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

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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?

One reference: National Research Council (2007) "Decadal Survey Objectives" [Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, The National Academies Press, 2007, 456 pp.]

SCALE

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

APPROACH

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

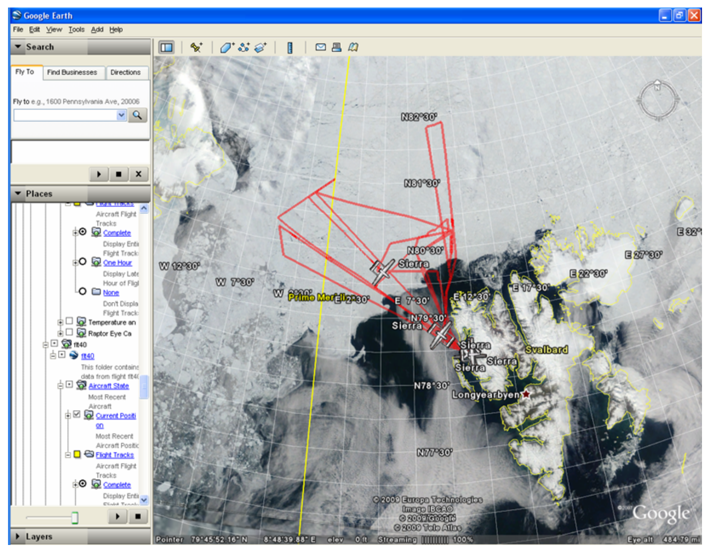
NASA AMES SIERRA: Cold-Weather System Test with CU-ULS (March 2009)

