ETH zürich

Tropospheric path delays derived from very high-resolution GNSS-based troposphere models and spaceborne SAR interferometry

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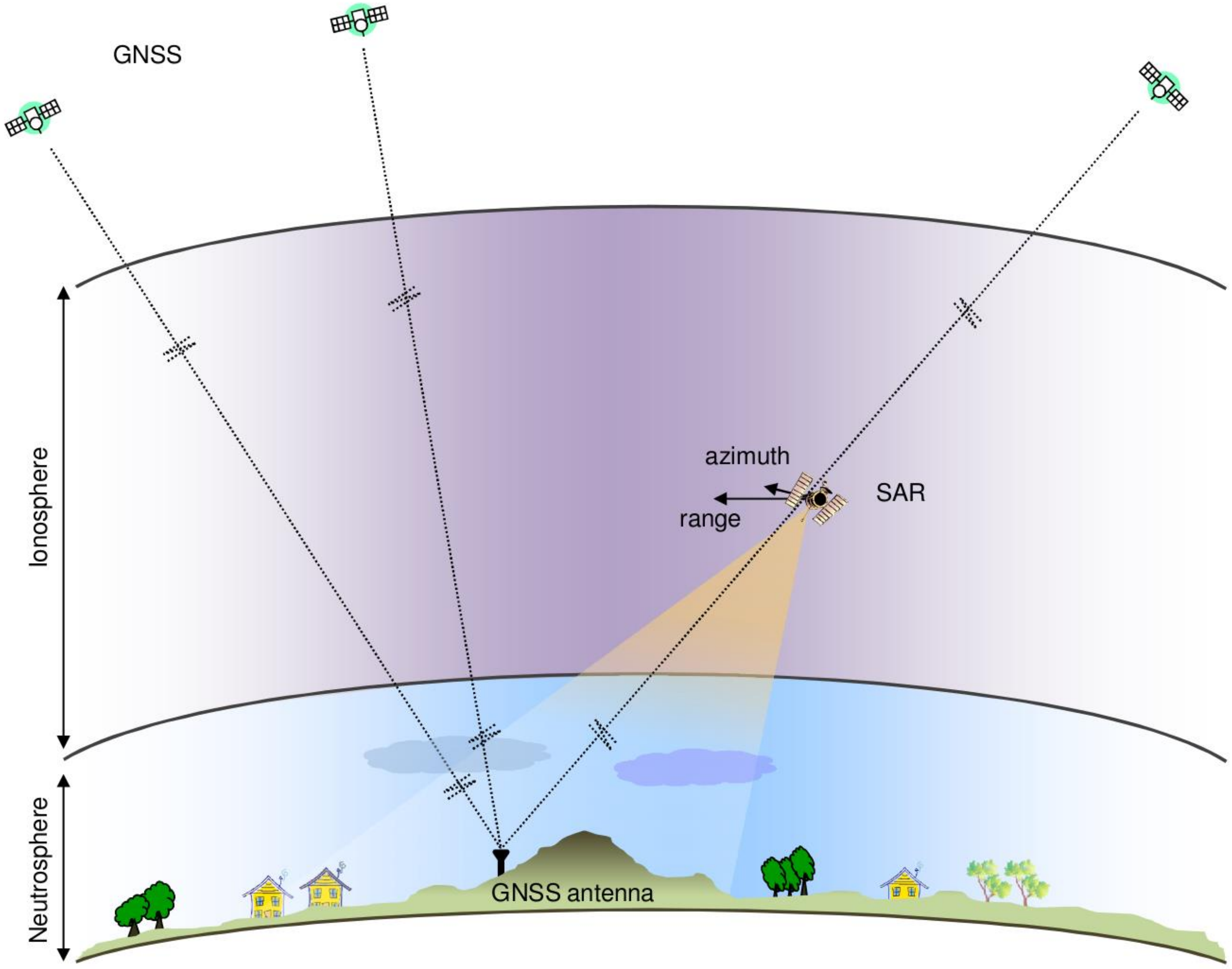
Motivation



