Microwave spectrum

Measurement, modelling and information content

Alan Geer

Thanks to: Peter Bauer, Bill Bell

EUMETSAT/ECMWF NWP-SAF satellite data assimilation training course, 23 March, 2026

ECMWF

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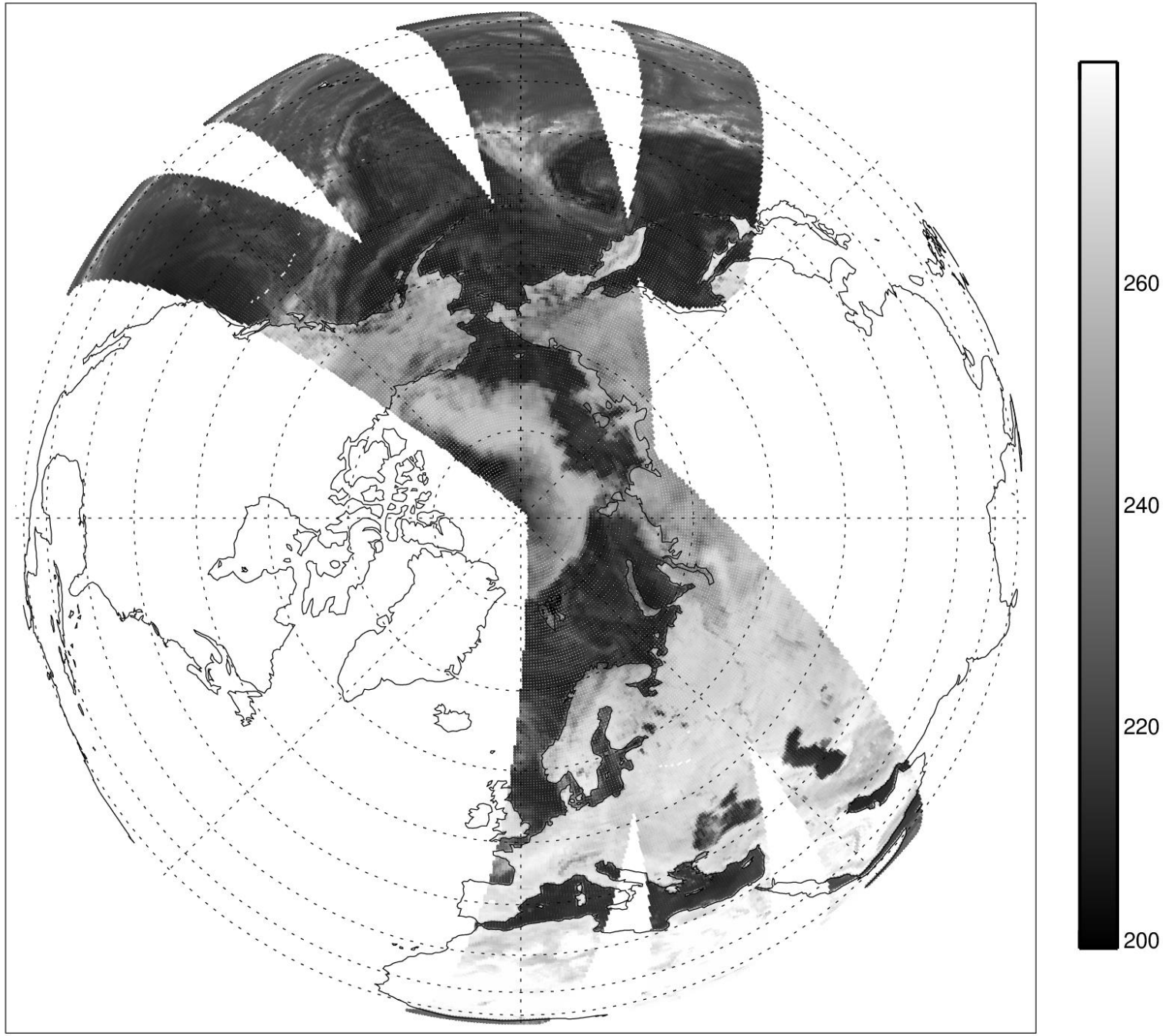
Advanced Scanning Microwave Radiometer (AMSR-2)

Observation composite for 1st Nov 2021

Brightness temperatures [Kelvin] at 37 GHz, v-polarised



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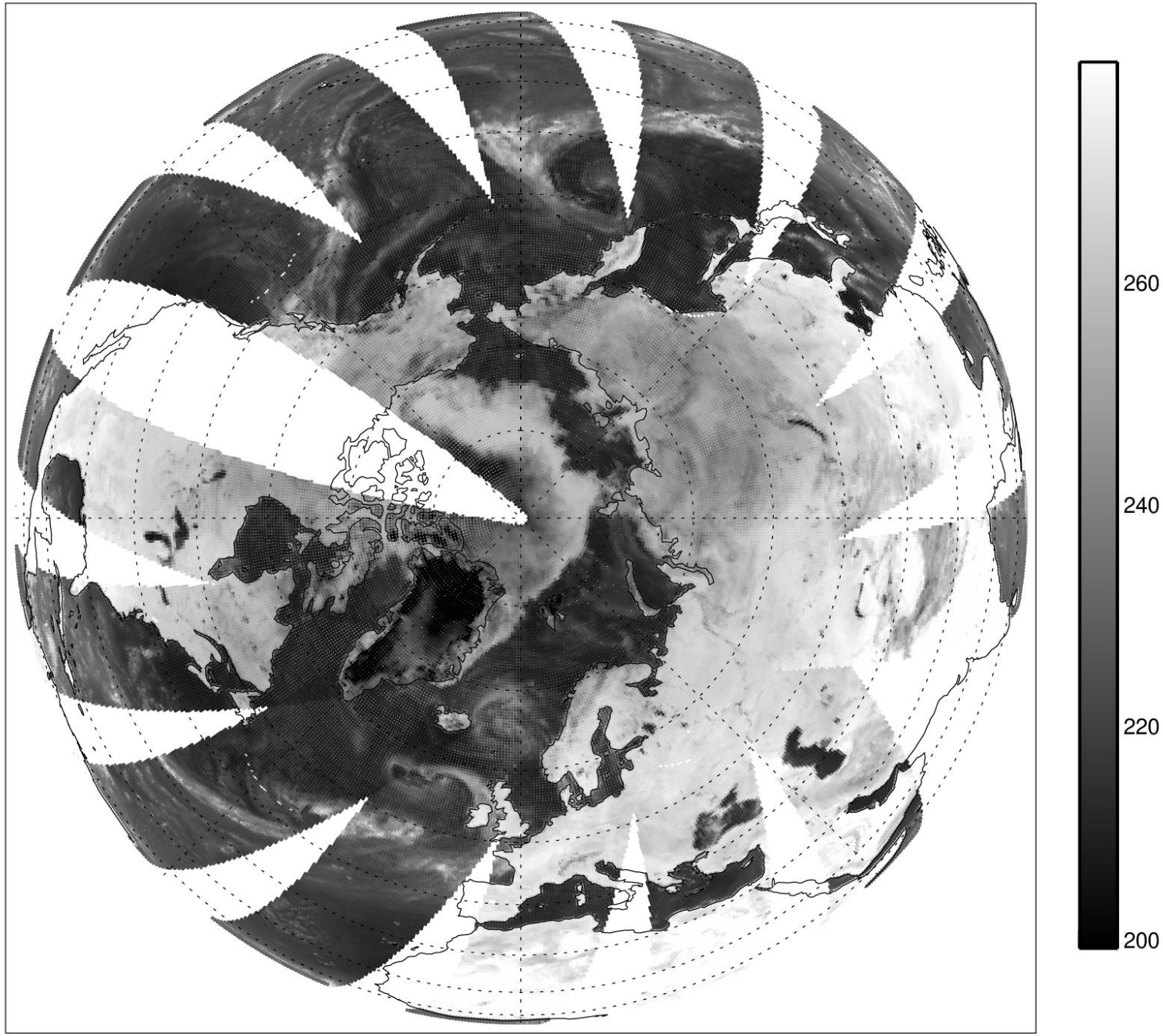

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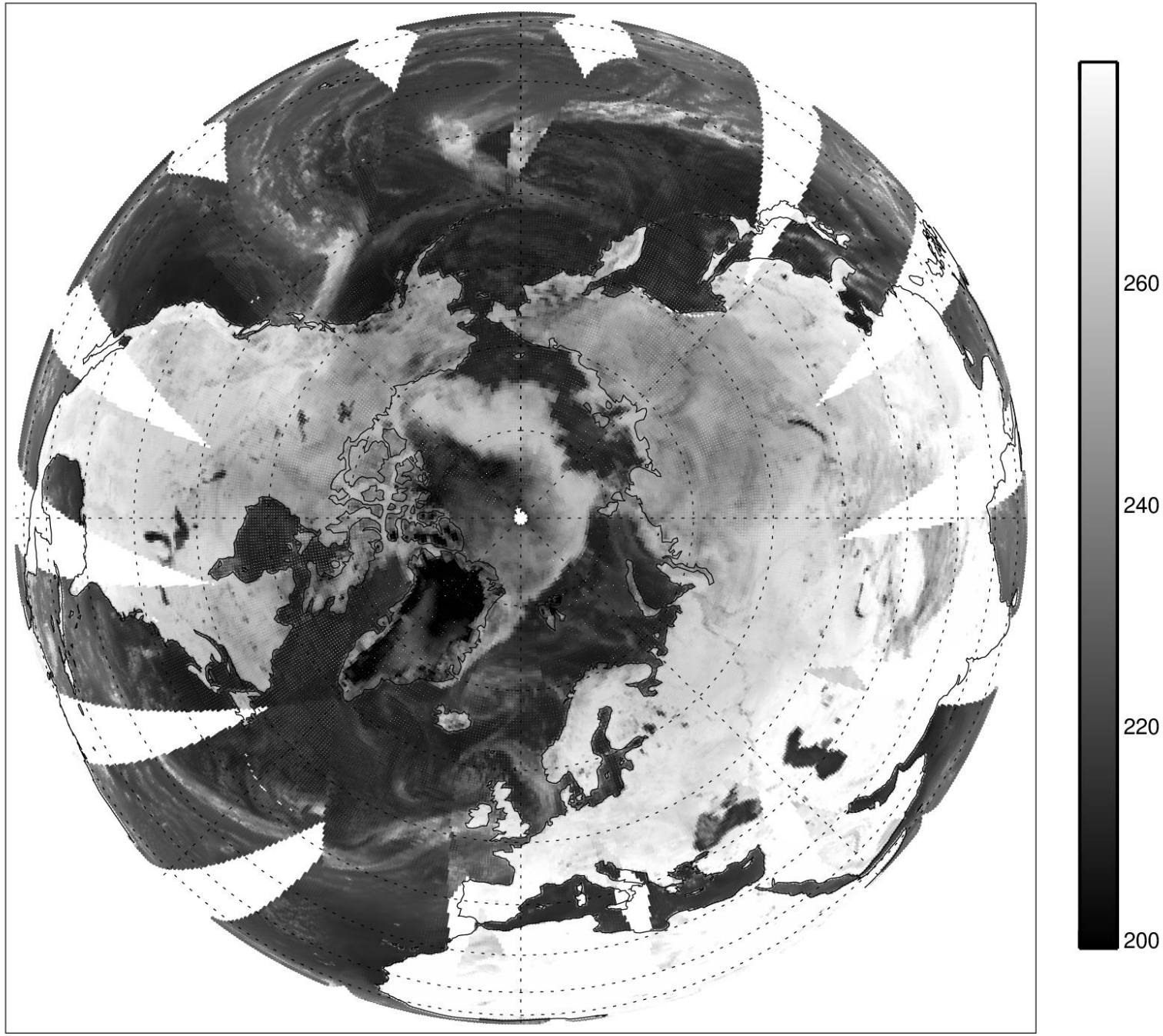

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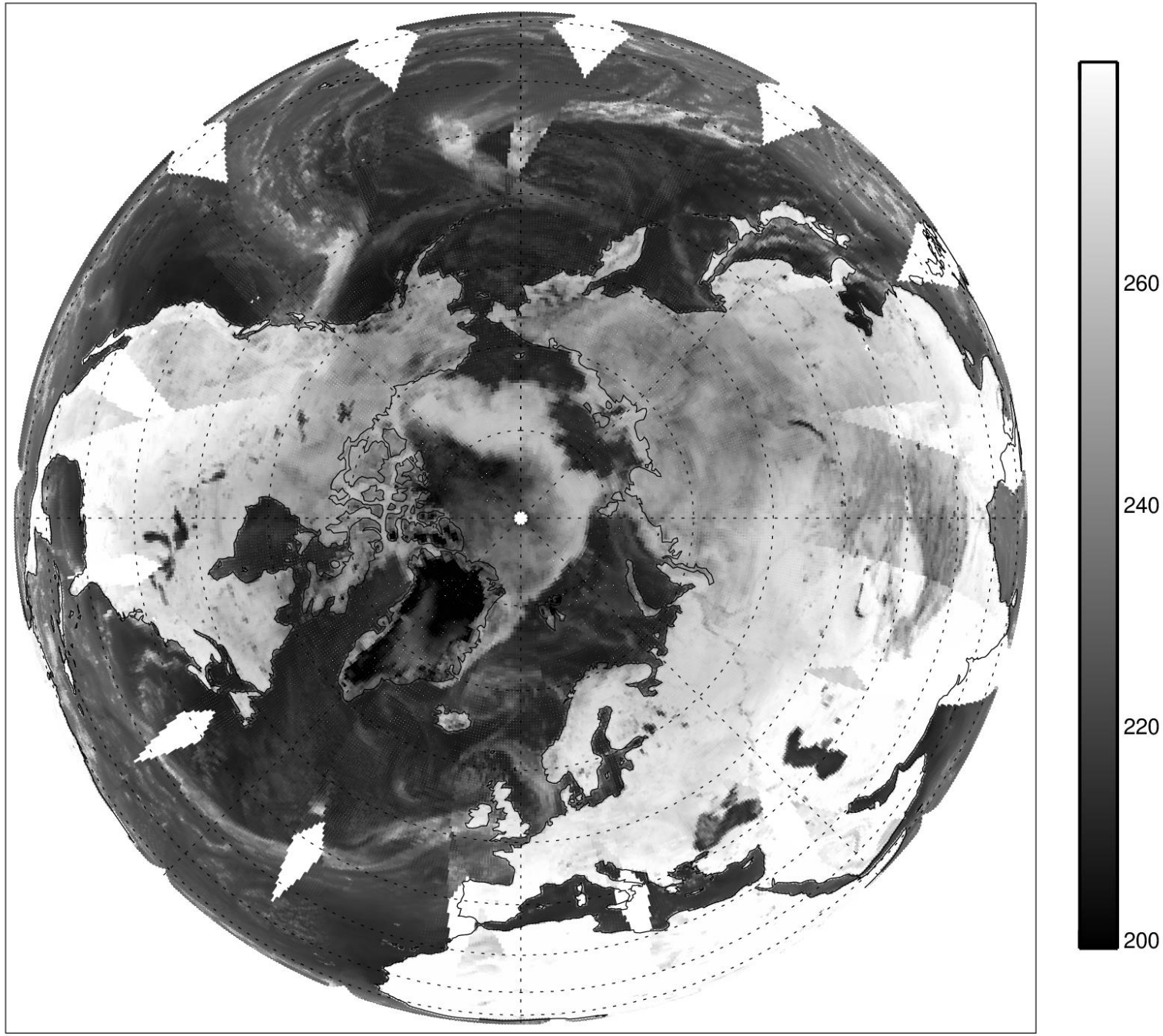

