

GNSS4Met

G.Guerova

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GNSS Meteorology: state-of-the-art and challenges

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Department of Meteorology and Geophysics
Physics Faculty
Sofia University



19 September 2019, GNSS Meteorology workshop
WUELS, Wroclaw, Poland

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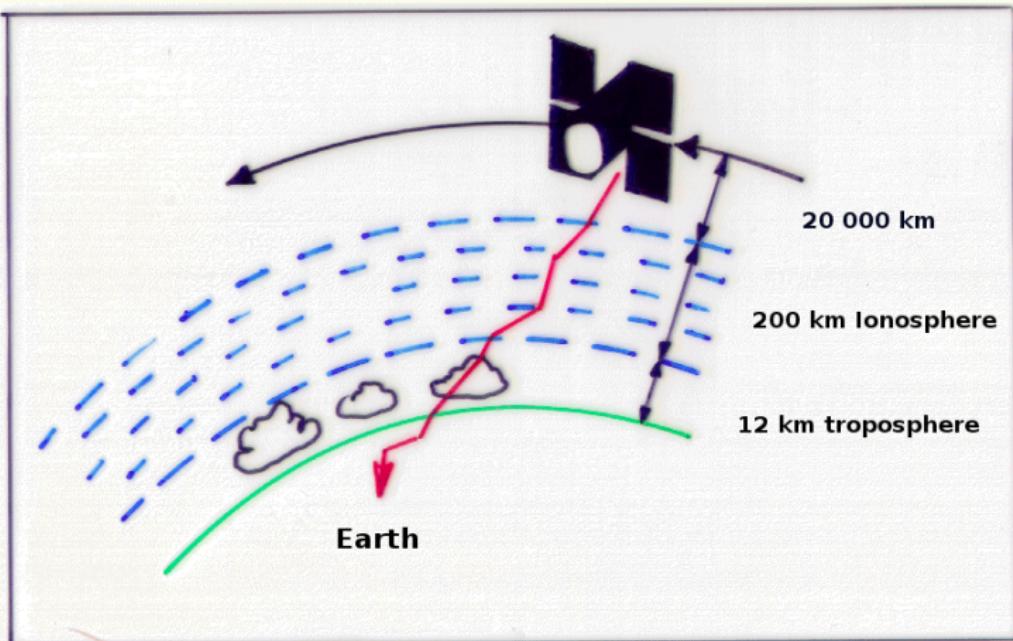
E-GVAP

Challenges

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- Propagation errors in GNSS

- ionosphere: delay in the range of 30 m
- troposphere: 2 m delay at zenith, up to 20 m at low elevation



Atmospheric composition: dry and moist air

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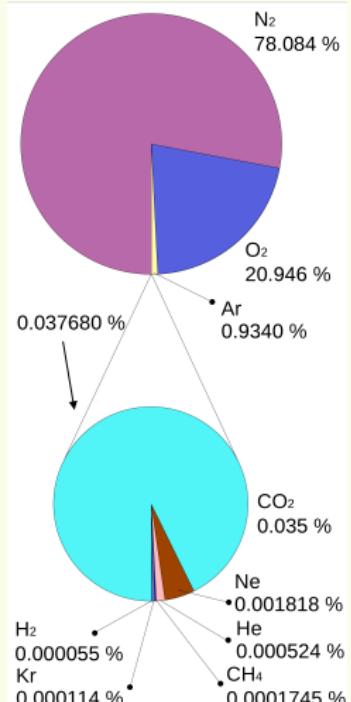
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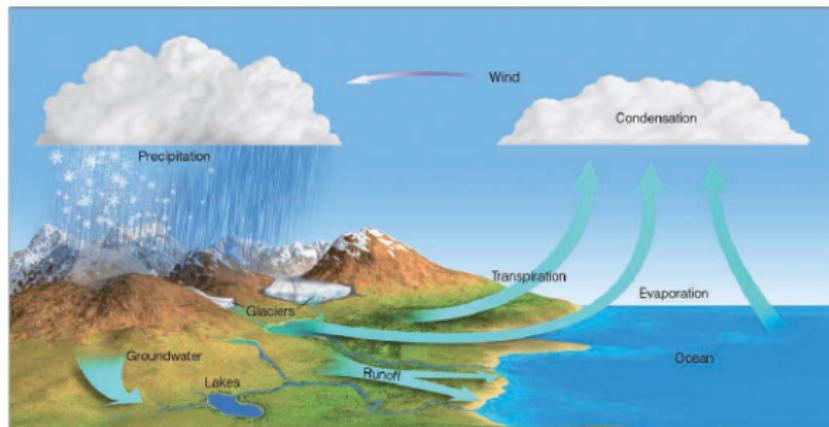
Permanent gases	% (by volume)	mol. weight
Nitrogen (N ₂)	78.08	28
Oxygen (O ₂)	20.95	32
Argon (Ar)	0.93	40
Variable gases		
Water vapour (H ₂ O)	0 - 4	18
Carbon dioxide (CO ₂)	0.035	44
Methane (CH ₄)	0.00017	16

$$\text{dry air} = N_2 + O_2 + Ar + CO_2 + CH_4$$

$$\text{moist air} = \text{dry air} + H_2O$$

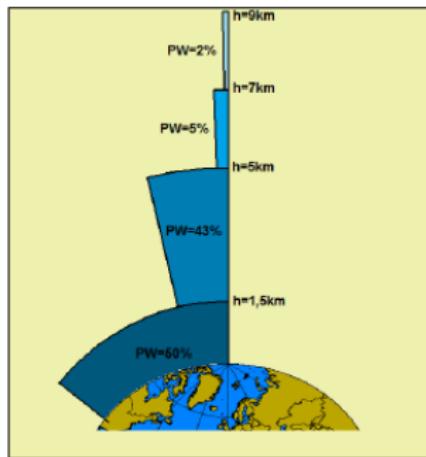
moist air is LIGHTER than dry air same T, p and V

- evaporation = water vapour
- condensation = liquid water
- precipitation = liquid or solid
- about 1-2 weeks renewal time in the atmosphere
- evaporation: 15 % - land, 85 % - ocean



C. Donald Ahrens, Meteorology Today, 2008, Thomson Brooks/Cole 9th Edition

- 5.5 billion liter per year
- 25 mm globally
- 93% below 5 km



Measuring water vapour

	Radiosonde	Microwave radiometry	GNSS
temporal resolution	low	high	high
spatial resolution	low	low	high
vertical resolution	high	low	low
cloud/rain waterproof	yes	no	yes
cost	high	high	low
data set length	about 40 years	since 1990	since 1990



