SUPERVISED LEARNING FOR TRACKING INLAND GLACIER FLOWS USING TOPS DATA

Andrea Pulella [1,*], Claire Renaud [1], Pau Prats-Iraola [1], Francescopaolo Sica [2]

[1] German Aerospace Center (DLR), Microwaves and Radar Institute, 82234 Weßling, Germany – Andrea.Pulella@dlr.de

[2] Institute of Space Technology and Space Applications, University of the Bundeswehr Munich, 85579 Neubiberg, Germany

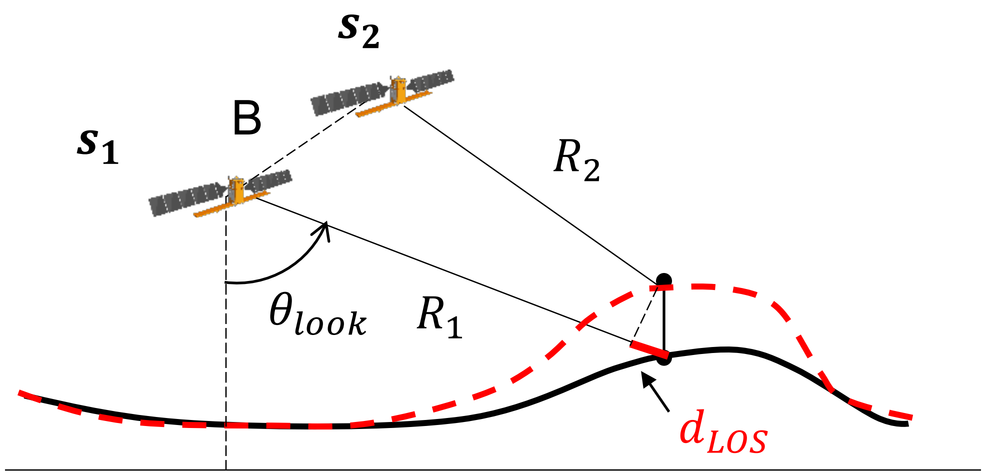
FRINGE 2023

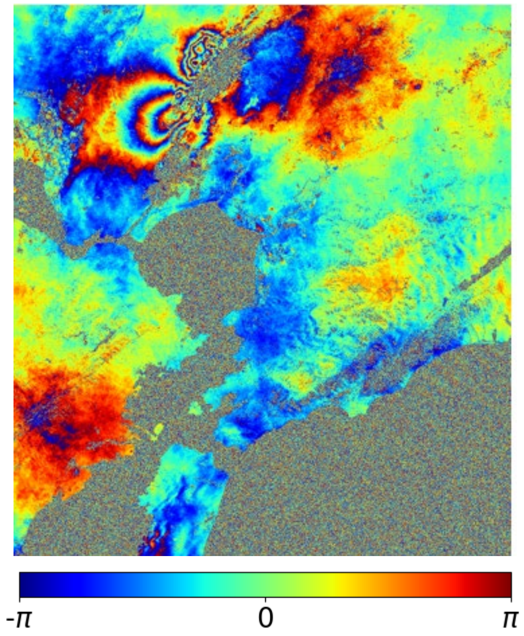
DLR

Overview

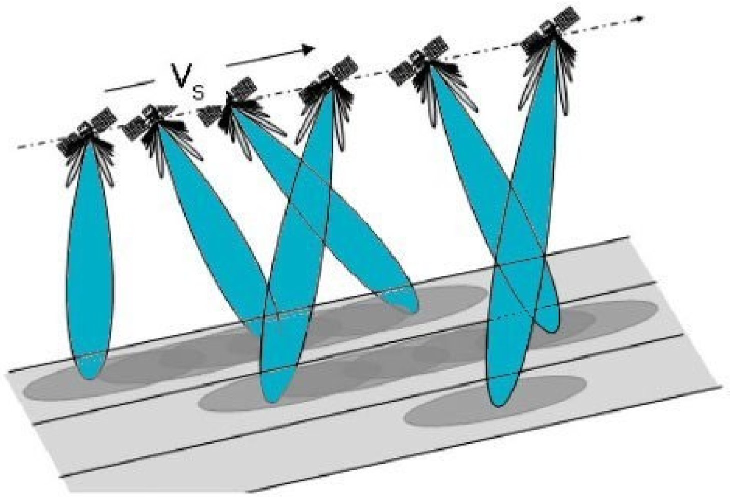
- Introduction & motivation
- Proposed methodology
- Experimental results
- Conclusions & outlooks

Introduction & motivation





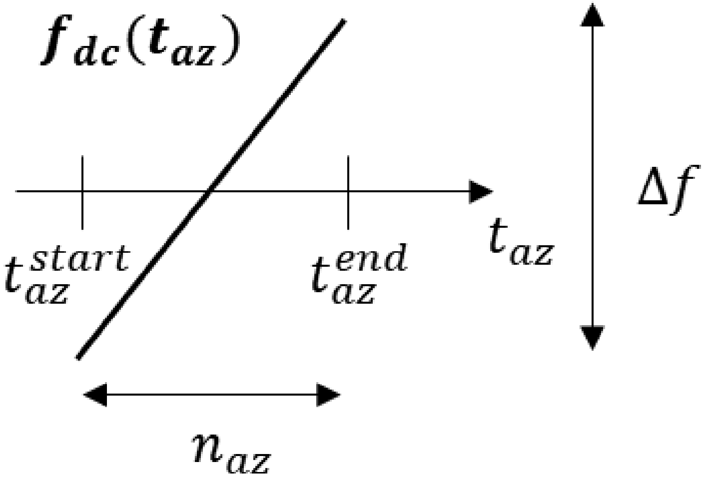
Sentinel-1 Stripmap
Napa Valley
earthquake
August 2014



TOPS (Terrain Observation by Progressive ScanSAR):

- Advanced ScanSAR technique in most modern SAR systems (e.g. Sentinel-1)
- Increased coverage and lower azimuth resolution
- Switch between subswaths and electronic antenna beam steering along azimuth.

Introduction & motivation



Δf Doppler centroid frequency shift [Hz]

