Community Land Model: Update on Progress, Plans, and Results from CCSM4 Simulations

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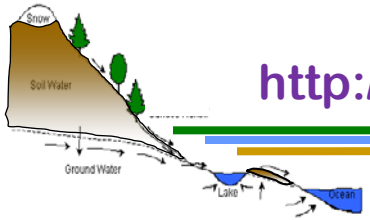
NCAR Earth System Laboratory

with input from lots of LMWGers

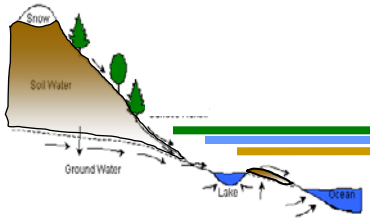
NCAR is sponsored by the National Science Foundation



Journal of Climate Special Collection papers

http://www.cesm.ucar.edu/publications/jclim10/docs/ccsm4.html

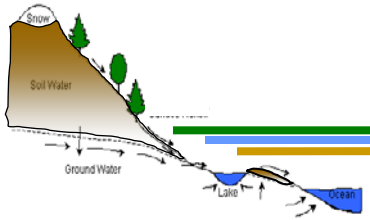
- The CCSM4 land simulation, 1850-2005: Assessment of surface climate and new capabilities
  - Lawrence D et al.
- The biophysical and biogeochemical impacts of landcover and land use change over 20th and 21st centuries
  - Lawrence P et al.
- Contrasts between urban and rural climate in CCSM4 CMIP5 climate change scenarios
  - Oleson
- Simulation of Present-day and Future Permafrost and Seasonally Frozen Ground Conditions in CCSM4
  - Lawrence D et al.



Journal of Climate Special Collection papers

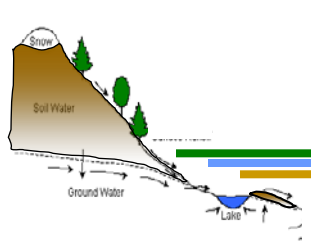
CESM1 submitted by Aug 1

- Mean and variability of the carbon cycle in CESM1
  - Lindsay et al.
- The transient carbon cycle response in CESM1
  - Lindsay et al.
- An assessment of terrestrial carbon and nitrogen cycling in CESM1
  - Thornton et al.
- Dynamic Vegetation in CESM1
  - Castillo and Levis
- Land-atmosphere interactions across several generations of CAM/CLM
  - Lawrence D et al.
- Crops in CESM1
  - Levis et al.

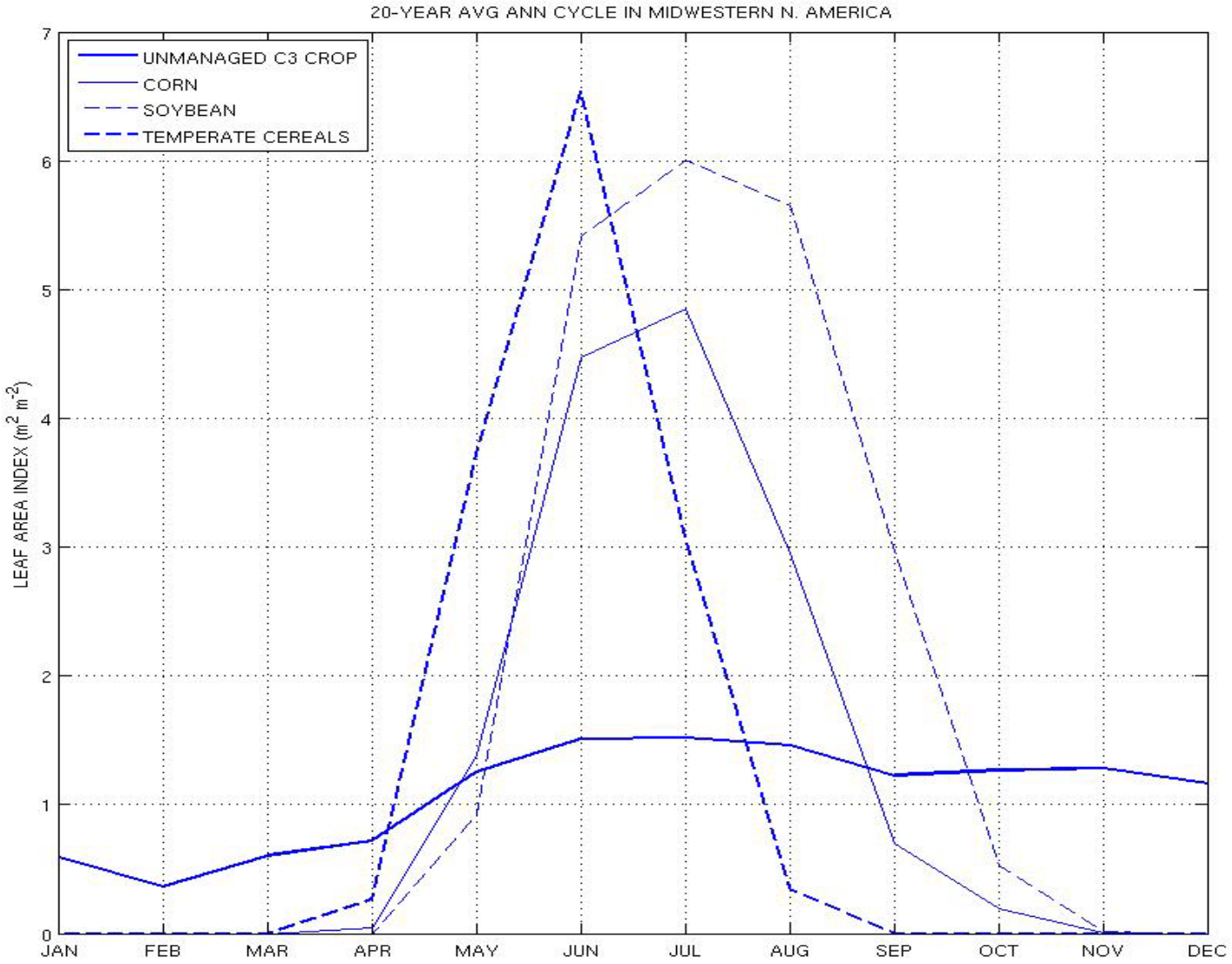


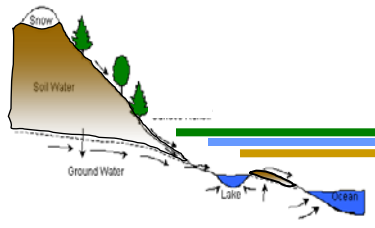
CESM1.0.3: Released on June 15, 2011

- **CLM4**
  - Crops (spring wheat, corn, soybean): planting, growth, harvesting
  - Irrigation: Area equipped for irrigation, water taken from runoff to maintain soil wetness above wilting point
  - Support for Flux Tower Site simulations (PTCLIM)
  - PFT physiology and RTM directional file converted to netCDF
  - Parallel I/O


Snow
Soil Water
Ground Water
Lake

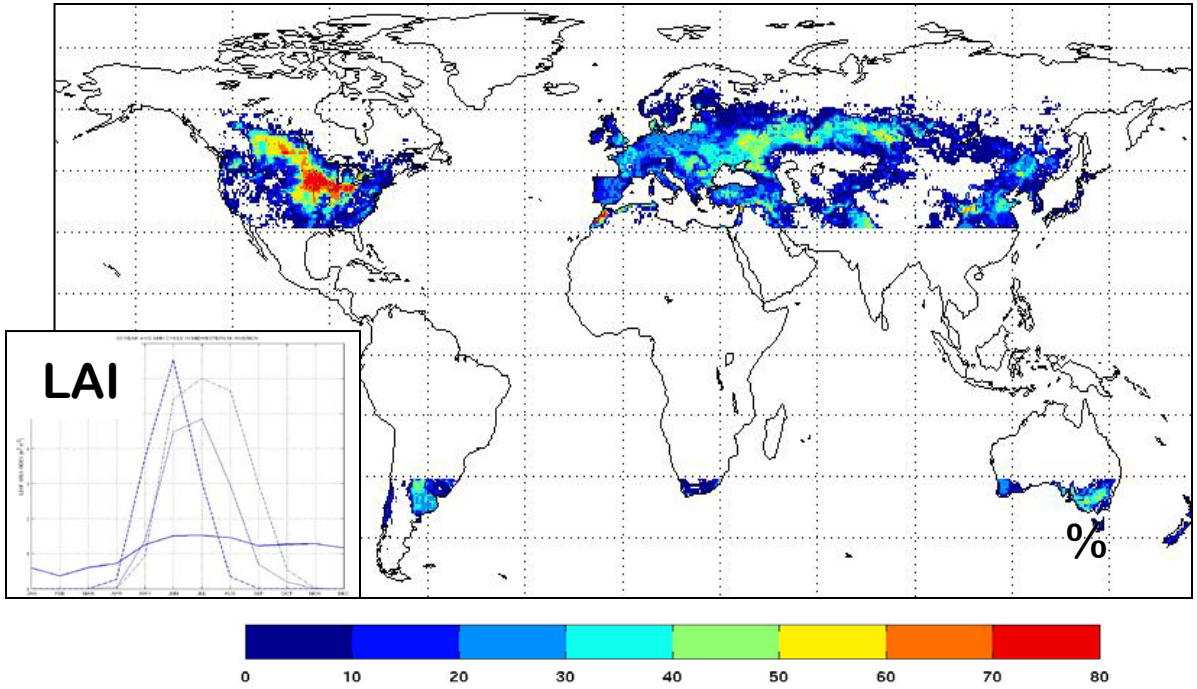
Crop LAI


20-YEAR AVG ANN CYCLE IN MIDWESTERN N. AMERICA
UNMANAGED C3 CROP
CORN
SOYBEAN
TEMPERATE CEREALS
LEAF AREA INDEX (m2 m-2)
0
1
2
3
4
5
6
7
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC



Optional Crop model (based on AgroIBIS)

Managed crop area



lake	wetland	glacier	urban
soil with unmanaged vegetation		unmanaged crop	
		corn	
		temperate cereal	
		soybean	

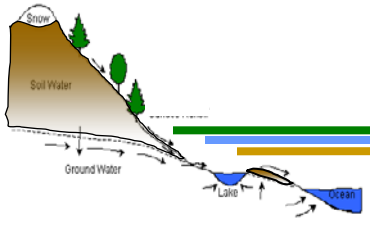
Effects of managed crop types:

- Ann. cycle of crop LAI vastly improved
- Ann. cycle of NEE improved
- CAM simulation affected
- Central U.S. summer precip improved

Applications:

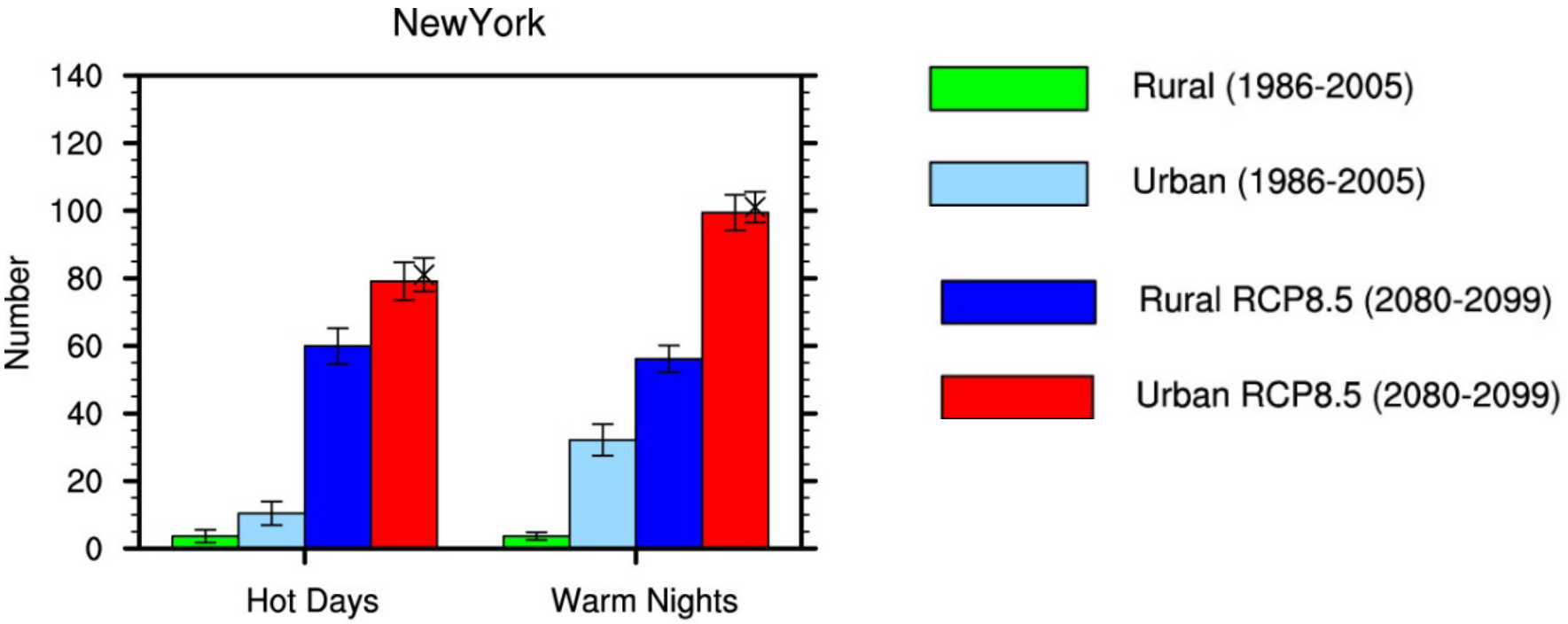
- Food… crop yields
- Fuel… biofuels
- Biogeophysical and biogeochemical land/atm interactions

Results from CCSM4



Changes in hot days and warm nights – RCP8.5

Hot days (warm nights) – Number of days per year that daily TMAX (TMIN) exceeds 99th percentile of present day Rural daily TMAX (TMIN)



