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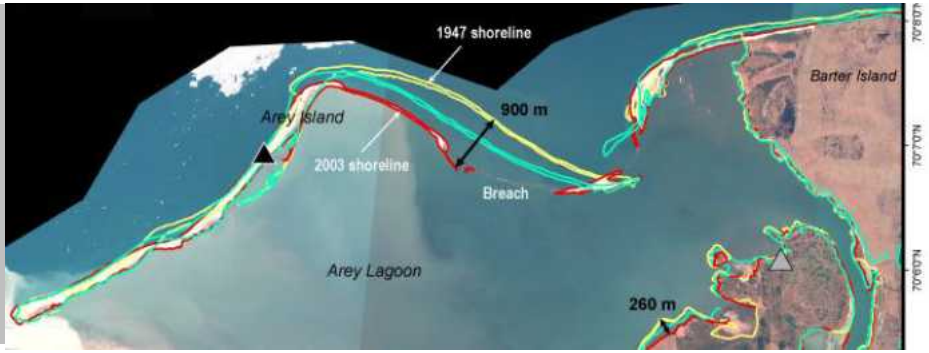

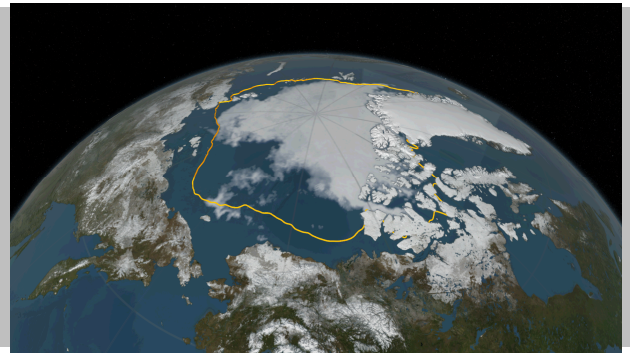

A Predictive Model for Arctic Coastal Erosion
Proposed Field Work Campaign

PI: Diana Bull (00159), PM: Lori Parrott (08863)
Jennifer Frederick, Matt Thomas, Craig Jones, Jeremy Kasper, Alejandro Mota, Jesse Roberts, Ben Jones
Jim McClelland, Craig Connolly, Ken Dunton

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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Arctic Coastal Erosion Cross-section

T_{atm} f(x,y,t)

surface energy balance

erosion rate

ice wedge (failure surface)

sediment strength f(Temp,t)

permafrost bluff

sum of torques

shear failure plane

permafrost temperature field f(x,z,t)

ice content

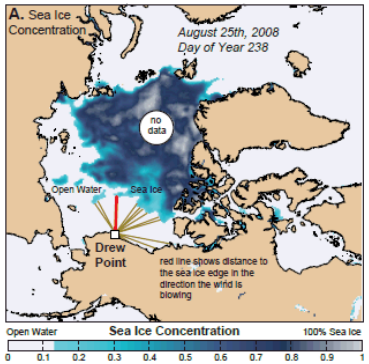
niche growth

z

x

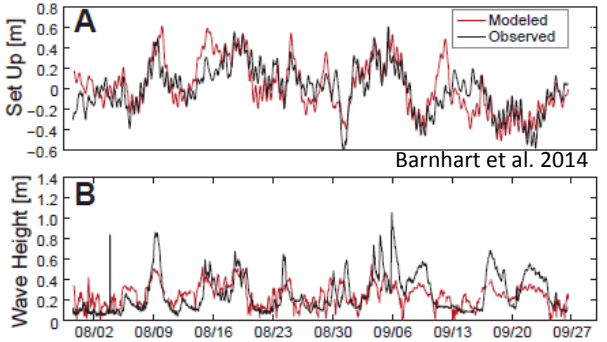
Earth system and sea ice-ocean models

Barnhart et al. 2014



wave energy density spectrum

ocean circulation model



Barnhart et al. 2014

$Temp_{ocean}$ $Salinity_{ocean}$ f(x,y,t)

sediment flux

bathymetry

submarine permafrost

J. M. Frederick, M. A. Thomas, D. Bull, C. Jones, and J. D. Roberts (2016) The Arctic coastal erosion problem, SAND2016-9762, Sandia National Laboratories, NM.

Field Campaign

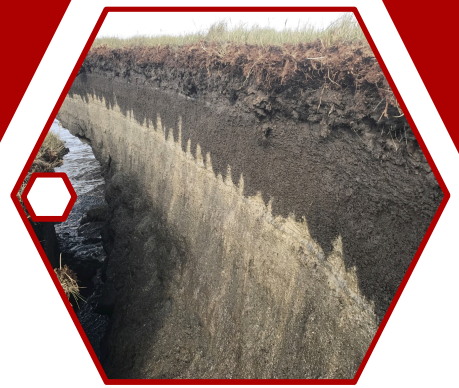
Oceanography

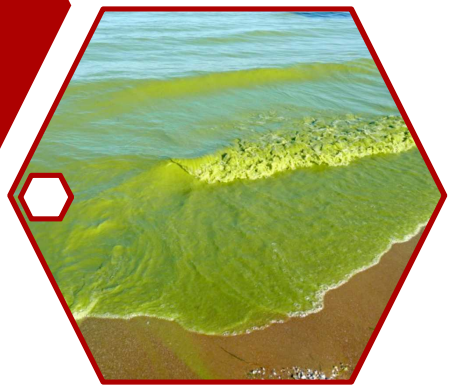
Coastal Morphology

Permafrost

Biogeochemical

Atmosphere





OCEANOGRAPHY

Variables to Measure

- Wave Spectra (Significant wave height, direction and period)
- Water Temperature
- Water Salinity
- Water Depth
- Water Currents
- Bathymetry
- Ice Thickness and Velocity

ADCP

- Sensor: Sentinel V20 5 beam with external battery case (3 lithium-ions)
- Deployment
  - Location: ~10 m water depth, offshore of Drew Point
  - Duration: Minimum Aug 2018 – Aug 2019

    Maximum Aug 2018 – Aug 2020 with data retrieval Aug 2019
  - Mechanism: Sea Spider Seafloor Platform Kit (drag line retrieval, potential for an acoustic release)
- Data Collection
  - Rate: 20min samples every hour
  - Onboard Memory: 16GB (~400 days at 20 min samples hourly)
  - Collected Variables: currents, directional wave energy, ice thickness, ice velocity

CTD

- Sensor: Seabird Microcat
- Deployment
  - Location: ~10 m water depth, offshore Drew Point
  - Duration: Minimum Aug 2018 – Aug 2019

    Maximum Aug 2018 – Aug 2020 with data retrieval Aug 2019
  - Mechanism: Sea Spider Seafloor Platform Kit, co-located on mooring with ADCP
- Data Collection
  - Rate: 2.5 minutes
  - Onboard Memory: 425,000 samples (As an example: mcats can sample 2 years at 1 sample/2.5 minutes)
  - Collected Variables: conductivity and temperature, pressure

