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Megha Tropiques Ground Validation plan

Part 1 : MADRAS derived rainfall products

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This document provides a general overview of current plans to evaluate the MeghaTropiques (MT) Rainfall estimates based on the MADRAS microwave imager on board MT and other platforms : BRAIN Algorithm Level 2 (instant rainfall, flags and profiles) products and Level 4 (1°x1day gridded accumulations) from TAPEER. MT GV will also supply microphysical information to adjust BRAIN parameterization.
Two companion documents describe i) the validations plan for the water vapor products based on MT/SAPHIR-MADRAS (H Brogniez) and ii) calibration/ validation plans for the SCARAB based TOA RB (O Chomette).

Highlights :

*The **French contribution** to MeghaTropiques GV focuses primarily on the West African Region where a substantial field deployement will be set up. The reasons for this focus are three-fold :i) Africa is the largest continental mass in the intertropical zone and offers a variety of rainfall regimes and eco-climatic zones where the products need to be tested. ii) This is also a zone where the operational raingages networks are scarce. Accessing to a quality ground reference in this region therefore requires dedicated measurements. iii) West africa and in particular the Sahel zone is one the hot spots in term of vulnerability of population to rainfall variability; in this region reliable rainfall products are needed for a variety of operational and research applications (flood/drought monitoring ; water resources and crop predictions etc.). This effort is part of a global validation plan which includes* *measurements from many locations over the Tropical belt, in order to cover several tropical climate zones and sample the variety of conditions the convective systems propagate through. Ground validation activities led by Indian scientist and ISRO will take place in* ***India****, inland and over the Indian ocean. In* ***Brazil*** *the INPE is planning a series of short specific campaign as part of the CHUVA program and is gathering an extensive data base as part of the CENADEM center for natural risk monitoring.*

The proposed strategy will combine several complementary approaches both in term of observations and methods :

*-**Satellite to satellite comparison** is the only possibility to compare MT products to a reference data base on a global basis.*

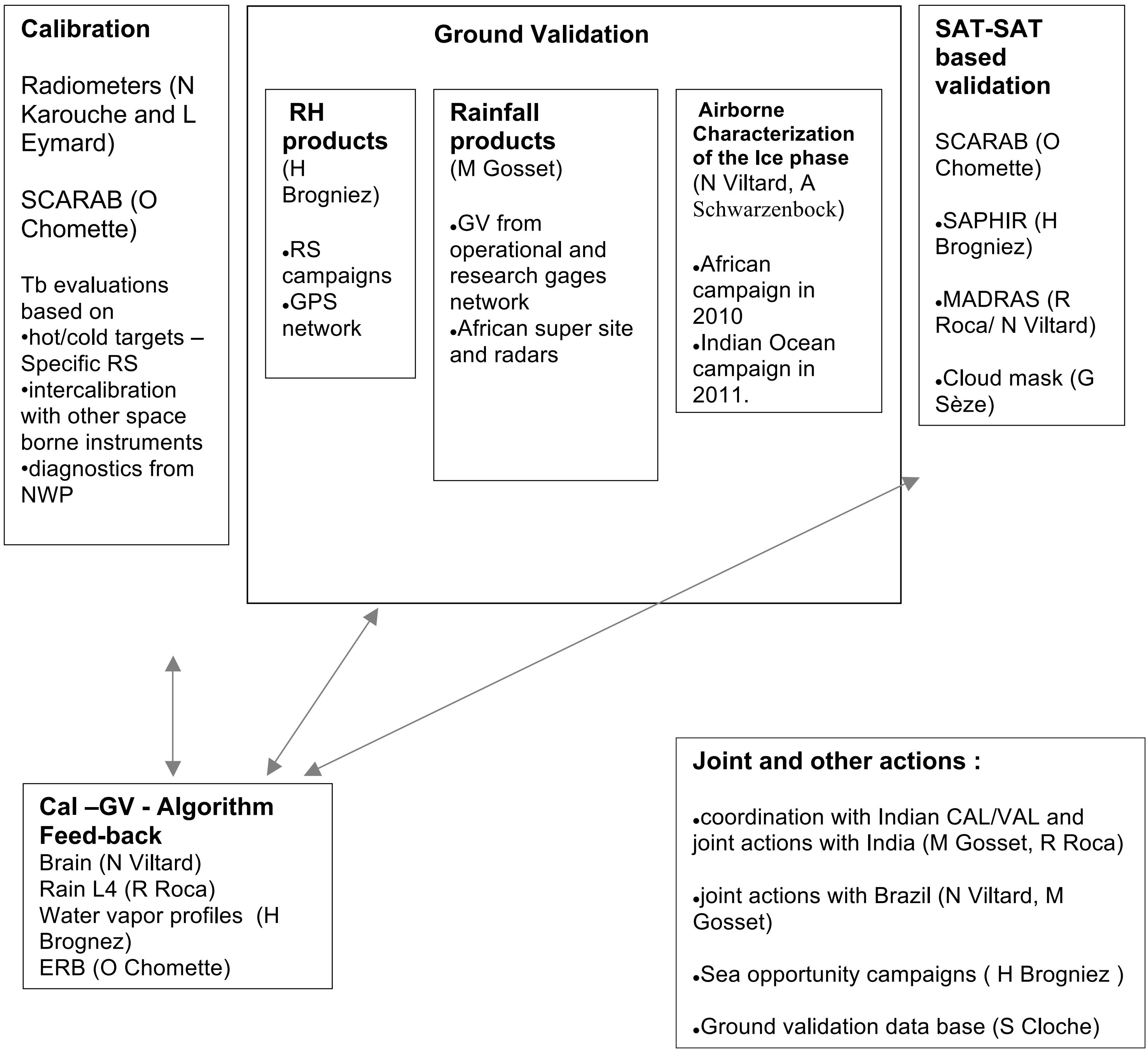
*-**Existing networks** can provide valuable data. Both operational network, such as National weather services and research networks set up by the scientific community for the long term monitoring of climate and the environment, will be used. Also data from global program (such as IPWG validation data set) will be used.*

