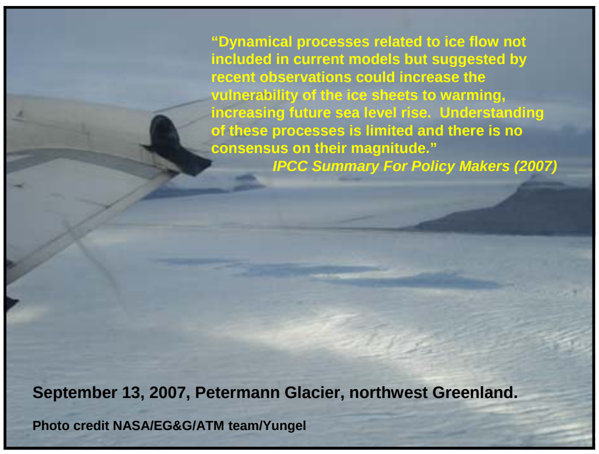
Ice Sheet Mass Balance and Sea Level (ISMASS):

St. Petersburg and beyond

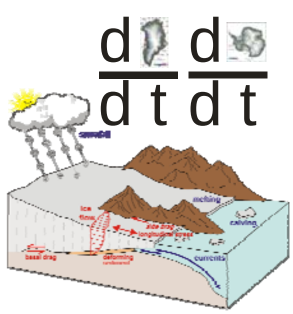
Kees van der Veen

University of Kansas

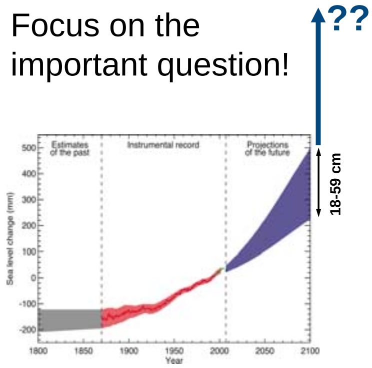


Challenges for Glaciologists

- Improve understanding of processes
- Develop quantitative prognostic models
- Incorporate small-scale processes into whole ice-sheet models



Focus on the important question!



Ice-sheet modeling (1)

VOL. 81, NO. 6 JOURNAL OF GEOPHYSICAL RESEARCH FEBRUARY 20, 1976

A Three-Dimensional Numerical Model of Ice Sheets: Tests on the Barnes Ice Cap, Northwest Territories

M. W. Mahaffy

Institute of Arctic and Alpine Research, and Cooperative Institute for Research in the Environmental Sciences University of Colorado, Boulder, Colorado 80302

A three-dimensional numerical model of ice flow has been developed to study the areal distribution of mass in an ice sheet of arbitrary shape that is not necessarily in a steady state. The model was applied to the 5900 km² Barnes Ice Cap, Baffin Island, Northwest Territories, Canada, as a test case, and the results were compared with the present day ice cap. The results were generally consistent with glaciological and glacial geological field evidence. The results suggest that basal sliding may be occurring beneath the southwestern side of the present ice cap. The model has general applicability to several studies involving the question of the speed of ice sheet development and the time/load history of the last major glaciation.

1909 Ford Model T

Ice-sheet modeling (2)

Journal of Glaciology, Vol. 18, No. 80, 1977

A THREE-DIMENSIONAL POLAR ICE-SHEET MODEL

By D. Jenssen

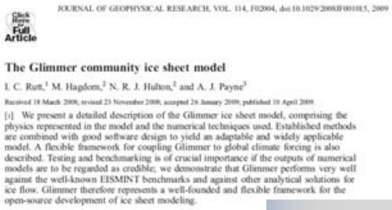
(Meteorology Department, University of Melbourne, Parkville, Victoria 3052, Australia)

Abstract. A three-dimensional model of the temperature and velocity distribution within any arbitrary-shaped ice mass is described. There is a mutual interaction in the model between the flow of the ice and its thermodynamics, since the flow law used in the model is temperature-dependent.

Ice growth in three dimensions is governed by mass accumulation through precipitation, by mass depletion through loss of ice over the ocean, and by continuity requirements. Phase changes at the base of the ice are accounted for. The model has been applied in an exploratory manner to the Greenland ice sheet. Changes in the ice shape and temperature are presented and discussed. The basic shortcoming of the model as here presented appears primarily due to the coarse finite-difference mesh used, and to an unsophisticated approach to modelling the boundary ice.

