Monitoring of Polar Ice Response to Climate Change

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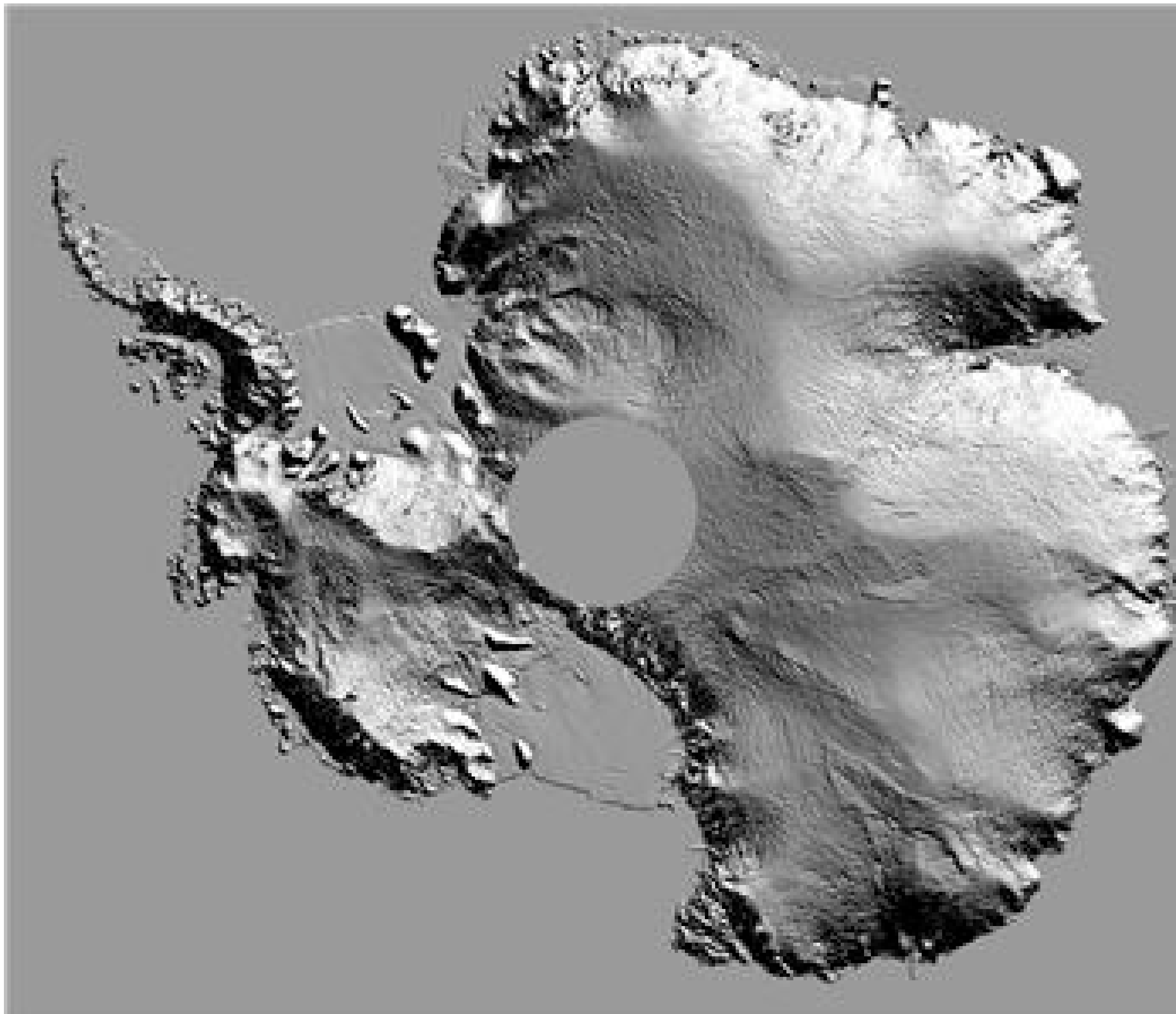
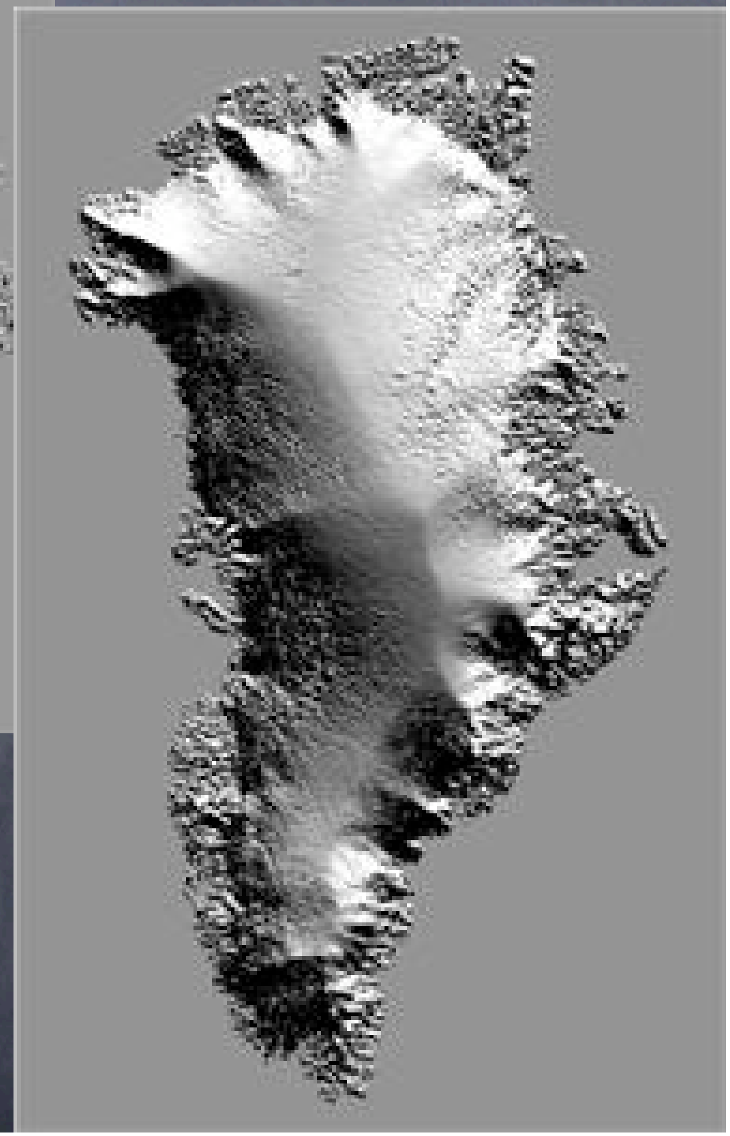
For the purpose of this talk
Polar ice = ice sheets

