How multi-temporal remote sensing data improve our understanding of climate change impacts on glaciers

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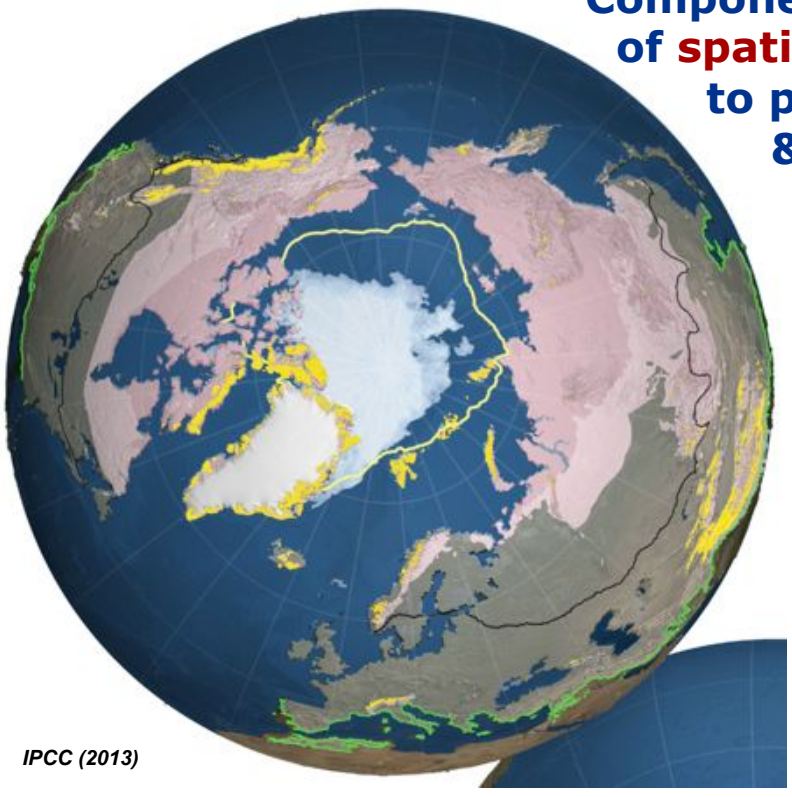
esa

glaciers cci

Google Earth

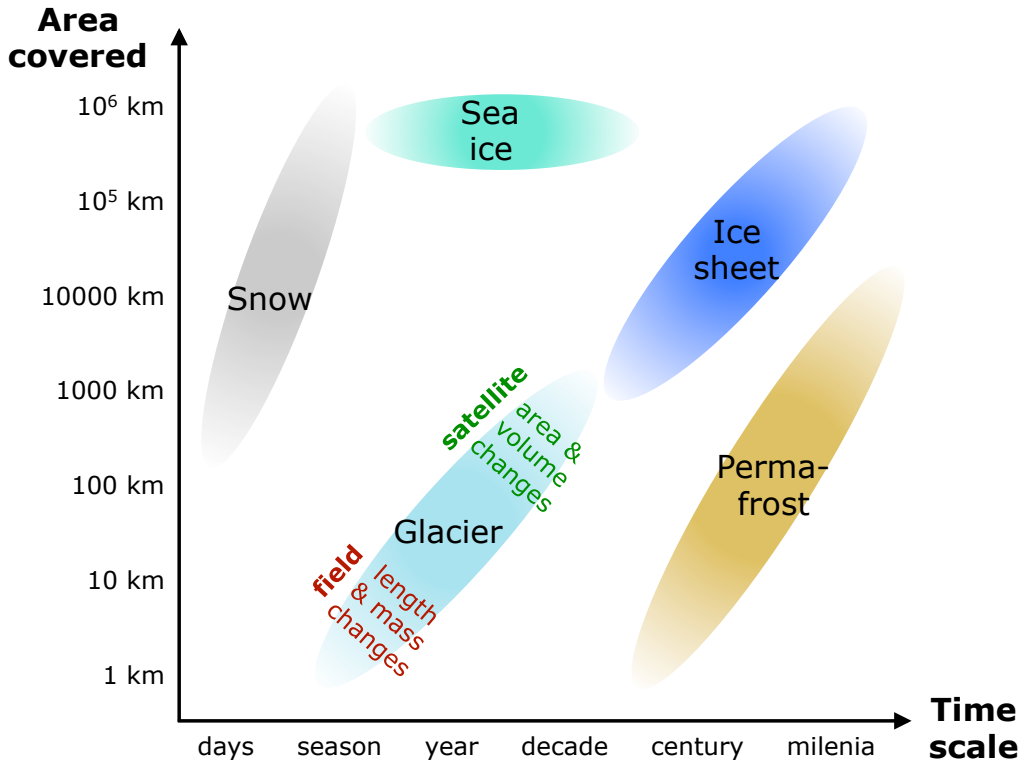
Cryospheric components

Components cover a wide range of spatial scales (from glaciers to permafrost distribution) & temporal scales (from snow cover variability to ice sheet changes)

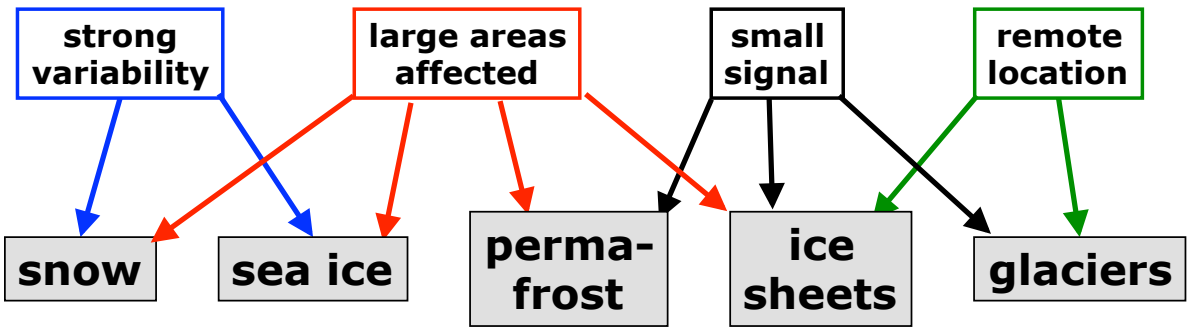


IPCC (2013)

