Land Model and Biogeochemistry
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Modeling the Above and Below Ground C and N Stocks in Northern High Latitude Terrestrial Ecosystems

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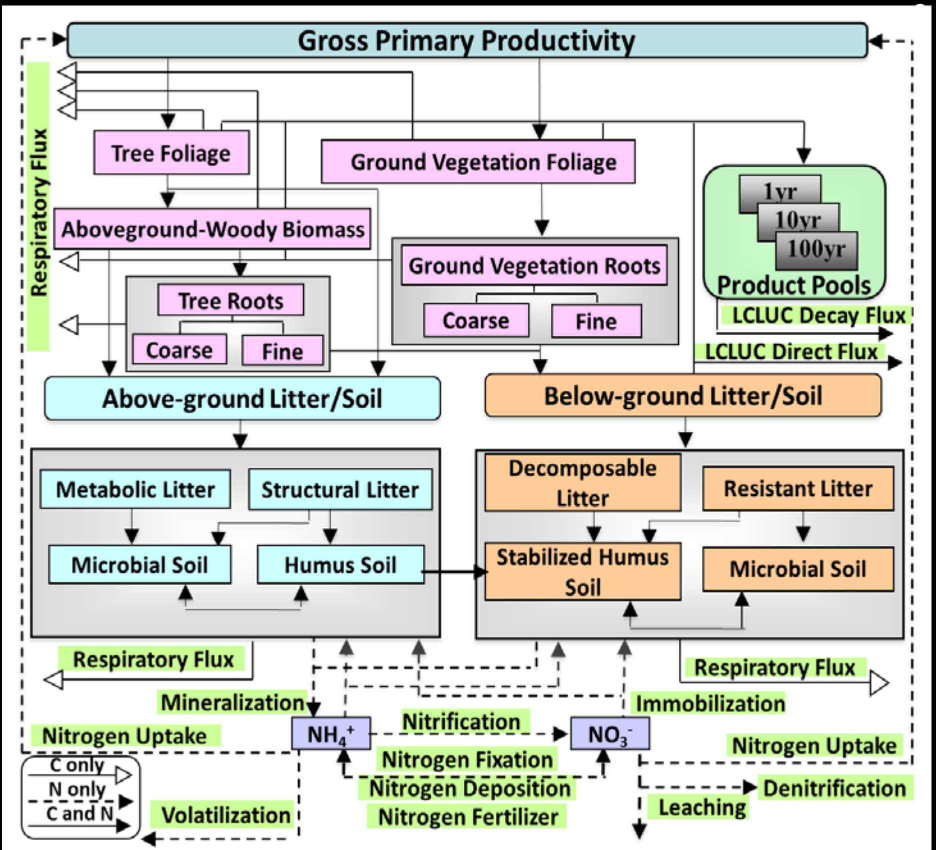
Acknowledgements
Bassil El-Masri & Rahul Barman
US DOE

Overall Objective

- Investigating the interactions between biogeophysical and biogeochemical processes in the Northern high latitudes using ISAM land surface model
  - how biogeochemistry (carbon and nitrogen dynamics) responds to improved biogeophysics (hydrology and energy) in the Northern high latitudes.

ISAM Land Surface Model



Model spatial and temporal resolution

- Spatial Resolution:0.5°x0.5°
- Biogeophysics Time step: 30 minutes
- Biogeochemistry Time step: 1 Week

Biogeochemical Processes

- Coupled C and N dynamics (*Jain et al., 2009*)
- Comprehensive above and below ground litter and SOM decompositions (*Yang et al., 2009*)
- Land Cover and Land Use Change, including secondary forest dynamics (*Yang et al., 2010*)
- Dynamic rooting depth formulations, vegetation phenology *(Arora and Boer, 2005)*

Biophysical Processes

- Above-ground canopy biogeophysics from the **CoLM pocesses**
- Originally, soil hydrology adapted from the NCAR **CLM3.5**
- Many Further **modifications** in biogeophysics, including recent advances in vegetation, soil, snow interactions

Modeling Strategy

- Integrated recent improvements in canopy, soil/snow, and carbon-nitrogen cycle processes in the ISAM
- Evaluate the model processes with several data sets

Biogeophysics

- site level FLUXNET eddy-covariance data: *Baldocchi et al. (2001)*
- globally upscaled FLUXNET data: *Beer et al. (2010); Jung et al. (2011)*
- GRDC Runoff: *Fekete et al. (2002)*
- permafrost extent: *Brown et al. (2002)*

Biogeochemistry

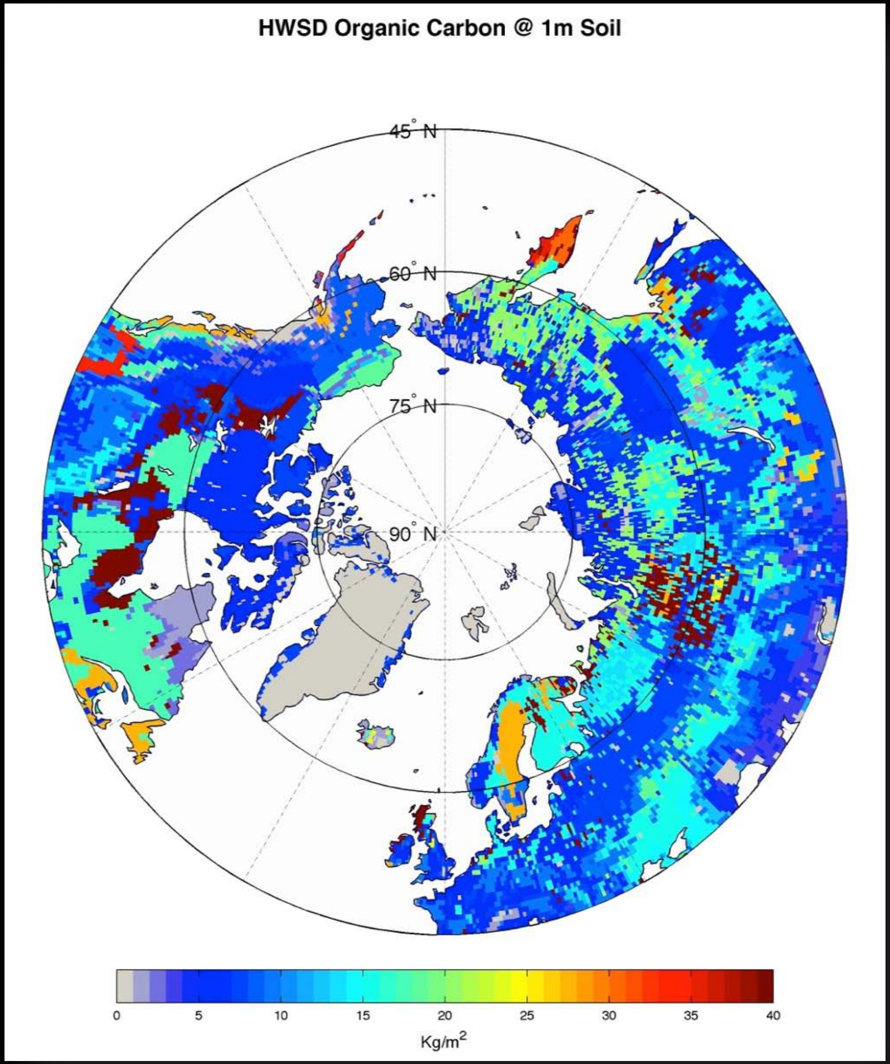
- Harmonized World Soil Database (HWSD): *(FAO/IIASA/JRC, 2012)*
- Northern Circumpolar Soil Carbon database: *Tarnocai et al. (2009)*
- Long-Term Intersite Decomposition Experiment Team (LIDET) plant litter data : *LIDET (1995)*

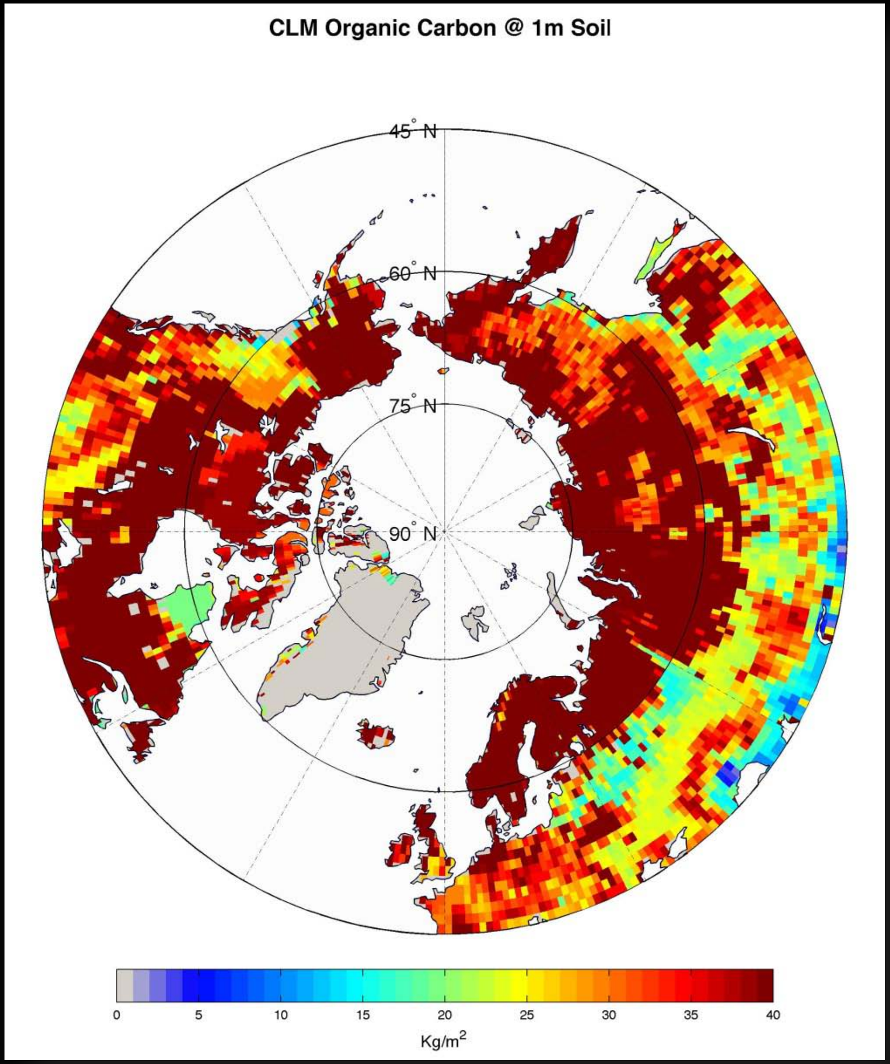
Improving the Representation of Soil & Snow Thermal Processes in ISAM

1. Processes impacting soil thermal conductivity & heat capacity
   a. soil organic carbon
   b. representation of deep soils *[Lawrence and Slater (2008): CLM]*
2. Processes impacting snow thermal regime
   a. melting
   b. thermal ageing
   c. weight compaction of snow
   d. wind compaction of snow *[Schaefer et al. (2009): SiB-CASA]*
   e. depth hoar (DH) development *[Schaefer et al. (2009): SiB-CASA]*
3. Most models have not accounted for wind compaction of snow & depth hoar development, which are thought to be very important for the NHL