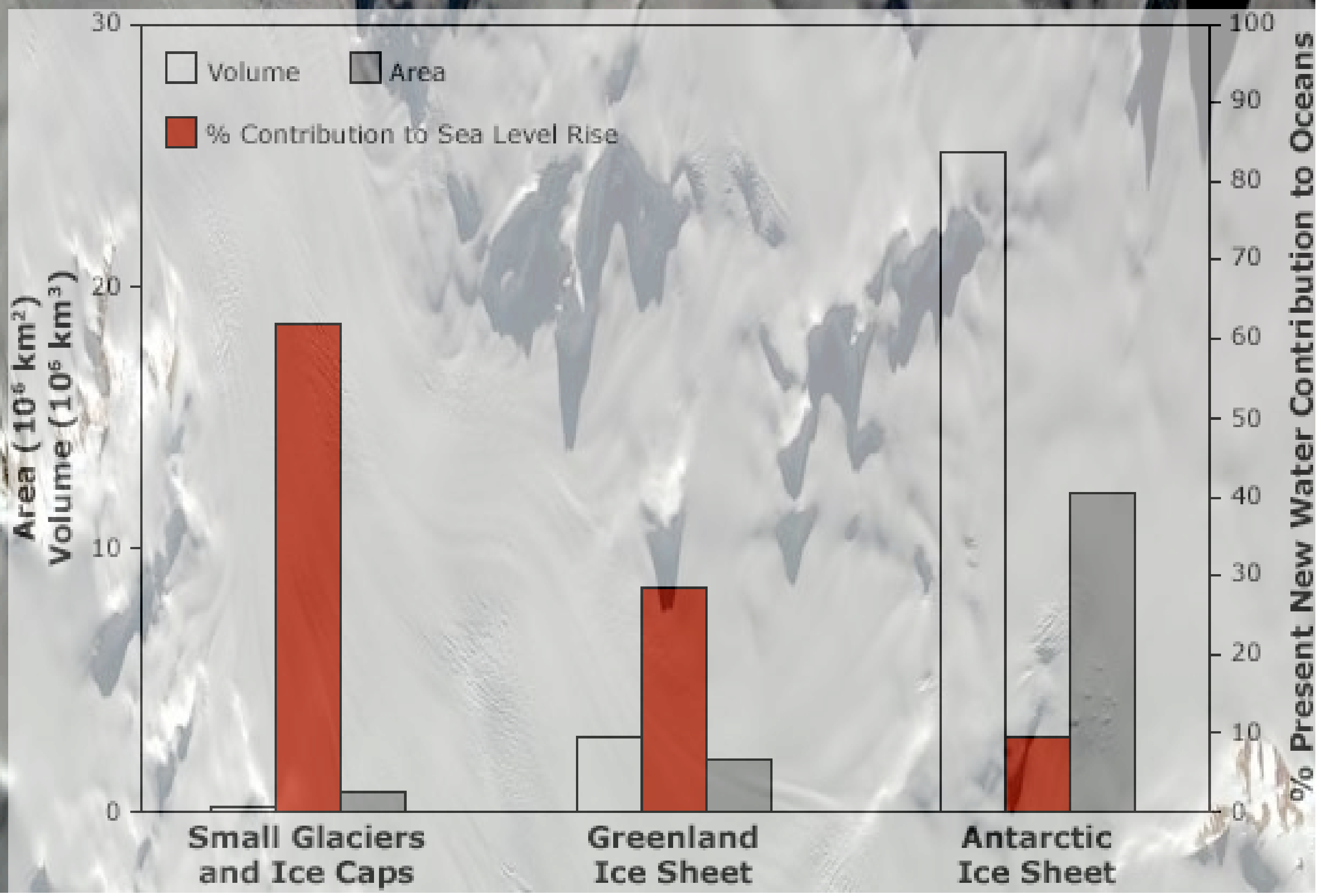




ICESat surface topo data - NSIDC

Quick facts: area, volume, recent contribution to