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Mapping Surface Elevation and Elevation Change of the (Greenland) Ice Sheet

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Overview

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- Why do we need ice elevation data?
- Greenland Ice sheet Mapping Project (GIMP) DEM
- Elevation Change Measurements and Applications
- Exciting New Developments

Why do we need ice elevation?

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- Mass-balance
  - If surface and firn density constrained, gives us ice column thickness change
  - Elevation at the grounding zone and velocity gives us discharge.
- Constraining/validating numerical models
  - Ice Sheet shape (and speed) is the model calibration criteria
  - Change in thickness constrains transient models
- Image orthorectification
  - Currently large geolocation errors in imagery (up to 100's of m in Landsat!) due to topographic distortion
  - Accurate DEM essential for feature tracking and InSAR mapping of velocities
- Altimeter slope correction and filtering
  - Collinear analyses of repeat-tracks
  - Threshold filters

Need High-Resolution DEM

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- Existing Available DEM's
  - Bamber et al. (2000), ~1 km resolution.
  - SRTM, No data north of 60 degrees.
  - IceSAT DEM, Large gaps between tracks.
  - AVHRR Photoclinometry (Scambos and Hanlan), ~500 m resolution, big errors at coasts
  - GDEM, big errors over ice sheets, masking issues
- Higher Resolution (< 100 m) needed especially along high-relief coasts.

GIMP Overview

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The Greenland Ice Mapping Program (GIMP)

- Funded by NASA MeASURES to generate benchmark geospatial datasets for the glaciological community.
- Key Datasets Include:
  - High Resolution (< 100m) Digital Elevation Model (DEM) using primarily photogrammetric techniques.
  - Ice Surface Speed Velocity
    - InSAR, Speckle and Feature Tracking
    - RADARSAT-1&2, TerraSAR-X, Landsat 1-7, ASTER, SPIRIT..
    - Several annual “snapshots” of entire ice sheets
    - More frequent (seasonal or less) maps for rapidly-changing outlet glaciers.
  - Annual Image Mosaics from Multiple Sensors

GIMP High-Resolution DEM

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- Multi-Sensor Approach
  - Low-relief interior
    - MODIS/AVHRR photoclinometry and Radar Altimetry
      - 100's of meter resolution
  - High-Relief Coasts
    - Photogrammetry
      - ASTER
      - SPOT5 (SPIRIT Program)
      - Radar Altimetry (RADARSAT fine-beam)
    - 10's of meters resolution
  - All vertically registered to ICESat

GIMP High-Resolution DEM

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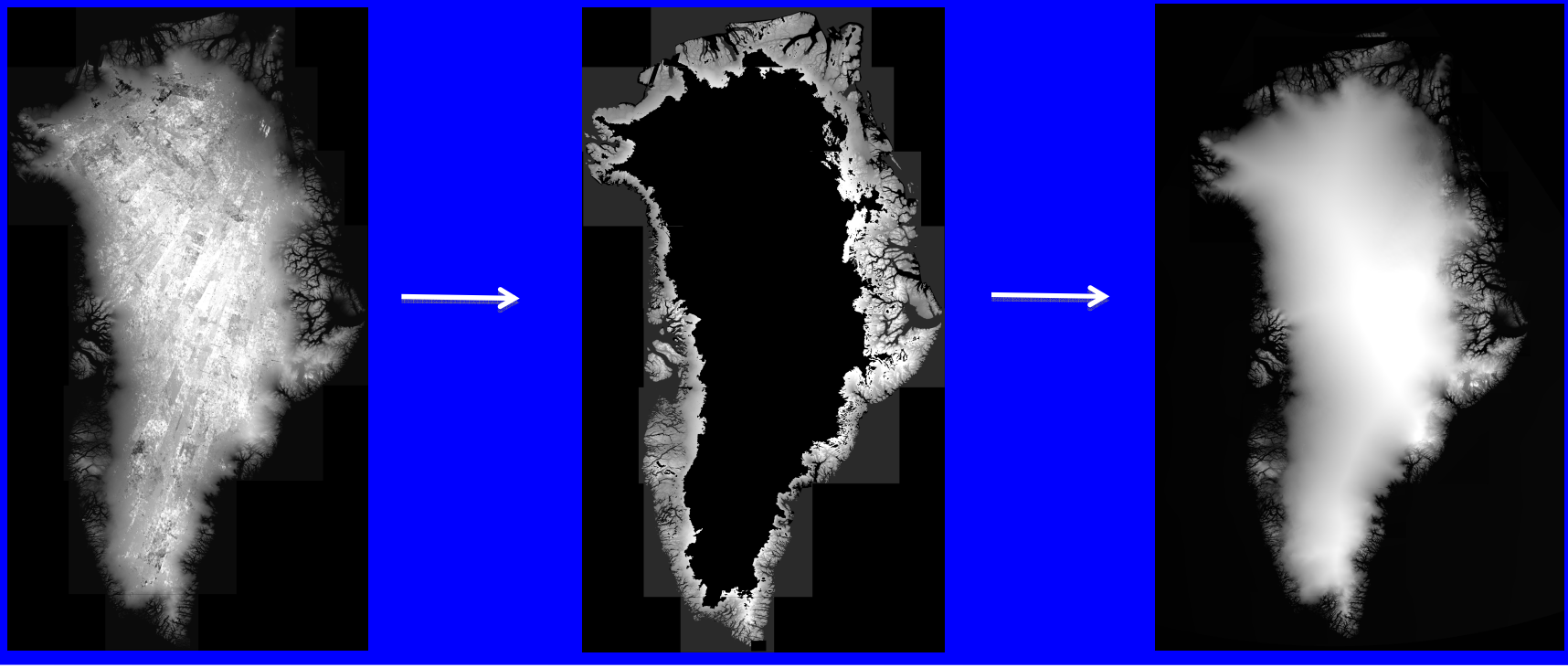
- Methodology
  - Start with “reference” DEM
    - AVHRR Photoclinometry + masked 30 m ASTER GDEM



Raw ASTER GDEM Mosaic

Masked ASTER GDEM Mosaic

Merged BAMBER & masked GDEM

High-Resolution DEM

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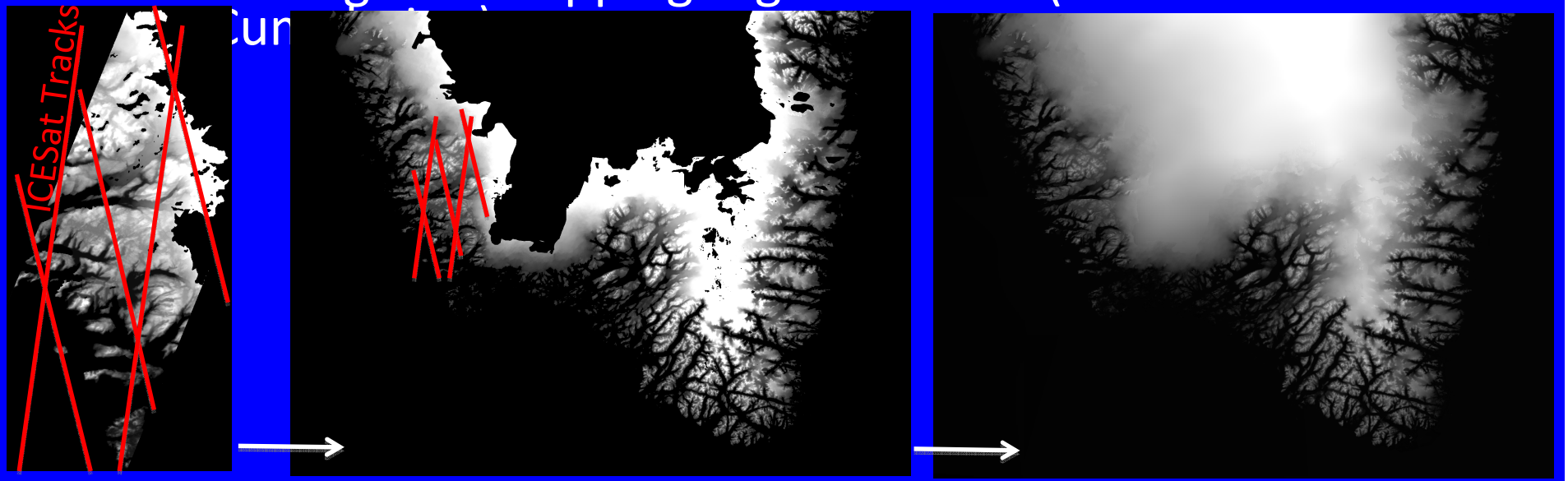
- Methodology
  - Add data granules to improve altimetry validation score
    - Masked SPOT5 SPIRIT DEM (40 m)
    - Masked ASTER DEM (AST14, LPDAAC, 30 m)
    - Each added DEM vertically registered using laser altimetry
      - Bilinear Surface Fit
  - Average Overlapping High-Res Data (Data Cur



