Ministry of Science and Higher Education
Republic of Poland

JAGIELLONIAN UNIVERSITY IN KRAKÓW

esa EUROPEAN SPACE AGENCY

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Along-Track Interferometry with Sentinel-1C/D

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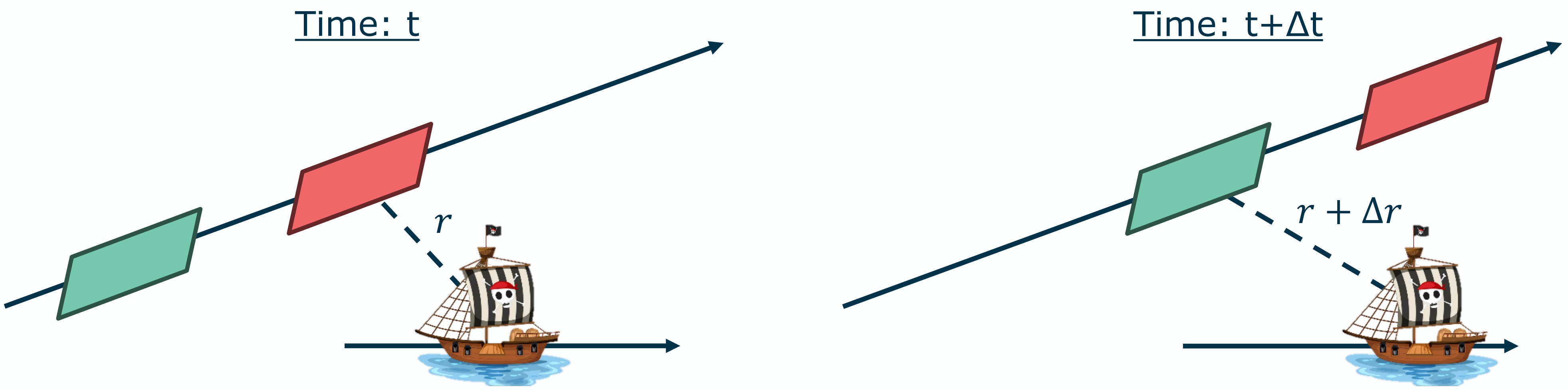
ATI concept

Along-track interferometry (ATI) measures the radial velocity of moving targets, with potentially better sensitivity than Doppler-based measurements.



The radial velocity is proportional to the ATI phase:

$$\boxed{\begin{aligned} \phi_{ATI} &= \Delta r k_r \\ V_r &= \phi_{ATI}/(k_r \Delta t) \end{aligned}}$$

Motivation

Sentinel-1NG will be a HRWS system featuring a **MAPS-8 SAR antenna** (current phase B2 concept).

Azimuth channels are recorded and downlinked individually.

Key features (IW)

- Resolution 25 m^2
- NESZ < -25 dB
- Swath > 250 km
- ATI capability

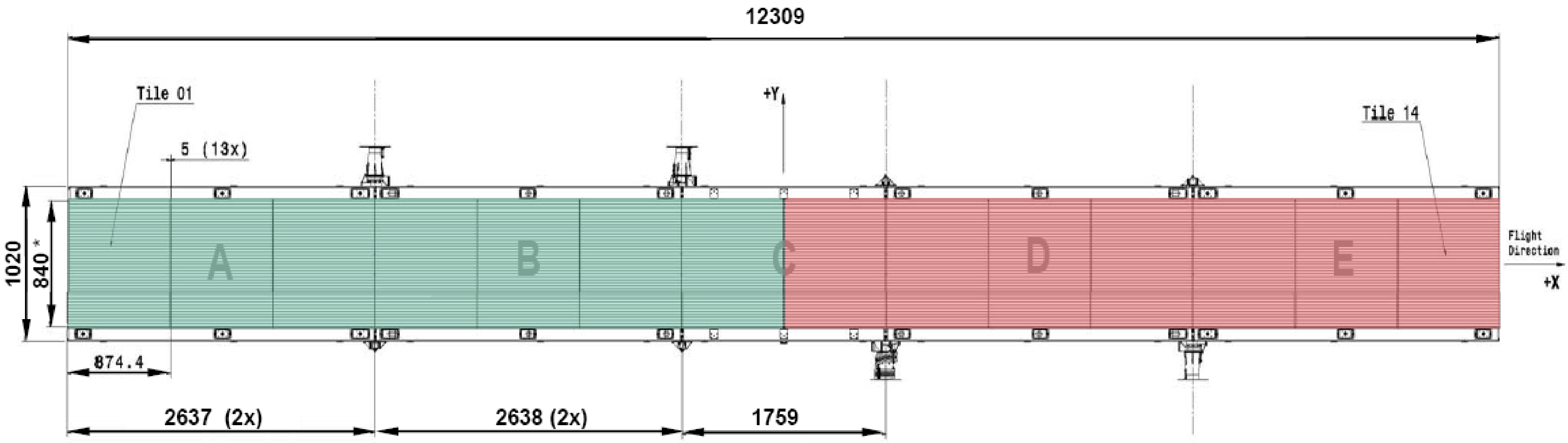
➢ The ATI capability comes inherently in a MAPS system.

➢ We want to explore ATI as an operational product to improve radial velocity maps (currently based on Doppler).

ATI mode rationale

Sentinel-1 has a **single channel antenna** – Signals from each element are combined in the RF backend.

How do we get 2 individual channels?



ATI mode rationale

A **new SAR mode** was implemented to achieve azimuth spatial diversity, needed for ATI.

- Operate at a high PRF, **toggling half-antenna Rx phase by 180° on each PRI**.

