Ice Sheet Model Validation

Verification

Is our model solving the equations we think it is?
(confirm with analytical & manufactured solutions)

Validation

Is our model a good representation of the natural system we are trying to understand & mimic?
(compare model output with observations)

Validation vs. Initialization

We have limited observations of ice sheets and we need these for both model initialization and model validation.

How do we make best use of our limited data?

Do initialization and validation need to be treated as completely separate processes?

In general (and with some obvious exceptions), should we use long-timescale data with for initialization and short-timescale date for validation?

Remote Sensing Observations (satellite & airborne)

InSAR - surface velocities [S]

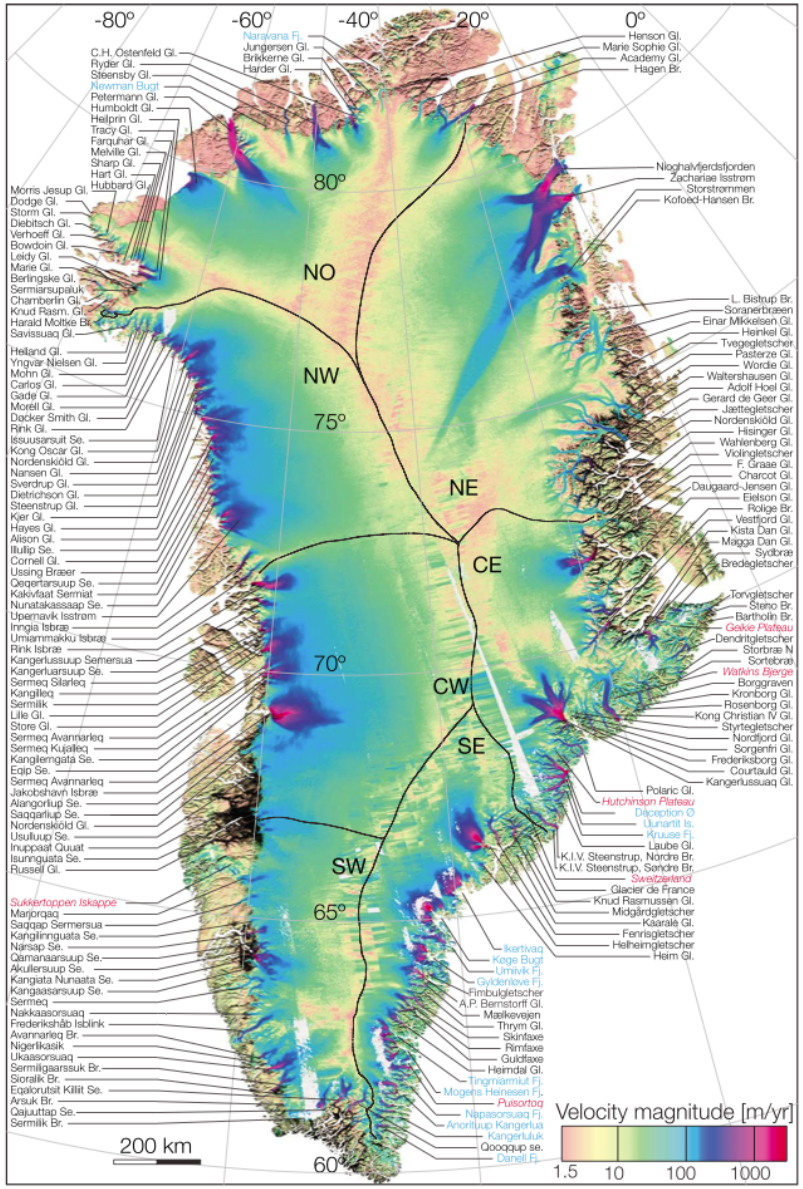
laser / radar altimetry - rates of surface elevation change [S]

gravity - rates of mass change [S]

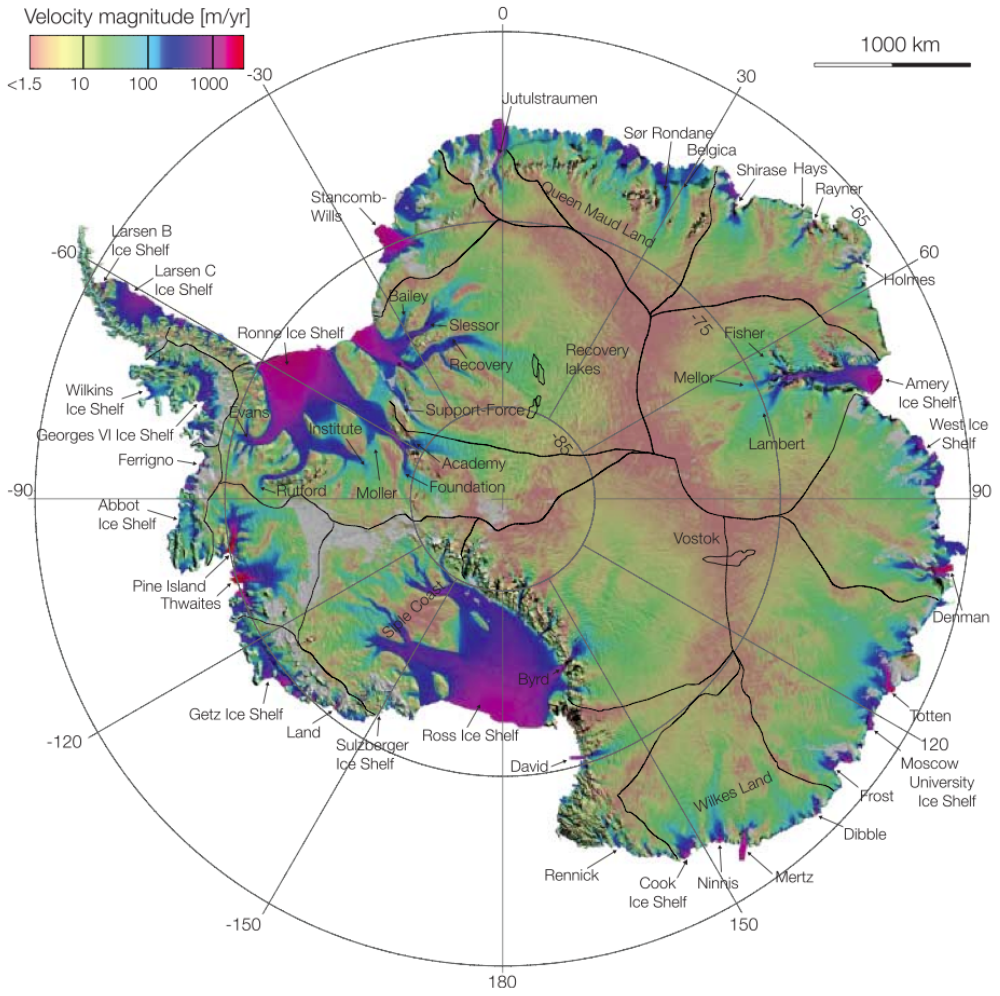
ice penetrating radar - internal layers (isochrons) [S,T]

