A Multi-Model and Model-Data Comparison Tool for ISMIP-6 and SIMIP-6

Ute C. Herzfeld[1,2,3], Elizabeth Hunke[4]
Thomas Trantow[1], Mattia Astarita[1,5] and Samuel Bennetts[1,6]

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(1) Department of Electrical, Computer and Energy Engineering
(2) Cooperative Institute for Research in Environmental Sciences
(3) Department of Applied Mathematics
(4) T-3 Fluid Dynamics and Solid Mechanics Group, Los Alamos National Laboratory
(5) Department of Aerospace Engineering Sciences
(6) Department of Computer Sciences
University of Colorado Boulder

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Talk Topics

(I) MAPCOMP: A Synthesis Tool for ISMIP6/SIMIP6/CMIP6:
A Multivariate Map-Comparison Method for Spatial Evaluation of Model Experiment and Model-Data Comparison

(IA) Land Ice:
SeaRISE Greenland Experiments Revisited

(IB) Sea Ice:
Ridging in CICE Sensitivity Studies and Deformation in CASIE Laser Altimeter Data

(I) MAPCOMP

ISMIP-6, SIMIP-6, CMIP-6: Need for analysis of multi-variate multi-model spatial experiment results and multiple spatial data sets

Existing methods for analysis comparison of many models/ model results/ experiments/model-data/maps:

- line plots of summarizing parameters
- difference maps
- one map of a summarizing parameter

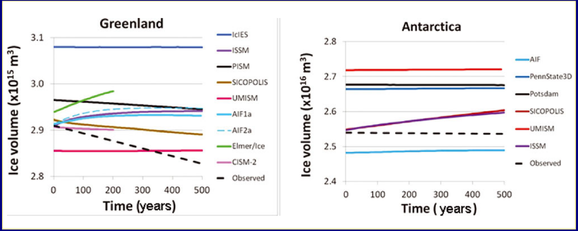


Figure 1. Change in ice-sheet volume (grounded ice plus ice shelves) for control runs of the Greenland and Antarctic ice sheets for different models. Models are identified and described in Table 2 and Appendix A. Black dashed lines begin with the current volume of each ice sheet at 0 years and apply a recently published rate of ice-sheet mass change (Shepherd and others, 2012). Fig. 1 from Bindschadler et al. 2013.

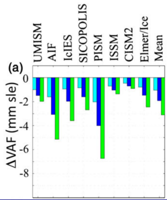


Figure 2. The change (experiment-control) in volume above flotation for the basins of the Greenland ice sheet after 100 simulated years. Atmospheric forcings for N Basin C1, C2, and C3 (light blue, blue, and green). Figure 4a from Nowicki et al. 2013.

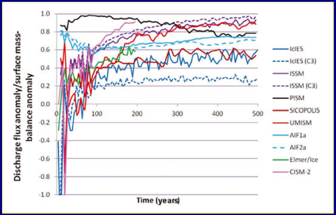


Figure 3. Ratio of discharge flux anomaly to surface mass-balance anomaly for the C1 ($1\times$A1B) climate experiment of the Greenland ice sheet. Anomalies are calculated by differencing discharge flux and surface mass-balance values from the respective control experiments. For comparison, the equivalent ratios for the C3 ($2\times$A1B) experiment for the IciIES and ISSM models are also shown as short-dashed lines. Fig. 4 from Bindschadler et al. 2013.

MAPCOMP Idea

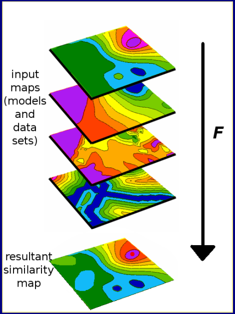


Figure 4. Schematic illustration of the map-comparison method. F denotes the MAPCOMP operator.

