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On the observation of unusual high concentration of chain-like aggregates of small ice crystals near the top of a deep convective system during the CIRCLE-2 experiment

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During the CIRCLE-2 experiment carried out over Western Europe in May 2007, in situ and remote observations have been obtained with the DLR Falcon aircraft in cirrus clouds and convective systems. The aircraft was equipped with a unique set of instruments including the Polar Nephelometer, FSSP-300, Cloud Particle Imager (CPI) and PMS 2D-C for the extensive in-situ cloud measurements of microphysical and optical properties and the DLR WALES Lidar (Water Vapor Lidar Experiment in Space) for nadir looking remote sensing observations. This poster illustrates results of combined observations performed near the top (-58°C) of an overshooting convective cell over Germany (26 May situation). In situ measurements reveal the occurrence of very high concentration of **chain-like aggregates of small ice crystals** with subsequent very large extinction and ice water content values at these altitudes. The analysis of co-located remote sensing data from both the lidar WALES and the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) aboard Meteosat Second Generation (MSG) confirms these unusual cloud properties. Outflow cirrus cloud properties observed in the vicinity of the convective cell are described for comparison purposes. Quasi co-located CALIPSO and CloudSat observations are available along the Falcon track 30 min earlier the convective cell penetration. Despite this time lag, the cloud feature is nicely identified from space active remote sensing measurements. Scientific issues related to the microphysical properties and structure of deep convective are discussed with some possible insights regarding engineering issues related to the flights of commercial aircraft through areas of high ice water content.

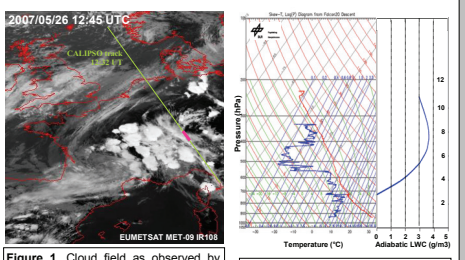

Figure 1. Cloud field as observed by SEVIRI (10.8 µm channel) on 26 May at 12:45 UT. The CALIPSO track (12:32 UT) is superimposed on the image with the Falcon flight track by thick line.

Figure 2. Temperature & Dew-point profiles measured by the Falcon (left panel). The right panel shows the calculated adiabatic LWC profile.

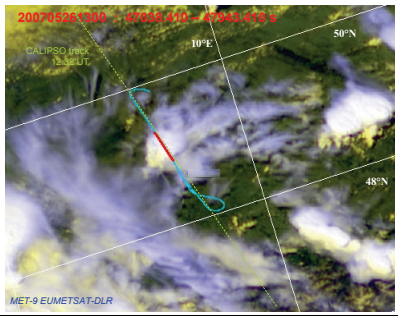

Figure 3. False color composites of MET-9/SEVIRI observations from 26 May 2007 at 13:00 UT. The Falcon trajectory (between 12:45 and 13:15 UT) is superimposed (blue line). The flight segment in red color indicates the penetration in the convective cloud. The CALIPSO track is also displayed.

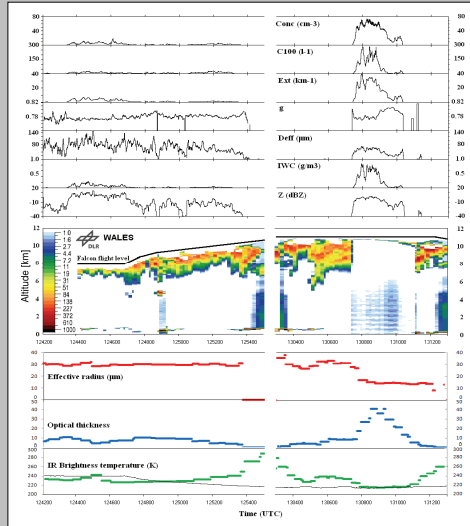

Figure 4. ***1st panel***: Time-series of cloud in situ parameters : *Conc and C100*: Concentration of ice particles (d> 3 µm and d>100 µm, respectively); *Ext*: Extinction, *g*: Asymmetry parameter; *Deff*: Effective diameter; *IWC*: Ice water content and *Z* : Reflectivity factor. ***2nd panel***: Attenuated backscatter ratio (at 1064 nm) from WALES lidar. ***3rd panel***: Time-series of retrieved parameters along the Falcon flight from SEVIRI observations *(Bugliaro et al., ACP, 2010)*: Effective radius, Optical depth and IR (10.8 µm) Brightness temperature (green curve). The air temperature measured by the Falcon is also reported (black curve). The first sequence reports outflow cirrus (1242 – 1254 UT). The overshooting convective cloud sampled near the top at 11.2 km level (1307 – 1311 UT, see red segment on Fig. 1) is coherently described by combined observations. The high ice concentration (80 cm^{-3}) of small ice particles (40 µm) with large extinction (40 km^{-1}) and IWC (~ 1 g/m^3) lead to a strong lidar attenuation. SEVERI retrieved parameters confirm the occurrence of small ice crystals (compared to the outflow cirrus) with high optical thickness (40). The IR brightness temperature fits remarkably well with the in situ temperature measurements near the top of the convective cell.