Time	0	1 PRI	2 PRI	3 PRI	···
Tx	Y	Y	Y	Y	
Rx	Y	0° / 180°	Y	0° / 180°	

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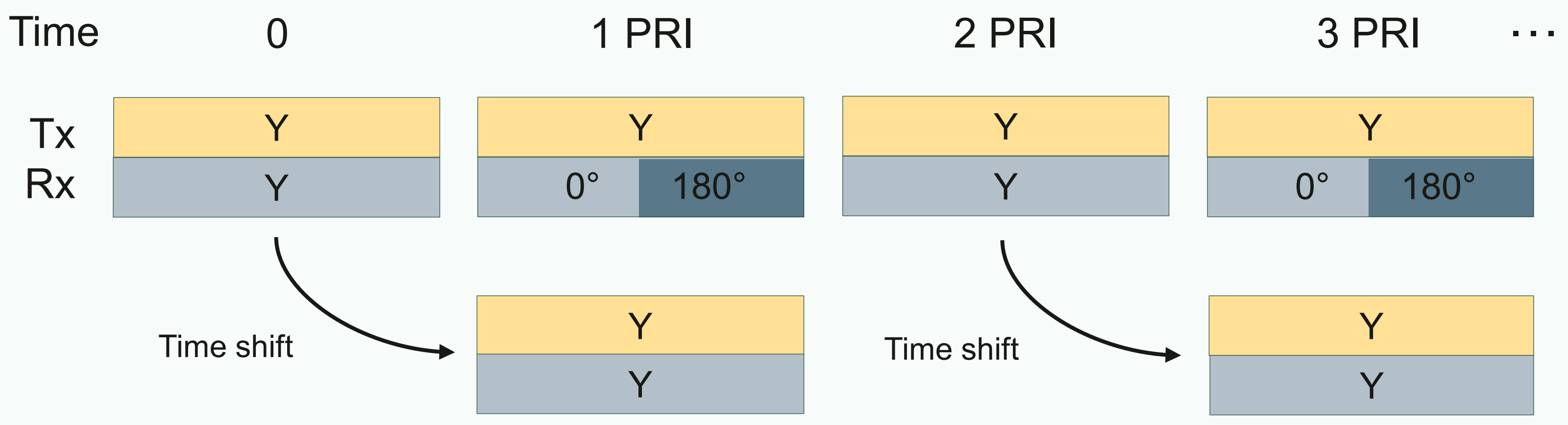

➢ A half-sample shift is applied to the sub-sequence corresponding to even PRI’s

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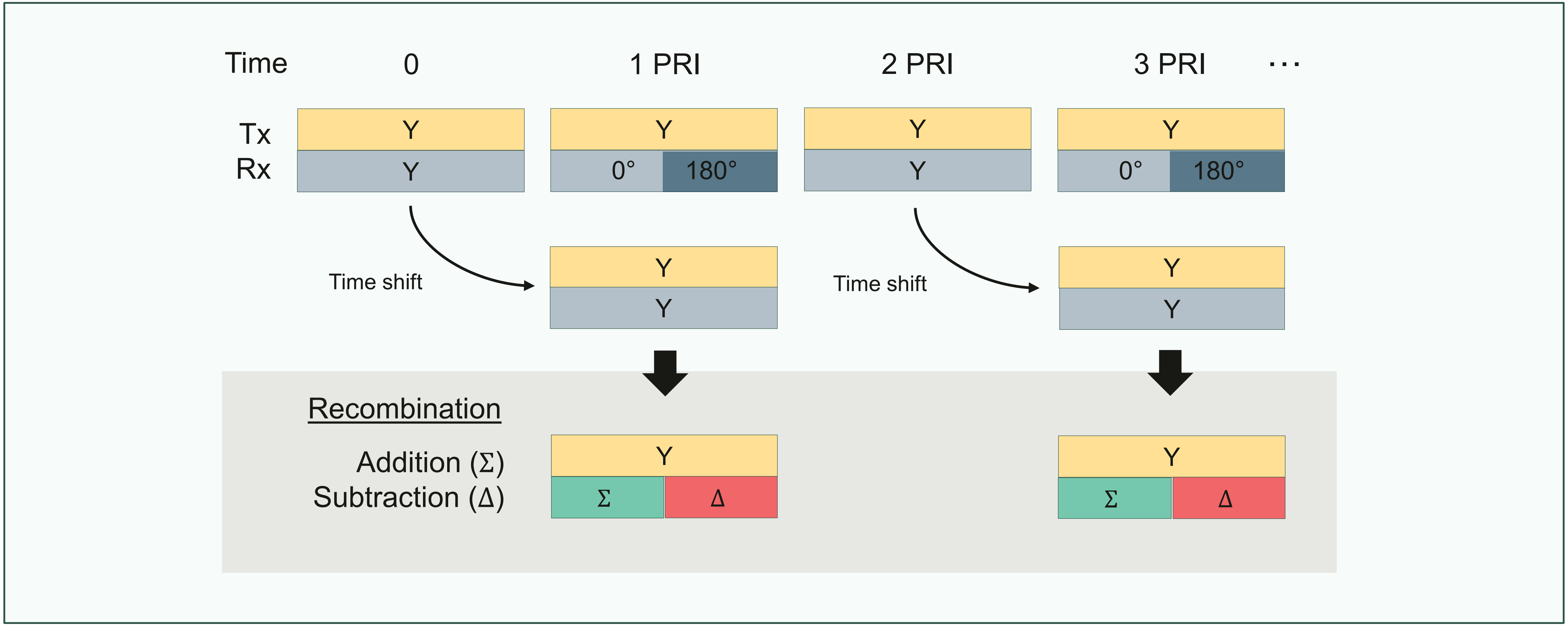


