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The GPS tropospheric tomography as an GGOS contribution to water vapour distribution studies.

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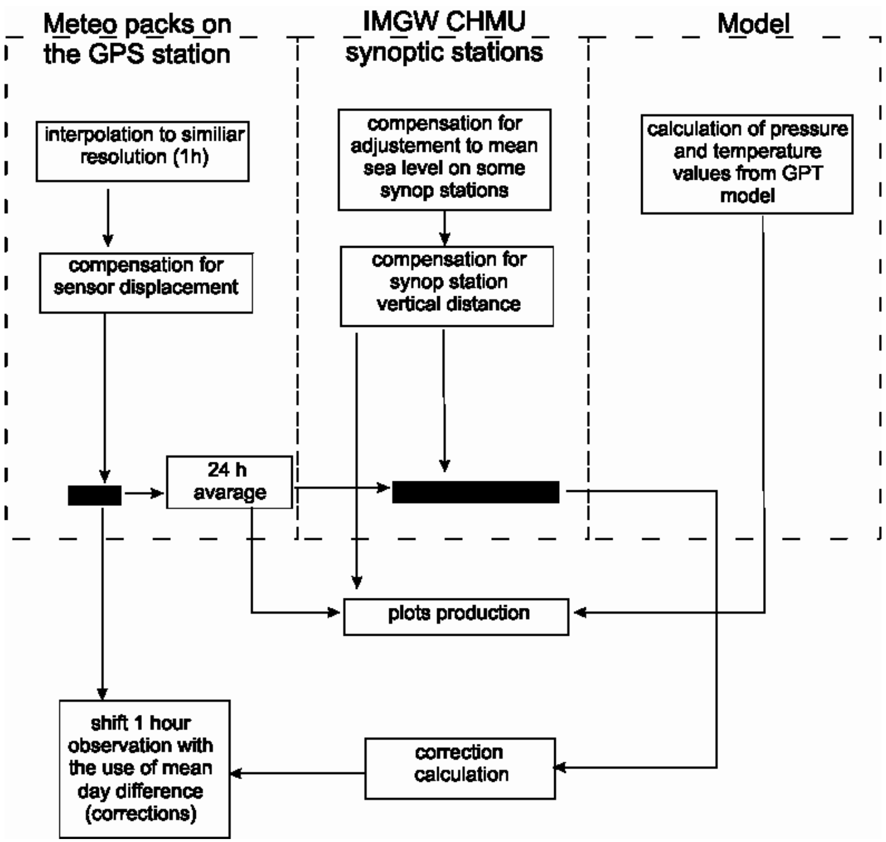
ZTD verification: sources of meteorological parameters

- meteo packs mounted close to GPS antena
  - pressure: 0.3 – 0.5 hPa
  - temperature: 0.3 – 0.5 ^{0}C
  - humidity: 3 - 5%
- National Meteorological Services (working in the WMO network)
  - pressure: 0.2 hPa
  - temperature: 0.2 ^{0}C
  - humidity: 2%
- GPT model
  - pressure: 5 hPa
  - temperature: 3 ^{0}C

ZTD verification: meteorological parameters



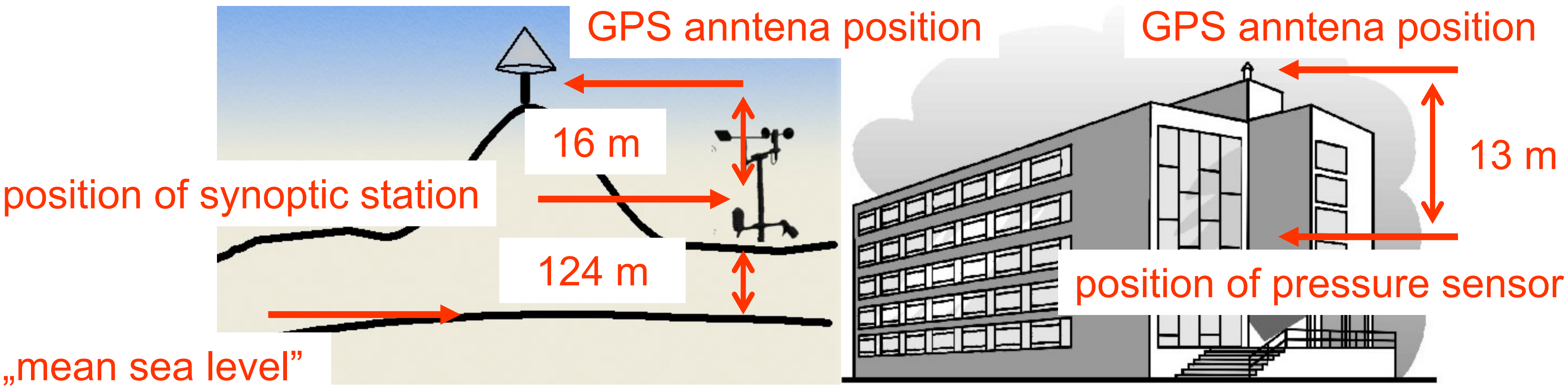
Examples of data resolution

Station	meteo files time resolution [s]
WROC	300
GOPE	60
BISK	30
SNEC	30

ZTD verification: meteorological parameters

compensate for recalculation to mean sea level on some synop stations

compensate for meteorological station vertical distance



Meteorogical data verification: results

Bias is a mean difference between calibrated and not calibrated data

Error is a standard deviation of difference between calibrated and not calibrated data

