



Developing InSAR atmospheric delay correction model based on GEONET ZTD and its gradient

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Atmospheric delay in InSAR

Atmospheric propagation delay: The effect that a microwave experiences the refraction due to Earth's atmosphere. The refraction causes an apparent displacement in the phase.

- The difference of spatial heterogeneity is critical
- There is no definitive method to correct InSAR delay

Most difficult to mitigate because of the poor reproducibility of the atmospheric water vapor.

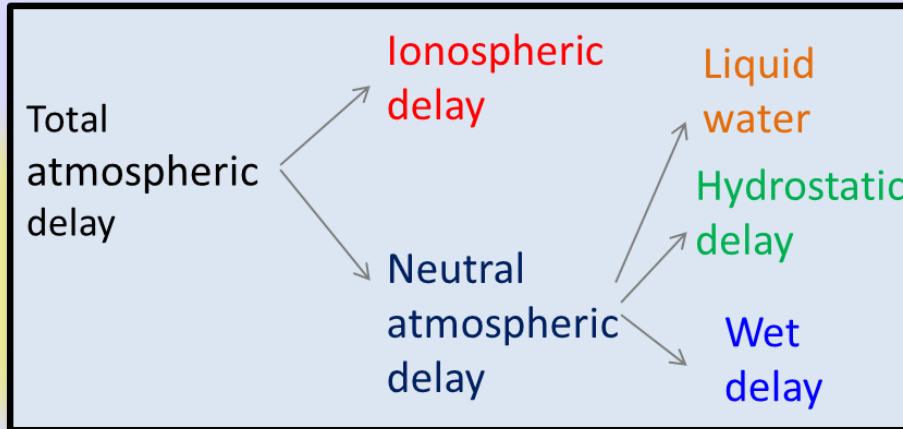
Methods proposed by now

- ✓ Fitting the topography data to the IFG.
- ✓ Use GNSS (GPS) or other observations such as satellite remote sensing.
- ✓ Use numerical weather models.
- ✓ Time series analysis such as PS and SBAS.

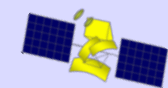
Propagation delay

Principle: same as GNSS (GPS)

Snell's law



SAR satellite
GNSS satellite



$$n_p = 1 - \frac{40.3 \cdot n_e}{f^2}$$

ϕ_{iono} : Ionosphere

Dispersive

$$N = 10^6 (n - 1) = k_1 \frac{P_d}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2}$$

$$\text{Delay} = \underbrace{\int_L (n - 1) ds}_{\text{Vel change}} + \underbrace{(L - G)}_{\text{Bending}}$$

ϕ_{NAtm} : Neutral atm

Vapor

Hydrometeors

Wet delay

見かけ上の
超過距離

GPS受信機

Method	Stratified delay	Turbulent delay	Availability	Spatial Scale	memo
Topography fitting (DEM-based)	○	×	◎	unlimited	can't use when topo-correlated disp exists.
Numerical weather model (data provided)	○	×	△	> 10 km (able to mitigate against smaller-scale Strat. delay)	Turbulent delay can't be corrected
Numerical weather model (simulate oneself)	○	?	×	> 500m (depends on model grid interval)	need to have special knowledge
GNSS	?	?	△	> 10km	depends on station density
Satellite IR	?	○	×	> 100m	no simultaneous obs
Time series	△	○	△	unlimited	need many SLCs
GACOS (ERA-I + GNSS)	○	△	◎	> 10km	easy to use

Retrieve ZTD map with GNSS ZTD & Gradient

I used the algorithm proposed by Arief and Heki (2020) to estimate 2D ZTD map. (although they retrieved ZWD map)
The model has sea level ZTD (ZTD_0) and linear height-dependent component.
(coefficient is independent to location)

$$ZTD_{obs} = ZTD_0 + a \cdot Height$$

$$G_e = \{ZTD_0(i+1, j) - ZTD_0(i, j)\} \frac{H}{D_e}$$

$$G_n = \{ZTD_0(i, j+1) - ZTD_0(i, j)\} \frac{H}{D_n}$$

- use 5-min GNSS PPP data provided by Nevada Geodetic Lab.
- Least squares inversion
- free boundary smoothing
- Model resolution is set to 5 km.

Concept of ZTD map retrieval

Input Data

- ZTD
- Delay Gradient

Green function

$$ZTD_{obs} = ZTD_0 + a \cdot Height$$

$$G_e = \{ZTD_0(i+1, j) - ZTD_0(i, j)\} \frac{H}{D_e}$$

$$G_n = \{ZTD_0(i, j+1) - ZTD_0(i, j)\} \frac{H}{D_n}$$

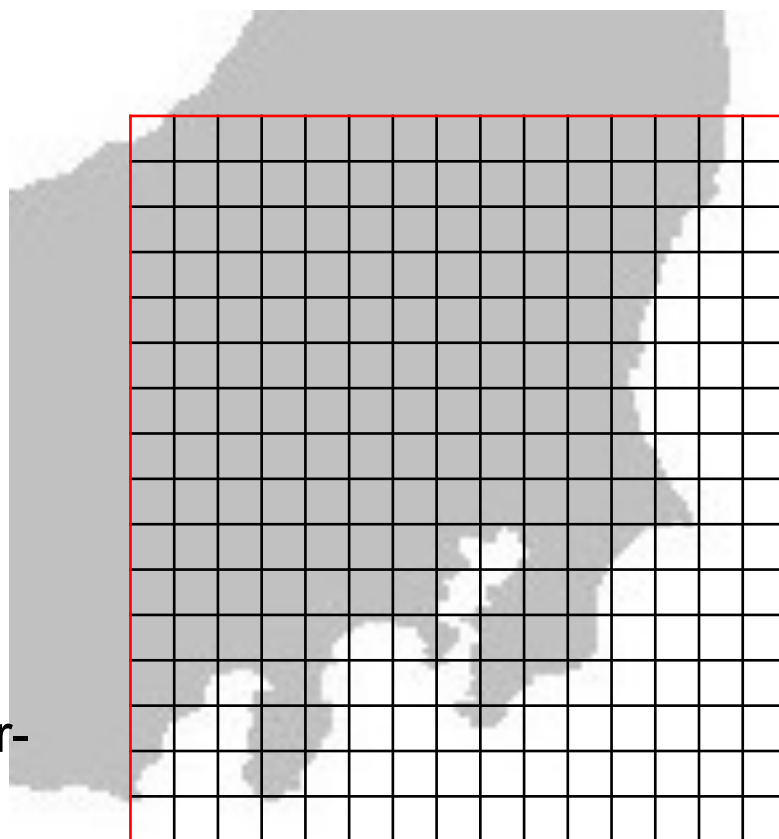
Arbitrary params

- Grid interval
- smoothing hyper-parameter

Cost function (LS inversion)