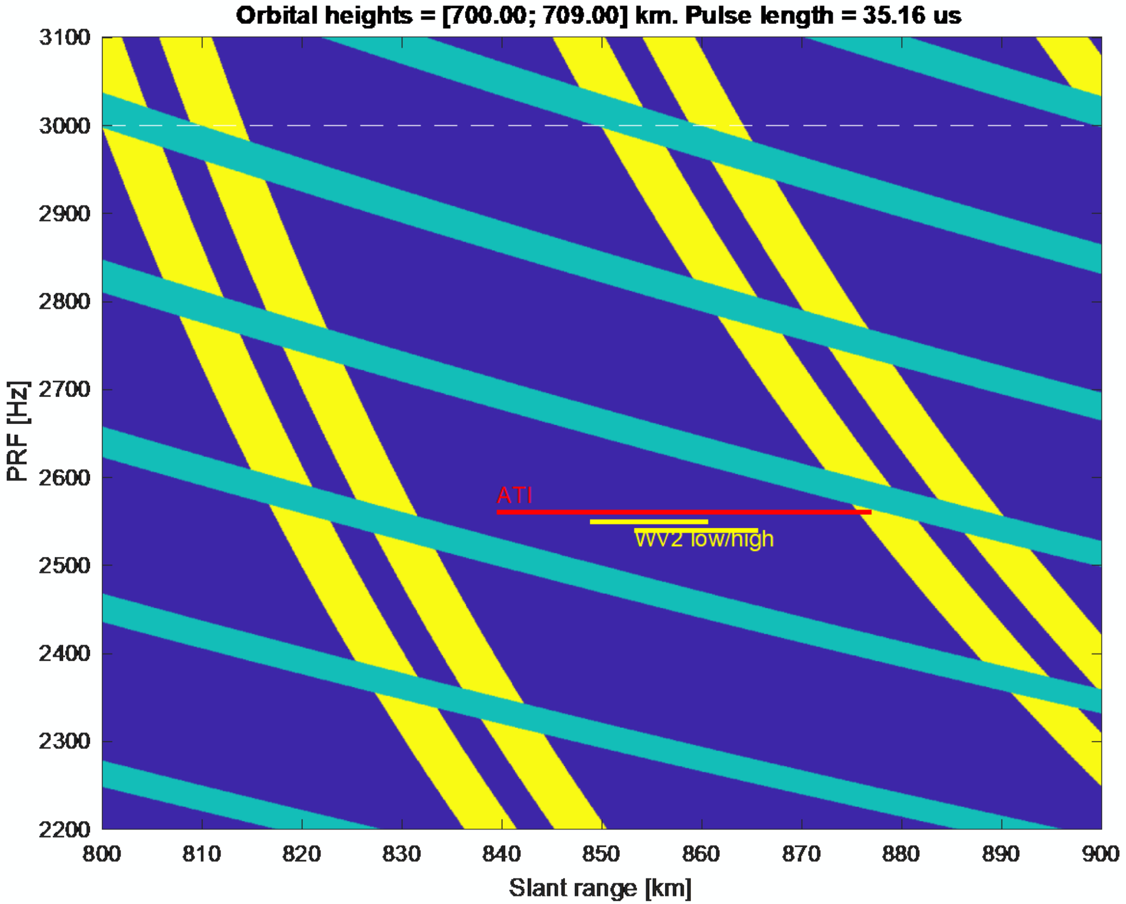
ATI mode parameters

Parameter	Value
Instrument PRF	2560 Hz
Incidence angle	36.5 deg
Swath width	60 km
NESZ	-26 dB
DTAR (az | rg)	-17 dB | -19 dB
Resolution (grd) (az × rg)	7.6 m × 5.4 m

Effective along-track baseline: $B = L/4 = 3.075\ \mathrm{m}$

Equivalent time separation: $\Delta t = B/v_s \approx 0.40\ \mathrm{ms}$

ATI phase sensitivity: $\frac{d\phi_{ATI}}{dv_{grd}} \approx 0.85 \frac{\mathrm{deg}}{\mathrm{km/h}}$



ATI datatakes

Most datatakes acquired over fast current regions

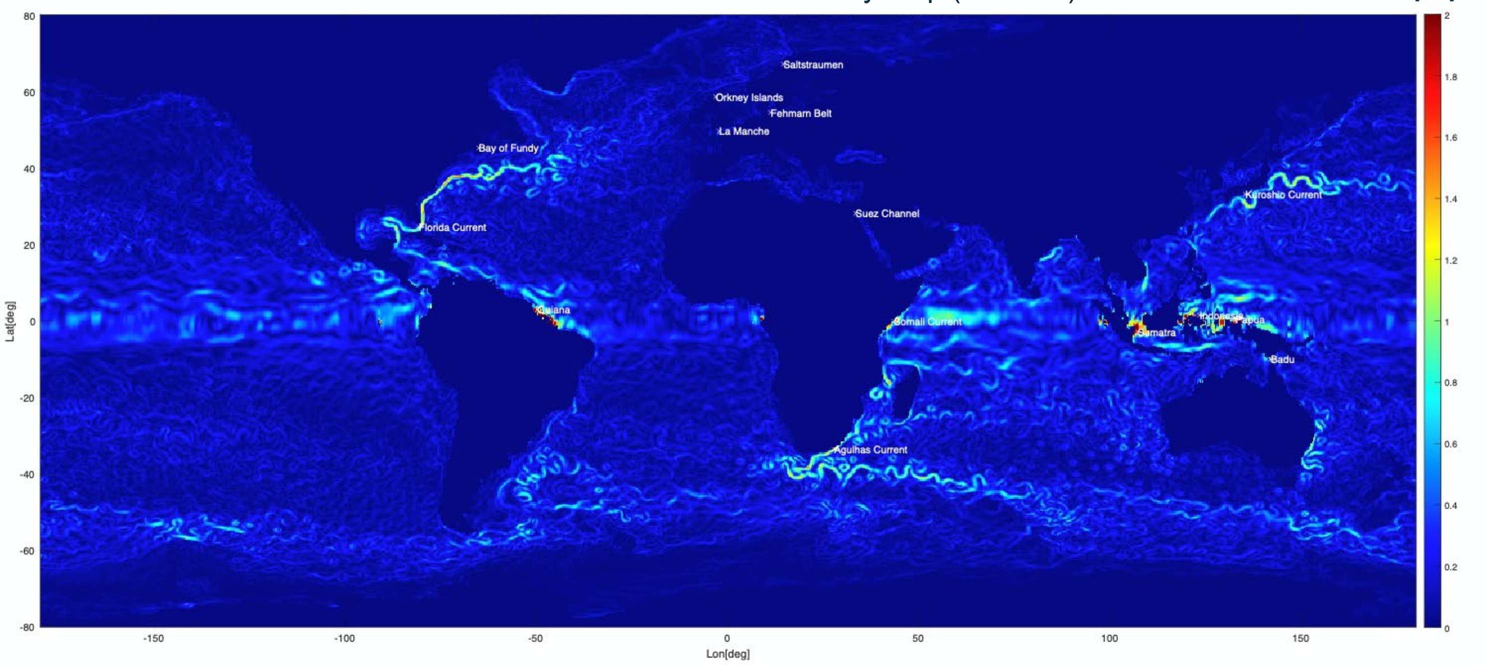
Sentinel-1C

- 17 datatakes including S1C AIS
- 3 datatakes near-simultaneously with RADARSAT-2 in MODEX mode

