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Improved hydrology over peatlands in a global land modeling system

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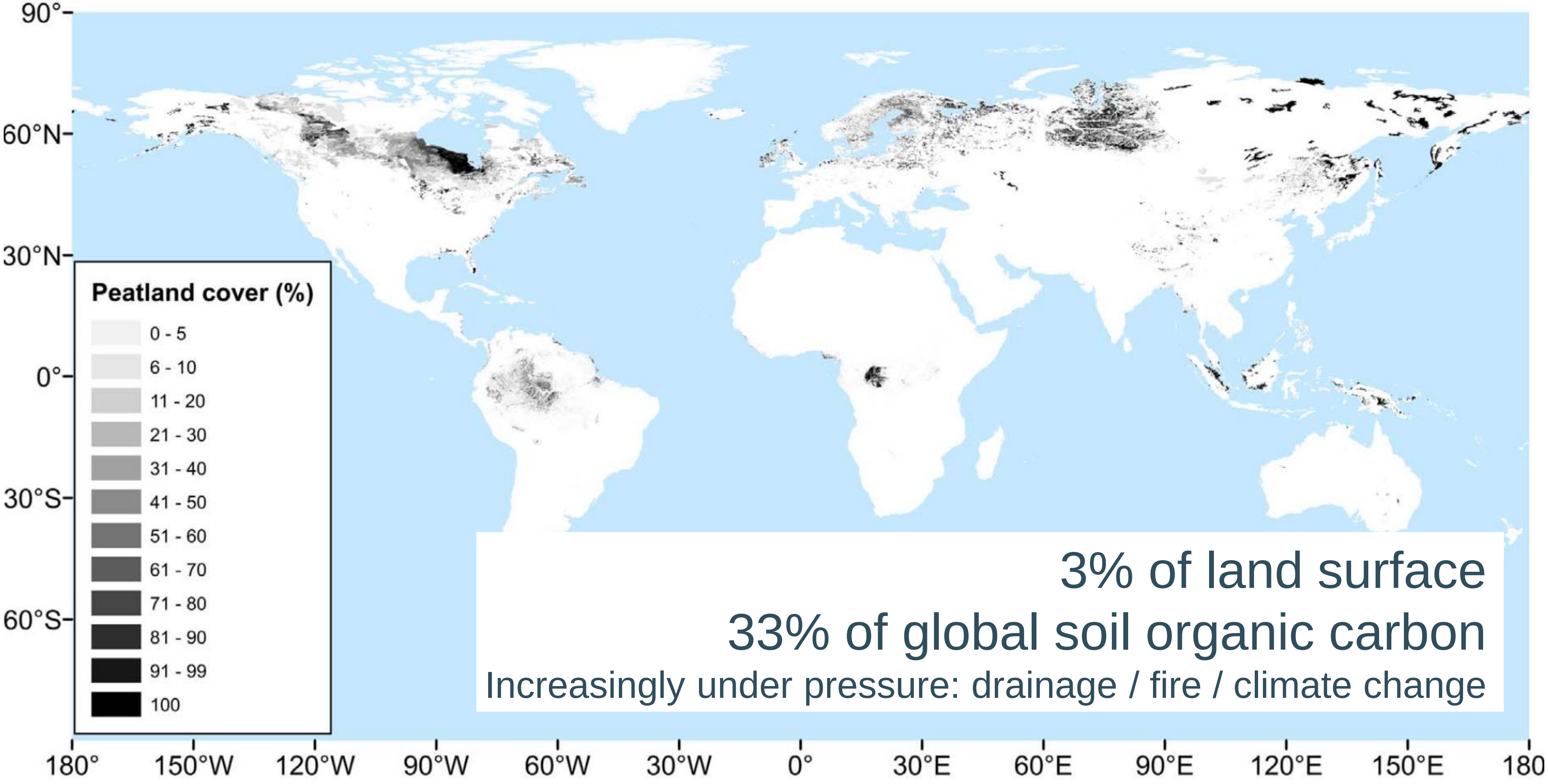
Background: Peatlands Under Pressure



3% of land surface

33% of global soil organic carbon

Increasingly under pressure: drainage / fire / climate change

Global Peatland (Histosol) Distribution; Xu et al., 2018

Long list of ‘peatland ecohydrological models’

- Focus: Carbon Cycle (with or without hydrological simulation)
- Water Level simulation challenging

Peat accumulation model	(Hilbert et al., 2000)
PCARS	(Frolking et al., 2002)
McGill Wetland	(St-Hilaire et al., 2010)
Biome-BGC	(Bond-Lamberty et al., 2007)
Wetland-DNDC	(Zhang et al., 2002)
Ecosys	(Dimitrov et al., 2011)
InTEC	(Ju et al., 2006)
BEPS	[Chen et al., 2007, 2005]
DigiBog	(Baird et al. 2012, Morris et al. 2012)
PEATBOG	(Wu et al., 2013)
… and several more	

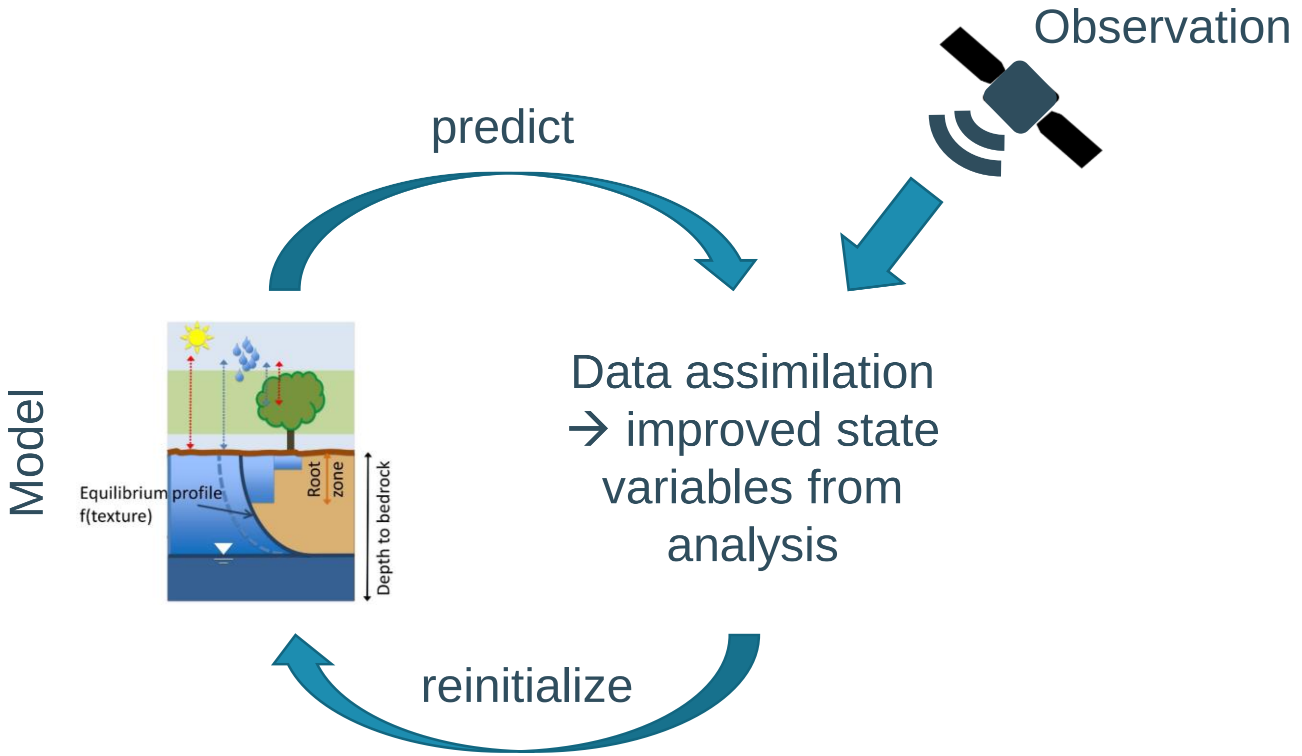
Integration into continental/global land surface schemes