1928 Ford Model A

Ice-sheet modeling (3)


JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 114, F02004, doi:10.1029/2008JF001015, 2009

Click Here for Full Article

The Glimmer community ice sheet model

I. C. Rutt,[1] M. Hagdorn,[2] N. R. J. Hulton,[2] and A. J. Payne[3]

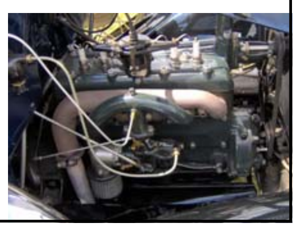
Received 18 March 2008; revised 23 November 2008; accepted 26 January 2009; published 10 April 2009.

[1] We present a detailed description of the Glimmer ice sheet model, comprising the physics represented in the model and the numerical techniques used. Established methods are combined with good software design to yield an adaptable and widely applicable model. A flexible framework for coupling Glimmer to global climate forcing is also described. Testing and benchmarking is of crucial importance if the outputs of numerical models are to be regarded as credible; we demonstrate that Glimmer performs very well against the well-known EISMINT benchmarks and against other analytical solutions for ice flow. Glimmer therefore represents a well-founded and flexible framework for the open-source development of ice sheet modeling.

1966 Ford Mustang

The engine of ice-sheet models

- Laminar flow
- Basal sliding
- Temperature calculation



1931 Ford Model A Roadster

Available extra options

- Ice shelves
- Basal hydrology
- Isostasy
- Calving
- ……

Ice-sheet modeling (4)

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 108, NO. B8, 2382, doi:10.1029/2002JB002329, 2003

A new three-dimensional higher-order thermomechanical ice sheet model: Basic sensitivity, ice stream development, and ice flow across subglacial lakes

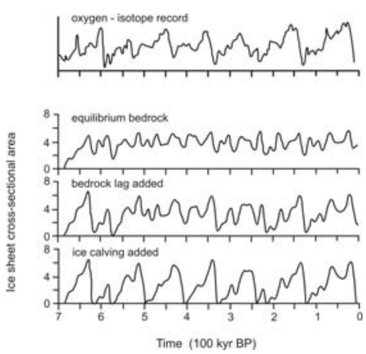
Frank Pattyn
Department of Geography, Vrije Universiteit Brussel, Brussels, Belgium

Received 29 November 2002; revised 27 March 2003; accepted 17 April 2003; published 16 August 2003.

[1] A new three-dimensional thermomechanically coupled ice sheet model is developed. Contrary to the majority of three-dimensional ice sheet models (shallow ice approximation), higher-order stress gradients (longitudinal and transverse) are accounted for in the force balance equations. The horizontal velocity field is determined from the force balance equations in their "derivative form" (elliptical equation) using the method presented by *Pattyn* [2000, 2002a]. The model is solved on a regular grid in the horizontal and an irregular grid in the vertical and is numerically stable. Basic experiments include the European Ice Sheet Modeling Initiative (EISMINT) benchmarks for large-scale ice sheet models and a comparison with the Saito-Blatter ice sheet model including higher-order stress gradients [*Saito et al.*, 2003]. Detailed calculations of ice flow over three-dimensional bedrock perturbations showed the validity of the higher-order solution. The model is capable of simulating the evolution of an ice stream within the ice sheet and shows important aspects of observed ice stream features, such as the surface flattening and the importance of side drag. The simulation of the ice flow over a subglacial lake results in a flattening of the surface, a local velocity increase over the lake, and a deviation of the ice flow from the main flow direction, features which are also observed at Lake Vostok, Antarctica. *INDEX TERMS:* 1827 Hydrology: Glaciology (1863); 1863 Hydrology: Snow and ice (1827); 3230 Mathematical Geophysics: Numerical solutions; *KEYWORDS:* higher-order, ice sheet model, thermomechanical, ice stream, subglacial lake

2009 Toyota Prius

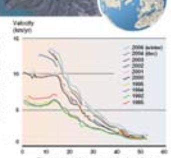
Model applications: slow physics



The new paradigm?

