Sentinel-1 TOPS InSAR
technical challenges & opportunities

Lessons learned (TOPS context)

Stripmap	Spotlight	ScanSAR

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Baseline for all InSAR processing steps	Time-varying doppler	Time-varying doppler Bursted data

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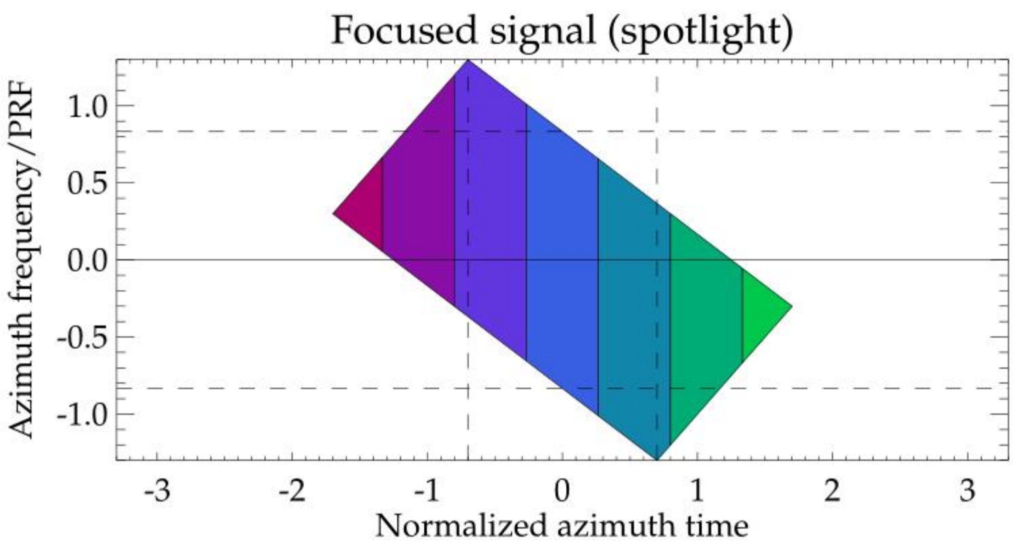
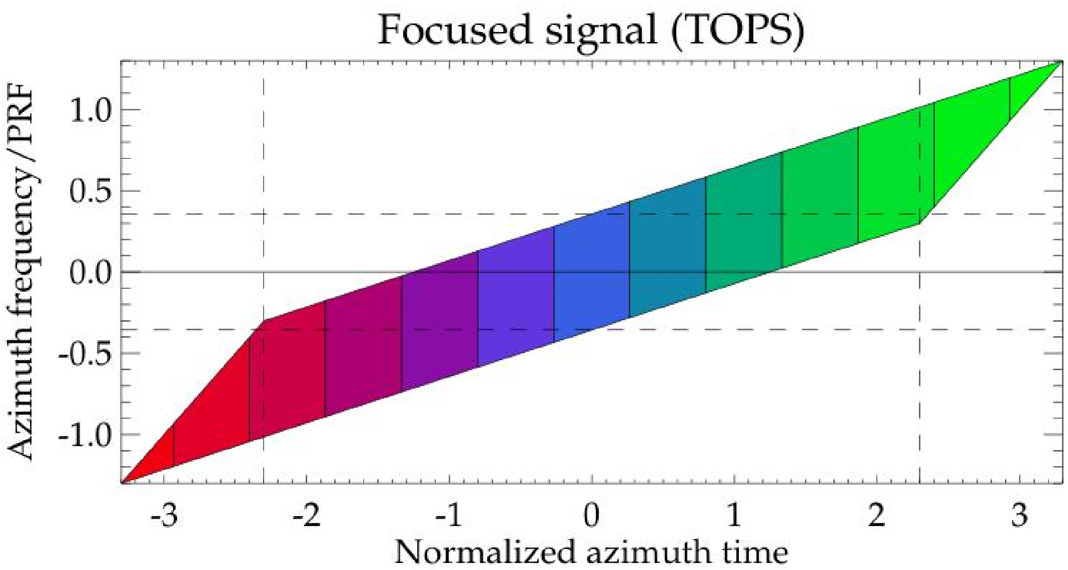
Continuous	**Single-Burst**	**Multi-Burst**

Analogy between Spot. and TOPS

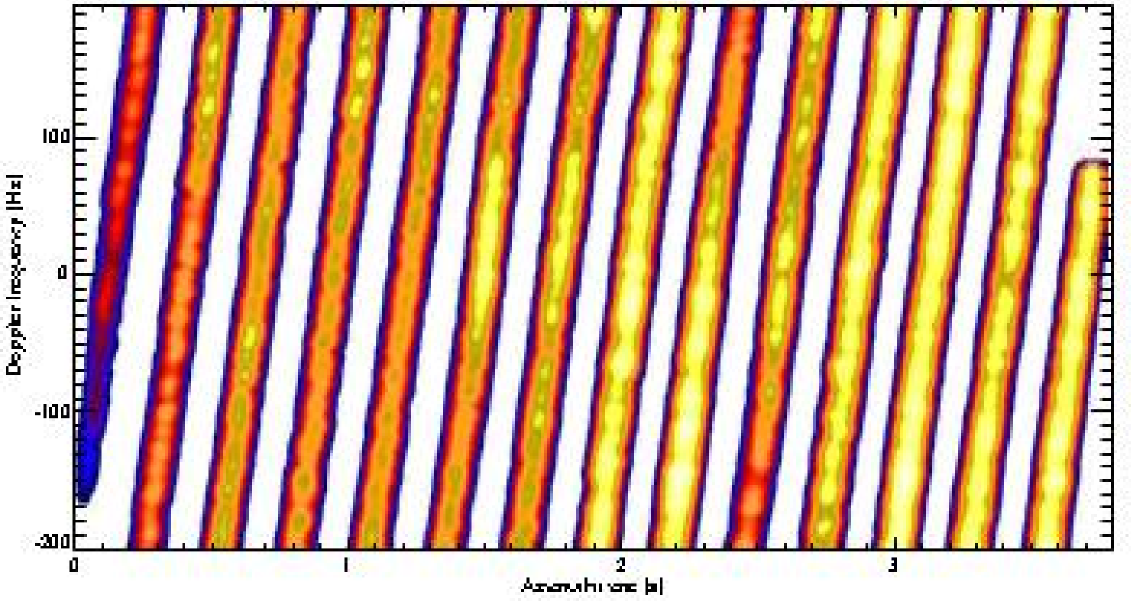


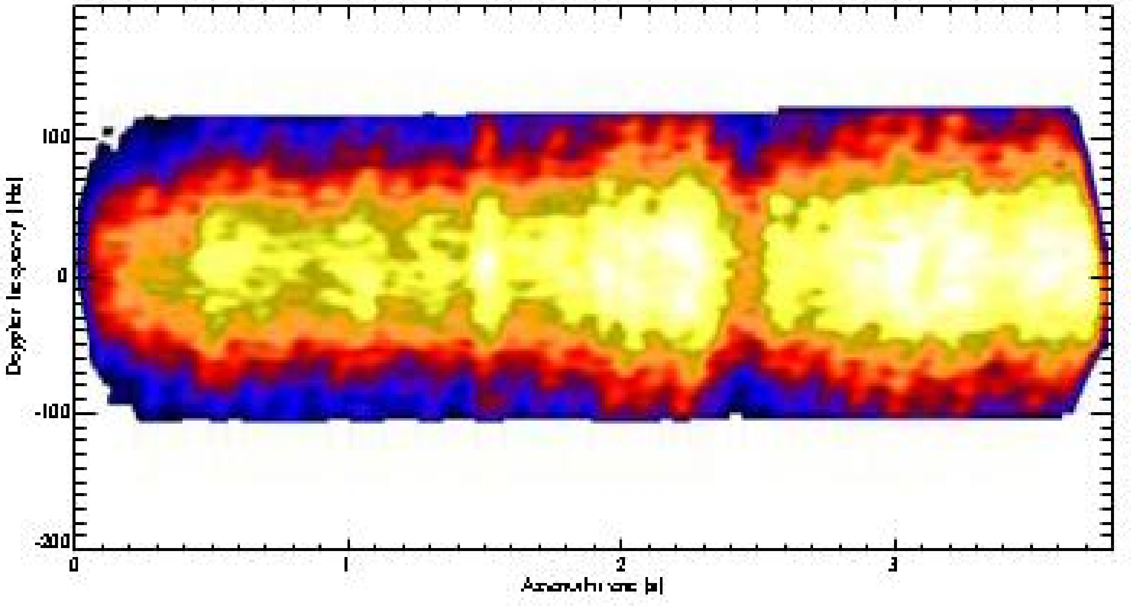


Spectral equivalence of Spotlight and TOPS modes

"...if one knows how to form Spotlight interferogram, it can easily leverage that experience in computation of per-burst TOPS interferorams"

