Humidity Profiling with a VHF Wind Profiler and GPS Measurements

Vladislav Klaus°, Joël Van Baelen*, and Yves Pointin*

(°) Centre National de Recherches Météorologiques (CNRM), Météo France, Toulouse, France
(*) Laboratoire de Météorologie Physique (LaMP), CNRS / UBP Clermont-Ferrand, France

OUTLINE

- Measurement principles and basic equations
- Implementation concerns
- Simulations using radiosondes
- The Puy de Dome framework
- Concluding remarks

Measurement principles: the Basics

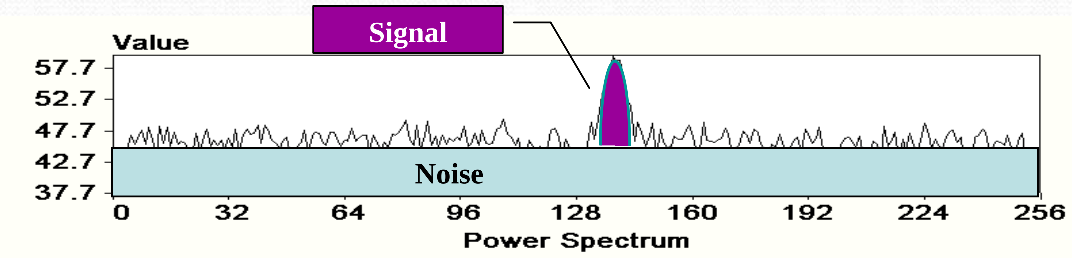
- **Radar Mesurements**

  SNR ➔ Reflectivity

  Spectral width ➔ Turbulent dissipation rate

$$\eta = \alpha . r^2 \frac{Signal}{Noise}$$

$$\varepsilon \approx 0{,}5 N \sigma^2 \quad \text{or} \quad \varepsilon = f(\sigma)$$



- **Temperature Profile -> *N***
  - Radiometer, climatology …

$$N^2 = g.\frac{d \ln \theta}{dz} = \frac{g}{T}.\left(\frac{dT}{dz} + \Gamma\right)$$

- **At least 1 humidity reference**

  (point measurement or integrated)
  - GPS, AMDAR, …

Basic Equations (part 1) (Tsuda et al., 2001)

Refractive Index Gradient : *M* → *q*

$$M = -77{,}6x10^{-6} . \frac{P}{T}\left[\frac{N^2}{g}.\left(1 + 15600\frac{q}{T}\right) - \frac{7800}{T}\frac{dq}{dz}\right]$$

$$\frac{dq}{dz} - \left(\frac{2N^2}{g}\right) q = 1{,}652\frac{T^2}{P} M + \frac{T}{7800}\frac{N^2}{g}$$

Where: $N^2 = g.\frac{d \ln \theta}{dz} = \frac{g}{T}.\left(\frac{dT}{dz} + \Gamma\right)$

$$q(z) = \theta^2 \left\{ \int_{z0}^{z} \left[1{,}652\frac{T^2}{P} M + \frac{1}{7800}\left(\frac{dT}{dz} + \Gamma\right)\right] \theta^{-2} dz + \frac{q_0}{\theta_0^2} \right\}$$

Radar Mesurements → *M*

$|M| = K L_0^{-2/3} \eta^{1/2}$ (Gage and Balsley, 1980)

$|M| = K' F^{1/2} N \varepsilon^{-1/3} \eta^{1/2}$ (Tsuda et al., 2001)

L_0 = External Scale (constant ?)

F = Filling Factor (constant ?)

Signe of *M* ? (> 0 si N^2 < threshol)

Basic Equations (part 2) (Stankov et al., 2003)

Potential Refractivity Gradient : $\varphi \rightarrow q$

(Gossard et al. 1995)

$$\phi = \frac{77{,}6\, p_r}{\theta}\left(1 + \frac{7{,}73\, q}{\theta}\right)$$

$$\frac{\partial \phi}{\partial \theta} = -\frac{77{,}6\, p_r}{\theta^2}\left(1 + 15{,}46\frac{q}{\theta}\right) = -a_0$$

$$\frac{\partial \phi}{\partial q} = 77{,}6\, p_r \frac{7{,}73}{\theta^2} = b_0$$

