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LIMITS and POTENTIAL of FIXED WINGS and LTA

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HAPS PLATFORMS: FIXED WINGS AND LTA

The **first edition of the workshop HAPS4ESA (2017)** identified the potential of stratospheric platforms both **Lighter Than Air (LTA)** and **Fixed Wing Systems**. In the near-space, both categories operate at altitudes around 20 km, although some test of fixed-wing has reached 25 km.

Three categories of platforms can be identified: the **fixed wings**, the **LTA** and the **hybrid systems**.
In order to reach and maintain the operational altitude, the first ones use **aerodynamic thrust only**, the second ones the **aerostatic thrust**, the third ones **both of them**.

For maintaining the altitude, fixed wings systems are forced to move in circles with a limit radius depending on their structure and wind force, LTA and hybrid systems must counteract the wind force.
LTA are, in turn, further divided in two types: **circular base LTA** and **ellipsoidal base LTA**.
The first type has an energy cost for the higher counteraction compared to the second, with the advantage that this is only proportional to the wind speed.

The second type, which can operate as a hybrid system, is instead subject to larger the energy costs necessary to align to the wind direction and it is therefore proportional to the wind speed and direction, as well as to the frequency of variability of the wind direction.

All payloads applicable to fixed wings are also usable on LTA. The reverse is not true. All proposals of fixed wings are similar. For all of them the weight is an insurmountable limit. Their current bound, which is also technological chance/challenge, is focused on the wingspan in order to get more solar power and on the aerodynamic seal of the wings.

For the LTA the shape is not always the same, the potential of photovoltaic energy is infrequently used.
The physical and technological challenge inherent to all presentations, although mostly not indicated, is the ascent and descent process, the variation of the weight/volume ratio and their rate.

The cornerstone of the platform is its buoyancy. The propulsive power necessary for stationing is a second priority connected to the aerodynamic drag and to the shape of the platform for any optimization.
Similarly, the aerodynamic thrust, which is obtained also from stationing, must be considered as a disturbance and the horizontal displacement a consequence of its stationing capability.

The main challenges are: take-off/landing, the climb to cruising altitude. This implies a change in the weight/volume ratio. No presentation exists of the procedure to alter this ratio.
It is our opinion that any prefixed conceptual approach prevents a proper view of the key issues.
Starting from the objectives, for instance monitoring of the Earth's atmosphere, we search for the system capable to carry on board the payload necessary for that purpose. The success of fixed wings inevitably pushes to develop this type of vector capable to meet the predetermined goal.

The difficulties of the fixed wings addressed the choice towards aerostatic systems, in particular the *PARSIFAL*. Even if some change has occurred (e.g., the *STRATOBUS* and *CIRA* models), the driving elements are:

- A stratospheric platform has to use the aerodynamic aspect.
- The platform must be associated to a specific purpose.

These two statements represent the conceptual limit that prevents to identify a solution capable to build up a platform. Which is the ultimate objective? The platform, which can meet the above-mentioned challenges and carry indefinitely on board any instrument, whose unique feature is the weight.
Any deviation from these conditions runs the risk of not being able to obtain a solution.

MEASUREMENT OF UPPER TROPOSPHERIC WATER VAPOUR

Most of the Outgoing Longwave Radiation (OLR) emitted by the upper part of troposphere occurs in the Far InfraRed (FIR) spectral region between 15 and 100 µm (667-100 cm^{-1}). This spectral region and the atmospheric components present here are very important for establishing the thermal equilibrium of the region, which in turn has a big influence on the weather and climate systems.
The spectral exploitation of the FIR allows us to retrieved with improved accuracy the most important atmospheric component presents in the upper troposphere, i.e. water vapour (WV).