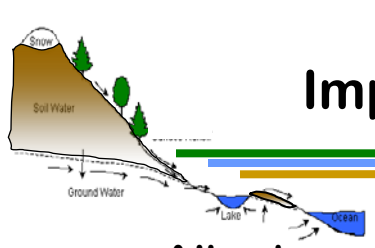
Present-day climate

Cities have more hot days and warm nights than rural land

21st century climate change

Cities increase more in hot days and warm nights than does rural land

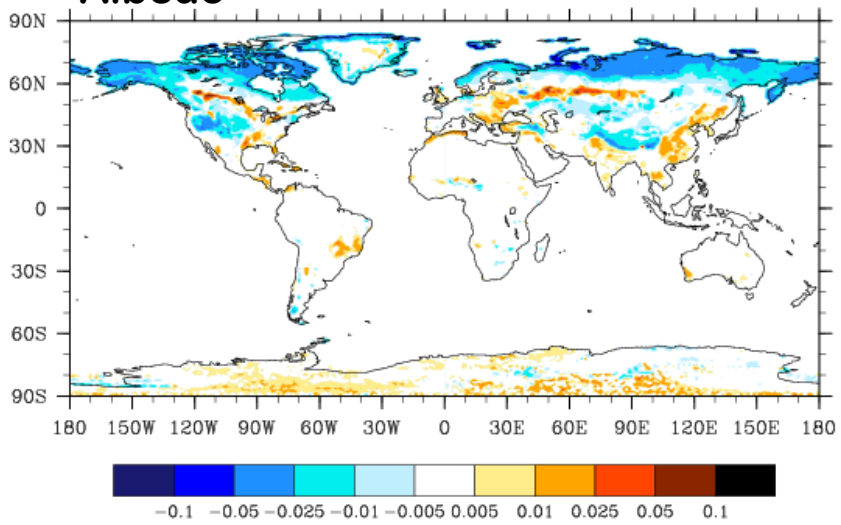
Slide courtesy K. Oleson



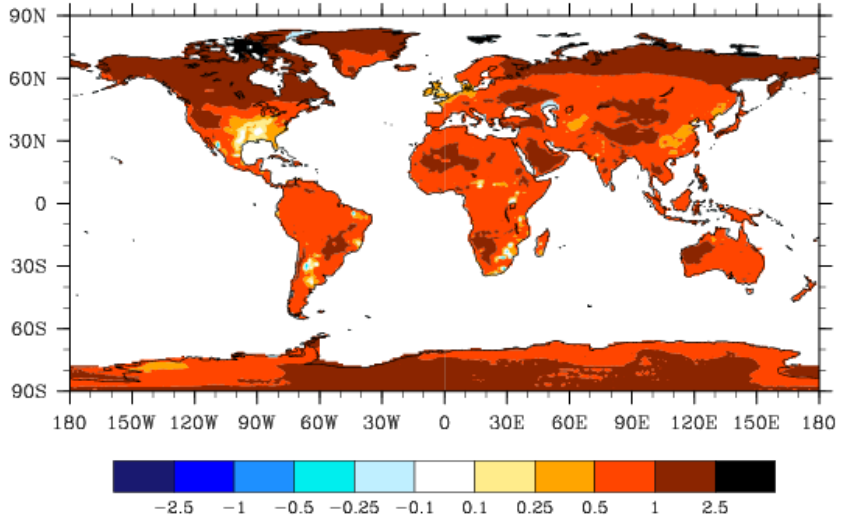
Impact of land cover change (1976-2005 minus 1850-1879)

All forcings

Albedo

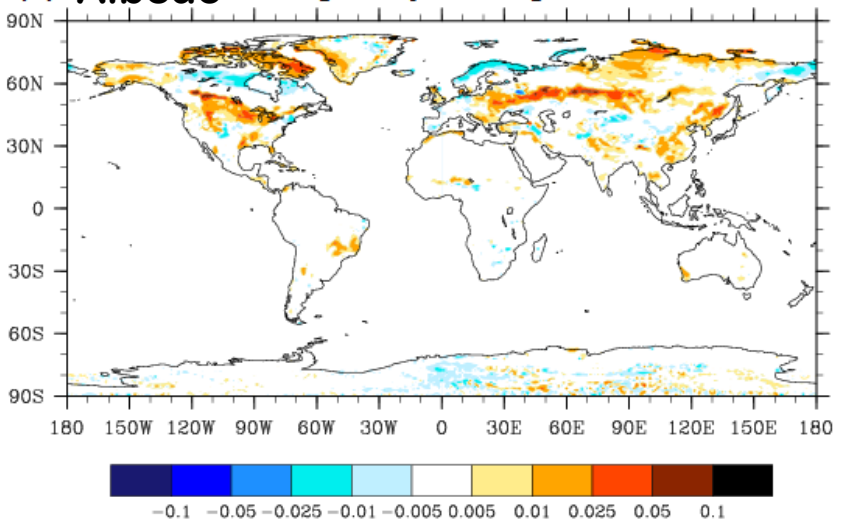


Air Temperature

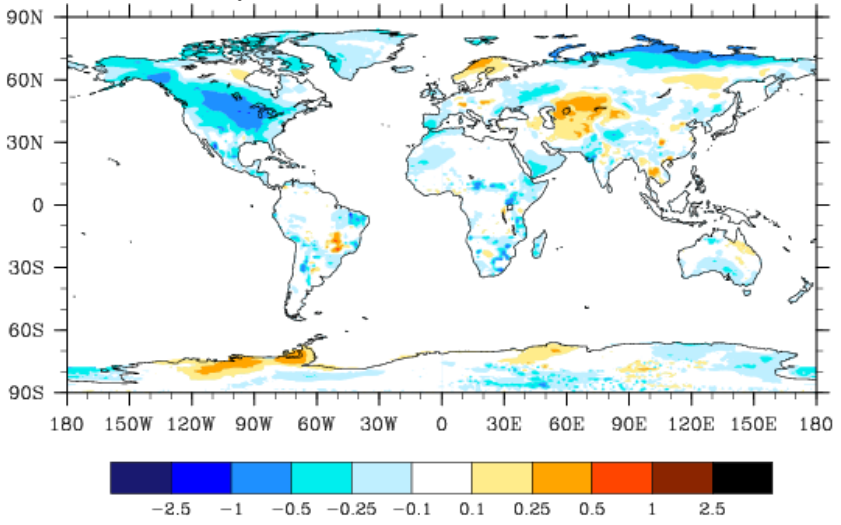


Land cover change only

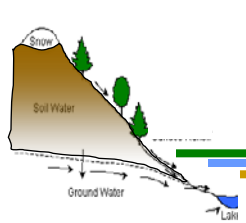
Albedo



Air Temperature

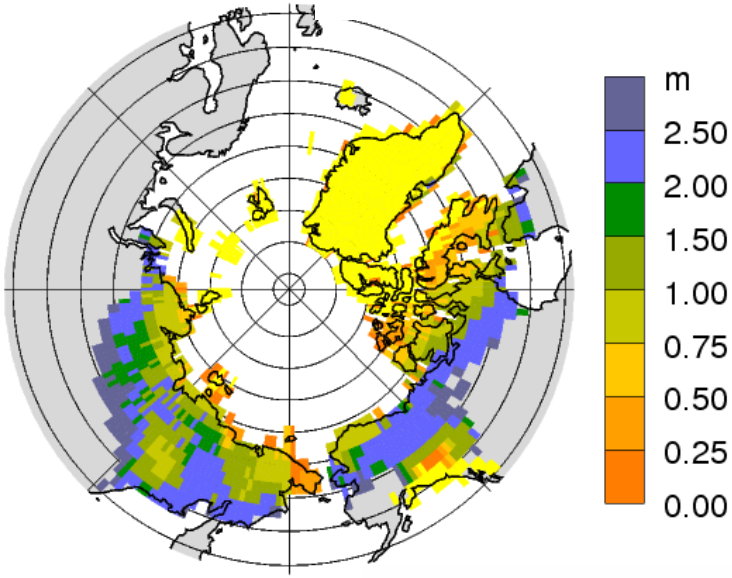


Lawrence, P. et al., 2011, J. Clim

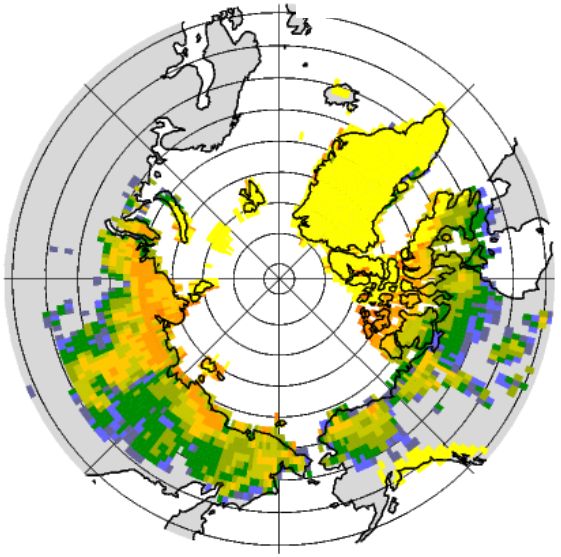


Near-surface permafrost extent and ALT in CCSM (1980-99)

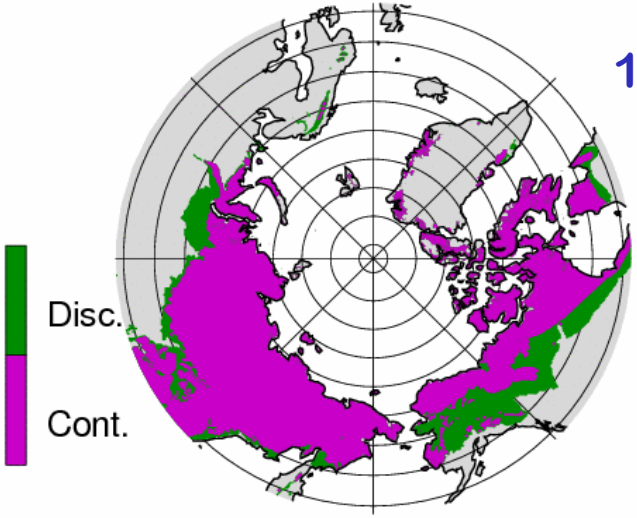
CCSM3 **10.7 million km^2**



CCSM4 **12.5 million km^2**

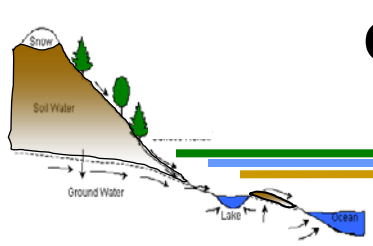


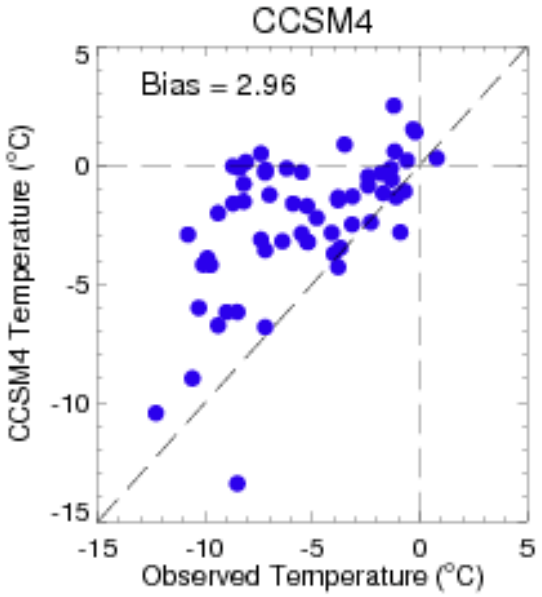
IPA Observed Extent

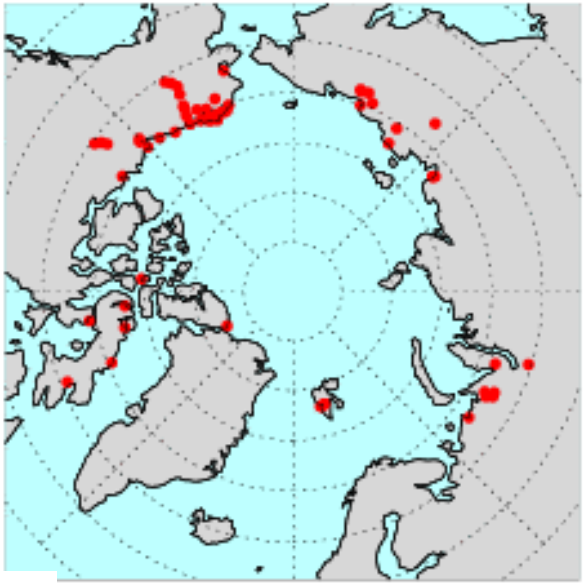


11.8-14.6 million km^2

Coupled versus offline comparison of deep ground (> 15m deep) temperatures

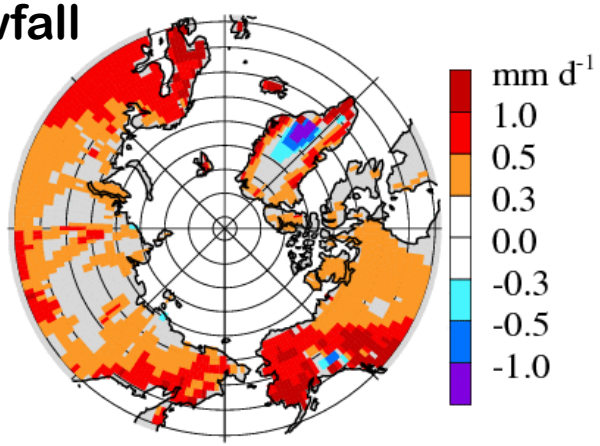






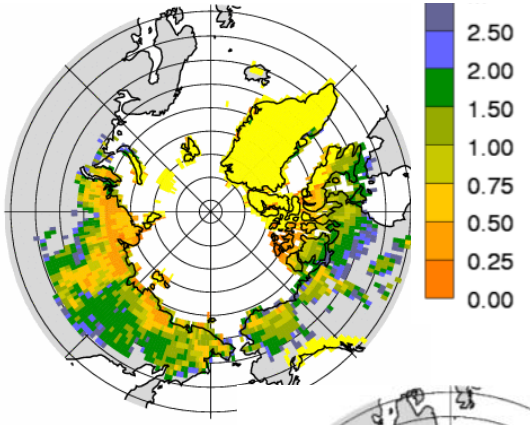
CCSM4
NDJFMA Bias = 0.49mm d^{-1}

Snowfall

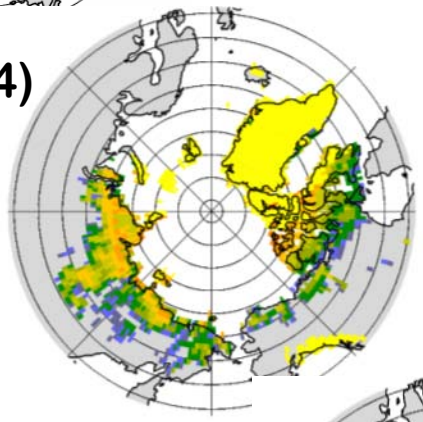


Projections of degradation of near-surface permafrost in CCSM4

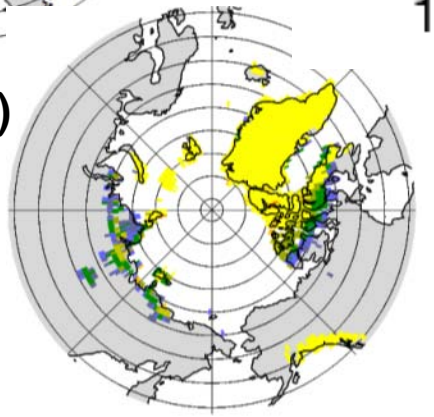
1970-1990 (12.5)

