Continuous Humidity Profiling using Wind Profilers

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1. Objective :

Retrieval of vertical profiles of water vapour content by combining radar reflectivity (C_n^2) provided by a UHF or VHF profiler and the temperature profile either from radio soundings or Meso-NH model (MNH).

2. Methodology :

The scattering characteristics of electromagnetic waves in clear air depend on the air refractive index n, which depends on air temperature, pressure and water vapor. It is convenient to define potential refractivity Φ, analogous to the potential temperature Θ (q is the specific humidity).

$$n = 1 + 77.6\ 10^{-6}\ T^{-1}\ (p + 4800\ e / T)\ ;$$

$$\phi = 1 + 77.6\ 10^{-6}\ \theta^{-1}\ (p + 7800\ q / \theta)\ ;$$

$$M = \partial\ \phi / \partial\ z = (\partial\phi/\partial\theta\ \partial\theta/\partial z + \partial\phi/\partial q\ \partial q/\partial z)\ ;$$

$$M = -77.6\ 10^{-6}\ p\ T^{-1}\ (\ N_B^2 / g\ + 15600\ q\ N_B^2 / T\ g - 7800\ \partial q/\partial z / T\ )\ ;$$

$C_n^2 = a^2\ \alpha'\ \varepsilon^{2/3}\ N_B^{-2}\ M^2 = a^2\ \alpha''L_o^{4/3}\ M^2$

$\eta = 0.38\ \lambda^{-1/3}\ C_n^2$

The structure function of refractive index C^2_n for the turbulence echo is related with the volume reflectivity η. See besides the pertinent relationship used. The radar provides M^2 from which dq/dz can be derived, using assumptions and knowing dΘ /dz.

The humidity profile is obtained by integrating from an initial value of Q_o and Θ_o. In the present study, the temperature profile must is given by an additionnal mean such as a radiosounding or a simulation result. The following expressions are used according to the level (and then stability conditions) :

$$Q(z) = (b)^{-1} \int_{z_0}^{z} \left[\frac{dM}{dz} + a \frac{d\theta}{dz} \right] dz$$

in the atmospheric boundary layer (Gossard et al., 1982)

$$Q(z) = \int_{z_0}^{z} \left[1.65 \frac{T^2}{p} M + \frac{1}{7800} \left(\frac{dT}{dz} + \Gamma_d \right) \right] dz + \theta^2 \frac{q_0}{\theta_0^2}$$

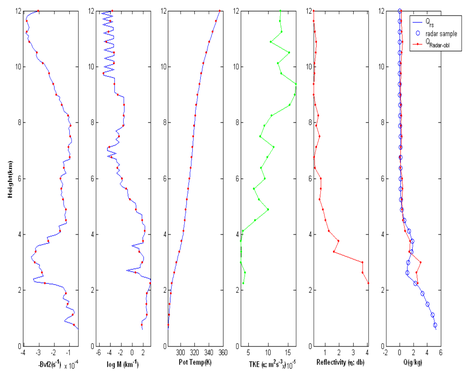
in the free troposphere (Tsuda et al., 2001).

Γ_d is the dry adiabatic lapse rate.

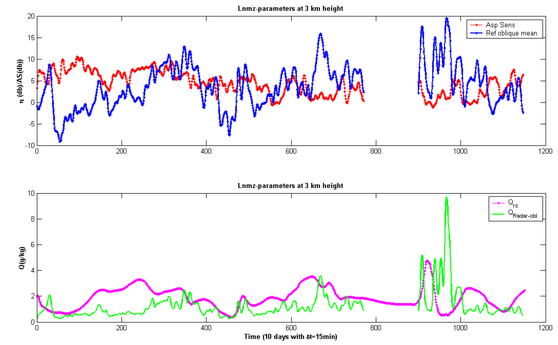
3. Error sources :

- Sign of M
- Radar calibration coefficient
- Anisotropy of the electromagnetic wave (especially with VHF radars)
- Values of constants

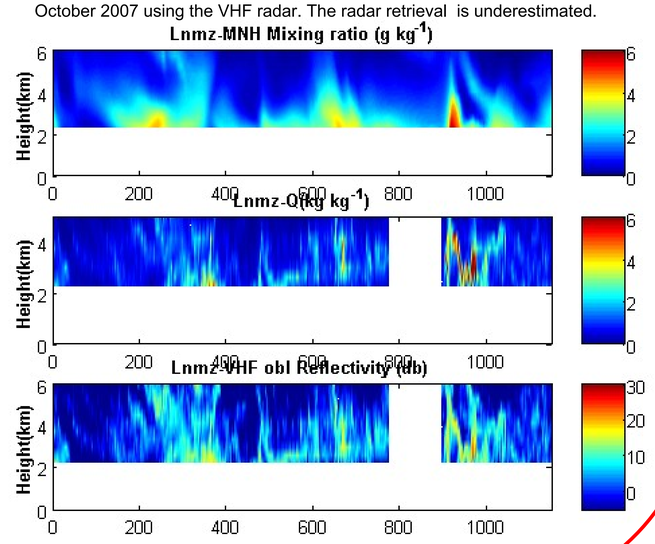
5. Results : *using* VHF radar over Lannemezan during 2007 and MNH profiles of temperature



Right profiles : an example of humidity profile obtained during 2007 with the Lannemezan VHF wind profiler (red) compared to a MNH profile (blue) during October 2007. Time and height resolutions are respectively 15' and 350m.