Real deramping Data Example



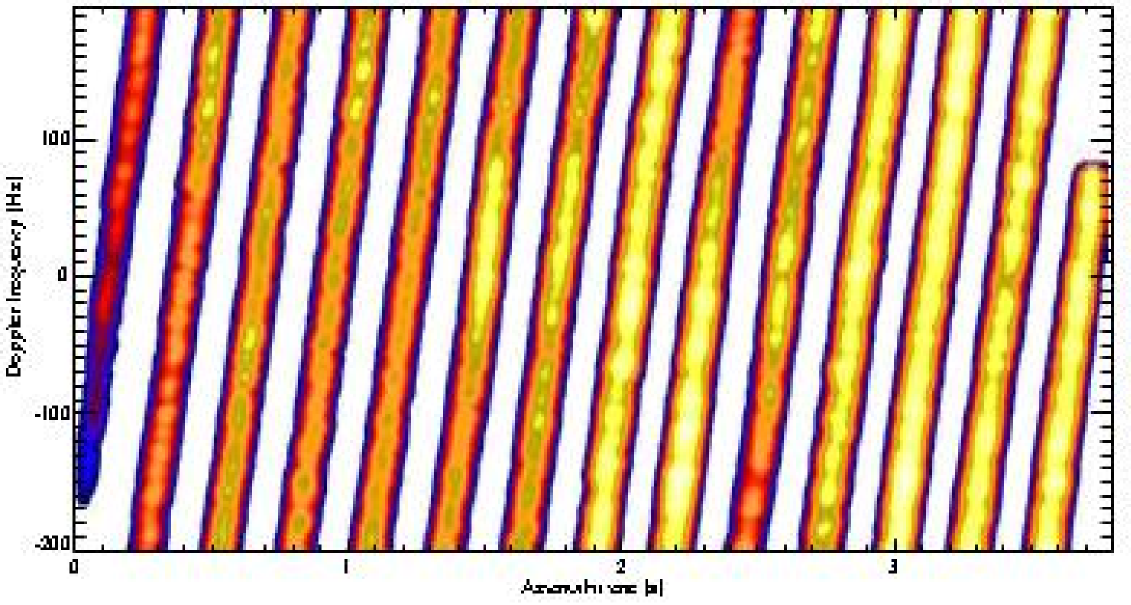


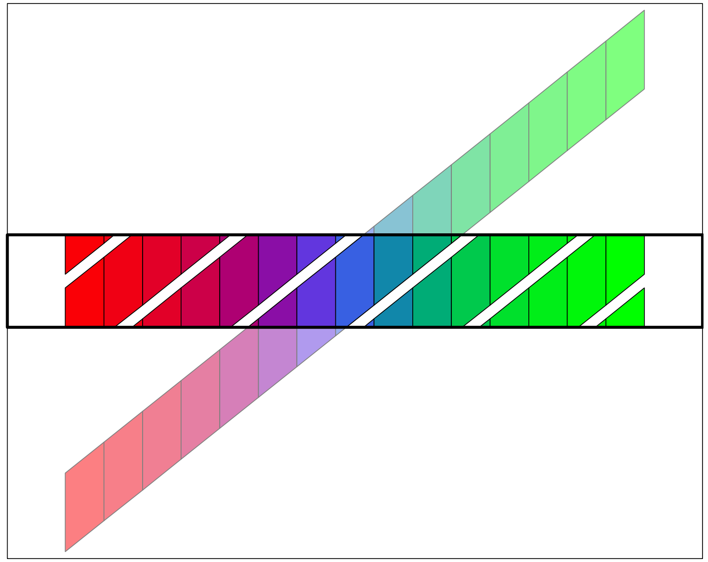
Deramping of:

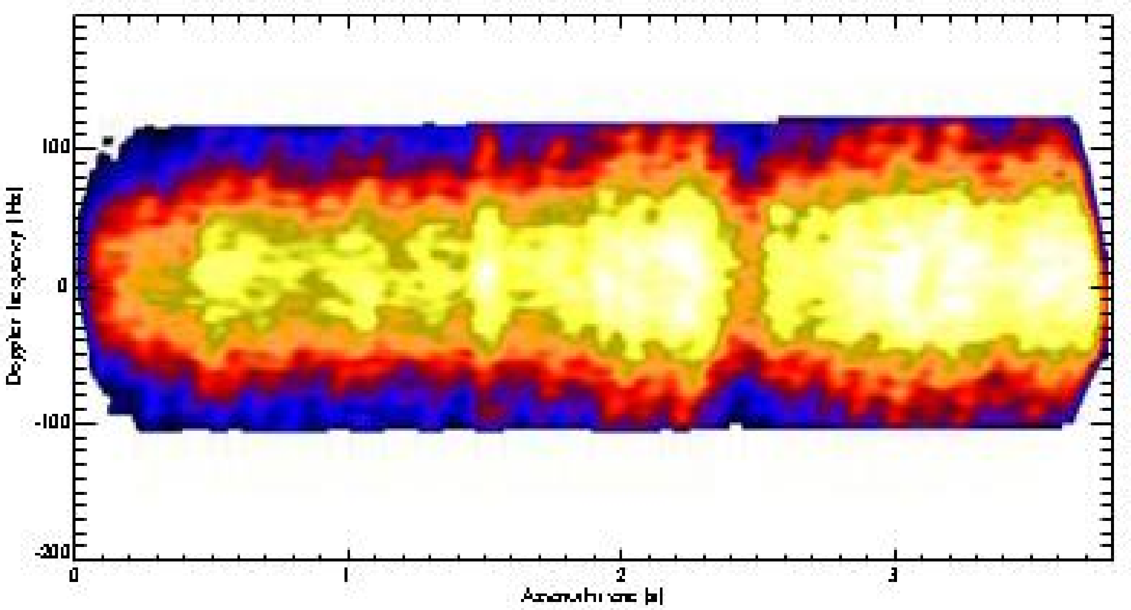
'*Lancaster Sound*'

