Remote Sensing of Water Vapor Using Microwave Radiometer

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Vivek
Earth Observing Laboratory
National Center for Atmospheric Research
Boulder, Colorado, USA

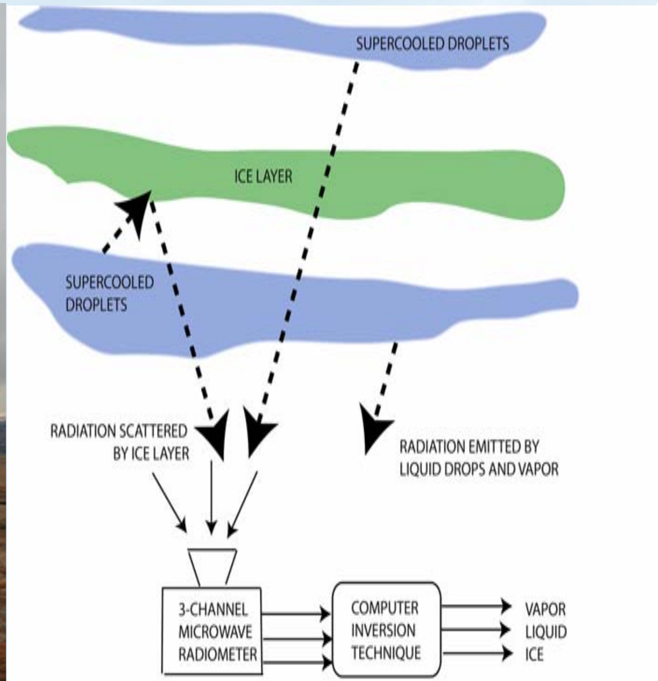
SwaroopSahoo and Steve Reising
Colorado State University
Fort Collins, Colorado, USA

Instruments

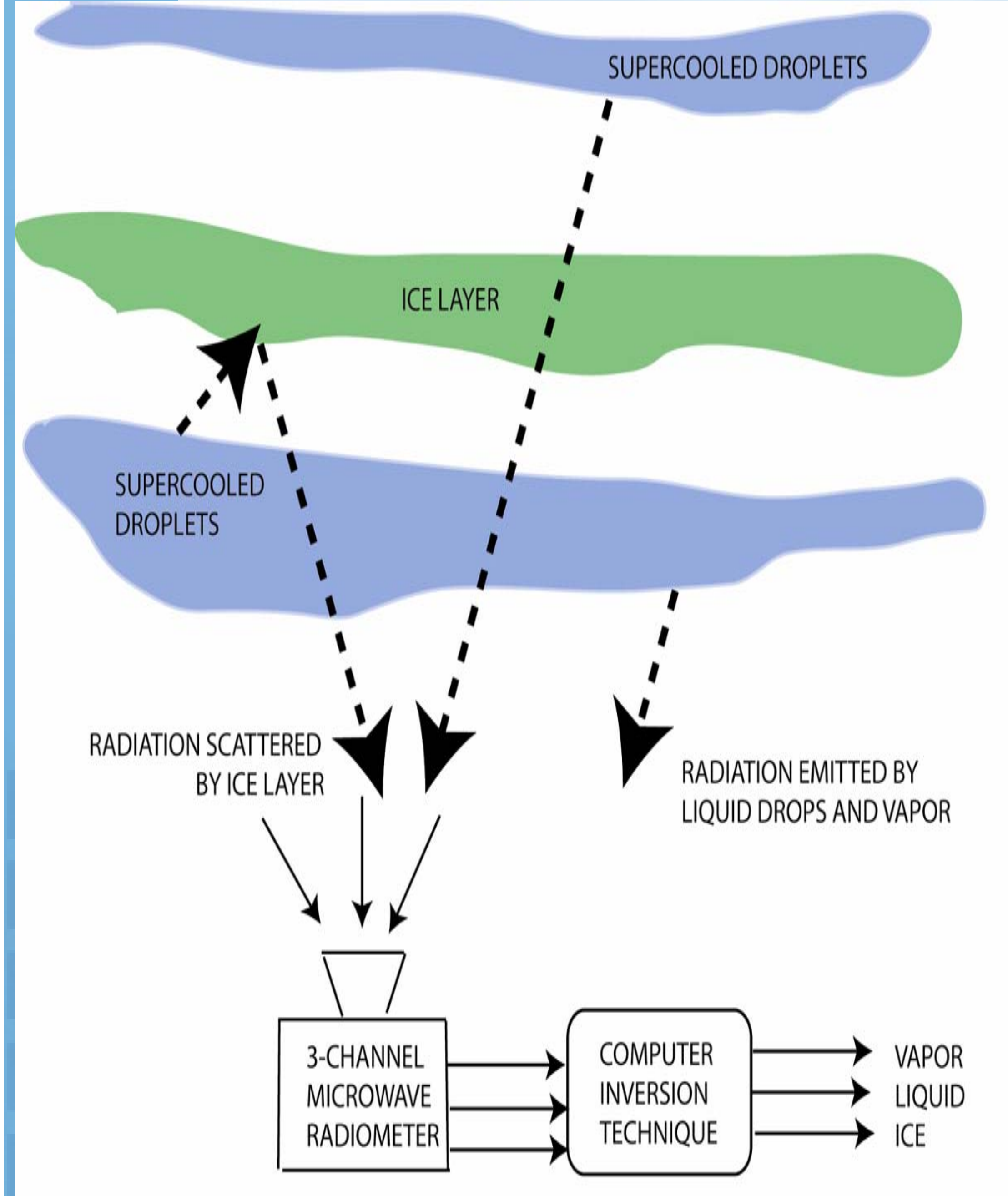
•Ground-based radar: (i) total phase or delay and (ii) absorption using a dual-wavelength radar

