living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

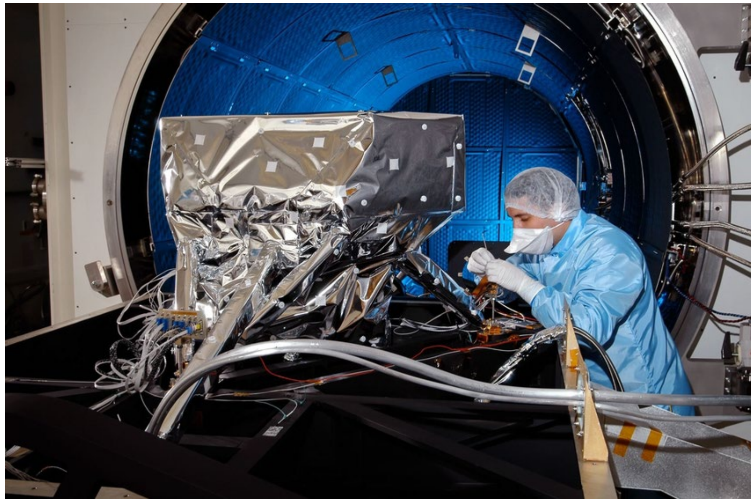
BARODAR: Global Mission for Active Microwave Surface Air-Pressure Sensing

Emal Rumi

24/05/2022

RAL Space

BARODAR: Global Mission for Active Microwave Surface Air-Pressure Sensing

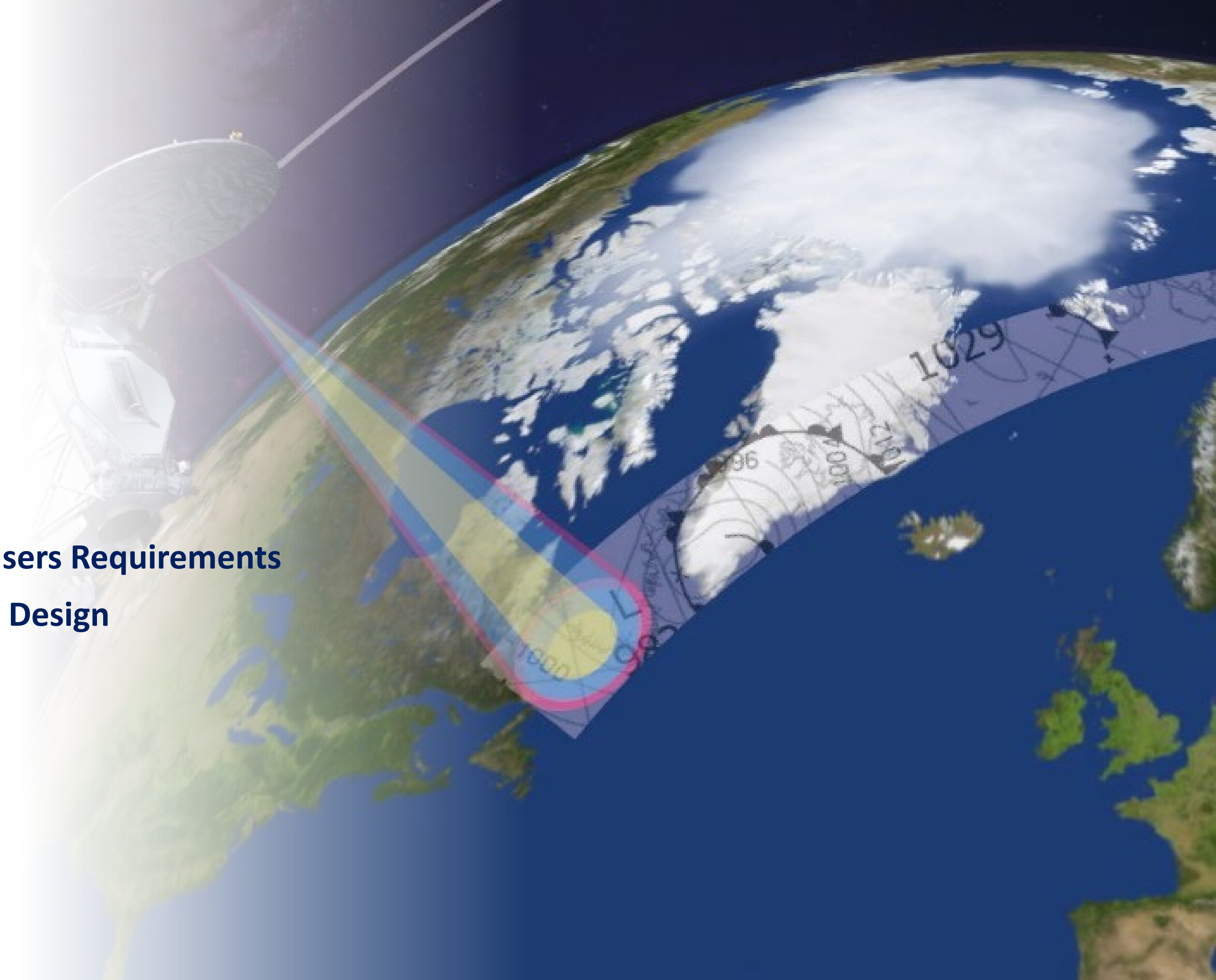




Emal Rumi, John Bradford, Brian Ellison, Judith Jeffery, Daniel Gerber, Manju Henry, Brett Candy, Salvatore Daddio, Christine Gommenginger, Richard Reeves, Hui Wang, Fiachra Cahill, Diego Pardo, Ishuwa Sikaneta, Christopher Buck

Met Office | UKRI Science and Technology Facilities Council | UK Space Agency | esa European Space Agency | Centre for EO Instrumentation | National Oceanography Centre, Southampton – University of Southampton and Natural Environment Research Council

Outline

- Introduction
- Mission Justifications
- Concept Design
- Operational and Scientific Users Requirements
- Bench Model Demonstrator Design
- Summary and Future Work



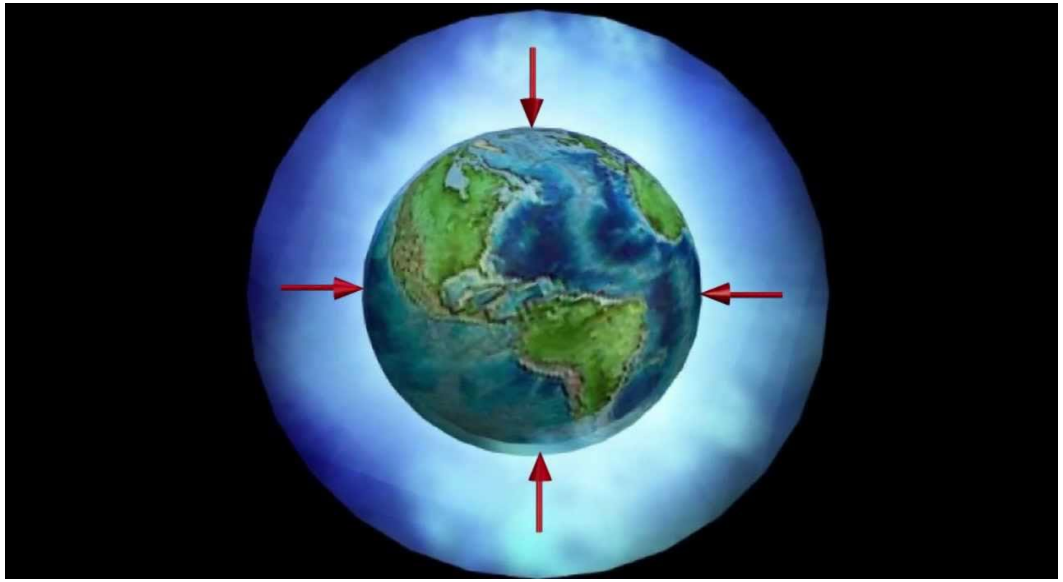
BARODAR: BAROmetric Differential Absorption Radar

Our atmosphere determines the living planet's environment weather and climate.

BARODAR is a concept for an **EO** mission to provide near-global, regular, and consistent **surface pressure** measurements **from space for the first time**.