station	bias press (hPa)	error press (hPa)	bias temp (^{0}C)	error temp (^{0}C)
karl	-0.22	0.41	0.10	0.34
wtzr	-0.52	1.16	0.54	0.71
mate	0.69	0.00	0.20	0.56
pots	2.33	0.47	0.35	0.34
ptbb	-0.92	0.48	0.12	0.45
bisk	23.95	1.27	0.79	1.03
casc	0.46	0.37	0.17	0.87
delf	-0.02	0.33	0.10	0.42
eusk	-0.25	0.87	-0.66	1.14
gaia	0.06	0.58	0.65	0.68
wroc	0.98	0.74	0.79	0.57
hers	0.09	0.50	0.63	0.43
hert	-0.02	0.51	0.65	0.51
ista	-2.08	0.50	-0.09	0.65
joz2	0.91	0.49	0.17	0.42
kraw	-0.94	1.92	0.70	0.74
lama	7.57	11.27	-0.38	2.38
helg	-0.35	0.37	0.04	0.13
orid	-0.22	0.37	0.33	0.41
pdel	0.47	0.53	1.75	0.38
mets	-0.72	0.57	0.17	0.85
reyk	NaN	NaN	0.48	0.54
sass	0.42	0.30	0.30	0.33
snec	-0.07	0.39	0.21	0.37
sofi	-0.33	0.91	0.15	0.70
svtl	2.15	0.62	0.51	0.93
trab	-0.66	0.56	0.08	0.31
tubo	-0.02	0.67	0.30	0.32
warn	0.24	0.79	-0.23	0.49
gope	-0.98	1.03	0.11	0.71
nico	-0.12	0.42	-1.13	0.65

data with bias above 1 hPa or 1 ^{0}C

ZTD verification data sources

- Euref product mean weekly solution from all LAC's:

Local Analysis Center \examples\	Apriori model	Estimates
OLG since 1397	Dry Niell + MF	ZTD (each 1h). Wet Niell MF, HG (tiliting) for 24 hours
BKG since 1320	Dry Saastamoinen + dry-Niell MF	ZWD (each 1h) + Wet Niell MF
BKG since 1400	Dry Niell	Zenith delay corrections (1h each station), wet-Niell MF. HG (tilting) for 24 hours.

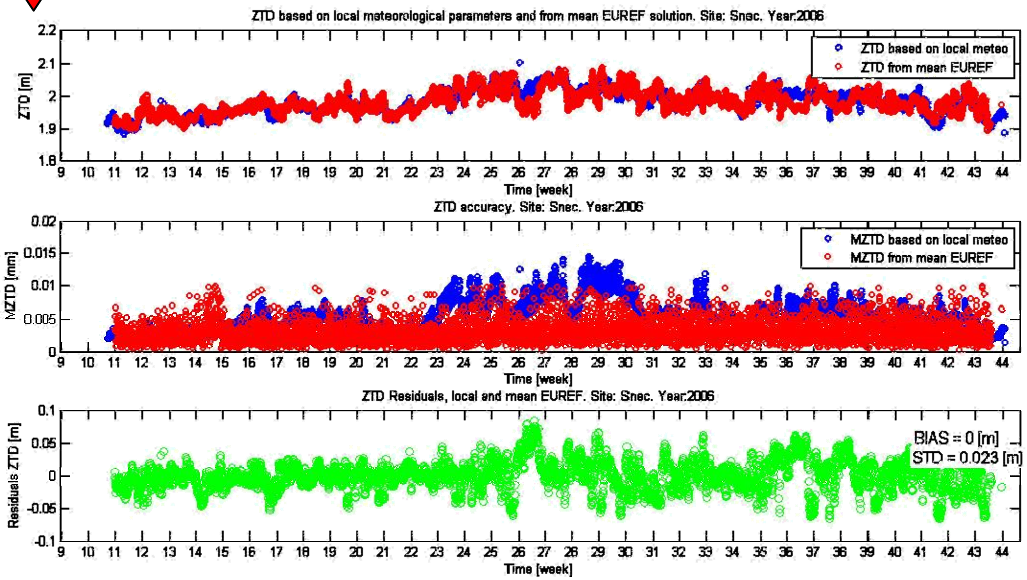
- Tropospheric delay - Saastamoinen eqations:

$$ZWD = 0.002277 \cdot \left(\frac{1255}{T_0[^oK]} + 0.05 \right) \cdot e_0[hPa]$$