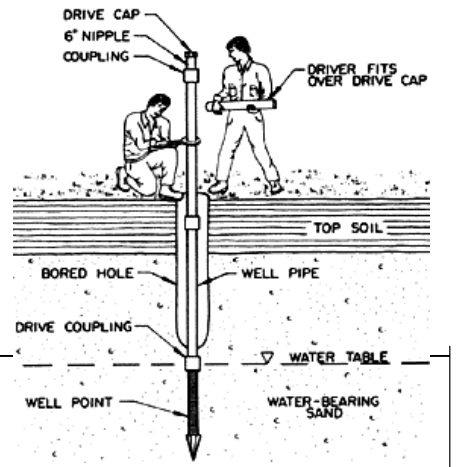
Nearshore Water Depth

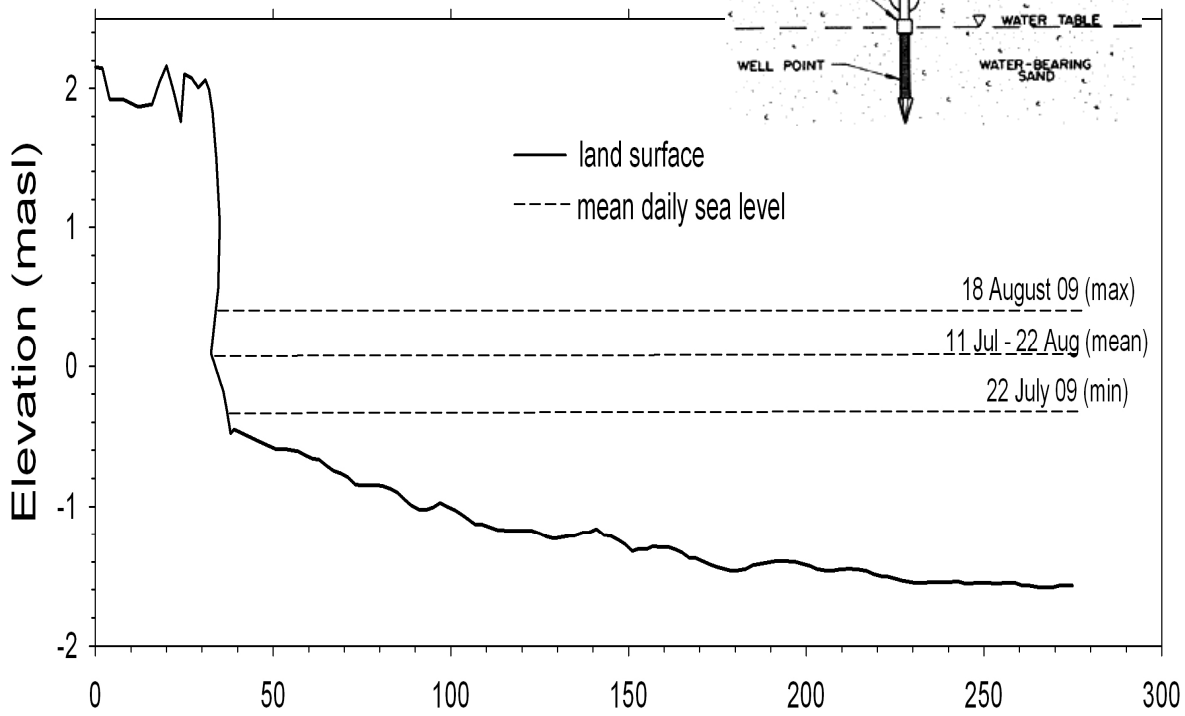
- Sensor: Starmon TD temp & depth logger or/and RBR Duo (desire for redundancy)
- Deployment
  - Location: ~1-2 m water depth, offshore of Drew Point
  - Duration: June-October 2018

    June-October 2019
  - Mechanism: TBD, consult with Craig Tweedie and others
    - potentially in a sheathed core sample location (1.5” OD wellpoint or 3” OD wellpoint) (downside is that would not get nondirectional wave spectra, only water height)
- Data Collection
  - Rate: up to 20 Hz, burst
  - Onboard Memory: 8.4M measurements (3.2 mins/burst for 1 year, 5 Hz burst. Very flexible. Plenty of memory for 5 month deployment)
  - Collected Variables: Pressure and temperature (derive: nondirectional wave spectra)

Nearshore Water Depth - Beach

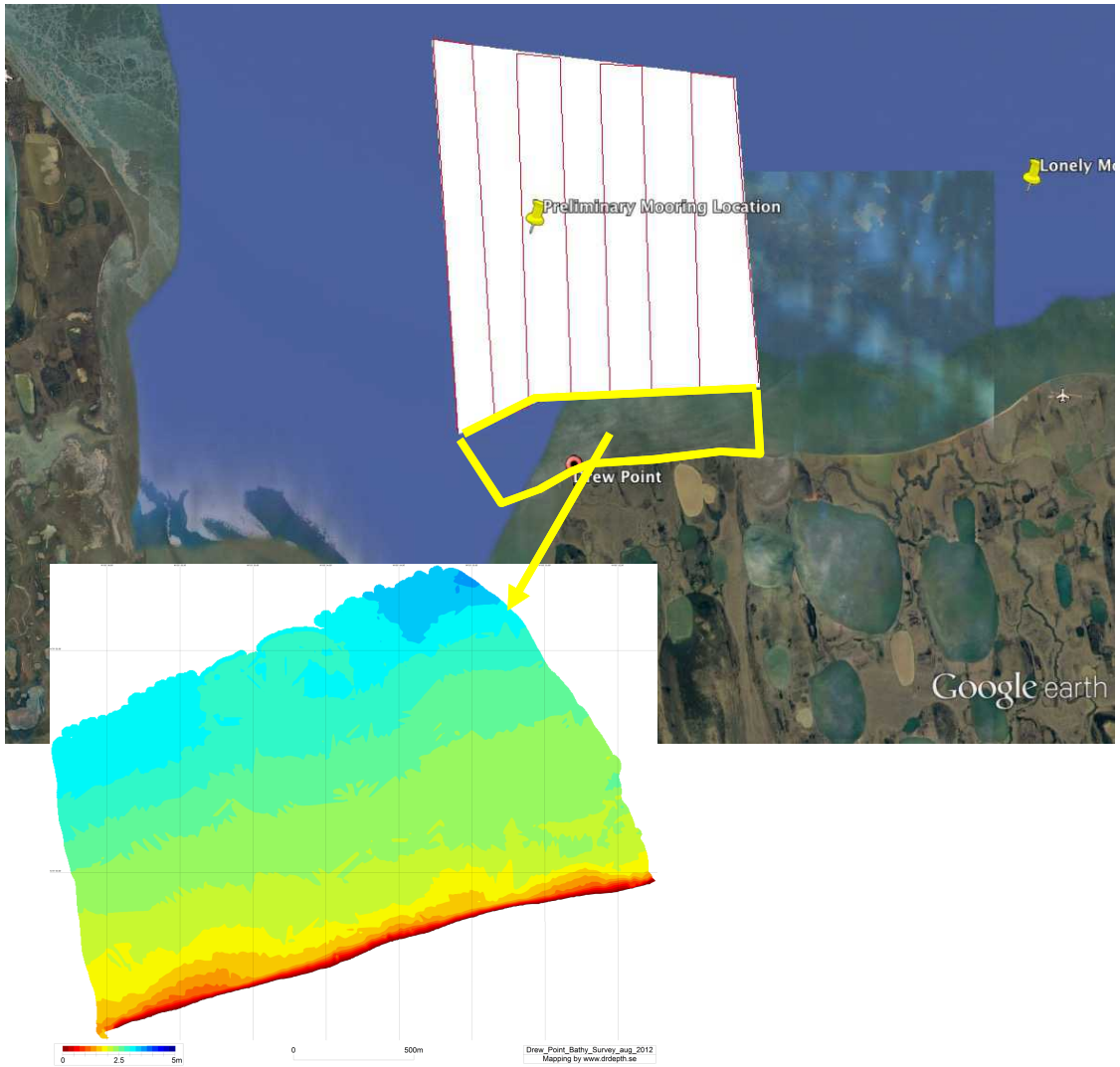
- Sensor: Onset HOBO (or other)
- Deployment
  - Location: Well point established in beach and in lagoon
  - Duration: June-October 2018
    June-October 2019
  - Mechanism: Augering into beach sediments on the spit west of Drew Point and in lagoon behind spit
    - potentially in a sheathed core sample location (1.5” OD wellpoint or 3” OD wellpoint) (only water height)
- Data Collection
  - Rate: 1 min sampling and 10 minute logging
  - Onboard Memory: 20,000 samples
  - Collected Variables: conductivity, temperature, pressure (primarily capturing tidal fluctuations and storm surge height)





