

# An operational AVHRR Cloud Top Temperature and Height retrieval and its validation

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## Introduction

It is still today a common practice at NMS's worldwide to use the uncorrected brightness temperature information from AVHRR IR imagery as a rough estimation of cloud top temperatures. For the optically thick clouds this estimation is in most cases acceptable. However, for pixels containing semi-transparent or fractional clouds (often representing a large fraction of cloudy pixels) this information is definitely misleading, yielding sometimes to quite a large underestimation of true cloud top heights.

Within the Eumetsat Satellite Application Facility (SAF) project to support Nowcasting and Very Short Range Forecasting (NWCSAF) SMHI has developed algorithms and software to extract four cloud and precipitation products from AVHRR and AMSU/MHS data (see e.g. Dybbroe and Thoss, 2003). Here we present the algorithm to retrieve the cloud top temperature and height (CTTH) product, and attempts for an objective validation using ground based remote sensing.

## CTTH retrieval

The main outline of the CTTH retrieval applied to all cloudy pixels as given by the Cloud Type product (see Dybbroe and Thoss, 2003) is shown below. It consists of a pre-processing step which can be performed prior to satellite data acquisition, an algorithm for opaque and another for fractional and semi-transparent clouds:

- Cloudfree and cloudy TOA radiances and brightness temperatures are calculated for the AVHRR channel 4 and 5 applying the RTTOV radiative transfer model using temperature and humidity profiles taken from NWP (analysis or a short range forecast). The overcast simulation results are available for each pressure level given by RTTOV and are derived using an emissivity of one (black clouds). The radiance simulations are done on a coarse horizontal resolution (segments of high-resolution pixels). The segment size is configurable but should be chosen so as to be comparable to the grid resolution of the NWP model used.

- Retrieve the cloud top pressure or temperature depending on the cloud type:

- For all pixels classified as opaque cloud: The cloud top pressure is derived from the best fit between the simulated and the measured T11. The simulated T11 from the segment closest in space to the given pixel is chosen.
- For all pixels classified as semi-transparent cirrus or fractional water cloud: A histogram technique based on the work of Derrien et al., (1988) and Inoue (1985) and detailed by Korpela et al (2001) is applied.

- Retrieve the cloud top height and temperature from the pressure for the opaque cloud pixels and retrieve the cloud top height and pressure from the temperature for the semi-transparent cirrus and fractional water cloud pixels.

