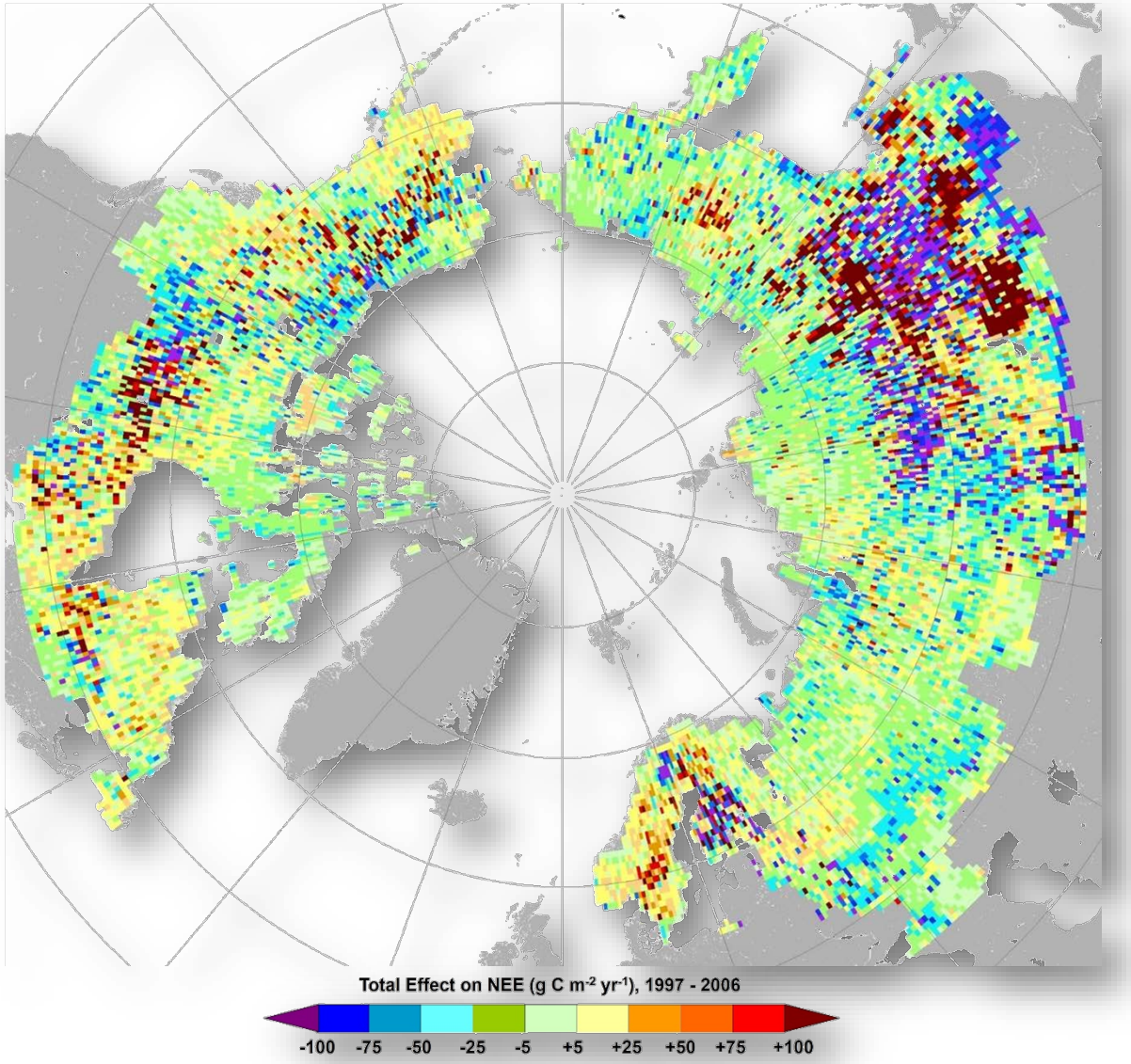
The role of remote sensing in process-based modeling of Arctic ecosystems

14th International Circumpolar Remote Sensing Symposium

Daniel Hayes
13 September 2016
Homer, Alaska



A model-data integration framework for NASA-ABoVE: Simulation, Scaling and Benchmarking for Key Indicators of Arctic-Boreal Ecosystem Dynamics

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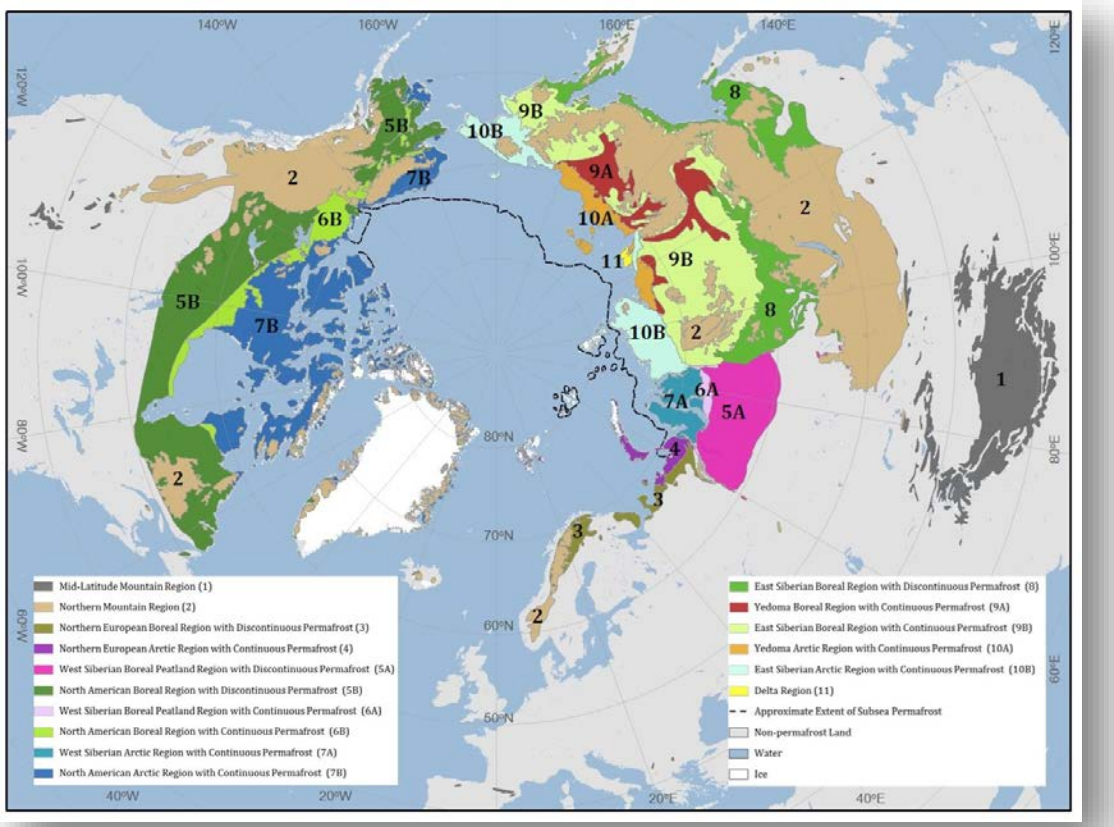
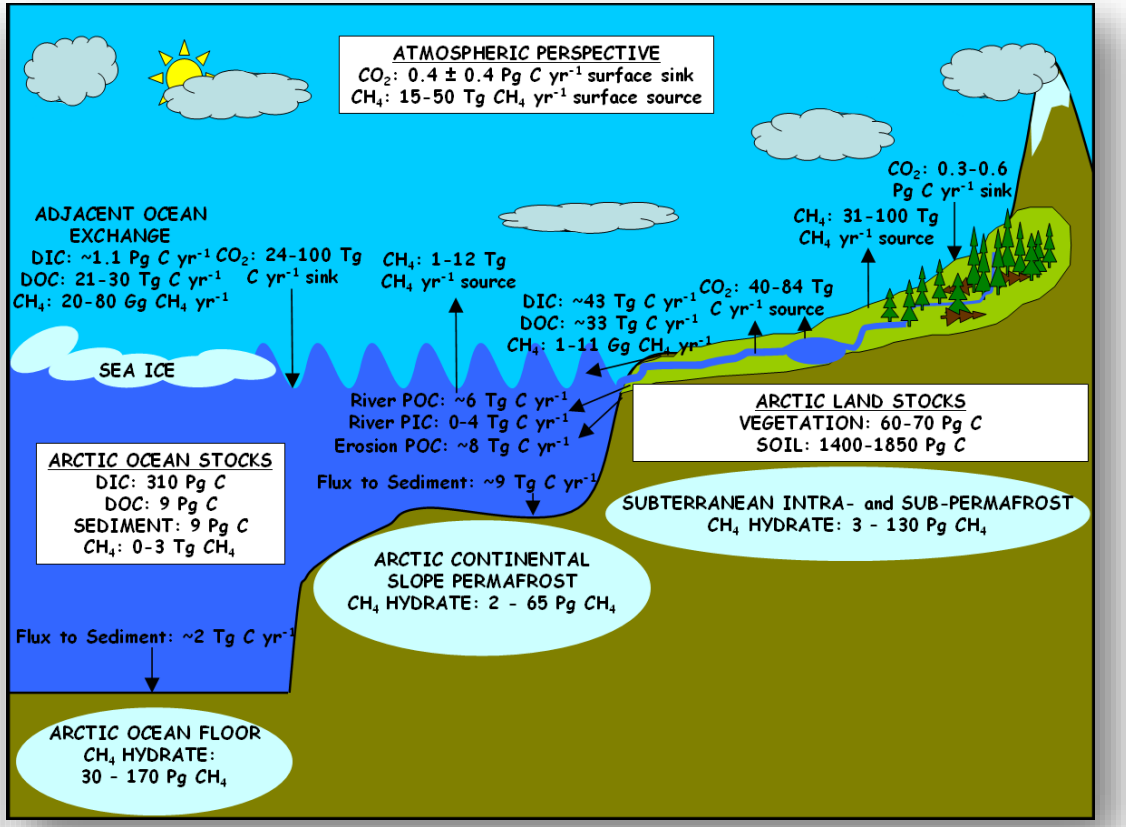
A. David McGuire, USGS / University of Alaska Fairbanks

