Calibrating measurements of precipitable water vapour

F. Kerber et al.

European Southern Observatory

at Site 2010 Kislovodsk

Collaboration

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- **U. Valparaiso**
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- **GMT, Las Campanas**
  - **J. Thomas-Osip, G. Prieto**
- **TMT**
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- **ESO**
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Outline

- **PWV - why & how**
- **E-ELT site testing**
- **Goals**
- **Archival data - reconstructing the past**
- **PWV campaigns - what we have learned**
- **Results**

Atmospheric Water Vapour

- **Precipitable water vapour (PWV)**
  - **column of atmospheric water [mm]**
  - **crucial for atmospheric opacity in IR**
  - **Long-term: site quality**
  - **Short-term: operational issue**

E-ELT site testing

- **PWV is one factor for site selection**
- **Better understand atmospheric PWV**
  - **Variability**
  - **Calibrate measurements**
- **La Silla & Paranal well-established sites**
- **Report to Site Selection Advisory Committee**

Goals:

- **Reconstruct Record of Precipitable Water Vapour (PWV) over Paranal & La Silla**
- **Correlate with satellite data to establish Paranal & La Silla as reference sites for E-ELT site evaluation**
- **Evaluate merit of methods for operational use at observatory**

Reconstructing the PWV History

- **La Silla Paranal**
  - **UVES & FEROS**
- **Standard Star Observations**
  - **White dwarfs - featureless spectrum**
  - **Taken every UVES night; ~1200 observations useable**
  - **Time coverage: 2000-2009**
  - **Wide slit: 5/10 arcsec**
  - **UVES reprocessing with master calibration files**

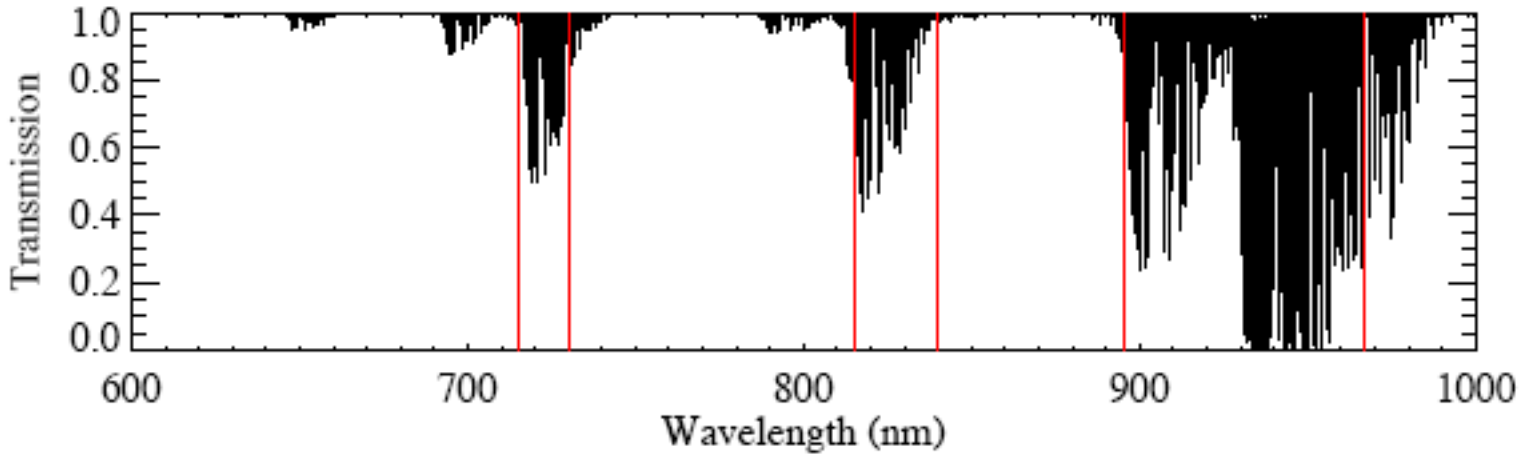
Atmosphere Model: PWV

- **Atmospheric model BTRAM (Univ. Lethbridge)**
  - **HITRAN (2008)**
  - **Multi-layer atmospheric radiative transfer model**
  - **Mid-latitude profile modified with site-specific archival radiosonde data from Antofagasta**
  - **580-980 nm, >1000 lines**
  - **Validated at LCO with MIKE observations**
  - **Comparison with IRMA (Querel et al. 2008)**

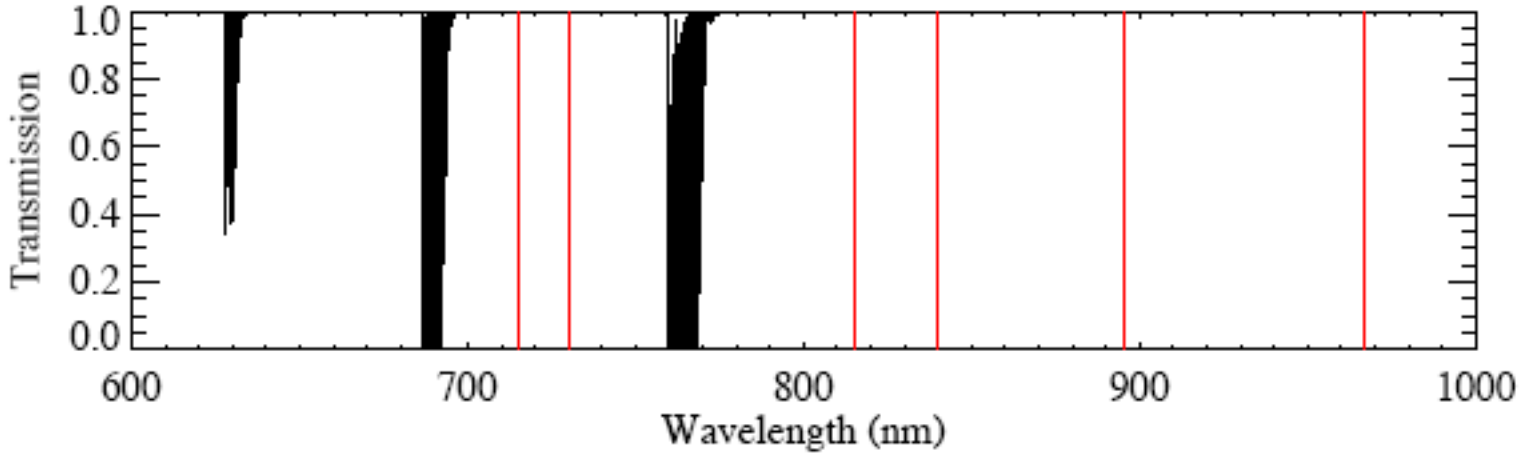
Atmospheric Model: PWV

BLUE SKY SPECTROSCOPY BTRAM

H_2O only, PWV = 1 mm



All other constituents: CO_2, O_2



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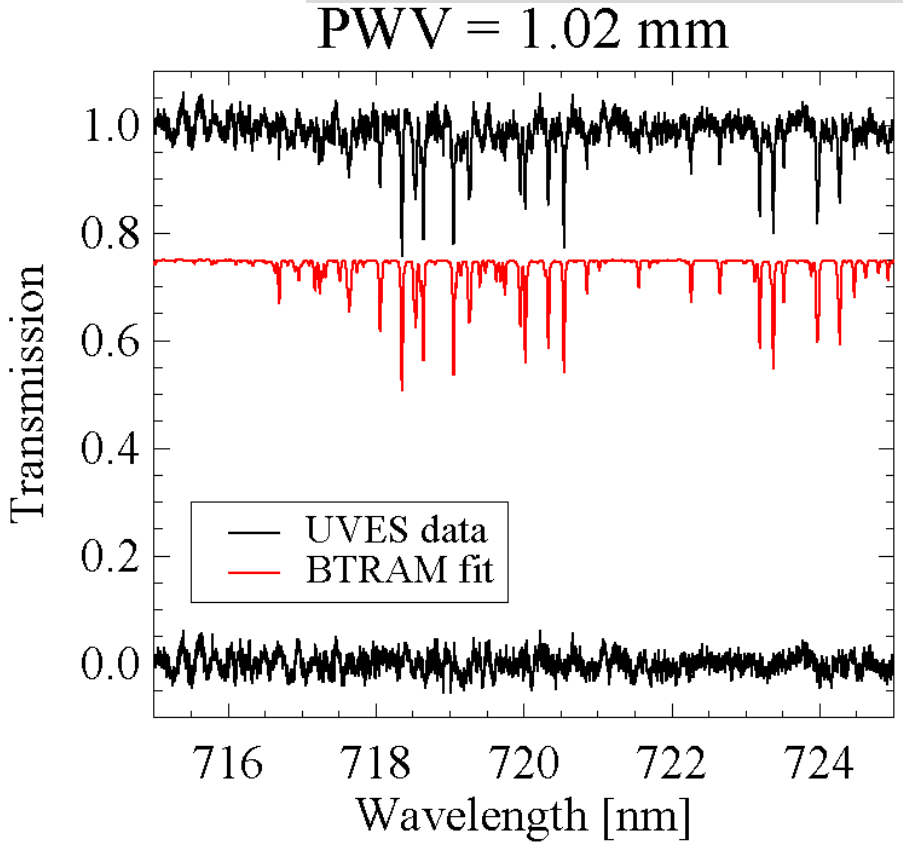
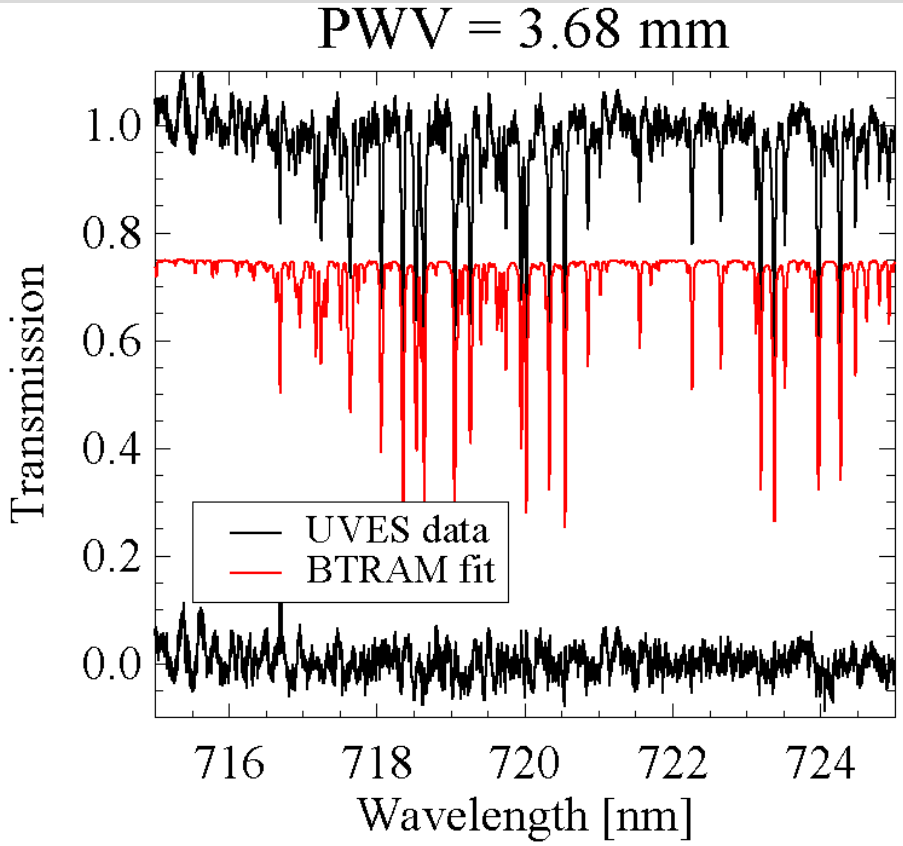
Paranal: wet & dry





