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Megha Tropiques Ground Validation plan

Part 2 : Validation of humidity products

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1. SAPHIR overview

The SAPHIR instrument is a multi-channel passive microwave humidity sounder, measuring brightness temperatures (BT) in 6 channels located close to the 183.31 GHz water vapour absorption line (±0.2, ±1.1, ±2.7, ±4.0, ±6.6 ±11.0 GHz). Such channels allow for a description of the humidity content of the first 10-12km of the atmosphere. The radiometer has a cross-track scanning geometry, with a 10km resolution at nadir, and a swath of 1700km.
Additional information on the humidity content is brought by the 23.8GHz channel (integrated content) and by the two 157GHz channels (water vapor continuum) of the MADRAS radiometer.

The retrieval of the relative humidity (RH) profiles is based on an artificial Neural Network (NN) algorithm that will consider all the SAPHIR and MADRAS channels to extract the information of the vertical humidity distribution (Aires et al., 2011). The algorithm retrieves the humidity profile based on the SAPHIR/MADRAS observations, on a monthly mean climatology of land-surface emissivities (Prigent et al., 2008), and on some a priori information provided by the ECMWF (surface and atmospheric temperatures). A neural network algorithm has also been developed for the determination of the total column water vapour (TCWV).
The retrieval methods will be applied on the SAPHIR and MADRAS pixels of the level 1 A3 (projection of all the pixels onto the MADRAS 89GHz grid "10km size pixels centres"), for non-precipitating cases.

A third product has been developed during the spring 2011: the Upper Tropospheric Humidity is a SAPHIR-only product that provides an estimate of the mean relative humidity of a layer defined by the jacobian ($\partial TB/\partial RH$) of the atmospheric column. In fact the retrieval algorithm (e.g. Spencer & Braswell, 1997; Brogniez & Pierrehumbert, 2006; among others) can be applied to the 3 central channels of SAPHIR (±0.2, ±1.1, ±2.7).

Thus, three products require validation:

- Relative Humidity Profile (in %) provided on 6 layers + 1 level for the surface;
- Total column water vapor (in kg/m^2) defined as the total amount of water vapor in the column.
- UTH (in %) for each of the 3 central channels of SAPHIR.

The RH and TCWV retrieval algorithms have been developed under a reduced configuration of microwave observations, using radiometers the closest to the MT payload (Aqua: AMSR-E & HSB ; MetOp: AMSU-A & MHS). The uncertainties due to the retrieval algorithm have been evaluated in these reduced configurations. It is expected that the true MT products will have a reduced uncertainty. Two months of observations of the continental tropics from Aqua have been used to provide an evaluation of the retrieval, against quality-controlled radiosoundings launched at night. The profiles of the mean bias and rms are presented on Figures 1 a) & b). For this degraded case, the profiles of rms lies between 6% and 22% (systematic absolute mean bias between -4 and +5%), depending on the altitude (largest bias in clear air in the mid-troposphere) and on the cloud cover.

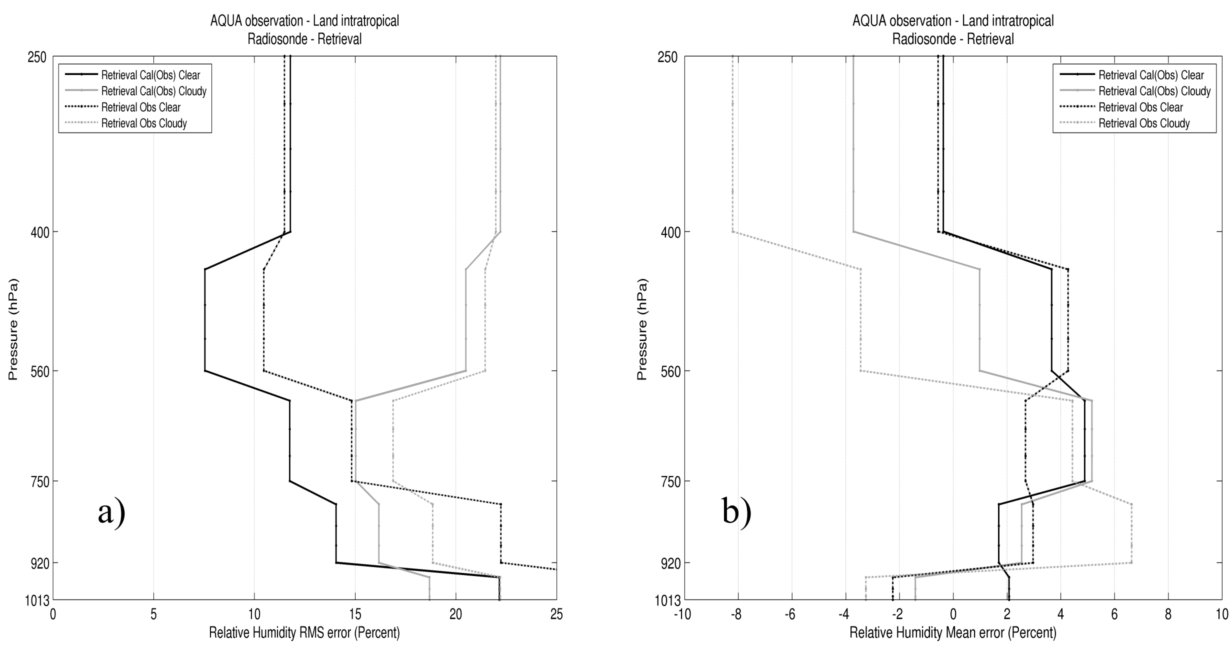
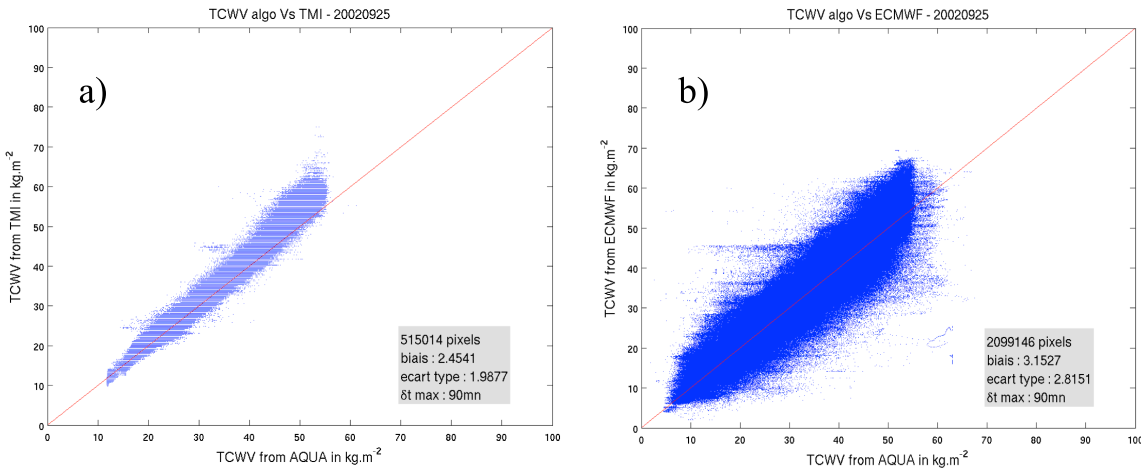


