



# amazing pattern

self-organization in northern peatland  
ecosystems

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Maarten Eppinga

Stefan Dekker

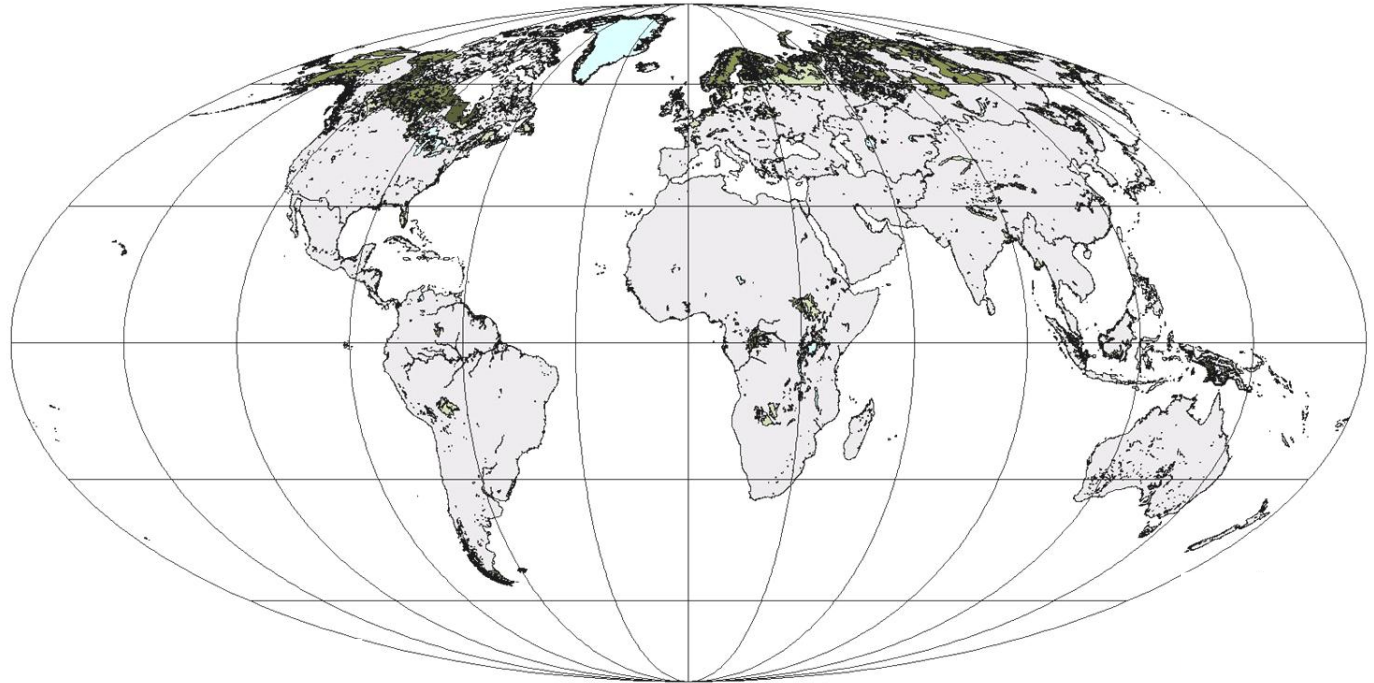
Hugo de Boer

Max Rietkerk

Martin Wassen

# Global distribution of peatlands and their storage of Carbon

APPROXIMATE GLOBAL PEAT DISTRIBUTION



2 % of land surface

30 % global terrestrial Carbon (C) pool

Northern peatlands: 550 Gt C (Tropical: 50 Gt C)

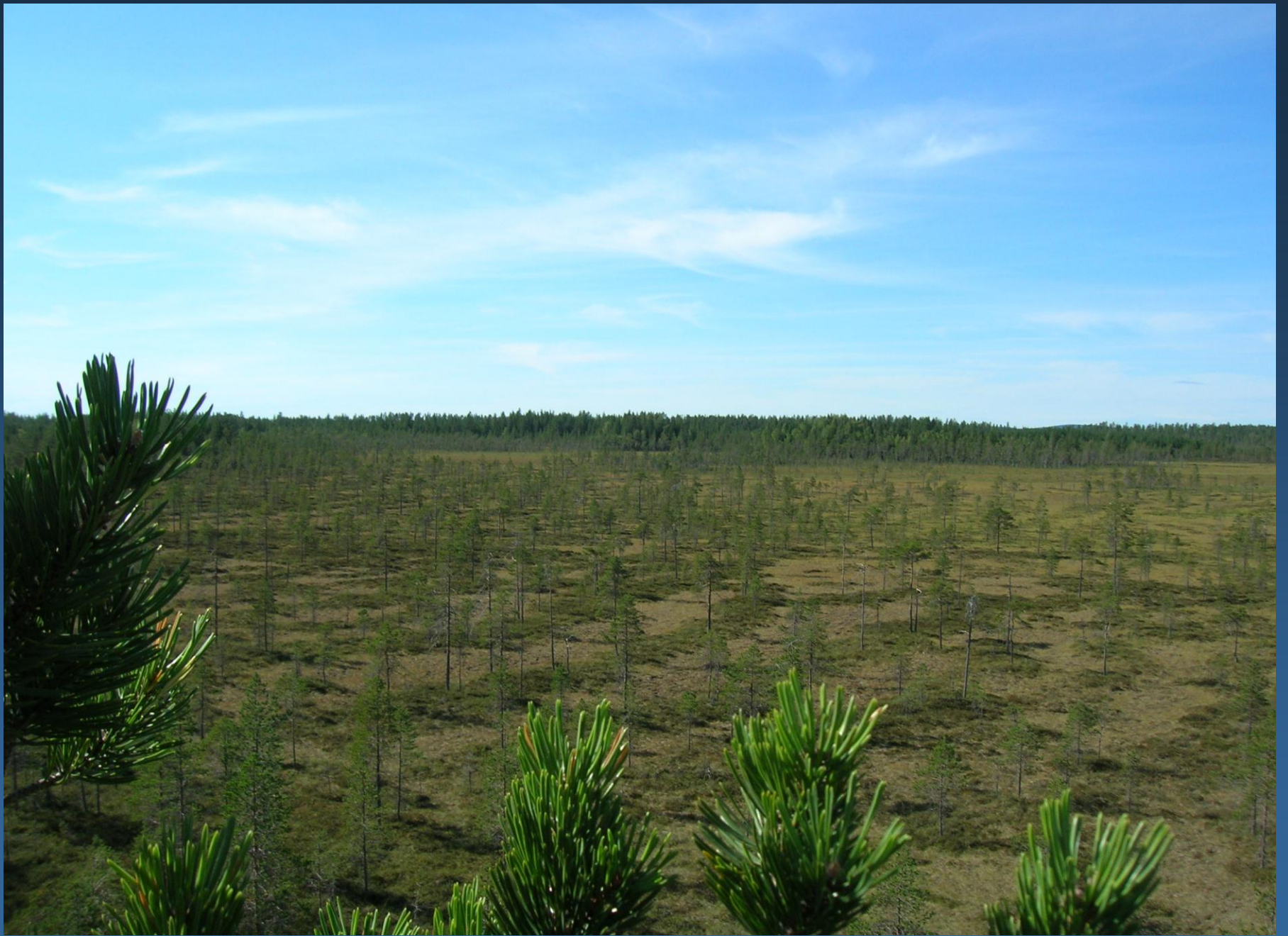
Yu et al., *Geophysical Research Letters*, 2010

