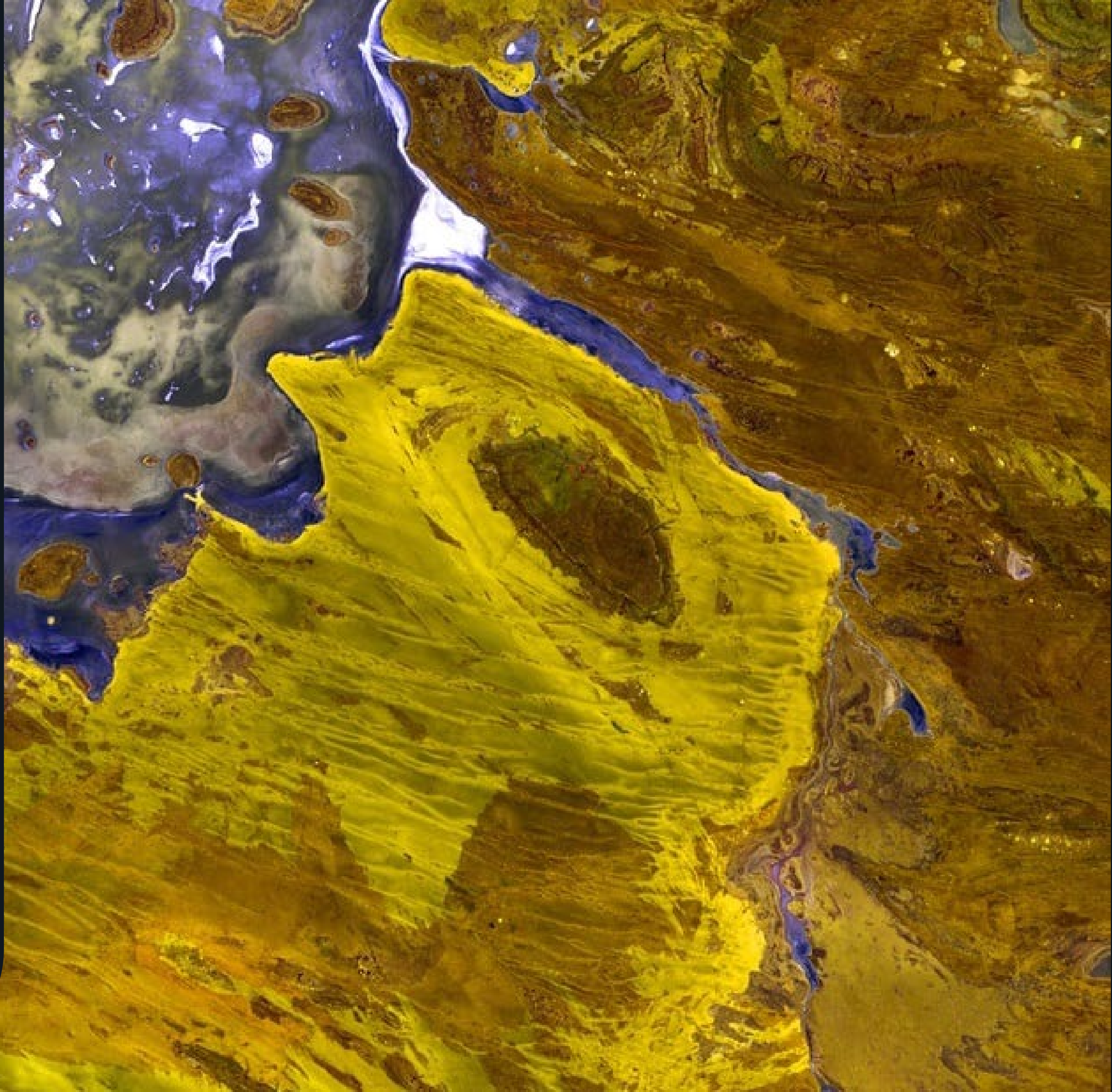
Enabling 3D Deformation Monitoring with the CHORUS SAR Constellation

Fernando Greene Gondi, Jayson Eppler, Ron Caves and MDA CHORUS TEAM
Fringe
2023.09.14

TABLE OF CONTENTS

SECTION 1

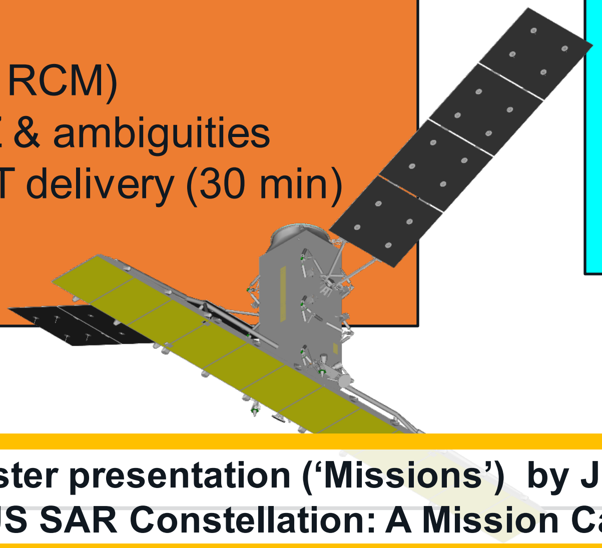
CHORUS MISSION OVERVIEW



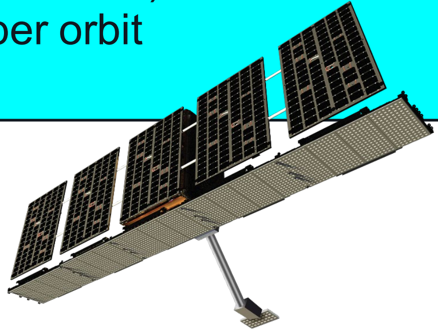
CHORUS Constellation Mission

- Building upon the substantial heritage of the RADARSAT program, MDA is developing CHORUS, a next generation commercial SAR mission to
  - Provide continuity for current users of RADARSAT-2
  - Better address emerging needs of the geointelligence market
- The CHORUS constellation is a dual-frequency mission including both a C-band and an X-band SAR satellite

CHORUS-C
- RADARSAT 4th generation
- Designed, built, owned and operated by MDA
- Broad area coverage, up to 700 km swath
- Right- and left-look
- Dual-aperture on receive (2 x RCM)
- Stepped receive: lower NESZ & ambiguities
- Fast tasking (1 hour) and NRT delivery (30 min)
- Imaging 20 minutes per orbit
- 2x 300 Mbps downlink



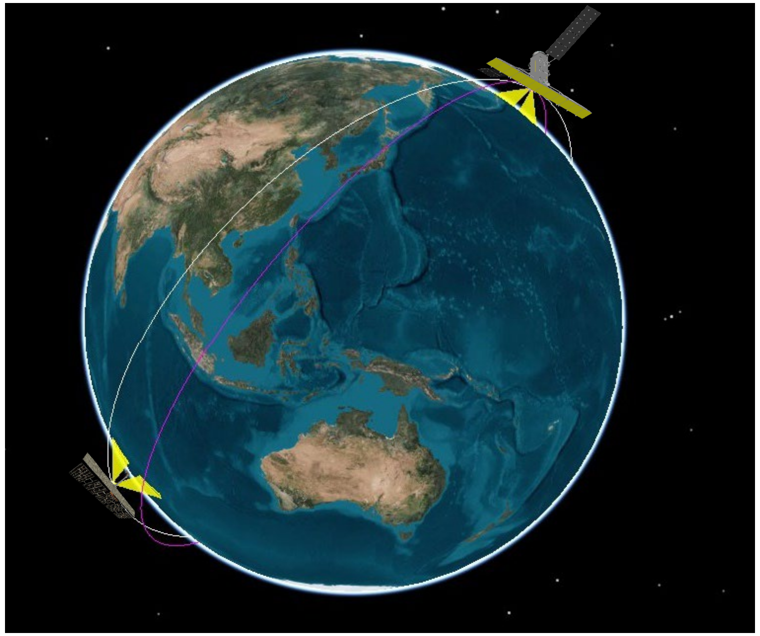
CHORUS-X
- Supplied by leading commercial X-band SAR provider
- Sub-metre resolution
- Right- and left-look
- Trailing CHORUS-C ground track by 1 hour
- Tip and cue from CHORUS-C
- Very fast tasking (<< 1 hour) & NRT delivery (30 min)
- Imaging 3 minutes per orbit
- 500 Mbps downlink



See poster presentation ('Missions') by Jayson Eppler et al.: CHORUS SAR Constellation: A Mission Capability Overview

CHORUS Orbit

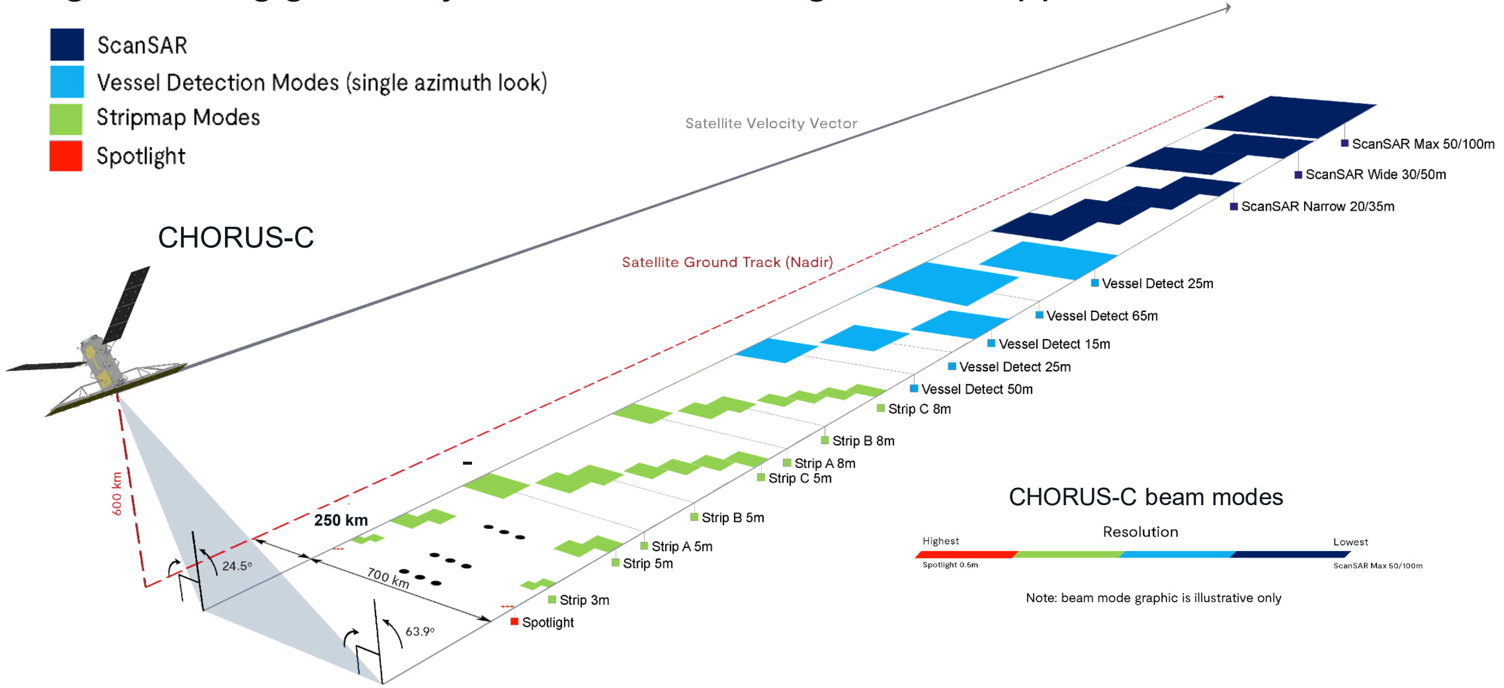
Parameter	Value	Comment
Altitude	~600 km	Similar to RCM
Inclination	53.5°	Medium inclined prograde (W to E) non-sun-synchronous orbit. Access to ± 62.5 deg latitude.
Local time at nadir	Variable	Decreasing by about 20 minutes per day
Repeat cycle	9.85 days (147 orbits)	Much shorter than RADARSAT-2 (24 days). Balances access with revisit time, incidence angle diversity and change detection latency.
Phasing	1 hour	Same ground track but with CHORUS-X trailing CHORUS-C by 1 hour

