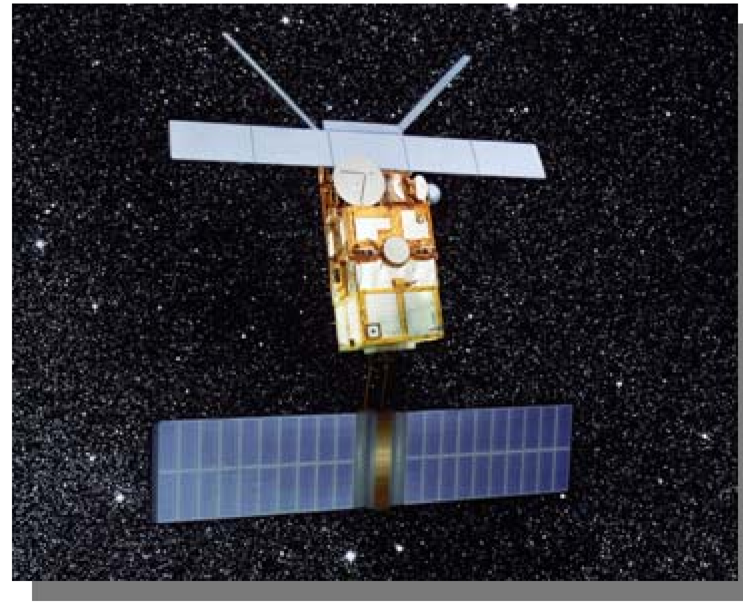
Airborne And Satellite-based Insar Observations Of Icelandic Ice Caps (A Progress Report)



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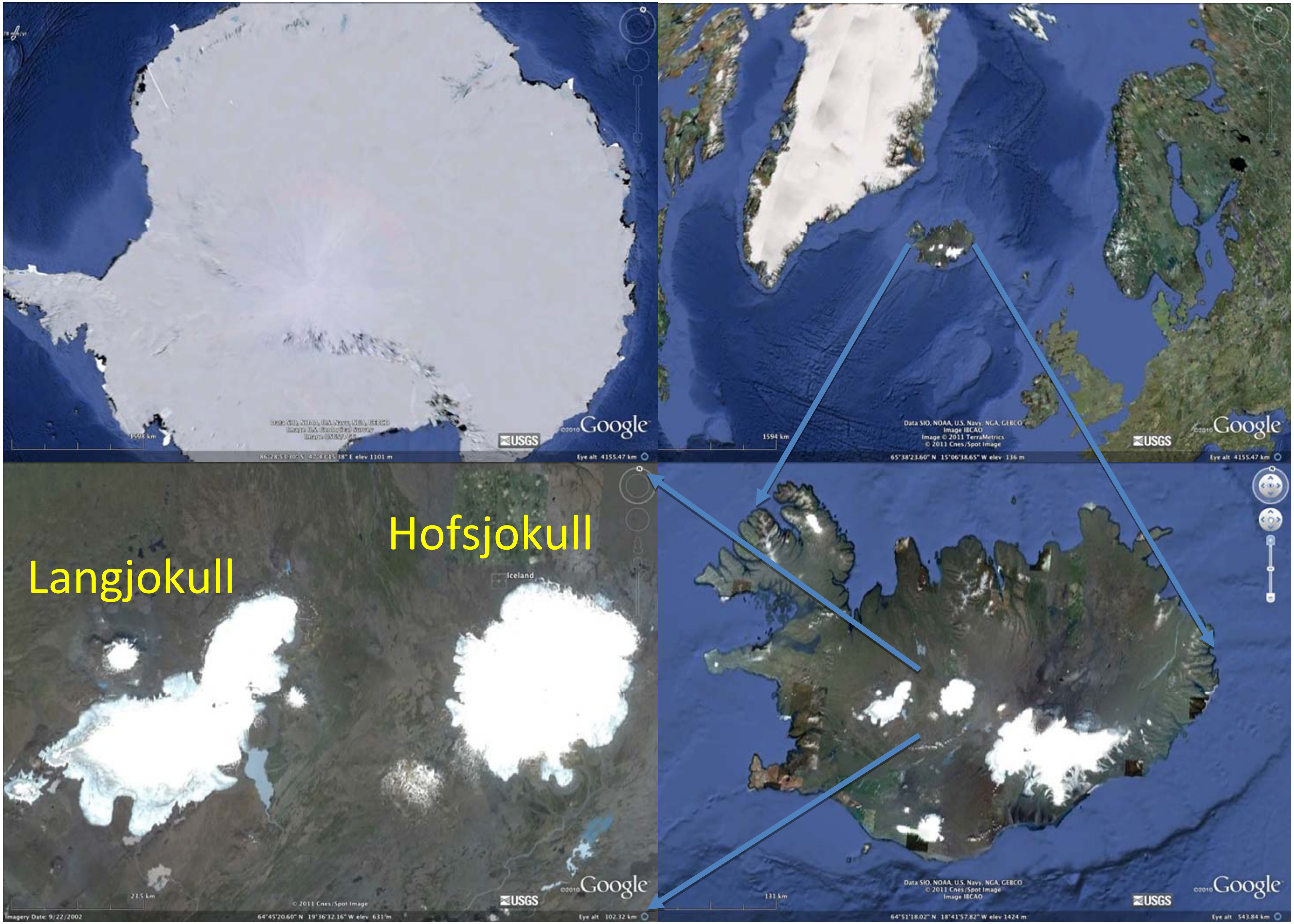

Hofsjokull
Langjokull
Iceland
Google
USGS

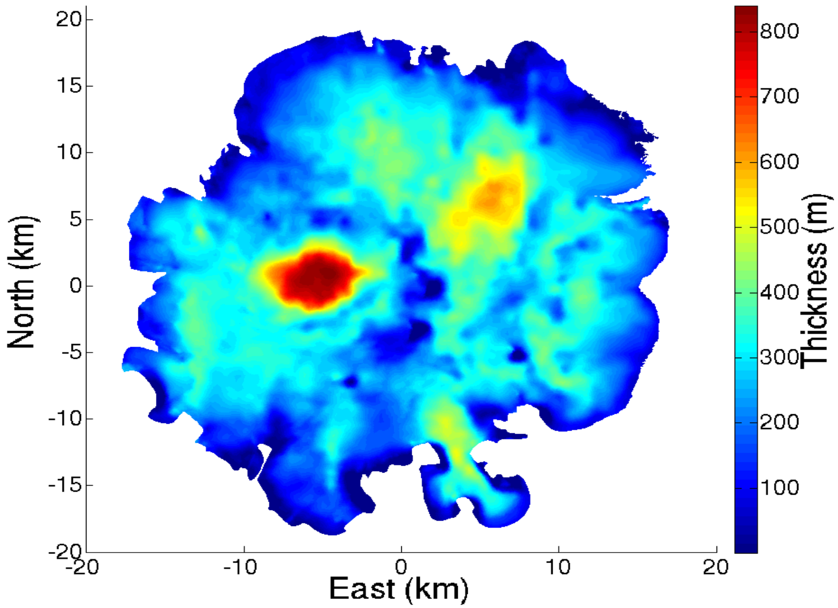
Motivation

1. Icelandic ice caps are an ideal natural laboratory for studying mechanics of glaciers and testing glacier modeling tools
   - Limited size (computational tractability)
   - Long history of study with extensive supporting observations
   - Relatively easy access
2. Ice rheology and basal tractions of an entire temperate ice cap, including seasonal and yearly variations
3. Evaluate interferometric decorrelation mechanisms for temperate ice (estimation of accumulation rates, radar skin depth, and planning future InSAR missions)
4. Develop PolSAR and PolInSAR techniques for glacial monitoring (surface moisture content, accumulation rates, etc.)

