Ice clouds observed by microwaves

GdR microwave radiometry for atmospheric studies

Observatoire de Paris, Salle du Conseil

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The objectives of the meeting are first recalled: to promote the interactions in the remote sensing community about the ice phase in clouds, and if possible to foster joint projects.

Presentations were solicited, others were spontaneously offered. The program of the day and the list of participants are given in Annex. Below is a summary of presentations. These presentations are available on the website.

'Observed ice clouds by passive remote sensing: What did we learn from the GEWEX Cloud Assessment?' Claudia Stubenrauch, LMD .

C. Stubenrauch summarizes the work of inter-comparison and evaluation of cloud estimates at global scale from satellite, focusing on ice clouds. The results of this work are available on http://climserv.ipsl.polytechnique.fr/gewexca. An average of 68% of the globe is covered by clouds. There are differences between the ice cloud cover estimates, especially for thin ice clouds. These differences are explained by differences in the satellite instrument sensitivity to the ice. To reduce these uncertainties, the interest of using the instrument synergy is obvious. It will be noted however that the spatial structures of the cloud cover are very similar from an estimate to the other.
To estimate the optical and microphysical properties of the cloud ice, the first step is to determine the cloud phase. This can be derived from polarization information, from temperature measurement, or from multi- spectral information. Again, it is crucial to assess the sensitivity of each instrument, especially when comparing satellite estimates to models (for example, filtering semi -transparent clouds in some cases).
Claudia then mentions recent work on the estimation of ice cloud profiles, from lidar / radar data (DARDAR) and AIRS (Feofilov et al., 2013). The ice content is often assumed constant along the profile, but the analysis shows many different types of profiles that

affect the radiative cooling of the atmosphere. It should be noted that these types of profiles do not appear to be related to the season or region.

'In situ characterization of the ice phase ', Alfons Schwarzenboeck LAMP.

A. Schwarzenboeck first recalls the mechanisms of formation of ice crystals and their growth. Growth by vapor diffusion can produce pristine ice crystals with regular shapes (plates, column, dendrites), but other mechanisms (aggregation and icing) lead to very irregular particles. Most ice particles have very complex growth and as a consequence have very complicated shapes. The pristine ice is mainly present at the poles. Airborne instruments for the in situ characterization of ice particles are described: the 2D imagers to estimate the crystal size, the spectrometers that measure the scattering spectra with possible information about sphericity and roughness, the ' bulk condensed water content device ' for measuring density. The problem of instrument saturation is raised, when there is too much ice water content (>1g/m^3, which is common). The determination of particle size distribution often requires the use of different imaging devices, and 'connecting' the different estimates is not trivial. With regard to the shape, the LAMP defines 10 types of shapes. But these type classifications, automatic or manual, can differ. To solve the problem of the relationship mass / diameter $m(D) = \alpha D^{\beta}$, the radar observations at 94 GHz is a powerful tool to complement in situ measurements. The parameters α and β are adjusted to meet both radar reflectivity and in situ data, the link between the two being the simulation of reflectance by the T matrix. Mass / diameter laws are deduced and they appear quite general. They could therefore be very useful for radiative transfer modeling and for satellite inversions.

'Explicit treatment of clouds in Meso-NH', Jean -Pierre Pinty, LA.

J.-P. Pinty presents first a reminder about the different types of cloud mesoscale models, depending on their complexity.
The objective of the new scheme (LIMA for Liquid Ice Multiple Aerosols) is to take into account the presence of aerosols, while maintaining good computational efficiency for high-resolution simulations. The different processes of formation and conversion of the particles are described.
Aerosol estimates from MACC at ECMWF (combination of satellite data and modeling) are used to initialize Meso-NH. Depending on the particle types, different modes are activated.
LIMA new scheme was tested at km scale on 400x400x50 grid points during the HYMEX campaign (IPO6). It shows an increase in rainfall over 24 h as compared to the previous scheme and it agrees better with the observations of rain (rain gauges and radar). LIMA should also improve the representation of hail in ice clouds. Coding is ready: the simulation of IOP6 is to be performed. Other simulations were achieved for other HyMeX case. The scheme is stable. The shape of the crystals must be introduced in an upcoming development LIMA pattern.

