Assimilation of humidity and temperature observations retrieved from ground-based microwave radiometers into a convective-scale NWP model

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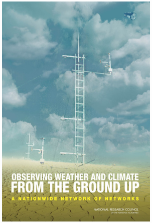
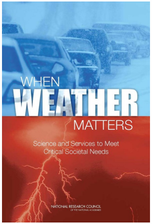
Motivation (1/3)

From U. S. National Research Council reports[1]:

- The planetary boundary layer (PBL) is the single most important under-sampled part of the atmosphere,
- The structure and variability of the PBL is not well known because vertical profiles of **water vapour, temperature**, and winds are not systematically observed,
- This is particularly important in nowcasting (0- to 6-h range).





[1] *Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks* (2009),
When Weather Matters: Science and Service to Meet Critical Societal Needs (2010).

Motivation (2/3)

WMO Statement of Guidance on observations for high-resolution NWP[2]:

Five critical atmospheric variables are not adequately measured (in order of priority):

- wind profiles
- **temperature and humidity profiles** (in cloudy areas)
- precipitation
- snow mass
- soil moisture.

[2] https://www.wmo.int/pages/prog/www/OSY/SOG/SoG-HighRes-NWP.pdf

Motivation (3/3)

- Ground-based microwave radiometers (MWRs) provide **temperature and humidity profiles**
  - low-to-moderate vertical resolution
  - continuous unattended operations
- Current regional numerical weather prediction (NWP) systems run at kilometre scales ⇒ need **high-resolution observations** both in time and space
- Yet **MWR observations are not assimilated** by any NWP system

CEAMA-UGR HATPRO
(© J. Fernandez Galvez/MWRnet)

Context

Two international initiatives:

- **HyMeX**: Hydrological cycle in the Mediterranean experiment (Drobinski et al. 2014, `http://www.hymex.org/`).
    - a 2010–2020 international programme endorsed by WWRP & WCRP
    - devoted to a better understanding and quantification of the hydrological cycle in the Mediterranean, with emphasis on high-impact weather events.
- European COST Action **TOPROF**: Towards operational ground-based profiling with ceilometers, Doppler lidars and microwave radiometers for improving weather forecasts (`http://www.toprof.imaa.cnr.it/`).

An opportunity study:

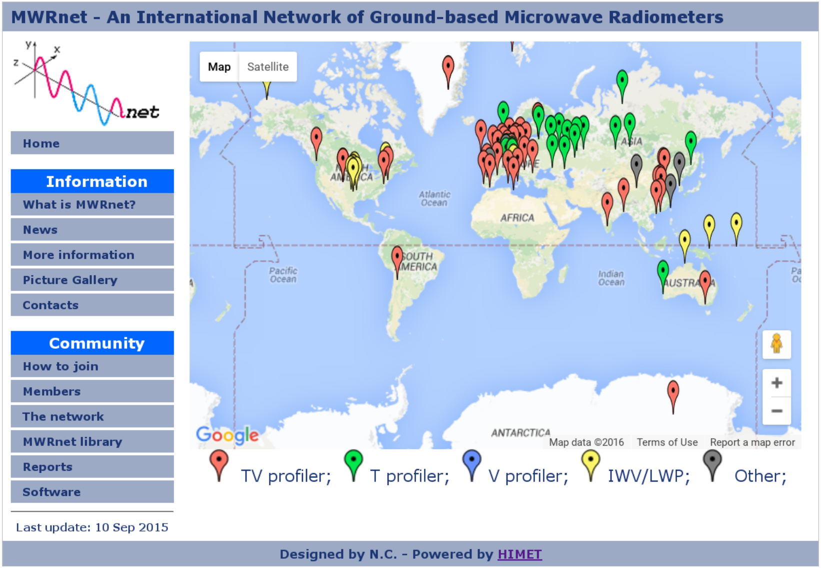
- Autumn 2011 with many **heavy-precipitation events** in the Mediterranean region,
- MWR data available from **MWRnet**,
- **Arome-Western Mediterranean (WMed)** prototype available.

