Multi-pass ERS-ENVISAT Cross-Interferometry Methods and Results

Urs Wegmüller, Charles Werner, Othmar Frey,
Tazio Strozzi, and Maurizio Santoro

Gamma Remote Sensing AG, Gümligen, Switzerland,
http://www.gamma-rs.ch, wegmuller@gamma-rs.ch

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ERS–ENVISAT cross interferometry

- Between 2002 and 2010 the ENVISAT satellite was operated on the same orbit as ERS-2 (35 days repeat cycle) with a very short temporal separation of 28 minutes
- However, the radar center frequency of ENVISAT ASAR (5.331 GHz) has been slightly changed compared to ERS-2 (5.300 GHz)
- At perpendicular baselines around 2 km the baseline effect can composite the frequency difference effect on the reflectivity spectrum allowing to get coherent interferograms

→ 28 minute interval and 2km perpendicular baseline

ERS–ENVISAT cross interferometry

$$\phi = \phi_{orb} + \frac{4\pi}{\lambda}\frac{B_{\perp}}{r \cdot \sin\theta}h + \frac{4\pi}{\lambda}r_{disp} + \phi_{path} + \phi_{noise}$$

- Ambiguity height 4.7m (2km perp. baseline)
  → very sensitive to elevation
- 2.8 cm displacement per phase cycle
  but displacement is for a short 28 minute interval
  → suited for relatively fast displacements

2-pass interferometry

- At present predominantly ***2-pass differential interferometry*** is used (SRTM availability):

  - Ground-displacement mapping:
    Simulate orbital and topographic phase (using DEM)
    Subtract → deformation phase + error terms

  - DEM generation:
    Simulate orbital and initial topographic phase (using DEM)
    Assume no deformation
    → residual topographic phase + error terms

Multi-pass interferometry

- Basic idea: Use two or more observations to resolve interferometric phase equations for terrain height and displacement rate

  - Preconditions:
    - different baselines (or time intervals)
    - sufficient coherence
  - Assumptions:
    - identical terrain height
    - motion is uniform

- Unwrapping done:

  - solve equations to retrieve terrain height, displacement rate and quality information

- Unwrapping not done:

  - derive suited combined interferogram(s)

Combined interferograms

1) Scale unwrapped phase of one interferogram and subtract it from another interferogram to get a combined interferogram without topographic phase

2) Combine two interferograms with same observation interval to eliminate the deformation phase

   $$\text{phase}\ (s_1 s_2^*) = \text{phase}\ (s_1) - \text{phase}\ (s_2)$$

3) Generate combined interferogram with strongly reduced sensitivity to terrain height or deformation
   - can be done without phase unwrapping
   - scaling with integer factors possible

   e.g. pair1 ($B_\perp$ 205m) – 2x pair2 ($B_\perp$ 100m)
   → combined interferogram with 5m effective baseline

Combined EET interferograms

- EET CInSAR characteristics:
  - $B_\perp$ ~2000m (1400m to 2600m)
  - dt 28 min.
- EET combined interferogram characteristic (pair1 – pair2):
  - relatively short effective baseline
  - negligible effective time interval

→ much reduced topographic phase sensitivity (fewer topographic fringes)

→ not affected by uniform motion

- Application potential:
  - facilitate phase unwrapping (more robust DEM generation)
  - DEM over uniformly moving surface (not affected by motion)
  - separation of topographic and displacement phase
  - mapping fast non-uniform motion (e.g. tidal motion of ice sheets)