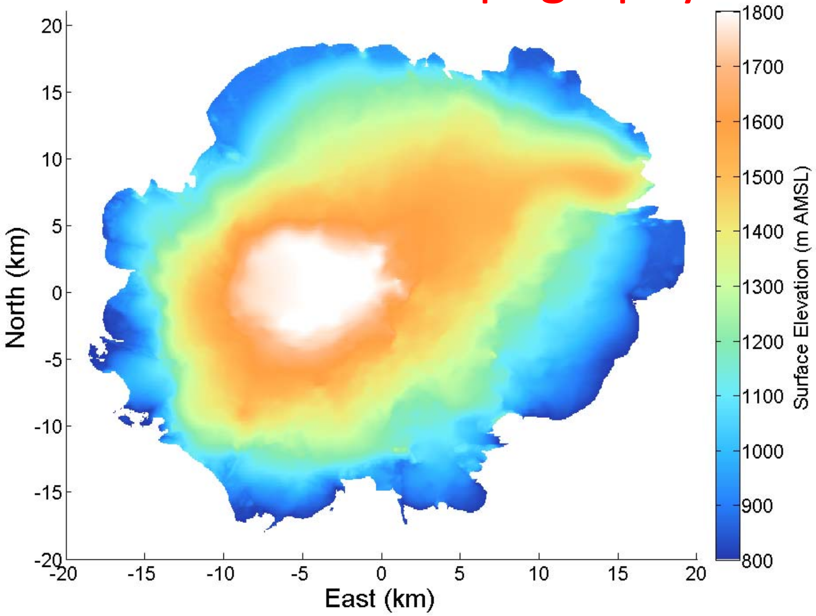
Natural Laboratory Potential

- Ice cap geometry
- Estimates of annual mass balance and ground-based estimates of surface velocities at selected points

Ice thickness



Surface topography



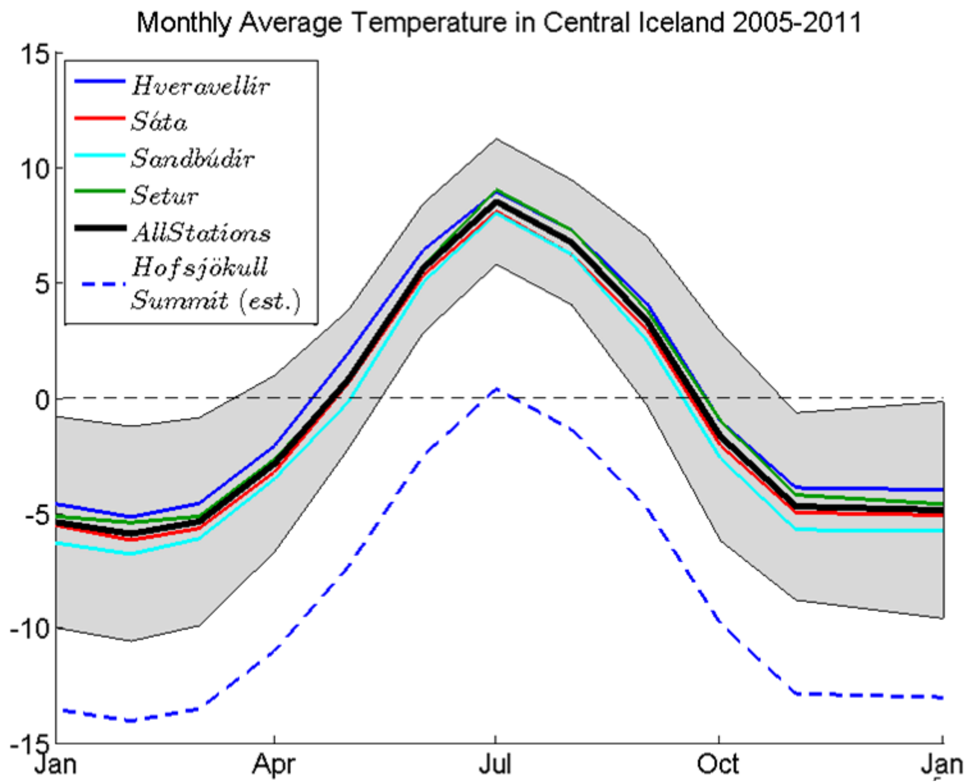
- Accessible temperate glacier
- Extreme weather events are rare
- Gentle surface topography allows imaging from any angle

Glacier surface and basal topography courtesy of Björnsson and Pálsson

Temperate Environment

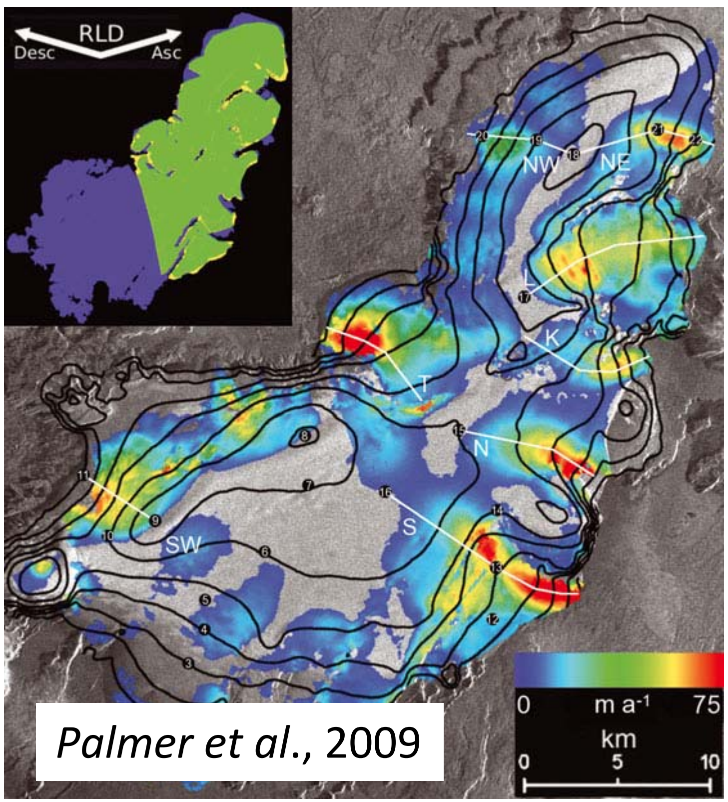
- Temperatures typically vary between +/- 10˚C
- Total annual precipitation < 5 m in most areas
- Average temperature approaches 0˚C over all of Hofsjökull during the summer
- Average temperature in winter remains well below freezing
- Variability of temperature causes ice characteristics to vary substantially between summer and winter and on a daily basis in summer.

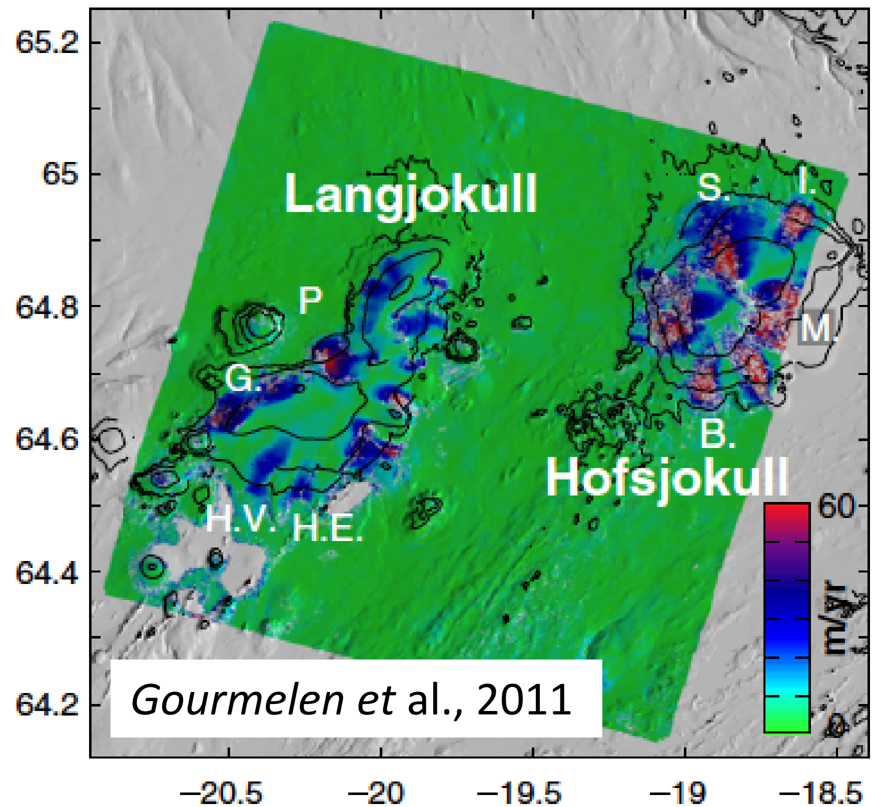
Observed 2005-2011 average and standard deviation as well as estimated Hofsjökull summit temperature. (Data courtesy of IMO)



Previous work: ERS Velocity Field (1994 ΔT = 3 days)