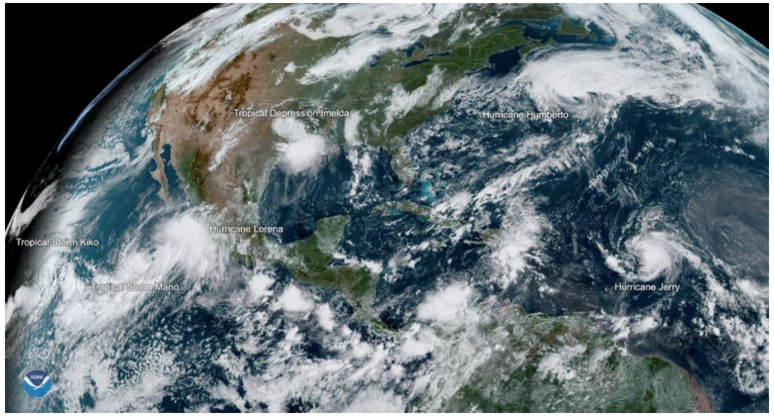
Surface Air-Pressure is a result of the fluid and thermodynamics of the atmosphere above the Earth. It is therefore **critical** for **assessing the state** of both the **atmosphere** and **oceans**.

ESA-ITT GSP started in 2017
- Feasibility study, possible techniques
- A concept design of the a potential instrument capable of measuring surface-air pressure from space with sufficient accuracy of (~1 hPa)
- Assessed of the impact of such a mission
- Collaboration with Met Office and NOC

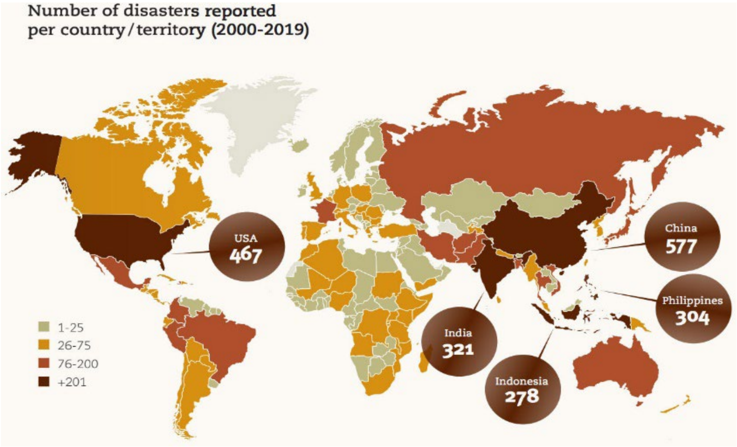


Mission Justification

- 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)** .

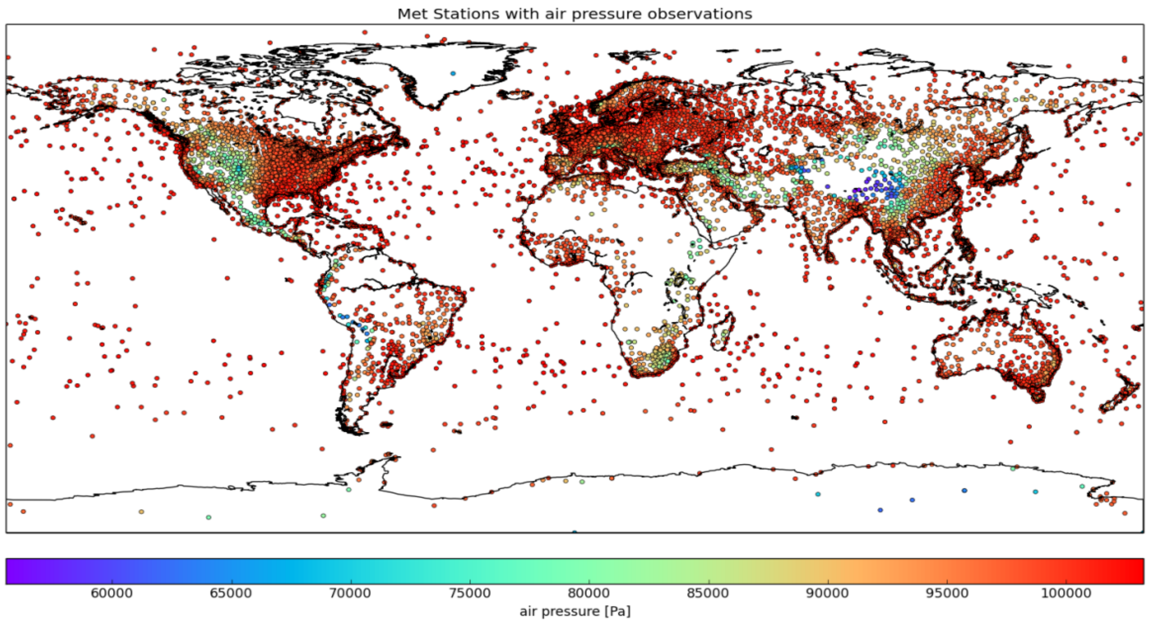


Limited measurements on land, and at sea, limit forecasting capability.

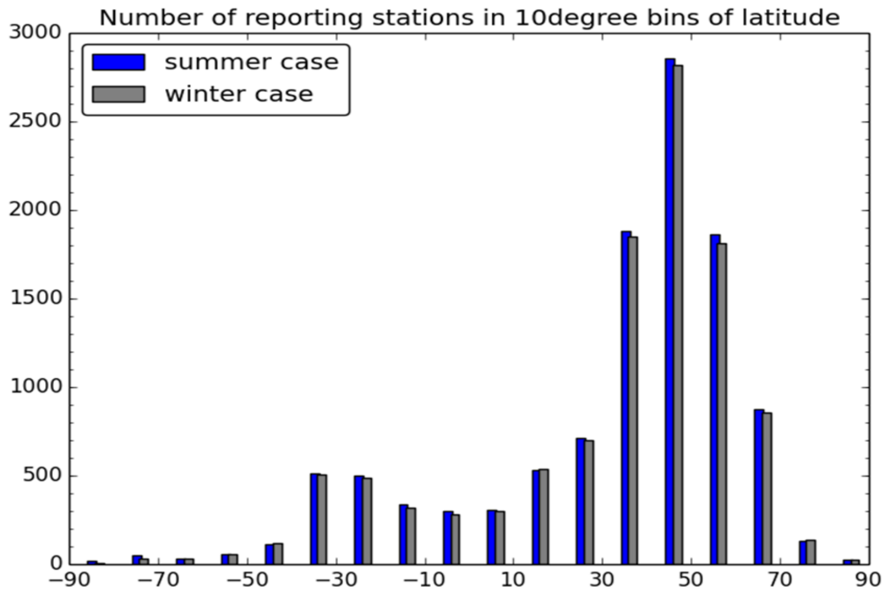


CREDIT: UNITED NATIONS OFFICE FOR DISASTER RISK REDUCTION

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.