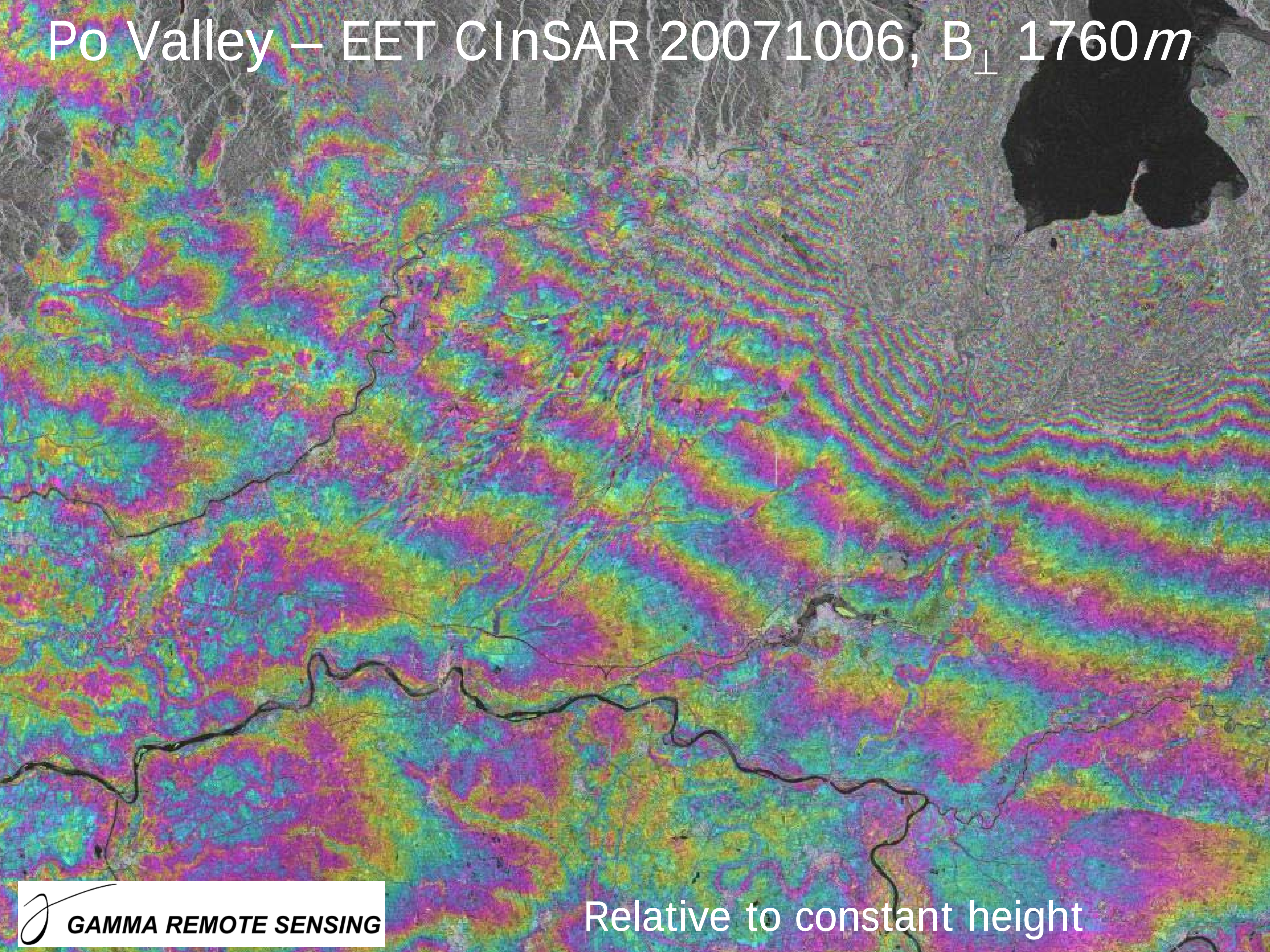
DEM generation with 4 EET CInSAR pairs

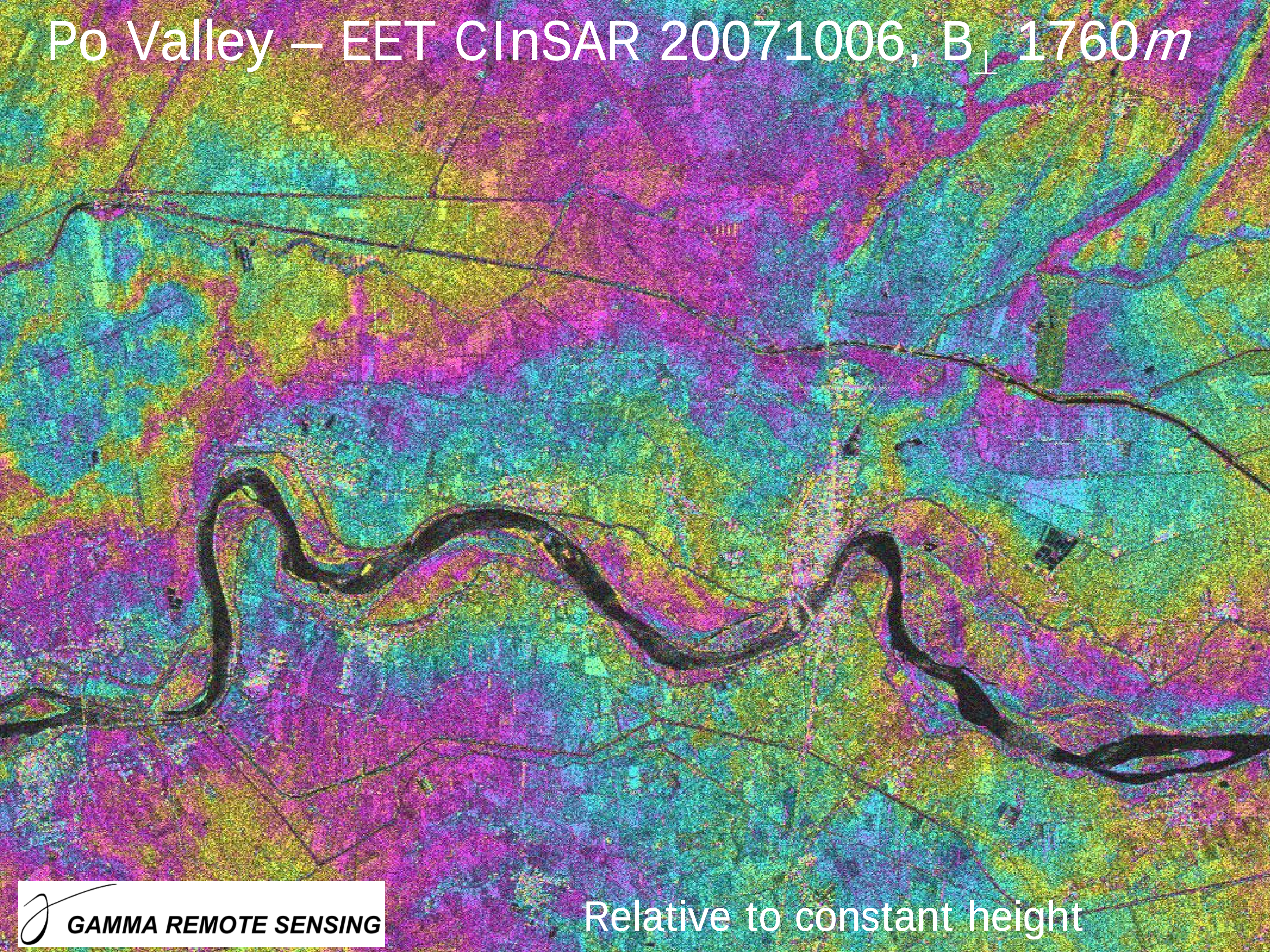
Po Valley, Italy

Descending track 165 EET pairs:

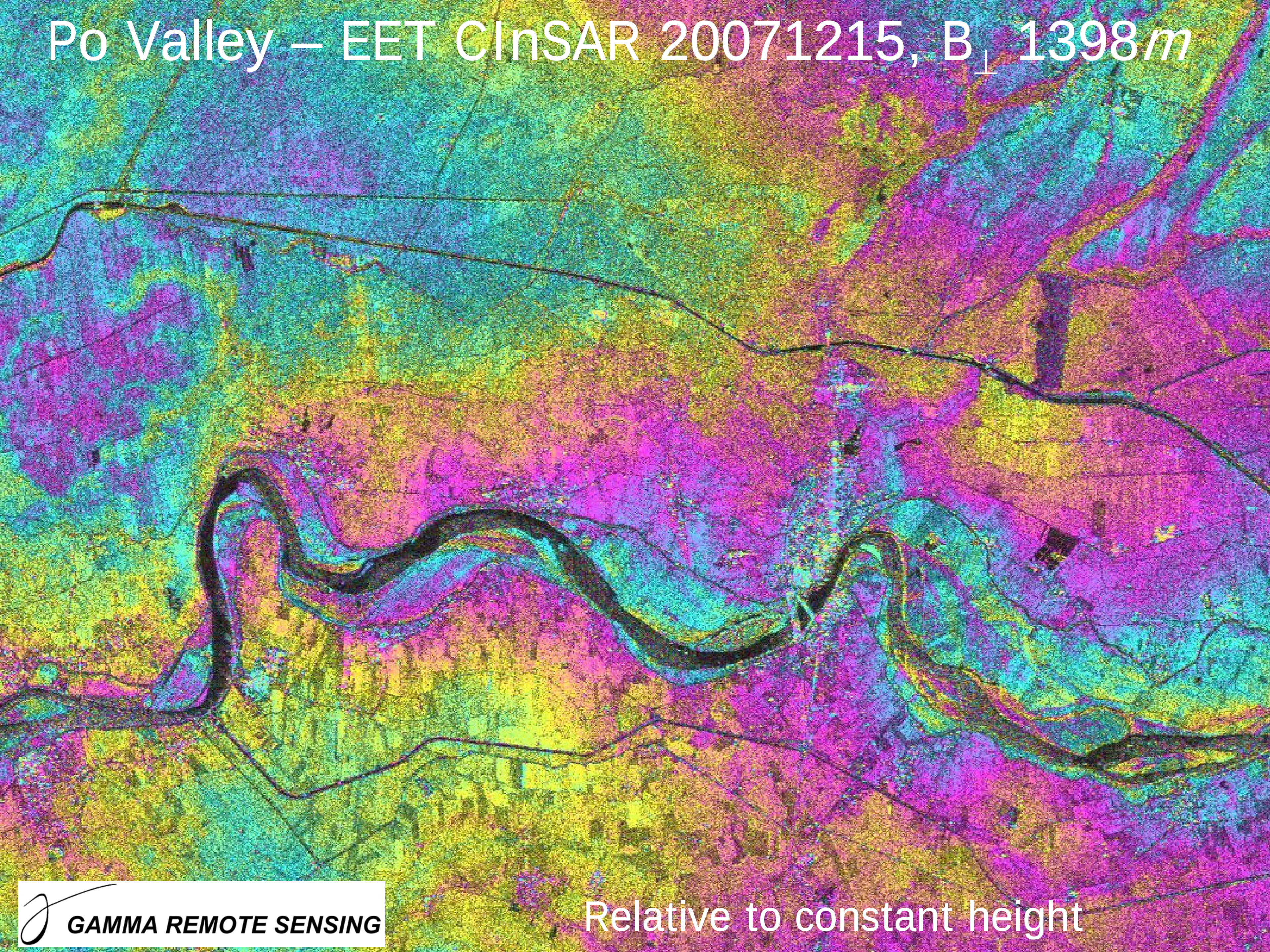
Date	$B_\perp$ [m]	dDC [Hz]
20071006	1760	754
20071215	1398	699
20080223	1674	359
20090207	2203	861