⇒ First attempt to assimilate data from a real network of ground-based MWRs,
⇒ Focus on Mediterranean heavy-precipitation events.

Outline

MWRnet

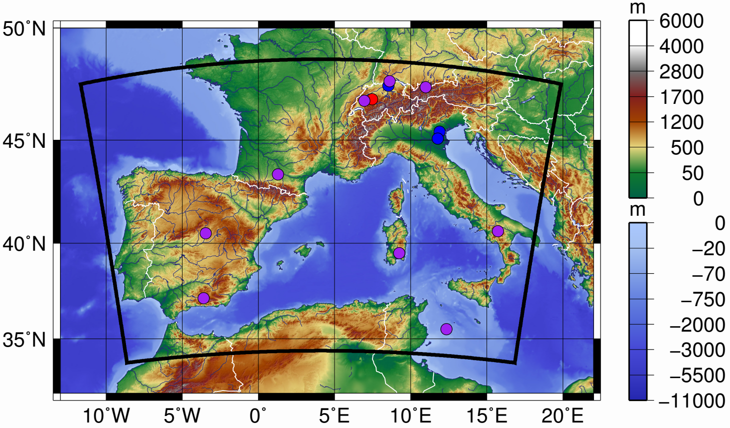
URL: `http://cetemps.aquila.infn.it/mwrnet/`



MWR stations

13 MWR stations (different instruments, different processing) from MWRnet members

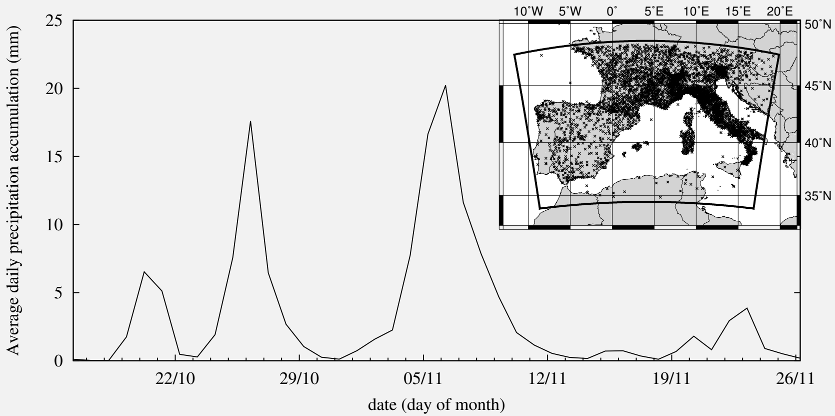
- 1 humidity profiler (red)
- 3 temperature profilers (blue)
- 9 temperature and humidity profilers (violet)



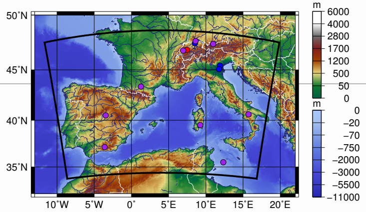
Period under investigation

15 October 2011 to 25 November 2011 (41 days)

Time series of mean daily precipitation accumulation;
insert: rain gauges (crosses)