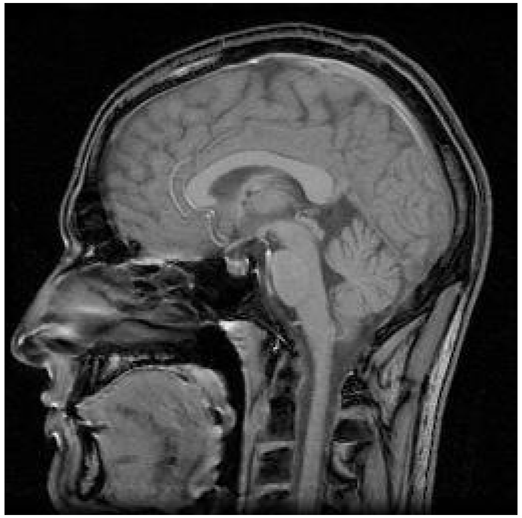
$$ZHD = \frac{0.0022767 \cdot \left[\frac{m}{hPa} \right] \cdot P_o}{1 - 0.00266 \cdot \cos 2\varphi - 0.00028 \cdot \left[\frac{1}{km} \right] \cdot h_e}$$

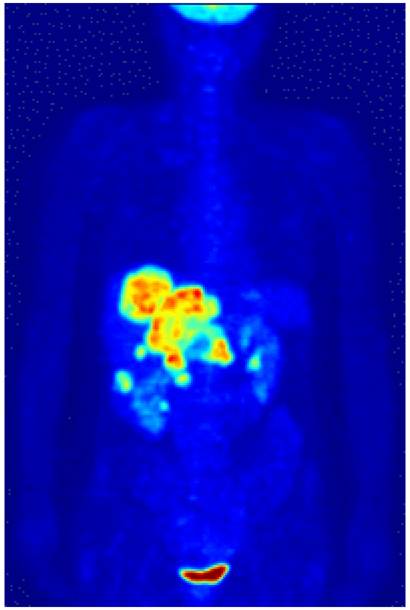
ZTD Verification results

Station	ZTD residuals		
	bias [m]	error [m]	correlation coeficience
WROC	0.01	0.03	0.89
GOPE	-0.05	0.03	0.83
SNEC	0.01	0.04	0.81
BISK	0.16	0.04	0.88



Tomography: The princples





Was discovered by:

Johann Radon lecturer at Wroclaw University between year 1928 and 1945

The first tomograph constructed by Godfrey Newbold Hounsfield (Nobel 1979 - medicine)

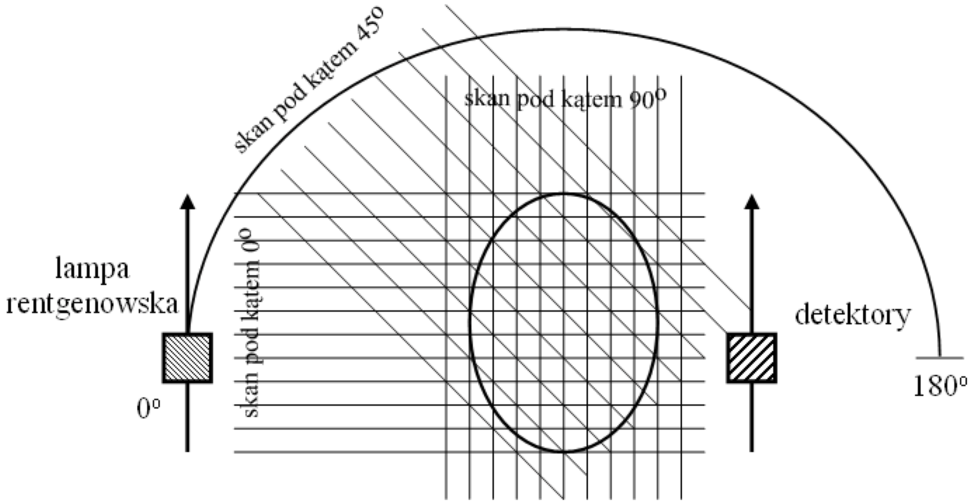
Presently (CT, PET, MRI) used in medicine for:

- brain examination
- hearth examination
- inflammations
- tumors detections

Tomography: The principles

The results of the measurements of the parameters, the a priori information on model parameters, and the information on the physical correlations between observable parameters and model parameters can all be described using probability densities (Tarantola 2005)