• Ground-based multi-wavelength microwave radiometer

• Satellite-borne microwave radiometer



Radiometer Technique



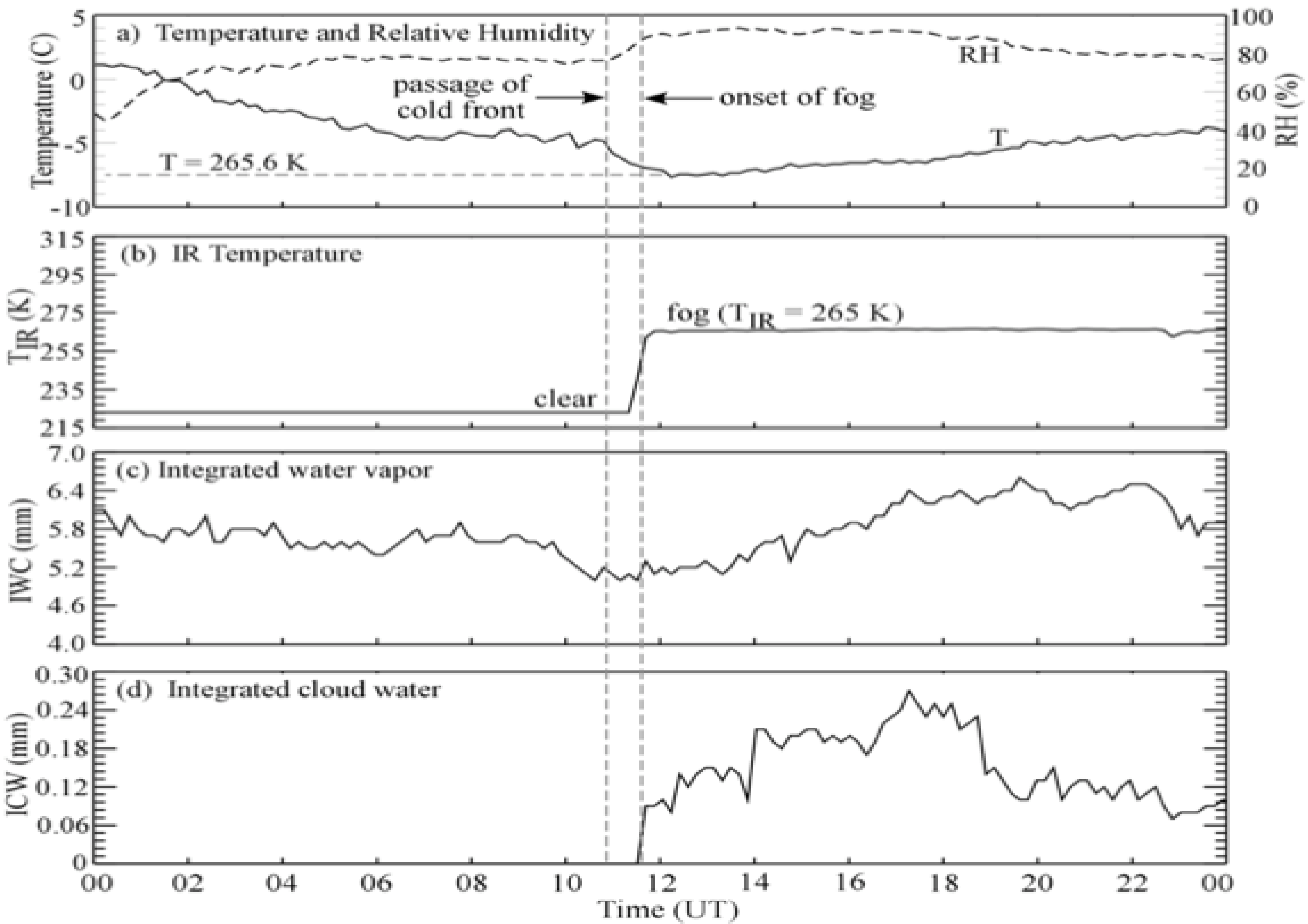
- Radiometers measure brightness temperatures T_b, that are converted into optical depths, τ.

