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

laser / radar altimetry - rates of surface elevation change

gravity - rates of mass change

ice penetrating radar - internal layers (isochrons)

\(^S\) wide spatial coverage

\(^T\) long temporal coverage
Surface Velocity


Rignot et al., *Science*, **333** (2011)
Rate of Surface Elevation Change

\[
\frac{\partial H}{\partial t} = -\nabla \cdot (\overline{U} \ H) + \dot{b} + \dot{m}
\]
Greenland

Rate of Mass Change

Antarctica

Velicogna, GRL, 36 (2009)

Chen et al., Nat. Geosc., 2 (2009)
Internal Layers (Isochrons)

Radar data from of CReSIS & NASA OIB

Layer tracing & database by Joe MacGregor (UTIG)
Using NorthGRIP only

Internal Layers (Isochrons)

Courtesy of Joe MacGregor (UTIG)
Internal Layers (Isochrons)

Courtesy of Joe MacGregor (UTIG)
Figures from http://www.nsidc.org
Borehole Observations

- Ice temperature profiles
- Ice age profiles
- Chemistry & stable isotope profiles
- Internal deformation rates

Crystal fabric; Water & impurity content

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

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

Csatho et al., *J. Glaciol.*, 54 (2008)
Geologic Observations / Constraints

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