Report on the Joint workshop on uncertainties at 183GHz

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Joint workshop on uncertainties at 183GHz

29 & 30 June 2015

Workshop summary

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1. Overview

A two day workshop was held 29-30 June 2015, in Paris, to discuss biases observed between measurements at 183 GHz and calculations using different radiative transfer models and using either radiosondes (RAOBS) or short range forecasts from Numerical Weather Prediction (NWP) systems. There were three main objectives of the workshop: firstly to describe the biases, trying to separate those biases which were common to all approaches from those which may have been a result of a particular methodology; secondly to identify and, where possible, quantify uncertainty in every component of the comparison; and lastly, where possible to begin the process of attribution of the biases, which could in due course lead to their elimination.

In order to address these ambitious goals, experts in many different aspects were assembled. This included specialists in RAOBS calibration, NWP models and data assimilation, instrument biases and radiative transfer models, both the models themselves and the underlying spectroscopy. Comparisons were also undertaken with other techniques for sensing humidity information such as Global Navigation Satellite Systems (GNSS), Differential Absorption Lidar (DIAL), Raman lidar and infrared (IR) radiances. The workshop was built around overview presentations and working group discussions.

The presentations and the working groups triggered intense and valuable discussions.

The agenda of the workshop is given in Appendix A. The presentations of the workshop are available from a password protected ftp site, hosted by the Institut Pierre Simon Laplace. The password may be obtained by contacting H. Brogniez. The list of participants, with their affiliations and email addresses, is provided in Appendix B.

2. Background

The Advanced Technology Microwave Sounder (ATMS, onboard Suomi-NPP) and the Sondeur Atmospheric du Profil d'Humidité Intertropical par Radiométrie (SAPHIR, onboard Megha-Tropiques) give an improved sampling of the 183GHz water vapour absorption line. ATMS provides the traditional observations at ±1.0GHz, ±3.0GHz and ±7.0GHz that are supplemented by observations at ±1.8GHz and ±4.5GHz, whereas SAPHIR has nearly identical channels plus a ±0.2GHz channel very close to the center of the line and a ±11.0GHz channel that observes the wings of the line.

Cross-comparisons between existing sounders, adding the Microwave Humidity Sounder (MHS onboard MetOp-A and B and NOAA-18 and 19) to the list, show a very good consistency among them, within the radiometric noises of the instruments (Wilheit et al., 2013; Moradi et al, 2015). However, when the measurements are assimilated in a NWP model, or compared to radiative transfer model calculations that use radiosonde profiles of temperature and humidity, a channel-dependent bias that increases from the center to the wings of the 183 GHz line is observed (Chambon et al., 2014; Clain et al., 2015). Figure 1 shows clearly this pattern.

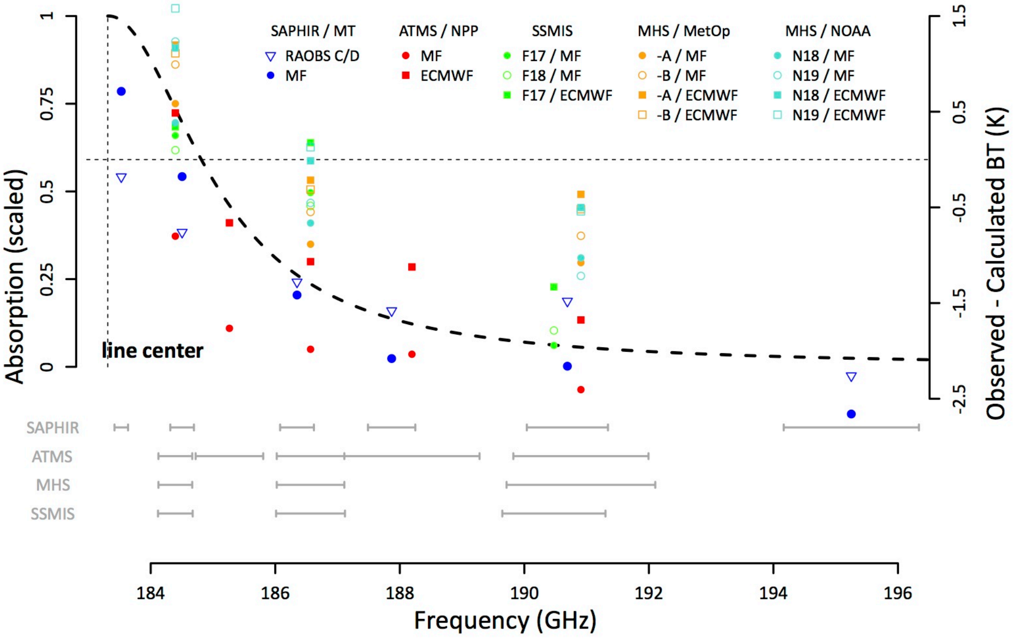

Figure 1: Observed minus calculated BT using either radiosondes measurements (RAOBS from the CINDY/DYNAMO/AMIE field campaign, winter 2011-2012, triangles) or NWP models of Meteo-France (MF, circles) or of European Center for Medium-range Weather Forecasts (ECMWF, squared). Each colour refers to a specific sensor, specified in the legend. All the calculated BTs have been done using the RTTOV model.