*-**A devoted super site** will be set up for profiles validation, high resolution (both in space and time) data and focused in situ measurements.*

*-Detailed information on the property of **ice phased hydrometeors** (crystal density and size) has emerged as a strong need to improve and validate the rain restitutions from BRAIN algorithm. Aircraft campaigns, dedicated to the sampling of ice crystal properties for several rain conditions are planned for this specific need (two have already occurred, one in Niamey, in 2010 and one in the Maldivas area in 2011 as part of the DYNAMO program) .*

*- The **Rainfall products** validation must include the evaluation of both the **surface rainfall** (both L2 and L4), and of the rain water content and **hydrometeors type profiles**. The latter requires to set up ground instruments that provide information on the 3D structure of convective systems. Polarimeric radars will be deployed on the dedicated super site for that purpose and they will also provide high resolution Quantitative Precipitation Estimates (QPE) in the vicinity of the super site. A reliable evaluation of the surface rainfall requires rainfall maps over areas more extended than one dedicated super site ; this will be provided by existing rain gages networks : regional scale, daily rainfall from operation networks and high resolution, sub-daily time steps rainfall from research networks.*

MT CAL/VAL overview



1 Ground Validation of rainfall products.

(M Gosset, N Viltard, R Roca)

Two type of products need to be validated :

- the level 2 products below the foot print : 'instantaneous' rain rate at the surface, profiles of the water and ice content, including particle type, and a convective/stratiform flag, from the BRAIN algorithm on the MADRAS instrument (and other microwave instrument on other platforms such as TMI).
- The level 4 rain blended product will provide gridded rain amounts with a typical resolution of 1°/1 day (global product) , from the TAPEER algorithm that will use multi-platform, geo IR and LEO microwave data.

As mentioned previously, the French effort will focus on the ground validation (GV) activities over the West African region as described below. This African GV will be coordinated with similar activities over India and Brazil, through collaborative actions.

The main challenges which need to be addressed in the ground validation plan are related to :

-the scarcity and quality assessment of the ground data;

-the ponctual nature of in situ measurements versus the spatial structure of the rainfield;

-the limited number of direct overpass contrasting with

-the variety of rain systems and the extreme space/time variability of the rainfall, at all scale, in West Africa.

To tackle these various issues the proposed strategy combines observations over a range of scale :

- **Regional scale** : data at this scale is needed to apprehend the spatial variability of rainfall and assess the quality of the derived product for several eco-climatic zone and rain regime and also as a function of the space/time scale considered. This part of the GV relies on **operational rain gages networks** which data will be available through collaboration with national or regional services such as AGRHYMET.
- **Meso-scale** : at this scale the gages network can be densified and high temporal resolution gages set up. This allows the analysis of the diurnal cycle , the detailed characterization of rainy systems and within them convective/stratiform rain type and the provision of rain intensity probability distributions. These GV activities will rely on 2 main **research gages network** already set up in Africa : the Niger (Niamey square degree) and Benin (Oueme) gages network of the AMMA-CATCH observing system, and a smaller network to be installed around the Ouagadougou (Burkina faso) Super Site.
- **Super-site** : a specific instrumental deployment is needed to address the highest space/time resolution and provide detailed information on the vertical profiles. For that purpose a **polarimetric radar** , will be set up in the Ouagadougou Super site.

Climatological studies have shown that rainfall in West Africa is characterized by a strong seasonal and inter-annual variability. In consequence the GV activities will be sustained for **two complete African monsoon rainfall seasons**. Also, some of the algorithms and products can be tested -to some extent- on existing platform (such as TMI for BRAIN /

TAPEER rainfall) using already available ground data (AMMA campaign, CILSS or IPWG validation gridded data)

An important source of uncertainty in the retrieval arises from a lack of knowledge on the **properties of the icy hydrometeors**, specially over the continent where only the highest frequency channels of MADRAS can be used because of land contamination. BRAIN pre-validation campaign, based on the joint use of airborne in situ measurements and polarimetric radar information below is a key component of our strategy. A first campaign occurred in Niamey, in 2010; a second is going on in the Gan/Maldives area, in the Indian Ocean, end of 2011. It will allow to gather the information on the ice size and density, and thus scattering properties, which are necessary to tune BRAIN.