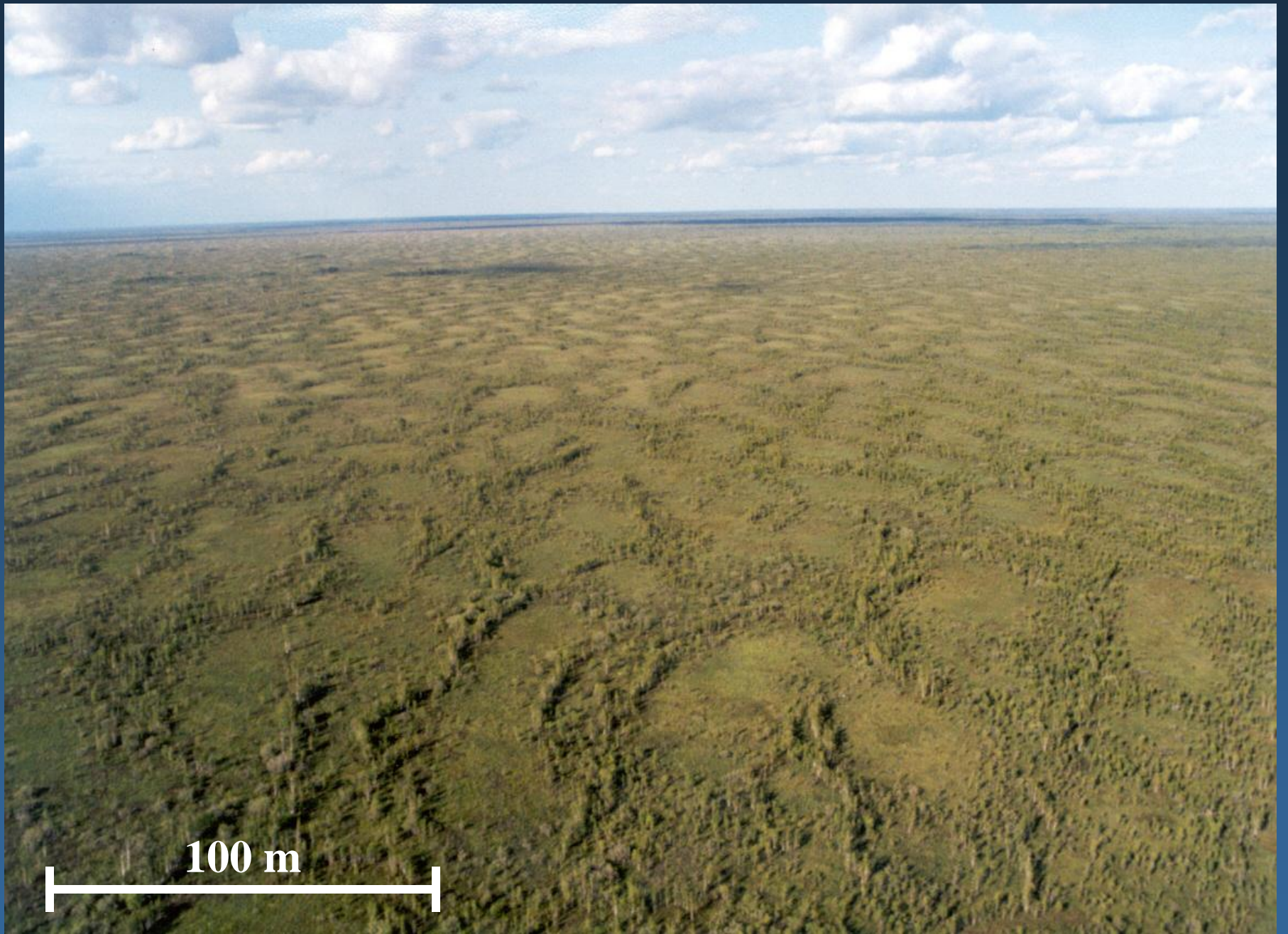


**Hummock**

**Hollow**



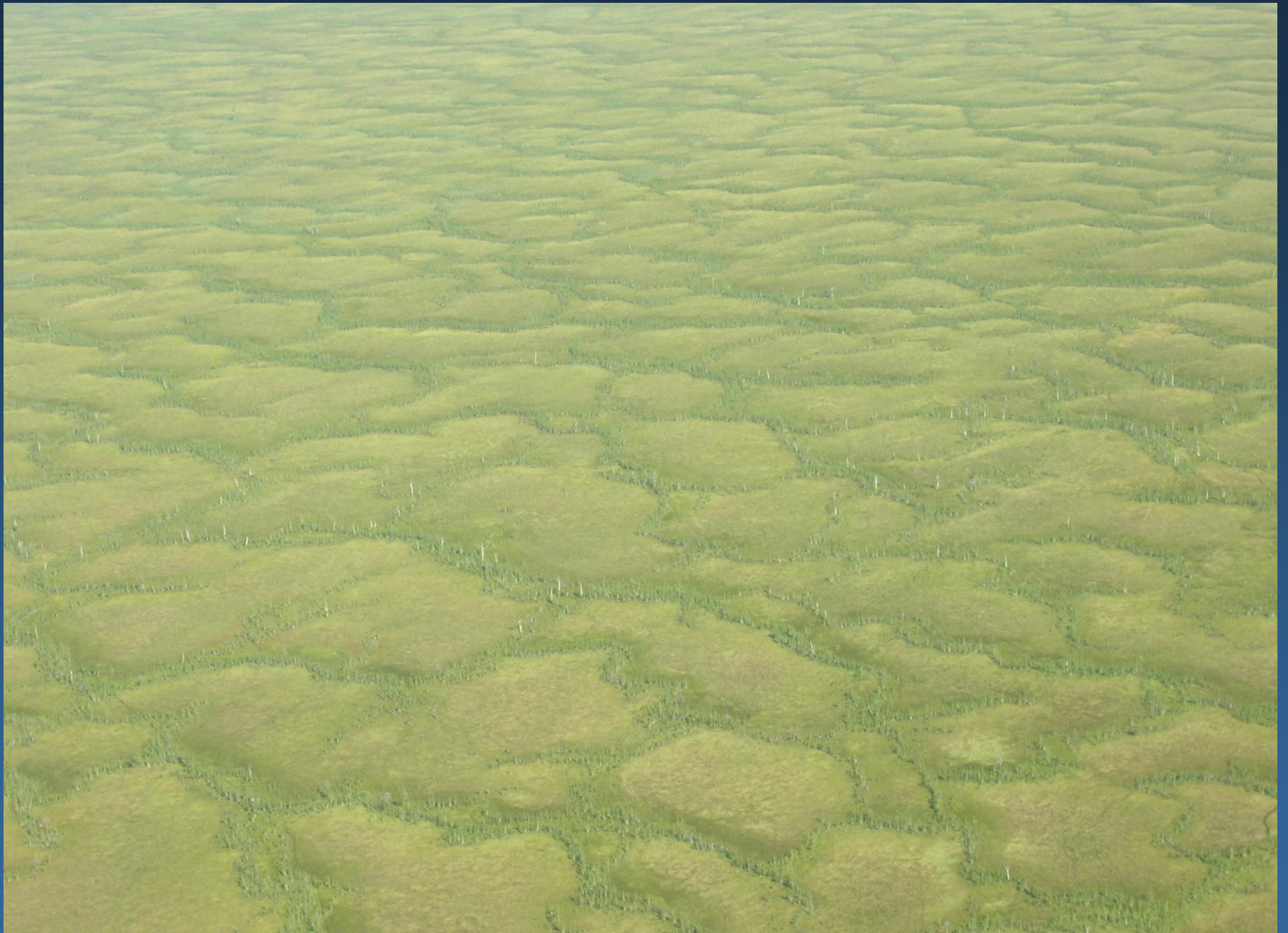










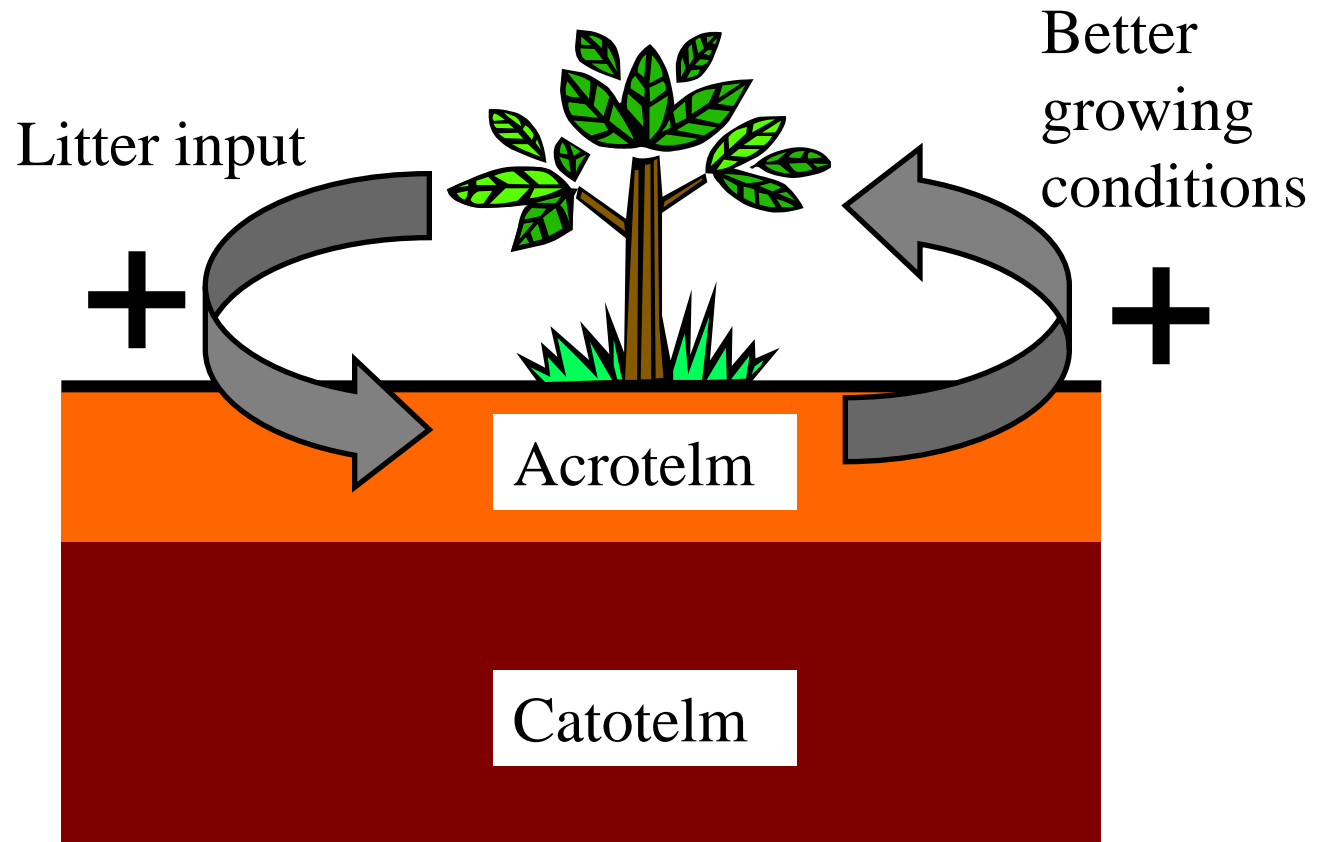


# Mechanisms of spatial self-organization in peatlands

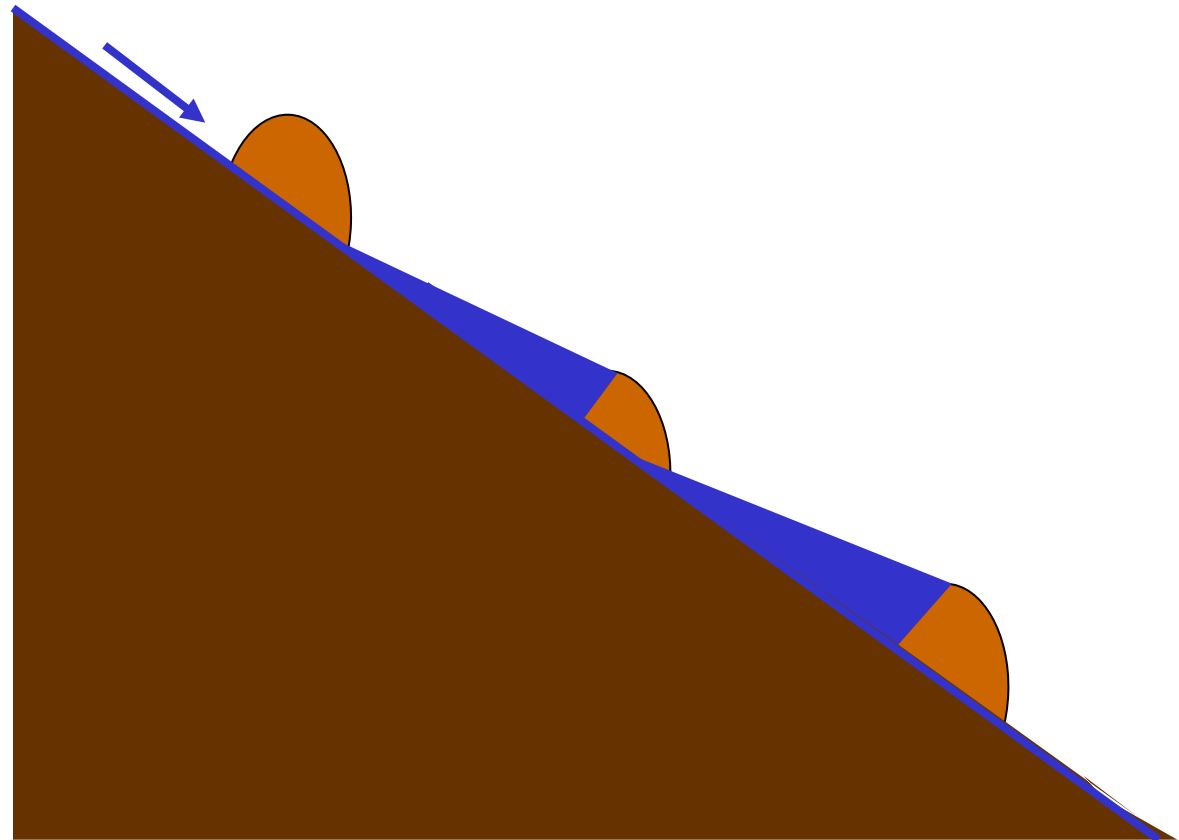
- The peat accumulation mechanism
- The water ponding mechanism
