Comparison between GRUAN GNSS GDP and other techniques

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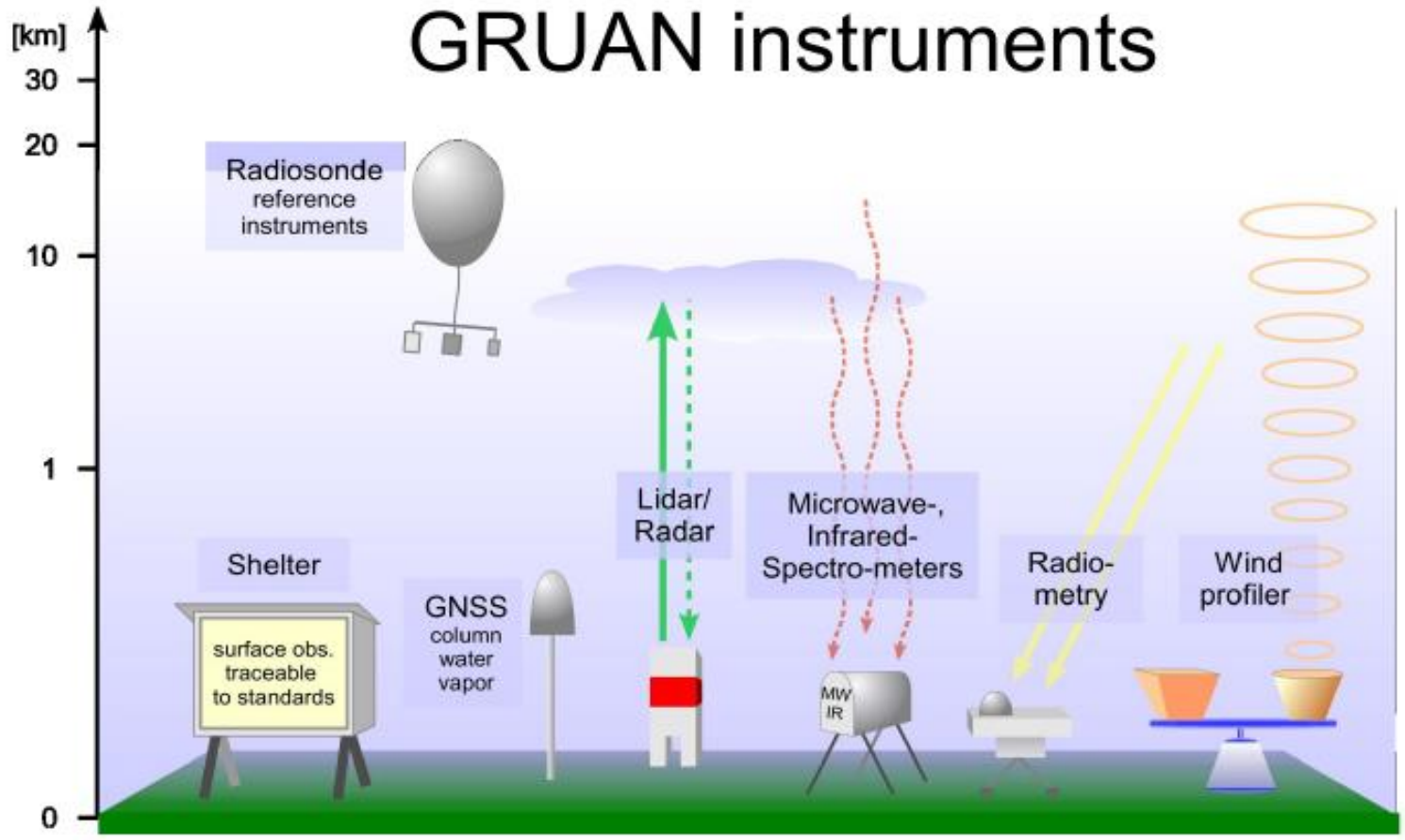


What is a GRUAN Data Product (GDP)?

1. Well-documented, fully disclosed **corrections** algorithms
2. Estimates of measurement **uncertainties** of all measurands
3. **Traceability** to SI standards

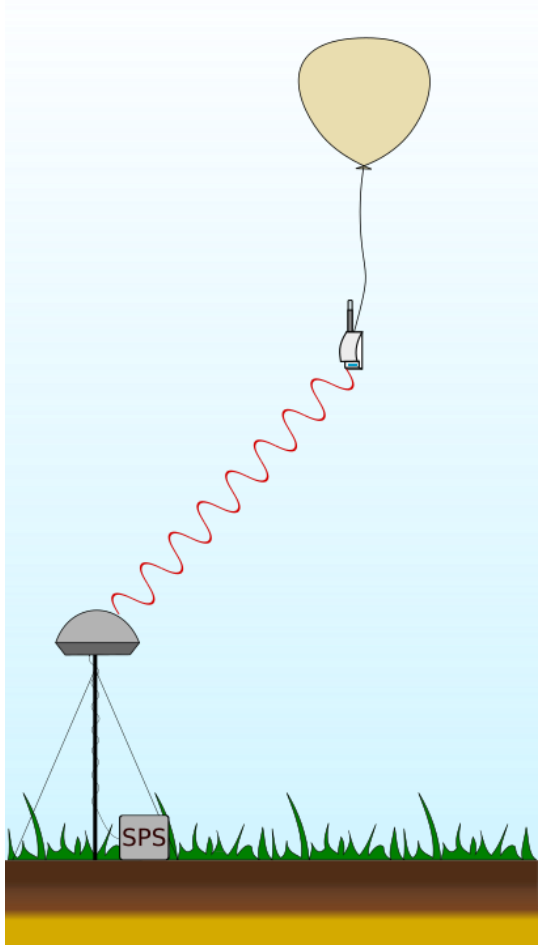
RS41GDP IWV Observations

Vaisala RS41 radiosonde

- PTU + GPS
- 1 second time resolution
- 5 m/s ascend rate to 30-35km altitude

GRUAN Data Product

- Full uncertainties
- Temperature:
  - Radiation correction
  - Time lag correction
- Relative humidity:
  - Time-lag correction
  - Independent ground check
- IWV integrated over whole profile with uncertainty



GNSS IWV GDP Observations

- Calculate Slant Total Delays (STD) along the signal path
- Transfer STD's into Zenith Total Delays (ZTD) with a Mapping Function
- Calculate the wet part of the ZTD:

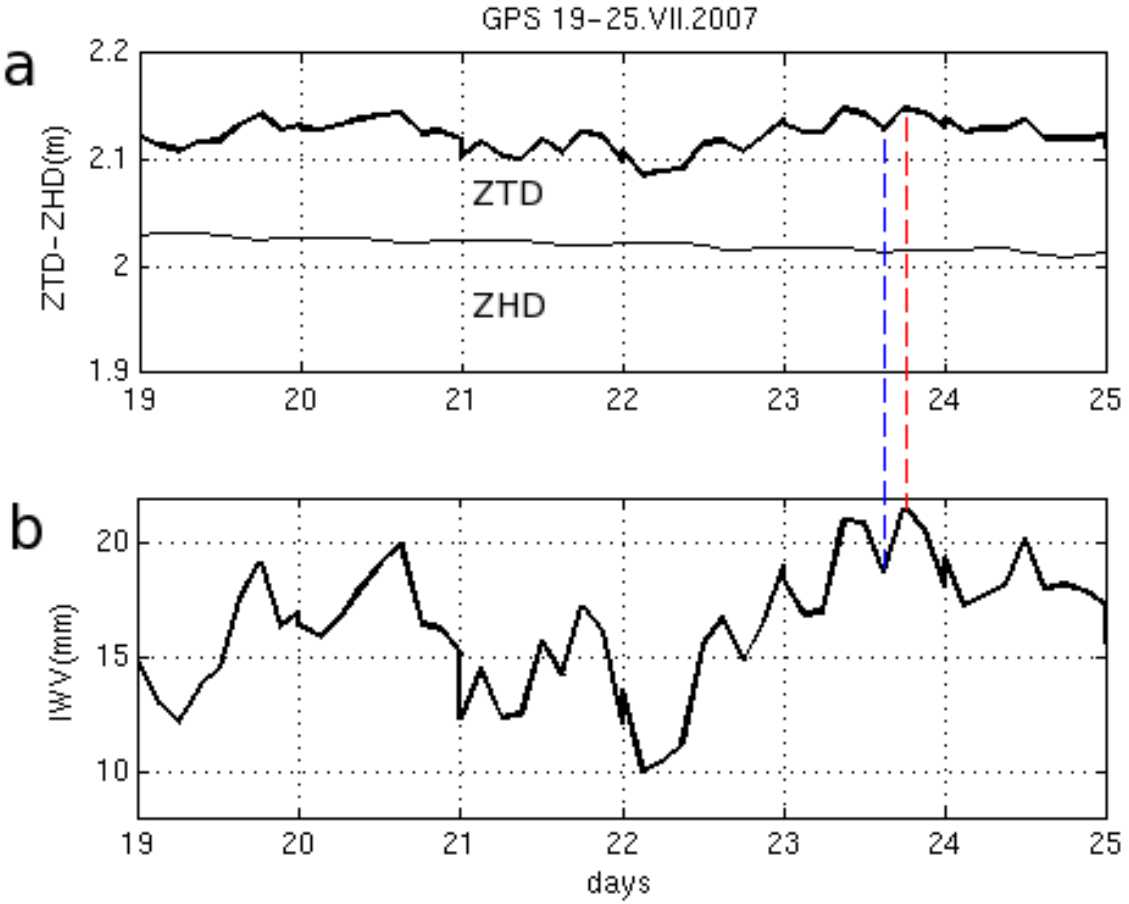
$$ZWD = ZTD - ZHD.$$

$$ZHD = (2.2768 + 0.0024)\frac{p_s}{f(h,\theta)}$$

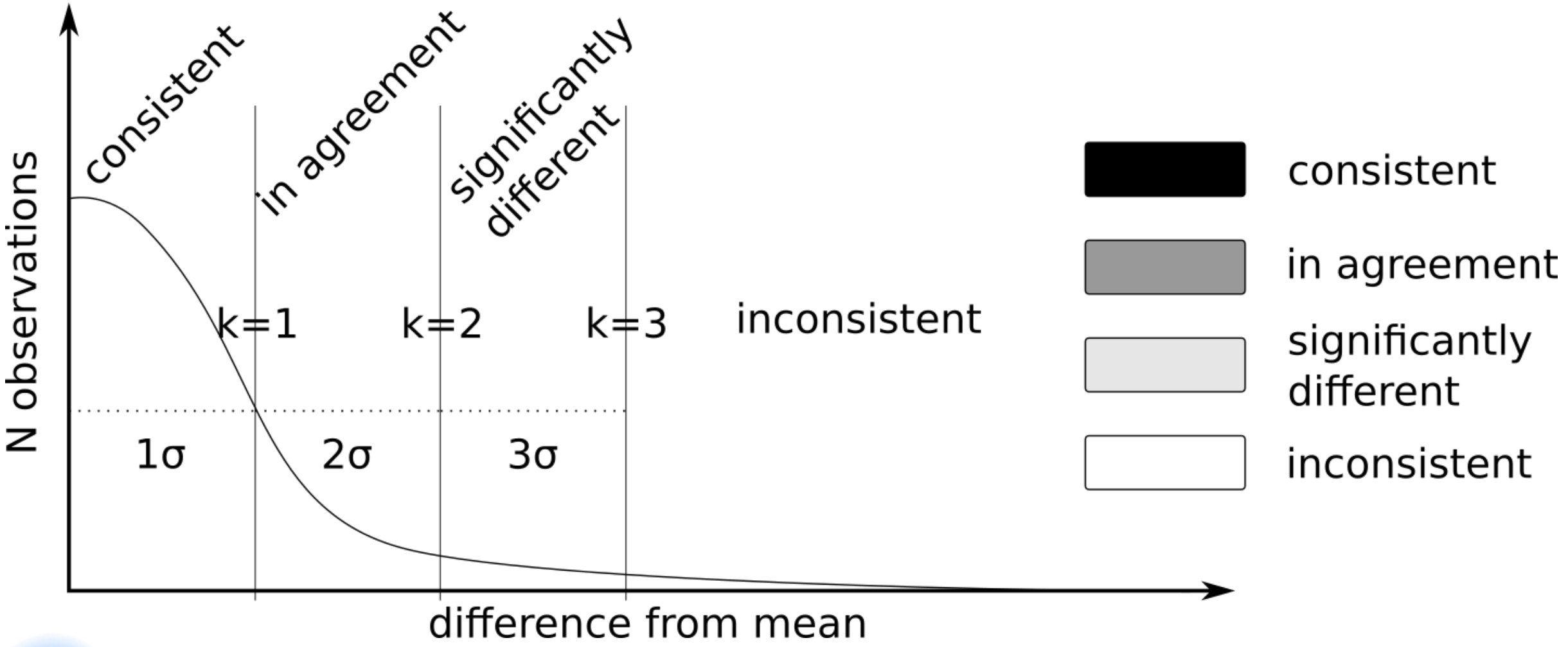
- Derive Integrated Water Vapour (IWV) from ZWD:

$$IWV = \frac{10^6}{(k_3/T_m + k_2')R_v} ZWD,$$

- Derive horizontal gradients
- Full uncertainty budget



Consistency with uncertainties



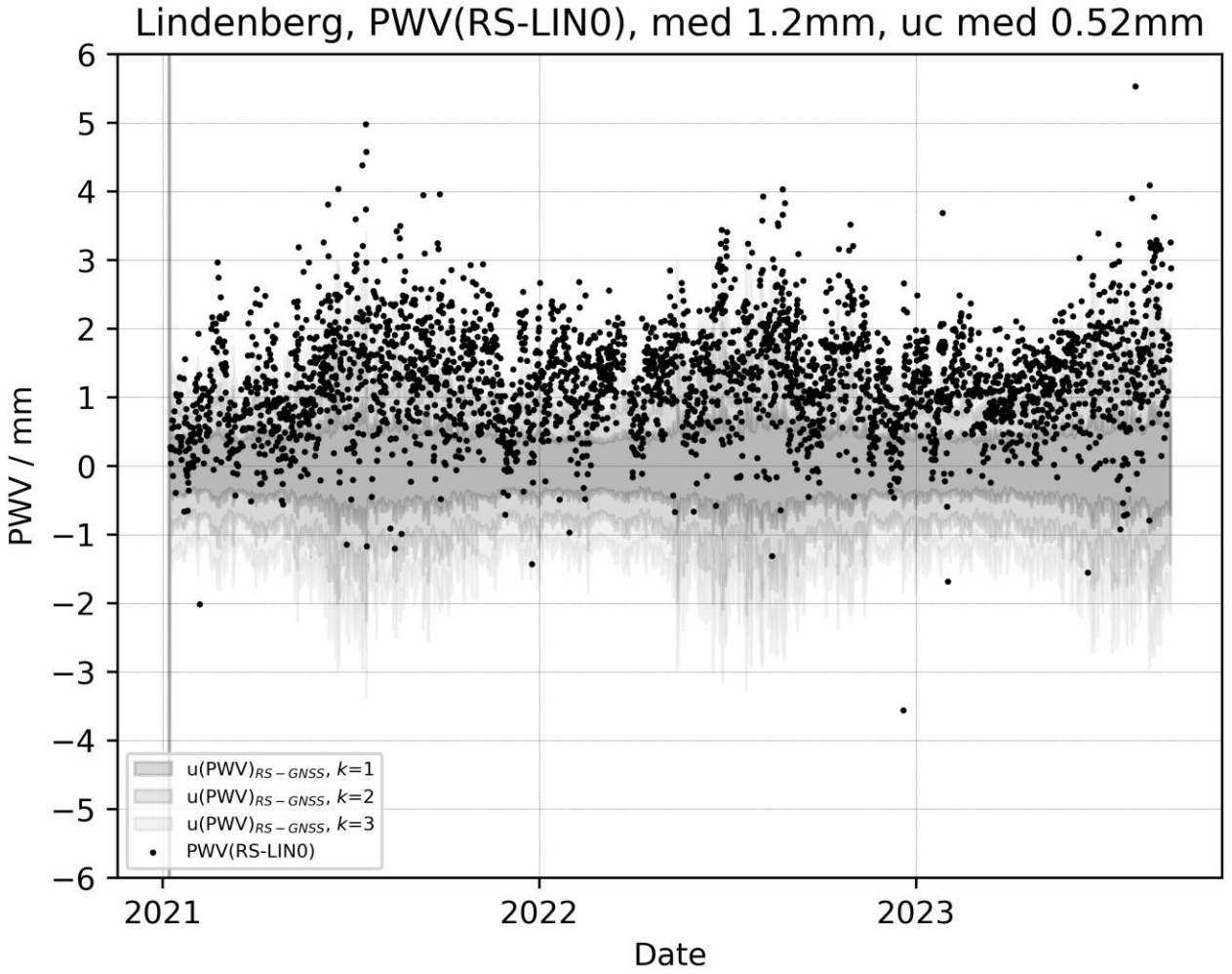
Lindenberg

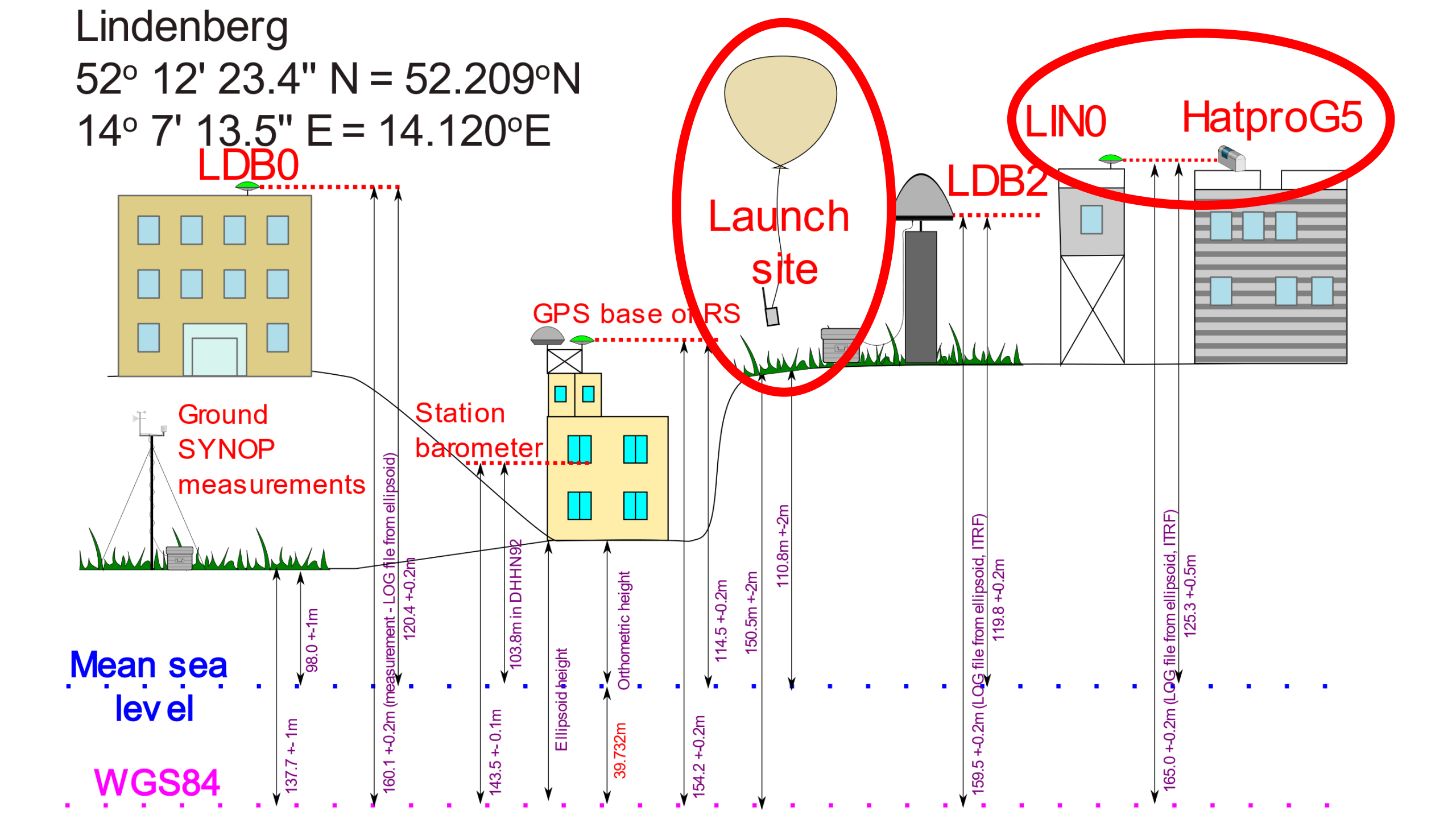
PWV direct from GDP's from NRT

Data description

- RS41GDP from GRUAN LC in MOL-RAO
- GNSS PW-GDP from GFZ Potsdam
- ":g.Measurement.PrecipitableWaterColumn" from RS41GDP
- "PWV" from NRT .tro files from GFZ
- u(PWV) in RS41GDP recorded with **k=2**
- u(PWV) from NRT .tro files from GFZ taken as **k=1**