3. Session 1: Biases in in-situ observations *(chaired by S. English)*

During their talks, June Wang and Peter Thorne discussed the uncertainties in the measurements of water vapour from radiosondes (RAOBS) and GNSS receivers and the metrological closure when comparing two measurements (co-location effects, uncertainties, etc.). Andreas Berhendt presented the use of lidar systems to estimate atmospheric water vapour.

An emphasis was put on the GCOS Reference Upper-Air Network (GRUAN) and the Gap Analysis for Integrated Atmospheric ECV Climate Monitoring (GAIA-CLIM, Horizon 2020) project. On one hand, the aims of GRUAN are to establish a reference network of temperature and humidity measurements with traceability to SI standards, full metadata description and best possible characterization of uncertainties (GRUAN, Dirksen et al., 2014; Bodeker et al., 2015). On the other hand, GAIA-CLIM focuses on establishing methods for the characterisation of satellite-based Earth Observation data (atmosphere, ocean and land) by surface-based and sub-orbital measurement platforms.

- Radiosondes: Uncertainties in RH arise mainly from the calibration procedures, the calibration corrections, time-lags and (for some probes) the solar radiation heating of the sensor. In the Vaïsala RS92-SGP (hereafter RS92), one of the most common RAOBS probes used for the operational network and field campaigns, the fully traceable characterized uncertainty in RH measurements after correcting known biases is overall below 6%RH and the only uncorrected bias is a dry bias of ~5%RH at night at temperatures colder than -40°C (Dirksen et al., 2014). Therefore radiosonde errors could only explain biases near the line center (corresponding to upper tropospheric humidity, see Clain et al., 2015) whereas the biases are significant towards the wings.

The reliability of the RS92 product in the troposphere has been verified by comparisons with frostpoint hygrometer (FPH) measurements, which are highly accurate balloon borne humidity measurements at several locations including both tropical and extra-tropical regions. The GRUAN RS92 profile for humidity does not vary greatly from the default processing until reaching upper tropospheric levels, assuming that the site uses the most recent processing packages (Yu et al., 2015). Further, the most recent intercomparison campaign (Nash et al., 2011) held in Yangjiang (a tropical site in South China) showed good agreement between RS92 sondes and most other operational sondes up until the mid-to upper troposphere. For a subset of flights, these comparisons included FPH measurements. In the lower to mid-troposphere there is therefore robust agreement and evidence that sonde biases could at most be a few percent with somewhat broader random uncertainties on individual ascent profiles.

- GNSS receivers: GNSS estimations of the atmospheric precipitable water (PW) rely on the measurement of the zenith total delay induced by the presence of water vapour (the “wet” delay) and by the dry gases of the troposphere (the “dry” delay). The GNSS estimated PW has a mean uncertainty of ~2% (<1.0mm) (Tong et al., 2015). A recent analysis of the upper-air sounding network deployed during the CINDY/DYNAMO/AMIE field campaign has revealed an unclear, and statistically significant, dry bias in the GNSS values (~2.0mm in PW) at moist conditions (Ciesielski et al., 2014).
- Lidar systems: Two types of lidars can be used to measure water vapour profiles (e.g., Behrendt et al., 2007a,b; Bhawar et al., 2011). Differential absorption lidars (DIAL) measure the water vapor number density with two backscatter signals (at high -online- and low -offline- absorption wavelengths, in the near-IR) yielding a self-calibrating system. It relies only on the difference of the water vapour absorption cross-sections s_{on} and s_{off} at these two wavelengths. Performance simulations as well as intercomparisons have confirmed an accuracy < 5% in the troposphere (see Wulfmeyer et al. 2015 for a recent detailed overview). Water vapor Raman lidars are based on inelastic scattering of atmospheric water vapour molecules. These systems require one calibration factor for all heights to obtain the water vapour mixing ratio. Reports from intercomparisons show a typical accuracy of < 5% for water vapour Raman lidar in the troposphere (see also Wulfmeyer et al. 2015). All lidar systems provide data in the cloud-free atmosphere or until the laser beam reaches an optically thick cloud.

