

# *ESA Earth Observation Summer School*

## *Earth System Monitoring & Modelling*



## Remote Sensing of Glaciers and Ice Caps

### Glacier flow

Andreas Kääb

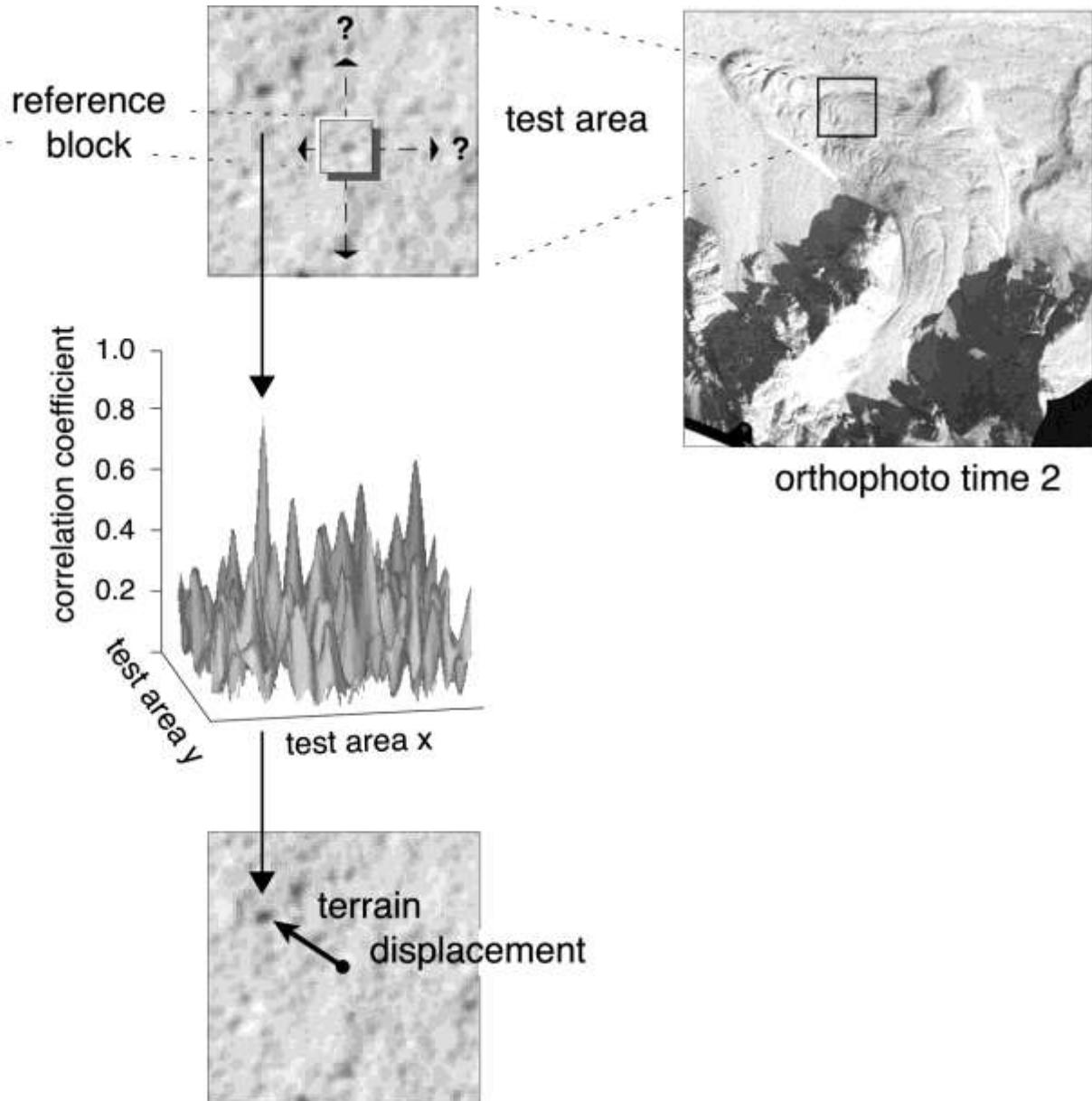
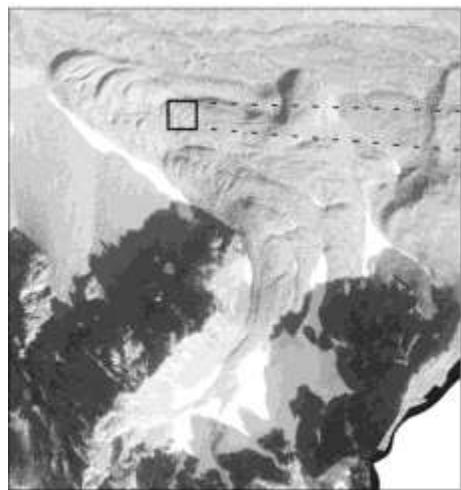
*Department of Geosciences, University of Oslo*

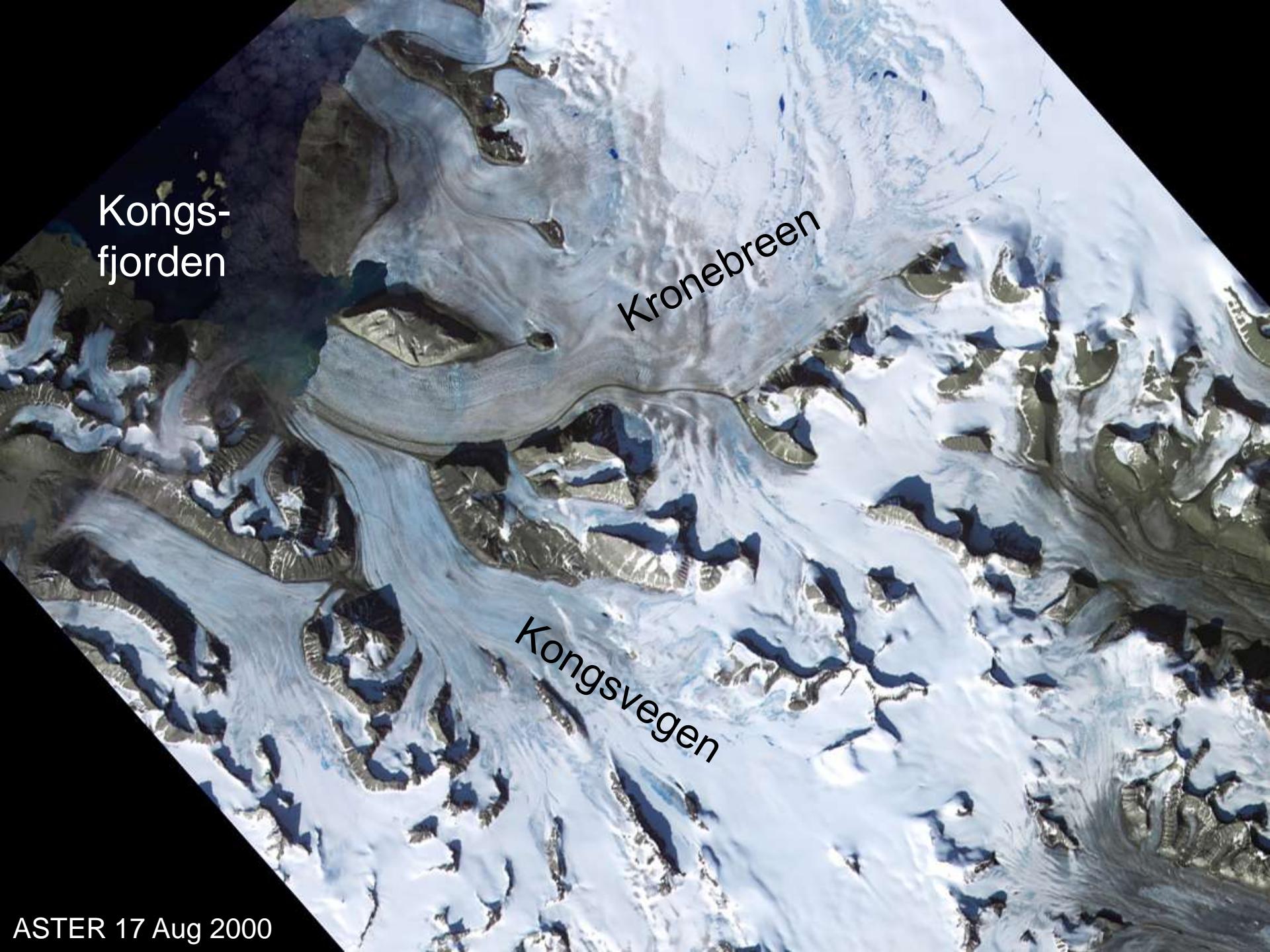
*kaeaeb@geo.uio.no, http://folk.uio.no/kaeaeb*

