RF Earth Remote Sensing

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National Academies Committee on Radio Frequencies

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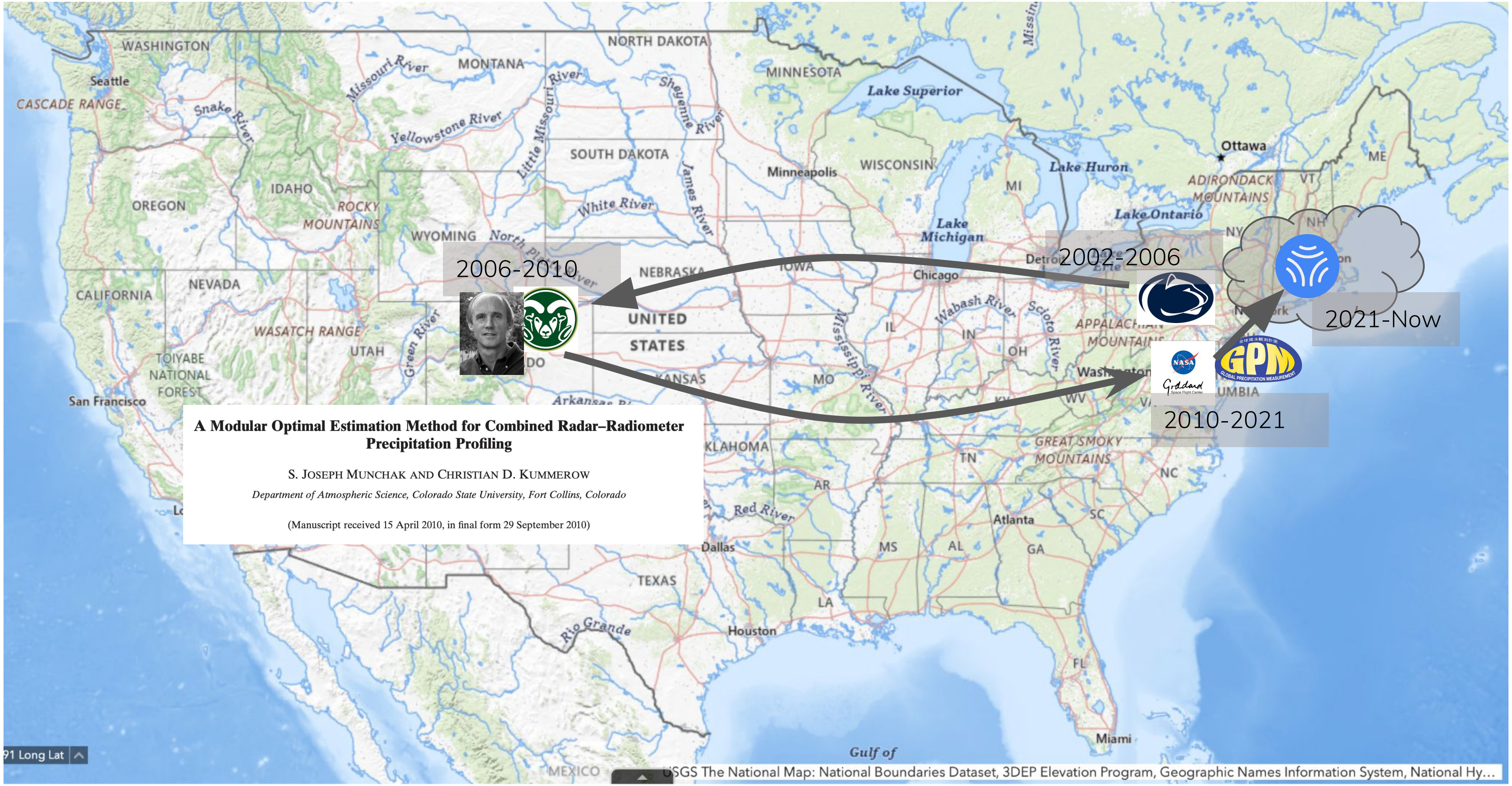
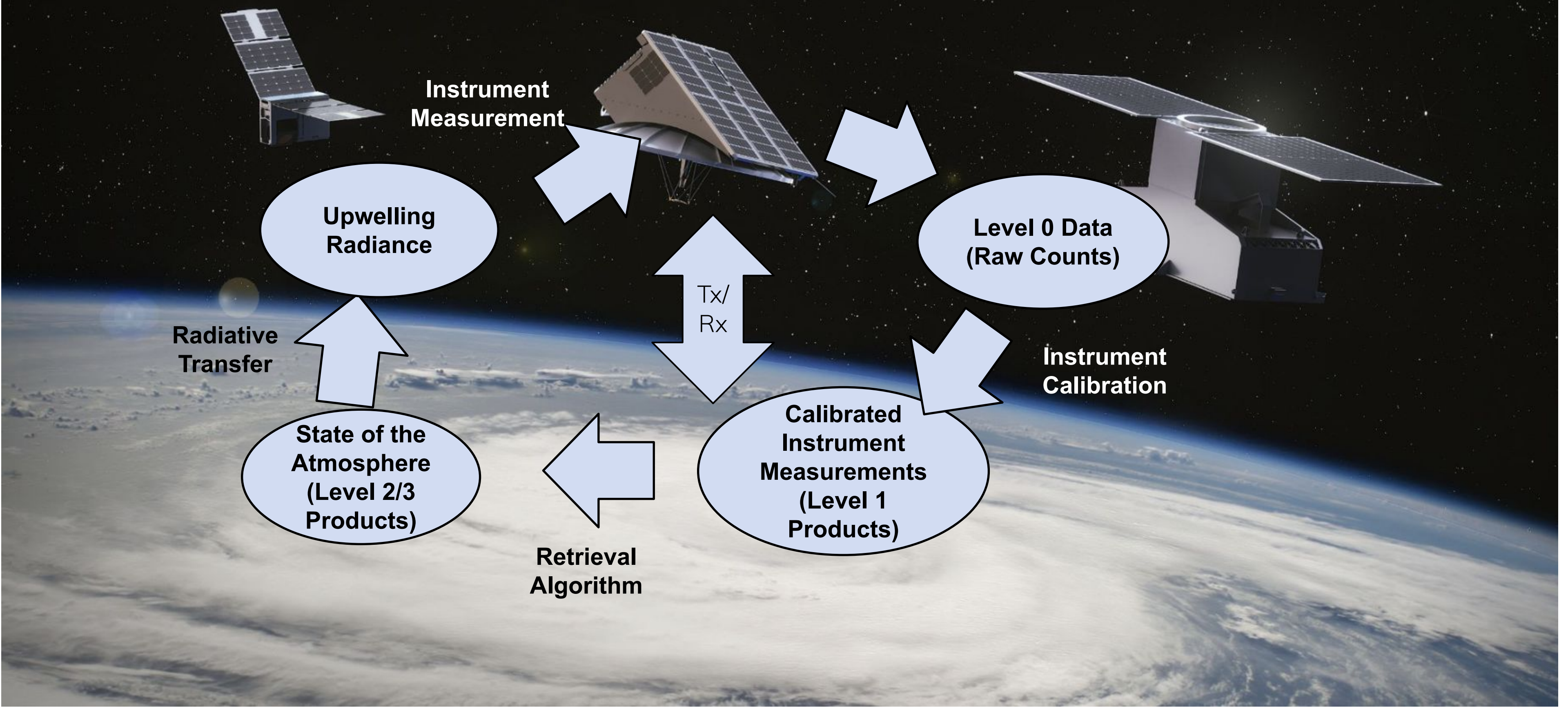
Outline