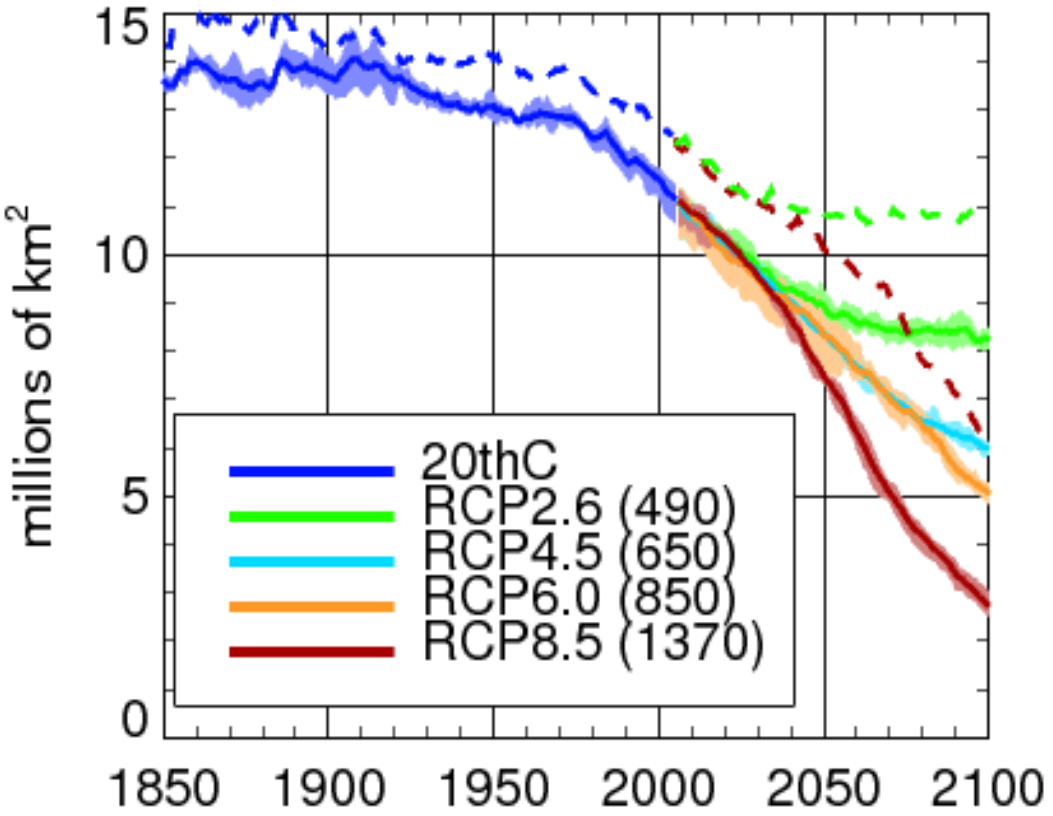


RCP2.6 (8.4)
2080-2100

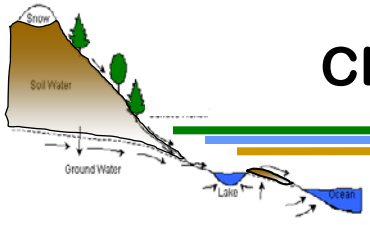


RC8.5 (3.5)
2080-2100

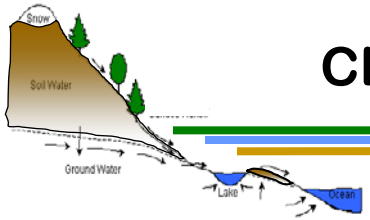




Lawrence et al., 2011, J. Clim.



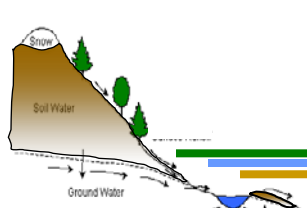
CLM4.5 (potential release with CESM update, late 2012)

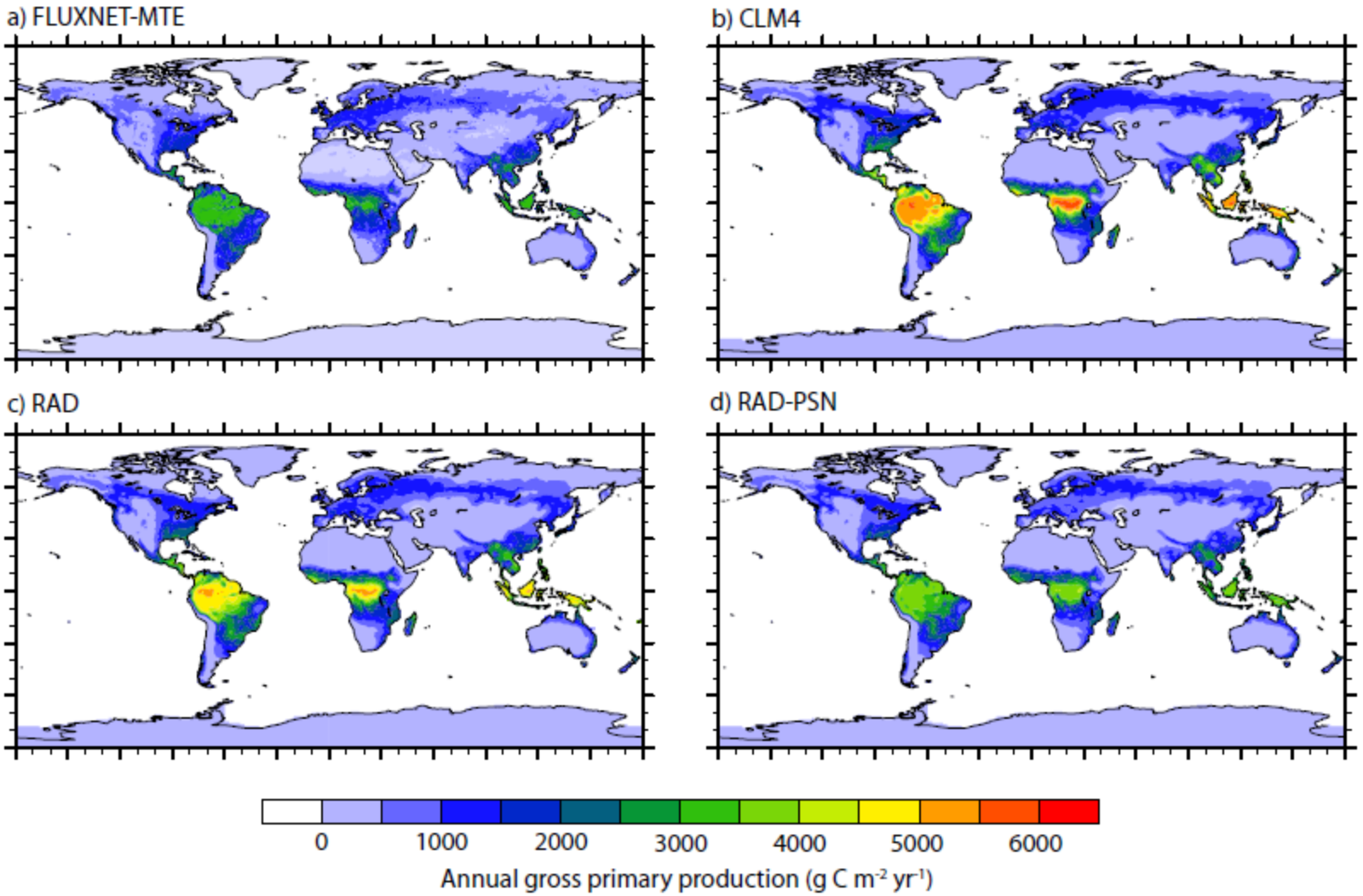


CLM4.5 (potential release with CESM update, late 2012)

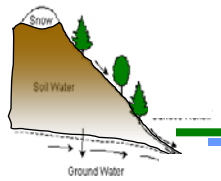
- **Crops and irrigation**
  - Connect crops and irrigation
  - Fertilization and other updates, expand #/area crop PFTs
- **Canopy physiology**
  - Update GPP (Bonan et al. 2011); multilayer canopy radiation and photosynthesis, leaf optimization
- **Revised cold region hydrology**
  - Impedance factor, perched water table
  - Surface water store (prognostic wetlands)
  - New snow cover fraction param; separate surface energy calc for snow covered, surface water, and bare ground surfaces
  - 2-way CLM grid cell – RTM interactions (flooding)
  - Variable flow velocity based on slope

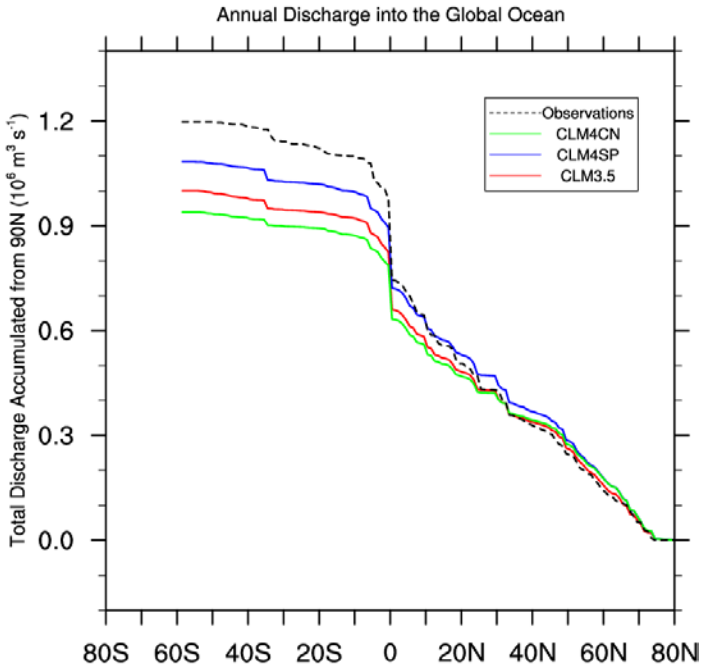
Gross Primary Productivity

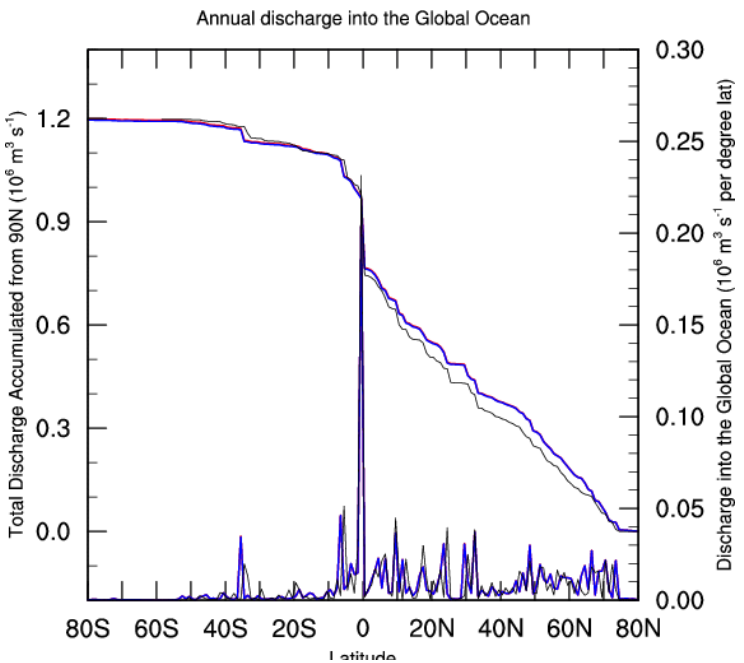


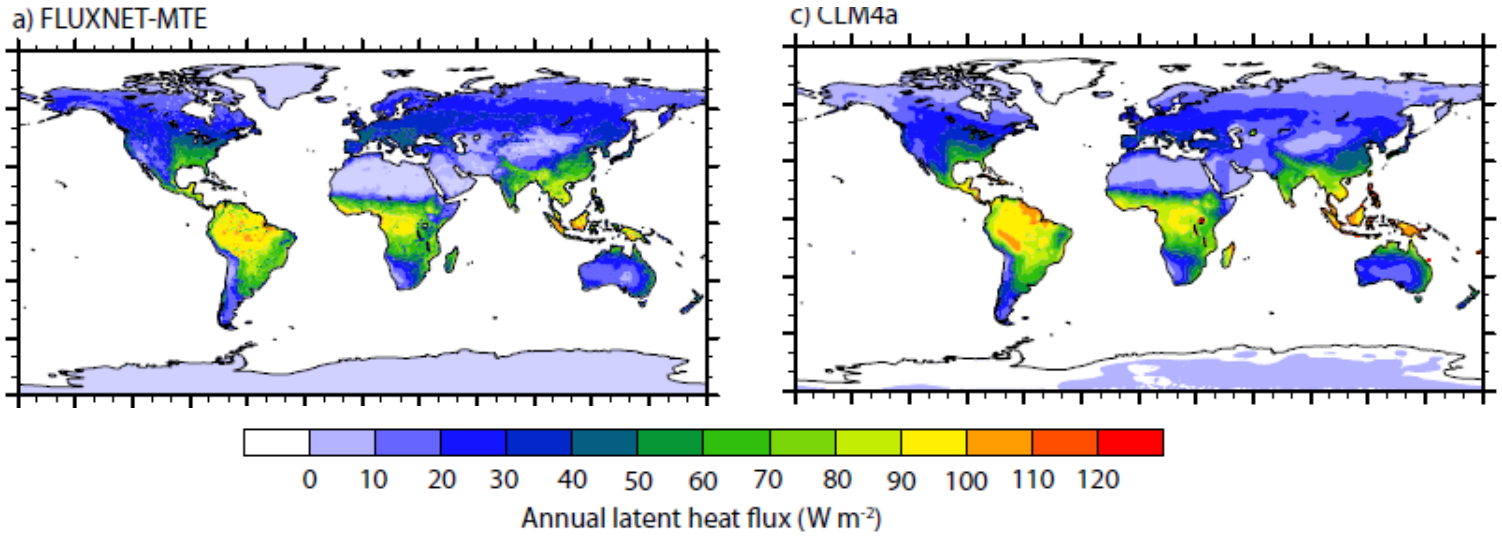


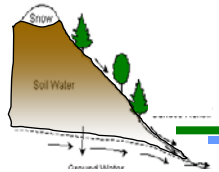
Impact of canopy physiology improvements on evapotranspiration



