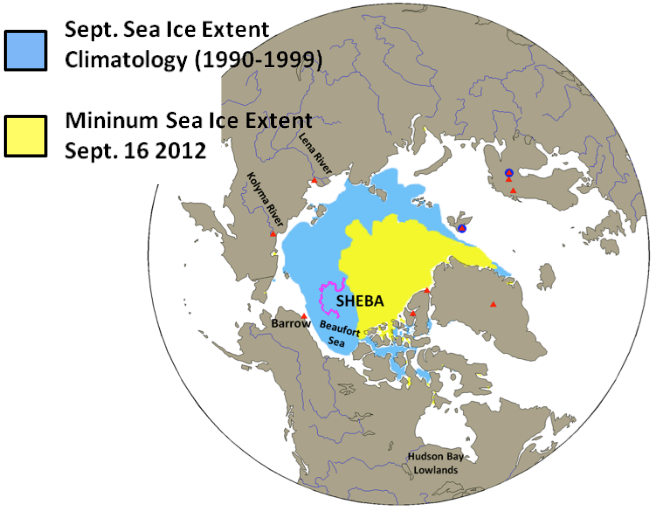
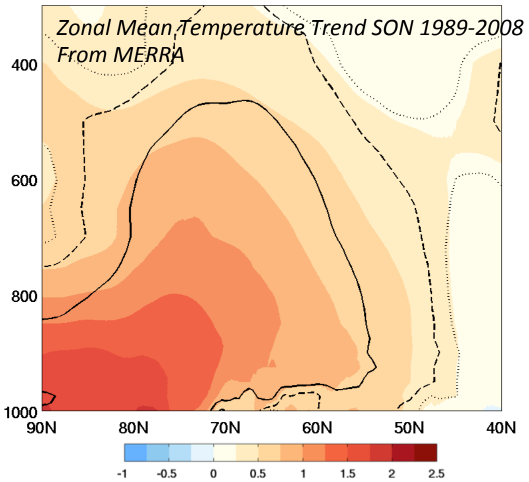
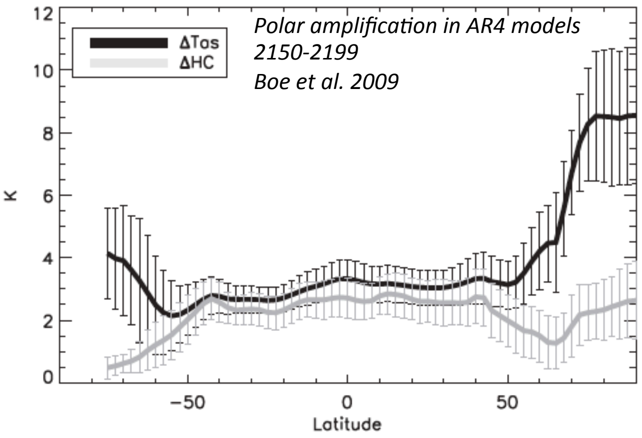
Earth System Modeling and Field Experiments in the Arctic-Boreal Zone

NASA Workshop Summary







Motivation for the Workshop

There is a large uncertainty in model predictions of the extent, timing and hierarchy of mechanisms involved in the anticipated ABZ warming. The range and type of field experiments proposed for the region should be directed in reducing this uncertainty and improving model realism and performance.

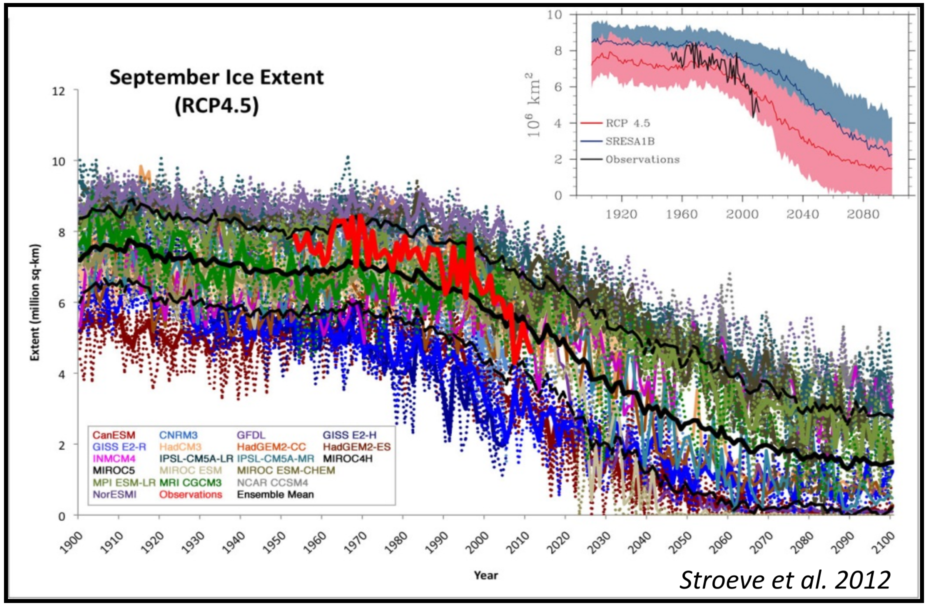
To this end, a workshop was proposed to assess limitations in current Earth System Model (ESM) performance with a view to identifying submodel weaknesses that could be addressed by future field experiments.

A two-day workshop was held at NASA/GSFC in May 2012 with 30 participants representing all aspects of Physical Climate System (PCS) and Biogeochemical (BGC) modeling within Earth System Models (ESMs).

http://science.gsfc.nasa.gov/610/ABZ_workshop/ABZ_home.html

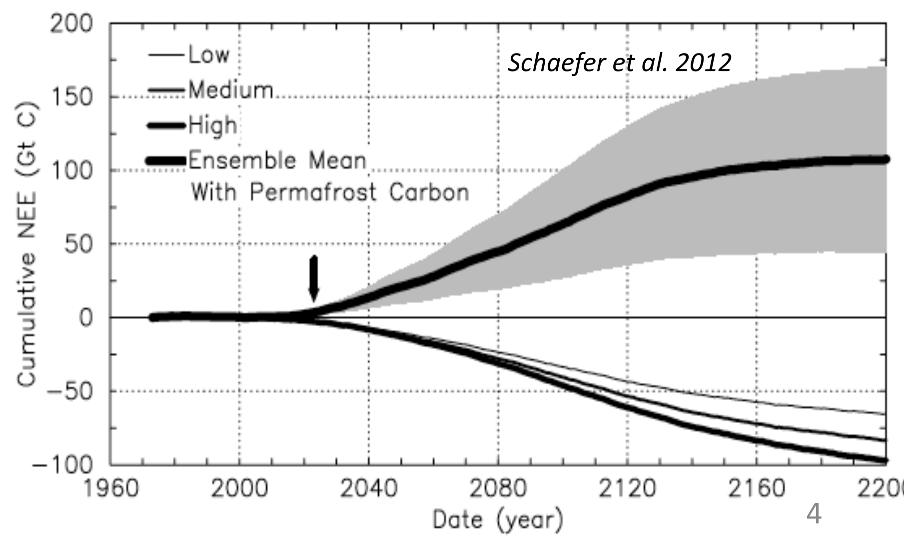
Workshop report: Table of Contents

(1) **Introduction**



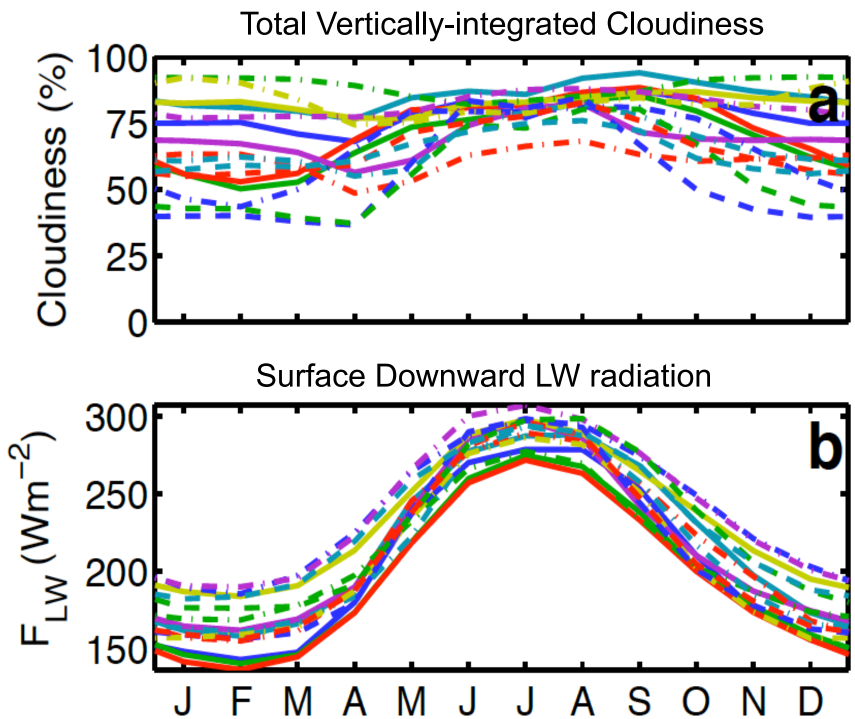
Climate models vary widely in their warming trajectories over the 21st century with no consensus of the timing of an ice-free Arctic. *An ice-free Arctic could emerge 20-30 years earlier than projected!*

