

Microwave spectrum

Measurement, modelling and information content

Alan Geer

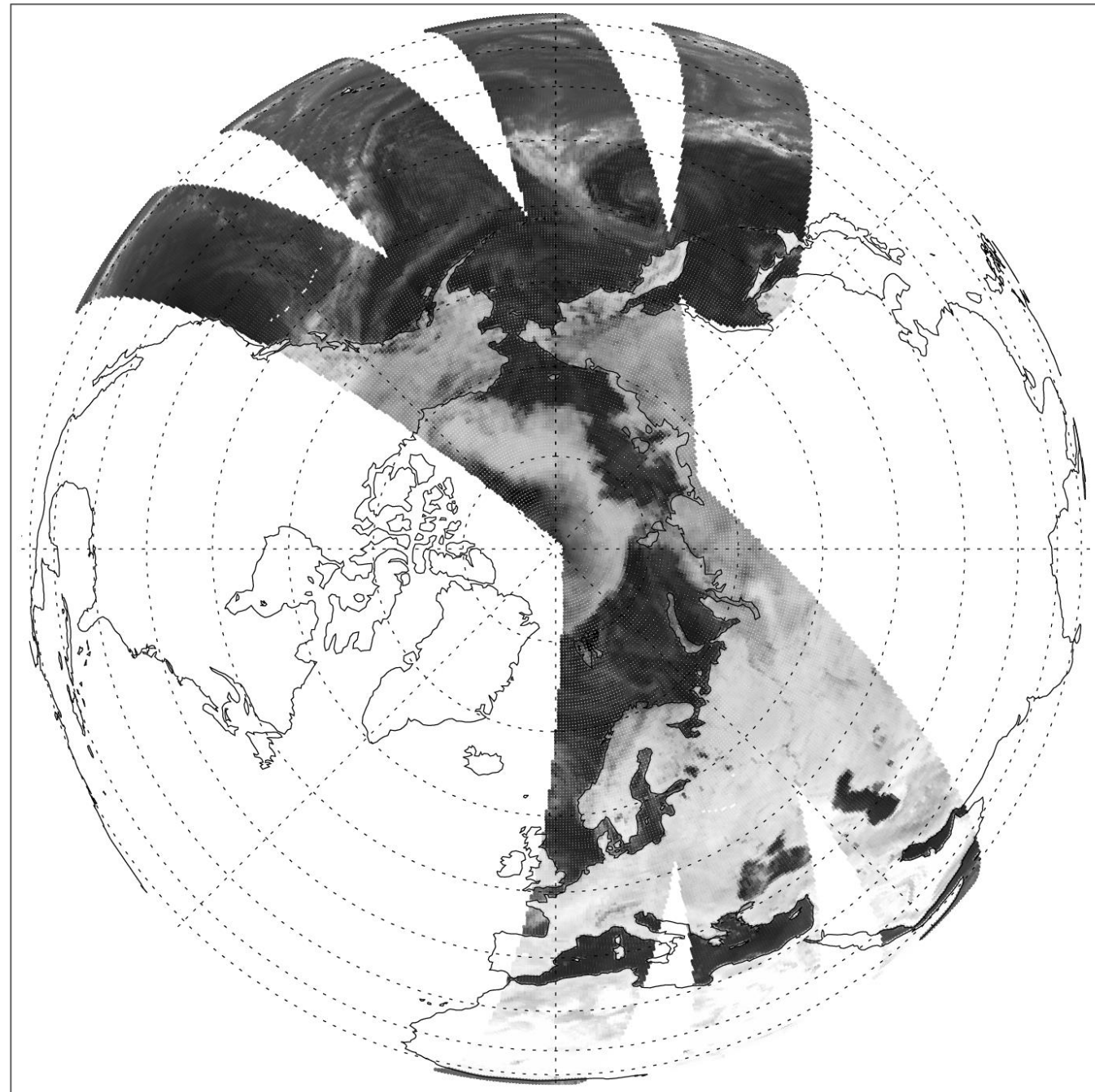
Thanks to: Peter Bauer, Bill Bell

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

Advanced Scanning Microwave Radiometer (AMSR-2)

Observation composite for 1st
Nov 2021

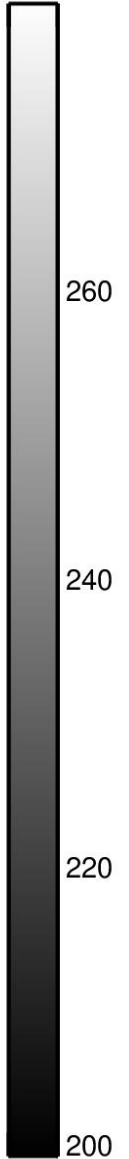
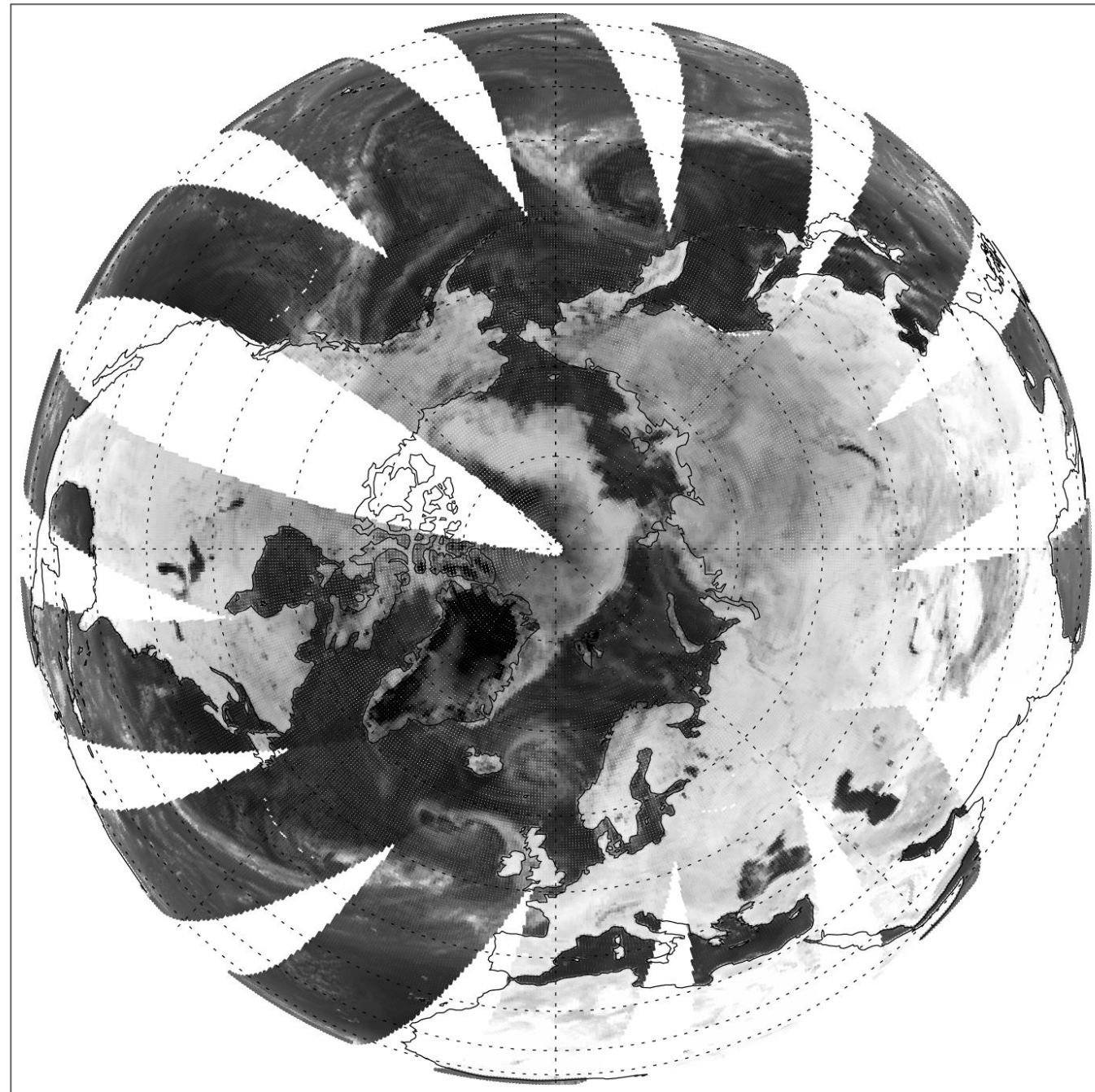
Brightness temperatures
[Kelvin] at 37 GHz, v-polarised