1. Who am I?
2. Overview of Radio Frequency (RF) Earth remote sensing
3. Impact of RF Interference for passive RF sensing

A brief biography…



Earth System Remote Sensing from Space



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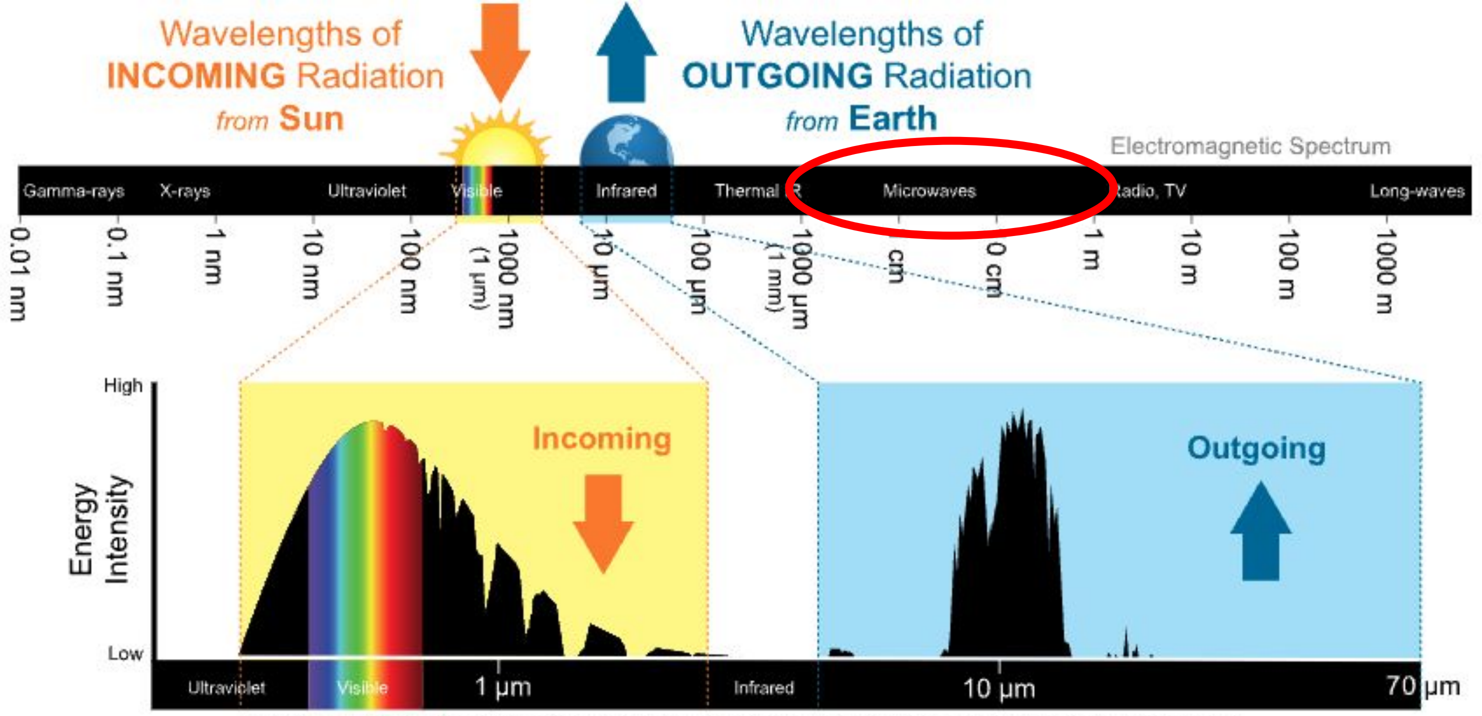
What is so special about the microwave spectral region?



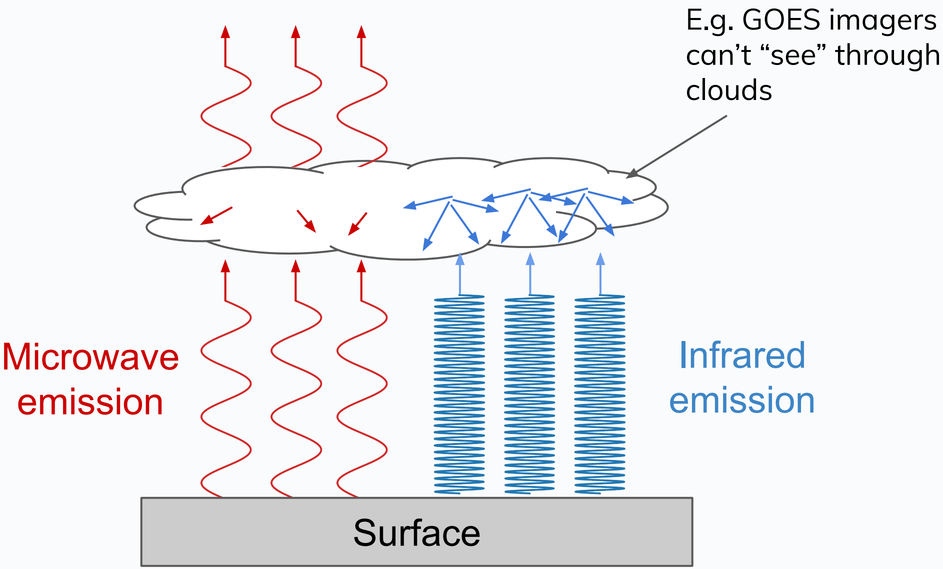
Incoming energy from the sun and outgoing energy from the earth relative to the electromagnetic spectrum.