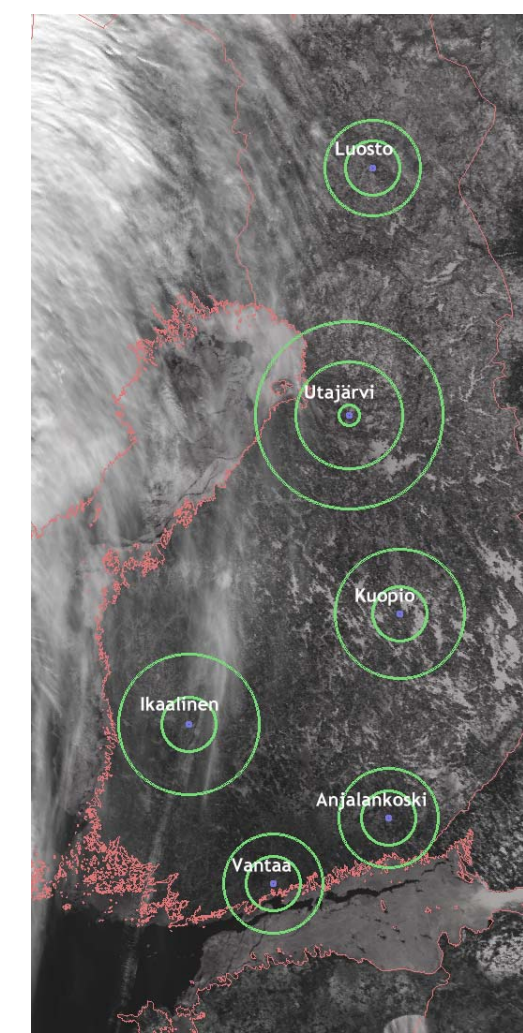
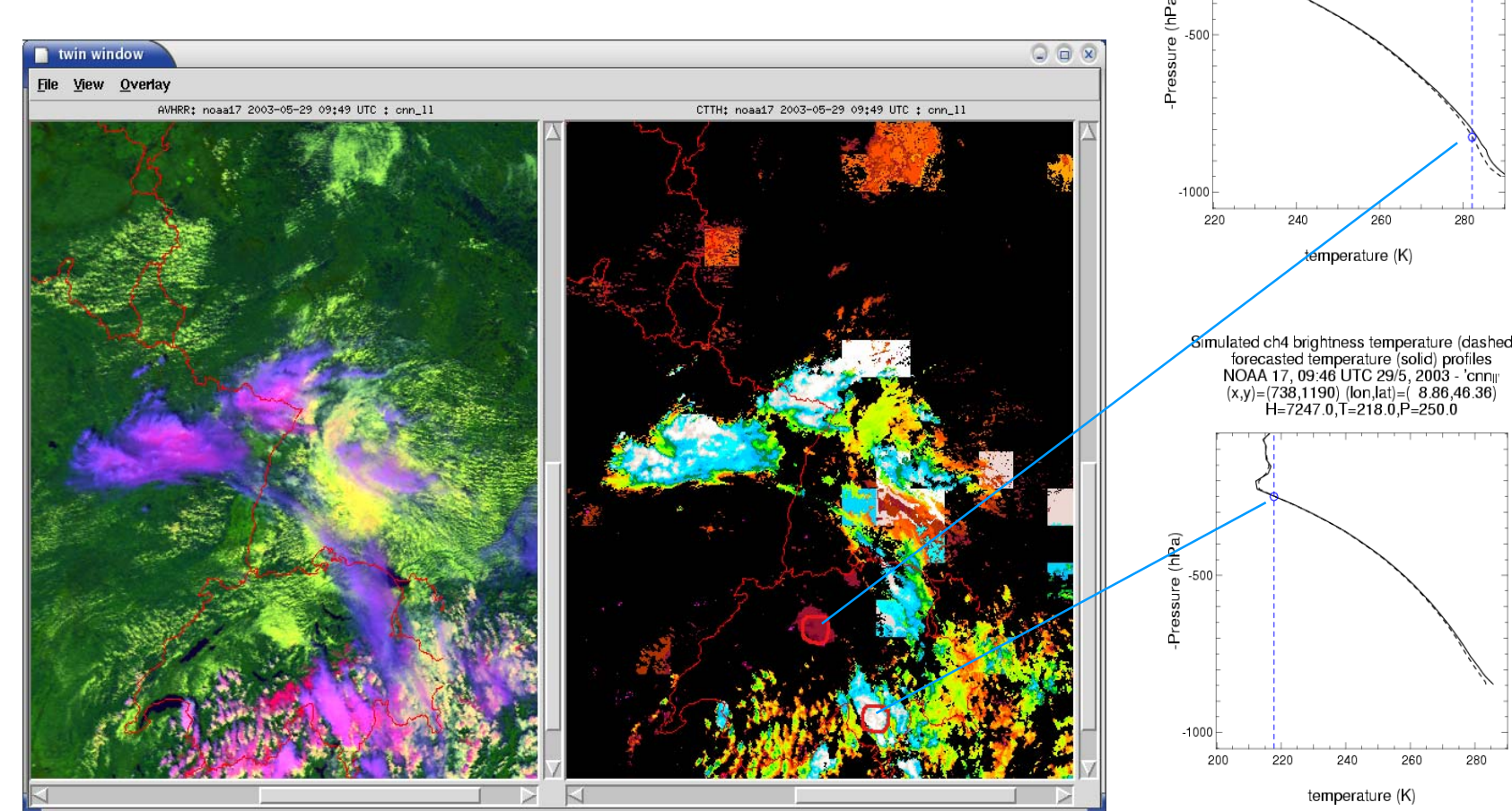


Figure 1: Satellite image with location of weather radar sites superimposed. The green circles show for each radar the detectable ranges given in table 1. The smallest is  $r_{min}$  and the last is  $r_s$ . Only in the case of Utajärvi also the  $r_{10}$  (middle circle) is shown.