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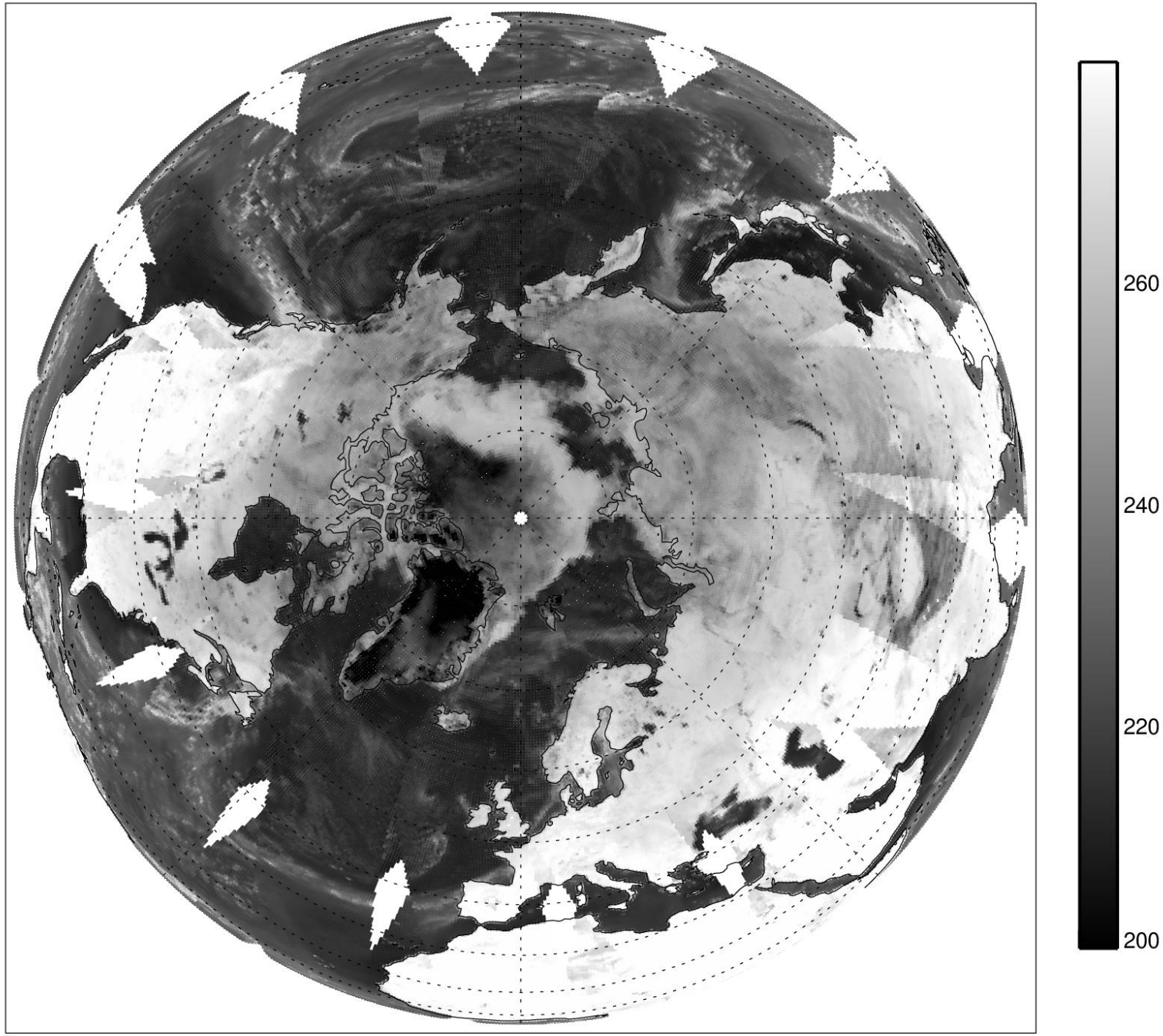
Advanced Scanning Microwave Radiometer (AMSR-2)

Observation composite for 2nd Nov 2021

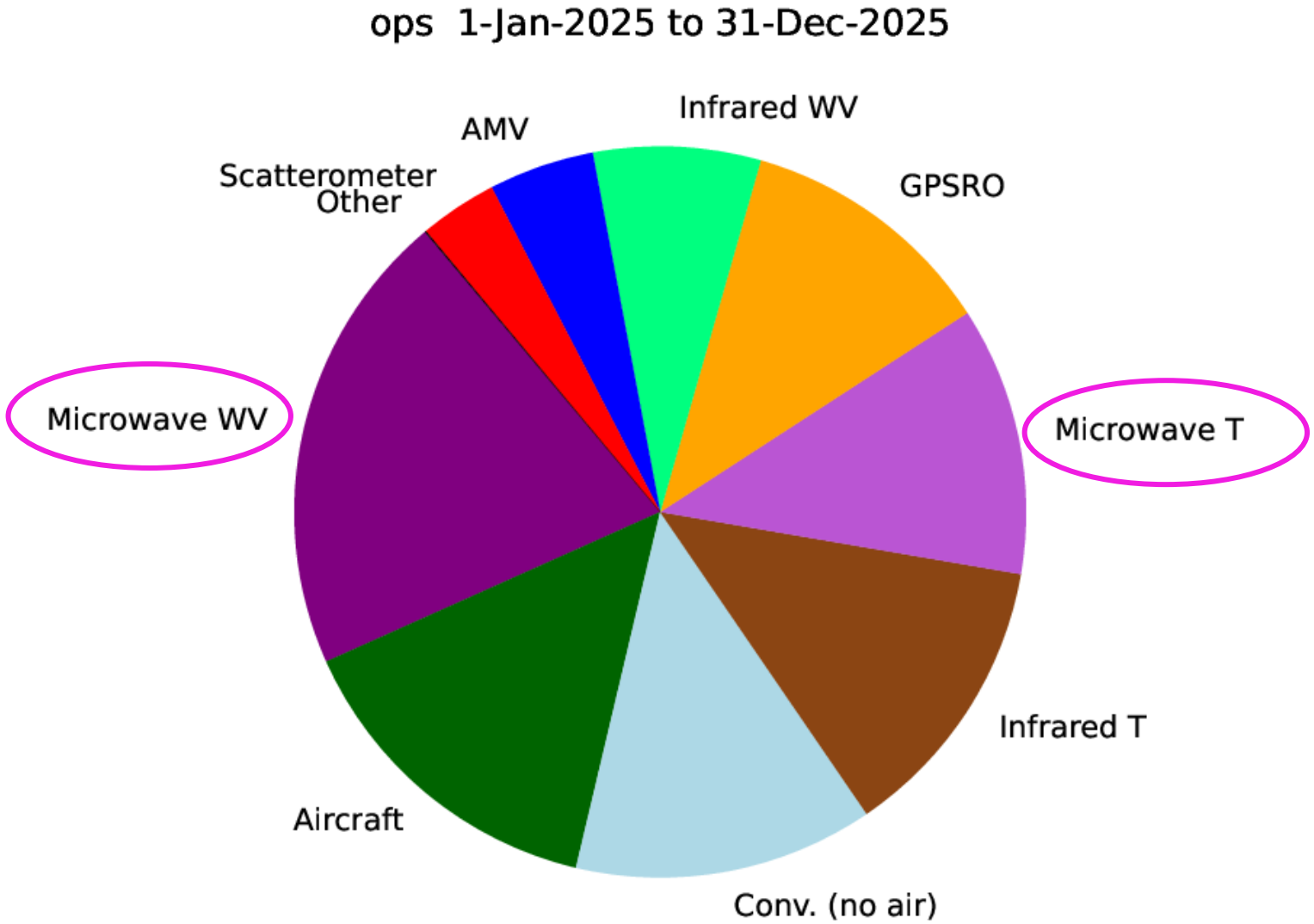
Radiances shown as brightness temperatures [Kelvin] at 37 GHz, v-polarised



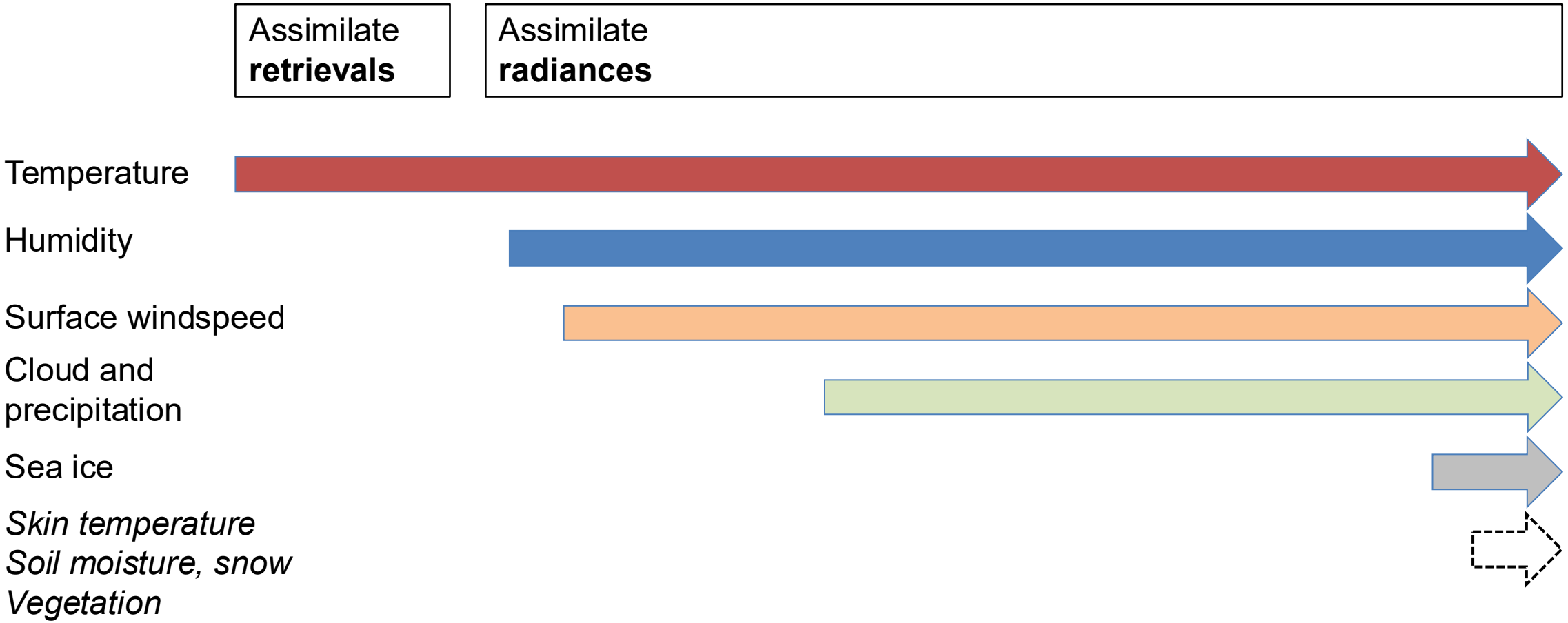
ECMWF

Relative impact of observations at ECMWF: 2025

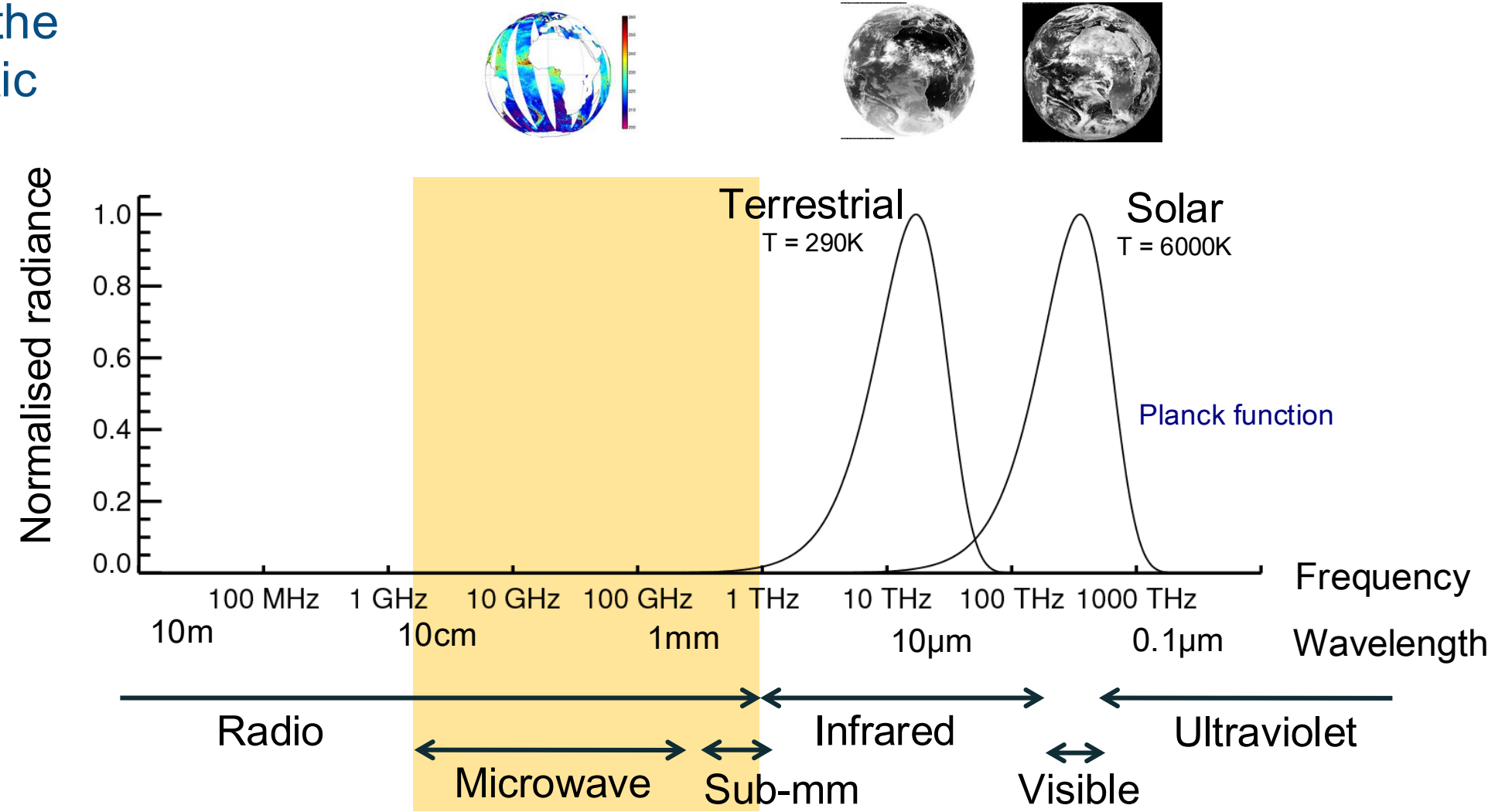
Relative sensitivity of 24 hour forecast error to observation impact (FSOI)



Rough timeline of satellite microwave data assimilation in ‘atmospheric’ DA



Where is the microwave in the electromagnetic spectrum?

