Remote Sensing/GIS, and Cold Regions Expertise: Data and Modeling Interests, Capabilities, and Products of USACE/ERDC/CRREL

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CRREL

11/13/2015
• Glaciers and LiDAR
• Sea ice
• Albedo (ice sheets, melt ponds)
• Snow and snowmelt

• Permafrost
• Coastal erosion
• Extreme environments
• Oil & gas
LiDAR

Ground-based LiDAR sled
LiDAR
Control target
Snow pit
GPS-enabled snow depth probe
Coring for snow water equivalent
Aircraft flying w/ GPS
Airborne LiDAR
GPS satellite
Glacier monitoring

glacierresearch.org

Hover over a location to see more information:

- Hubbard Glacier
- Helheim Glacier
- Columbia Glacier
- Valdez Glacier
- Scott Glacier
- Gulkana Glacier
- Wovenne Glacier

Hubbard Glacier
Coordinates
59°09′39.818″N, 139°29′10.655″W

Sensors
- Climate station
  Permanent climate station with real-time data transmitted via satellite link.
- LIDAR data
  High resolution point-cloud data.
- Satellite linked time-lapse camera
  Permanent time-lapse camera with real-time transmission of images via satellite link

ERDC
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Glacier watching
Snow melt modeling
US Coast Guard: Arctic Shield 2012

Ship traffic through the Bering Strait has nearly doubled from 2009 to 2010, reaching 430 vessels a year, but:

- Few certified ice-breakers exist
- Nearest deep-water refueling port nearly 1,000 miles away in the Aleutian Islands

The Coast Guard is proposing a gradual ramping up of operations in the Arctic, with the potential of expanded deployments in the future.
Discrete Element Sea Ice Modeling

- Enhance awareness
- Achieve effective presence

High resolution regional forecast model
- Routing
- Operations planning
- Oil spill dispersion

Ice-ship/structure interaction model
- Estimate ice loads
- Safe speeds through ice guidance
- Ice management

Courtesy Arnold Song, CRREL
Ice-Ship Interactions

DEM model features:

- Dynamics ice-ship interaction are explicitly modeled
- Geometry and thickness of floes is explicitly defined
- Floe is also subject to stresses at the atmosphere-ice and ocean-ice interface to highlight weather and current effects on ice motion that in turn affect shipkeeping
- Able to test a variety of floe fields (rubble ice, small first year floes, large multi-year floes) giving insight into the capability of hull designs for routing and operational planning (i.e., operational seasons)
- 3-dimensional, 6-DOF buoyancy model allows for realistic ice motion including floe underturning and rafting

Detail view of DTMB 5415 hull traveling through ice field

Spring floes

Summer floes

Courtesy Arnold Song, CRREL

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BUILDING STRONG®

Original SAR image:
30 km x 43 km region
2.5 m/px

Discrete element method (DEM) sea ice model
• High fidelity, high resolution sea ice forecast model
• Discrete description of ice field and Lagrangian floe trajectories
• Well-suited for local and regional scale sea ice forecasting (trajectory, concentration, estimate of breakup timing, etc.)
• Realistic floe geometries derived directly from remote sensing imagery
• Assimilation of high resolution remote sensing imagery (e.g., SAR) for model initialization and nudging
• Integration of weather forecast data for model forcing
• Straightforward parallelization for deployment onto HPC systems to achieve operationally relevant run times

Areal ice concentration:
DEM resolution – 200 m/px
CICE resolution – 4 km/px

Model comparison

Domain size: 14.4 km x 17.6 km
Particle size: 200 m
• Uniform wind field (10 m/s, L to R)
• Fixed top and bottom boundaries (in green)

Remote sensing assimilation

Preliminary result

Courtesy Arnold Song, CRREL
Sea ice: In situ

Icebreakers

Optical properties

Ice growth and melt

Ice camps

Snow properties

Ice properties

Ice thickness

Ice dynamics

Courtesy J. Maslanik
Arctic sea ice simulation

Comparison with SHEBA camp drift path:
Jan 19 – Feb 26, 1998 (38 days)

- Particle size: 7 km
- Particle number: ~150,000
- Surface wind data: POLES

Courtesy Arnold Song, CRREL

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Model inputs

Remote sensing
- SAR
- Visible
- IR

Derived sea ice extent
- MASIE

Weather forecast
- GFS
- NAVGEM
- WRF

Courtesy Arnold Song, CRREL
Sea ice: Remote sensing

- Arctic sea ice surveys made in March/April, 2009 – 2015
  - Cross-basin gradients are apparent
  - Older ice has more snow
  - Extensive first year ice in Beaufort and Chukchi Seas
- Quick-look product: Snow depth and ice thickness estimates within 1 month
  - Initiated in 2012; used to support seasonal ice forecasts

Courtesy J. Richter-Menge, CRREL
Sea ice: Autonomous buoys

Courtesy J. Richter-Menge, CRREL
Sea ice: Ice mass balance buoys

**Measures**
- Position
- Barometric pressure
- Start of freezeup
- Start of melt
- Ice growth
- Surface melt
- Bottom melt
- Temperature profile
- Air, snow, ice, ocean
- For up to 3 years
Sea ice: Operations