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Nov 2021

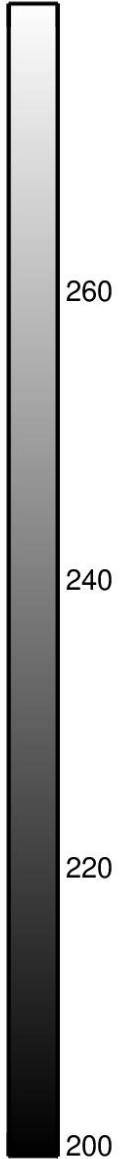
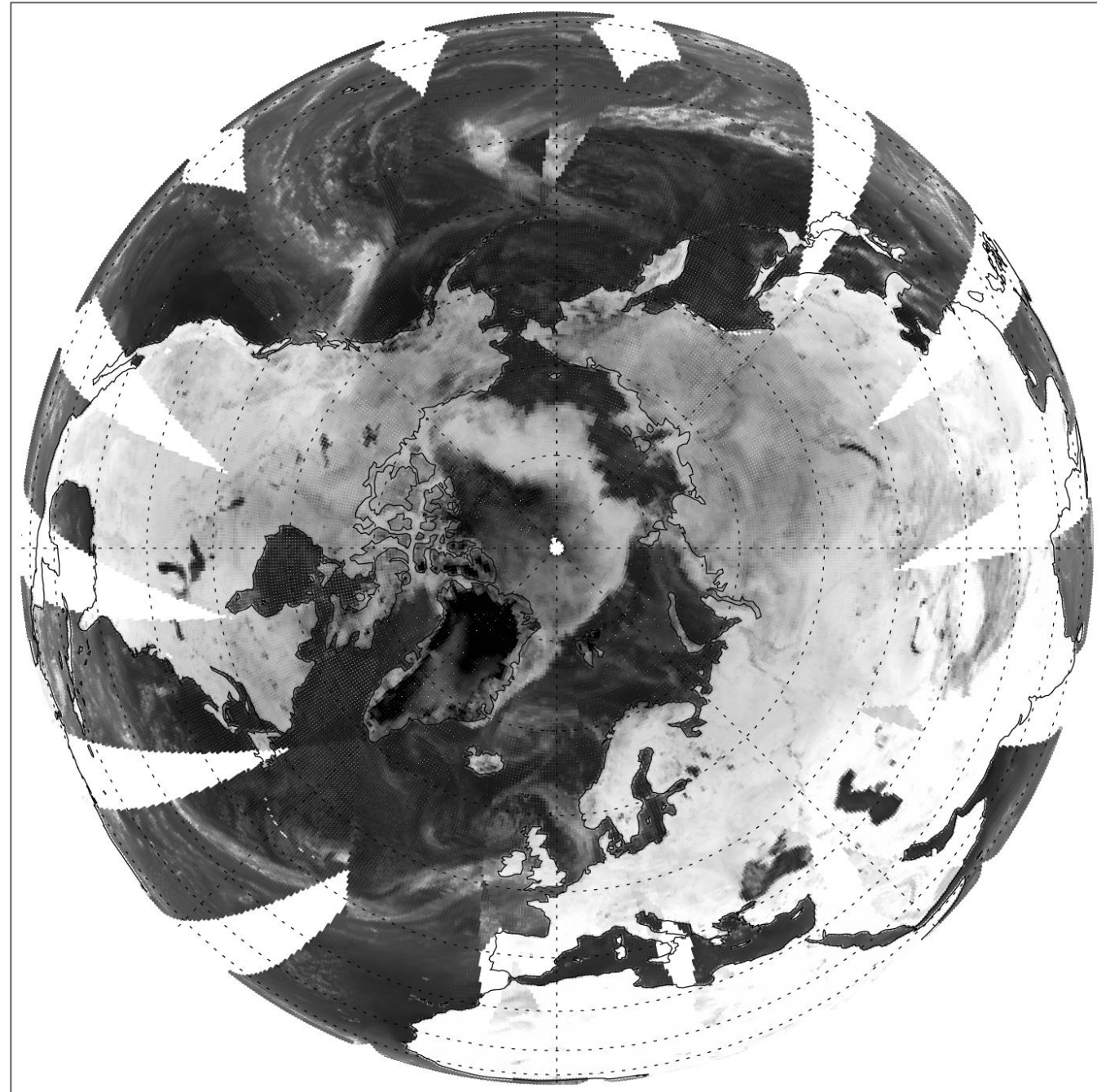
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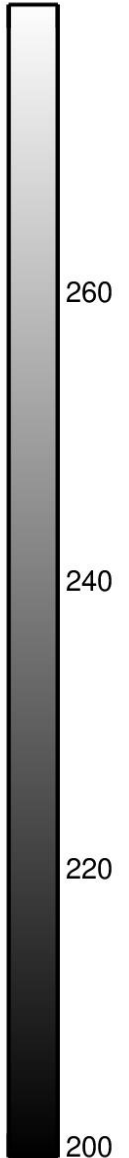
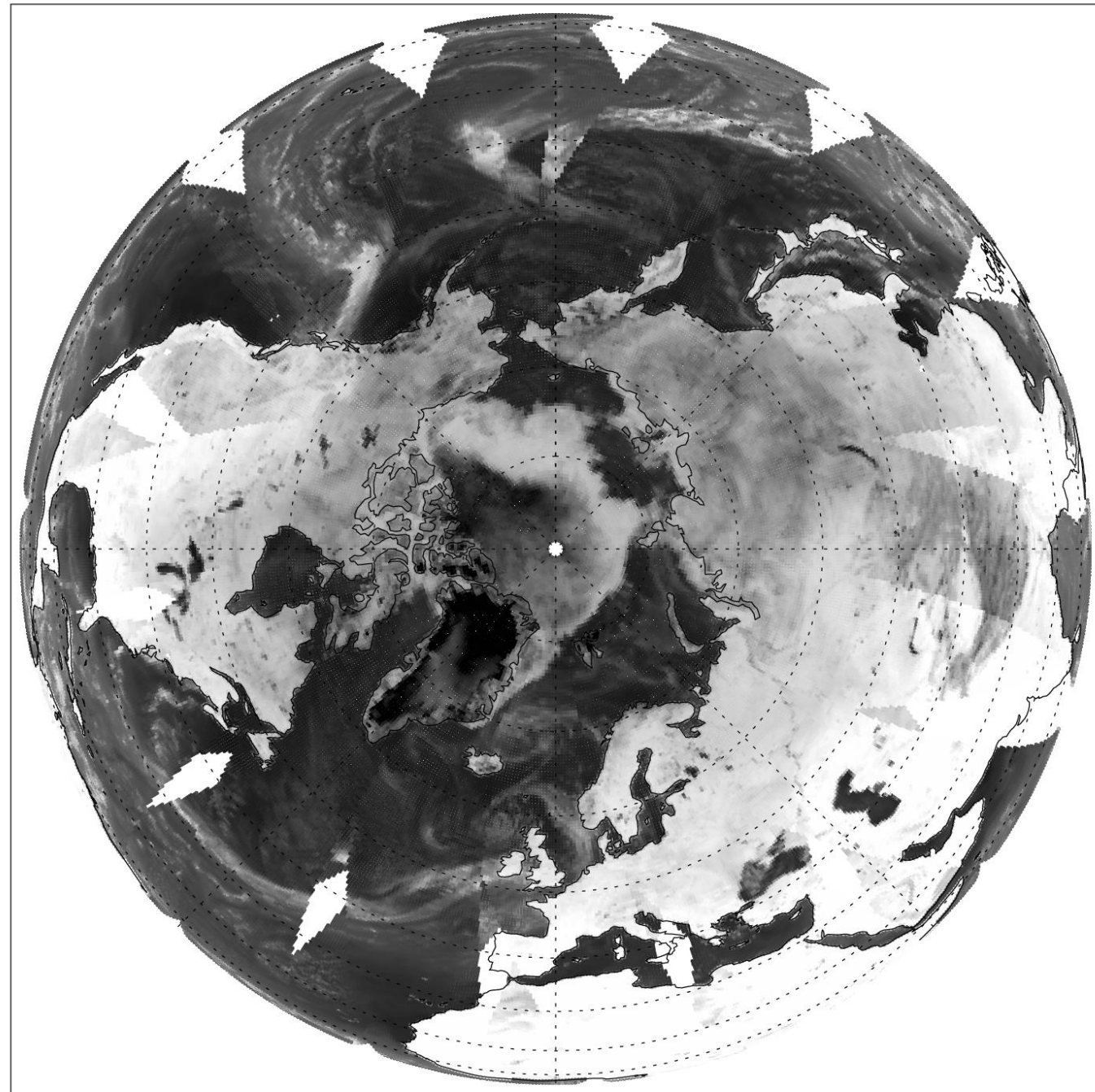
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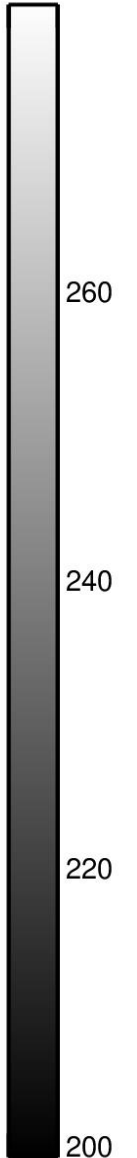
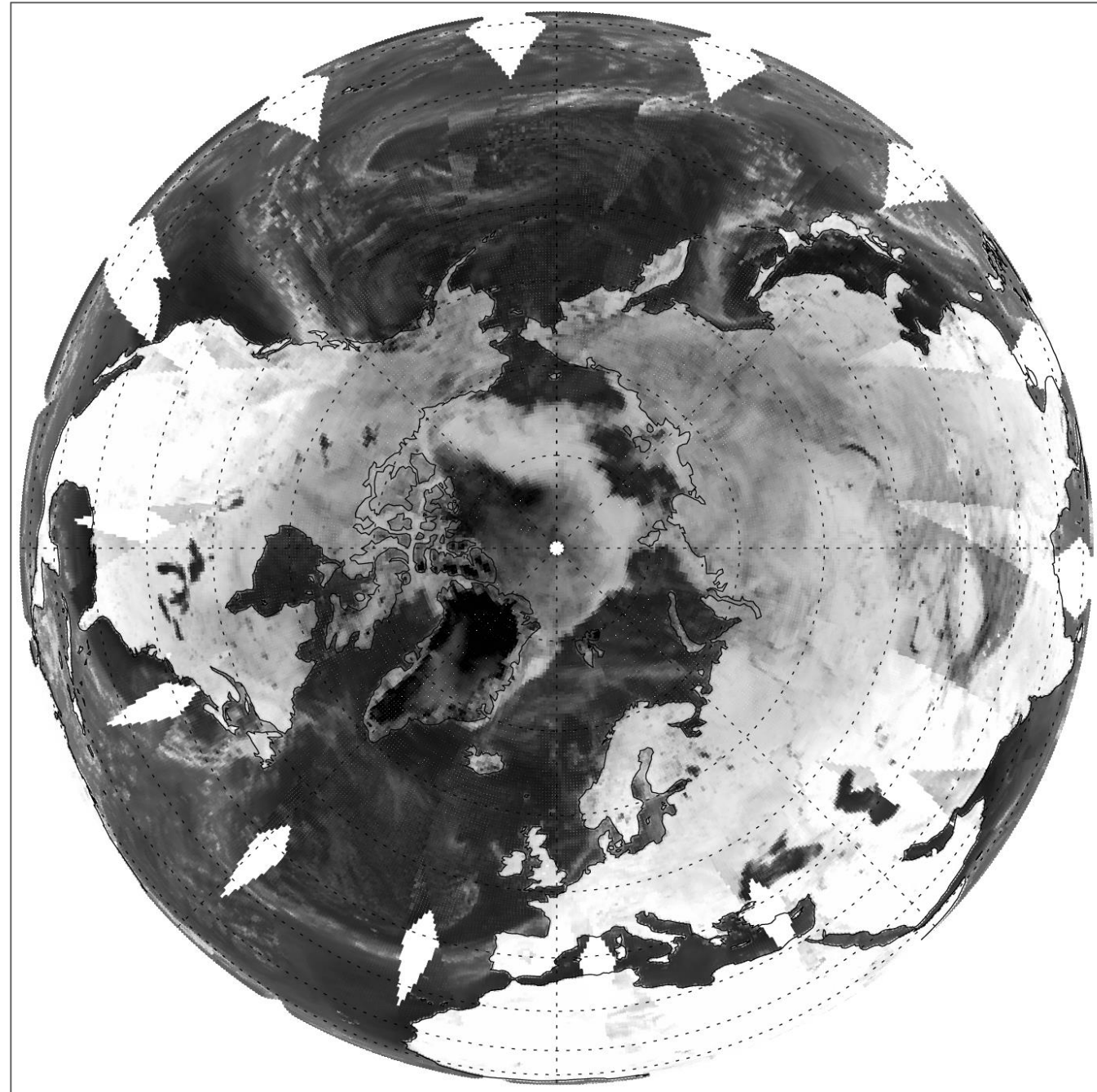
Brightness temperatures
[Kelvin] at 37 GHz, v-polarised



Advanced Scanning Microwave Radiometer (AMSR-2)

Observation composite for 2nd
Nov 2021

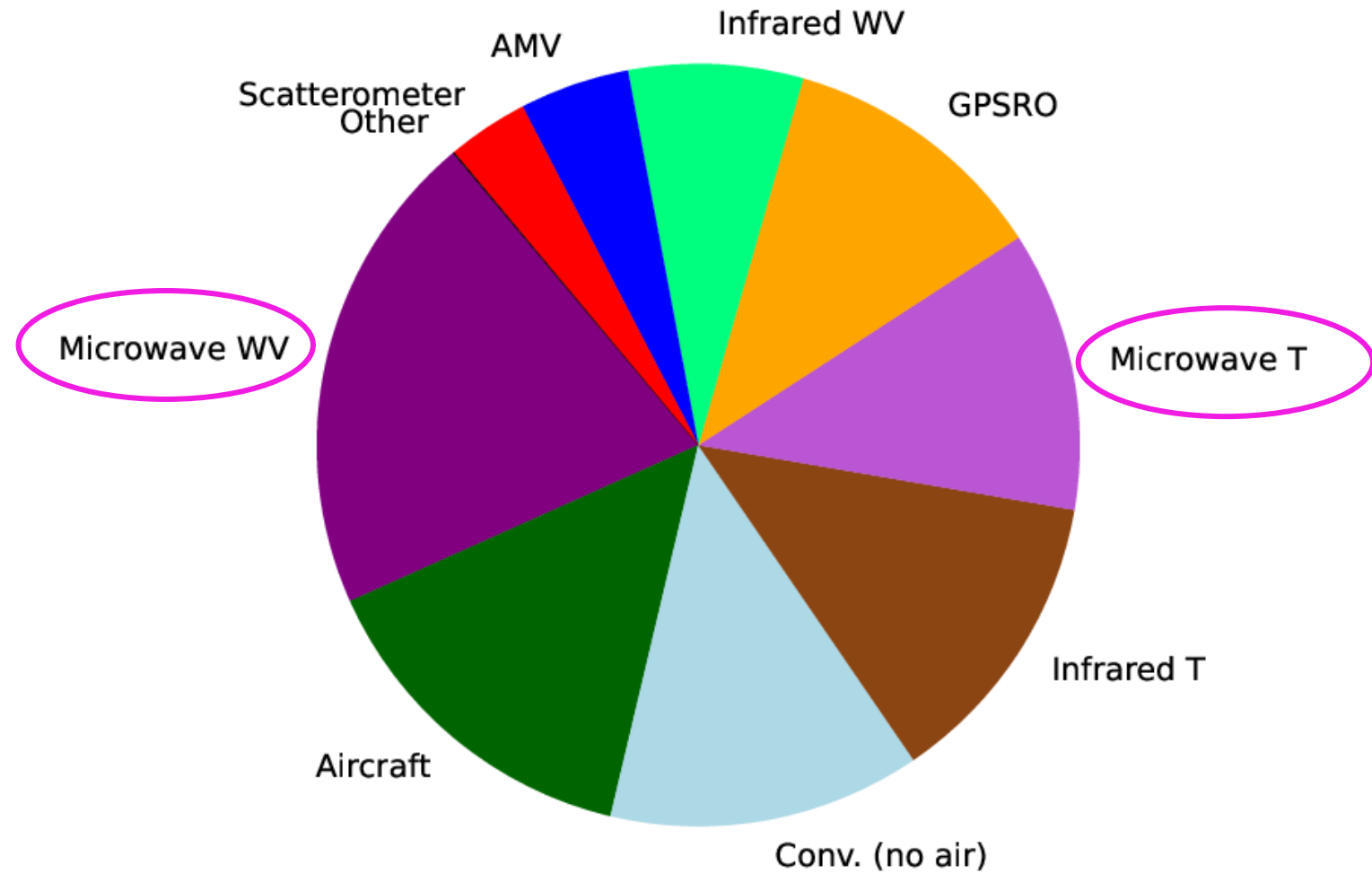
Radiances shown as
brightness temperatures
[Kelvin] at 37 GHz, v-polarised



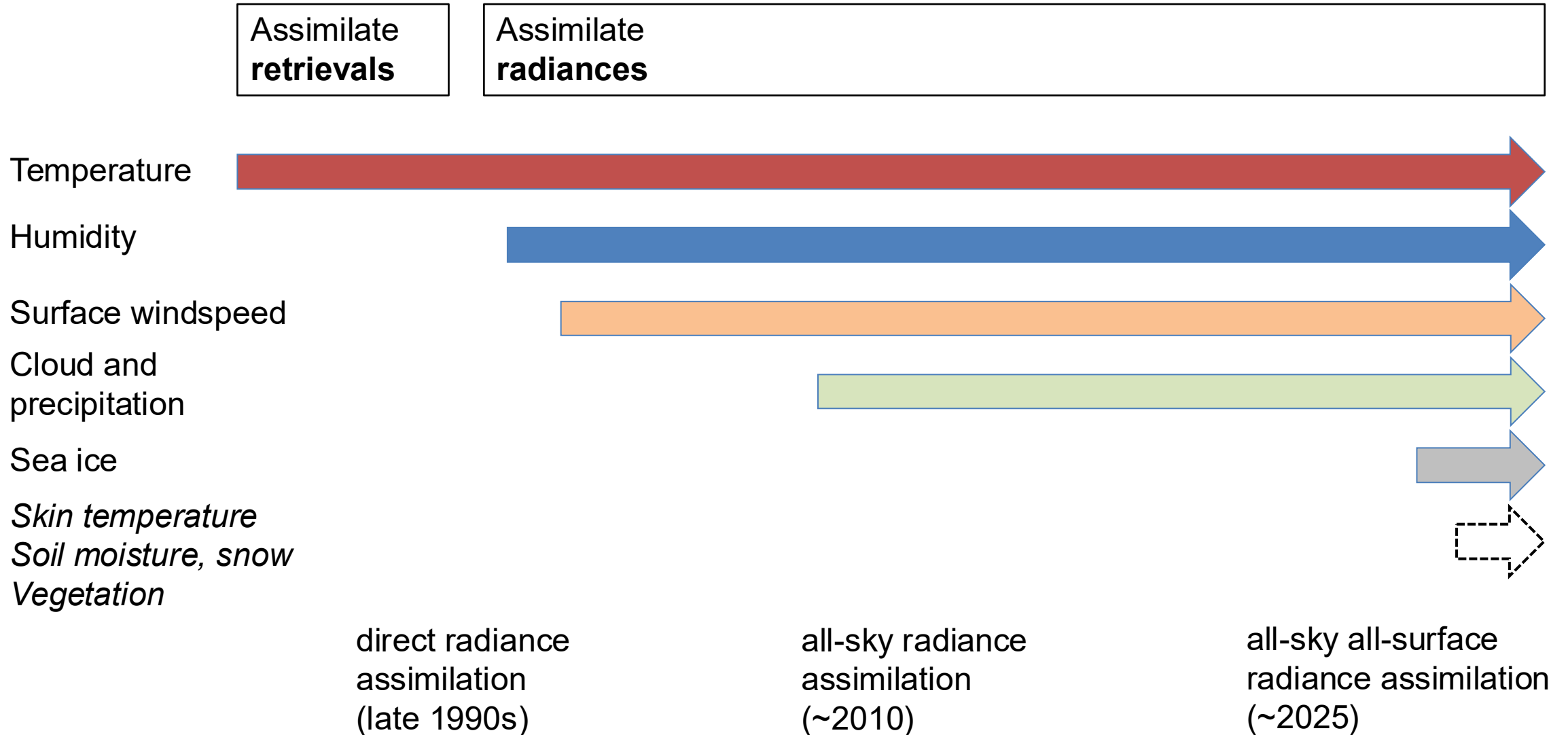
Relative impact of observations at ECMWF: 2025