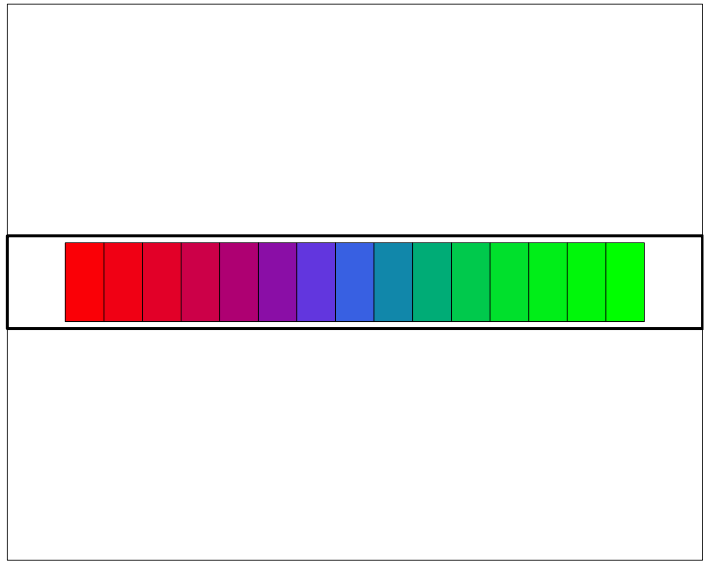
real R2 TOPS data

Real deramping Data Example

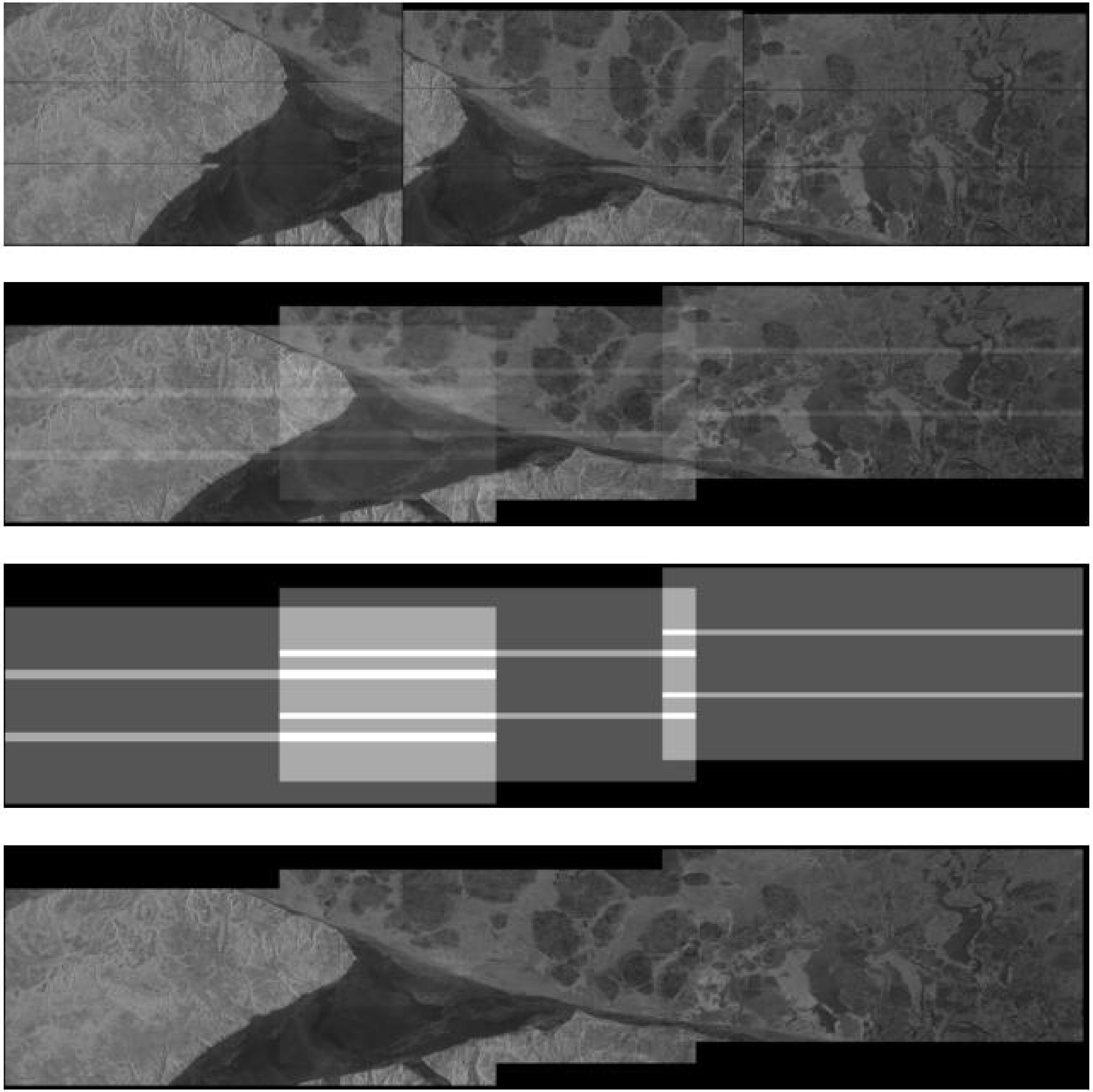








Bursted nature of TOPS data



Now TOPS InSAR....

Brief theoretical intermezzo:

Sensitivity of InSAR phase on coreg errors

$$\phi_{\mathrm{az\_err}}(r,t) = 2\pi f_{\mathrm{DC}}(r,t)\Delta t$$

$$\phi_{\mathrm{rg\_err}}(r,t) = \frac{4\pi}{\lambda}\Delta r\left[1-\sqrt{1-\left(\frac{\lambda f_{\mathrm{DC}}(r,t)}{2v}\right)^2}\right]$$

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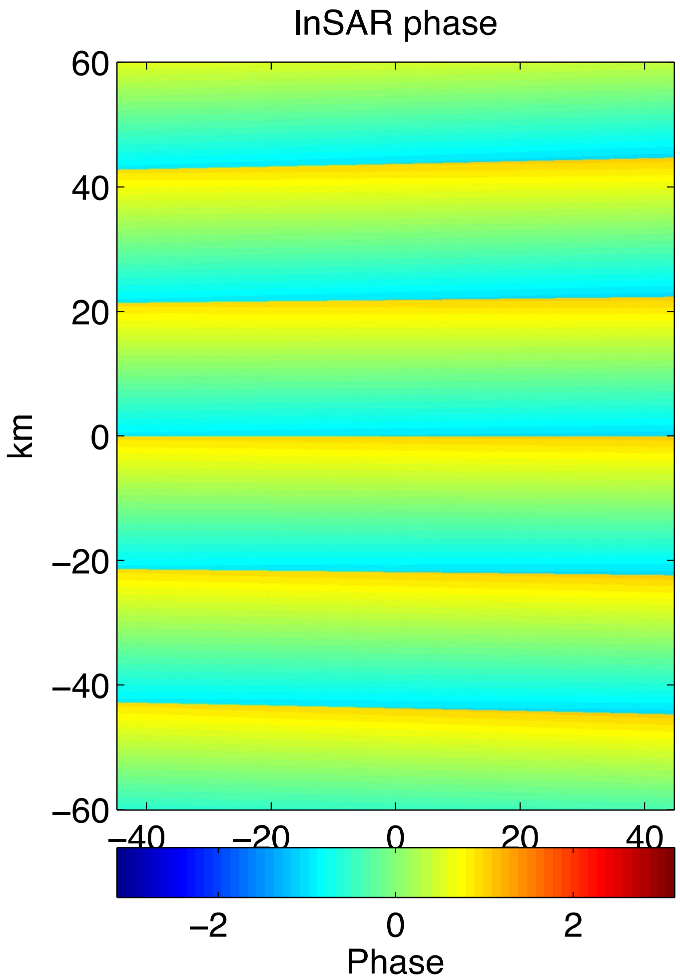
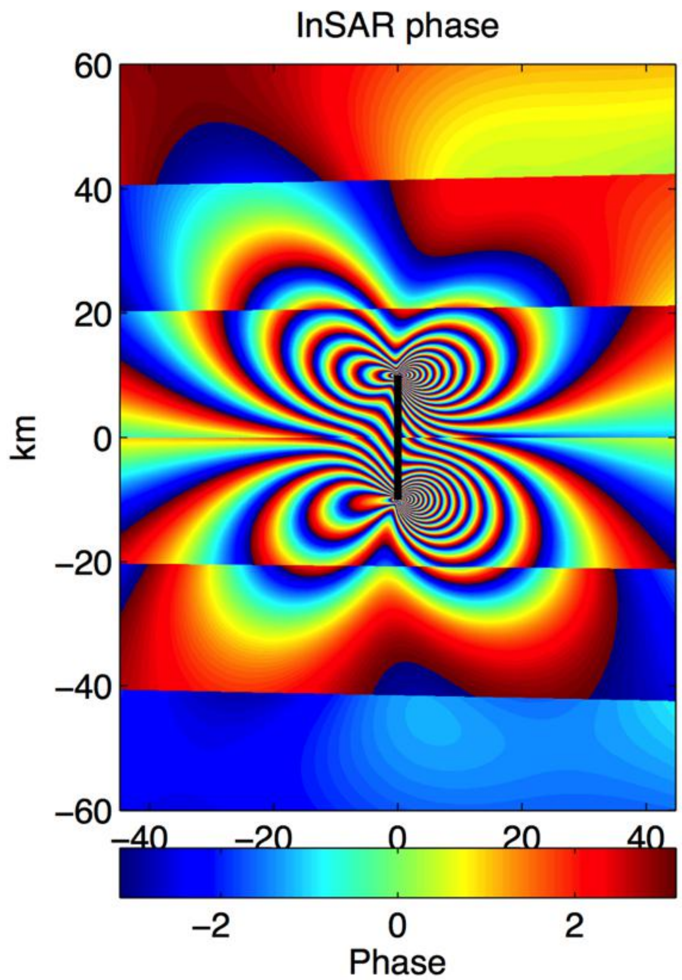
Effect of misregistration

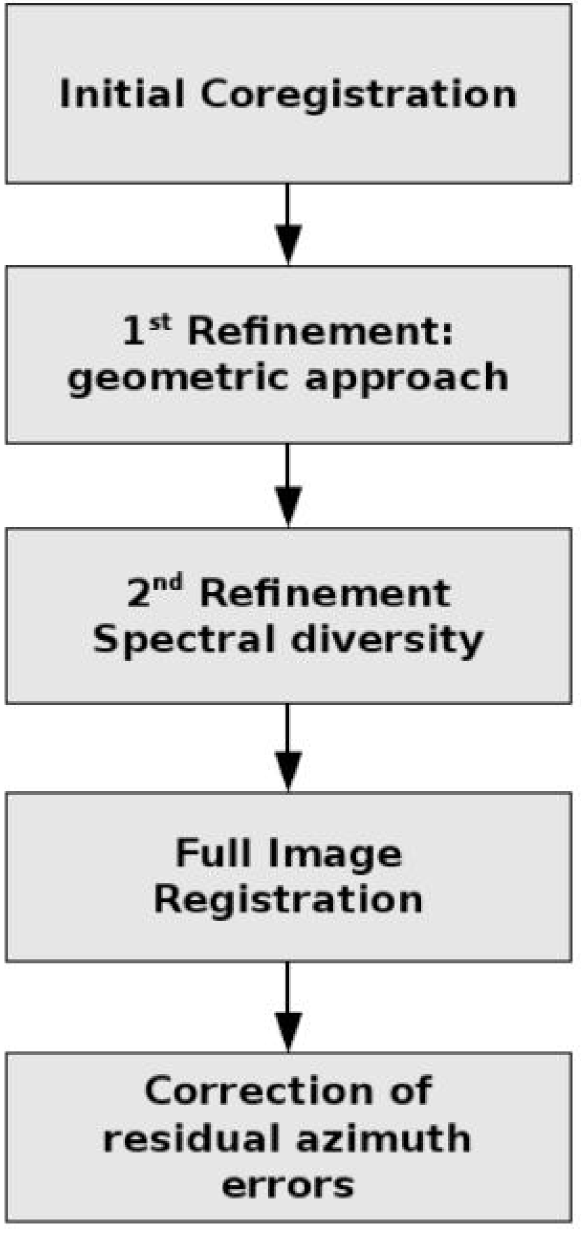
Case study:

- Simulated strike slip quake, 2m slip
- Effect of constant offset 0.05 pixels





It's all about Coregistration



High level flow diagram for the proposed (and validated) coregistration strategy

Highlights:

- **Geometric approach**
- Reliable initial orbits assumed
- Utilization of burst overlap phase
- Flexible: designed for overall coreg but can also be down-scaled to a single burst level

Coregistration Dissection [1/2]

Initial Coregistration:

Use available geo/orbit/metadata for the initial coreg

Refinements:

- **First Refinement:**

  Use m/s offset from 'traditional' coregistration to model orbit errors, while still following a geometric approach.