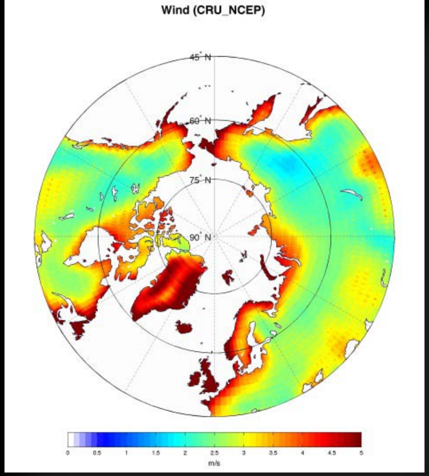
Incorporation of Newer Datasets

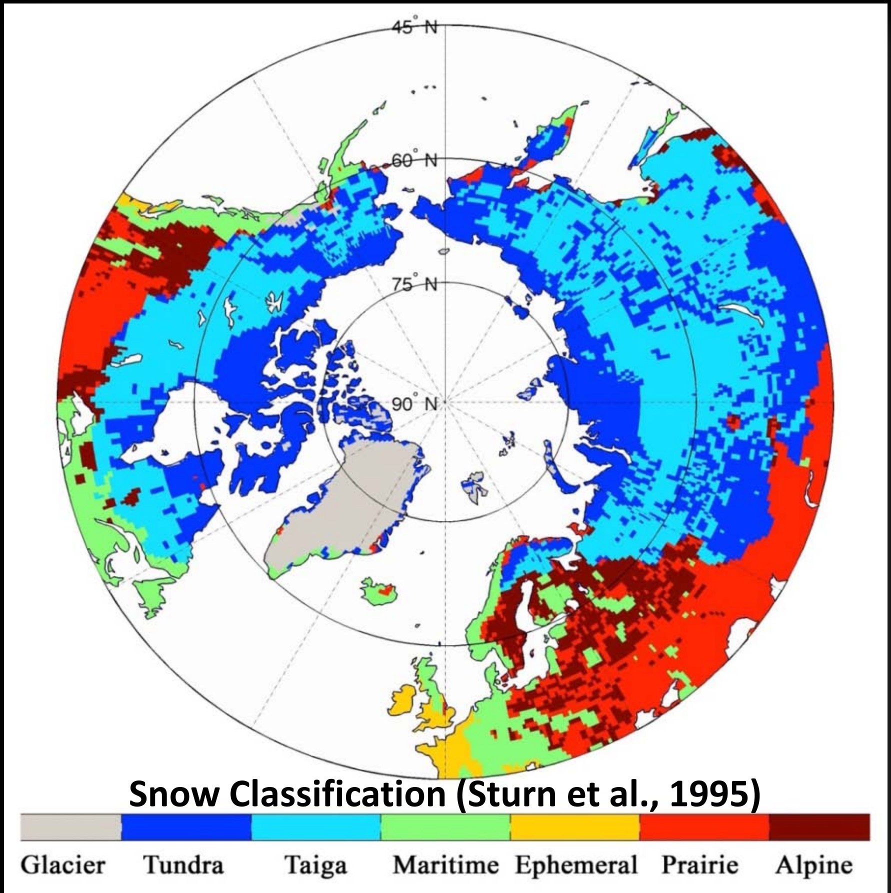
Soil organic Carbon dataset

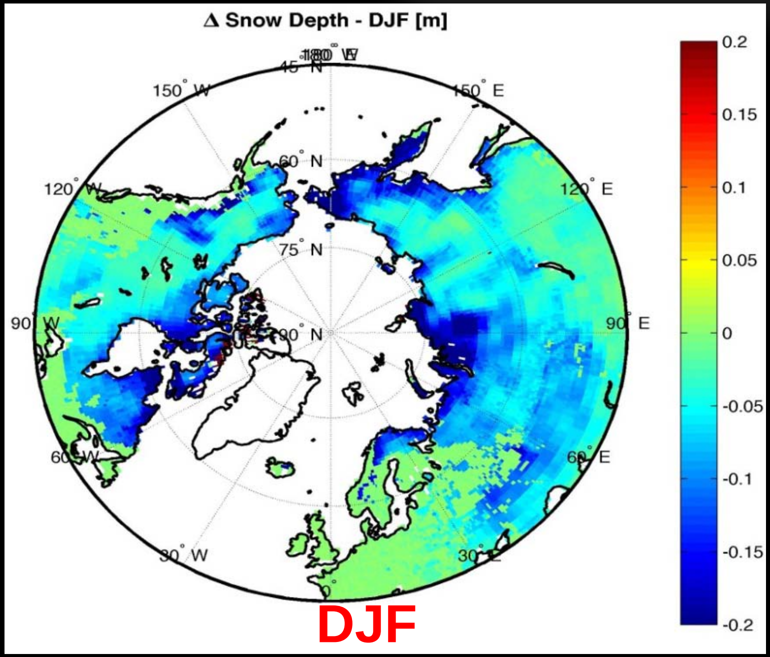




ISAM Estimated Wind Compaction Effect on Snow Depth



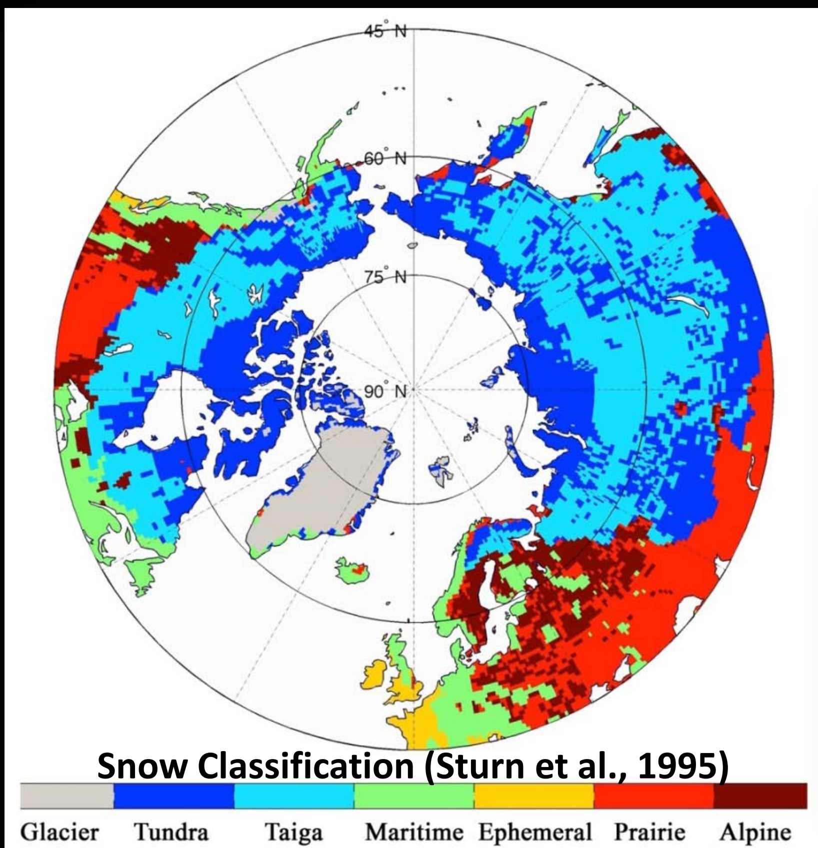




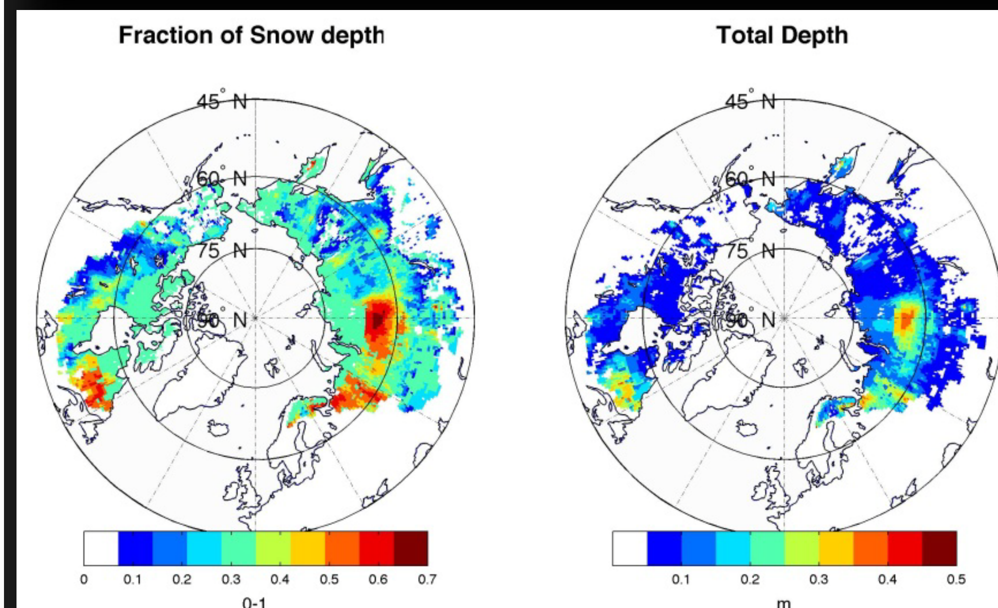
Significant decrease of Snow Depth in Tundra snow class

Barman et al. 2013c (to be sub.)

Implementation of Depth Hoar (DH) Fraction and Depth in ISAM



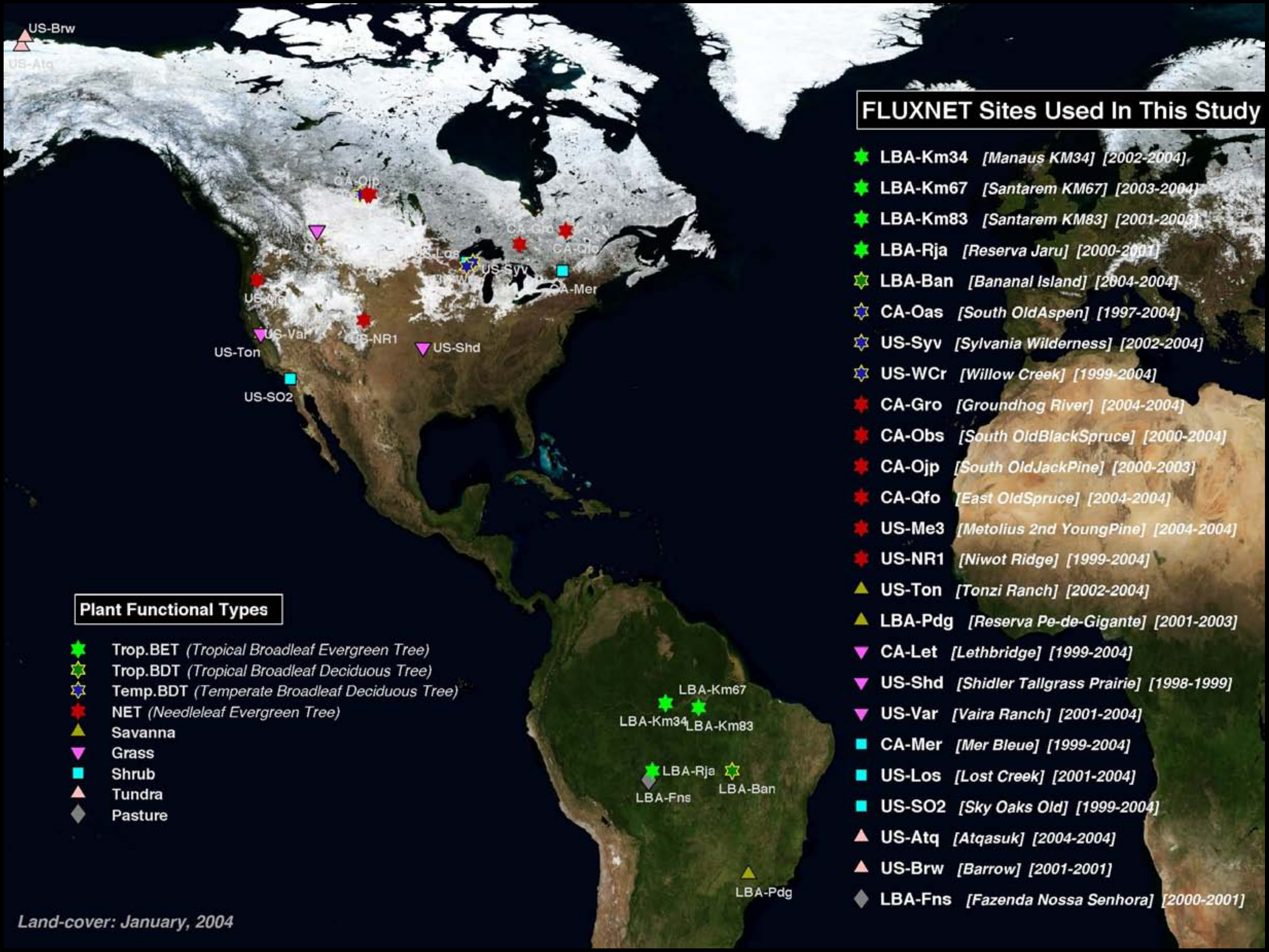
Depth hoar formation (Tundra & Taiga)



Dominated in Taiga snow class

Barman et al. 2013c (to be sub.)

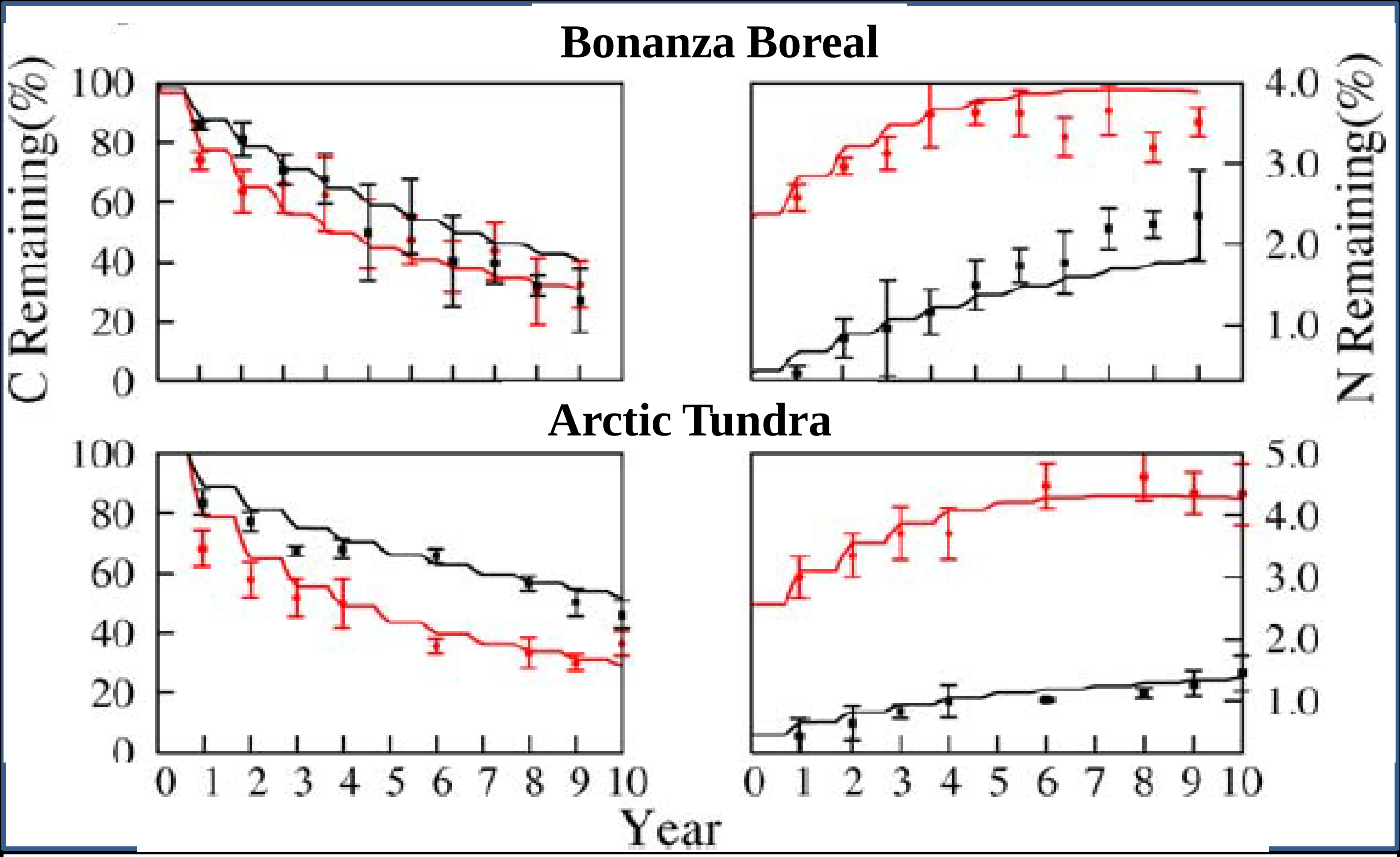
Improving the ISAM Using FLUXNET Data



Litter Decomposition Module - Model Calibration and Evaluation Sites

- Litter C and N data from the LTER sites (Arctic and Bonanza) were used to calibrate/evaluate the ISAM
  - above and below ground litter decomposition rates and
  - carbon release and N amount remaining.