Figure 6A.6: Landsat satellite image of Jakobshavn Isbrae and its fjord, showing locations of the calving ice front in years from 1851 to 2006. The glacier extends through the Ilulissat Icefjord, surrounded by mountains. Icebergs calve off from the main glacier, pile up and block the fjord before being released into Qeqertarsuup Tunua (Disko) Bay and Davis Strait. The whiter areas in the fjord are piled up icebergs and the "real" glacier ends where the greyish striped section ends – showing that this image is from 2001.
The graph shows glacier-velocity profiles for 1985 to 2006. During this period Jakobshavn Isbrae, already the world's fastest glacier, doubled its speed to almost 14 km per year after rapid thinning and break up of its floating ice tongue.

Source: NASA/Goddard Space Flight Center Scientific Visualization Studio. Historic calving front locations courtesy of Anker Weidick and Ole Bennike. Source: based on Howat and others 2007



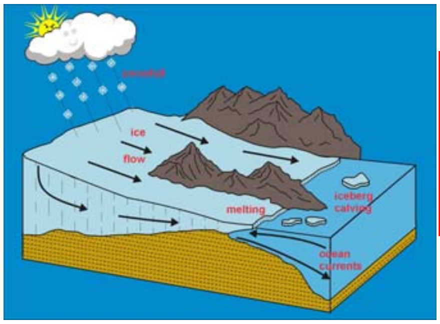
Addressing the IPCC AR4

November 2007

Overarching questions

- Will climate change lead to irreversible (non-linear, rapid) ice sheet response?
- Do rapid changes lead to large mass changes?
- Are observed rapid ice-sheet changes “natural variability”, response to recent warming (ice shelf break up), basal switch?

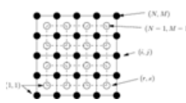
Integrated approach

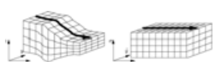


- Englacial processes
- Surface forcing
- Basal conditions
- Marine margin
- Numerical issues

High-resolution Full Stokes is not enough…..

- Yes, we can, and should (long-term objective)
- Remain aware of limitations
- Processes necessarily excluded
  - Shear margins
  - Subglacial valleys
  - Weak basal layers
  - …..
- Boundary conditions

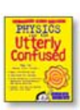




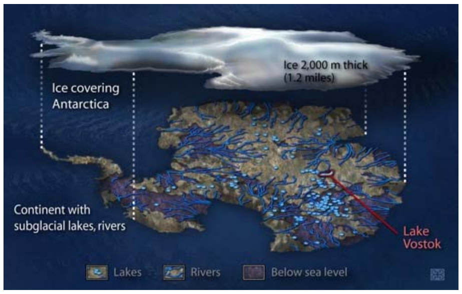
What ice-sheet models need (1)

Better understanding of physics

- What processes are important?
- On what scales should ice sheets be modeled?
- Acceptable parameterizations of physics
- …..

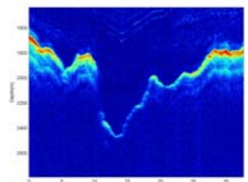


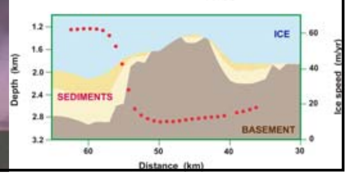
What happens under the ice?



Subglacial morphology

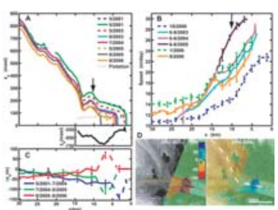
- Channels and trenches
- Sediment versus hard beds
- Geothermal heat flux
- Bed topography at grounding line



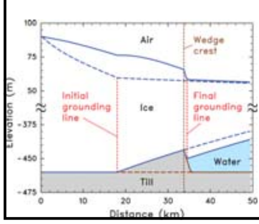


Grounding-line stability

- Topography of the bed
- Sediment deposition
- May be more important to include than Schoof's transition zone



(Howat et al., 2007)



(Alley et al., 2007)

What ice-sheet models need (2)

Bed topography

- Resolve small-scale topography

Geothermal heat flux

- Spatial variations

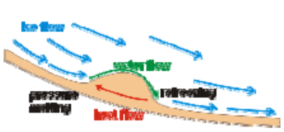
Subglacial hydrology

- Subglacial lakes
  - Water storage
  - Importance of drainage events
- Interaction of till and subglacial water
- Addition of supraglacial meltwater
- Subglacial water budget of different hydrologic systems
- Coupling to ice-flow model
  - Water transport and storage
  - Sediment production and transport

What ice-sheet models need (3)

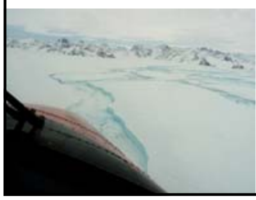
Sliding relation

- Basal pressure
- Water storage
- Sediment strength
- …..