Sentinel-1D

- 14 datatakes including S1D AIS
- 8 datatakes near-simultaneously with RADARSAT-2 in MODEX mode

OSCAR ocean surface current velocity map (03/2023)



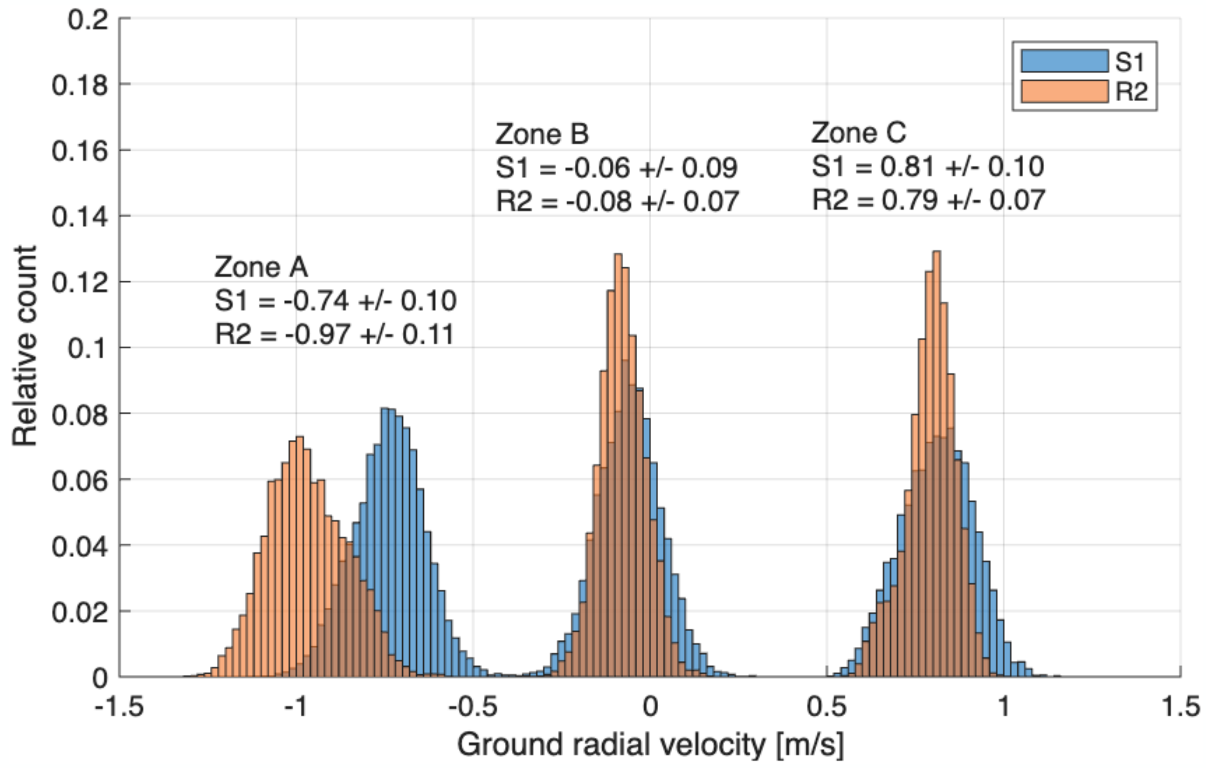
[*] MODEX (Moving Object Detection Experiment) is the 2-channel receive mode in RADARSAT-2

Agulhas Current – S1C

Agulhas Current – S1C

ATI velocity estimates comparison

Time between datatakes ~ 10 min

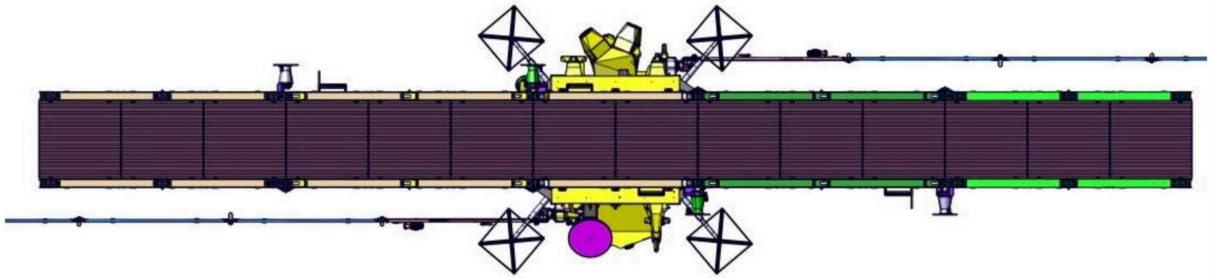


Agulhas Current – S1C

The **Sentinel-1 AIS** detected a total of 12 ships over the Agulhas Current scene.