$$T^2 = (d - Gm)^T W_d^{-1} (d - Gm) + \lambda (p - Cm)^T D_p^{-1} (p - Cm)$$

Retrieved Grids



Free boundary

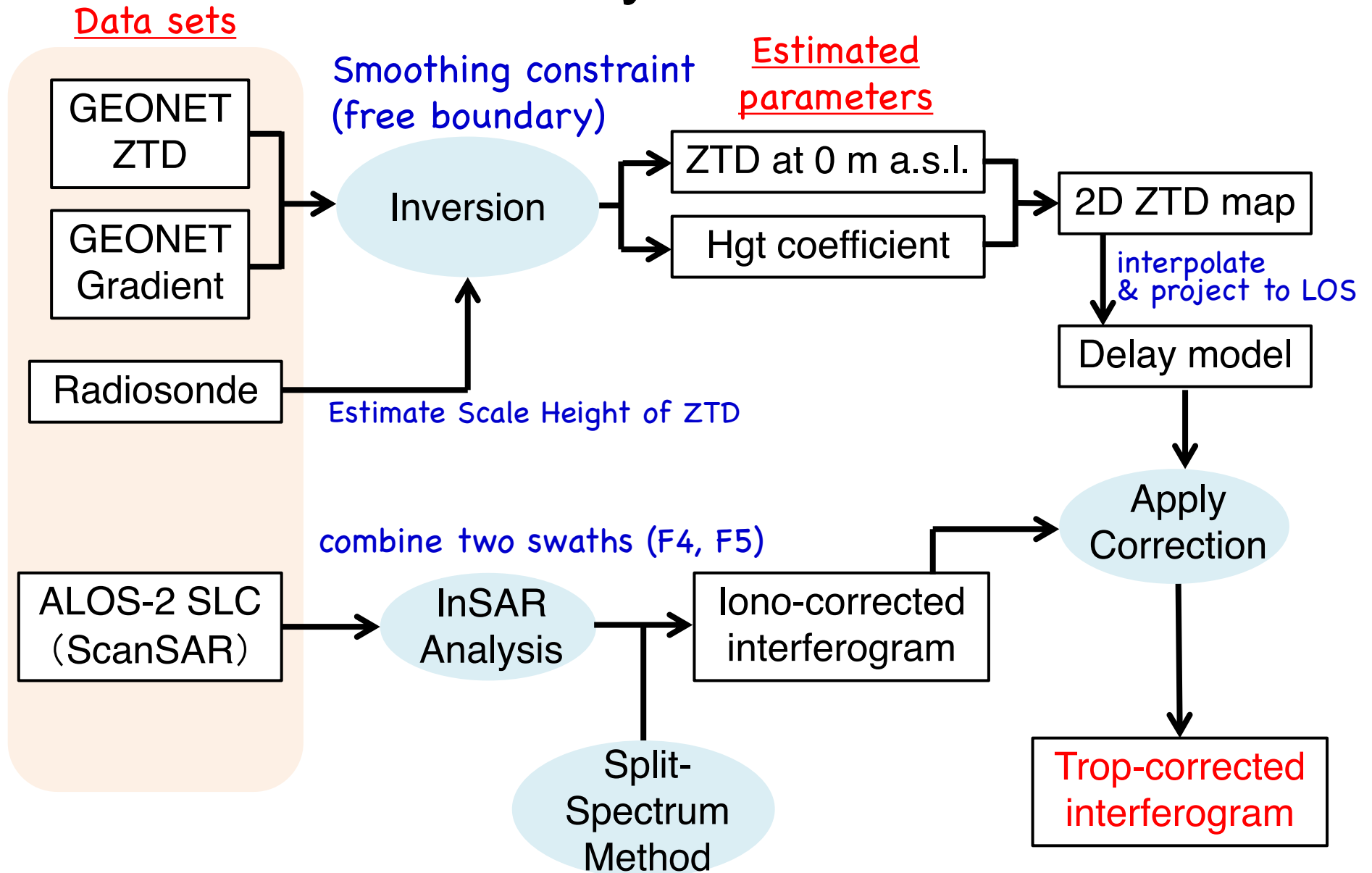
Estimated parameters

- Sea level ZTD (N grids)
- Linear slope to topography (1)

Unknowns: N+1
(N depends on grid interval and extent)

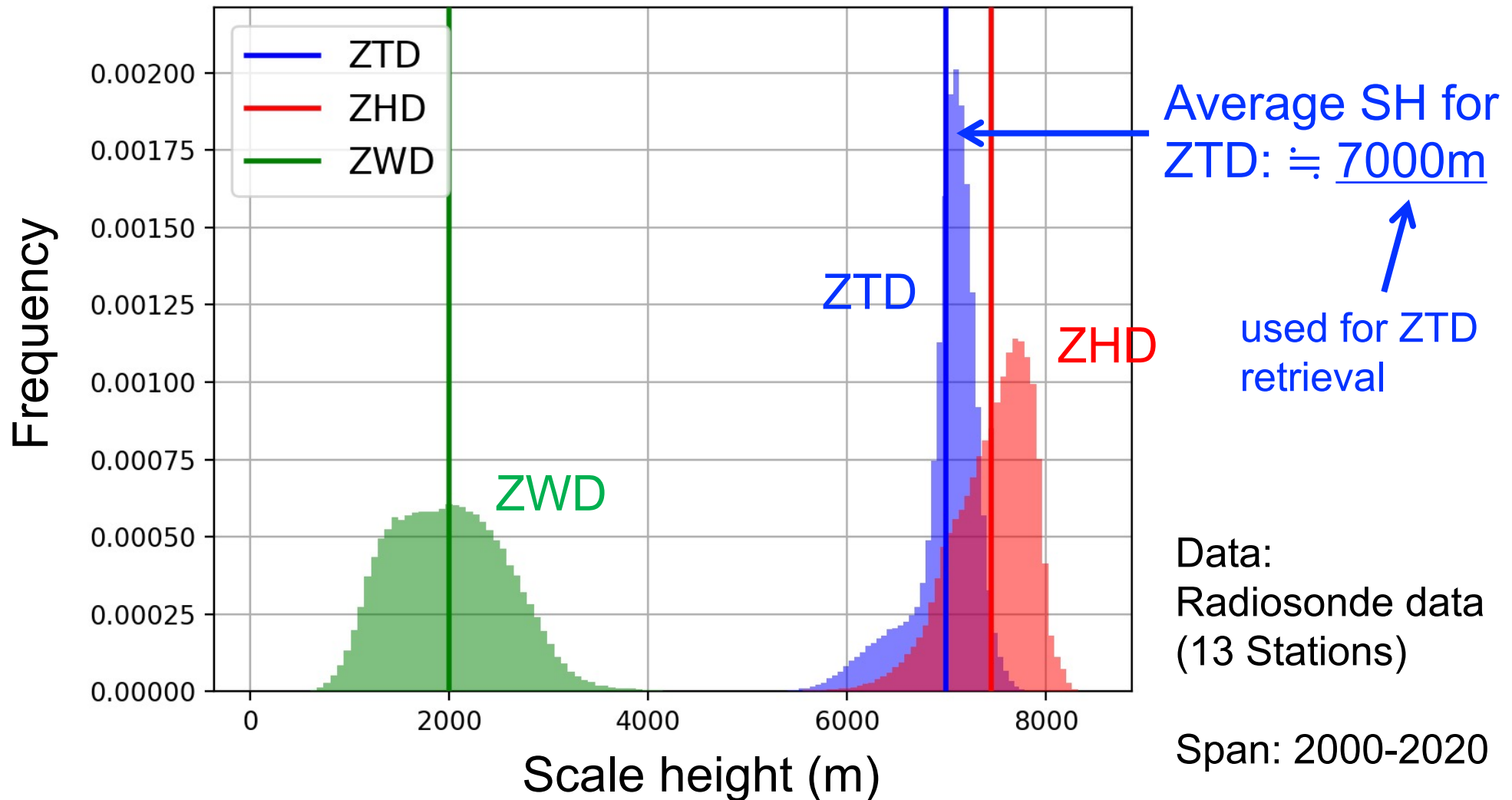
This inversion becomes **under-determined problem** in most cases. So we add a **smoothing constraint** to suppress it.