Some biogeochemical cycle (BGC) models indicate that warming in the ABZ could lead to widespread permafrost thaw. This alone could contribute around 90 ppm CO_2 to the atmospheric CO_2 burden by 2100. *Uncertainties in predicted future fluxes are huge!*



(2) Predictive Models – Status and Gaps

Clouds, Aerosols, Radiation, Boundary Layers



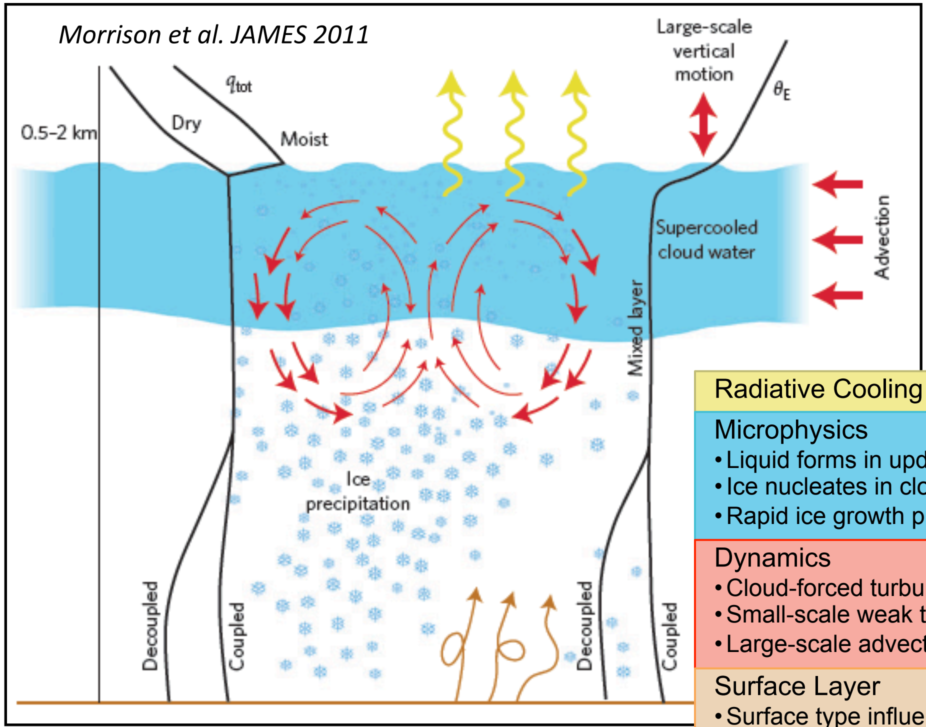
Eisenman et al. GRL 2007

- Large inter-model differences in simulating Arctic cloud cover, produce significant differences in downwelling long-wave radiation and equilibrium ice thickness.
- Overproduction of winter clouds
- Direct comparisons with satellite data (through simulators) show that modelled clouds have radiatively-compensating biases.

(2) Predictive Models – Status and Gaps

Clouds, Aerosols, Radiation, Boundary Layers

Primary processes and basic physical structure of persistent Arctic mixed-phase clouds



Radiative Cooling

Microphysics
- Liquid forms in updrafts or within the inversion layer
- Ice nucleates in cloud
- Rapid ice growth promotes sedimentation from cloud

Dynamics
- Cloud-forced turbulent mixed layer
- Small-scale weak turbulence in cloudy inversion layer
- Large-scale advection of water vapor

Surface Layer
- Surface type influences interaction with cloud

- Models have incomplete microphysics - ice nucleation parameterization development is a priority.
- Understanding how cloud condensation nuclei (CCN) and and ice nuclei together impact cloud microphysical properties, phase partitioning, and evolution is lacking.
- Arctic aerosol properties are different from those at lower latitudes so representation of microphysical properties of CCN is deficient.

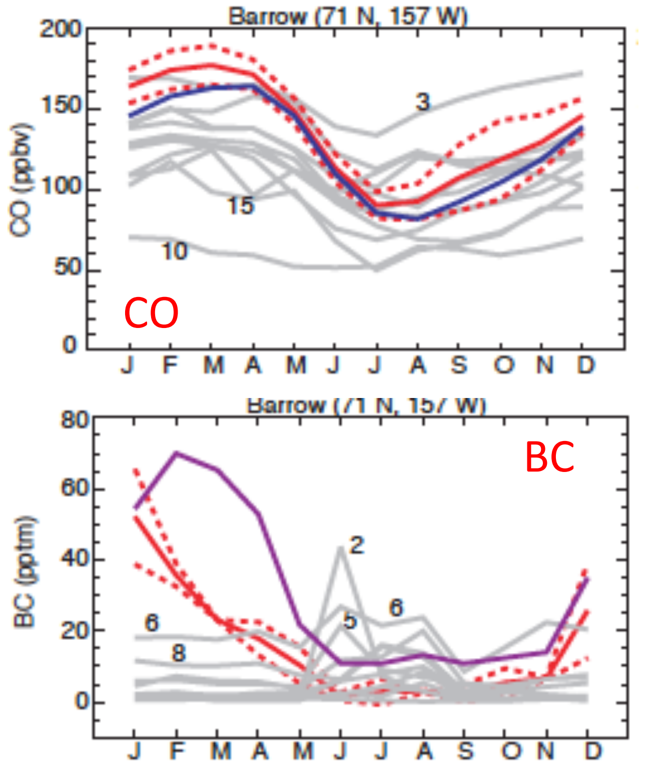
Development of *cloud microphysics parameterizations* to model super-cooled liquid, mixed-phase and ice clouds in GCMs is a priority.

Because of the many known gaps in our knowledge of cloud processes, *comprehensive field experiment case studies* are required to evaluate simulation fidelity.

(2) Predictive Models – Status and Gaps – part (i)

Clouds, Aerosols, Radiation, Boundary Layers

Seasonal cycle of CO and BC



Shindell et al. ACP 2008

- 17 models
- Observations (CO: 1992-2006; BC 1996-1998)
- Std. dev. of obs
- CO obs, 2001
- BC obs, 1989-2003

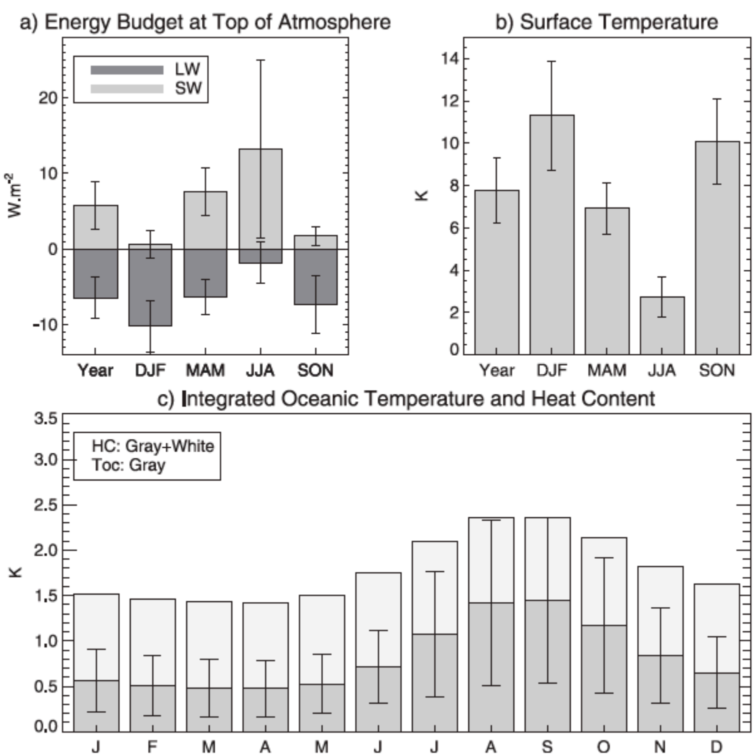
- Models struggle to reproduce the observed aerosol seasonality at least in part because of deficiency in wet scavenging.
- Removal of Black Carbon (BC) in ice clouds and mixed-phase clouds is more uncertain than in liquid clouds
- Over-estimate of low clouds leads to underestimate of BC and other aerosols, impacting surface albedo.
- Transport of pollutants from lower latitudes during winter, including aerosol type, needs to be quantified.

A field campaign targeting aerosol wet removal by super-cooled liquid, mixed-phase and ice clouds, along with *analysis of CloudSat, CALIPSO and other A-train observations*, would increase understanding of aerosol transport to the Arctic from lower latitudes and deposition onto snow and ice within the Arctic, and help improve the representation of these processes in global models.