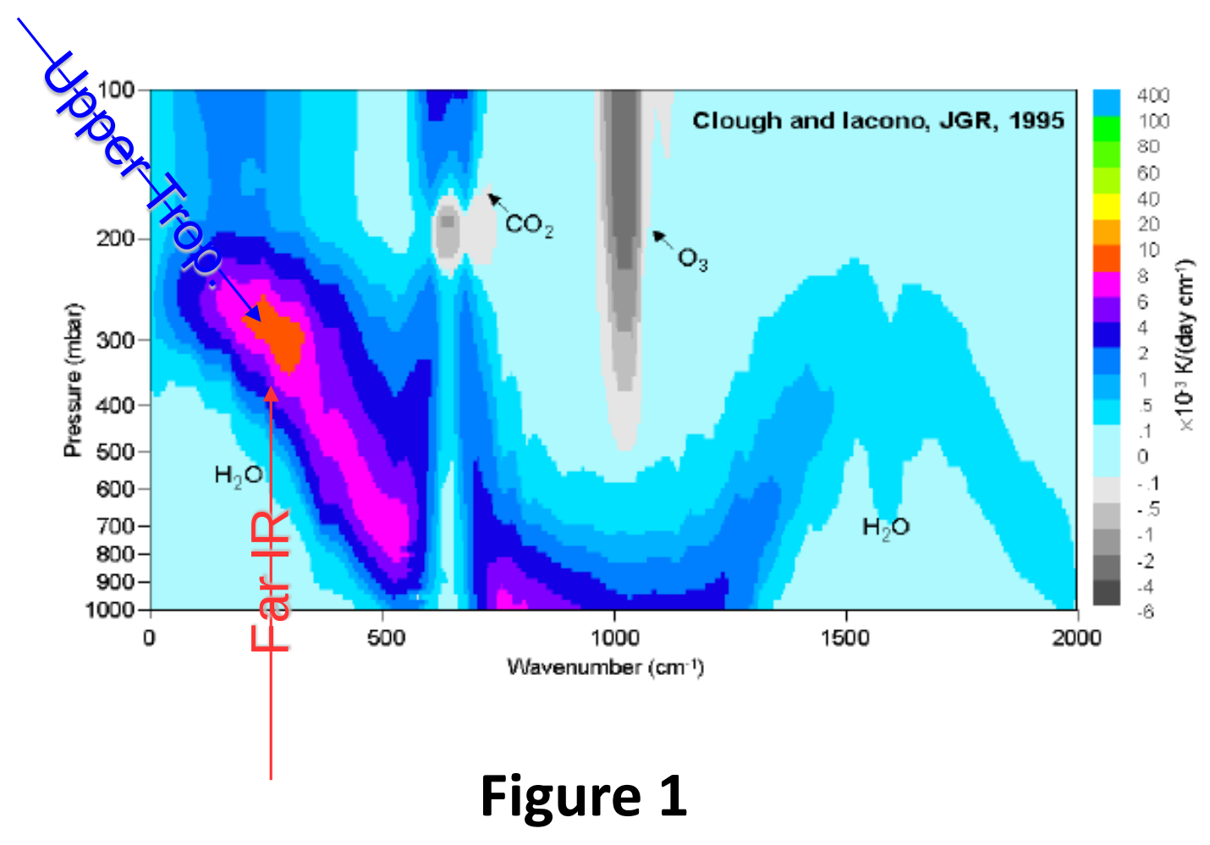
