Ice Deformation in Fram Strait — Comparison of CICE Simulations with Analysis and Classification of Airborne Remote-Sensing Data

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- NSF Arctic Sciences
- NSF Hydrological Sciences
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- University of Colorado UROP Program
Need to Study the Cryosphere: Observations and Modeling

Modeling:

– new collaborative project with Elizabeth Hunke:

*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*

Observations:

– What do we have to measure?
– At what spatial resolution and accuracy?
– Are repeat measurements necessary?
– If so, how often?
– Is global coverage needed?

Note: Observations and analysis methods depend on scale

**Large Scale:**

Altimetry – Elevation and Elevation Change – Spatial Interpolation

Examples: Some Antarctic glaciers

**Small Scale:**

Generalized spatial surface roughness as indicator of dynamic processes

Examples:

- Arctic Sea ice
- Greenland
- Bering Glacier Surge 2011
Using Geomathematics to Connect Science and Engineering

→ Applying Spatial Statistics to Design Cryospheric Observations, Instrumentation, Satellite, Airborne and Field Campaigns

← Understanding Environmental Change through Geomathematical Analysis of Remote-Sensing Data
Objectives

Cryospheric science objective:
Detect and quantify different forms of change in the cryosphere and attribute changes to sea-ice-morphogenetic processes

Remote-sensing objective:
Present and analyze observations from new instruments (GLAS (ICESat), ICESAt-2, UA laser profilometer, SAR, microSAR)

Geomathematical objective:
– Realize new methodological components for spatial structure analysis
– Identify, characterize and classify forms from hidden information in
  (a) Undersampled situations
  (b) Oversampled situations
Measurement objective:

Development of instrumentation to survey (Micro-)topography and roughness of ice surfaces

(1) Glacier Roughness Sensor (GRS)
(2) UAV Laser Profilometer
(UAV- Unmanned Aerial Vehicle)

Contribution to new Satellite and Airborne Observation Technology

(1) ICESat-2
(2) MABEL
(3) SIGMA (data analysis)
(4) CryoSat2
Survey campaigns and satellite missions
→ tiers of observations
SCALE
Objectives of Ice Classification

(1) Characterization of ice provinces: Establish a unique quantitative description of each ice type
(2) Classification: Assign a given object to a surface class, using the characterization
(3) Segmentation: Create a thematic map by applying the classification operator in a moving window

Transfer to Modeling

(1) Parameterization of spatial sea-ice properties, based on characterization
(2) Summarize properties of ice types, based on classification
(3) Simplify regional ice-type distributions for model input at larger/ regional scale, based on segmentation
CASIE – Characterization of Arctic Sea Ice Experiment

July/August 2009 from a base in Nye Alesund, Svalbard

Objective: Collection of high-resolution microtopographic and roughness data

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 AMES SIERRA: Cold-Weather System Test with CU-ULS (March 2009)
photograph by Don Herlth
BYU mSAR panels integrated in SIERRA
NASA AMES SIERRA: Ny Alesund, Svalbard

photograph by Ian Crocker
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flight tracks
Sea Ice Types — Fram Strait, from CASIE 2009

(a) near ice edge

(b) rubble – lead – floes
Sea Ice Types — Fram Strait, from CASIE 2009

(c) refrozen lead

(d) flooded floes – ridging
Laser altimeter data, videographic data and microASAR data from CASIE
What is spatial surface roughness?

- a derivative of (micro)topography
  → characterization of spatial behavior

Why do we need spatial surface roughness?

- sub-scale information for satellite measurements
- indicator variable for other, harder to observe processes
- parameterization of sub-scale features or processes
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How do we analyze surface roughness?

The analytically defined spatial derivative needs to be calculated numerically from a data set.

One way to do this:

\[
\lim_{x \to x_0} \frac{z(x_0) - z(x)}{x_0 - x}
\]

surface slope in a given location \(x_0\)

To characterize morphology, better use averages...
Definition of Vario Functions

\[ V = \{(x, z) \text{ with } x = (x_1, x_2) \in \mathcal{D} \text{ and } z = z(x)\} \subseteq \mathcal{R}^3 \]

discrete-surface case or

\[ V = \{(x, z) \text{ with } x \in \mathcal{D} \text{ and } z = z(x)\} \subseteq \mathcal{R}^2 \]

discrete-profile case

Define the first-order vario function \( v_1 \)

\[ v_1(h) = \frac{1}{2n} \sum_{i=1}^{n} [z(x_i) - z(x_i + h)]^2 \]

with \((x_i, z(x_i)), (x_i + h, z(x_i + h)) \in \mathcal{D}\) and \(n\) the number of pairs separated by \(h\).
Higher-Order Vario Functions

The first-order vario-function set is

\[ V_1 = \{(h, v_1(h))\} = \mathcal{V}(V_0) \]

Then: get \( V_2 \) from \( V_1 \) in the same way you get \( V_1 \) from \( V_0 \). The second-order vario function is also called varvar function.

