Using a simple, process-based model to examine relationships between climate, land-use, and decadal to millennial peatland carbon cycling

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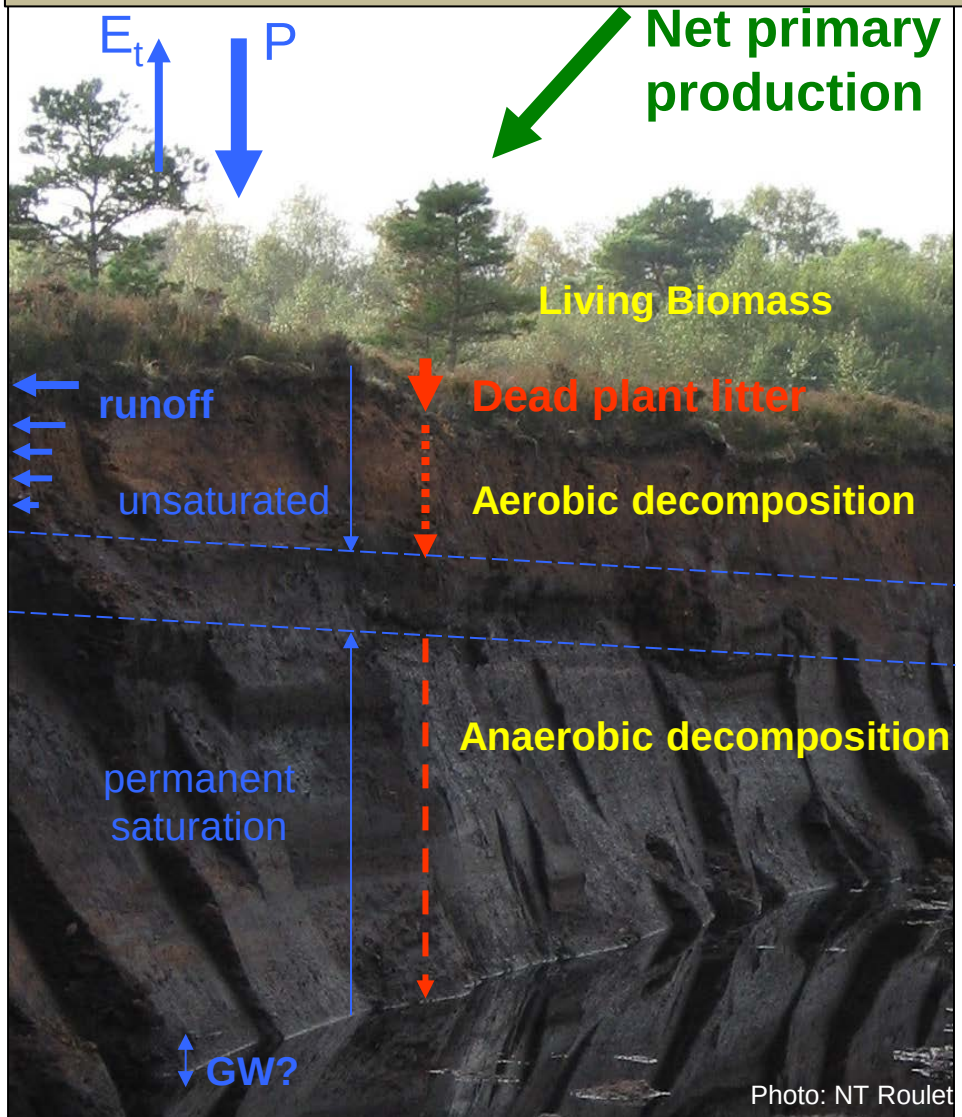
Postcard: Co. Galway, Ireland