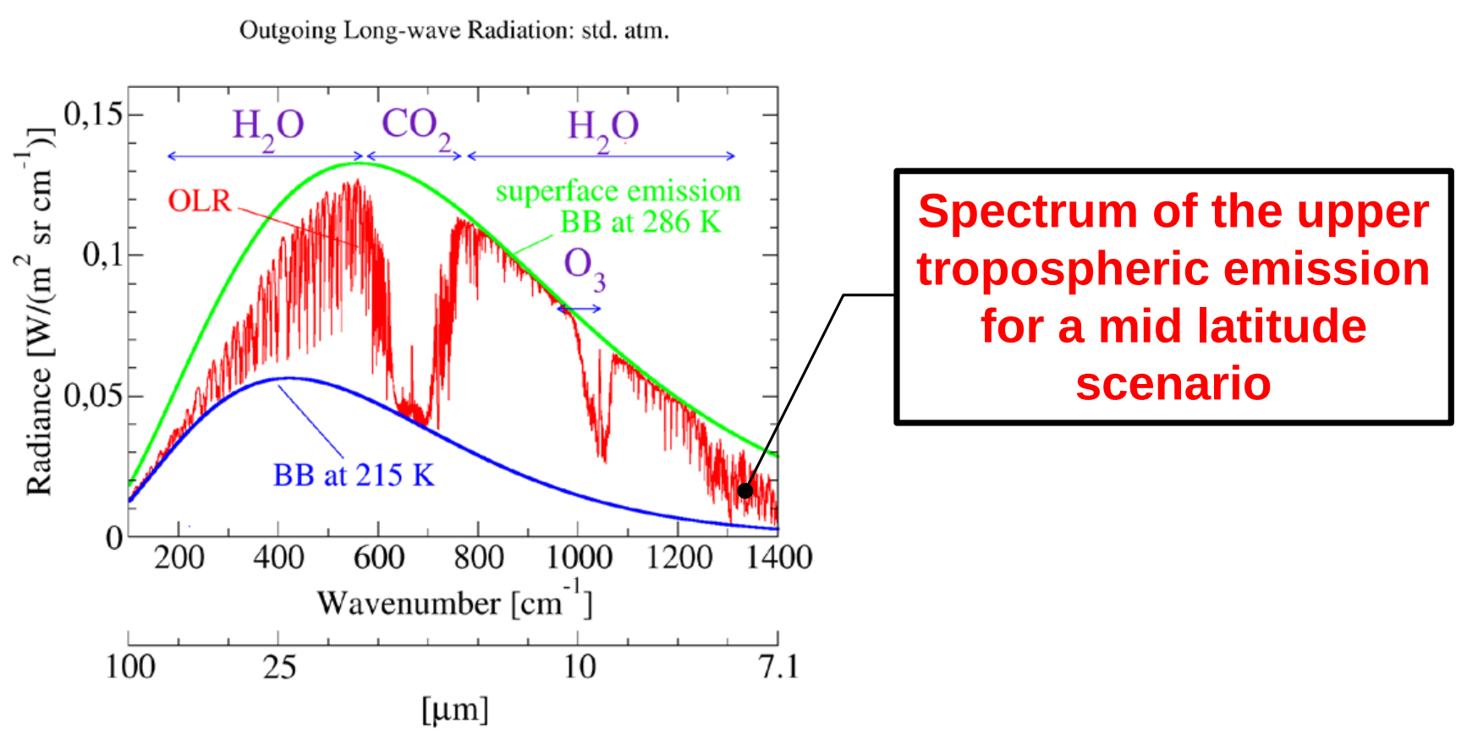


