Water vapour Raman lidar and microwave profiler: comparisons and synergies

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CNR-IMAA Water vapour Raman Lidar

**LASER: Nd:YAG laser (Coherent – Infinity)**
- Max. Pulse Energy@ 355nm: 170mJ
- Maximum repetition rate: 100Hz
- Beam divergence: <0.3 mrad
- Pulse duration: 3 ÷ 4 ns

**RECEIVING SYSTEM: Cassegrain telescope**
- Primary mirror diameter: 0.5 m
- Combined focal length: 5 m
- Night-time field of view: 1 ÷ 2 mrad
- Daytime field of view: 0.2 mrad

**SPECTRAL SELECTION: interferential filter**
- Wavelengths (nm): 386, 407, 355
- Out of band rejection: <10^{-10}, <10^{-8}, <10^{-6}
- Night-time bandwidth (nm): ~1.0, ~1.0, ~1.0
- Daytime bandwidth (nm): ~ 0.5, ~ 0.3, ~ 0.5
- Transmission efficiency: ~ 60%, ~ 60%, ~ 33%

**DETECTORS: photomultiplier**
- THORN EMI 9202 QB355, 386, 407 nm

**ACQUISITION: photon counting mode**
- EG&G MCS - PCI
  - Minimum dwell time: 100 ns
  - Bandwidth: 150 MHz
  - PHILLIPS SCIENT. Fast discriminator
  - Bandwidth: 300 MHz
CNR-IMAA Water vapour Raman Lidar

**Measurements**

- Operative since May 2002
- 2 measurements per week are systematically performed
- Since November 2006 systematic measurements performed with PEARL (Potenza EARlinet lidar)

**Involvements**

- Validation of ENVISAT/MI PAS water vapour product
- NDACC (The Network for the Detection of Atmospheric Composition Change) for UT/LS water vapour monitoring

**Measurements Campaigns**

- EAQUATE campaign (6-10 September 2004)
- LAUNCH campaign (September - October 2005)
CNR-IMAA Water vapour Raman Lidar

Water Vapor profiles characteristics

Night time measurements
60 m - 12000 m a.l.s.
15-150 m vertical resolution
10 minutes temporal resolution

Daytime measurements
90 m - 4500 m a.l.s.
15 m vertical resolution
10 minutes temporal resolution

11 November 2002

Lidar 19:48-19:57 UT
Sonda 19:52 UT

02 October 2005

Lidar 12:07-12:17 UT
Sonde start 12:12 UT
- Routine comparisons with numerical models (CloudNET)
- Long time series of measurements (campaigns, special events)
- Improvement of model parameterization
The microwave profiler measures the sky brightness temperature at 12 frequencies:

- 5 frequencies are in the K-band (22.235, 23.0335, 23.835, 26.235, 30 GHz), around 22 GHz water vapour resonance band;
- 7 frequencies are in the V-band (51.250, 52.280, 53.850, 54.940, 56.660, 57.290, 58.800 GHz), around 60 GHz spin-rotation oxygen band.

**Rate:** > 12 s  
**Accuracy:** 0.5 K  
**Resolution:** 0.25 K  
**Range:** 0 - 700 K  
**Operational range:** -20° - 50° C  
**Scanning capabilities:** 3D sky  
**Beam width:** 6.3° at 22.2 GHz, 4.9° at 30 GHz, 2.5° at 51.3 GHz and 2.4° at 58.8 GHz (full width half power)

**Output products** (Neural network retrieval)  
Temperature, water vapour, relative humidity and cloud liquid water profiles up to 10 km above the ground

Vertical step: 100 m from 0 to 1 km, 250 m above up to 10 km

**Ancillary parameters.**  
Cloud base temperature measured using an infrared thermometer (IRT).  
Surface meteorological parameters (T, RH, p)

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**CNR-IMAA Water vapour Microwave profiler**

**Courtesy of Radiometrics Corporation, Boulder, CO, USA**

**WG1 Workshop WaVaCS – Lindenberg 21 -23 May 2008**
CNR-IMAA Water vapour Microwave profiler

Measurements

✓ Operative since February 2004
✓ Continuous measurements (24h, 7 days per week)