- Use of ASC and DSC InSAR + MAI
- Conversion to E, N, U

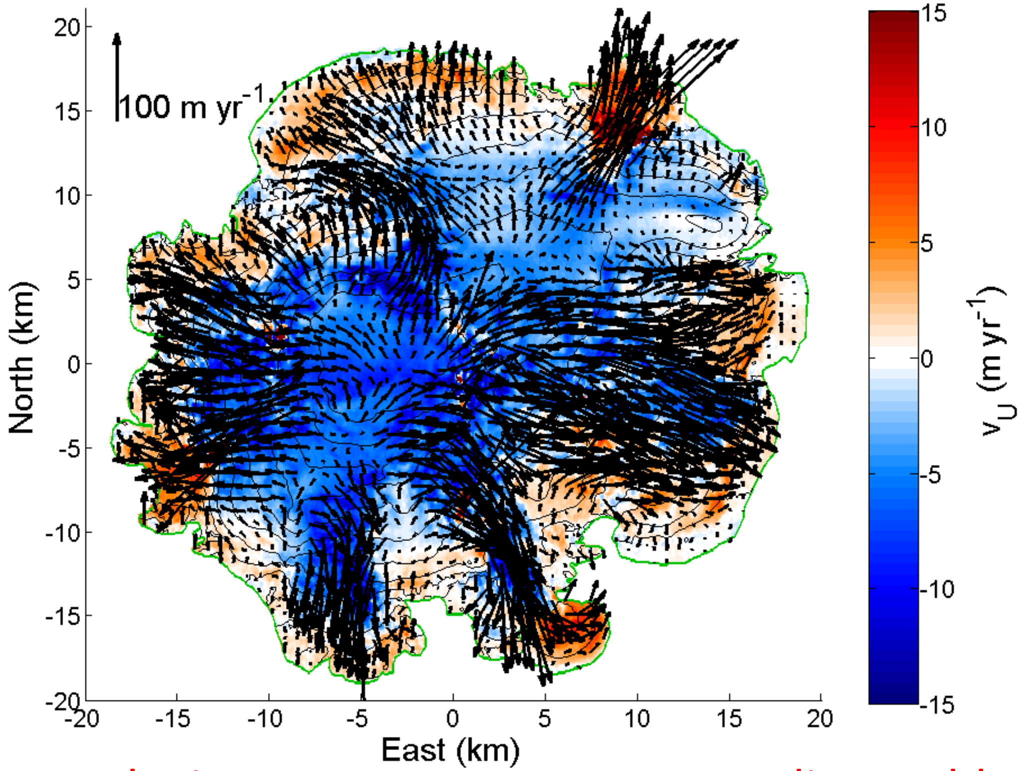




Revisit: ERS Velocity Field (1994 ΔT = 3 days)

A basis for estimating temporal variations

3D decomposition was formed using 2 LOS and 1 along track MAI image (*Gourmelen et al.*, 2011)



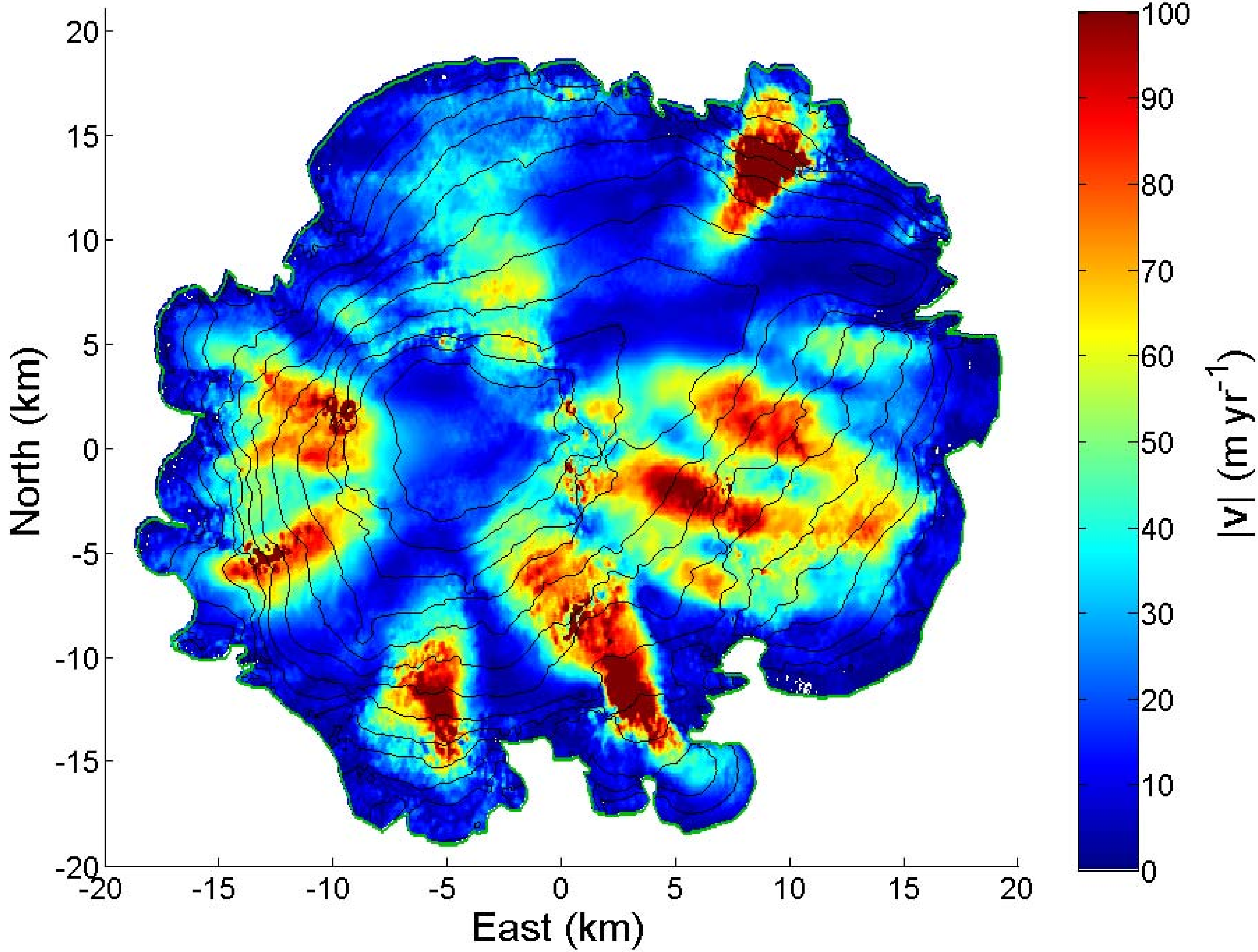
Descending orbit
- Track 38, Frame 2295
- February 22 and 25, 1994
- Bp =138 m

Ascending orbit
- Track 30, Frame 1305
- February 24 and 27, 1994
- Bp = 306m

Velocity components on surrounding stable rock

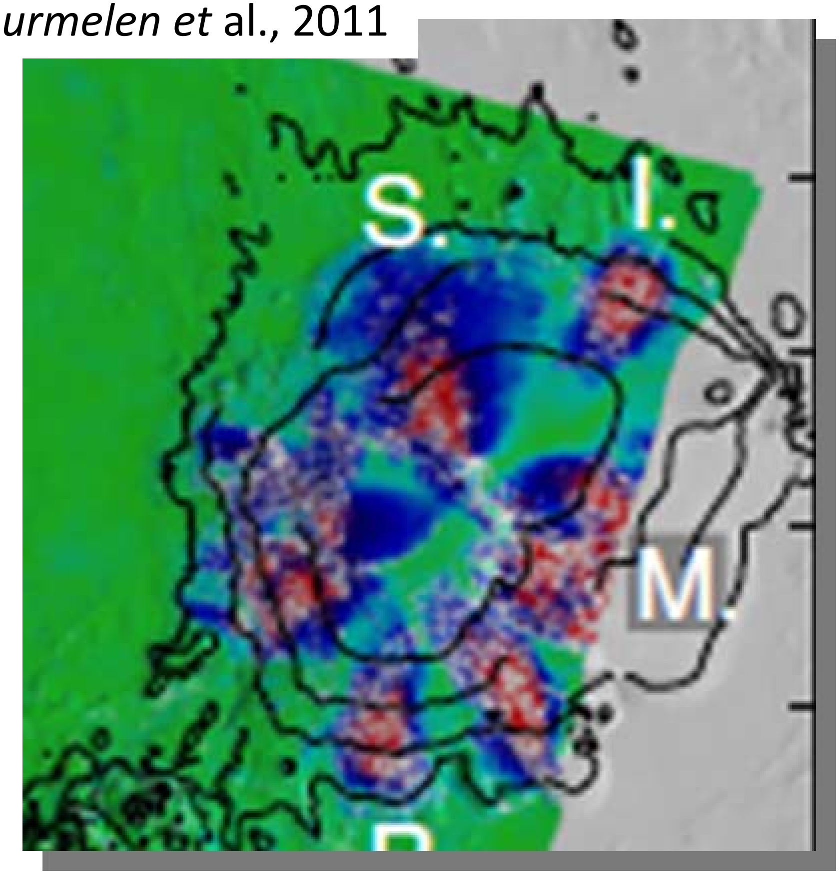
- std_{east} = 0.9 (m/yr)
- std_{north} = 10.4 (m/yr) ➔ driven by MAI noise
- std_{up} = 1.4 (m/yr)