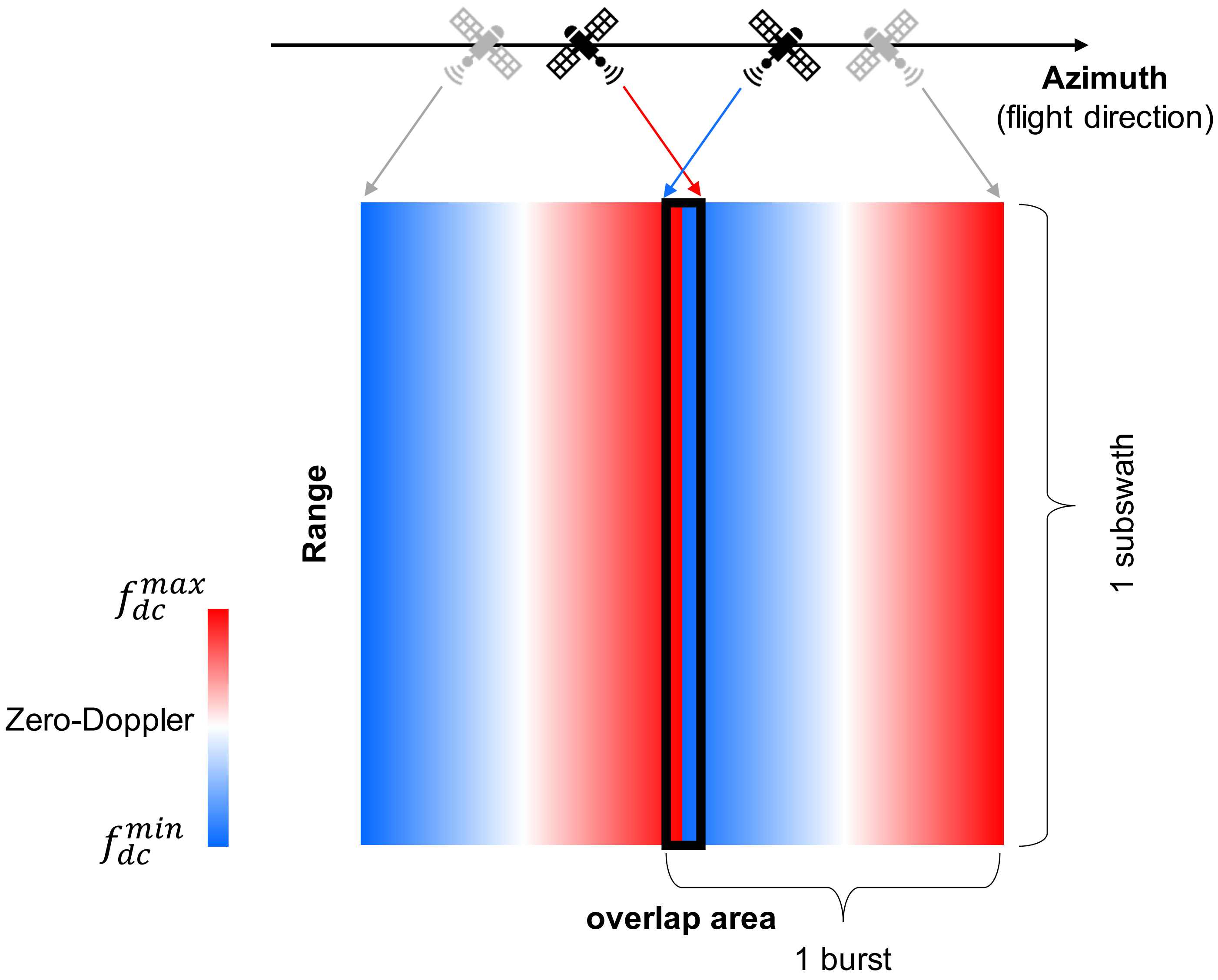
$$\Delta f = K_t \cdot n_{az} \cdot \Delta_t > \Delta f_{ovl}$$

f_{dc} Doppler centroid frequency at mid-burst (mid-azimuth, range variant) [Hz]

n_{az} Burst size along azimuth

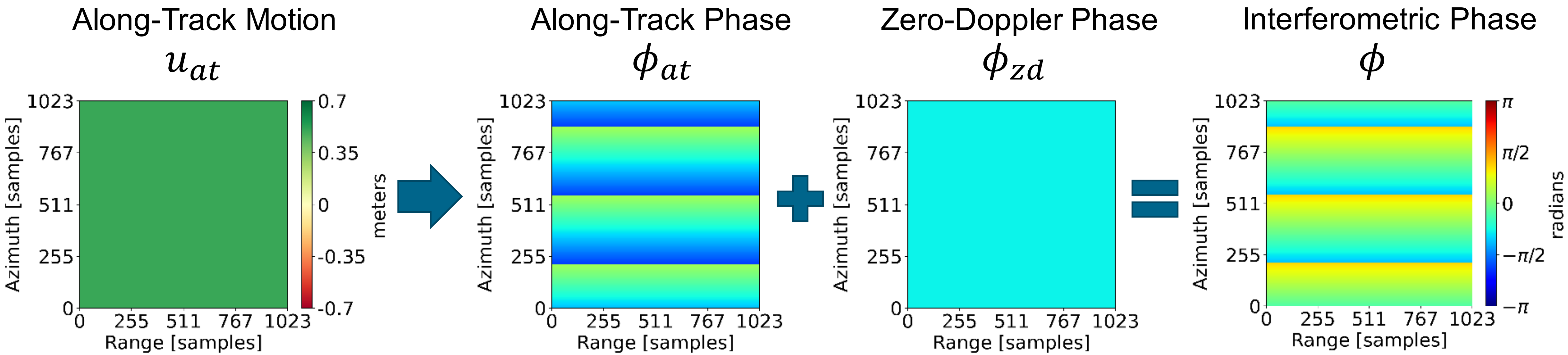
Δ_t Azimuth time spacing [sec]

K_t Doppler frequency modulated rate (mid-azimuth, range variant) [Hz/sec]



Introduction & motivation

Hp: constant deformation $u_{ENU} = [0.5\ m, 0.5\ m, 0.5\ m]$



Phase jumps between adjacent bursts:

- Potentially interfere with the phase unwrapping step
- Do not allow a Zero-Doppler displacement estimation

Invert the deformation from the phase differences in the overlap areas!

*ENU=East-North-Up (radar) coordinate system

Proposed methodology: interferometric phase model

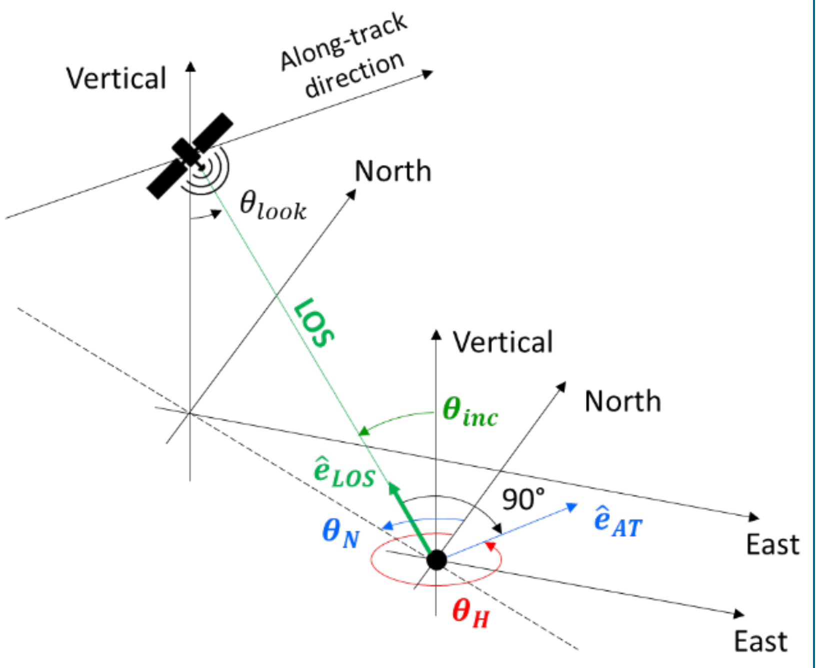
SLCs
$$\begin{cases} s_1 = A_0 w_1 & \text{primary} \\ s_2 = s_1 \rho^* e^{j\phi_{theo}} + A_0 w_2 \sqrt{1-\rho^2} & \text{secondary} \end{cases}$$