photograph by Don Herlth

BYU mSAR panels integrated in SIERRA

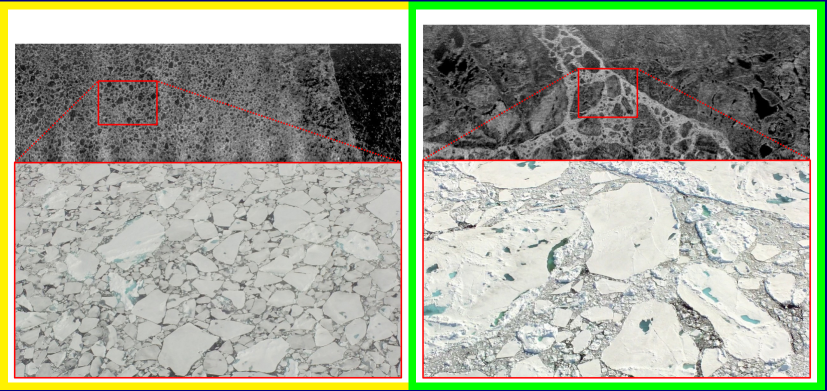
NASA AMES SIERRA: Ny Alesund, Svalbard

photograph by Ian Crocker



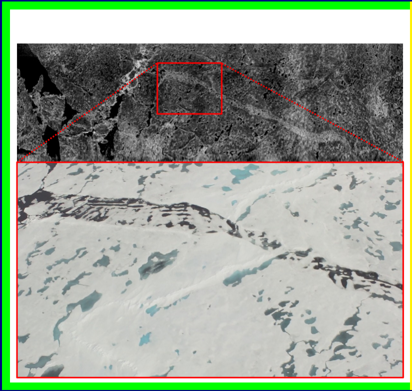
flight tracks

Sea Ice Types — Fram Strait, from CASIE 2009

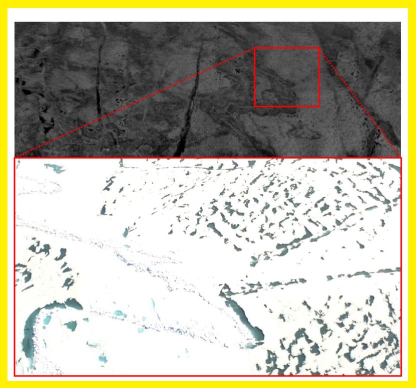


(a) near ice edge (b) rubble – lead – floes

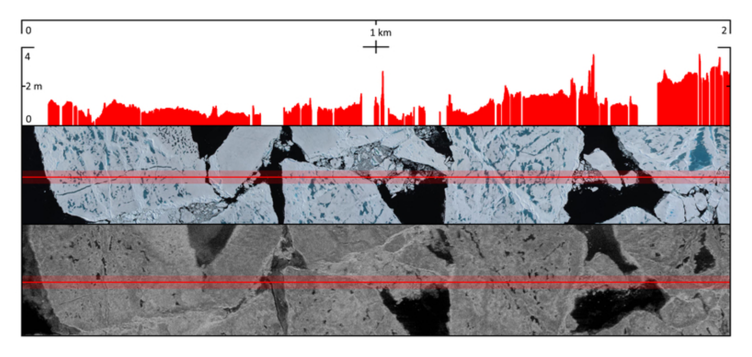
Sea Ice Types — Fram Strait, from CASIE 2009



(c) refrozen lead



(d) flooded floes – ridging



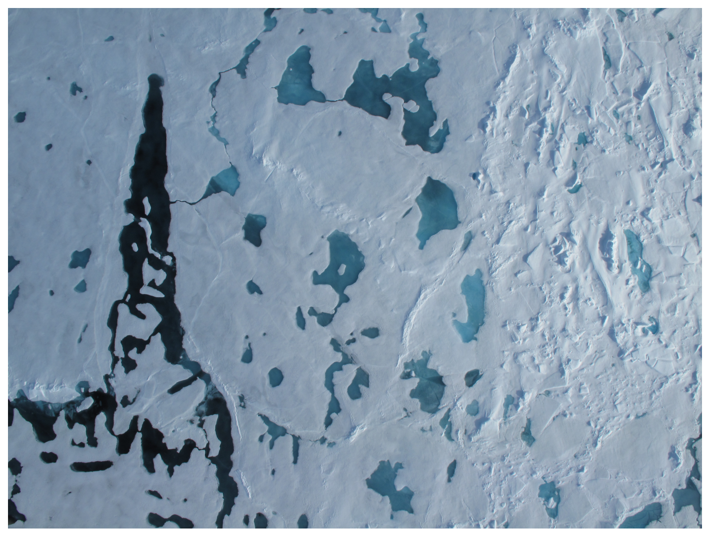
Laser altimeter data, videographic data and microASAR data from CASIE

What is spatial surface roughness?

- a derivative of (micro)topography
  $\longrightarrow$ 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



CASIE image 20090725-15.36.22-IMG-9080.jpeg

(4.) 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

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

discrete-surface case or

$$V = \{(x, z) \text{ with } x\epsilon\mathcal{D} \text{ and } z = z(x)\} \subseteq \mathcal{R}^2$$

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 $(x_i, z(x_i)), (x_i + h, z(x_i + h))\epsilon\mathcal{D}$ and n the number of pairs separated by h.

Higher-Order Vario Functions

The first-order vario-function set is

$$V_1 = \{(h, v_1(h))\} = \underline{v}(V_0)$$

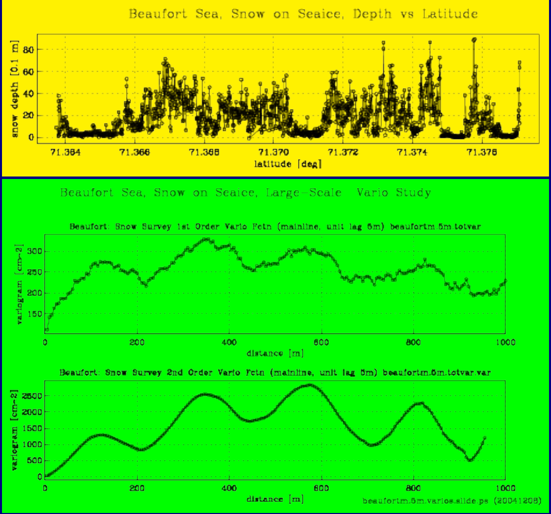
Then: get V_2 from V_1 in the same way you
get V_1 from V_0. The second-order vario function is also called varvar function.