Typical temporal and spatial scales



Monitoring challenges



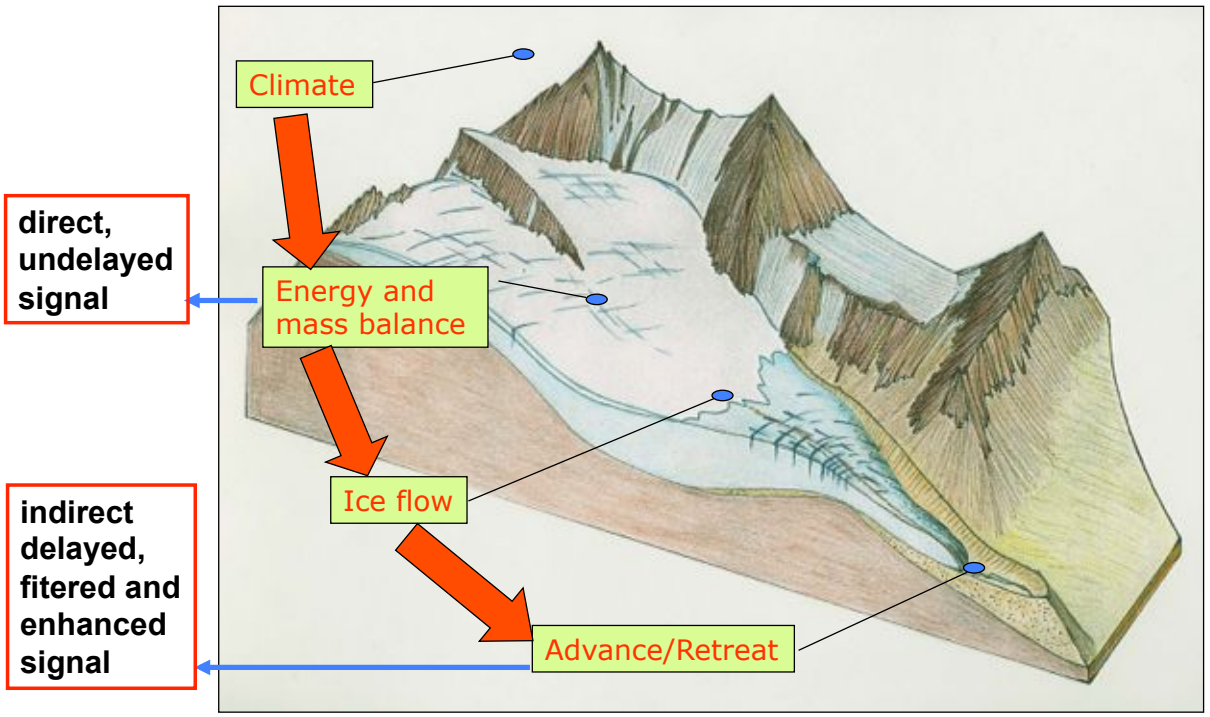
Field surveys

- long time series (century)
- precise at point locations
- well organized by GTN-G
- undersampling (space/time)
- inter-/extrapolation required
- representativeness?

Remote sensing

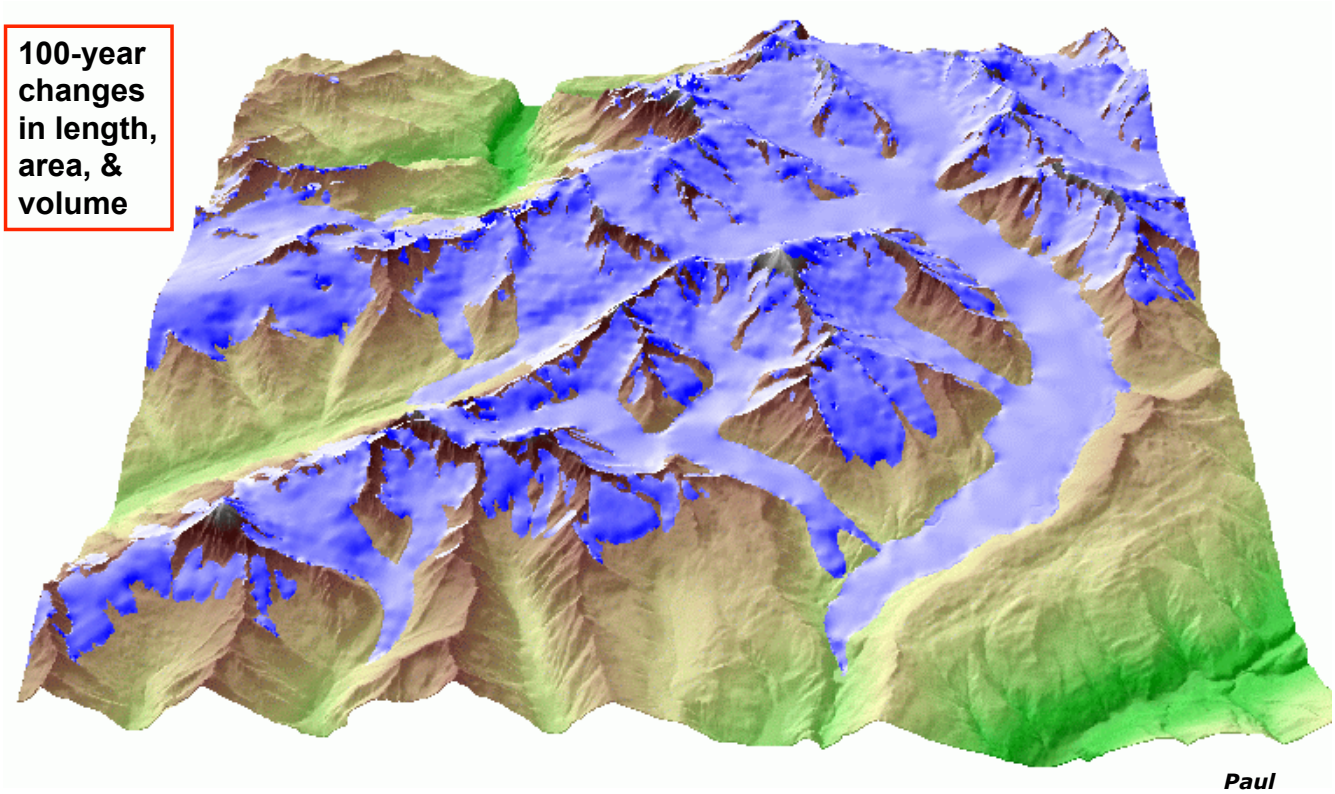
- short time series (decade)
- less precise, entire regions
- science based (not coord.)
- standardization, archives?
- complimentary sampling
- other products (velocity)

