Multistatic Observations of Surface Wind and Current Vectors with STEREOID

Paco López-Dekker and others…

TU Delft

STEREOID for Earth Explorer 10

Lead Investigator		
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Proposing Team		
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3	Johnsen, Harald, Dr.	NORUT
4	Collard, Fabrice, Dr.	Oceandatalab
5	Hansen, Morten, Dr.	Nansen Enviro
6	Korosov, Anton, Dr.	Nansen Enviro
7	Rott, Helmut, Dr.	ENVEO IT

phase 0 study (

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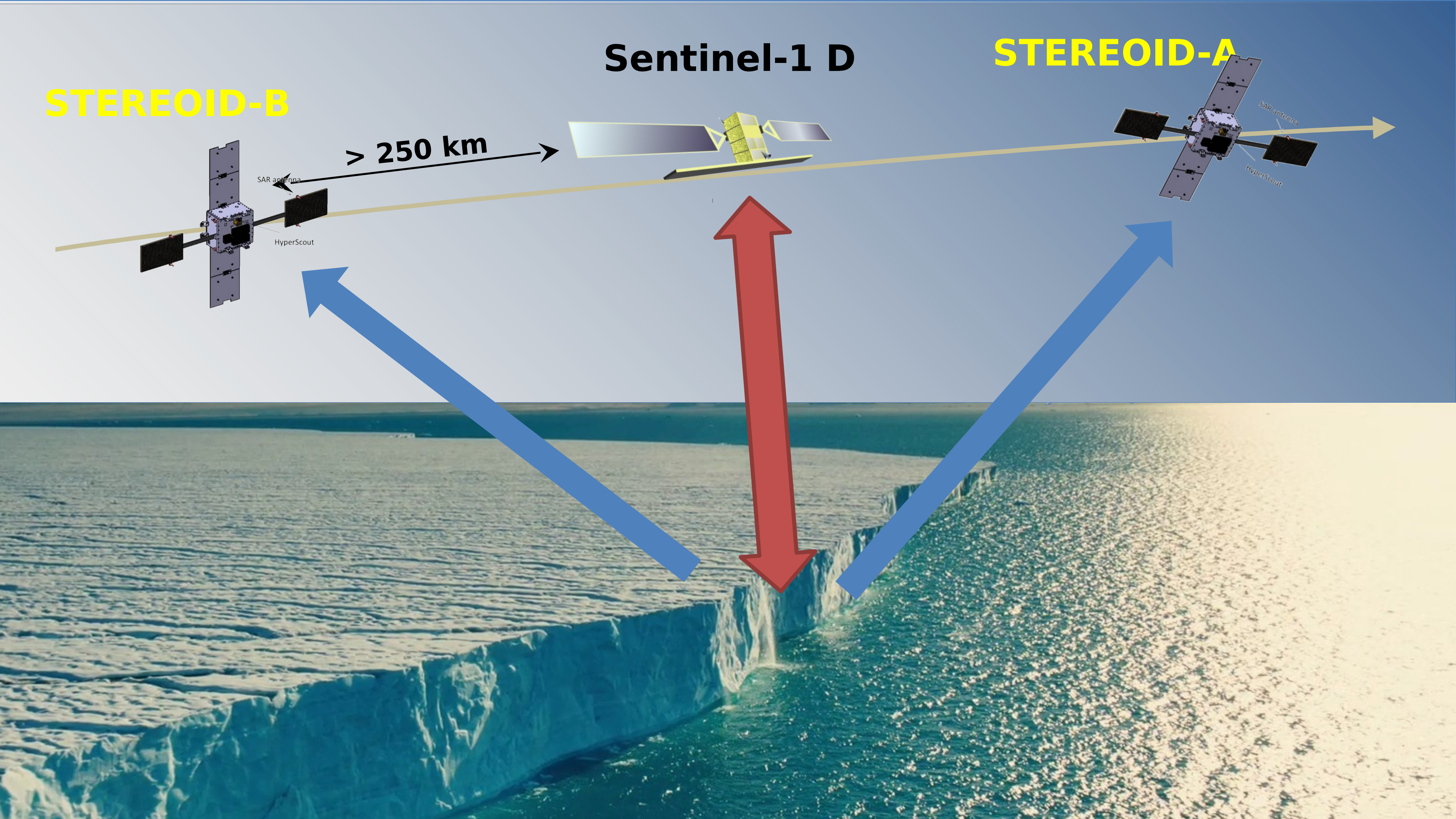
Mission architecture


Sentinel-1 D
STEREOID-A
STEREOID-B
> 250 km
SAR antenna
HyperScout

Mission objectives (1 min overview)

Solid Earth

- 3D surface deformation (volcanic, seismic, landslides)
- Sudden topographic changes

Cryosphere

- Glacier and ice sheets topography/volume/mass change
- High resolution ice flows/deformation
- Sea ice drift and topography
- Marginal Ice Zone variability

Oceans

- High resolution surface currents and wave data for coastal processes
- Small-scale (100 m to 10 km) ocean dynamics
- Surface deformation field () Divergence/strain, vorticity, shear
- Extreme weather events

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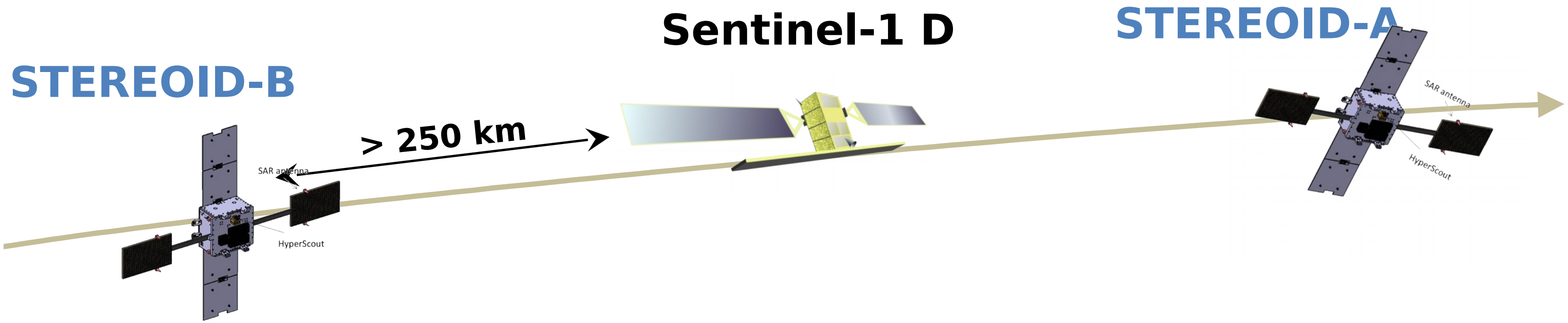
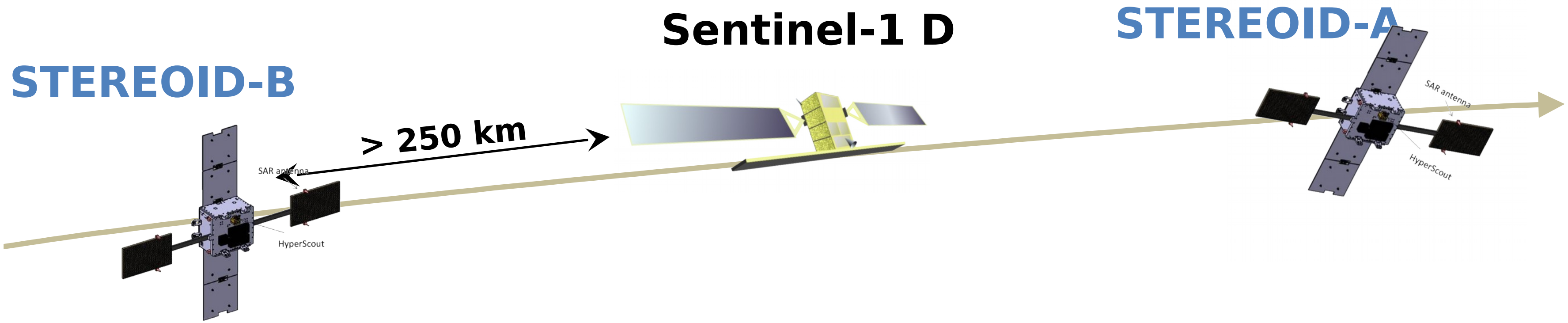
Flight configurations



- **Stereo formation**
  - Maximum line-of-sight diversity
  - Best for surface current vectors and 3-D surface deformation

Flight configurations



- **XTI formation**
  - Close-formation (TanDEM-X style)
  - Intended for DEM time-series
  - 400 m to 1 km baselines
- **ATI formation**
  - 100 m to 200 m along-track separation

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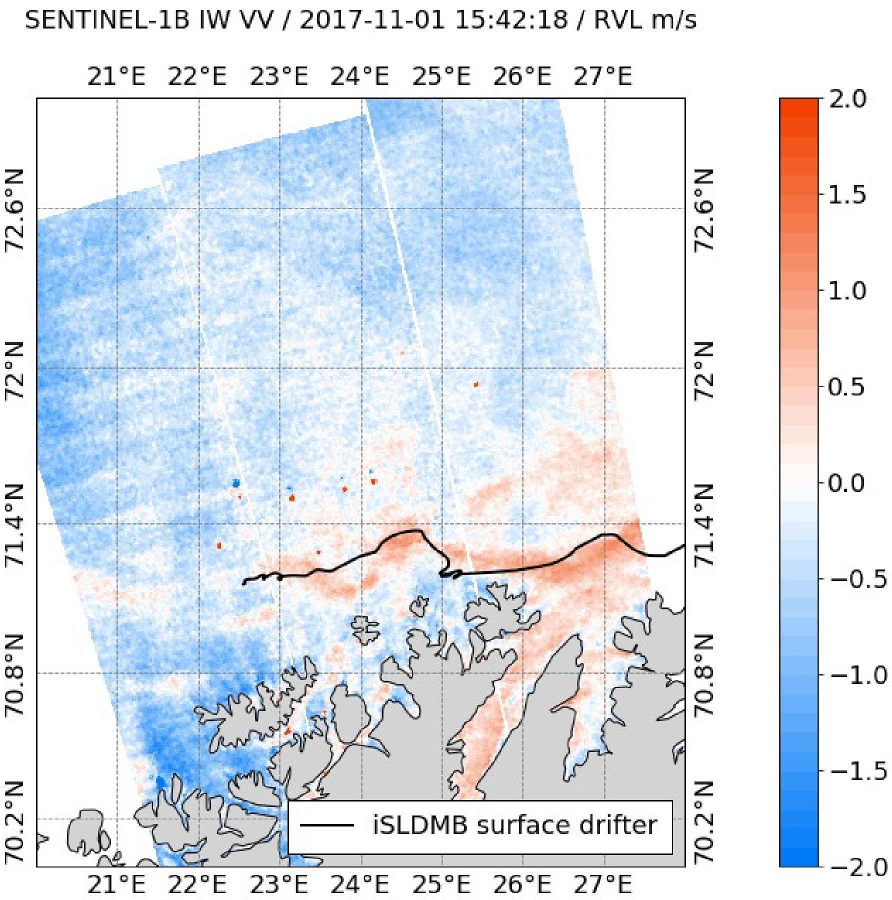
Radial velocities measured by Sentinel-1