$$\tau = \log\left(\frac{T_m - T_{sky}}{T_m - T_b}\right)$$

- Optical depths are linearly related to LWP and VWP
- k_l and k_v are path averaged coefficients.
- τ_d is the 'dry' optical depth
- Two wavelengths, two equations, two unknowns – retrieve LWP and VWP.

$$\tau = k_l LWP + k_v VWP + \tau_d$$

Times series measurements of temperature, integrated vapor and liquid



Spatial and Temporal Resolutions

(a) Radiosondes:

- Synoptic scale; twice daily. Thermodynamic vertical profiles for weather diagnostics and prediction

- Don't resolve microscale and mesoscale features of minutes to hours and 1-10 km scale

(b) Satellite:

Crude vertical resolution within boundary layer

(c) Radiometer: Continuous observations to fill temporal gaps between radiosondes

(i) Microwave: Measurements during both cloudy and clear air

(ii) Infrared: Biased in cloudy condition

Vertical resolution declines in proportion to height above ground level

Ground-based radiometer

Profiling Using a Microwave Radiometer

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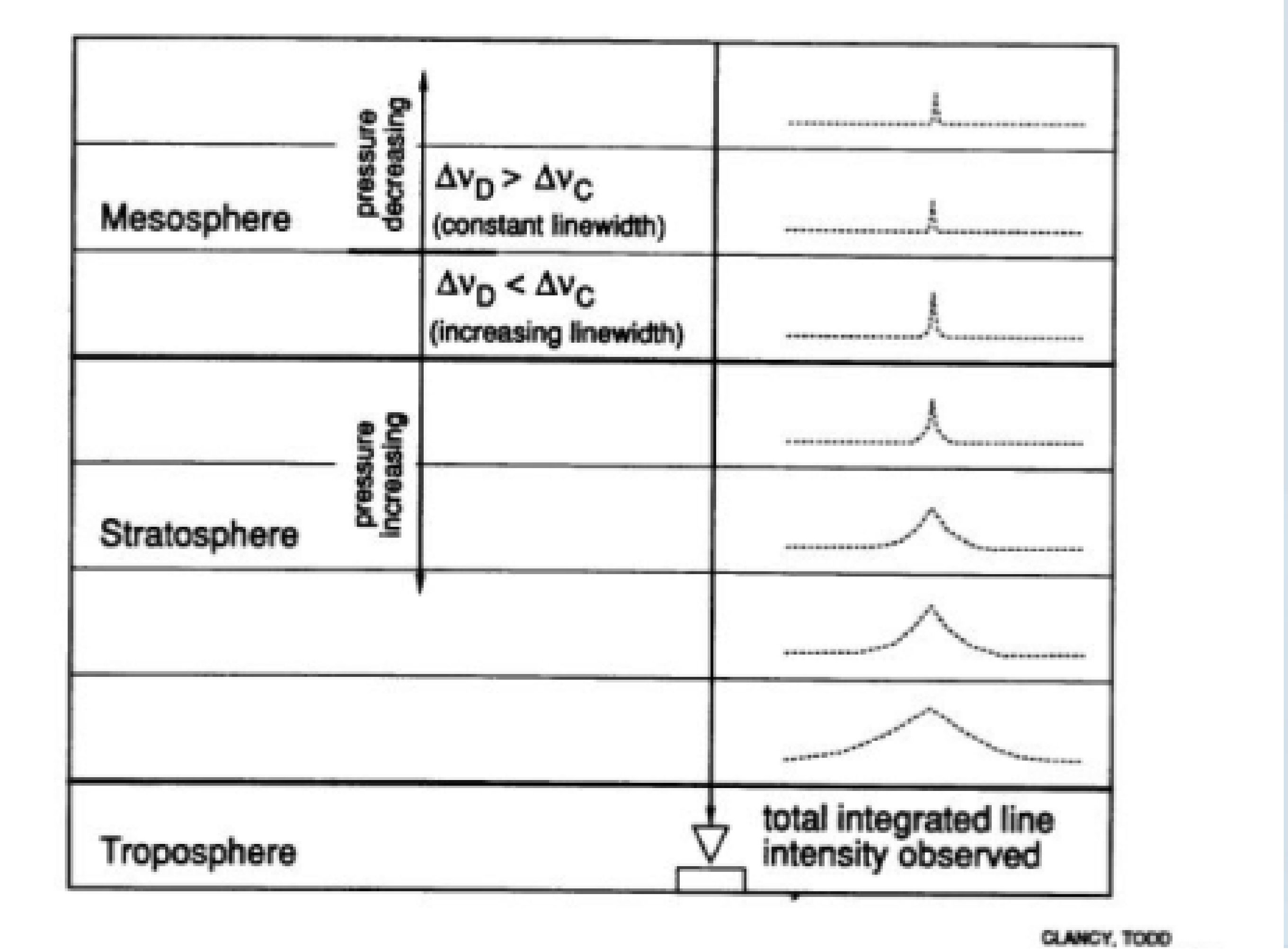
Frequency of the emitted radiation
Bohr's Equation