CLM	(Shi et al., 2015)
CLASS–CTEM	(Wu et al. 2016)
ORCHIDEE-PEAT	(Qui et al., 2017)

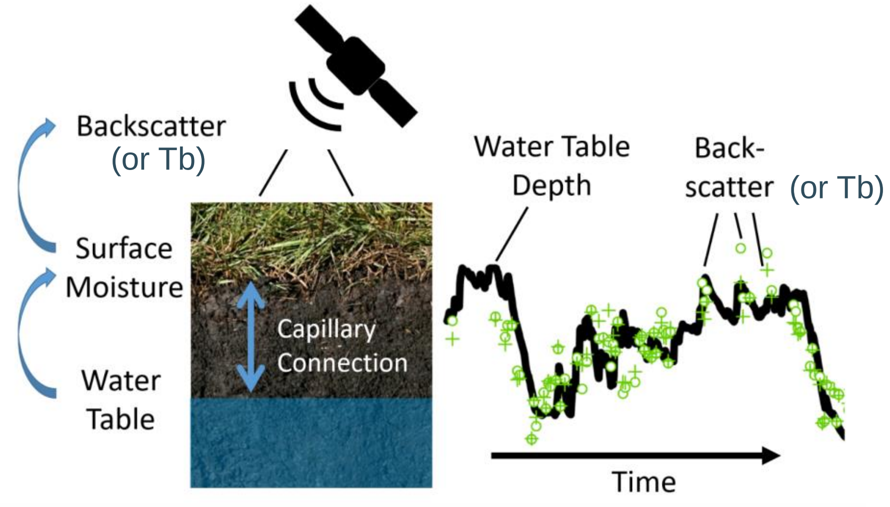
+ PEAT-CLSM
CLSM: Catchment Land Surface Model of NASA’s Goddard Earth Observing System Model (GEOS-5)

Motivation: Why CLSM of GEOS-5 ?

1) Coupled Ocean-Atmosphere-Land Model: Changed energy balance over peatlands affects atmospheric simulations
2) Land Data Assimilation System (→ e.g. SMAP L4 Soil Moisture Product)

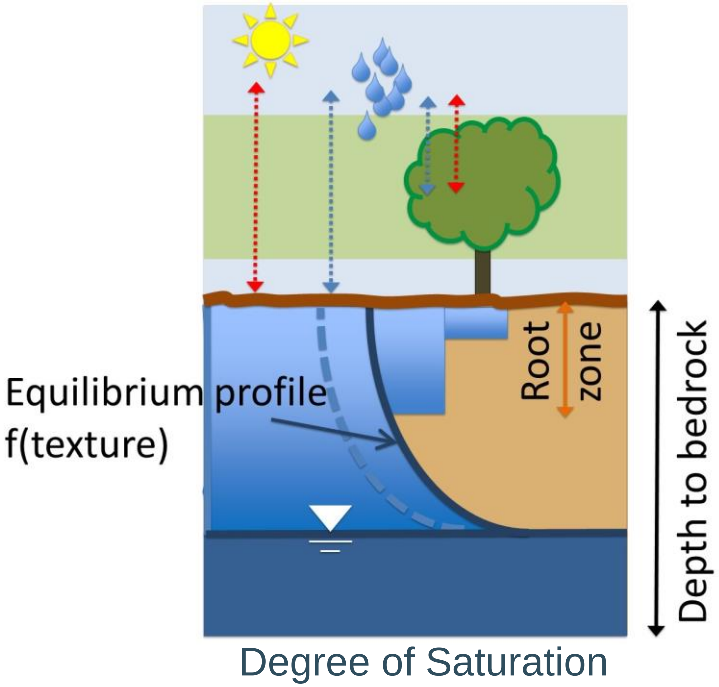


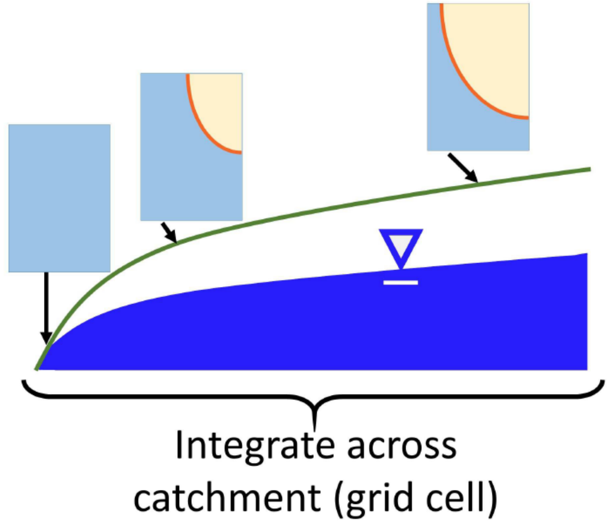
Peatlands: Potential to monitor wetness variation with passive and active microwave observations (Kim et al. 2017, Bechtold et al. 2018)



CLSM: Main Characteristics

- High emphasis on efficiency (global appl.) (Koster et al. 2000)
- Partitioning of land surface into hydrologic catchments
- Topographic Wetness Index based model
  → subgrid soil moisture + water level variability and runoff
- Each grid cell modeled with dominant catchment and soil
- No numerical coupling between grid cell





- Peat as soil class (De Lannoy et al. 2014, JAMES)

→ Water levels however mostly still far too deep (~ 2 meter) and dynamics not typical for peatlands

Objective

- Implement typical peatland hydrological characteristics into CLSM
- Maintain simplicity and efficiency of CLSM

Scope narrowed to

- Northern Peatlands
- Degree of groundwater influence highly variable and unknown at global scale → All peatlands treated as rain-fed peatlands