Observed and Modeled Mass of C Remaining and N concentration of Decaying Leaf Litter

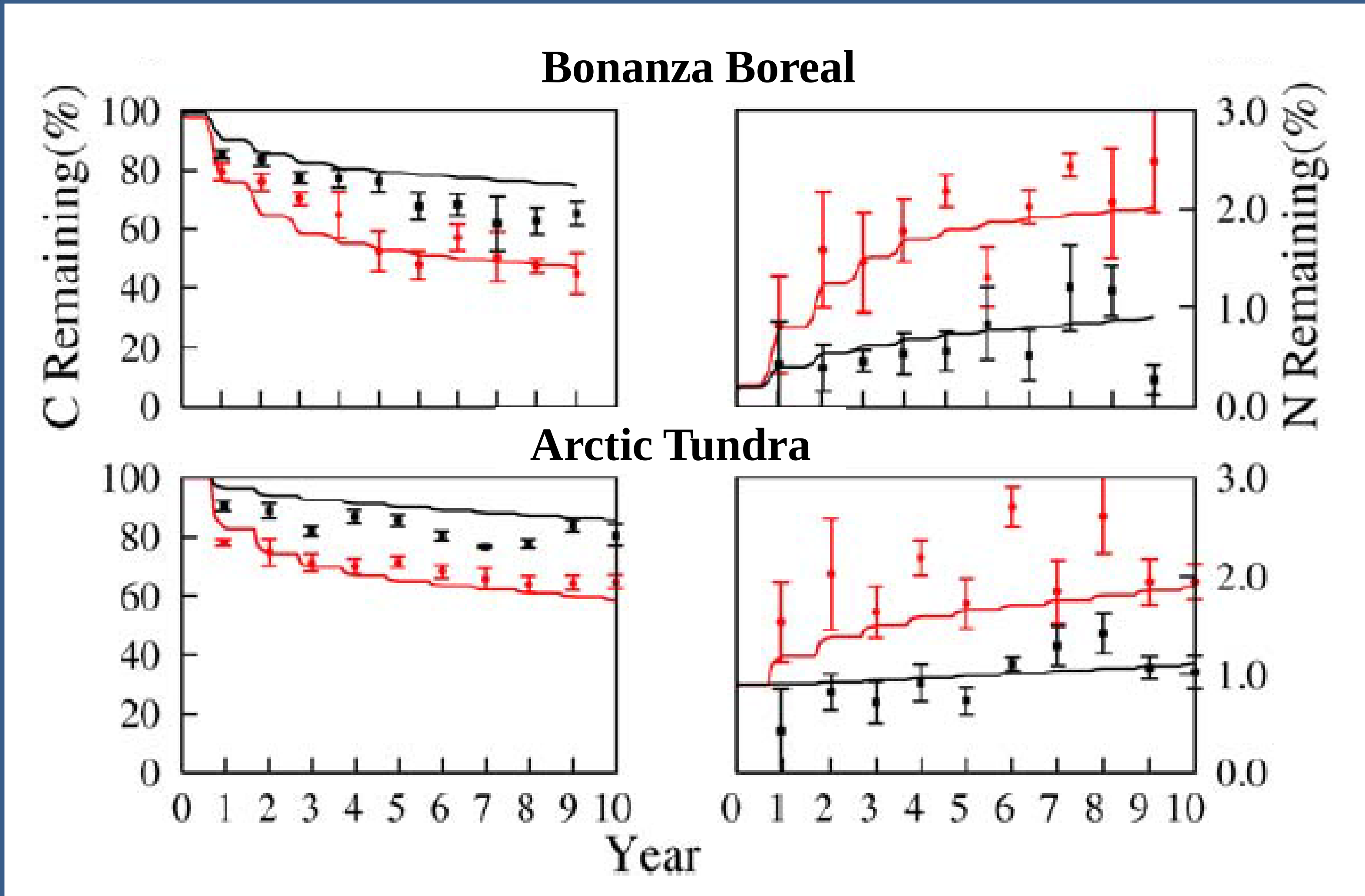


Red Line: 1.97 % N & 10.8 % Lignin

Black Line: 0.38% N & 16.2% Lignin

Yang et al. (GBC, 2009)

Observed and Modeled Mass of C Remaining and N concentration of Decaying Root Litter

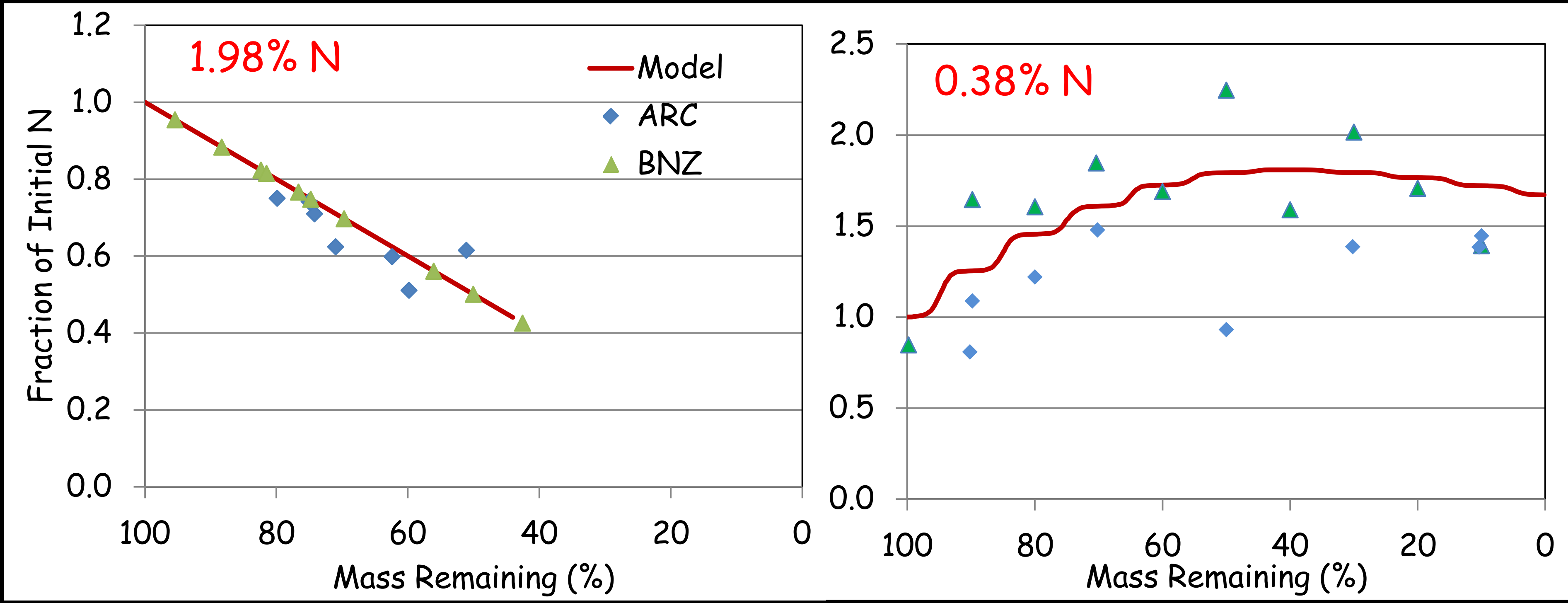


Red Line: 0.76% N & 16.1% Lignin

Black Line: 0.82% N & 34.9% Lignin

Yang et al. (GBC, 2009)

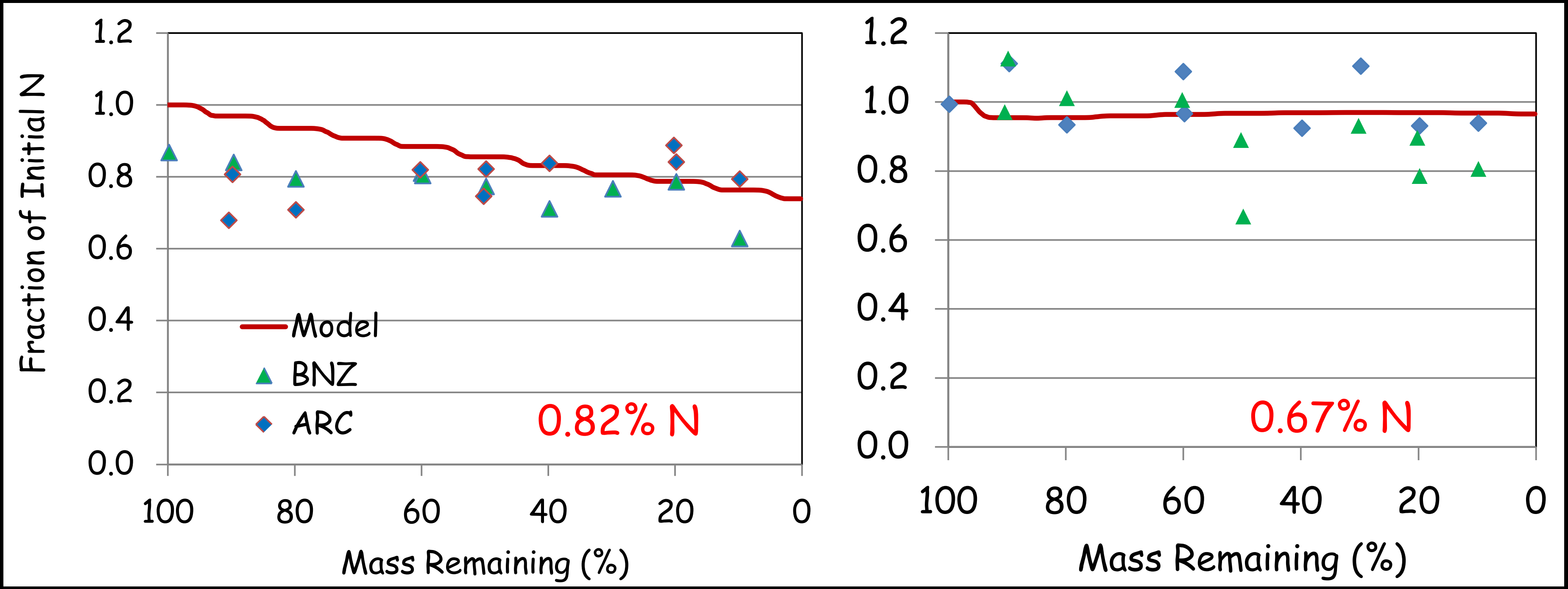
Fraction of Initial litter N Remaining as a Function of the Leaf Litter Mass Remaining



ARC: Artic Tundra
BNZ: Bonanza Boreal

Yang et al. (GBC, 2009)

Fraction of Initial Litter N Remaining as a function of Root Litter Mass Remaining



ARC: Artic Tundra
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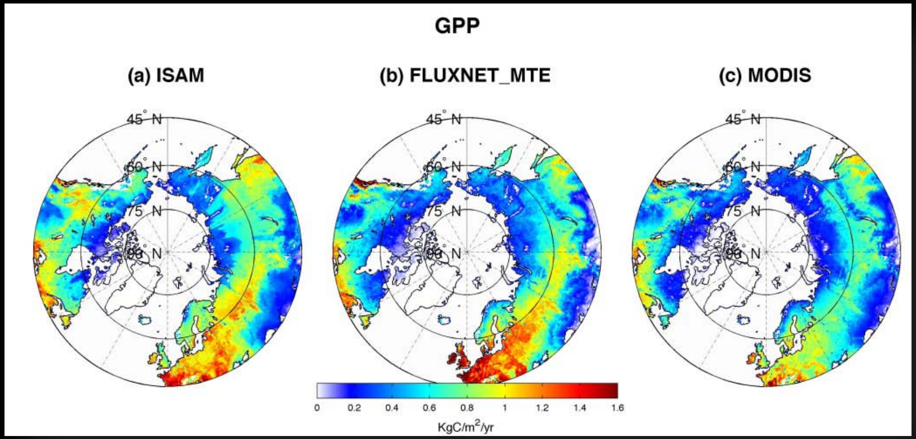
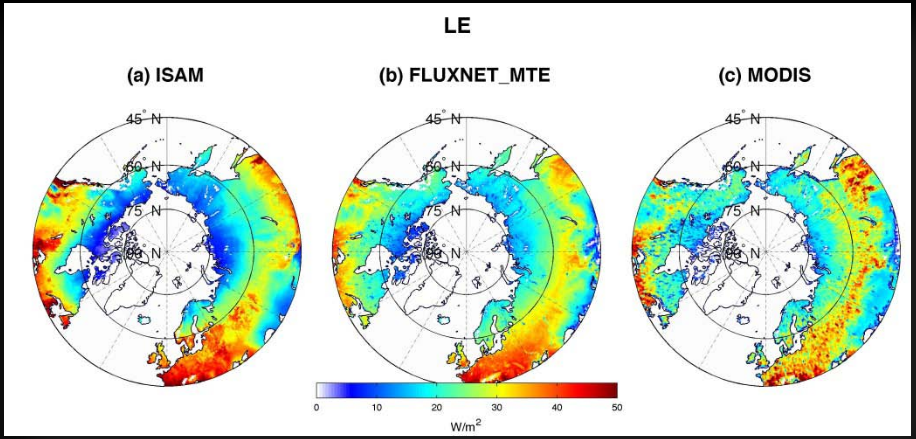
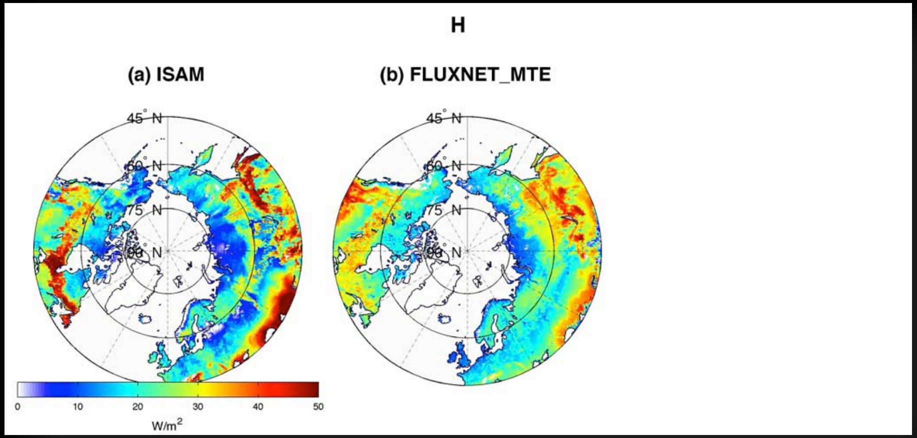
Yang et al. (GBC, 2009)