Excellent ATI-AIS radial velocity match: $\Delta v = 0.1 \pm 0.3$ [m/s]

S1CD deployed +Z view with the 4 AIS antennas



Agulhas Current – S1C

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IRENES RULE

Container Ship

Length = 186 m

Width = 35 m

Source: www.marinetraffic.com

Agulhas Current – S1C

Agulhas Current – S1C

SF CHALISA

Bulk Carrier

Length = 180 m

Width = 28 m

Source: www.marinetraffic.com

Agulhas Current – S1C

DHT JAGUAR

Tanker

Length = 333 m

Width = 60 m

Source: www.marinetraffic.com

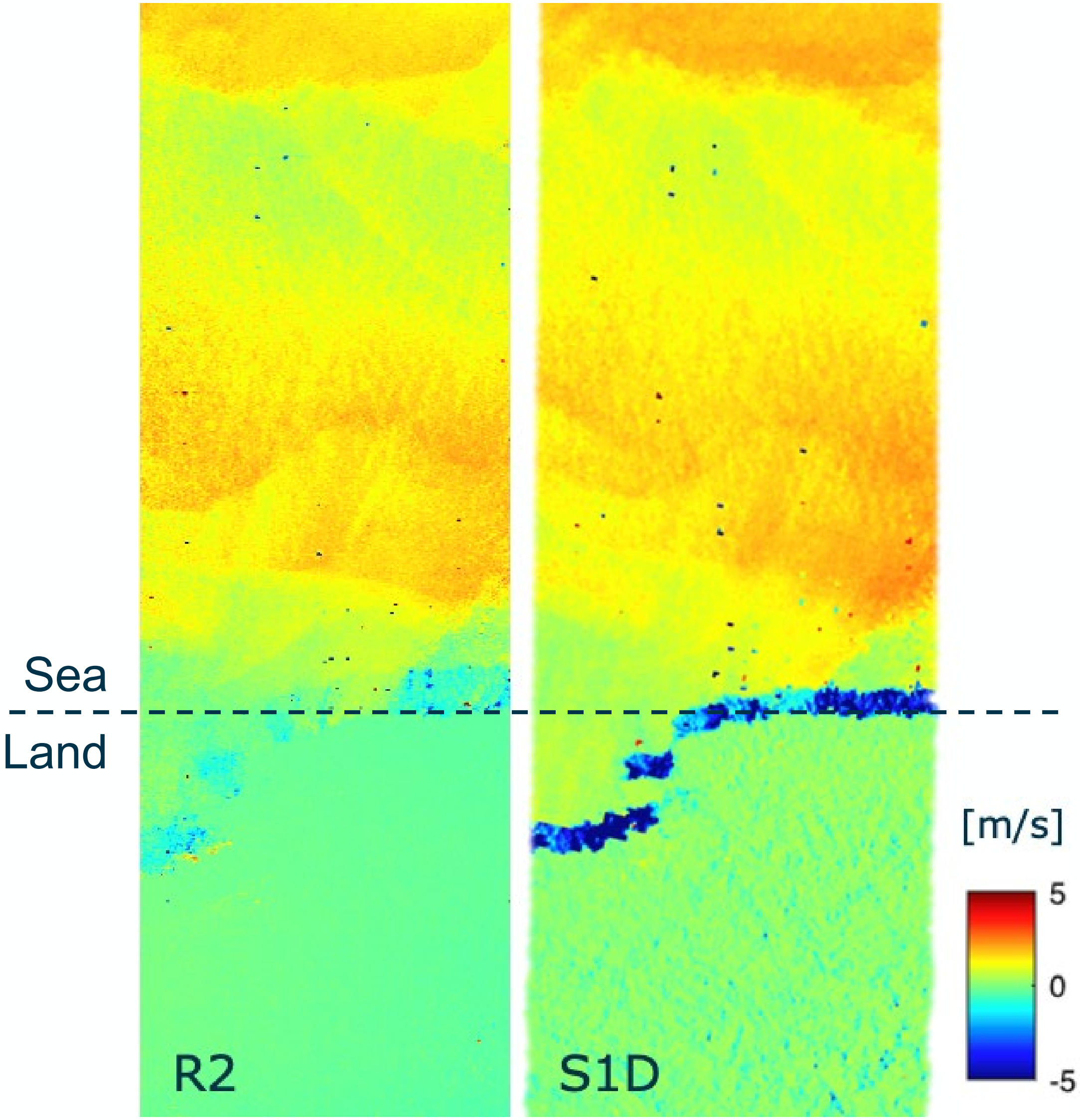
Kuroshio Current – S1D

Kuroshio Current, Japan (2026-02-12).

Radarsat-2 (left) and Sentinel-1D (right).
Time between datatakes ~ 10 minutes.

Similar sea surface velocity fronts are clearly observed in both maps.

Ships and their azimuth ambiguities are visible in both maps.