'Recent advances in the analysis of the ice phase in clouds from radar observations and from radar - lidar combinations', Julien Delanoe, LATMOS .

J. Delanoe summaries first the notion of volume scattering in the clouds. He recalls that the radar response changes with D^6 while the lidar is sensitive to D^2. He concludes that

the radar is mostly sensitive to the particle size whereas the lidar is rather sensitive to the ice concentration. As a consequence, these two measures are highly complementary.
To use the lidar / radar synergy, observations are inverted simultaneously, using a variational method consistently for the two types of observations. This inversion takes into account a priori, as well as instrument noises and radiative transfer errors. Tests were made adding an infrared radiometer, but they were not successful (likely because the optimal sensitivity of the IR is at the same altitudes than the other instruments, so it does not add significant information).
Very conclusive results of the lidar / radar synergy are presented on various airborne campaigns. Opportunities to fly with microwave / millimeter / sub-millimeter instruments in future campaigns are discussed.
The presentation ends with:

- The need for further airborne radar measurements (LATMOS + LAMP) to provide the community with realistic mass/diameter laws for a wide variety of environments. The radar makes it possible to extend spatially what is seen by the in situ measurements.
- The importance of the work on scattering models. For particles of similar size to the wavelength (Mie regime) , efforts are still needed to have realistic scattering estimates with reasonable computer time (e.g., Rayleigh-Gans [1] to quickly reproduce DDA results) .

'The different microphysical assumptions and their impact on microwaves' Victoria Galligani , LERMA .

Microwaves interact with the liquid phase in the clouds mainly through the transmission / absorption. Ice does not absorb in the microwaves and interaction with the radiation is primarily through scattering, when the ice particles are large enough as compared to the wavelength. Below roughly 80 GHz, there is little interaction between the ice phase in the clouds and the passive microwaves. Beyond this frequency, the presence of ice can be revealed by a decrease in the brightness temperatures measured from satellites.
The inversion methods to estimate the cloud properties from passive microwaves usually require a radiative transfer model and the quality of the inversion depends on the accuracy of the radiative transfer. In the presence of ice, scattering introduces complexity in the radiative transfer simulations, with a high sensitive to the ice particle properties. The particle density (mass / diameter law), the size distribution, as well as the shape and orientation of the particles affect the results.
To evaluate the radiative transfer, comparisons are made between simulations and microwave observations, both passive and active (MHS + CloudSat). The simulations couple the outputs of a cloud model (Meso -NH) with a radiative transfer code (ARTS).
The most significant differences are observed in the presence of snow, for which the microphysical properties are poorly known (especially the mass / diameter law). By adjusting these properties, it is possible to correctly simulate the observations, for both active and passive microwaves. This work must continue, to generate realistic learning databases for the derivation of statistical inversion algorithms of the cloud properties.

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[1] Equation for the microwave backscatter cross section of aggregate snowflakes using the Self-Similar Rayleigh-Gans Approximation Hogan, R. J., and C. D. Westbrook (submitted to JAS) and available at http://www.met.rdg.ac.uk/clouds/publications.html

'Microwave, millimeter and sub-millimeter observations: perspectives', Eric Defer, LERMA.

