Geostationary remote sensing of cirrus clouds using artificial neural networks

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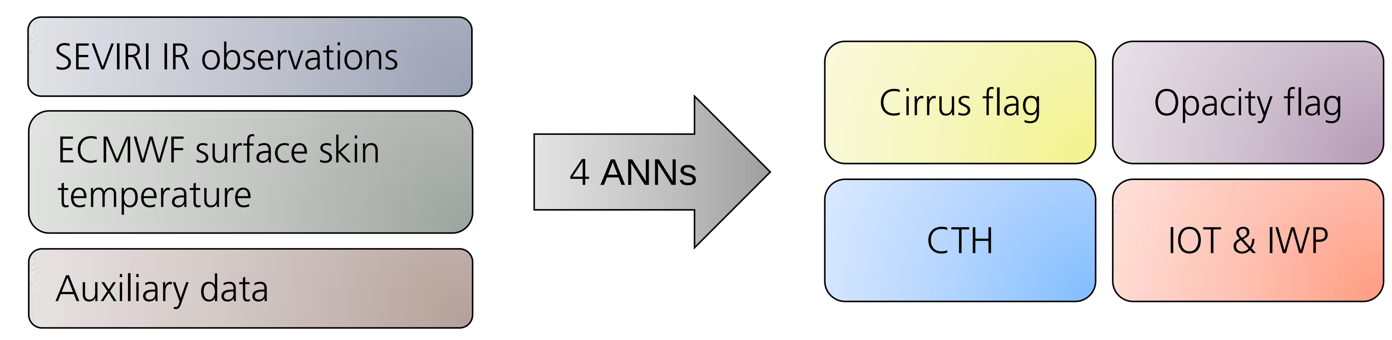
I) Satellite remote sensing of cirrus clouds

Cirrus clouds play an important role in climate as they reflect incoming solar radiation and absorb outgoing thermal radiation. Nevertheless, cirrus clouds remain **one of the largest uncertainties in atmospheric research** and the understanding of the physical processes that govern their life cycle is still poorly understood, as is their representation in climate models. To increase our understanding, **enhanced satellite retrievals are of key importance**.

From space, cirrus clouds and their properties are most accurately retrieved with the **CALIOP lidar,** measuring vertical profiles of attenuated backscatter from the polar orbit of the CALIPSO satellite. **Geostationary imagers** like **SEVIRI** lack the high sensitivity to thin cirrus clouds that a lidar has, but possess a large spatial coverage and a high temporal resolution required to study the temporal evolution and physical processes of cirrus clouds. Here we present a new algorithm that combines the information from CALIOP and SEVIRI using **artificial neural networks** (ANNs) for an enhanced cirrus cloud retrieval from SEVIRI.

II) CiPS – Cirrus Properties from SEVIRI

CiPS is a new algorithm that exploits the main idea of Kox et al. (2014) for the remote sensing of cirrus clouds from SEVIRI using ANNs. CiPS utilises a set of **four ANNs** for the **cirrus cloud detection** and **opacity identification** along with the retrieval of the corresponding cloud top height (**CTH**), ice optical thickness (**IOT**) and ice water path (**IWP**). CiPS is trained primarily with coincident SEVIRI IR observations and CALIOP L2 cloud layer data. The CiPS input and output data are illustrated below.