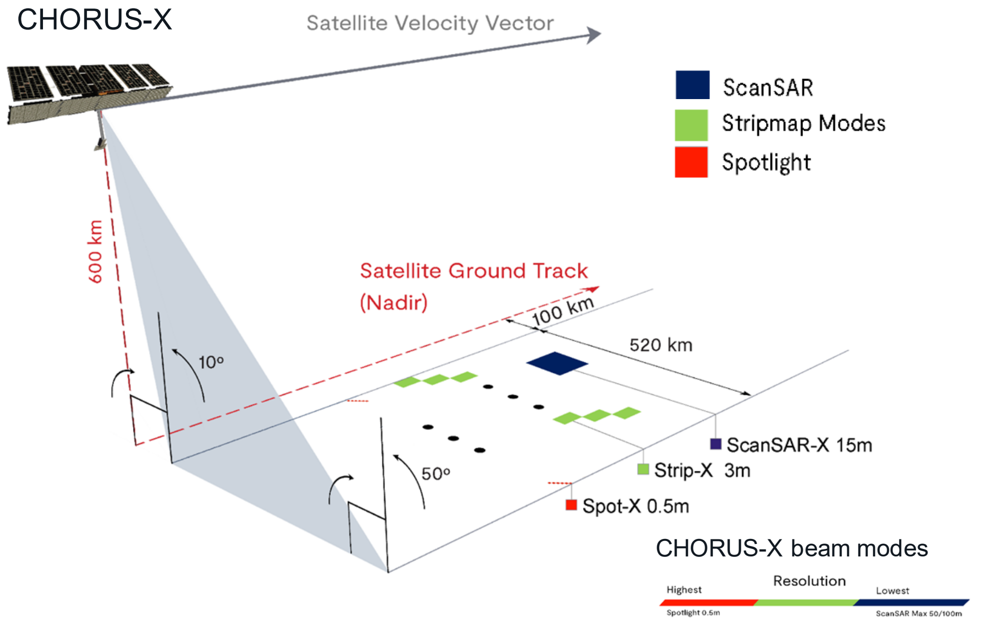


- The novel orbit inclination and varying local time change how and when we observe the world with SAR

CHORUS Beam Modes

Right-looking geometry shown, left-looking is also supported





CHORUS-C InSAR Supported Modes

Beam Mode		Swath width	Swath positions	Resolution	Looks (Rg x Az)	Incidence angle range	Sensitivity (max NESZ)	Polarization
Spotlight		10 km x 7 km	128	3 m x 1 m	1	24.5° to 63.9°	-17.5 dB	SP/DP/CP
Stripmap	3 m	50 km	26	3 m	1	24.5° to 63.9°	-20 dB	SP/DP/CP
	5 m	100 km – 180 km	20	5 m	1		-21 dB	
	8 m	120 km – 180 km	6	8 m	1		-23 dB	

CHORUS-X InSAR Supported Modes

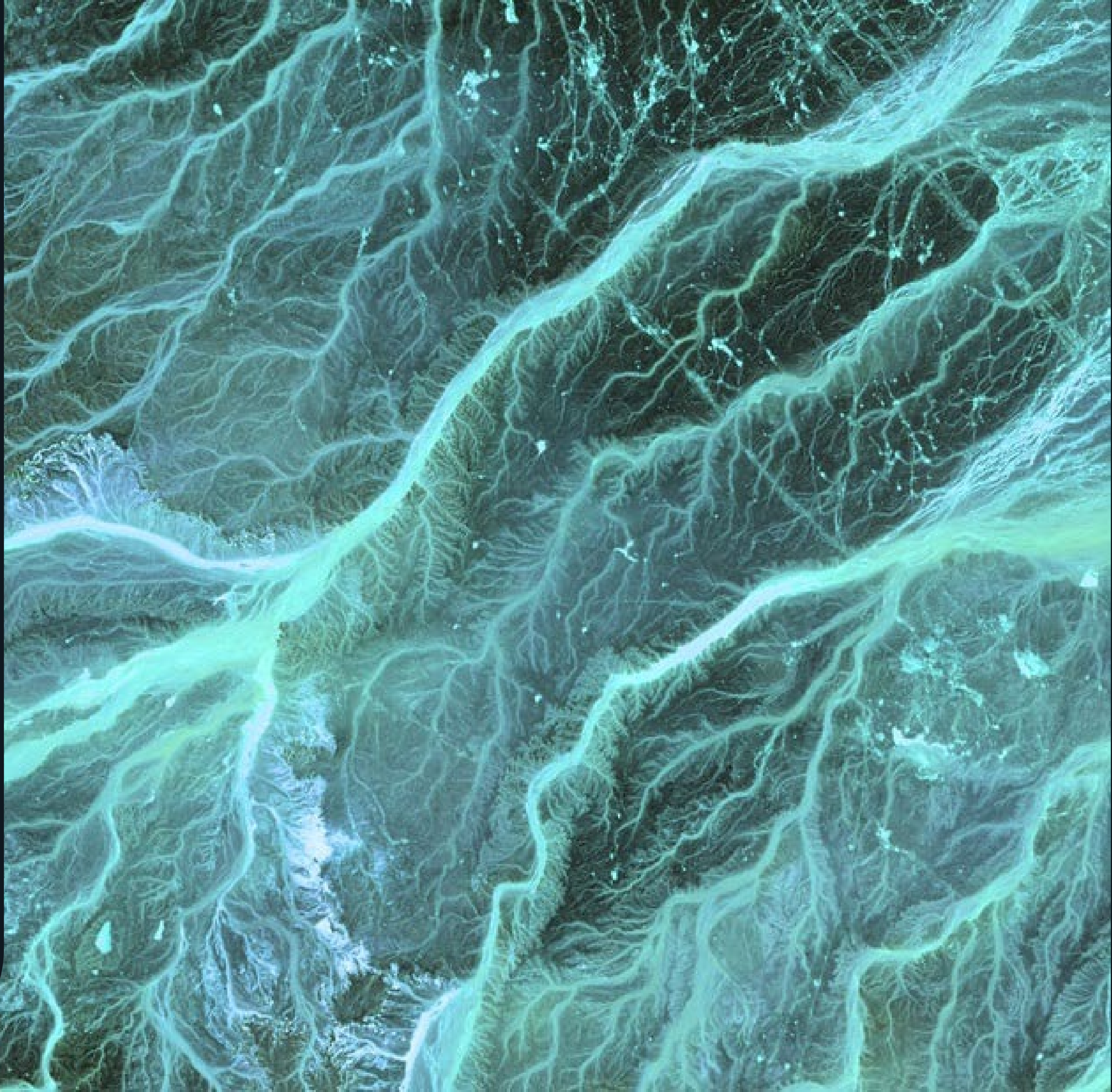
Beam Mode	Swath width	Resolution	Sensitivity	Polarization
Spotlight	5 km x 5 km	0.5 m x 0.25 m	-18 dB to -15 dB	VV
Stripmap	30 km	3 m	-21.5 dB to -20 dB	VV

CHORUS performance numbers are preliminary and subject to change

SP - Single polarization, DP - Dual polarization, CP - Compact Polarization

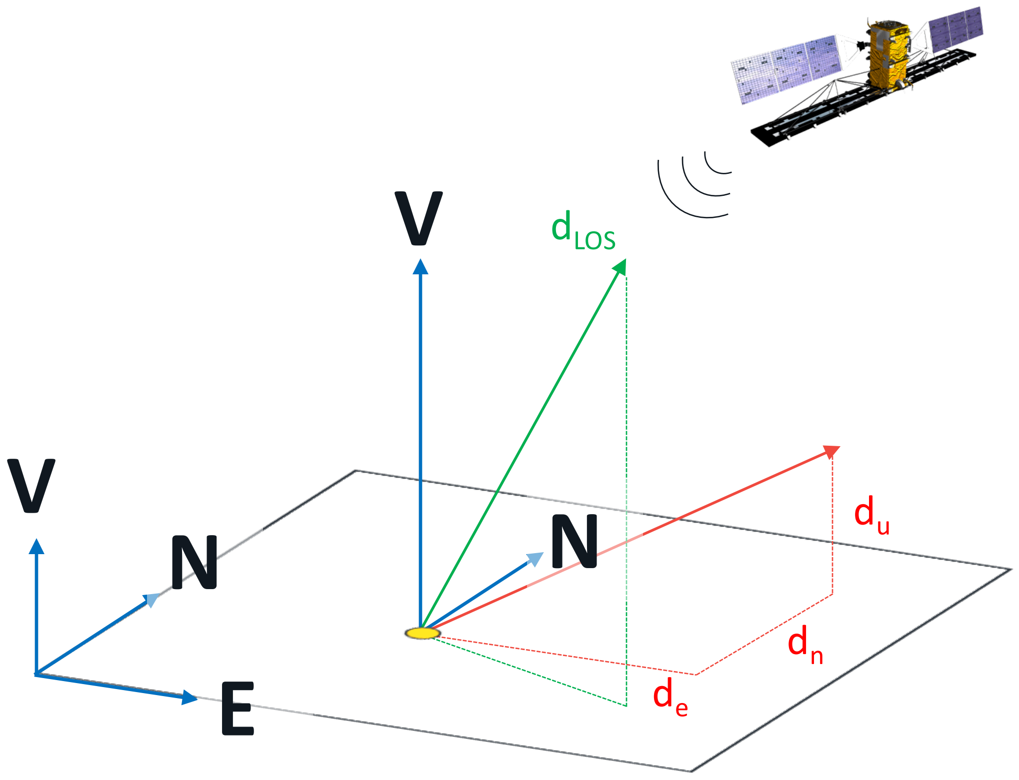
SECTION 2

CHALLENGES MONITORING 3D DEFORMATION



InSAR Limitation

- InSAR can only measure a one-dimensional motion along radar line-of-sight, leading to:
  - Challenging Interpretation of results
  - Ambiguous modelling processes
  - Insufficient information for full 3D displacements of interest to stakeholders

