Fringe 2015
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Phase inconsistencies and water effects in SAR interferometric stacks

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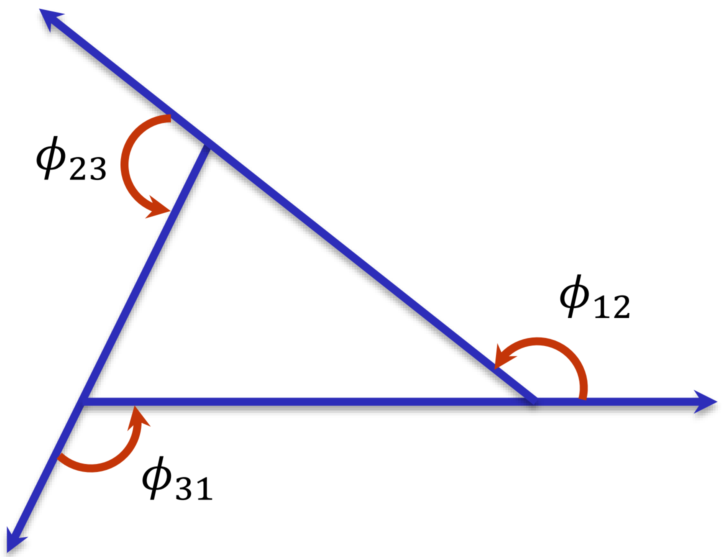
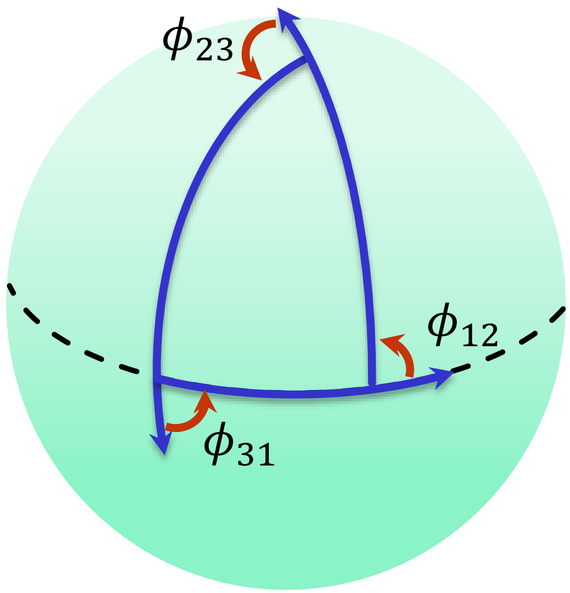
Concept of phase consistency

$$\Phi_{123} = \text{Phase}[< I_1 I_2^* >< I_2 I_3^* >< I_3 I_1^* >] = \phi_{12} + \phi_{23} + \phi_{31}$$





$$\phi_{12} + \phi_{23} + \phi_{31} = 0 \quad (2\pi)$$

$$\phi_{12} + \phi_{23} + \phi_{31} \neq 0 \quad (2\pi)$$

Basic sources of lack of consistency

- Statistical variation of averaged interferograms
  - Exploited in stack interferometric filtering (coherence based)
    - Phase Linking (Monti Guarnieri & Tebaldini)
    - SqueeSAR (Ferretti et al.)
  - Expected to disappear with multilooking

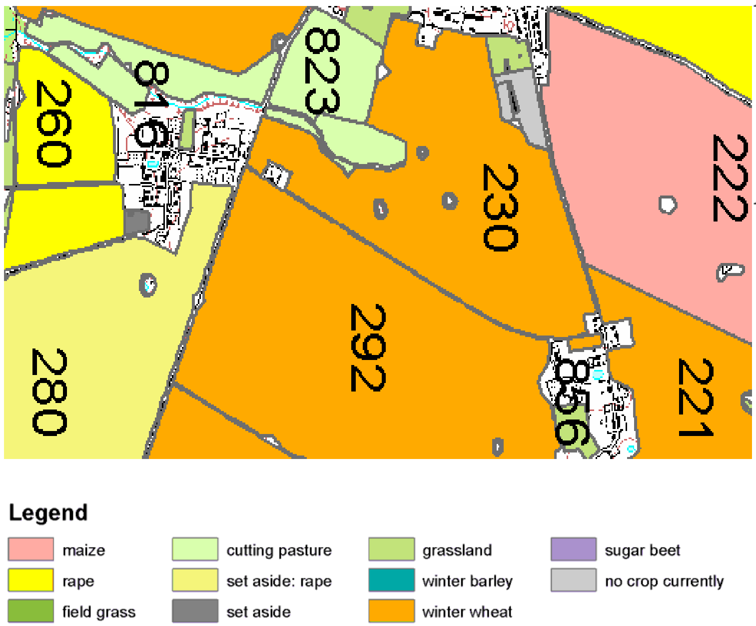
- Superposition of two or more scatterers with different interferometric behavior
  - Tomographic scenario (profile skewness, EUSAR 2014)
  - Two scatterers with different displacements
  - <u>Propagation variation in semi-transparent medium</u>
    - TGRS 2014: "A SAR Interferometric Model for Soil Moisture"

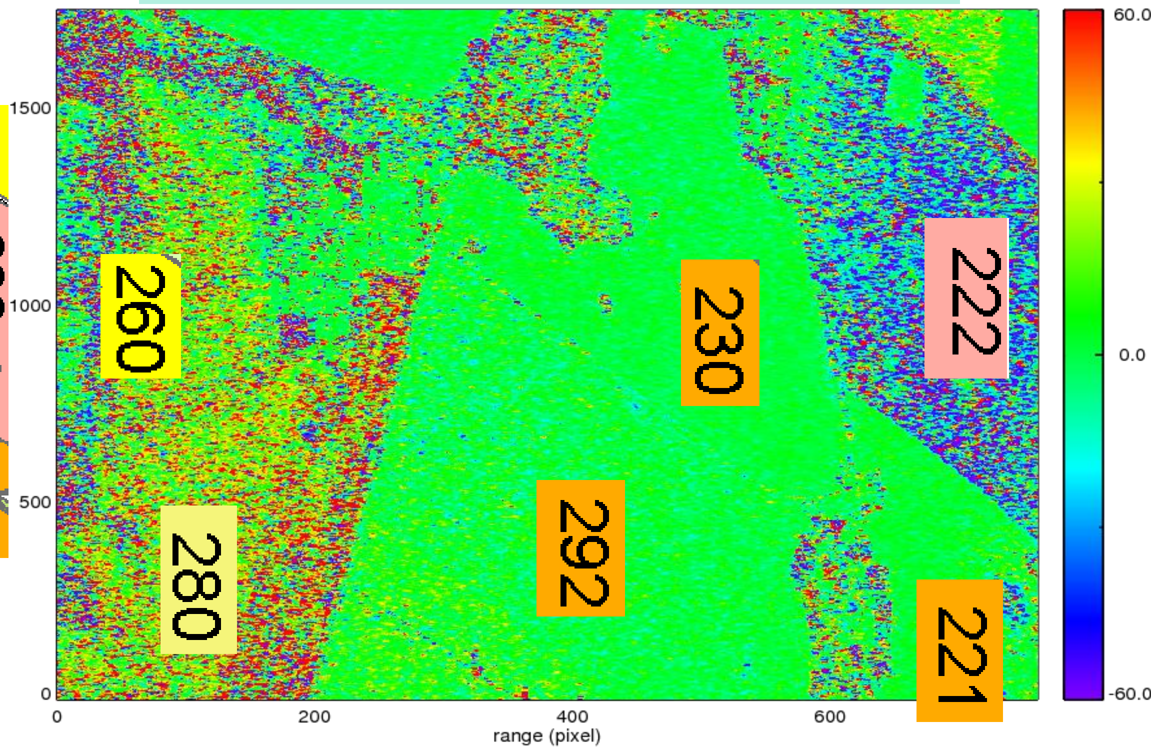
L-band over fields (agriculture)

- ESAR – AGRISAR Campaign
- Agricultural Fields

16/05/2006 13/06/2006 21/06/2006

Heights of ambiguity: 1087m, 81m, -75m





F. De Zan, A. Parizzi, P. Prats-Iraola, P. López-Dekker, "*A SAR Interferometric Model for Soil Moisture*" IEEE TGaRS, Vol. 52, No. 1, Jan 2014