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. $\rightarrow$ 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

Spatial Similarity Mapping — MAPCOMP

(1) Pre-Algorithm Standardization

Proportion-of-range standardization $\bar{y} = z_p(y)$

$$z_p(y_{ij}) = \frac{y_{ij} - ymin_j}{ymax_j - ymin_j} \tag{1}$$

Inverse proportion-of-range standardization z_{p^-}

$$z_{p^-}(y_{ij}) = \frac{ymax_j - y_{ij}}{ymax_j - ymin_j} \tag{2}$$

Log-linear transformation

$$z_{ln,p}(y_{ij}) = z_p(z_{ln}(y_{ij})) \tag{3}$$

where

- $ymin_j$ and $ymax_j$ are the minimal and maximal values observed on the variable y_j (for $j = 1, \ldots, n$ with n the number of variables)
- y_{ij} are observations/ model values of y_j (for $i = 1, \ldots, r_j$, r_j the number of observations on y_j)

Spatial Similarity Mapping — MAPCOMP

(2) Semi-Norm in Comparison Space

Define a norm in $\mathcal{R}^{n,n}$ as

$$F(x) = \frac{1}{k} \sum_{s<t,\ t=1}^{n} |d_{st}(x)| \tag{4}$$

where

- M map area
- n the number of input maps
- $M_1, \ldots, M_n$ input maps
- $\overline{m_k(x)}$ the standardized value of map M_k at location x,
- $D(x) \epsilon \mathcal{R}^{n,n}$ difference matrix with $d_{st}(x) = \overline{m_s(x)} - \overline{m_t(x)}$, $M_s, M_t, s, t = 1, \ldots, n$
- $k = n(n-1)/2$ the number of comparisons

Spatial Similarity Mapping — MAPCOMP

(3) MAPCOMP Operator

$$F(x) = \frac{\sum_{s<t,\ t=1}^{n} w_s w_t |\overline{m_s(x)} - \overline{m_t(x)}|}{\sum_{s<t,\ t=1}^{n} w_s w_t} \qquad (5)$$

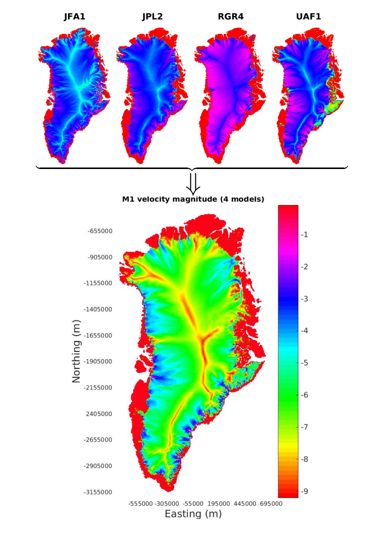
where

- w_i weight assigned to the input map M_i for each $i \epsilon 1, \ldots, n$ that captures the importance of map M_i

All weights must be nonnegative and at least one positive. If a zero weight is used, the right-hand-side of equation (5) is actually only a semi-norm.

MAPCOMP: 4 Models - 1 Variable (Velocity) -

Experiment: M1 (ice-ocean melt)



linear standardization, log colorscale for input maps

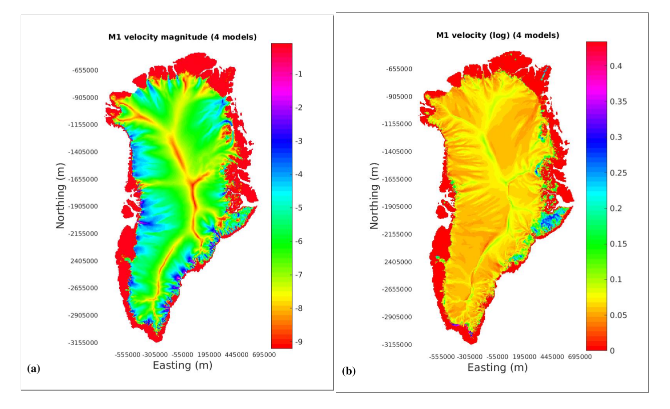
Results group by drainage basins: Largest for W and SE Greenland, where ocean-induced melt is highest.