Source: F. Alshawaf, PhD thesis

days - weeks between SAR acquisitions

↓

different atmospheric conditions, especially for water vapor

↓

tropospheric phases may be misinterpreted as deformations

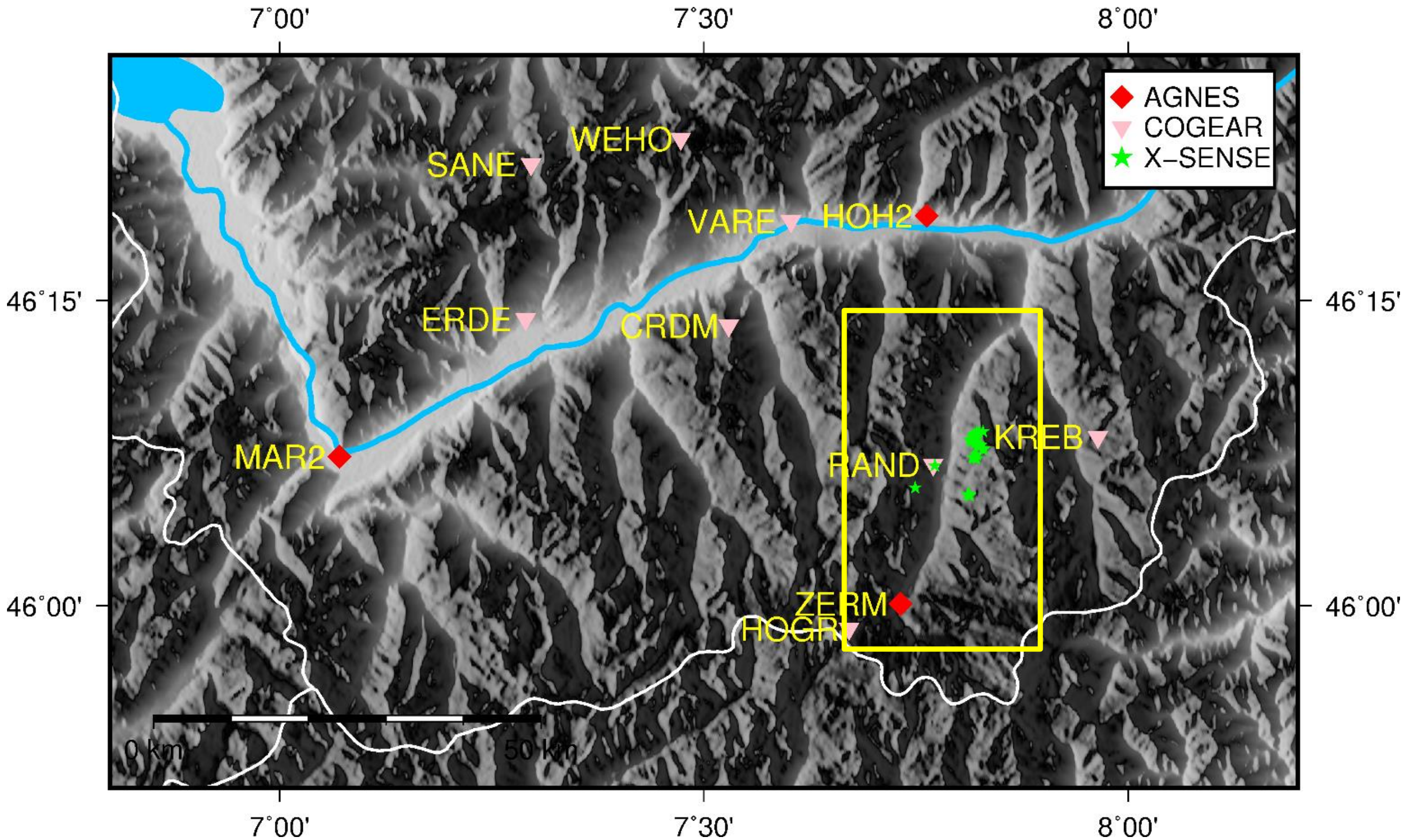
Motivation

- The long-term goal is to use GNSS-derived tropospheric path delays to mitigate DInSAR images (as a first correction).
- Another possible application is to be able to derive tropospheric path delays with very high resolution from InSAR images.
- In the first step, we compare the tropospheric delays derived from both techniques – GNSS and InSAR from the PS (persistent scatterers).
- Specific case in high mountains (high relief causing large spatial and temporal variability of the atmospheric signals).

source: Wikipedia

source: www.artisansofleisure.com/luxury-travel-blog

Study area (Alpine region Valais, Switzerland)



Data period:
2008 – 2013

32 SAR acquisitions (June – October)

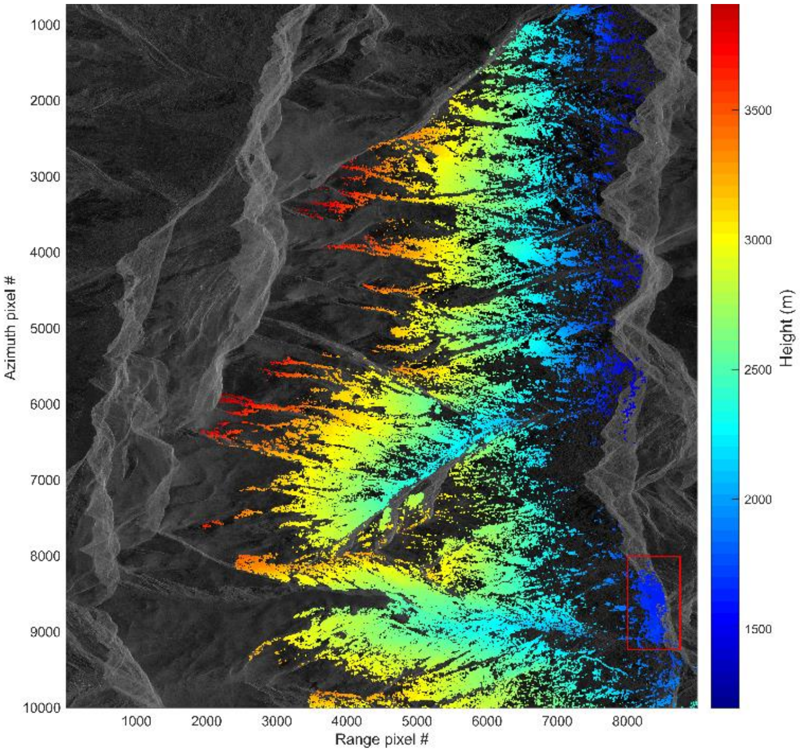
5 – 12 GNSS permanent stations in the area of interest
source: swisstopo

InSAR:
Cosmo-SkyMed
X-band, λ=3.12 cm

326552 identified persistent scatterers

test area: ~12 km x 25 km
height: 1200 m – 4100 m a.s.m.l.

Persistent scatterer interferometry (PSI)



PS in the test area

$$dSTD_{InSAR} = APD \frac{\lambda}{4\pi}$$

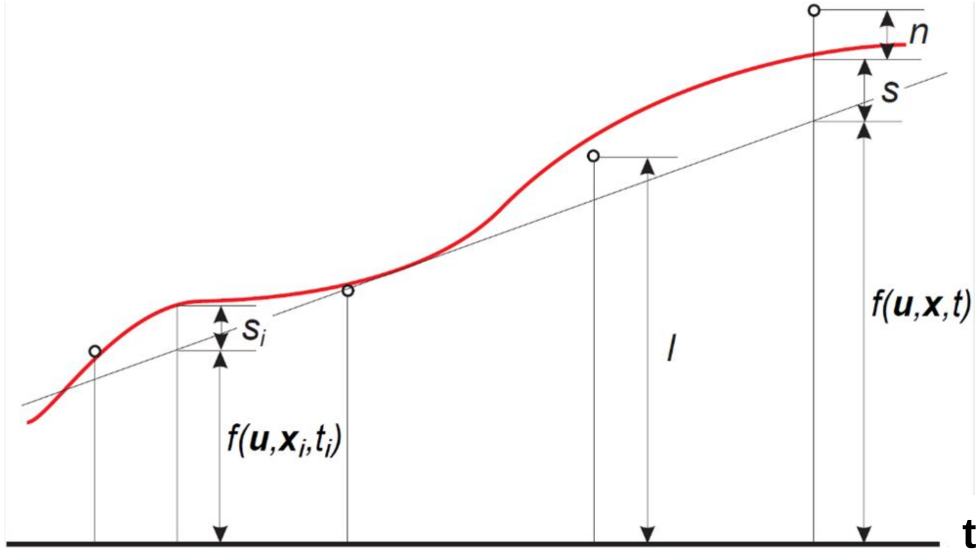
- **The SAR interferometr**y is essentially exploiting **the phase differences among two or more SAR images**, and **estimates the deformation** by extracting the deformation-related phases among other phase contributions
- PSI is a state-of-the-art method for deformation assessments
- **PSI identifies the coherent targets** for which the **atmosphere-induced phase can be isolated from other phase components**, mainly residual topography and deformation
- The **natural terrain** in alpine regions generally **limits PS behavior** (few scatterers)
- PS calculated using IPTA toolbox from Gamma software

More info: Siddique MA et al. IEEE TGRS (2018) doi.org/10.1109/TGRS.2018.2855101

Methodology – GNSS interpolation

- COMEDIE: Least-squares collocation software developed at ETH Zürich
- Stochastic and deterministic interpolation and screening of meteorological/tropospheric data
- Outline: using software COMEDIE to interpolate ZTDs from the GNSS stations to the locations of PS

$$l = f(u, x, t) + s(C_{ss}, x, t) + n$$



More about methodology:
Wilgan K et al. J Geod (2017) 91: 117
doi.org/10.1007/s00190-016-0942-5