- **Second Refinement:**

  Apply the spectral diversity method on burst overlaps to estimate residual azimuth registration error.

Note: Range errors not significant by SD can be also applied on range.

Coregistration Dissection [2/2]

Registration/Resampling of full image:

- Twice refined geometry
- Moderate Topography: SAR geometry should be sufficiently good, only small/negligible phase errors
- Rough Topography: DEM info needed, depending on the baseline.

Correction of residual Az coreg errors:

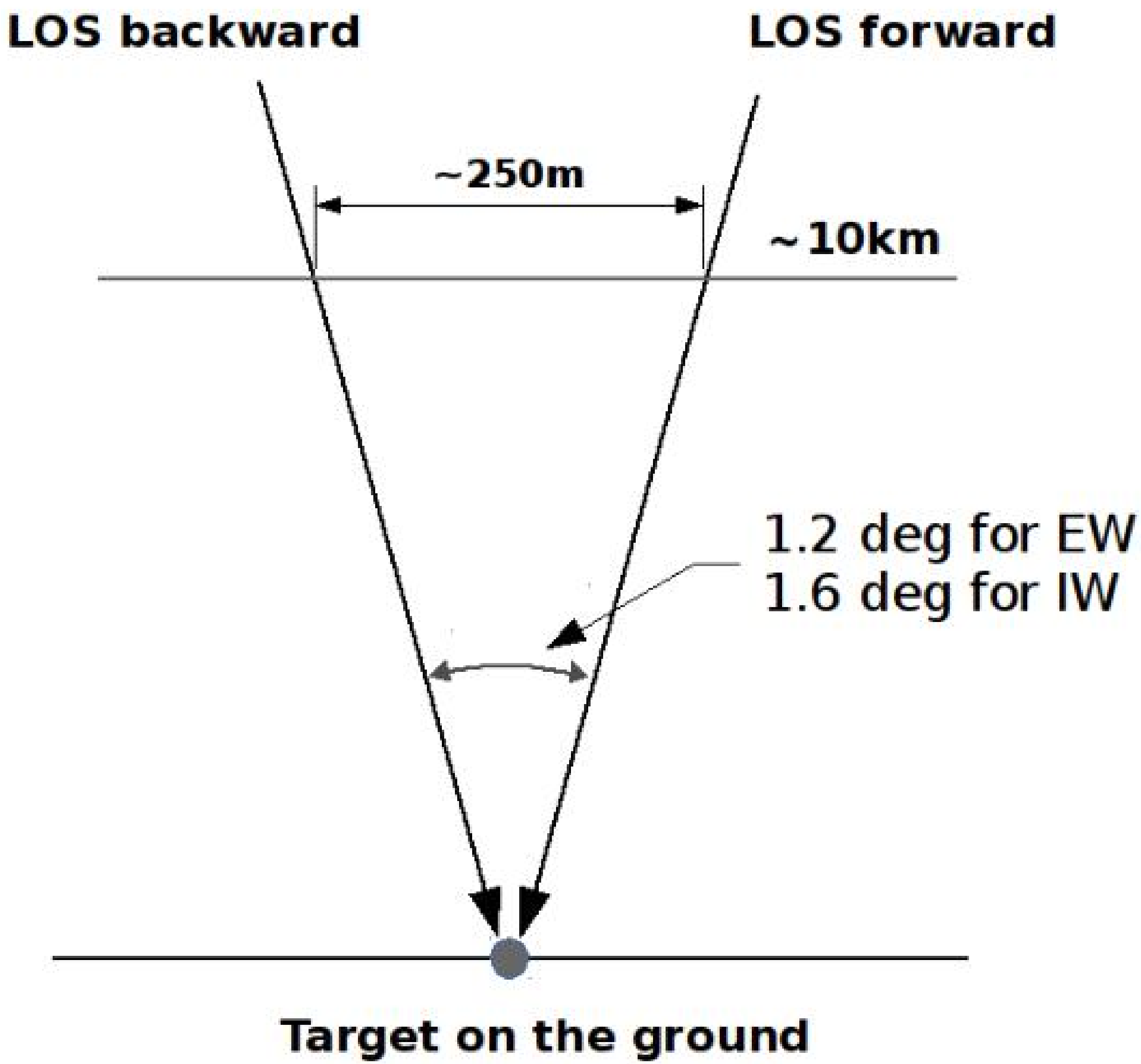
- Residual coreg Az error → phase difference between bursts
- Geometric approach → this difference is a single number

For geometric strategy to work:

- **Assumption #1: Orbit Quality**
  - Master orbit is error free:
    - State vectors within 10cm
    - Satellite velocity and direction very high precision
    - Absolute positioning errors on 10cm level not important
- **Assumption #2: Source of Residual Coreg Error**
  - After correcting for geometry difference between m/s <u>residual coreg error</u> is due to:
    - constant azimuth timing error
    - constant radial error of the slave orbit

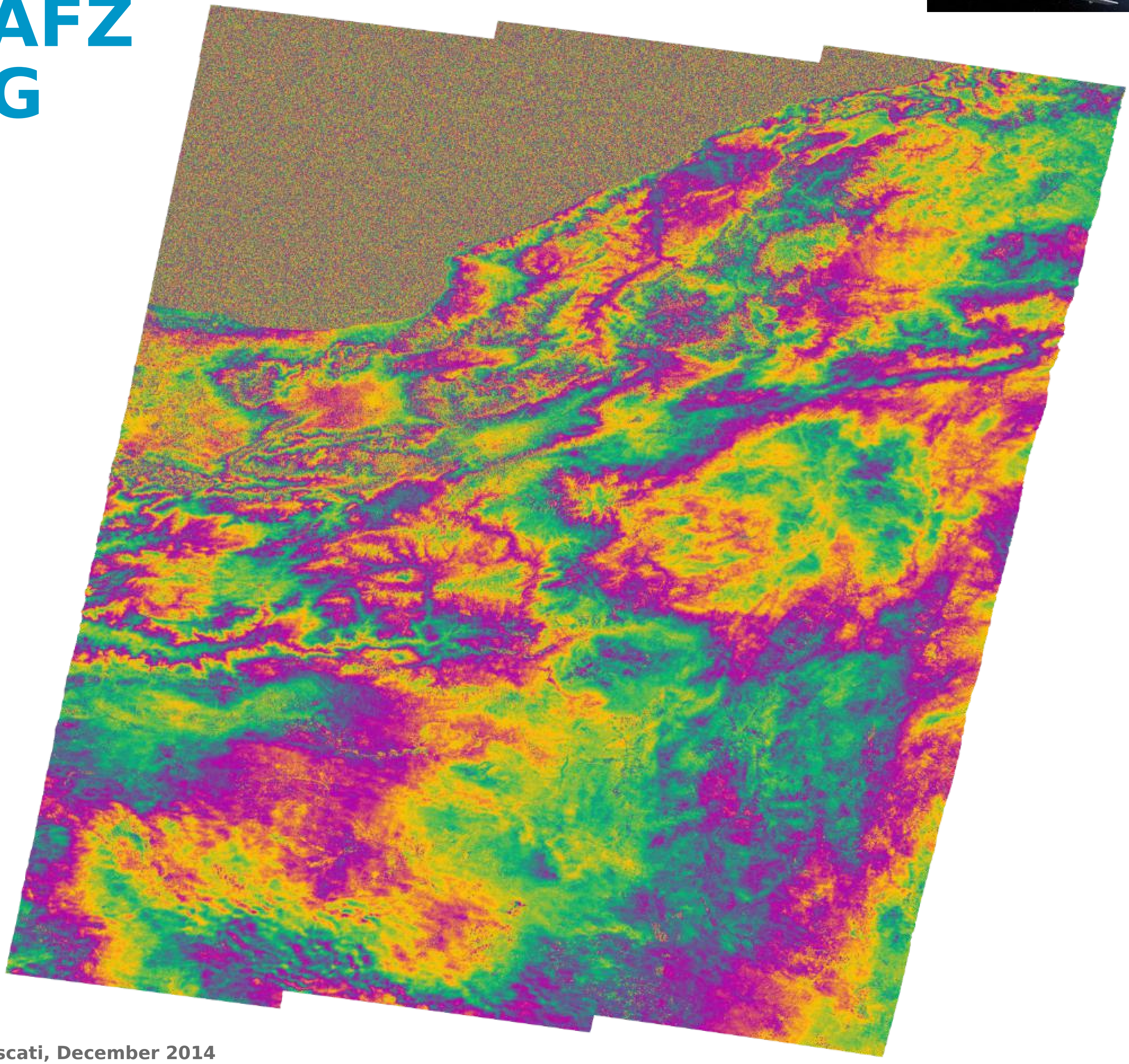
Assumption 1 & 2 → Coregistration problem reduced to geometric approach

Review of “overlap zones”



Sketch of a geometry of two-looks on a target in the burst overlap zone

Example: NAFZ 2-slice IFG



TOPS InSAR
Stack Processing Considerations

Transition to S-1 TOPS stacks

DInSAR

- Coregistration, coregistration, coregistration…

Time Series Analysis

- No big difference wrt existing modes, in principle “business as usual”
- The 'new' thing is availability of multiple overlapping bursts/swaths
  - Similar to ScanSAR, which hasn't been utilized to its full potential for InSAR yet
- Implementation reliability of existing strategies an issue, rather than new algorithmic issues

Operational considerations

- Data volumes – storage, distribution, bandwidth, etc.