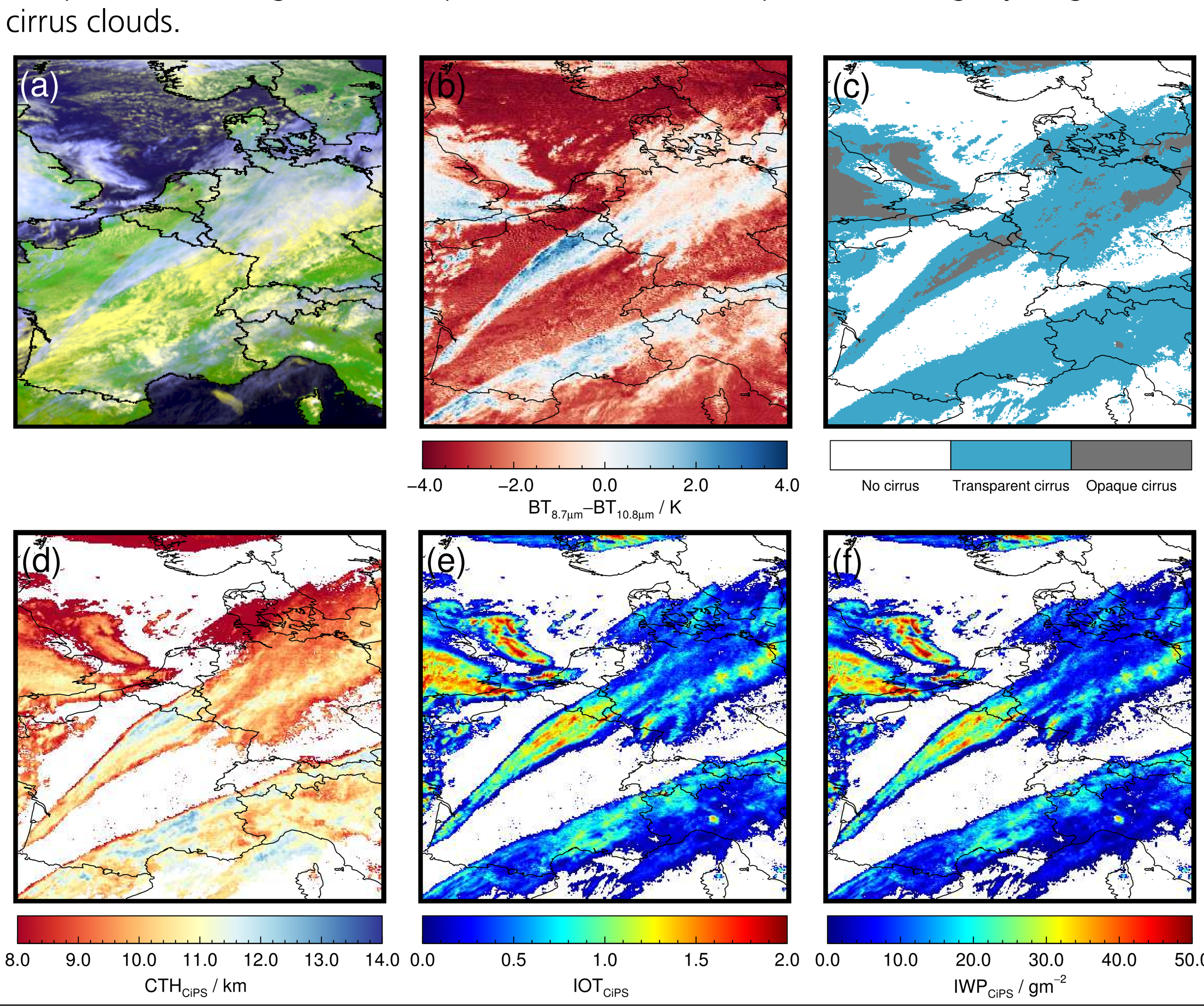


The **opacity flag** is a new variable that identifies cirrus clouds that CALIOP could not fully penetrate. This information is necessary since the retrieved IOT and IWP should not be trusted in such situations. Using only the IR observations from SEVIRI allows for **day and night retrievals**.

Strandgren et al. (2017)

III) CiPS snapshot over Europe on June 1, 2015 at 12.30 UTC

(a) SEVIRI false colors RGB composite (ch1,ch2,ch9) and (b) the brightness temperature difference between 8.7 and 10.8µm (ch7-ch9) along with the corresponding (c) cirrus cloud mask (d) CTH, (e) IOT and (f) IWP retrieved by CiPS. Cold cirrus clouds appear as white and bluish, whereas warmer liquid water clouds appear as yellowish in the RGB composite. The brightness temperature difference is positive or slightly negative for cirrus clouds.