Noise-free interferometric phase
$$\phi_{theo} = mod_{2\pi}(\phi_{zd} + \phi_{at})$$

Zero-Doppler phase
$$\phi_{zd} = \frac{4\pi}{\lambda}[-\cos(\theta_{inc}) \cdot u_U + \sin(\theta_{inc}) \cdot \cos(\theta_N) \cdot u_N + \sin(\theta_{inc}) \cdot \sin(\theta_N) \cdot u_E]$$

Along-track phase
$$\phi_{at} = \frac{2\pi f_{dc}}{v_g}[\sin(\theta_N) \cdot u_N - \cos(\theta_N) \cdot u_E] = \frac{2\pi f_{dc}}{v_g} u_{at}$$

$$\boxed{\hat{\phi} = \angle E\{s_1 s_2^*\} \Rightarrow \phi_{zd}, \phi_{at}, u_{at}}$$



$\theta_{inc} = incidence\ angle$
$\theta_N = north\ angle = \theta_H + \frac{\pi}{2}$
$\theta_H = heading\ angle$

Proposed methodology: synthetic dataset generation

LAND ICE: PROMICE [1]

- PROMICE: Programme for Monitoring of the Greenland Ice Sheet
- Annual winter velocity (m/days) mosaics (2016-) freely available
- Nominal resolution: 500 m
- Based on offset tracking retrieved using Sentinel-1 SAR Backscatter

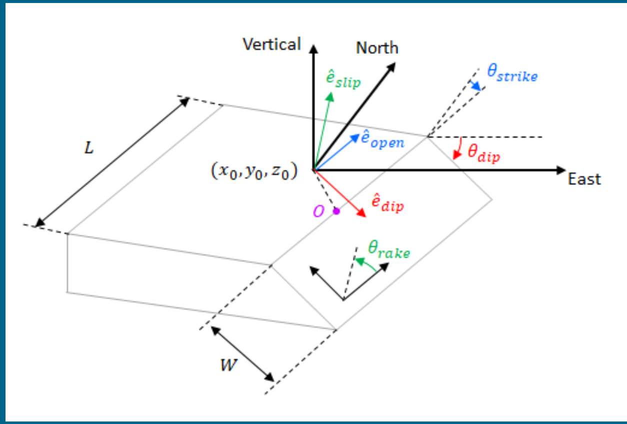
$$u = v \cdot \Delta T$$

* for test only

SOLID EARTH: Okada [2]

- In origin for seismic events (e.g. dip-slip fault), here used for data augmentation.
- Surface deformation in cartesian coordinates from a set of geometric parameters of the fault.

$$[u_X, u_Y, u_Z]$$
$$\downarrow$$
$$[u_E, u_N, u_U]$$

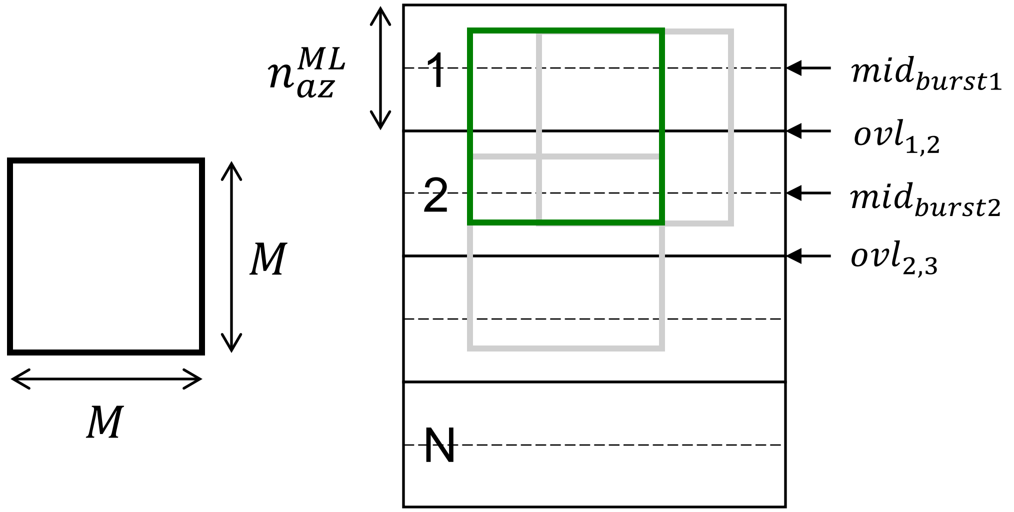


[1] A. Solgaard, A. Kusk, J. P. Merryman Boncori, J. Dall, K. D. Mankoff, A. P. Ahlstrøm, S. B. Andersen, M. Citterio, N. B. Karlsson, K. K. Kjeldsen, N. J. Korsgaard, S. H. Larsen, and R. S. Fausto, "Greenland ice velocity maps from the PROMICE project," Earth System Science Data, vol. 13, no. 7, pp. 3491–3512, 2021.

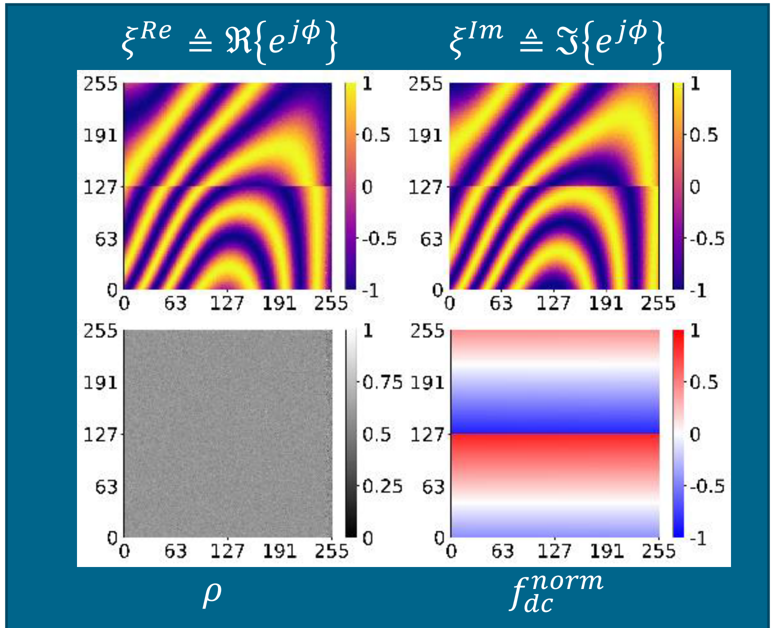
[2] Y. Okada, "Surface deformation due to shear and tensile faults in a halfspace," Bulletin of the Seismological Society of America, vol. 75, no. 4, pp. 1135—1154, Aug. 1985.

