Towards a new community software for data-model connection

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The Status Quo

(A) Rapid advances in modeling

(B) The data revolution:
especially satellite observations with TB-PB of data

$\rightarrow$ a widening gap

A New Community Software Project

Element: Software: Data-Driven Auto-Adaptive Classification of Cryospheric Signatures as Informants for Ice-Dynamic Models

- a project funded by the NSF Offices for Cyberinfrastructure for Sustained Scientific Innovation (CSSI) and Arctic Natural Systems (ANS)

Two Levels of Complexity

1. Data-model comparison
2. Data-driven modeling using a parameterization approach

Cryospheric Areas

1. Land ice component
2. Sea ice component

Community Involvement!

Objectives and Software Components

(1) An auto-adaptive characterization and classification system (Prototype: land ice surface types, crevasse classes, satellite image data)

(2) Generalization of the characterization/classification system to other data types

(3) Generalization of the characterization/classification system generalized for another user community: Sea Ice research

(4) A pre-processor that facilitates transfer of the classification software to new applications and data types

(5) Auto-adaptive data-driven modeling:

Development of an automated data model-link: Use location- and time-dependent parameters from the classification to derive model parameters

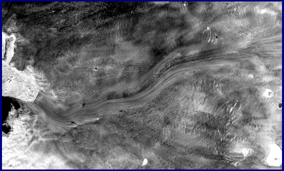
(6) Application of a metric to evaluate success of the data-model-link: Spatial map comparison and optimization

(7) Development along several pilot studies in land ice and sea ice

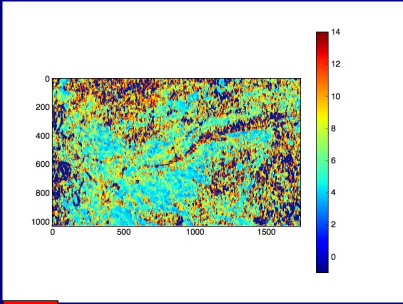
Examples

1. Connectionist-geostatistical classification of surge-glacier surfaces
2. Classification as an aid in model-data comparison
3. Classification as an aid in constraining basal sliding
4. Spatial comparison of results from data analysis and modeling (The SeaRISE Project)
5. Sea-ice characterization and parameters in data analysis and modeling

Crevasse Characterization



(a)

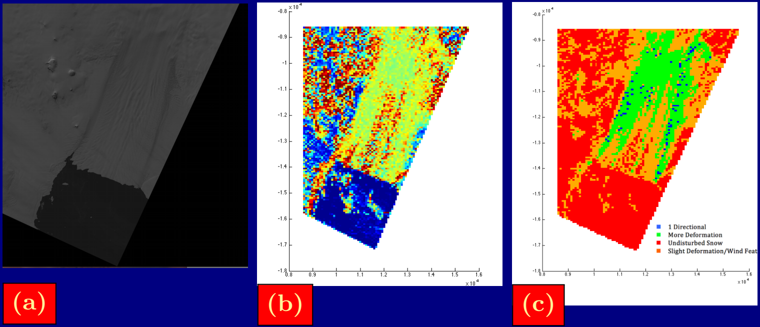


(b)

Crevasse characterization (*mindist* parameter) of LandSat-8 imagery on Jakobshavn Isbræ, Greenland.

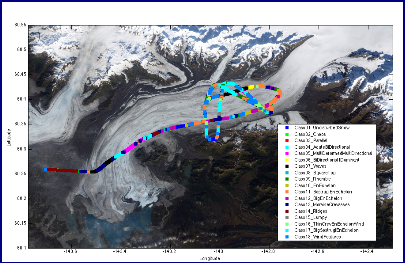
(a) Landsat-8 image LC80090112014216LGN001. (b) Map of *mindist* parameter used to characterize size, spacing and orientation of crevasses.