Vulnerability of Arctic Ecosystems to Climate Change

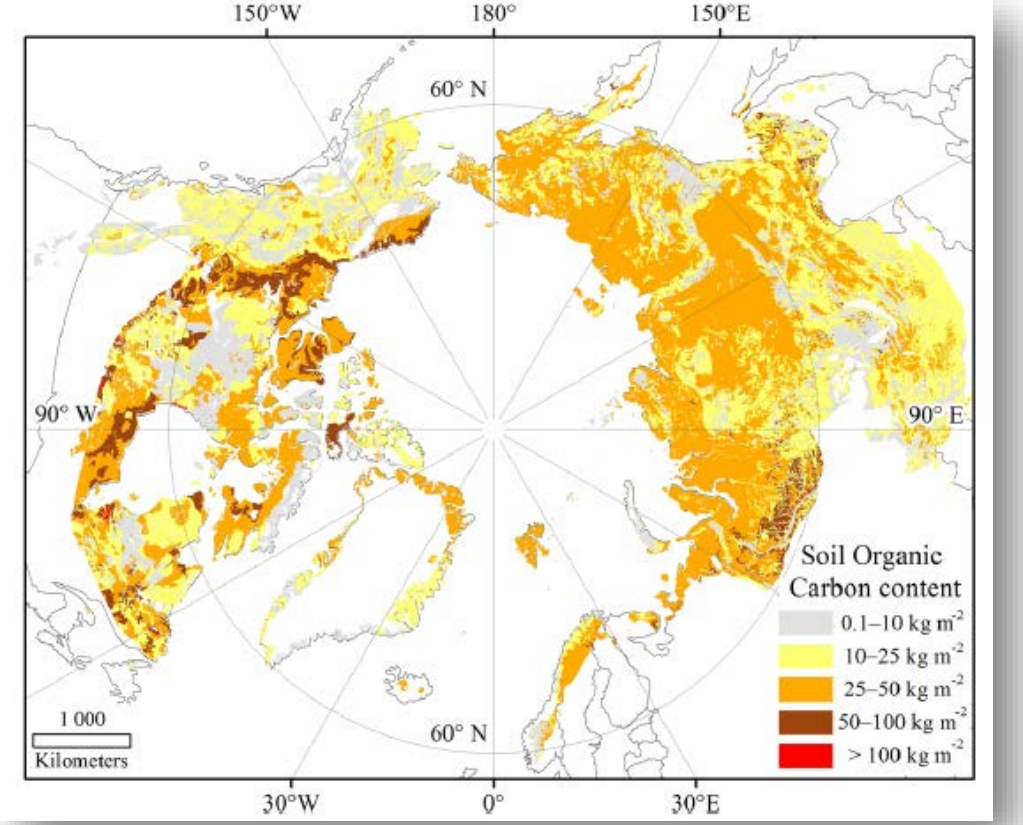


Permafrost Regionalization Map
(PeRM; *permafrostcarbon.org*)

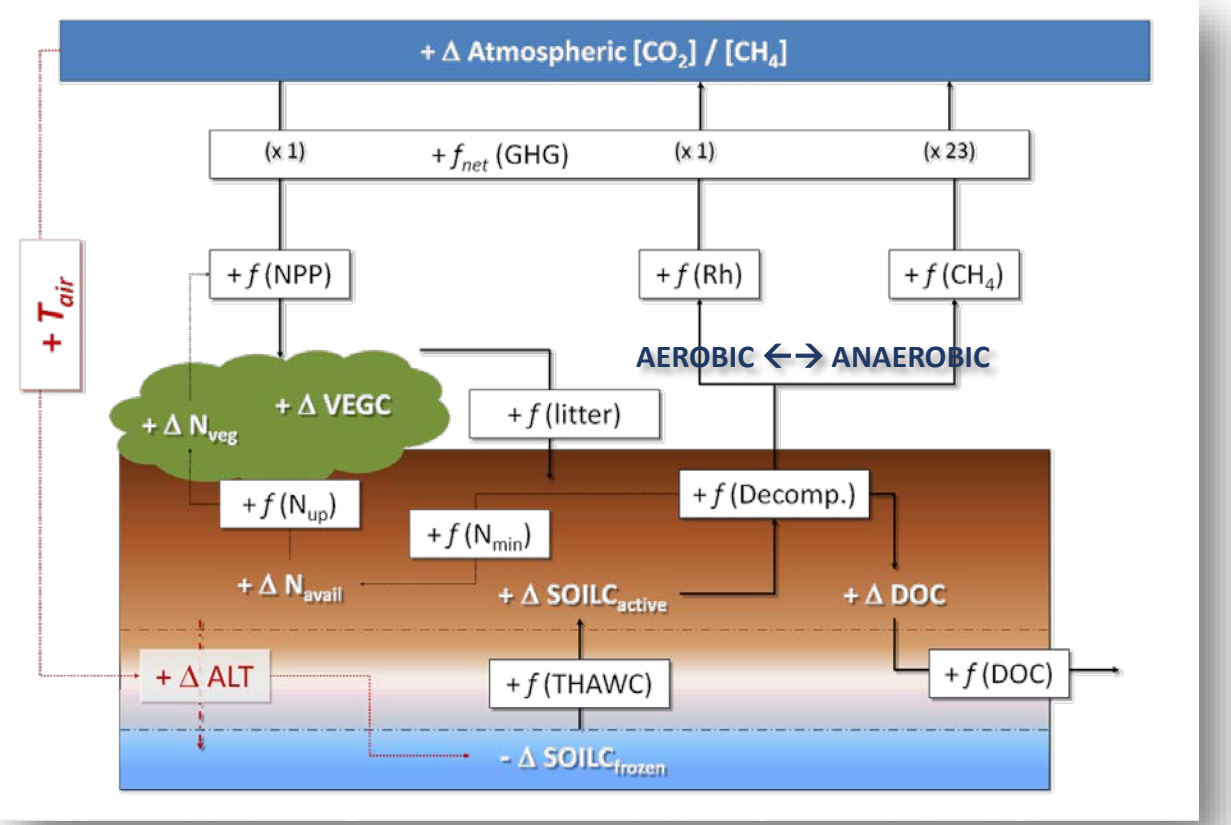


Sensitivity of the Carbon Cycle of the Arctic to Climate Change (McGuire et al. 2009)

Vulnerability of Arctic Ecosystems to Climate Change

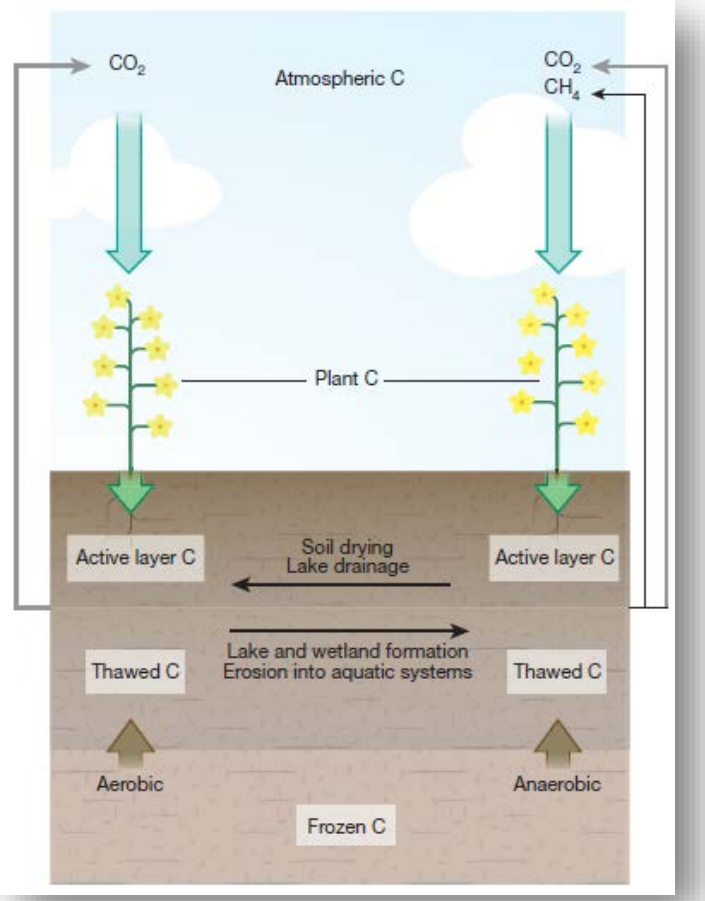


Northern Circumpolar Soil Database (NCSD; Hugelius et al. 2013)

