Complexity in Sea-Ice Deformation and Morphogenesis — Observations, Analysis and Implications for Modeling

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- NASA Cryospheric Sciences
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- NASA AMES Research Center
- University of Colorado UROP Program

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

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

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

Examples of Applications to Arctic Sea Ice

(1) CASIE 2009: Passive and active microwave observations from unmanned aircraft to characterize sea ice properties and their changes in the FRAM Strait

(2) Roughness length and ice types

(3) Ice provinces as reflected in ICESat Geoscience Laser Altimeter System (GLAS) data and Airborne Topographic Mapper (ATM) data

(4) Classification of sea-ice provinces

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

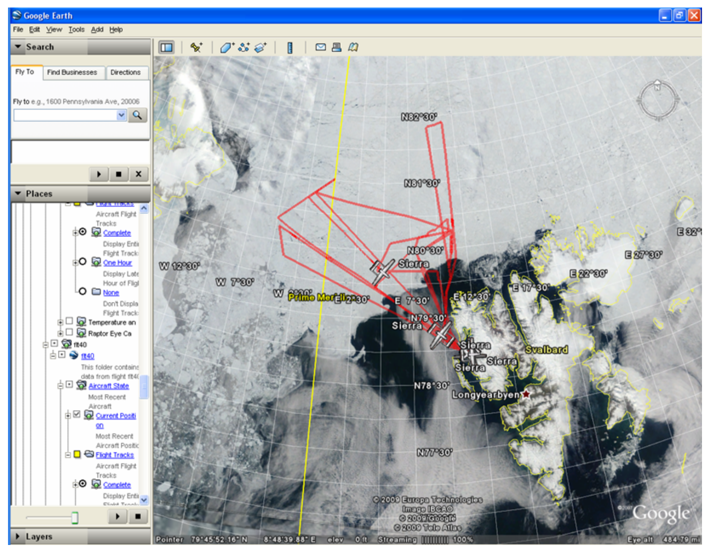
NASA AMES SIERRA: Cold-Weather System Test with CU-ULS (March 2009)