Ice shelves and other (near) floating peripherals

- Mechanisms for break up
- Role of sea ice
- Sub-shelf circulation and melting
- Restraints on interior ice?

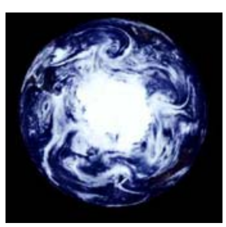



What ice-sheet models need (4)


Calving “law” that works for all scales of icebergs and bits

Surface mass balance

- Accumulation
  - Predict changes over time
  - Coastal/slope areas
  - Drifting snow
- Ablation
  - Extent and duration
  - Runoff and percolation

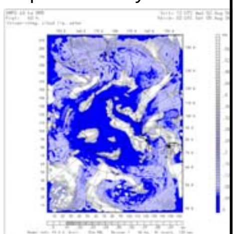



What ice-sheet models need (5)

Better meso-scale models for Greenland and Antarctica

- Accumulation does not depends on temperature only
- Changing circulation patterns
- Effect of changing sea-ice cover
- Slope effects
- …..

AOGCM can provide the boundary conditions, but are inadequate for applications over the polar ice sheets



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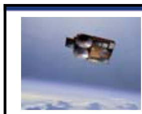
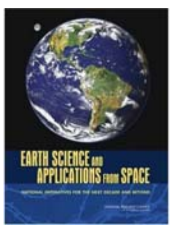
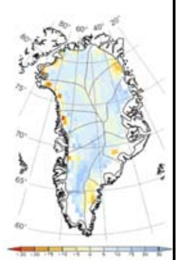
Model Validation





THE NATIONAL ACADEMIES

"Evaluation and assessment of model capability will increasingly be the focus of future measurement activities. Demonstrating model capability is likely to be a driver for developing and evolving observation systems and field campaigns."



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How well do our models apply to real ice sheets?

- Model inter-comparisons
- Data for validation
- Capability of simulating past and current changes

What ice-sheet models need (6)

Data for calibration and validation

- What data?
- Open data access
- Compatible formats
- "easy to use"

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The next step

ICSU International Council for Science

WCRP

SCAR

National Science Foundation

IASC

Cooperative Institute for Research in Environmental Sciences

CReSIS Center for Remote Sensing of Ice Sheets

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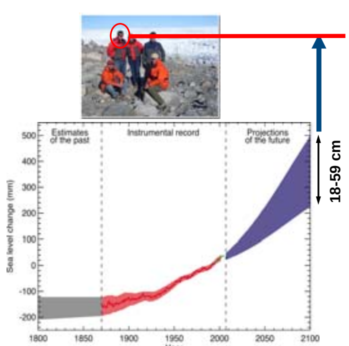
The long road ahead….



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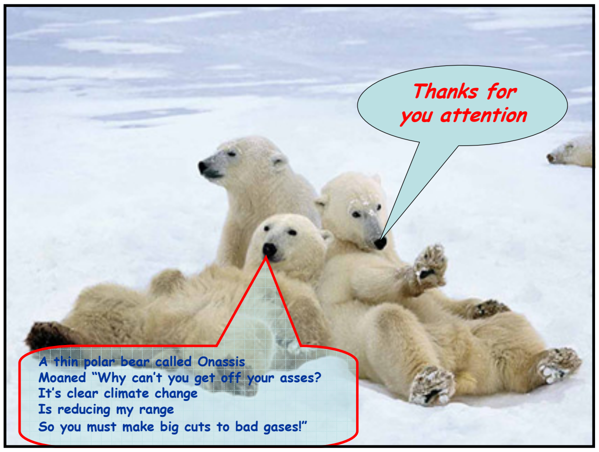
Thanks for you attention
A thin polar bear called Onassis
Moaned "Why can't you get off your asses?
It's clear climate change
Is reducing my range
So you must make big cuts to bad gases!"