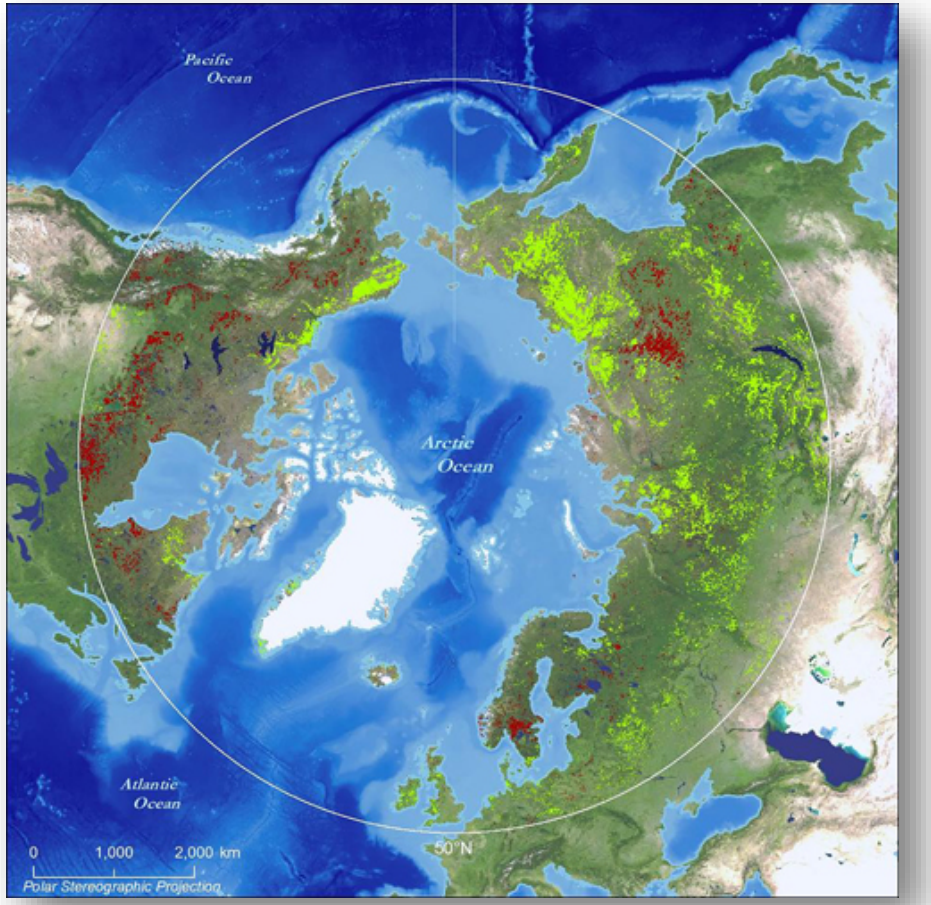


The impacts of permafrost thaw on pan-arctic greenhouse gas exchange (Hayes et al. 2014)

Vulnerability of Arctic Ecosystems to Climate Change

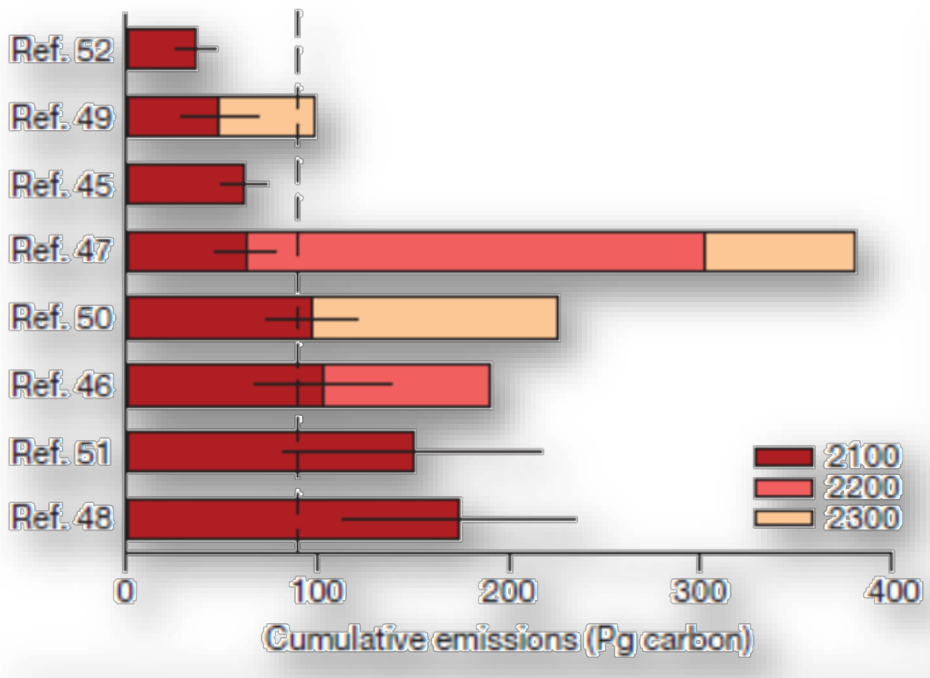


The "Permafrost Carbon Feedback"
(Schuur et al. 2015)



The "Greening of the Arctic"
(Goetz et al. 2007)

Modeling Uncertainty



Modeled estimates of permafrost carbon release (Schuur et al. 2015)

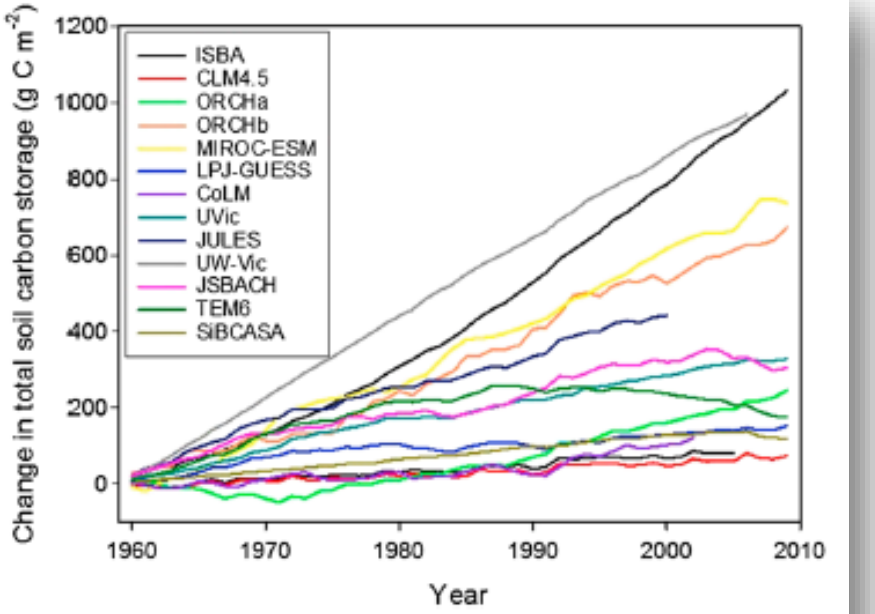
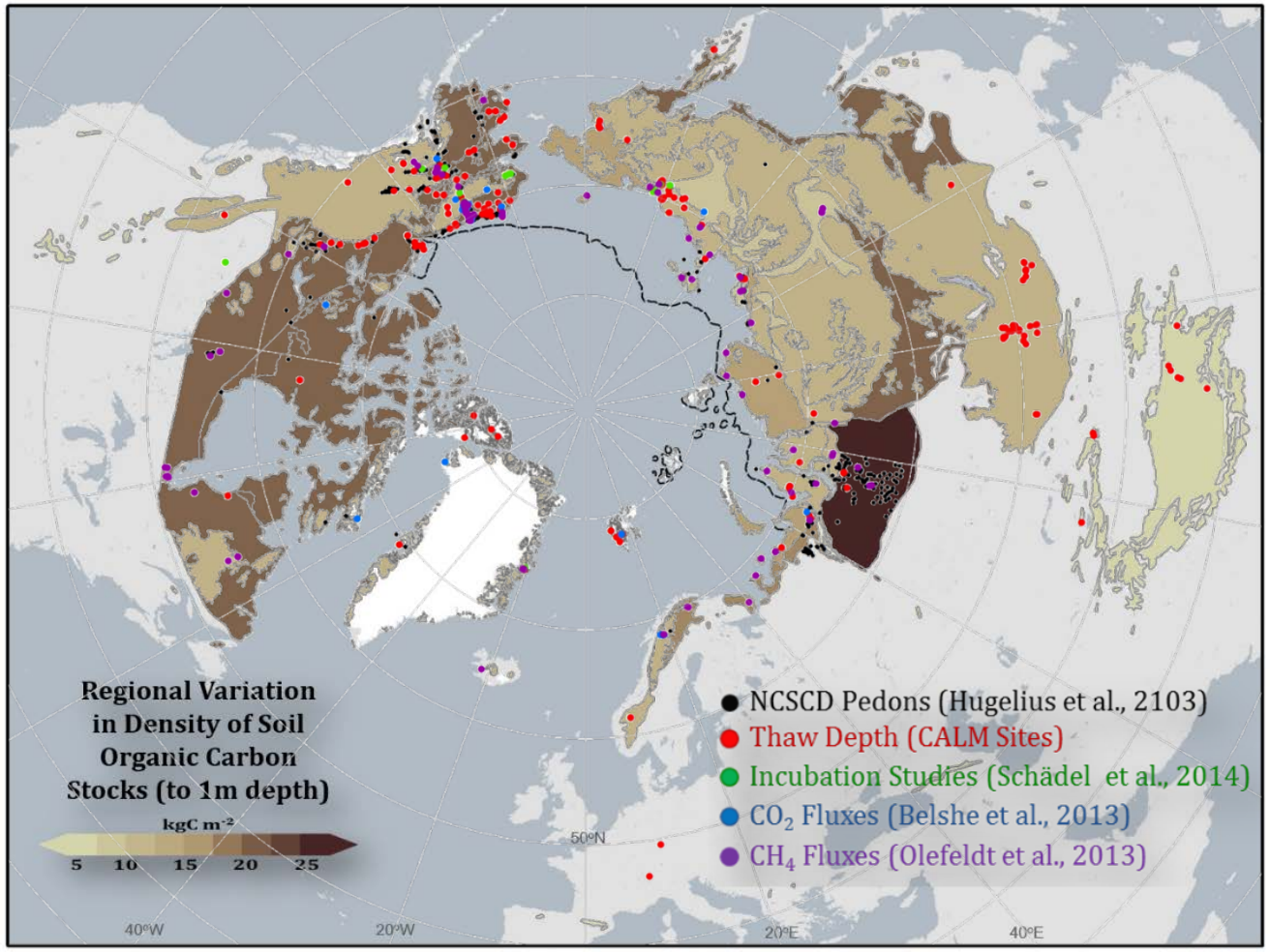


Figure 7. Simulated changes in soil carbon storage between 1960 and 2009 among the models.

