CHARACTERIZATION OF THE MICROPHYSICS OF ICE IN TROPICAL CONVECTION FOR RAIN RETRIEVAL ALGORITHMS

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CONTEXT AND OBJECTIVES

The purpose of this study is to characterize the type of ice particles found in precipitating systems in order to improve the rain retrieval algorithm used operationally in the context of the Megha-Tropiques satellite.

The latter is a joint mission between France and India to study the water and energy cycle in the Tropics. The satellite is part of the GPM constellation and provides an exceptional sampling of the 23° S-23° N region because of the low inclination of its orbit (20°) combined with the large swath (1700 km) of its main instrument MADRAS. This conical-scanning passive microwave radiometer has 9 channels in the 18-157 GHz range and is dedicated mainly to precipitation retrieval. Bauer et al (2005) showed that the most critical source of uncertainties in the precipitation retrieval in the Tropics and over land comes from the ice microphysics characteristics. The retrieval algorithm under consideration here is of the Bayesian type and relies on a retrieval database to provide a rain rate from a set of brightness temperature. To build this retrieval database, radiative transfer simulation of MADRAS brightness temperatures is necessary and thus an adequate parameterization of the precipitating ice is required.

The Megha-Tropiques Algorithm Validation Campaigns were designed to characterize the ice particles as a function of the region, the synoptic situation and the life cycle of the systems. Two field campaigns were set up in order to address this specific problematic one in Niamey in August 2010 (Niger) and one in Gan in November 2011 (Maldives) during the CINDIE-DYNAMO international experiment. A series of airborne measurements were eventually performed and give an excellent insight of the microphysics but are very limited in time. So the aim is here to check if the polarimetric radar are useful to distinguish the various ice species in the various parts of the system and if it is possible to correlate these with observed brightness temperatures, and ultimately develop a corresponding parameterization to be used in the Radiative Transfer Model (RTM) to simulate the relevant brightness temperatures for the retrieval algorithm known as BRAIN (Viltard et al. 2006).

DATA SETS

In this particular paper we will focus on two data sets, the one from the field experiment in Gan (2011) and the data from the Brazilian-driven CHUVA experiment. Gan 2011 was specifically designed to study these ice particles. A combination of ground-based (X and S-band) and airborne (W-band) radars was used in conjunction with in-situ microphysics. CHUVA on the other hand is more generally dedicated to study the rain regimes over various regions of Brazil and the main instrument of interest for us is the ground-based polarimetric X-band radar. We will show some comparisons of Particles IDentification (PID) made from the various polarimetric radars in Indian Ocean and continental Brazil respectively and see how they correlate with brightness temperatures measured by TMI on TRMM and MADRAS on Megha-Tropiques.

CHUVA

CHUVA is actually a series of 7 campaigns distributed over various location of Brazil. The various campaign are taking place between 2010 and 2014 (http://chuvaproject.cptec.inpe.br/portal/noticia.ultimas.logic) and the one we are focusing here was in Vale do Paraiba, a coastal region of the Sao Paulo State from October 2011 to March 2012.

CINDY-DYNAMO

CINDY-DYNAMO is a nippo-american initiative whose objective is to study the conditions for the development of active convection in episodes of the Madden-Julian oscillation in the Indian Ocean (http://www.eol.ucar.edu/projects/dynamo/). The instrumental set up is an area composed of the islands of Gan (0.7°S, 73.2°E) and Diego Garcia (7.3°S, 72.5°E), and two research vessels station, one at (0.7°S, 79°E) and the other at (7.3°S, 79°E). The campaign is classically divided into several phases: an *Extensive Observation Period* (EOP) from the 1st October 2011 to the 31 March 2012, an *Intensive Observation Period* (IOP) from the 1st October 2011 to the 15 January 2012 and a *Special Observation Period* (SOP) from 1 October 2011 to 15 November 2011. The Megha-Tropiques Algorithm Validation (phase II) component consisted of the deployment of the Falcon 20 from 17 November to 15 December at Gan Airport with a flight zone of about 300 km around the airport. The ground based SMART-R C-band radar (PI. C. Schumacher) was used to guide the plane through rain systems while the SPol-Ka (PI. R. Houze) is used for particles identification.