Crevasse Characterization and Classification

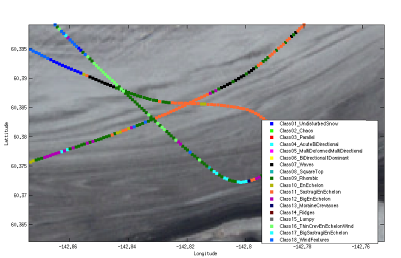


Classification of Landsat-8 data on Thwaites Glacier, Antarctica.
(a) Landsat-8 Panchromatic image of Thwaites Glacier.
(b) Characterization of surface roughness through derivation of the *pond* parameter.
(c) Neural network crevasse classification.

Connectionist-geostatistical classification of surge-glacier surfaces



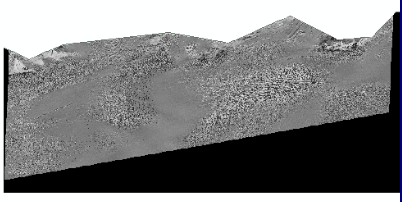
(a)



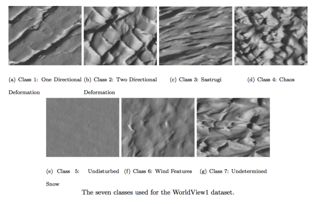
(b)

Crevasse types in Bering Glacier, identified using a Neural Network applied to airborne image data. (a) Central Bering Glacier, (b) zoom into crossover.

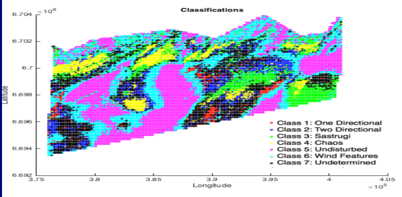
Classification of Satellite Image Data from WorldView1



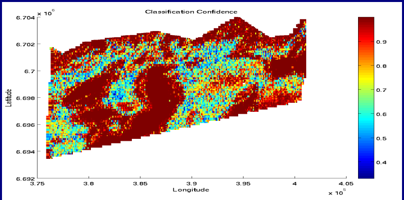
(a) Bering Glacier WorldView1 Data (March 21, 2011)



(b) Crevasse Classes for Neural Network



(c) Neural Net Crevasse Classification



(d) Classification Confidence

Constraining Model Parameters Using Surge Crevassing

1. Data Analysis: Measure crevasse distribution using a geostatistical characterization parameter
2. Modeling: Full-Stokes model of ice dynamics during surge of Bering Glacier
3. Data analysis criterion for crevassing: Parameter threshold
4. Criterion for simulated crevassing: Von Mises criterion, applied to stress field
5. Map comparison method MAPCOMP applied to demonstrate that the data-based and model-based criteria for crevassing match
6. Model-data comparison techniques yield a cost function
7. Stepwise optimization of the cost function leads to a constraint on the basal sliding parameter

Physics in Bering Model

Governing Equations

Full-Stokes:

$$\nabla \cdot \boldsymbol{\sigma} + \rho \boldsymbol{g} = \nabla \cdot (\boldsymbol{\tau} - p\boldsymbol{I}) + \rho \boldsymbol{g} = 0,$$

$$\nabla \cdot \boldsymbol{u} = tr(\dot{\boldsymbol{\epsilon}}) = 0,$$

$\boldsymbol{\sigma}$ – stress tensor
p – pressure
$\rho = 916.2 kg/m^3$ – ice density
$\boldsymbol{g} = (0, 0, -9.81)$ – gravity vector
$\boldsymbol{u}$ – velocity vector
$\dot{\boldsymbol{\epsilon}} = \frac{1}{2}(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T)$ – strain-rate tensor

Glen's flow law:

$$\boldsymbol{\tau} = 2\eta \dot{\boldsymbol{\epsilon}},$$

η – effective viscosity:

$$\eta = \frac{1}{2} A^{-1/n} \dot{\epsilon}_e^{(1-n)/n}$$

$A = A(T)$ – rheological parameter
$T = 0^\circ C$ – constant temperature
$\dot{\epsilon}_e$ – effective strain-rate
$n = 3$ – Glen exponent

Boundary Conditions

Ice/atmosphere boundary – stress-free boundary:

$$\boldsymbol{\sigma} \cdot \boldsymbol{n_s} = -p_{atm} \boldsymbol{n_s} \approx 0,$$