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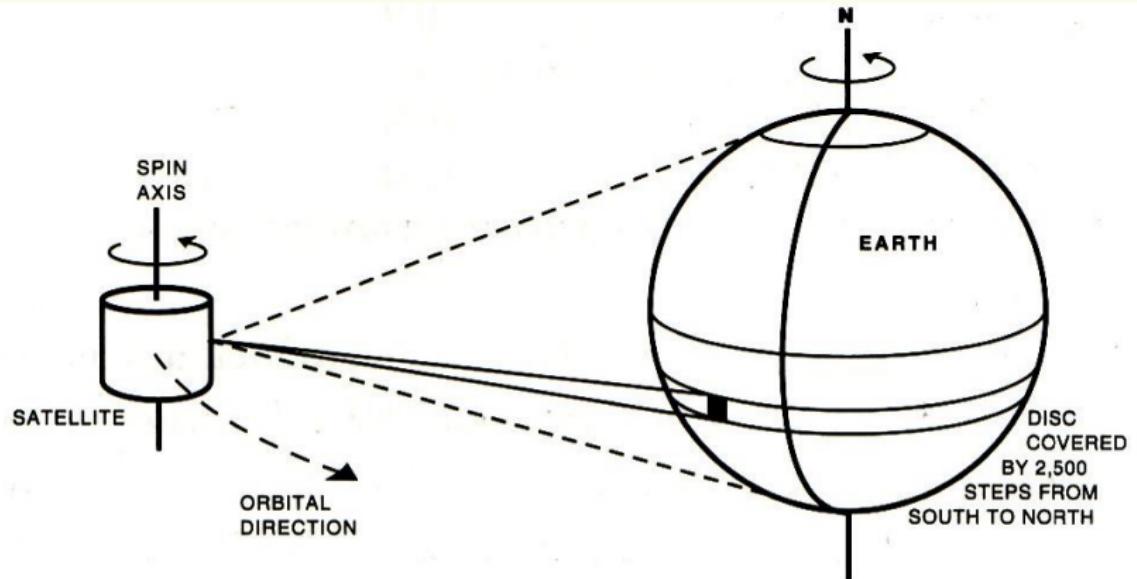
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Challenges

Ref

- orbit 36 000 km above the Earth
- above the equator scanning to 55°
- updated every 15 minutes



Geostationary satellite: black body emissions

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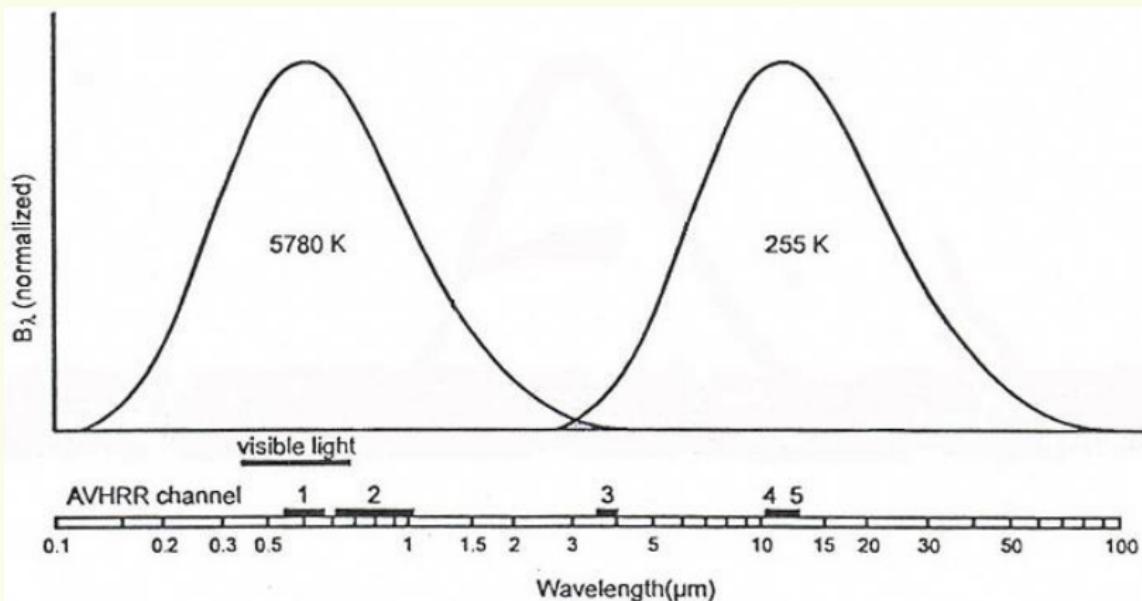
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Challenges

Ref

- Visible (VIS) region - Sun temperature 5780 K
- Infrared (IR) region - Earth and clouds 255 K



MSG (SEVIRI) Channel Characteristics

Channel Number	Spectral Band (μm)	Spectral range (μm)	Resolution at Nadir (km)
1	VIS 0.6 Solar channel	0.56 - 0.71	3
2	VIS 0.8 Solar channel	0.74 – 0.88	3
3	NIR 1.6 Solar channel	1.50 – 1.78	3
4	NIR 3.9 Thermal channel	3.48 – 4.36	3
5	WV 6.2 Absorption channel	5.35 – 7.15	3
6	WV 7.3 Absorption channel	6.85 – 7.85	3
7	IR 8.7 Window channel	8.30 – 9.10	3
8	IR 9.7 Absorption channel "Ozone" Pseudo sounding	9.38 – 9.94	3
9	IR 10.8 Window channel	9.80 – 11.80	3
10	IR 12 Window channel	11.00 – 13.00	3
11	IR 13.4 Absorption channel "CO ₂ " Pseudo sounding	12.40 – 14.40	3
12	HRV High Resolution Visible	Broadband (0.4–1.1 μm)	1

Geostationary satellite: channels

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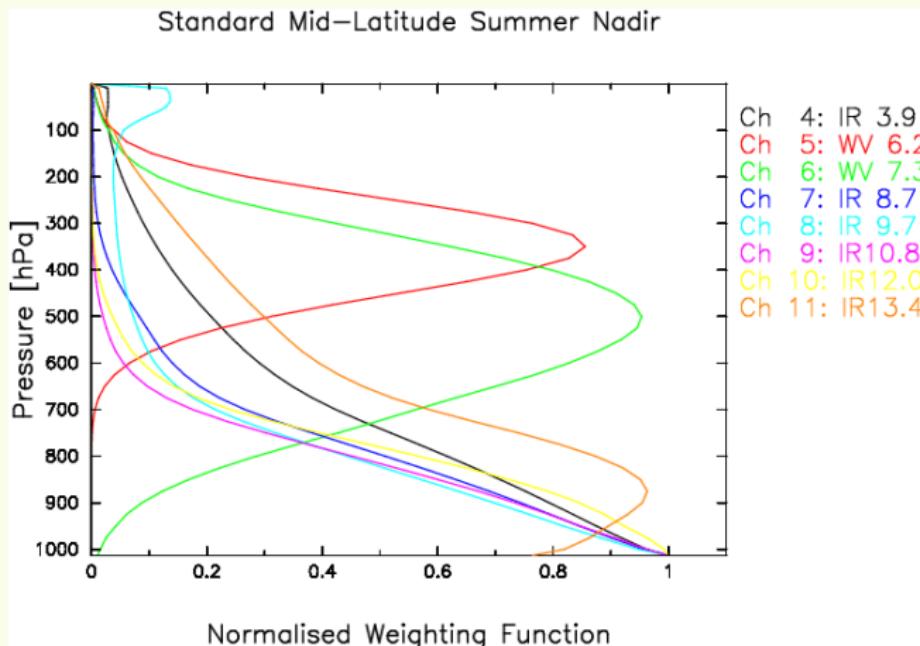
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Challenges