- The nutrient accumulation mechanism



# Peat accumulation mechanism: Acrotelm thickness $\leftrightarrow$ productivity



# Water ponding mechanism: Hummocks pond water upslope



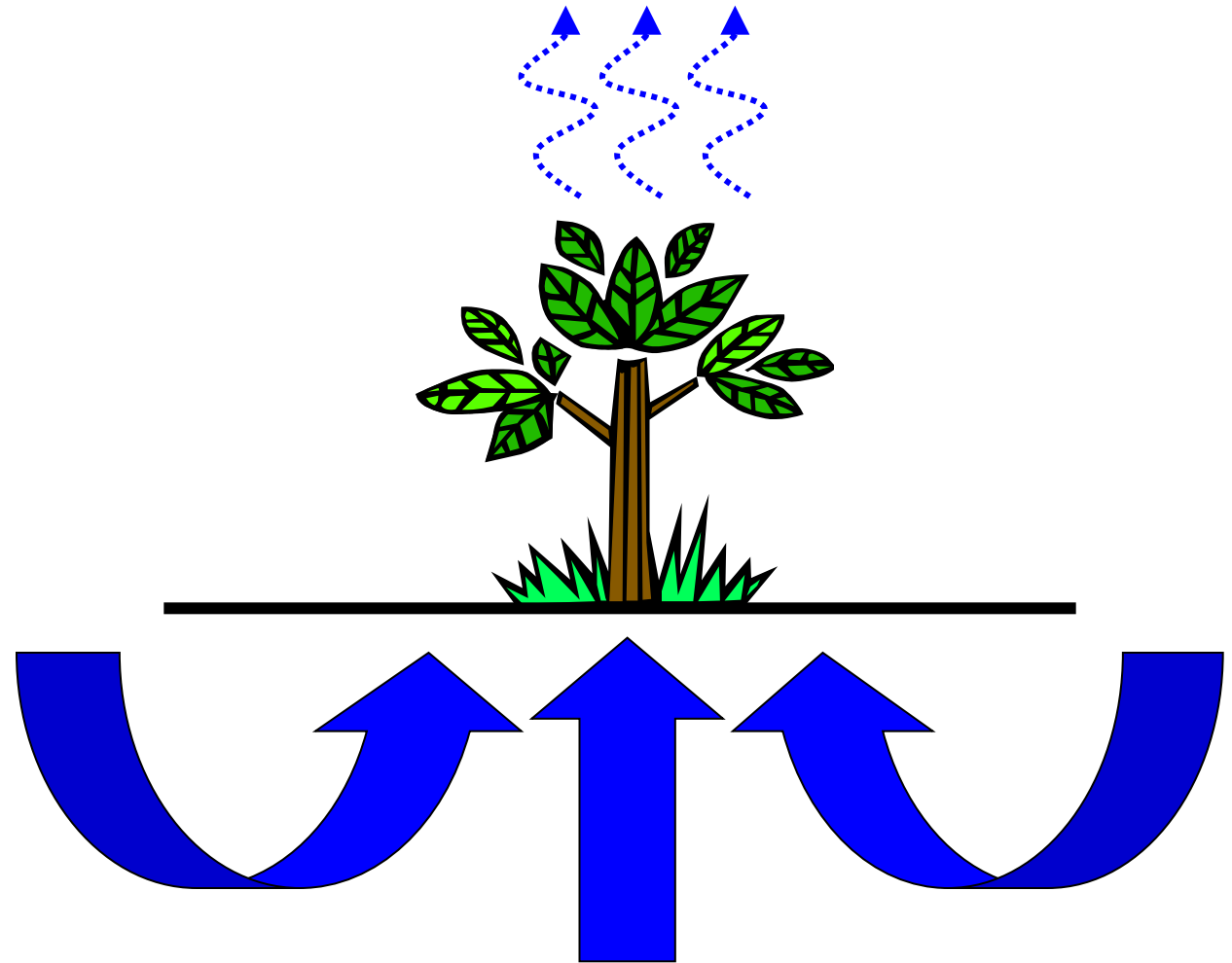
Swanson & Grigal, *Oikos*, 1988  
Couwenberg & Joosten, *Journal of Ecology*, 2005