$\boldsymbol{n_s}$ – surface normal vector

Ice/bedrock boundary – allow no normal flux:

$$\boldsymbol{u} \cdot \boldsymbol{n_b} = 0$$

and a linear friction law:

$$\sigma_{nt_i} = \beta u_{t_i}, \quad i = 1, 2$$

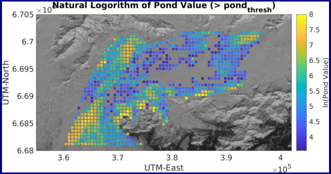
β – linear friction coefficient
$\sigma_{nt_i} = (\boldsymbol{\sigma} \cdot \boldsymbol{n_b}) \cdot \boldsymbol{t_i}$ – basal shear stresses
$u_{t_i} = \boldsymbol{u} \cdot \boldsymbol{t_i}$ – basal velocities
$\boldsymbol{t_i}$ $(i = 1, 2)$ – unit tangent vectors
$\boldsymbol{n_b}$ – unit surface normal vector pointing outward of the bedrock surface

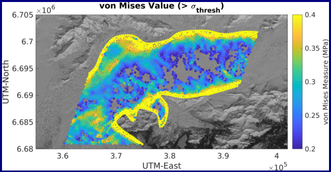
Lateral boundary

Similar to ice/bedrock only with a different friction parameter β

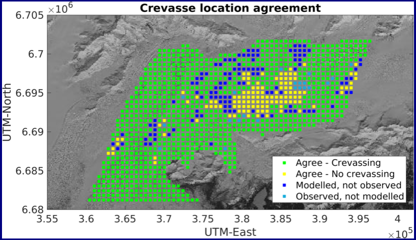
Is crevassing observed and modeled at some location?

Observed →





Modeled ←



Comparison Measures for Crevasse Location

Total comparison nodes (N) $=$ 1185

Total model-data agreement nodes (green+yellow) (N_{agree}) $=$ 1041

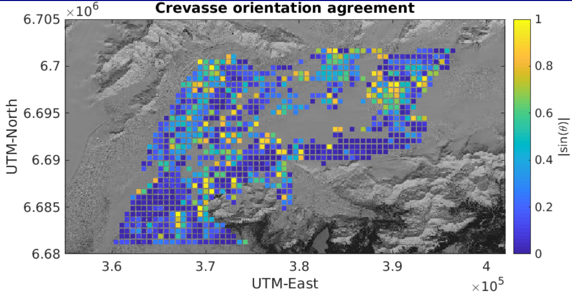
Total disagreement nodes (light blue + dark blue) ($N_{disagree}$) $=$ 144

Fractional agreement ($\frac{N_{agree}}{N}$) $=$ 0.8785

Trantow and Herzfeld, JGR, 2018

Crevasse orientation comparison

- Areas of dark blue show modeled orientations in the same bin as those observed ($\theta \leq 11.25°$)
- Areas of green and yellow show disagreement of at least 3 bins ($\theta > 33.75°$)
- The number of nodal locations where crevasses exist as agreed upon by both the model and observations is $N_{crev} = 928$.



A map of crevasse orientation comparison where each data point is given by $|sin(\theta)|$ where θ is the absolute difference between modeled and observed crevasse orientations.

Trantow and Herzfeld, JGR, 2018

Spatial map comparisons via MAPCOMP

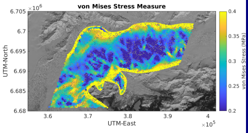


Fig 1 ↔

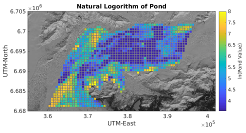
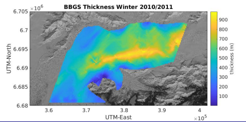


Fig 2 ↔



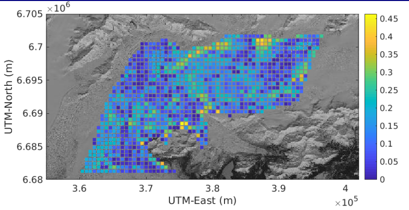


Fig 1. Map similarity (MAPCOMP) comparison between the *logpond* map and the von Mises stress map: measures of crevassity? (lower value = more similarity)

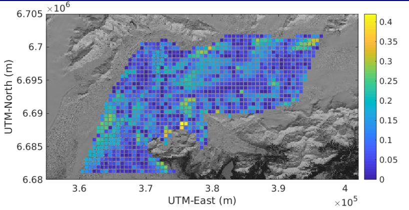


Fig 2. Map similarity (MAPCOMP) comparison between the *logpond* map and the (negative of) ice thickness map: importance of bedrock topography.