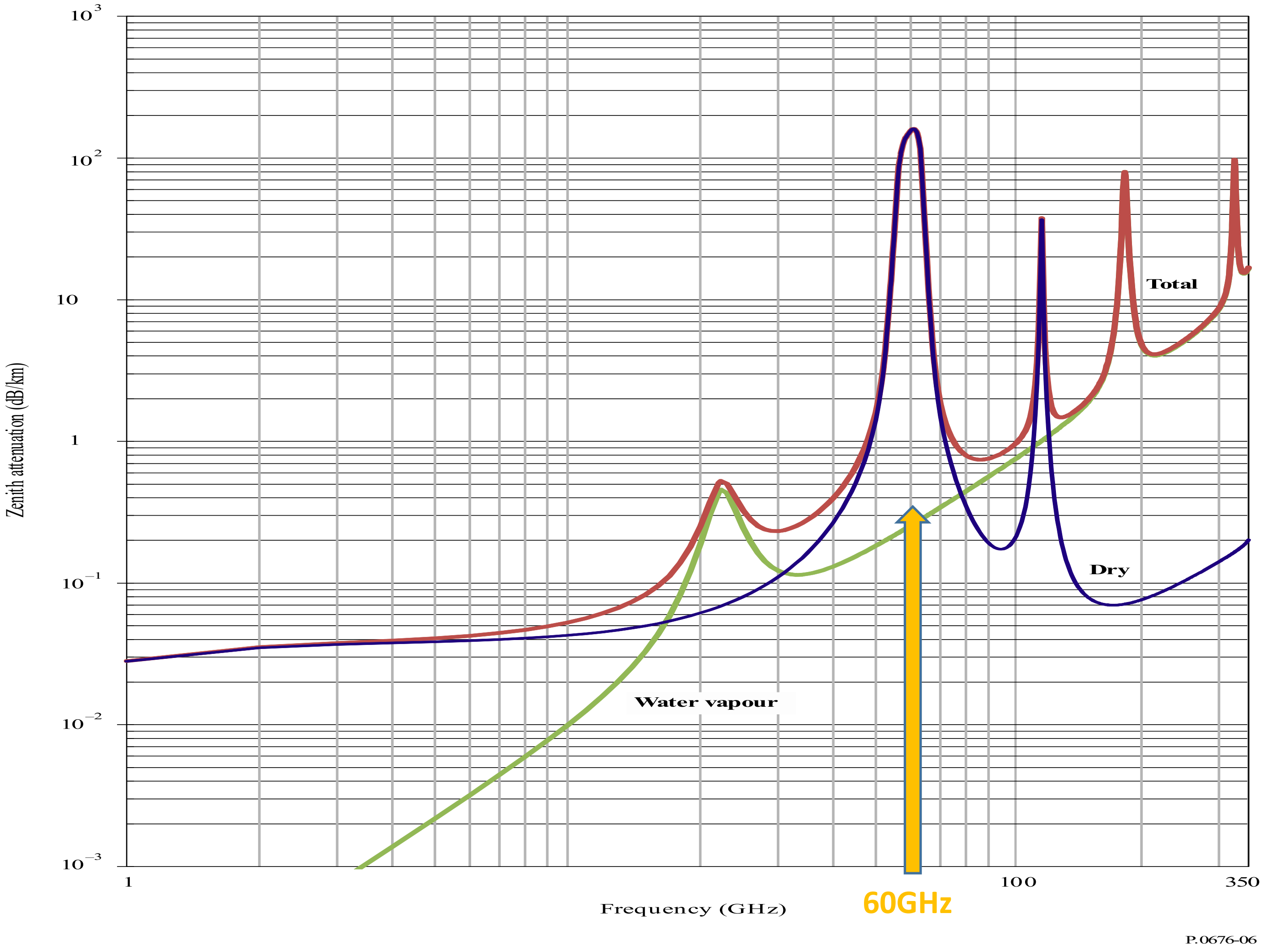
Distribution of in-situ stations reporting pressure for 1st Jan 2017 (winter) and 17th July 2017 (summer), based on the observations available from the Met Office operational database received via the WMO Global Telecommunication System.

- **Only 30%** of the Earth is currently measured
- **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.

BARODAR Mission Concept Design

- Electromagnetic waves are mainly absorbed in the atmosphere by oxygen (O_2) and water vapour (H_2O).
- Oxygen **uniquely** has **a constant mixing ratio** over the full range of atmospheric conditions and latitudes.
- **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**.
- Active remote sensing using the **differential absorption radar (DAR)** provides potential technique for surface pressure measurements.
- Novel design of three channels DAR
- The choice of the operational frequencies is critical



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/m³), Rec. ITU-R P.676-11

Operational and Research sers requirements

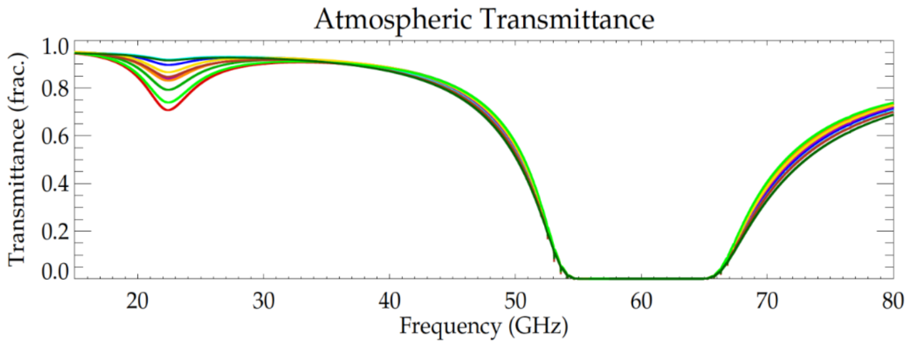
	Numerical weather prediction	Ocean dynamics and sea level	Climate modelling	Gravity monitoring	Atmospheric composition monitoring
Repeat distance/grid (km)	1 - 500	1 - few x 100	Few x 10	200	3 - 100
Repeat rate (hours)	0.5 - 24	0.5 - 12	3 - 24	3 - 6	2 – 4 weeks
Uncertainty ±(hPa)	0.5 - 2.0	0.2 - 10.0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

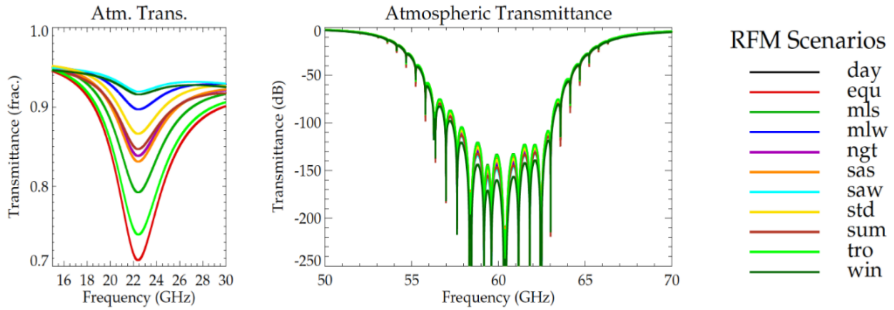
Key findings from WMO and OSCAR requirements + users survey

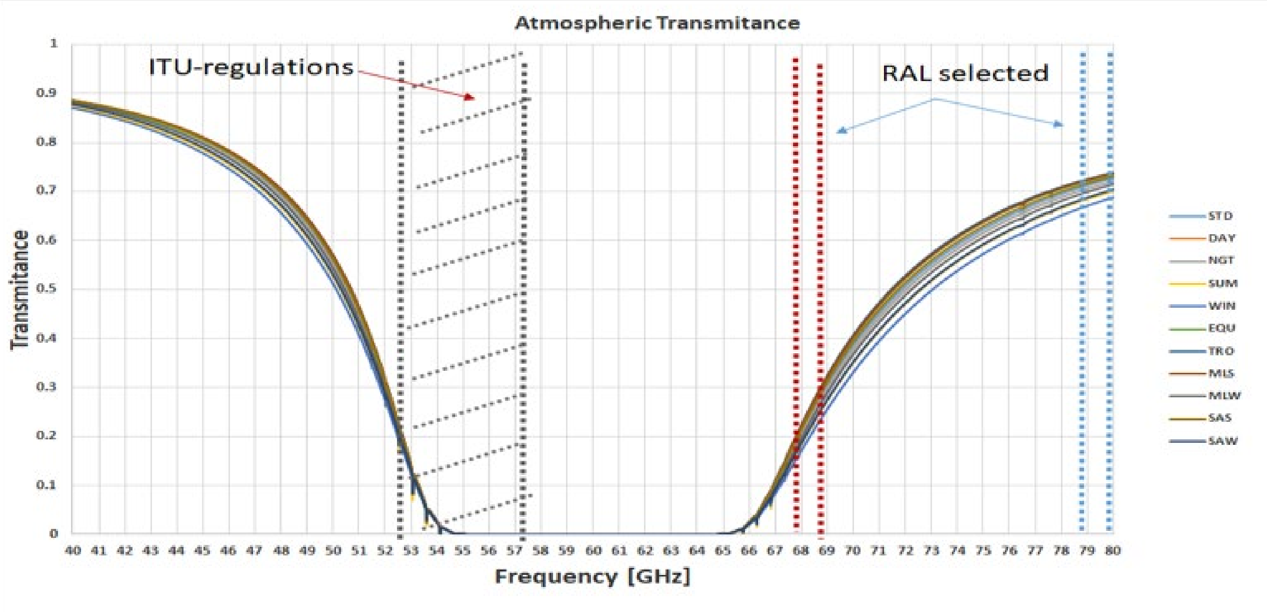
- Uncertainties of **±0.5hPa** would be of **significant** benefit for **NWP** and Climate Modeling.
- Accuracy requirements are found to be **more restricting for oceanographic applications** and an uncertainty of **± 0.2hPa** is needed for **coastal areas especially** considering storm and hurricane 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**.
- Spatial resolution varies for all applications.

Selected design frequencies

- RFM radiative transfer model with 11 scenarios
- The lower (V-band) and the upper wing (E-band) of the oxygen bands were studied.
- Both V- band and E-band were found possible for DAR operation.
- Due to ITU spectrum restrictions the right upper wing was selected.
- High absorption difference within the pair is required.
- The aim is to create two ratios to reduce uncertainty.
- Three frequencies were selected by RAL space in the E-band.