Figure 1



Spectrum of the upper tropospheric emission for a mid latitude scenario

Figure 2

The **Upper Tropospheric FIR Spectrometer (UTFTS)** has been designed to perform this measurement with a compact and **innovative Fourier Transform Spectrometer (FTS)** with a double-input/double-output port configuration that was designed for measuring with high accuracy the wideband atmospheric emission without requiring any cooled components ([1], [2]).
A key technical feature of this instrument is the **use of uncooled detectors**. which minimise the complexity and the power consumption making the application very reliable for continuous operation onboard HAPS.

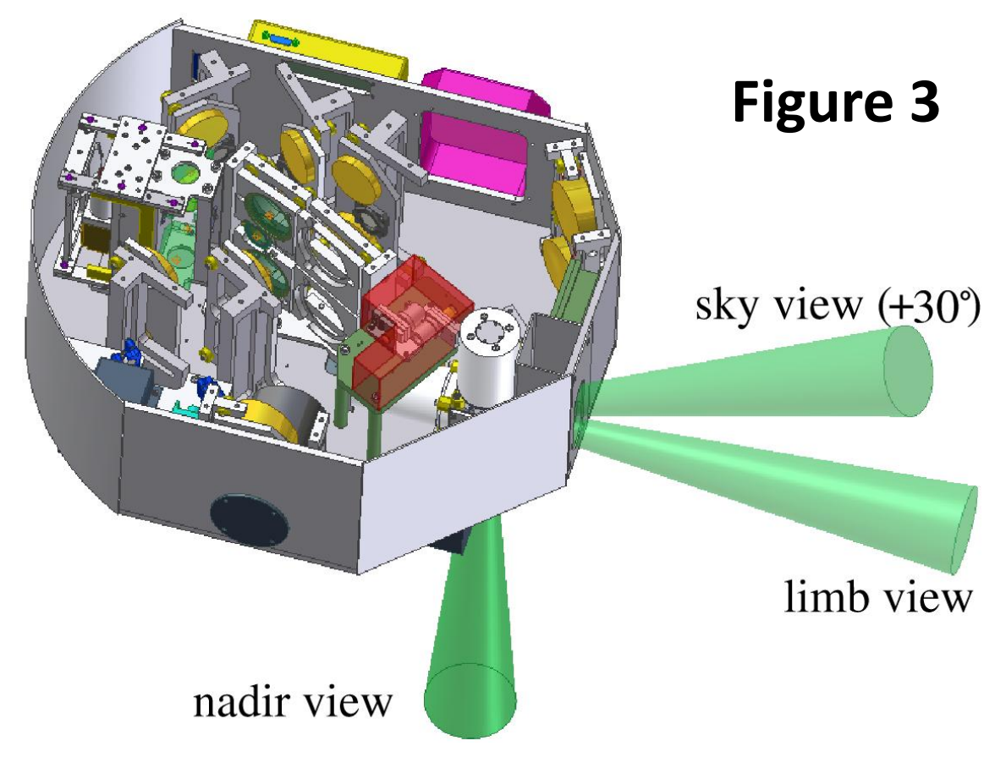


Figure 3

UTFTS is an adaptation of **the Radiation Explorer in the Far InfraRed - Prototype for Applications and Development (REFIR-PAD)** (Fig. 3) currently installed in Antarctica at Concordia station, Dome-C [3].
http://refir.fi.ino.it/rtDomeC

Payload characteristics	
Size	60 cm x 50 cm x 30 cm (h)
Total mass	50 kg
Power	50 W (70 W peak)
Base telemetry for telecommands and housekeeping	9600 bps
Spectral data telemetry	9600 bps

UTFTS spectrometer specifications	
Interferometer type	Mach-Zehnder with double-input/double-output
Detector system	2 room-temperature DLATGS
Spectral range	100–1400 cm^{-1}
Spectral resolution	0.3 cm^{-1}
Optical throughput	0.01 cm^2 sr
Field of view	0.1 rad
NESR	nadir, limb and "deep" space at +30 deg. elevation angle
Acquisition time	5 min every 5 min
Mean calibration error	
Radiance noise	0.8–2.5 mW/(m^2 sr cm^{-1})

MEASUREMENT OF LOWER TROPOSPHERIC WATER VAPOUR

Global monitoring of atmospheric water vapour vertical distribution poses particular challenges mostly due to the large uncertainties associated to the measurements of water vapour concentration in the lower troposphere by space-borne remote-sensing systems, such as GNSS radio occultation and infrared sounders

The **Normalized Differential Spectral Attenuation** (**NDSA**) [4] is a new method based on active microwave sounding of the Integrated Water Vapour (IWV) along the transmission path of signals at two relatively close frequencies in the Ku and K bands (e.g., 18.8 GHz and 19.2 GHz) between two co-rotating (or counter-rotating) LEO satellites.

A series of theoretical **ESA studies** (**AlMetLEO**, **ACTLIMB**, **ANISAP**) demonstrated that **Spectral Sensitivity S** - i.e.. the normalized incremental ratio of the spectral attenuation – is linearly related to the IWV along the LEO-LEO path and that the inversion of a set of IWV measurements at different tangent altitudes of the limb geometry is capable to retrieve the vertical profile of IWV and/or WV ([5] and references therein).