Peatland coupled carbon–water system



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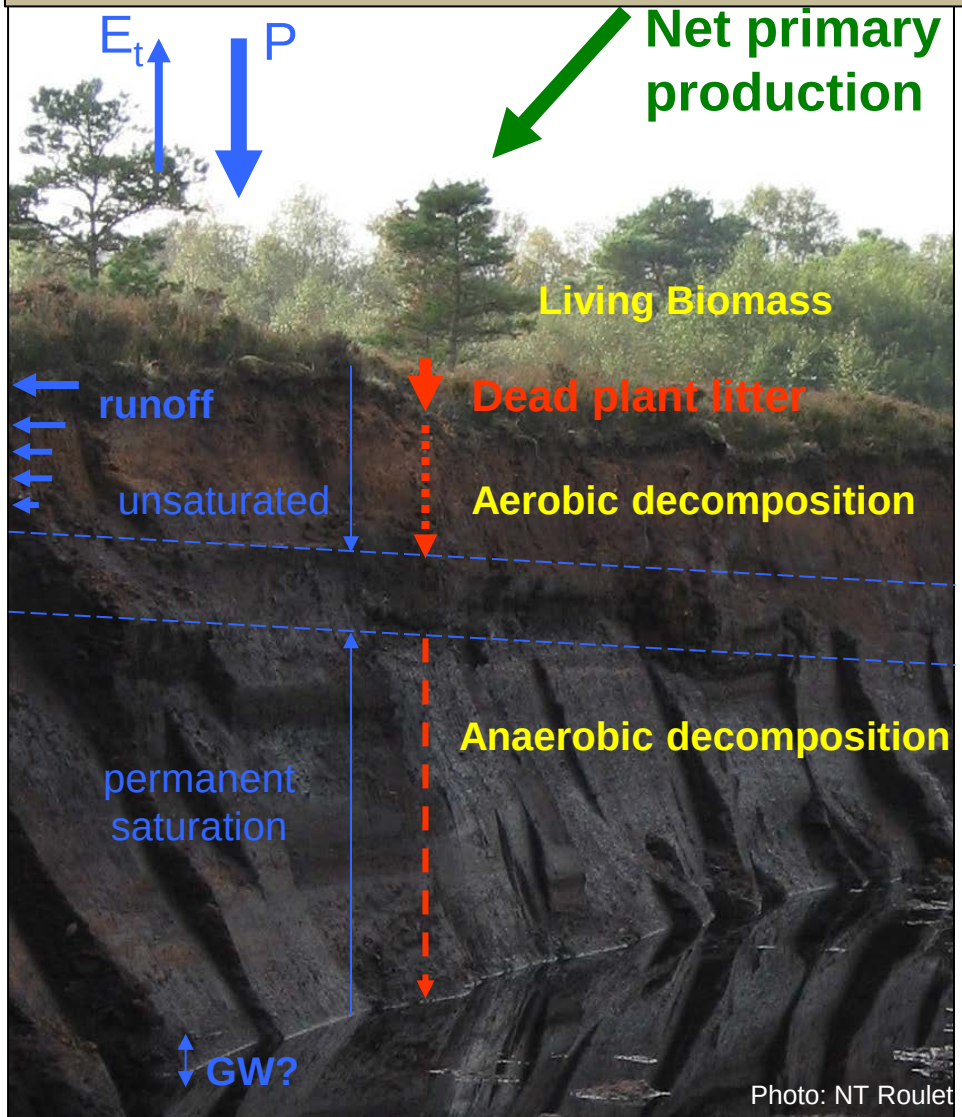
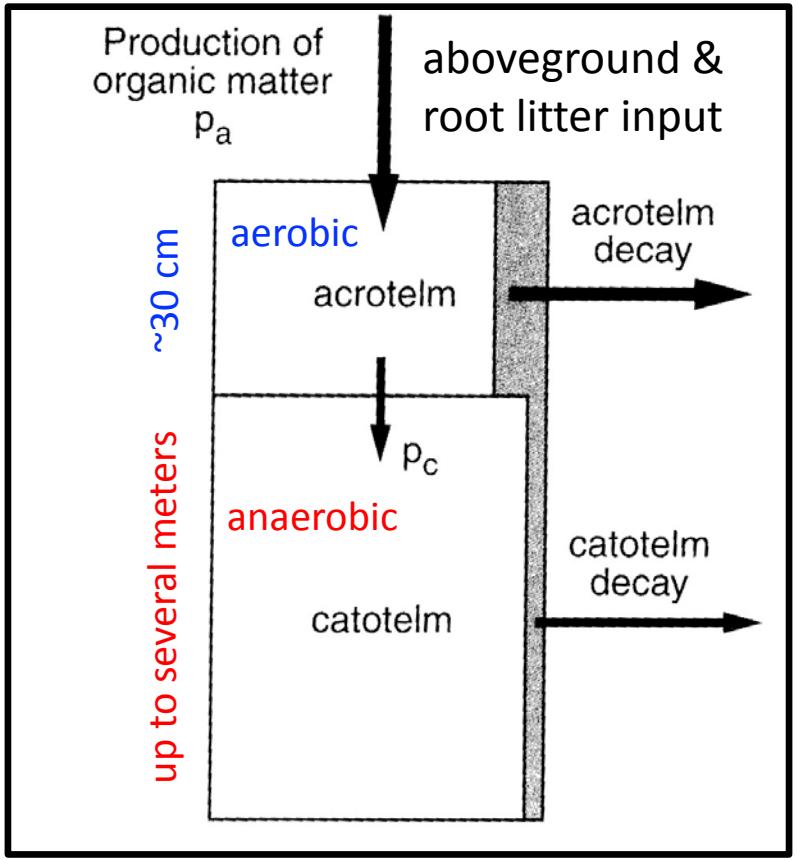
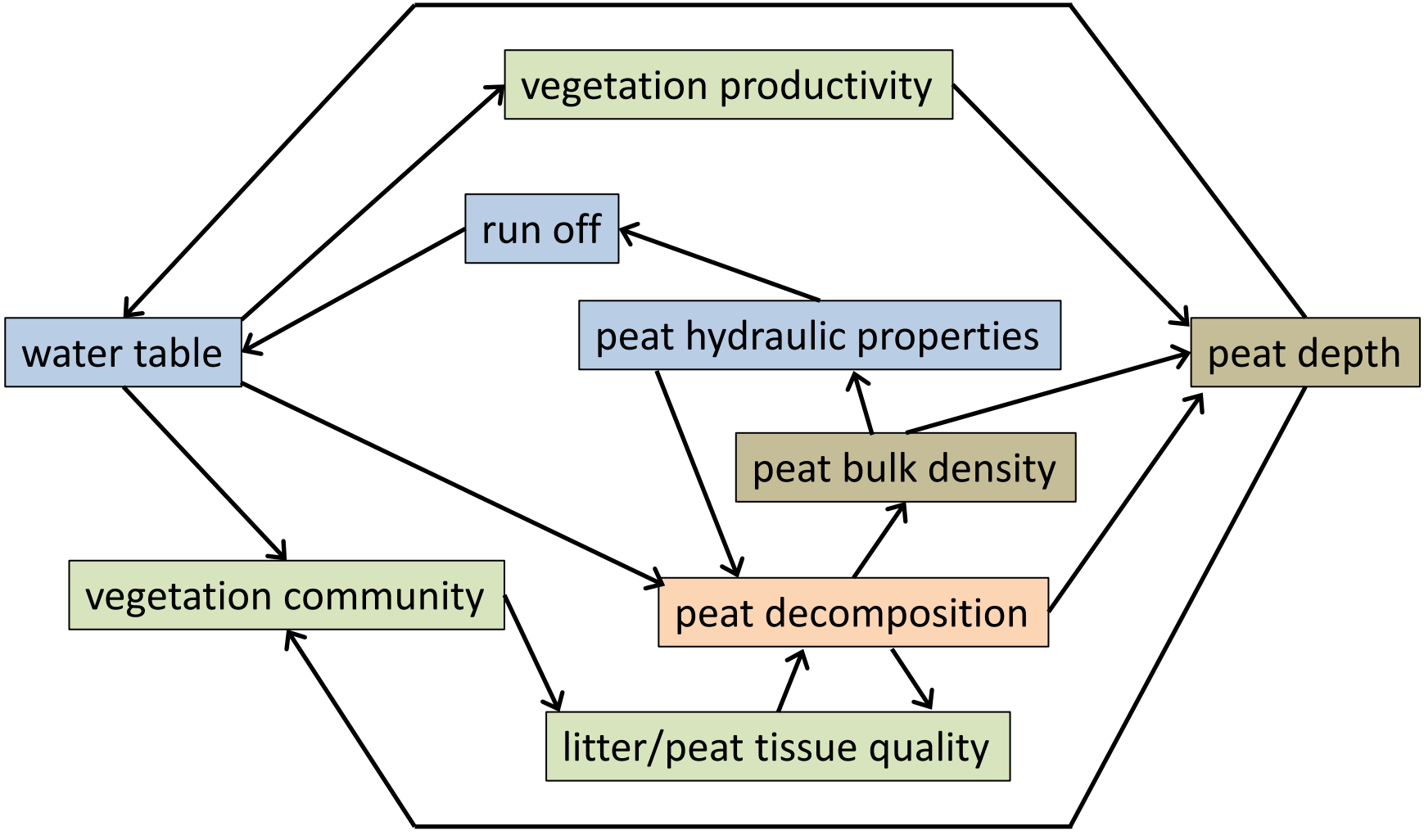


