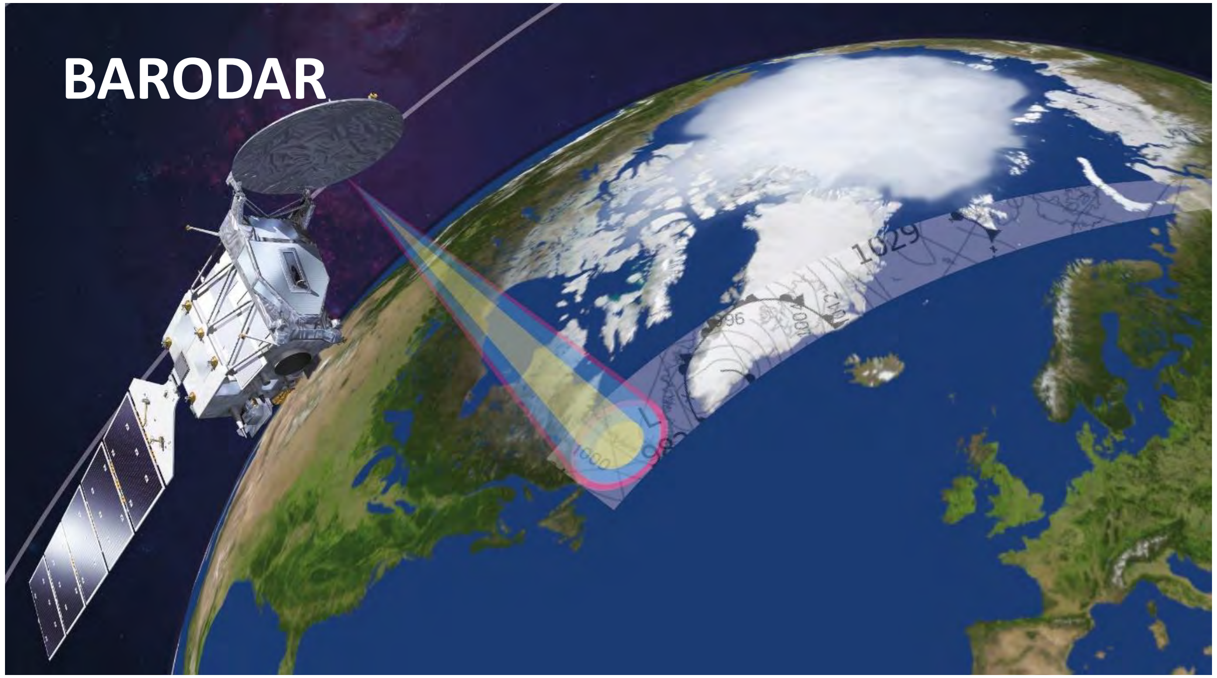
RAL Space

"BARODAR: Global Surface Air-Pressure Mission"



Science and Technology Facilities Council

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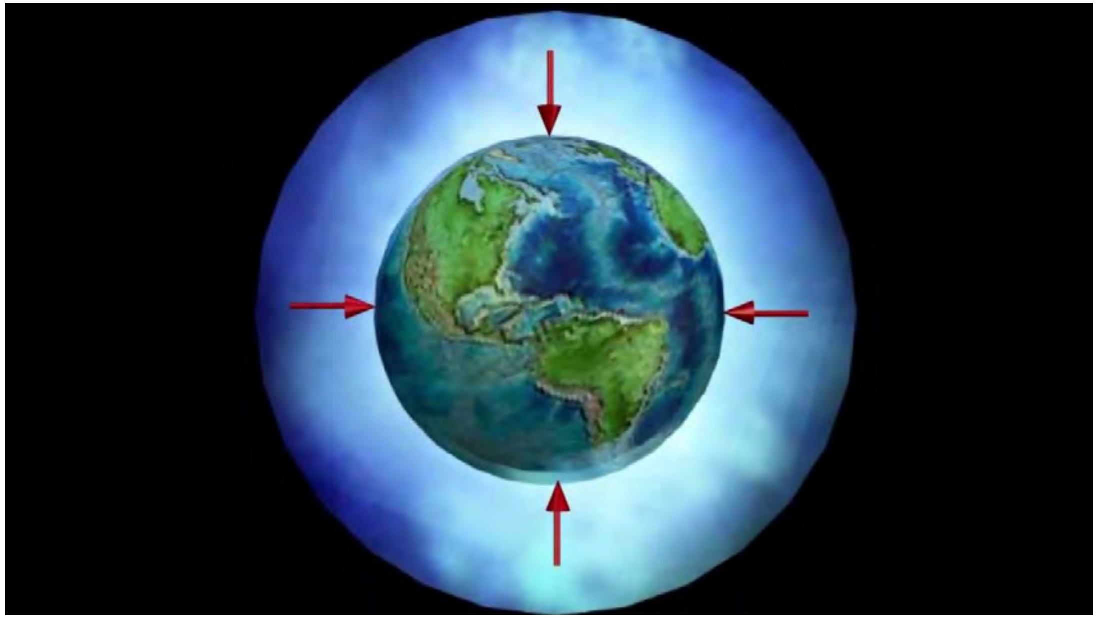
CEOI-EO Week 10th September 2021

European Space Agency

BARODAR: BAROmetric Differential Absorption Radar

BARODAR is an **EO** mission to provide global, regular, and consistent **surface pressure** measurements **from space for the first time**.
Surface Air-Pressure is a result of the fluid and thermodynamics of the atmosphere. It is therefore **critical** for **assessing the state** of both the **atmosphere** and **oceans**.

