Developing the use of hyperspectral MW observations for global NWP in an Ensemble of Data Assimilations (EDA)

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Introduction

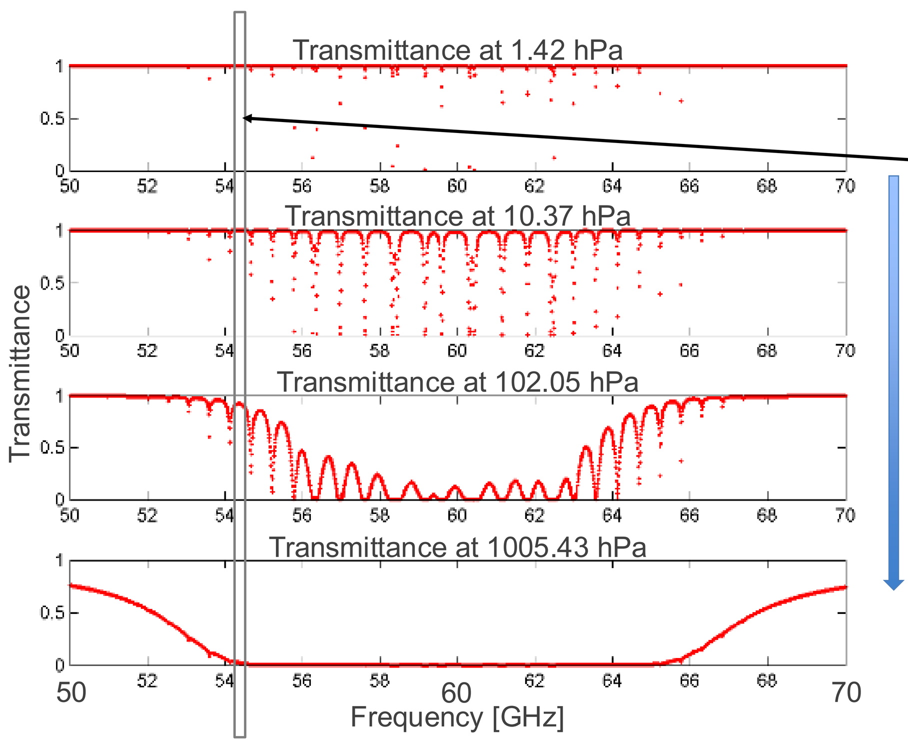
The advent of space-borne hyperspectral microwave (MW) instruments brings a major change to MW sensor technology that has been relatively stable for many years. In this ESA funded study, we will assess the potential benefit to global NWP of a hyperspectral MW instrument using the Ensemble of Data Assimilations (EDA) method, building on experience from earlier studies using the technique (e.g. [1], see also poster 3p.02). To achieve reliable impact evaluation, we must first develop an appropriate strategy to simulate and assimilate the observations, as well as adequate representation of expected uncertainties. In this poster we outline the advantages of the denser spectral sampling and introduce the hyperspectral instrument based on the Hyperspectral Microwave Sounder (HyMS) instrument developed by Spire and RAL Space. The challenges in the assimilation are discussed including consideration of a channel selection (full details can be found in [2]).

Potential for hyperspectral MW

A literature review was conducted to consolidate findings on the prospects of hyperspectral MW technology. Studies applying 1-D information content techniques showed key benefits around the following themes:

- Improved retrieval of temperature and humidity profiles exceeding impact from heritage instruments in clear and cloudy conditions
- Advantages in Radio Frequency Interference (RFI) detection
- Better sensing of lower troposphere and improved characterisation of hydrometeors/cloud parameters