Trantow and Herzfeld, JGR, 2018

MAPCOMP: A Multivariate Map-Comparison Method for Spatial Evaluation of Model Experiment and Model-Data Comparison

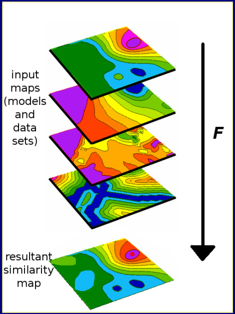


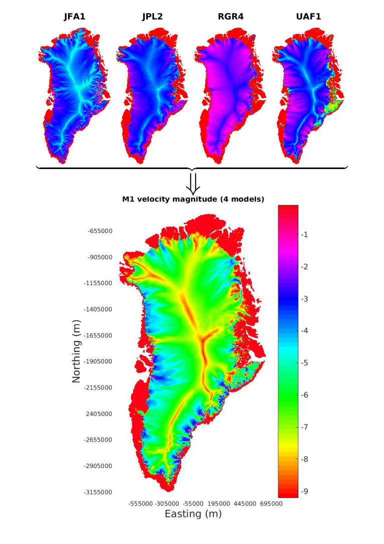
Figure 4. Schematic illustration of the map-comparison method. F denotes the MAPCOMP operator.

MAPCOMP Math

- Assume there are n maps/ model results/ experiment results/ data sets to be compared (n input maps).
- The MAPCOMP operator calculates an algebraic semi-norm in a space of $\frac{n(n-1)}{2}$, the number of comparisons possible.
- Uses a matrix functional at each grid node.
- The result is a single similarity map (or comparison map), with values in [0,1]. Close to zero - good similarity; close to one - high dissimilarity. $\longrightarrow$ Indicates regions and processes that may need improvement.
- Weighting options
- Options for missing-data handling
- Several methods for pre-analysis standardization to compare the same or different variables/ units
- Use netcdf and other modeling standards
- MAPOPT - Optimization of parameters or testing of simple functional relationships

MAPCOMP: 4 Models - 1 Variable (Velocity) -

Experiment: M1 (ice-ocean melt) [MAPCOMP for SEARISE]



linear standardization, log colorscale for input maps

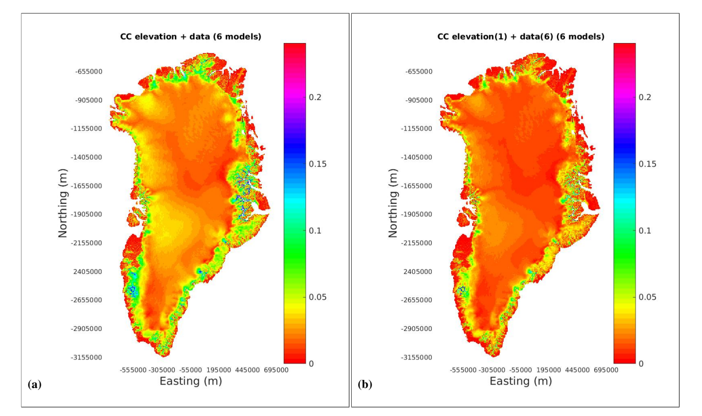
Results group by drainage basins: Largest for W and SE Greenland, where ocean-induced melt is highest.