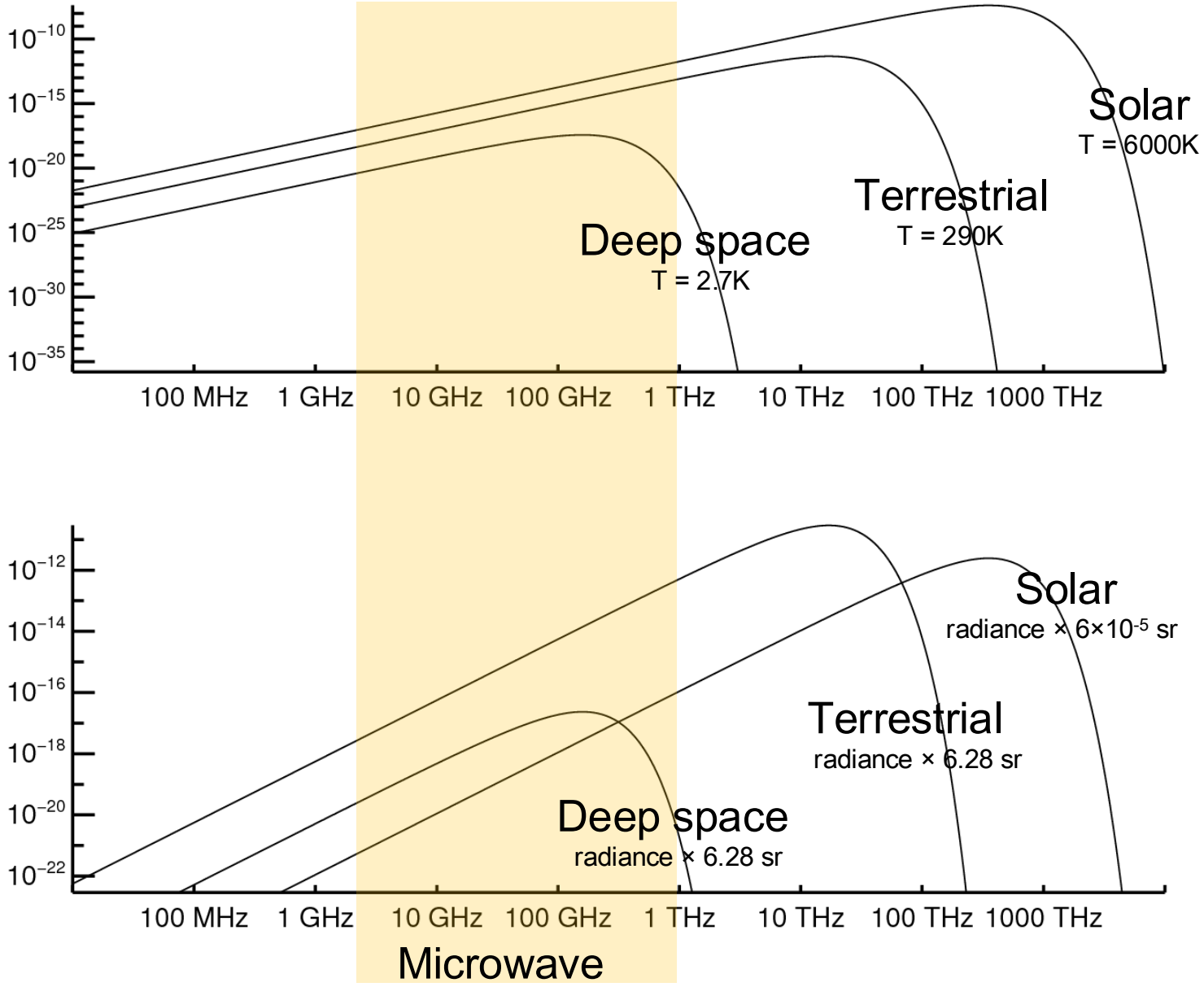


How much energy?

Planck Function Radiance

W m^{-2} sr^{-1} Hz^{-1}

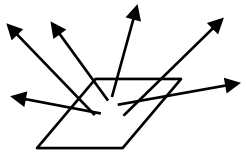
Travelling in a beam



Flux

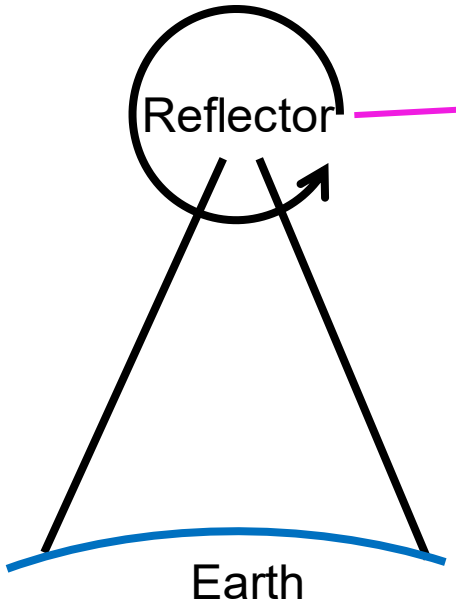
W m^{-2} Hz^{-1}

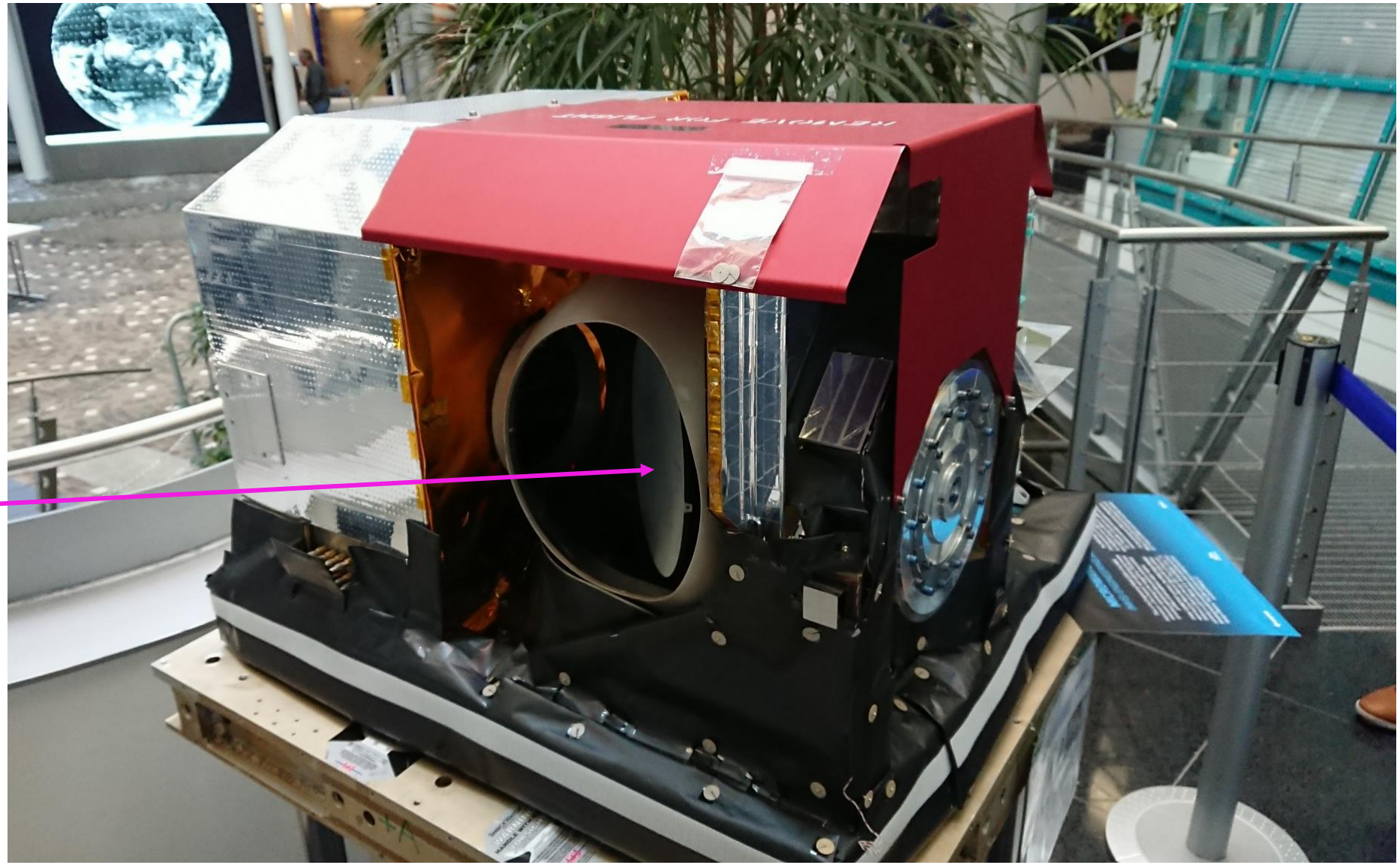
Travelling through an area (in one direction)



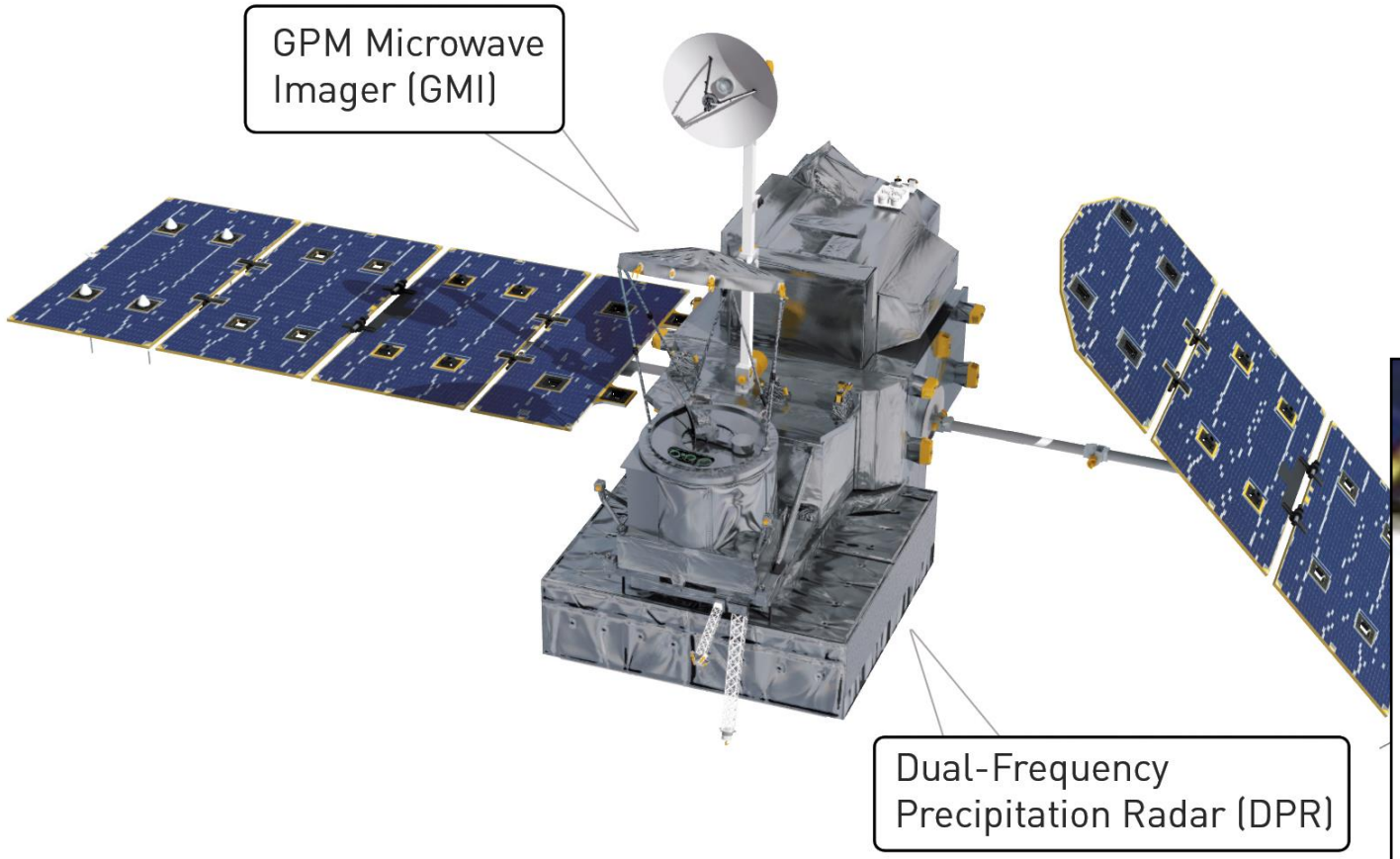
sr – Steradian (unit of solid angle)