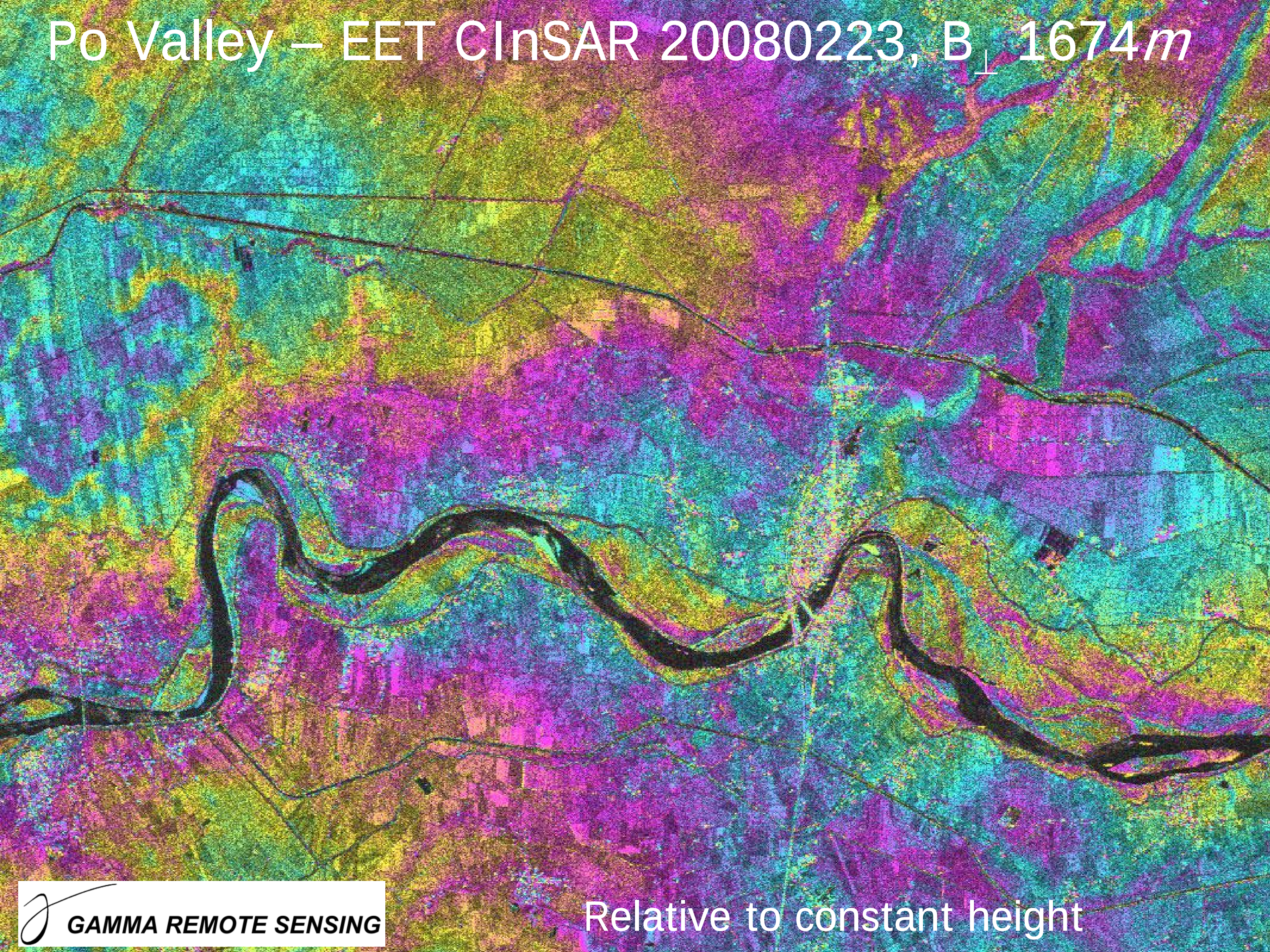
Po Valley – EET CInSAR 20071006, $B_{\perp}$ 1760m



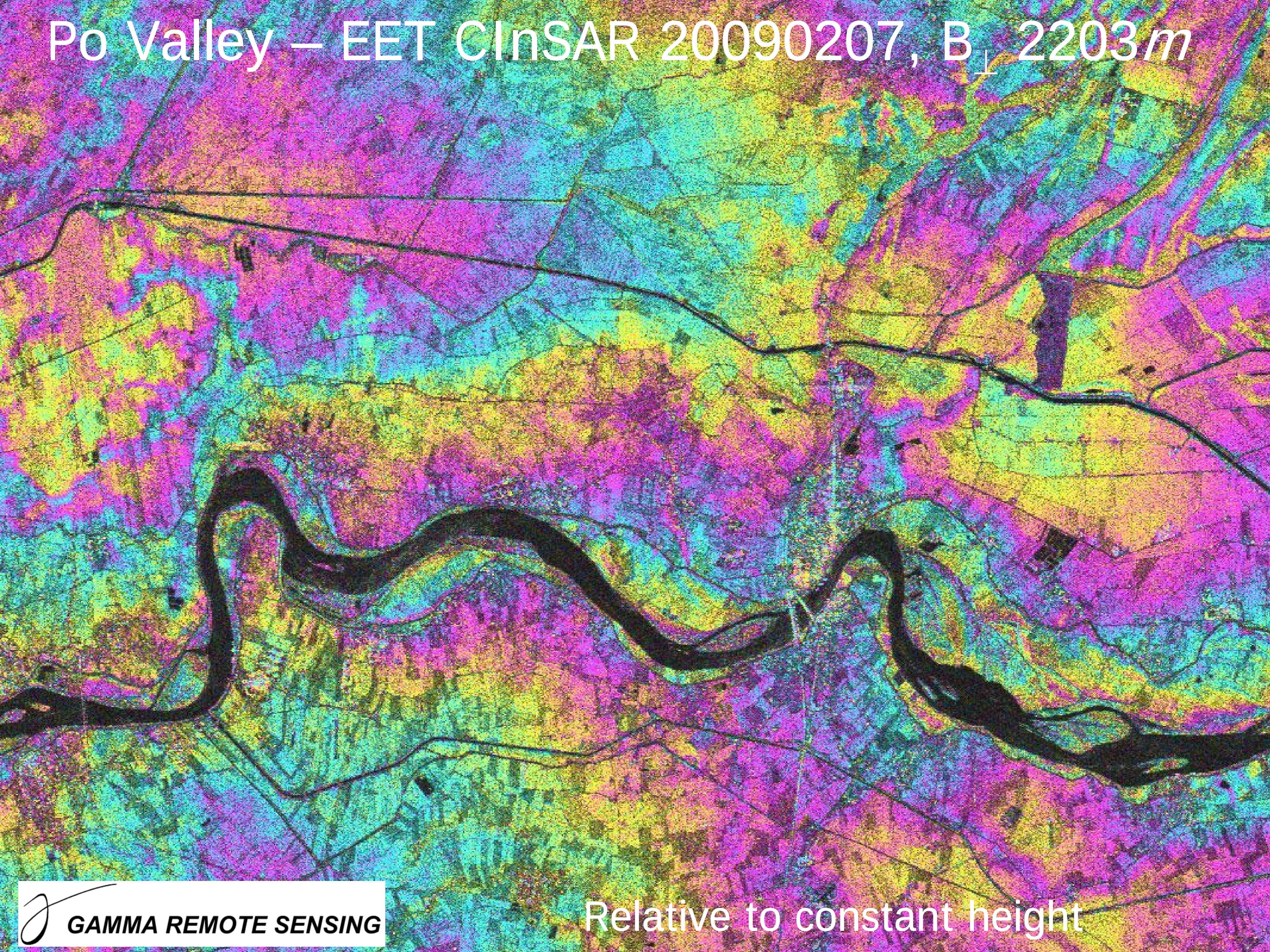

Po Valley – EET CInSAR 20071006, $B_{\perp}$ 1760*m*
GAMMA REMOTE SENSING
Relative to constant height