1.1Validation of L2 instantaneous products (and algorithm)

The level 2 products to be validated are the **instantenous rainfall at the footprint**, and the water and ice content of the **profiles** with a distinction between rain, snow, graupel, cloud water and ice, and also the rain/no rain as well as the **convective/stratiform flags**.

The validation of the instantaneous rain products arising from MADRAS will be performed through a 3 step process. First, the validation of the MADRAS brightness temperatures through the calibration phase, second the validation of the products themselves and third the validation of some of the key parameters involved in the retrieval.

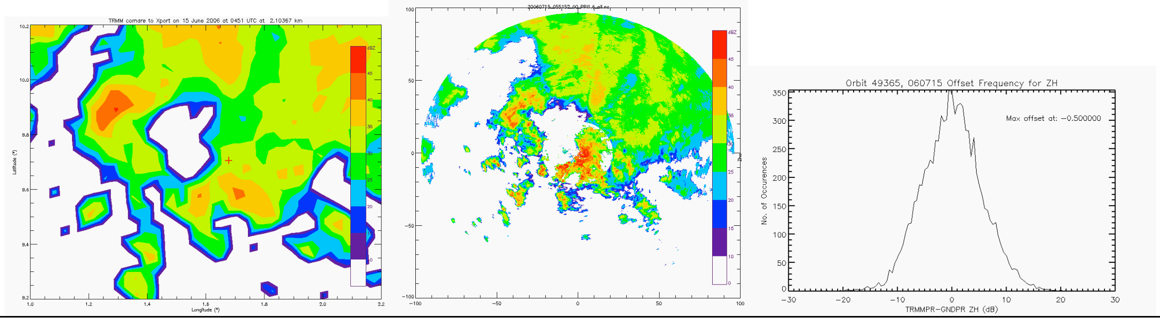
1.1.1Instantaneous Surface Rain Validation

Rainfall is a highly transient and heterogeneous variable which makes validation particularly difficult. The probability of simultaneous overpass of the satellite while rain is present and the ground validation instruments are in operation is not very high. In addition evaluating an instantaneous rain rate at ground level, rather than rain accumulations over a longer time step, is difficult. For this reason the validation will be based on both direct and statistical comparisons.

The estimated base error on the retrieval algorithm (BRAIN) is about 20% on average. Recent work, testing BRAIN on the TMI platform, shows that the error is strongly intensity-dependent (Kirstetter et al., 2011). The geographical dependence has also been shown (within the sahelian and soudanese regions of West Africa for instance) ; and any sensitivity to the time of the day, and the type of systems should also be investigated.

The rain rates will be estimated at ground from the **meso-scale high resolution rain gages network and from the radar**(s) over the african super site. The radar provides a continuous rain rate monitoring with a 5 to 10 minute sampling over an area of about ~200kmx200km, with a high spatial resolution (typically 1 km). Radar does not measure directly a rainfall rate but rather one or several variables which can be related to the rainfall under various assumptions. With a polarimetric radar such as the Xport radar which will be used in the Niamey super site, the measurement accuracy is improved and the sensitivity to rainfall properties variability is reduced (Zahiri et al., 2008; Gosset et al., 2010). The measurements from the high resolution tipping buckets gages will be converted to area estimate at 5 minutes time step, using dynamical interpolation techniques (like lagrangian kriging, Vischel et al, 2011 ; Amani and Lebel, 1998).

The base resolution of the BRAIN retrieval varies depending on the considered satellite ; for MADRAS a **20kmx20km** resolution is anticipated. The ground based rain estimates will be downgraded to this resolution, and the product and reference will be compared accounting for errors in the ground base estimate (using kriging interpolation).
When available (as below), the direct comparison of the instant rainfields will provide a direct assessment of the biases and will help diagnose specific problems in the retrieval scheme. However the number of overpass during rainy conditions is limited and only partial conclusions are expected from the direct comparison exercise on a small sample.



Example of TRMM (left), Xport radar (middle) direct comparison from one everpass during the AMMA campaign. The histogram of reflectivity differences over each pixel of the image is showed in the right.

More robust assessment are expected from the comparisons of the statistical and structural properties of both the ground reference and the satellite based rain fields :

-probability distributions of rain intensity

-properties of rain texture (horizontal gradients, correlation distance, isotropy, for different up- and downscaling)

-rain/no rain definition and statistics (threshold used to estimate the amount of missed light rain)

-convective/stratiform rain occurrence statistics

-system type classification (propagating squall lines, local convection, warm rains, etc.)