Clymo's model from 1984



Plant-peat-water feedbacks in peat accumulation



HPM (Holocene Peat Model)
- annual carbon balance (*PD*)
- annual water balance (*WTD*)

HPM calculates:
- *PD* & *WTD* – peat & water table depth
- m/m_0 – fraction of initial litter remaining
- ρ – annual cohort bulk density
- changes in plant community

Evapotranspiration
- *influenced by: WTD*
- *influences: WTD*

Precipitation
- *influences: WTD*

Run-on
- *influenced by: WTD, PD*
- *influences: WTD*

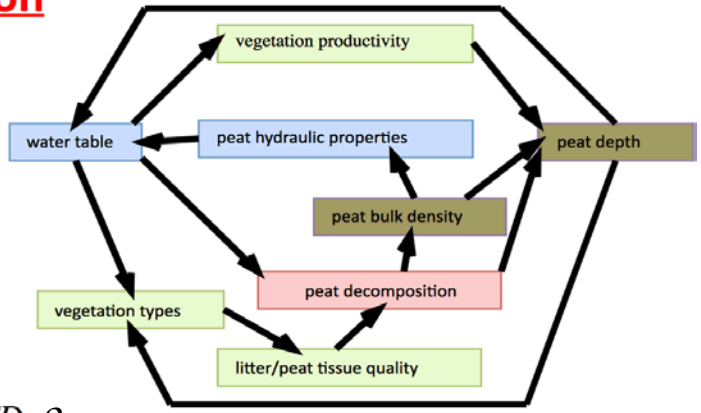
vascular/moss NPP
- *influenced by: WTD, PD*
- *influences*: litter quality and inputs