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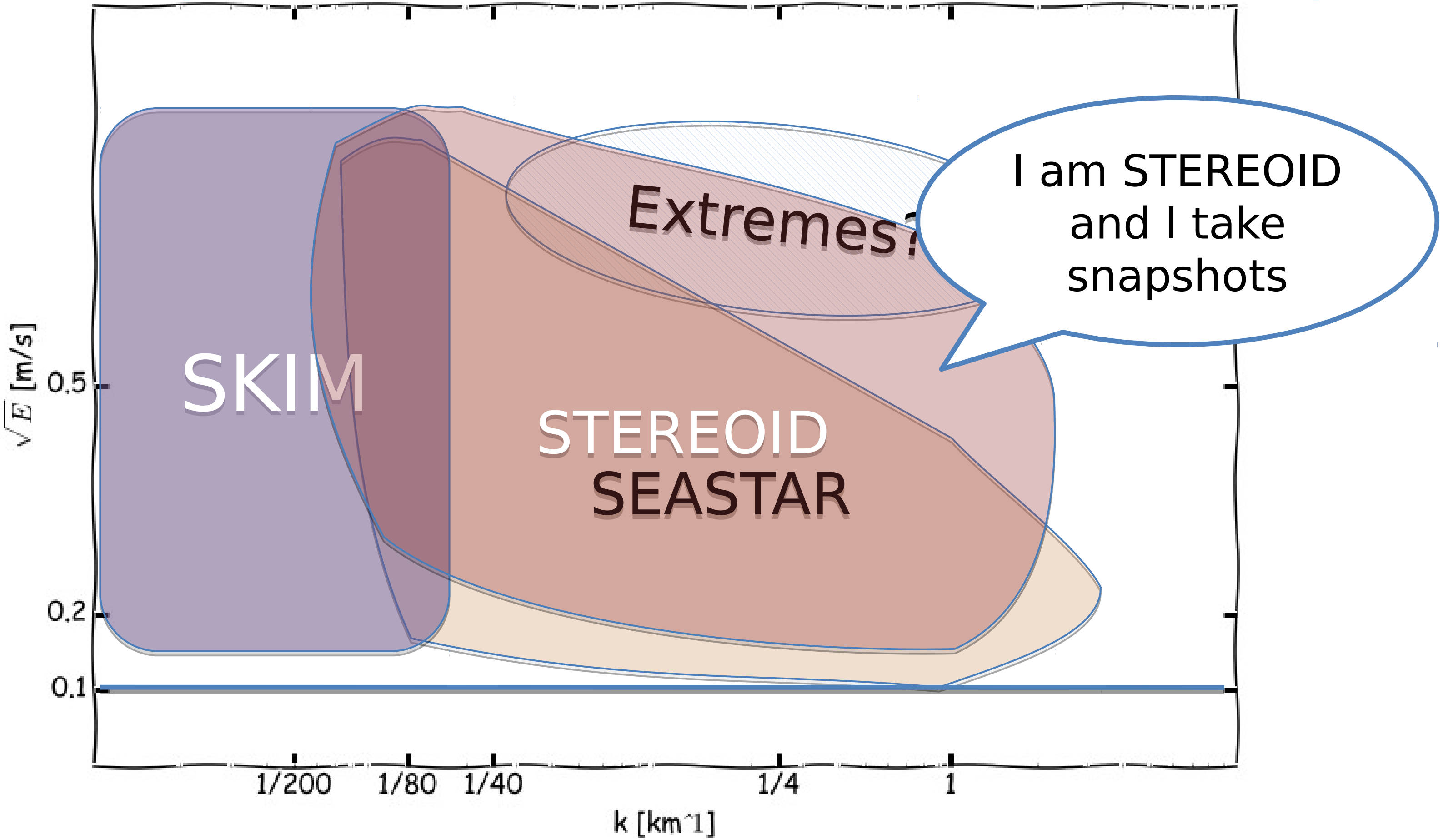
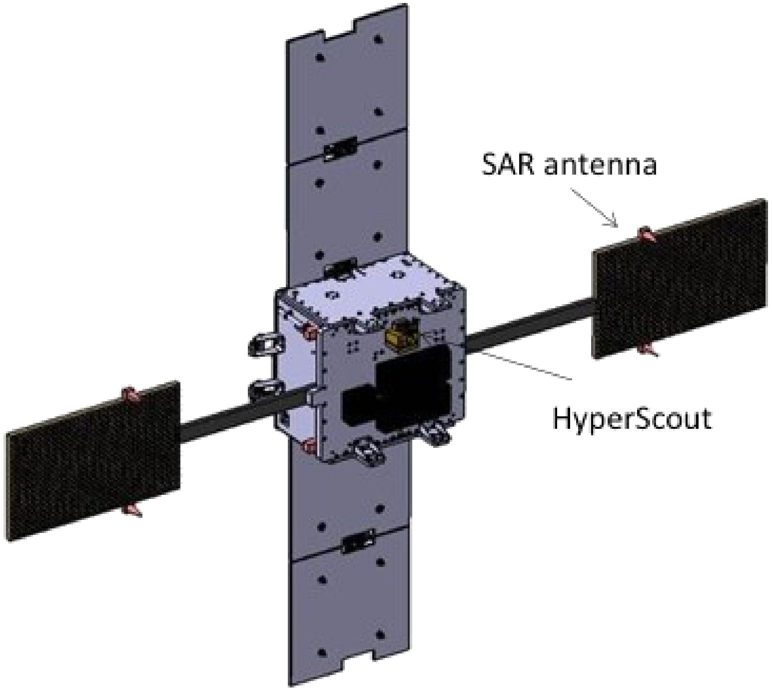
And attempt to contextualize STEREOID (TSCV)



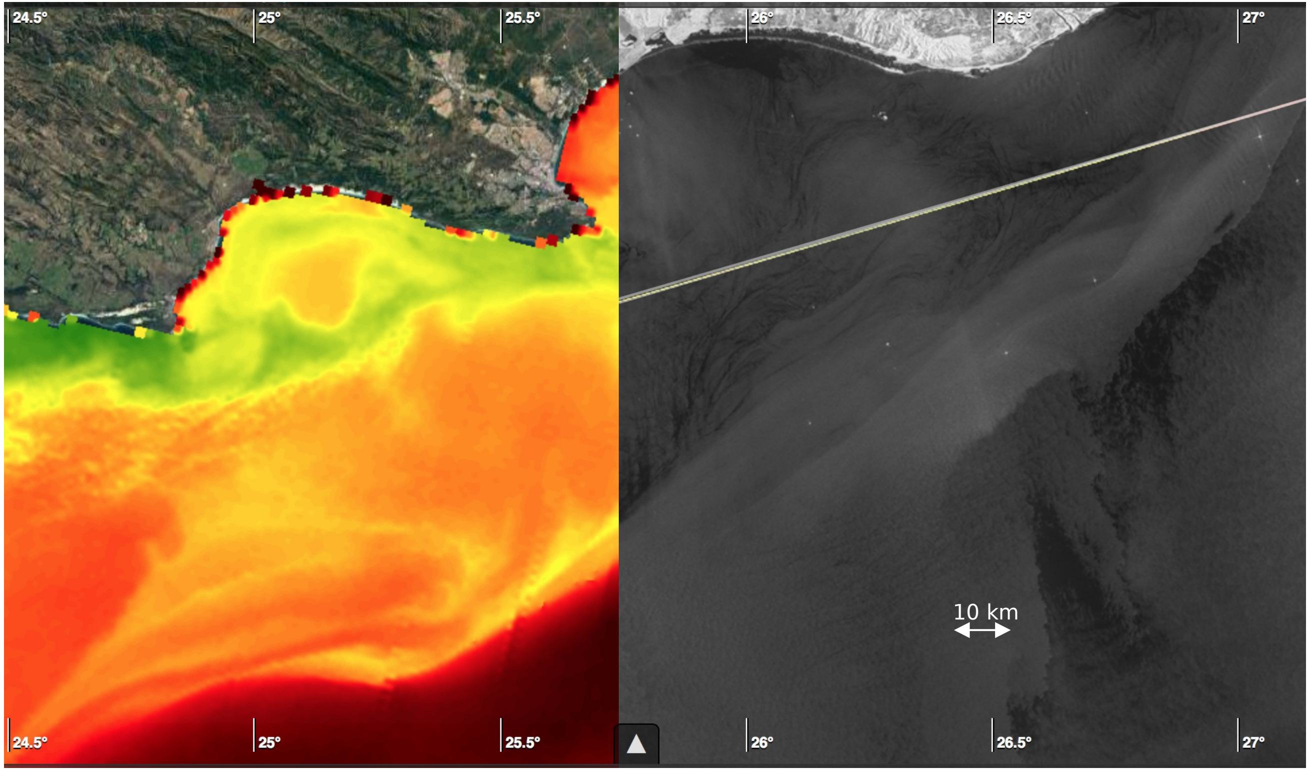
Space-segment



Platform

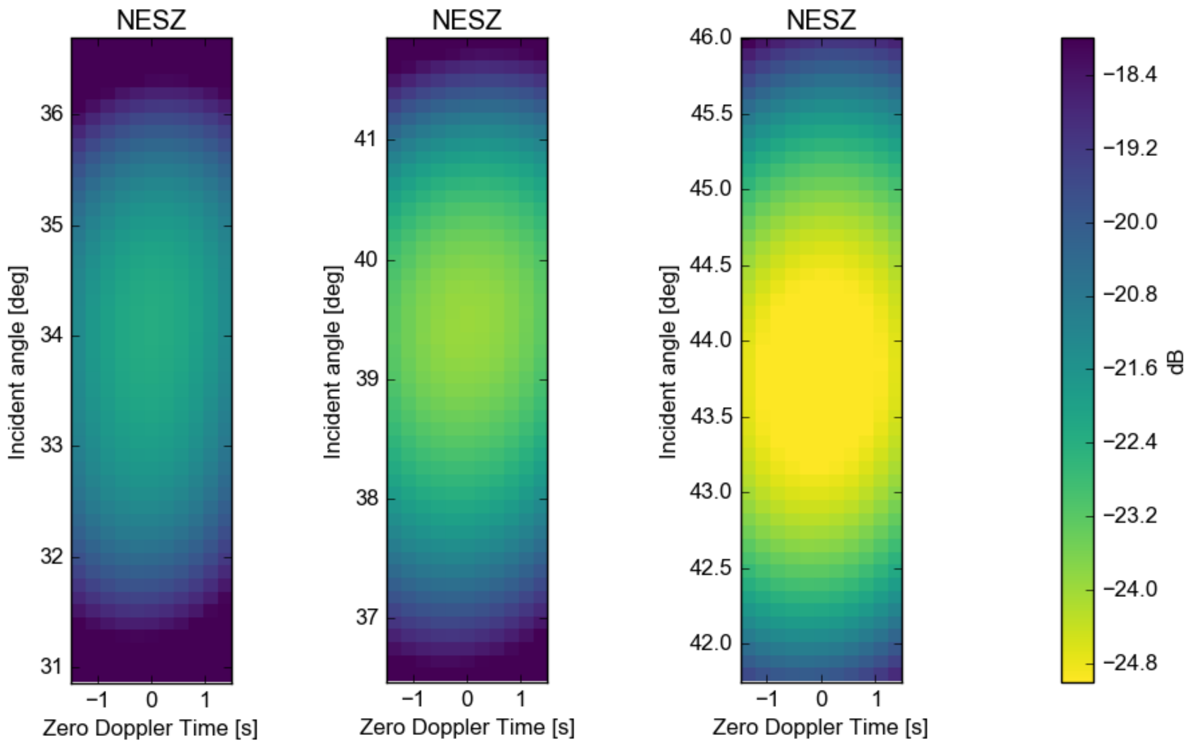
- < 500 kg
- Dual launch in Vega not an issue

TIR + radar rationale



Imaging performance: NESZ (IW mode)

sub-swath 1 sub-swath 2 sub-swath 3



Position in burst

- NESZ generally adequate to good
- Probably a bit less gain in exchange of wider elevation beams would be better.
- Or SCORE
- + 3dB for ATI mode

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Imaging performance: AASR (IW mode)