# The nutrient accumulation mechanism



Rietkerk et al., *The American Naturalist*, 2004  
Eppinga et al., *Plant Ecology*, 2009

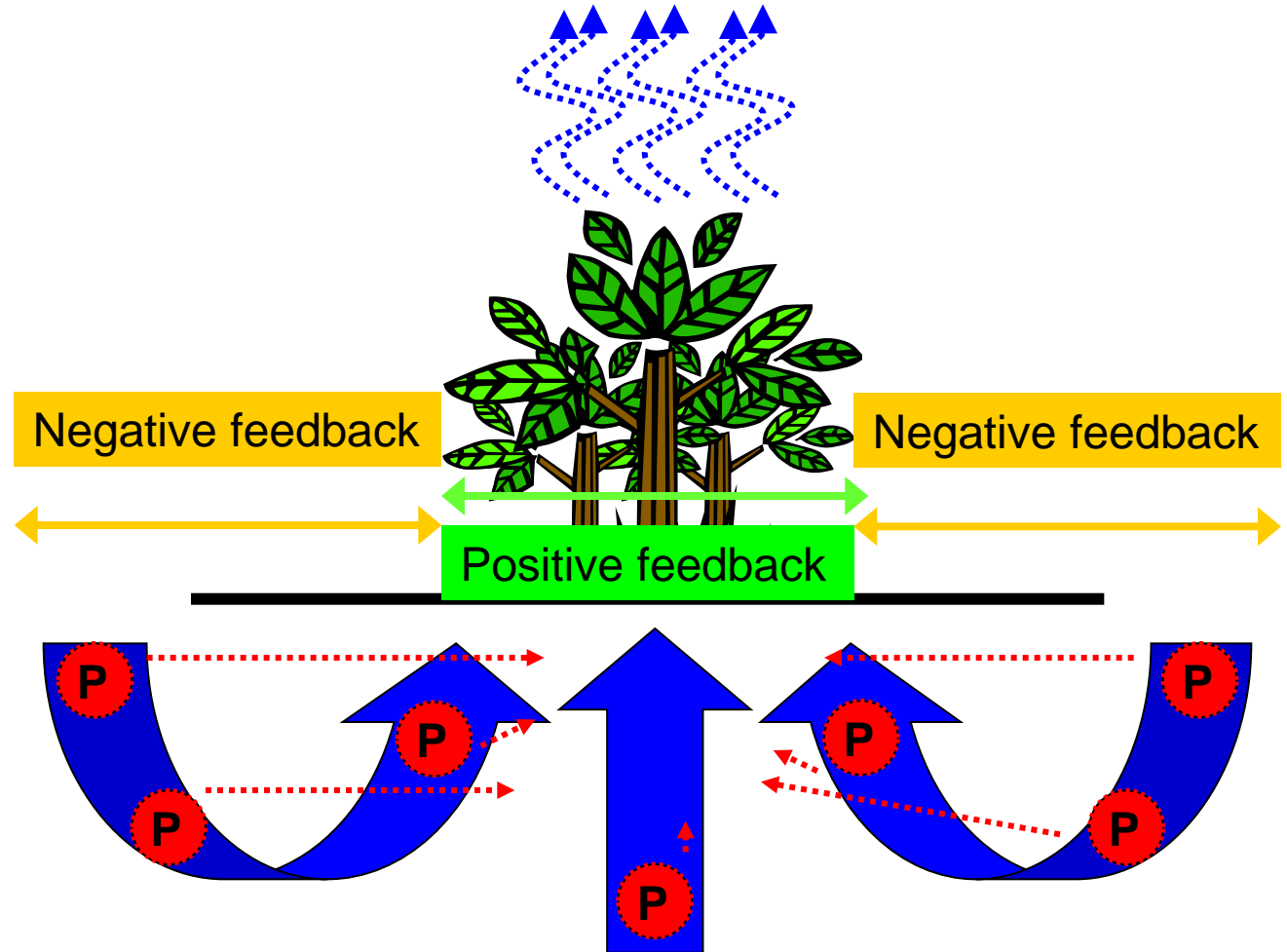
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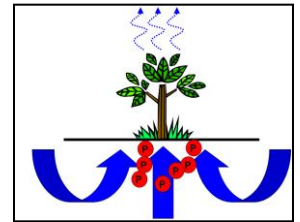
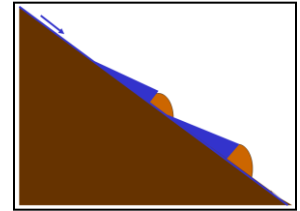
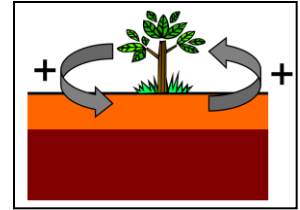
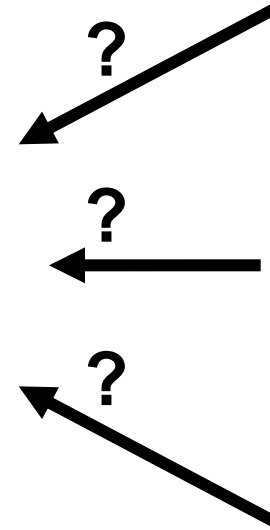
# The nutrient accumulation mechanism



Rietkerk et al., *The American Naturalist*, 2004

Eppinga et al., *Plant Ecology*, 2009

# Classical problem



An ecological phenomenon

*(here: self-organization into hummock-hollow  
patterning of peatlands)*

can be explained by **multiple models**  
that consider **different mechanisms**

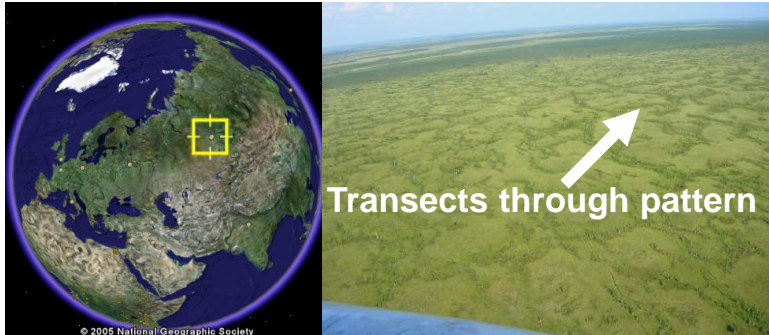


# Particular problem

Difficult to compare peatland model results due to their different structure:

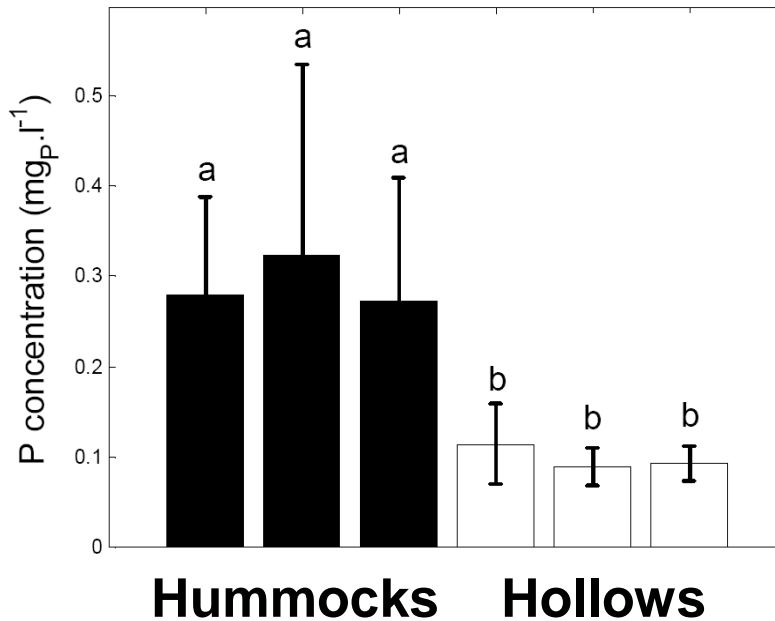
Model (1 <sup>st</sup> author)	Acrotelm dynamics	Catotelm dynamics	Water table depth	Nutrients	Biomass dynamics	Space
Hilbert	✓	✓	✓	✗	1/2	✗
Belyea	✓	✗	1/2	✗	1/2	✗
Couwenberg	✗	✗	1/2	✗	✗	✓
Rietkerk	✗	✗	1/2	✓	✓	✓