Transition to S-1 TOPS stacks

DInSAR

- Coregistration, coregistration, coregistration…

Time Series Analysis

Note: *Driver for change and algorithmic evolution of stacking methods will mainly be the new opportunities offered by the spatial and temporal coverage, as well as the redundancy due to the bursted nature of S-1 TOPS data.*

S-1 TOPS is an opportunity to do more and better…

Operational considerations

- Data volumes – storage, distribution, bandwidth, etc.

S-1 Time Series: Open Q's

It's all about burst management/stacking:

1) When?

2) How?

3) Why?

When to stitch the bursts?

Phase space?

- Merge bursts interferograms before deformation estimation

Deformation space?

- Single track:
  - merge deformation results from burst stacks (or even subbursts stacks) from a single TOPS track
- Multiple tracks (aka WAP):
  - merge deformation results from subbursts/bursts/swaths/tracks

How to stitch the bursts?

Phase space?

- Use overlap phase metric for correction

Deformation space?

- Exploit existing WAP like processing algorithms

How to stitch the bursts?

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Special case: Non-stationary scenes

- How to 'merge' signal that observes different phenomena

How to stitch the bursts?

Phase space?

- Use overlap phase metric for correction

Deformation space?

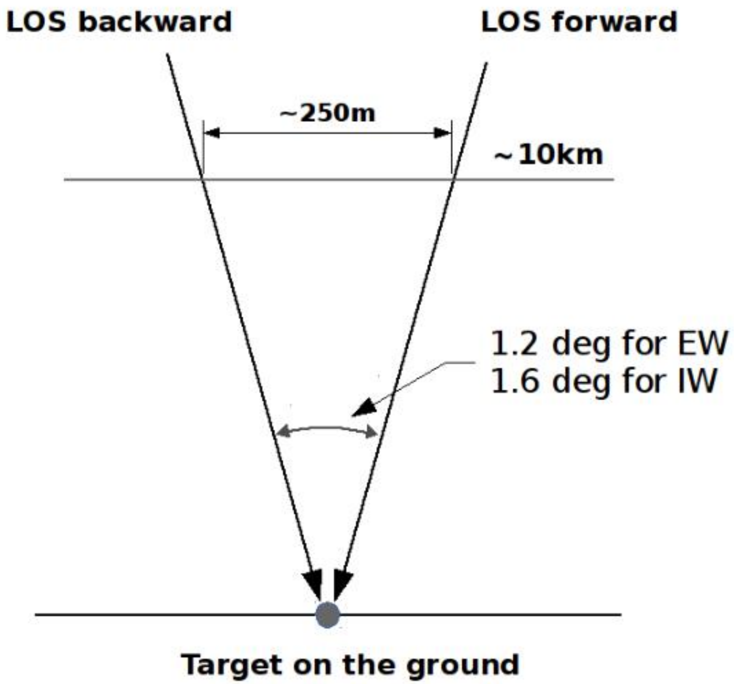
- Exploit existing WAP like processing algorithms

Or maybe not to merge them at all? Case for localized deformation....

Answer for optimal stitching...?

...depends!

- On the application, and processing framework
- Extent of signal of interest
- Are we seeing the same PS points – "flashing fields"



...we do not have a definite answer yet

S-1 TOPS Time Series Analysis
Initial Results

S-1 stack over Mexico City

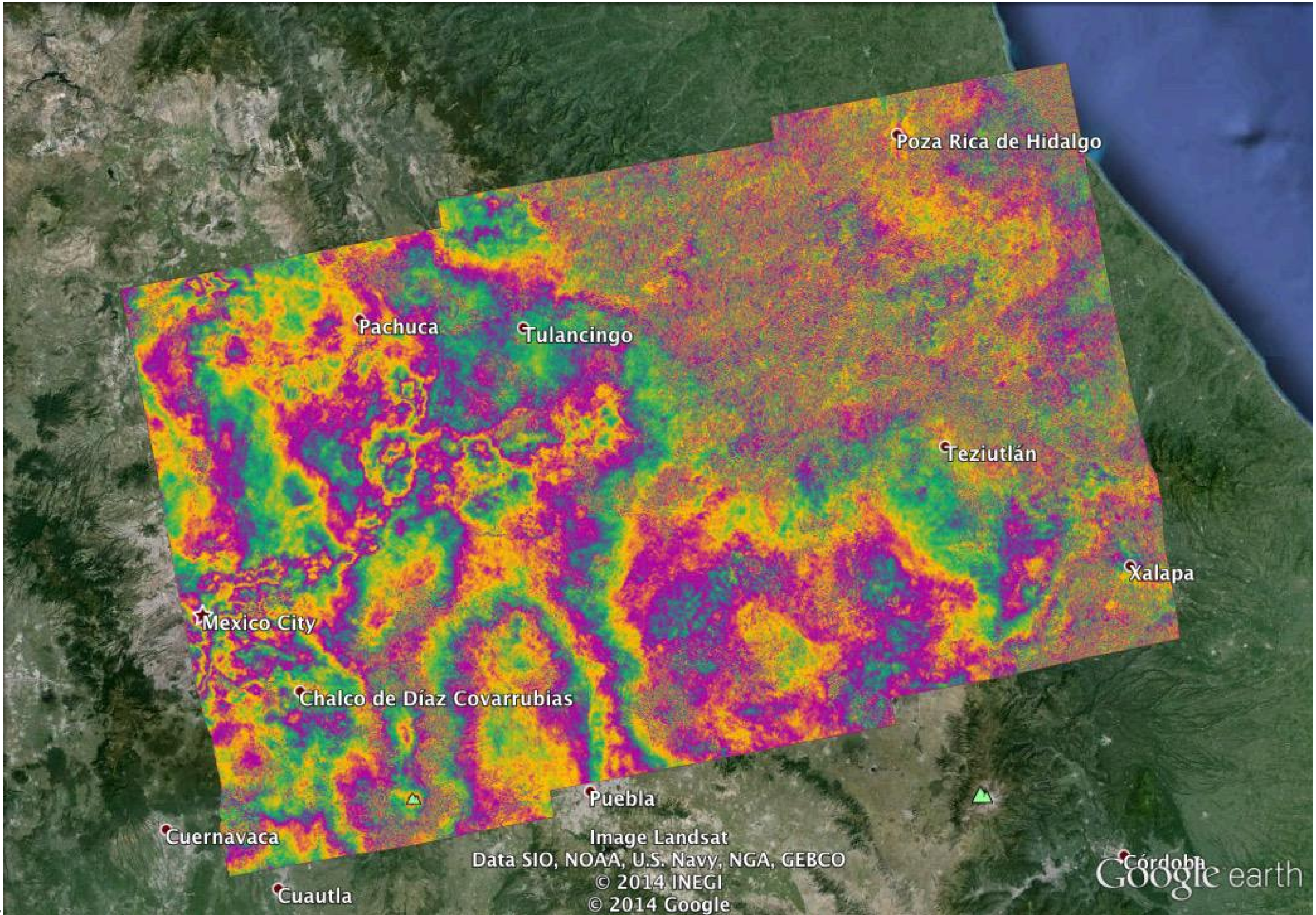
Data:

- Stack of 6 singe slice data sets
- Time period 60 days, Oct 6 – Dec 5
- Ascending track
- Bperp sampling [6,76] meters
- All 15 interferometric combinations generated
- All data available on SciHub

Algorithm:

- DinSAR: with proposed geometric coregistration approach
- Spectra management inherited from Spotlight algorithms
- 'Simple' stacking
- Straightforward SBAS