Working Group Discussions:

- A possible contributor to a bias in the observed-calculated BT difference could be also a spatial and temporal mismatch between the satellite measurements and the reference station (radiosonde/GNSS/lidar). One aim of GAIA-CLIM is to understand and characterize such spatio-temporal mismatch. It has been recalled that NWP analysis acts as a transfer function in time/space for radiosonde data, which it is anchored by. That is why we see the similar results between the comparisons using NWP models and those using radiosondes.

- It was also noticed that radiosondes can have additional instruments: for instance a group in Reading is adding a small radiometer to radiosonde probes which gives an idea of when the instrument goes through cloud and when it comes out at the top.

- The next generation of Vaisala probes is RS-41: it has lower random errors and less need for bias corrections => When is planned the next WMO intercomparison campaign? This campaign should include both RS-92 and RS-41 in order to state clearly on the improvements brought by RS-41 with respect to RS-92. Intercomparisons are currently performed within GRUAN.

- A campaign took place in La Réunion island early 2015 that included a lidar and several types of radiosondes (e.g. Modem M10, RS92, CFH), while the NOAA Reconnaissance program gathered dropsonde measurements under tropical cyclones over the 1996-2012 period (Wang et al., 2015; https://www.eol.ucar.edu/content/noaa-hurricane/dropsonde-archive) => Could be used to confirm the results found to date, as well as AMDAR (Aircraft Meteorological Data Relay, WMO program): ECMWF studies suggest that aircraft humidity might be more accurate than conventional RAOBS at low temperatures.

4. Session 2: Biases in space-borne observations *(chaired by C. Accadia)*

The calibration status of the 183GHz channels of GPM GMI and of the other sensors were presented by Wesley Berg, while William Ingram discussed the homogenisation procedures of microwave humidity sounders.

- Calibration status of various sensors: Recent comparisons of the 183.31 GHz channel calibrations have been performed by the Global Precipitation Mission (GPM) intercalibration working group (XCAL team). The comparison of the GMI brightness temperatures (BTs) with the 183.31GHz centered channels from the four operational MHS sensors as well as ATMS and SAPHIR instruments have been performed. These intercalibration differences were derived using a double difference technique, which computes the observed minus simulated BT differences for coincident observations between GMI and the cross-track sounders. Since GPM is in a precessing orbit with an inclination of 65°, it frequently crosses the orbits of the other sounders typically providing near coincident observations several times each day. Post launch, a series of GPM calibration maneuvers was performed, and the resulting data was used to develop corrections for magnetic-induced biases, cross-track biases and updates to the pre-launch spillover corrections as well as to verify the channel polarizations. The resulting GMI calibration is based on the data from these calibration maneuvers and does not depend on radiative transfer models. The GMI calibration is also completely independent of the calibration of the MHS, ATMS, and SAPHIR instruments, thus providing a useful measure of the absolute calibration accuracy of the 183.31GHz channels for these sensors. The differences show very consistent results, with values within 1K for all channels. It was also noticed that errors in the calibration of the SSMIS 183.31GHz channels are substantially larger due to substantial biases caused by a too emissive reflector and solar intrusion issues (Berg and Sapiano, 2013).
- Homogenisation procedures: Several ways to compare the measurements by different instruments onboard satellites have been established: the simultaneous nadir overpasses technique, the use of “natural targets” that have very little variability, and the averaging over a lot of scenes. NWP data assimilation systems estimate and remove systematic biases between the observations and the model short range forecast, but there can be visible discontinuities in analysed bias when new satellite data streams are included. Observation departures provide a way of comparing instruments on different satellites and act as a transfer function for comparing all the scenes of one instrument with another one, even though there is no direct overlap between the two.

Working Group Discussions:

Three points have been discussed: 1) the availability of the spectral response functions for all instruments, 2) the importance of satellite maneuvers, and 3) finding a way to combine pass bands for the split bands.

1) The recording and availability of digital data and metadata of spectral response functions (SRF), antenna patterns, etc are strongly encouraged for the future instruments. It seems a number of different agencies are currently working on providing this (GOES Chem, WMO, ITWG). One central data base would be better including a point of contact for each instrument.

Note: SATURN (Satellite User Readiness Navigator: http://www.wmo-sat.info/satellite-user-readiness/) could provide this. It will be a single portal for information about all forthcoming launches, with test data etc. All space agencies are involved. We need to make sure that all the required information is there and that it is correct. => Action on us to look at SATURN and feed back to WMO anything that is missing from that database.

For the RTTOV model: Instrument spectral response functions are available on the NWPSAF website. However these are not always from measurements by the instrument manufacturers. For example sometimes they are averaged over the pass band, for example assuming a hat shape of the SRF (this is the case for SAPHIR).

