Automatic error-term separation approach in InSAR time-series analysis and application to Arima-Takatsuki fault zone, western Japan

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Abstract

InSAR time-series (InSAR-TS) analysis enables us to obtain the displacement time-series by using a number of SAR images repeatedly acquired on the area. Among the factors affecting the accuracy of the InSAR-TS analysis, this study focuses on three factors that may severely affect the signal detection limit: 1) the selection of the reference point (determining the offset in each interferogram), 2) ramp-type artifact that originate from inaccuracy in the orbit data or ionospheric disturbance, and 3) altitude-correlated tropospheric noise. Fukushima et al. (2019, Earth, Planets and Space) proposed an InSAR-TS analysis method to simultaneously solve for the displacement time-series and the error terms mentioned above as well as the error in the digital elevation model. In the proposed method, the unwrapped phase in interferograms is assumed to be composed of a linear combination of the LOS displacement, offset, planar ramp, altitude-correlated phase, and error in the used digital elevation model. A set of unwrapped small-baseline interferograms is then inverted to simultaneously obtain the displacement time-series and the parameters describing the error terms under the minimum norm condition on the displacement time-series. In this study, I applied the above-mentioned method after some updates such as introduction of the temporal constraint adopted by the NSBAS algorithm (Doin et al., 2011) and data masking, on the ALOS-2 data acquired around the Arima-Takatsuki fault zone in western Honshu, Japan. Data of four different Paths (20 and 21 from descending orbit, 127 and 128 from ascending orbit) obtained between August 2014 and March 2021 were analyzed. Some of the original interferograms contained severe noise such as a phase ramp equivalent to approximately 25 cm of LOS displacements. The average velocity field obtained by applying the method captured a relative range decrease of a few mm/year on the southern side of the fault, consistent with the results obtained from Sentinel-1 data analysis. Given the fact that the Sentinel-1 dataset had much favorable conditions (much larger number of data and much smaller ionospheric noise), the consistency in the average velocity field suggests the effectiveness of the proposed approach.

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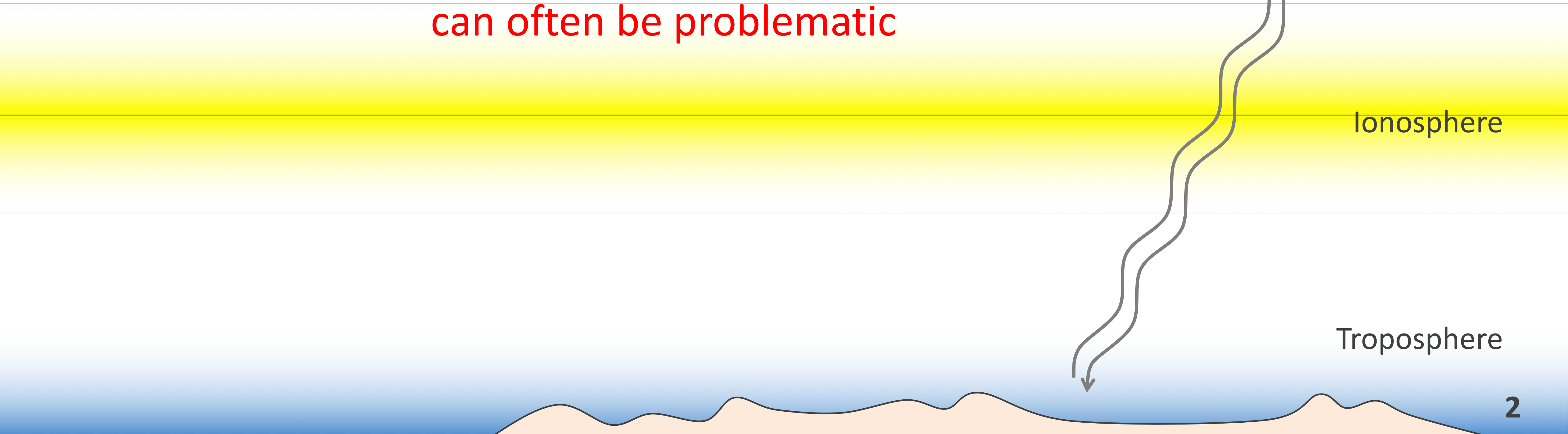
“Noise” terms in InSAR

Observed phase of an interferogram:

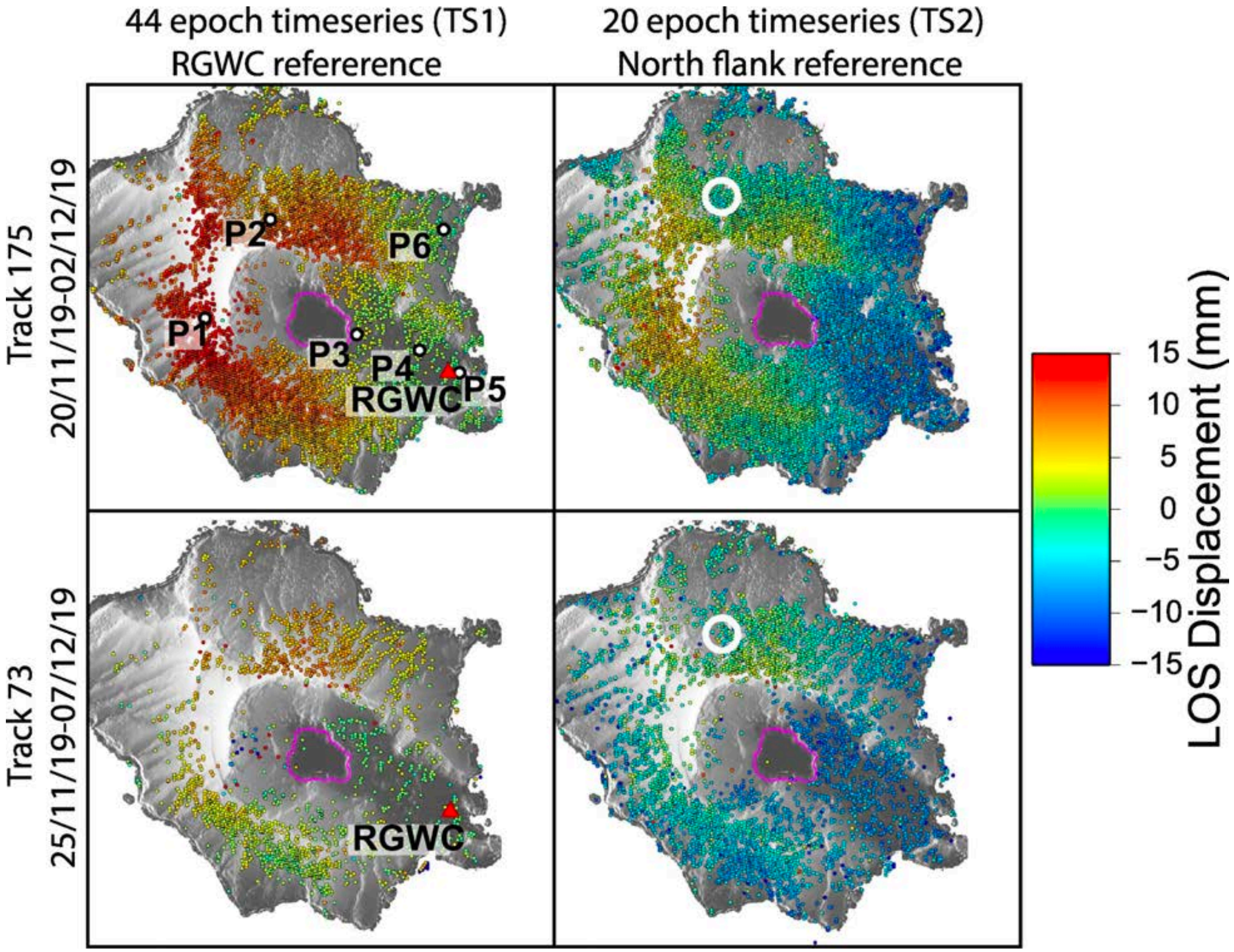
$$\phi_{observation} = \phi_{deformation} + \phi_{offset} + \phi_{orbit} + \phi_{ionosphere} + \phi_{troposphere} + \phi_{DEMerror} + \phi_{noise}$$