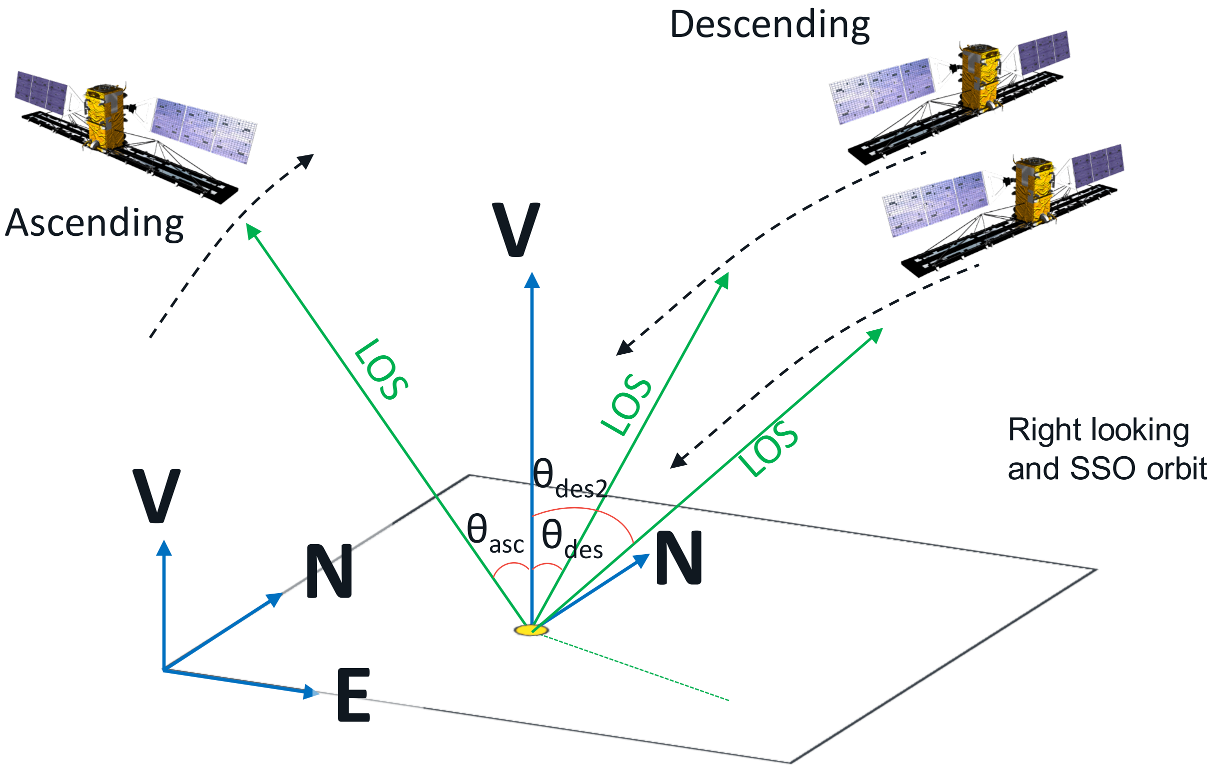


V: Vertical, **N:** North, **E:** East

Figure modified from Wietske Brouwer (2021)

Partial Solution

- To retrieve three motion components, at least ***three*** non coplanar LOS vectors are needed
- Can be achieved using ascending and descending orbits, different incidence angles, and left & right observations
- Almost all SAR images are acquired using right-looking and near-polar orbits
    - High East-West deformation sensitivity
    - ***Very low North–South deformation sensitivity***



Results for each stack can be combined to obtain east-west and vertical deformation calculated

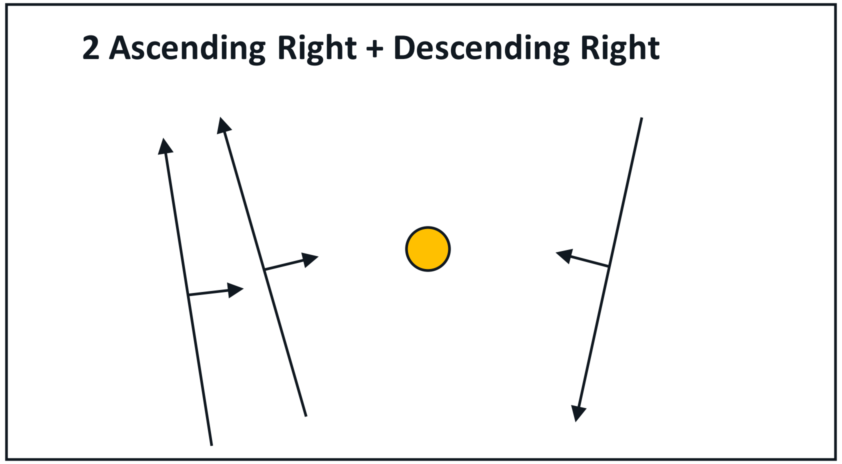
Figure modified from Wietske Brouwer (2021)

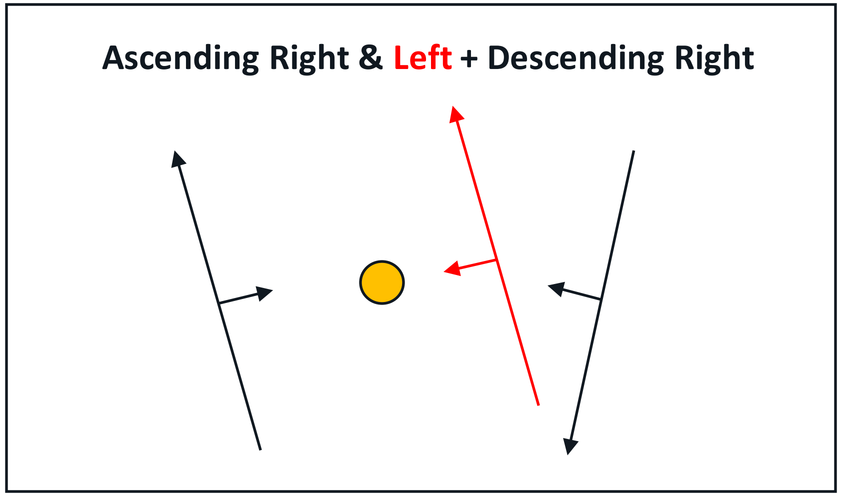
Lack of Angular Diversity

Three non coplanar LOS vectors don't solve the issue

Orbits	3
Satellites	RS2,RS2,RS2
Pass	A,D,A
Look	R,R,R
Heading	350°,190°,348°
Incidence	45°,42°,22°
East	1.0 mm/yr
North	19.3 mm/yr
Vertical	2.6 mm/yr

σ^2_{LOS} = 1 mm/yr





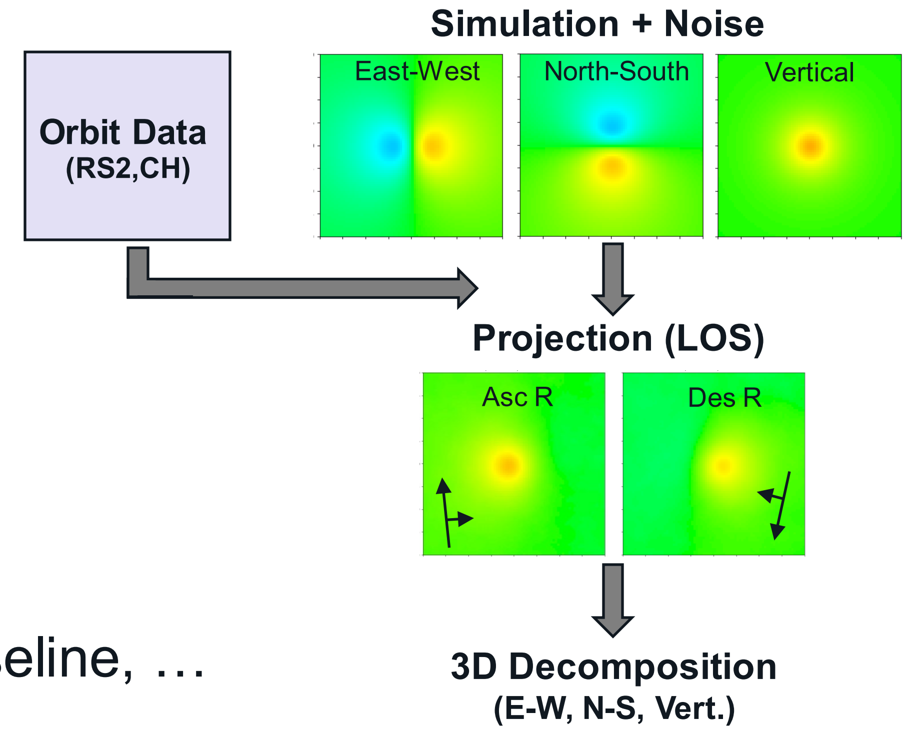
Orbits	3
Satellites	RS2,RS2,RS2
Pass	A,D,A
Look	R,R,**L**
Heading	350°,188°,348°
Incidence	37°,47°,40°
East	1.0 mm/yr
North	5.6 mm/yr
Vertical	0.9 mm/yr

