MW/SUB-MM SOUNDING FROM GEOSTATIONARY ORBIT

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ABSTRACT

Studies, both scientific and technological, for a Geostationary Microwave Observatory have been conducted during the past triennium in the U.S., and there is now a formal proposal for a Geostationary Observatory for Microwave Atmospheric Sounding submitted to ESA by a group of 40 European and U.S. proponents. The paper will review the underlying principles of sounding air temperature/humidity, cloud liquid/ice water and precipitation at 15-min intervals by using millimetre and submillimetre radiometry, dwelling on the bands and channels selection process. The antenna concept, with active control of the deformations, and the radiometric performance achievable by state-of-the-art technology will be briefly discussed. It is argued that GEM/GOMAS could be flown in the 2007-2009 timeframe.

INTRODUCTION

Over the past decade meteorological requirements for atmospheric sounding have become increasingly stringent, particularly with regard to the required temporal resolution. Global-scale numerical weather prediction (NWP) systems now have target time resolutions of 1 h, with a threshold of 12 h for the data to only be of significant interest. For regional-scale NWP the target time becomes 0.5 h and the threshold for precipitation is reduced to 3 h. For nowcasting, temperature and humidity sounding is required every 15 min, with a threshold of 1 h, and for precipitation this is reduced to 5 min target and 15 min threshold. These figures can only be achieved on a synoptic scale by geostationary observations. Infrared (IR) temperature and humidity soundings from geostationary orbit commenced with the U.S. NOAA GOES satellites, and are anticipated to advance through improved spectroscopic sensitivity under the NASA NMP-E03 GIFTS program. However, since IR sounding is only useful in cloud-free or broken cloud conditions microwave (MW) sounding is needed for the important heavily-clouded and precipitating regions. For precipitation, visible and IR imagery can only provide very indirect inferences on the underlying parameters, and is mostly limited to convective situations. MW is needed for more direct, accurate and regular observation.

On the other hand, MW observations from the geostationary altitude (~36,000 km) require large antennas to achieve the required spatial resolutions of ~30 km for temperature/humidity and ~10 km for precipitation. In order to use antennas of affordable size, it is necessary to use higher microwave frequencies, particularly those in the submillimetre wavelength range. The typical frequencies used from polar orbit are within the 50-60 GHz O_2 band for temperature (NOAA AMSU-A), the 183 GHz H_2O band for humidity (NOAA AMSU-B), and window channels at ~6, ~10, 19, 37 and 89 GHz for precipitation (e.g., TRMM TMI, ADEOS-II AMSR, EOS-Aqua AMSR-E). For temperature, it is possible to use other O_2 bands, e.g. around 118 and 425 GHz. For humidity, H_2O bands around 325 or (more preferred) 380 GHz are available, as are several others of higher opacity. For precipitation, however, the traditional frequencies that are directly sensitive to near-surface rain require antennas of far too large aperture size, therefore a technique less direct, but exploiting higher frequencies to reduce antenna size, is required. The new technique is based on sounding the atmosphere in several absorption bands (54, 118, 183, 380, and 425 GHz), each differently sensitive to liquid or ice water parameters such as density and drop size. Precipitation parameters can thus be detected using differential observable degrees of freedom, with profiling performed in manner analogous to that of temperature/humidity vertical profiling. These ideas are supported by several airborne experiments, to continue in the near future.

Studies, both scientific and technological, for a Geostationary Microwave Observatory (GEM) have been conducted during the past triennium in the U.S., and there is now a formal proposal for a Geostationary Observatory for Microwave Atmospheric Sounding (GOMAS) submitted to ESA by a group of 40 European and U.S. proponents. The GOMAS concept, heavily capitalising on GEM, is based on a 3-m diameter antenna to provide spatial resolutions ranging from ~10 km for precipitation, to ~20 km for water vapour and cloud liquid / ice water, and to ~30 km for temperature. A sector of ~1/12 of the Earth's disk will be scanned every ~15 minutes, with the center of this sector being movable towards zones of interest. Also, the satellite can be shifted along the equator between the American continent and the Indian Ocean for seasonally-driven experiments. A first launch of GOMAS is proposed for 2007-

2009, with operations to be coordinated with the NASA NMP-EO3 GIFTS system for a full assessment of the benefit of combined high-vertical-resolution IR sounding and nearly all-weather MW/Sub-mm sounding.