-diurnal cycle statistics

-seasonal/intra seasonal statistics (implies at least two seasons of data)

The figure below (from Kirstetter et al. , 2011) illustrates the use of quantile-quantile plots to analyze the products biaises and their distribution, as a function of the region considered.

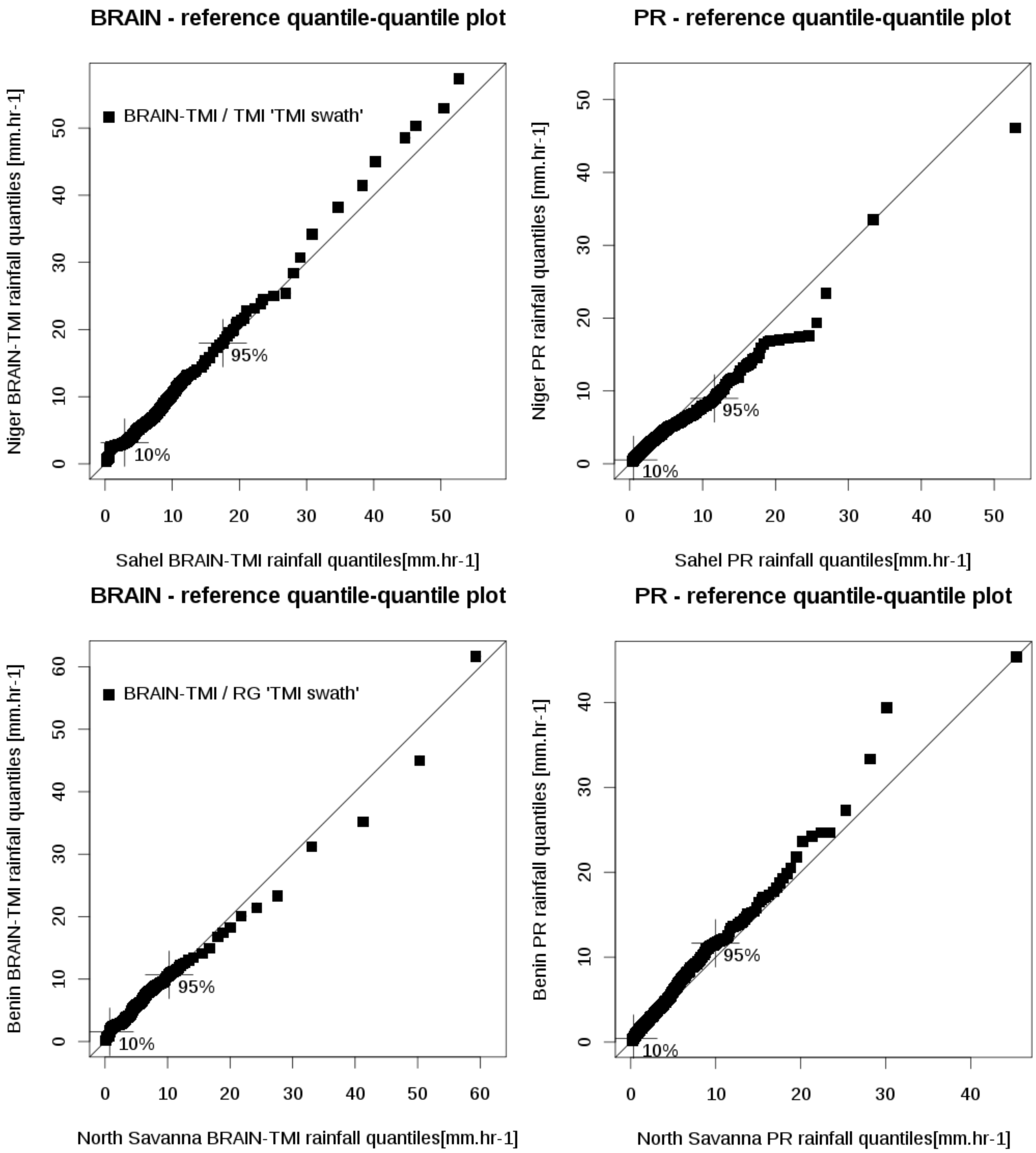


Figure 5 (Kirstetter et al., 2011): quantile-quantile plots of the rainfall distribution for the GV sites (y-axis) and the regional area (x-axis) r, over Niger / Sahel ((a) and (b)) and Benin / Northern Savanna ((c) and (d)), for BRAIN-TMI (left) and PR (right). The positions of 10 and 95 percentiles are showed for each distribution.

These products will be used to assess the performances of BRAIN in the two targeted zones of the West African region. The specific aspects to be validated, beyond the surface rain itself are :

-capability of the algorithm to detect light rain and warm rain intensity over land

-possible systematic bias associated to the rain type (convective/stratiform) or the type of convective system

-performances of the algorithm as a function of rain rate.

-possible systematic bias depending on hour of overpasses

-possible systematic bias depending on the season or year considered

-bias related to the evaporation of the rain, as it falls. The problem will be analyzed with 3D radar data as explained below.