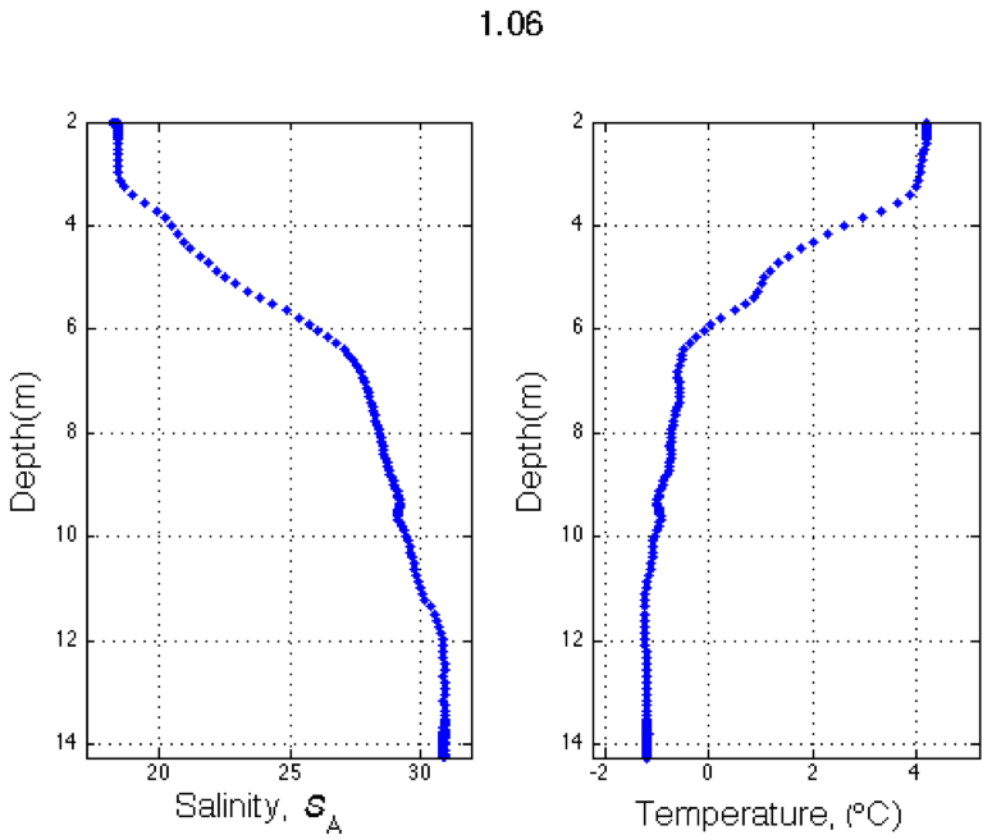
Bathymetric Survey

- Multi-Beam, mid to late July from R/V Ukpik (white box)
  - Reson Seabat 7125 w/ Applanix IMU and dual L1/L2 RTK GNSS antennae
  - Example survey area and transects are shown to the right (survey from ~3 m to ~15 m isobath
  - RTK GNSS base antenna on-shore
- Single-Beam (near shore survey – yellow box)
  - Sonarmite-BT interfaced with a Trimble GeoXH and tied back to a benchmark that will be surveyed at the beginning and end of the bathymetric survey using a Leica Viva DGPS
  - Surveys to be conducted in August 2018
    - Open for other methods
    - AWI geophysics crew



CTD Cast Campaign

- Sensor: SBE 25 and SVP
- Deployment
  - Method: Vessel casts in multiple locations during the bathymetric survey
- Data Collection
  - Rate: 16Hz
  - Collected Variables: stratification of temp and salinity in area, sound velocity
  - Derived: sound velocity for multibeam speed of sound corrections
- Representative S/T stratification from the region shown to the right



Remotely Sensed Variables

- Variables:
  - Sea ice concentration
  - Wind
  - Water Temperature
  - Wave energy
- Reanalysis Sources for Atmospheric Conditions:
  - North American Regional Reanalysis.
    - Produced by the National Centers for Environmental Prediction (NCEP). Assimilates data to create accurate weather information in 3-hourly increments.
  - Chukchi-Beaufort Seas High-Resolution Atmospheric Reanalysis (CBHAR)
    - Produced by UAF from downscaled ERA interim and WRF
  - Arctic System Reanalysis
    - produced using high-resolution versions of the Polar Weather Forecast Model (PWRF) and the WRF-VAR and High Resolution Land Data Assimilation (HRLDAS) data assimilation systems that have been optimized for the Arctic

Air Temperature	Albedo
Cloud Frequency	Cloud Liquid Water/Ice
Evaporation	Freezing Rain
Humidity	Hydrostatic Pressure
Potential Temperature	Precipitation Amount
Runoff	Sea Level Pressure
Snow	Snow Cover
Snow Water Equivalent	Soil Moisture/Water Content
Surface Winds	Total Precipitable Water
Upper Level Winds	Vegetation Cover
Wind Shear	

Canopy Characteristics	Cloud Base Pressure
Cloud Top Pressure	Dew Point Temperature
Geopotential Height	Heat Flux
Longwave Radiation	Planetary Boundary Layer Height
Precipitation Rate	Rain
Shortwave Radiation	Skin Temperature
Snow Depth	Snow Melt
Soil Temperature	Surface Pressure
Tropopause	Upper Air Temperature
Vertical Wind Velocity/Speed	Water Vapor

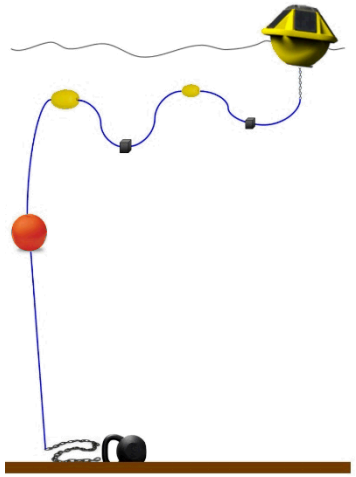
Remotely Sensed Variables Cont.

