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

Ute C. Herzfeld$^{1,2,3}$, Elizabeth Hunke$^4$ and Brian McDonald$^1$

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CESM Polar Working Group Meeting, NCAR, Feb11-13, 2013
Thanks to my collaborators and students …

Geomath Team: Phil Chen, Bruce Wallin (now NMTech), Ian Crocker, Maciej Stachura, Alex Weltmann, Lance Bradbury, Alex Yearsley, Griffin Hale, Sean O’Grady, Steve Sucht, Scott Williams (now google)

ICESat and ICESat-2: Waleed Abdalati (CUB), Bea Csatho (U Buffalo NY) and ICESat science team/ ICESat-2 SDT Alexander Marshak, Steve Palm; Thorsten Markus, Tom Neumann and the ICESAt-2 Project, Kelly Brunt, Jay Zwally, John DiMarzio, Anita Brenner, Kristine Barbieri, LeeAnne Roberts (NASA Goddard Space Flight Center)

IceBridge: William Krabill, Serdar Manizade (NASA Goddard Space Flight Center) and collaborators;

CASIE and SeaiceIPY: James Maslanik (CCAR, CU Boulder), Ron Kwok (JPL), John Heinrichs (Ft. Hays State Univ, KS), David Long (BYU Provo), Matt Fladeland and SIERRA Team at NASA Ames Research Center
... and for support through

- Los Alamos Institute for Geophysics and Planetary Physics
- NASA Cryospheric Sciences
- NSF Arctic Sciences
- NSF Hydrological Sciences
- Deutsche Forschungsgemeinschaft (DFG), Antarctic and Arctic Research Program
- 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
  - Undersampled situations
  - 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 Experiment 2009
Fram Strait

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

Ute C. Herzfeld$^{1,2,3}$, Elizabeth Hunke$^4$ and Brian McDonald$^1$

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NASA AMES SIERRA: Ny Alesund, Svalbard

photograph by Ian Crocker
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
Ute C. Herzfeld\textsuperscript{1,2,3}, Elizabeth Hunke\textsuperscript{4} and Brian McDonald\textsuperscript{1}

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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

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

discrete-surface case or

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

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

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

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

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

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

Beaufort Sea, Snow on Seaice, Depth vs Latitude

Beaufort Sea, Snow on Seaice, Large Scale Vario Study
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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\textsuperscript{1}Department of Electrical, Computer and Energy Engineering \textsuperscript{2}Cooperative Institute for Research in Environmental Sciences \textsuperscript{3}Institute of Marine and Earth Science \textsuperscript{4}T-3 Fluid Dynamics and Solid Mechanics Group Los Alamos National Laboratory

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Ice Deformation in Fram Strait — Comparison of CICE Simulations with Analysis and Classification of Airborne Remote-Sensing Data
Laser altimeter data — correction method

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:

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

Segment 1 (msar104), Flight 9, 2009-07-25, CASIE 2009
ARL from CASIE Laser Data

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

Ute C. Herzfeld\textsuperscript{1,2,3}, Elizabeth Hunke\textsuperscript{4} and Brian McDonald\textsuperscript{1}
ARL Histogram from CASIE Laser Data - Water

CASIE ULS ARL Histogram 79.55033875-7.34017944-hist-arl.png \([m^2]\)

Ute C. Herzfeld\(^1,2,3\), Elizabeth Hunke\(^4\) and Brian McDonald\(^1\)

Ice Deformation in Fram Strait — Comparison of CICE Simulations
Ice Deformation in Fram Strait — Comparison of CICE Simulations with Airborne Remote-Sensing Data
CICE- CASIE Comparison:
Percent Deformed Ice Area from ULS ARL

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

Ice Deformation in Fram Strait — Comparison of CICE Simulations with Analysis and Classification of Airborne Remote-Sensing Data
CICE Model Run For CASIE Flight 09 Time Sail Height – July 2009

07 2009
<table>
<thead>
<tr>
<th>CASIE</th>
<th>arl</th>
<th>pond</th>
<th>% level</th>
<th>% ridged</th>
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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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<tr>
<td>0.1000</td>
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<table>
<thead>
<tr>
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<th>38.2</th>
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<td></td>
<td>$C_f = 10$</td>
<td>36.0</td>
<td>64.0</td>
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<tr>
<td></td>
<td>$\mu_{rdg} = 5$</td>
<td>78.7</td>
<td>21.3</td>
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</table>

used $pond = 0.01 m^2$, 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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<tbody>
<tr>
<td>original</td>
<td>31.1634</td>
<td>38.1931</td>
</tr>
<tr>
<td>astar.03</td>
<td>32.4175</td>
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<td>astar.07</td>
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<td>murdg4</td>
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<td>Cf10</td>
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</tr>
<tr>
<td>Cs.5</td>
<td>36.6809</td>
<td>50.2486</td>
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</table>
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

mindist

pond

pond filtered: $60 \leq pond < 200$

Ute C. Herzfeld$^{1,2,3}$, Elizabeth Hunke$^4$ and Brian McDonald$^1$
### Deformed Ice from CASIE Images *(pond)*

<table>
<thead>
<tr>
<th>Latitude</th>
<th>Longitude</th>
<th>% Ridged Ice</th>
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<tbody>
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<td>80.06551361</td>
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<td>81.53162384</td>
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</tbody>
</table>

- from 25 nodes (ice-covered regions only)

- threshold for classification: 60 < Pond < 200 to determine ridged ice areas

**Ute C. Herzfeld**¹,²,³, **Elizabeth Hunke**⁴ and **Brian McDonald**¹

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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
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