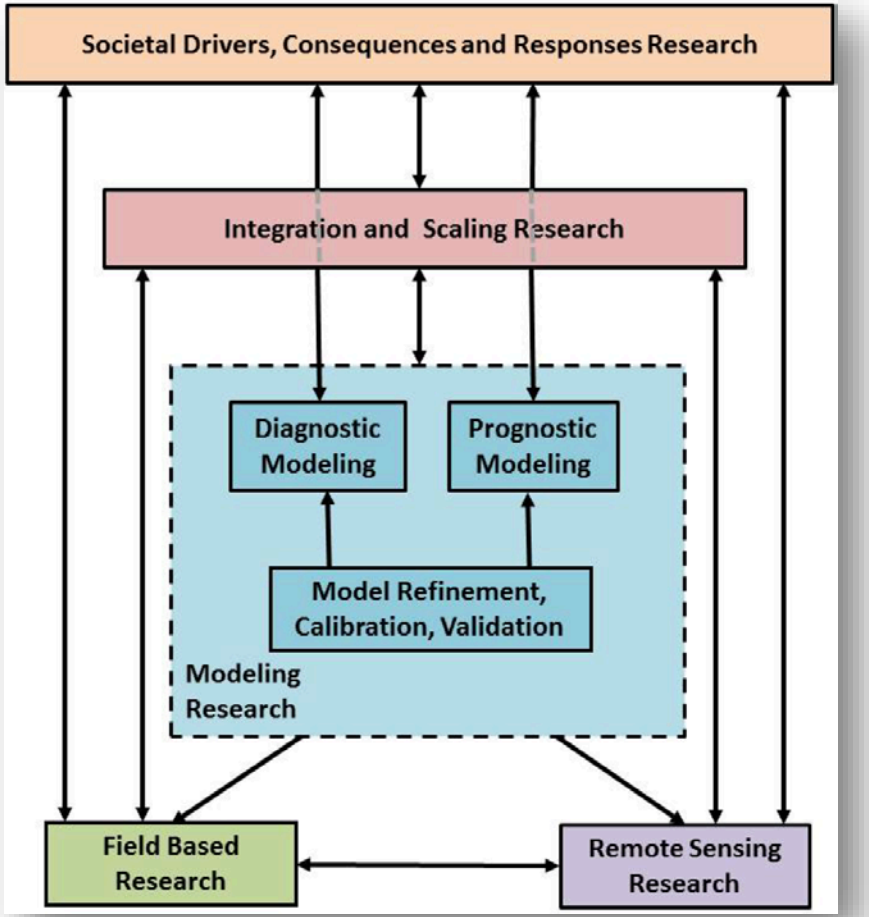
Variability in the sensitivity among model simulations of permafrost and carbon dynamics (McGuire et al., 2016)

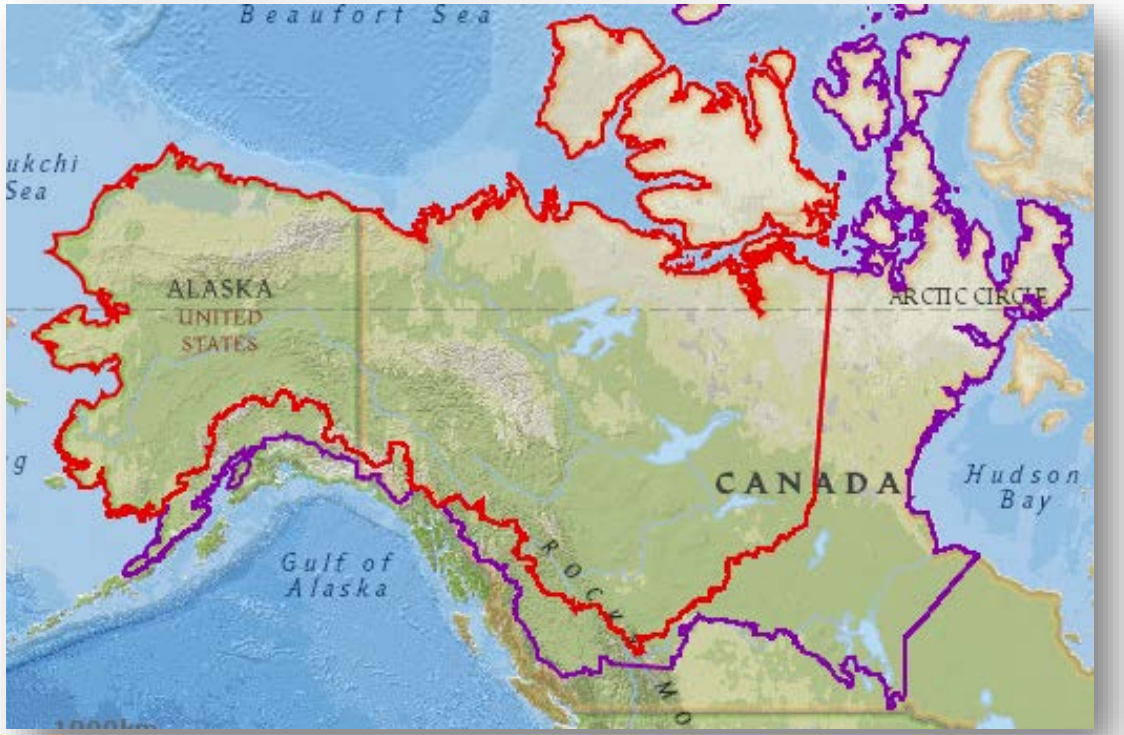
Data Representativeness & Scaling Uncertainty

COMPONENT	INDICATOR	DATA SET	DATA TYPE
MAGNITUDE?	Soil Organic Carbon (SOC)	NCSD (Hugelius et al. 2013)	Spatially extrapolated pedon point data
RATE?	Change in Active Layer Thickness (ΔALT)	CALM (Brown et al. 2000)	Thaw depth measurement sites
TIMING?	Decomposability / turnover time (t)	(Schädel et al. 2014; Treat et al. 2015)	Laboratory incubations
IMPACT?	Form of carbon emissions (CO_2 vs CH_4)	(Olefeldt et al. 2013; Belshe et al. 2013)	Chambers and flux tower sites



ABoVE: a large-scale study of environmental change





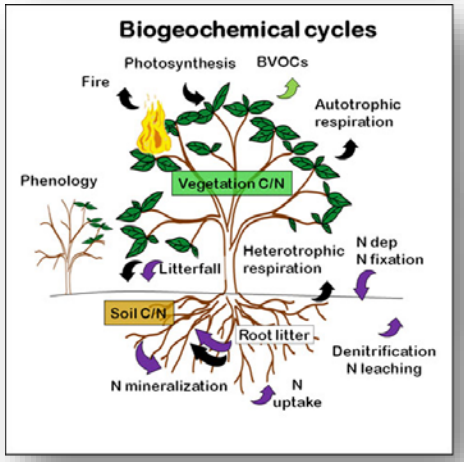
ABoVE: a large-scale study of environmental change