- **No corrections, raw GDP's**
- **No altitude compensation**




Lindenberg
52° 12' 23.4" N = 52.209°N
14° 7' 13.5" E = 14.120°E
LDB0
LDB2
LIN0
HatproG5
Launch site
GPS base of RS
Ground SYNOP measurements
Station barometer
Mean sea level
WGS84
98.0 +-1m
120.4 +-0.2m
160.1 +-0.2m (measurement - LOG file from ellipsoid)
103.8m in DHHN92
Ellipsoid height
Orthometric height
39.732m
114.5 +-0.2m
150.5m +-2m
110.8m +-2m
119.8 +-0.2m
159.5 +-0.2m (LOG file from ellipsoid, ITRF)
125.3 +-0.5m
165.0 +-0.2m (LOG file from ellipsoid, ITRF)
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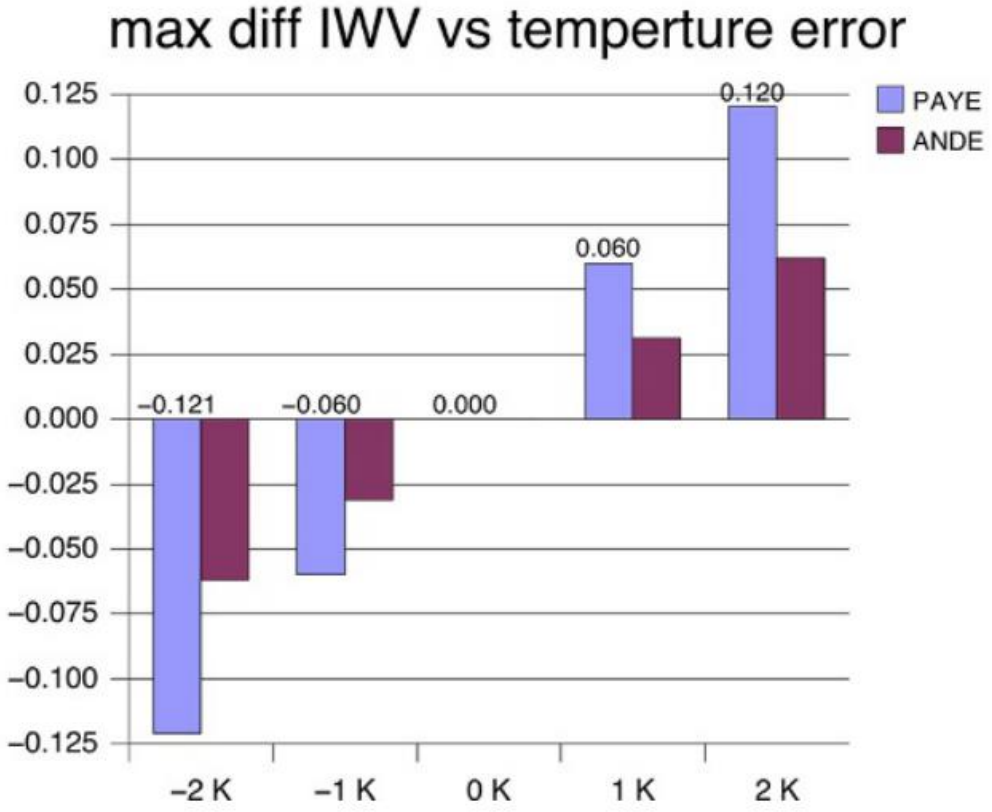
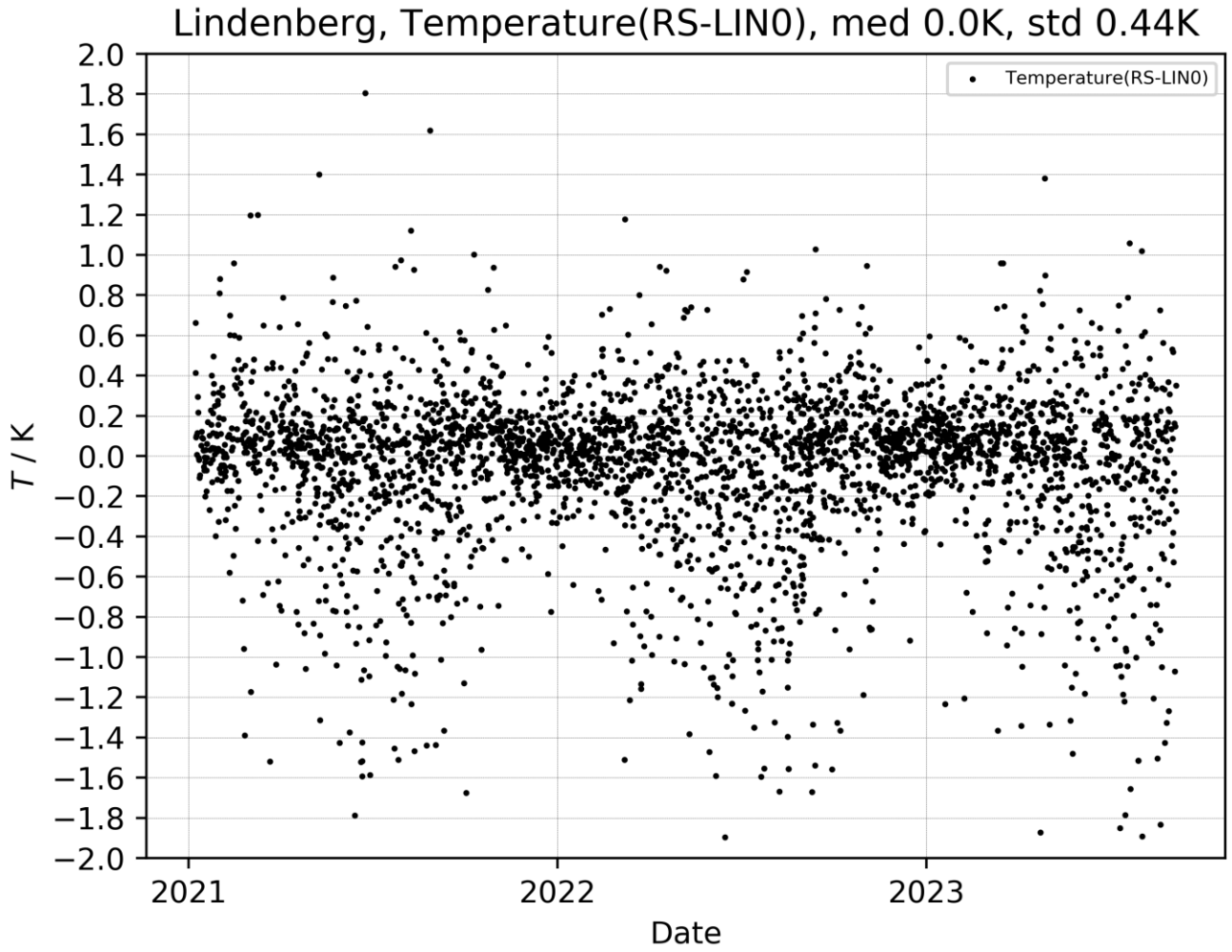
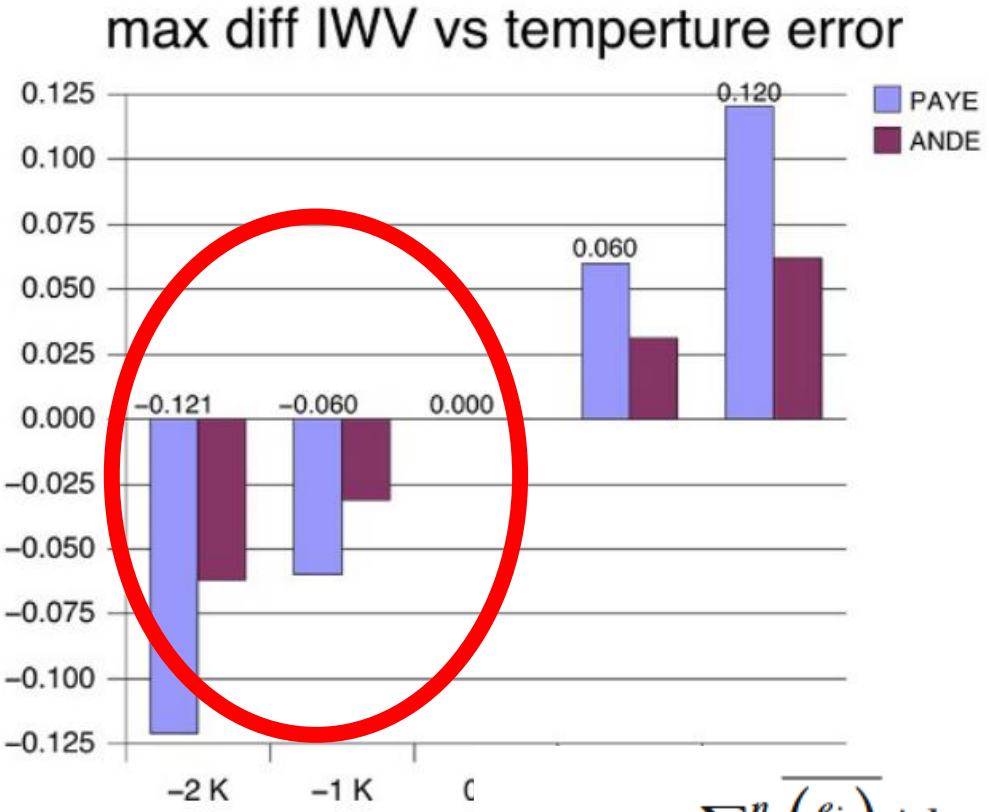
143.5 +-0.1m
154.2 +-0.2m