Next:

→ Model Modifications

→ Validation

→ Summary and Outlook

Model Modification #1

At large scales peatlands are nearly flat → replaced by …

Topographic Wetness Index Distribution from Catchment Topography

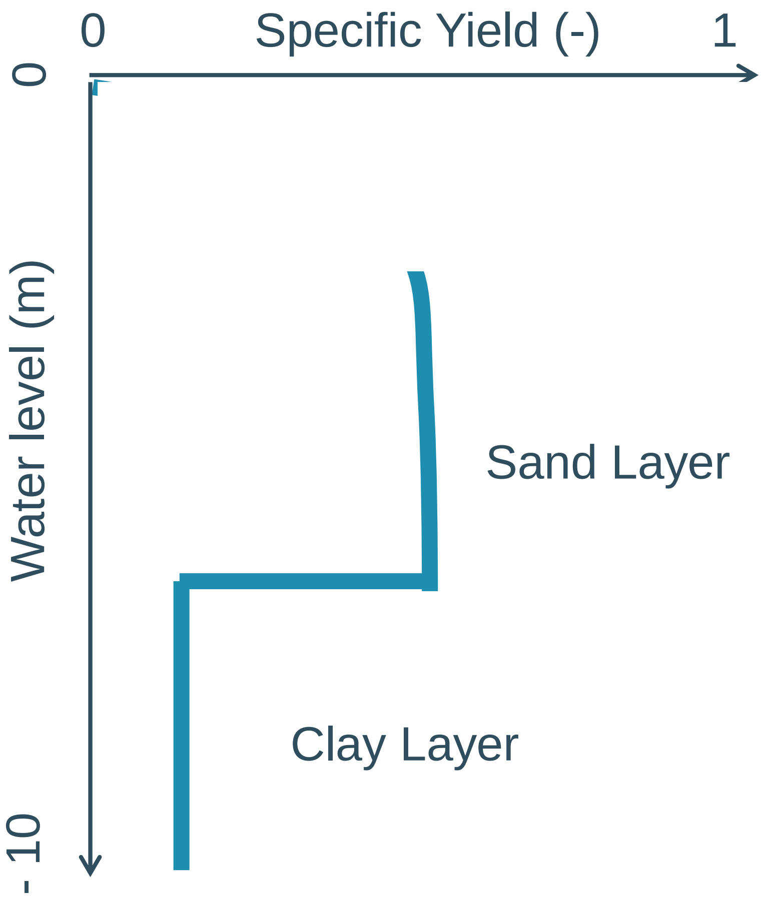
Elevation Distribution from typical Peatland Micro-topography

Weston et al. 2015
Example of “hummock and hollow microtopography”

Model Modification #1: dynamic surface water storage

Mineral land surface (here: no microrelief)

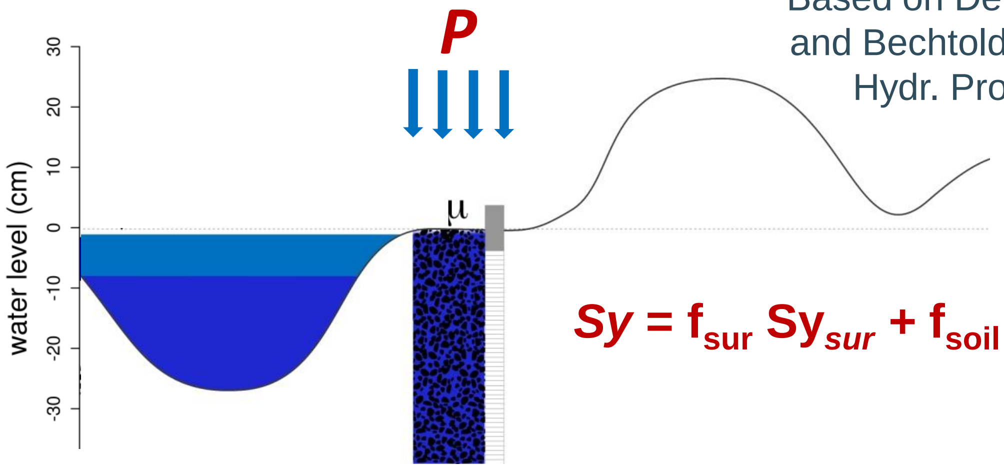
$Sy = \Delta WS \,/\, \Delta WL$



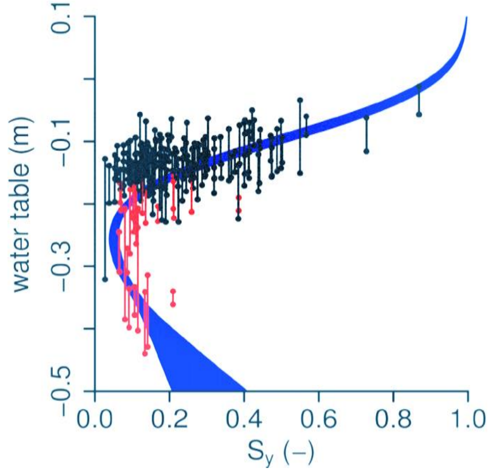
Groundwater Hydrogeology: Specific Yield as layer constant

Peatland surface (microrelief)

Based on Dettmann and Bechtold (2015 Hydr. Proc.)