2) Satellite maneuvers like pitching and looking at cold space should be carried out when possible. This has already been done with success for many past instruments. EUMETSAT will put this into the science plan of future instruments and we can present that as a requirement from the users but we need to specify accuracy of required data. => Make this recommendation to the CGMS (Coordination Group for Meteorological Satellites)

3) A question about the use of double sidebands was raised. Apparently, it is easier to build the instrument and it provides some protection against frequency shifts. There is also a trade-off between the signal to noise ratio and the bandwidth because the main scientific benefit is to have lower NEΔT. However, it makes some channels very broad with an asymmetry effect. This was studied for MHS and AMSU-B by Kleespies and Watts (2006). This question could be revisited in this context but seems unlikely to explain the observed biases => Look at the difference between the two side bands channels and a single band channel (MHS)

5. Session 3: Radiative transfer biases *(chaired by H. Brogniez)*

Stefan Buehler and Marco Matricardi presented the state-in-the-art in the radiative transfer modelling in the MW and IR domains. Vivienne Payne overviewed the current issues in the estimation of spectroscopic parameters with an update on very recent laboratory measurements made by Tatiana Odintsova, more specifically on water dimers.

- MW domain: There have been many radiative transfer (RT) model intercomparisons over the years. For instance, Garand et al. (2001) have compared different reference and fast models from the operational meteorology community for the 183±1GHz channel. They find the agreement to be better than 0.5K in BT, which is consistent with the results of Melsheimer et al. (2005), with differences within roughly 0.5, 1.5, and 2.5K, respectively for 183±1, ±3, and ±7GHz channels. The differences are mainly attributed to the differences in spectroscopy and continua and not the RT models themselves. This was confirmed by Buehler et al. (2006), which showed that the difference between two completely independent models (fast model RTTOV.v7 (Saunders at al, 1999) and line-by-line model ARTS (Eriksson et al., 2011)) is below approximately 0.2K, except for a few extreme atmospheric situations. The O_3 line as a small impact (0.2-0.3K) in the simulations around 184GHz.
- IR domain: The parallel with MW was done thanks to results obtained with the IASI instrument (Infrared Atmospheric Sounding Interferometer), in channels located in the water vapour band (6.3µm). Sensitivity studies carried out using the RTTOV.v11 model showed that for the channels with weighting functions peaking in the middle and lower troposphere - similarly to what is observed in the analogous MW channels, the bias increases with the inverse of the peak altitude of the weighting function. The same qualitative behaviour is observed irrespective of the atmospheric state used in the simulations (i.e. either radiosondes or NWP data). During the course of the study it was found that, on a purely empirical basis, the pattern of increasing bias can be removed by applying corrections to the humidity fields (3 to 10% increase below 500hPa) used in the simulations and/or to the strength of the continuum absorption (30% increase in foreign continuum plus a 20% increase of self-continuum) used in the RT calculations. This does not necessarily mean that the same mechanisms should be responsible of the biases observed in the MW radiances.
- Spectroscopy: With the current generation of fast RT models, it is possible to very accurately reproduce the radiances/BT calculated by line-by-line models. One of the considerations for the accuracy of the line-by-line RT models is the spectroscopic input for the modeling of molecular absorption. The main contributions to the molecular absorption in the MW region of the spectrum are from water vapour, oxygen and nitrogen, with some minor contributions from ozone and nitrous oxide. The details of how the molecular absorption is modeled may vary between different models, but the absorption is most commonly calculated for both the contribution near the line centers and the smoothly-varying continuum. Line parameters may be obtained from laboratory experiments or from theoretical calculations and collated in databases such as the widely used HITRAN compilation (Rothman et al., 2013). The current edition of the HITRAN compilation provides parameters for modeling of Voigt line shape profiles, although future editions of the database will allow for inclusion of additional parameters for more sophisticated line shape models (Tennyson et al., 2014). In order to evaluate the impact of spectroscopic line parameter uncertainties on modeled BT in the region of the 183GHz line, sensitivity tests were performed using the Monochromatic Radiative Transfer Model (MonoRTM) (Payne et al., 2011; Clough et al., 2005) a line-by-line radiative transfer model. MonoRTM uses a Voigt line shape and the MT_CKD continuum model (Mlawer et al., 2012). The parameters required for the Voigt line shape are the line position and strength, the air-broadened half-width, the self-broadened half-width, the temperature exponent of the width and the pressure shift. The uncertainties on the line position and strength are assumed to be negligible compared to the uncertainties on other parameters. It was noted that estimated uncertainties on the foreign- (+/-3%) and self-broadened (+/-15%) half widths (Payne et al., 2008) are certainly too small to explain the observed bias. In addition, the spectral shape of associated with an error in the line width is not consistent with the spectral shape of the observed bias. Assumed uncertainties on

the temperature exponent (15%) and the pressure shift (20%) cannot be used to explain the observed bias either, and the spectroscopic community (lab and modellers) believes that confident limits on these parameters are lower than those assumed above.