Single S-1 TOPS ifg results



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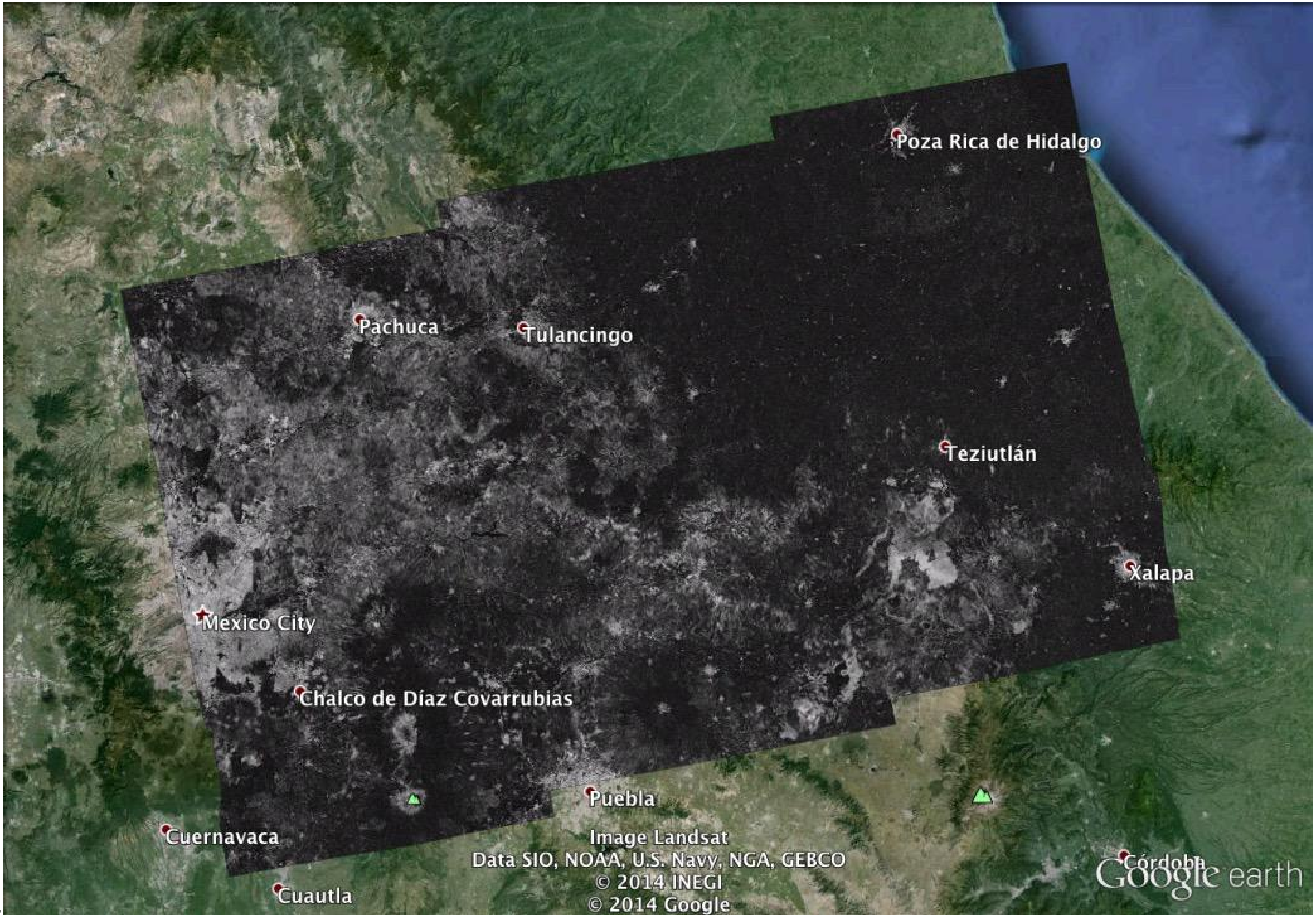
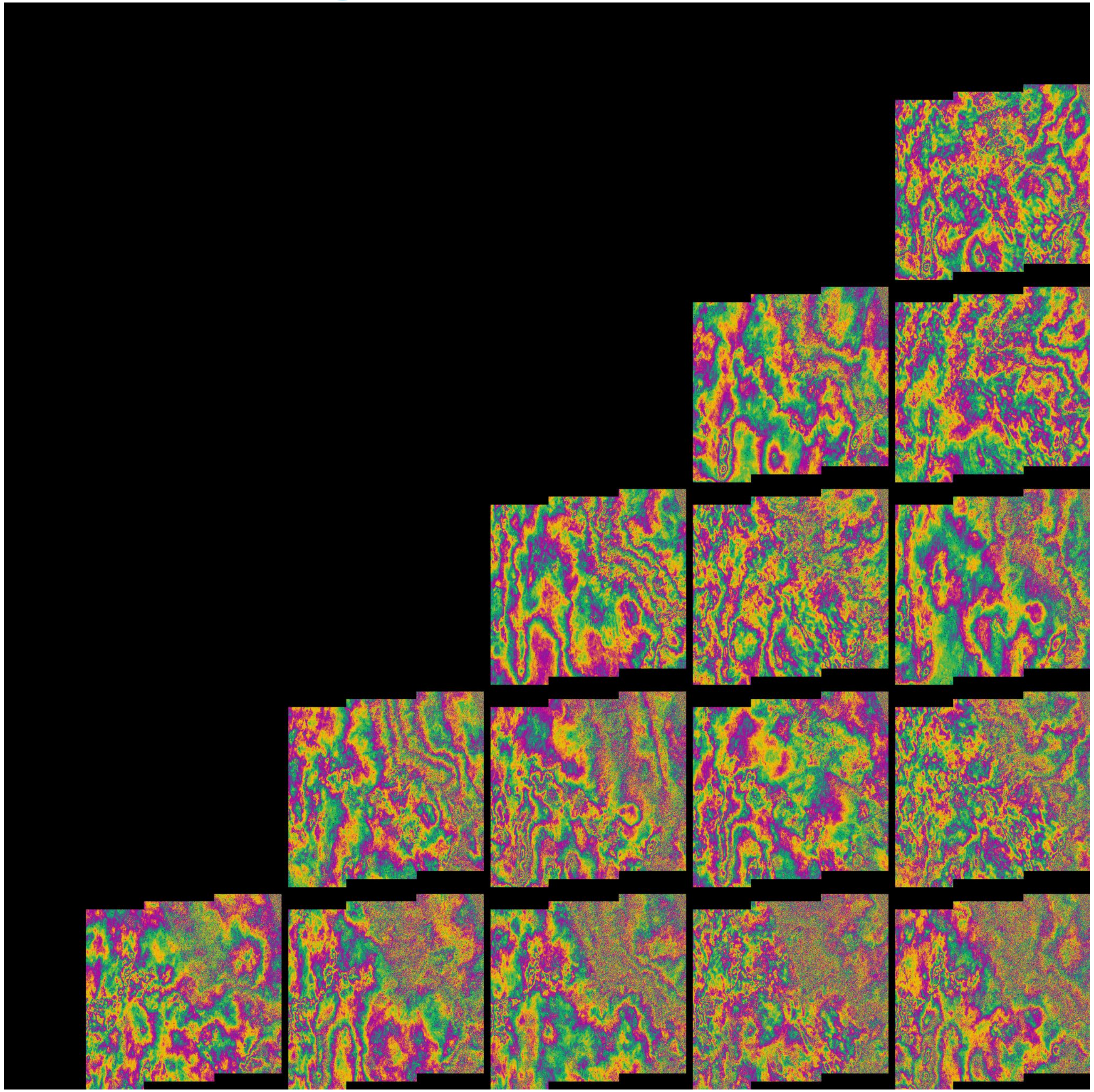