ops 1-Jan-2025 to 31-Dec-2025

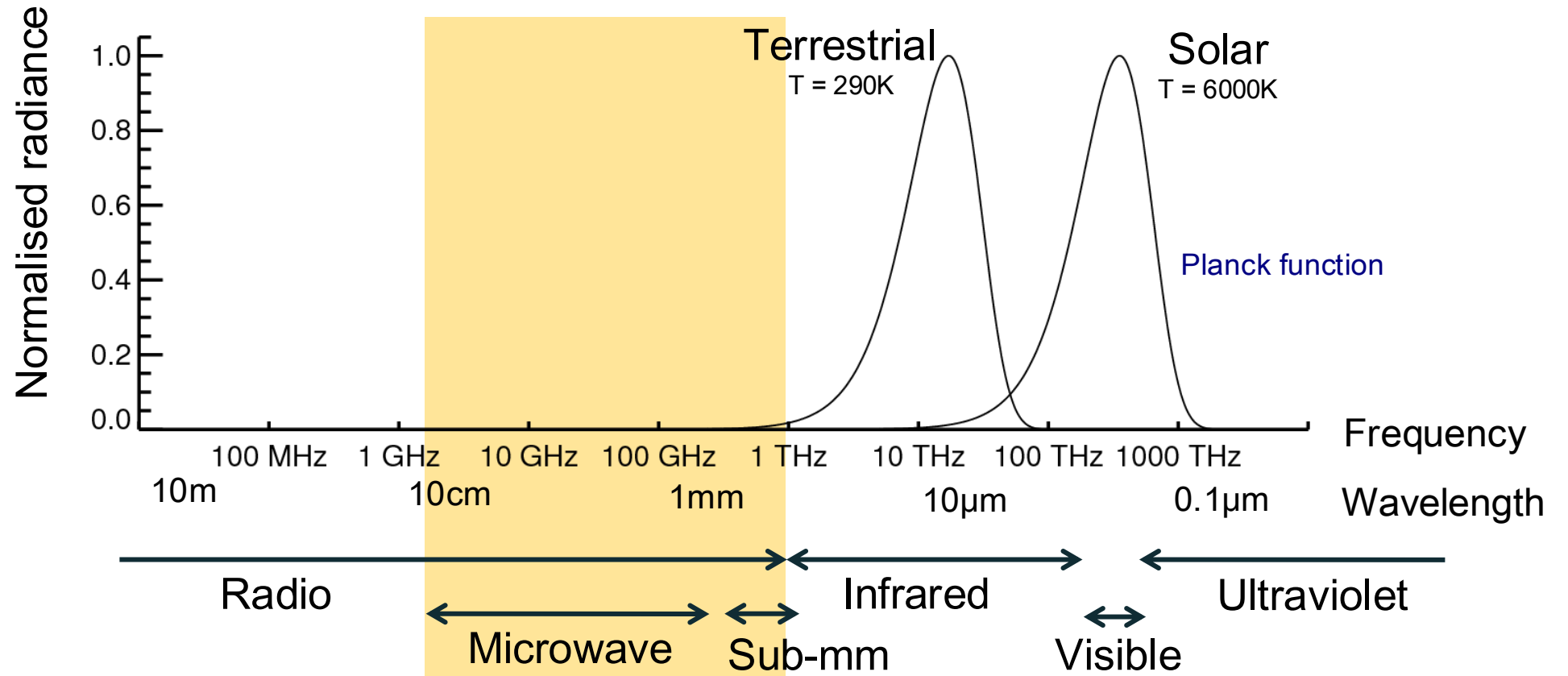
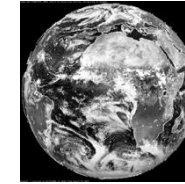
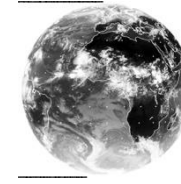
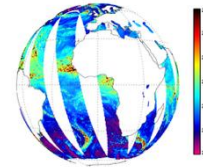
Relative sensitivity
of 24 hour forecast
error to observation
impact (FSOI)



Rough timeline of satellite microwave data assimilation in 'atmospheric' DA



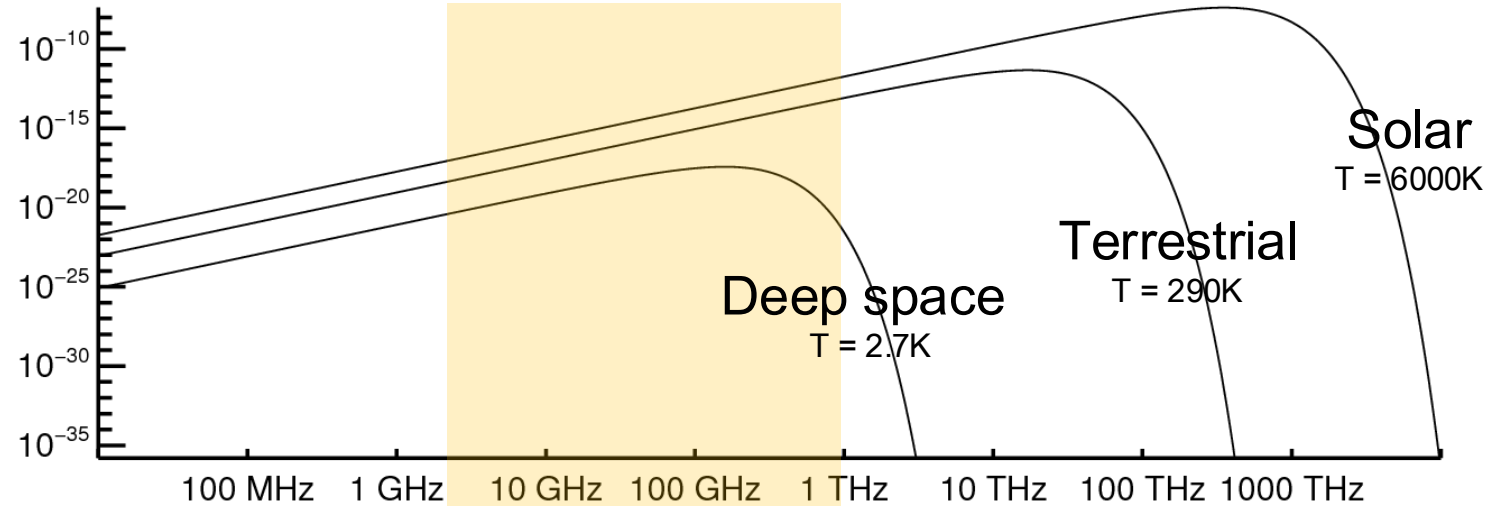
Where is the microwave in the electromagnetic spectrum?



How much energy?

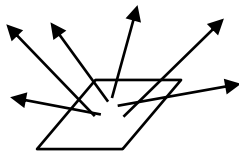
Travelling in a beam

Planck Function Radiance
 $W m^{-2} sr^{-1} Hz^{-1}$

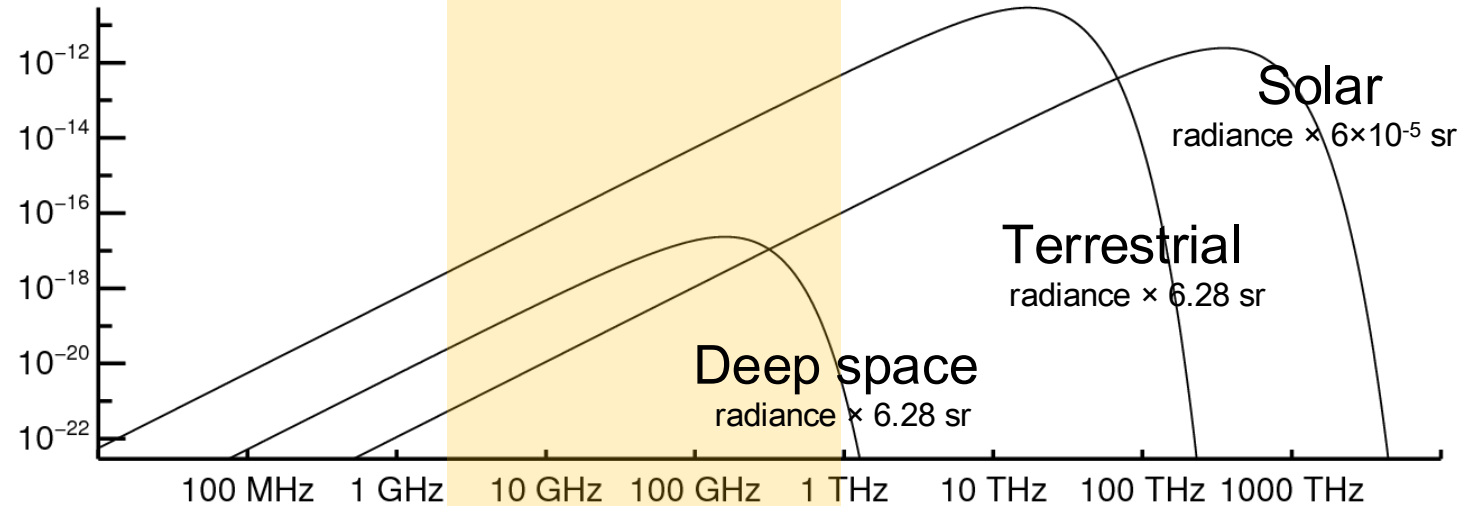


Travelling through an area (in one direction)

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



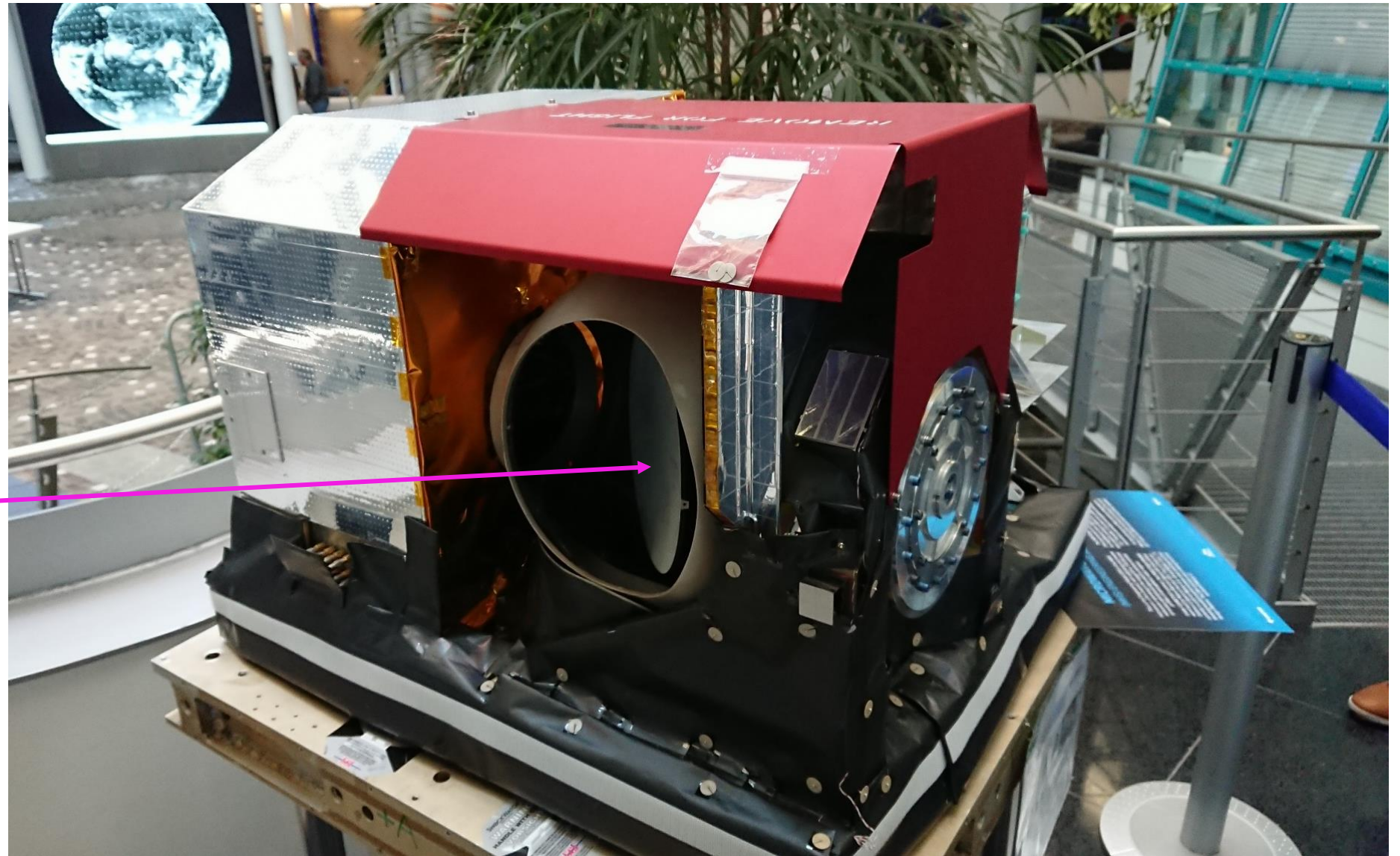
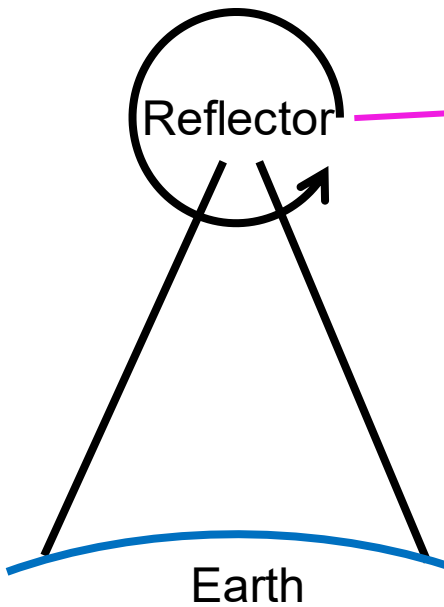
sr – Steradian (unit of solid angle)



Microwave

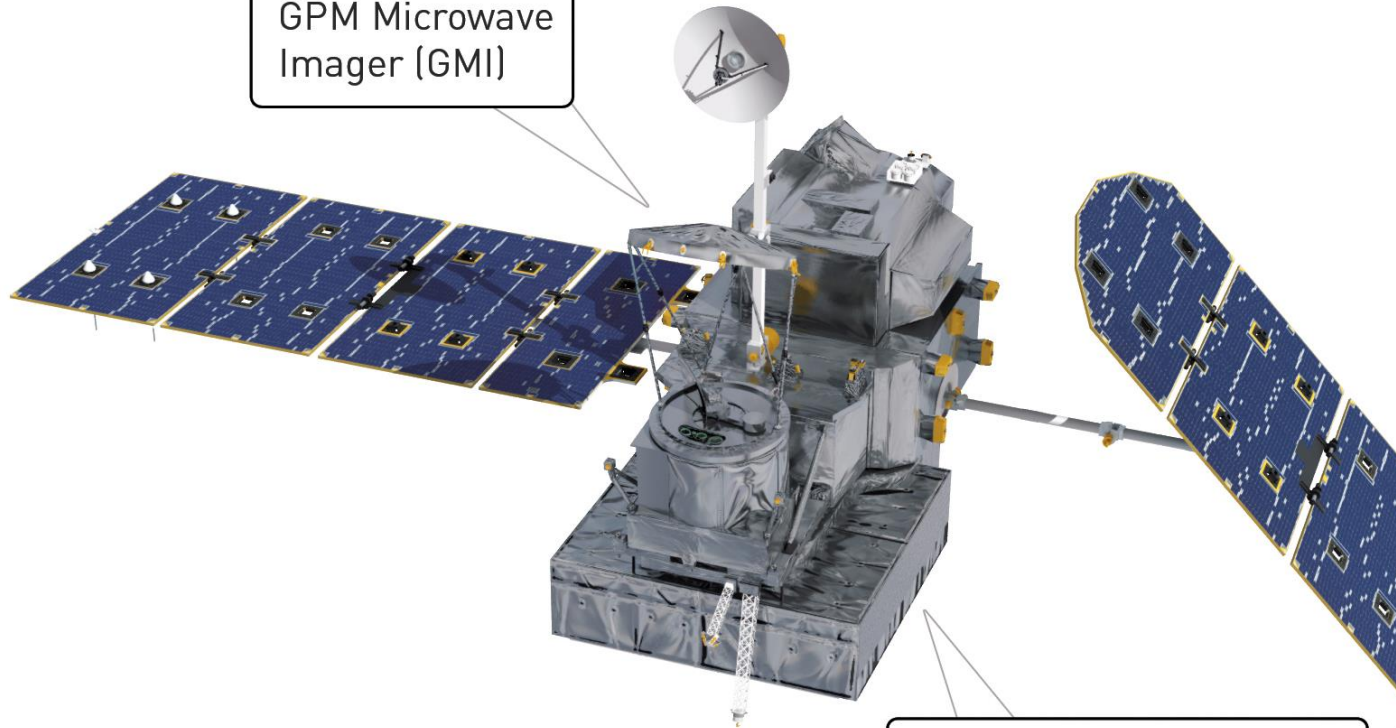
The Microwave Humidity Sounder (MHS) at EUMETSAT