The uncertainty of the dry air absorption including dry continuum and resonance absorption by O2, O3, N2O, NO, CO and other minor polar atmospheric constituents, as well as uncertainty related to wings of neighboring water lines is not thought to be large enough to account for the observed model-measurement bias.

The physical origin and properties of the water vapor continuum have been debated and probed with measurements for decades. In the current version of the MT_CKD continuum model (used by MonoRTM), water vapor contributions are modeled as monomer absorption and the spectral variation of the continuum is assumed to be extremely smooth (for instance, MT_CKD continuum coefficients are stored every 300GHz). Figure 2 summarizes comparisons of the continuum coefficients between those obtained from known laboratory measurements and fields (~1km path along the surface) measurements against the continuum parameters that would provide an agreement with radiometric data within the same propagation model. It shows discrepancies that are not yet understood. There is thus an inconsistency between two large sets of experimental data, namely laboratory and surface path measurements (which are insensitive to vertical distribution of absorbers) and radiometric measurements within currently accepted modeling. This is confirmed by Payne et al. (2011) who concluded that for atmospheric path lengths (up-looking from ground to cold space) the combination of MPM foreign and self-continuum (solid lines in Fig 2) is inconsistent with the radiometric measurements (high column water vapor amounts).

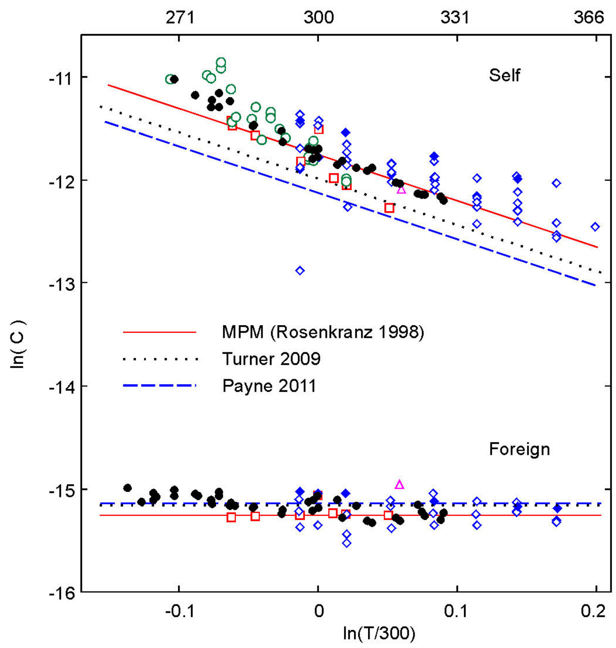

Figure 2: Self (top: pure water vapour or quadratic with humidity) and foreign (bottom: mixture with air or linear with humidity) continuum coefficients, as in Rosenkranz (1998). Symbols are field and laboratory data (Bauer et al., 1995 & 2003; Godon et al., 1992; Katkov et al., 1995; Liebe et al. 1984 & 1987). Satistical uncertainty of points in each series approximately equal or less than spread of points. Solid lines are continuum coefficients derived by Rosenkranz (1998) for MPM. Dotted and dashed lines correspond to scaling of these coefficients on the basis of radiometric data suggested by Turner (2009) and Payne et al. (2011).

Finally, recently laboratory studies have resulted in unambiguous detection of water vapour dimer absorption in the millimeter-wave range (Tretyakov et al., 2013; Serov et al., 2014) and the development of a model to describe the absorption (Odintsova et al., 2014). The water vapour dimer absorption shows spectral variation on scales that are not accounted for in the current version of

MT_CKD, or in widely-used continuum models based on the work of Liebe (e.g. Liebe 1989; Rosenkranz, 1998). Results presented in Odintsova et al. (2014) indicate that the inclusion of dimer absorption can result in small-scale spectral variation of 0.5 to 1K in up-looking (ground-based) millimeter-wave spectra. The impact of accounting for dimer absorption on RT modeling for the 183GHz satellite radiometer channels has yet to be determined.