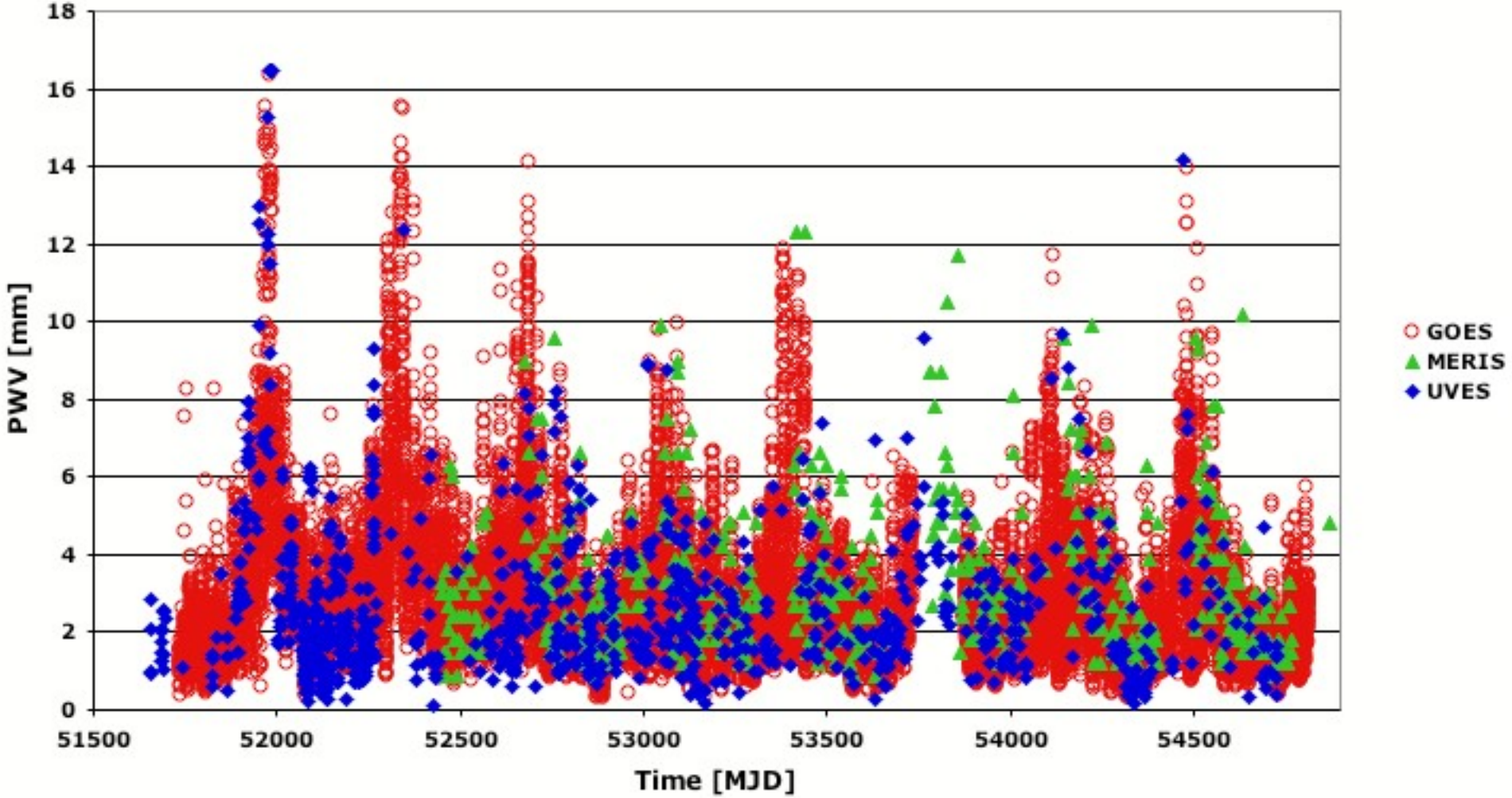
Satellite Data

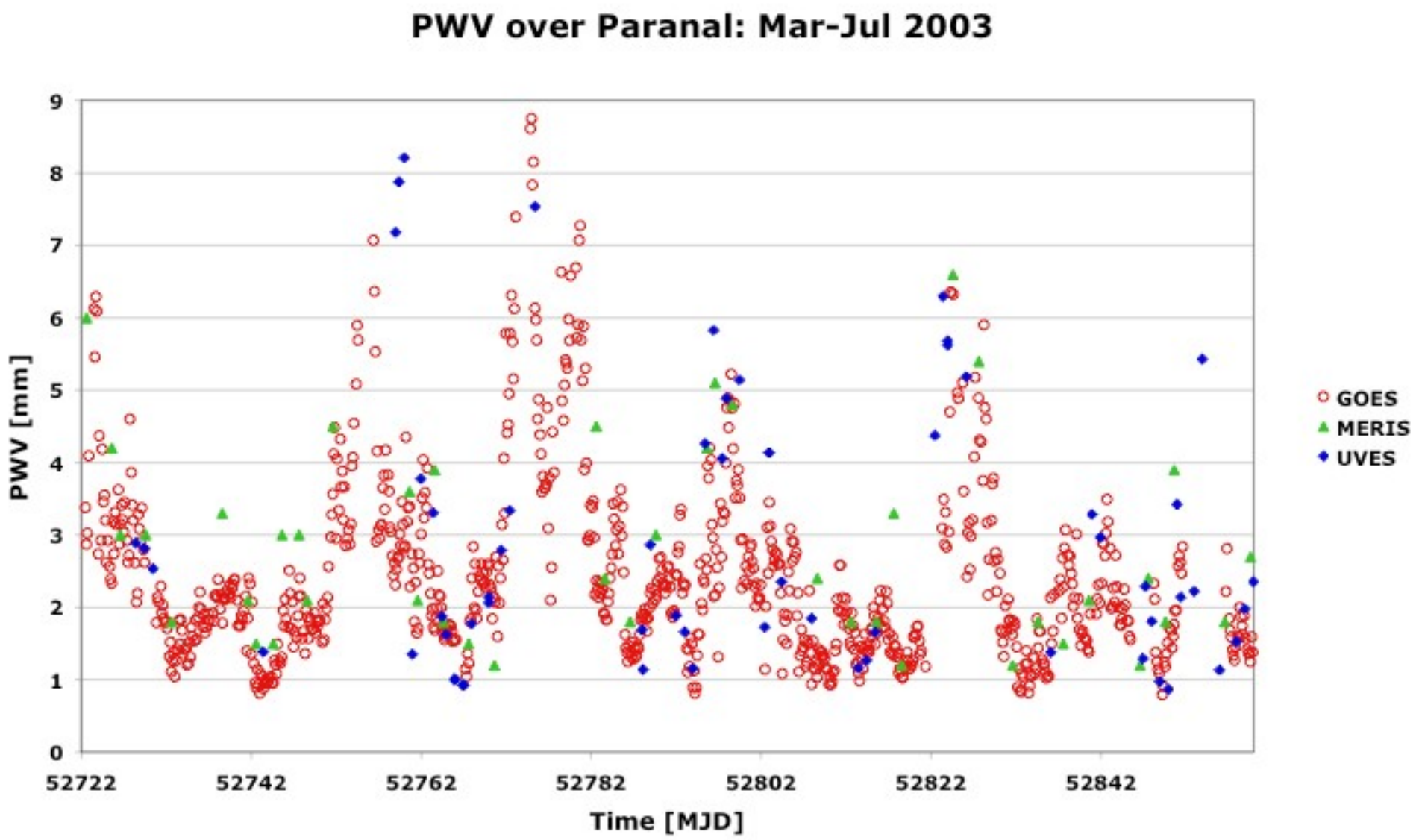
- **GOES**
  - **Time resolution 1 every 3 h, 24 h a day**
  - **Spatial resolution 12 by 12 km (3 pixel binning)**
  - **Brightness at 6.5 & 10.7 μ m - clear nights only**
- **ENVISAT**
  - **Time resolution 1 every 2-3 days, daytime**
  - **MERIS: Spatial resolution 1 by 1 km**
  - **Spectrum: 890-900 nm**

