Ice Sheet System model

User interface

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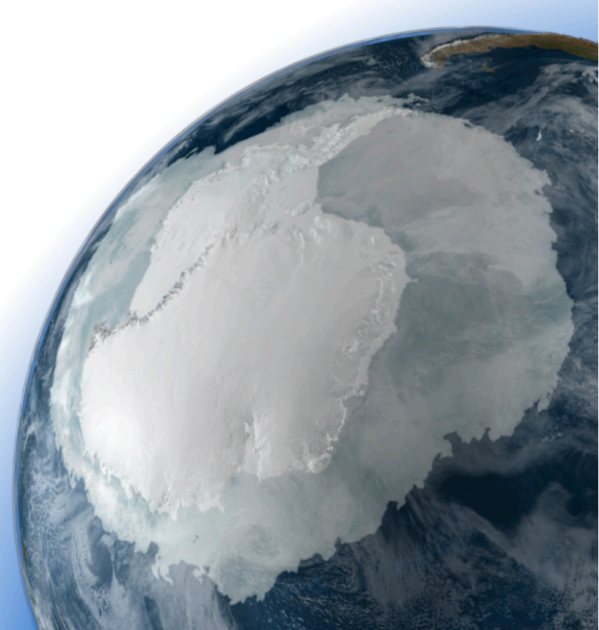

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Startup file

- `startup.m` must be present when matlab is launched
- Automatically executed by matlab at “start up” to load all ISSM tools

```
1  %Recover ISSM_TIER and USERNAME
2  ISSM_TIER=getenv('ISSM_TIER');
3  USERNAME =getenv('USER');
4  if (isempty(ISSM_TIER)),
5     error('issmdir error message: ''ISSM_TIER'' environment variable is empty! You should ...
           define ISSM_TIER in your .cshrc or .bashrc!');
6  end
7
8  %Now add all issm code paths necessary to run issm smoothly.
9  %We capture the error output, so that we can warn the user to update
10 %the variable ISSM_TIER in this file, in case it is not correctly setup.
11
12 %ISSM path
13 addpath([ISSM_TIER '/src/m/utils/']); %loads recursivepath
14 addpath([ISSM_TIER '/doc']);
15 addpath([ISSM_TIER '/bin']);
16 addpath(recursivepath([ISSM_TIER '/src/m']));
17 addpath(recursivepath([ISSM_TIER '/externalpackages/scotch']));
18 addpath(recursivepath([ISSM_TIER '/externalpackages/canos']));
19 addpath(recursivepath([ISSM_TIER '/externalpackages/kml']));
20 addpath(recursivepath([ISSM_TIER '/externalpackages/googleearthtoolbox/']));
21 addpath(recursivepath([ISSM_TIER '/externalpackages/export_fig']));
```

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Matlab Model class

```
>> md=model

md =

              mesh: [1x1 mesh]              -- mesh properties
              mask: [1x1 mask]              -- defines grounded and floating elements
          geometry: [1x1 geometry]          -- surface elevation, bedrock topography, ice ...
                    thicknes,...
         constants: [1x1 constants]         -- physical constants
   surfaceforcings: [1x1 surfaceforcings]   -- surface forcings
    basalforcings: [1x1 basalforcings]      -- bed forcings
         materials: [1x1 materials]         -- material properties
          friction: [1x1 friction]          -- basal friction/drag properties
      flowequation: [1x1 flowequation]      -- flow equations
      timestepping: [1x1 timestepping]      -- time stepping for transient models
    initialization: [1x1 initialization]    -- initial guess/state
             rifts: [1x1 rifts]             -- rifts properties
             debug: [1x1 debug]             -- debugging tools (valgrind, gprof)
           verbose: [1x1 verbose]           -- verbosity level in solve
          settings: [1x1 settings]          -- settings properties
            solver: [1x1 solver]            -- PETSc options for each solution
           cluster: [1x1 none]              -- cluster parameters (number of cpus...)
  balancethickness: [1x1 balancethickness]  -- parameters for balancethickness solution
       diagnostic: [1x1 diagnostic]         -- parameters for diagnostic solution
     groundingline: [1x1 groundingline]     -- parameters for groundingline solution
         hydrology: [1x1 hydrology]         -- parameters for hydrology solution
       prognostic: [1x1 prognostic]         -- parameters for prognostic solution
          thermal: [1x1 thermal]            -- parameters for thermal solution
      steadystate: [1x1 steadystate]        -- parameters for steadystate solution
        transient: [1x1 transient]          -- parameters for transient solution
         autodiff: [1x1 autodiff]           -- automatic differenciation parameters
            flaim: [1x1 flaim]              -- flaim parameters
        inversion: [1x1 inversion]          -- parameters for inverse methods
              qmu: [1x1 qmu]                -- dakota properties
          results: [1x1 struct]             -- model results
     radaroverlay: [1x1 radaroverlay]       -- radar image for plot overlay
    miscellaneous: [1x1 miscellaneous]      -- miscellaneous fields
```