photograph by Don Herlth

BYU mSAR panels integrated in SIERRA

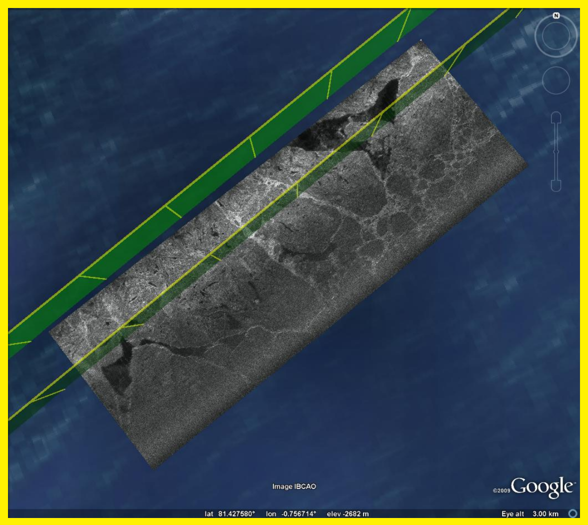
NASA AMES SIERRA: Ny Alesund, Svalbard

photograph by Ian Crocker



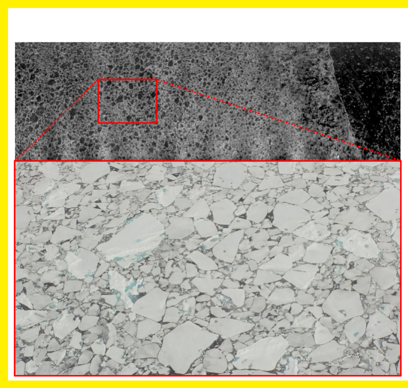
flight tracks

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

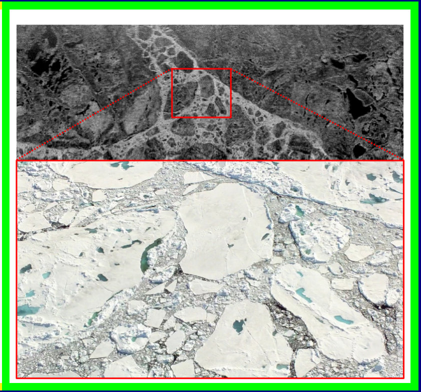


(2) Roughness length and ice types

Sea Ice Types — Fram Strait, from CASIE 2009

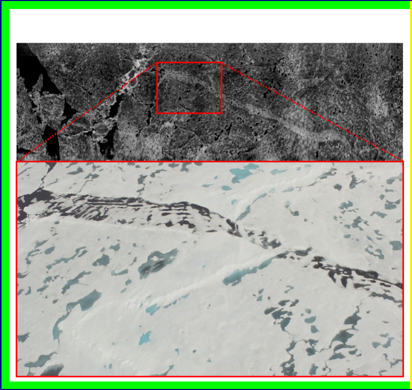


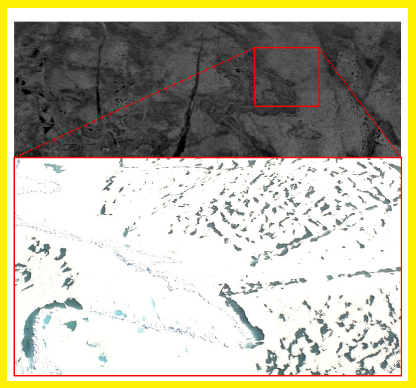
(a) near ice edge

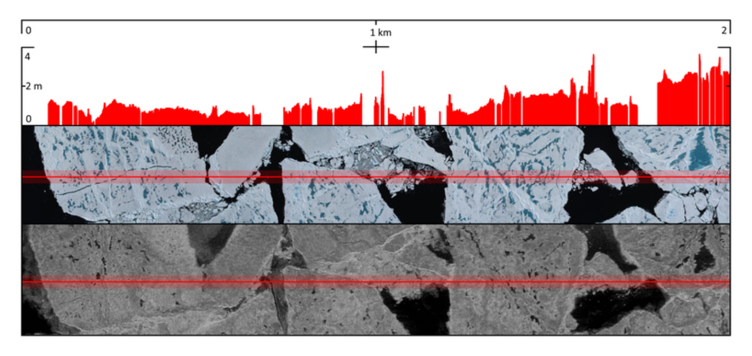


(b) rubble – lead – floes

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

Analysis approach: Spatial surface roughness

(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

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

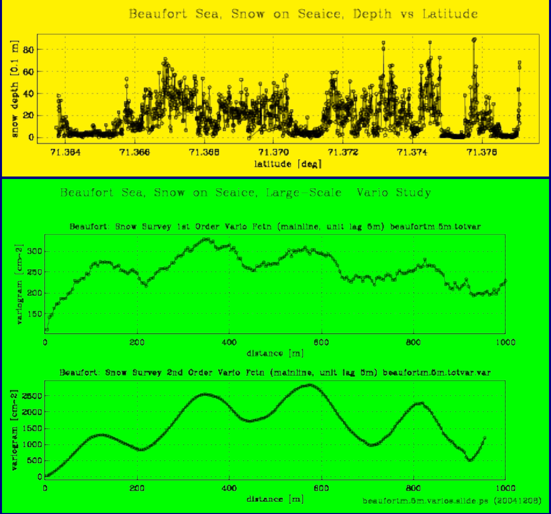
Then: get V_2 from V_1 in the same way you get V_1 from V_0. The second-order vario function is also called varvar function.