Peat humification
- *influenced by: m/m0*
- *influences: ρ, WTD*

Run-off
- *influenced by: WTD, PD, ρ*
- *influences: WTD*

Decomposition
- *influenced by: WTD, m/m0*, PFT
- *influences: m/m0, PD*

Anoxia
- *influenced by: WTD, ρ*
- *influences*: decomposition rate



Frolking et al. 2010. *Earth System Dynamics*, 1:1–21, doi:10.5194/esd-1-1-2010

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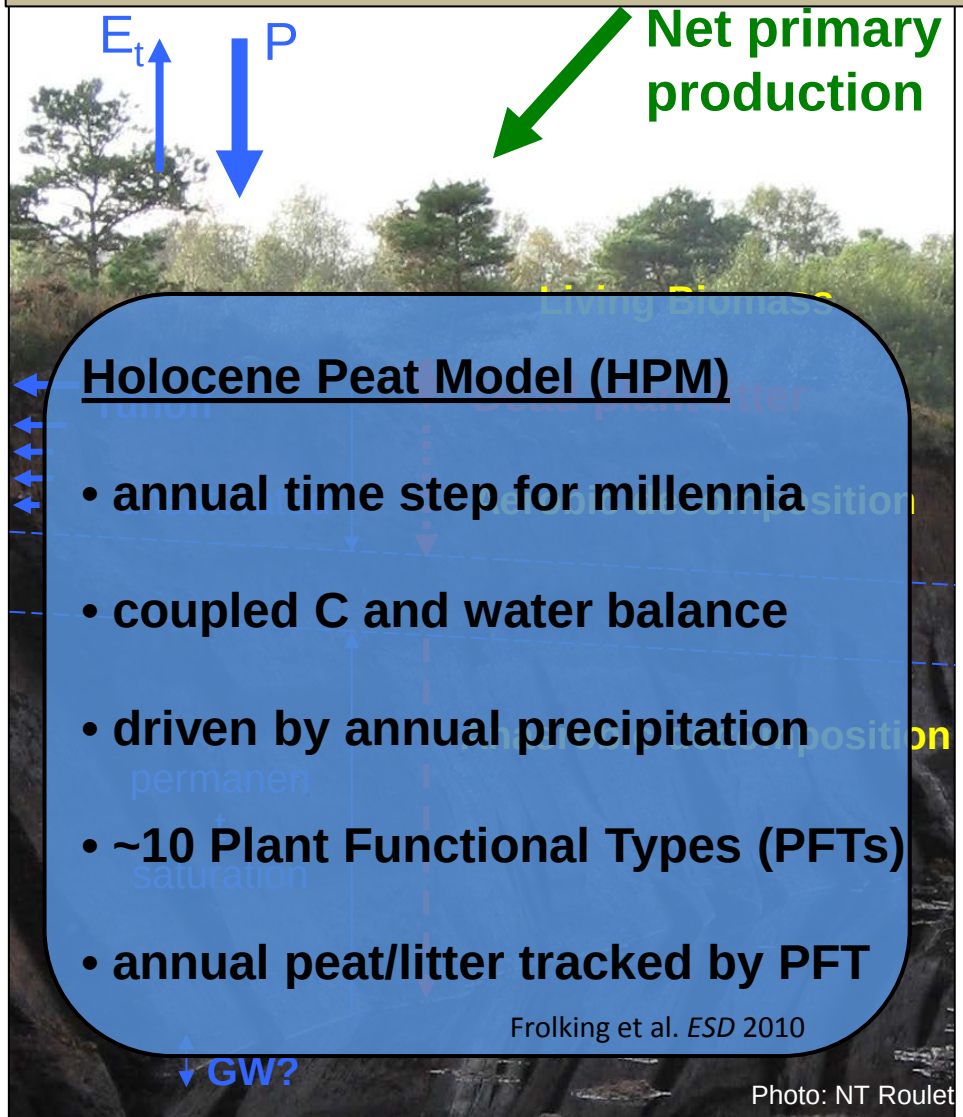
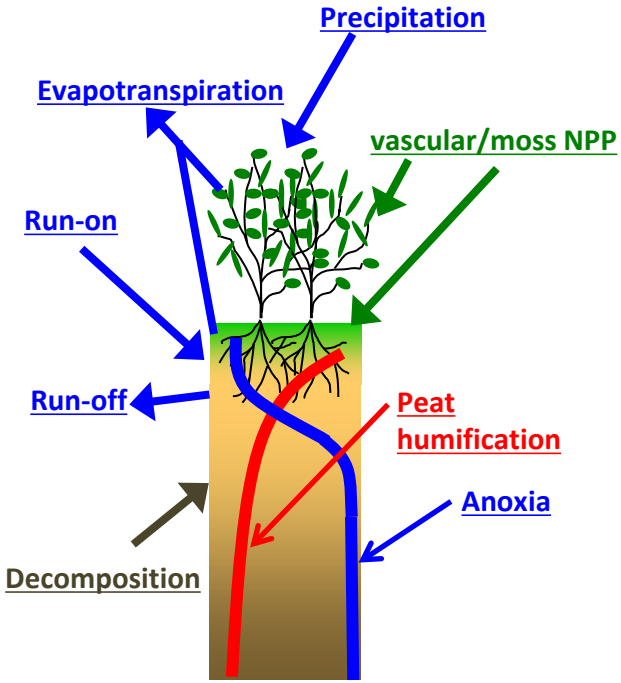
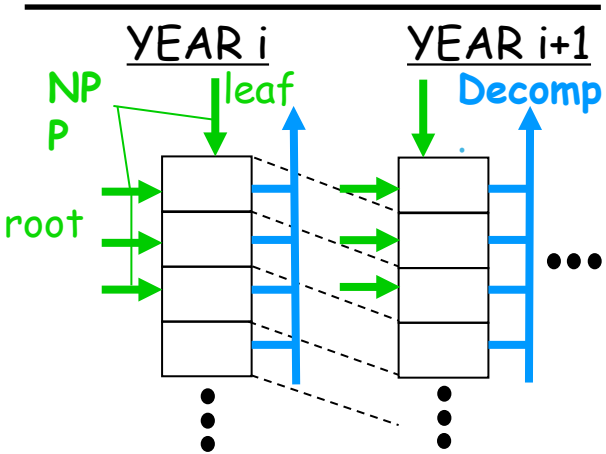