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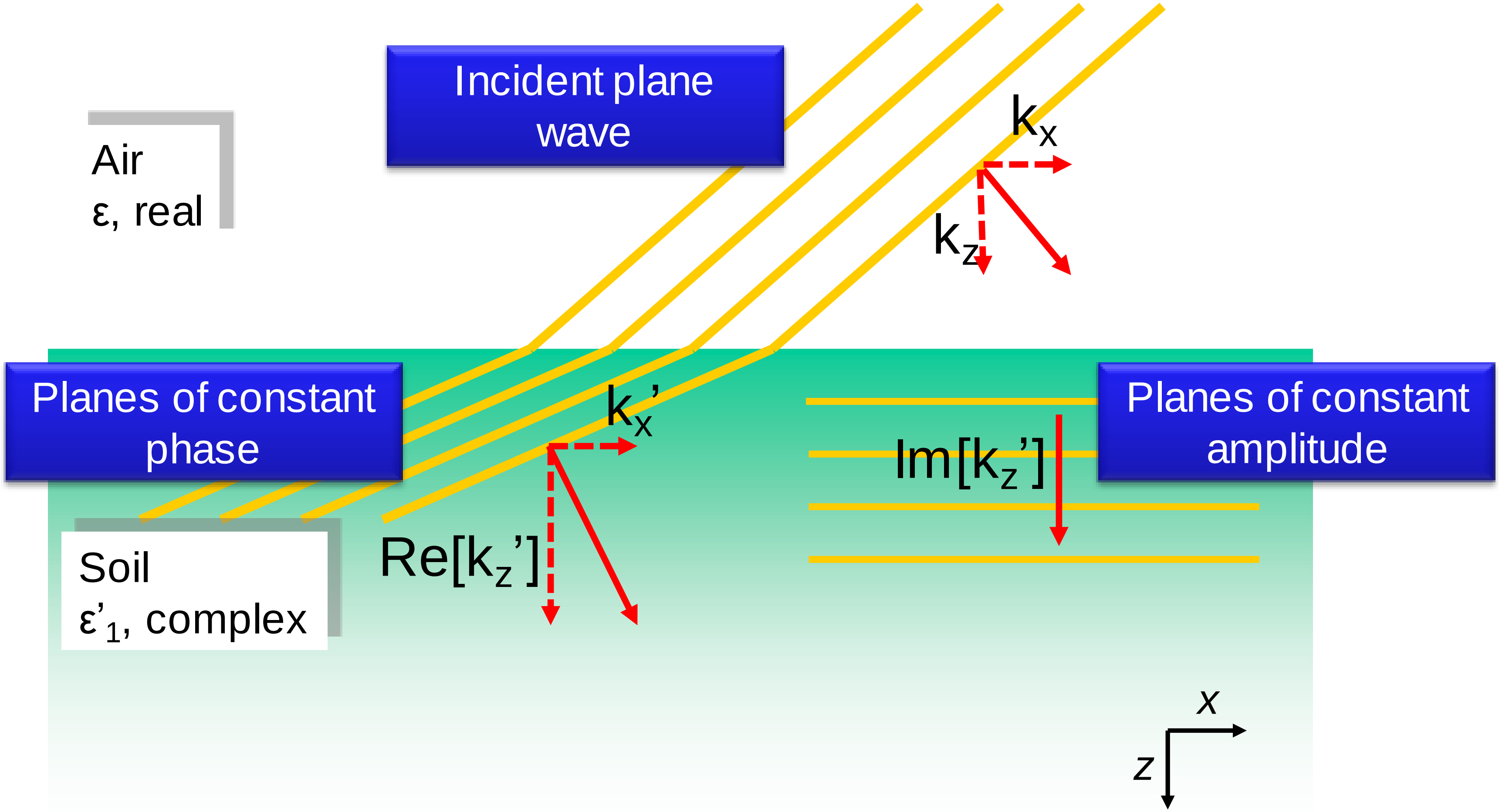
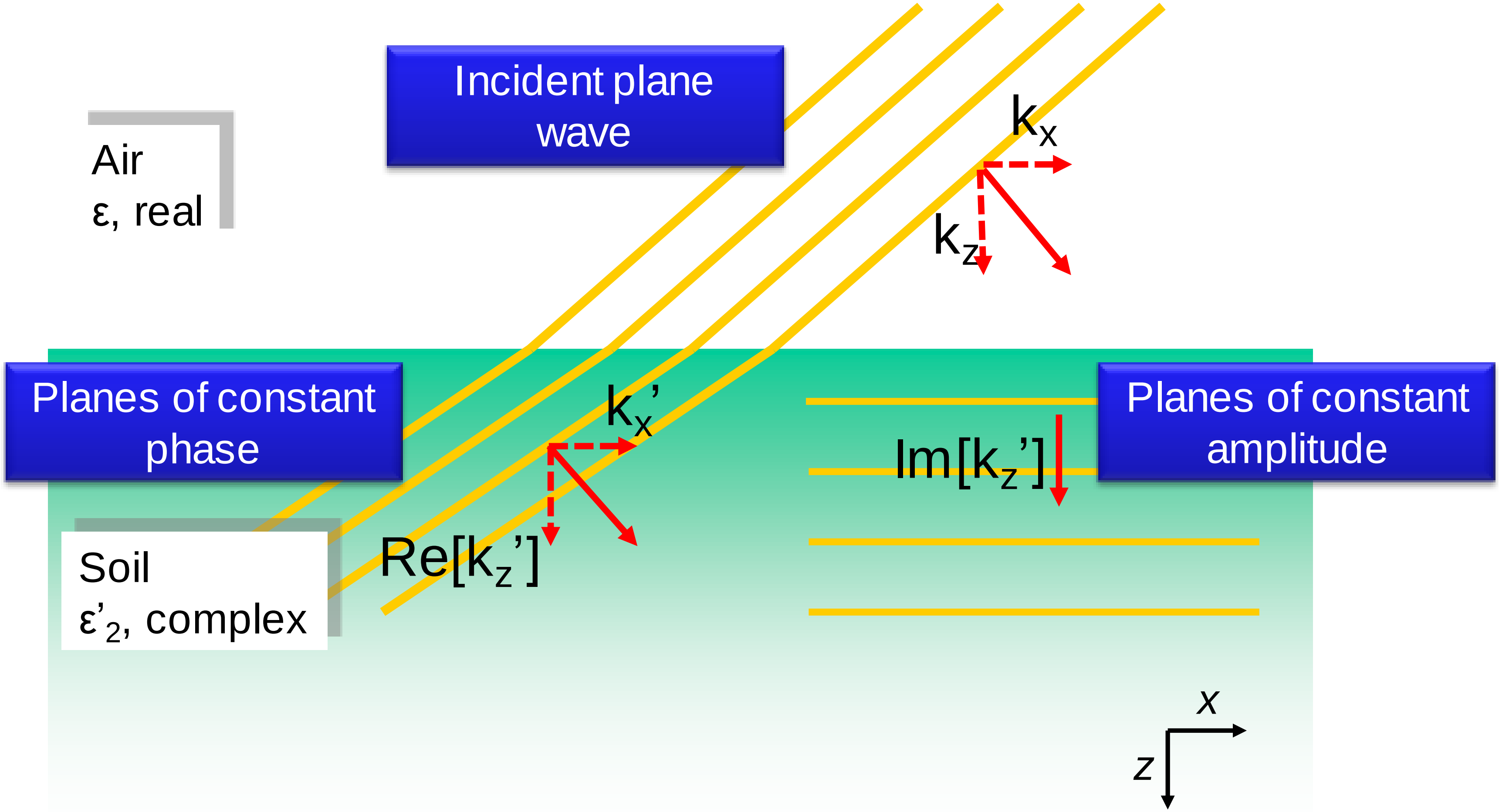
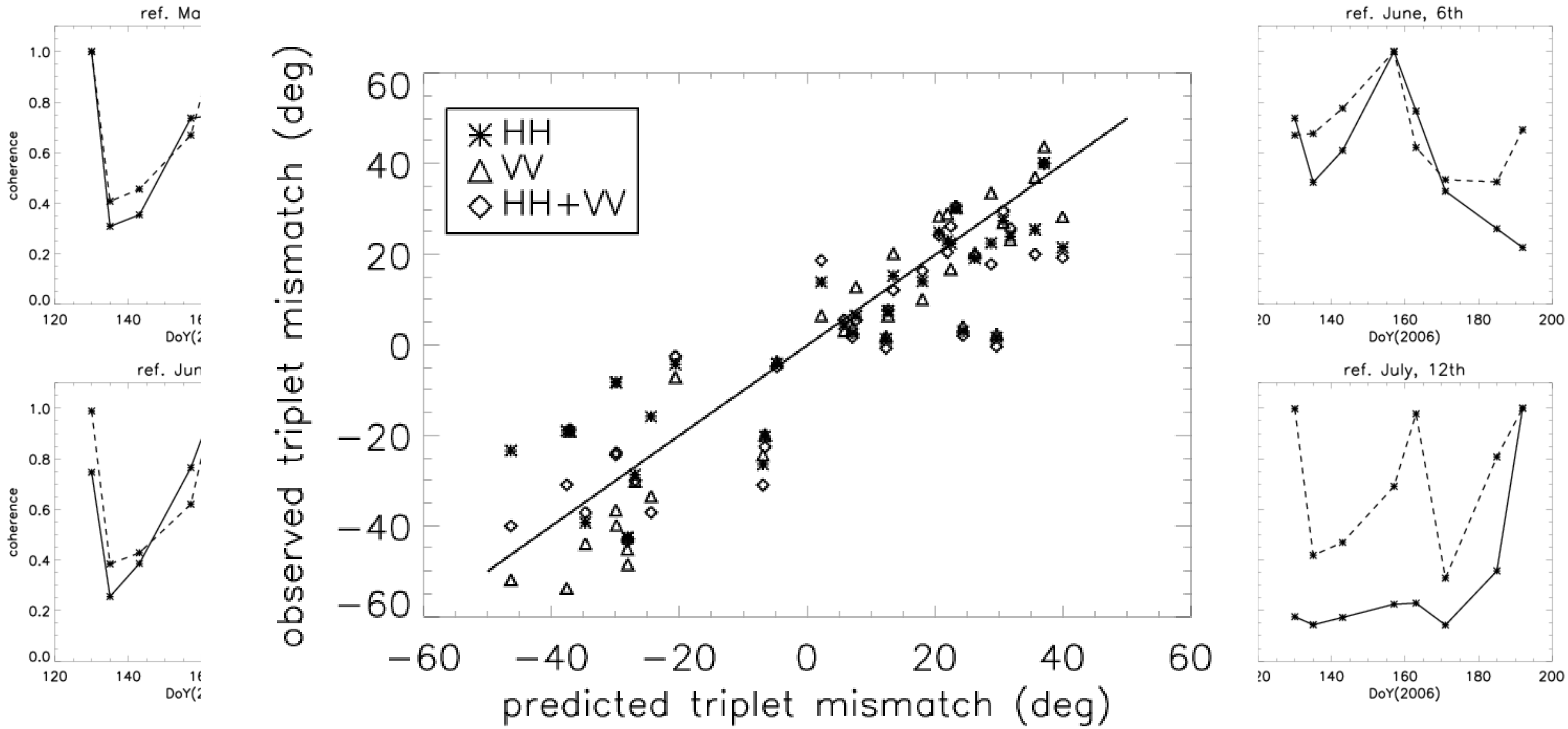
Oblique incidence on lossy dielectric



Oblique incidence on lossy dielectric



Comparison of coherences and inconsistencies (modeled and observed with AGRISAR 2006 data)



Data provided by the European Space Agency - © 2006

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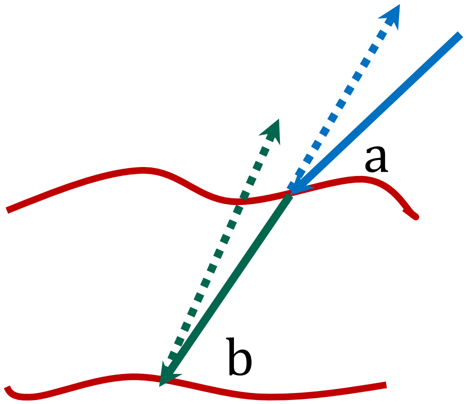
Origin of phase inconsistencies