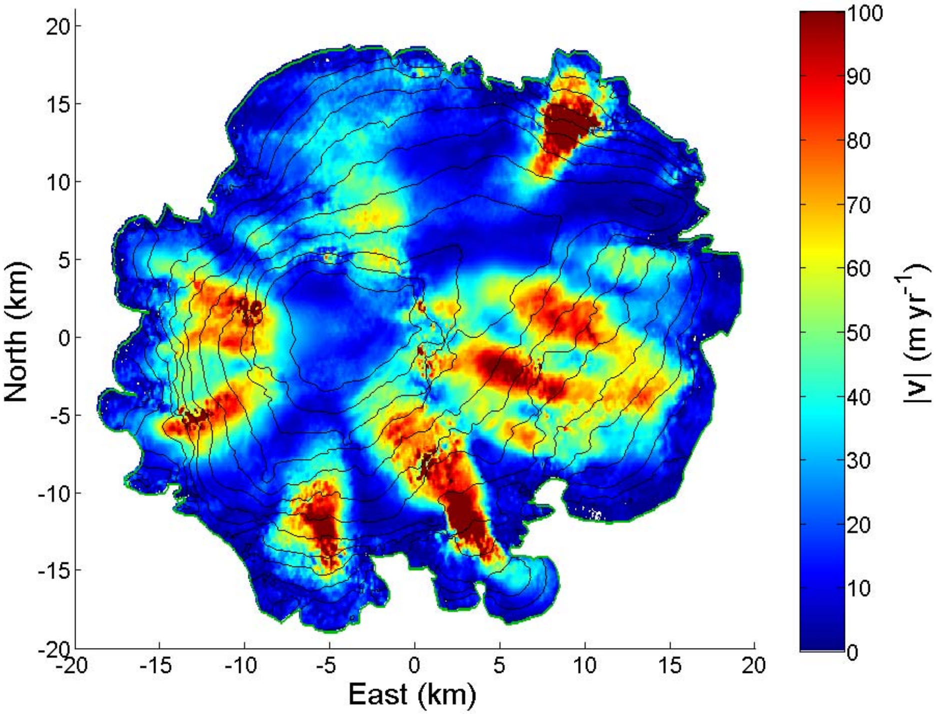
Velocity Magnitude (1994 ΔT = 3 days)



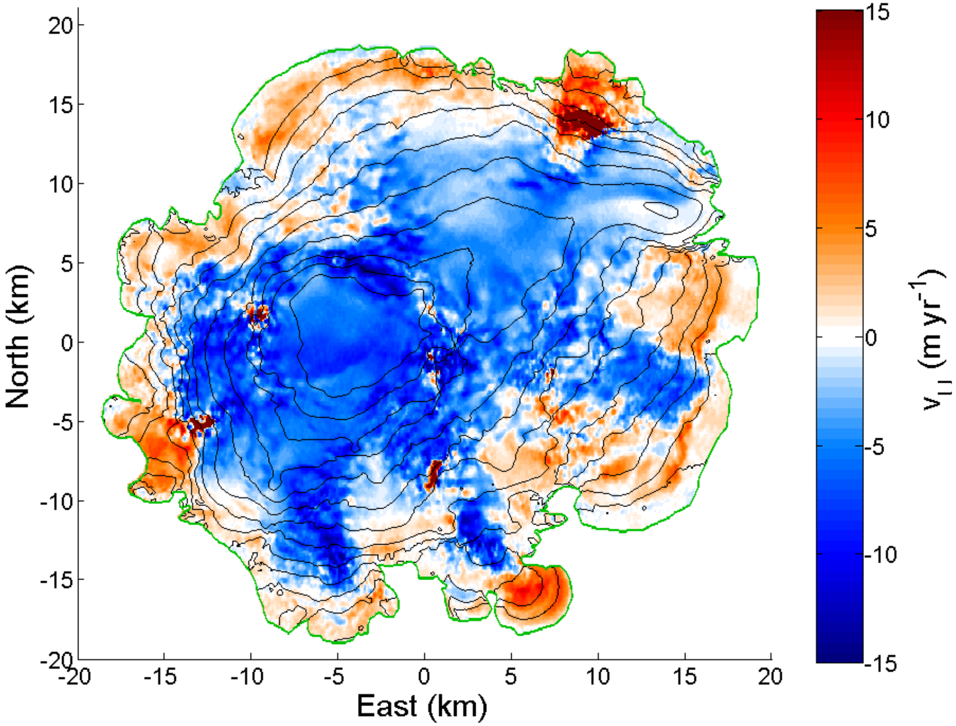
Velocity Magnitude (1994 ΔT = 3 days)

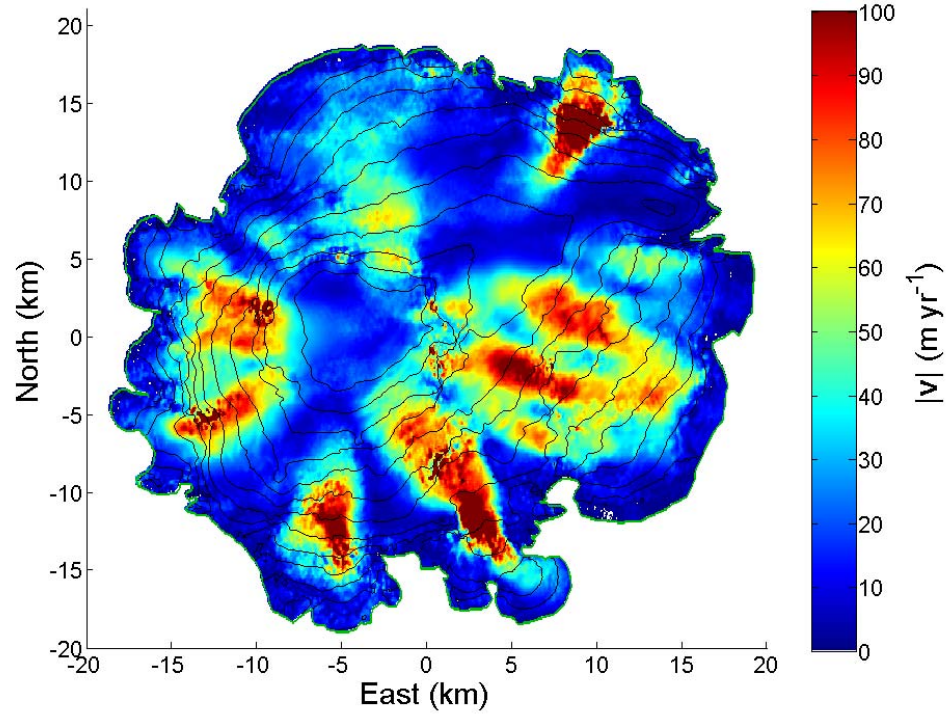
Gourmelen et al., 2011





Vertical Component (1994 ΔT = 3 days)