Holocene Peat Model (HPM)

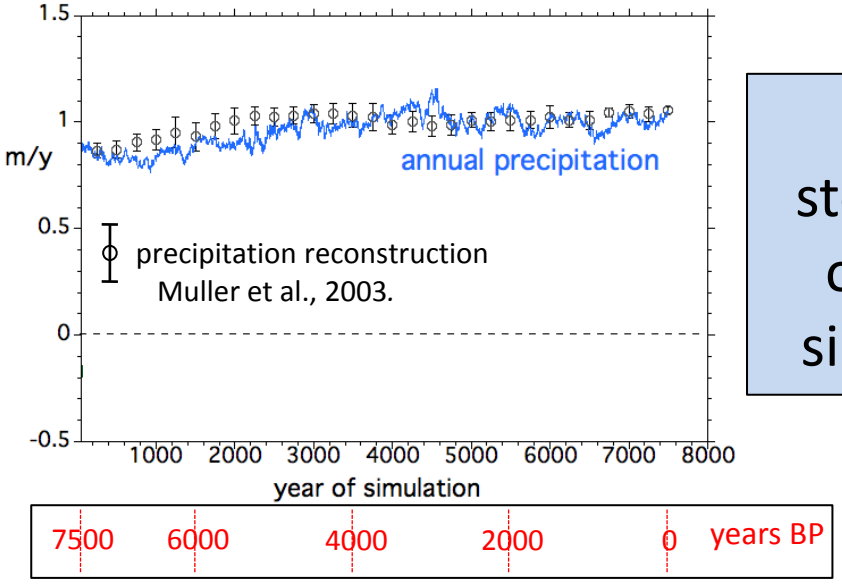
- annual time step for millennia
- coupled C and water balance
- driven by annual precipitation
- ~10 Plant Functional Types (PFTs)
- annual peat/litter tracked by PFT

Frolking et al. *ESD* 2010





Temperate bog (Mer Bleue, Ontario) simulation



Model is driven by stochastic reconstruction of annual precipitation since peatland initiation.

Model computes annual:

- Water balance
- Water table depth
- Vegetation composition
- Net primary productivity
- Decomposition
- Peat accumulation (or loss)

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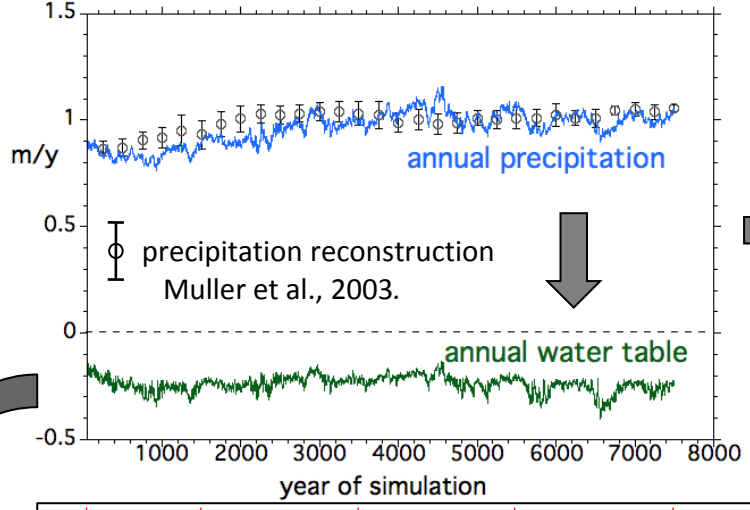