1-The SPol-Ka Radar

Polarimetric radars give access to the measurement of additional target characteristics besides conventional reflectivity. Abundant literature can be found on polarimetric radar techniques and more specifically on Particles IDentification (PID), a good reference being Vivekanandan (1991). The PID are defined according to the mean values and distributions of size, shape, composition, and spatial orientation of the particles filling the radar resolution volume. The general principle of PID is to use a fuzzy logic approach to combine the information brought by the various polarimetric measurements in order to come up for each radar bin with a particle type. Through simulation or direct measurements, a number of particle signatures are identified. Then a fuzzy logic algorithm is used to compute the most probable species present in a given radar bin. Only the most probable species is kept, while eventually the answer might sometimes be ambiguous with two species having very close probability. The various species are somewhat defined in a bulk sense with an unspecific characteristic like “wet snow” or “dry graupel”, providing a broad spectrum of possible particles in terms of density, size distribution or orientation. The usual species found in cloud model simulations are most of the time the closest particle type that can be assumed if one needs to quantify the particle properties. At the same time the limited number of measurement from the polarimetric radar does not allow more than a dozen species to be identified anyway. This is important to remember when the correlation between the TB and the species will be examined.

COLOCALISATION PID-SATELLITE

In order to extract information on the ice particles, we combine the PID information provided by NCAR, the satellite brightness temperature at 85 GHz Horizontal polarization and the BRAIN rain retrieval algorithm output. Because PID are non continuous information it is not possible to average the particle type within a satellite pixel. In order to overcome this difficulty, we substitute the average with a pie-wedge representation that gives the proportion of each species within the satellite pixel. If only one species is present within the pixel it will come out as a solid one-color pixel/pie-wedge. If two species are present in the satellite pixel, the pixel/pie-wedge will come out as divided between two colors etc... The proportion of each species is indeed simply the ratio between the number of radar bin of a given species within the pixel divided by the total number of radar bin inside the pixel and comprised between two arbitrarily set altitudes.

A simplified but complete geometry is taken into account. For each pixel, the direction to the satellite is computed from the satellite nadir projection on Earth. Then using the 53° zenith angle for a pixel, a slanted path through the radar domain is computed to identify those radar bin that will be contributing to a given brightness temperature/given pixel. A simple Gaussian weighting is used to take into account the satellite antenna pattern. The nominal resolution of a 85 GHz pixel of TMI is approximated as a circle of 3.5 km radius which is a compromise between the 5 and 7 km of the actual elliptical shape of the pixel.
The reflectivity from the radar is converted into ice content using a simple Ice Water Content (IWC)-reflectivity (Z) relationship given in Hogan et al. (2006) as:

$$\log10(IWC) = 0.060*Z-0.0212*T-1.92$$

Where Z is the horizontal reflectivity given in dBZ, T is the temperature at the considered altitude bin in Celsius and IWC is given in g.m-3. The temperature profile is at that point just taken as standard tropical profile.

Note that the two classification algorithms used here are two different versions of the same principle. The S-PolKa radar data were processed by NCAR with an in-house algorithm (Vivekanandan and al. 1999), while the CHUVA X-Band data were processed with GEMATRONIC's ECLASS (Echo CLASSification) software using the BMRC (Keenan, 2003) parameters for the fuzzy logic algorithm (with adaptation from C-to-X band).

Two representations are obtained: the first one is a projection of the pie-wedge at each satellite pixel position on the map. For clarity on these images, only one every other TMI pixel was considered. This image allows a visual understanding of the structure of the system as horizontal transport of the ice can be important specially in the Indian Ocean around Gan where strong vertical shear of horizontal wind was observed. The second one is a representation of the same pie-wedge but plotted with, for each pixel, their respective integrated ice content as coordinate and their corresponding brightness temperature as a coordinate. This last graph shows a more direct view of the respective influence of the particles type and the ice content on the observed brightness temperature.

Figure 1-a shows a PPI representation of the case of the 23 November 2011. This event was among the most intense observed during the campaign in terms of rain amounts on Gan. It is a long lasting case of very active convective cells embedded in a large stratiform area observed about 12 hours after it appeared. The PPI shows that the warm and cold microphysics are strongly constrained by the level of the 0° C layer which is at a radial distance of about 70 km from the radar. ***Figure 1-a*** shows indeed that the coldest brightness temperatures North of Gan are associated with heavy rain and the presence of graupel eventually.