[S] wide spatial coverage
[T] long temporal coverage

Surface Velocity



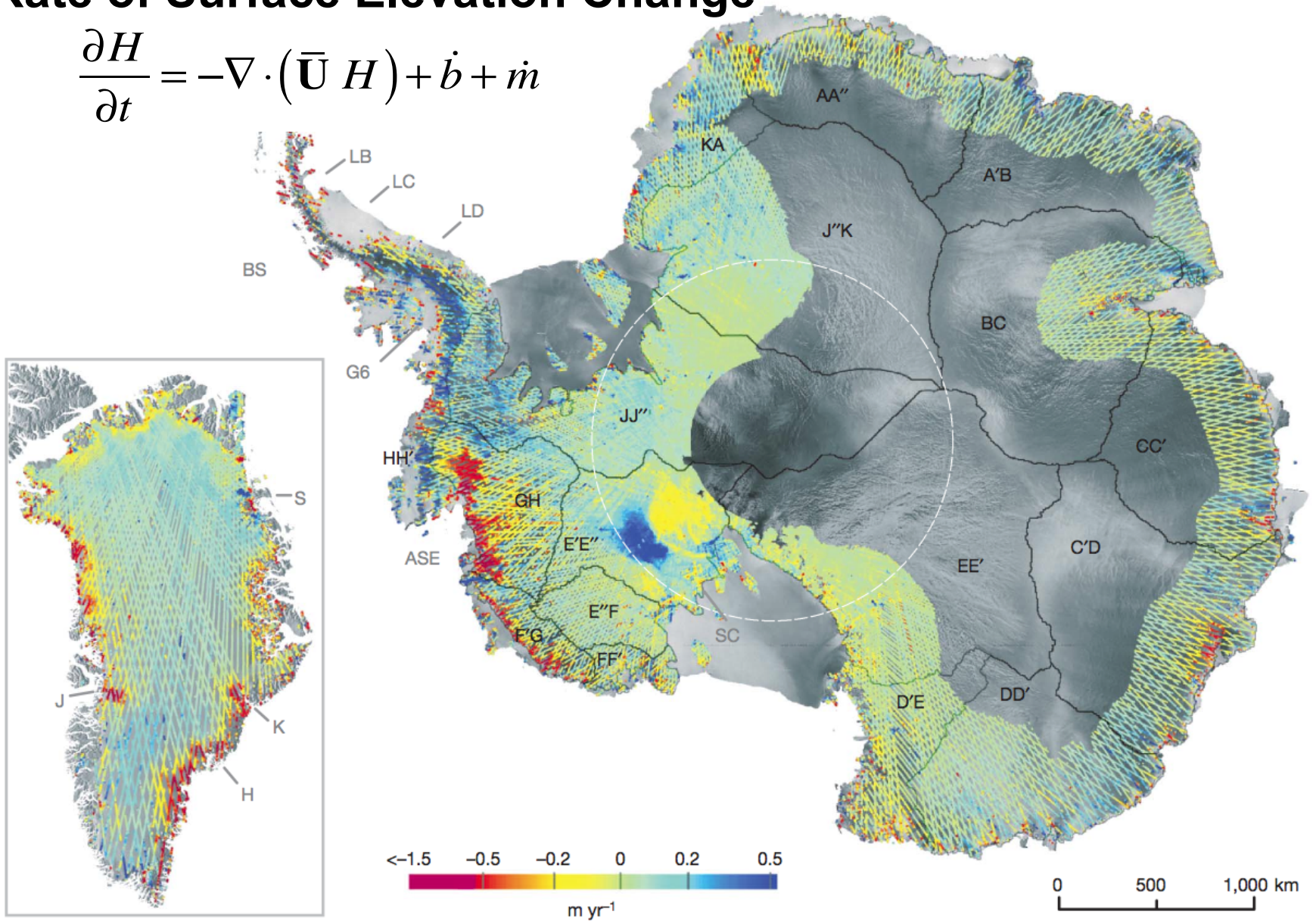
Rignot & Mouginot, *GRL*, **39** (2012)



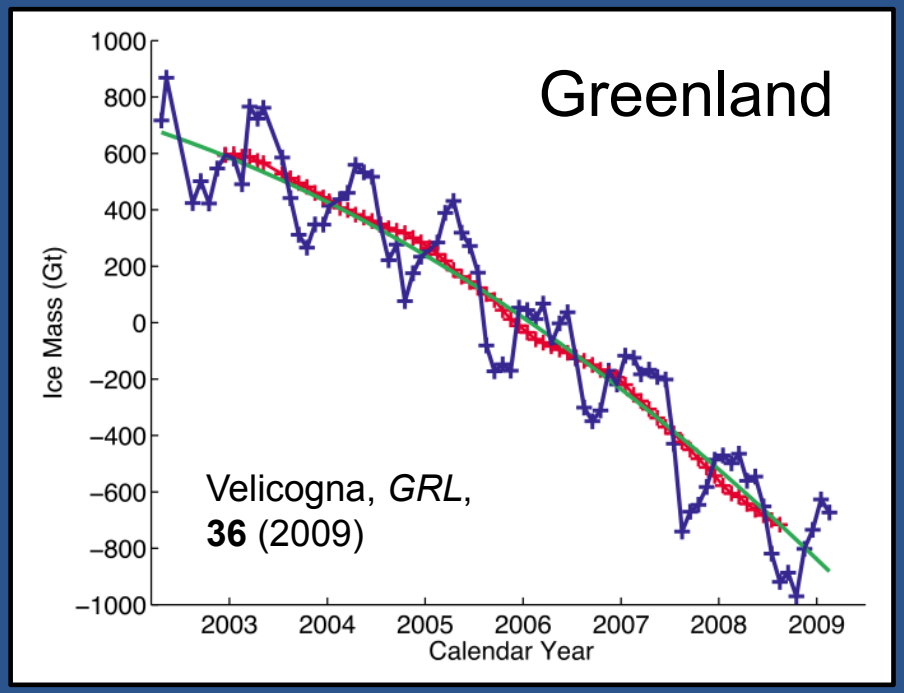
Rignot et al., *Science*, **333** (2011)

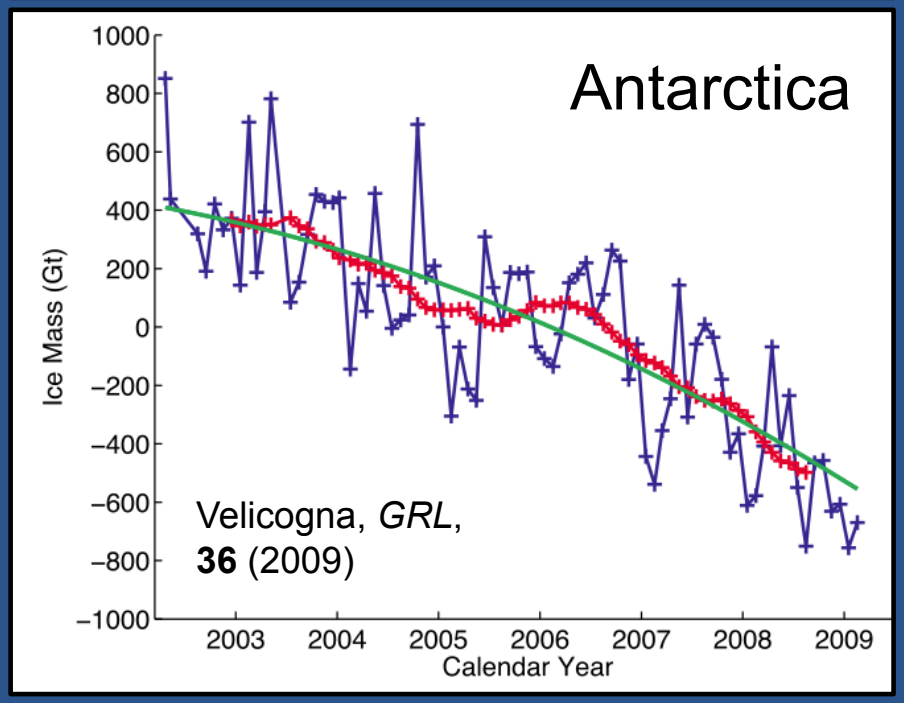
Rate of Surface Elevation Change

$$\frac{\partial H}{\partial t} = -\nabla \cdot \left(\bar{\mathbf{U}}\, H \right) + \dot{b} + \dot{m}$$