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: Standardization Methods

4 Models - 1 Variable (velocity) - M1

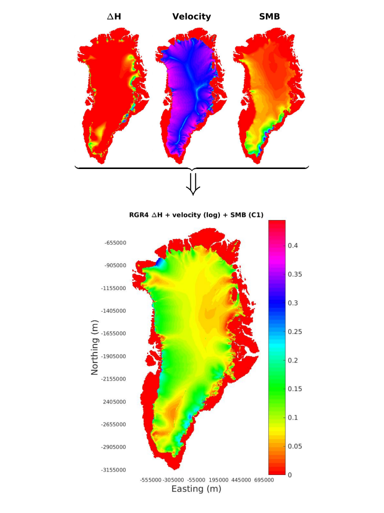


(a) linear standardization and (b) log-linear standardization of input maps

Results enhance different types of features.

MAPCOMP: 1 Model - 3 Variables

Experiment: C1 (climate change scenario)

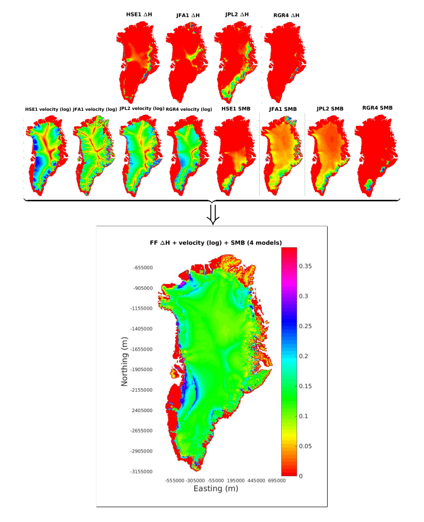


Velo (log-linear trafo), SMB and elev change (linear trafo).

Humboldt Glacier (high velocities, low elev change, low SMB) and SE Greenland (high SMB, low velo and elev change) stand out.

MAPCOMP: 4 Models - 3 Variables

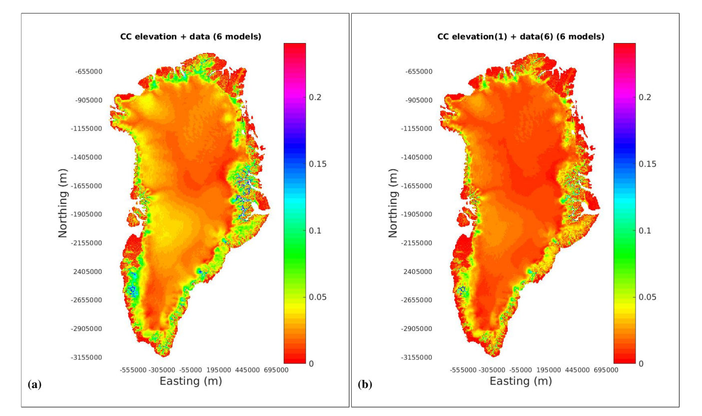
Experiment: R8.5 (realistic scenario for AR5)



Velo (log-linear trafo), SMB and elev change (linear trafo).
Different limits of ice retreat cause the largest dissimilarities.

MAPCOMP: Data-Model Comparison (and Weighting)

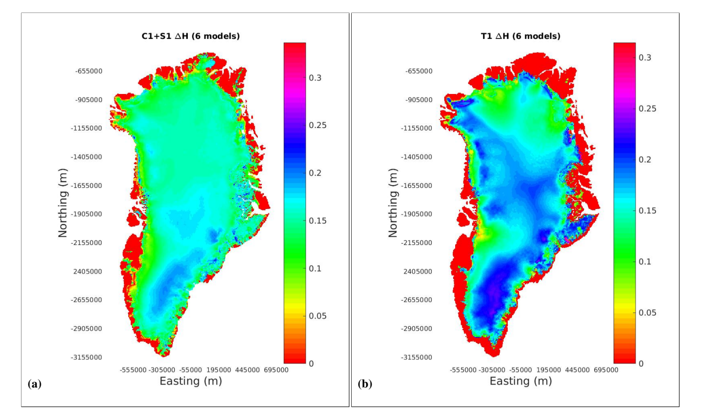
Constant Climate Control Run, 6 Models - 1 Data Set (Surface Height)



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

MAPCOMP: Value of Combination Experiments

C1+S1 versus C1S1, 6 Models (Volume Loss)