- ❑ Mission Justification
- ❑ Instrument Design
- ❑ Update
- ❑ Summary & future work

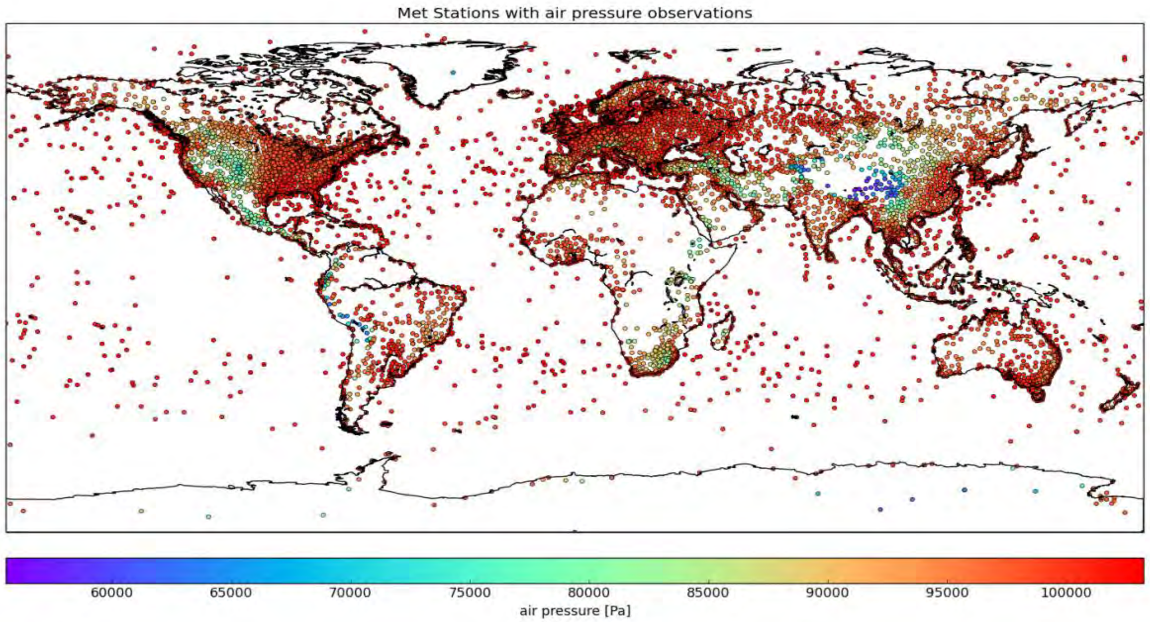


Mission justification

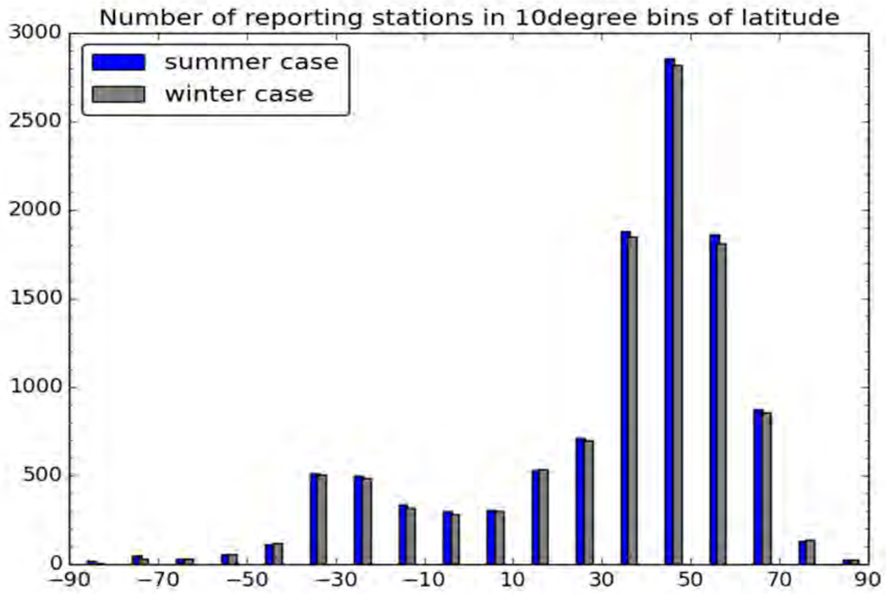
- Due to climate change **extreme weather events** becoming **more frequent** and **more intense**.
- Better forecasting required for forward planning, **protection and defence** against extreme weather.
- Extreme events such as **storm surges and hurricanes are significantly underestimated in models, partly due to insufficient data of surface pressure**.
- **Pressure is the most important parameter used in Numerical Weather Prediction (NWP) Models and Climate Models, General circulations model (GCM) .**
- Most EO missions measure **altimetry, wind**, **temperature, gravity** and others require accurate pressure measurement to retrieve accurate results.