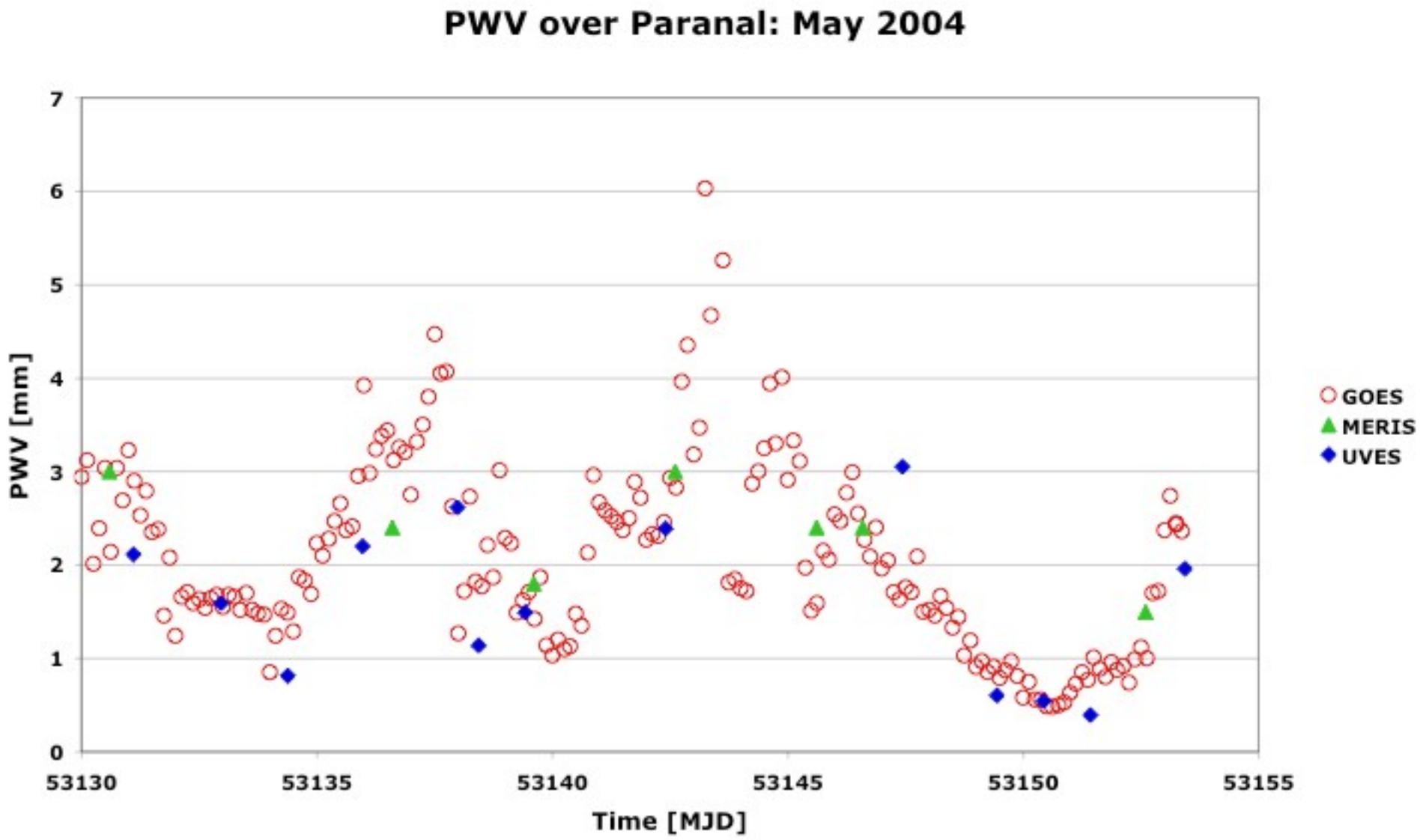
Paranal

UVES archival Data

Record of Precipitable Water Vapour over Paranal 2000-2008




PWV over Paranal: Mar-Jul 2003
PWV [mm]
0
1
2
3
4
5
6
7
8
9
52722
52742
52762
52782
52802
52822
52842
Time [MJD]
GOES
MERIS
UVES


PWV over Paranal: May 2004
PWV [mm]
0
1
2
3
4
5
6
7
53130
53135
53140
53145
53150
53155
Time [MJD]
GOES
MERIS
UVES

PWV site statistics

Paranal	Median PWV [mm]	< 1 mm [%]	< 1.5 mm [%]	< 2 mm [%]
UVES	2.1 ± 0.3 (2.2)	13.5	32	47.3
GOES	2.4 ± 0.5 (1.8)	4.8	18.9	38
MERIS	2.7 ± 0.3 (2.0)	1.5	7.9	29

PWV site statistics

La Silla	Median PWV [mm]	< 1 mm [%]	< 1.5 mm [%]	< 2 mm [%]
FEROS	3.4 ± 0.4 (2.4)	3.3	9.2	18.4
GOES	5.9 ± 0.6 (2.5)	0.02	0.4	1.8
MERIS	3.6 ± 0.5 (2.3)	0.8	11.2	20

PWV Campaigns

Jul/Aug & Nov 2009

PWV Campaigns in technical time

- **Paranal:**
  - **UVES - 700 nm (~950 spectra, cadence 30-60s)**
  - **BACHES - 700 nm (140 spectra, 15-30 min)**
  - **CRIRES - 5050 nm (110 spectra)**
  - **VISIR - 19.5 μ m (65 spectra)**
  - **IRMAs - 20 μ m (~700 h, cadence sec)**
- **Radiosonde balloon launches (U Valparaiso)**
  - **1-1.5 h, 20-25 km altitude**
  - **~70 launches (La Silla, Paranal)**