Stack of S-1 ifgs: Matrix plots



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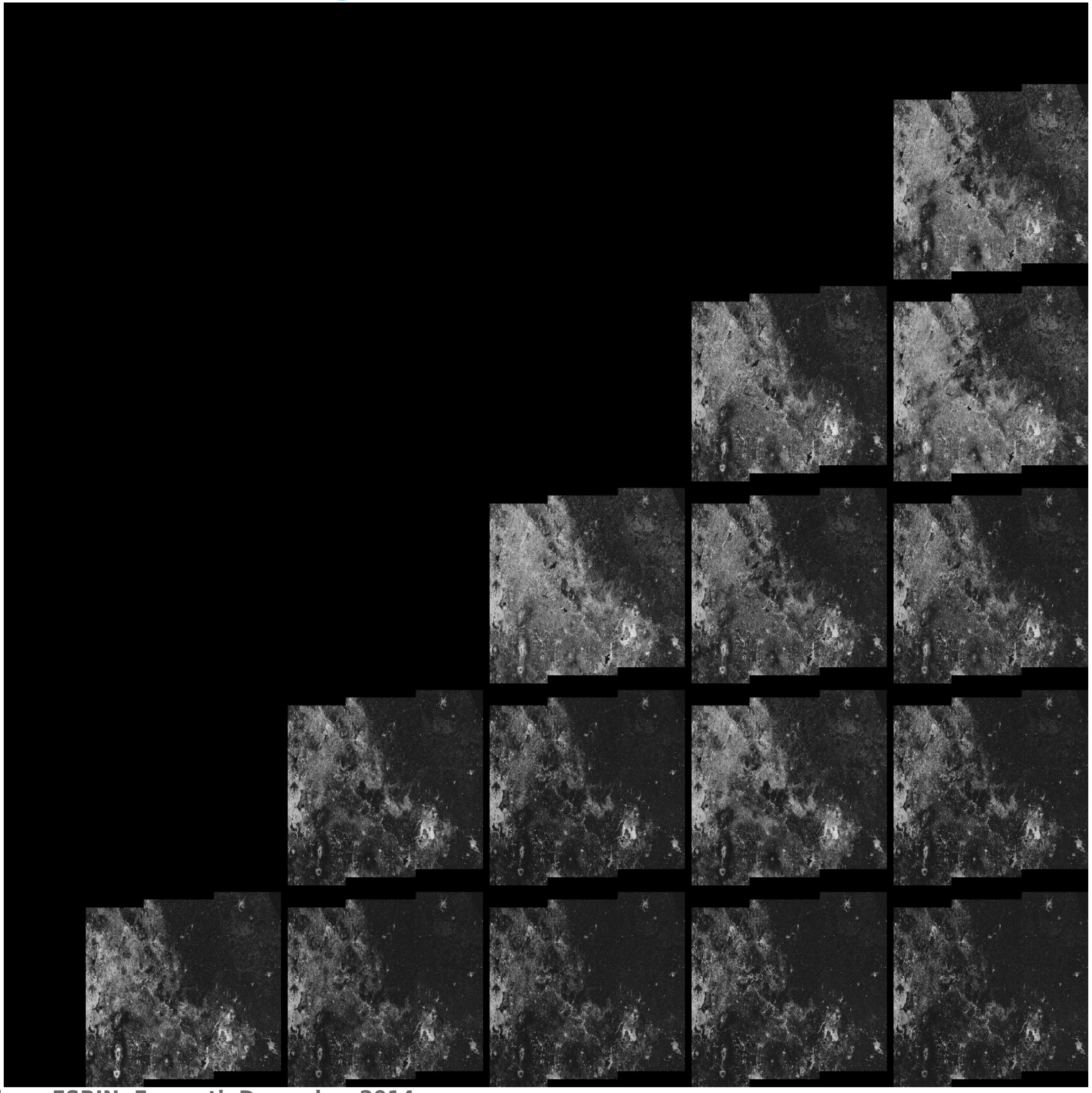
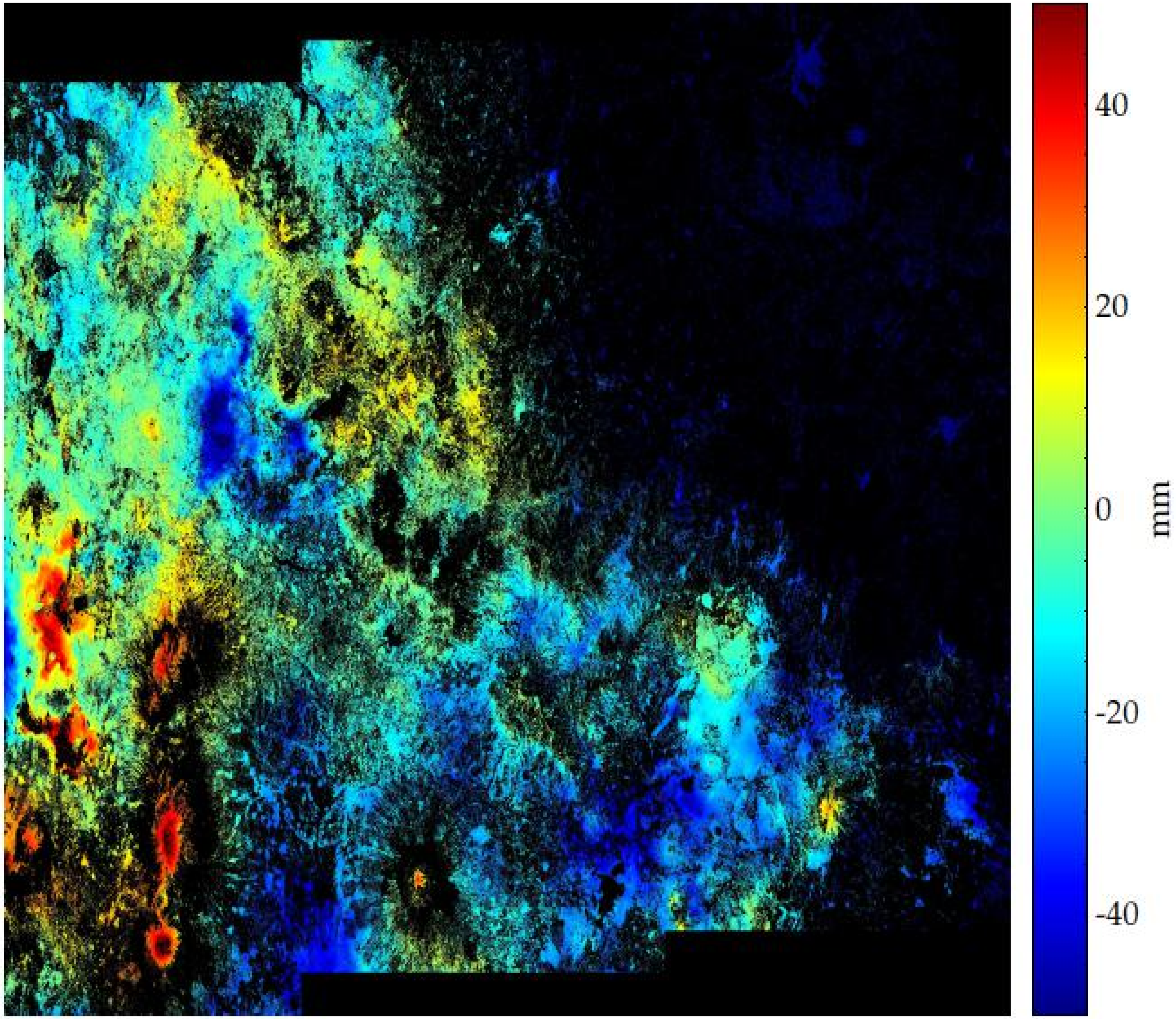
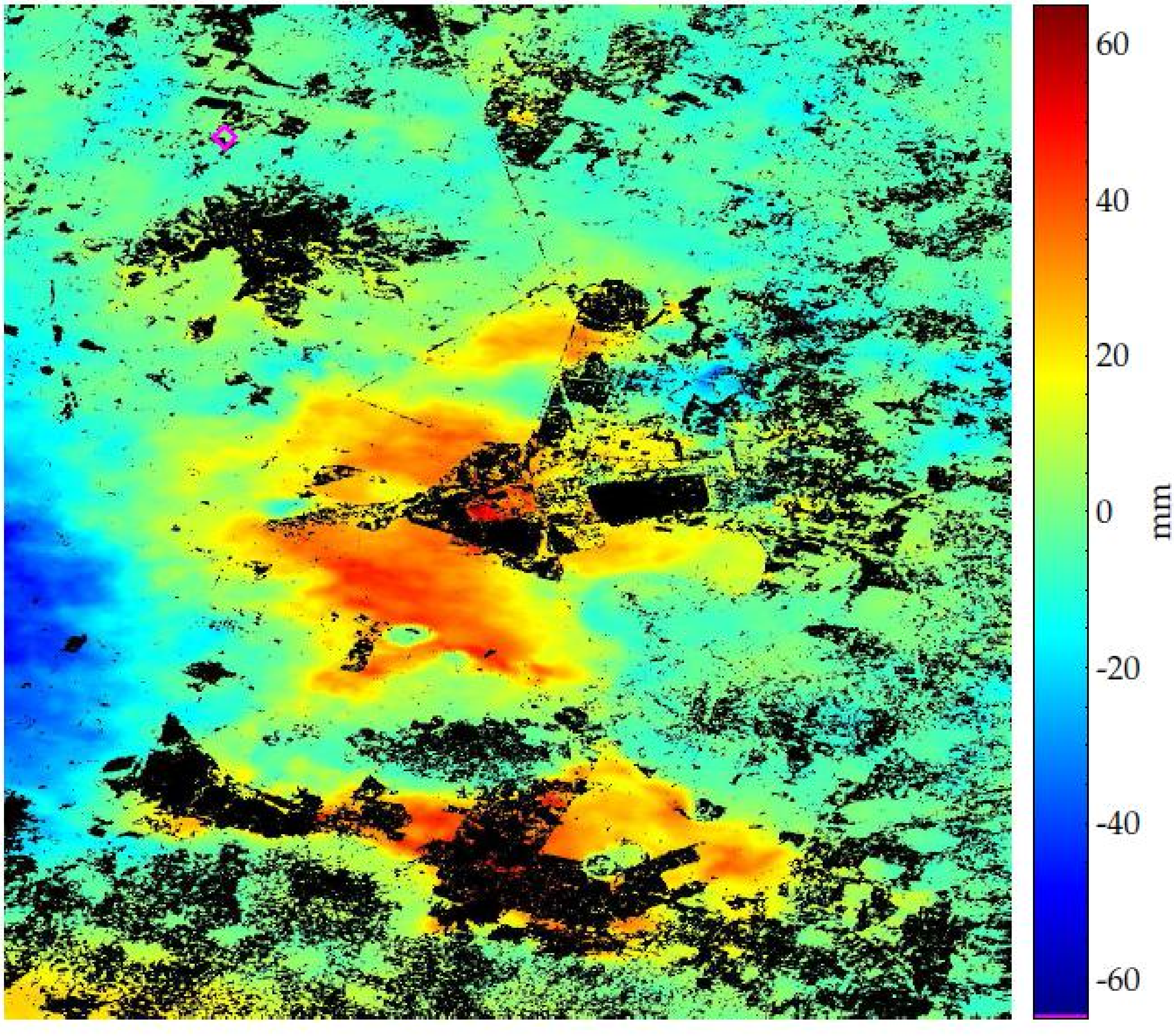


