http://ccplot.org/* (Peter Kuma)

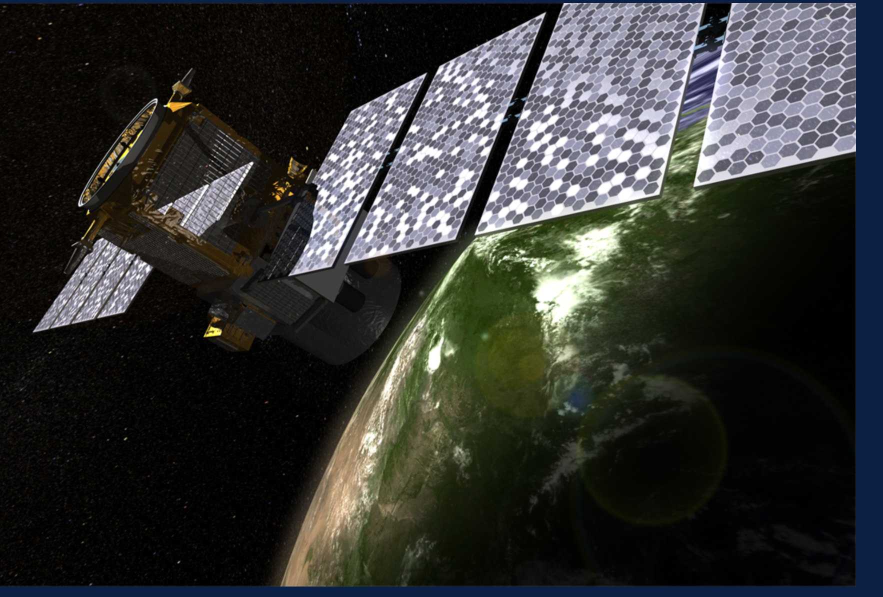
CloudSat browse archive

http://www.cloudsat.cira.colostate.edu/dpcstatusQL.php



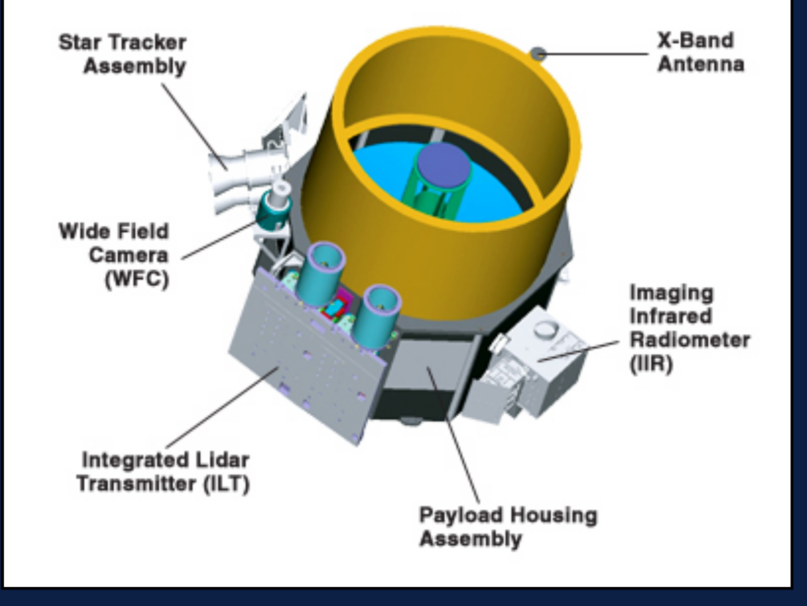
CALIPSO

Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)



1064 nm lidar (backscatter, 1 channel)
532 nm (2 channels, orthogonally polarized)

- vertical resolution 30-60 m
- horizontal resolution 333 m



Other CALIPSO instruments:

CALIPSO Wide Field Camera (WFC)

125 m / 1 km resolution
61 km swath

CALIPSO Infrared Imaging Radiometer (IIR)

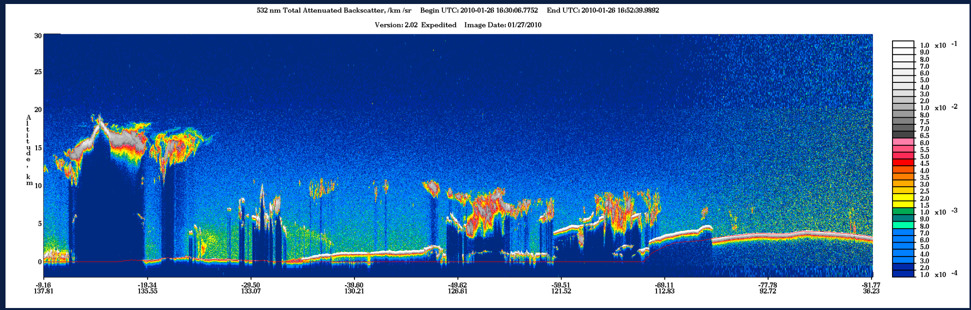
1 km resolution
64 km swath
IR bands 8.7, 10.6 and 12 μm

CALIPSO data and products: *http://eosweb.larc.nasa.gov/PRODOCS/calipso/table_calipso.html*

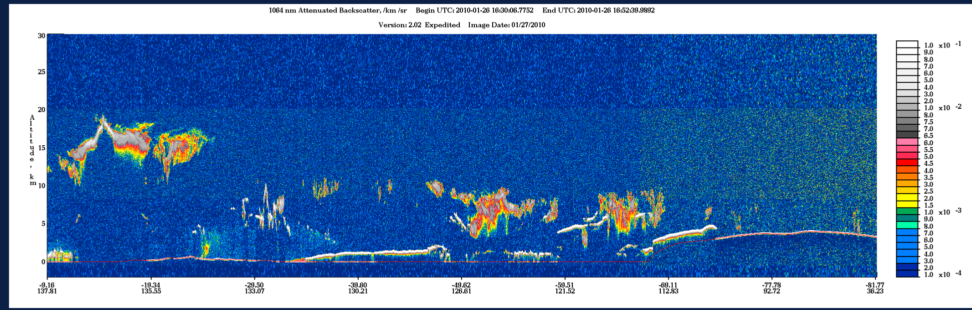
CALIPSO

CALIOP browse archive and quick-look products

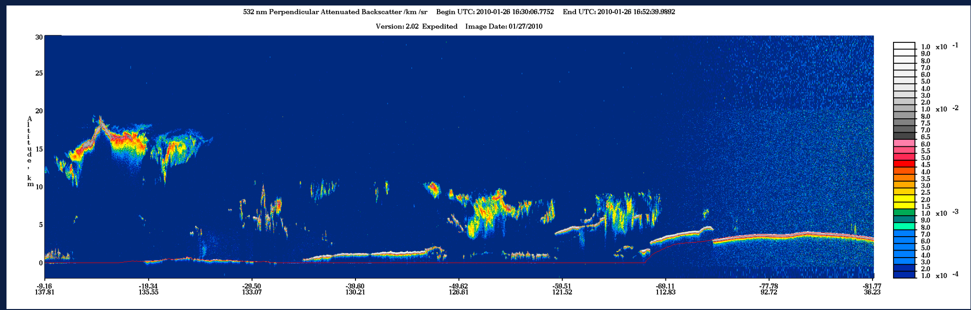
http://www-calipso.larc.nasa.gov/products/



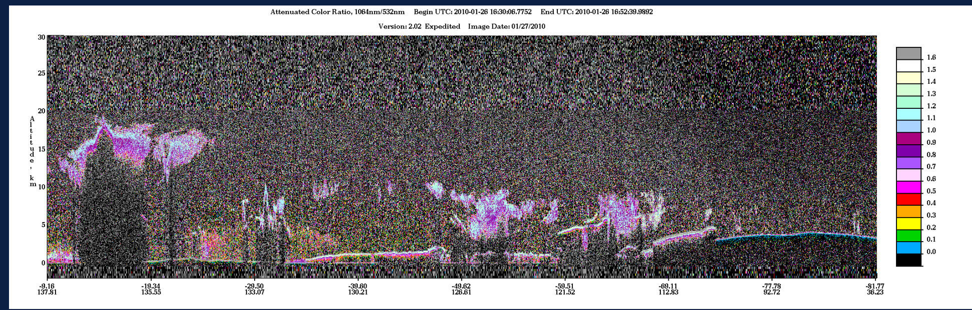
532 nm Total Attenuated Backscatter



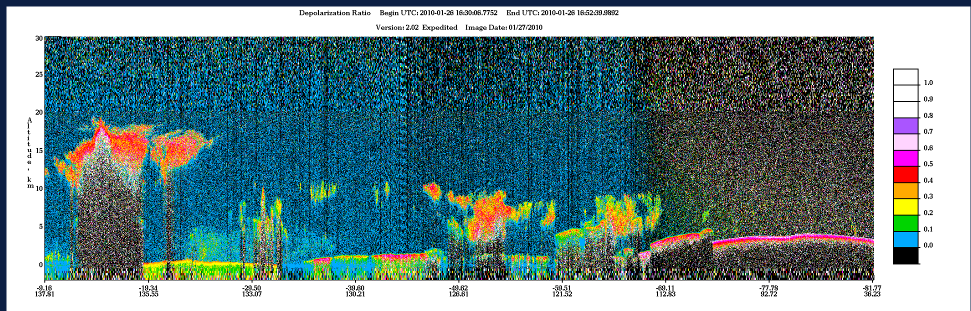
1064 nm Attenuated Backscatter



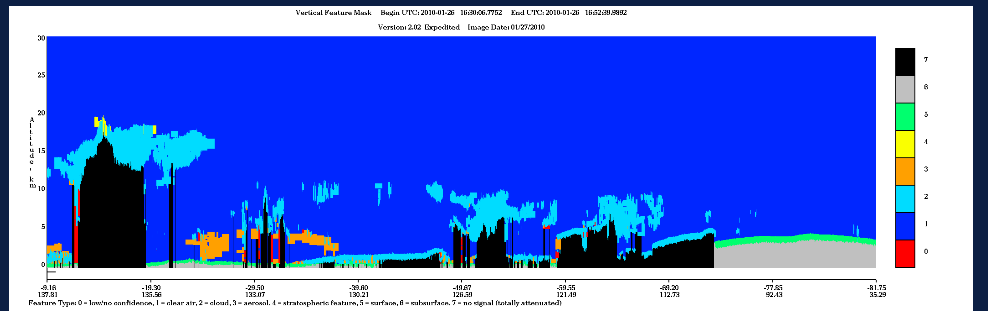
532 nm Perpendicular Attenuated Backscatter



1064nm/532 nm Attenuated Color Ratio



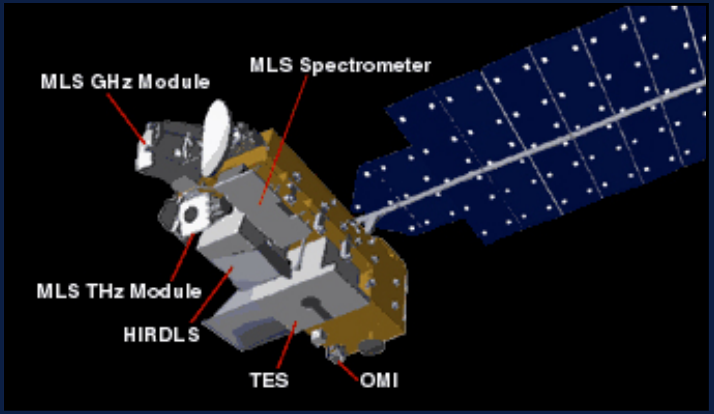
Depolarization Ratio



Vertical Feature Mask

Aura

High Resolution Dynamics Limb Sounder (HIRDLS)
Microwave Limb Sounder (MLS)
Ozone Monitoring Instrument (OMI)
Tropospheric Emission Spectrometer (TES)



MLS

- passive microwave limb-sounding radiometer/spectrometer
- measures thermal emission from the atmospheric limb (millimeter and submillimeter wavelengths)
- provides reliable measurements even in presence of dense cirrus and volcanic aerosol
- resolution varies for different parameters;
  5 km cross-track x 500 km along-track x 3 km vertical
  (typical values)
- more information on MLS here:
  http://aura.gsfc.nasa.gov/instruments/mls.html
- MLS data:
  http://mls.jpl.nasa.gov/

A-Train references (summary):

Aqua
http://aqua.nasa.gov/

MODIS-Atmosphere home page
http://modis-atmos.gsfc.nasa.gov/

MODIS Aqua quick-look images
http://modis-atmos.gsfc.nasa.gov/IMAGES/index_myd021km.html
http://rapidfire.sci.gsfc.nasa.gov/realtime/

MODIS level 1B data
http://ladsweb.nascom.nasa.gov/data/search.html

CloudSat
http://cloudsat.atmos.colostate.edu/

CloudSat quick-look images and data browser
http://www.cloudsat.cira.colostate.edu/dpcstatusQL.php

CALIPSO
http://www.nasa.gov/mission_pages/calipso/spacecraft/index.html

CALIPSO / CALIOP quick-look images browser
http://www-calipso.larc.nasa.gov/products/lidar/browse_images/show_calendar.php

Aura
http://aura.gsfc.nasa.gov/

MLS data access
http://mls.jpl.nasa.gov/

Observations of convective storms – general comments:

- Timing of the early afternoon orbit of the A-Train satellite fleet is not optimal for studies of mid-latitude deep convection, larger storms and their systems typically only begin to form by then ➡ low chance of detection of daytime mature storms;

- even if the A-Train captures already developed storms, typically it misses their cores, specific area, or features of interest;

- delay between the Aqua, and the CloudSat & CALIPSO satellites (1-2 minutes) poses a certain problem when observing rapidly developing features (namely the overshooting tops) ➡ need to also utilize the WFC and IIR data;

- nocturnal observations: more cases (typically longer-lived MCS), but absence of the MODIS solar bands, on the other hand better quality of the CALIOP data (lower noise).

Technical notes:

- When plotting the CloudSat and CALIPSO tracks into the MODIS images, it is crucial to use the LAT/LON information accompanying the relevant CPR and CALIOP HDF data sets, and not the track based on TLE data of the two satellites.

- For detailed studies of small-scale storm-top features (such as overshooting tops), the parallax shift of the CloudSat and CALIPSO data tracks needs to be applied; for storm tops at 12 – 16 km, the parallax shift is approximately 3 - 4 km east.

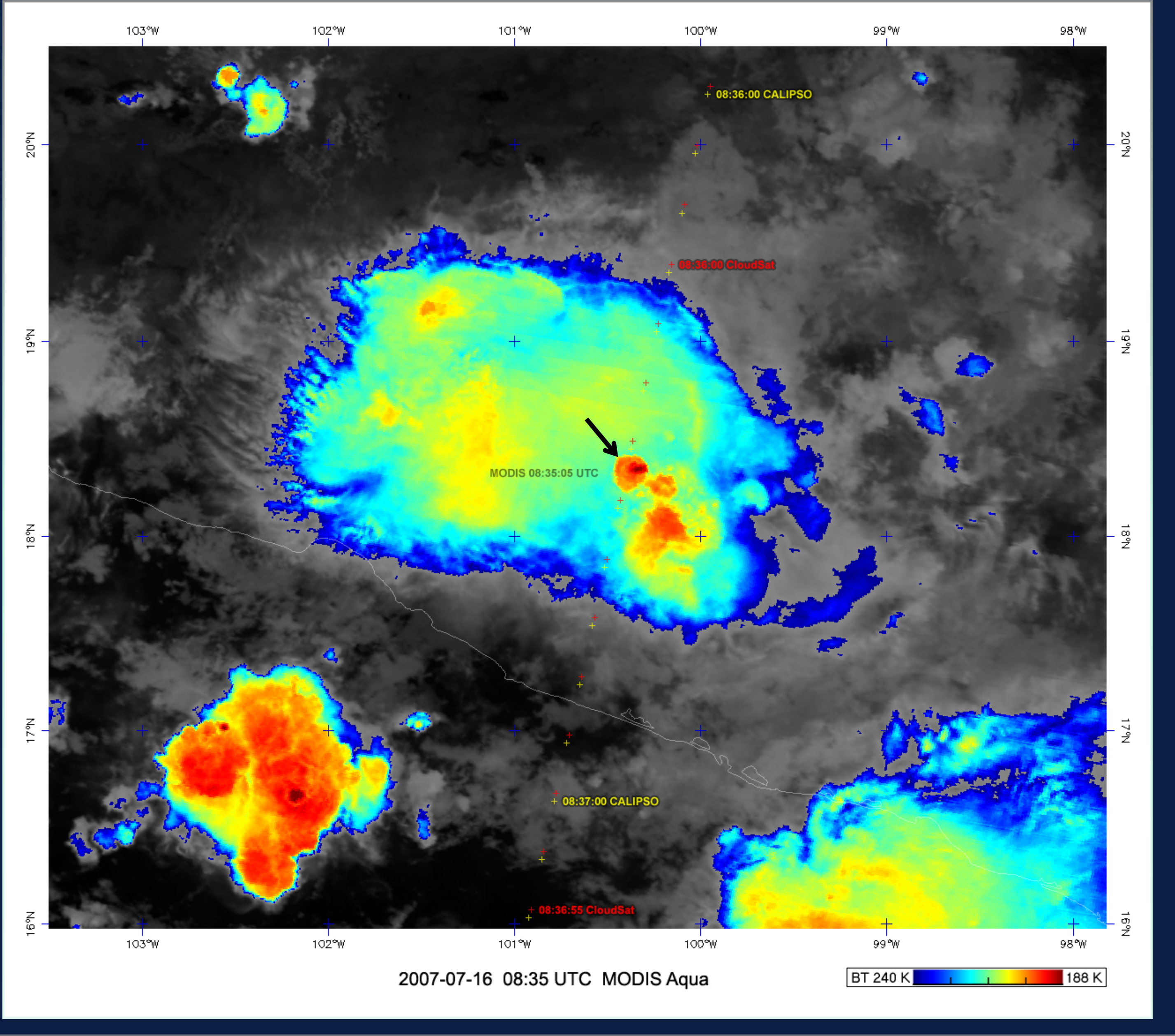
Selected cases and examples ...

16 July 2007   08:35 UTC

Mexico

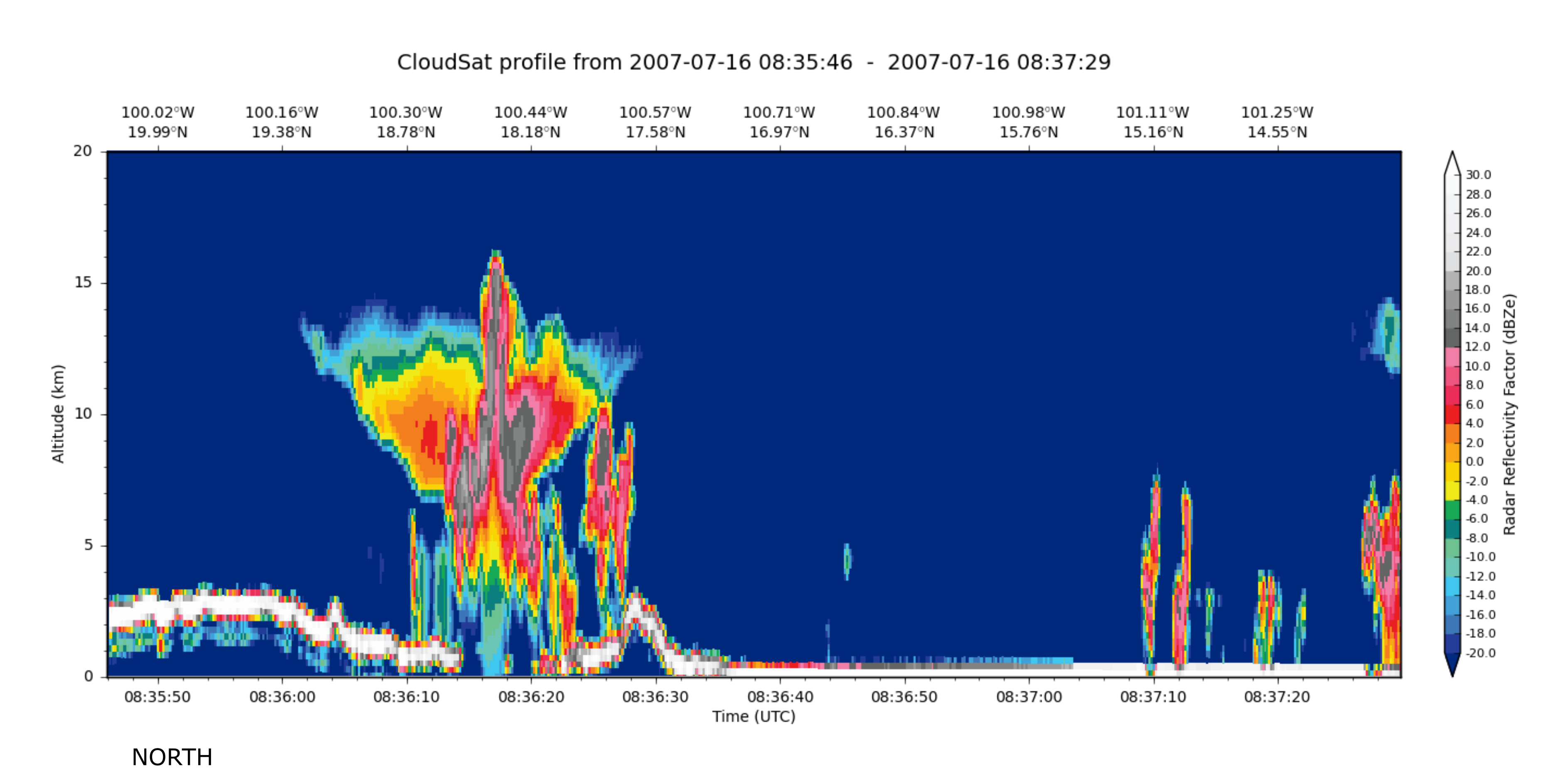
Cloud top of convective storms – CloudSat versus CALIPSO

2007-07-16 08:35 UTC Mexico



Cloud top of convective storms – CloudSat versus CALIPSO

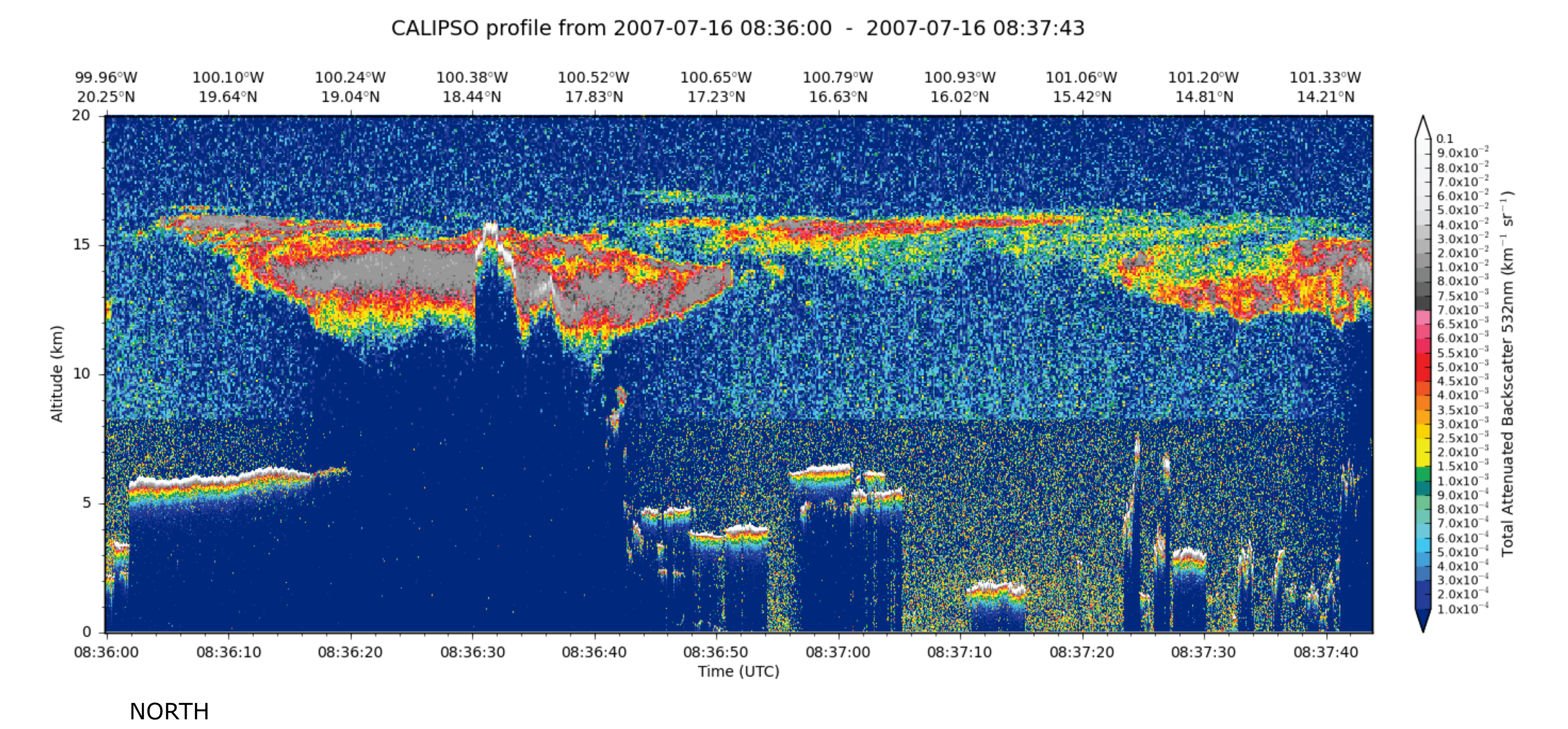
2007-07-16 08:35 UTC Mexico



An example where the CloudSat's CPR detects much fewer cloud particles at the anvil top area surrounding the overshooting top (OT), and places the "cloud top" much lower as compared to the CALIPSO/CALIOP data (next slide). Similar cases may lead to false overestimation of the OT magnitude (when utilizing CloudSat data only).

Cloud top of convective storms – CloudSat versus CALIPSO

2007-07-16 08:35 UTC Mexico

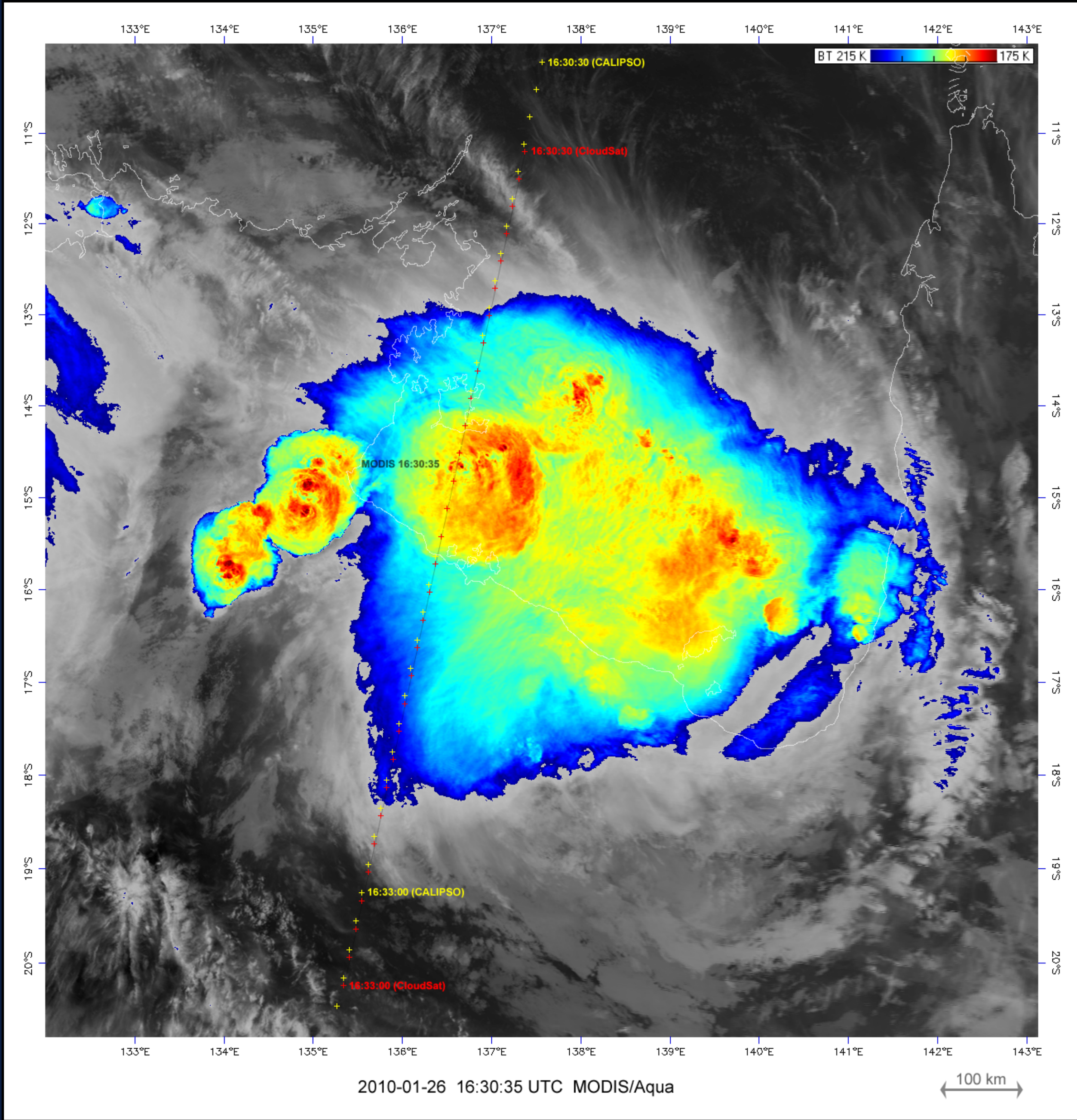


In this image, the CALIPSO vertical profile much better detects the "cloud top", composed of semi-transparent material. Here the overshooting top rises much less above the surrounding cloud top than what might be inferred from the CloudSat profile. Also, the very thin layers at higher levels escape detection by CloudSat's CPR. In contrast, CALIPSO does not "see" the lower storm levels, its lidar signal is more attenuated at higher levels.