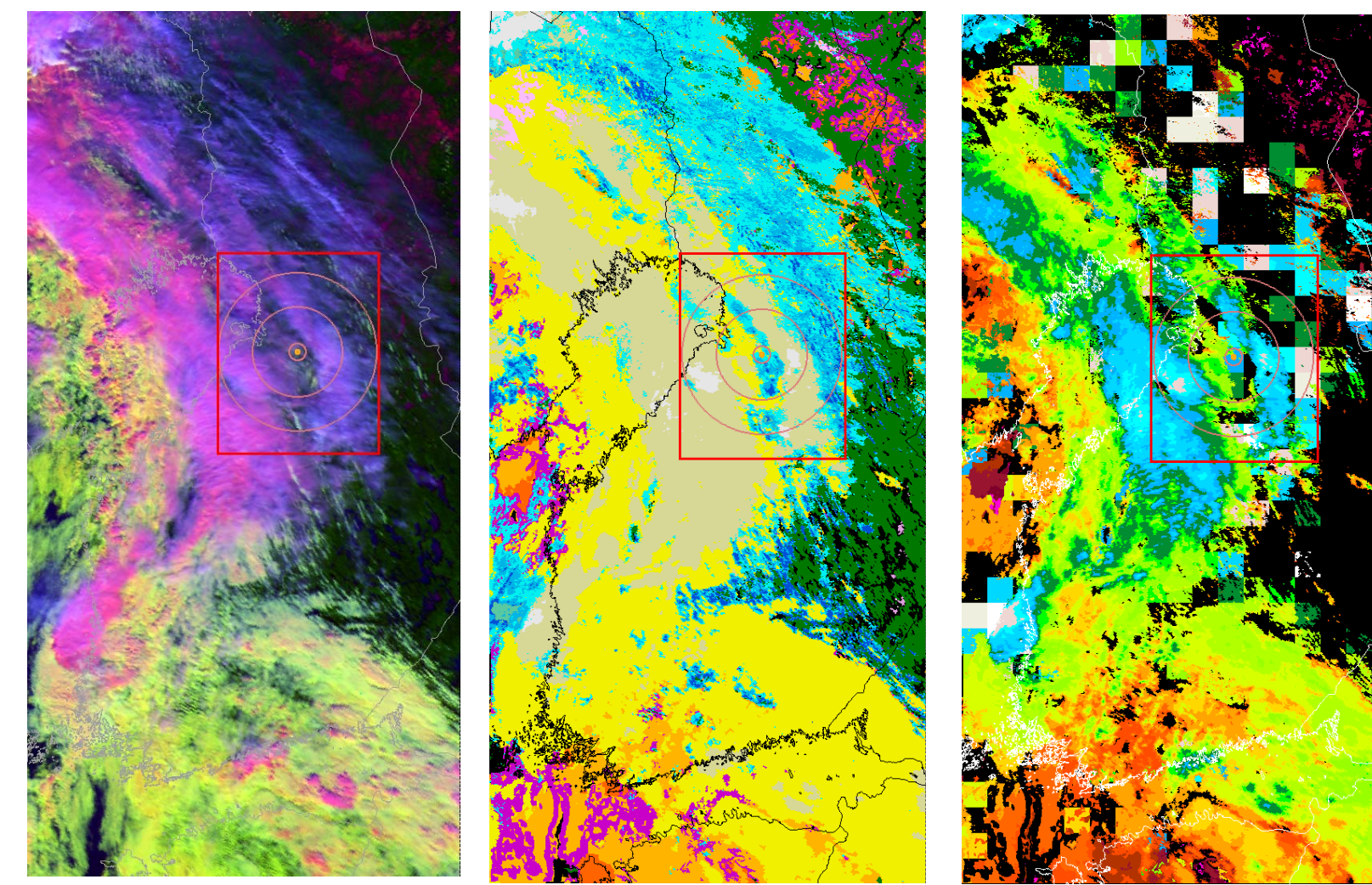
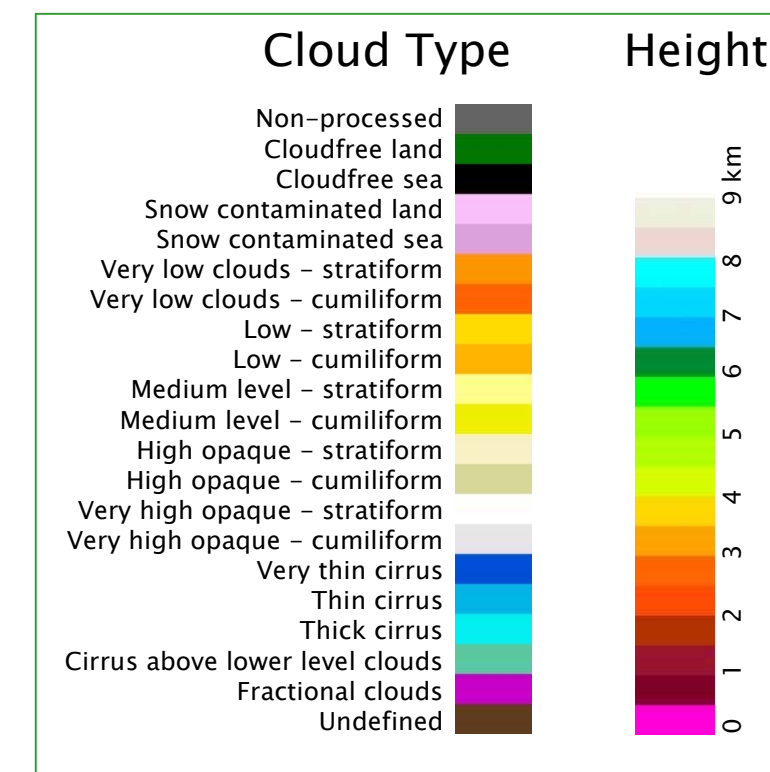