weather.gov/jetstream/absorb

wikipedia.org

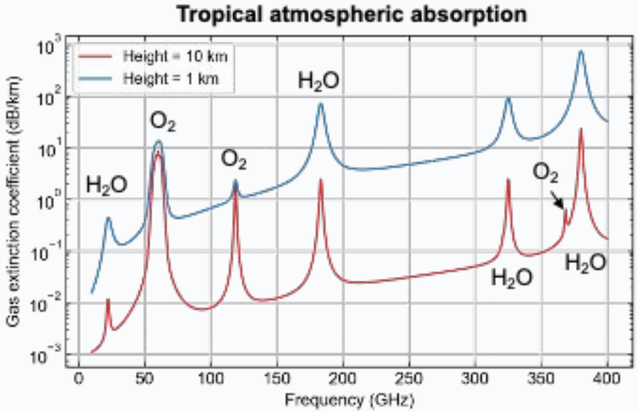
What is so special about the microwave spectral region?

Ability to penetrate clouds & precipitation

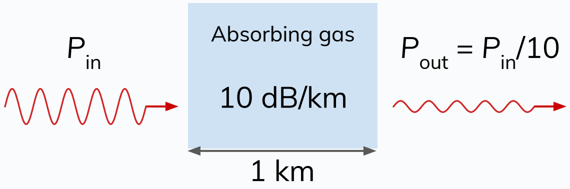


Microwave signals are measurably affected, but not necessarily extinguished, by atmospheric gases and particles/hydrometeors

Sensitivity to atmospheric gases (and therefore temperature & humidity)

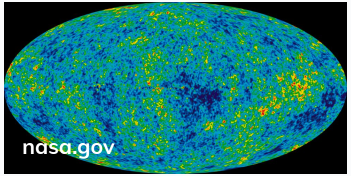


What does absorption mean anyway?



Terminology: Radiometry? Sounding?

E.g., Cosmic microwave background

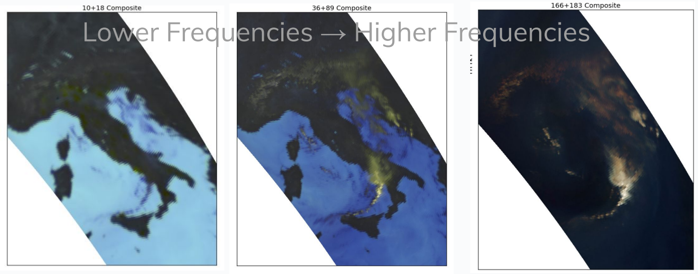


Radiometry = radio + meter (calibrated measurement of thermal radiation)

E.g., Infrared thermometer

- Microwave Imaging
- Microwave Sounding
- Infrared Sounding

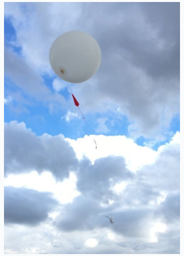
Imagers take "pictures" of the Earth in the microwave spectral region.



Sounding = Measurement of vertical profiles of geophysical parameters - usual **temperature** and **humidity/water vapor**

Radiosonde = radio sounding

RF transmitter to downlink measurements

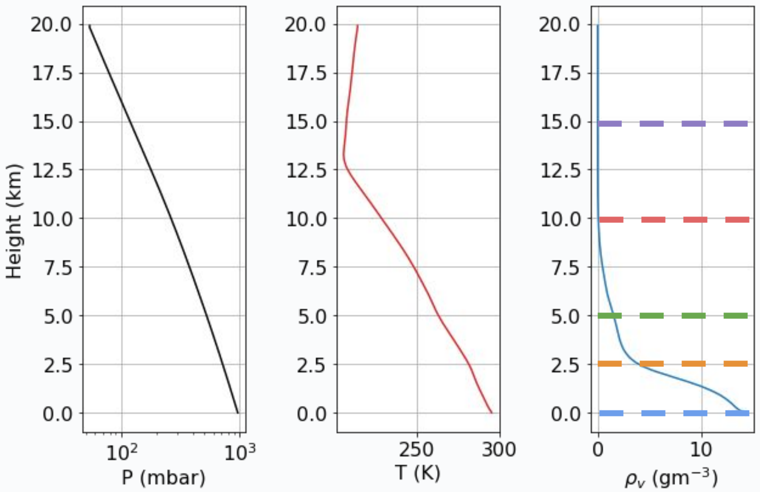


Q: Why "sounding"? There are no acoustics involved...

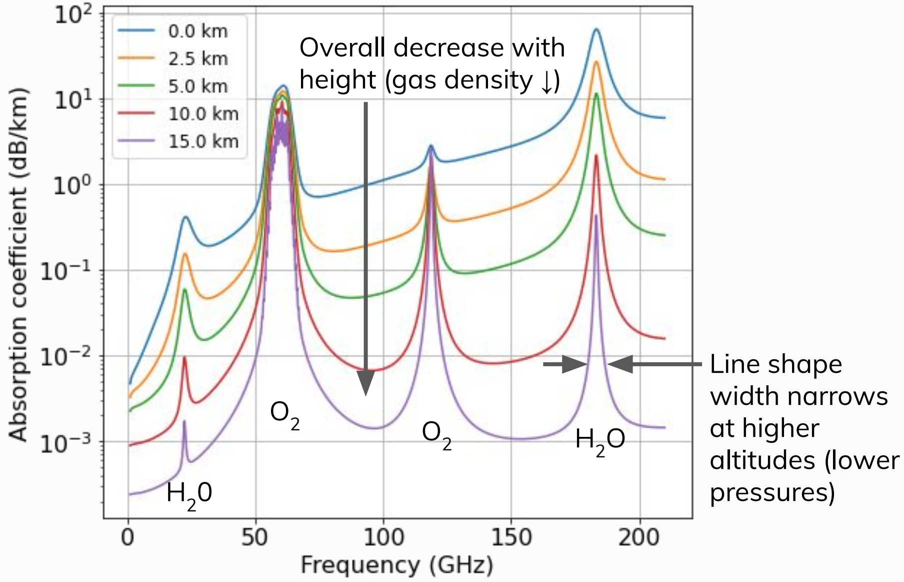
A: It is borrowed from the nautical terms "depth sounding" and "echo sounding" (a sonar technique) tomorrow.io