Proposed methodology: patch formation

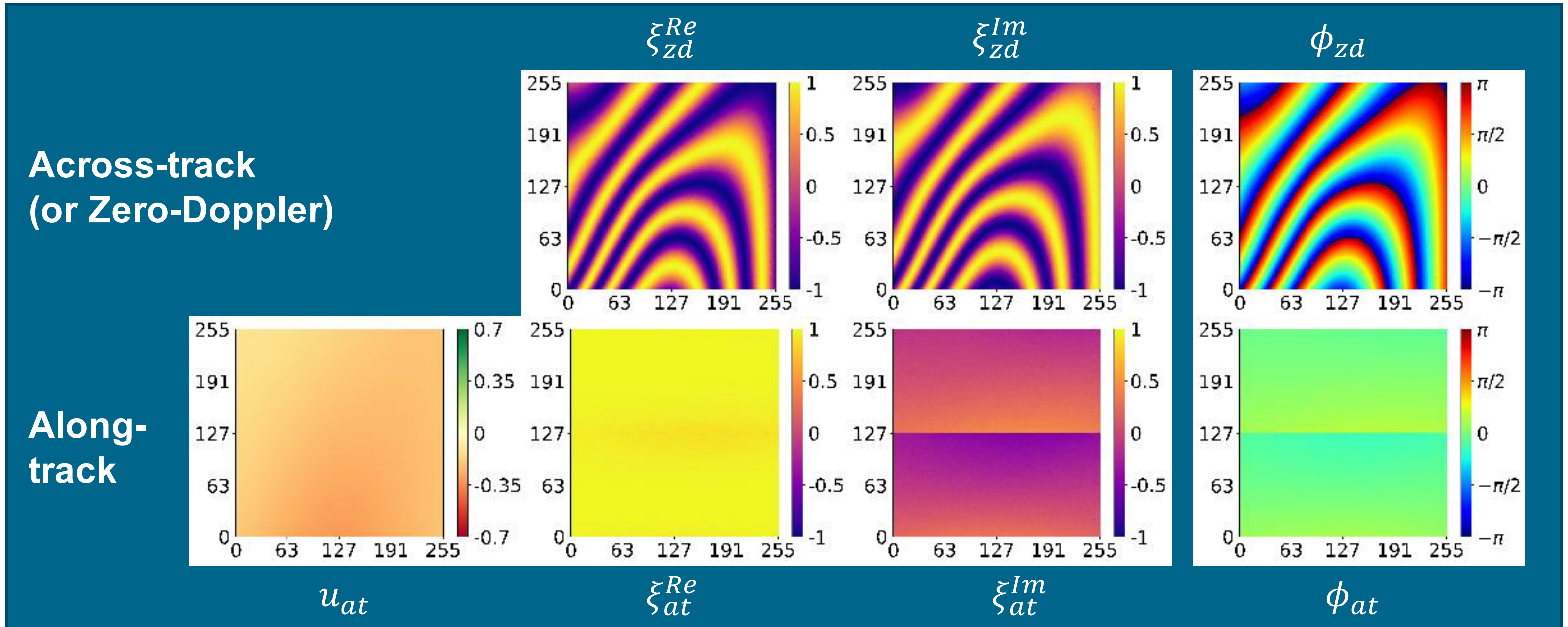
- Patches centered at mid-overlap
- Multi-source deformation dataset
- ~100k synthetic patches for the generalization of the problem