Participating Models from SeaRISE

Model name	**SeaRISE model abbreviation**	**Developers**	**References**
Anisotropic Ice Flow Model (AIF)	WWA1, WWA2	Wei Li Wang	[Wang et al., 2012]
Community Ice Sheet Model version 2 (CISM2)	CSM2	Stephen Price, William Lipscomb	[Price et al., 2011, Lemieux et al., 2011, Bougamont et al., 2011, Evans et al., 2012]
Elmer/Ice	HSE1	Hakime Seddik	[Seddik et al., 2012]
Ice sheet model for Integrated Earth-System Studies (IcIES)	AAB1, AAB2	Ayako Abe-Ouchi, Fuyuki Saito	[Saito and Abe-Ouchi, 2004, Saito and Abe-Ouchi, 2005, Saito and Abe-Ouchi, 2010, Greve et al., 2011]
Ice Sheet System Model (ISSM)	JPL2	Eric Larour, Mathieu Morlighem, Helene Seroussi	[Morlighem et al., 2010, Seroussi et al., 2011, Larour et al., 2012]
Parallel Ice Sheet Model (PISM)	UAF1	Ed Bueler, Andy Aschwanden, Constantine Khroulev	[Bueler and Brown, 2009, Aschwanden et al., 2011]
Simulation Code for POLythermal Ice Sheet (SICOPLIS)	RGR4	Ralf Greve	[Greve et al., 2011, Sato and Greve, 2012]
University of Maine Ice Sheet Model (UMISM)	JFA1	Jim Fastook	[Fastook, 1993]

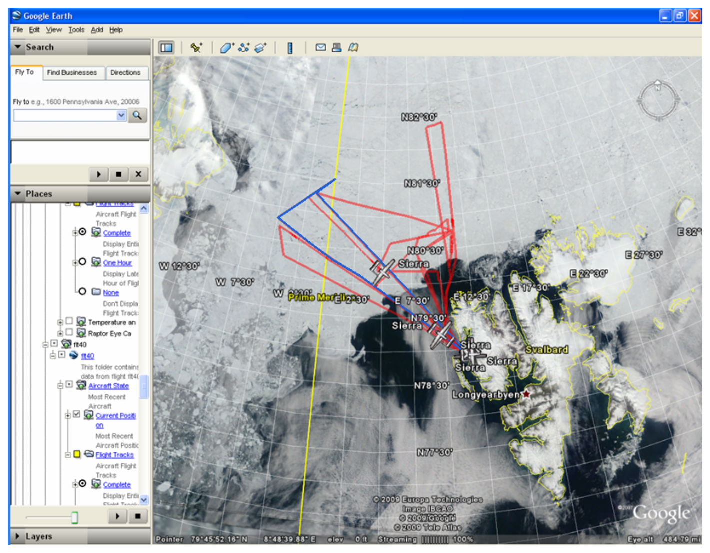
MAPCOMP: Data-Model Comparison (and Weighting)

Constant Climate Control Run, 6 Models - 1 Data Set (Surface Height)



(a) unweighted (1,1,1,1,1,1,1) and (b) weighted (all 6 models weighted 1, data set weighted 6)

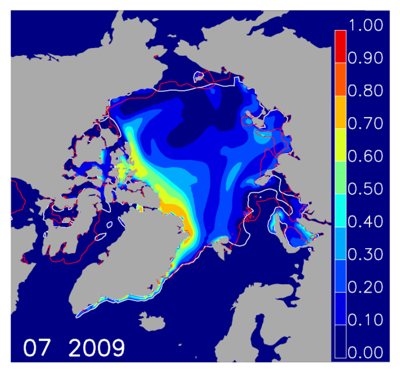
Sea Ice Example: Fram Strait – Ridging Processes



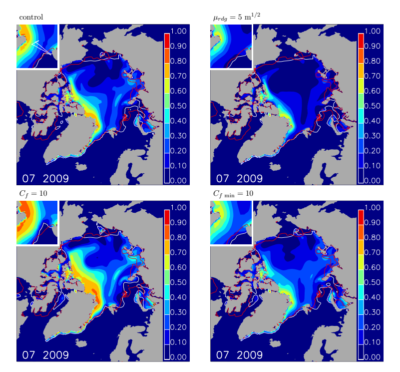
Flight tracks of the CASIE Experiment July/August 2009.

Data used here stem from flight 9 (marked blue).