Ref

- WV contribution: 700-200 hPa above 3 km



source: EUMETSAT

MSG satellite image: VIS0.6 on 29 September 2015

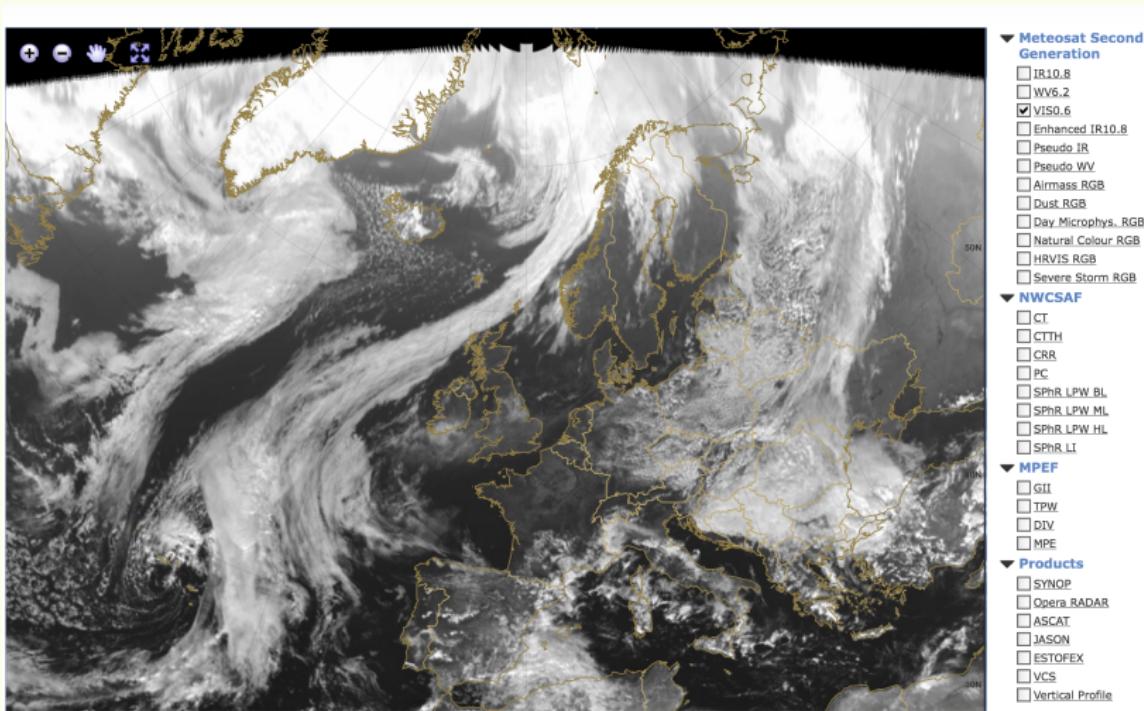
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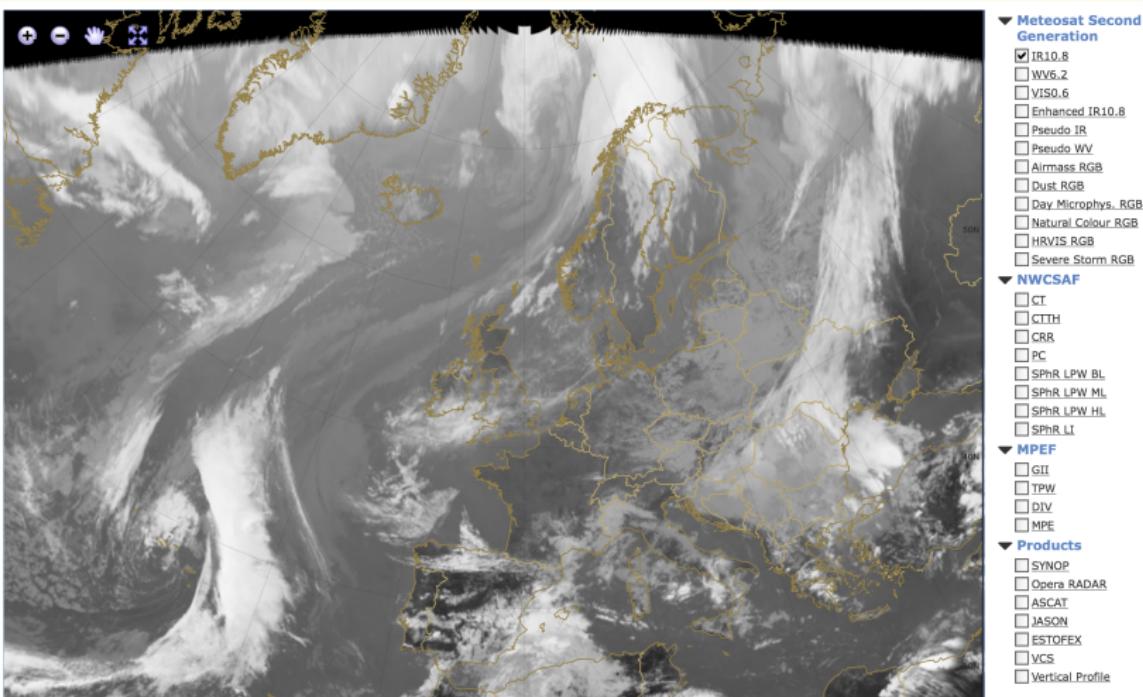
- reflected by Earth surface or clouds solar radiation
- 256 shades of grey - large radiation intensity → white colour



source: <http://www.eumetrain.org/eport/view.php?width=1280&height=800&date=2015092912®ion=euro>

MSG satellite image: IR10.8 on 29 September 2015

- emitted by the Earth and clouds radiation
- 256 shades of grey - low temperature —> white colour



source: <http://www.eumetrain.org/eport/view.php?width=1280&height=800&date=2015092912®ion=euro>

MSG satellite image: WV6.2 on 29 September 2015

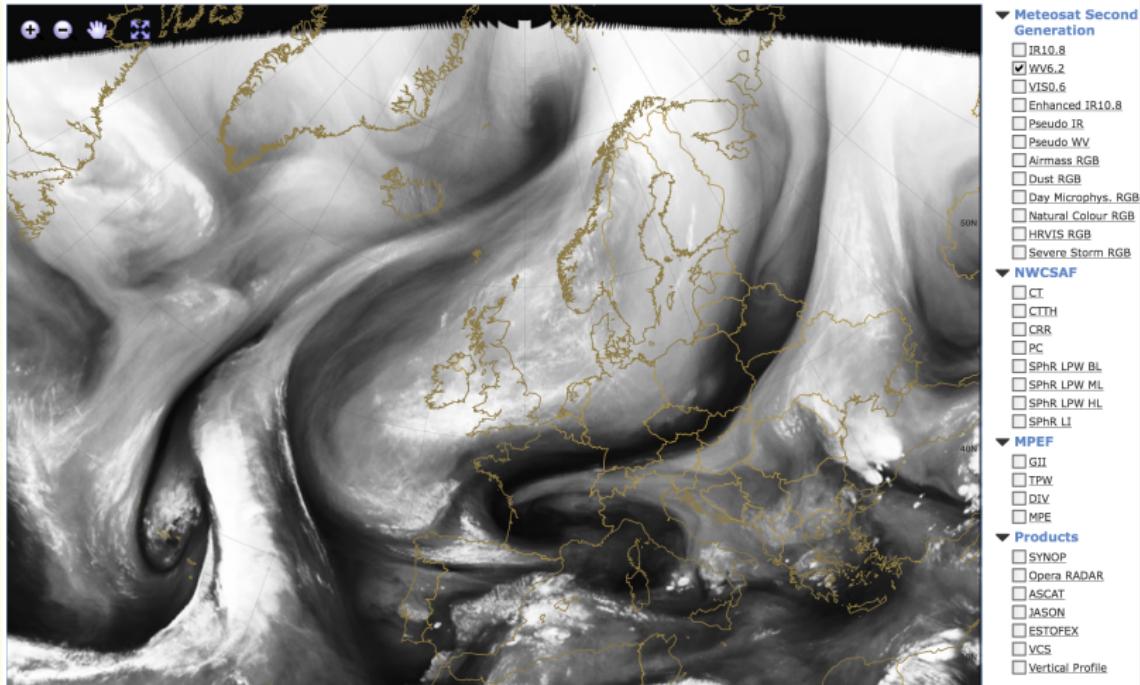
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source: <http://www.eumetrain.org/eport/view.php?width=1280&height=800&date=2015092912®ion=euro>

- COST 716 - 15 countries - 1 hourly updated ZTD products
- GNSS4SWEC - 32 countries - sub-hourly ZTD products, very dense networks



Guerova et al., "Review of the state-of-the-art and future prospects of the ground-based GNSS meteorology in Europe", Atmos. Meas. Tech., 2016.