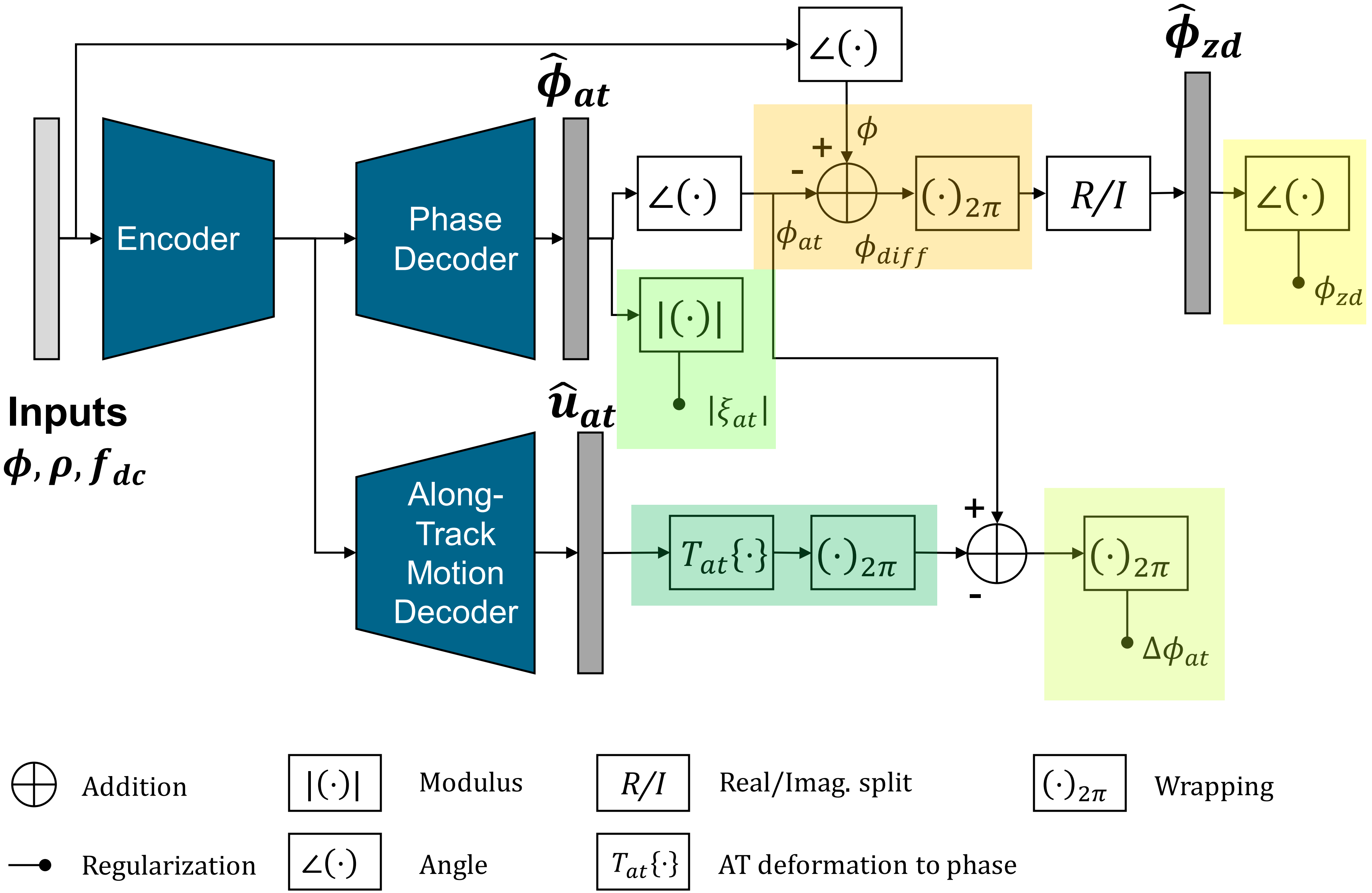
4 INPUTS



5 OUTPUTS + 2 RECONSTRUCTED PHASES



Proposed methodology: multi-task neural network



Interconnections

$$\phi_{zd} = mod_{2\pi}(\phi - \phi_{at})$$

$$\phi_{at} = mod_{2\pi}\left(\frac{2\pi f_{dc}}{v_g} u_{at}\right)$$

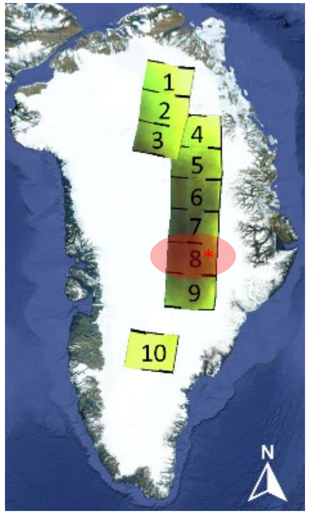
Regularizations

ϕ_{zd} must be continuous

$|\xi_{at}| \rightarrow 1$, i.e. $\xi_{at} = e^{j\phi_{at}}$

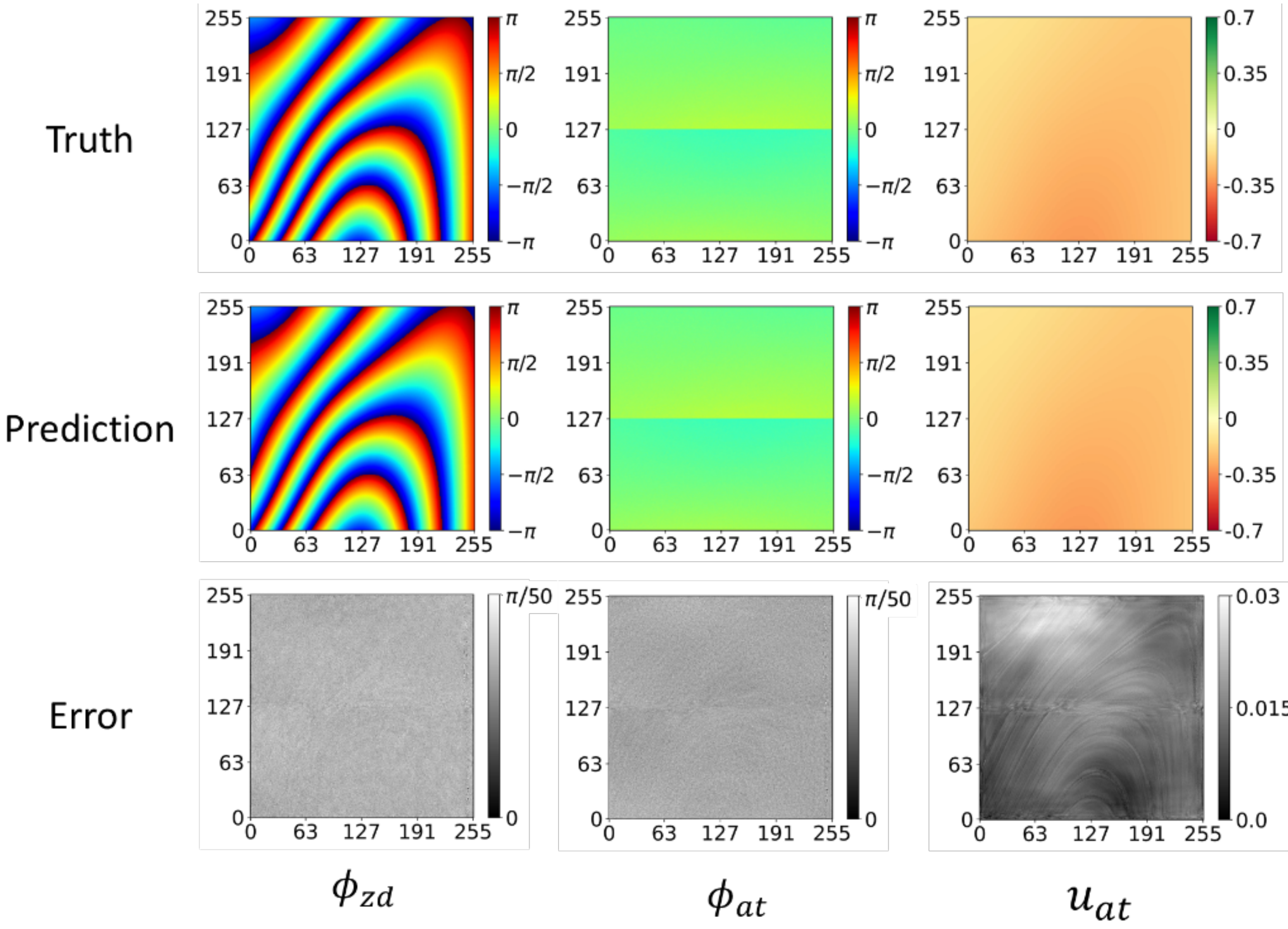
$mod_{2\pi}(\phi_{at} - T_{at}\{u_{at}\}) \rightarrow 0$