$$\nu_{mn} = \frac{E_m - E_n}{h}$$

Total internal energy of a molecule:

$$E_{int} = E_e + E_v + E_r$$

Two important rotational transitions: 22.235 and 183.31 GHz



Brightness Temperature and weighting function

T_B : Brightness temperature
W(f,z) : Weighting function
g(z): Water vapor density

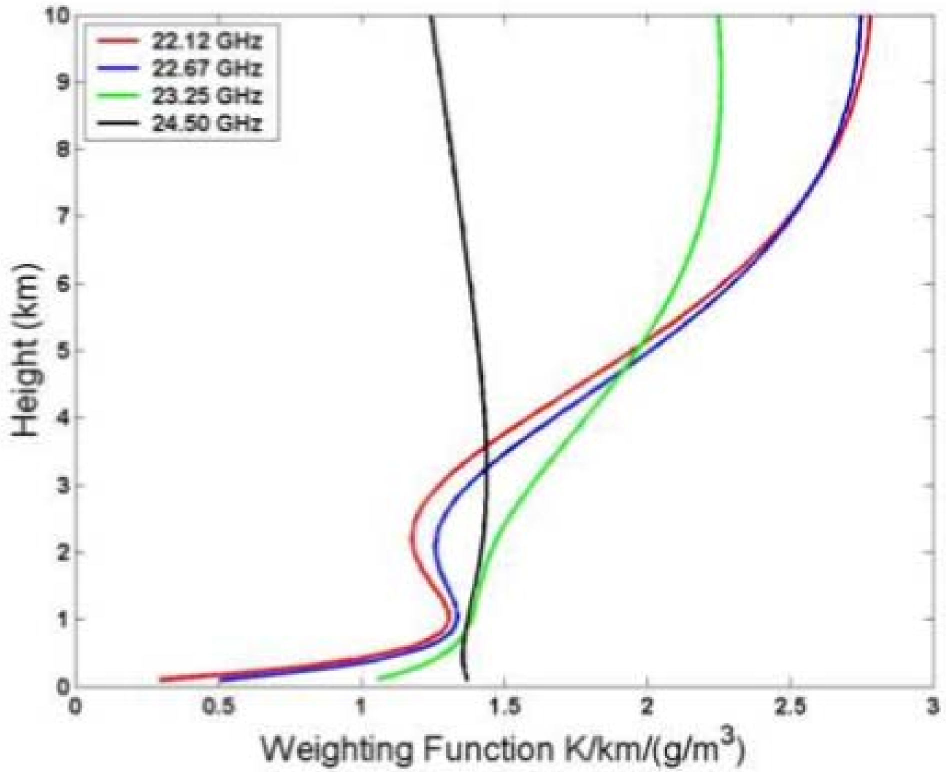
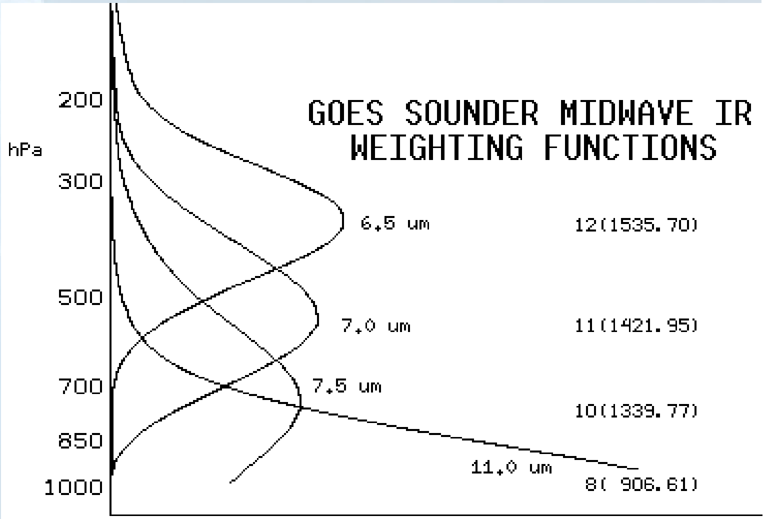