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Model fields

- Model properties are sorted by type:
  - mesh properties in `md.mesh`
  - material properties in `md.material`
  - ...
- Each model field is itself a matlab object with fields
- Default parameters are provided (physical constants, etc)

```
>> md.materials

ans =

 Materials:

   rho_ice                 : 917          -- ice density [kg/m^3]
   rho_water               : 1023         -- water density [kg/m^3]
   mu_water                : 0.001787     -- water viscosity [N s/m^2]
   heatcapacity            : 2093         -- heat capacity [J/kg/K]
   thermalconductivity     : 2.4          -- ice thermal conductivity [W/m/K]
   meltingpoint            : 273.15       -- melting point of ice at 1atm in K
   latentheat              : 334000       -- latent heat of fusion [J/m^3]
   beta                    : 9.8e-08      -- rate of change of melting point with pressure [K/Pa]
   mixed_layer_capacity    : 3974         -- mixed layer capacity [W/kg/K]
   thermal_exchange_vel...: 0.0001       -- thermal exchange velocity [m/s]
   rheology_B              : N/A          -- flow law parameter [Pa/s^(1/n)]
   rheology_n              : N/A          -- Glen's flow law exponent
   rheology_law            : 'Paterson'   -- law for the temperature dependance of the ...
          rheology: 'None', 'Paterson' or 'Arrhenius'
```

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Saving and loading a model

- `md` is a placeholder for all parameters, constants, geometrical properties, etc.
- No additional file required, everything is in ONE matlab variable.
- Use matlab's `save` command to save a model in binary format
- Use `loadmodel` to reload a model from a binary file

→ makes sure that old models are loaded correctly

```
1   >> md=model;
2   >> md.miscellaneous.name
3
4   ans =
5        ''
6
7   >> md.miscellaneous.name='test';
8   >> md.miscellaneous.name
9
10  ans =
11       'test'
12
13  >> save myfirstmodel md
14  >> loadmodel md;
15  >> md.miscellaneous.name
16
17  ans =
18       'test'
```

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Display model fields

- `plotmodel` can be used to display any model field/result
- Arguments (pairs of options):
  1. model
  2. `'data'`
  3. name of model field
  4. name of option1
  5. option1 value
  6. name of option2
  7. option2 value
  8. ...

```
1  >> plotmodel(md,'data',md.mesh.x);
2  >> plotmodel(md,'data',md.mesh.x,'colorbar',0,'caxis',[0 500000]);
3  >> plotmodel(md,'data','mesh');
4  >> plotmodel(md,'data','BC');
5  >> plotmodel(md,'data','BC','data',md.mesh.x,'data','mesh');
```

- More info:
  - `plotdoc`
  - `http://issm.jpl.nasa.gov/documentation/usersmanual`

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EXP format

- We rely on Argus' format for geometrical files
- Argus files have an `exp` extension
- Example for a square domain:

```
1  ## Name:domainoutline
2  ## Icon:0
3  # Points Count  Value
4  5 1.
5  # X pos Y pos
6  0 0
7  100000 0
8  100000 100000
9  0 100000
10 0 0
```

- ISSM has tools to read/write/modify `exp` files
- This format is used for:
  - domain outline (mesh boundary)
  - floating ice extension
  - flag elements or vertices inside a profile

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Mesh generation with triangle

- `triangle` is used to generate simple uniform unstructured meshes
- Arguments:
  1. model
  2. name (string) of the domain outline
  3. element mean size

```
1  md=model;
2  md=triangle(md,'Square.exp',10000);
```