Masked ASTER DEM Swath Reference DEM (w/o Bamber) Merged Updated DEM + Bamber

High-Resolution DEM

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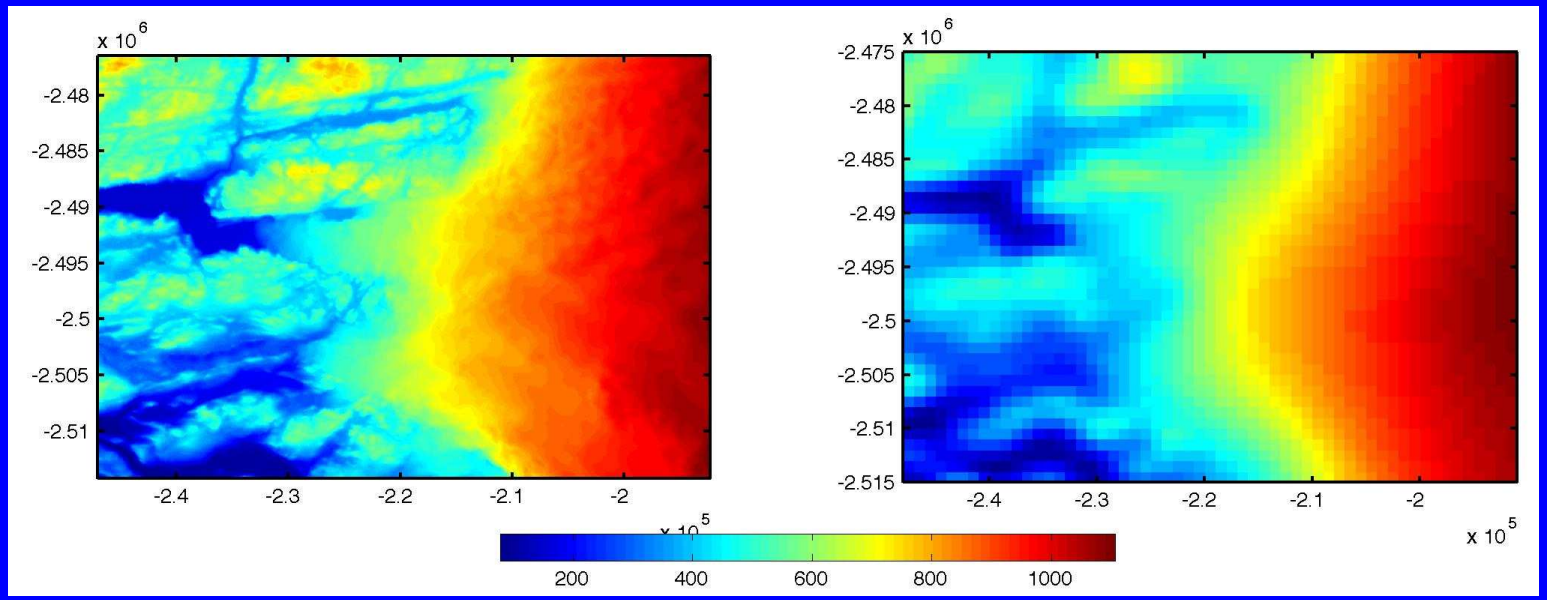
Russell Glacier, Greenland

GIMP DEM (30m)

Bamber DEM (1 km)



meters above wgs84

High-Resolution DEM

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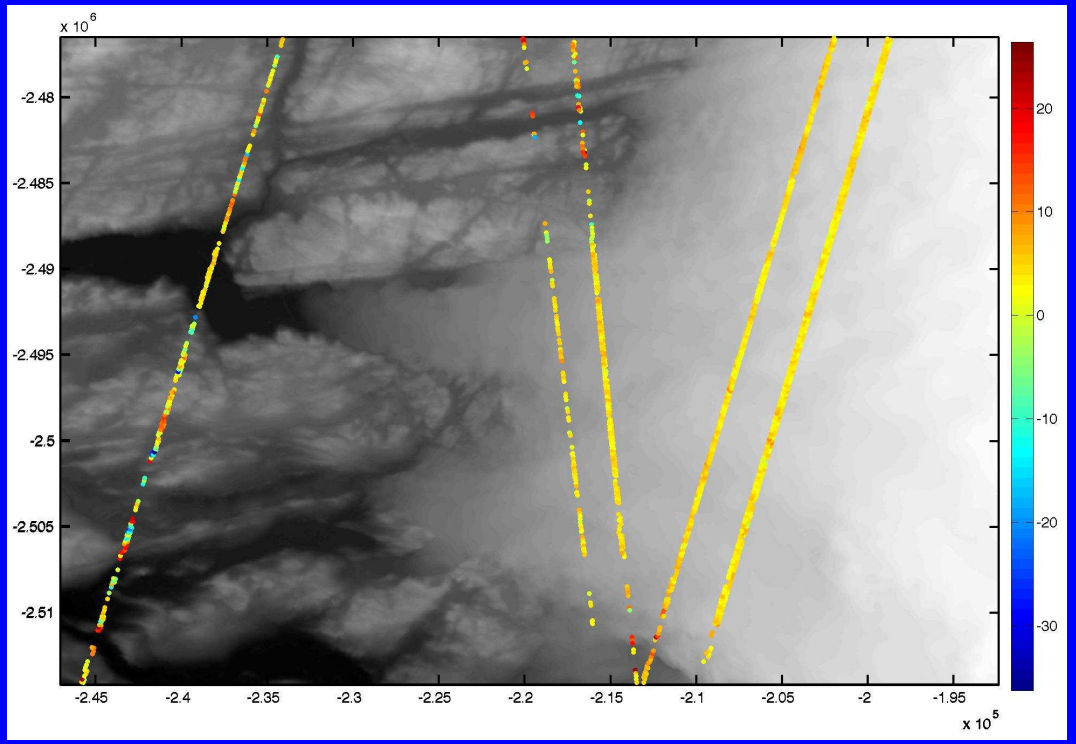
- Data Registration and Validation
  - DEM Validated Using ICESat and ATM laser altimetry
    - Target RMSE: over ice +/- 5 m, over land: +/- 7 m

Russell Glacier, Greenland
ICESat – GIMP DEM



GIMP High-Resolution DEM

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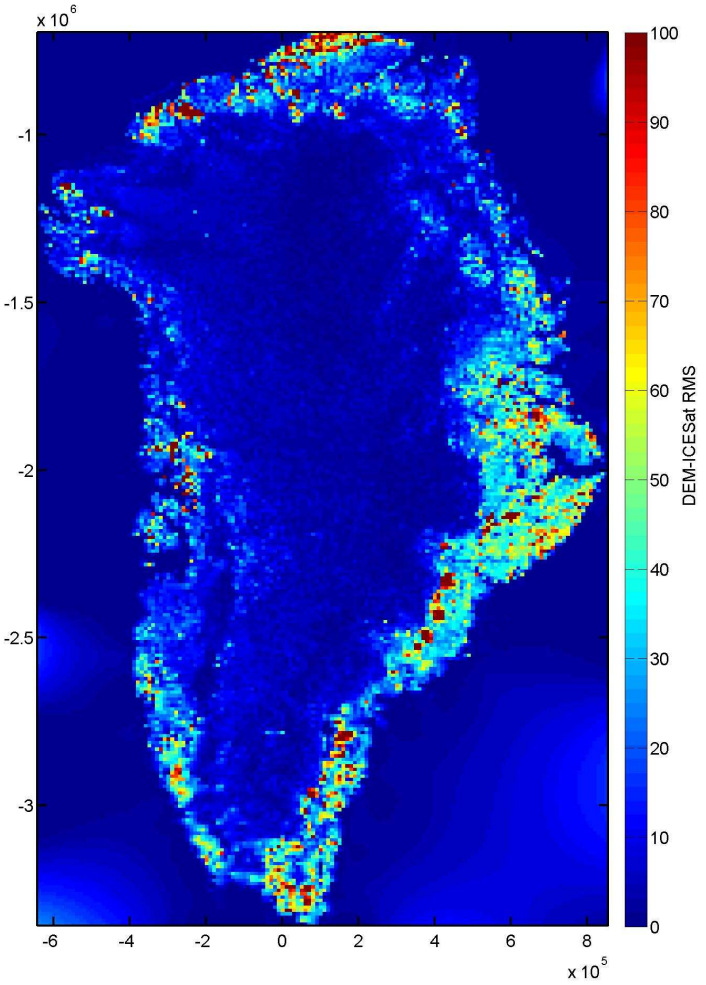
- Version 1 validation
- Large errors (~100 m) on
  - SE coasts and south:
    - steep topography
    - poor contrast
  - North
    - No ASTER data yet – only 500 m AVHRR
- Will improve as more data is added with time
  - Complete ASTER database
  - IceBridge altimetry
- Time-stamping