Climate change and glacier response



Haeberli

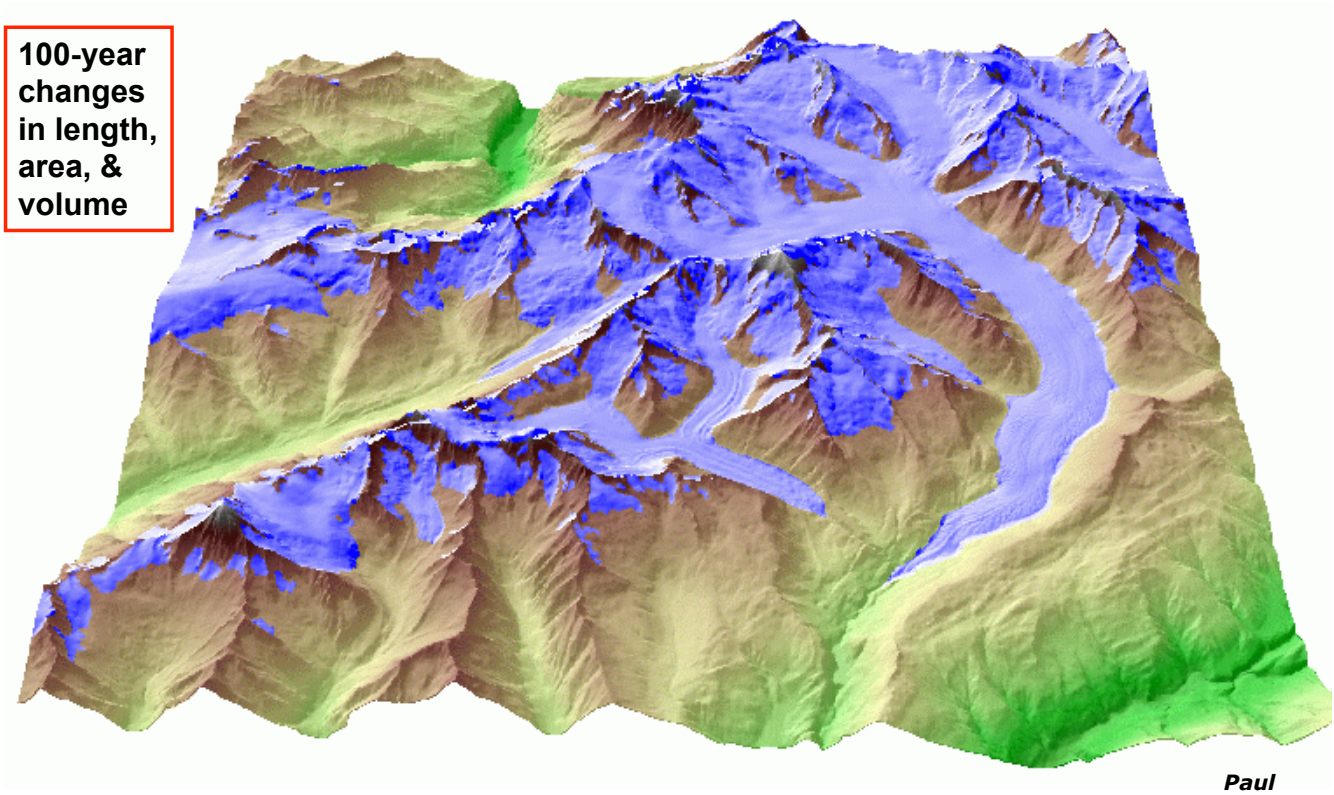
The century time scale: Aletsch 1850



Paul

The century time scale: Aletsch 1973

100-year changes in length, area, & volume



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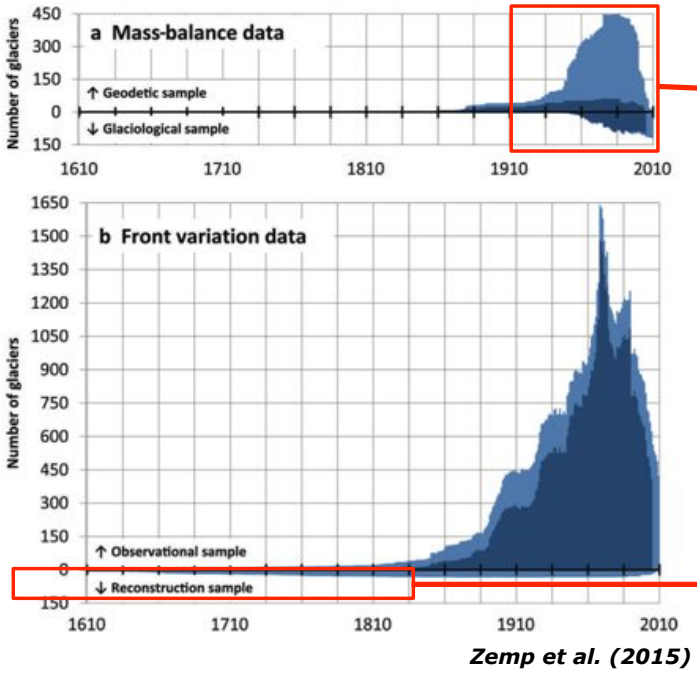
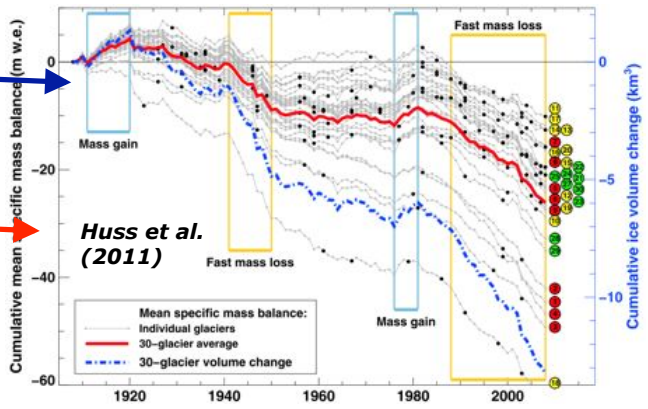
Field measurements: long time-series

Mass balance history from combining geodetic volume changes with annual observations and meteo data in a model

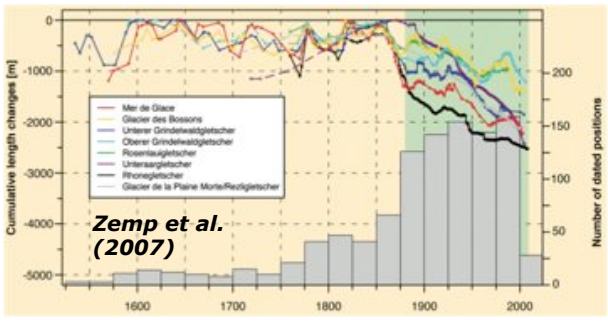


Zemp et al. (2015)

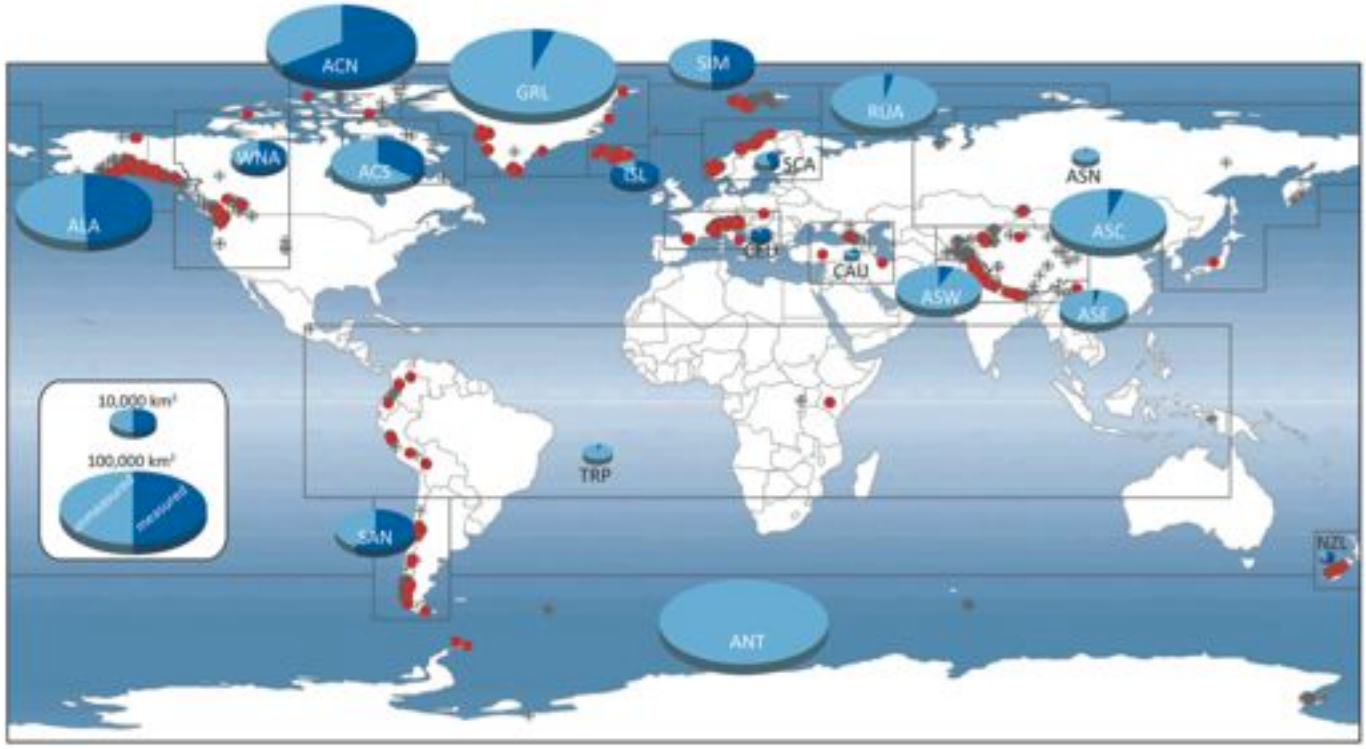


Huss et al. (2011)

Reconstructed length changes (back 15th Cen.)