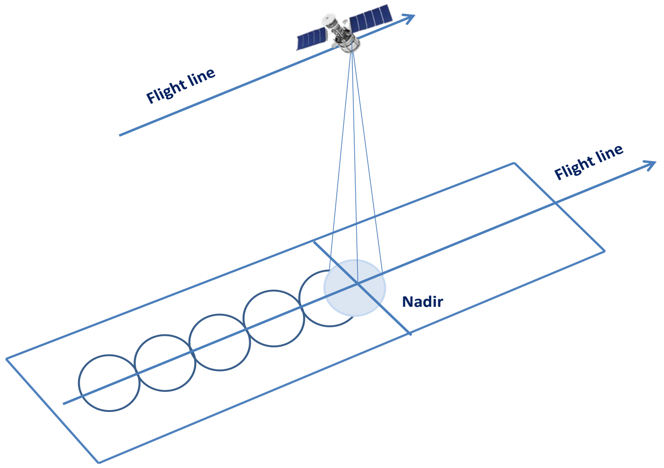






Mission design considerations

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



- **Nadir** looking observation
- The **maximum value of radar normal cross section σ^o** is obtained when incident in normal angle, and it decreases as angle reduces.
- The σ^o of the sea surface **depends** on sea state, incident angle, antenna pattern and frequency.
- The **sea surface changing** continuously spatially and in time, therefore the coherence of the reflected signal is destroyed.
- The intensity of the signal varies statistically with **Rayleigh distribution**.
- Therefore the average of **a large number** of independent samples **is required** to achieve the necessary accuracy.
- The **antenna diameter** is mainly determined by the need to collect a large number of **independent samples**.
- The difference in σ^o between the selected frequencies was found to be negligible.

$$r = \frac{t \; V \, D \, {F_A}^2}{0.89}$$

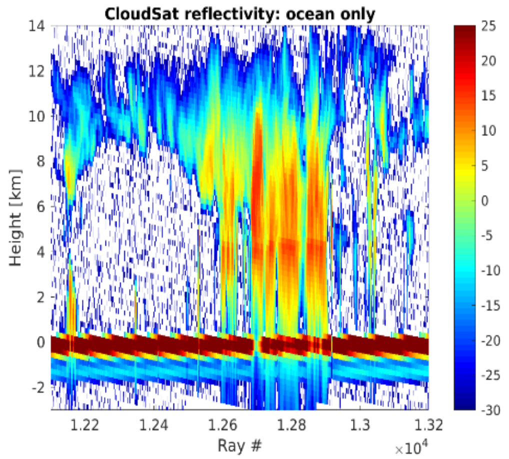
Where		
	r	antenna radius
	t	integration time
	V	satellite speed
	D	duty cycle
	F_A	fractional accuracy

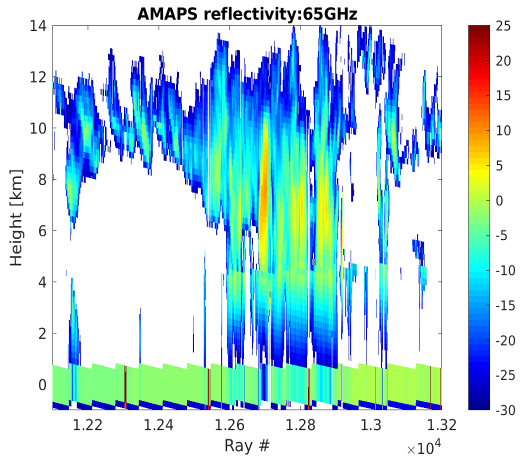
Relationship between samples collection rate and the size of the antenna [1978 Flower and Peckham]

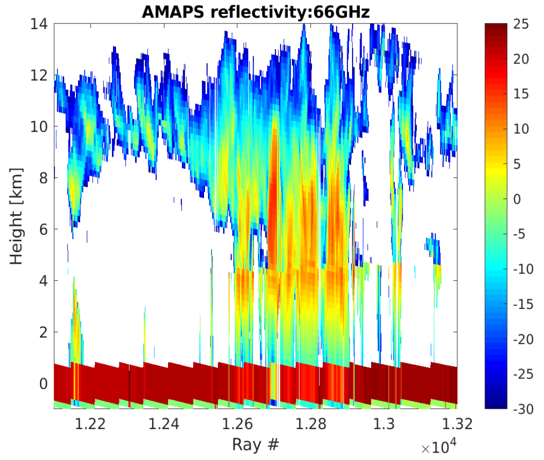
Spatial coherence length is 0.89r for circular antenna

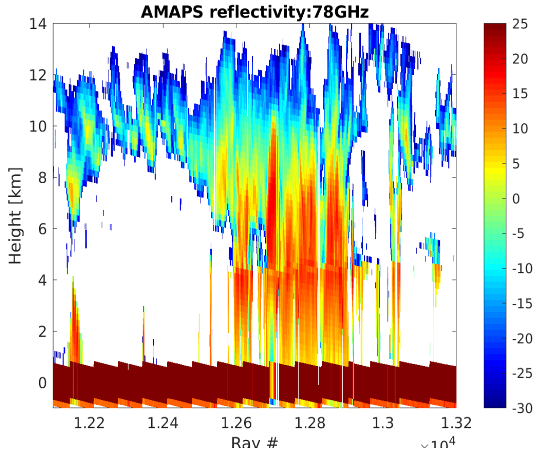
Antenna radius is fully determined by the accuracy required.

Simulation using CloudSat products for AMAPS sensitivity study







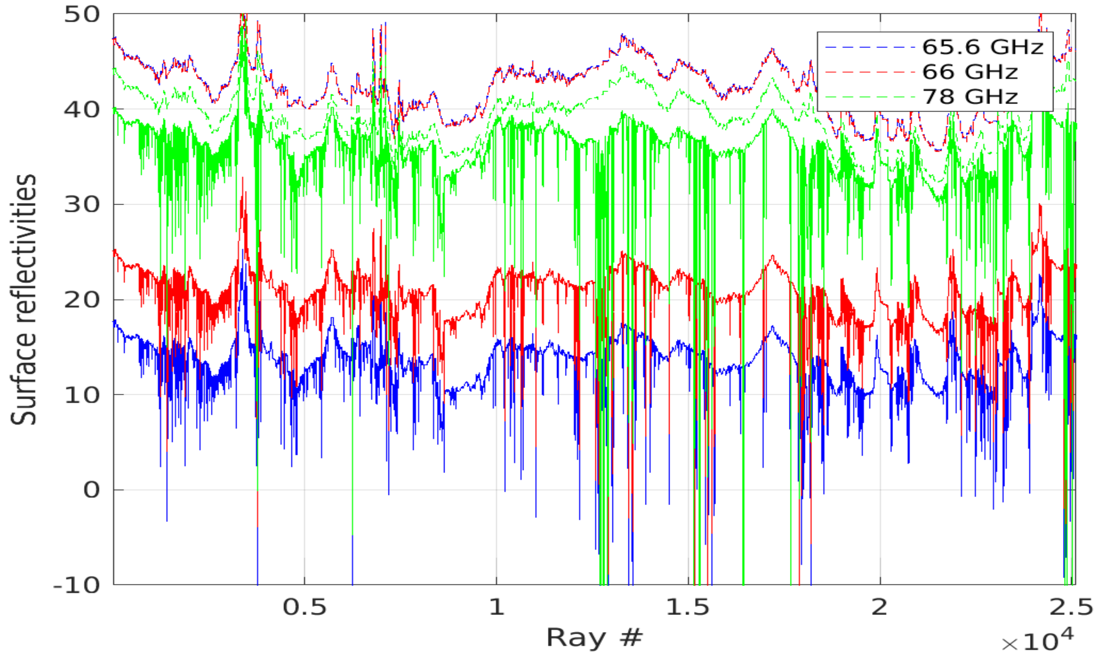


CloudSat **ocean only** products used forward model profiles of reflectitivities at different frequencies to see impact of differential attenuation on surface differential return

Temporal PIA (Path Integrated Attenuation) can be used to flag the data with high attenuation due to hydrometeor

The **ratios of gas vs hydrometeor attenuation** is completely different.