can often be problematic



Problem of reference location selection in InSAR time-series analysis

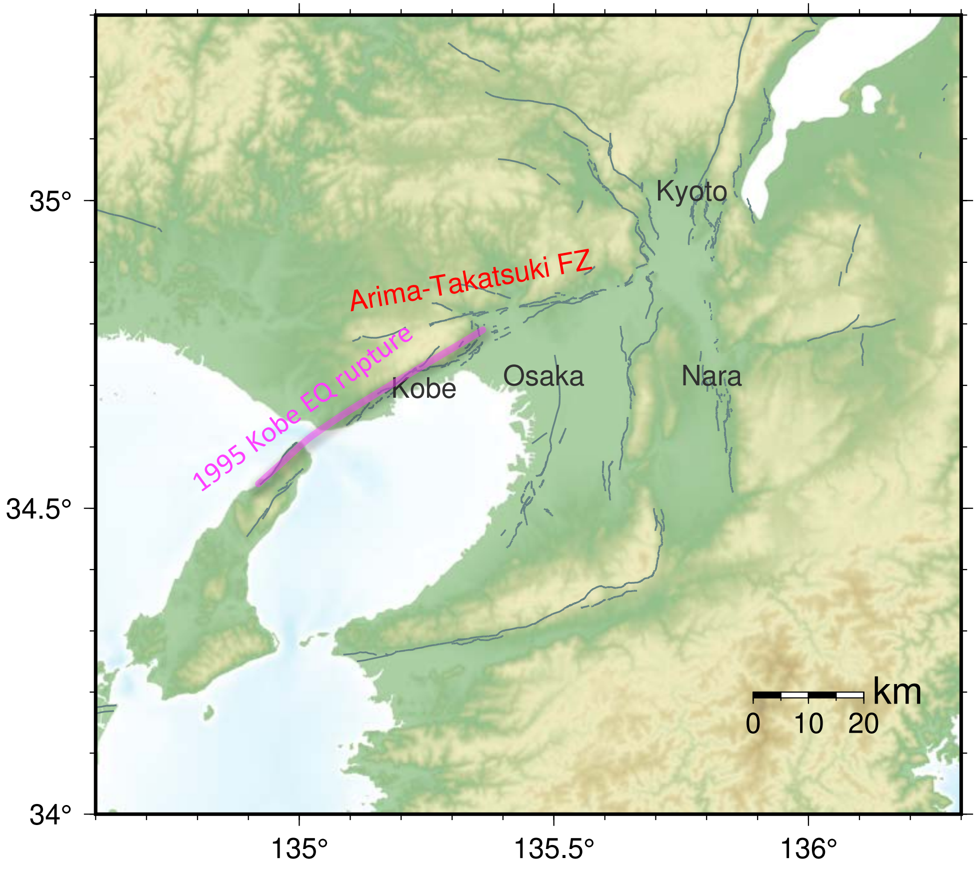
Problematic if the reference point was actually moving and/or the location was affected by atmospheric noise.



Hamling and Kilgour (2021)

Purpose

- By adopting **De-Noising while solving for Time-Series (DeNTiS)** approach, this study derives InSAR displacement time-series while automatically minimizing other noise components
- Apply the DeNTiS algorithm on Osaka plain area, in which Arima-Takatsuki Fault Zone (ATFZ) is located.
- About ATFZ:
  - Located north of the 1995 Kobe earthquake (M7.2) rupture fault
  - Right-lateral
  - Ruptured in 1596 (M~7.5, slip ~ 3m)



DeNTiS Algorithm

Essence: Small-baseline analysis, solve for velocity time-series and noise components (coefficients of linear functions) with regularization.
(Based on Fukushima et al., 2019, EPS, doi: 10.1186/s40623-019-1096-5)

For the *i*-th interferogram, *m*-th time step, and *k*-th pixel:

Observation Equations

$$d_{i,k} = d_{i,k}^{deform} + d_{i,k}^{error}$$

$$d_{i,k}^{deform} = \mathbf{g}_i \mathbf{v}_k$$

$$d_{i,k}^{error} = \underline{a_i + b_i x_k + c_i y_k + \ldots} + f_i h_k$$

Topography↓

↑Can be any order of polynomials

+

Regularization Equations

$$\Sigma_m (v_{m,k} \Delta t_{m,k}) = \bar{v}_k \Sigma_m (\Delta t_{m,k})$$

↑Const. velocity (NSBAS, LiCSBAS)

$$\Sigma_m v_{m,k} = 0$$

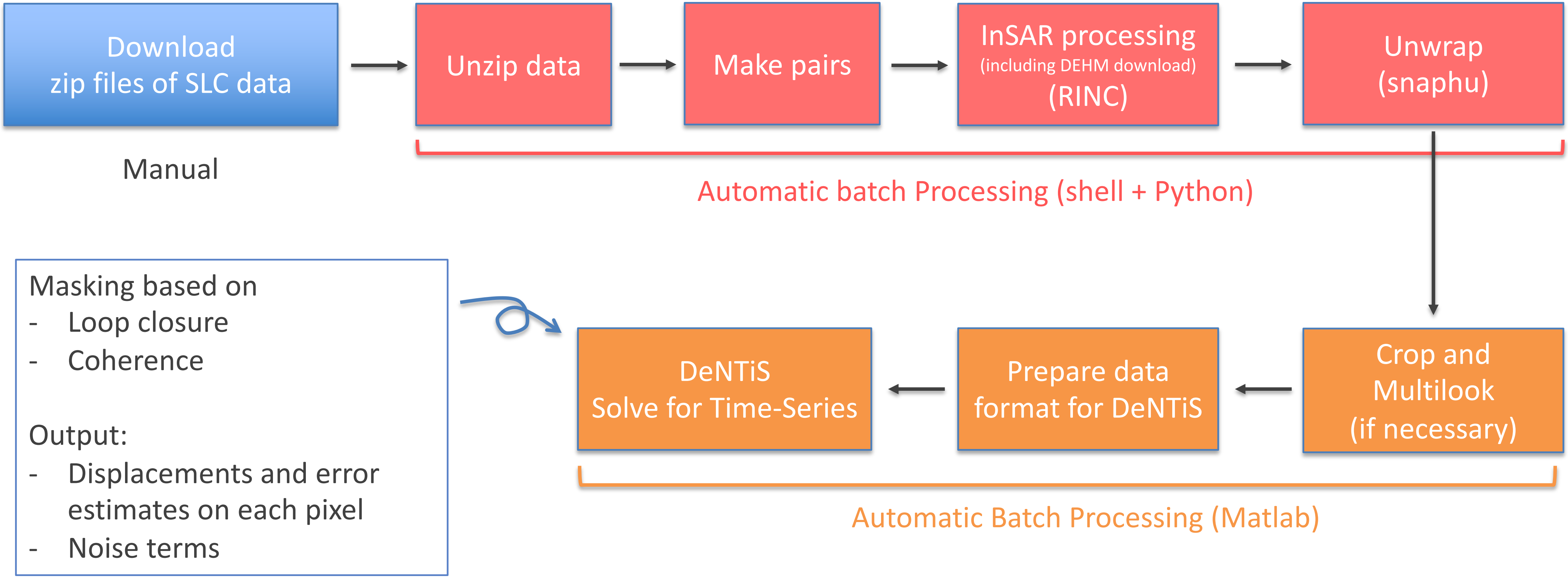
↑Min. cumulative velocity (only 1st step)

※ **Weights of these regularization are made small enough**

1st step: Estimate the noise terms from subsampled points

2nd step: px-by-px inversion on denoised ifgs.