The ABoVE Tier 2 **Science Questions:**

Disturbance

Hydrology

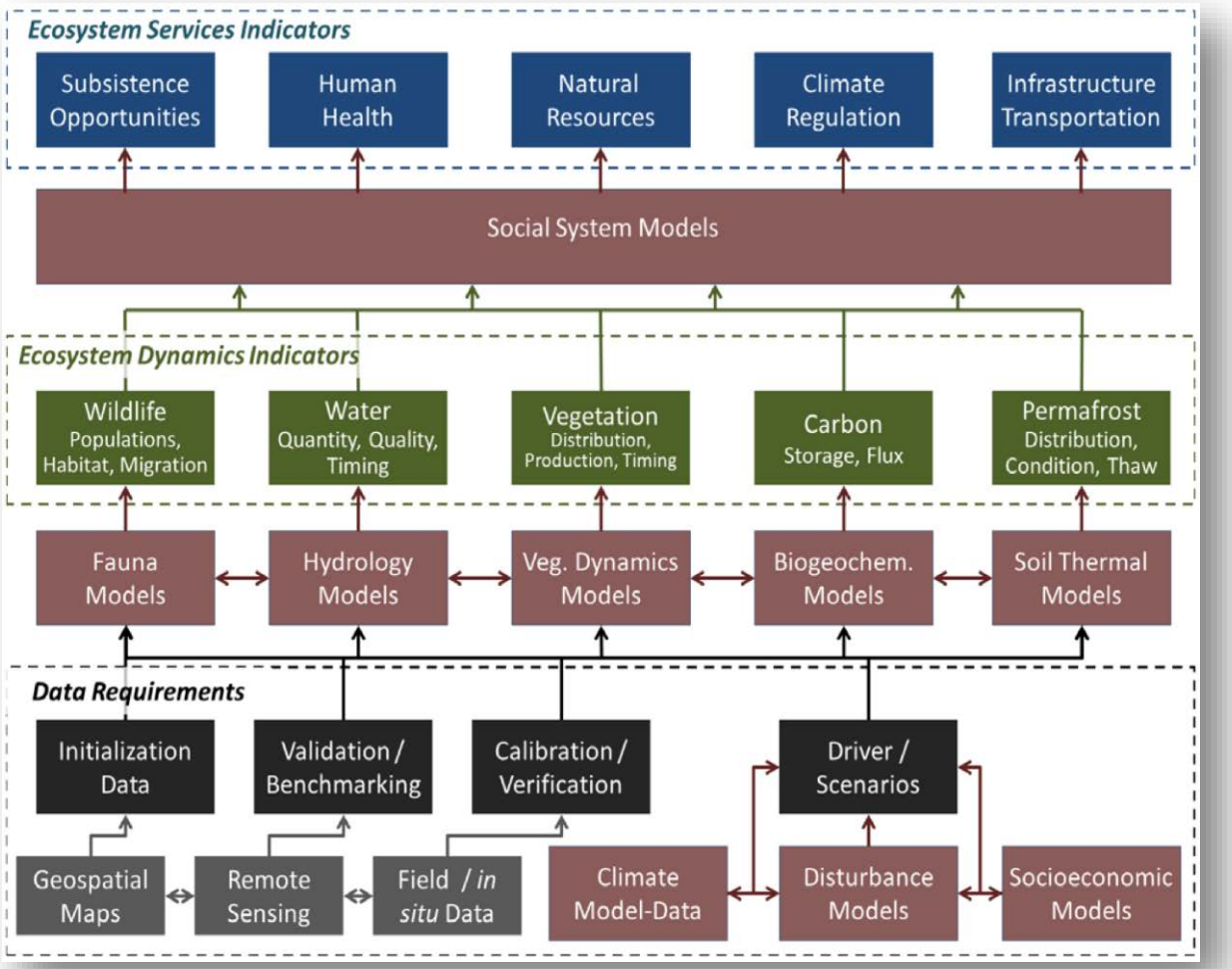
Flora / Fauna and Ecosystem Function



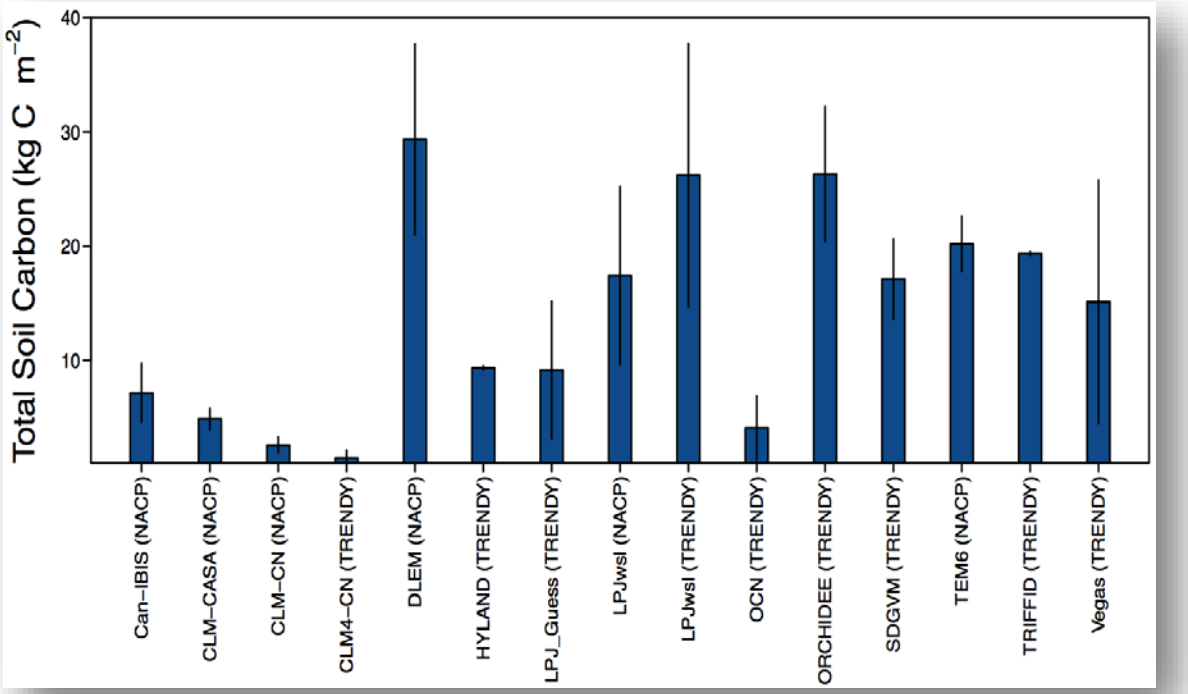
Carbon Pools and Biogeochemistry

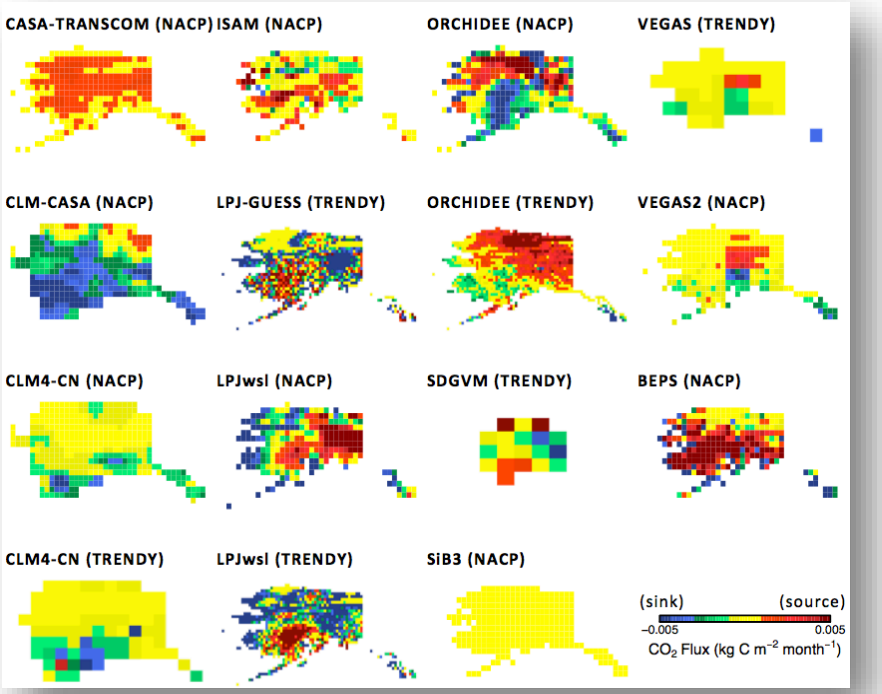
Permafrost

ABoVE: a large-scale study of environmental change



Modeling Uncertainty





Soil Organic Carbon estimates for the Alaskan Arctic span a 20-fold difference in estimates across models (Fisher et al. 2014)

Models exhibit every possible combination of net carbon flux source/sink pattern for Alaska (Fisher et al., 2014)

Analysis of Multiple Constraints

Time Period	Observations	Regional Process-Based Models	Global Process-Based Models	Inversion Models
CO_2 Exchange				
1990–1999				
Central Estimate	138	−166	−78	−13
Uncertainty	−102 to 378	−255 to −55	−188 to 0	−321 to 140
2000-2006*				
Central Estimate	−202	−187	−93	−117
Uncertainty	−628 to 224	−312 to −28	−222 to −1	−439 to 243
1990–2006*				
Central Estimate	−103	−177	−86	−96
Uncertainty	−297 to 89	−284 to −41	−205 to −1	−331 to 173

An assessment of the carbon balance of Arctic tundra (McGuire et al. 2012)

Data Needs for Model Development & Testing

Key Structural or Process Issue
Permafrost structure
Depth of soil column 50 to 100 m
Moss insulation
Organic horizon insulation
Effects of unfrozen water on soil thermal dynamics
Snow insulation
Biogeochemical structure
Representation of soil C with depth and segregated into organic and mineral horizons
Loss of C through CH_4 emissions
Loss of C through wildfire
Loss of C through lateral transfers
Influence of N availability on C uptake
Biogeochemical process issues
Sensitivity of GPP to CO_2 fertilization
Canopy phenology
Ecosystem/heterotrophic respiration
Sensitivity of heterotrophic respiration in organic and mineral horizons to temperature and soil moisture

Structural Issues to Implement and Processes to Constrain in Models (McGuire et al. 2016)

Green = modality is strongly relevant for retrieving variable; yellow = modality can support variable retrieval, subject to limitations in accuracy.

	Composition			Structure				Productivity					Disturbance		
	IGBP Landcover	Species/ Functional Type	Canopy Pigments	Leaf Area	Canopy Cover	Vertical Structure	Biomass	NDVI / fPAR	Phenology	GPP /LUE / Fluorescence	CO2, CH4 concentration	Active Fire	Burned Area	Harvest	Other Natural
Passive Optical (MS, <10m) (Ikonos, Quickbird, Worldview, Skybox)															
Passive Optical (MS, <100m) (Landsat, SPOT, Sentinel-2, CBERS, AWiFS)															
Passive Optical (MS, >100m) (AVHRR, MODIS, MERIS, SPOT-Veg)															
Hyperspectral (AVIRIS airborne, Hyperion, ENMAP)															
Lidar (ICESat, GEDI, LVIS airborne)															
Synthetic Aperture Radar (SAR) (JERS, PALSAR, ERS, Sentinel-1, NISAR)															
Atmospheric instruments (GOSAT, OCO-2, SCIAMACHY)															

Key variables needed to scale ecosystem studies or parameterize process models, and the relevant remote sensing modalities for their retrieval (Masek et al., 2015)