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

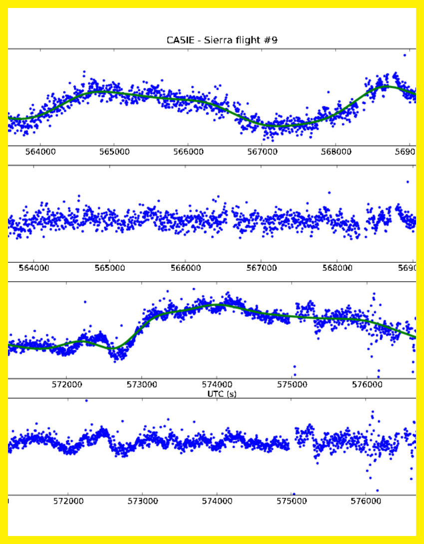
$$avgspac = \frac{1}{n} \sum_{i=1}^{n} \frac{1}{i} \; h_{min_i}$$

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

Roughness length approximation:

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

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

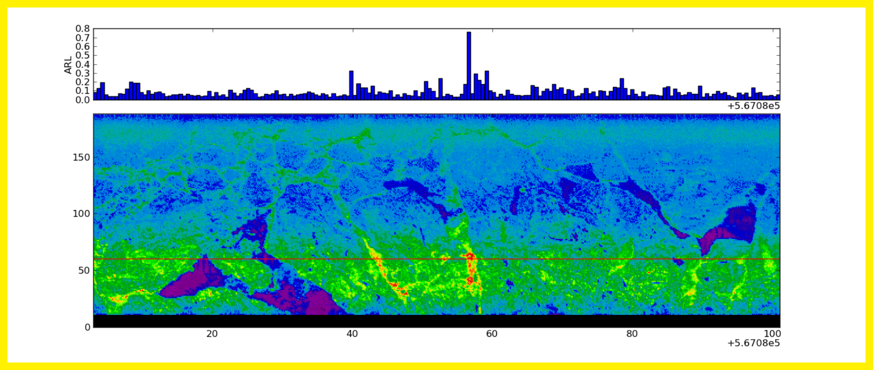
Shown at left: 2 segments with double tracks, altimetry over microASAR

Top: Segment 1, Flight 9

Bottom: Segment 2, Flight 9

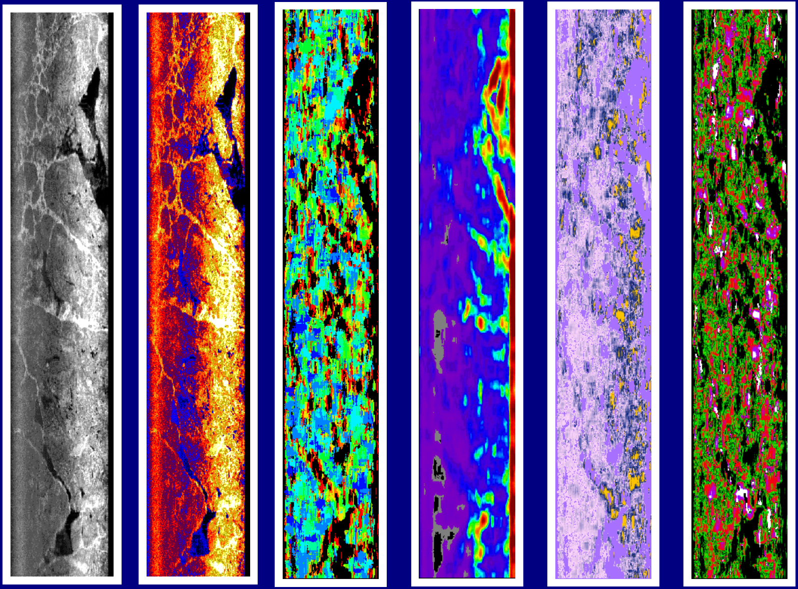
2009-07-25

ARL from altimetry and matching microASAR data



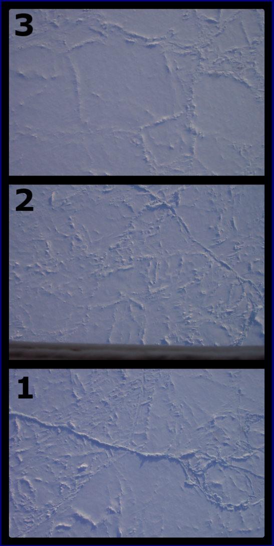
Segment 1 (msar104), Flight 9, 2009-07-25, CASIE 2009