The basics of microwave sounding

“Thermodynamic profiles” = profiles of pressure, temperature, and water vapor vs. height

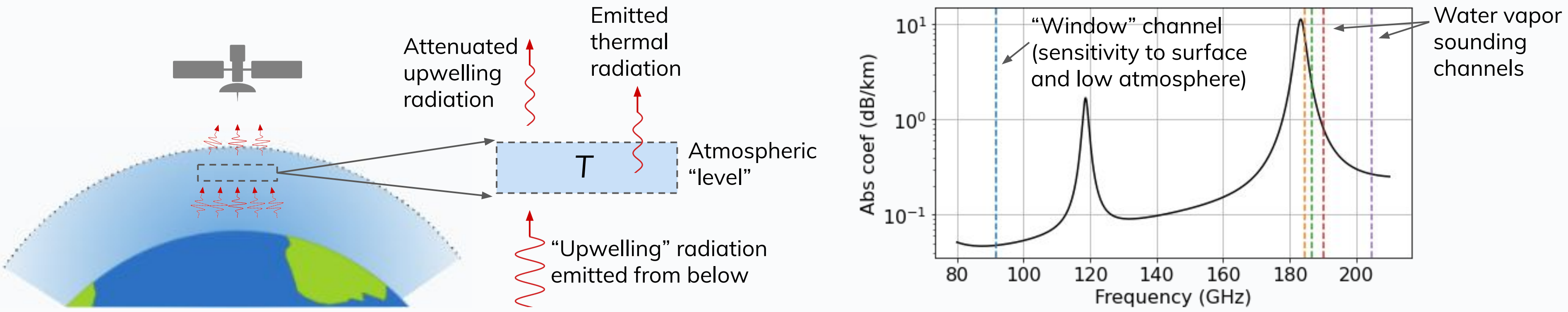


Resulting absorption spectrum

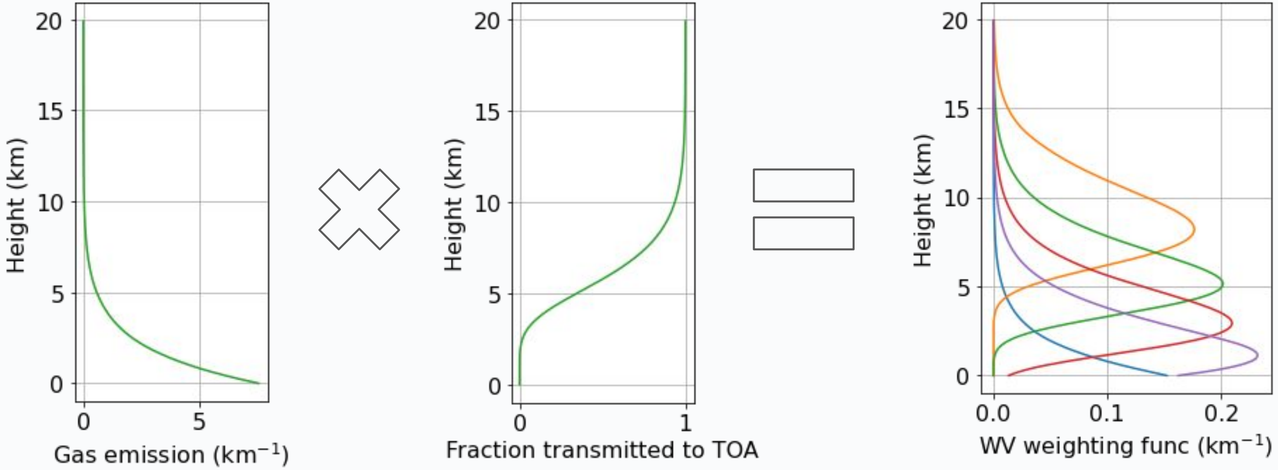


⇒ Depending on which microwave frequency is being observed, the radiometric measurement contains information about H_2O and O_2 at different levels throughout the atmosphere.

The basics of microwave sounding: Vertical level sensitivity



"Weighting functions" quantify the sensitivity of a particular frequency to water vapor at different atmospheric levels.

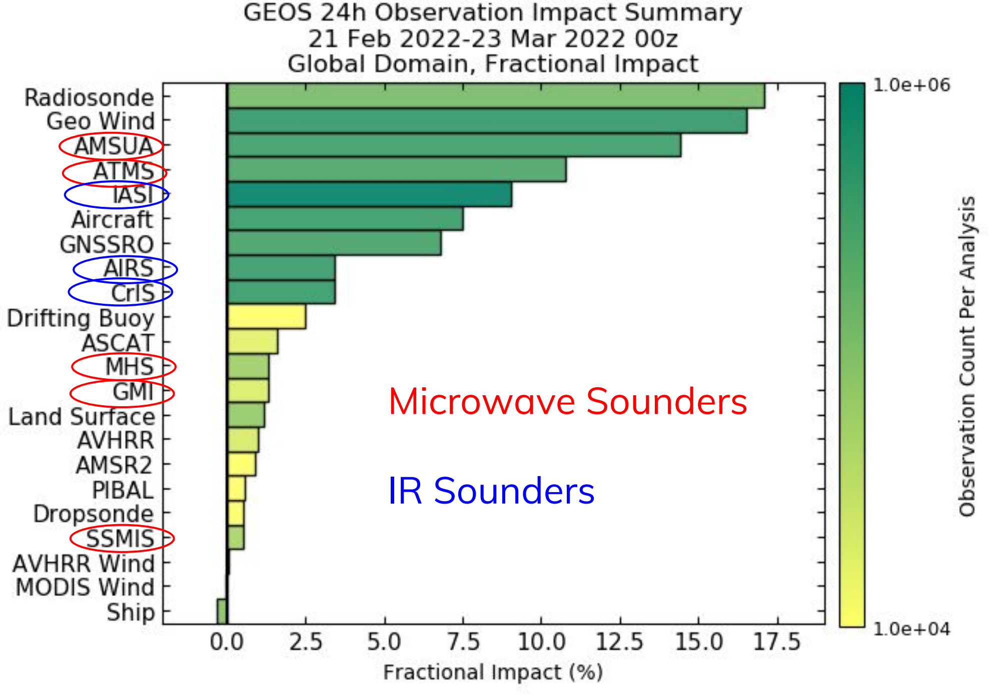


Importance of microwave sounding to NWP models

Impact depends on:

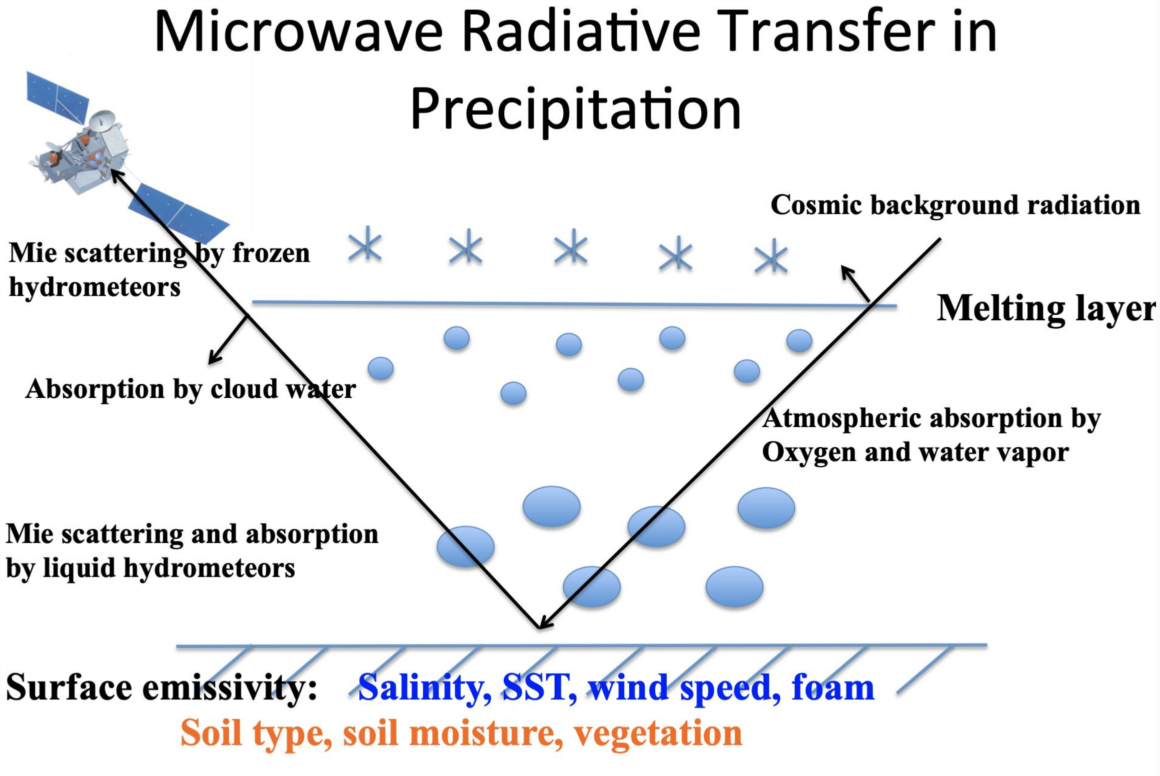
1. Measurement relevance to atmospheric state
2. Number of independent observations

"Significant further benefit is observed from additional sounders, with the impacts largest at higher latitudes and no saturation evident in the maximal setup" - Duncan et al., 2021 (ECMWF study on impact of additional microwave sounders)



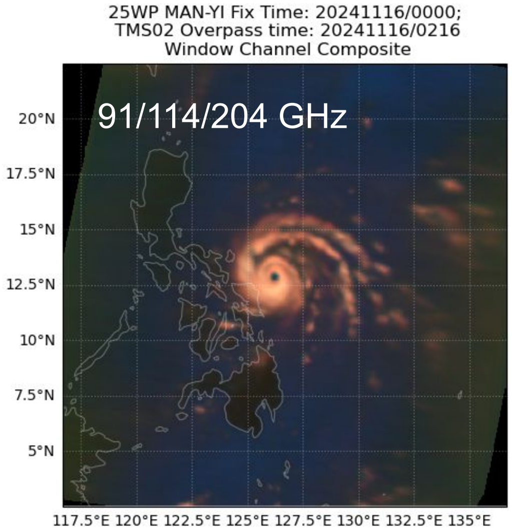
Source: https://gmao.gsfc.nasa.gov/forecasts/systems/fp/obs_impact/

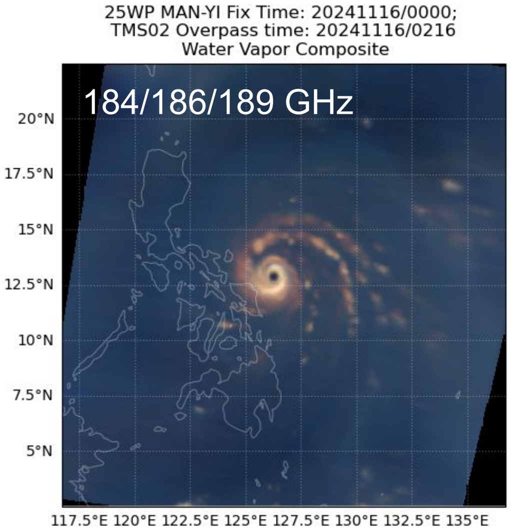
Microwave sounders as precipitation sensors



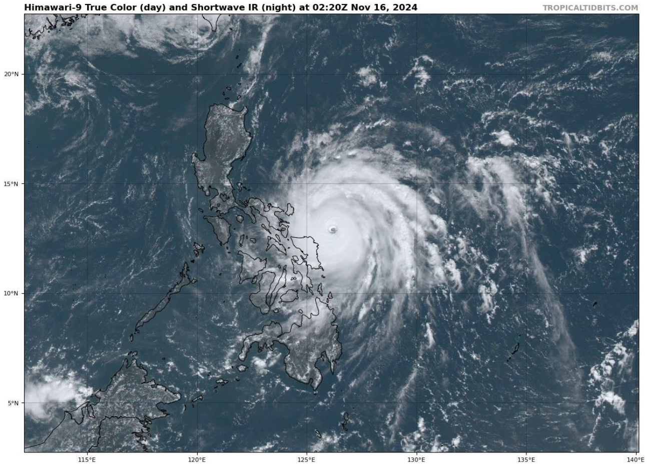
Originally presented at the 8th International Precipitation Working Group Meeting: https://www.eorc.jaxa.jp/IPWG/meetings/bologna-2016/Bologna2016_Training/2_Munchak.pdf