Temperature difference



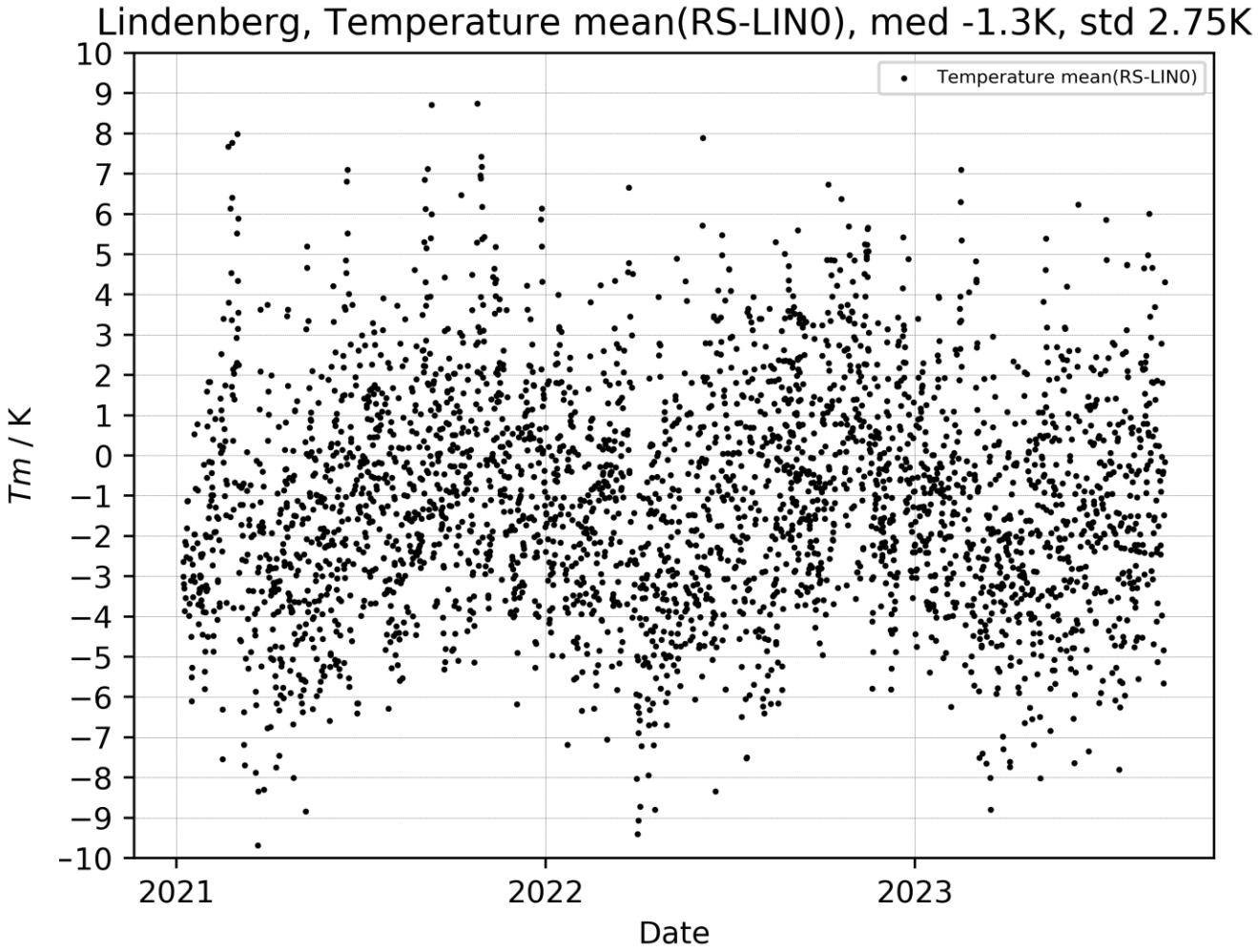


Weighted mean Temperature difference

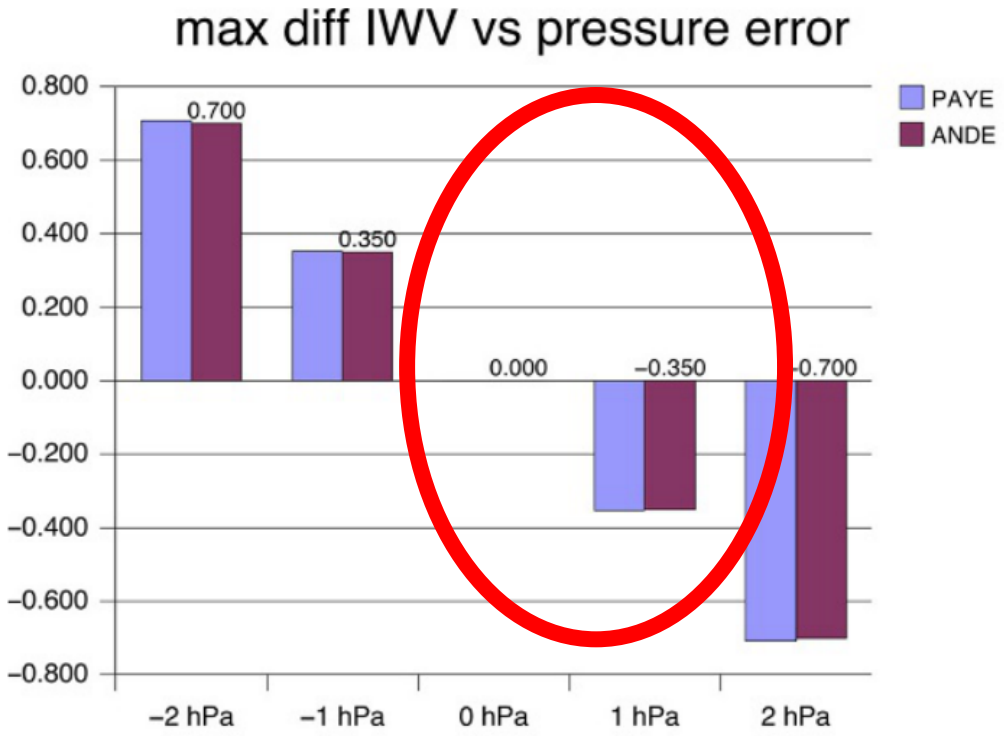


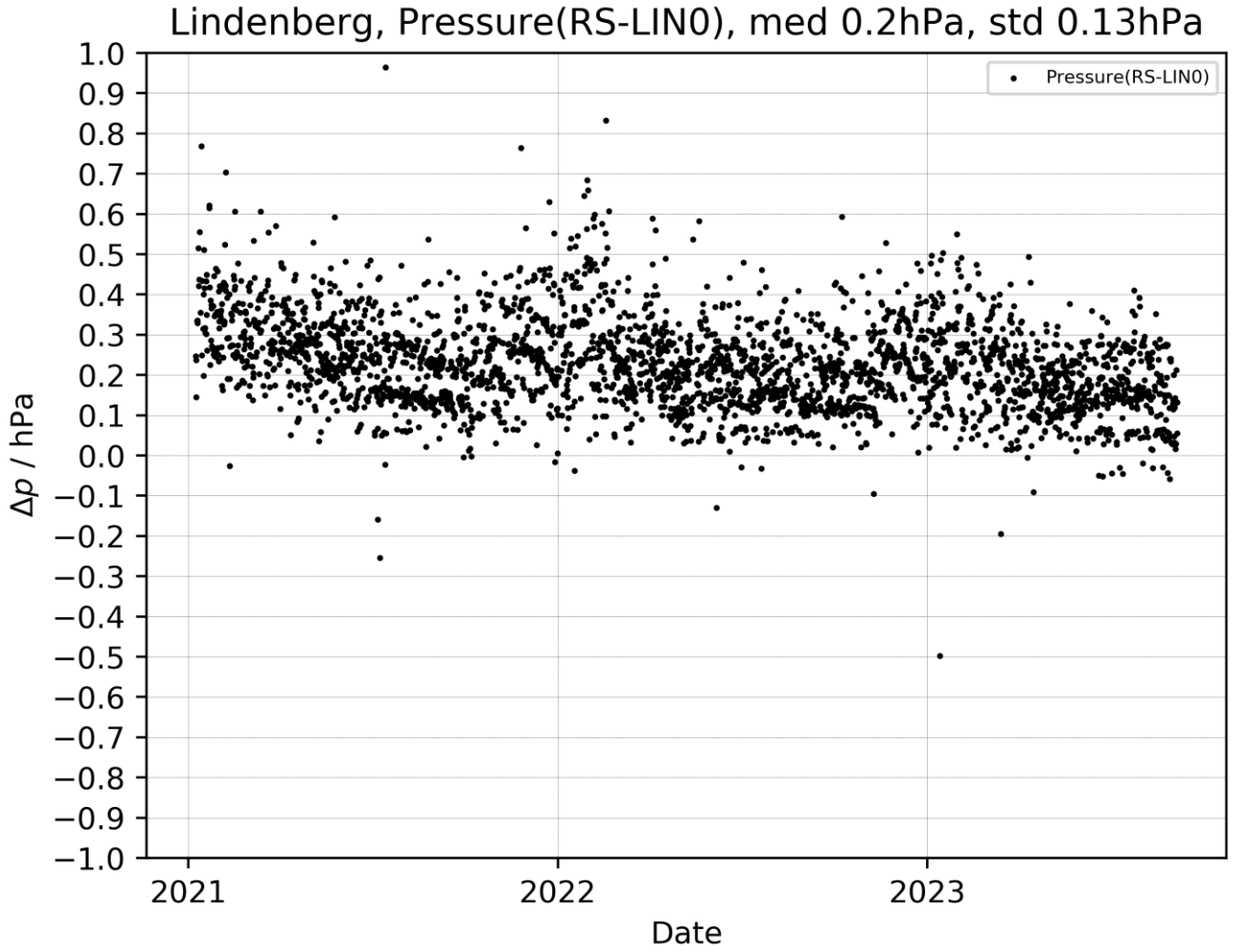
$$T_m = 70.2 + 0.72T_s$$

$$T_m = \frac{\sum_1^n \overline{\left(\frac{e_i}{T_i}\right)} \Delta h_i}{\sum_1^n \overline{\left(\frac{e_i}{T_i^2}\right)} \Delta h_i}$$



Pressure difference stat. bar. Vs GNSS

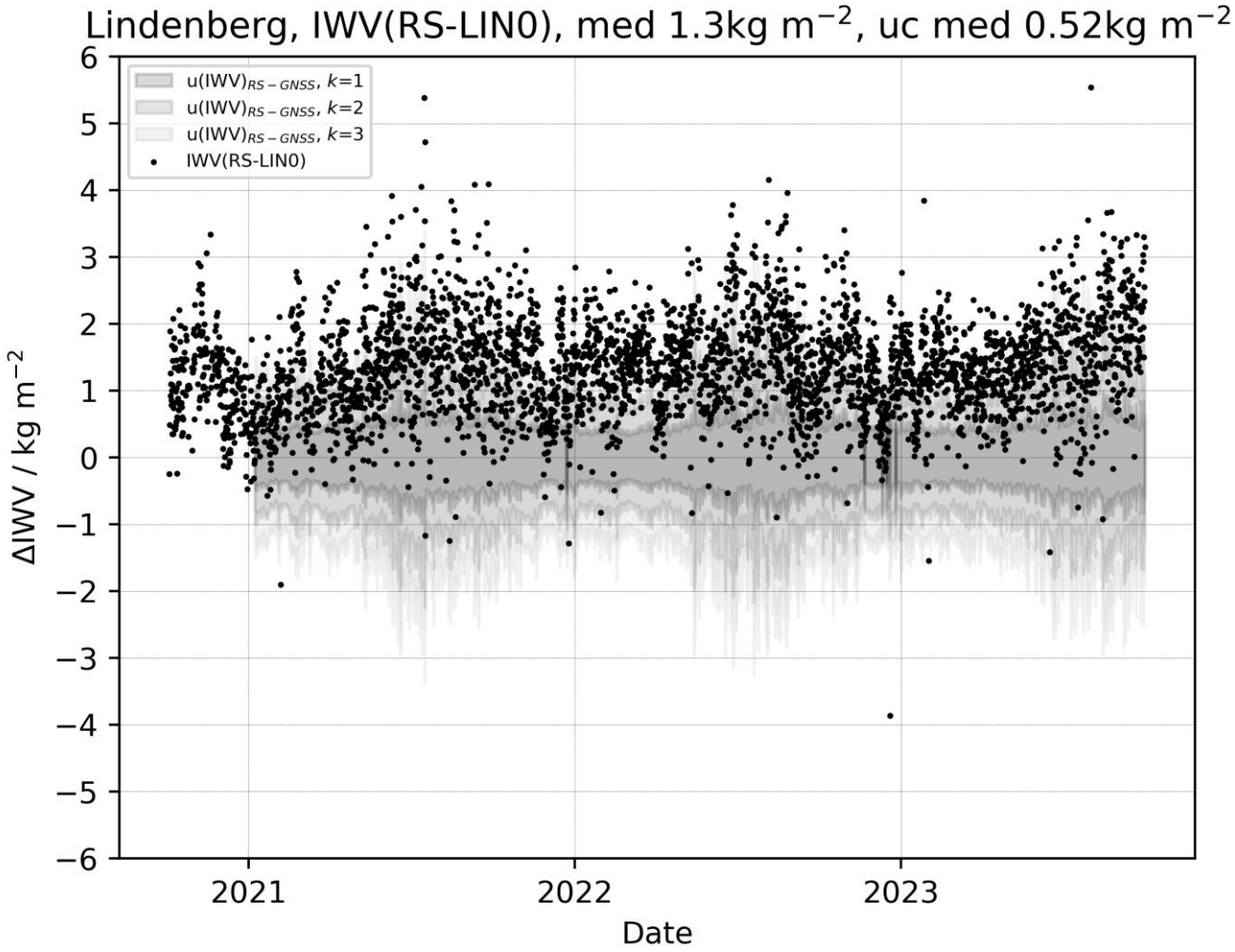




Corrected IWV's from GNSS-GDP

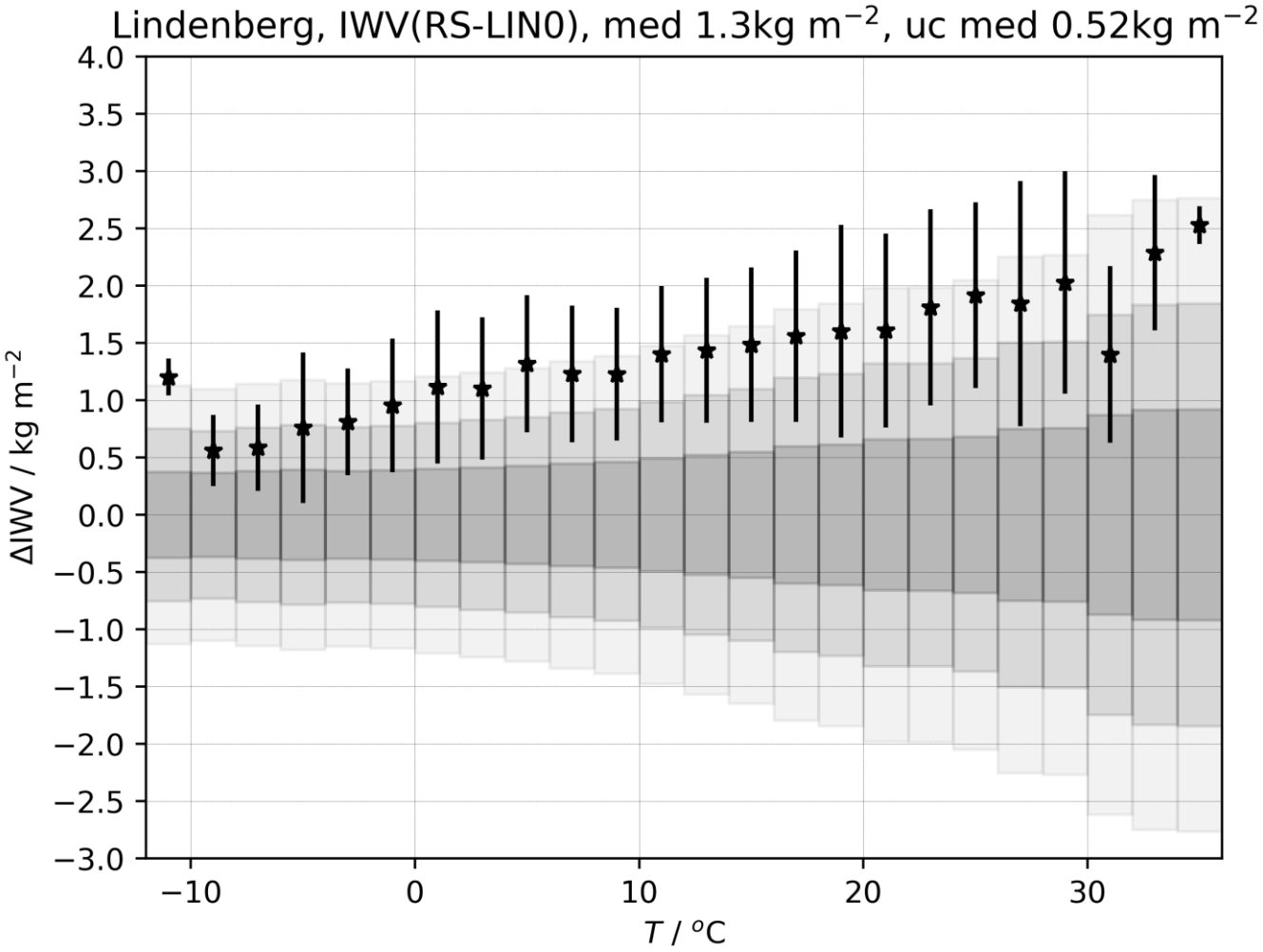
Data description

- "ciwv(time)" from RS41GDP
- GNSS IWV calculated:
  - ZTD from NRT .tro files from GFZ
  - Weighted mean temperature from RS41GDP
  - Surface pressure interpolated from RS41GDP
- "ciwv_uc(time)" in RS41GDP, **k=2**
- u(PWV) from NRT .tro files from GFZ taken as **k=1**
- **Altitude difference compensated**



