Microwave Remote Sensing for Atmospheric Studies

GdR 3187

First meeting Report
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Millimeter and sub-millimeter observations of the atmosphere : applications and instrumentation

(Version 1.0)

available at http://lerma7.obspm.fr/~gdr/Home.html

Introduction:

The main objective of the CNRS GdR (Groupement de Recherche) 'Microwave remote sensing for atmospheric studies' is to foster collaborations among the researchers who deal with microwave radiometry for atmospheric studies, in different labs, and with different objectives.

The main themes of the GdR are:

I. Temperature and water vapor profiling in the atmosphere
II. Analysis of the trace gases
III. Cloud and rain studies
IV. Surface contribution to the atmospheric signal (ocean and land)
V. Instrumentation

The theme of the first meeting of this group 'Millimeter and sub-millimeter observations of the atmosphere'. This subject has been selected because:

- is of *interest to different aspects of atmospheric studies* (atmospheric sounding of temperature, water vapor, and trace gases, cloud/rain retrieval, planetary atmospheres)
- is the *object of several satellite mission projects*
- is *technologically challenging*

More than 30 participants from 18 different labs attended this one-day meeting (see the participant list attached). In the millimeter and sub-millimeter domains, long-term collaborations have been set up between different French labs and the European comunity, both on scientific and technical aspects. Experts from other countries have been invited to present their work and views to this meeting and several European labs were represented (CSIC, Spain; RAL, UK; University of Lulea, Sweden; University of Chalmers, Sweden).

The program of the meeting included several presentations and a discussion, the objective being to favor exchanges among participants. The invited talks tended to cover the different aspects of the millimeter and sub-millimeter domains. The list of the presentations is given below, along with a short summary of each presentation. The presentations are available on the web site of the GdR at:
http://lerma7.obspm.fr/~gdr/Home.html

Presentations

- Ground-based microwave activities at Laboratoire d'Aérologie, Toulouse (Philippe Ricaud, LA)
  The NDACC (Network for the Detection of Atmopsheric Composition Change) has 70 stations around the world, to measure the chimical and physical state of the upper stratosphere and the stratosphere. The LA contributes to three of these stations, one in the Pyrenees in the South of France, one in La Réunion, and one in Antarctica at Dome C. These stations have different ground-based instrument, including microwave radiometers, to measure O_3, H_20, and NO_2 among other components. Instruments around the 22.235 GHz and the 183 GHz water lines have been successfully tested at LA and are or will equip the three sites.

- Remote sensing of ice clouds (Carlos Jimenez, LERMA)
  Ice clouds are a major component of the hydrological cycle in the upper troposphere, having a large radiative impact on the climate system. Although observations techniques in the VIS-NIR, IR, mm and sub/mm are already available to characterize them, each technique having different strengths and shortcomings, further observational data are needed in order to validate the representation of ice clouds in climate models and produce less uncertain climate predictions. The mm/sub-mm range offers the potential to greatly contribute to these efforts by exploiting the scattering signals produced by the ice clouds to characterize cloud bulk properties (such as the integrated ice water content), that are essential to constrain the model parameterizations. To fulfill this potential, deployment of new instruments measuring in the sub-mm range, and realistic radiative transfer simulations of cloudy scenes are required.

- Remote sensing of precipitation (Eric Defer, LERMA)
  Rain is characterized by a high spatial and temporal variability and complex thermodynamic, kinematics and microphysics processes. Different techniques have been designed to measure rain from rain gauge to satellite measurements. The Tropical Rainfall Measuring Mission (TRMM) has shown its relevance for the instantaneous rain detection and quantification. However low orbit missions provide a poor revisiting time for the monitoring of severe weather events even with the use of multiple platforms such as the Global Precipitation Mission (GPM). A way to alleviate that problem consists in using sensors on geostationary orbit, but the use of traditional radiometric frequencies below 100 GHz, would require the deployment of large antenna to achieve adequate spatial resolution. A solution is to use of millimetre/sub-millimetre wave radiometry. Radiometry at these wavelengths is predominantly sensitive to the cloud ice particles and rain detection/ quantification is mainly derived from correlation between the ice particles above the rain. The GOMAS project proposes to deploy multiple O_2 and H_2O channels on a geostationary platform. With the use of the cloud-resolving model Méso-NH and of the radiative transfer code ATM (Atmospheric Transmission at Microwaves) we perform simulations at GOMAS frequencies and determine the performances of such mission for retrieving rain rate. The theoretical results indicate that errors below 50% are expected for rain rate above 1 mm/h, ie, within the user requirements. It demonstrates the potential of mm/submm radiometry, especially at a time when mm/submm radiometric technology is available in Europe. The operation of mm/submm demonstrators on airborne platforms will definitively help promote mm/submm radiometry, validate instrumental concepts, and investigate scientific questions.

