Atmospheric temperature and water vapor profiles, transmittance calculations, and radiative transfer

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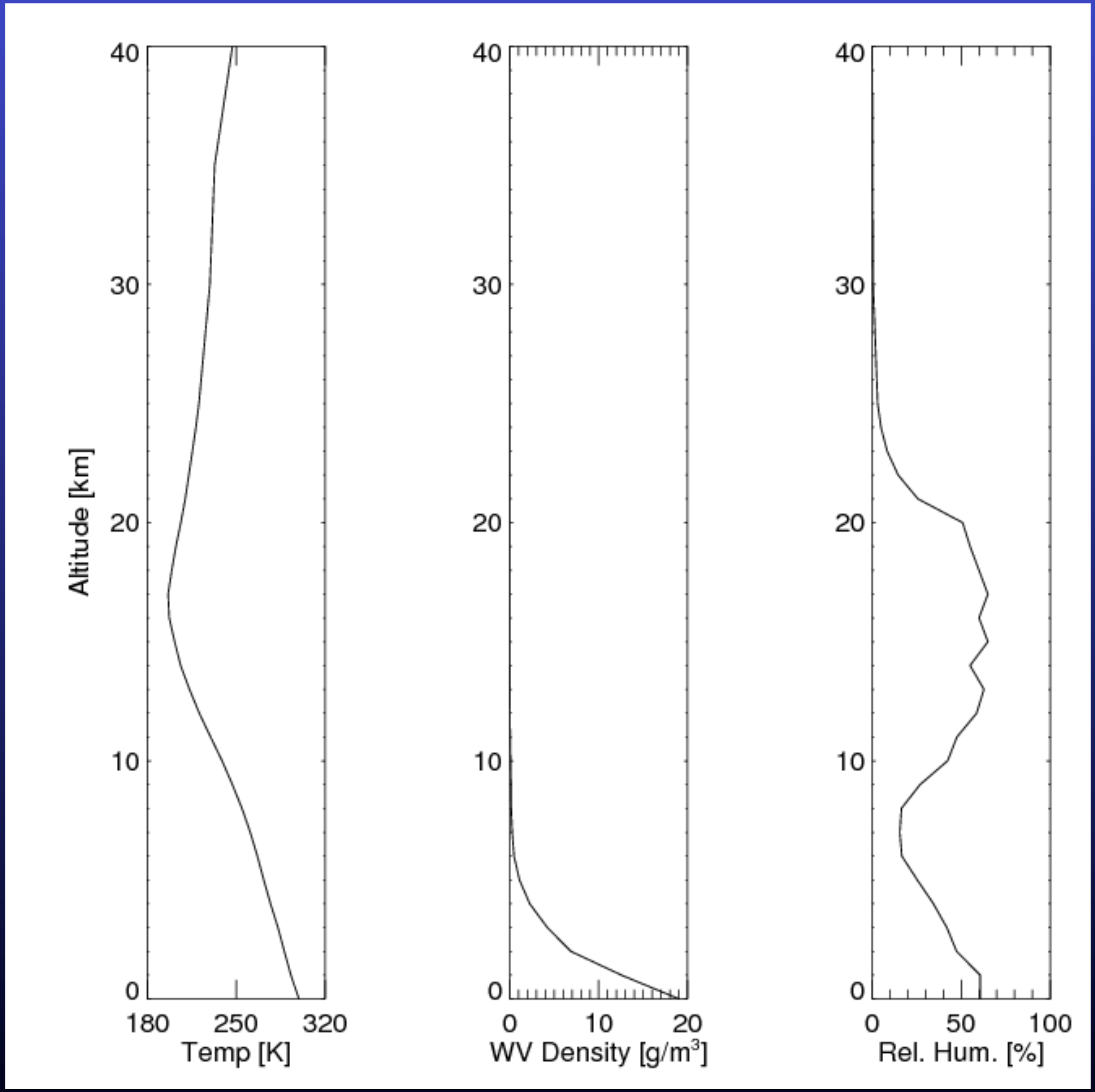
Outline

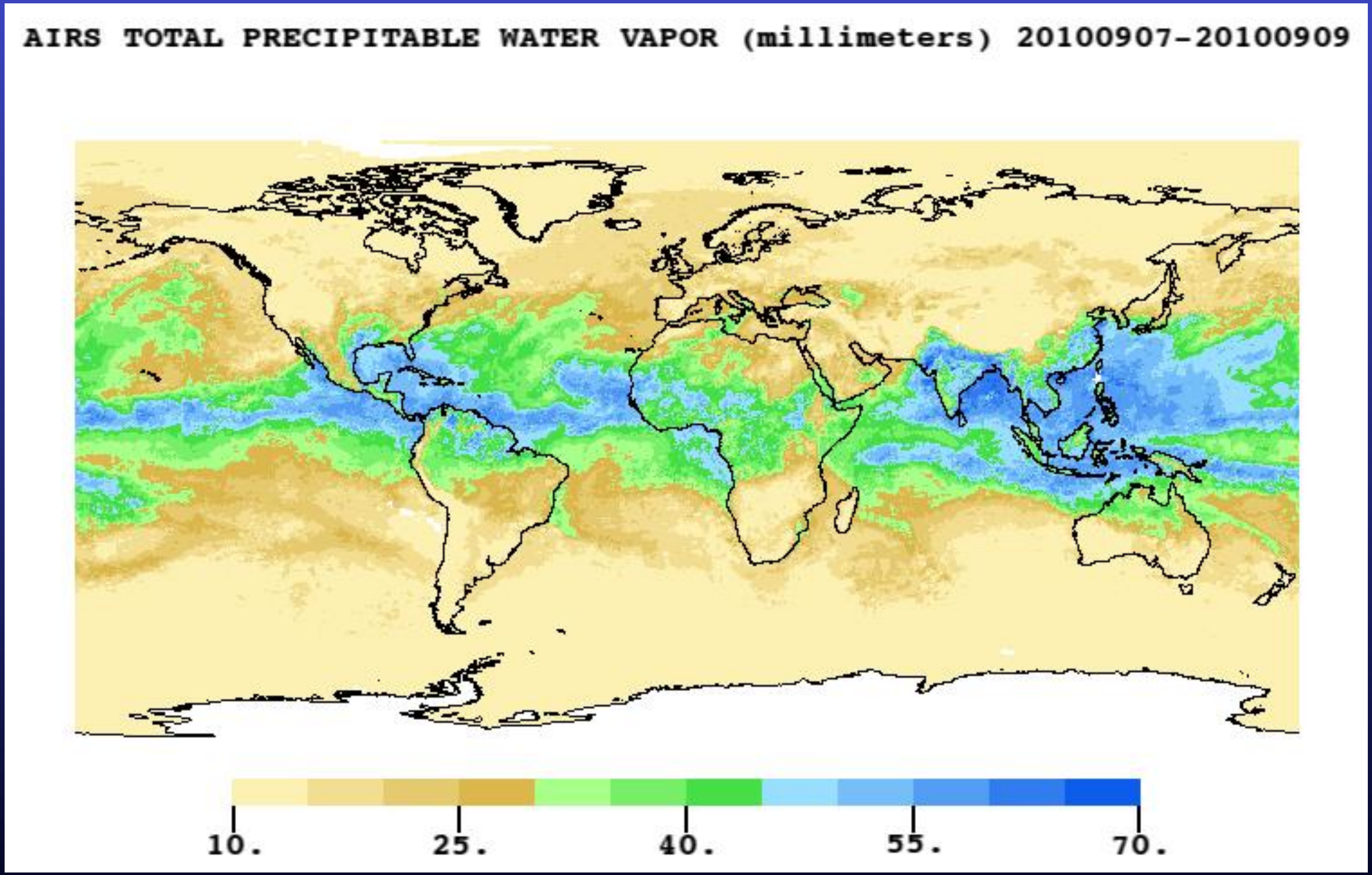
- Introduction
- Temperature and water vapor profiles
  - Radiosondes
  - Microwave radiometers
  - Global remote sensing measurements
  - Forecasts/analyses
- Short-wave radiative transfer
  - Water vapor spectroscopy and retrievals
- Conclusions

Atmospheric temperature and moisture profiles

- Pressure scale height roughly 7.5 km
- Water vapor scale height 1-2 km



Atmospheric temperature and moisture profiles



Observing water vapor and temperature profiles

- Local:
  - Radiosonde
  - Ground-based remote sensing
- Global:
  - Satellite remote sensing

