Multidisciplinary drifting Observatory for the Study of Arctic Climate

Matthew Shupe, Markus Rex
& the international MOSAiC consortium

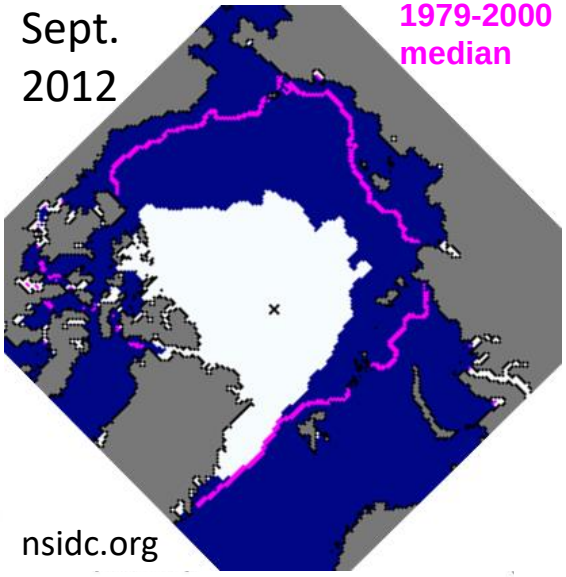
A major international research initiative to improve the representation of Arctic coupled processes in weather forecast and climate models

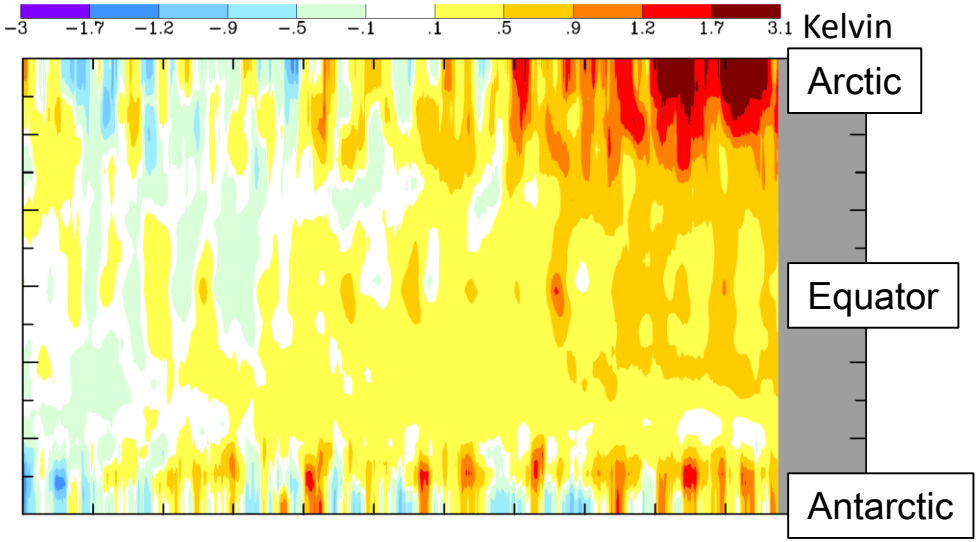
MOSAiC
The International Arctic Drift Expedition