sea level changes (Meier et al., 2007)

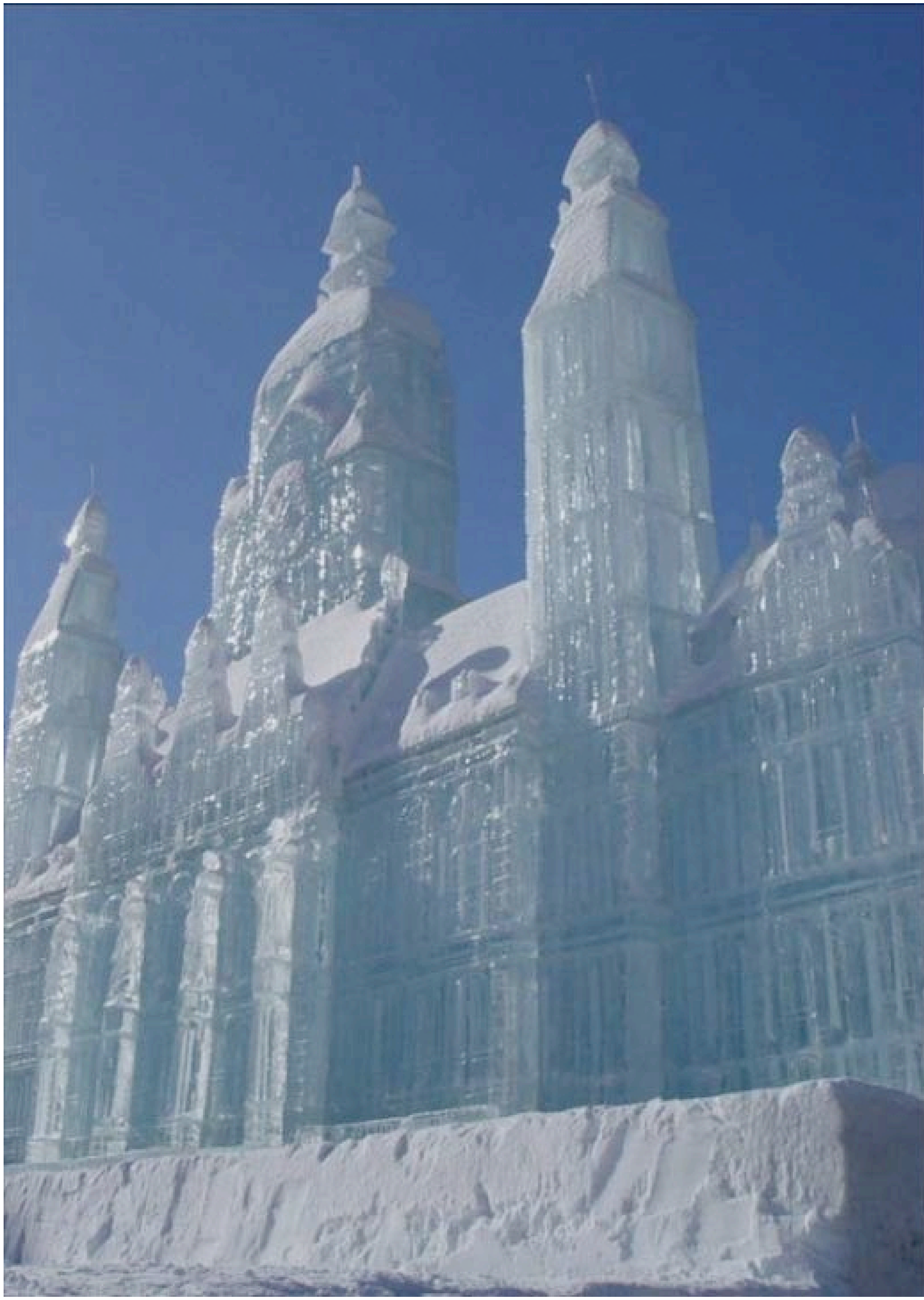
Quickbird image courtesy of Dr. P. Morin (AGIC)