IV) Validation against CALIOP

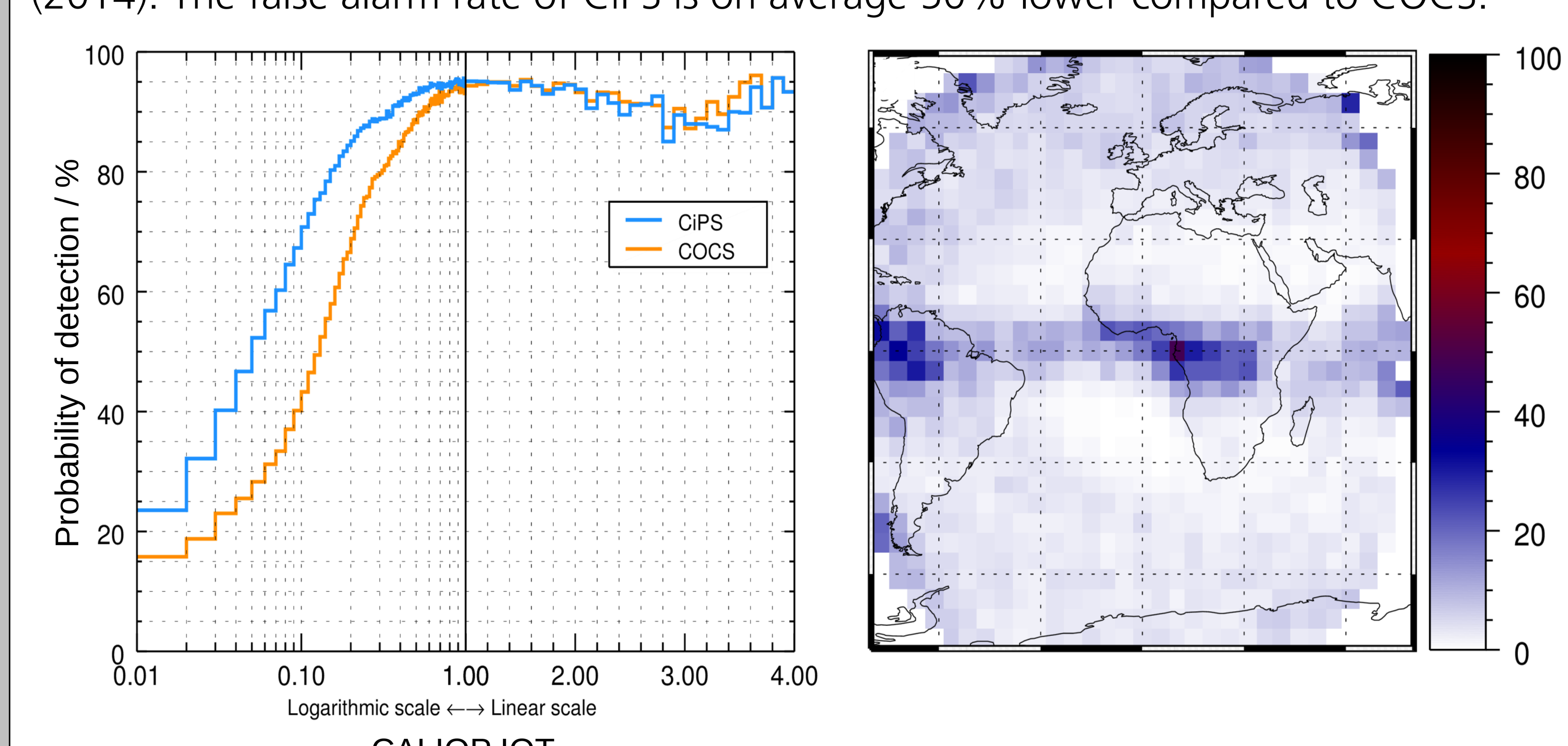
CiPS is validated against CALIOP using 5 million SEVIRI-CALIOP collocations covering a time period from April 2007 to January 2013. This dataset was not part of any training of CiPS.