Analysis flow

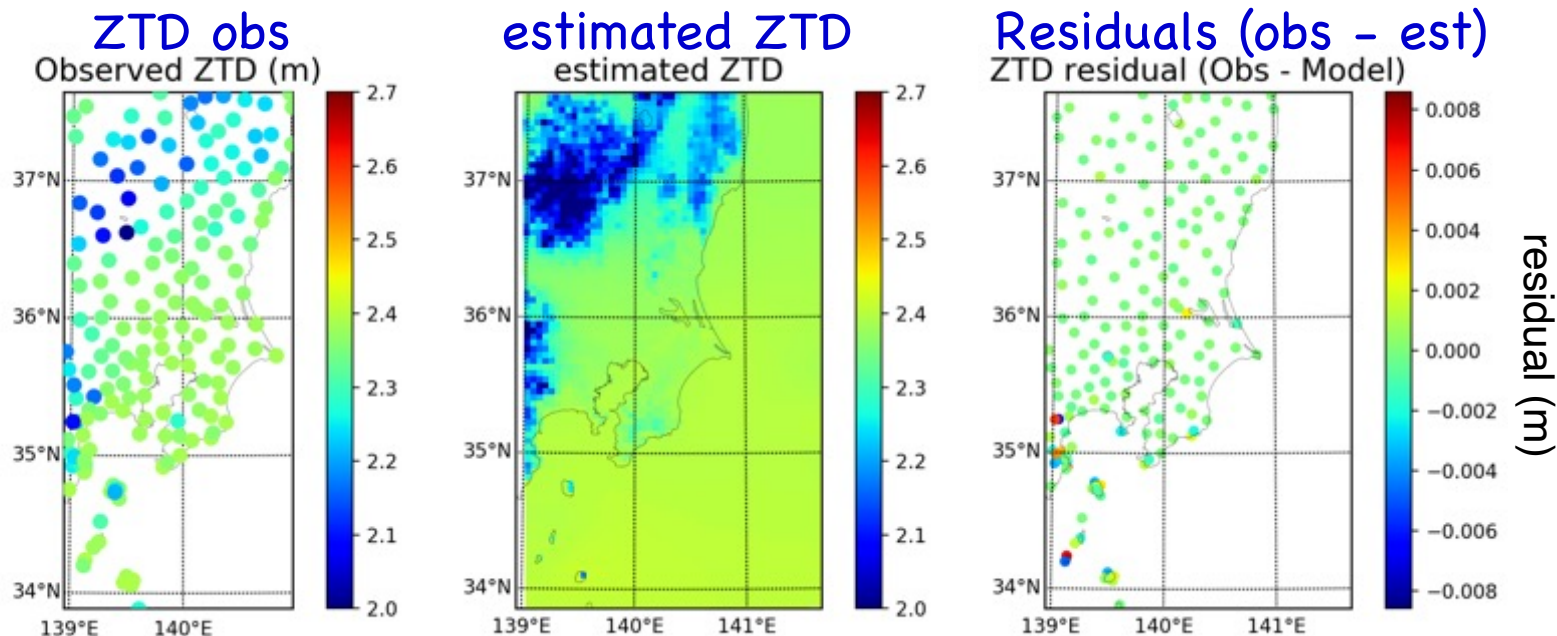


Estimation of ZTD Scale Height

Observed scale heights derived from radiosonde data in Japan



Result 1: Retrieval of ZTD map



Example: 2016/01/23 02:30 UT

HGT coef: -0.000288 m/m

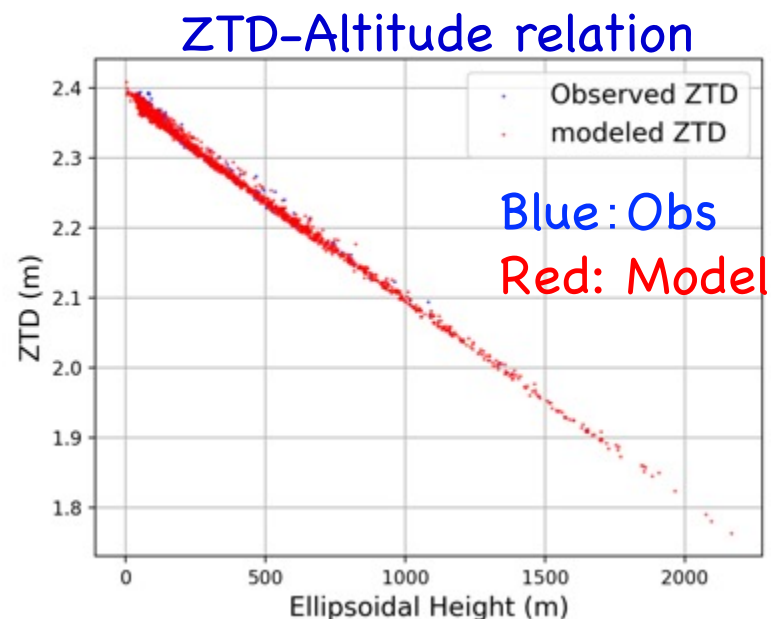
residual mean: 0.054046 mm

residual STD: 1.636760 mm

Stats of all IFGs

residual mean: 0.078470 mm

residual STD: 2.142828 mm



InSAR analysis

Sensor: ALOS-2

Mode: WD1 (ScanSAR)

Path-Frame: 17-2900

Swath: F4 & F5

DEM: SRTM 1-arcsec

Software: RINC (ver0.41r)

Range looks: 18 ($\approx 110\text{m}$)

Az looks: 30 ($\approx 90\text{m}$)

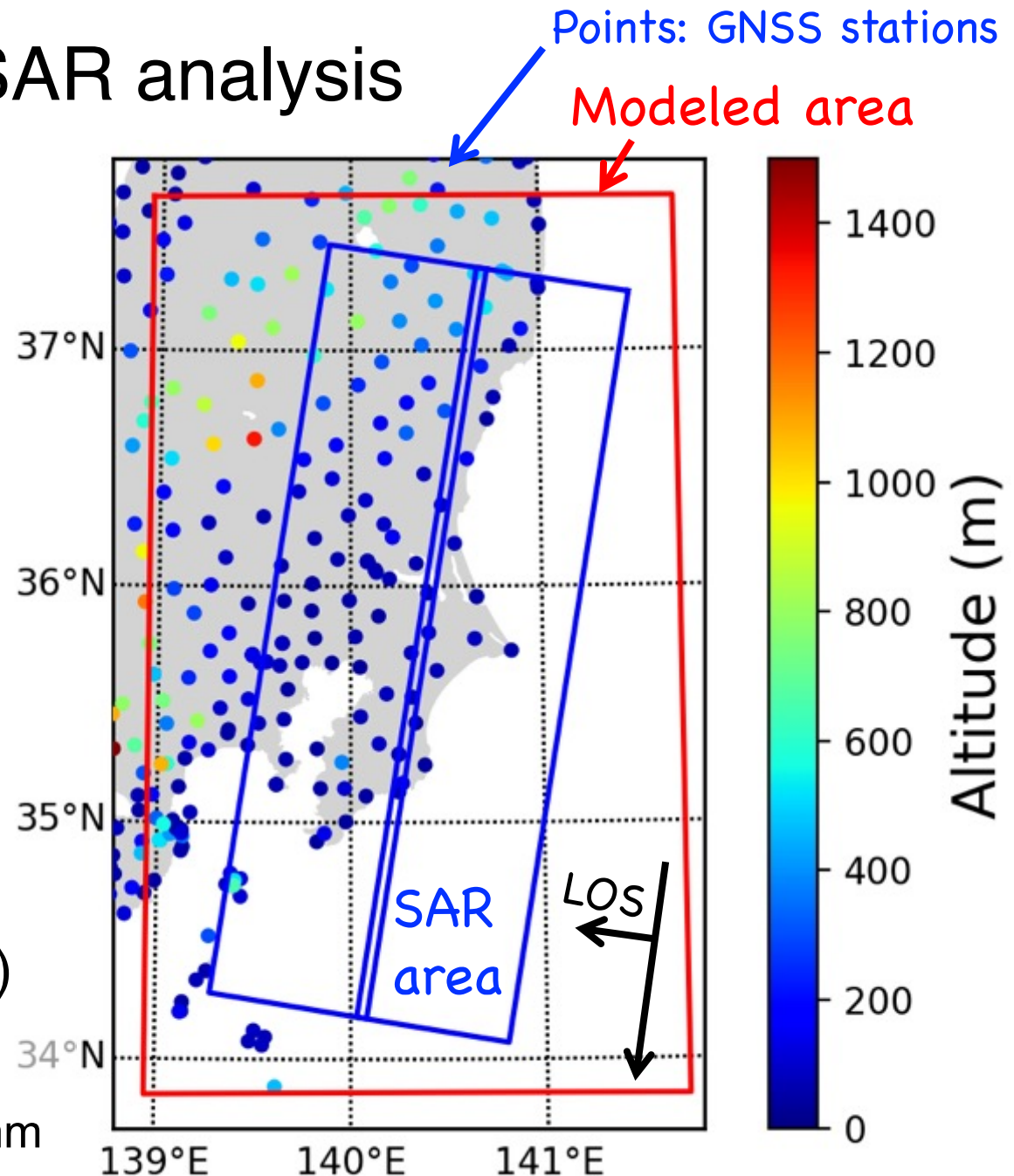
Bperp: $< 613\text{ m}$

Iono-correct: Split Spectrum
Method (SSM)