ICESat – GIMP DEM
RMSE of 10 km bins



Mapping Elevation Change

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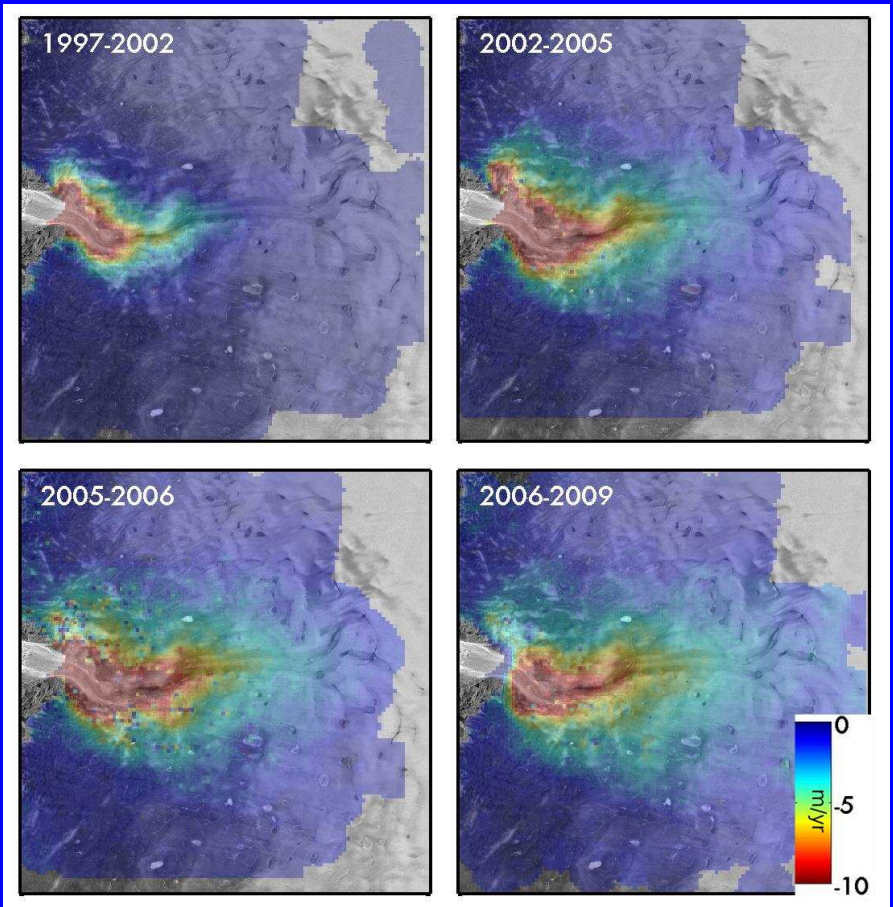
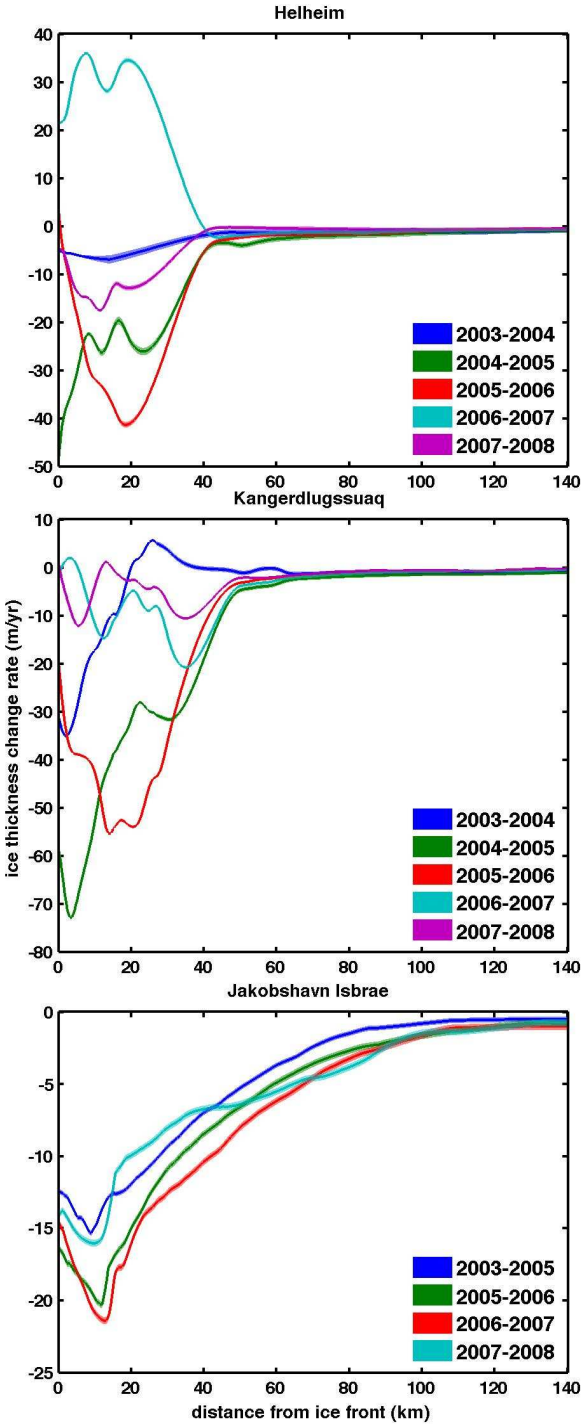
- How is the interior ice sheet responding to changes at the margin?
- What's dynamic and what's surface mass balance?
- How can we use this information for predictions?



Jakobshavn Isbrae
surface elevation change from repeat ATM

Mapping Elevation Change

- Big changes at coast within narrow outlet glaciers resolved with photogrammetry.
- Smaller, more spatially uniform changes over interior interpolated from laser altimetry (ICESat) tracks.



Elevation change rate of Helheim, Kangerdlugssuaq and Jakobshavn glaciers from merged datasets. Width of each line represents standard deviation from an accumulation model (Burgess et al., 2010)

Mapping Elevation Change

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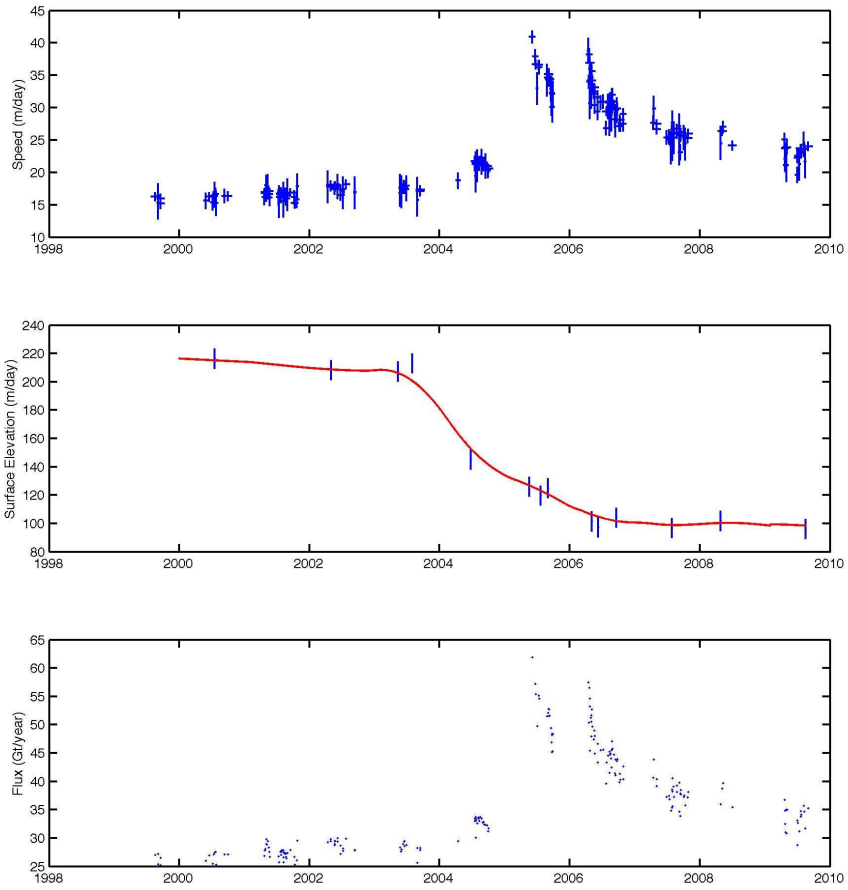
- High-resolution of speeds and thickness changes at ice fronts gives us time series of discharge/mass-balance.



Kangerdluqssuaq glacier: (top) ice speed near the front (middle) ice thickness (bottom) ice discharge.