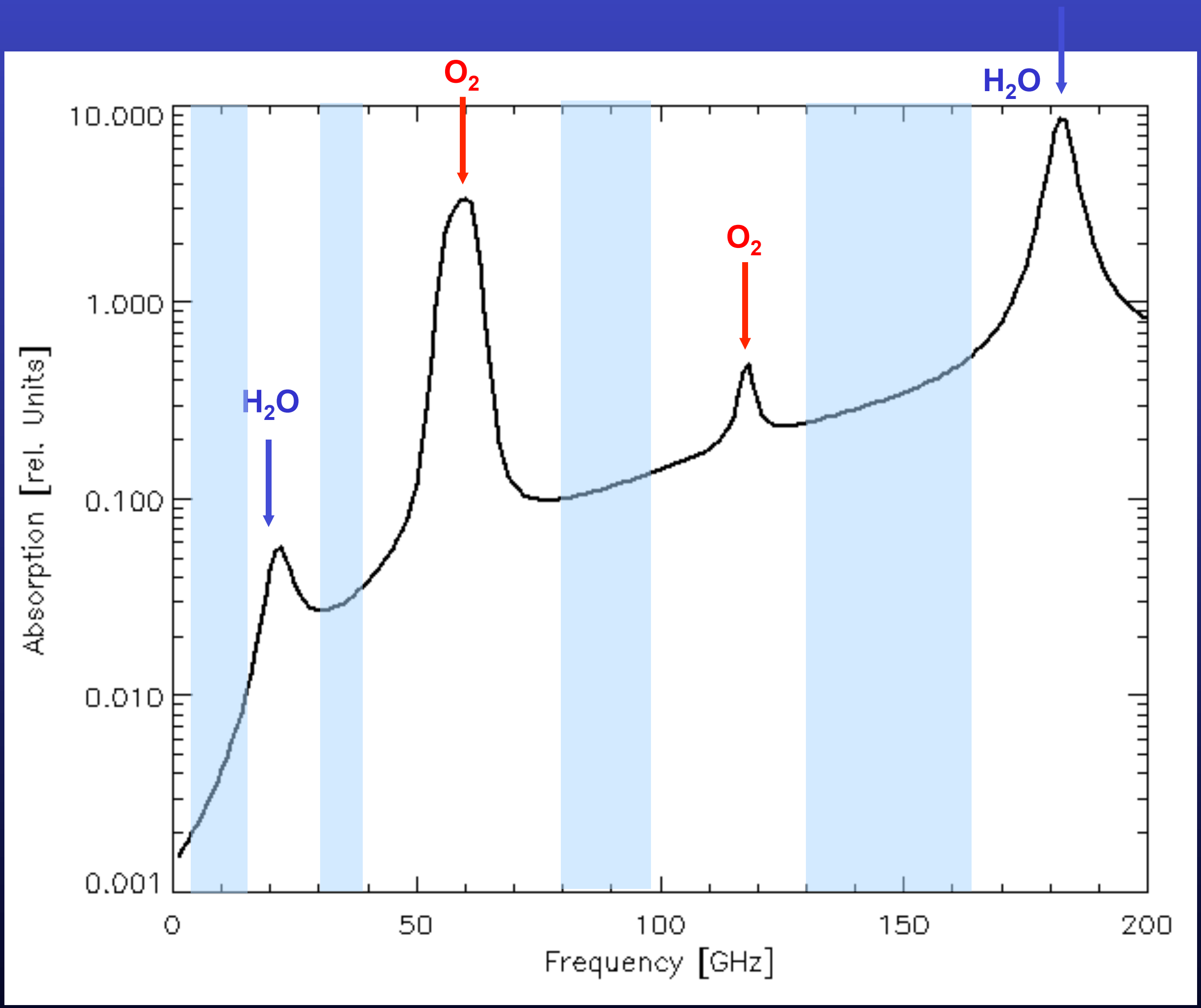
Radiosonde

- Temperature, pressure, relative humidity as it ascends through the atmosphere
- High vertical resolution
- Small sampling volume
- Requires operator

Ground-based microwave radiometers

- MW-radiances in spectral range 10-200 GHz
- Lower vertical resolution
- Runs continuously
- Runs automatically, if needed
- High accuracy

Microwave spectral range



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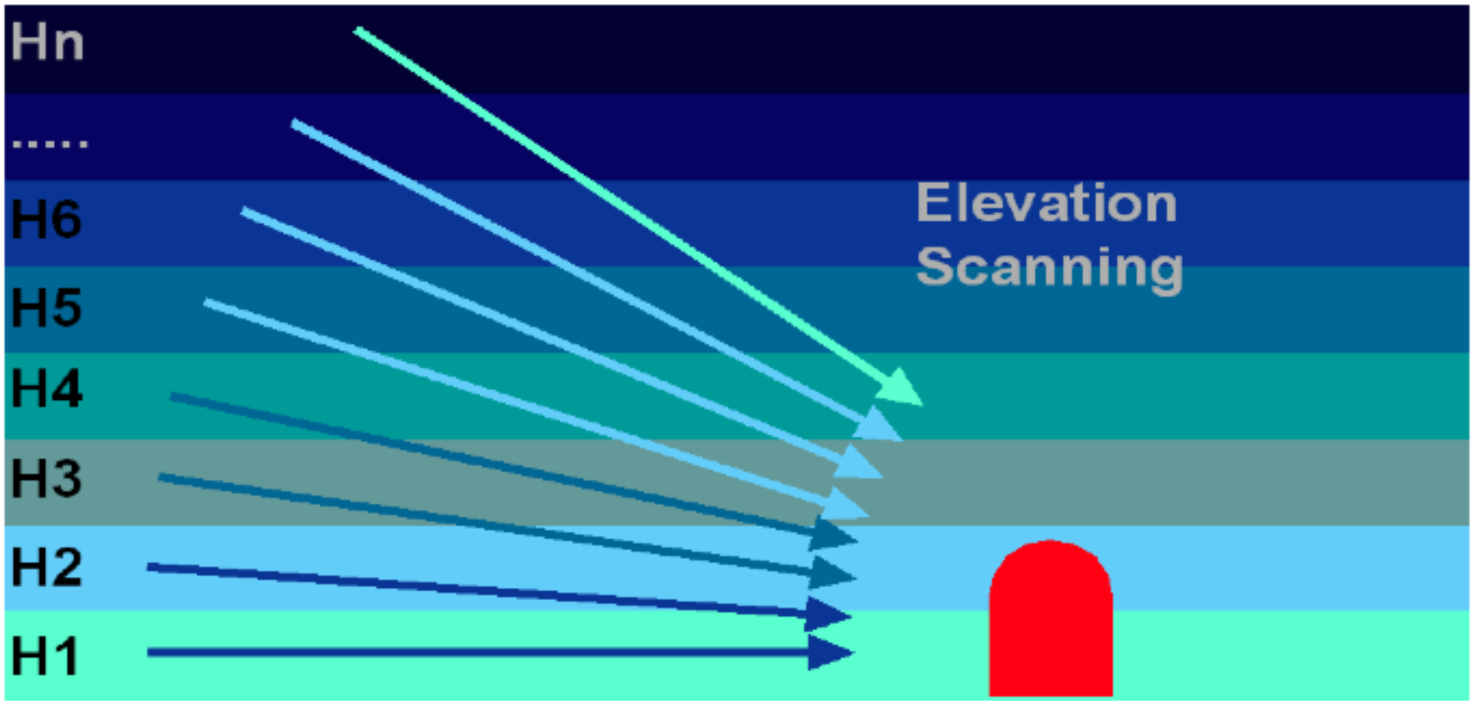
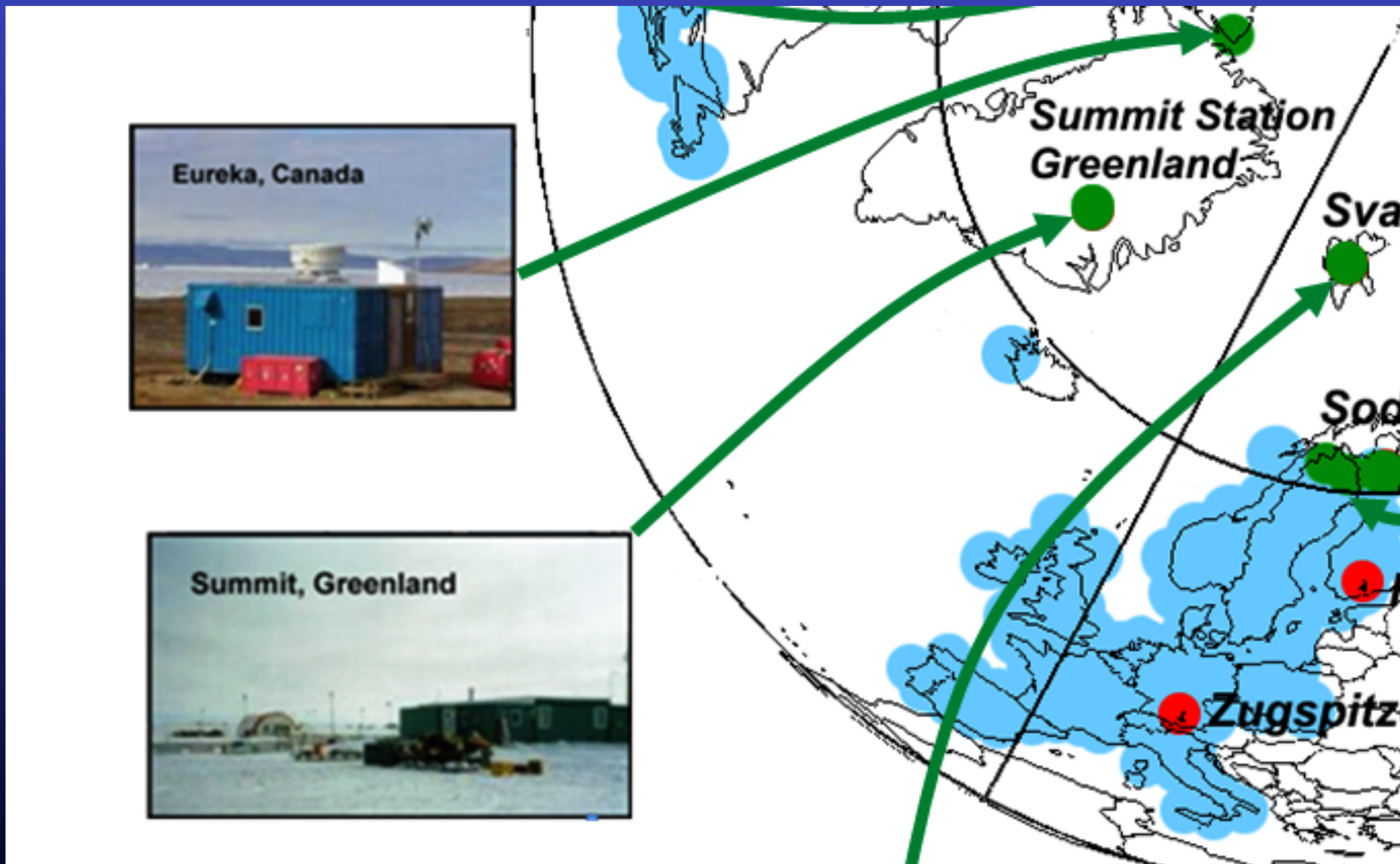