σ^2_{LOS} = 1 mm/yr

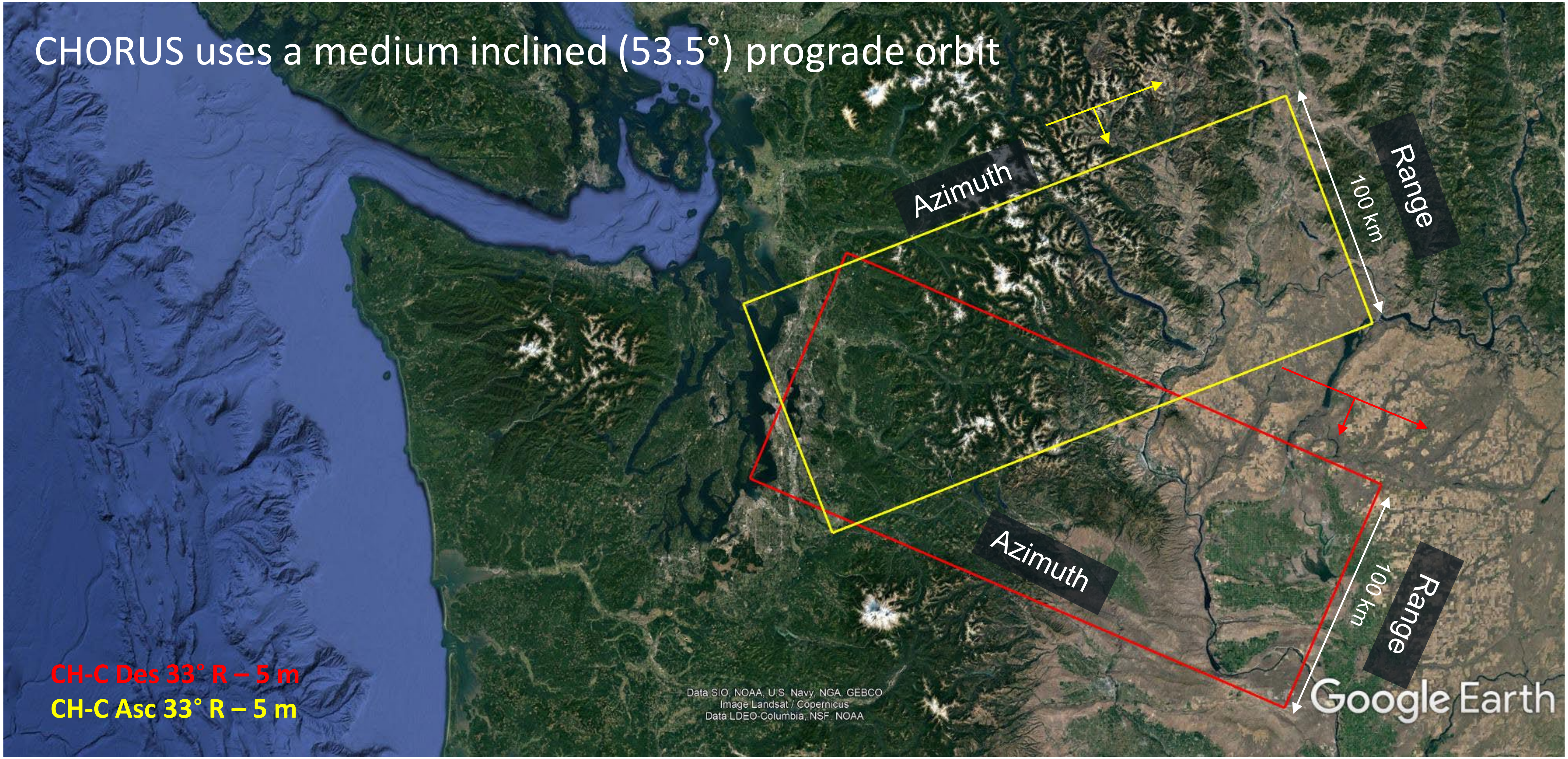
Precision for the estimated displacement obtained using error propagation law as in Wietske Brouwer (2021)

Potential Benefits of CHORUS-C to Retrieve 3D Deformation Field

- **Hypothesis:** the inclined orbit (53.5°) of CHORUS-C provides a wider diversity of lines of sight (vs SSO orbits SARs) that can better enable 3D deformation monitoring at low to mid latitudes
- **Goal**: demonstrate this via simulation at different latitudes
- **Process**:
  - Use RADARSAT-2 and CHORUS-C orbits
    - Selected sites at different latitudes with RS2 data available + CH-C orbits
  - Build models of deformation
  - Project model to line-of-sight + noise
  - 3D Decomposition
- **Assumptions**:
  - Phase stable, zero Doppler centroid, zero spatial baseline, …

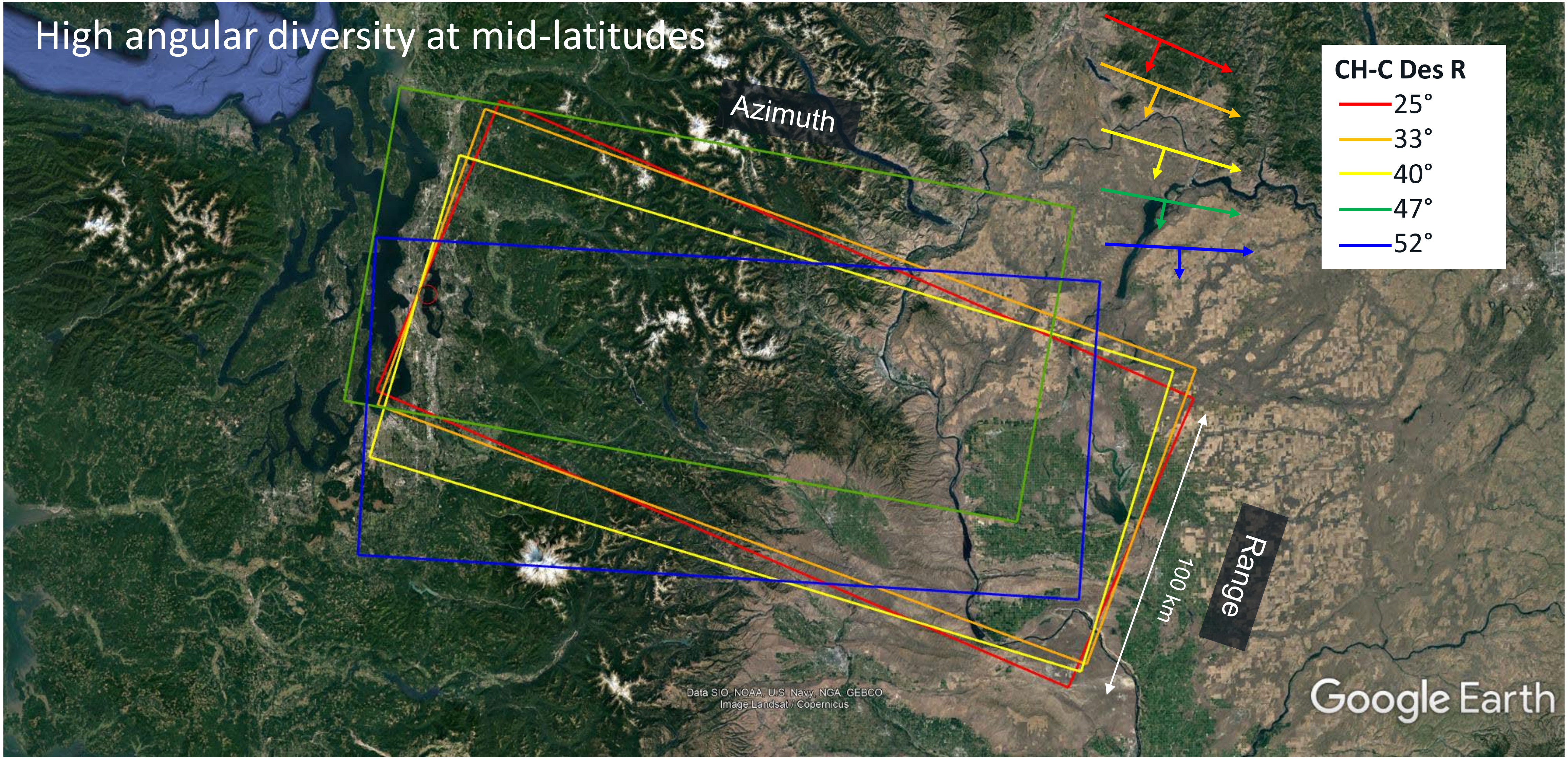


Example of CHORUS-C Footprint at a Latitude 48°



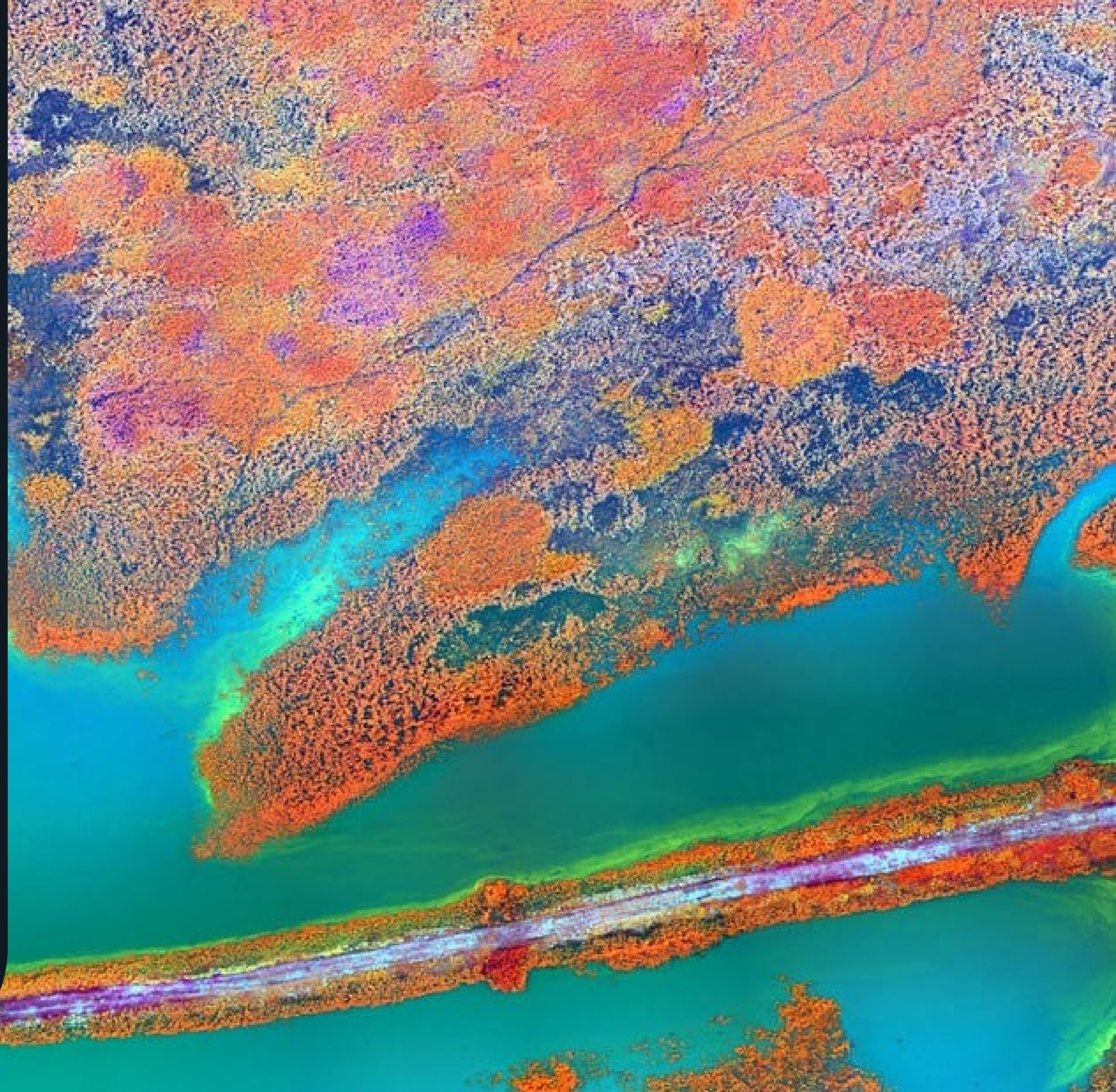
~2 Frames per swath

Heading Variations vs Incidence Angles (Latitude: 48°)