The Microwave Humidity Sounder (MHS) at EUMETSAT



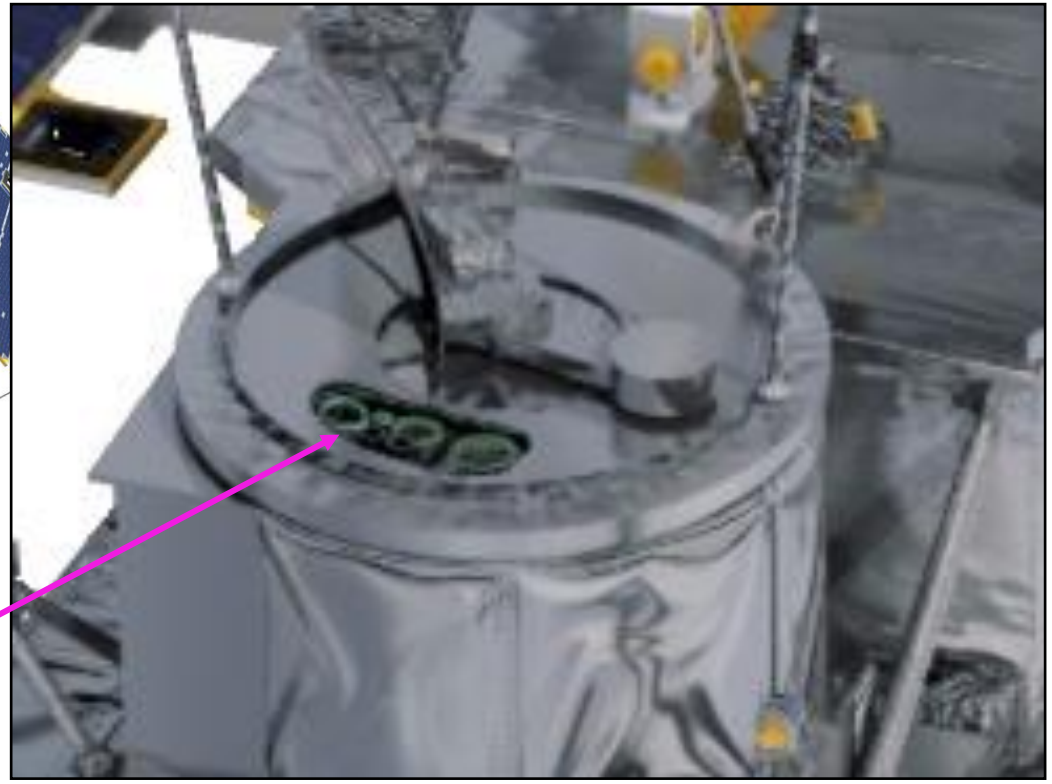


Global precipitation mission (GPM)



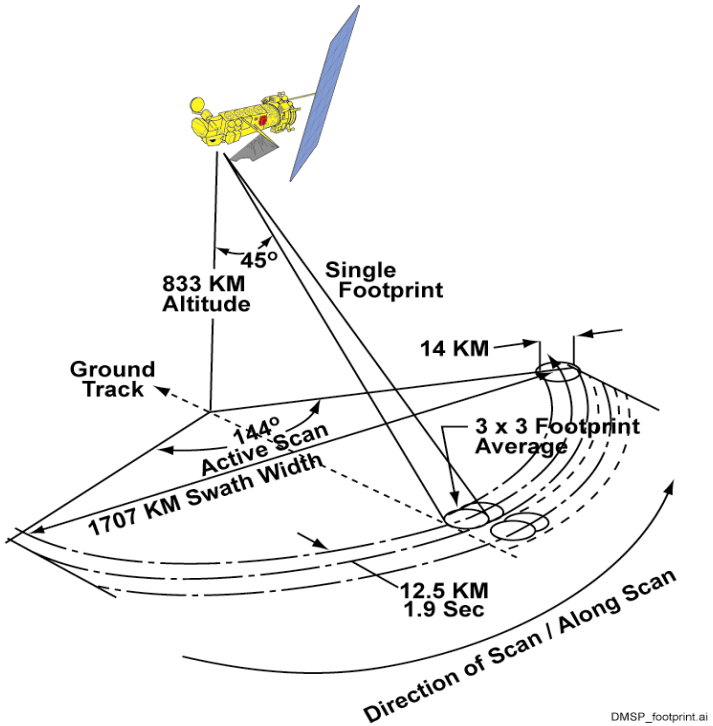
Global precipitation mission:

- Launched Feb 2014

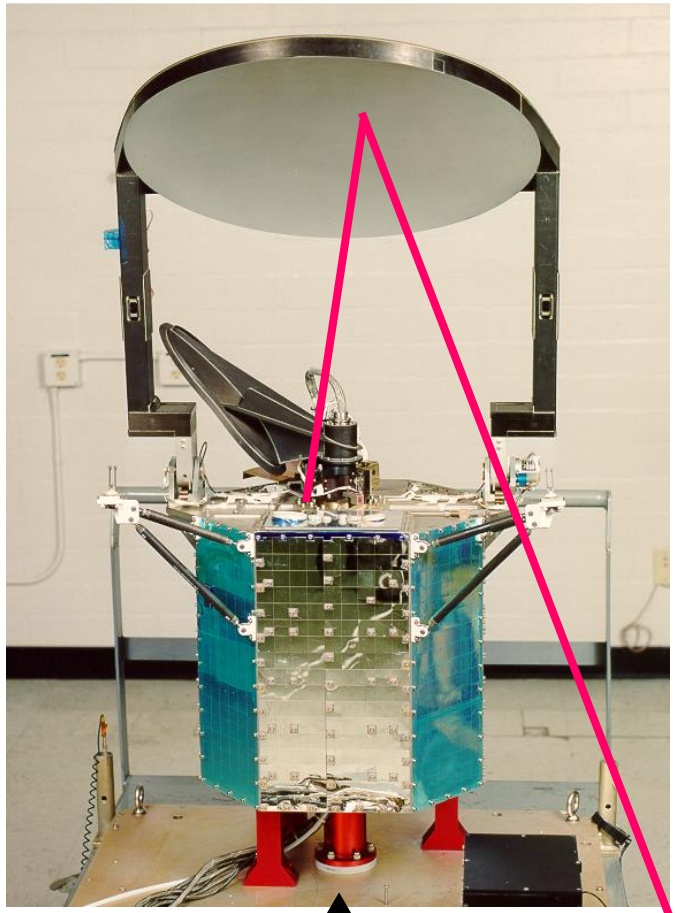


Special Sensor Microwave Imager / Sounder (SSMIS)

Conical scanning geometry



60 cm



Main Reflector

Cold Calibration Reflector

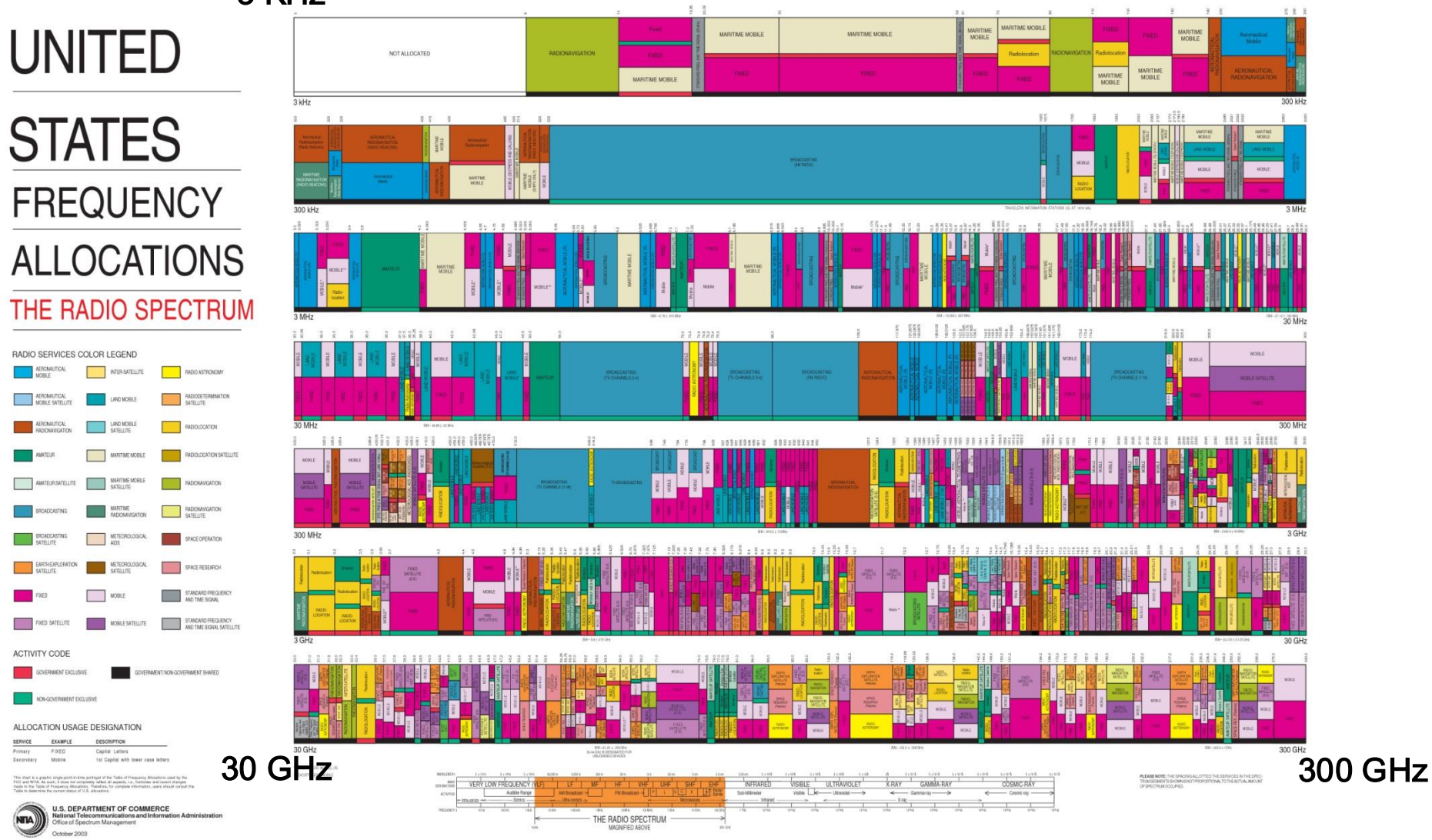
Warm Load

Feedhorns

From the earth

Other users of the spectrum

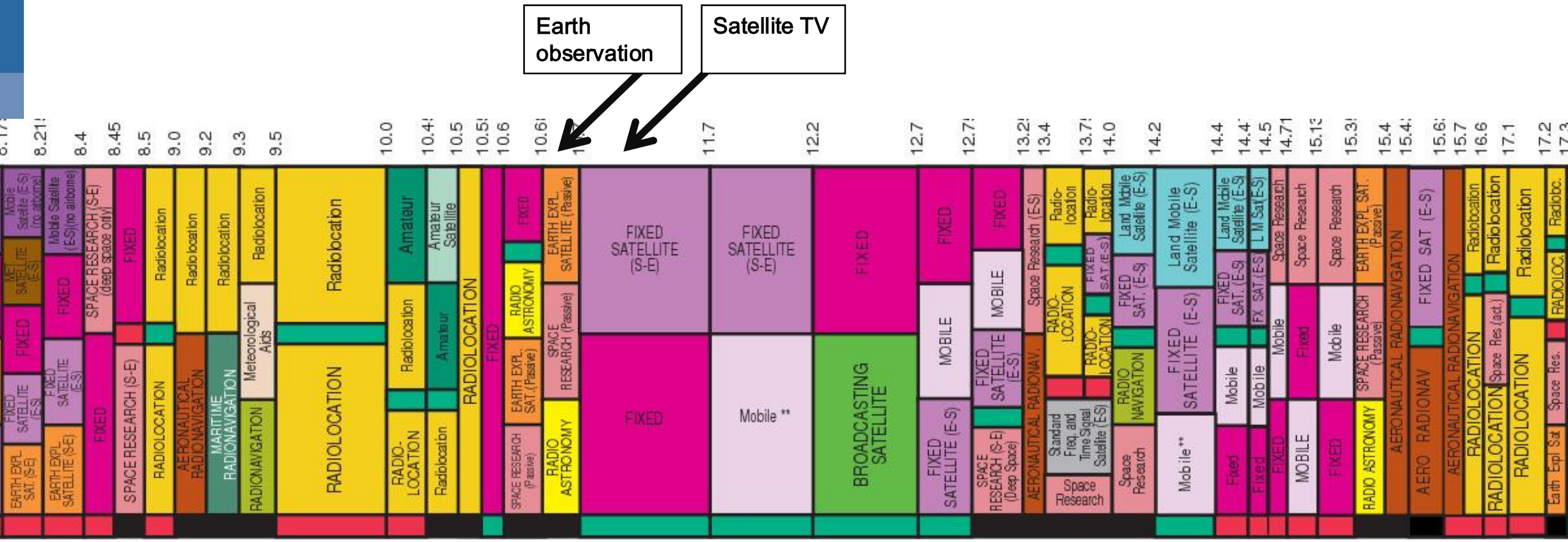
3 KHz



30 GHz

300 GHz

Other users of the spectrum



Information content

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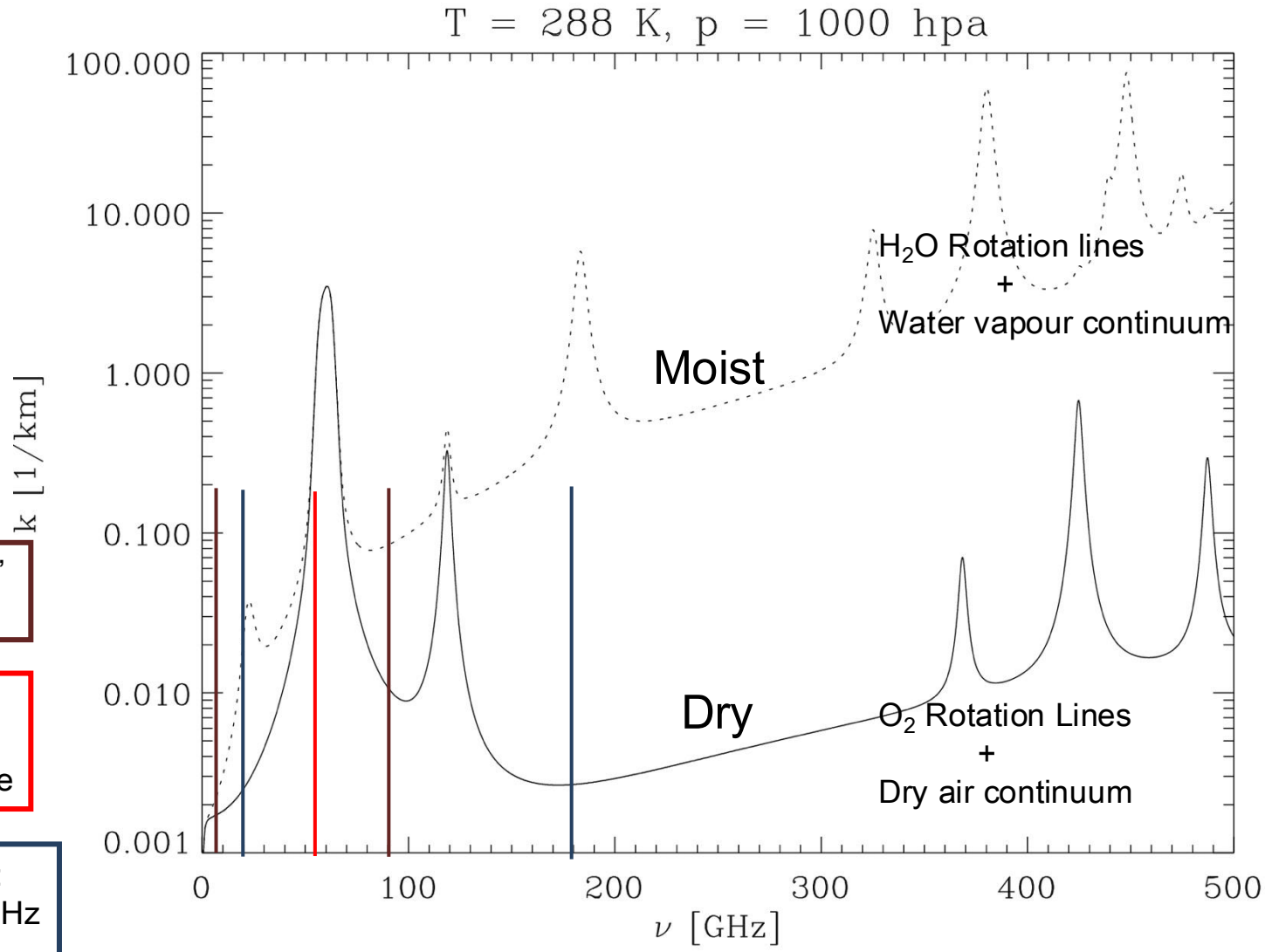
Gas absorption: the microwave spectrum