BANDS AND CHANNELS SELECTION

The e.m. spectrum in the MW and Sub-mm range provides several bands relevant to sound atmospheric temperature (by O_2) and water vapour. They are shown in Fig. 1, from [1]. It can be observed that, beyond the 54 band of AMSU-A, O_2 has a next band around 118 GHz and a next "clean" one around 425 GHz. For H_2O, beyond the 183 GHz band of AMSU-B, there is one around 325 GHz and a next one, preferred, around 380 GHz. Both O_2 and H_2O have several other bands at higher frequencies, but the increasing level of water vapour and nitrogen continuum (and ozone line density) makes them progressively useless for tropospheric sounding. The selected set is therefore: 54, 118, 183, 380 and 425 GHz. Table 1 reports the resolution at the sub-satellite-point (s.s.p.) for these frequencies, function of several antenna diameters. A need for 3-m is evident.

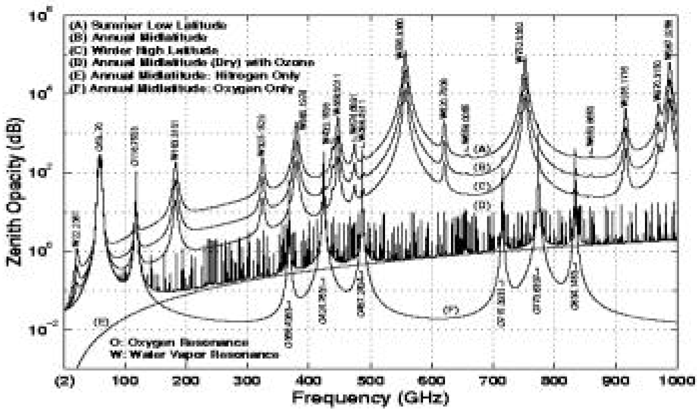


Fig.1 - Atmospheric spectrum in the MW/Sub-mm ranges [1]).

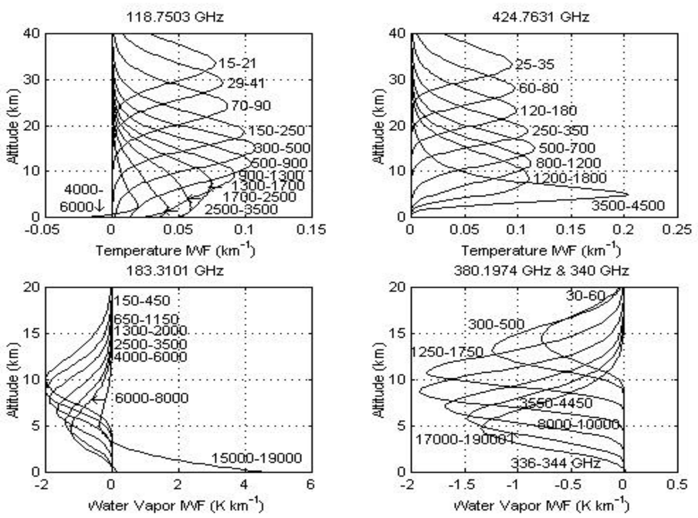
Table 1 - Resolution v/s frequency & antenna diameter

Ø	54 GHz	118 GHz	183 GHz	380 GHz	425 GHz
1 m	242 km	112 km	73 km	35 km	31 km
2 m	121 km	56 km	36 km	18 km	16 km
3 m	81 km	37 km	24 km	12 km	10 km
4 m	60 km	28 km	18 km	8.8 km	7.8 km

The resolution figures reported in Table 1 can be improved by deconvolution techniques if substantial oversampling is applied. This is certainly the case of the bands at lower frequency, since sampling is driven by the precipitation objective, thus must be in the range of 10 km. Effective resolution with a 3-m antenna could be < 30 km for temperature sounding, < 20 km for water vapour and cloud liquid/ice water, ~10 km for precipitation.