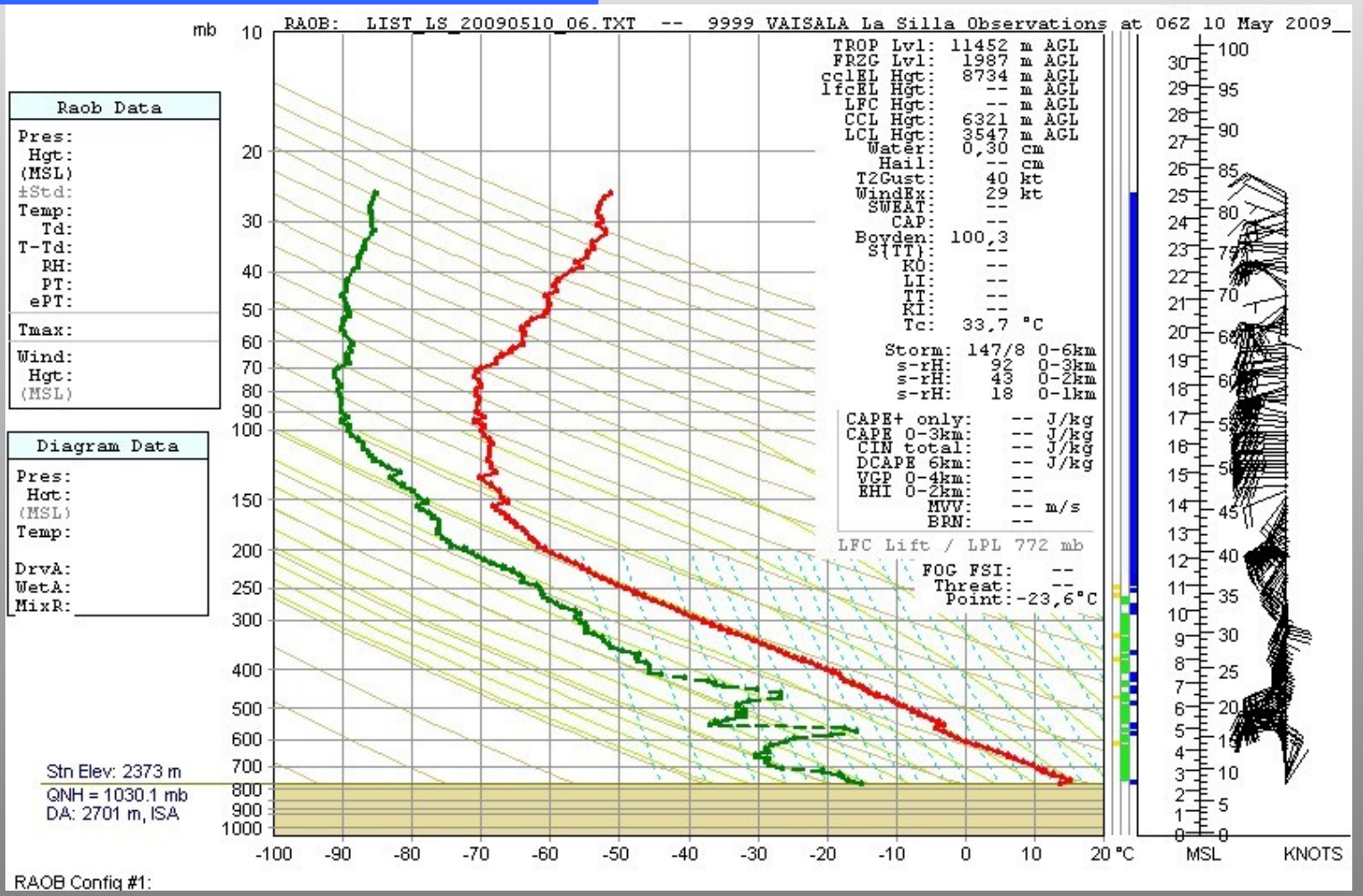
Radiosondes

A. Chacón et al. (U. Valparaiso)

Radiosonde Profiles

Temperature

Dew Point



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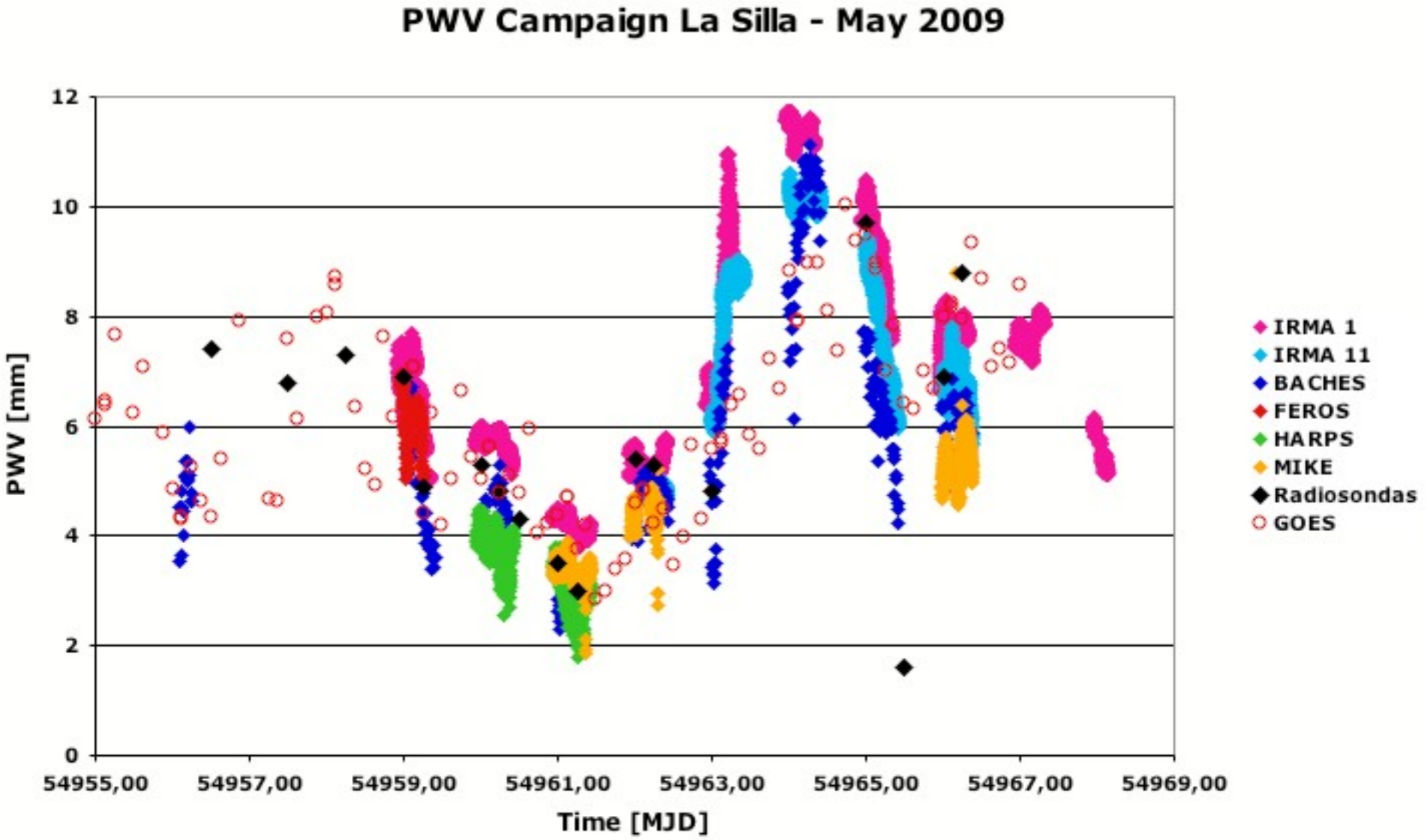
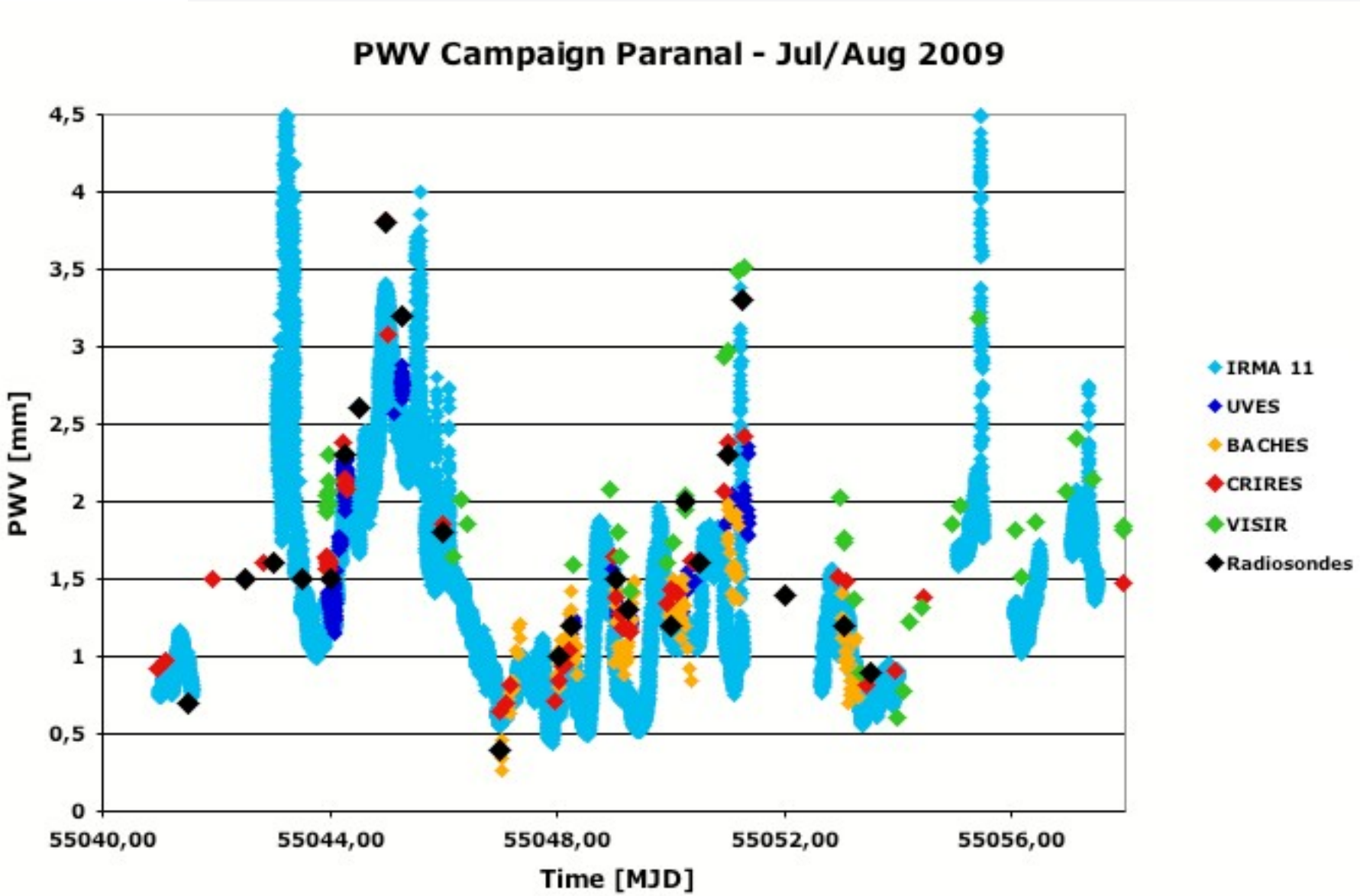
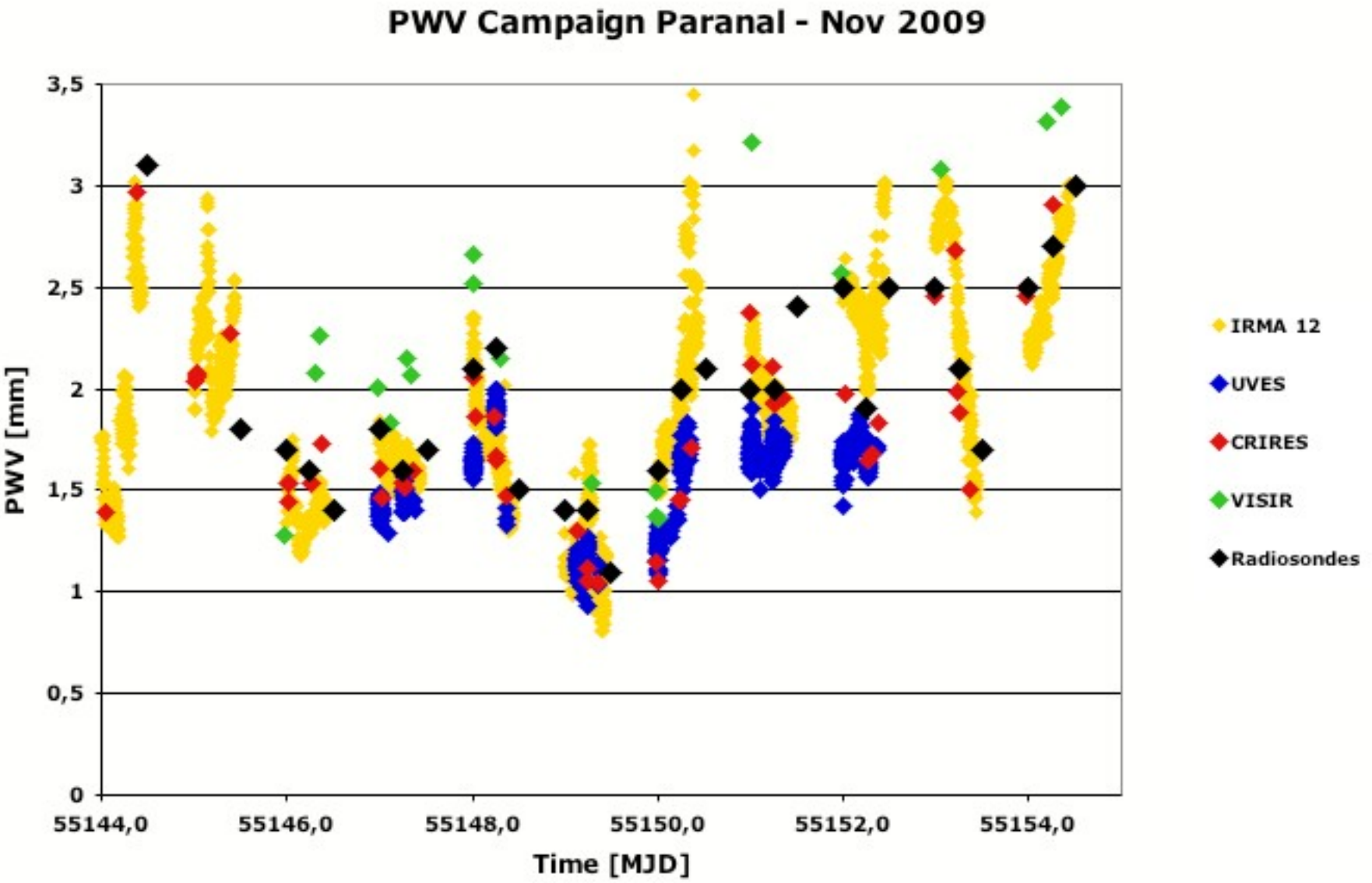
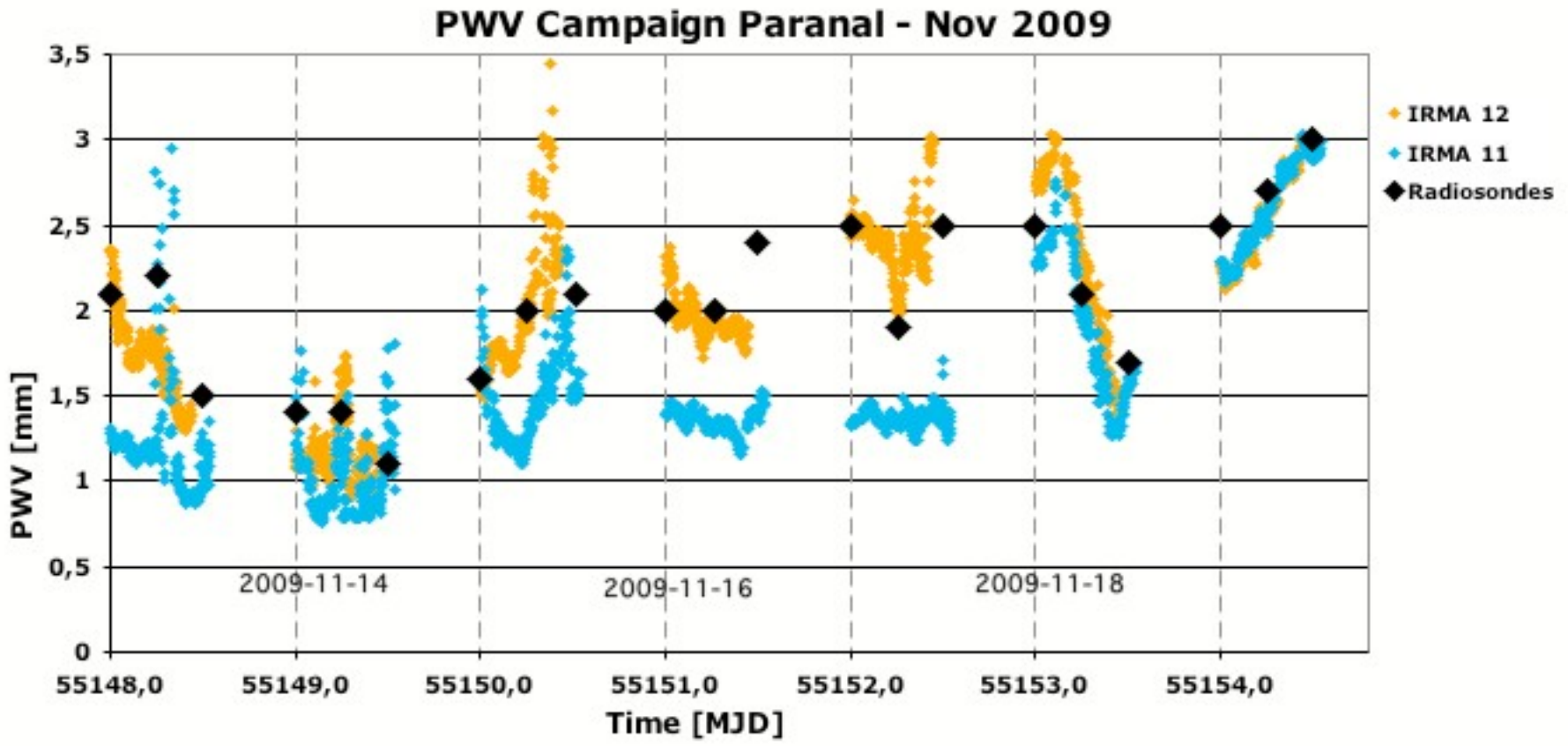
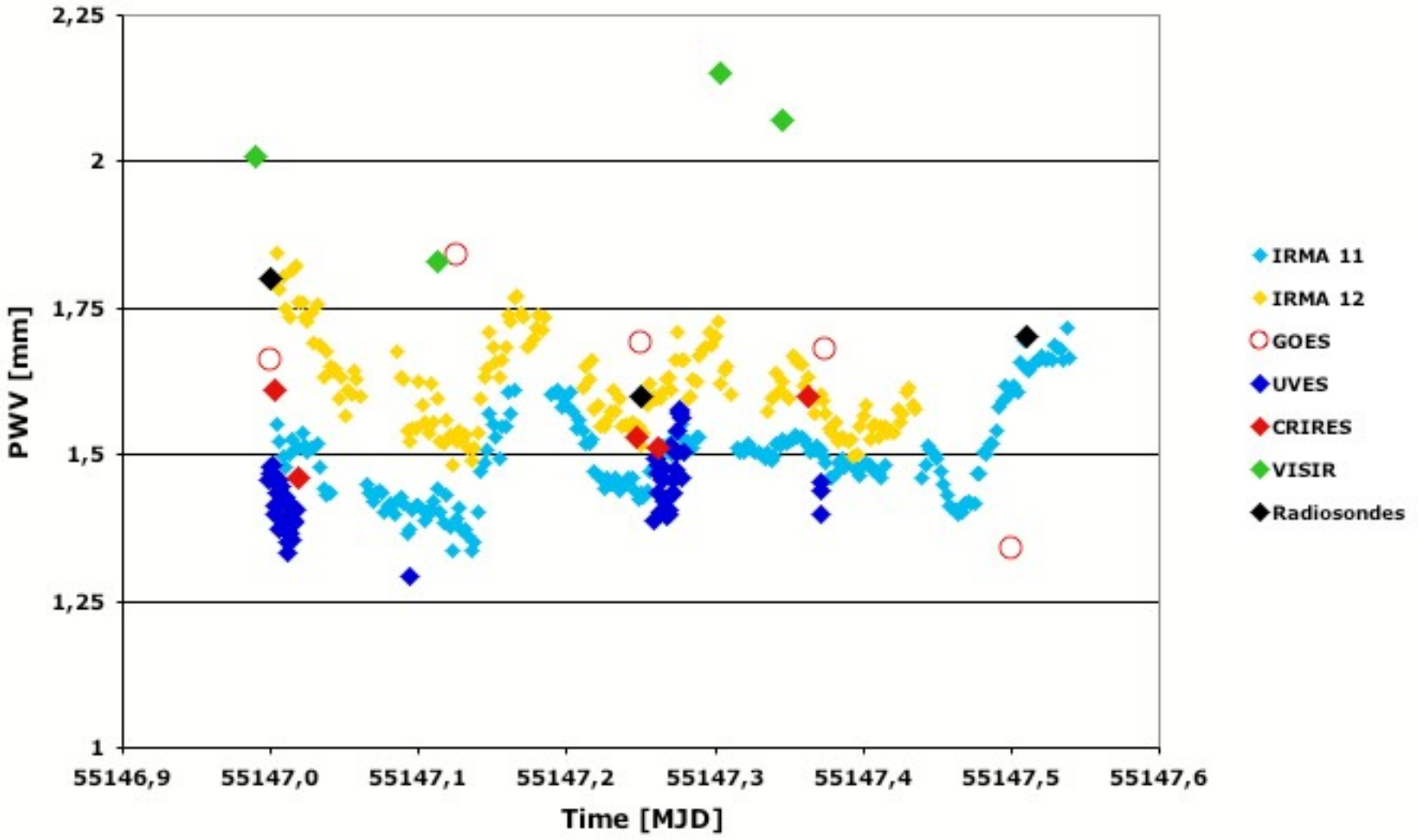