GNSS Meteorology: Slant vs Zenith Delay

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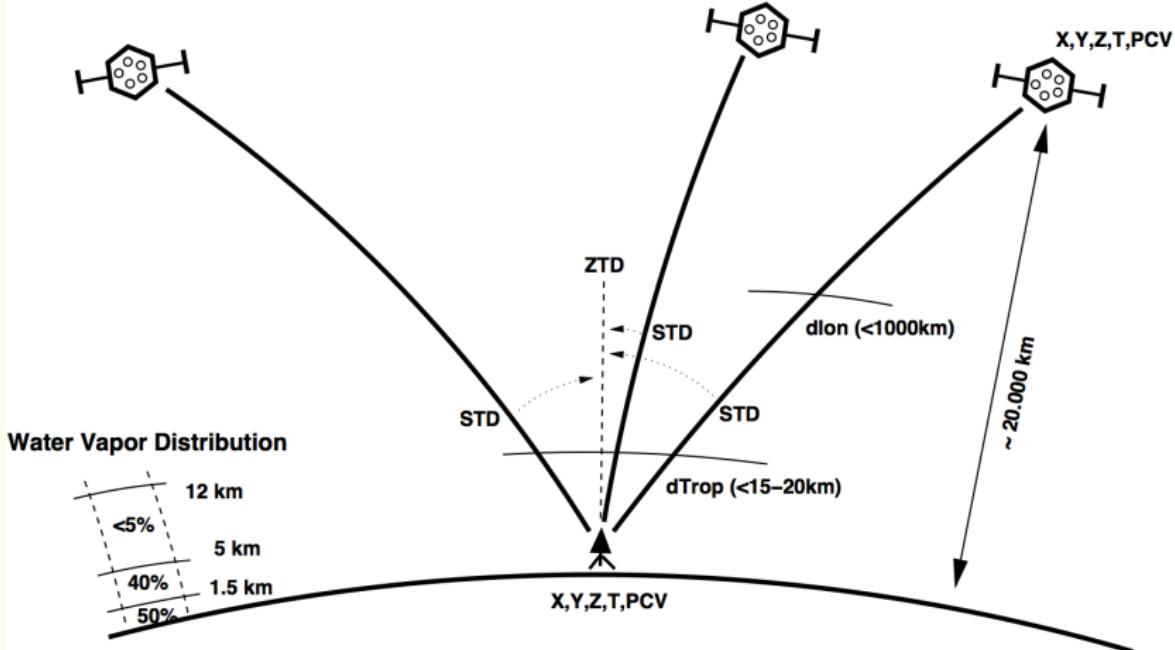
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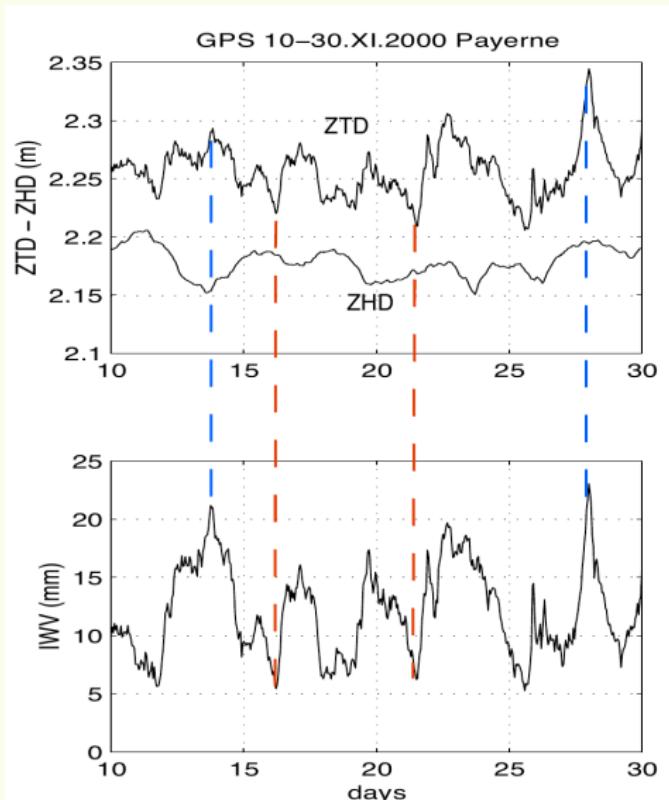
GNSS Meteorology: Integrated Water Vapour IWV

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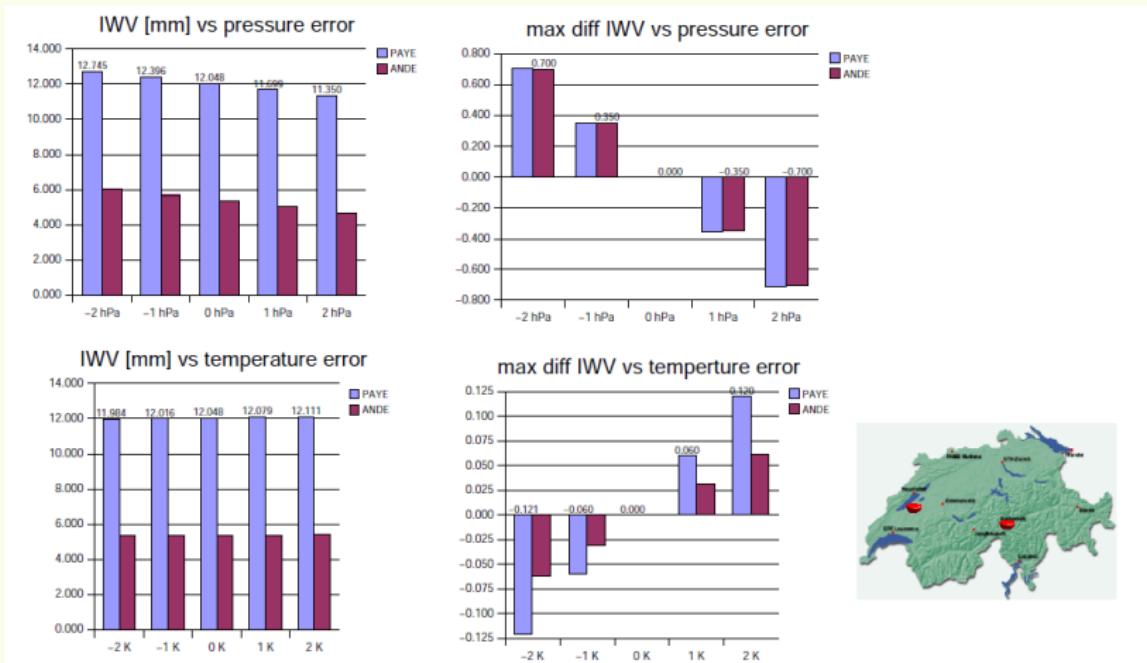
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$$IWV = \frac{10^6}{(k_3/\textcolor{red}{T_m} + k_2')R_v} [ZTD - (2.2768 \pm 0.0024) \frac{p_s}{f(\theta, h)}] \quad (1)$$