Cross-track sounder



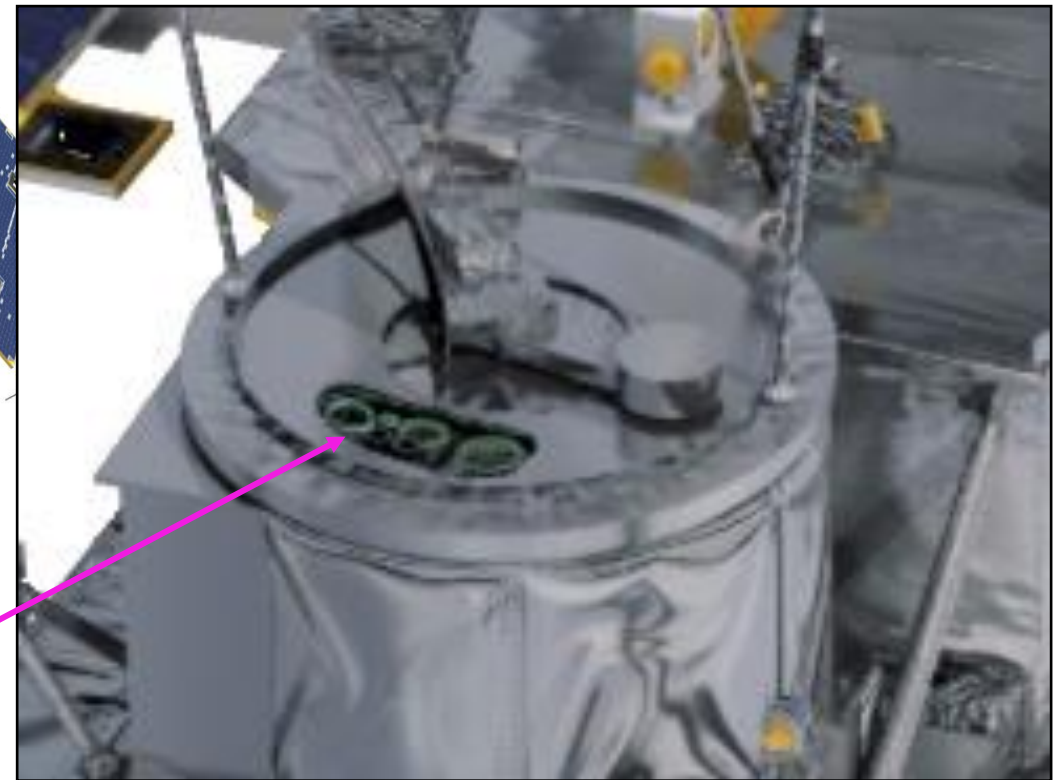
Global precipitation mission (GPM)

GPM Microwave Imager (GMI)



Dual-Frequency
Precipitation Radar (DPR)

Feedhorns

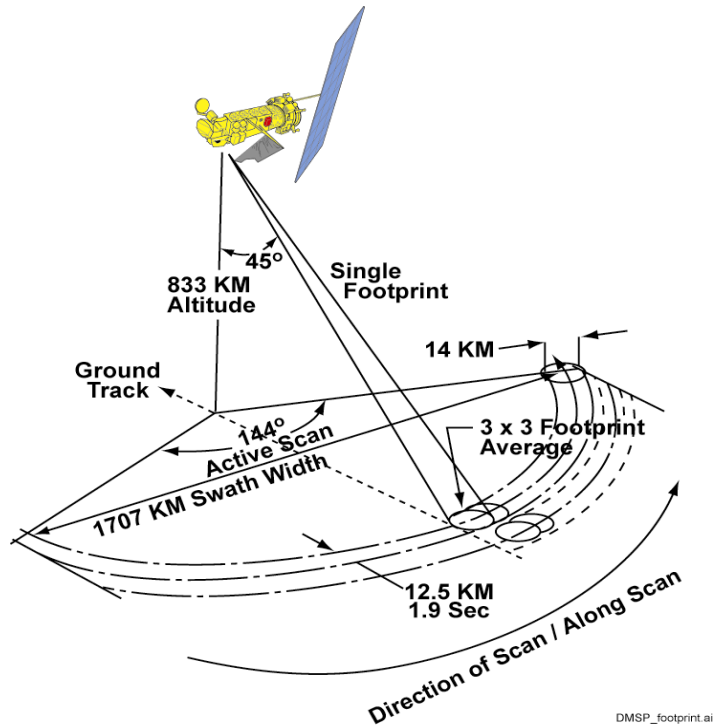


Global precipitation mission:

- Launched Feb 2014

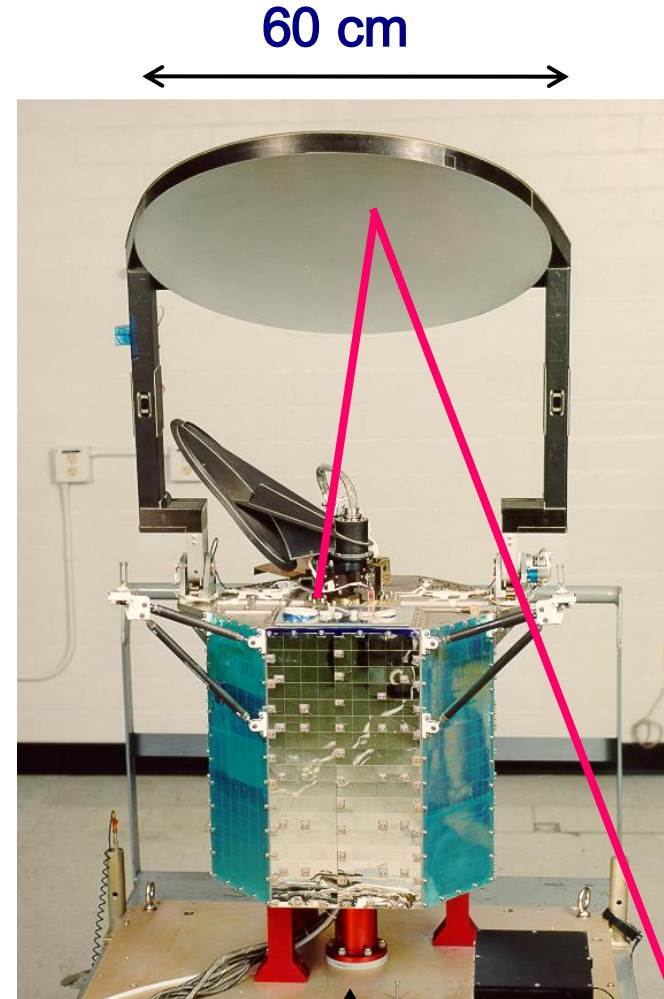
Special Sensor Microwave Imager / Sounder (SSMIS)

Conical scanning geometry



Main Reflector

Cold Calibration Reflector
Warm Load
Feedhorns



Other users of the spectrum

3 KHz

UNITED STATES FREQUENCY ALLOCATIONS THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

	AERONAUTICAL MOBILE		INTER-SATELLITE		RADIO ASTRONOMY
	AERONAUTICAL MOBILE SATELLITE		LAND MOBILE		RADIO DETERMINATION SATELLITE
	AERONAUTICAL RADIONAVIGATION		LAND MOBILE SATELLITE		RADIOLOCATION
	AMATEUR		MARITIME MOBILE		RADIOLOCATION SATELLITE
	AMATEUR SATELLITE		MARITIME MOBILE SATELLITE		RADIONAVIGATION
	BROADCASTING		MARITIME RADIONAVIGATION		RADIONAVIGATION SATELLITE
	BROADCASTING SATELLITE		METEOROLOGICAL AID		SPACE OPERATION
	EARTH ORBITATION SATELLITE		METEOROLOGICAL SATELLITE		SPACE RESEARCH
	FIXED		MOBILE		STANDARD FREQUENCY AND TIME SIGNAL
	FIXED SATELLITE		MOBILE SATELLITE		STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

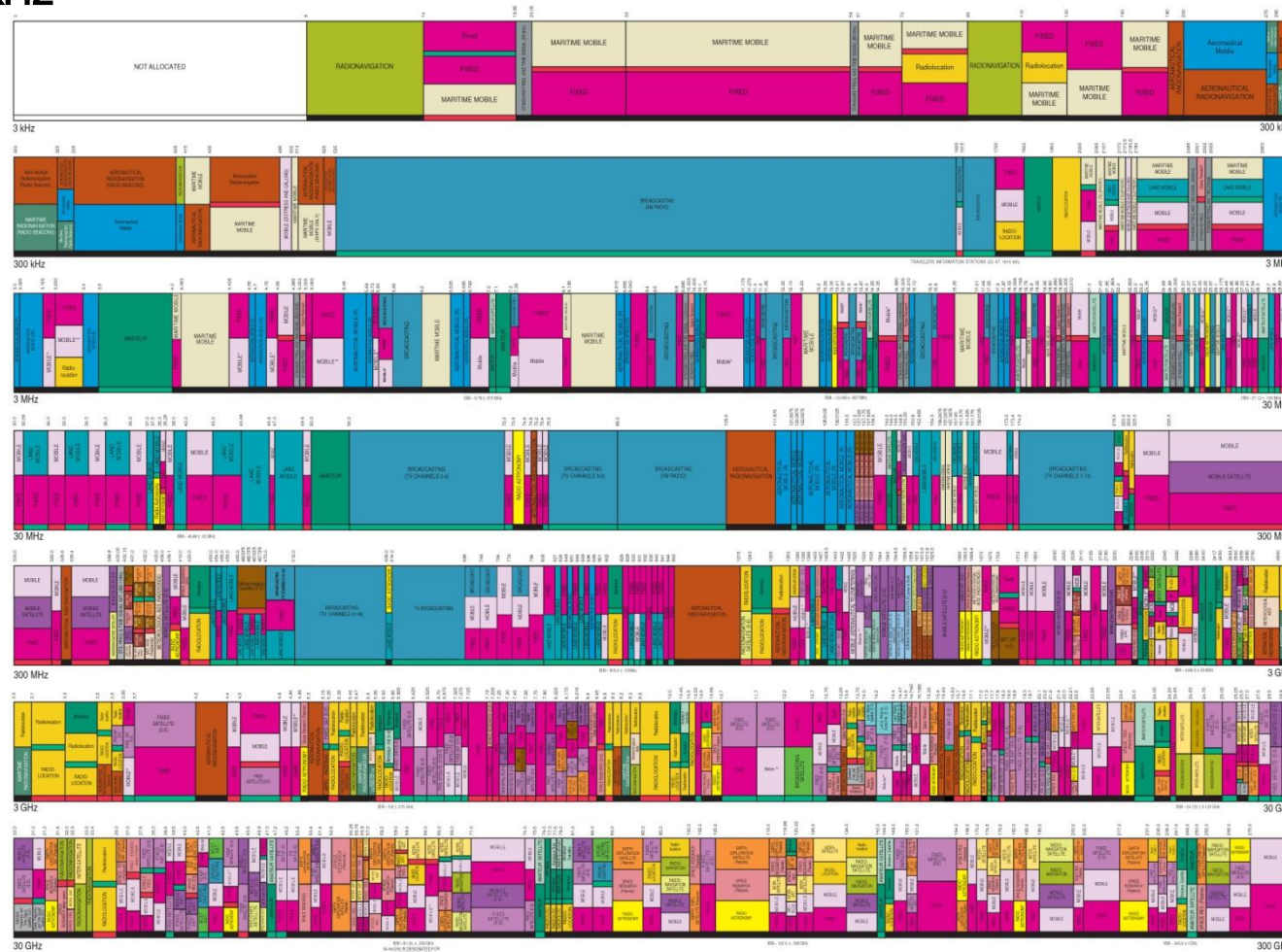
	GOVERNMENT EXCLUSIVE		GOVERNMENT-NON-GOVERNMENT SHARED
	NON-GOVERNMENT EXCLUSIVE		

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

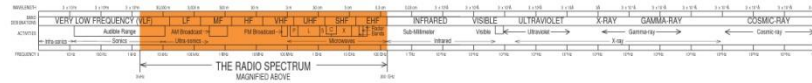
This chart is a graphic representation of the portion of the Table of Frequency Allocations used by the FCC and NTIA. It is not intended to be a substitute for the Table of Frequency Allocations. It is intended to provide a visual summary of the Table to assist in the interpretation of the Table.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
October 2003



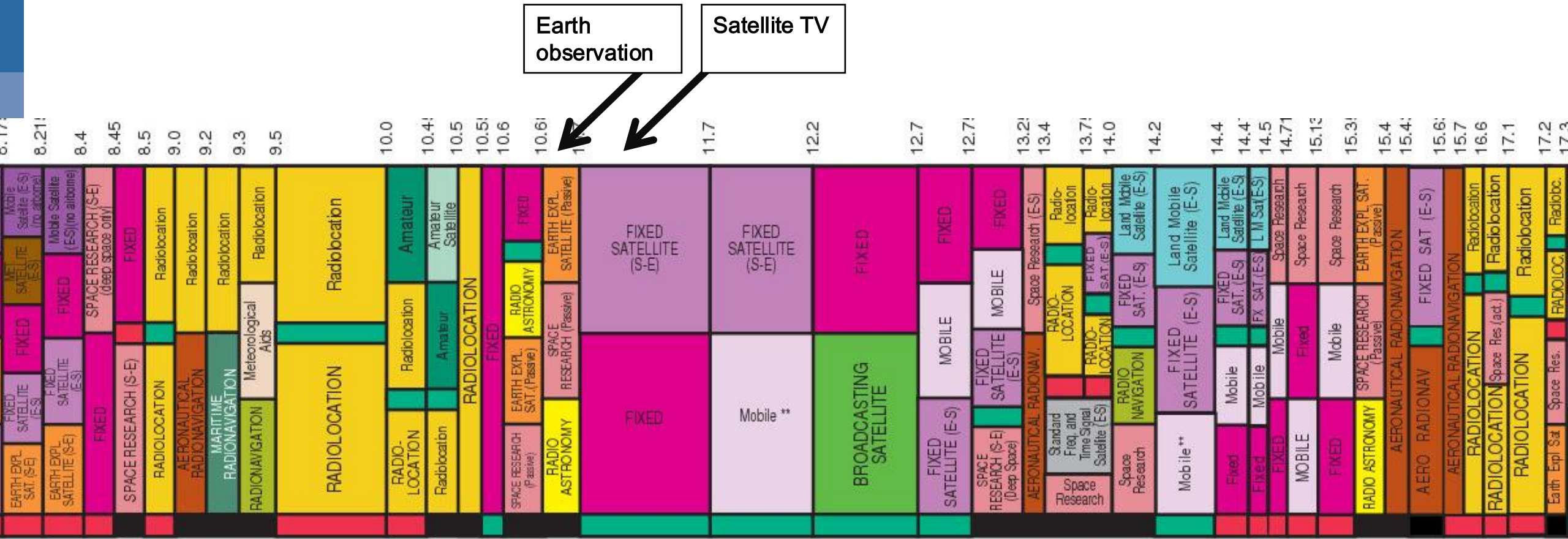
30 GHz

300 GHz



PLEASE NOTE: THE FREQUENCIES LISTED IN THIS CHART ARE SUBJECT TO CHANGE WITHOUT NOTICE. FOR THE MOST CURRENT INFORMATION, PLEASE CONTACT THE NATIONAL TELECOMMUNICATIONS AND INFORMATION ADMINISTRATION.