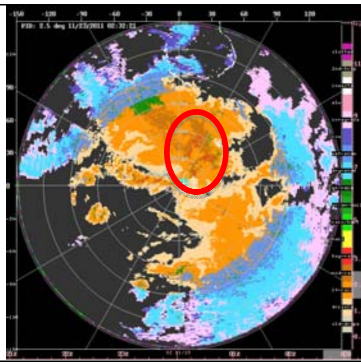

Figure 1-a : *Example of a PID for a 2.5° elevation Plan Position Indicator at 02 :32 TU on the 23th November 2011 with the SPol-Ka radar. Each circle is 20 km from the radar.*

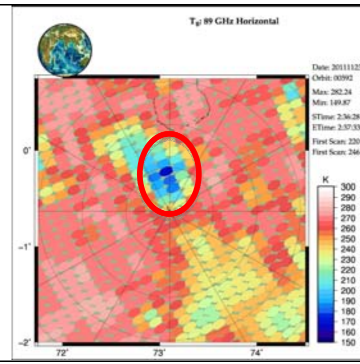

Figure 1-b : *Brightness temperature at 85 GHz (in K) for the same day and the same hour as* ***Figure 1-a****. The pixel size and orientation is at scale.*

Figure 2-a shows a PPI at 4.6° elevation at 15:00 UTC on January 1st 2012 during CHUVA Vale do Paraiba. We chose this event because at the same time, TMI was over passing the radar. At this elevation and since the radar altitude itself is about 700 m, the freezing height is met at about 43 km from the radar. Between the radar and this distance the main particles type are a mix of drizzle and wet graupel. The wet graupels are probably melting ice particles that persist through the freezing level.

Figure 2-a: *Example of a PID for a 4.60° elevation Plan Position Indicator at 15:00 TU on 1st of January 2012 with the CHUVA X-band radar*

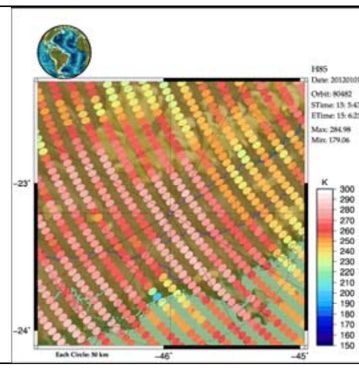

Figure 2-b : *Brightness temperature at 85 GHz (in K) for the same day and the same hour as* ***Figure 2-a****. The pixel size and orientation is at scale*

Figure 3-a shows the proportion of each ice species within the TMI pixel for the same case as presented in ***Figure 1***. We chose to start at 5 km altitude in order to be clear of the melting layer. The vast majority of the pixels in the picture are a mix in various proportions of "ice", "irregular ice" and "dry snow". The region where the scattering signature is the strongest (right North of the radar) is a region where almost exclusively dry snow is found by the radar between 5 and 13 km, with a hint of "graupel" for one or two pixels.

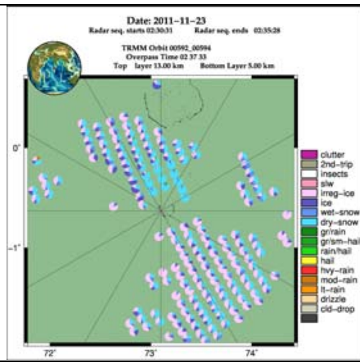	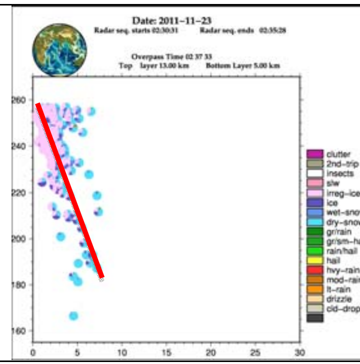
***Figure 3-a**: PID found in each pixel of the TMI overpass on November 23rd 2011 at 02:32 UTC over the SPol-Ka radar in Addu Atoll. The radar bins are taken between 5 km and 13 km altitude.*	***Figure 3-b**: Dependence of the 85 GHz brightness temperatures (in K) as a function of the integrated ice content (in kg.m^{-2}) on the beam path and between the two indicated altitudes.*

The ***Figure 3-b*** shows the respective influence of integrated ice content and PID on the brightness temperature. One can see that the expected correlation: when the ice content increases, the scattering increases leading to a colder temperature at 85 GHz. The pixel dominated by "irregular ice" line up nicely along the red line, while the pixels with various proportions of "dry snow" seem to gather at the coldest end of the same red line, somewhat departing from it, either above or below. It is to be noted that pixels with a little bit of "graupel" signature are not necessarily the coldest ones.