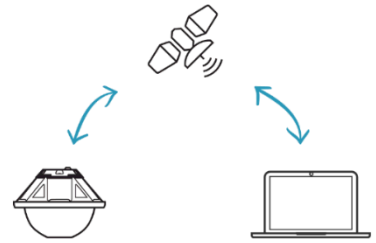
- Other Sources (real-time-ish…):
  - **Wind**: TerraSAR X, RadarSat2
  - **Sea Ice Concentration**: NAVGEM,SSMI, Advanced Microwave Scanning Radiometer 2 AMSR2, CICE2 (assimilates SAR data), GOFS3.1 (assimilates SAR data), IFREMR/SSMI, CryoSat, Interactive Multisensor Snow and Ice Mapping System (IMS), LANDSAT 8 (15m resolution), MEDEA (1 m resolution)
  - **Sea surface altimetry (significant wave height)**: Sentinel (-1, -3, -1A), TerraSAR X , Jason -3, CryoSat, HY-2A (china), SARAL (india), RadarSat2, ALOS-2 SAR, ASCAT via Ifremer, CosmoSkymed
  - **Sea Surface Temperature:** Multi-scale Ultra-high Resolution (MUR) Sea Surface Temperature (https://mur.jpl.nasa.gov/)
  - **Shoreline Change via altimetry (spatial and time resolution):** National Geospatial Intelligence Agency – WARP archive
  - **Terrestrial Surface Temperature**: MODIS LST product

Some of these sources are not free and / or publicly accessible

Spotter Wave Measurement Buoy (potential)

- Sensor: Spoondrift Spotter
- Deployment
  - Location: TBD
  - Duration: June/July to August 2019 Tentative
  - Mechanism: Mooring requires ~ 50 lb anchor with 2x water depth mooring (tested in 20ft + storm conditions)
- Data Collection
  - Rate: 20min every hour
  - Onboard Memory: XX samples (XXyears) and iridium communication.
  - Fully solar powered
  - Collected Variables: directional wave energy spectra





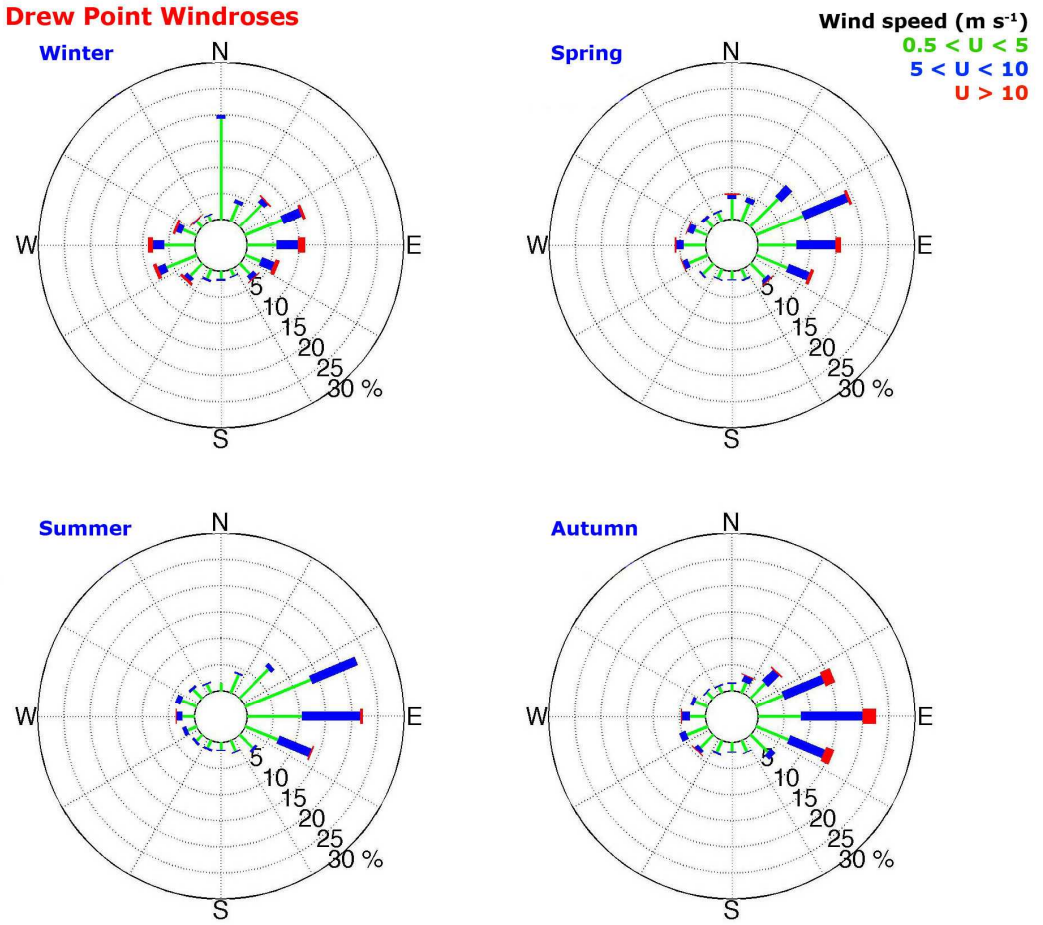
ATMOSPHERE

Measured Variables

- Air Temperature
- Incident / reflected solar flux
- Wind speed / direction @ 3 m above ground
- Snow depth
- Atmospheric pressure
- Ground temperature (10 depths: 5-120cm)
- Soil Moisture
- Rainfall

Instrumentation

- Sensor: USGS Met Station
- Deployment
  - Location: Within 0.5 miles of the Drew Point coast
  - Duration: Aug 1998 – Aug 2020
  - Mechanism: Ground mounted on 3 m high mast
- Data Collection
  - Details: https://pubs.usgs.gov/ds/812/introduction.html
  - Rate (variable according to sensor/measurement)
  - Onboard Memory: 62,000 samples (radio telemetered)
  - Collected Variables: 19 (previous slide)