26 January 2010   13:30 UTC

Australia

Storm top – CloudSat versus CALIPSO, and BTD (WV - IR window)

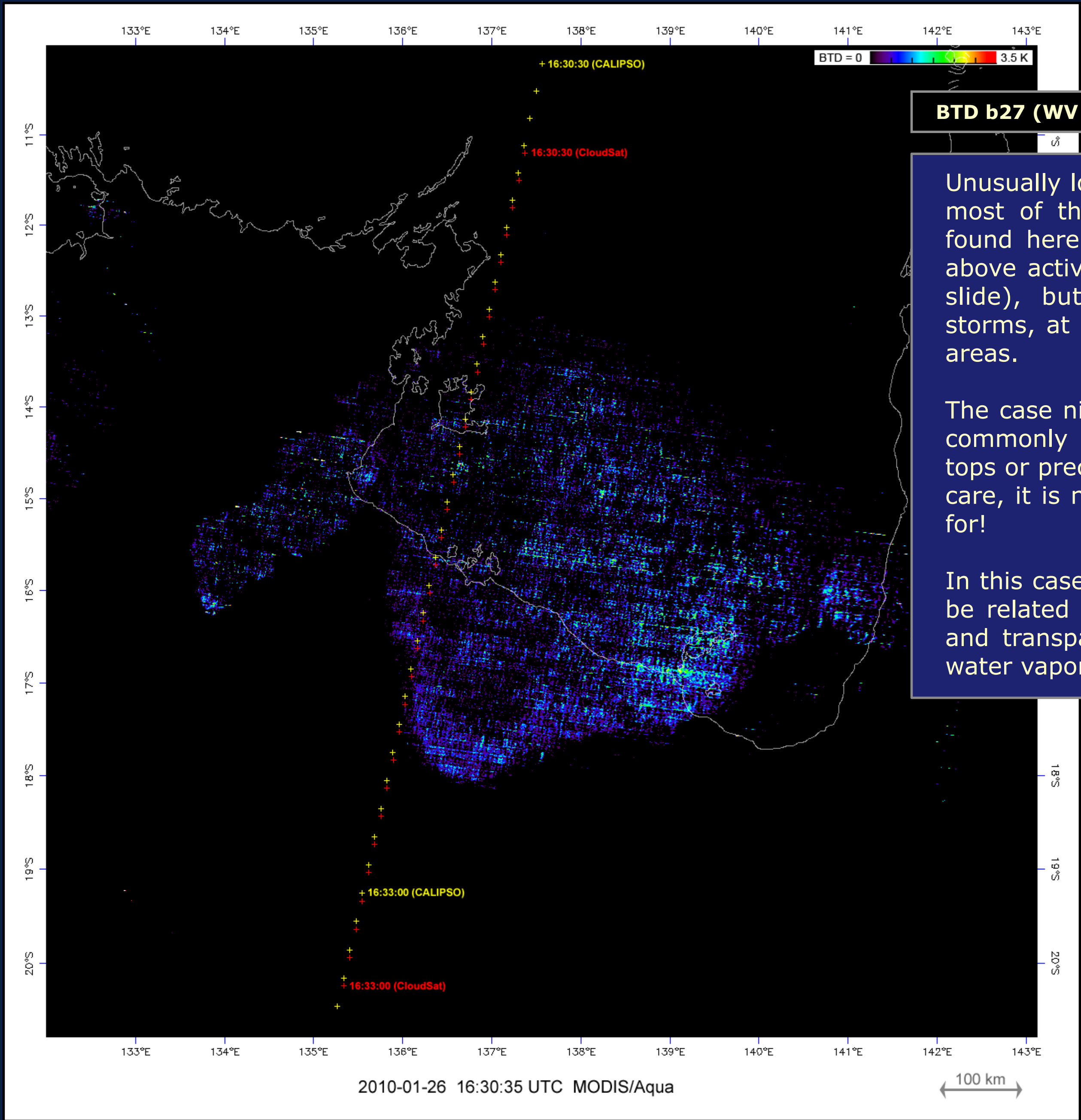


2010-01-26 13:30 UTC Australia

MODIS band 31 BT 175 – 215 K

Storm top – CloudSat versus CALIPSO, and BTD (WV - IR window)

2010-01-26 13:30 UTC Australia



BTD b27 (WV abs. band) – b31 (IR window) <0K, 3.5K>

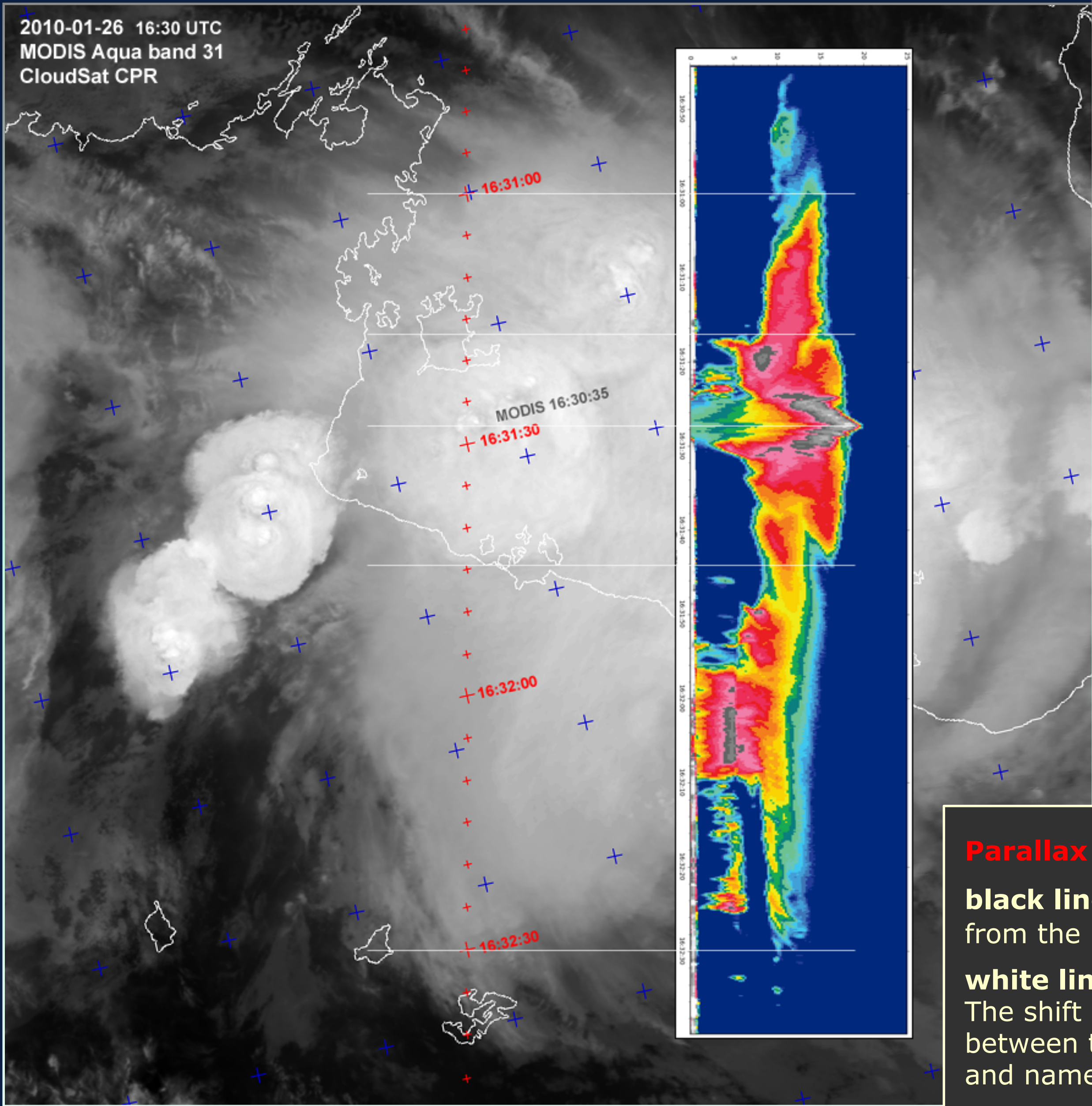
Unusually low BTD (WV - IR window) values over most of the storm. Higher BTD values can be found here not above the overshooting tops or above active storms (compare with the previous slide), but rather at the outskirts of these storms, at their non-active dissipating stratiform areas.

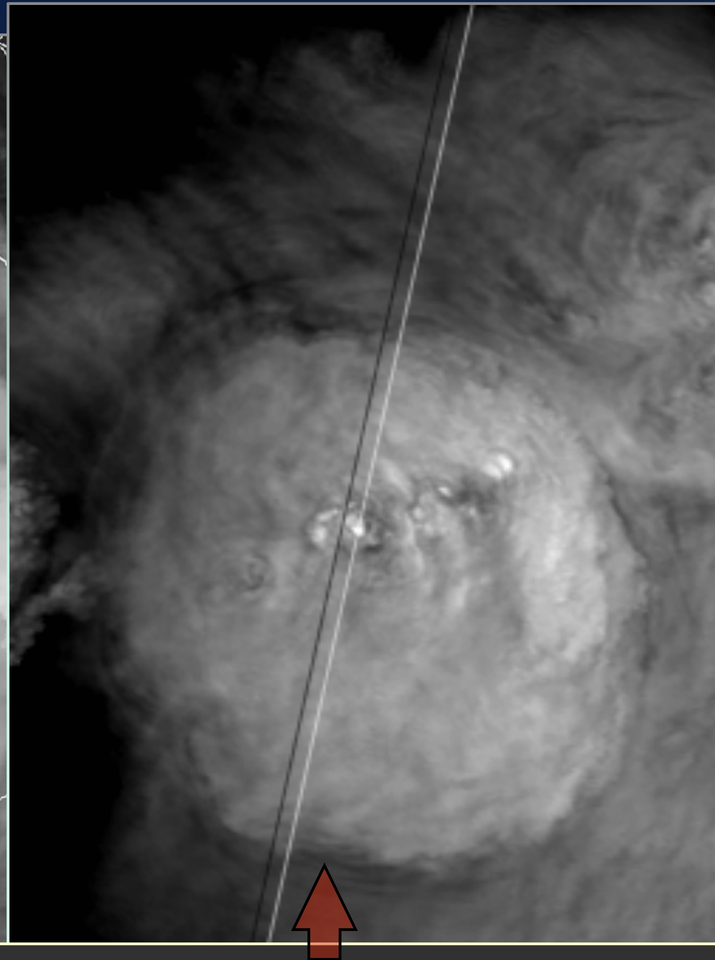
The case nicely illustrates that this BTD product, commonly used for detection of overshooting tops or precipitating clouds, must be treated with care, it is not capable of what many are using it for!

In this case, the positive BTD values are likely to be related to cloud-top microphysics (emissivity and transparency of the cloud), and not to the water vapor above the cloud.

Storm top – CloudSat versus CALIPSO

2010-01-26 13:30 UTC Australia





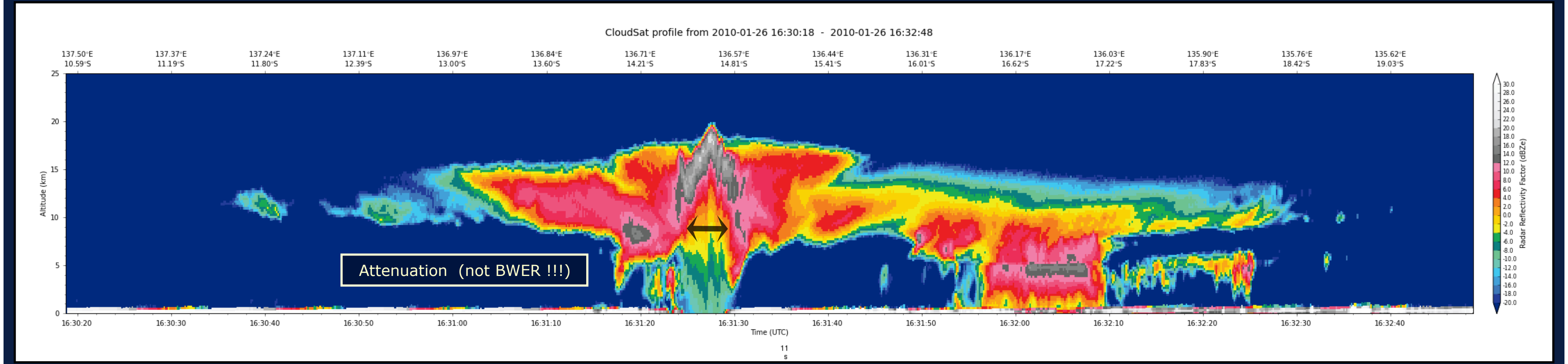
Parallax shift of the CloudSat and CALIPSO tracks

black line – track based on LAT/LON coordinates from the HDF file

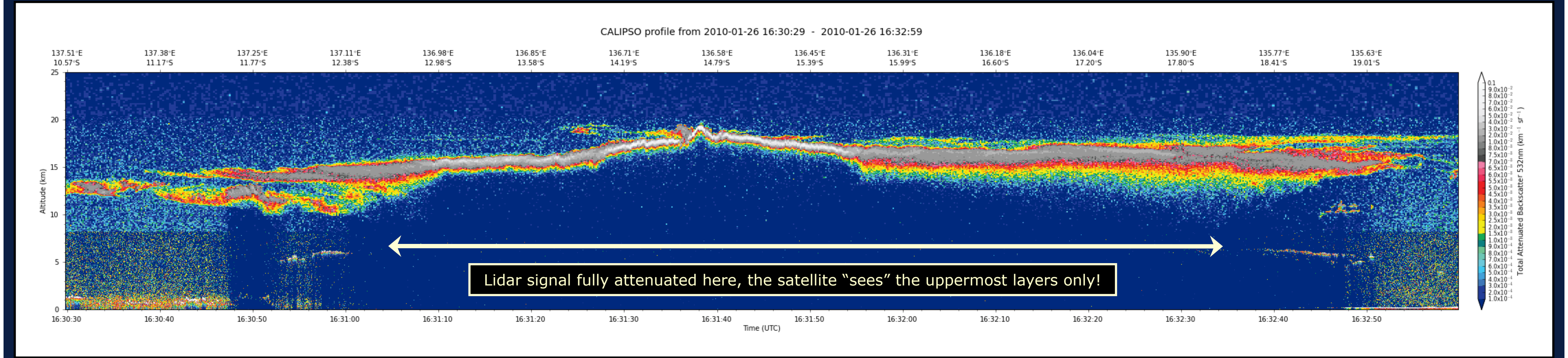
white line – the same track after the parallax shift. The shift itself (~ 4 to 6 km) depends on the interval between the Aqua and CloudSat/CALIPSO overpasses, and namely on the specific cloud top height.

Storm top – CloudSat versus CALIPSO

2010-01-26 13:30 UTC Australia



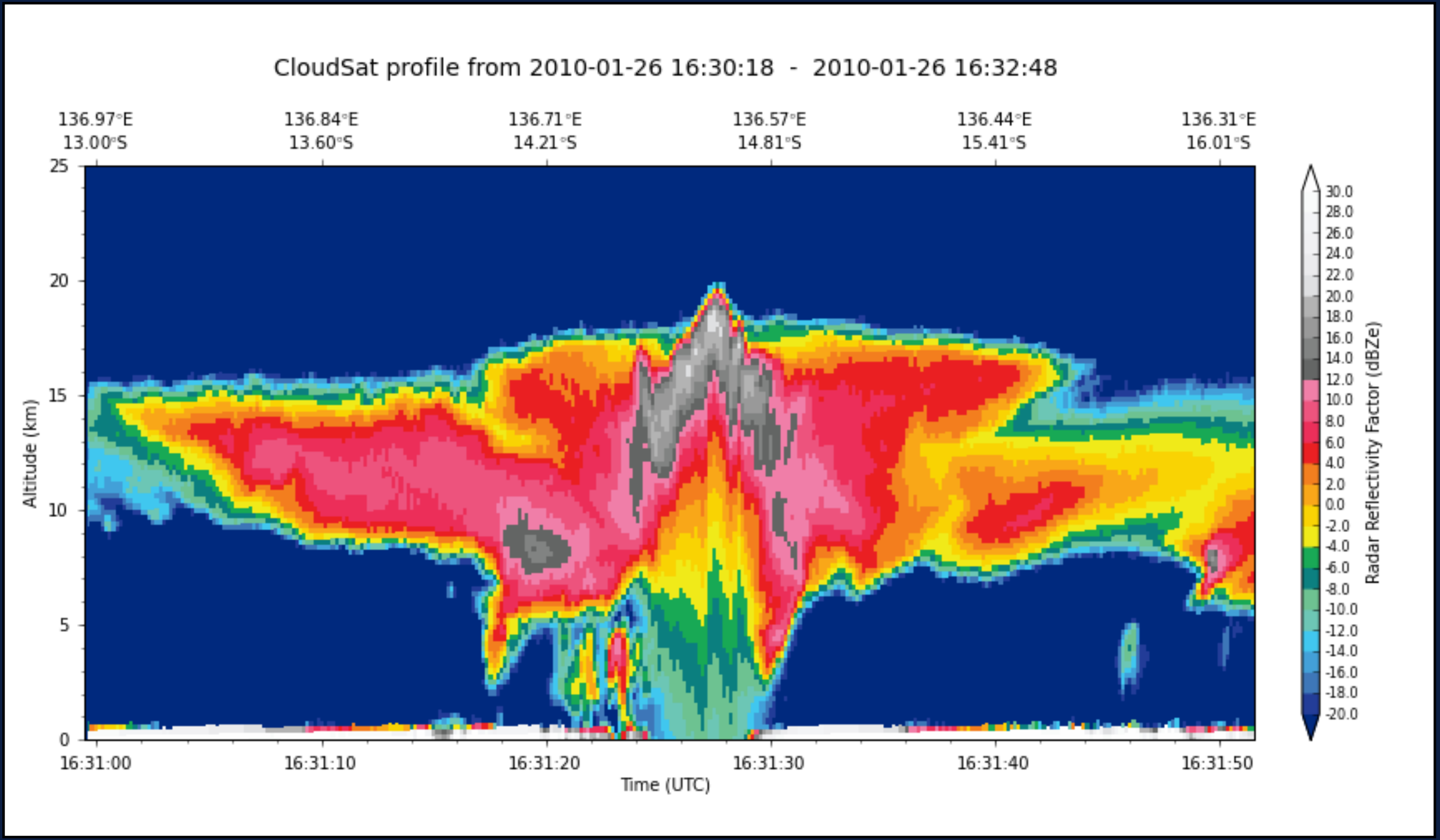
CloudSat/CPR profile



CALIPSO/CALIOP profile

Storm top – CloudSat versus CALIPSO

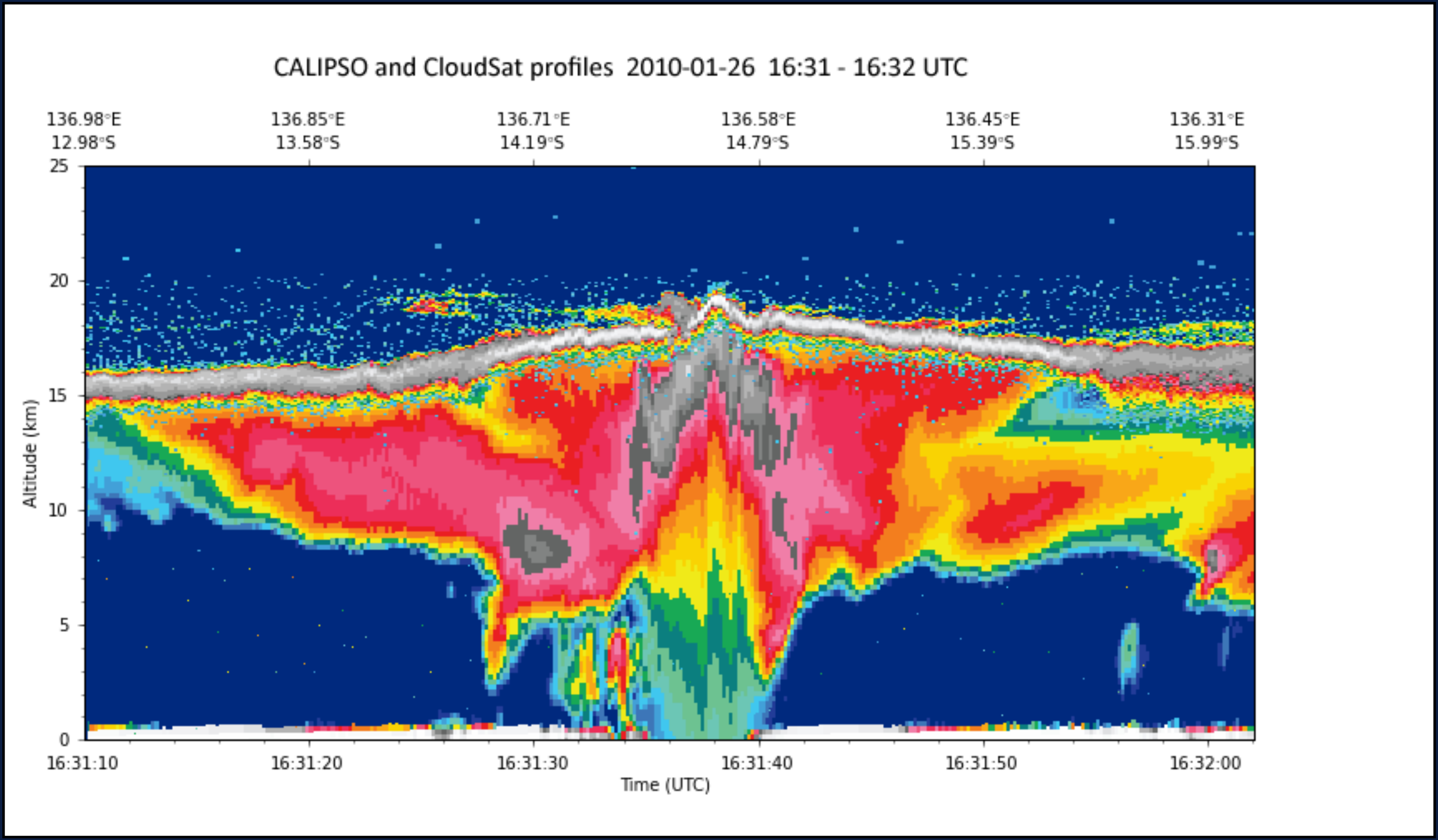
2010-01-26 13:30 UTC Australia



CloudSat/CPR profile

Storm top – CloudSat versus CALIPSO

2010-01-26 13:30 UTC Australia

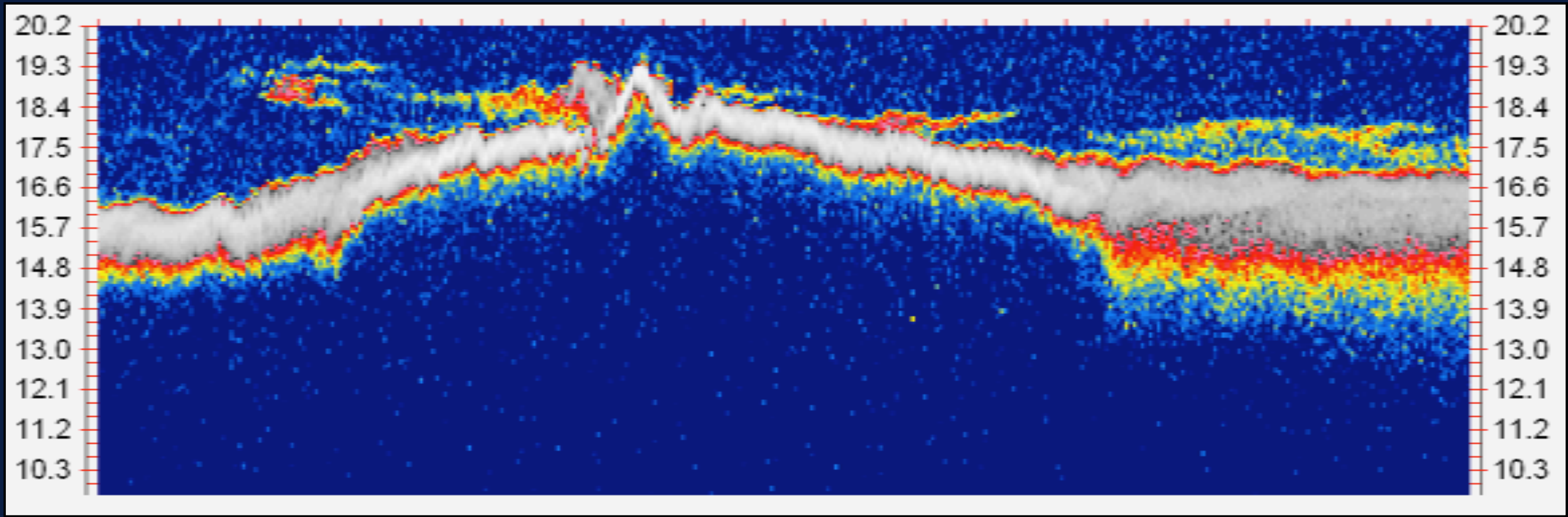


CALIPSO/CALIOP (Total Attenuated Backscatter at 532 nm) superimposed above the CloudSat/CPR profile.

In cases like this one, when the CALIPSO profile shows very high backscatter values, the "cloud-top" as observed by the two satellites is very close. One of the consequences is that the overshooting top height (its height above the flat part of the anvil-top) can be considered realistic.

In general, the older the anvil top is, the larger are the differences of the cloud-top appearance as observed by CloudSat and CALIPSO.

Example of use of the CALIPSO data for very-fine detail studies:



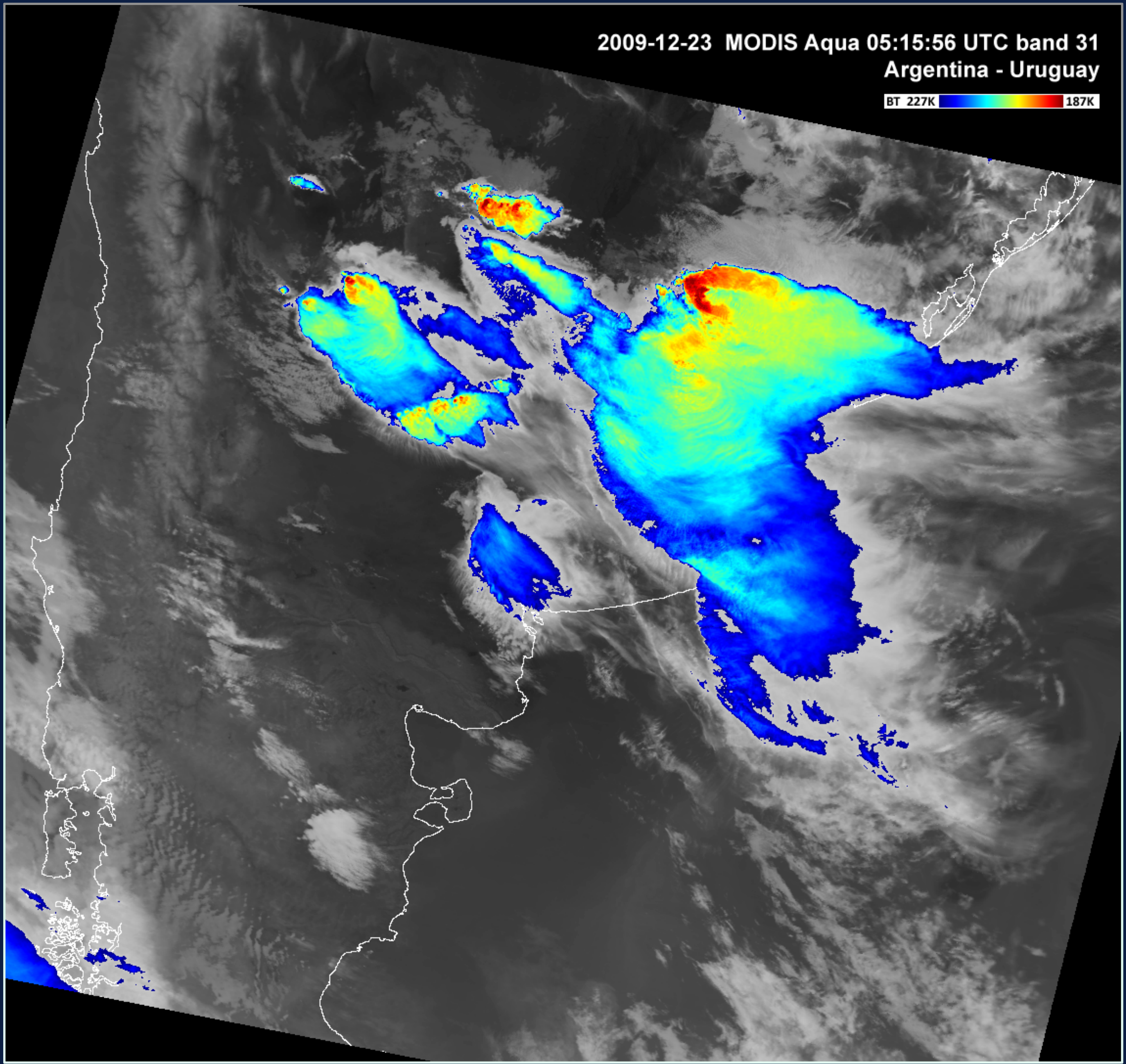
CALIPSO/CALIOP (Total Attenuated Backscatter at 532 nm) – detail of the cloud top.