A Model–Data Integration Framework (MoDIF)
for ABoVE Phase I Research

1. **Foundational**

   Initial model inter-comparisons to identify and prioritize data gaps

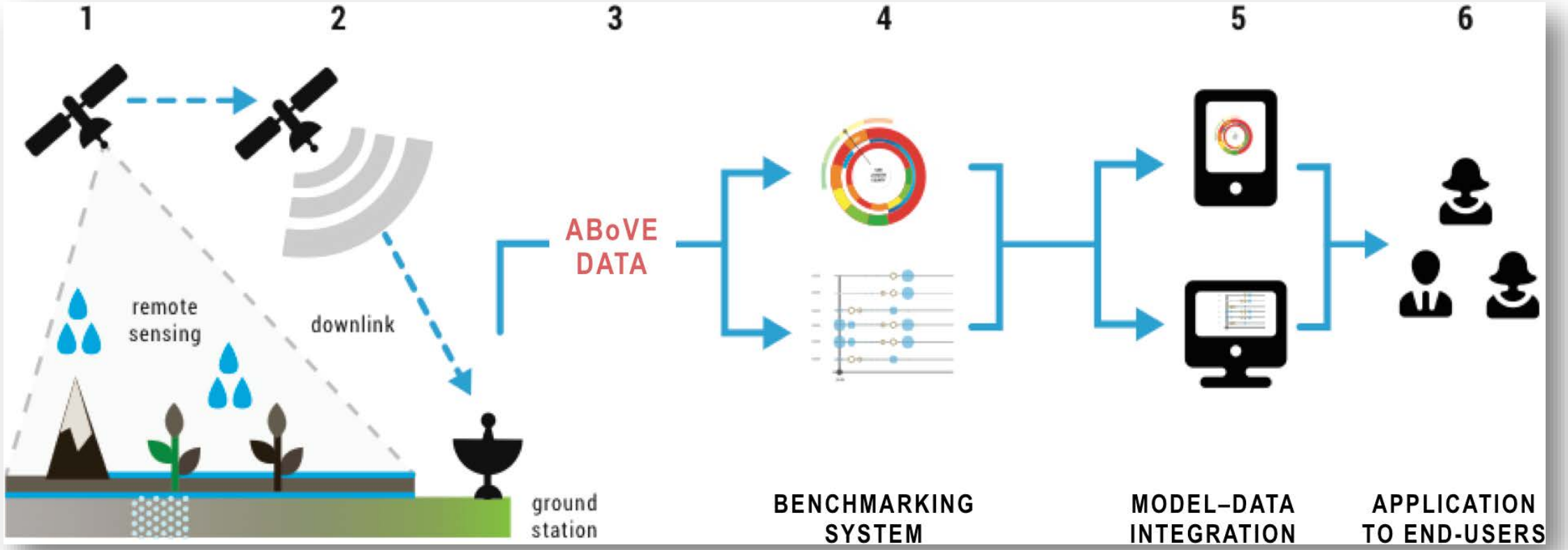
2. **Structural**

   Model-data integration and process-structural refinement

3. **Synthesis**

   Simulation and benchmarking framework for model evaluation

A Model–Data Integration Framework (MoDIF)
for ABoVE Phase I Research



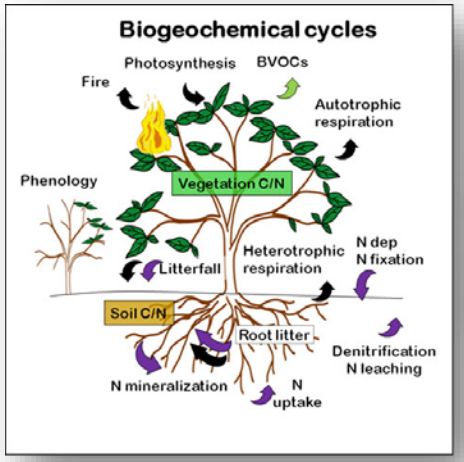
MoDIF 1. Foundational

The evaluation is centered on the ABoVE Tier 2 **Science Questions:**

Disturbance

Hydrology

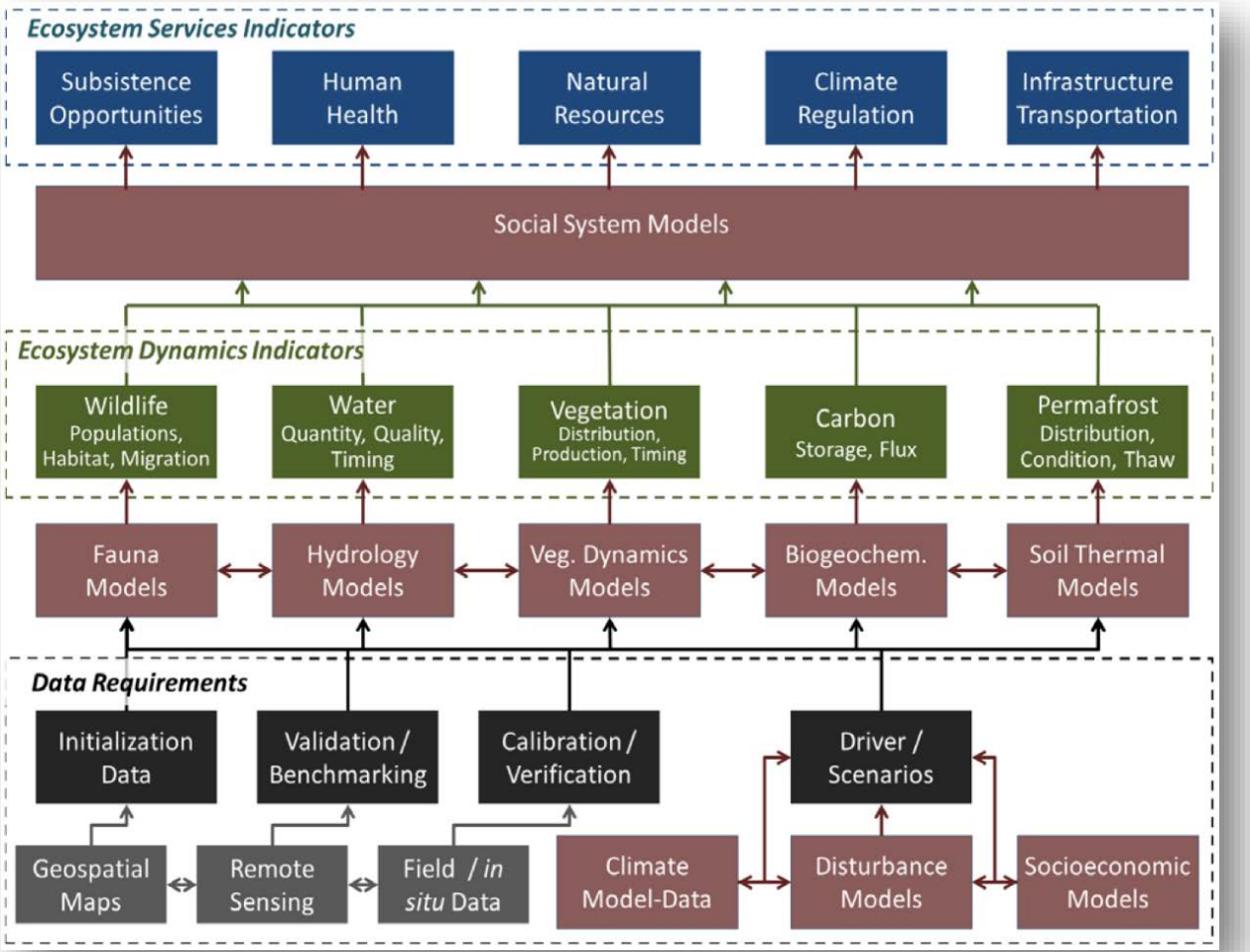
Flora / Fauna and Ecosystem Function



Carbon Pools and Biogeochemistry

Permafrost

Role of modeling in ABoVE



Terrestrial Biosphere Models

- Over 19 different institutions
- Over 20 different models
  - ~6 dynamic vegetation models
  - ~9 models have prognostic fire
  - ~2 data assimilation models
- Most models participated in NACP site and/or regional interim synthesis activities

VEGAS	DLEM	CLM-VIC	ISAM
SIPNET	PRIPLEX-GHG	LPJ-wsl	Ecosys
MC1	CLASS-CTEM-N+	GEMS	ORCHIDEE
SiB	SiB-CASA	TEM	CLM-CN
Biome-BGC	IRC	ED	GTEC

+ *multiple models out of JPL*

Multi-scale Synthesis and Terrestrial Model Intercomparison Project (Huntzinger et al. 2013 *GMD*)

Terrestrial Biosphere Models (TBMs)

North American Carbon Program
MsTMIP
MULTI-SCALE SYNTHESIS AND TERRESTRIAL MODEL INTERCOMPARISON PROJECT

Biome-BGC	LPJ-wsl
CABLE	MC1
CLASS-CTEM-N+	ORCHIDEE-LSCE
CLM4	ORCHIDEE-JPL
CLM4-VIC	TEM6
DLEM	SiBCASA
ECOSYS	SiB3-JPL
GTEC	TRIPLEX-GHG
Hyland	VEGAS
ISAM	VISIT
JULES	

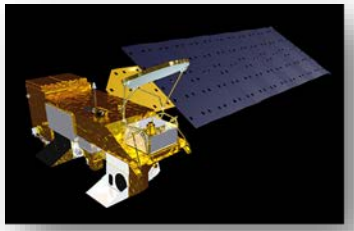
TRENDY	
HYLAND	JULES
LPJ	LPJ-GUESS
CLM4	ORCHIDEE
OCEAN	SDVGM
VEGAS	

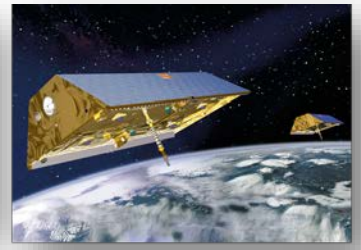
Model-data Evaluation

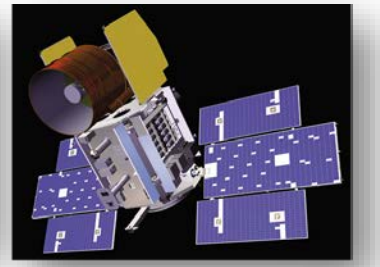
Benchmarking data to be used in our MoDIF project spans the full range of Indicators for ABoVE ecosystem dynamics.