Absorption coefficient β_a [1/km]



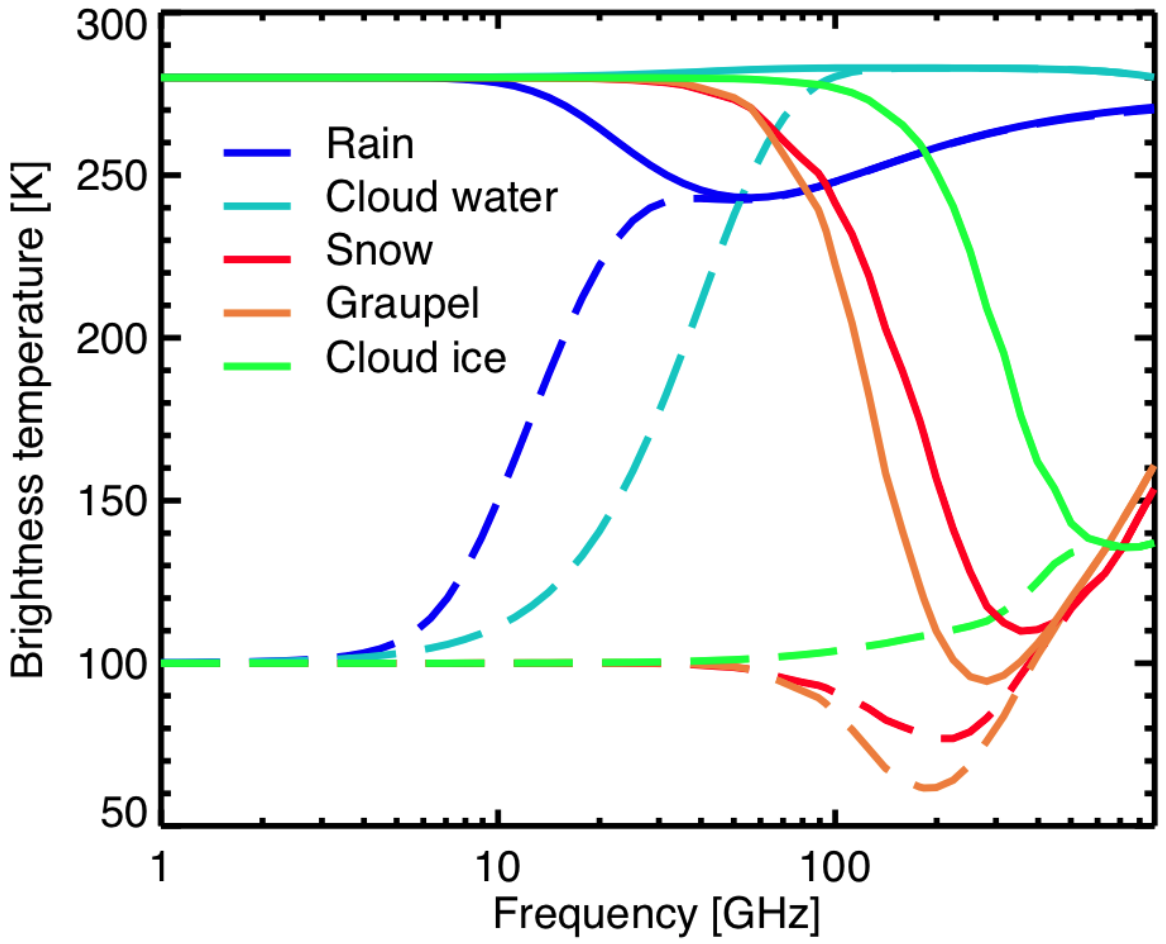
"Imaging channels" in the windows

Temperature sounding: 60 GHz oxygen line

Moisture sounding: 22 GHz and 183 GHz water vapour lines

Cloud and precipitation optical properties: the microwave spectrum

More in the next microwave lecture

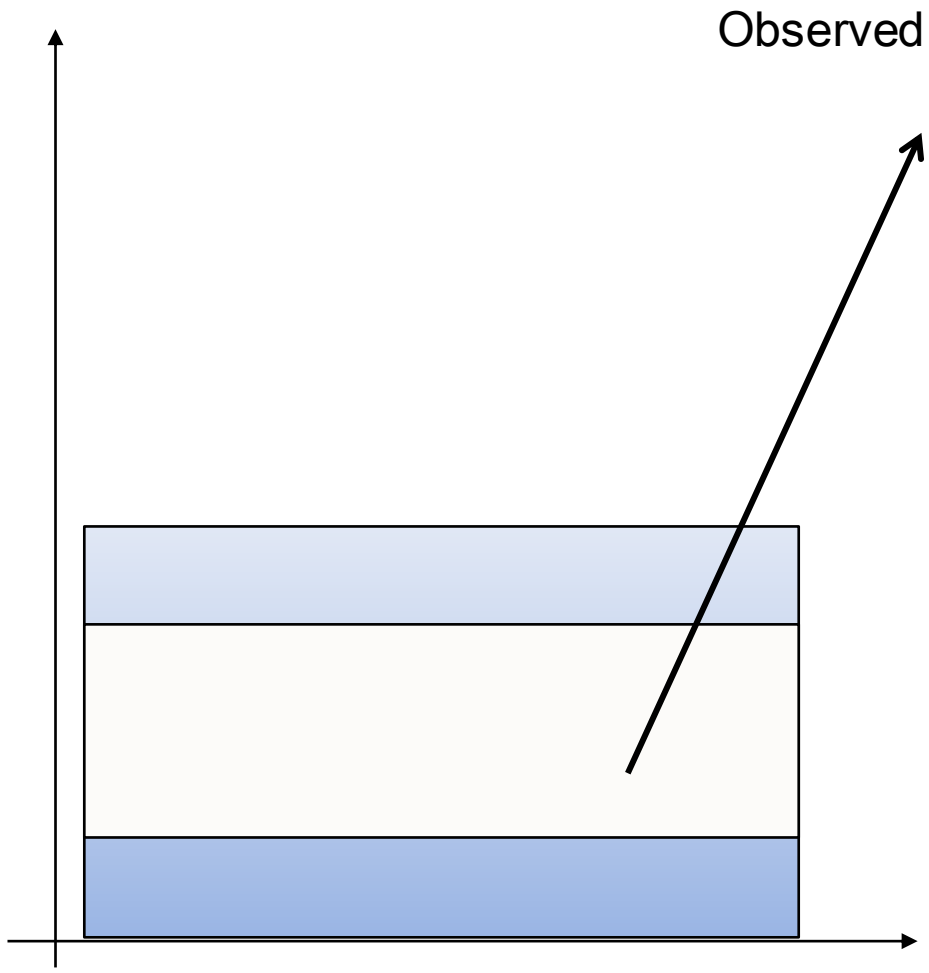


Slab cloud at 283K above a 280K surface (solid)

Slab cloud at 283K above a 100K surface (dashed)

Geer et al. (2021, GMD, Bulk hydrometeor optical properties for microwave and sub-millimetre radiative transfer in RTTOV-SCATT v13.0)

Radiative transfer: sounding channels (ignoring scattering)

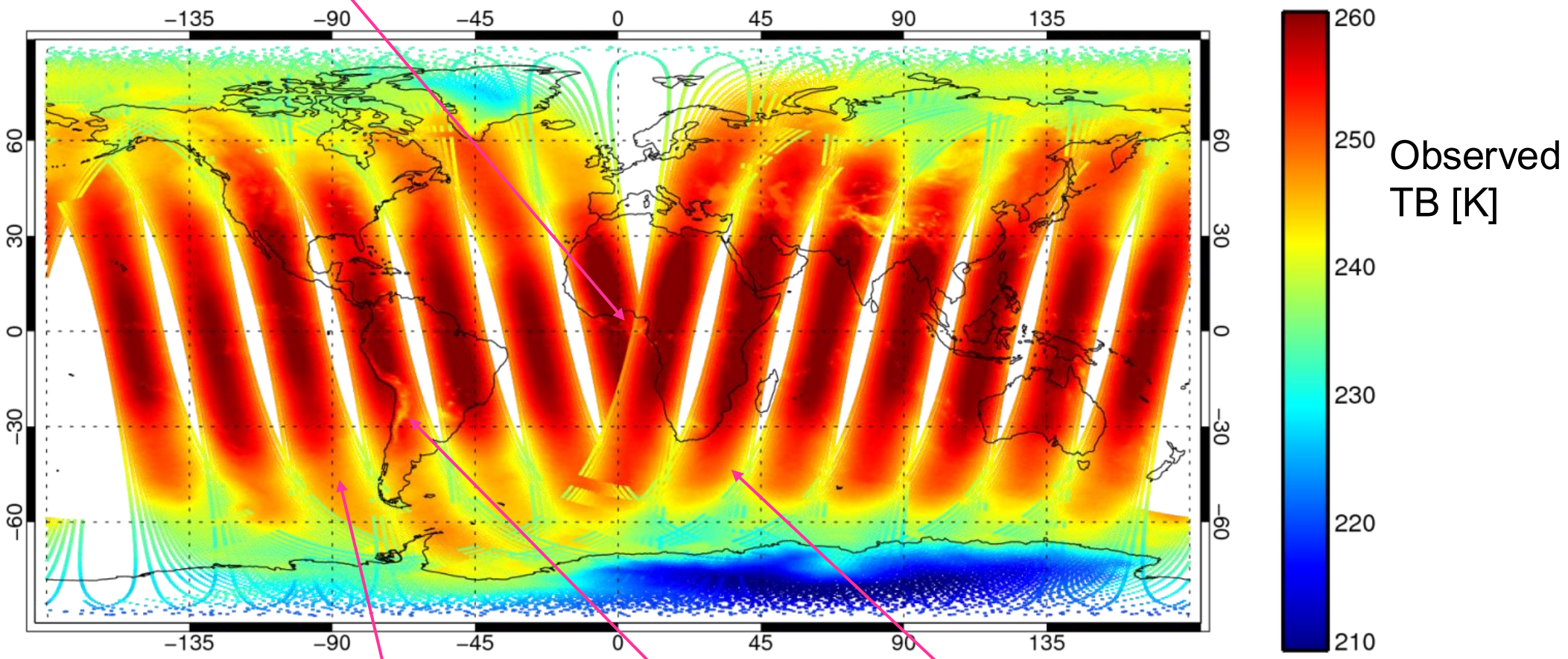


One source of radiation:

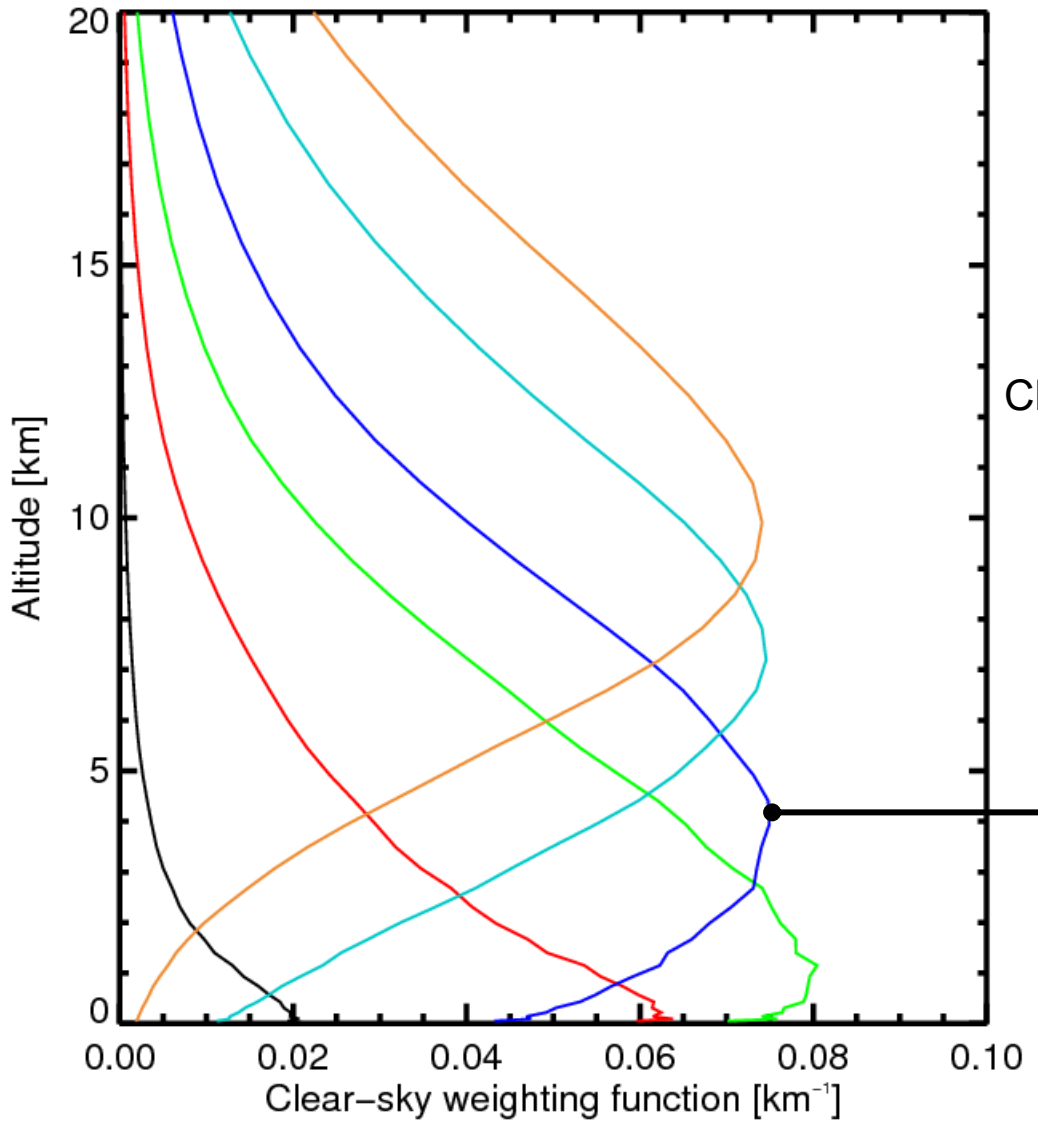
1. Radiation emitted by the atmosphere

Sensitivities: temperature sounding channels

AMSU-A channel 5 radiances:
Metop-A satellite, 9pm 25/4 to 9am 26/4/2012
Cross-track scanner