# Image matching



# Image matching

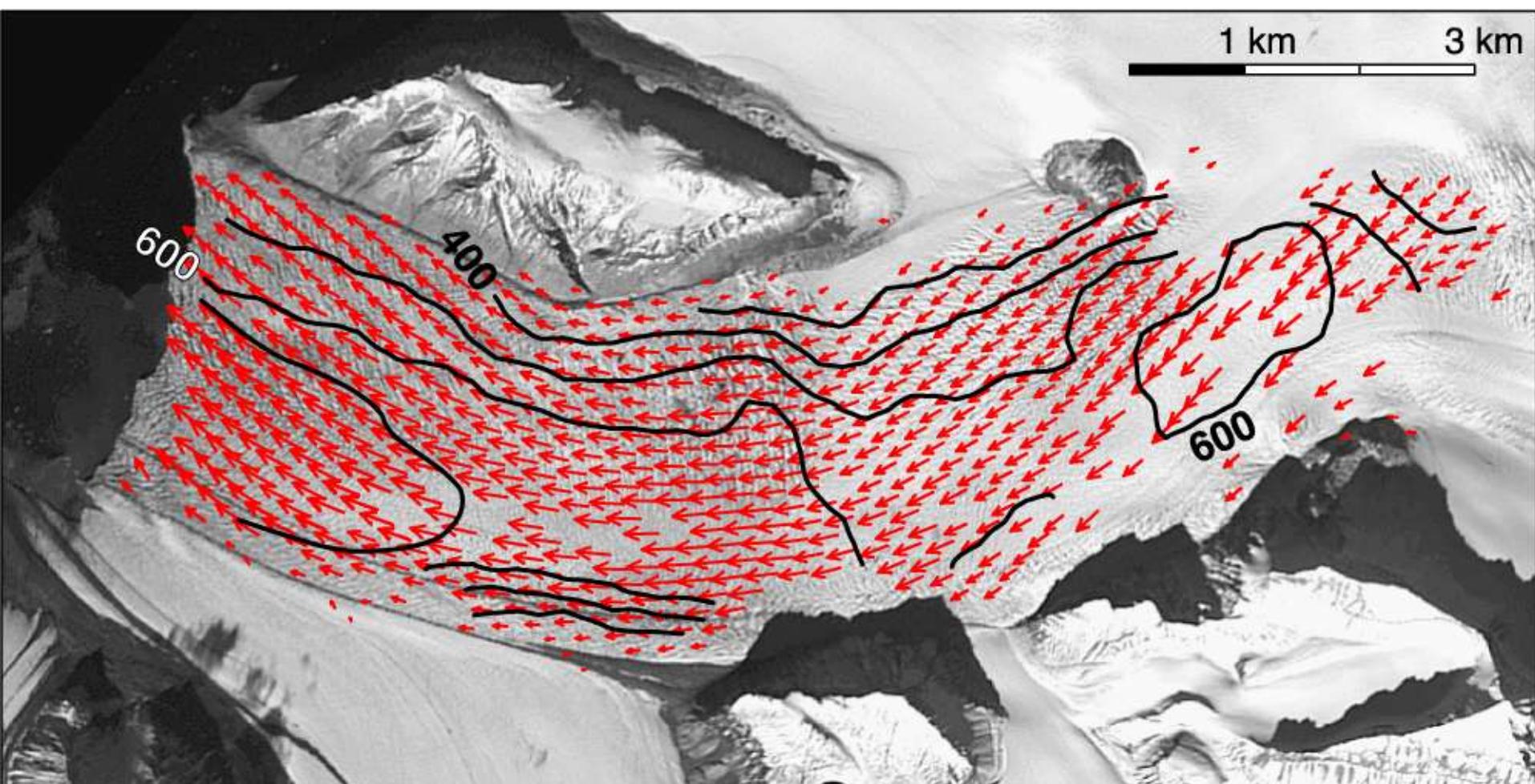




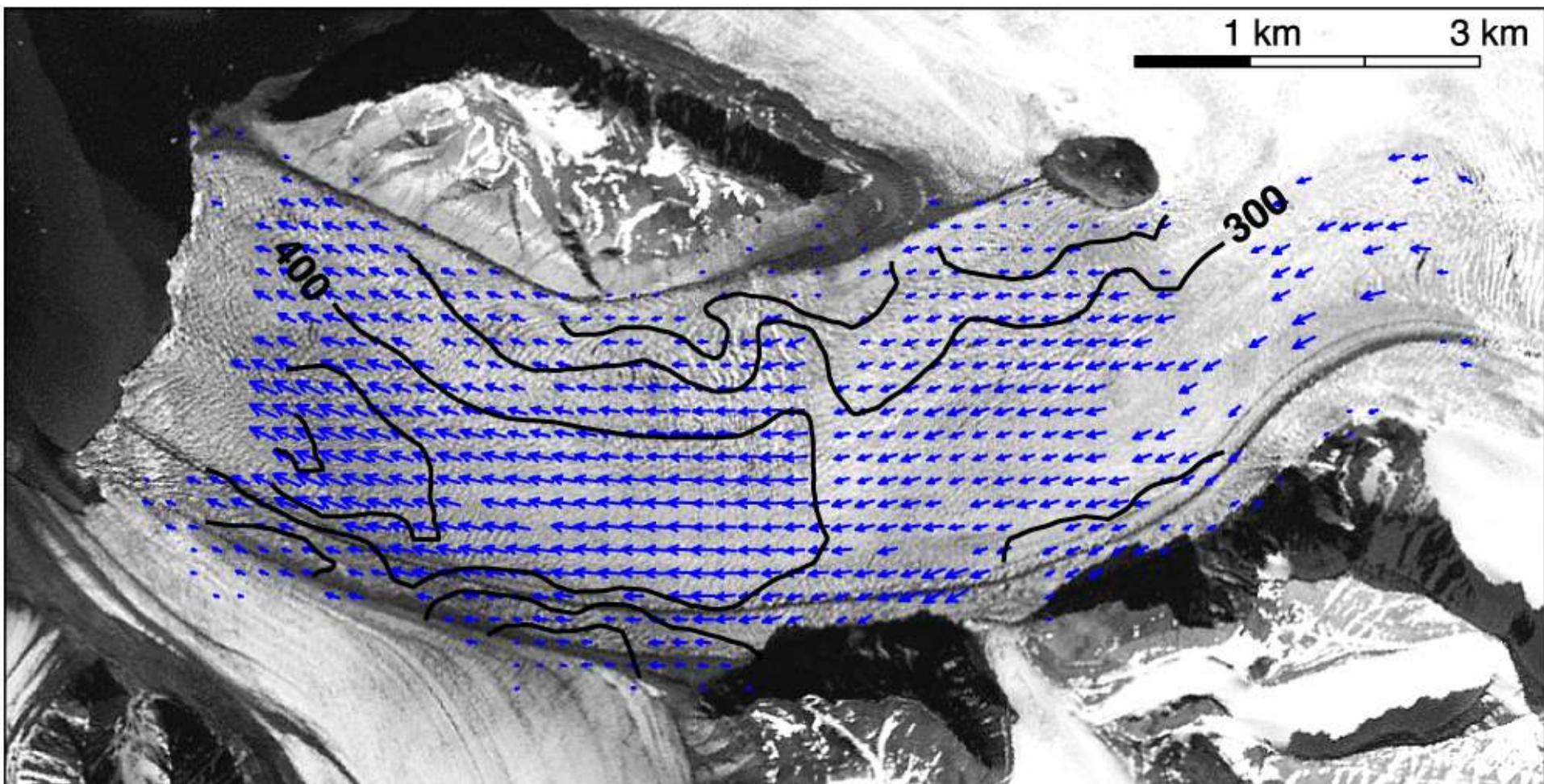
Kongs-  
fjorden

Kronebreen

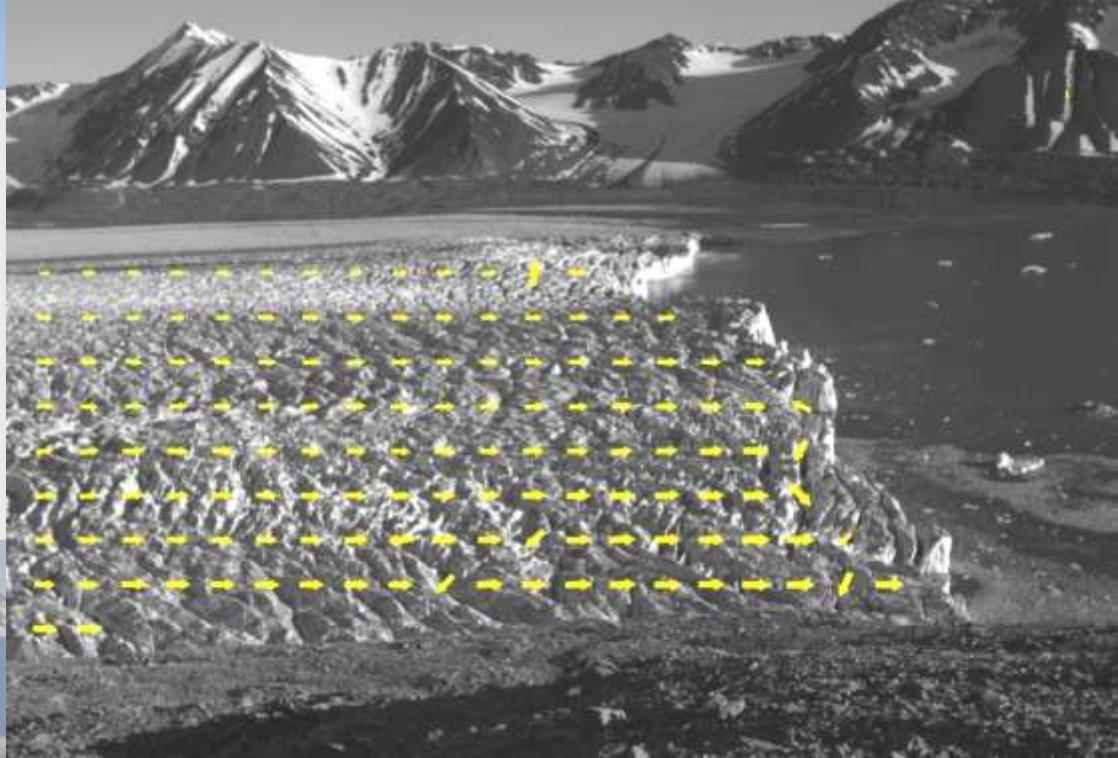
Kongsvegen



# Average annual velocity 1999 - 2000



# Automatic cameras



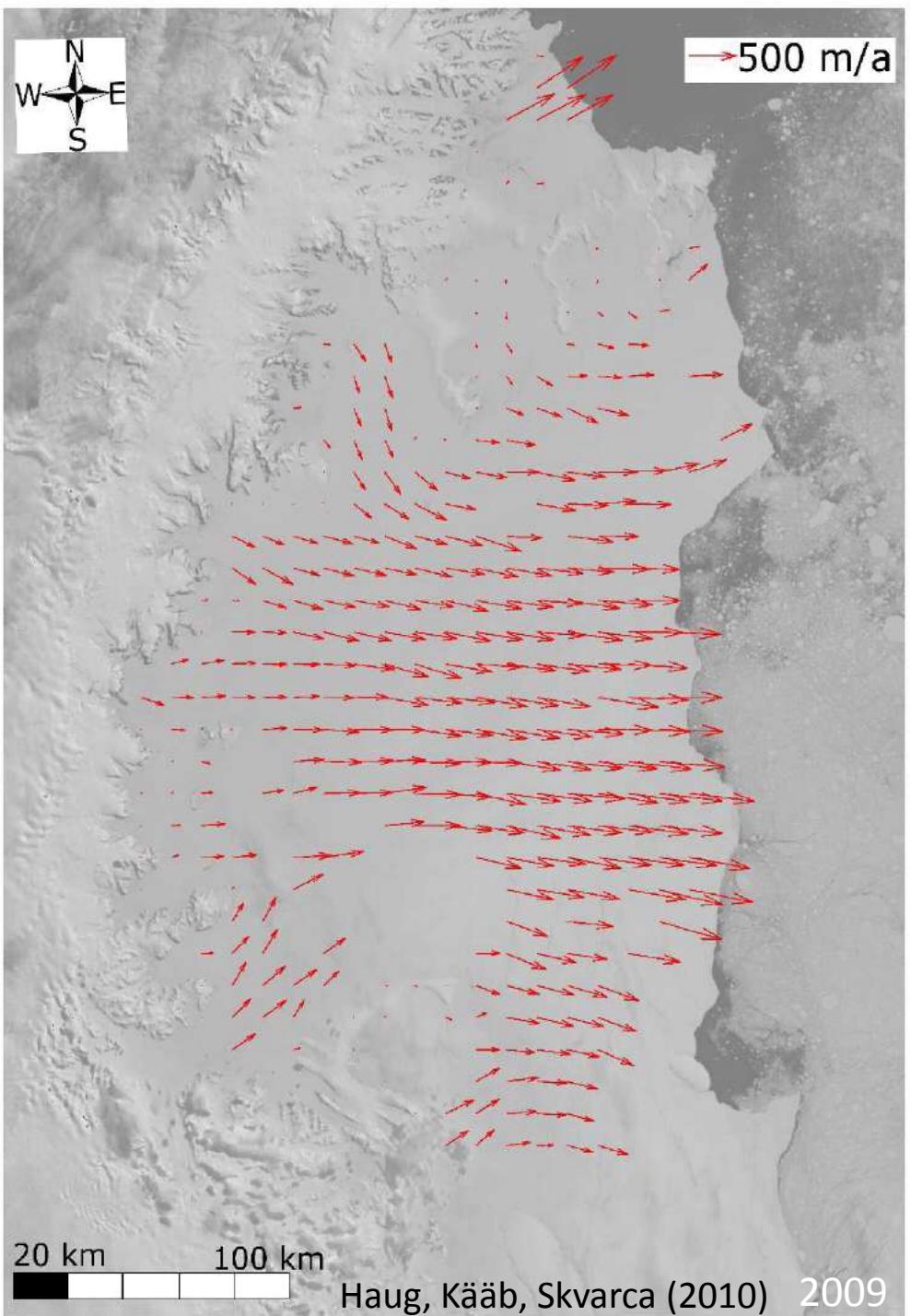
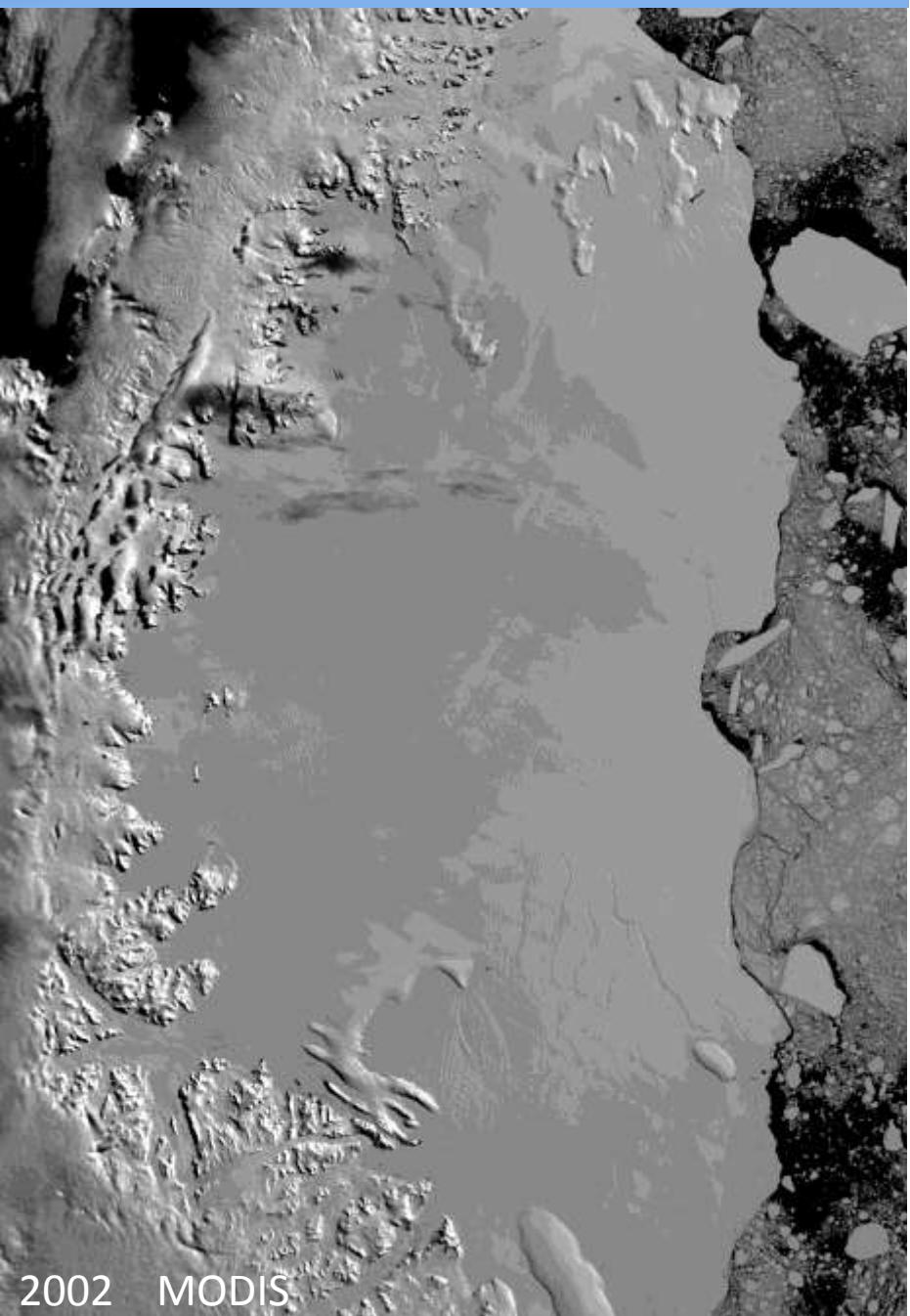
M. Sund



Hispar Glacier, Karakorum



# Larsen C

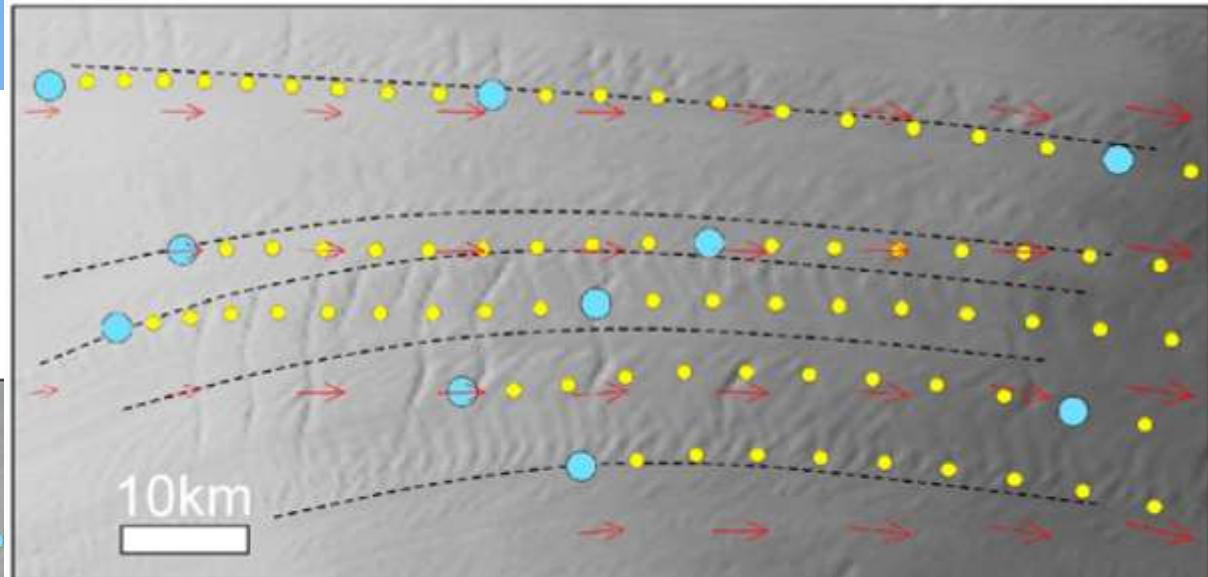
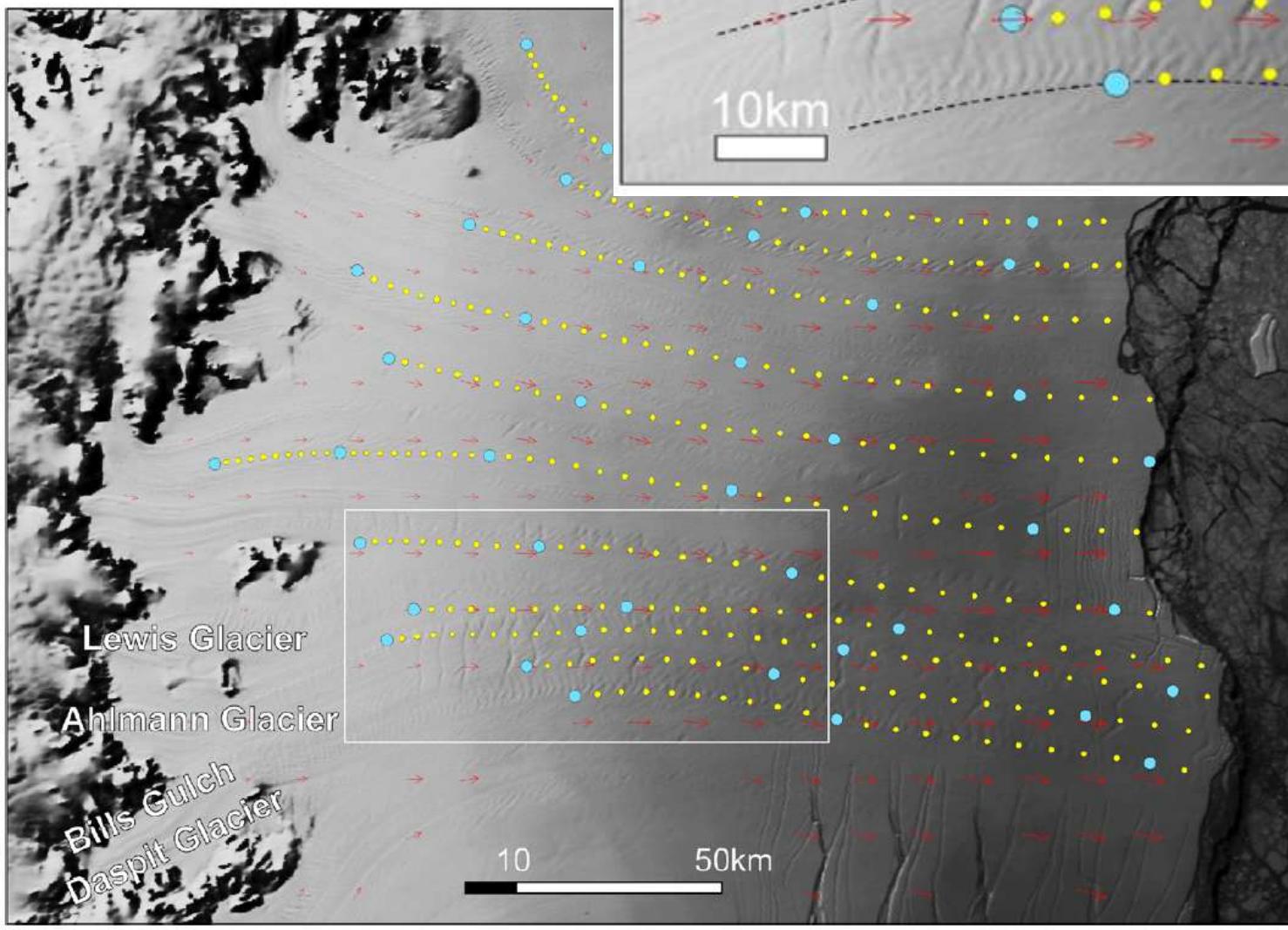


2002 MODIS

20 km 100 km

Haug, Kääb, Skvarca (2010) 2009

# Larsen C



Haug, Kääb, Skvarca (2010)

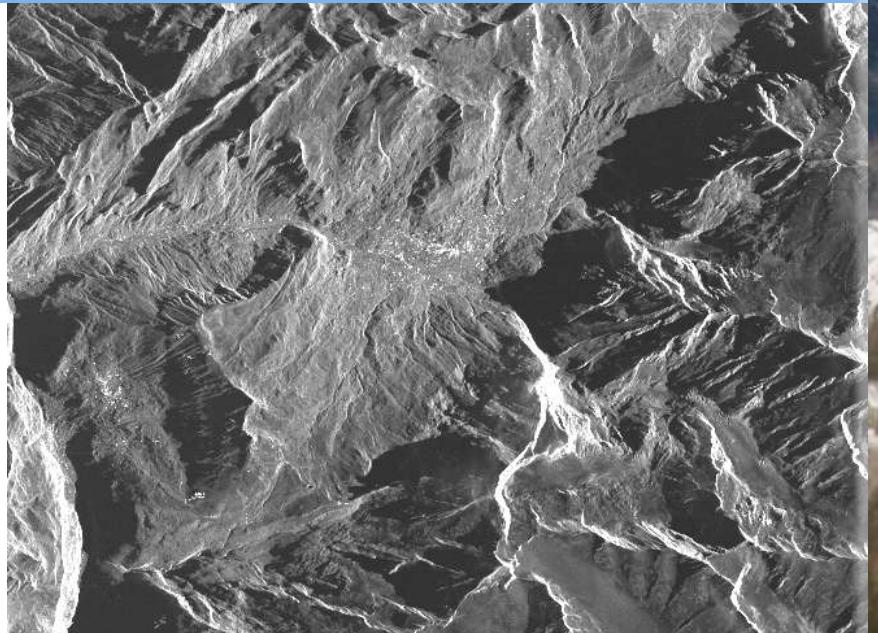
# Synthetic Aperture Radar (SAR)

15.07.2010

Radarsat data:



# SAR intensity tracking (TSX)

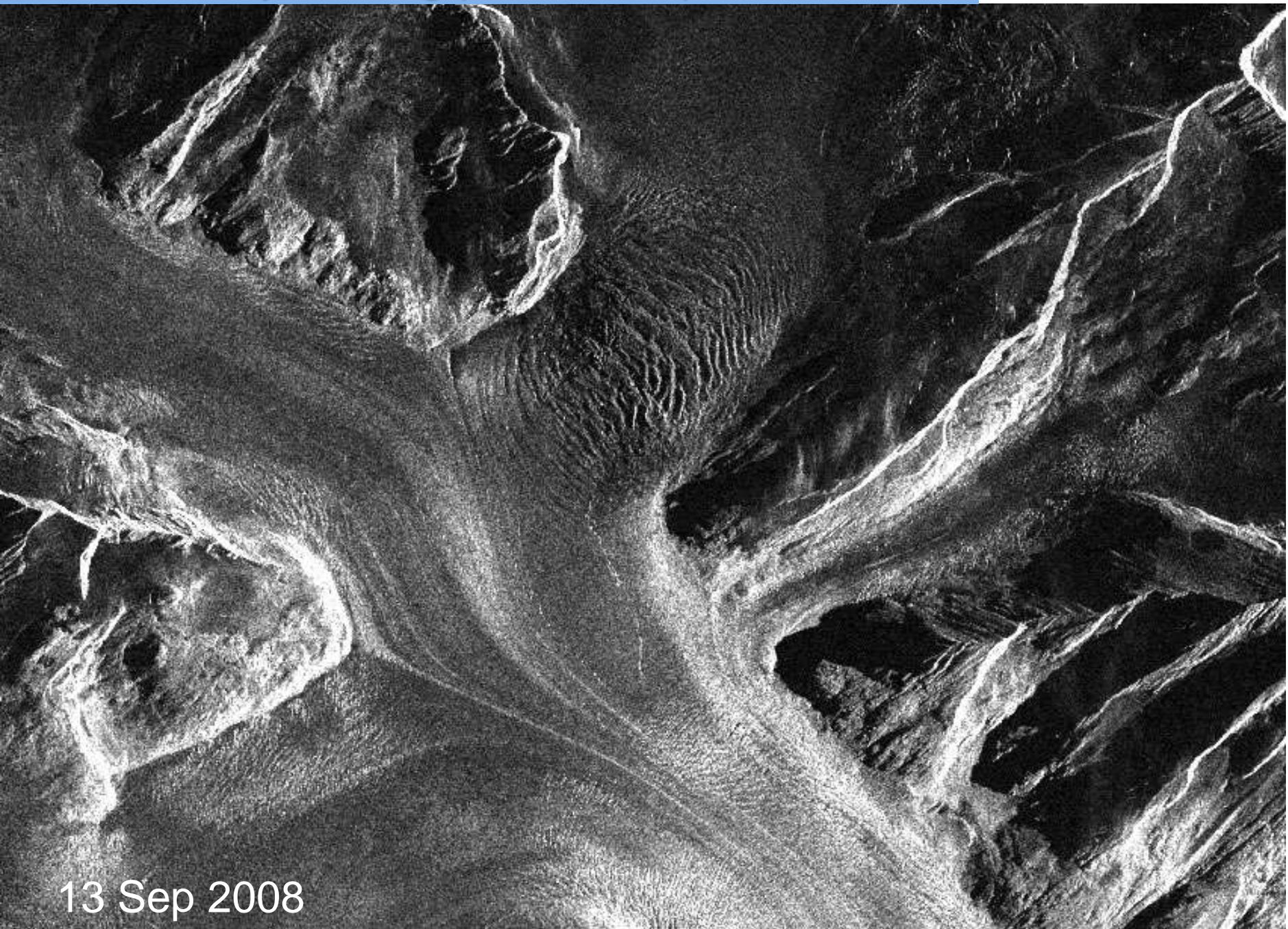


# SAR intensity tracking (TerraSAR-X)



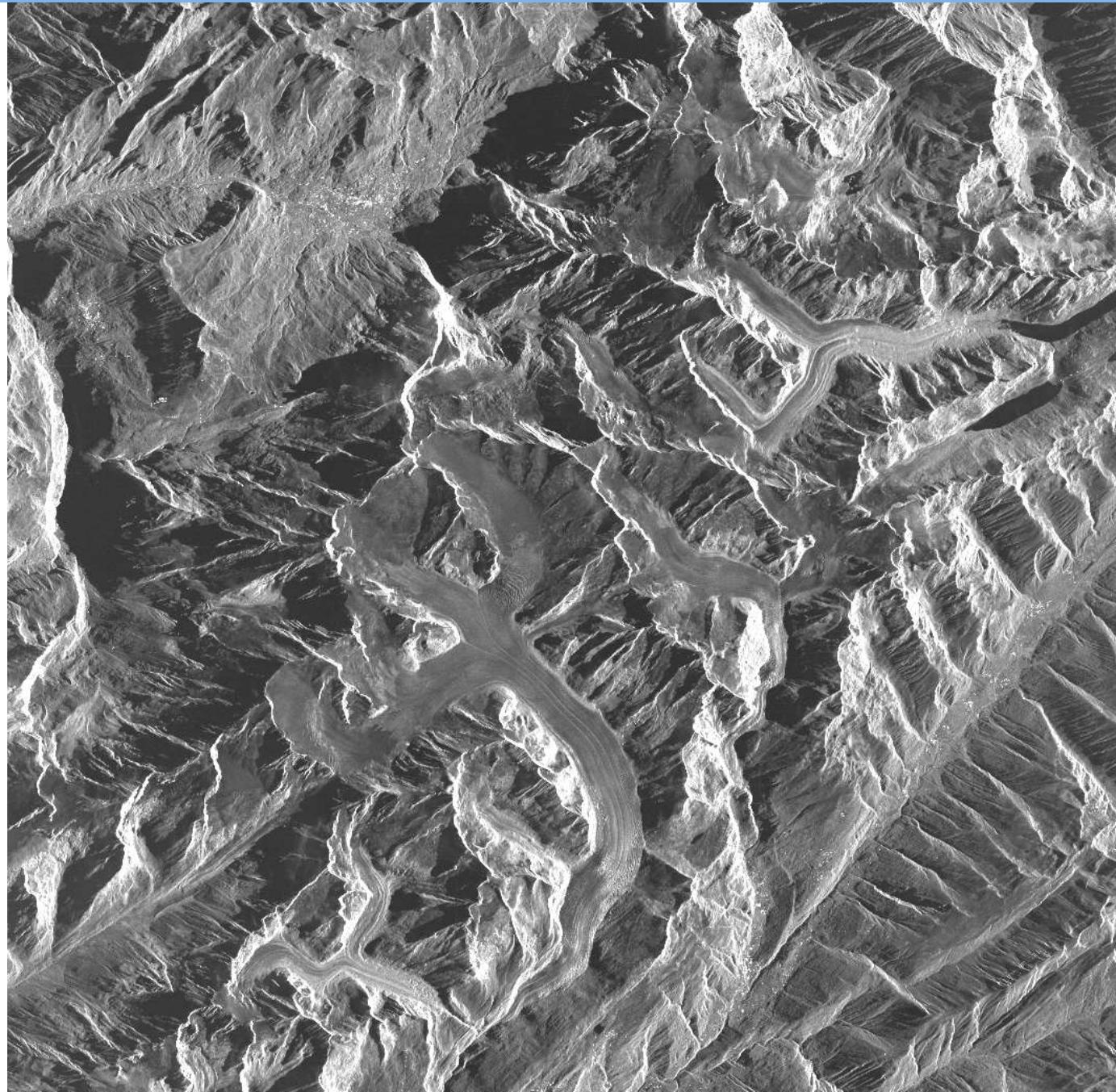
22 Aug 2008

# SAR intensity tracking (TerraSAR-X)

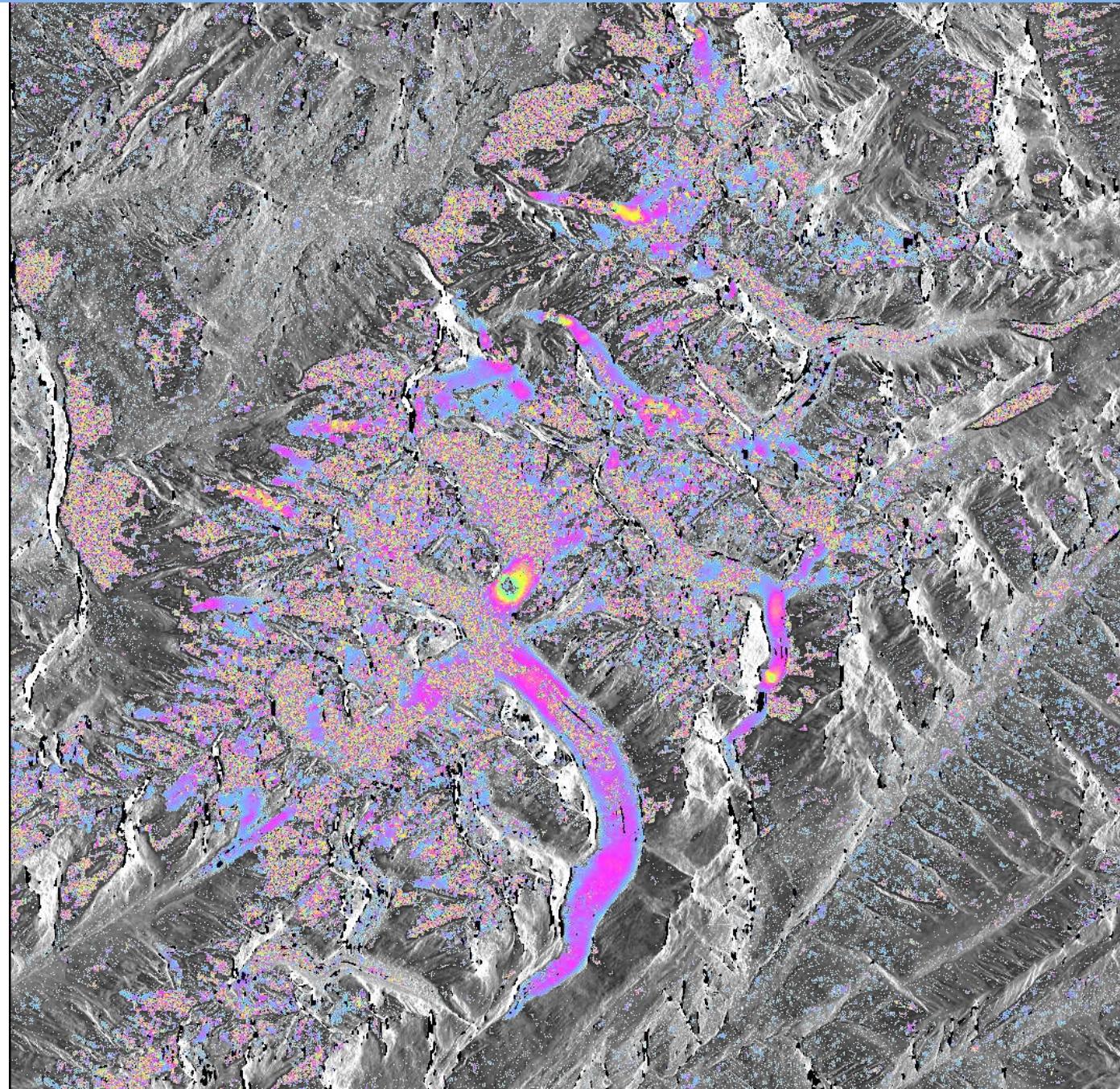


13 Sep 2008

# SAR intensity tracking (TerraSAR-X)



# SAR intensity tracking (TerraSAR-X)



0                  500 m/yr

A horizontal color bar at the bottom right of the map, consisting of a gradient from blue to yellow. It is labeled '0' at the left end and '500 m/yr' at the right end, indicating the range of movement tracked by the SAR analysis.

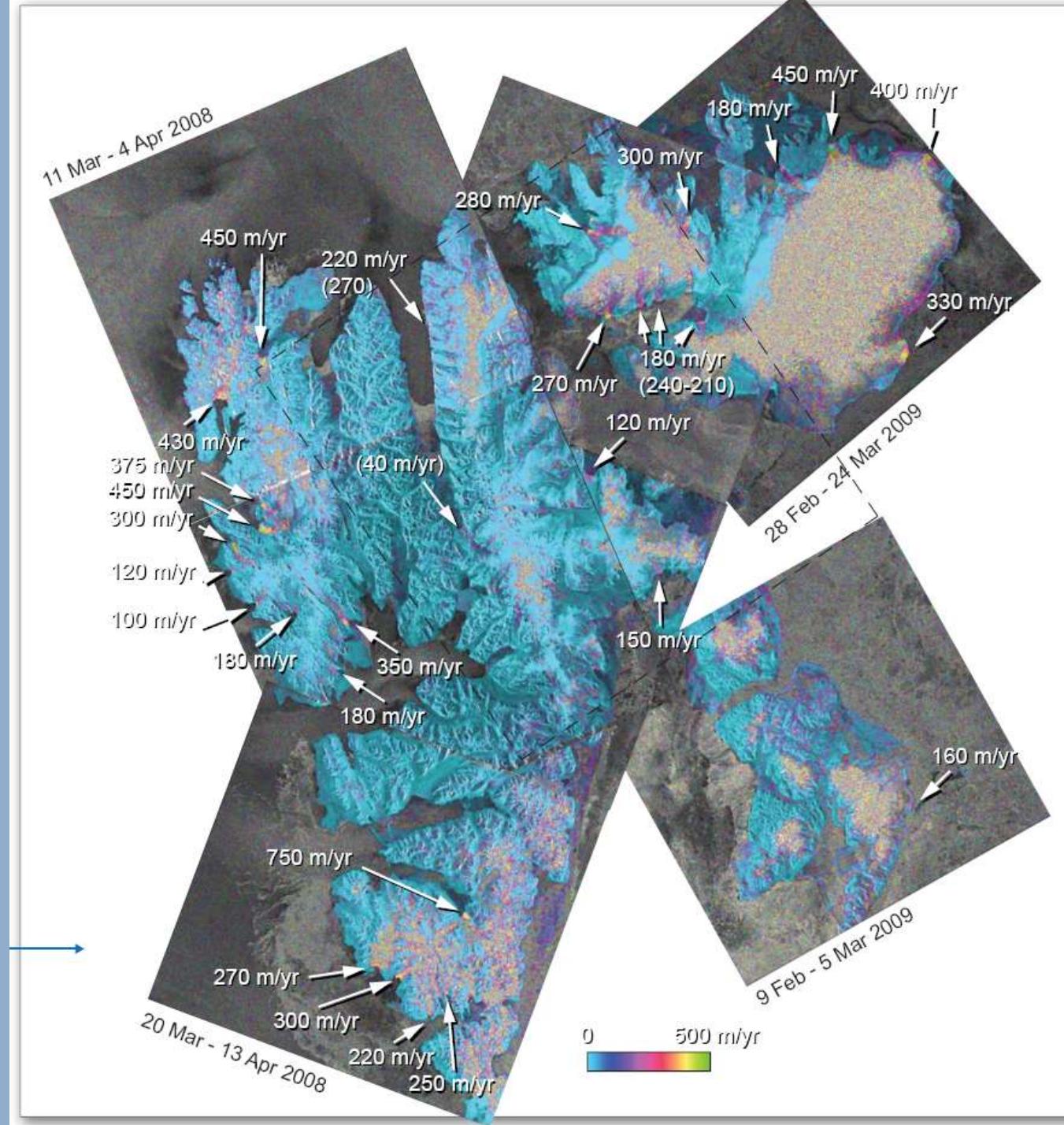
A. Kääb

# Glacier flow / offset tracking

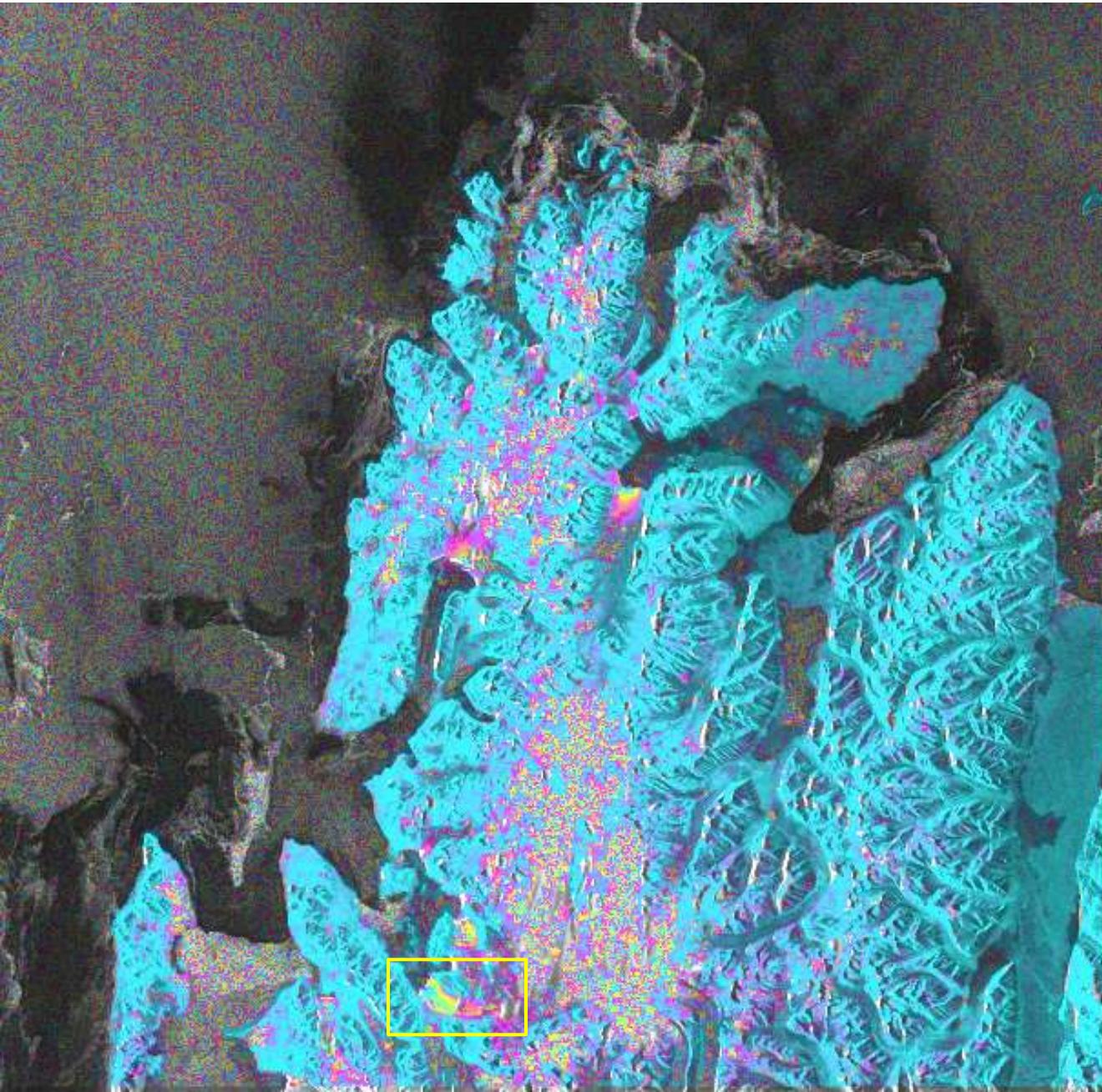
Radarsat data:



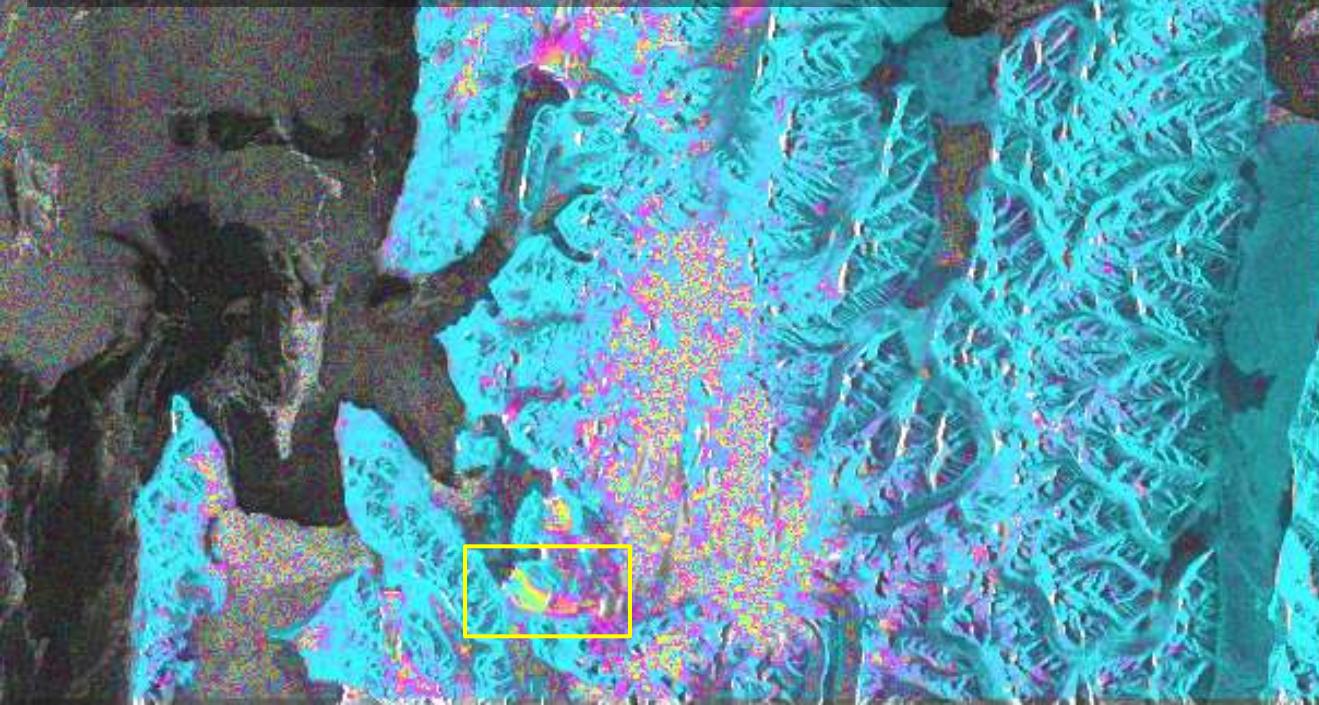
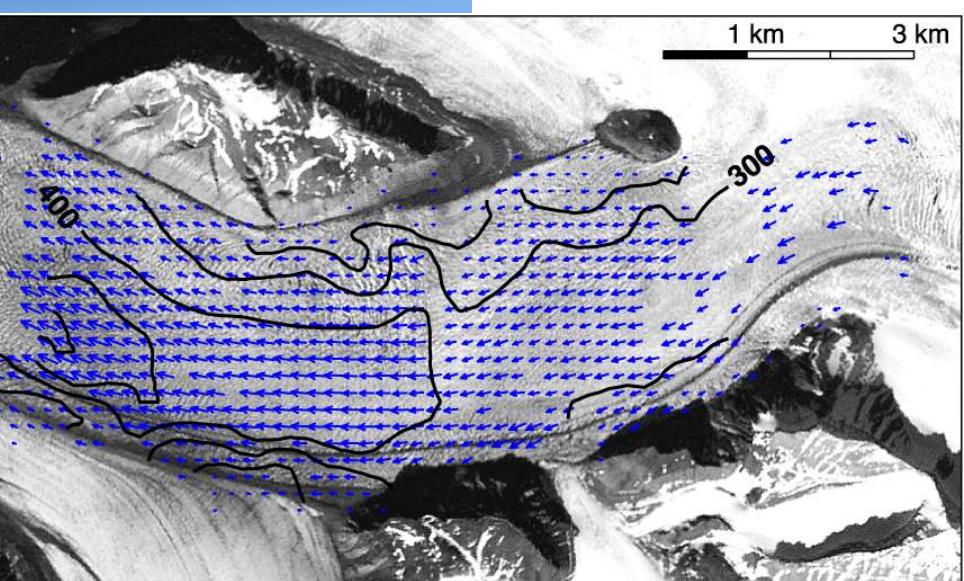
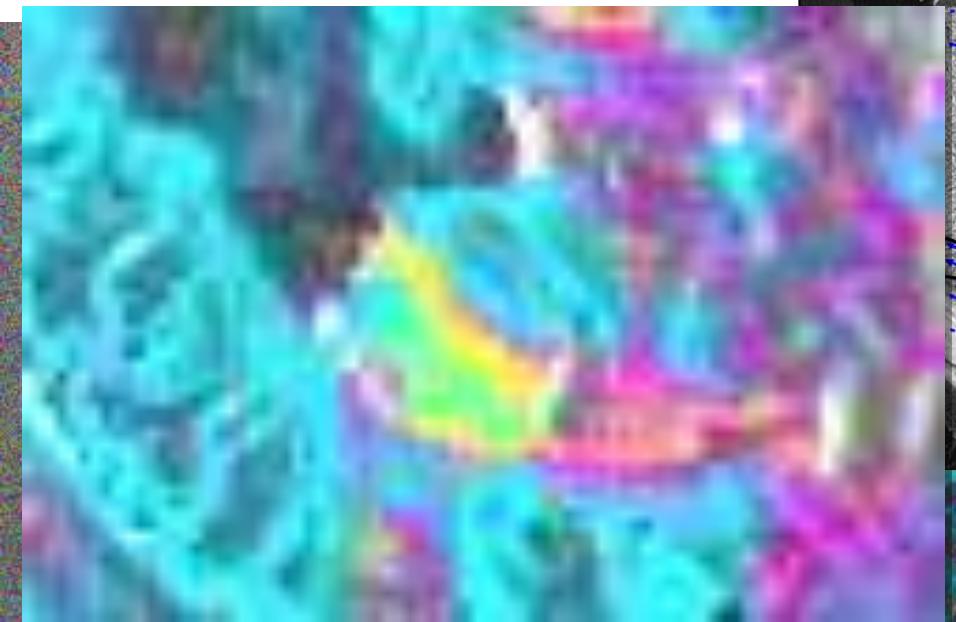
KONGSBERG