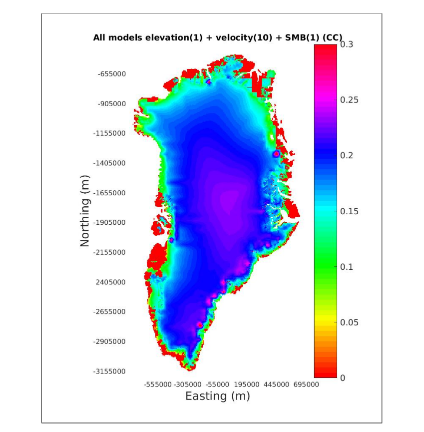
(a) Thickness change from S1 and from C1 and (b) thickness change from combination experiment C1S1

Results differ regionally and in total (the two prescribed changed enhance each other)

and hence it is worth running combination experiments.

MAPCOMP: Find Experiment Outliers

CC (Control Run), 8 Models, 3 Variables (Surface Height, Velocity, SMB)



Velocity (log-linear trafo), height and SMB (linear standardization).

One model in the input stack creates artifacts. MAPCOMP can be applied for trouble-shooting.

Plans for ISMIP6:

- Create MAPCOMP/MAPOPT for Greenland, Antarctica and regional studies and ISMIP6 standards
- Apply MAPCOMP to analyze results from all experiments and models
- Apply MAPCOMP in model-data comparison, especially using ice-surface elevation, but also any other output parameter.
- Identify regions of agreement and disagreement among models and models/data

A first reference:

Herzfeld et al., A Multivariate Map-Comparison Method for Spatial Evaluation of Model Experiments and Model-Data Comparison — A Synthesis Tool for CMIP-6 Illustrated Using Results from SeaRISE, GMD, to be submitted Dec 2016

Sea Ice Example

Ridging in CICE Sensitivity Studies and Deformation in CASIE Laser Altimeter Data:

(1) Model Sensitivity Studies

(2) Model-Data Comparison

Models and Observations (Sea-Ice Example)

- Comparison between model results and observations
  $\rightarrow$ Validation of physical concepts
- History
  - physical understanding of sea-ice processes was ahead of observation technology for decades
  - new remote-sensing technology now yields data which facilitate insight in sea-ice processes ("now" - in the last few years)
- Bridging the data world and the modeling world is not trivial:
  - requires parameterizations from data that match models
  - scale matching: high-resolution observations — models run on relatively low-scale grids
  - spatial coverage and generalization: models cover entire ocean or hemisphere — observation campaigns often localized
  - time scale: observations happen at a short, specific time frame — models cover decades or centuries
- Comparison can lead to
  - either validation of physical concepts
  - or need to include different physical concepts in sea-ice models
  - sometimes different parameterizations in models are sufficient

Topics

- Arctic sea ice coverage continues to decrease
- Change from a perennial sea-ice cover to a seasonal sea-ice cover? (ice-free summers in the Arctic)
  $\rightarrow$ Consequences for Arctic ecology and human living, for weather and climate everywhere
- Loss of old ice
- Need to study the more complicated processes and properties of Arctic sea ice:
  - Deformation processes
  - Ridged ice (and rafted ice)
  - Melt-pond formation and localization
  - Relationships and interactions of the above processes

– Results from a collaborative project *Parameterization of Ridges and Other Spatial Sea-Ice Properties From Geomathematical Analysis of Recent Observations for Improvement of the Los Alamos Sea Ice Model, CICE*

CASIE Experiment July/Aug 2009 – Fram Strait
Characterization of Arctic Sea Ice Experiment