# Testing nutrient predictions with field data

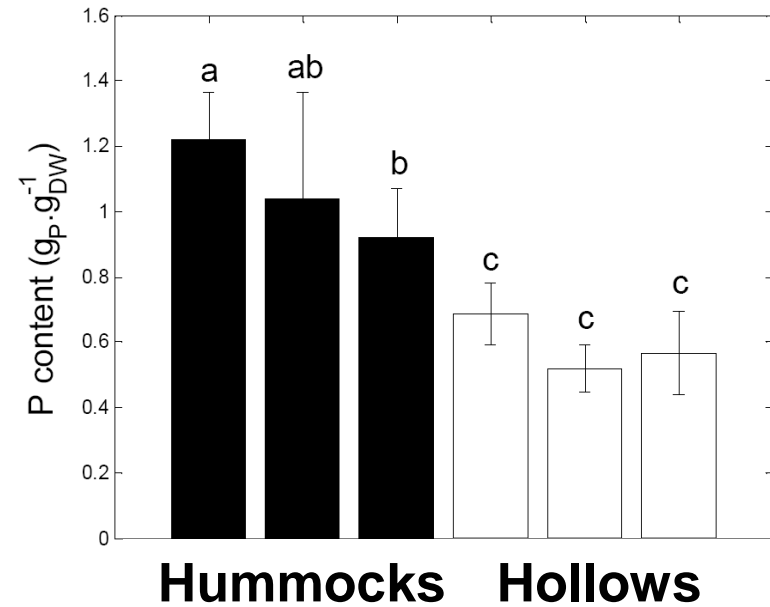


Great Vasyugan Bog,  
Siberia

Water



Vegetation



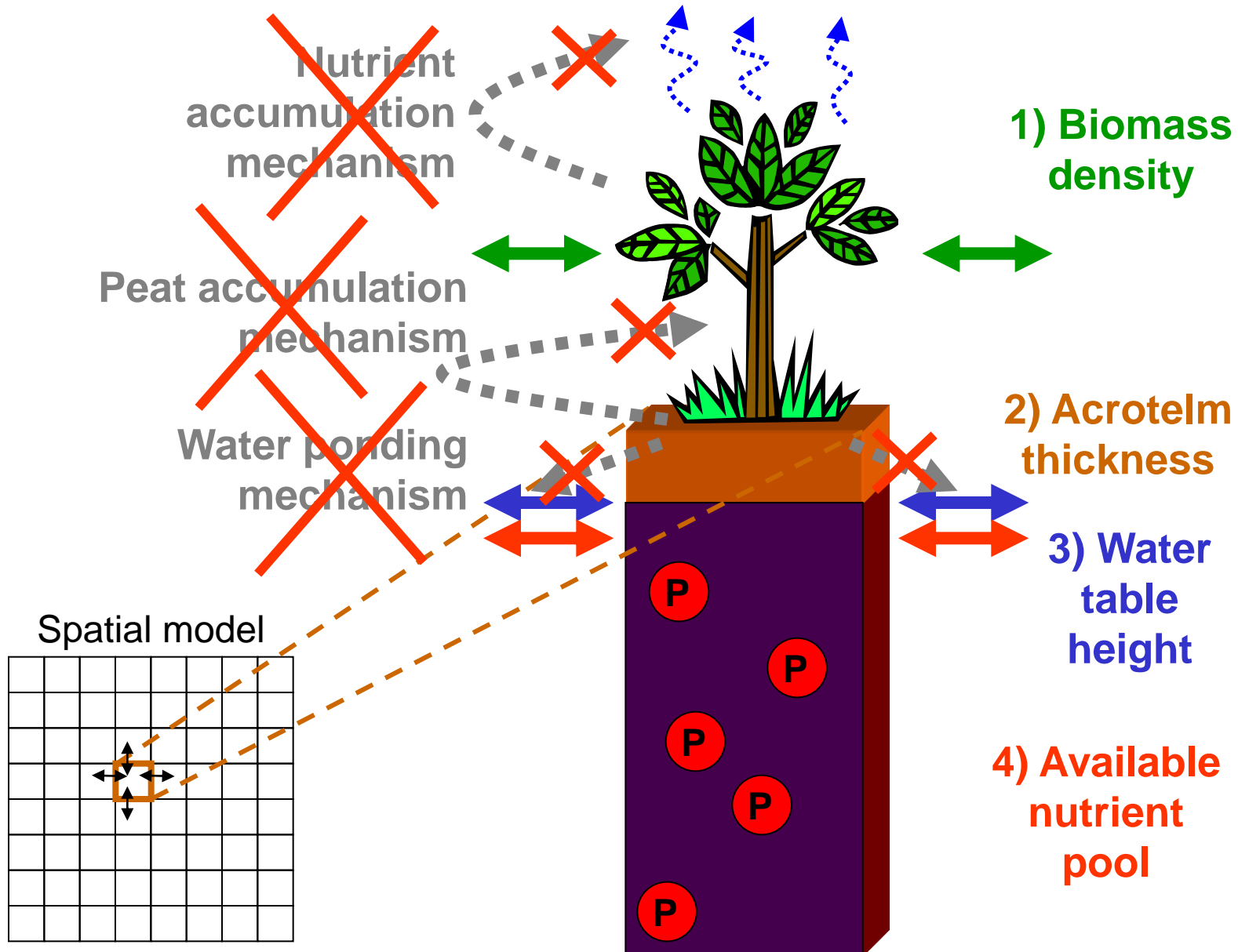
Eppinga et al., *Ecosystems*, 2008

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Rietkerk	✗	✗	1/2	✓	✓	✓

# Description of new model



# Full-factorial analysis

## Flat ground

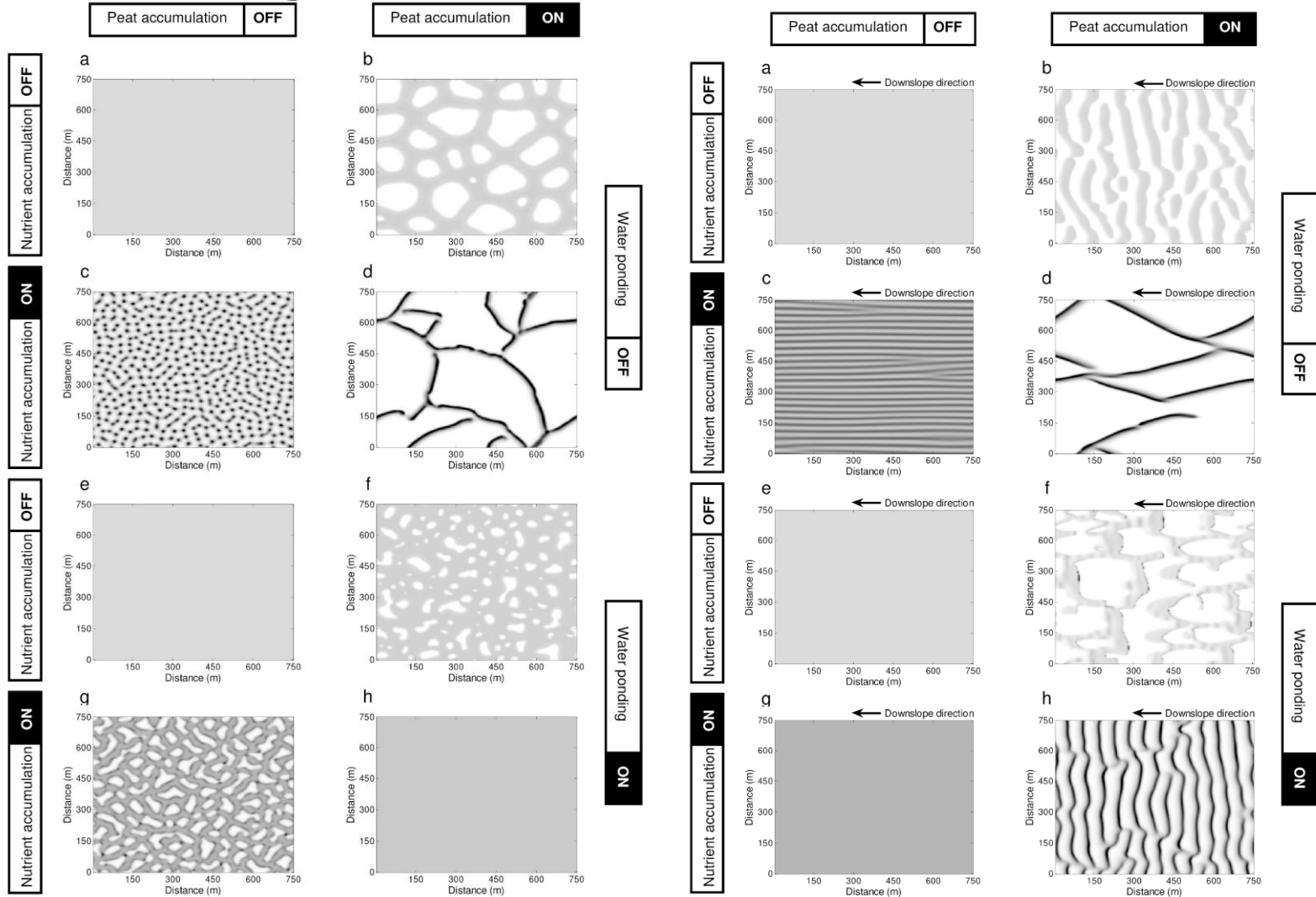
## Slope



# Model simulation results

## Flat ground

## Slope



# Implications of model results

Important result: driving mechanism may depend on climate conditions, and is reflected in nutrients & hydrology