Cirrus cloud detection

Probability of detection: fraction of cirrus covered pixels correctly identified as cirrus

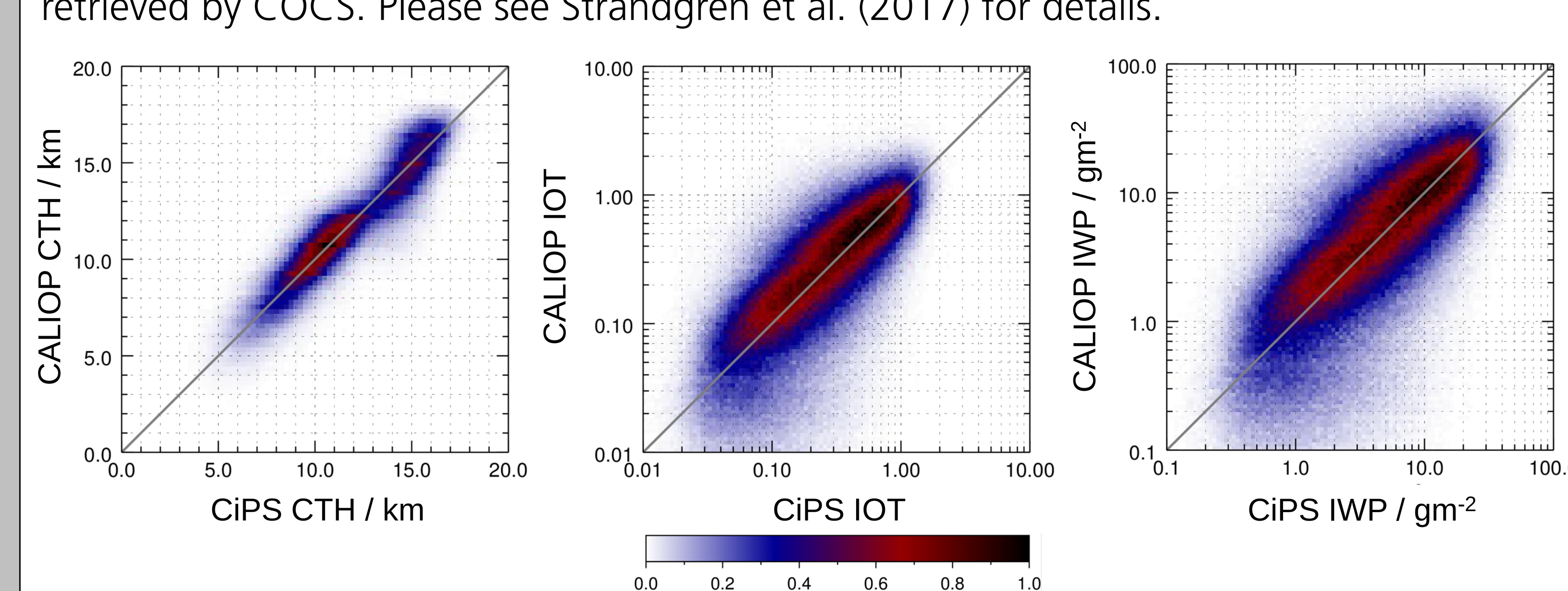
False alarm rate: fraction of cirrus free pixels falsely identified as cirrus.

The orange line shows the performance of the COCS algorithm developed by Kox et al. (2014). The false alarm rate of CiPS is on average 50% lower compared to COCS.