ARM/ASR Meeting 16 Mar 2017

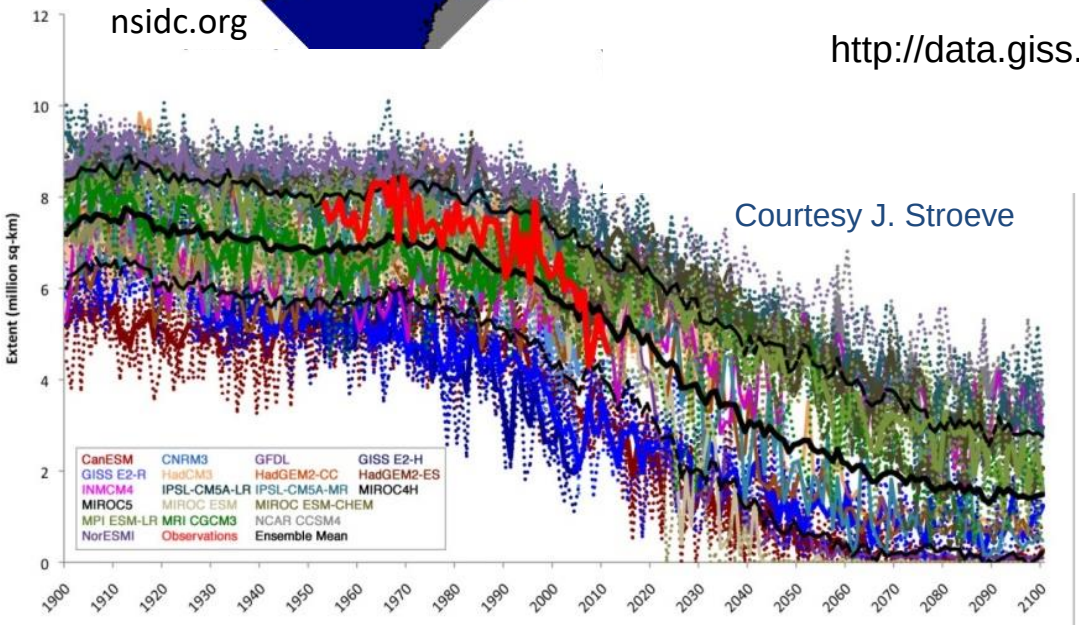
IASC

Motivation: Changing Arctic





http://data.giss.nasa.gov/gistemp/time_series.html

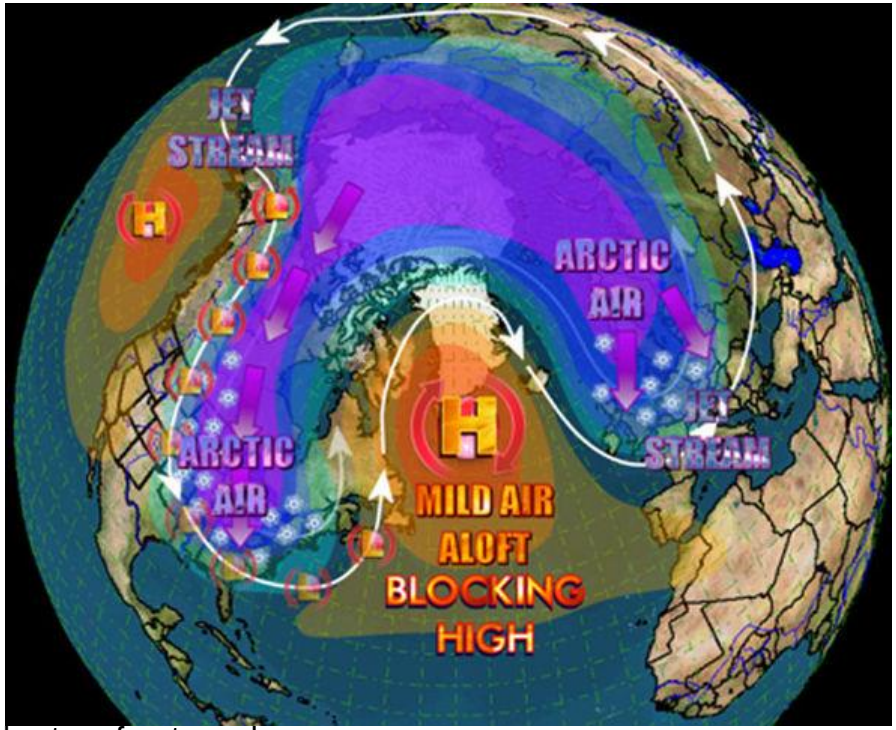


Courtesy J. Stroeve

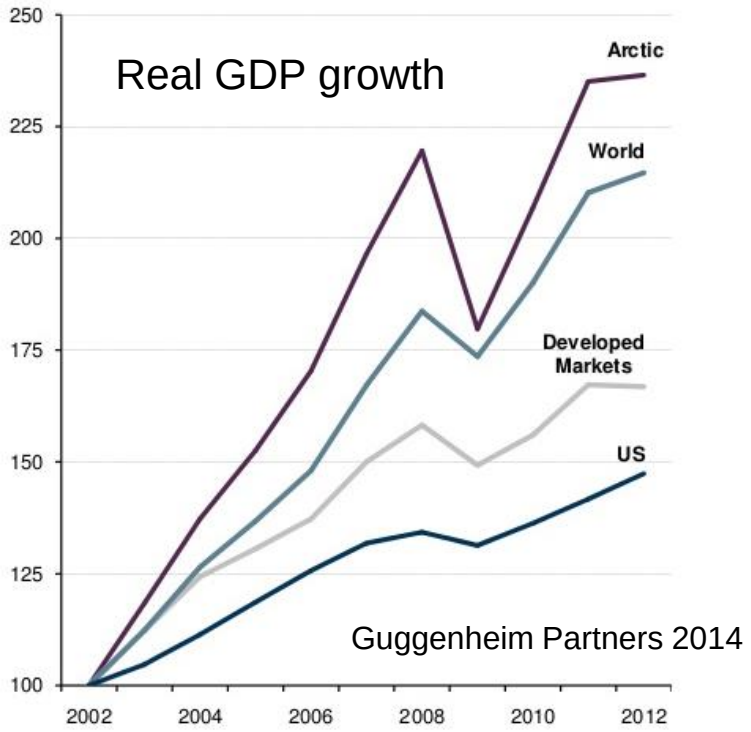
- **Sea ice decline**
- **Arctic amplification**
- **Large model spread**
- **Challenges representing Arctic system**

Implications of Change

- **Regional: resource development, shipping, fisheries, communities, weather forecasting, coastlines, ecosystems, productivity**
- **Hemispheric: Large-scale linkages and feedbacks**
- **Climate: Emergence of new processes, tipping points**



kcstormfront.wordpress.com



Need for Improved Models

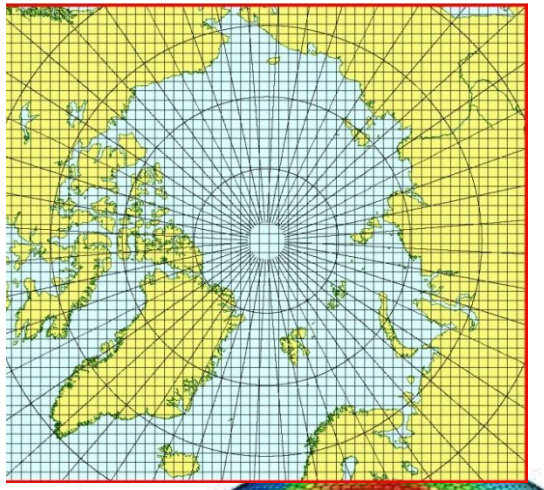
1) Weather; 2) Climate; 3) Sea-ice

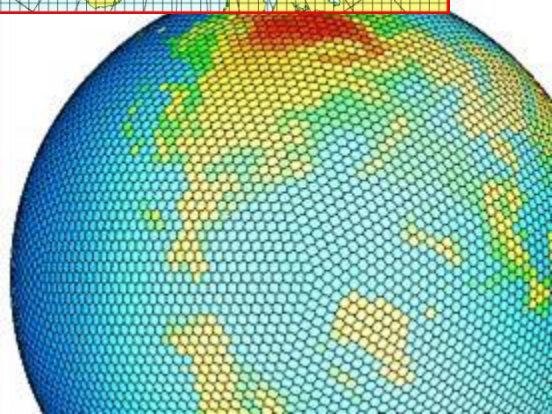
All require physical representation of a changing Arctic

Conclusions from IPCC

Major deficiencies in Arctic: clouds, boundary layer, winds, surface fluxes, ocean mixing.

Lack of observational data



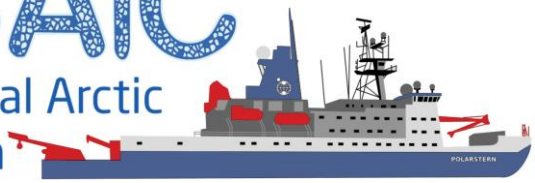


Coupled global models are the new frontier

Overarching Goal

To improve the understanding of coupled atmosphere-ice-ocean-ecosystem processes in the Central Arctic to support improved sea ice forecasting, regional weather forecasting, and climate predictions.

MOSAiC
The International Arctic Drift Expedition



Multidisciplinary drifting Observatory for the Study of Arctic Climate

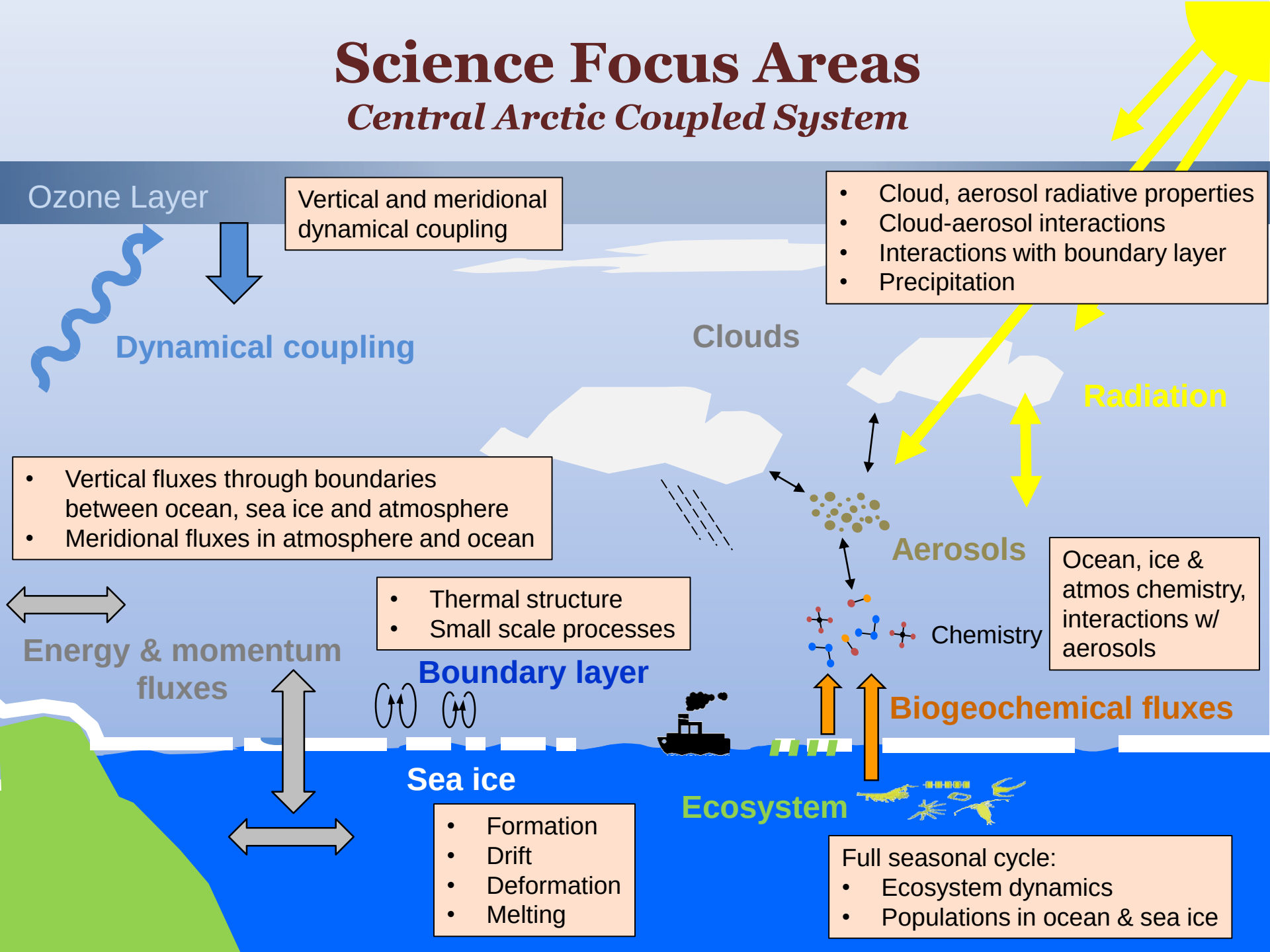
MOSAiC Science Drivers

"What are the causes and consequences of an evolving and diminished Arctic sea ice cover?"