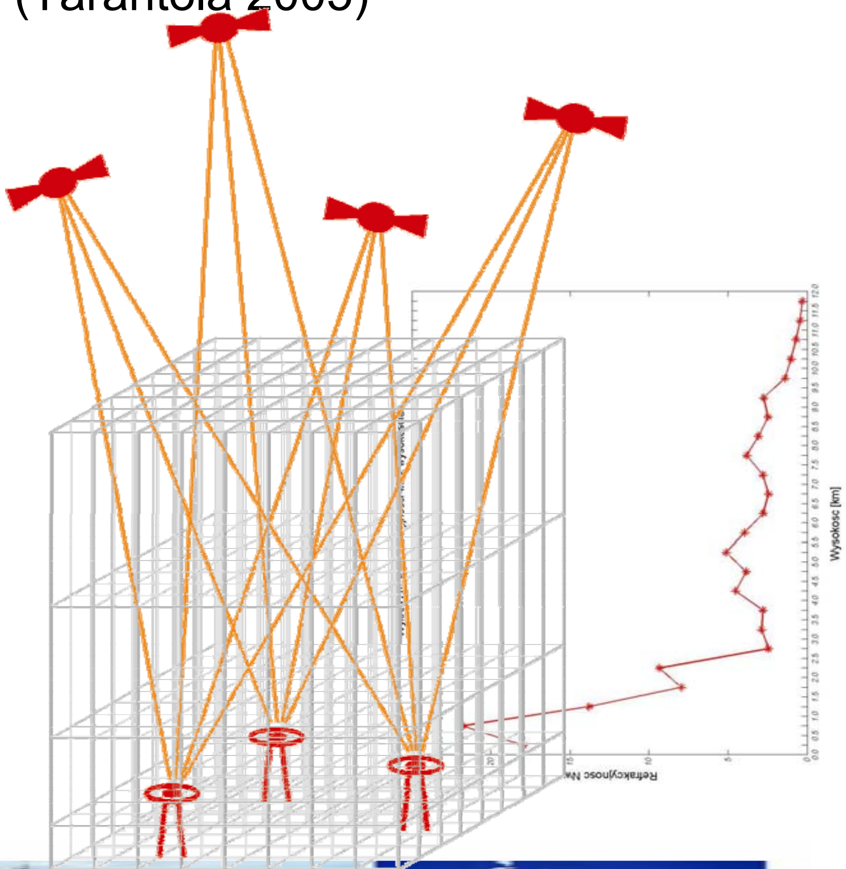
parameters: amount of radiation absorbed by the patient's head
a priori information: density distribution
physical correlation: amount of absorbed radiation is correlated with the density distribution in head



Tomography: The principles

The results of the measurements of the parameters, the a priori information on model parameters, and the information on the physical correlations between observable parameters and model parameters can all be described using probability densities (Tarantola 2005)

parameters: the Slant Wet Delay (SWD)
a priori information: temperature and pressure distribution in the model domain
physical correlation: the SWD is correlated with the amount of water vapor on the signal path

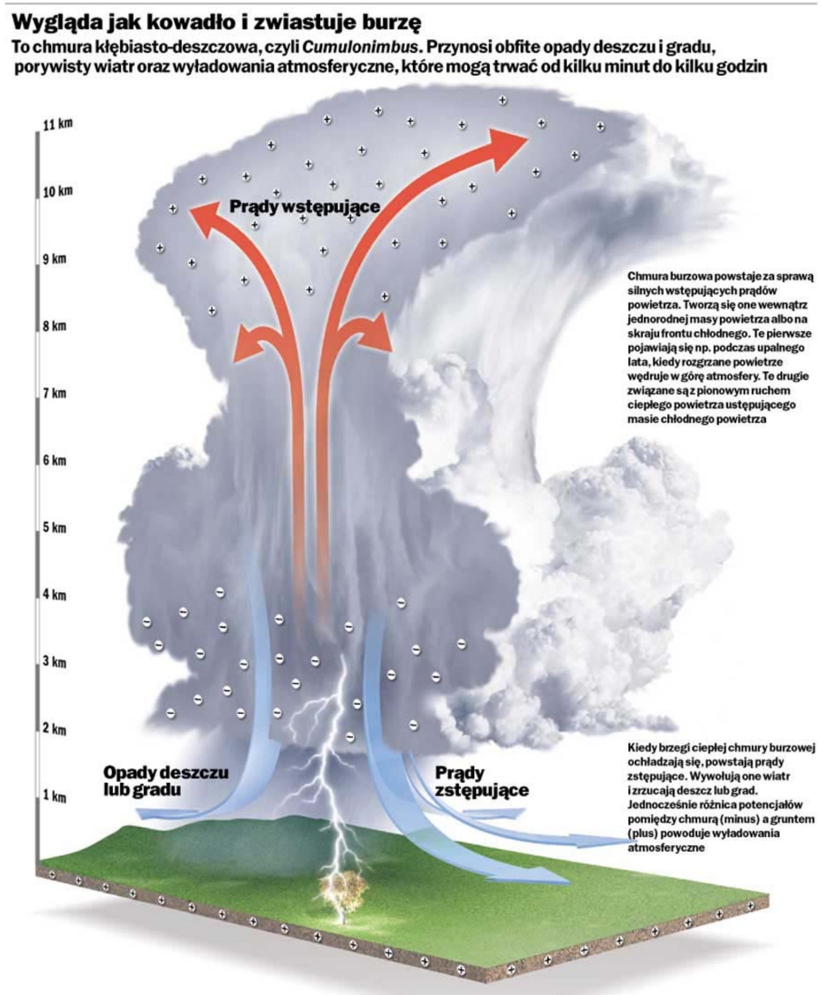


$$N_d = k_1 \cdot \frac{P_d}{T} \cdot Z_d^{-1}$$

$$N_v = \left(k_2 \cdot \frac{e}{T} + k_3 \cdot \frac{e}{T^2} \right) \cdot Z_v^{-1}$$