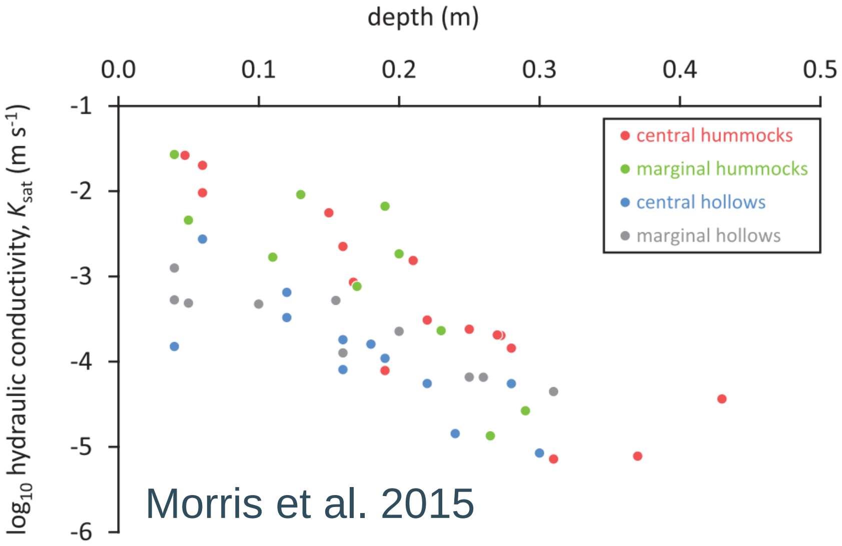


$Sy = f_{sur}\, Sy_{sur} + f_{soil}\, Sy_{soil}$

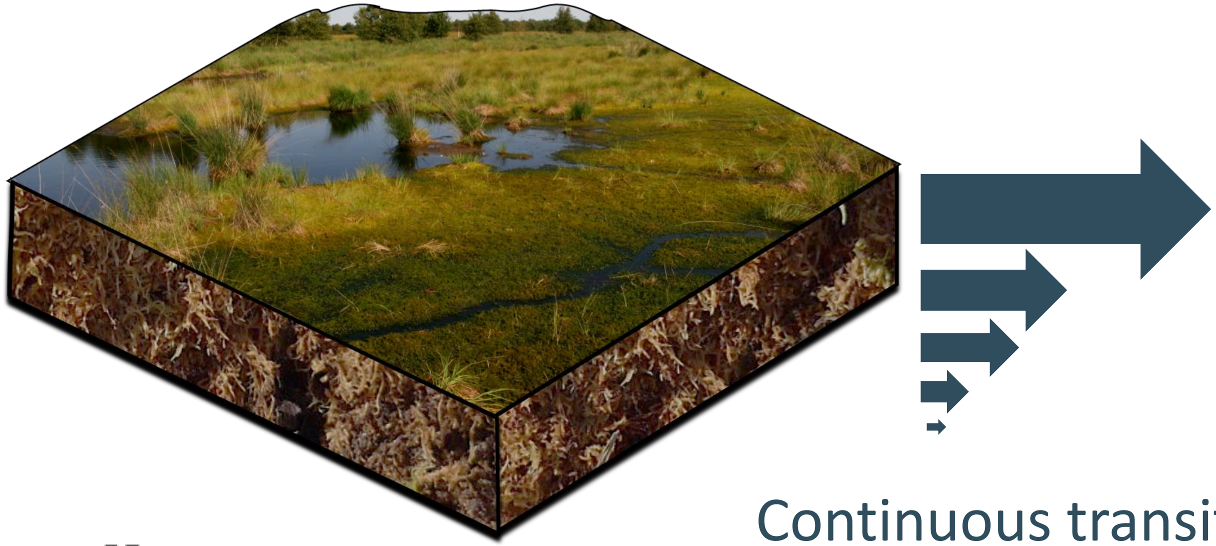


Example of specific yield profile (Dettmann and Bechtold 2016, VZJ)

Model Modification #2: Runoff



Morris et al. 2015



Continuous transition from baseflow to overland flow

Romanov, 1968, Ivanov 1975

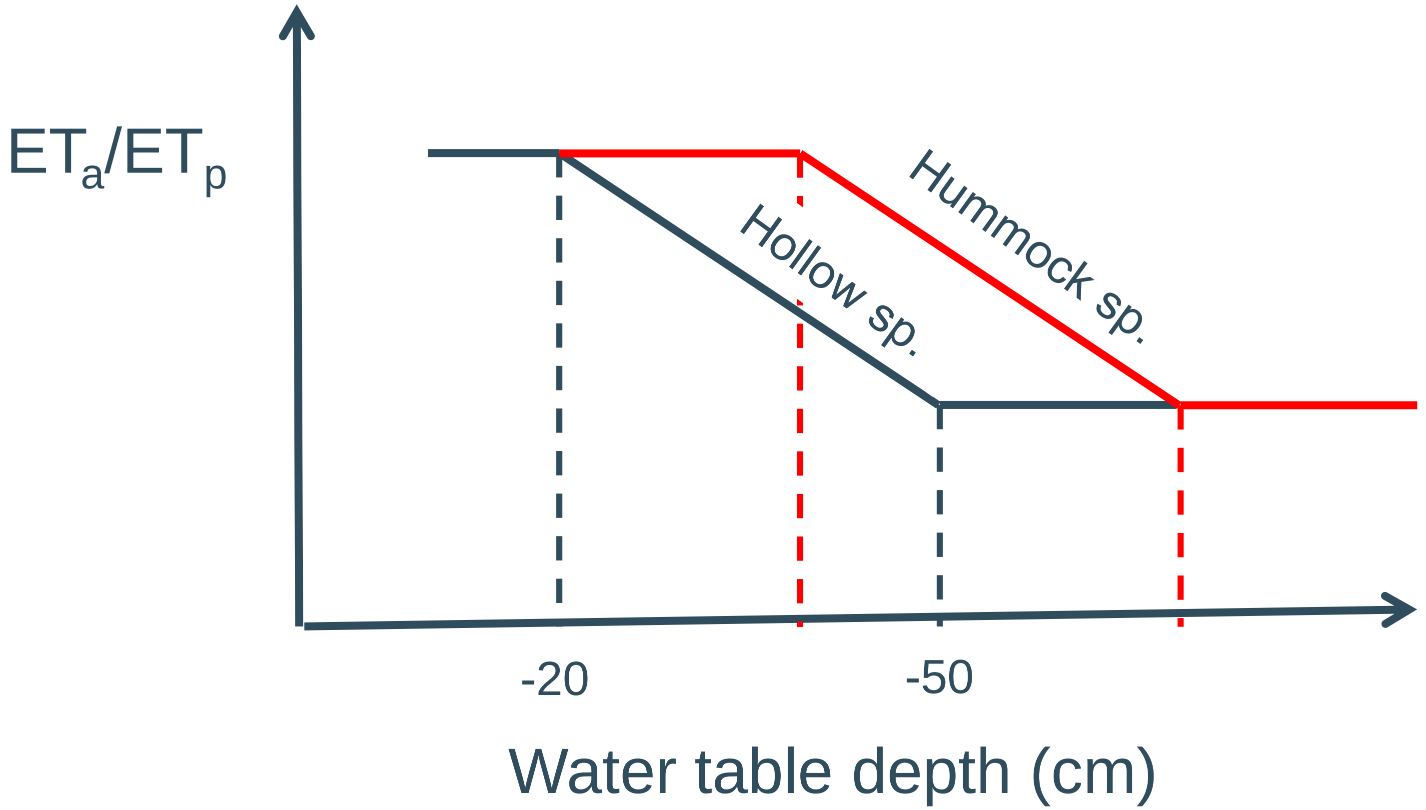
Conductivity: $$K_s(z) = \frac{K_{s,z=0}}{(1-z)^m}$$

Transmissivity: $$T_a(WTD) = \int_{z_{ac}}^{WTD} K_s\,(z)dz$$

Runoff: $$r(WTD) = v\,T_a$$

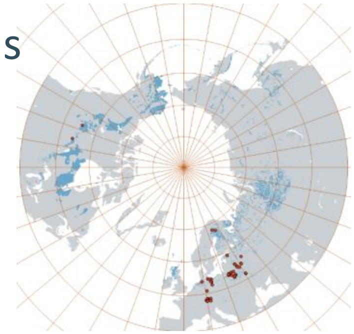
Model Modification #3: Evapotranspiration