Experimental results: test on synthetic patches

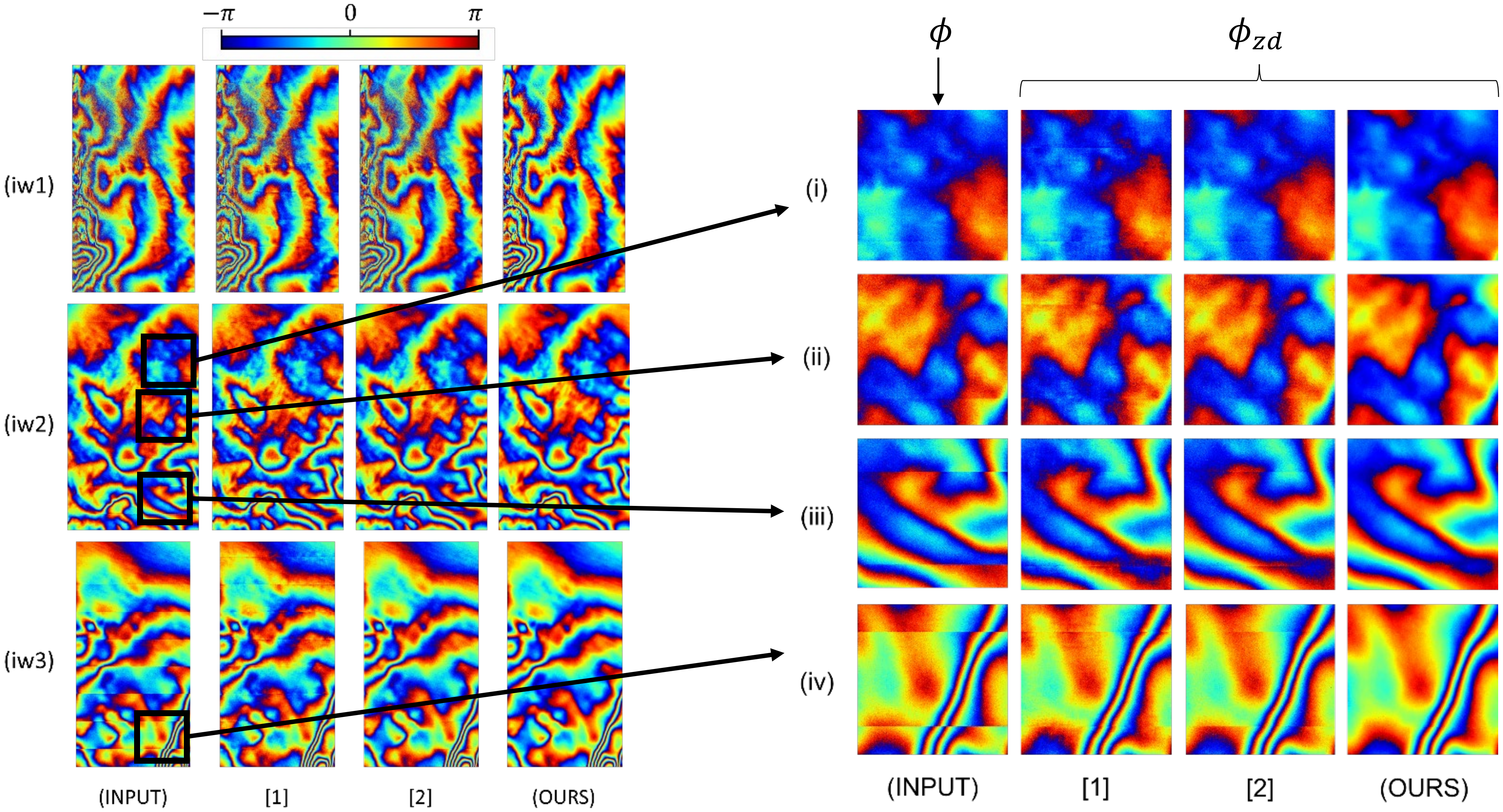


- Test area:
  - footprint # 8
- PROMICE deformation induced in the mixing model
- 3 subswaths split in patches

RMSE on the outputs				
Case		A	B	C
ZD fringes		low	medium	high
ϕ_{at} [rad]	Mean	0.024	0.024	0.024
	StdDev	0.001	0.001	0.001
ϕ_{zd} [rad]	Mean	0.28	0.271	0.277
	StdDev	0.055	0.063	0.031
u_{at} [m]	Mean	0.008	0.008	0.008
	StdDev	0.003	0.004	0.004



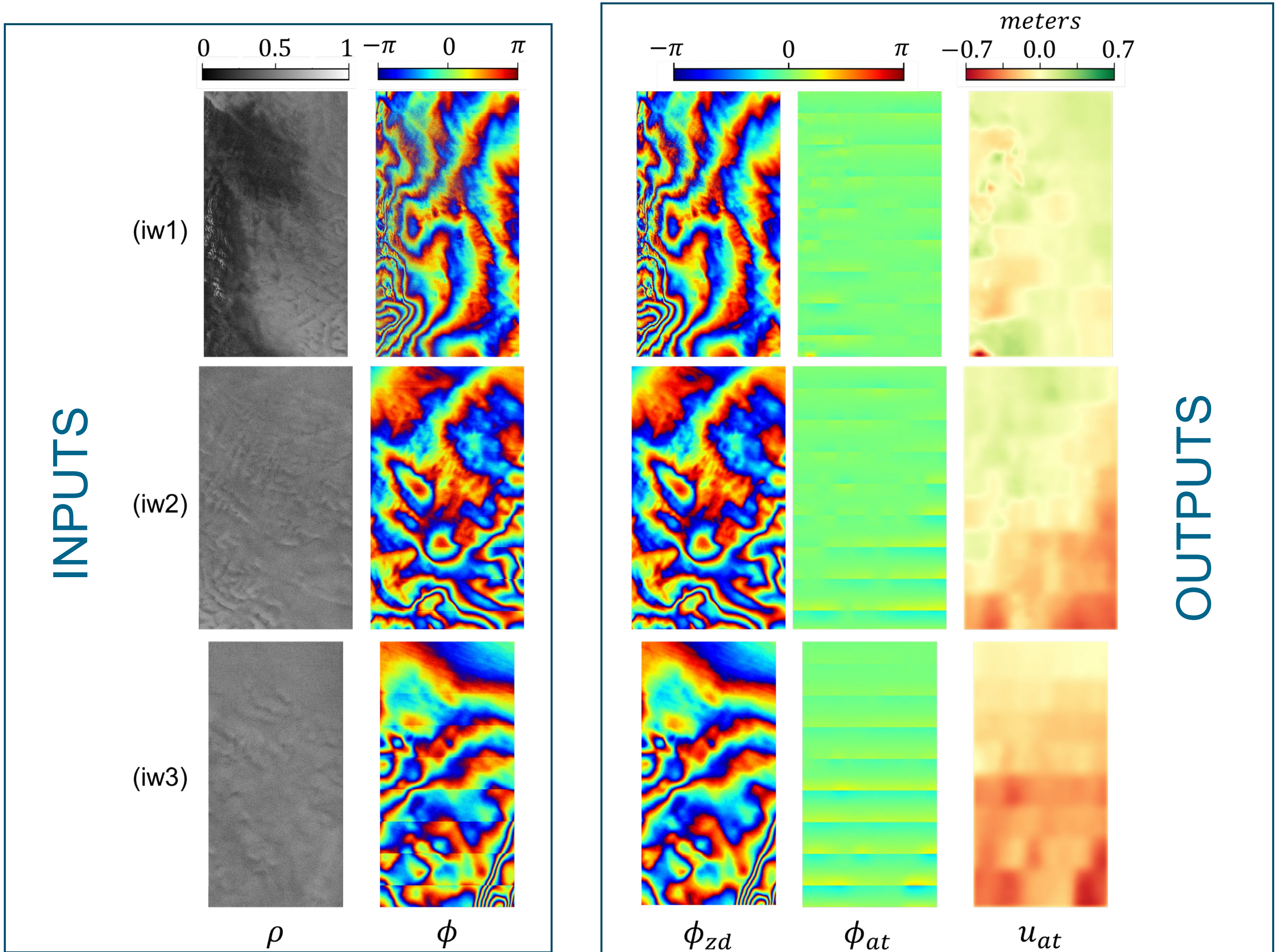
Experimental results: real interferometric pair



[1] R. Scheiber, et al. “Speckle Tracking and Interferometric Processing of TerraSAR-X TOPS Data for Mapping Nonstationary Scenarios,” IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 8, no. 4, pp. 1709–1720, 2015.

[2] P. Prats-Iraola, et al. “Interferometric investigations with the Sentinel-1 constellation,” in 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 2017, pp. 5537–5540.

Experimental results



Conclusions & outlooks

- **Conclusions**
  - We propose a methodology for phase source separation
  - We provide a proxy for surface displacement estimation that is superior to the state-of-the-art.
  - We are able to estimate glacier inland flow where both state-of-the-art algorithms cannot provide a solution

- **Outlooks**
  - Complete the study over Greenland and compare with the PROMICE maps
  - Investigate self-supervised methodologies
  - Apply the methodology to other sensors

THANK YOU FOR YOUR ATTENTION!