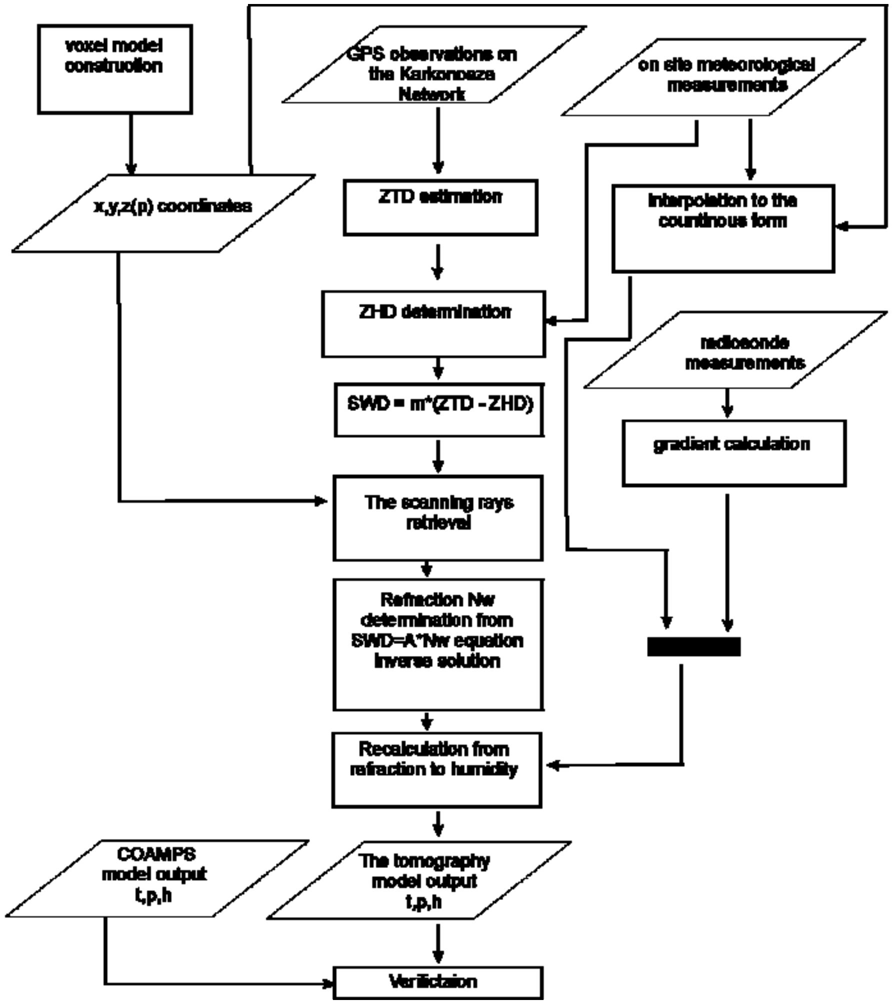
Tomography: the troposphere

- The layer of the atmosphere that is nearest to the earth surface
- In average the temperature in troposphere decreasing with altitude (division criterion)
- Space where most of the weather processes take place
- The state of the troposphere is defined by three basic quantity: temperature, pressure and humidity