(2) Predictive Models – Status and Gaps

Clouds, Aerosols, Radiation, Boundary Layers

Changes in the Arctic from 13 AR4 models
2150-2199 minus 1900-1949
Boé et al. J. Climate 2009



- Downwelling LW radiation is still poorly known over both land and ocean, especially in winter.
- Models overestimate surface absorption of solar radiation partly due to problems in the parameterizations of atmospheric absorption, clouds and aerosols.
- Direct comparisons with satellite data (through simulators) show that modelled clouds have radiatively-compensating biases.

The DOE ARM observations should be extended, with an emphasis on getting better observations of cloud ice properties and their effects on the radiation budget.

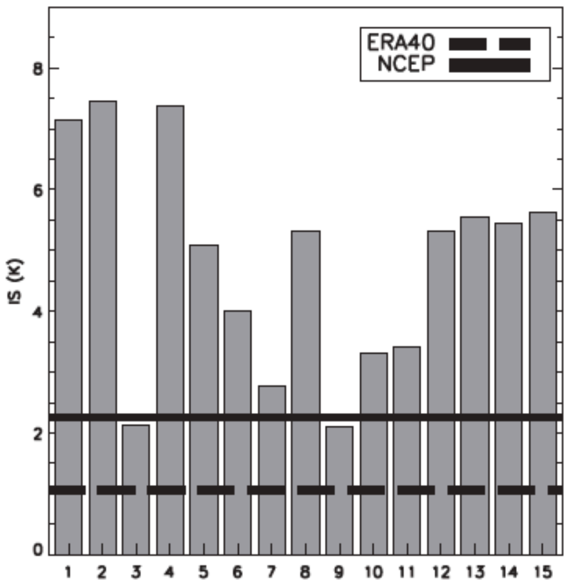
A long-term follow-on to SHEBA – like the proposed MOSAiC – should be conducted with 21st century observing capabilities that sample many different environments under clean and polluted situations, providing insights into the larger-scale controls on cloud properties. Satellite remote sensing will be an important component.

(2) Predictive Models – Status and Gaps

Clouds, Aerosols, Radiation, Boundary Layers

Climatological inversion strength ($T_{850} - T_{1000}$)
for the Arctic (> 70N), 1960-1999
from reanalyses and CMIP3 models

Boé et al., J. Clim 2009



Accurate representation of boundary layers is important for physical climate feedbacks and for trace gas fluxes and transport.

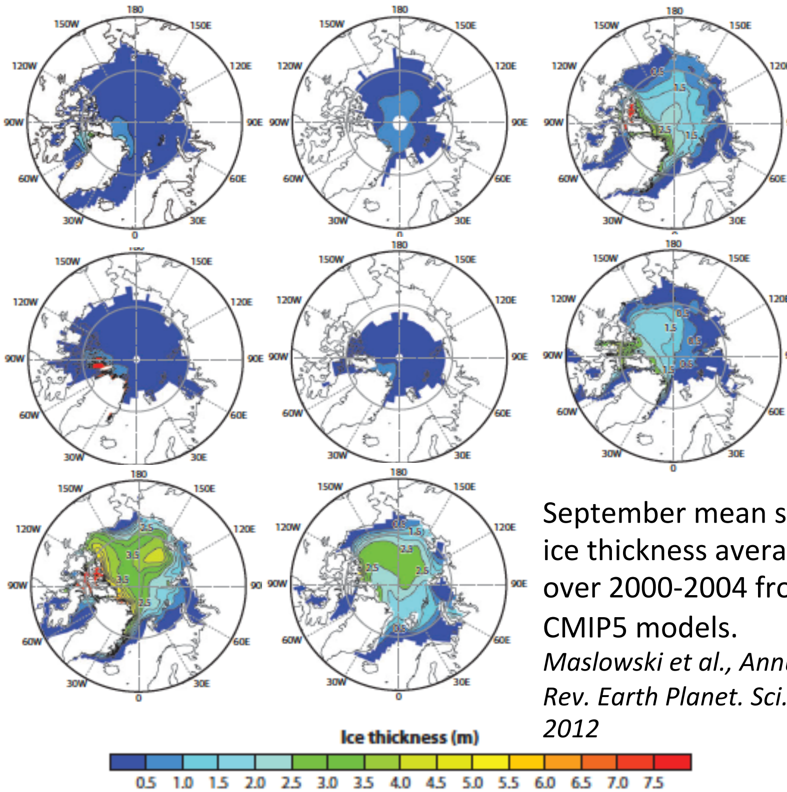
- Models over predict atmospheric inversion strength; some models exaggerate stable and underestimate unstable regimes.
- In recent models, surface inversions are too strong (by nearly a factor of two) and too numerous.
- Models overestimate stable PBL height.

A priority for future model development should be to improve boundary layers in the highly stratified Arctic.

In-situ measurements of PBL height (e.g., using LIDAR) over an expanded area are needed to compare with models. Raman LIDAR for moisture profiles should be added to any backscatter lidar measurements.

(2) Predictive Models – Status and Gaps

Ocean and Sea Ice – PCS



September mean sea-ice thickness averaged over 2000-2004 from CMIP5 models. *Maslowski et al., Annu. Rev. Earth Planet. Sci. 2012*

- Some model simulations have unrealistic sea-ice thickness, some unrealistic extent.
- Realistic sea-ice thickness is a challenge because of inadequate representation of air-ice and ocean-ice interactions.
- Atmospheric biases have huge impacts on modeled ocean circulation and sea-ice distribution which in turn impact simulations of the terrestrial environment.
- Ocean models need higher resolution and improvements in near-surface processes (air-sea interaction and mixing).

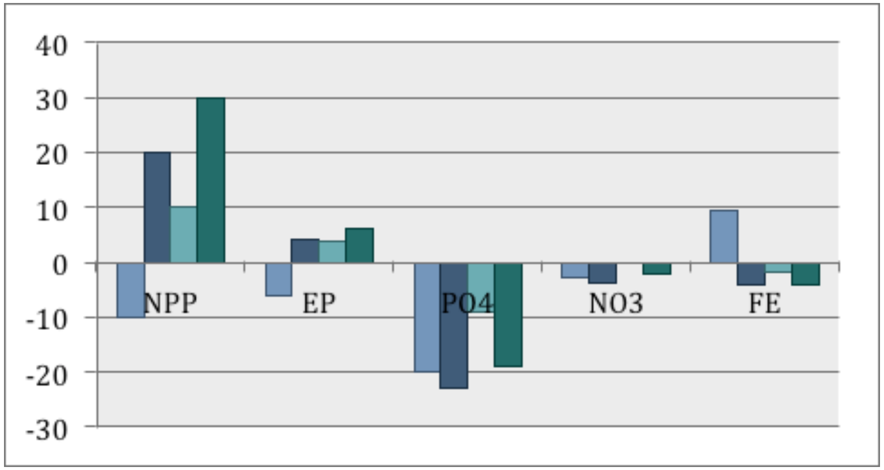
Research with remote-sensing observations and a SHEBA follow-on campaign are needed to improve model parameterizations and support model evaluations. Detailed analyses of changes in sea ice thickness and volume are needed to determine the actual rate of melt of Arctic sea ice.

Model development should emphasize getting the right distribution of sea ice that survives the summer and of multi-year ice.

A field campaign focused on the Beaufort Sea would address: What are the processes involved in melting sea-ice and controlling ocean stratification in the western Arctic?

(2) Predictive Models – Status and Gaps

Ocean and Sea Ice – BGC



Long-term trends (2090-2099 minus 1860-1869) of NPP, EP and related properties in the Arctic as projected by four models in Steinacher et al. (Biogeosciences, 2010).
PP and EP: mg C $m^{-2}day^{-1}$; PO_4: 10 μ mol/m^3; NO_3: mmol/m^3; Fe: 10 nmol m^{-3}.

- Models disagree on which factor, light or nutrient supply, controls present-day Arctic productivity.
- ESMs disagree on projected NPP and related properties.
- Better simulation of marine BGC needs better ocean and atmospheric models.
- Current knowledge of Arctic Ocean ecosystems is limited by undersampling; existing observations are very sparse and biased toward summer.

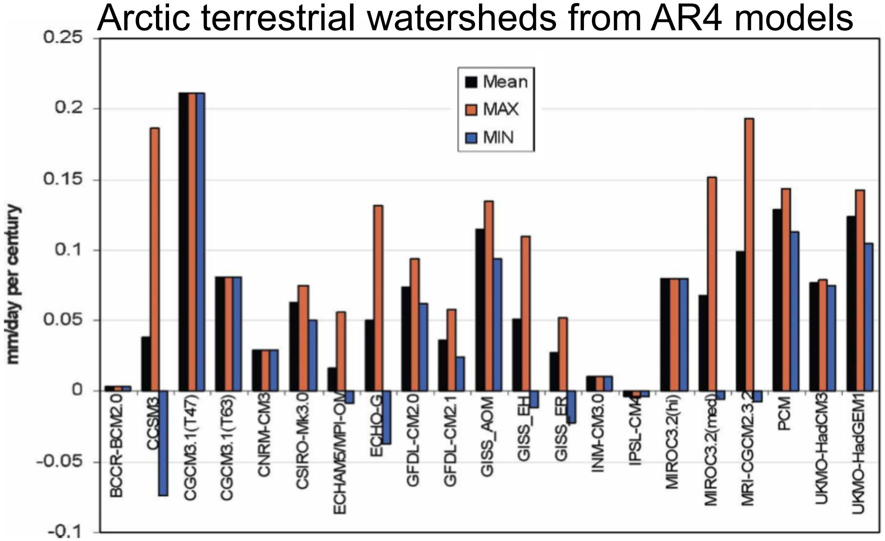
Year-round time series measurements of biological and chemical concentrations, parameters, and distributions, such as for biomass, nutrient concentrations, and biological rates are needed.