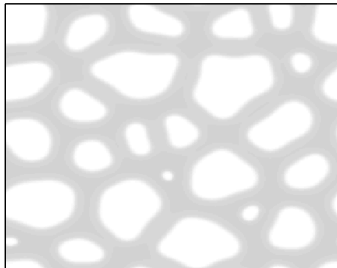
**ET/Prec  $\ll 1$**

Drainage-dominated

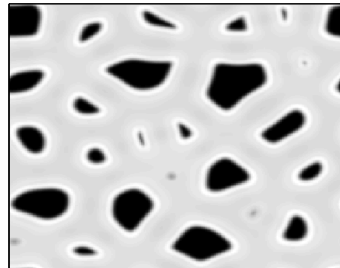
Peat accumulation mechanism

Highest nutrient concentrations in sparsely vegetated *hollows*

Biomass



Nutrients



**ET/Prec  $\rightarrow 1$**

Evapotranspiration-dominated

Nutrient accumulation mechanism

Highest nutrient concentrations in densely vegetated *hummocks*

Biomass



Nutrients



# Empirical test of predictions

## Test model predictions

Site	Prec(mm.yr <sup>-1</sup> )	ET (mm.yr <sup>-1</sup> )	ET/Prec
(1) Inverewe, Scotland	1700	250-380	<b>0.15-0.22</b>
(2) Degerö Stormyr, Sweden	520	227-337	<b>0.25-0.62</b>
(3) Vasyugan Bog Siberia	500	300-500	<b>0.60-1.00</b>



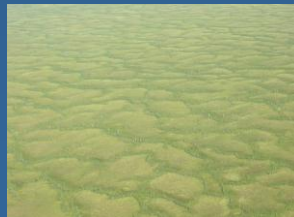
### 1) Inverewe



### 2) Degerö



### 3) Vasyugan

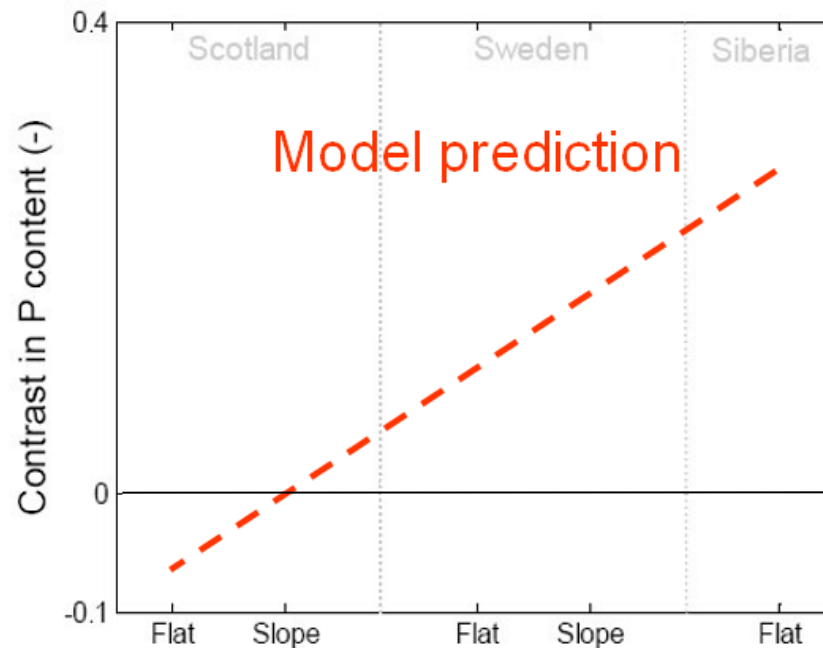




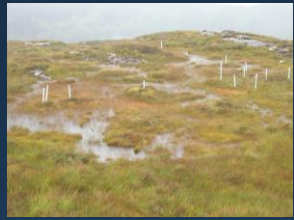
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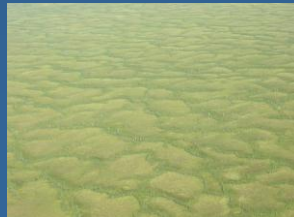
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### 2) Degerö



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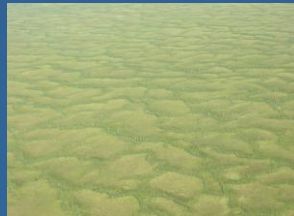
### 1) Inverewe