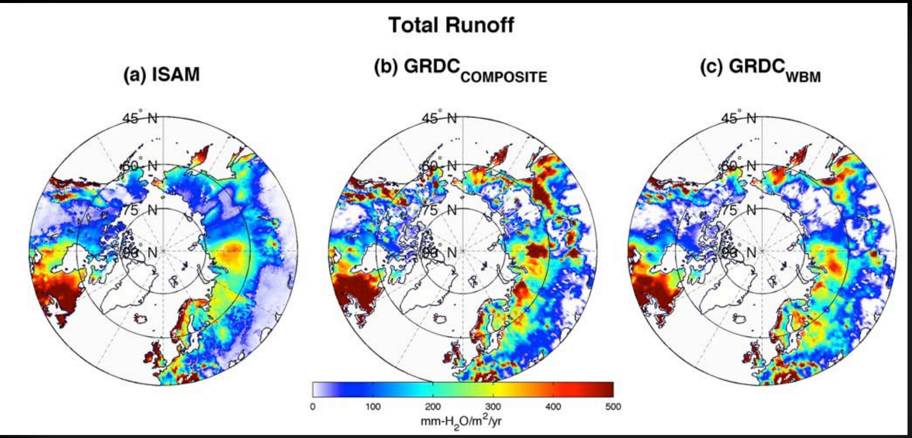
GPP, Energy and Water Fluxes: ISAM Evaluation

ISAM simulations (1985 - 2010) using the CRU-NCEP reanalysis dataset; land-cover and land-use change datasets from *Meiyappan and Jain (2012)*



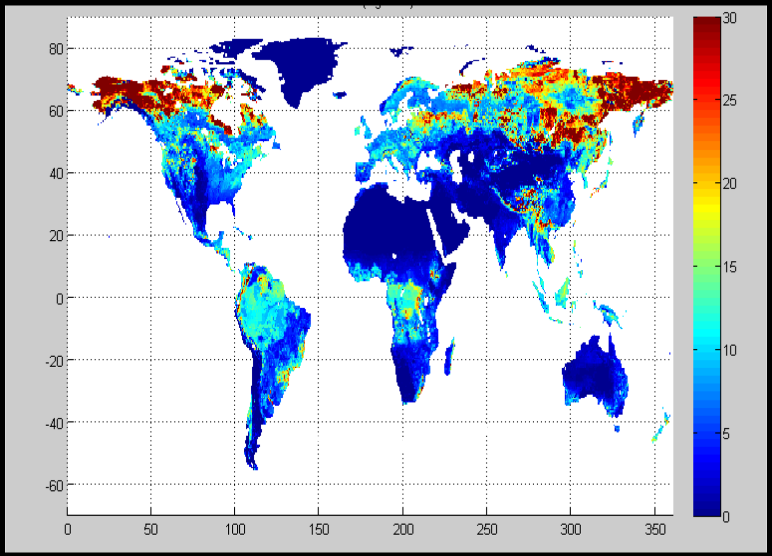






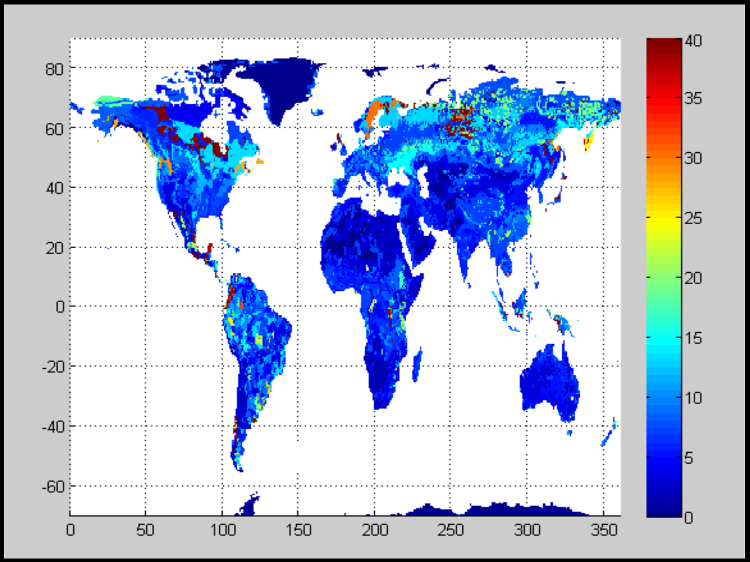
Modeled vs. Measured Global Soil C

Modeled

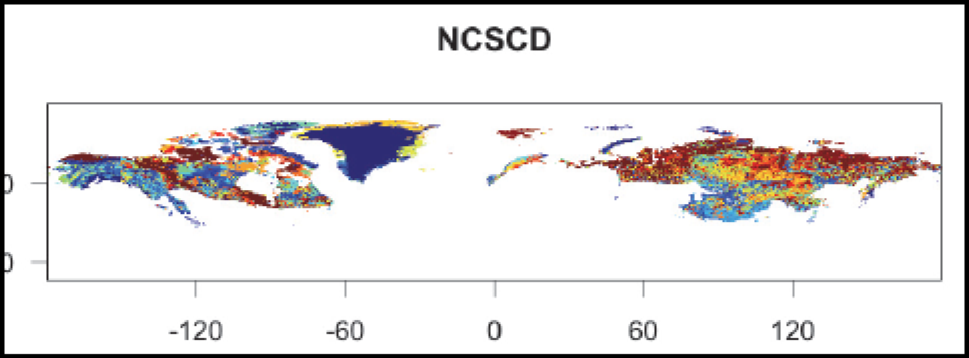


1086 GtC

HWSD

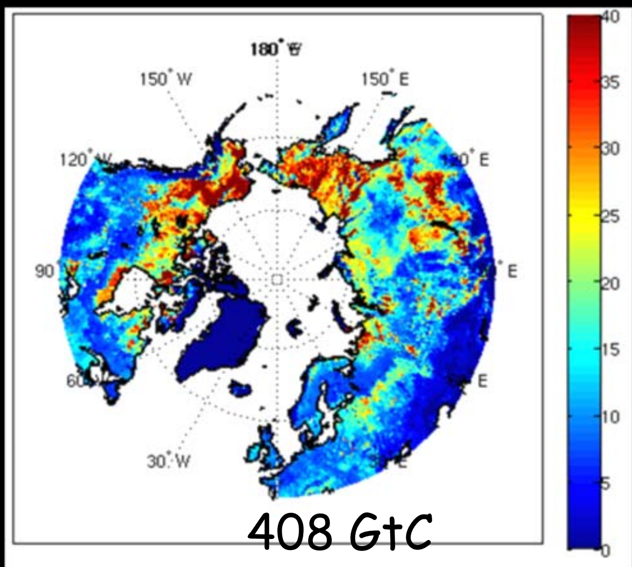


1255 GtC

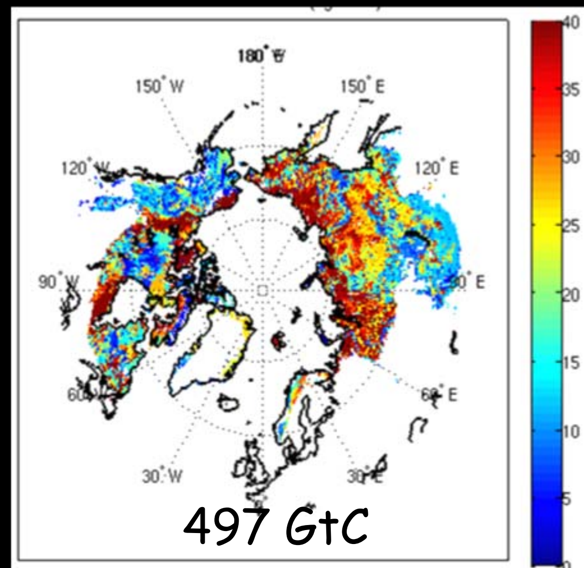


Modeled vs. Measured NHL Soil C (Unit: Kg C/m^2)

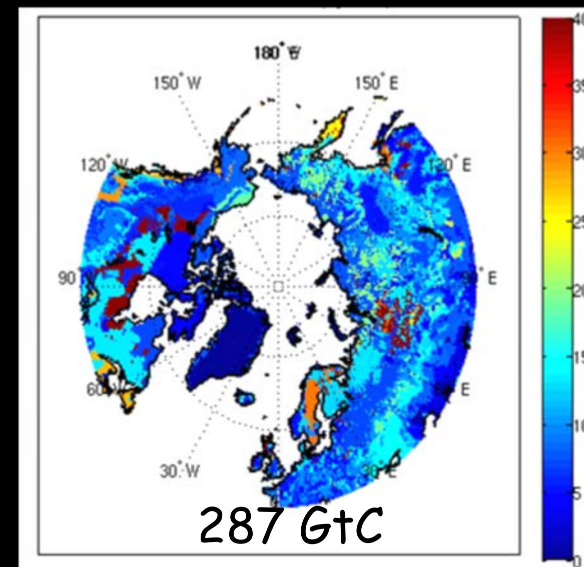
Modeled



Tarnocai et al.



HWSD

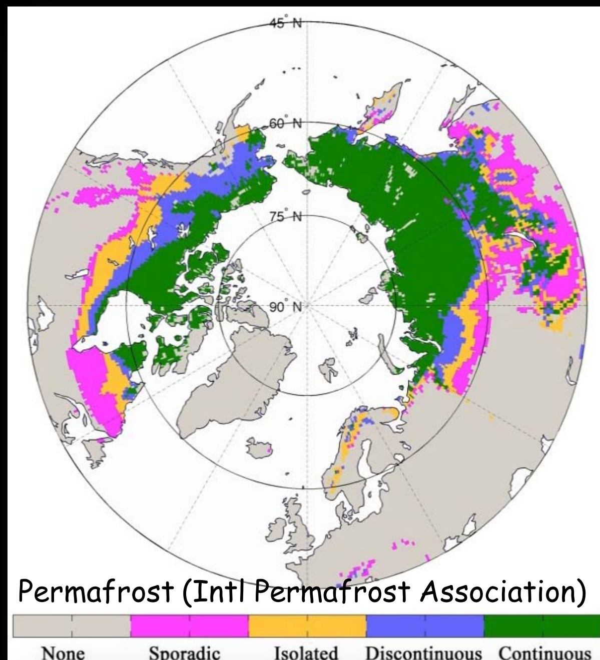


ISAM Simulations

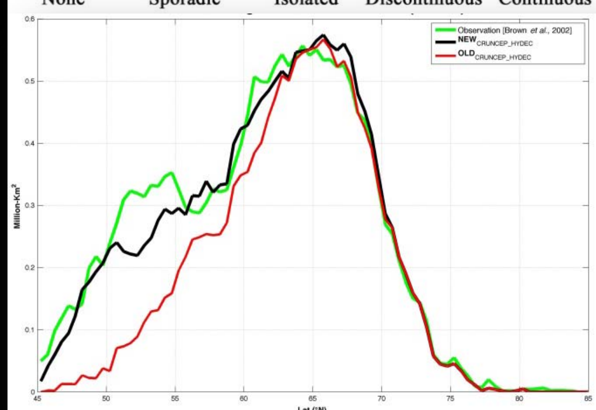
- Sensitivity of four processes/variables
  a. Deep soil representation
  b. Soil organic carbon
  c. Wind compaction of snow
  d. Depth hoar formation
- Six model simulations:
  a. NEW: include all four processes (standard model version)
  b. OLD: exclude all four processes
  c. NODS: only exclude deep soils from NEW
  d. NOSOC: only exclude soil organic carbon from soils from NEW
  e. NOWS: only exclude no wind effects from NEW
  f. NODH: only exclude depth hoar effects
- CRU_NCEP meteorology, HYDE land-cover dataset: *Meiyappan and Jain (2012)*

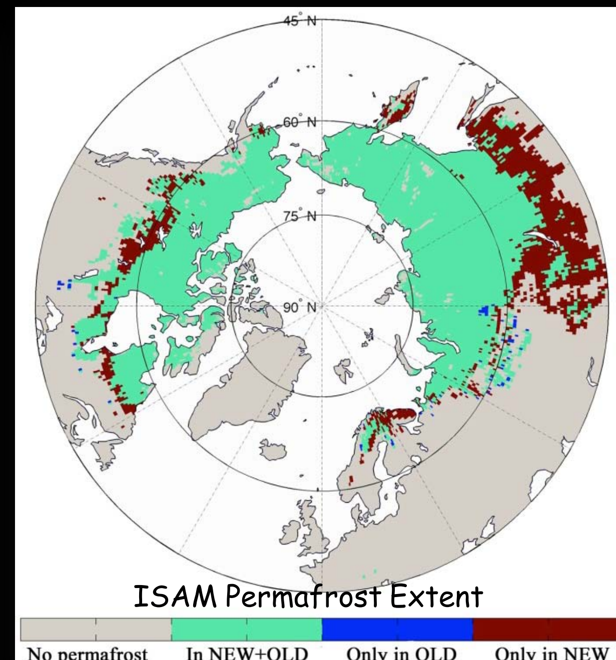
Permafrost Extent: Impact of Added Model Processes

Area Containing Near Surface Permafrost (45-90°N)



Permafrost (Intl Permafrost Association)