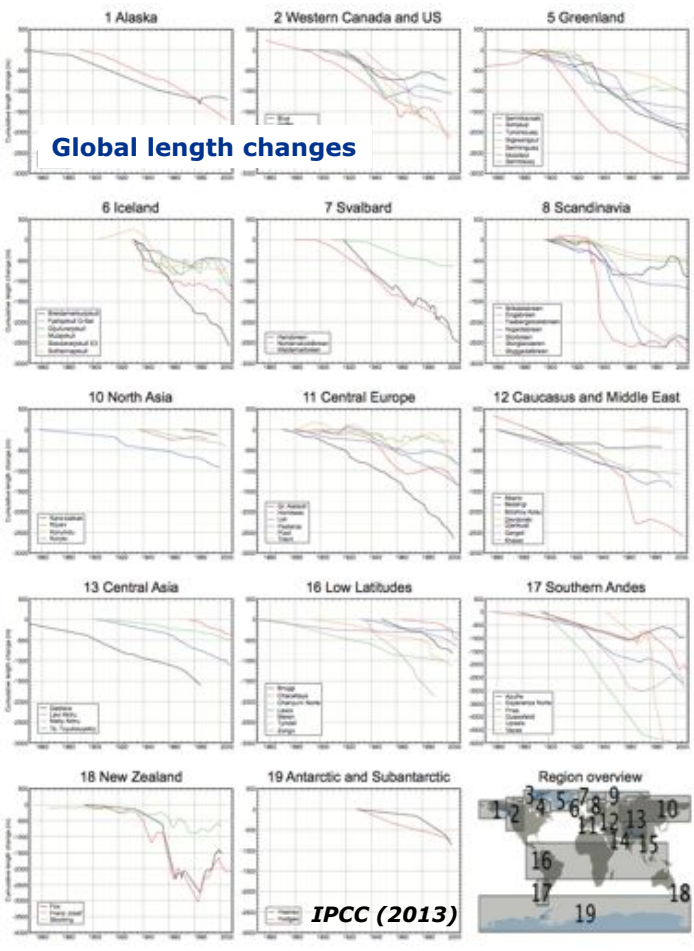
WGMS in-situ network: selected glaciers



o: active series
+: abandoned

Zemp et al. (2015)

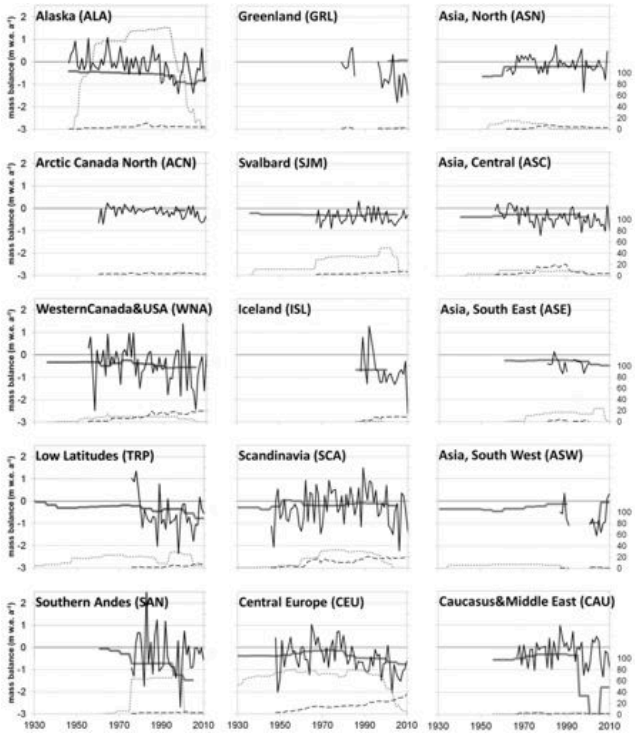
Global length changes



IPCC (2013)

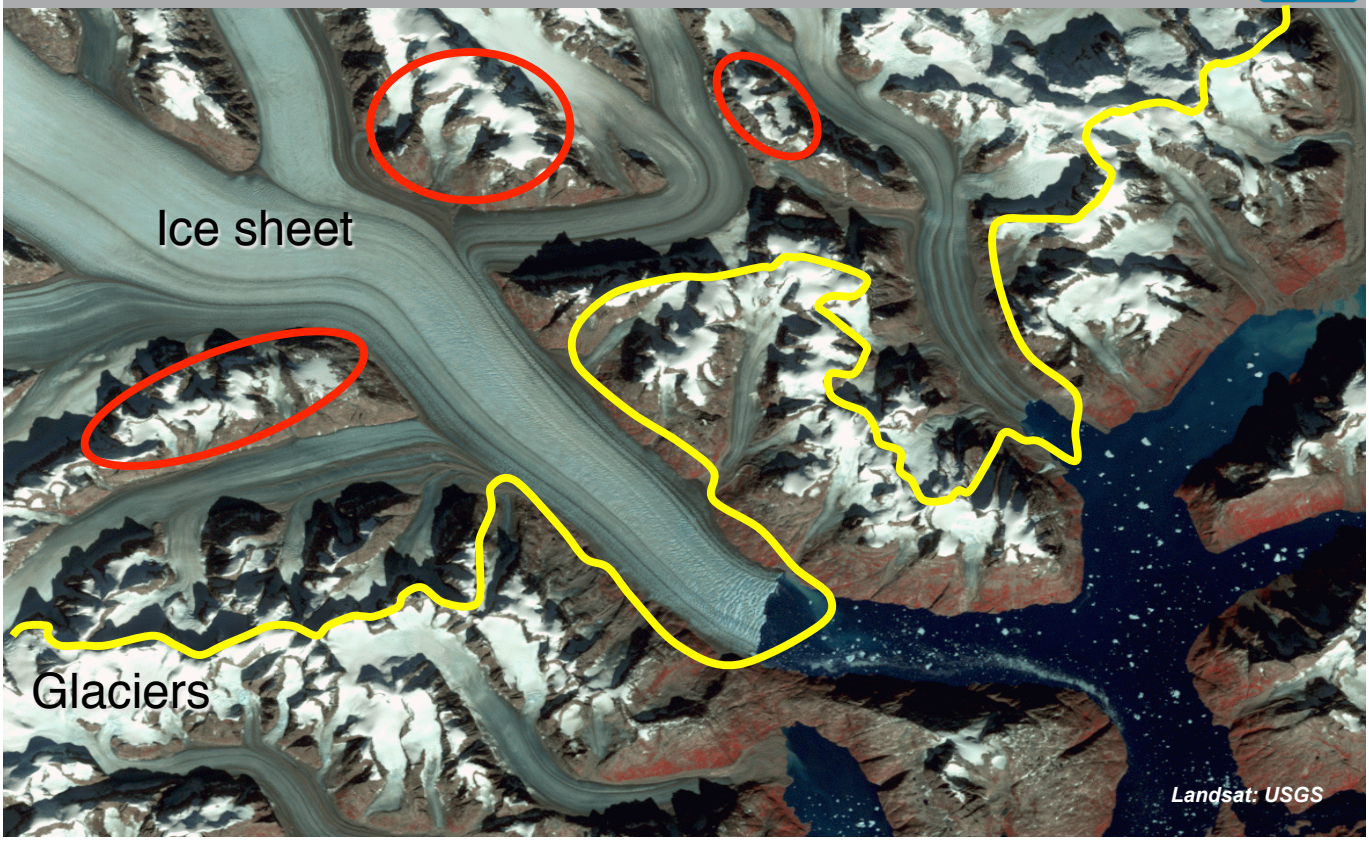
Global Length changes & mass balance trends