Variable	Dataset
Carbon Dynamics	
NDVI, EVI, LAI, fAPAR, NPP	MODIS
Soil Carbon Stocks / Depth	Pedons
Soil Carbon Residence Time	Incubations
CO_2 fluxes	AmeriFlux, MPI-BGC
CO_2, CH_4 concentration	CARVE, GOSAT, OCO-2/3, SCIAMACHY
Biomass	ICESat/GLAS, GEDI, CFS
Canopy height	ICESat/GLAS, GEDI
Water Dynamics	
Soil moisture	SMAP, SMOS, ISMN
Evapotranspiration	MODIS, ECOSTRESS
Total Water Column	GRACE
Snow characteristics	NASCN, NOAA Snow Cover,
Energy Dynamics	
Soil, surface temperature	GTN-P, BOREAS, MODIS
Freeze/thaw	SMAP
Active layer depth	InSAR, CALM/GTN-P
Albedo	MODIS, VIIRS
Fire counts, burnt area	MODIS
Net radiation	MODIS

Model-data Evaluation

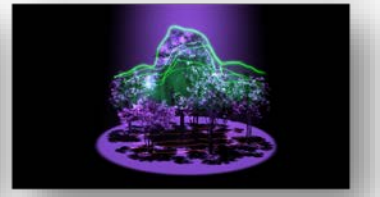

MODIS (On Aqua)


GRACE


ICESat

SMAP

OCO-2


GEDI

ECOSTRESS

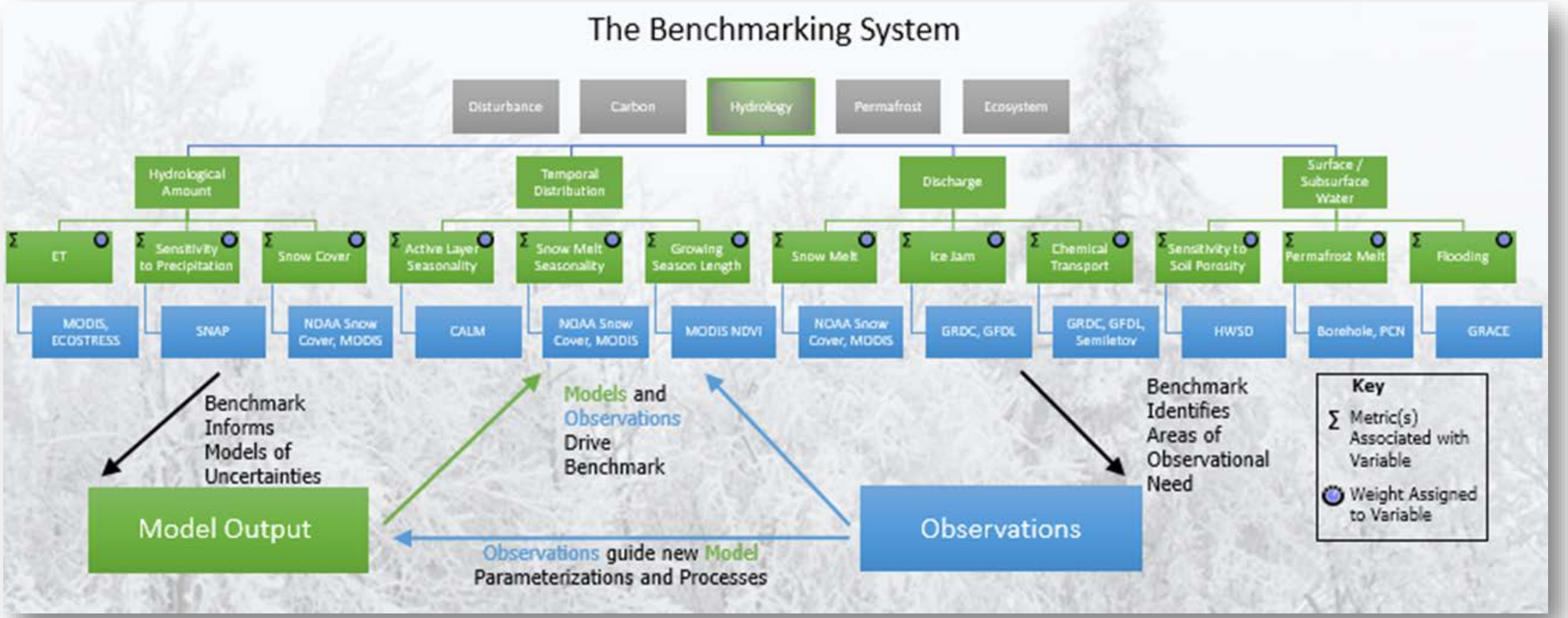
Established Remote Sensing Data

- MODIS
- GRACE
- ICESat

Newer Remote Sensing Instruments

- SMAP
- OCO-2/3
- ECOSTRESS
- GEDI

Model-data Evaluation Framework



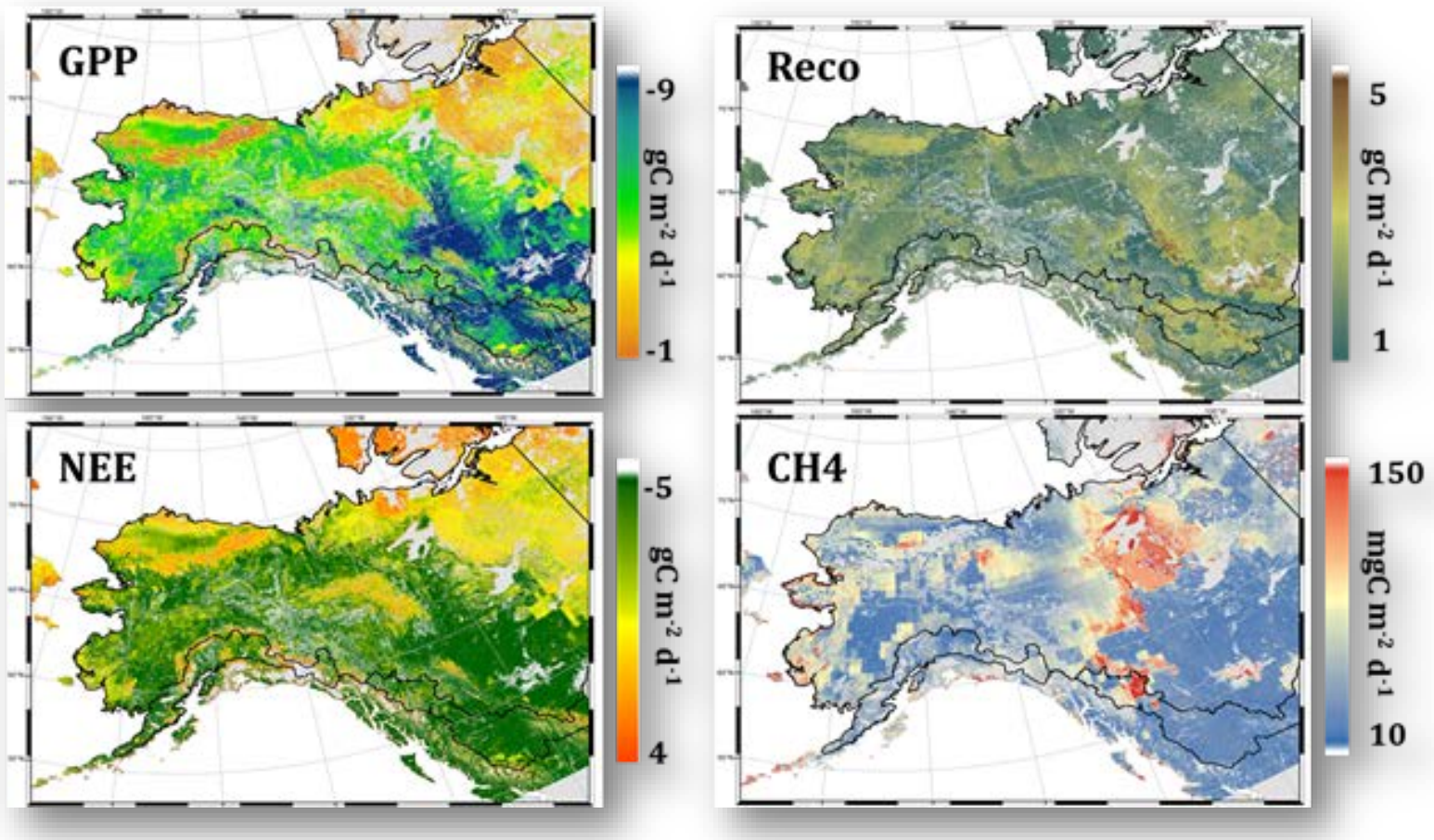
MoDIF 2. Structural

Table 1
Examples of different formulations of process-based models and how remote sensing data is used in simulating forest and ecosystem productivity. The examples shown here are taken from models participating in North American Carbon Program synthesis and inter-comparison activities (Huntzinger et al., 2012, 2013). Photosynthetic formulation is categorized by either enzyme kinetic (EK) or light use efficiency (LUE).

Model	Photosynth. formulation	Vegetation distribution	Phenology	Leaf area index	Fire	Land use change	Reference
CASA GFEDv2	LUE	MODIS	GIMMS NDVI	Assimilated from remote sensing	Prescribed (MODIS)	None	van der Werf et al. (2004)
CLM4	EK	MODIS	Prognostic	Dynamically calculated	Prognostic	Modeled	Thornton et al. (2009)
ISAM	LUE	AVHRR	N/A	Assimilated from remote sensing	Implicit	Modeled	Jain and Yang (2005)
TEM6	EK	AVHRR	Prognostic	Dynamically calculated	Prescribed (various RS products)	Modeled	Hayes et al. (2011)
VEGAS2	LUE	Dynamic	Prognostic	Dynamically calculated	Prognostic	Modeled	Zeng et al. (2005)

Prognostic models predict LAI (EK), **Diagnostic models** prescribe LAI based on remote sensing inputs (LUE) (Huntzinger et al. 2013; Masek et al., 2015)

Diagnostic Modeling



ABoVE Domain Flux Simulations (Aug. 2003-15) from TCF model (Kimball et al.)

MoDIF 2. Structural

Table 2. Environmental driver and initialization datasets that we will organize within the ABoVE Science Cloud and make available for ABoVE modeling research.