- Evapotranspiration: Water stress coupled to water table depth
- Vegetation classes and evapotranspiration calculation as in CLSM



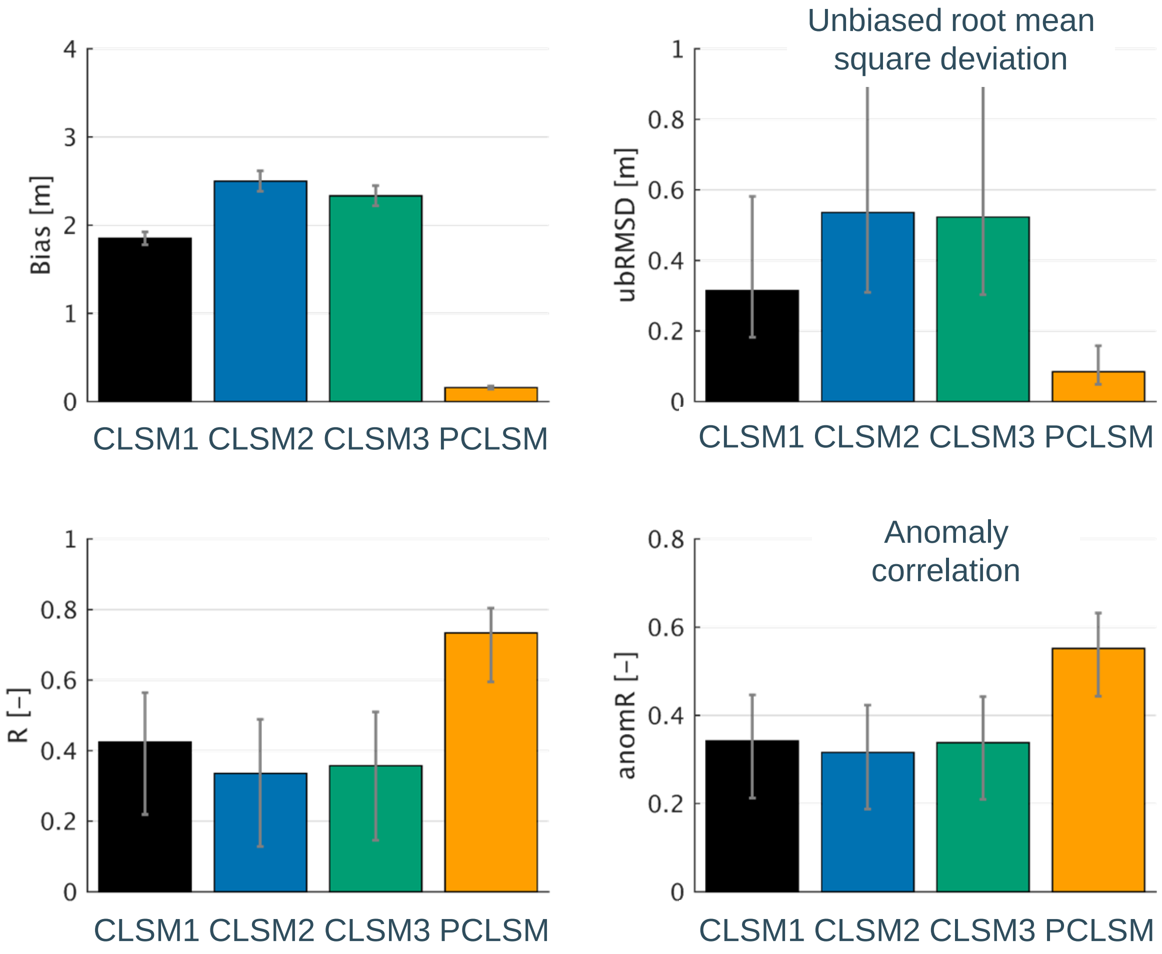
Validation (water table depth data)