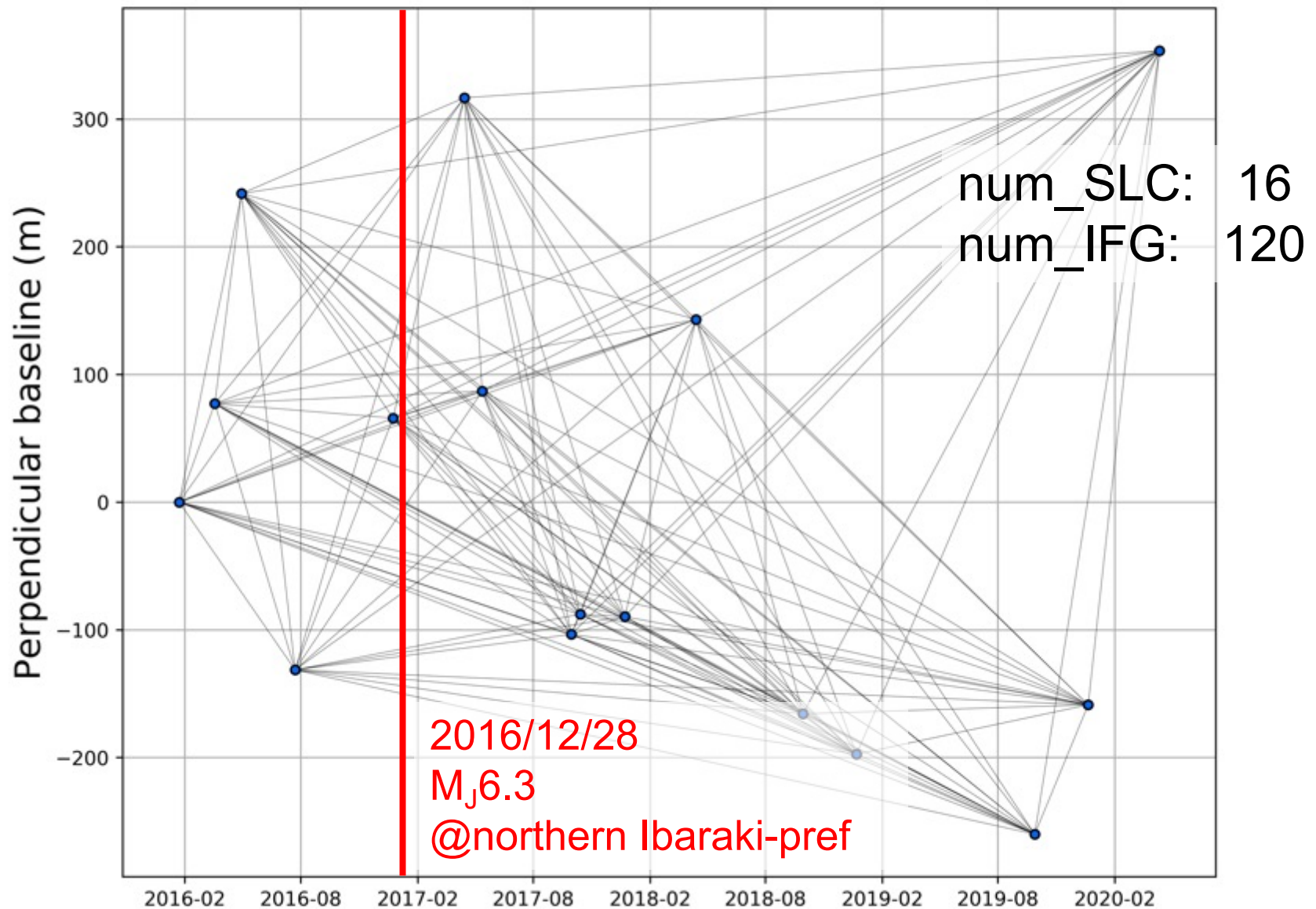
Stats of all IFGs (90) applying SSM

Phase STD before SSM: 104.2 mm

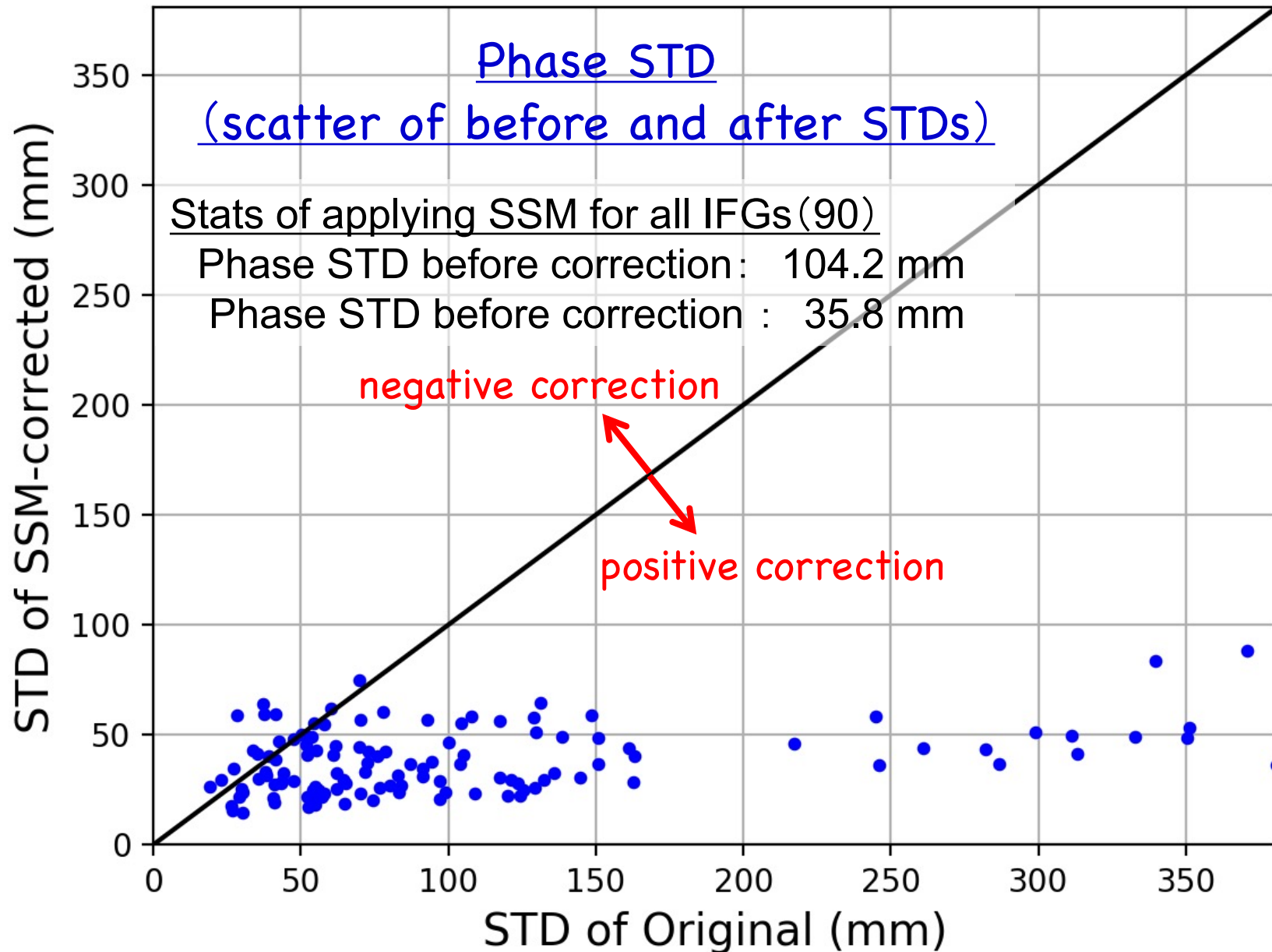
Phase STD after SSM : 35.8 mm



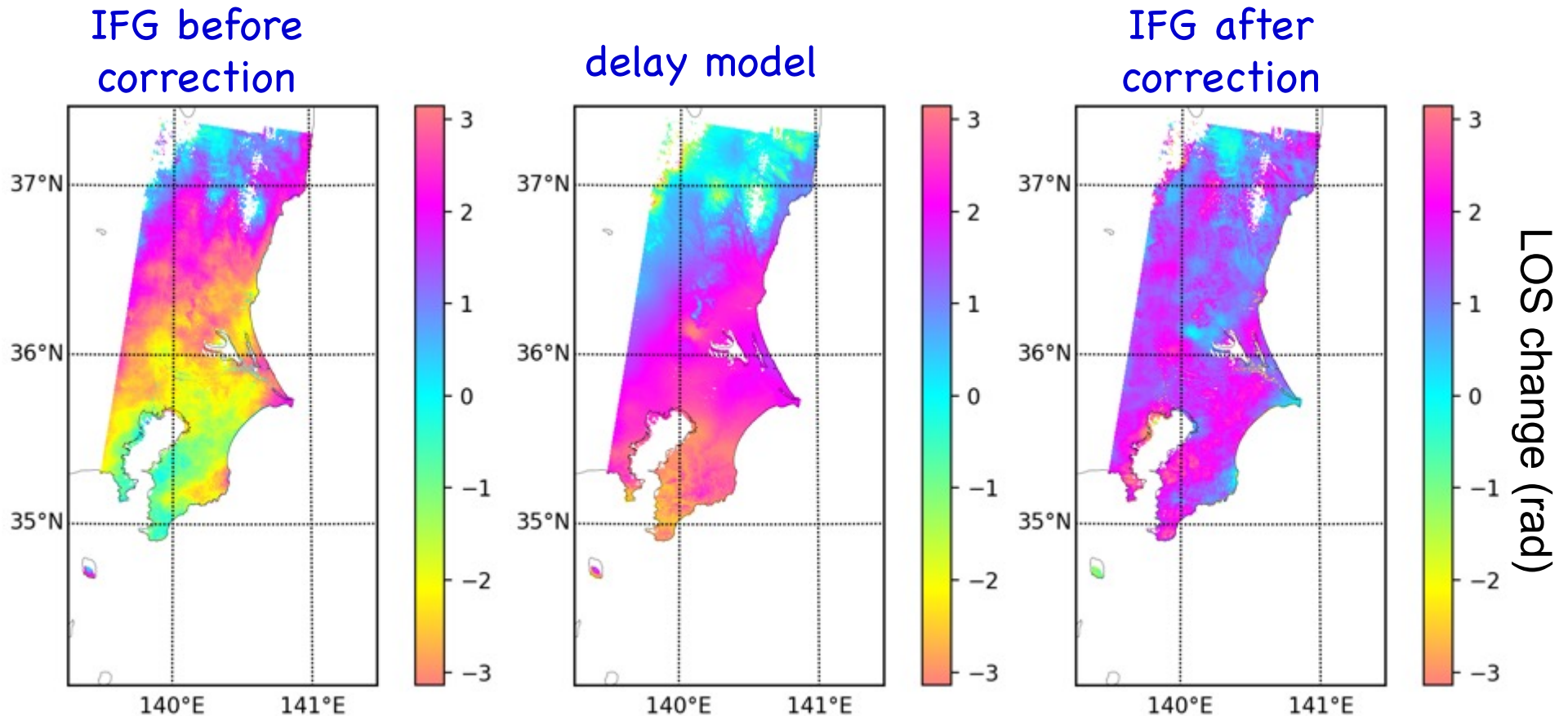
InSAR perpendicular baselines



Impact of applying SSM



Result 2: calculate InSAR delay model



Example: 2016/01/23 - 2016/03/19

Stats of all IFGs (90)

Phase STD before correction: 26.68 mm