Working Group Discussions:

- The discussions started with a brief presentation of ATOMMS (Active Temperature, Ozone, Moisture Microwave Spectrometer) by Rob Kursinski (Kursinski et al., 2012). ATOMMS is a radio occultation active spectrometer that performs a high spectral resolution sampling of the 22 and 183GHz lines, with a 100m vertical resolution, temperature precision and accuracy of 0.4K and 0.05K respectively and water vapour to 1% precision and still better accuracy. As shown on Figure 3a, results from tests performed with the ground-based, prototype instrument revealed discrepancies with respect to the Liebe MPM93 model (=> the base model on which RTTOV, among other RT models, is tuned in the MW). While the measured shape near the line center closely matched (0.3%) with the spectral model AM6.2 of Scott Paine (Paine et al., 2011; Harvard-Smithonian Center for Astrophysics), a spectral discrepancy was revealed in the wings, where the measured opacity is apparently higher than the modelled opacity, which translates into a too high BT (the modelled radiation coming from deeper in the atmosphere) than should be. This is visible on Figure 3b.

=> Understanding these discrepancies requires more examination.

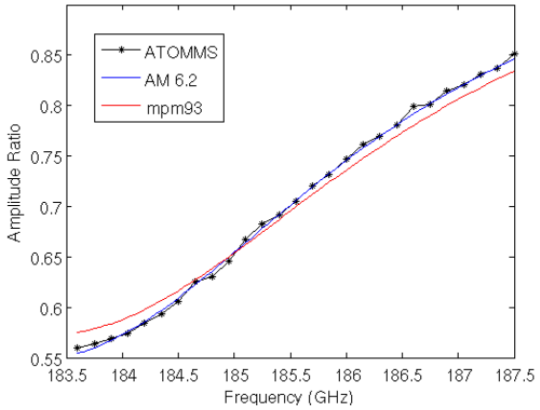

Figure 3 (a): Evaluation of line-shape functions based on ATOMMS measurements on a 820m path experiment. This shows amplitude ratio of the spectra obtained when the maximum specific humidity is observed and at a chosen normalization time. Ratio computed by two microwave propagation models, AM6.2 (blue) and MPM93 (red), at the corresponding measurements of pressure and temperature are also represented. From Kursinski et al. (2012).

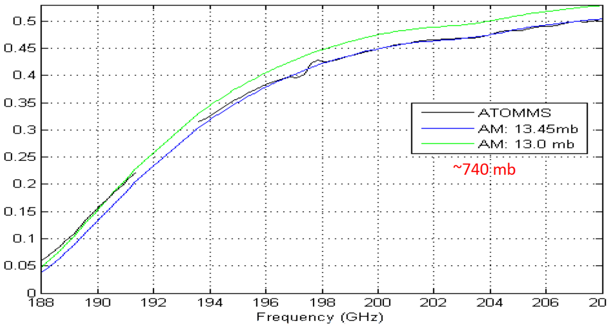

Figure 3 (b): Spectral opacity measured by ATOMMS (black line) over a 5.4km path between two mountain tops. The opacities computed by the microwave propagation model AM6.2 model using two different water vapour pressures.
(Unpublished results, experiment detailed in Kursinski et al. (2012))

- For the purposes of atmospheric remote sensing, consistency with atmospheric radiometric measurements is key. Then, the cause of the apparent discrepancy between the laboratory measurements and the atmospheric results remains an open question. => Is it possible that there are effects apparent in atmospheric measurements that the currently available suite of laboratory measurements may not be sensitive to?

- There is a recommendation to test new spectroscopic data sets such as the one presented during the workshop. => New/continuing lab measurement are strongly encouraged, since it is a fundamental science, while exploring new line shape parametrisations should be performed.

- The use of ground based 183GHz instruments can help to better constrain the parametrisations, more specifically because the surface does not contaminate the measurements. For instance, measurements at high PWV (> 3cm) are required to constrain the self-broadened continuum.

- It was decided to get in touch with HITRAN people and determine whether a dedicated "183GHz" session can be arranged. Such a session would include discussions of line shape parametrisations and new measurements.

Caution has to be observed when changing of testing the impact of the continuum, cutoff and line shape since they are highly intertwined.

- There is a clear recommendation to encourage stronger coordination between instrument & calibration experts and RT modellers. This would ensure consistency between the way the simulation is done and the actual instrument calibration.

- In the future, it is considered likely that Radio Frequency Interference (RFI) may become a threat at 183 GHz. It is therefore important both to measure the bandpasses of the instrument accurately, and also to ensure there is no sensitivity to bands outside the protected frequency. In order for regulatory authorities to take action about RFI it is necessary to be able to prove to the authority that what is seen is occurring in the protected band => This point reinforces the need to have (an easy) access to the SRF of each instrument. And the conversion procedures between counts/radiances/BT should be available.