- Millimeter and sub-millimeter technology developments in France (Alain Maestrini, Université Pierre et Marie Curie – Paris 6 / Observatoire de Paris - LERMA)

  Schottky mixers, frequency multipliers, and millimeter-wave low noise amplifiers are essential components of radiometers. Traditionally at frequencies above 150GHz, a typical receiver front-end would include a Schottky mixer and a local oscillator made of a fixed-tuned W-band (75-110GHz) Gunn diode, followed or not by a chain of Schottky frequency multipliers. It is now possible to replace the mixer by a low-noise amplifier for frequencies up to about 180GHz without compromising the sensitivity. This should facilitate the fabrication of compact multi-pixel radiometers. On the local oscillator side, the Gunn diode can now be replaced by a centimeter-wave synthesizer, a W-band active multiplier and a W-band power amplifier. This novel type of sources outperform Gunn diodes in terms of output power and offer the possibility of fast frequency switching. HIFI, the heterodyne instrument on the Herschel Space Observatory, is the first and only space-borne instrument to exploit such possibilities. It is believed that space-borne radiometers or spectro-radiometers dedicated to the sciences of the atmosphere will eventually use similar solutions. In France, technological researches are conducted in the three areas mentioned above : low noise amplifiers design and fabrication at 150-180GHz, Schottky diode fabrication and Schottky mixer and frequency multiplier design and fabrication at millimeter and submillimeter wavelengths.

- Millimeter and sub-millimeter technology: the European perspective (Dave Matheson, RAL, UK)

  For more than 30 years, astrophysics and remote sensing were the main drivers for submillimeter-wave technological developments. Several device technologies are now mature enough for space: submillimeter-wave planar Schottky diodes, Superconductor-Insulator-Superconductor mixers, Hot Helectron Bolometer mixers, InP LNAs at 150GHz or above. In addition, new emerging technologies like THz Quantum Cascade Lasers, sub-millimeter-wave photomixers for LO generation are being used on the ground for astronomical applications. However, focal plane heterodyne receiver arrays with more than a few elements are still a problem. The main reasons are threefold: the lack of powerful solid-state sources, the complexity of injecting the Local Oscillator signal to each mixer of the array, the difficulty and the cost in terms of volume, mass and DC consumption of amplification and spectral analysis of the Intermediate Frequency signals coming out of each mixer. Commercial availability of critical component technology is limited - but is improving, in part because of the technology required for ALMA, HIFI and non-space applications. European laboratories or companies are heavily involved in technological developments and are the world leaders in many areas.

  Post-Herschel space missions considered by ESA for Cosmic Vision include TSSM for the exploration of Titan / Enceladus and JSSM for the exploration of Europa / Jupiter. Should TSSM or JSSM being selected, a submillimeter-wave heterodyne instrument employing some of the technology mentioned above has a good chance of being on the payload. For the sciences of the atmosphere, several space instruments are discussed with channels up to 3.5THz though most of the proposed instruments only feature receivers working below 400GHz. On the contrary, several European airborne platforms will in fact host path-finder instruments working in the 300-900GHz range to prepare future space missions.

- Sub-millimeter cloud satellite projects (Stefan Buehler, Lulea University of Technology, Sweden)

  The lack of reliable ice cloud information is first emphasized, with extremely large differences (an order of magnitude in some regions) observed between the various estimates from climate models or from satellite retrievals. The existing satellite observations (IR, UV/VIS, microwave up to 200GHz, radar, lidar) or the planed missions (including EarthCare) do not and will not provide the necessary information. The millimeter and sub-millimeter observations have a high potential to provide global ice cloud characterization. The history of the millimeter/sub-millimeter satellite projects for ice cloud measurement is reviewed, insisting on the changes in the channel selection

philosophy due to changes in the retrieval methodology. The CIWSIR mission has been proposed to ESA with 6 frequency bands between 183 and 873 GHz (limited to 5 frequency bands and 647 GHz after optimization). It has not been selected but an aircraft demonstration is encouraged. Projects are underway on the UK Met Office and the DLR aircrafts.
The Kiruna SAT group is welcoming collaborations in the field of ice clouds remote sensing as well as in radiative transfer modeling. This group is willing to participate actively in the aircraft instrumentation projects.