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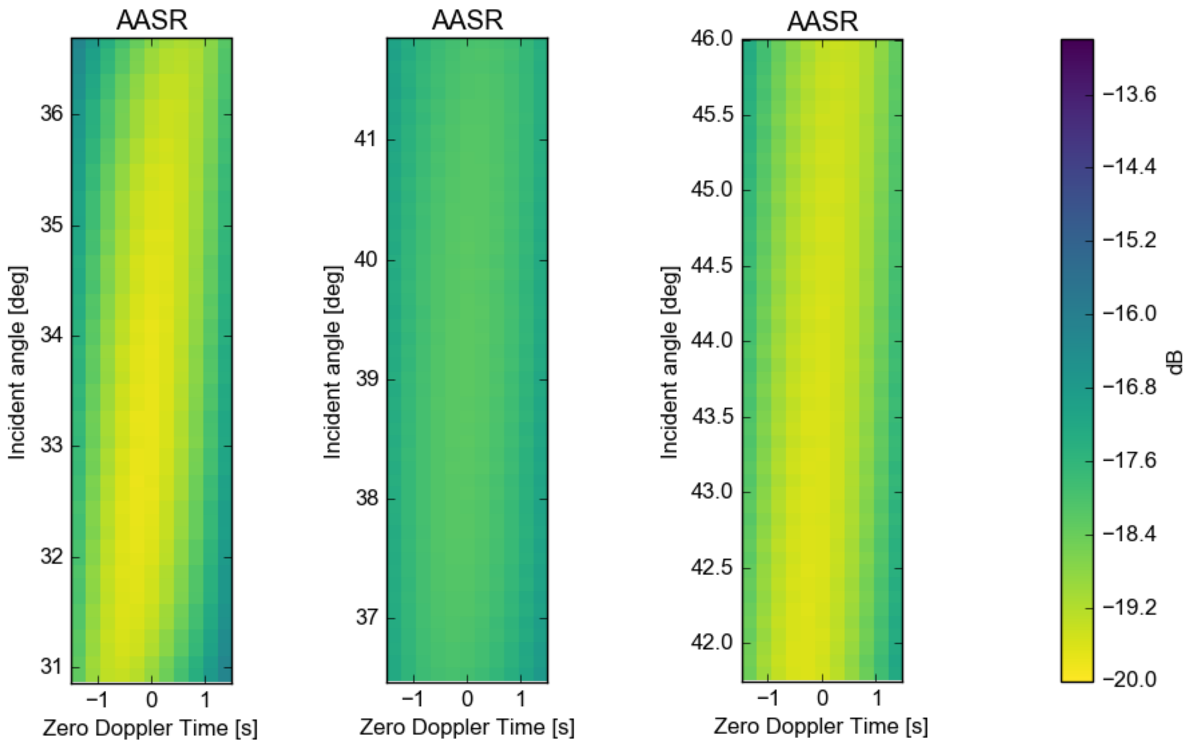
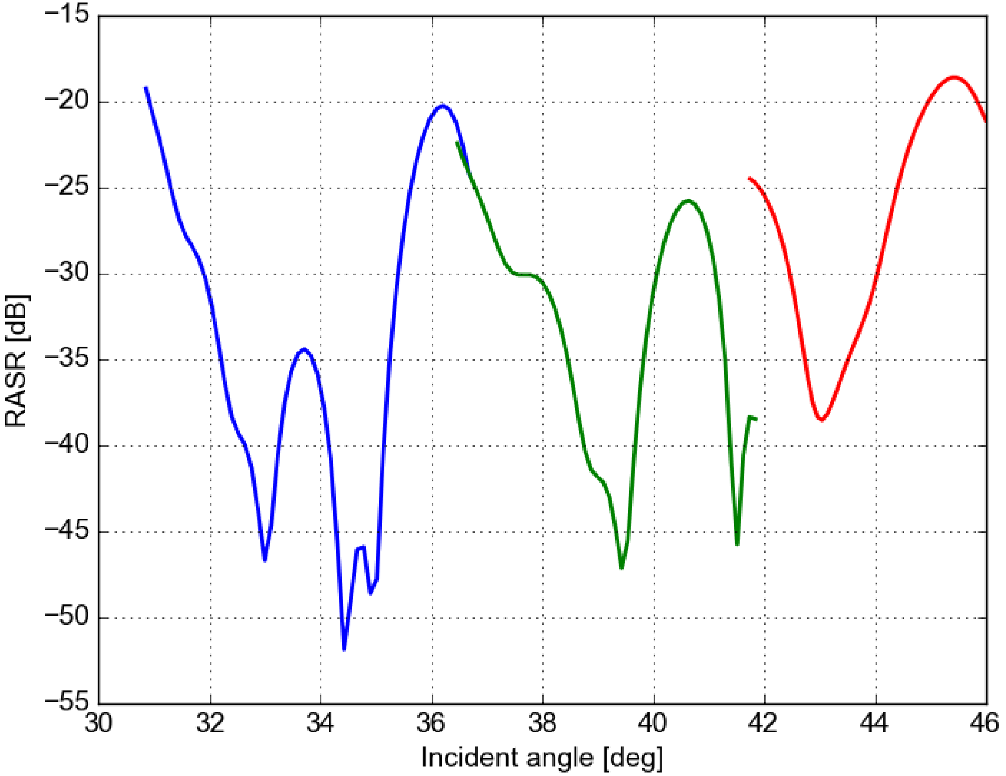


Position in burst

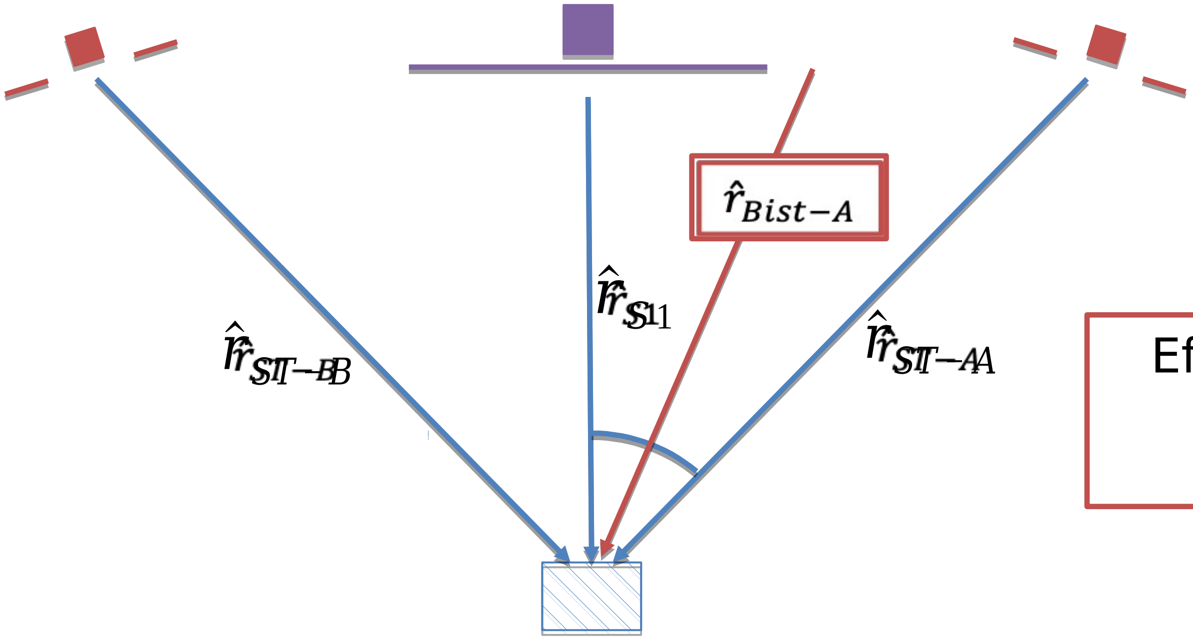
- AASR in -17 to -18 dB range.
- Quite good given small total antenna area
- Sub-swath variability due to Sentine-1 PRFs

Imaging performance: RASR



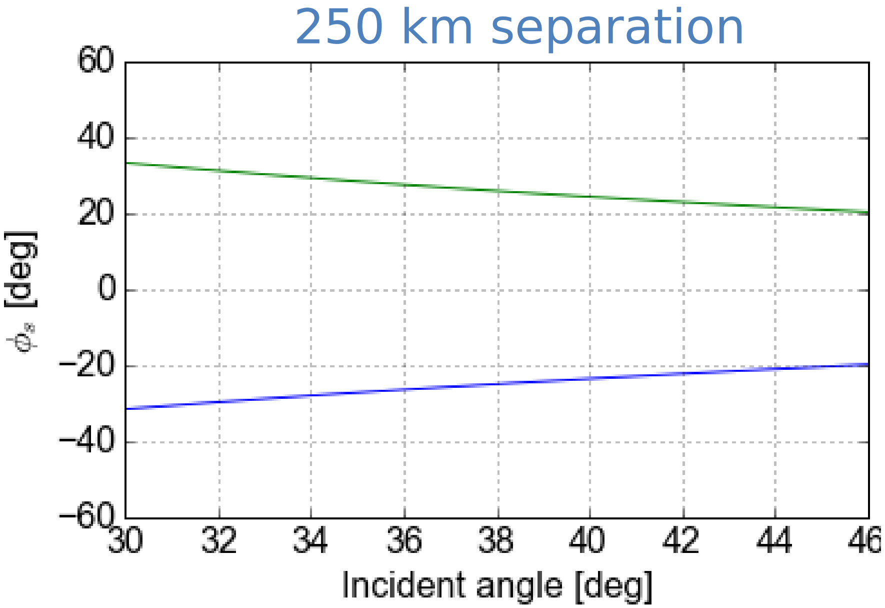
- RASR < -20 dB
- Good, but we need to accommodate large dynamic ranges (varying wind conditions)

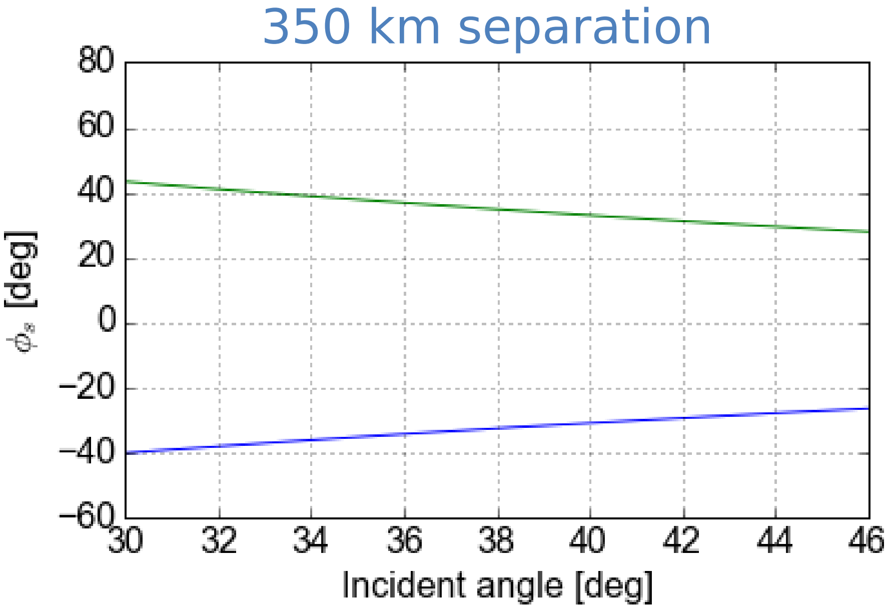
Squint angles (top view)