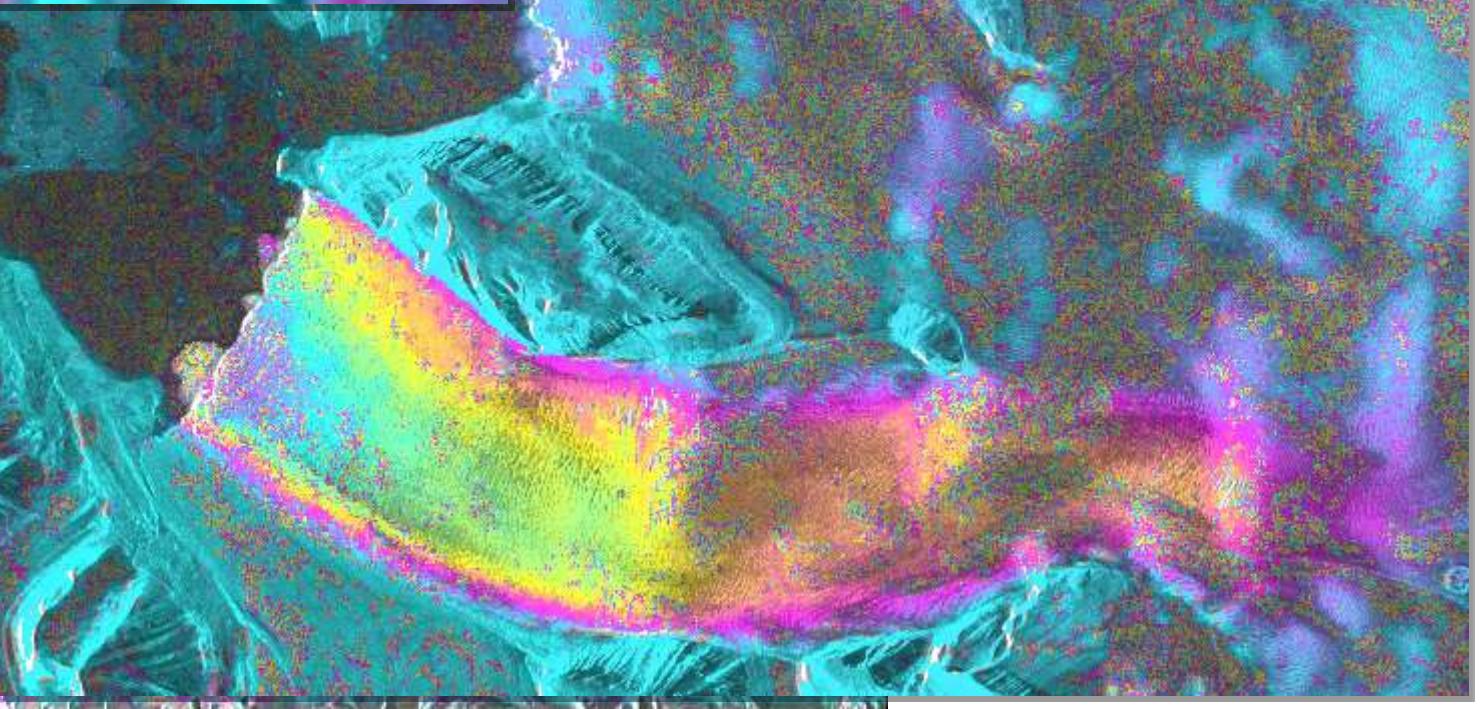
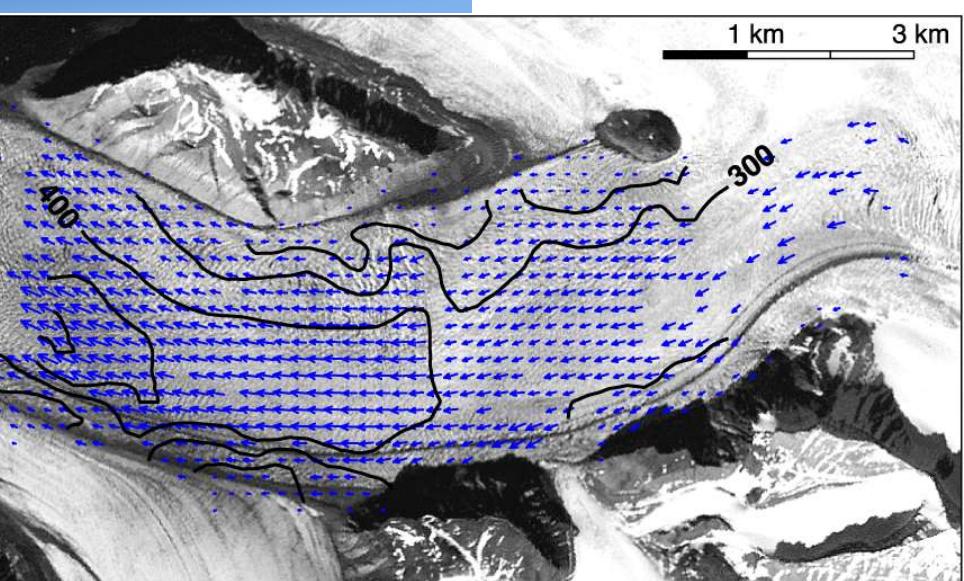
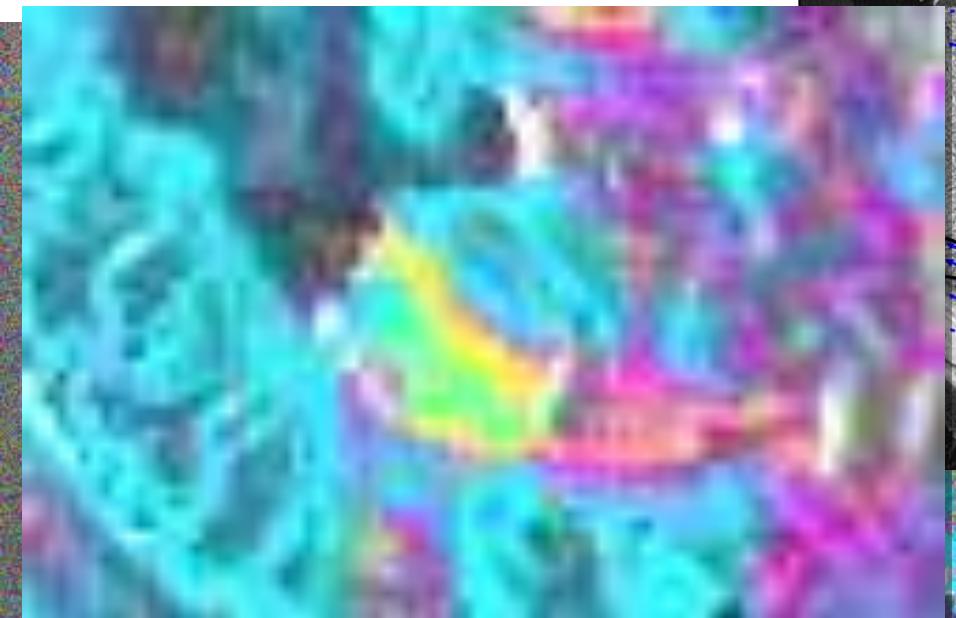
# SAR offset tracking



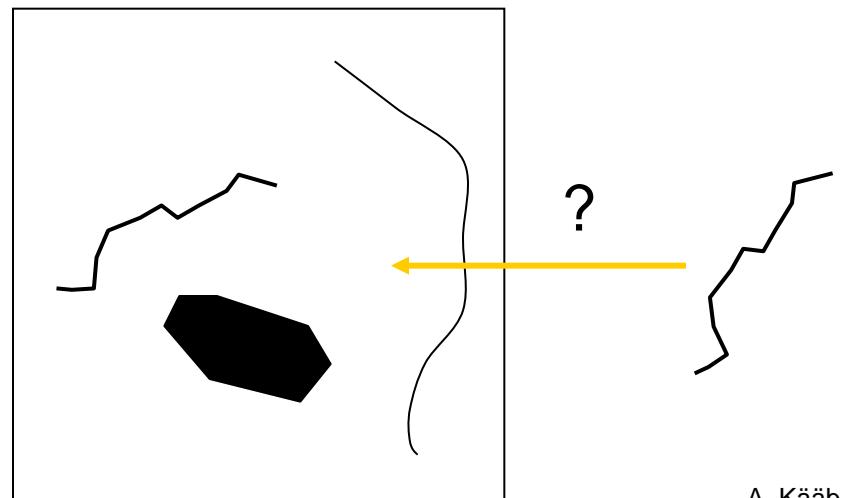
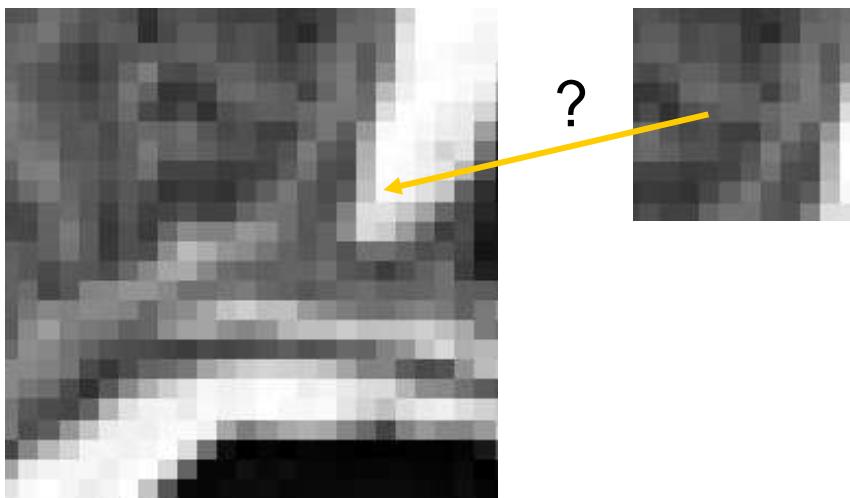
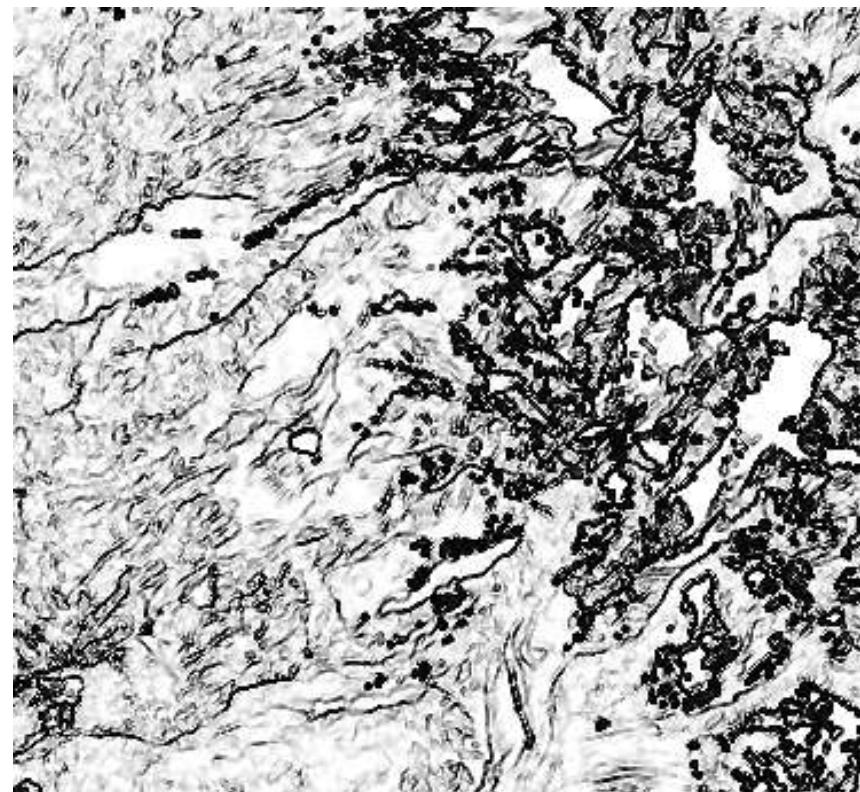
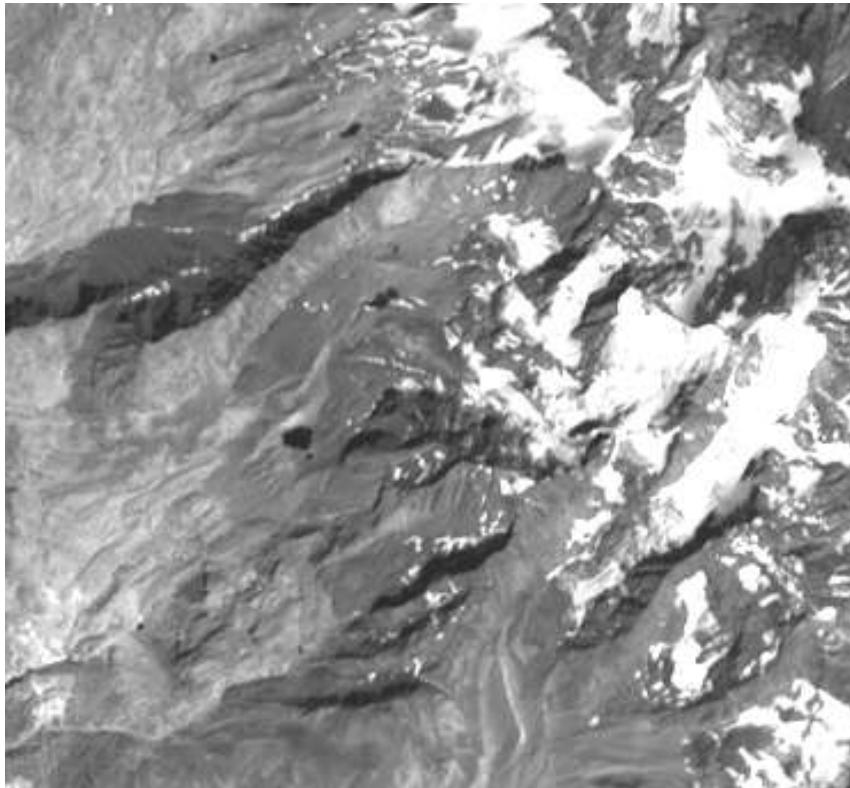
# SAR offset tracking



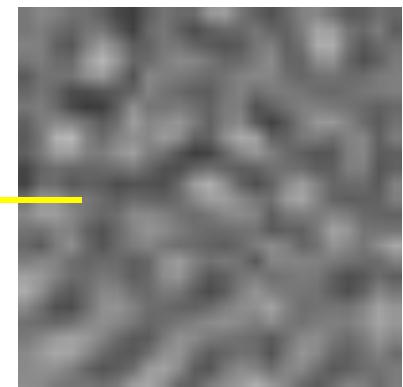
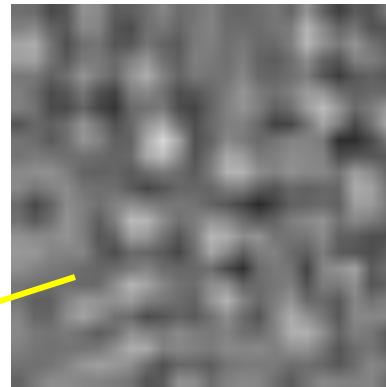
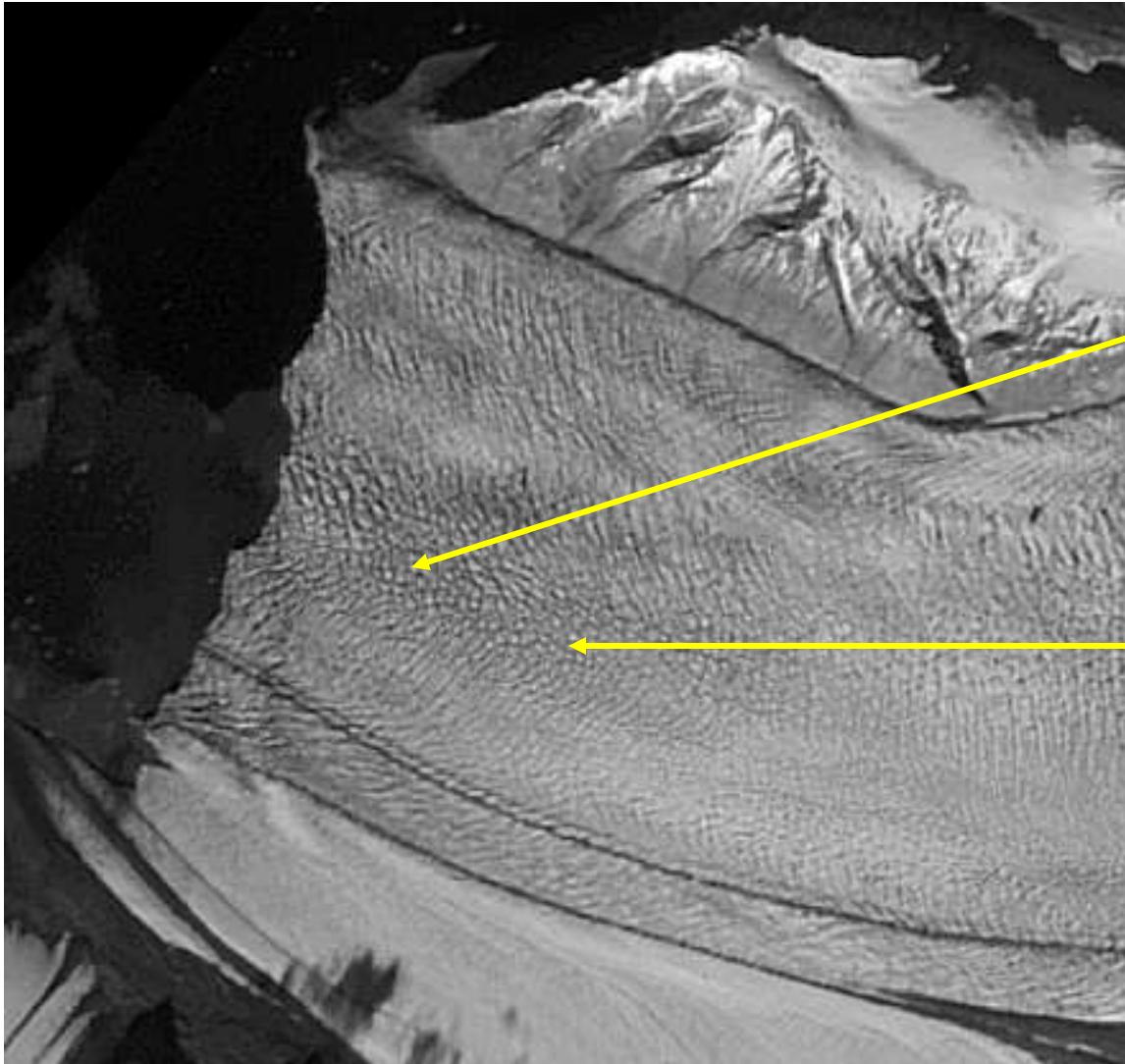
# SAR offset tracking



# Image matching: area based (block matching) – feature based



# Self-similar objects





2000

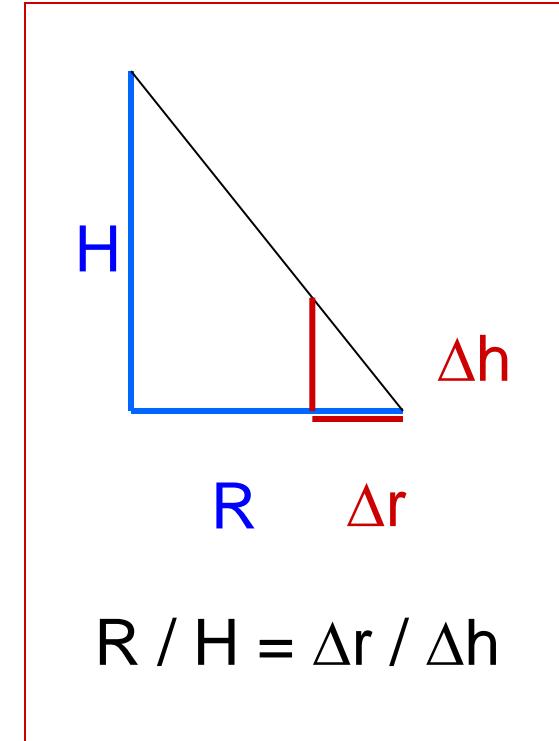
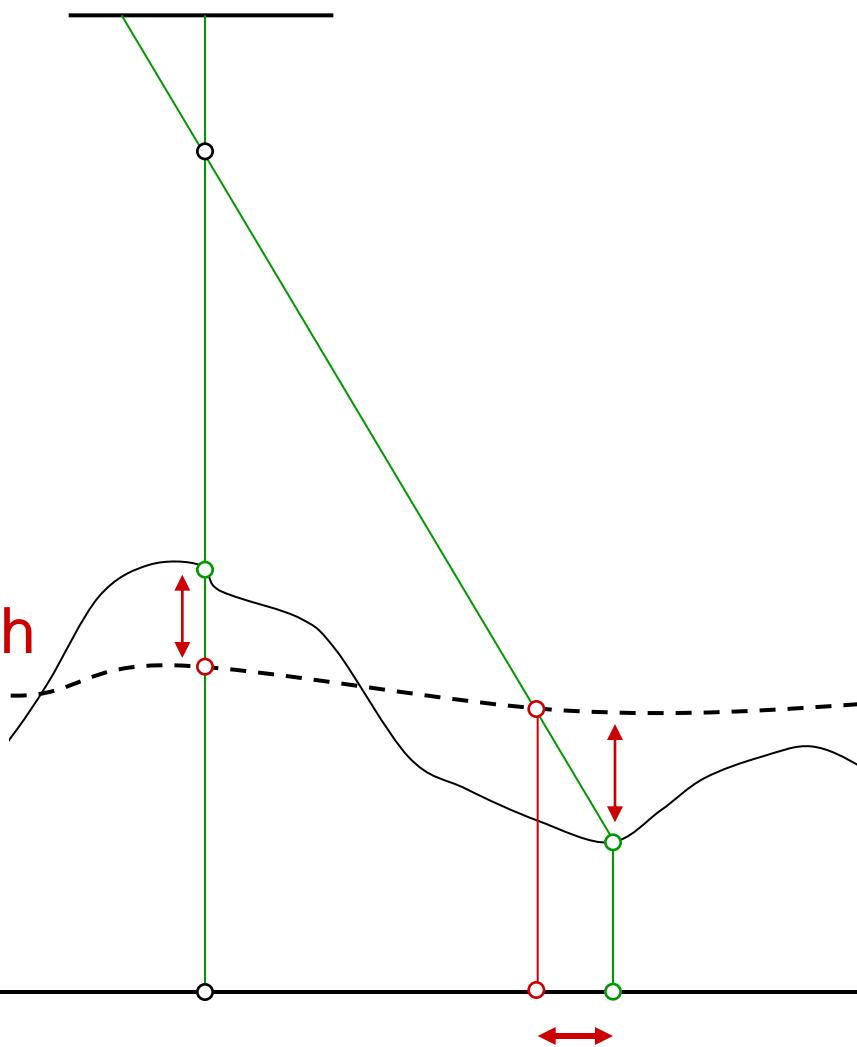
Batura Glacier, Karakorum