- Two (or more) scattering contributions in the same resolution cell or, at least, in the same averaging window
- Independent phase and/or amplitude variations

$$y_1 = a_1 + b_1 e^{j\varphi_1}$$

$$y_2 = a_2 + b_2 e^{j\varphi_2}$$

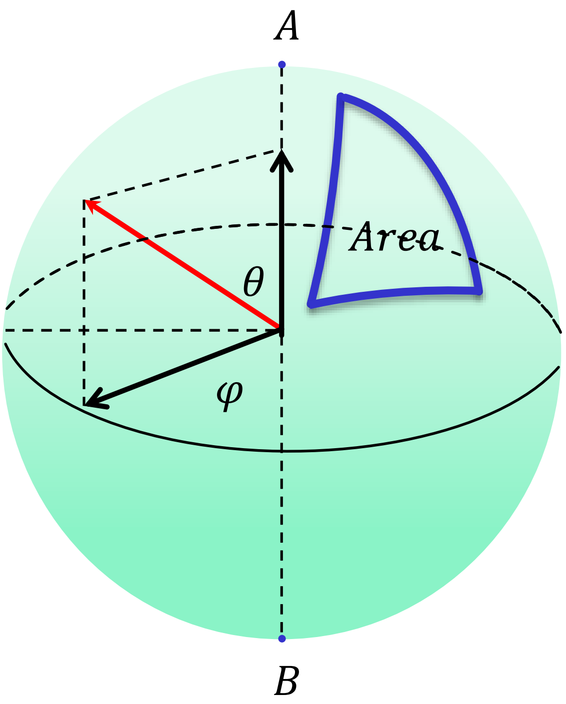
$$y_3 = a_3 + b_3 e^{j\varphi_3}$$



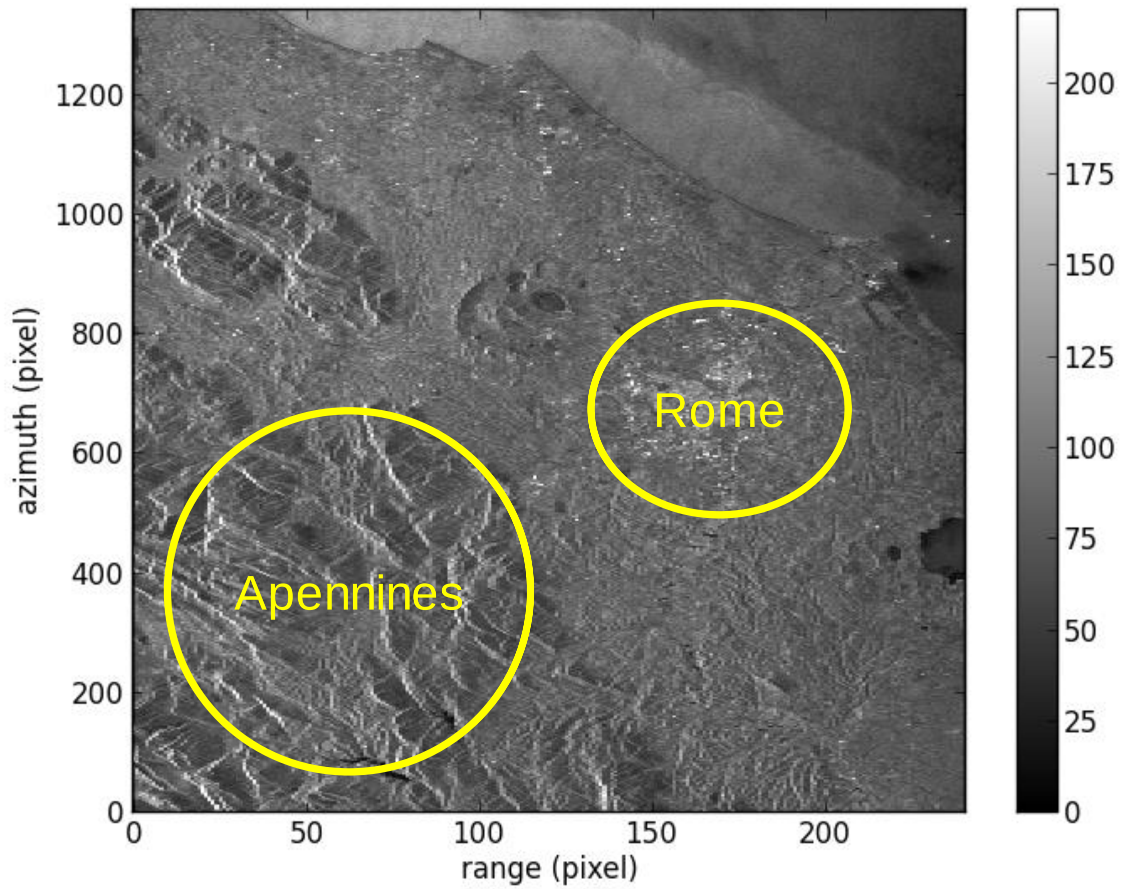
$$\mathrm{E}[y_n y_k{}^*] = \mathrm{E}[a_n a_k{}^*] + \mathrm{E}[b_n b_k{}^*] e^{j(\varphi_n - \varphi_k)}$$

Quantum mechanical parallel

- Mapping a Q-bit on Bloch's sphere
  - Two independent states at opposite poles: A and B
  - Relative weight controlled by θ
  - Relative phase controlled by φ
  - Phase inconsistency $\Phi = Area/2$
- $S = A \qquad\qquad + B$
- On this sphere one can easily study the inconsistency (area) relation to
  - relative phase changes
  - relative weight changes



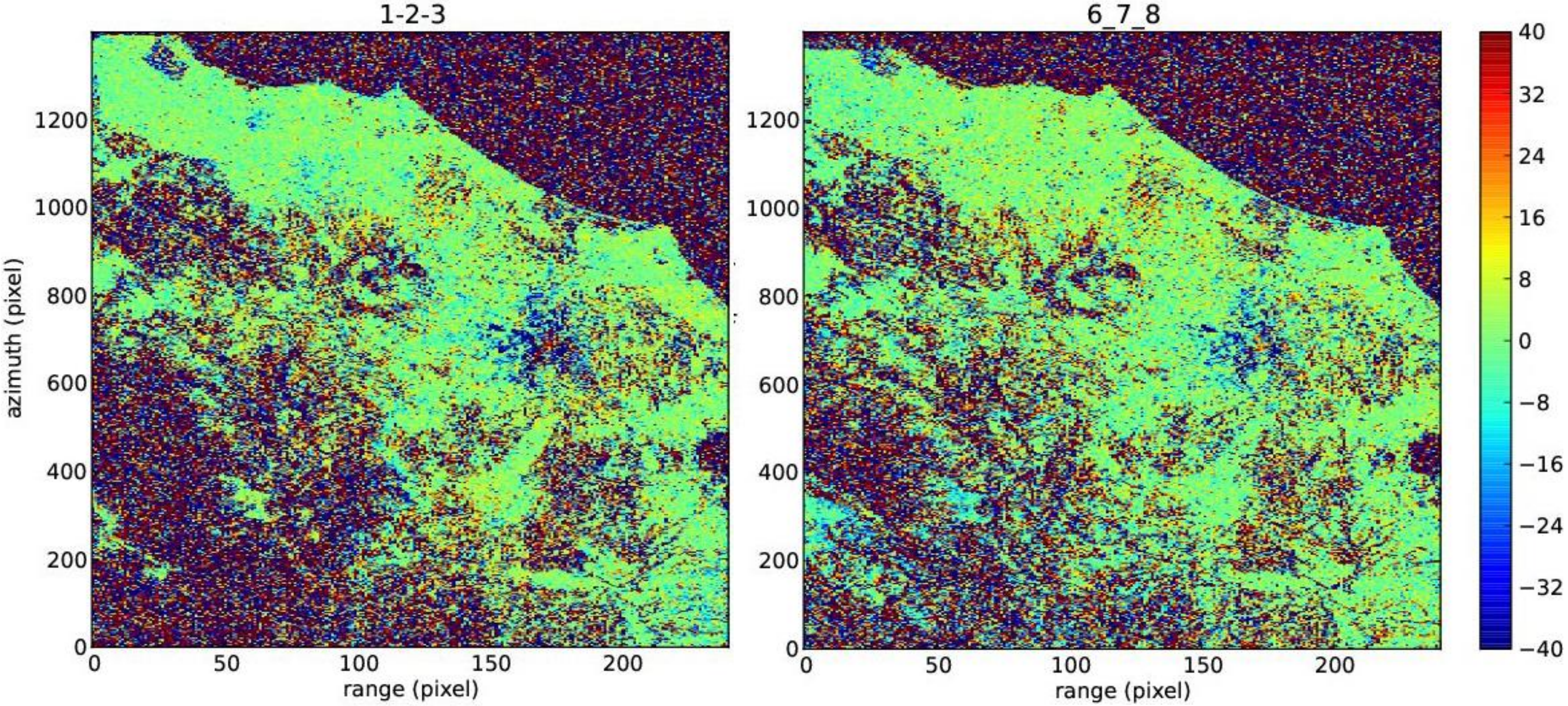
ERS-1 Data from 3-day-repeat phase of 1993-1994



Volumetric effects

Date	26/12/1993	29/12/1993	01/01/1994
k_z (rad/m)	0.1182	0.1047	-0.2296
Height of amb.	53.1 m	60 m	-27.3 m