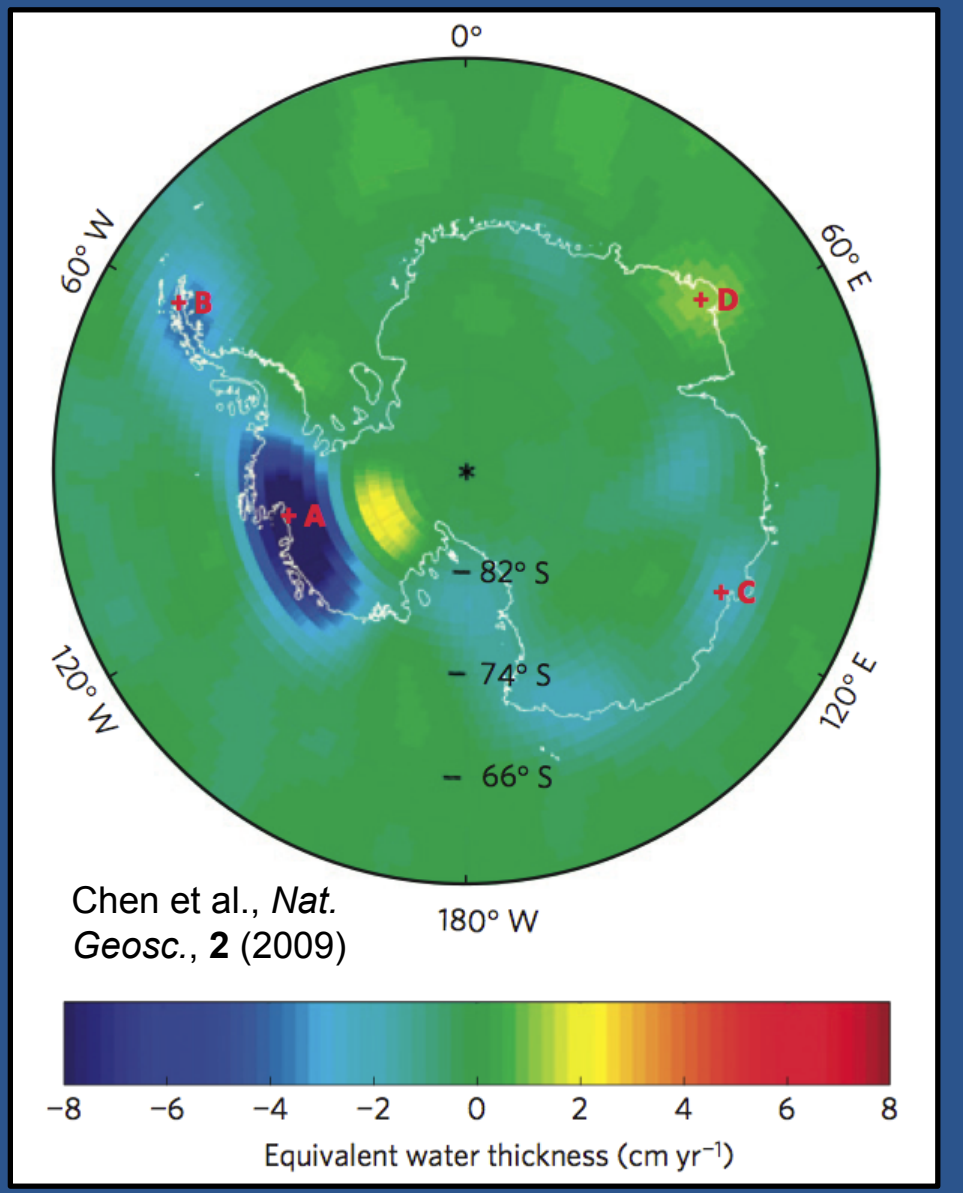


Pritchard et al., *Nature*, **461** (2009)