Figure 1: Profiles of the (a) root-mean-square differences (RMS) and the (b) mean error on the relative humidity from a comparison between radiosounding measurements and coincident retrievals from Aqua observations. The comparisons are performed for two months of data, at night, over tropical land scenes, and for clear (black lines) and cloudy (grey lines) cases. Also represented is the effect of the calibration of the satellite data (plain lines vs dashed lines) on the quality of the retrieval. Extracted from Aires et al. (2009).

For the TCWV, comparisons against the SSM/I retrievals over the oceans have revealed a centered difference (null bias) with a small standard deviation of 3.5 kg/m^2. Additional comparisons against the TMI retrieval and the TCWV provided by the ECMWF are shown on Figure 2, and confirm the small bias (2.4 kg/m^2 for TMI; 3.1 kg/m^2 for ECMWF) and standard deviation (1,9 kg/m^2 for TMI; 2,8 kg/m^2 for ECMWF).



<u>Figure 2</u>: Scatter plots of the TCWV estimated in the Aqua configuration versus (a) the operational TCWV from the TMI/TRMM radiometer and (b) the ECMWF estimates. The comparison is performed over 1 day of Aqua observations (25 sept 2002) with a max time delay of 90min for the colocation.

The validation plan relies on direct (*in situ*) comparisons with radiosoundings (RS) and indirect comparisons with estimations from ground and spaceborne remote sensing measurements.

2. Validation with radiosoundings

The validation against radio-soundings will be a basic statistical analysis with studies of the bias under various conditions that might affect the retrieval:

- the **water vapor content** of the profile (to evaluate a large dynamical range of the data).
- the **cloud cover**: although the microwave radiation penetrates most of the clouds, some types of clouds could affect the retrieval. Its is thus likely that the cloudy cases will have a different errors compared to the clear cases.
- the **surface type** (land/sea, vegetation type, sea surface conditions). Since the retrieval is based on the combined used of the SAPHIR and MADRAS channels, the observations will be more or less affected by the surface type and its spectral signature. The variation of the surface emissivity only affects the lowest layers of the troposphere, and its impact will need to be addressed.
- the **day/night contrast**: indeed it is not totally ruled out that the error in the retrieval will reveal a diurnal cycle that might come from the solar heating of the antennas of the radiometers, or from a change in the surface properties. It will be thus worth working on the diurnal cycle of the product.

It is worth noticing that although the RH profiles will be operationally retrieved on 7 layers, the design of the retrieval algorithm allows for a finer vertical resolution (43 levels corresponding to the radiative transfer model vertical resolution used for the design of the retrieval algorithm) that will be used to deepen the bias studies.

2.1 Choice of the sensor

Relative humidity measurements for research and operational applications are most widely performed with the Finnish Vaïsala RS92 radiosondes (Nash et al., 2005 –WMO; Nash et al., 2011 –WMO). Indeed, as in July 2007 (last update in the WMO catalogue, an update is still expected), about 1/3 of the upper air measurements from national weather services performed in the tropical belt were identified as RS92 type. The remainder stations use one of the following sensor type/manufacturer:

- the previous Vaïsala sensor RS80;
- the MODEM/M2K2 sensor (French, currently progressively replaced by the M10);
- the MEISEI sensor (Japanese);
- the IM MK3 sensor (Indian);
- the Shang sensor (Chinese);
- and the Sippican-VIZ sensor (American).

Most of the studies on the accuracy of water vapor measurements by radiosondes concerns the Vaïsala type. Only a few studies have provided a characterization of the accuracy of the Indian (IM MK3) and Chinese (Shang) sensors. Among them, the study by Wang and Zhang (2008) has highlighted the large errors of both Shang and IM MK3 sensors in the estimation of the precipitable water, translating into a large bias for the vertical profile of water vapor. The MEISEI sensor is characterized by insensitivity to changes in moisture under dry conditions (RH < 33%; Ciesieleski et al, 2010). The MODEM and Sippican sensors have shown reasonable accuracy under warm and moist conditions, while they have a strong bias under cold or dry conditions (Miloshevich et al., 2006). Studies on the accuracy on those two latter sensors concluded that, because insufficient information on the calibration procedures are provided by the manufactures, it is difficult to develop an accurate correction algorithm. Finally, the Vaïsala RS80 sensor is characterized by a strong dry bias with respect to the RS92 version, with a susceptibility to icing effect when entering an area with prolonged ice-supersaturation (Nuret el al., 2008).

