Convective cloud top altitude estimates from geostationnary satellites

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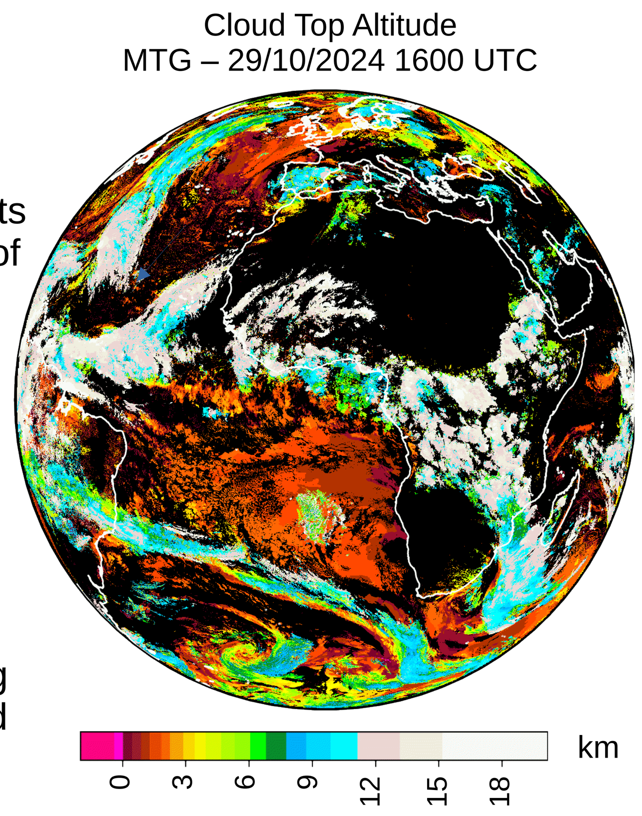
Motivation

Estimating cloud top altitude and temperature is particularly useful for analyzing and tracking convective clouds. Nowcasting Eumetsat Satellite Aplication Facility (**NWC SAF**) develops a software package (**GEO**) for the near real time generation of a set of meteorological products from geostationnary satellites. **Météo France** is in charge of the algorithms retrieving cloud properties, such as **Cloud Top Temperature and Height** (CTTH).

The polar satellite **EarthCARE** launched in 2024 carries an imager (MSI), a Cloud Profiling Radar (**CPR**) and a Atmospheric LIDar (ATLID), enabling cloud profiles to be produced vertically from the satellite, and thus a precise measurement of cloud top altitude.

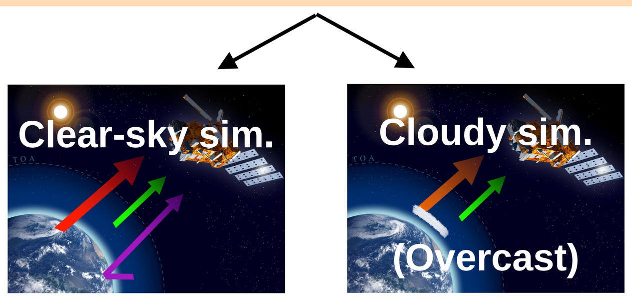
It offers great opportunities for evaluating and improving our algorithms, which is the purpose of the study presented hereafter.



Retrieving methods

Methods used for CTTH retrieving are partly based on simulations performed with the **radiative transfer model RTTOV** (*Saunder et al., 2018*) from NWP SAF.

NWP profiles + radiometer characteristics of the satellite



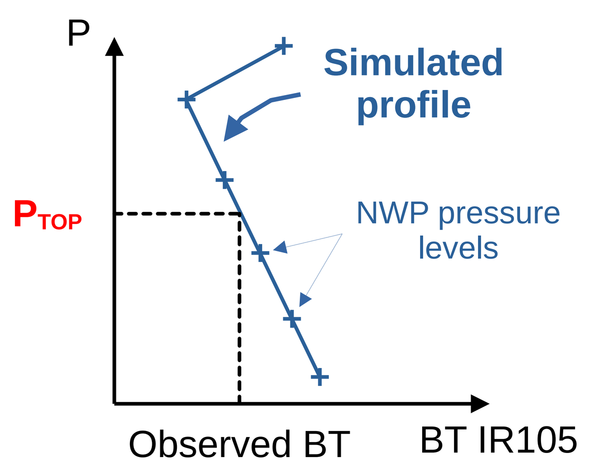
2 kind of simulations:
- "**clear-sky**" → no cloud
- "**overcast**" → opaque cloud at NWP level (one simulation by pressure level)

Opaque Clouds

Principle
Intercept between the observed IR105 brightness temperature (BT) and the simulated BT overcast profile.