Figure 3.1: Weighting function at the four CMR-H frequencies



Corrections for finite beamwidth and mean radiating temperature

T_B : Corrected brightness temperature

Retrieval Method: 1-D VAR (Variational Assimilation Retrieval)

W: m X n matrix

m: # of measurements
n: # of altitudes at which the WV density is desired

m<n i.e. # of measurements are smaller than # of unknowns

$\rho_{v,a}$: a priori water vapor profile

: Error covariance matrix of the a priori water vapor profile

: Error covariance matrix of the measurements

Comparison of RAOB and CMR-H Retrieved Water Vapor Density Profile on Oct 9, 2007

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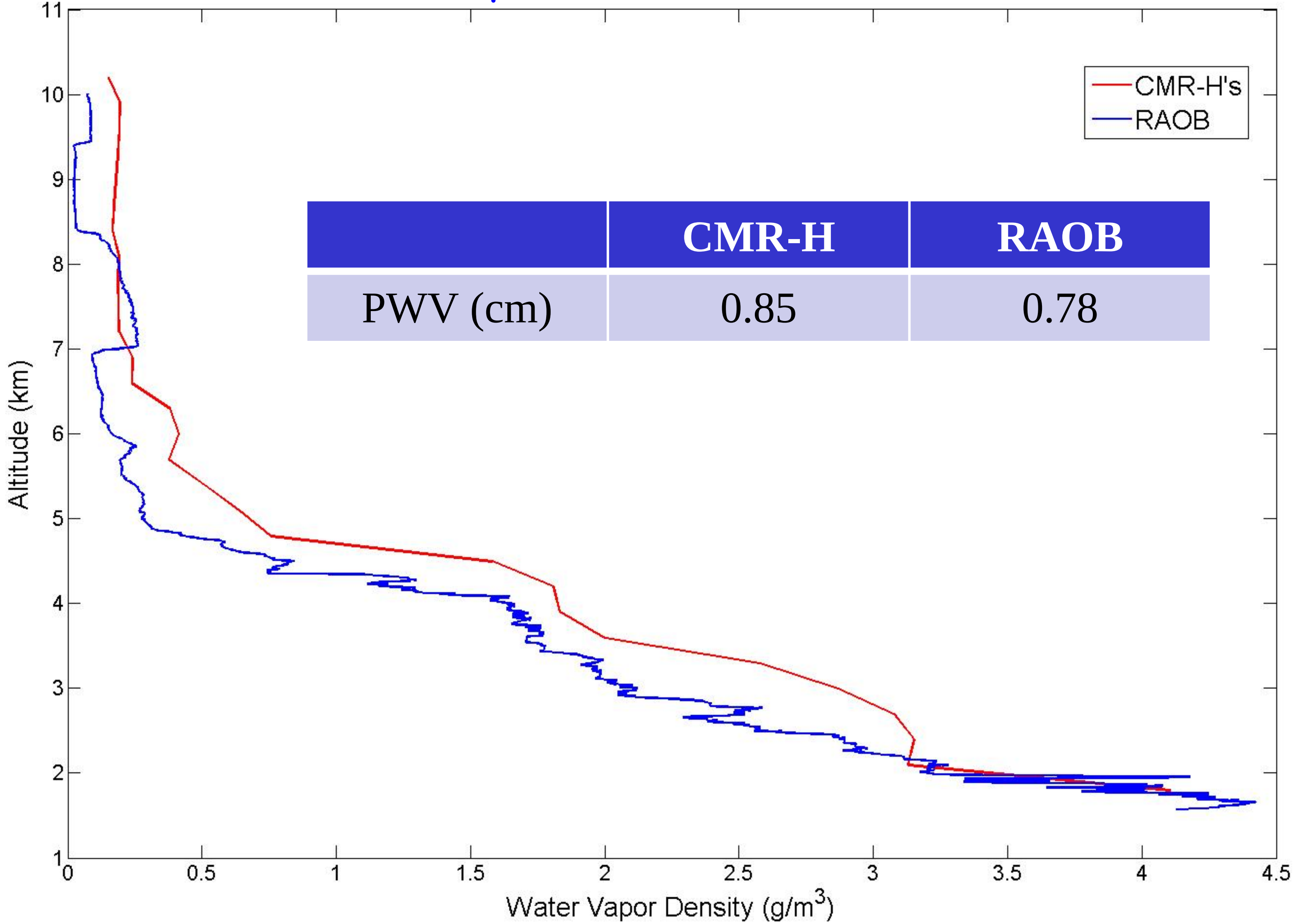
09 Oct 07 at 6 UT. A priori from Denver Station RAOB at 0 UT