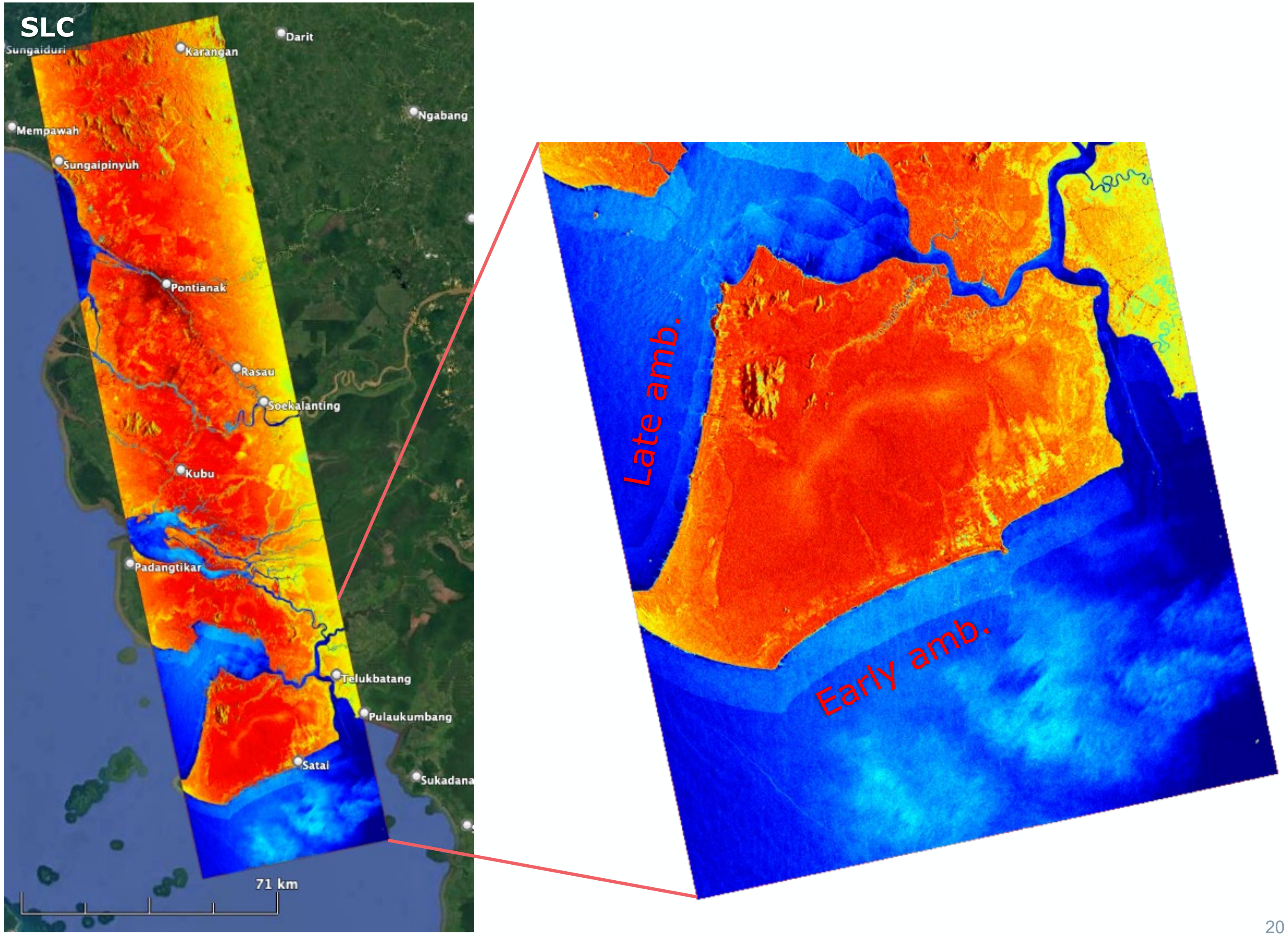
Borneo – S1C

Azimuth ambiguity mitigation

Strong azimuth ambiguities in transition areas (e.g. coast, rivers)

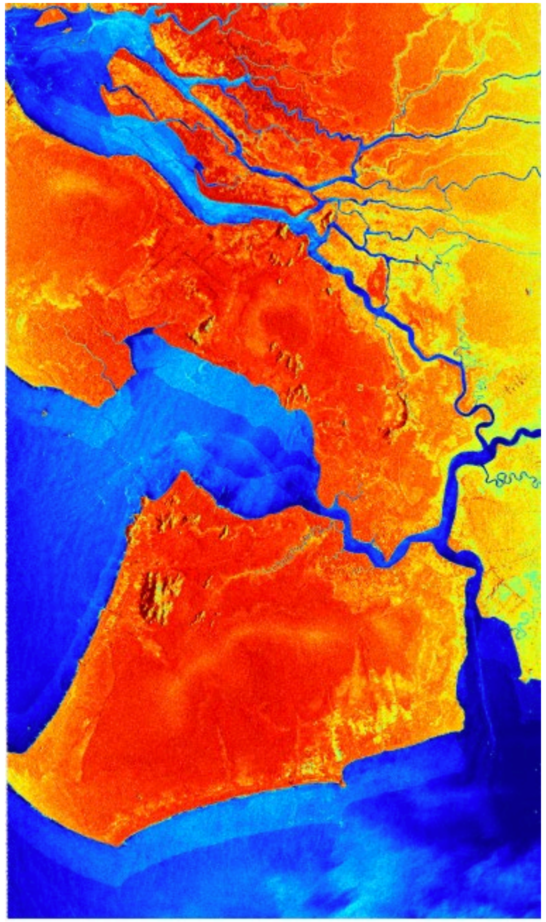
The halved effective antenna length on Rx raises azimuth ambiguities.

Ambiguities are coherent, biasing the ATI phase. But this can be mitigated at interferogram level.