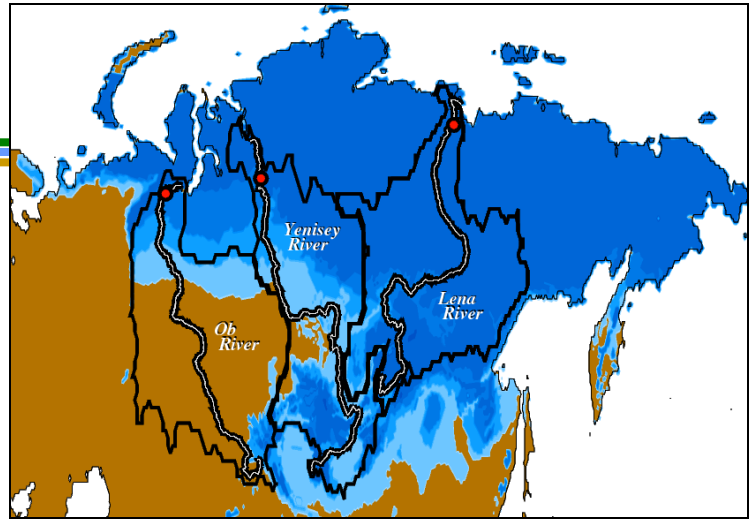








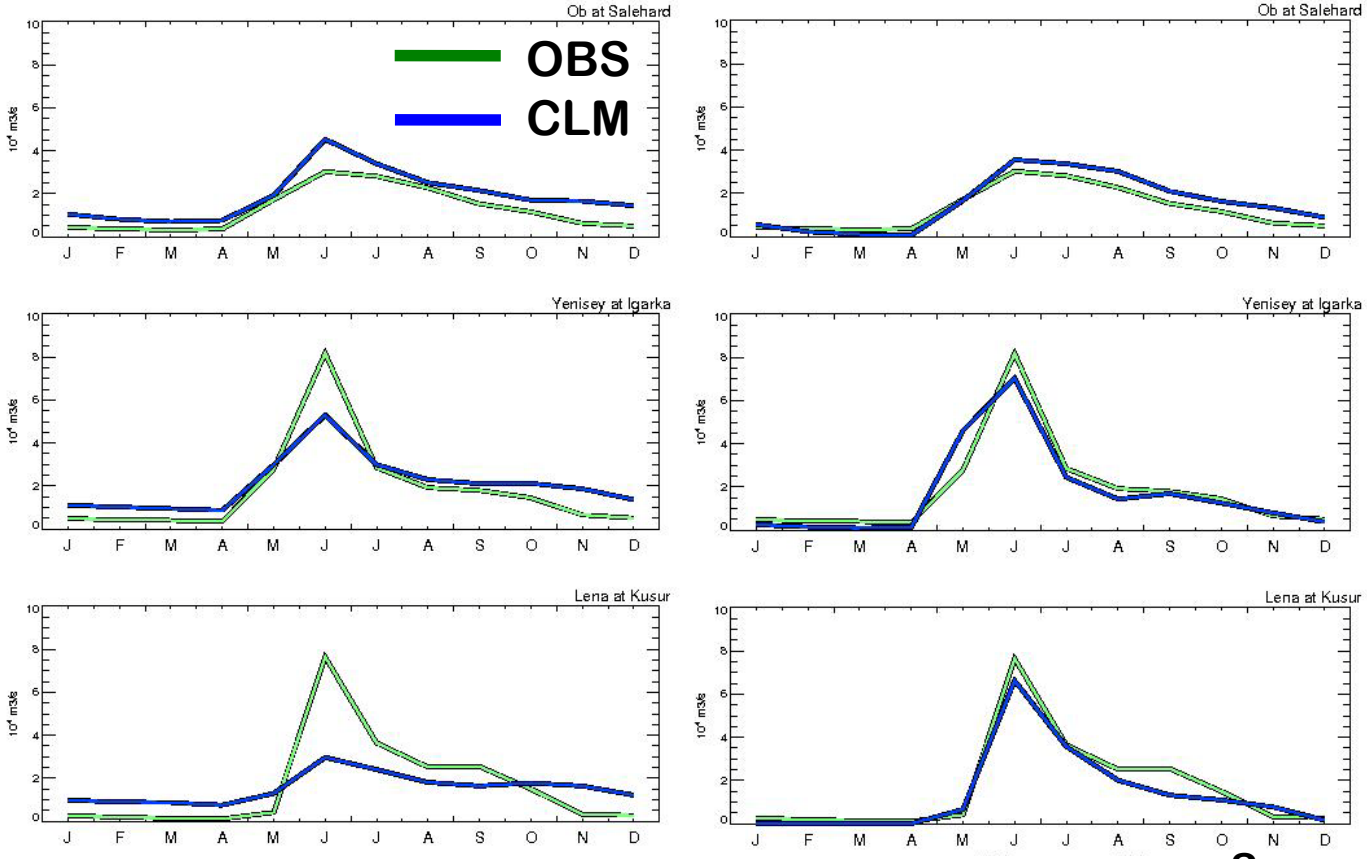
Cold region hydrology



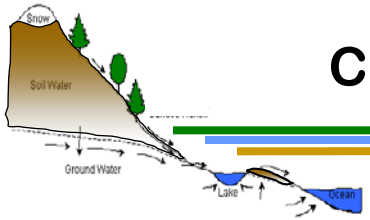
Results: better hydrographs for both permafrost basins and non-permafrost basins, better active layer hydrology, better vegetation?

Control

Ice Impedance + Wetlands



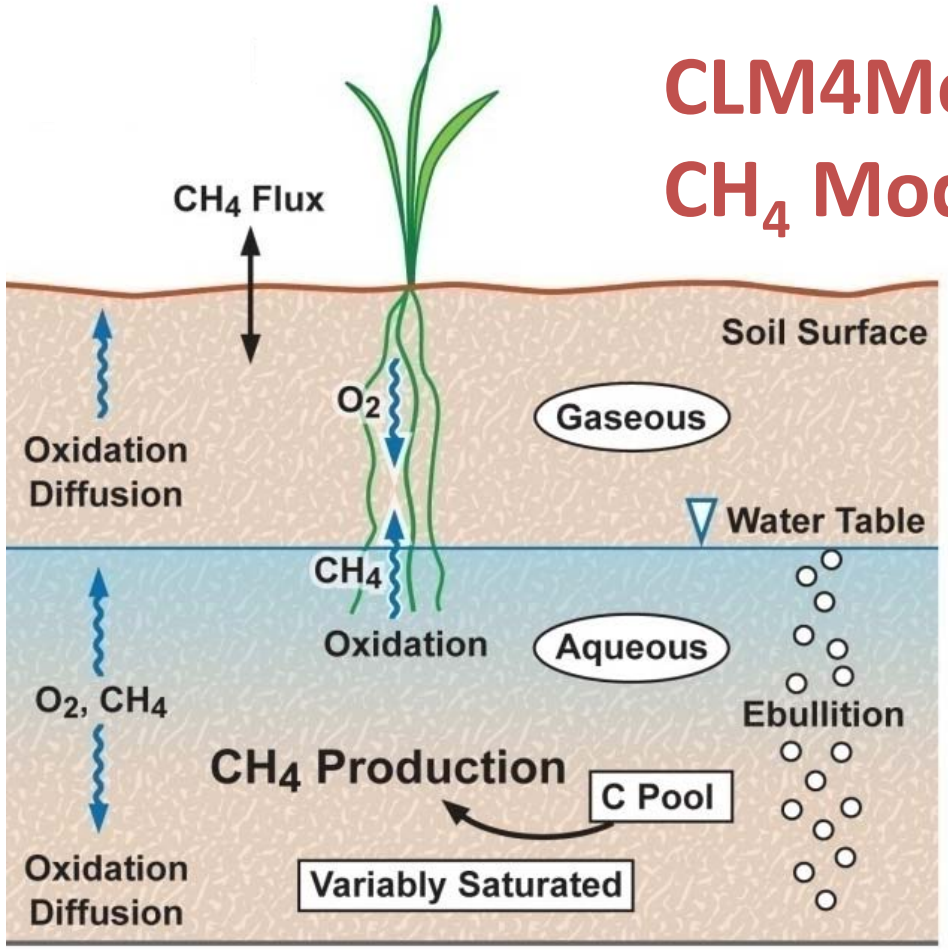
Swenson and Lawrence, in prep



CLM4.5 (potential release with CESM update late 2012)

- **Improved fire algorithm**
  - Includes human triggers and suppression (Kloster et al., 2010)
- **Methane emissions model (CLM4Me)**
  - Based on Riley et al. 2011; with options from Meng et al. 2011 (?)
- **Revised lake model**
  - New lake physics and lake area dataset (Subin et al. 2011)
- **Dynamic landunits**
  - Land unit transitions: e.g., glacier to vegetated, vegetated to crop, vegetated to urban, etc.

CLM4Me - CH_4 Model



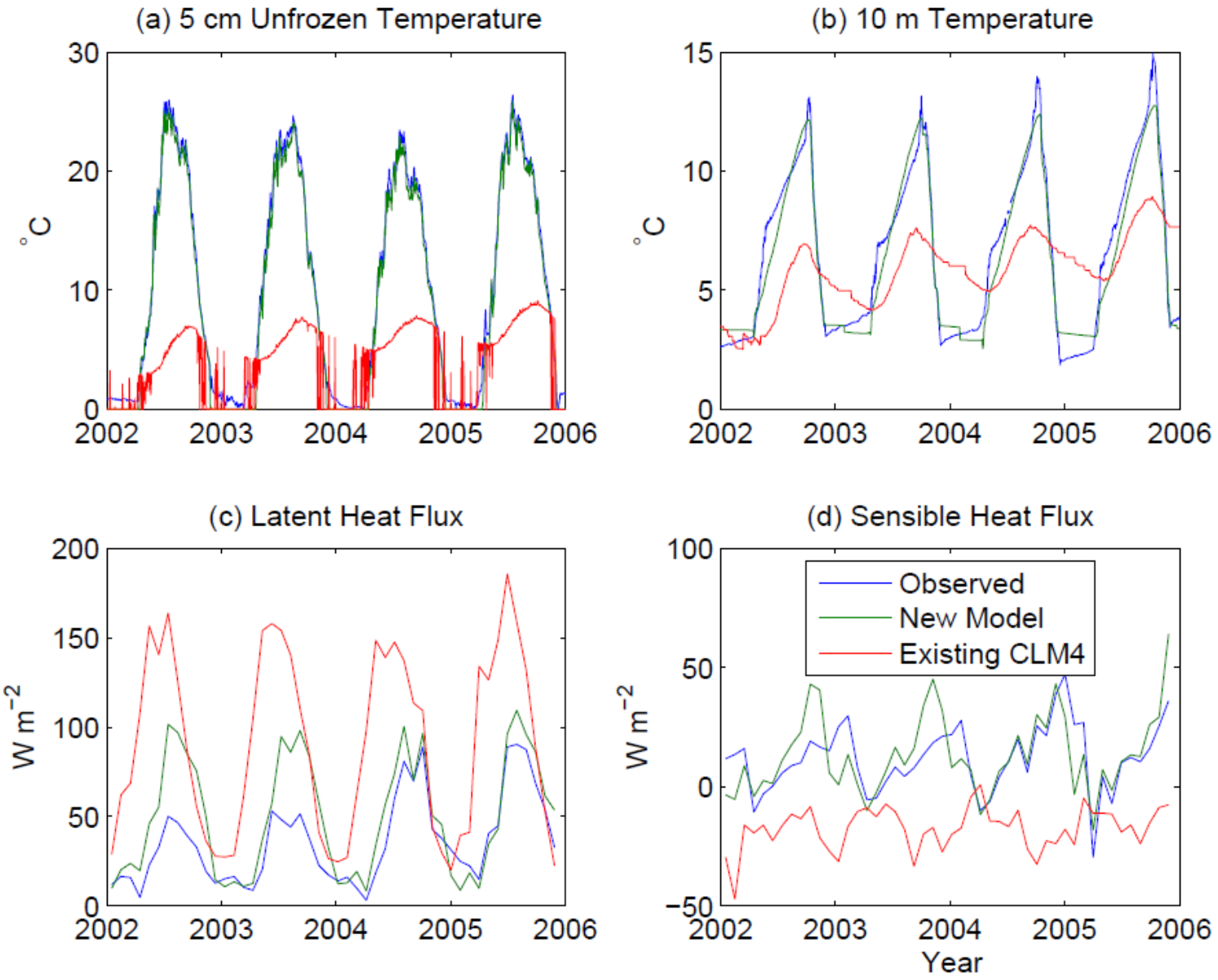
$$\underbrace{\frac{\partial (RC)}{\partial t}}_{\text{Net change}} = \underbrace{\frac{\partial F_D}{\partial z}}_{\text{Diffusion}} + P(z,t) - \underbrace{E(z,t)}_{\text{Ebullition (bubbling)}} - A(z,t) - \underbrace{O(z,t)}_{\text{Oxidation}}$$