Recursively, the vario function set of order $i+1$ is defined by

$$V_{i+1} = \underline{v}(V_i)$$

for $i \epsilon \mathcal{N}_0$.

Beaufort Sea



Geostatistical Classification Parameters

significance parameters:

slope parameter:

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

relative significance parameter:

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

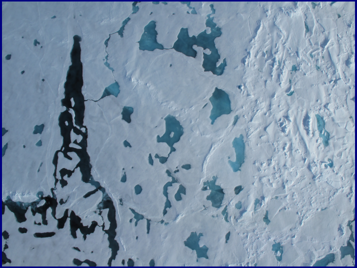
pond – maximum vario value

mindist – distance to first min after first max

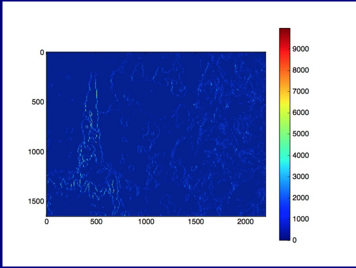
$$avgspac = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{i} \; h_{min_i}$$

typically for $n = 3$ or $n = 4$

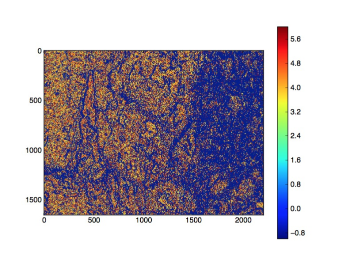
Geostatistical Classification Parameters Applied To Sea-Ice Image



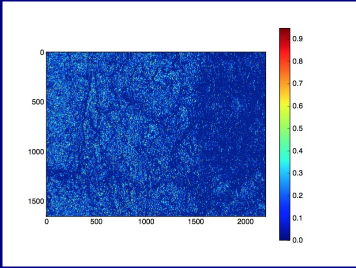
image



pond

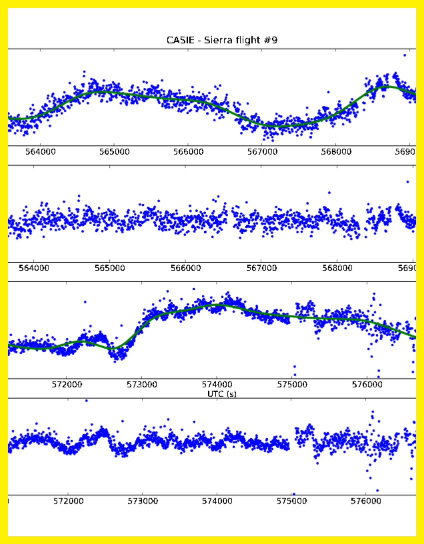


mindist



p2

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

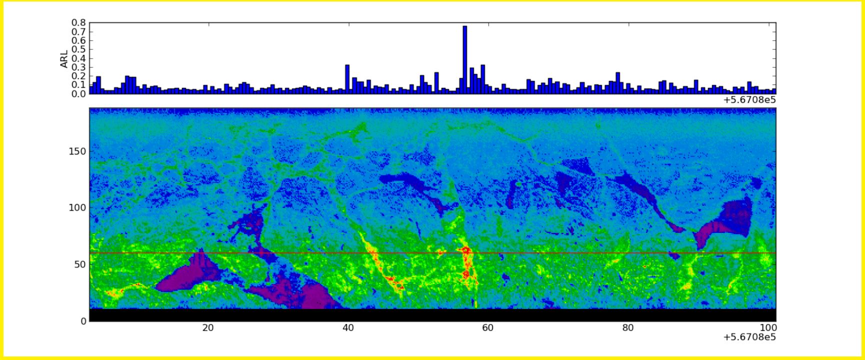
Bottom: Segment 2, Flight 9

2009-07-25

Roughness length approximation:

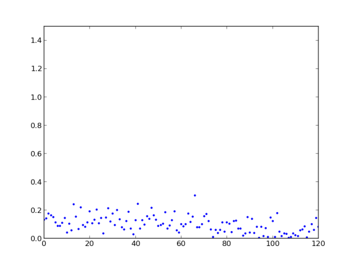
$$arl = \frac{1}{2}\sqrt{2pond}$$

ARL from altimetry and matching microASAR data

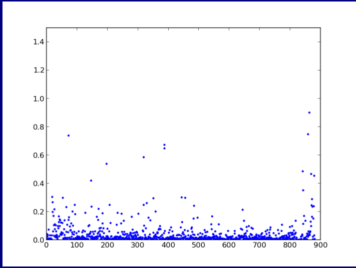


Segment 1 (msar104), Flight 9, 2009-07-25, CASIE 2009

ARL from CASIE Laser Data

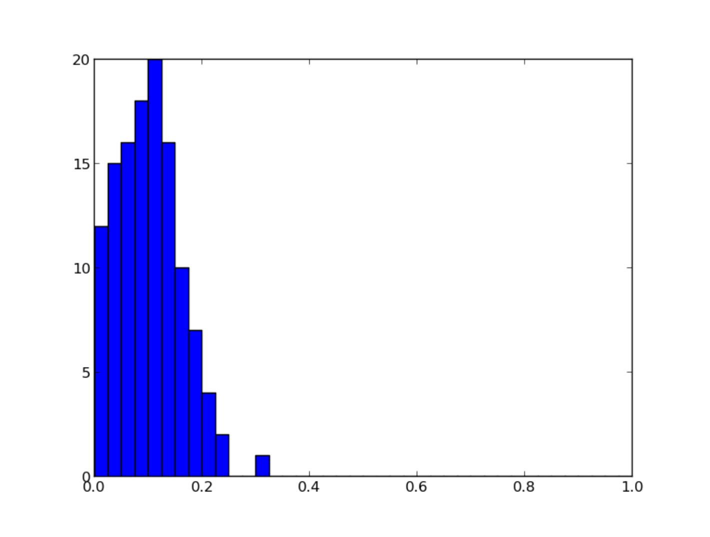


water



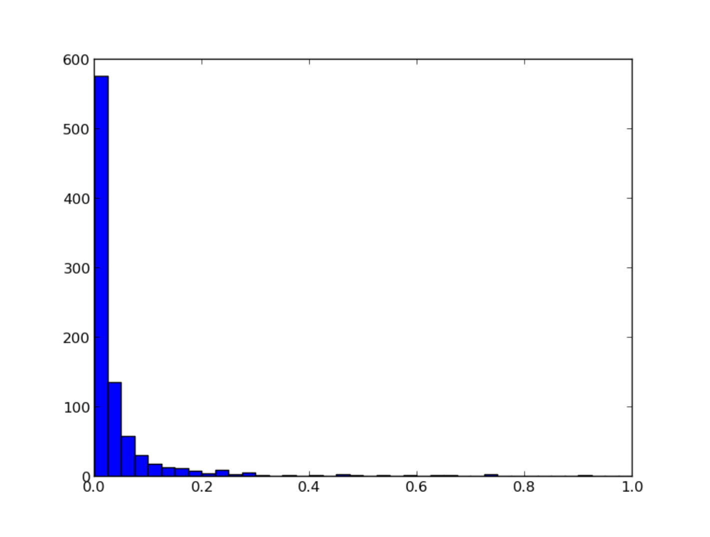
sea ice

ARL Histogram from CASIE Laser Data - Water