Mass balance time series

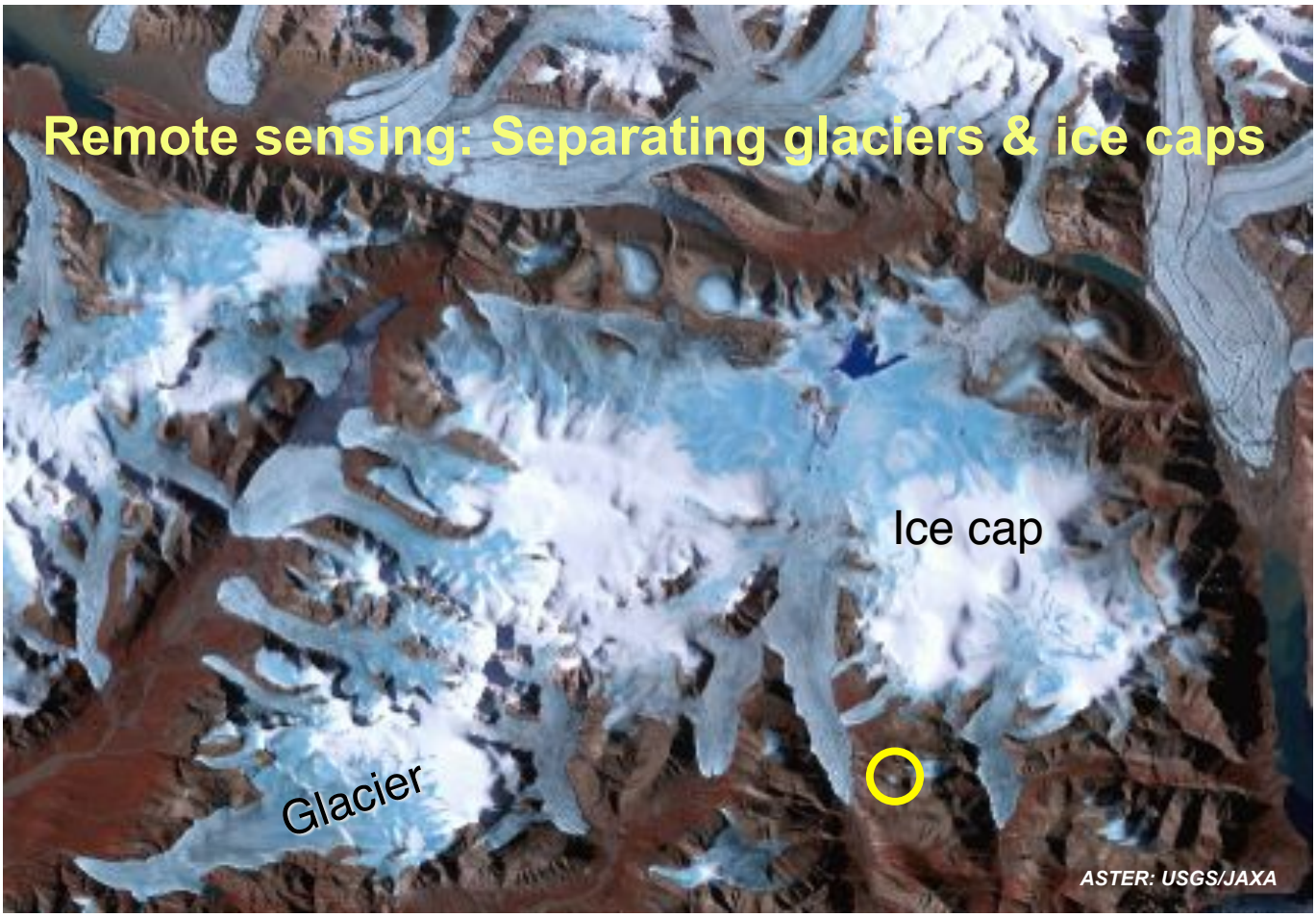


Zemp et al. (2015)

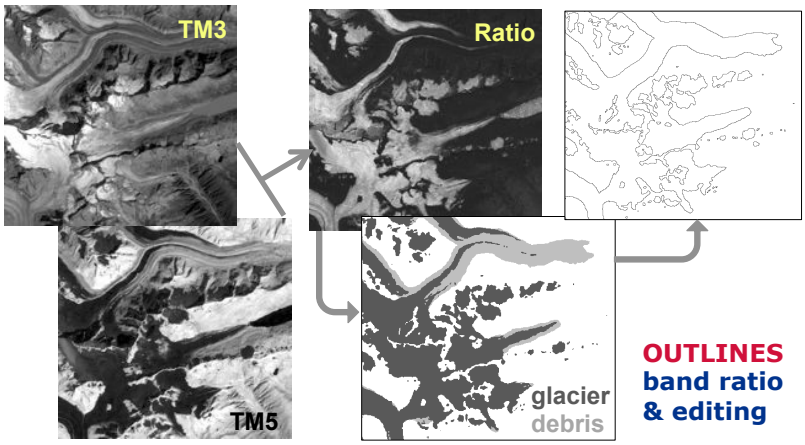
Remote sensing: Separating glaciers & ice sheets



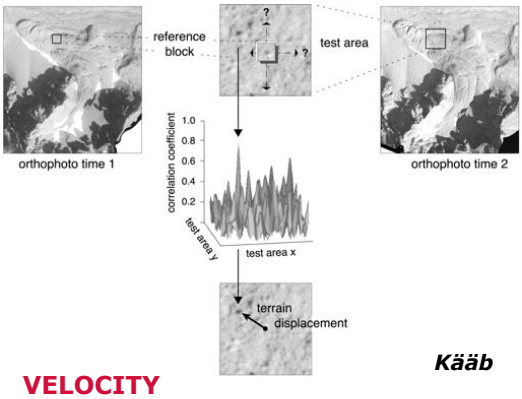
Remote sensing: Separating glaciers & ice caps



Methods for product generation



OUTLINES
band ratio & editing

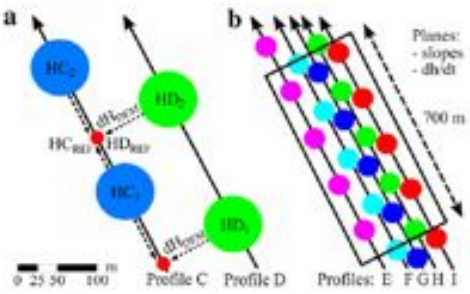


Kääb

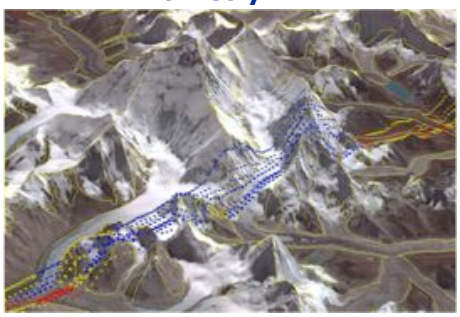
VELOCITY
cross-correlation & offset tracking