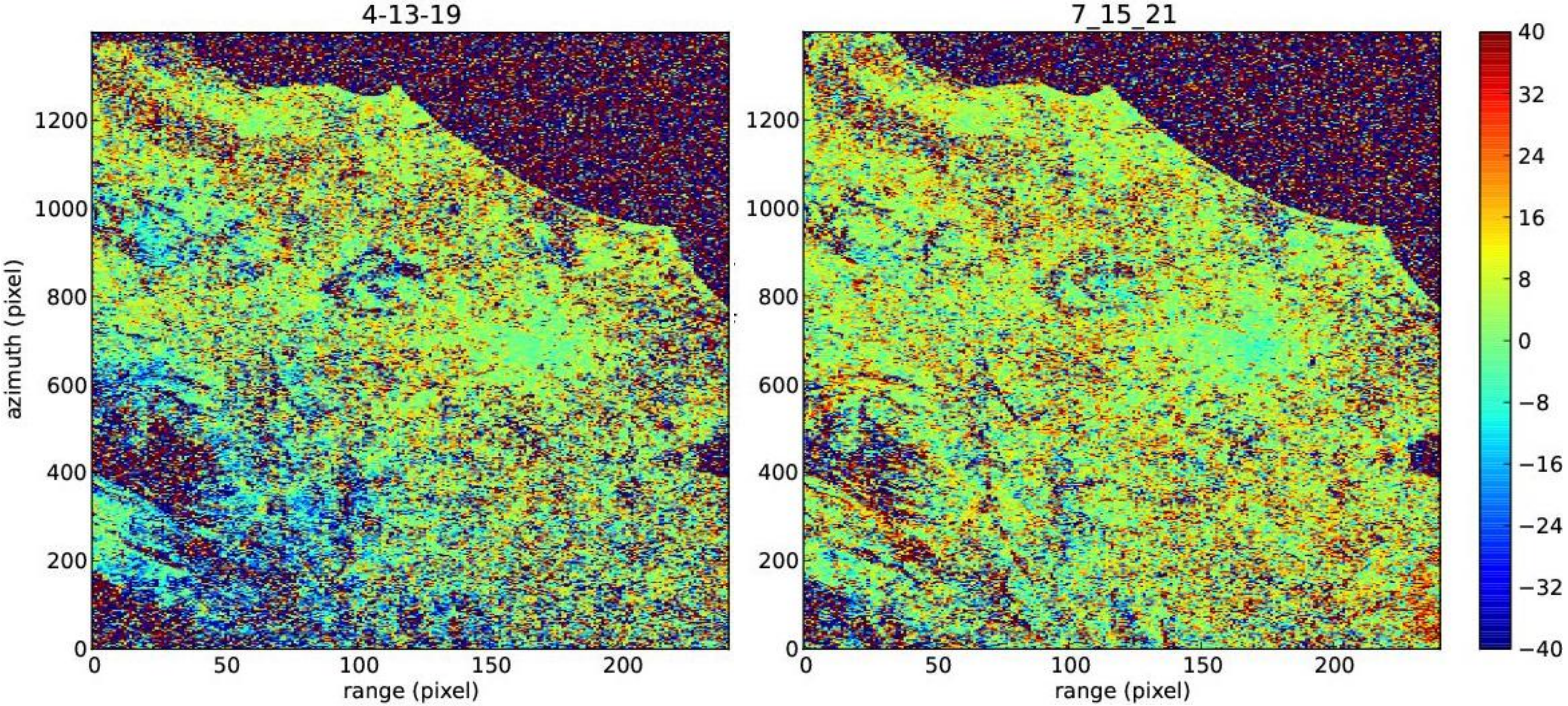
Date	19/01/1994	31/01/1994	03/02/1994
k_z (rad/m)	-0.204	0.0774	0.1266
Height of amb.	-30.8 m	81.2 m	49.6 m



Propagation effects in the forest?

Date	07/01/1994	24/02/1994	07/03/1994
k_z (rad/m)	-0.009	0.038	-0.029
Height of amb.	-698.1 m	-165.3 m	-216.6 m

Date	31/01/1994	05/03/1994	23/03/1994
k_z (rad/m)	-0.009	0.019	-0.009
Height of amb.	-698.1 m	-330.7 m	-698.1 m



TropiScat: ESA P-band scatterometer

- P-band experiment in French Guiana from 2011-2012
  - Scatterometer on a tower overlooking tropical forest
  - Acquisitions every 15 minutes for long periods
    - Tomography
    - Polarimetry
    - Interferometry

- One of the main goals: study temporal decorrelation at different time scales and the variations with height

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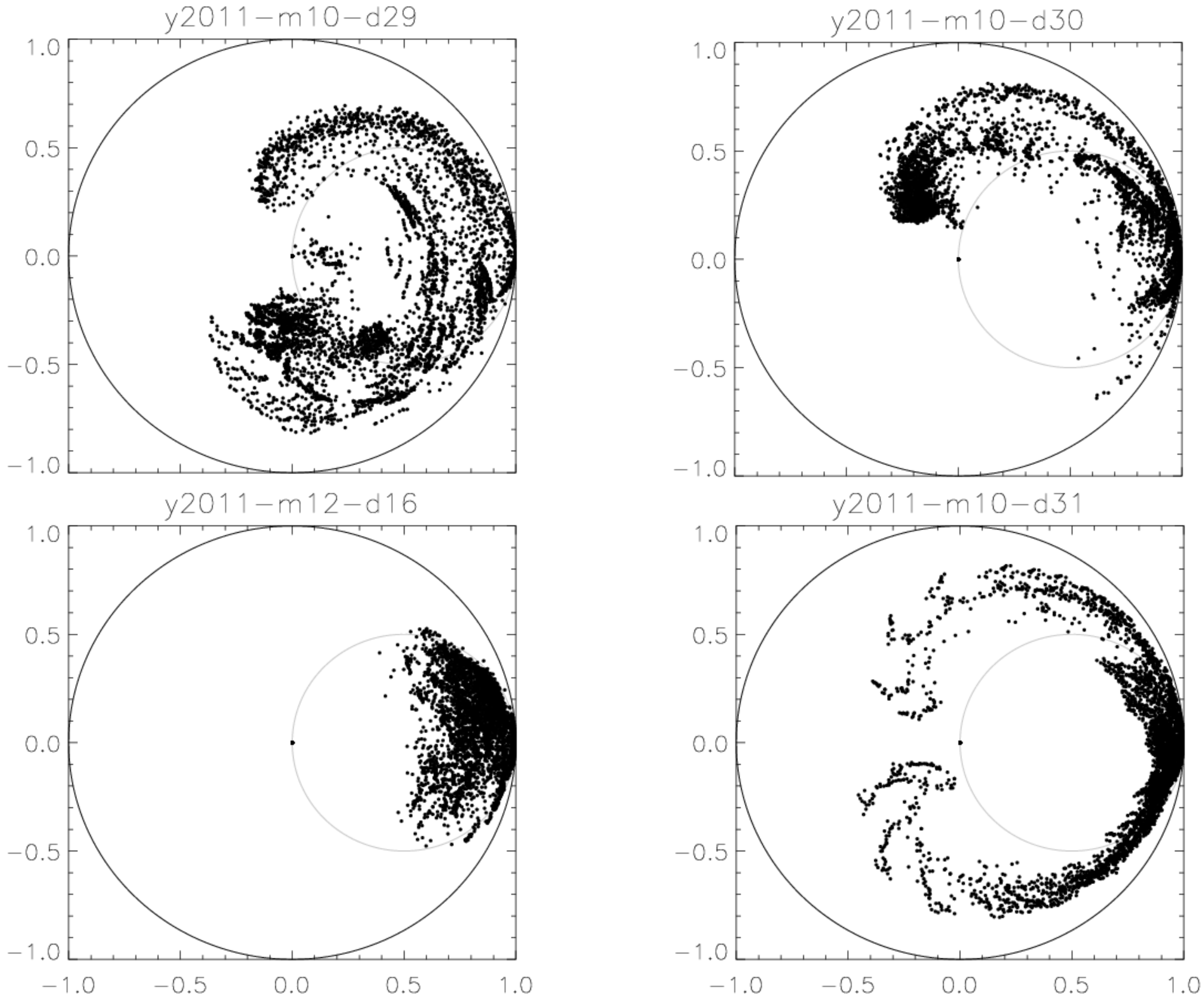
TropiScat intra-day complex coherences (examples)



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Tomographic - Interferometric analysis on TropiScat

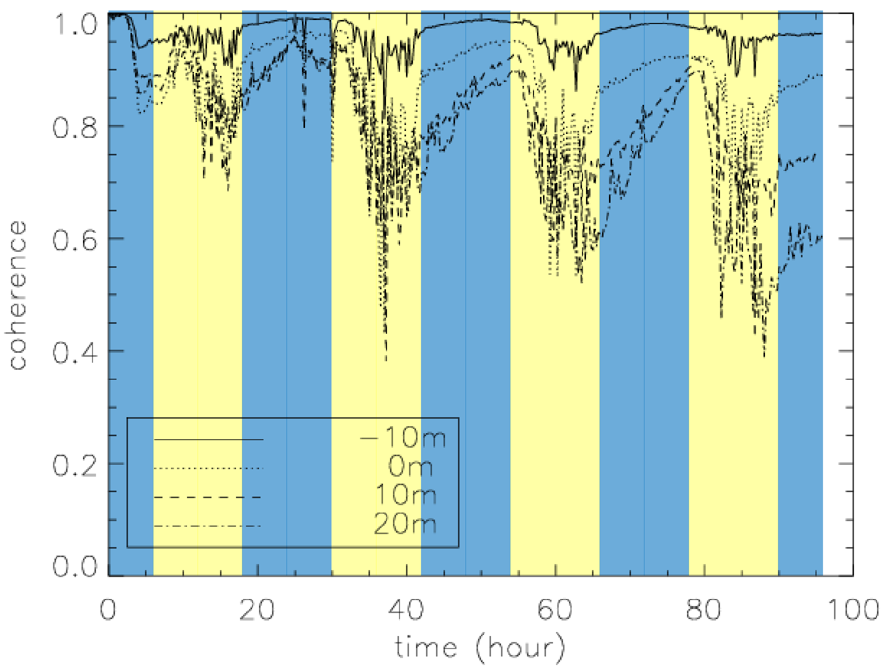
- Study of interferometric coherences at different heights, for different polarizations
  - First: tomography to slice the volume vertically
  - Then: interferometry on each slice

- A very similar study was done by the team POLIMI-CESBIO-ONERA, but we also looked at interferometric phases:
  - Phase and coherence variations are strongly coupled
  - Clear nightly trends
  - Possible explanation with water recharge
  - Decorrelation as coherent mechanism