Clear sky AMSU-A weighting functions (nadir)

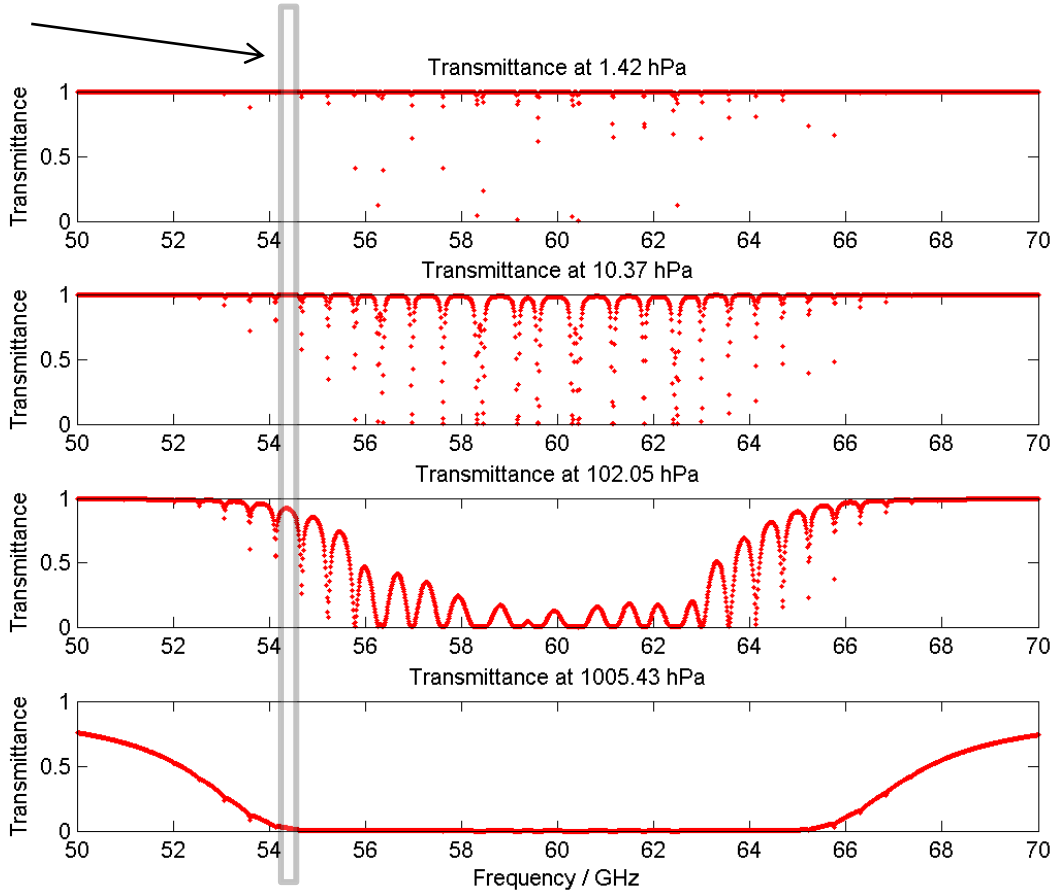


AMSU-A channels are at frequencies mainly sensitive to oxygen, a well-mixed gas: weighting functions are effectively fixed

Channel	Transmittance surface to space
7	0%
6	0%
5	5%
4	19%
3	56%
2	92%

Fine scale structure in the 60 GHz oxygen line

Typical MW radiometer passband at 54.4 GHz

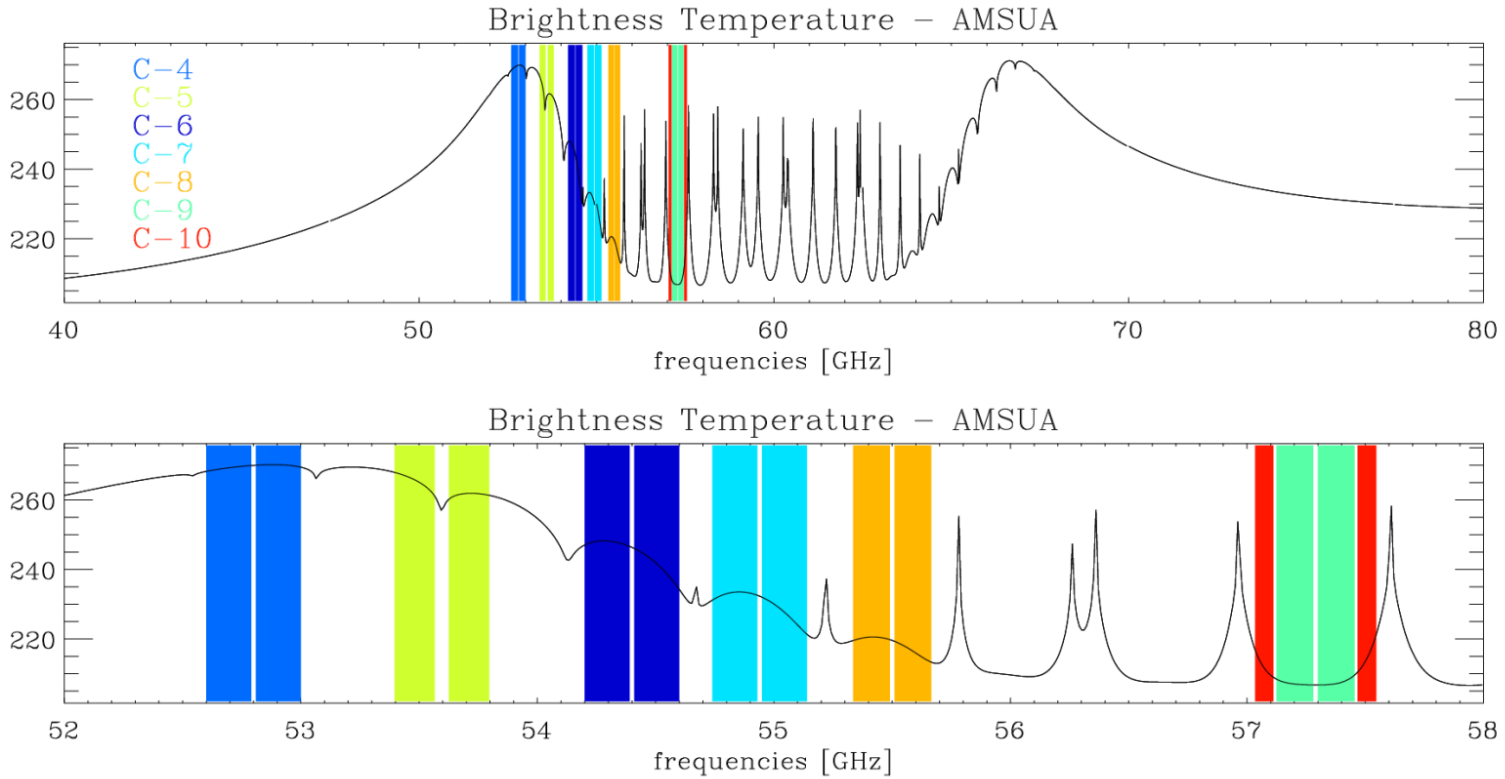


Level to TOA transmittance from Liebe MPM 92 model

Narrow lines ~ several MHz

Increasing pressure broadening

AMSU-A 50 – 60 GHz channels

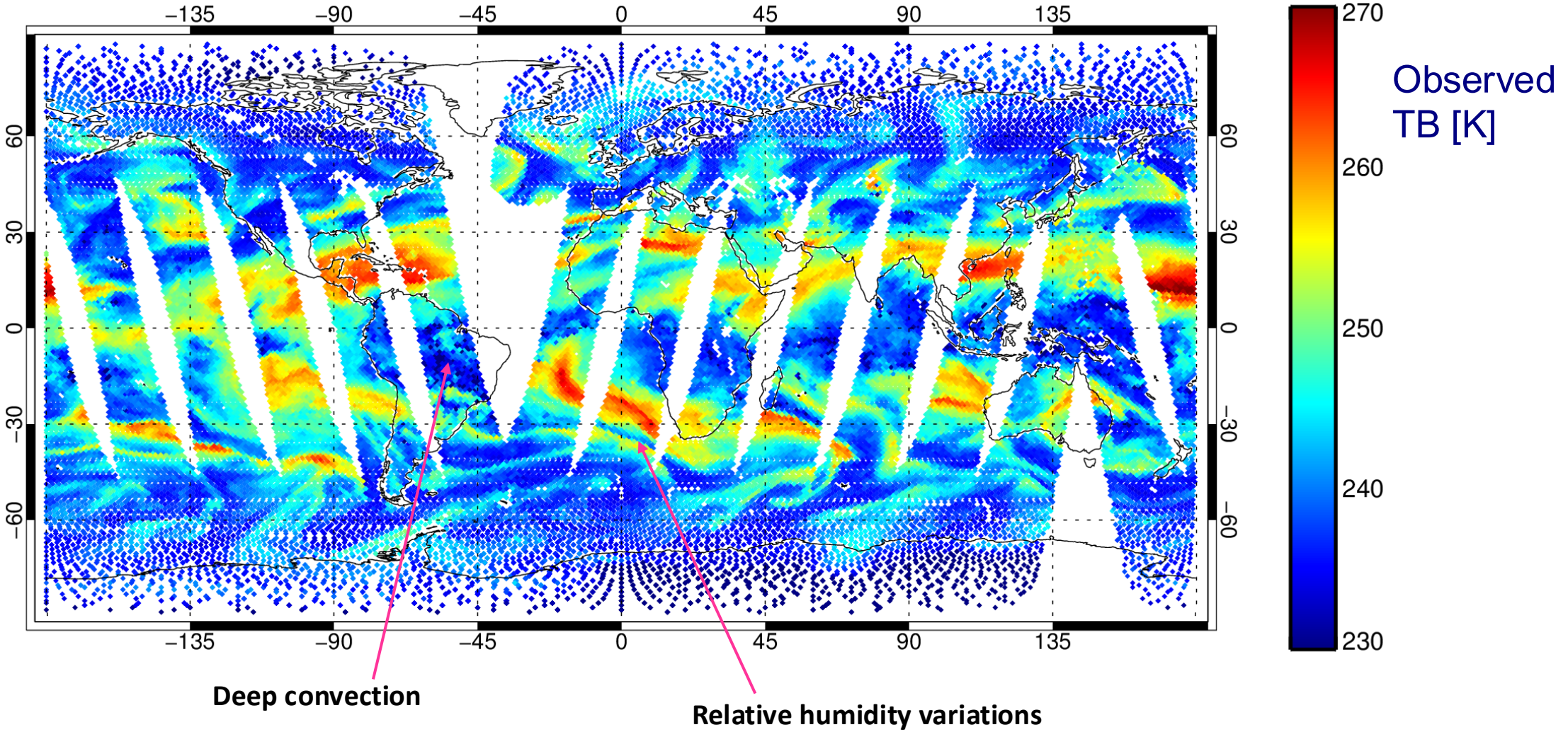


Channel positions and bandwidths are based on trade-offs aimed at simultaneously optimising :

- width of the band (wider bands give lower noise)
- *flatness* of optical depth across the band (narrow weighting functions)

Humidity sounding channels

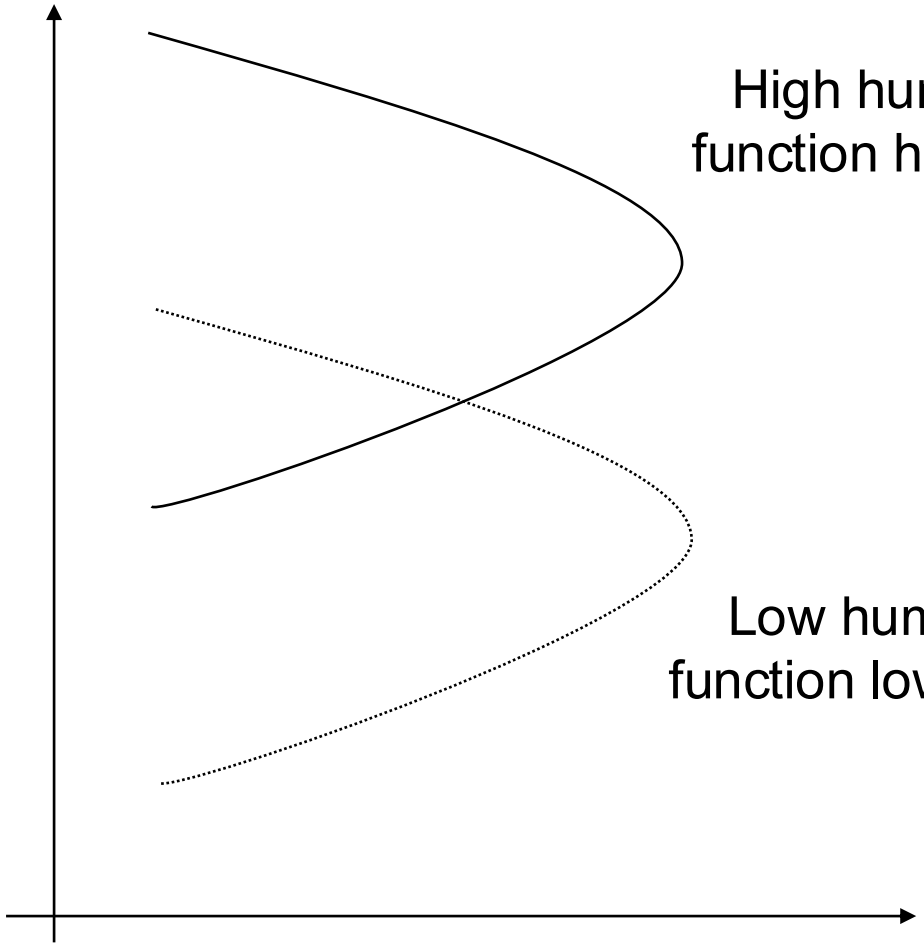
SSMIS F-17 channel 11 (183±1 GHz)
Conical scanning imager and sounder