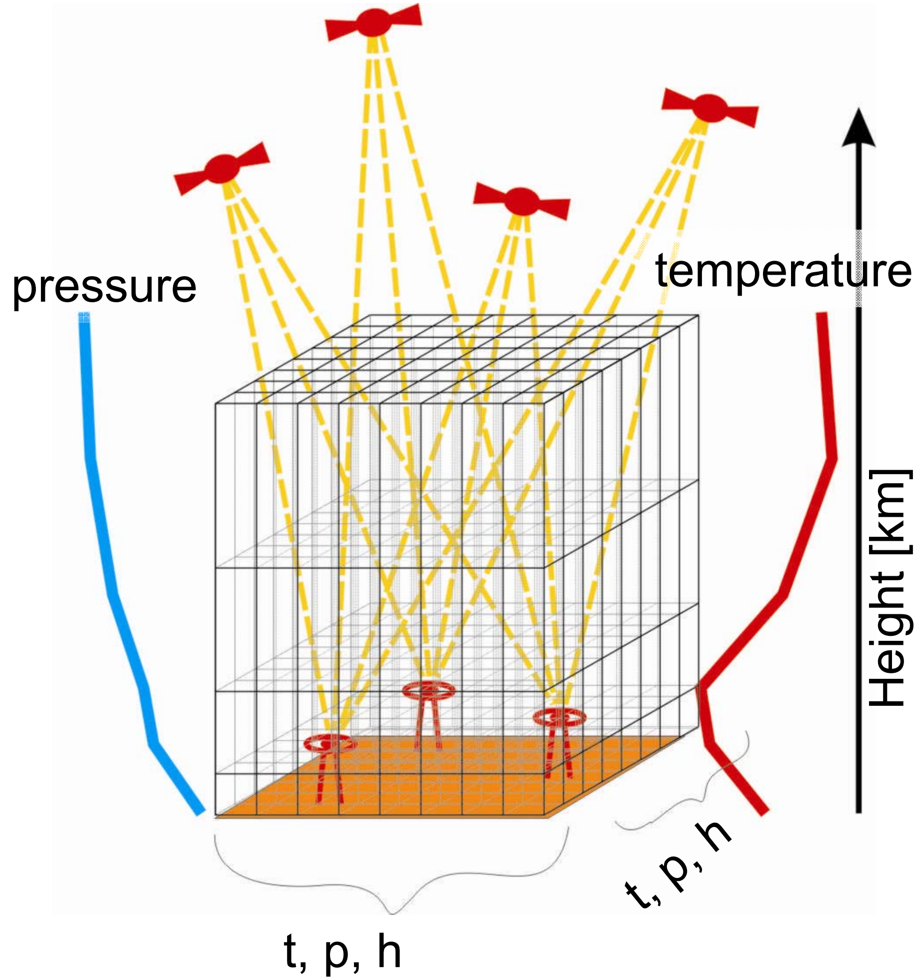
Tomography: model construction

1. GNSS and meteorological data acquisition
2. tropospheric delay estimation
3. scanning rays retrieval
4. inverse solution
5. verification with the use of COAMPS data



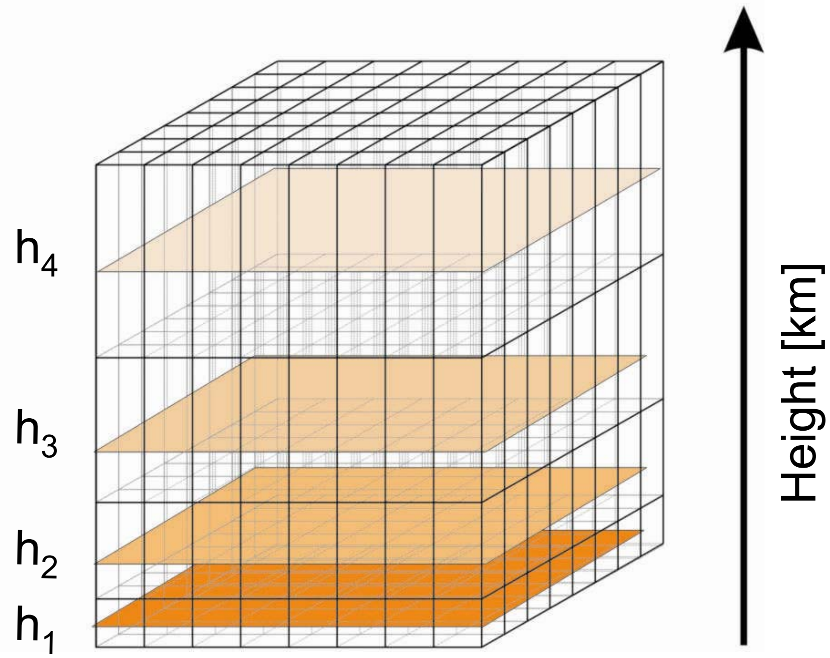
Tropospheric Tomography in Karkonosze Mts.: input

- continues meteorological parameters
- the SWD values
- local laps rates and local pressure gradients



Tropospheric Tomography in Karkonosze Mts.: output

- the 3D water vapour distribution
- procedures that may be adopted in the active GPS network (ASG-PL)
- verification or external source for (COAMPS, ALLADIN, UM)