GNSS Meteorology: IWV accuracy

$$IWV = \frac{10^6}{(k_3/T_m + k_2')R_v} [ZTD - (2.2768 \pm 0.0024) \frac{p_s}{f(\theta, h)}] \quad (2)$$



GNSS Meteorology: I WV GNSS - RS

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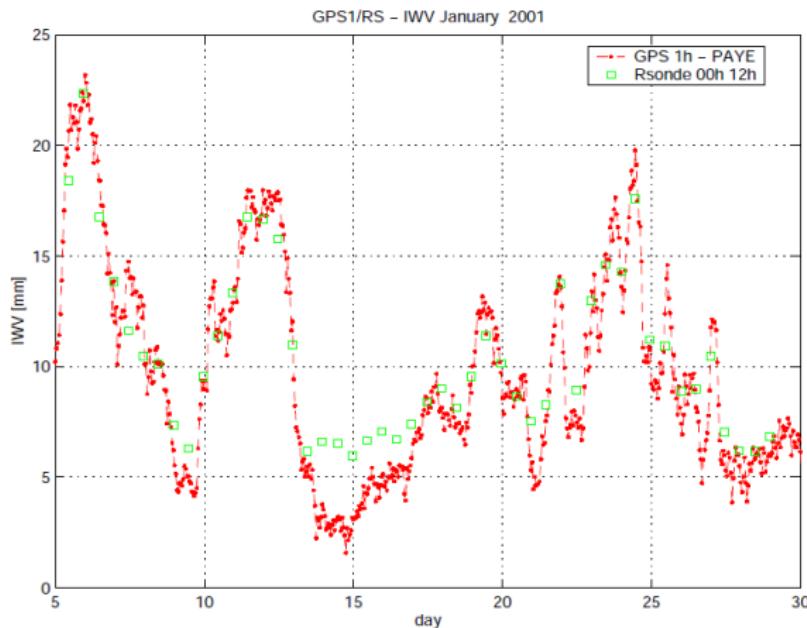
GNSS4SWEC

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Challenges

Ref

- note the large difference between GNSS (red dots) and RS (green squares) from 14 to 16 January



GNSS Meteorology: IWV GNSS - RS - LM Meteoswiss

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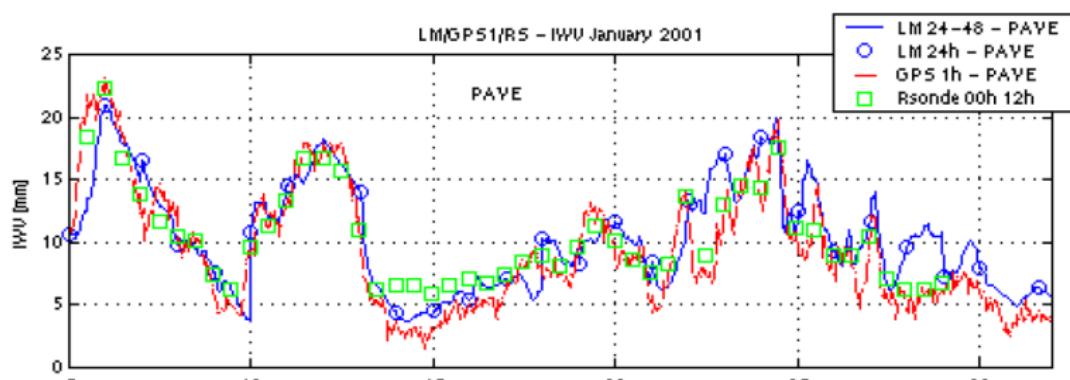
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Challenges

Ref

- note the similarity between GNSS (red dots) and Local Model (blue line) from 14 to 16 January



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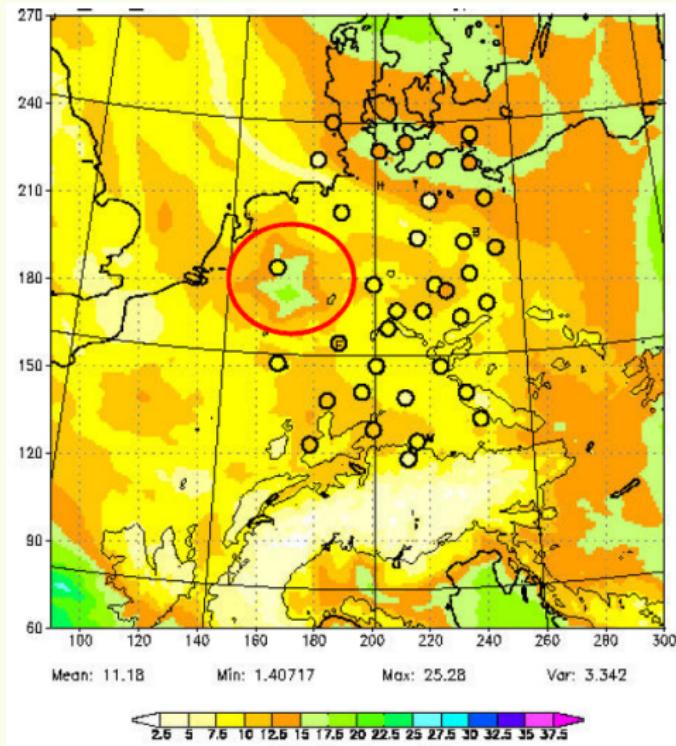
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Challenges

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Quiz time: IWV from GNSS and LM: one day in April 2001



- a) GNSS problem
- b) LM problem
- c) not my problem ;-)

GNSS Meteorology: IWV and precipitation NWP

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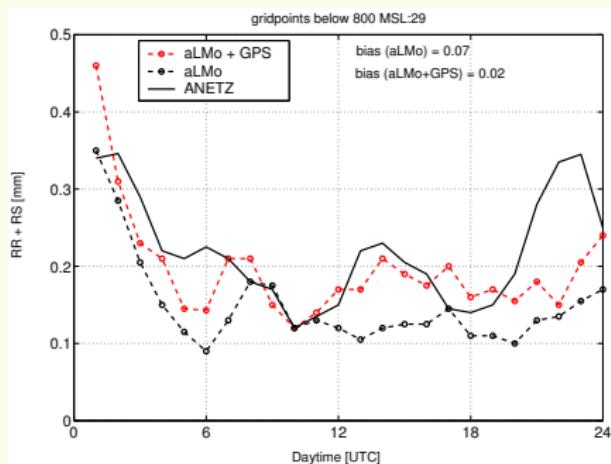
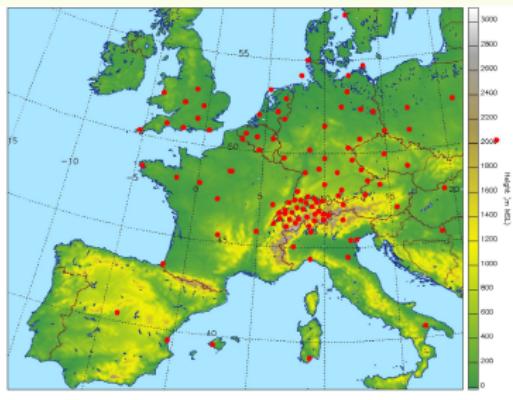
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Challenges

Ref

- GNSS IWV improvement in diurnal precipitation
- improved model precipitation scores*



Guerova et al., "Assimilation of the GPS-derived Integrated Water Vapour (IWV) in the MeteoSwiss Numerical Weather Prediction model - a first experiment", Phys. Chem. Earth., 29, 2-3, 177-186, 2004.