NB1: Simulated profile is artificially extended above tropopause to account for overshooting tops.

NB2: For high clouds, this basically means that the measured BT is assumed to be equal to the cloud top temperature.



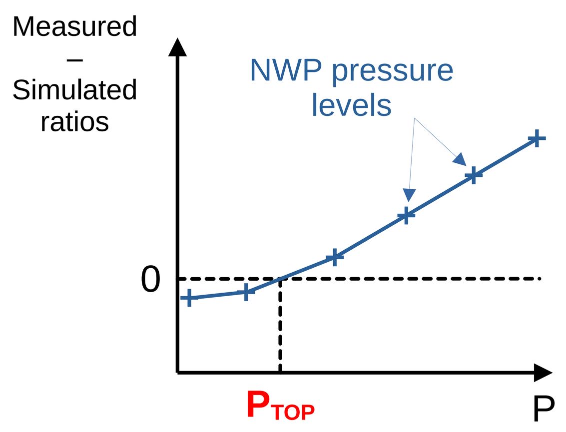
Semi-transparent Clouds

In that case, IR105 BT are contaminated by the underlying surfaces.

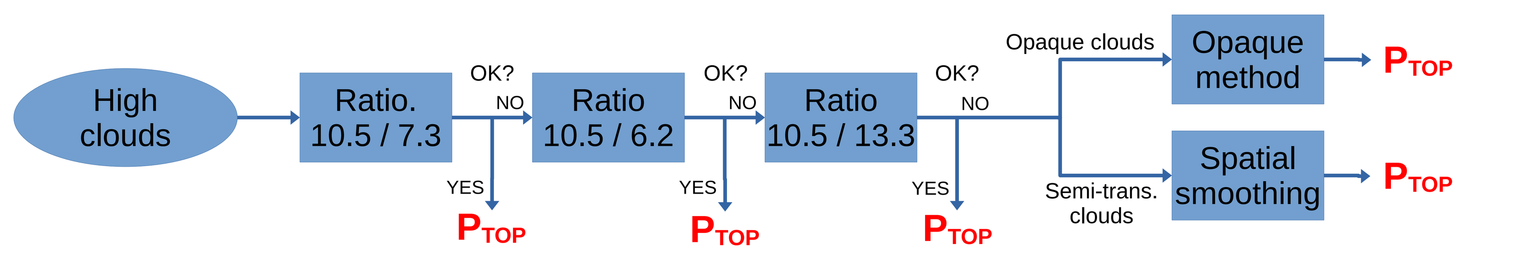
Principle
Radiance ratioing technique (*Menzel et al., 1982*).
Use of 2 IR channels: 10.5 µm + 6.3, 7.3 or 13.3 µm.
We look for the pressure (*P*) that verifies:

$$\underbrace{\frac{R_{m1}-R_{clear\,1}}{R_{m2}-R_{clear\,2}}}_{\text{Measured ratio}} - \underbrace{\frac{R_{ovc\,1}(P)-R_{clear\,1}}{R_{ovc\,2}(P)-R_{clear\,2}}}_{\text{Simulated ratio}} = 0$$

R_{clear1}: Clear-sky radiance (channel 1)
$R_{ovc1}(P)$: Overcast radiance at pressure *P* (channel 1)



GEO-CTTH flowchart for high clouds



N.B.: Another method named "**intercept method**" (*Schmetz et al., 1993*) can be used for semi-transparent clouds. However, it is more suited for the extensive semi-transparent clouds observed in synoptic-scale cloud systems and is therefore not considered in this presentation.