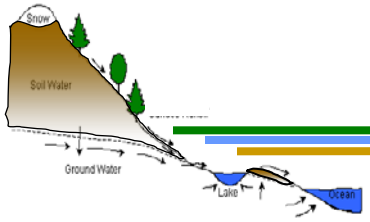
Production

Aerenchyma (tissue)

Riley et al., 2011, JGR-Biogeosciences

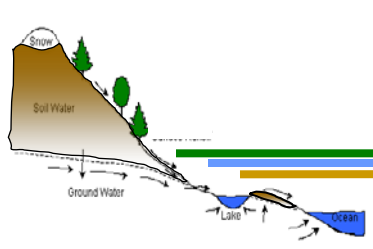
Sparkling Lake (WI): CLM4 Comparison





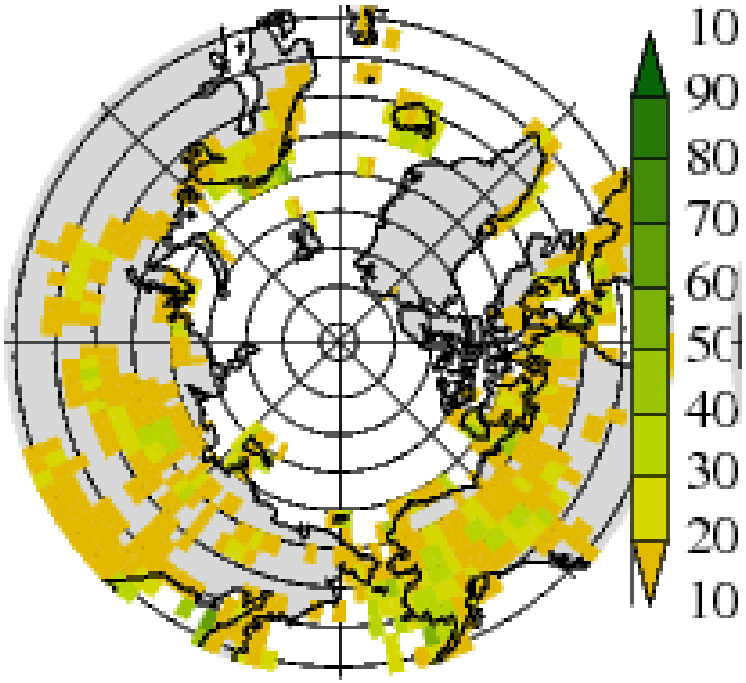
High resolution input datasets

Input dataset	CLM4 resolution	Updated resolution
PFT distribution	0.5° (MODIS)	1km (MODIS)
LAI / SAI	0.5° (MODIS)	1km (MODIS)
% Glacier	0.5° (IGBP DISCover)	1km (USGS)
% Lake	0.5° (Cogley, 1991)	1km (GLWD)
% Wetland	0.5° (Cogley, 1991)	Prognostic
% Urban	0.5° ()	1km
Soil texture (%sand, %clay)	~10km (IGBP)	??? (HWSD)
Soil organic matter	1.0° (IGBP)	??? (WISE, HWSD)
Soil color	0.5° (MODIS)	1km (MODIS)

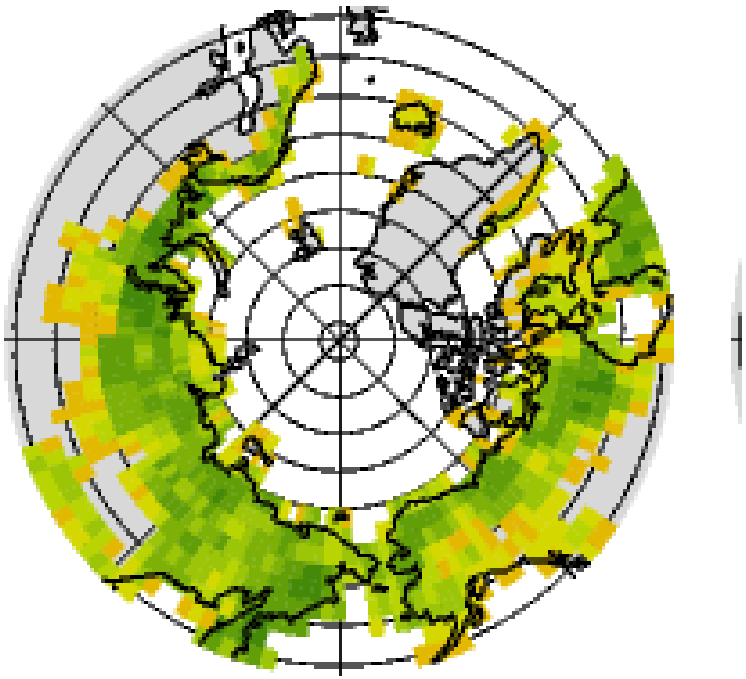


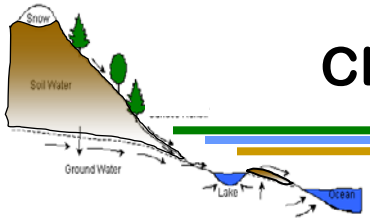
Arctic vegetation map

Arctic C3 Grass



Boreal Shrub





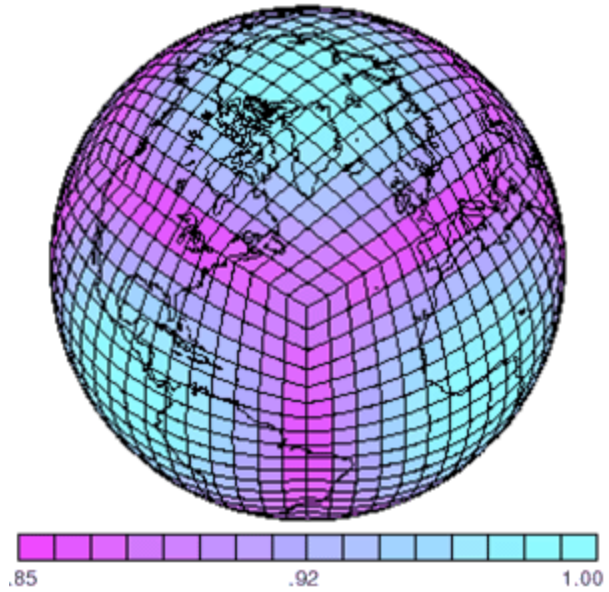
CLM4.5 (potential release with CESM update, late 2012)

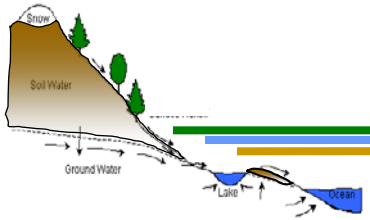
- **Software engineering**
  - High resolution: new input datasets; update tools mksrfdat, interpinic
  - Simplified soil C and N pools coding structure
  - Move CN (and other) model parameters to input file or namelist
  - Model output: by default PFT/column – level output
  - Unstructured grid support

CLM and Unstructured Grids

- Capability introduced to run with non lat/lon or logically rectangular grids
  - *New* surface dataset generation tool for non lat/lon grids (faster)
  - *New* CLM code support to deal with non lat/lon surface datasets and generate appropriate history files
  - *New* offline post-processing utility to map non lat/lon history files to 2d for visualization
- New ways to run CLM
  - Regionally refined grids (e.g. over USA)
  - Cubed sphere grid with and

    without regional refinement
  - "Collection" of tower sites in parallel
  - Catchment grid





Other CLM development activities

- Soil biogeochemistry, above/below ground litter pools, plant N-store
- Riverine transport of nutrients, carbon, and sediments
- N_2O emissions
- Ecosystem demography, temporal response to disturbance
- VIC hydrology
- Sub-surface hydrological processes – lateral redistribution of water
- Sub-grid soil moisture and snow heterogeneity
- Integrated Assessment Modeling
- 3-D canopy radiation
- Water (and carbon?) isotopes
- Phenology
- Peatlands
- Phosphorous cycle
- Data assimilation

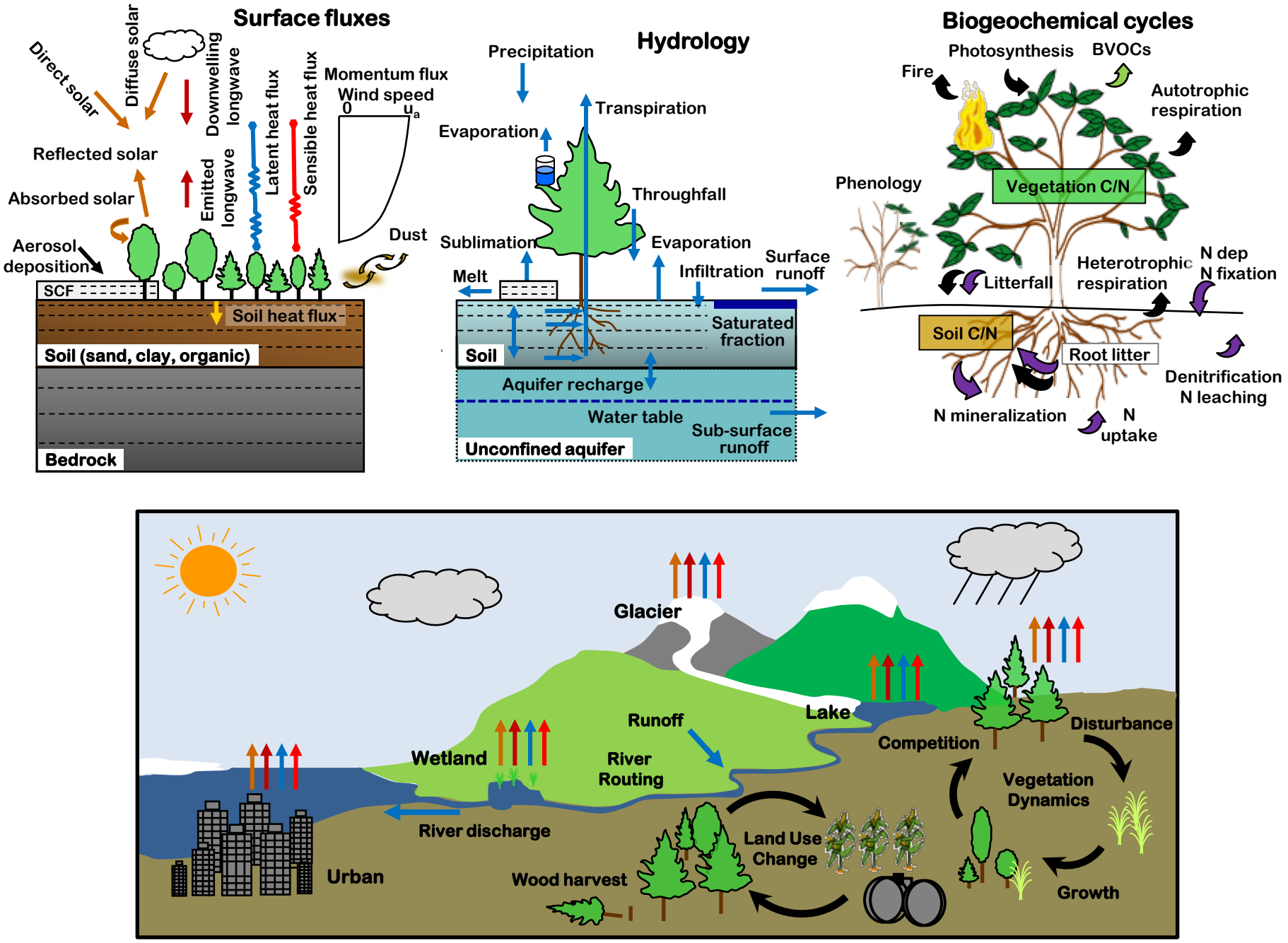
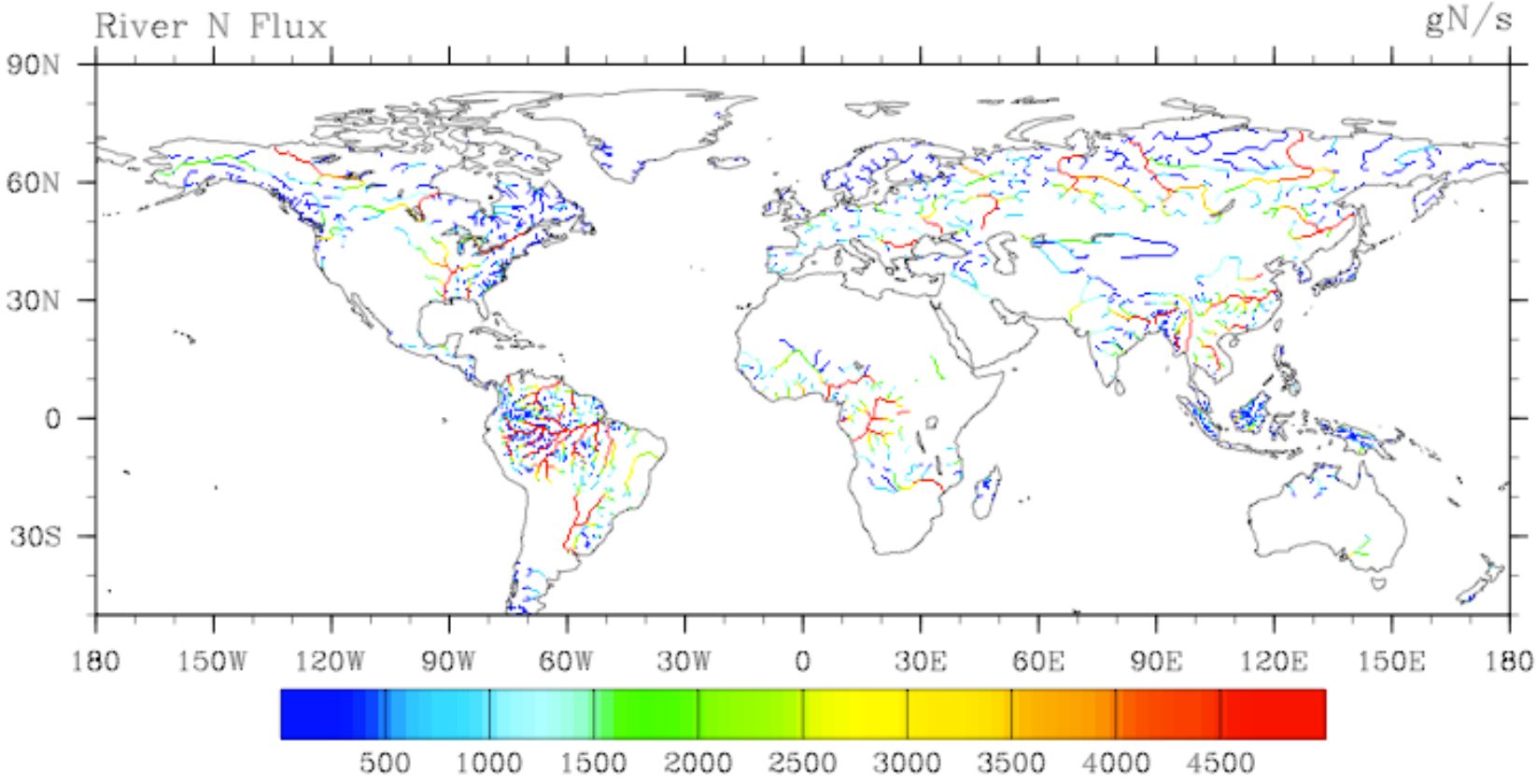
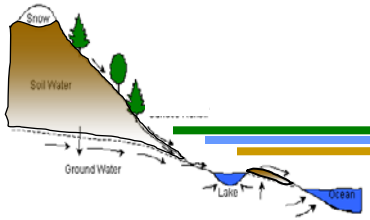