Estimated from Standard Atmosphere

$$\frac{d\phi}{dz} = \frac{\partial \phi}{\partial \theta}\cdot\frac{d\theta}{dz} + \frac{\partial \phi}{\partial q}\cdot\frac{dq}{dz}$$

$$\frac{dq}{dz} = \left[\frac{d\phi}{dz} + a_0\frac{d\theta}{dz}\right].b_0^{-1}$$

$$q(z) = \int \quad q(z_0) + [\varphi(z) - \varphi(z_0) + a_0(\theta(z) - \theta(z_0))].b_0^{-1}$$

Radar Measurement → ϕ

(Gossard et al., 1982)

$$\left(\frac{d\phi}{dz}\right)^2 = \frac{C_\varphi^2}{C_w^2}\left(\frac{L_w}{L_\varphi}\right)^{4/3} S^2$$

Structure Parameters

$$C_\phi^2 = \frac{\eta}{0.38}\lambda^{1/3}$$ Potential Refractivity

$$C_w^2 \approx 2.80\,\varepsilon^{2/3}$$ Vertical Velocity

External Scale

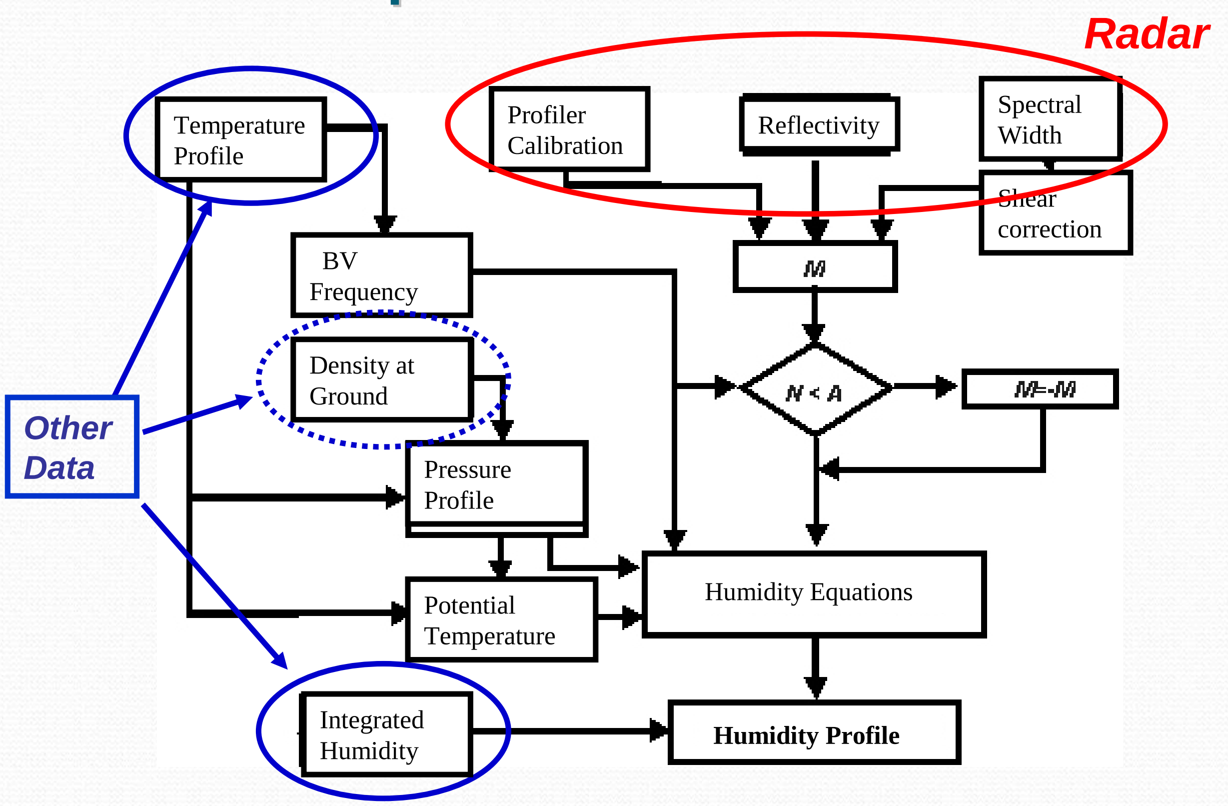
$$L_w / L_\varphi \approx 2 \leftrightarrow 6$$