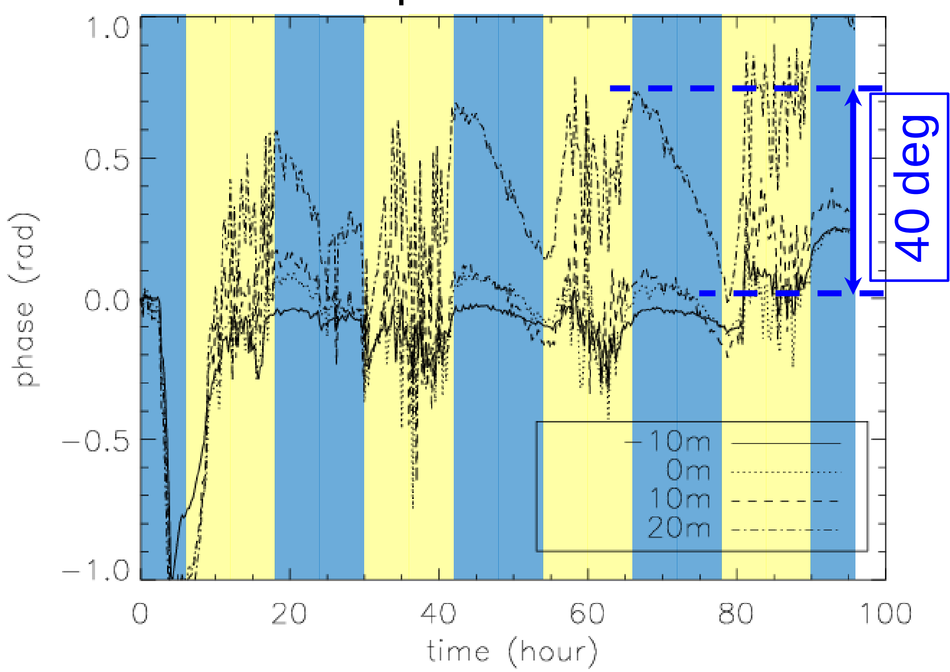
Tomographic-interferometric coherences and phases 2011-12-15:00H00 → 2011-12-18:23H45 (4 days)

HH Polarization

coherence

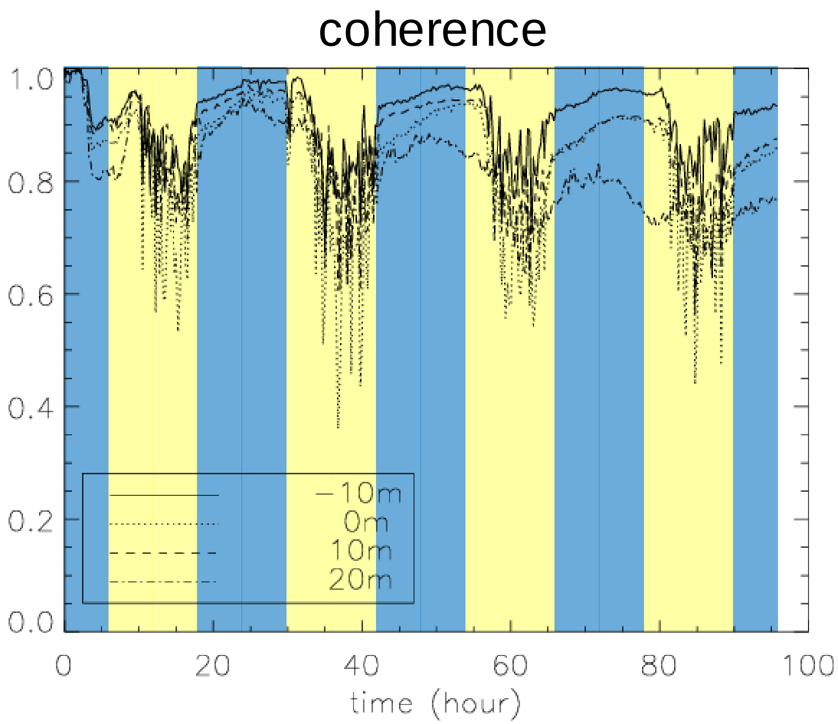


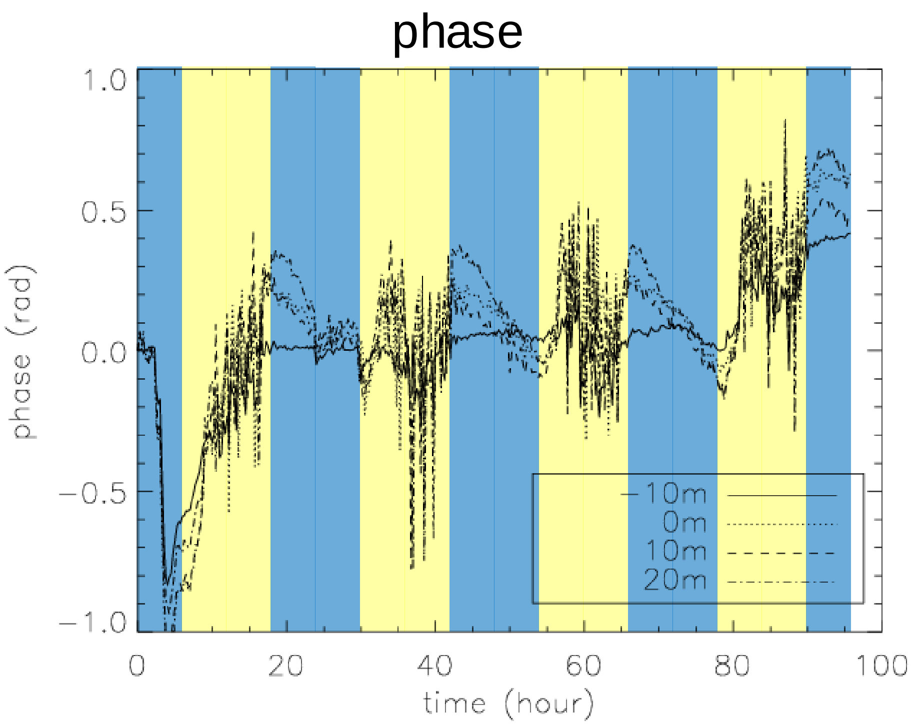
phase



Tomographic-interferometric coherences and phases 2011-12-15:00H00 → 2011-12-18:23H45 (4 days)