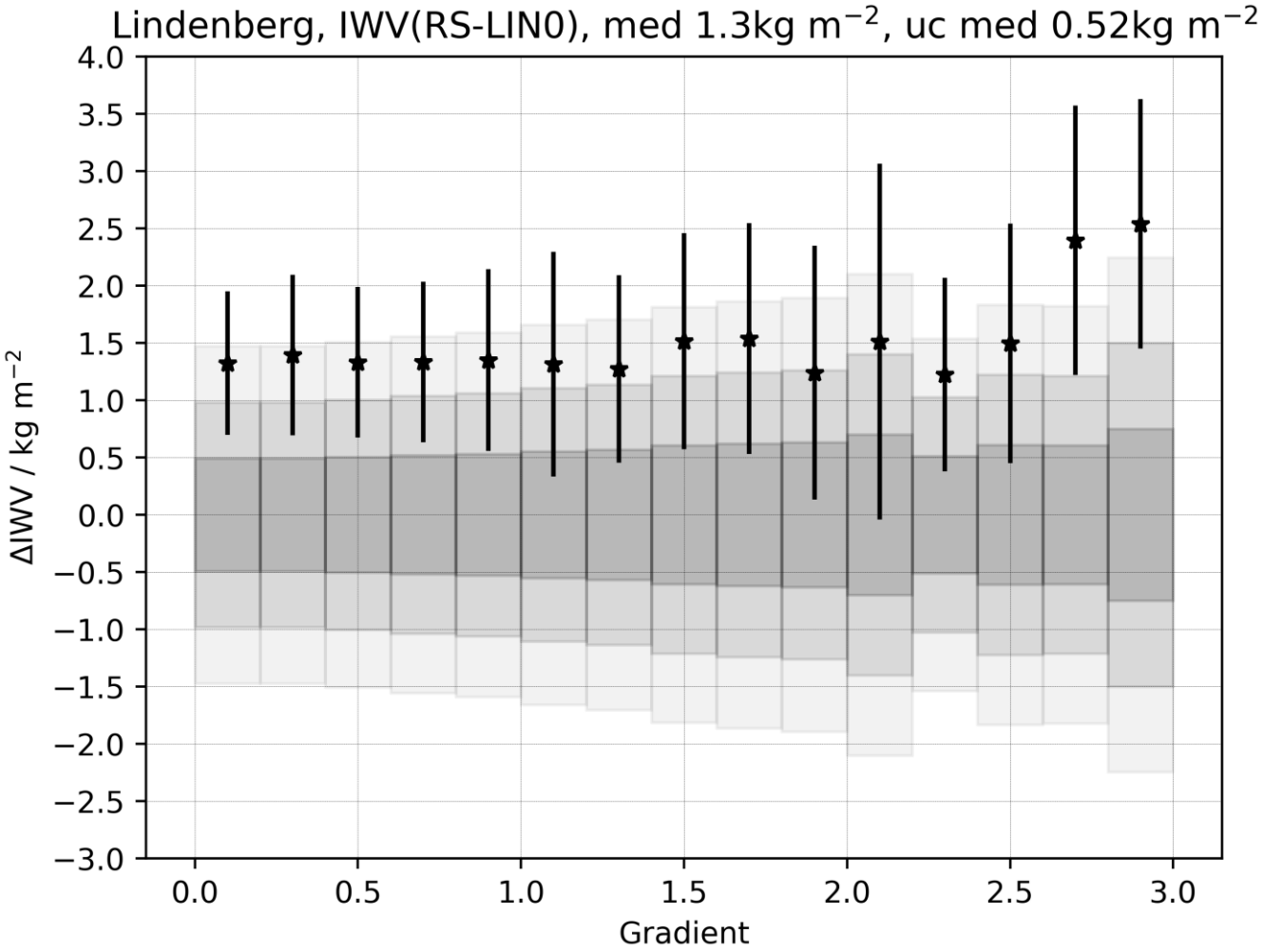
Corrected IWV's from GNSS-GDP

- **IWV as function of temperature observations by radiosonde at altitude of GNSS antenna**



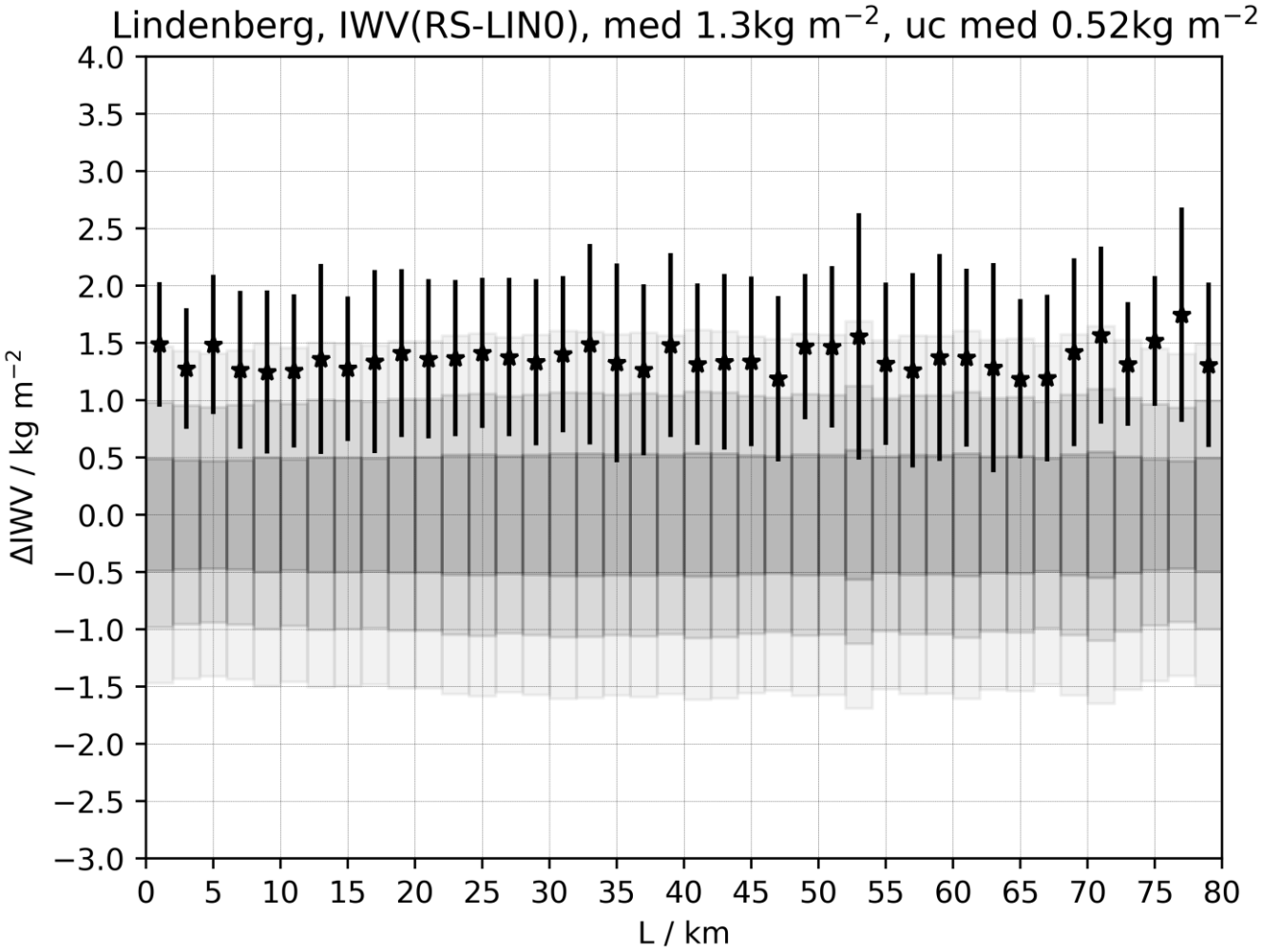
Corrected IWV's from GNSS-GDP

- **IWV as function of total GNSS horizontal gradients**



Corrected IWV's from GNSS-GDP

- **IWV as function of distance travelled by radiosonde to the top of the Troposphere**



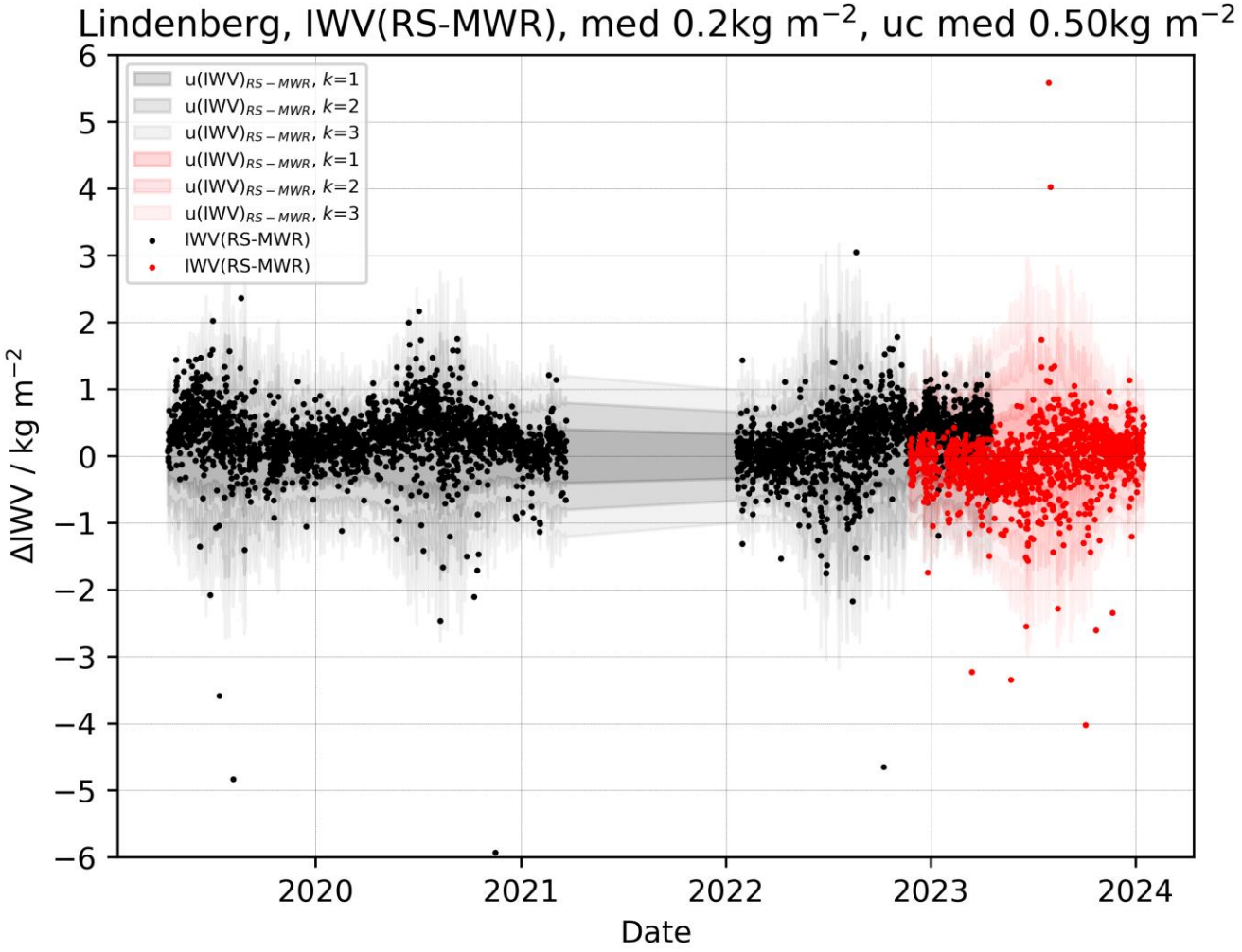
Microwave Radiometer?

IWV (RS41GDP – Hatpro G5 MWR)

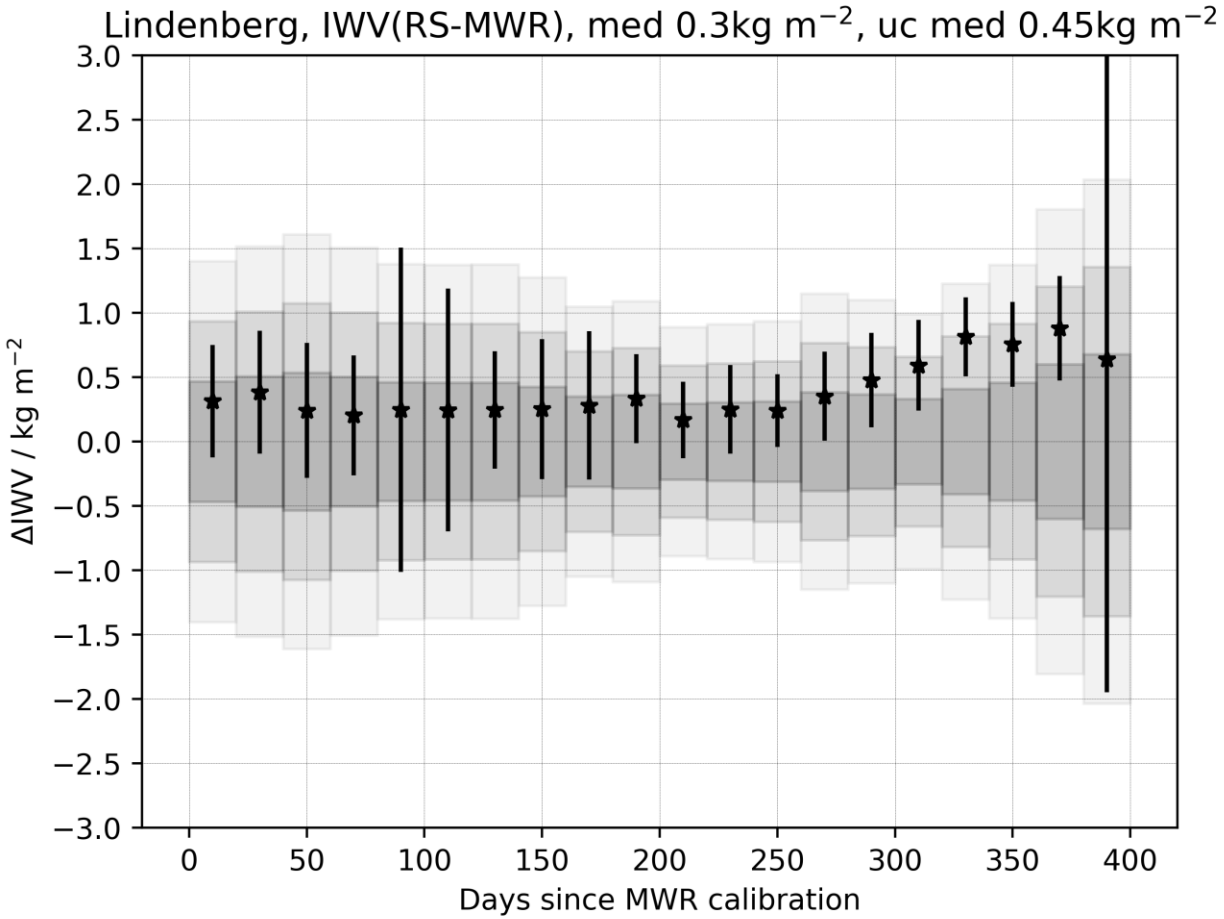
MWR:

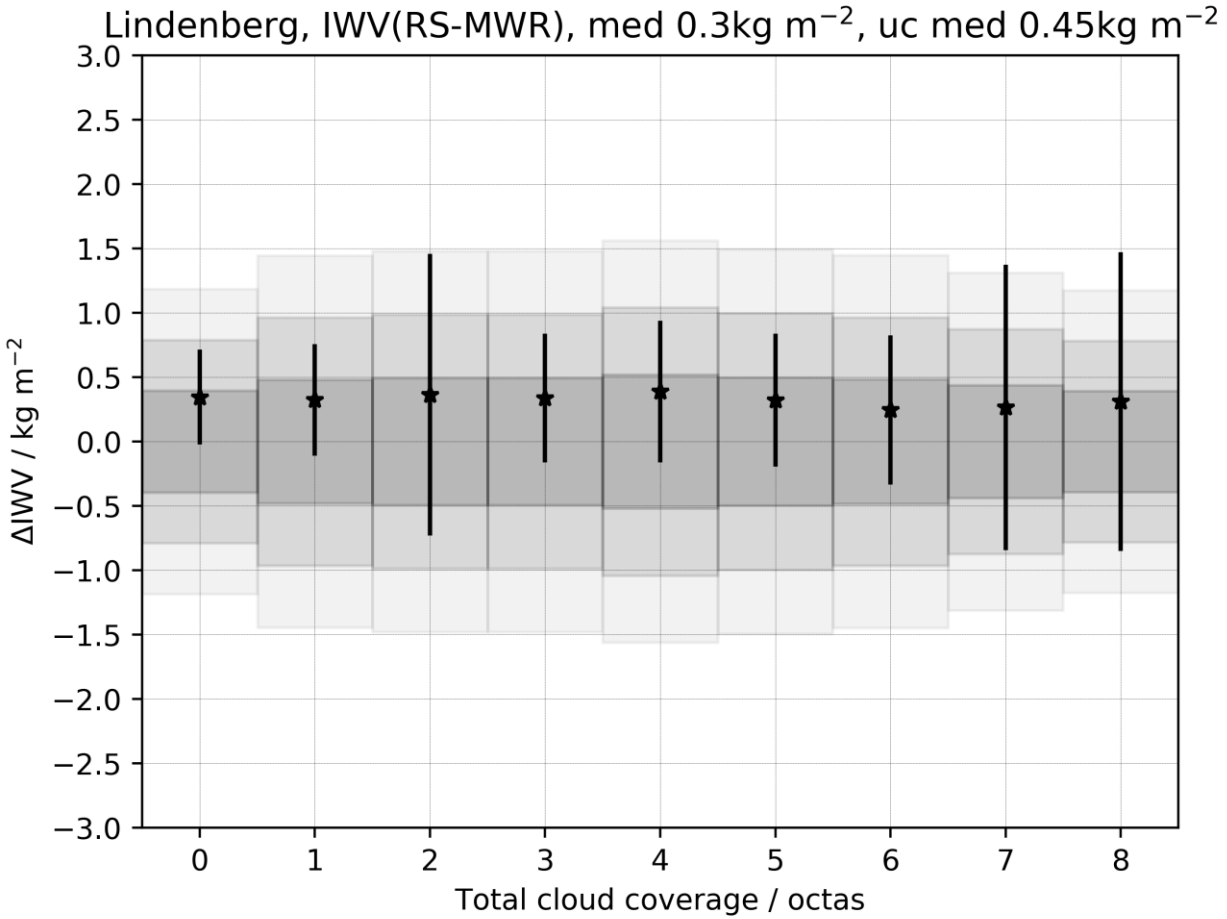
- Passive observation of Brightness temperature :
  - K-band (22.5 GHz)
  - V-band (60 GHz)
- IWV from **2x** Hatpro G5 data with 1s resolution
- Data averaged for 15 minutes after RS launch
- Systematic uncertainties from Hatpro G5 technical description
- Random uncertainties from std(IWV) of the 15 minutes time window
- Independent calibration
- **MWR trained with RS data**

Altitude difference compensated!



IWV (RS41GDP – Hatpro G5 MWR)





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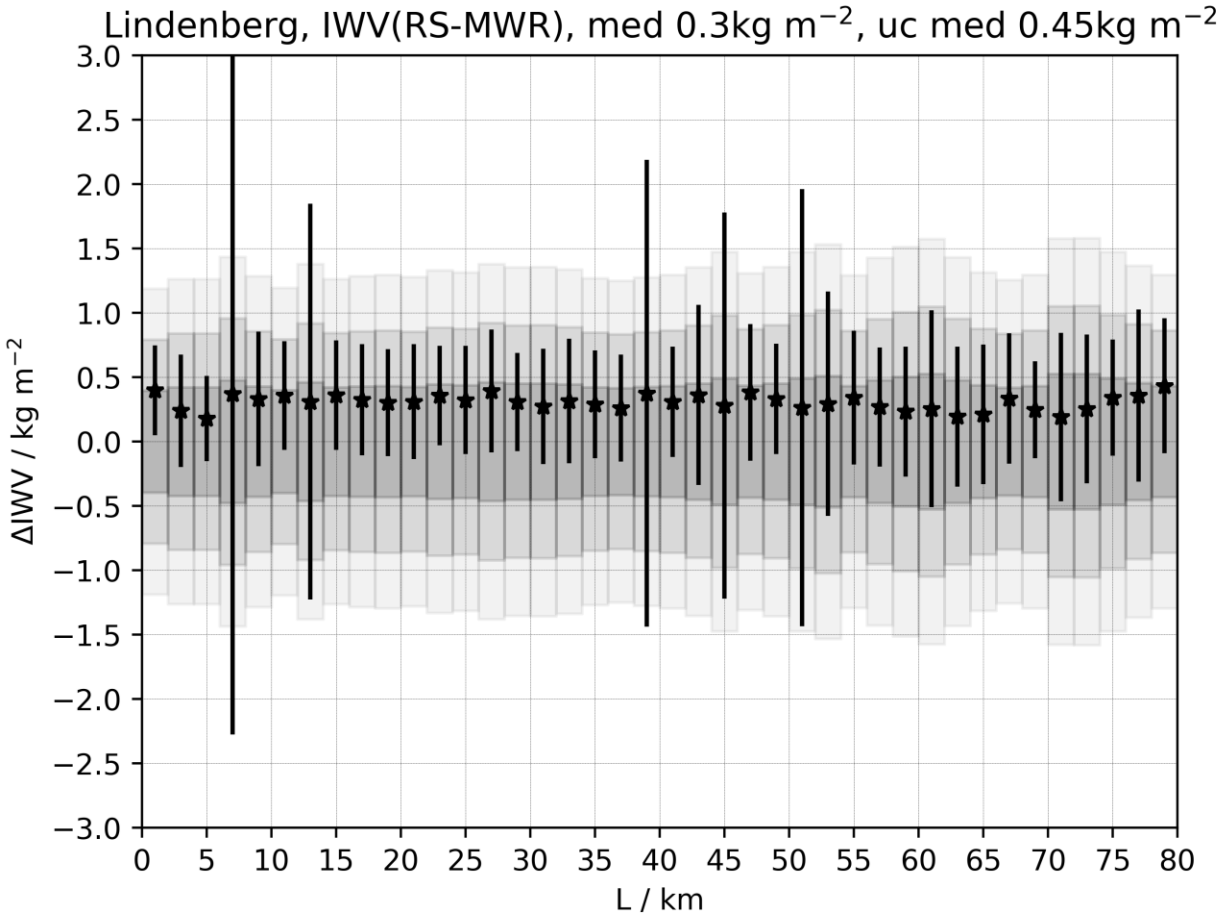
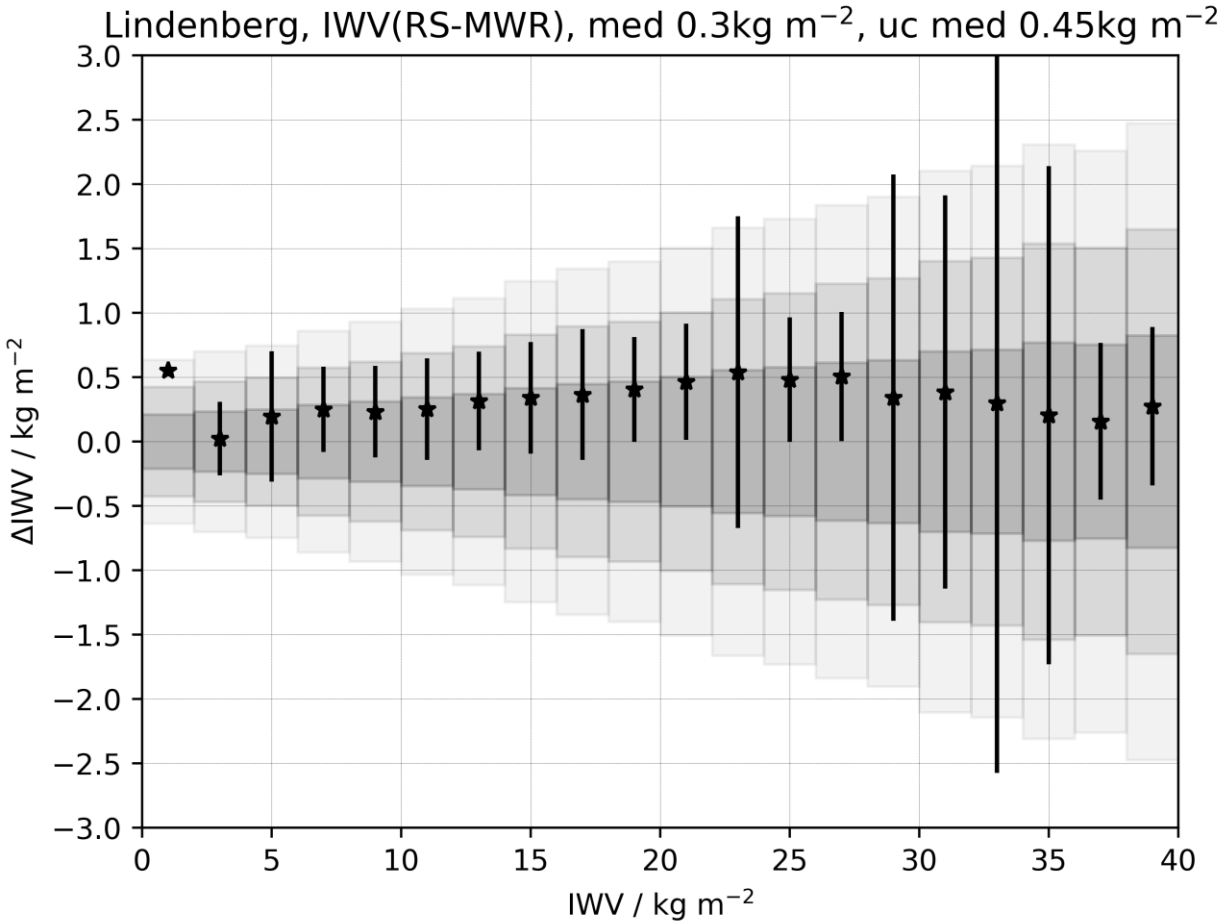
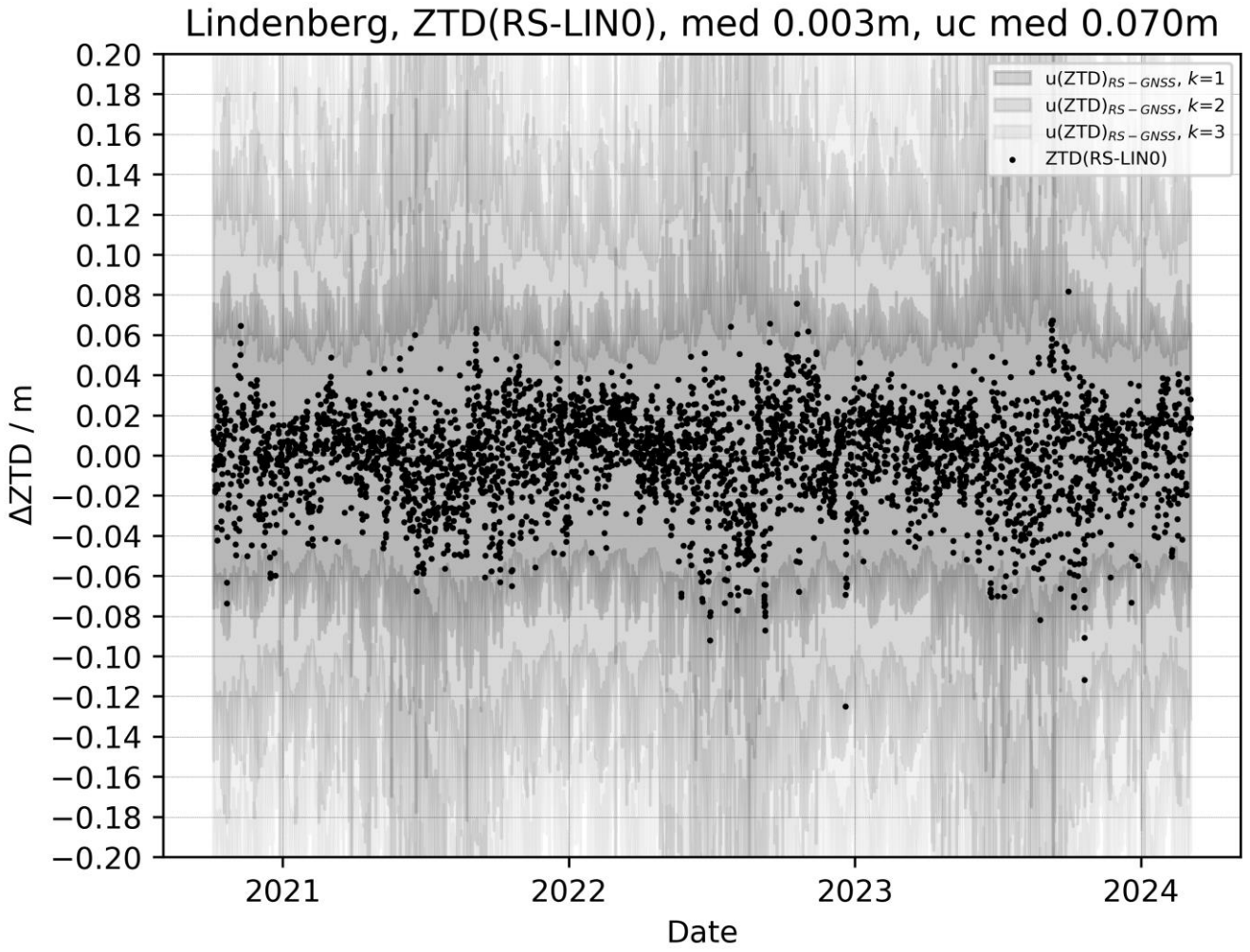