# Orthoprojection errors due to DTM errors

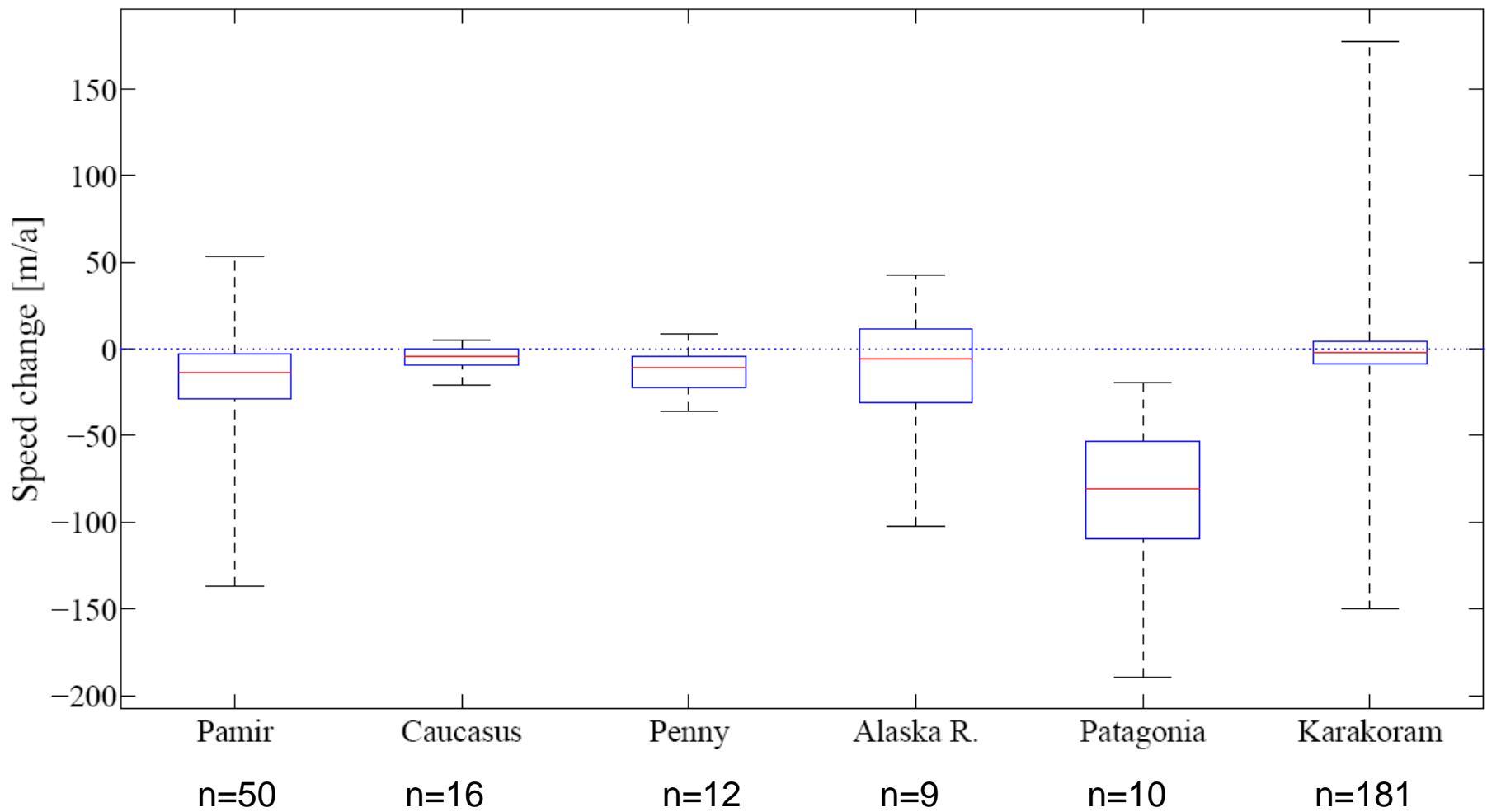
Image plane

Vertical  
DTM error  $\Delta h$

Map plane



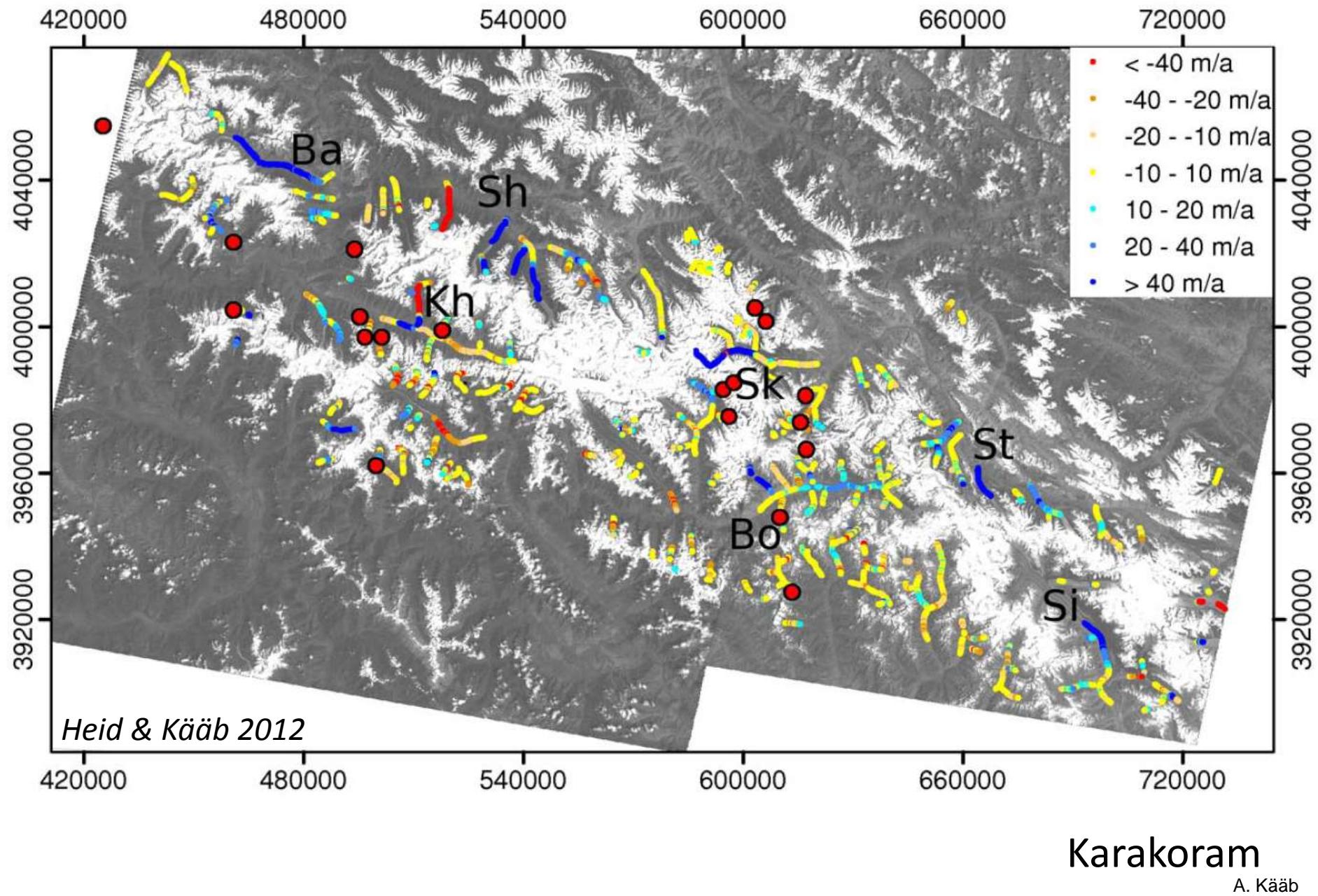
Horizontal distortion  $\Delta r$

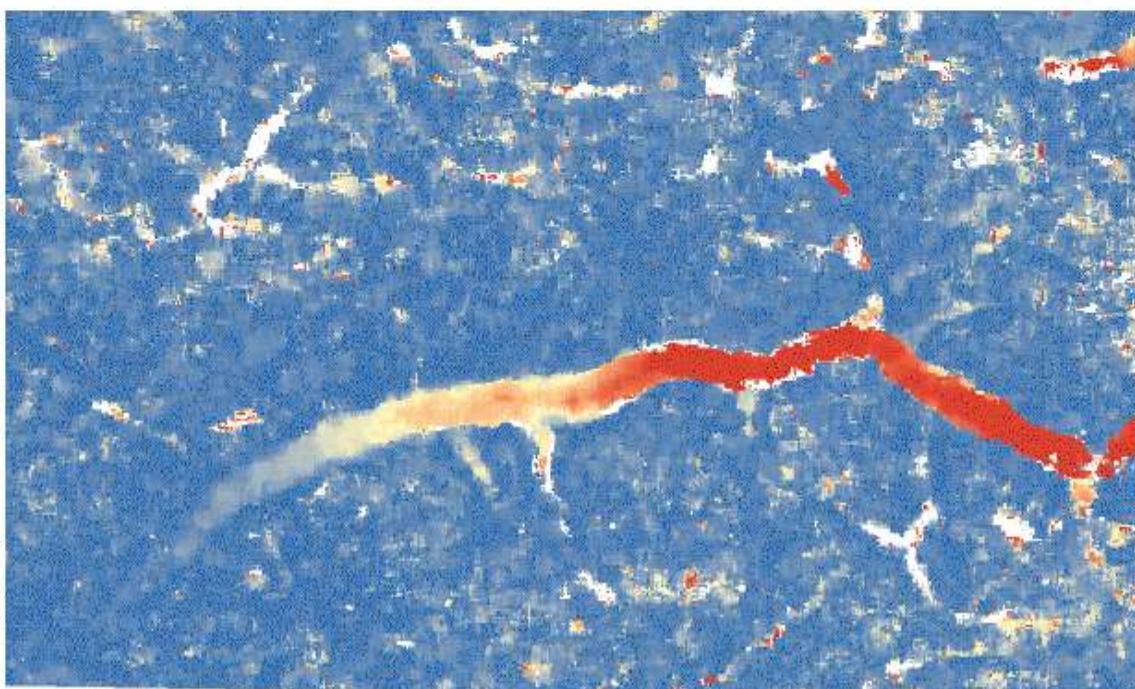
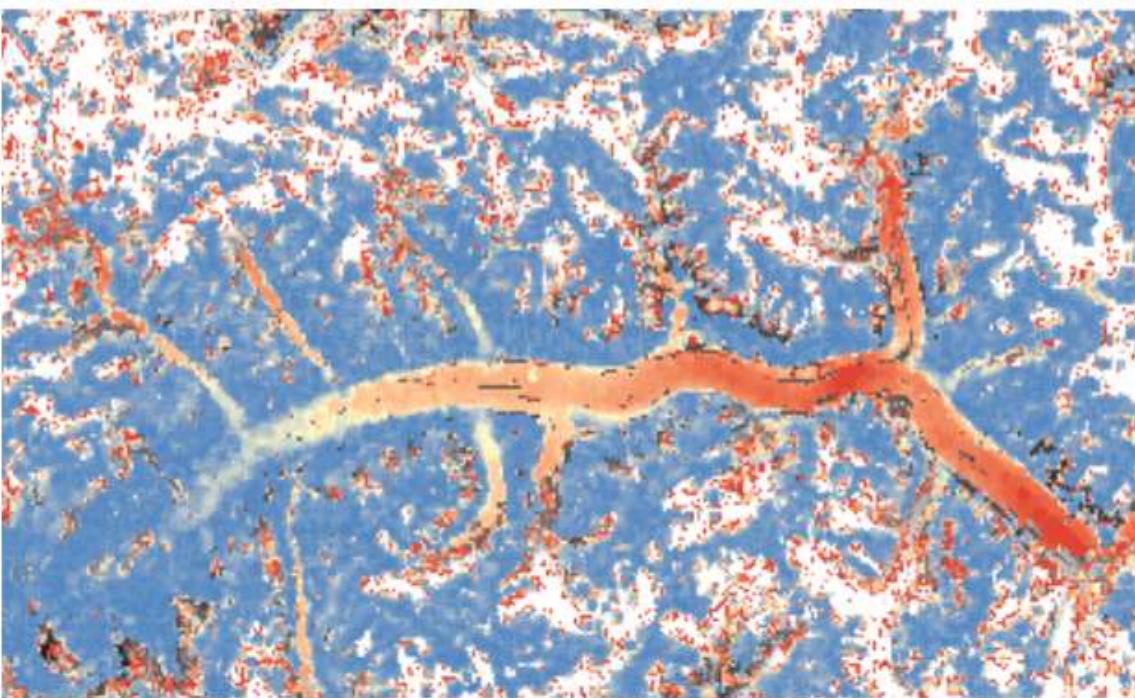


Heid & Kääb 2012

Karakoram

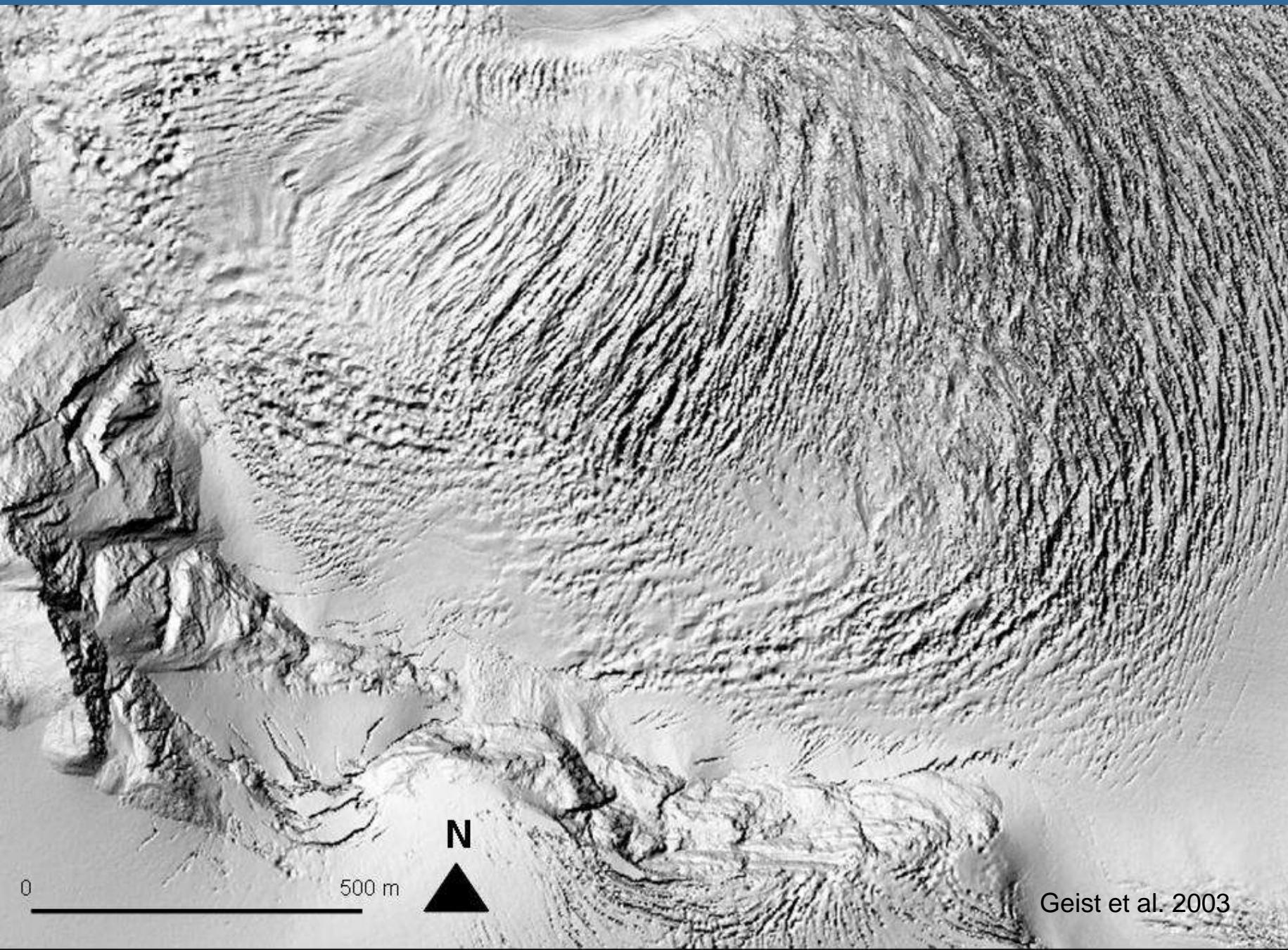
A. Kääb





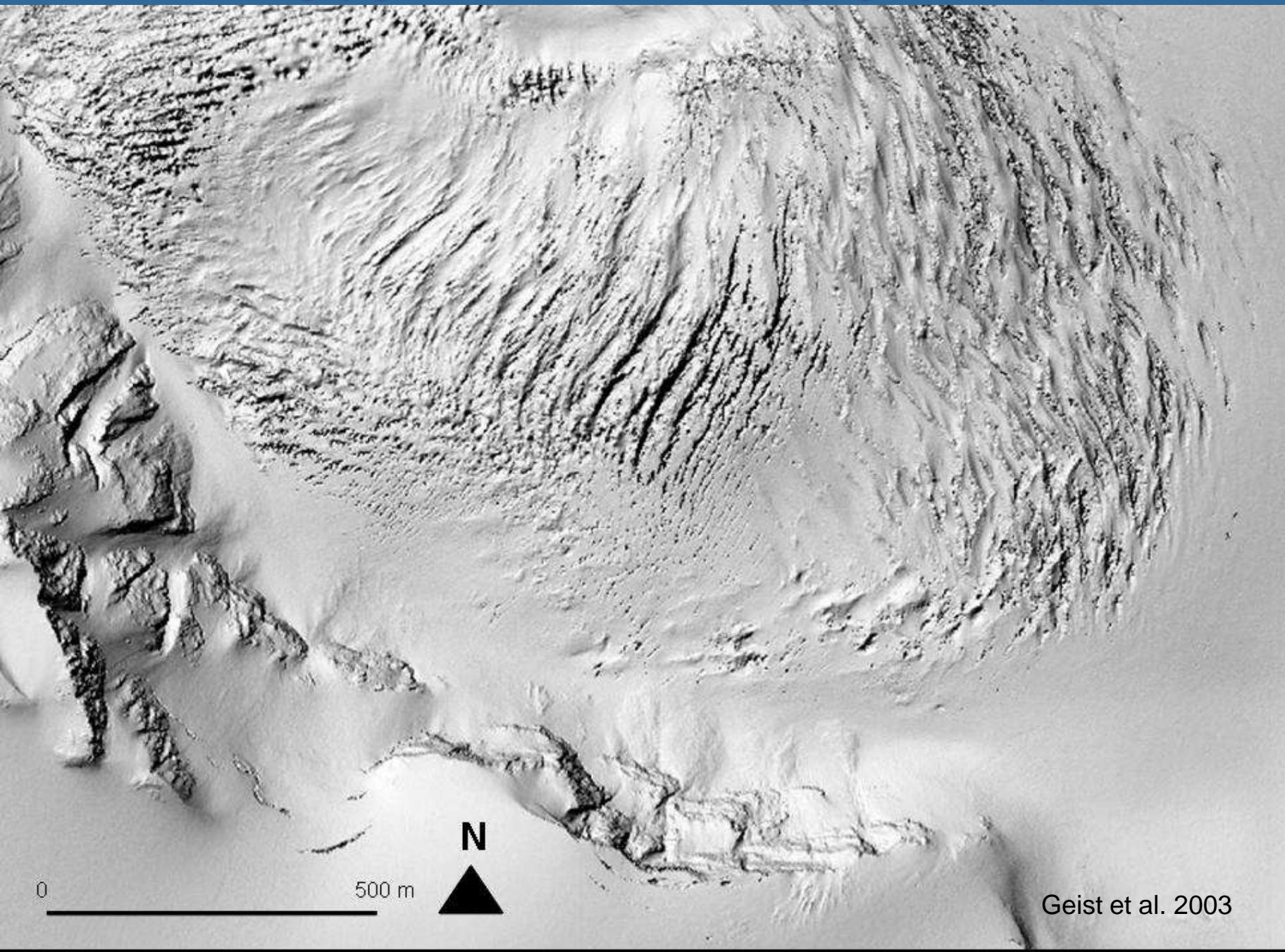
A. Luckmann

# Laserscanning (light detection and ranging, LIDAR)



Geist et al. 2003

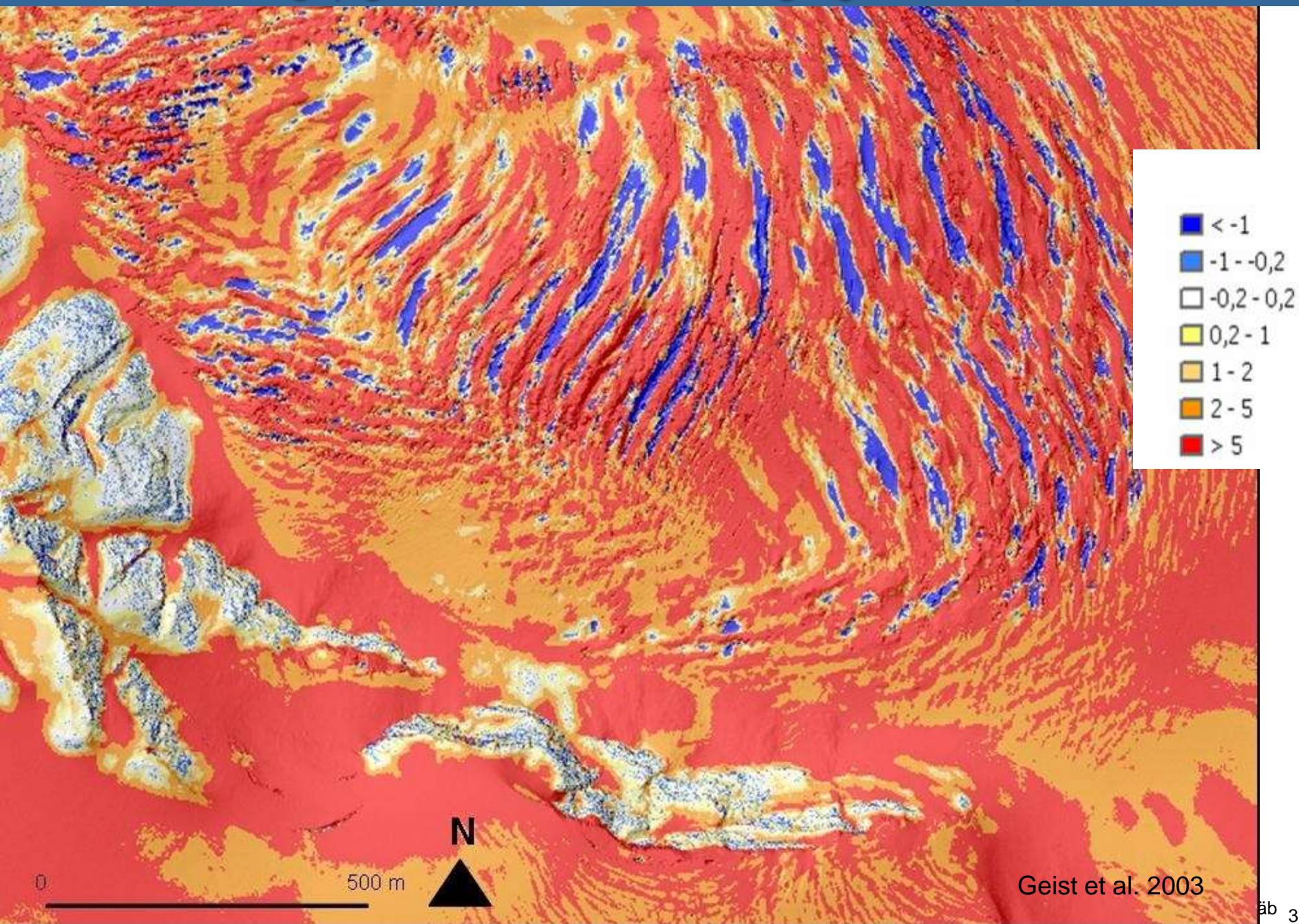
# Laserscanning (light detection and ranging, LIDAR)