Effective squint angle limited by bistatic geometry

Squint angles





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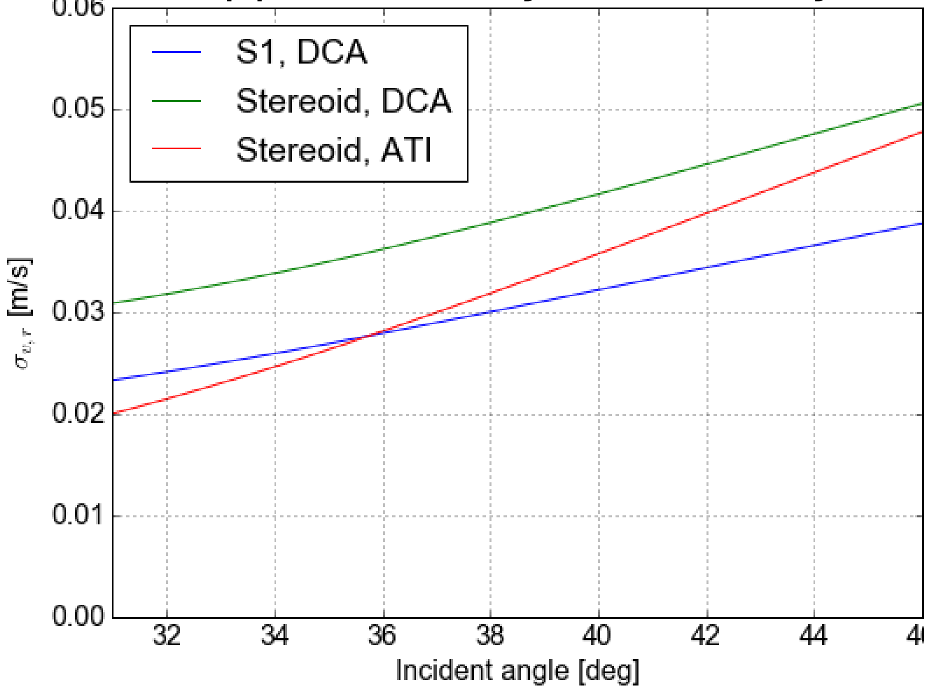
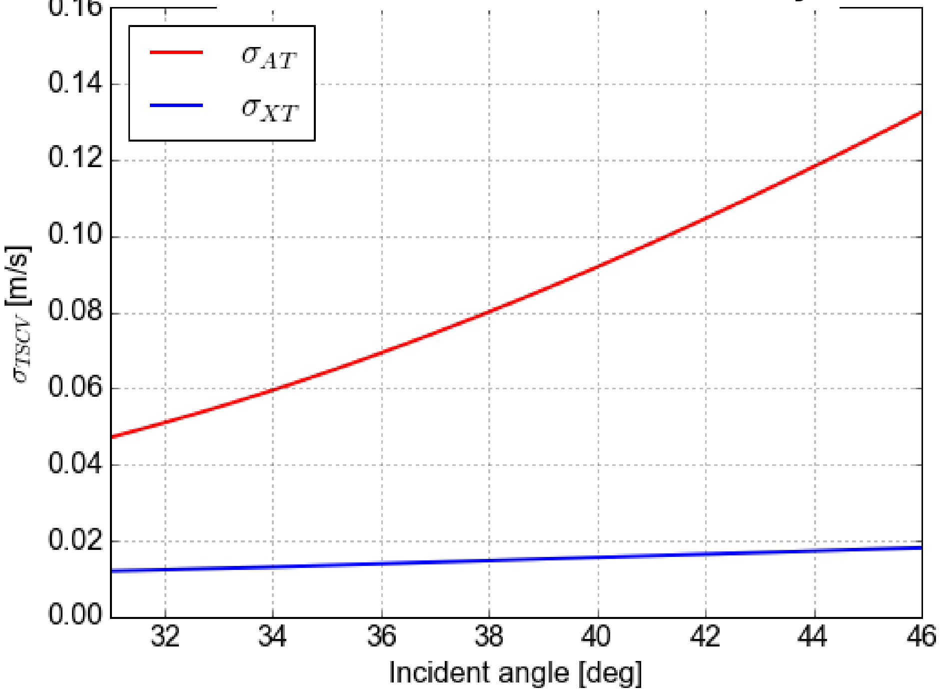
System Sensitivity (ideal retrieval)

- 3 km resolution
- 6 m/s wind
- 250 km separation

Doppler velocity uncertainty



TSCV vector uncertainty



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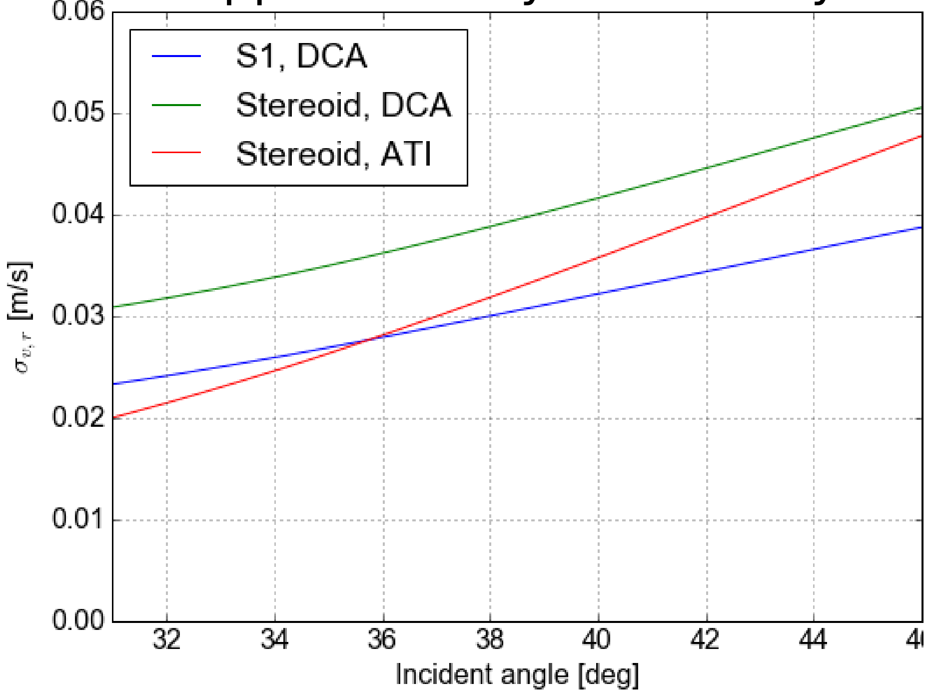
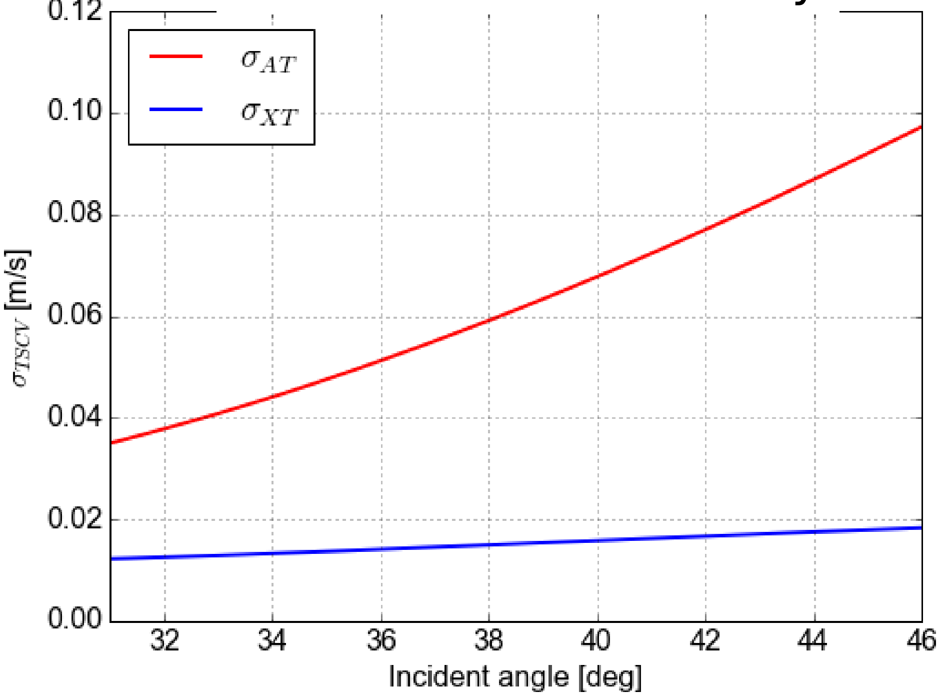


TSCV vector uncertainty



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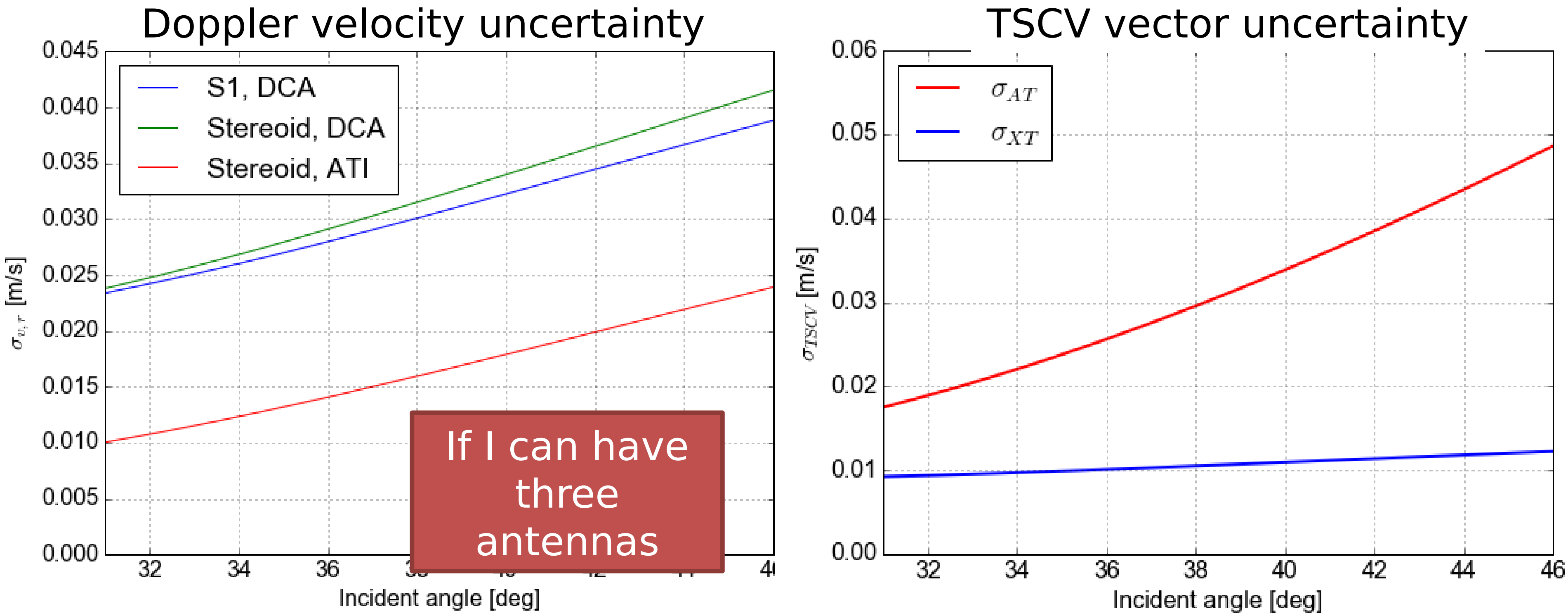

If I can have three antennas

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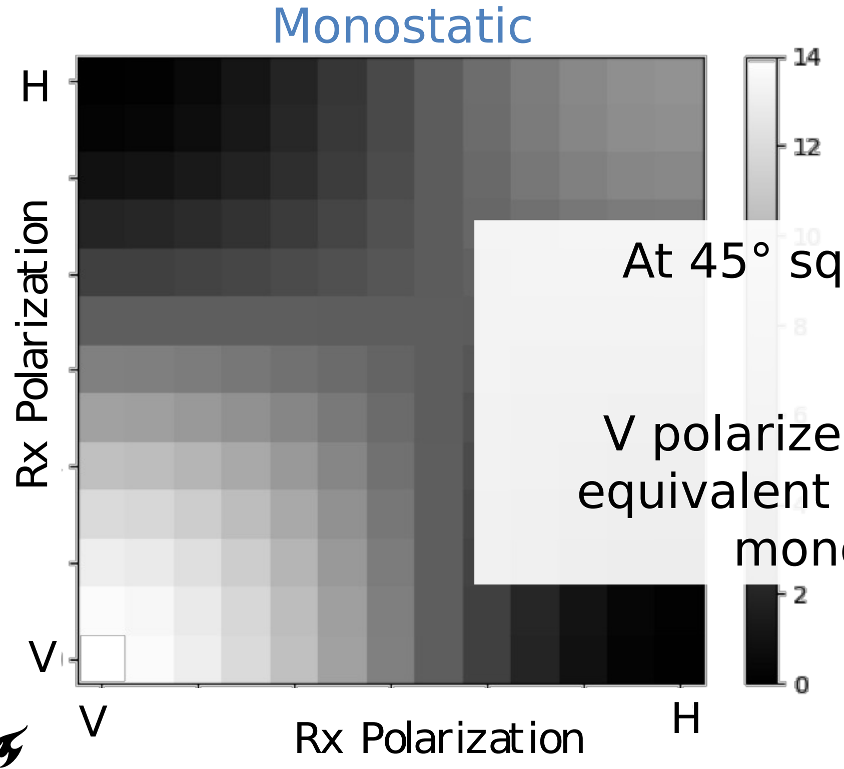
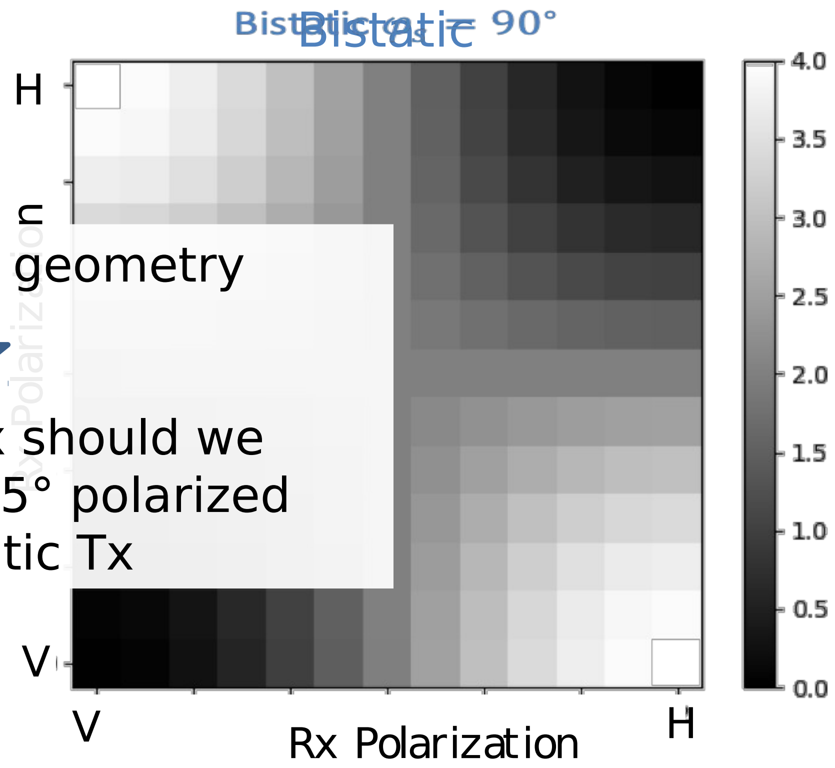
Polarimetry