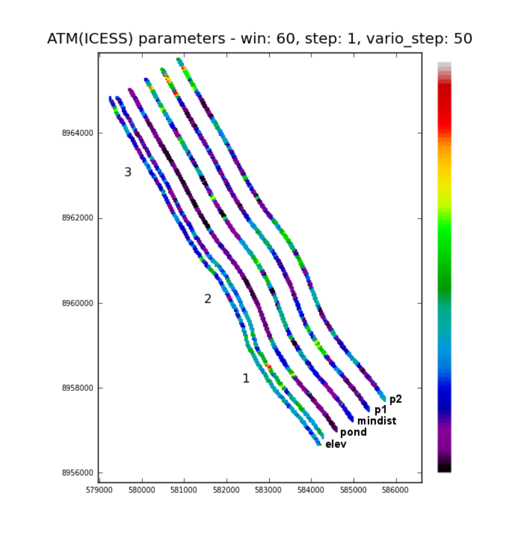
BYU MicroSAR data and roughness parameters



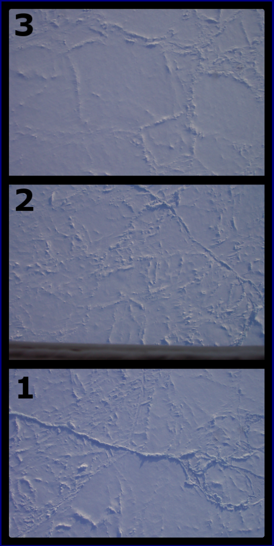
mSAR mSAR mindist pond p1 p2

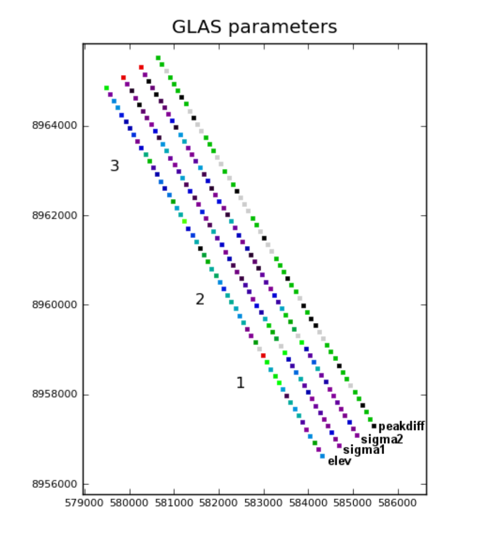
Surface characterizations derived from March 2006 ATM - ICESat underflight over Arctic sea ice





Surface characterizations derived from March 2006 ATM - ICESat underflight over Arctic sea ice