Lw : for Vertical Velocity

Lφ : for Potential Refractivity

Horizontal Wind Shear: *S*

Practical Implementation Flow Chart



Practical Implementation:Example

$q(z)$ Equation

$$q(z)=\theta^2\left\{\int_{z0}^{z}\left[1{,}652\frac{T^2}{P}M+\frac{1}{7800}\left(\frac{dT}{dz}+\Gamma\right)\right]\theta^{-2}dz+\frac{q_0}{\theta_0^2}\right\}$$

$$q(z)=1{,}652\,\theta^2\int_{z0}^{z}\frac{T^2M}{P\,\theta^2}dz+\frac{\theta^2}{7800\,g}\int_{z0}^{z}\frac{T\,N^2}{\theta^2}dz+\theta^2\frac{q_0}{\theta_0^2}$$

Radar :

$$M_{atm}=K\,M_{radar}=K\,M$$

$$q(z)=K\,a_0(z)+b_0(z)+c_0(z)q_0$$

+ Integrated form : $qt=K\,A_0+B_0+C_0\,q_0$

2 unknowns: *K* et q_0 → 2 references needed

If *qt* and *q(zi)* known:

$$K=\frac{[q(z_i)-b_0(z_i)].C_0-[qt-B_0].c_0(z_i)}{a_0(z_i).C_0-A_0.c_0(z_i)}$$

$$q_0=\frac{-[q(z_i)-b_0(z_i)].A_0+[qt-B_0].a_0(z_i)}{a_0(z_i).C_0-A_0.c_0(z_i)}$$

If *q(zi)* and *q(zj)* known:

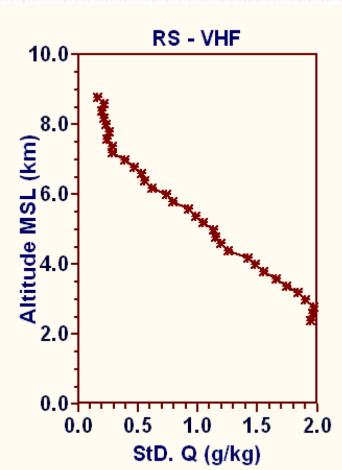
$$K=\frac{[q(z_i)-b_0(z_i)].c_0(z_j)-[q(z_j)-b_0(z_j)].c_0(z_i)}{a_0(z_i).c_0(z_j)-a_0(z_j).c_0(z_i)}$$

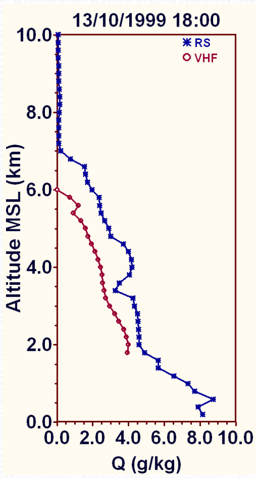
$$q_0=\frac{-[q(z_i)-b_0(z_i)].a_0(z_j)+[q(z_j)-b_0(z_j)].a_0(z_i)}{a_0(z_i).c_0(z_j)-a_0(z_j).c_0(z_i)}$$

Simulations using RS (MAP 99)

1 reference value:

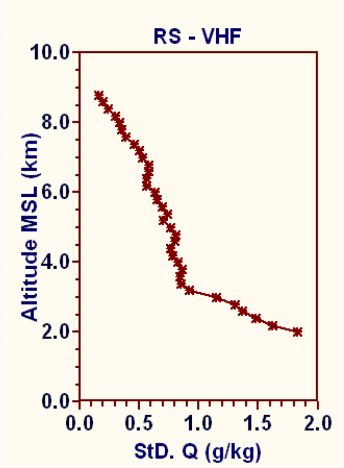
- *Q* ≈ 0 at 9 km height

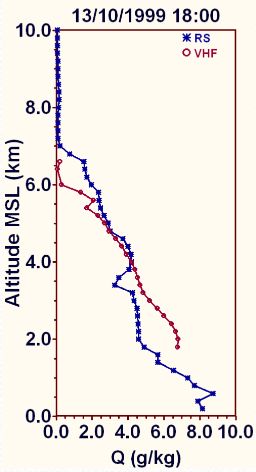




Simulations using RS (MAP 99)

