The C2Omodo Concept: A Tandem of New Generation High Resolution All-Sky Atmospheric Sounders in the Frame of the AOS Mission

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ABSTRACT

Convective systems are responsible for energy transfers between the lower and upper atmospheric layers and play a fundamental role in the water cycle, weather and climate evolution. With a tandem of high resolution and wide swath all-sky atmospheric sounders, the C²OMODO concept allows the measurement of vertical dynamics of cloud ice particle within deep convective systems.

Index Terms— microwave radiometer, new generation, time-derivative, convective mass flux, instrumental synergy

1. INTRODUCTION

Vertical structures, processes and interactions between various components of the atmosphere are much more complex to measure and monitor in cloudy or precipitating skies. Their understanding is crucial as such processes are responsible for global energy, water and air transfers from the lower atmosphere to the free troposphere. Tropical atmospheric convection for instance plays a fundamental role in the water cycle, meteorological monitoring and prediction, and for climate understanding. Even though convection has been extensively studied for the past century [1], measurements of the vertical processes that they involve are scarce, if not available, due to their high variability in time and space, and to the complex vertical processes involved, which occur in deep convection. The C²OMODO (Convective Core Observations through MicrOwave Derivatives in the trOpics) concept would make it possible to measure deep convection's life cycle, the energy processes and transfers, and to better explain the water cycle by exploiting the temporal evolution of the brightness temperatures at frequencies sensitive to the cloudy ice particles. Two microwave radiometers, the new generation multi-spectral, high-resolution, all-sky atmospheric sounders, SAPHIR NG [2], form the C²OMODO tandem. These instruments inherit from the SAPHIR instrument [2] on-board the French-Indian Megha-Tropiques mission [3] and benefit from technological improvements since the design of SAPHIR, which data is successfully used more than ten years after its launch [4][5][6][7][10]. The C²OMODO concept is currently part of the NASA AOS (Atmosphere Observing System) mission, which addresses the following objectives: low and high clouds, convective storms, cold clouds and precipitation, air quality and aerosol attribution, aerosol redistribution and processing, and aerosols direct and indirect effects.

2. THE C²OMODO CONCEPT IN THE FRAME OF THE AOS MISSION

2.1. The AOS mission

The C²OMODO concept is the French contribution to the AOS mission lead by NASA, providing measurements of the atmospheric vertical structure that will describe interactions and feedback processes between aerosols, clouds, atmospheric convection and precipitation. With an international collaboration between NASA centers, JAXA, CSA and CNES, AOS includes several instruments such as lidars, radars, radiometers, polarimeters and stereocameras organized in two orbital planes : the polar and inclined (55°) orbits, at an altitude of ~430km.

2.2. The C²OMODO concept

C²OMODO is a tandem of two microwave radiometers separated by a few minutes time gap. Each instrument is on-board one platform of the inclined orbit: the AOS-I platform, operated by NASA and the PMM platform operated by JAXA. With its wide swath of ~800 km and high resolution measurements (<=5km), C²OMODO will enable to map the small scale vertical mass fluxes of cloud ice within the convective core of tropical and sub-tropical convective systems. This will be obtained by providing temporal derivatives of Brightness Temperature (dBT/dt) measurements [8][9] at high frequencies within the 183.31 GHz and 325,15 GHz absorption lines. It thus addresses two of the eight AOS objectives: high clouds and convective storms.

2.3. Instrumental synergy

Thanks to the high variety of instruments over the different orbits, the instrument synergy is the key stone of the AOS mission as it offers new perspectives to improve our understanding of convective dynamics and processes, enabling more accurate predictions of rain and severe weather, and thus to better constrain meteorological and climatic models. For instance, [8] underlined the high potential of combining Ka Doppler radar high vertical resolution measurements and C²OMODO observations to derive upward motion of ice particles over a wide horizontal extent thanks to C²OMODO's wide swaths.