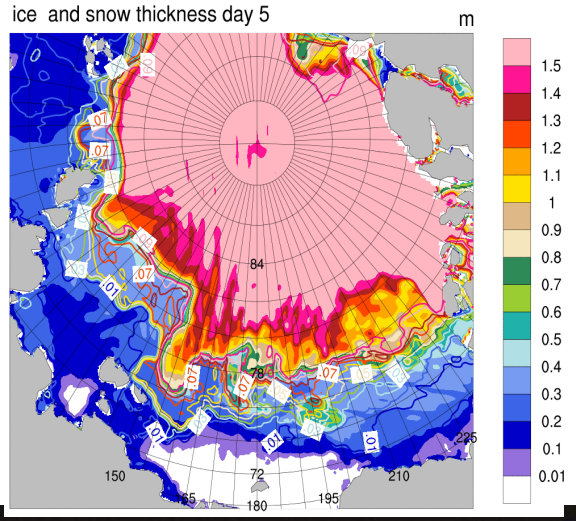
1. **Sea-ice energy budget**
2. **Ice movement & deformation**
3. **Clouds / Precip / Aerosols**
4. **BioGeoChemistry and Ecosystems**

Science Focus Areas

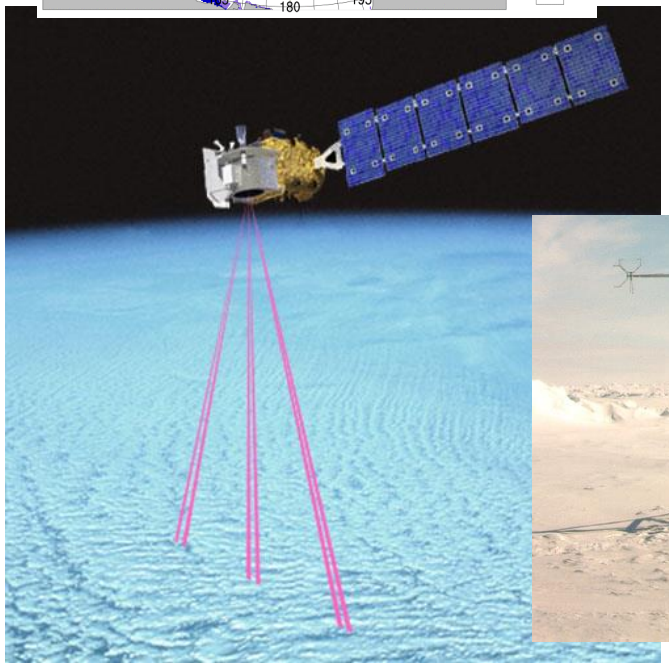
Central Arctic Coupled System



MOSAiC Operational Drivers



- Enhanced Observing System
- Interfacing w/ Satellites
- Data Assimilation
- Multi-scale Modeling/Forecasting
- Large-scale Implications
- Outreach/Education

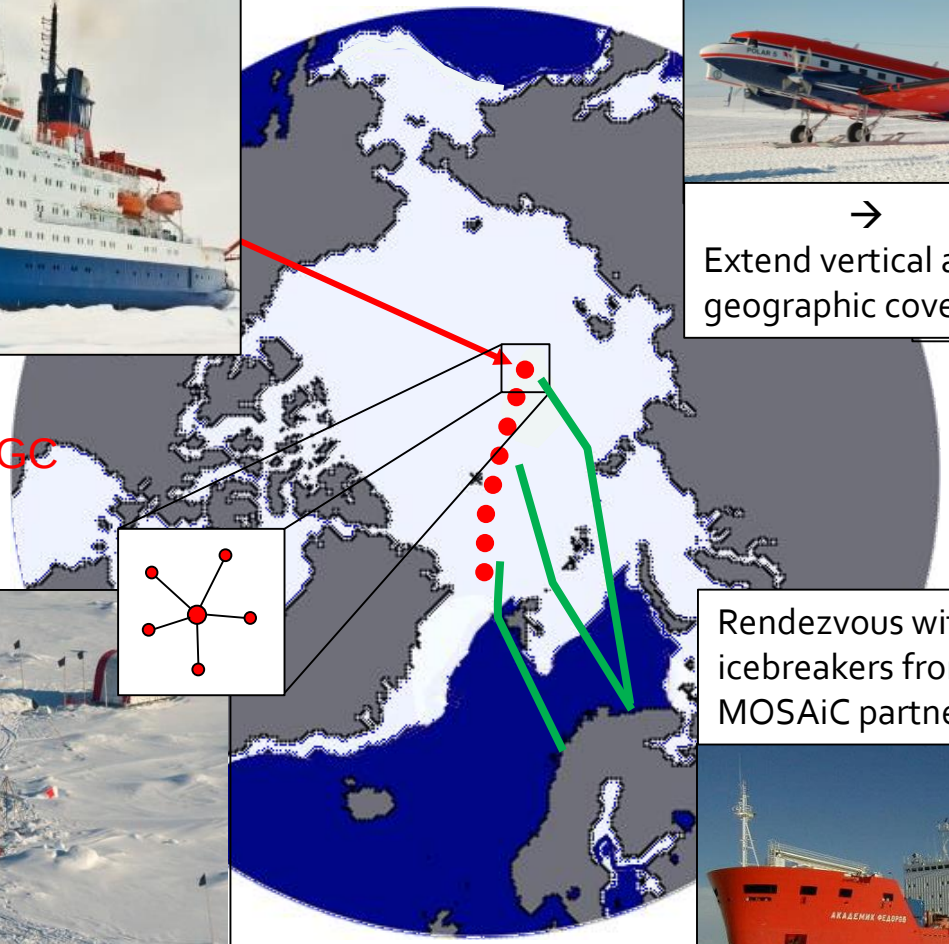


MOSAiC
The International Arctic Drift Expedition

Year round observations in the Central Arctic

Central Observatory:
RV Polarstern

Intensive coupled
Atmos-Ice-Ocean-Eco-BGC
Fall 2019 > Fall 2020



Research aircrafts and helicopters

→
Extend vertical and geographic coverage

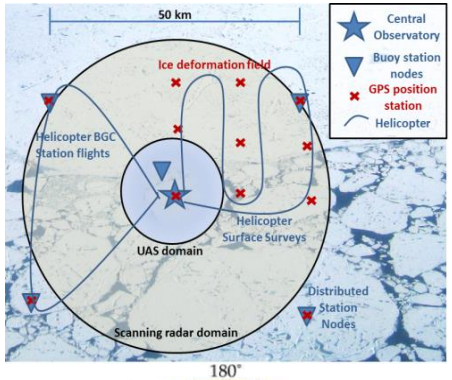
Distributed network of satellite stations

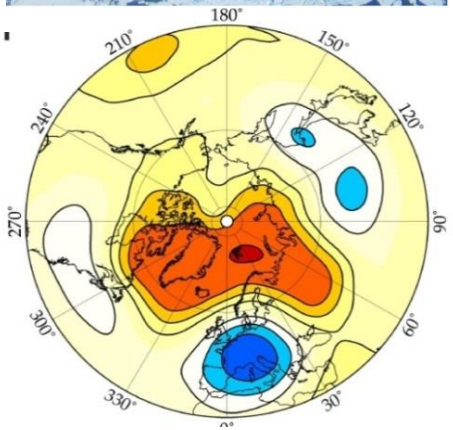
Autonomous systems,
UAS, AUV, camps

Rendezvous with icebreakers from MOSAiC partners

→
Broader geographic coverage & supply

Multiscale Design





Central Observatory
- Ship/ice based
- Attended observations
- Stable platform
- ➢ Process scale observations