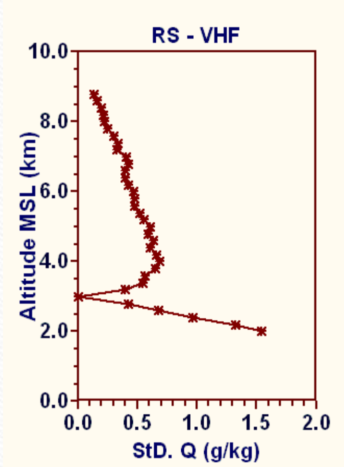
2 reference values:
- $Q \approx 0$ at 9 km height
- + total Q

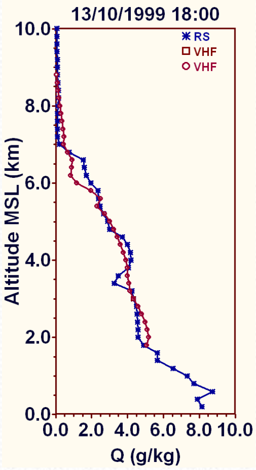




Simulations using RS (MAP 99)

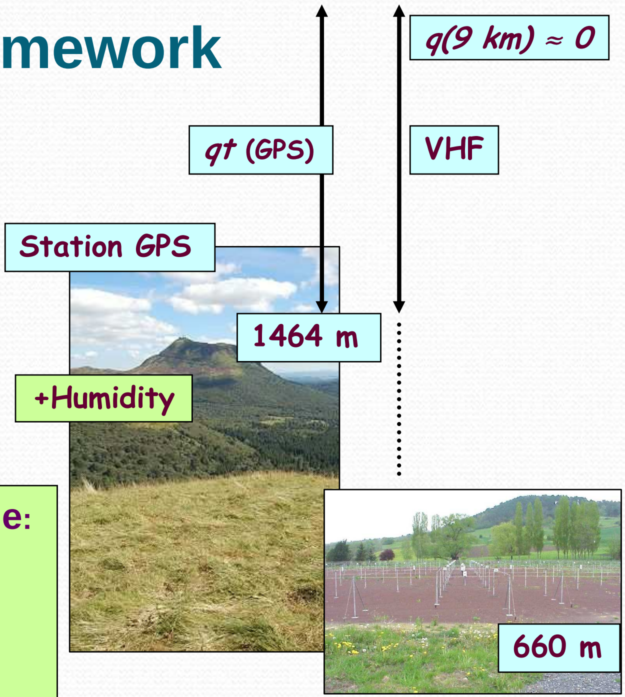
3 reference values:
- $Q \approx 0$ at 9 km height
- + total Q
- + Q at the base of the radar range (3 km in our example)