Involvements

✓ CloudNET
✓ Departement of the Italian Civil Protection

Measurements Campaigns

✓ EAQUATE campaign (6-10 September 2004)
✓ LAUNCH campaign (Ziegendorf, Germany, August - October 2005)
✓ COPS (Hornisgrinde, Germany, June - August 2007)
CNR-IMAA Water vapour Microwave profiler

- Comparisons with numerical prediction models (DWD - Lokall Modell) are routinely performed.
- Operational measurements (special scanning strategies)
- Intercomparison campaign
Comparisons

- Differences in the resolution
- Microwave continuous measurements
- Possible synergies and integration LIDAR – Microwave profiler
Calibration

Vaisala radiosonde RS80, RS90 and RS92 PTU measurements (also wind speed/direction for RS92)

Calibration campaigns with co-located radiosondes

More than 200 radiosonde launches since May 2002

Calibration is checked systematically with radiosondes

Continuous monitoring of Raman lidar calibration constant stability

The IPWV retrieved using the neural network algorithm is used to calibrate the water vapour Raman lidar profile

• Calibration factor results constant within 5%
Case study: 30 Sep – 03 Oct 2005

- Presence of a dry intrusion around 5 km a.g.l.
- Minimum penetration level 2.5 km a.g.l. with a minimum value of the WVMR of 0.16 g/kg and a corresponding RH of 16 %.
- Strong uplift of moisture structures up to 7.5 km a.g.l. after the passage of the intrusion.
Case study: 30 Sep – 03 Oct 2005

- Intrusion of a dry layer coming from about 5.5 km a.g.l. and moving down to less than 2 km on 2 October 2005.
- At 00:00 UTC on 2 October, the lidar resolves three distinct dry layers.
- The highest layer is characterized by a minimum WVMR of 0.18 g/kg and a maximum penetration level of 1.75 km a.g.l. where a WVMR value of 0.46 g/kg is measured.
Case study: 30 Sep – 03 Oct 2005

- Images from the VISSR (on board of Meteosat) water vapour channel at 5.7 - 7.1 µm for 28 September 2005 (a), 29 September 2005 (b), 30 September 2005 (c) and 1 October 2005 (d) at 06:00 UTC (Courtesy of University of Dundee).
Integration techniques

- Kalman filter integration *MODULAR* scheme

- Low time consuming
- Second-Order effects in the retrieval
- Expansion to other profilers
Integration techniques

• Extended Kalman filter integration (1 Filter)

- FIRST GUESS
- TIME UPDATE
- RTM
- FOEKF MEAS. UPDATE
- FINAL GUESS
- RH (MWP)

• High time consuming
• Integration
• Expansion to other profilers – Higher computational burden
• Technique to reduce the burden

Work in progress.....

- COPS (Intensive scanning measurements)
- CloudNET (Raman lidar, microwave profiler, ceilometer)
- EuroClouds proposal
Thank you
Case study: 30 Sep – 03 Oct 2005

- Potential vorticity at 300 hPa surface (in PVU, 1 PVU = 10^-6 m^2 s^-1 K kg^-1) on 28 September 2005 at 06:00 UTC from 31-level ECMWF analysis with 1.125° resolution.
Interpolated time series of the potential temperature retrieved using the pressure and temperature profiles measured with the radiosoundings performed at Lindenberg observatory on 30 September 2005.
Integration: preliminary results

CASE I: 26-27/02/2006 (Night time)
Optical depth in the last 10 minutes is 0.03

The time variation of the lidar ratio can be correlated to the cloud phase next to its base.
Synergy

WG1 Workshop WaVaCS – Lindenberg 21 -23 May 2008
Temperature – 20 June 2007

Graphs showing temperature and height data for MP3014 and other identifiers at different times.
Temperature – 24 August 2007

Graphs showing temperature (K) versus height (m a.s.l.) for different times:
- MP3014 RS 05:32
- MP3014 RS 07:56
- MP3014 RS 10:58
- MP3014 RS 13:56
- MP3014 RS 17:01
Humidity – Models (15 July 2007)

Met Office NAE (North Atlantic and European) model

MP3014 CNR-IMAA microwave profiler
Humidity – Models (20 July 2007)

Met Office NAE (North Atlantic and European) model

MP3014 CNR-IMAA microwave profiler
Humidity – Models (01 August 2007)

Met Office NAE (North Atlantic and European) model

MP3014 CNR-IMAA microwave profiler
Cloudnet is an European pilot network of stations for clouds profiles observation.