Phase STD before correction: 35.95 mm

Phase STD after correction: 12.17 mm

Phase STD after correction: 25.84 mm

Comparison with other methods

Target 1. GACOS

Global standard?

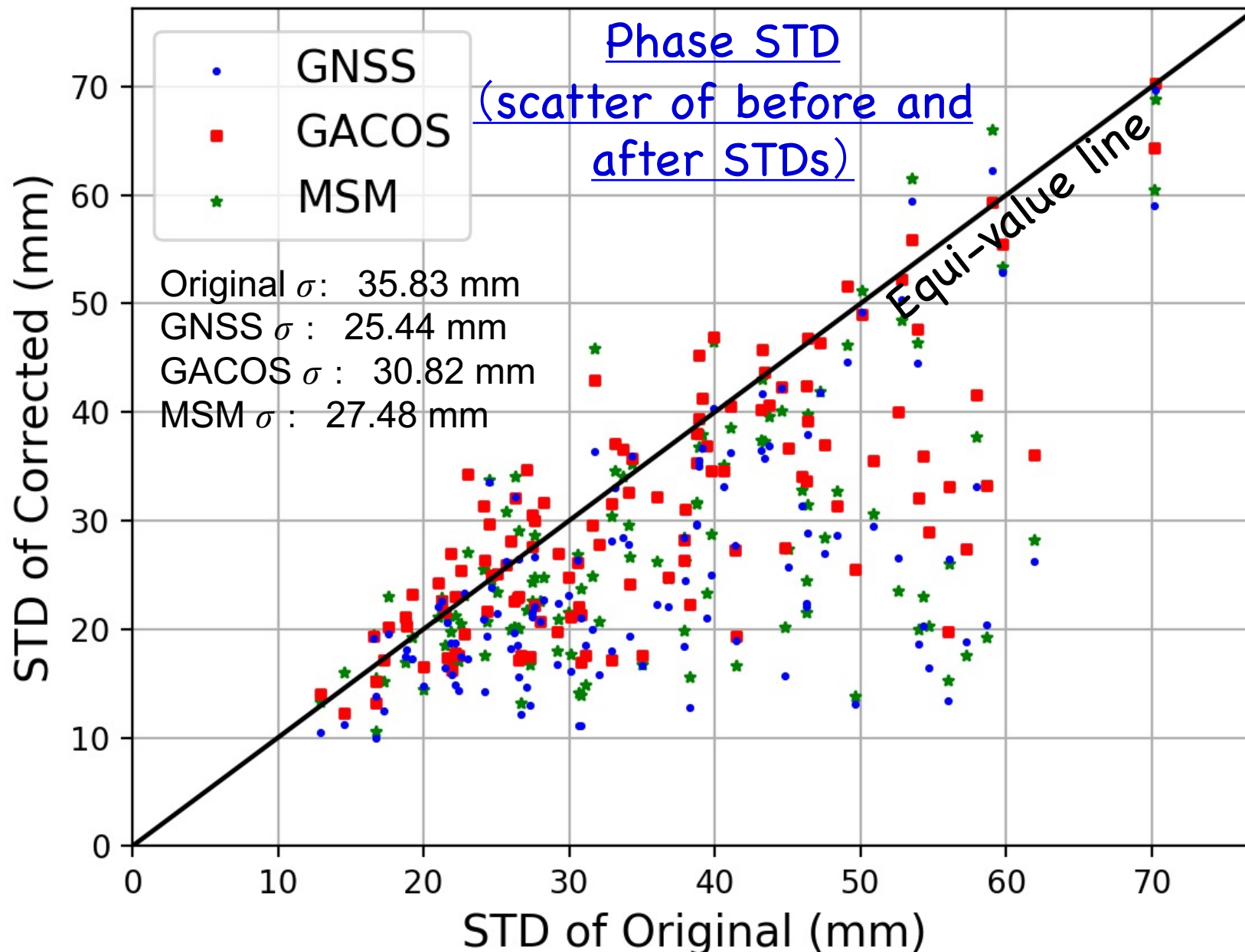
InSAR atmospheric correction online-service based on ECMWF ERA-Interim data. ERA-Interim is provided every 6 hours and thus GACOS interpolates the time to SAR observation.