Observational networks and multi-scale field observations should be coordinated with complementary modeling to facilitate *sampling over a broad range of scales and upscaling information from fine-scale observations to global-scale ESMs*.

(2) Predictive Models – Status and Gaps

Land Surface – Climatology and Hydrology

P-E trends (mm/day/century) for 1965-1999 over Arctic terrestrial watersheds from AR4 models



Kattsov et al., J. Hydromet 2007

- Model hydrological biases are related to surface spatial variability/complexity and biases in large-scale atmospheric circulation and sea ice distribution.
- Development of improved parameterized relationships between the unresolved spatial variability of snow and available diagnostic variables is hindered by the lack adequate surface observations.
- Evaluation of model simulations of Arctic hydrologic variables is hindered by uncertainties in observations.

An assessment of surface energy budgets of Arctic and Boreal ecosystems – what is done well and what is done poorly in ESMs, and why – is needed.

Comprehensive evaluations of surface moisture fluxes, both simulated and observed, are needed.

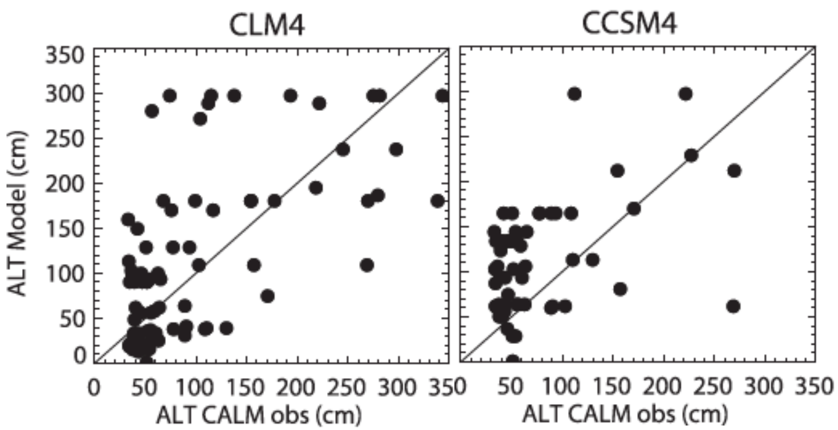
More work is needed to retrieve *snow water equivalent and surface albedo from satellite data.*

More basic research with in-situ measurements targeted towards *improvement of macroscale model algorithms is needed.*

(2) Predictive Models – Status and Gaps

Land Surface – Climatology and Hydrology

Active layer thickness for CALM sites vs model for CLM4 and CCSM4.
Model: ensemble mean climatology 1980–99



Lawrence et al, J. Climate. 2012

- CMIP5 ESMs differ widely in representation of direct thermodynamic freezing processes for permafrost.
- Comparisons of model predictions of permafrost-related variables like active layer depth with observations show large scatter.
- Current permafrost models do not incorporate local subgrid disturbances such as thermokarst.

Model development is needed to improve simulation of permafrost spatial variability.

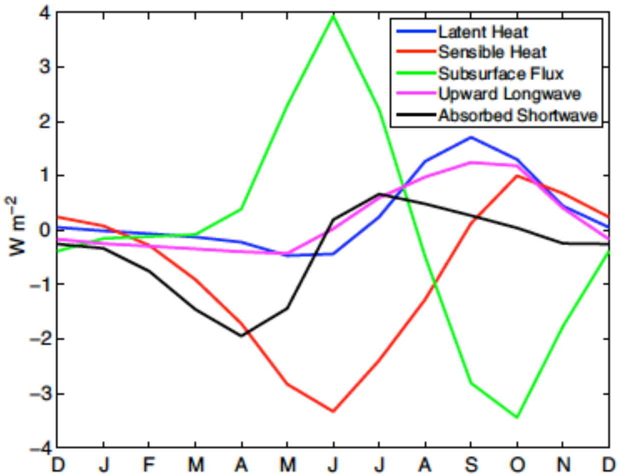
Baseline measurements should be established for longer-term monitoring of settling due to permafrost ice loss and thermokarst as a way of detecting changes to permafrost.

Airborne or remote sensing observations will be critical for upscaling of permafrost properties from point measurements to regional scales.

(2) Predictive Models – Status and Gaps

Land Surface – Climatology and Hydrology

Surface flux anomalies
CLM4 using GLWD* minus default lake configuration
Offline simulation



*Global Lake and Wetland Database

Subin et al., Tellus A 2012

- ESM representation of lakes needs to be refined. Observations are not available for testing simple approaches to capturing the fluxes of GHGs from lakes.
- There are uncertainties in riverine fluxes which are important to land-ocean BGC fluxes.
- 1-D treatment of processes in many LSMs is insufficient for redistribution of water and energy across landscapes.
- A more sophisticated representation of covariances in sub-grid heterogeneity (vegetation, hydrology, and thermal regimes) might be needed.

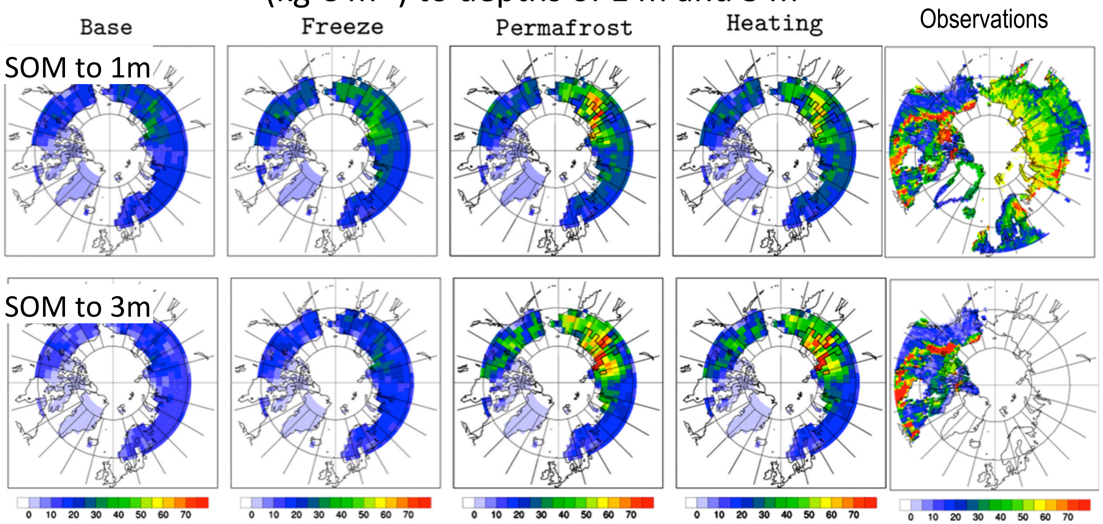
Gravity remote sensing (e.g., GRACE) should be used to detect *macroscale changes in lake storage and river runoff* and help *validate PCS models*. A critical focus should be testing parameterizations in ESMs.

Surface energy budget calculations based on statistical representations of the land surface variability – best obtained from remotely-sensed data – must be rigorously evaluated at regional (10 – 1000 km) scales as well as at the scale of individual process study sites (10 m – 10 km).

(2) Predictive Models – Status and Gaps

Land Surface BGC – Soils

Soil model sensitivity experiments: initial soil carbon (kg C m^{-2}) to depths of 1 m and 3 m



Koven et al., PNAS 2011

BGC soil models in ESMs fail to represent

- Steep vertical gradients, with low decomposition in permafrost, leads to buildup of deep labile material.
- Organic layers, which build up in saturated and/or cold soils and contain large amounts of carbon that could be mineralized or combusted.
- Anoxic decomposition and the production/consumption of CH_4, NO_2.
- Microbial dynamics, which might be important in places with very dynamic changes in soil microenvironment.

Priority should be given to *mapping permafrost and soil properties across the ABZ* using satellite data and in-situ data sets, with a significant effort to *correlate soil, vegetation and hydrological attributes to remotely-sensed data* using sophisticated soil-vegetation models.

To *credibly account for scaling effects*, a key aspect of *field campaigns* will be to use observations gathered over a range of spatial scales – surface site, airborne sensors and satellite sensors.