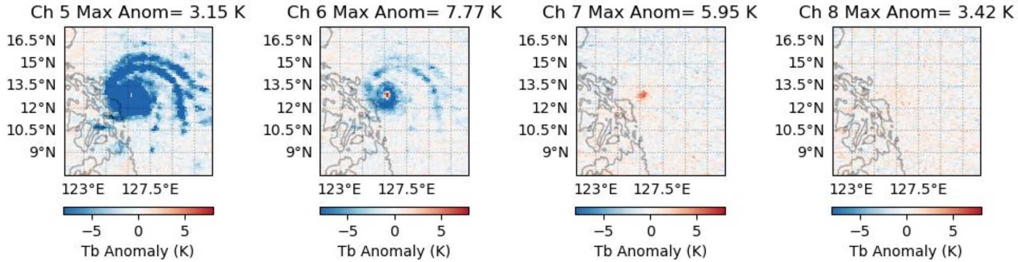
Super Typhoon Man-Yi from Tomorrow-S2





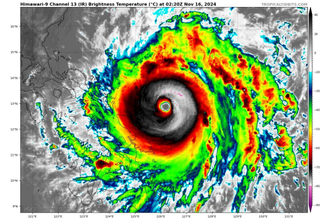
Multi-channel (true color) visible from Himawari-9





116-118 GHz

False-color 10.4 µm IR from Himawari-9



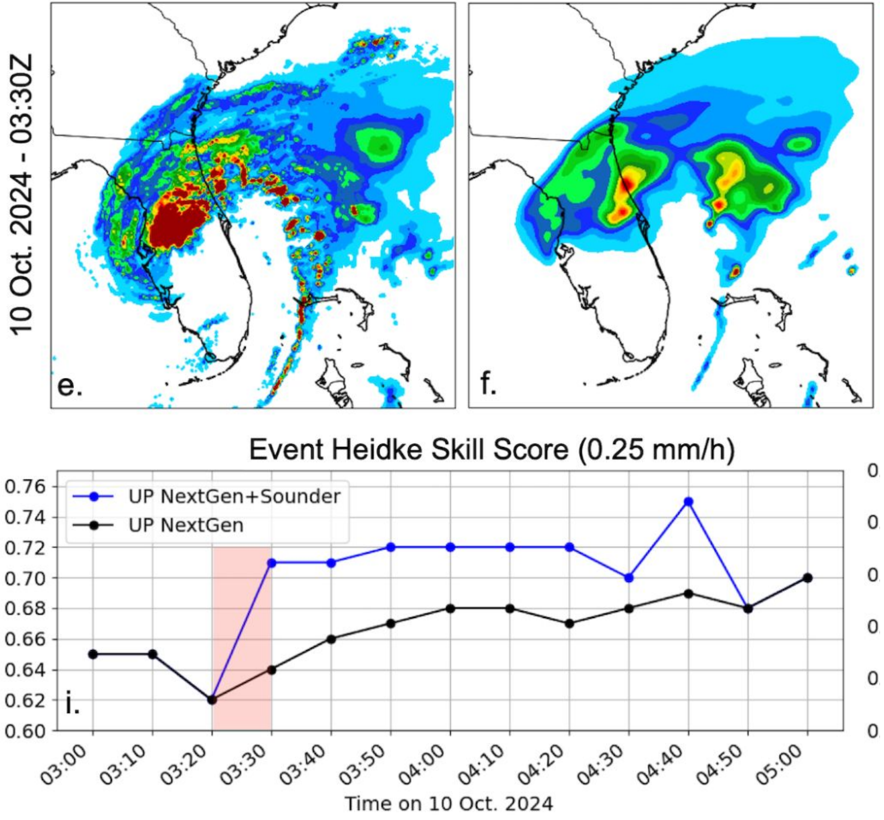
Impact of Microwave Sounders on Precipitation Nowcasts

Nowcast = short-term (up to 6 hr) forecast that is initialized directly from observations.

Different than NWP (estimate state of atmosphere, then model produces precipitation based on simulation of cloud physics)

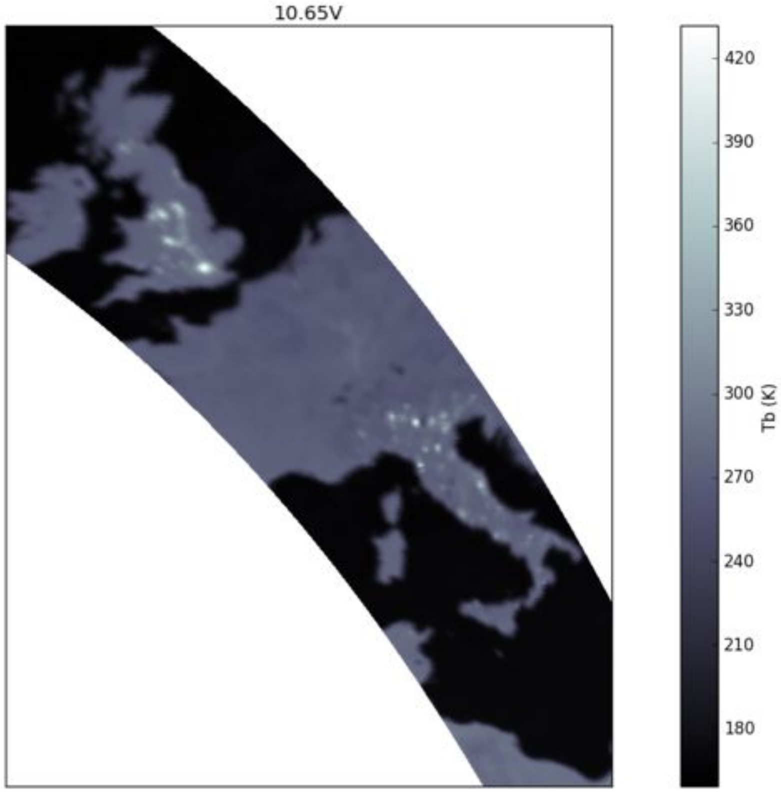
Traditional nowcast methods propagated precipitation (usually radar-derived) in direction of motion. Newer methods use machine learning to predict future motion based on large databases of past observations.

Tomorrow.io's ML-based nowcast demonstrates increased skill when satellite observation is made, and skill improvement is maintained for more than 1 hour after observation time.



Radio Frequency Interference (RFI) (artificial sources of microwave radiation)

Ground source RFI at 10.65 GHz



– Usually increase Tb
– Can decrease Tb if cold cal target is affected

• Not always obvious!