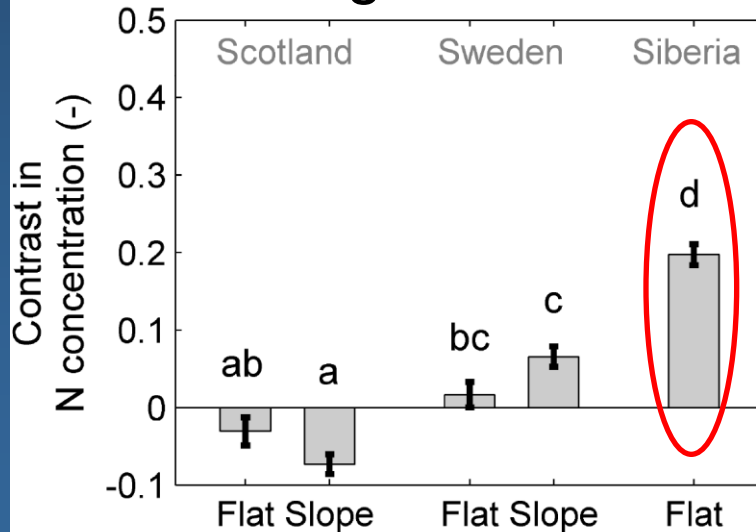
### 2) Degerö



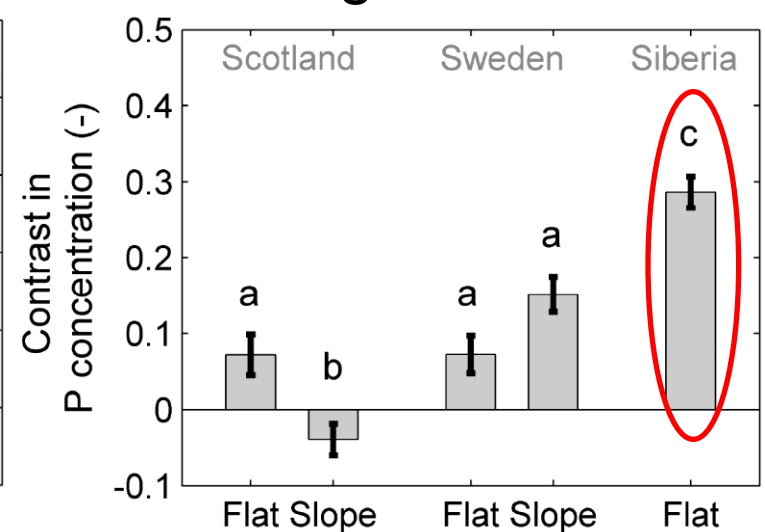
### 3) Vasyugan



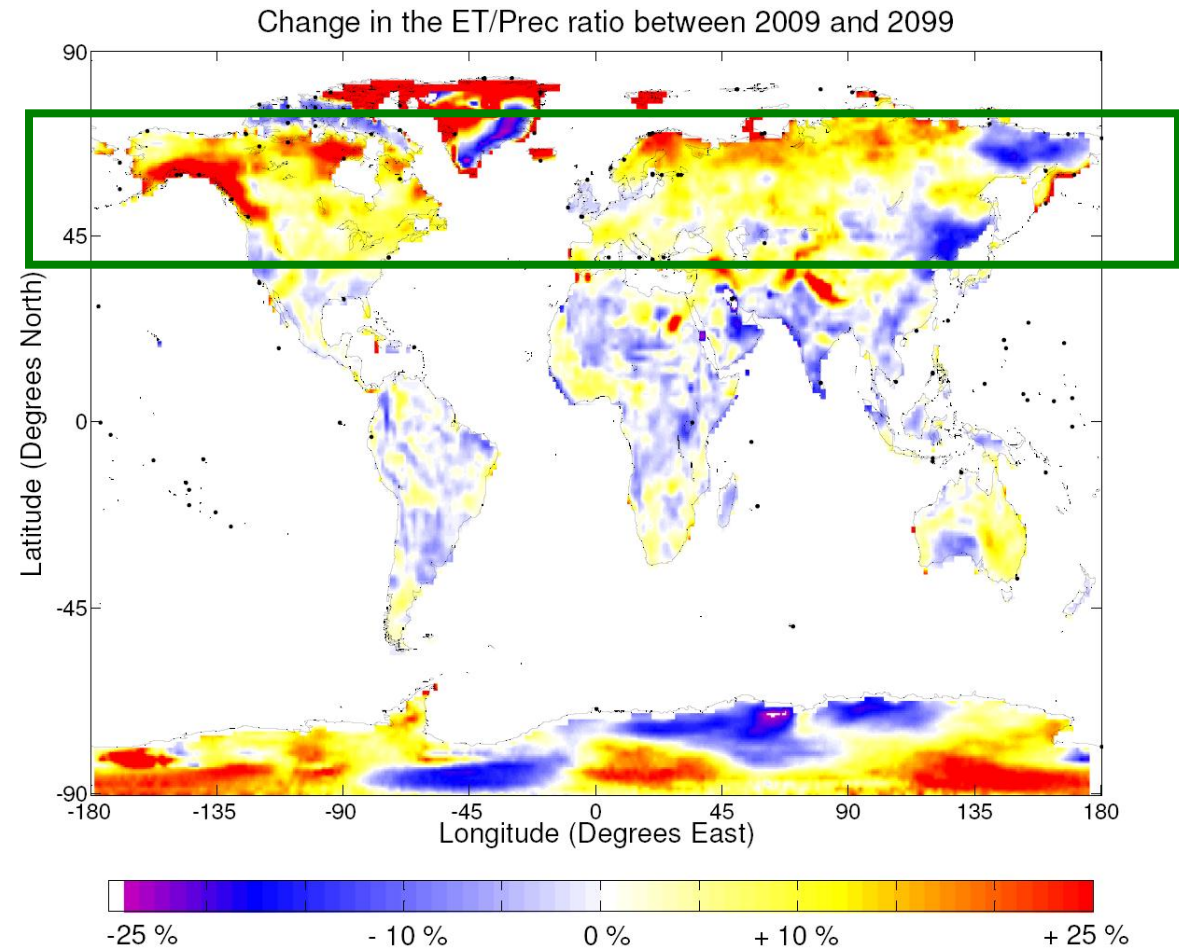
### Vegetation N



### Vegetation P

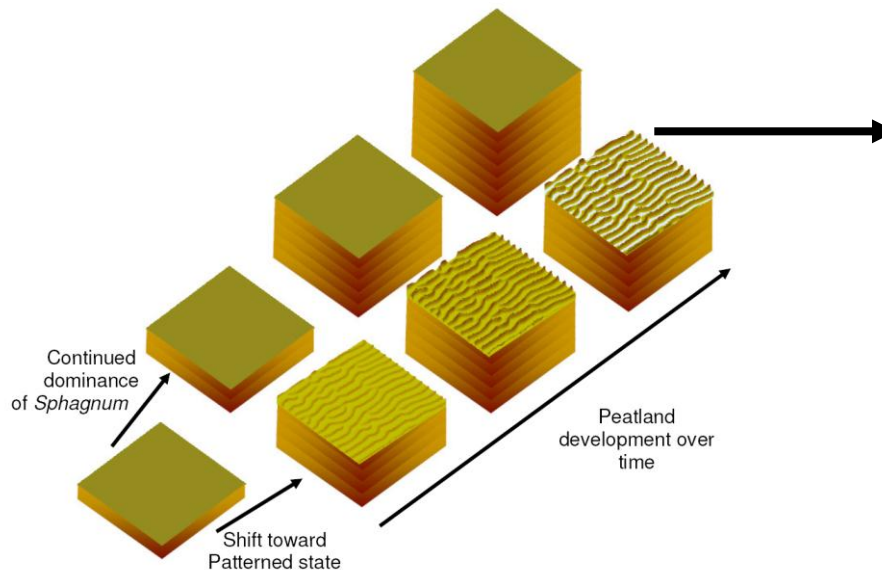
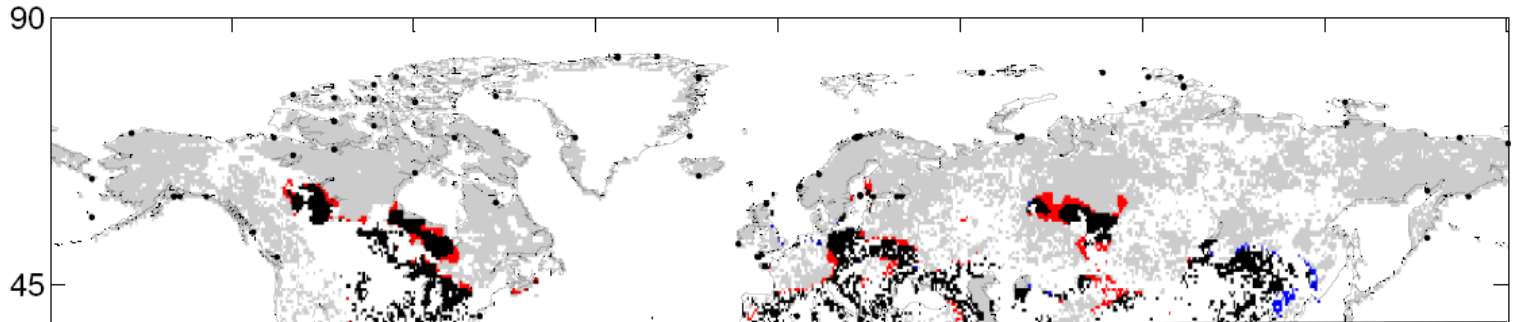


# Nutrient accumulation mechanism more important? Changes in ET/Prec ratio



# Perspectives on peatland ecosystem functioning

Effect of climate change on the distribution of peatlands that could possibly be affected by the nutrient accumulation mechanism



Model simulations:  
low C-storage  
capacity in nutrient  
accumulation-driven  
patterned systems

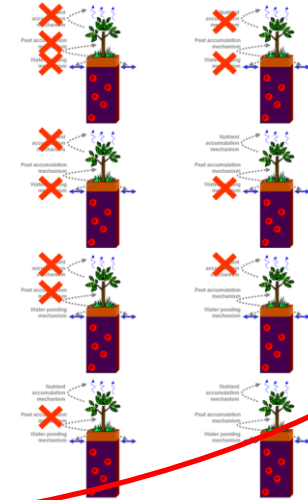
# Summary northern peatlands

## Phenomenon



## Confront explanations in model

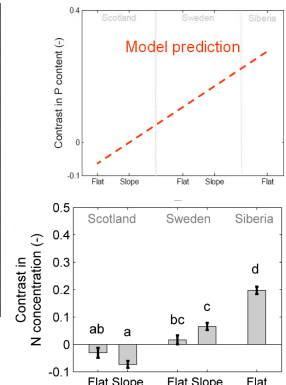
### Flat ground



## Derive contrasting hypotheses

$ET/Prec \ll 1$		$ET/Prec \rightarrow 1$	
Drainage-dominated		Evapotranspiration-dominated	
Peat accumulation mechanism		Nutrient accumulation mechanism	
Highest nutrient concentrations in sparsely vegetated <i>hollows</i>		Highest nutrient concentrations in densely vegetated <i>hummocks</i>	
Biomass	Nutrients	Biomass	Nutrients