3. TRADE-OFFS FOR THE C²OMODO CONCEPT

3.1. Towards an optimized tandem of instruments

In order to capture the geophysical variations of the signal that are directly linked to the vertical hydrometeor mass fluxes within the different parts of the convective cells at various stages of their development, both radiometers of the tandem are separated by a specific time gap of 30s to 3min, along the same orbit. Scientific studies lead by the C²OMODO Science Team are ongoing to define the optimal time gap and tolerance to address C²OMODO scientific objectives. This optimal is a compromise between: 1) temporal scale of convective cells' evolution ; 2) instrument's radiometric performances (the smallest BT variation measured by the instrument), related to technological constrains ; and 3) manoeuver constrains of the AOS inclined orbits for time gap stability maintaining.

3.2. Towards optimized spectral configuration and radiometric performances

The SAPHIR-NG instruments enable measurement of the atmospheric electromagnetic field at frequencies ranging in the [0.2 GHz ; 11 GHz] band within the 183.31 GHz and 325.15 GHz water vapor absorption lines. Complementary information on the column-integrated and vertical profile of cloud ice content is thus provided over a wider altitude range, and a wider ice particle size range than with the single 183.31 GHz absorption band, as sensitivity of 325 GHz measurements to higher altitudes and smaller cloud ice particles are exploited. Moreover, the channels within the [0.2 GHz; 11 GHz] band within both absorption lines show different sensitivities of to ice change in time [9]. The C²OMODO Science Team is currently undertaking multi-spectral sensitivity studies of the retrieved dIWP/dt, vertical ice momentum and velocity to the channel configuration , according to the type and development stage of the convective cells. Various spectral configurations are evaluated: SAPHIR-like (with varying channel bandwidths), AWS-like ICI-like spectral configurations, and a combination of such spectral configurations, and illustrated in Figure 1. Such sensitivity studies result in a trade-off between:

- the vertical sampling of the information content (driven by the number of channels and their respective bandwidths),
- the quality of the information content (driven by the channel bandwidths directly impacting radiometric performance). The use of high performance elements in the 325 GHz Front-End sub-system is currently evaluated and tested to improve radiometric sensitivity (see section 4.1.2).
- the instrumental constraints (weight/consumption/size budgets and technological maturity)

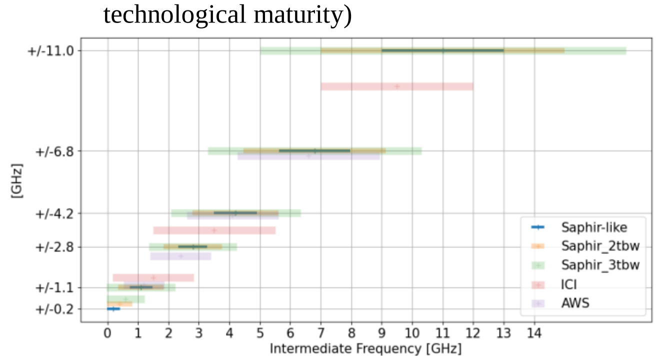

Figure 1: Channels within the [0.2 GHz; 11 GHz] band with respect to intermediate frequency, in GHZ, for the various spectral configurations analyzed.

4. INSTRUMENT RECENT TECHNICAL ADVANCES

4.1. Instrument architecture innovations

Several innovations were integrated to the SAPHIR-NG instrument, the driver being the radiometric performances improvement. Two sub-assemblies are considered in the following section of the paper: the antenna sub-system, that emulates the radiation pattern for the 3 frequencies, and the Front-End at 325 GHz, which translates the RF signal into the intermediate frequency (IF).

4.1.1. Quasi-optical network

The Quasi-optical network (QON) enables co-location and co-registration of the measurements at the different frequencies. Its aims and functions for SAPHIR NG are described in [2]. The QON design must follow accommodation constraints to feed the 3 different receivers and to fit in a reduced allocated instrumental volume.