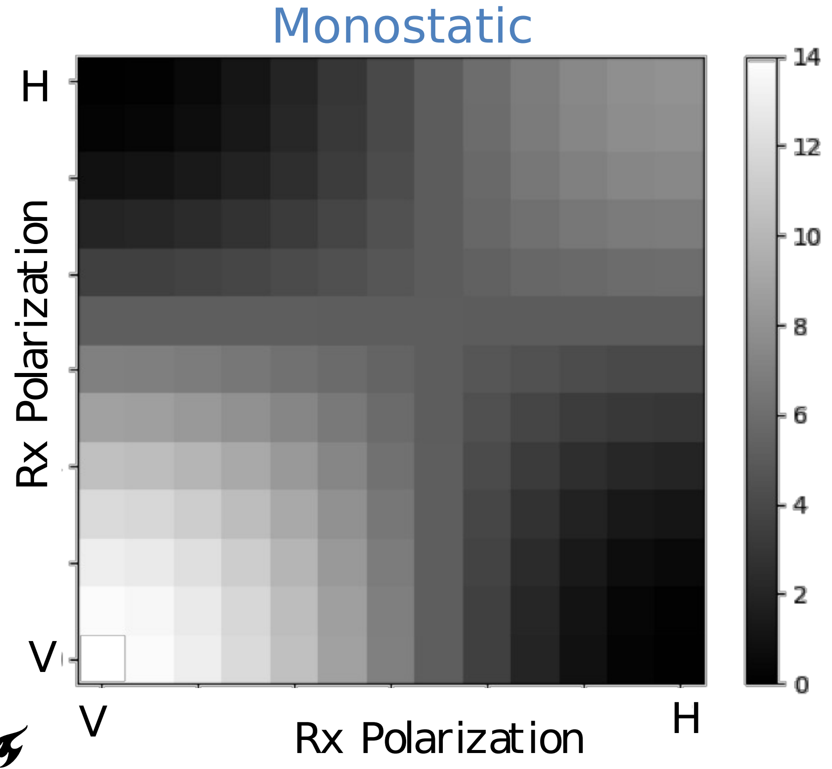


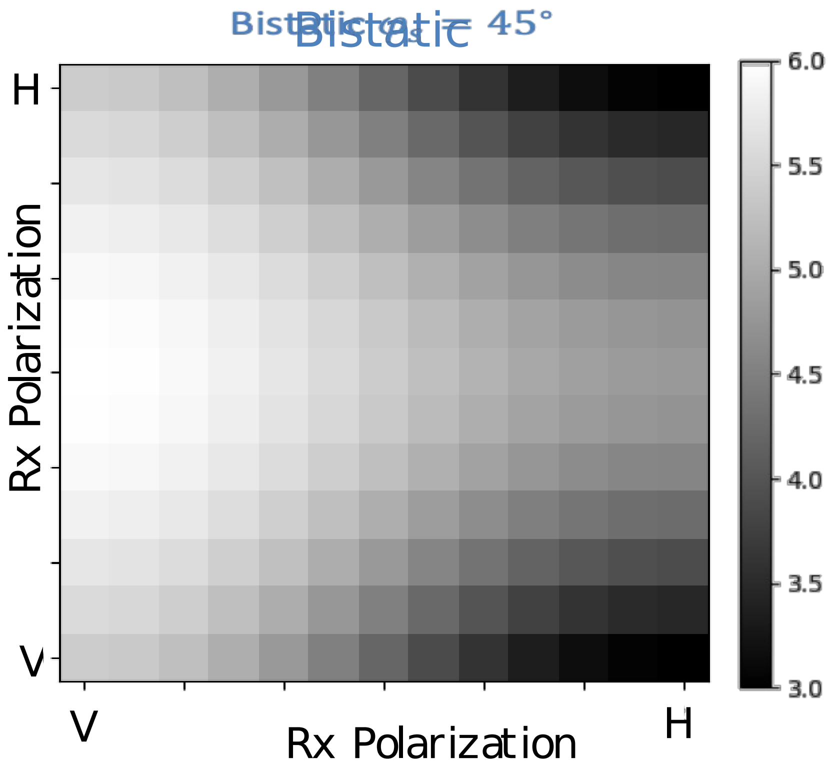


At 45° squint geometry

V polarized Tx should we equivalent to 45° polarized monostatic Tx

Polarimetry





Main sources of systematic (non-geophysical) errors

	DCA	Short-ATI	Long-ATI
Sentinel-1 pointing	Mispointings weighted by 1/beamwidths		
Companion mispointing			
Formation knowledge			Leads to ATI phase offset
Oscillator frequency offsets	Is a point of concern, but seems technically solved		

But emphasis on gradients

We can mostly live with low-pass systematic errors

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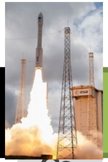
Outlook, status

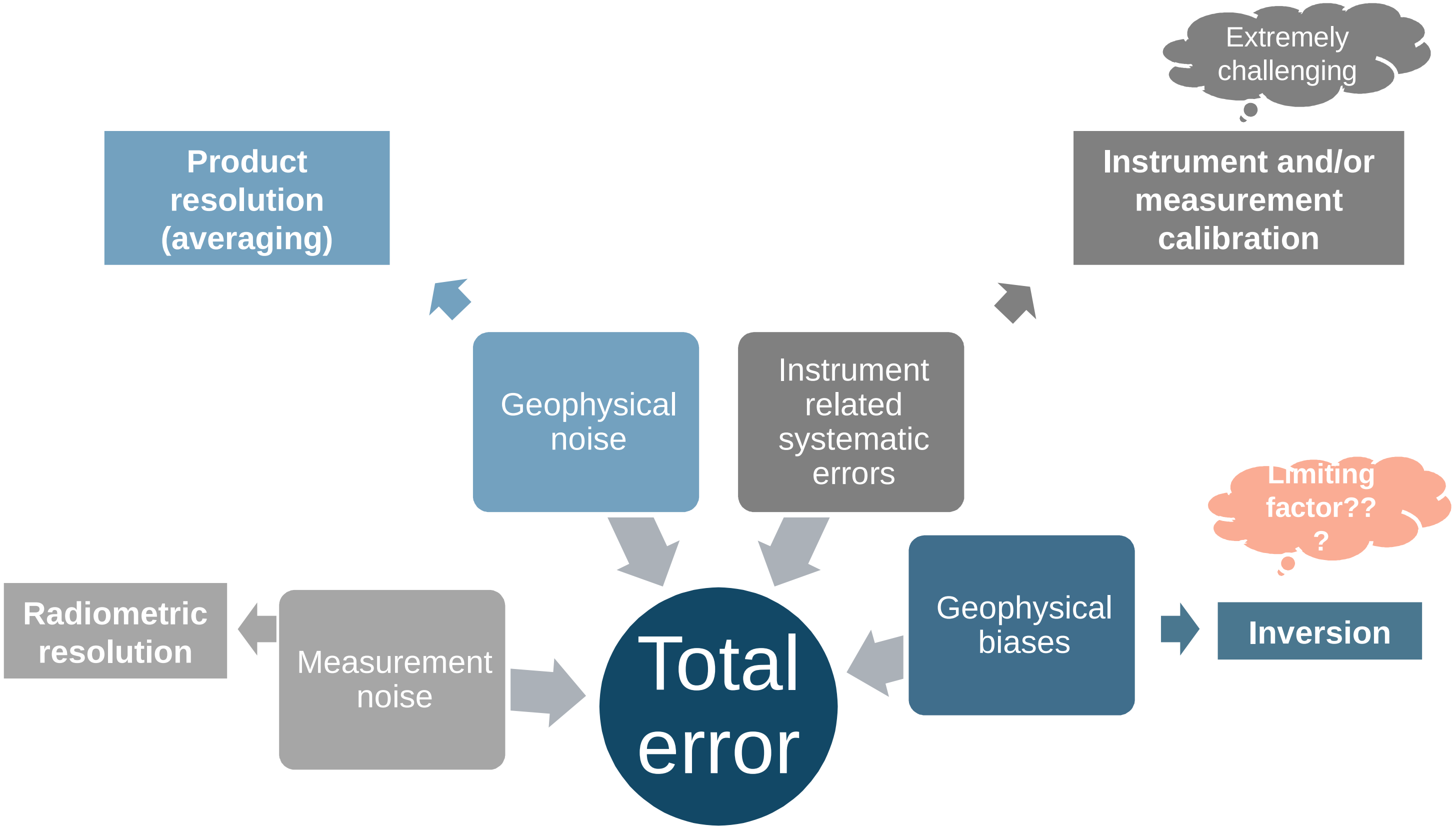
- Phase-0 science and system stu… …rently under preparation to be kicked-o…
- No technical show-stoppers up to…
- Exciting and challenging science.
- A true Earth Explorer, serving multiple communities