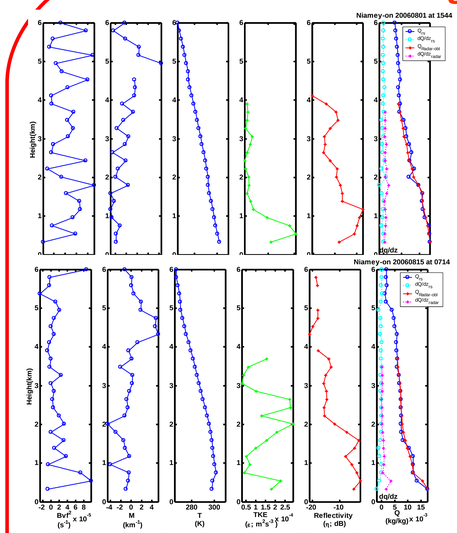


Time evolution of radar reflectivity and aspect ratio (top). Comparison of Q retrieved (green) with MNH value (pink), at 3 km over Lannemezan from 20 - 31 October 2007 using the VHF radar. The radar retrieval is underestimated.

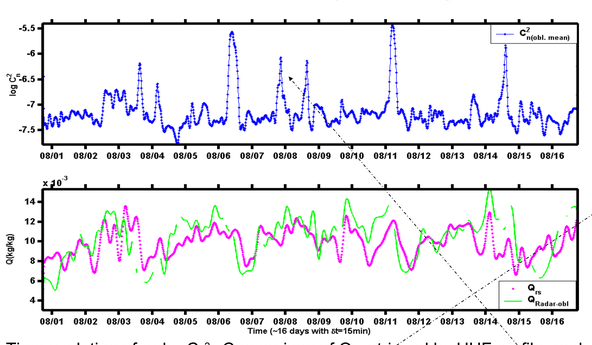


Time-height cross sections of Q profiles from radar (middle panel) and from MNH (top panel) and radar reflectivity (bottom panel) during the same period. The under estimation is confirmed. The radar needs to be corrected for anisotropy.

4. Results : *using* UHF radar over Niamey during AMMA 2006 and co-located radiosoundings

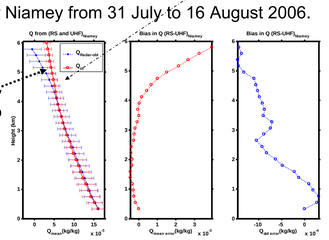


Right profiles: Some examples of humidity profiles obtained during AMMA with the ARM UHF wind profiler (red) compared to Niamey radio sounding data (blue) during August 2006. Time resolution is 15' for the radar and 3 hours for the RS. Height resolution is 210 m for the radar.

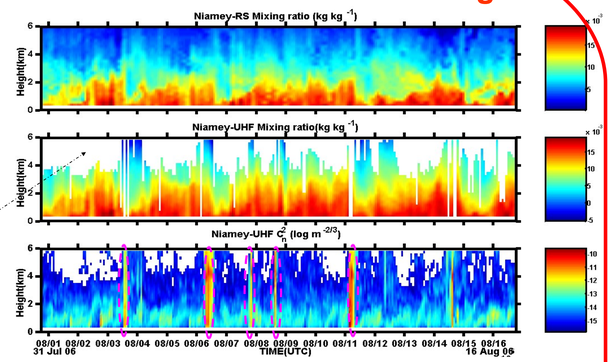


Time evolution of radar C_n^2. Comparison of Q retrieved by UHF profiler and observed at 2.2 km over Niamey from 31 July to 16 August 2006.

The large discrepancy above 4 km is due to sparse radar data there



Statistical comparison of the profiles during the 17-day period



Time-height cross sections of Q profiles retrieved and observed, and radar C_n^2 over Niamey from 31 July to 16 August 2006 using the UHF radar and RS. Over estimation of radar retrieved Q above 2.4 km can be noticed. Pink dotted circles represent precipitation events.

Spikes correspond to rainfall events. It is necessary to choose clear air radar data in order to avoid precipitation. This can be done by using a threshold on radar reflectivity and vertical velocity.

In order to obtain a better height coverage of retrieved humidity profile it is needed to use a combination of UHF and VHF radars.

6. Summary and Conclusions

- Mixed layer humidity profiles retrieved from UHF radar show good comparison with RS except slight over estimation above 2.5 km.
- In UHF or VHF radar, maximum height coverage depends on atmospheric conditions.
- During precipitation, due to change in scattering mechanism, radar reflectivity is strong and the method fails. So, care is required on selecting only clear air radar data in order to avoid precipitation using threshold on radar reflectivity and vertical velocity.
- Radiosonde or MNH meteorological profiles are necessary to provide the temperature profile. The time resolution does not need to be as good as the radar time resolution.
- Humidity retrieval procedure used for VHF radar needs to be improved using correction for echoes aspect sensitivity (anisotropy) .

References :

Tsuda, T., M. Miyamoto, and J. Furumoto, 2001: Estimation of a humidity profile using turbulence echo characteristics. *J. Atmos. Oceanic Technol.*, **18,** 1214–1222.

Gossard, E. E., R. B. Chadwick, W. D. Neff, and K. P. Moran, 1982: The use of ground-based Doppler radars to measure gradients, fluxes and structure parameters in elevated layers. *J. Appl. Meteor.*, **21**,211–226.