70 monitoring wells
18 peatlands

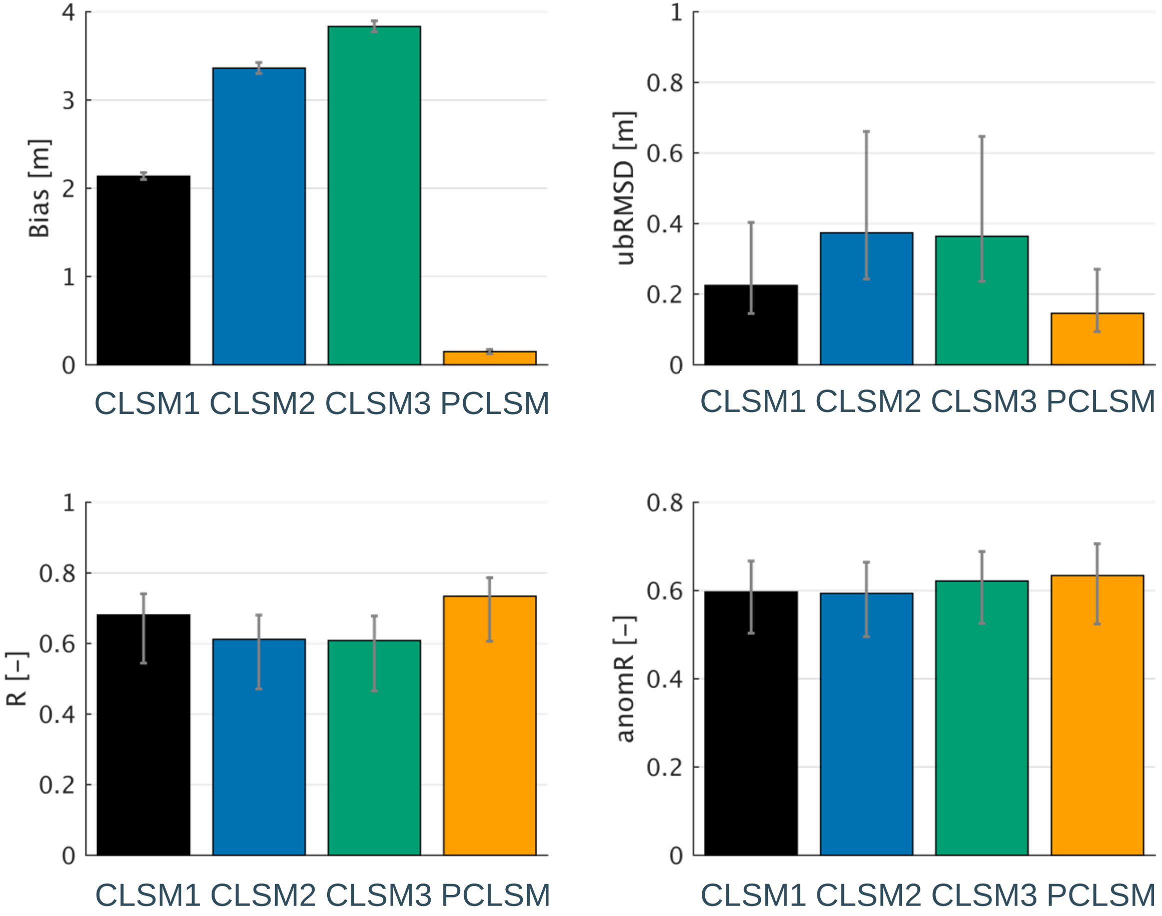


Temporal statistics

Bogs



Fens



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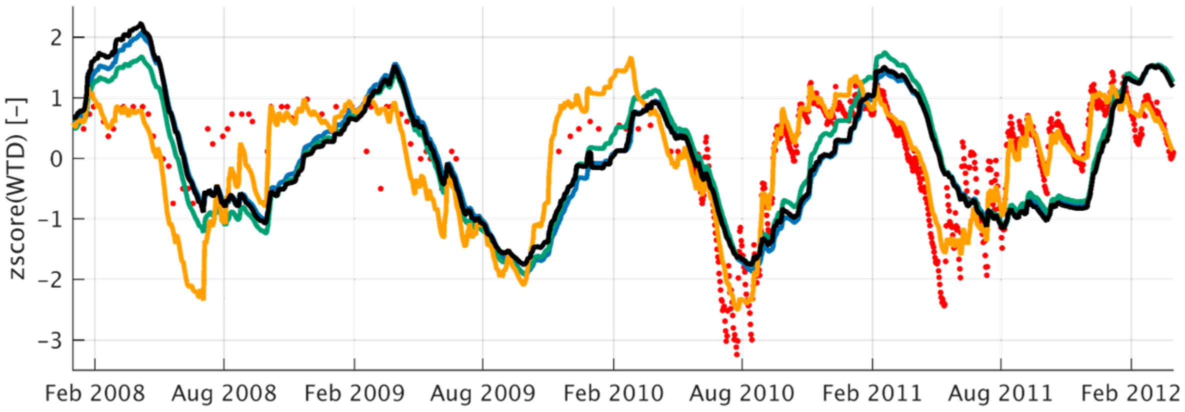
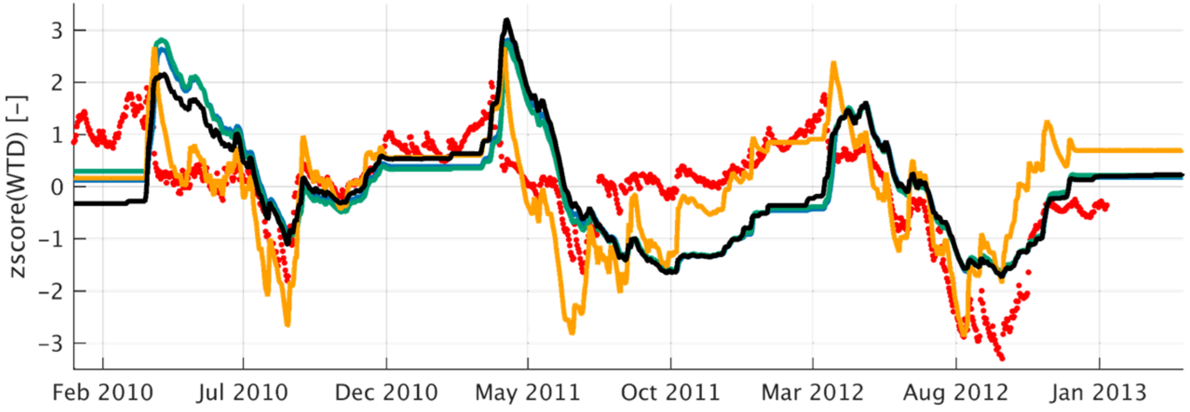
Validation (water table depth data)

Example 1: Bog in NW Germany
Mild winter, high precipitation, R=0.9



Example 2: Bog in Belarus
Long freezing period, R=0.6



in situ
CLSM1
CLSM2
CLSM3
PCLSM

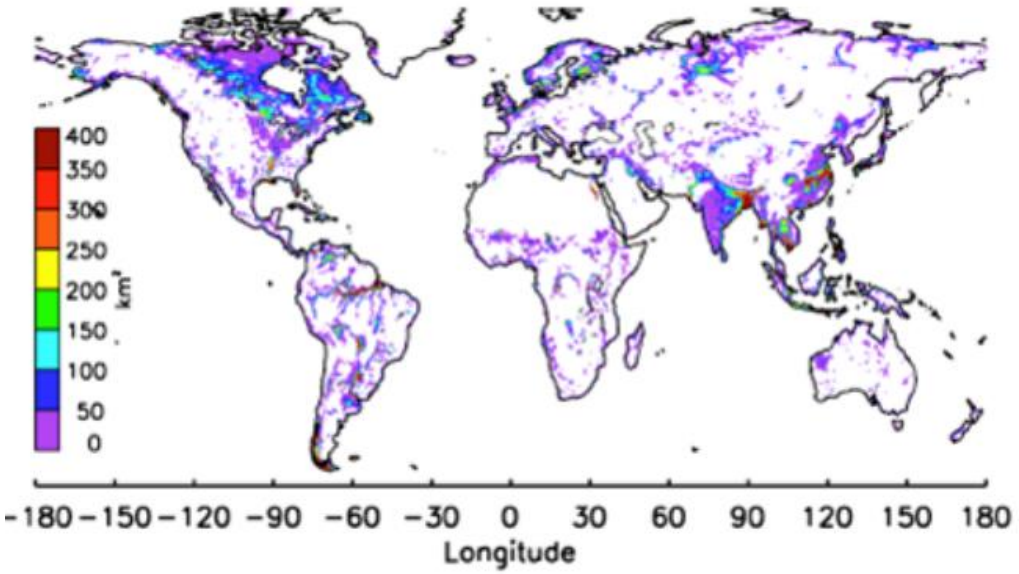
Here:
bias + std
corrected

- Water levels level off smoothly close to surface
- Capability to predict summer anomalies
- Capability to predict snow melt peaks