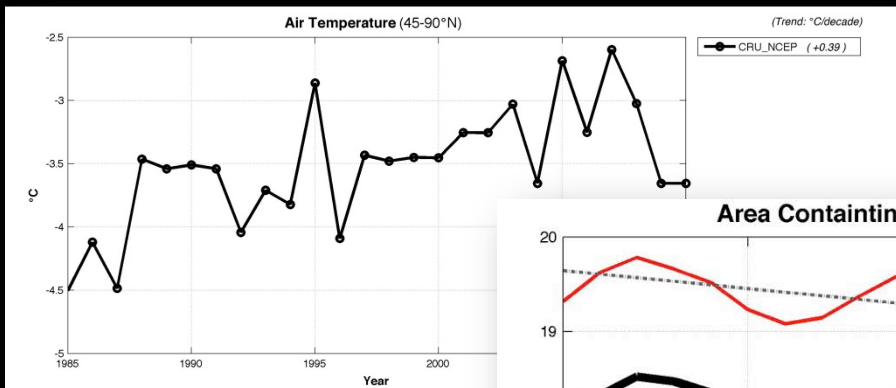


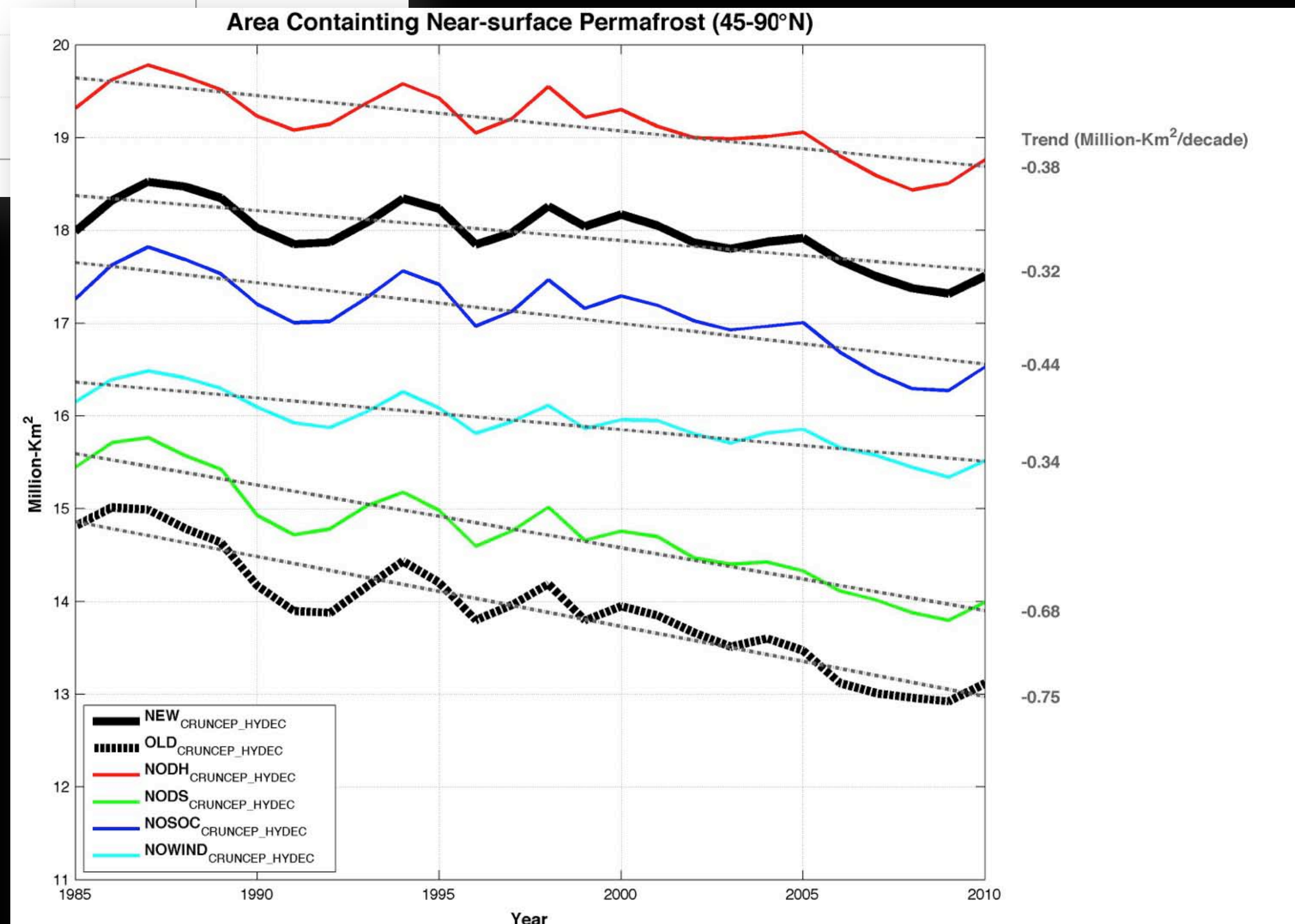
ISAM Permafrost Extent

Area containing near-surface permafrost (45 – 90°N) (million Km^2)

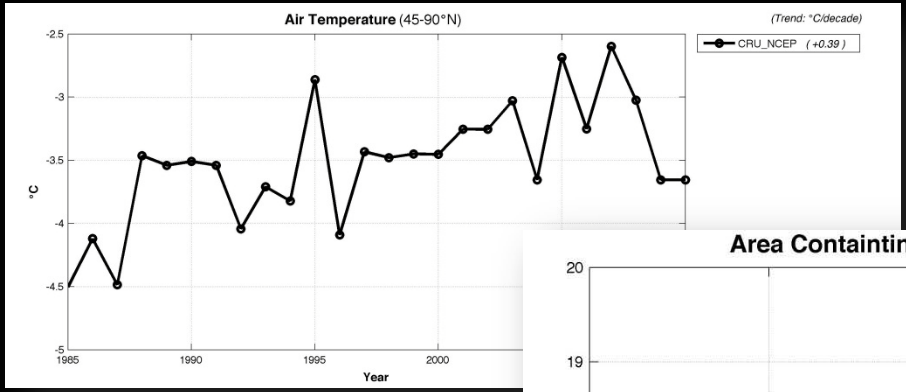
- Observations ~ 19.35
- OLD ~ 15 million Km^2
- NEW ~ 18 million Km^2

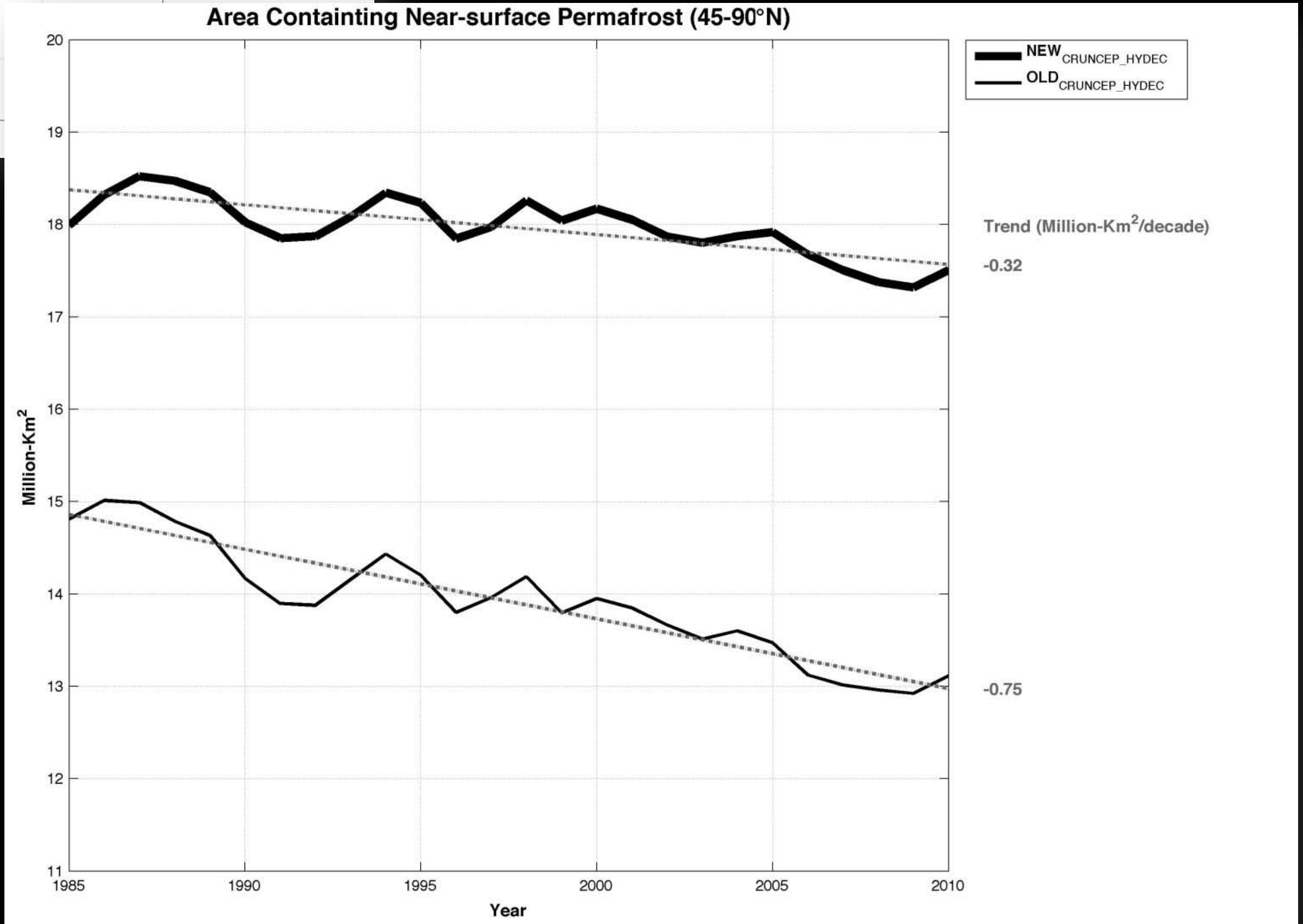
Permafrost Degradation: Impact of Added Model Processes





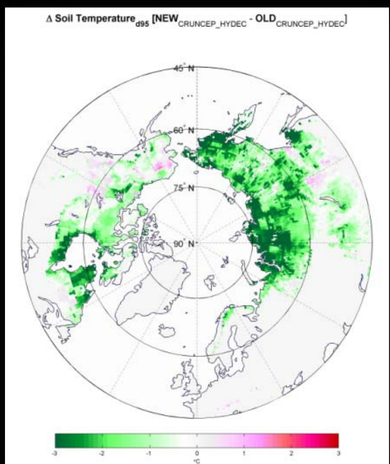
Permafrost Degradation: Impact of Added Model Processes



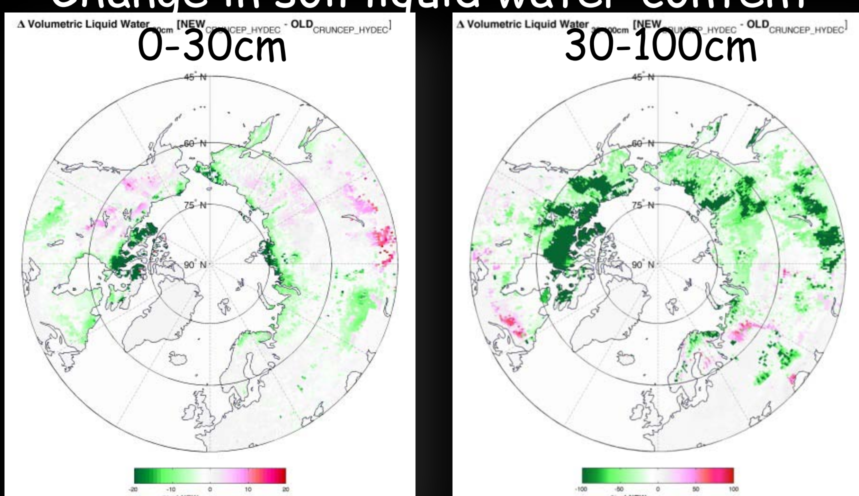


Impact of Added Processes on Permafrost Soil Temperature & Hydrology (model spun up for ~30,000 years)

Change in soil temperature (^{O}C)



Change in soil liquid water content



<u>Deep Soils</u>

- Modifies the thermal dynamics in the soil by changing the tem gradient from top to bottom of soils ; usually cool the lower soil layers

<u>Soil Organic Carbon</u>

- Impact the soil thermal conductivity

<u>Wind Compaction</u>

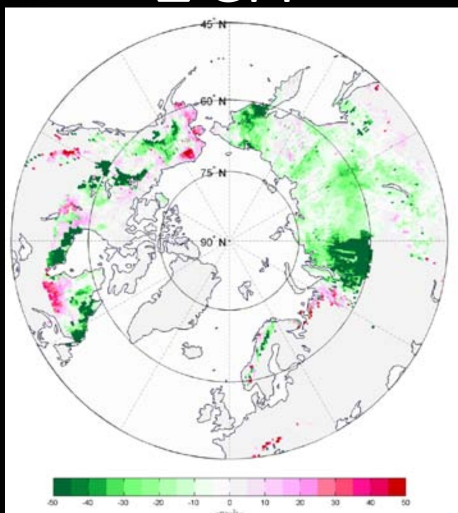
- Cooler Soil Temp due to more efficient heat flow out of the soil in winter

<u>DH</u>

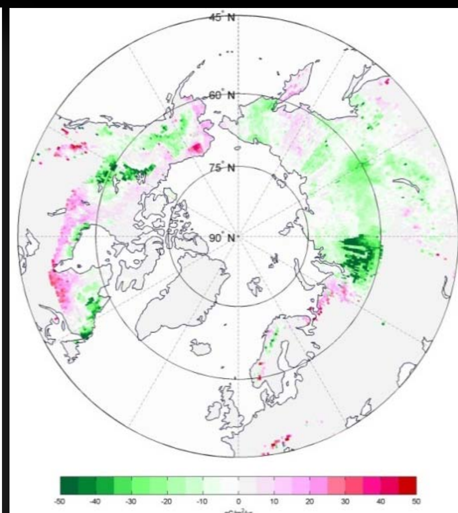
- Warmer soil temp because DH has low thermal conductivity

Impacts of Biogeophysics Improvements on Permafrost GPP, NPP, Soil C & N (model spun up for ~30,000 years)

