Spatial Roughness and Spatial Characterization of Sea Ice

Ute C. Herzfeld
Cooperative Institute for Research in Environmental Sciences
Department of Electrical, Computer and Energy Engineering
and
Department of Applied Mathematics
University of Colorado Boulder

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Thanks to my collaborators and students ...

Geomath Team: Brian McDonald, Phil Chen, Bruce Wallin (now NMTech), Steve Sucht, Ian Crocker, Maciej Stachura, Danielle Lirette, Patrick McBride, Scott Williams (now google)
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... and for support through

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Avenues for contributions to improving sea-ice modeling in CESM

(1) Statistics and Geomathematics: Approaches to capture complex spatio-temporal phenomena; scaling; parameterization of (subscale) physical phenomena for model input

(2) Observations: Data and data analysis of sea-ice characteristics from satellite and airborne campaigns

Survey campaigns and satellite missions
→ tiers of observations
SCALE

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

APPROACH

Using Geomathematics
to Connect Science and Engineering

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

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

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

Classification
Spatial Surface Roughness

Arctic Sea Ice

1. Sea-ice types and spatial surface roughness
2. Classification of sea ice near Pt Barrow from SAR data
3. CASIE 2009: Passive and active microwave observations from unmanned aircraft to characterize sea ice properties and their changes in the FRAM Strait
4. Simulation of scale-dependent roughness

Rubbled Ice (March 2003) (J. Maslanik photo)

Beaufort Sea, Ridge (March 2003) (J. Maslanik photo)

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

(1.) What is spatial surface roughness?

- a derivative of (micro)topography

→ characterization of spatial behavior

(2.) Why do we need surface roughness?

- morphologic characteristics are captured in surface roughness (not in absolute elevation)
- subscale information for satellite data

(3.) How do we measure surface roughness?

- Glacier Roughness Sensor (land ice)
- A UAV with laser profilometer

(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

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

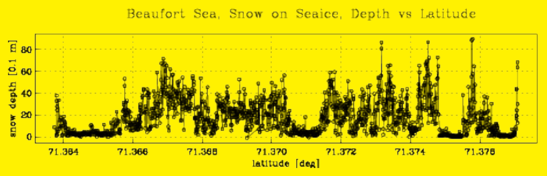
Then: get V_2 from V_1 in the same way you
get V_1 from V_0. The second-order vario function is also called varvar function.

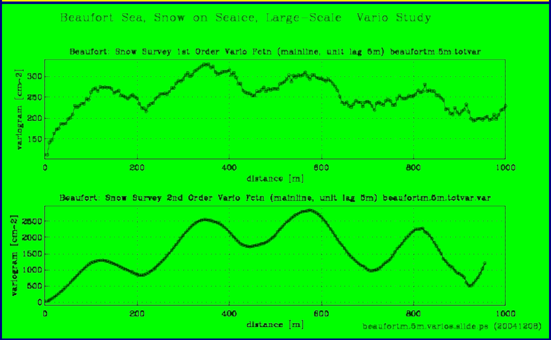
Recursively, the vario function set of order $i+1$ is defined by

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

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:

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

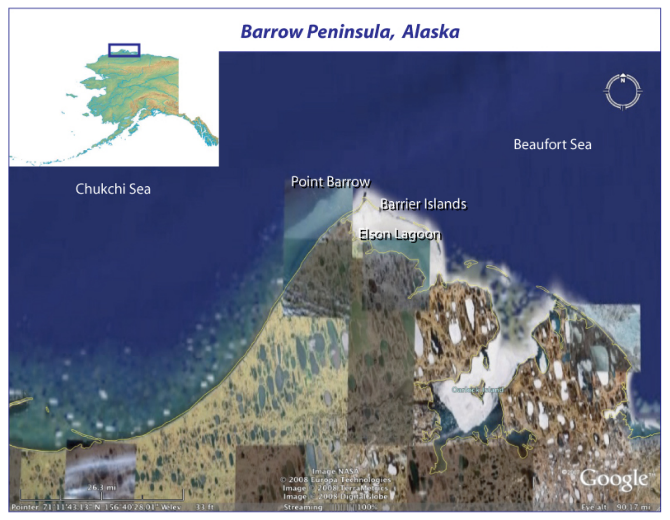
pond – maximum vario value

mindist – distance to first min after first max

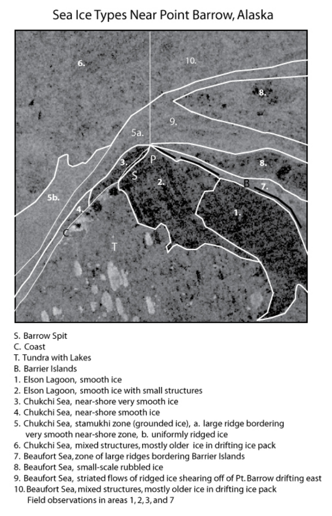
$$avgspac = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{i} \; h_{min_i}$$

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

Study areas near Point Barrow, Alaska: Chukchi Sea, Beaufort Sea and Elson Lagoon



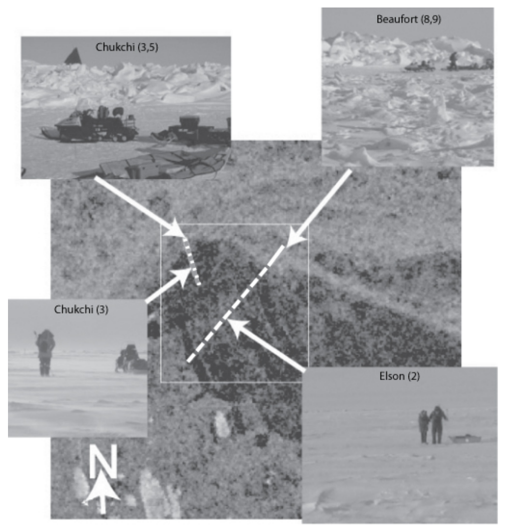
Sea Ice Types Near Point Barrow, Alaska: SAR Data



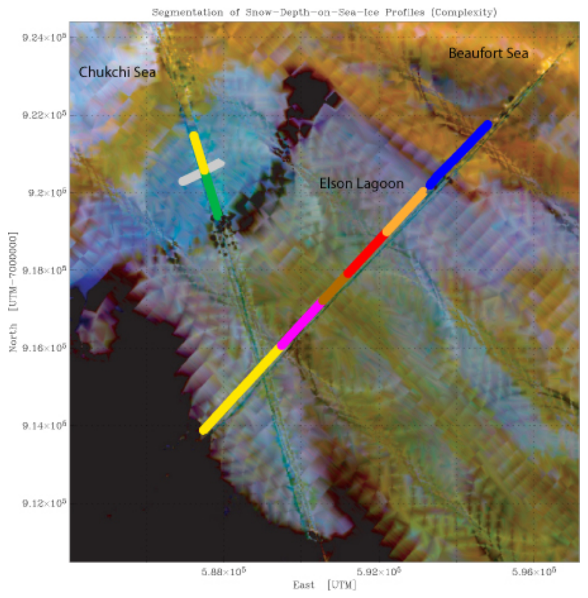
Sea Ice Types Near Point Barrow, Alaska

S. Barrow Spit
C. Coast
T. Tundra with Lakes
B. Barrier Islands
1. Elson Lagoon, smooth ice
2. Elson Lagoon, smooth ice with small structures
3. Chukchi Sea, near-shore very smooth ice
4. Chukchi Sea, near-shore smooth ice
5. Chukchi Sea, stamukhi zone (grounded ice), a. large ridge bordering very smooth near-shore zone, b. uniformly ridged ice
6. Chukchi Sea, mixed structures, mostly older ice in drifting ice pack
7. Beaufort Sea, zone of large ridges bordering Barrier Islands
8. Beaufort Sea, small-scale rubbled ice
9. Beaufort Sea, striated flows of ridged ice shearing off of Pt. Barrow drifting east
10. Beaufort Sea, mixed structures, mostly older ice in drifting ice pack
Field observations in areas 1, 2, 3, and 7