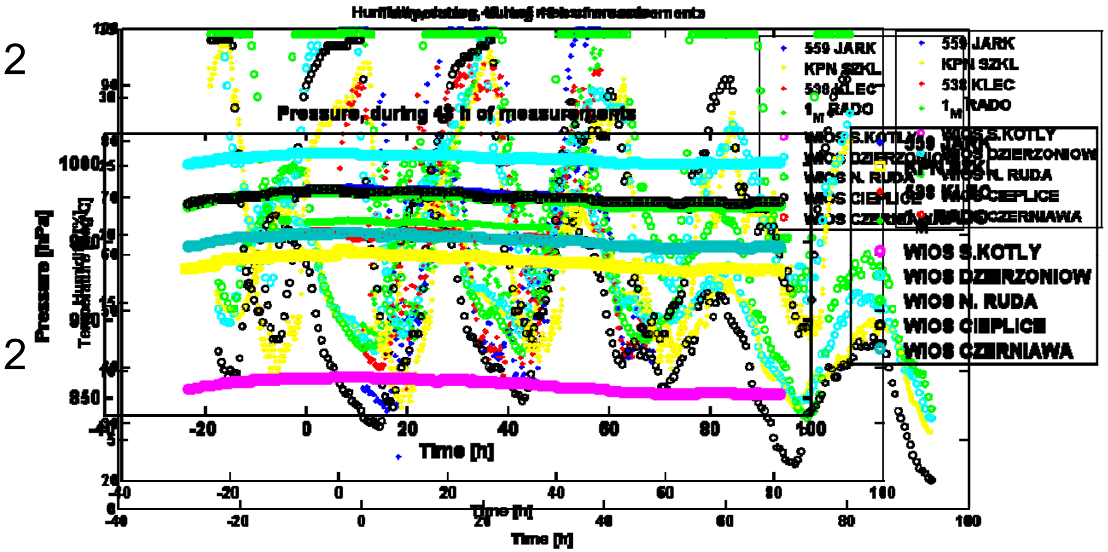


GPS Campaign KARKONOSZE Mts 2007
25,26 August 2007

- GPS epoch observations at the points of KARKONOSZE network:
  - KLEC, SNEC, SZRE, RADO, JARK
- Meteorological observations (t, p, h) at 15 meteorological stations and radio sounding on collocated area
  - IMGW
    - Śnieżka, Jelenia Góra, Zgorzelec, Wałbrzych, Kłodzko
  - WIOŚ
    - Cieplice, Czerniawa, Snieżne Kotły, Nowa Ruda, Dzierżoniów
  - PWr
    - Szrenica
  - KPN
    - Szklarska Poręba
  - Meteo hand-helds
    - Jarkowice, Stara Kamienica, Radomierz
  - Radio sounding:
    - Wrocław, Berlin, Praga

Meteo data preparation: coherence

- WIOŚ i IMGW :
  - data from time of campaign +/- 2 day
  - data from July, August, September 2006
- Karkonoski Park Narodowy:
  - data from time of campaign +/- 2 day
- Hand held meteorological instruments:
  - calibration inside weather station

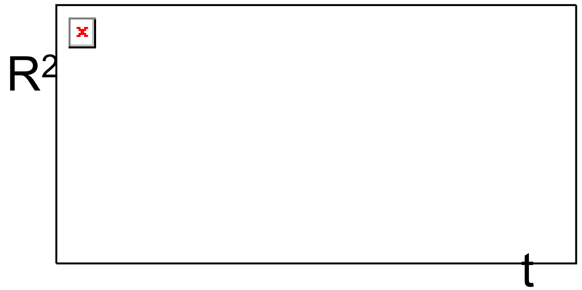


Meteo data preparation: discrete to continuous cooperation Maciej Kryza

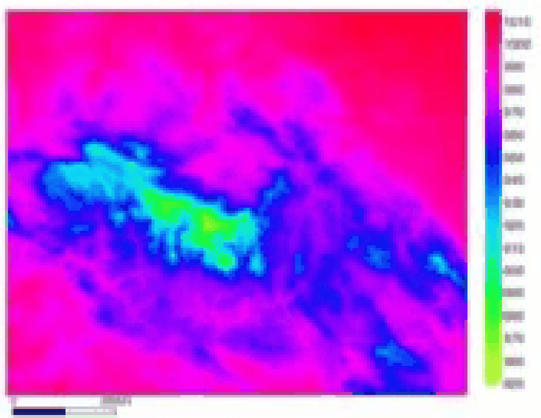
determination coeficience R2 for linear regression in time: p / t / h w.r.t altitude