(2) Predictive Models – Status and Gaps

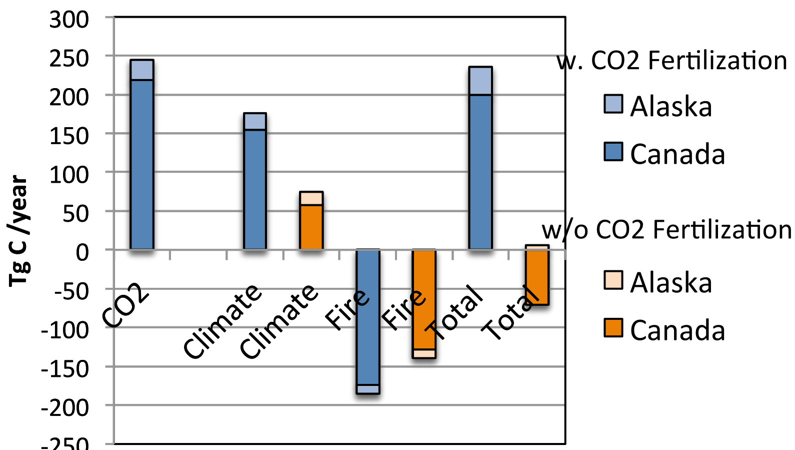
Land Surface BGC – Disturbance

Drought, warming, pests, fire

Mean annual changes in carbon storage for N. America from 2003 to 2100 driven by SRES A2

TEM forced by output by Canadian GCM

Positive values indicate carbon sequestration



Balshi et al., Glob. Ch. Biol. 2009

- Disturbances are stochastic by nature. The range of predicted outcomes is huge.
- Subgrid-scale processes related to all disturbances need to be integrated with macro-scale models.
- The challenge is to upscale these relationships to the continental scale of ESMs.
- A coupled mechanistic climate-vegetation-fire frequency relationship might not be needed in the ESM itself. ESMs could generate output drivers for an ensemble of disturbance/BGC models to be run offline to get a statistics of model outcomes.

Better remote sensing methods are needed to map disturbance. *Better records of past disturbance are needed* – perhaps from the Landsat record – particularly for northern Eurasia.

Disturbance severity needs to be represented in LSM-BGC models. Temporal and spatial scaling of these non-linear disturbance effects on carbon, energy and water is a high priority and would benefit from *coordinated and focused field experiments*.

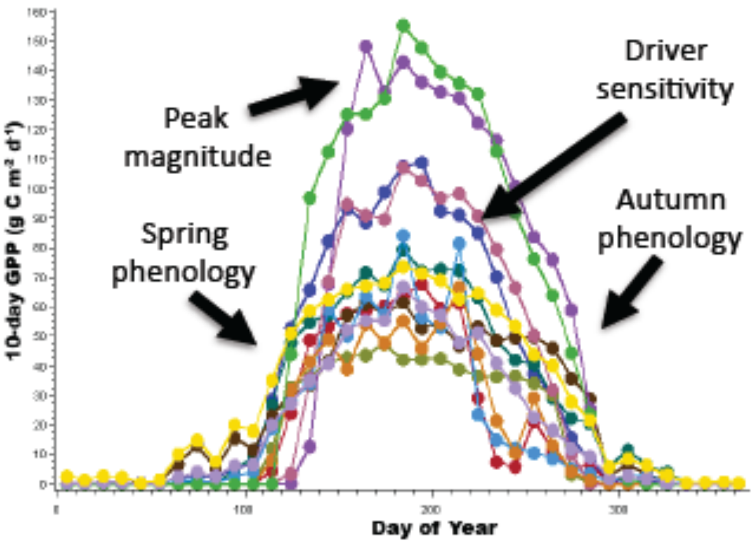
Further research is needed to *determine how variations in vegetation cover, fuel amounts and fuel conditions influence fire occurrence* so that these effects can be included in ESMs.

(2) Predictive Models – Status and Gaps

Land Surface BGC – Ecosystem Dynamics

The 10-day GPP (g C m^{-2} day^{-1}) for deciduous broadleaf forest at the Old Aspen Site in Canada from 14 ecosystem models participating in MsTMIP

Richardson et al., AGU 2010



- There is huge uncertainty in predicted surface atmospheric CO_2 and CH_4 fluxes.
- None of the models included in the Multi-scale Synthesis and Terrestrial Model Intercomparison Project (MsTMIP) matched estimated GPP within observational uncertainty.
- Better phenological models are needed since models show large biases during transition periods and large differences in peak magnitudes of GPP.
- Sub-grid scale processes in DGVMs are important for modeling species migration and succession after disturbance.

GPP model improvements require better leaf-to-canopy scaling and better values of model parameters that control the maximum potential GPP (such as light use efficiency).

A better description of the treeline which incorporates gradients of tree canopy density is needed for realistic model representation of the transition between Arctic tundra and the boreal biomes and associated changes in albedo and radiative forcings.

DGVMs need improved treatment of plant diversity and mechanistic treatment of migration and competition among plant types.

(2) Predictive Models – Status and Gaps

Integrated Systems

Observational and model component enhancements are needed to increase understanding of small-scale carbon flux processes and improve the ability of ESMs to integrate, simulate and predict such processes.

Land surface hydrology and carbon cycle

ESMs should have explicitly modeled peatlands and peatland hydrology along with soil freezing and thawing and permafrost dynamics.

Thermokarst and other disturbances should be integrated into permafrost models to better quantify and predict the impact of disturbances on high-latitude SOC pools.

To facilitate ESM evaluation and improvements, improved characterization and reduced uncertainty in ABZ physical (e.g., permafrost distribution) and biogeochemical (e.g., carbon in peatlands) properties are needed. In-situ measurements of riverine chemistry could contribute to BGC model validation.

Observations are needed to test the ability of the simple approaches used to represent lakes and wetlands in ESMs to capture the fluxes of greenhouse gases accurately.

Marine processes, land-ocean exchanges and carbon cycle

Models need to represent sea-ice distributions better and include more complete treatments of ocean ecosystems, micronutrient limitation, and ocean acidification impacts on the calcium carbonate cycle as well as improvements to sea-ice biology.

Measurement of riverine fluxes is important to evaluate the model estimates of land-ocean BGC fluxes.

(2) Predictive Models – Status and Gaps

Integrated Systems

Trace gas concentrations and fluxes

Improved characterization of ABZ CO_2 and CH_4 fluxes require improvements in (i) trace gas concentration and flux measurements through a combination of ground-based, aircraft, and satellite observations, and (ii) our understanding of local scale processes.

An expansion of existing ground-based networks is necessary to characterize changes in the regional carbon budget on longer timescales. Aircraft field campaigns are essential for validating satellite observations and providing information on spatial variability during periods without satellite CO_2 and CH_4 observations.

Priority model developments include better characterization of model transport error in the ABZ, and development and evaluation of improved up- and downscaling techniques appropriate for the region.

Inverse modeling, upscaling and downscaling methodologies

Forward and inverse modeling approaches should be refined to improve estimates, including uncertainties, in CO_2 and CH_4 fluxes.

A combination of flux towers, flux aircraft and remote sensing data collection and validation efforts should all be used to address the scale gap between the in-situ process studies and the ESM scales.

The network of atmospheric CO_2 and CH_4 concentration measurements should be expanded, using 4DDA and OSSEs to determine the optimal deployment pattern and schedule for inversion studies.

(2) Predictive Models – Status and Gaps

Integrated Systems, carbon cycle and scaling methodologies

Four interlocking techniques can be applied:

- Inverse modeling techniques
- Upscaling methods
- Forward model scaling approach
- Downscaling techniques