Water vapour is a highly variable gas in the atmosphere: weighting function is not fixed

TB = 230 K (found at approx. 400 hPa)

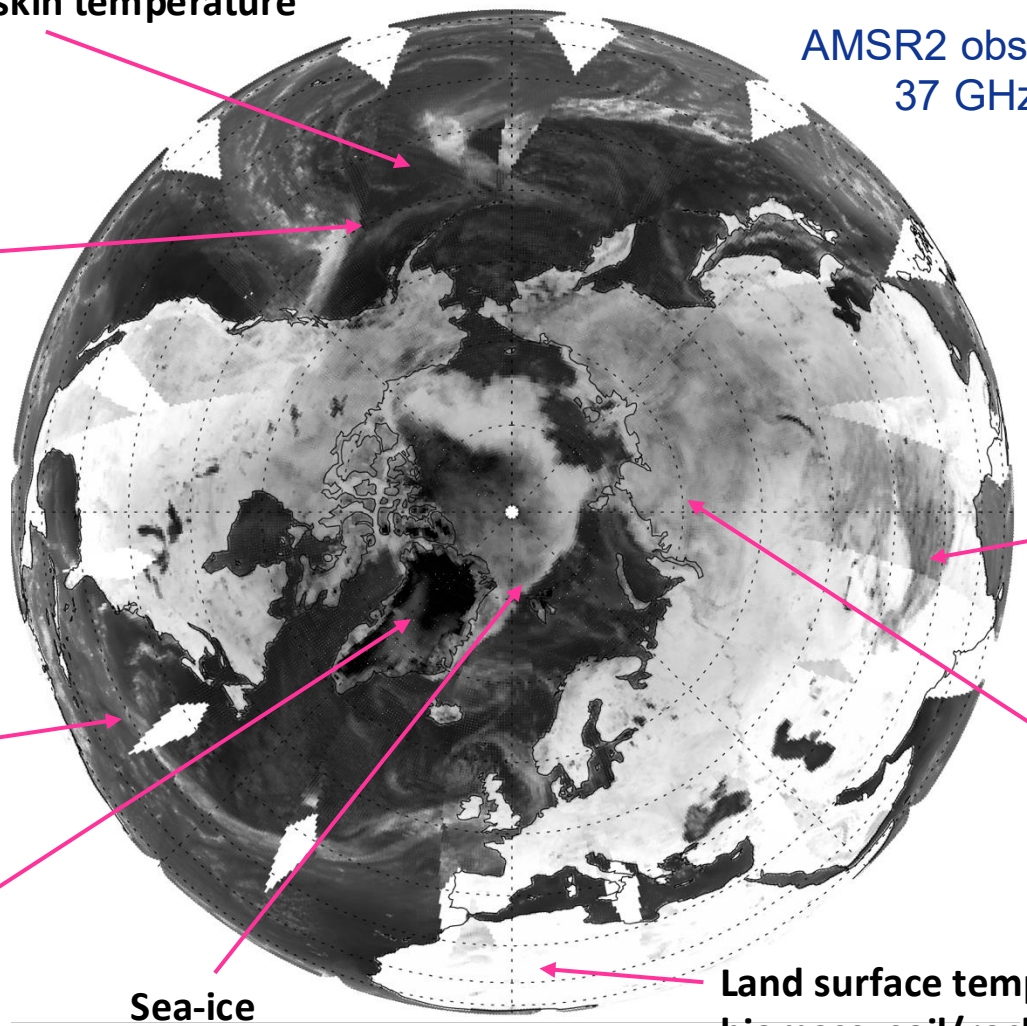
TB = 265 K (found at approx. 700 hPa)



High humidity: weighting function high in troposphere

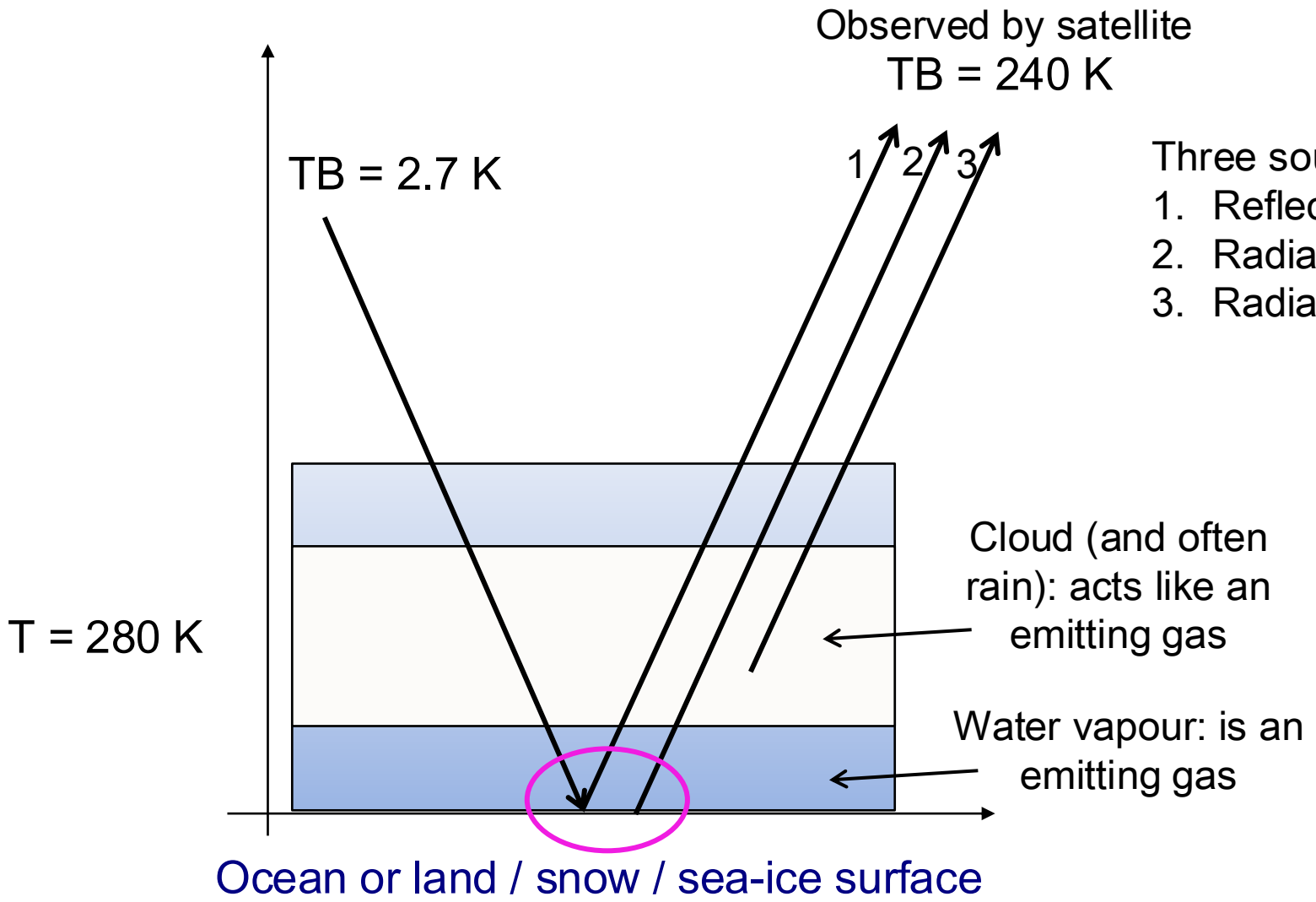
Low humidity: weighting function lower in troposphere

Information content: window (i.e. surface sensitive) channels



AMSR2 observation composite for 2nd Nov 2021
37 GHz, v-polarised brightness temperature

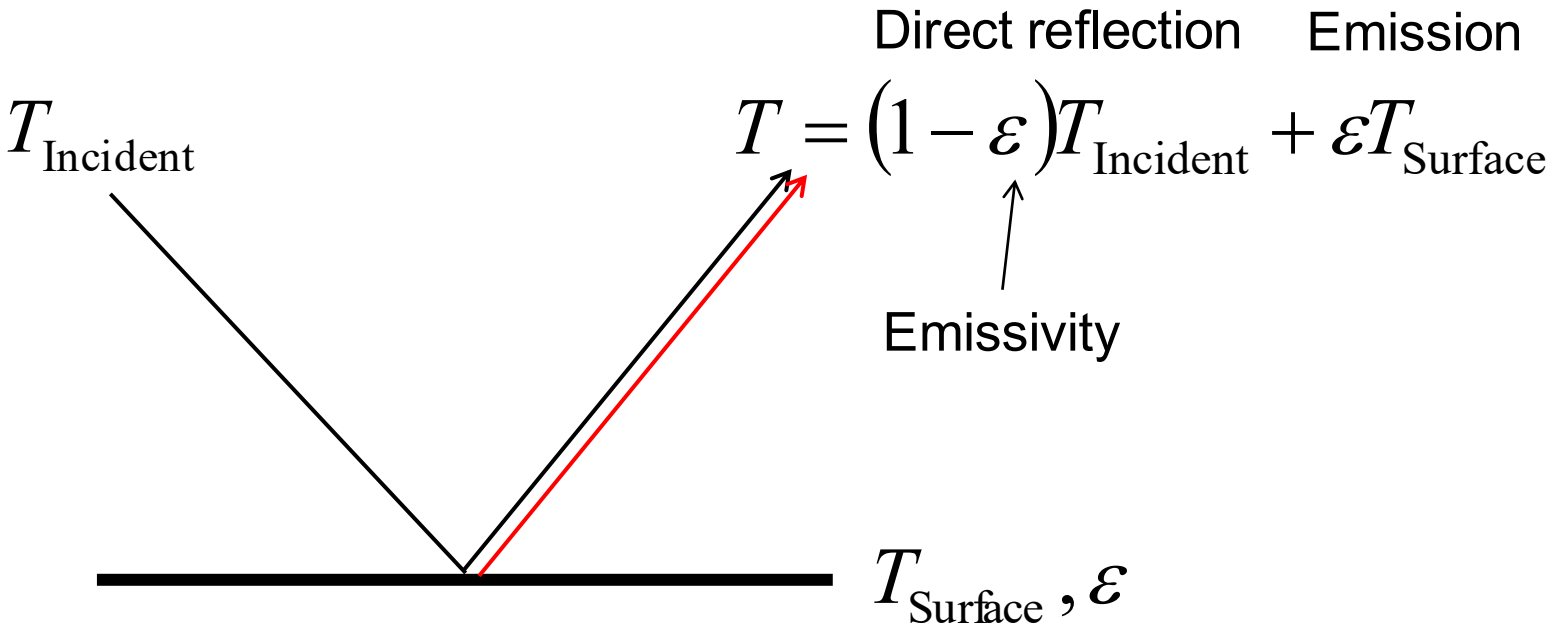
Radiative transfer: window channels (ignoring scattering)



Three sources of radiation:

1. Reflected downwelling
2. Radiation emitted by the surface
3. Radiation emitted by the atmosphere

Describing the surface interaction: specular emissivity

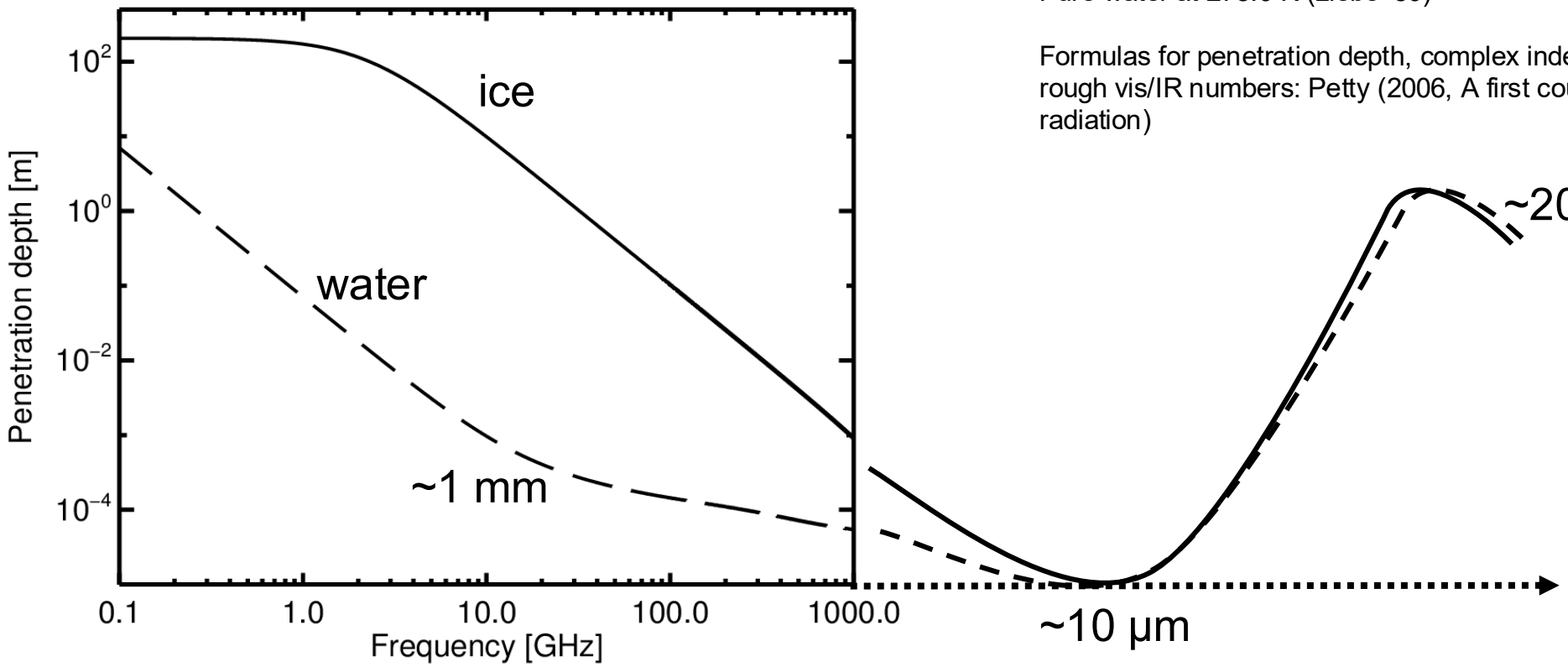


Water and ice: penetration depth

Relative permittivity of pure ice at 263.0 K (up to ~1000 GHz): Mätzler (2006, Microwave dielectric properties of pure ice)

Pure water at 278.0 K (Liebe '89)

Formulas for penetration depth, complex index of refraction, rough vis/IR numbers: Petty (2006, A first course in atmospheric radiation)