< 5 km

Distributed Network
- Autonomous stations
- UAS, ocean gliders
- Heterogeneity
- Process & regional model
- ➢ Model grid cell

< 50 km

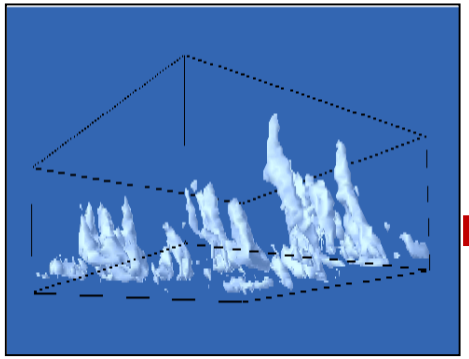
Large-scale linkages
- Collaborating research vessels and supply cruises
- Aircraft campaigns (Polar 5/6, Halo, etc.)
- Arctic buoy networks, satellites
- Data assimilation studies
- ➢ Arctic regional & global models

> 1000 km

Modeling Strategy

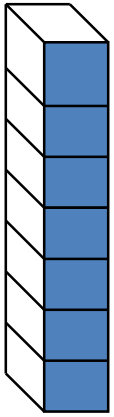
Process Understanding

Process, Large Eddy Simulations

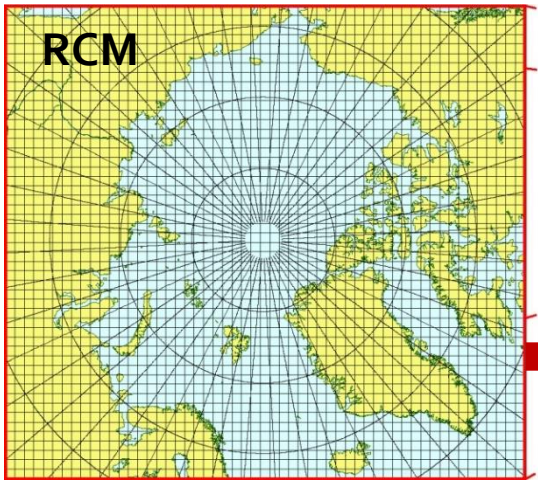


Validation Evaluation

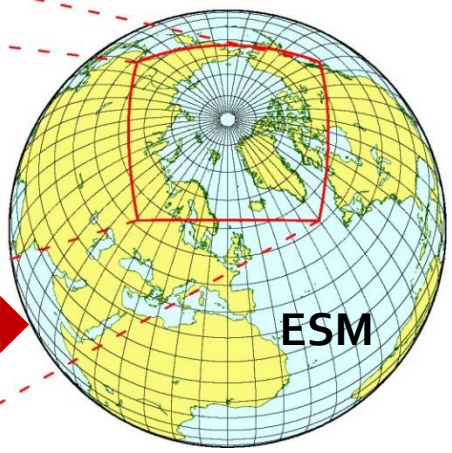
1D-SCM

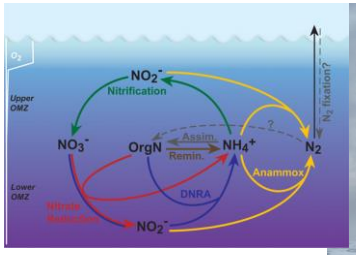


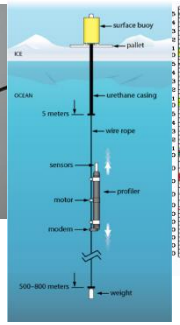
Regional System Understanding

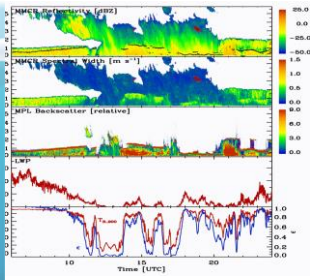


Projections Predictions



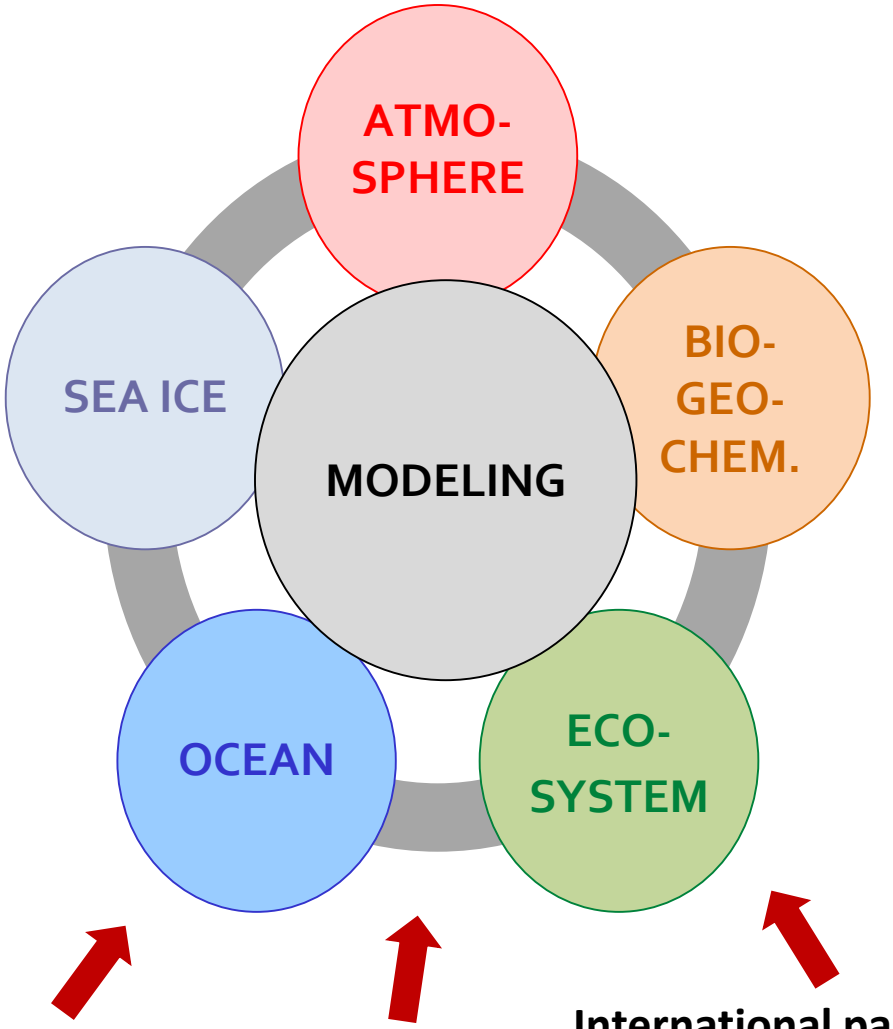






Detailed observational foundation

Working Group Structure



Cross cutting working groups:

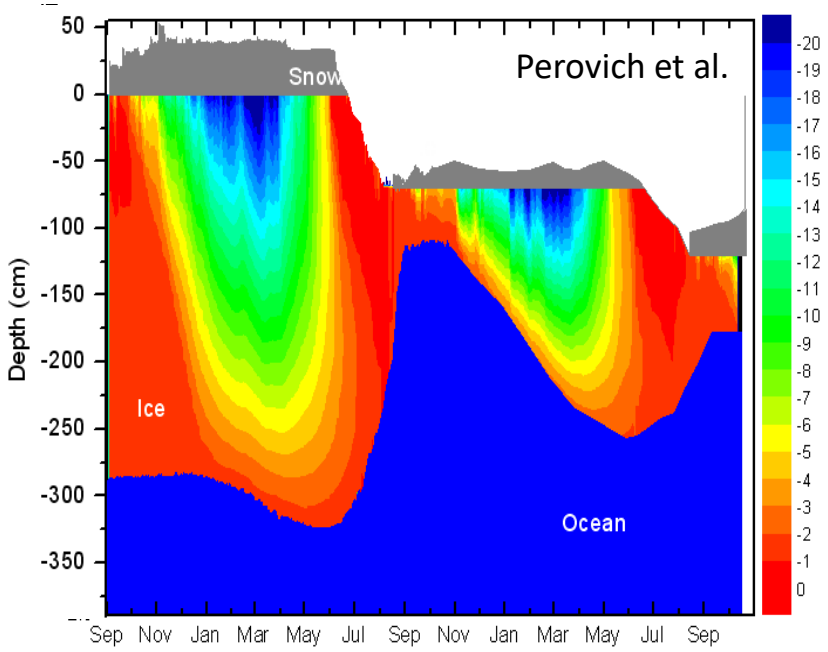
- Aircraft operations
- Remote Sensing
- Earth System modelling
- Outreach / Education
- Stakeholder engagement:
  - Indigenous communities
  - Fishery industry
  - Shipping companies
  - Etc.