The **SWAMM** (Sounding Water Vapour by Attenuation Microwave Measurements) project, funded by Regione Toscana tested for the first time the NDSA concept on an instrument prototype operated in a ground-to-ground configuration and obtained the first real data of IWV along a radio link in static position.

The in-depth understanding and knowledge gained with the ESA studies and with the first acquisition of actual measurements conducted with the SWAMM prototype set the path to the ultimate goal of exploitation of the NDSA method from space.

The **deployment of the instrument in one of the possible configurations involving a HAPS platform** (i.e., with the transmitter on ground and the receiver onboard the HAPS) might offer a significant added value for more than one reason: as a key step in the process to achieve the adequate TRL of an instrument concept originally proposed for space operation and as an independent payload for scientific campaign aimed to monitoring of lower tropospheric WV, not to mention the longer term possibility of acting as a source of fiducial reference measurements in validation campaigns of spaceborne observations.

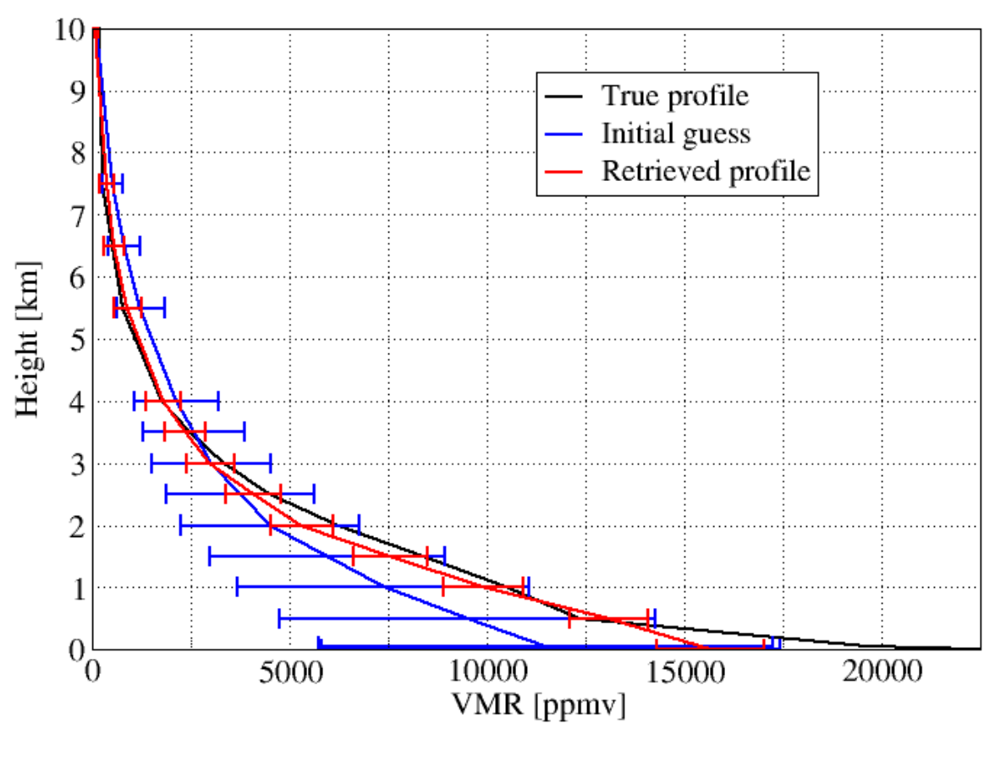


Figure 4

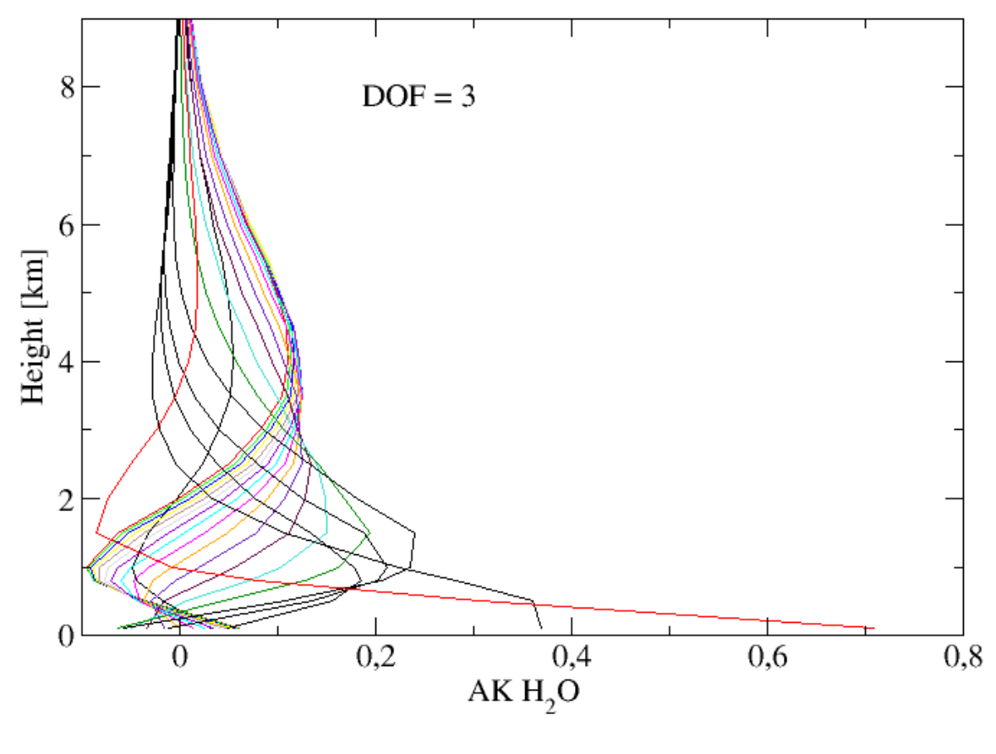


Figure 5

We have conducted simulations of a measurement configuration with the transmitter based on-ground and the receiver on-board an HAPS platform operating at an altitude of up to 20 km. The atmospheric scenario has been generated have been generated through a state-of-the-art NWP mesoscale model: the *Weather Research and Forecasting* (WRF) model version 3.8 and the initial guess and a priori profiles used by the retrieval are taken from the IG2 database [6]. Fig. 4 shows the capability of the inversion process to retrieve the true values of WV VMR especially at the lowermost altitudes below approximately 3 km.
This is also highlighted in Fig. 5, showing the plot of the averaging kernels of the measurements with peak values larger than 0.2 for tangent altitudes less than ~3 km.