Figure 1: Lawrence et al., Journal Advances Modeling Earth Systems, 2011

Coupled CLM-CN/RTM Model of River N Export





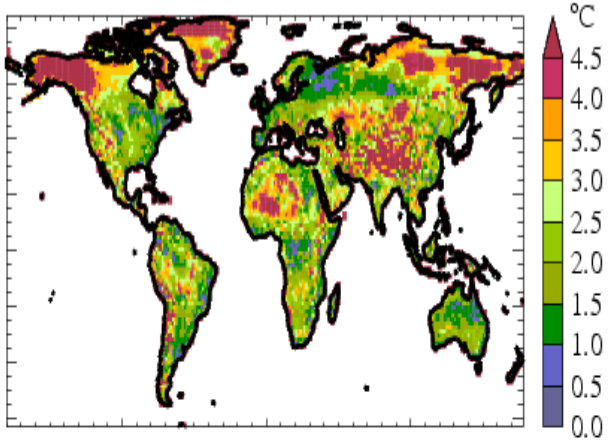
CCSM4 data

- 1850 control and 20th century and RCPs ensembles
  - All simulations: CLM is fully active with CN on and transient land cover change, aerosol and nitrogen deposition
  - Data posted on Earth System Grid (ESG) on or about May 1, 2011

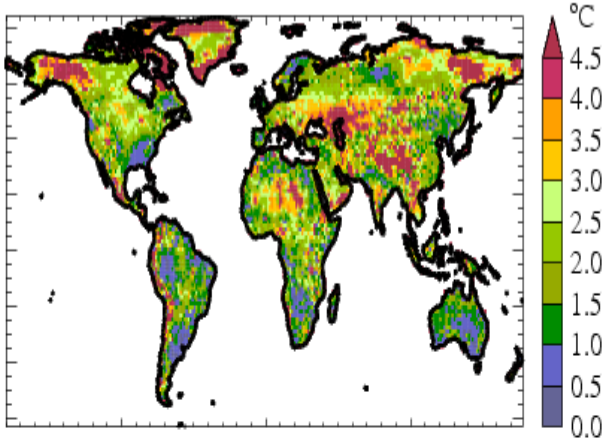
T_{air}: RMSE and Annual Mean Bias (CCSM4 vs CCSM3)

Reduced RMSE at high lats and in tropics
Mixed results for bias, E. Europe warm bias related to no aerosol indirect?

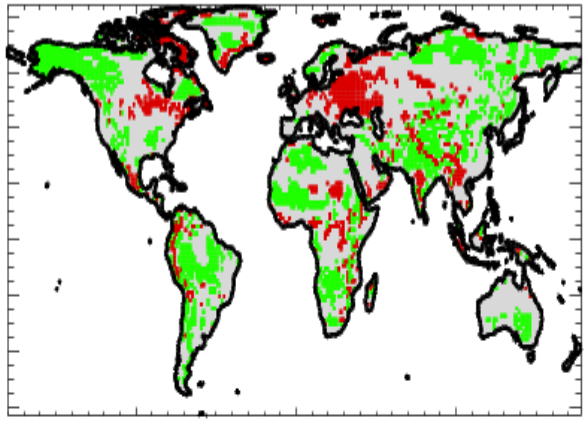
T_{air} RMSE: CCSM3
3.01°C



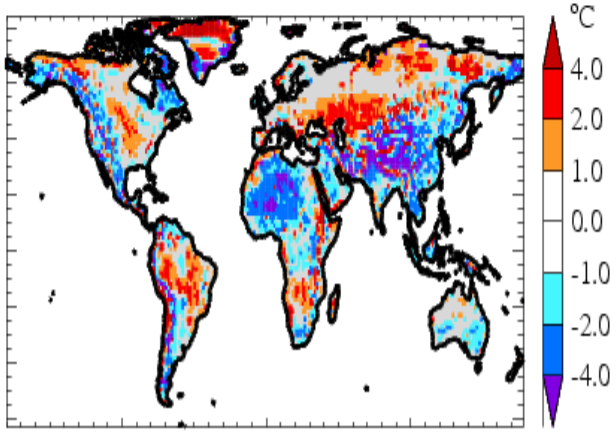
T_{air} RMSE: CCSM4
2.71°C



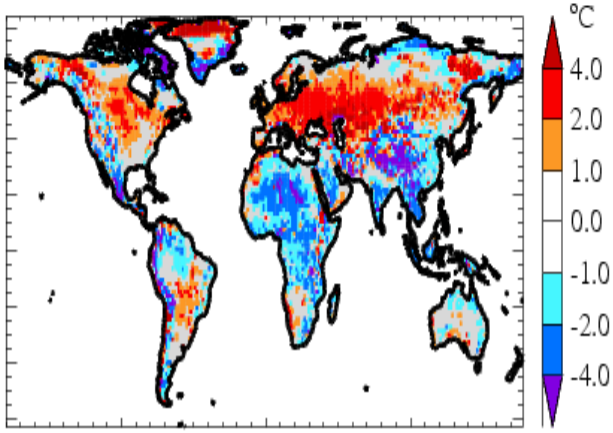
T_{air} RMSE: CCSM4 vs CCSM3
27.1%(+) 12.9%(−)



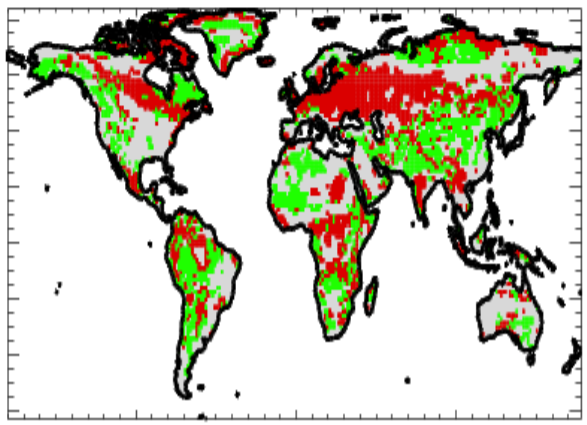
T_{air} ANN Mean Bias: CCSM3
-0.28°C

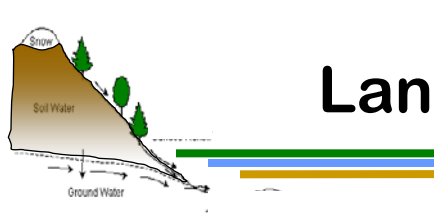


T_{air} ANN Mean Bias: CCSM4
-0.17°C

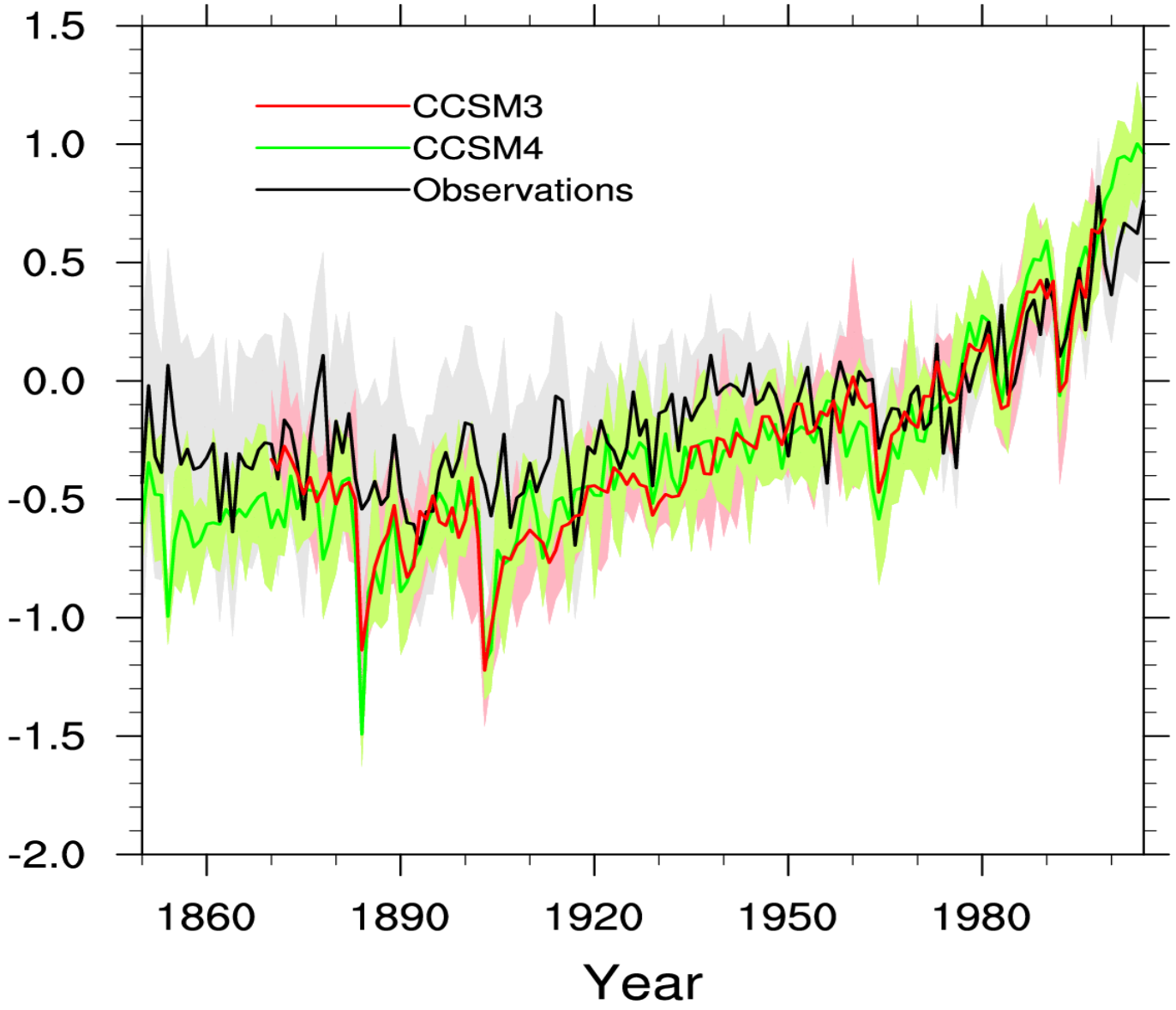


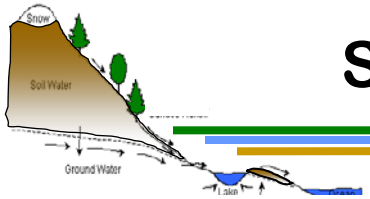
T_{air} ANN Mean Bias: CCSM4 vs CCSM3
27.7%(+) 28.3%(−)





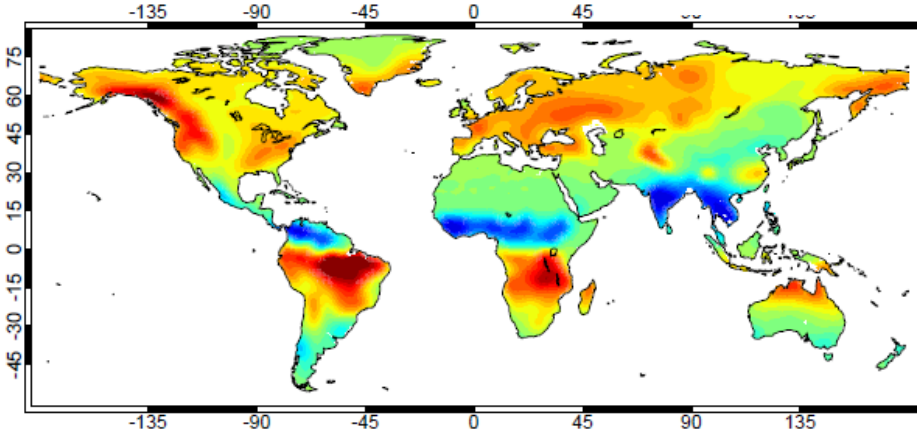
Land temperature anomalies from 1961-1990