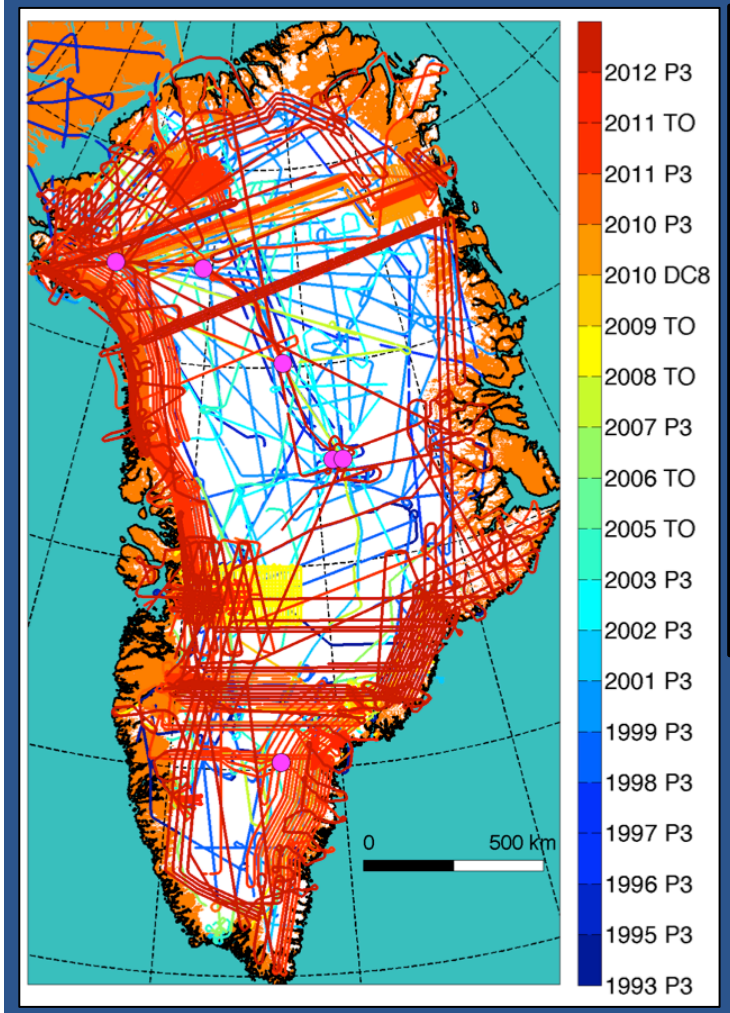


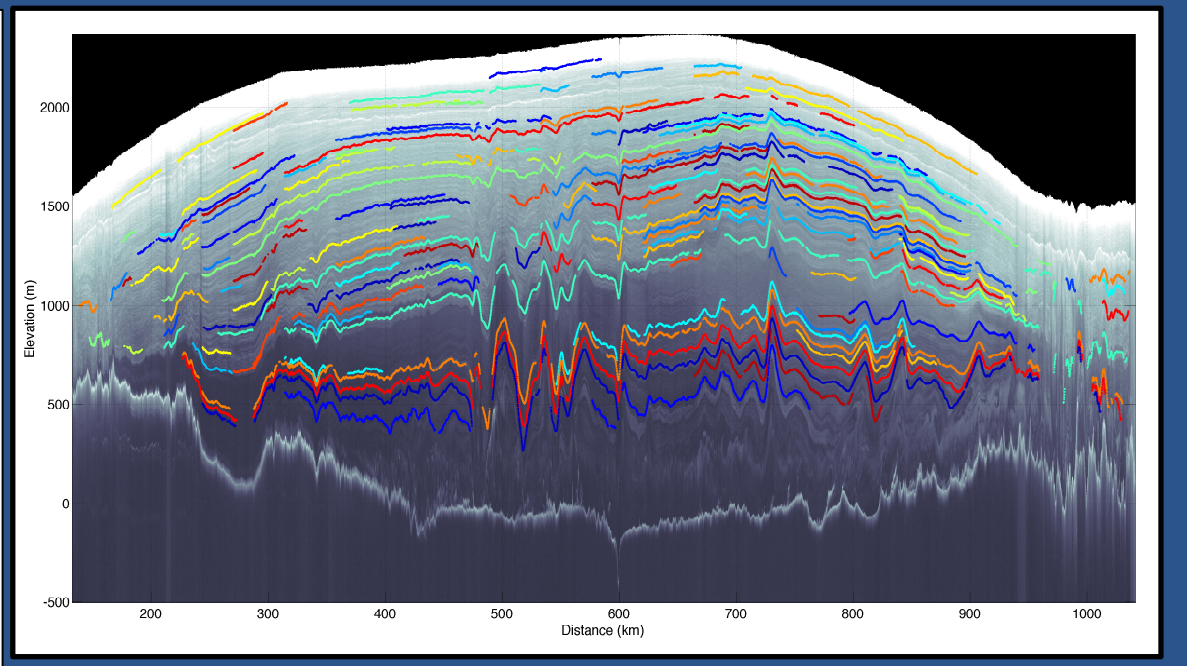


Rate of Mass Change



Internal Layers (Isochrons)

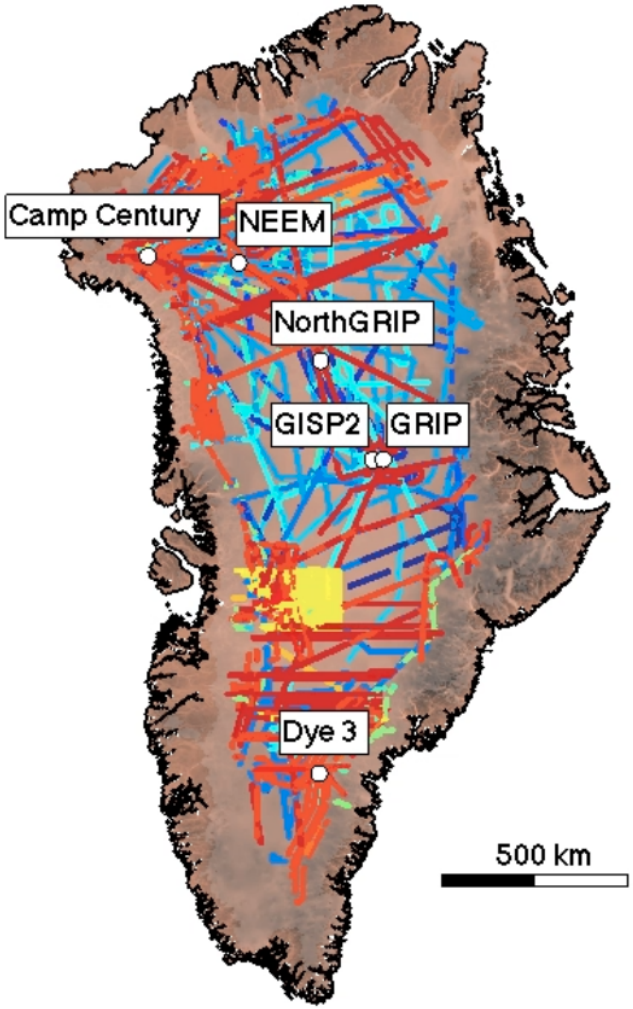




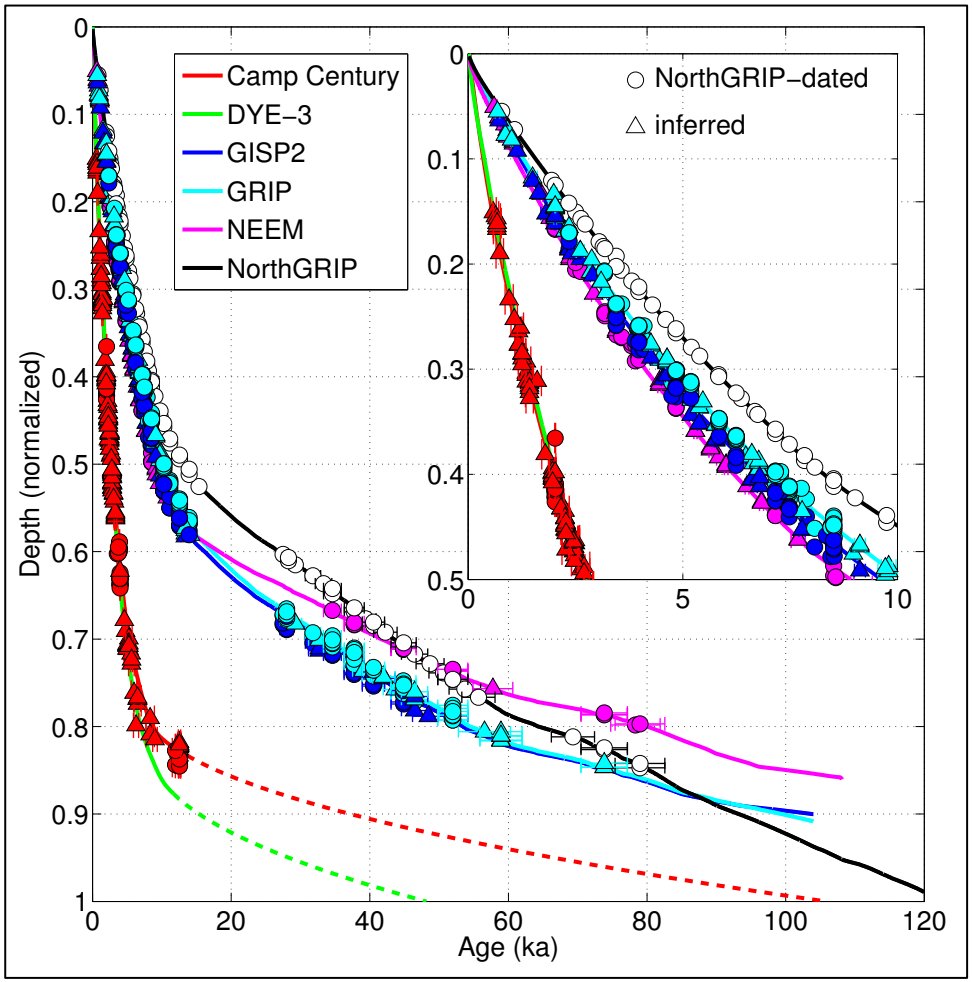
Radar data from of CReSIS & NASA OIB

Layer tracing & database by Joe MacGregor (UTIG)

Internal Layers (Isochrons)