Po Valley – EET CInSAR 20071215, $B_{\perp}$ 1398 m




Po Valley – EET CInSAR 20080223, $B_{\perp}$ 1674m
GAMMA REMOTE SENSING
Relative to constant height

Po Valley – EET CInSAR 20090207, $B_\perp$ 2203*m*



GAMMA REMOTE SENSING

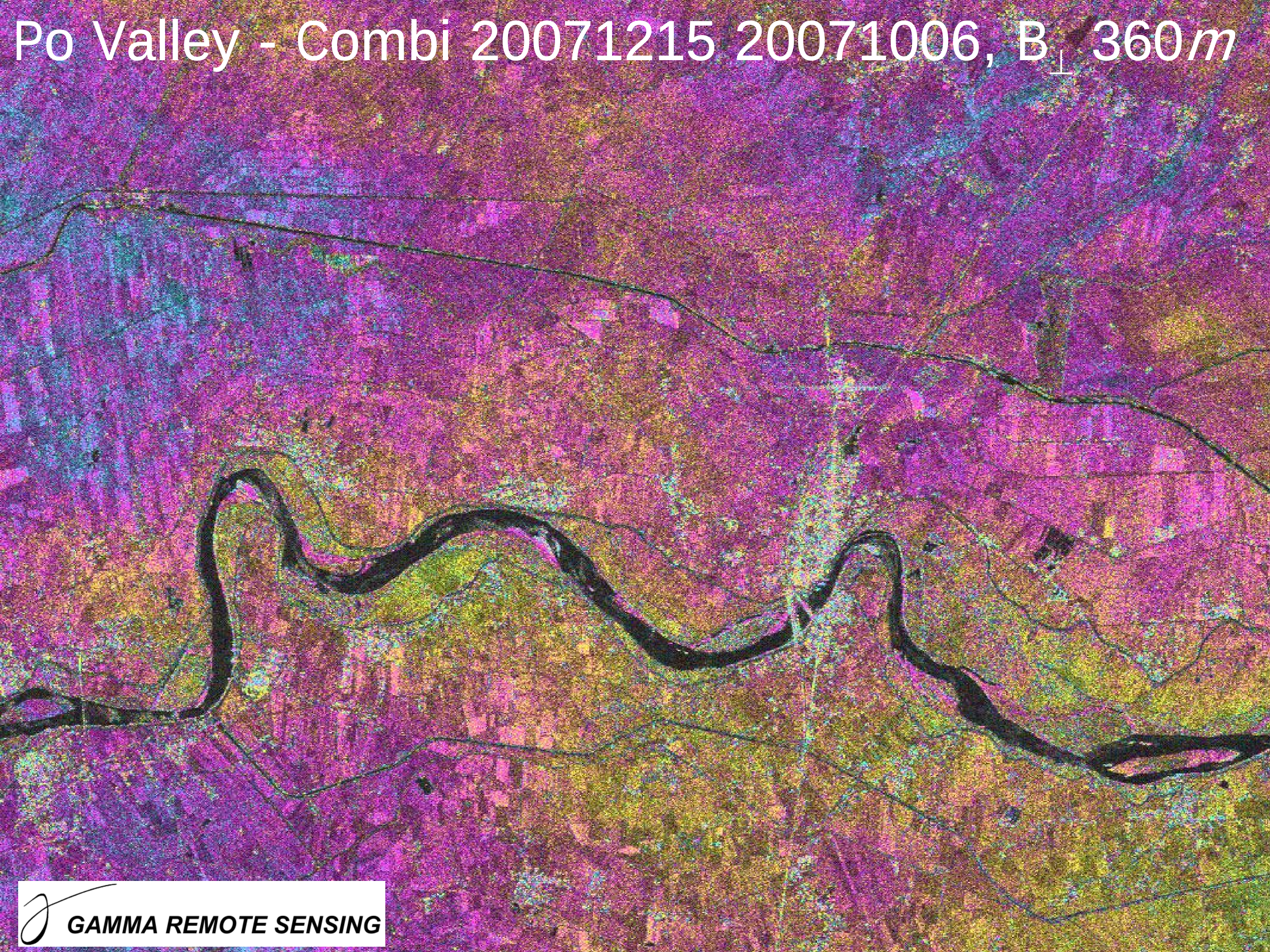
Main problems

1) Atmospheric errors
   → can be reduced by combination of individual DEMs
2) Unwrapping problems even in relatively flat areas due to distinct height steps /steep ramps with elevation changes > 3m
   → can be reduced using combined interferograms

Track 165 combined interferograms considered:

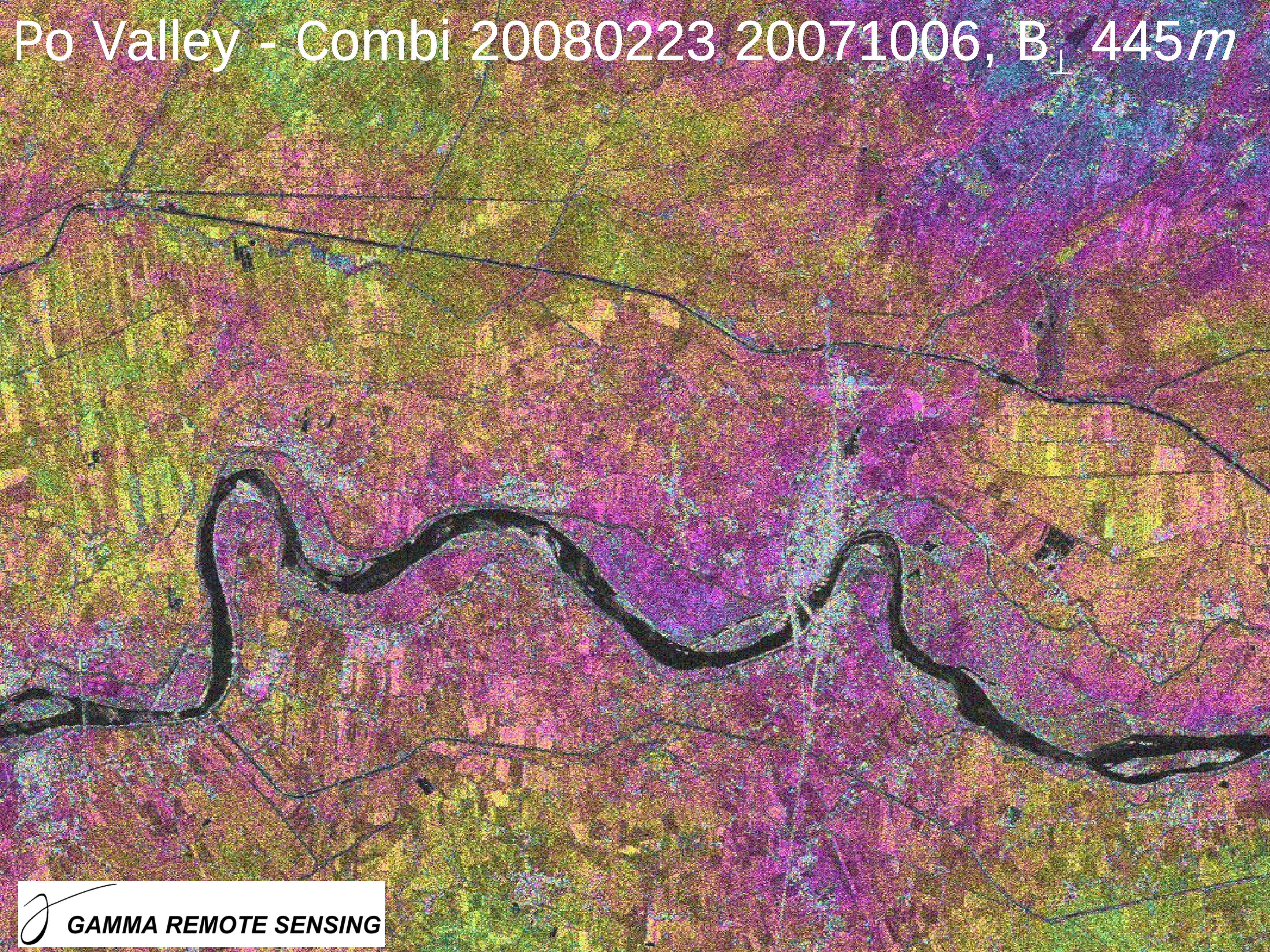
Date 1	Date 2	$B_\perp$ [m]
20071215	20071006	360
20071215	20080223	280
20090207	20071006	445
20090207	20080223	525