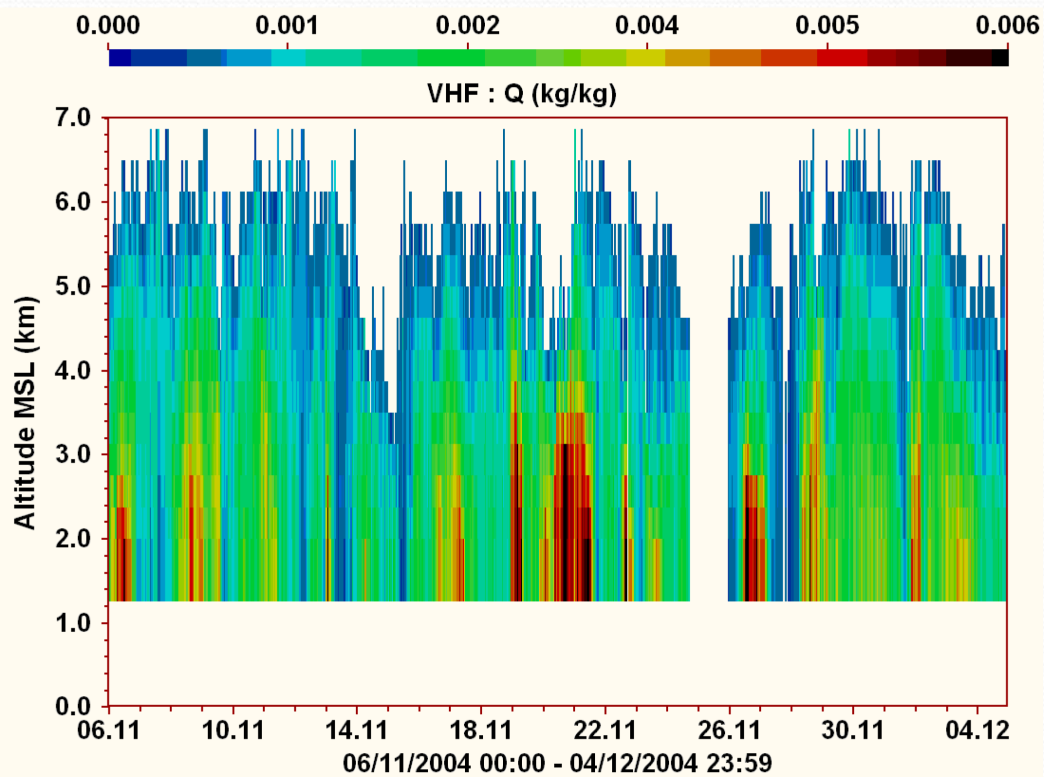
The puy de Dôme Framework

- VHF Profiler At Ompe
  - ⬄ Hypothesis $q(9\text{ km}) \approx 0$
- Temperature Profile (Climatology)
- Profiler first gate <u>and</u> GPS station at puy de Dôme
  - ⬄ $qt = qt$ (GPS)
- ➔ Humidity Profile