6. Session 4: Biases arising from analysis techniques *(chaired by JF. Mahfouf)*

Philippe Chambon and Alan Geer presented respectively the clear sky and all sky assimilation systems at Météo-France and ECMWF. Antonia Gambacorta reported on the inversion module of ATMS, including the bias-tuning step before the inversion. Sid Boukabara discussed the signature of clouds, ice and rain in the 183GHz BT.

- Assimilation: Meteorological analyses, performed routinely in NWP centers across the globe, estimate humidity alongside the dynamical state of the atmosphere. Data assimilation is used to combine short-range model forecasts (often known as the 'first guess') with observations. The main observation types influencing humidity analyses are in-situ data like radiosondes and AIREP (AIRcraft REPorts) and remote sensing observations from IR and MW sensors (Andersson et al., 2005). Absolute precision is not the primary aim of these humidity analyses, which must combine together observations with different bias characteristics into a forecast model that itself may be biased compared to the truth. Cai and Kalnay (2005) have illustrated how a balance can arise between models and observations in the analysis. Nowadays Variational Bias Correction (VarBC) techniques have been developed to adaptively estimate, within the minimization of a variational system, a bias correction for each of the various assimilated observations (Dee, 2005; Auligné et al., 2007). In the ECMWF system, for example, bias correction is applied to the AIREPs and satellite observations (as well as to other observation types not connected to humidity). In order to anchor the bias corrections and the final the humidity analysis, radiosondes are not bias corrected with VarBC (although corrections are applied to standardize them to night-time RS92 observations; see Agusti-Panareda et al. 2009). Hence it is possible that humidity analyses share similar bias characteristics to RAOBS, which might explain some of the consistency between the spectral gradient-dependent bias found with both in situ measurements and NWP simulations. An issue that affects most comparisons between 183GHz observations and a reference is cloud detection, because the effects of clouds and precipitation are not usually included in radiative transfer simulations. Assuming the model cloud and precipitation fields are unbiased compared to reality, a negative first guess departure in a 183GHz channel would indicate that the observation selection would be too cloudy (i.e. cold). This would be consistent with a cloud detection that is missing some cloud-affected scenes. In any case, it is difficult to screen all clouds and residual biases may be present. The all-sky first guess departures from ECMWF (e.g. Geer et al. 2014) are the only comparison which attempts to take into account the effects of cloud and precipitation in the radiative transfer. These biases can be compared to those computed using clear-sky radiative transfer and cloud-screening, suggesting that 0.4K of bias in the ±7GHz channel can be explained by residual cloud effects However, this is not enough to explain all of the bias.

- Retrieval methods: The NOAA Unique CrIS ATMS Processing System is based on a “unique” retrieval algorithm with common treatments of the observations in the MW and IR in order to produce a homogeneous integrated dataset of environmental data record: same underlying spectroscopy, same assumptions, same look-up-tables. It is designed to use all available sounding instruments. It is a sequential iterative scheme that uses a climatological startup (TIGR ensemble, Chédin et al., 1985). Prior to the estimation of the geophysical variable, a bias-tuning step is applied. For ATMS, the comparison of Temperature Data Records (TDR, calibrated antenna temperatures) and Sensor Data Records (SDR, BT after applying a beam efficiency and scan position dependent bias correction) for channels 18 to 22 (the 183.31GHz channels) shows the same behaviour as reported previously, meaning that the TDR to SRD conversion is not responsible for the bias. Nevertheless, the conversion seems to introduce some dependence to the viewing angle.
- Hydrometeor impacted microwave observations: Cloudy and rainy BTs have a highly nonlinear signatures in the 183GHz line: the presence of clouds and precipitation naturally reduce the BTs in the lower-peaking channels, either by scattering or by absorption, which increases the altitude of the weighting function. This introduces strong discontinuities both in space and time. However, the variations of the BTs with respect to the properties of the hydrometeors are locally linear which make them compatible with 1D variational inversion schemes. The major sources of uncertainties in the 183GHz line are the shape, the density, and the particle size distribution of solid precipitating particles.

Working Group Discussions:

Results seem to suggest that about 0.5K of the bias might come from undetected clouds: a better cloud screening could be done using VIS/IR cloud detections (e.g. from AVHRR and SEVIRI) => action on us to look into this and quantify it

7. Towards recommendations and actions

- Improved quantification of the effect of undetected cloud is needed for MW instruments. The use of cloud masks derived from visible-IR algorithms must account for sampling biases.
- Reinforce the links between instrument designers/calibration experts and spectroscopy experts.
- Encourage cross comparisons of water vapour measurements by lidar, radiosondes and models.
- The knowledge of the SRF of the instruments is mandatory, as well as the record of digital data and meta data of antenna patterns etc.
- Whilst recognizing the high confidence reported at the workshop in spectroscopic parameters there is a need for new and continuing laboratory measurements to confirm the uncertainty levels for the main parameters. It is thus important to discuss funding opportunities for new 183 GHz spectroscopic measurements during the HITRAN meetings.
- Test impact of new spectroscopic data sets from the Russian laboratory work on 183 GHz calculations
- Call for a “183GHz” session during the HITRAN meetings.