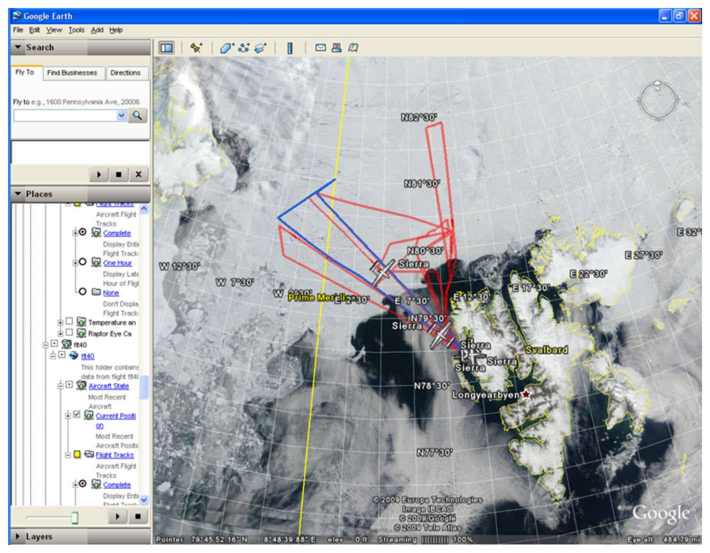
NASA AMES SIERRA: Ny Alesund, Svalbard (photograph by Ian Crocker)

Objective: Collection of high-resolution microtopographic and roughness data: laser altimetry, imagery, microASAR

SIERRA UAV, NASA AMES Research Center: Matthew Fladeland and collaborators

Experiment science: Jim Maslanik (P.I.), Ute Herzfeld (Co-I.), David Long (Co-I.), R. Kwok (Co-I.), Ian Crocker, K. Wegrezyn

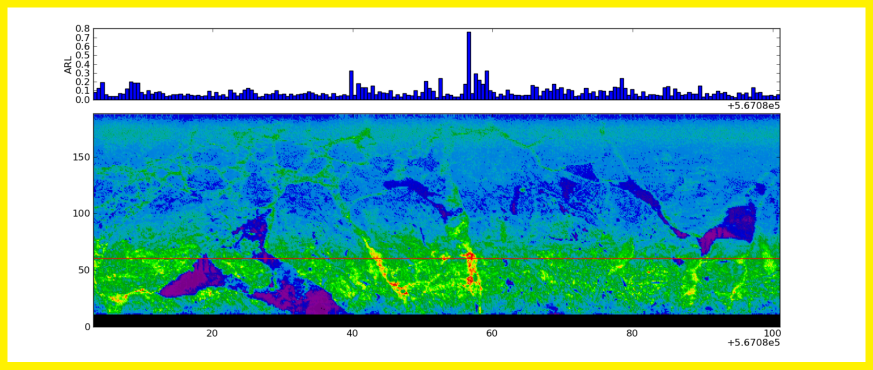
NASA IPY sea-ice roughness project: J. Maslanik, U. Herzfeld, J. Heinrichs, D. Long, R. Kwok



Flight tracks of the CASIE Experiment July/August 2009.

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

ARL from altimetry and matching microASAR data



Segment 1 (msar104), Flight 9, 2009-07-25, CASIE 2009

Geostatistical Classification Parameters

significance parameters:

slope parameter:

$$p1 = \frac{\gamma_{max_1} - \gamma_{min_1}}{h_{min_1} - h_{max_1}}$$

relative significance parameter:

$$p2 = \frac{\gamma_{max_1} - \gamma_{min_1}}{\gamma_{max_1}}$$

pond – maximum vario value

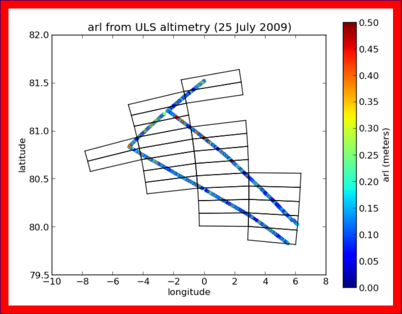
mindist – distance to first min after first max

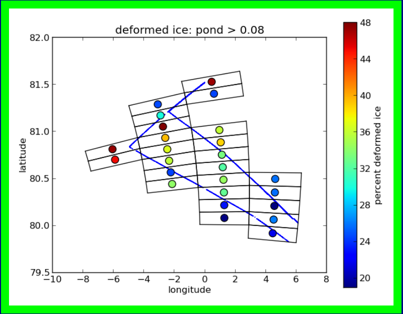
Roughness length approximation:

$$arl = \frac{1}{2}\sqrt{2pond}$$

CICE-CASIE Comparison:

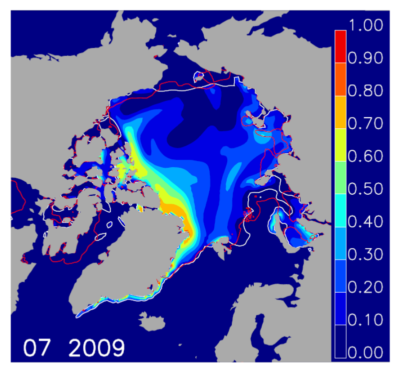
Ice-Surface Roughness (arl) and Percent Deformed Ice Area from Laser Altimetry



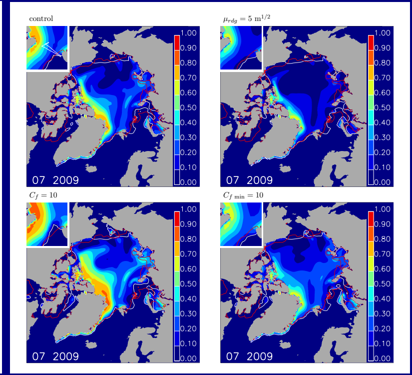


25 CICE grid nodes over sea ice; sea-ice water boundary determined using returned-signal counts

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

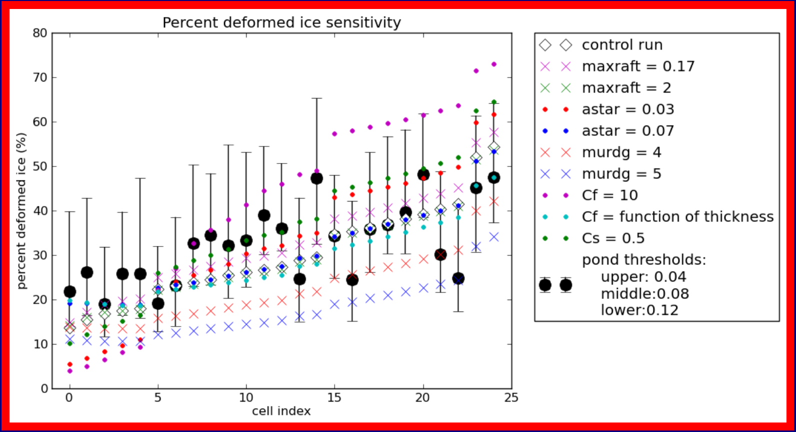


(a) Control Run



(b) Sensitivity Study

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

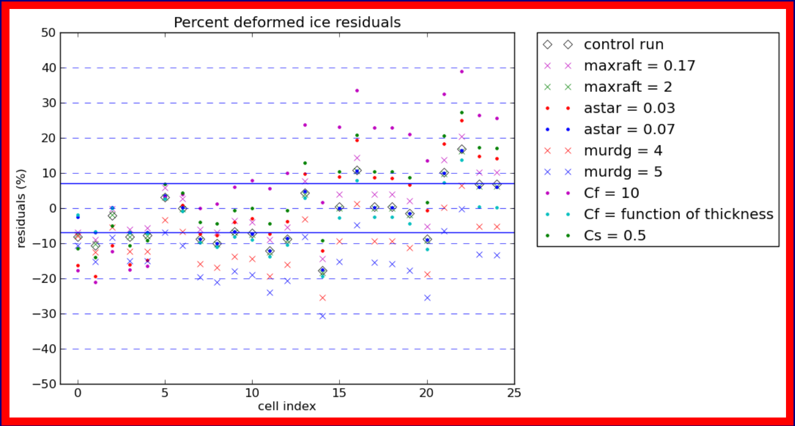


25 CICE grid nodes over sea ice

(Herzfeld, Hunke, McDonald , Wallin, 2014)

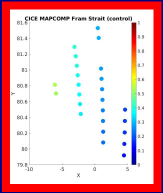
CICE-CASIE Comparison: Sensitivity Studies