Denser frequency sampling is particularly beneficial for the 50-70 GHz band



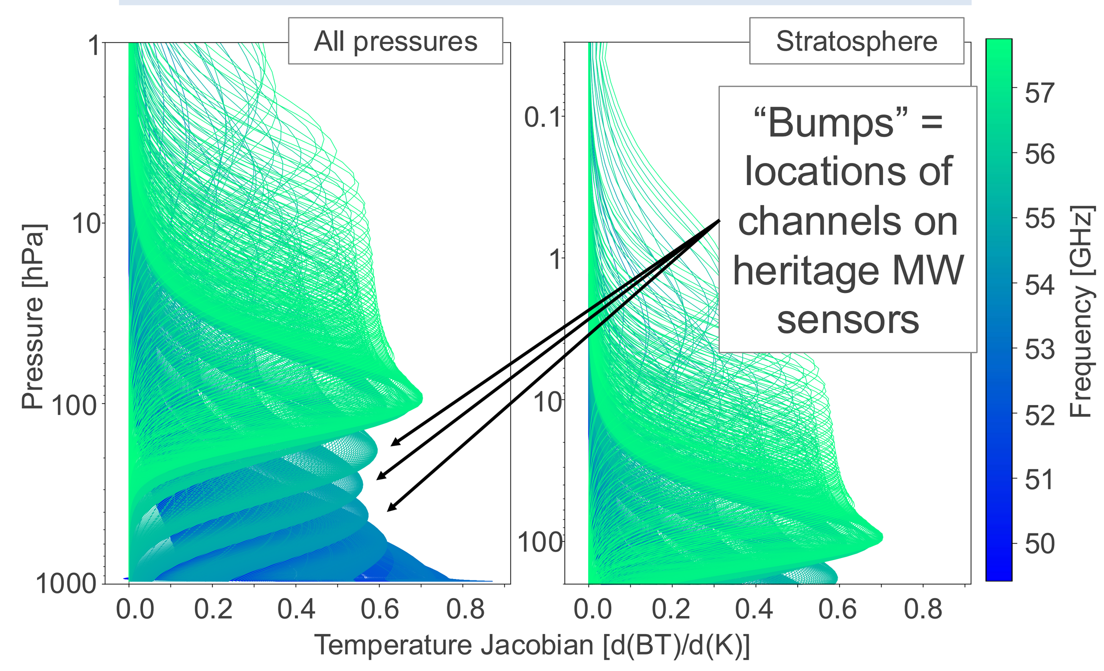
Transmittance from pressure levels to top of atmosphere (Reproduced from [3])

Finer sampling from hyperspectral MW can better probe smaller structures in oxygen absorption line leading to greater diversity in weighting functions.

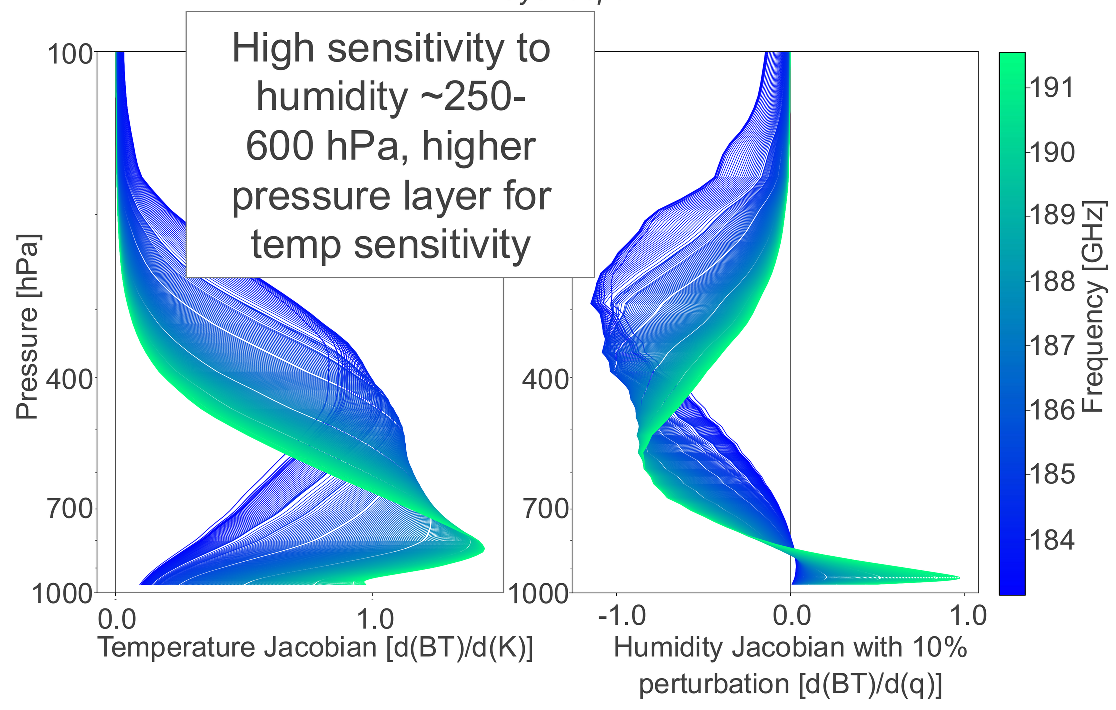
Benefit from measuring previously unsampled parts of spectrum with advantages for effective noise performance when all channels considered together.

Channel selection

Dense vertical coverage of HyMS channels



Temperature Jacobians for the HyMS temperature-sounding channels. Average profile of 5000 variable atmospheric profiles and normalised by log of model layer depth.



Temperature and humidity Jacobians for the HyMS humidity-sounding channels. Average profile of 5000 variable atmospheric profiles and normalised by log of model layer depth.