GNSS Meteorology: IWV GNSS - NWP

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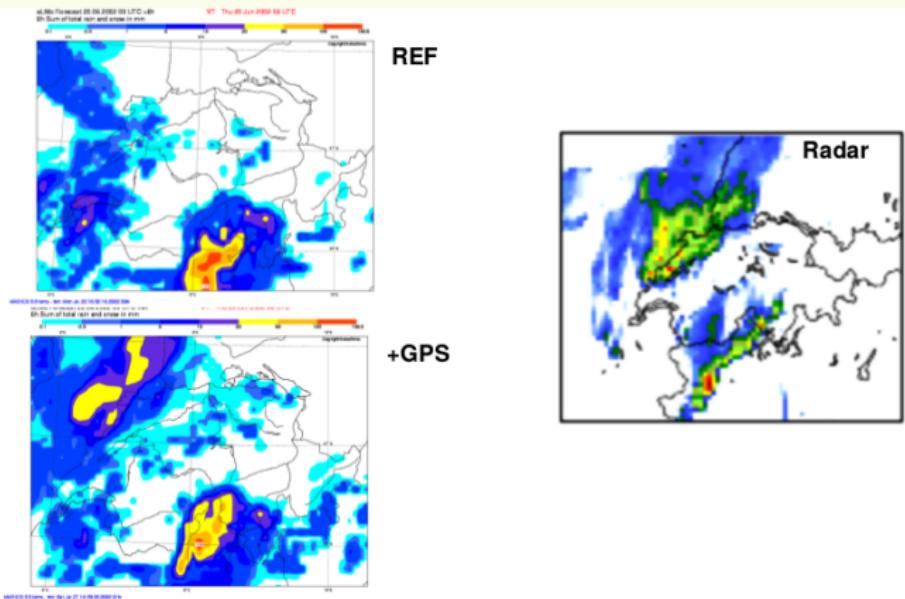
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- GNSS assimilation recover missing precipitation pattern in the forecast*
- proven potential to add value to operations NWP in active weather regimes



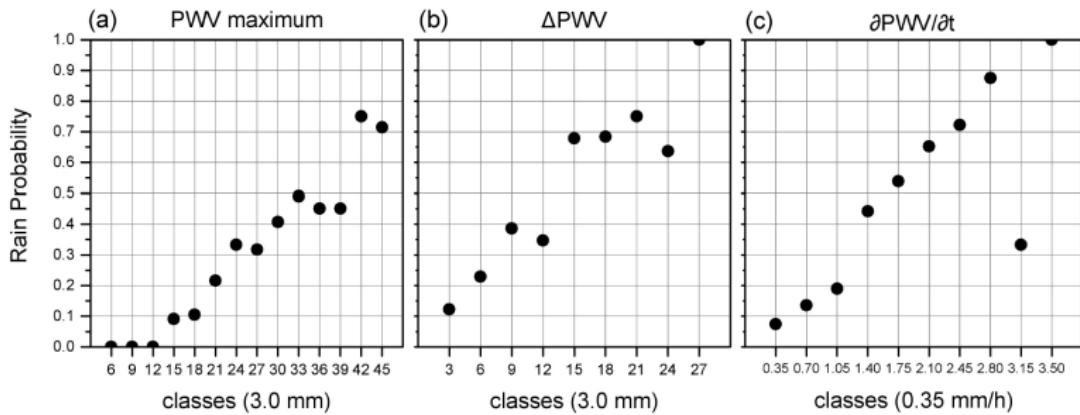
Guerova et al, 2006. Assimilation of COST 716 Near Real Time GPS data in the non hydrostatic limited area model used at MeteoSwiss. Meteorol. Atmos. Phys., 91, 1-4, 149-164.

Case study Portugal: IWV and precipitation*

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Benevides et al., 2015. "On the inclusion of GPS precipitable water vapour in the nowcasting of rainfall." Natural Hazards and Earth System Sciences 15.12, 2605-2616.

Case study Argentina: I WV and hail*

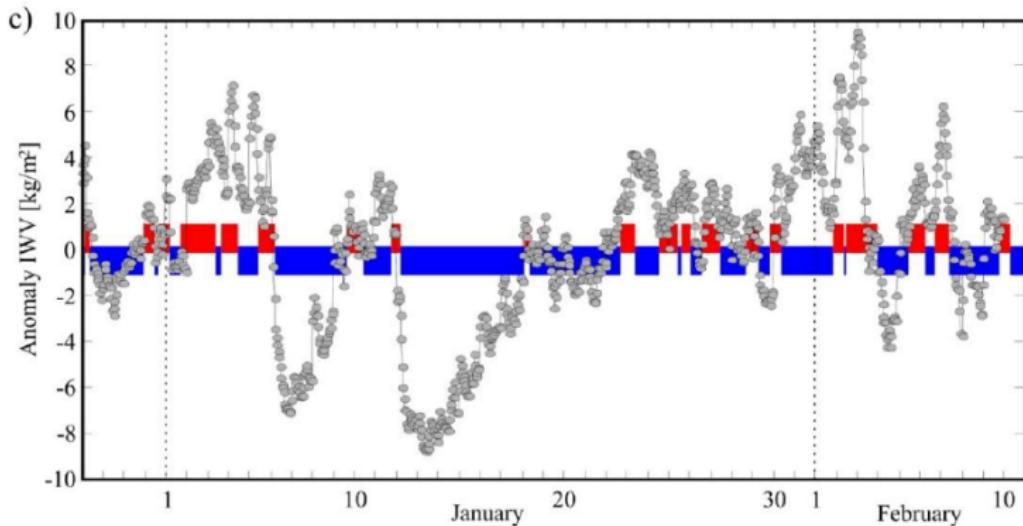
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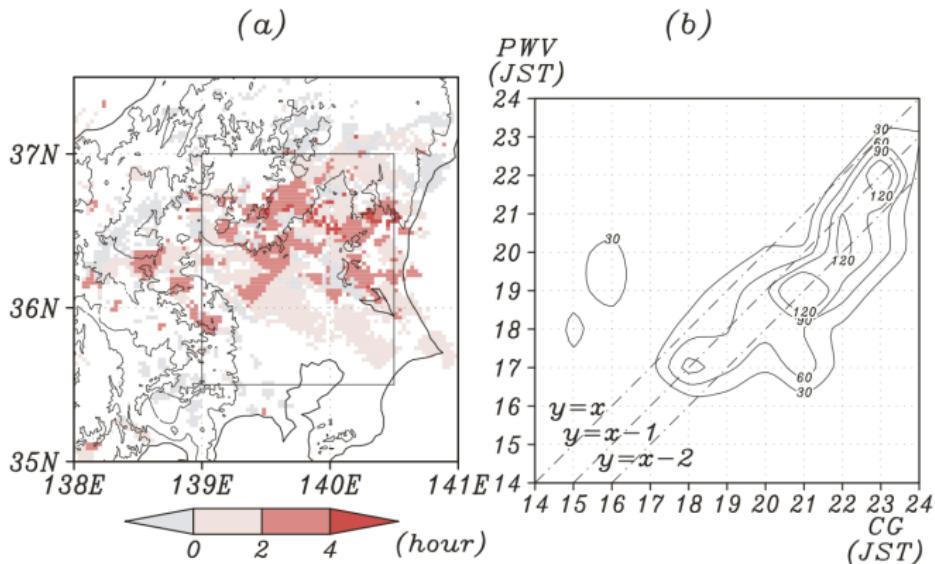
- 45 days with daily deep convection with/without hail
- hail storm development - accumulation of humidity in genesis region



Calori et al. 2016. "Ground-based GNSS network and integrated water vapor mapping during the development of severe storms at the Cuyo region (Argentina)." Atmospheric Research 176, 267-275.