Other users of the spectrum



Information content

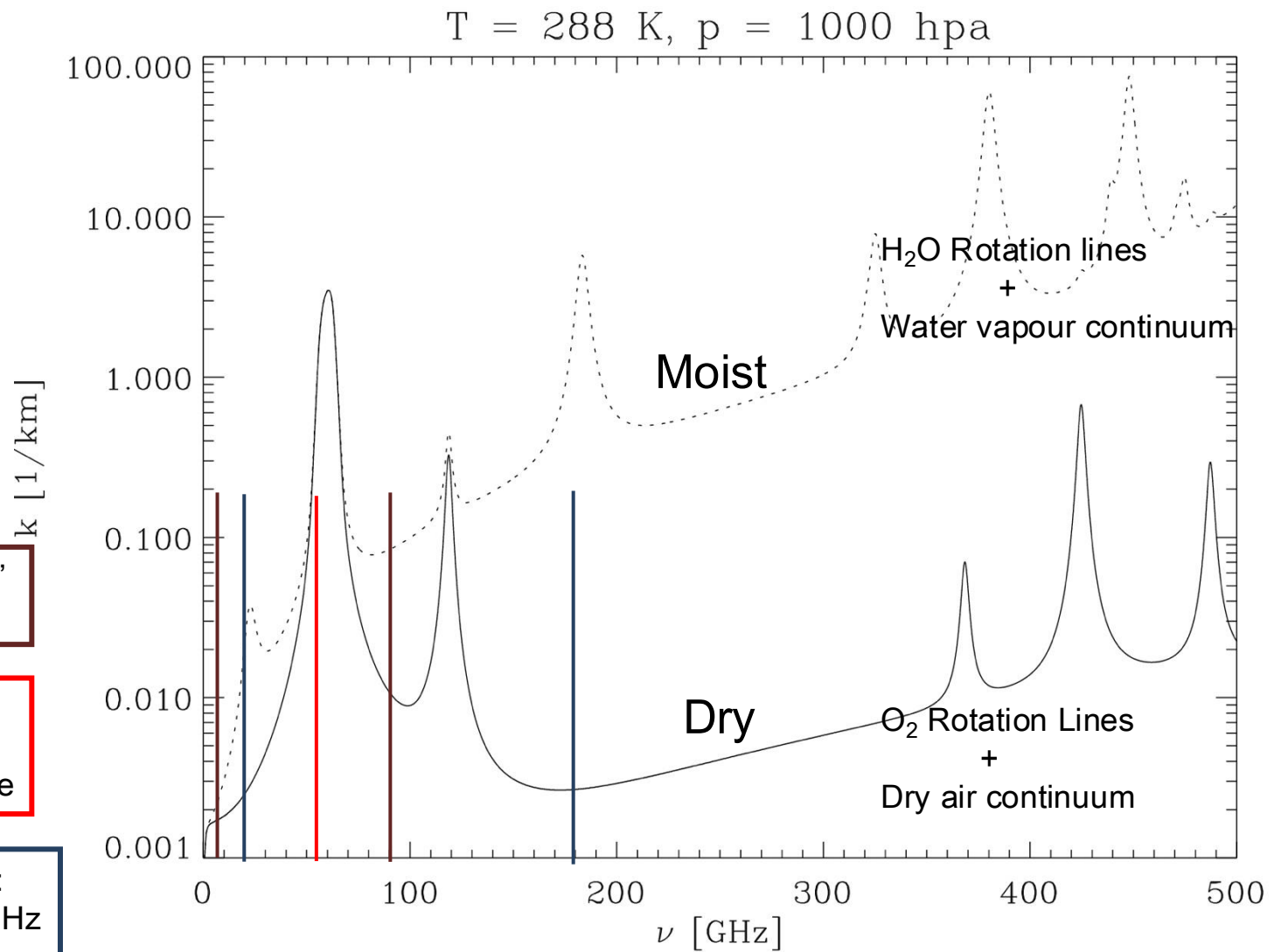
Gas absorption: the microwave spectrum

Absorption coefficient β_a [1/km]

“Imaging channels” in the windows

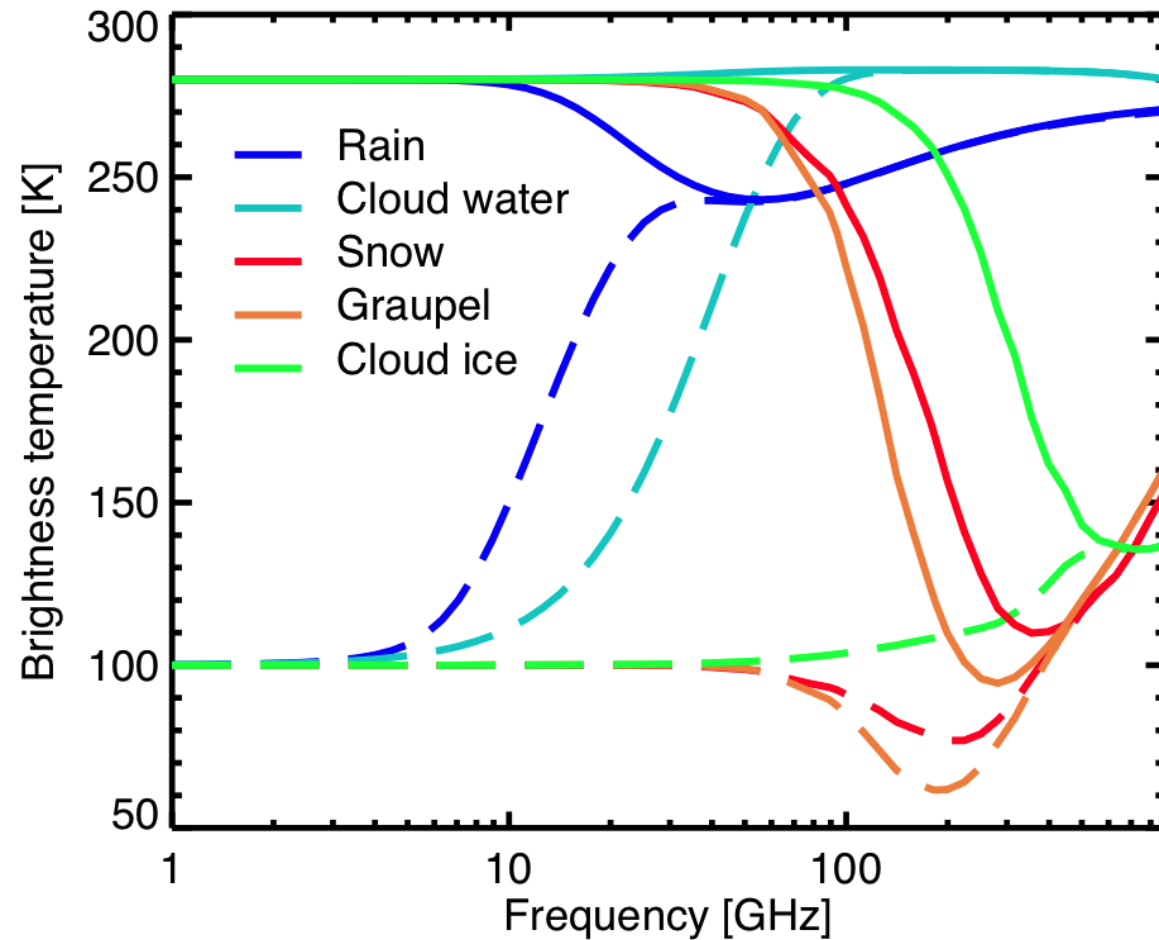
Temperature sounding: 60 GHz oxygen line

Moisture sounding: 22 GHz and 183 GHz water vapour lines



Cloud and precipitation optical properties: the microwave spectrum

More in the next microwave lecture

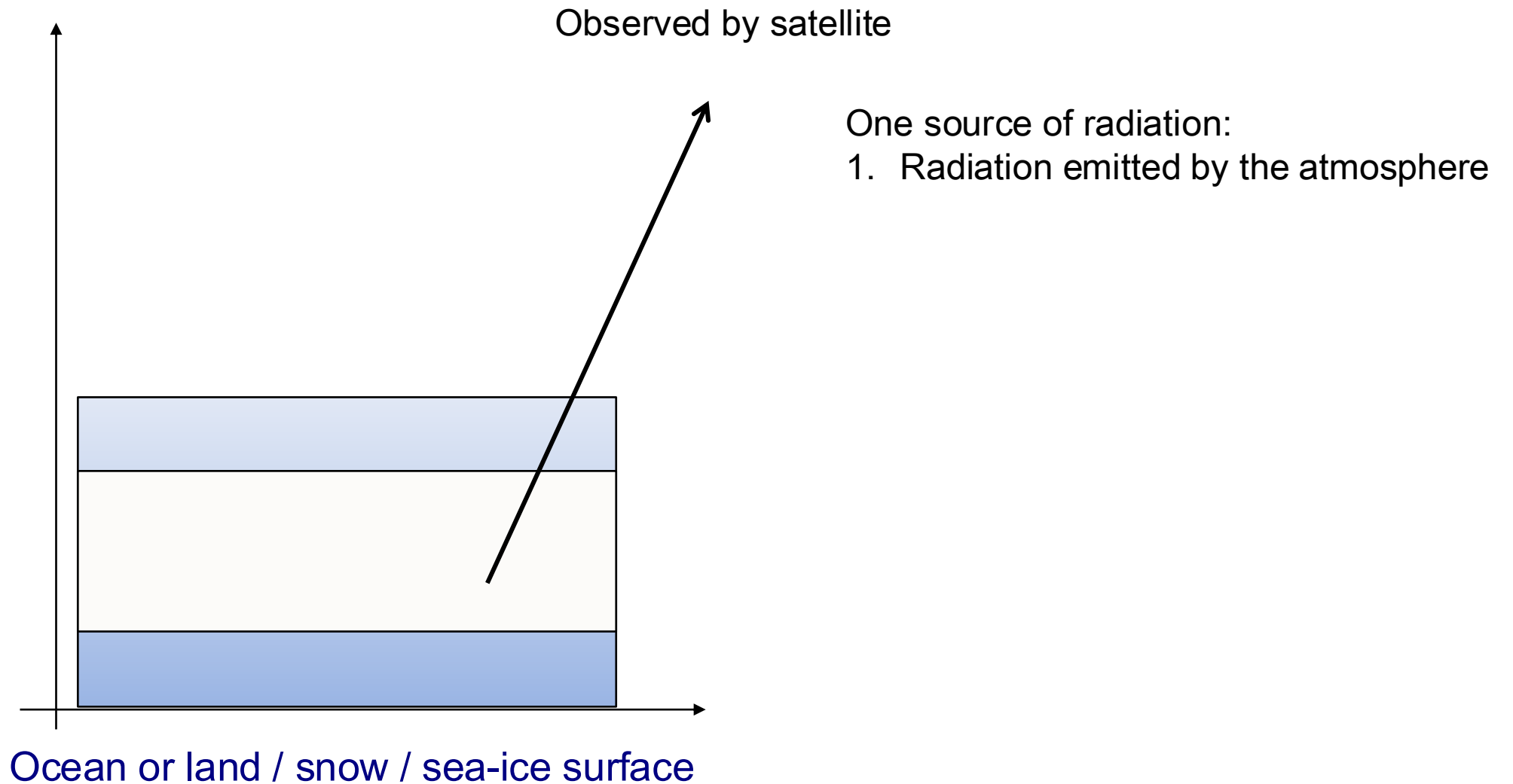


Slab cloud at 283K above a 280K surface (solid)