Limited measurements on land, and more importantly at sea, limit forecasting capability.

Current distribution of in-situ surface-air pressure sensor



Coverage of surface pressure observations for the 00 UTC assimilation cycle on 19th July 2017 in the Met Office global model. Observations are used from 10 236 stations globally, some reporting hourly, giving approximately 40 000 observations assimilated in a 6 hour window.



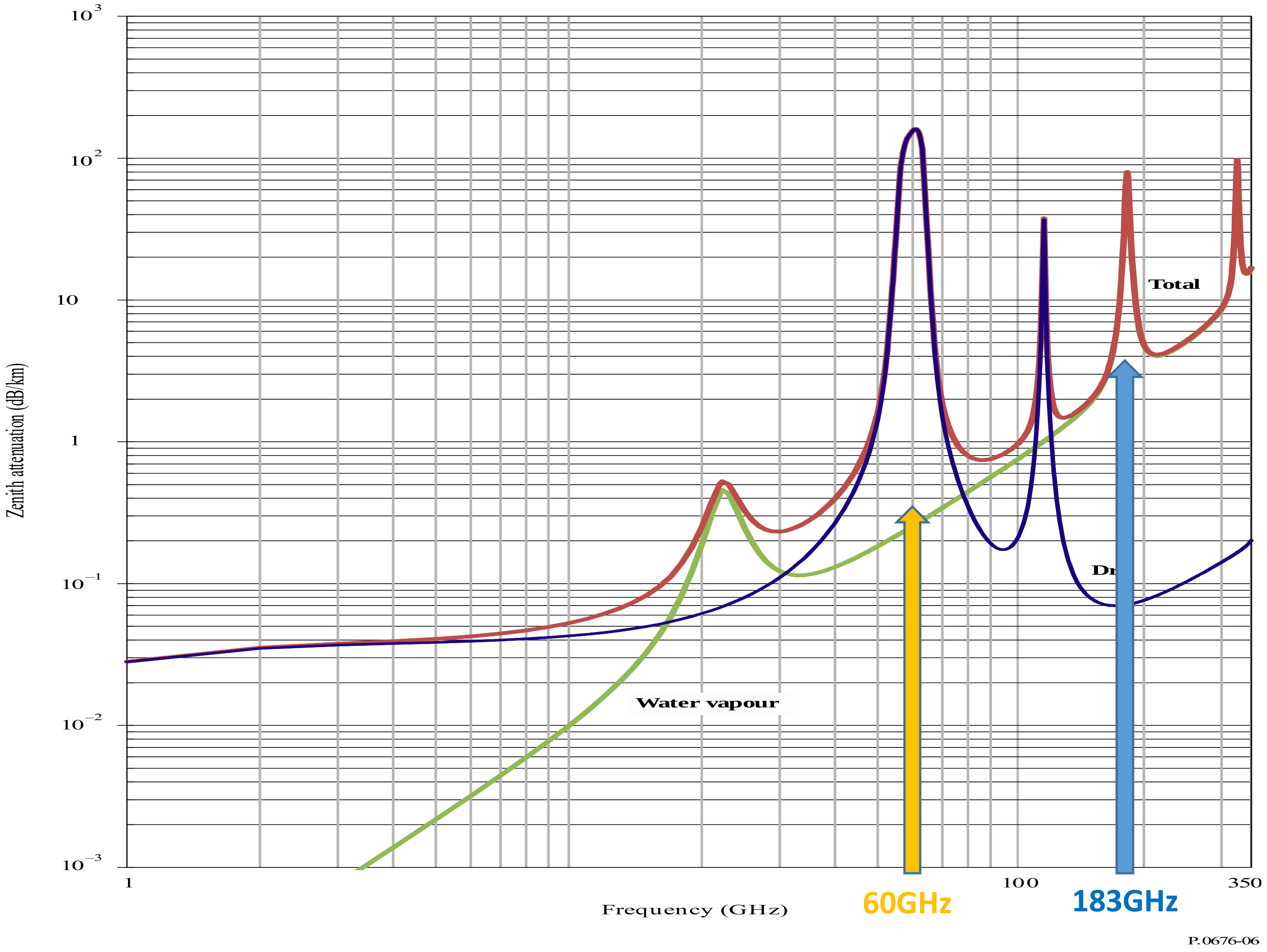
Distribution of in-situ stations reporting pressure for 1st Jan 2017 (winter) and 17th July 2017 (summer), based on the observations available from the Met Office operational database received via the WMO Global Telecommunication System.