PWV Campaign La Silla - May 2009
PWV [mm]
0
2
4
6
8
10
12
54955,00
54957,00
54959,00
54961,00
54963,00
54965,00
54967,00
54969,00
Time [MJD]
IRMA 1
IRMA 11
BACHES
FEROS
HARPS
MIKE
Radiosondas
GOES

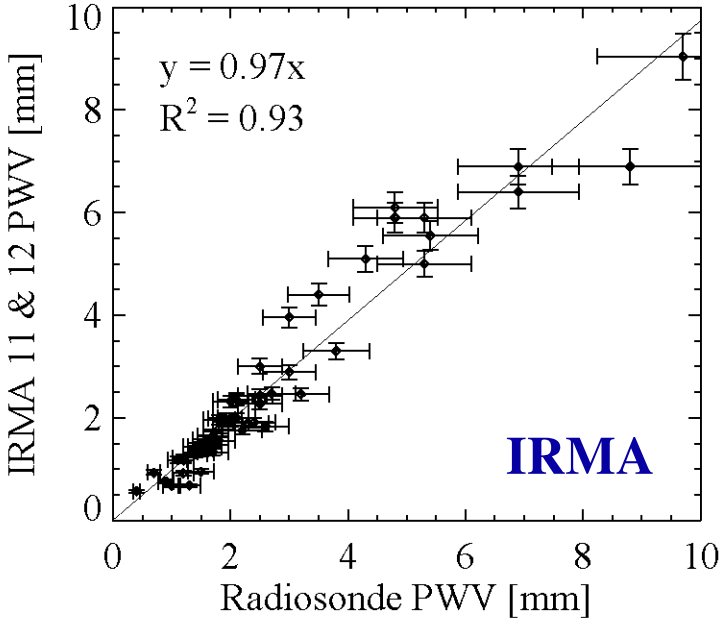

PWV Campaign Paranal - Jul/Aug 2009
PWV [mm]
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
55040,00
55044,00
55048,00
55052,00
55056,00
Time [MJD]
IRMA 11
UVES
BACHES
CRIRES
VISIR
Radiosondes

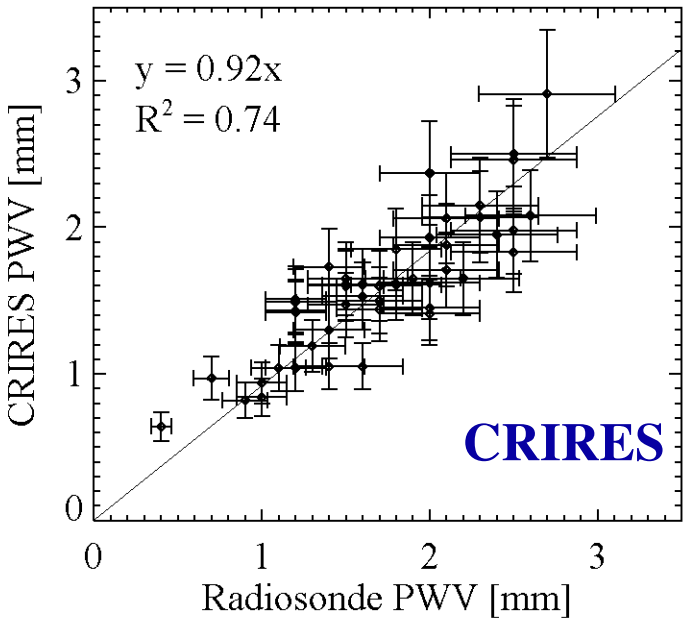

PWV Campaign Paranal - Nov 2009
PWV [mm]
3,5
3
2,5
2
1,5
1
0,5
0
55144,0
55146,0
55148,0
55150,0
55152,0
55154,0
Time [MJD]
IRMA 12
UVES
CRIRES
VISIR
Radiosondes