Major challenge for the next 10-20 years:

Improve predictive ice sheet models (IPCC, 2007)
-what is the mass balance of polar ice sheets now?
-how will it evolve in the next 100-1000 years?

Quickbird image courtesy of Dr. P. Morin (AGIC)



Satellite data are needed to sculpt equations into an ice sheet model:

- Boundary conditions
- Initial conditions
- Parameterizations of subgrid processes

$$\nabla \cdot \sigma(x,y) = \dot{a}(x,y) - \frac{\partial h}{\partial t} \tag{32}$$

$$\begin{aligned}
\frac{\partial u}{\partial x} + \frac{u}{\omega}\frac{\partial \omega}{\partial x} + \frac{\partial w}{\partial z} &= 0\,, \\
\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xz}}{\partial z} &= 0\,, \\
\epsilon_2 \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{zz}}{\partial z} &= \rho g\,,
\end{aligned}$$

Key needed satellite data sets (horizontal pixel size, vertical resolution, temporal coverage):

SURFACE

S1. Elevation (<100-1000m, <1m, annual/seasonal)

S2. Elevation change (<100-1000m, <0.1m/yr, annual/seasonal)

S3. Ice surface velocity (<100m, <1m/yr, annual/seasonal)

S4. Surface mass balance, net accumulation, net melting (<100m, <0.1m/yr, sub-seasonal)

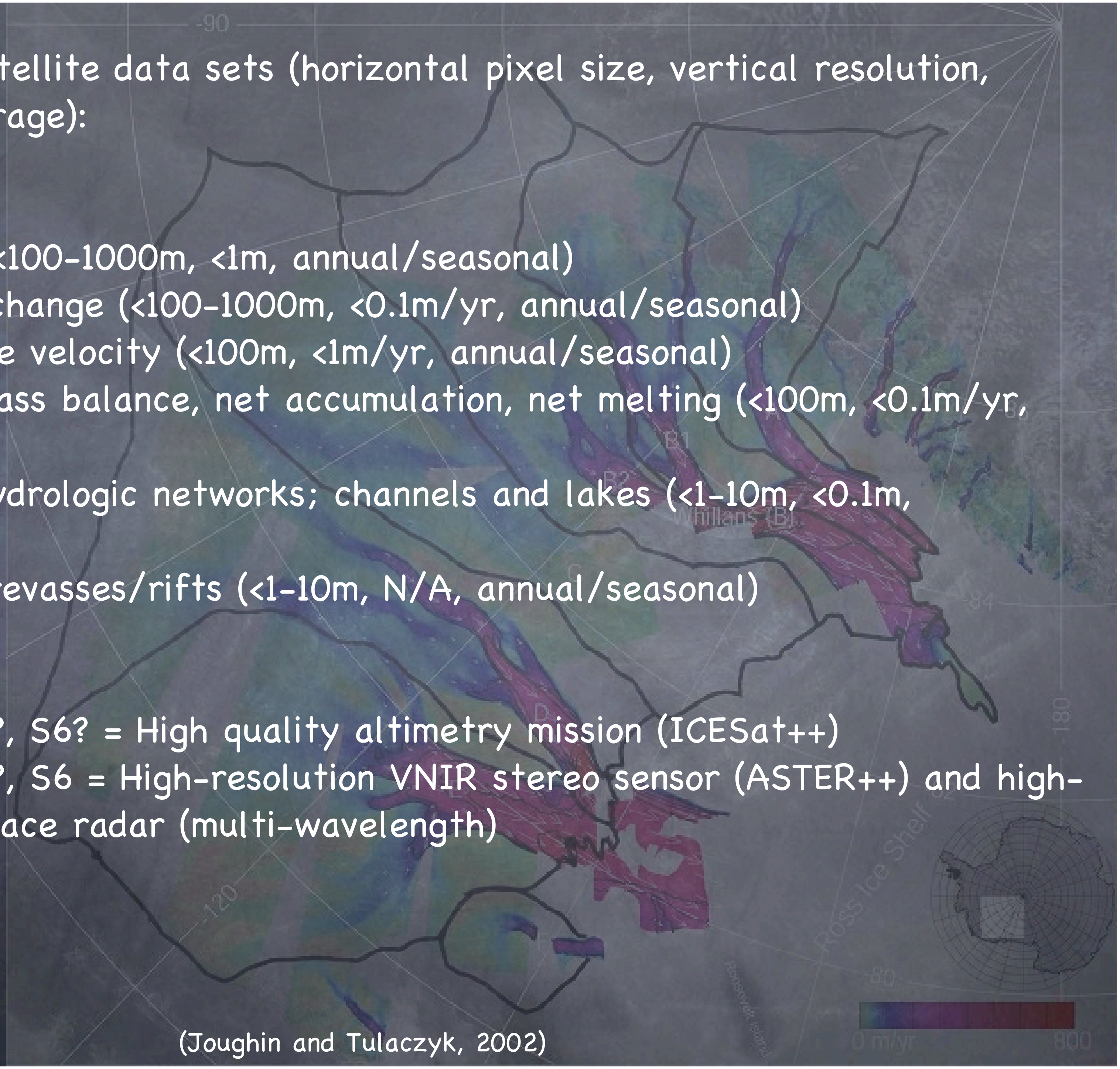
S5. Surface hydrologic networks; channels and lakes (<1-10m, <0.1m, daily/weekly)