Mapping Elevation Change

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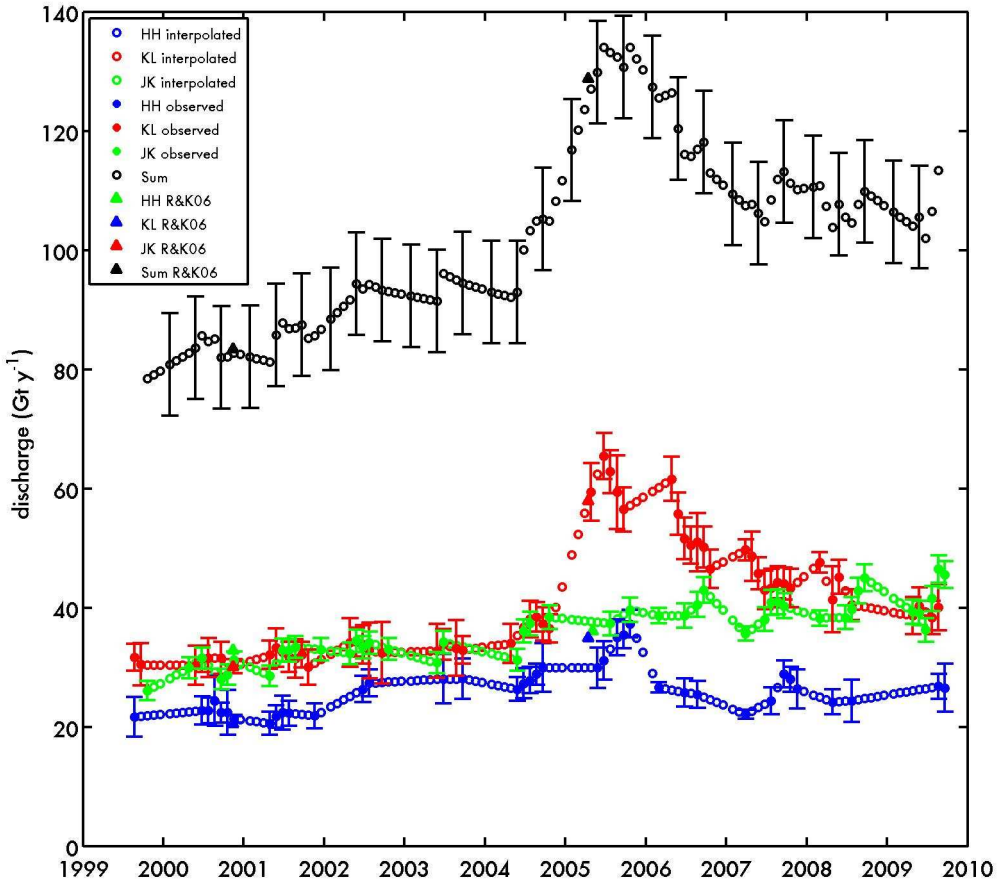
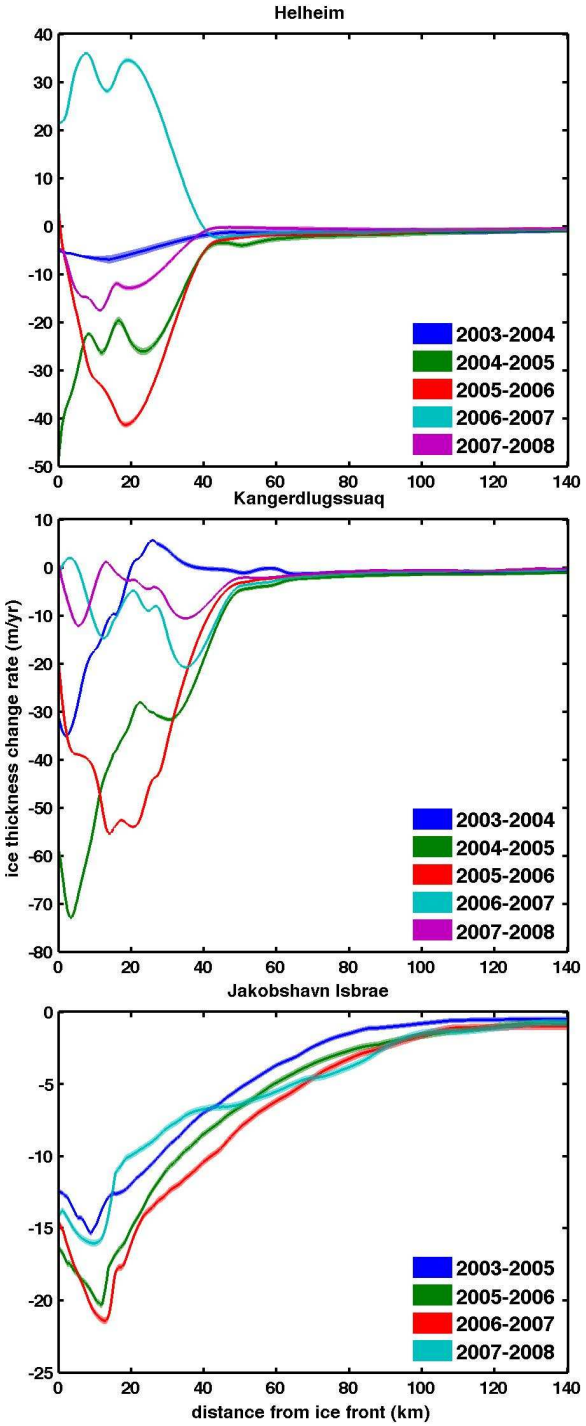
Discharge of three largest Greenland glaciers and total discharge.

Closed circles are measurements
Open circles are interpolated.



Mapping Elevation Change

- Lots of interesting variability in response to outlet glacier retreat between different glaciers.



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Mapping Elevation Change

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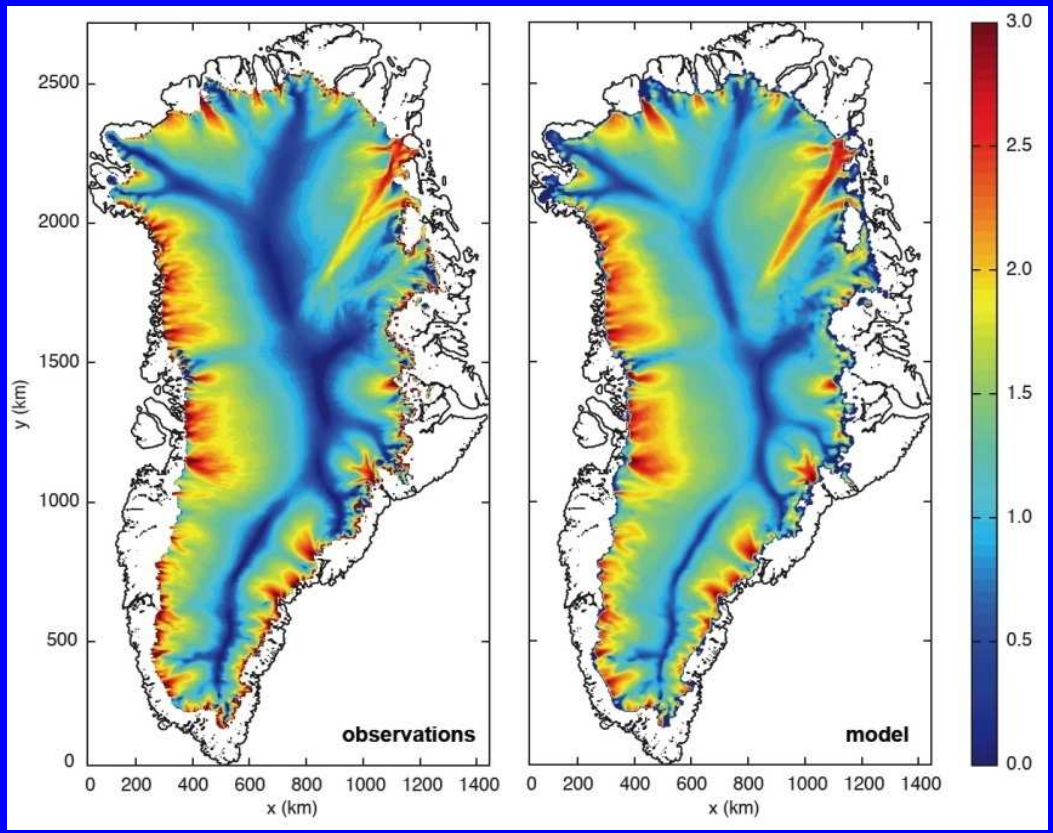
- Use observations to constrain models



Left: Balance velocity based on Bamber et al. 2000

Right: Steady-state velocity field from Glimmer-CISM ice sheet model (Price et al., in prep)

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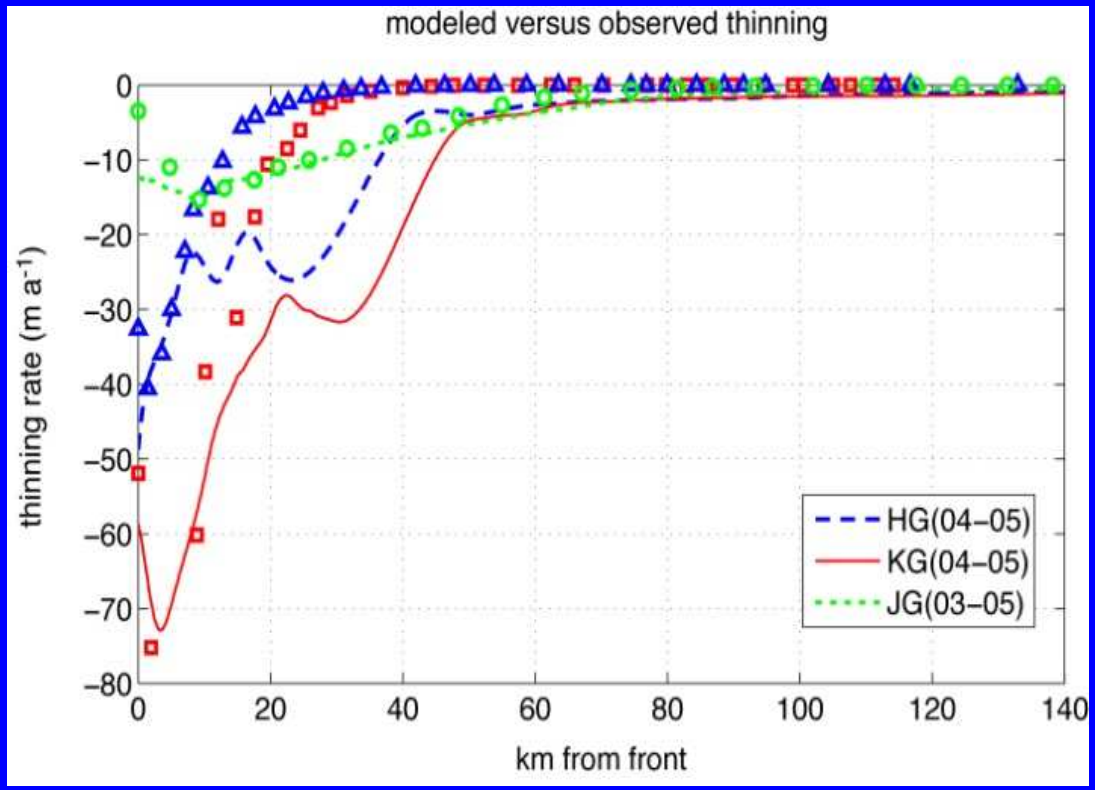

Solid curves: Observed ice elevation change 2004-5.

Markers: Modeled elevation change rate 2-4 years after step perturbation applied.