1.1.2Vertical profiles and CONVective/STRATiform flag from radar.

Details on the vertical profiles and the ability to detect the proportion of Convective and Stratiform rain are valuable outputs of BRAIN for the study of MCS budget and latent heat profiles. BRAIN will provide rain profiles over 28 levels with various species of hydrometeors (rain and ice) and also a rain type flag.

The best information for the validation of the rain and hydrometeors profile will come from the **radar 3D data** with the methods developed by Kirtetter et al.. The technique currently tested on the radars from the AMMA campaign, classifies the Convective and stratiform region of the radar image, retrieves the rain vertical profiles and can also provide information on the vertical evolution of the Drop/crystal size distributions and the ice density. In addition, information on the system and rain type will be obtained from the analysis of the rain **hyetograms** over the other **gages networks** (Depraetere et al., 2009) and also from the Drop Size Distribution (DSD) information provided by **disdrometers** (Moumouni et al., 2008).

Statistics of retrieved rain profile are required to be compared with ground-based radar measurements. Statistics of the various microphysics species obtained from **polarimetric radar** above the 0°C isotherm will be compared with BRAIN's retrieved profiles. General properties of the ground-measured profiles will be looked for :

-existing correlation between surface rain and ice amount aloft, link with dynamics;

-evaporation rates along the profile;

-altitude of freezing level, thickness of the melting layer (a good proxy for the ice density above);

-effect of scaling on the retrieved features of the rain system (convective vs. stratiform part, isolated cells, rain/no rain threshold).

1.1.3 Ice characterization from airborne measurements

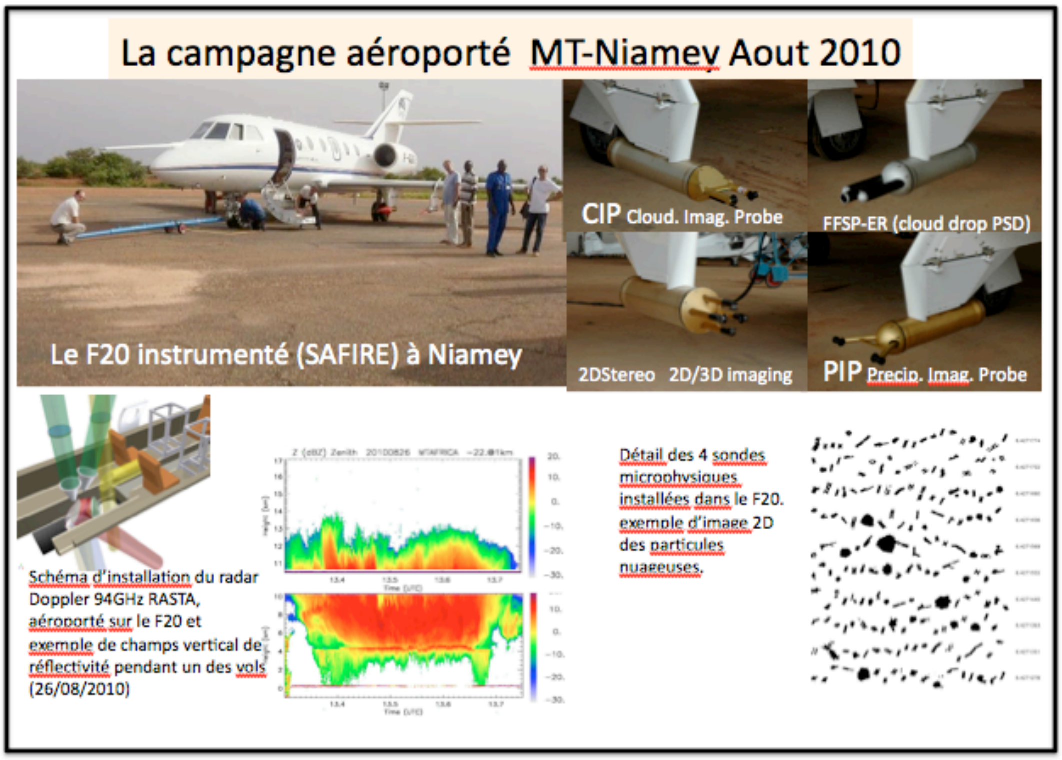
An important source of uncertainty in the rain retrieval from microwave radiometric measurements arises from a lack of information on the characteristics of the icy hydrometeors. Above land in particular, the radiometric signal sensed by MADRAS will come essentially from the ice phase (85GHz and 157GHz channels) and the rainfall profile below will be deduced from it. The radiometric signature of ice is related to both i) the density number of particles ii) the ice density of the particles; unless both are known, the retrieval is ambiguous.

An important effort of our validation activities will be devoted to the derivation of statistics on the ice content and ice density under several tropical rainfall conditions. The proposed strategy is to combine i) direct but punctual information from dedicated aircraft sensors and ii) longer time series and extended 3D coverage provided by the polarimetric radar retrieval to extend the statistics.