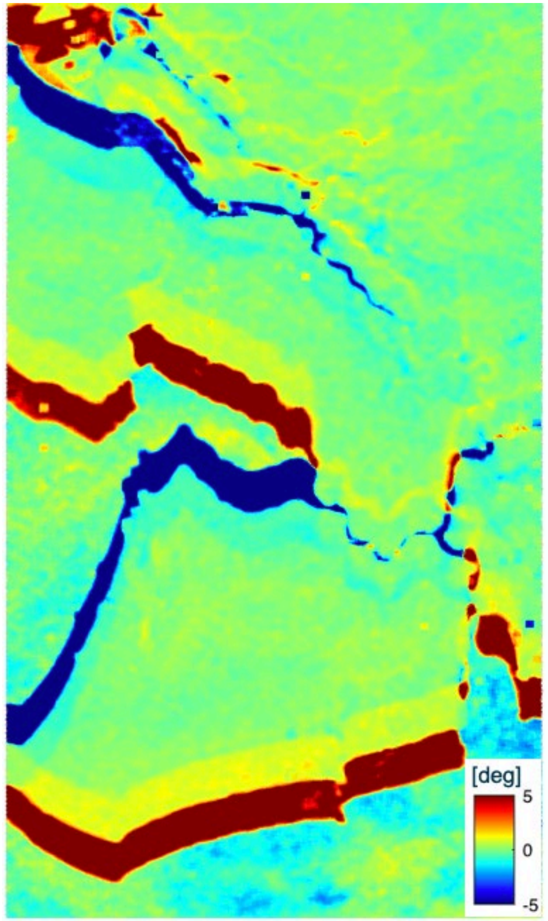


Borneo – S1C

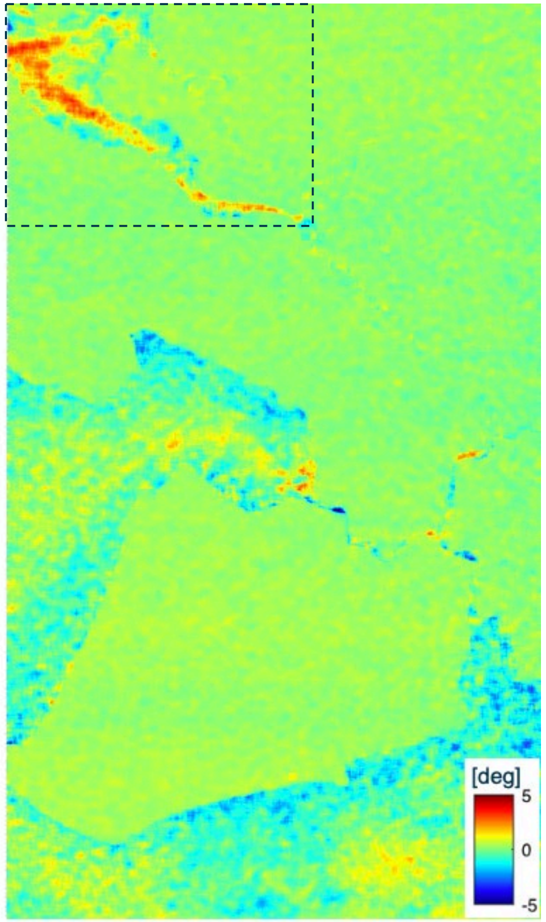
Intensity



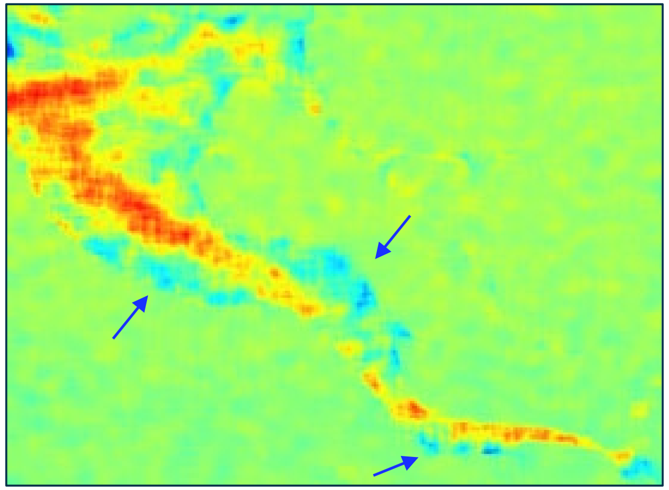
ATI



ATI compensated



Zoom on river



Arrows: recirculation areas along the riverbank

Azimuth ambiguity suppression method from D. Richter et. al., “Coherent azimuth ambiguity suppression based on linear optimum filtering of short along-track baseline SAR interferograms,” EUSAR 2022.

Conclusions

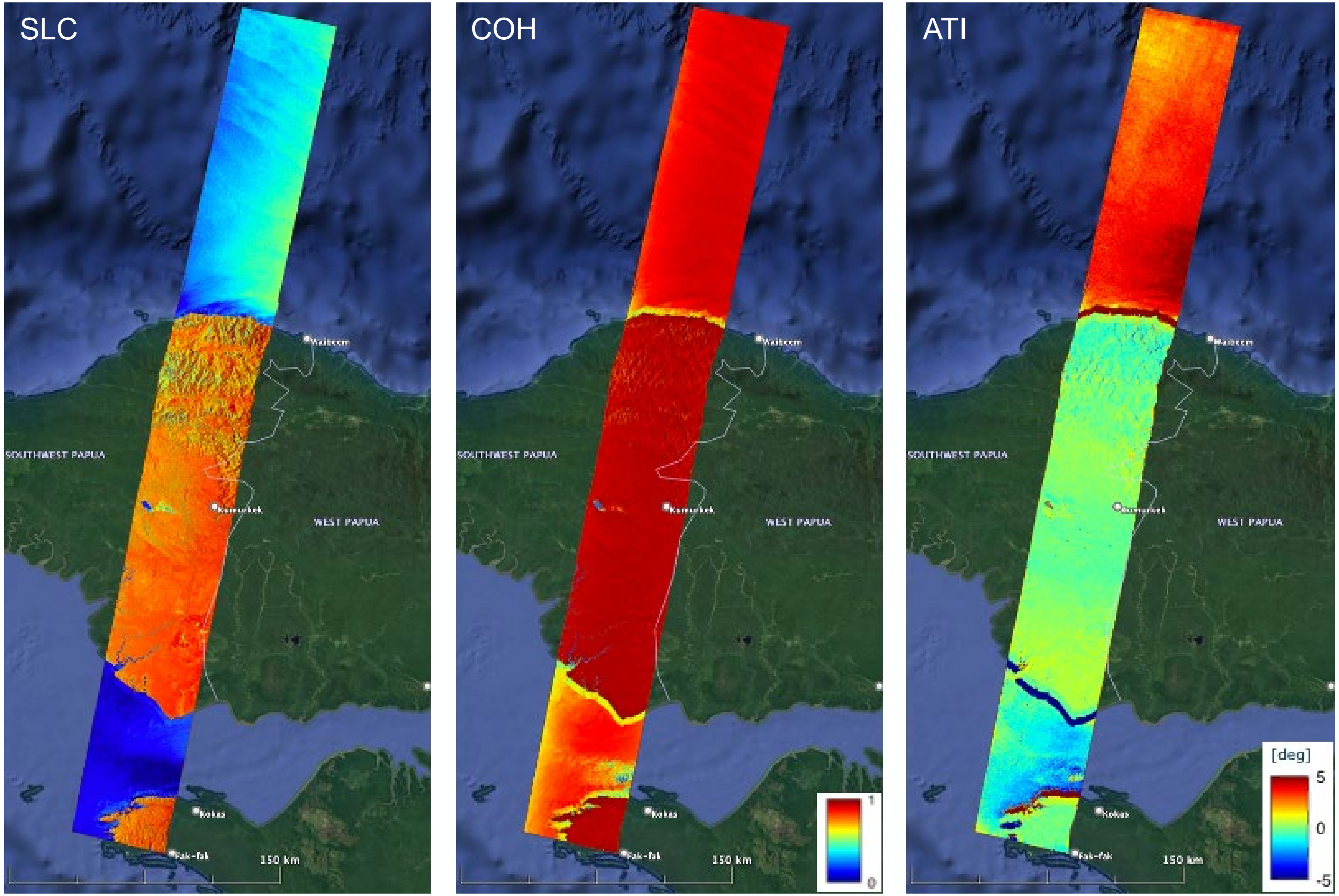
- The ATI experiment with S1C&D was successful
- ATI velocity estimates resulted very accurate, despite the short along-track baseline
    - Excellent agreement with RADARSAT-2 and AIS velocities
- Azimuth ambiguity suppression at interferogram level proved very effective
- Next steps: evaluating the feasibility of an operational ATI product with S1NG