	CMR-H	RAOB
PWV (cm)	0.85	0.78

Mathematical model fordescribing spatial resolution

Measurement: .... (1)

Retrieved WV: .... (2)

Retrieved WV = f(weighting function, retrieval coeff., measurement errors)

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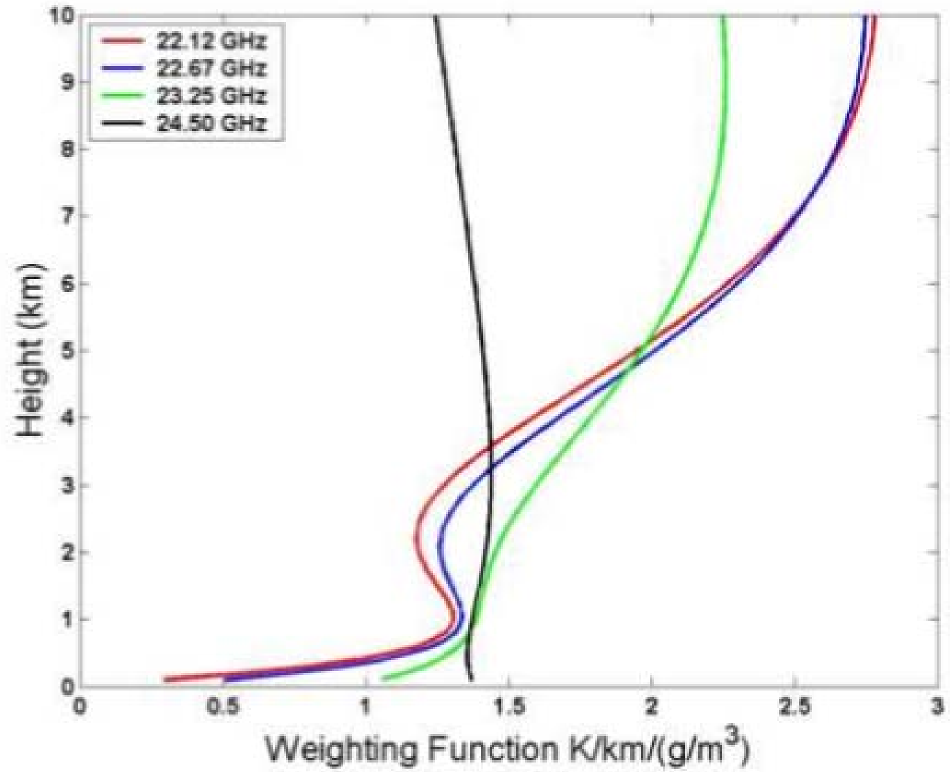
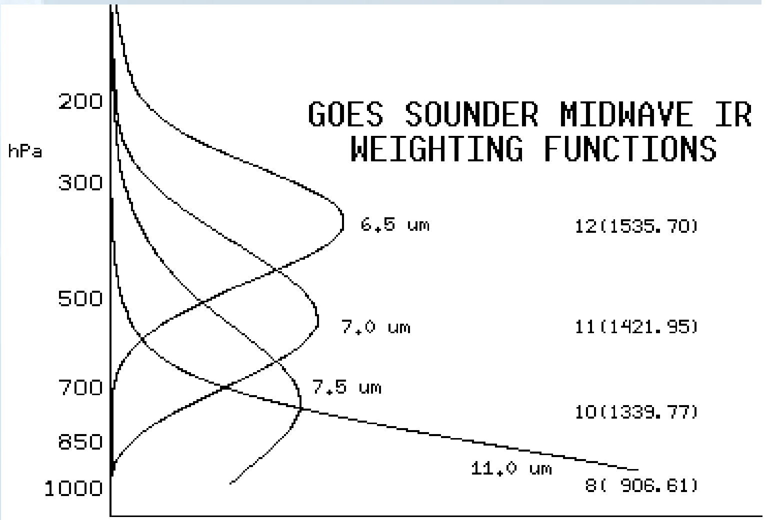