Several aircraft campaigns (french F20) with microphysical probes and the RASTA radar are planned. A first campaign was held in 2010 in Niamey (see details in the ‘bilan/prospective cal/val MT document, provided for TOSCA ; in French)

Aircraft campaigns are an essential component of the BRAIN algorithm validation campaign. They are needed to gather the necessary in situ information on the properties of hydrometeors in the topics (vertical profiles of crystal density related to size) to improve and validate the parameters in the inversion algorithm. The results of microphysical studies in convective cloud systems within the AMMA 2006 campaign using both the 2D-C cloud and 2D-P precipitation probes, in parallel to the airborne radar RASTA, all mounted on the French research aircraft Falcon-20 are convincing. They show that this combination of instruments helps reducing the uncertainty on the relationship between cloud particle density and size, which is a key parameter for remote sensing inversion algorithms. One principal finding is the fact that **existing density-diameters relationships from literature are inadequate for tropical convective systems over the continent**. However, these results need to be confirmed and extended to precipitating clouds which were poorly sampled during AMMA. Also simultaneous measurements of the icy hydrometeors from aircraft and ground polarimetric radars could not be obtained during AMMA; this is needed to adjust polarimetric based water/ice retrievals from radar and then obtain radar based extended statistics on the ice properties.

MT Niamey 2010 aircraft_radar microphysics campaign : set up sumary.



Details of the equipment of the Niamey 2010, airpplane/radar campaign..

It is most crucial to improve our knowledge of the ice particle density assumption $\rho(D)$ in order to validate the inversion algorithms within Megha Tropiques. The overall objective is to minimize the uncertainty in this relationship with more data, and an improved state of the art in situ instrumentation. An important point is to analyse the most adequate procedure to upscale those high quality in situ findings to the satellite pixel. In particular the variability of this relationship on the vertical, as well as the variability as a function of the distance to the convective cores (which can be considered as a measure of "age" of the cloud) will be studied in order to provide observational basis for further improvements of the assumptions held in the MT algorithms related to ice density. More generally, the multi-campaign approach has been designed in such a way that the presumably large variability of the ice density – size relationship in the tropical belt be quantified and parameterized.

COMBINING DIRECT AIRCRAFT MEASUREMENTS AND GROUND RADARS

Aircraft campaigns will measure detailed profiles of hydrometeors containing the ice phase (crystal density as a function of particle size), in order to compare them with those used by BRAIN. An important point in our strategy is to combine continuous and long term sampling from ground active remote sensing (polarimetric radars) with punctual aircraft measurements, to establish a climatology of different types of hydrometeor classes. The radar classification, not yet validated extensively for continental tropical systems, will be cross-checked by a series of Falcon flights.

Since the MT high frequency radiometric signal comes from a large thickness of the cloud, spiraling climbs and descents should be performed to get a maximum of vertical information. This will be combined with constant-altitude flights, performed at different levels. An important point in the strategy is to have simultaneous measurements from ground based polarimetric radars. Systematic variation in ρ(D) and possible regional discontinuities of the density function need to be documented for BRAIN. Ideally several airborne validation campaign will be held in order to document the regional variabilities between several tropical continental masses. Following the campaign held in Niamey in 2010, the MT team is organizing a similar campaign as part of the Dynamo project (http://www.eol.ucar.edu/projects/dynamo/) in the Indian Ocean area.

The West Africa Super Site

In the previous version of this document, the operation of a Super Site in Niamey, Niger was announced. Niamey was indeed used as a base for the MT Africa pre-launch radar/airborne campaign that occurred in August 2010. Unfortunately, the dramatic events that happend in September 2010 (causing many casualties after the kidnapping of two French men), have obliged us to modify our plans. It is now planned to install a super site in BurkinaFaso, which offers similar advantages as Niamey in terms of latitude (i.e. overpasses), rainfall regime and importantly, scientific collaboration.

1.2Level 4 Surface rainfall combined products

We remind that the level 4 precipitation products rely on blended techniques mixing passive microwave, geostationary sensors and raingauges network (With some similarities with GPCP products -Huffman et al, 1997). Product elaboration will be split in three steps.

- First of all a blended microwave estimator will be computed, based on a posteriori calibration: BRAIN algorithm will run on various heliosynchronous MW sensors (AMSR-E, SSM/I) and homogeneization will be based on MT level 2 rainfall intensity estimator.
- Then the MW estimator will be combined with ground network data (Global Precipitation Climatology Center) and the rough scale product (2.5°/1 month) will be computed by a linear combination of these two previous estimators based on respective estimation bias.
- The last step will be to down scale this product by integration of geostationary satellite infrared data similarly to the EPSAT-SG method but with some variation according to the location (continent/global) and the availability of various Geostationary products. The product will be delivered on two different scale: 1°/1 day for the global estimator (and possibly 0.5°/6 H for the day2 product).