Case study Japan: IWV and lightning*

- IWV peaks 15-30 min before lightning stroke - 40 % of the thunderstorms
- large IWV and IWV increment - 1 h before stroke



Inoue et al., 2007. "Characteristics of the water-vapor field over the Kanto district associated with summer thunderstorm activities." SOLA 3 101-104.

Case study Southeast Europe: convection 26 June 2012

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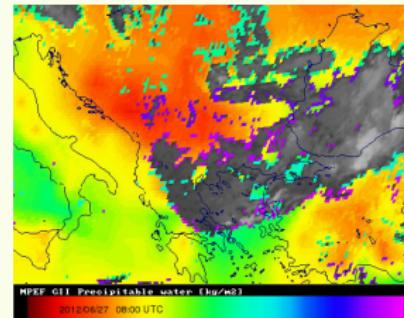
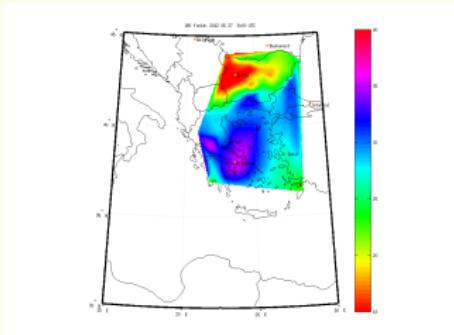
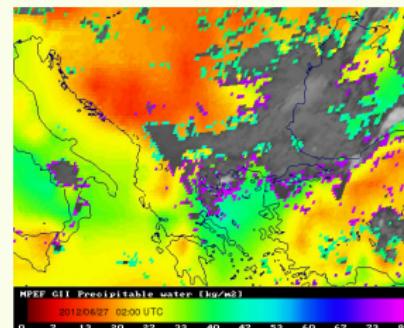
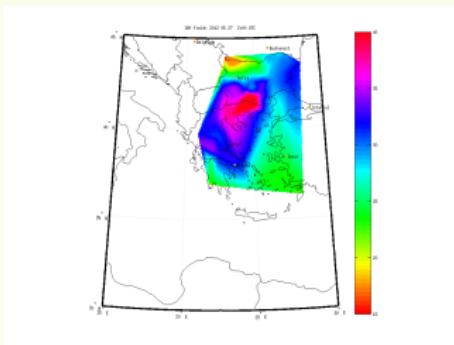
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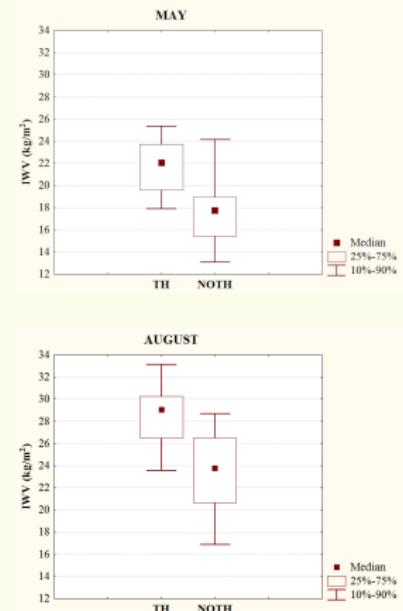
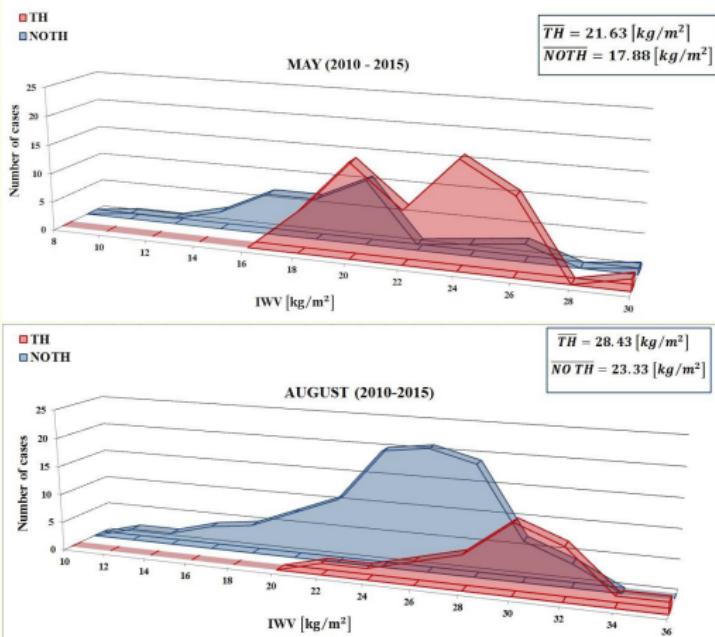
Ref

- cold air advection from NW
- the Balkan mountain: barrier for the cold air which accumulates in the flatland around Danube river



Case study Bulgaria: IWV and lightning* 2010-2015

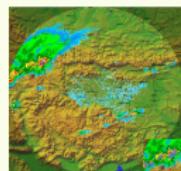
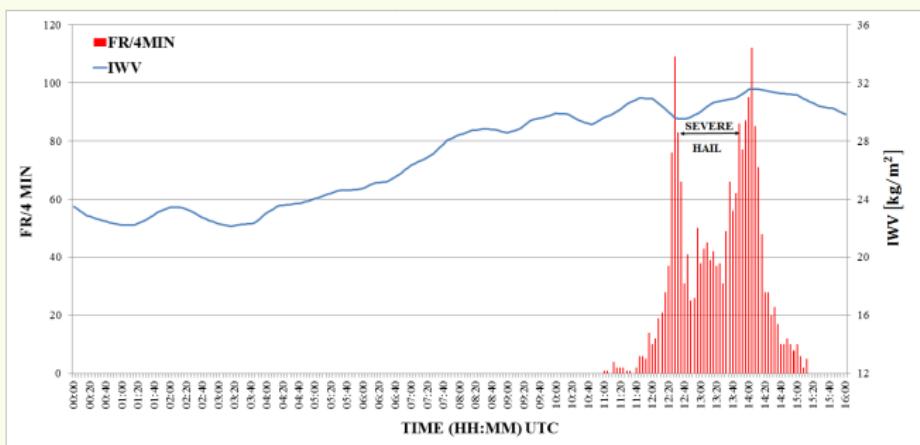
- clear destruction between IWV for thunder and no-thunder cases



Georgiev et al., 2018. "Study of thunder and hail storms in Bulgaria using GNSS water vapour products" EMS presentation.

Case study Bulgaria: IWV and lightning*

- IWV increase before the lightning and hail detection
- lightning number jump observed before the hail start
- drop of the number of lightning during hail storm



Georgiev et al., 2018. "Study of thunder and hail storms in Bulgaria using GNSS water vapour products" EMS presentation.