A design study of the whole assembly has enabled to define the architecture of the optimal solution in terms of radiometric performances and accommodation, and is illustrated in Figure 2.

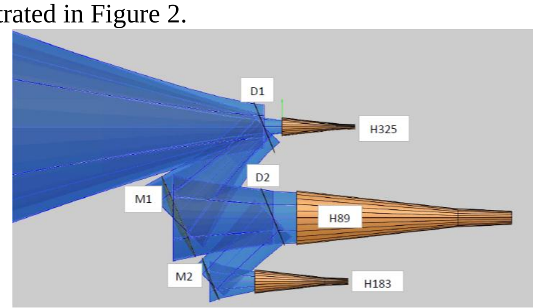

Figure 2: QON architecture

Taking into account the performances of the dichroïcs versus frequency and their behavior either in transmission or in reflection, the optimized solution was to select a high pass scheme for the 89-183/325 GHz dichroïc D1 design. Wide band performances of the D1 dichroïc, over the total bandwidths of the three central frequencies at 89 GHz, 183 GHz and 325 GHz were demonstrated by modelling by Cardiff University [11]. The measured values in transmission for the whole bandwidth of interest [315-335] GHz are given in Figure 3 for D1 versus the incidence angle.

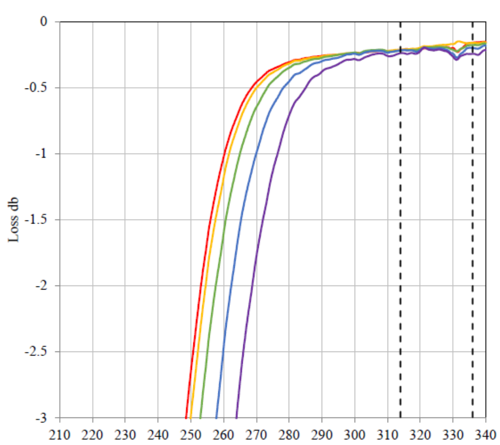

Figure 3: Transmission Losses (dB) versus frequency (GHz) for incidence angles of 2.5 (red), 12.5 (orange), 22.5 (green), 32.5 (blue) and 42.5 (Indigo) degrees

The measured RF losses in reflection for D1 for the 2 bandwidths of interest within 89 GHz and 183 GHz demonstrated very low values, below 0,1 dB over the whole incidence angle range.

Such performances confirm its functions of transmission of the 325 GHz signal and of reflection of the 89 and 183 GHz signals. They are quite stable for a wide range of incidence angles. This means that the quasi-optical network (QON) will be robust regarding the position of D1 towards the main incident beam. The next step of the development will be to perform the detailed RF design of the whole assembly.

4.1.2. 325 GHz Front-End

A high performance 325 GHz mixer has been designed by the LERMA laboratory [12] in order to improve the noise performance of the 325 GHz Front-End. Three different topologies have been extensively studied: the 325 GHz Sub-Harmonic Mixer (SHM) MMIC (Monolithic Microwave Integrated Circuit) design, the 325 GHz Fundamental Balanced Mixer (FBM) MMIC design, and a 325 GHz subharmonic discrete diode mixer. All these topologies integrate anti-parallel Schottky diode structures on GaAs substrate. The main difference between SHM and FBM lies on the needed power coming from the local oscillator sources, for which the required level is higher in the FBM case at 325 GHz.

A discrete diode mixer was first designed. C2N laboratory has produced many discrete diodes with different anode size for the sub-harmonic type mixer. These components can be easily mounted (flip-chip mounted on the quartz surface) on the existing mixer mechanical blocks. This was manufactured and tested together with an IF (Intermediate Frequency) Low Noise Amplifier (LNA) (NF (Noise Figure) of 1.16 dB, see Figure 4).