- Microwave limb sounding of the middle atmosphere: past, present, future (Jo Urban, Chalmers University of Technology, Sweden)
  Key components of the middle atmosphere have transitions in the millimeter and sub-millimeter and the composition and variability from the upper troposphere to the mesosphere can be deduced from measurements in this frequency range in a limb sounding geometry. The successive generations of microwave limb sounder were described - MSL on board UARS launched in 1991, the Odin SMR since 2001, AURA MLS since 2004. Important results include the long time record of the variability of stratospheric water vapor and HNO3. The JEM/SMILES Japanese satellite project at 640 GHz will have the first SIS cooled receiver in space. The STEAM/PREMIER project will observe in the 310-360 GHz range and has been pre-selected by ESA, with objectives including the monitoring of the upper tropospheric H_2O, strato-tropo exchanges of O_3, H_2O and CO, and the continued surveillance of O_3 and ClO. The project of a Scanning Microwave Limb Sounder is also mentioned. Airborne instruments such as ASUR on the DLR Falcone or Marshals on the Geophysicae help test and demonstrate the measurement capabilities of the future satellite instruments. The MOLIERE-5 radiative transfer model and associated inversion code is also briefly presented. It is dedicated to millimeter and sub-millimeter applications for both Earth and planetary atmospheres.

- Atmospheric characterization for astronomical purposes and potential fallouts (Juan Pardo, CSIC, Spain)
  For ground-based millimeter and sub-millimeter astronomical observations, the atmospheric contribution has to be accurately estimated, both its absorption (the imaginary part of the refractivity) and its phase delay (the real part of the refractivity) in case of interferometry (e.g., the Atacama Large Millimeter Array (ALMA) project). Direct measurements of the atmospheric absorption are performed from different astronomical sites using FTS experiments, up to 1.5 THz, with special emphasis on the continuum problem. The measurements are compared with radiative transfer model prediction to estimate the continua and analyze its sources. In interferometry projects, the phase fluctuation is a real issue that can be corrected for using water vapor radiometry at 183 GHz, which implies very accurate modeling of the phase delay across the spectrum. Very good modeling has been obtained with the ATM code. The atmospheric water vapor fluctuations have already been measured at Mauna Kea, Hawai, using water vapor radiometry. The temporal power spectra have been estimated. The ALMA astronomical project, planed for 2012, will provide a unique database to study atmospheric turbulence and water vapor behavior, an excellent opportunity for the astronomical and atmospheric communities to collaborate.

- Applications to planetary atmospheres (François Forget, LMD)

  A comprehensive review of the microwave instrument projects for atmospheric sounding on board planetary missions and their applications is presented.
  TheNASA Juno microwave radiometer, to be lunched in 2009, will probe the Jupiter atmosphere and measure NH_3 and H_2O. The MIRO instrument on board the Rosetta mission to comets, launched in 2004, is also mentioned, with 190 and 562 GHz radiometers for H_2O and isotopes, CO, CH_3OH, among other components.

Mars atmosphere has a fascinating meteorology, including complex seasonal cycles of dust, water, and ozone, that could be remotely studied using microwave radiometric measurements from space missions, to complement other measurements from space (IR, UV). Ground-based microwave radiometry already show great potential (Doppler shift winds, temperature monitoring, H2O column…). The MAMBO project had planed observations in the 320-350 GHz band, both in nadir and limb geometry. The main objective is to map accurately the wind and temperature fields of the atmosphere, to provide an estimate of the 4D circulation of the planet atmosphere. Other objectives include the estimate of the H_2O profiles and the D/H ratio, to get insight into the water cycle and cloud microphysics of the planet. This project has not been approved, but other opportunities might occur (ESA Mars Next or NASA Mars Science Orbiter).
Sub-millimeter atmospheric sounding of the atmosphere of Titan (up to 1.3THz) is also planed within the TANDEM mission, for temperature sounding, wind measurements and chemistry studies of this moon of Saturn.

DISCUSSION

Several themes were covered. The outcome of the discussion is summarized below.

- ***Status of the millimeter/sub-millimeter satellite mission projects***

The ***JEM / SMILES*** (Japonese Experiment Module / Superconducting Submillimeter-Wave Limb-Emission Sounder) mission will measure stratospheric trace gases in the 640 GHz band. It is to be launched in 2009. It will use for the first time a SIS cooled (4K) receiver in space. The main objective of this mission is to prove the feasibility of this technique in space.

Three satellite missions with millimeter and sub-millimeter instruments were submitted to the ***ESA call for Earth explorer missions***, in 2006. The proposals are available on the GdR site.

- PREMIER (Process Exploration through Measurements of Infrared and millimeter-wave Emitted Radiation): IR and millimeter wave limb and nadir sounding for trace gases measurements. IMIPAS is the IR imager and STEAM-R the microwave one. PI Brian Kerridge (RAL, UK)
- CIWSIR (Cloud Ice Water Sub-millimeter Imaging Radiometer) : a conical imager in a polar orbit for ice cloud characterization. PI Stefan Buehler (Lulea University, Sweden)
- GOMAS (Geostationary Observatory for Microwave Atmospheric Sounding): a millimeter instrument on a geostationary orbit for the measurement of precipitation and atmospheric profiles. PI Bizarro Bizarri (Italy).