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Appendix A: Agenda of the workshop

Monday 29th

8 : 30 Coffee and registration
9 : 00 Welcome and aims of the workshop (H. Brogniez / S. English / JF Mahfouf)
9 : 15 **Session 1 : Biases in in-situ observations (chair : S. English, ECMWF)**

9 : 15 *Uncertainties of humidity measurements from radiosondes and ground-based GNSS receivers : How does this matter for satellite validation ?*

Junhong Wang (Univ. of Albany) – 30 min

9 : 45 *State-of-the-art and uncertainties of humidity measurements with Raman lidar and water vapor differential absorption lidar*

Andreas Behrendt (Univ. of Hohenheim) – 15 min

10 : 00 Coffee break

10 : 15 *GRUAN and GAIA-CLIM: Gaining metrological closure on in-situ comparisons through SI traceability, uncertainty quantification, co-location effects quantification and data provision*

Peter Thorne (Maynooth University) – 30 min

10 : 45 Plenary discussion to prepare the WG1
11 : 00 **Session 2 : Biases in space-borne observations (chair : C. Accadia, EUMETSAT)**

11 : 00 *Calibration status and requirements of the 183GHz channels for GPM GMI and the other constellation sensors*

Wesley Berg (Colorado State Univ) – 30 min

11 : 30 *Limits and uncertainties associated to intercalibration & homogeneisation procedures*

William Ingram (MetOffice, Hadley Center) – 30 min

12 : 00 Plenary discussion to prepare the WG2
12 : 30 Lunch
14 : 00 **WGs on observational biases**

WG1 : in-situ (room : amphi Durand)	WG2 : Space-borne (room : #2)
Chair : Bruce Ingleby (ECMWF)	Chair : Edward Kim (NASA)
Rapporteur : Peter Thorne (Maynooth Univ.)	Rapporteur : Wesley Berg (CSU)

15 : 30 Coffee break
16 : 00 **Session 3 : Radiative Transfer biases (chair : H. Brogniez, LATMOS)**

16 : 00 *Biases in radiative transfer simulations of microwave radiances*

Stefan Buehler (Univ. of Hamburg) – 30 min

16 : 30 *Biases in radiative transfer simulations of infrared radiances*

Marco Matricardi (ECMWF) – 30 min

17 : 00 *Uncertainties in spectroscopic parameters for the 183GHz line*

Vivienne Payne (JPL, Cal. Institute of Tech)

17 : 30 Plenary discussion to prepare the WG3
18 : 00 Cocktail

Tuesday 30th

9 : 00 **Session 4 : Biases arising from analysis techniques (chair : J-F. Mahfouf, Meteo-France)**

9 : 00 *Uncertainties and errors linked to retrieval methods (MW only and multispectral)*

Antonia Gambacorta (NOAA) – 20 min

9 : 20 *Hydrometeor-Impacted Microwave Observations: Information Content, Uncertainties and Implications for the Assimilation and Inversion Problems*

Sid Boukabara (NOAA) – 20 min

Status of 183GHz observations assimilation in the Météo-France NWP systems

9 : 40

Philippe Chambon (Météo-France) – 30 min

10 : 10 *Analysis of atmospheric humidity within an all-sky assimilation system*

Alan Geer (ECMWF) – 30 min

10 : 45 Coffee break

10 : 55 Plenary discussion to prepare the WG4

11 : 15 **WGs on biases in tools & techniques**

WG3 : RT (room : amphi Durand)	WG4 : Methodology (room : #2)
Chair : Vivienne Payne (JPL, CalTech)	Chair : Philippe Chambon (Météo-France)
Rapporteur : Sid Boukabara (NOAA)	Rapporteur : Vinia Mattioli (EUMETSAT)

12 : 45 Lunch

14 : 00 Summary of the 4 WGs (the 4 chairman/woman) : 4 x 15 min

15 : 00 **WGs on attribution of biases and way forward**

WG - A (room : amphi Durand)	WG – B (room : #2)
Chair : Hélène Brogniez (LATMOS)	Chair : Stephen English (ECMWF)
Rapporteur : Amy Doherty (MetOffice)	Rapporteur : Stefan Buehler (Univ. of Hamburg)

16 : 45 Coffee break & preparation of presentations for final session

17 : 00 Summary of the workshop

Appendix B: List of participants

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