Fig.2: Boundary layer scanning mode with different elevation angles.

Ground-based microwave radiometers



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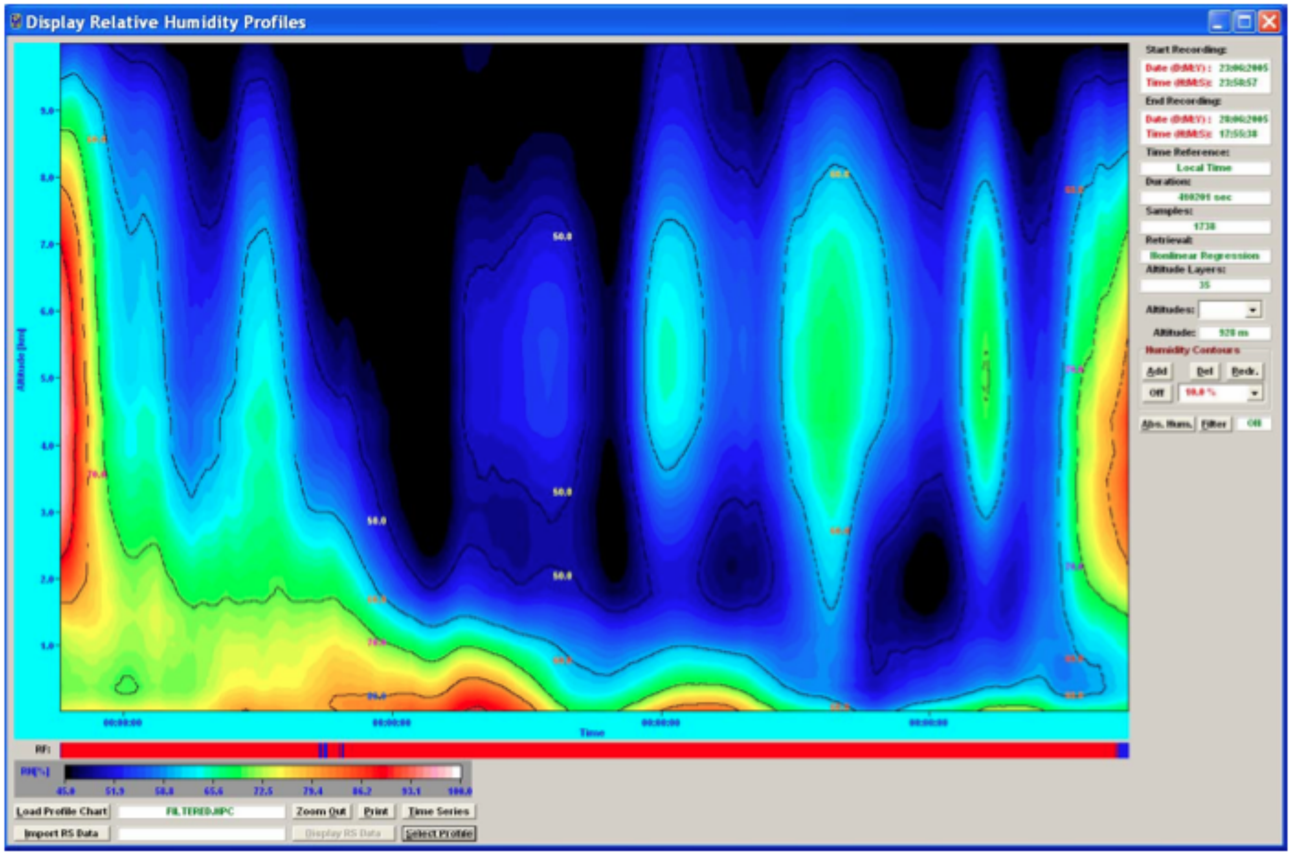

Fig.11: Relative humidity map for the full troposphere (up to 10 km) computed from absolute humidity profiles and temperature profiles both measured in zenith mode.

Non-scattering radiative transfer theory (Schwarzschild 1906)

$$\frac{dI}{ds} = \underbrace{-\beta_A I}_{\text{Attenuation}} + \underbrace{\beta_A B}_{\text{Thermal Emission}}$$

I : Radiance

B : Planck-function

β_A : Absoprtion cross-section per unit volume $[\mathrm{m}^2/\mathrm{m}^3]$

a.k.a volume absorption coefficient

Non-scattering radiative transfer theory

$$I^{\downarrow}(0) = I_C t(0,\infty) + \frac{1}{\mu}\int_0^{TOA} B(z)\beta_A(z)\ t(0,z)dz$$