Analysis Flow



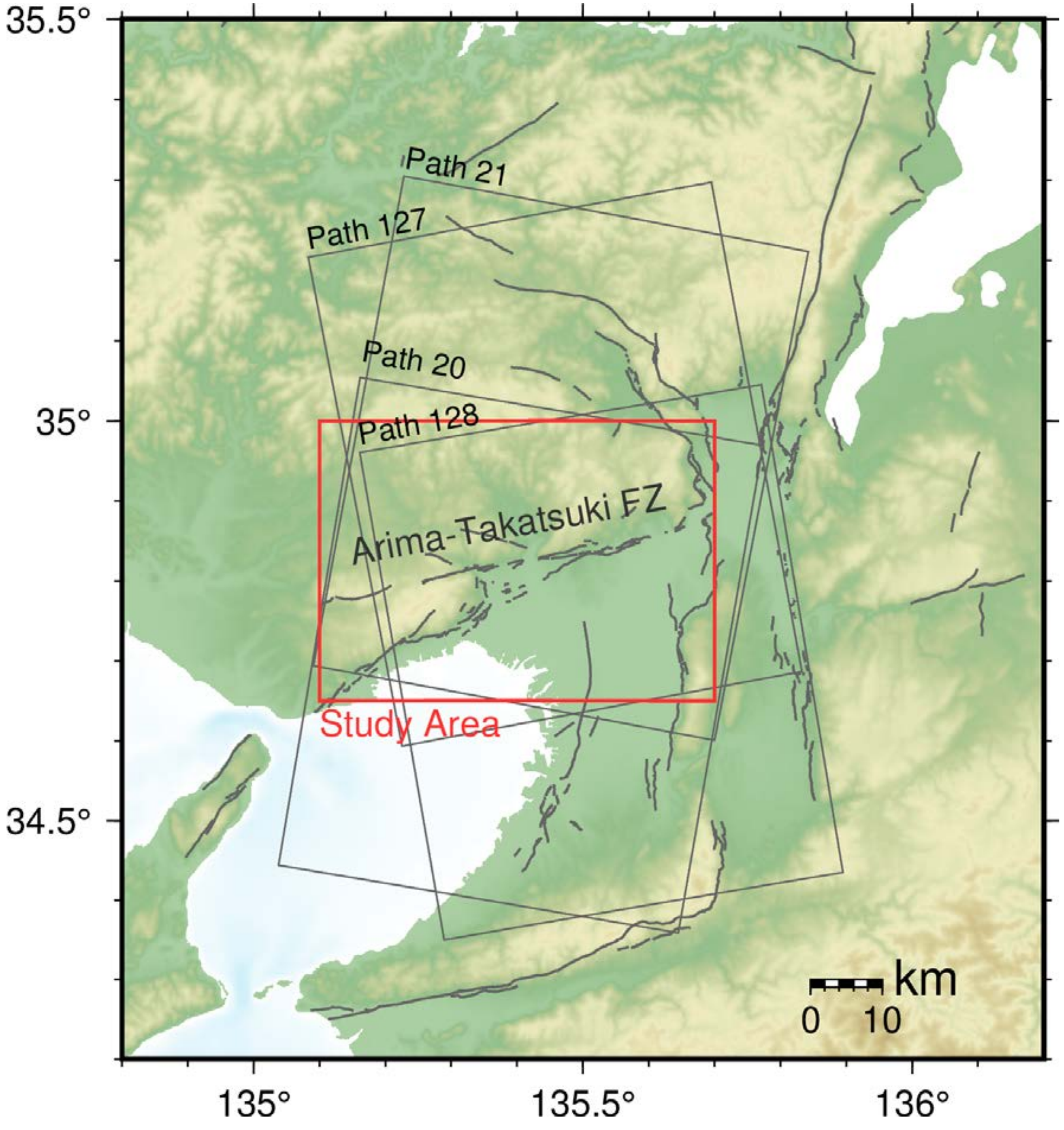
Data

ALOS-2, Ultra-Fine-Beam Mode (SM1)

Acquired betw. Aug 2014 – Mar 2021

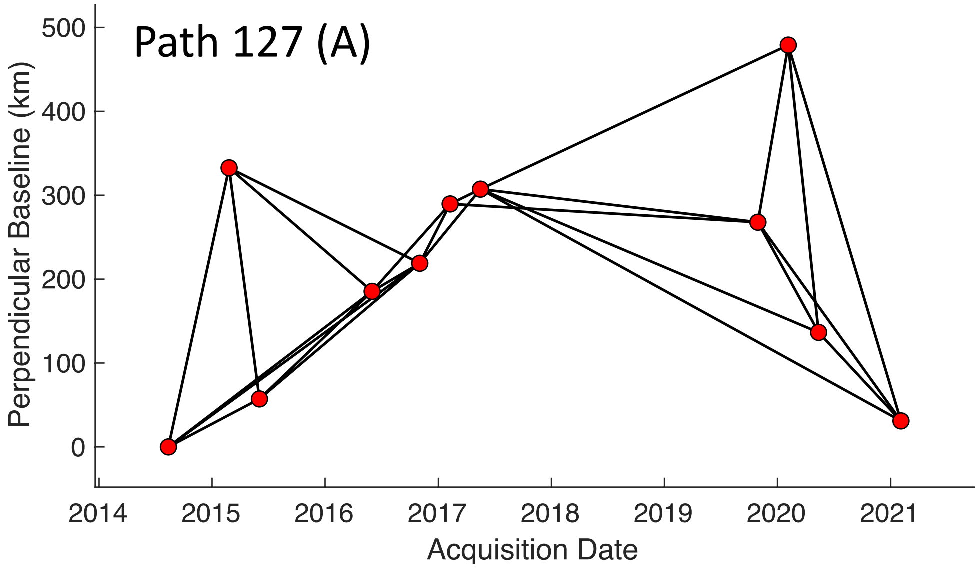
Data sets of four paths:

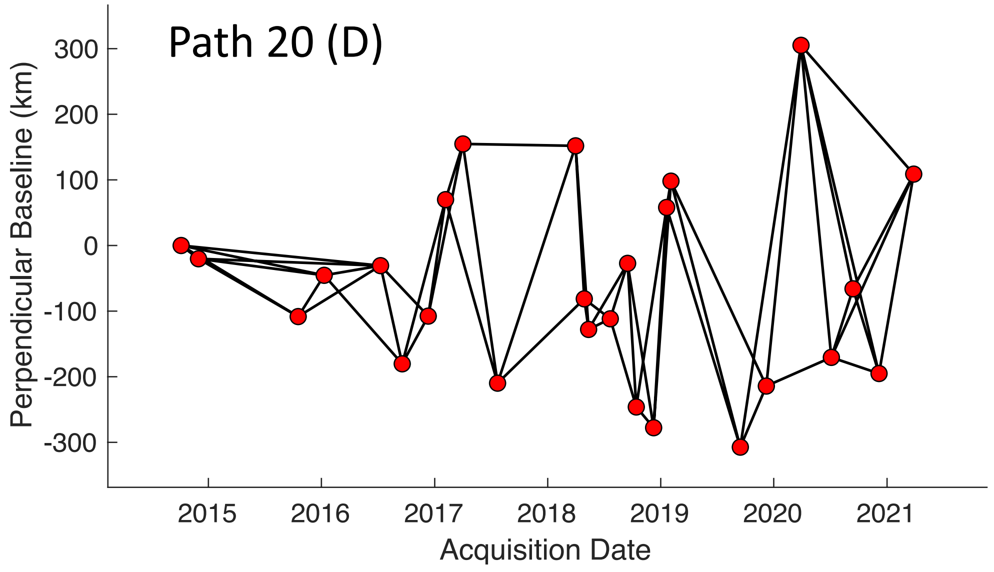
Path	Orbit	Incidence Angle (deg)	Number of Images	Number of Interferograms
20	D	42.9	26	55
21	D	32.4	24	51
127	A	32.4	11	25
128	A	42.9	16	35