- 90% of stations are on **land and concentrated on the Northern Hemisphere**.
- Ground based instruments are **not homogeneous**, data quality control, installation, maintenance and **calibration** are challenging.
- Surface air pressure was **never measured globally** from space before

Satellite remote sensing is the only way to provide, global consistence and continuous observations.

Active Microwave Technique

- Oxygen **uniquely** has **a constant mixing ratio** over the full range of atmospheric conditions.
- **Total oxygen** is a proxy for atmospheric **pressure measurements.**
- A pair of pressure sensing frequencies on the **lower or the upper wing** of the oxygen absorption band provide **distinctive attenuations**.
- The **differential absorption radar (DAR)** provides potential technique for surface pressure measurements.
- **Water Vapour** measurements with **MWR** is needed to correct for clouds and **precipitation**.



Total, dry air and water-vapour zenith attenuation from sea level
(Pressure = 1 013.25 hPa; Temperature = 15°C; Water Vapour Density = 7.5 g/m^3), Rec. ITU-R P.676-11

Operational and Research users requirements

A concept design **started in 2017 with ESA funding.**

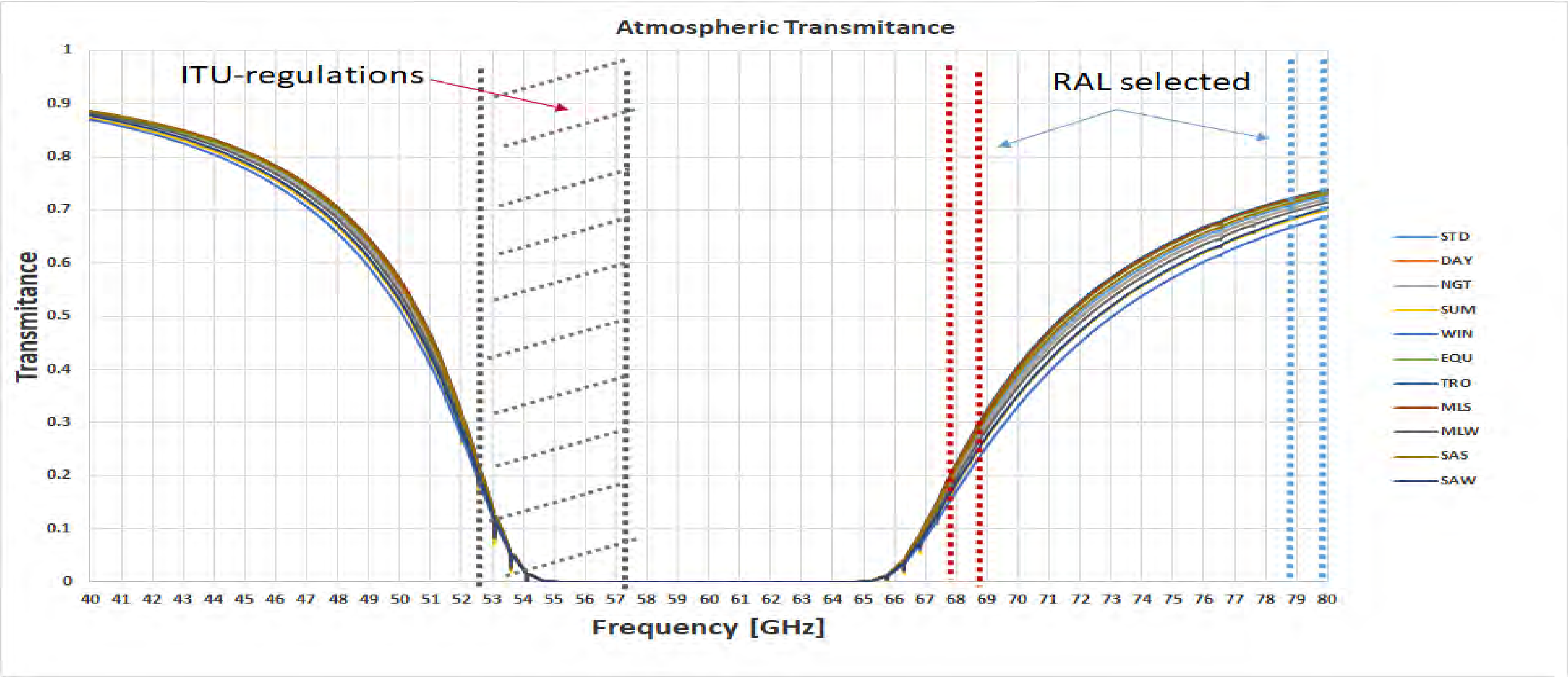
	Numerical weather prediction	Ocean dynamics and sea level	Climate modelling	Gravity monitoring	Atmospheric composition monitoring
Repeat distance/grid (km)	1 - 500	1 - few x 100	Few x 10	200	3 - 100
Repeat rate (hours)	0.5 - 24	0.5 - 12	3 - 24	3 - 6	2 – 4 weeks
Uncertainty ±(hPa)	0.5 - 2.0	0.2 - 10.0	0.5 - 1.0	1 - 2	1

WMO and OSCAR requirements + users survey

- Uncertainties of **±0.5hPa** would be of **significant** benefit for **NWP** and **Climate** Modelling.
- Uncertainty of **± 0.2hPa** is needed for **coastal areas especially** for storm and hurricane forecasting.
- Achieving this will be a **break through** as **it will satisfy all users** as well as providing accuracy comparable with **the in-situ measurements**.