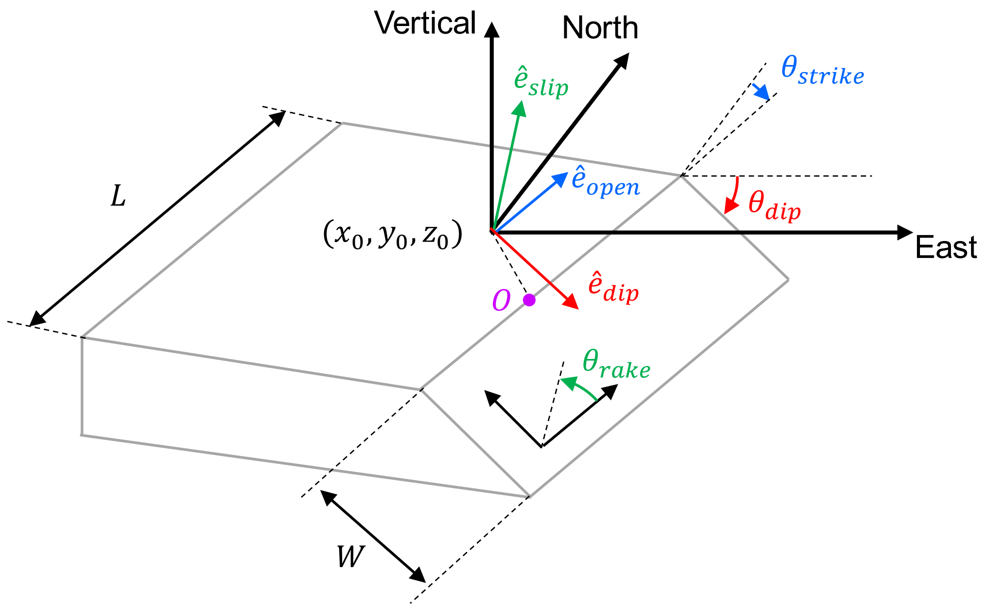
THANK YOU FOR YOUR ATTENTION!

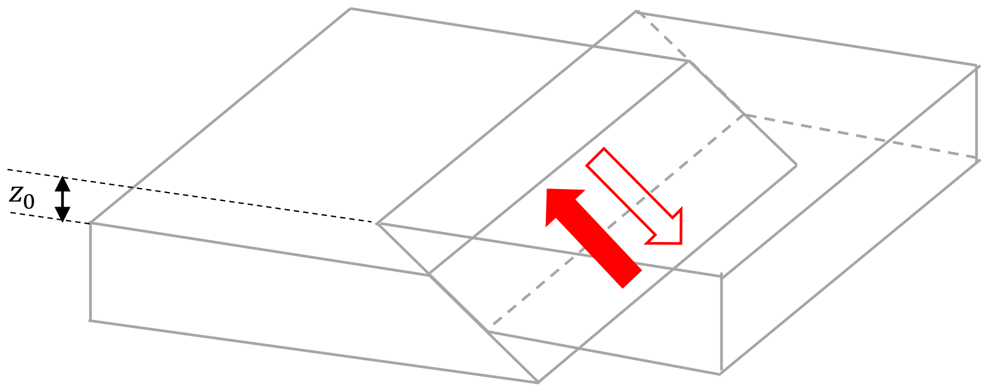
EXTRA

Okada Model: dip-slip fault

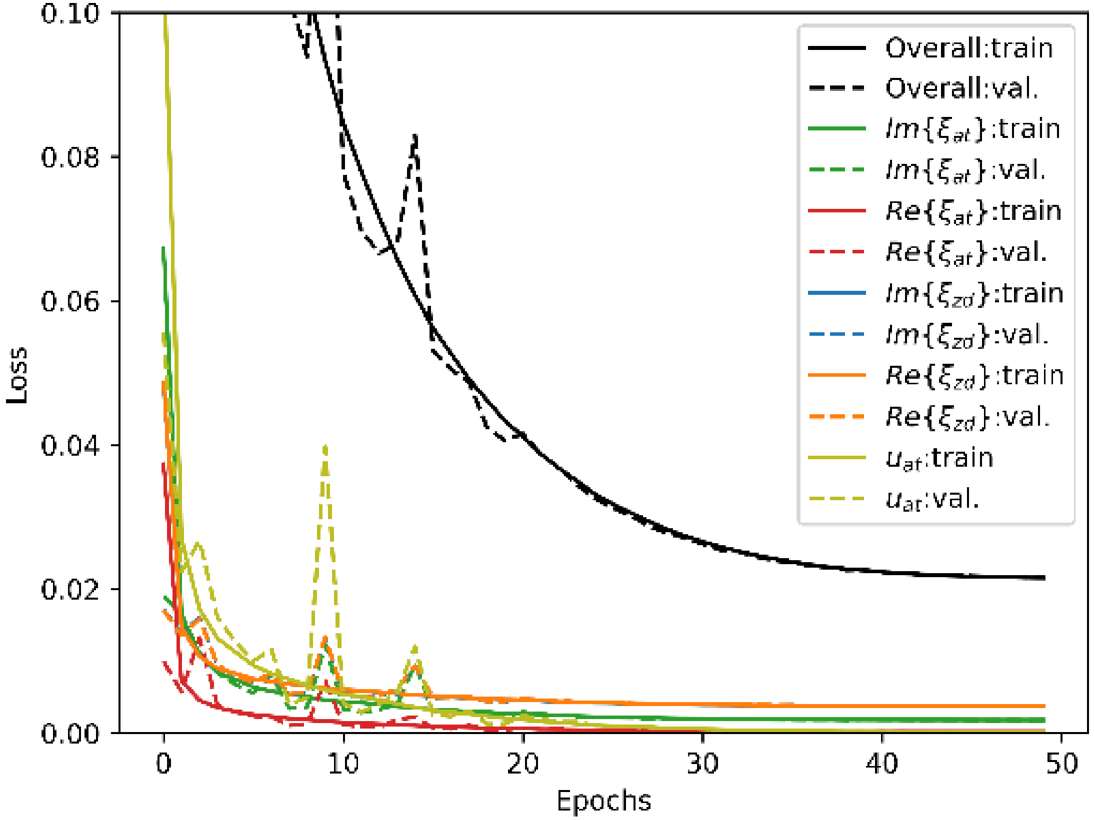
TABLE I
OKADA PARAMETERS USED FOR GENERATING 224 DIFFERENT DEFORMATIONS ACCORDING TO FIG. 11.