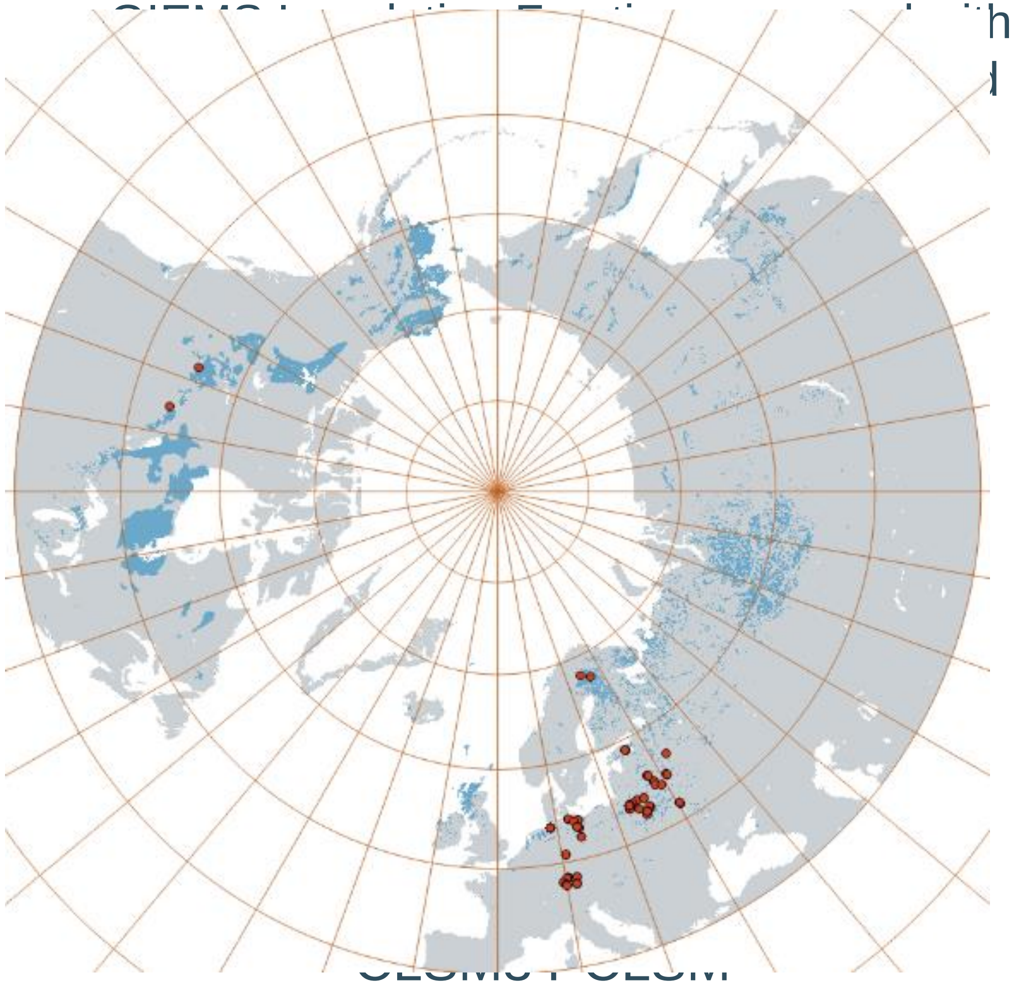
Validation: Inundation Extent

GIEMS: Global Inundation Extent from Multi-Satellites

1993-2007: monthly, 28km resolution
No calibration/validation over peatlands



Prigent et al., 2007



Summary

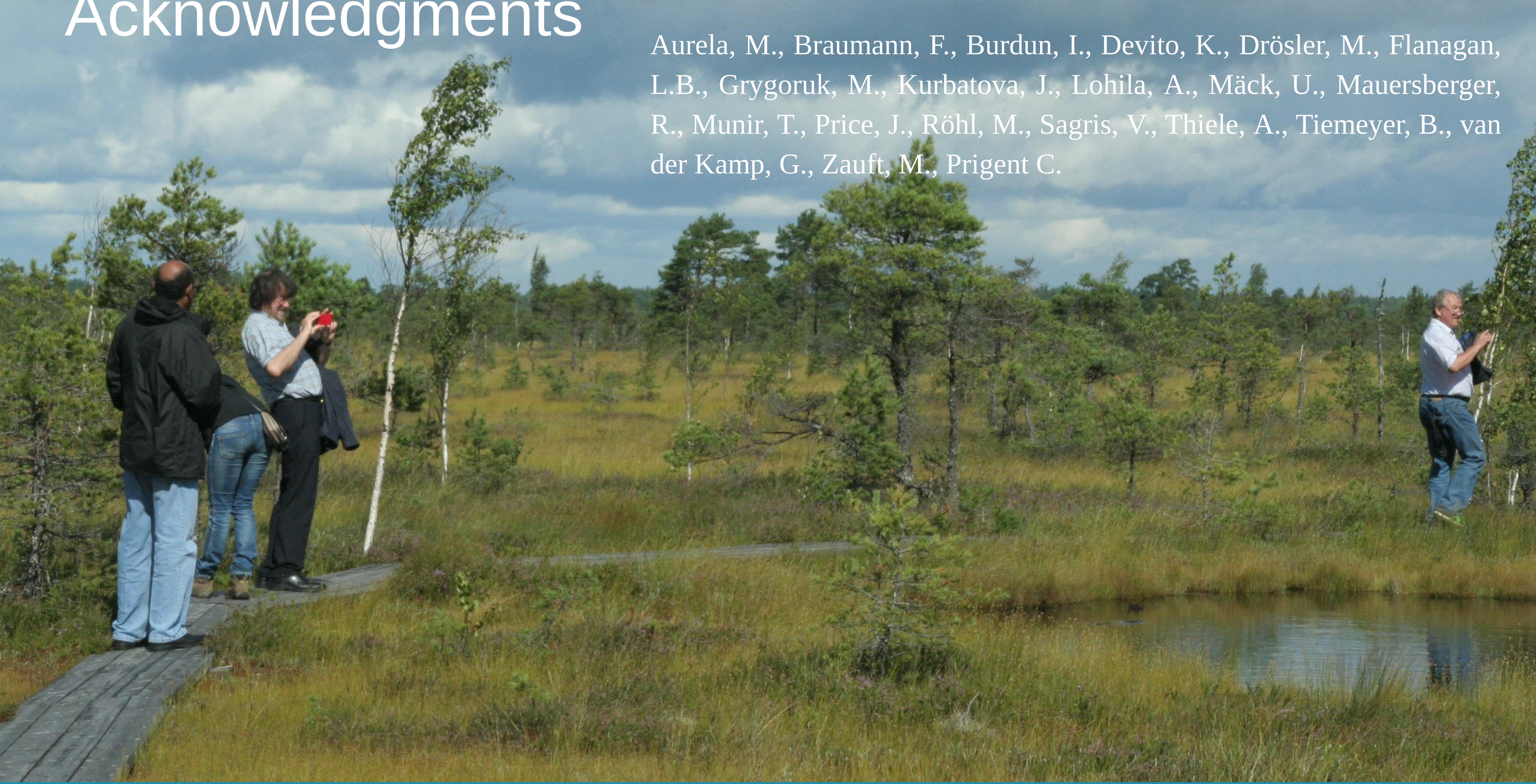
- Peatlands have a specific hydrological dynamics
- Simple solutions for global land surface models with significant effects