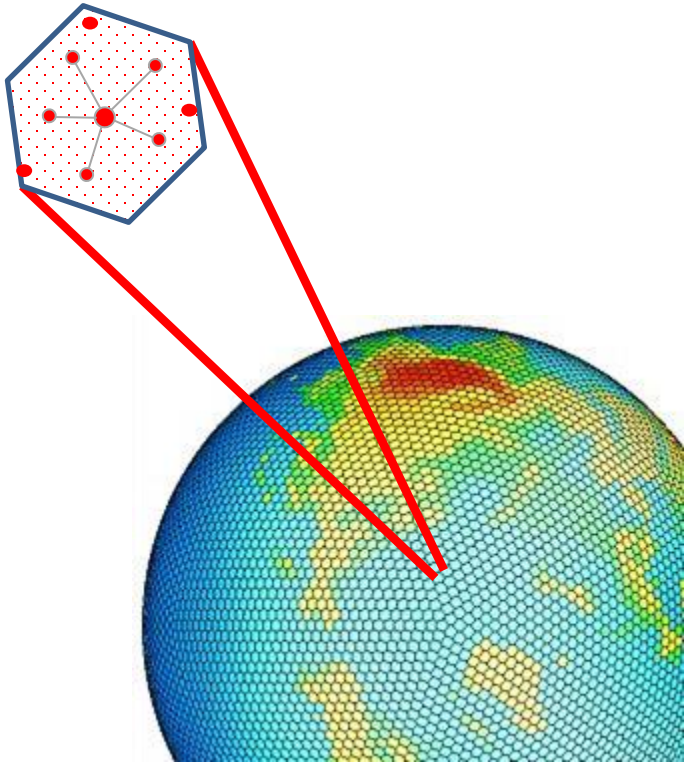
International partners:

Germany, Russia, US, China, Japan, Korea, UK, Sweden, Norway, Finland, Canada, France

Distinctive

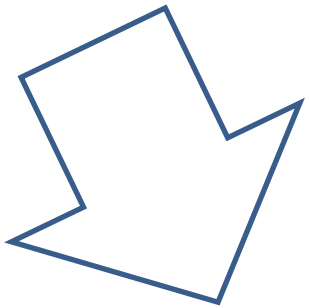
1) **Fills observing gap:** Coupled system processes
2) **Year round:** continual change, evolving processes, interseasonal linkages, what happens in winter?
3) **Heterogeneity:** upscaling for models





ARM/ASR Science

1. Surface energy budget of sea ice
2. Cloud and precip processes
3. ABL Structure and processes
4. Aerosol properties and interactions



Coupled System Research

Infrastructure

- AMF2 + AMF1-AOS + MAOS

Instrument	Measurement	Science Justification
Balloon-Borne Sounding System (radiosonde)	Twice-daily profiles of P, T, RH, winds	Thermodynamic profiles, ABL structure, link with clouds and surface
Microwave Radiometer, 3 channel (MWR3C)	Liquid water path, Water vapor path	Thermodynamic and cloud property characterization.
Microwave Radiometer (MWR)	Liquid water path, Water vapor path	Thermodynamic and cloud property characterization
High Spectral Resolution Lidar (HSRL)	Backscatter, depol ratio, cloud micro properties	Cloud property characterization; aerosol profile info
Micropulse Lidar (MPL)	Backscatter, depol ratio, cloud micro properties	(May not be needed if HSRL is present)
Doppler Lidar	Air motions, turbulence	Wind, turbulence in ABL, cloud-atmosphere interactions
Total Sky Image (TSI)	Visible hemispheric sky pictures	Visual documentation of cloud/sky coverage
Scanning W-band ARM Cloud Radar (SWACR)	Radar moments; Scanning; Cloud micro/dynamical properties	(Similar to Ka-SACR; not needed)
Marine W-band ARM Cloud Radar (M-WACR)	Vertical radar moments and spectra; motion stabilized	Cloud/precip characterization; Cloud-ABL dynamics; Dual-frequency synergy with KAZR
Ka-band Scanning ARM Cloud Radar (Ka-SACR)	Scanning radar moments; Joint with X-SACR;	Cloud/precip characterization and spatial organization.
X-band Scanning ARM Cloud Radar (X-SACR)	Scanning radar moments; Joint with Ka-SACR; Polarimetry.	Cloud/precip characterization and spatial organization.
Ka-band ARM Zenith Radar (KAZR)	Vertical radar moments and spectra	Cloud/precip characterization; Cloud-ABL dynamics; Dual frequency synergy with M-WACR
Vaisala Ceilometer	Cloud base, backscatter	Robust cloud presence and height
Radar Wind Profiler, 915 MHz (1290-MHz)	Wind profiles	BL wind structure (sub-optimal system for Arctic operations)
Infrared Sounder Spectrometer for IR Spectral Technology (ASSIST)	IR spectral radiance at zenith or other angles	Cloud property characterization; cloud radiative properties
Atmospheric Emitted Radiance Interferometer (AERI)	IR spectral radiance at zenith or other angles	Cloud property characterization; cloud radiative properties
IR All-sky Camera	IR radiation, spatial	Sky radiative heterogeneity
Multifilter Rotating Shadowband Radiometer (MFRSR)*	Solar irradiance at multiple wavelengths	Atmospheric / aerosol optical depth
Upwelling Radiation (GNDRAD)*	Upwelling broadband LW, SW fluxes	Surface radiation/energy budget, albedo characterization
Downwelling Radiation (SKYRAD)*	Downwelling broadband LW, SW fluxes	Surface radiation/energy budget, cloud radiative properties
Eddy Correlation System (ECOR)*	Surface turbulent fluxes, carbon dioxide.	Surface energy balance; turbulent momentum, heat, CO_2 fluxes
Surface Energy Balance System (SEBS)*	Up/down SW/LW radiation, soil moisture	(little added value beyond GNDRAD, SKYRAD)
Video Disdrometer (VDIS), 2D*	Precip DSD and fall speed	Precipitation mass/rate
Rain Gauge, weighing bucket*	Precipitation rate	Precipitation mass/rate (Difficult to operate in cold temperatures)
Met. Instrumentation*	Near-sfc P, T, RH, winds	Meteorological state for context
Inertial Nav. System	Platform pitch, roll, heave	Informational, context