VV Polarization

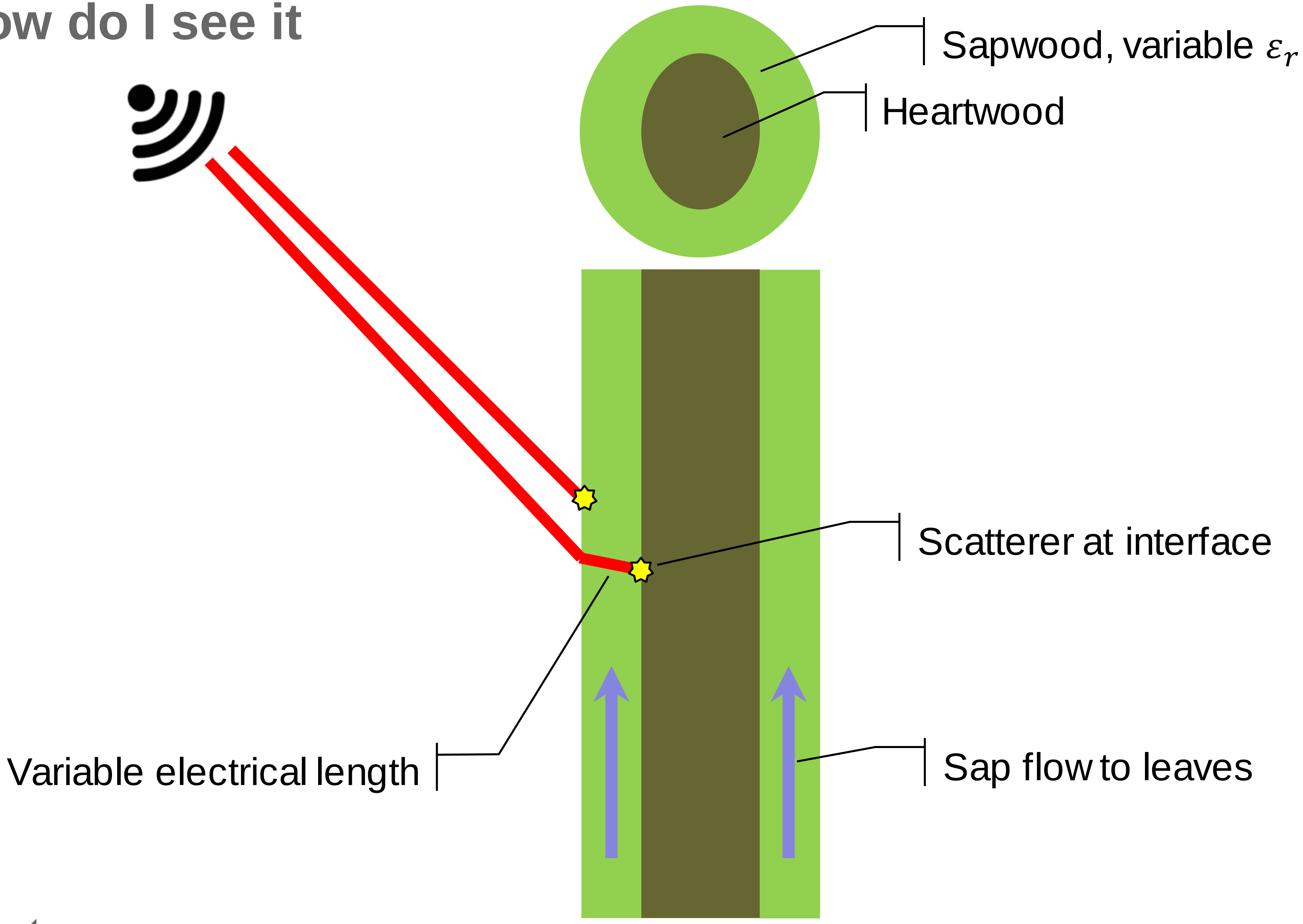


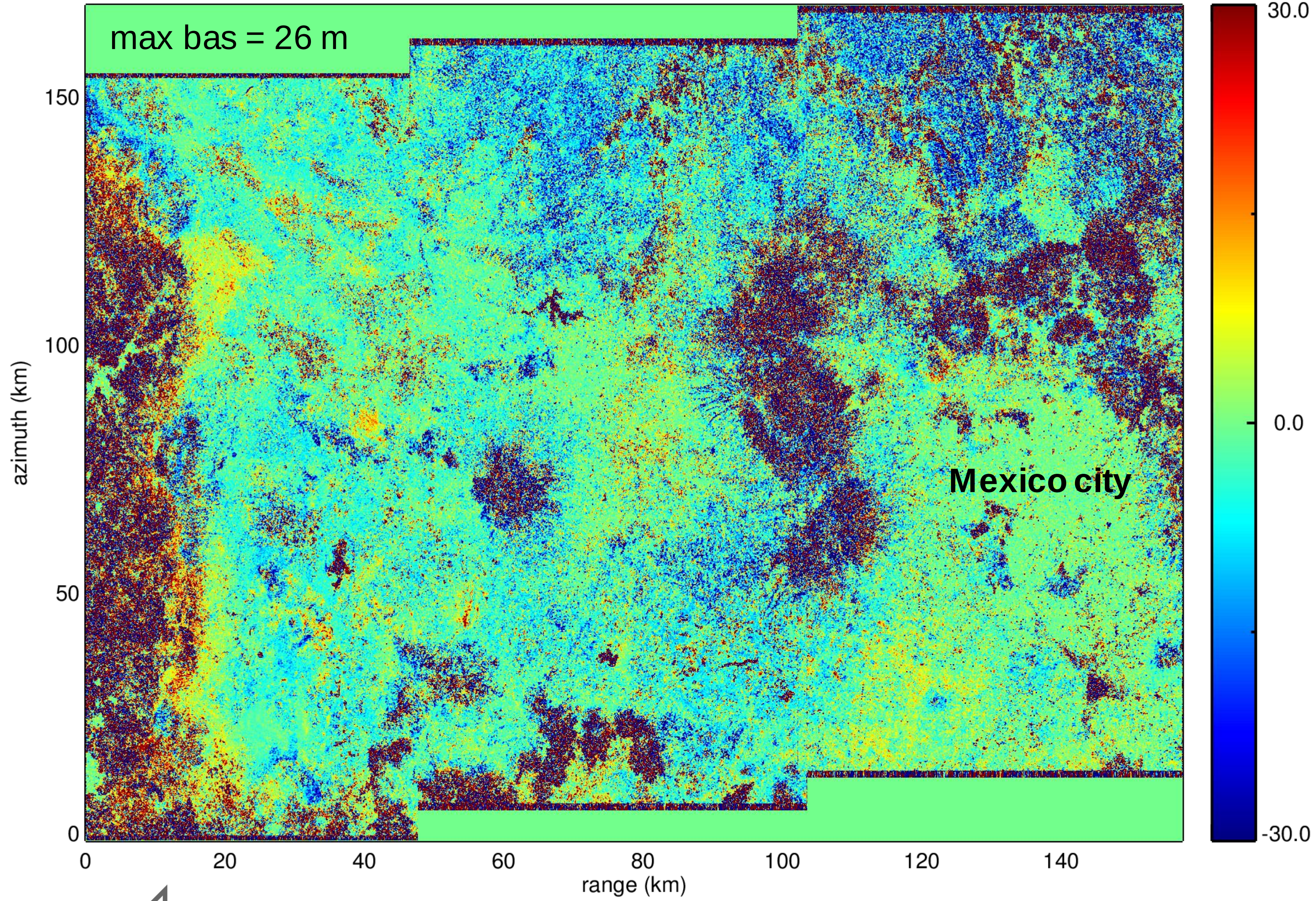


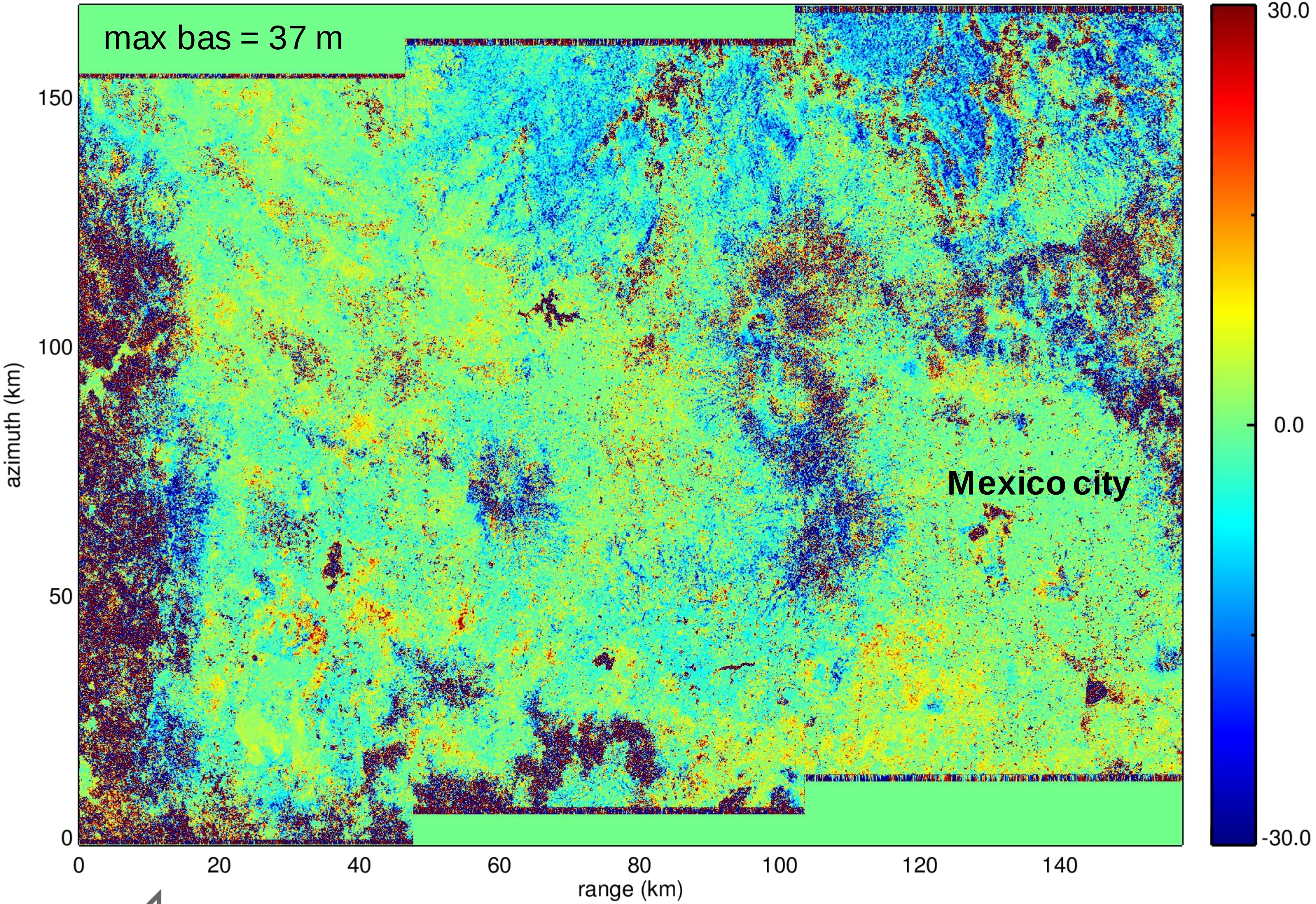
Interpretation and modeling

- A negative phase corresponds to a delay: scatterers appear to move away from the radar during the night!
- Hypothesis: scatterers "seen" through sapwood
  - Interferometric phase function of dielectric constant and amount of fluids; variation stronger with height
  - 40 deg (@ P-band) = 3.7 mm of water = 3.3 cm of air
  - Daily and nightly variations of dielectric constant in trees
    - See: K.C. McDonald, R. Zimmermann, and J.S. Kimball, "*Diurnal and spatial variation of xylem dielectric constant in Norway Spruce (Picea abies [L.] Karst.) as related to microclimate, xylem sap flow, and xylem chemistry*," TGARS, vol. 40, no. 9, 2002

How do I see it




max bas = 26 m
Mexico city
150
100
50
0
azimuth (km)
0
20
40
60
80
100
120
140
range (km)
30.0
0.0
-30.0