Sea Ice Types Near Point Barrow, SAR Data and Photos



Sea Ice Classification: PSR and Field Data (Snow Depth)

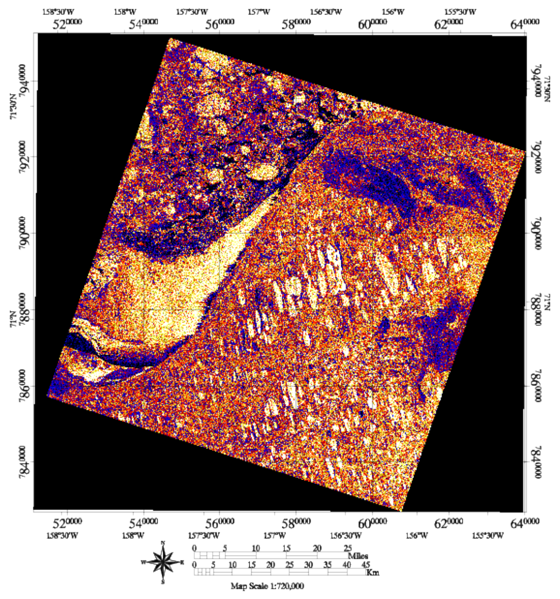


from

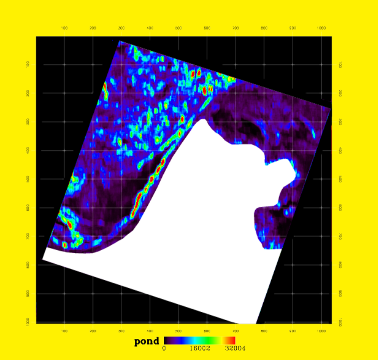
Herzfeld, Maslanik and Sturm,

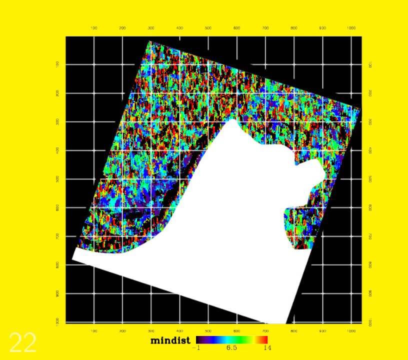
IEEE TGRS 2006

Sea Ice Classification: SAR Data

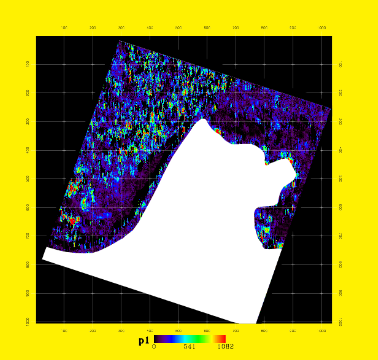


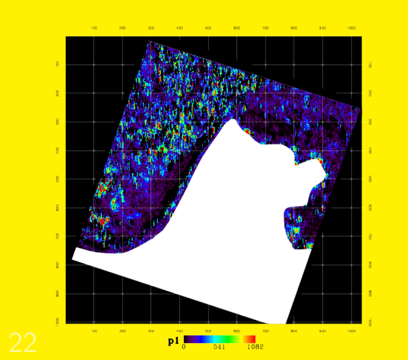
parameter maps: pond and mindist



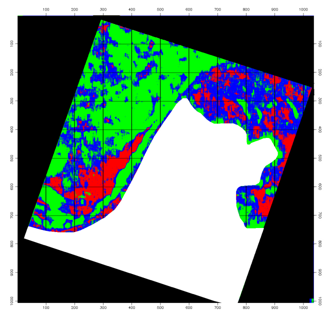


parameter maps: p1 and p2

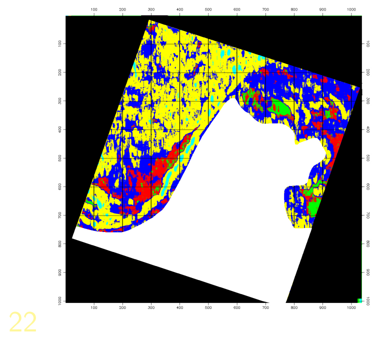




statistical-geostatistical supervised classification: maximum-likelihood criterion



