Ice Sheet System Model

From Science to Software

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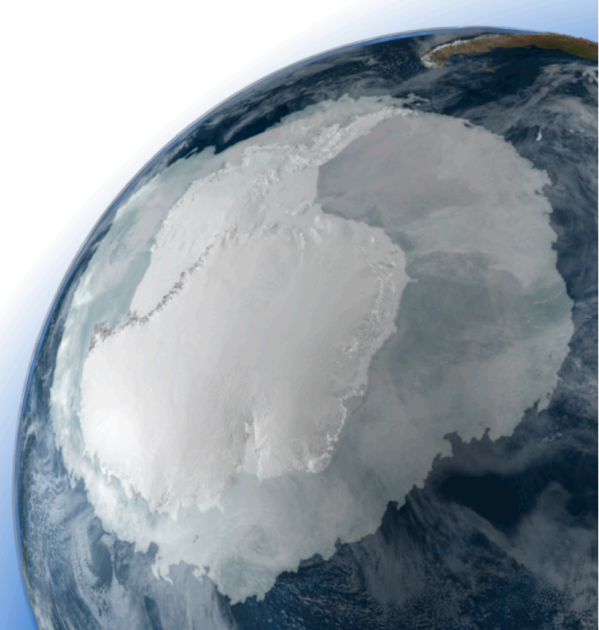


Outline

Introduction

- Why ice sheet modeling at NASA/JPL?
  - → NASA missions (InSAR, ICESat, GRACE, EOS)
  - → NASA science mission to planet Earth to observe, understand and predict changes in the Earth system in response to human influence
- IPCC AR4 sea level rise in the 21st century excludes rapid changes from ice sheets

  "What's the use of having developed a science well enough to make predictions, if, in the end, all we're willing to do is stand around and wait for them to come true?" (Prof. Sherry Rowland, Nobel Prize in Chemistry 1995).

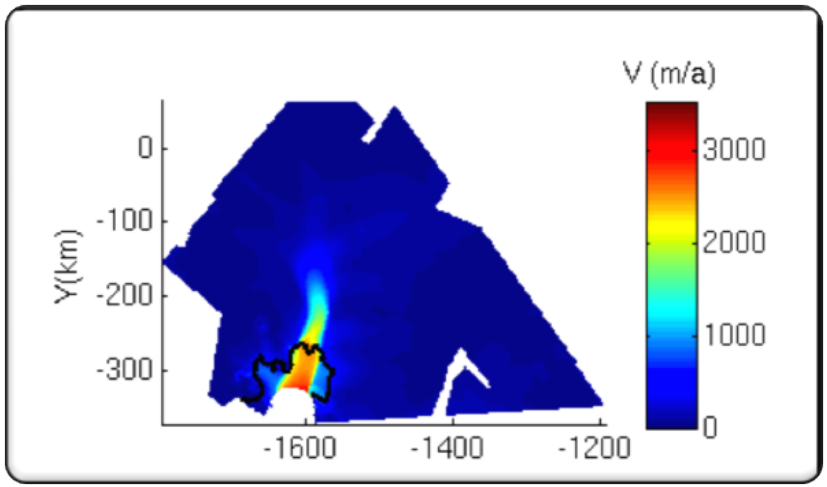
  Root cause of the failure of numerical models: lack of observations to evaluate their physical skills and time scales.