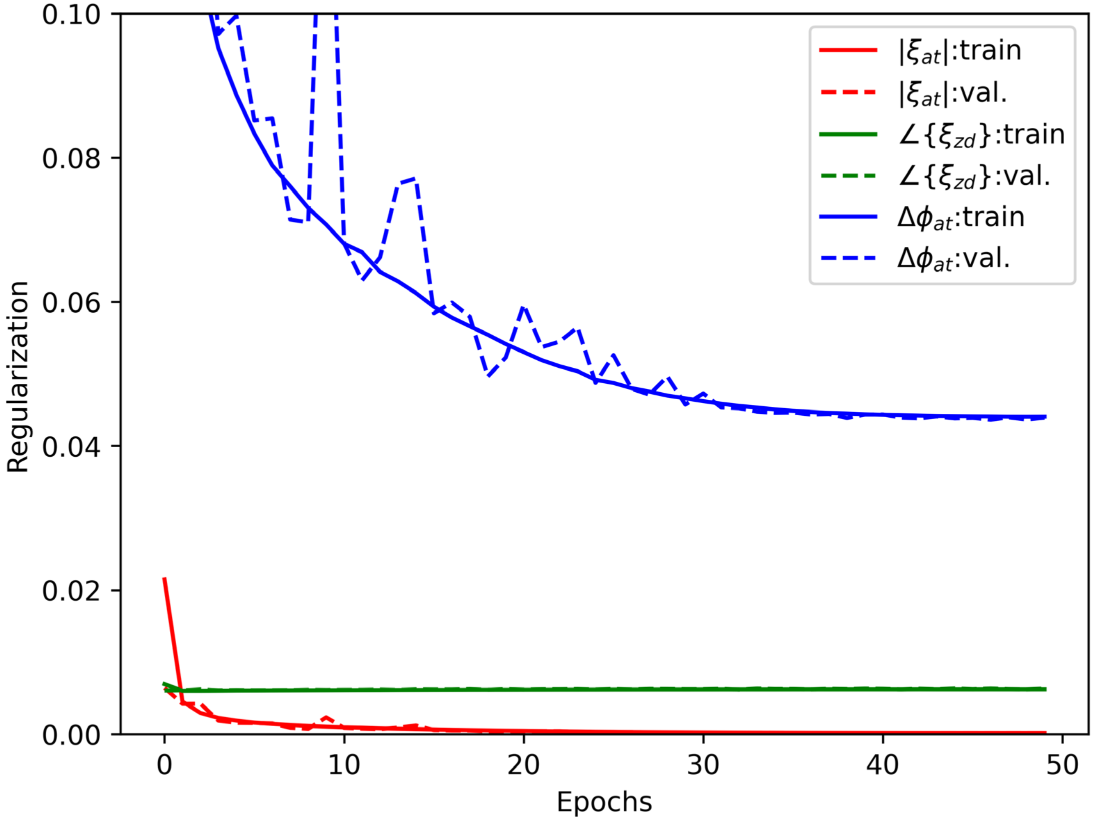
Parameter	Description	Unit	Value
θ_{strike}	Fault trace direction w.r.t. North pole, defined so that the fault dips to the right side of the trace	deg	30/45/60/ 120/135/ 150/165
θ_{dip}	Angle between the fault and a horizontal plane	deg	30/60
θ_{rake}	Direction the hanging wall moves during rupture, measured relative to the fault STRIKE	deg	45/90
d_{slip}	Dislocation in RAKE direction	m	1/2
d_{open}	Dislocation in tensile component	m	0
L	Fault length in the STRIKE direction	Km	200
W	Fault width in the DIP direction	Km	30/60
x_0	X location of center bottom of fault	m	0
y_0	Y location of center bottom of fault	m	0
z_0	Z location of center bottom of fault	m	50/100





Proposed methodology: evaluation performance



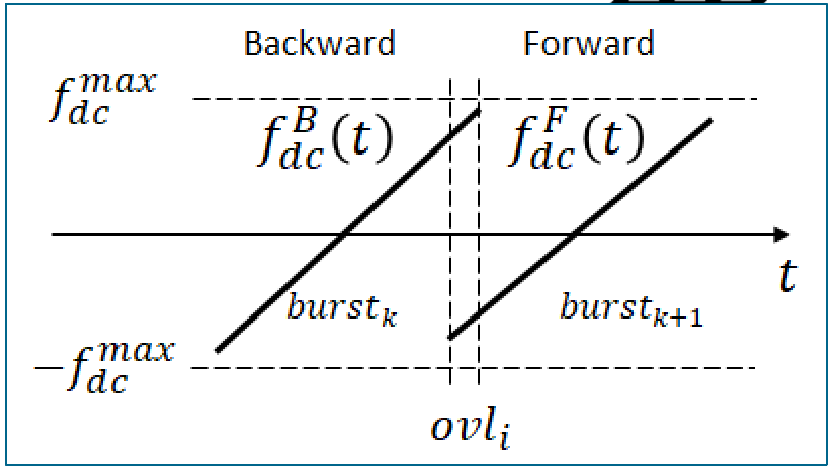


Experimental results: comparison

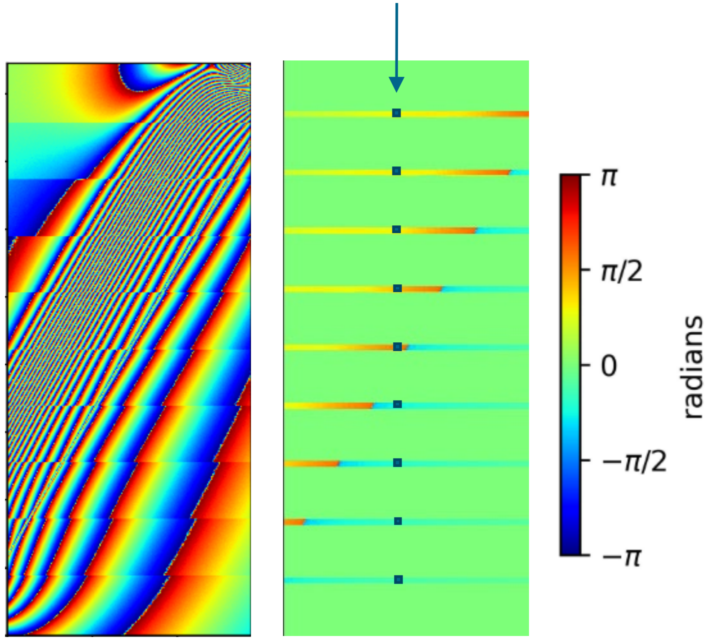
Traditional differential interferogram used in ESD

$$\phi_{ESD}^{ovl_i} = mod_{2\pi}(\phi_{F,ovl_i} - \phi_{B,ovl_i})$$

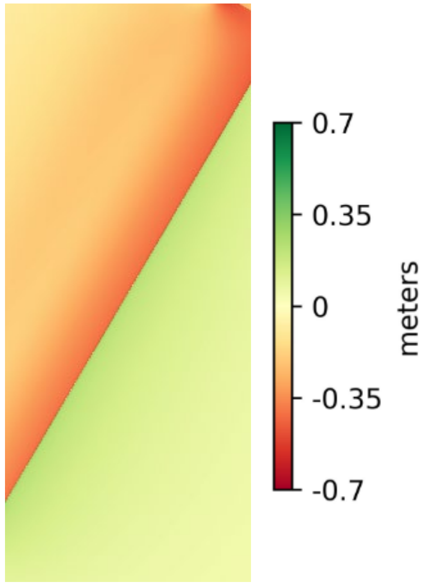
$$\phi_{at}^{ovl_i} = mod_{2\pi}\left(\phi_{at}^{F,ovl_i} - \phi_{at}^{B,ovl_i}\right) = mod_{2\pi}\left(\frac{2\pi\Delta f_{dc}^{ovl_i}}{v_g} u_{at}\right)$$



$\sim 0.06\ km^2$



ϕ $\phi_{at}^{ovl_i}$



u_{at}