Frequency selection criteria

RFM radiative transfer model with 11 scenarios

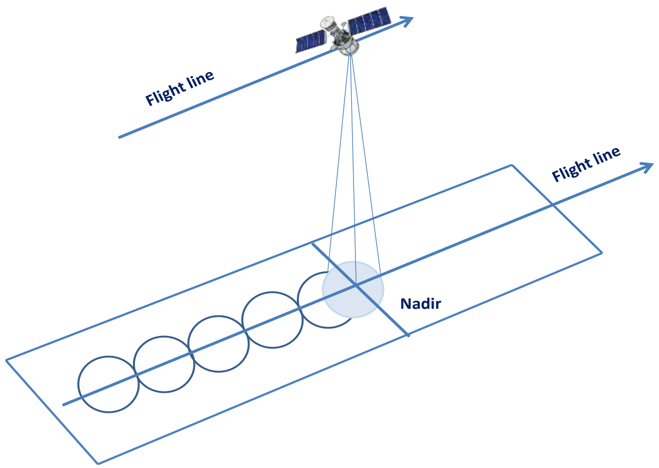


$$\mathbf{SNR} = \left(\left(\frac{P_t \;\; G_r \; G_t \, \lambda^2 \;\; \sigma^o}{(4\,\pi)^3 \; h^4}\right) - \, la\right)/N$$

- Outside the ITU astronomy allocated bands.
- Strong correlation with column O2 amount
- Close enough to use the same antenna.
- Careful selection to increase attenuation ratio of a pair.
- Not too deep in the oxygen band to maintain good SNR.

Observation method and design considerations

- **Nadir looking observation to maximise radar cross-section**
- **Antenna radius is fully determined by the accuracy required.**
- **Accuracy relates to the total number of samples averaged.**