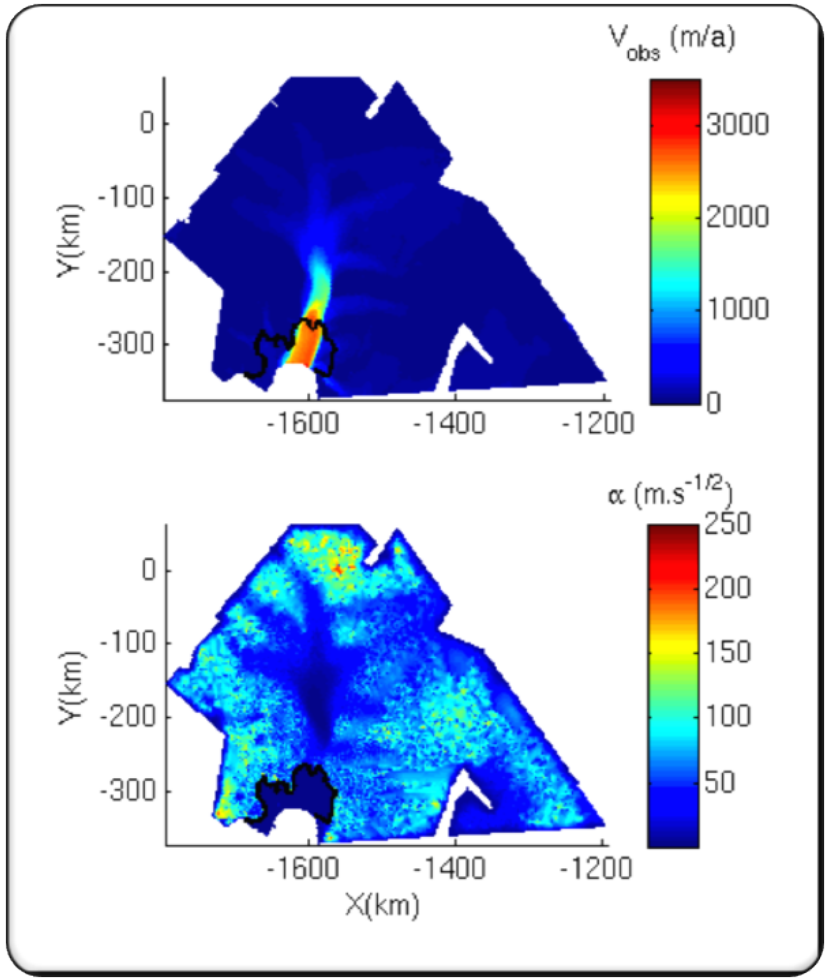
Engineering drivers

Inverse methods

Infer unknown parameters (basal friction, ice rigidity) using an ice flow model to best-fit InSAR surface velocities:

$$J = \int\int_{\text{Surface}} \frac{1}{2}\left[(u-u_{\text{obs}})^2+(v-v_{\text{obs}})^2\right] dxdy$$