For all these reasons, it has been decided to restrict the evaluation of the MT humidity profiles to Vaïsala RS92-SGPD only, despite its inaccuracies, in order to minimize discrepancies in data quality and biases. Indeed, with the numerous studies on its evaluation against reference sensors, algorithms have been proposed to correct the data. Inaccuracies in the measurements by the RS92 come from two sources: from the sensor itself, and from the measurement conditions. The following biases are given in absolute values:

- From the sensor itself, the slow sensor response at low temperature (< 45°C) to humidity changes implies a time-lag correction (Miloshevich et al., 2004 & 2006). Therefore, this lag is important above and below cirrus layers and at the tropopause, where humidity gradients may be steep, and results in a distortion of the profile. The correction is generally temperature dependant.

- The calibration performed by Vaïsala has also inaccuracies, which are functions of temperature and humidity (Miloshevich et al., 2006). Comparisons with reference sensors of known accuracy during nighttime have indeed revealed a moist bias in the lower (P>400hPa) troposphere (about 3-10% for RH> 10%, 10-30% for drier conditions) and a dry 10-23% bias for the upper levels (most RH conditions).
- During daytime, the solar heating of the sensor induces a dry bias, which is mainly a function of the solar elevation angle and of the cloud cover. Comparisons against references have shown that this error lies between 9% at the surface to about 50% in the upper troposphere (~15km) and depend on the relative humidity (Vömel et al., 2007; Miloshevich et al., 2009).

As illustrated on Figure 3, the two main corrections (calibration and solar heating error) have an impact of up to 20%, in absolute values, in the upper troposphere. After the corrections, the accuracy of the RS92 (with respect to a reference sensor) is 1% in the low troposphere (temp > -20°C), <2% in the mid-troposphere (temp in [-50°C; -20°C]) and < 3% in the upper troposphere (temp < -50°C) (Miloshevich et al., 2006 & 2009).

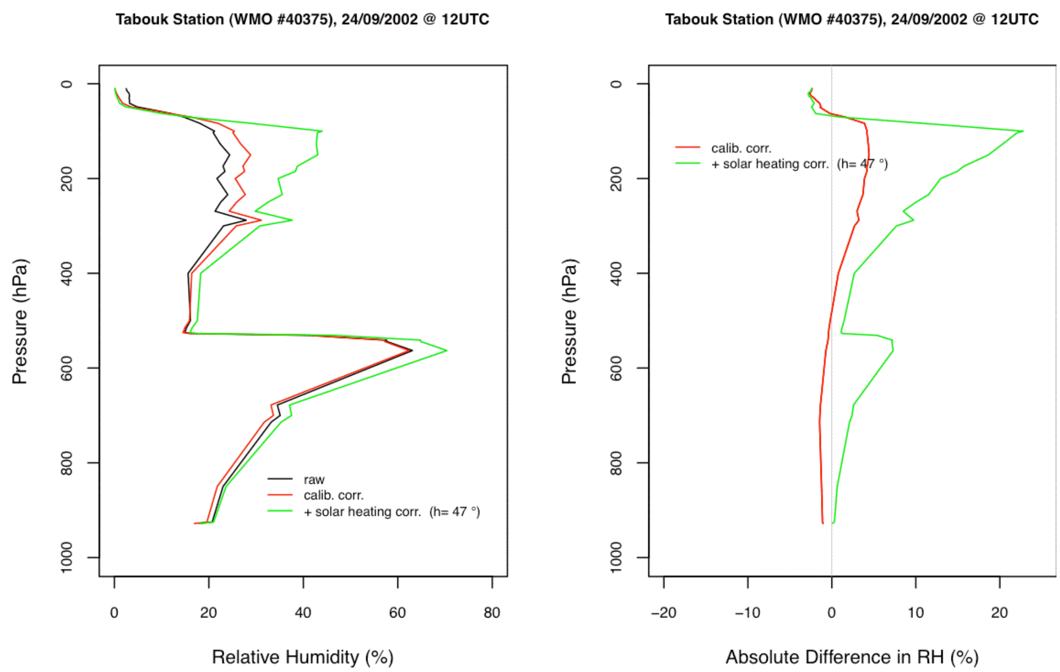


Figure 3: Effect of the calibration and solar heating corrections on the relative humidity measured by a Vaïsala RS92 sensor (from Miloshevich et al, 2006 & 2009).

However, those corrections depend strongly on the version of the software that processes the raw measurements: indeed in December 2010 Vaïsala released version v3.64 of the

Digicora software that performs the correction of the sensor time-lag error and of the solar heating error.
The last campaign of intercomparison of radiosonde systems performed by WMO (Nash et al., 2011) has again underlined the very good performances of the Vaïsala RS92-SGPD system, even further improved with the software correction. The level of correction required will thus depends on the date of production of the sensors and on the software used.
(http://www.vaisala.com/en/meteorology/products/soundingsystemsandradiosondes/soundingdatacontinuity/Pages/humiditymeasurementimprovedalgorithm.aspx)

Despite improvements in the calibration procedure (Vaïsala performs an annual re-calibration of their factory reference) and software updates, it will be wise to check the quality of the measurements with a reference sensor. This evaluation is described in section 2.3.

2.2 In West Africa: the dedicated campaign

The French GV activities will focus on the West African region and on the super-site of Ouagadougou (12°N, Burkina Faso). As detailed above, the validation approach should take into account the various climatic conditions encountered in the tropics and thus sample (i) the 0-100% relative humidity range to test the retrieval according to the thermodynamic, (ii) a variety of cloud cover to check the sensitivity of the retrieval to the cloud type, and (iii) a variety of surface type to evaluate the influence of the surface in the retrieval scheme. This site will be an asset for the validation since orbital studies of the MT configuration by M. Capderou have shown that a mean of up to 5.5 daily overpasses are expected around 12-15° (N/S). The use of the orbitography software Ixion (http://climserv.ipsl.polytechnique.fr/ixion.html) thus allows forecasting the hours of overpasses (uncertainty of 15min). The overpasses for the period May to August 2012 are shown on Figure 4.