Po Valley - Combi 20071215 20071006, $B_\perp$ 360*m*

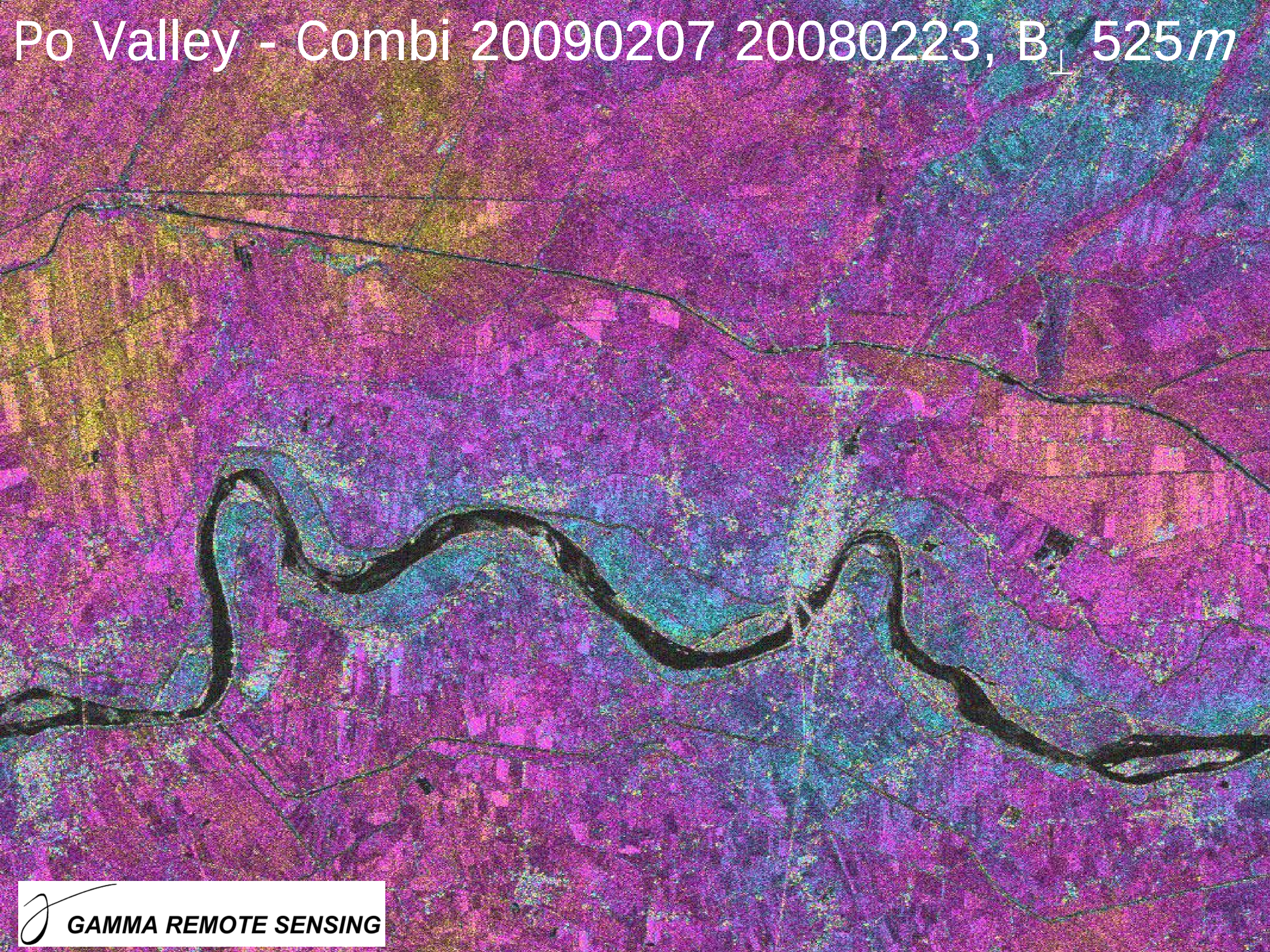


Po Valley - Combi 20071215 20080223, $B_\perp$ 280m

Po Valley - Combi 20080223 20071006, $B_{\perp}$ 445 m



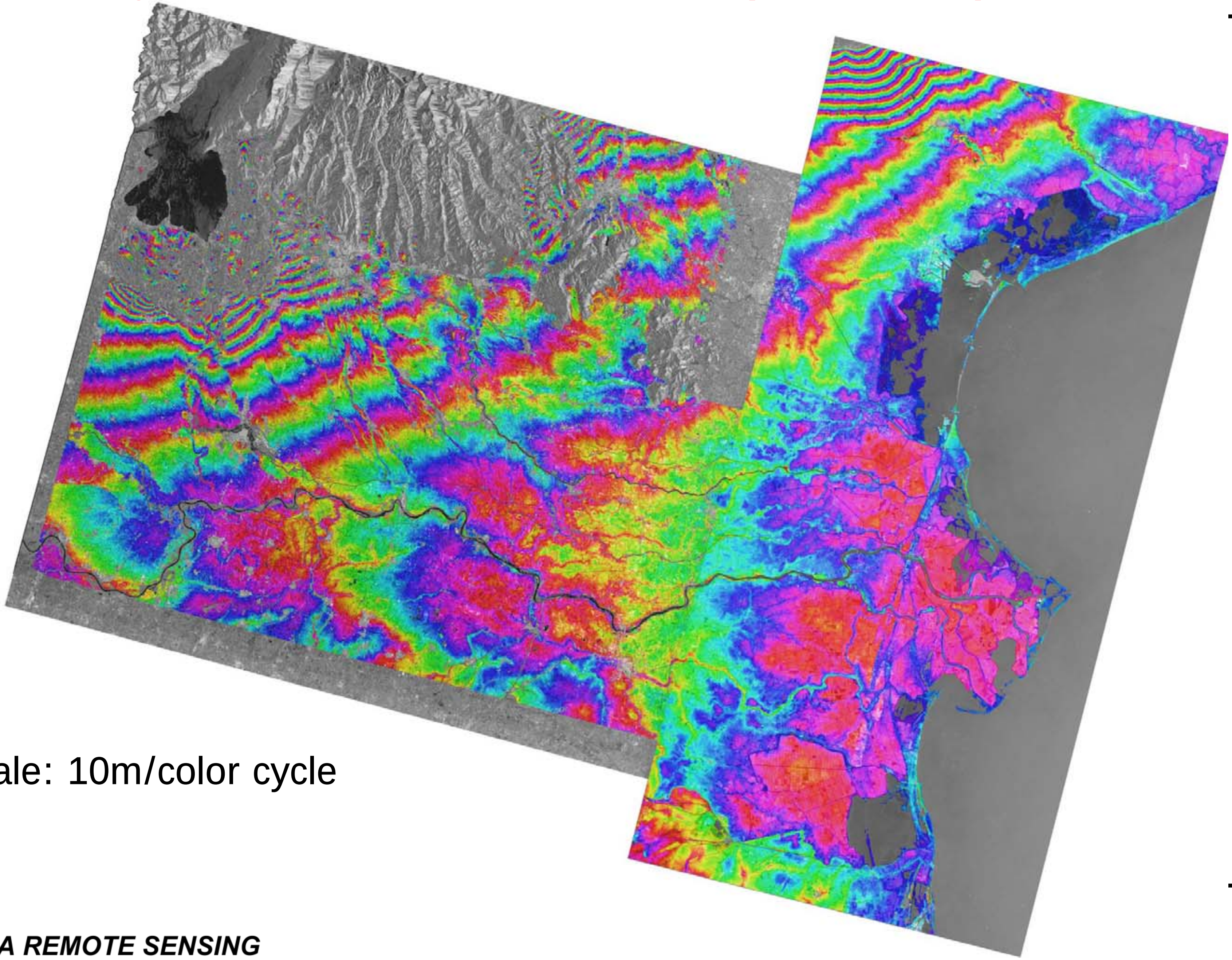
Po Valley - Combi 20090207 20080223, $B_{\perp}$ 525*m*