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

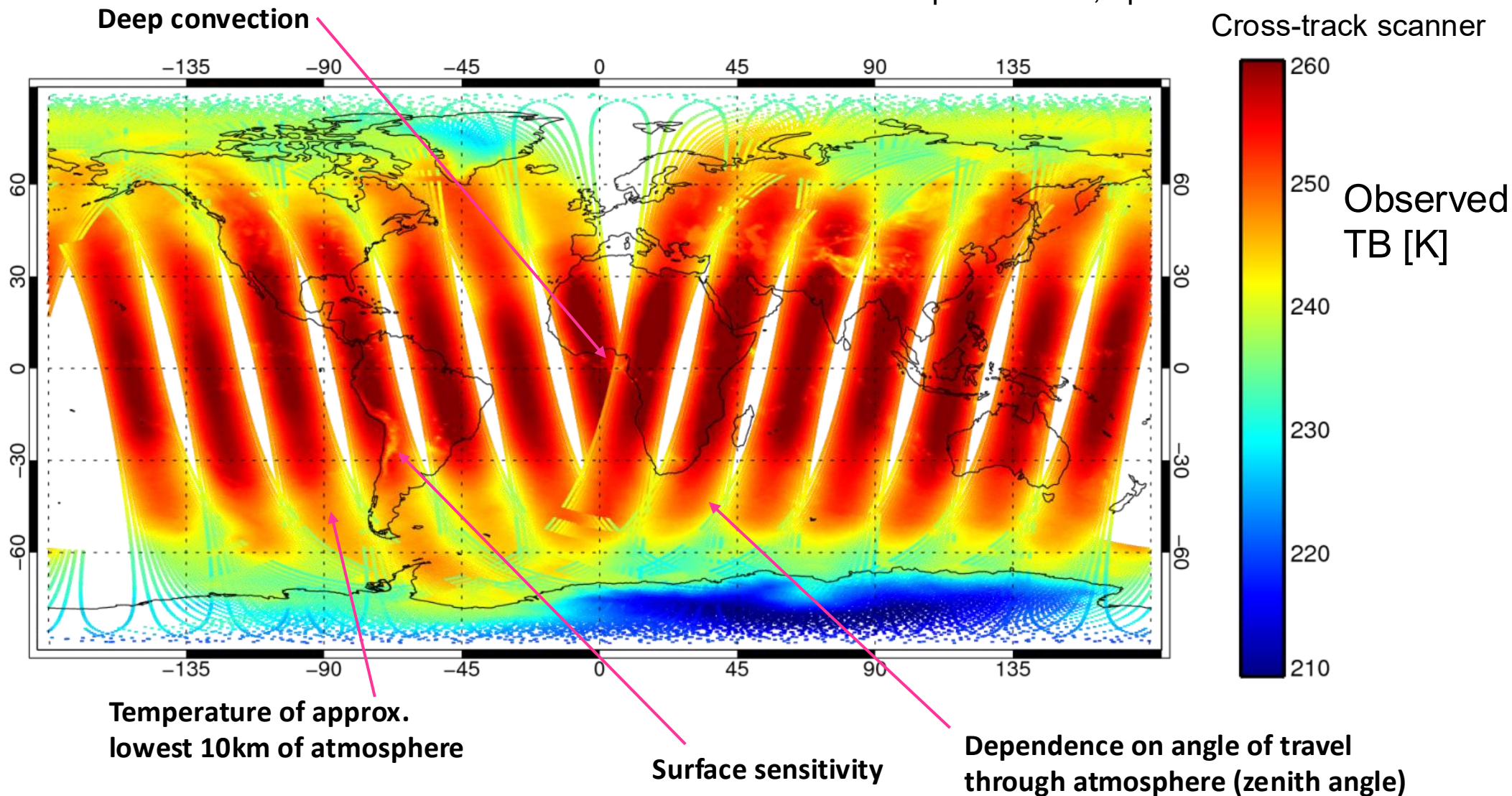
Geer et al. (2021, GMD, Bulk hydrometeor optical properties for microwave and sub-millimetre radiative transfer in RTTOV-SCATT v13.0)

Radiative transfer: sounding channels (ignoring scattering)

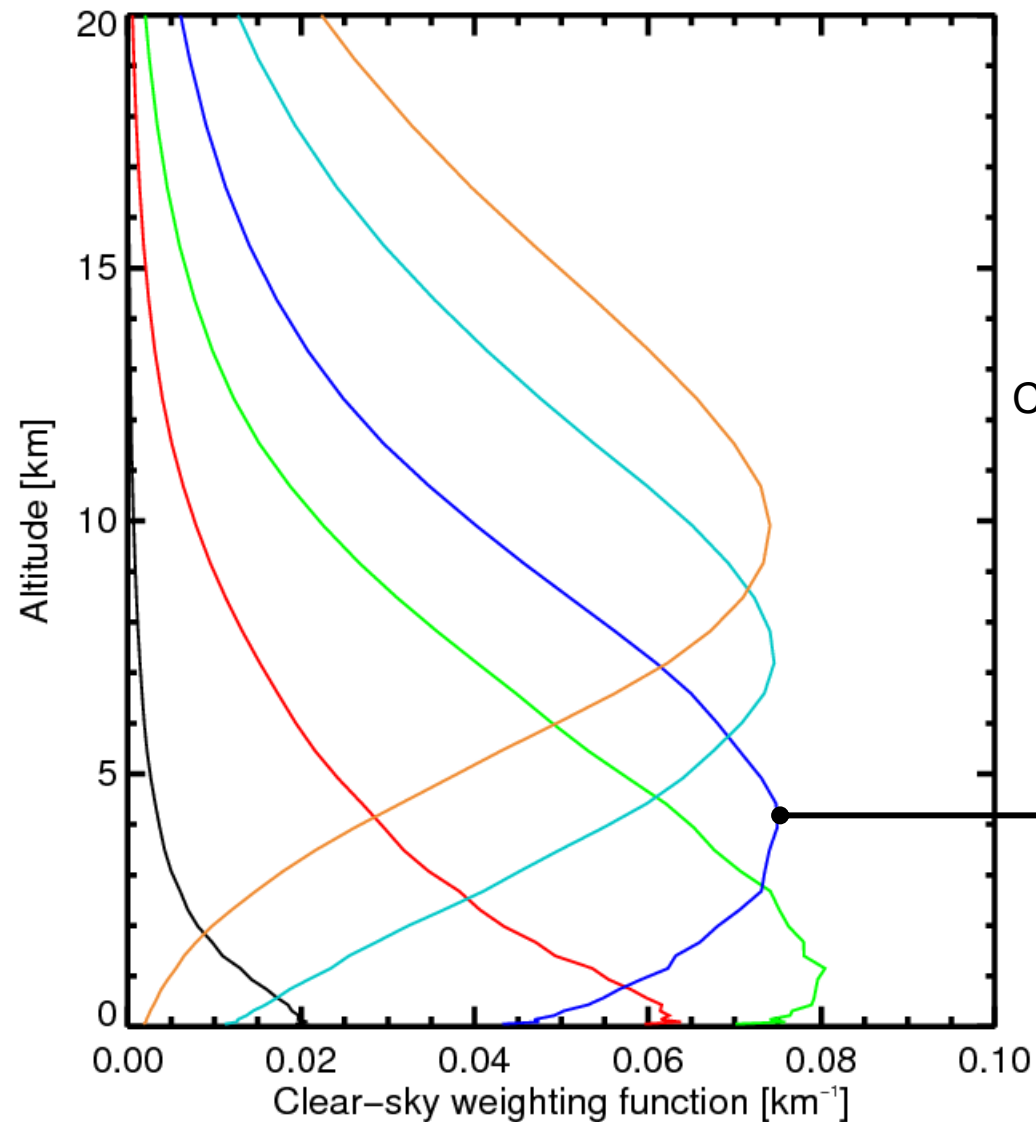


Sensitivities: temperature sounding channels

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)

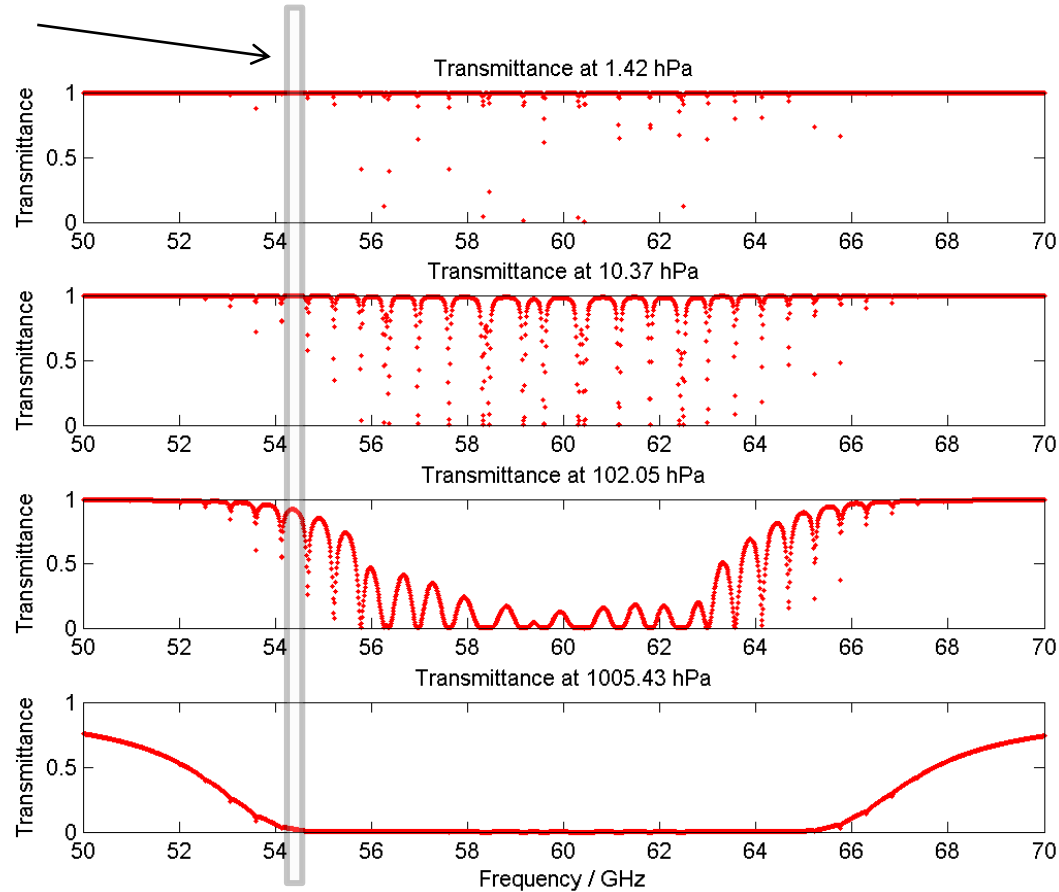


AMSU-A channels are at frequencies mainly sensitive to oxygen, a well-mixed gas: weighting functions are effectively fixed

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

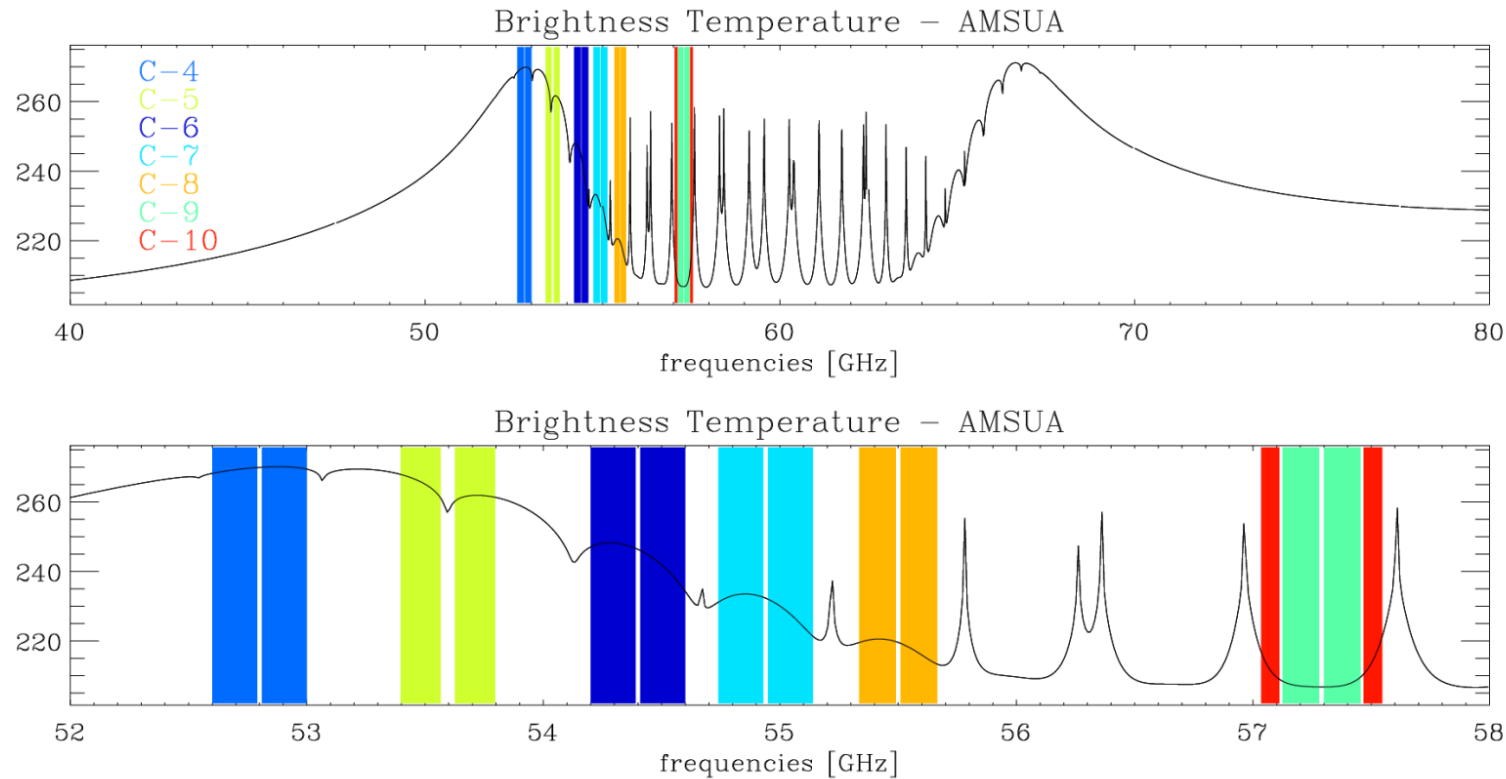


Level to TOA transmittance
from Liebe MPM 92 model

Narrow lines ~ several MHz

Increasing pressure
broadening

AMSU-A 50 – 60 GHz channels

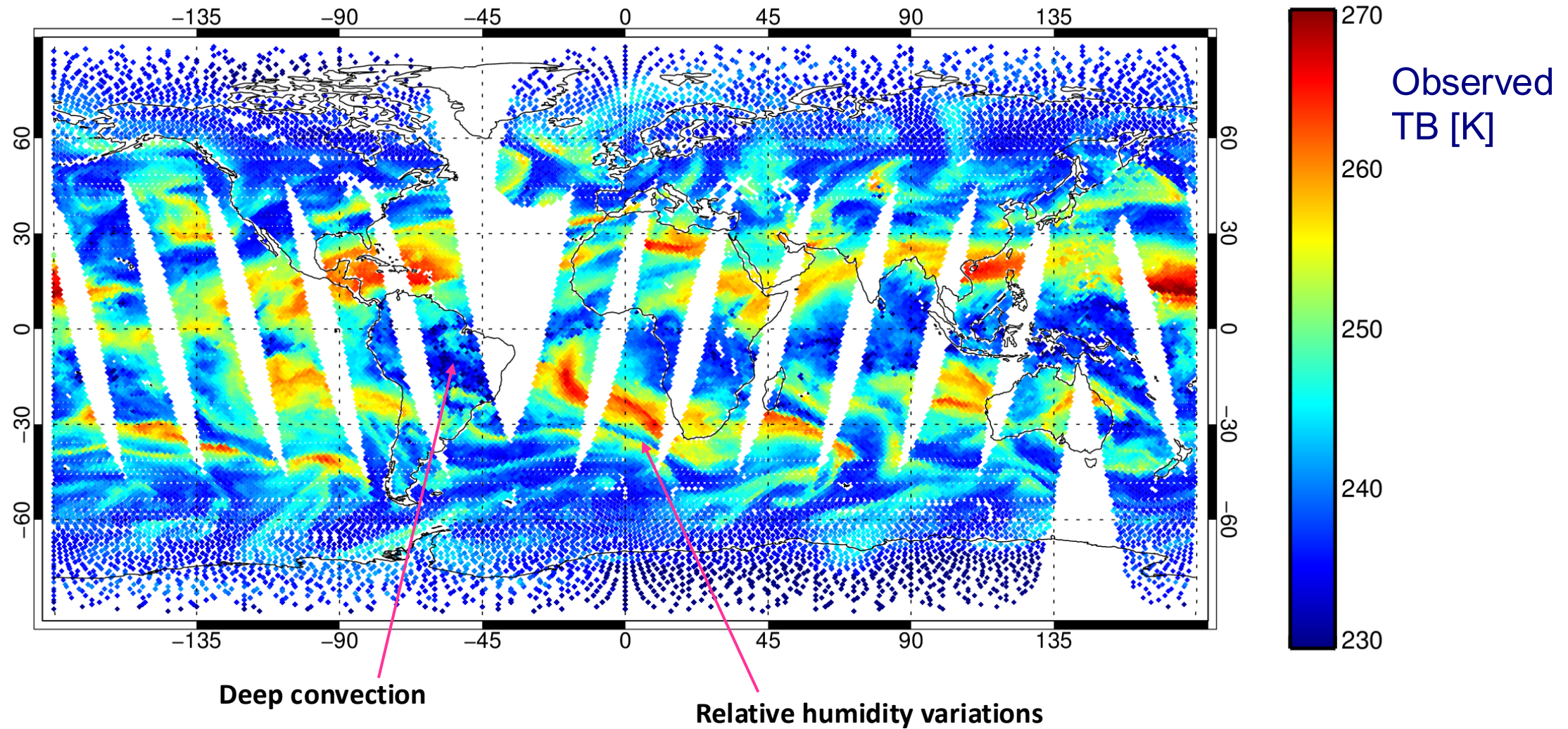


Channel positions and bandwidths are based on trade-offs aimed at simultaneously optimising :