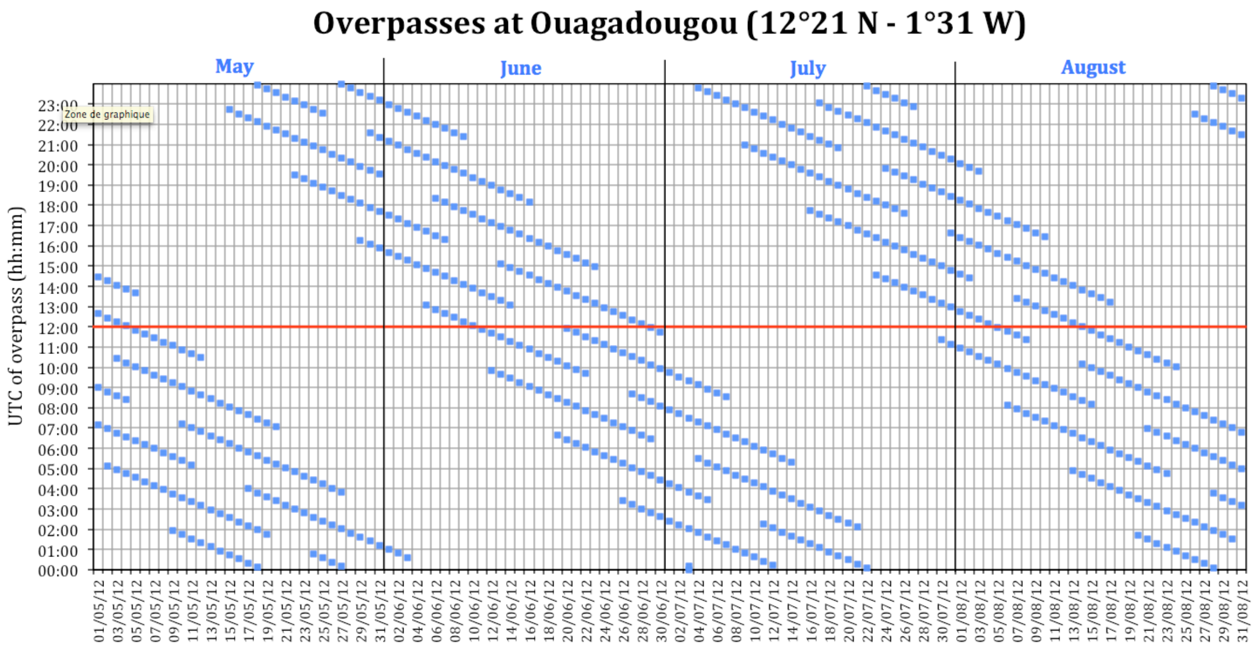


Figure 4: Forecasts of the hours (UTC) of MT overpasses over Ouagadougou (Ixion software) for the period May-August 2012. The red line indicates the operational sounding @12 UTC.

The validation of the retrieval under the various atmospheric conditions of the tropics yields to plan at least two distinct periods (i.e. 2 × 2 weeks) for the launches of RS: the pre-monsoon period (a dry phase), and the monsoon period (a moist phase). An efficient validation of the profiles will rely on a large sampling of atmospheric conditions in order to document the error and to perform a robust feedback to the algorithm.
In collaboration with ASECNA, launches of RS92-SPGD will be performed once a day in order to sample one overpasse of the satellite. Currently, there is one operational sounding (MODEM system) launched at Ouagadougou by ASECNA/DNM at 12h UTC.

In order to avoid any overlap between the operational sounding and the validation soundings, and thus avoid any logistic problem that could be induced for instance by the inflation of the balloons, the 2 periods of validations are:

- 25/05 → 05/06
- 14/07 → 26/07

with 5 overpasses between 3 pm and 2 am.

Following the validation plan designed for AIRS/AMSU/HSB on Aqua (Fetzer et al., 2003) 2 RS will be launched, under clear sky conditions, at each overpass to evaluate the mid-to-upper troposphere and the lower levels: one first launch 45 min before the overpass will lead to almost synchronized observations of the UT and a second launch 10 min prior will sample the lower levels.

→ thus 2 × 14 days × 2 RS/day + 8 additional RS in order to cope for eventual problems = 64 RS

A particular effort to reduce the temporal gap between the Megha-Tropiques observations and the RS will be required. It is also important to notice that the bias analyses will include the differences induced by the spatial resolution, between the MT footprint (10km for the Level 1A3) and the air mass considered by the sensor. The drift of the balloon during its ascent is also an issue in this kind of evaluation and should be taken into account while doing layer-to-layer comparisons. A recent study by Seidel et al (2011) shows that at 300hPa the mean observed drift, among more than 400 stations, reaches 50km in the tropical belt during the summer.

Finally, the data will be transmitted through the GTS in order to be assimilated by the forecast models (ECMWF).
Training on the Vaïsala Digicora acquisition system will be performed during the 1st semester of 2012 with the help of Dominique Legain.

2.3 Over the Tropical belt: use of available data

2.3.1 The MeteoFrance tropical stations

In agreement with the DSO of MeteoFrance, the high resolution soundings (raw) that will be performed operationally at each of the 7 tropical sites (Le Raizet - Gouadeloupe; Noumea - N. Calédonie; Rochambeau - Guyane; Gillot - La reunion; Atuona, Faaa, Rikite - Polynésie Fr.) will be made available for the whole year 2012.
A securised ftp server, hosted by Climserv/IPSL, has been created in order to stock the raw data and exploit them.