- To display the mesh:

```
3  plotmodel(md,'data','mesh');
```

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Parameterization file

- The parameter file sets up all required fields of a model:
  - Geometrical properties (Upper surface elevation, thickness,...)
  - Boundary conditions (friction, front,...)
  - Solver settings
  - ...
- Example for a square ice shelf:

```
1   hmin=300;
2   hmax=1000;
3   ymin=min(md.mesh.y);
4   ymax=max(md.mesh.y);
5   md.geometry.thickness=hmax+(hmin-hmax)*(md.mesh.y-ymin)/(ymax-ymin);
6   md.geometry.bed=-md.materials.rho_ice/md.materials.rho_water*md.geometry.thickness;
7   md.geometry.surface=md.geometry.bed+md.geometry.thickness;
8
9   pos=find(md.mask.vertexonfloatingice);
10  md.friction.coefficient=200*ones(md.mesh.numberofvertices,1);
11  md.friction.coefficient(pos)=0;
12  md.friction.p=ones(md.mesh.numberofelements,1);
13  md.friction.q=ones(md.mesh.numberofelements,1);
14
15  md.initialization.vx=zeros(md.mesh.numberofvertices,1);
16  md.initialization.vy=zeros(md.mesh.numberofvertices,1);
17  md.initialization.vz=zeros(md.mesh.numberofvertices,1);
18  md.initialization.vel=zeros(md.mesh.numberofvertices,1);
19
20  md.materials.rheology_B=paterson((273-20)*ones(md.mesh.numberofvertices,1));
21  md.materials.rheology_n=3*ones(md.mesh.numberofelements,1);
22
23  md=SetIceShelfBC(md,'Front.exp');
```

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Interpolation modules

- Interpolation from a regular grid to a mesh: `InterpFromGridToMesh`

```
md.initialization.temperature=InterpFromGridToMesh(x,y,temp,md.mesh.x,md.mesh.y,250);
```

- Interpolation from between two meshes: `InterpFromMeshToMesh2d`

```
md.initialization.temperature=InterpFromMeshToMesh2d(index,x,y,temp,md.mesh.x,md.mesh.y);
```

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SeaRISE example

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%Greenland parameters%%%%%%%%%%
   md.miscellaneous.name='SeaRISEgreenland';

   modeldatapath     =[issmdir '/projects/ModelData/SeaRISE/Greenland5km_v1.2'];
   thicknesspath     =[modeldatapath '/thk.mat'];
   surfacepath       =[modeldatapath '/usrf.mat'];
   bedrockpath       =[modeldatapath '/topg.mat'];
   vxpath            =[modeldatapath '/surfvelx.mat'];
   vypath            =[modeldatapath '/surfvely.mat'];
   temperaturepath   =[modeldatapath '/surftemp.mat'];
   precippath        =[modeldatapath '/smb.mat'];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%Some hardcoded parameters for this deck%%%%%%%%%%
   disp('      reading geometry');
   md.geometry.thickness=InterpFromFile(md.mesh.x,md.mesh.y,thicknesspath,0);
   pos0=find(md.geometry.thickness<1);
   md.geometry.thickness(pos0)=1;
   md.geometry.surface=InterpFromFile(md.mesh.x,md.mesh.y,surfacepath,0);
   md.geometry.bathymetry=InterpFromFile(md.mesh.x,md.mesh.y,bedrockpath,0);
   md.geometry.bed=md.geometry.surface-md.geometry.thickness;

   disp('      reading velocities ');
   md.inversion.vx_obs=InterpFromFile(md.mesh.x,md.mesh.y,vxpath,0);
   md.inversion.vy_obs=InterpFromFile(md.mesh.x,md.mesh.y,vypath,0);
   md.inversion.vel_obs=sqrt(md.inversion.vx_obs.^2+md.inversion.vy_obs.^2);
   md.initialization.vx=md.inversion.vx_obs;
   md.initialization.vy=md.inversion.vy_obs;
   md.initialization.vz=zeros(md.mesh.numberofvertices,1);
   md.initialization.vel=md.inversion.vel_obs;

   disp('      creating friction parameters');
   md.friction.p=ones(md.mesh.numberofelements,1);
   md.friction.q=ones(md.mesh.numberofelements,1);
   md.friction.coefficient=30*ones(md.mesh.numberofvertices,1);
   min_drag_coeff=35; background_drag_coeff=200;
   md.friction.coefficient=background_drag_coeff*ones(md.mesh.numberofvertices,1);
   pos=find(md.inversion.vel_obs>30);
   md.friction.coefficient(pos)=background_drag_coeff+(min_drag_coeff-background_drag_coeff)/maxvel*md.inversion.vel_obs