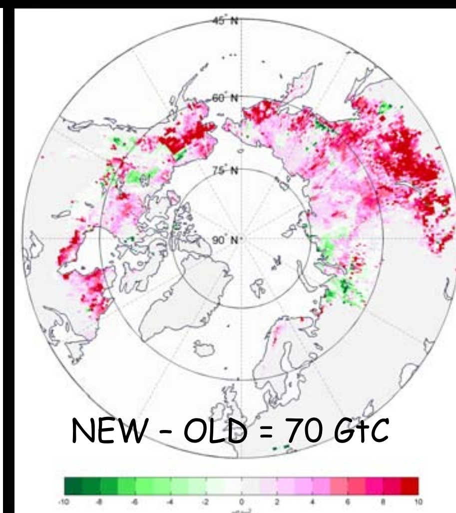
Δ GPP



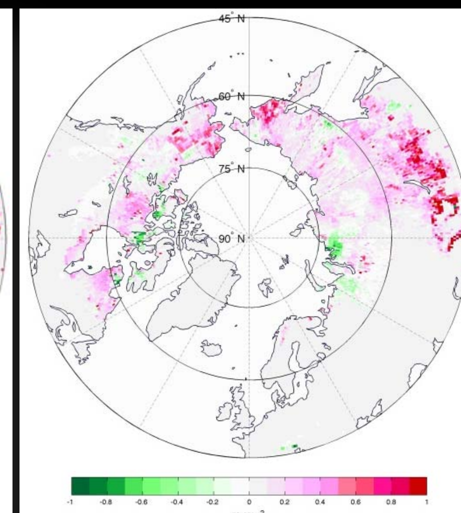
Δ NPP



Δ Soil Carbon

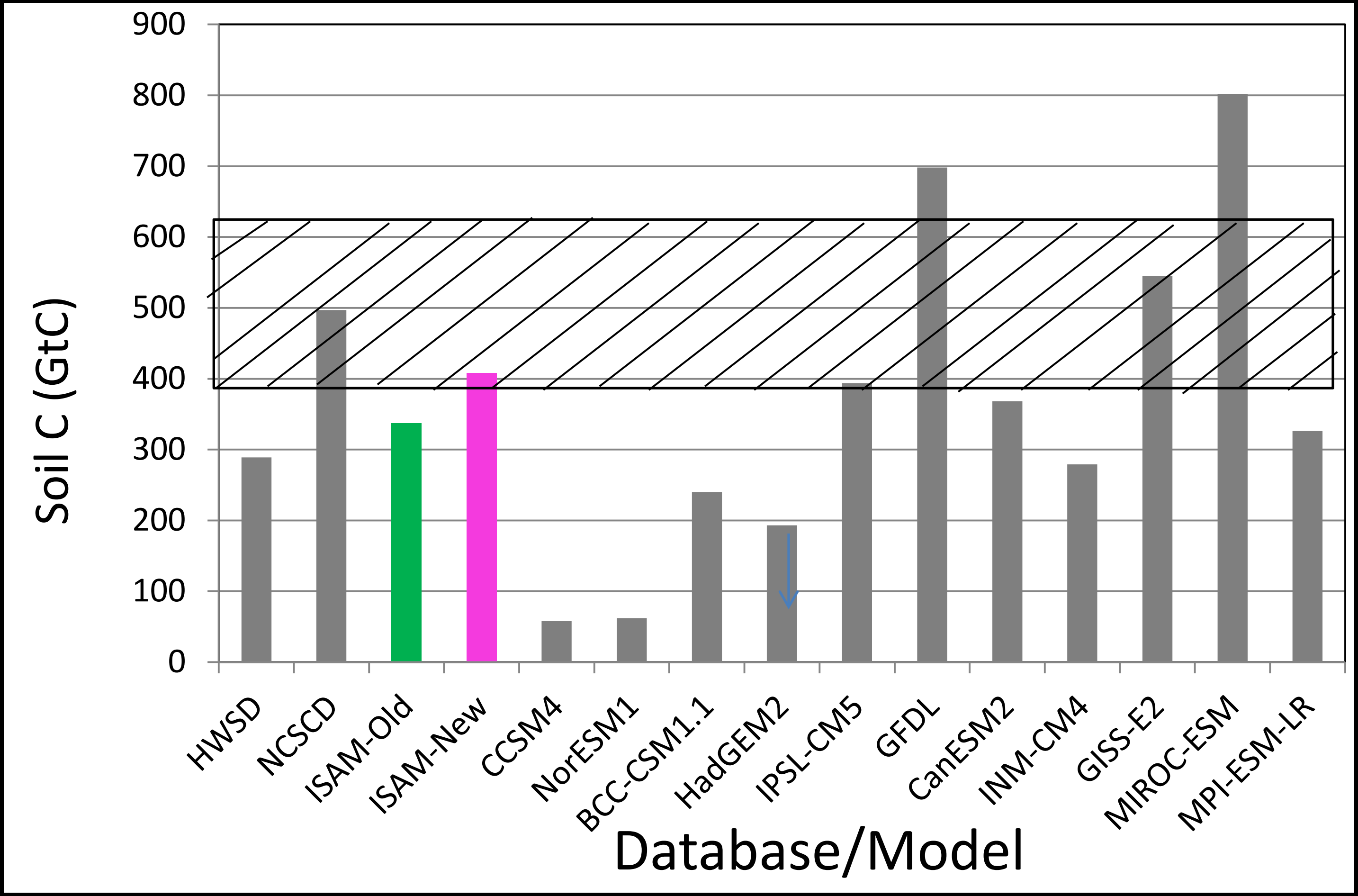


Δ Soil Nitrogen



(Δ = New minus Old)

Comparison of ISAM Estimated Soil Carbon With Datasets (HWSD & NCSCD) and CMIP5 Models



Modified based on Todd-Brown et al (2012)

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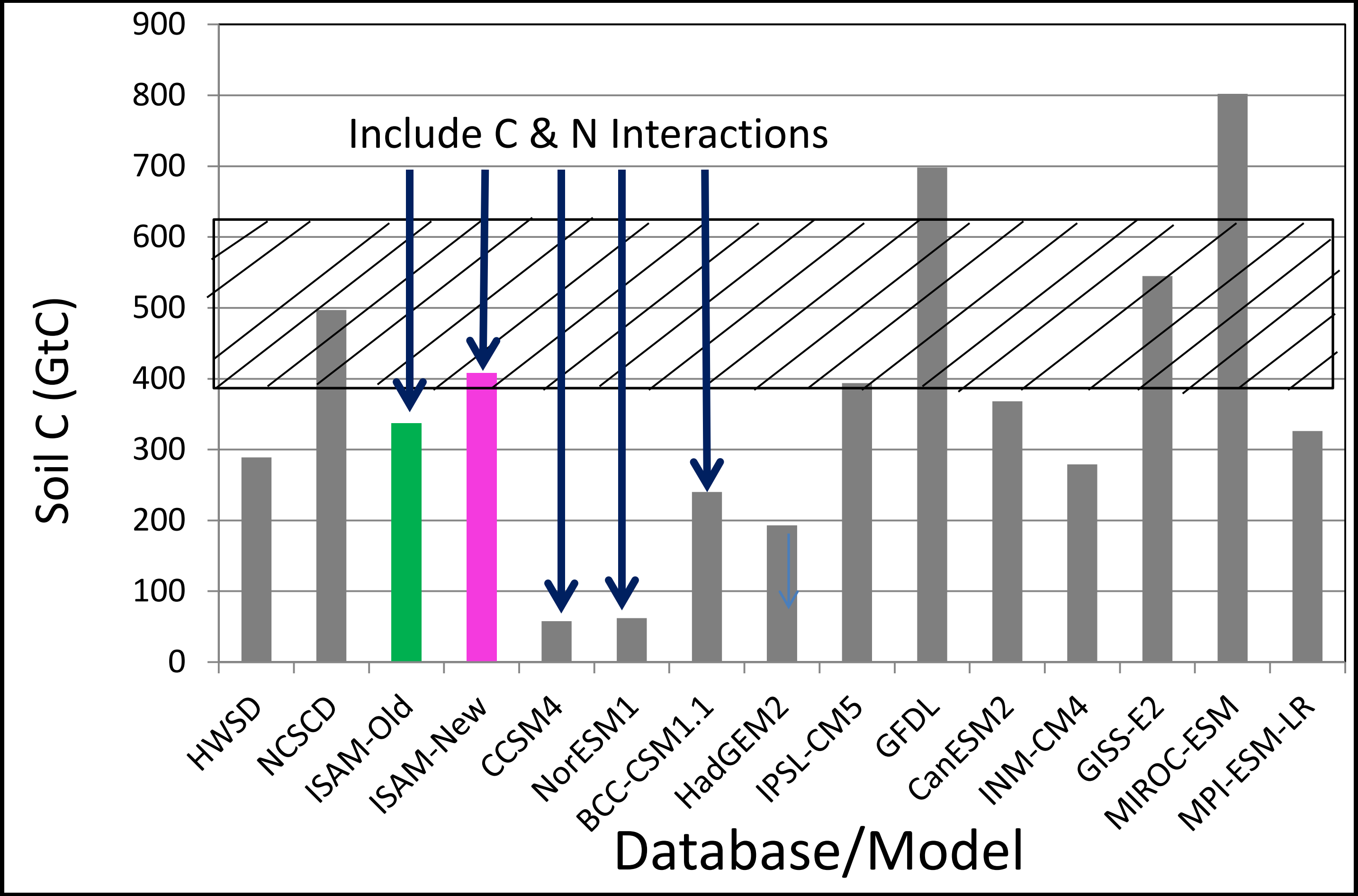


Modified based on Todd-Brown et al (2012)

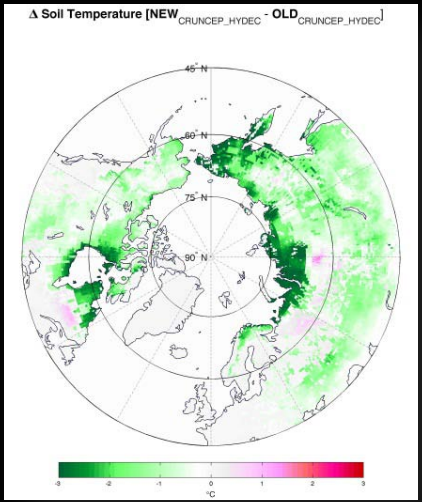
Conclusions

- Improvements in biogeochemistry processes alone do not help to improve the soil biogeochemistry
- Improvements in soil data and biogeophysical processes improve the characteristics of the permafrost and soil biogeochemistry
- In-situ observational for the NHL are infrequent/scarce, which hinders the model evaluation process

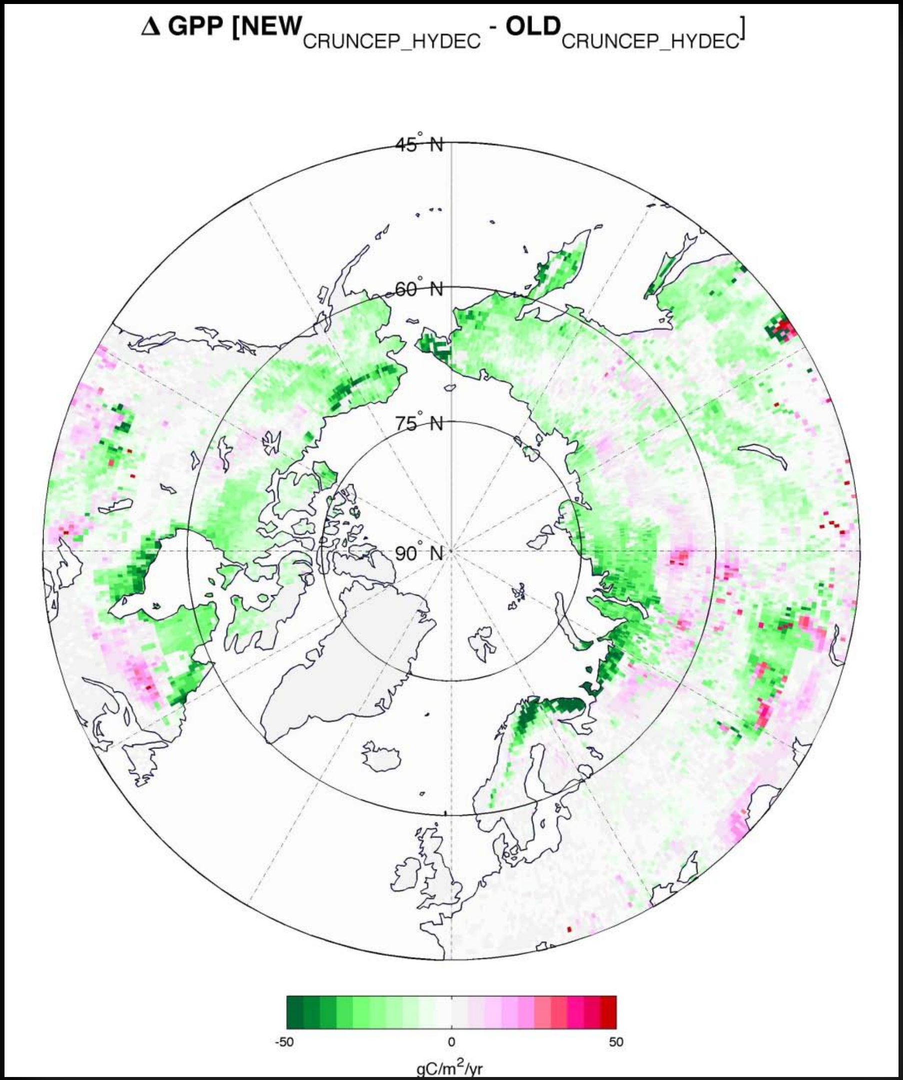
Extra Slides

Impact on Soil Temperature & Hydrology on GPP: Averaged Over 2000-2004

Change in soil temperature (^{O}C)