2.3.2 The Global Telecommunication System

In order to perform a tropical wide validation, profiles of temperature and humidity available from the Global Telecommunication System (GTS) will be used.
The data are freely available via the Integrated Global Radiosonde Archive (IGRA) from the National Climatic Data Center (NCDC) of NOAA (Durre et al., 2006). This archive includes the (GCOS) Reference Upper-Air Network (GRUAN) (Immler et al., 2010). The Figure 2 below gives the distribution of the IGRA stations according to the sensor type (as in July 2007, record from the WMO), and it shows clearly the importance of using this archive to complete the West African site (see section 2.3).
Each sounding undergoes a stringent quality control before it is made available through IGRA. The quality checks concern 7 categories that eliminate successively erroneous measurements: a so-called “sanity check” (date and physical limits of the measurements),

checks on surface elevation, consistency checks (physical relationships between variables and vertical consistency for each variable), checks of excessive repetition of values, climatological check (comparisons with respect to long-term climatology), additional checks on the temperature (temporal and vertical consistency), and checks for data completeness. Following section 2.1, the use of the IGRA network is restricted to the stations using Vaïsala RS92 sensors.

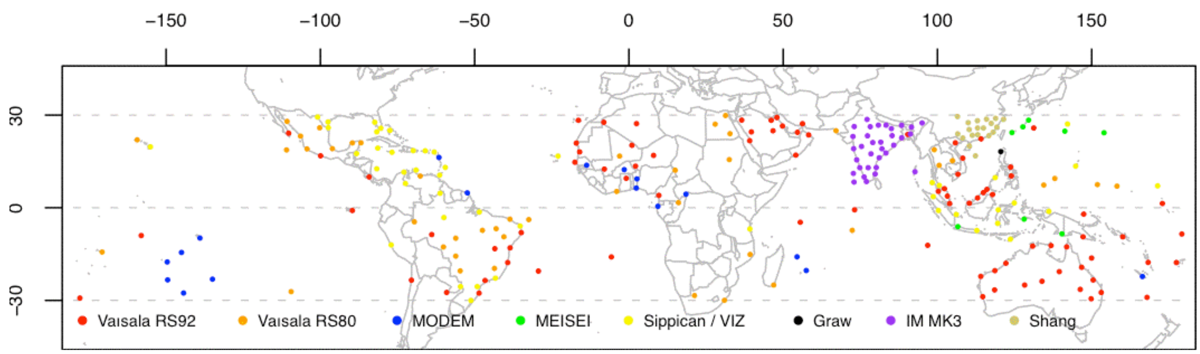


Figure 5: Distribution of the IGRA stations according to the sensor type, still active in 2007 and located at altitude below 1000m.

Since IGRA is updated on a daily basis, the data of all tropical stations (±30°) using RS92 sensors will be downloaded daily to perform a systematic evaluation of the RH profile at each time of overpass by the satellite. Figure 3 illustrates such evaluation for a test retrieval for the Aqua platform (AMSR-E/HSB configuration) with a single overpass with the Tabouk station (Saudi Arabia), and with accumulated coincidences over a week (24-30 sept 2002). It is important to note that Figure 3 is just an illustration, that relies on a reduced configuration (3 water vapor channels) and it is likely that the three additional channels of SAPHIR (1 sounding higher in the troposphere and 2 soundings in the lower troposphere) will improve the quality of the retrieval. The horizontal error bar for the retrieval has been evaluated in this reduced configuration and does not prefigure the error of the MT retrieval.

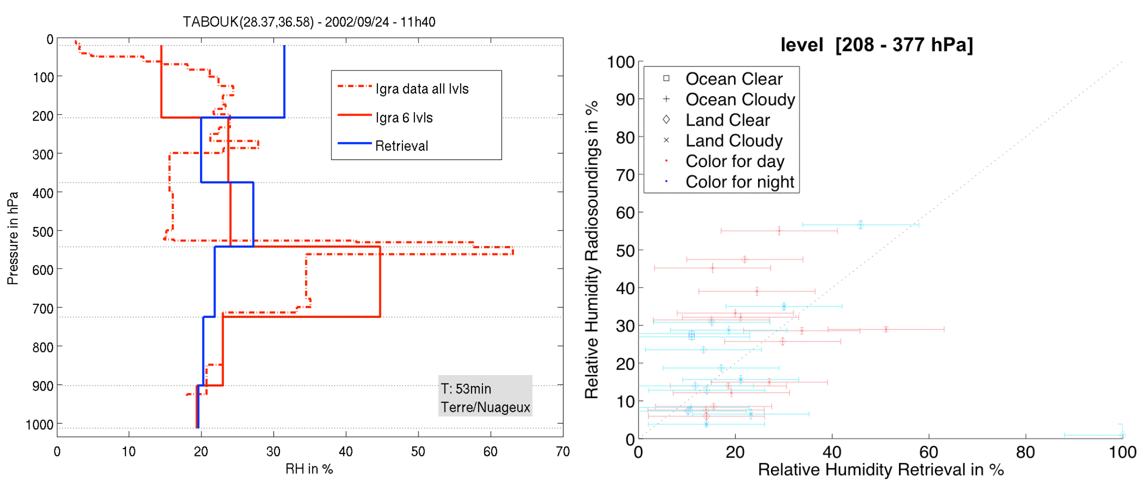


Figure 6: (left) Comparison between a retrieved relative humidity profile (blue) and the coincident measurement from a radiosounding launched on 24 sept 2002 @ 11h40 (LT). (right) Comparisons accumulated over a week (24-30 sept 2002) for the layer 208-377 hPa. For the evaluation, a maximum distance of 1h30 and of 1° are authorized, and corrections on the measurements by the RS92 are applied following the discussion of section 2.1.