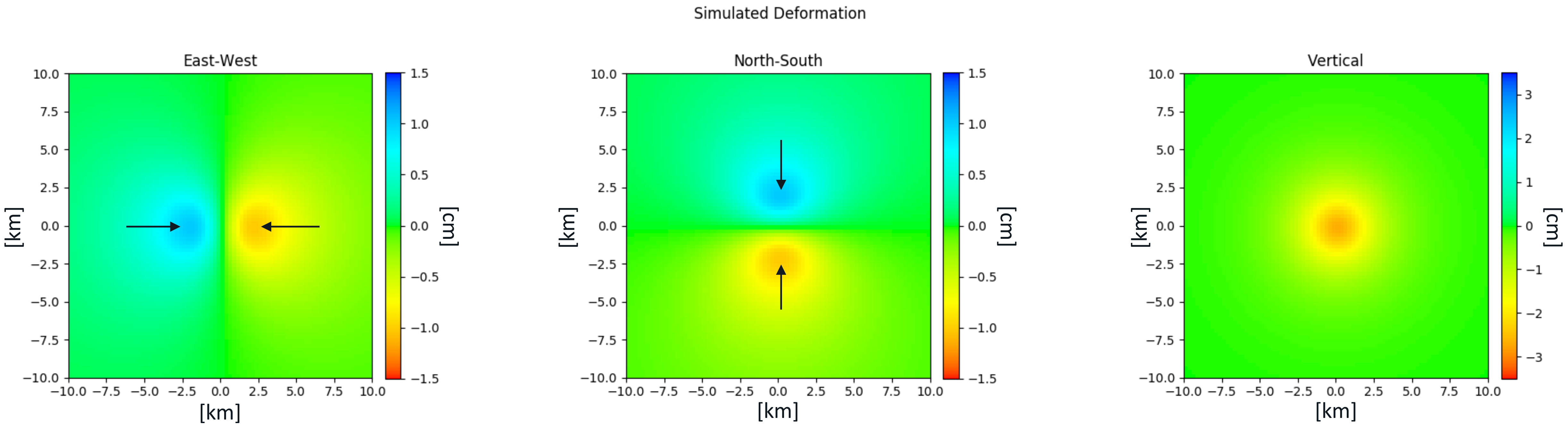
SECTION 3

SIMULATIONS AND 3D DECOMPOSITIONS



Simulated Deformation

A point source is utilized to understand the impact of using multiple viewing geometries to retrieve the 3D deformation field



Blue moves toward the east and **red** towards the west

Blue moves toward the south and **red** towards the north

Red area is subsiding

Introduced short/intermediate wavelength noise using an isotropic 2D fractal surface with a power law behavior[1]
Tested different noise levels: 1 mm to 5 mm (MAD)

[1]Hanssen, R. F. (2001): Radar interferometry data interpretation and error analysis.

Decomposed Deformation (2 Orbits)

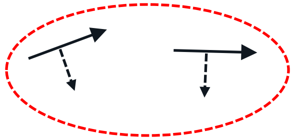
Decomposed Deformation (Latitude 48°)

2 orbits

RS2 Asc 37 R + RS2 Des 47 R

2 orbits

CH Asc 33 R + CH Des 52 R

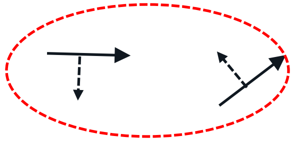


2 orbits

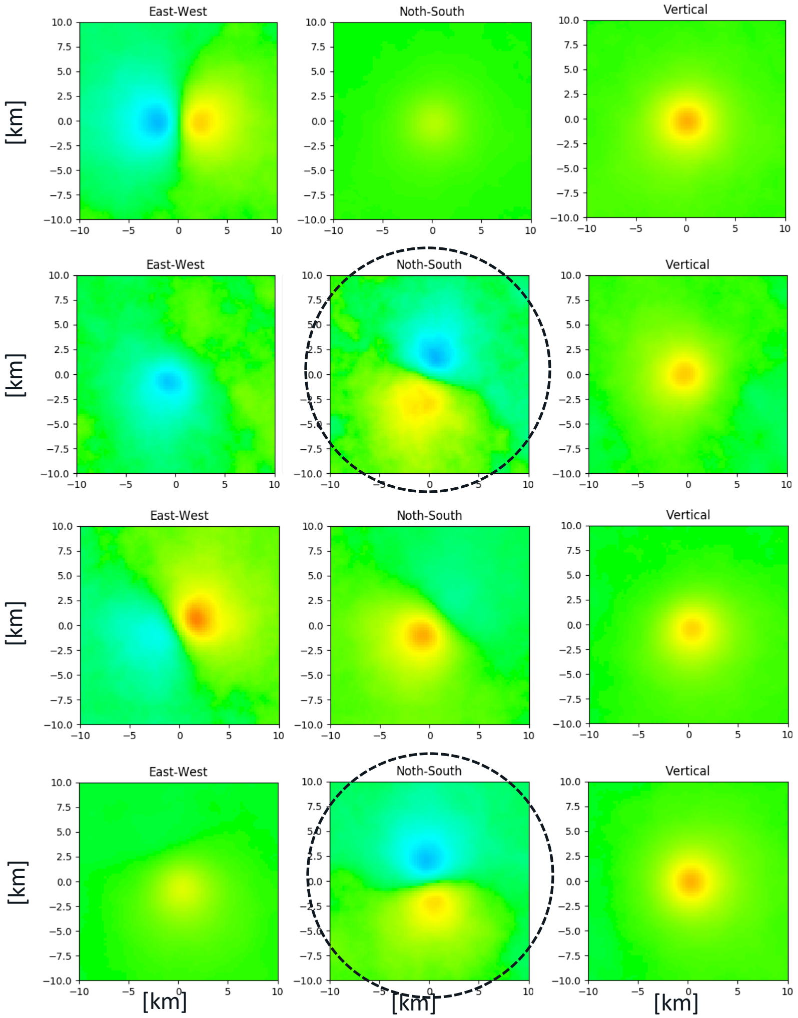
CH Asc 25 L + CH Des 60 L

2 orbits

CH Asc 25 L + CH Des 52 R



Solution remains unknown

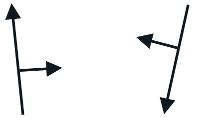


1.5 cm horizontal - 1.5 cm 3 cm vertical - 3 cm

Decomposed Deformation (Latitude 17°)