$\tau(0,z) = \int_0^z \beta_A(z)dz$: Optical depth between $(0,z)$

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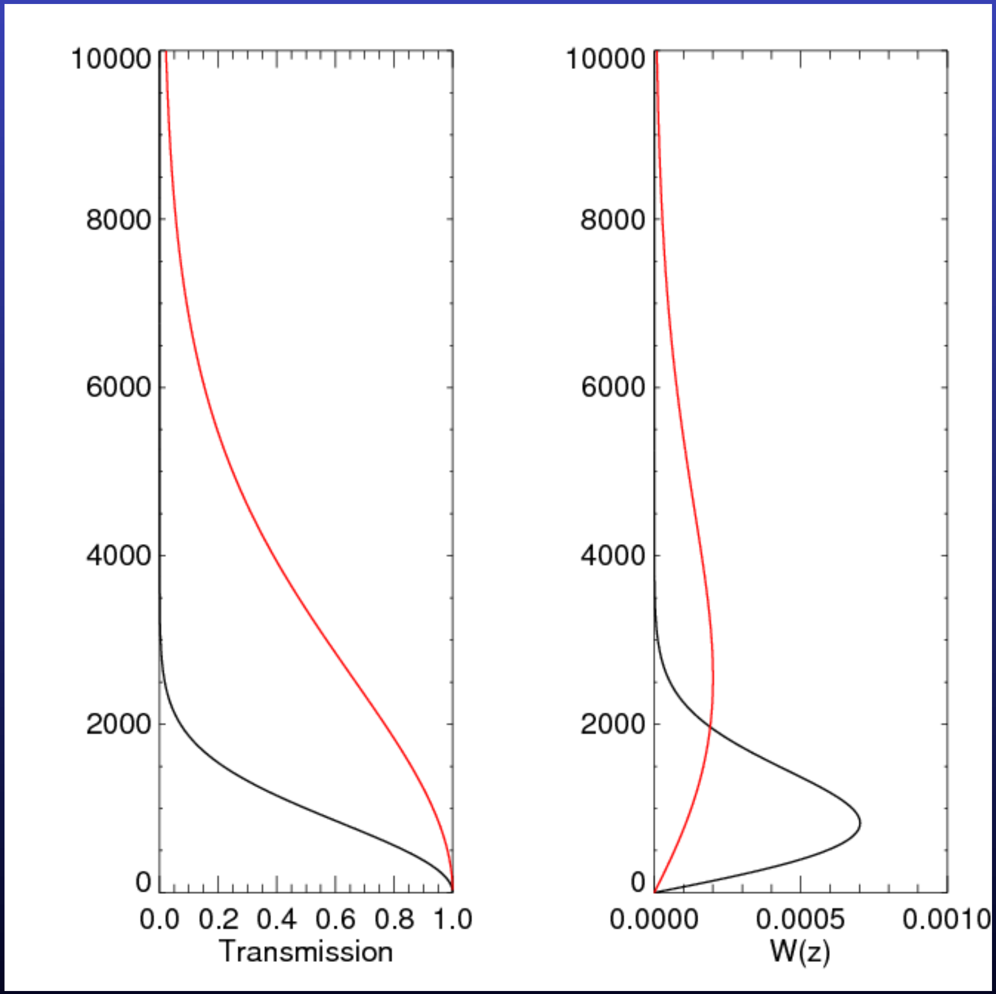
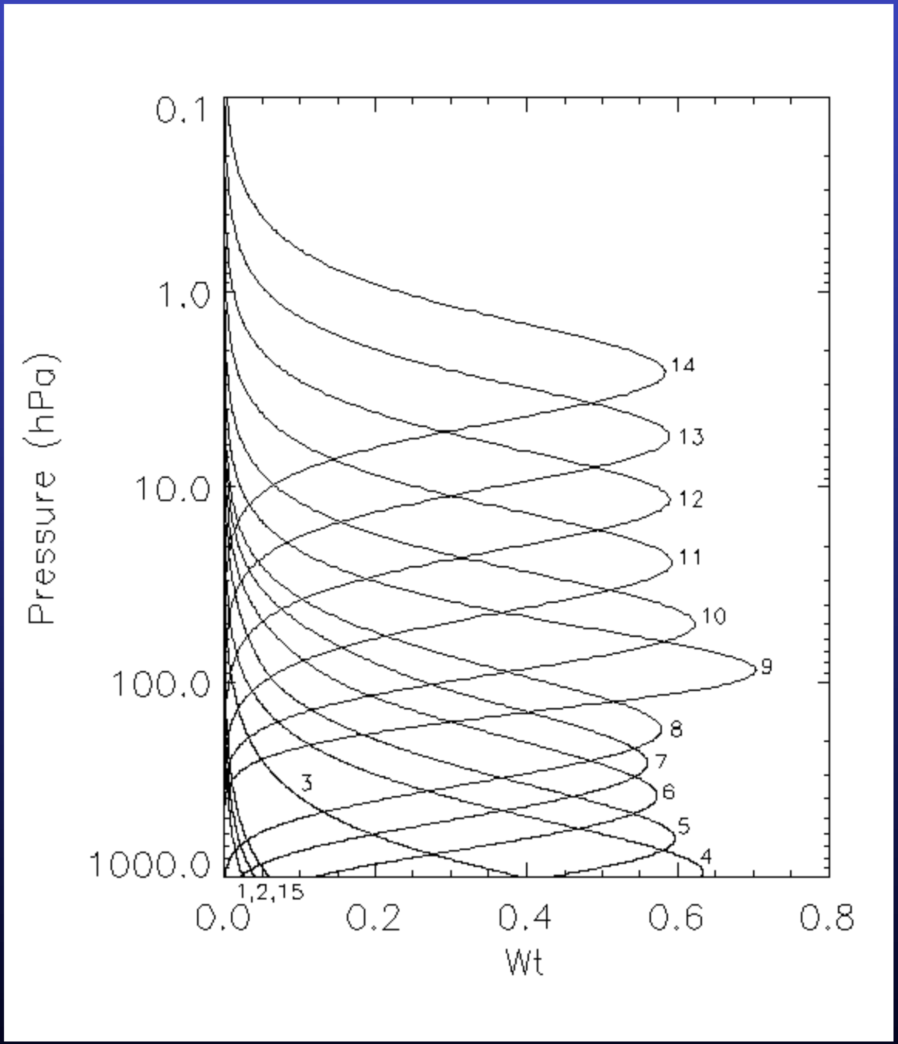
Schematic example of weighting functions

- Black: More strongly absorbing wavelength
- Red: less strongly absorbing wavelength



Actual microwave weighting function example

- E.g. 15 Channel instrument observing O_2-absorption band at 50-60 GHz



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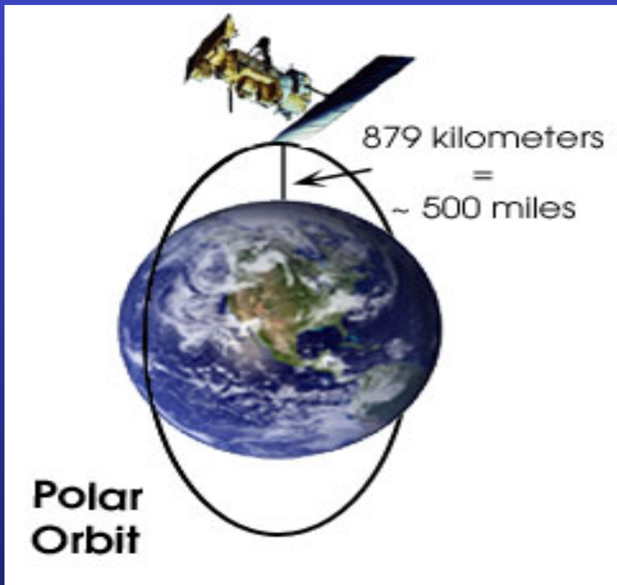
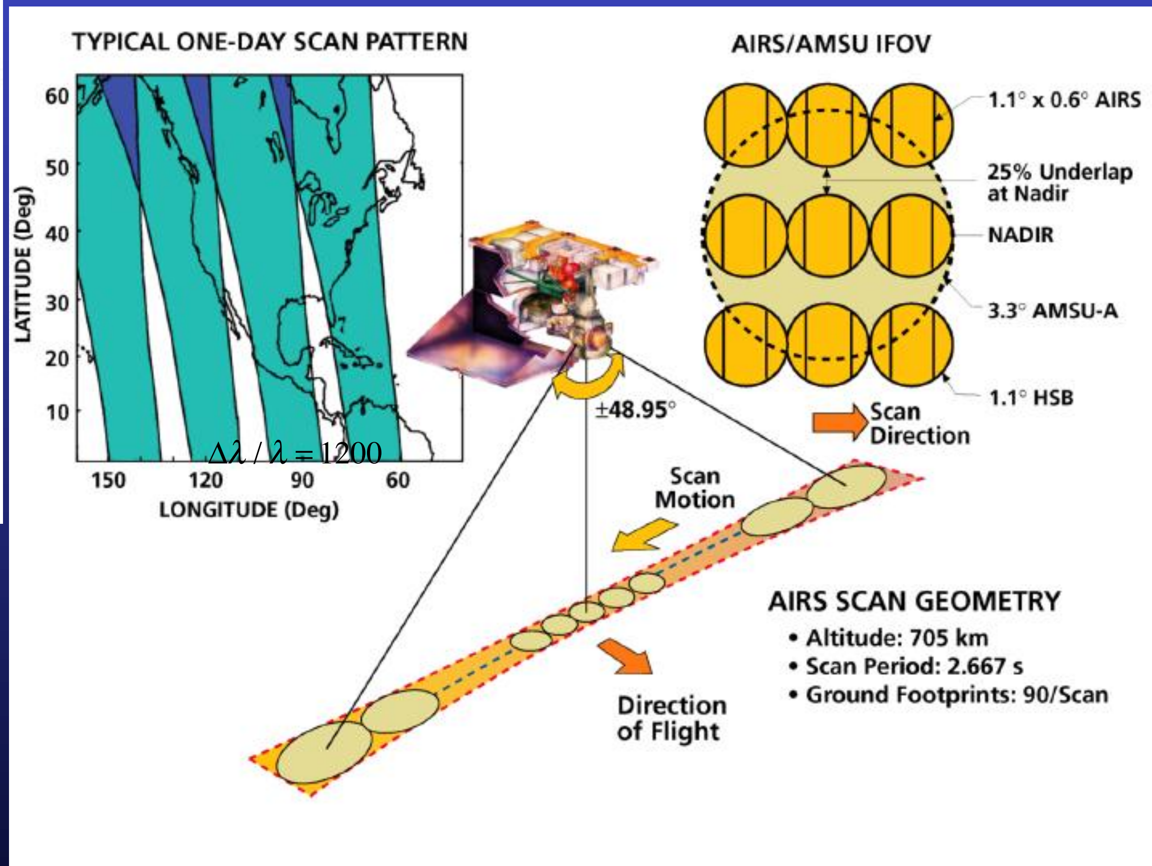
Example: Atmospheric InfraRed Sounder (AIRS)