Such database will be used to perform a long-term monitoring of the quality of the retrieved RH, before and after the dedicated validation campaign in West Africa.

2.3.3 Opportunity campaigns

a) The CYNDI/DYNAMO for the study of the Madden-Julian Oscillation [1/10/2011-31/03/2012]
During this campaign, all the soundings are Vaïsala RS92-SGPD, and the software is the last software released by Vaïsala (Digicora III, v3.64) that includes the solar heating correction.

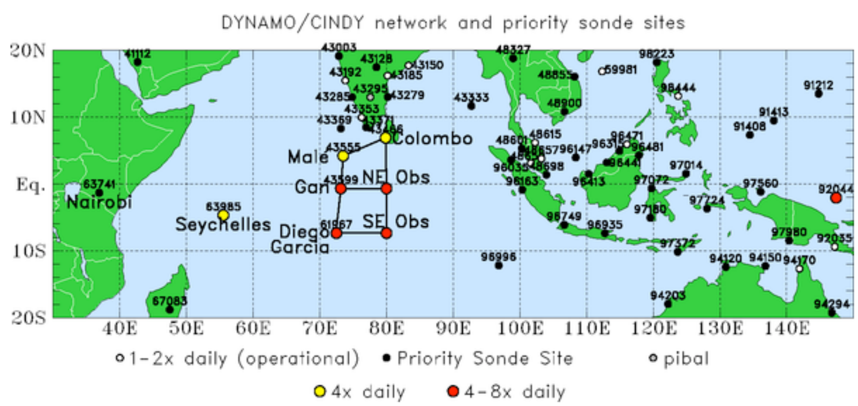


Figure 8: map of the CINDY/DYNAMO network.

Following the experimental design book, the launch plan is the following:
- SOP (1^{st} oct → 9 nov 2011 = 40 days) : 8 RS/d (Δt=3h) from every island and all ships.
- IOP (10 nov 2011 → 15 jan 2012 = 67 days) : 4 RS/d except in Gan where 8 RS will be performed
- EOP (16 jan → 31 march 2012 = 75 days) : 4 RS/d in Gan

The table below summarizes the scheduled soundings during the campaign, while Figure 9 shows the number of launches performed since the begining of the campaign.

Site	Gan *(US - ARM)*	Diego Garcia *(US)*	Seychelles	Darwin	Cocos	R/V Revelle *(US)*	R/V Mirai *(Japon)*	R/V Southern Surveyor *(Australie)*	Sagar Kanya *(Inde)*	Total
SOP *(40j)*	Δt=3h	Δt=3h	Δt=6h	Δt=6h	Δt=6h	Δt=3h	Δt=3h	Δt=3h	Δt=3h	2400
IOP *(67j)*	Δt=3h	Δt=6h	Δt=6h	Δt=6h	Δt=6h	Δt=6h	Δt=6h	Δt=6h	Δt=6h	2680
EOP *(75j)*	Δt=6h	-	Δt=12h	Δt=12h	Δt=12h	-	-	-	-	750
Total	1156	588	578	578	578	588	588	588	588	**5830**

Figure 9: Number of sondes launched from each site since 01/10/2011 until 27/11/2011.

The data are currently available through the GTS and thus at a reduced resolution, which does not allow for reaching the radiometric sensitivity required when doing sounding-versus-satellite comparisons.
A request to have access to the high resolution data for the Megha-Tropiques validation has been send (21/11/2011) to Richard Johnson (NCAR/CSU) and to K. Yoneyama (JAMSTEC) which are in charge of the US and Japanese CYNDI/DYNAMO soundings experiments:

- We have access to the soundings performed onboard the R/V Mirai, the R/V Sagar Kanya and from Colombo Island.
- Concerning the NCAR & CSU soundings, the access to the high-res data is also accepted but a lot of work concerns the sanity check of the data that will be not granted at first by the team.

b) The ANR funded campaign TRO-pico (Coordinator: E. Rivière, GSMA at Univ. of Reims) will take place in Bauru, Brazil (22°S) during the 2011-2012 winter.
TRO-pico is a four-year project dedicated to the study of the water budget around the tropical tropopause at different time and space scale. It is based on a field campaign (mostly balloon-borne) in Bauru, SP, Brazil, at two different time-scales. The first period of sampling, so-called SMOP (six month observation period in two phases, from January to March 2012 and from October to December 2012), will study the water vapor evolution at the wet season scale with regular soundings. Embedded into the SMOP, the IOP (intensive observation period) of two months (January-February 2012) will measure water vapour and other atmospheric parameters (CH_4, CO_2, O_3, NO_x, Electric fields, Aerosols or ice particles) for specific convective cases. The main instrument that will measure water vapor during TRO-pico is the pico-SDLA infrared laser hygrometer developed at DT-INSU and GSMA. In the frame of TRO-pico, a task is dedicated to the validation of satellite-borne water vapor measurements (e.g. IASI, Megha-Tropiques). The high-resolution profiles obtained during the campaign in the UTLS, where the RS are

known to be inaccurate or biased, will be an input for the validation of the SAPHIR products in the UT. The idea is to use at least some of the SMOP flights of pico-SDLA to make this evaluation. The SMOP flights will be performed at the same time of the day during all the sampling period to avoid a diurnal cycle effect in the seasonal tendency. The time will be chosen to be coincident with a satellite overpass.

2.3.4 The ARM sites

Currently, there are three ARM sites active in the tropical belt (Tropical Western Pacific: Darwin, Manus Island & Nauru Island) that provide measurements of the atmospheric humidity (profile + integrated content) and of the cloud liquid water via balloon-borne sounding systems and microwave radiometers.

It is also important to emphasize that the validation campaign (RS sites + cruise) planned by the Indian science group will complement the database.