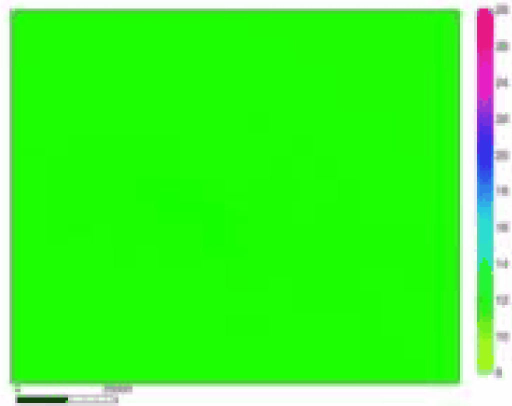
Pressure

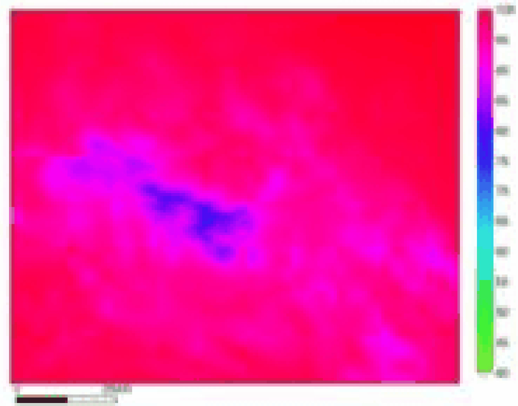
Temperature



Humidity





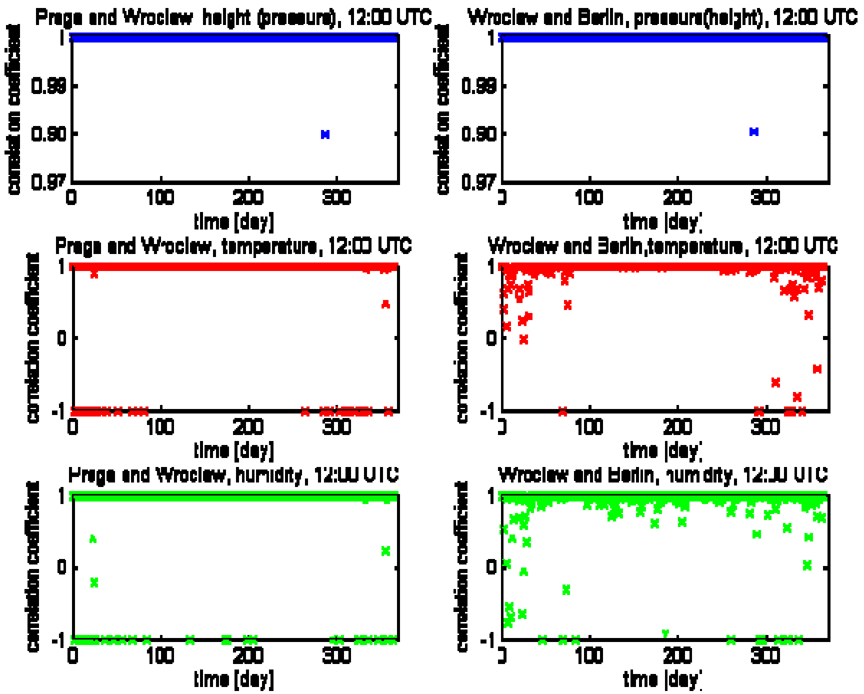


Meteo data preparation: radio sounding

Estimation of local gradient in (t, p, h) from stations in:

- WROCLAW II (airport)
- BERLIN
- PRAGA

confirmed correlations for mandatory isobaric levels in the bottom troposphere (despite local effect) up to 1500 m.s.l.



Verification: NWP principles

Numerical forecasting is based upon the statement that all equations governing changes in the atmosphere are known. These equations are known as primitive equations.

1. Advection equation

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - \omega\frac{\partial u}{\partial p} + fv - g\frac{\partial z}{\partial x} + F_x \qquad \frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - \omega\frac{\partial v}{\partial p} + fu - g\frac{\partial z}{\partial y} + F_y$$

2. Divergence equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial p} = 0$$

3. Equilibrium equation

$$\frac{\partial z}{\partial p} = -\frac{RT}{pg}$$

4. Thermodynamic equation

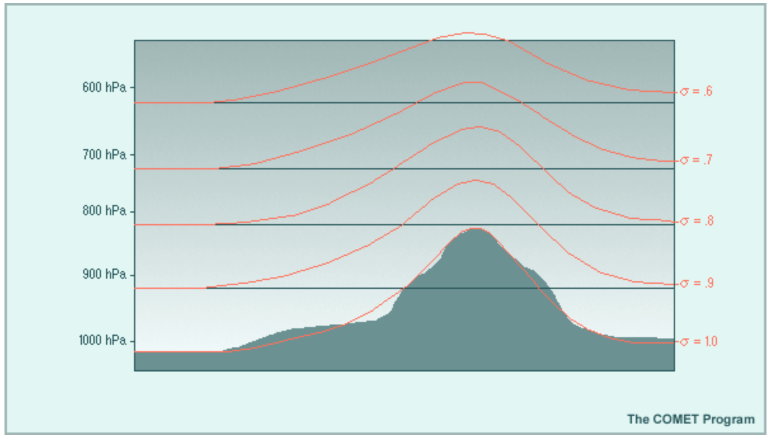
$$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - \omega\left(\frac{\partial T}{\partial p} - \frac{RT}{C_p p}\right) + \frac{H}{C_p}$$

5. Humidity equation

$$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - \omega\left(\frac{\partial q}{\partial p}\right) + E - P$$

Verification

- Discrepancy estimation, the conditions
  - meteorological parameters in the model variables (t,q,z),
  - the continuous construction of model domain
  - similar planar resolution 81, 27, 9 km
  - similar vertical division



Thank you for your attention

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