• Mitigation strategies:

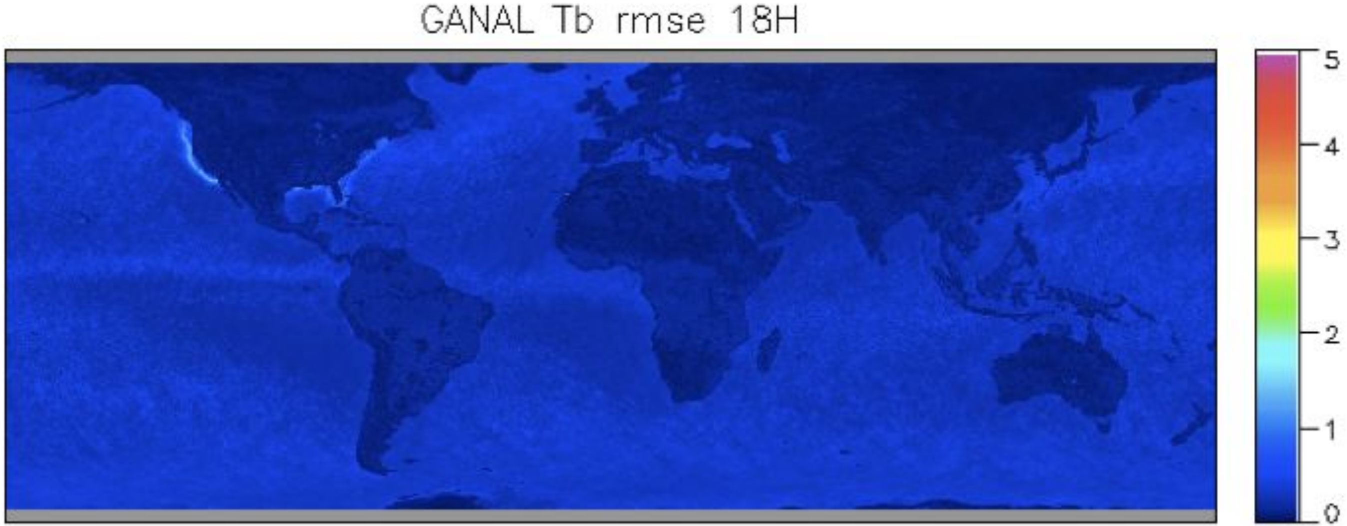
– Frequency sub-sampling

– Time series Kurtosis

8th IPWG / 5th IWSSM Joint Workshop

Originally presented at the 8th International Precipitation Working Group Meeting: https://www.eorc.jaxa.jp/IPWG/meetings/bologna-2016/Bologna2016_Training/2_Munchak.pdf

Reflected RFI (satellite source) at 18.7 GHz



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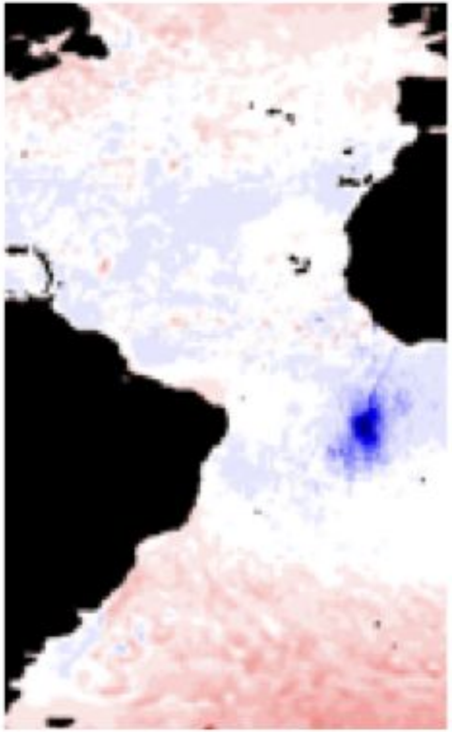
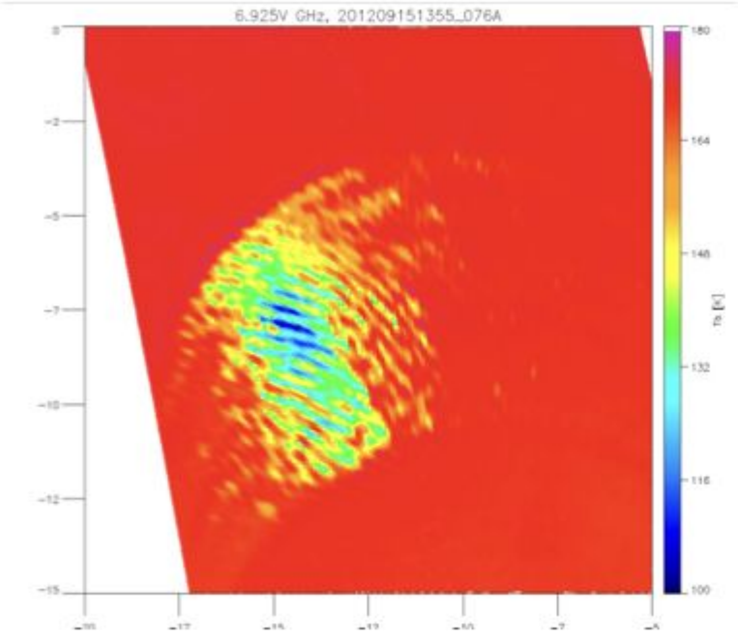
Negative RFI in AMSR2 6.9 GHz channel





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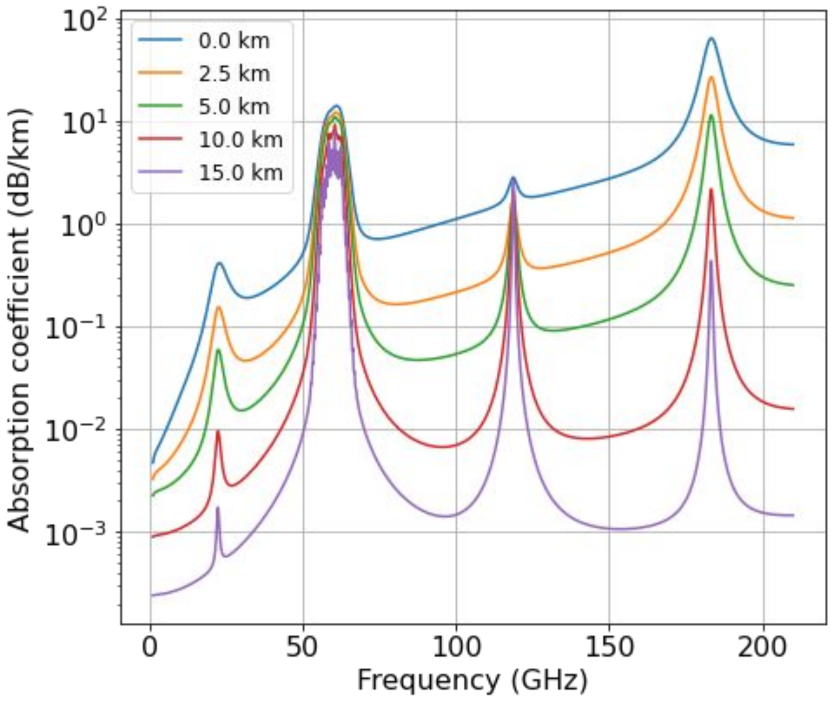
Up until now, RFI has mostly affected lower frequencies (< 80 GHz)