S6. Surface crevasses/rifts (<1-10m, N/A, annual/seasonal)

Tools?:

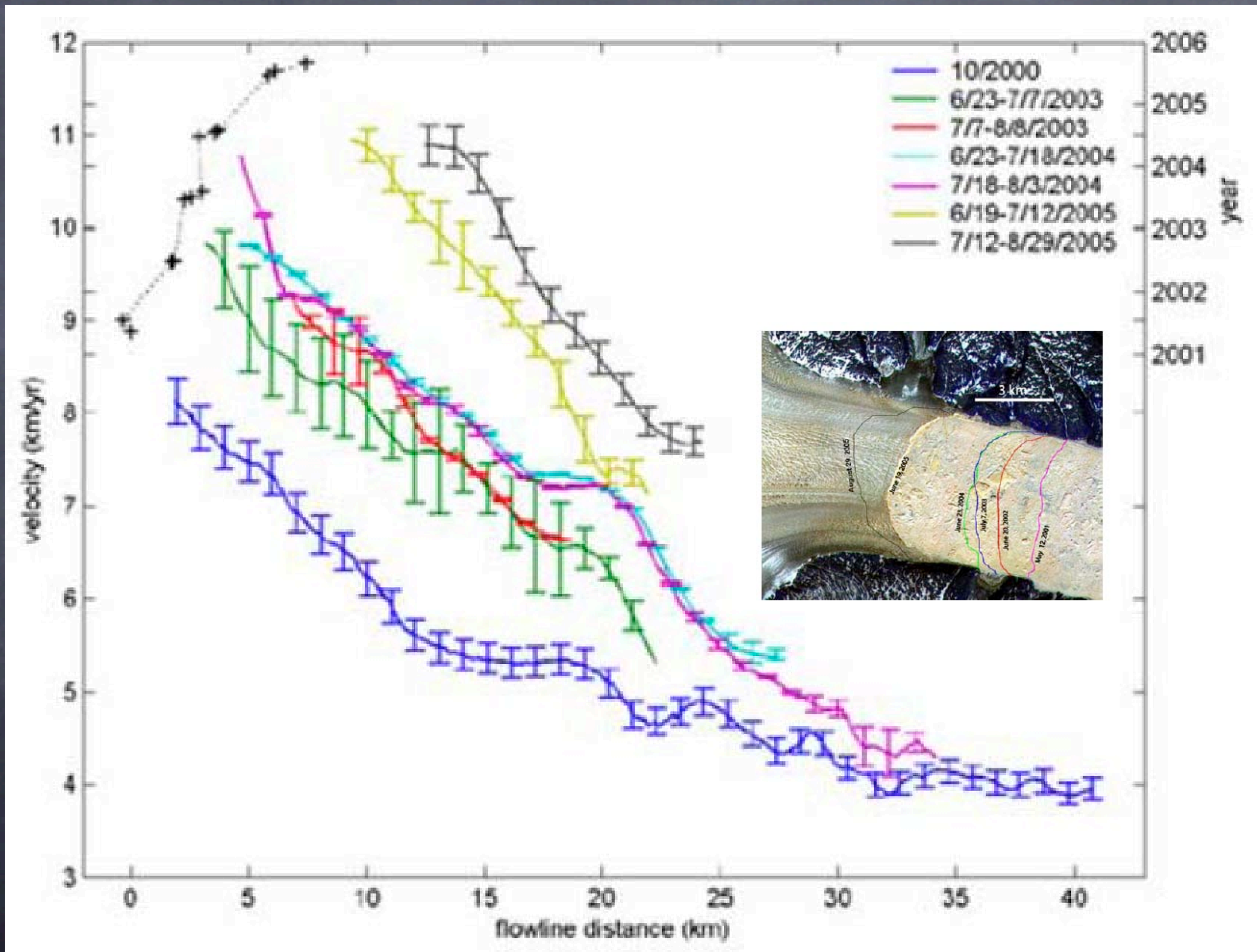
S1, S2, S4, S5?, S6? = High quality altimetry mission (ICESat++)