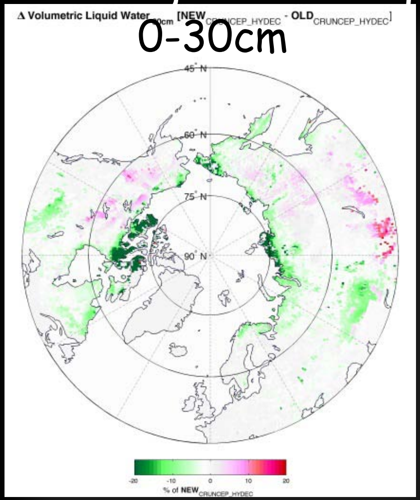


Change in GPP

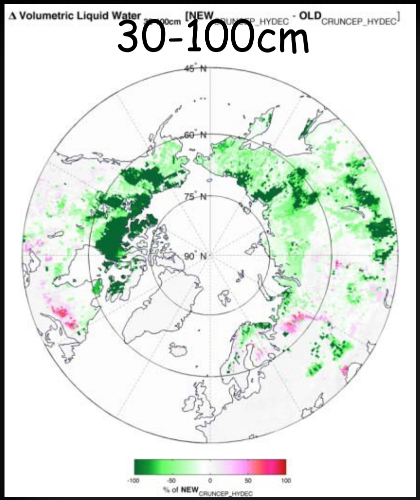


Change in soil liquid water content

0-30cm

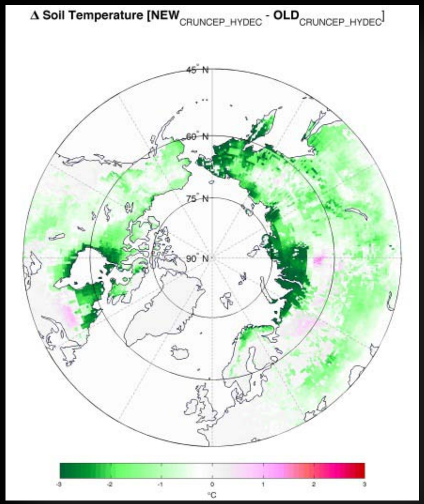


30-100cm



Impact of Added Processes on Soil Temperature & Hydrology : Averaged Over 2000-2004

Change in soil temperature (^{O}C)



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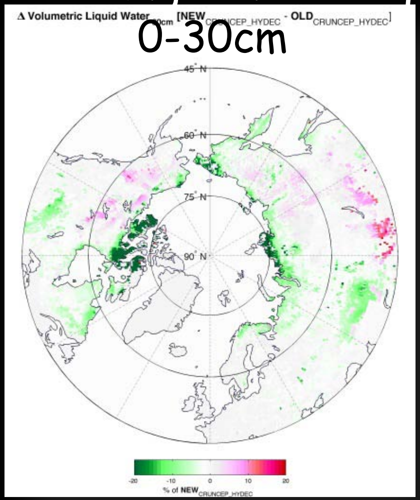

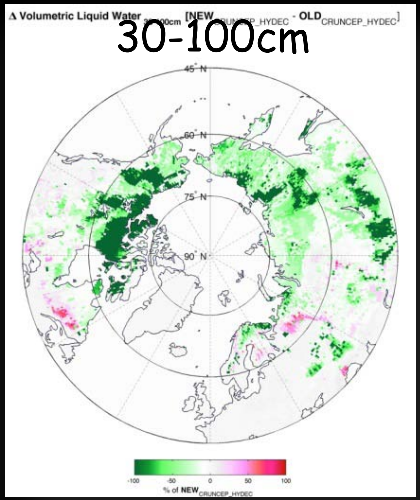

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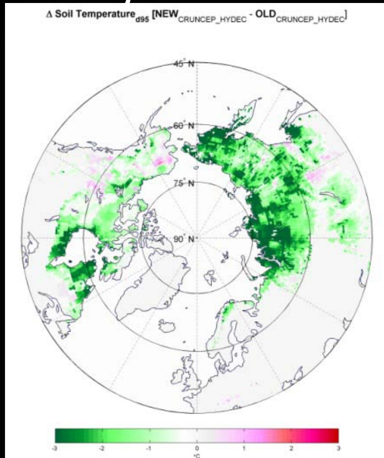
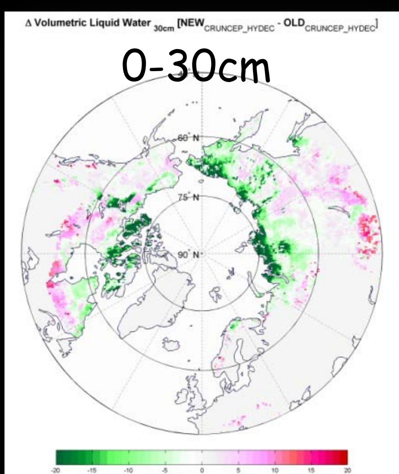
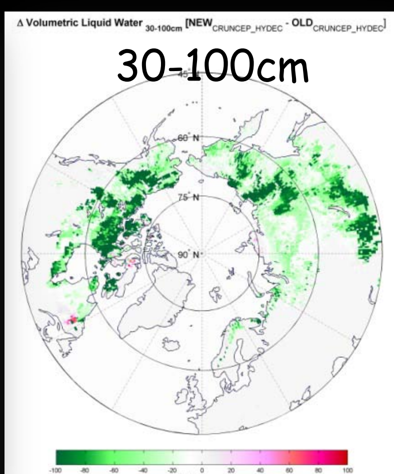
Impacts of Biogeophysics Improvements on Permafrost GPP
(model spun up for ~30,000 years)

Change in soil temperature (°C)

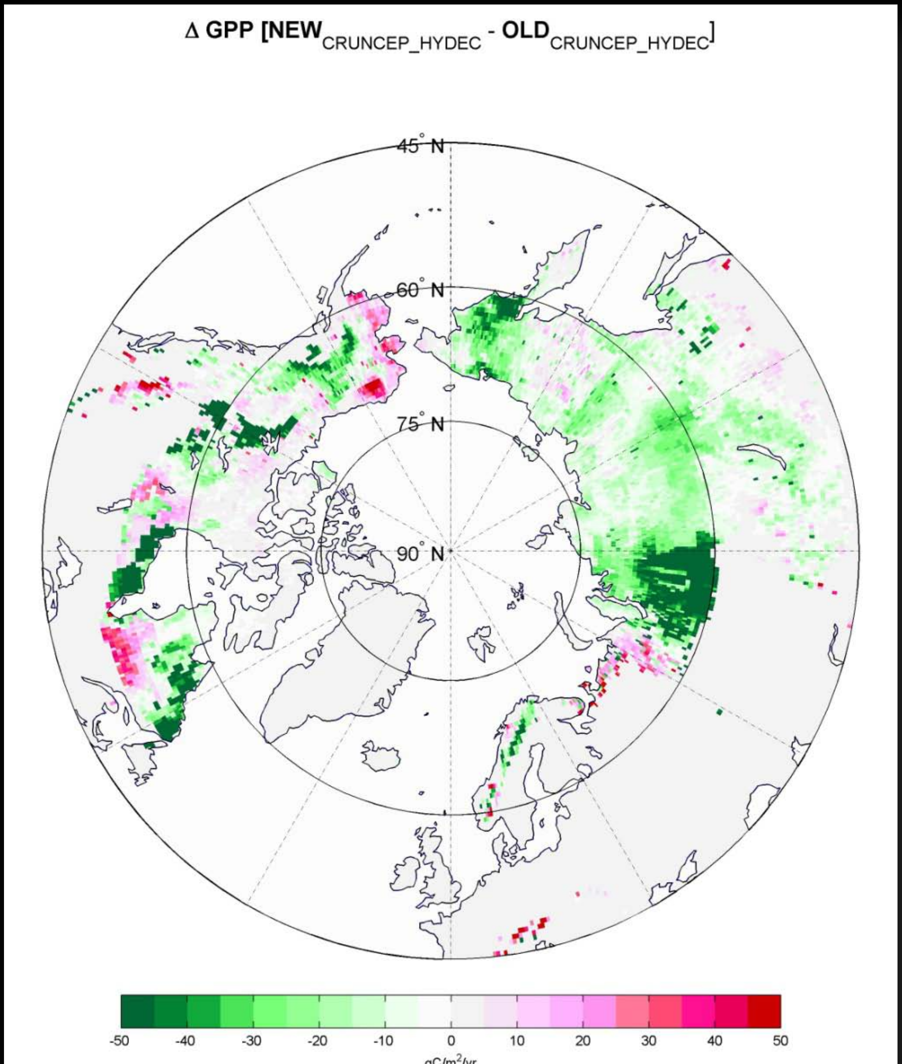


Change in soil liquid water content



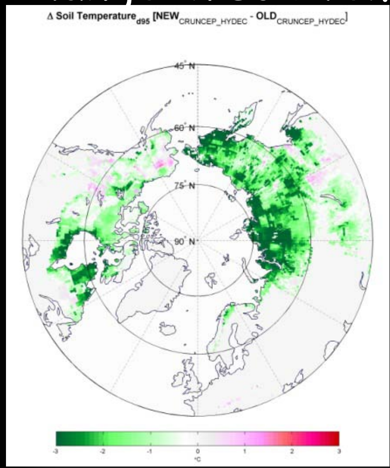


Change in GPP

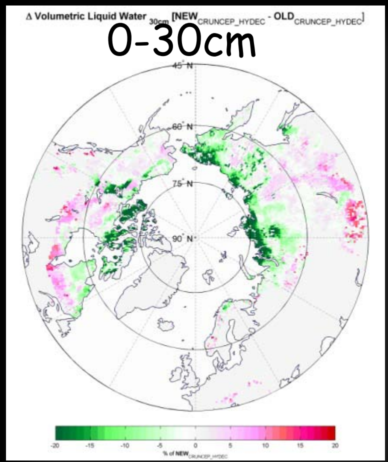


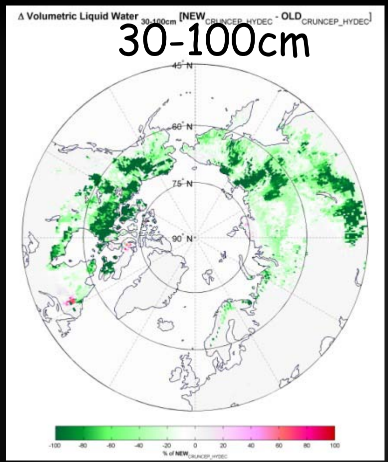
Impacts of Biogeophysics Improvements on Permafrost Soil C Accumulation (model spun up for ~30000 years)

Change in soil temperature (^{O}C)

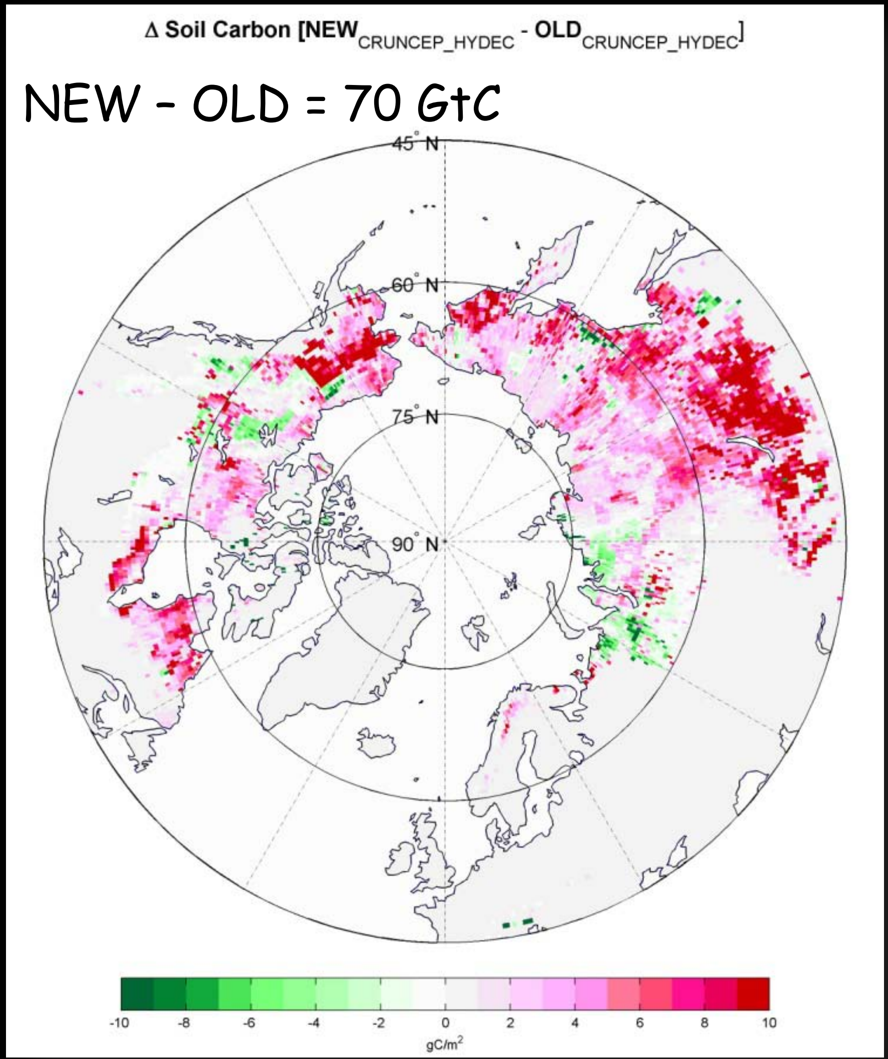


Change in soil liquid water content



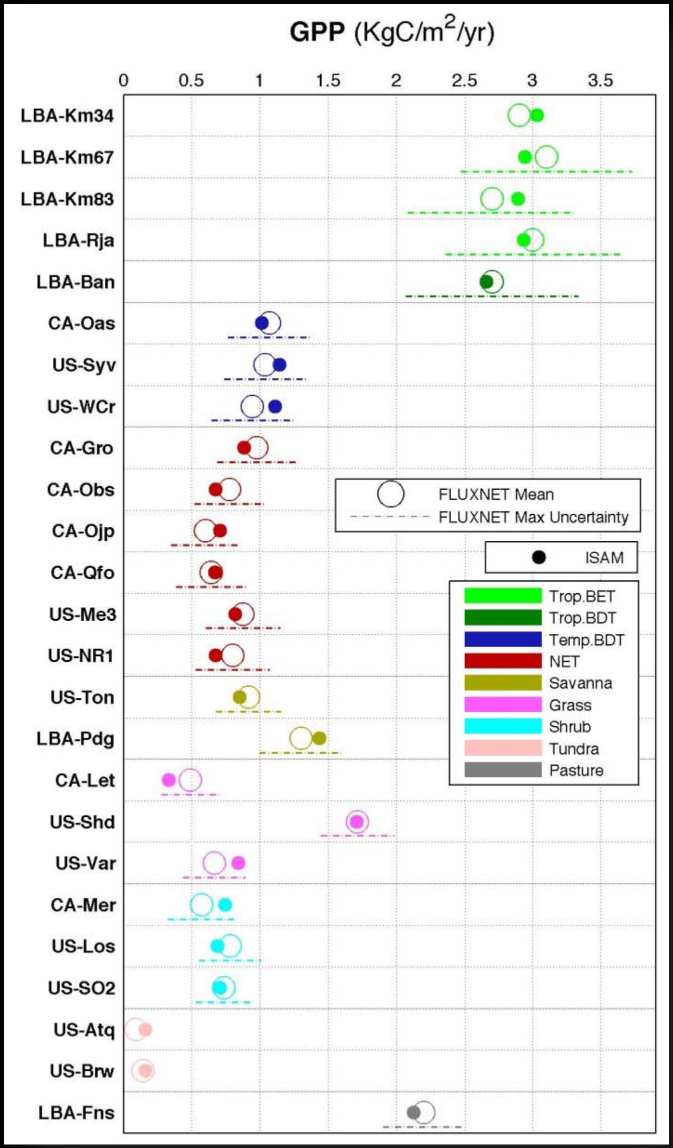


Change in Soil Carbon (NEW – OLD)