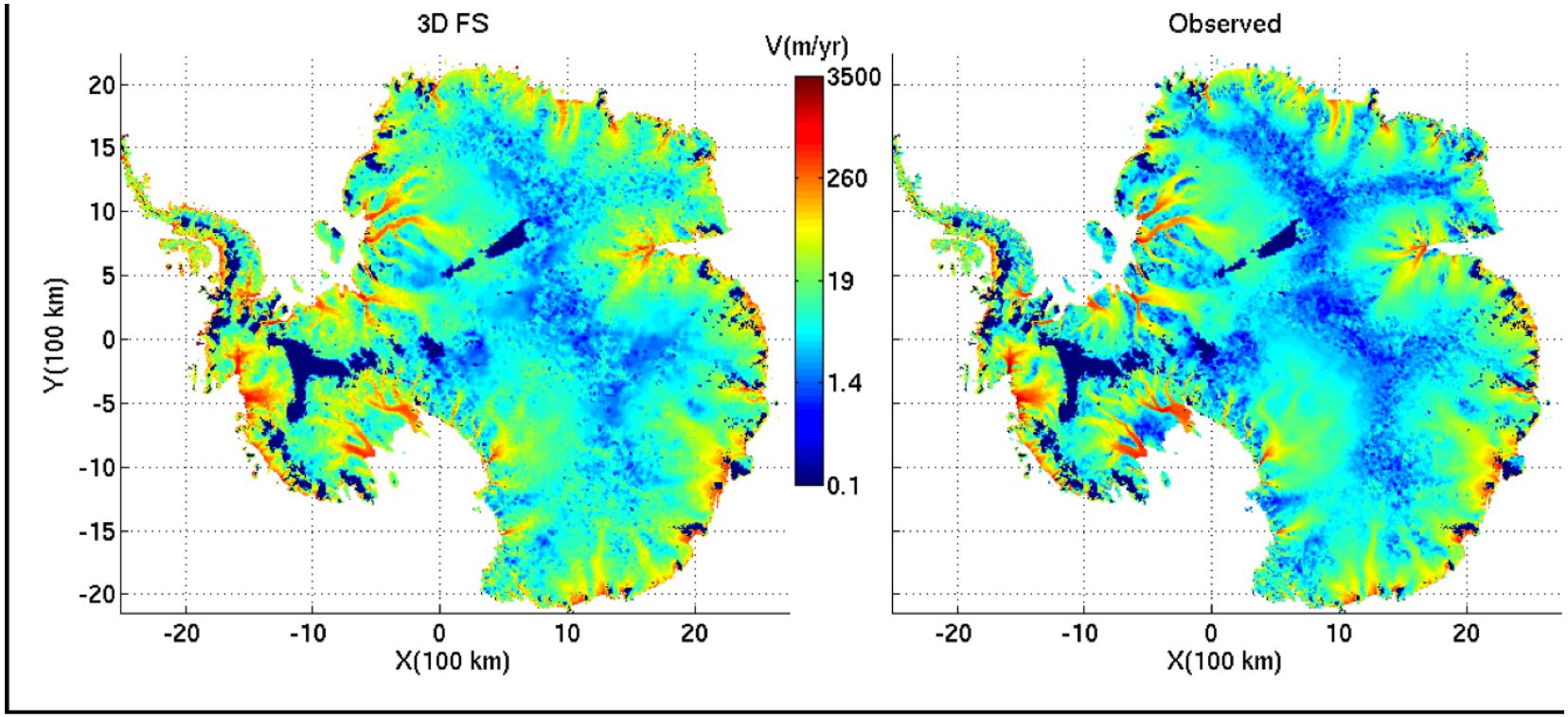




Engineering drivers

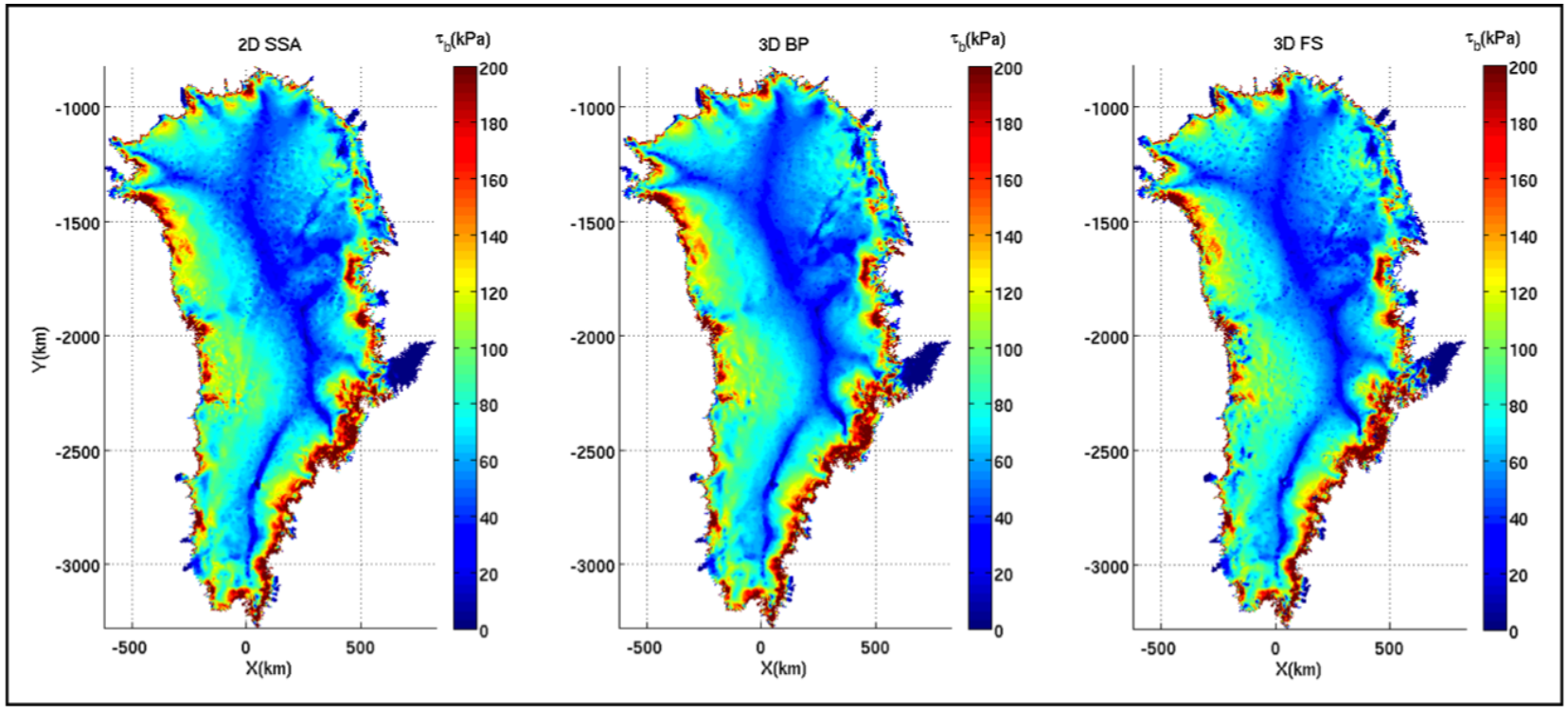
High resolution, large scale simulations