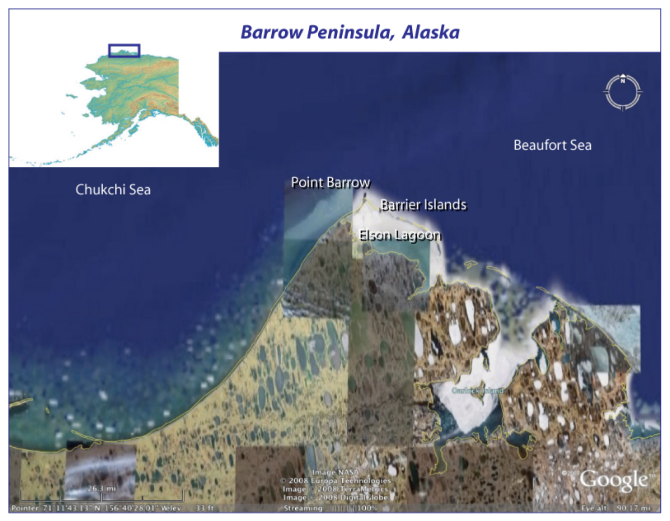




Example (4): Classification of sea-ice provinces

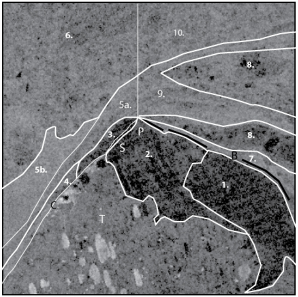
Mapping of spatial properties of sea ice and sea-ice classification for larger areas

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



Sea Ice Types Near Point Barrow, Alaska: SAR Data

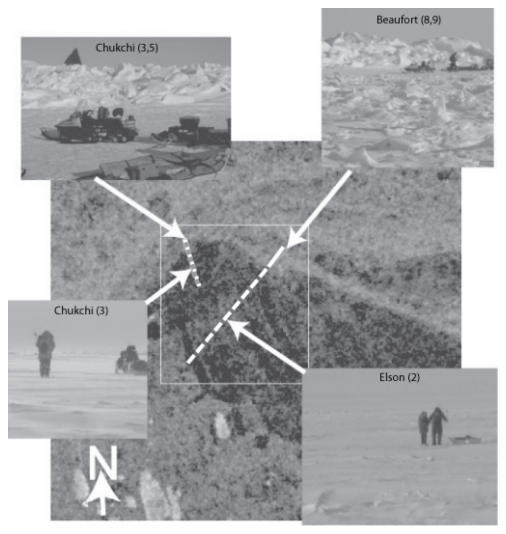
Sea Ice Types Near Point Barrow, Alaska



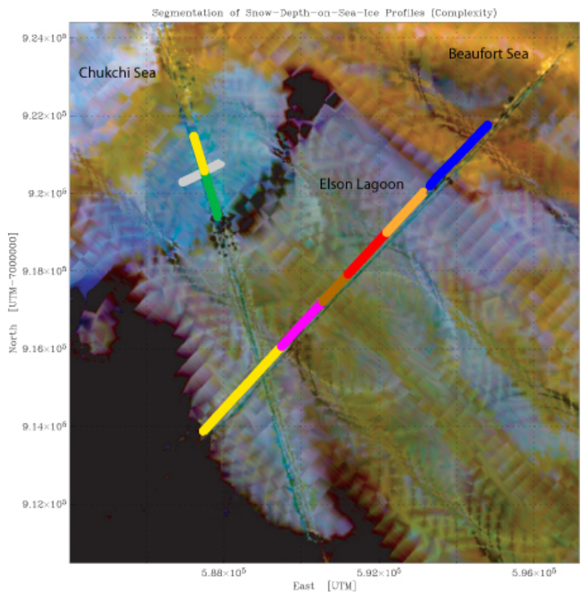
S. Barrow Spit
C. Coast
T. Tundra with Lakes
B. Barrier Islands
1. Elson Lagoon, smooth ice
2. Elson Lagoon, smooth ice with small structures
3. Chukchi Sea, near-shore very smooth ice
4. Chukchi Sea, near-shore smooth ice
5. Chukchi Sea, stamukhi zone (grounded ice), a. large ridge bordering very smooth 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

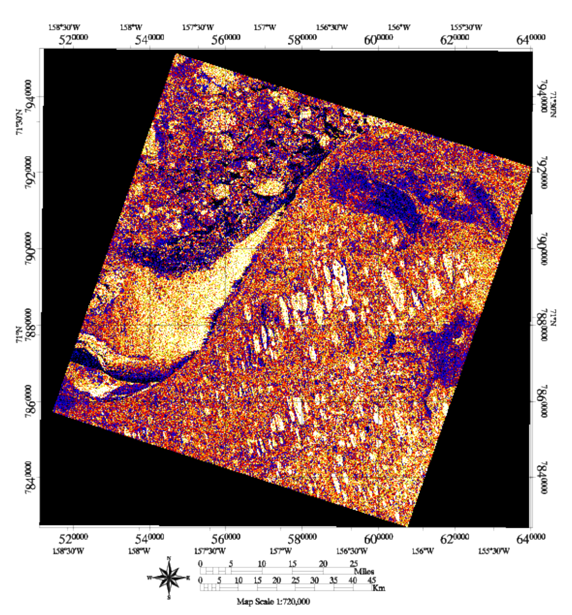


Sea Ice Classification: PSR and Field Data (Snow Depth)