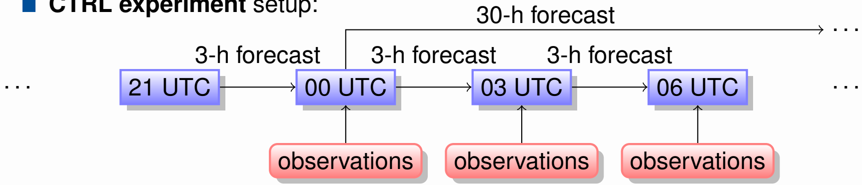


Model and configuration



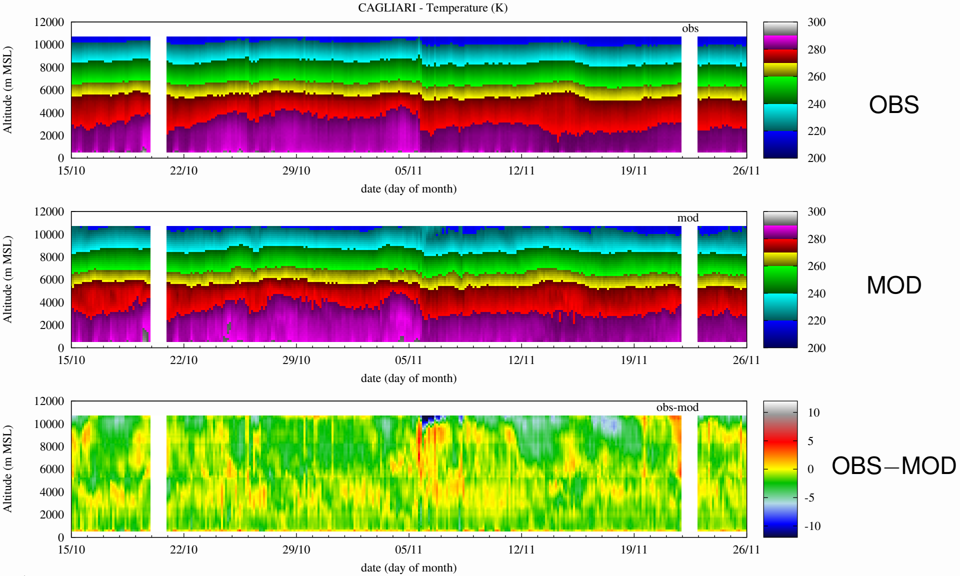
Arome-WMed (Fourrié et al. 2015, *GMD*)

- Prototype based on **Arome** operational NWP system (Seity et al. 2011, *MWR*)
- Domain covering **western Mediterranean** basin
- Forward model and data assimilation (DA) system at **2.5-km horizontal resolution**
- **Non-hydrostatic** model with **detailed physics** inherited from Meso-NH, coupled every hour with Arpege
- **3DVar** DA analysing observations from radiosondes, wind profilers, aircrafts, ships, buoys, automatic weather stations, satellites, GPS stations, and weather radars
- **CTRL experiment** setup:



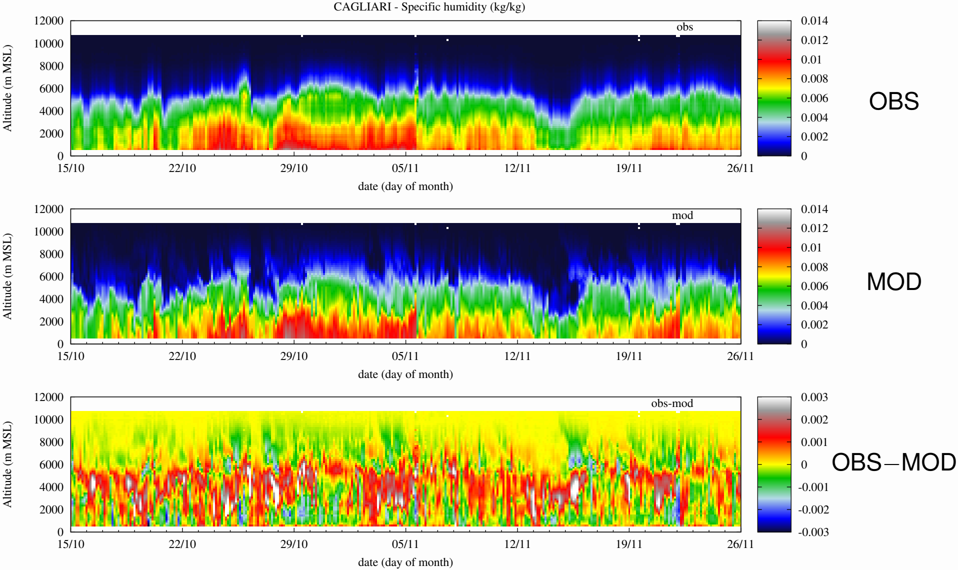
Monitoring of observations w.r.t. 3-h forecasts