Can we measure atmospheric refractivity using Radiosonde data?

ZTD (RS41GDP – GNSS)

- Saastamoinen (1972) simplified + correction for atmosphere center of mass
- $ZTD = 0.002277 \frac{\left[p+\left(1255/T+0.05\right)e\right]}{1-0.0026cos\varphi-0.00028H}$
  - T – surface temperature
  - p – surface pressure
  - e – surface WV partial pressure
  - φ – latitude
  - H – altitude
- **ZTD typical values 2-2.5 m**
- $u(ZTD_{GNSS})$ typical values 1-5 mm
- $u(ZTD_{RS})$ typical values 5-10 cm



What about other GRUAN stations?

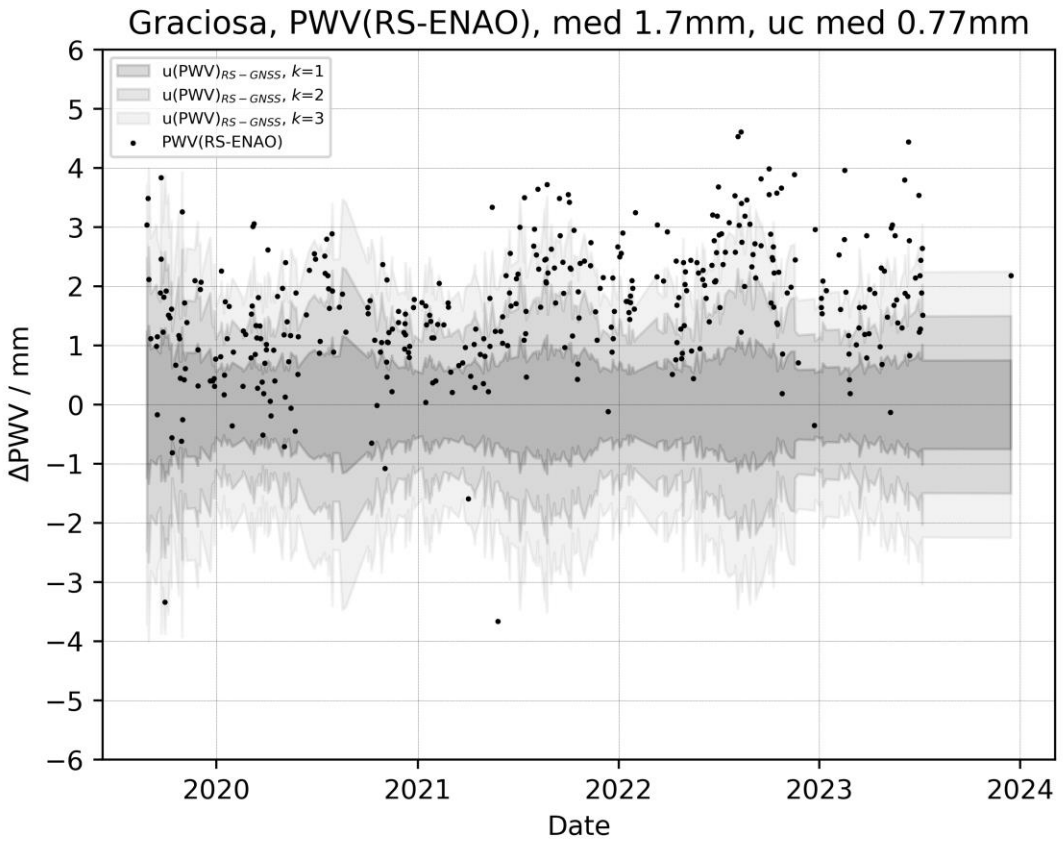
GRUAN network IWV(RS – corrected GNSS)

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

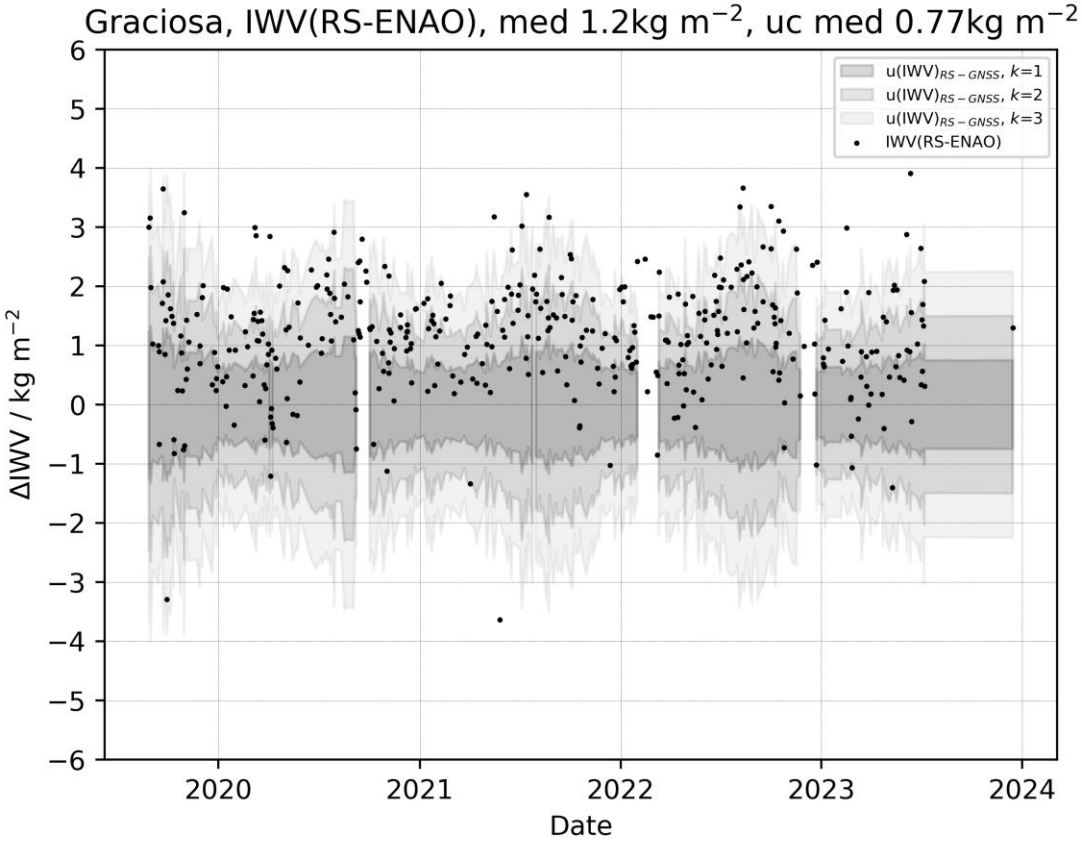
Station	Period	Num obs	ΔIWV mean	σ(ΔIWV)	u(ΔIWV) mean	IWV Consistent	ΔZTD	Verdict
Barrow	2018 – 2024	2353	1.1 kg m^{-2} **+ trend**	0.73	0.42 kg m^{-2}	17 / 19 %	**2 mm no trend**	Inconsistent Sig. Different
Beltsville	2018 – 2024	**70**	0.3 kg m^{-2}	1.03	0.77 kg m^{-2}	66 / 24 %	-4 mm	**Consistent** (small sample)
Graciosa	2019 – 2024	417	1.2 kg m^{-2}	0.97	0.77 kg m^{-2}	30 / 40 %	**15 mm**	In Agreement
Lauder	2018 – 2024	2685	0.6 kg m^{-2}	**3.78**	0.55 kg m^{-2}	49 / 10 %	9 mm	Sig. Different
Lamont	2019 – 2024	4113	0.9 kg m^{-2}	0.99	**0.84** kg m^{-2}	39 / 41 %	-4 mm	In Agreement
Lindenberg	2019 – 2024	4066	1.3 kg m^{-2}	0.74	0.51 kg m^{-2}	**9** / 20 %	**3 mm**	Sig. Different
NyAlesund	2018 – 2024	2485	0.7 kg m^{-2}	0.61	0.39 kg m^{-2}	35 / 29 %	11 mm	In Agreement
Payerne	2019 – 2024	2204	0.6 kg m^{-2}	0.72	0.57 kg m^{-2}	41 / 36 %	7 mm	In Agreement
Ross Island	2019 – 2024	1012	-0.1 kg m^{-2}	0.46	0.35 kg m^{-2}	**83** / 12 %	5 mm	**Consistent**

Graciosa IWV(RS–GNSS)

Raw data



Corrected data



Conclusions

RS-GNSS IWV:

- Significant metrological opening
- Observations suspicious
- **Differences in the range of 10% of IWV**
- Focus: GNSS IWV conversion from ZTD