E. Defer reminds that today observations from satellites are limited to 200 GHz for weather forecasting, whereas the sensitivity to the ice phase increases with frequency. The next generation of European operational meteorological satellites (MetOp-SG) will carry an imager in the 180-700 GHz range, the Ice Cloud Imager (ICI), for the characterization of ice clouds, in addition to a microwave imager and sounder at lower frequencies (MWI and MWS). 3MI and IASI-NG will also contribute to the characterization of the ice phase on the same platform.
Airborne instrumentation is being developed in Europe in the microwave to sub-millimeter range. HALO, the German aircraft is equipped with a radiometer between 22 and 190 GHz, and a 36 GHz radar. These instruments have recently flown successfully. With the recent addition of ISMAR, the airborne instruments on the UK Met Office aircraft cover from 22 to 700 GHz (a 875 GHz radiometer is also under development). The first flights should take place soon and LERMA will participate.
Recent work on the analysis of existing microwave observations (MADRAS data, TRMM, A- train) is quickly presented in synergy with other observations, in the infrared, the visible, and with active microwaves.
The possibility of flying ISMAR on board an Airbus is discussed, in the framework of the project HAIC (HAIC: High Altitude Ice Crystals (www.haic.eu)).

'Use of high frequency passive microwaves to detect precipitation', Chantal Claud, LMD.

C. Claud uses microwave sounder observations in the water vapor line at 183 GHz to detect precipitation, through the scattering by ice cloud. The correlation between the ice scattering signal and the precipitation is low and there may be problems of saturation problems. Coincident satellite and in situ rainfall observations are used to construct a climatology of convective precipitation occurrences. Cases were analyzed during HyMeX to adjust the method. Comparisons were made with in situ rainfall measurements and CloudSat estimates.
AMSU and MHS provide observations at 183 GHz since late 1998. ATMS also measure these frequencies, but the instrument is less efficient (lighter than its predecessors but likely with less sensitivity). Tests will be conducted to ensure that the method can be used for this instrument. For the derivation of a climatology, instrument changes are problematic and inter- calibration of measurements is crucial.

'Simulation of the microwave sounder SAPHIR in cloudy areas with the ALADIN-Réunion', J.-F. Mahfouf , Météo- France .

A scattering module was added to RTTOV and it has been refined recently. New tables of Mie were calculated (RTTOV11) to minimize the differences between simulations and observations over the entire frequency range between 20 and 200 GHz (Geer et al., 2014), both for stratiform and convective precipitation. The scattering was not sufficient at low frequency and was too high at high frequencies, as compared to observations. The properties of the dry snow have been modified with the help of the Liu (2008) database, derived from DDA computations.

At Météo- France, work has been undertaken to assess RTTOV11, interfaced with the outputs of the Aladin model over the Réunion area (Aladin-Réunion). Radiometric simulations with Aladin / RRTOV are compared with observations from SAPHIR on board Megha -Tropiques. Compared to the original version of RTTOV-SCATT, scattering is better represented, but differences still exist. There is still not enough scattering as compared to observations (simulated Tbs still too warm in areas of high scattering within tropical cyclones). Further efforts will be conducted to simulate sub-grid convective phenomena in the Aladin model and to take them into account in the RTTOV-SCATT radiative transfer model.
Inconsistencies exist between the assumptions used to describe the microphysical processes in atmospheric models and the radiative transfer models (laws of distribution, shape and density of particles).

'Observation of precipitation in Antarctica from CloudSat', Cyril Palermo LGGE.

Precipitation over the Antarctic continent is poorly known. Precipitation has a different nature in the coastal region and in the middle of the continent, with much smaller particles inside the continents ('diamon dust').
At LGGE, comparisons were undertaken between ERA–Interim, CloudSat, and accumulation snowfall estimates (accumulation is derived from in situ measurement and from extrapolation from satellite data). CloudSat seems to underestimate the snow compared to other estimates in the middle of the continent. Questions arise about the validity of CloudSat estimates in regions with topography and when the particles are very small.
These studies need to be consolidated. This is a first step in an area where very little information is available.

'Characterization of the ice phase in clouds from POLDER and MODIS', Jérôme Riedi, LOA.