ELEVATION CHANGE

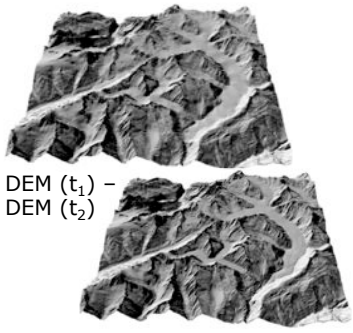
Repeat Altimetry



Altimetry-DEM



DEM differencing



Processing of >70 scenes for Greenland inventory

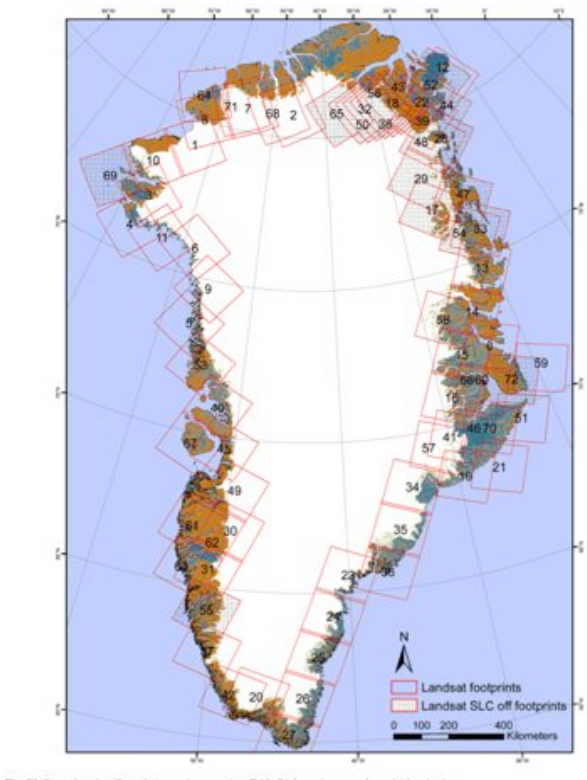
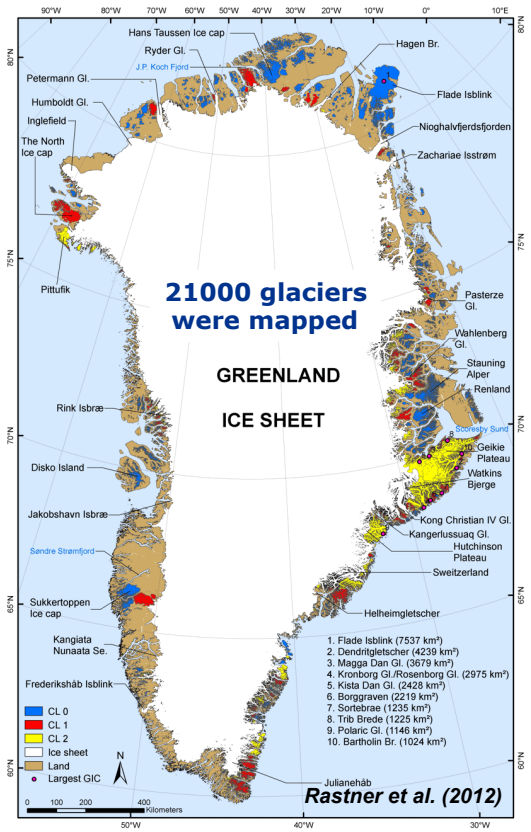


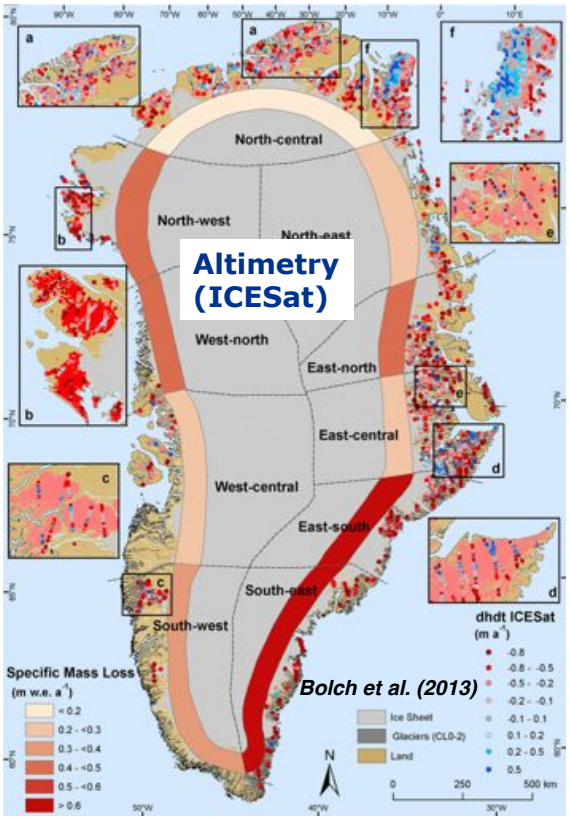
Fig. S1. Scene location (footprint) overview map (see Table S1 for path, row and acquisition date).

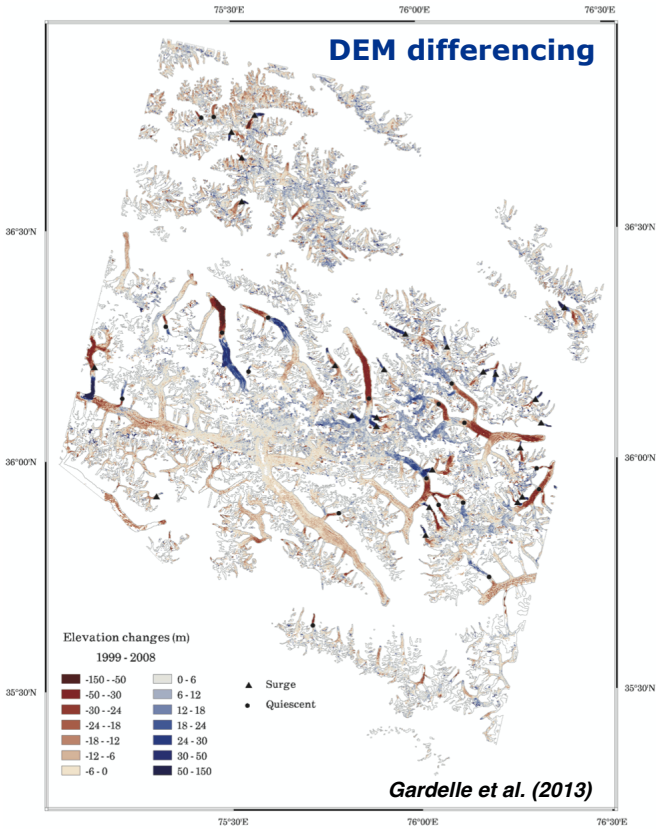
Rastner et al. (2012)



Rastner et al. (2012)