Figure 2: NOAA 17 scene (orbit 4590) received at Norrköping 10:47 UTC May 13, 2003, covering Finland. RGB composite using channel 13a4 (left), Cloud type (middle) and an image of the height of the CTTH product (right). The red box outlines the area around the Radar site at Utajärvi shown in greater detail in figure 3.

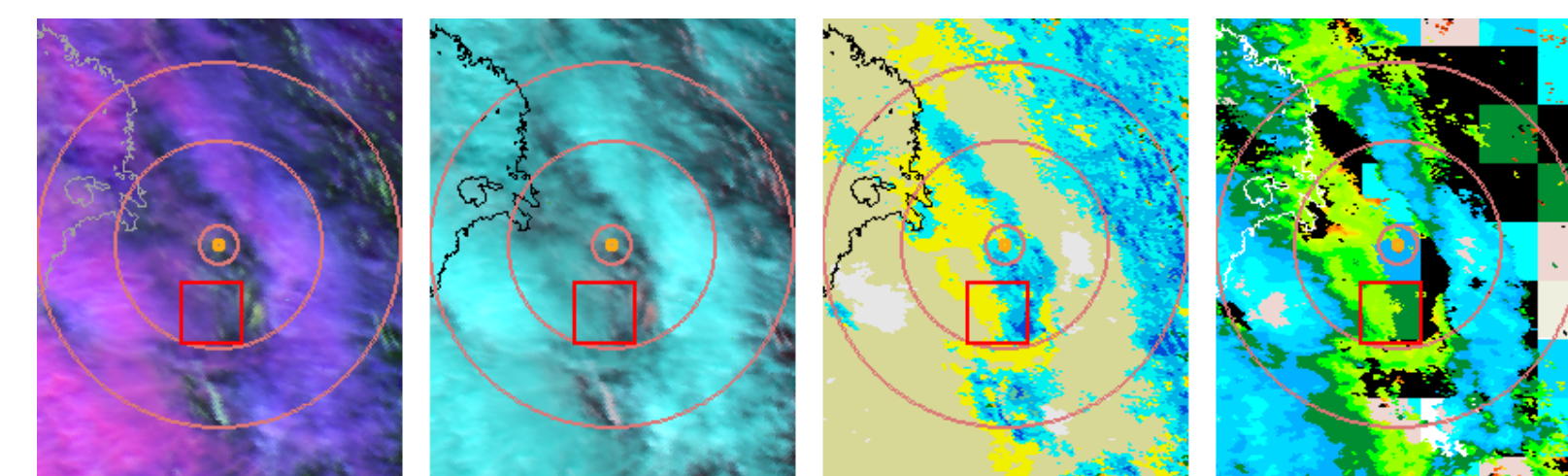


Figure 3: Close-up of the area outlined in figure 2. From left to right: channel 13a4 RGB, channel 3a45 RGB, Cloud Type, and an image of the height of the CTTH product. The cloud top heights inside the small red box derived from both satellite and radar is shown in figure 4. The cloud field inside the box seem to consist of a layer of cirrus with decreasing opacity to the east overlaying some lower level clouds. The box is within the  $-10$  dBZ range.