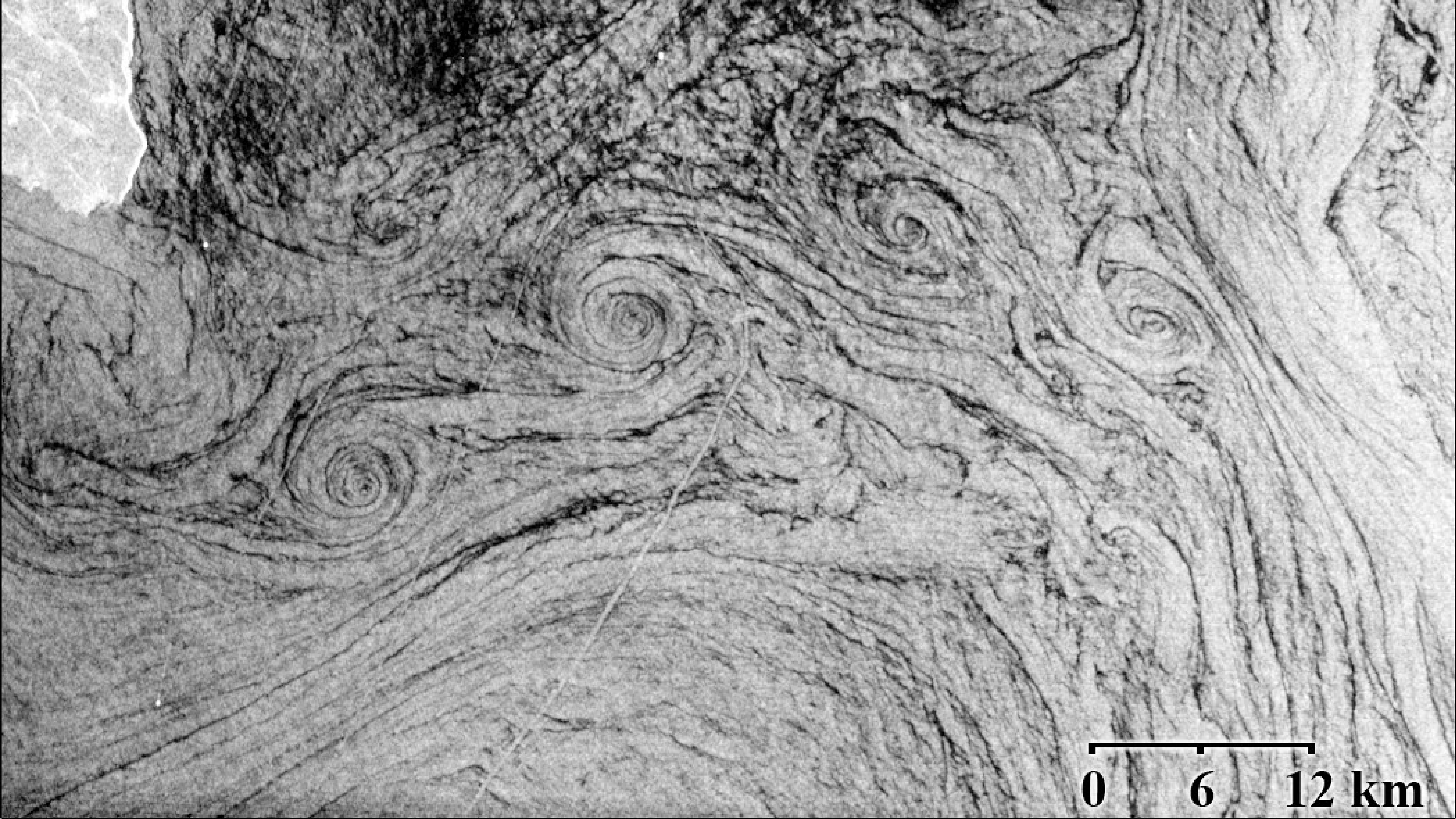
Call for MAG members now open!!!

Phase-0 | Phase-A | Phase-BCDE | Exploitation

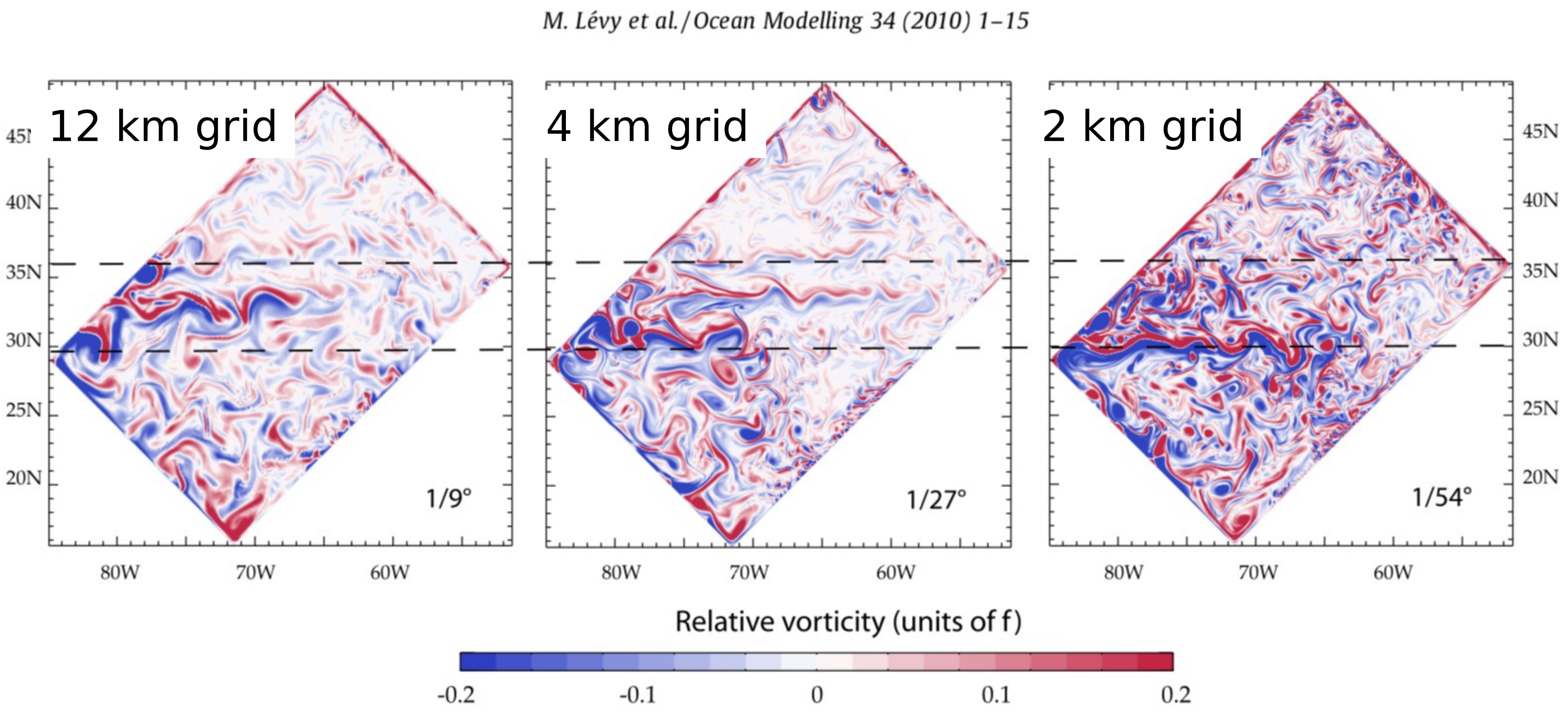


2020 | 2022 | 2028


Extremely challenging
Product resolution (averaging)
Instrument and/or measurement calibration
Geophysical noise
Instrument related systematic errors
Limiting factor???
Radiometric resolution
Measurement noise
Total error
Geophysical biases
Inversion


0 6 12 km

The value of resolution (for example, vorticity)



Main open issue: (wind) wave bias

- Problem:

$$v_{\text{Doppler}} = v_{\text{Wave-Bias}} + v_{\text{TSC}}$$

- Approaches being studied
  - Measure waves → estimate bias
  - Estimate wind from backscatter → model waves → estimate bias
  - Exploit polarimetric dependency of wave-bias

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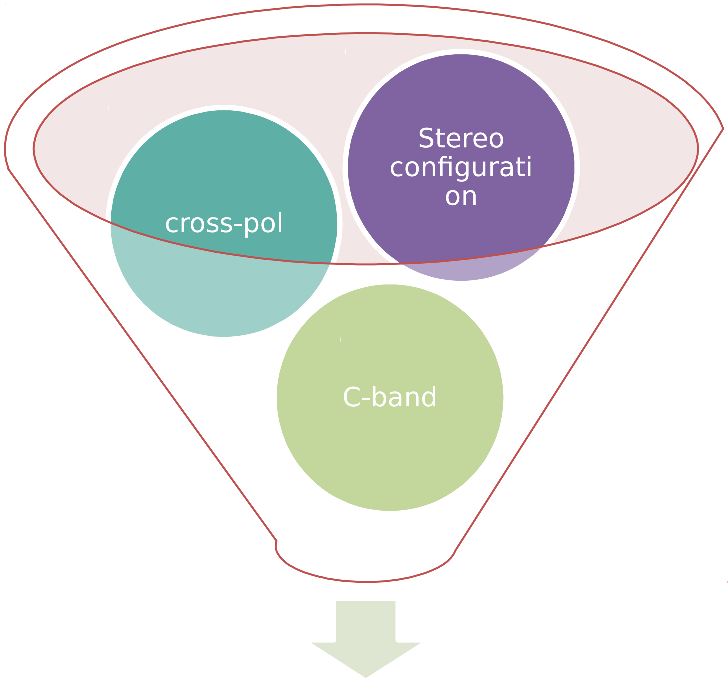
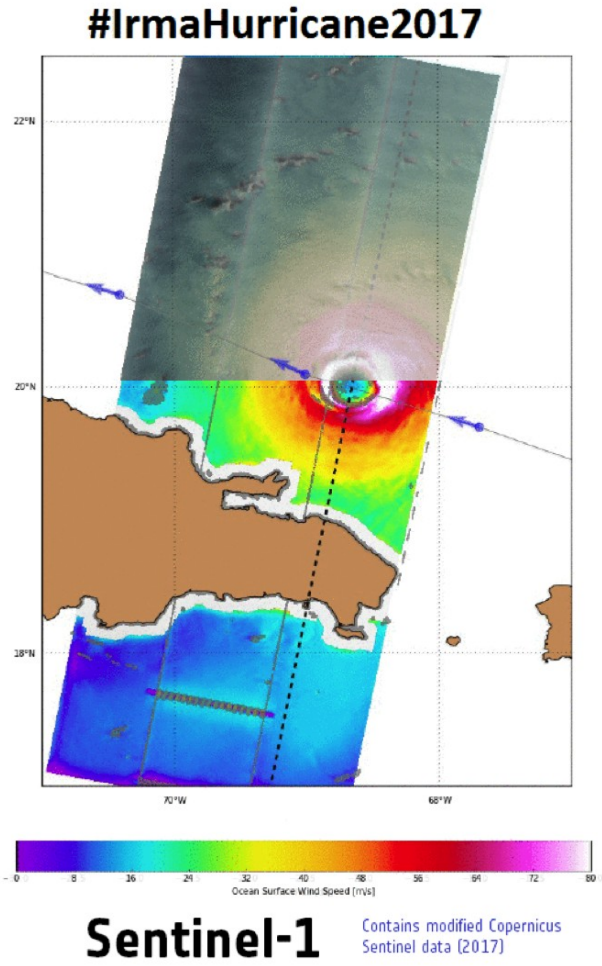
Extreme weather [Stereo]



Surface winds + TSCV

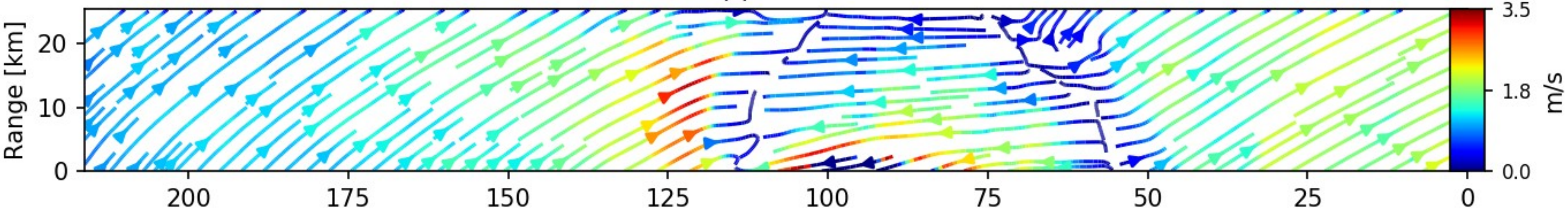


Main open issue: (wind) wave bias

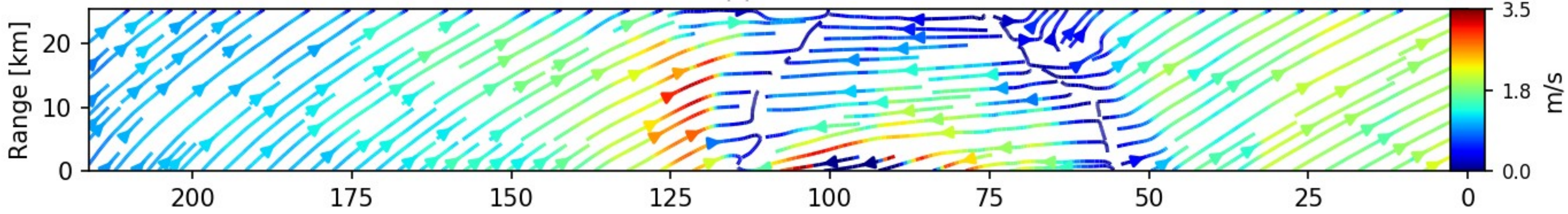
- Problem:

$$v_{\text{Doppler}} = v_{\text{Wave-Bias}} + v_{\text{TSC}}$$

TanDEM-X experimental dual-beam Doppler field

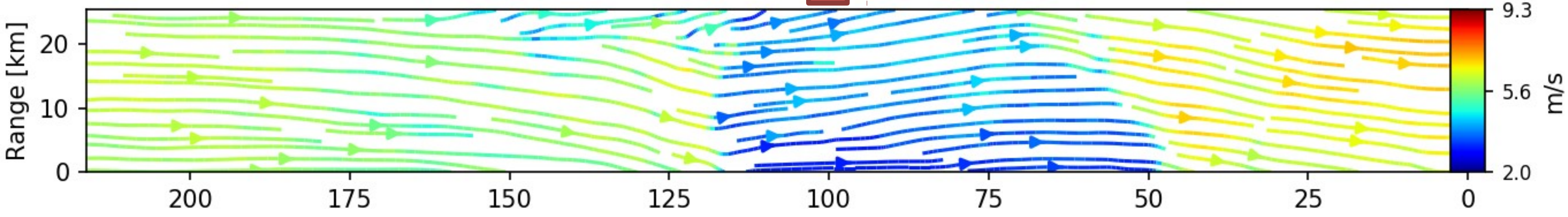


Measured Doppler field



Wind to Doppler mapping using Asymptotic model

Estimated wind



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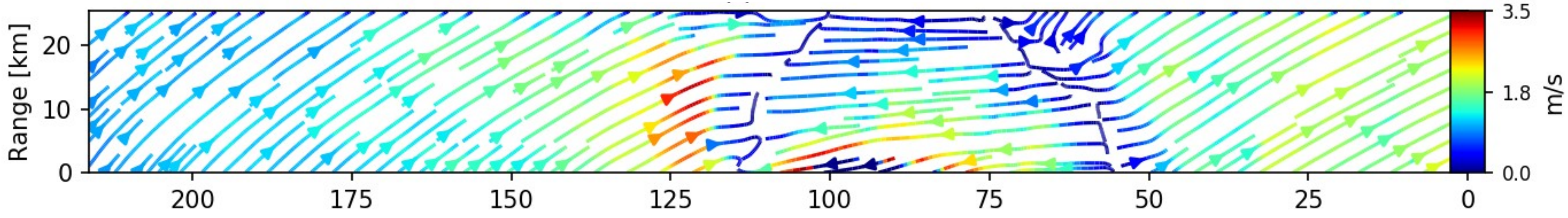
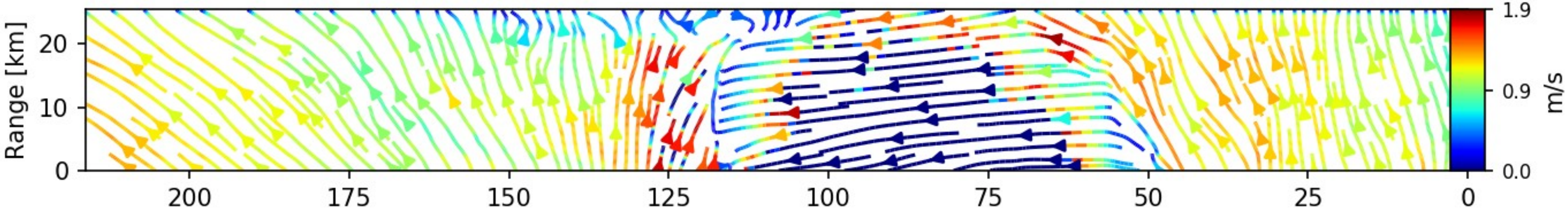
Measured Doppler field



Estimated current



Space-segment side challenges

- **Formation flying**
  - Formation safety
  - Cross-track baseline knowledge
  - Common Doppler and along-track baseline control
- **Synchronization**
  - Phase
  - Echo window
- **SAR performance**
  - Sensitivity
  - Ambiguities

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Formation flying: cross-track baseline knowledge

- LOS baseline error translates directly into phase error:

$$\Delta\phi = 2\pi \cdot \frac{\Delta B_{\parallel}}{\lambda_0}$$

$$\epsilon_h = R \cdot \sin\theta_{inc} \cdot \frac{\Delta B_{\parallel}}{B_{\perp}}$$

Baseline rotation

- $R \sim 800$ km
- $B_{\perp}$ 200 m to 400 m
- Target $\epsilon_h \sim 10$ cm

Baseline knowledge requirement from O(0.1 mm))

Common Doppler loss

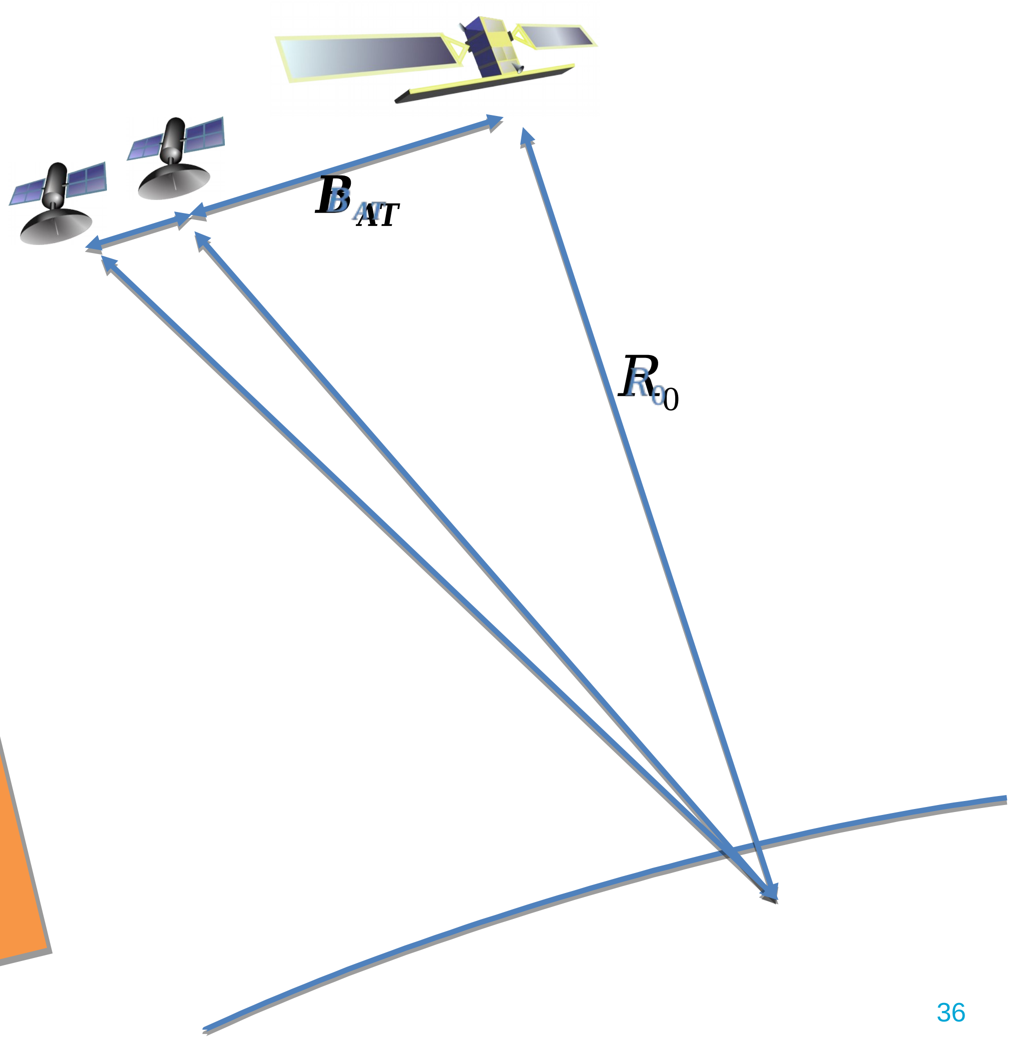
$$\Delta f_{Dop} = \frac{v_{orb}}{\lambda} \cdot \frac{B_{AT}}{R_0}$$

Should be small compared to processed Doppler bandwidth.

TOPS
SESAME

$$B_{AT} \ll \frac{\lambda \cdot R_0}{v_{orb}} \cdot B_{proc}$$

For SESAME
O(300 m)
separation
OK



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Space-segment side challenges

Formation flying			Synchronization		SAR performance	
Formation safety	Cross-track baseline knowledge	Common Doppler and along-track baseline control	Phase	Echo window	Sensitivity	Ambiguities

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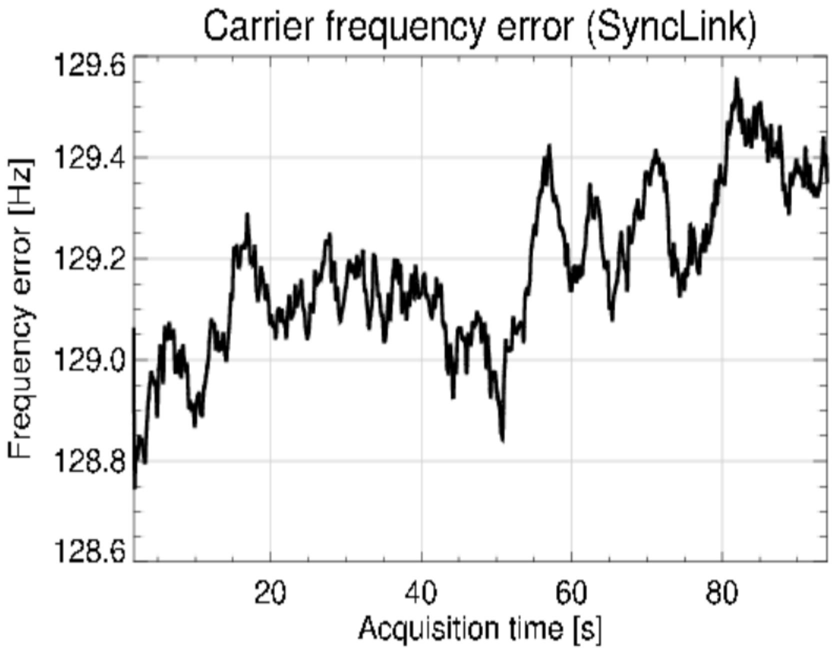
Phase synchronization



From TanDEM-X SyncLink

Frequency and phase synchronization always a critical issue.

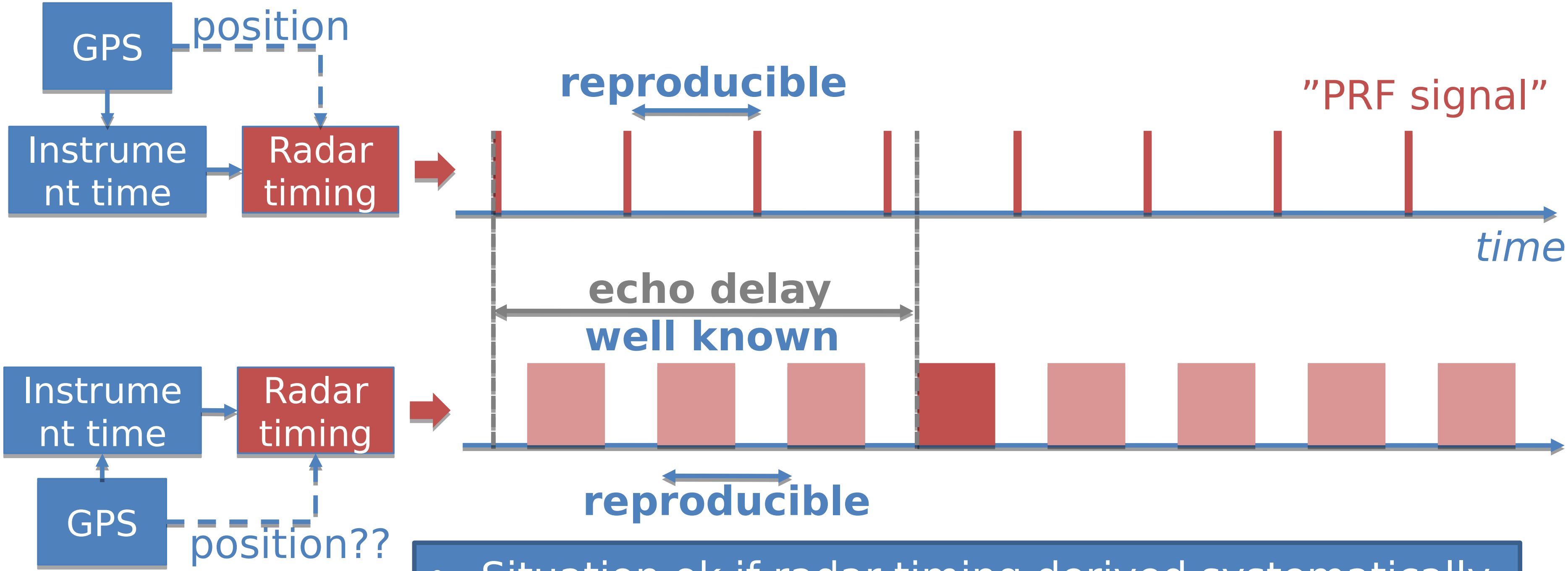
Carrier frequency and phase synchronization: lessons we think we have learnt

- GPS tagging/disciplining ➡ Frequency offsets

- Data driven (AutoSync, etc) ➡ Relative phase errors
  - Often good enough
  - Issues for sure

- Explicit synchronization link
  - Two way synchronization between receivers needed

Echo window synchronization



- Situation ok if radar timing derived systematically from GPS-referenced instrument time
- Position derived timing potential trouble maker.