3 classes



5 classes

Herzfeld, Williams, Heinrichs, Maslanik, Sucht, JMG, in press 2010

CASIE Experiment 2009
Fram Strait

CASIE – Characterization of Arctic Sea Ice Experiment

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

Obejective: 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

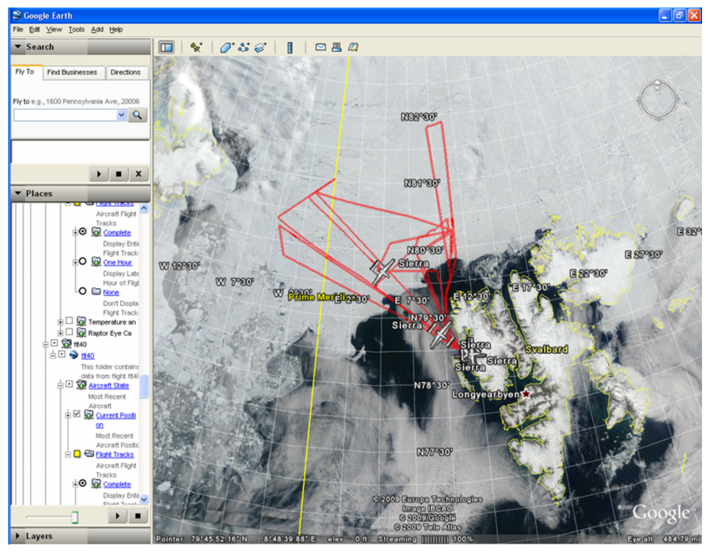
NASA AMES SIERRA: Cold-Weather System Test with CU-ULS (March 2009)