## Validation

The objective validation of satellite derived cloud top height is a challenging task. Direct measurements require expensive observation campaigns using aircrafts, and are thus scarce. Earlier validation attempts using aircraft measurements were presented in Korpela et al. (2001).

### Data

To objectively validate the CTTH retrieval we use data from a network of C-band weather radars over Finland (see figure 1 and table 1). Finnish rather than Swedish radar data are used mainly for two reasons: The Finnish radars are more sensitive, and a TOPS product is routinely derived and has been used operationally, i.e. by the Finnish Air Force, since the 1980's.

Radar site	Lat	Lon	$Z_{1km}$ (dBZ)	$\phi_{max}$ (deg)	$r_{min}$ (km)	$r_{10}$ (km)	$r_s$ (km)
Anjalankoski	60.904	27.109	-39.25	20	28	29	52
Ikaalinen	61.767	23.080	-42.38	20	28	42	74
Kuopio	62.862	27.385	-41.69	20	28	38	68
Luosto	67.139	26.901	-39.06	20	28	28	50
Utajärvi	64.774	26.322	-44.94	45	10	56	99
Vantaa	60.271	24.873	-39.31	20	28	29	52

Table 1: For each radar: Location, sensitivity (minimum detectable signal at 1 km -  $Z_{1km}$ ), maximum elevation angle ( $\phi_{max}$ ), minimum detectable range ( $r_{min}$ ), and maximum detectable ranges at the thresholds  $-5$  dBZ and  $-10$  dBZ ( $r_s$  and  $r_{10}$ ).

The TOPS product gives for each pixel the height of the highest occurrence of a dBZ contour. When the appropriate (configurable) threshold value is selected the TOPS algorithm makes a downward search at constant range in cylindrical coordinates to determine when the threshold is crossed and a cloud top height is derived from interpolation.

From measurements by the Finnish Air Force a threshold value of  $-10$  dBZ has proved to give reliable top heights of "raining clouds", when the cloud top mainly consist of ice particles.

In this study we use collocated radar/satellite data of April and May 2003.