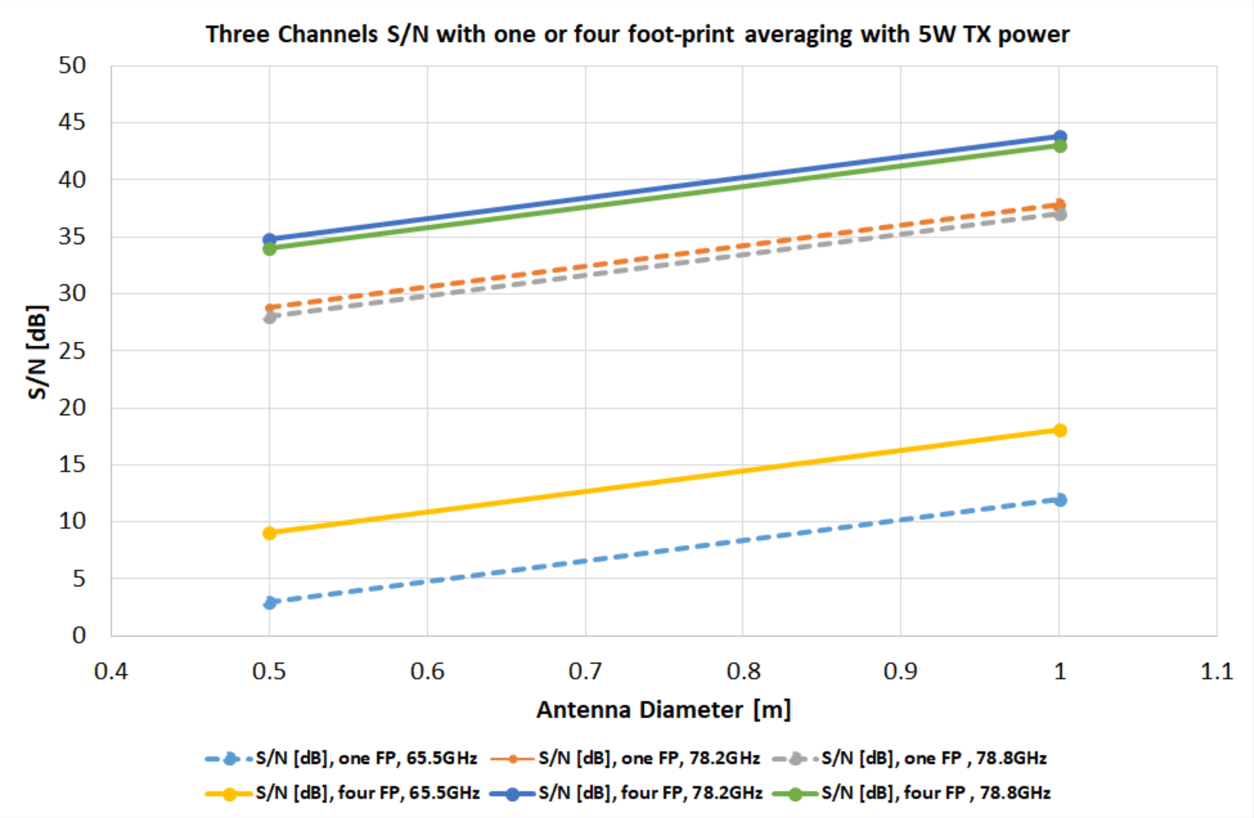


$$V(t) = I^2(t) + Q^2(t)$$
$$I = \sum i \text{ and } Q = \sum q$$

Antenna radius is a function of :

t	integration time
V	satellite speed
D	duty cycle
F_A	fractional accuracy

Relationship between samples collection rate and the size of the antenna [1978 Flower and Peckham]



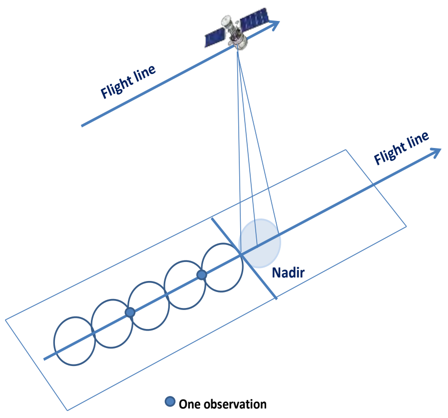
25dB differential absorption available.

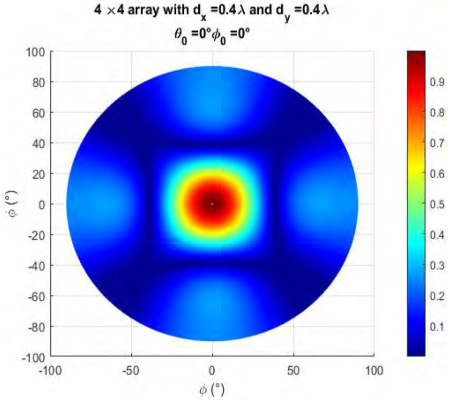
Trade-Offs:

- Increasing the averaging time will improve accuracy but will increase spatial resolution.
- 6dB gain due increasing antenna diameter from 0.5m to 1m.
- 3dB gain with 10W transmit power.

System design specifications

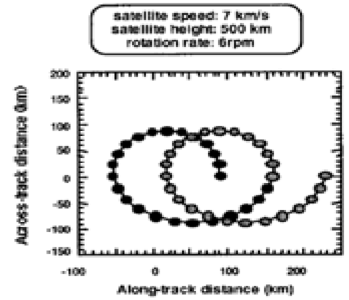
Base-line design

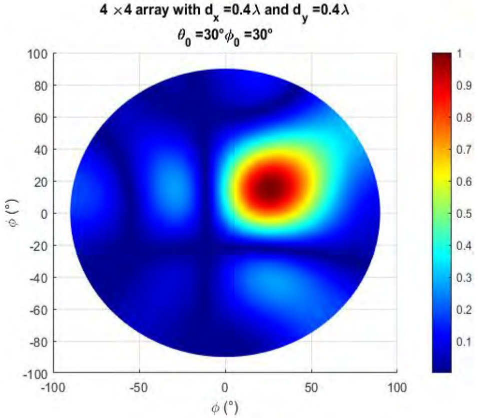


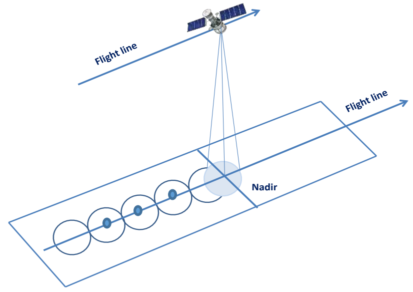


Parameter	Base-line design	Improved design	Unit
Instrument	3 frequency radar	3 frequency radar	
Frequencies	(65, 78, 79)	(65, 78, 79)	GHz
TX power	5	5	W
Antenna diameter	0.5	0.5	m
Altitude	500	500	km
Pulse width	10	10	µs
Bandwidth	100	100	kHz
Spatial resolution	5 (swath) x 10 (along)	5 (swath) x 5 (along)	km
Statistical accuracy for 1σ	0.33	0.05	%
Statistical accuracy per channel	±1.65	±0.28	hPa