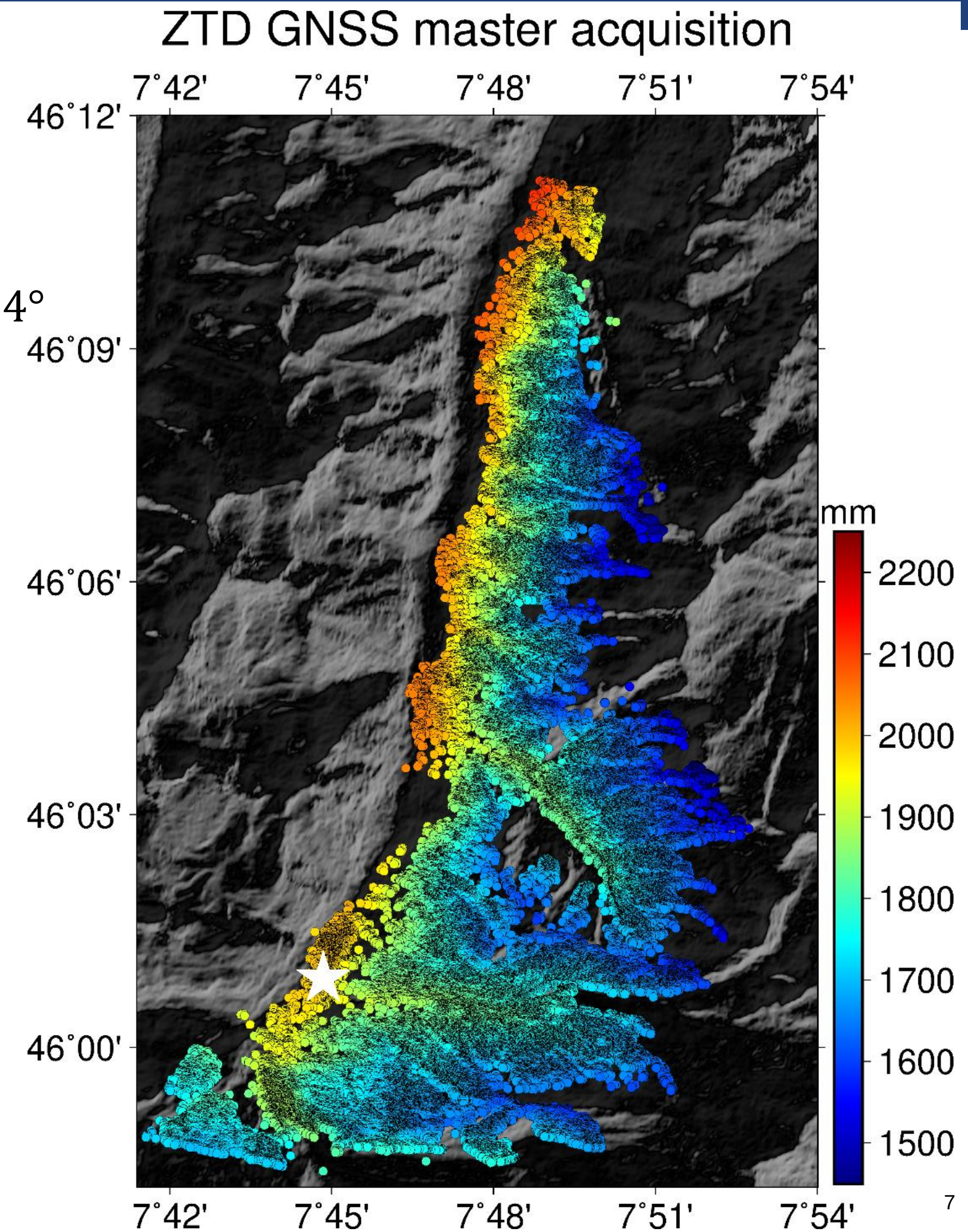
Differential STDs from GNSS

$$STD = \frac{1}{cos\theta} ZTD \qquad 24.5° < \theta < 25.4°$$

$$dSTD(x,t) = \\ = \left(STD(x,t) - STD(x,t_m)\right) \\ - \left(STD\left(x_{ref},t\right) - STD\left(x_{ref},t_m\right)\right)$$

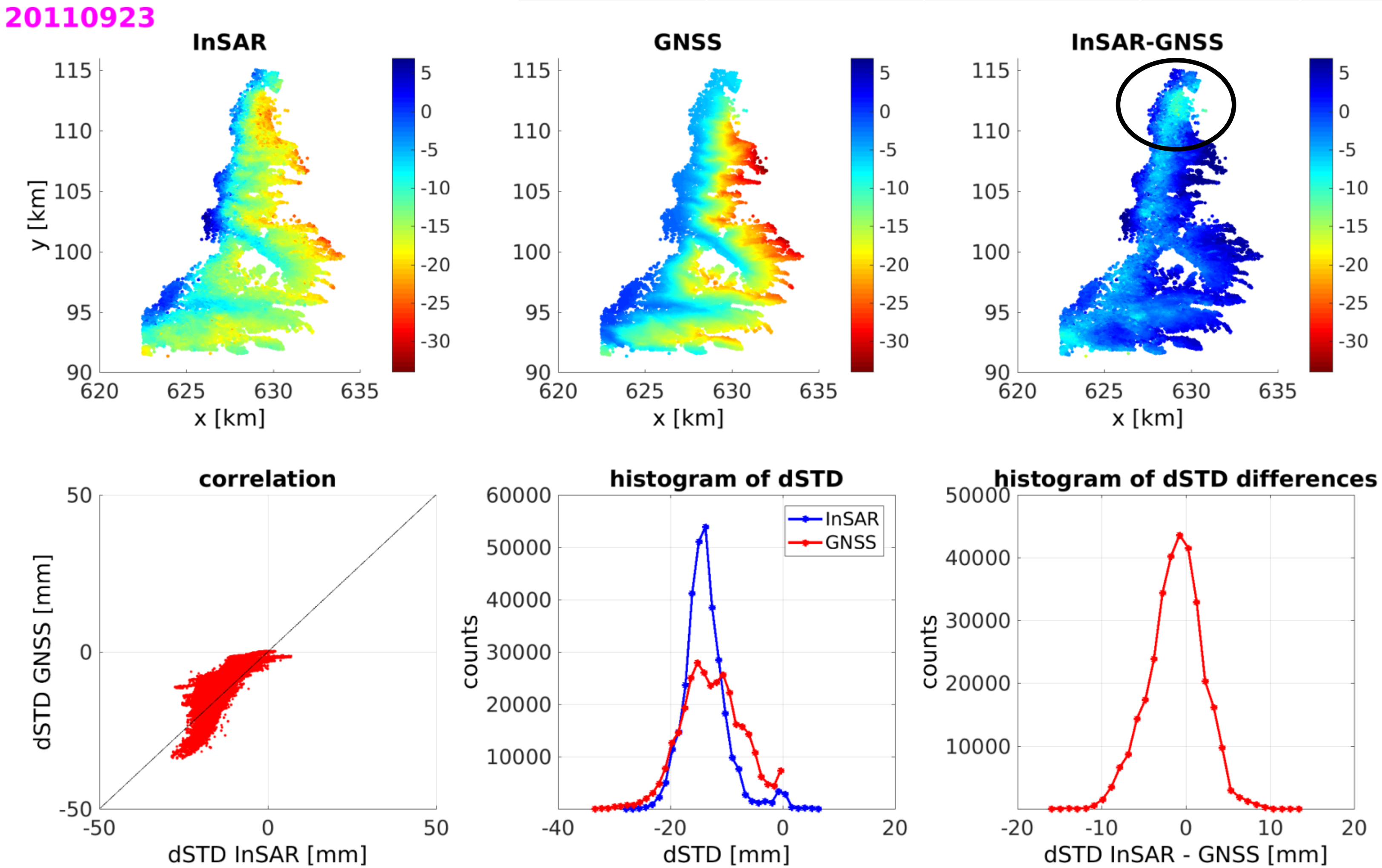
t_m - master acquisition (2010-09-20, 17:46:45)
x_{ref} - reference point