As anticipated, with increasing frequency, the capability to sound the lower troposphere decreases. Fig. 2, mostly from [1], shows the Incrementing Weighting Function of several channels in the five spectral bands. It is noted that bands 54, 118 and 183 GHz have channels sounding down to the ground, whereas bands 380 and 425 are close to blind below the height of 3-5 km. The (provisional) results of the channel selection process indicated the need for a total of slightly over 40 channels (11 in bands 54 and 118 GHz, 7 in band 183 GHz, 6 in band 380 GHz and 8 in band 425 GHz). Channel frequencies and bandwidths can be read on Fig. 2.

Different frequency bands are differently affected by liquid water or ice water concentration and drop size. In each band, channels of different absorption, from peak to window, "slice" clouds penetrating into different height in the troposphere. This effect can easily be visualised in Fig. 3, showing image strips observed by an airborne radiometer operating at 89, 150, 183 (three channels), 220 and 325 GHz (three channels) [2]. The 380 GHz channel is expected to behave similarly to the 325 GHz band.



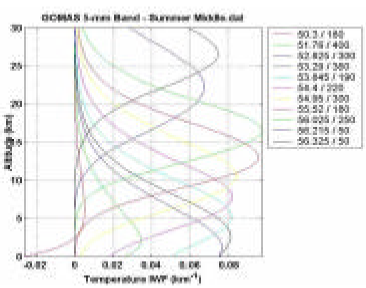


Fig. 2 - Incremental weighting functions (IWF) for temperature and humidity in the bands 118, 183, 380 and 425 GHz (above). The numbers attached to the curves indicate the distance (in MHz) from the frequency of the peak ([1]). The more familiar IWF's relative to the 54 GHz band are also plotted (aside).

It is therefore clear that, by observing the atmosphere by several narrow-bandwidth channels in several absorption bands, it is possible not only to measure temperature and humidity profiles in nearly-all-weather conditions, but also to infer the columnar content or the gross profile of cloud ice and liquid water, and precipitation. It is stressed that this is probably the unique way to observe precipitation at the appropriate time scale of few minutes for use in Regional NWP and Nowcasting. The usefulness of very frequent temperature/humidity sounding in nearly-all-weather conditions, however, should not be understated, since the 4-D assimilation of frequent sounding allows to derive information on the wind field, that is the most important parameter for NWP, difficult to be directly observed from space (cloud-motion winds are inaccurate and at a single level, Doppler radar from low orbiters provides very infrequent coverage).

To confirm the capability of absorption bands to observe precipitation, Fig. 4, from [3], compares a horizontal map of precipitation derived by the operational AMSU sounder, equipped with the 54 and 183 GHz bands, and a corresponding rain map from a ground-based meteorological radar network. Fig. 5, from [4], shows what can be inferred by exploiting differential information from the 54 and 118 GHz bands. In the top figure the ratio between temperature profiles independently obtained from the 118 and the 54 GHz bands is reported, as the aircraft travels. If there is no precipitation the ratio of the two temperature profiles is unity throughout the entire vertical range. When precipitation is present the ratio becomes less than unity below the altitude of the precipitation cell due to the higher attenuation at 118 GHz than at 54 GHz. The bottom figure reports the precipitation profile simultaneously recorded by the Doppler radar onboard ER-2 (EDOP). The agreement is striking, and it can be inferred that GEM/GOMAS would give information similar to what is currently obtained by ground-based radar. Pending confirmation by GEM/GOMAS multi-band sounding at 15 min intervals, meteorologists will have available ***a proxy rain radar operating over continental field of view, and particularly over oceans and mountainous terrain.***