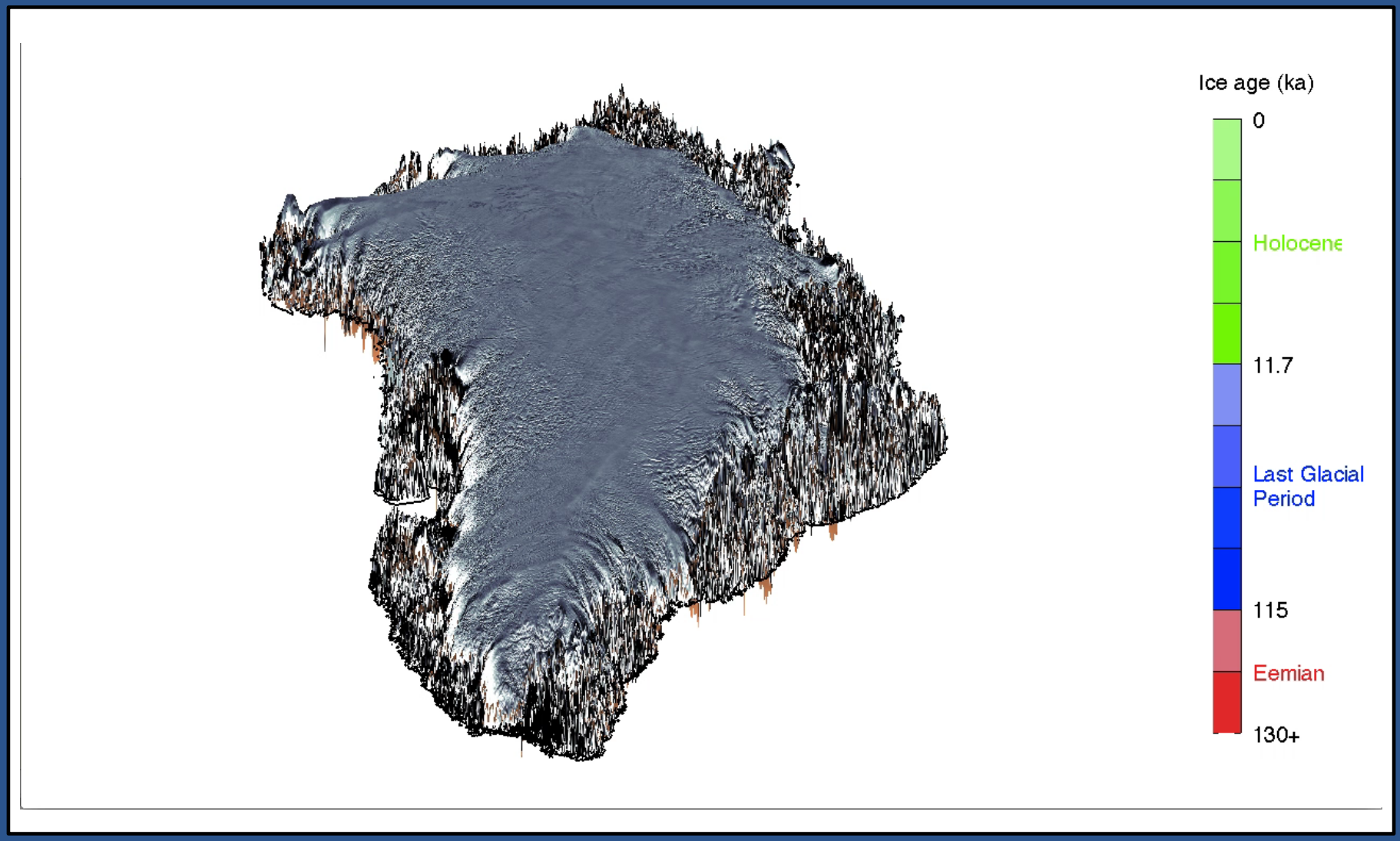


Using NorthGRIP only



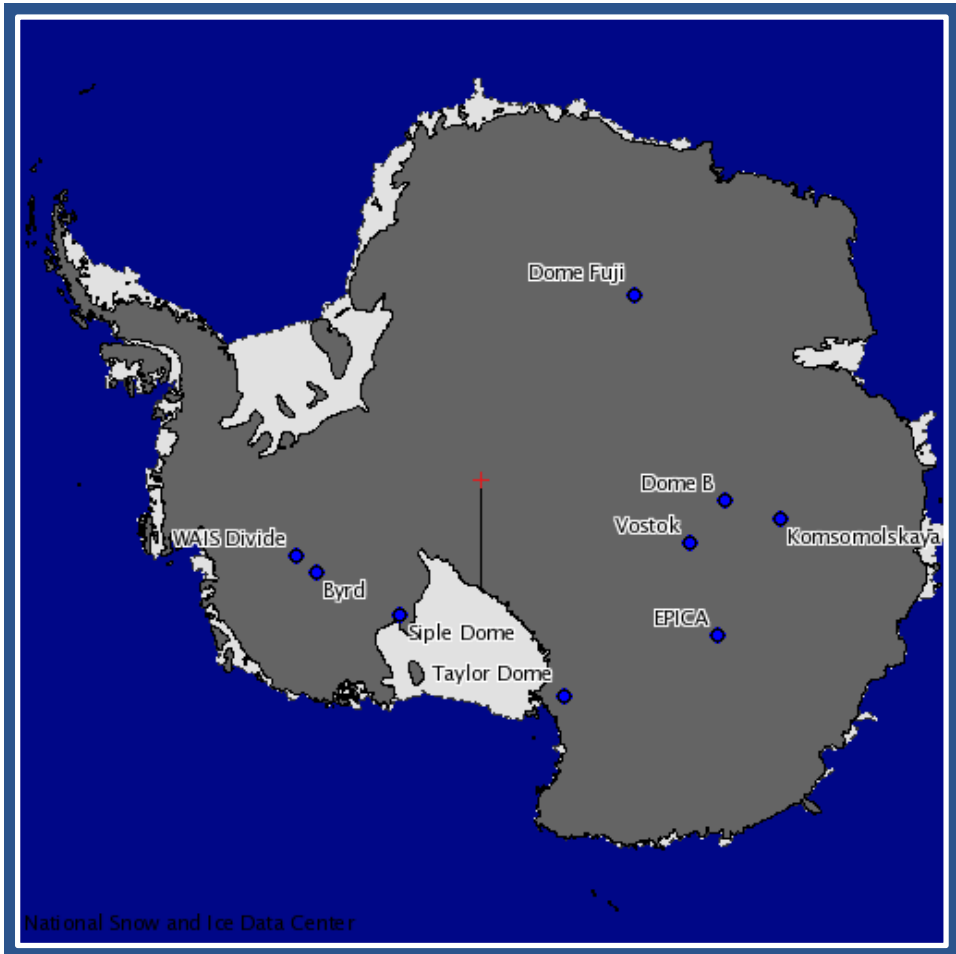
Courtesy of Joe MacGregor (UTIG)