2 orbits

RS2 Asc 46 R + RS2 Des 29 R



2 orbits

CH Asc 52 R + CH Des 33 R

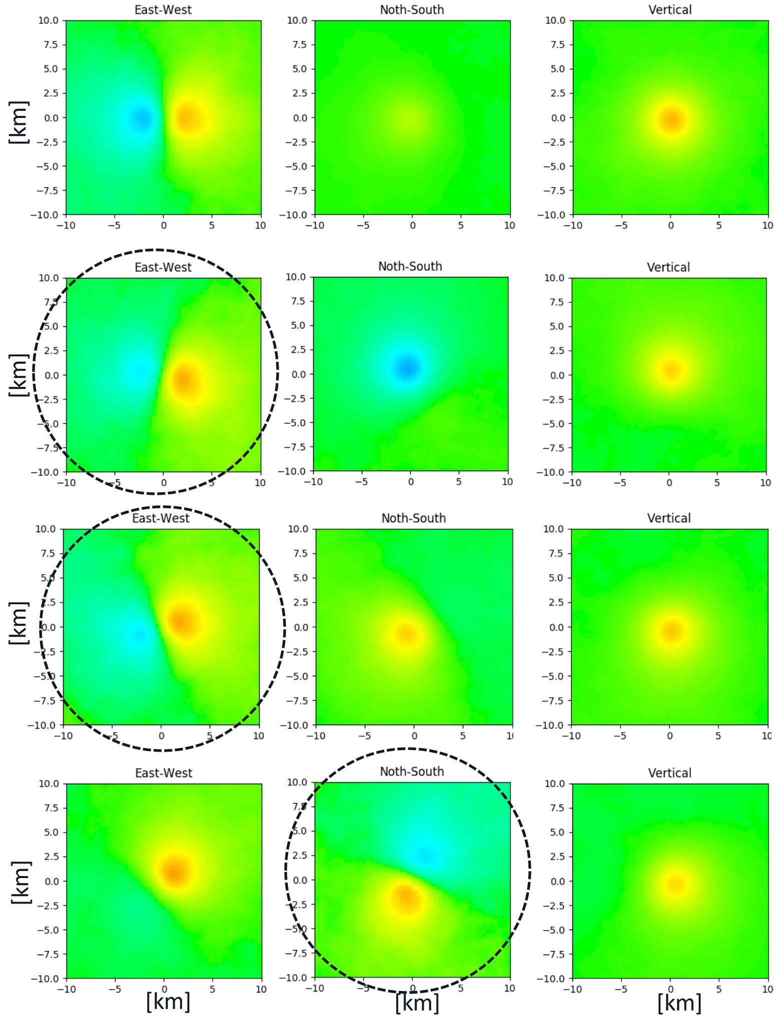
2 orbits

CH Asc 25 L + CH Des 60 L

2 orbits

CH Asc 25 L + CH Des 52 R

Solution remains unknown



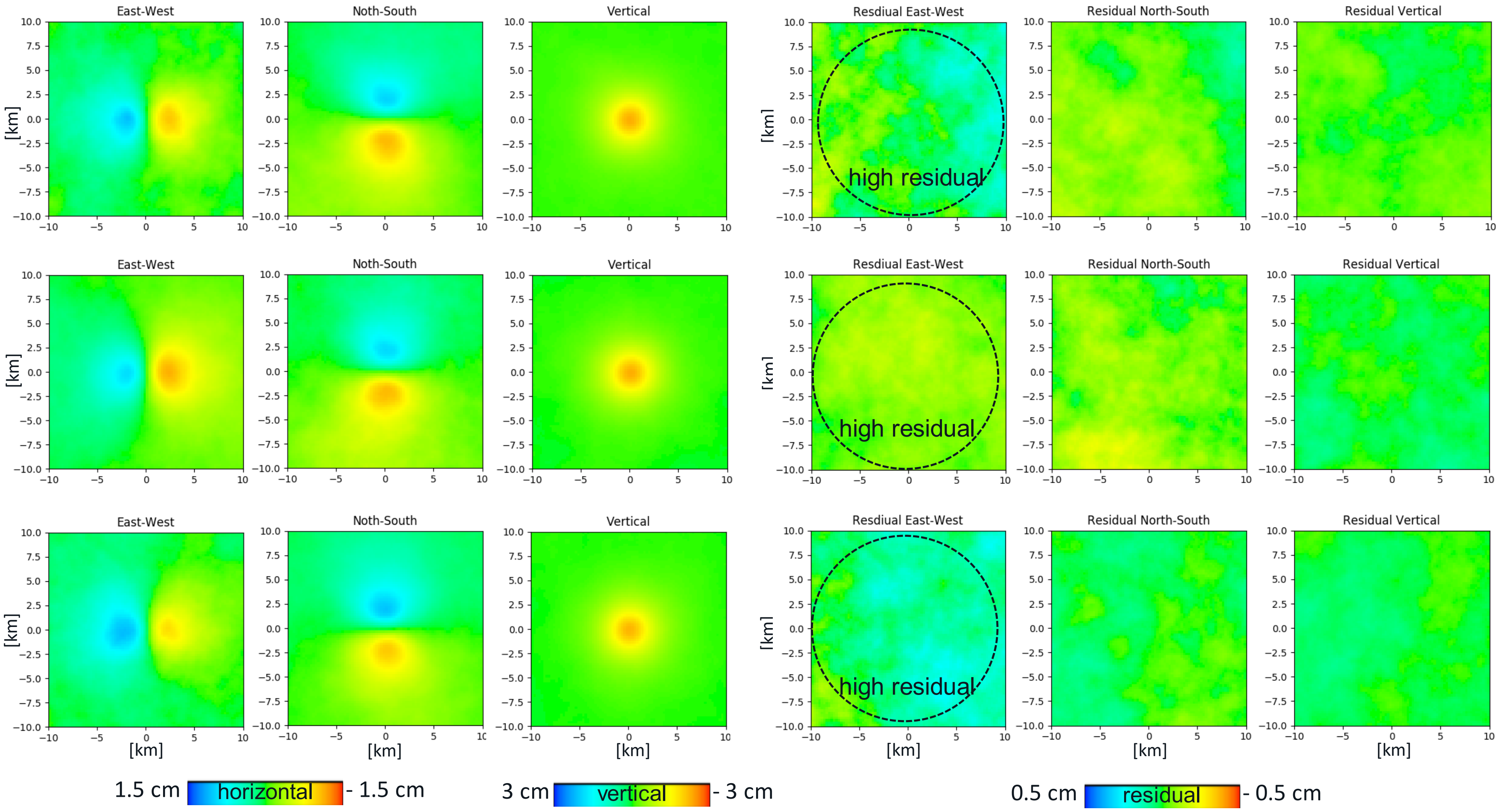
1.5 cm horizontal - 1.5 cm 3 cm vertical - 3 cm

RS2: RADARSAT-2, CH: CHORUS, Asc: Ascending, Des: Descending, R: Right Looking, L: Left Looking

Decomposed 3D Deformation (3+ Orbits) – Latitude 48°

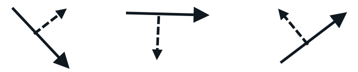
Decomposed Deformation

Residuals



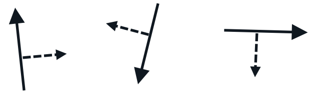
3 orbits

CH Asc 25 L + **CH** Des 52 R + **CH** Des 60 L



3 orbits

RS2 Asc 37 R + **RS2** Des 47 R + **CH** Des 52 R



4 orbits

CH Asc 25 L + **CH** Des 60 L + **CH** Asc 33 R + **CH** Asc 52 R

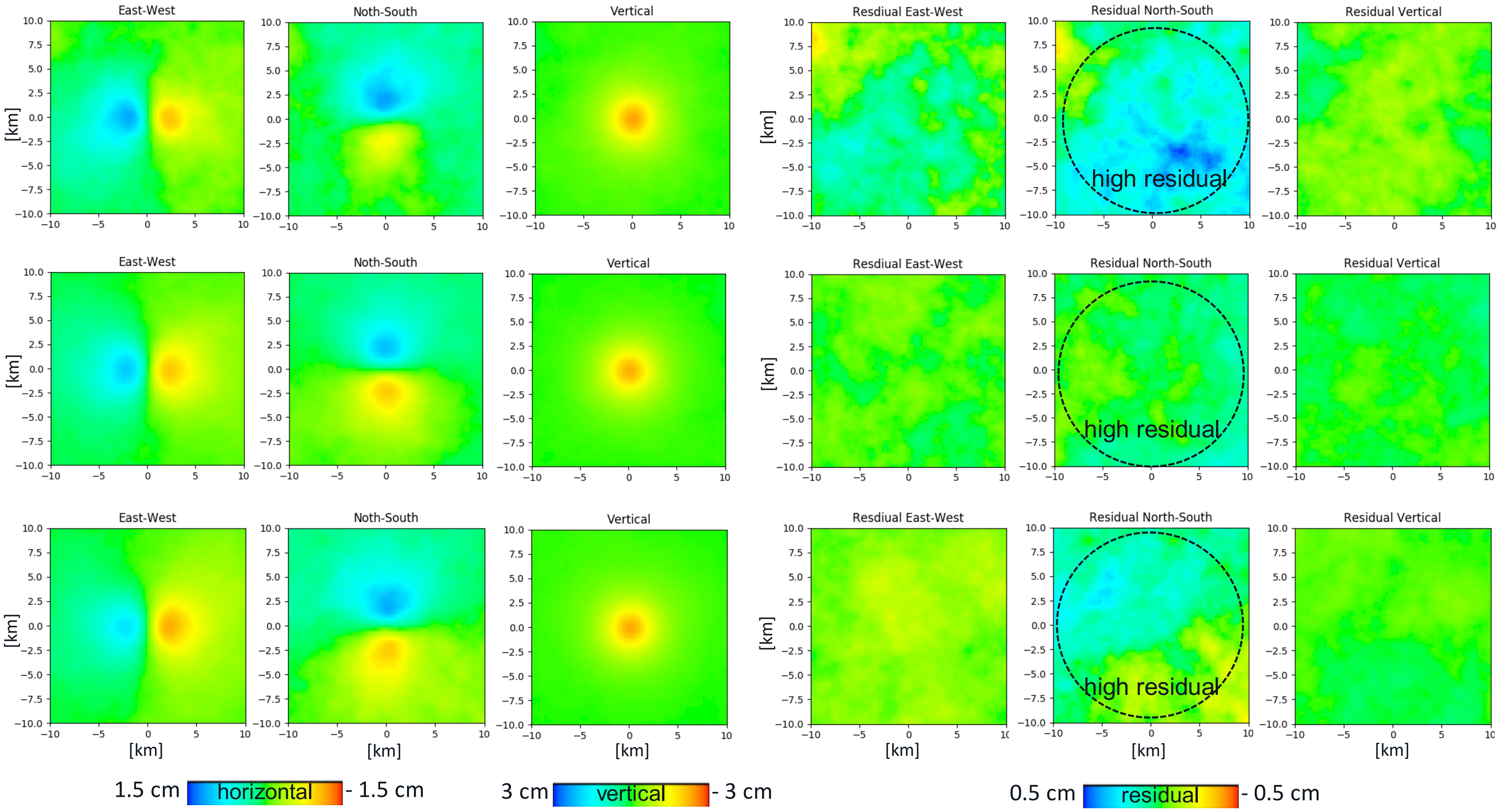
Noise: 1 mm MAD

RS2: RADARSAT-2, CH: CHORUS, Asc: Ascending, Des: Descending, R: Right Looking, L: Left Looking

Decomposed 3D Deformation (3+ Orbits) – Latitude 17°

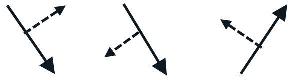
Decomposed Deformation

Residuals



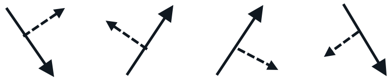
3 orbits

CH Asc 25 L + CH Des 52 R + CH Des 60 L



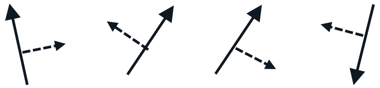
4 orbits

CH Asc 25 L + CH Des 52 R + CH Des 60 L + CH Asc 52 R



4 orbits

RS2 Asc 46 R + RS2 Des 29 R + CH Asc 25 L + CH Asc 52



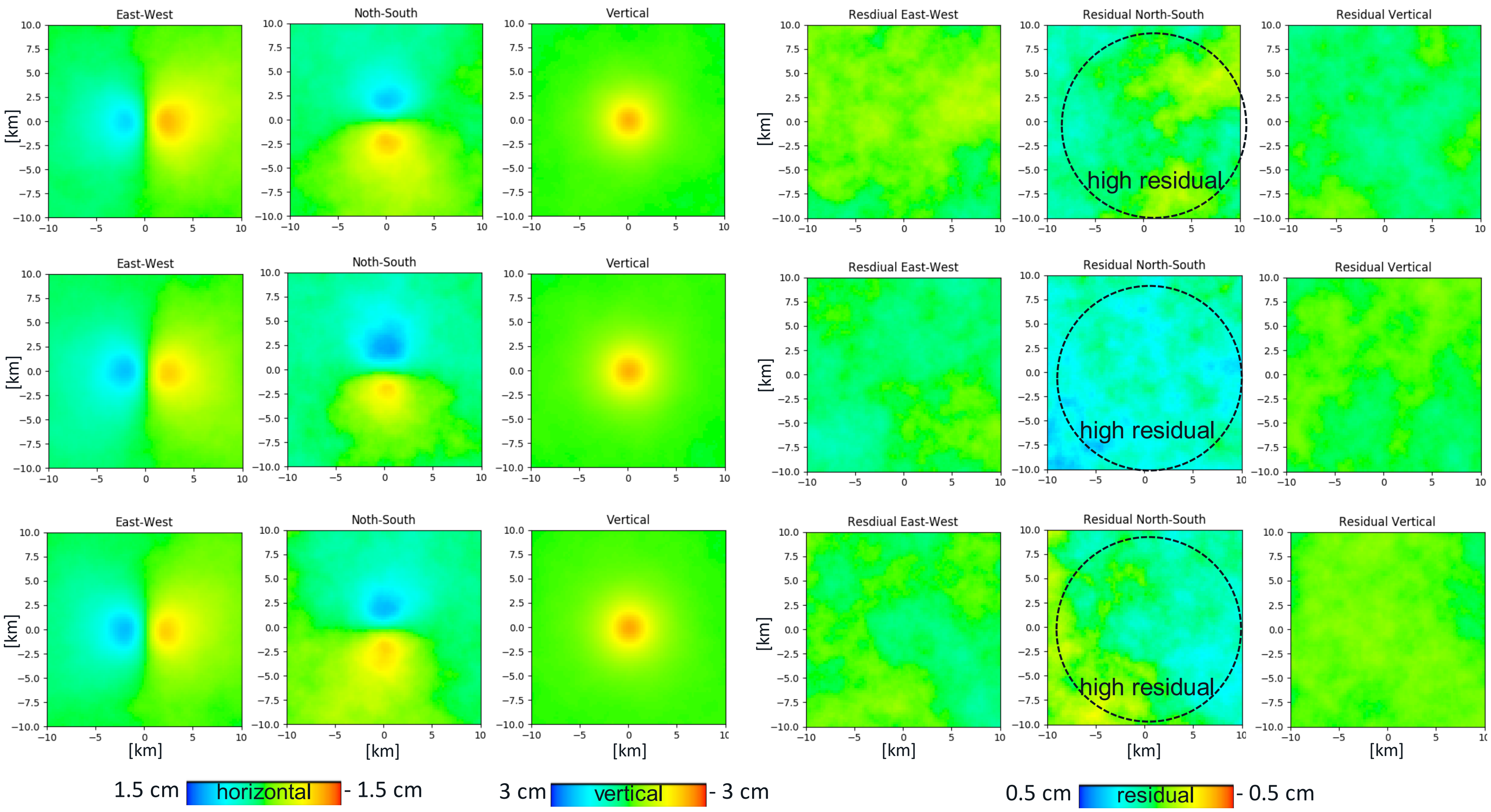
Noise: 1 mm MAD

RS2: RADARSAT-2, CH: CHORUS, Asc: Ascending, Des: Descending, R: Right Looking, L: Left Looking