- 2378 channels
- 3.7-15.4 micron
- dL/L=1200

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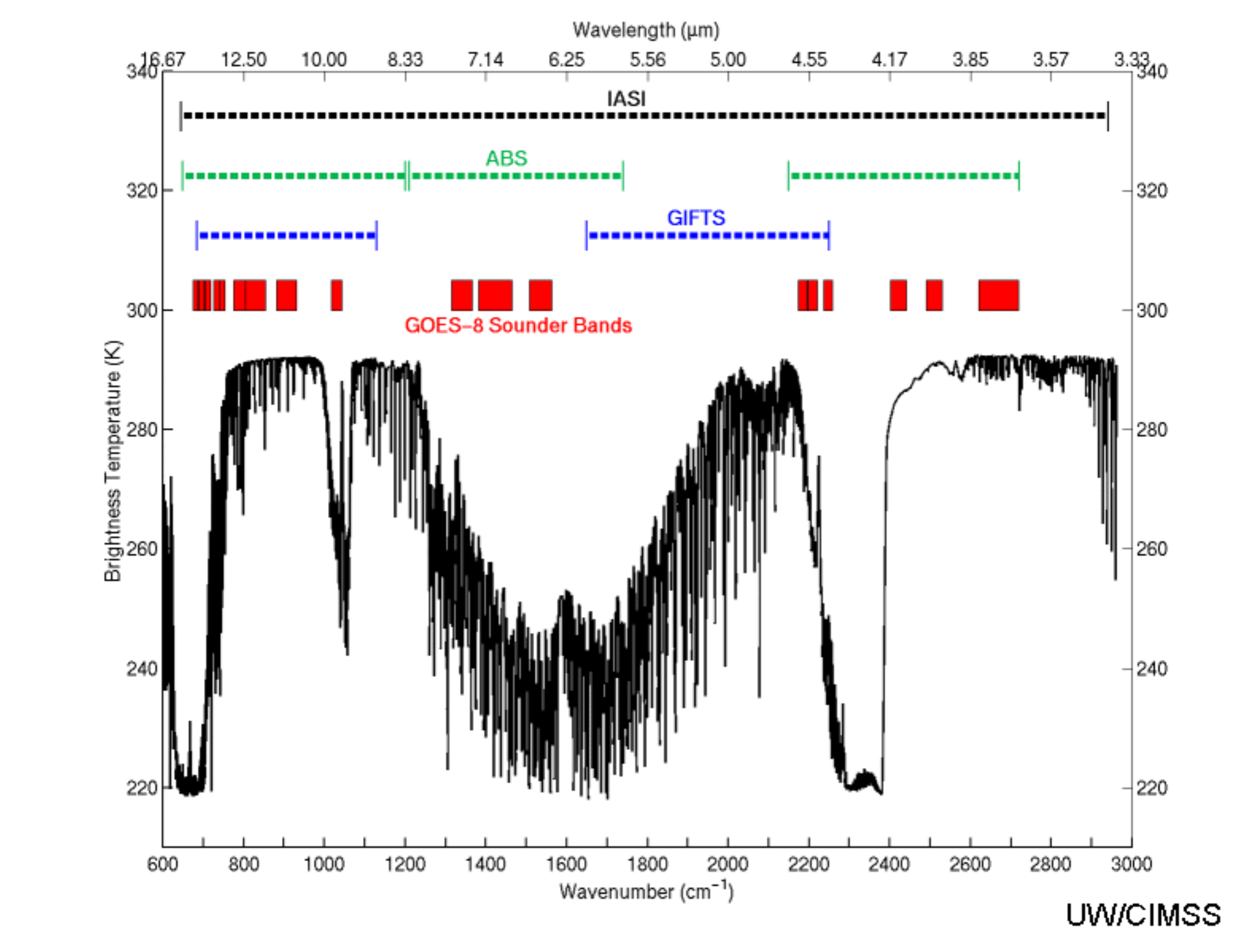

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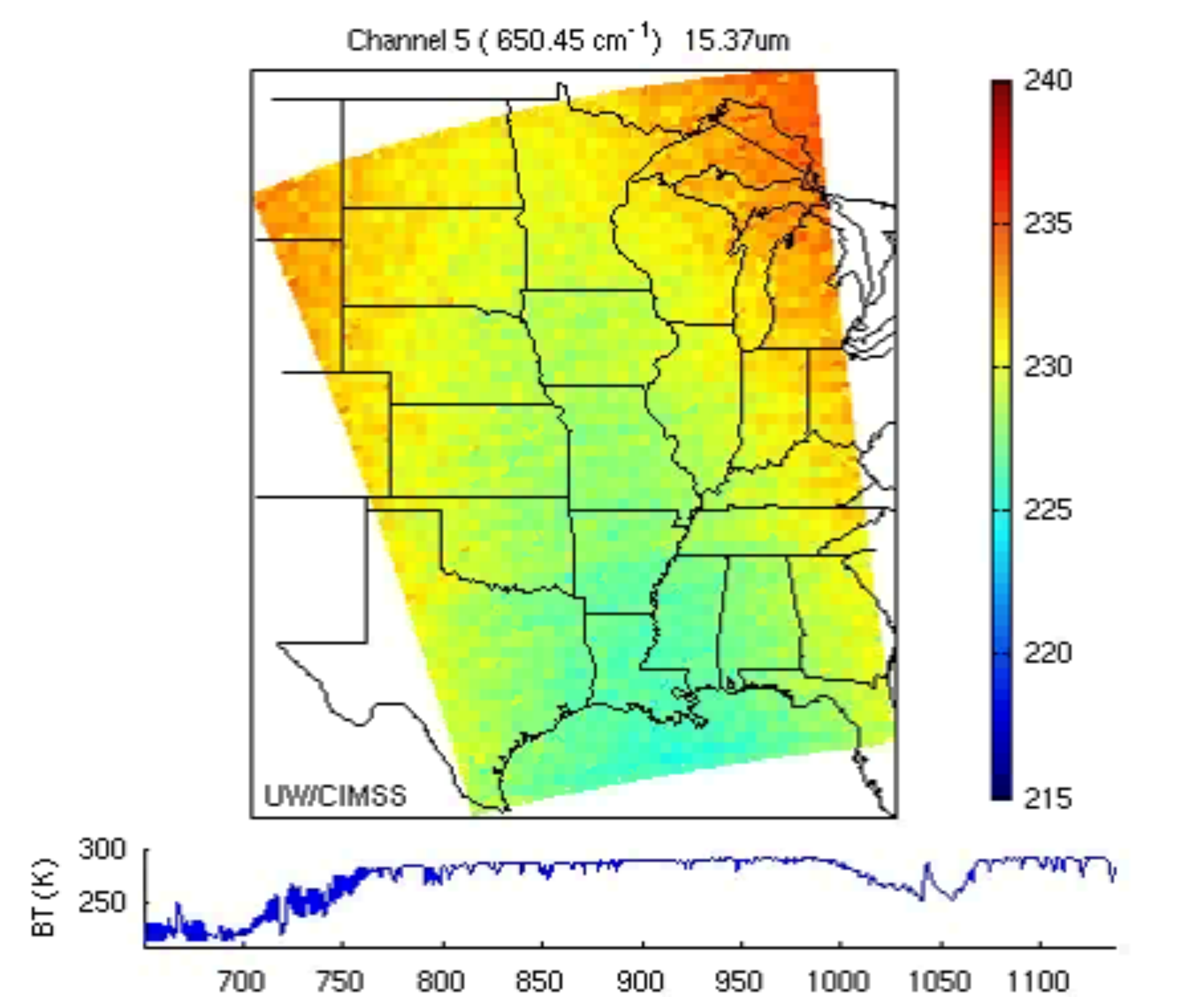


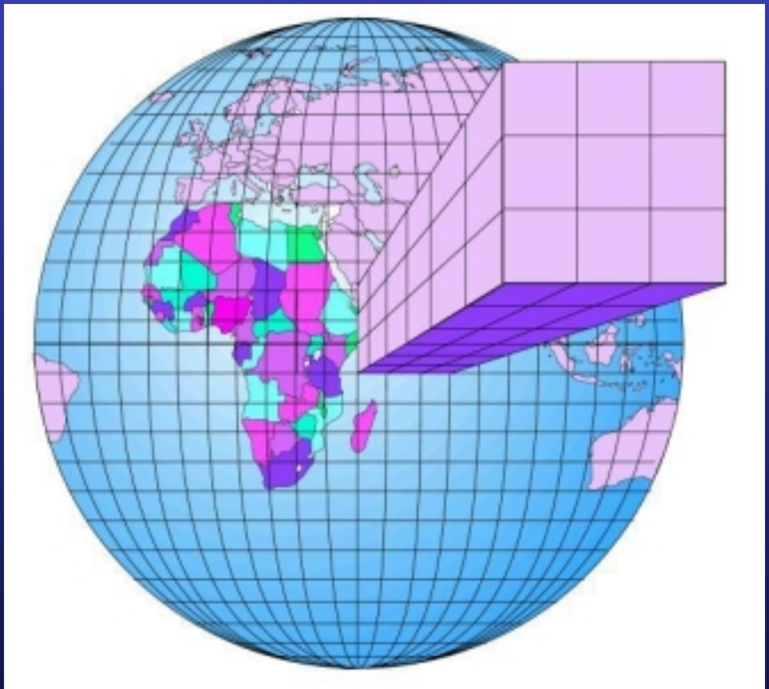
Example: Atmospheric InfraRed Sounder (AIRS)

- Provides data since mid 2002
- Temperature and water vapor profiles available globally about once every 12hours
- Spatial resolution about 15 km horizontally
- Accuracy T : ±1K @ dz=1km
- Accuracy RH : ±10% @ dz=1km
- Other, similar instruments out there. Data continuity high priority for NOAA and EUMETSAT

Numerical Weather Prediction Models

Numerical Weather Prediction Models

- Integrates Navier Stokes equations forward in time on a rotating spherical grid.
- Variables: T, p, q, (u,v,w)
- Examples:
  - NCEP's Global Forecasting System (GFS, GDAS)
  - ECMWF's Integrated Forecasting System (IFS)



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- How to incorporate the sparse observations into an optimal analysis → Data assimilation.