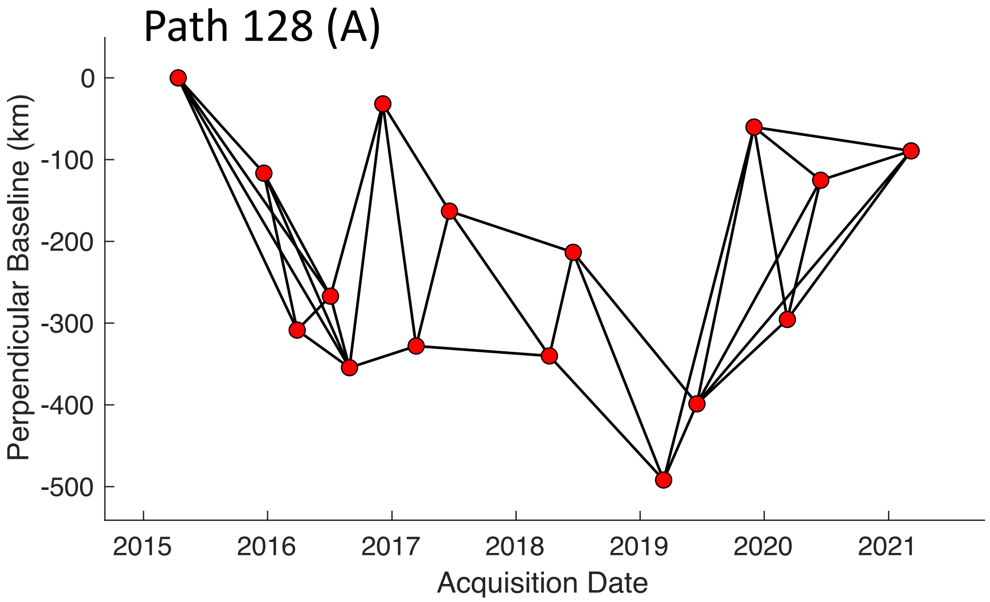


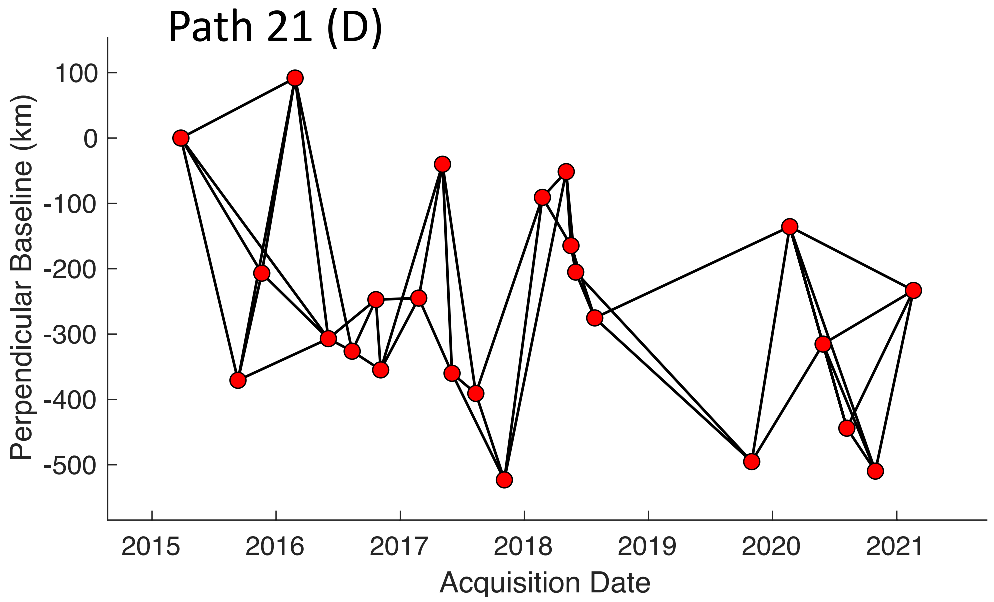
Baselines

3 or 4 ifgs per acquisition



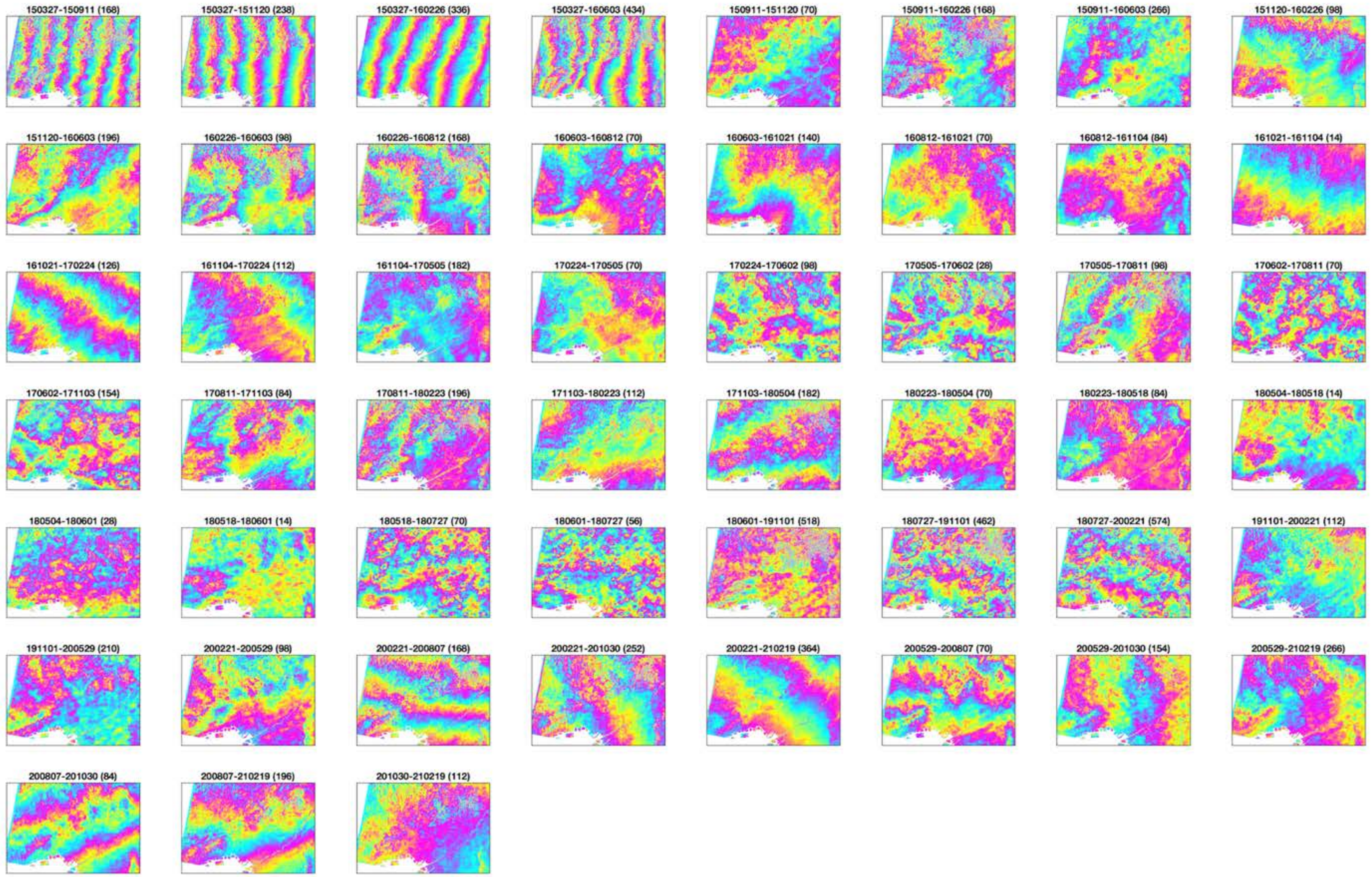






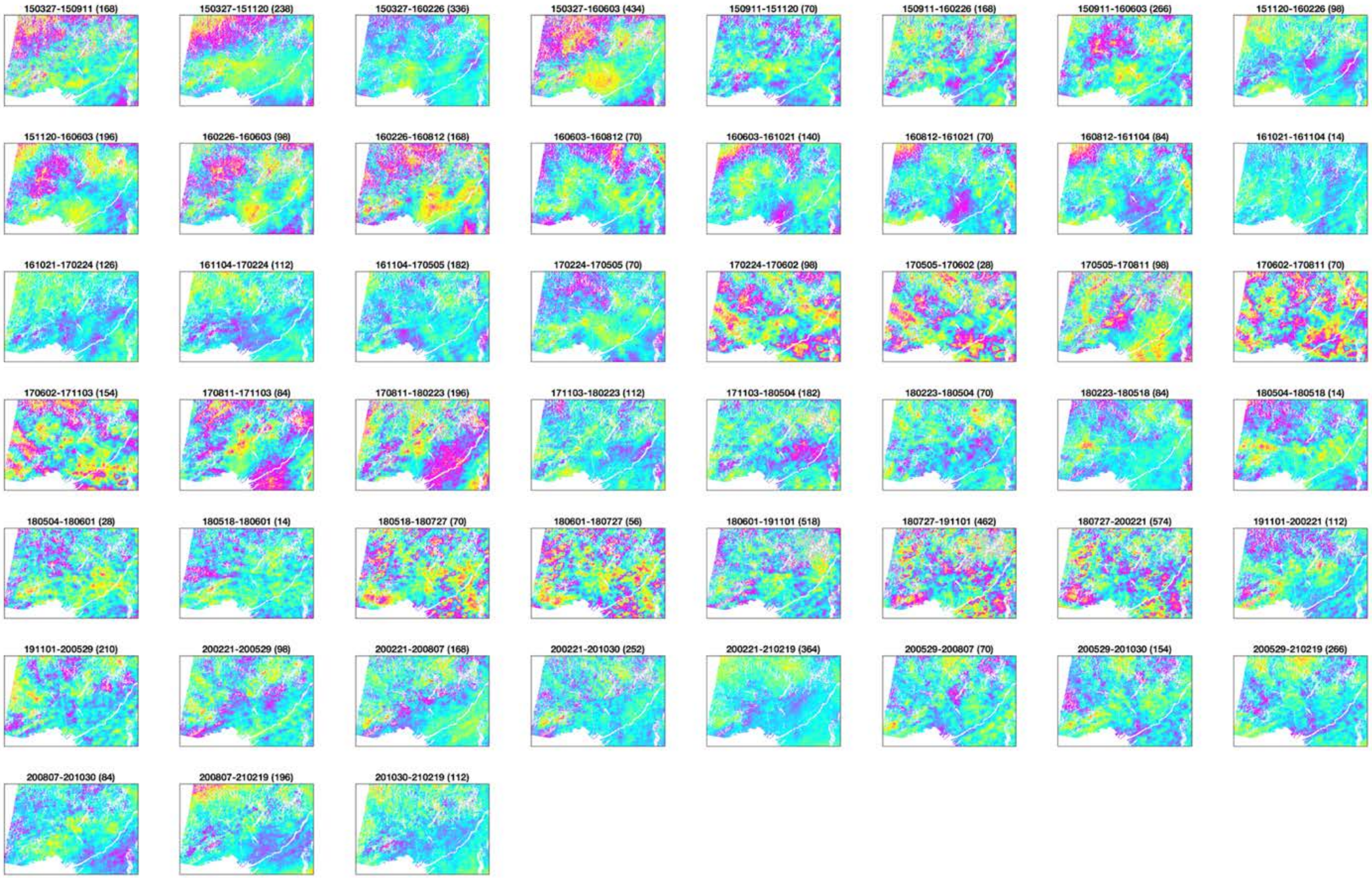