The detection of the ice phase with POLDER and MODIS is very different. For POLDER, the polarization information is used: ice and liquid particles do not have the same phase function. For MODIS, the differential absorption and temperature is used.
Microphysical models are very important to estimate the instrument response. Depending on the shape and the surface quality (roughness), different answers are obtained in terms of scattering angle dependence and polarization. The objective is to find generic forms that represent the best satellite observations. Consistency between POLDER and MODIS estimates of the ice phase are analyzed to better constrain the problem (the relationship with the temperature of the cloud, the relationship between particle size and temperature). Aggregates with irregular surfaces are best suited to represent the observations (asymmetry factor of the order of 0.7).
The constraints imposed by the simultaneous study of multiple observations allow significant progress in understanding the phase microphysics ice. The next available observations aboard MetOp-SG (3MI, ICI) still provide new constraints.

'The ice phase as seen from visible and infrared and the link with the microwaves', Vincent Noel, LMD.

With the lidar, the separation between the ice and the liquid phases uses the polarization. The non-spherical ice crystals alter the polarization of the reflected signal.
CALIPSO was launched in 2006. EarthCare will also be equipped with a lidar. The swath of Calips is very narrow and there is a need to integrate over a long period of time to have a global spatial coverage (a season). Note that Calipso measurements during the day are not used, because of the confusion with the solar photons.
Originally Calipso pointed at 0.3° from nadir, but the effect of oriented crystals resulted in underestimates of the optical thicknesses. The incidence angle was changed to 3°. The percentage of oriented crystals essentially depends on the temperature and shows little spatial variation. It is 8-10 % at -10° -20°.

Analyzes have focused on the detection of sub- visible cirrus. They are an indicator of the drying air masses. They are mostly found in the tropics and probably related to strong convective events (as studied with retro-trajectories of convective systems).
Identifying ice clouds with Calipso is relatively easy. However, retrieval of the ice phase throughout the vertical column is much more complex: multiple scattering in the column changes the polarization. The transition between the water and ice phases was determined by Calipso, without information on the temperature. This information was used to modify the cloud scheme in LMDZ.

Discussion

It emerged from the presentations and discussions of important similarities between the problems visible to microwaves, with the need for a good understanding of the microphysics of ice phase to enable the modeling of scattering parameters.

Ice microphysics

In the microwaves, both passive and active, the mass / diameter relationship ($m = \alpha D^{\beta}$) implicitly defines the density and shape of the particles is essential. The joint work at LATMOS / LAMP with radar and in situ data provides estimates that can help modeling passive microwave. These parameterizations should be tested with passive microwave observations.

During the observation campaigns, the radar measures a significant volume of the cloud (up and down from the aircraft). Radar and in situ measurements provide a vertical profile of the cloud, for a significant volume, similar to what is observed within a passive microwave pixel. For measurements in coincidence with satellite passive microwave observations, consistency tests should be made. LERMA, LATMOS, LAMP and Météo-France must coordinate to find situations common observations on the latest campaigns (campaigns Megha -Tropiques validation).

A discussion followed on the representativeness of the campaigns that should represent the variability of the global environments.

Radiative transfer model

We must ensure that all parties speak the same language. The effective radius is the ratio of the moment of order 3 of the PSD versus its moment of order 2. In microwave, this is not always the definition adopted.

Questions arise about the need for 3D radiative transfer, from the visible to the microwave. We all agree that the beam filling effect has to be taken into account. Geer et al. (JAMC, 2009) is quite instructive. It uses the concept of "effective cloud" that allows to simply represent this effect. Quite convincing comparisons quite convincing are made with the Independent Column Approach (ICA). Regarding the 3D radiative effect itself (related to the 3D structure of the cloud and the leakage of photons on the cloud sides), it is not yet clear that we should take into account, in the microwave paper. A recent paper by Bennartz and Greenwal (QJRMS, 2011) examine this problem.

With regard to the assimilation of passive microwave observations in forecasting models, many satellite observations are available. Currently the data that the model cannot accurately describe are not assimilated (this was the case at the ECMWF for high microwave frequencies for rainy atmospheres, before the changes proposed by Geer et al. (2014) in RTTOV-SCATT).