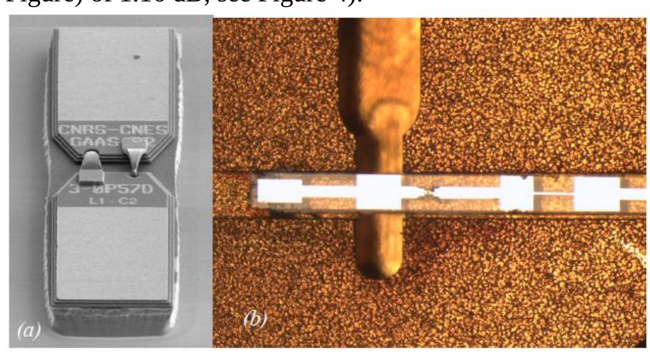

Figure 4: (a) Discrete diodes made by LERMA/C2N. (b) Mounting of the discrete diodes inside the 325 GHz sub-harmonic discrete diode mixer block.

As a second step, the sub-harmonic MMIC mixers with different anode size of the diodes were designed and fabricated by the C2N laboratory with their mechanical block. For this topology, the anti-parallel diode circuit is included on the same substrate with the other RF functions. The noise temperature of the complete chain including the

IF LNA (with the same NF as in the previous case) was measured, using a 155-185 GHz source. In order to get the results over the whole frequency range, an automatic test bench was set-up at LERMA, to assess the receiver noise temperature versus the frequency, as shown in Figure 5.

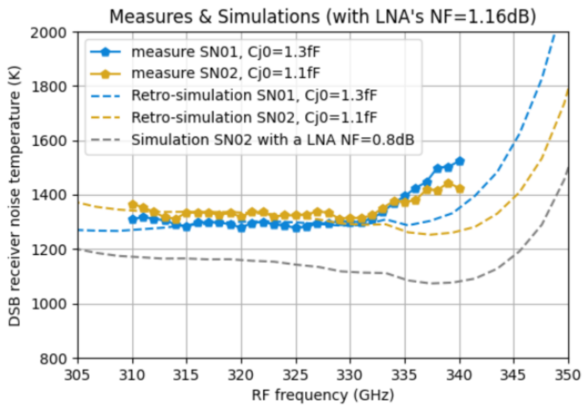

Figure 5: Noise temperature measurement versus frequency of the 325 GHz sub-harmonic MMIC mixer with 2 different blocks (SN01 and SN02 with different anode size) at 300K room temperature for raw and corrected measurements at an optimal input power with dedicated LO unit.

The noise performances of the DSB receiver are quite stable versus frequency with a value below 1400 K in the bandwidth of interest for both blocks and more particularly with values of 1320K@325 GHz for the first one and of 1280K@325 GHz for the second one, in accordance with retro-simulation. The last simulation curve in grey demonstrates the potential improvement in case of the use of a high performance LNA (NF=0.8 dB).

4. CONCLUSION

The C²OMODO concept is a tandem of high resolution multi-spectral all-sky atmospheric sounders which provides measurements of convective systems' vertical structure and dynamics during their life cycle. It addresses two of the eight objectives of the NASA AOS mission, a fruitfull collaboration between NASA agencies, JAXA, CSA and CNES, and providing global measurements of the aerosols and cloud/precipitation interactions and feedbacks. The contribution of C²OMODO to the AOS mission is twofold, both thanks to the high added value of the time-derived observations of the tandem; and thanks to the potential of AOS instrumental synergy (by combining C²OMODO's wide swath observations and KuDPR high vertical resolution measurements, for instance). To best fit the C²OMODO scientific objectives, various sensitivity studies to the information content are ongoing, to define an optimized time gap of the tandem, and spectral configuration of both instruments of the tandem . The SAPHIR NG sounders also benefit from several technical improvements since the SAPHIR instrument, both to ensure time and spatial co-location of measurements at the different frequencies, though the advances made on the QON sub-system, and to improve radiometric performances, through the system temperature decrease.

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