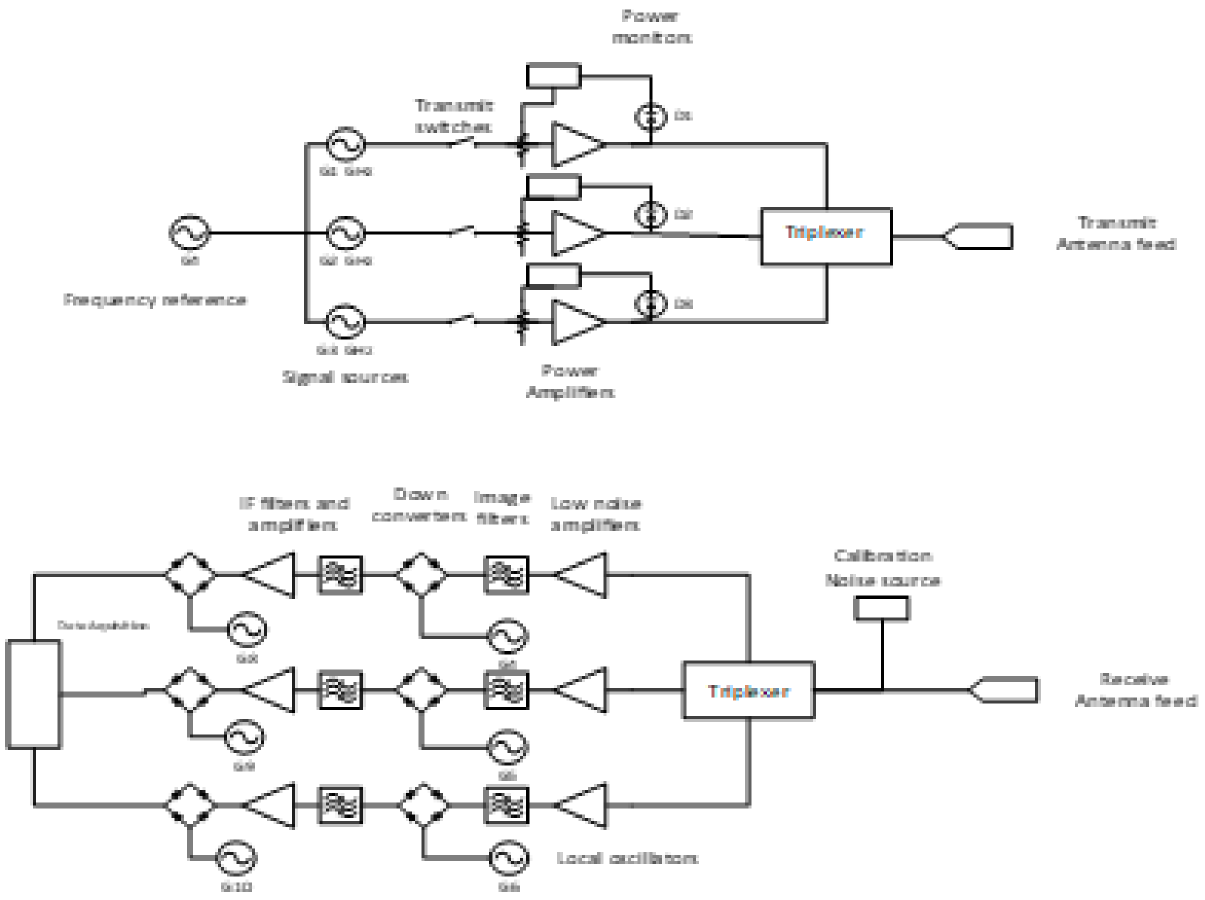
Room for disentangling gas and hydro attenuation



Credit to Professor Alessandro Battaglia, May22

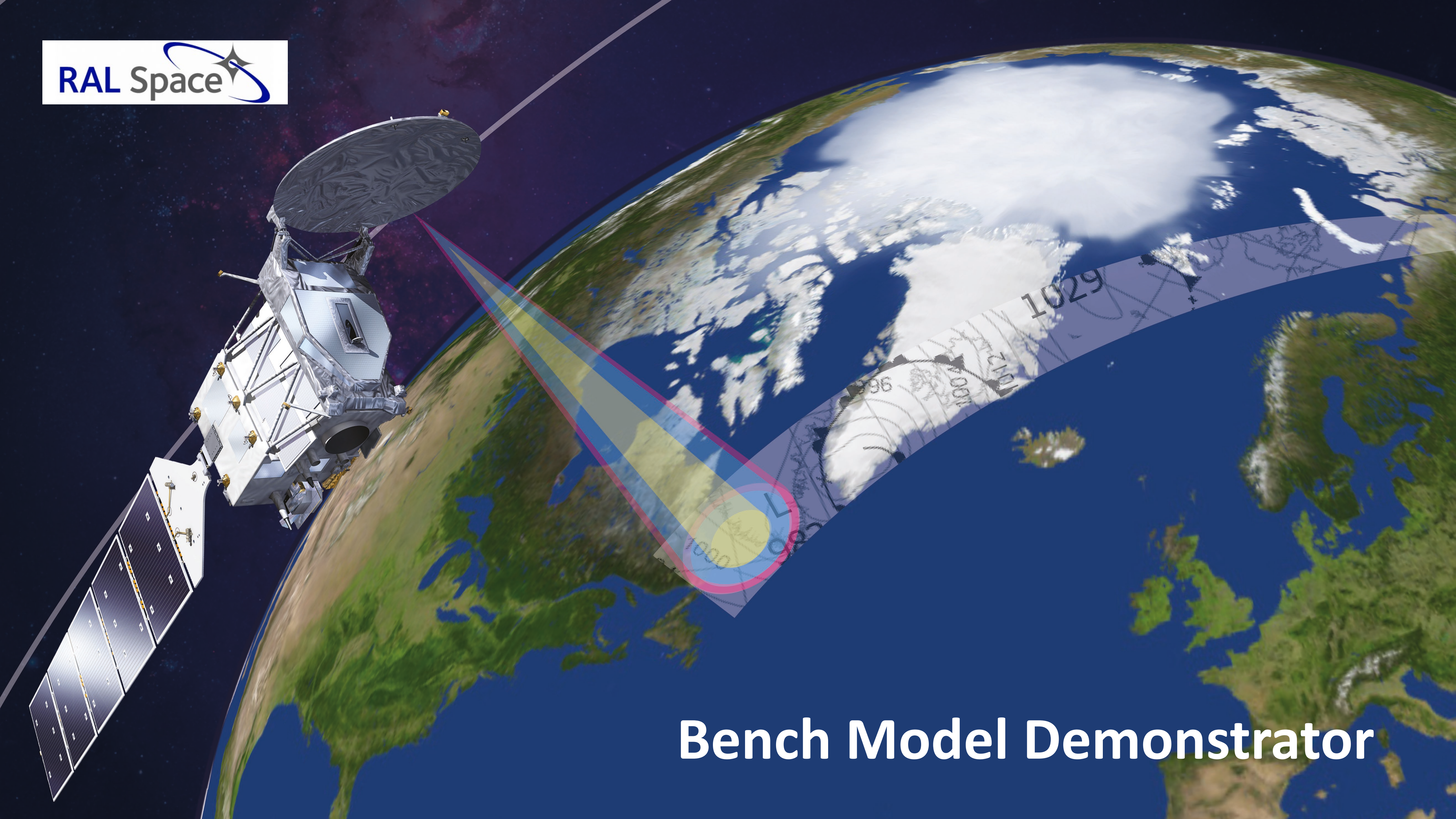
System design specifications with three channels pulsed radar

Three frequency radar transceiver



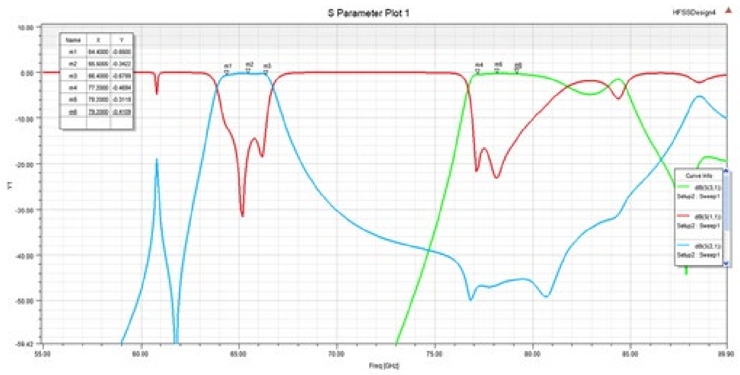
Parameter	Base-line design	Improved design	Unit
Instrument	3 frequency radar + Microwave Radiometer	3 frequency radar + Microwave Radiometer	
TX power	5	5	W
Frequencies	(65, 78, 79)	(65, 78, 79)	GHz
Antenna diameter	0.5	0.5	m
Altitude	500	500	km
Pulse width	10	10	μs
Bandwidth	100	100	kHz
Receiver Noise Figure	5	5	dB
Spatial resolution	4 (swath) x 8 (along track)	2(swath) x 6 (along track)	km
Repeat Rate	12 to 24	12 to 24	hr
No. of independent samples	90,000, based on a 0.5m antenna, with beam scanning	912,000, based on a 0.5m antenna, with beam scanning	
Statistical accuracy for 1σ	0.33	0.104	%
Statistical accuracy per channel	±1.65	±0.52	hPa