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

Humidity sounding channels

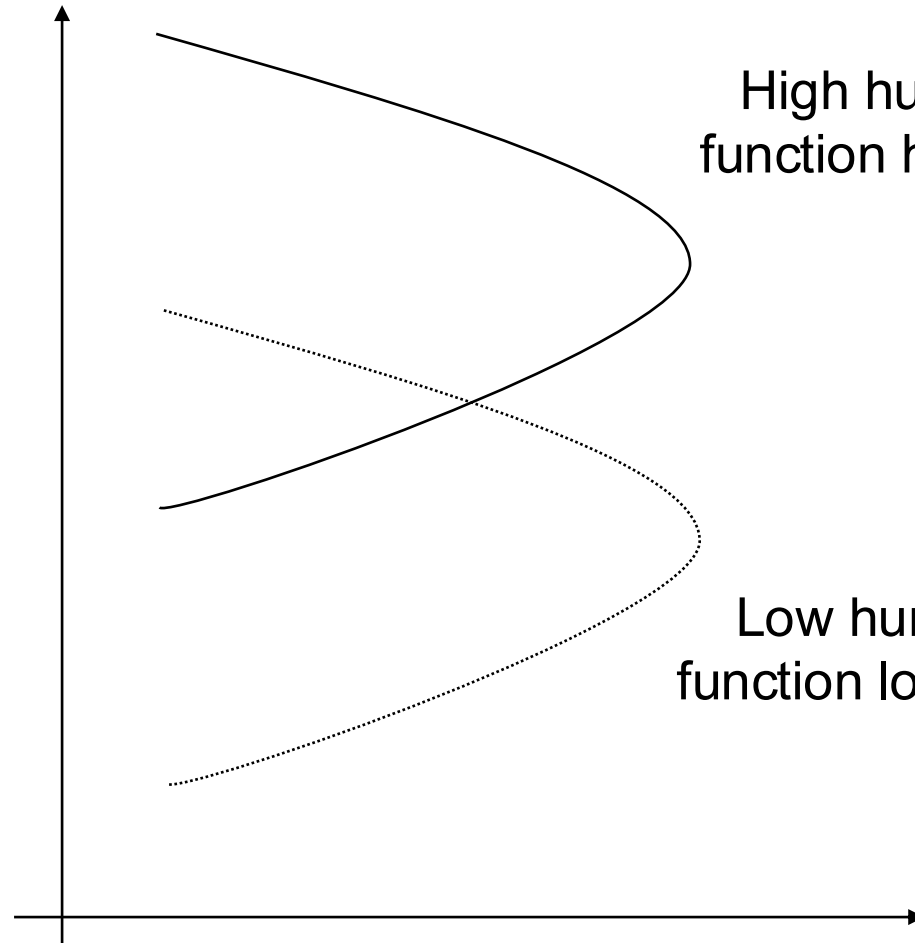
SSMIS F-17 channel 11 (183±1 GHz)
Conical scanning imager and sounder



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

Ocean waves, wind, skin temperature

Atmospheric water vapour

Cloud and precipitation

Special snow and ice conditions

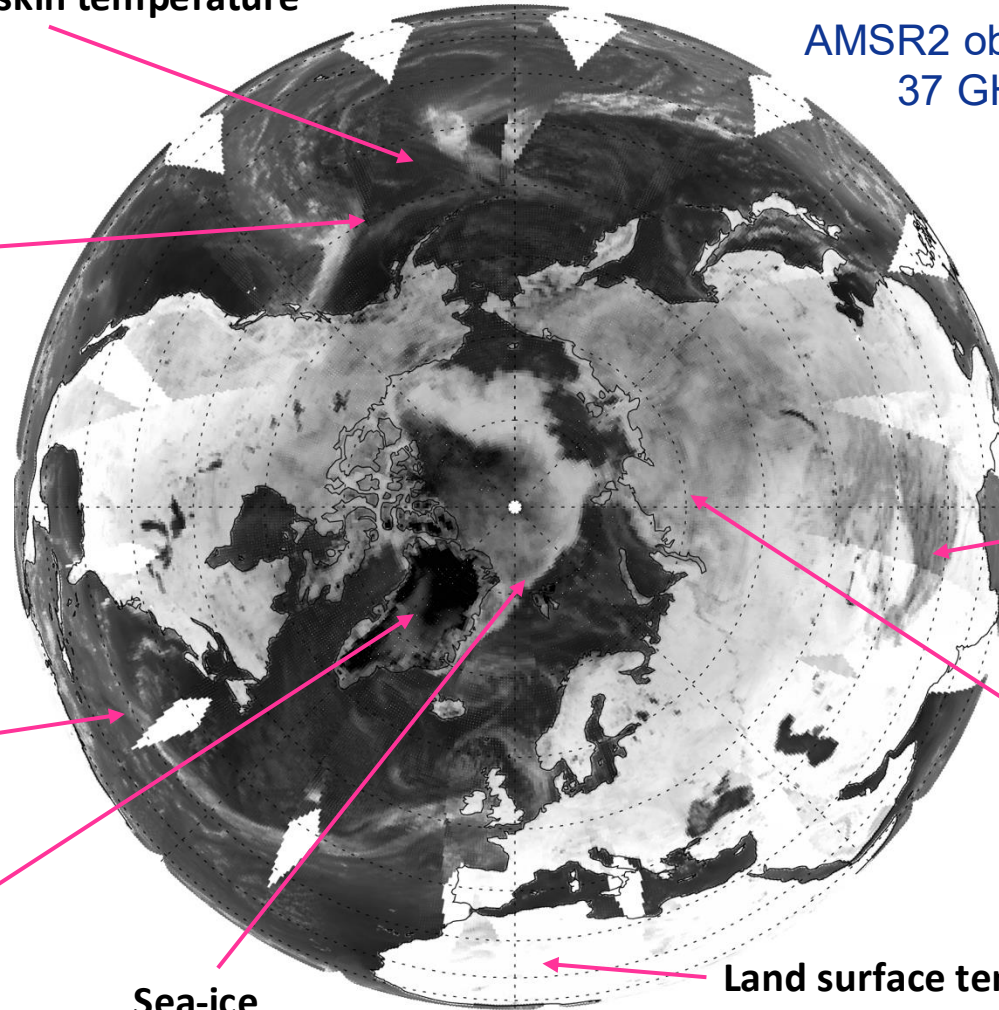
Sea-ice

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

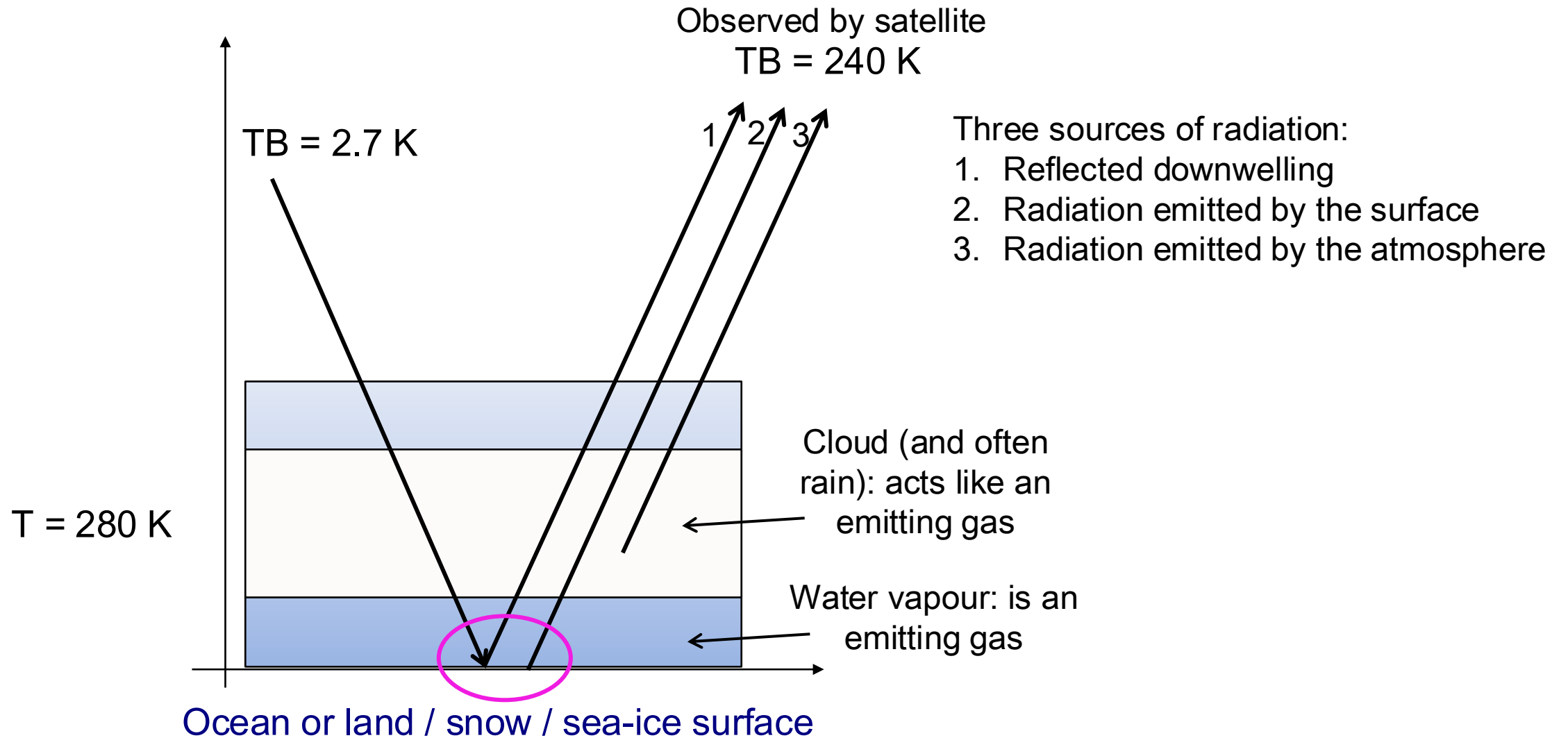
High altitude

Snow cover

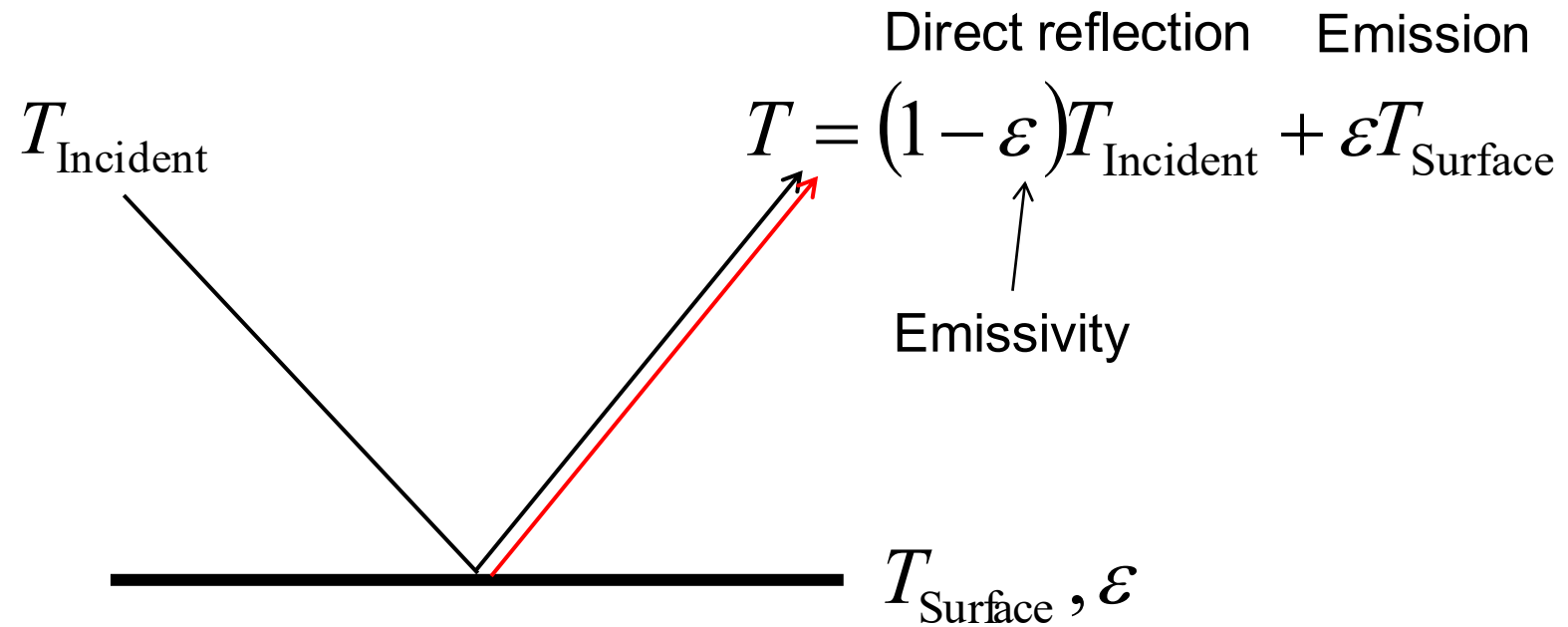
Land surface temperature, biomass, soil/rock, soil moisture