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Technical challenges

Formation flying

- Formation safety
- Cross-track baseline knowledge
- Common Doppler and along-track baseline control

Synchronization

- Phase
- Echo window

SAR performance

- Sensitivity
- Ambiguities

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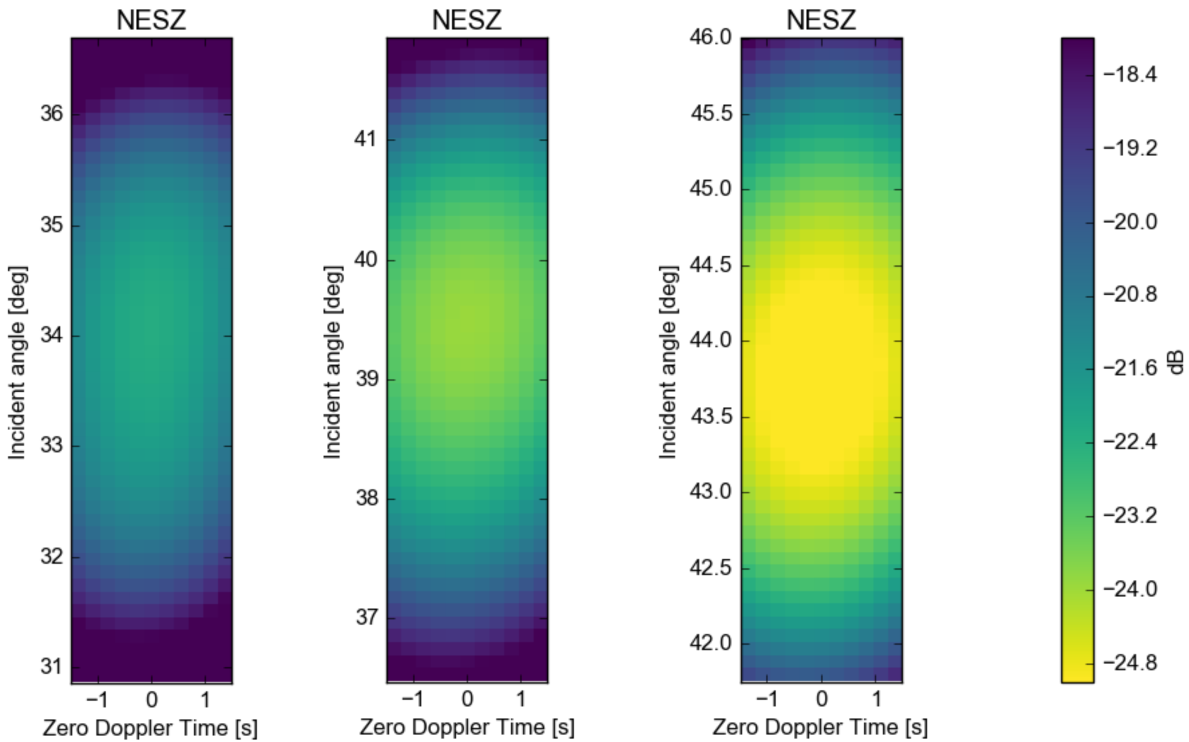
Imaging performance: NESZ (Imaging mode)

sub-swath 1 sub-swath 2 sub-swath 3



Position in burst

- NESZ generally adequate to good
- Probably a bit less gain in exchange of wider elevation beams would be better.
- Or SCORE
- + 3dB for ATI mode

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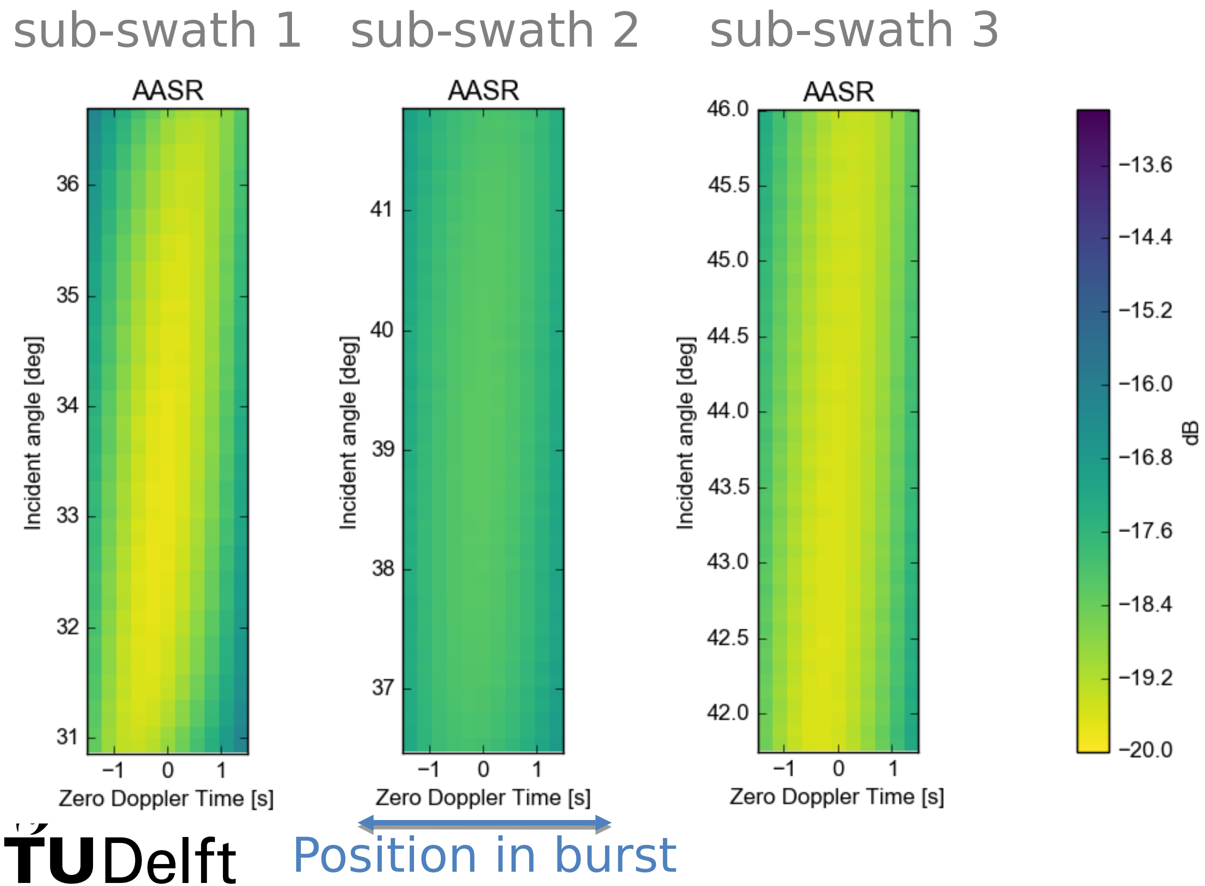

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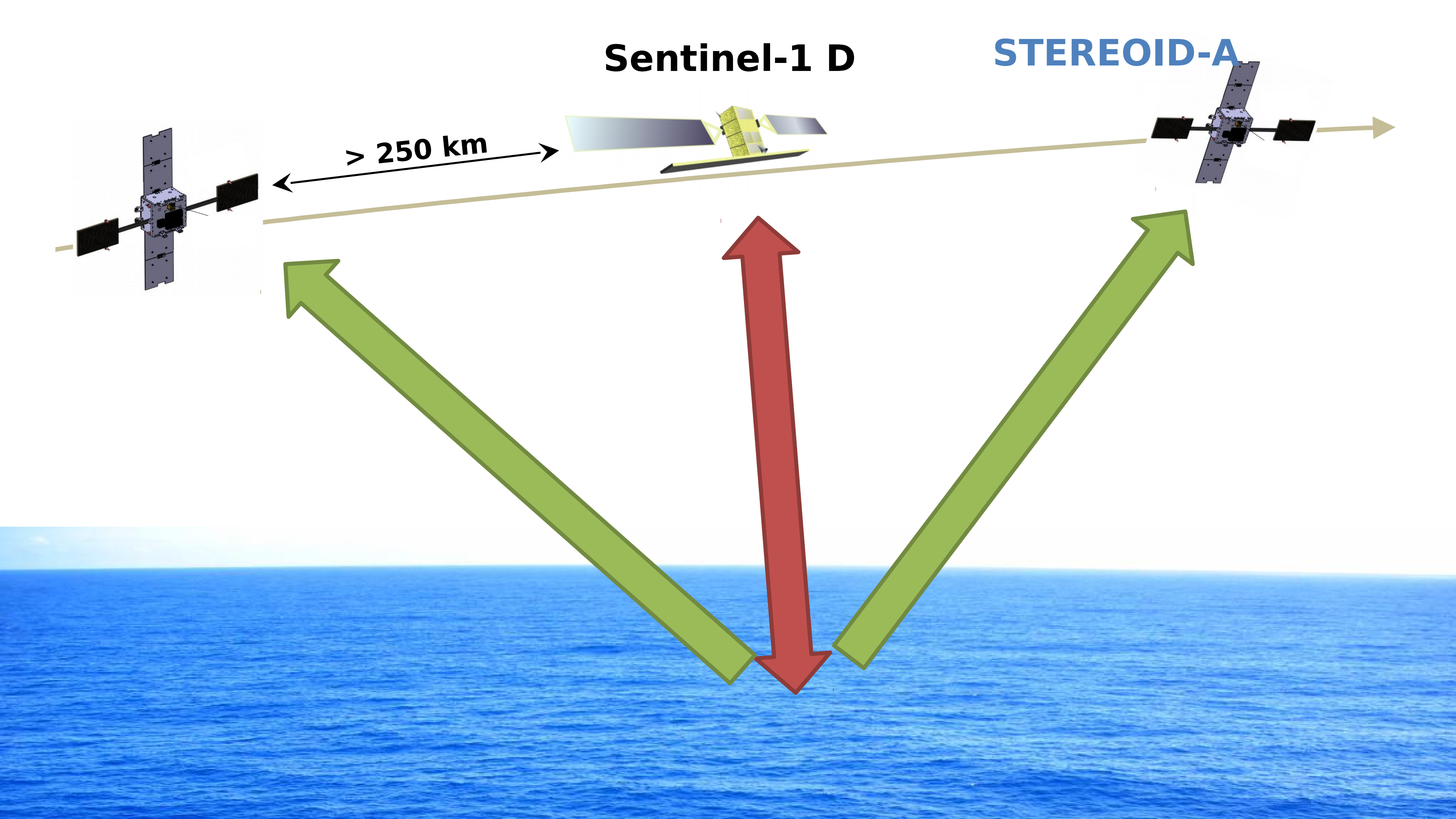
- Quite good given small total antenna area
- Sub-swath variability due to Sentine-1 PRFs


Sentinel-1 D
STEREOID-A
> 250 km