GNSS Meteorology: GNSS4SWEC benchmark campaign*

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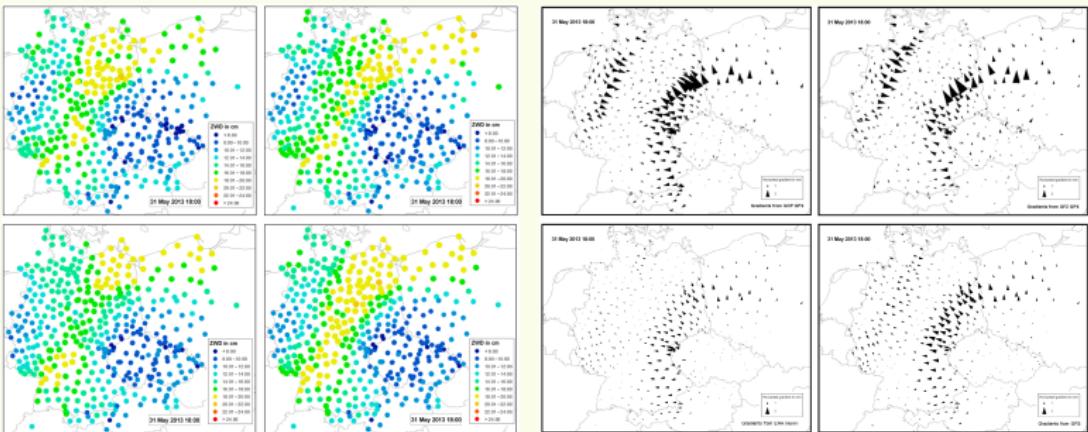
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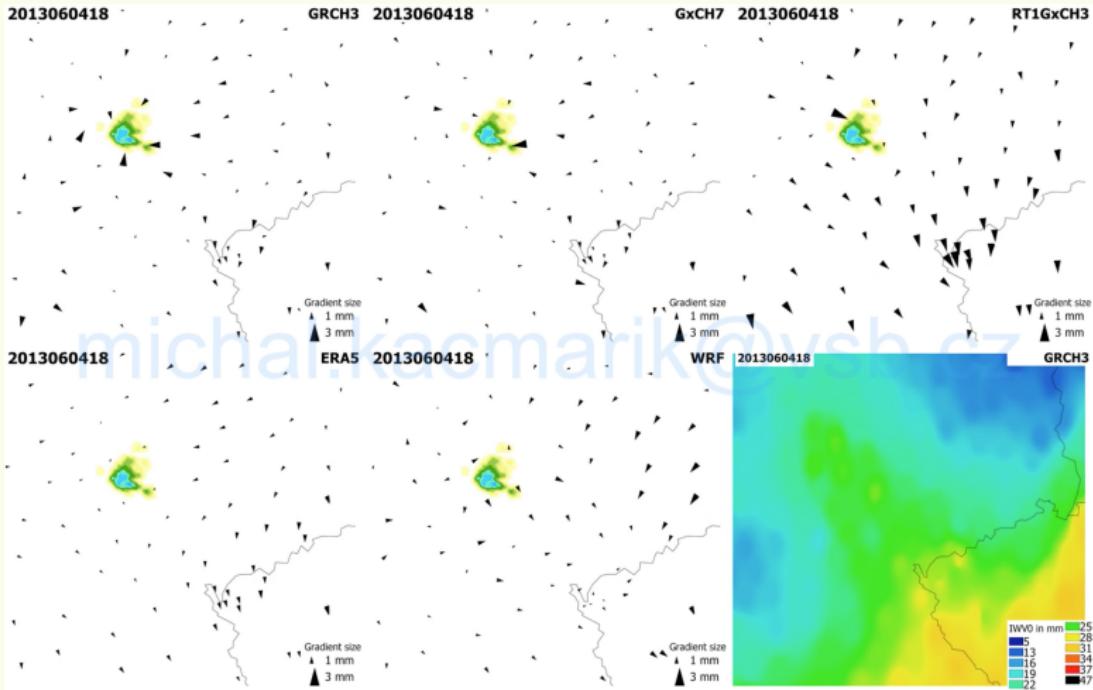
Ref

- GNSS4SWEC network 2013-2017, final report coming soon (500 pages ;-)
- 430 GNSS stations: high speciotemporal resolution ZTD, ZWD, GRAD, SPD
- !INB GNSS data screening - very important



Dousa et al. 2016, Benchmark campaign and case study episode in central Europe for development and assessment of advanced GNSS tropospheric models and products, Atmos. Meas. Tech., 9, 2989-3008.

GNSS Meteorology: GNSS4SWEC benchmark gradients*



Kacmarik et al., 2019: Sensitivity of GNSS tropospheric gradients to processing options, Ann. Geophys.

GNSS Meteorology: E-GVAP phase IV & BeRTISS

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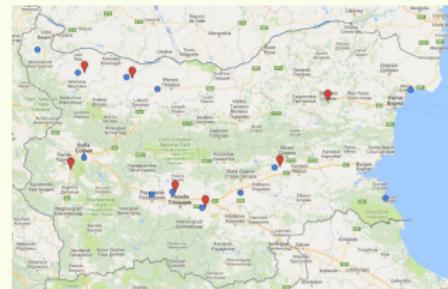
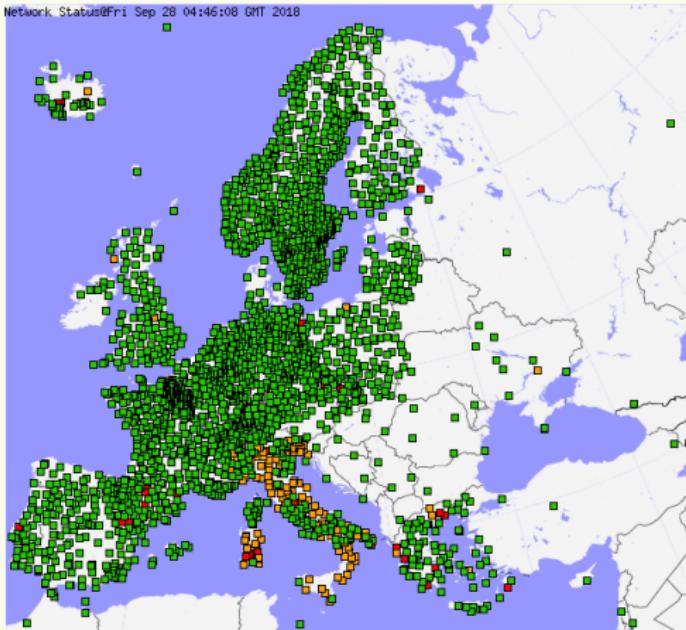
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source: E-GVAP <http://egvap.dmi.dk> & http://suada.phys.uni-sofia.bg/?page_id=4102

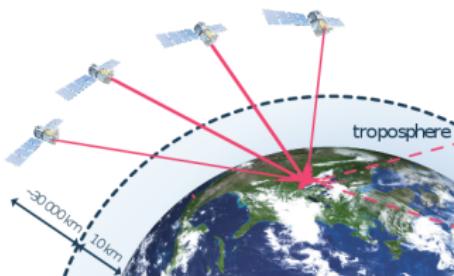
- BIGER, BETTER, FASTER - real time monitoring of severe weather
- new products - different challenges, processing gradients and slants are still not satisfactory
- Synergies with other observations **Prospective:**

- more case studies needed - various regions in Europe and global
- Final report COST Action ES1206 "Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)" published in 2018*
- GALILEO 2015-2020

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GNSS (GPS, GLONASS, Galileo)

Ground-based
GNSS networks
& usersCOST Action
GNSS4SWECWeather & Climate
centres

GNSS tropospheric products



THANK YOU FOR THE ATTENTION!