More about ZTD models in the Alps:
Wilgan K & Geiger A J Geod (2018)
doi.org/10.1007/s00190-018-1203-6



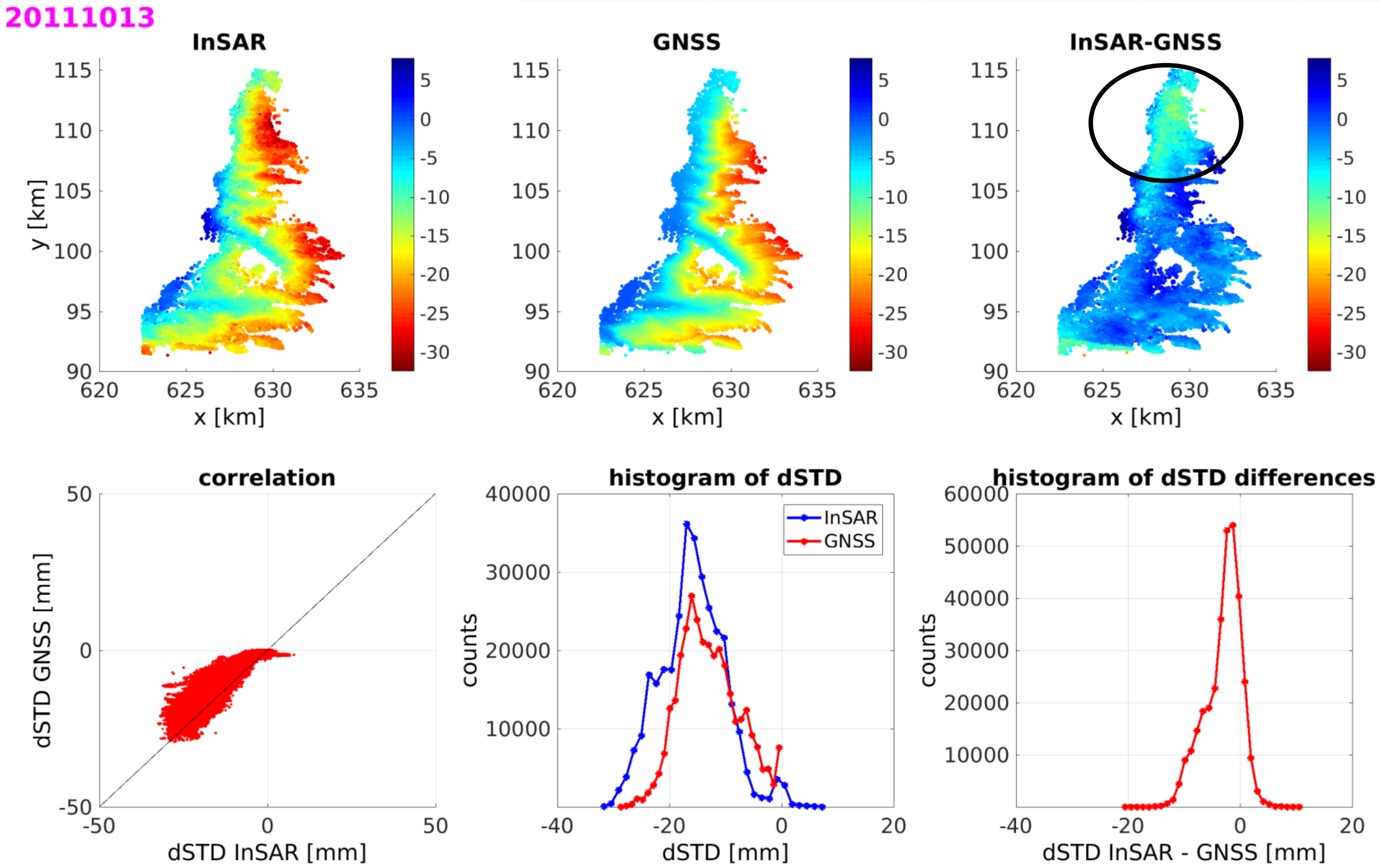
GNSS vs InSAR – good agreement

R	ioa	bias	SD	SD GNSS
0.82 [-]	0.63 [-]	-1.2 [mm]	3.2 [mm]	5.5 [mm]



