Integrated Raman Lidar and Microwave Radiometer Retrieval of Atmospheric Water Vapor

J. VanKerkhove[1], R. J. Sica[1], A. Haefele[2,1]
[1]Department of Physics and Astronomy, The University of Western Ontario, London, ON, Canada
[2]Federal Office of Meteorology and Climatology, MeteoSwiss, Payerne, Switzerland

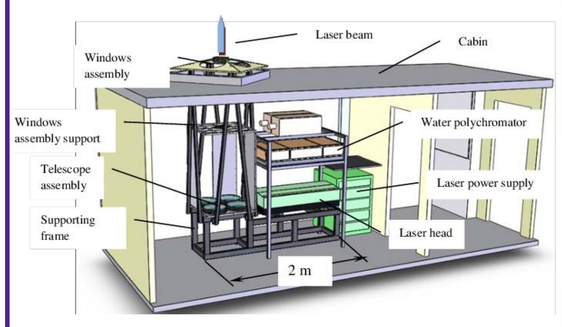
Instruments we use to measure water vapor

Instrument	Advantages	Disadvantages
Radiosonde (weather balloon)	• Widely used at meteorological stations globally (GCOS Upper-Air Network) • Launched during any weather	• Limited observation period (launched 2 times/day) • Corrections needed for low temperatures (<-40°C) and humidity (<5% RH)
Cryogenic Frostpoint Hygrometer	• Doesn't require low temperature/humidity correction	• More expensive than radiosonde (even more limited observation period) • Minor wet bias • Does not work well in cloudy skies
Raman Lidar	• Very good height (m/km)/temporal (min/hours) resolution for remote sensing instrument • Very high precision at lower altitudes	• Observes only during clear weather • External calibration needed (usually based on radiosonde)
Microwave Radiometer	• Operates all the time (except during precipitation) • Absolute calibration (hot/cold load)	• Poor height resolution (>10km)

Take-home point: No single instrument can be used for a comprehensive analysis of atmospheric water vapor!

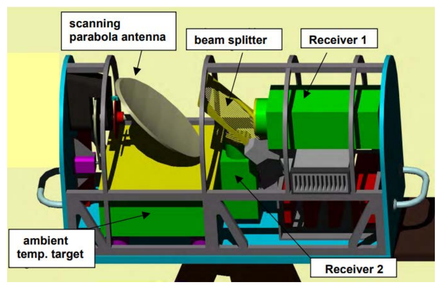
A Tale of Two Instruments

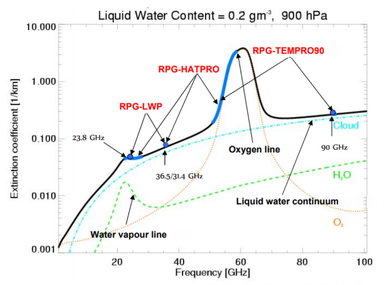
RALMO (Raman Lidar for Meteorological Observation)



Dinoev et al. 2013, [1]

RPG-HATPRO (Humidity And Temperature PROfiler)





RPG-HATPRO manual, [5]

Optimal Estimation Method Retrieval

Goal: To develop a single forward model that includes lidar and radiometer information, which uses the radiometer's total water measurement to calibrate the lidar profile continuously.

a priori information (x_a, S_a)

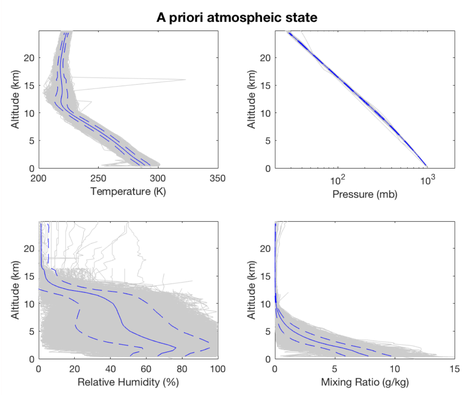


Figure: Atmospheric state data compiled from radiosonde profiles. The solid and dotted lines represent the mean profiles and standard deviation.

Determining *a priori* covariance matrix:

$$S_{ij} = \sigma_i \sigma_j \exp\left(\frac{-2|z_i - z_j|}{l_i - l_j}\right)$$

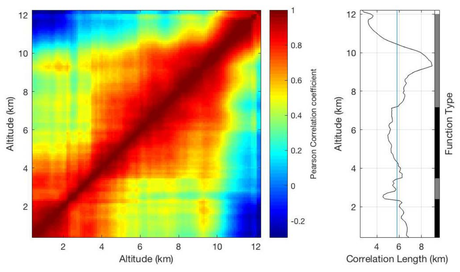


Figure: (Left) Autocorrelation of mass mixing ratio using radiosonde climatological data. **(Right)** Fit of matrix rows to determine correlation length, and function type (grey=exponential, black=tent, white=Gaussian) for the *a priori* covariance matrix.