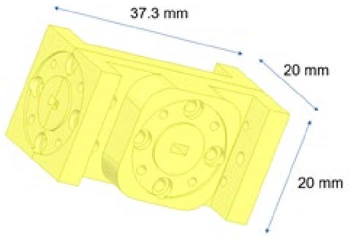
RAL Space



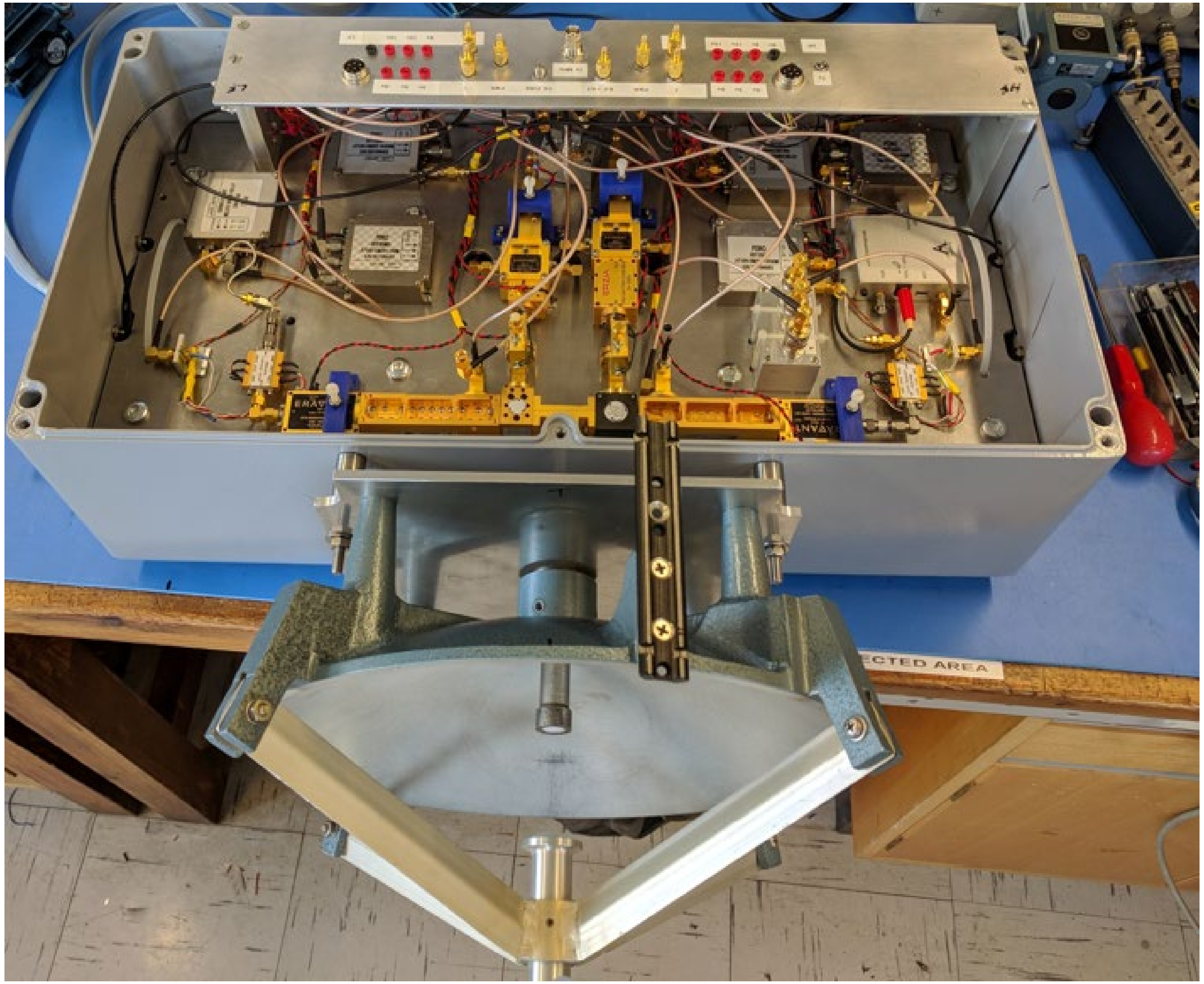
Bench Model Demonstrator

Diplexer and dual channel radar HW





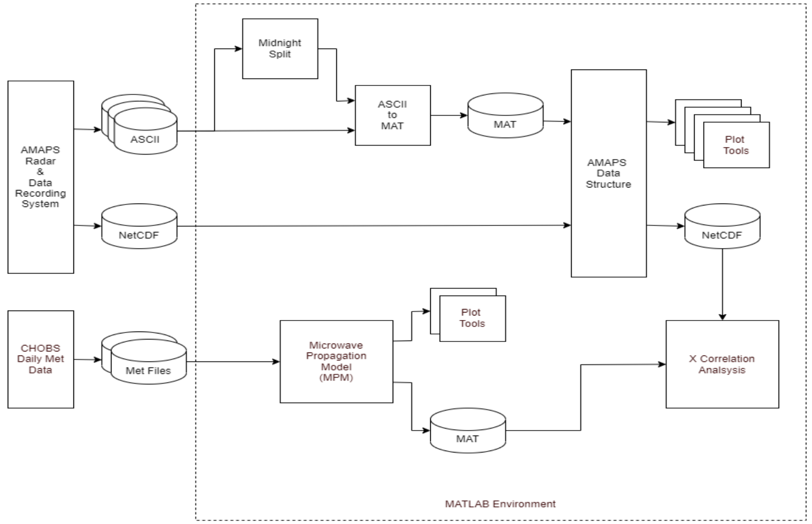
- **Diplexer** based on H plane T junction and waveguide resonant cavities band pass filters in WR12
- **HFSS Simulation results**
- S21 and S31 around -0.4 dB in the band pass
- S21 and S31 better than -20 dB out of band
- S11 better than -10 dB
- Port 2 (6 poles filter)
- Port 3 (7 poles filter)