It is recalled that RTTOV now simulates from the visible to the microwave (all classical instruments that measure in the solar spectrum are present in RTTOV 11 AVHRR, VIIRS, IASI, MODIS...). This model can be used very broadly to simulate a suite of instruments with consistent assumptions. It is a good compromise between speed and accuracy.

Connection with the meso-scale model

Developments in the modeling of large particles are not expected in the near future in Meso-NH. Efforts are currently focusing on the small particles, their shape and the role of aerosols.

Can one consider changing the laws of mass in the model, to be closer to the recent observations? The model and the microwave observations are not sensitive to the same aspects of microphysics: radar observes reflectivity profiles whatever the ice particle type, while the model separates snow, graupel, and hail. With in situ measurements from an airplane, measurements are essentially made along a transect at constant altitude whereas the variability is essentially in the vertical. These two visions of microphysics are not easy to reconcile.

The possibility of forcing radar inversions from aircraft with a priori information on the profiles is discussed. For example, if a bright band is observed, has the microphysical profile special properties that could be exploited to reduce uncertainty? Could we use the vertical gradient information, in addition to the reflectivity only?

The possibility of joint observations at different wavelengths

Campaigns took place recently with the HALO aircraft, with passive and active observations.

Opportunities are discussed to fly the ISMAR demonstrator on the UK Met Office aircraft with RASTA on the Falcon. This has to be discussed for the next campaigns. Coincidences between the aircraft measurements and satellite observations form the visible to the microwave have to be favored.

Program of the day

9:15 Introduction, Catherine Prigent, LERMA.

9:30 Ice Clouds Observed by passive remote sensing: What did we learn from the GEWEX Cloud Assessment, Claudia Stubenrauch, LMD.

10:00 In situ characterization of the ice phase, Alfons Schwarzenboeck LAMP.

10:30 Explicit treatment of clouds in Meso-NH, Jean -Pierre Pinty, LA.

11:00 Recent advances in the analysis of the ice phase in clouds from radar observations and from radar-lidar combinations, Julien Delanoe, LATMOS.

11:30 Break

12:00 The different microphysical assumptions and their impact on microwaves, Victoria Galligani, LERMA.

12:30 Microwave, millimeter and submillimeter observations: perspectives, Eric Defer, LERMA .

13.00 Lunch

14:00 Passive microwaves at high frequencies to detect precipitation, Chantal Claud, LMD.

14:30 Simulation of the microwave sounder SAPHIR in cloudy areas with the ALADIN-Réunion model, J.-F. Mahfouf, Météo-France .

15:00 Observation of precipitation in Antarctica with CloudSat, Cyril Palermo, LGGE.

15:30 Characterization of the ice phase in clouds with POLDER and MODIS, Jérôme Riedi, LOA.

16:00 The ice phase as seen from the visible and the infrared and the link with the microwaves, Vincent Noel, LMD.

16:30 Discussion

17:00 End of the meeting

Participants

1. Chaboureau Jean-Pierre. LA.
2. Chepfer Helene, LMD.
3. Claud Chantal, LMD.
4. Defer Eric, LERMA.
5. Delanoe Julien, LATMOS
6. Descloitres Jacques, ICARE.
7. Eymard Laurence, OSU ECCETERA.
8. Genthon Christophe, LGGE.
9. Guignard Anthony, LATMOS.
10. Jimenez Carlos, Estellus.
11. Legras Bernard, LMD
12. Lifermann Anne, CNES.
13. Listowski,Constantino LATMOS.
14. Maattanen Anni, LATMOS.
15. Mahfouf Jean-Francois, Météo-France
16. Noel Vincent, LMD.
17. Palerme Cyril, LGGE.
18. Pinty Jean-Pierre, LA
19. Prigent Catherine, LERMA.
20. Riedi Jérôme Riedi, LOA
21. Rysman Jean-François, LMD
22. Schwarzenboeck Alfons, LaMP
23. Souyris Jean-Claude, CNES.
24. Stubenrauch Claudia, LMD
25. Szczap Frédéric, LaMP.
26. Veyre Philippe, CNES.
27. Wang Dié, LERMA.