The PREMIER mission was pre-selected while the two others were not. Nevertheless, studies are on going for the three missions. An aircraft instrument is under study under ESA contract to demonstrate both CIWSIR and GOMAS missions. Links between both scientific teams should be encouraged as both missions are based on very similar measurement principles.

In the ***post-EPS framework***, Thierry Phulpin (CNES) specify that two instruments with channels above 200 GHz are under discussion. A 229 GHz window channel for integrated water vapor information is planed with priority 1 on the MicroWave Souding (MWS) mission, the successor of the AMSU_A+MHS instruments. For the MicroWave Imager instrument, several millimeter wave channels are planed with priority 1 (325, 340, 448) for cirrus characterization (ice water path and effective radius) along with additional channels with priority 2 (2 additional channels around 325, 2 as well around 448, and one at 664 GHz). The document ‘Post EPS mission requirement document’ (draft) provided by T. Phulpin is available on the web site.

The Scanning Millimeter Limb Sounder (JPL) is a new concept to provide high spatial/temporal resolution of upper troposphere and lower stratosphere. It will provide 50kmx50km horizontal scanning, with a low noise cooled (4K) SIS receiver.

A millimeter/sub-millimeter mission for ice cloud characterization has been proposed to the CNES. The selection process is on going.

- ***Radiative transfer modeling and spectroscopy***

This subject has been partly discussed in the French community, at the CNES radiative transfer workshop in April 2008.

The need for strong links between the spectroscopists and the satellite data users is stressed. First they can provide new measurements of specific trace gases or their isotopes. Second the remote sensing community does not have the necessary background to understand and benefit from the newest developments in spectroscopy and needs the help of the spectroscopists to extract the information from the spectroscopy literature. A comprehensive dataset of spectroscopic parameters relevant for radiative transfer calculation can be provided by the spectroscopist (Agnès Perrin, LISA).

The collaboration of Juan Pardo (ATM code) is solicited to refine the modeling of the continuum and the Zeeman effect in the ARTS code.

The speed of the current radiative transfer mode working in ‘research mode’ is often a problem and Pascal Brunel (Météo-France) mentions that the RTTOV group should soon provide the code that is used by RTTOV to derive the coefficient for the absorption parameterization.

- ***Status of the airborne instrumentation projects***

The UK Met Office recently decided to equip its aircraft (the FAAM) with a millimeter and sub-millimeter instrument and financial support is already secured for several receivers. However, the UK Met Office solicits the contribution and collaboration of external teams to add other complementary receivers. There is an ongoing ESA study to specify the characteristics of this instrument, and potentially, ESA could also fund part of it. Stefan Buehler will ask for Swedish funds to participate to this instrument. Thierry Phulpin mentions that the CNES could also consider supporting such an instrument.

The Halo, a recent German aircraft, will be equipped with a low frequency radiometer (below 100 GHz), supported by German funds. An ongoing ESA study is also analyzing the possibility of millimeter and sub-millimeter receivers on board this aircraft.

The Marschals instrument is dedicated to the measurement of trace gases in the 300-350 GHz. An upgrade of this instrument should start soon, under ESA funding (Dave Matheson). It will fly again on the Geophysicae aircraft.

The interest for an active mode at millimeter and sub-millimeter frequencies is discussed. The first reaction is rather negative, with unexpected advantages as compared to the 94 GHz radar (CloudSat, Earth Care). However, with sub-millimeter radars now feasible, this possibility might be worth further investigations, using simulations.

- ***Program for instrument developments***

The feasibility of a radar working at about 300GHz is discussed in more details, in particular on the source side, the most critical one. Such a radar will be an excellent driver for technological developments. Some attendees believe that the current lack of submillimeter sources could explain the fact that no active instruments at these wavelengths are being considered for atmospheric sciences. It appears that the Jet Propulsion Laboratory should be able to build a watt-level fully-solid-state and frequency agile source at 300GHz within a couple of years (currently about 50mW can be generated at 300GHz with multiplier sources). LERMA is involved in this program. To achieve such a high power at 300GHz Europe needs to improve its own technology of high power W-band amplifiers, preferably on GaN. RAL and LERMA were interested in submitting a proposal for technological developments for such a radar but the idea was not backed by scientists that think it may not bring much more information than a 94GHz radar.
Other themes were also discussed such as calibration of large arrays and the use of LNAs at frequencies above 150GHz. It appears that Europe have made very good progress it the later field but that the USA are working on 350GHz+ amplifiers for several years now with unrivaled technology.

List of participants

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Buehler Stefan (Lulea University, Sweden)
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Defer Eric (LERMA)
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Guillet Bruno (ENSI CAEN)
Goldstein Christophe (CNES)
Goutoule Jean-Marc (EADS)
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