max bas = 37 m
Mexico city
azimuth (km)
0
50
100
150
range (km)
0
20
40
60
80
100
120
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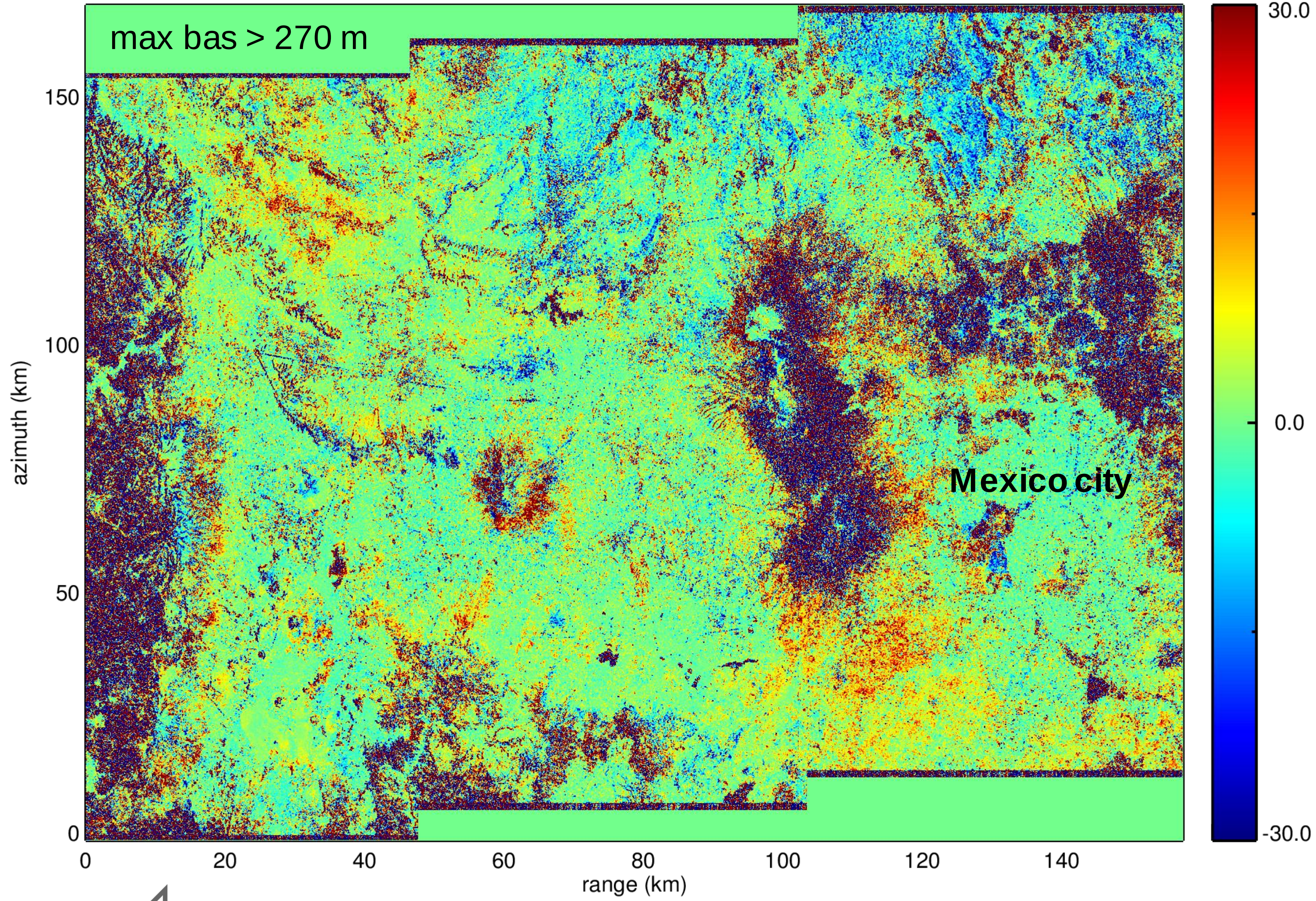
30.0
0.0
-30.0



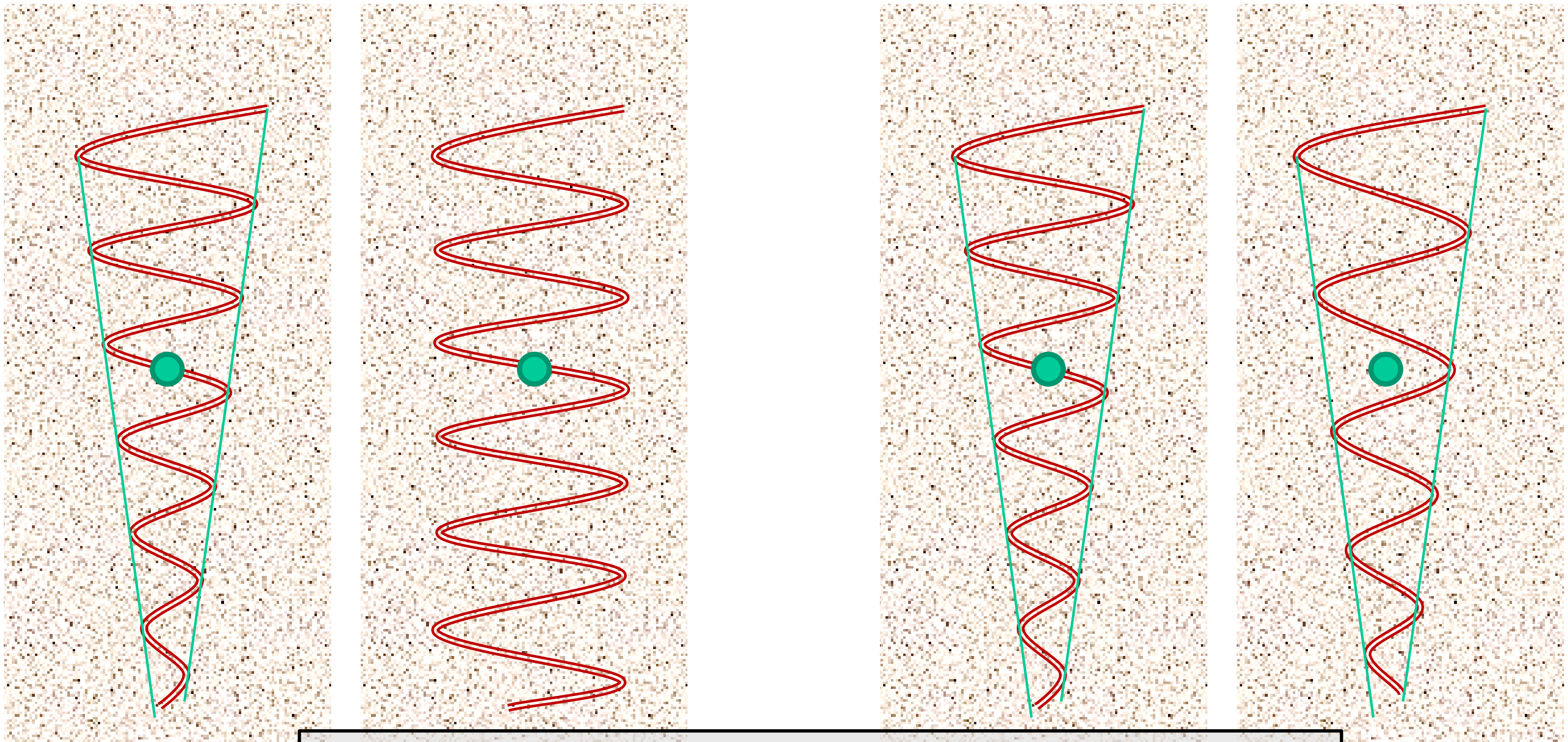
max bas > 270 m
Mexico city
azimuth (km)
range (km)
0
50
100
150
0
20
40
60
80
100
120
140
30.0
0.0
-30.0

END

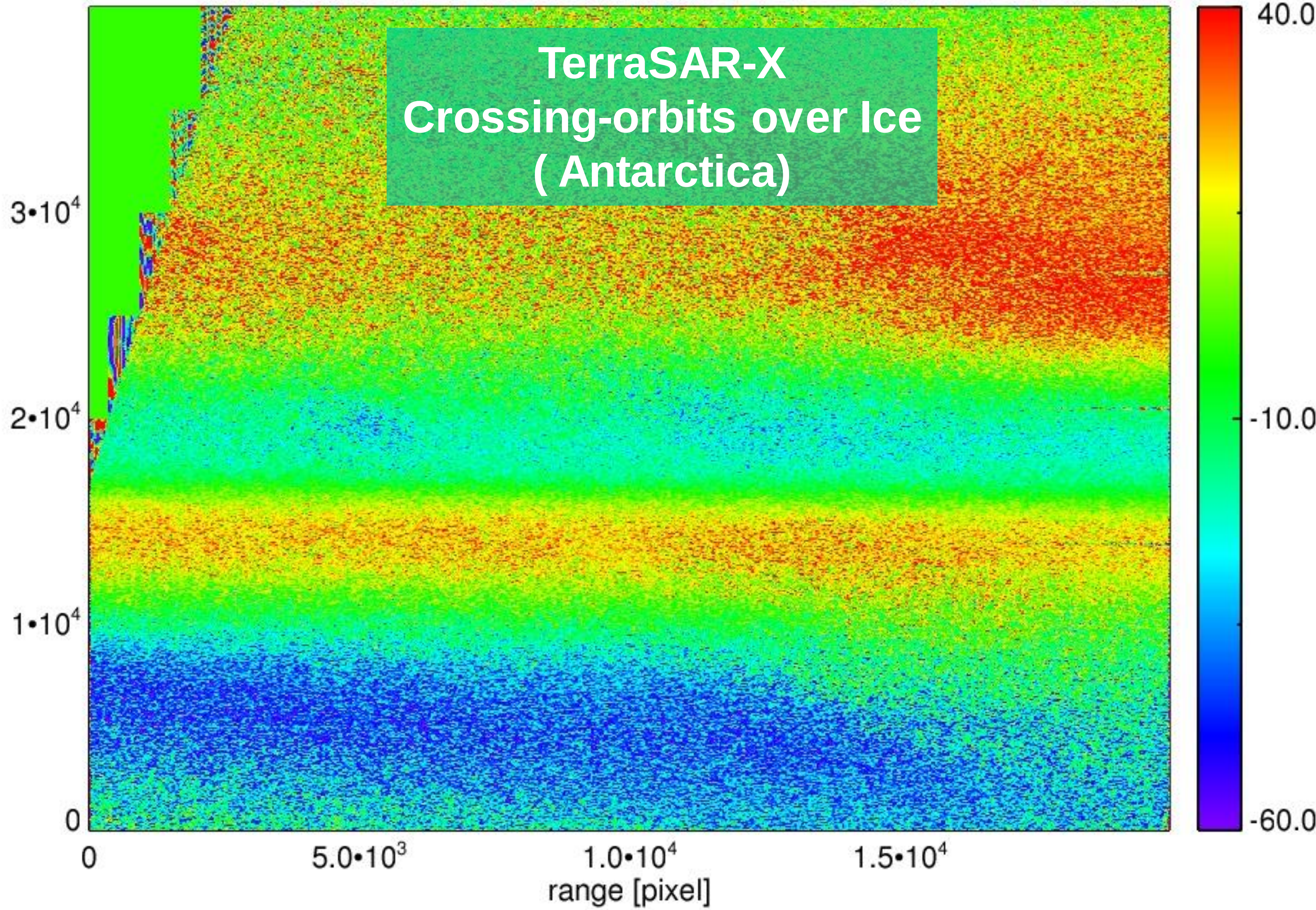
Interferometric effects of vertical wavenumber change

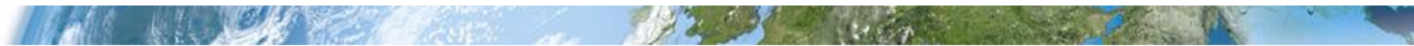
Change in the imaginary part only
no effect on the mean phase
(no differential effect)