Vertical profile time series of **temperature** at Cagliari, Italy:



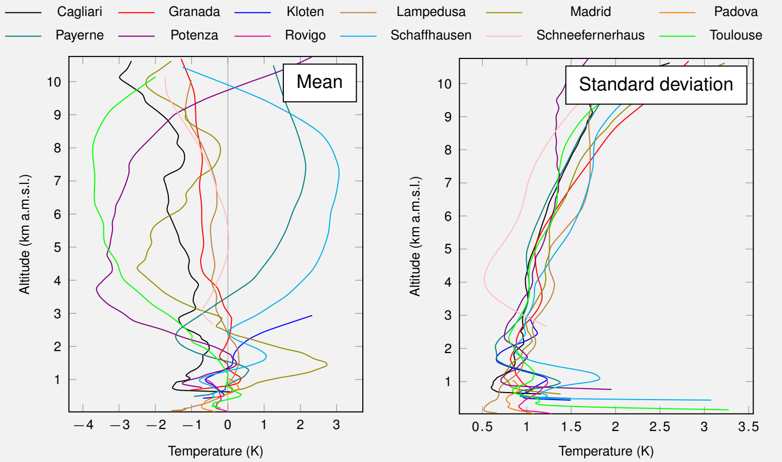
Monitoring of observations w.r.t. 3-h forecasts

Vertical profile time series of **specific humidity** at Cagliari, Italy:



Monitoring of observations w.r.t. 3-h forecasts

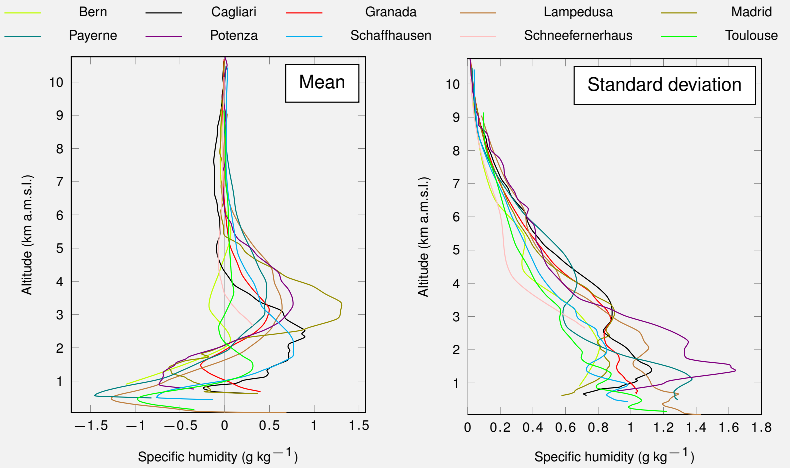
Vertical profiles of the mean (left) and standard deviation (right) of observation-minus-background **temperature** (K) for each MWR station.



- Bias can be quite large (> ±3 K), especially above 2 km;
- Standard deviations from different MWRs have the same order of magnitude.

Monitoring of observations w.r.t. 3-h forecasts

Vertical profiles of the mean (left) and standard deviation (right) of observation-minus-background **specific humidity** (g kg^{-1}) for each MWR station.



- Similar biases and standard deviations for all MWRs,
- Standard deviations have the same order of magnitude as for radiosondes.