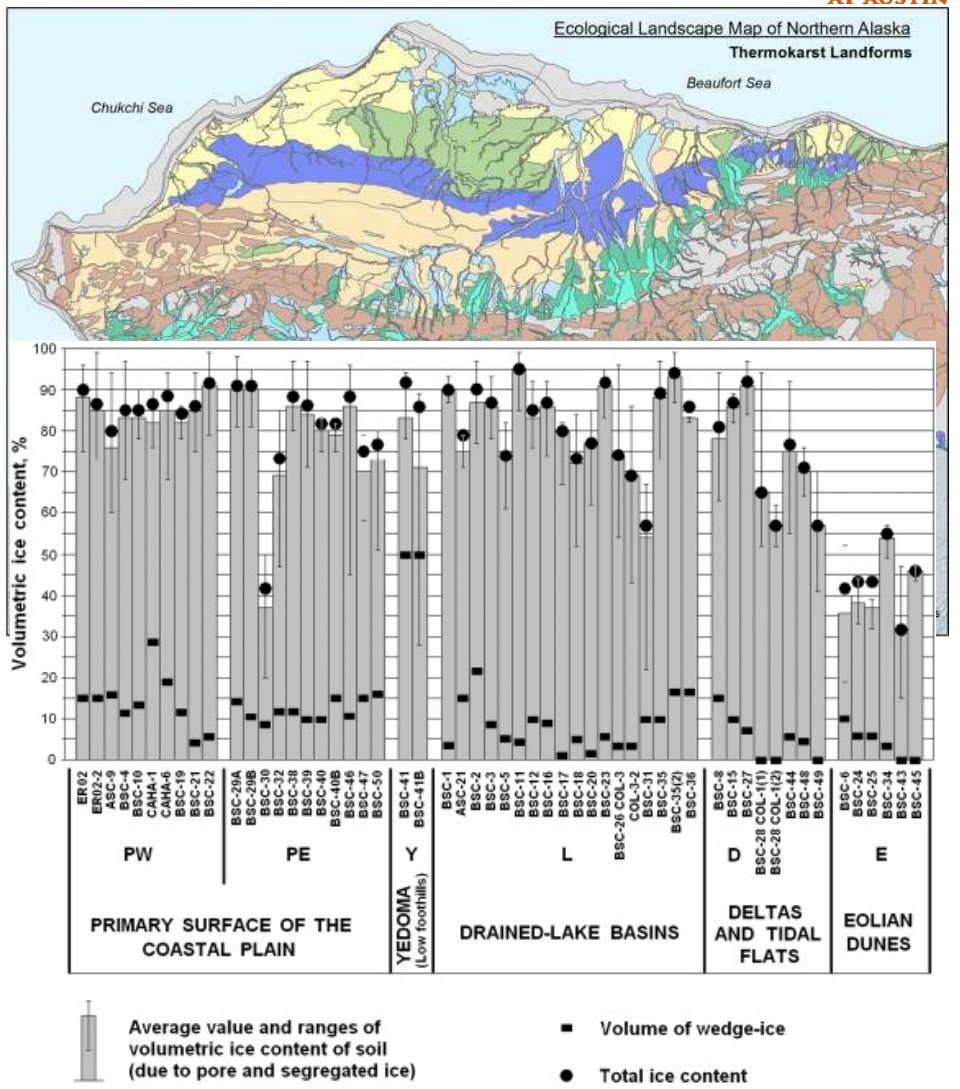
winter (December, January, February), spring (March, April, May), summer (June, July, August), and autumn (September, October, November).

PERMAFROST

Measured Variables

- Ice content
  - Brine layer in permafrost, frozen vs. unfrozen content
  - Cryostructure (how ice crystals are formed / visually displayed in core)
- Salinity content
- Grain size characteristics
- Silt / sand fraction
- Stress-Strain Analysis (soil strength testing) as a function of temperature (up to thawing)
- Permafrost Temperature
- Active Layer Depth
- Niche Geometry

Grey text indicates uncertainty around the measurement

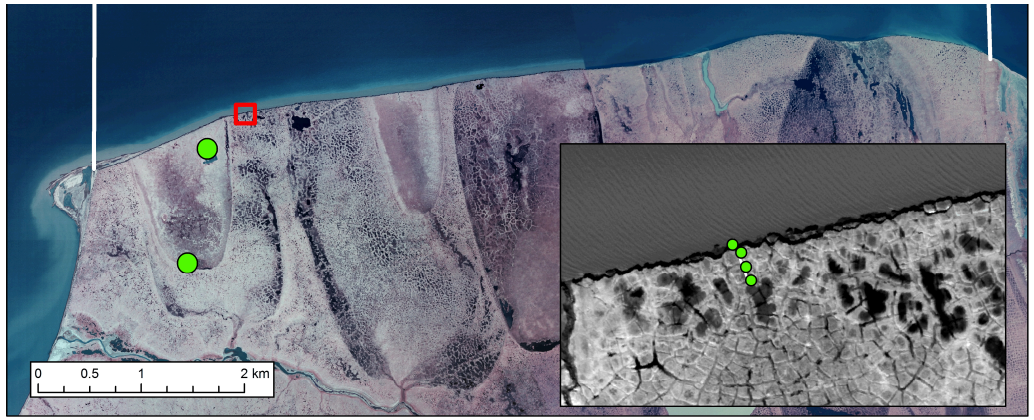


Permafrost Coring

- System: 5” diameter sipre core barrel mounted on a mast. Capable of collecting continuous 8-10 m long cores; a second 5” diameter SIPRE core barrel driven by an engine auger and two people to collect several up to 2-4 m long cores or paired terrestrial and nearshore beach cores down to ~8 m depth when combined
- Deployment
  - Location:. 3 repeats at ~4 areas different terrain units at Drew Point
    - submarine permafrost, near bluff, recent drained lake basin (300 yr old drainage), old drained lake basin (4000-5000 yrs ago)
  - Duration: April 2018 and April 2019 – one week a year
  - Mechanism: Access via snowmachine from Barrow, 10 m long core on special tripod set-up and shorter cores where appropriate
- Data Collection
  - Rate: 2 days in January 2018, one week in April 2018, one week in April 2019, more if necessary
  - Max Depth: 10 m

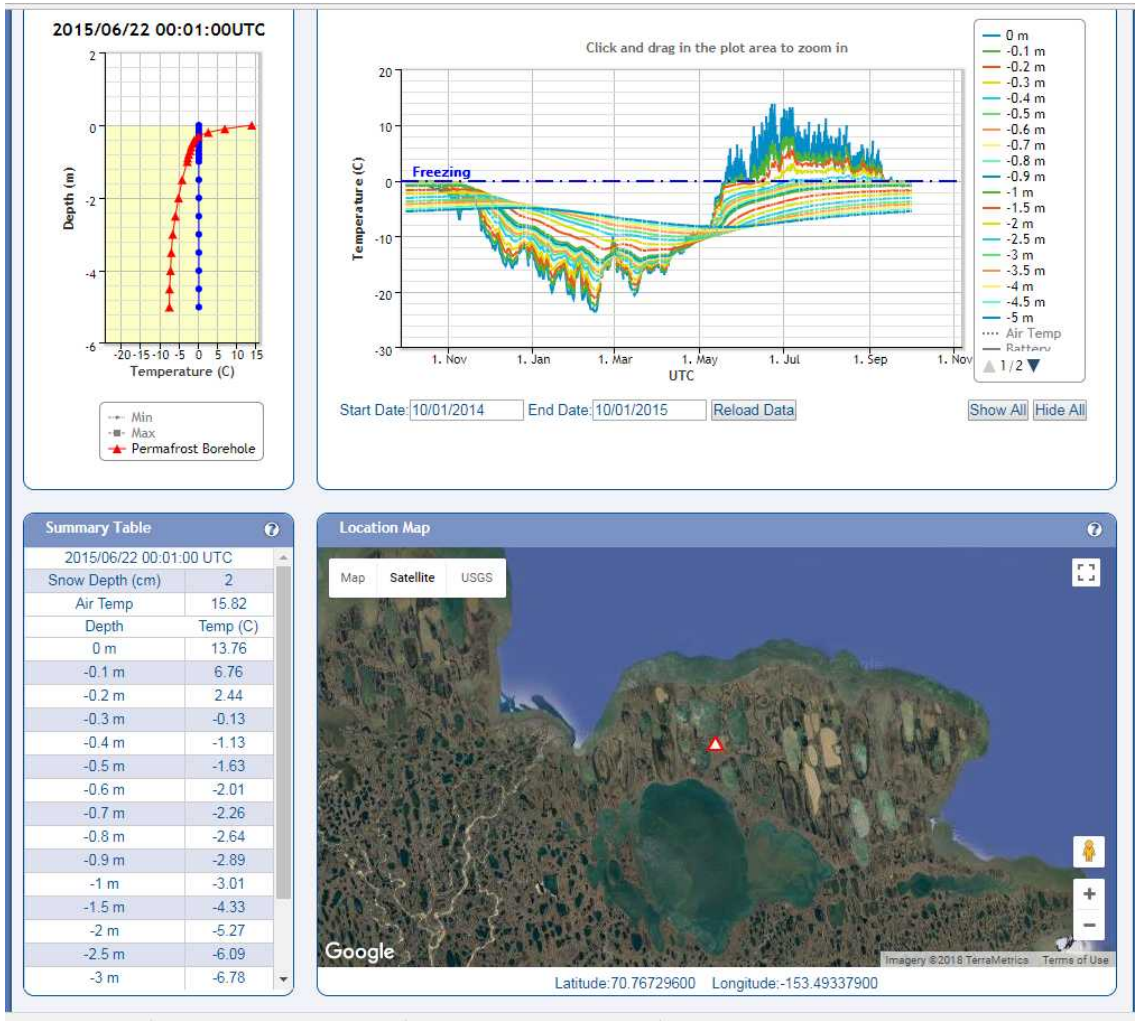
Exposure Data Collection (potential)