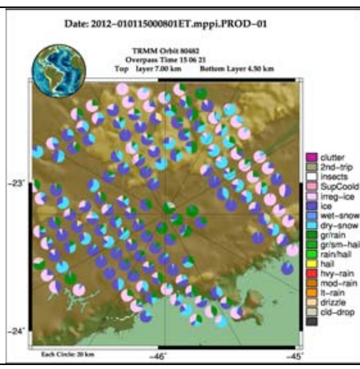	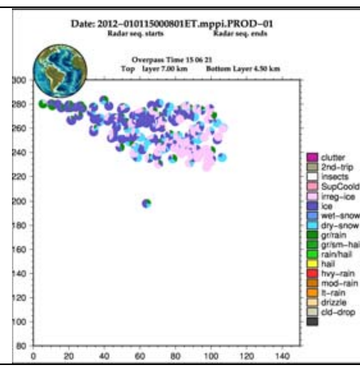
***Figure 4-a**: PID found in each pixel of the TMI overpass on January 1st 2012 at 15:00 UTC over the X-band radar in Vale do Paraiba. Only one every other TMI pixel is plotted for the sake of clarity.*	***Figure 4-b**: Dependence of the 85 GHz brightness temperatures (in K) as a function of distance to the radar (in km).*

Figure 4-a is similar to ***Figure 3-a*** but for the CHUVA campaign and for a layer between 4.5 and 7 km altitude, which is right above the melting layer. Within this layer, the dominating species are either "wet snow" or "dry snow" with "irregular ice" on the periphery of the radar domain. Some patches of "graupel with rain" can also be found near the radar and North and South of it. ***Figure 4-b*** shows the same pixels plotted as a function of their distance to the radar on the x-axis and their brightness temperature at 85 GHz on the y-axis. There seem to be a dependency indeed between the PID and the distance to the radar. Denser particles like graupel are found closer to the radar, and as you go further from the radar it seems that wet snow, dry snow and then irregular ice are dominating repsectively. This might mean that some more work has to be done on those radar data or that the sampling strategy might not be adequate for our application. This needs to be investigated further in the future.

DISCUSSION

These preliminary results are meant to show that it is possible to somewhat fill the gap between in-situ and satellite measurements through the use of ground based polarimetric radar data. Co-location between the radar data and the satellite pixels will always retain some uncertainties but the bulk picture of the correlation should be captured nonetheless. The main problem remains rather that the definition of the various classified species remains somewhat vague, so one has to keep in mind that those species are just the expression of different signatures in the polarimetric space rather than solid definition of species. At the same time, the idea here is to get some general sense of the type of particles that can be associated with the various part of the systems, namely convective and stratiform regions.

The correlation between T_Bs and PID is not always straightforward in those two examples in the sense that one would have expected: graupels dominating in the convective regions leading to strong scattering and snow-like particles dominating in the more stratiform regions leading to warmer T_Bs. It appears nonetheless that there is some signal at least in the more convective case over Gan where one can see specific particles distribution associated with the colder T_Bs. The CHUVA case might not be optimal because it is an old system with very little active convection and the ice species might be very randomly distributed over the whole ice cloud.

The next steps will be to find more cases both from CHUVA and CINDY-DYNAMO to consolidate the correlations that were observed. We are also planning to use not only the 85/89 GHz channel but also the 150/157 GHz channels found on MADRAS and SSMIS to see how the correlation happens also with these higher frequencies that are sensitive to smaller ice particles. Last, we will compare the classifications with those cases when the French Falcon-20 was performing in-situ and W-band ice measurements within the radar range. These comparisons will allow us to nail down more precisely the true species that are classified by the ground radars.

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