Radio-frequency radar: e.g. SAR

L-band e.g. SMOS

Microwave imagers, e.g. AMSR2

Sub-mm, e.g. ICI

Humidity sounders, e.g. MHS

Hyperspectral infrared., e.g. IASI

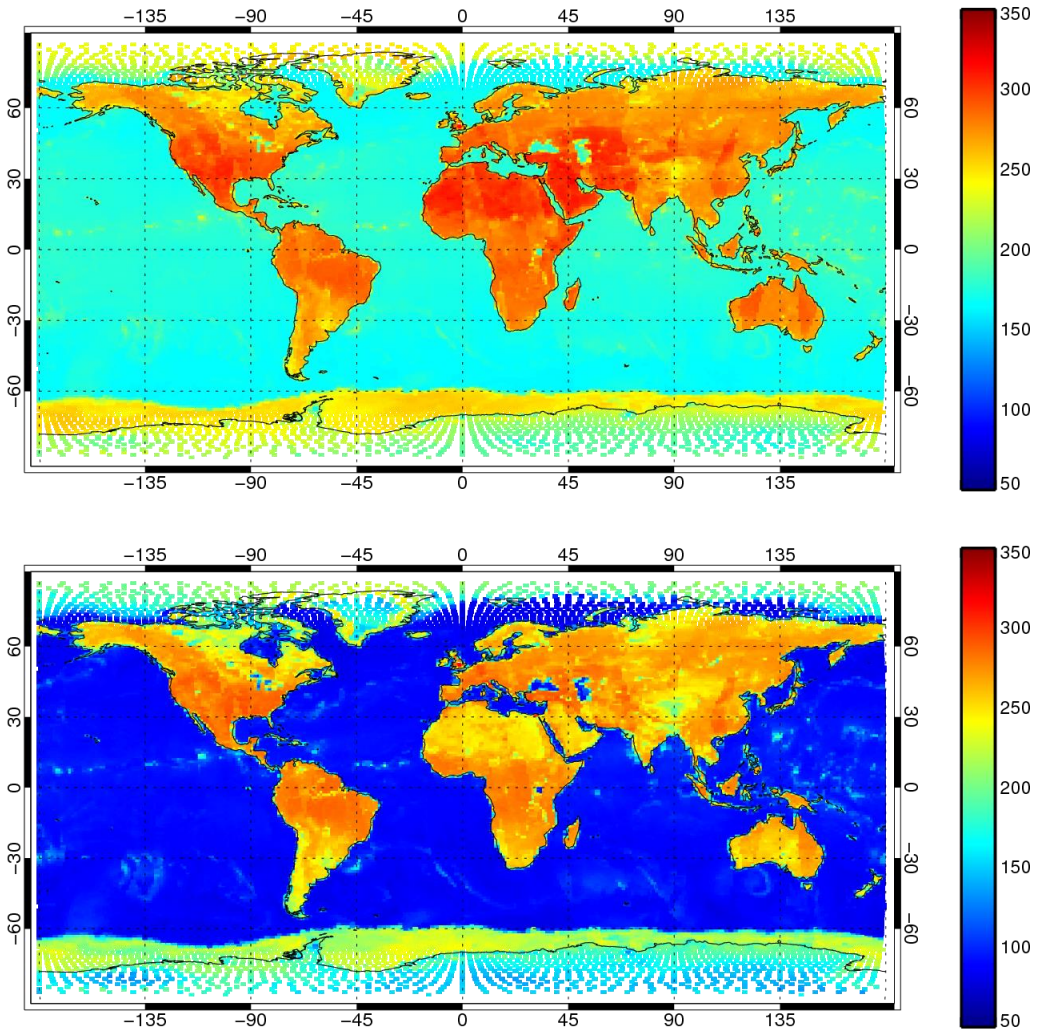
Visible

Surface reflection and emission: ocean

- Plane water surface: low emissivity - Fresnel equations
- Macro structure: waves, swell – geometric optics
- Micro structure, e.g. cm: diffraction from capillary waves
- Foam: much higher emissivity than water
- Correction for non-specular reflection

Approximately – a surface wind speed dependence

Ocean surface: is strongly polarised and reflective at low frequencies



TB [K]
10 GHz v-pol

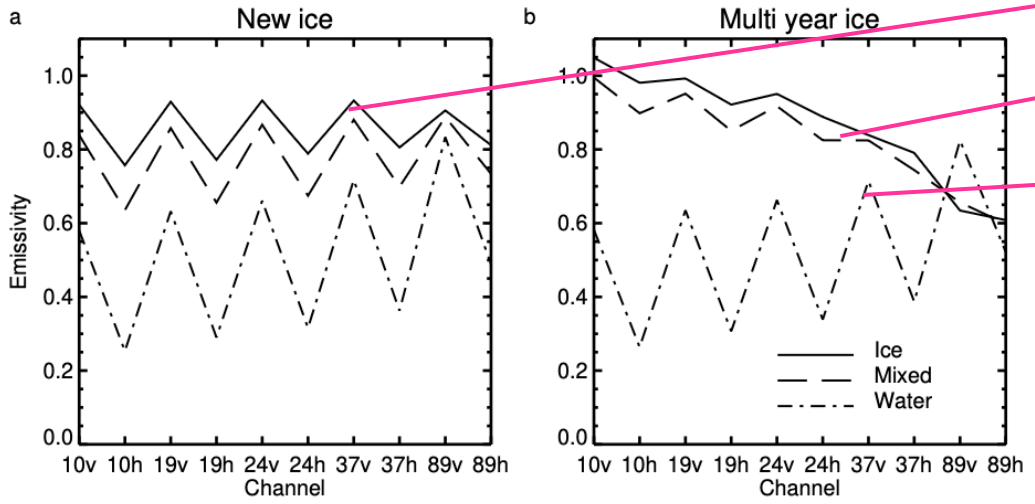
Ocean TB:
~150 K vertical (v)-polarisation
~90 K horizontal (h)-polarisation

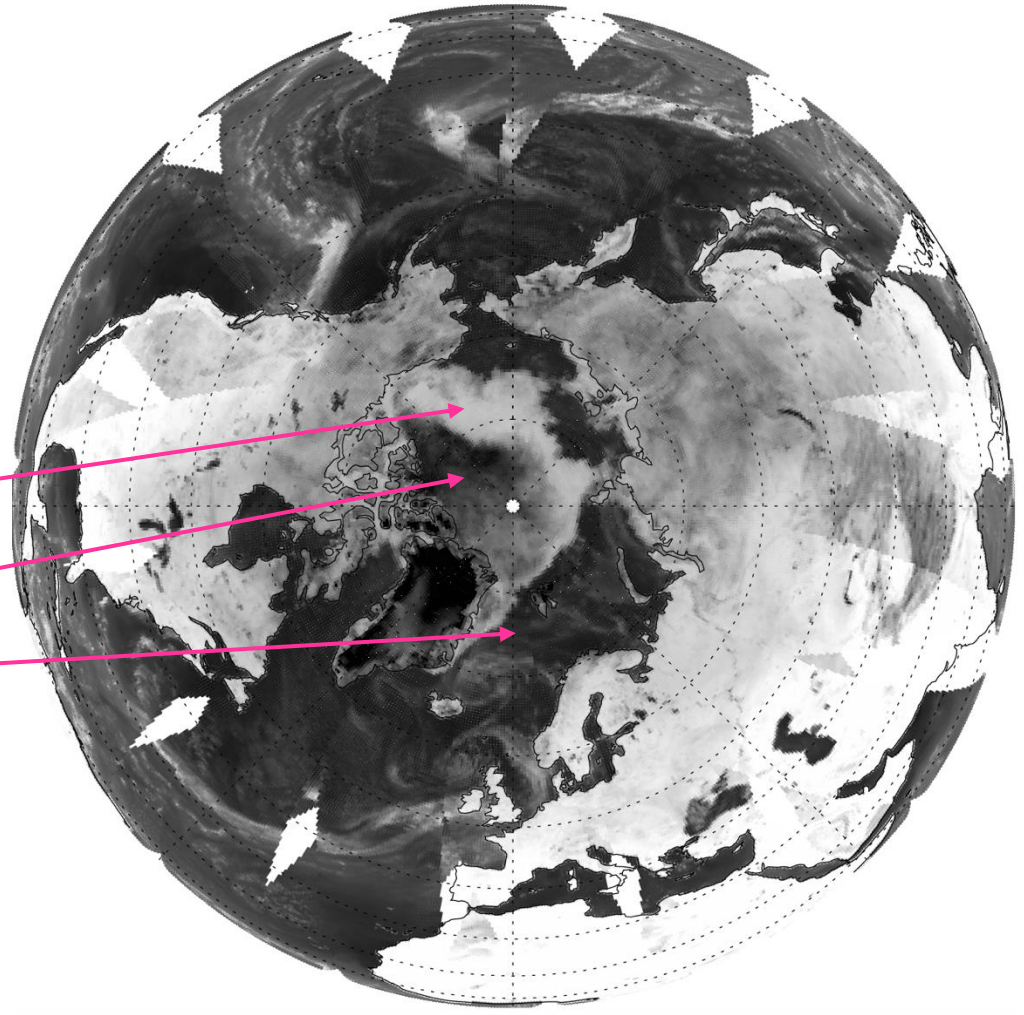
$$T = (1-\varepsilon)T_{\text{Incident}} + \varepsilon T_{\text{Surface}}$$

TB [K]
10 GHz h-pol

Sea ice surface emissivity

$$T = (1-\varepsilon)T_{\text{Incident}} + \varepsilon T_{\text{Surface}}$$

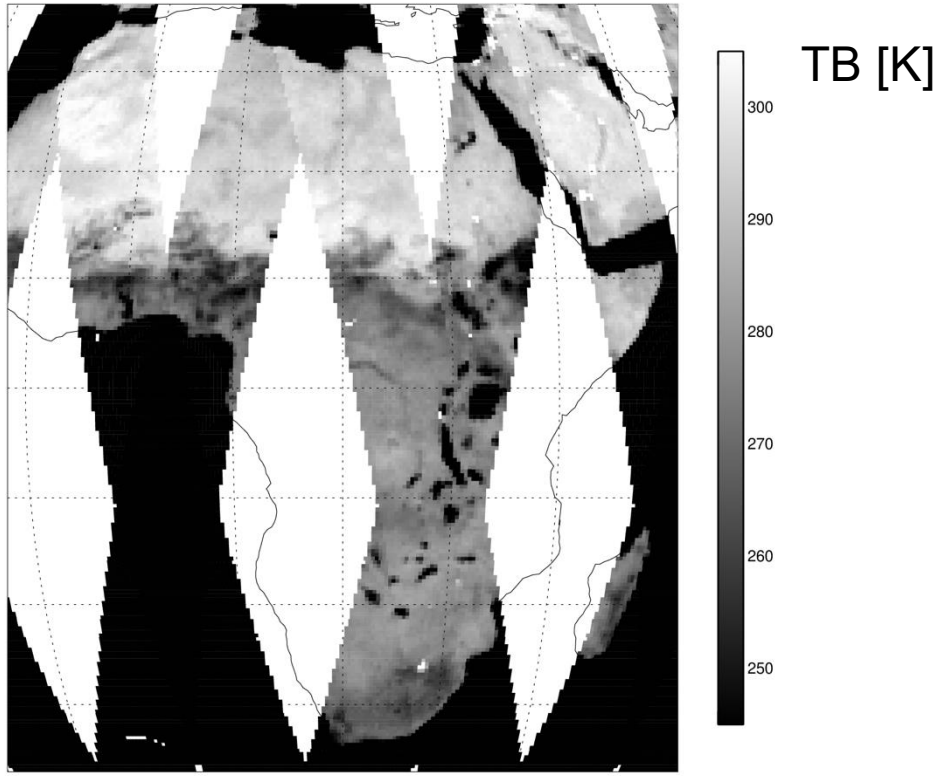




AMSR2 Observation composite for 2nd Nov 2021
37 GHz, v-polarised brightness temperature

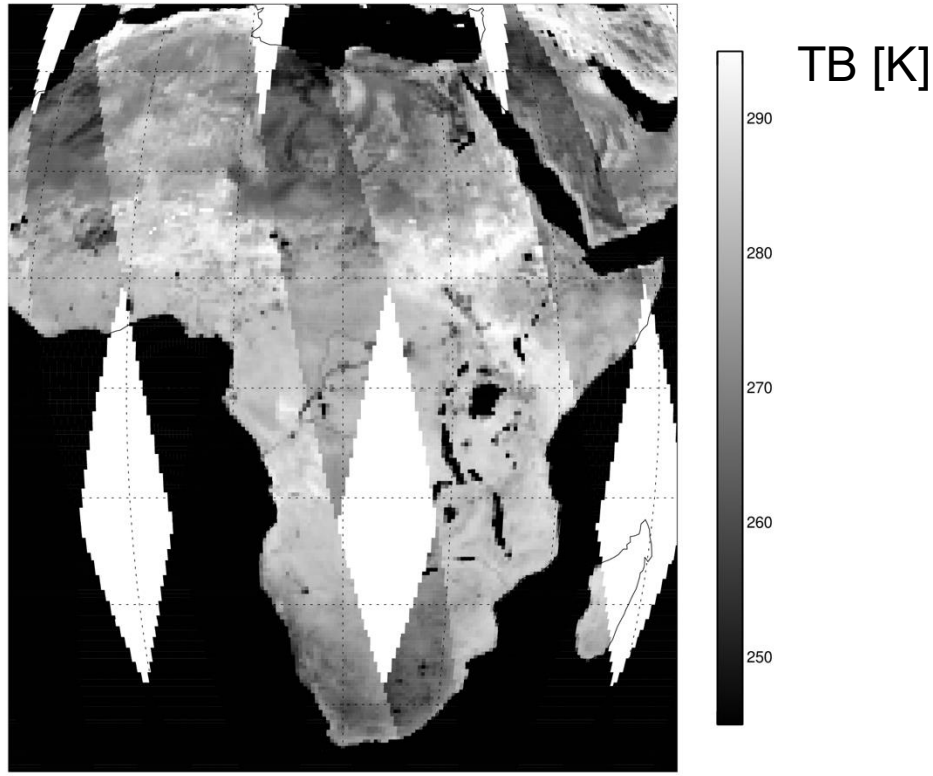
Soil, moisture and vegetation

Observation composites for 1st July 2020



SMAP 1.4 GHz, v-polarised

Moisture makes soil darker
(less emissive)



AMSR2 37 GHz, h-polarised

Volume scattering can make dry soil dark
Vegetation emission is relatively bright

Questions?

Radiance and brightness temperature

- Radiance: W m^{-2} sr^{-1} Hz^{-1}
  - Watts (energy)
  - per metre squared
  - per unit of “direction” (solid angle)
  - per unit frequency

- Planck’s function (Rayleigh-Jeans approximation, valid in microwave)

Radiance $\longrightarrow B_\lambda(T_B) = \frac{2c}{\lambda^4} k_B T_B \longleftarrow$ Brightness temperature

c = speed of light; λ = wavelength; k_B = Boltzmann’s constant