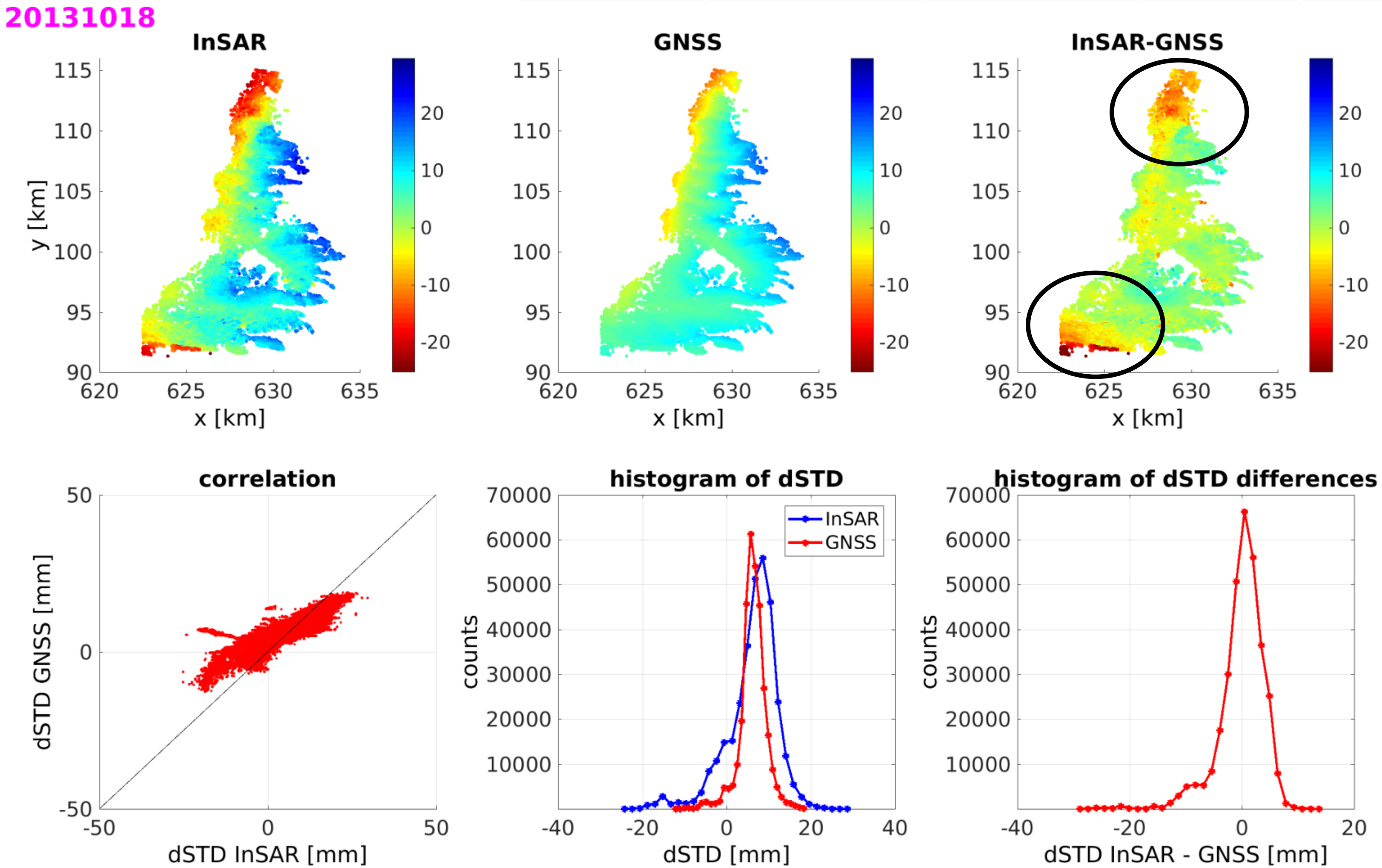
GNSS vs InSAR – good agreement

R	ioa	bias	SD	SD GNSS
0.84 [-]	0.64 [-]	-3.0 [mm]	3.2 [mm]	5.4 [mm]



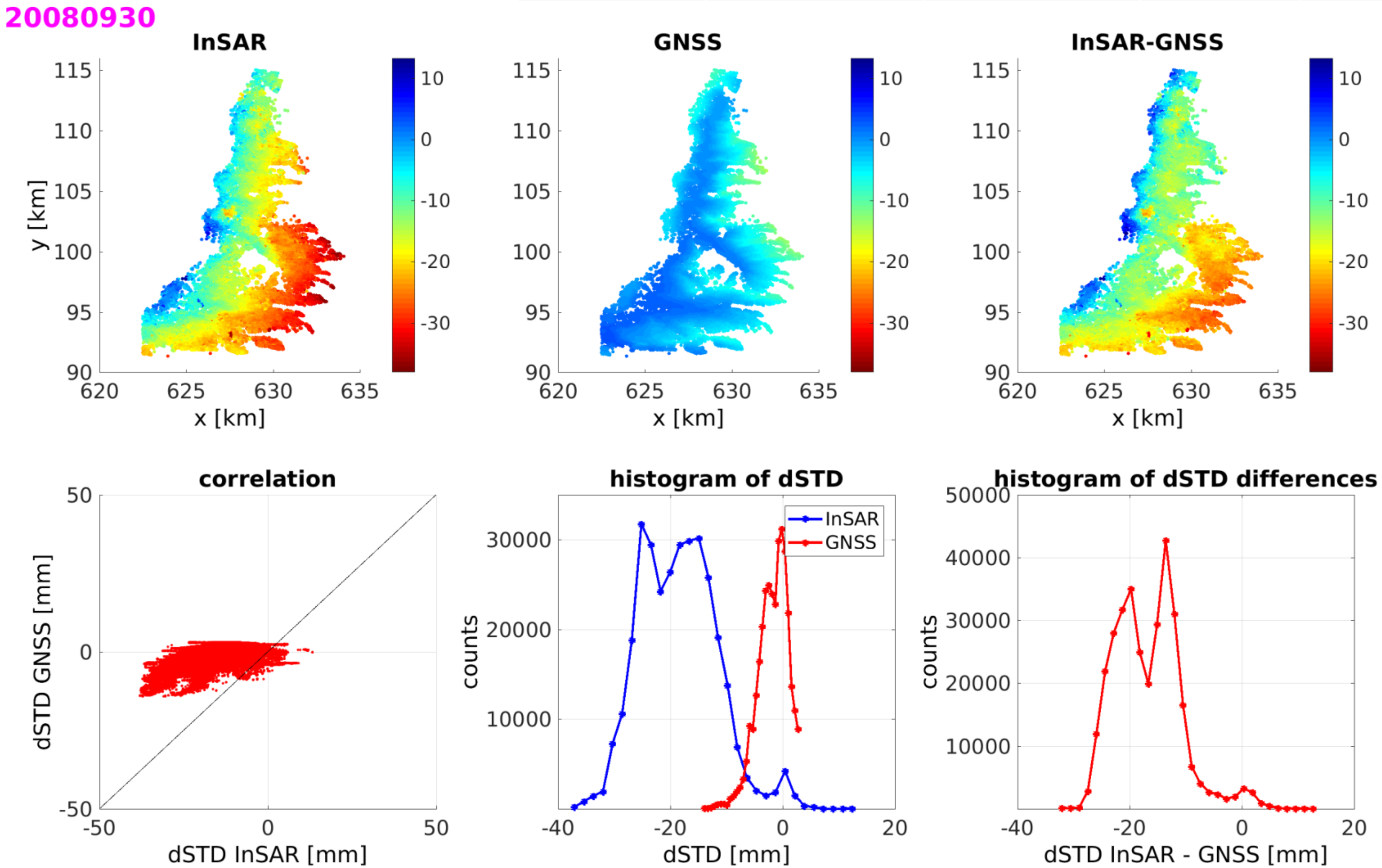
GNSS vs InSAR – average agreement

R	ioa	bias	SD	SD GNSS
0.79 [-]	0.57 [-]	0.0 [mm]	4.0 [mm]	3.2 [mm]