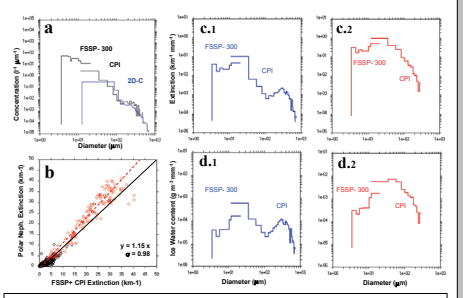

Figure 5. (a): Composite representation of the particle size distributions from FSSP-300, CPI and 2D-C. (**b**): Extinction comparison between PN and FSSP + CPI derivations. **(c)** and **(d)**: Extinction and IWC size distributions measured in the outflow cirrus (c.1, d.1) and convective cloud (c.2,d.2) respectively. The results highlight a quite good consistency of microphysical parameters derivations.

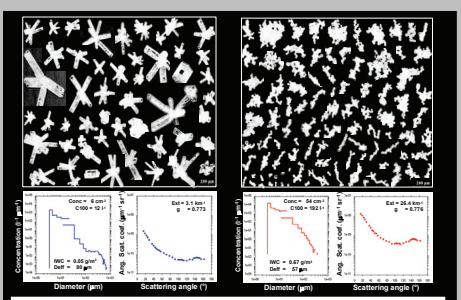

Figure 6. Examples of ice crystal images measured by the CPI. ***Left panel***: Bullet-Rosettes sampled near -45°C in the outflow cirrus. ***Right panel:*** **Chain-like aggregates** observed near the top of the convective cloud (11.2 km/ -58°C). The correspondind particles size distributions and scattering phase functions with mean values of parameters are displayed on the bottom panel.

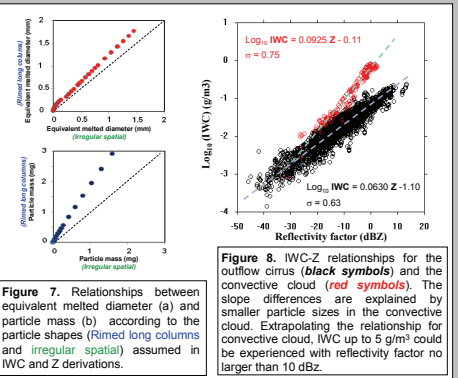

Figure 7. Relationships between equivalent melted diameter (a) and particle mass (b) according to the particle shapes (Rimed long columns and irregular spatial) assumed in IWC and Z derivations.

Figure 8. IWC-Z relationships for the outflow cirrus (***black symbols***) and the convective cloud (***red symbols***). The slope differences are explained by smaller particle sizes in the convective cloud. Extrapolating the relationship for convective cloud, IWC up to 5 g/m^3 could be experienced with reflectivity factor no larger than 10 dBz.

CONCLUSIONS

- First observations of chain-like aggregate ice crystals are reported near the top (11.2 km/-58°C) of an overshooting convective cell in mid-latitude continental area. As reported by *Connolly et al. (QJRMS, 2005)* the aggregation processes result from electric field alignment of ice crystals. Supercooled droplets lofted in the updrafts are frozen by homogeneous nucleation near the -38°C level, producing high concentrations of very small primary ice particles. Indeed, theoretical adiabatic IWC values may reach 3 g/m^3 at the tropause level.
- The overshooting-convective cloud properties are coherently described by combined observations. The high ice concentration (80 cm^{-3}) of small ice particles (40 µm) with large extinction (40 km^{-1}) and IWC (~ 1 g/m^3) lead to a strong lidar attenuation from WALES and CALIOP data. SEVIRI retrieved parameters confirm the occurrence of small ice crystals with high cloud optical thickness (40).
- Significant differences in IWC-Z relationships are found between usual outflow cirrus and the overshooting cell. Extrapolating the relationship for convective cloud, IWC up to 5 g/m^3 could be experienced with reflectivity factor no larger than 10 dBZ.
- These observations address scientific issues related to the microphysical properties and structure of deep convective cloud and are contrary to the findings that particles larger than 50 µm control the radiative properties in convective-related clouds. These unusual observations may also provide some possible insights regarding engineering issues related to the flights of commercial aircraft through areas of high ice water content and high concentration of small ice crystals.

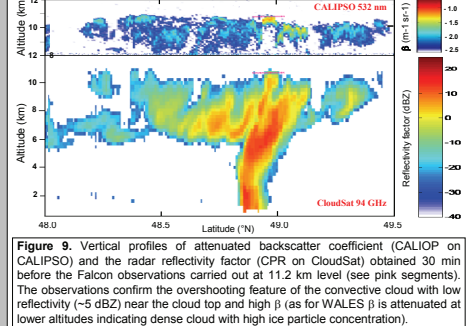

Figure 9. Vertical profiles of attenuated backscatter coefficient (CALIOP on CALIPSO) and the radar reflectivity factor (CPR on CloudSat) obtained 30 min before the Falcon observations carried out at 11.2 km level (see pink segments). The observations confirm the overshooting feature of the convective cloud with low reflectivity (~5 dBZ) near the cloud top and high β (as for WALES β is attenuated at lower altitudes indicating dense cloud with high ice particle concentration).

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