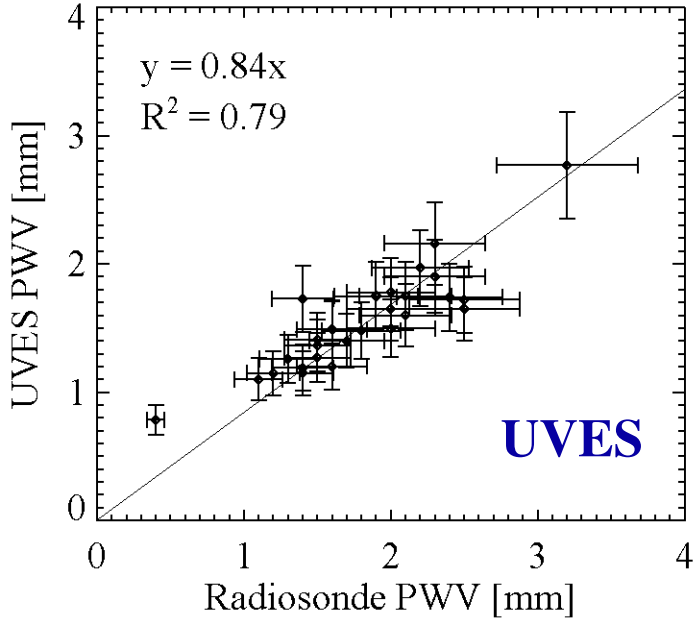
Paranal vs Armazones

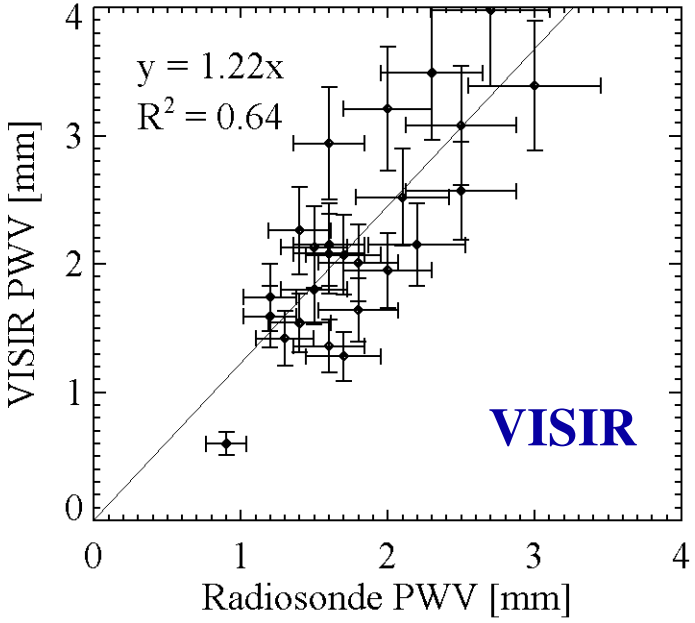



2,25
2
1,75
1,5
1,25
1
PWV [mm]
55146,9
55147,0
55147,1
55147,2
55147,3
55147,4
55147,5
55147,6
Time [MJD]
IRMA 11
IRMA 12
GOES
UVES
CRIRES
VISIR
Radiosondes

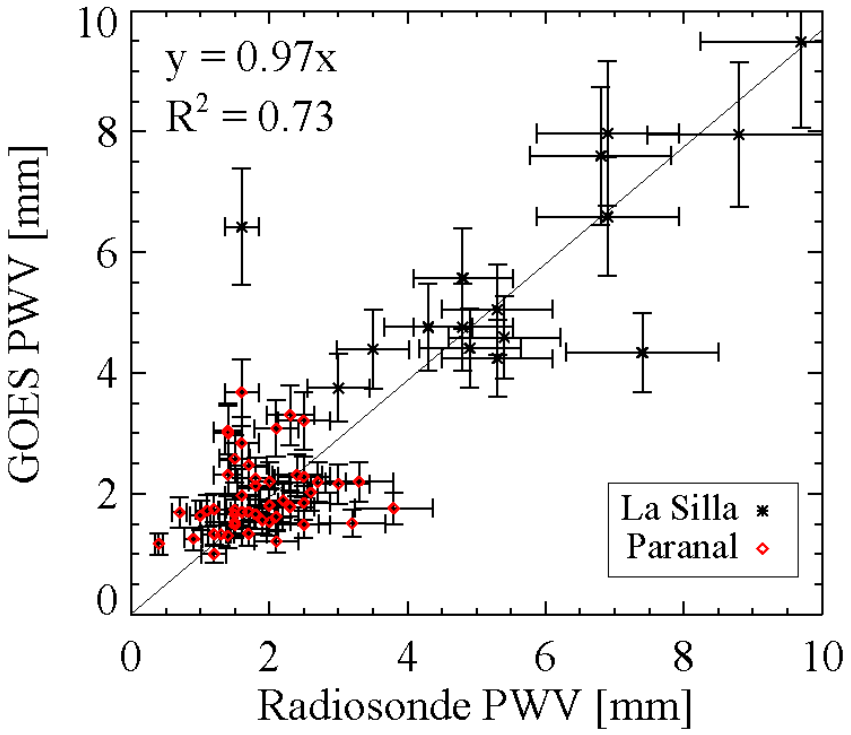

y = 0.97x
R² = 0.93
IRMA
IRMA 11 & 12 PWV [mm]
Radiosonde PWV [mm]
0
2
4
6
8
10

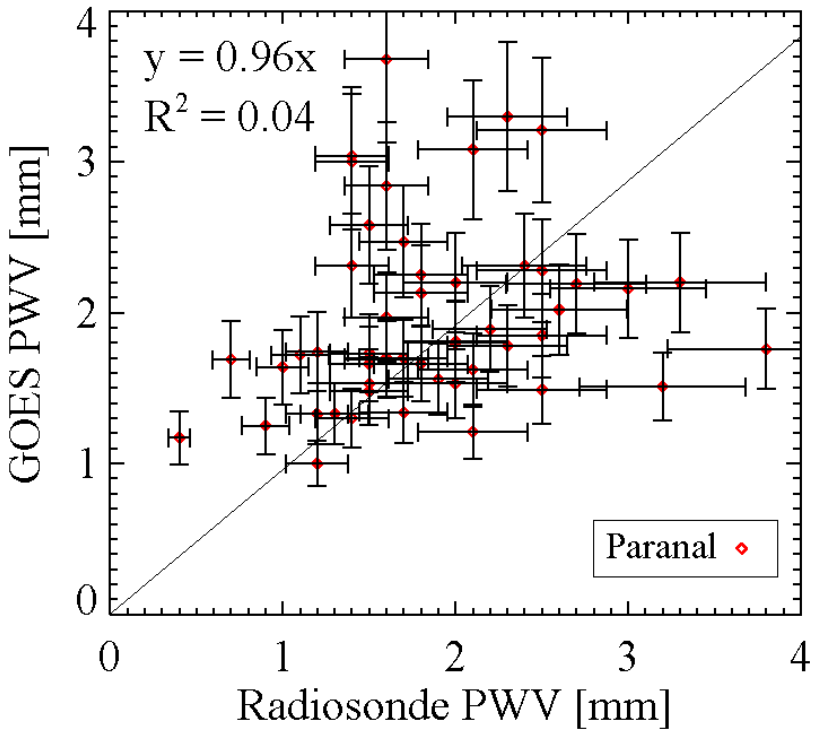

y = 0.92x
R² = 0.74
CRIRES
CRIRES PWV [mm]
Radiosonde PWV [mm]
0
1
2
3


y = 0.84x
R² = 0.79
UVES
UVES PWV [mm]
Radiosonde PWV [mm]
0
1
2
3
4


y = 1.22x
R² = 0.64
VISIR
VISIR PWV [mm]
Radiosonde PWV [mm]
0
1
2
3
4

Radiosonde vs GOES





Results

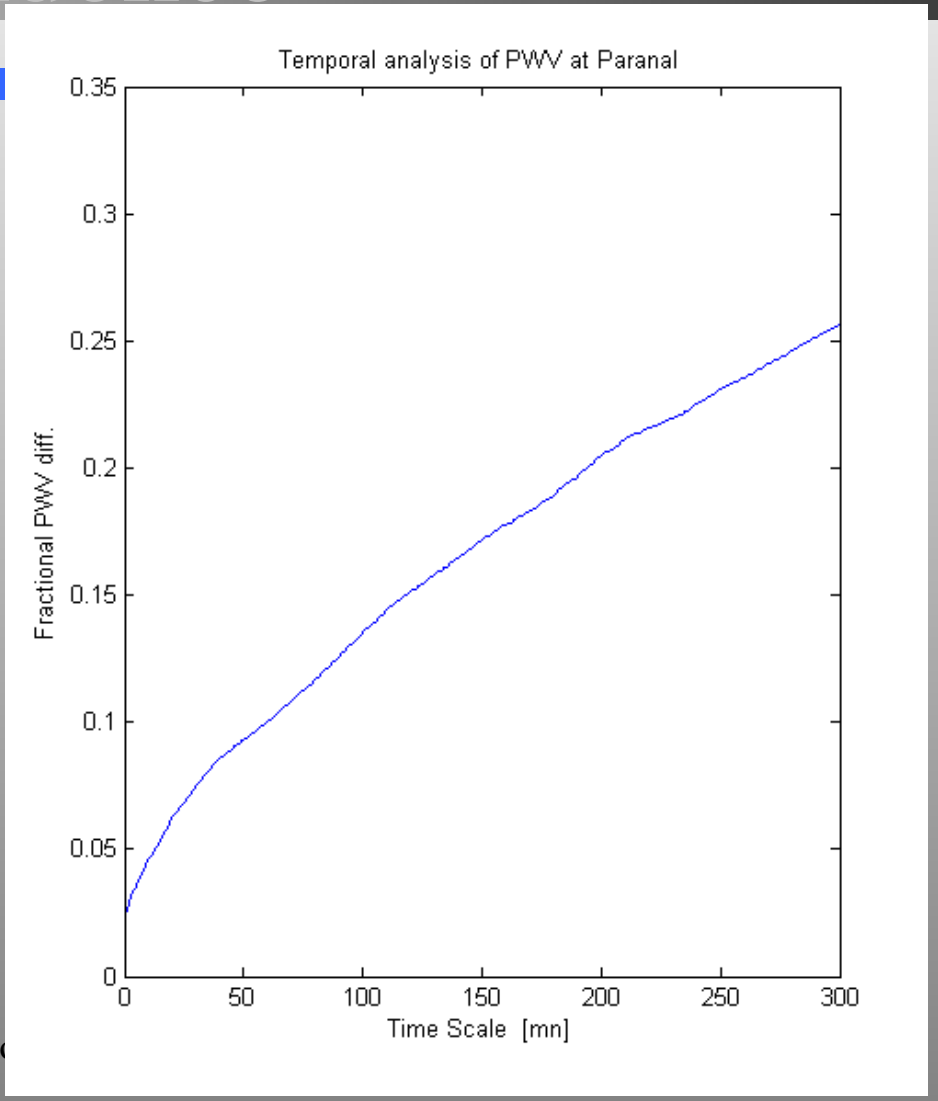
- **Median PWV over La Silla Paranal - E-ELT site evaluation**
  - **Paranal 2.4 mm**
  - **La Silla 3.7 mm**
  - **Armazones 2.1 mm (Otárola et al. 2010: 2.9 mm)**
- **Validated various methods with respect to radiosondes**
  - **700 nm - 20 μ m**
  - **5-20%; ≥0.25/0.5 mm**
- **Remote sensing data (satellites) usable for statistical analysis only, ok for site evaluation**