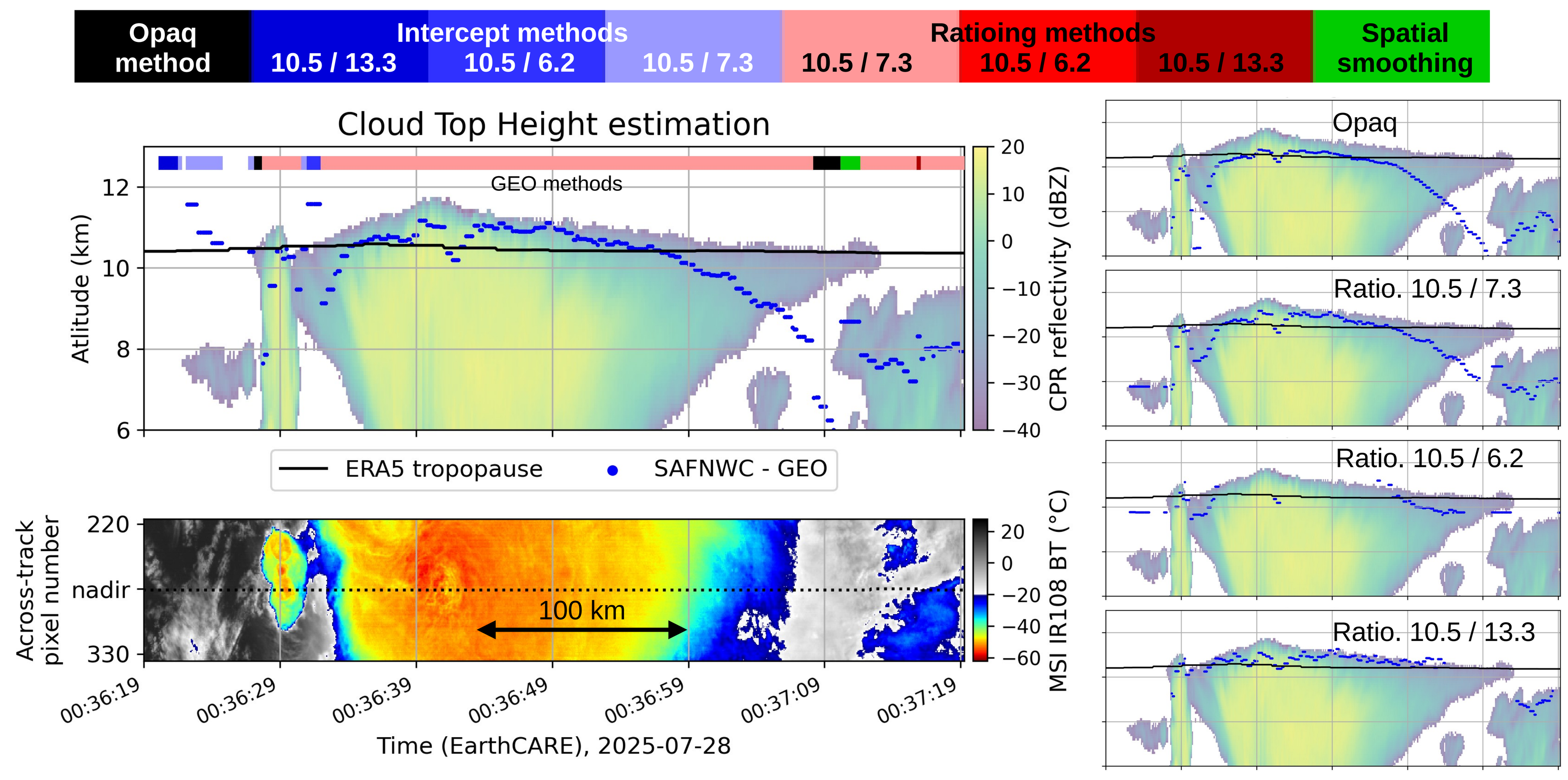
AI model

An AI version of the CTTH retrieval is under development. A basic model has been used here:
- Type of model: **Multilayer perceptron**
- Training dataset: 441 563 points from 51 days between March and July, 2025
- Input: **MTG obs. BT and sim. clear-sky BT** at 3.8, 6.3, 7.3, 8.7, 9.7, 10.5, 12.3 and 13.3 µm + CPR Cloud Top Height (target variable)
- Hiden layers sizes: (64, 128, 128, 64)
- Loss func / activation func / epochs: Mean Absolute Error / ReLU / 200

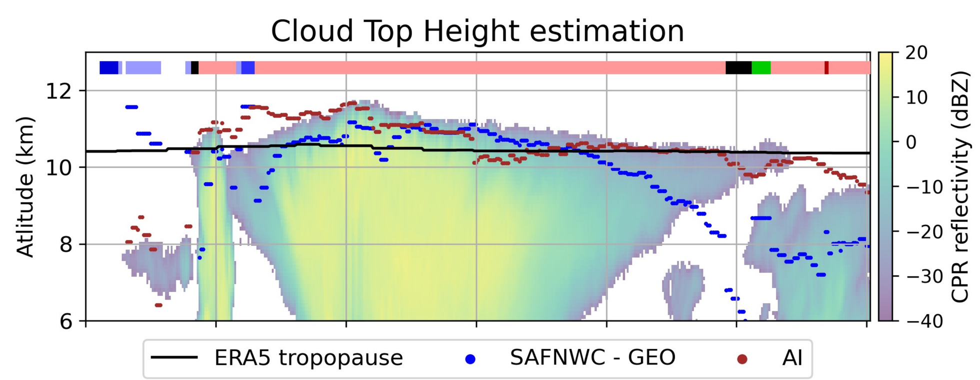
Case study #1

During the night from July 27 to 28, 2025, a strong and widespread convective system affected the Veneto region (Italy).