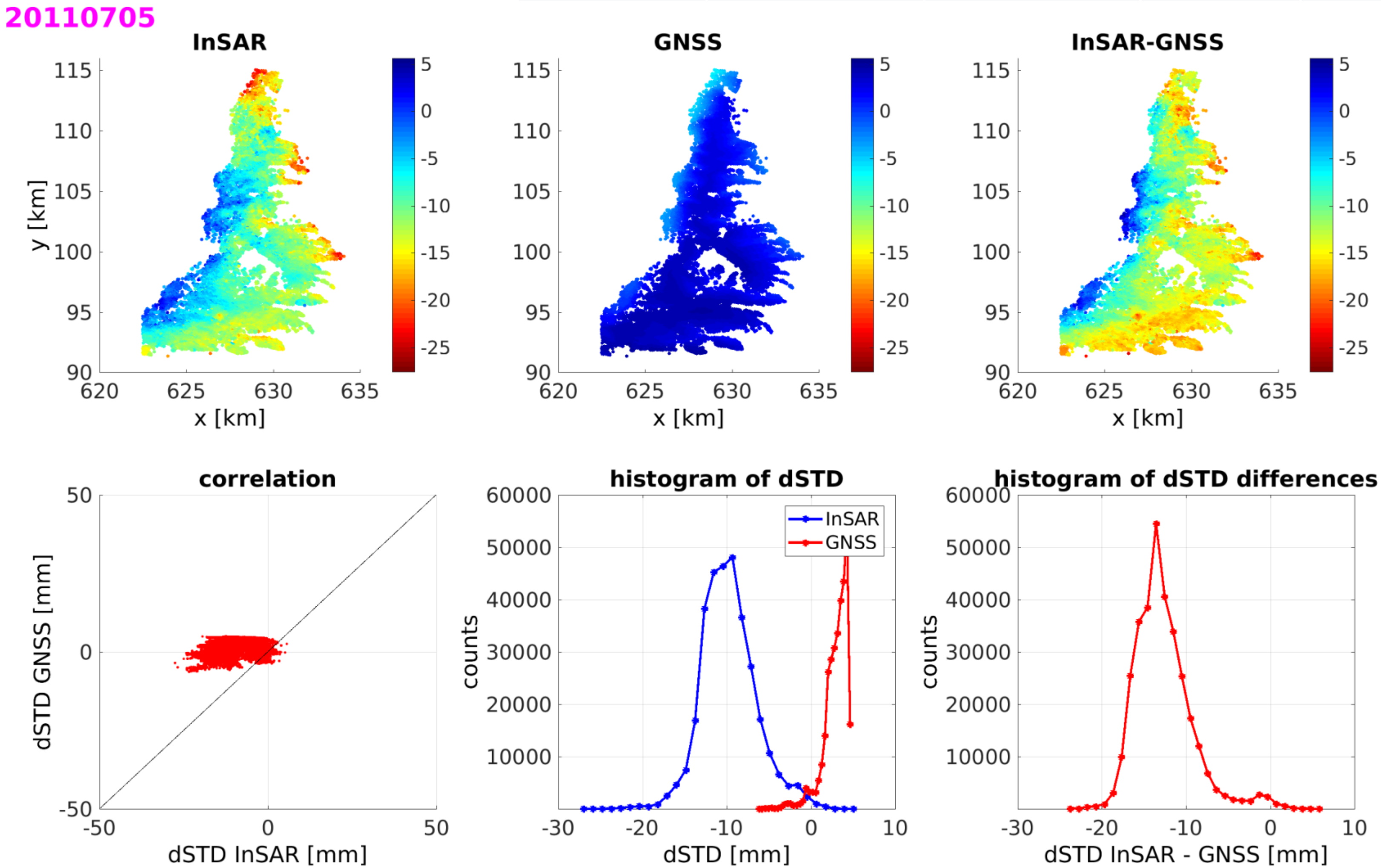
GNSS vs InSAR – bad agreement

R	ioa	bias	SD	SD GNSS
0.51 [-]	0.24 [-]	-16.7 [mm]	5.9 [mm]	2.6 [mm]



GNSS vs InSAR – bad agreement

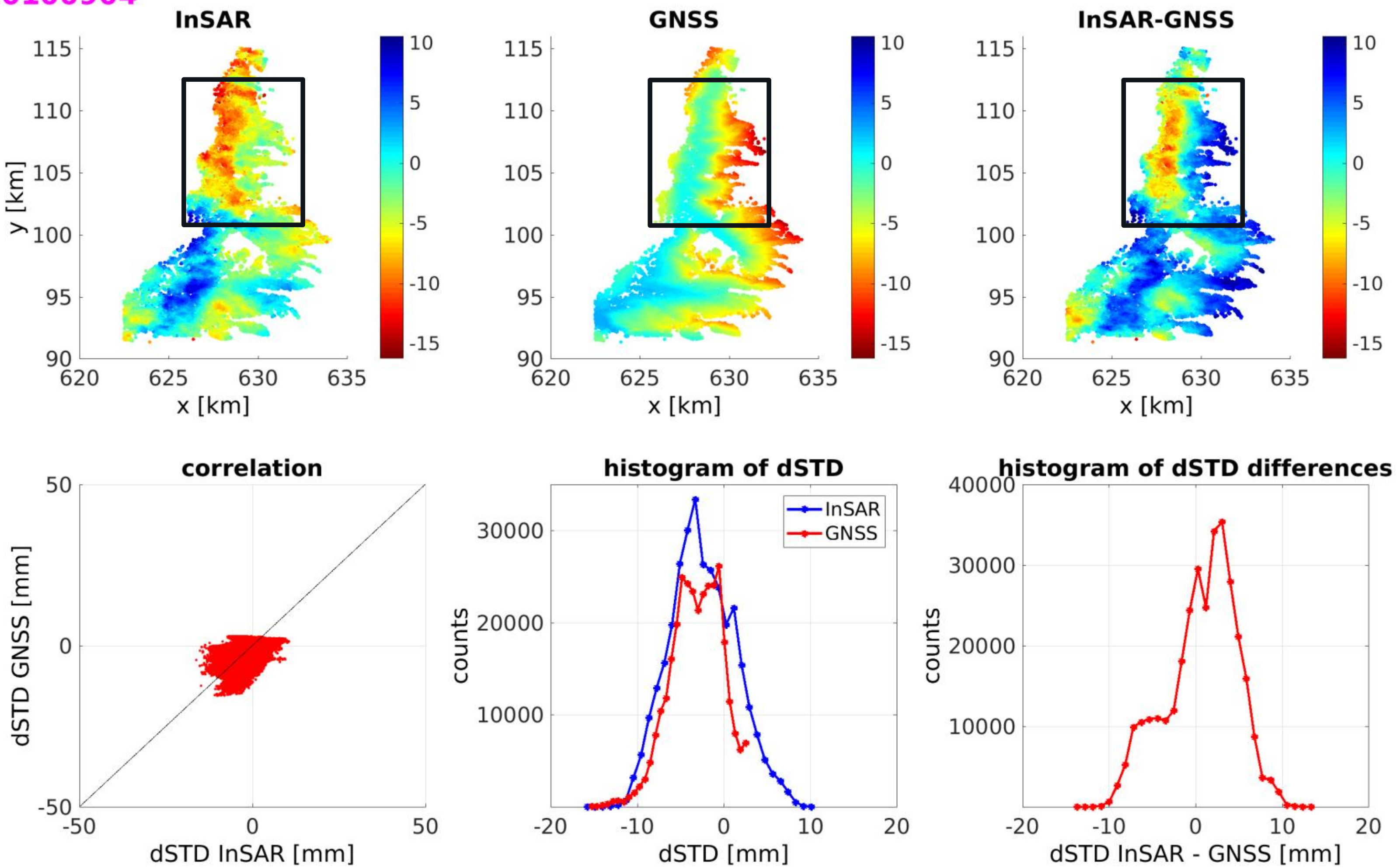
R	ioa	bias	SD	SD GNSS
0.07 [-]	0.16 [-]	-12.6 [mm]	3.4 [mm]	1.4 [mm]