  Due to the lag of two months before GPCC broadcast, the level 4 land rainfall estimator will be distributed in two versions: a real time satellite only and a deferred time integrating raingauges.

It is important to validate the various steps of the product elaboration. Previous works on the topics and especially within the AMMA and PMM frameworks have shown that the biases and the differences among different satellite product are very i) **time scale dependant** (Jobard et al., 2010., Roca et al., 2010) and ii) vary strongly between geographical areas and specially between land and sea.

In summary there is a need to characterize the bias in the products **at different scales** making use of i) ground based measurements over land and ii) satellite intercomparison over both land and ocean

Validation over the mesoscale dense gages networks :
The validation of the product at the smallest time step (24 hours for day1 – possibly 6 hours for day 2) will rely on the two high resolution rain gages network, and super-site. This is the scale where sub daily bias and the retrieval of the **diurnal cycle** can be assessed. The ground data resolution will be degraded (block kriging of the gages data and area mean of radar data) to match the product spatial resolution. However the information at the finest spatial scale is needed to assess the **ground truth accuracy,** whether it is derived from gages (Amani and Lebel, 1998) or radar (Russel et al., 2010 ; Gosset et al., 2010), in order to take these errors into account in the evaluation of the satellite product (Roca et al., 2010). Example of TAPEER / gages comparison over a 2009 test set are given in the document (MeghaTropiques cal-val Bilan 2010, prospective 2011 ; in french)

Validation at Regional scale with operational networks:

The CILSS will provide the main validation dataset and will deliver **daily interpolated** data at Sahel scale, through the AGRHYMET Regional Center. Whereas GPCC product is mainly based on GTS real time network, the ARC collects data from the secondary network and apply quality control process on them. AGRHYMET network covers all the CILSS countries. As its mandate has been recently extended to some of the southern countries down the gulf of Guinea, the provided gridded data could cover a larger area in the future. Presently however, the access to this data set with a delay compatible with cal/val activities (e.g. within the month of production) is difficult.
The validation data set provided daily (NRT) as part of the International Precipitation Working Group (IPWG) /validation actvities (0°5/daily data processed by CPC, ftp://ftp.cpc.ncep.noaa.gov/precip/CPC_UNI_PRCP/GAUGE_GLB/) will be a valuable data set to extend MT val over the Tropics.

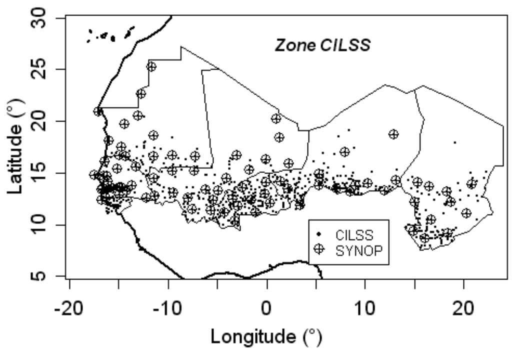
The evaluation will be done **over a range of spatial and temporal scales**, in order to evaluate what scale can be used for a given application. A special focus will also be paid to hydrological/land surface application requirements. A precise quantitative estimation of the rain amounts at basin scale is needed and the spatial and temporal resolution where this can be achieved need to be determined. The product evaluation versus gages should be made over the whole life of the mission in order to study regional, intra-seasonal and inter-annual variability and skill stability.

1.3Rain Ground observations overview

West African scale operational rain gages

This data will be available via collaboration with AGRHYMET - with possible addition from national weather services (DMN) if needed..

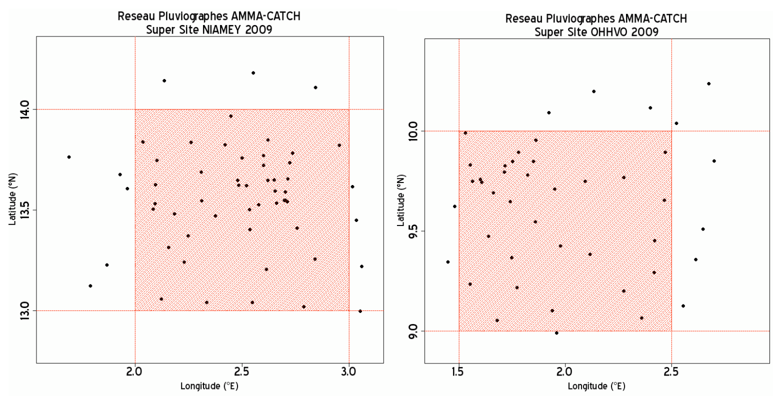
The data will be delivered on a **regular spatial grid (0.5 ° resolution**), for different time steps (**daily, decadal and month**), and with the associated **maps of estimation variances** (from kriging theory).