Price et al., in prep

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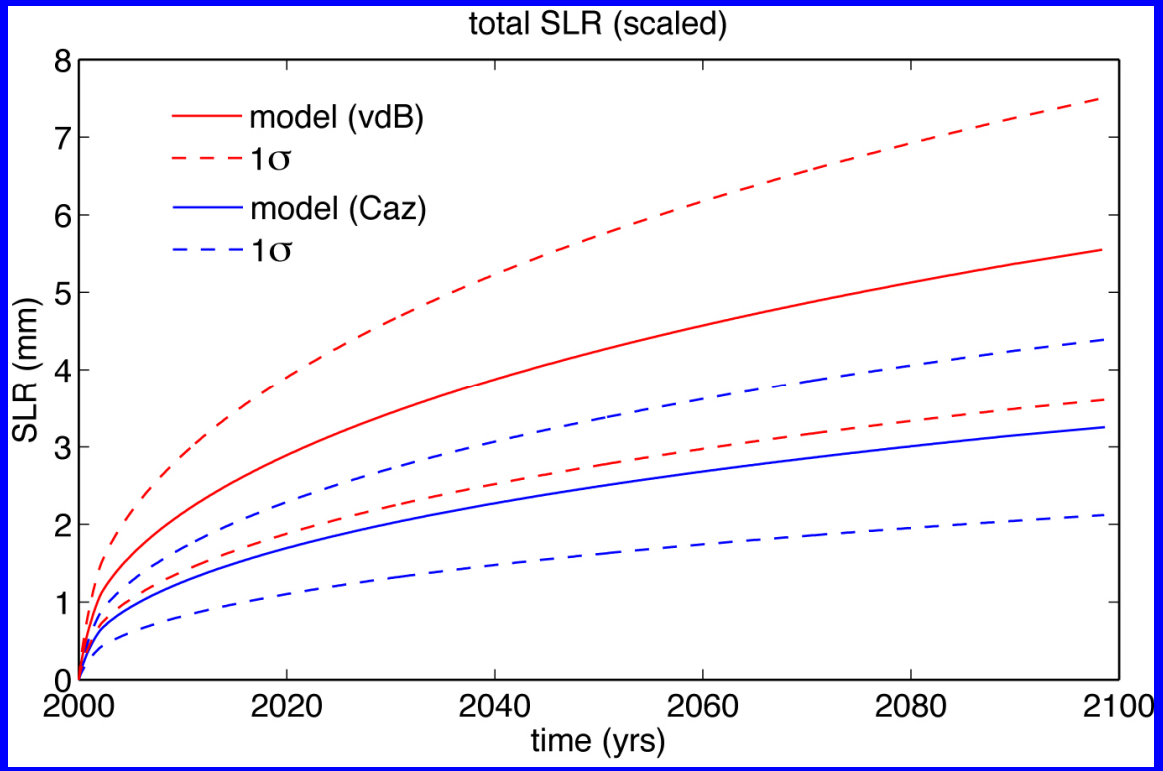

Modeled total sea level rise contribution from Greenland Ice Sheet dynamics based on current discharge rates (scaled from three benchmark glaciers) by 2100. Blue and red are based on different scaling assumptions.

Price et al., in prep

Exciting New Developments…..

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- US Commercial Satellite Data Access through the National Geospatial Agency (NGA) and Antarctic Geospatial Information Center (AGIC)
  - Constellation of 5 (and maybe more soon), sub-meter resolution panchromatic satellites.
    - Worldview 1&2, Geoeye, Quickbird, Ikonos, etc.
  - Near-real-time tasking
  - 5 or possibly more repeats per day
  - Virtually unlimited tasking
  - Stereo-mode capabilities

AGIC
Antarctic Geospatial Information Center

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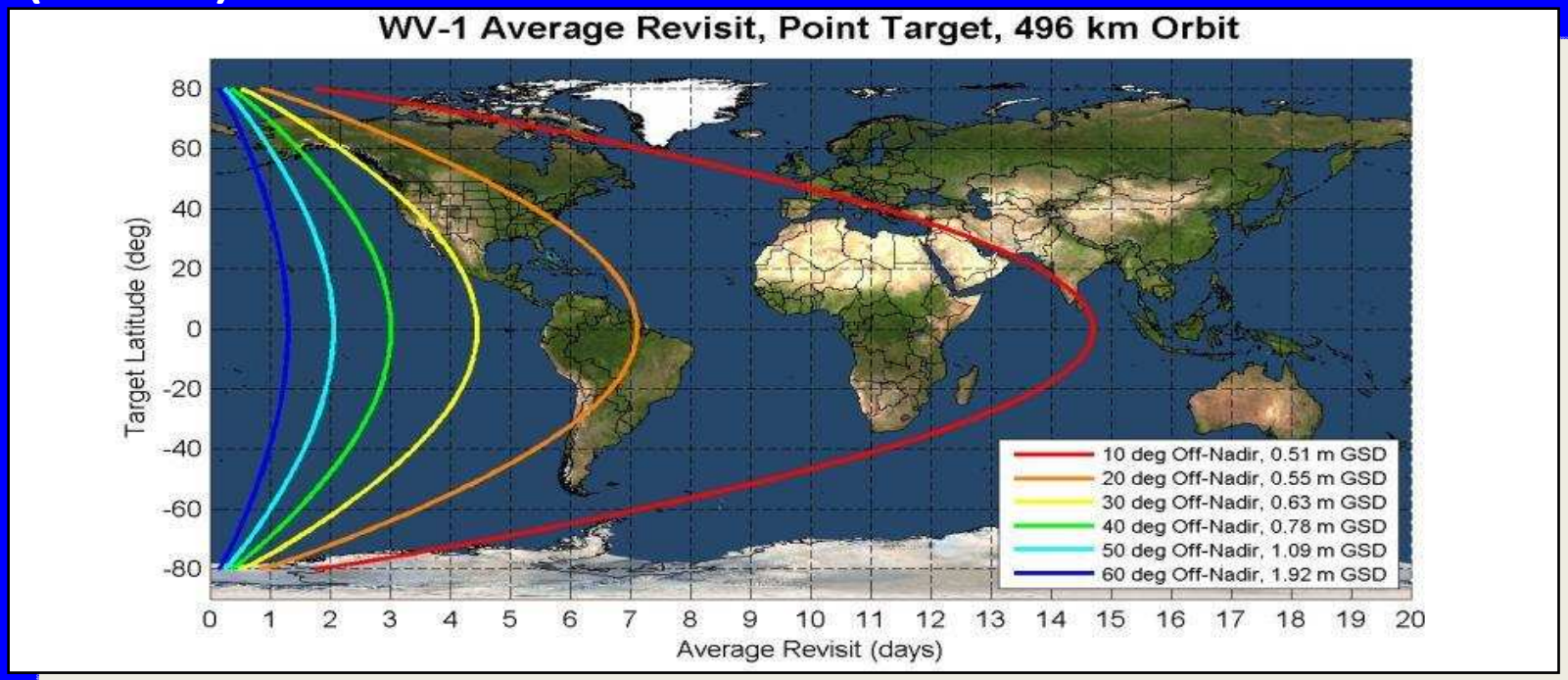

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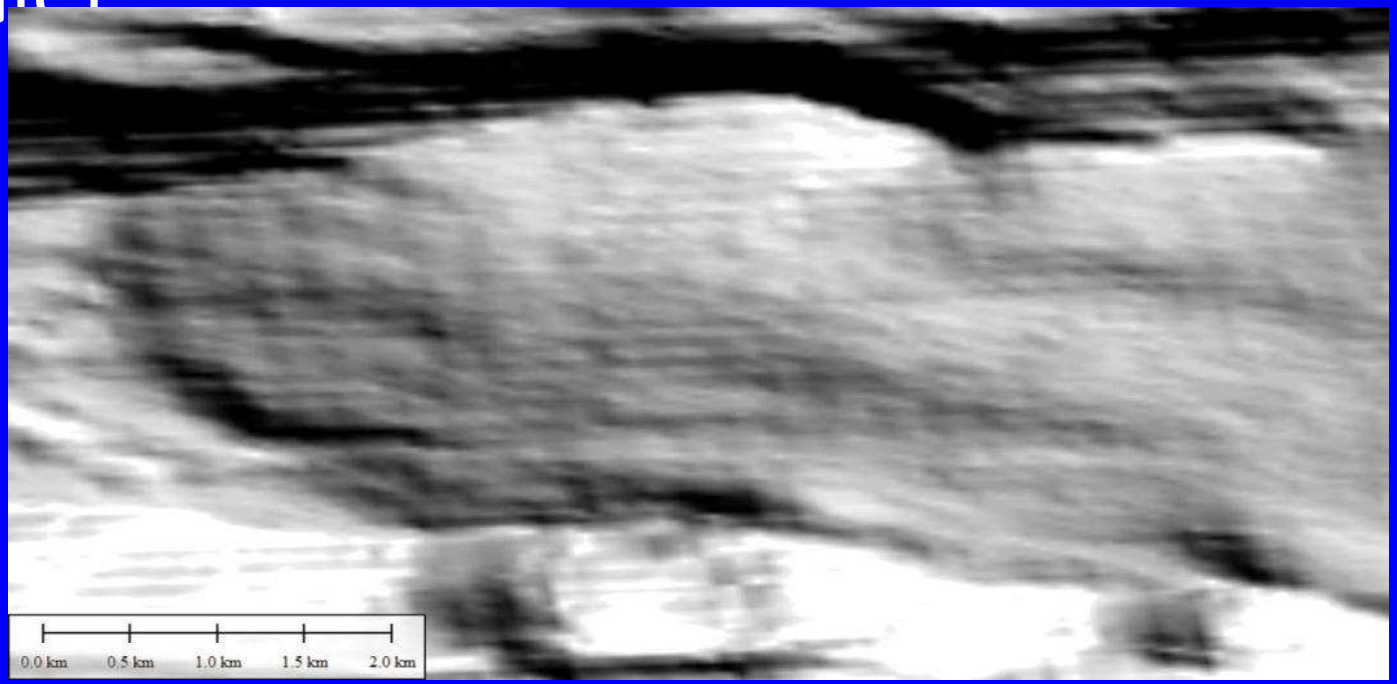