GNSS vs InSAR – bad agreement

R	ioa	bias	SD	SD GNSS
0.29 [-]	0.38 [-]	0.7 [mm]	4.0 [mm]	2.9 [mm]

20100904



Assessment overview

	R	ioa	bias	SD	SD GNSS
2011-09-23	0.82	0.63	-1.2	3.2	5.5
2011-10-13	0.84	0.64	-3.0	3.2	5.4
2010-08-19	0.85	0.61	-3.1	3.8	7.1
2012-09-09	0.81	0.58	-2.7	2.8	4.7
2013-10-18	0.80	0.58	0.0	4.0	3.2
2013-07-26	0.80	0.66	-1.0	4.6	7.7
2013-07-10	0.73	0.63	-0.3	4.9	6.5
2011-07-21	0.57	0.39	-4.3	3.2	3.1
2013-08-11	0.69	0.52	-2.7	4.6	5.3
2011-09-27	0.86	0.47	-5.9	3.3	5.4
2013-08-27	0.88	0.40	-7.7	3.2	5.1
2010-08-03	0.43	0.42	-1.9	3.5	3.4
2011-06-03	0.81	0.32	-8.2	3.3	4.8
2012-08-08	0.42	0.43	2.0	4.8	4.8
2013-09-28	0.44	0.44	3.2	4.2	4.4
2012-07-23	0.49	0.48	-3.9	5.8	4.3
2013-08-31	0.49	0.42	-3.8	3.5	3.0
2012-06-05	0.43	0.38	-4.0	3.2	1.7
2010-09-04	0.29	0.38	0.7	4.0	2.9
2012-06-21	0.81	0.32	-11.8	4.4	4.2
2011-09-11	0.88	0.35	-11.7	3.8	6.3
2010-10-06	0.90	0.25	-11.6	3.6	1.8
2010-10-22	0.67	0.24	-10.9	3.3	3.8
2013-09-12	0.44	0.26	-6.3	3.1	2.5
2012-07-07	0.58	0.24	-11.2	3.8	3.0
2011-07-05	0.07	0.16	-12.7	3.4	1.4
2008-09-30	0.51	0.24	-16.7	5.9	2.6
2008-10-16	0.50	0.26	-11.8	4.7	3.5

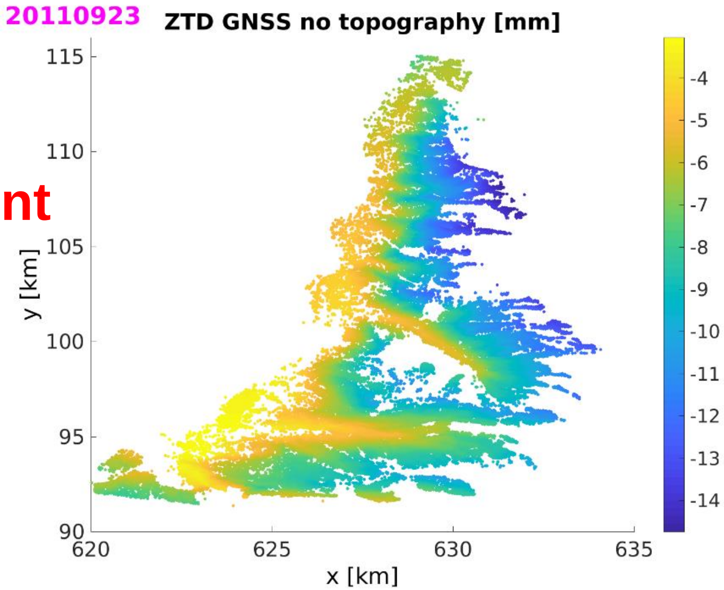
R [-] – Pearson correlation coefficient
IOA [-] – index of agreement (Willmott, 1981)
SD [mm] – standard deviation
Bias [mm] – mean error

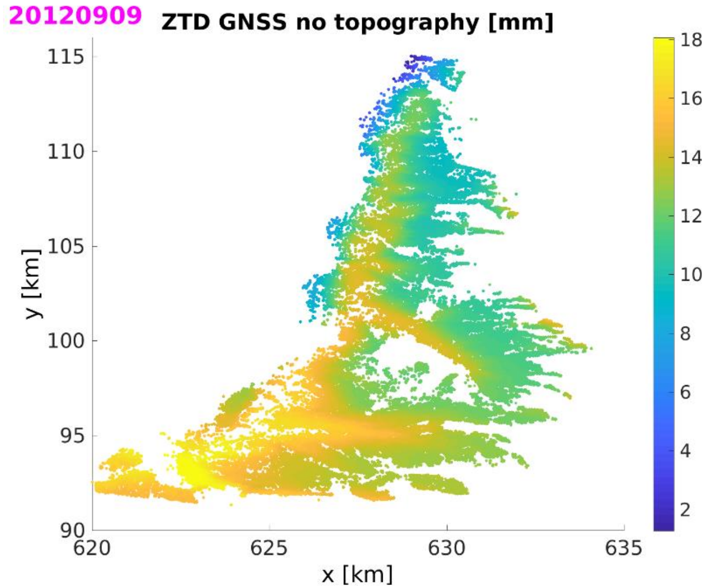
7	good	R>0.8, ioa>0.6, |bias|<2, SD<3.5
8	ok	R>0.5, ioa>0.4, |bias|<5, SD<5
8	bad	R>0.4, ioa>0.3, |bias|<10, SD<6
5	very bad	R<0.4, ioa<0.3, |bias|>10, SD>6