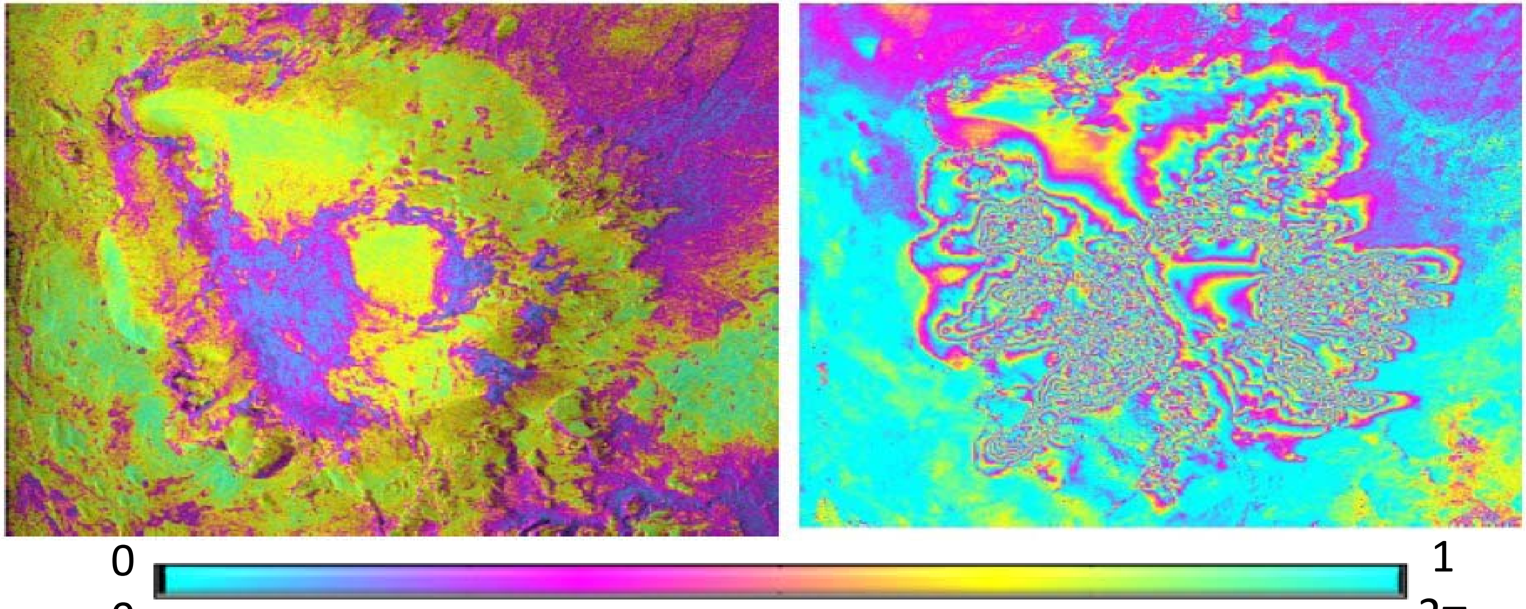




Consistent equilibrium line

ERS Summary

- February 24/27 1994 + ERS tandem ERS
- 2011 ERS-2 Phase (Jan-June)
  - Of 35 interferometric pairs in ascending and descending geometries only 2 interferograms are viable, remaining are heavily decorrelated
  - 6% success rate for ~75% coverage



Descending ERS pair collected March 25/28, 2011

UAVSAR: Mission Objectives

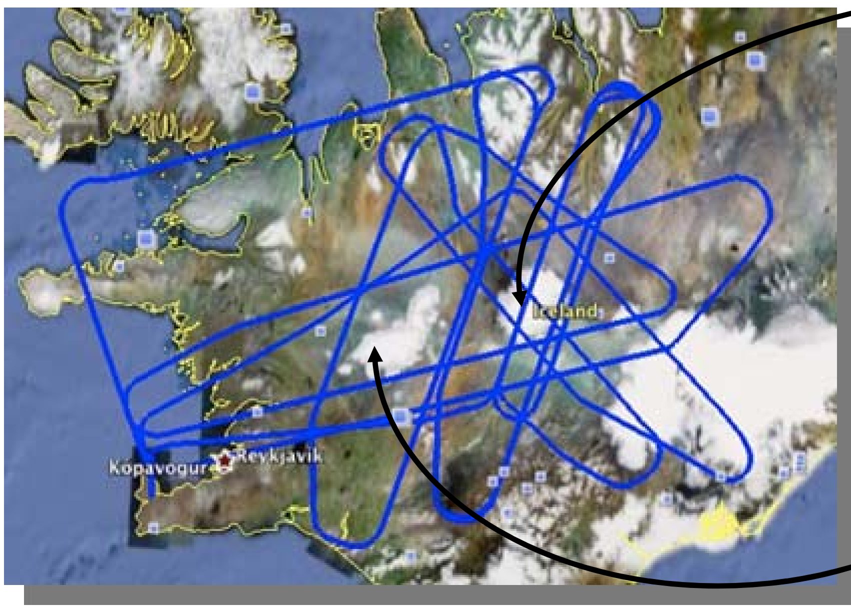
- Investigate yearly and seasonal characteristics of temperate Icelandic glaciers
  - Use L-band InSAR to generate 3D velocity fields of two major Icelandic ice caps, Hofsjökull and Langjökull
  - Compare UAVSAR-derived velocity fields with GPS measurements and with satellite-based InSAR measurements
  - Study deformation (flow) characteristics coupling velocity fields with mechanical ice sheet models (using the JPL ISSM suite)
- Constrain requirements on temporal baselines for acceptable L-band decorrelation over temperate ice
  - Analyze the mechanisms of decorrelation using small-temporal-baseline UAVSAR data and PolSAR techniques
  - Estimate the temporal decorrelation rate at L-band

Table 1: UAVSAR radar operational parameters

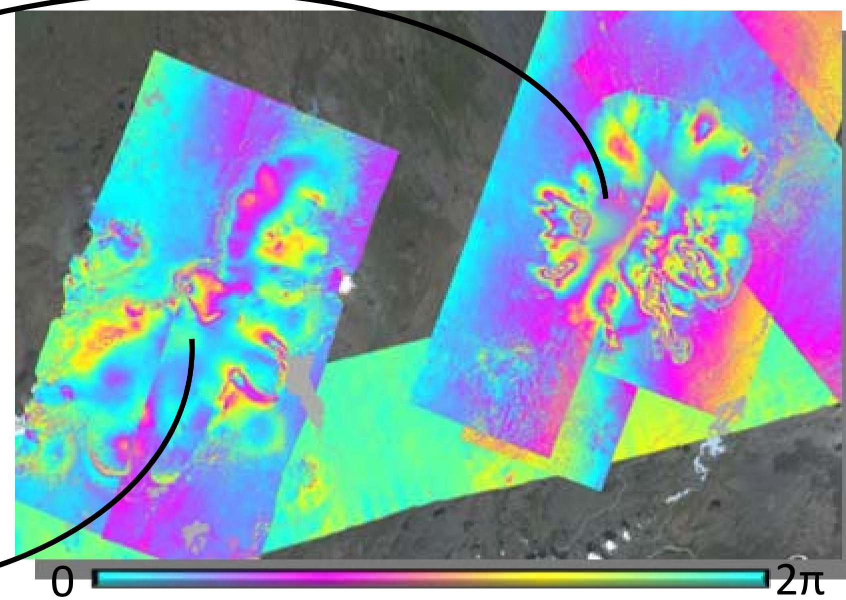
Frequency	1.2575 GHz
Wavelength	0.2379 m
Bandwidth	80 MHz
Pulse Duration	40 μs
Polarization	Quad Polarization
Operating Altitude	12.5 km
Ground Speed	220 m/s
Range Swath	22 km
Look Angle	$22° - 65°$
Slant Range Resolution	1.7 m
Azimuth Resolution	1.0 m
Transmit Power	3.1 kW
Cross Pol Isolation	-25 dB

June 2009 UAVSAR mission

- 5 consecutive data collection days (June 10-14,2009)
- ~6 flight hours per day (exhausted flight crew)
- 11 unique flight tracks in total which provide 3D coverage of Hofsjökull and 2D coverage of Langjökull
  - All tracks were repeated daily (June 10-13)
  - 3 tracks were flown twice each day ~4 hours apart
  - Additional data was collected on departure from Iceland