Left of the overshooting top is a feature resembling jumping cirrus (revealed by Fujita in 1980's) and a plume. Right of the OT appears to be a wave-like feature, probably a gravity wave, and also a tiny feature resembling a plume.

23 December 2009 05:15 UTC

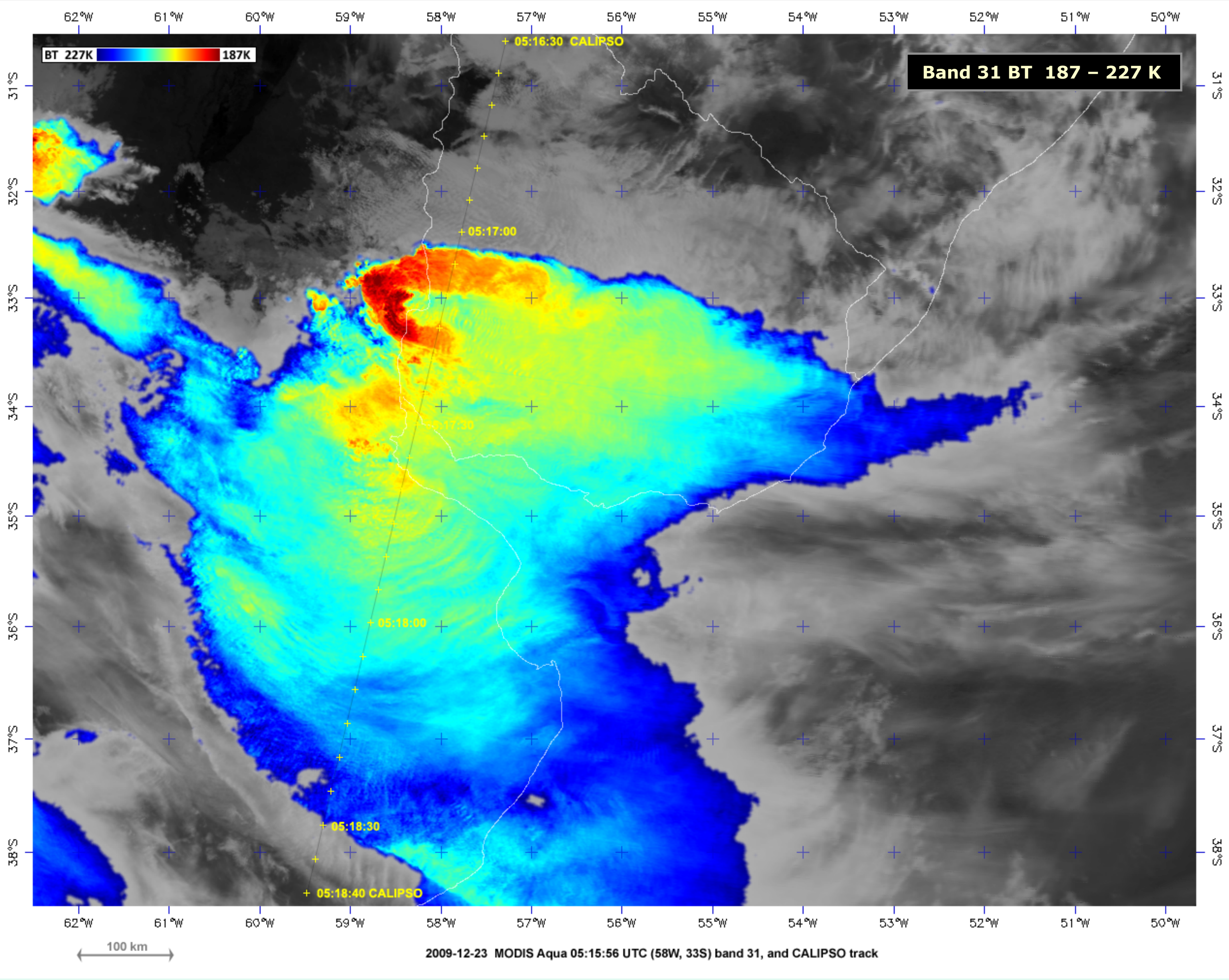
Argentina, Uruguay

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)



Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

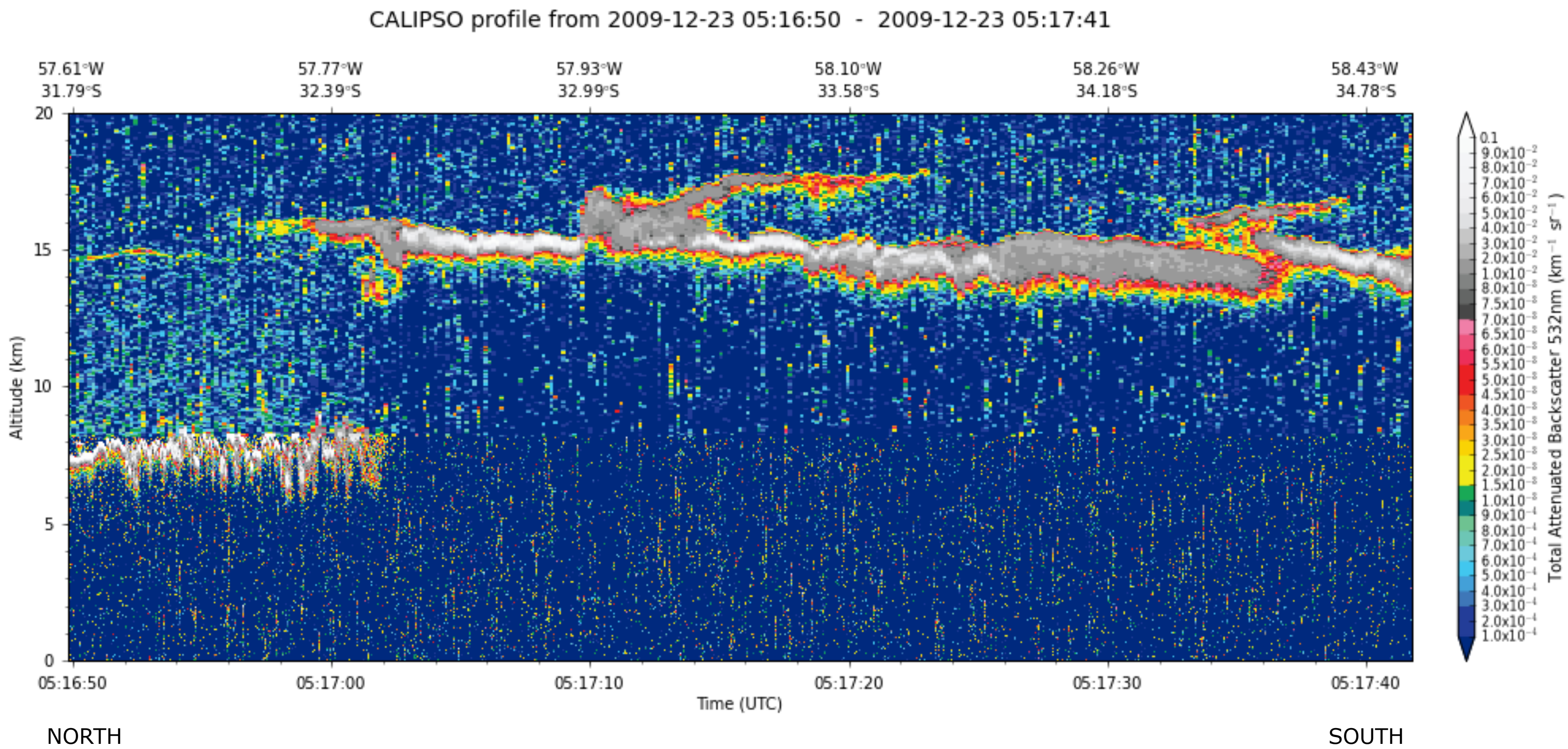
2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



2009-12-23 MODIS Aqua 05:15:56 UTC (58W, 33S) band 31, and CALIPSO track

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

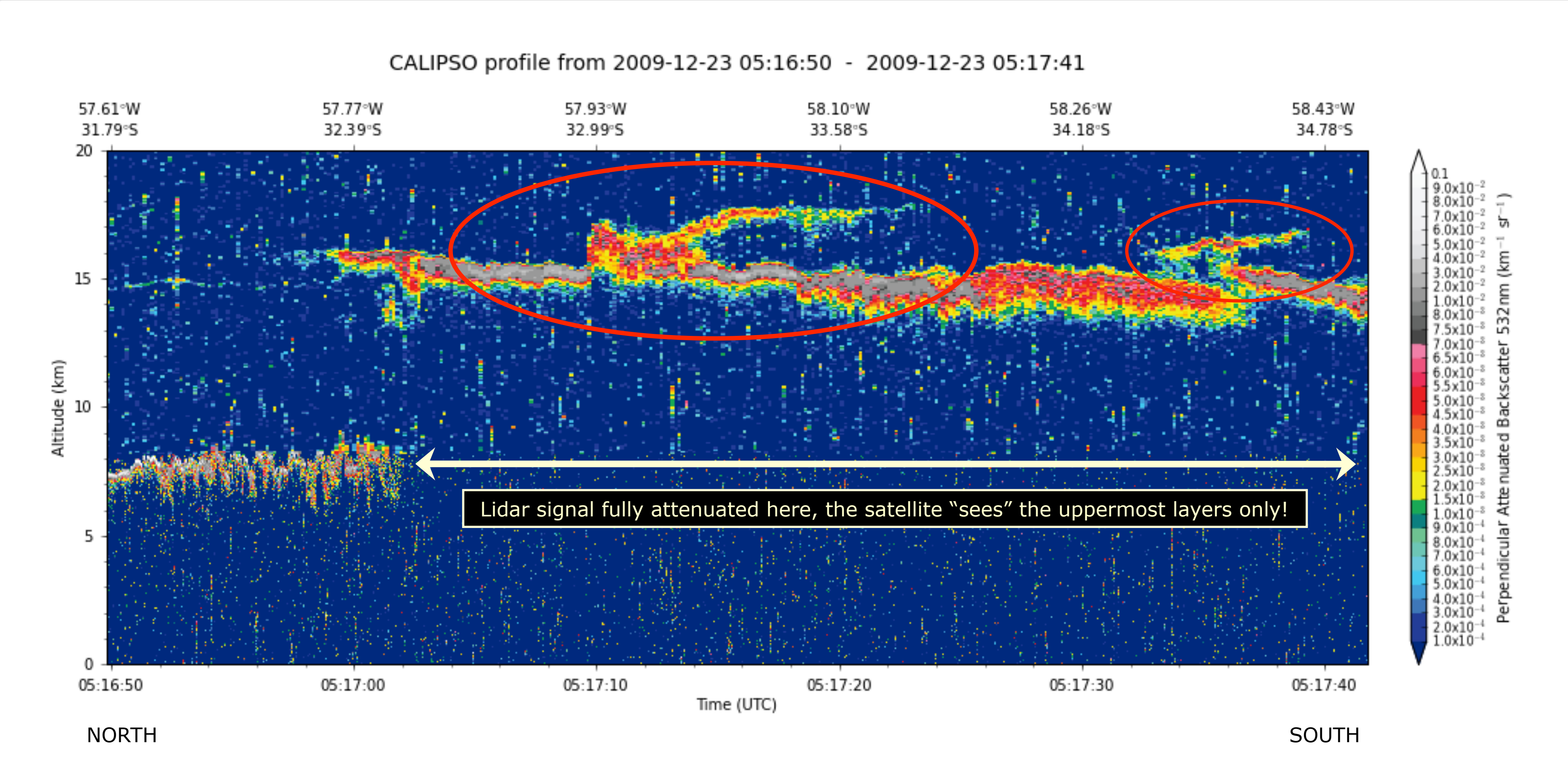
2009-12-23 05:17:15 UTC CALIPSO/CALIOP profile



CALIOP Total Attenuated Backscatter at 532 nm

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

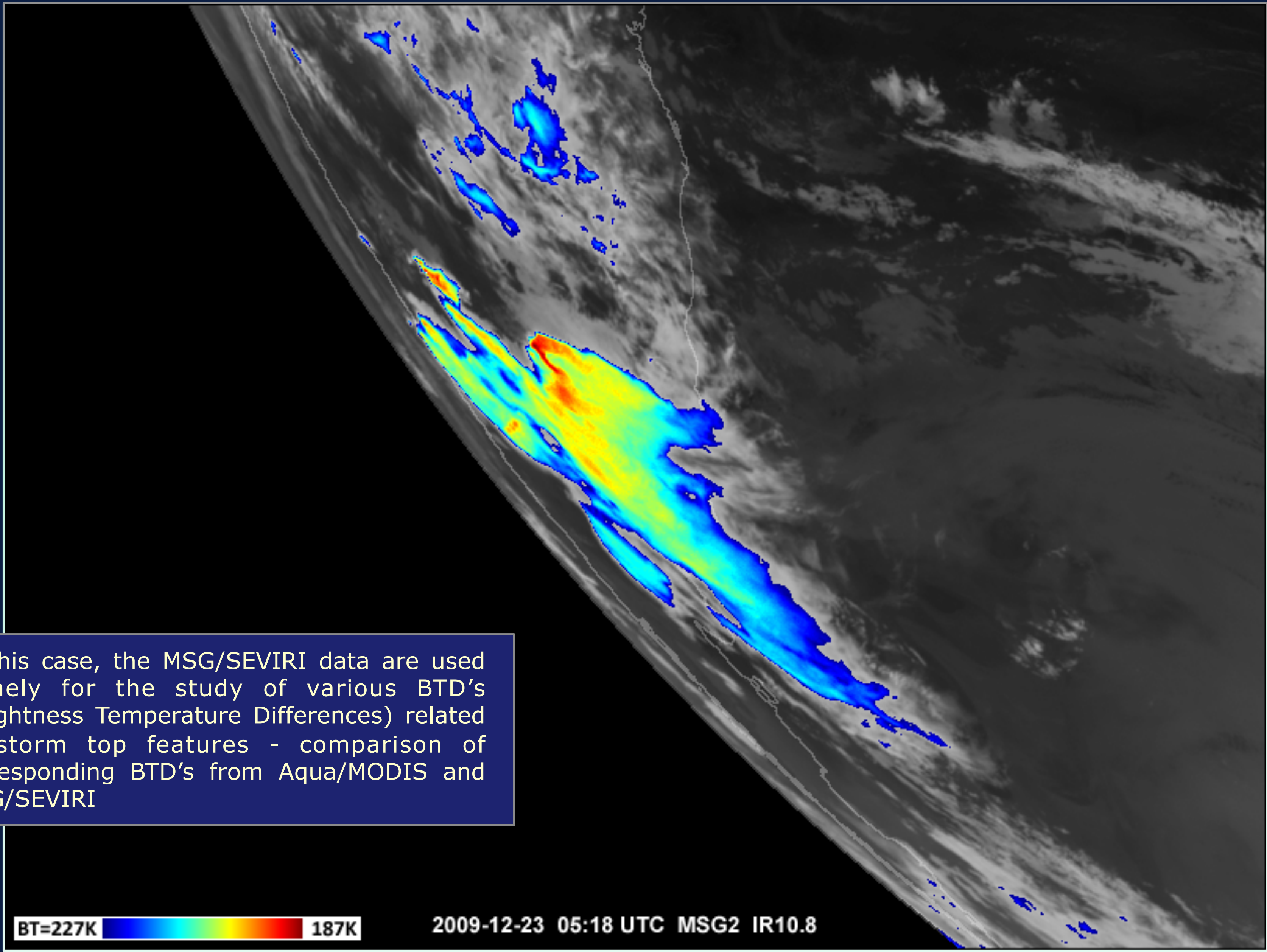
2009-12-23 05:17:15 UTC CALIPSO/CALIOP profile



CALIOP Perpendicular Attenuated Backscatter at 532 nm

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:18 UTC Meteosat-9 (MSG-2)



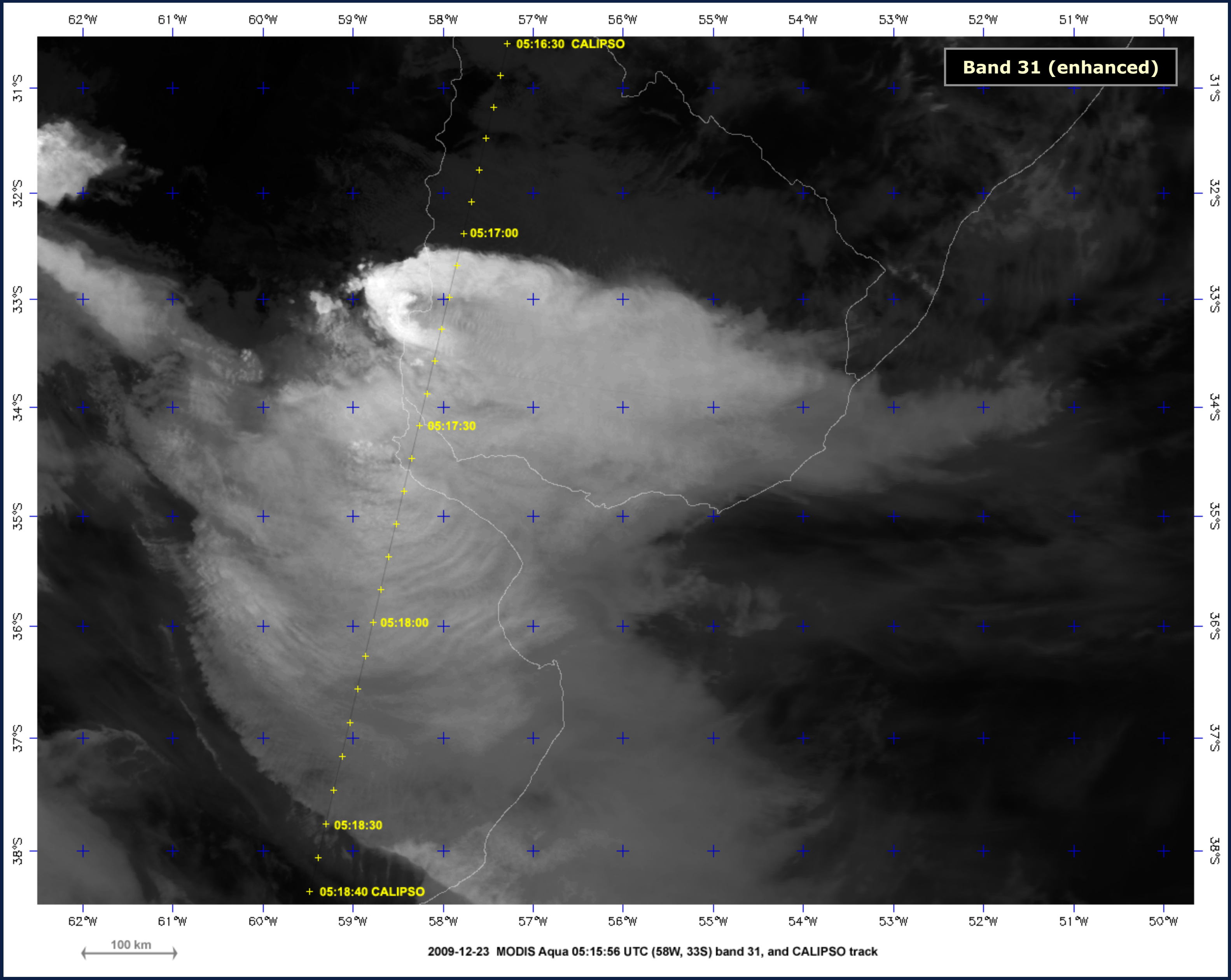
In this case, the MSG/SEVIRI data are used namely for the study of various BTD's (Brightness Temperature Differences) related to storm top features - comparison of corresponding BTD's from Aqua/MODIS and MSG/SEVIRI

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

Comparison of the CALIPSO/CALIOP storm-top profile
with cloud-top features observed by the Aqua/MODIS

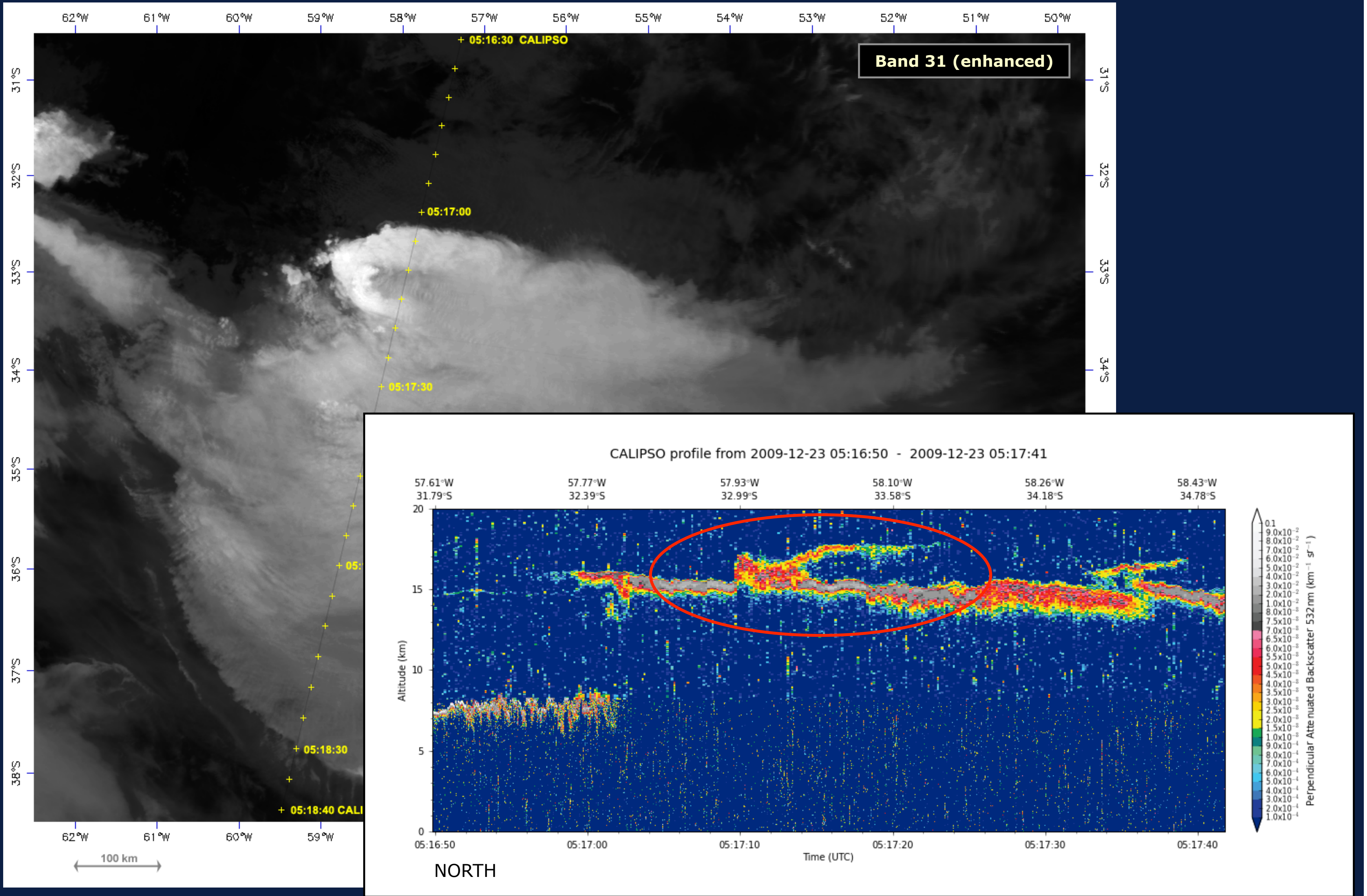
Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



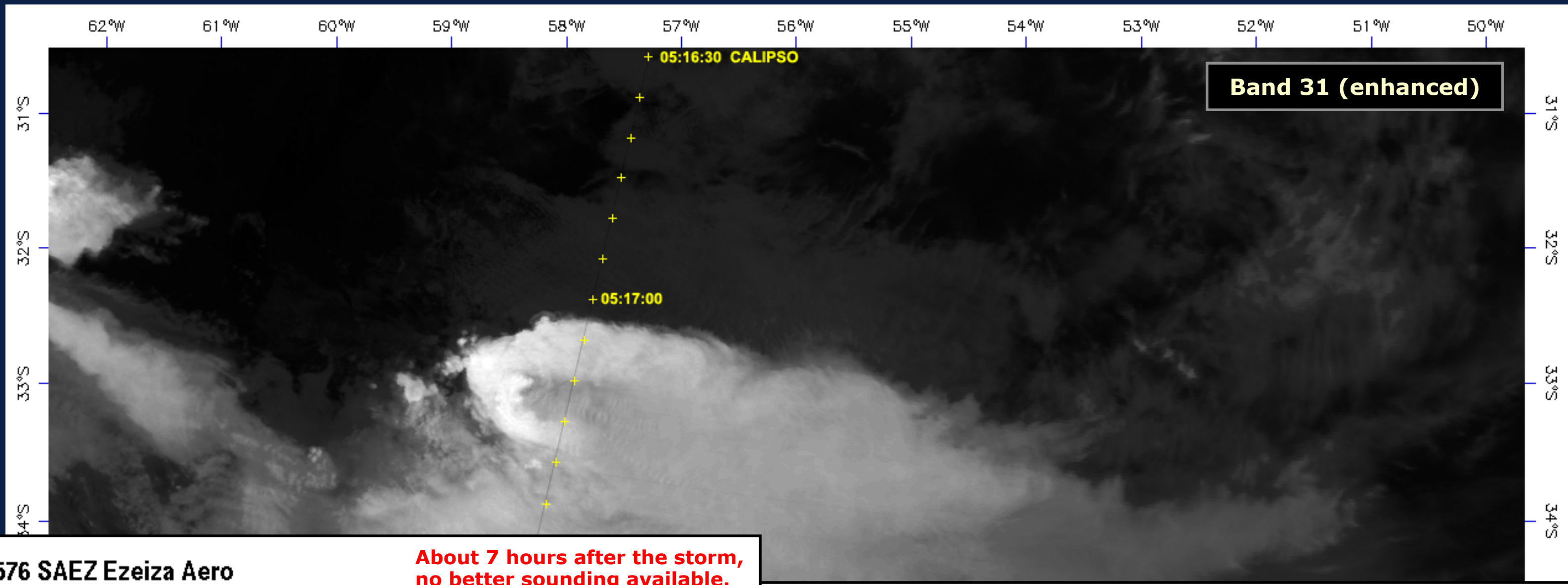
Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

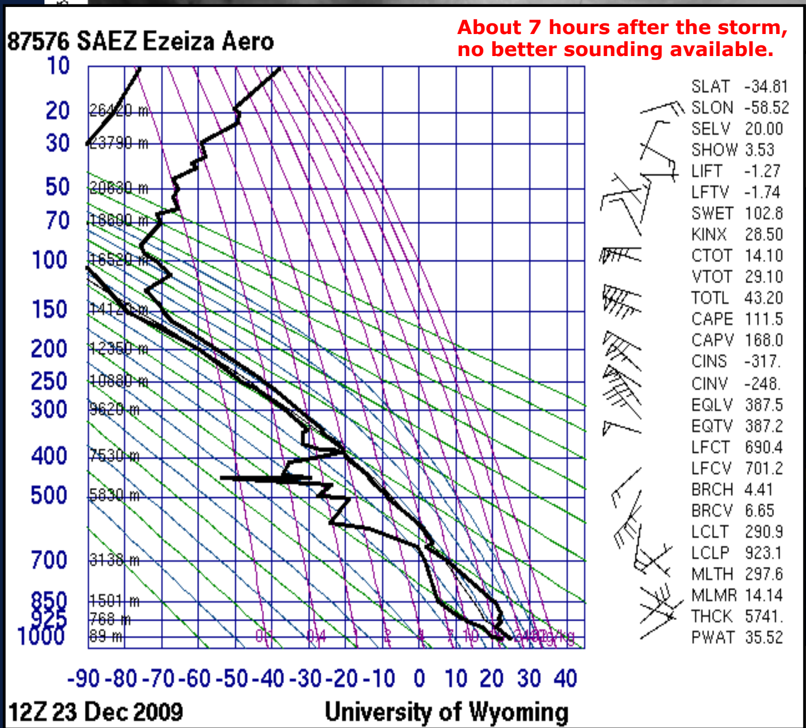
2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay

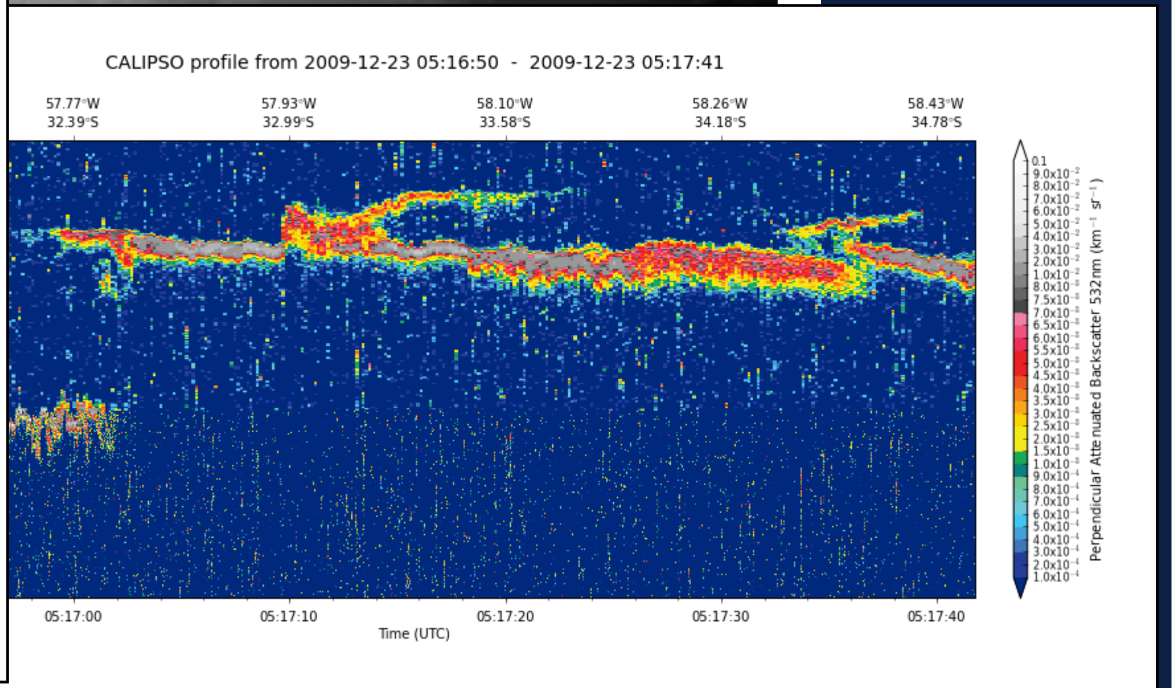


Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



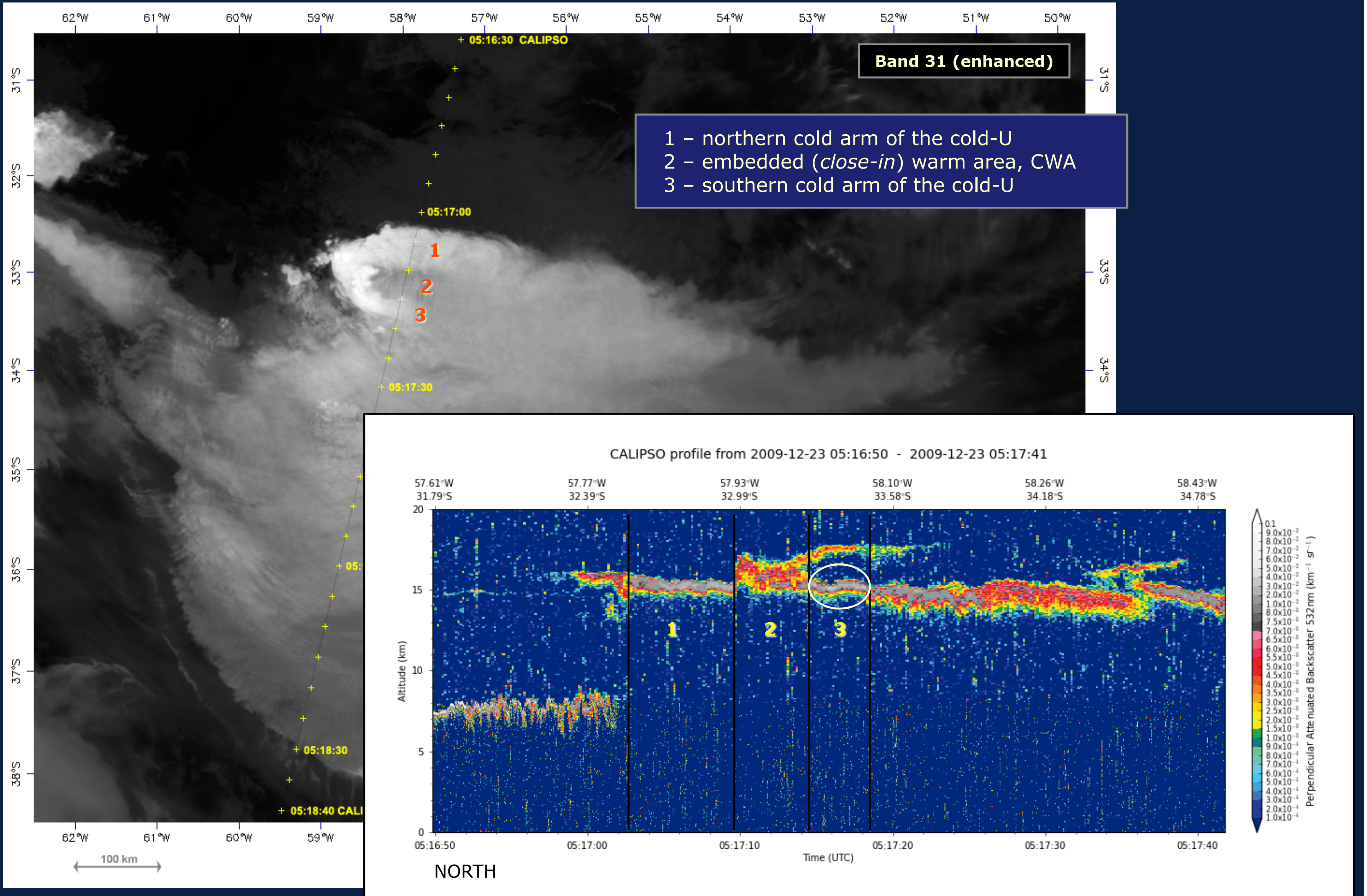




Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

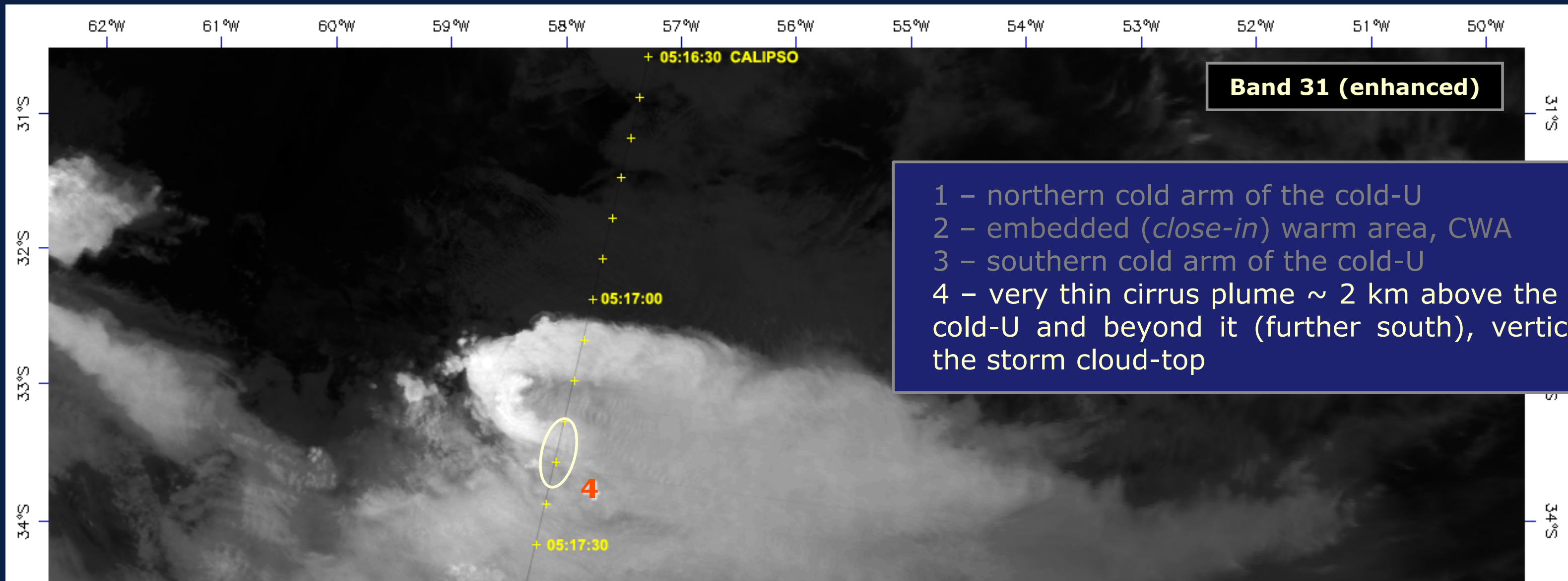
2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay

1 – northern cold arm of the cold-U
2 – embedded (*close-in*) warm area, CWA
3 – southern cold arm of the cold-U

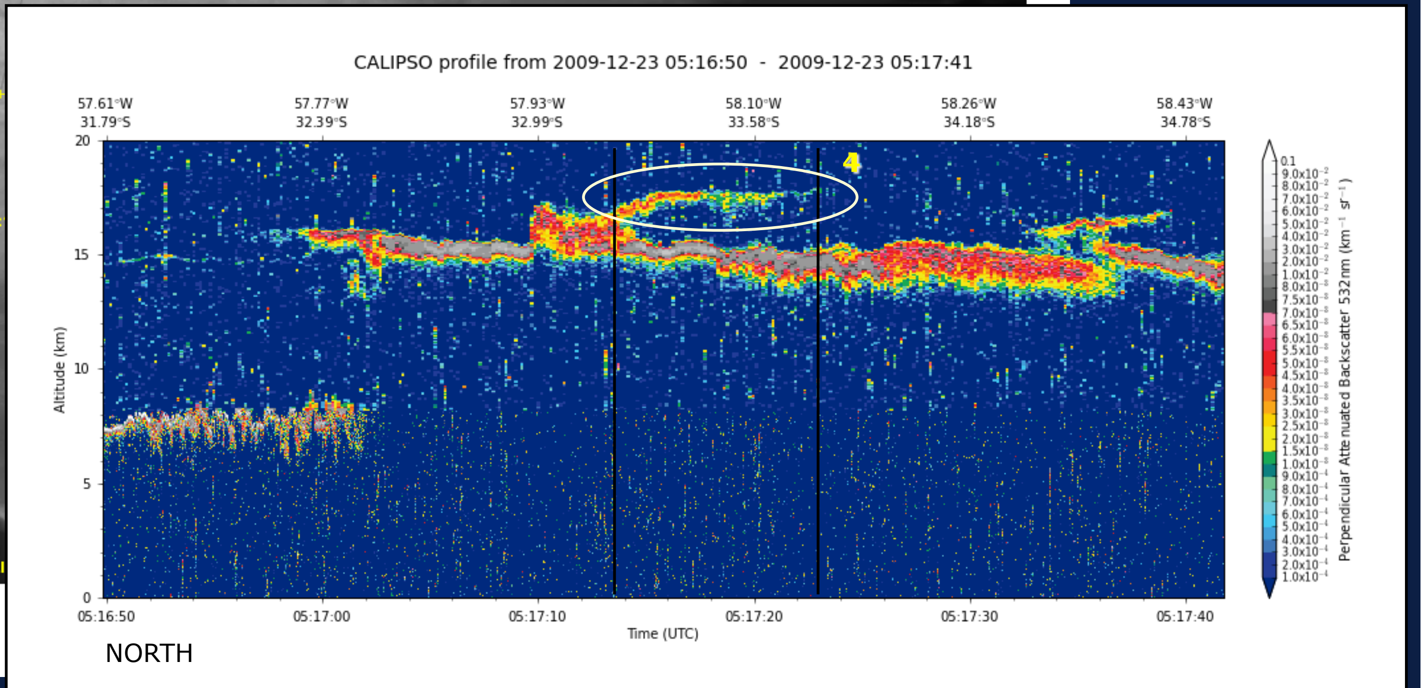


Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay

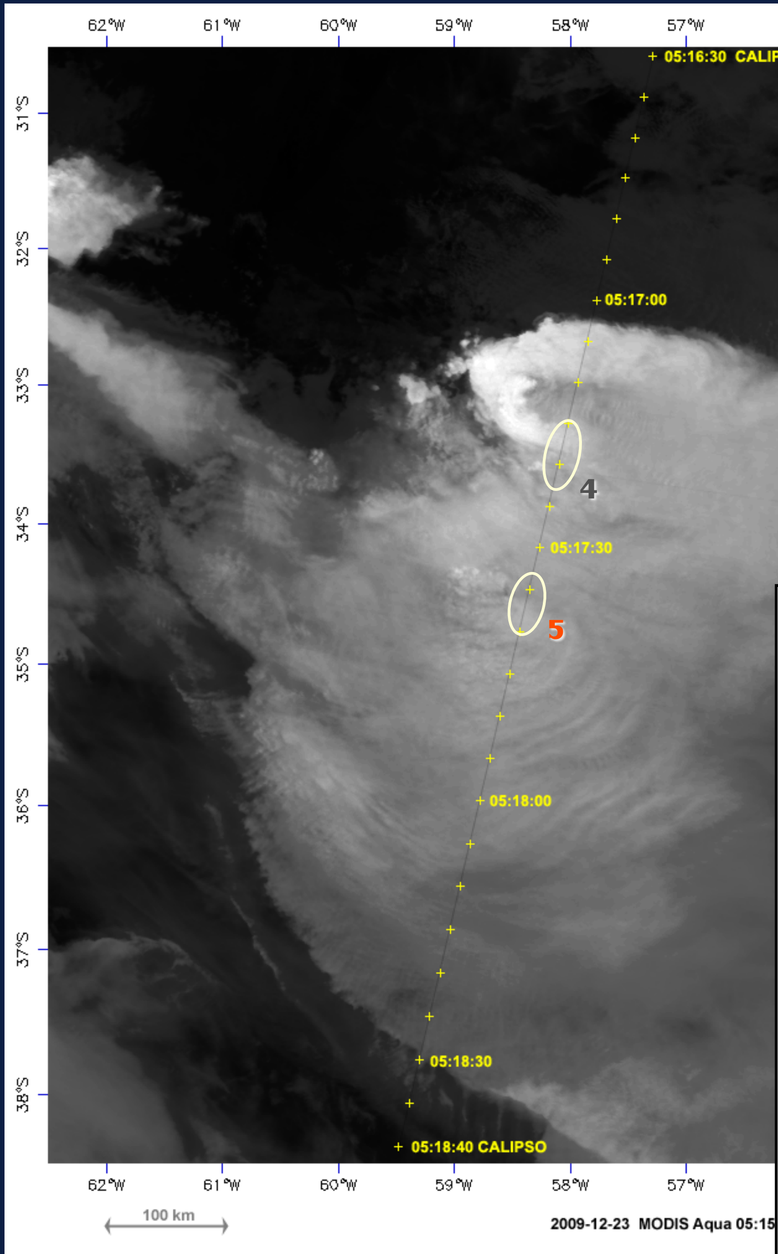


1 – northern cold arm of the cold-U
2 – embedded (*close-in*) warm area, CWA
3 – southern cold arm of the cold-U
4 – very thin cirrus plume ~ 2 km above the southern arm of the cold-U and beyond it (further south), vertically separated from the storm cloud-top

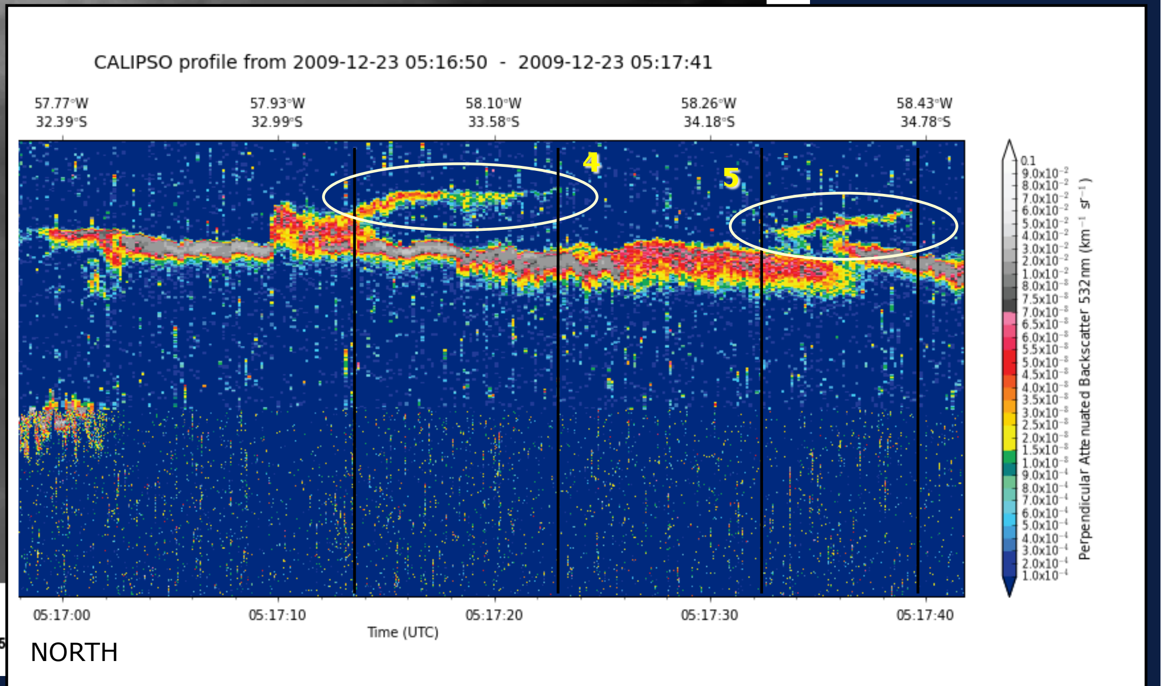


Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay

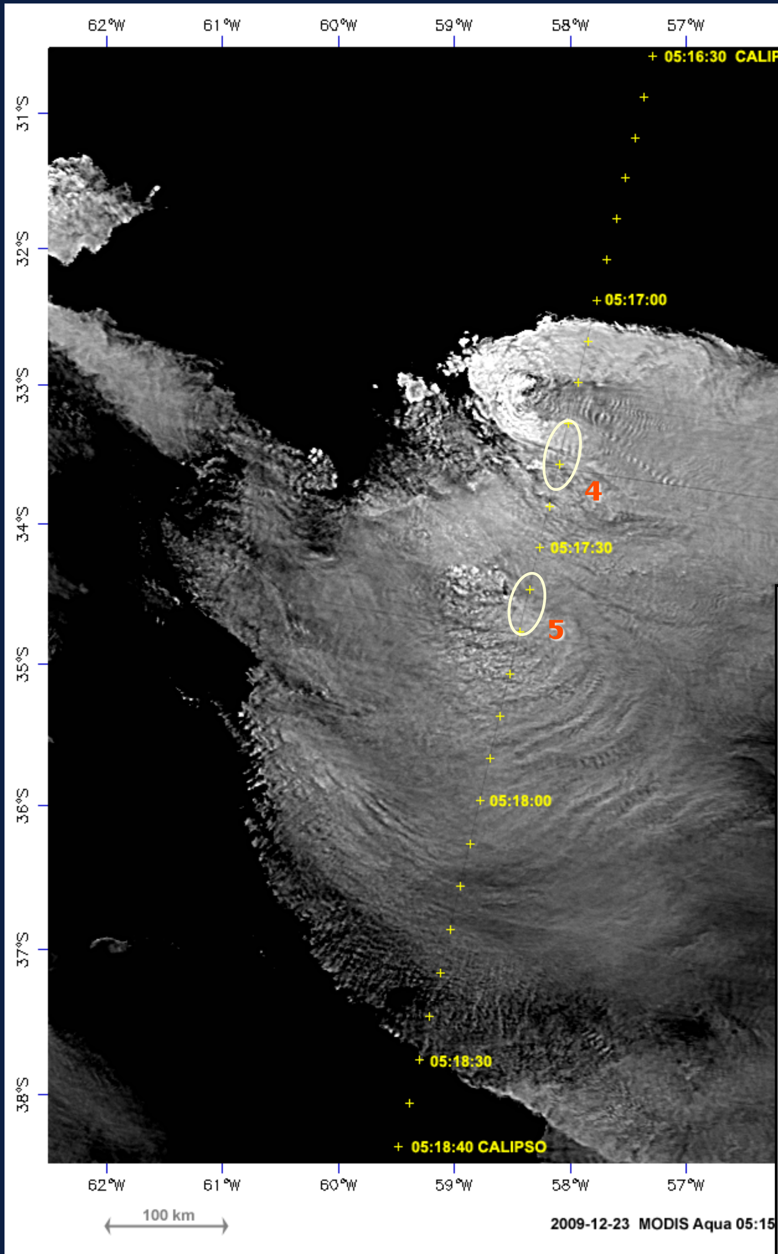


1 – northern cold arm of the cold-U
2 – embedded (*close-in*) warm area, CWA
3 – southern cold arm of the cold-U
4 – very thin cirrus plume ~ 2 km above the southern arm of the cold-U and beyond it (further south), vertically separated from the storm cloud-top
5 – similar plume-like feature further south



Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



1 – northern cold arm of the cold-U
2 – embedded (*close-in*) warm area, CWA
3 – southern cold arm of the cold-U
4 – very thin cirrus plume ~ 2 km above the southern arm of the cold-U and beyond it (further south), vertically separated from the storm cloud-top
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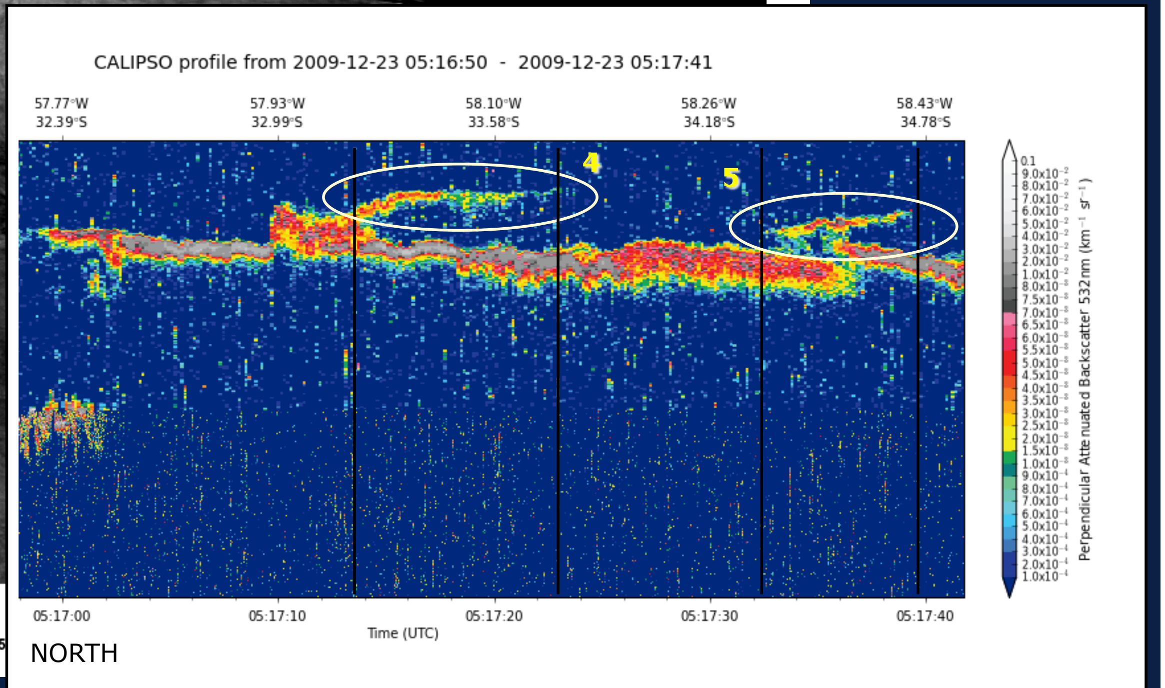
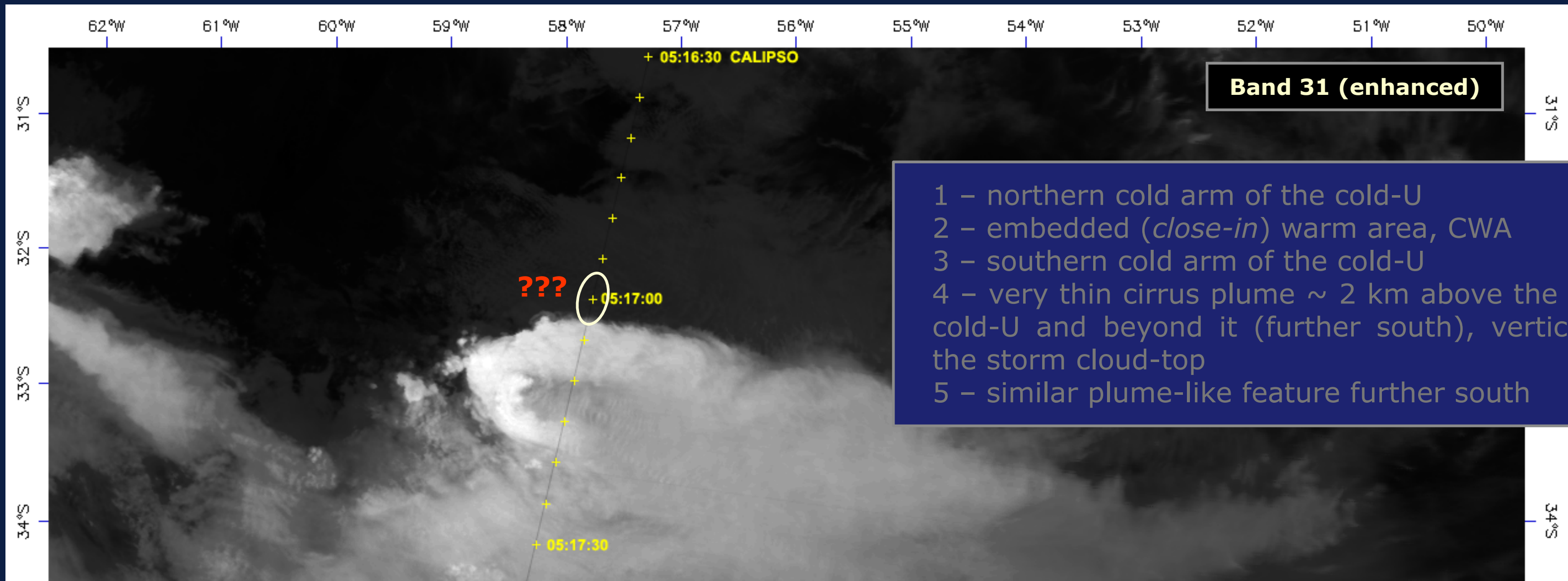


Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



1 – northern cold arm of the cold-U
2 – embedded (*close-in*) warm area, CWA
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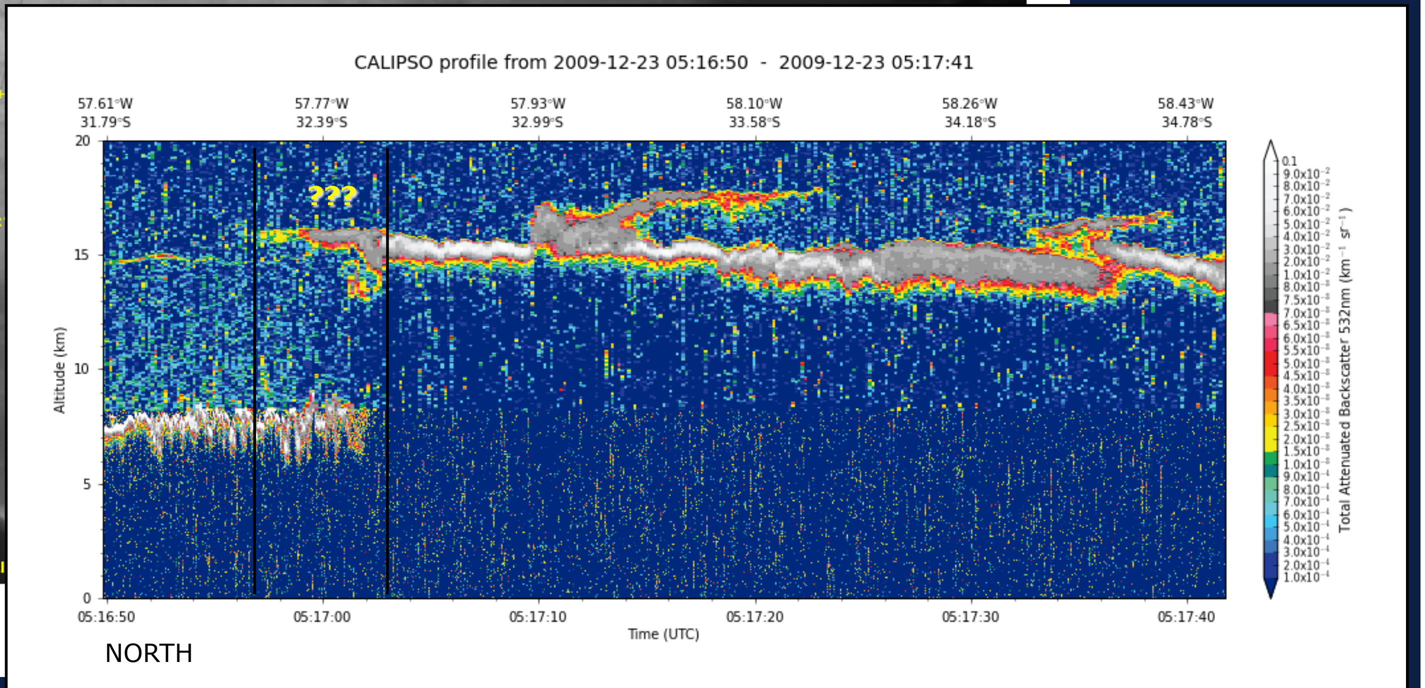
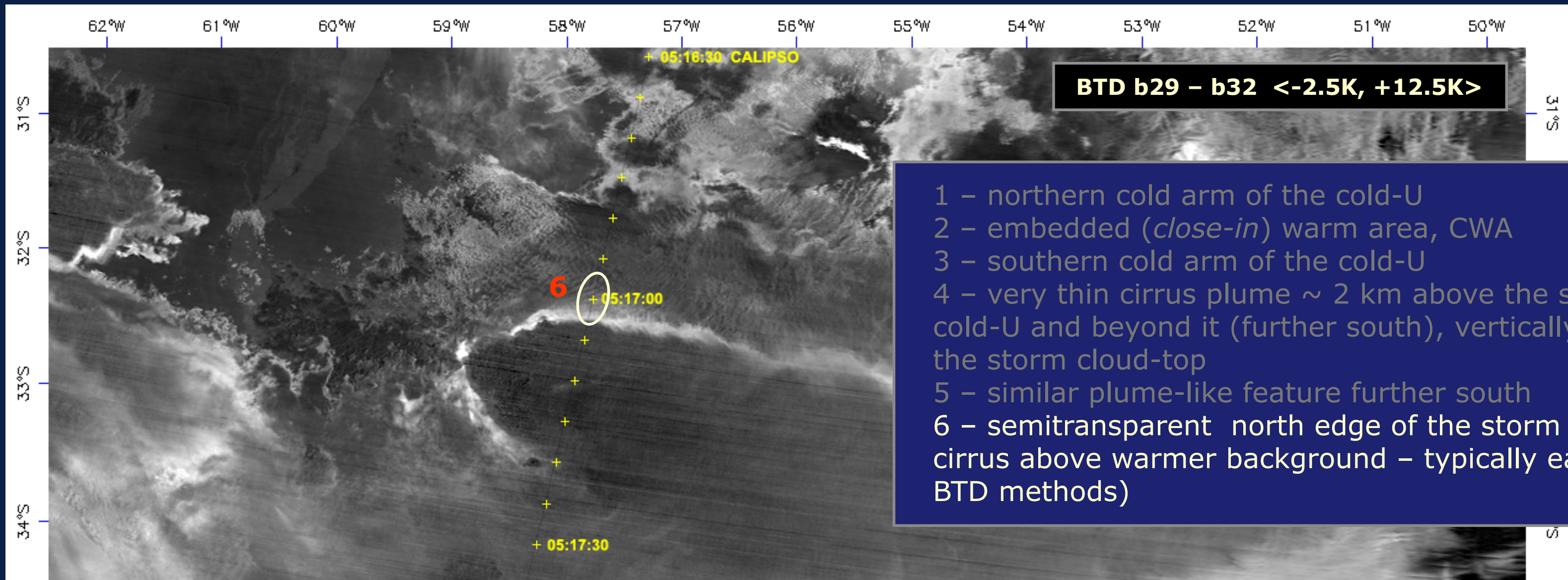


Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



1 – northern cold arm of the cold-U
2 – embedded (*close-in*) warm area, CWA
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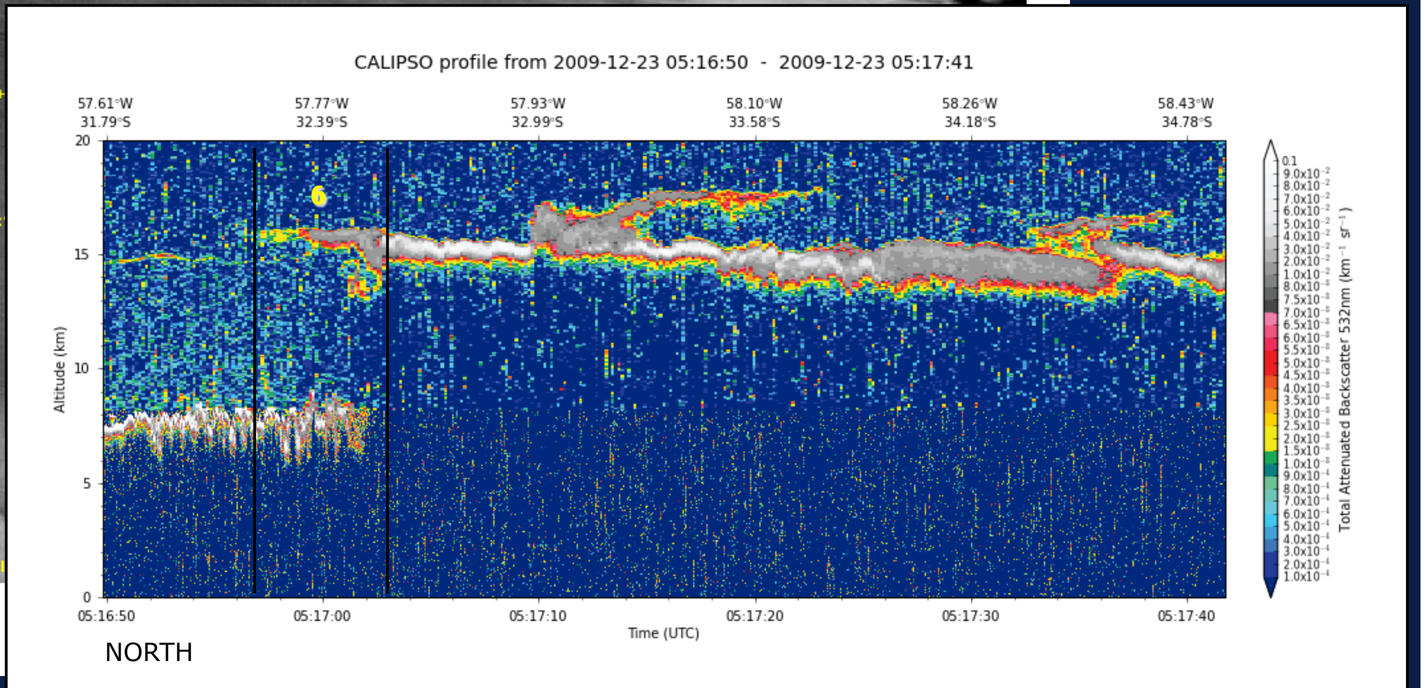
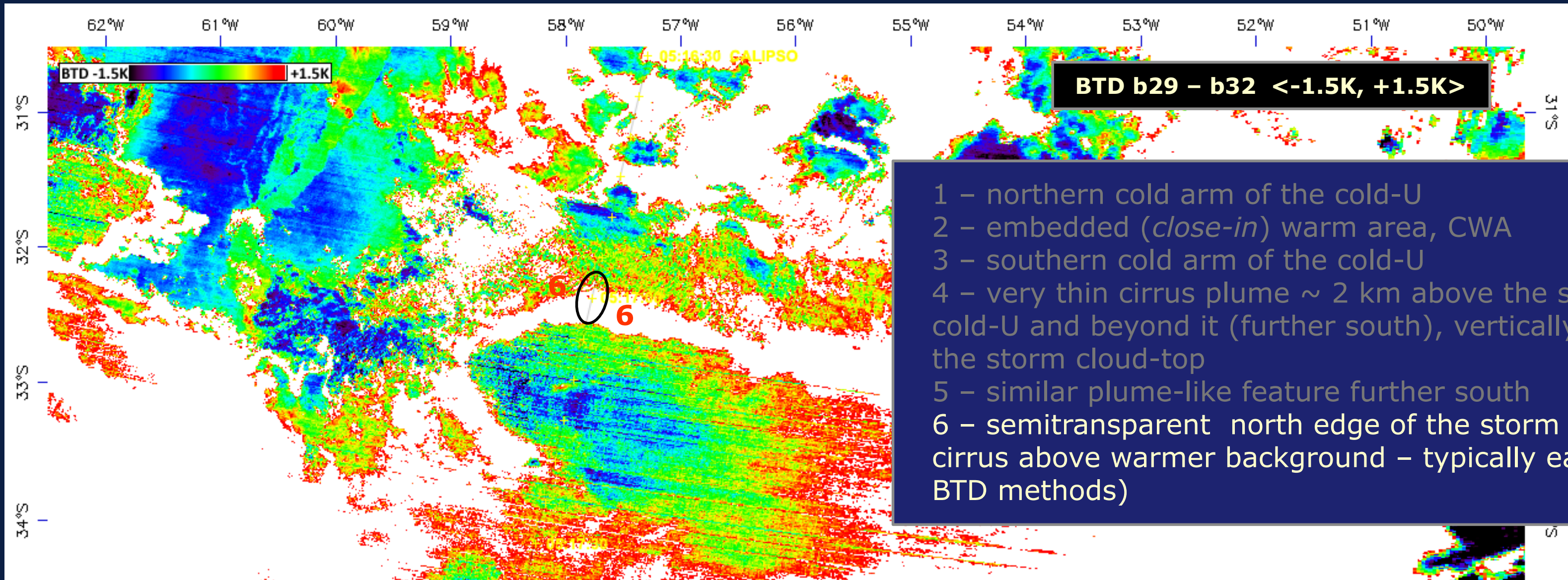
4 – very thin cirrus plume ~ 2 km above the southern arm of the cold-U and beyond it (further south), vertically separated from the storm cloud-top
5 – similar plume-like feature further south
6 – semitransparent north edge of the storm anvil (very thin cirrus above warmer background – typically easy to detect by BTD methods)



Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



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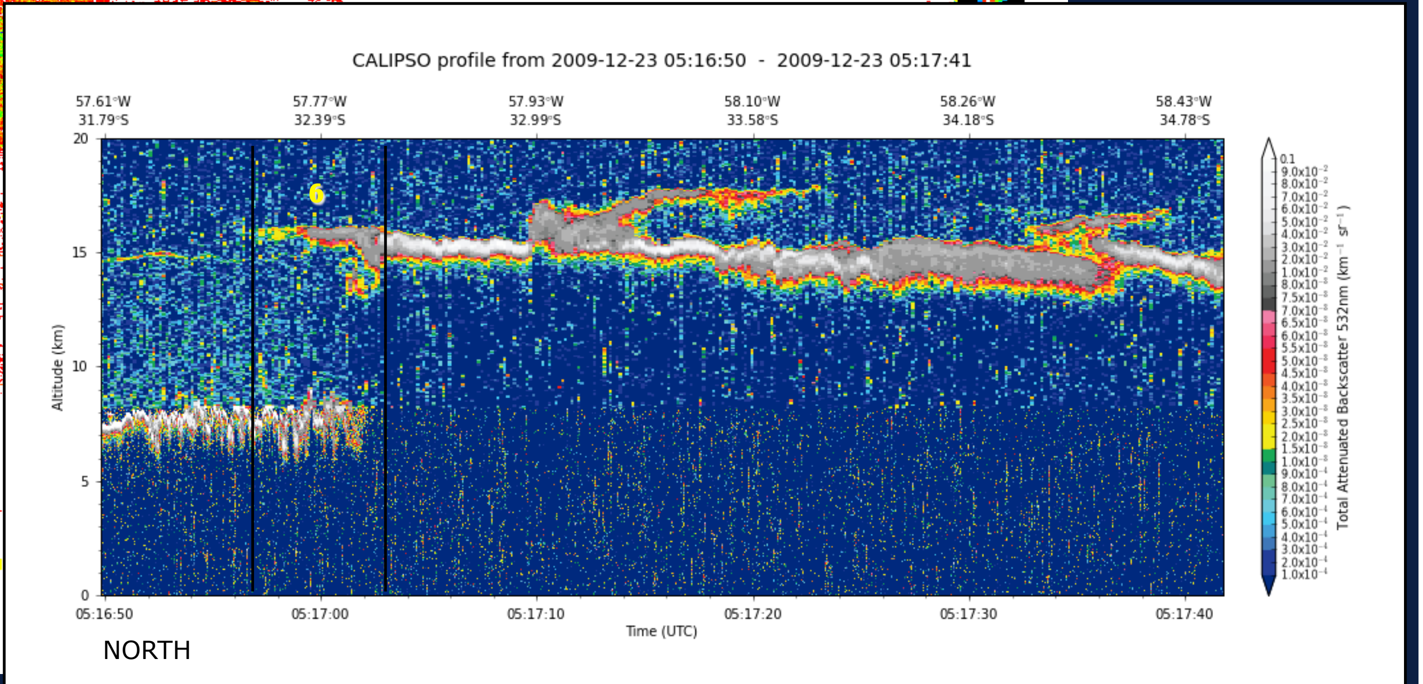
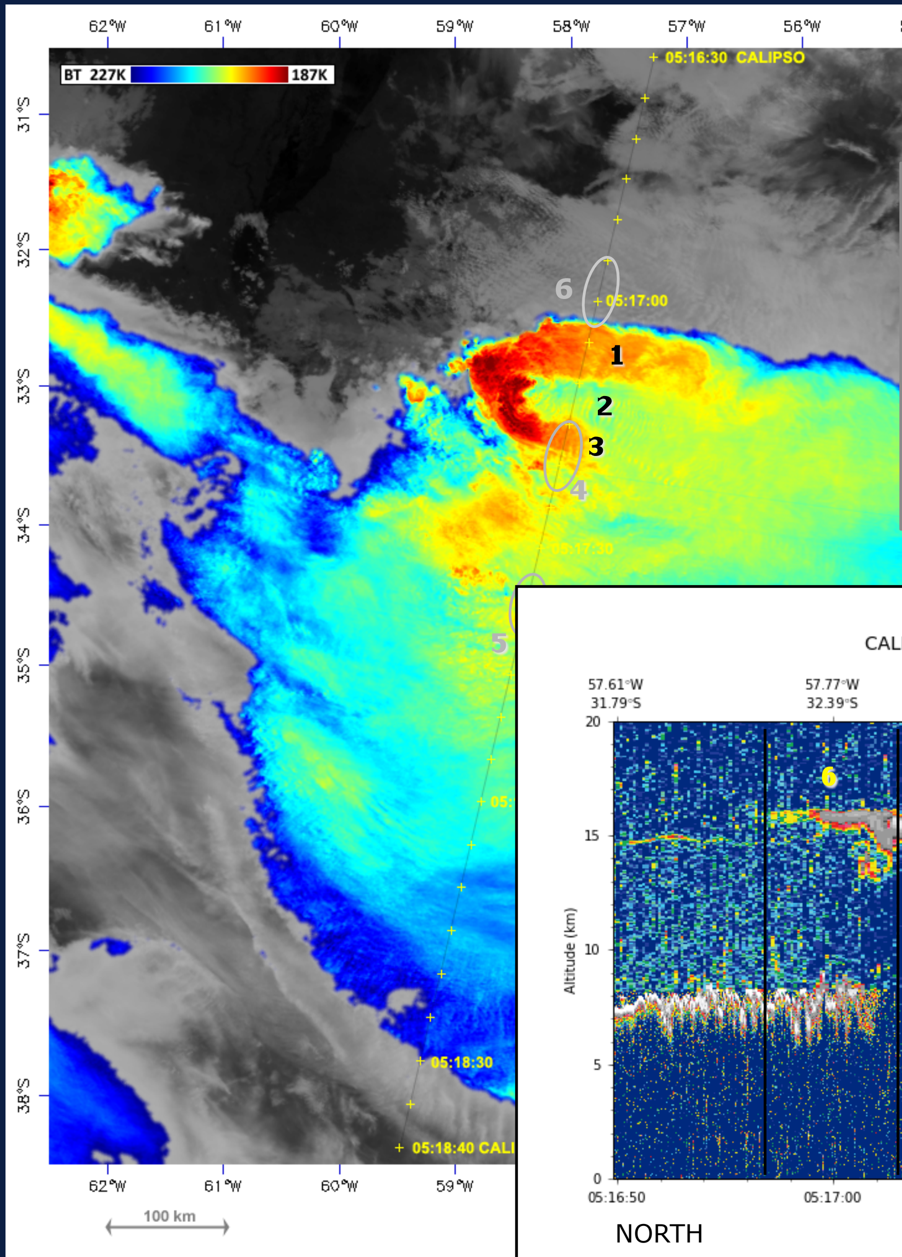


Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

Summary of this part

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



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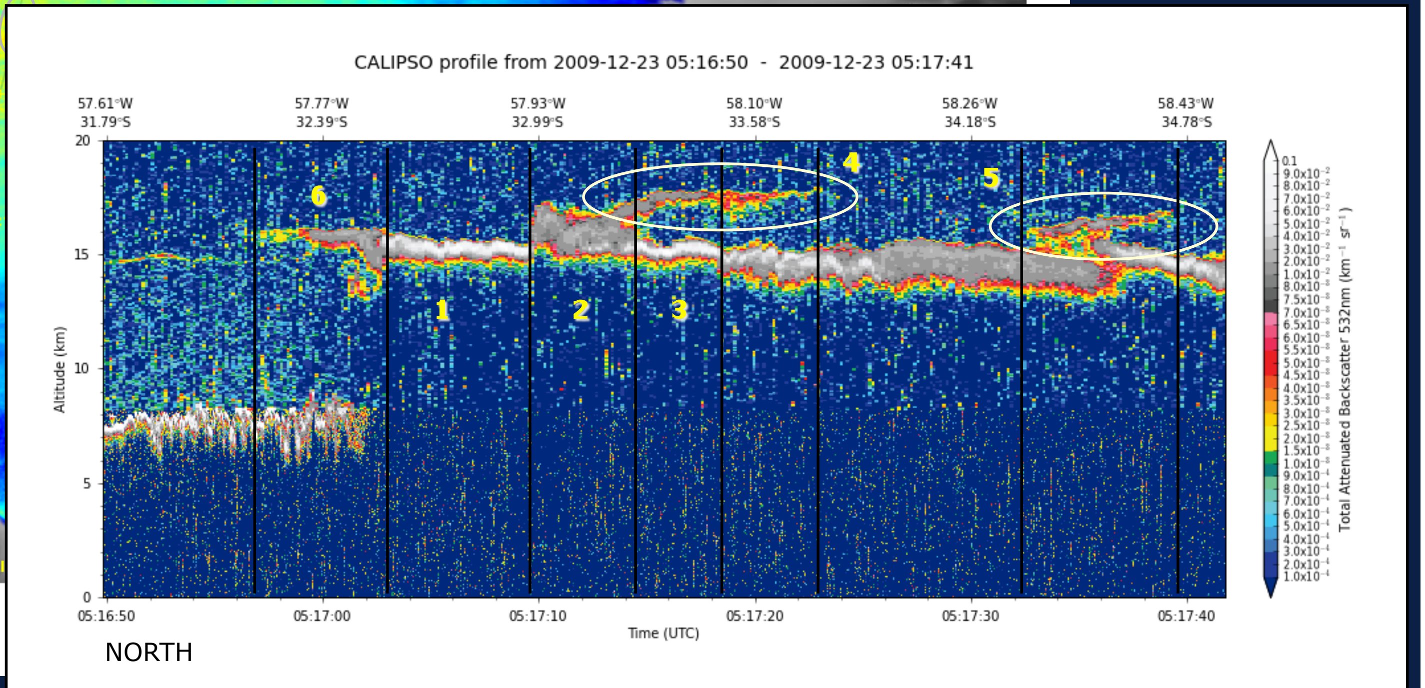
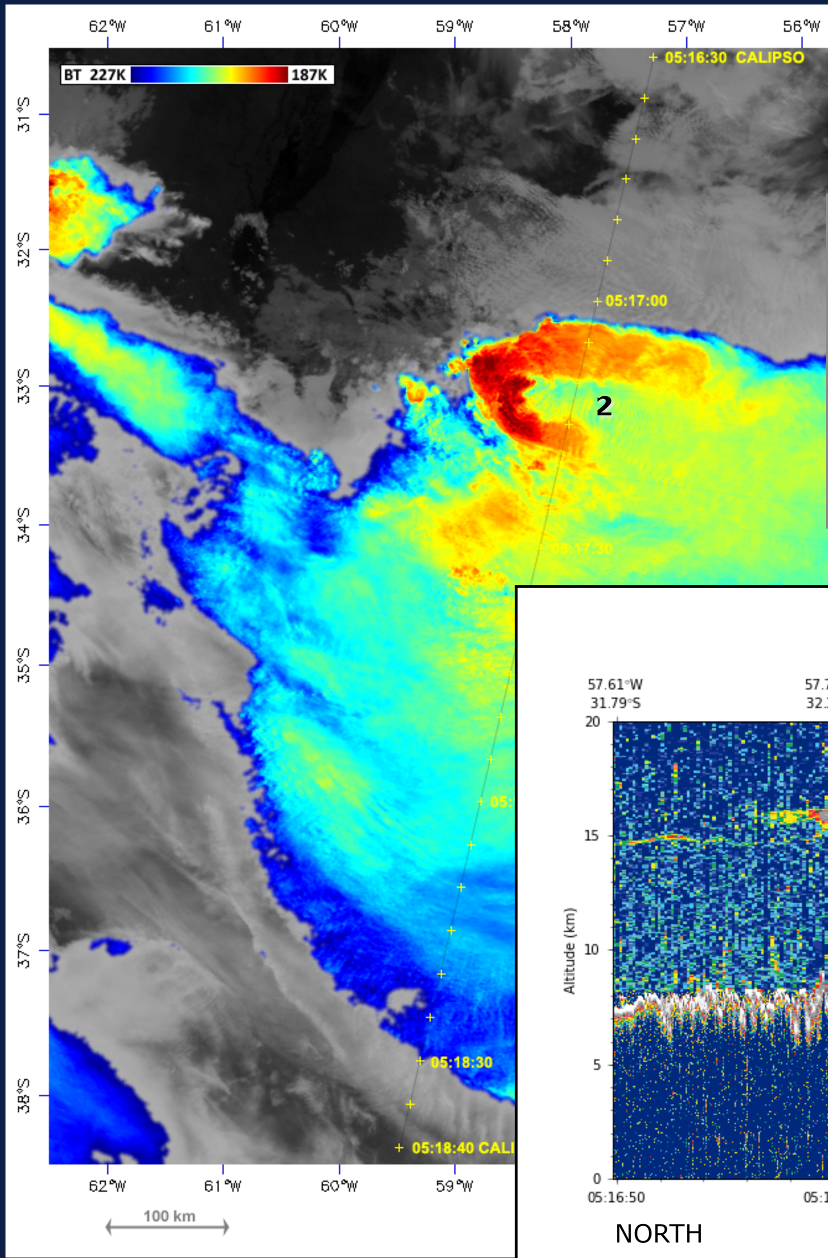


Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

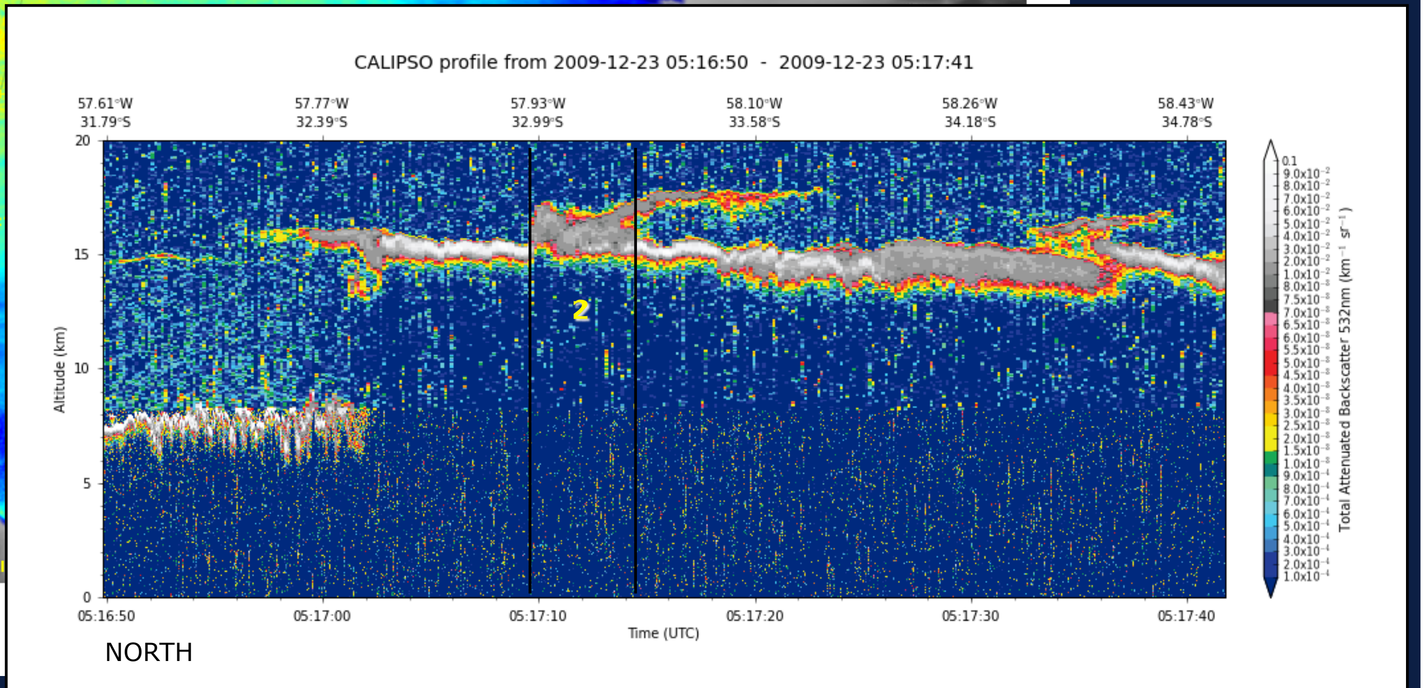
Summary of this part

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



In this case, the embedded warm area (CWA, (2)) inside the cold-U feature is composed of a deep layer of optically thinner material, stretching up ~ 1.5 – 2.0 km above the cloud-top of the surrounding optically thick cold arms. Therefore, the cold-U appearance of this storm results from the presence of the warmer layer of elevated cirrus clouds (possibly a plume), a "plume-masking mechanism".

Unfortunately, no CloudSat profile is available for this case to show the cloud optical thickness under the CWA.