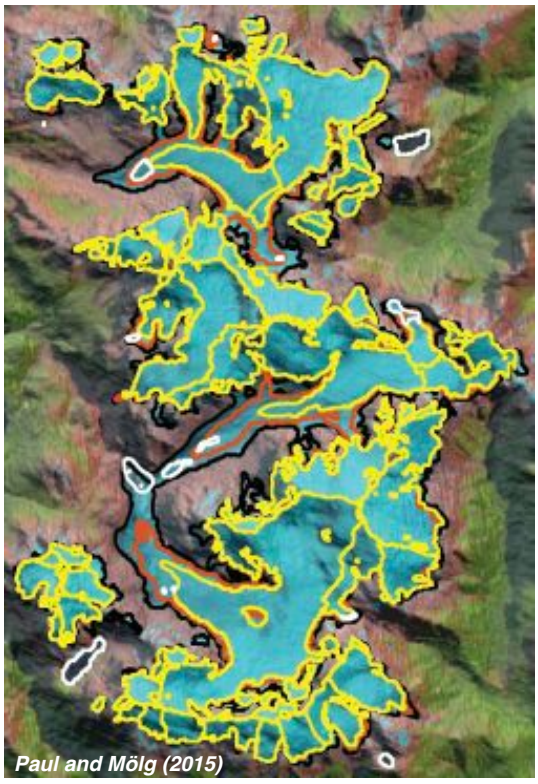
Inventory applications: Elevation changes