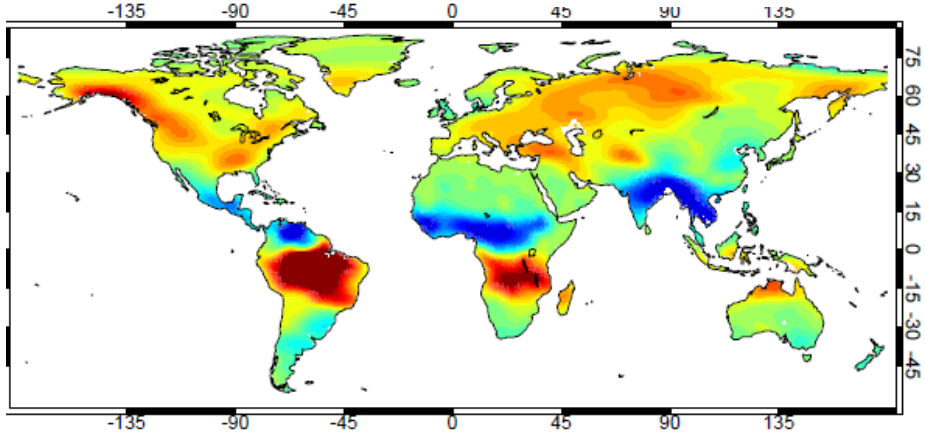


Soil (and snow) water storage (MAM – SON)

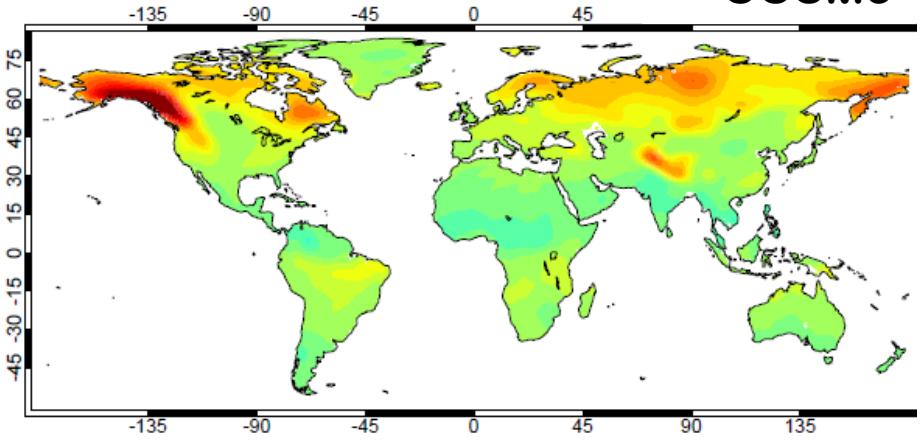
CCSM4



GRACE (obs)



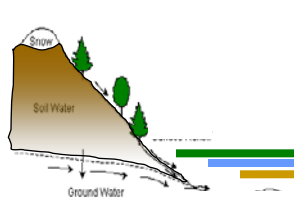
CCSM3



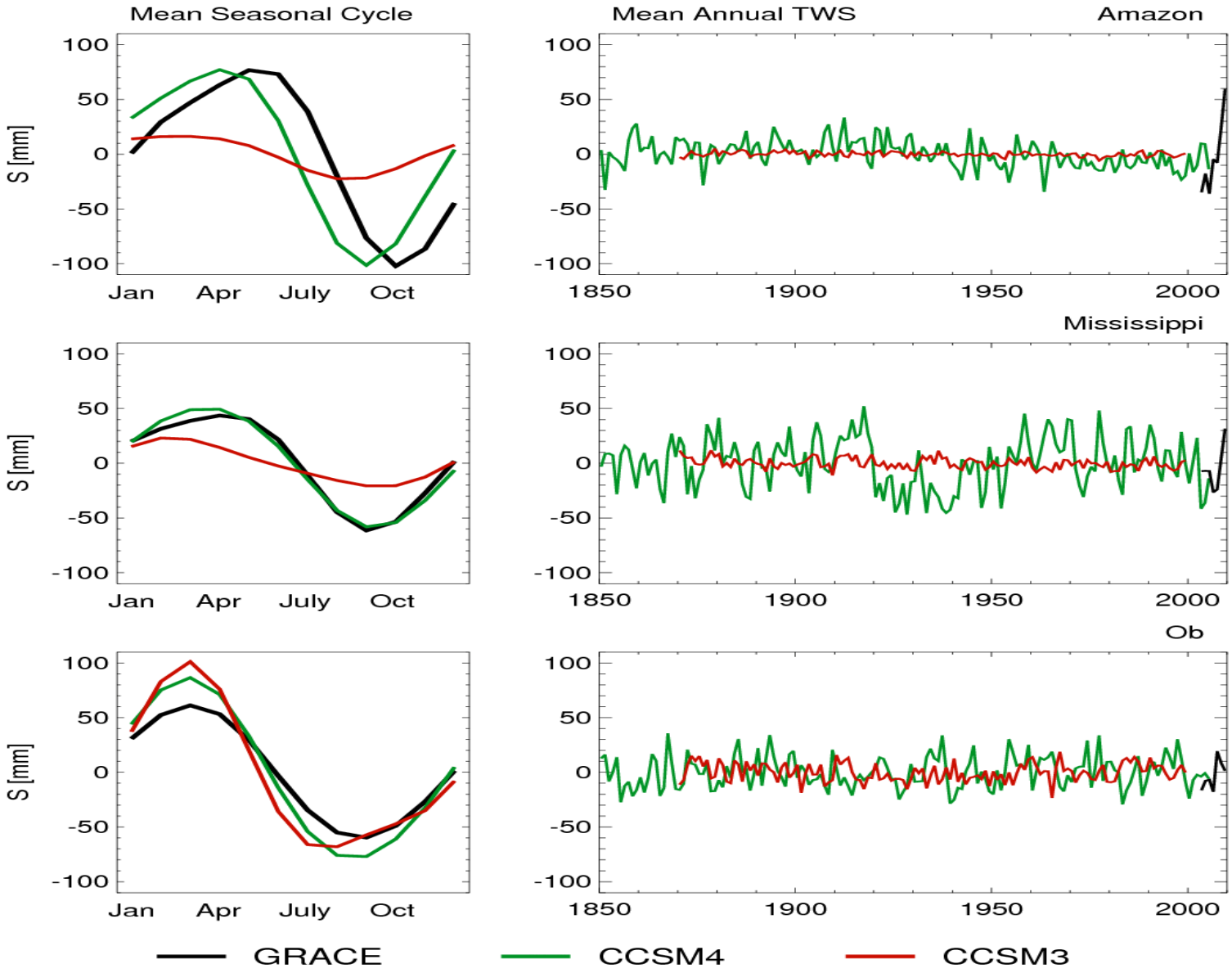
300 200 100 0 -100 -200 -300 (mm)

GRACE satellite measures small changes in gravity which on seasonal timescales are due to variations in water storage

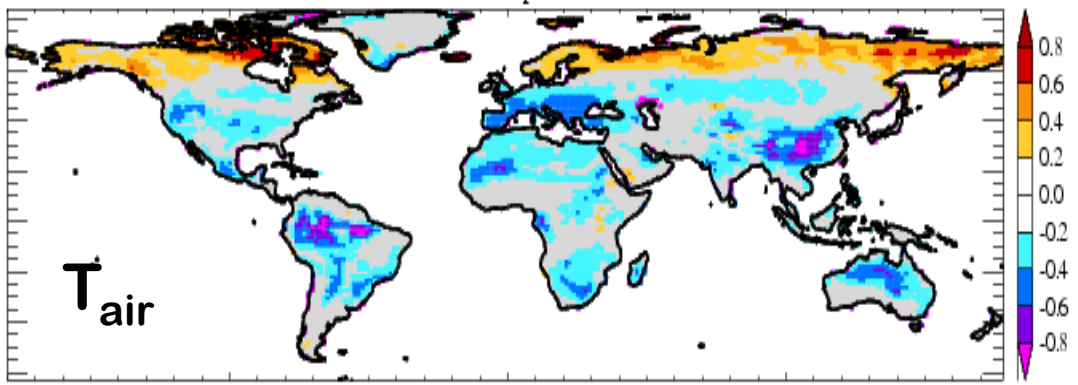
CCSM3 and CCSM4 data from 1870 and 1850 control

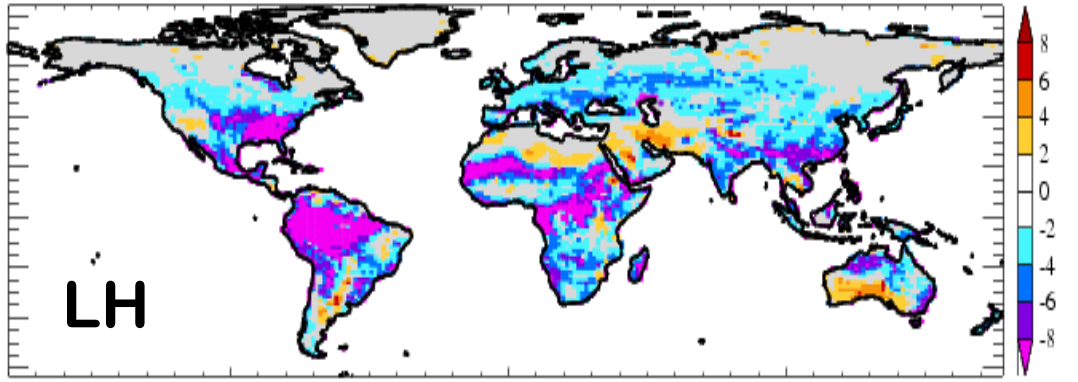


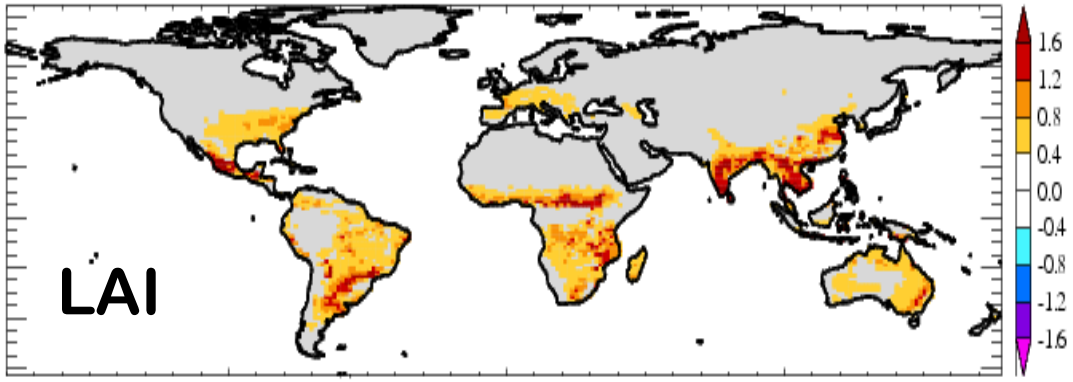
Total Land Water Storage (CCSM vs GRACE)



CCSM4 – CCSM3 (St. Dev.)

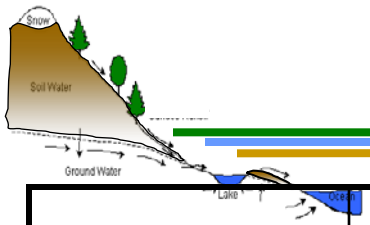






Despite increase in LAI variability (by definition) lower variability in LH and T_{air} due to wetter model

Planning supplementary 1850 control and 20th century simulation with prescribed MODIS LAI



Tower flux statistics (15 sites, hourly)

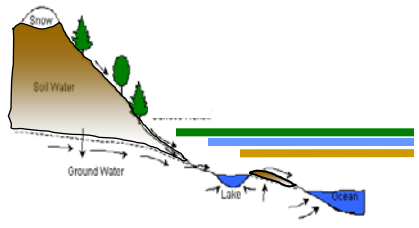
	Latent Heat Flux		Sensible Heat Flux	
	r	RMSE (W/m^2)	r	RMSE (W/m^2)
CLM3	0.54	72	0.73	91
CLM3.5	0.80	50	0.79	65
CLM4SP	0.80	48	0.84	58