Data Assimilation

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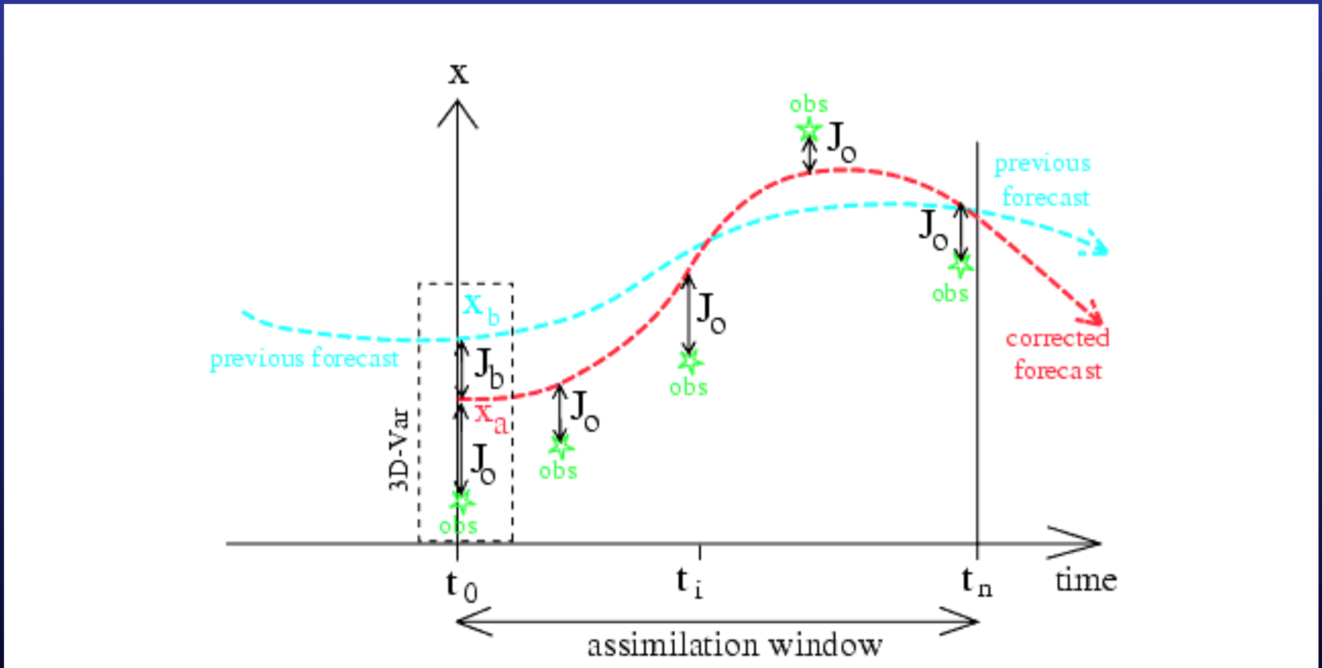


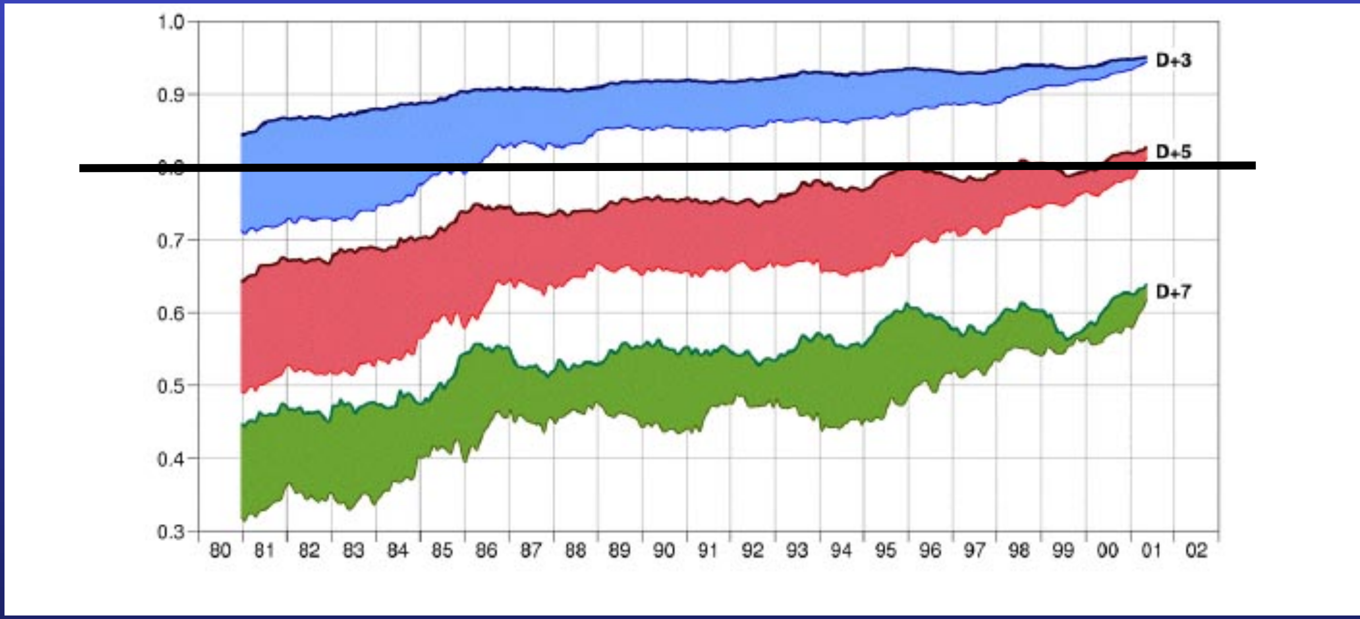
Numerical Weather Prediction Models

- Forecast at time t: Best estimate of the state of the atmosphere at some future point in time t.

- Analysis at time t: Best estimate of the state of the atmosphere point in time t based on forecast + sparse observations.

- Both, forecast and analysis provide estimates of T,p,q everywhere on the globe.

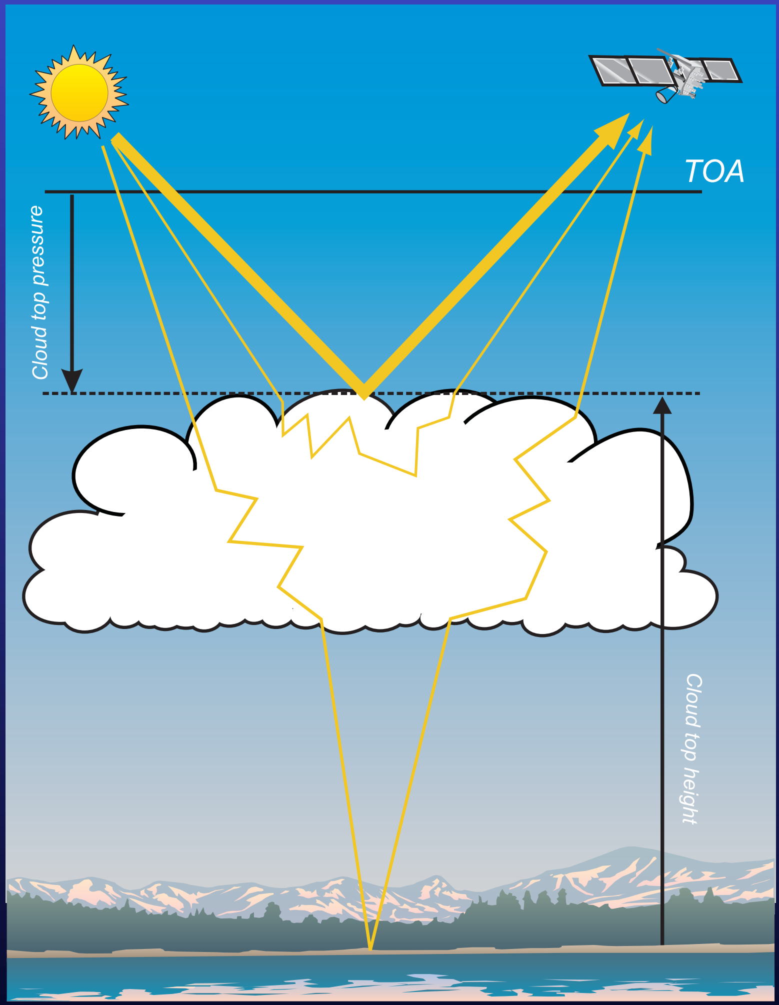
NWP Forecast Skill



- 0: No skill, 1: perfect skill (based on anomaly correlations)
- 5 day forecast 2001 better than 3 day forecast 1980
- Improvements due to satellite (better initial conditions) and better computer technology.