- Activity: Detailed description of exposed permafrost bluffs
- Deployment
  - Location: Target primary terrain units exposed along Drew Point coast
  - Duration: August 2018 during field campaign
  - Mechanism: Walking and boating along exposed bluffs and quantifying wedge ice, cryostructure, additional material sampling
- Data Collection
  - Rate: August 2018 during field campaign
  - Max Length: 4 kilometers



Thermistor Arrays

- Sensor: Beaded Stream D405 Data Logger and Digital Temperature Cable
- Deployment
  - Location: Three locations along transect from beach to bluff to hinterland
  - Duration: April 2018 to End of Project
  - Mechanism: Installation in 5 cm pvc lined borehole
- Data Collection
  - Rate: hourly
  - Onboard Memory: 4 MB non-volatile flash memory has capacity to store data from 100 TAC sensors once per hour for 12 months minimum.
  - Telemetry: Iridium satellite data stream and dashboard
  - Collected Variables: Temperature (x10)



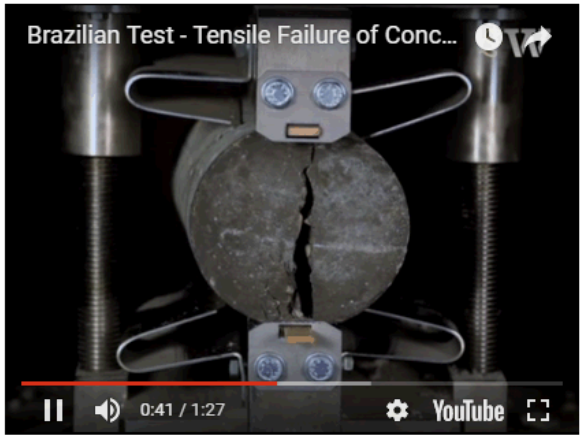
Core Analysis Cont.

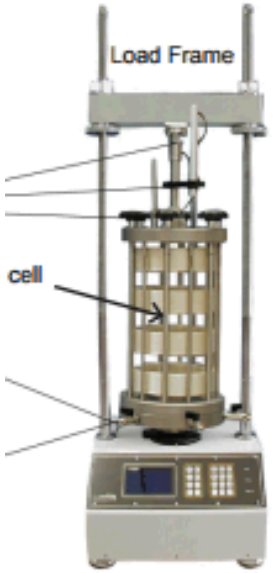
- Basic characterization:
  - Measure frozen/unfrozen water content (ASTM D2216).
  - Measure liquid limit and plastic limit (ASTM D4318)
  - Measure dry density and wet (bulk) density (ASTM D7263).
  - Measure particle size distribution (ASTM D7928).
- For a given ice content and/or temperature condition:
  - Use water-jet cutting to trim intact core to desired size?
  - Brazilian Splitting Method (ASTM D3967)
    - **Tensile strength**
    - 0.2 to 0.75 thickness-to-diameter ratio (e.g., 38 mm thickness & 75 mm diameter)
  - Uniaxial & Triaxial Compression Tests (ASTM D7012, D7300).
    - Cohesion, Friction angle, **Bulk modulus, Shear modulus**
    - 2 to 2.5 length-to-diameter ratio (e.g., 90-115 mm length & 45-55 mm diameter)
  - If wide range of intact ice content is not sampled, also consider repacking?

E Young's modulus, and G shear modulus,

υ Poisson's ratio. K bulk modulus,

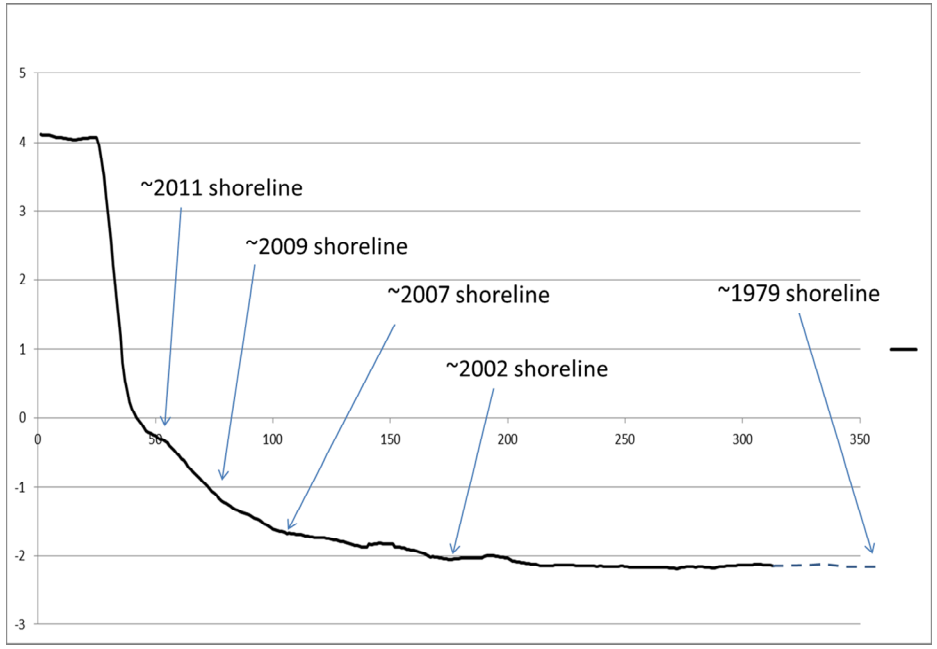
$$G = \frac{E}{2(1+\upsilon)} \qquad K = \frac{E}{3(1-2\upsilon)}$$