### Example

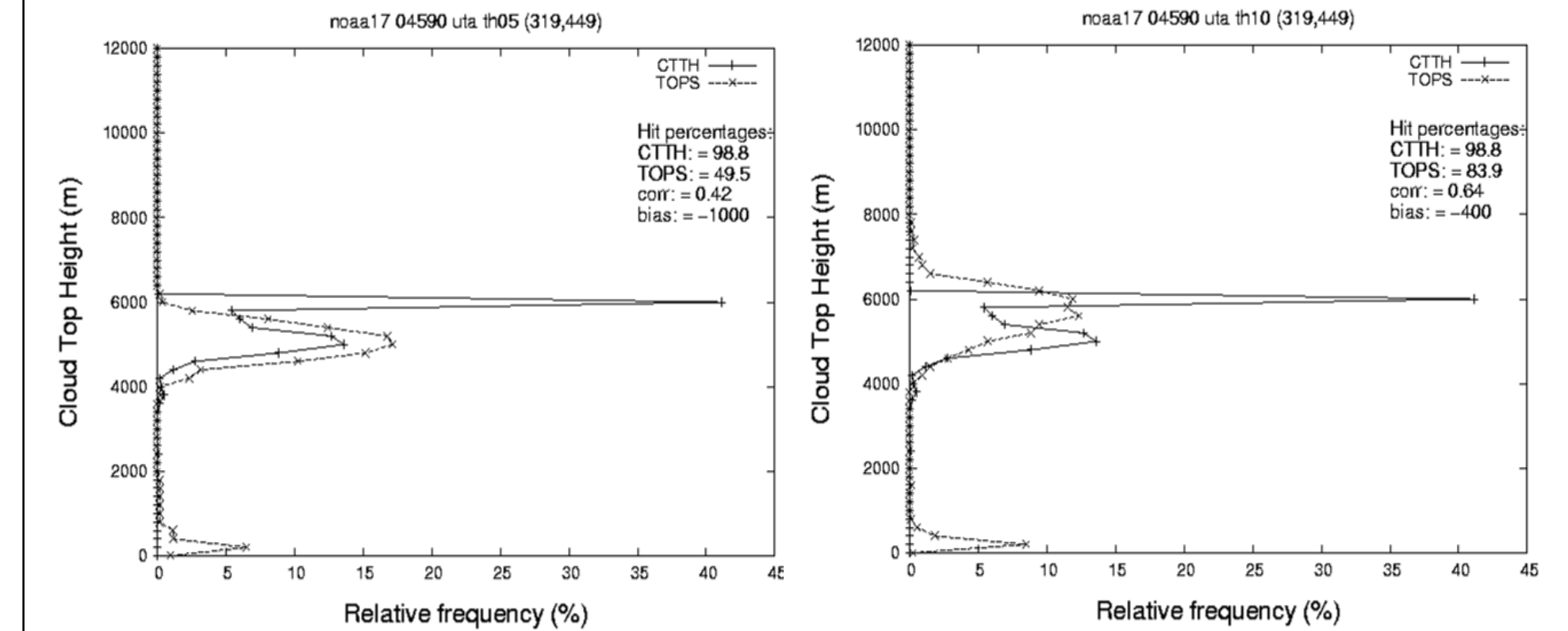


Figure 4: Cloud top height from Satellite and radar using the radar thresholds  $-5$  dBZ (left) and  $-10$  dBZ (right). Good agreements are found for the opaque clouds (secondary maximum) using the  $-5$  dBZ threshold, and for the thin cirrus (bias=400m) using the  $-10$  dBZ threshold.

## Histogram method

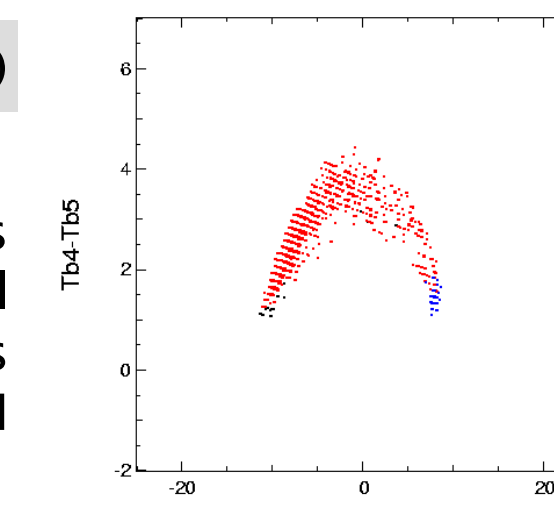
The technique to derive the top temperature of semi-transparent and broken clouds use two-dimensional histograms of AVHRR channel 4 and 5 composed over the larger segments. A thermodynamic cloud top temperature valid for all broken and thin clouds inside the segment is derived.

$$T_4 - T_5 = (\sigma_4 - \sigma_4^\beta)(T_{s,4} - T_c) - \sigma_4^\beta(T_{s,5} - T_{s,4})$$

The above equation describes an arch as displayed in the two-dimensional histogram to the right. Least squares fitting solves for  $T_c$  and  $\beta$  using RTM calculations for  $T_s = T_{s,4}$  and  $d_s = T_{s,5} - T_{s,4}$ :

$$y(x, \beta) = \left( \frac{x - T_c}{T_s - T_c} - \left[ \frac{x - T_c}{T_s - T_c} \right]^\beta \right) \cdot (T_s - T_c) - \left[ \frac{x - T_c}{T_s - T_c} \right]^\beta d_s$$