2.4 Ship campaigns

In addition to the validation of the products over land, oceanic regions will be also considered. Therefore ship campaigns of opportunity are needed to perform the dedicated calibration plan but also the validation of the products.
At the beginning, the 2012 PIRATA campaign (FR22, leaded by LEGOS, PI: Bernard Bourlès) was the only ship campaign considered.
The plan was to participate actively (4 RS / day + the DRAKKAR radiometer) to the cruise in order to have coincident RS with the overpasses and a continuous monitoring of the TCWV thanks to the radiometer.

However, the access to the hundreds of high-resolution radiosounding measurements of the CYNDI/DYNAMO campaign with various oceanic conditions (see section 2.3.3-a) put down the interest of our participation to the 2012 PIRATA cruise.

Nevertheless there is still a strong interest in the PIRATA cruises: a scientific evaluation of the processes, such as the humidity fluxes, observed by Megha-Tropiques could be thus performed during the 2013 cruise.

2.5 Evaluation of the RS92 sounding system

In every field campaign it seems essential to include a phase of evaluation of the measurement system with an intercomparaison using a reference.

Two systems are currently considered as reference: the Snow-White hygrometer (SW, Meteolabor) and the Cryogenic Frostpoint Hygrometer (CFH, NCAR). It is however important to keep in mind that while the SW hygrometer is usually considered as a reference under moist conditions in the lower to mid-troposphere (1-2% absolute accuracy, see Miloshevich et al., 2006), this sensor does not seem to be able to measure under very dry conditions where RH < 3-6% or within and above thick clouds (Fujiwara et al., 2003; Miloshevich et al., 2006), which is not a problem for the RS92.

With the currently known biases (see section 2.1), two ways will be used to evaluate the RS92:

- use the GRUAN correction method: H. Vömel, head of the GRUAN, has proposed to include the raw RS92 data from the MT field campaign in the GRUAN processing chain that correct the biases, the reference being the CFH.
- use the Vaïsala software: the correction can be turned off/on.

The CYNDI/DYNAMO team is also planning to evaluate Vaïsala's correction and GRUAN's correction with 15 CFH launches from the R/V Mirai (both nighttime and daytime), with GPS data.

According to the results of these independent evaluations, we might need to schedule in 2013 a dedicated intercomparison phase using either SW or CFH, and with the goal to adapt the Nuret et al (2008) CDF-matching method. In order to adapt this method, measurements during nighttime and daytime, at two solar elevations (7:30 and 11:30 am), are mandatory.

2.6 The Raman lidars of the tropical belt

Currently, in the one water vapor lidar (Raman) located at Mauna Loa Observatory (Hawaï) is providing continuous measurement of the water vapor through the NDACC network.
A second lidar (Rayleigh-Mie-Raman) should provide similar measurements, up to 20 km, from the Observatoire de Physique de l'Atmosphère de la Réunion. Its operation should start in April 2012, at the Maïdo site, and should join the NDACC network.

A joint work with Philippe Keckhut will be done in order to evaluate the MT profiles with respect to the profiles observed by the lidar.

3. Ground network measurements of TCWV

It is indeed important to characterize not only the relative humidity profile, but also the integrated content since a preliminary step in the validation of the profiles is the verification of the total content of humidity before the evaluation of its vertical distribution.
Moreover, an important part in the design of the retrieval algorithm of the humidity products concerns the implementation of the continental surface emissivity, determined at the Megha-Tropiques frequencies by interpolation from an existing SSM/I atlas (Prigent et al, 2009). Such design reduces considerably the error in the simulation of brightness temperatures over land with respect to default values used in the radiative transfer code. Hence tests on AMSU-A/MetOp channel at 23.8GHz (sensitive to the integrated content of water vapor) have revealed a reduction on the RMS from ~15K to ~7K in the case of

the vertical polarization and from ~30K to ~6K for the horizontal polarization, this reduction being only due to the implementation of a realistic surface emissivity. The GPS and AERONET networks will thus complement the RS network for the validation of the products over land, within the tropical belt.

3.1. Over the Tropical belt

A continuous monitoring of atmospheric water integrated contents (TCWV) will be done using ground remote sensors (ex: photometers, radiometers, GPS) belonging to existing networks. These sensors record data continuously, at short time steps, which is ideal to study the diurnal cycle. Integrated contents from ground-based instruments will be an additional quality control for the RS profiles.

The AERONET network provides also a good coverage in the Tropics, with TCWV measurements from sunphotometers (940nm) every 15min with an accuracy of 10% (Schmid et al., 2001). The Figure 4 below shows the location of the AERONET sites.

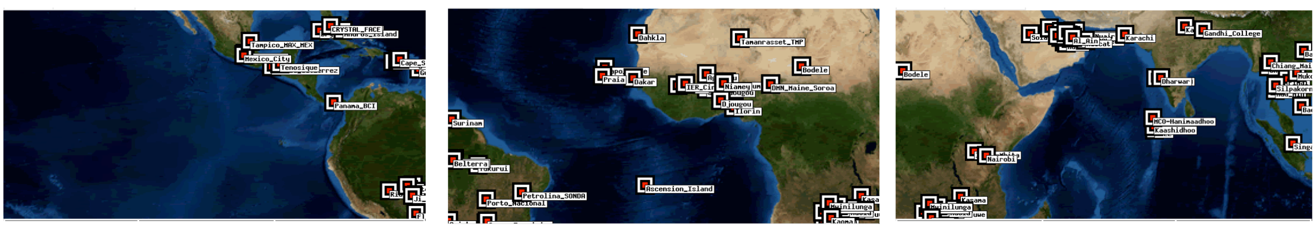


Figure 10: A total of 120 AERONET stations are located in the tropical belt (including 10 in the Pacific Islands)

The estimation of the integrated content of water vapor can be done via the GPS tropospheric delays (Bock et al., 2007), with uncertainties of 1-1.5 mm (1-2 kg/m^2 of IWV) (Elgered et al, 1998). During AMMA, 6 sites were equipped with GPS stations (Tamale, Ouagadougou, Tombouctou, Djougou, Niamey and Gao) and provided integrated contents every hour or so (Bock et al., 2007, 2008). Hence, the use of the International GNSS (Global Navigation Satellite System) Service (IGS) (Dow et al., 2005, Figure 5) will be done in collaboration with Olivier Bock (IGN). Note that GPS water vapor retrievals are also useful for verifying RS humidity measurements (Bock et al., 2008; Wang and Zhang, 2008).