Next Steps

- **Complete analysis (typical time scale of variability)**
- **Monitoring at Paranal:**
  - **http://www.eso.org/qc/GENERAL/PWV/HEALTH/trend_report_ambient_PWV_HC.html**
  - **http://www.eso.org/sci/facilities/paranal/sciops/CALISTA/pwv/data.html**
- **VISIR upgrade includes PWV**
- **PWV forecasting using WRF model (U. Valparaiso)**

PWV Time dependence

- **IRMA 10 days**
- **PWV typical time constant is hours**



T. Travouillon

PWV Time dependence

A. Otárola

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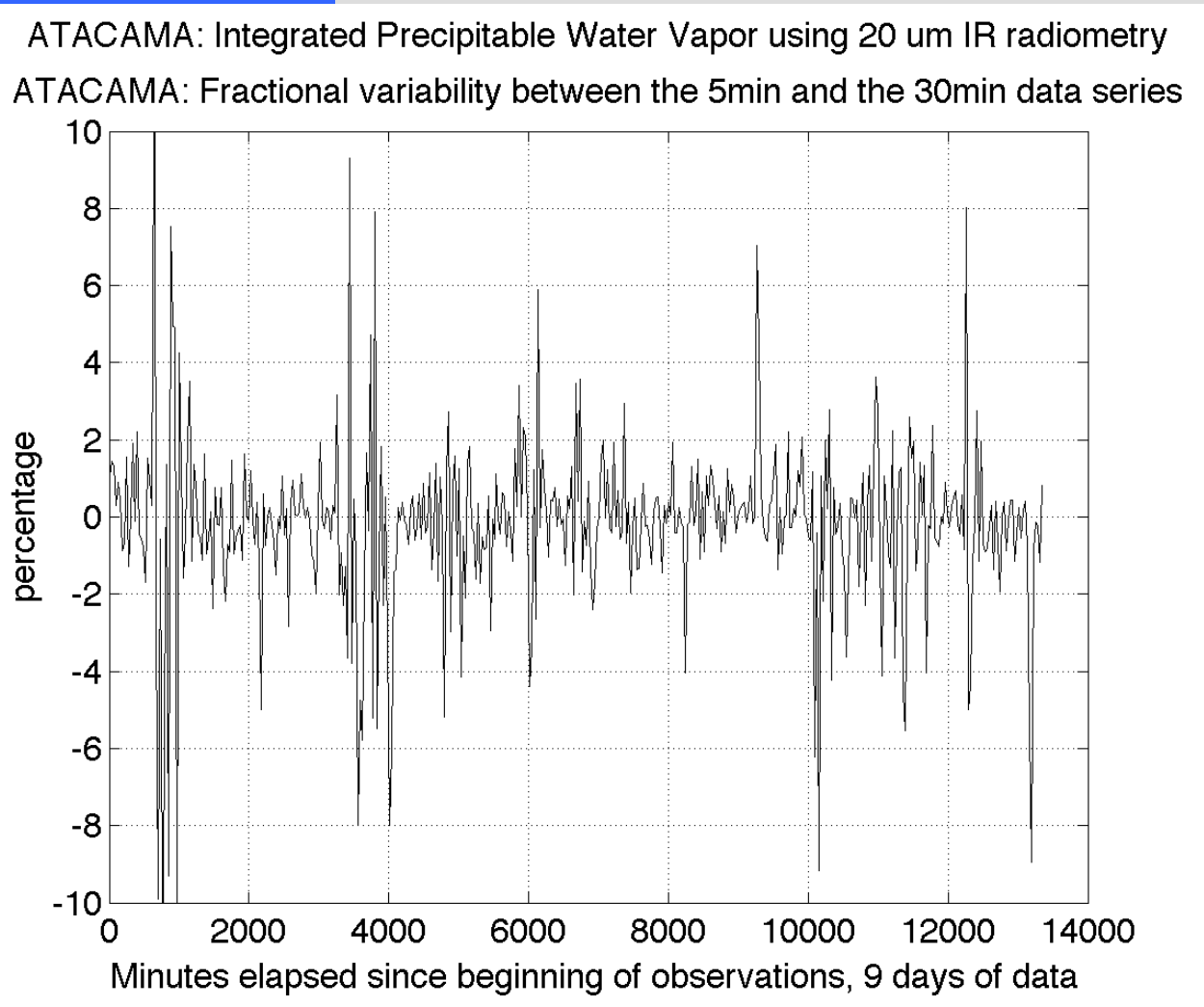
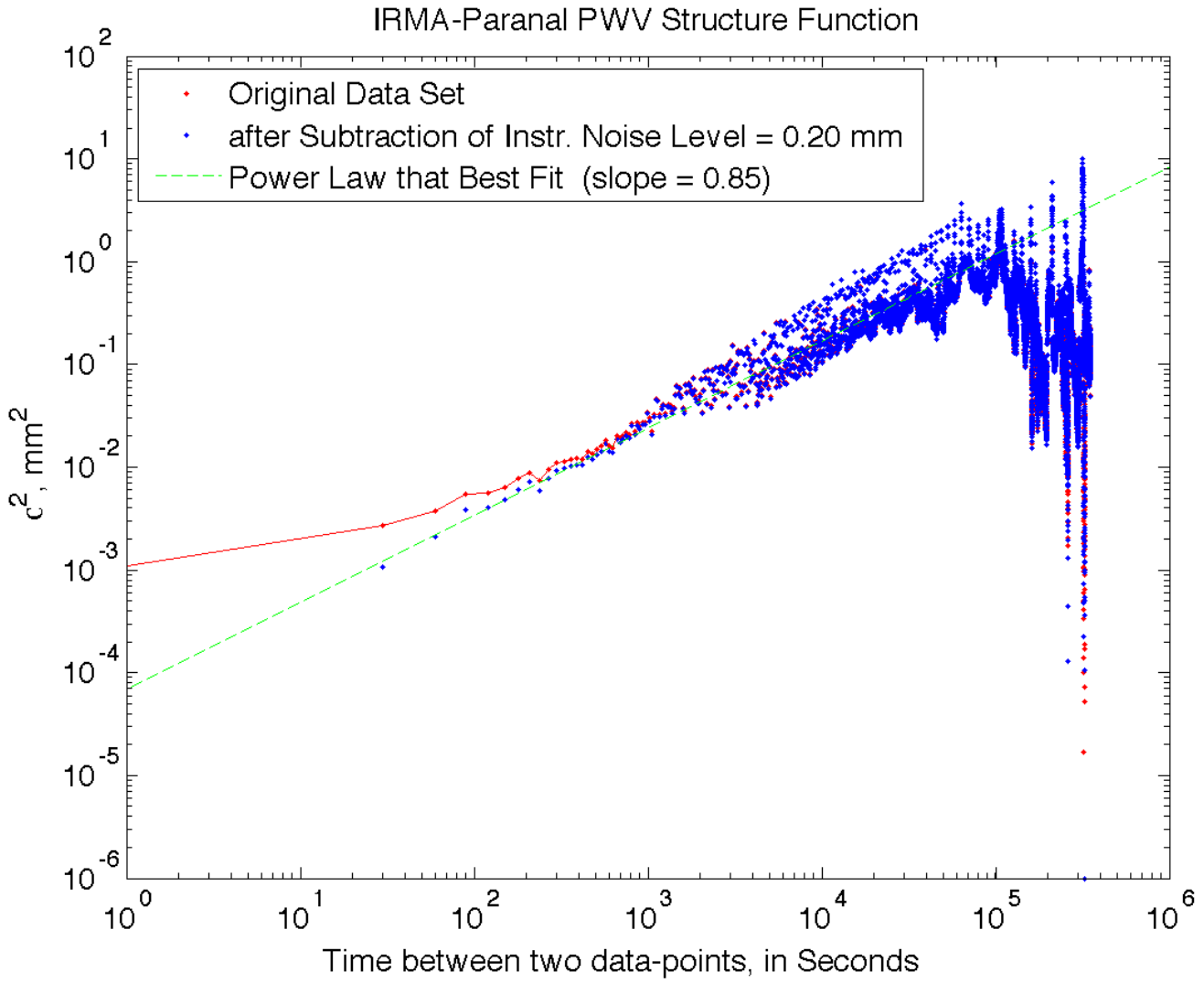


PWV Time dependence



A. Otárola

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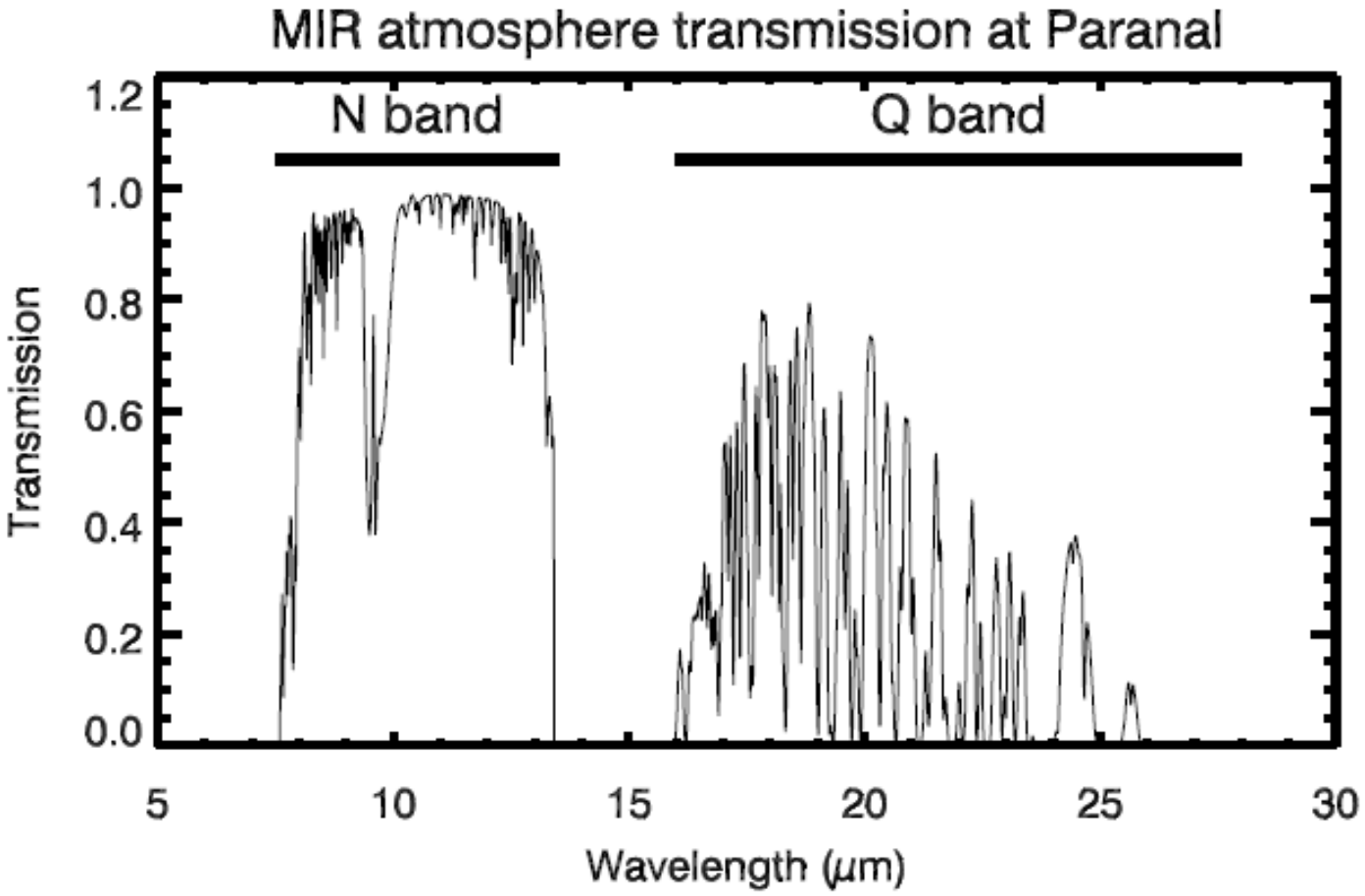
VISIR upgrade project