GIMP 30 m DEM
Isunnguata Sermia, West Greenland

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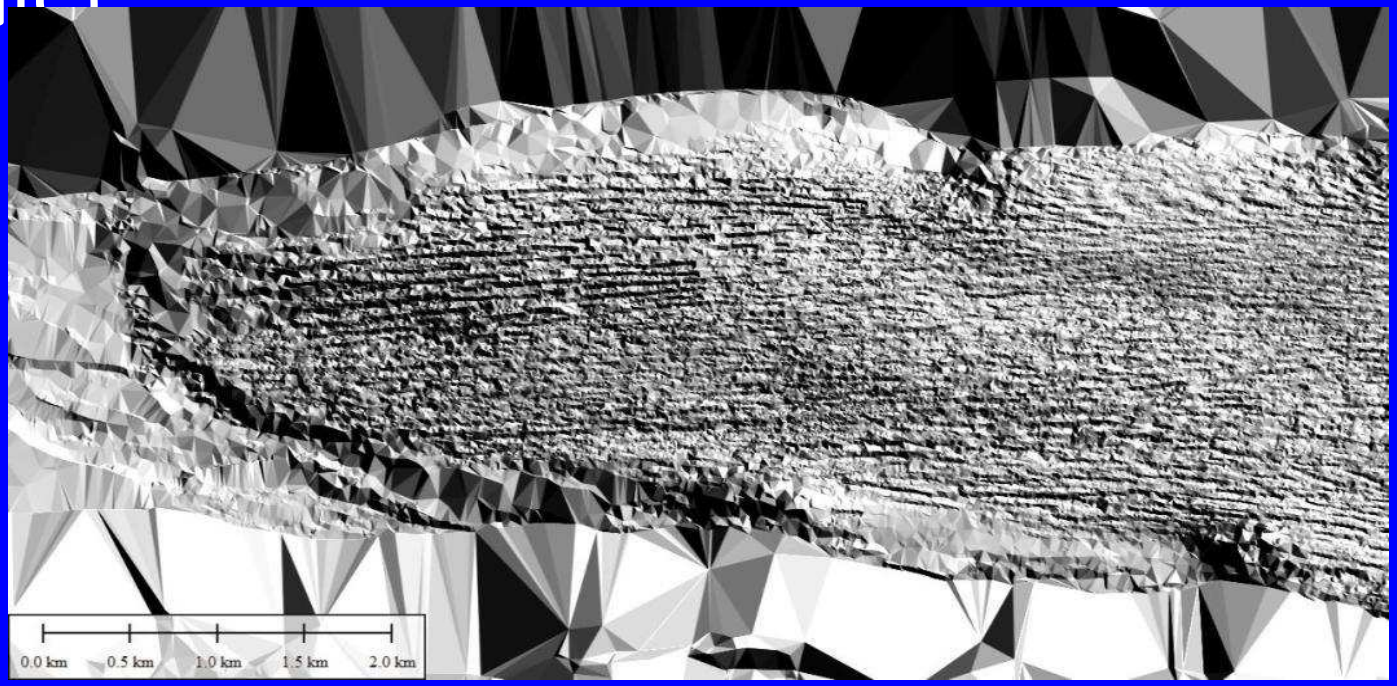

WV-1 , 2 m DEM
Isunnguata Sermia, West Greenland

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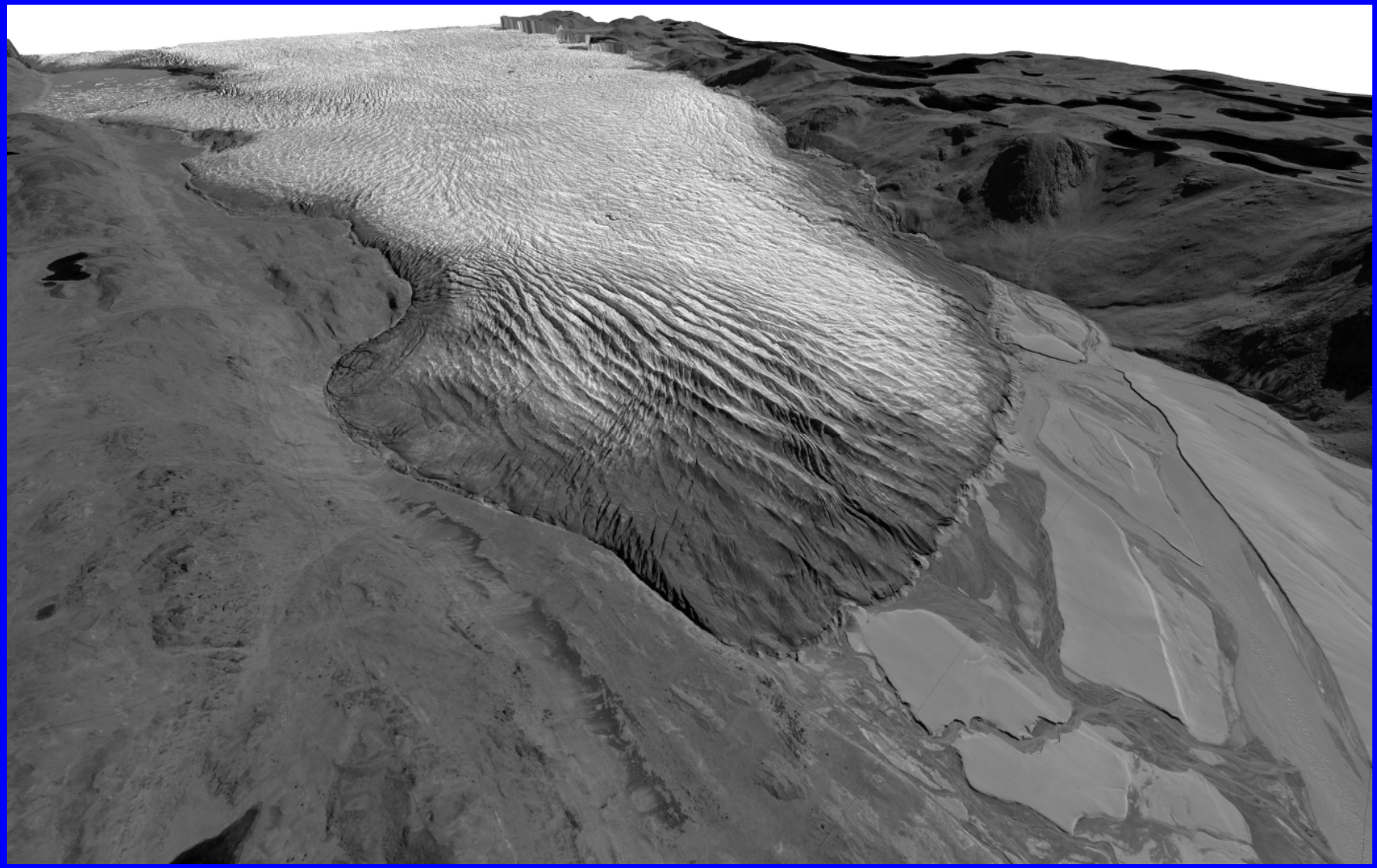

Isunnguata Sermia, West Greenland

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- US Commercial Satellite Data Access through the National Geospatial Agency (NGA) and Antarctic Geospatial Information Center (AGIC)
- Data is there, it's free, but it's huge (>10 TB for Antarctica alone…. and that's before we started tasking).
- No system in place for tasking, processing or distribution.
- Rapid Ice Sheet Change Observatory (RISCO)
  - $1.3 Million multi-institutional proposal pending with NASA to make this data available in easily-accessible form to the science community
  - Should hear on this any day (told 30 days, 28 days ago)

Exciting New Developments…..

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- NASA IceBridge
  - 6-year airborne altimetry extravaganza
    - 2010-2012 Greenland-focused
    - 2013-2015 Antarctic-focused
  - Altimetry is priority 2, bed topography is priority 1
  - 2 laser altimeters:
    - Low/mid elevation: Airborne Topographic Mapper (ATM)
      - Flying for almost 20 years
      - Narrow swath (100-200 m)
    - High-Altitude : Laser Vegetation Imaging Sensor (LVIS)
      - 1.5-km swath, 5 m posting
      - 0.4-m precision
      - Covers a lot of ground quickly

Exciting New Developments…..