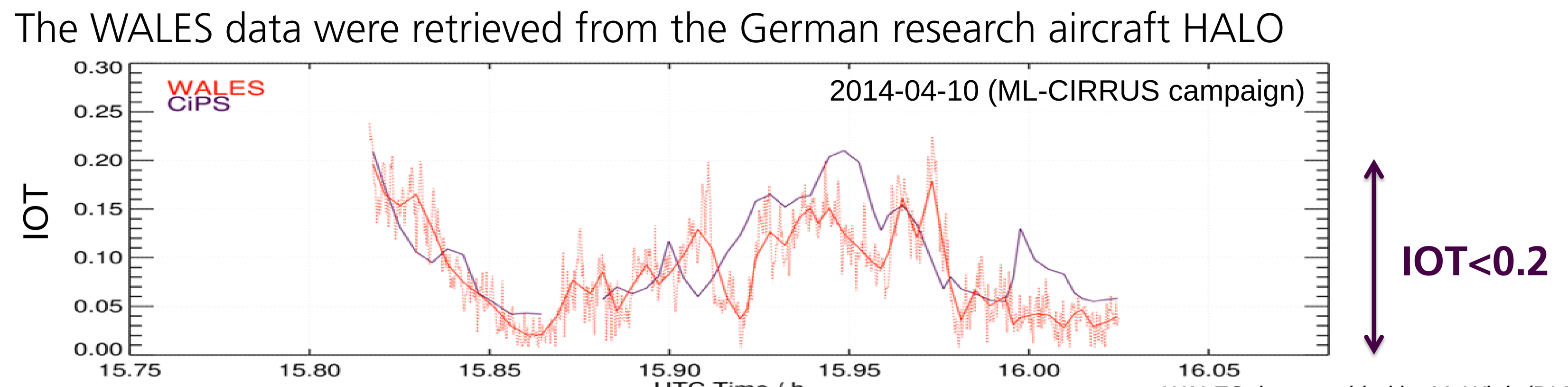
Cirrus cloud properties

The retrieval accuracy with respect to CALIOP is visualized with 2D density plots. The retrieval accuracy is typically between **5-15%** for the **CTH** retrieval and **50-150%** for the **IOT** and **IWP** retrievals. This is up to several orders of magnitudes better compared to COCS for low (CTH) and optically thin (IOT) cirrus clouds. The IWP is a new variable not retrieved by COCS. Please see Strandgren et al. (2017) for details.



V) Comparison with an airborne high spectral resolution lidar

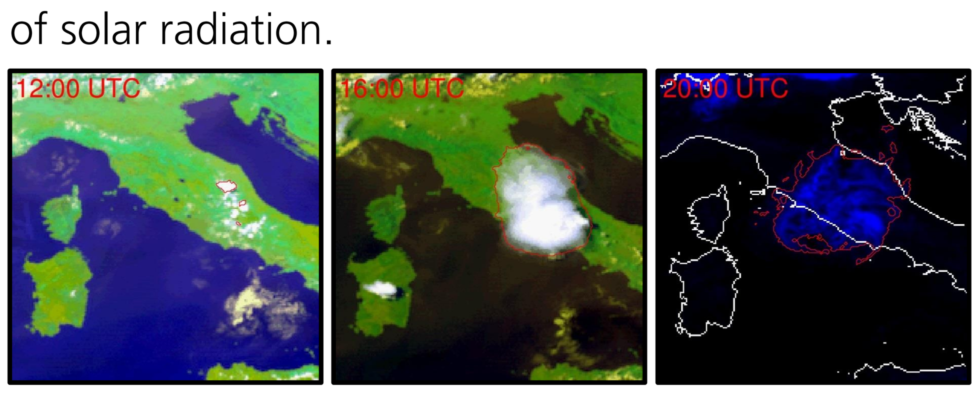
The WALES data were retrieved from the German research aircraft HALO