Domains and Sites

<u>Atmospheric Sampling Sites</u>

- TCCON – active
- TCCON – inactive
- ESRL Observatories
- AERONET

<u>Heritage Field Sites</u>

- BOREAS and BERMS
- ABLE

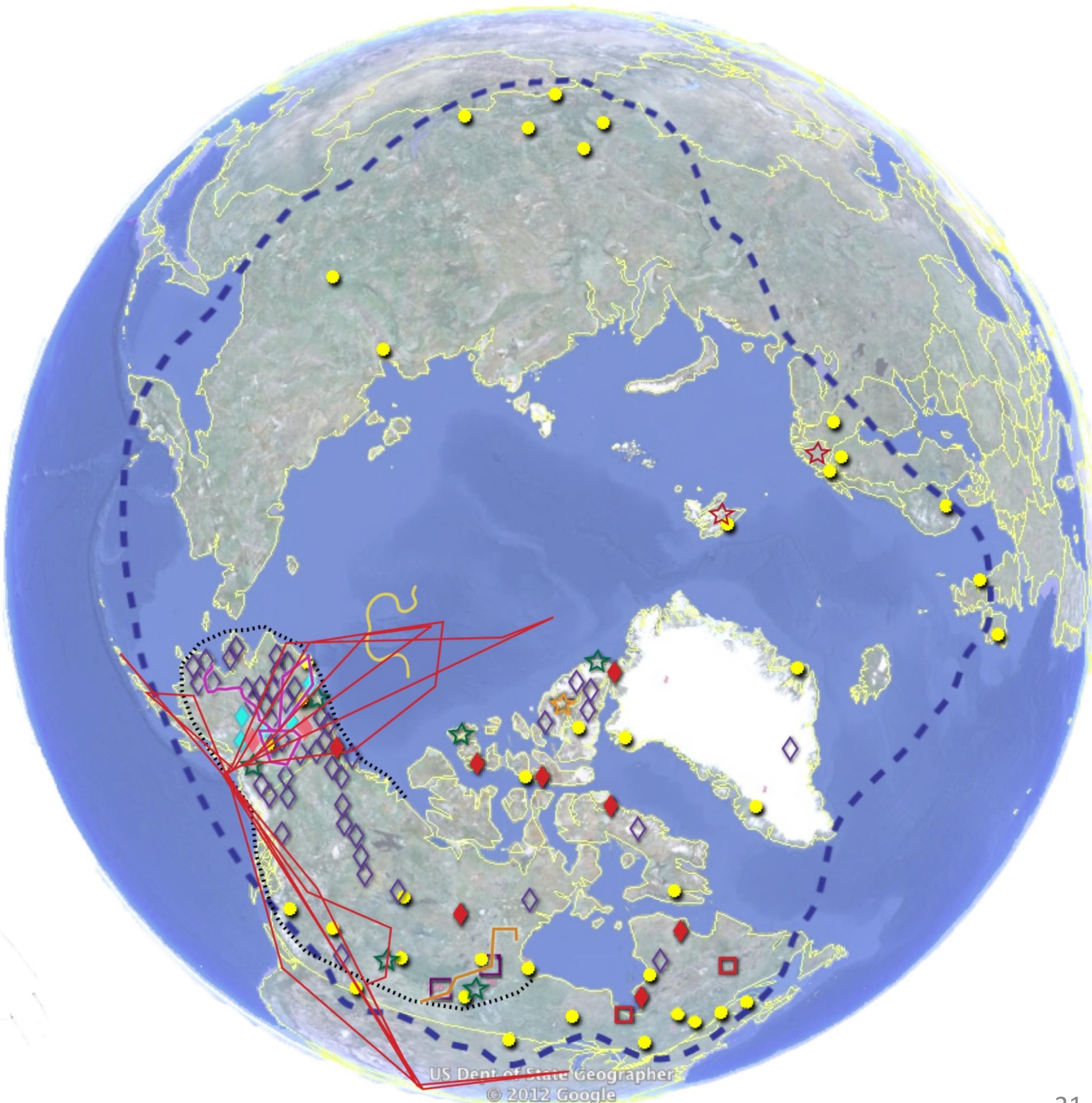
<u>Active Field Sites</u>

- LTER
- NGEE
- ADAPT
- CALM
- NEON

<u>Airborne Concentration & Flux Sampling</u>