Decomposed 3D Deformation (3+ Orbits) – Latitude 1°

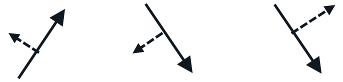
Decomposed Deformation

Residuals



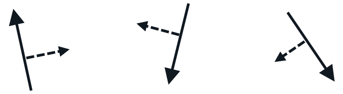
3 orbits

CH Asc 47 L + CH Des 47 R +
CH Des 47 L



3 orbits

RS2 Asc 40 R + RS2 Des 42 R +
CH Des 47 R



4 orbits

RS2 Asc 40 R + RS2 Des 42 R +
CH Des 47 R + CH Des 56 L

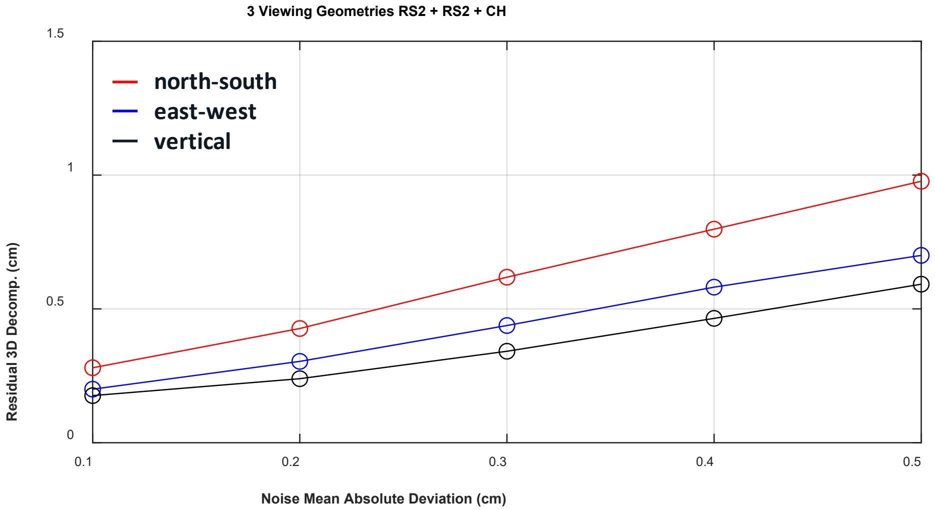
Noise: 1 mm MAD

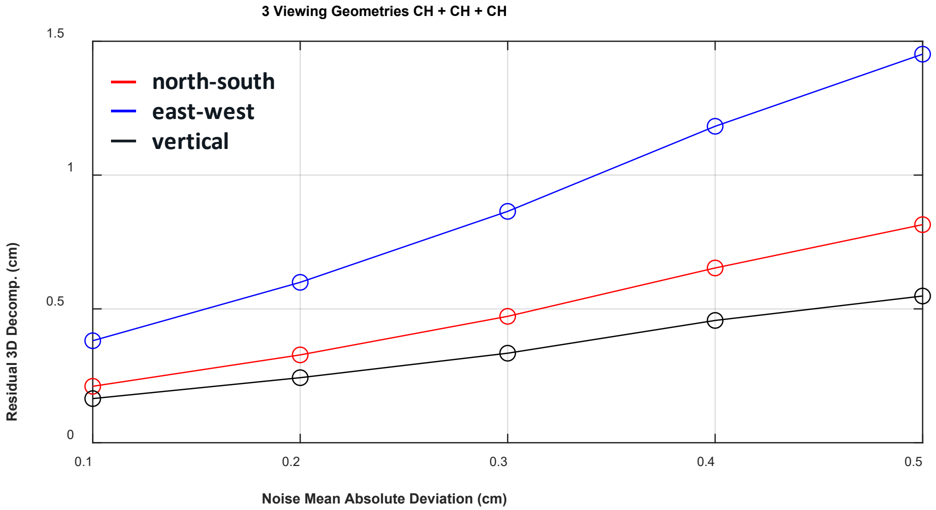
RS2: RADARSAT-2, CH: CHORUS, Asc: Ascending, Des: Descending, R: Right Looking, L: Left Looking

Impact of Noise in 3D Decomposition

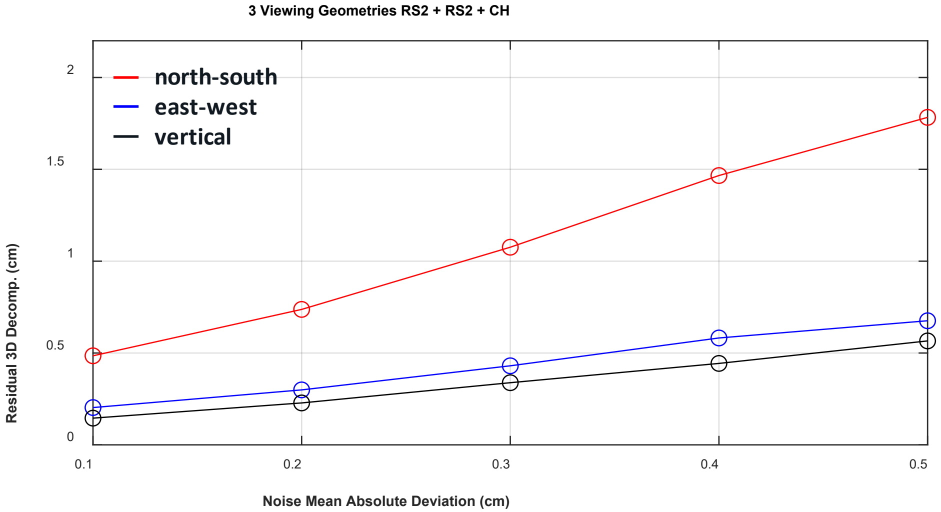
Max simulated horizontal deformation 1 cm, Max simulated vertical deformation 2.65 cm