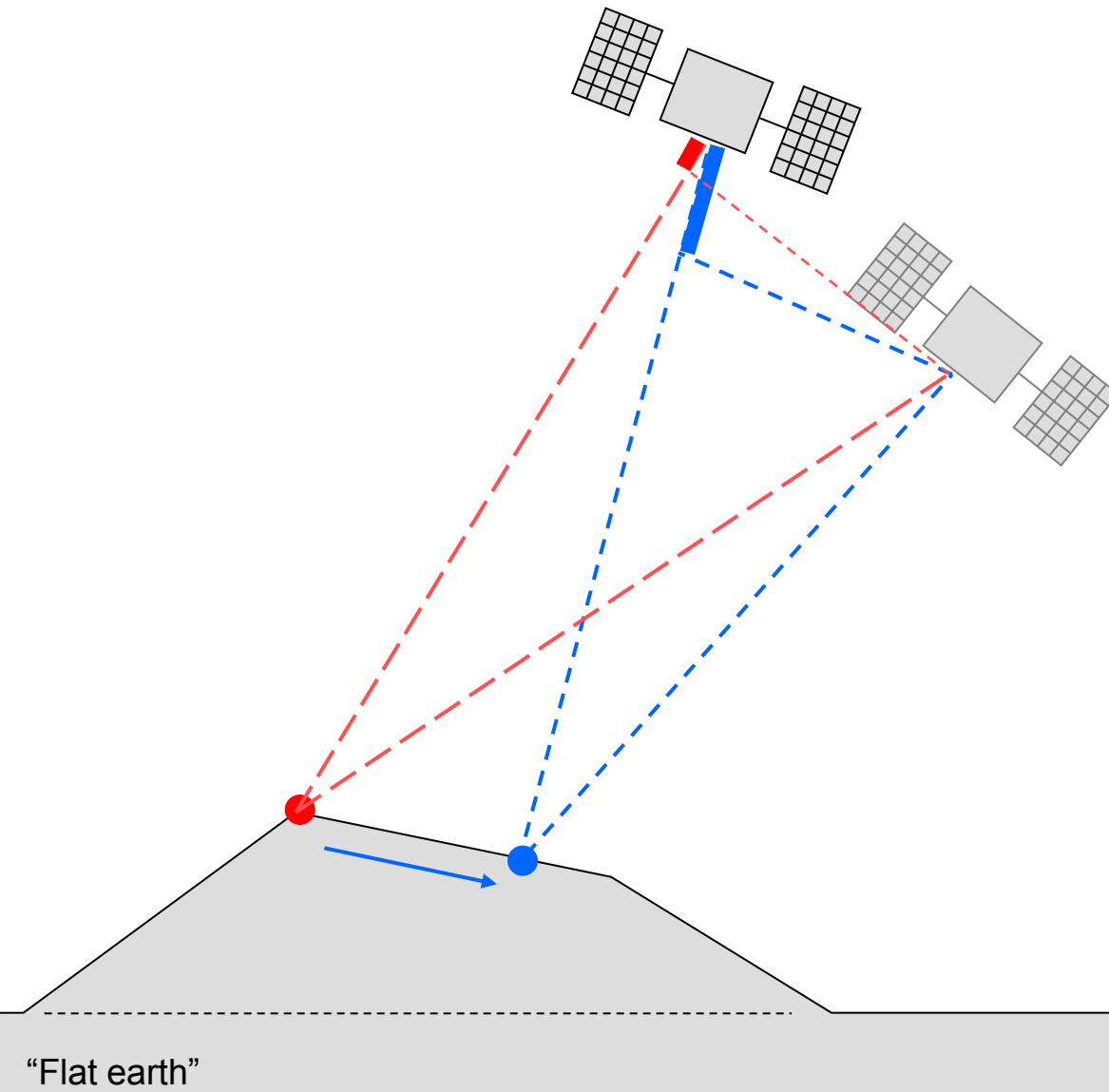
Geist et al. 2003

ab 30

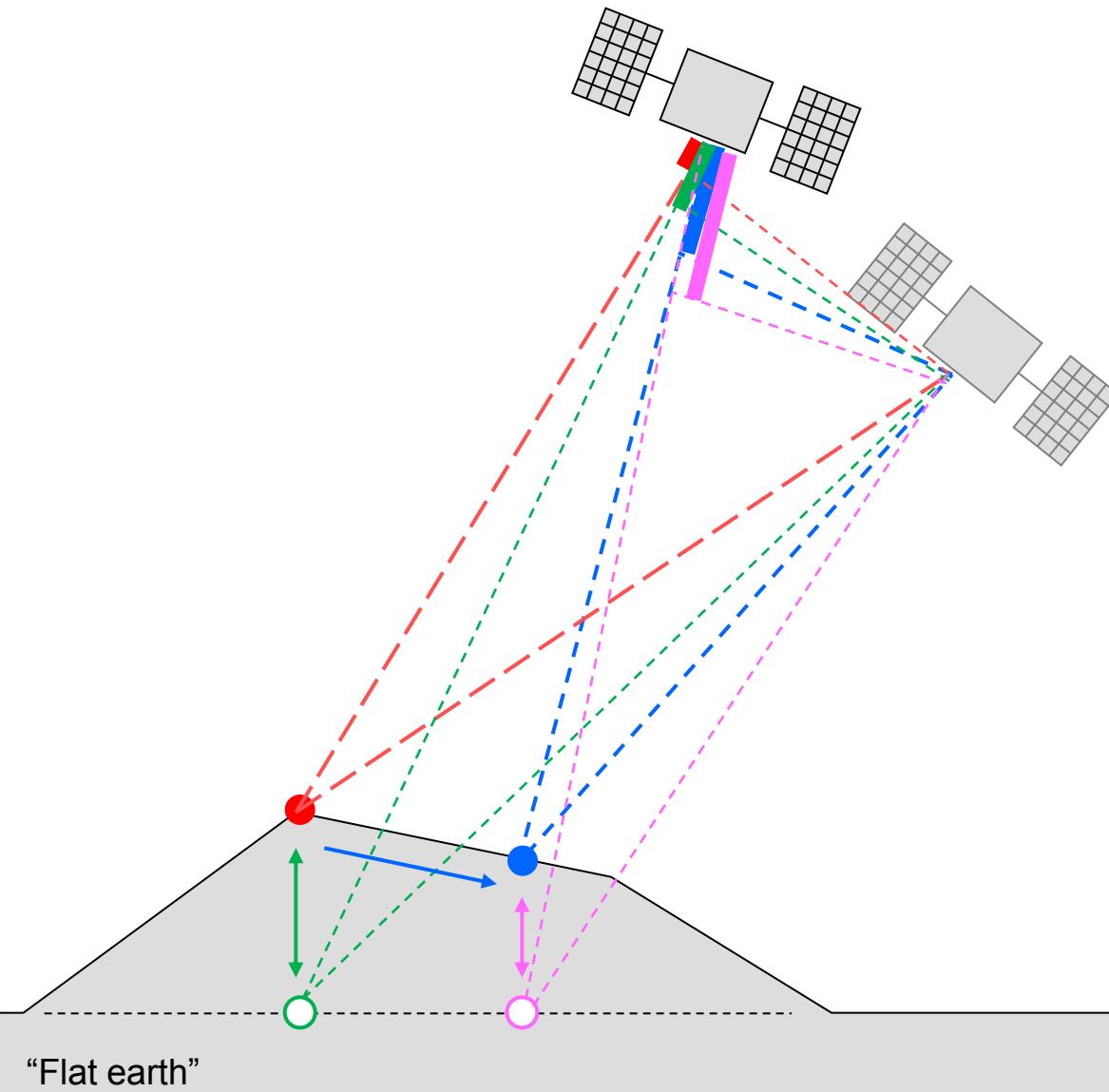
# Laserscanning (light detection and ranging, LIDAR)



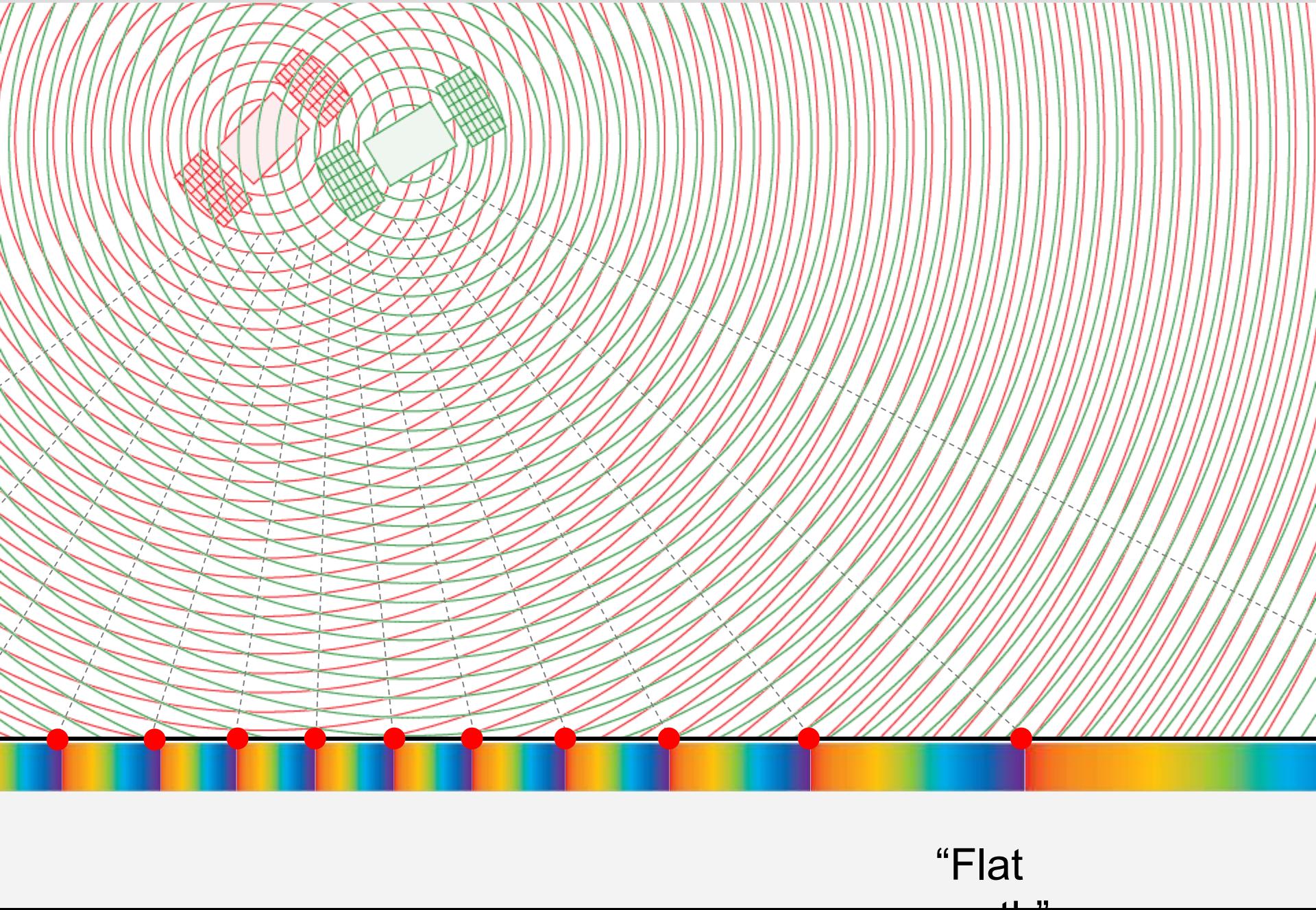
# Terrain displacements from SAR interferometry



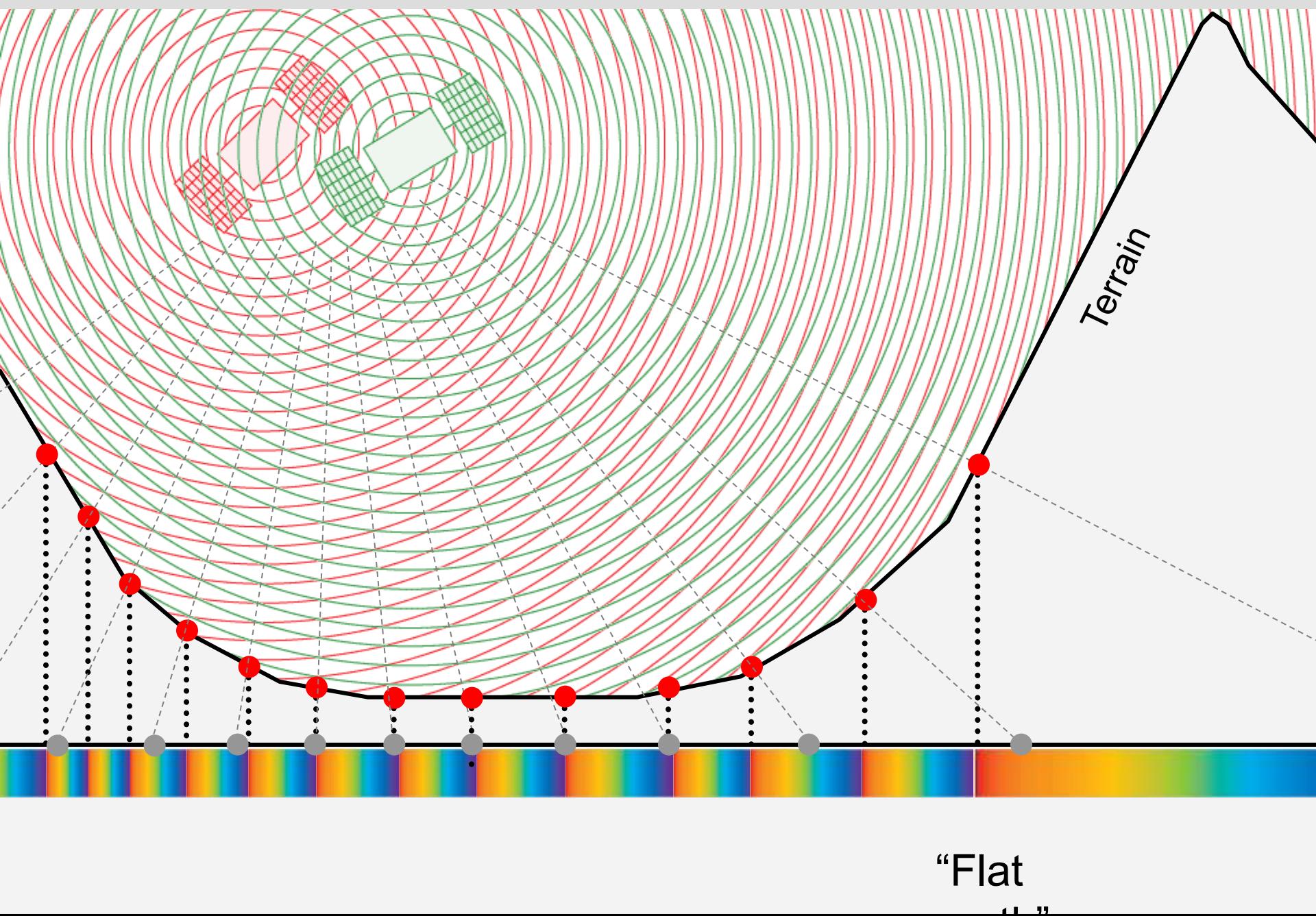
# Terrain displacements from SAR interferometry



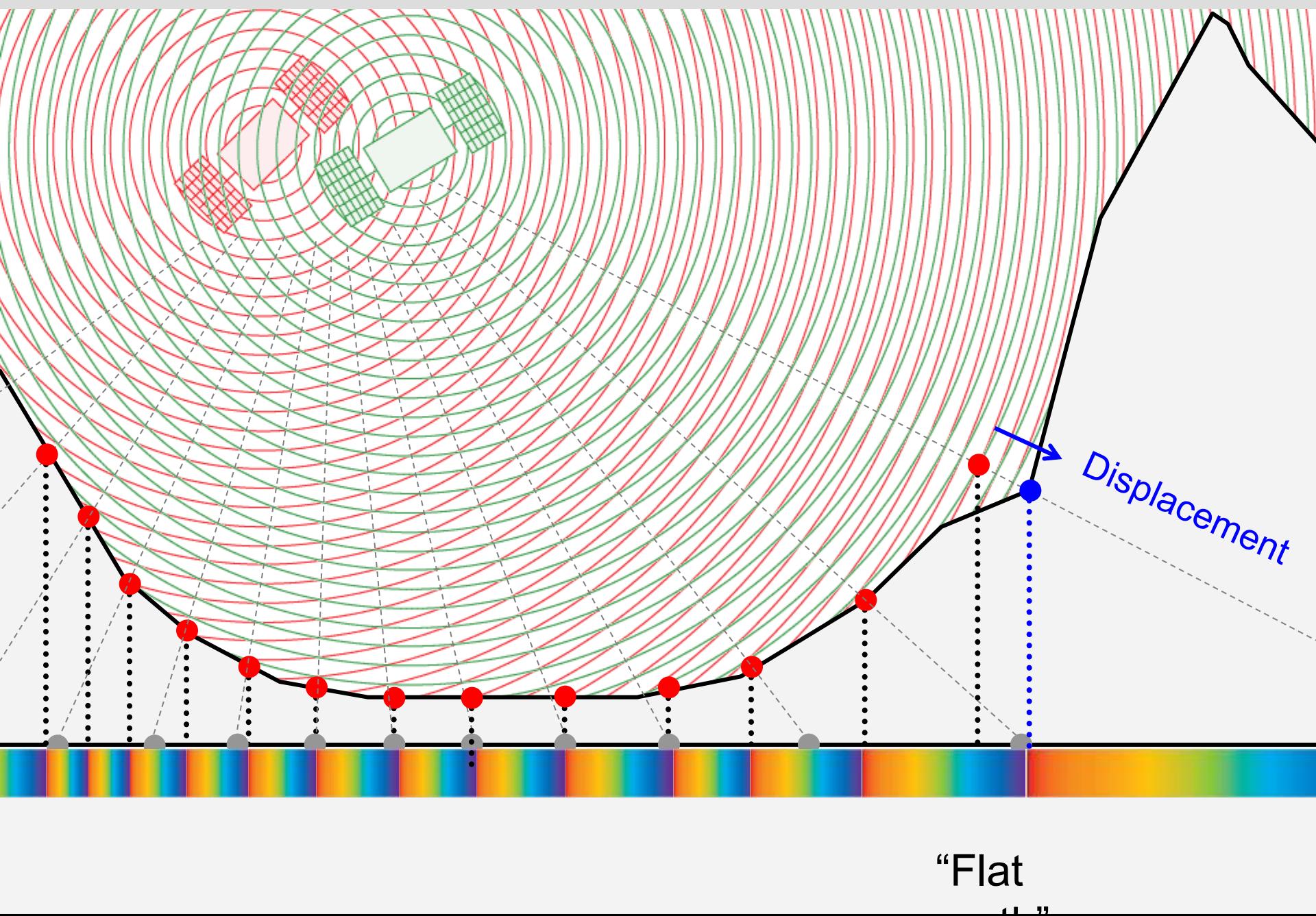
# Interferometric SAR (InSAR)