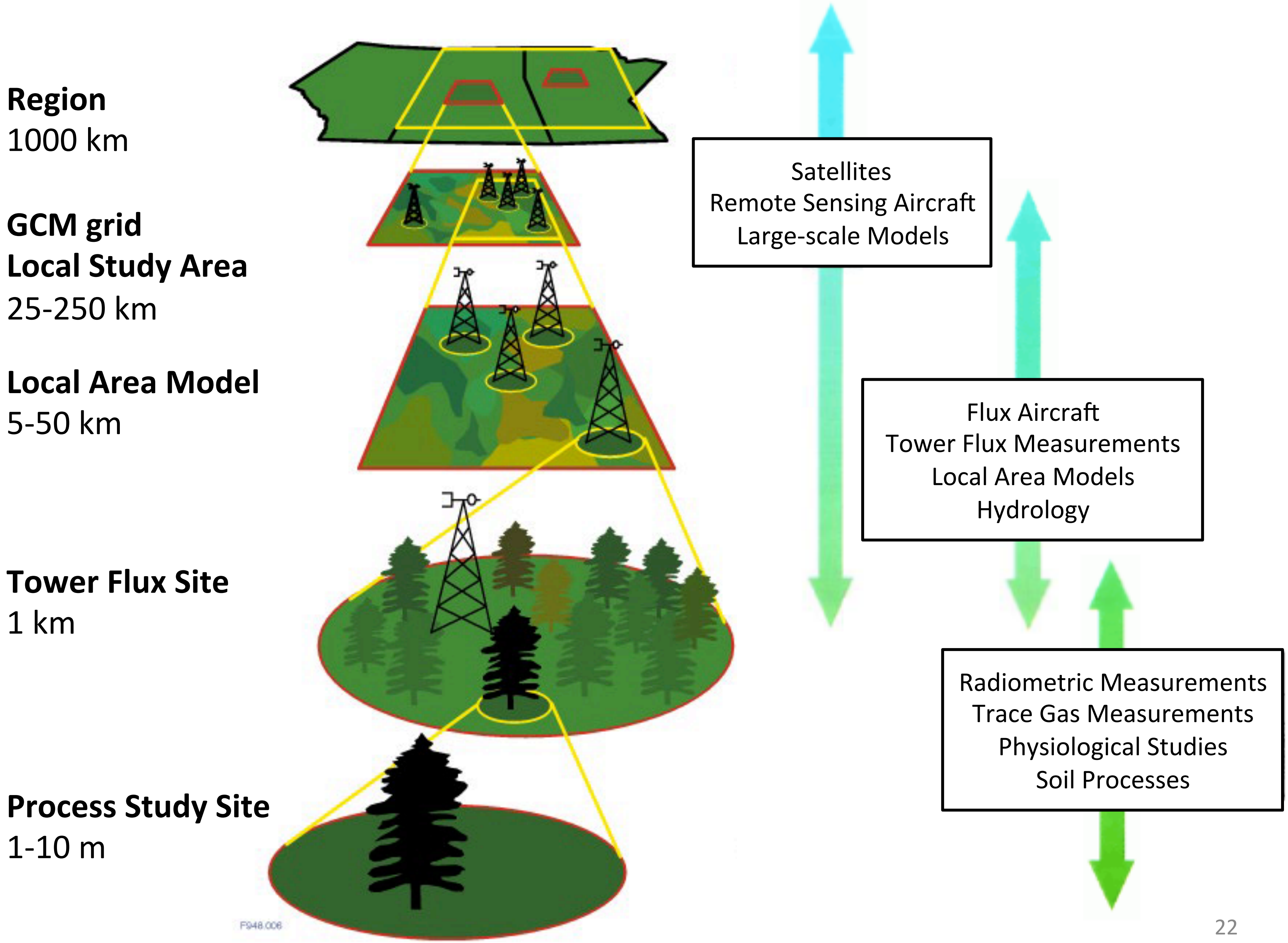
<u>Possible ABoVE Domain</u>

<u>ABZ extent</u>

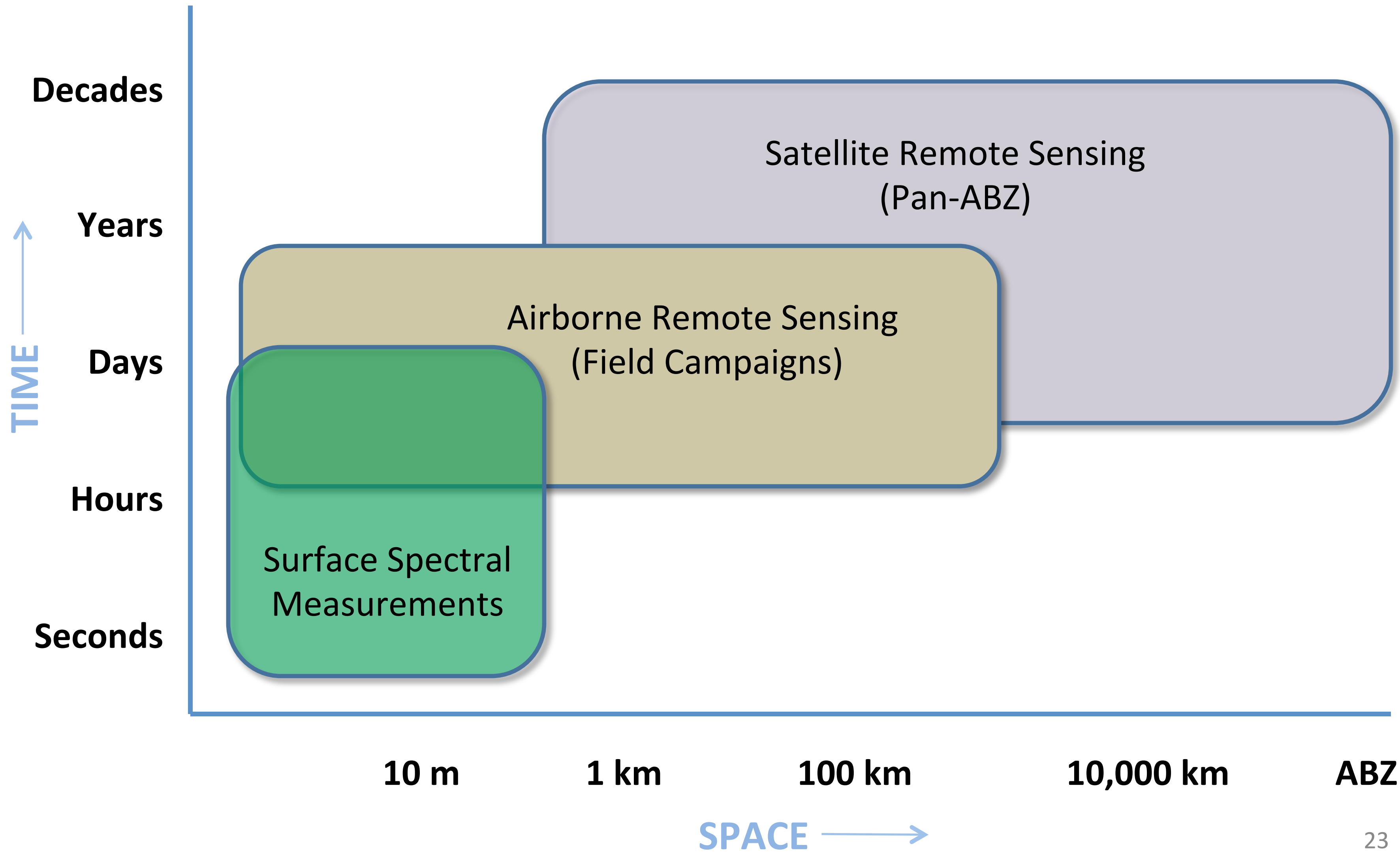


Artwork: Beth Nelson, NASA Carbon Cycle & Ecosystems Office

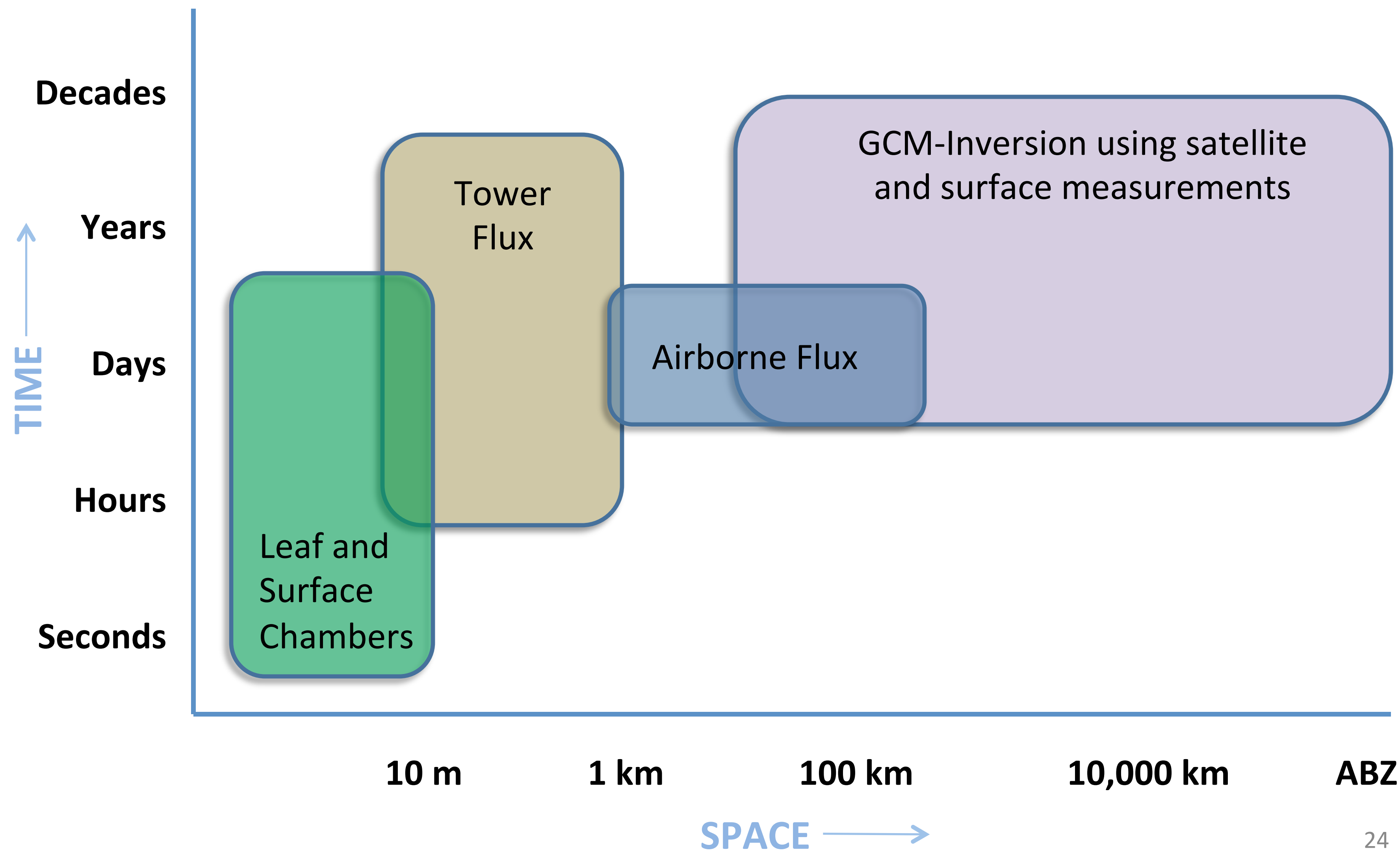
Classical Field Experiment Scaling Approach



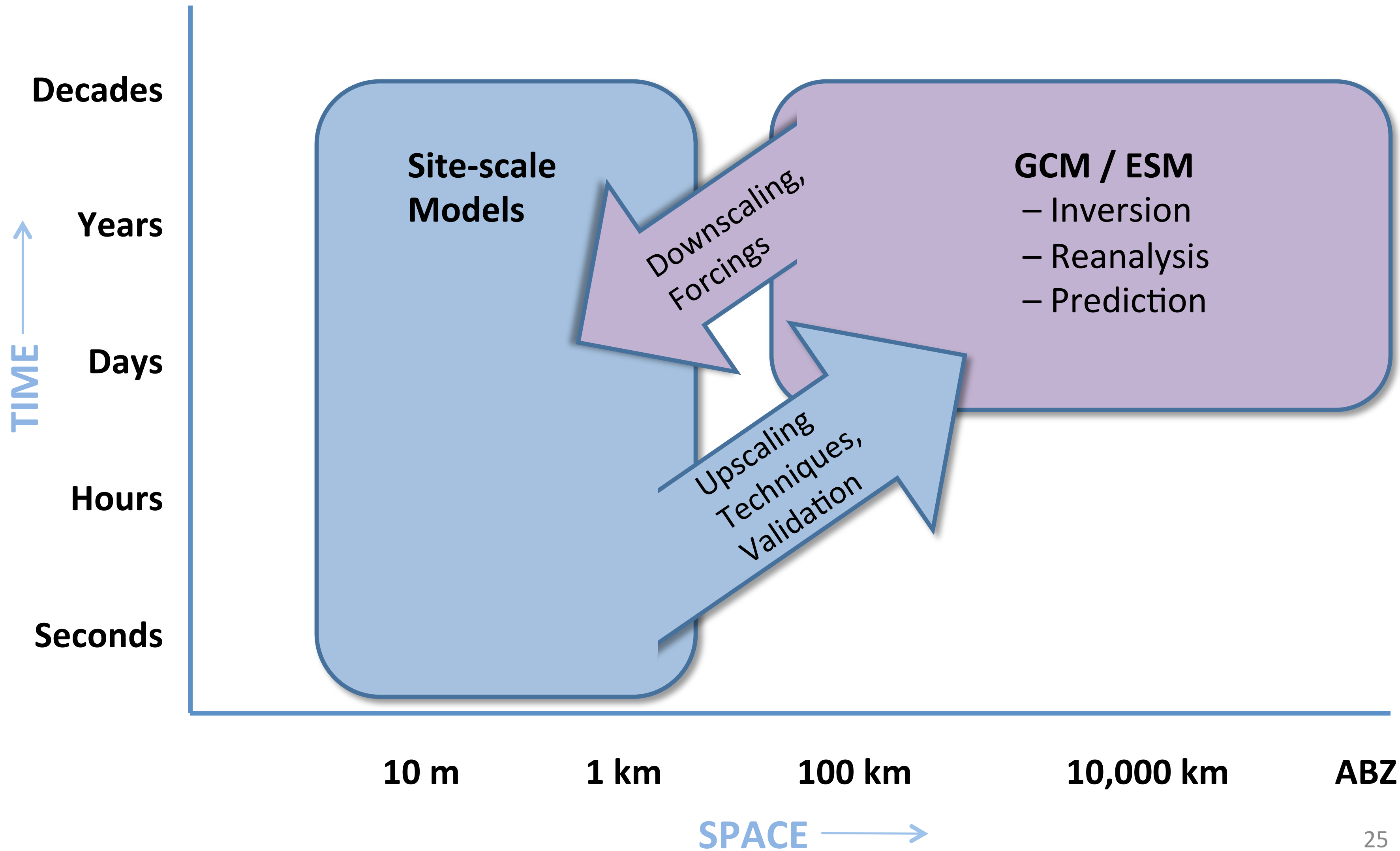
Upscaling and Downscaling Remote Sensing