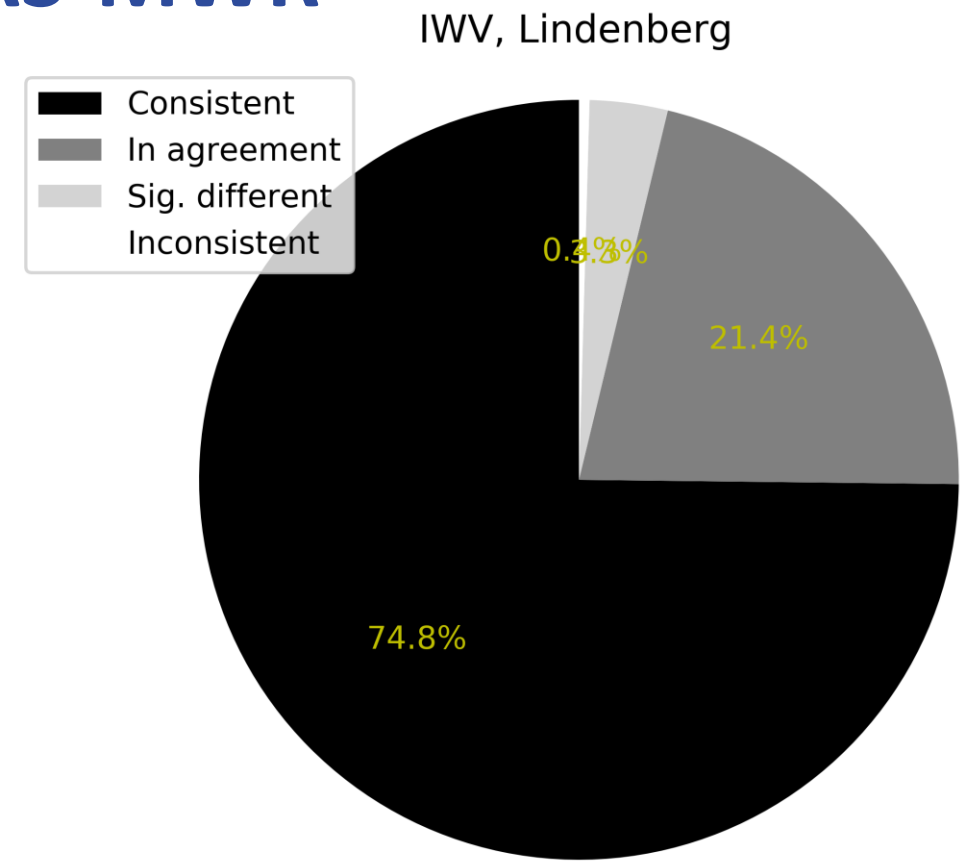
RS-MWR IWV:

- Towards metrological closure
- Observations consistent
- Focus: MWR GDP

ZTD(RS-GNSS)

- **Diffrences less than 1% of ZTD**
- Observation consistent

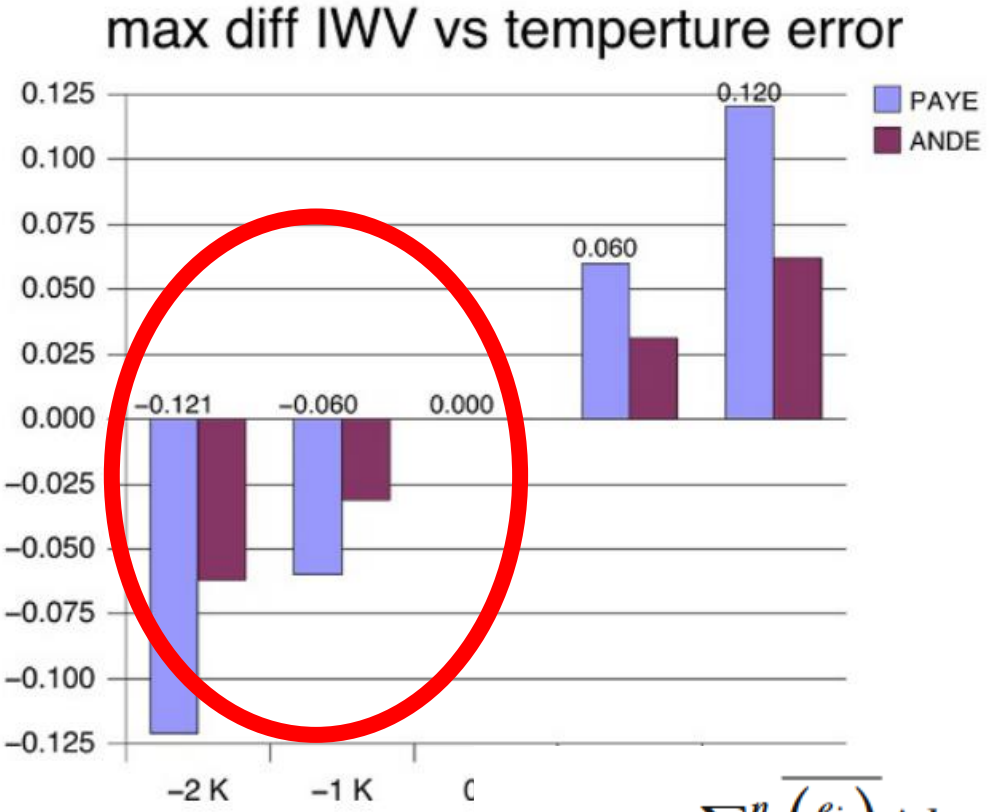
RS-MWR



Use RS observations to improve GNSS observations in GDP's?

Bind GDP's?

Weighted mean Temperature difference



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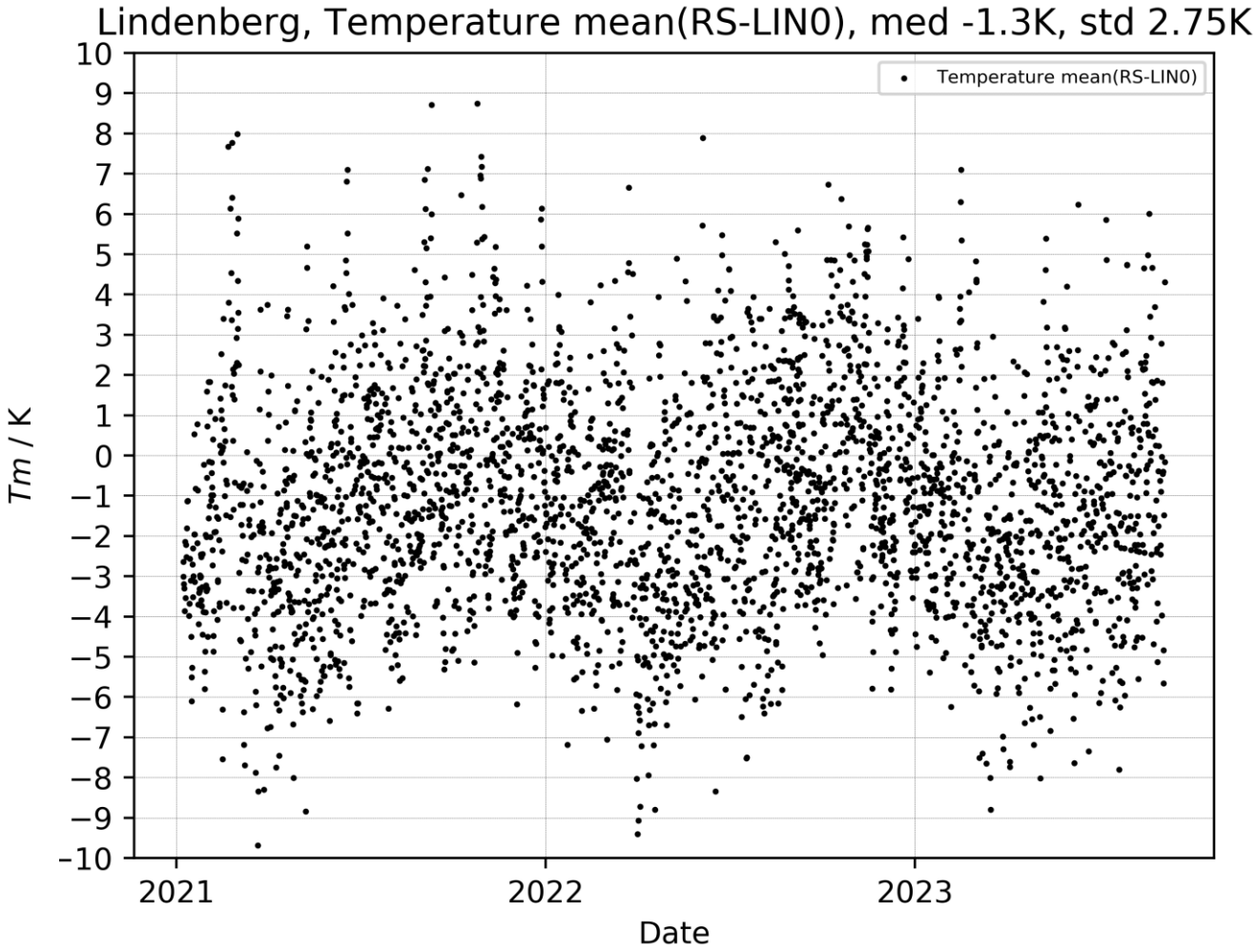

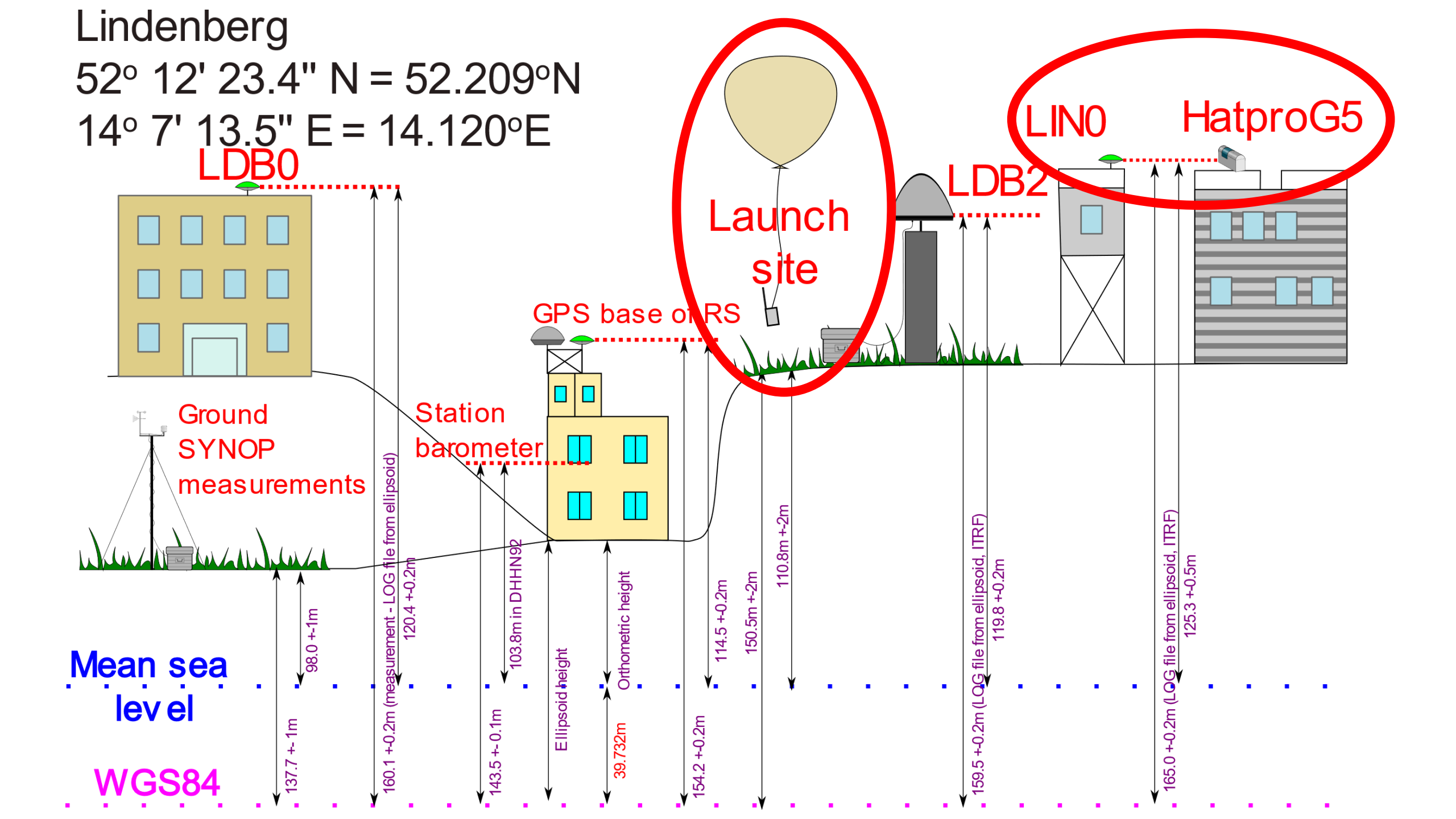
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