The EU CloudNET project offers an extended database of water vapor profiles provided by five operational forecast models of ECMWF, the MetOffice, MeteoFrance, KNMI and DWD.

<table>
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<th>Horizontal Resolution</th>
<th>Temporal Resolution</th>
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COMPARISON APPROACH

1. Lidar high resolution profiles are reduced into a large grid boxes: vertical and temporal resolution are reduced to those of the model.

2. The new time grid is calculated on the base of wind speed to take into account the advection time.

3. Only lidar data with a total error less than 20% are considered.

Long record of measurements (about 30 hours) has been collected at CNR-IMAA on 1-3 October 2005, during the LAUNCH 2005 international campaign.
COMPARISON APPROACH - AN EXAMPLE

Lidar at ECMWF model grid

Lidar at MeteoFrance model grid

ECMWF model data

MeteoFrance model data
More quantitative comparison can be carried out in terms of the probability density function (pdf) calculated for both models and lidar data reduced at models resolutions in different altitude ranges.
LONG TERM COMPARISON

✓ Sistematic comparison has been performed between lidar data and models.

✓ 1 comparison per month is carried for September 2002 - February 2006 period.

✓ The longest measurements run is chosen for each month.

✓ Models and lidar data reduced at models grid are collected for different altitude ranges.

✓ Lidar and models Pdf are compared for 0-2 km, 2-4 km, 4-6 km, 6-8 km altitude ranges.
LONG TERM COMPARISON – ECMWF

3 modes are slightly shifted in ECMWF

Higher values occurrences underestimated by ECMWF

Pdf shape is generally well reconstructed in each interval
LONG TERM COMPARISON – 6-8 km Altitude Range

Lidar Measurements

DWD model

Frequency of occurrences

Water Vapor Mixing Ratio (g/kg)

MetOffice model

Frequency of occurrences

Water Vapor Mixing Ratio (g/kg)

MeteoFrance model

Frequency of occurrences

Water Vapor Mixing Ratio (g/kg)

SMHI L40 model

Frequency of occurrences

Water Vapor Mixing Ratio (g/kg)

Pdf well reconstructed, but larger pdf for observed wv high values

87TH AMS ANNUAL MEETING
LONG TERM COMPARISON – 4-6 km Altitude Range

DWD

MeteoFrance

MetOffice

SMHI L40

Pdf well reconstructed, but larger pdf for observed wv high
LONG TERM COMPARISON – 2-4 km Altitude Range

- **DWD**: Two modes observed. DWD overestimates the center of the 2nd mode.
- **MeteoFrance**: Observed values in 0–8 g/kg range. Model underestimates occurrences of high values.
- **MetOffice**: Lidar Measurements. Pdf shape well reconstructed.
- **SMHI L40**: Lidar Measurements. Pdf shape well reconstructed.

87th AMS Annual Meeting

SAN ANTONIO, TX 14 JANUARY — 18 JANUARY 2007
LONG TERM COMPARISON – 0-2 km Altitude Range

Fair agreement, but large differences for each model exist.
PRELIMINARY RESULTS

4-6 km and 6-8 km altitude ranges

Pdf is well reconstructed even if data show also higher wv values that models do not forecast

2-4 km altitude range

Pdf shape is well reconstructed.
2 modes are observed on DWD grid, but DWD overestimates the 2nd mode center.
MeteoFrance and ECMWF underestimate occurrences of values > 2 g/ kg

0-2 km altitude range

Fair agreement in terms of pdf, but large differences for each model exist.
FUTURE PLANS

✓ Investigation of possible seasonal behavior of differences in model/observed data

✓ Classification of data in cases with and without Free Troposphere humid layers

✓ Extending comparison dataset adding further data