Desirable to use as much frequency spectrum as possible. A channel selection will be carried out in 3 stages:

1. Exclude frequencies rejected in assimilation screening steps or at high risk of RFI contamination.
2. Consider creating lower noise "super channels" of averaged neighbouring channels in higher surface sensitivity frequencies.
3. If necessary for data volume management, use of iterative Degrees of Freedom for Signal (DFS) method to assess information content (as done for hyperspectral IR).

In future, could be revisited with Principal Component techniques.

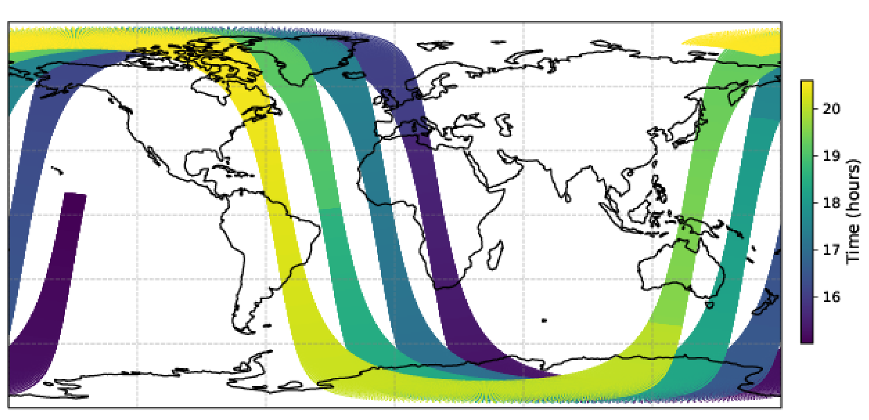
The HyMS instrument

The hyperspectral MW instrument evaluated is based on HyMS which covers a finely sampled temperature-sounding band around 50 GHz, a humidity-sounding band around 183 GHz and a broad passband window channel at 89 GHz.

Instrument characteristic	HyMS	ATMS
No. of channels	1689 x 49.42-57.75 GHz 1 x 89 GHz 212* x 183.13-191.55 GHz	13 x 50.3-57.62 5 x 182.31-190.31 GHz 1 x 23.8, 31.4, 88.2, 165.5 GHz
Channel bandwidths	6.34 MHz for 50 band 40 MHz for 183 GHz band	155-400 MHz for tropospheric 50 GHz, 500-2000 MHz for 183 GHz
No. of fields of view	45	96
Max. scan angle	45 deg	52.7 deg
Sample NEDT	1.53 K for temp-sounding 1.63 K for humidity-sounding	~0.25 K for temp-sounding ~0.4 K for humidity-sounding

*Channels in 183 GHz band are already combined into bins of 8 neighbouring channels

Significant inter-channel error correlation in NEDT between adjacent channels will need to be accounted for in simulating brightness temperatures (BTs).



Typical coverage for the cross-track scanning HyMS instrument for 6-hour timeslot

The HyMS demonstrator mission (expected launch late 2025) will have a Local Equator Crossing Time (LECT) of 1700 complementing Metop (0930) and JPSS (1300) LECTs

Assimilation challenges

Assimilation of HyMS will closely follow the current MW all-sky scheme with 3 key areas requiring adaptation:

Radiative transfer modelling over land

Current sensors use a dynamic surface emissivity retrieval from a surface sensitive channel. Initial pragmatic choice to use only surface insensitive channels over land. Potential to revisit with use of averaged "super channels".

Quality Control

Selection strategy for screening e.g. where low peaking channels are currently removed over polar regions. A threshold on transmittance could be considered.

Observation Error

Following the all-sky error model, observation error values increase in the presence of cloudy signals in the observation or model. The adaptation for HyMS will focus on:

- Defining suitable indicators of cloud to estimate the cloud presence
- Treatment of inter-channel error correlations – explicit definition preferred (shown to be beneficial for IR) or suitable error inflation strategy

Next steps

Technical development of the simulation/assimilation system is ongoing. Initial simulations of BTs will help inform screening choices and forming an appropriate channel subset for assimilation. Development of representation of observation uncertainties is also a key activity, defining appropriate perturbations to the simulated BTs to represent instrument noise and the adapted all-sky error model.

References

[1] Lean, K., Bormann, N., Healy, S., English, S., Schüttemeyer, D. & Drusch, M. (2025): Assessing forecast benefits of future constellations of microwave sounders on small satellites using an ensemble of data assimilations. Q. J. Roy. Met. Soc., e4939. doi: 10.1002/qj.4939

[2] Lean, K. and Bormann, N. (2025): Evaluation of hyperspectral MW observations for global NWP: Simulation framework consolidation, ESA Contract Report, ESA contract no 4000145264/24/NL/IB/ab

[3] ECMWF training course material https://events.ecmwf.int/event/375/contributions/4249/attachments/2308/4037/microwave1_2024.pdf