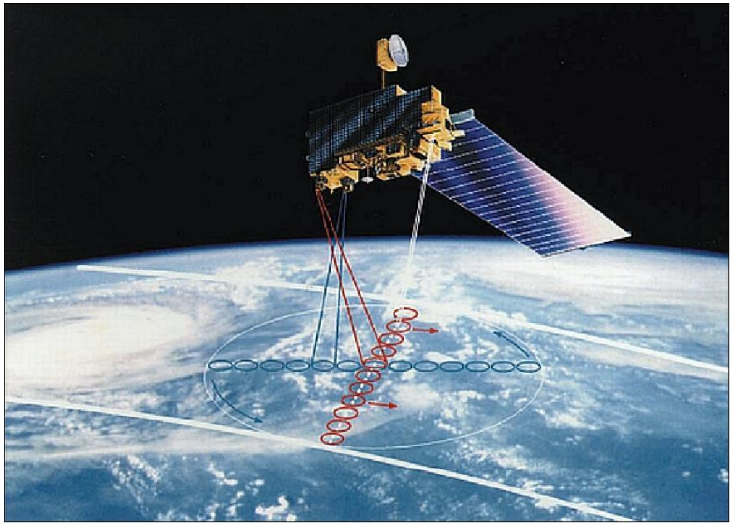
Instrument	Measurement	Science Justification
CCN200 (dual col.)	CCN concentration	Baseline characterization of CCN
Condensation Particle Counter (CPC)	Aerosol number concentration > 10nm	Baseline characterization of total aerosol concentrations
Ultrafine Condensation Particle Counter (UCPC)	Aerosol number concentration > 2.5 nm	Small particle concentration, new particle formation, & source attribution
Hygroscopic Tandem Differential Mobility Analyzer (HTDMA)	Aerosol mass, size, and # distribution as g(RH), particle growth factor	Baseline characterization of aerosol size dist'n; aerosol hygroscopicity
Ultra High Sensitivity Aerosol Spectrometer (UHSAS)	Aerosol size dist'n, 50–1000 nm	Baseline characterization of size dist'n
Scanning Mobility Particle Sizer (SMPS)	Aerosol size dist'n, 15-450 nm	Baseline characterization of size dist'n
Nephelometer	Aerosol light scattering coeff at dry RH, 3 wavelengths	Aerosol scattering, radiative effects
Wet Nephelometer	Aerosol light scattering coeff as f(RH), 3 wavelengths	Aerosol scattering, radiative effects
Humidigraph	Aerosol light scattering coeff as f(RH)	Aerosol scattering, radiative effects
Particle Soot Absorption Photometer (PSAP)	Aerosol light absorption at 3 wavelengths	Aerosol absorption, radiative effects
Photo-Acoustic Soot Spectrometer	Aerosol light absorption at 3 wavelengths	Aerosol absorption, radiative effects (Low sensitivity in the Arctic)
Aethelometer	Aerosol light absorption at 7 wavelengths	Aerosol absorption, radiative effects (Redundant with PSAP)
Aerosol Chemical Speciation Monitor (ACSM)	Aerosol mass spectrum measurements	Characterization of aerosol composition
Single Particle Soot Photomoter (SP2)	Black carbon mass concentration	Role of black carbon
Photon Transfer Reaction Mass Spectrometer	Volatile organic compounds	Characterization of aerosol composition (some similar info to ACSM)
PILS-IC-WSOC	Water soluble organic carbon	Characterization of aerosol composition (labor intensive, similar info to ACSM)
NOx, NOy, CO, CO_2, O_3	Gas concentrations	Airmass source, age, transport
Vaisala WXT520	P, T, RH, winds	Context
Sodar	Vertical wind	Context
Cimel Sunphotometer	Aerosol optical depth	(Similar info to MFRSR)

Other Measurements: Atmos

- Raman lidar (Polly XT) – T/q profiles (TROPOS)
- HATPRO MWR – PWV, LWP, T/q profiles (TROPOS)
- Sky imager (TROPOS)
- Radiation and met (TROPOS)
- Doppler lidars – Wind profiling (Uni. Trier, FMI, U. Leeds?)
- 20-30m Tower – Turb flux, ABL (CU/NOAA proposed)
- Surface flux stations – Turb/Rad flux (CU/NOAA, proposed)
- Gas flux – CO2, CH4, O3, DMS (CU/NOAA, proposed)
- Aerosol/gas – DRUM and filter samples, composition, inorg. ions, carbon isotopes, IN (Collaborative, proposed)
- UAS thermos profiling, surface fluxes (CU, proposed)

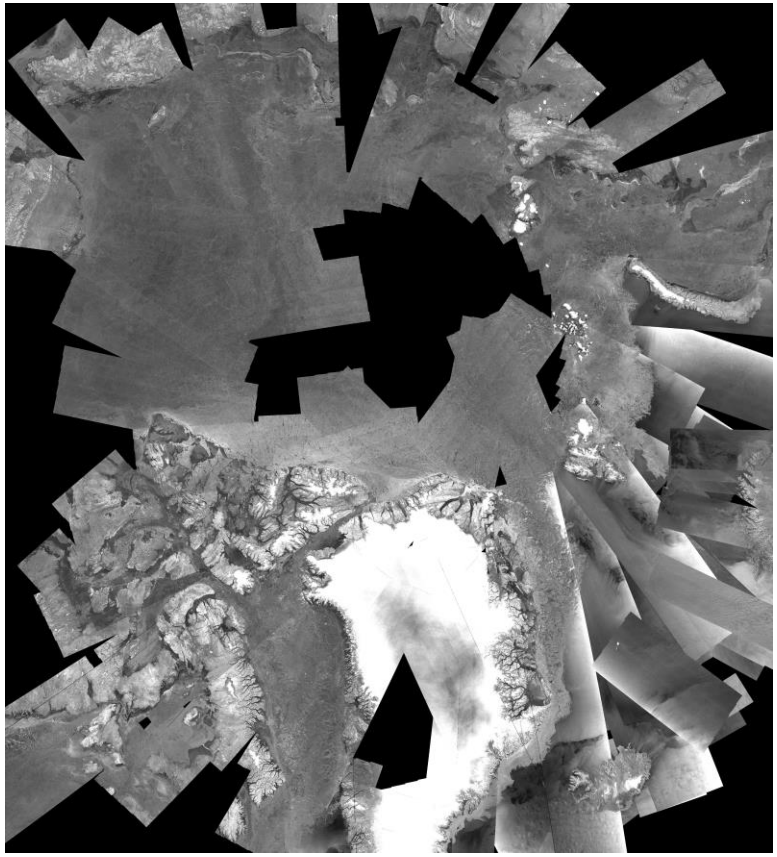
Other measurements

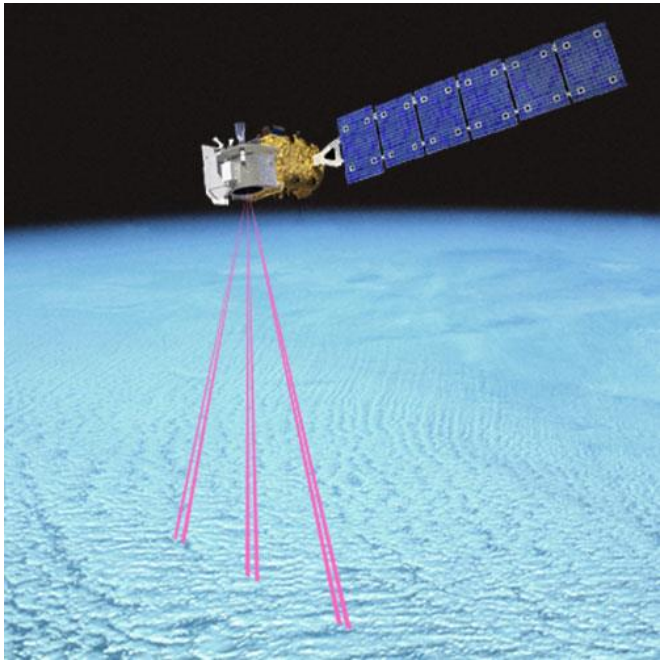
- Sea ice thickness, mass balance, thermo
- Sea ice position > deformation, motion
- Sea ice optical properties, morphology
- Ocean state profiling, currents, mixing
- Ocean heat fluxes, optics
- BGC in ocean & ice, C, N, etc.
- Ecosystems: PP, nutrients, lower trophic levels