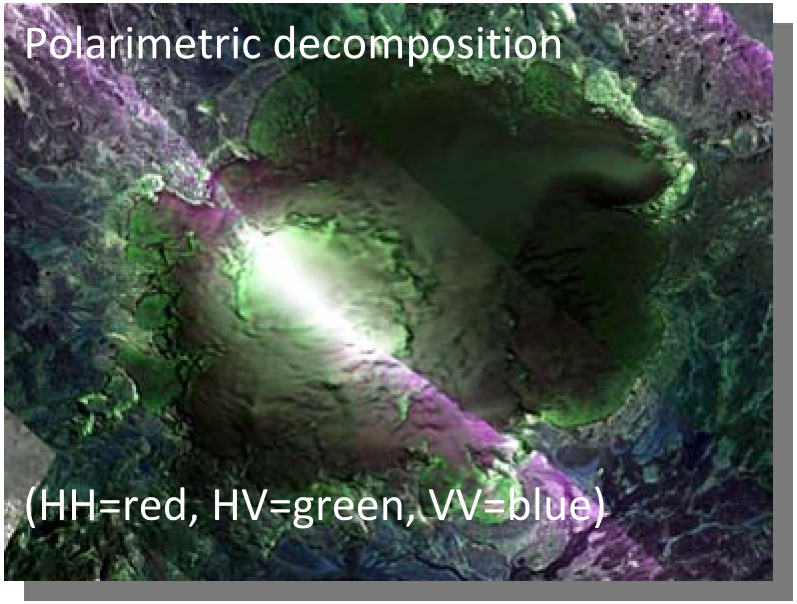
Daily flight path for June 2009 mission

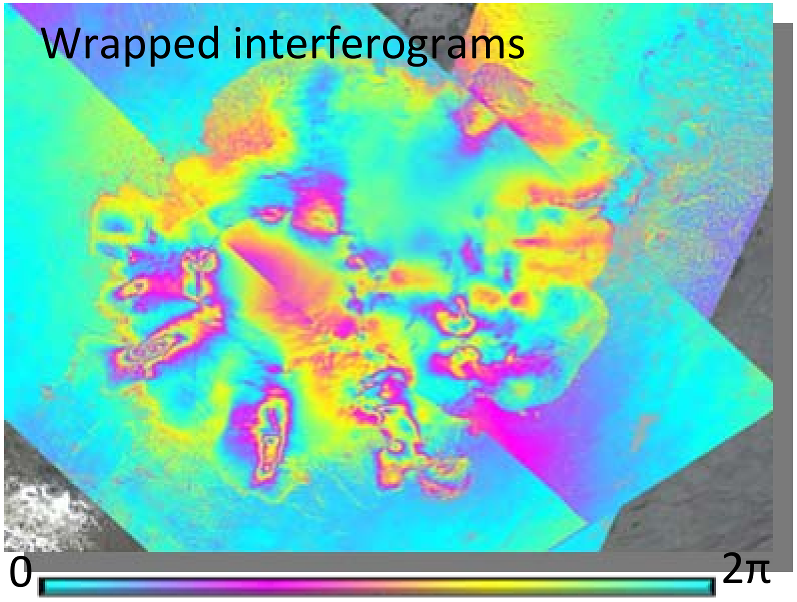


Example wrapped interferograms showing data coverage

June 2009 UAVSAR mission

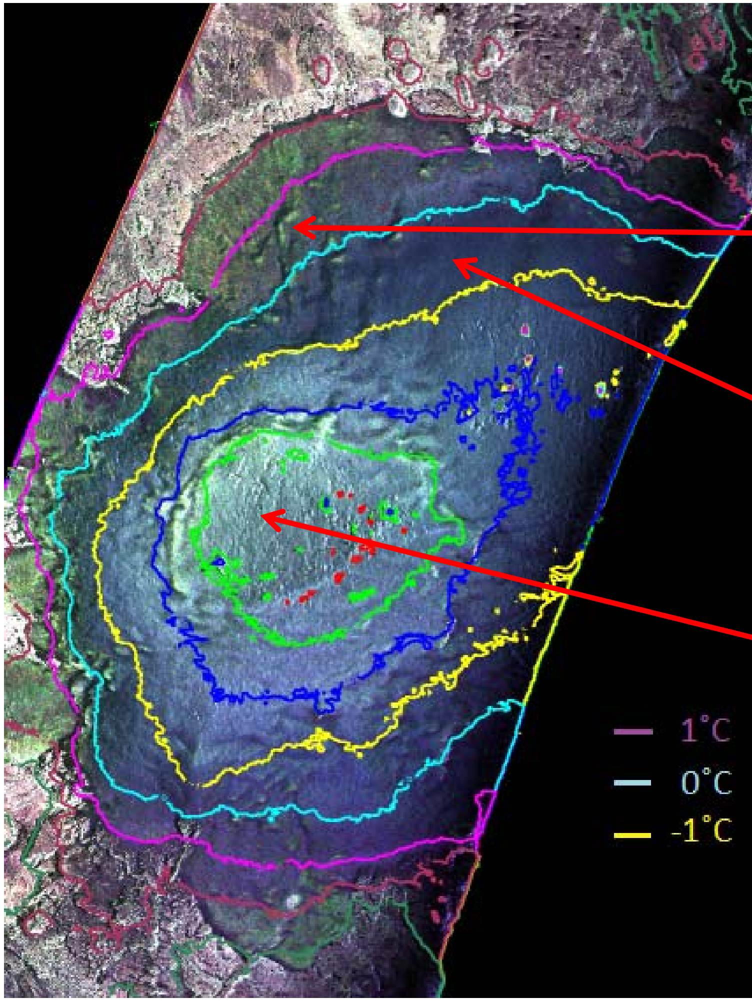
- All data was collected in quad-pol mode (HH, HV, VH, VV polarizations)
- Every line was flown in repeat-pass mode (B_{perp} < 10 m) at least 4 times
- ~100 possible InSAR pairs at each polarization
- > 125 pairs have been processed





Mosaic images of Hofsjökull acquired by UAVSAR June 2009

PolSAR Results

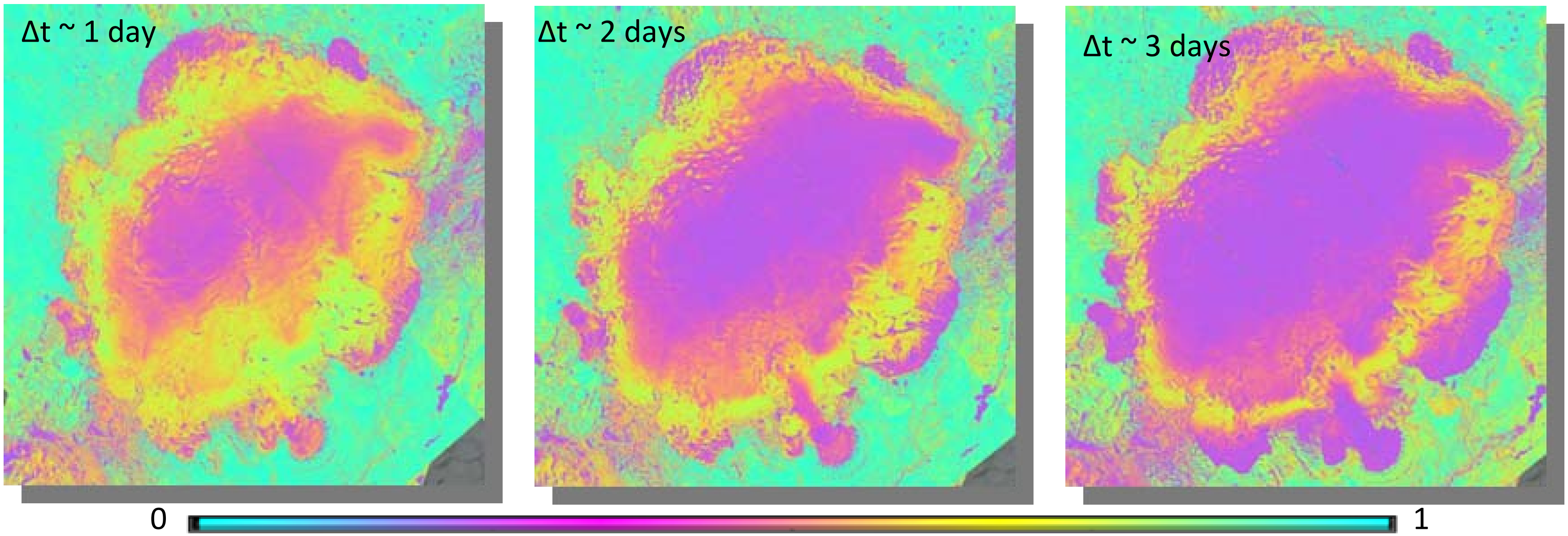


|HH-VV| |HV| |HH+VV|

- Polarimetric products were used to identify glacial zones and infer scattering properties of glaciers:
  - Ablation zone shows strong depolarizing properties – scattering from a rough, wet surface
  - Equilibrium line shows reduced backscatter on gentle slopes – scattering from relatively smooth, wet surface
  - High elevations show higher backscatter and even distribution of scattering properties – volumetric scatter (deeper radar penetration)