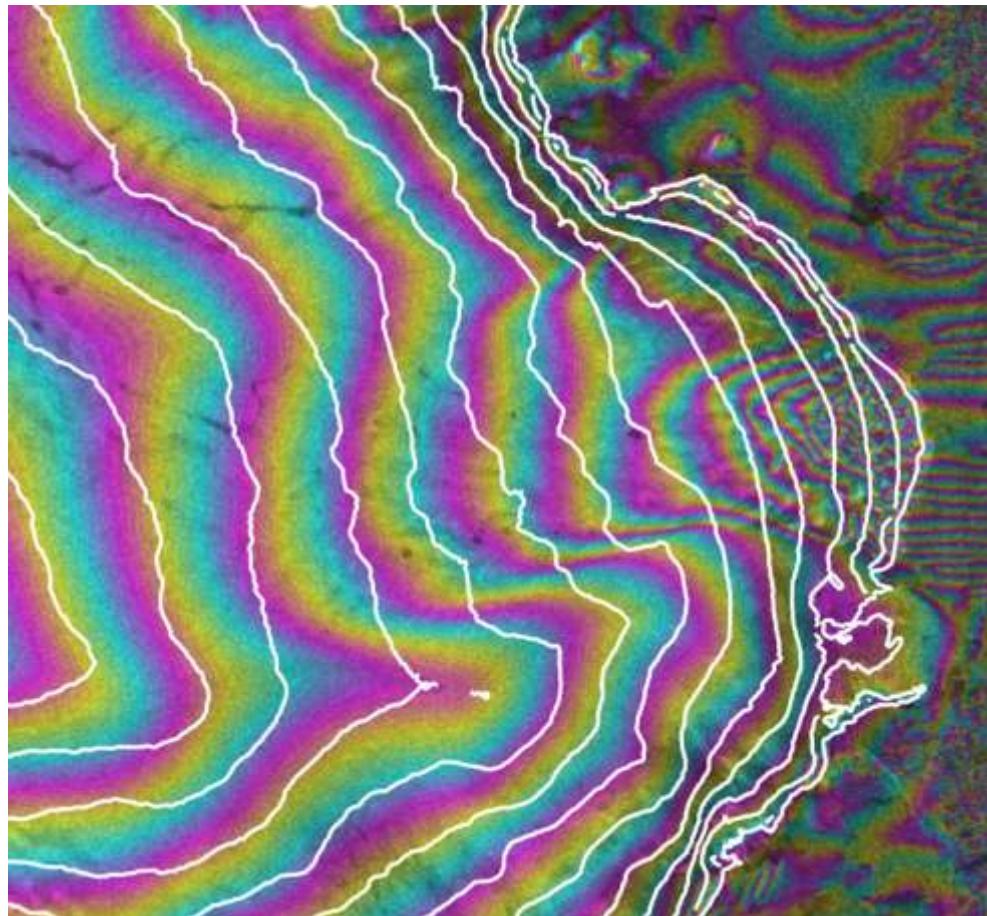
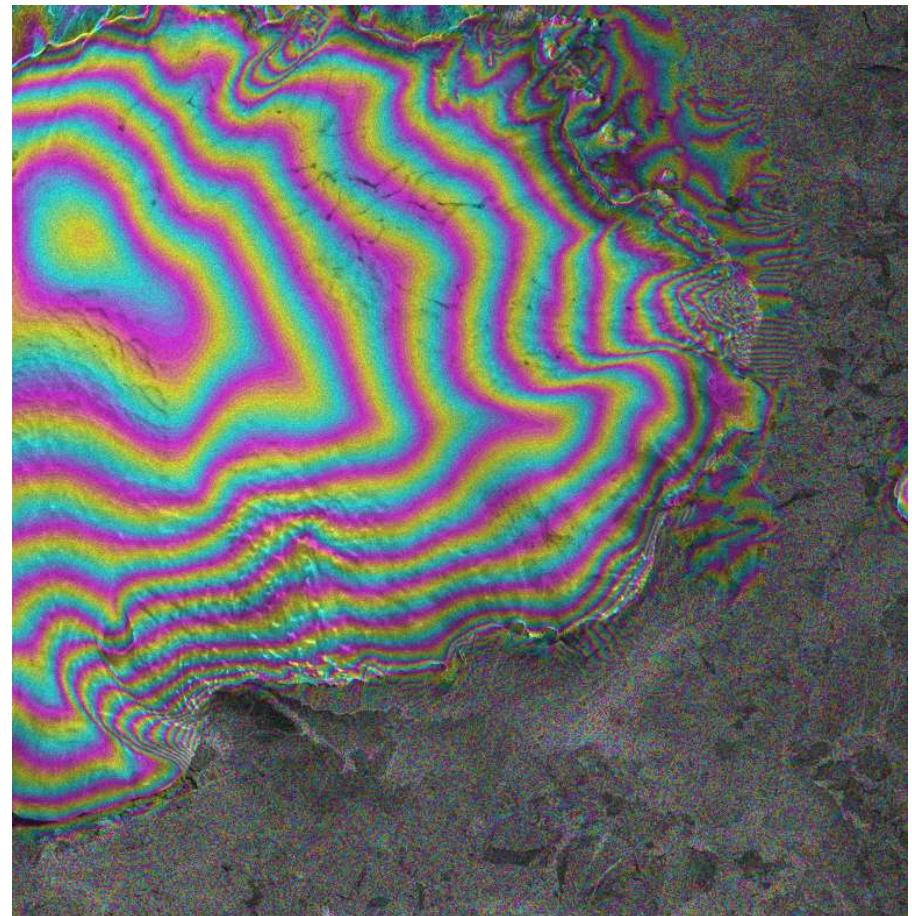
# Interferometric SAR (InSAR)



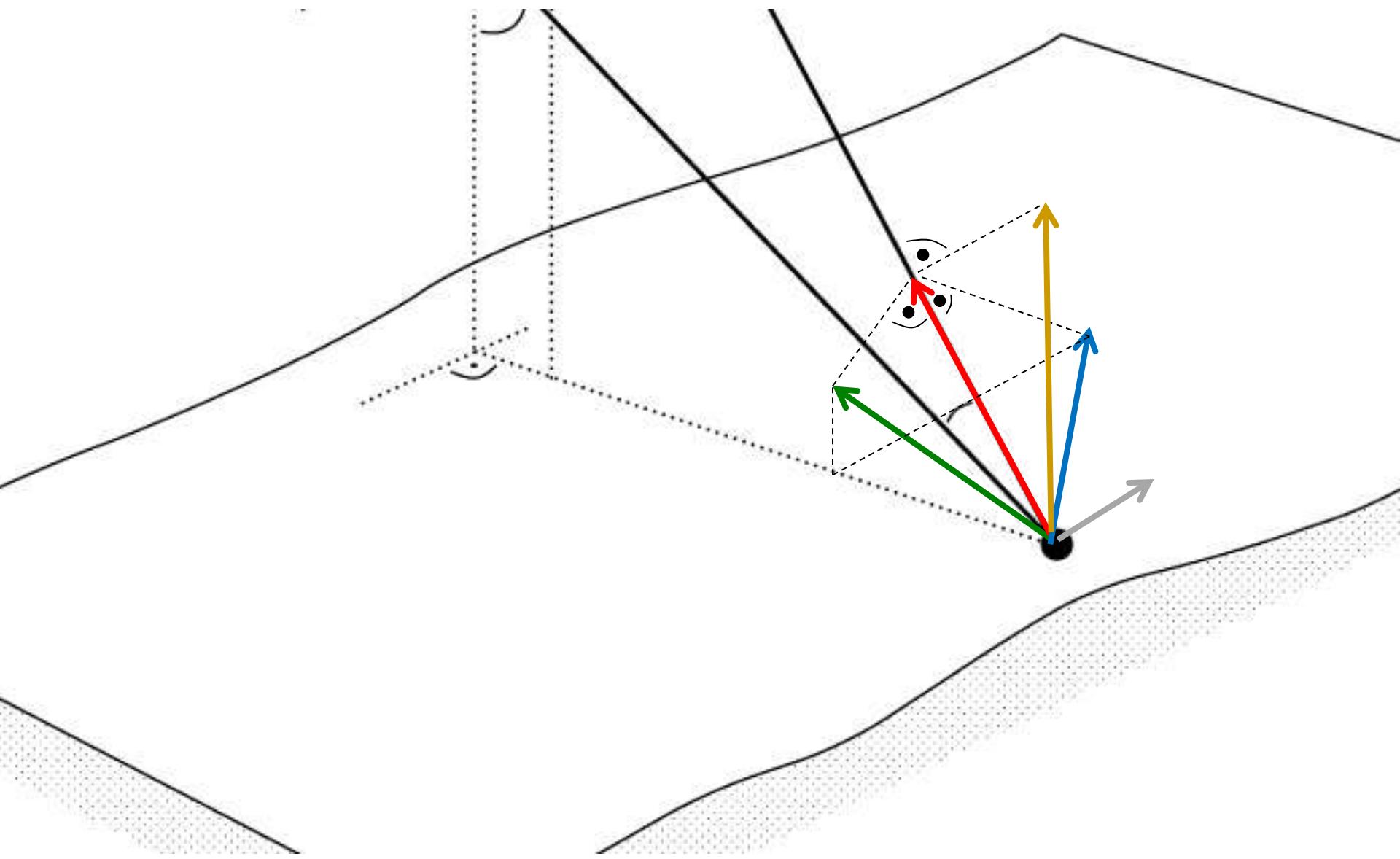
# Interferometric SAR (InSAR)



# Interferometric phase

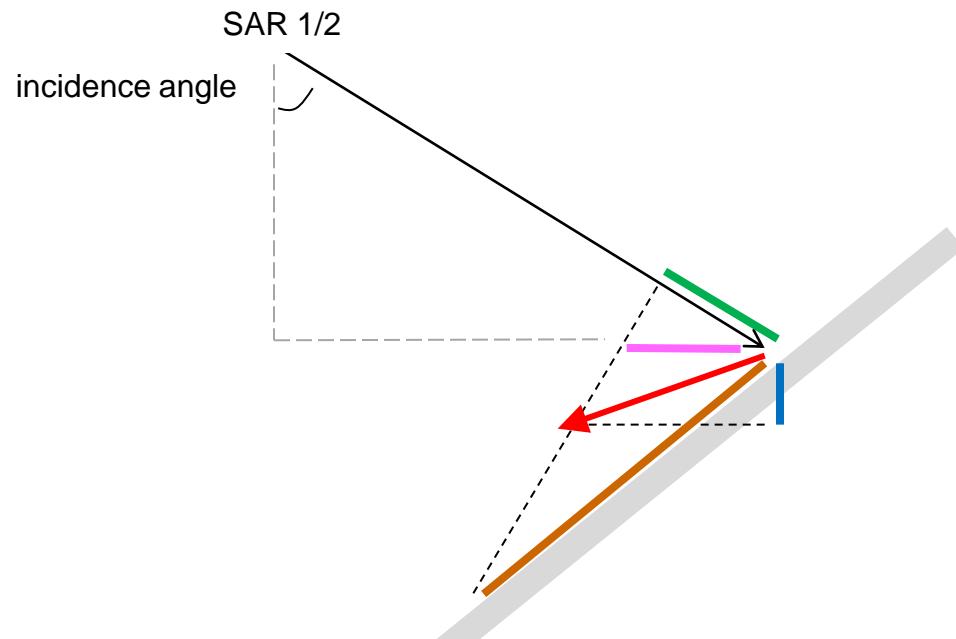


# Line-of-sight displacement



# Line-of-sight displacement

Assumption for vertical displacement angle:



# DInSAR

5-6 Apr 1996  
Bperp = 12m

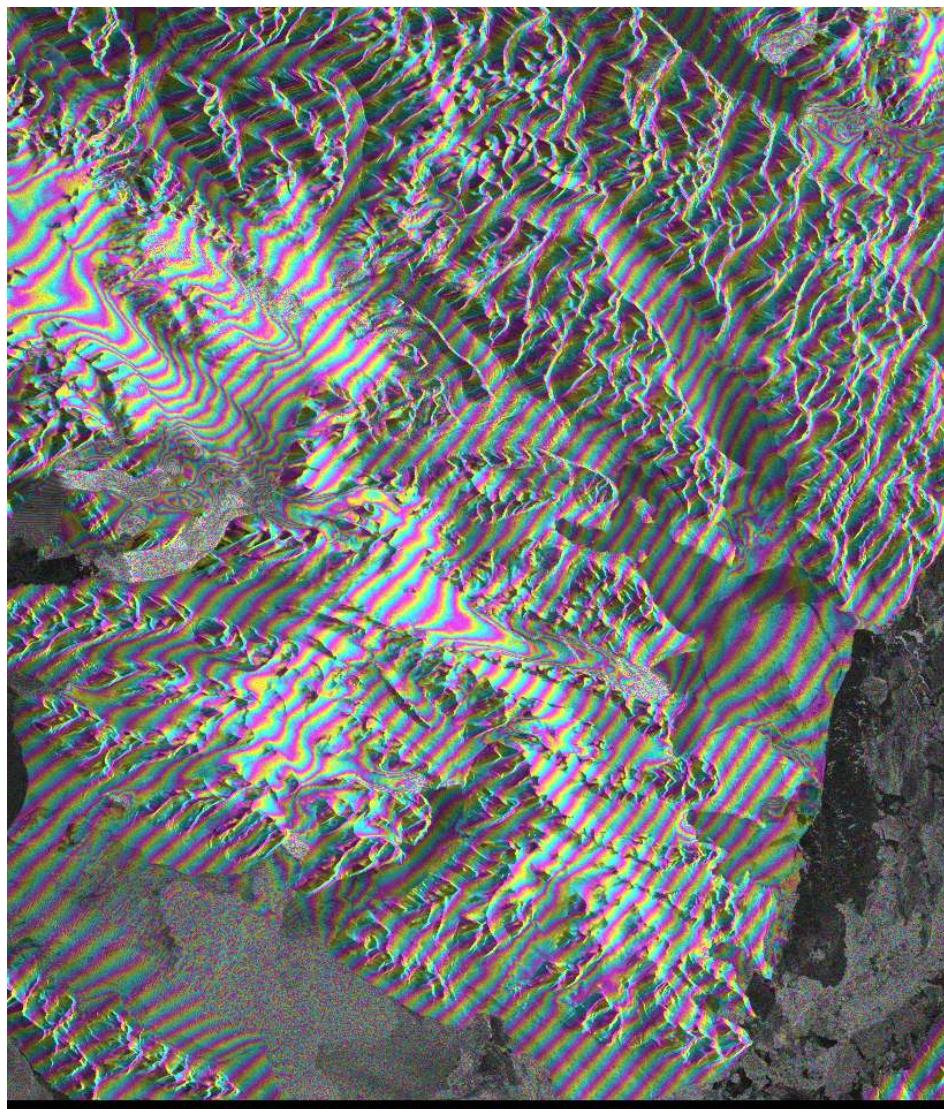


10-11 May 1996  
Bperp = 66m

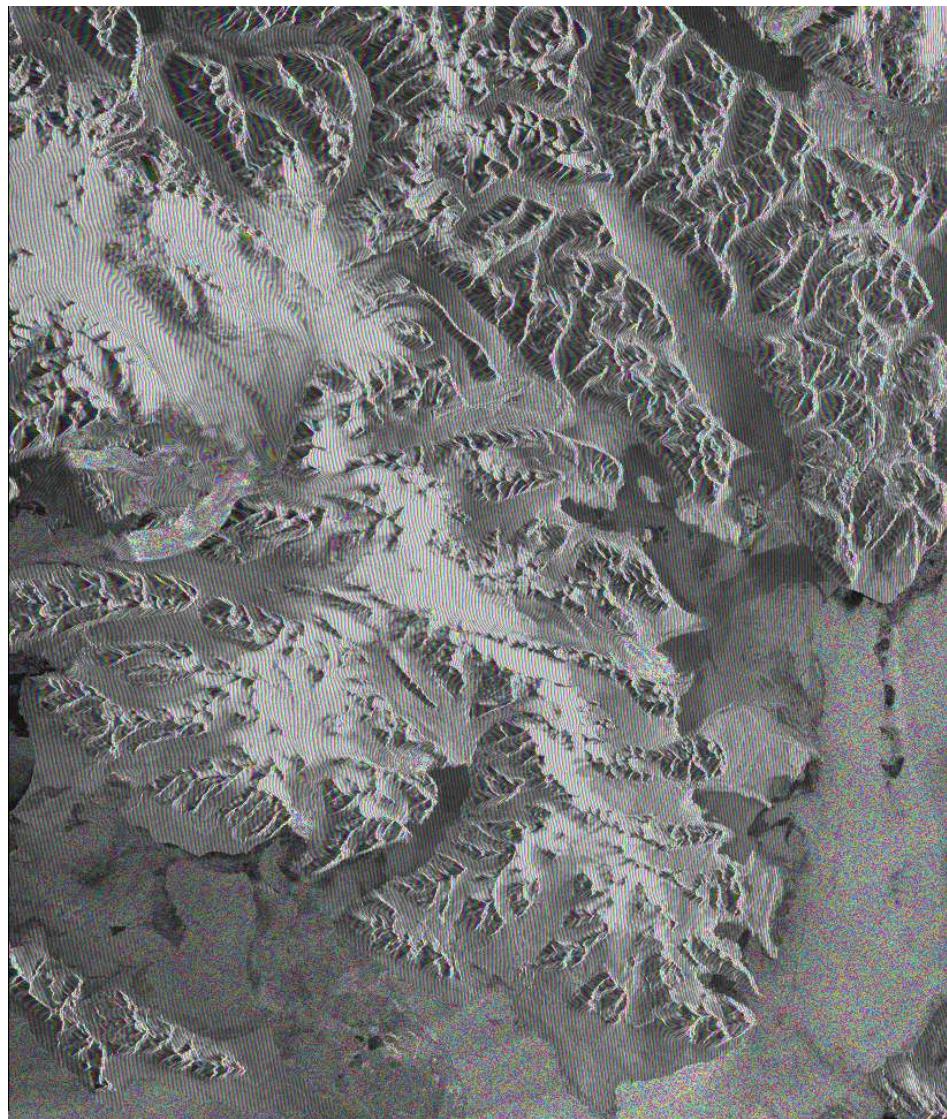


# DInSAR

5-6 Apr 1996  
B<sub>perp</sub> = 12m

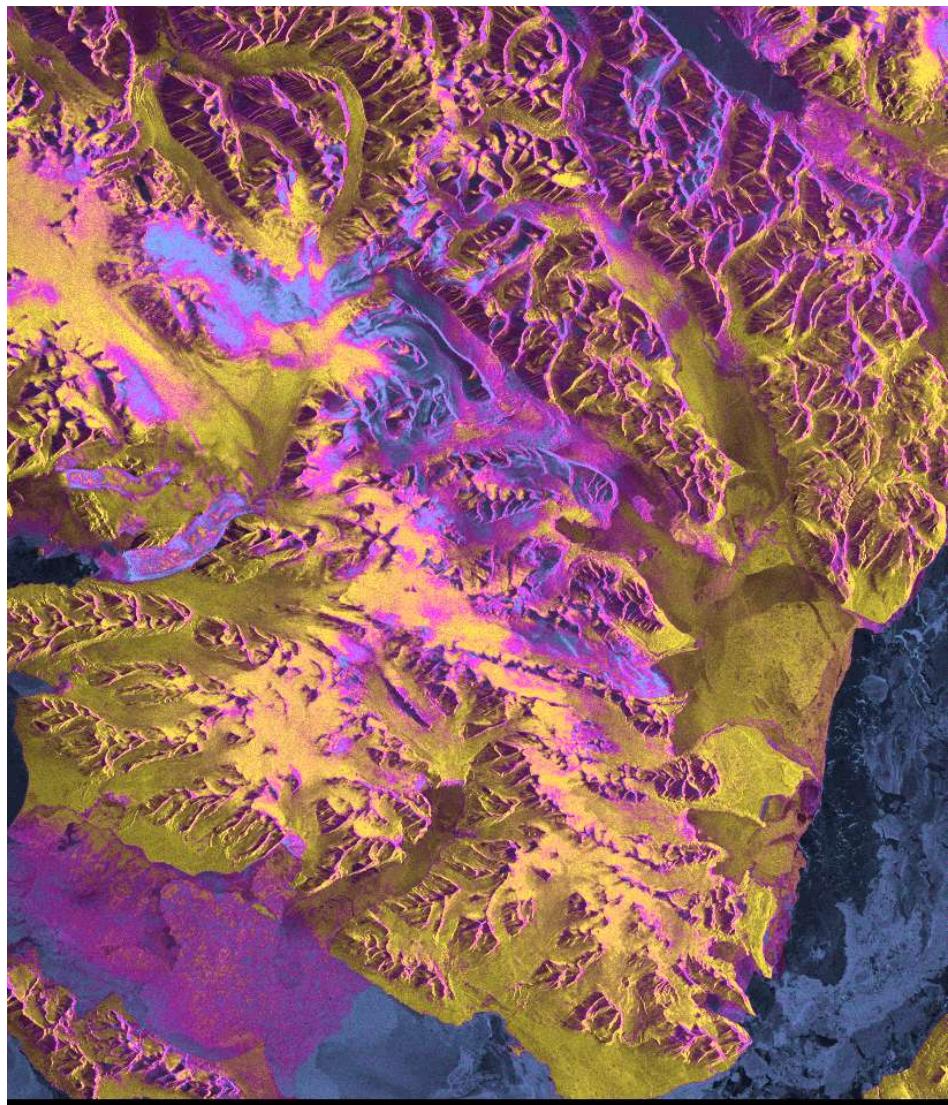


10-11 May 1996  
B<sub>perp</sub> = 66m



# DInSAR

5-6 Apr 1996  
Bperp = 12m

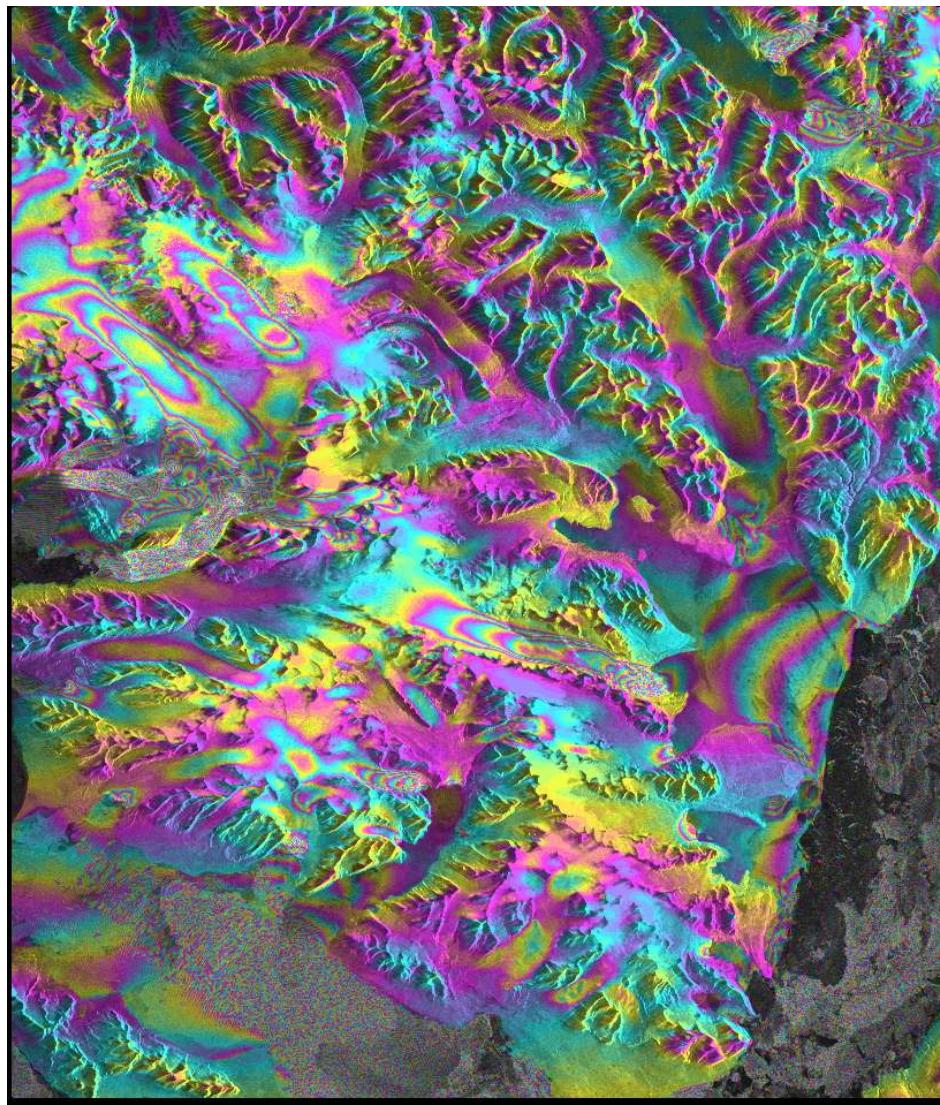


10-11 May 1996  
Bperp = 66m

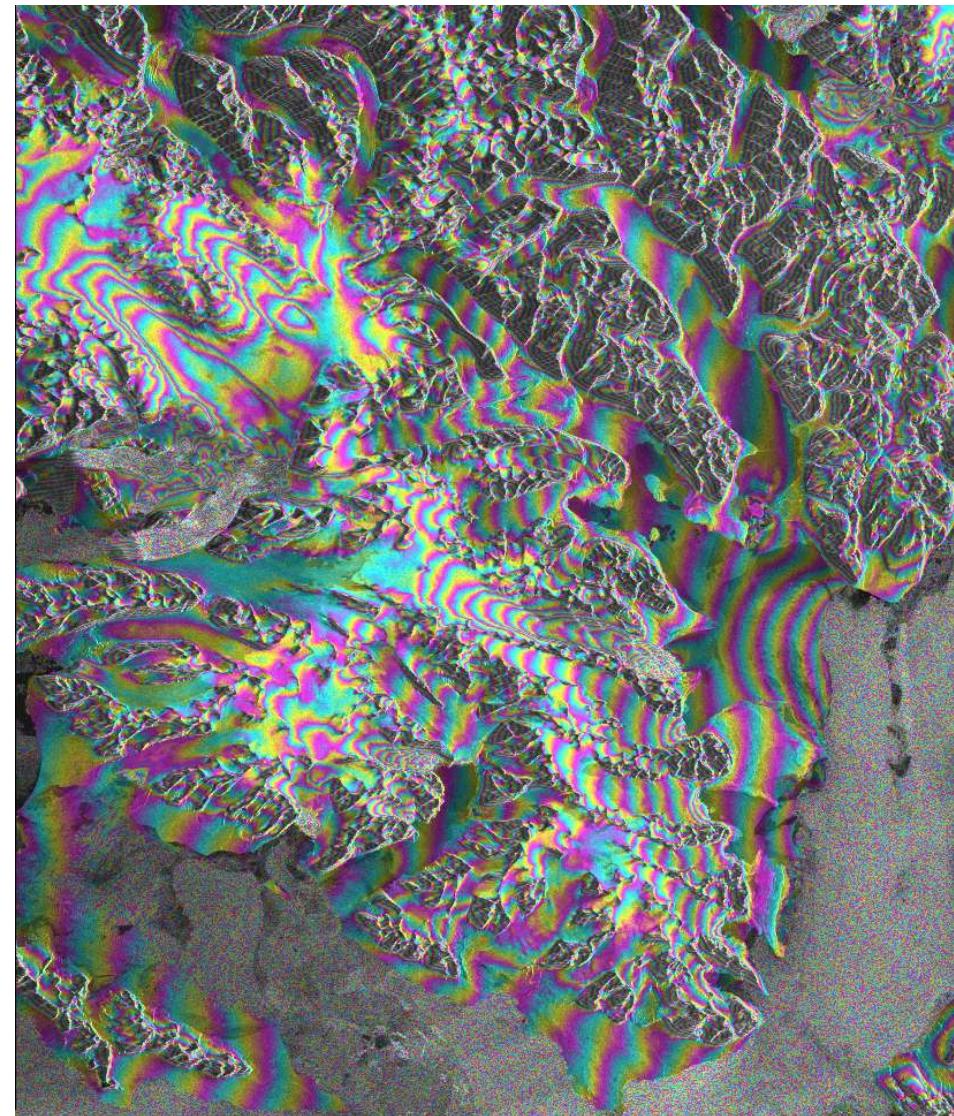


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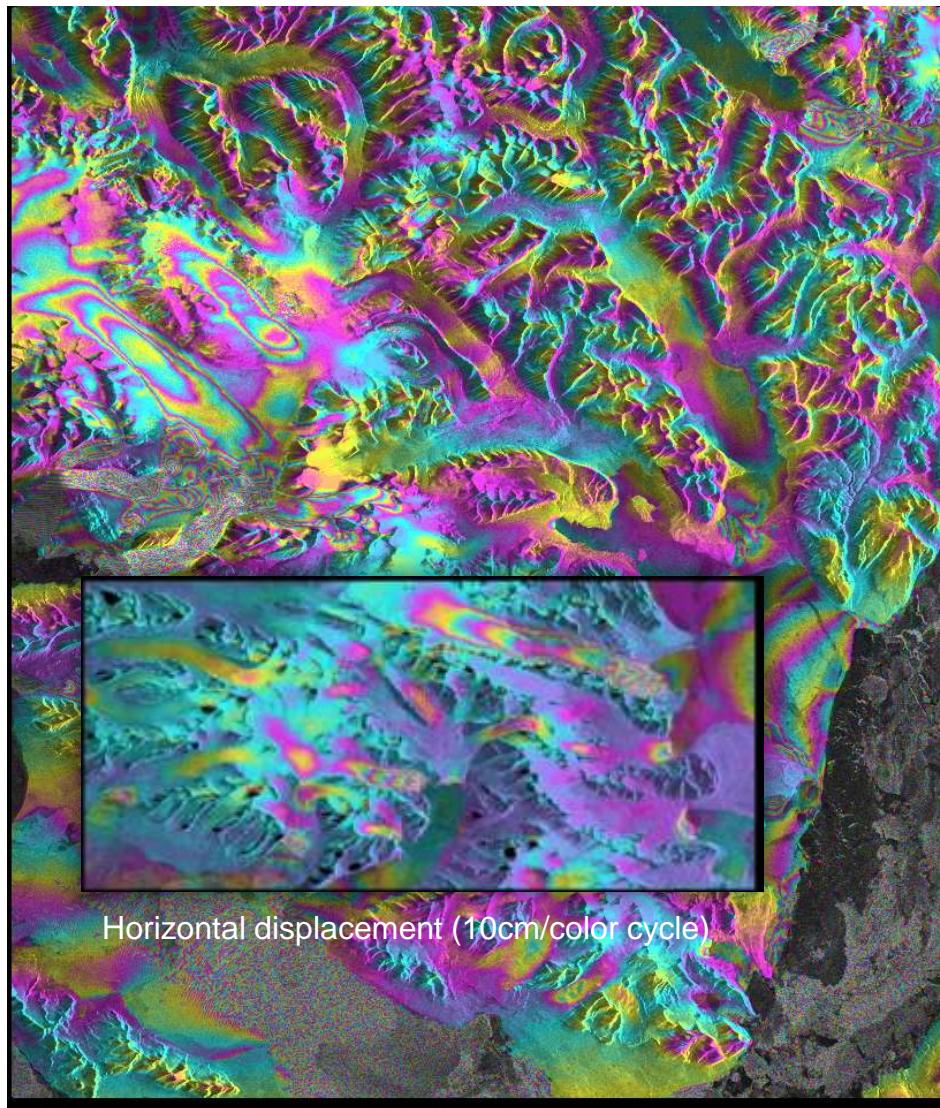


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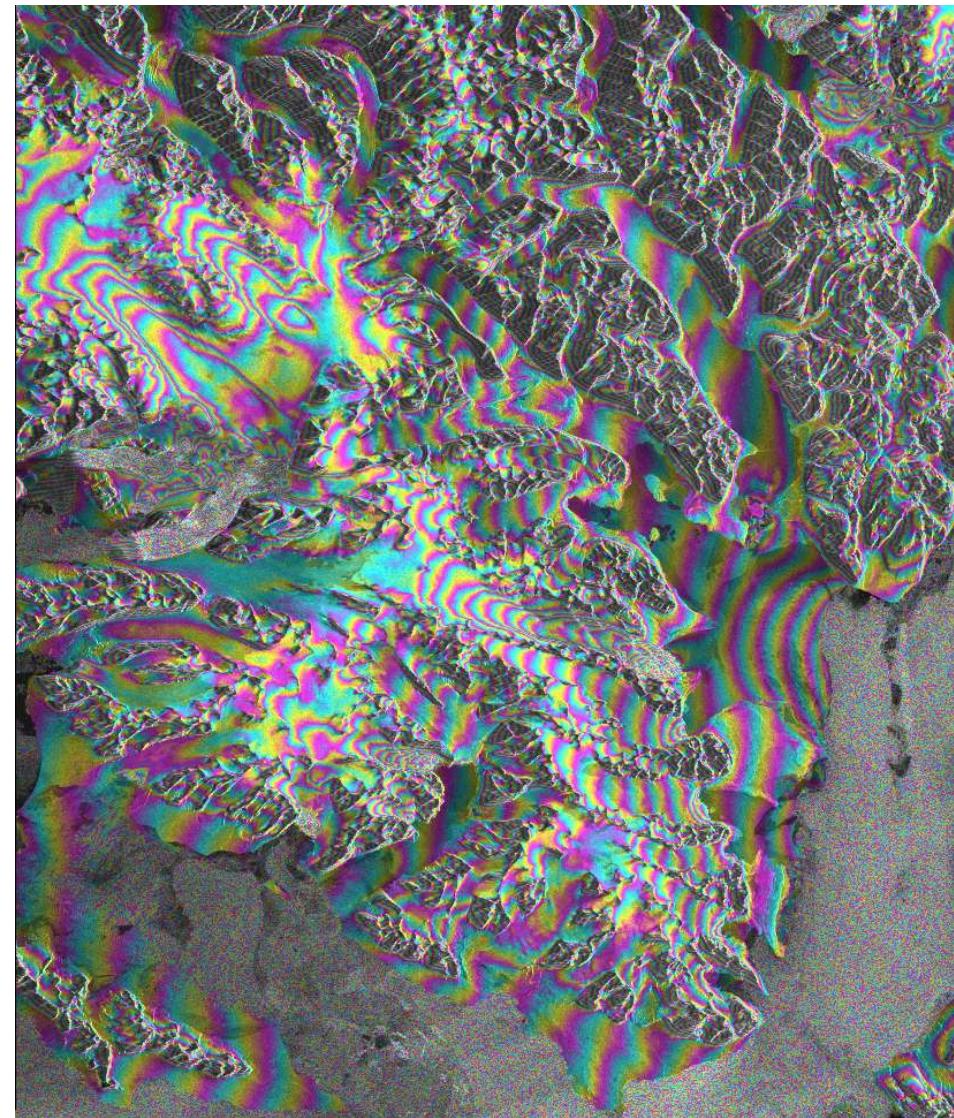


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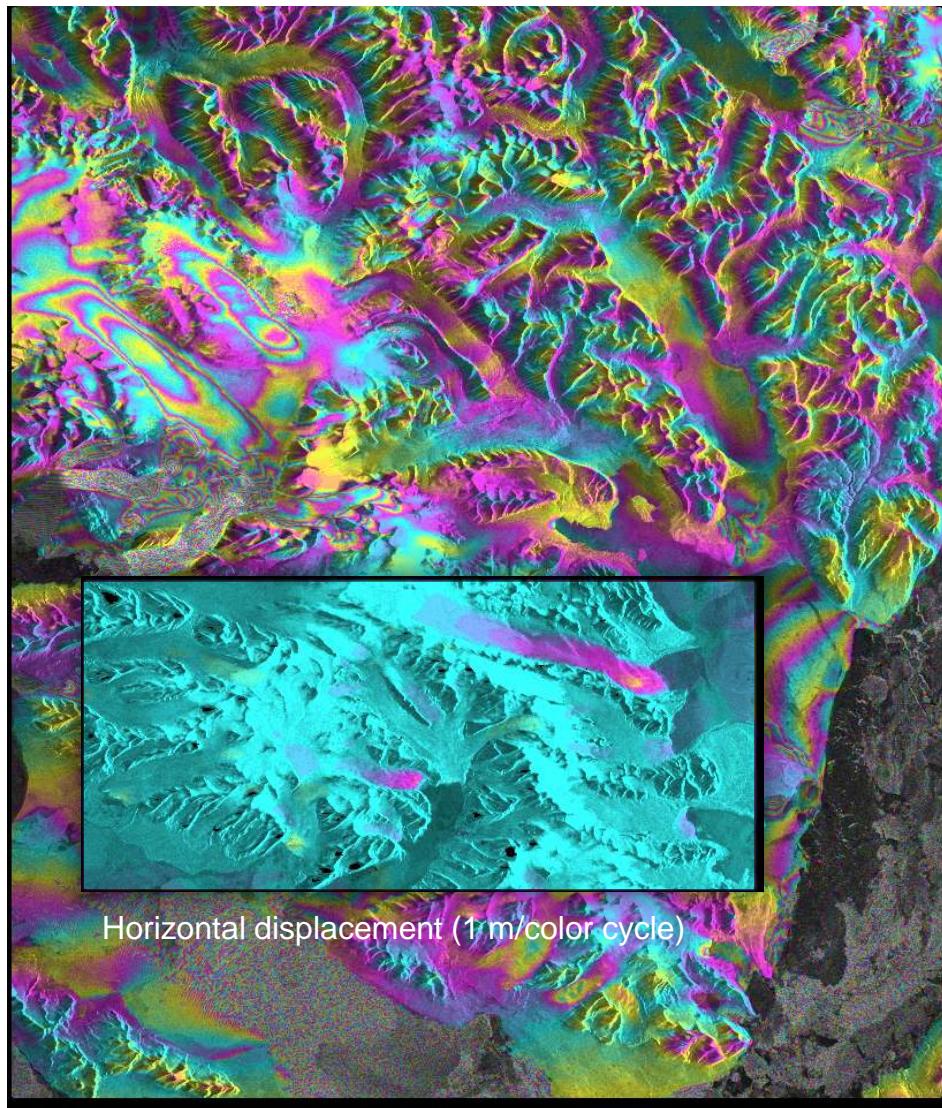


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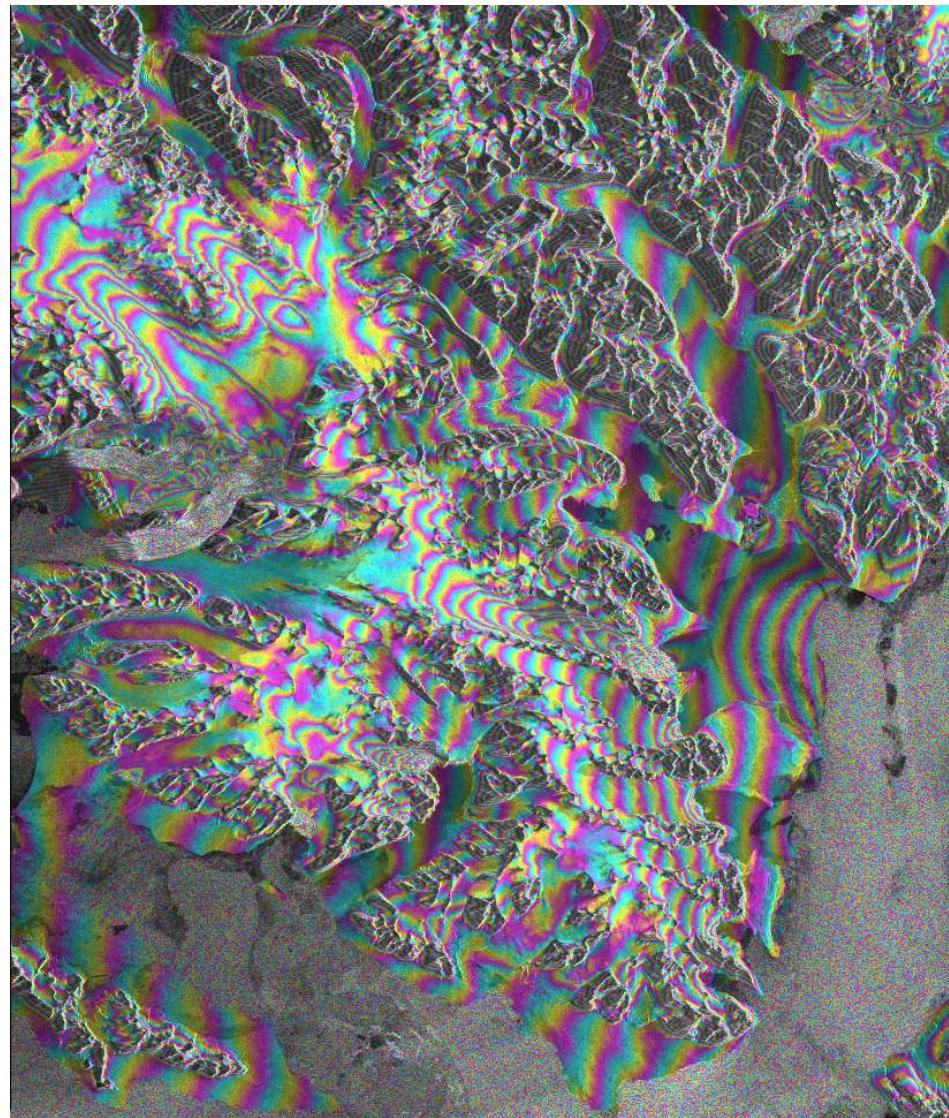


# DInSAR

5-6 Apr 1996  
Bperp = 12m



10-11 May 1996  
Bperp = 66m



C-band SAR mission, 2 satellites:

5 x 5 m @ 80 km swath

5 x 20 m @ 250 km swath

1-3 days @ 250 km swath