DA experiments – Setup and evaluation

Numerical setup:

- 4 experiments:

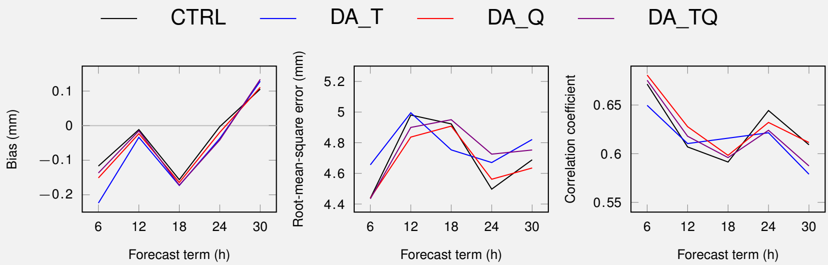
  CTRL: assimilation of operational data only (incl. radiosonde data)
  DA_T: as CTRL + MWR-derived temperature
  DA_Q: as CTRL + MWR-derived specific humidity
  DA_TQ: as CTRL + MWR-derived temperature and specific humidity

Evaluation of analyses and forecasts over the whole period and domain:

- Very small differences among all experiments regarding analyses and forecasts w.r.t. assimilated observations:
  - Surface pressure, humidity, temperature, and wind,
  - Upper-air observations.
- More perceptible differences regarding quantitative precipitation forecasts (QPFs) w.r.t. rain gauge observations.

Impact on QPF — Continuous scores

Time series of continuous scores for 6-h accumulated precipitation.

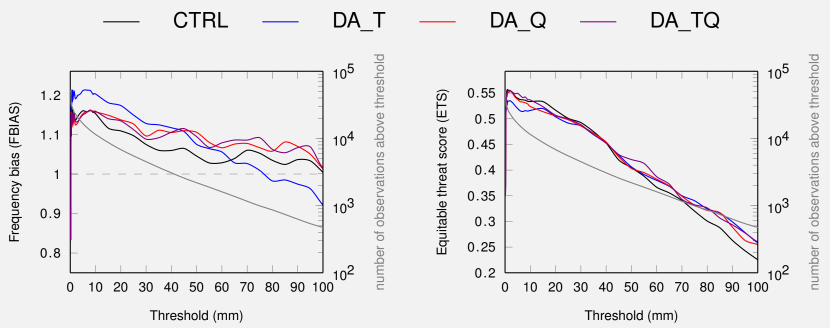


⇒ Bias worse. Problem with model physics?

⇒ Benefit of assimilating MWR data up to 12-18 h (RMSE and R).

Impact on QPF — Categorical scores

Time series of categorical scores for 18-h accumulated precipitation.



$\Rightarrow$ FBIAS worse up to 50–70 mm.

$\Rightarrow$ ETS mainly worse up to 40 mm and mainly better beyond.

Provisional conclusions

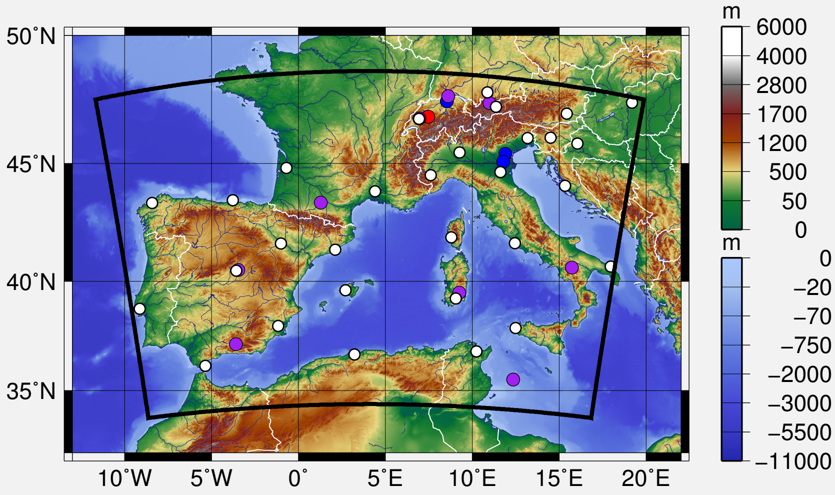
- Demonstration of the **feasibility** of assimilation of ground-based MWR data from a real network into NWP.
- No clear-cut impact of DA on pressure, temperature, humidity, and wind (not shown), but **QPF improved up to 12-18 h** (in terms of RMSE and R) and **for larger rainfall accumulations**.
- Several MWR stations co-located with radiosonde (RS) sites and both instruments provide similar information (except wind for MWR) ⇒ Limited impact?