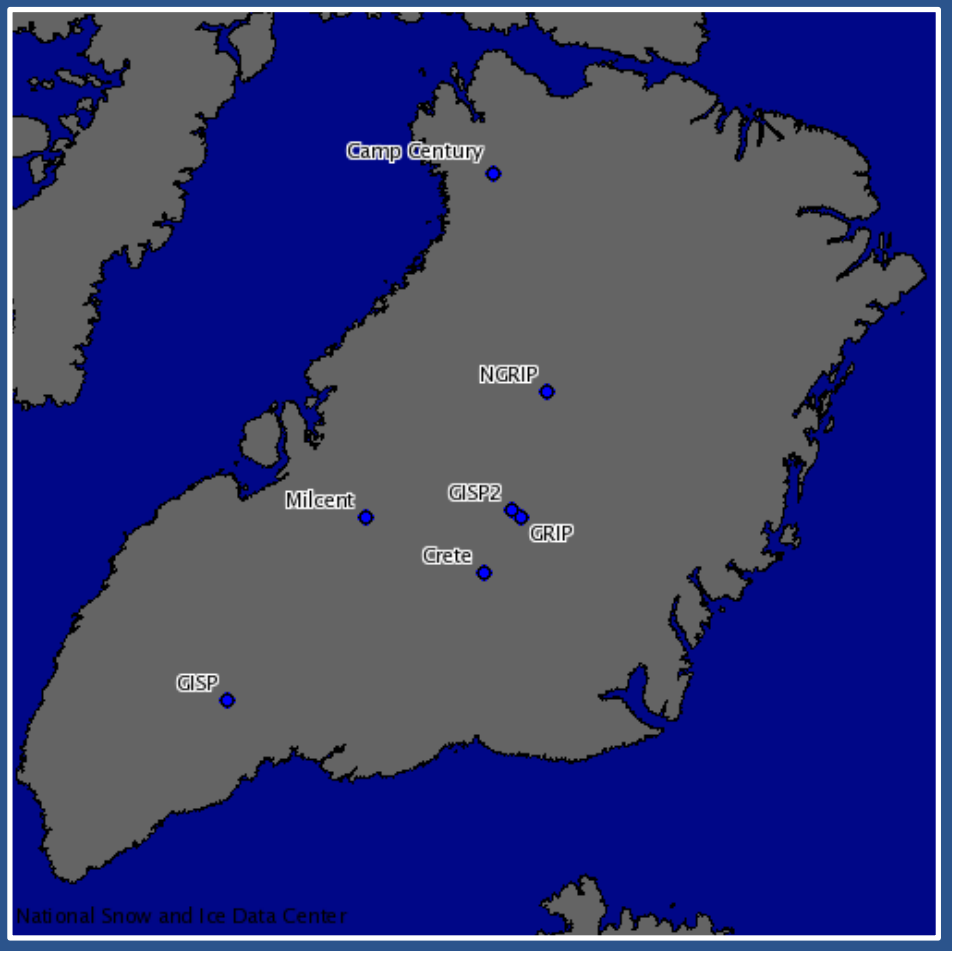
Internal Layers (Isochrons)



Courtesy of Joe MacGregor (UTIG)

Deep Borehole Observations





Figures from http://www.nsidc.org

Borehole Observations

Ice temperature profiles ^{T}

Ice age profiles ^{T}

Chemistry & stable isotope profiles ^{T}

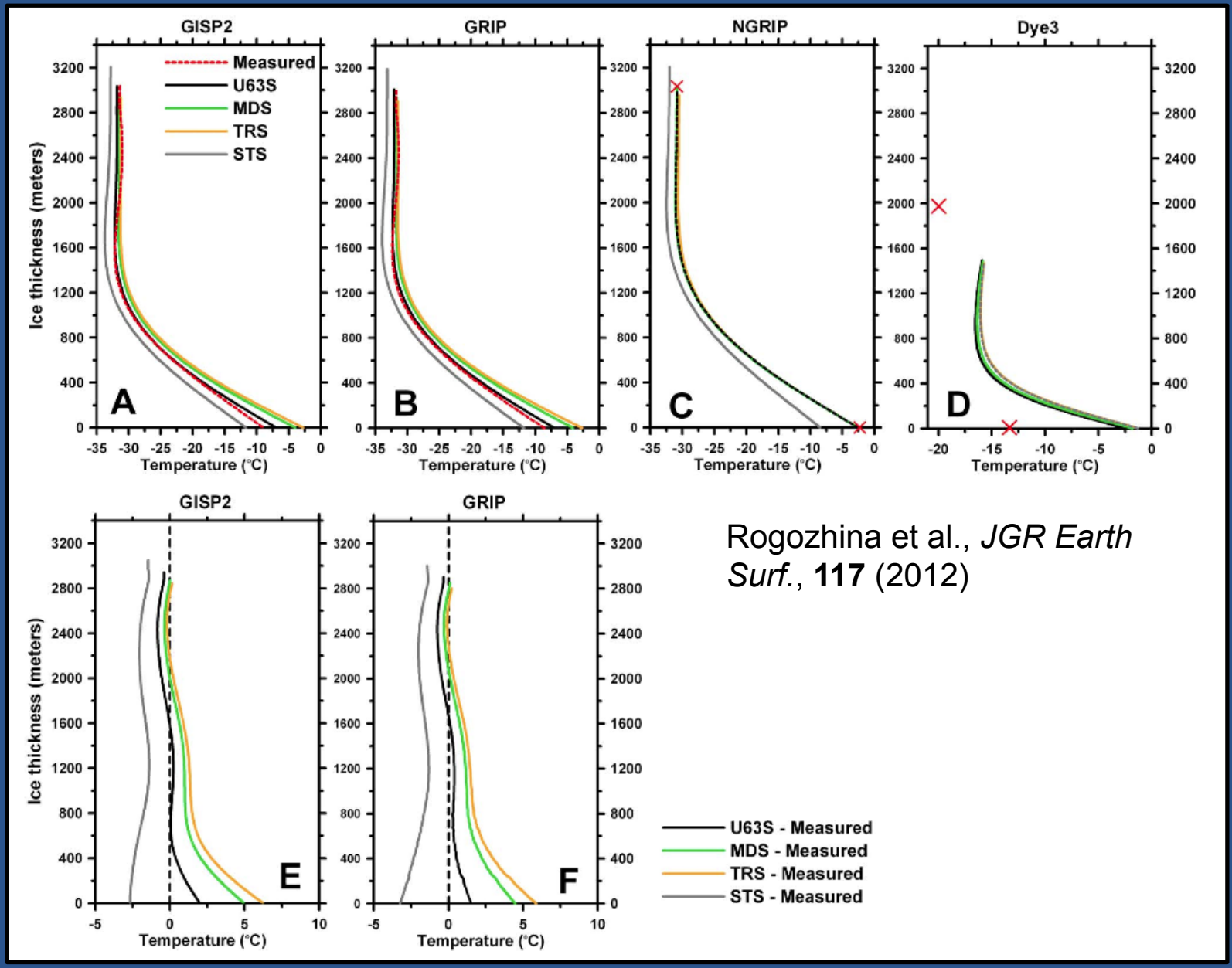
Internal deformation rates

Crystal fabric; Water & impurity content

Basal properties:

- Rock or sediment (thickness, type, properties)
- Geothermal flux constraints
- Subglacial hydrologic system

Greenland Ice Sheet Borehole Temperature Data



Rogozhina et al., *JGR Earth Surf.*, **117** (2012)