Minimum observed IR108 BT: -56°C / Max. cloud top altitude : 11 700 m



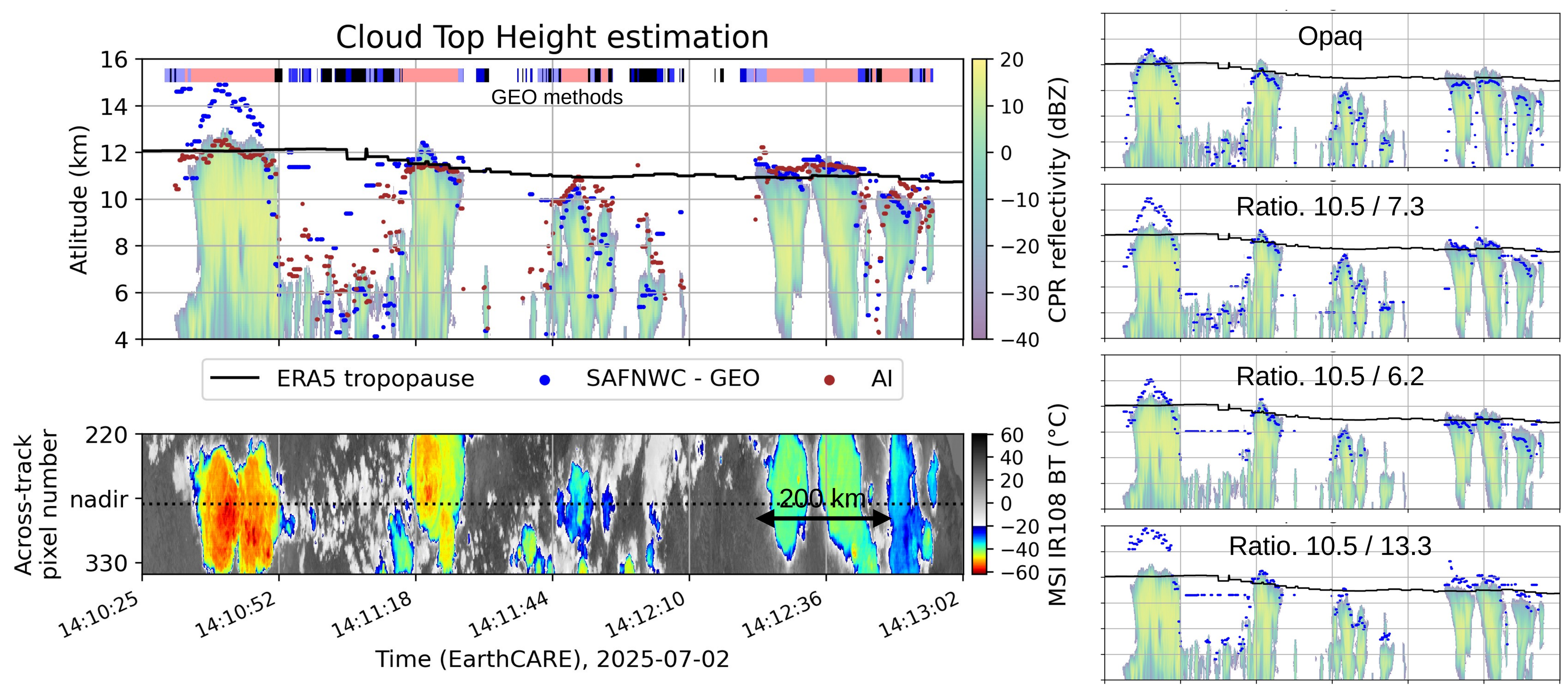
10.5 / 7.3 ratioing method is largely favoured by the GEO CTTH algorithm. Here, using the **10.5 / 13.3 pair would give much better results**, especially at the edges of the convective system where the clouds are less dense.
The method for opaque clouds struggles to return altitudes above the tropopause, probably due to the partial transparency of the clouds at the top, and the inaccurate correction of the NWP temperature profile made in the software to account for overshooting tops.