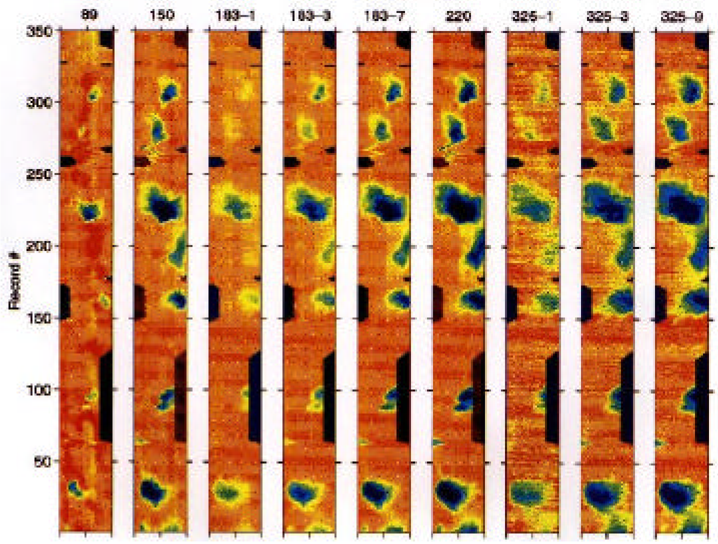


Fig. 3 - Image strips of convective precipitation cells over ocean obtained by a multi-channel airborne radiometer. Scenes of 40 km (width) x 200 km (length) ([2]).

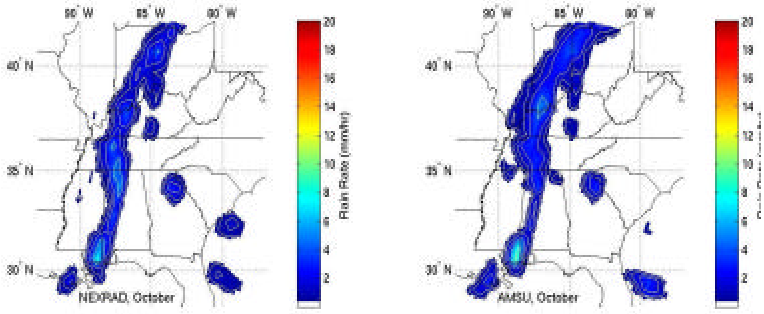


Fig. 4 - Precipitation images from a cold front on October 7, 1998: NEXRAD precipitation map smoothed to 15 km resolution (left image), and NOAA/AMSU precipitation map obtained using a neural net retrieval technique (right image) ([3]).

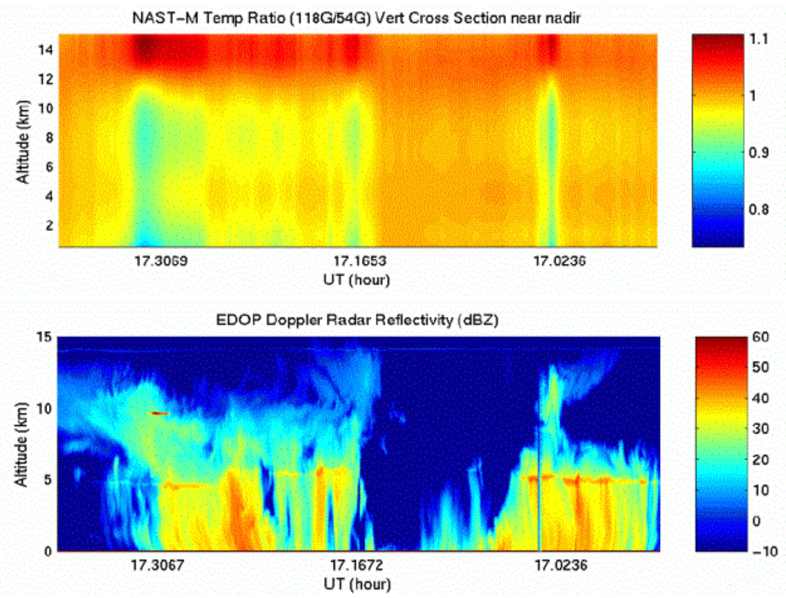


Fig. 5 - Comparison between the 118/54 GHz profile ratio from the NAST-M microwave radiometer on the NASA ER-2 aircraft and simultaneous EDOP Doppler radar reflectivity observation. Hurricane Bonnie at 17 GMT on August 26, 1998 ([4]).