S-1 TOPS Stacking results



- Full slice result
- 160x250 km area
- Simple stacking with a reference point
- Strong presence of APS
- Defo-signal in expected range

S-1 TOPS Stack: Zoom-in on MC



- Zoom-in on Mexico City
- 35x70 km area
- Defo-signal in expected range
- Possible water related uplift
- Unfortunately city at the edge of track
- Opportunity for validation of multi-track integration strategies

Technical Summary

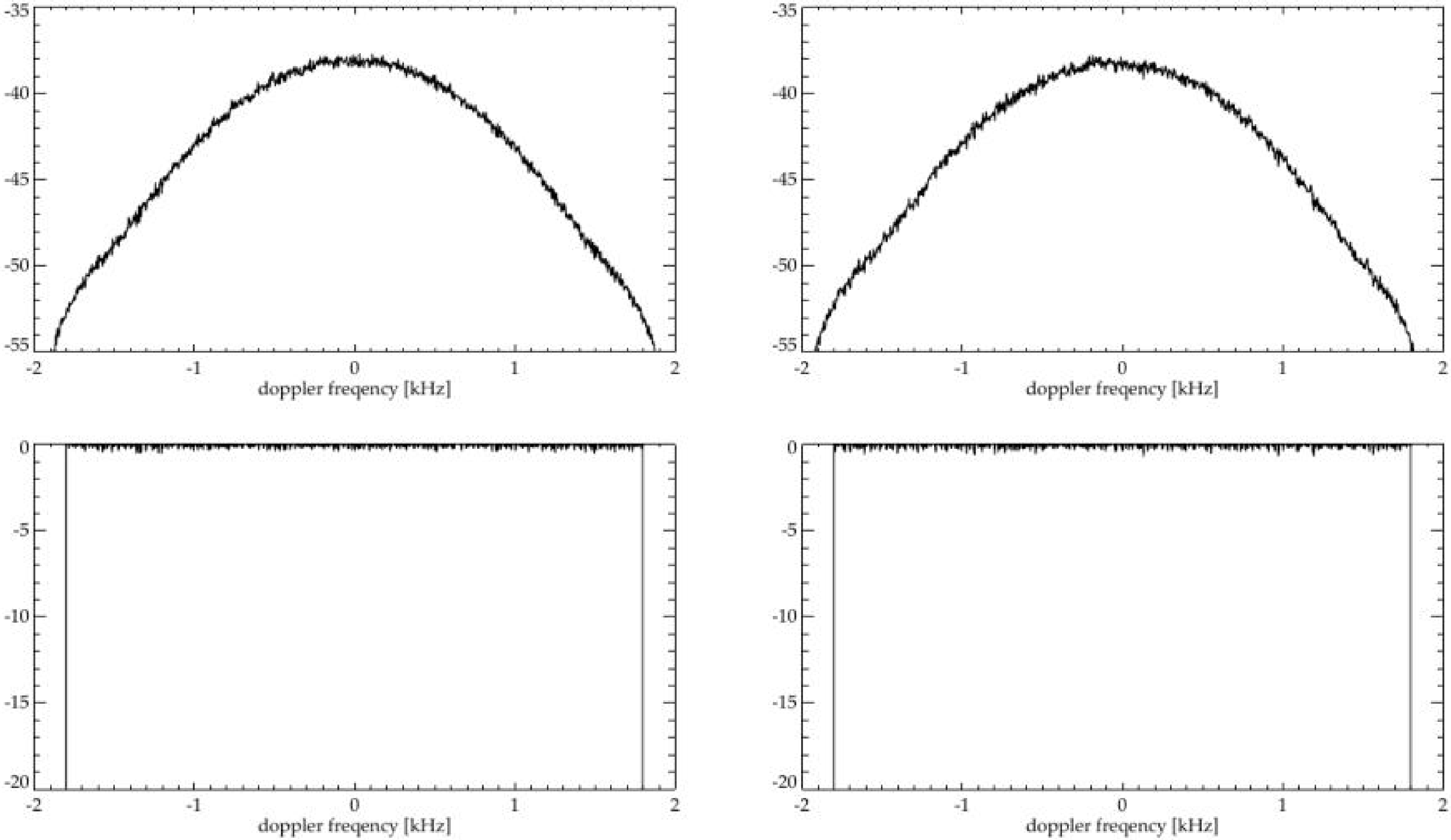
- S-1 TOPS has that critical component – it works!
- Problem of TOPS InSAR coregistration has been conceptually understood
- Many challenges, but also many opportunities to do more, much much more!
- We still have a lot to learn for time-series analysis and applications of large spatial scale and extent
- Optimizations for handling of large data volumes, and further development of data flow model are a must

Operational Challenges

- **You cannot solve 21st century EO/InSAR problems with 20th century technology**
- **We believe that currently available tools are not on a level to support the scientific community yet**
- **Just investing in new hardware is not a sufficient solution**
  - Since launch of S-1 we observed hard-disks filling up with unprecedented rate, and it is not only about storage

Backups

“Spectral Diversity”: Example



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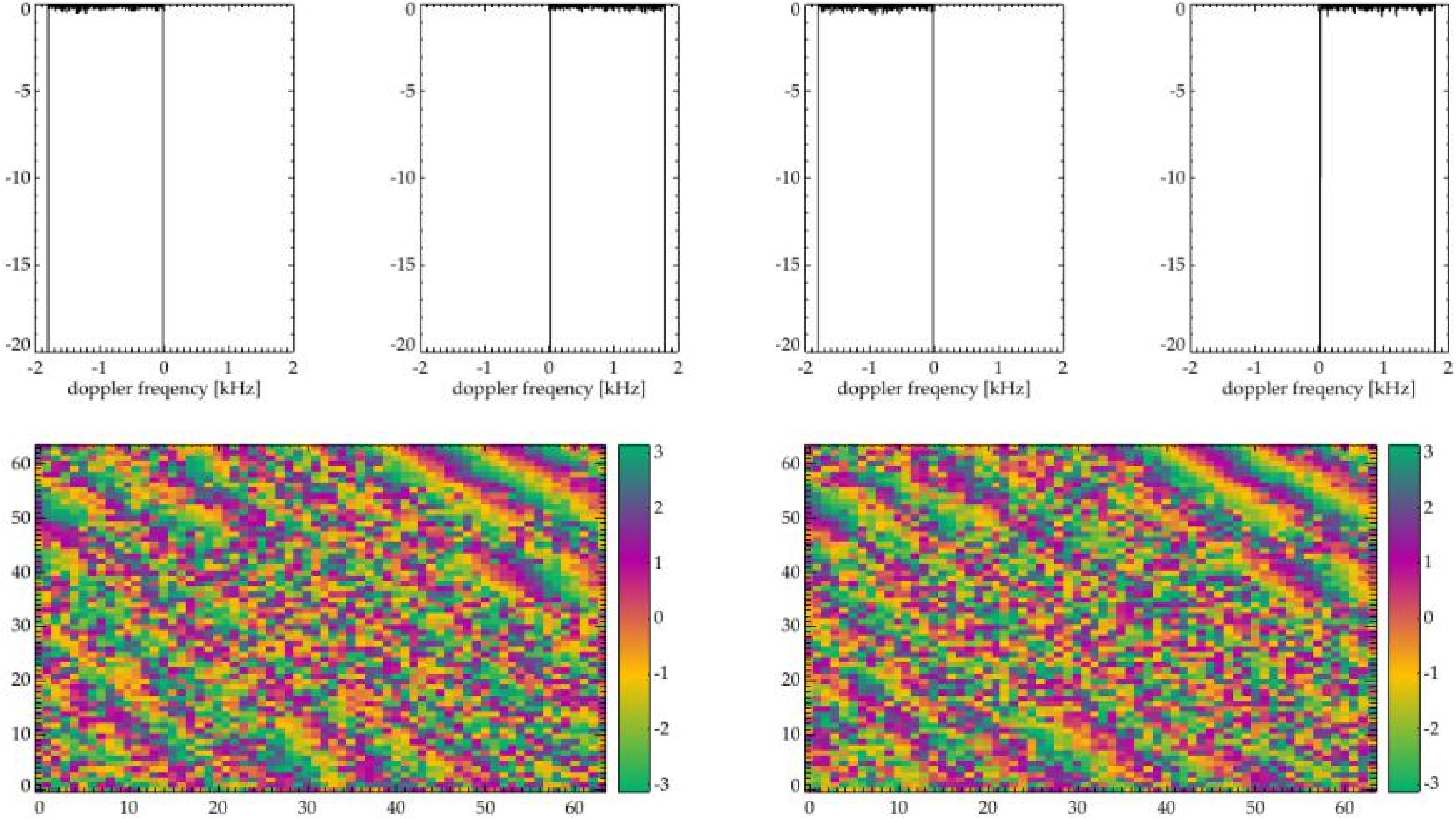

“Spectral Diversity”: Example