Colored contours indicate estimated air temperature

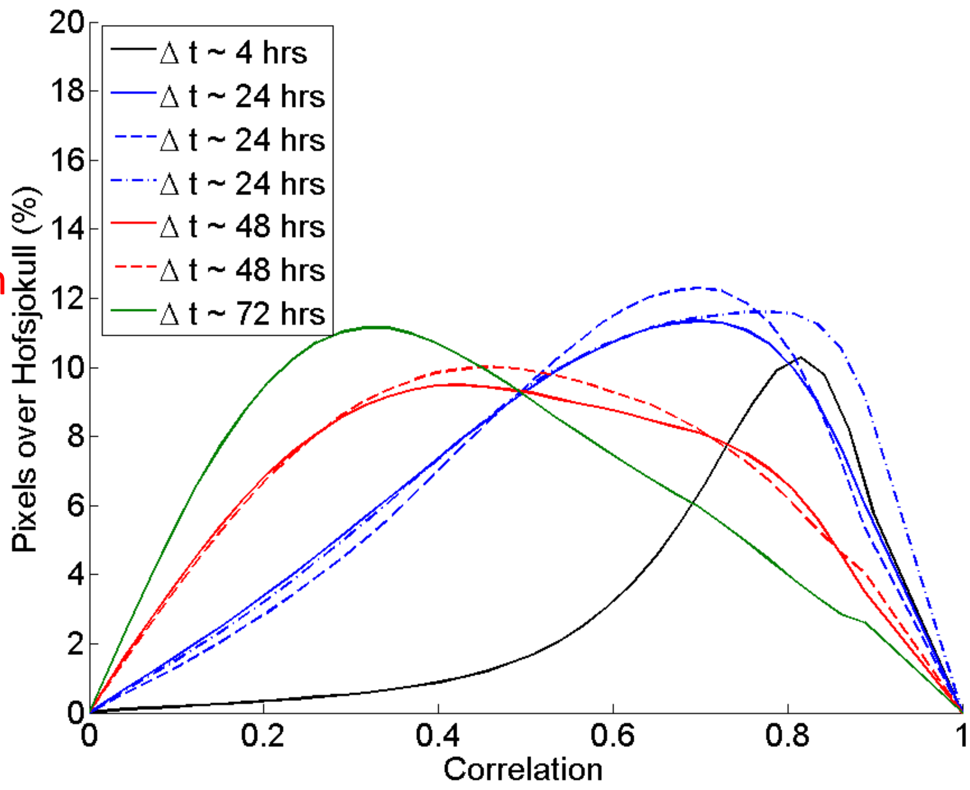
Temporal Decorrelation Studies

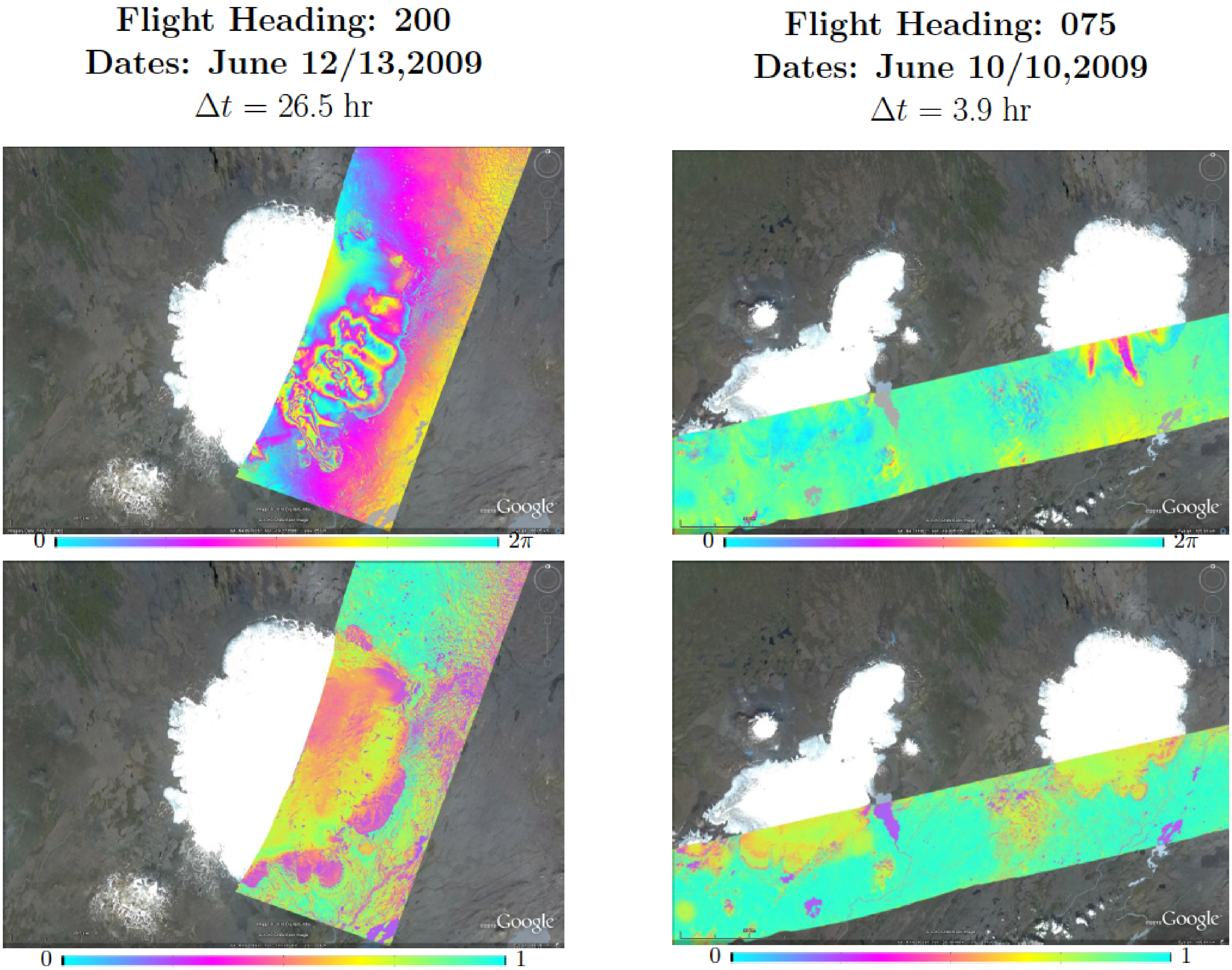


- Mosaics of multiple tracks at different LOS
- Decorrelation caused by:
  - changes in near-surface temperature and near-surface moisture content
  - accumulation or ablation
  - fast moving ice

Temporal Decorrelation Studies

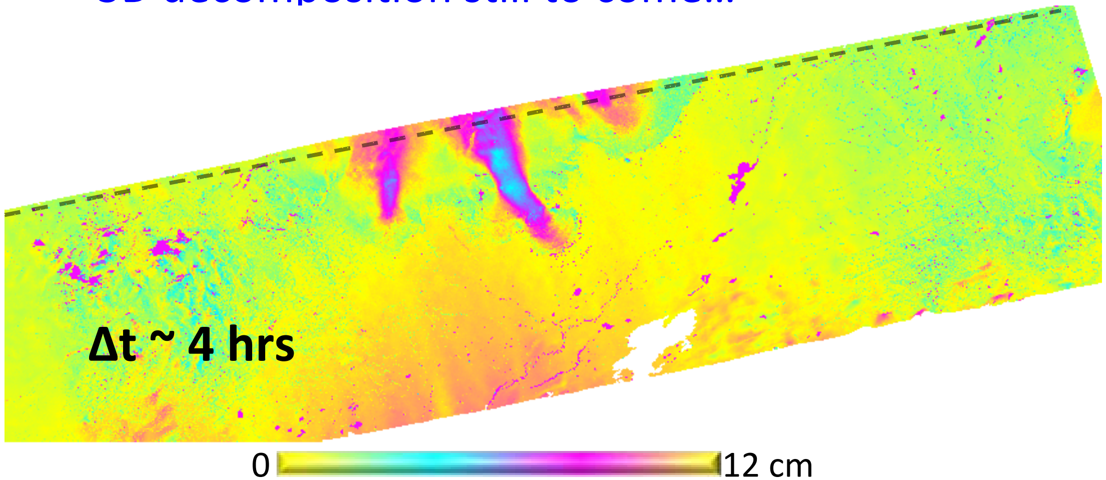
- Decorrelation
  - increases from Δt = 1 to 2 days
  - relatively stable for Δt = 2 or 3 day
- Higher elevations decorrelate quickest due primarily to volumetric scattering
- Ablation zone shows relatively high decorrelation rate due to scattering from wet, rough surface
- Mid-elevation areas show relatively stable correlation over Δt ≥ 3 day
- Decorrelation at Δt ≥3 days consistent with paucity of usable satellite data
- Need to evaluate relationship between local weather and decorrelation (precipitation & temperature)

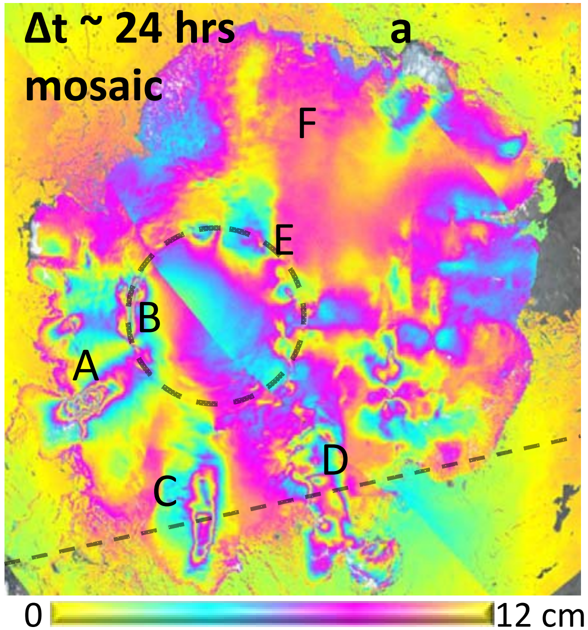



Flight Heading: 200
Dates: June 12/13,2009
$\Delta t = 26.5$ hr
Flight Heading: 075
Dates: June 10/10,2009
$\Delta t = 3.9$ hr
Google
0
2π
Google
0
2π
Google
0
1
Google
0
1