Borehole Observations

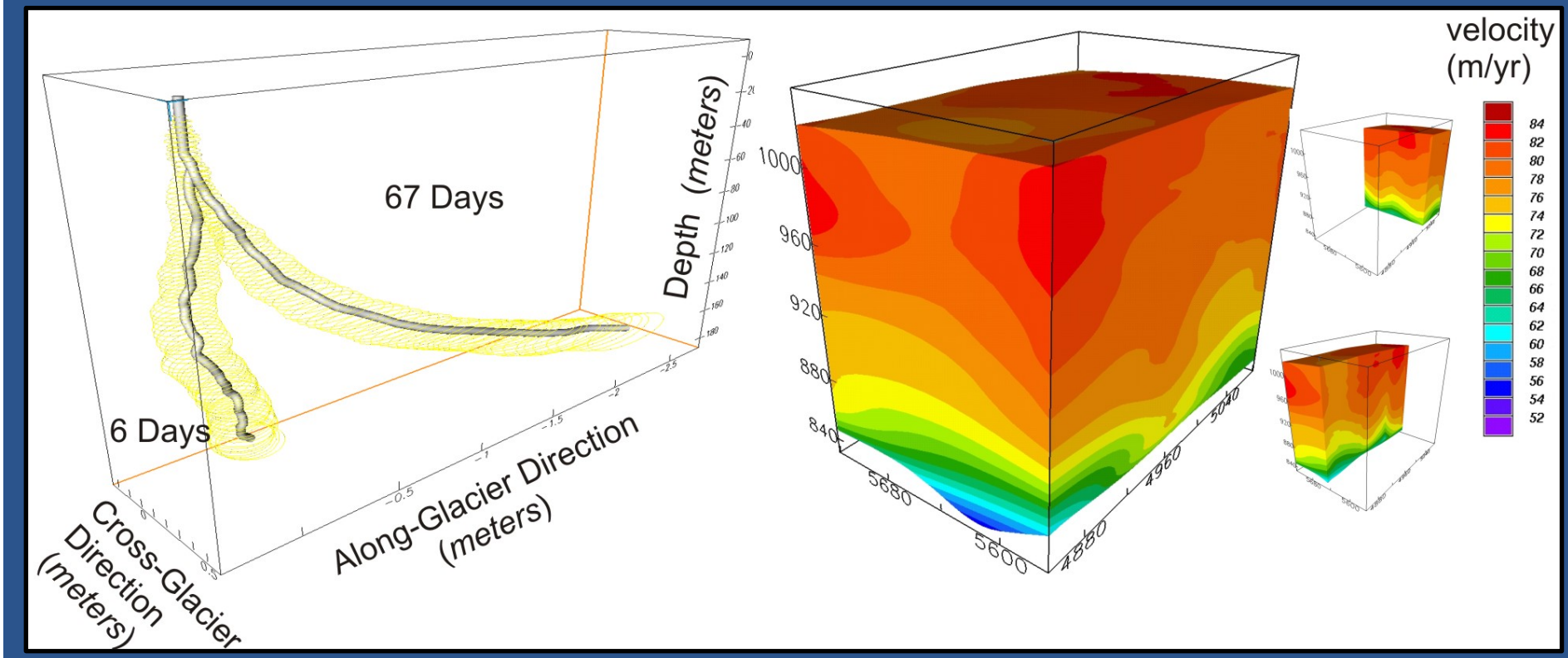
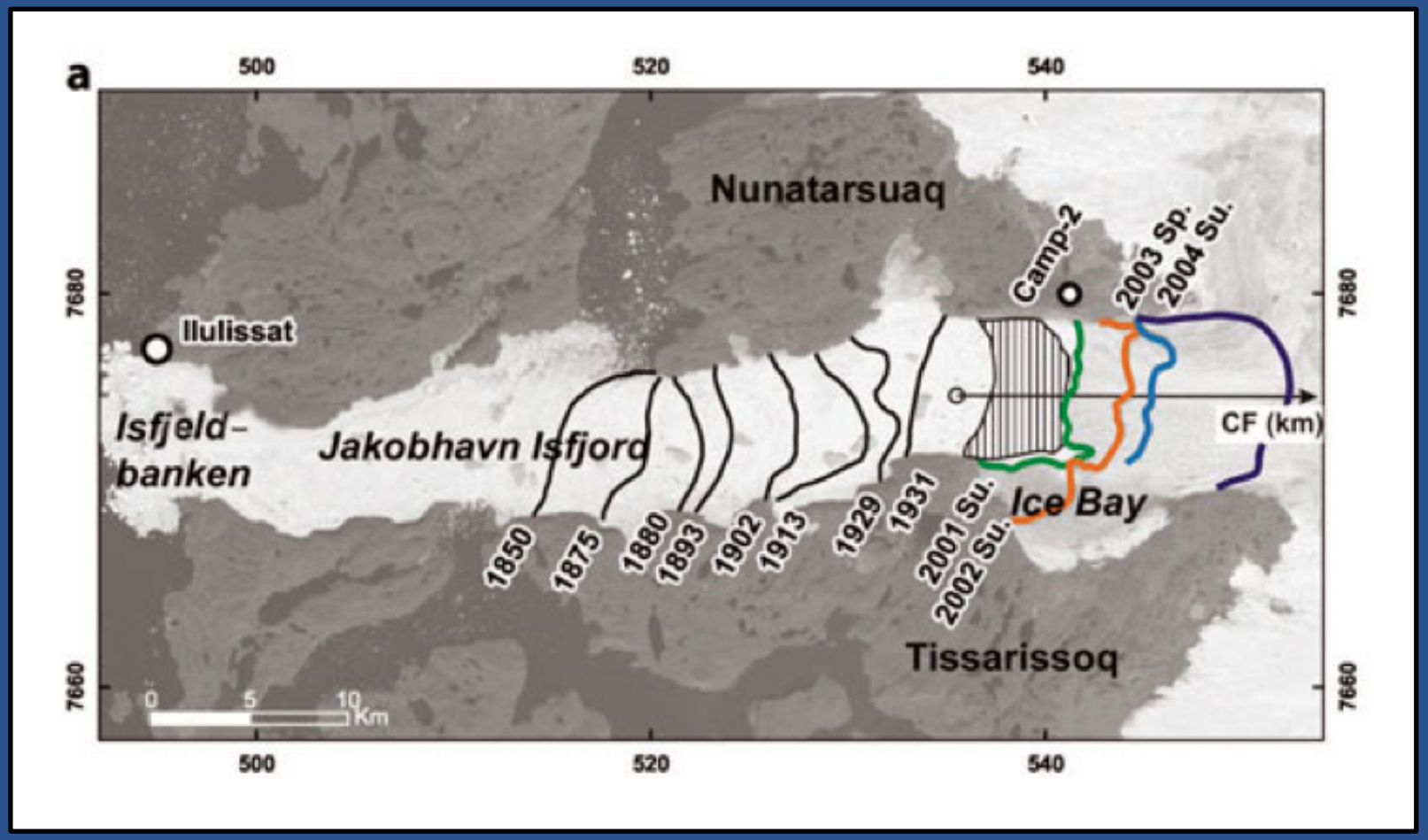