⇒ Additional DA experiments without radiosondes:

CTRL:	assimilation of operational data only (incl. radiosonde data)
DA_T:	as CTRL + MWR-derived temperature
DA_Q:	as CTRL + MWR-derived specific humidity
DA_TQ:	as CTRL + MWR-derived temperature and specific humidity
CTRL−RS:	as CTRL − radiosonde data
DA_TQ−RS:	as DA_TQ − radiosonde data

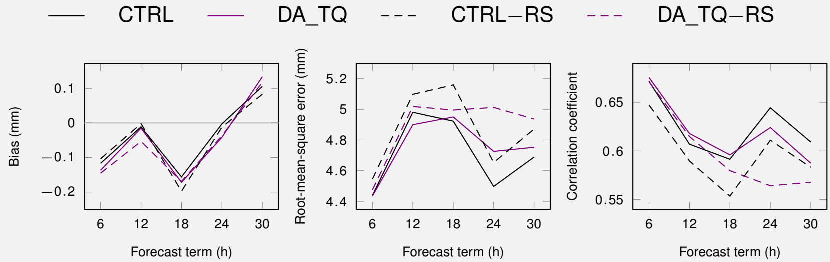
Locations of radiosonde launching sites

Large, colour circles: MWR stations (13 stations).
Small, white circles: RS sites (30 sites).



Impact on QPF — Continuous scores

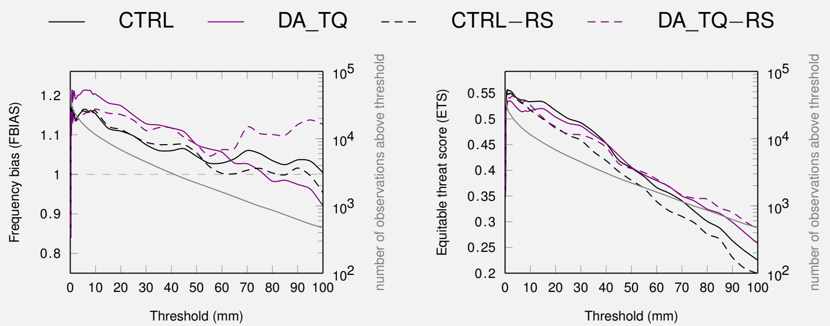
Time series of continuous scores for 6-h accumulated precipitation.



- ⇒ Bias of DA_TQ−RS worse than that of CTRL−RS (but bias of CTRL−RS better than that of CTRL?!)
- ⇒ Improvement in R and RMSE up to >18 hours, more marked than when RS assimilated.

Impact on QPF — Categorical scores

Time series of categorical scores for 18-h accumulated precipitation.



⇒ FBIAS degraded (with CTRL−RS better than CTRL beyond 60 mm?!),

⇒ ETS improved for all thresholds.

Conclusions and Future work

Conclusions

- Demonstration of the **feasibility** of assimilation of ground-based MWR data from a real network into NWP.
- O−B statistics show **uneven biases**, but **consistent, moderate standard deviations**.
- No clear-cut impact of DA on pressure, temperature, humidity, and wind (not shown), but **QPF improved up to 12-18 h** (in terms of RMSE and R) and **for larger rainfall accumulations**.
- More marked impact on QPF when RS data are not assimilated (less redundancy).