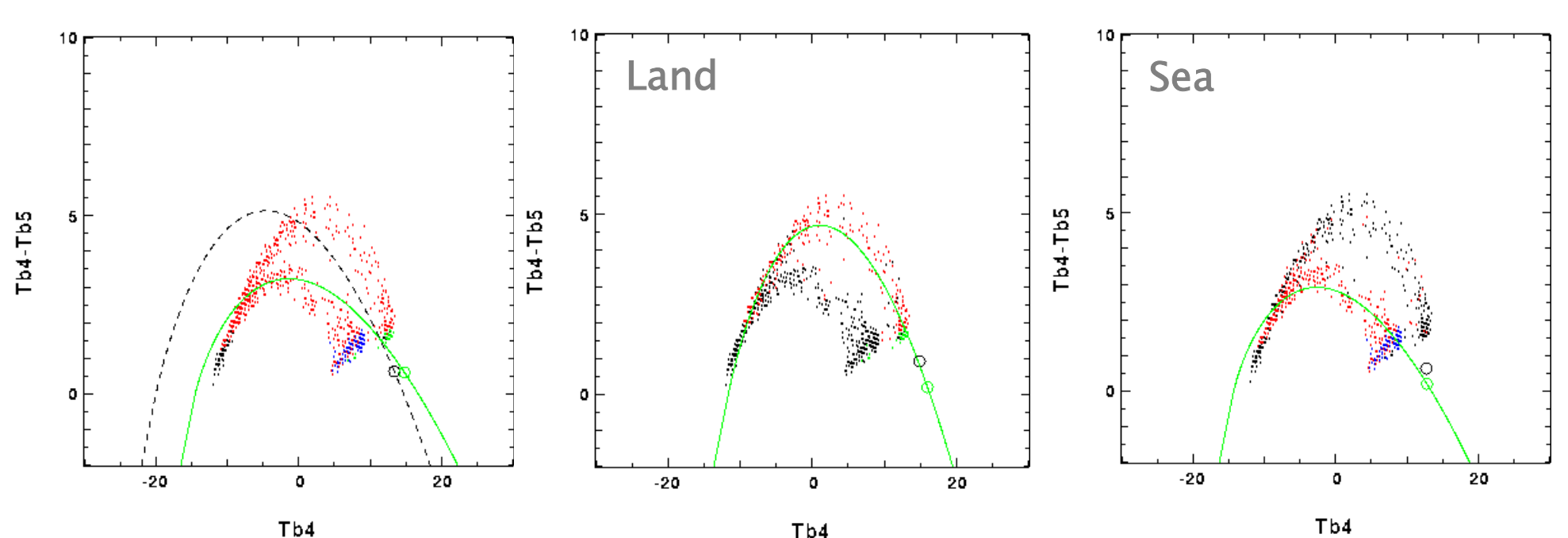
using  $\sigma_i = \left( \frac{T_i - T_c}{T_{s,i} - T_c} \right)$  and where  $\vec{p} = (T_c, \beta, T_s, d_s)$



### Assumptions:

- Single layered cloudiness
  - Constant  $\alpha$  throughout cloud layer
  - $T_b$  depends linearly on radiance
  - No atmospheric absorption
  - Local thermodynamic equilibrium
- $\beta = \alpha^5 / \alpha^4$   
 $\alpha_i$ : absorption coefficient at channel  $i$   
 $\sigma_4$ : transmittance at channel 4  
 $T_s$ : Surface temp  
 $T_c$ : CTT  
 $T_i$ :  $T_b$  at channel  $i$   
 $T_{s,i}$ : Cloud free  $T_b$  at channel  $i$

### Solving for land and sea:



Cloudfree Sea (red), Semi-transparent (green), Cloudfree land (blue), Opaque (black)

## Summary and future work

An operational AVHRR Cloud Top Temperature/Height retrieval for the Eumetsat SAF's has been introduced, and a validation approach using weather radar data and an example of the results is presented. This particular example showed fairly good agreement between radar and satellite, but this is far from always the case. Sometimes the opaque and semi-transparent satellite retrievals give results further apart from each other than shown in this example, and also the radar may provide more than one solution. Furthermore the appropriate dBZ threshold (the  $-10$  dBZ is said to apply for "raining clouds") is likely to depend on the cloud type. Two months of co-located data shall be analysed in details and summary statistics generated.

## References

Derrien, M., Lavanant, L., and Le Gleau, H., 1988: Retrieval of the cloud top temperature of semi-transparent clouds with AVHRR. Proceedings of the IRS'88, Lille, France, pp. 199-202, Deepak Publ., Hampton.  
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