ANNEX

West Papua – S1D

West Papua (2026-02-26)

Sea surface velocity up to 6 km/h in the northern part, being slower and with an opposite direction in the southern part.



ATI phase bias calibration

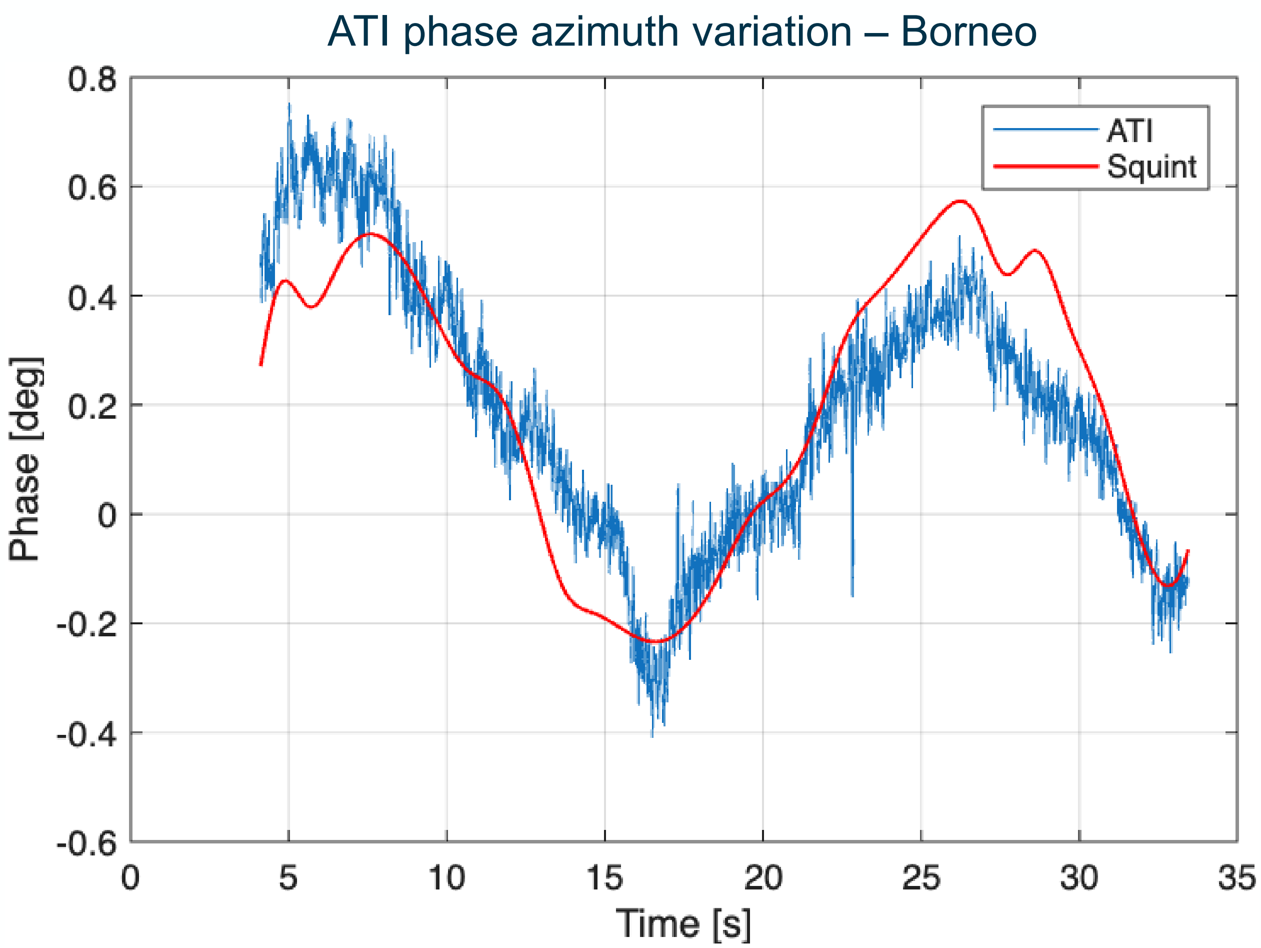
ATI phase bias estimated over land

Considering all datatakes, the ATI phase bias was -1.9 ± 0.6 deg.

The standard deviation of 0.6 deg is comparable with the expected impact from the SAR antenna elements phase quantization.

The mean represents a relative difference of just 0.15 mm between the phase center positions of each Rx half in LOS.

ATI phase bias calibration



Azimuth variation of ATI phase measured over land, overlaid with the bias predicted from attitude quaternions.

$$\Delta\phi_{ATI} = \frac{4\pi}{\lambda} B_{AT} \sin(\eta_{sq})$$

The squint angle excursion corresponds to Yaw and Pitch variations of less than ±1 mdeg.

ATI vs DCA estimate

ATI vs DCA comparison from RADARSAT-2 over the Agulhas scene.

ATI achieves a lower variance than the DCA estimate (ACCC).

Note: velocity sign flipped