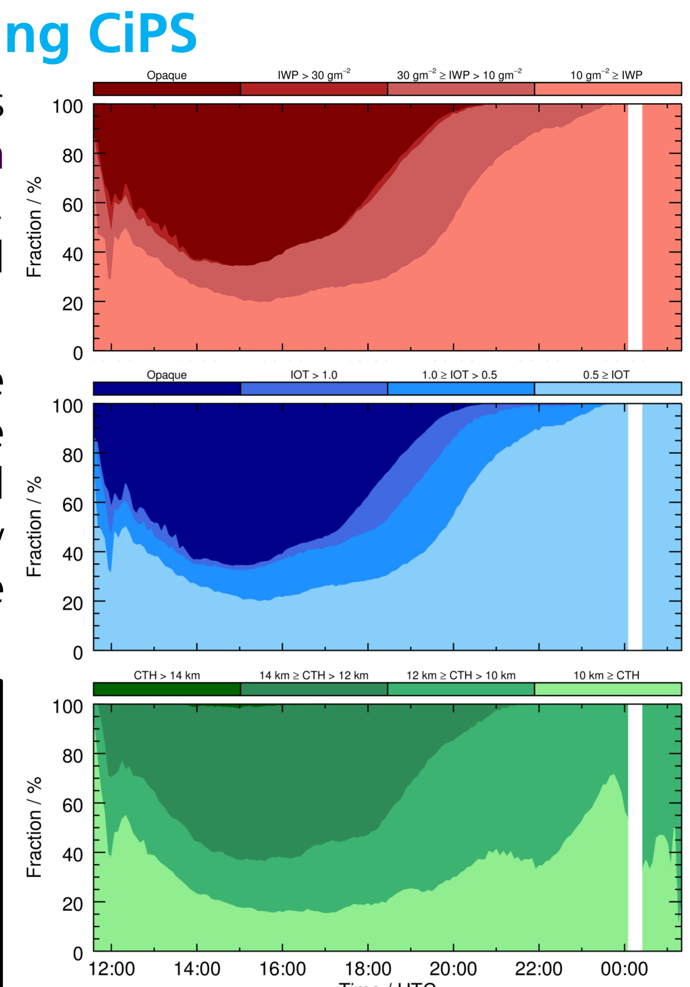


VI) The life cycle of an anvil cirrus using CiPS

The temporal evolution of the CTH, IOT and IWP is investigated with a **temporal resolution of 5 min** throughout the life cycle of an anvil cirrus cloud, originating from a cumulonimbus cloud over central Italy on July 7-8, 2015.

The RGB composites show three snap shots of the cloud that is analysed, including the contour of the CiPS cirrus cloud mask. The same channel combination as above is used, leading to a solely blue contribution at 20.00 UTC due to the absence of solar radiation.





VII) Summary & conclusions

- A new algorithm (CiPS) has been developed for the remote sensing of cirrus clouds using IR observations from the geostationary imager SEVIRI
- CiPS detects 71 and 95% of all cirrus clouds with an optical thickness of 0.1 and 1.0 respectively, with respect to the space-borne CALIOP lidar
- The retrieval of CTH, IOT and IWP shows a good agreement with CALIOP, also for thin cirrus clouds
- In addition to new output variables (IWP, opacity flag), CiPS shows clear improvements compared to the COCS algorithm that uses a similar approach
- A direct comparison between CiPS and an airborne high spectral resolution lidar shows an impressive agreement in IOT for an optically very thin cirrus (IOT<0.2)
- The capability of CiPS is demonstrated by analysing the life cycle of an anvil cirrus

References

Strandgren, J., et al. Cirrus cloud retrieval with MSG/SEVIRI using artificial neural networks, Atmos. Meas. Tech. Discuss., in review, 2017.

Kox, S., et al. Retrieval of cirrus cloud optical thickness and top altitude from geostationary remote sensing, Atmos. Meas. Tech., 7, 3233–3246, 2014.

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