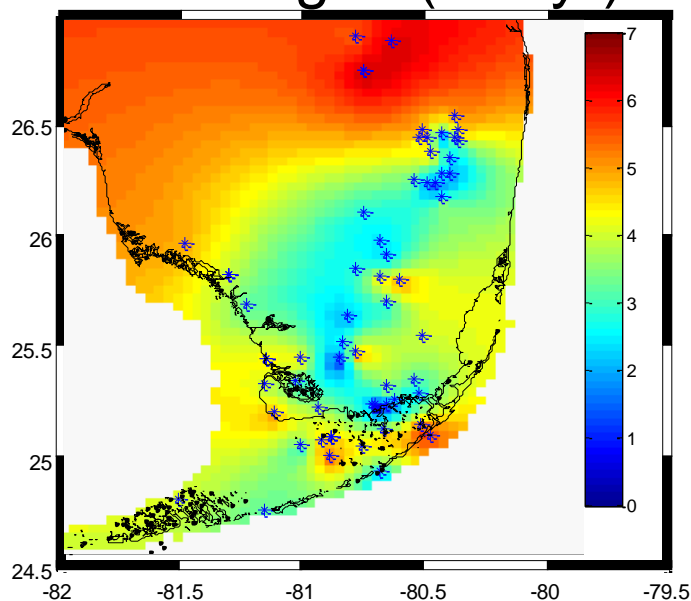
## Test hypotheses empirically



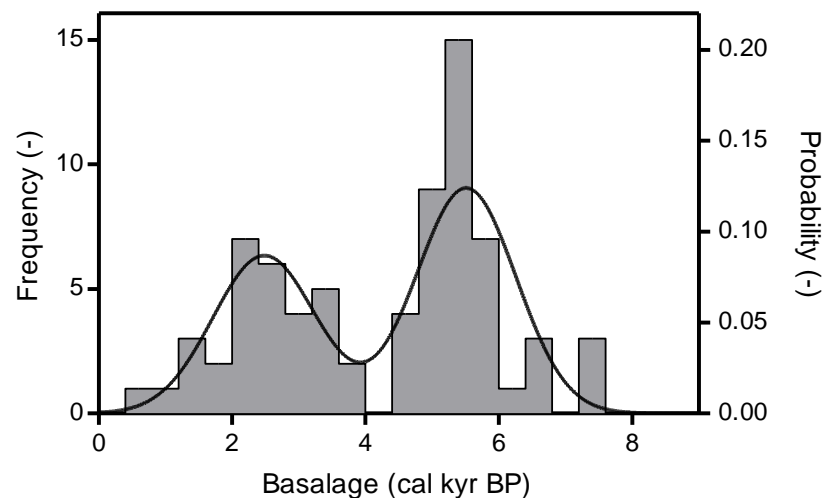
# Peat initiation in South Florida

**Phenomenon:** Two major episodes of peatland initiation

Basal ages ( $10^3$  yr)



Frequency distribution

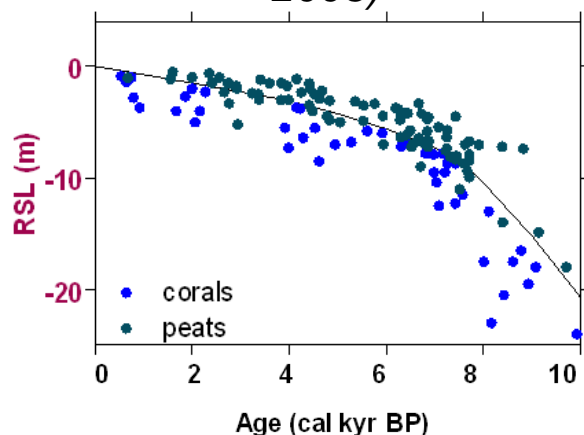


o.a. Wanless & Tagett 1989, Gleason & Stone 1994, Willard et al. 2001, Winkler et al. 2001, Bernhardt & Willard 2009

# Peat initiation in South Florida

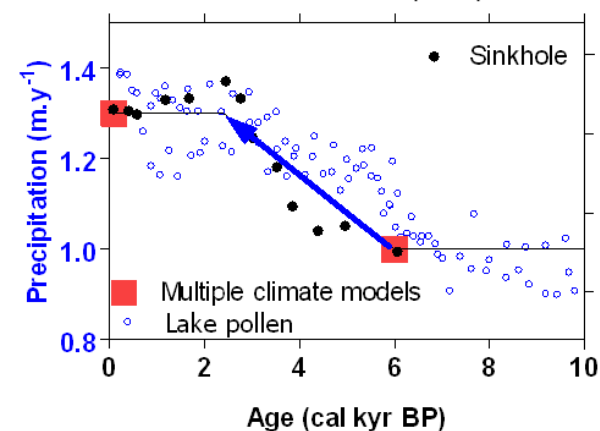
Alternative explanations: for climatic drivers of peatland initiation in the South Florida region

## 1) Sea level rise (Toscano & Macintyre 2003)

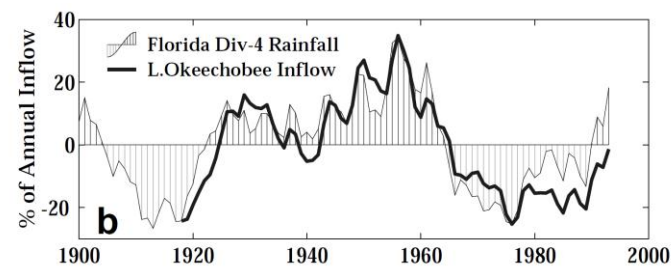
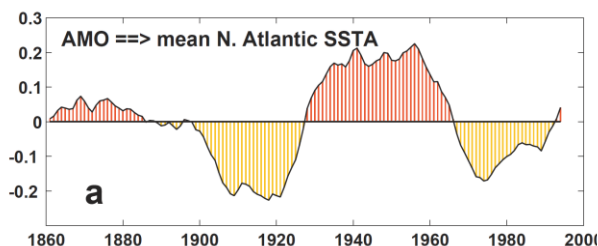


## 2) Precipitation increase

(Filley et al. 2001, Braconnot et al. 2007, Donders et al. 2011)

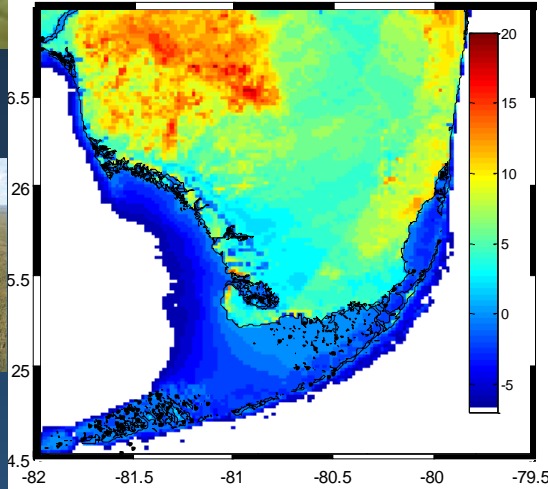


## 3) Climatic fluctuations (Enfield et al. 2001)



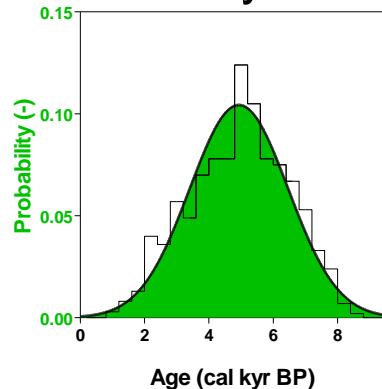
# Confrontation in model

Elevation (m)

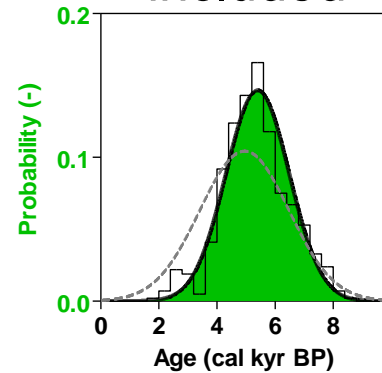


- South Florida divided in 1' by 1' gridcells
- Modeling large scale water flows (pdf of drainage characteristics)
- Peat accumulation processes for 1000 peatlands (from pdf)
- Keep track of peatland initiation over 10,000 year period

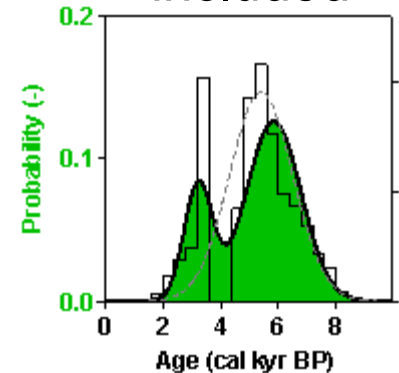
Sea level rise only



Precipitation included



Fluctuations included





# Wrapping up

- Multiple driving mechanisms proposed for self-organized spatial patterns in northern peatlands
- Modeling suggests that driving mechanism of patterning may depend on climatic conditions
  - *Underlying patterns in nutrients and hydrology reflect driving mechanisms*
- Field data across climatic gradient corroborates predictions
- Approach/philosophy can be extended to other questions & peatland types