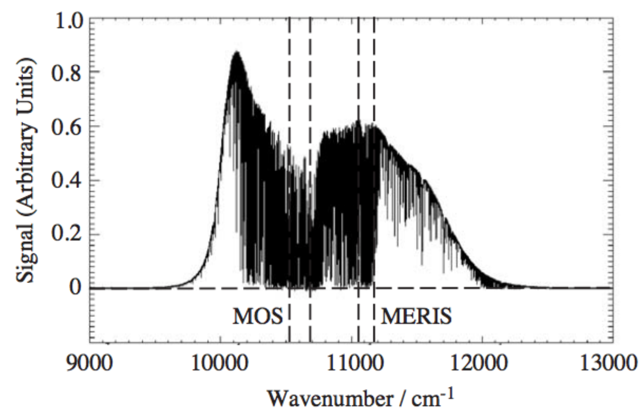
Short-wave (300-3000 nm) radiative transfer

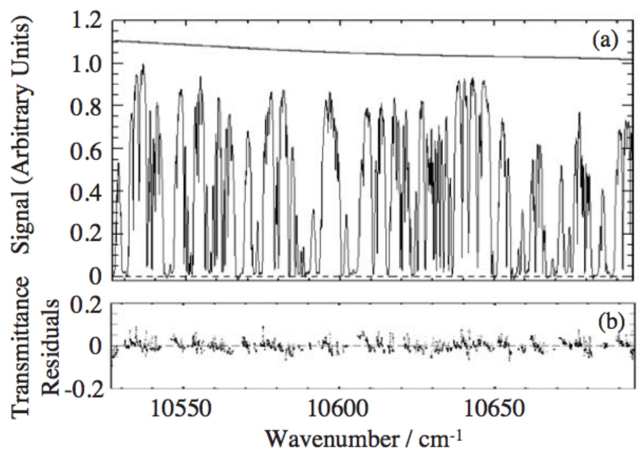
- Scattering become important, RT gets way more complicated than infrared
- How to determine aerosol scattering properties
  → Eloranta talk
- Formal radiative transfer solutions and absorption/ scattering interaction



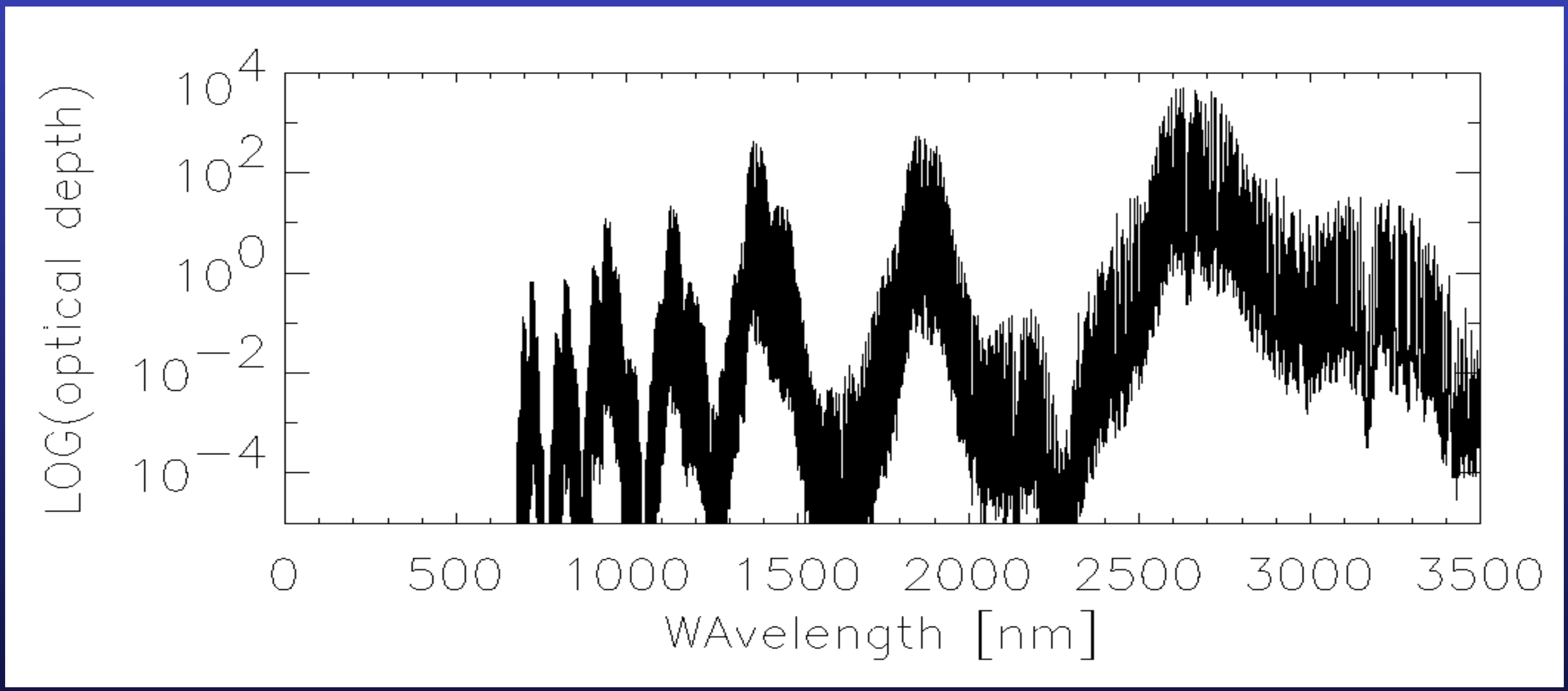
Example: Solar radiative transfer example water vapor spectroscopy in the water vapor rst-band (945 nm)