Change in the real part only
phase effect
(differential effect)



$$\exp(-jk_z z) = \exp(\mathrm{Im}[k_z]z)\exp(-j\,\mathrm{Re}[k_z]z)$$


TerraSAR-X
Crossing-orbits over Ice
(Antarctica)
3•10⁴
2•10⁴
1•10⁴
0
0
5.0•10³
1.0•10⁴
1.5•10⁴
range [pixel]
40.0
-10.0
-60.0



Volumetric scattering and cross-track baseline

- The autocorrelation in the baselines is the Fourier transform of the profile

$$R(k_z) = \int_{-\infty}^{+\infty} f(z) e^{jk_z z} dz$$

autocorrelation (interferogram)

profile

- Let's separate the autocorrelation in amplitude and phase

$$R(k_z) = A(k_z) e^{j\varphi(k_z)}$$

Amplitude (coherence)

interferometric phase

- There is an interesting **relation of interferogram coherence and phase with the profile moments**

Taylor expansion of interferogram phase and amplitude

- Amplitude and phase show even and odd symmetries because the autocorrelation $R(k_z)$ is Hermitian
- The Taylor expansions reflect the symmetries
  - Only odd terms in the phase expansion

$$\varphi(k_z) = \cancel{\varphi(0)} + \varphi'(0)k_z + \tfrac{1}{2}\cancel{\varphi''(0)k_z^2} + \tfrac{1}{6}\varphi'''(0)k_z^3 + \cdots$$

  - Only even terms in the amplitude expansion

$$A(k_z) = A(0) + \cancel{A'(0)k_z} + \tfrac{1}{2}A''(0)k_z^2 + \tfrac{1}{6}\cancel{A'''(0)k_z^3} + \cdots$$

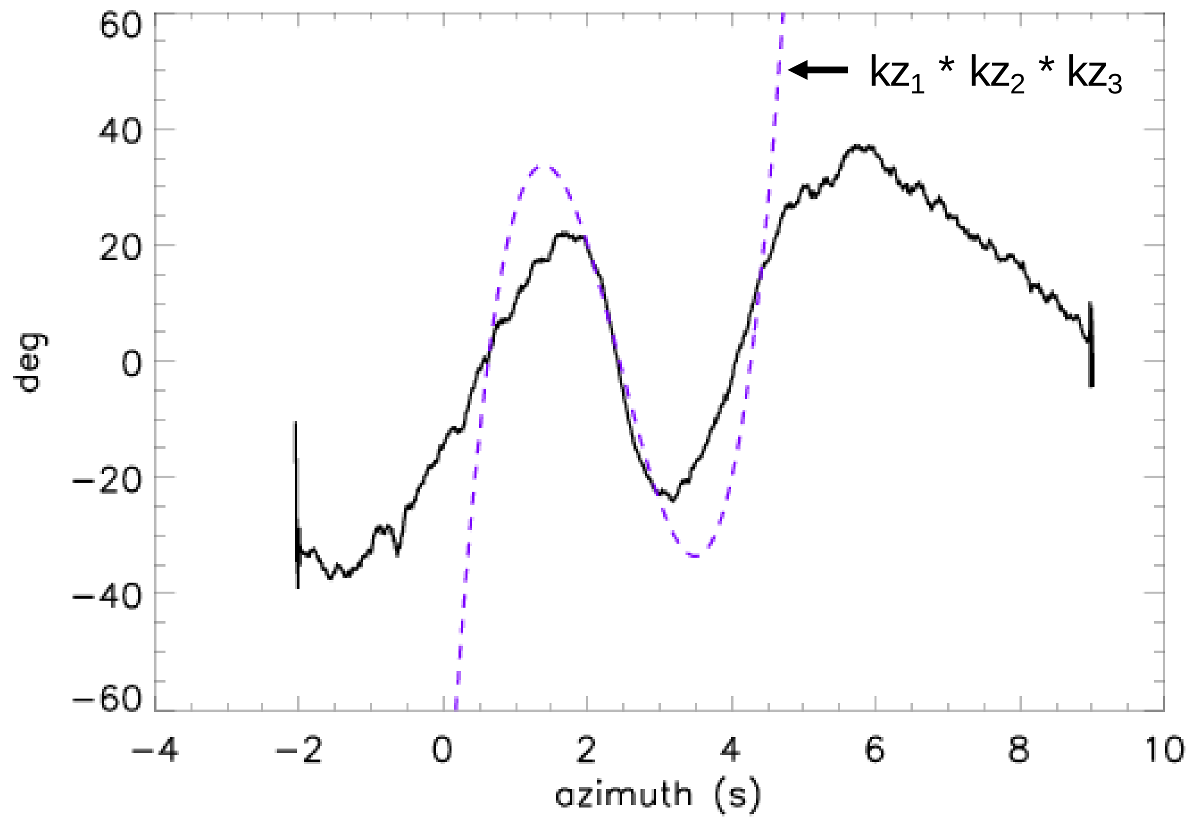
- Consequence
  - The phases describe the odd part of autocorrelation (even moments)
  - The amplitudes describe the even part of autocorrelation (odd moments)

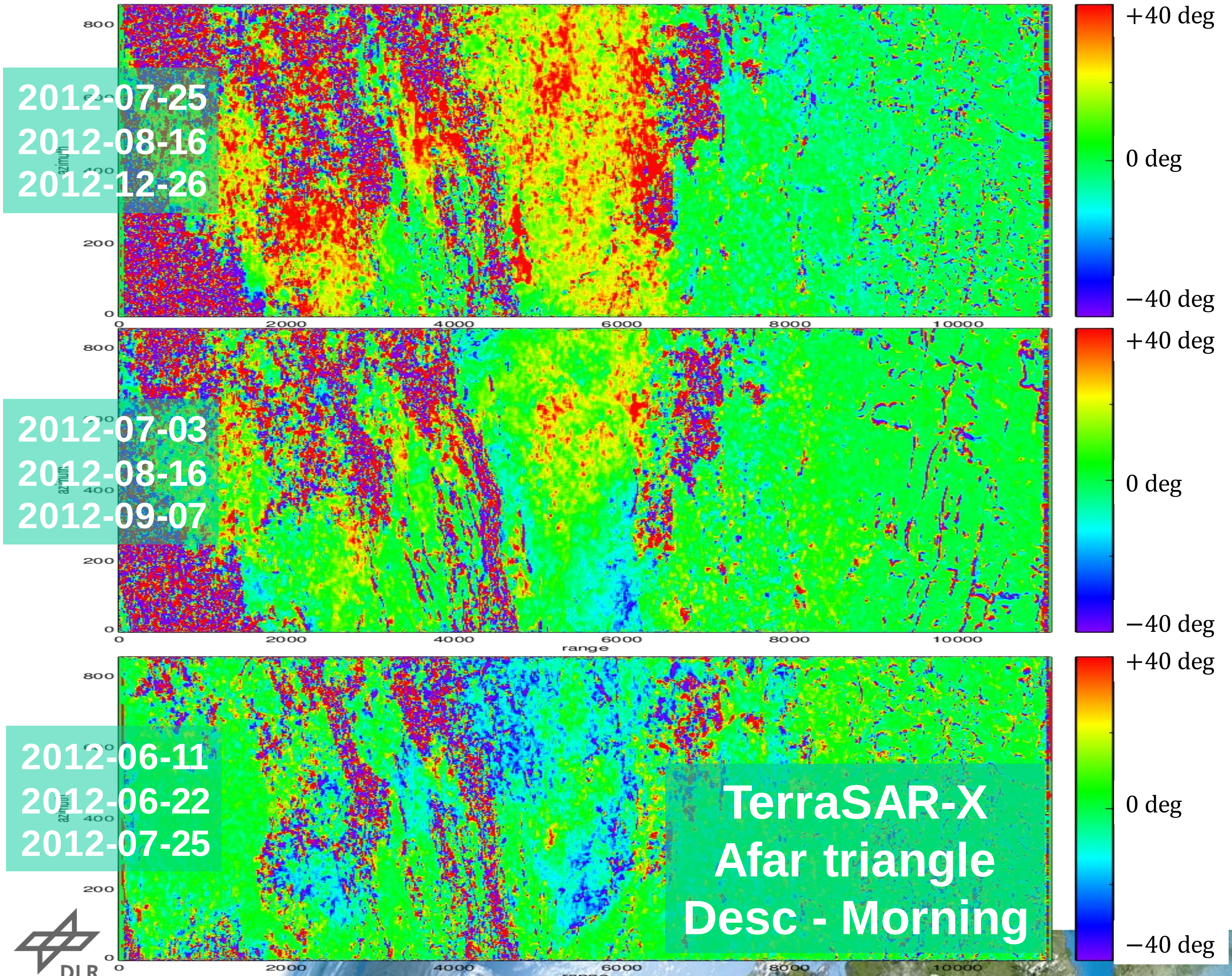
Profile moments and derivatives of autocorrelation

- From $\left(\frac{d}{dk_z}\right)^n R|_{k_z=0} = j^n E[z^n]$ one can show that:
  - Mean: $\varphi'(0) = E[z] = \mu_z$
  - Variance: $A''(0) = -\mathrm{E}[(z-\mu_z)^2]$
  - Skewness: $\varphi'''(0) = -\mathrm{E}[(z-\mu_z)^3]$
  - Kurtosis: $A^{IV}(0) = \mathrm{E}[(z-\mu_z)^4]$

- With Taylor approximations
  - $\varphi(k_z) = \mu_z k_z + \cdots$
  - $\gamma(k_z) = 1 - \frac{1}{2}\mathrm{Var}(z)k_z^2 + \cdots$
  - $\varphi(k_z') + \varphi(k_z'') - \varphi(k_z' + k_z'') = \frac{1}{2}\mathrm{E}[(z-\mu_z)^3](k_z' + k_z'')(k_z' k_z'') + \cdots$

Each baseline varies linearly -> product is a cubic

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2012-08-16
2012-12-26
2012-07-03
2012-08-16
2012-09-07
2012-06-11
2012-06-22
2012-07-25
+40 deg
0 deg
−40 deg
range
azimuth
TerraSAR-X
Afar triangle
Desc - Morning