Figure 3.1: Weighting function at the four CMR-H frequencies



Improvement in resolution by adding scanning measurements to vertical pointing observations

Radiometer retrieval of temperature, RH, and liquid water content during a supercooled fog event (Knupp et al., JAOT 2009)

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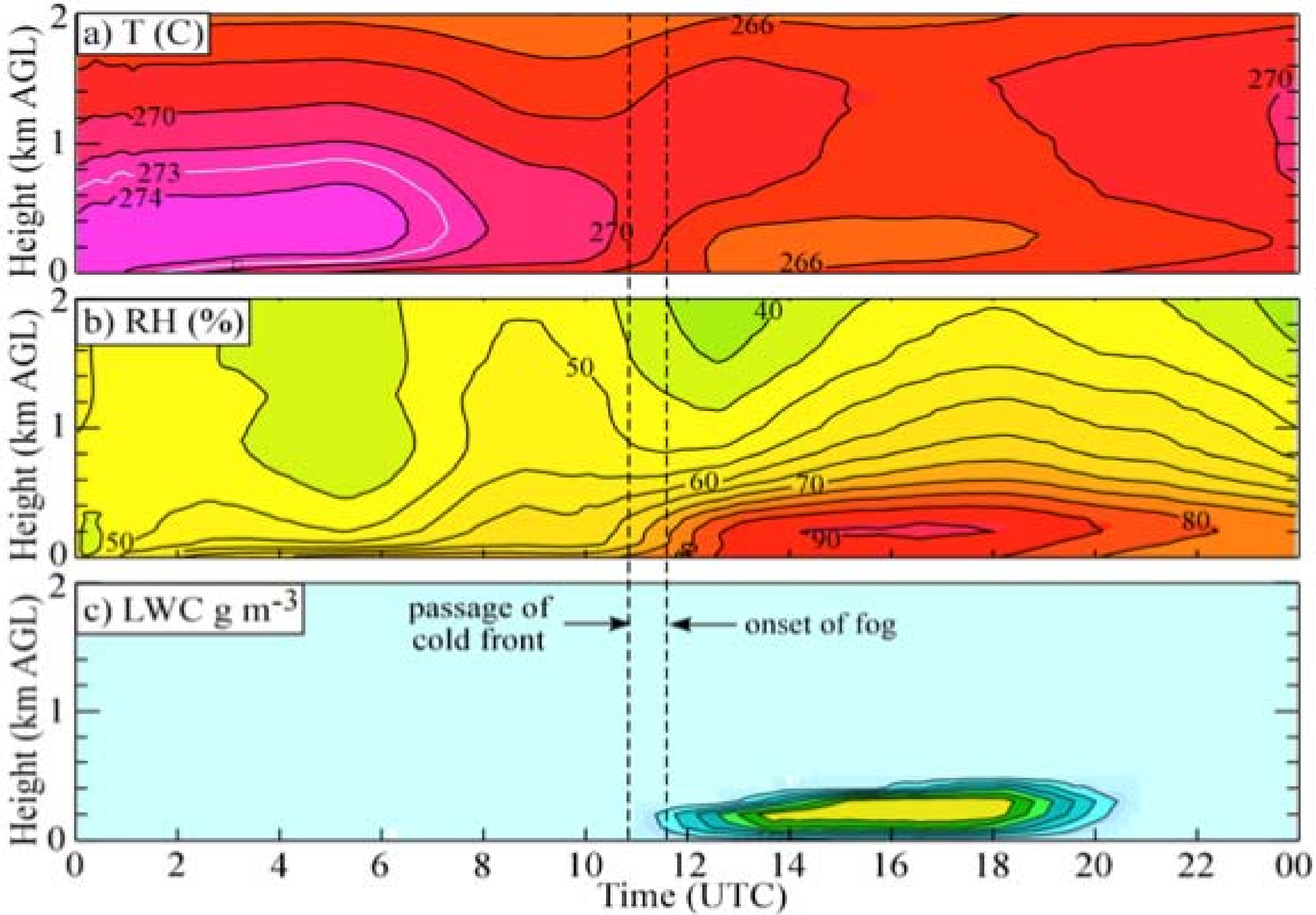
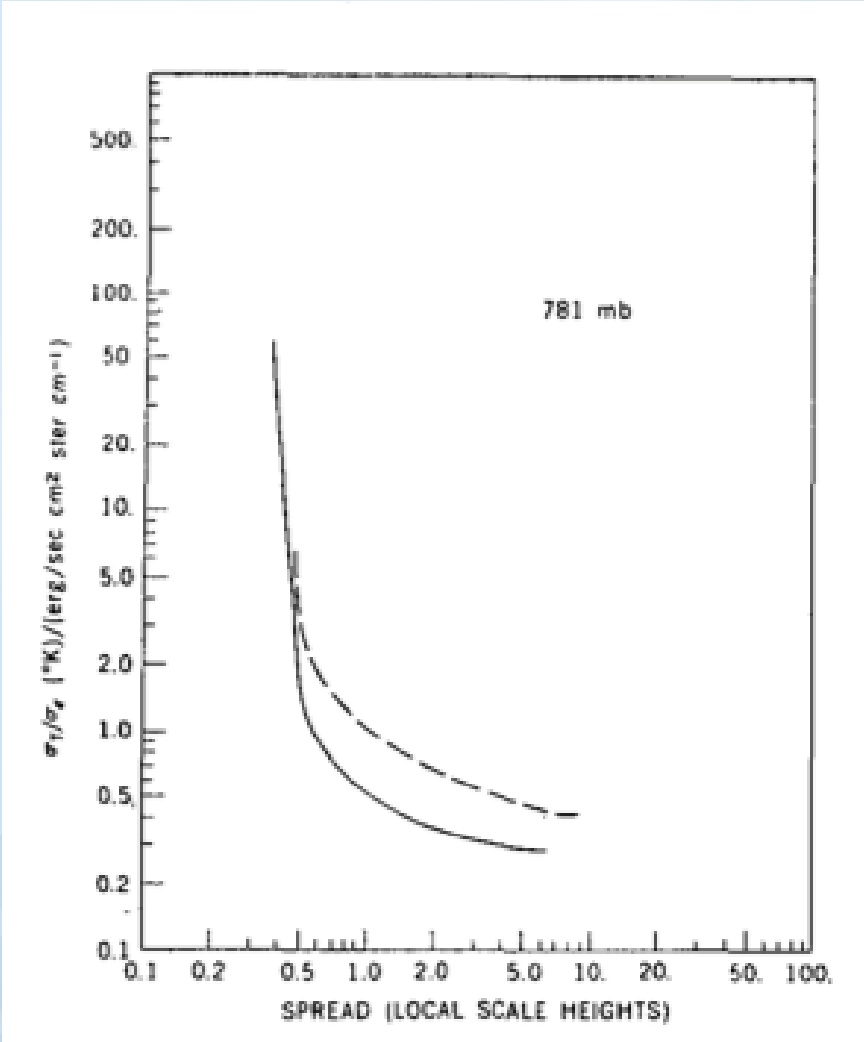