INSTRUMENT FEATURES

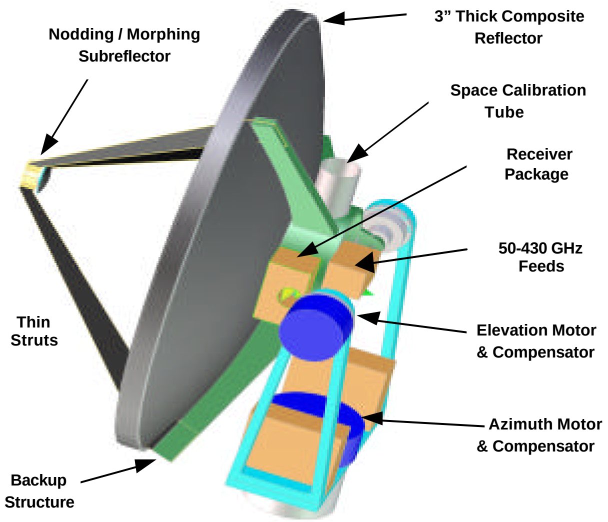


Fig. 6 - GOMAS antenna system (as from the GEM concept

The GOMAS concept is based on a 3-m antenna and a 5-band/40-channel spectrometer, depicted in Fig. 6. The antenna surface has a quiescent accuracy of ~10 µm. Thermal and inertial deformations are monitored by a series of sensors on the antenna border and actively compensated using a nodding/morphing subreflector, which also provides for limited image scanning. Gross movements (e.g., to change the observation sector) are performed by the elevation and azimuth motors. A single feedhorn path is baselined so as to provide hardware co-alignment of all feeds for the five bands. An option of a feed cluster to simplify the receiver design is still being studied. The baseline receiver uses a quasi-optical multiplexer and includes five individual spectrometers for the five bands. State-of-the-art HEMT technology for high performance, reduced volumes, and low electrical consumption is exploited. Critical parameters are:

- antenna: ∅ = 3 m, 40 kg, 40 W
- radiometer: 30 cm x 50 cm x 50 cm, 67 kg, 95 W
- total payload: 107 kg, 135 W, data rate 115 kbps.

Fig. 7 - Earth's disk and reference GOMAS coverage

Within the current technological state-of-art it is not possible to scan the full Earth disk in the required short time at the required resolution. A compromise is achieved by scanning a sector of about 1/12 of the disk (250 x 500 pixels; see Fig. 7) with an integration time of ~6 ms per pixel. Averaging over a convenient number of 10-km pixels provides the required radiometric sounding accuracy. In practice it will be possible to drive the scanning mechanism with different speeds and over areas of different size, and the reference sector of 1/12 of the disk can be selected anywhere within the disk so as to track interesting events as they evolve. In addition, since in the GOMAS concept the instrument is embarked on a dedicated satellite, the longitude of stationarity can be shifted during the satellite lifetime so as to allow observation over the American continents to the Indian ocean following seasonal events. For this dedicated satellite the critical parameters would be:

- mass: 860 kg (430 kg dry); power: 600 W (peak); volume (stowed): 3.0x3.0x3.0 m^3; data rate: 128 kbps (S-band).

CONCLUSION

GOMAS is proposed as a ***demonstration mission***. It would be a ***precursor*** for future operational applications. From the technical standpoint, and building on the studies conducted on GEM, it is believed that no enabling technology is currently missing and that the GOMAS satellite could be developed in time for a launch in the 2007-2009 timeframe.

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