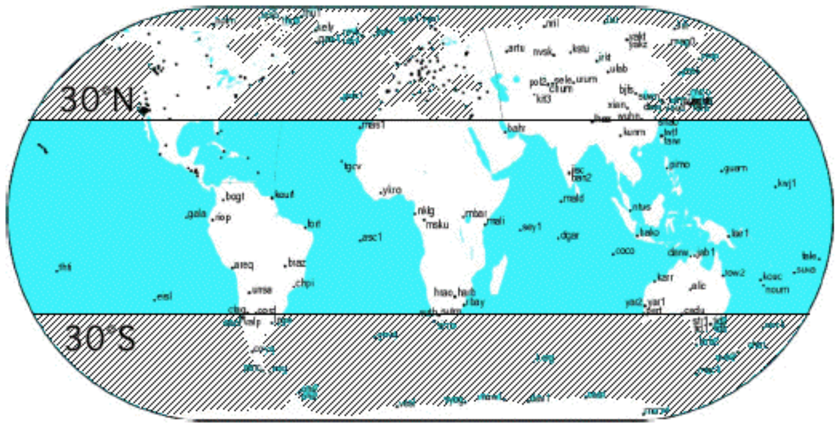


Figure 11: Distribution of the IGS sites in the tropical belt. From Dow et al. (2005)

3.2. In West Africa

The IGS GPS data will be complemented with specific observations over Africa (cf figure 5) provided by stations installed in the framework of AMMA (Bock et al., 2008). These stations will be maintained through collaborations established with national agencies (mapping institutes and meteorological services) and ASECNA as follow-on to AMMA.

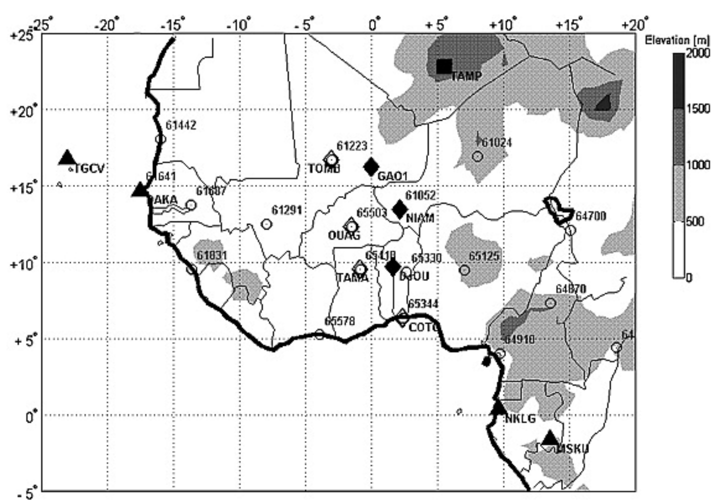


Figure 12: Distribution of the GPS sites (4 letters) during the AMMA EOP and SOP campaigns. From Bock et al. (2008)

4. Evaluation of the Upper Tropospheric Humidity product

The UTH can be considered as the relative humidity profile weighted by the relative humidity jacobian J_i^{RH}, that reflects the contribution of each level of the troposphere to the measurement at the top-of-the-atmosphere in the 183 GHz band.

Therefore, all the soundings performed for the validation of the RH profile will be used to evaluate the UTH, coupled with the same radiative transfer model (RTTOV) to define the J_i^{RH}.

5. Evaluation against other satellite products

Satellite observations provide a global coverage of the globe and can complement the validation sites with a large additional number of points.

Water vapor retrievals (profiles & integrated contents) from other satellite platforms cannot be used as a reference for the absolute evaluation of the Megha-Tropiques products, since their retrieval error characteristics similar to those of MT. They are however very useful for monitoring trends and to check pattern consistencies.

The amount of possible satellite-to-satellite comparisons will depend on the availability of the data, and more specifically on the life of the missions, which is an uncertainty. The table below lists the instruments that will be considered.

radiometer	Specified uncertainties	Estimated uncertainty	Retrieval	Period of operation
AIRS (Aqua)	spec hum profile: 15% in 2-km layers (Susskind et al, 2003)	< 20% in the tropical UT (Gettelman et al, 2004)	clear sky + up to 70% cloud cover	launchedw in 2002 (+6) and still operational
IASI (MetOp)	spec hum profile : 10% in 1-km layers	//		MetOp-A launched in 2007 (+5) MetOp-B scheduled in 2012
SSM/I; SSM/T2 ; AMSU(MHS)		integrated content (IWC): 4-5 kg/m^2	ocean	
SEVIRI (MSG)		total water vapor column (PW): 0.2 mm (Schroedter-Homscheidt et al, 2007)	cloud-free land surfaces	

6. Feedback validation - algorithm

During the validation phase, a phase will be dedicated to include the observed biases into the algorithm and correct them.

The correction will differ according to the type of bias: a systematic bias induced by an asymmetry in the scan or by a calibration issue will require an adapted correction scheme before the application of the retrieval, while a thermodynamic-dependant bias (e.g. systematic dry bias in the moist layers) would require an adjustment of the neural-network through a improved training.

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