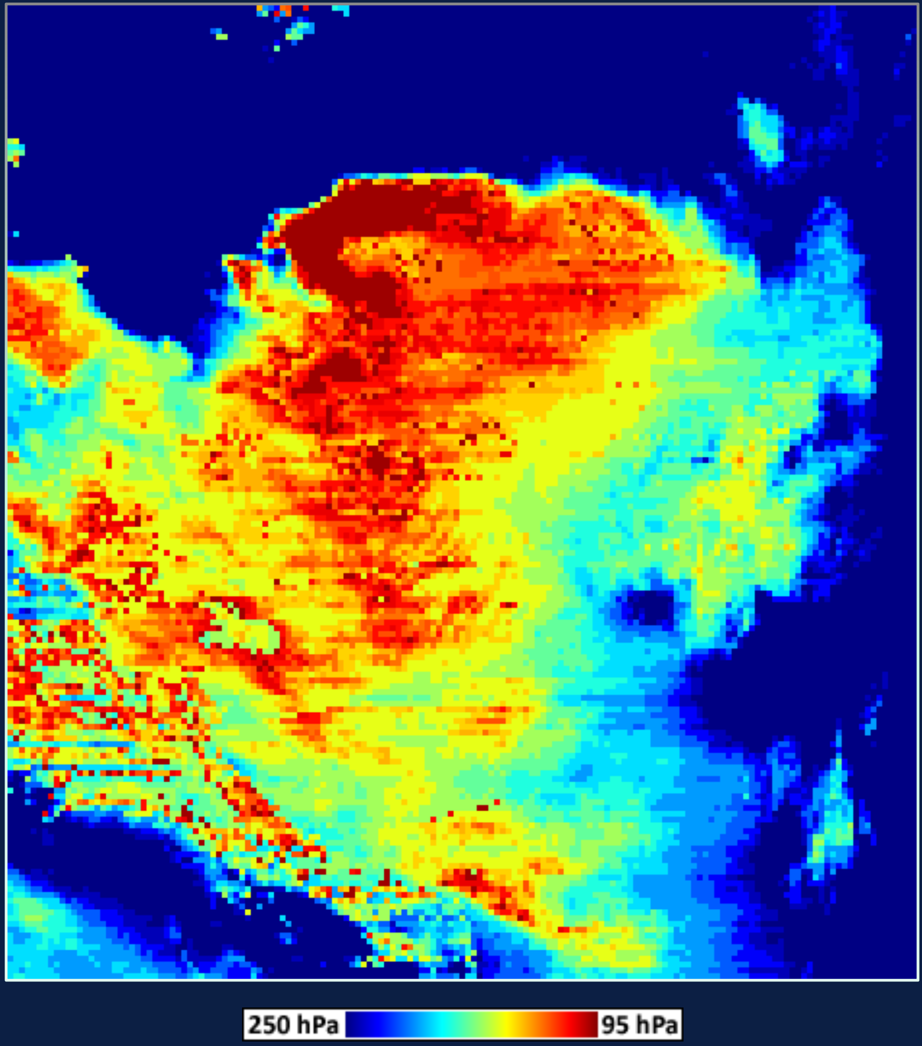
Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

In this case, the elevated nature of the embedded warm area was unambiguously proved by means of the CALIPSO/CALIOP profile. Thus, this case can be used as a "reference case" for tests of various satellite-based cloud-top pressure (CTP) or cloud top height (CTH) products.

These products typically fail when applied to storms exhibiting the cold-U/V (enhanced-V) or cold-ring features, interpreting the embedded warm areas as located at lower (warmer) levels. Consequently, this misinterpretation affects other satellite derived products, which utilize the CTP/CTH information.

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



Example of the Cloud Top Pressure (CTP) product, MODIS L2 data (Data Set #14).

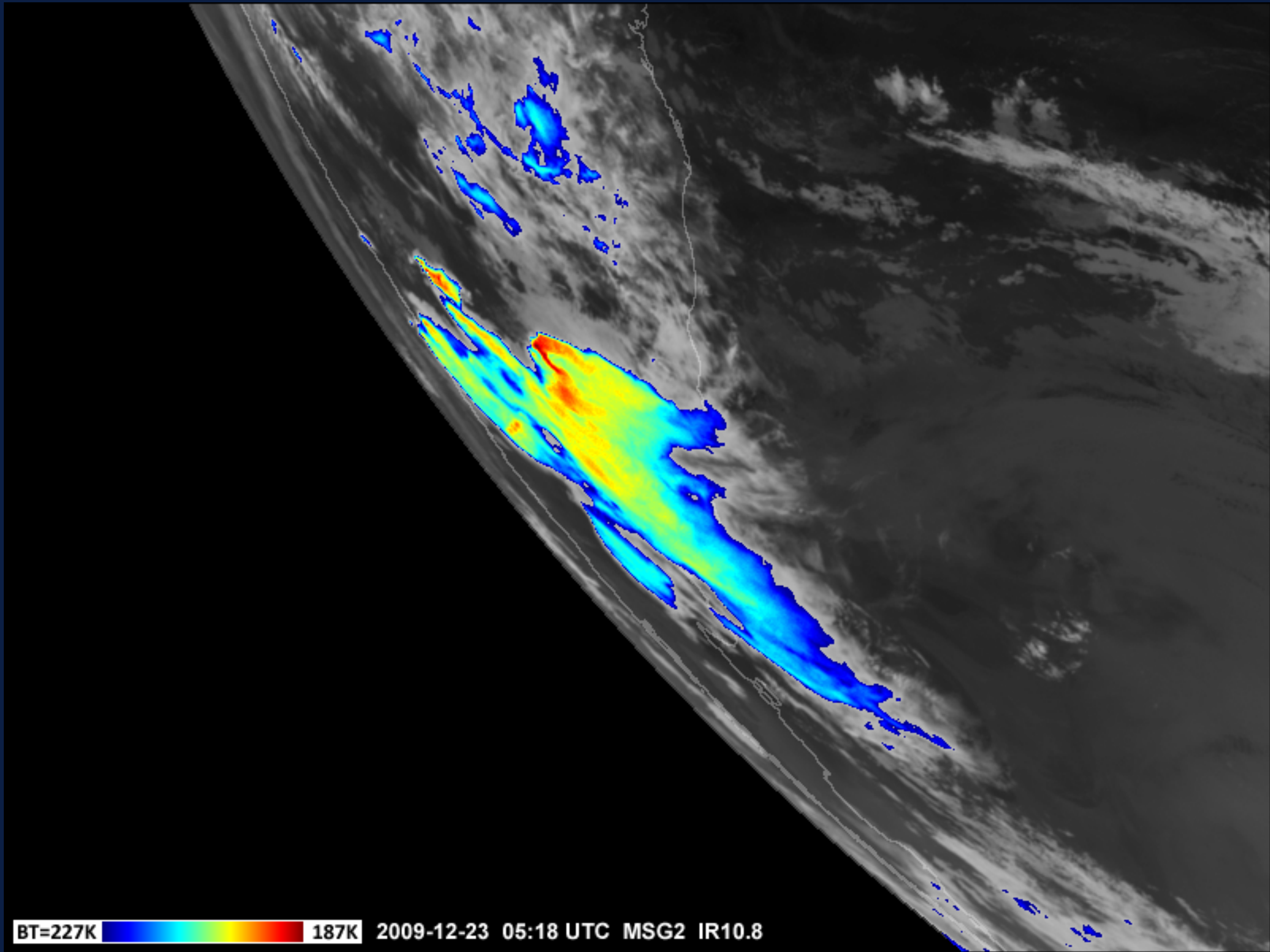
The embedded close-in warm area (CWA) is interpreted by this product as being at lower levels (higher CTP), as compared to the cold arms of the cold-V feature.

Many of the present operational nowcasting or CTP/CTH products utilize some of the brightness temperature differences (BTDs), namely the BTDs of water vapor absorption band and IR window band (WV-IRw), or CO2 absorption band and IR window band (CO2-IRw). These combinations typically show the embedded warm areas similarly as any other parts of the anvil emitting at the same temperature, not discriminating these by the BTD value, rather more or less copying the BT field itself (highest BTD values above the coldest pixels).

First, several Meteosat-9 (MSG-2) products are shown as an example. Given the proximity of the storm to the edge of the globe (as viewed by the MSG satellite), the limb-effect increases the BTDs as compared to values typical e.g. for western or central Europe.

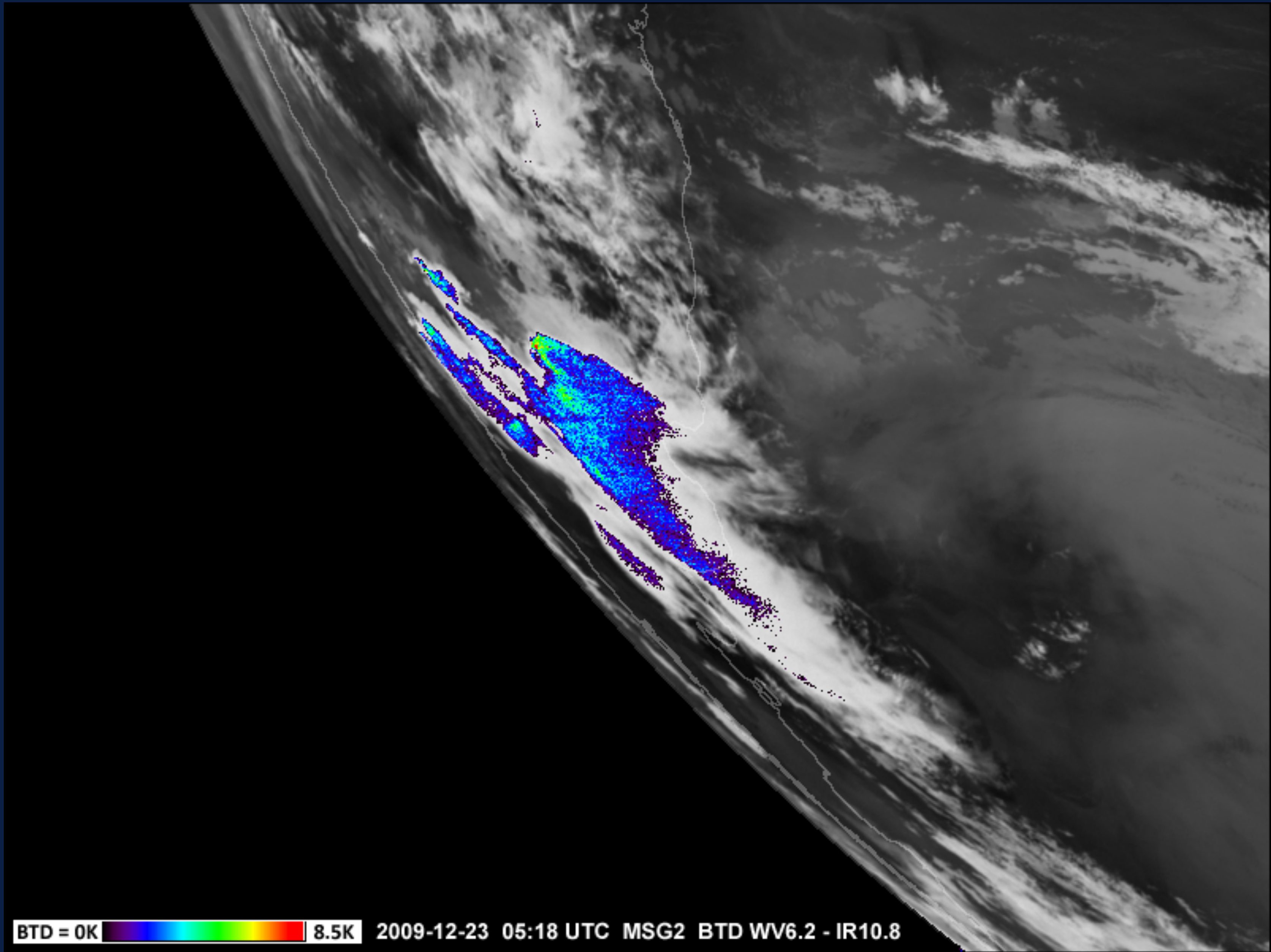
Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:18 UTC Meteosat-9 (MSG-2)



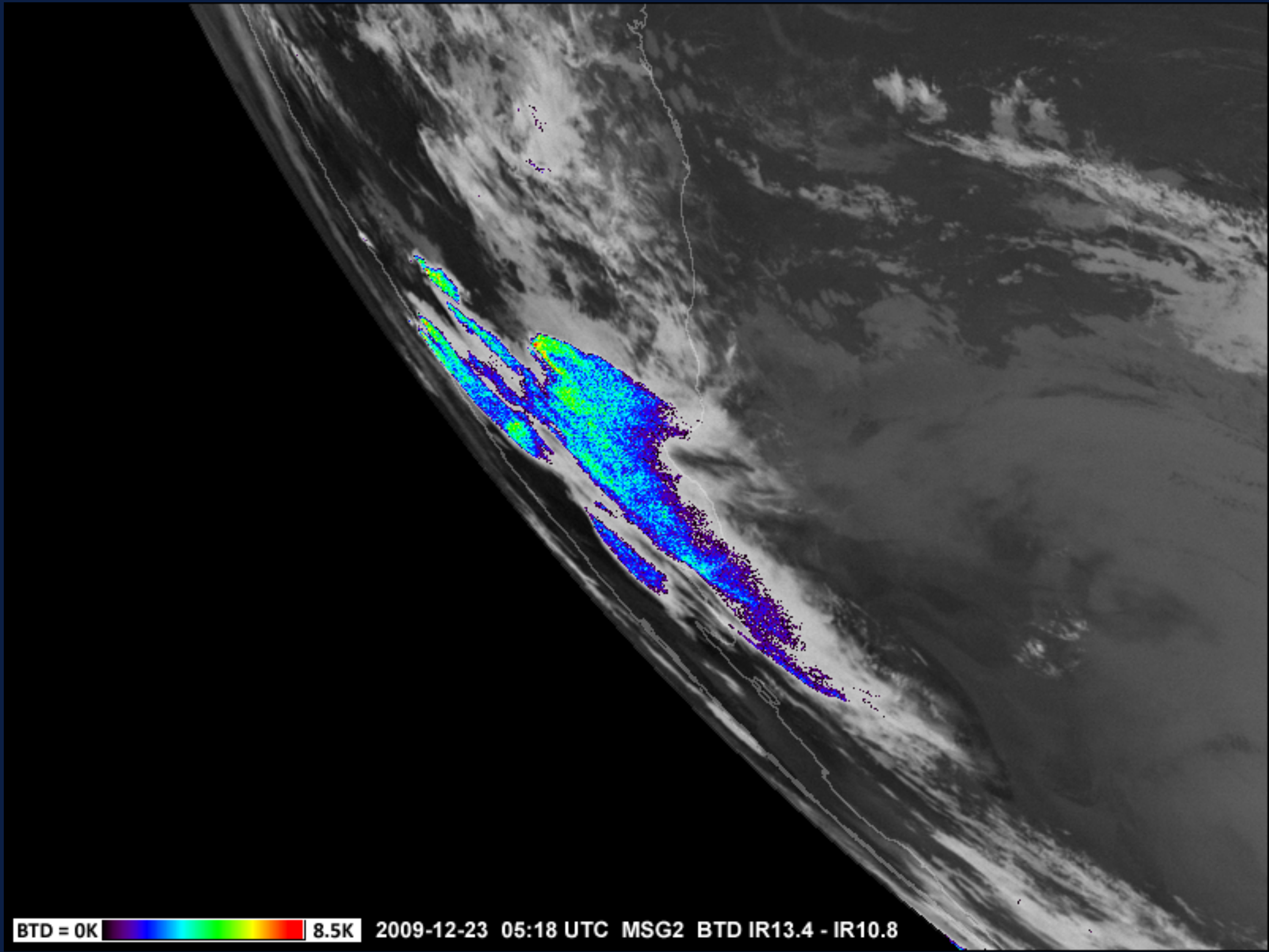
Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:18 UTC Meteosat-9 (MSG-2)



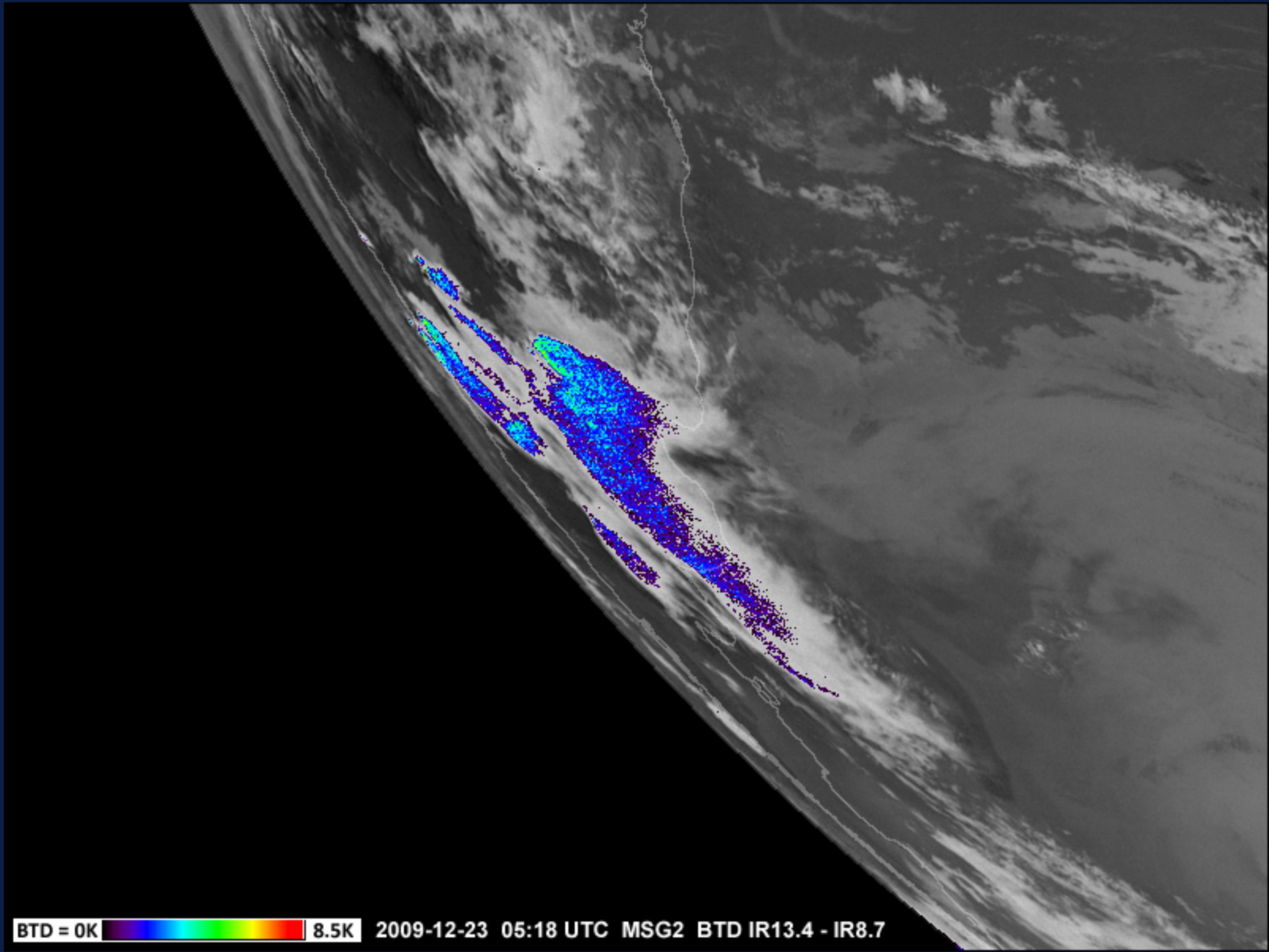
Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:18 UTC Meteosat-9 (MSG-2)



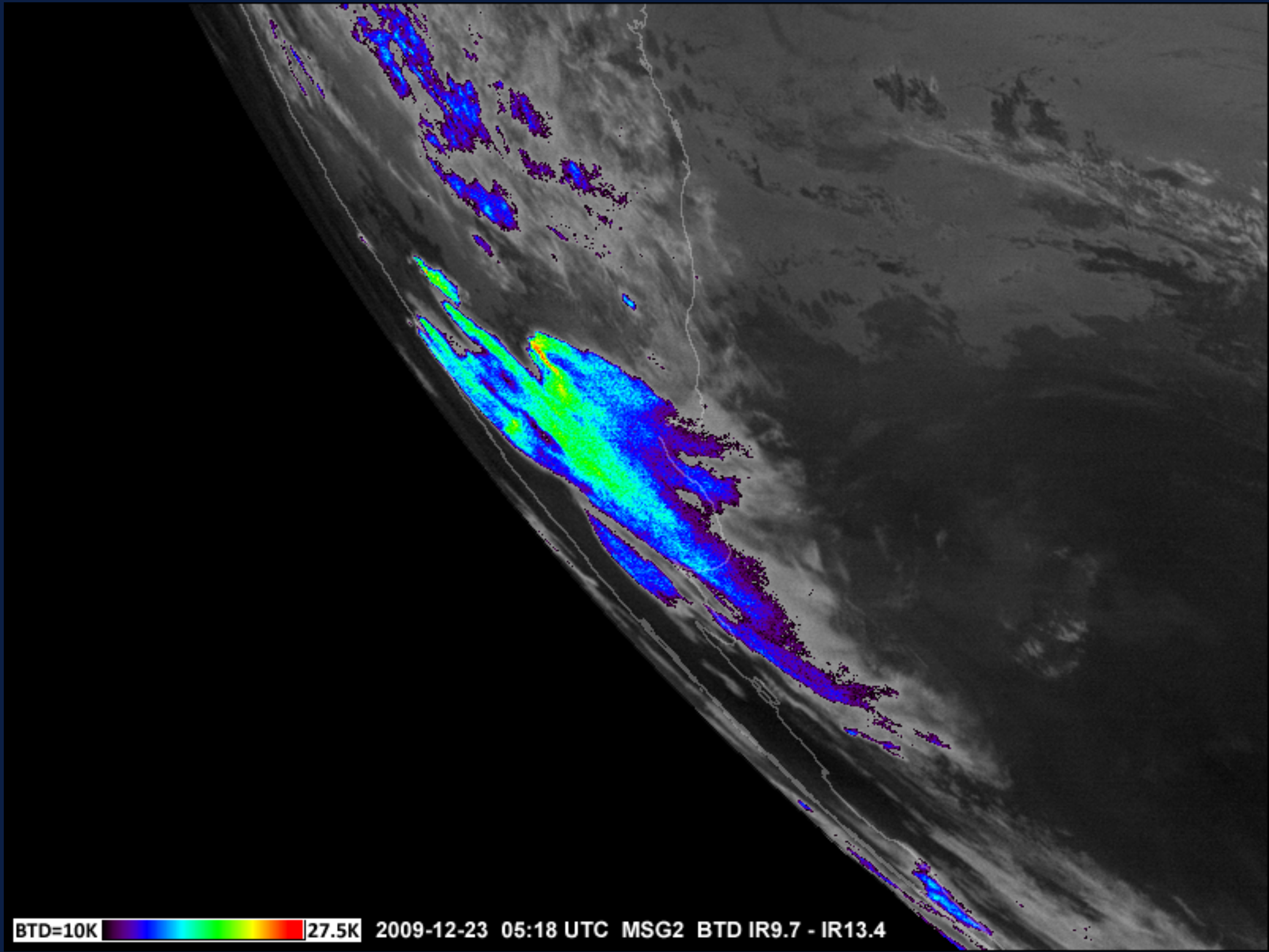
Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:18 UTC Meteosat-9 (MSG-2)



Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:18 UTC Meteosat-9 (MSG-2)



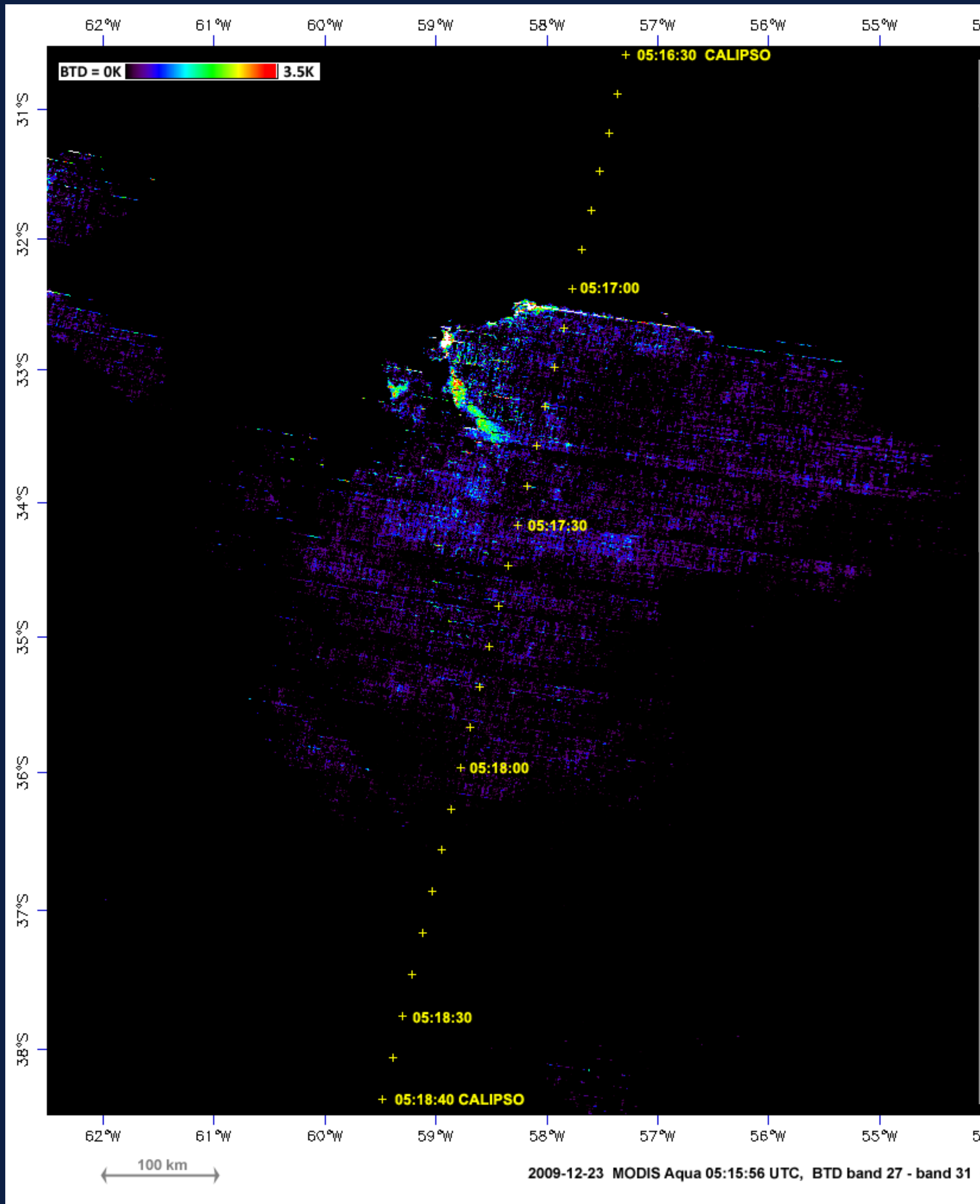
None of the existing BTDs based on MSG/SEVIRI bands is capable of detecting the elevated embedded warm area unambiguously, all BTDs show this area similarly as other warmer anvil regions, located at somewhat lower levels.

Thus, the question stands if there is any other BTD which would be capable of identifying the warm plume of the embedded warm area unambiguously. The height factor (nature of the plume) suggests to test the BTDs based on IR absorption bands, as the different cloud top level implies different total amounts of the absorbing gas above. Obviously, the cloud-top microphysics still can play a role in the final BTD.

The following examples show various BTDs based on the MODIS data. This instrument covers the CO2 absorption band to somewhat longer wavelengths (up to 14.2 µm, band 36) as compared to MSG/SEVIRI instrument (with its IR 13.4 µm band). This results in much stronger CO2 absorption at the MODIS band 36 as compared to the MSG IR13.4 band.

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay

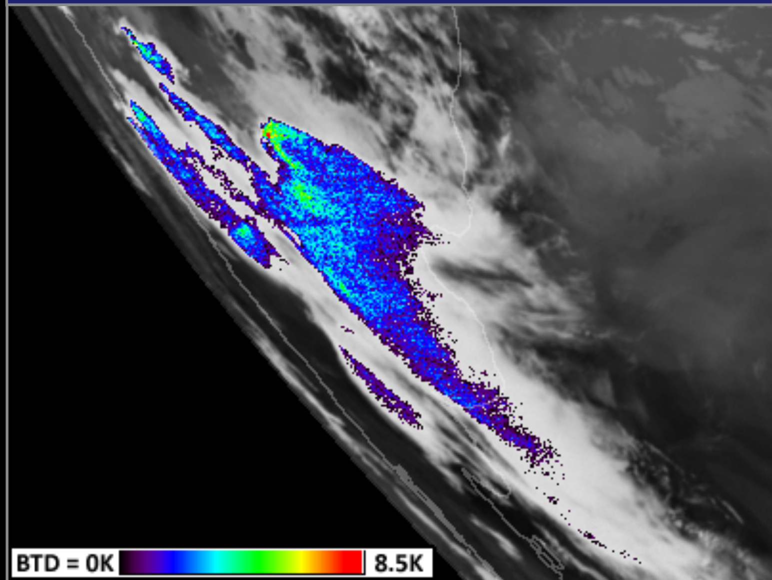


BTD b27 (WV abs. band) – b31 (IR window) <0K, 3.5K>

Unusually very low BTD (WV-IRw) values over most of the storm. Higher BTD values only at the semitransparent anvil edges - most likely the same effect as e.g. with the BTD of bands 29 and 32.