The CILSS gages network available via AGRHYMET.
Notes that the expertise zone of the AGHRYMET has now ***been extended further south*** *and data from the Gulf of Guinea zone are added to the network.*

Research gages network

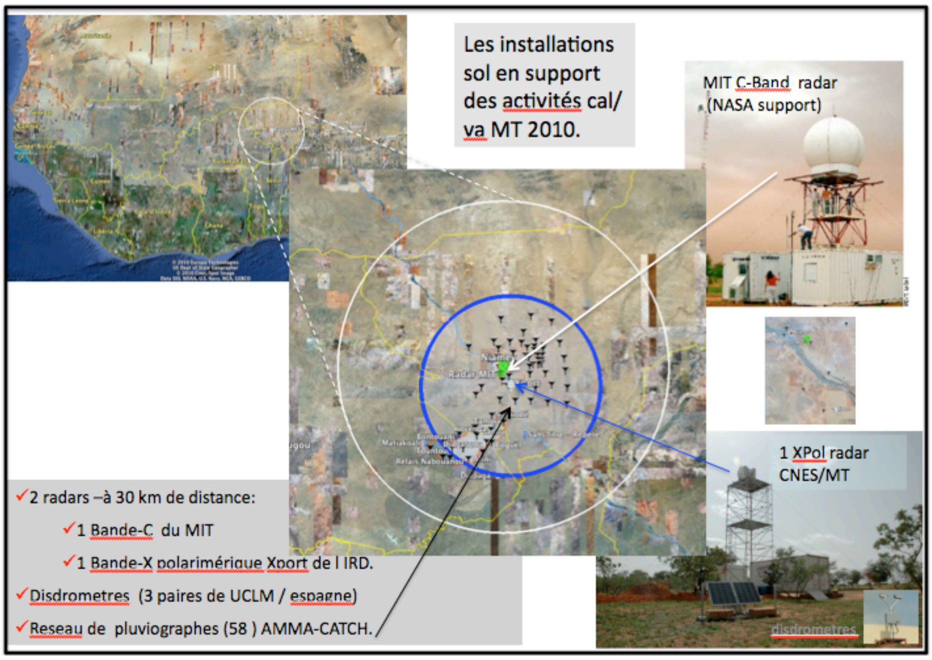
These are networks of tipping bucket rain gages with a resolution of 0.5 mm. The average density is 1 gage / 200 km^2 , for both main meso-scale sites (See Fig below).



Stations AMMA-CATCH utilisables pour constituer les séries de référence sur le site du Niger (gauche) et Bénin (droite). La maille (1°×1°) sur laquelle produit et référence sont comparés est en rosé.

Super site radar deployment

The French **polarimetric radar Xport**, which successfully operated in Benin during the AMMA EOP, and recently in Niamey in 2010, is a base instrument of our African Super site. The picture below illustrate the Supersite deployment that was set up in Niamey, during the summer 2010.



Given the recent events in Niamey (Sept 2010), it was necessary to install the super site in another area in West Africa.

Given its many advantages (location, climate, collaboration opportunities) Ouagadougou has been chosen to host the MT cal/val super site, from 2012. The dual polarisation measurements are useful to improve rainfall measurement accuracy (makes it less dependant on rain drop size distribution uncertainties and radar calibration) and to access detailed information on the hydrometeor properties (Dolan and Rutledge, 2009; Matrosov, 2009). With this equipment the expected accuracy on instant rain rate is about 20% and close to 10% on the daily amount (and can be improved if adjustment with rain gages is performed ; Gosset et al. 2010).

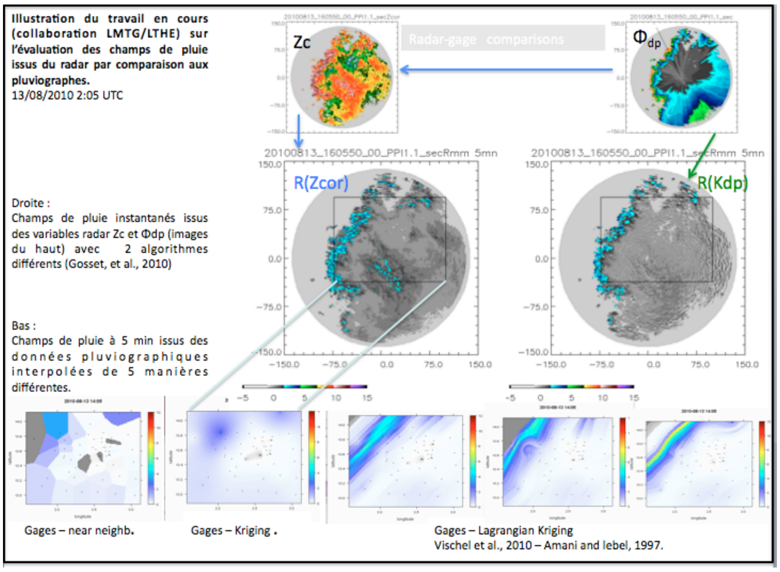


Illustration of Xport radar processing and QPE derivation, and comparison with the gages rainfall from different interpolation techiniques. From the 13/08/2010 case in Niamey.

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