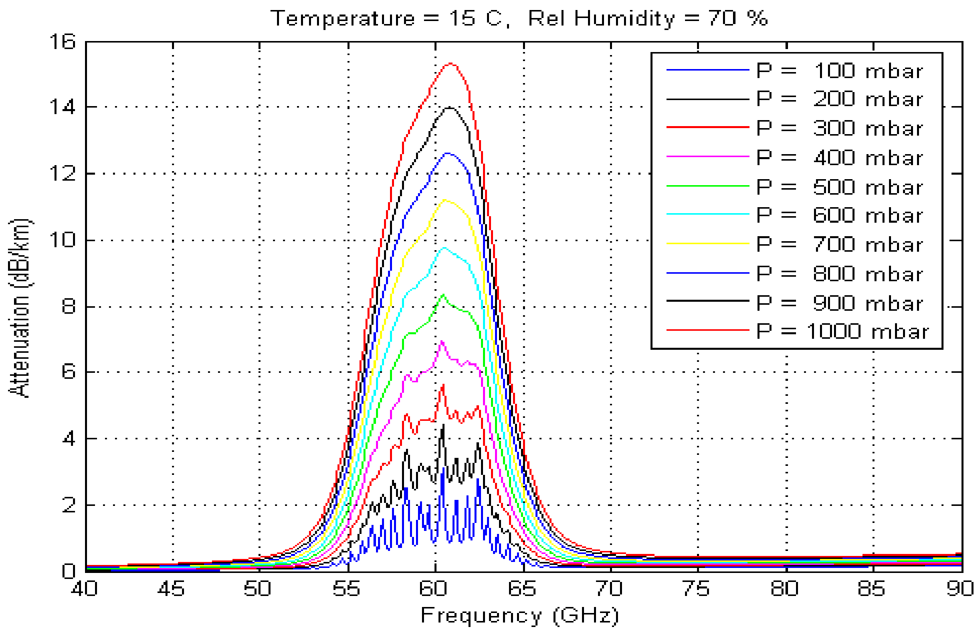


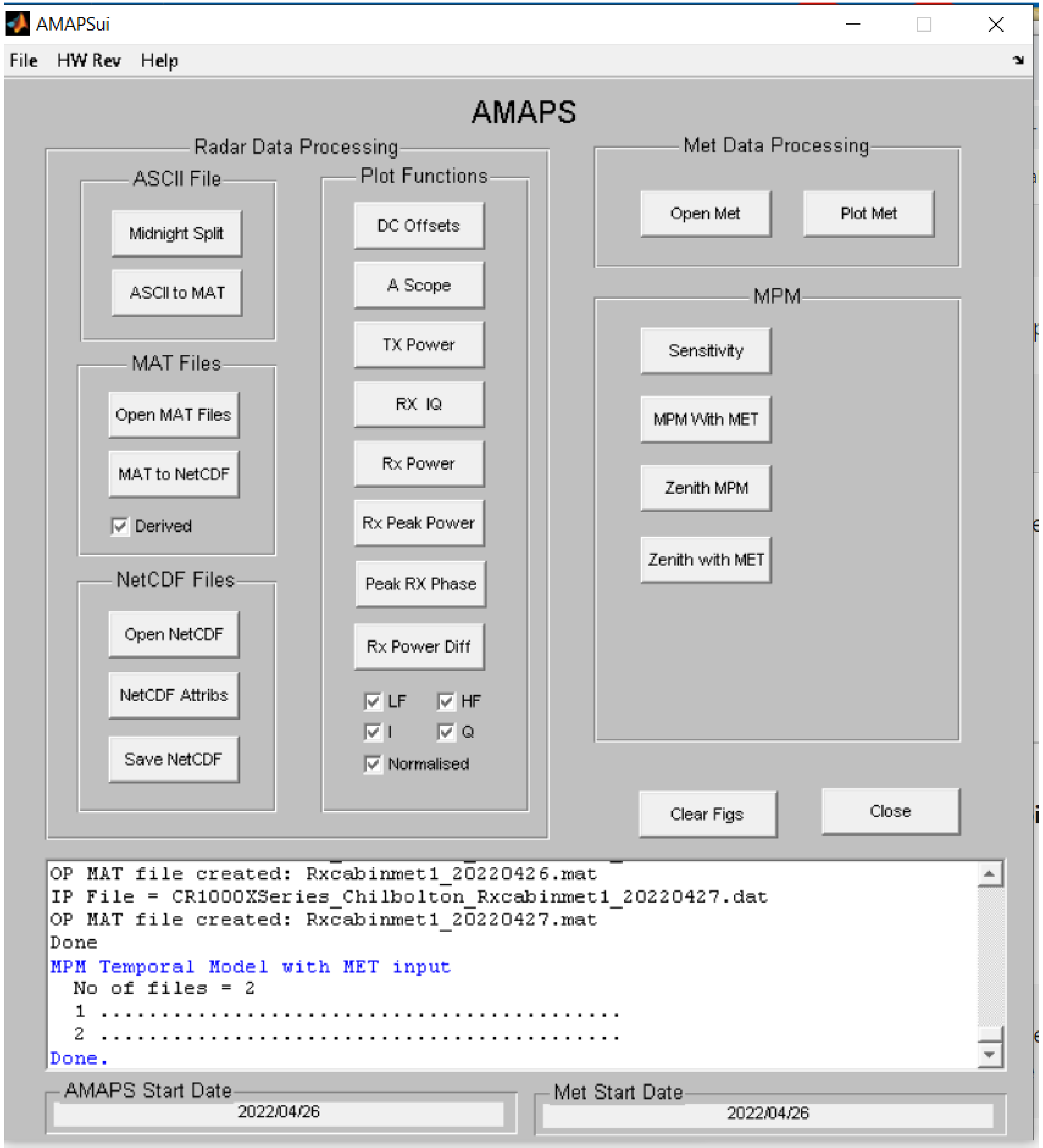
Science and Technology Facilities Council