P. Albert et al. / Journal of Quantitative Spectroscopy & Radiative Transfer 84 (2004) 181–193 187



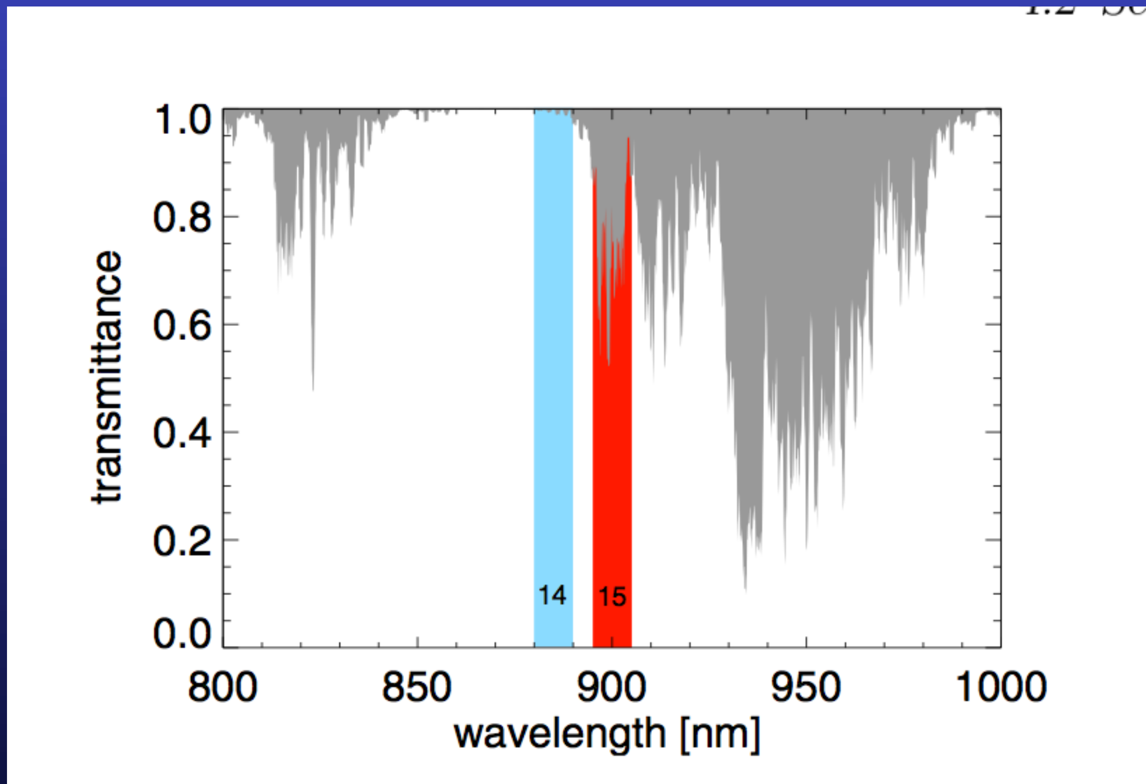


Broad band water vapor absorption in the NIR



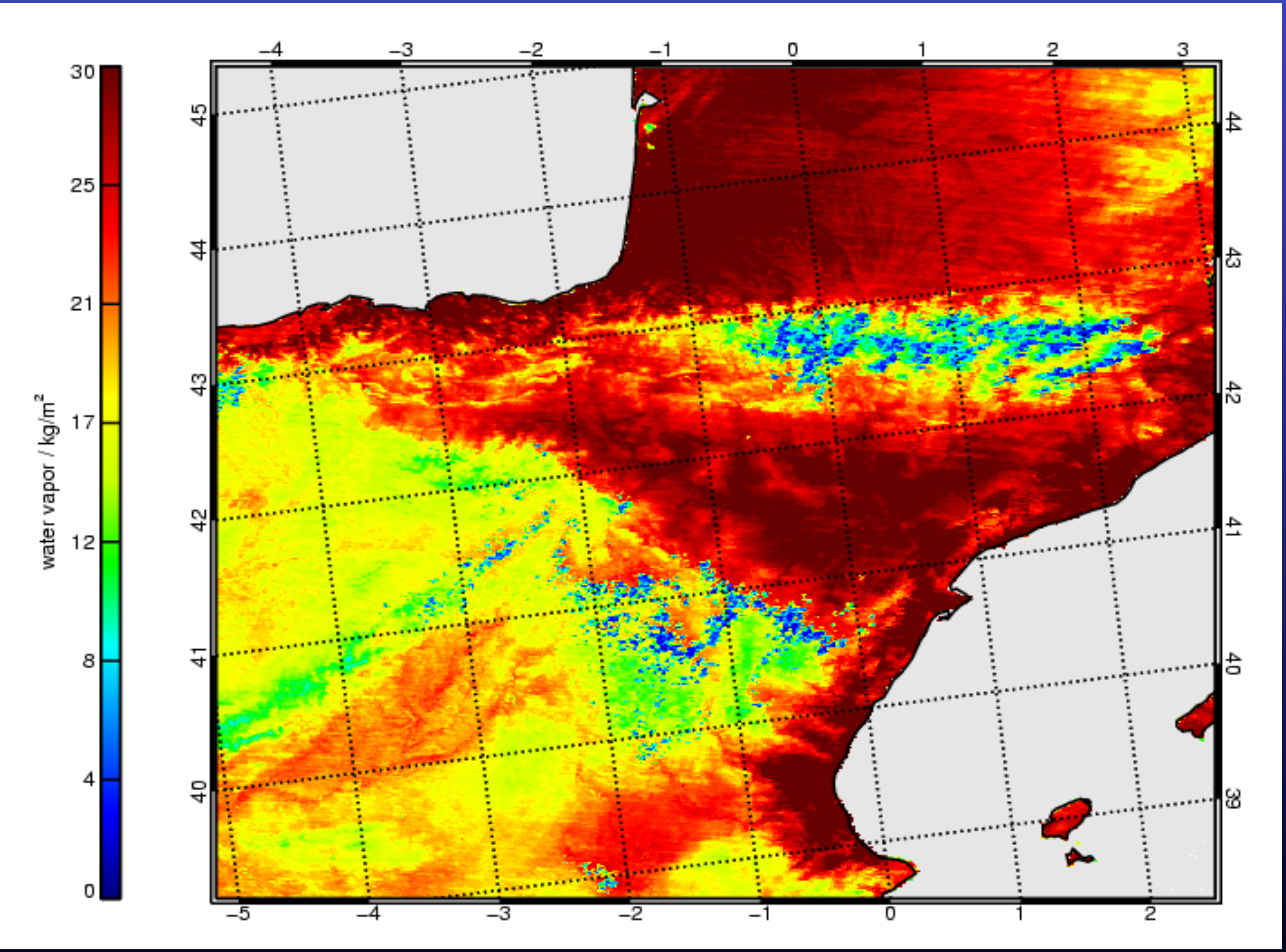
Mid-latitude summer atmosphere

Differential absorption water vapor spectroscopy



Operationally used on satellites/aircrafts since 2000. (E.g. Bennartz and Fischer 2001, Rem. Sens. Env.)

Near infrared MODIS water vapor – example

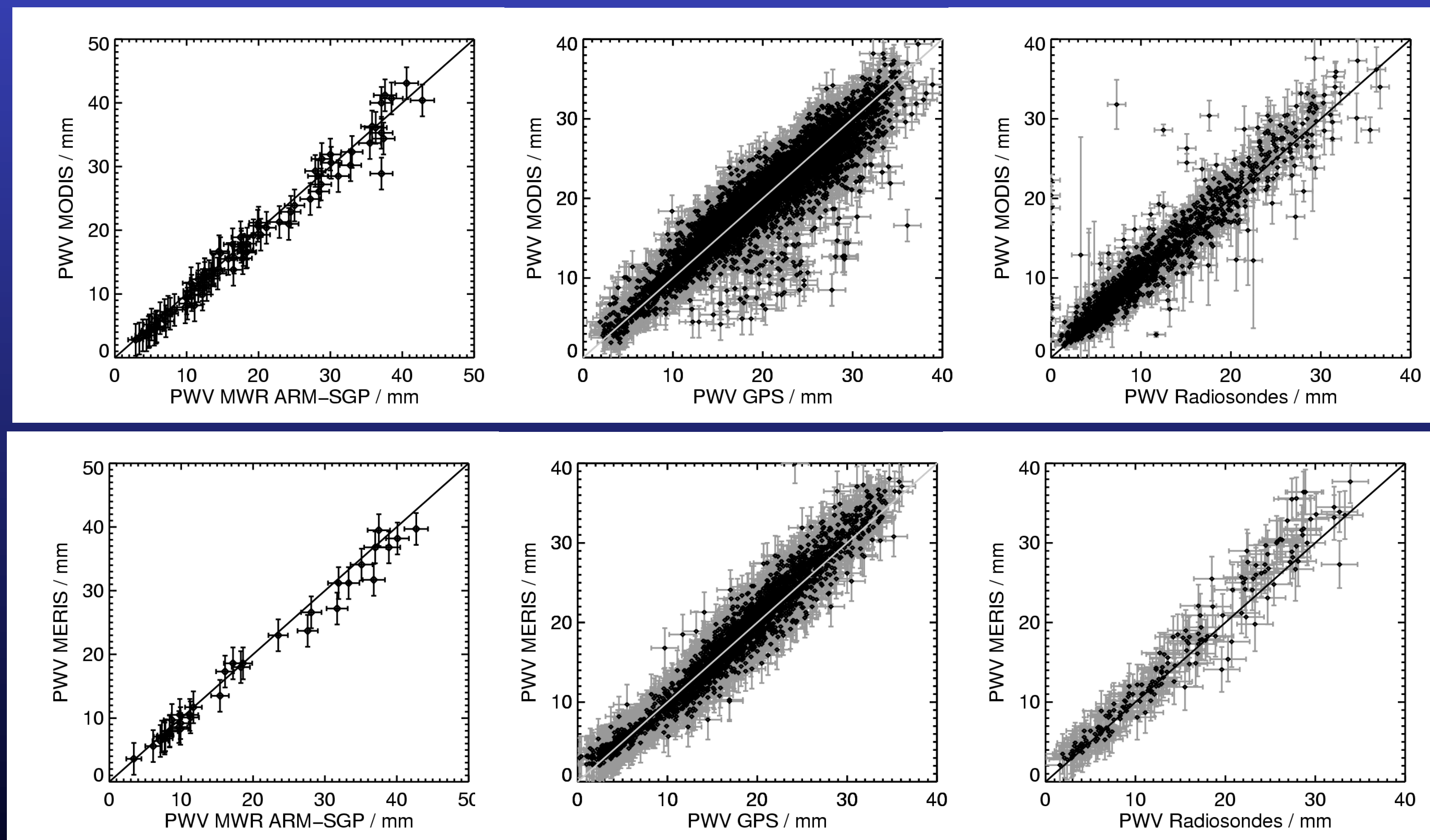


Validation of Near infrared water vapor estimate over land (Accuracy: 1.5-2 kg/m^2 (about 10%))

Microwave | GPS | Radiosonde

MODIS

MERIS



(Bennartz & Fischer, 2001; Albert et al., 2005)

Summary

- Infrared and microwave spectrometers provide excellent opportunity to observe temperature and humidity.

- NWP models (forecasts/analyses) provide good estimates but are less reliable in data sparse regions (southern versus northern hemisphere).

- Ground-based observations of temperature and water vapor → microwave radiometer (stable, accurate, cheap (30K), runs automatically).

- Various radiative transfer tools, models etc.. (Monte-Carlo, adding-and-doubling, photon pathlength…)