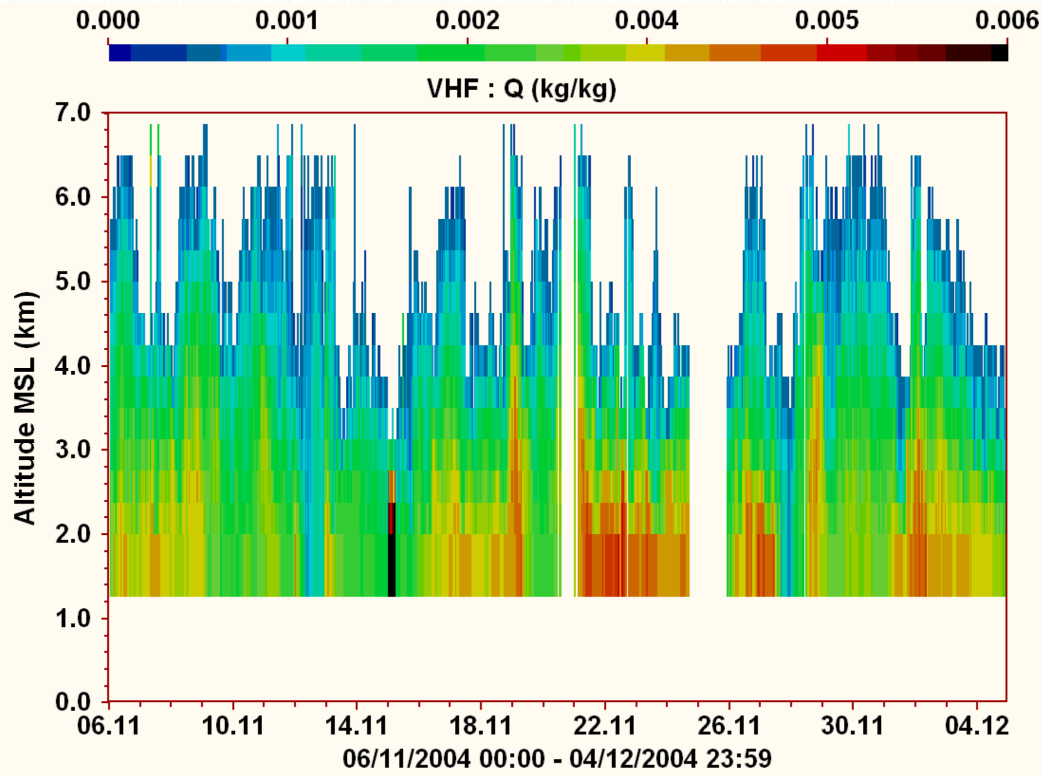


- + Humidity sensor at puy de Dôme:
  - Comparison possible between:
    - $(qt - q_{zi})$ and $(q_{zi} - q_{zj})$
    - Control of hypothesis coherency
  - Possibility to use
    - 3 equations with 3 unknowns: qt, $q(zi)$ and $q(zj)$
    - Allowing either
      - L0(z) (Gossard, Tatarskii)
      - F(z) (Tsuda)

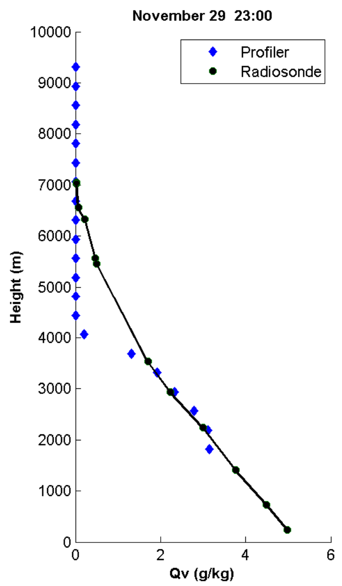
First Results: 6 Nov – 04 Dec 2004 -- (qt, q_{zi})

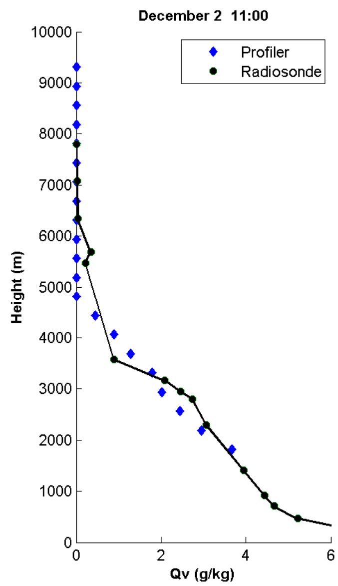


First Results: 6 Nov – 04 Dec 2004 -- (qt , q_{zi}, q_{zj})



RS Comparisons (Lyon 160 km to East)

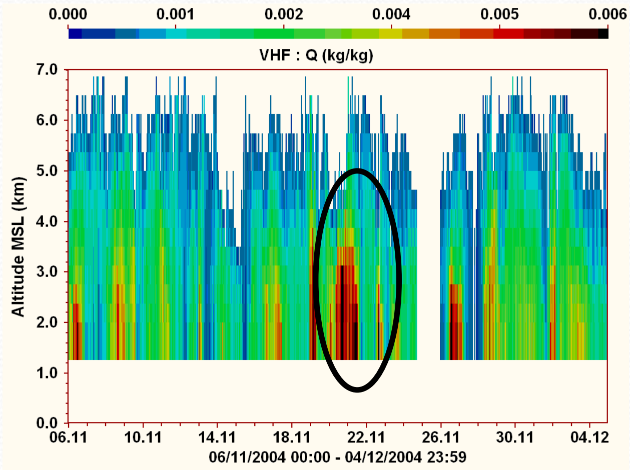




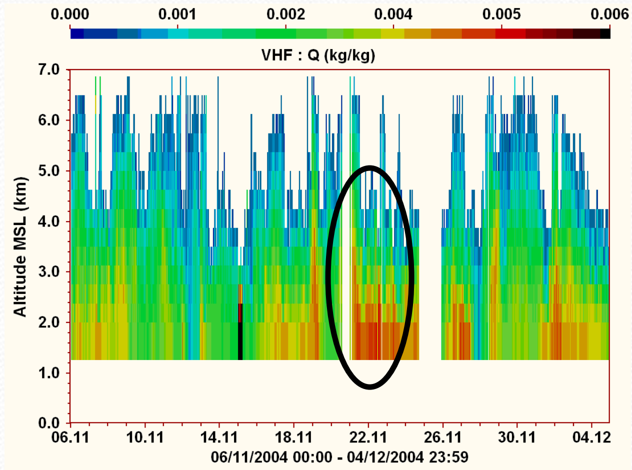
Using **(qt , q_{zi}, q_{zj})** results

Some discrepancies between results !