S1, S3, S4, S5?, S6 = High-resolution VNIR stereo sensor (ASTER++) and high-resolution surface radar (multi-wavelength)



(Joughin and Tulaczyk, 2002)

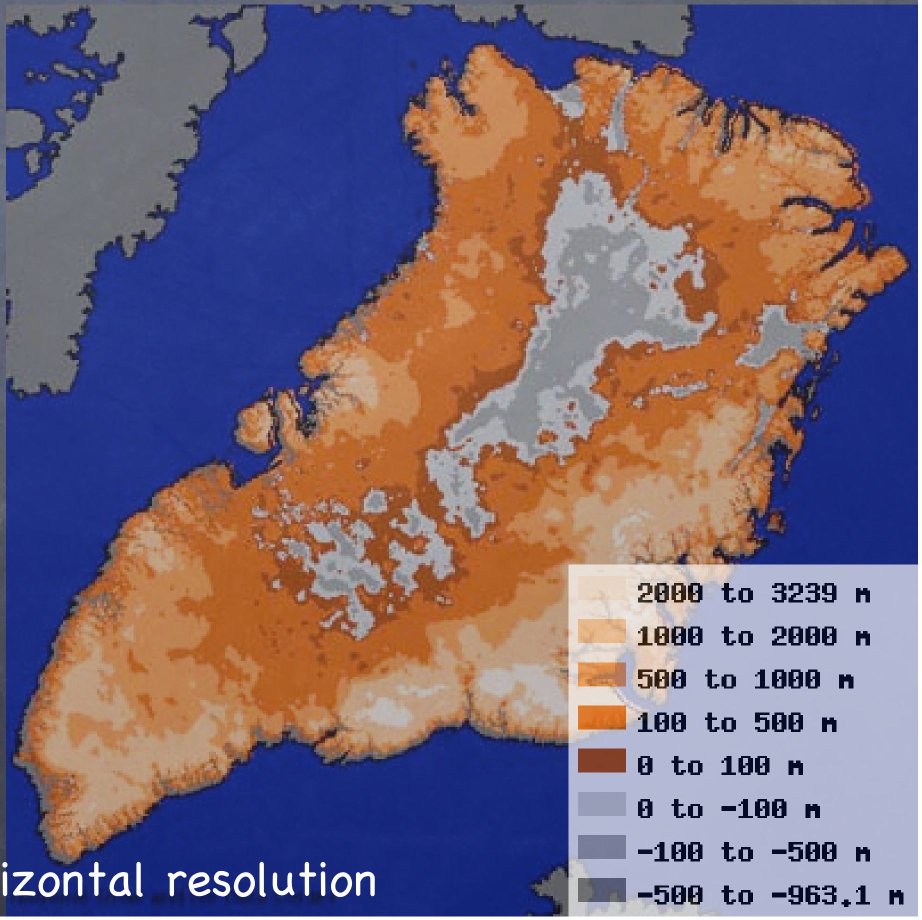
Velocities and ice surface can change quickly in some dynamic (i.e. interesting) parts of ice sheets (e.g. Howat et al., 2005)