- **AI method** outperforms the operational method in most of the convective system.
- **Better estimation in the overshooting top area** than 10.5 / 13.3 ratioing method
- Few spatial **discontinuities**.

Case study #2

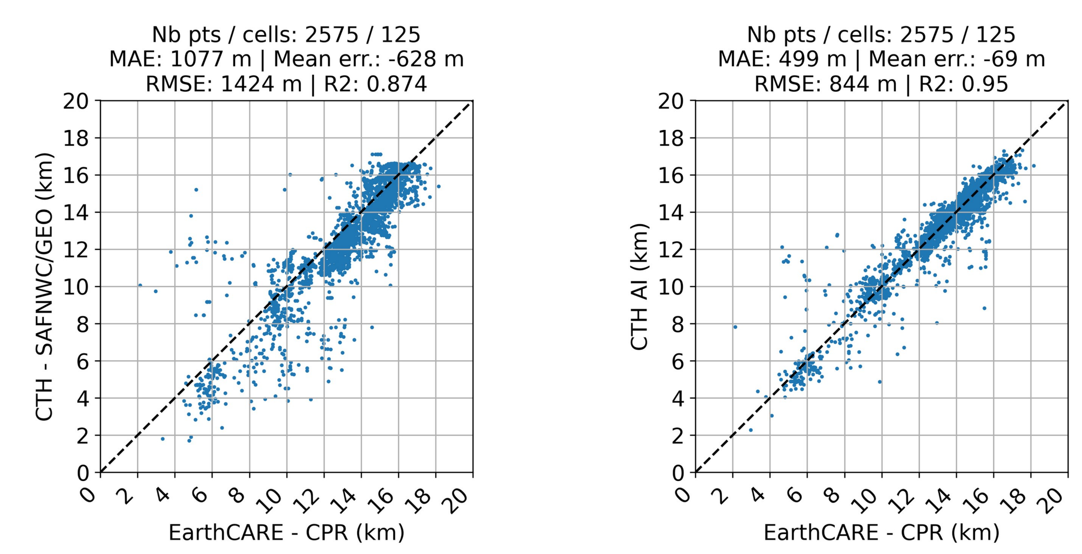
On July 2nd, 2025, EarthCARE sampled several convective cells over Belgium and France.



Again, GEO software preferred the 10.5 / 7.3 ratioing method. Estimations are relatively correct, except for the largest and deepest system for which the opaque method better performs. The 10.5 / 13.3 ratioing method has also strong difficulties for estimating the cloud top altitude of this particular system. **AI method provides an interesting compromise** even if overshooting tops of deepest convective clouds are underestimated by a few hundred meters.

General AI model evaluation on convective cells

The **Rapid Detecting Thunderstorms (RDT)** product from NWC SAF enables convective cells identification on geostationary satellite images.
We applied the AI model to RDT cells identified over 7 days between March and July 2025 across the entire MTG disk.



- Significant reduction in altitude underestimation observed with GEO
- Dispersion is also much less significant.

Conclusion and perspectives

- GEO software combines various methods for an optimal retrieval of the cloud top temperature and height.
- Their articulation in the algorithm is not always optimal and can have a significant impact on the result (→ area for improvement).
- A simple AI model trained with EarthCARE data is capable of producing promising results.
- It is important to maintain and continue developments on the current algorithm especially to compensate for the lack of training data when EarthCARE is shut down.
- The AI version of the CTTH retrieval is planned at the latest for end of 2026

Ref.

Menzel W.P., Smith W.L., and Stewart T.R., 1983, Improved Cloud Motion Wind Vector and Altitude Assignment using VAS, Journal of Climate and Applied meteorology, 22, 377-384.
Saunders, R., Hocking, J., Turner, E., Rayer, P., Rundle, D., Brunel, P., Vidot, J., Roquet, P., Matricardi, M., Geer, A., Bormann, N., and Lupu, C., 2018, An update on the RTTOV fast radiative transfer model (currently at version 12), Geosci. Model Dev., 11, 2717–2737
Schmetz J., Holmlund K., Hoffman J. and B.Strauss, 1993, Operational cloud motion winds from Meteosat infrared images. J.Appl.Meteor, 32, 1207-1225.
EUMETSAT NWC SAF Website: https://www.nwcsaf.org/