Improving the ISAM Using FLUXNET Data

Gross Primary Production

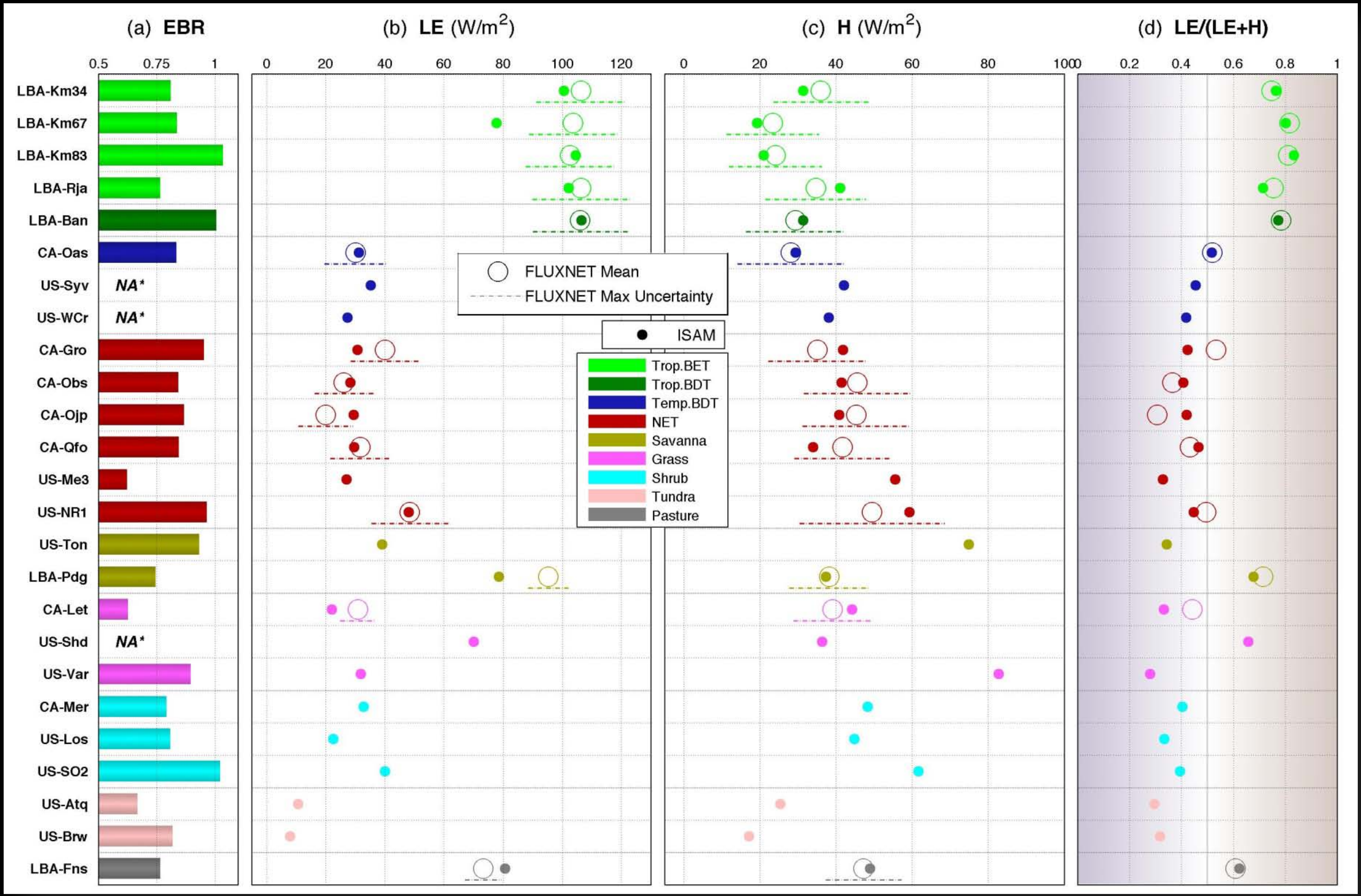


- V_{cmax25}^{opt} *f(N):* Maximum carboxylation capacity, down-regulated by nitrogen
- V_{cmax25}^{opt} *f(N)* in ISAM consistent with observed estimates from the TRY database ***[Kattage at al., 2009]***
- NHL ecosystems:
  - Implementation of low temperature stress on GPP reduced winter GPP bias, and also allowing for the use of V_{cmax25}^{opt} *f(N)* consistent with observations
  - Temperate & boreal forests: radiation, humidity & water-limited response to GPP
  - Cold grasses & cold shrubs: water-stress related response to GPP (i.e., dependent on precipitation, humidity, cold temperature)
  - Tundra: Temperature-limited response to GPP

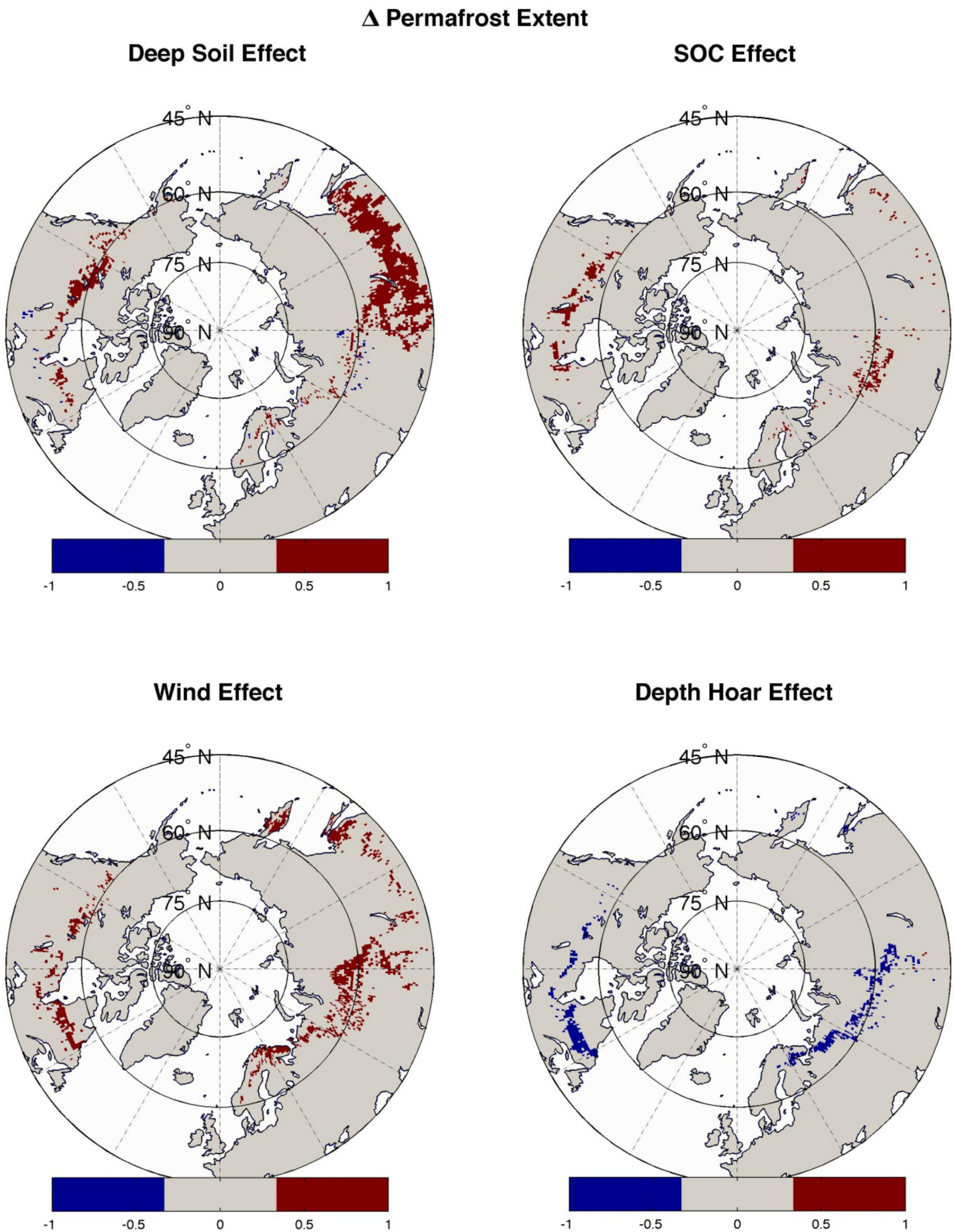
Barman et al. 2013a (to be sub.)

Improving the ISAM Using FLUXNET Data

Latent Heat (LE) & Sensible Heat (H) fluxes

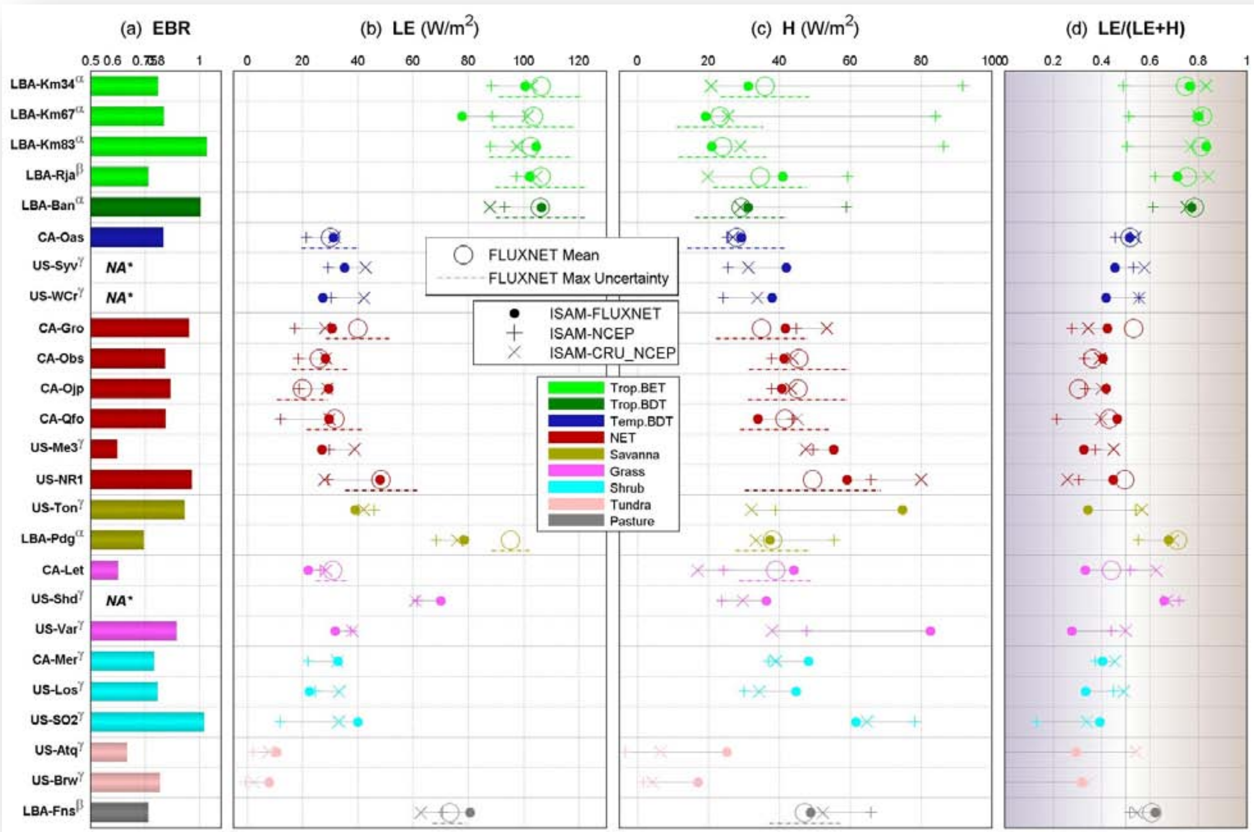


Barman et al. 2013b (to be sub.)


Δ Permafrost Extent
Deep Soil Effect
SOC Effect
Wind Effect
Depth Hoar Effect
45° N
60° N
75° N
90° N
-1
-0.5
0
0.5
1

Analysis of meteorology-driven model biases

Impact on Latent Heat (LE) & Sensible Heat (H) fluxes



(EBR: Energy Balance Ratio)

Barman et al. 2013b (to be sub.)

1. *High energy/water flux biases observed using the NCAR-NCEP dataset; henceforth, the **CRU-NCEP** dataset was chosen as the primary driver for the model simulations*

Permafrost degradation: impact of dataset uncertainties