Original interferograms

Path 21 (descending)
Rewrapped to [0, 5cm]



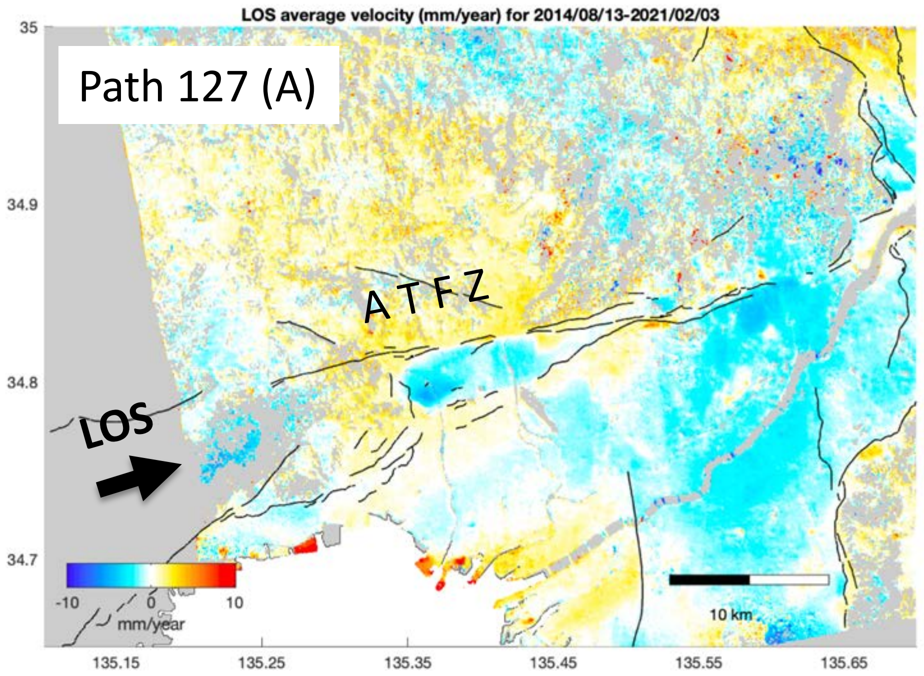
Denoised interferograms

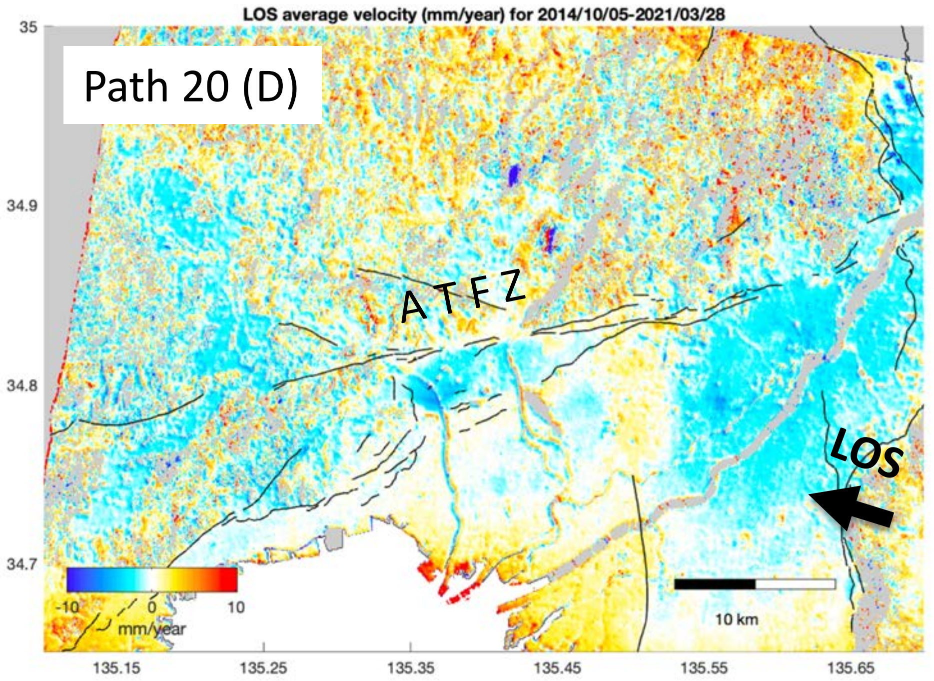
Path 21 (descending)
Rewrapped to [0, 5cm]