Target 2. JMA MSM

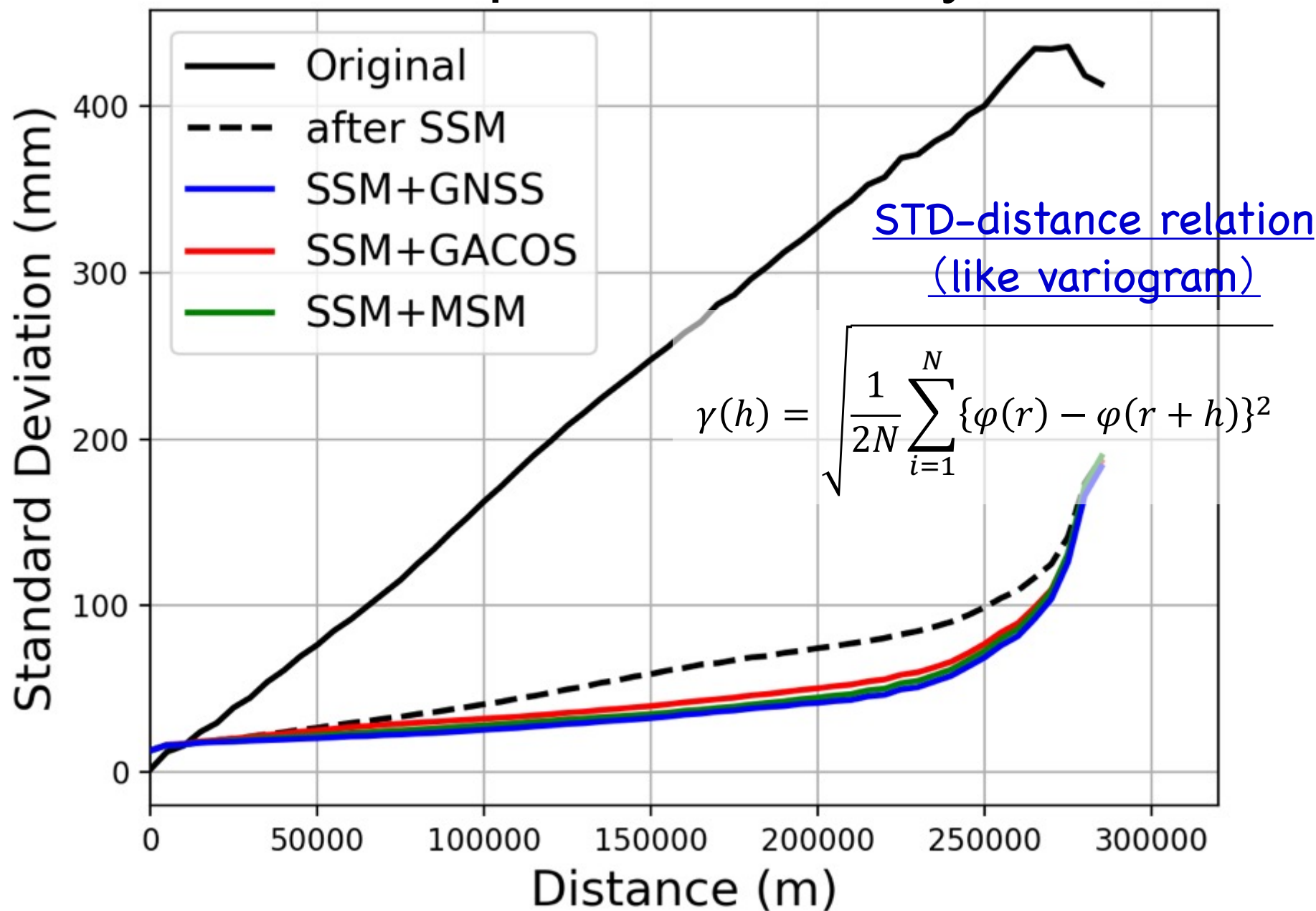
National standard?

The NWM objective analysis data for JMA Meso-Scale Model (MSM). The MSM model covers only Japan but the spatial grid interval is 10km, which is better than most of global atmospheric models. The MSM data is provided every 3 hours and thus the time interpolation is needed as well as GACOS.