InSAR Results

- 24 hour repeat pairs resolve Hofsjökull well (lower right)
- Examples of rapid flow are visible at A, B, C, and D (right image)
- Ice can be seen pouring over the caldera lip (shown with dotted circle) at B and E
- 2 day and 3 day Δt show similar features
- 4 hr repeat pair (lower left) resolves fast-moving ice and has excellent correlation everywhere
- 3D decomposition still to come…

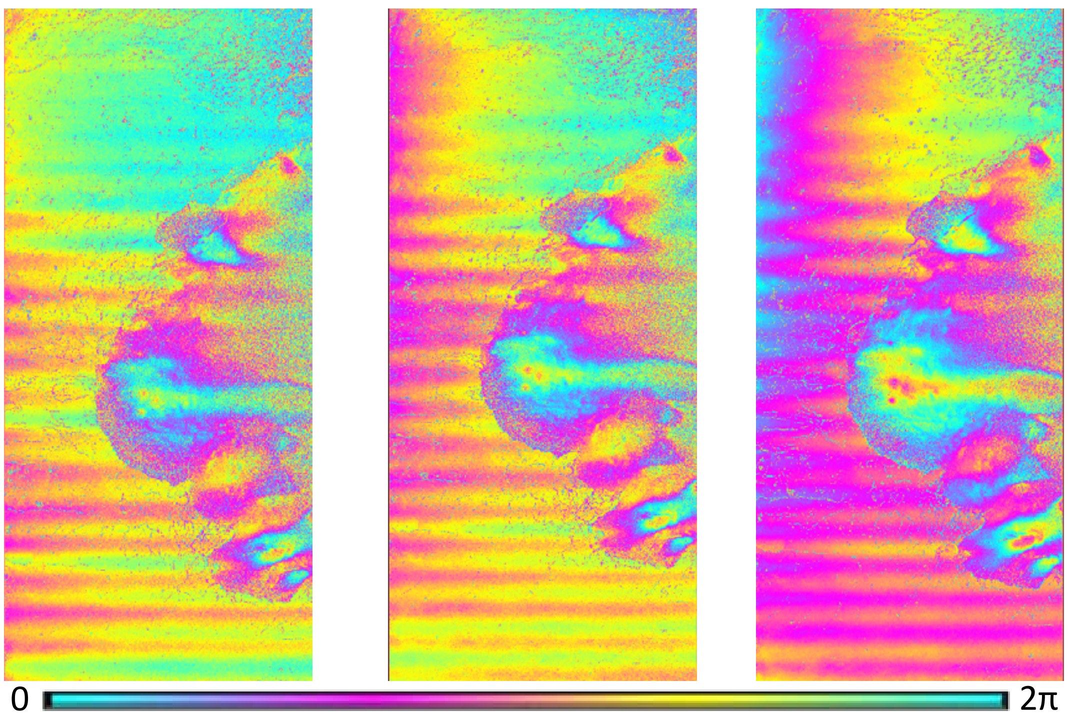




Unwrapped interferograms of Hofsjökull generated from 4 hour (left) and 24 hour (right) UAVSAR repeat pairs. Dashed circle (right) indicates the approximate location of the caldera rim, and the dashed line in each image shows a common transect.

Processing Challenges

- Several of the East/West trending tracks were inadvertently but consistently acquired with a 5˚ forward squint in each acquisition
- Currently: azimuth-varying banding even after motion compensation



No motion compensation | One iteration of motion comp. | Two iterations of motion comp.

- Left: Wrapped interferograms with persistent error in the E/W flight tracks
- Characteristics of residual motion
- Applied a low-pass filter to the GPS data associated with each of the affected flights, but errors remain
- Error is present everyday and not present in other interferograms collected on the same day => not related to GPS dilution of precision

InSAR Processing Challenges

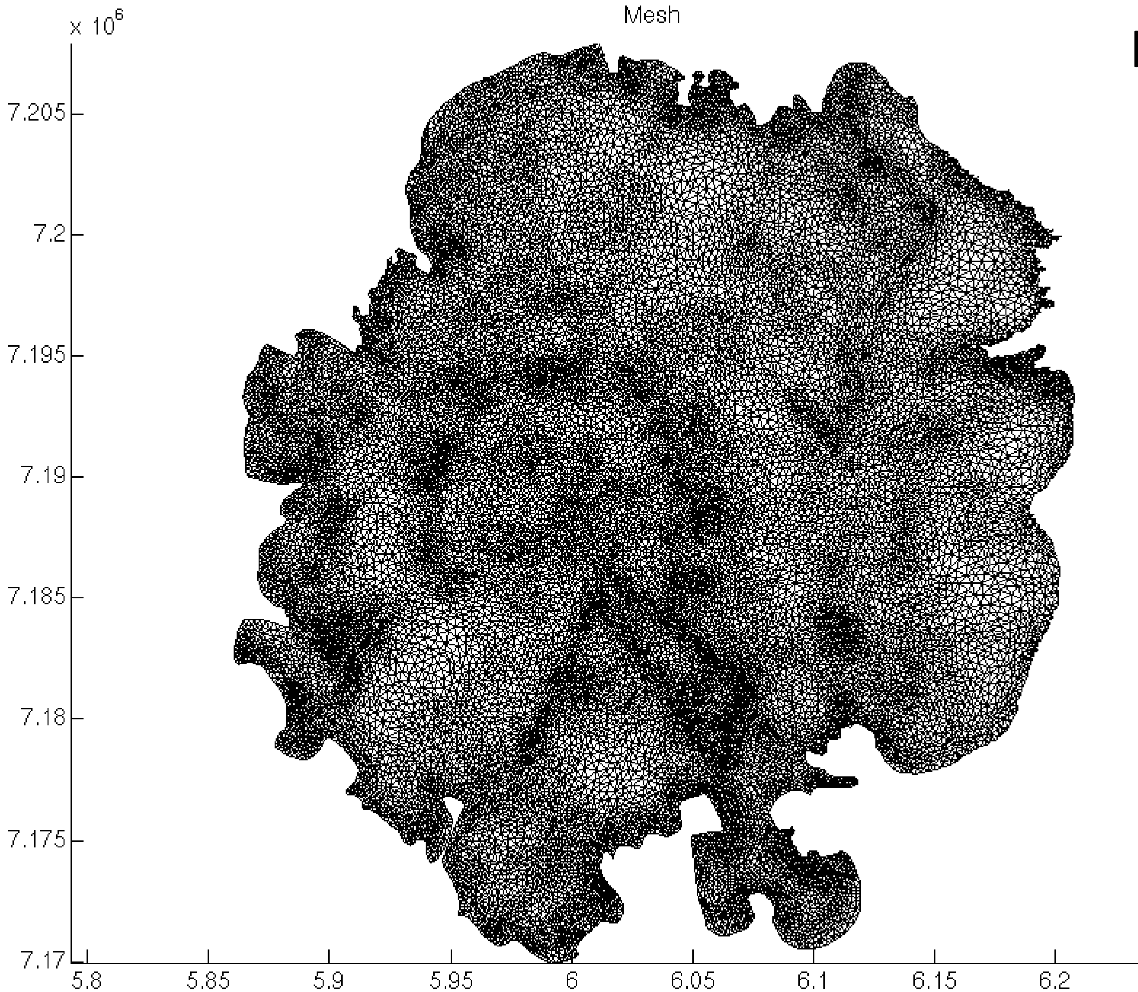
- Lines that affected by the squint issue constitute ~1/3 of the total data collected in June 2009 and 2/3 of the 4-hour repeat-pass data

- The problem is likely within the processor and not related to aircraft motion or erroneous inputs from the GPS or INU

- Eventual solution to this problem should aid in the development of a multi-squint processor that will increase UAVSAR's capabilities

Proposed 2012 UAVSAR Flight Plan

- Image both Langjökull and Hofsjökull from 3 different LOS directions (providing data for 3D velocity field)
- Campaign in summer and winter
- *In situ* GPS and snow characterization campaigns will begin a few days before UAVSAR arrives in Iceland and will continue for a few days after



http://issm.jpl.nasa.gov/

Hofsjökull:
Anisotropic mesh in ISSM

JPL ISSM development team

Eric Larour

Eric Rignot

Helene Seroussi

Mathieu Morlighem

Conclusions

- $\Delta T \geq 3$ days: Difficult to preserve phase coherence – time series nearly impossible (~10% success rate)
- L-band UAVSAR success at 4 hrs, 1, 2 & 3 days
- Fantastic potential for 3D velocity fields
- High resolution airborne InSAR excels at studying "predictable" deformation sources allowing for short dT and multiple LOS coverage
- Needs to be flown at different seasons
  - Flow mechanics
  - Backscatter / decorrelation studies
  - Inform requirements for future L-band airborne and spaceborne missions
- A lot of analysis still to come (time variability, 3D decomposition, modeling)

Thank you esa for 20 years of ERS-1/2