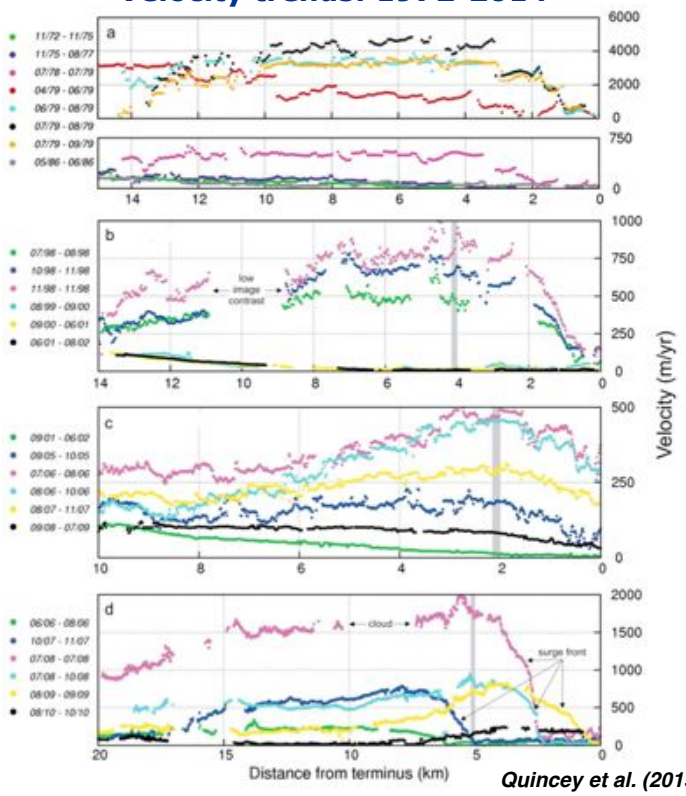


Time series: Area changes and velocity trends

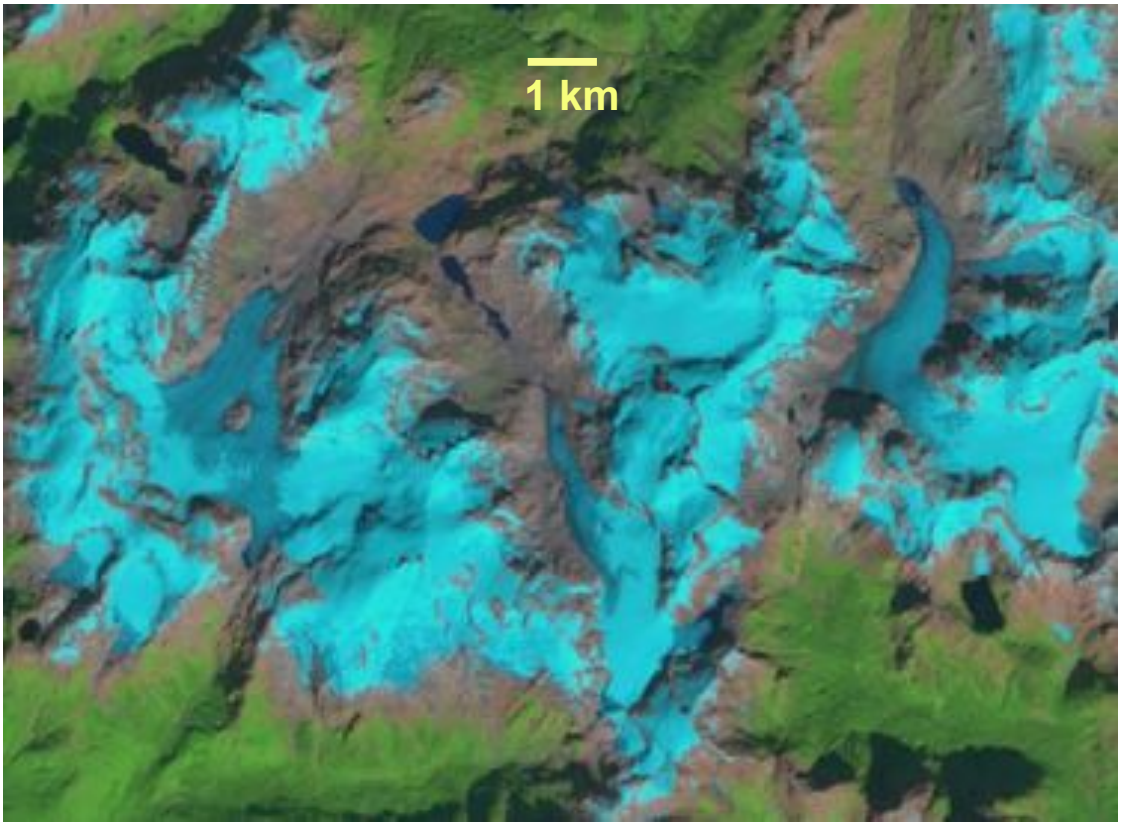
Area changes: 1985-2014



Velocity trends: 1972-2014



Annual time series Patagonia: 1998-2014



USGS

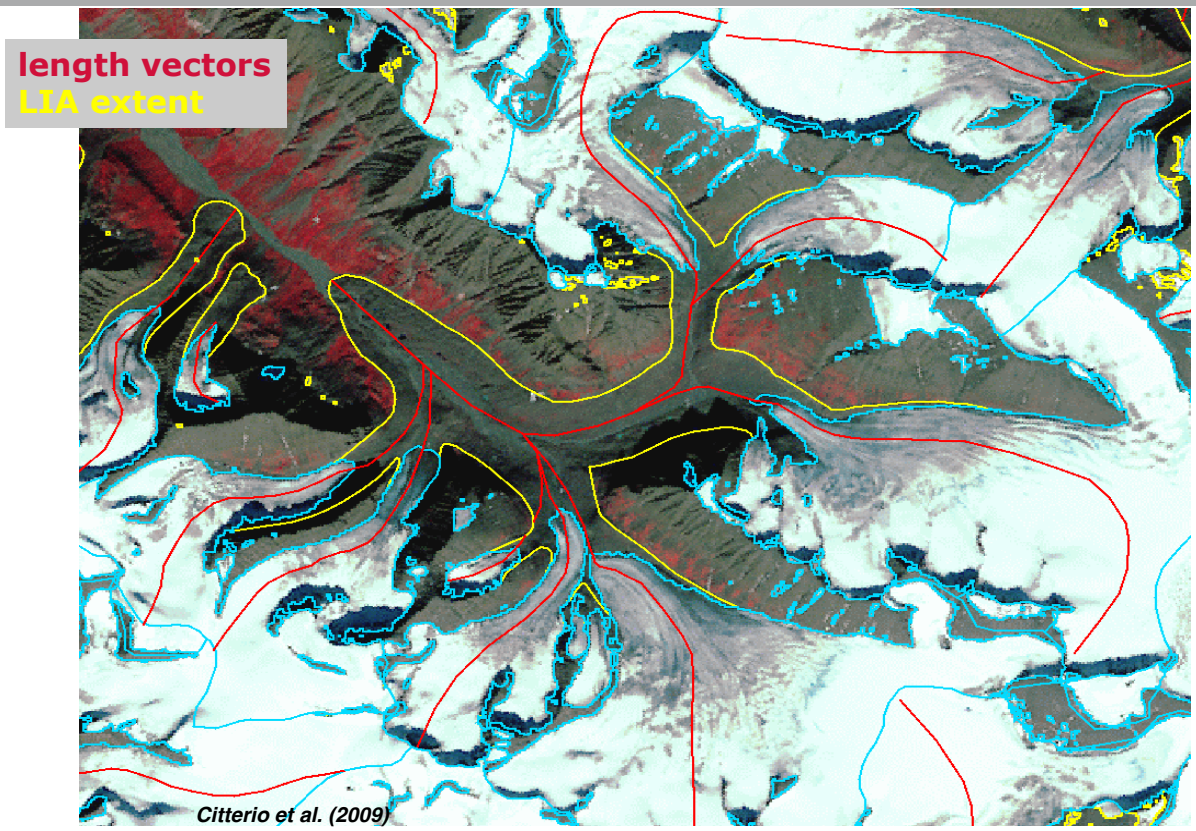
Overview: Products, sensors, challenges

Product	Area	Elev. change (ALT)	Elev. change (DEM)	Velocity
Sensor	Optical	Altimeter (opt./radar)	Optical / Radar	Optical / Radar
Format	Shape file (vector)	Shapefile (csv)	Geotiff (raster)	Shapefile (csv)
Sources	GLIMS/RGI	Science (WGMS)	Science (WGMS)	Science(GLIMS)
Validation method	Manual editing (visual)	Filtering (slope, outlier)	Co-registration, stable ground differences	Stable ground velocity, in-situ data
Validation datasets	High-resolution data (Google Earth), coherence images	Aerial missions (IceBridge / Cryovex)	ICESat, LIDAR & national DEMs	Automatic GNSS
Challenges	Global consistency, debris, snow, clouds, shadow, water, ice bergs, sea ice	clouds / footprint size, interpolation, short time series	Co-registration, data voids, penetration, cell size, projection, sensor biases (jitter)	orthorectification of input data (DEM accuracy), lack of contrast (optical)
Archived datasets	Corona, Hexagon Landsat MSS / TM	ICESat GLAS EnviSat RA-2	SRTM, GDEM2, RAMP NED / CDED, GIMP, SPOT-SPIRIT	ERS-1/2, ALOS PALSAR Envisat ASAR, Landsat TM / ETM+ (SLC on)
Ongoing missions	Landsat ETM+ / OLI Terra ASTER, SPOT	Cryosat 2	ASTER14 DMO, TanDEM-X	ALOS PALSAR 2, ASTER TerraSAR-X, Landsat OLI Cosmo-Skymed
Forthcoming datasets	Sentinel 2	Sentinel 3, ICESat 2	World-DEM	Sentinel 1 and 2

Variability in interpretation with Quickbird

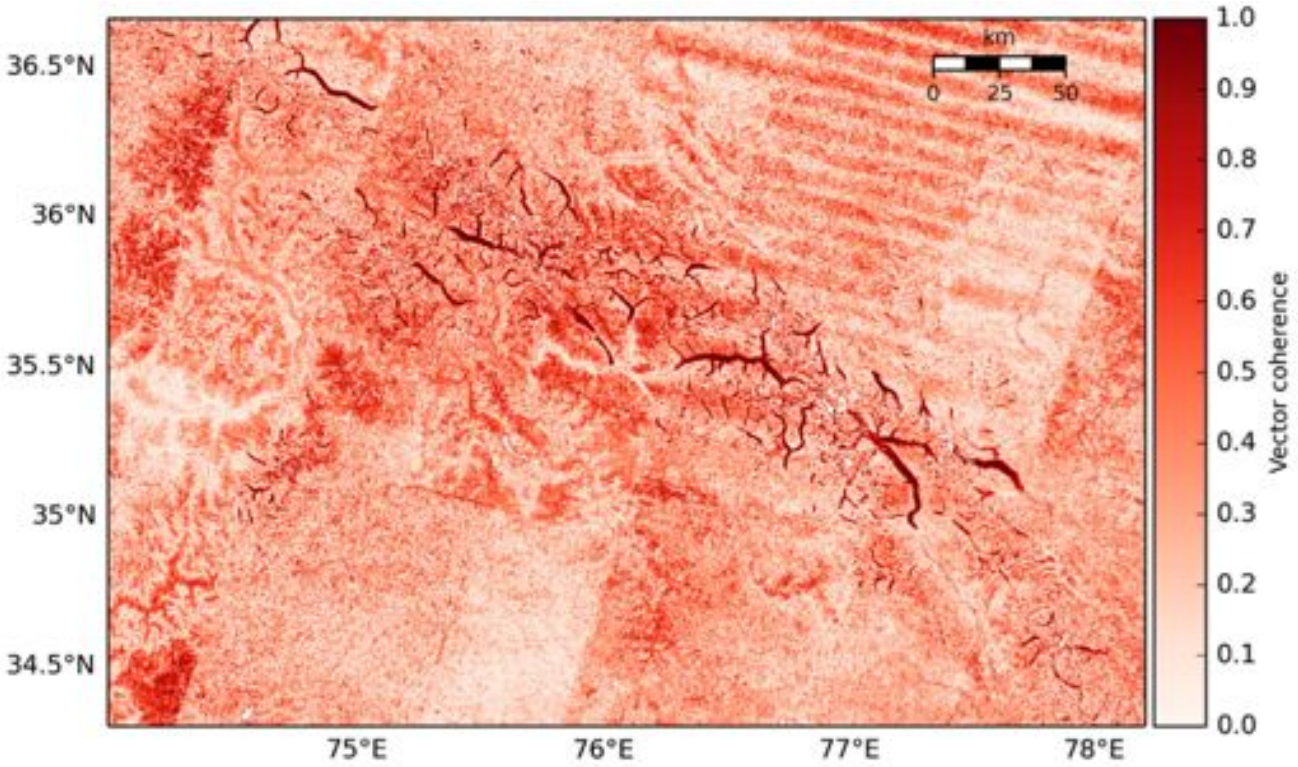
Paul et al. (2013)

Future trends: trimline mapping (LIA extent)



Citterio et al. (2009)

Future trends: Archive processing (velocity)



Dehecq et al. (2015)

Outlook

- **Glacier outlines**
  - stack processing instead of best scene selection
  - changes without debris, automated length changes, time series
- **Elevation changes**
  - altimetry: denser datasets, seasonal trends, challenges solved
  - DEMs: higher accuracy, better resolution, no gaps
  - global assessment of geodetic balance, representativeness of field obs.
- **Velocity**
  - automated processing lines, entire archives, global maps & trends
  - further applications (ice thickness distribution, mass loss by calving)
- **Old and new challenges**
  - clouds, snow, debris cover and shadow (algorithm development)
  - turning science into monitoring (long-term funding: Copernicus?)
  - vast amount of new data (from Sentinel 1a/b and 2a/b), processing?