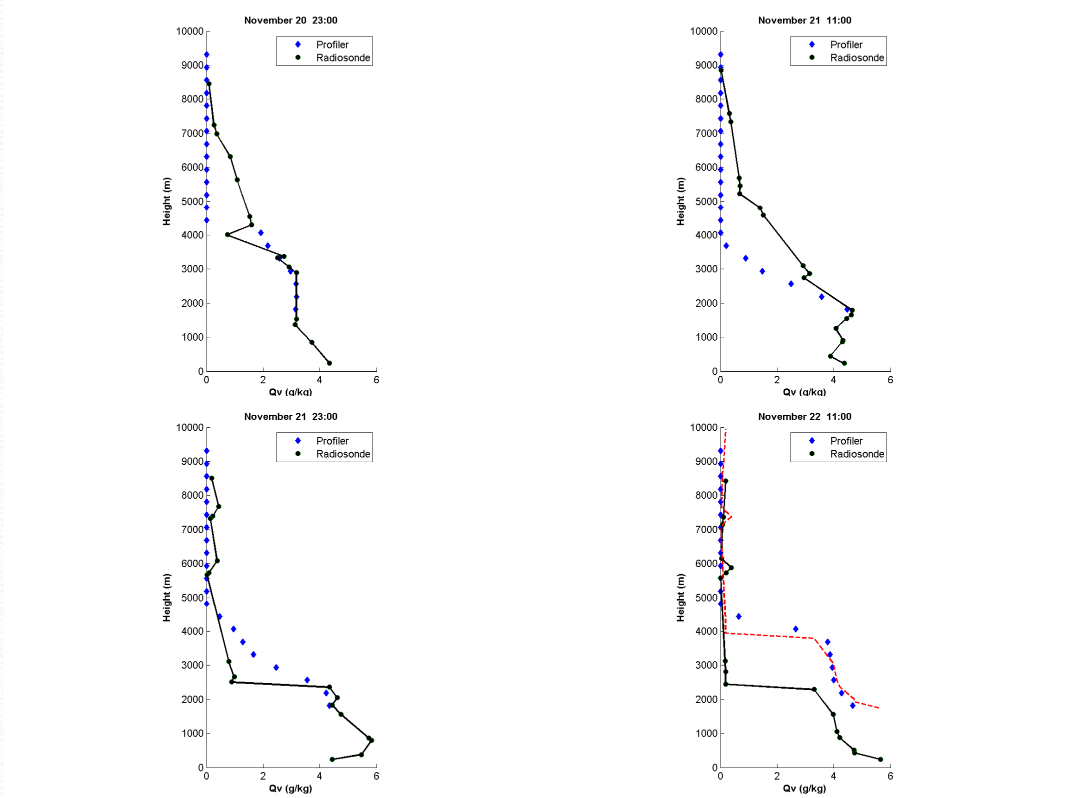
With (***qt, qzi***)



With (***qt , qzi, qzj***)



RS Comparisons with (*qt , qzi, qzj*)



Conclusions

- The Puy de Dôme geographical configuration is optimum to test the synergy between :
  - VHF profiler and GPS (*qt*)
  - VHF profiler, GPS (qt) and In situ humidity sensor ($q_{Puy\ Dome}$)

  in order to retrieve the humidity profile

- Preliminary results are encouraging:
  - 3 parameter retrieval seems to improve restitution of humidity profile
  - BUT… detailed testing and statistical comparison between different approaches still underway,
  - … need to understand differences with RS

- Future developments include:
  - Comparison of humidity profiles retrieved with local Raman Lidar
  - Measured temperature profile VS climatology based
  - Real time application to get model analysis monitoring feedback, for future assimilation
  - Increased altitude coverage towards BL with UHF profiler and local GPS network

Thank You for your Attention…

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