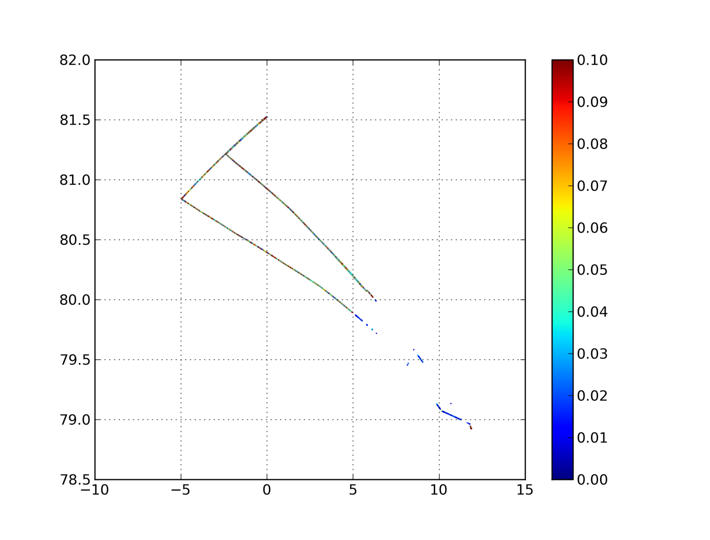
CASIE ULS ARL Histogram 79.55033875-7.34017944-hist-arl.png [m^2]

ARL Histogram from CASIE Laser Data - Sea Ice

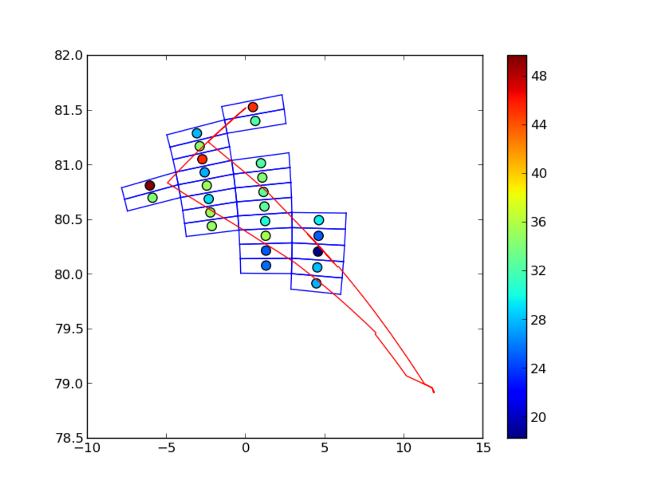


CASIE ULS ARL Histogram 781.17401123-2.92260742-hist-arl.png [m^2]

Along-track ARL - CASIE July 2009



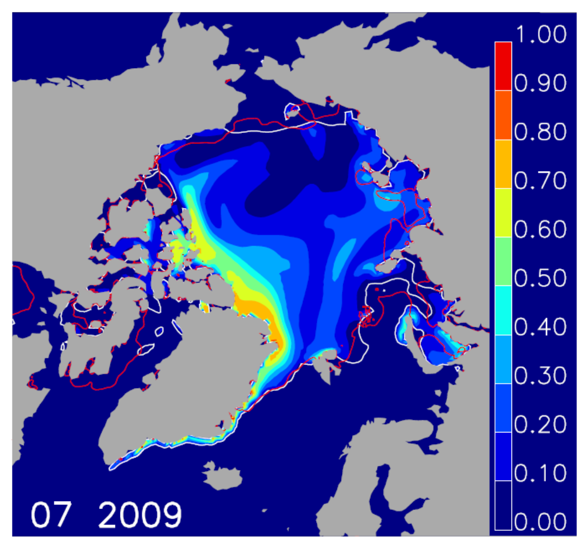
CICE- CASIE Comparison: Percent Deformed Ice Area from ULS ARL