Missing Processes and Biases

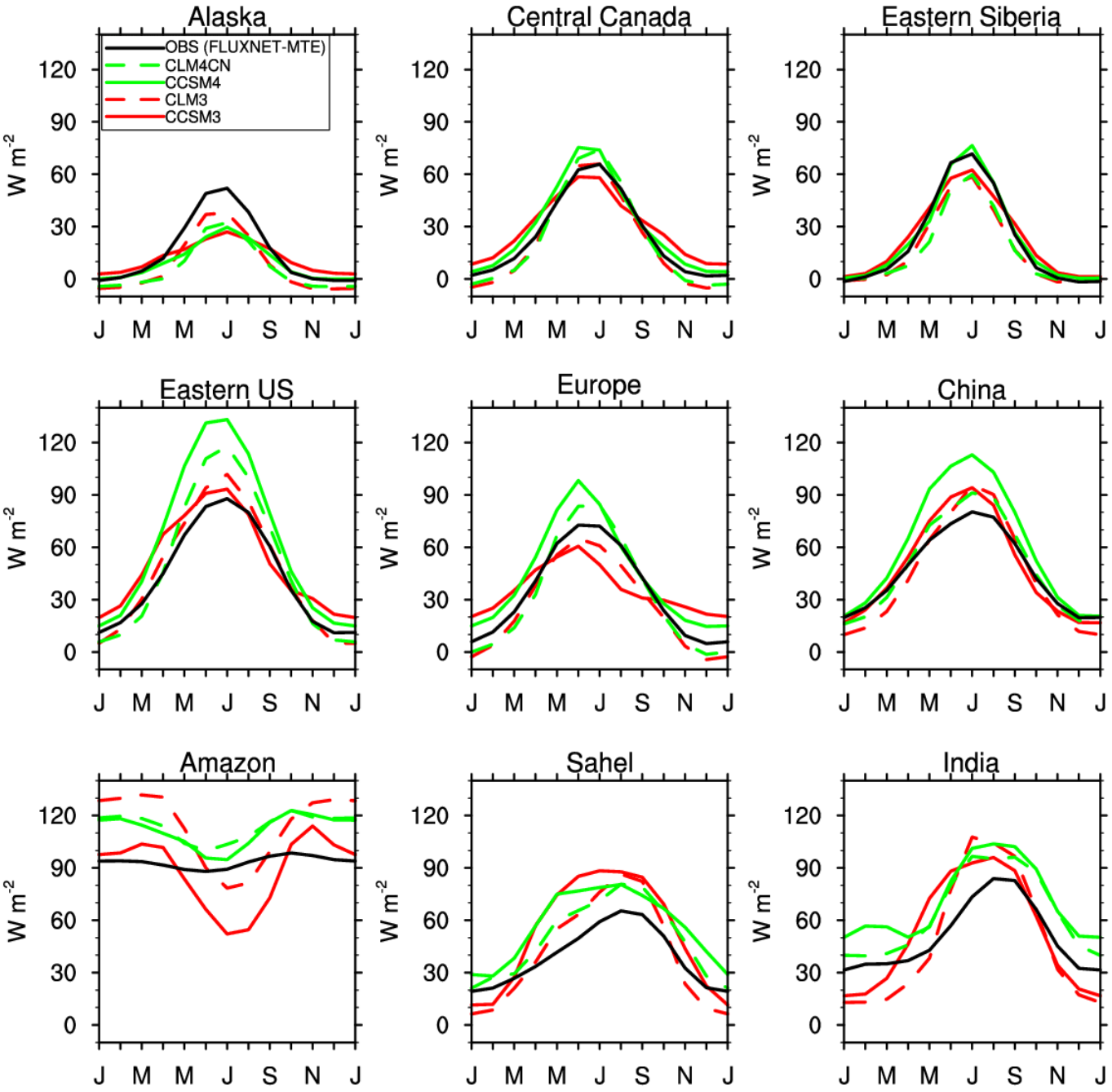
• Wetlands, which exist across much of the high latitudes, are not represented in a prognostic, interactive way

• Wetlands affect albedo, surface fluxes, and carbon cycling via organic carbon accumulation and anaerobic decomposition

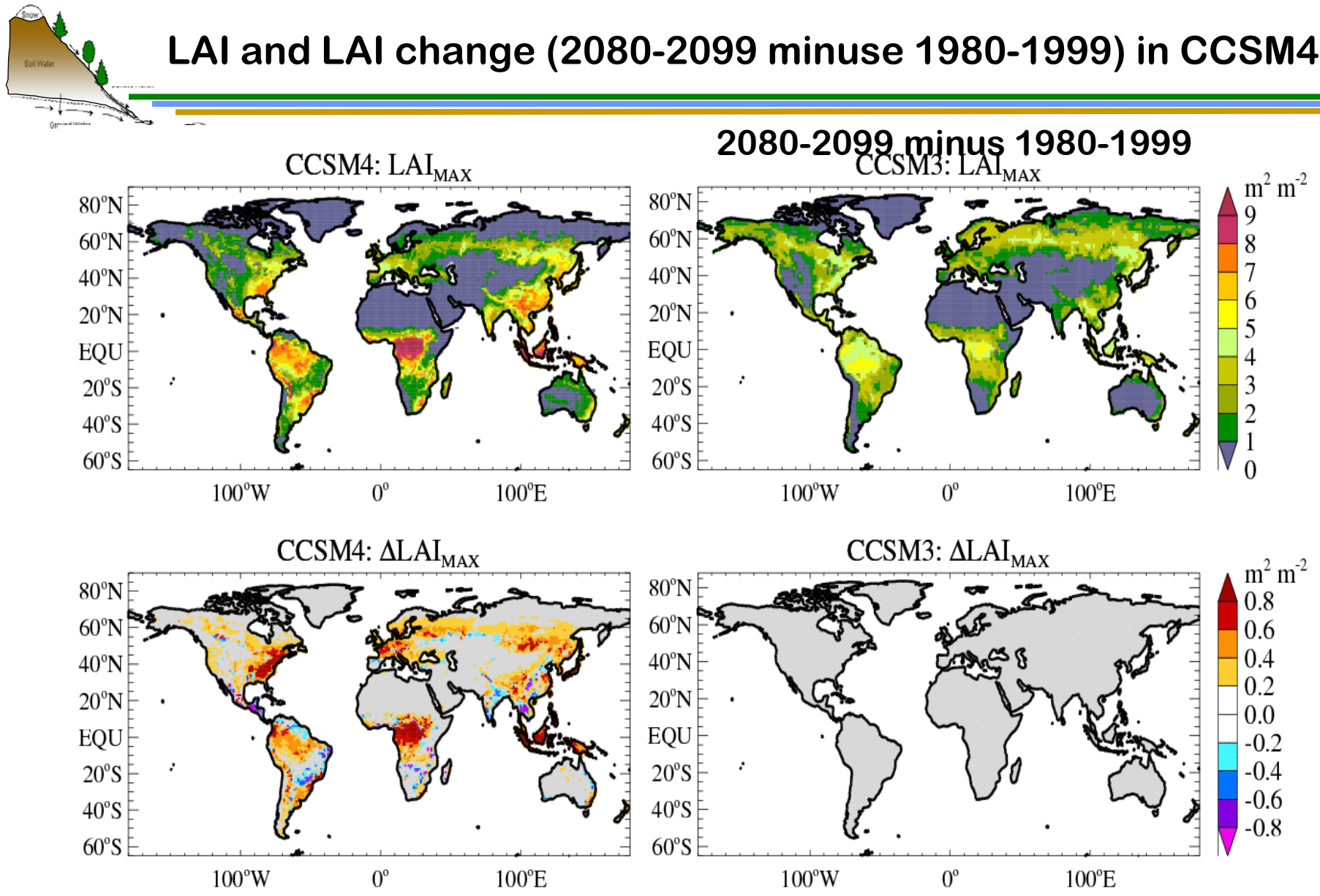
• Biases include relatively dry near-surface soil moisture, colder than observed temperatures, and lower than observed river discharge.



Latent Heat Flux



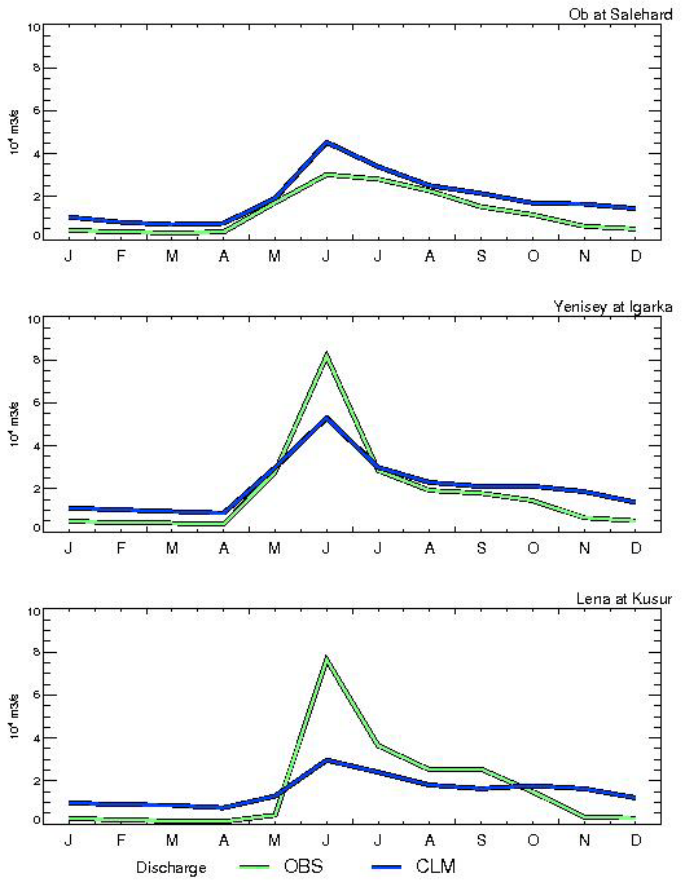
LAI and LAI change (2080-2099 minuse 1980-1999) in CCSM4



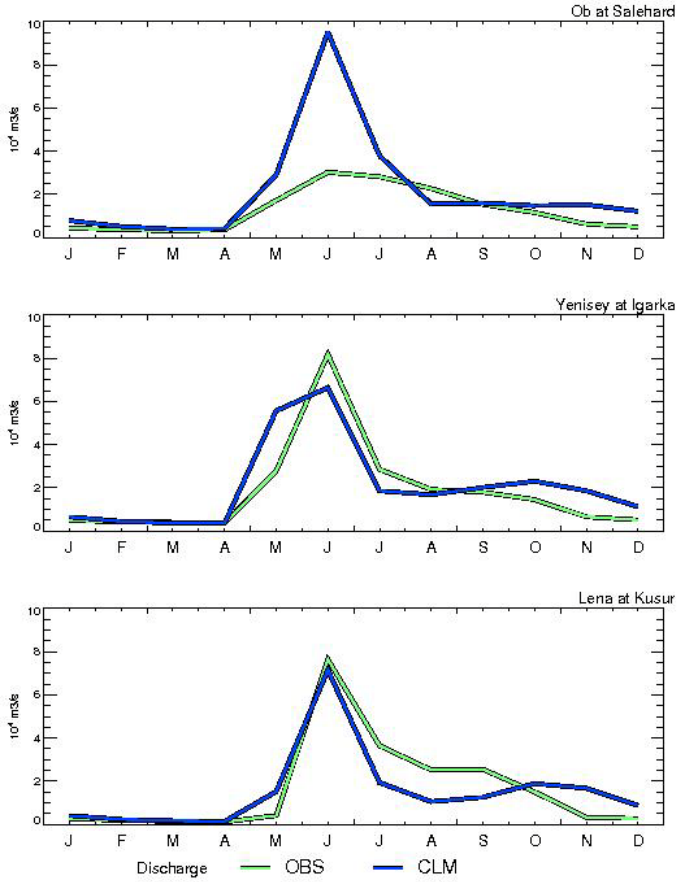
River Discharge in Modified CLM4

Results are mixed: better hydrographs for permafrost basins, but degraded simulation in non-permafrost basin

Control



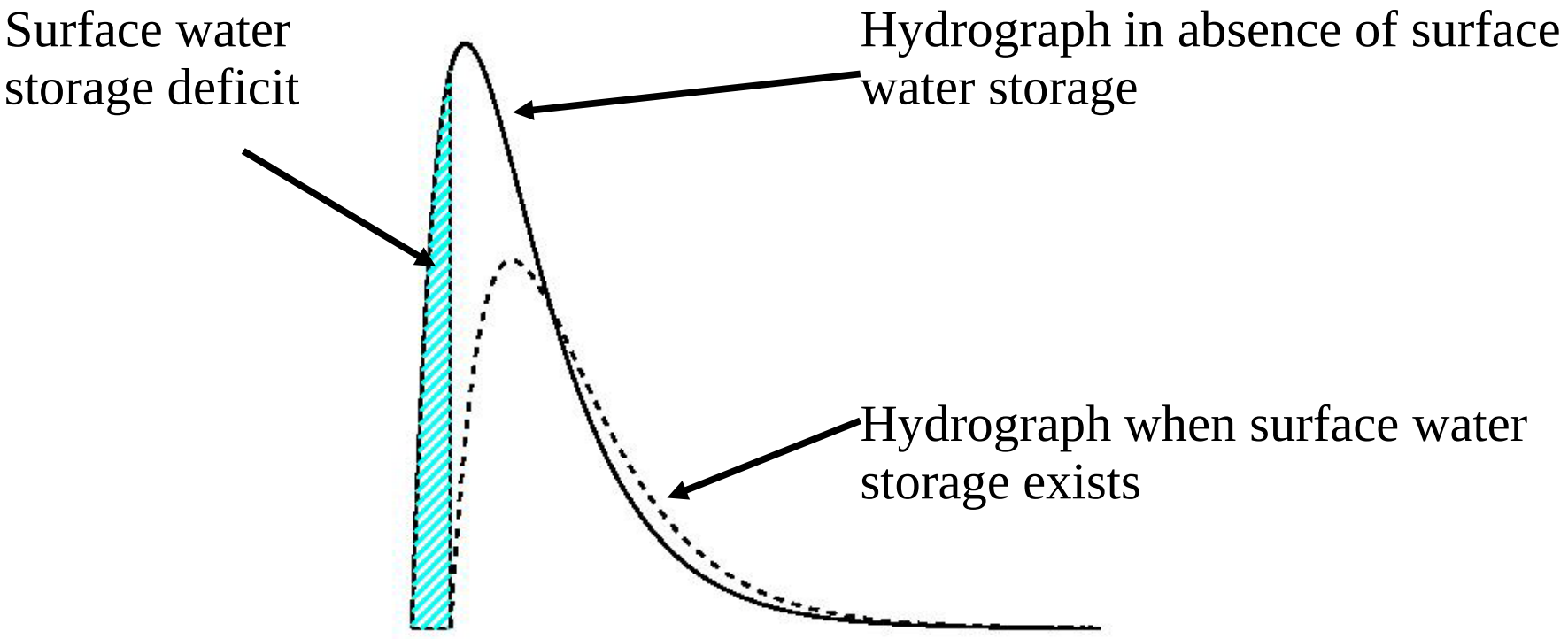
Ice Impedance



OBS

CLM

Impact of Runoff Thresholds on Hydrograph



CCSM 4 Sensitivity to Lake Area

- 2° CLM4: 0.7 million km^2 (Cogley 1991)
- 2° GLWD: 2.3 million km^2 (Lehner & Döll, 2004)
- Mostly missing in N. Canada

- Hi – Lo area experiments
  - 25 yr offline
  - 200 yr slab ocean