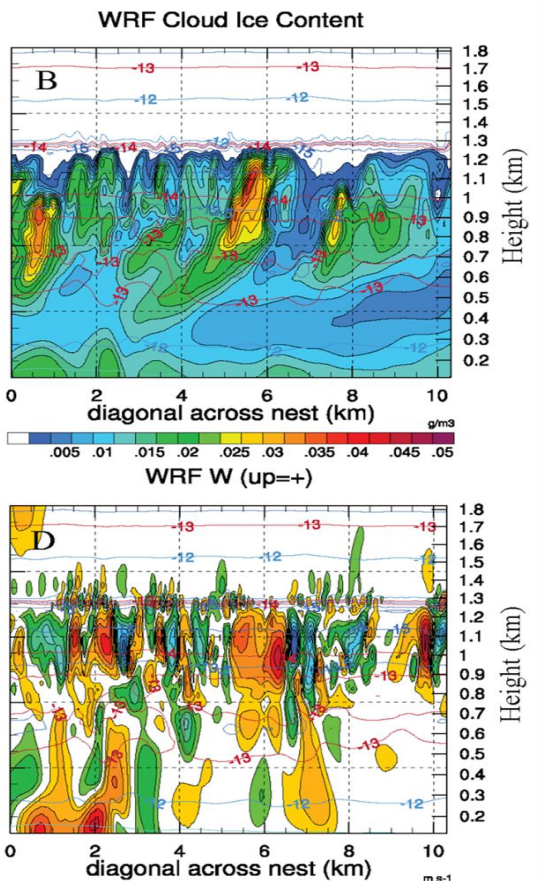
Satellite Concepts

- **High res sea ice: SAR**
- **Steerable sensors: ICESat-2, CERES**
- **Cal-Val: Many**



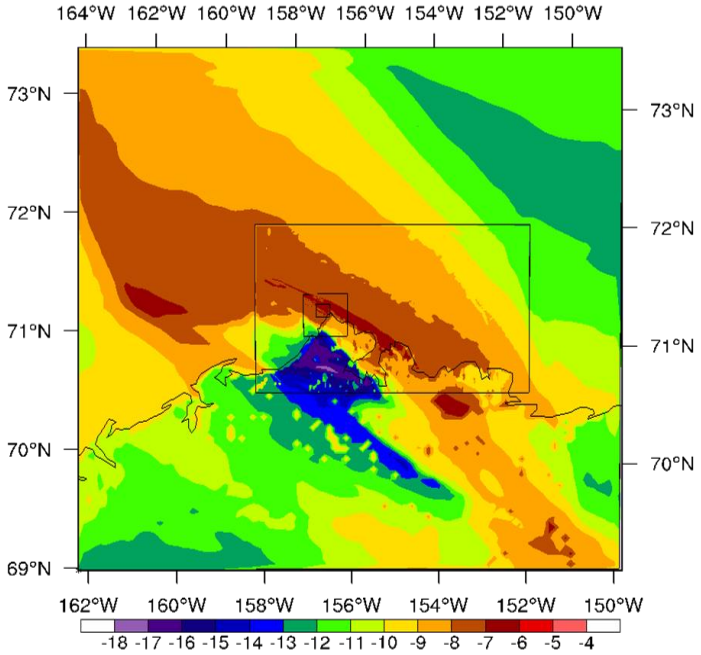


Process Modeling



LES <-> Obs Synergy

Solomon et al.



Nested domains link mesoscale to LES

LES, SCM, and /or nested mesoscale models

- Process understanding / fluxes
- Idealized studies
- Link across scales

Experimental Sea-Ice Forecasting

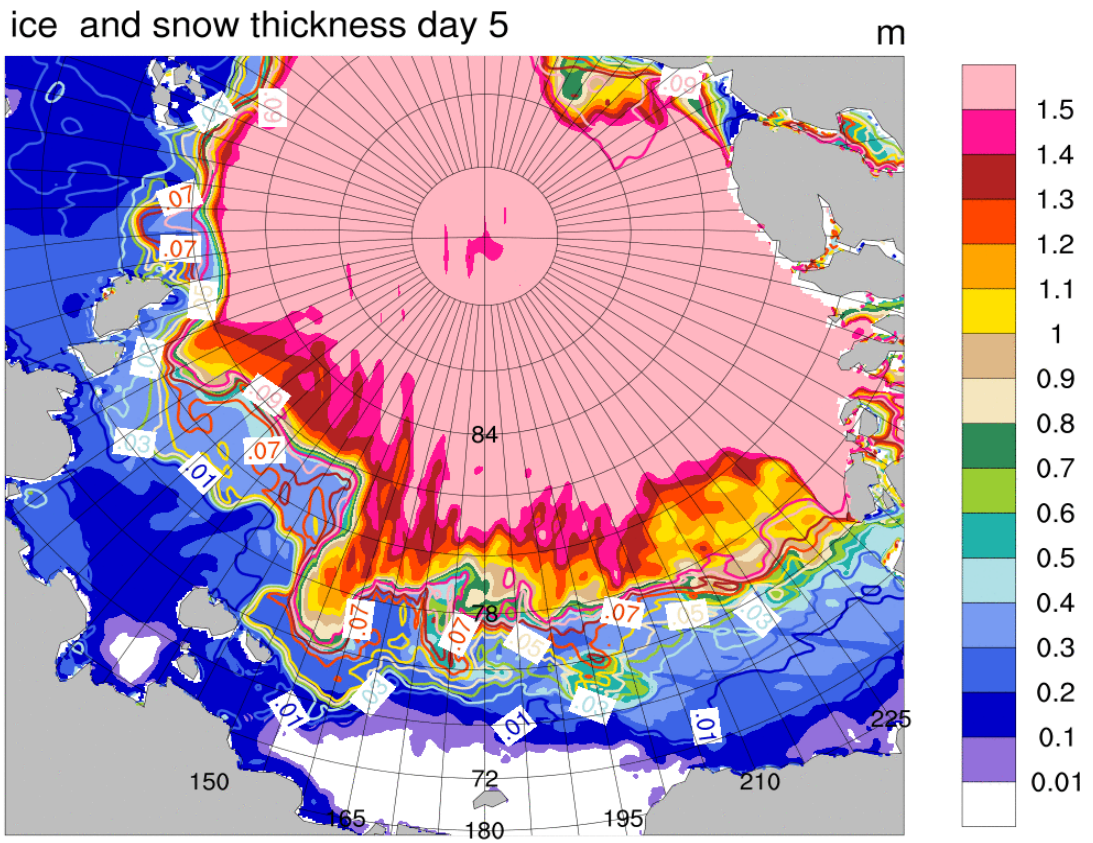
Solomon et al.

RASM-ESRL

- Based on RASM
- 10km res.
- Forced by GFS

For MOSAiC

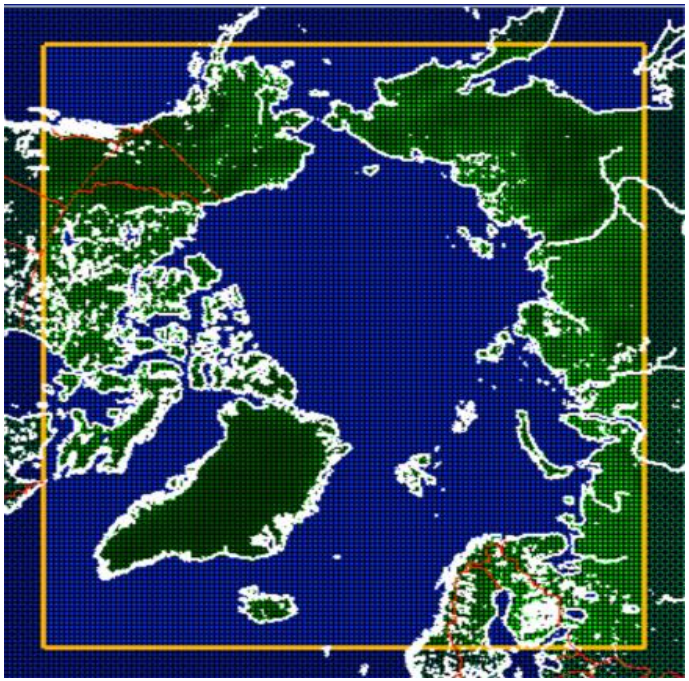
- Daily 5-14 day forecasts
- Forecast and assessment for full year



Regional Model Intercomparison

Arctic CORDEX

- Circum-Arctic domain
- Horiz. resol. of 0.44° or higher
- Driven by ERA-Interim



Rinke et al.