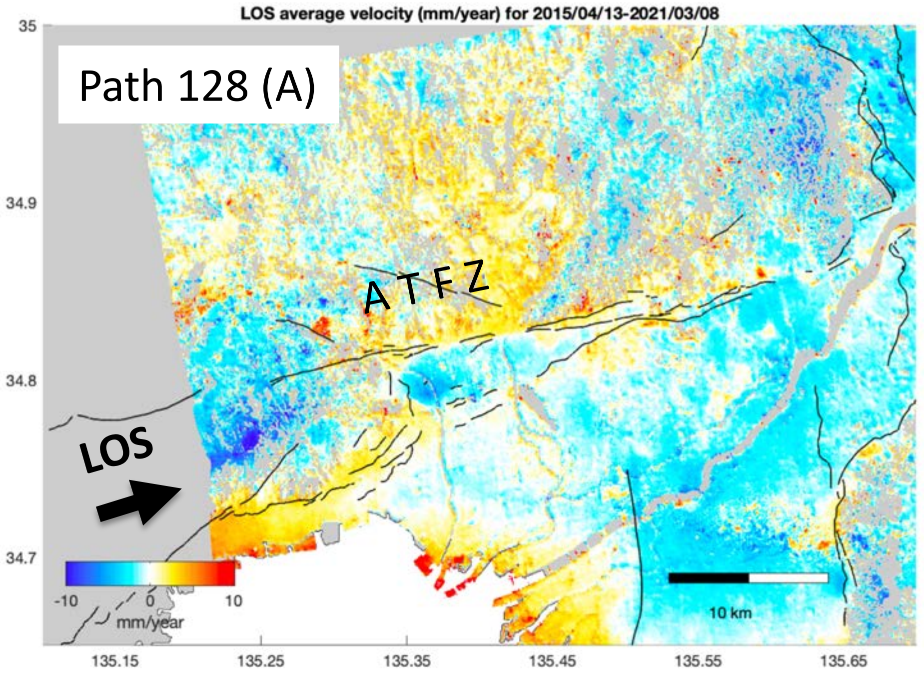


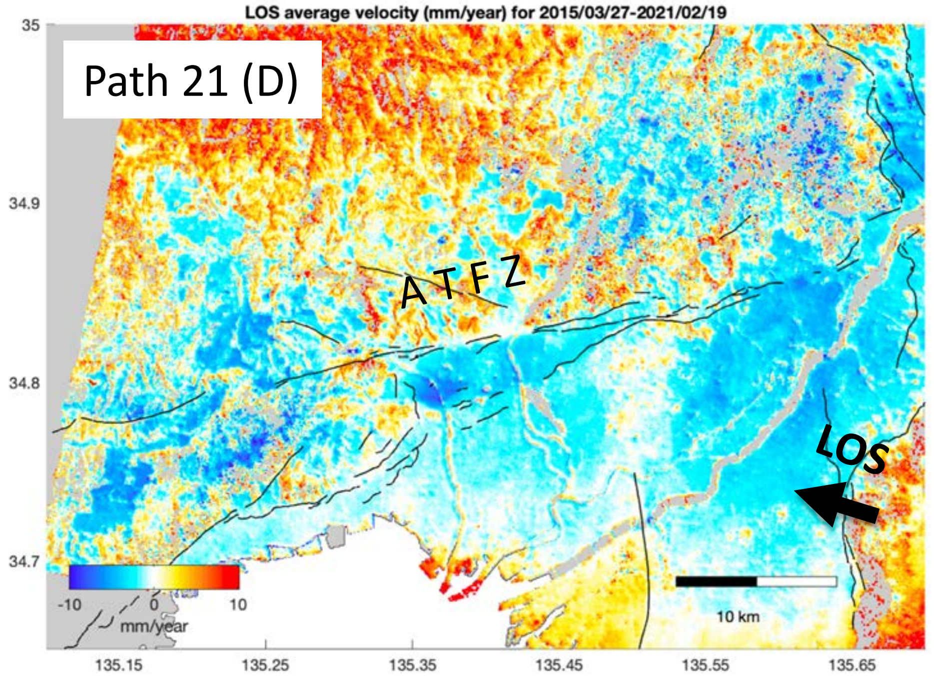
Mean Velocity

Red: away from satellite
Blue: toward satellite

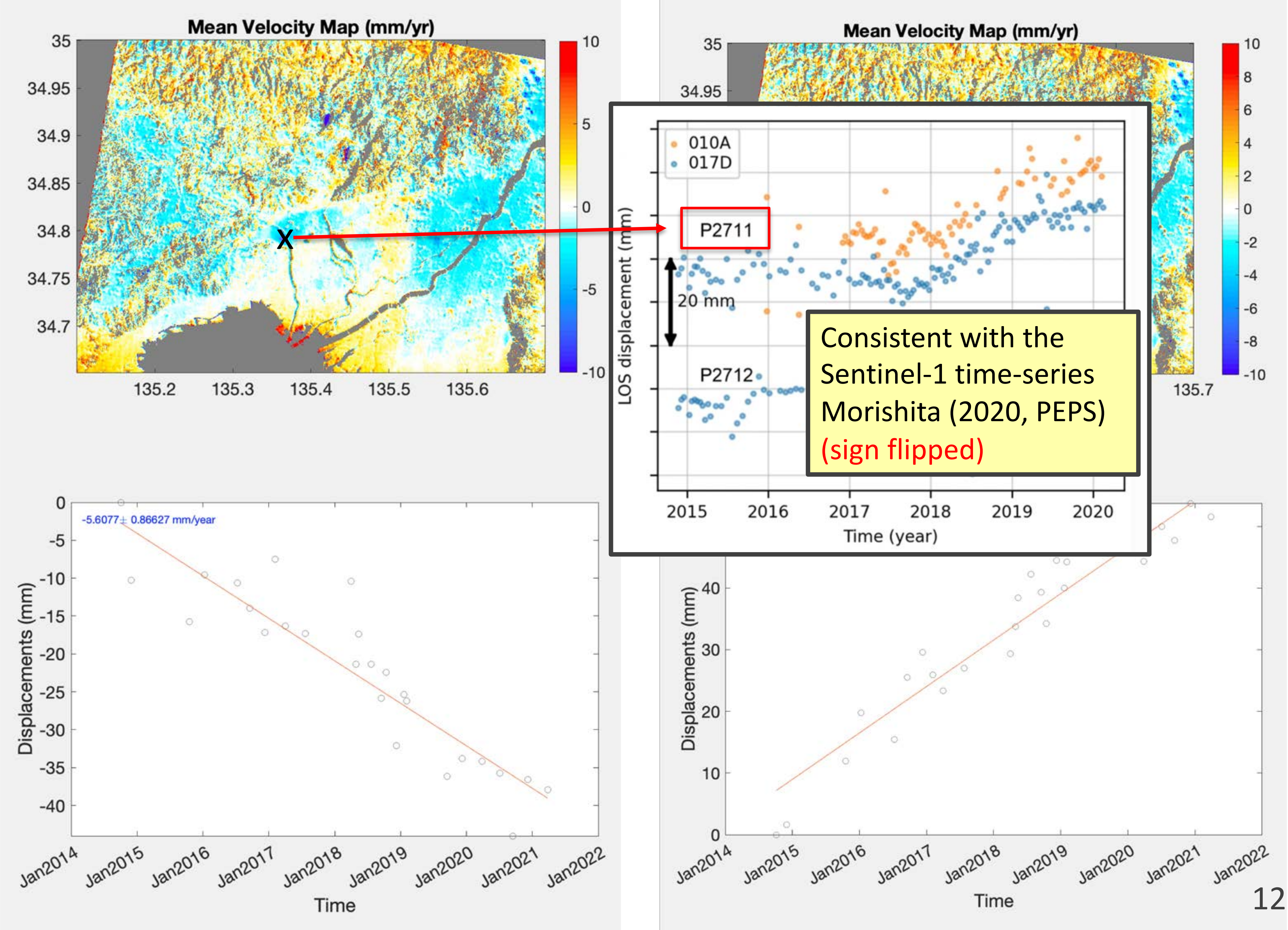




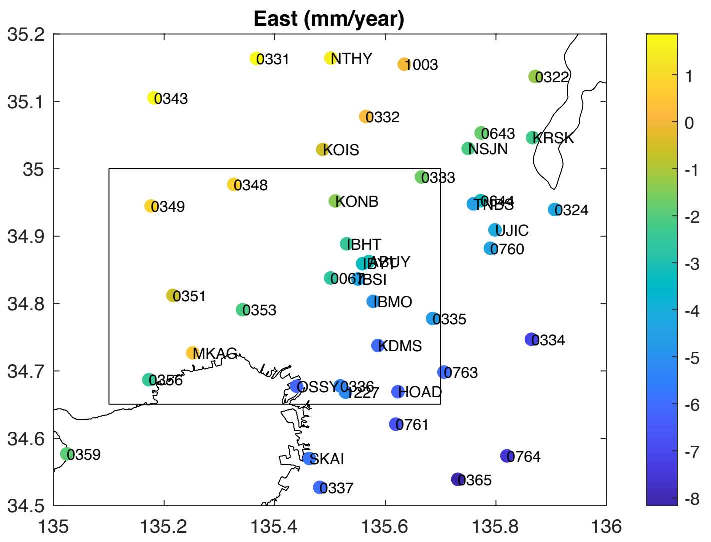


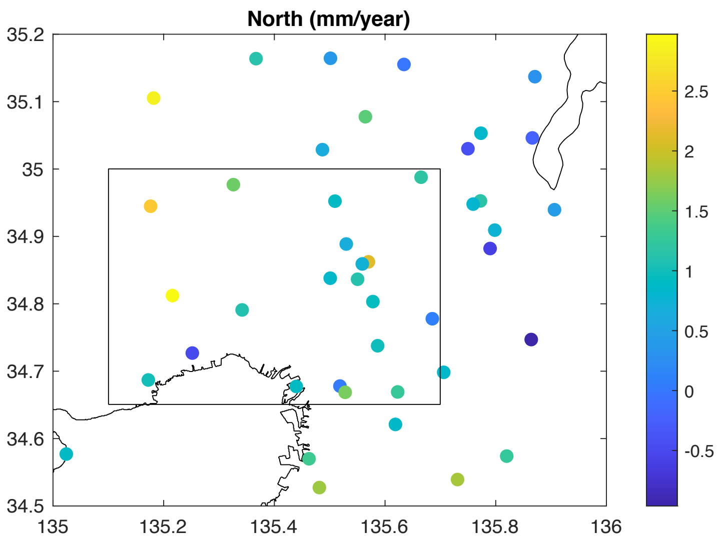


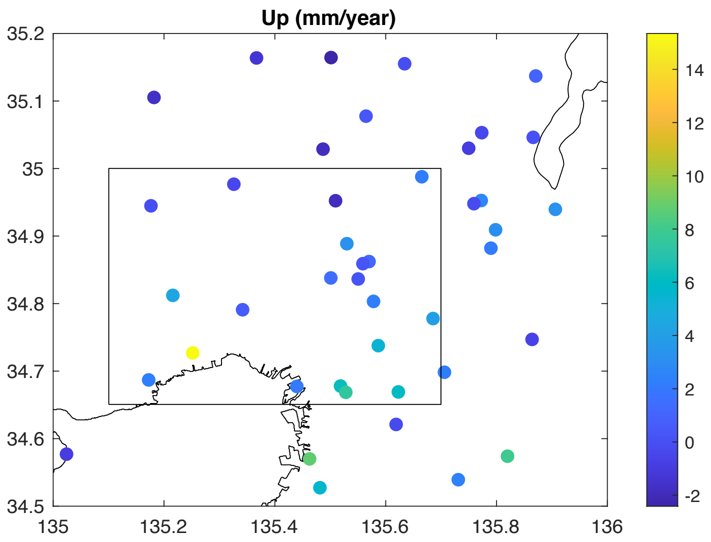
Examples of time-series (Path 20)