   disp('      loading temperature ');
   md.initialization.temperature=InterpFromFile(md.mesh.x,md.mesh.y,temperaturepath,0)+273.15;
   md.initialization.pressure=md.materials.rho_ice*md.constants.g*(md.geometry.surface-md.mesh.z);
   ...
```

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Mask

- `setmask` is used to generate areas where ice is grounded and floating
- Arguments:
  1. model
  2. floating ice domain
  3. grounded ice inside the floating ice
- Ice considered grounded by default
- Input files in Argus format
- Examples

  `md=setmask(md,'','')` → all grounded
  `md=setmask(md,'all','')` → all floating
  `md=setmask(md,'IceShelves.exp','')` → grounded with some floating parts
  `md=setmask(md,'all','Islands.exp')` → floating with some grounded parts

- To display the mask:

```
1  >> plotmodel(md,'data',md.mask.elementonfloatingice)
```

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Flow equation

`setflowequation` is used to generate the approximation used to compute the velocity

- Arguments:
  1. model
  2. approximation names
  3. approximation domains
- Domains can be Argus files or array of element flags
- Approximation available
  - stokes (Full-Stokes model)
  - pattyn (Higher-order model)
  - macayeal (Shallow Shelf Approximation)
  - hutter (Shallow Ice Approximation)
- Model coupling possible (see tomorrow's presentation)

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Flow equation

`setflowequation` is used to generate the approximation used to compute the velocity

- Examples

```
1  md=setflowequation(md,'hutter','all')
2  md=setflowequation(md,'stokes','all')
3  md=setflowequation(md,'macayeal',md.mask.elementonfloatingice,'pattyn',md.mask.elementongrounded
4  md=setflowequation(md,'macayeal','IceShelves.exp','fill','pattyn)
```

- To display the type of approximation:

```
1  >> plotmodel(md,'data','elements_type')
```

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Diagnostic parameters

Most diagnostic parameters can be found in `md.diagnostic`

```
>> md.diagnostic

ans =

  Diagnostic solution parameters:

    Convergence criteria:
      restol                 : 0.0001          -- mechanical equilibrium residue convergence criterion
      reltol                 : 0.01            -- velocity relative convergence criterion, NaN -> not applied
      abstol                 : 10              -- velocity absolute convergence criterion, NaN -> not applied
      maxiter                : 100             -- maximum number of nonlinear iterations
      viscosity_overshoot    : 0               -- over-shooting constant new=new+C*(new-old)

    boundary conditions:
      spcvx                  : N/A             -- x-axis velocity constraint (NaN means no constraint)
      spcvy                  : N/A             -- y-axis velocity constraint (NaN means no constraint)
      spcvz                  : N/A             -- z-axis velocity constraint (NaN means no constraint)
      icefront               : N/A             -- segments on ice front list (last column 0-> Air, 1-> Water, 2->Ice

    Rift options:
      rift_penalty_threshold : 0               -- threshold for instability of mechanical constraints
      rift_penalty_lock      : 10              -- number of iterations before rift penalties are locked

    Penalty options:
      jpenalty_factor         : 3               -- offset used by penalties: penalty = Kmax*10^offset
      jvertex_pairing         : N/A             -- pairs of vertices that are penalized

    Other:
      shelf_dampening        : 0               -- use dampening for floating ice ? Only for Stokes model
      stokesreconditioning   : 10000000000000  -- multiplier for incompressibility equation. Only for Stokes model
      referential            : N/A             -- local referential
      requested_outputs      : N/A             -- additional outputs requested
```

Launch diagnostic solution with:

```
>> md=solve(md,DiagnosticSolutionEnum)
```

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Boundary conditions

- » `md=SetIceSheetBC(md)`

→ Dirichlet BC for all nodes on boundary

- » `md=SetIceShelf(md,'Front.exp')`

→ Neumann BC for all nodes on boundary in `'Front.exp'`

→ Dirichlet BC for all other nodes on boundary

- » `md=SetMarineIceSheefBC(md)`

→ Dirichlet BC for all nodes on grounded boundary

→ Neumann BC for all nodes on floating boundary

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Prognostic parameters

Most prognostic parameters can be found in `md.prognostic`