Model whole continental ice sheets at high resolution (1 km horizontal, 10–20 layers vertically)



Engineering drivers

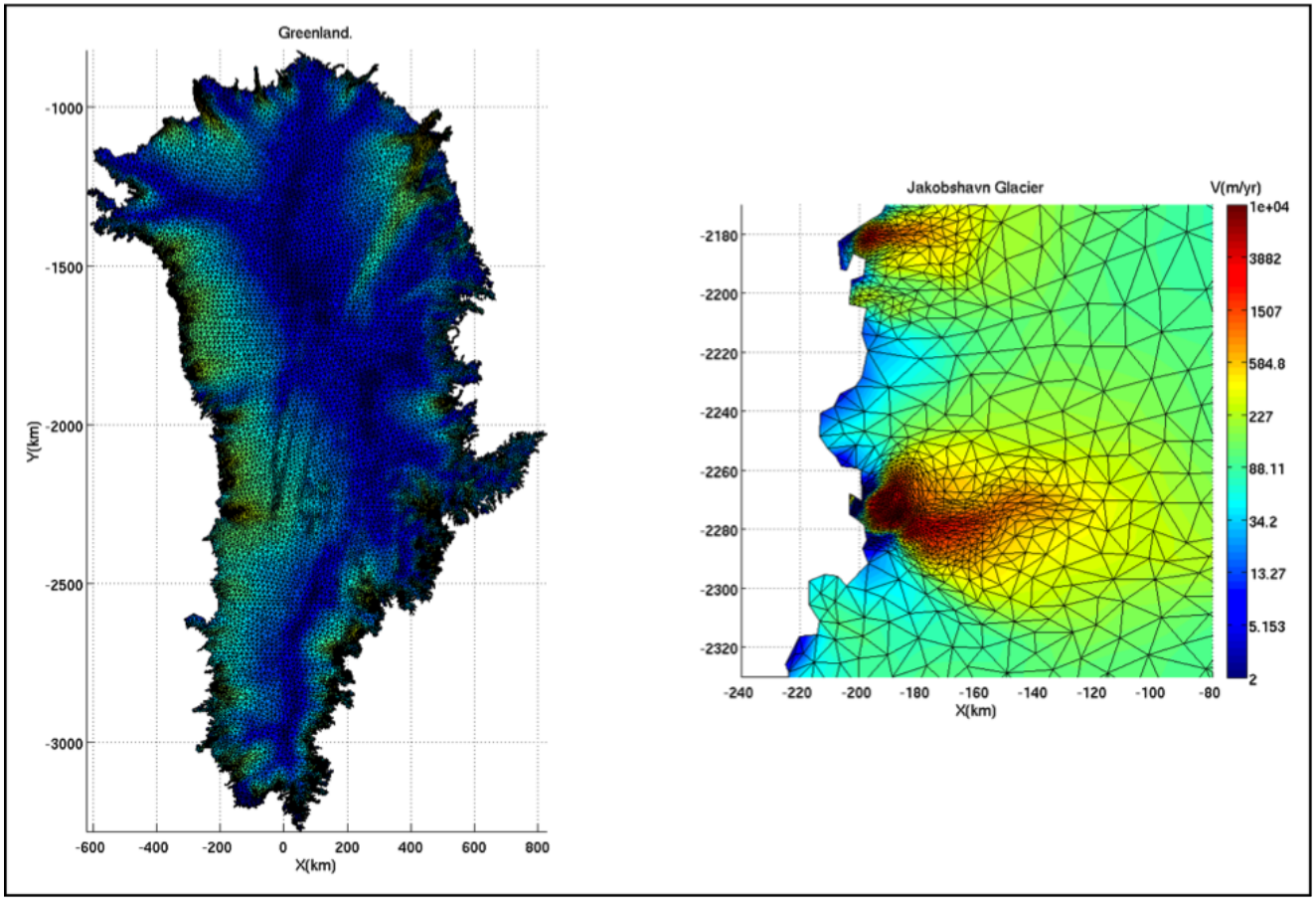
Higher-order modeling



Technology

Finite Element Method

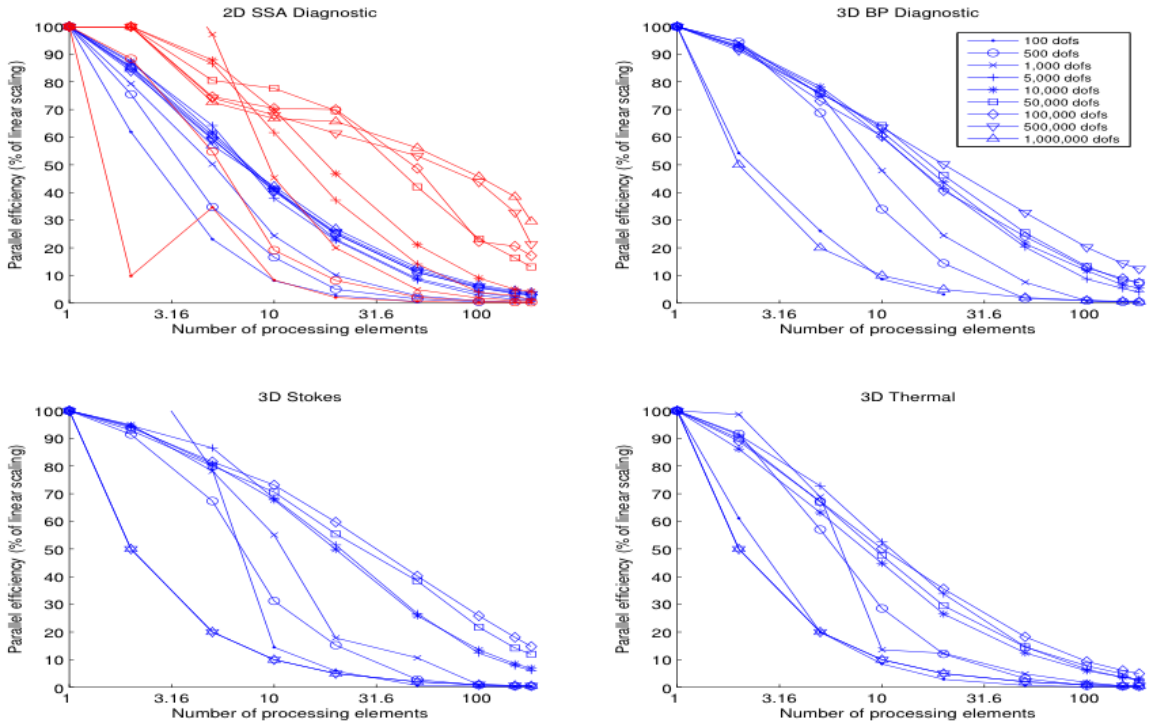
The Finite Element Method (FEM) seamlessly integrates fully unstructured meshes, multi-physics and anisotropic adaptivity.



Technology

Parallel computing

- ISSM was designed as a parallel architecture with serial capabilities, instead of the opposite. The goal is to make parallel computing as easy as possible.
- ISSM relies on PETSc and MPICH to run on any type of parallel platform, be it shared or distributed clusters, as well as multi-core desktops.
- Scaling is good for the entire architecture, with extensive work being carried out to apply efficient parallel iterative solvers.



Technology

MATLAB

- ISSM is hosted in MATLAB, a widely-used multi-purpose platform
  - ISSM is encapsulated within mex modules (MATLAB routines)
  - Pre and post-processing done in MATLAB
  - Serial runs carried out within MATLAB
  - MATLAB layer can be removed to compile a parallel executable for parallel computations
  - For computationally challenging processing routines, multi-threading seamlessly integrated within ISSM
- Example of pre-processing of thickness dataset:

```
>> disp('      reading thickness and bedrock');
>> load(thickness);
>> md.geometry.thickness=InterpFromMeshToMesh2d(index,x,y,thickness,md.mesh.x,md.mesh.y);
>> md.geometry.bed=InterpFromMeshToMesh2d(index,x,y,bed,md.mesh.x,md.mesh.y);
```

Technology

Multi-physics

- ISSM is entirely written in C++ and is therefore object-oriented. This allows for ice flow modeling formulations to be deeply integrated within the software. Every type of ice flow model is encapsulated in low-level routines which can be called by general drivers.
- Example: creation of a stiffness matrix:

```
for(i=0;i< elements->Size();i++){
element=elements->GetObjectById(i);
element->CreateKMatrix();
}
```

element is a derived object from a Tria or Penta class.

- Multi-physics and coupling between different types of formulations is transparent to the user, provided low-level routines are implemented.
- Code is structured to assimilate new models with minimal impact, as only additional low level routines are required.

Thanks!

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