Recursively, the vario function set of order \( i + 1 \) is defined by

\[ V_{i+1} = \mathcal{V}(V_i) \]

for \( i \in \mathbb{N}_0 \).
Beaufort Sea

Beaufort Sea, Snow on Seaice, Depth vs Latitude

Beaufort Sea, Snow on Seaice, Large Scale Variogram Study

Ute C. Herzfeld\textsuperscript{1,2,3}, Elizabeth Hunke\textsuperscript{4} and Brian McDonald\textsuperscript{1}
Geostatistical Classification Parameters

significance parameters:

slope parameter:

\[ p_1 = \frac{\gamma_{\text{max}1} - \gamma_{\text{min}1}}{h_{\text{min}1} - h_{\text{max}1}} \]

relative significance parameter:

\[ p_2 = \frac{\gamma_{\text{max}1} - \gamma_{\text{min}1}}{\gamma_{\text{max}1}} \]

pond – maximum vario value

mindist – distance to first min after first max

\[ \text{avgspac} = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{i} h_{\text{min}i} \]

typically for \( n = 3 \) or \( n = 4 \)
Geostatistical Classification Parameters Applied To Sea-Ice Image

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Correction ingredients

(1) 1 Hz GPS data, collected on-board SIERRA
(2) cubic splines to correct for longer range aircraft motion
(3) altimetry / geolocation residuals wrt to fitted splines

Shown at left: 2 segments with double tracks, altimetry over microASAR
Top: Segment 1, Flight 9
Bottom: Segment 2, Flight 9
2009-07-25
Roughness length approximation:

\[ arl = \frac{1}{2} \sqrt{2pond} \]
ARL from altimetry and matching microASAR data

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

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ARL from CASIE Laser Data

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water

sea ice
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Along-track ARL - CASIE July 2009
25 CICE grid nodes over sea ice

sea-ice water boundary determined using returned-signal counts
CICE Model Run For CASIE Flight 09 Time
Deformed Ice Area Fraction – July 2009

07 2009
CICE Model Run For CASIE Flight 09 Time
Sail Height – July 2009

07 2009

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<table>
<thead>
<tr>
<th>CASIE</th>
<th></th>
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<tbody>
<tr>
<td>arl</td>
<td>pond</td>
<td>% level</td>
<td>% ridged</td>
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<tr>
<td>0.1118</td>
<td>0.025</td>
<td>69.0</td>
<td>31.0</td>
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<td>0.1000</td>
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<table>
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<td>61.8</td>
<td>38.2</td>
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<td>$C_f = 10$</td>
<td></td>
<td>36.0</td>
<td>64.0</td>
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<tr>
<td>$\mu_{rdg} = 5$</td>
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<td>78.7</td>
<td>21.3</td>
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</table>

used $pond = 0.01m^2$, based on ULS data analysis
### Deformed Ice Dependent on CICE Model Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Northern Hem.</th>
<th>Casie Mask (35 Nodes)</th>
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<tr>
<td>original</td>
<td>31.1634</td>
<td>38.1931</td>
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<tr>
<td>astar.03</td>
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<tr>
<td>Cs.5</td>
<td>36.6809</td>
<td>50.2486</td>
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Ute C. Herzfeld\(^1\), Elizabeth Hunke\(^4\) and Brian McDonald\(^1\)

Ice Deformation in Fram Strait — Comparison of CICE Simulations
Definition revisited

What do we actually call “deformed sea ice”?

CASIE image 1-20090725-10-33-55-IMG-4580-R.jpg
Approach for measuring deformed sea ice areas from imagery

- Use high-resolution CASIE imagery
- Geo-reference all images individually using GPS data
- Define a pond-filter that identifies ridge areas
- Apply this to images in all grid cells

To Do: Compare that to ARL
CASIE image 1-20090725-10-33-55-IMG-4580-R.jpg
Determination of Deformed Ice Area Using Geostatistical Classification

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### Deformed Ice from CASIE Images (pond)

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Longitude</th>
<th>% Ridged Ice</th>
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<tbody>
<tr>
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<td>81.53162384</td>
<td>0.43930054</td>
<td>16.6952595206</td>
</tr>
</tbody>
</table>

- from 25 nodes (ice-covered regions only)
- threshold for classification: $60 < \text{pond} < 200$ to determine ridged ice areas

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What’s next?

- compare definitions of deformed ice areas:
  - from imagery and ARL
  - as used in CICE, dependent on parameters
- more test areas
- MABEL data analysis
- OIB data analysis
NASA Operation Ice Bridge — Flight Tracks

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