Sea ice runways

Ridge avoidance path

Oil in ice

Courtesy Sally Shoop, CRREL

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Sea ice – operations and logistics

NU ’14 Skiway Exercise Objectives

The objectives of the Skiway Exercise during NU ’14 were:

- Demonstrate the capabilities of the LC-130
- Develop a training relationship with Canada at JTFN
- Provide transport support to Canadian arctic ground forces
- Exercise the mobile maintenance recovery team
- Teach skiway construction techniques and procedures
- Exercise sea-ice landings & combat offload
- Train on Arctic runway reconnaissance techniques
- Document lessons learned and technology/research needs
- Readiness for future Arctic military support missions
Albedo and Arctic Amplification
Black carbon in Greenland

Melt Ponds on Arctic Sea Ice

Melt Ponds are the Predominate Driver of Ice Albedo (and probably transmission too)

Courtesy Chris Polashenski, CRREL
Sea Ice Albedos

Dry Snow Albedo ~0.85

Wet Snow Albedo ~0.75

Melting Snow-Free Ice Albedo ~0.6

Dark Melt Pond Albedo ~0.15

Courtesy Chris Polashenski, CRREL
Summer Evolution of Melt Ponds

June 1st
Albedo ~0.79

June 3rd
Albedo 0.59

June 7th
Albedo 0.35

June 10th
Albedo 0.44

June 15th
Albedo 0.52

June 20th
Albedo 0.42

Courtesy Chris Polashenski, CRREL
Predicted vs. observed melt pond fraction

![Graph showing Predicted and Observed Pond Fraction at Barrow, AK 2009]

Difference - 60 MJ/m²
Enough to melt ~20cm Ice

Courtesy Chris Polashenski, CRREL
Melt pond water balance

Melt Pond Coverage Along Transects

<table>
<thead>
<tr>
<th>Stage I</th>
<th>Stage II</th>
<th>Stage III</th>
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<tbody>
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</tbody>
</table>

- Percent Pond Coverage
- Date: 31-May, 2-Jun, 4-Jun, 6-Jun, 8-Jun, 10-Jun, 12-Jun, 14-Jun, 16-Jun, 18-Jun, 20-Jun, 22-Jun, 24-Jun, 26-Jun

Courtesy Chris Polasheski, CRREL
Research for operations: Snow

CRREL objectives:

► Improve spatial resolution for global applications
► Inform applications of mobility, hydrology, flood hazard, and drought
► R&D and transition to operational products with DoD and academic partners
Snow properties
from microstructure to watershed scales
through remote sensing, modeling, and data assimilation

- Snow-covered area (SCA)
- Bulk properties
  - depth
  - density
  - snow water equivalent (SWE)
- Snow microstructure
  - Snow wetness
  - diurnal amplitude variation (DAV)
- Snow modeling
- Data assimilation
Operational Snow Assessments

Operational Support:
For the past 8 winter seasons, provided bi-weekly assessments of the snowpack to U.S. Military personnel in Iraq and Afghanistan.

Clients
• Marine Corps Intelligence Agency
• American Embassy in Iraq
• Iraq Ministry of Water
• U.S. Central Command
• US Army - 82nd Airborne Division
• US Navy
• US Air Force, AFWA
• Canadian Forces
• British Forces
• NATO
• USGS
• USDA
• USAID
• Dept of Disaster Response
• German Embassy
• Academic Institutions
• National Geospatial-Intelligence Agency
• And others

Mission Relevance:
• Operation planning
• Supplies/Transport
• Flood forecasting
• Water supply
Snowmelt runoff estimates

Objective: To use the strong passive microwave response to wet snow to improve snowmelt runoff estimates.

Motivation: Snowmelt runoff can cause widespread, damaging floods. Observations of snowpack state are almost non-existent, and models can miss the timing or extent of melting, particularly in remote regions.
## Approach to domains of interest

- Select study areas of operational/tactical interest combined with analogues that exist in well-instrumented basins

<table>
<thead>
<tr>
<th>Operational/tactical domain</th>
<th>Well-instrumented analogue</th>
</tr>
</thead>
<tbody>
<tr>
<td>North/South Korea</td>
<td>New England, USA</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>Colorado, USA</td>
</tr>
</tbody>
</table>

- Build modeling capabilities in both tactical and well-instrumented domains at spatially relevant scales
- Explore sensitivity of different ancillary data sources to both models and satellite retrievals
  - Land cover type and distribution, forest density and canopy structure, elevation distribution (slope and aspect), snow grain size distribution, etc.
- Investigation of scale (both temporal and spatial) dependencies

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Courtesy Carrie Vuyovich, CRREL
Comparison of passive microwave SWE estimates from 4 global satellite-based products to SNODAS daily gridded SWE products in the U.S. on a watershed scale.