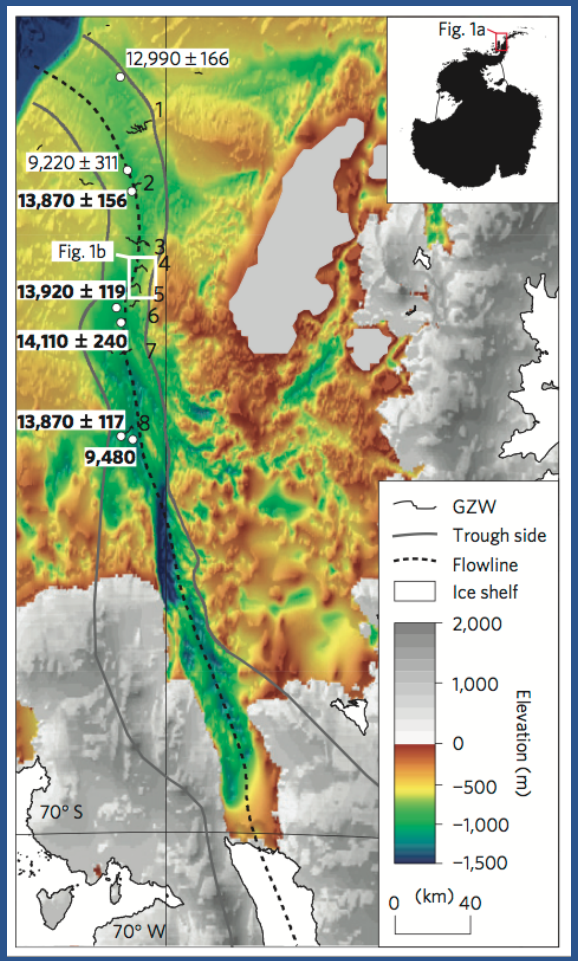
Figure courtesy of J. Johnson (UMT), GAP project,
Isunnguata Sermia and Russel Glacier, SW Greenland

Geologic Observations / Constraints [T]

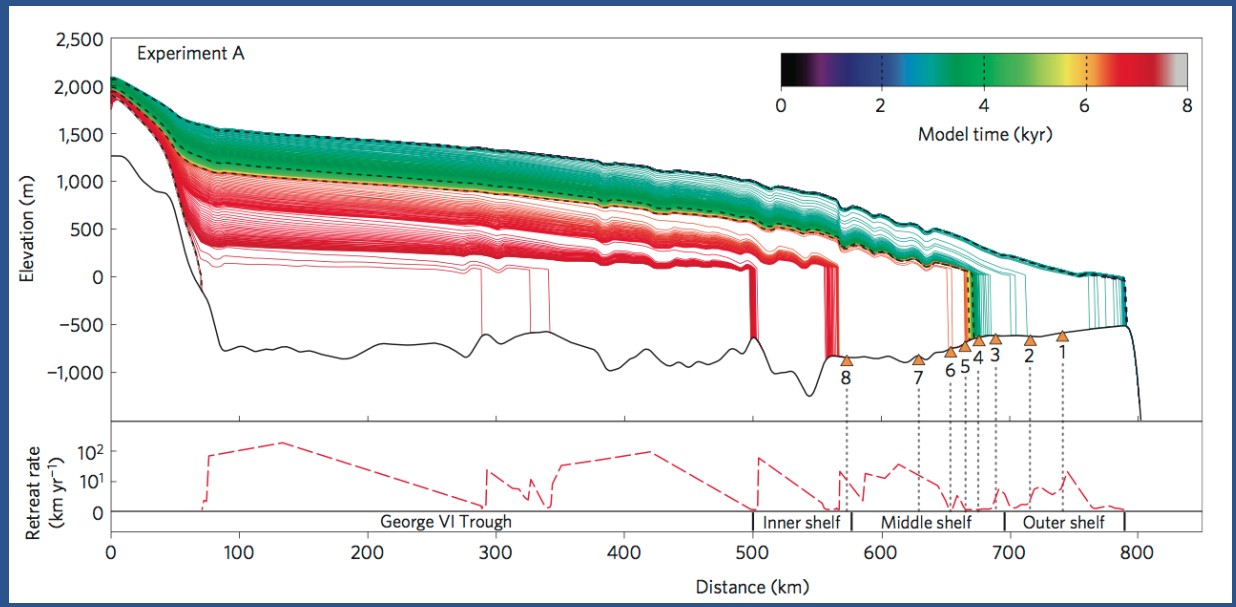


Csatho et al., *J. Glaciol.*, **54** (2008)

Geologic Observations / Constraints [T]



Jaimeson et al., *Nat. Geosc.*, **5** (2012)



Development Needed

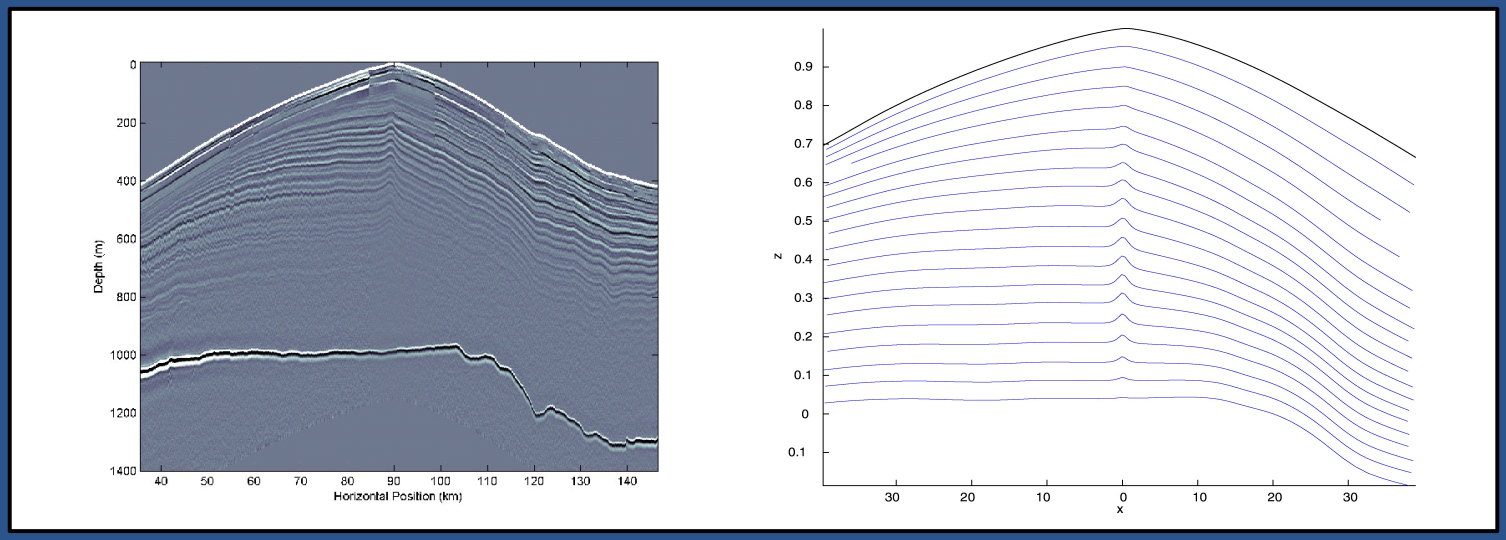
For comparing to obs. of elevation and mass change:

- Mapped time series of elevation change from altimetry in model friendly formats (in progress with NASA colleagues), and / or code to sample ice sheet model output as seen by airborne / satellite altimeter (e.g. IceSAT)?
- Mapped time series of mass change from gravimetry in model friendly formats and / or code to sample ice sheet model output as seen by GRACE?
- Data for SMB & dynamic forcing for ice sheet:
  - flux time series from major outlet glaciers
  - time series of SMB

Development Needed

For comparing to internal layers:

- Capability to generate model layers (isochrons):
  - Include age as tracer in ice sheet models (too diffusive?)
  - Explicit particle tracking (too expensive?)



For use in initialization, need all of the above plus time-dependent adjoints

Development Needed

For comparing to borehole observations:

- Extraction of standard model diagnostics at borehole locations (e.g., velocity & temperature profiles)
- Tracking of ice age
- Tracking & evolution of stable isotopes and /or other atmos. tracers?

For use in initialization (e.g. matching temperature profiles), also need time-dependent adjoints