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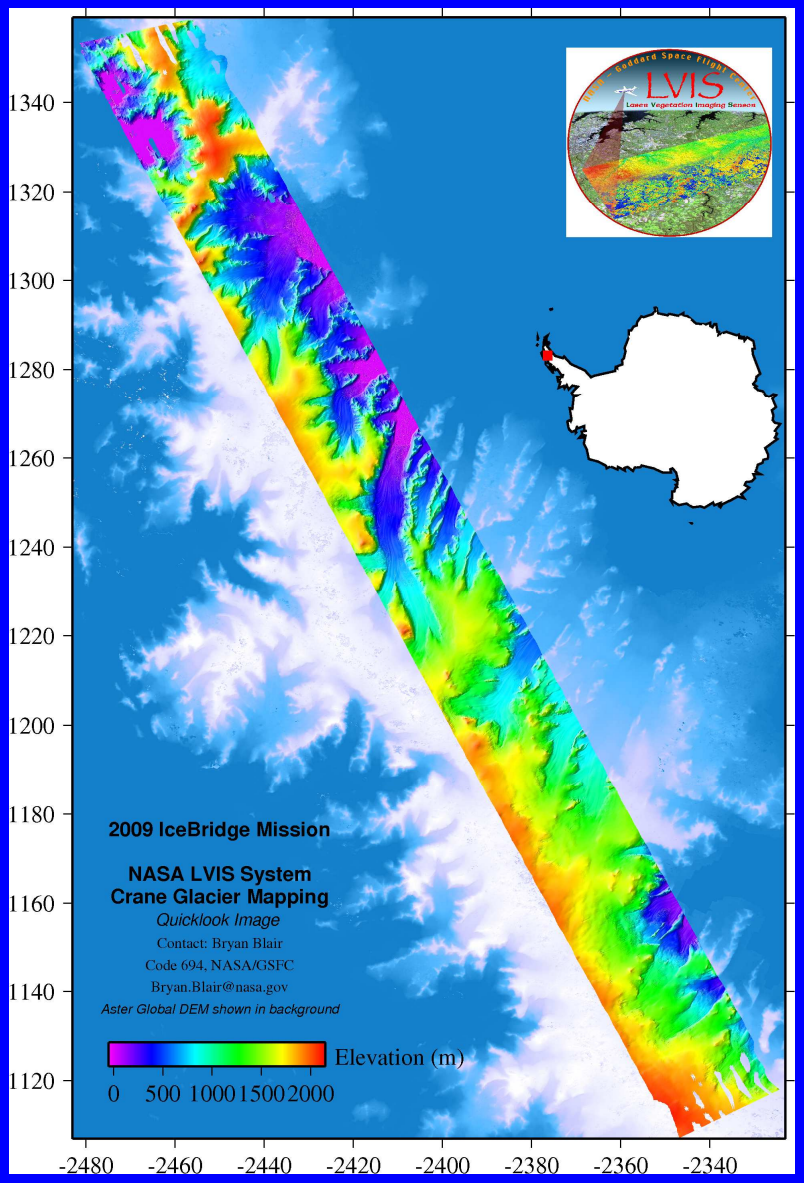
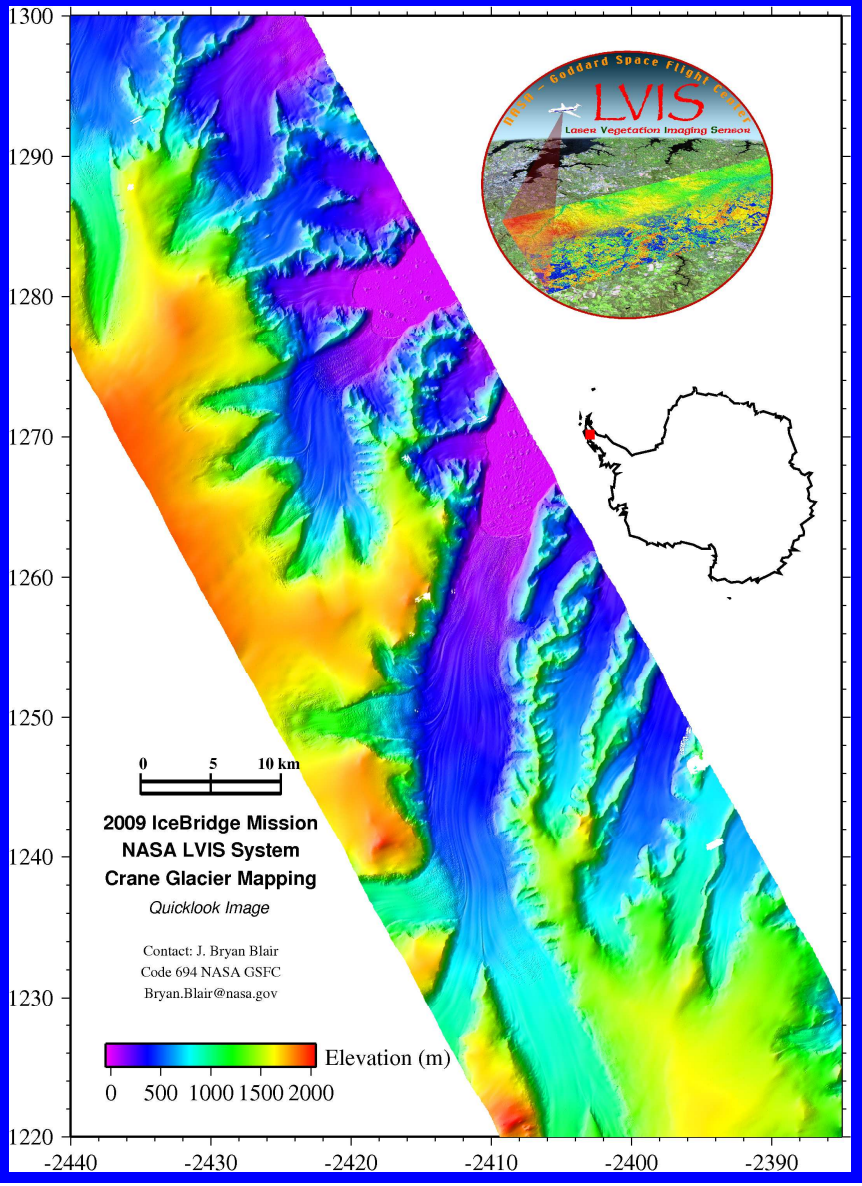
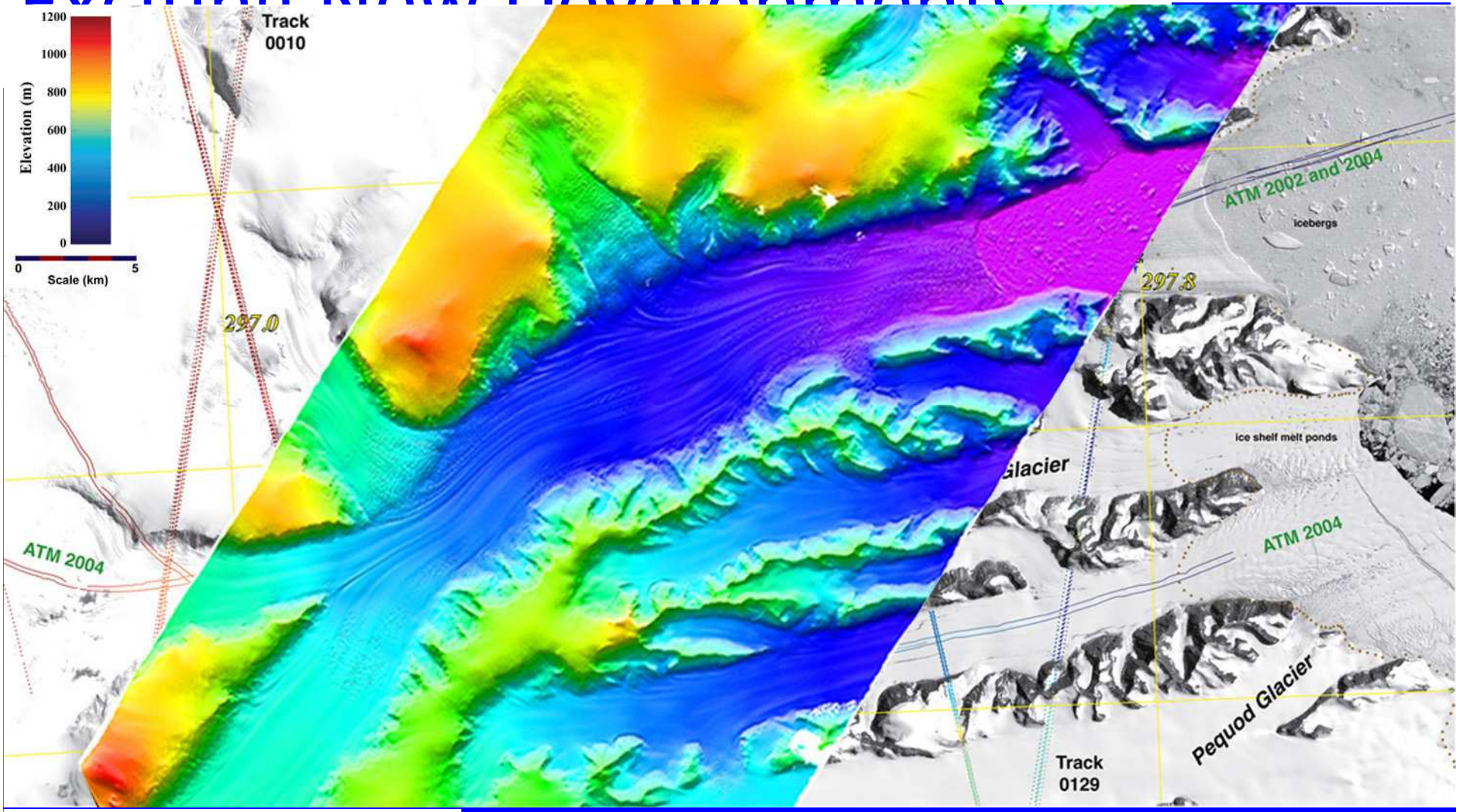




Exciting New Developments



Contact: J. Bryan Blair Code 694 NASA GSFC
Bryan.Blair@nasa.gov

Elevation (m)

500 1000 1500 2000

Exciting New Developments…..