BED

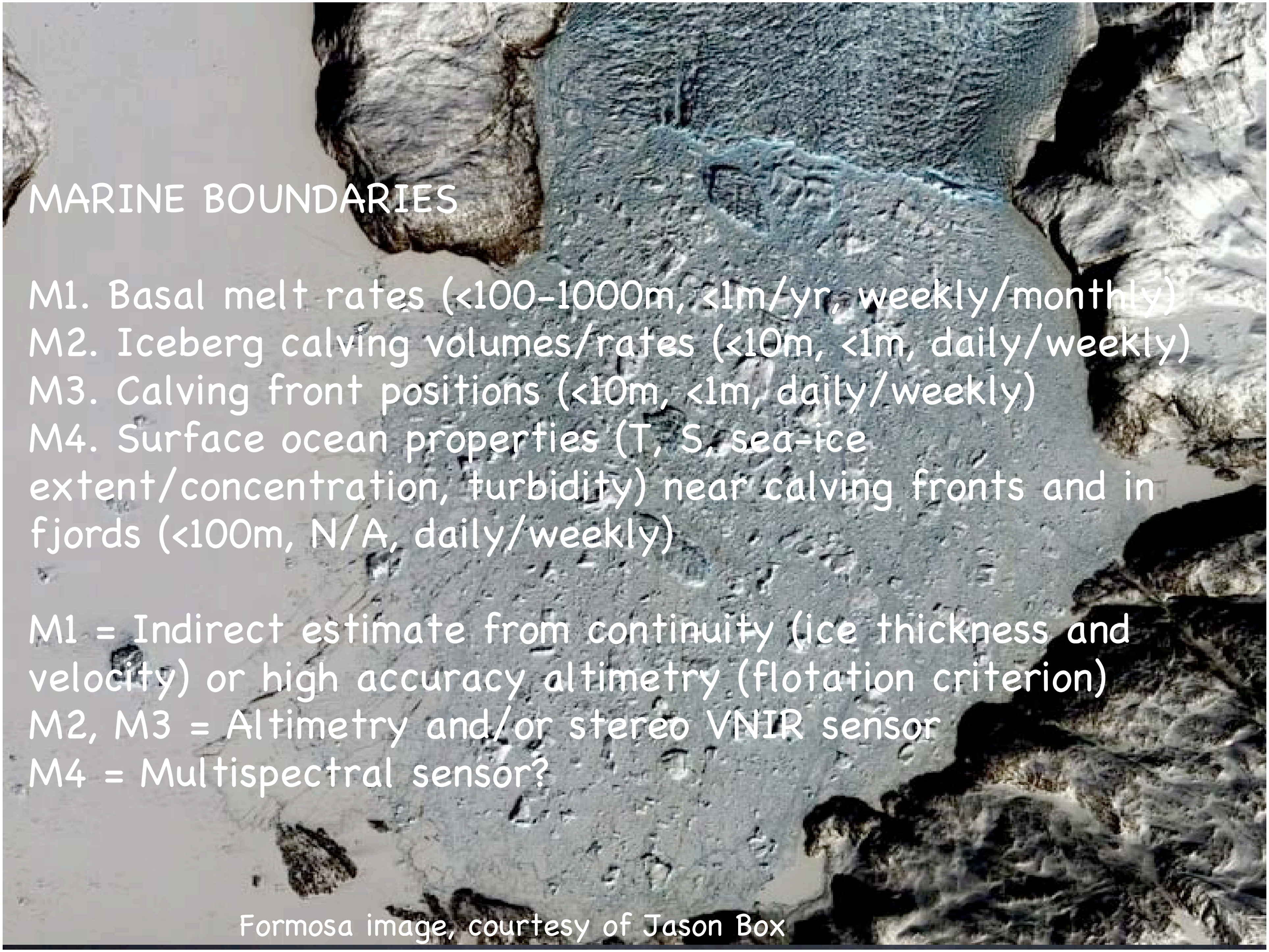
B1. Bed topography (<100-1000m, <10m, one time)
B2. Bed roughness (<100-1000m, <0.1m, annual to one time)
B3. Basal hydrological networks (<1-10m, <0.1m, a/s?)
B4. Basal melting (<100-1000m, <0.01m/yr), annual)
B5. Internal ice temperature and internal isochronal layers (<100-1000m, <1-100m, one time)

B1, B2, B3, B4, B5 =
Multi-wavelength ice-penetrating radar?



Greenland bed topo - NSIDC, 5km horizontal resolution

For comparison, this is how well we mapped out topography of Mars, about two orders of magnitude higher horizontal resolution