Improved design







The antenna scanning study for improved design was funded by ESA in 2019

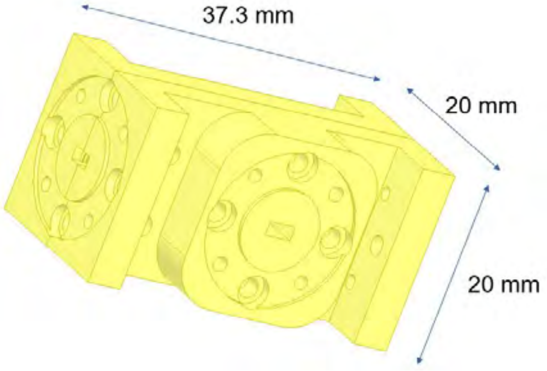
Components Design

STFC funding in 2020 to build:

- **Power amplifier** designed for the lower wing of the oxygen band

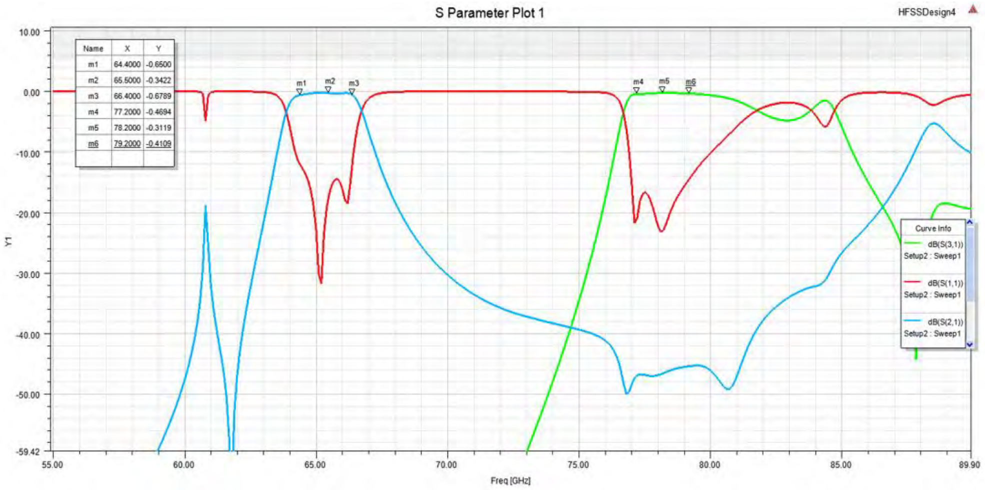
- **Diplexer** based on H plane T junction and waveguide resonant cavities band pass filters in WR12

Power Amplifier



Diplexer: E plane split
UG-387/U flanges

HFSS Simulation results
S21 and S31 around -0.4 dB in the band pass
S21 and S31 better than -20 dB out of band
S11 better than -10 dB

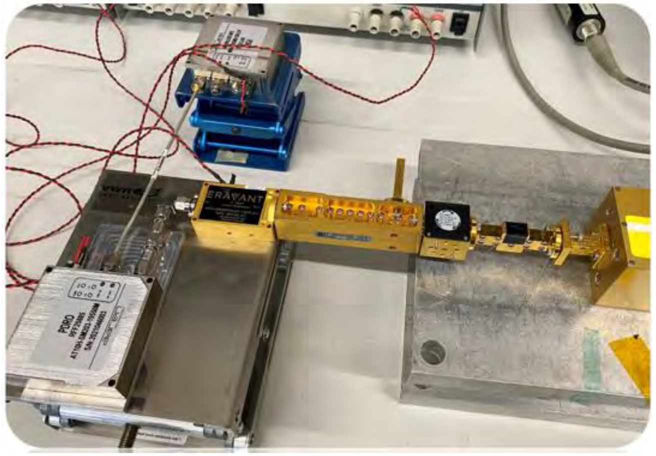


System integration test for bench model

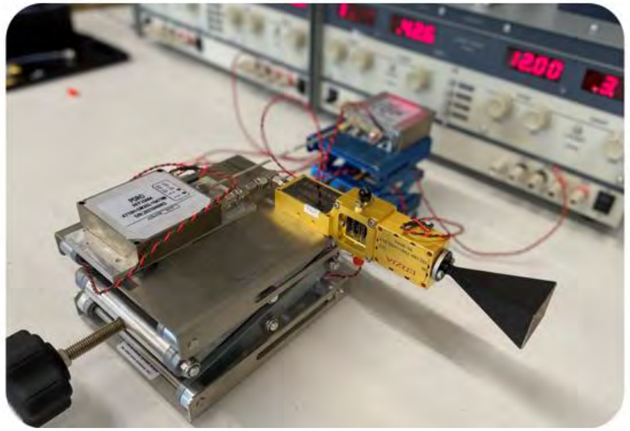
STFC funding in 2021 to build radar bench model

- Two channels radar was designed and built.
- Subsystems are under integration test.
- HYMS: Hyperspectral Microwave Sounder, currently tested on FAAM aircraft, CEOI funded.