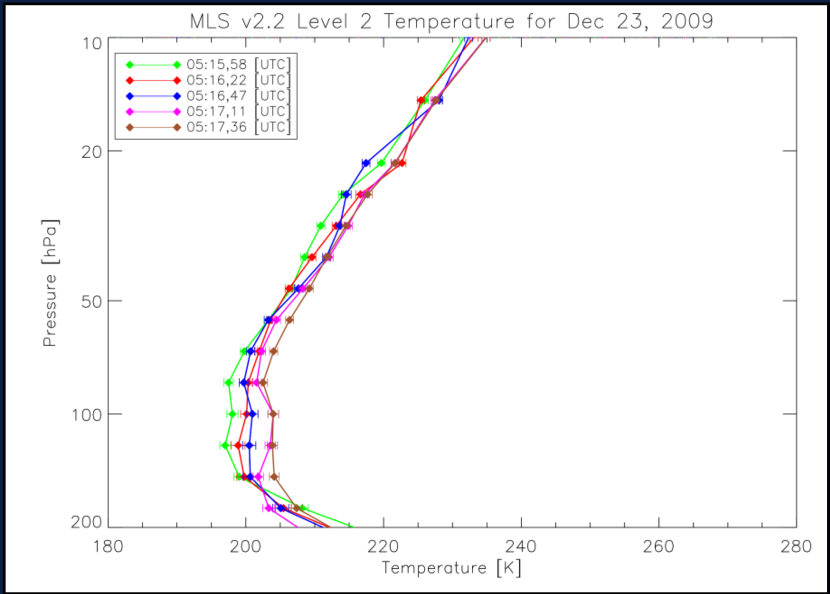
No trace of overshooting tops or the elevated warm plume in this product (in this particular case).

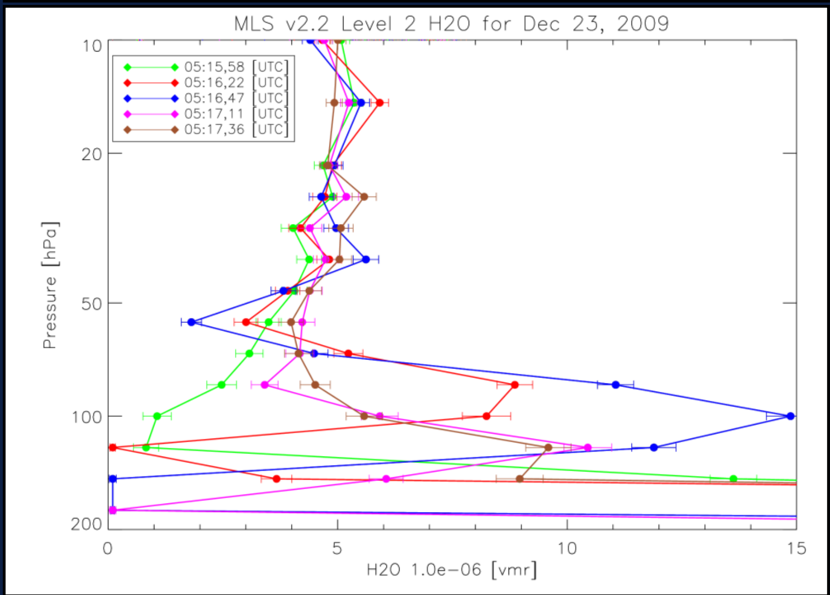
The corresponding MSG BTD image (below) shows higher BTD values, resulting from the tilted view from the satellite (limb effect).



Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

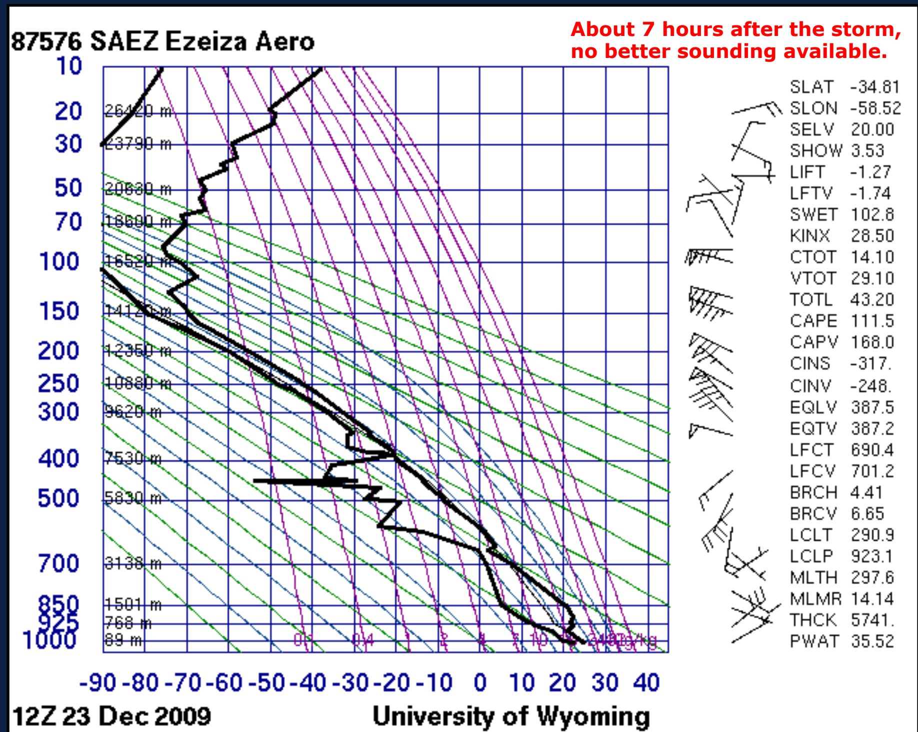
Possible Aura/MLS contribution to the BTD studies:





<<< Examples of H2O and temperature profiles measured by MLS above the storm ...

... additional input data (besides the standard soundings) to the RTM models.



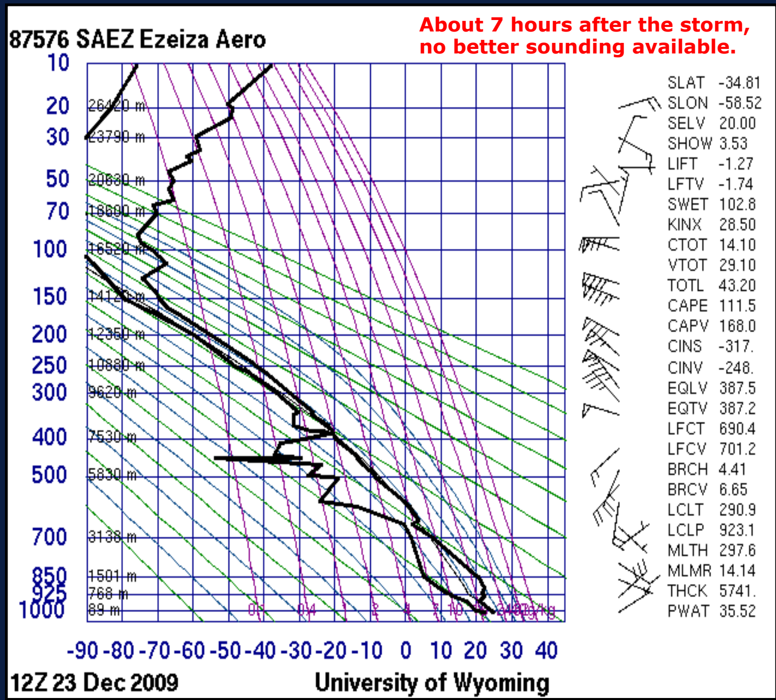
(no better sounding available for this case)

Some preliminary RTM simulations for the Argentina 2009-12-23 case (Dan Lindsey, Louis Grasso)

Using the SAEZ Azeiza Aero (87576) 12Z sounding, with the water vapor mixing ratio above the anvil top set to 0.001 g/kg. An opaque anvil top is placed at 200K (14.8 km, close to the tropopause), the “thin cloud” case assumes additional optically thin (0.25) cirrus layer between 15.3-16.4km (warm layer), while the “moisture” case assumes the same layer containing 0.007 g/kg of water vapor.

BTD (6.2-11.2) for GOES-E and “MSG”
BTD (6.8-11.0) for MODIS

Bare storm top – MODIS	0.0195 K
Bare storm top – GOES-E	0.0884 K
Bare storm top – MSG	0.8457 K
Thin cloud – MODIS	0.0455 K
Thin cloud – GOES-E	0.0441 K
Thin cloud – MSG	0.4619 K
Moisture – MODIS	0.0278 K
Moisture – GOES-E	0.1492 K
Moisture – MSG	0.9728 K

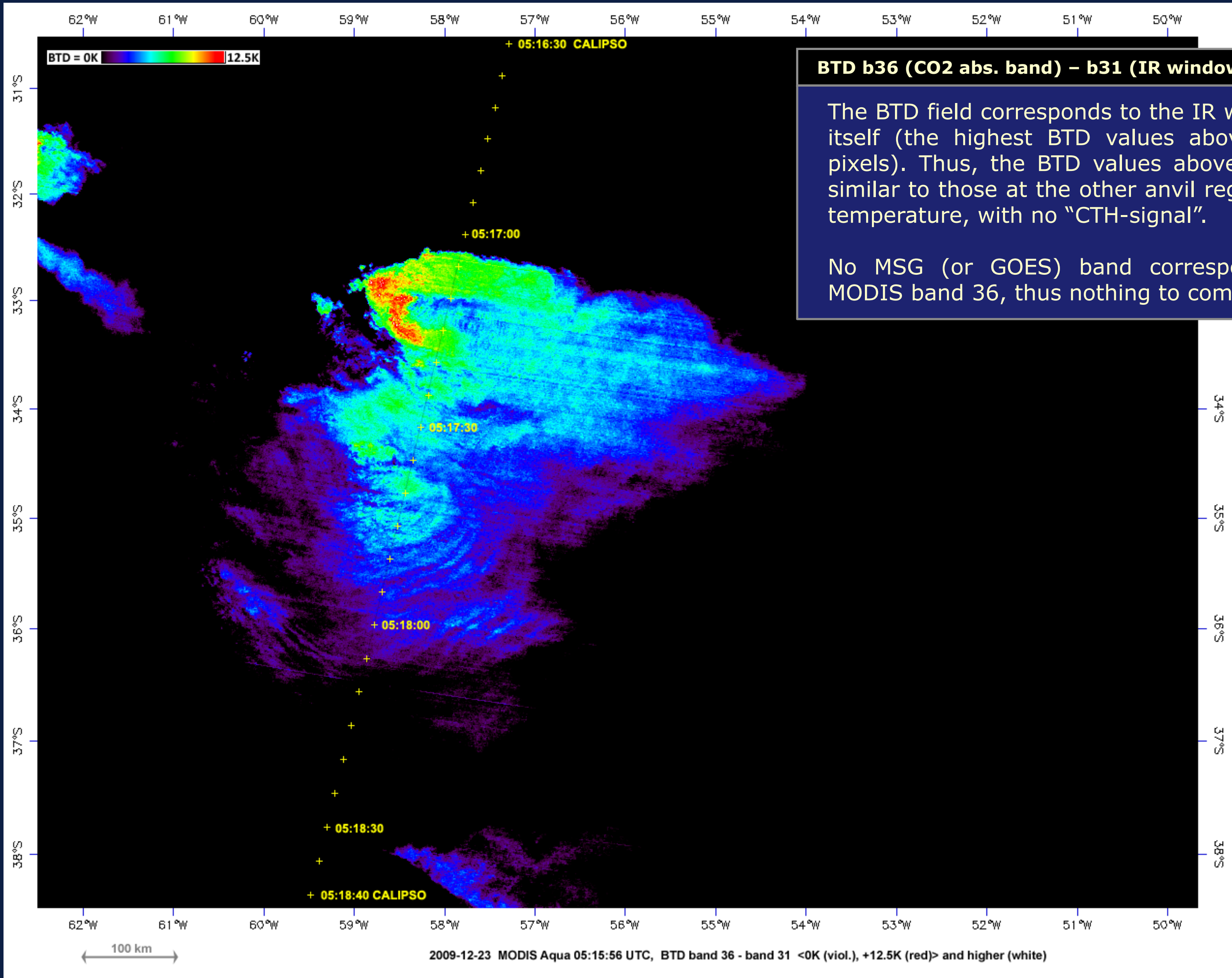


“GOES-E” assumes the GOES-R ABI bands, “MSG” represents the values if observed by GOES-R with the storm at a satellite-relative location as if viewed from MSG, and “MODIS” represents the nadir view.

These results confirm the “limb effect”, i.e., an increase of the BTD values when observing the storm close to the edge of the globe (tilted view). Similar effects also occur for other BTDs utilizing any of the absorption bands. For the “MSG” case, higher BTD values are seen even without increased moisture directly above the storm.

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



2009-12-23 MODIS Aqua 05:15:56 UTC, BTD band 36 - band 31 <0K (viol.), +12.5K (red)> and higher (white)

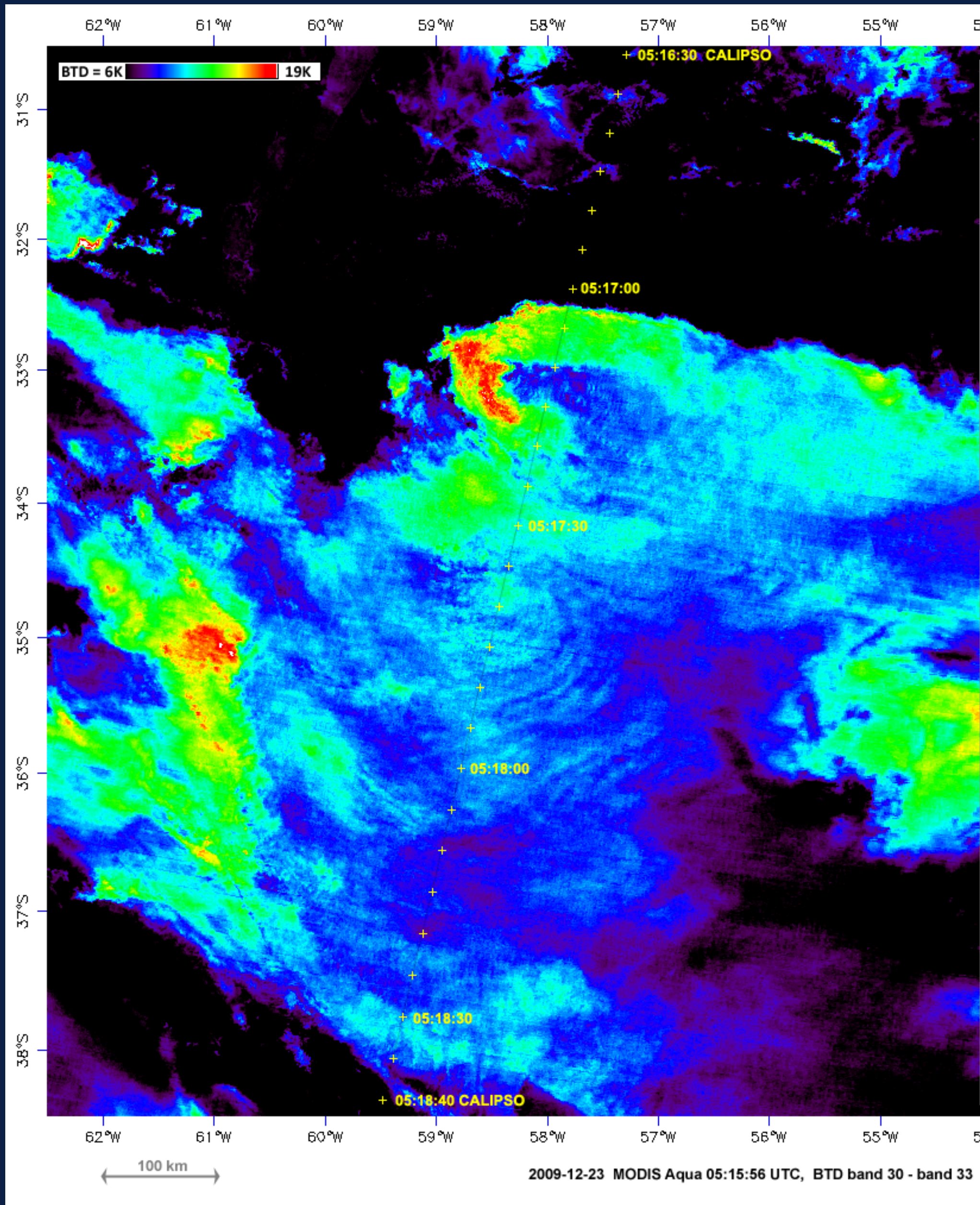
BTD b36 (CO2 abs. band) – b31 (IR window) <0K, +12.5K>

The BTD field corresponds to the IR window BT field itself (the highest BTD values above the coldest pixels). Thus, the BTD values above the CWA are similar to those at the other anvil regions at similar temperature, with no "CTH-signal".

No MSG (or GOES) band corresponding to the MODIS band 36, thus nothing to compare with.

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

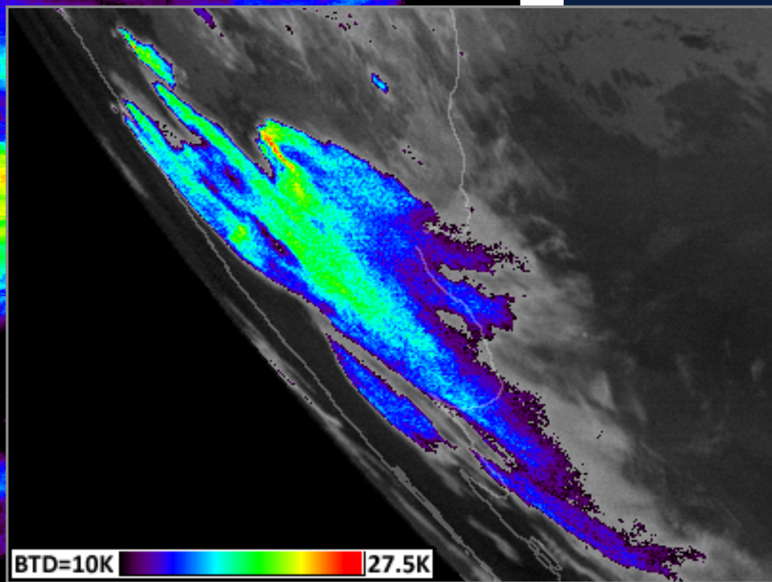
2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



BTD b30 (O3 abs. band) – b33 (CO2 abs. band) <+6K, +19K>

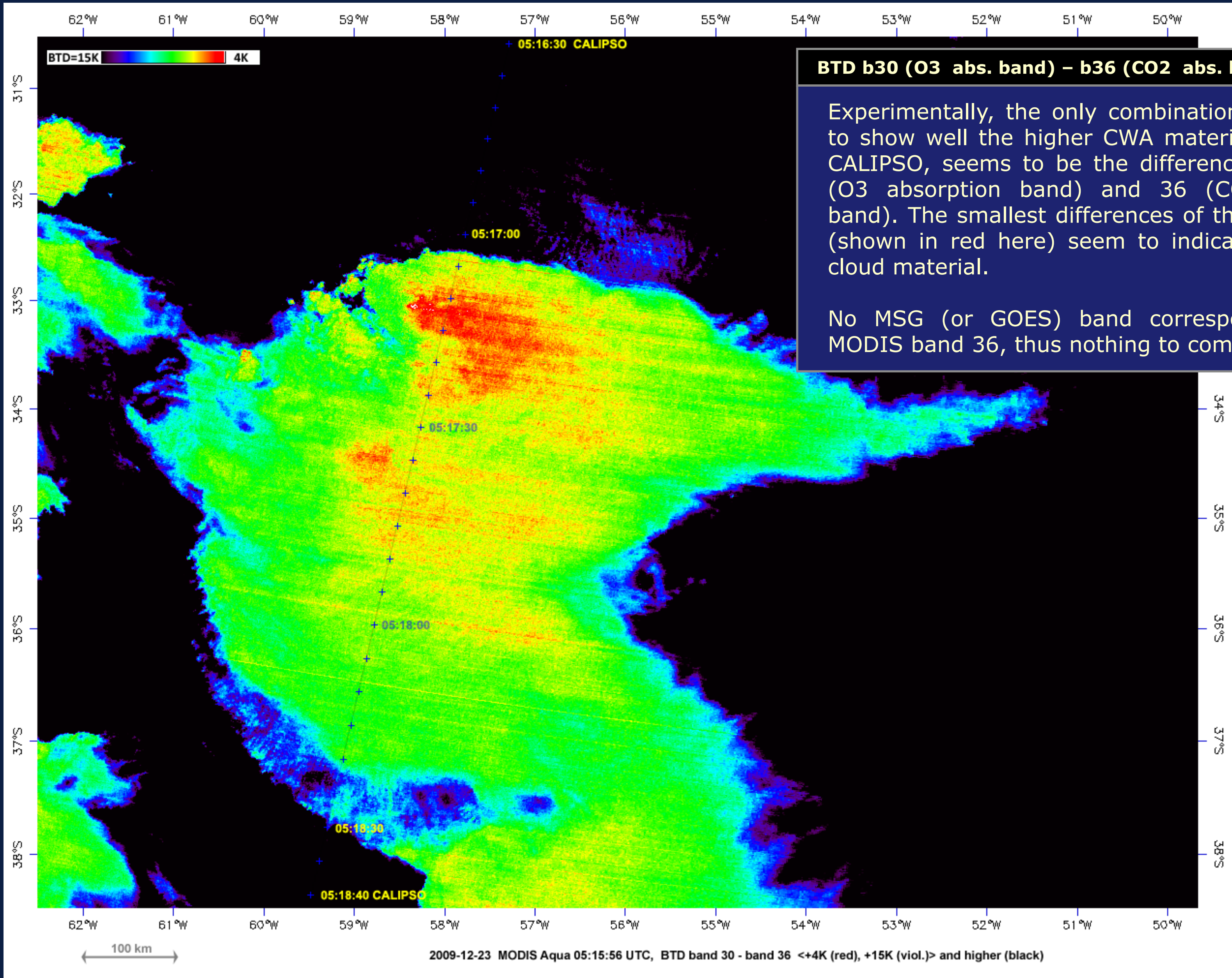
In this case, BTD product based on two absorption bands (O3 and CO2) is used. However, even in this case the BTD more or less mirrors the BT field itself, without any "signal" related to cloud top height.

Very similar to the corresponding MSG BTD product (SEVIRI bands IR9.7-IR13.4, image below), with the MSG BTD product exhibiting significantly higher BTD values due to the limb effect. (The *range of the color enhancements is not the same; the MSG BTD color scale is shifted to higher BTD values.*)



Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay



BTD b30 (O3 abs. band) – b36 (CO2 abs. band) <4K, 15K>

Experimentally, the only combination which seems to show well the higher CWA material detected by CALIPSO, seems to be the difference of bands 30 (O3 absorption band) and 36 (CO2 absorption band). The smallest differences of these two bands (shown in red here) seem to indicate the highest cloud material.

No MSG (or GOES) band corresponding to the MODIS band 36, thus nothing to compare with.

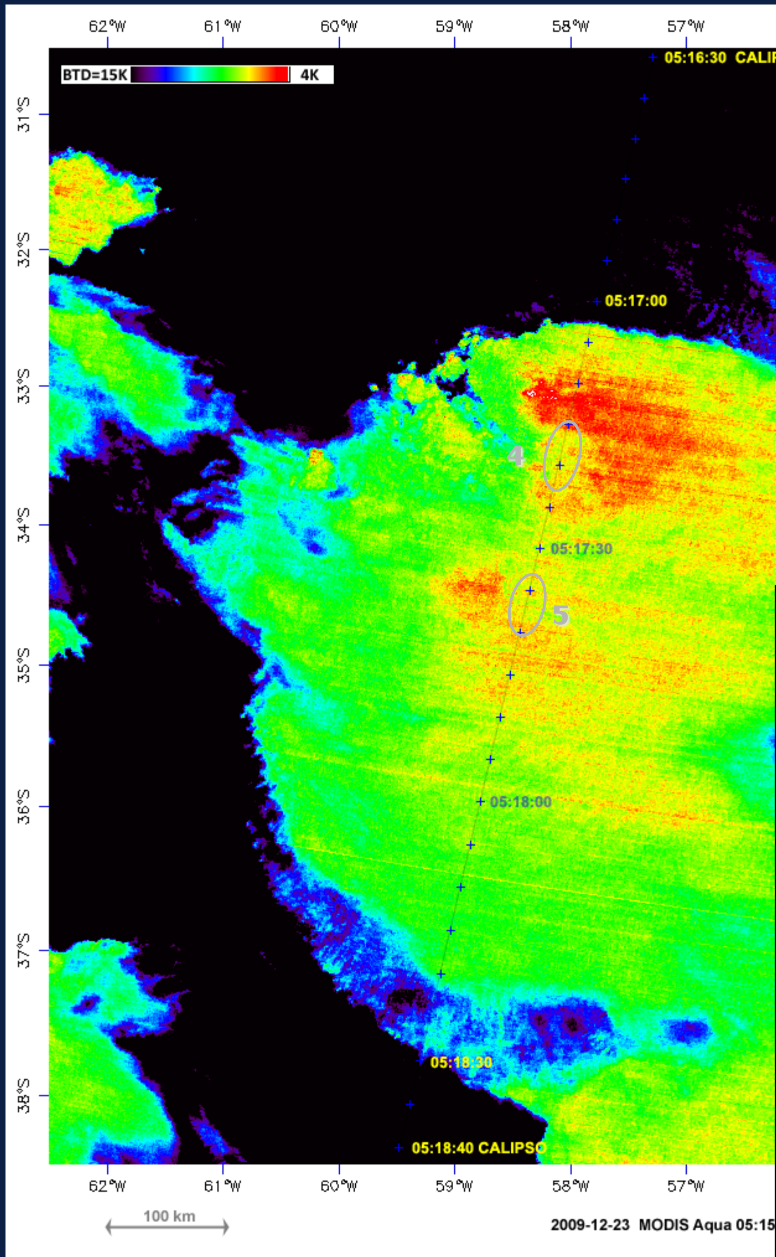
Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

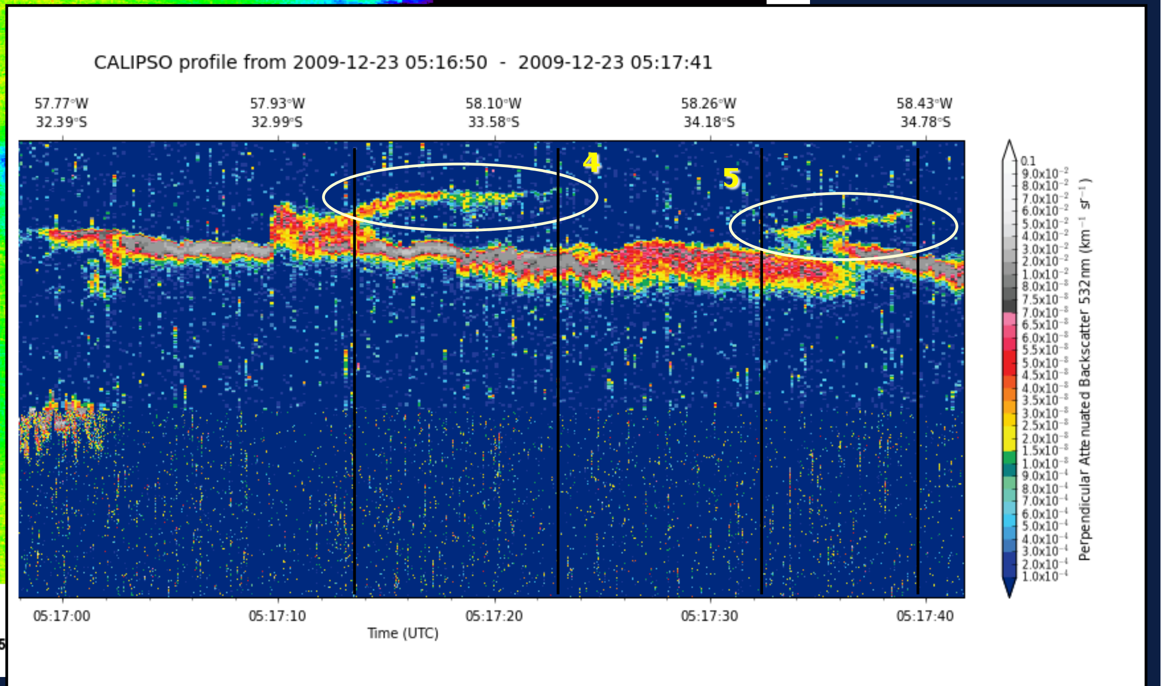
2009-12-23 05:15:56 UTC MODIS/Aqua Argentina & Uruguay

BTD b30 (O3 abs. band) – b36 (CO2 abs. band) <4K, 15K>

Experimentally, the only combination which seems to show well the higher CWA material detected by CALIPSO, seems to be the difference of bands 30 (O3 absorption band) and 36 (CO2 absorption band). The smallest differences of these two bands (shown in red here) seem to indicate the highest cloud material.

However, even this BTD fails to detect the very thin ice layers (4) and (5), detected by CALIPSO.





Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

Summary of this part:

- BTD products based on MSG data show in general higher BTD values as compared to the corresponding products (similar bands) based on MODIS data. This is most likely a result of the limb effect (tilted view, thus longer path of the radiance through the atmosphere).
- Though the MODIS-based BTD of WV and IR-window bands shows very low values above most of the storm, in MSG data the corresponding BTD shows significantly higher values – again limb effect, no link to the storm itself, contribution of the warmer stratosphere above the storm.
- None of the possible (available) BTDs is capable of detecting very thin cirrus layers (areas 4 and 5) above the cold anvil top underneath.

Cold-U/V feature (enhanced-V) and embedded warm area (CWA)

Summary of this part:

- The only BTD which seems capable of detecting the high warm plume and discriminating it from the rest of the storm top appears to be the BTD of band 36 (CO_2 absorption band) and band 30 (O_3 abs. band). As there are no matching bands centered at 14.2 µm on MSG or GOES satellites, it is not possible to compare this BTD with any similar product based on geostationary satellite data.

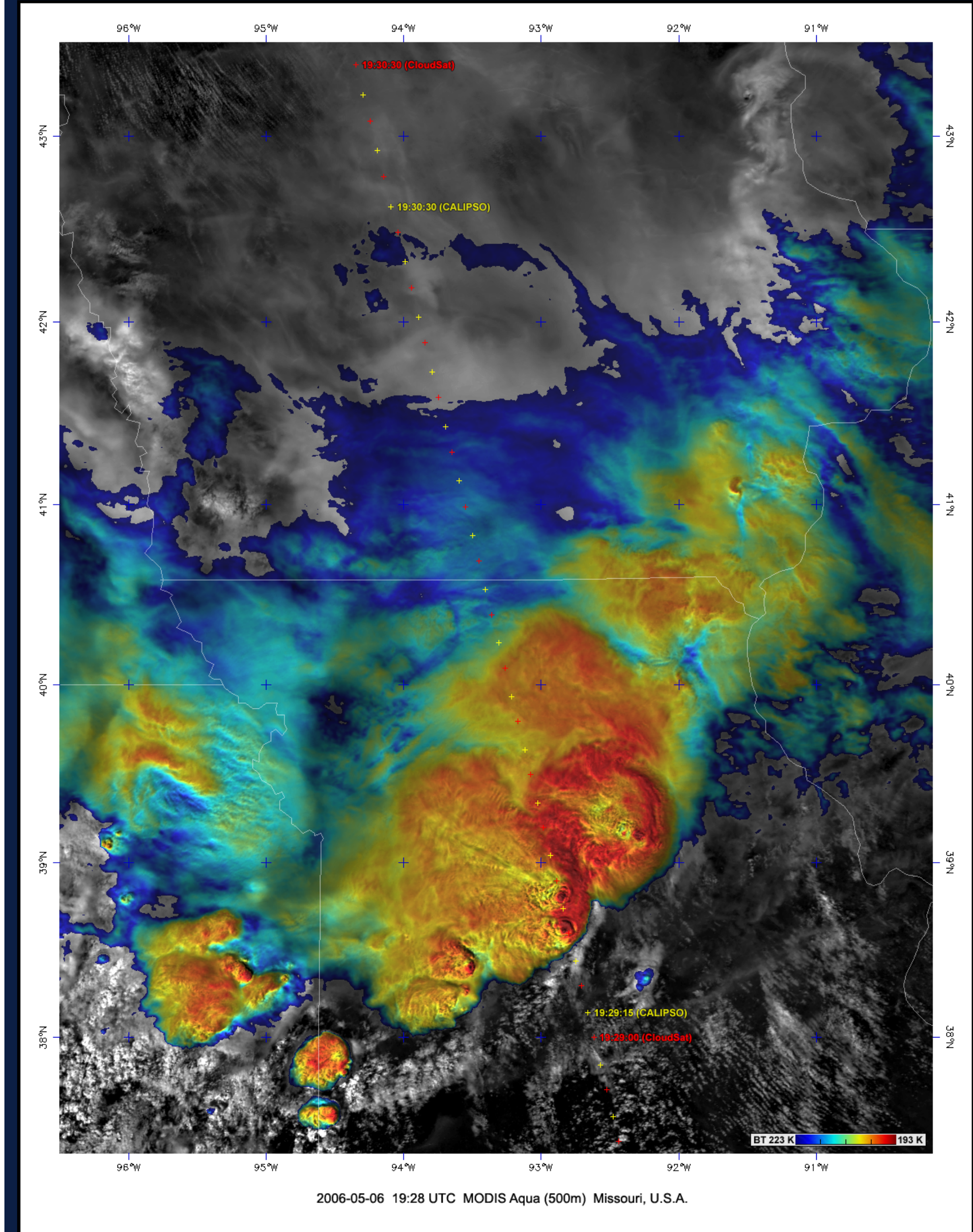
- The link between the lowest BTD values and highest cloud top heights needs to be validated on other cases, documented by CloudSat and CALIPSO data, preferably on overshooting top cases with opaque cloud tops, and simultaneously proved by means of RTM methods.

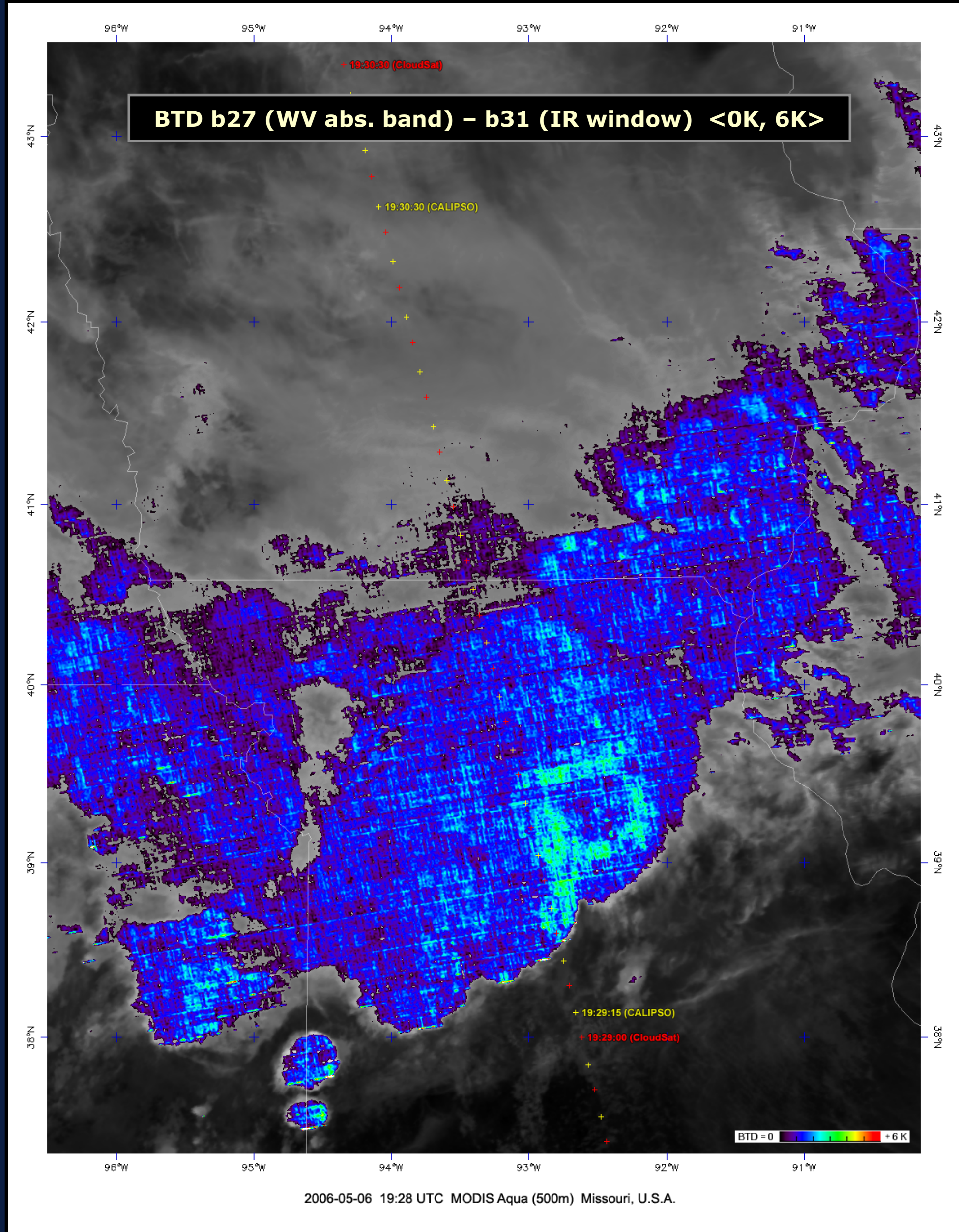
- Even if this BTD is confirmed as capable of discriminating the (relative) cloud-top height, its efficiency will strongly depend on the actual total O_3 and CO_2 amounts above the storm, both of which are highly variable in space and time (namely the total O_3) ...

6 May 2007 19:28 UTC

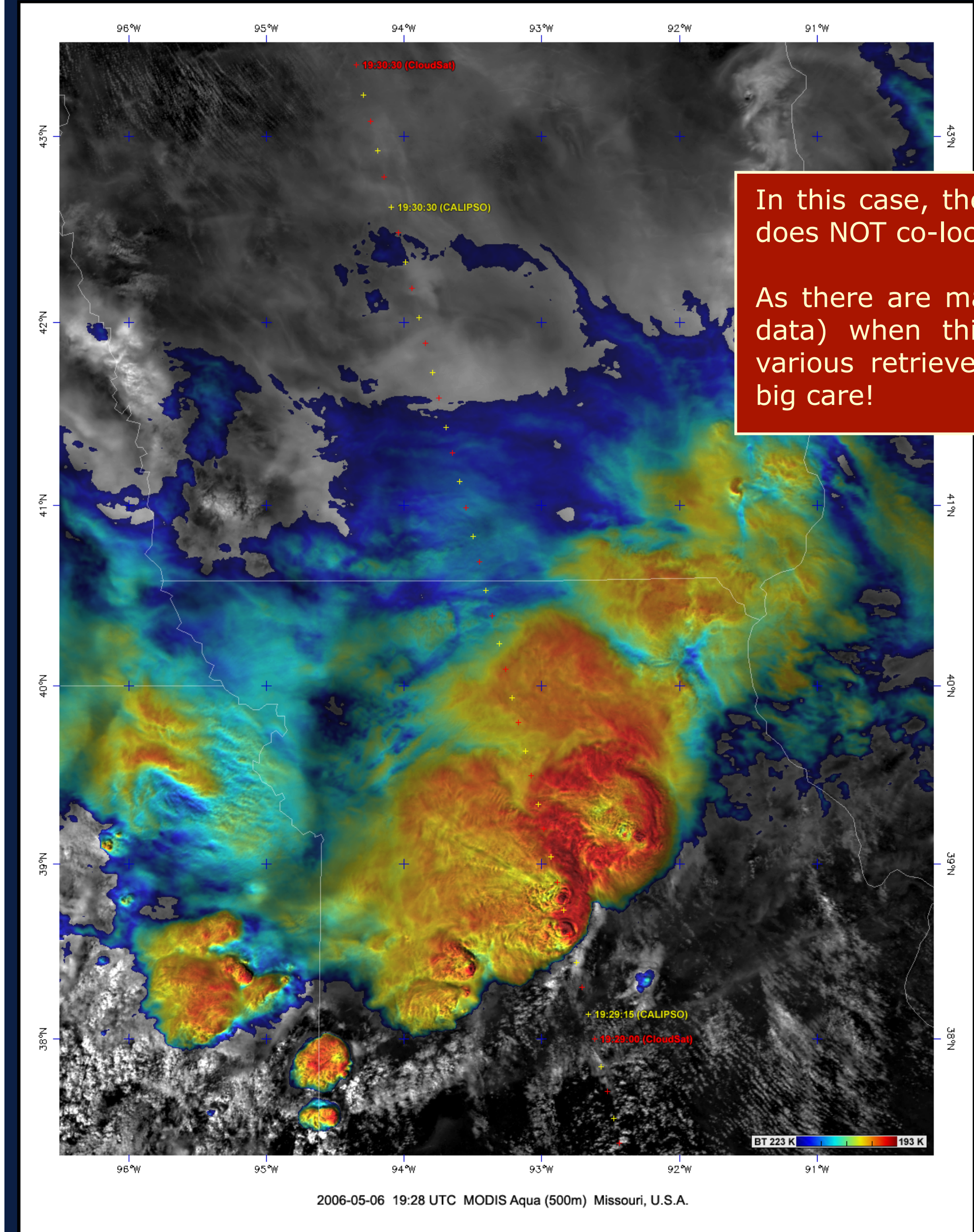
Missouri

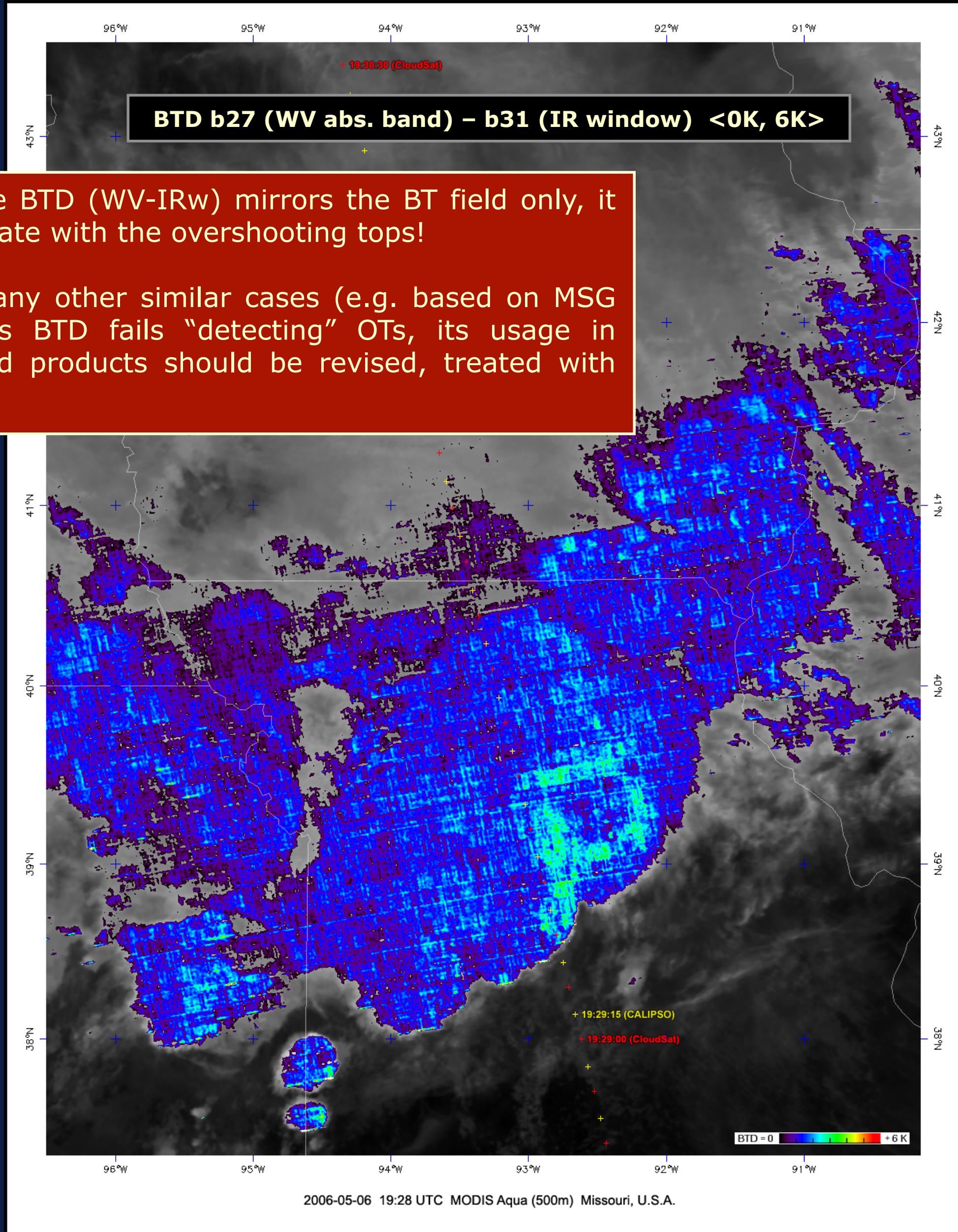
2007-05-06 19:28 UTC MODIS/Aqua, Missouri





2007-05-06 19:28 UTC MODIS/Aqua, Missouri

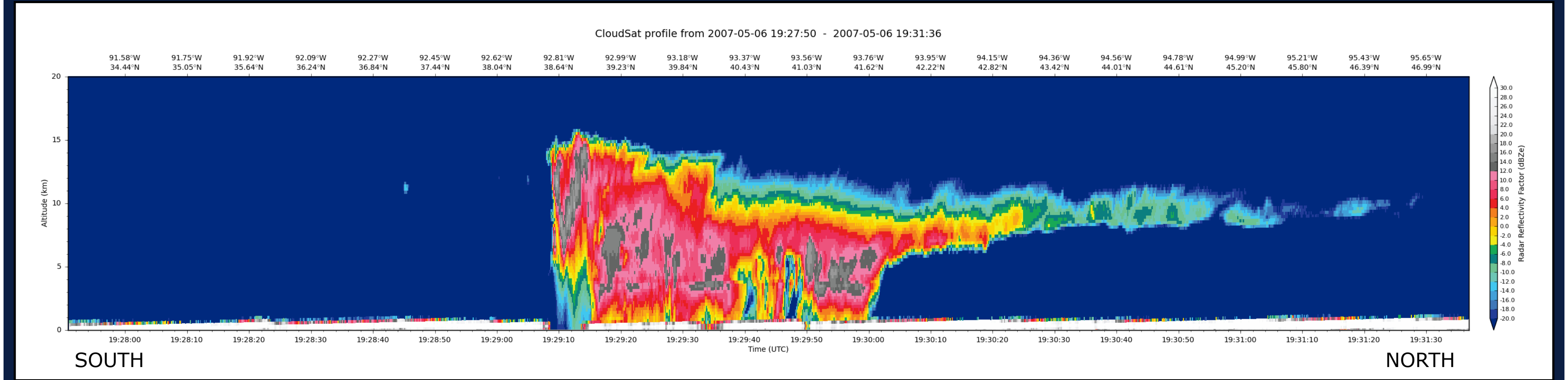




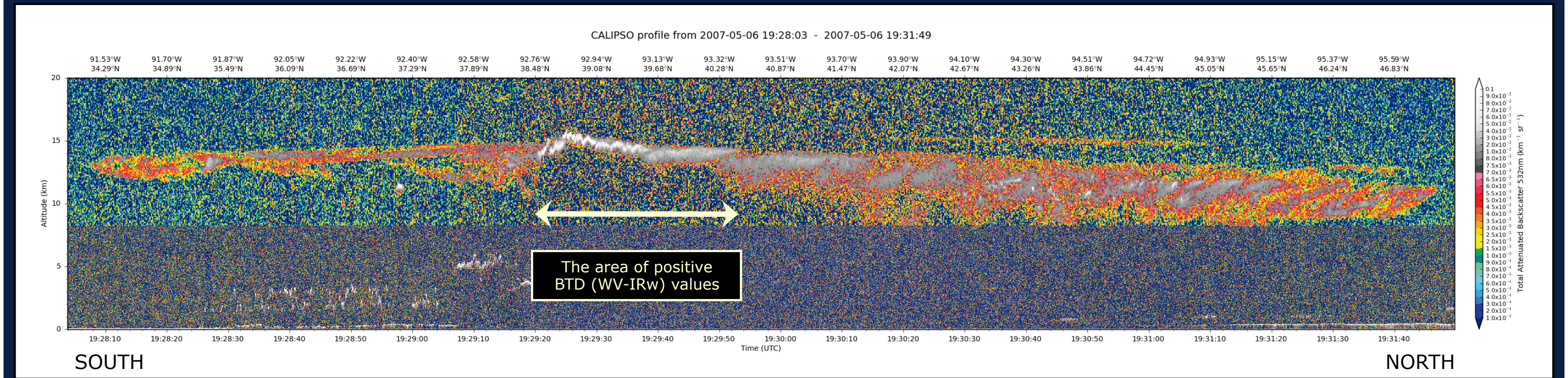
BTD b27 (WV abs. band) – b31 (IR window) <0K, 6K>

In this case, the BTD (WV-IRw) mirrors the BT field only, it does NOT co-locate with the overshooting tops!

As there are many other similar cases (e.g. based on MSG data) when this BTD fails "detecting" OTs, its usage in various retrieved products should be revised, treated with big care!



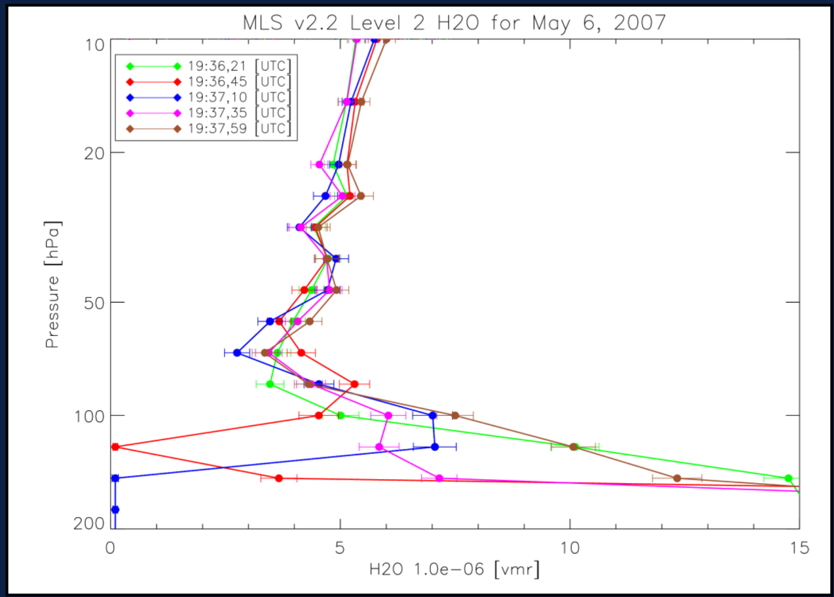
CloudSat/CPR profile

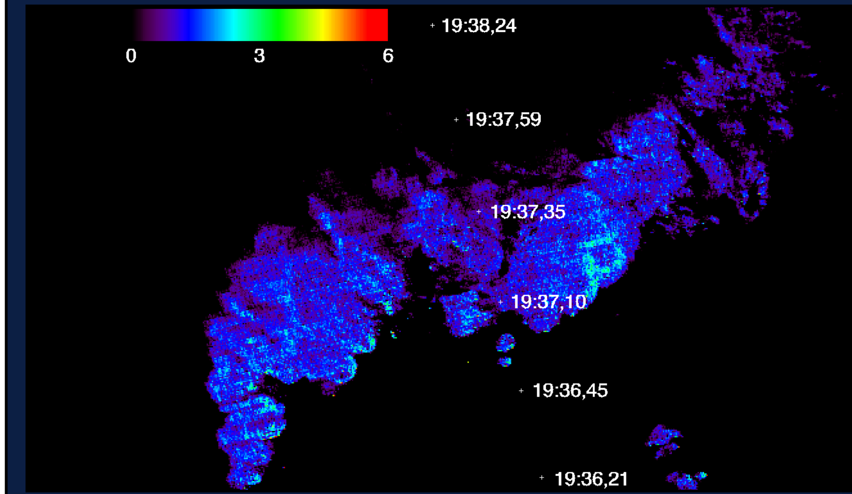


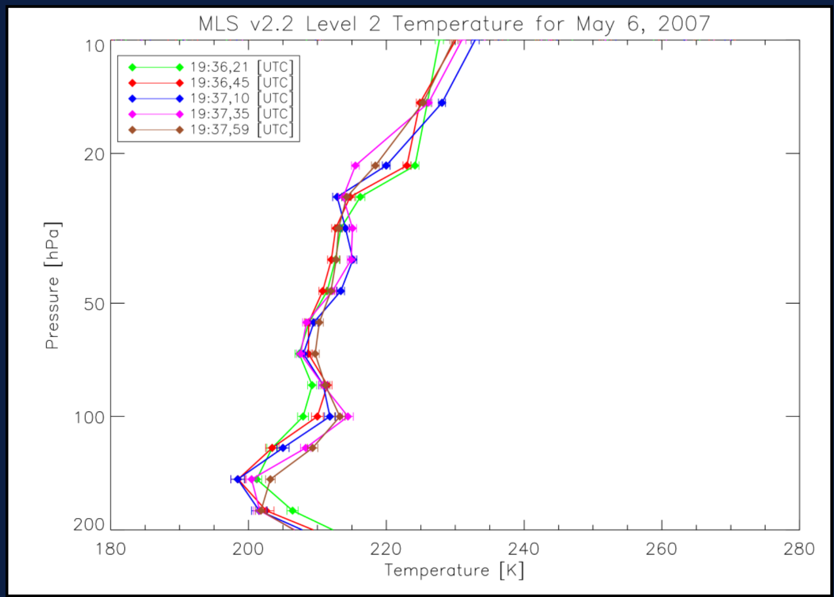
CALIPSO/CALIOP profile

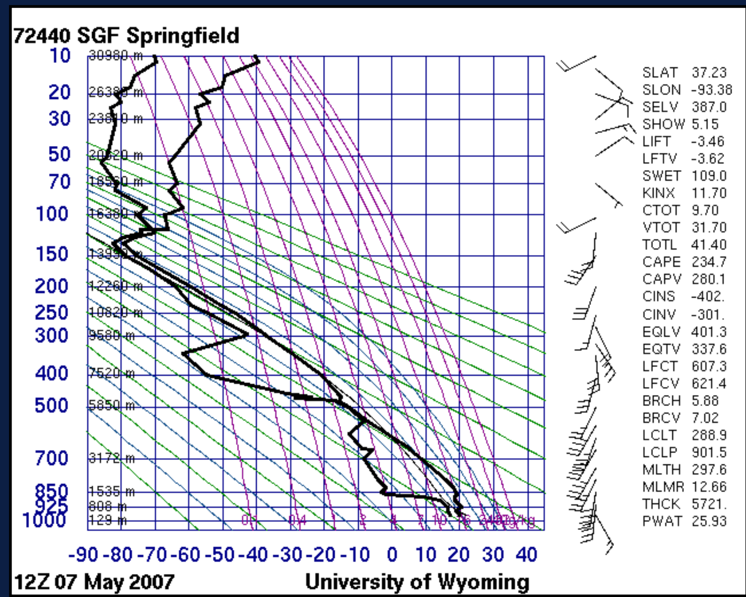
No thin cirrus above the area of positive BTD (WV-IRw) values >>> this means that the mechanism behind must be other than the thin cirrus above the storm top (at least in this particular case).

2007-05-06 19:37 UTC Aura/MLS, Missouri









More on interpretation of the BTD (water vapor – IR window) e.g. here:
Satellite Observations of Storm Tops, Part 2, EUMETSAT Training Library (2010)

Final remarks and future work …

- Detailed studies of storm-top features require using both CloudSat and CALIPSO data (whenever available). Also, very accurate co-location of the various datasets is crucial for proper interpretation of these.

- A closer link between the observations and RTM modeling is essential for better understanding of some of the observed cloud-top characteristics and processes.

- It appears that conceptual models of some of the storm-top features as observed by satellites (e.g. the overshooting tops) could be significantly improved if the satellite data were compared to detailed simultaneous observations by ground-based radars. Closer collaboration between satellite and radar specialists? Common observational experiments, campaigns (GOES or MSG rapid scan data X Polarimetric Doppler radar data)?

- Many other potentially interesting/important cases are still awaiting to be processed, and other aspects are to be addressed (e.g. storm-top microphysics). These studies can contribute significantly not only to better understanding of storm-top processes, but namely to efficient use of data and derived products from the future generations of geostationary satellites (e.g. Meteosat Third Generation and GOES-R).

- ESA/JAXA EarthCARE satellite – future replacement and extension of the present A-Train satellite constellation …

EarthCARE satellite

http://www.esa.int/esaLP/LPearthcare.html

ESA & JAXA (Japan Aerospace Exploration Agency)

Expected launch date: 2016

Orbit: Sun-synchronous, orbit inclination 97 deg.
orbit altitude: 450 km, 10:30 local time

- **Backscatter Lidar** (ATLID) (high-spectral resolution and depolarisation)
- **Cloud Profiling Radar** (CPR) (-36 dBZ sensitivity, 500 m vertical range, Doppler)
- **Multi-Spectral Imager** (MSI) (7 channels, 150 km swath, 500 m pixel)
- **Broadband Radiometer** (BBR) (2 channels, 3 views (nadir, fore and aft))

➡ possible continuation of research carried our by CloudSat/CALIPSO

http://www.bbc.co.uk/news/science-environment-12506847

http://www.jaxa.jp/projects/sat/earthcare/index_e.html

http://database.eohandbook.com/database/missionsummary.aspx?missionID=580

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THANK YOU!

http://www.setvak.cz/download/

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