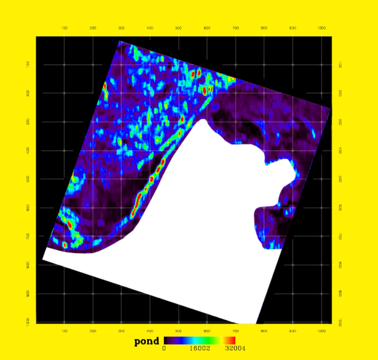


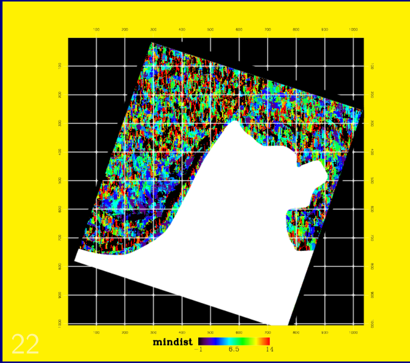
from
Herzfeld, Maslanik and Sturm,
IEEE TGRS 2006

Sea Ice Classification: SAR Data

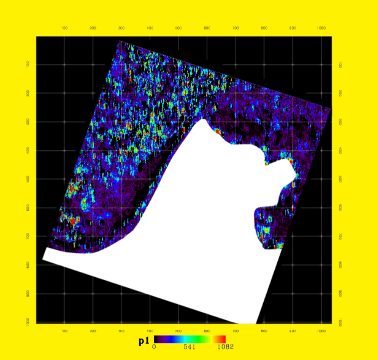


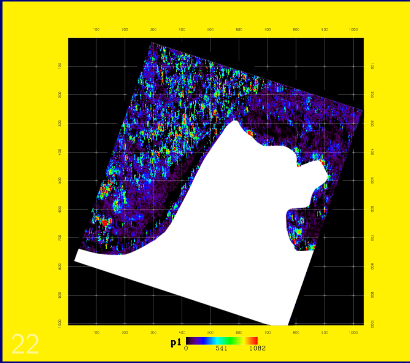
parameter maps: pond and mindist



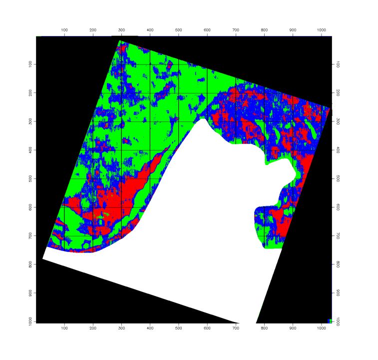


parameter maps: p1 and p2

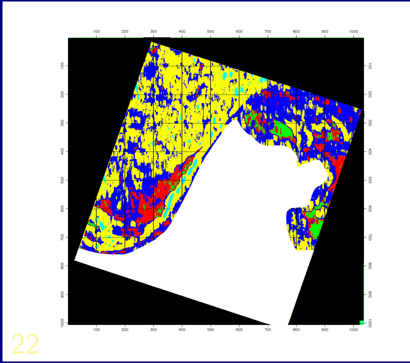




statistical-geostatistical supervised classification: maximum-likelihood criterion



3 classes



5 classes

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

New Project:

Realization of transfer between

(A) Earth observation and data analysis

(B) modeling: CICE

through parameterization of ridges in sea ice

— collaboration with Elizabeth Hunke, LANL

Questions?