Analysis specifically focused on:
- Regional differences
- Effects of vegetation, deep snow
- Relative magnitude
- Timing

01 JAN 2011 SWE (mm)

Courtesy Carrie Vuyovich, CRREL
“Kabul can be without gold but not without snow”
Afghan proverb
Spare slides…
Snow Loads
Snow Story

IPCC, 2013; Brown and Robinson 2011

- Decreased Snow Cover
- Decreasing and Increasing SWE

Liston and Hiemstra (2011)

Courtesy Chris Hiemstra, CRREL
ASCE Standard 7

Ground snow loads for a 50-yr mean recurrence interval (MRI)

Table 7-1  Ground Snow Loads, $p_s$, for Alaskan Locations

<table>
<thead>
<tr>
<th>Location</th>
<th>$p_s$</th>
<th>kN/m²</th>
<th>Location</th>
<th>$p_s$</th>
<th>kN/m²</th>
<th>Location</th>
<th>$p_s$</th>
<th>kN/m²</th>
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<tbody>
<tr>
<td>Adak</td>
<td>90</td>
<td>1.4</td>
<td>Galena</td>
<td>60</td>
<td>2.5</td>
<td>Petersburg</td>
<td>150</td>
<td>2.2</td>
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<tr>
<td>Anchorage</td>
<td>56</td>
<td>2.4</td>
<td>Galena</td>
<td>70</td>
<td>3.4</td>
<td>St. Paul</td>
<td>40</td>
<td>1.9</td>
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<tr>
<td>Angoon</td>
<td>70</td>
<td>3.4</td>
<td>Homer</td>
<td>40</td>
<td>1.9</td>
<td>Seward</td>
<td>30</td>
<td>2.4</td>
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<tr>
<td>Barrow</td>
<td>25</td>
<td>1.2</td>
<td>Juneau</td>
<td>60</td>
<td>2.9</td>
<td>Skagway</td>
<td>25</td>
<td>1.2</td>
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<tr>
<td>Bremerton</td>
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<td>1.7</td>
<td>Ketchikan</td>
<td>70</td>
<td>3.4</td>
<td>Sitka</td>
<td>50</td>
<td>2.4</td>
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<tr>
<td>Bethel</td>
<td>80</td>
<td>1.9</td>
<td>Kodiak</td>
<td>30</td>
<td>1.4</td>
<td>Yakutat</td>
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<td>Big Delta</td>
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<td>Kotzebue</td>
<td>60</td>
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<td>Unalakleet</td>
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<tr>
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<td>McGrath</td>
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<td>Valdez</td>
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<tr>
<td>Cordova</td>
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<td>4.8</td>
<td>Nome</td>
<td>80</td>
<td>3.8</td>
<td>Whittier</td>
<td>300</td>
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<tr>
<td>Fairbanks</td>
<td>60</td>
<td>2.9</td>
<td>Nome</td>
<td>70</td>
<td>3.4</td>
<td>Wasilla</td>
<td>60</td>
<td>2.9</td>
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<tr>
<td>Fort Yukon</td>
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<td>Palmer</td>
<td>50</td>
<td>2.4</td>
<td>Yakutat</td>
<td>150</td>
<td>7.2</td>
</tr>
</tbody>
</table>

Courtesy Kathy Jones, CRREL

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Change in CMIP5 30-yr snow loads (lb/ft²)

HadGEM2-A0 RCP8.5

INMCM4 RCP8.5

2007-2040

2067-2100

Courtesy Kathy Jones, CRREL
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CRREL Permafrost Tunnel

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Thawing permafrost

CRREL Archive

CRREL Archive

bakerinstitutealaska.org

nsidc.org

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CRREL Permafrost Initiatives

- Integrating technologies for delineating permafrost and ground state conditions
- Use of ground, air, and space-based platforms to delineate permafrost geomorphology
  - Boreholes, subsurface geophysics, multispectral, LiDAR, radar, etc. to map vegetation\ecosystem and surface subsidence
- Determine whether variety of measurements and methods can be synthesized into detection of patterns indicating permafrost conditions
Coastal Erosion

- Decreased sea ice buffer
- Increased storm action
- Thawing permafrost
Coastal Erosion

Modified from
Lantuit et al. (2012)
ERDC/CRREL Rapid Deploy Buildings for Extreme Environments

• In Collaboration with U.S. Army Natick Soldier Research Center

• Airbeam Quonset Huts
  • Light-weight & durable
  • Field tested outside of Thule, Greenland

• Current SBIR Project
  • Deploy w/in 20 min (2 people)
  • Withstand 100 mph winds
  • Endure temperatures of -50° to +60°C
  • Energy efficient
  • Antarctic deployment in phase 2.
Oil & Gas

U.S. Geological Survey believes the Arctic holds up to 25% of the world’s undiscovered oil and gas reserves

Gazprom, Shell, BP/Conoco
Hazardous Spill Detection and Response

- Detection of oil in/under ice
  - Oil and Gas Producers Joint Industry Project
  - Sub sea – camera, sonar, fluorescence, multibeam/low frequency acoustic
  - Surface/air – radar, spectral radiance, fluorescence, visible, infrared

- Mitigation and response
  - OHMSETT (Oil Spill Response Research Test Facility – Bureau of Safety and Environmental Enforcement)
  - Alaska Clean Seas – oil spill response training