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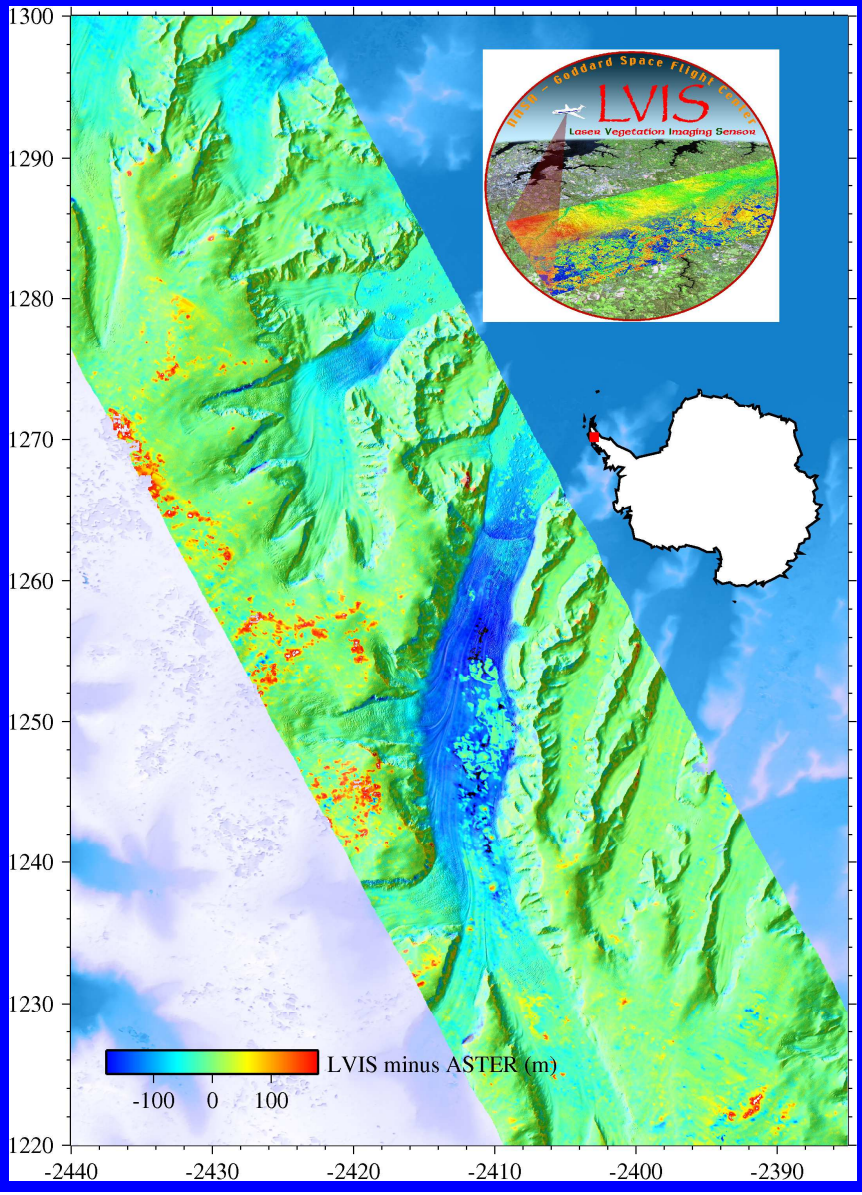

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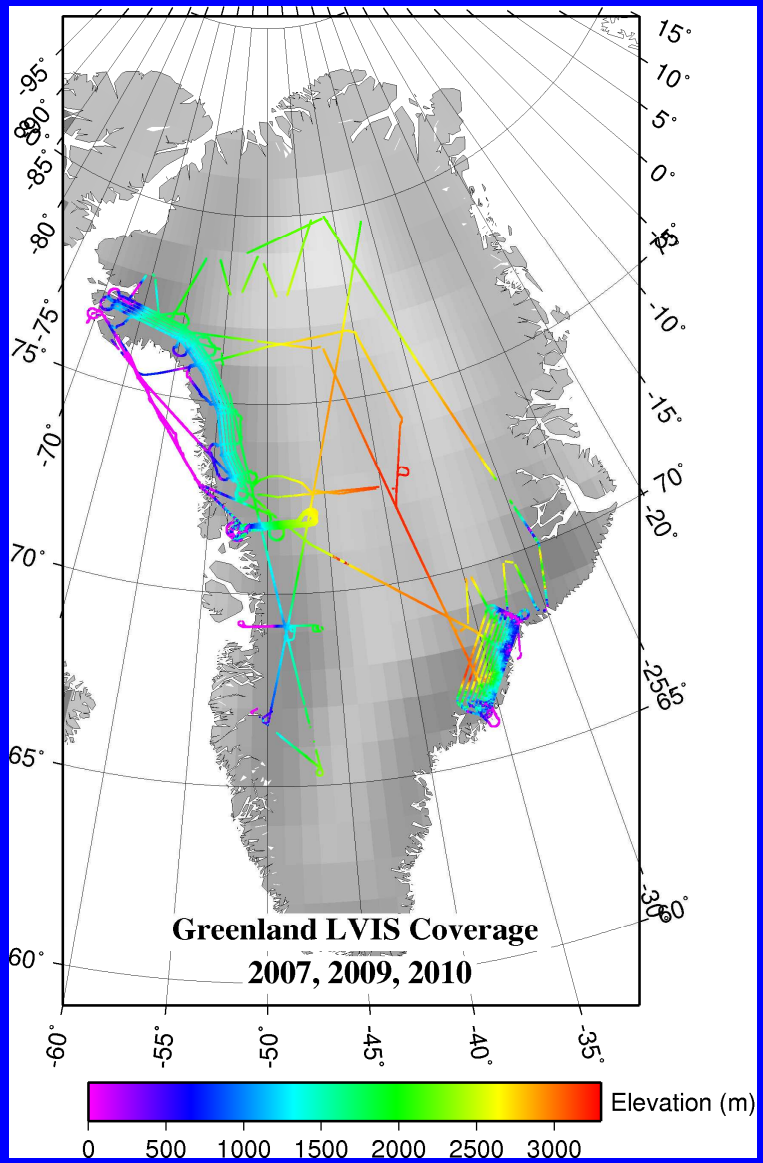

Exciting New Developments…..

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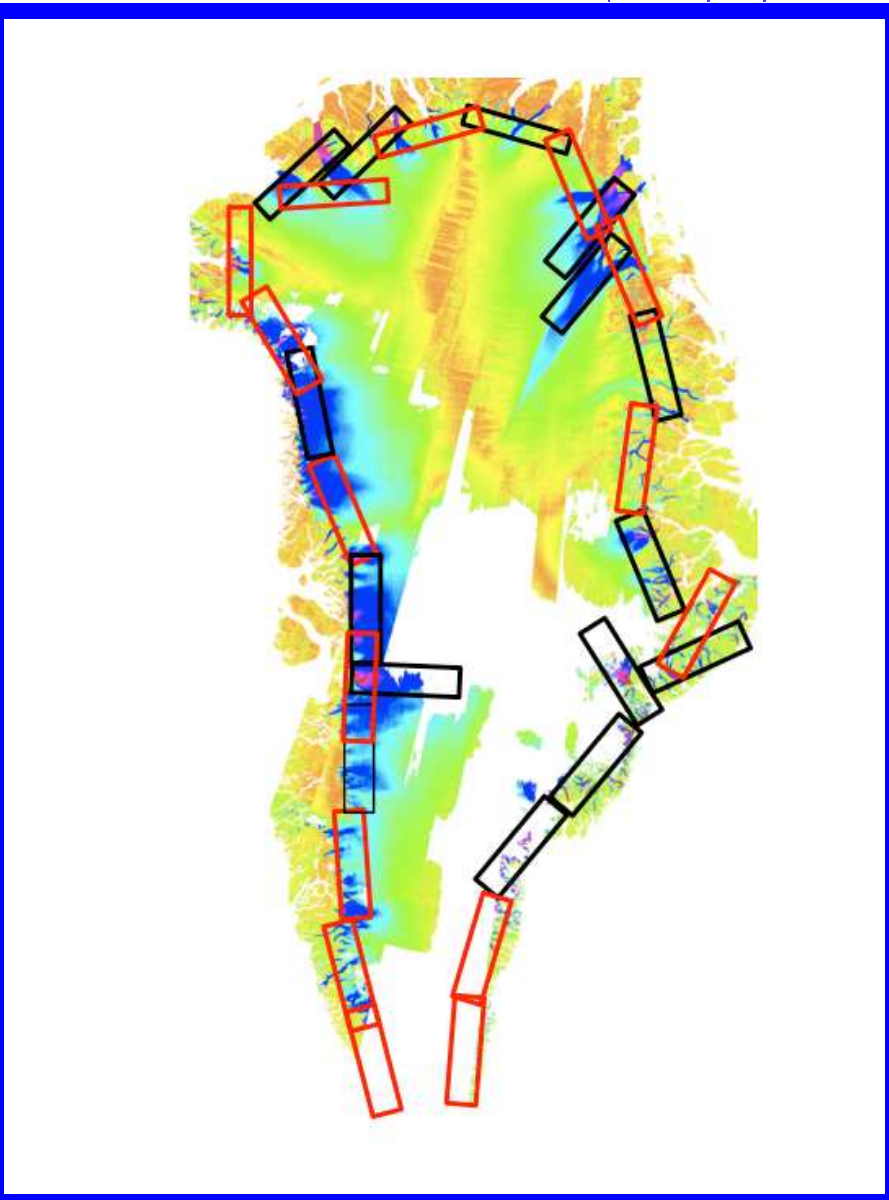
- Complete Greenland margin mapping with LVIS?
  - Complete, high-resolution benchmark dataset
- 2 seasons x 200 hours (~30 flights total) with G-5 or DC-8
- 10 Flights total with high-altitude UAV (Global Hawk)
- This is in reach