high GNSS SD > 5
low GNSS SD < 3

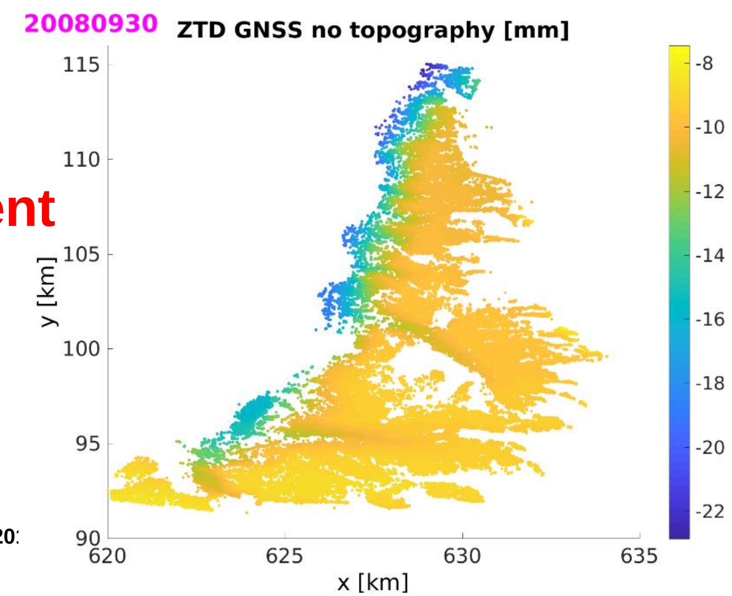
ZTDs without topography

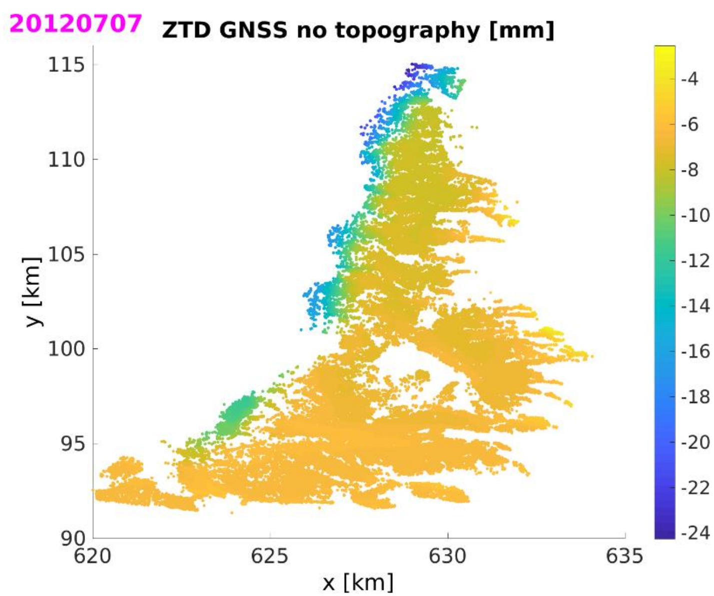
Good agreement



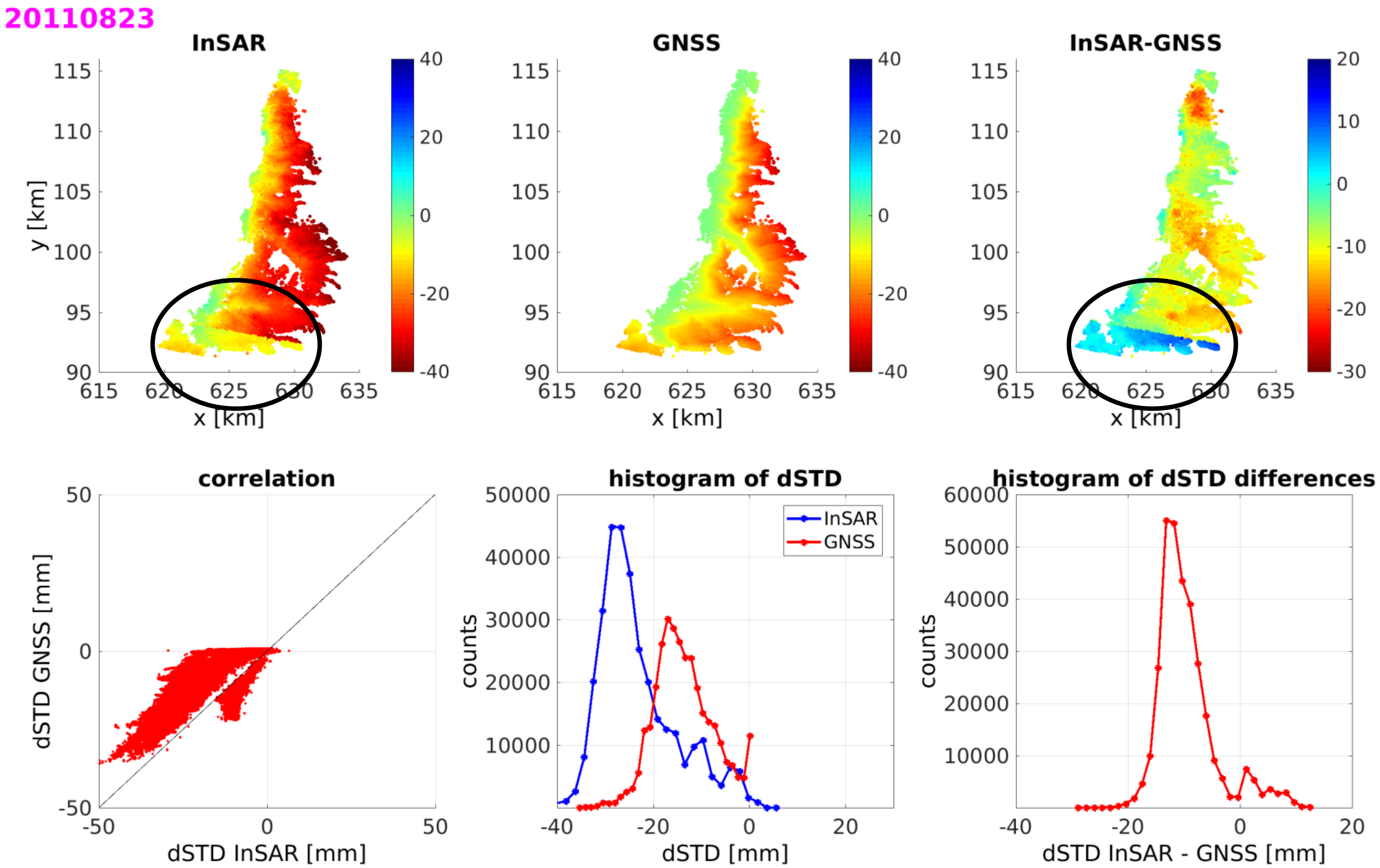


Bad agreement





Phase unwrapping error's detection



3 acquisitions with errors detected!

Conclusions

- We compared the GNSS and InSAR-derived dSTDs on the PS points for 32 InSAR acquisitions
- The highest agreement between GNSS and InSAR is for days of varying troposphere
- For such days, GNSS-based models could be used for mitigating the troposphere errors in InSAR
- For days with stable troposphere, the models from InSAR are more reliable
- GNSS can also help detecting the phase unwrapping errors


Thank you! 謝謝！
Questions? 問題？
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Methodology COMEDIE

Deterministic part (zenith total delay):

$$ZTD(x,y,z,t) = \left(ZTD_0 + a_{ZTD}(x - x_0) + b_{ZTD}(y - y_0) + c_{ZTD}(t - t_0)\right) \cdot \exp\left(-\frac{z}{H_{ZTD}}\right)$$

Stochastic parts:

$n \sim N(0, C_{nn})$ stochastic uncorrelated noise

C_{nn} diagonal matrix consisting of noise of particular measurements

$s \sim N(0, C_{ss})$ stochastic correlated signal

C_{ss} empirically determined covariance function, e.g.:

$$C_{ss}(i,j) = \frac{\sigma_0^2}{1 + \left[\left(\frac{x_i - x_j}{\Delta x_0}\right)^2 + \left(\frac{y_i - y_j}{\Delta y_0}\right)^2 + \left(\frac{z_i - z_j}{\Delta z_0}\right)^2 + \left(\frac{t_i - t_j}{\Delta t_0}\right)^2\right] \cdot e^{-\frac{z_i + z_j}{2 z_0}}}$$