CICE Model Runs For CASIE Flight Time (July 2009)
Deformed Ice Area Fraction



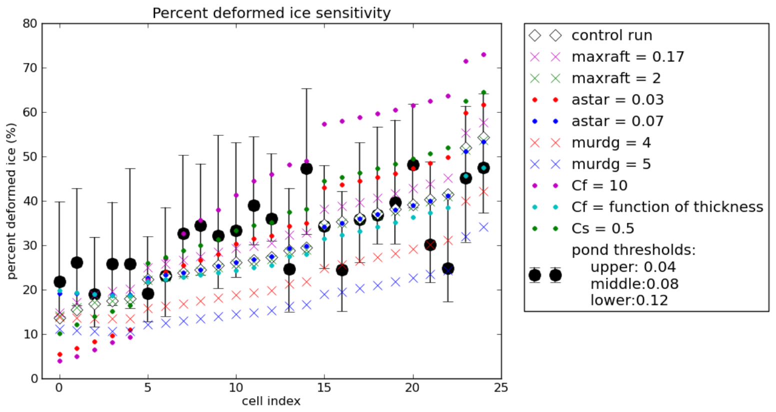
(a) Control Run



(b) Sensitivity Study

from Herzfeld, Hunke, McDonald, Wallin, 2014

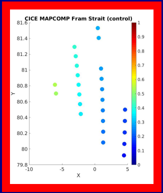
CICE-CASIE Comparison: Sensitivity Studies
Percent Deformed Ice Area from CICE and CASIE

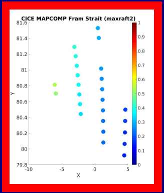


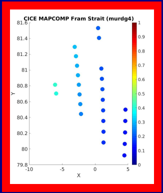
25 CICE grid nodes over sea ice

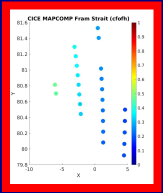
(Herzfeld, Hunke, McDonald , Wallin, 2014)

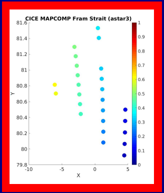
CICE Parameterization Sensitivity Experiments

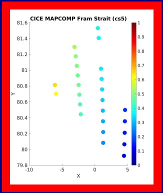


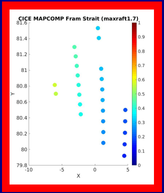


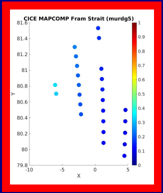


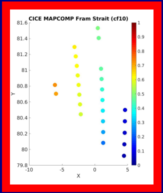


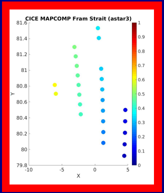


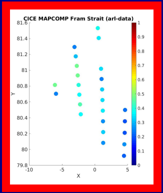












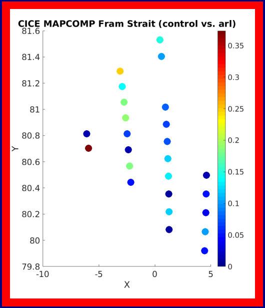
variable: area percent of ridged ice

parameters: control or cs - maxraft - murdg - cf - astar

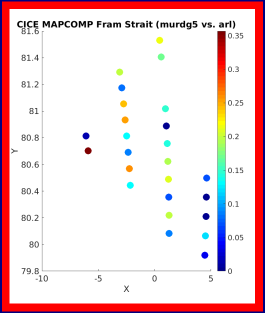
row 1: lower value, row 2: higher value

row 3: arl data from laser altimeter data

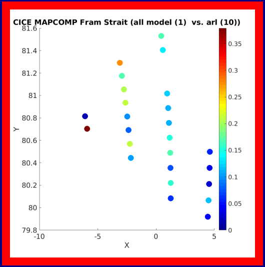
Similarity Mapping: CICE-CASIE Model-Data Comparisons



1 model run, arl weighted 1



1 model run, arl weighted 1



10 model runs, arl weighted 10

variable: area percent of ridged/ rough ice

similarity measure: mapcomp similarity [0,1], low: good similarity

Result: Now we can see where modeled and measured rough ice areas match, for each or all sensitivity studies. →

(1) Model-data comparison experiments (SIMIP)
(2) Model evaluation/ improvements

Next : larger regions and more data

Call for Participation

Questions?

Negribreen, Svalbard