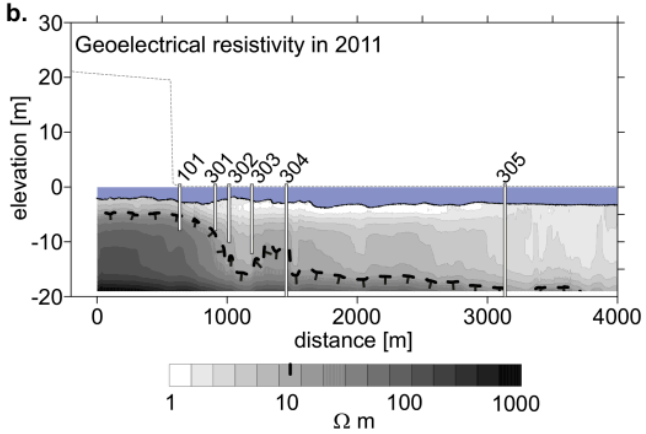




Geoelectrical Resistivity Surveys (AWI)

- Sensor: IRIS Syscal Pro™ system to collect apparent resistivity data.
- Deployment
  - Location: Drew Point and offshore to ~2 km
  - Duration: August 2018 for two weeks
  - Mechanism: Offshore tows by 16’ zodiac boat with 15hp Honda 4 stroke outboard
- Data Collection
  - Accuracy: Subsea permafrost table within 1m; depth estimated from resistivity profiles correspond to the depth range of the bulk sediment resistivity increase from 10 to 20 Ωm.
  - Collected Variables: Depth to the permafrost table; permafrost degradation rates; subsurface characteristics; will supplement with coring and temperature measurements





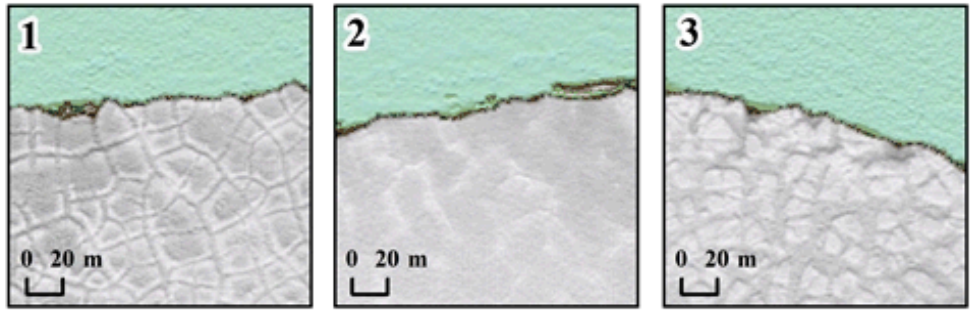
Ground Penetrating Radar (GPR) Surveys

- Sensor: 250 MHz MALA or Sensors and Software
- Deployment
  - Location: Tundra tows to image ice wedges in different terrain units
  - Duration: April 2018 during field campaign
  - Mechanism: Tow GPR behind snowmachine and collect continuous data; supplemented by augering
- Data Collection
  - Accuracy: ~1 m positional and 30 cm vertical
  - Onboard Memory: powered by laptop
  - Collected Variables: Ice wedge reflectors and other permafrost reflectors

COASTAL MORPHOLOGY

Measured Variables

- Ice Wedge Geometry derived from airborne LiDAR and paired with GPR and field measurements
- Shoreline positions on annual to sub-annual basis derived from very high resolution satellite imagery (<1 m)
- Shoreline and Beach 3-D Mapping derived from LiDAR and UAV SfM
- Niche Geometry derived from UAF SfM and paired with field surveys
- Vegetation survey



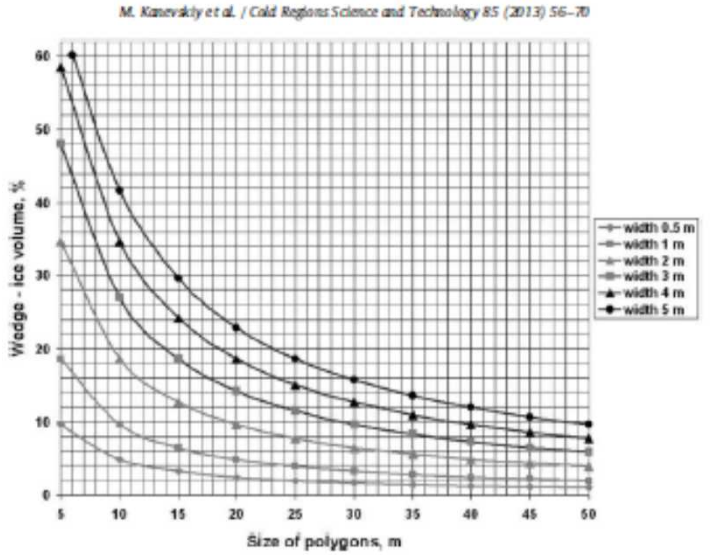


Fig. 3. Content of wedge ice with size of polygons and width of epigenetic ice wedges.

Camera System

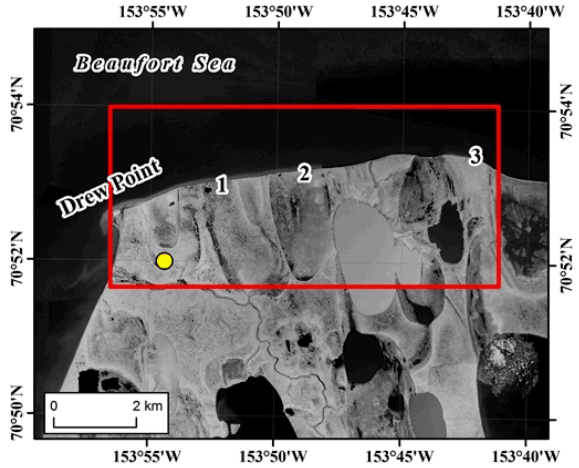
- Sensor: Buckeye X80 Camera (x 6)
- Deployment
  - Location: Several locations and aspects at Drew Point
  - Duration: April 2018 to October 2018, April 2019 to October 2019
  - Mechanism: Triggers cameras every 1 hr and transmits photo 12 miles south to Teshekpuk Lake Observatory then uploads to the WWW via a Hughesnet Satellite Dish
- Data Collection
  - Accuracy: every 1 hour
  - Onboard Memory: 32 GBs
  - Collected Variables: Coastal Phenology and Erosion