With STFC funding

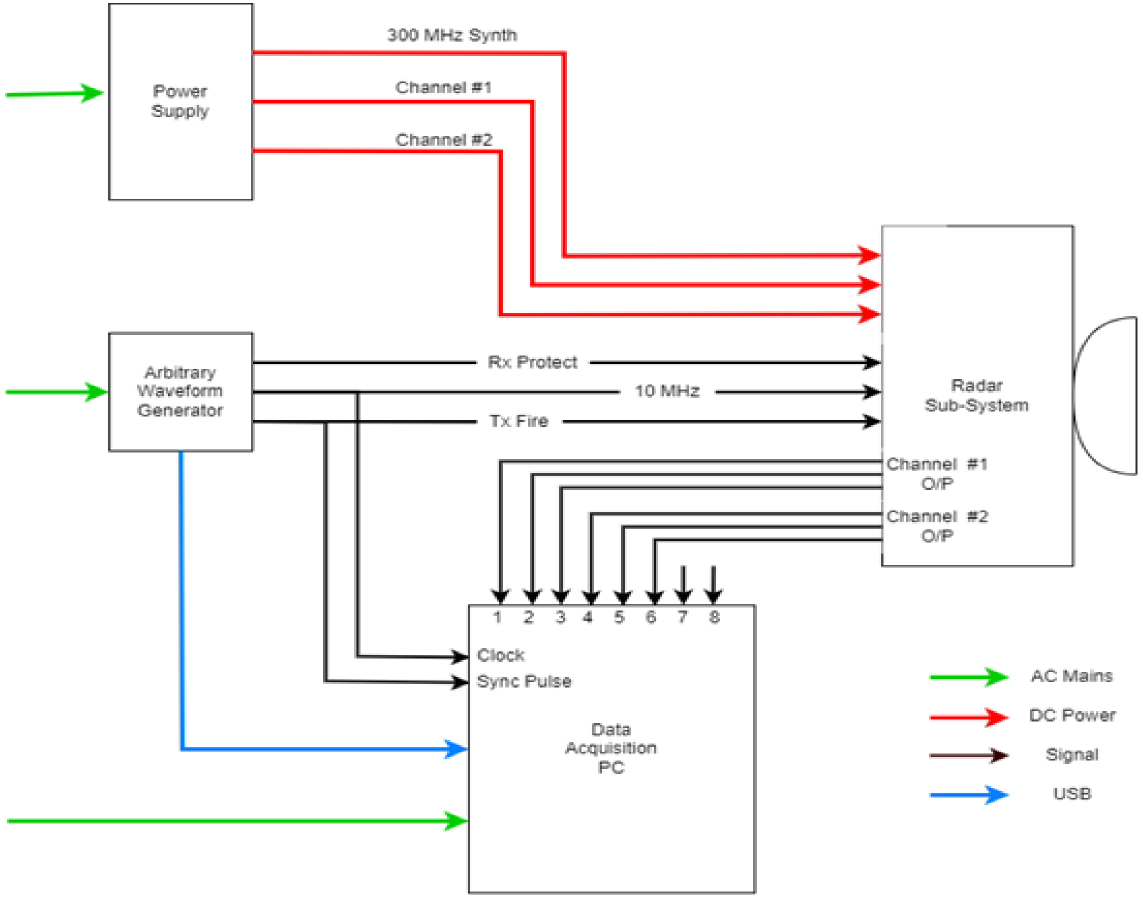
Data analysis

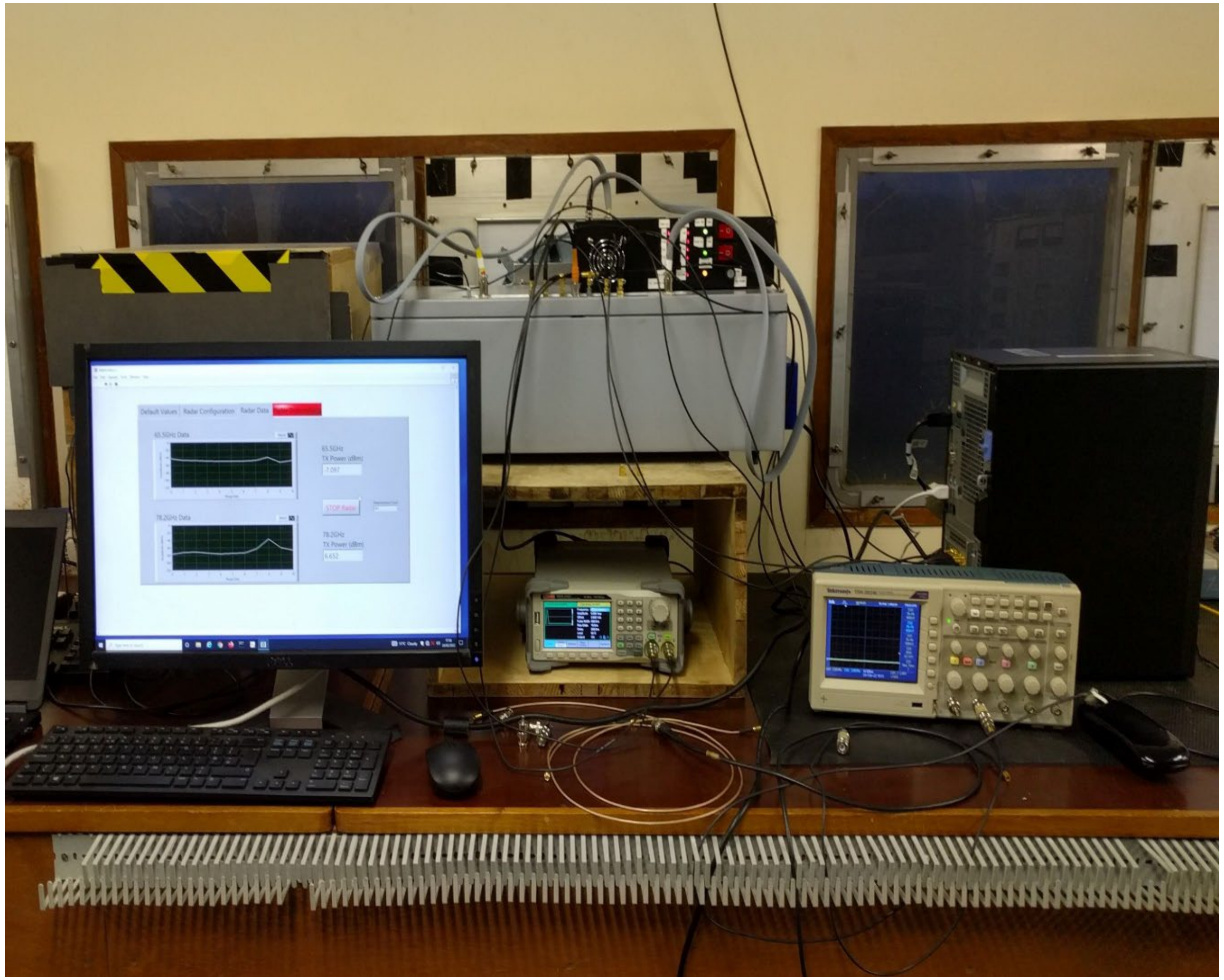






Radar system deployed at Chilbolton 500m range

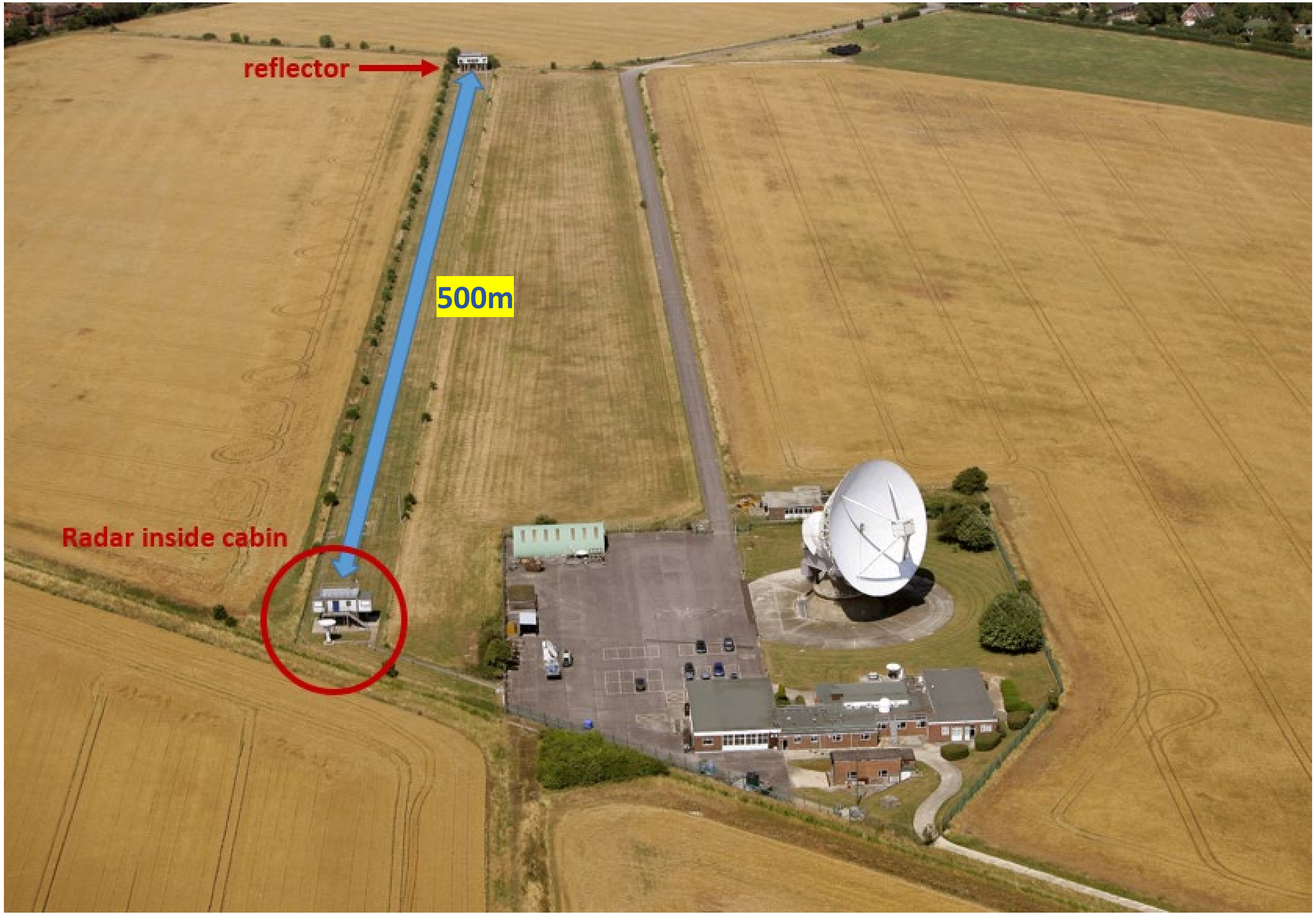




LabView software used to control the radar, interface with the data acquisition card and to generate a visual user interface.

Field test at Chilbolton observatory 500m range

- Historically used for communication links research
- Radar pointing through Goretex window
- Signal reflected back to the radar.



Summary and future roadmap

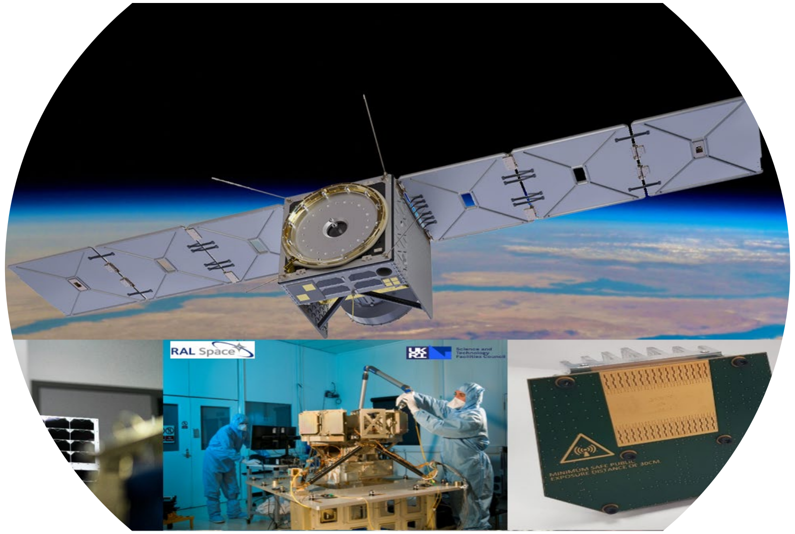
RAL Space

- **There is an** **urgent need** **for global observations of surface pressure to accurately predicting cyclone storms intensities**, **tracks** to **save lives and infrastructure.**

Future roadmap:

- Complete Dual-channel bench model demonstrator system test. (**STFC funded**)
- Build and test Triple-channel model. (**UKSA / CEOI funded**)
- Design and build an **air-borne demonstrator** to proof the concept, verify retrieval methodology and to optimise the selected frequencies.
- **Space-borne** demonstrator on small satellite.

FAAM: Facility for Airborne Atmospheric measurements



BARODAR

Questions

emal.rumi@stfc.ac.uk