Forward Model ($F(x,b)$, K)

Lidar: Lidar Equation

$$S_H = \frac{O T_L T_H C_H n_{air}}{z^2} e^q + B_H$$

$$S_N = \frac{O T_L T_N C_N n_{N2}}{z^2} + B_N$$

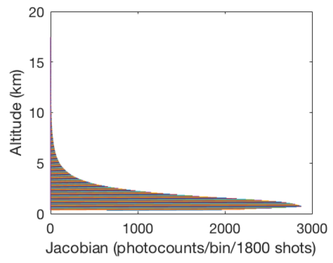


Figure: Jacobian for the photocount channels for water vapor mixing ratio.

Radiometer: Radiative Transfer Equation

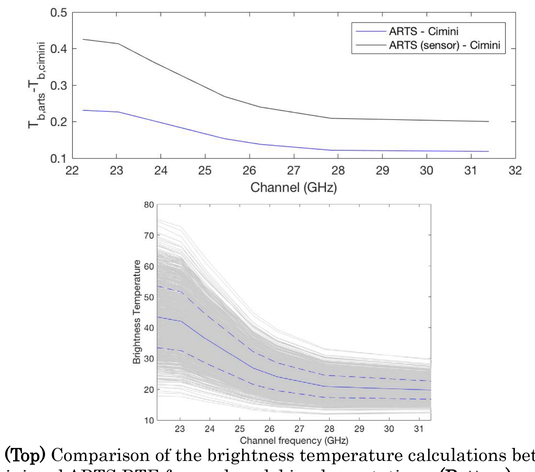
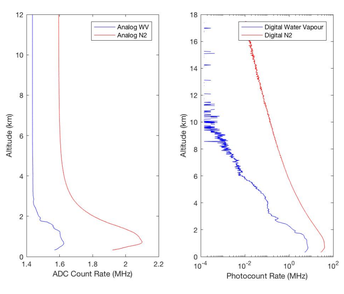


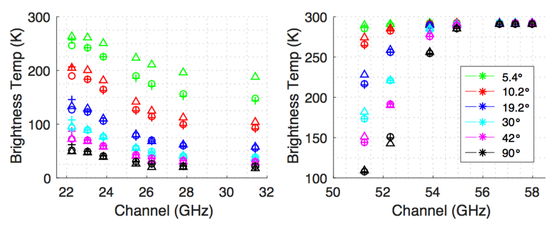
Figure: (Top) Comparison of the brightness temperature calculations between the Cimini and ARTS RTE forward model implementations. **(Bottom)** Superposition of brightness temperatures calculations using radiosonde profiles as the atmospheric state.

Measurement state (y, S_y)

Lidar: Height profiles of Raman-backscattered signal



Radiometer: Channel brightness temperatures

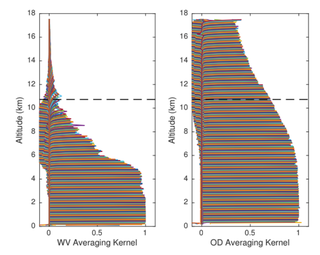


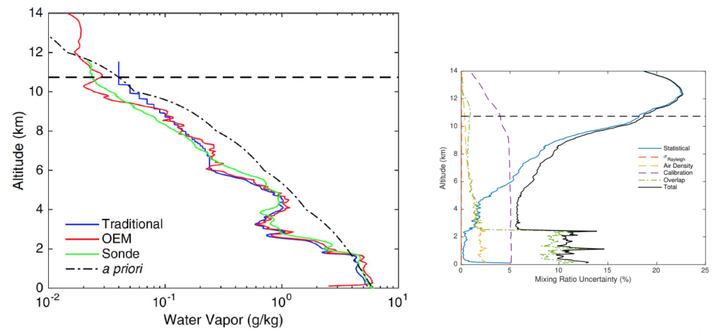
$$\hat{\boldsymbol{x}} = \boldsymbol{x_a} + \left(\boldsymbol{S_a^{-1}} + \boldsymbol{K^T S_y^{-1} K}\right)^{\boldsymbol{T}} \boldsymbol{K^T S_y^{-1}} \left(\boldsymbol{y} - \boldsymbol{F(x_a)}\right)$$

Retrieved state ($\hat{x}$)

What we want to retrieve:

- Calibrated, high-resolution height profiles of atmospheric water vapor
- Averaging Kernels
- Uncertainty budget





Sica & Haefele, 2016, [4]

Contact Info:
Jeff VanKerkhove
Purple Crow LIDAR
Department of Physics & Astronomy
University of Western Ontario
London, ON, N6A 2K7
jvankerk@uwo.ca

Sponsored by:

References:

1. Dinoev, Simeonov, & Arshshinov. Atmos. Meas. Tech., 6,1329, 2013.
2. Kampfer, N., editor. *Monitoring Water Vapour: Ground-based Remote Sensing and In-Situ Methods*, volume 10. Springer Science, 2013.
3. Rodgers, C., *Inverse Methods for Atmospheric Sounding: Theory and Practice*. World Scientific Publishing, London, 2000.
4. Sica, R. & Haefele, A. Appl. Opt., 55(4), 763, 2016.
5. Technical Instrument Manual. Radiometer Physics, RPG-MWR-STD-TM, 2013.
6. "Upper Troposphere and Lower Stratosphere (UTLS)", *Atmospheric Chemistry Observations and Modeling*, National Center for Atmospheric Research, acom.ucar.edu/utls