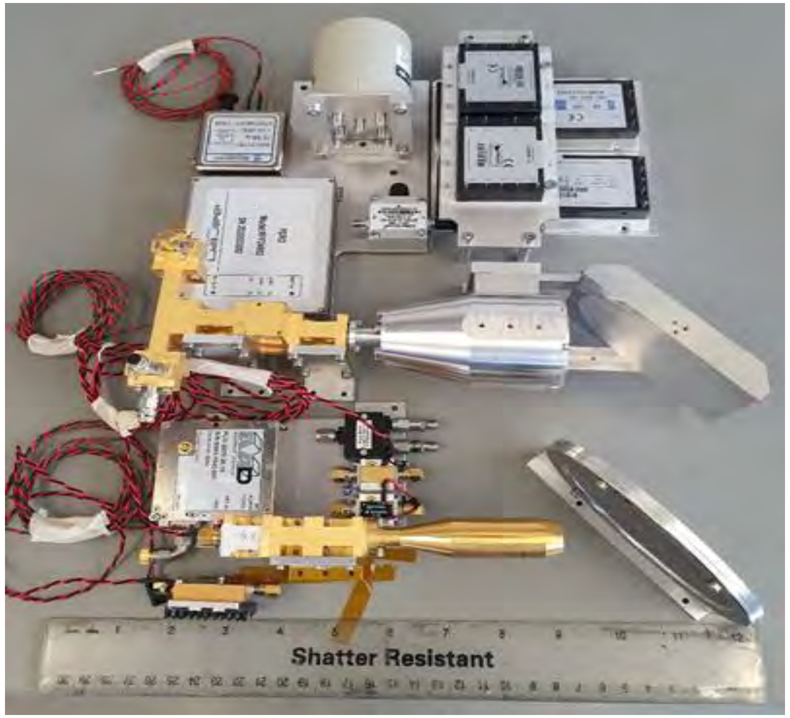
Radar TX



Radar RX



Radar PSU



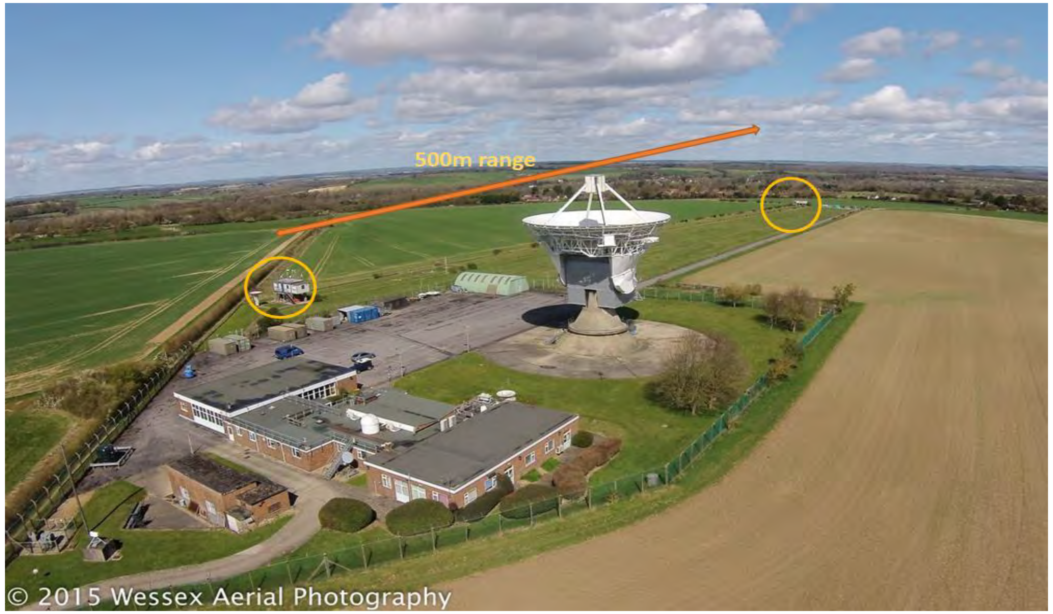
Hyperspectral Microwave sounder
ESA+CEOI funded

Summary and future roadmap

- **BARODAR** improves **Climate Change** forecasting.
- Contributes to **saving lives** and **infrastructure.**
- Complements **in-situ** and **RO** data to provide **near real time, global data**.
- With **5km x 5km** spatial resolution and high accuracy of **±0.2 hPa** will enable surface air-pressure data to be used with **high resolution NWP models**.
- This will allow monitoring of **cyclone storms intensities**, **tracks,** and location at a resolution **beyond current** capabilities, for **better disaster management**.

Future roadmap:

- Complete system test in the **lab** and at **Chilbolton 500m** range.
- Design an **air-borne demonstrator** to verify retrieval methodology. Supported by **ESA, No funding available yet.**
- **BARODAR** for a future **Earth Explorer** mission. Supported by **ESA**.



BARODAR

Questions

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