Outlook

- Validation: Evapotranspiration (Eddy Towers)
- Validation: Inundation (masking non-peatland areas, GIEMS 2.0)
- Data Assimilation using SMOS/SMAP Brightness Temperatures

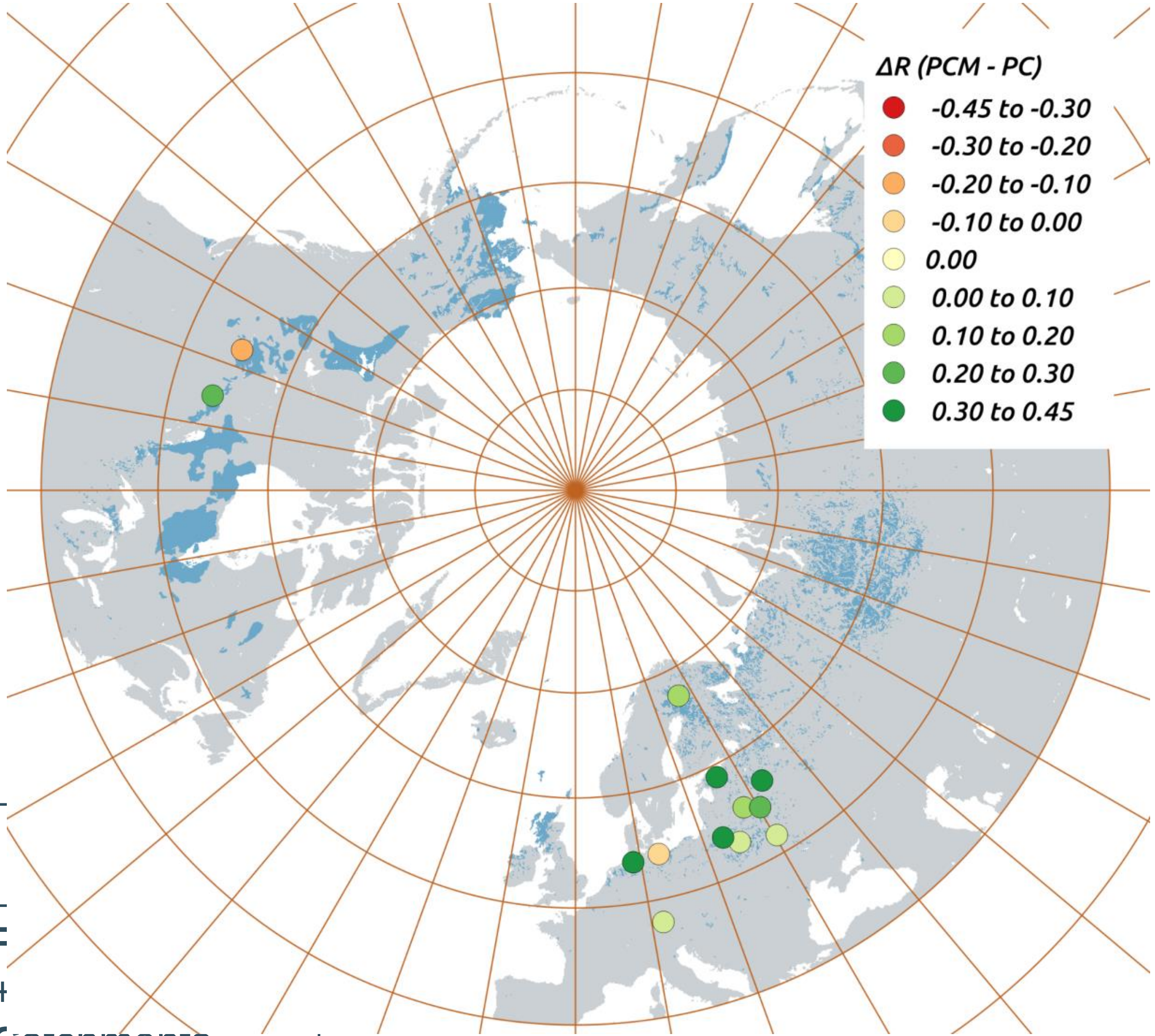
Acknowledgments

Aurela, M., Braumann, F., Burdun, I., Devito, K., Drösler, M., Flanagan, L.B., Grygoruk, M., Kurbatova, J., Lohila, A., Mäck, U., Mauersberger, R., Munir, T., Price, J., Röhl, M., Sagris, V., Thiele, A., Tiemeyer, B., van der Kamp, G., Zauft, M., Prigent C.



Validation

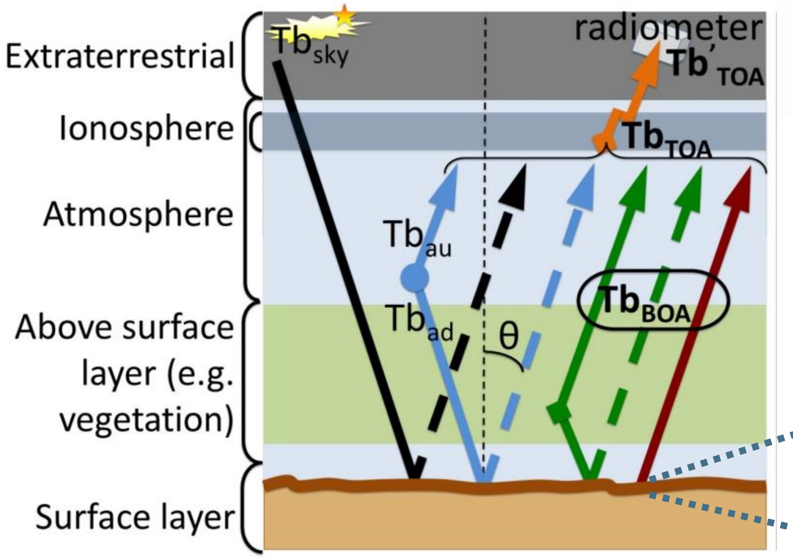
- Simulation experiments using different versions of the GEOS-5 Catchment Land Surface Model
- Domain: Northern Hemisphere
- Forcing data: MERRA-2 (corrected precip.)
- No parameter calibration for new model (PCM)
- Comparison with ~ 60 observed multi-year time series (13 clusters) of water table depth (WTD)



iment	M2	P	PC	
iption	Operational **M**erra-**2**, only mineral soils	Revised soil input including **P**eat class (De Lannoy et al. 2015)	**P**eat class + Refined Topography and **C**atchment delineation	**P** + **C**atchments + New **M**odel Structure
ution	2/3º x 1/2º	EASEv2 M09	5' x 5'	5' x 5'

Radiative transfer parameters

- Brightness Temperature (passive microwave)



Radiative transfer model

Dielectric constant of
soil-water-air mixture
= f (sand, clay, poros, wp, soil moisture…)

Soil reflectivity