MEASUREMENT OF LOWER TROPOSPHERIC WATER VAPOUR

The proposed payload, consisting of two instruments for passive remote sounding of upper tropospheric water vapour in the far-infrared region and active sounding of lower tropospheric water vapour in the microwave, offers a unique combination of complementary capabilities and sensitivity as a function of altitude for deployment onboard a HAPS platform.

As partly pointed out in previous sections, the deployment from HAPS of the FIR-FT spectrometer and of the NDSA system (in particular, of the receiver) for profiling of atmospheric water vapour offers an ideal case to demonstrate the potential of these platforms.

In fact, both instruments can acquire independent datasets in the frame of validation campaigns for future space missions, such as the **IASI-NG onboard Meteosat Third Generation** or the candidate Earth Explorer 9 **FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring)** or a constellation of co-rotating satellites for WV measurements using the **NDSA method**.

On the other hand, operation on the same platform from the altitude of 20 km and with possibility of hovering for long periods of time on a given region opens to unprecedented opportunities to combine the specific advantages of LEO and GEO satellite platforms, thus maximizing the performance both in terms of accuracy and precision, as well as of spatial and temporal resolution.

The availability of **innovative a posteriori data fusion techniques**, such as the **Complete Data Fusion** method (00) might further enhance the potential of this payload. By using the complementary information on the vertical distribution of WV retrieved from the two datasets with associated Covariance and Averaging Kernel Matrices, the method is able to provide the resulting fused products fully characterized in terms of uncertainty and vertical sensitivity by the corresponding CM and AKM.

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