photograph by Don Herlth

BYU mSAR panels integrated in SIERRA

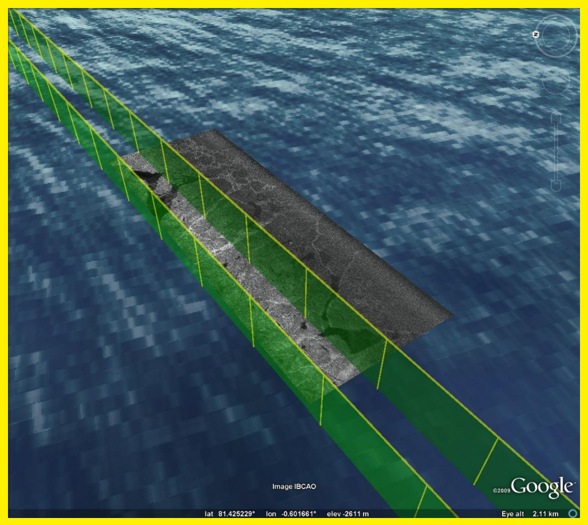
NASA AMES SIERRA: Ny Alesund, Svalbard

photograph by Ian Crocker

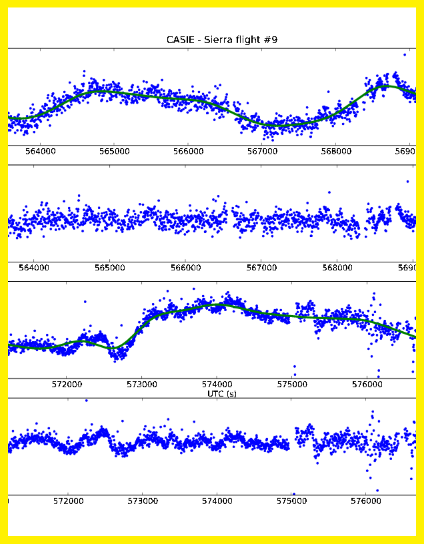


flight tracks

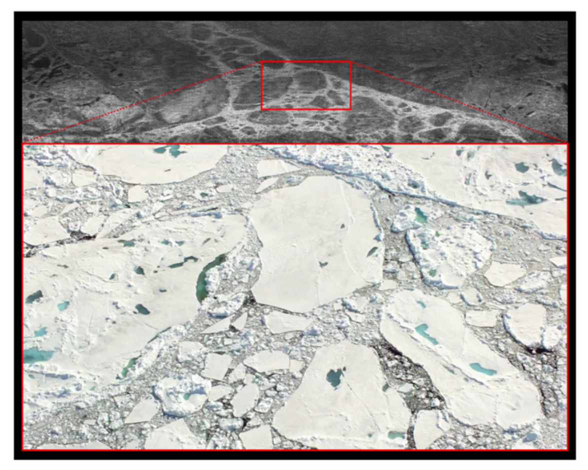
Data Acquisition CASIE (Fram Strait): ULS and MicroSAR (July 2009)



Laser altimeter data (corrected wrt GPS data)



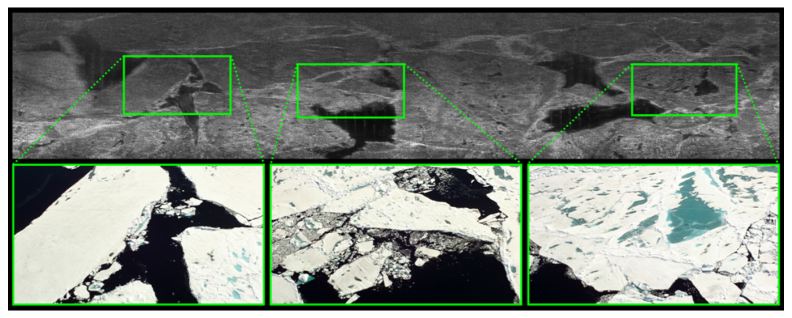
BYU MicroSAR data and video data



mSAR design and processing: David Long, Evan Zaugg, BYU

data co-location by Ian Crocker

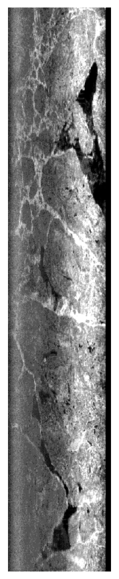
BYU MicroSAR data and video data



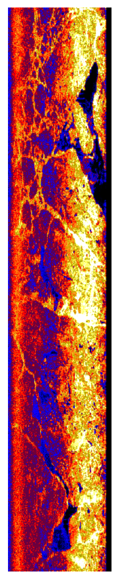
mSAR design and processing: David Long, Evan Zaugg, BYU

data co-location by Ian Crocker

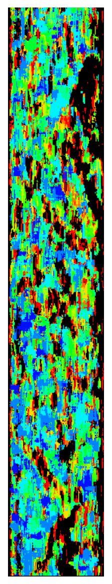
BYU MicroSAR data and roughness parameters



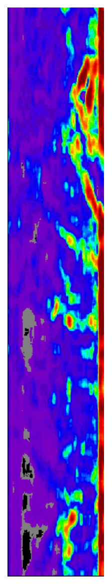
mSAR



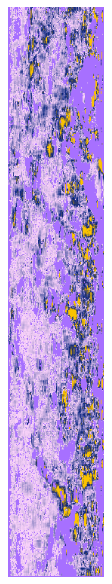
mSAR



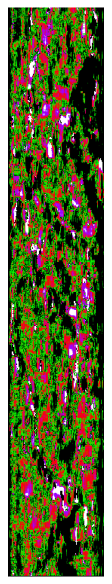
mindist



pond



p1



p2

Conclusion

Physically-based geomathematical modeling of data as a bridge between ice observation and Earth system modeling.