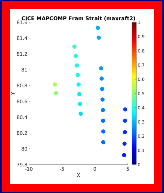
Residuals of Percent Deformed Ice Area from CICE and CASIE

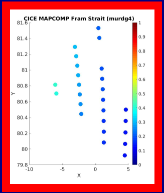


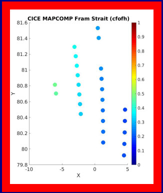
Results from model runs and data analysis match to within 7% of deformed ice area concentration when varying parameters in sensitivity studies (and to within 20% for control run)

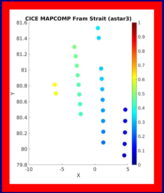
CICE Parameterization Sensitivity Experiments

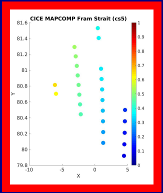


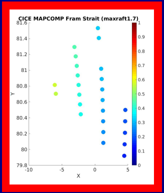


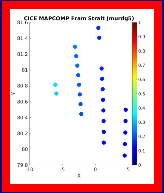


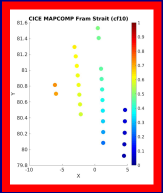


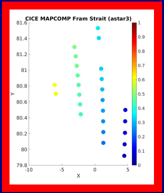


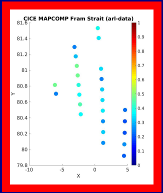












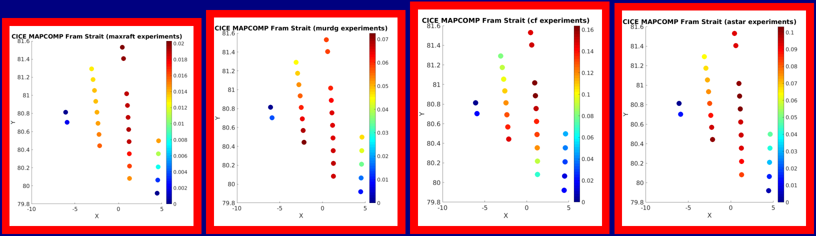
variable: area percent of ridged ice

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 Parameterization Sensitivity Experiments



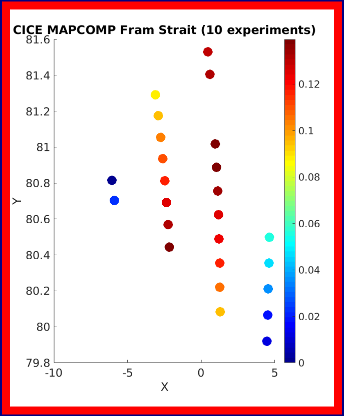
variable: area percent of ridged ice

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

number of model runs compared: 3 per map: control run - lower parameter - higher parameter

parameters: maxraft - murdg - cf - astar

Similarity Mapping: CICE Parameterization Sensitivity Experiments: All 10 Experiments



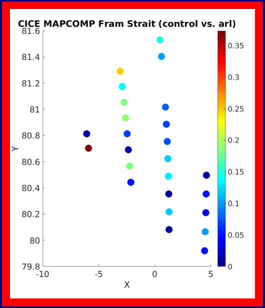
variable: area percent of ridged ice

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

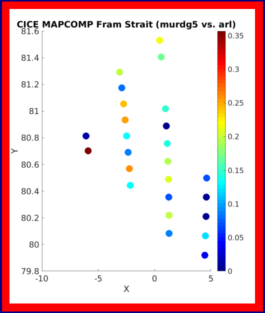
number of model runs compared: 10: control run - lower parameters - higher parameters

parameters: maxraft (2 experiments) - murdg (2 exp.) - cf (3 exp.) - astar (2exp.)

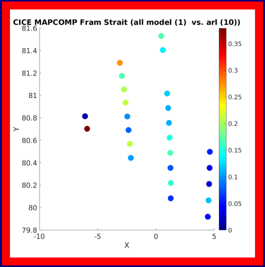
Similarity Mapping: CICE-CASIE Model-Data Comparisons



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 comparison experiments (SIMIP)

(2) Model evaluation/ improvements

Next : larger regions and more data

Questions?

Sheridan Glacier