13 participating institutes	
AWI	Potsdam, Germany
CCCma	Victoria, Canada
Colorado Uni.	Boulder, USA
DMI	Copenhagen, Denmark
EMUT	Trier, Germany
GERICS	Hamburg, Germany
ISU	Iowa, USA
Lund Uni.	Lund, Sweden
MGO	St. Petersburg, Russia
SMHI	Norrkoping, Sweden
UNI	Bergen, Norway
Ulg	Liège, Belgium
UQAM	Montreal, Canada

Large-scale Modeling

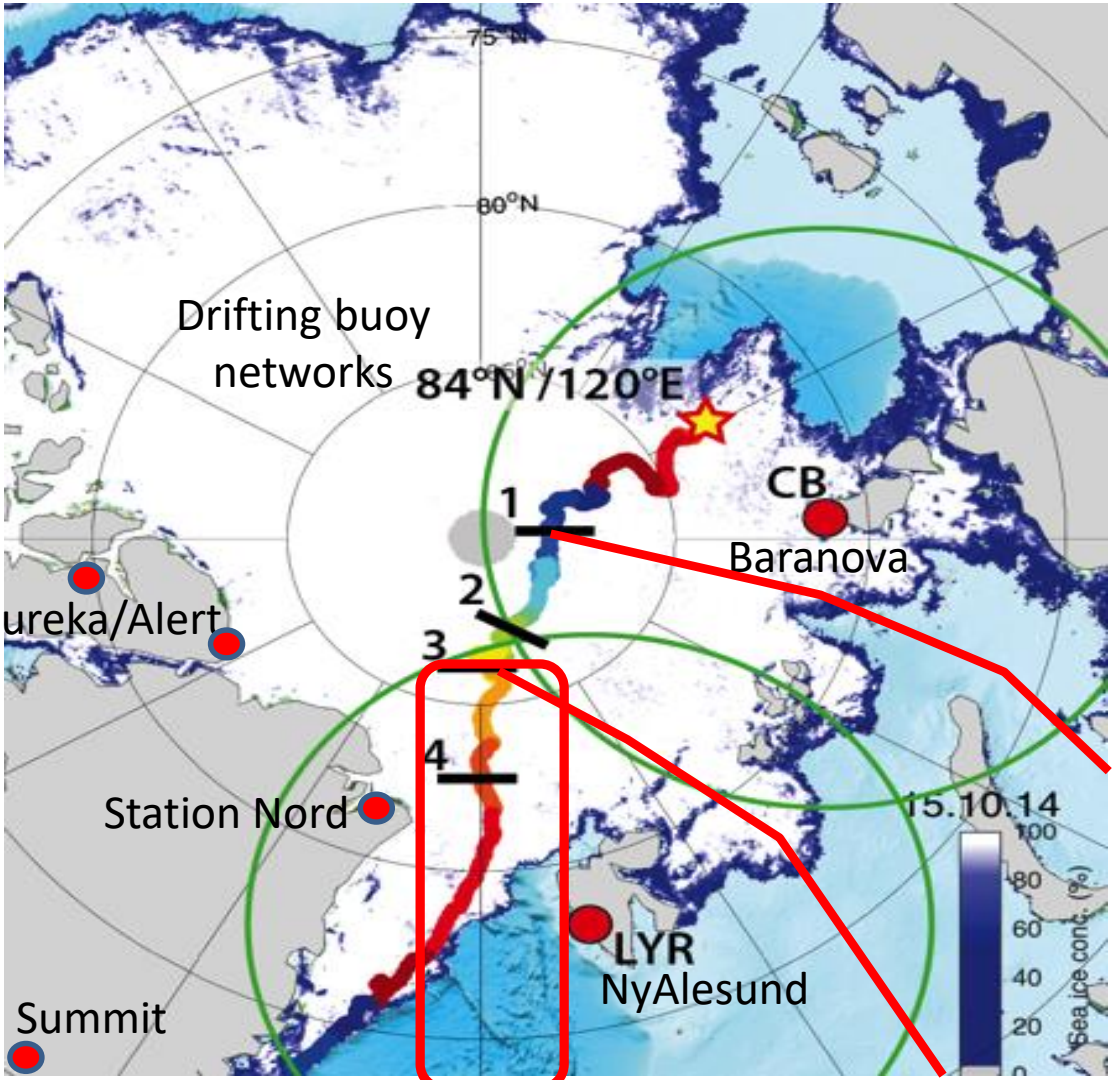
Strong Link with the Year of Polar Prediction =>
Global operational models (some coupled)

1) High resolution model output following the ship

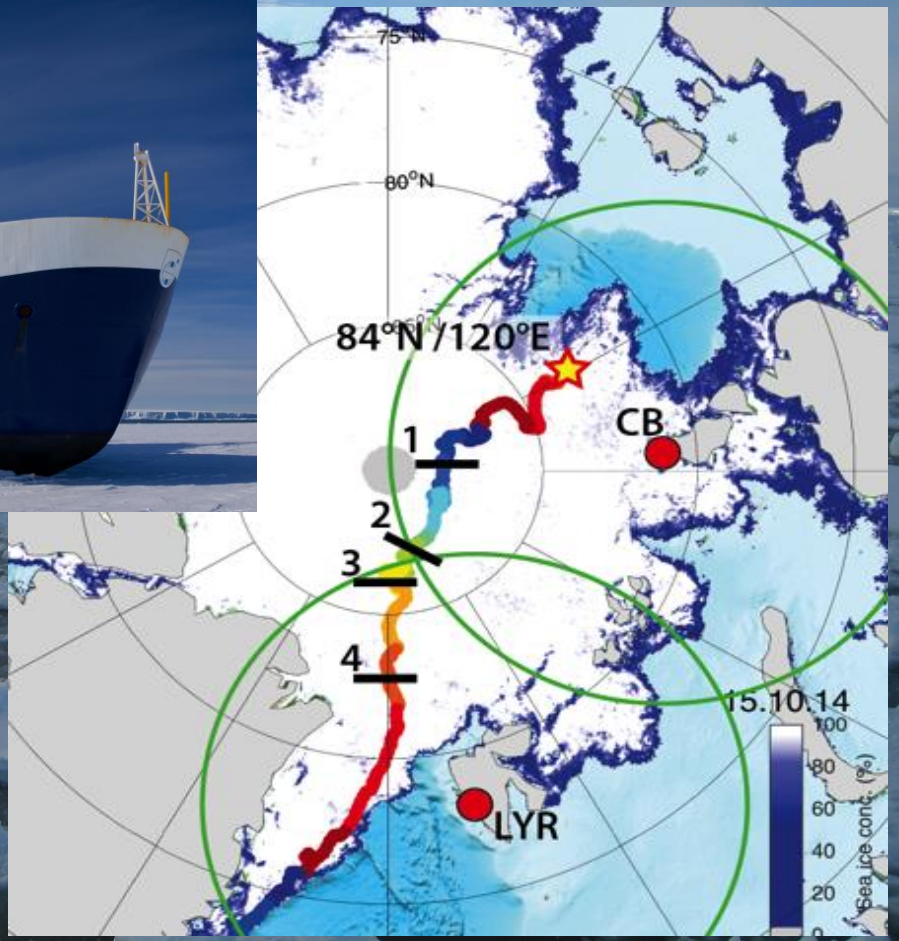
2) Community interested in process evaluation

Coordinated Activities

- Observatories
- Buoy Networks
- Resupply cruises
- Ships: Mirai, Araon, Oden, Amundsen
- Aircraft: AWI Polar5/6, DLR HALO, NASA?, UK FAAM?
- ONR polar cyclone project
- ONR technology development project
- INTAROS technology development project
- AC3 Transregional project (Germany)



Thanks!



Science and Implementation Plans

www.mosaic-expedition.org

Discussion Themes

- Prioritize Radars (other sensors)
  - Scanning X-Ka or W-Ka?
  - Vertical-pointing requirements?
  - Wind profiling
- Aerosol systems
  - Modify protocols? ACSM, HTDMA,…
  - SP2 plan
  - IN plan
- Modeling interests:
  - How to best position obs to support models?
  - What are most critical parameters?