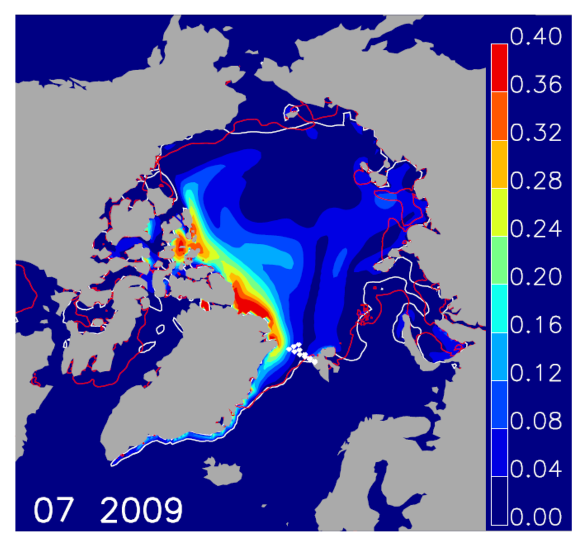
25 CICE grid nodes over sea ice

sea-ice water boundary determined using returned-signal counts

CICE Model Run For CASIE Flight 09 Time Deformed Ice Area Fraction – July 2009



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



CASIE / CICE Data Comparison July 2009

CASIE

arl	pond	% level	% ridged
0.1118	0.025	69.0	31.0
0.1000	0.020	64.1	35.9
0.0866	0.015	57.3	42.7
0.0707	0.010	47.7	52.3
0.0500	0.005	29.2	70.8

CICE

control		61.8	38.2
$C_f = 10$		36.0	64.0
$\mu_{rdg} = 5$		78.7	21.3

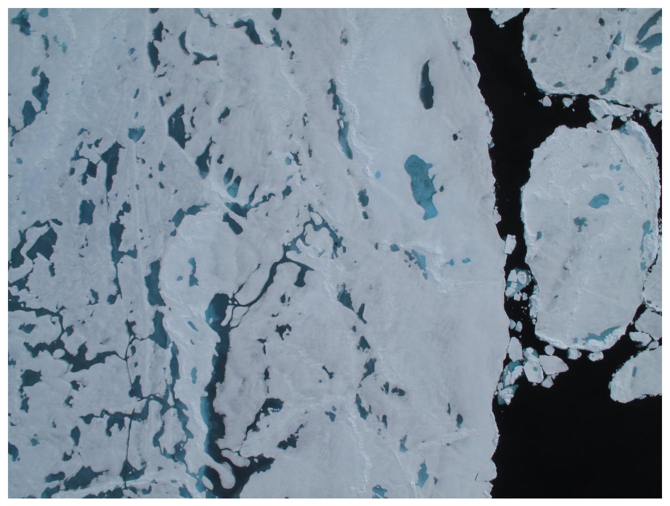
used $pond = 0.01m^2$, based on ULS data analysis

Deformed Ice Dependent on CICE Model Parameters

Parameter	Northern Hem.	Casie Mask (35 Nodes)
orginal	31.1634	38.1931
astar.03	32.4175	45.5128
astar.07	30.9051	39.2194
maxraft.17	33.0950	41.8181
maxraft2	30.7335	37.6406
murdg4	24.6877	27.6685
murdg5	20.2645	21.2877
Cf10	41.5542	63.9714
Cs.5	36.6809	50.2486

Definition revisited

What do we actually call "deformed sea ice"?