- Higher frequencies are more less transmissive - attenuates communications signals (even in clear sky)
- This is not the case at high altitudes
    - Raises concerns about aircraft/satellite communications use

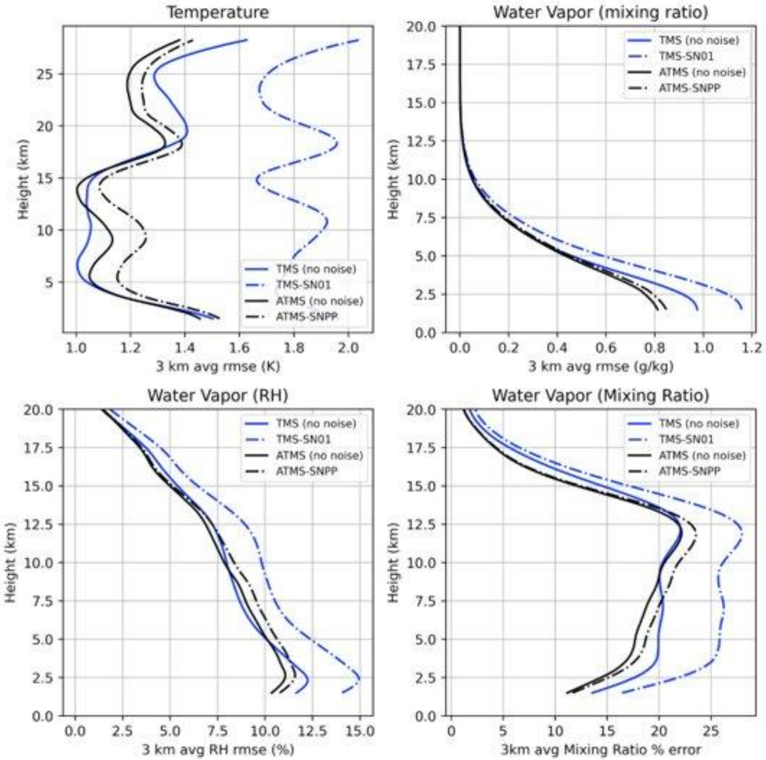


What is the impact of losing low frequencies (< 80 GHz)? Are 118 GHz/183 GHz sufficient for atmospheric sounding?

TMS: 12 channels, 91-204 GHz
ATMS: 22 channels, 23-190 GHz

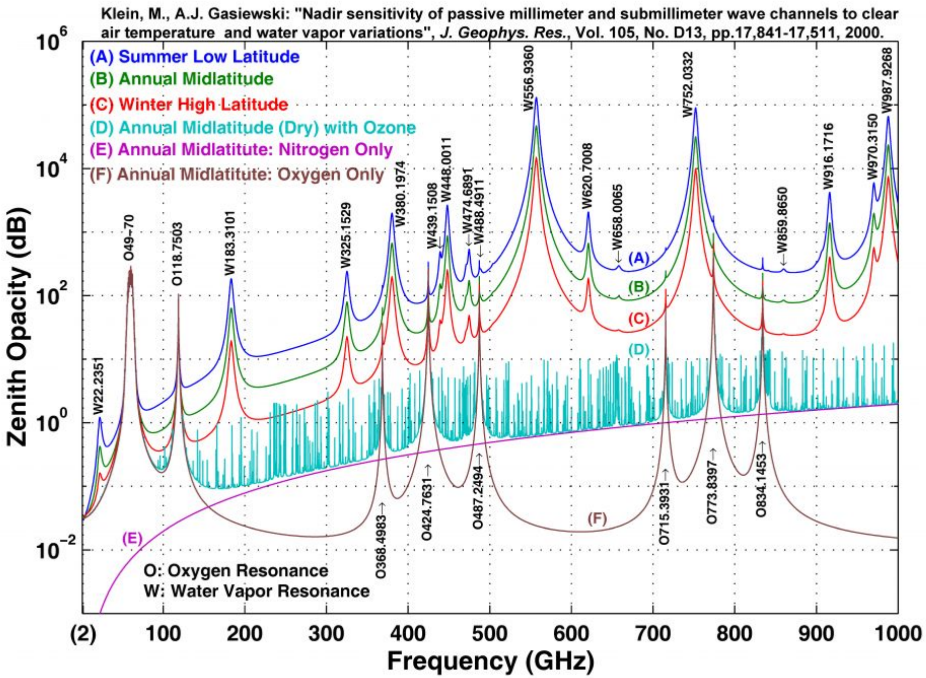
These are simulated retrievals with realistic noise (dashed) and no thermal (NEDT) noise (solid). ATMS is better due to lower noise, but without noise:

- TMS (118 GHz) more accurate for temperature at 5-10 km
- ATMS more accurate for temperature at 18+ km
- ATMS more accurate for low level (< 5 km) water vapor (impact of 23.8 GHz channel)



Outlook for passive remote sensing instruments (2025 and beyond)

- Operational sub-mm (325/640 GHz) sensing is beginning to emerge
  - Arctic Weather Satellite/EPS-Sterna
  - EUMETSAT Ice Cloud Imager
  - NASA PolSIR
- Hyperspectral capabilities enabled by digital ASIC spectrometers
- Wideband window channel measurements enabled by photonic integrated circuits



Summary

1. Passive microwave measurements from satellite are critical for weather prediction on all timescales
2. Both absorption bands (temperature/humidity sounding) and window regions (cloud/precipitation/surface) are needed to full characterize the Earth system
3. Loss of low frequencies would degrade low level water vapor and precipitation retrievals