Resulting DEM generation approach

1) Calculate combined interferograms
2) Unwrap combined interferograms
3) Generate individual DEMs
4) Generate DEM based on all combined interferograms
5) Unwrap EET Cross-interferograms using DEM from step 4
6) Generate individual EET DEMs
7) Generate DEM based on all EET Cross-interferograms and quality information

Po Valley – EET CInSAR DEM (2 tracks)



scale: 10m/color cycle

Multi-pass EET CInSAR over fast glaciers

Objectives:

1) Map glacier topography
2) Map glacier velocity

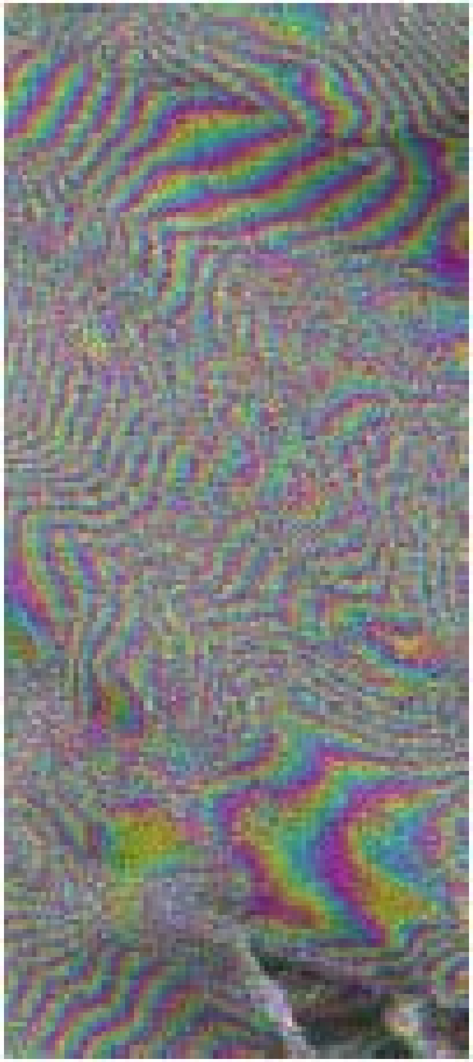
EET pairs used over West Antarctica:

Date	$B_\perp$ [m]	dDC [Hz]
20100226	2267	500
20100402	1940	380

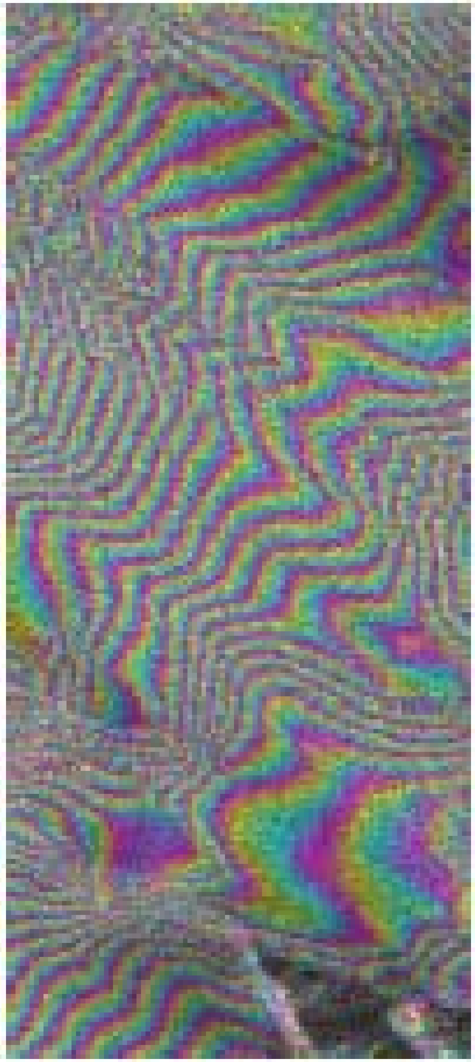
Multi-pass combination:

Date 1	Date 2	$B_\perp$ [m]
20100226	20100402	327

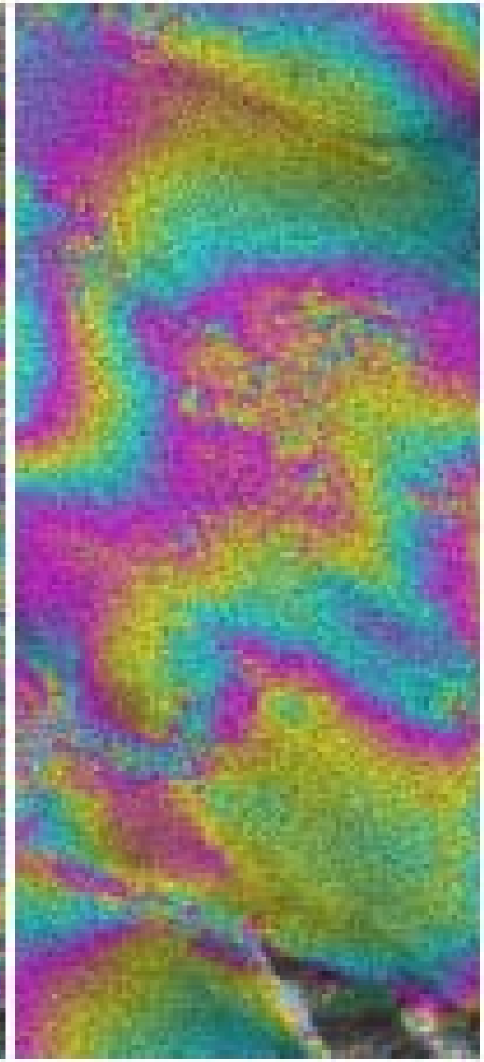
EET CInSAR and combined interferogram



26.2.10, 2267m



2.4.10, 1940m



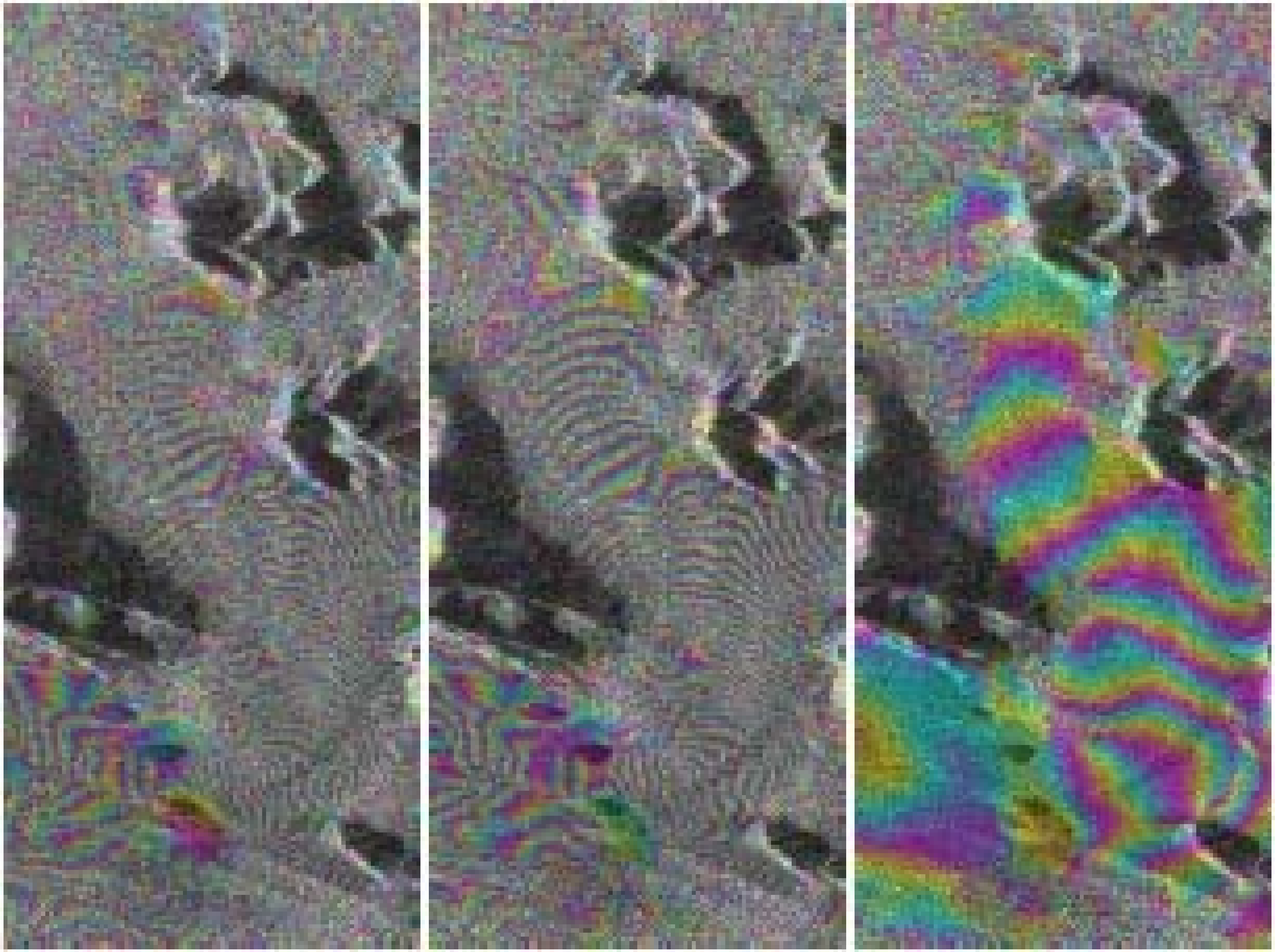
combi, 327m

combi:

topographic phase reduced

no phase from uniform motion

EET CInSAR and combined interferogram



26.2.10, 2267m   2.4.10, 1940m   combi, 327m

combi:

topographic phase reduced

no phase from uniform motion

Potential over fast glaciers

- Glacier topography can be mapped
  - unwrapping complexity reduced
  - no phase from uniform motion

- Generating glacier velocity maps failed (so far)
  - effective baselines for combined interferograms were all significantly smaller than EET baselines (e.g. 300m versus 2000m)
  - up-scaling topographic phase with a factor > 5 results in high phase noise and atmospheric errors which clearly dominate over the rel. small displacement phase typically expected (cm scale)

Multi-pass EET CInSAR for the mapping of the grounding line of shelf ice

Objectives:

1) Identify tidal phase
2) Map grounding line

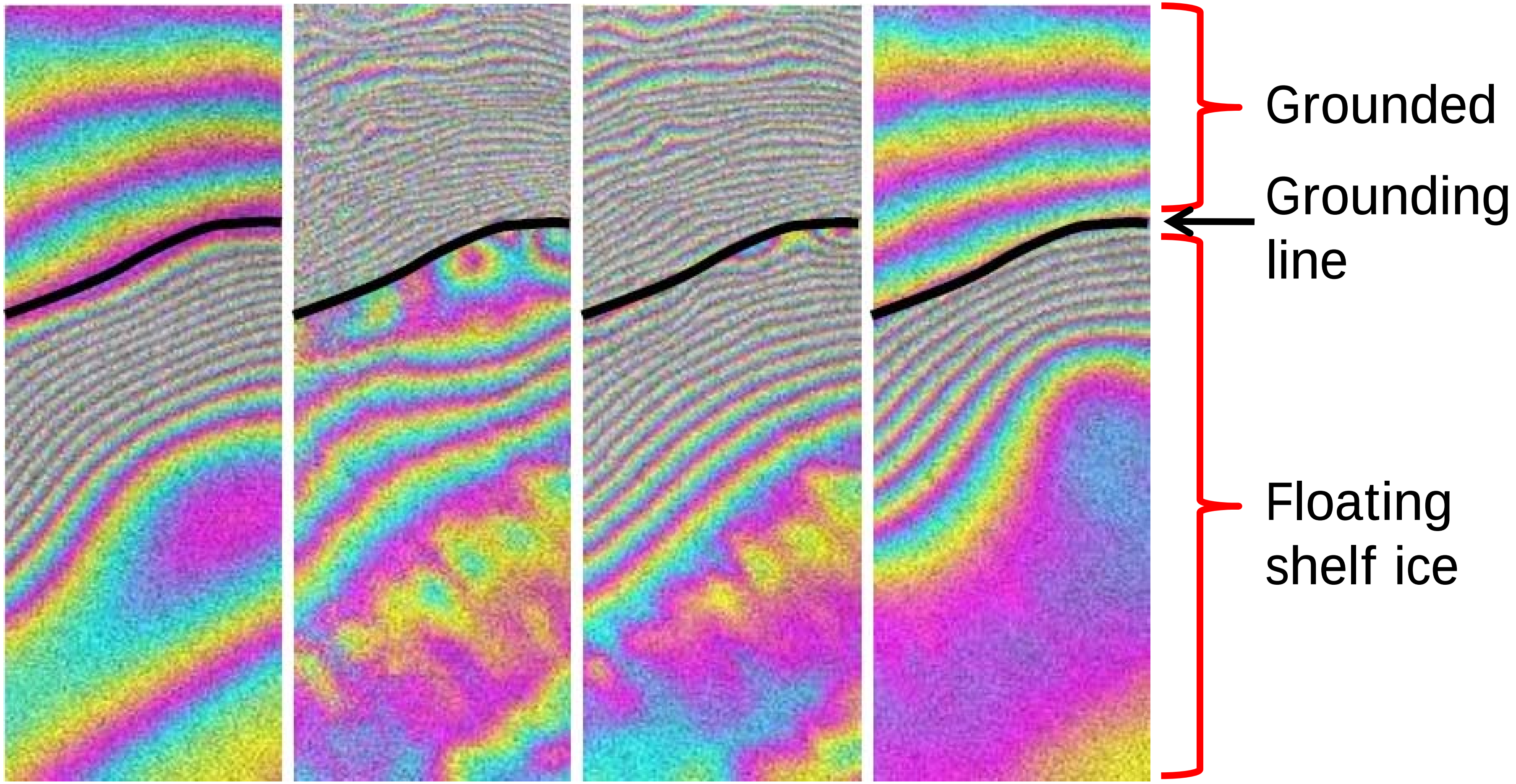
EET pairs used over West Antarctica:

Date	$B_\perp$ [m]	dDC [Hz]
20100226	2267	500
20100402	1940	380

Multi-pass combination:

Date 1	Date 2	$B_\perp$ [m]
20100226	20100402	327

Interferograms over partly grounded ice



E1/2 Nov.1995 $B_\perp$ 335m

EET Feb.2010 $B_\perp$ 2267m

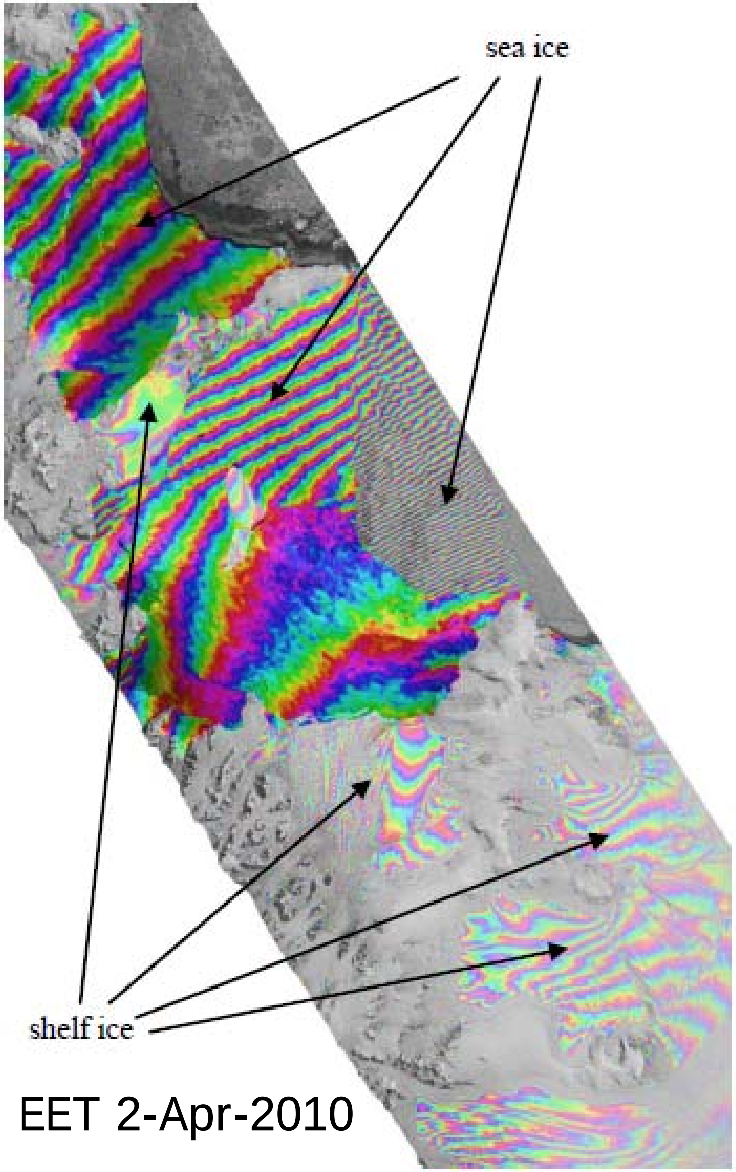
EET_Apr.2010 $B_\perp$ 1940m

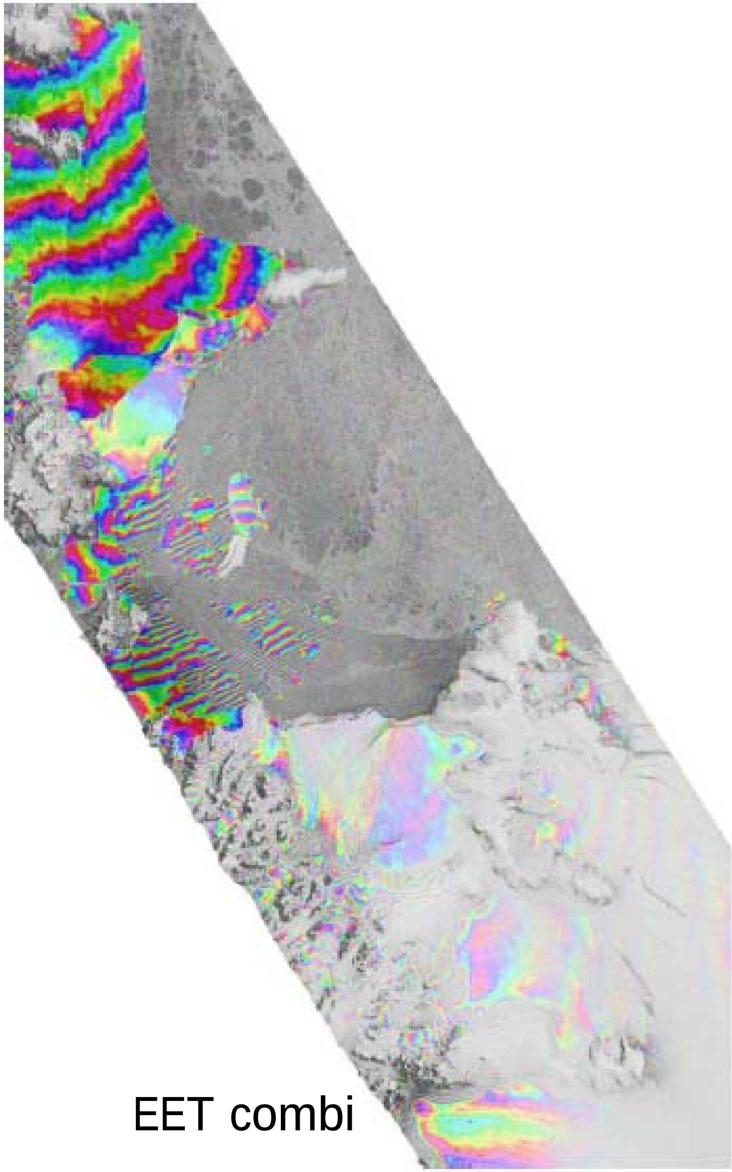
EET Combi $B_\perp$ 327m

Observations

- Grounding line mapping facilitated if sign of phase slope changes at grounding line position (E1/2, EET1, EET2)
- High sensitivity of EET pairs to topography results in high phase gradients over land which makes discrimination from tidal phase more difficult
- Combined EET interferogram well suited for grounding line mapping if:
  - effective baseline is short (in our example 337m)
  - sign of phase slope changes at grounding line position (not the case in our example)

Application over Larsen B ice shelf





Observations

- In EET pairs the grounding line can be determined in some areas
- In other areas this seems too difficult due to a too high phase gradients which makes it difficult to accurately locate the sign change of the phase slope
- In EET combination phase gradients are often similar over the tidal zone and over the grounded area (because of terrain slopes)
- In this EET combination (with no phase gradient phase change and a quite long effective baseline) the grounding line cannot be reliably mapped for most of the shelf ice in this area

Conclusions

Main potentials of EET multi-pass approaches:

- DEM generation gets more robust and more accurate
- DEM generation over fast uniformly moving surfaces
- Grounding line detection: good potential
  - with short effective baselines
  - if sign of phase slope changes at grounding line