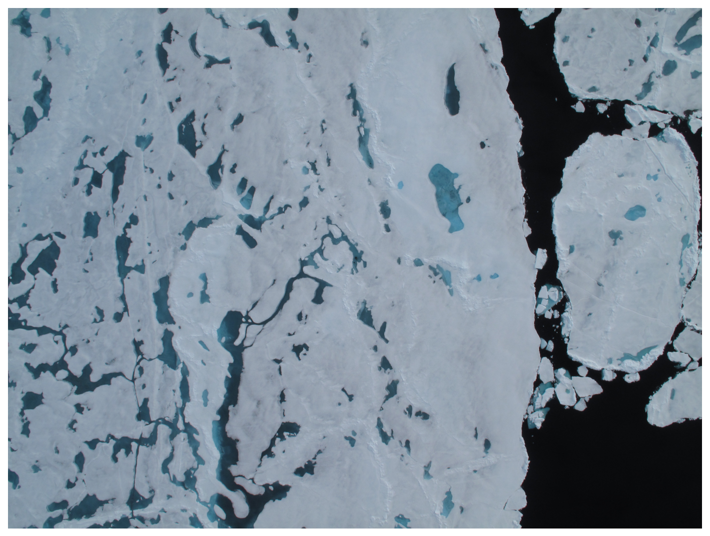


CASIE image 1-20090725-10-33-55-IMG-4580-R.jpg

Approach for measuring deformed sea ice areas from imagery

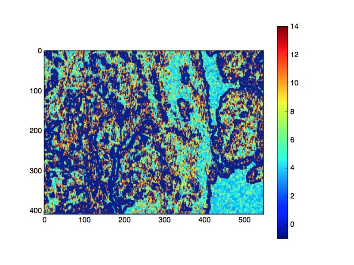
- Use high-resolution CASIE imagery
- Geo-reference all images individually using GPS data
- Define a *pond*-filter that identifies ridge areas
- Apply this to images in all grid cells

To Do: Compare that to ARL

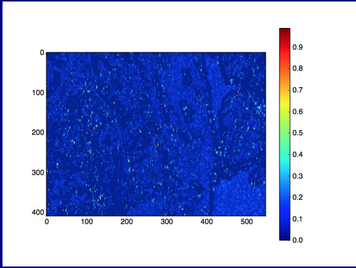


CASIE image 1-20090725-10-33-55-IMG-4580-R.jpg

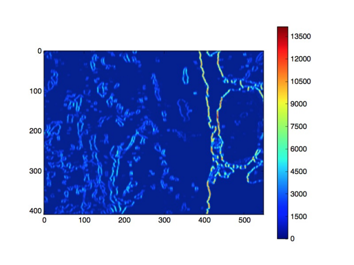
Determination of Deformed Ice Area Using Geostatistical Classification



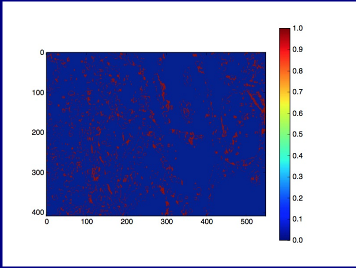
mindist



p2



pond



pond filtered: $60 \leqslant pond < 200$

Deformed Ice from CASIE Images (*pond*)

Latitude	Longitude	% Ridged Ice
80.06551361	4.50762939	9.46214414035
80.08296967	1.27127075	11.6643353086
80.21040344	4.5546875	13.6099826824
80.2192688	1.26473999	12.3897421788
80.35453033	4.58929443	11.8910531342
80.35469818	1.24539185	12.0757602732
80.44387054	-2.15808105	16.299423827
80.48925018	1.21295166	14.1650751776
80.49788666	4.6111145	10.9840662275
80.56816101	-2.25061035	18.5388512147
80.62290192	1.16702271	14.1661271789
80.69143677	-2.35668945	21.4184618124
80.70297241	-5.90551758	23.4446026942
80.75563049	1.10736084	15.0469354395
80.81368256	-2.47665405	23.4854014599
80.81427002	-6.0753479	18.4906210044
80.88742828	1.03353882	19.9097706637
80.93487549	-2.61074829	23.9840593802
81.01826477	0.94525146	13.8140709211
81.05499268	-2.75927734	17.2569472543
81.17401123	-2.92260742	17.0840548983
81.29190826	-3.1010437	14.5342062246
81.40483093	0.58953857	19.6372618836
81.53162384	0.43930054	16.6952595206

- from 25 nodes (ice-covered regions only)

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

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