Upscaling and Downscaling
H_2O, CO_2, CH_4, Surface Flux Estimation



Upscaling and Downscaling Modeling



(3) Key Questions to be addressed

1. ***Clouds, radiation and aerosols***: Are the observed seasonal changes of Arctic clouds primarily determined by the large-scale circulation or do microphysical and surface processes play a key role? What is the role of downwelling infrared radiation in the surface energy budget of the Arctic Ocean in winter? How does aerosol forcing affect the Arctic climate, and how will aerosol loadings change as a result of changes in land-use, industrial emission, desertification, and fire?
2. ***Ocean circulation and sea ice***: What are the processes involved in melting the sea ice and controlling ocean stratification in the Beaufort Sea?
3. ***Integrated systems, land surface hydrology, and carbon cycle***: What are the linkages between land surface hydrology, vegetation changes and the surface energy budget over the ABZ and how will these influence the evolving climate? How, and how rapidly, is the ocean-land interface changing in the ABZ?
4. ***Carbon balance***: How rapidly, in which direction, and by how much will warming and changing precipitation modify the ABZ net carbon balance, and will the impact on net CO_2 exchange be smaller or larger than the impact on net CH_4 exchange?

(4) Proposed Field Experiments and Studies

Atmosphere: Clouds, Aerosols, Radiation		
DOE/ARM	Facilities: Barrow, Atqasuk; Barrow Black Carbon Source and Impact Study, 2012/13	*Analyze existing data (CCN, IN) **Establish more sites; Spring aircraft campaign, include aerosol wet removal.
ICECAPS (NSF AON)	Field campaign: Summit	
AERONET/AEROCAN	19 sites across Canada	Augment network in ABZ.
CALIPSO, CloudSAT, MISR, MODIS	Cloud and aerosol profiles; column-integrated AOD	Conduct analyses related to ABZ.
Model Development		***Development of cloud microphysics parameterizations to represent super-cooled liquid, mixed-phase and ice clouds, and of cloud-aerosol interactions at the microphysical level. Improve representation of PBL.

*Proposed supplements to existing/planned activities

**Proposed new activities

***Activities that can proceed immediately

(4) Proposed Field Experiments and Studies

Atmosphere: CO_2, CH_4		
NOAA ESRL surface observatories	10 sites in ABZ	Augment with new sites; cheaper instrumentation; use 4DDA to position new sites
TCCON	2 sites operational in ABZ	
ABoVE	Remote sensing and field measurements in Northwest	US-Canadian downscaling effort. Evaluate requirements for US airborne flux measurements.
CARVE (2012-2015)	Airborne mission	Augment coverage/duration; assess adding airborne flux measurements to follow-on.
AIRS, IASI, MLS, GOSAT, OCO-2	With 4DDA, gives transport into ABZ	Use 4DDA for future mission planning for relevance to ABZ.
Model Development		Improve representation of PBL. Estimate uncertainty transport for inversion studies.

(4) Proposed Field Experiments and Studies

Land Surface: Permafrost and thermokarst scaling studies		
NGEE Phase 1	North Slope and Seward Pen.; field obs/lab/modeling	Augment upscaling approach with flux aircraft and remote rensing
ABoVE	Field campaign: northwest	Extend domain; incorporate heritage sites and scaling studies
NSF AON	>300 sites: active layer thickness	Data analysis
ADAPT (2011-2015)	Sites across N. Canada: impact of permafrost thaw	
Model Development		Improve permafrost models by integrating thermokarst and other disturbance processes.

(4) Proposed Field Experiments and Studies

Land Surface: Hydrology		
DOE ARM	Barrow Webcam for ITEX, Sept 2009-Aug 2012	Data analysis
ABoVE	Field and tower flux measurements; water chemistry	Upscale with remote sensing and flux aircraft measurements.
Satellite-retrieved snow products (MODIS)	Snow cover; SWE Products available from NSIDC	Upscale snow characteristics. Develop better estimates of SWE.
GRACE; SWOT SMAP (2014)	Ground water Soil moisture, freeze/thaw state	Derive parameterizations of permafrost spatial variability.
Model Development		Include inundation of surface lakes/ wetlands/floodplain. Improve representation of lakes. Improve macroscale land surface model representations of energy, water, and snow processes.
Product Development		Characterization of fresh snow density.

(4) Proposed Field Experiments and Studies

Land Surface: Biogeochemistry		
NGEE Phase 1	Assess process modeling structured by geomorphology	Upscale, high-resolution as function of plant type. Extend NGEE efforts if results support NGEE hypothesis.
ABoVE	LIDAR and SAR: disturbance impact Field campaign: response to permafrost & surface hydrology changes Regional soil mapping RS to link local SOC and other params.	Couple to pan-ABZ Remote Sensing effort.
Heritage sites	BOREAS, BERMS, ABLE-3A, ABLE -3B: previous field campaigns in Canada and Alaska	Revisit using flux tower and airborne flux measurements; assess changes since previous studies; add new sites. Derive process for temporal and spatial scaling of disturbance effects on carbon, water, and energy.
Model Development		Improve treatment of plant diversity and migration and competition among plant types; treeline; and phenology.
Product Development		Improve vegetation data sets; map of soil properties; change & disturbance mapping; records of past disturbance.

(4) Proposed Field Experiments and Studies

Ocean & Sea Ice		
SHEBA (1997-1998)	Concurrent measurement of the atmosphere, sea ice and upper ocean, including air-ice, ice-ocean, and air-ocean fluxes.	Contribute to MOSAiC, particularly with observations focused on the Western Arctic.
MOSAiC (~ 2017) (Proposed follow-up to SHEBA)	Manned, drifting observatory of atmospheric, oceanic, and sea-ice properties over 1-2-years. Expand with network of buoys, UAVs, AUVs, ships, aircraft, & RS	Coordinate multi-scale ecosystem observations with complementary modeling to facilitate upscaling information from small-scale observations.
Satellite-derived sea-ice extent (AMSR-E; SSMI/S)	Products available from NSIDC.	4DDA products for integrated view of variations and surface flux estimates.
CryoSAT-2, IceSAT-2 (2016)	Satellite-derived sea-ice thickness.	Use IceBridge measurements of opportunity for validation.
Model Development		Improve AGCM: SLP, surface fluxes. Improve ocean boundary layer parameterizations, mixing processes. Investigate modeling sea ice that survives the summer and of MY ice.

(4) Proposed Field Experiments and Studies

Integrated Systems		
Global Rivers Project	Sources, pathways and timescales of riverine export of carbon from land to ocean. Two rivers in Arctic basin.	Extend to rivers in Canadian Basin.
NSF-OPP Soil fluxes (water, C, N…)	Fluxes of water, carbon, nutrients from soils as function of climate and land surface.	Upscale with RS/flux aircraft.
DOE ARM Program	Sea Ice Effect on Arctic Precipitation, 2011-2013: O_2 and H isotopic compositions in precipitation at Barrow and Atqasuk .	Compare with integrative reanalyses.
Model Development		Improve up- and down-scaling techniques. Evaluate errors in inversions.
Product Development		Near-surface hourly weather drivers, at the highest resolution possible, for multiple decades.

(5) Next Steps

These proposed activities have to be considered in the light of activities funded by other agencies and would both leverage those activities and potentially contribute to them.

Develop a phased plan of activities and the required funding profiles:

- *NASA* cross-discipline discussion and planning – how this fits in with and influences priorities of existing ESD programs.
- NASA has the expertise – satellite data, field campaigns, models – to lead formation of a small interdisciplinary, *interagency* team to
  1) Assess current and planned activities in the context of this and other study reports, and
  2) Assess priorities, feasibility and resources required to conduct the recommended activities.

Initiate early activities that are relatively low-cost and can proceed without new observations. These can provide information for planning campaigns and new observational sites, e.g., model and new product development, 4DDA synthesis.

The task before us

Climate change in the ABZ

Probably the key environmental research issue for the next 10-20+ years.

ABZ is the global "Fleet leader" - changing even faster than expected.

Predictive models (ESM's) must perform better to be useful.

Experiments, model development and data analyses must all be integrated and proceed to together to yield improvements.

US and global research activities in the ABZ are not coordinated.

We need a plan, priorities and a framework to get the best results.

We need to organize - internally, inter-agency and internationally (Canada).

NASA has the capability to help set the pace.

Field experiments are high-visibility, useful tools for integration, training, etc..

Resources

This is a global-scale concern. Think big.

It will take a lot of time and a lot of players. We need to plan.

We'll need a lot of resources. We need to organize and persuade.