MARINE BOUNDARIES

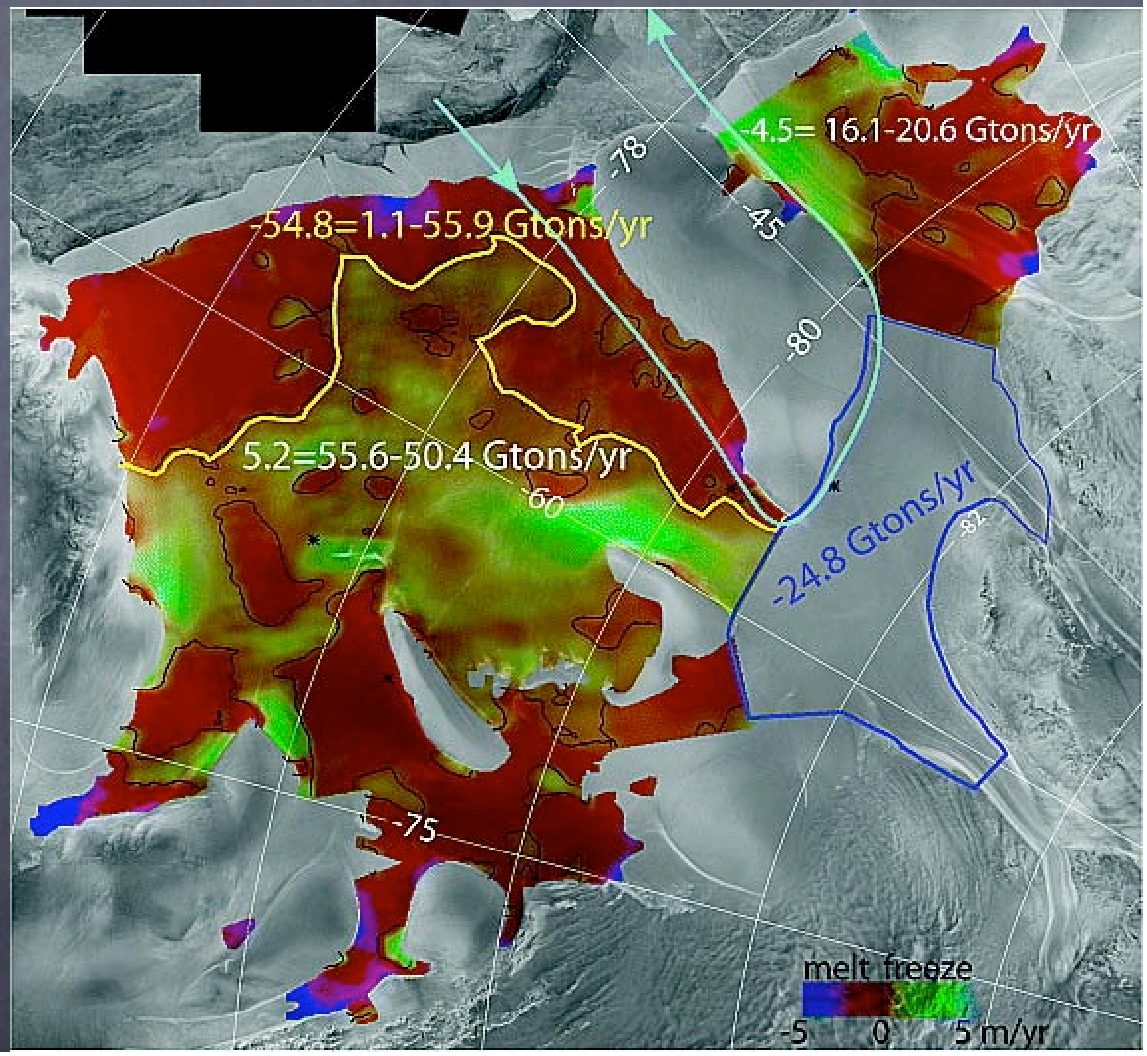
M1. Basal melt rates (<100-1000m, <1m/yr, weekly/monthly)
M2. Iceberg calving volumes/rates (<10m, <1m, daily/weekly)
M3. Calving front positions (<10m, <1m, daily/weekly)
M4. Surface ocean properties (T, S, sea-ice extent/concentration, turbidity) near calving fronts and in fjords (<100m, N/A, daily/weekly)

M1 = Indirect estimate from continuity (ice thickness and velocity) or high accuracy altimetry (flotation criterion)
M2, M3 = Altimetry and/or stereo VNIR sensor
M4 = Multispectral sensor?

Formosa image, courtesy of Jason Box

Calculation of basal melting beneath Filchner-Ronne ice shelf

(Joughin and Padman, 2003)



Challenges:

- The last 10 years demonstrated that fast-moving parts of ice sheets can change drastically on annual to decadal time scales (one time not enough).

- Atmospheric boundary conditions understood reasonably well but marine and basal boundary conditions still poorly constrained/mapped.

- Simultaneous observations with consistent spatial/temporal coverage/resolution will provide the best constraints on ice sheet models.

- Satellite data products have to be processed sufficiently to be readily incorporated in modeling efforts.

Discussion Points:

- What are best tools for these problems?

- Are these tools already out there/planned? (Surface is doing reasonable well = Cryosat2, ICESat1&2, DESDynI, but basal and marine boundaries are far behind)

- Airborne vs. satellite?

- How do we assure long-term data continuity given mission-based nature of funding?

- To what extent polar ice sensors are compatible with other applications?


Thanks