Radiative transfer: window channels (ignoring scattering)



Describing the surface interaction: specular emissivity

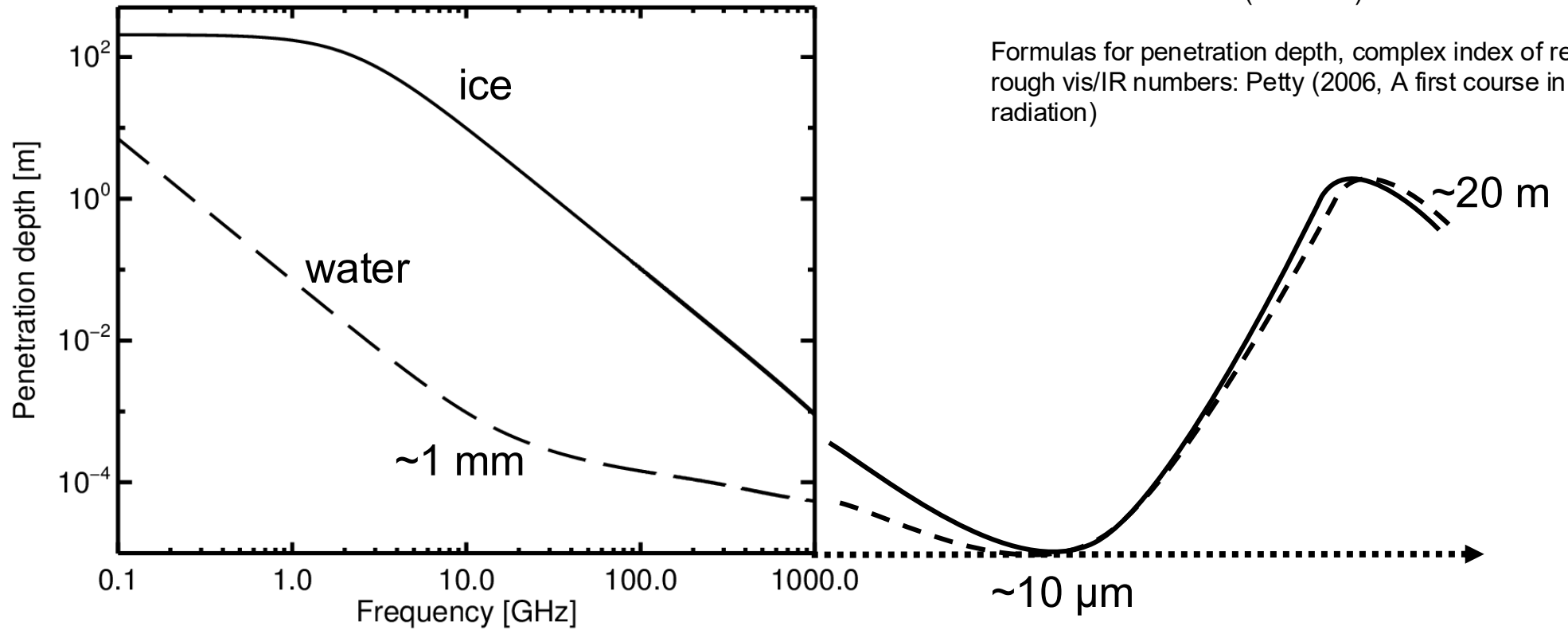


Water and ice: penetration depth

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

Humidity
sounders, e.g.
MHS

Sub-mm,
e.g. ICI

Hyperspectral
infrared., e.g.
IASI

Visible

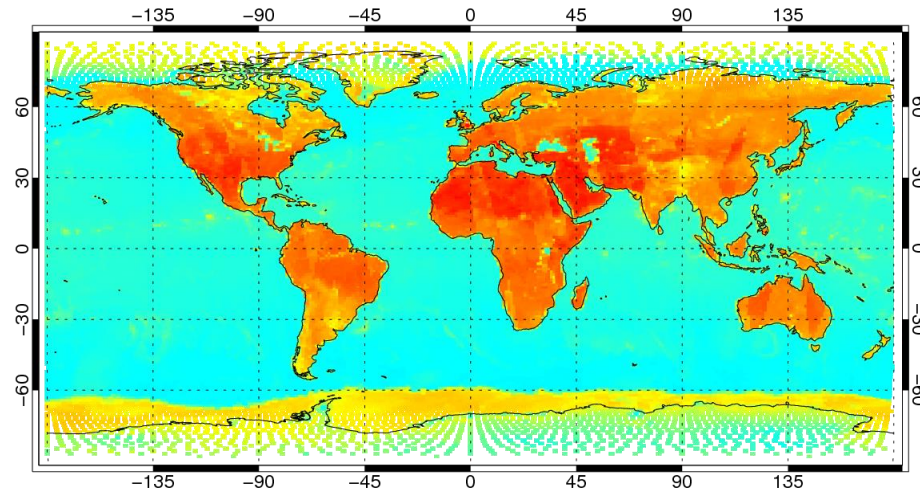
Surface reflection and emission: ocean



- 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

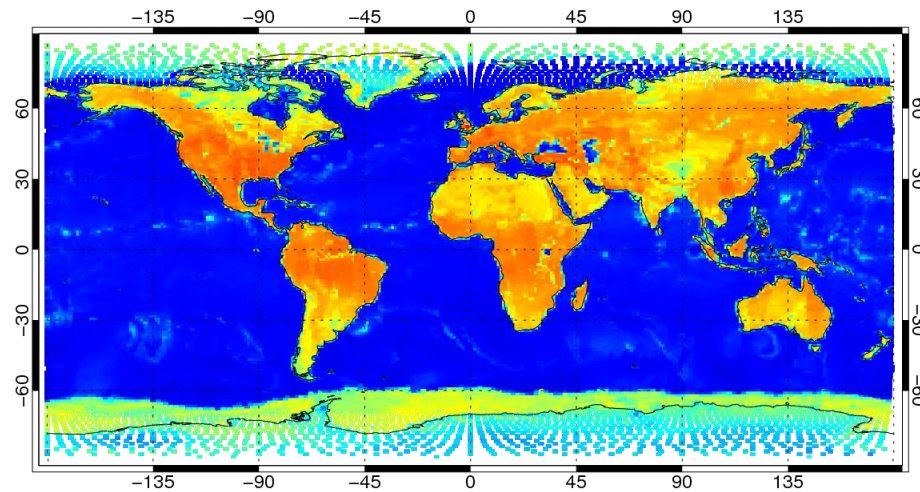
Approximately – a surface wind speed dependence

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

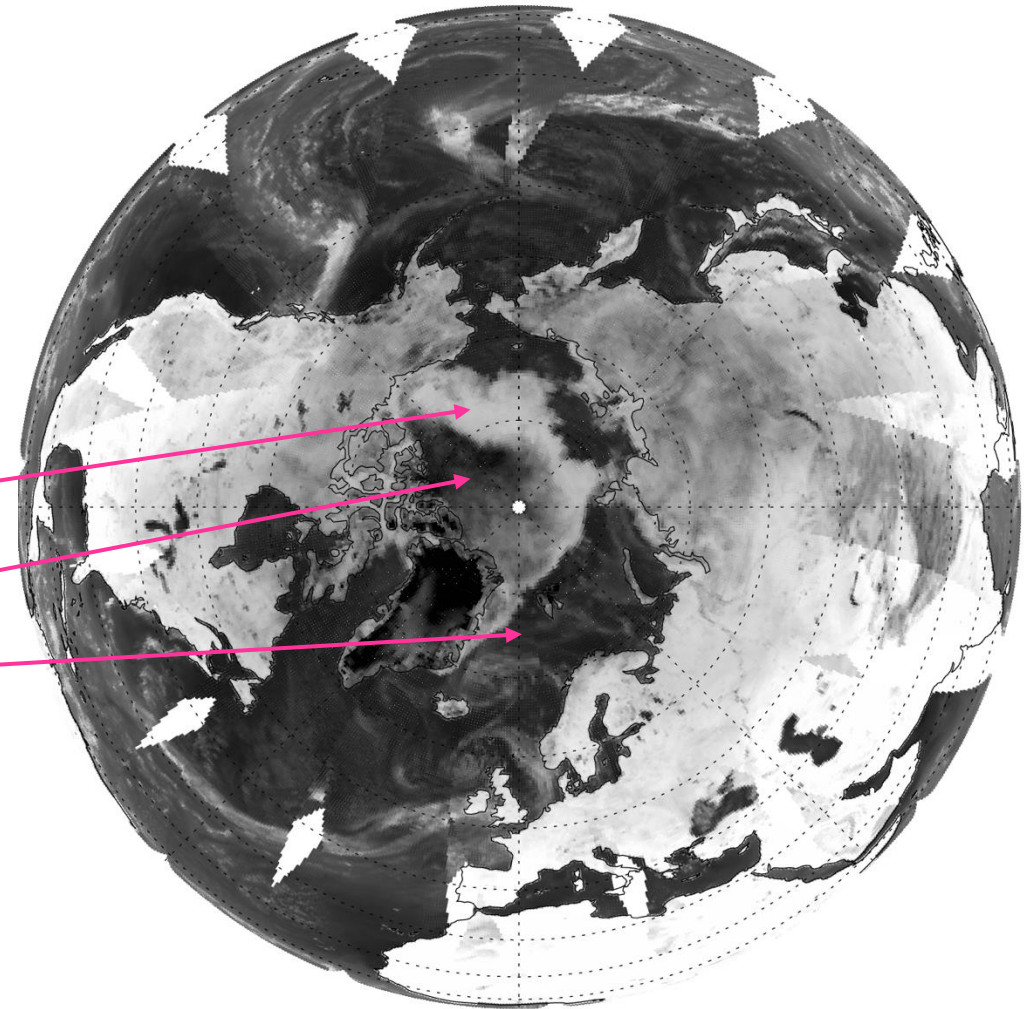
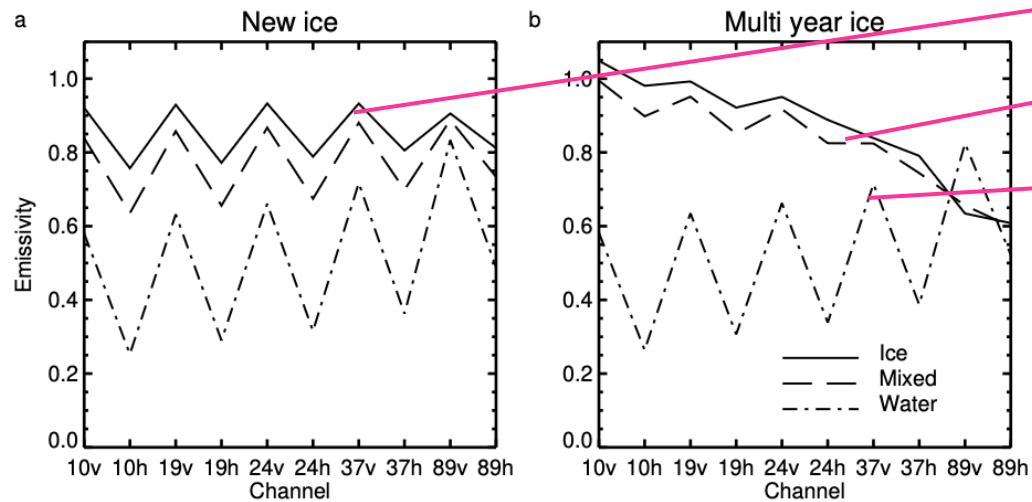


TB [K]
10 GHz h-pol

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

Sea ice surface emissivity

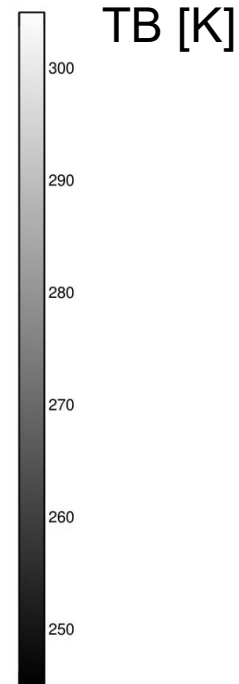
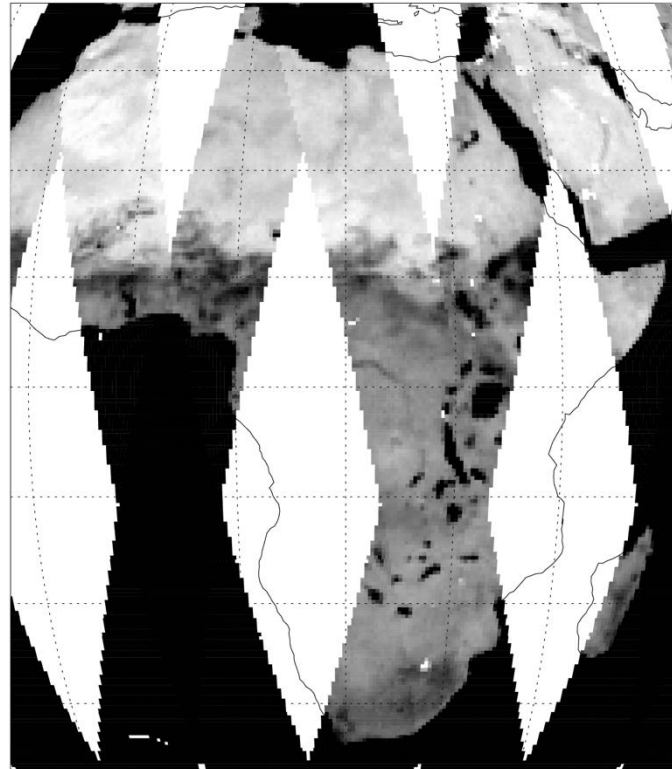
$$T = (1 - \varepsilon)T_{\text{Incident}} + \varepsilon T_{\text{Surface}}$$



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

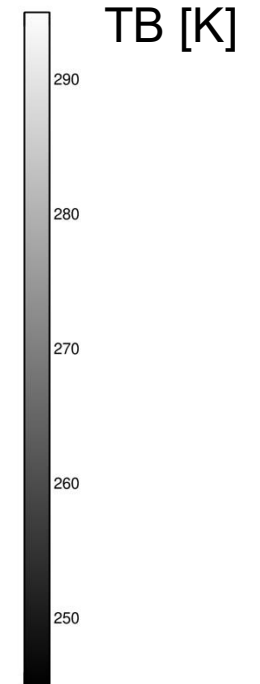
Soil, moisture and vegetation

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: $\text{W m}^{-2} \text{sr}^{-1} \text{Hz}^{-1}$
 - Watts (energy)
 - per metre squared
 - per unit of “direction” (solid angle)
 - per unit frequency
- Planck’s function (Rayleigh-Jeans approximation, valid in microwave)

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

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