⇒ **MWR provide useful information for DA purposes!**

- Even more positive impact expected if:
  - Denser network
  - Data quality improved
  - Brightness temperature instead of T+Q (to avoid retrieval errors)

Future work (on-going)

- **1-yr monitoring** of reference MWR stations vs. Arome-France.
- Adapt radiative transfer model to ground-based MWR and **consider brightness temperature** instead of retrievals (Martinet et al. 2015, *Tellus A*; De Angelis et al. 2016, *GMDD*).

Thank you
for your attention!

References

- De Angelis, F., D. Cimini, J. Hocking, P. Martinet and S. Kneifel, 2016: RTTOV-gb - adapting the fast radiative transfer model RTTOV for the assimilation of ground-based microwave radiometer observations. *Geosci. Model Dev. Discuss.*, 1–29, DOI: 10.5194/gmd-2016-65, URL: http://dx.doi.org/10.5194/gmd-2016-65.
- Drobinski, P. et al., 2014: HyMeX: a 10-year multidisciplinary program on the mediterranean water cycle. *Bull. Amer. Meteor. Soc.*, **95**(7), 1063–1082, DOI: 10.1175/bams-d-12-00242.1, URL: http://dx.doi.org/10.1175/BAMS-D-12-00242.1.
- Fourrié, N. et al., 2015: AROME-WMED, a real-time mesoscale model designed for the HyMeX special observation periods. *Geosci. Model Dev.*, **8**, 1919–1941, DOI: 10.5194/gmd-8-1919-2015.
- Martinet, P., A. Dabas, J.-M. Donier, T. Douffet, O. Garrouste and R. Guillot, 2015: 1D-Var temperature retrievals from microwave radiometer and convective scale model. *Tellus A*, **67**, DOI: 10.3402/tellusa.v67.27925, URL: http://www.tellusa.net/index.php/tellusa/article/view/27925.
- Seity, Y., P. Brousseau, S. Malardel, G. Hello, P. Bénard, F. Bouttier, C. Lac and V. Masson, 2011: The AROME-France convective-scale operational model. *Mon. Wea. Rev.*, **139**(3), 976–991, DOI: 10.1175/2010MWR3425.1.

Backup slide: MWR specs

Station	Institution	Lat. (°)	Lon. (°)	Alt. (m)	Prod.	Type	Chan.	Frequency range (GHz)	Retrieval method
Bern	IAP	46.88	7.46	905	H	MIAWARA	16,000	21.735–22.735	Optimal estimation
Cagliari	INAF/OAC	39.50	9.24	623	T, H	MP3000A	35	22.0–58.8	Neural network
Granada	IISTA-CEAMA	37.16	−3.60	683	T, H	HATPRO	14	22.24–58.00	Multivariate regression
Kloten	MeteoSwiss	47.48	8.53	436	T	TEMPRO	7	51.26–58.00	Multivariate regression
Lampedusa	ENEA	35.51	12.34	50	T, H	HATPRO	14	22.24–58.00	Multivariate regression
Madrid	UniLeon	40.49	−3.46	620	T, H	MP3000A	35	22.0–58.8	Neural network
Padova	ARPAV	45.40	11.89	30	T	MTP5-HE	1	56.60	Statistical regularization
Payerne	MeteoSwiss	46.82	6.95	491	T, H	HATPRO	14	22.24–58.00	Multivariate regression
Potenza	CNR-IMAA	40.60	15.72	760	T, H	MP3014	12	22.235–58.800	Neural network
Rovigo	ARPAV	45.07	11.78	23	T	MTP5-HE	1	56.60	Statistical regularization
Schaffhausen	MeteoSwiss	47.68	8.62	437	T, H	HATPRO	14	22.24–58.00	Multivariate regression
Schneefernerhaus	UniCologne	47.42	10.98	2,650	T, H	HATPRO	14	22.24–58.00	Multivariate regression
Toulouse	ONERA	43.38	1.29	144	T, H	HATPRO	14	22.24–58.00	Multivariate regression