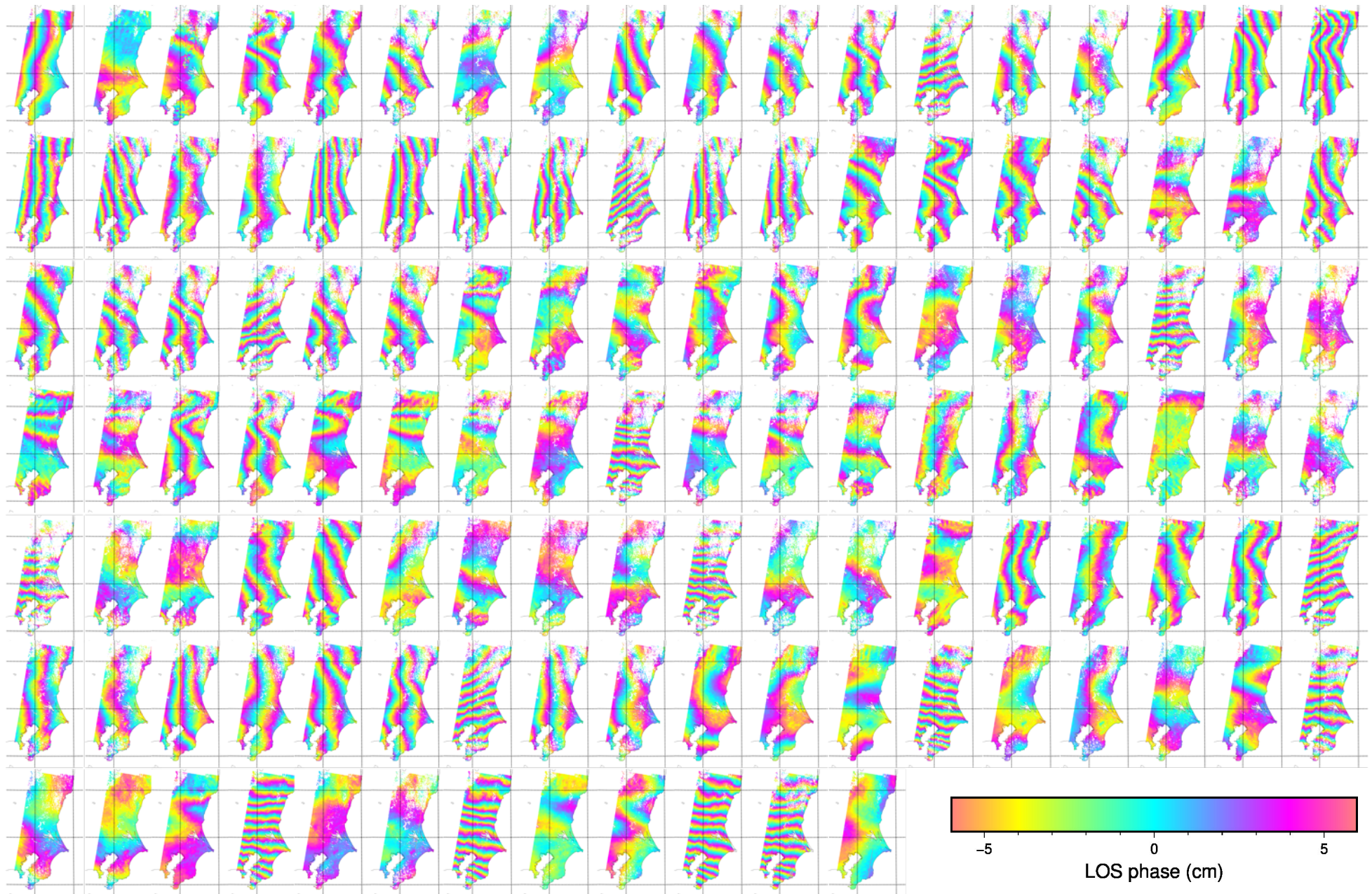
Result 3: comparison of delay model



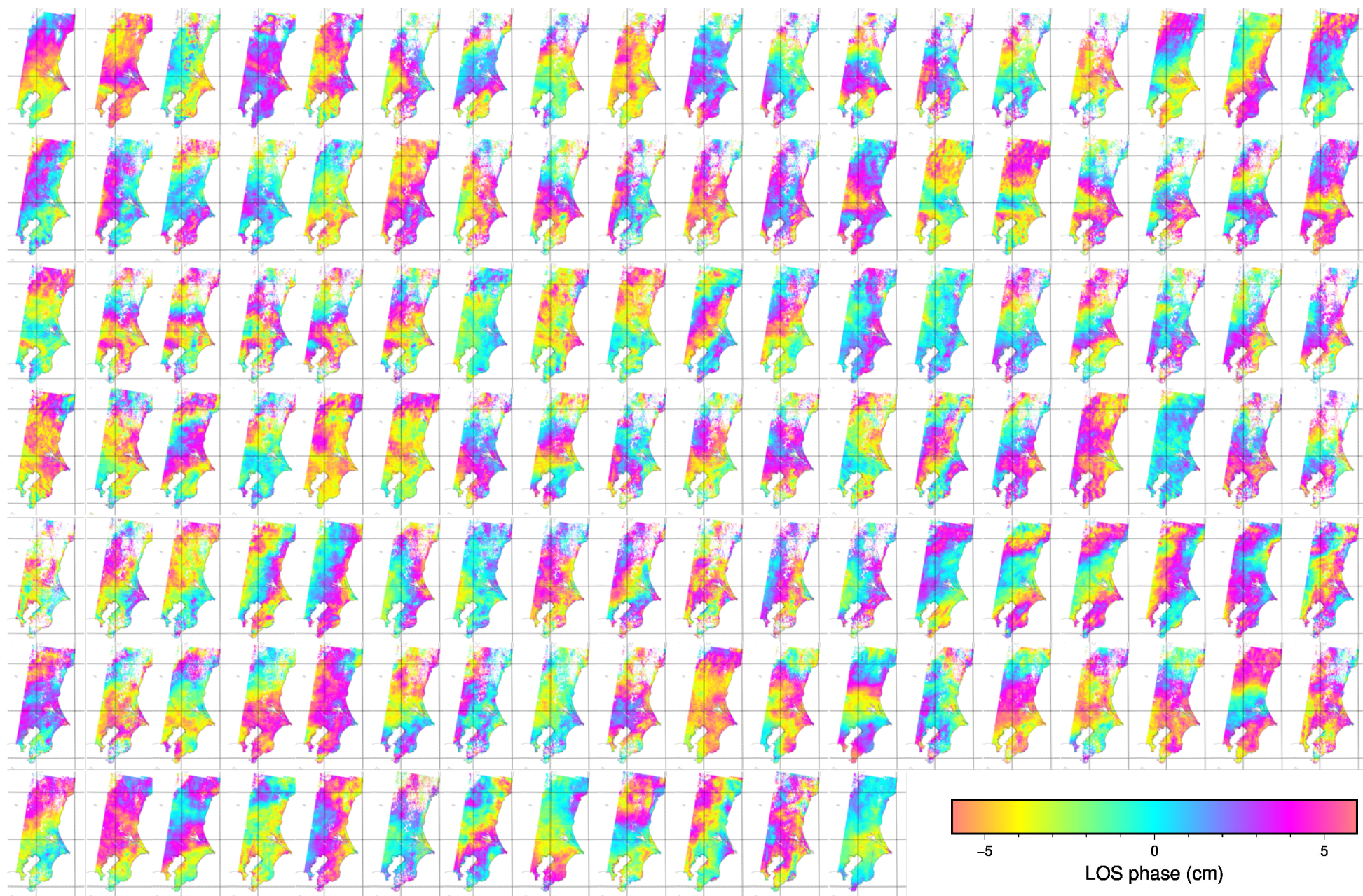
Result 3: comparison of delay model



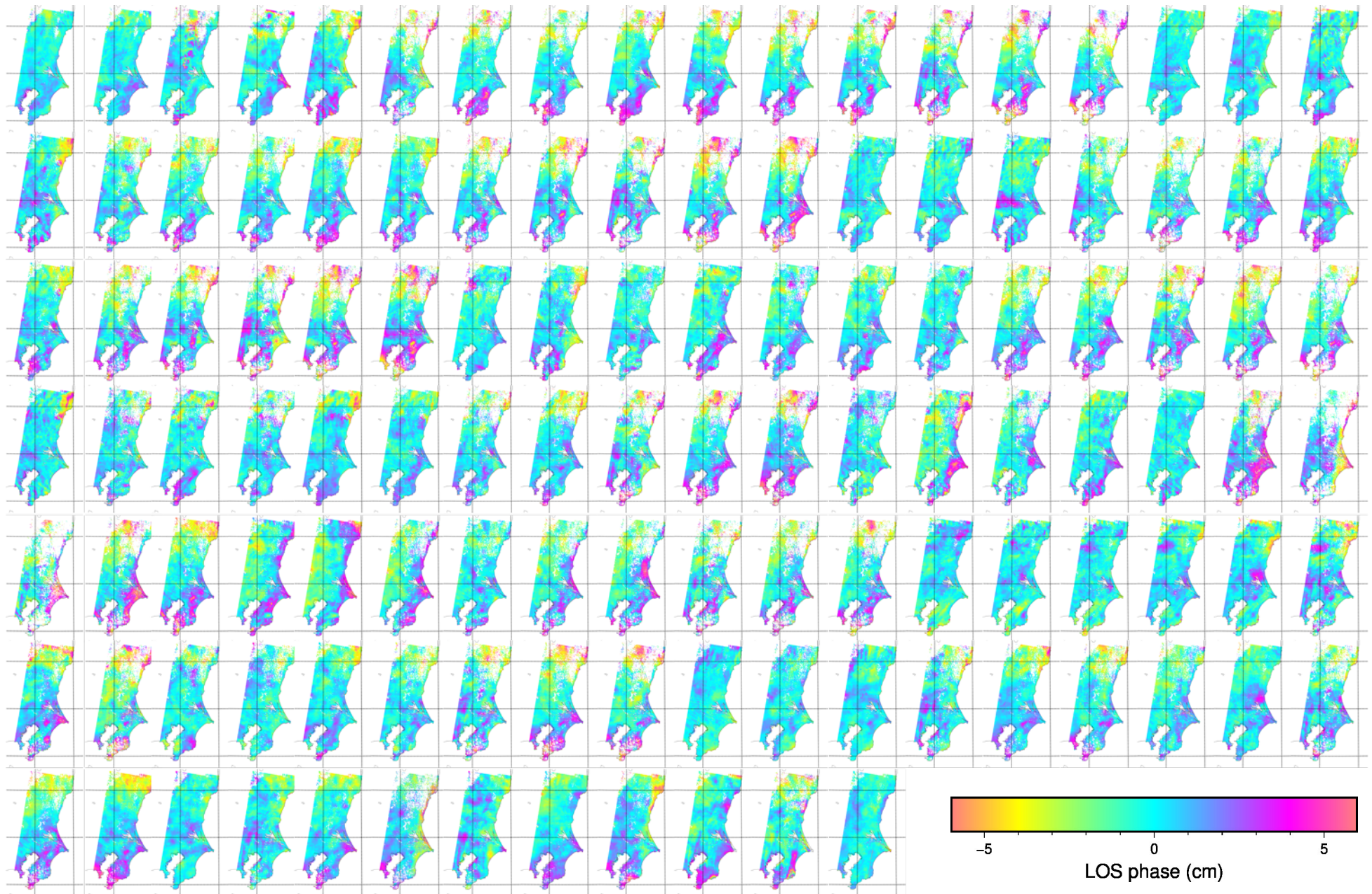
InSAR image (original)