Comparison with GNSS time-series



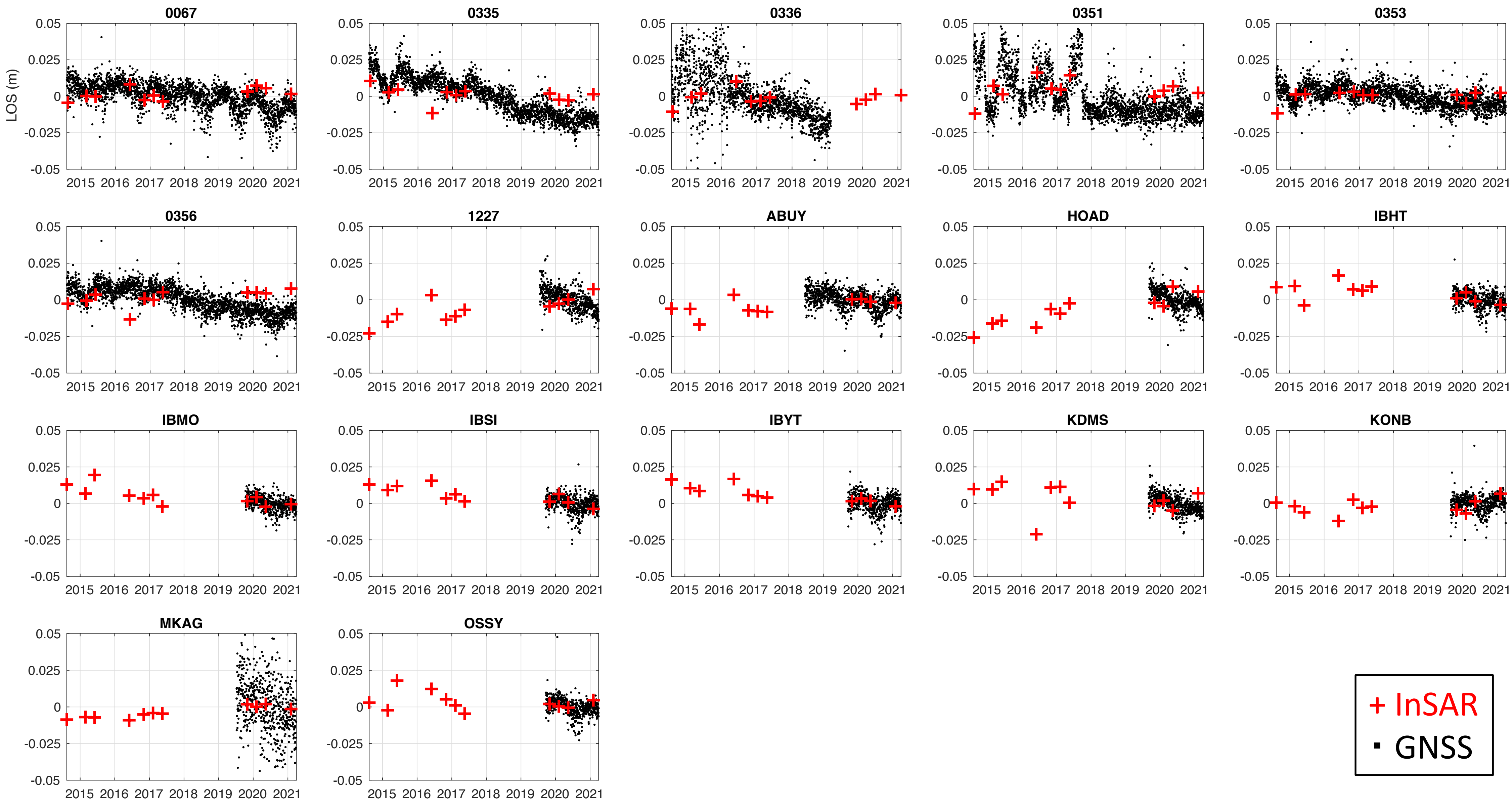




Data courtesy of GSI, T. Nishimura, and K. Miyahara

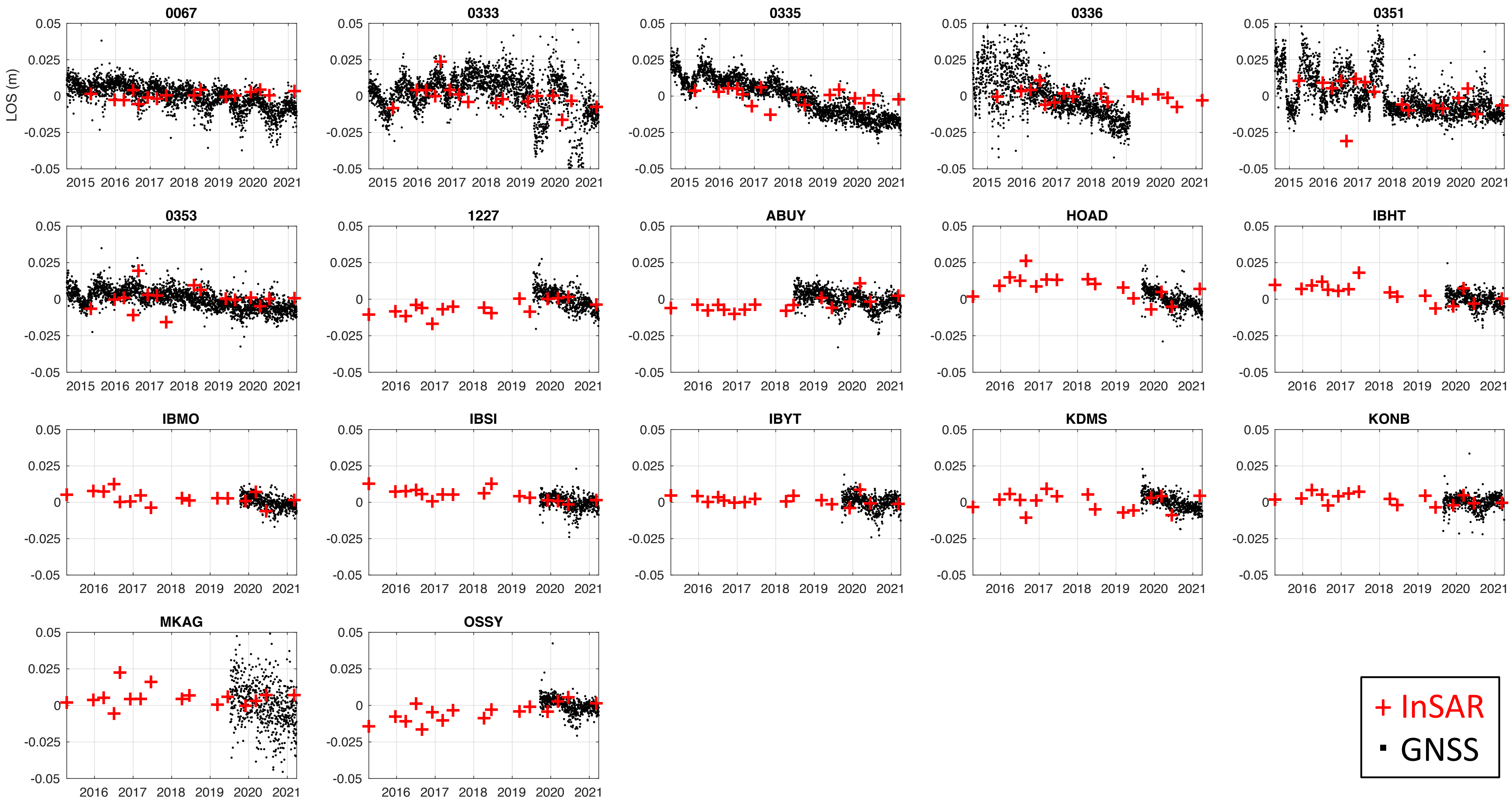
Comparison with GNSS time-series (Path 127)