Tradeoff curve: Uncertainty vs Spatial Resolution



From Conrath,B., J., 1972, JAS

Summary

- Radiometer is capable of providing high temporal estimates of water vapor.
- Inherent spatial or vertical resolution of water vapor estimate is limited.
- Vertical resolution of the water vapor can be improved by the following:

(i) narrow-beam radiometer

(ii) 1-D Var method

(iii)including scanning measurements to vertical pointing observations

(iv) tradeoff between std. error in WV and spatial resolution

Summary of spatial and temporal resolutions

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3-D WATER VAPOR MEASUREMENT TECHNIQUES

Sensor	Horizontal Resolution (km)	Vertical Resolution (km)	Temporal Resolution (hr)	Frequency Band
GPS Ground Network	50	0.5 -1 Expected	0.5	L-band
Radiosondes	~315 km spacing	0.1-0.5	12	N/A
COSMIC	200-600	0.1 – 0.5	0.5 (2-hr lag)	L-band
AMSU-B	20	2	12	G-band (183 GHz)
Network of CMR-Hs	0.5	0.5-1	0.16-0.25	K-band

Radiation Transfer Equation

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Radiation transfer equation:

$$\frac{dI_\nu}{ds} = -I_\nu \alpha + S$$

Solution to the above:

$$I_\nu(0) = I_\nu(s_0)e^{-\tau(s_0)} + \int_0^{s0} B_\nu(T)e^{-\tau(s)}\alpha ds$$

Rayleigh-Jeans limit to Plank's function:

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1} \approx \frac{2h\nu^3}{c^2}\frac{kT}{h\nu} = \frac{2kT}{\lambda^2}$$

Microwave radiometry:

$$T_b(\theta) = T_{bg}e^{-\tau(\theta)} + T_m(1 - e^{-\tau(\theta)})$$

Mathematical model fordescribing spatial resolution

Measurement: .... (1)

Retrieval of WV: .... (2)

.... (3)

..... (4)