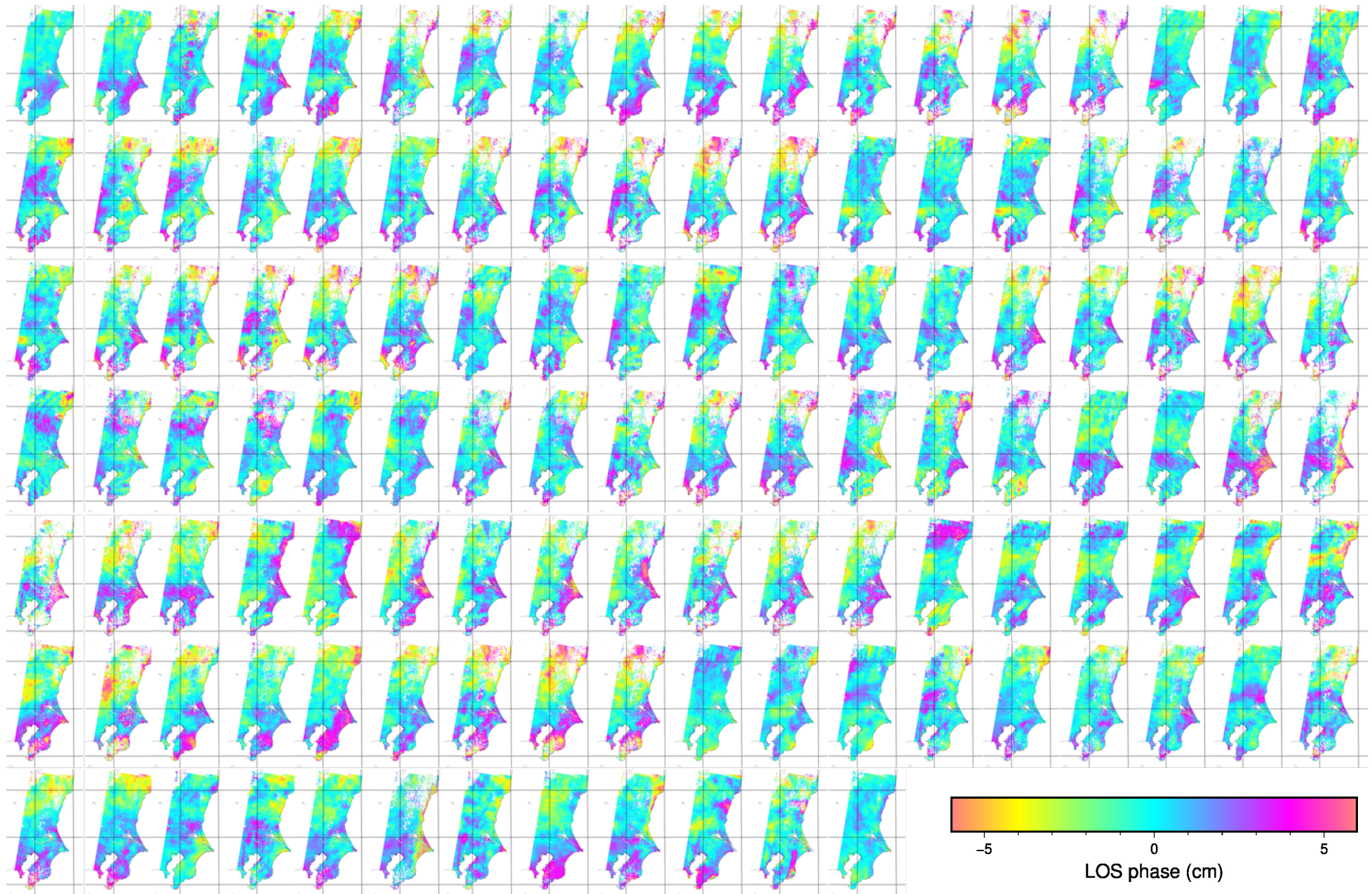
InSAR image (Apply SSM)



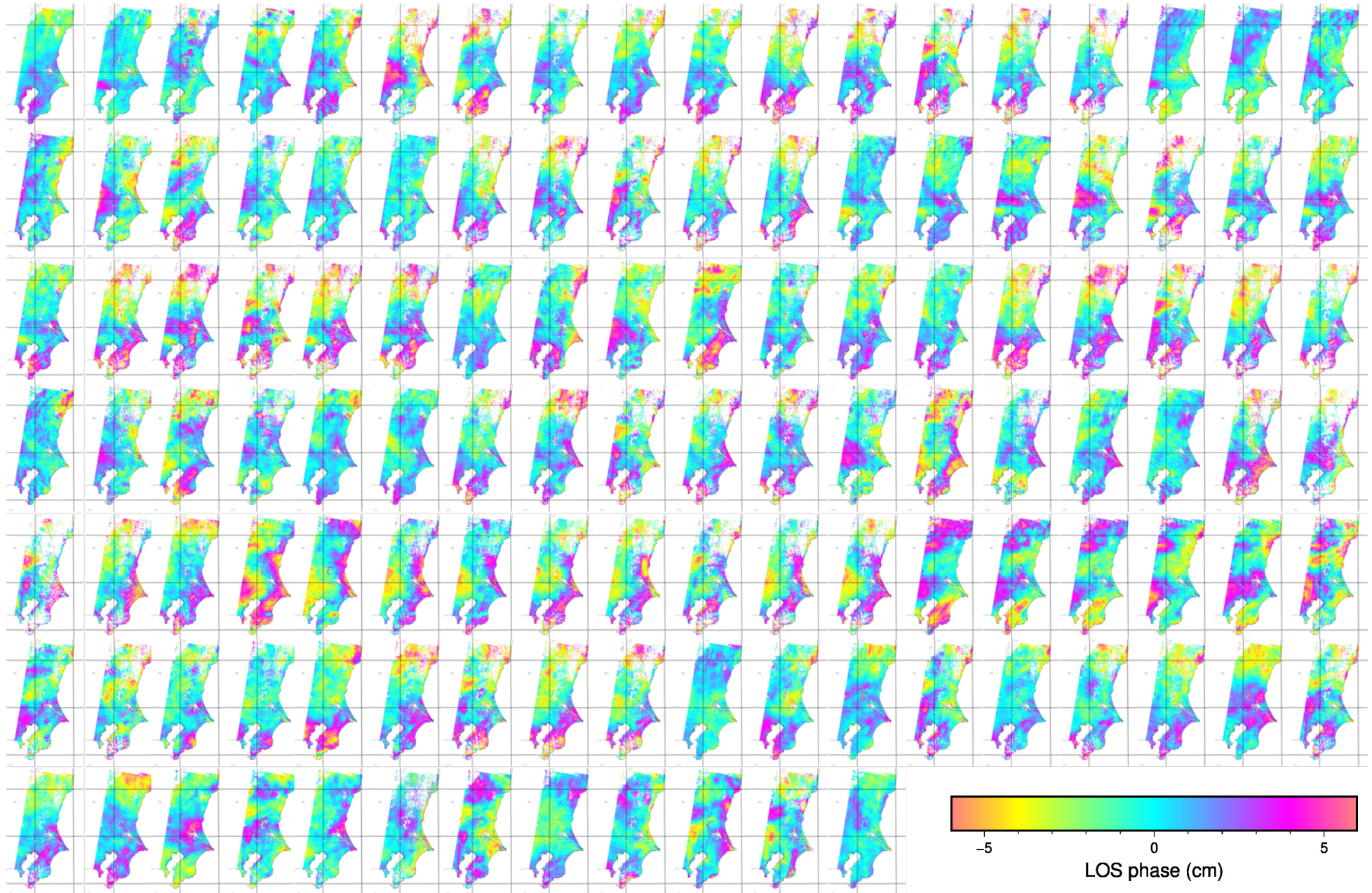
InSAR image (apply SSM & GNSS)



InSAR image (Apply SSM & MSM)



InSAR image (Apply SSM & GACOS)



Summary

- We developed a new InSAR delay correction model based on **GEONET ZTD & Gradient**.
- Applying SSM to ALOS-2 ScanSAR InSAR reduced the phase STD from 104mm to 36mm (66% ↓).
- Applying GNSS ZTD & Gradient correction reduced the phase STD from 36mm to 25mm (29% ↓). SSM+GNSS reduced the STD approximately 76% in total.
- Comparison between GNSS, GACOS, and JMA MSM showed that the proposed GNSS correction most effectively mitigated the atmospheric delay.

Acknowledgement

ALOS-2 SAR data was provided through 2nd Research Announcement on the Earth Observations (EO-RA2), and the Japan InSAR deformation research group PIXEL. GNSS atmospheric data was provided by the published database in the Nevada Geodetic laboratory at the University of Nevada, Reno. In InSAR processing, we used the RINC ver. 0.41r developed by Dr. Ozawa in NIED, and the 3-arcsecond SRTM DEM provided by USGS. JMA MSM data was provided through the data archive site in Research Institute for Sustainable Humanosphere, Kyoto University (<http://database.rish.kyoto-u.ac.jp/arch/jmadata/>). We also used the GACOS InSAR delay correction model through the web site (<http://www.gacos.net/>).