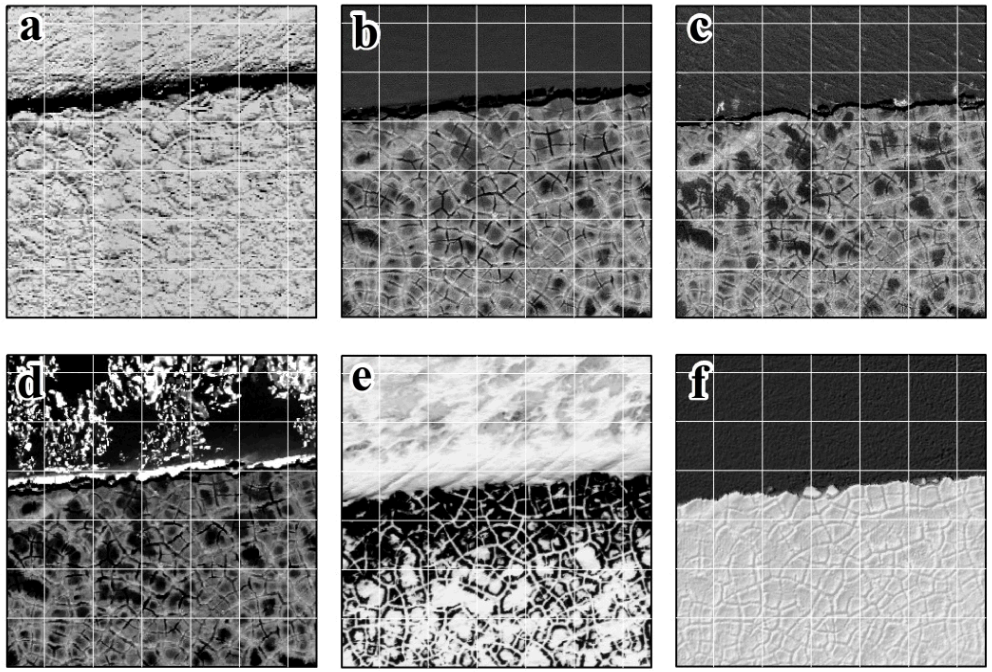
DGPS

- Sensor: Leica Viva DGPS and laser scanner
- Deployment
  - Location: Drew Point (5 km)
  - Duration: August 2018, August 2019
  - Mechanism: Walking and recording elevation along historical transects, noting ice wedge locations in log book, surveying bluff top and bluff bottom, benchmarks
- Data Collection
  - Accuracy: cm scale vertical and horizontal
  - Onboard Memory: 32 GBs
  - Collected Variables: Bluff top position, bluff bottom position, ice wedge configuration, shoreline elevation, Benchmarks for bathymetry and UAV surveys

Remotely Sensed (Satellite)

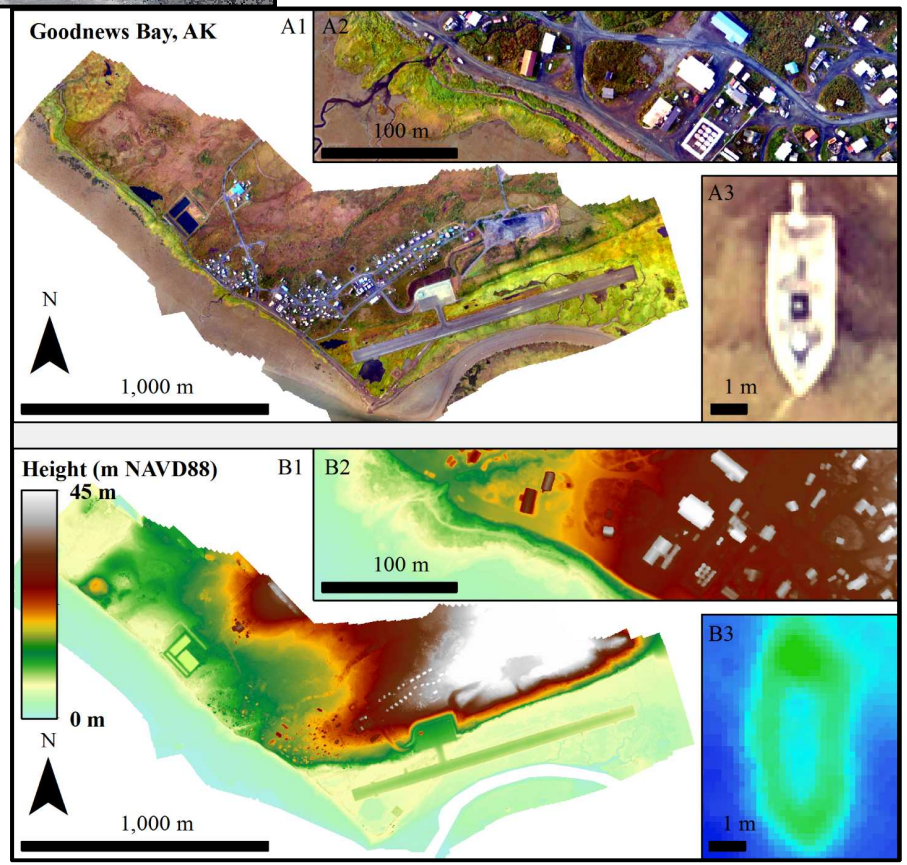
- Sensor: National Geospatial Intelligence Agency – WARP archive (high-res commercial imagery)
- Deployment
  - Location: Drew Point (9 km)
  - Duration: Annually since 2007 and sometimes seasonally
  - Mechanism: Remote Sensing and manual digitizing bluff edge
- Data Collection
  - Accuracy: < 1.2 m when comparing 0.5 m resolution imagery
  - Onboard Memory: N/A
  - Collected Variables: Bluffline position and change





Structure from Motion (potential)

- Sensor: DJI Phantom 3 Advanced w/ 12 MP camera, 94 degree FOV, autonomous mapping
- Deployment
  - Location: Drew Point
  - Duration: 2000 x 200 m with 3 batteries
  - Mechanism: Drone flights w/ control points, Walking and recording elevation along historical transects, noting ice wedge locations in log book, combined with ground photos of high angle features, i.e. taking pictures of bluffs from the beach or a boat for 3D model of underhangs and niches
- Data Collection
- Accuracy:
  - Orthomosaic resolution: 8-9 cm pixel size
  - Digital surface model: 16-17 cm pixel size
  - ASPRS horizontal accuracy class: 20 cm
  - ASPRS vertical accuracy class: 20 cm in non-vegetated terrain, 20-33.3 cm in vegetation
  - Collected Variables: 3-D shoreline and beach mapping, detailed niche geometries



BIOGEOCHEMICAL

Measured Variables

- Organic carbon, nitrogen, and phosphorus content (%) of eroding soils
- Biodegradability of organic matter
  - subset of samples collected for C, N, and P measurements
  - Incubations tracking microbial activity as reflected by CO_2 production or BOD

- Measurements on soils from cores collected at drew point (intervals TBD)
- Measurements on soils collected on exposed bluff faces (intervals TBD)
  - Drew Point
  - BLE-LTER sites (near Utqiagvik, Prudhoe Bay, and Kaktovik)

- Content data (C, N, P, percentages) will be used in concert with bulk soil erosion modeling to estimate element fluxes to marine environment

Instrumentation

- Thermo Scientific Flash 2000 elemental analyzer (for organic C and N)
- Varian Cary 50 Bio UV-visible spectrophotometer (for organic P)
  - Liquid extraction of soils with alkaline EDTA solution
  - Persulfate oxidation to convert organic P to orthophosphate
  - Measurement of orthorphosphate colorometrially on spectrophotometer
  - Organic P is calculated as difference between persulfate (total) P and extracted inorganic P analyzed on samples that do not undergo the persulfate digestion step

PLANNED CAMPAIGNS

2018 field work schedule

- January: Initial permafrost coring campaign and instrumentation
  - Ben with UAF colleague
- April: Permafrost Coring Campaign
  - Ben with UAF colleagues
- Late June / Early July: deploy sensors
  - Ben with Rich (?)
- Late July / Early August: Dedicated Field Campaign (2 weeks)
  - Ben leads with SNL, UT and potentially UAF team, AWI crew of 4
- Late July/ Early August: multi-beam bathymetry survey and ADCP deployment
  - Jeremy leads with 50ft R/V Ukpik out of Prudhoe (shallow water limitation of 2m)
- Late September / early October: recover sensors / time with storm event (?)
  - Either Ben solo or with one other colleague (Rich?)