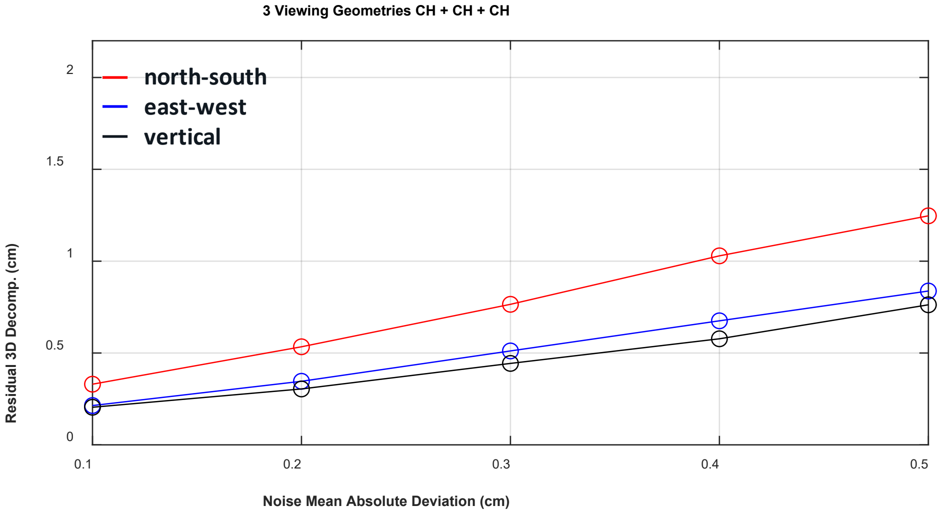
Latitude 48°





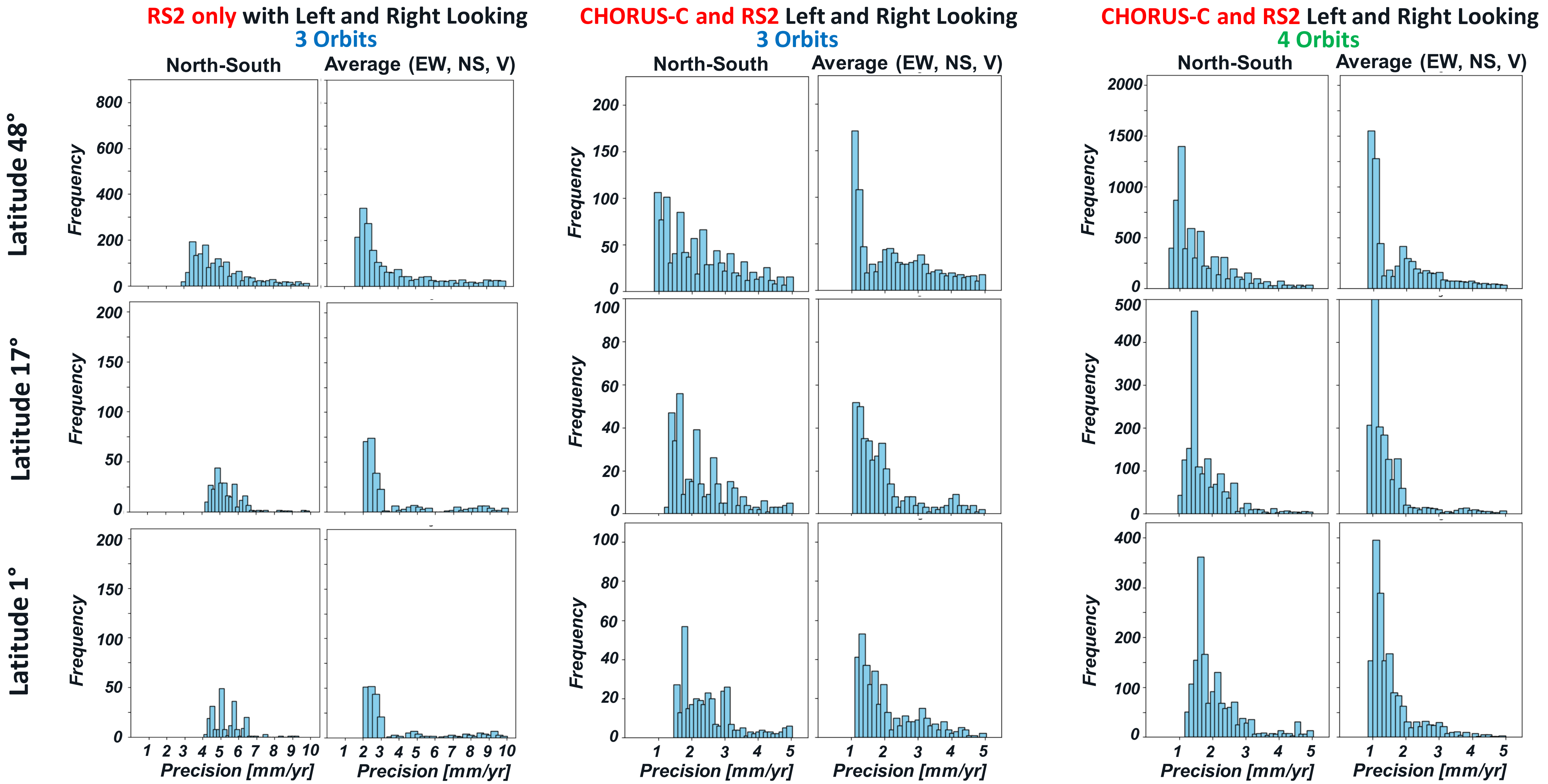
Latitude 17°





RS2: RADARSAT-2, CH: CHORUS, Asc: Ascending, Des: Descending, R: Right Looking, L: Left Looking

Distribution of Estimated Precisions (σ) – All Possible Viewing Geometries

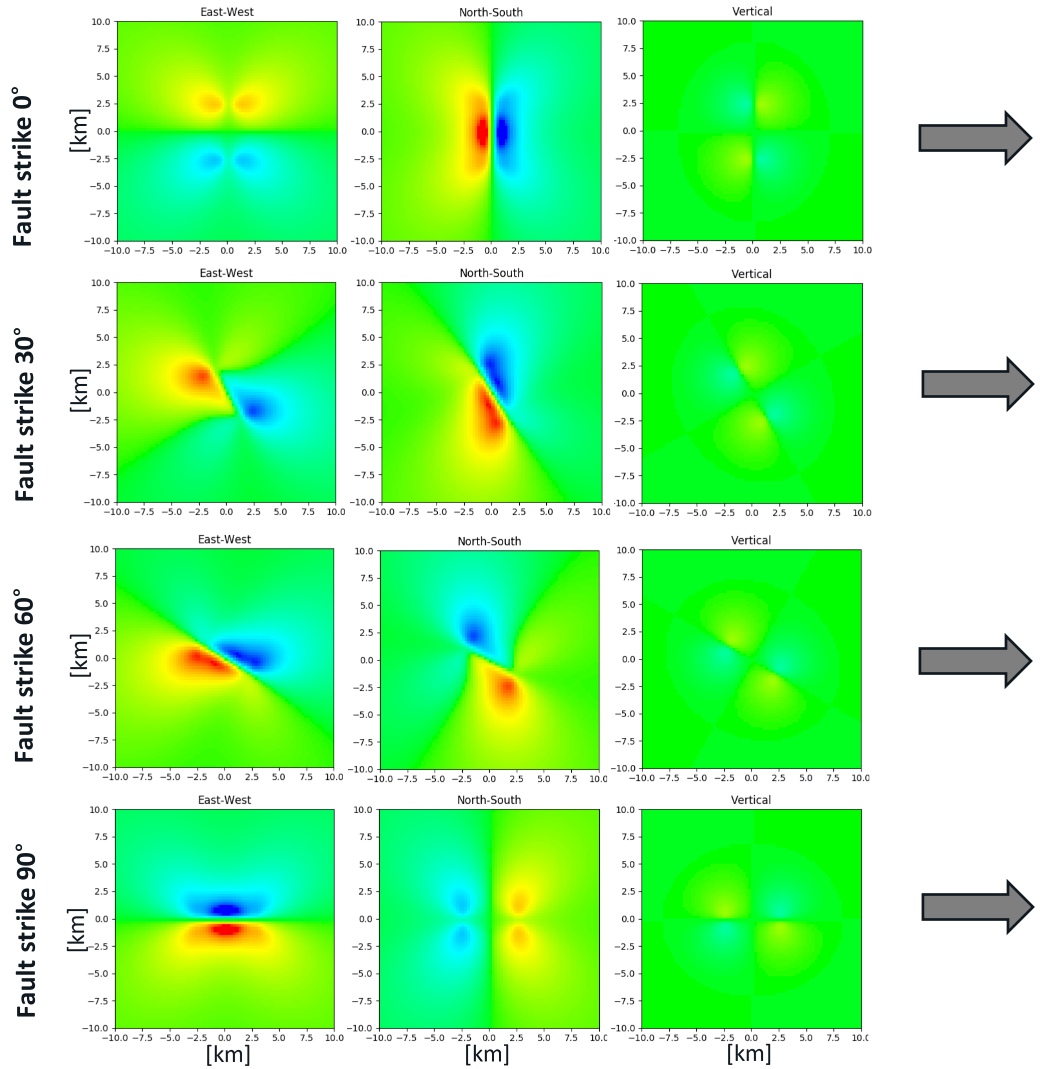


Precision for the estimated displacement obtained using error propagation law as in Wietske Brouwer (2021)

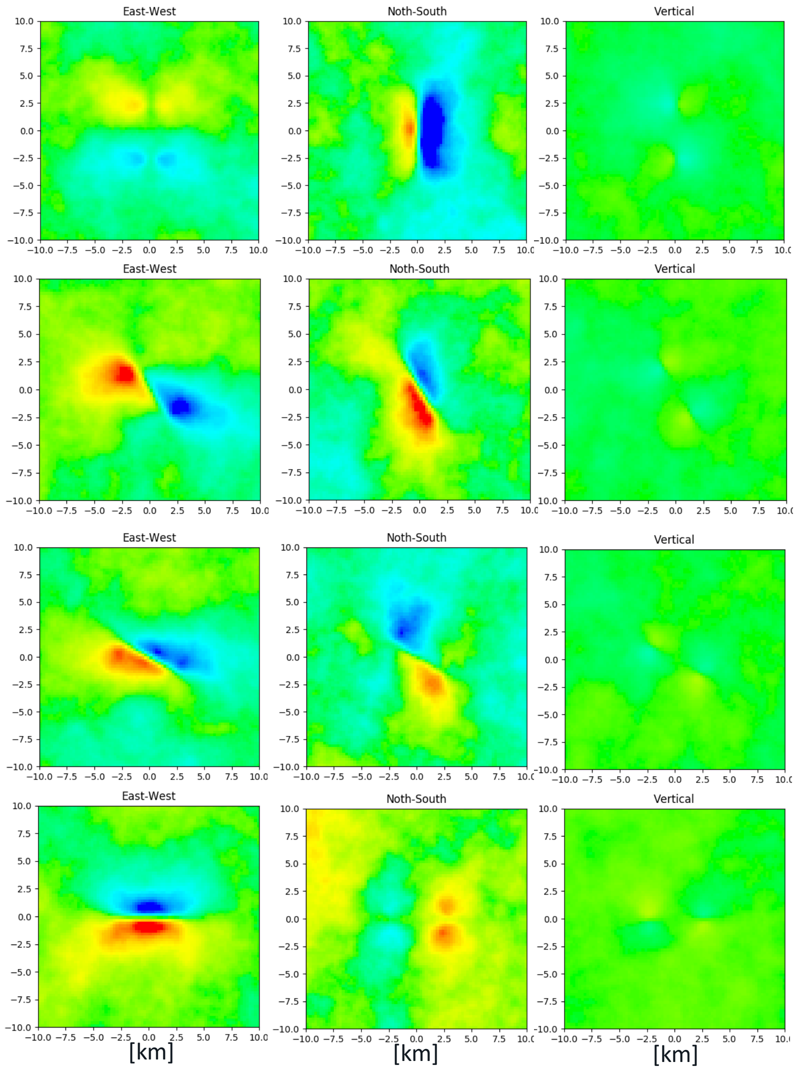
Example Strike Slip Fault – Latitude 48°

RS2 ASC R + RS2 DES R + CH DES R

Simulated Motion

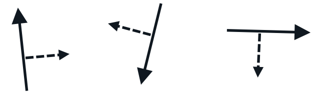


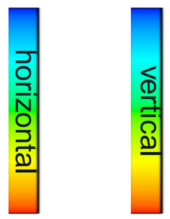
Decomposed 3D Deformation



3 orbits

RS2 Asc 37 R + RS2 Des 47 R +
CH Des 52 R





RS2: RADARSAT-2, CH: CHORUS, Asc: Ascending, Des: Descending, R: Right Looking, L: Left Looking

Okada Model – Right lateral strike slip motion on subvertical fault

Observations

- 3+ viewing geometries needed to obtain 3D deformation measurements
    - High angular diversity is key
    - More viewing geometries (>3) can be beneficial

- Advantages observed using mid-inclined and SSO orbits
    - High precisions in all components when combining mid-inclination and SSO orbits, specially at mid-latitudes
    - Best N-S precisions when using only mid-inclined orbits (different combinations of right/left and Asc/Des)
    - Higher precision than only using 3 SSO orbits (including right/left and Asc/Des)

- Highest precision of N-S component observed at mid-latitudes
    - Can be more accurate than E-W (mid-latitudes)
    - N-S precision decreases toward low latitudes
    - Overall, E-W component still remains more precise

- N-S component is more affected by noise (low latitudes)
    - Horizontal deformation signal easily contaminated by noise
    - Noise impact dependent on geometry configuration and latitude
    - Can be improved by including optimized geometries

- 3+ viewing geometries will enable measurements of pure horizontal motion (e.g. strike slip faults)

Summary

- Current missions don't provide enough angular diversity to accurately estimate 3D deformation

- CHORUS-C will provide broader angular diversity to better retrieve N-S deformation
    - Improved N-S precision at mid-to-low latitudes

- Benefits observed by combining sun-synchronous orbits and mid-inclination orbits (complementary)

- Proper acquisition planning will be required to obtain most benefits
    - e.g. minimize impact of noise, temporal offset, higher precision in N-S component

THANK YOU

CONTACT INFO:

MDA

fernando.greenegondi@mda.space