- **VI**
  - **–**
- **VI**
- **Op**
- **Sta**
- **PV**



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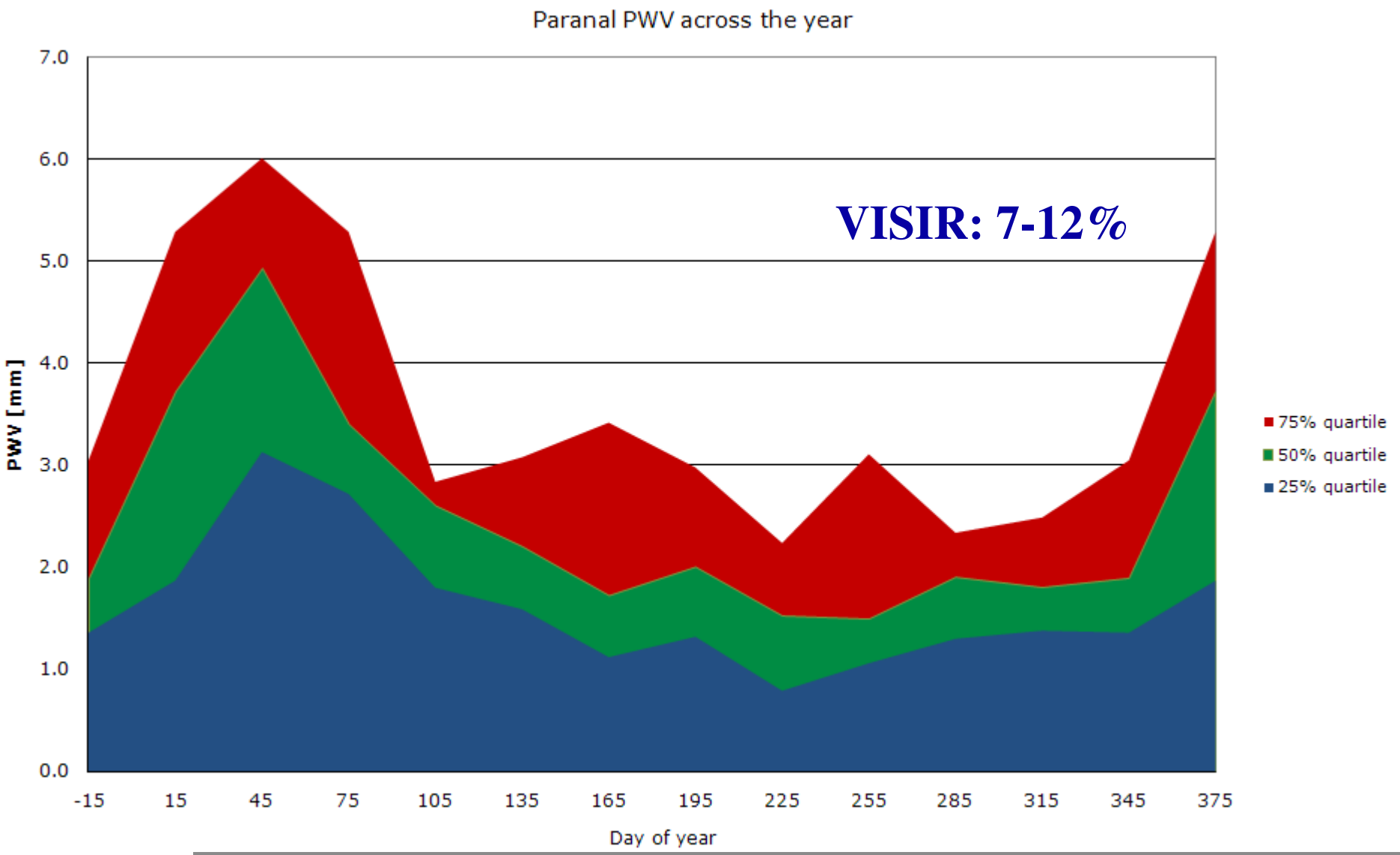
VISIR upgrade project

- **Science benefit for demanding observations**
  - **imaging of faint sources in Q,**
  - **high-precision photometry,**
  - **spectroscopy of H_2 0-0 S(1) at 17.02 µm,**
  - **imaging and spectroscopy in N-band < 8 µm,**
  - **detection of water vapour in circumstellar disks**

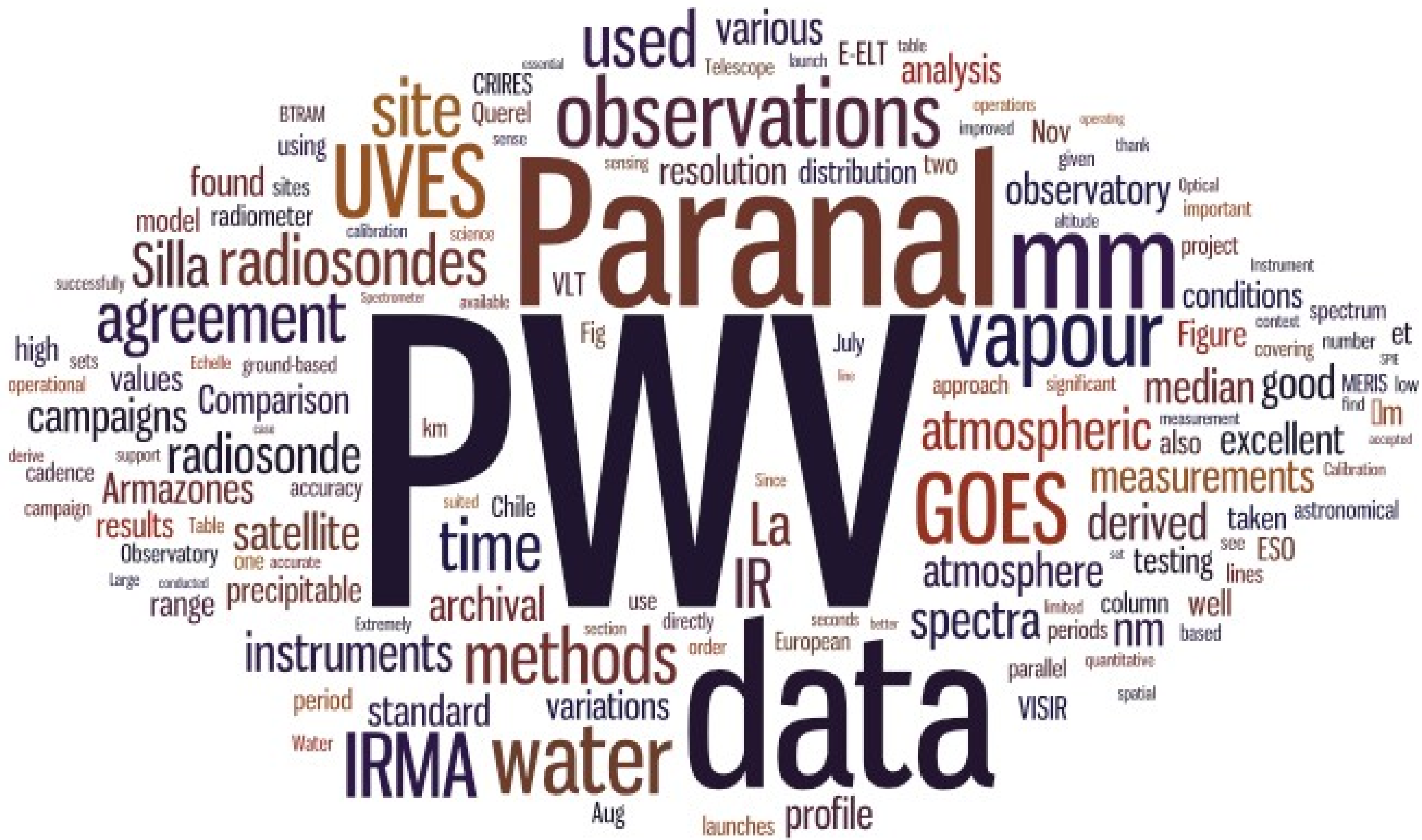

Paranal PWV across the year
VISIR: 7-12%
PWV [mm]
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
-15
15
45
75
105
135
165
195
225
255
285
315
345
375
Day of year
75% quartile
50% quartile
25% quartile

Summary - Goals met

- **History of PWV over La Silla & Paranal reconstructed from archival data**
- **Paranal as reference site for Northern Chile**
- **Feedback to Site selection process**
- **Merit for Observatory operations**
  - **Monitoring with high accuracy feasible**
  - **PWV crucial tool for scheduling of service mode**

Summary - Future

- **PWV monitor: Stand-alone, high time resolution, high accuracy**
- **VISIR: Observing constraint - service mode**
- **Benefit to other instrument (CRIRES, MIDI, ISAAC, …)**
- **Comprehensive atmospheric monitoring essential part of infrastructure for E-ELT**



Courtesy:Wordle.net