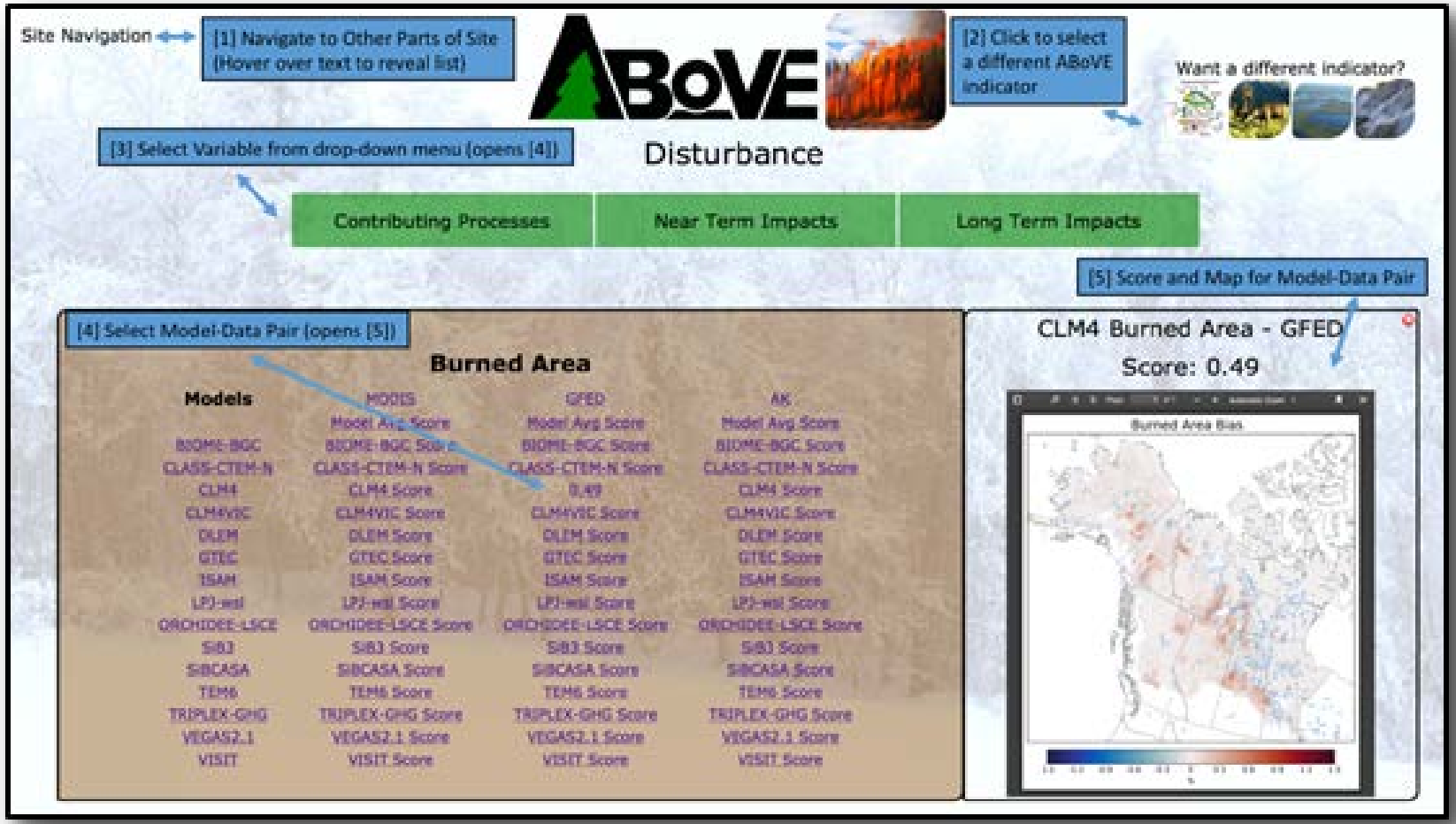
Driver data sets	Source	Temporal Resolution	Temporal Extent	Spatial Resolution	Spatial Extent
Climate fields (surface air temperature, precipitation, radiation, winds, humidity, etc.)	NARR	hourly	1970s-2000s	0.25°	North America
	DAYMET	daily	1980 - 2014	1 km^2	North America
	SNAP	monthly	1901-2009	2 km^2	ABoVE Domain
Potential vegetation	SYNMAP	-	-	0.25°	Global
	EOSD	-	-	1 km^2	Canada
	CAVM	-	-	1 km^2	Circumarctic tundra
Area burned	Canadian Large Fire Database	annual	1950s-2014	1 km^2	Canada
	AK Interagency Database	annual	1950s-2014	1 km^2	Alaska

Simulation Experiment Protocol

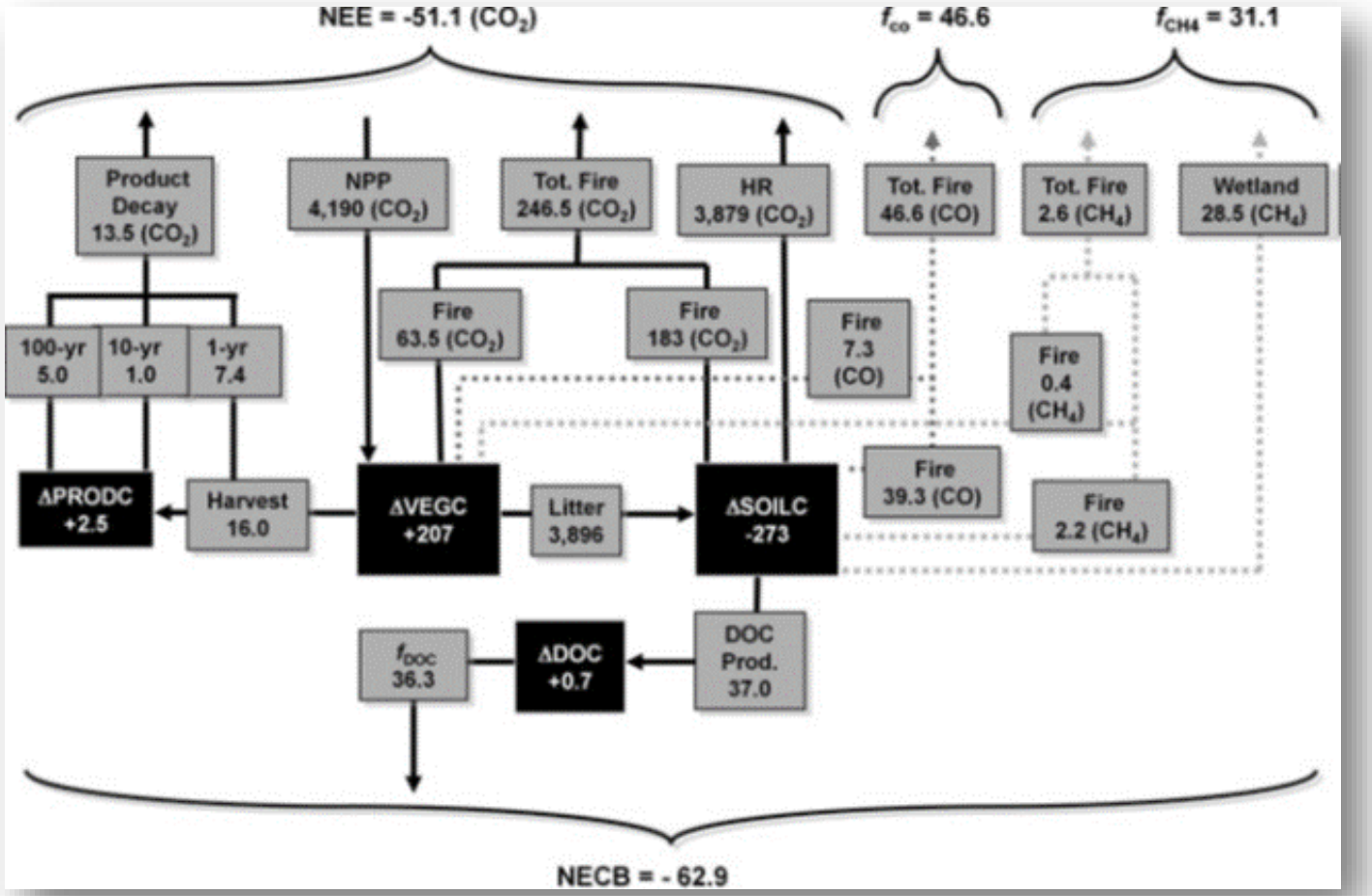
Order	Domain	Code	Climate	LULUC	Atm. CO_2	Nitrogen
1	Global	RG1	Constant	Constant	Constant	Constant
2		SG1	CRU+NCEP			
3		SG2		Hurtt et al.		
4		SG3			Observed	
5		BG1				Observed
6	North Amer.	RR1	Constant	Constant	Constant	Constant
7		SR1	NARR			
8		SR2		Hurtt et al.	Observed	
9		SR3				
10		BR1				Observed

Multi-scale Synthesis and Terrestrial Model Intercomparison Project (Huntzinger et al. 2013 *GMD*)

MoDIF 3. Synthesis



MoDIF 3. Synthesis



The major terrestrial carbon stock changes and fluxes (Tg C y-1) in northern high latitude ecosystems are captured by TEM6 (McGuire et al., 2010)

MoDIF 3. Synthesis

- Model-Data integration and benchmarking system software for ABoVE under development in conjunction with the International Land Model Benchmarking (ILaMB) framework and the ABoVE Science Cloud
- Survey distributed to 23 modeling groups around the world to collate national and international remote sensing and other data needs for model improvements in the ABoVE Domain
- Model uncertainty maps for the ABoVE domain produced and distributed to the ABoVE Science Cloud to target data acquisitions
- Existing ABoVE dataset collation; interfacing with the Permafrost Carbon Network

Thank You!

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