RMS = 10.8 mm



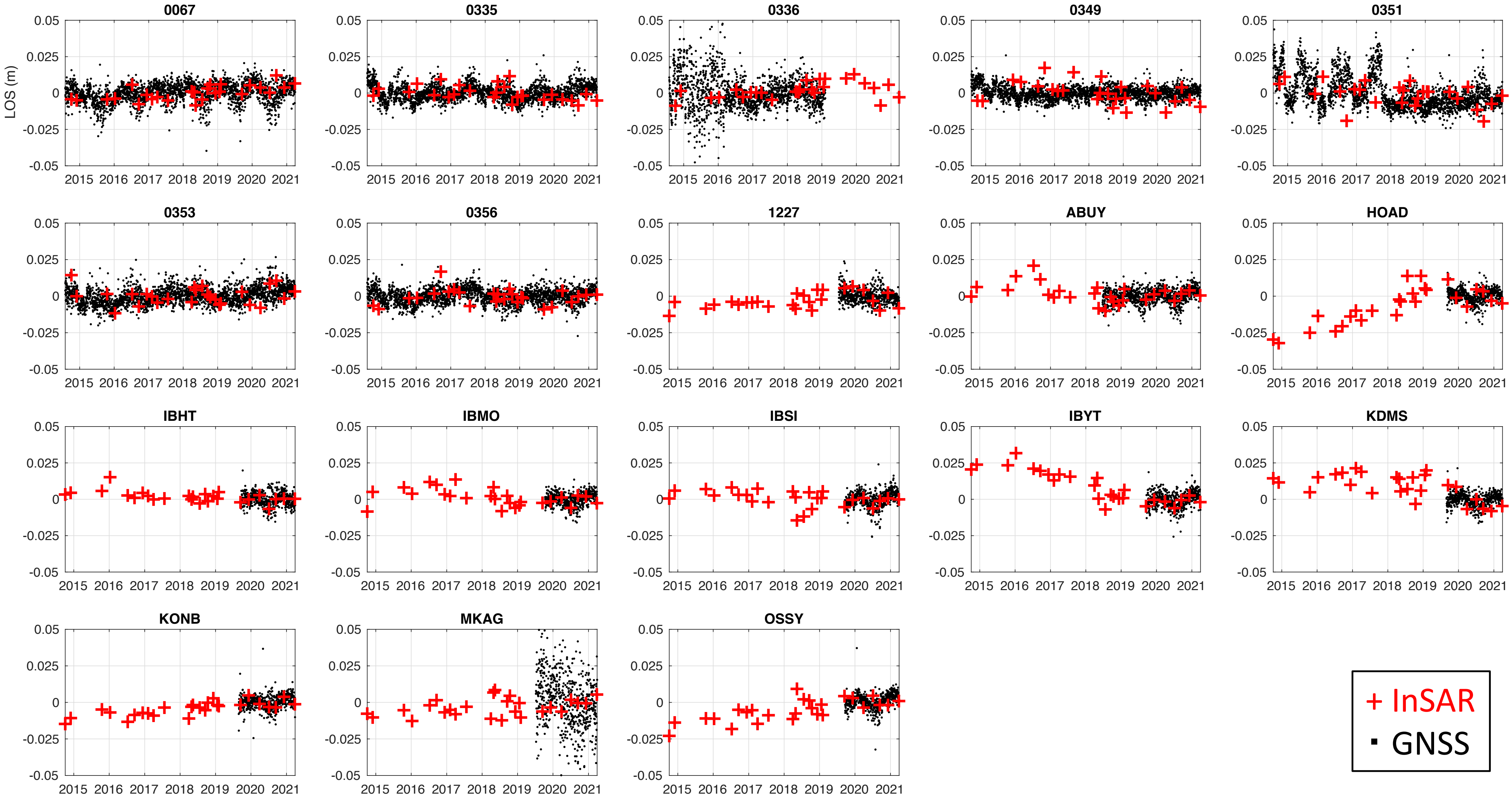
Comparison with GNSS time-series (Path 128)

RMS = 10.3 mm



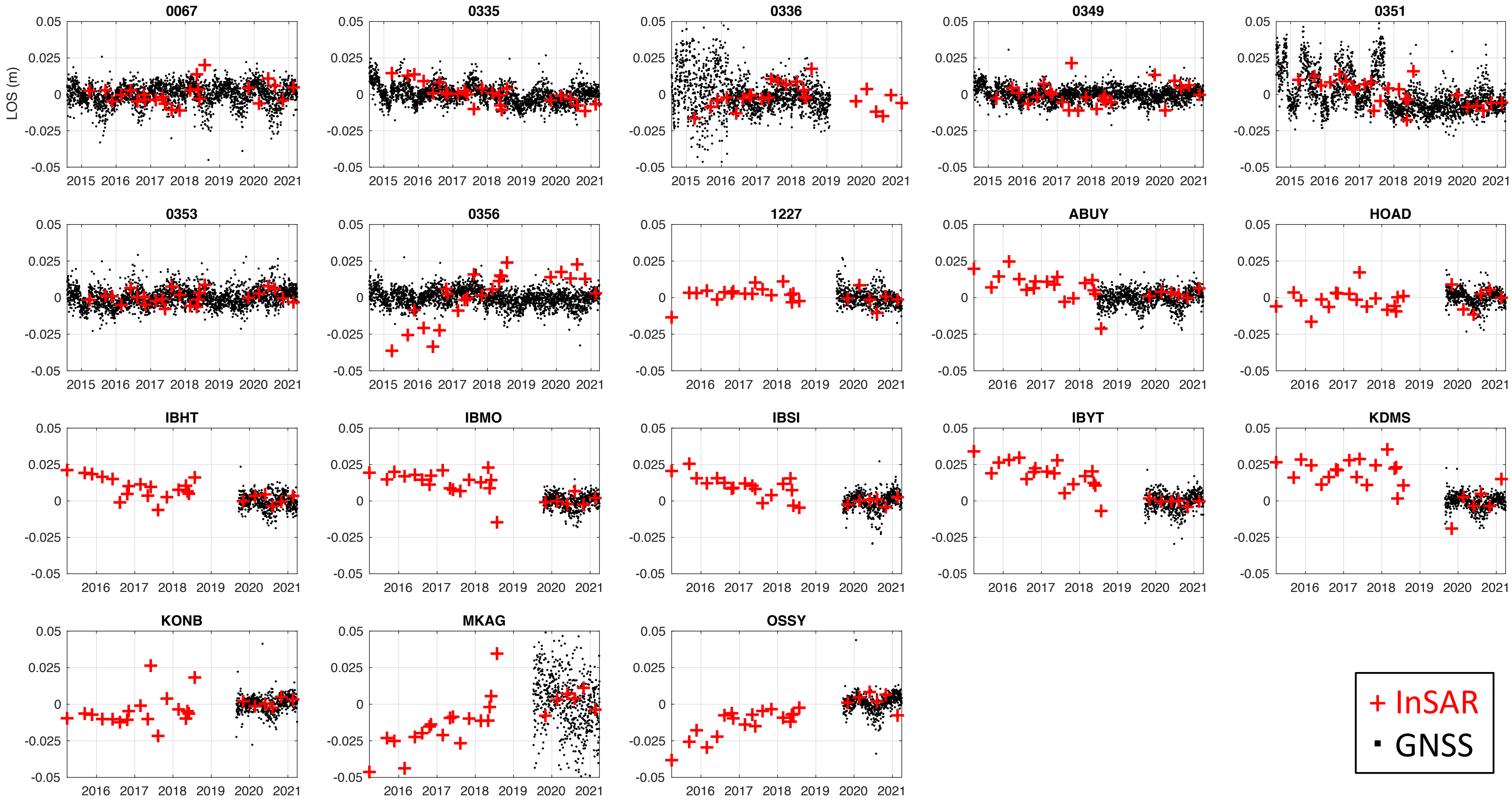
Comparison with GNSS time-series (Path 20)

RMS = 7.5 mm



Comparison with GNSS time-series (Path 21)

RMS = 10.0 mm



Summary

- De-Noising while solving for Time-Series (DeNTiS) algorithm is developed (formulation written in Fukushima et al. (2019, Earth Planets and Space).
- By applying DeNTiS on ALOS-2 data, the displacement time-series and the mean velocity map around the Arima-Takatsuki Fault Zone were obtained.
- Results consistent with those using Sentinel-1 data (much denser temporal sampling) were obtained, showing the effectiveness of the approach.

Please contact fukushima@irides.tohoku.ac.jp if you want to try the codes.

Acknowledgements

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