```
>> md.prognostic

ans =

  Prognostic solution parameters:
    spcthickness           : N/A          -- thickness constraints (NaN means no constraint)
    hydrostatic_adjustment : 'Absolute'   -- adjustment of ice shelves surface and bed ...
          elevations: 'Incremental' or 'Absolute'
    stabilization          : 1            -- 0->no, 1->artificial_diffusivity, ...
          3->discontinuous Galerkin

  Penalty options:
    penalty_factor         : 3            -- offset used by penalties: penalty = Kmax*10^offset
    vertex_pairing         : N/A          -- pairs of vertices that are penalized
```

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Prognostic parameters

Use `md.timestepping` to change the time step:

```
>> md.timestepping

ans =

  timestepping parameters:
    time_step               : 0.5     -- length of time steps [yrs]
    final_time              : 5       -- final time to stop the simulation [yrs]
    time_adapt              : 0       -- use cfl condition to define time step ? (0 or 1)
    cfl_coefficient         : 0.5     -- coefficient applied to cfl condition
```

Launch prognostic solution with:

```
>> md=solve(md,PrognosticSolutionEnum)
```

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Transient solution

Most transient parameters can be found in `md.transient`

```
>> md.transient

ans =

  transient solution parameters:
    isprognostic            : 1     -- indicates if a prognostic solution is used in the ...
           transient
    isthermal               : 1     -- indicates if a thermal solution is used in the transient
    isdiagnostic            : 1     -- indicates if a diagnostic solution is used in the ...
           transient
    isgroundingline         : 0     -- indicates if a groundingline migration is used in ...
           the transient
    requested_outputs       : N/A   -- list of additional outputs requested
```

Transient solutions in 2D combine:

- diagnostic
- prognostic
- grounding line

→ Some of these components can be deactivated

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Transient solution

Use `md.timestepping` to change the time step:

```
>> md.timestepping

ans =

  timestepping parameters:
    time_step               : 0.5     -- length of time steps [yrs]
    final_time              : 5       -- final time to stop the simulation [yrs]
    time_adapt              : 0       -- use cfl condition to define time step ? (0 or 1)
    cfl_coefficient         : 0.5     -- coefficient applied to cfl condition
```

Launch transient solution with:

```
>> md=solve(md,TransientSolutionEnum)
```

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Extrusion

- `extrude` is used to extrude the 2d mesh into a 3d mesh
- Arguments:
  1. model
  2. number of layers
  3. lower extrusion exponent
  4. upper extrusion exponent (optional)
- Examples

```
1  md=extrude(md,8,1)
2  md=extrude(md,10,1.5)
3  md=extrude(md,10,1.5,1.5)
```

- To display the mesh:

```
1  plotmodel(md,'data','mesh');
```

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Thermal solution

Most thermal parameters can be found in `md.thermal`

```
>> md.thermal

ans =

  Thermal solution parameters:
    spctemperature          : N/A              -- temperature constraints (NaN means no ...
          constraint)
    stabilization           : 1                -- 0->no, 1->artificial_diffusivity, 2->SUPG
    maxiter                 : 100              -- maximum number of non linear iterations
    penalty_lock            : 0                -- stabilize unstable thermal constraints ...
          that keep zigzagging after n iteration (default is 0, no stabilization)
    penalty_threshold       : 0                -- threshold to declare convergence of ...
          thermal solution (default is 0)
```

Thermal solution in 3D only to compute

- thermal steady state
- thermal transient

→ Controlled by `md.timestepping.timestep`

Launch thermal solution with:

```
>> md=solve(md,ThermalSolutionEnum)
```

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Transient solution

Most transient parameters can be found in `md.transient`

```
>> md.transient

ans =

  transient solution parameters:
    isprognostic            : 1     -- indicates if a prognostic solution is used in the ...
          transient
    isthermal               : 1     -- indicates if a thermal solution is used in the transient
    isdiagnostic            : 1     -- indicates if a diagnostic solution is used in the ...
          transient
    isgroundingline         : 0     -- indicates if a groundingline migration is used in ...
          the transient
    requested_outputs       : N/A   -- list of additional outputs requested
```

Transient solutions in 3D combine:

- thermal
- diagnostic
- prognostic
- grounding line

→ Some of these components can be deactivated


Thanks!