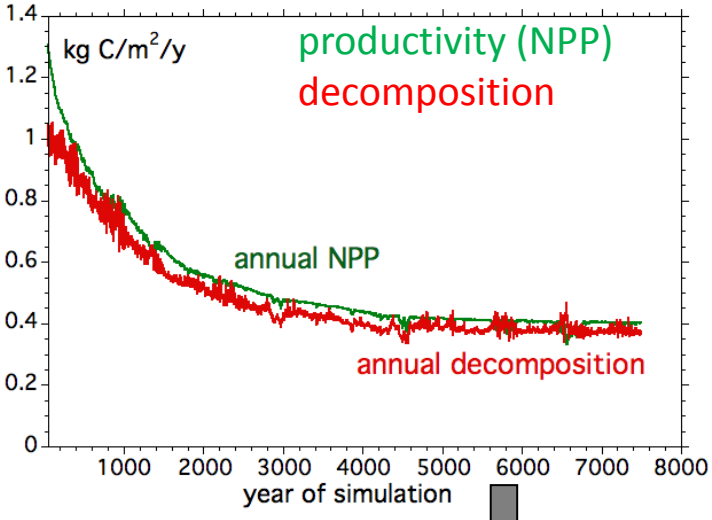

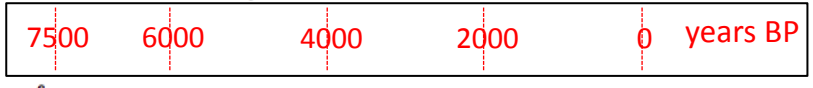

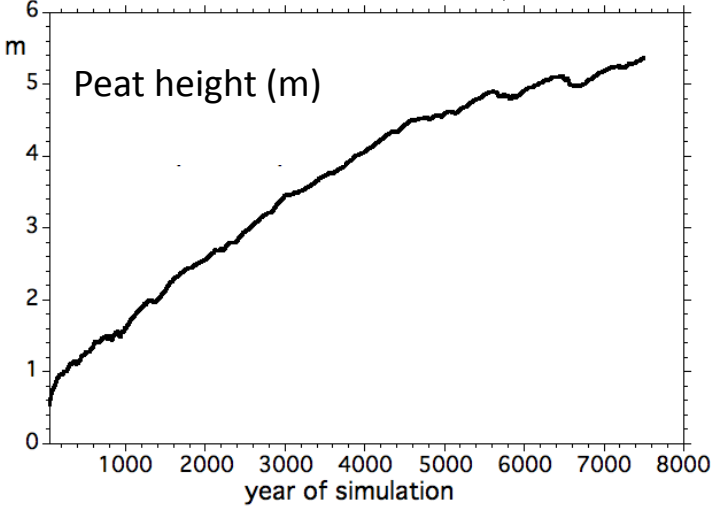

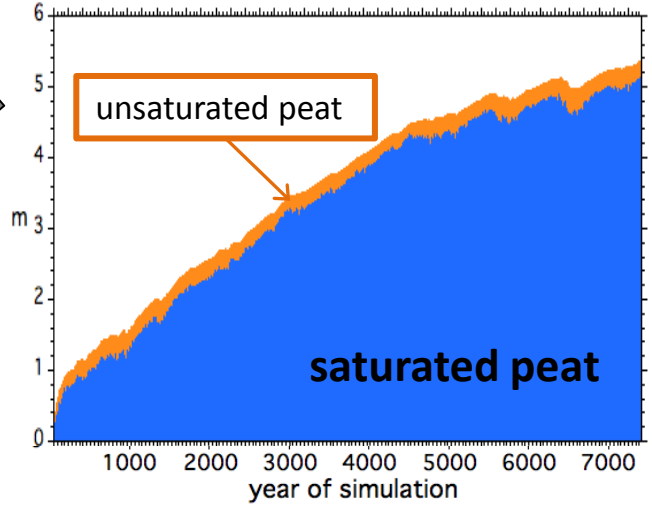

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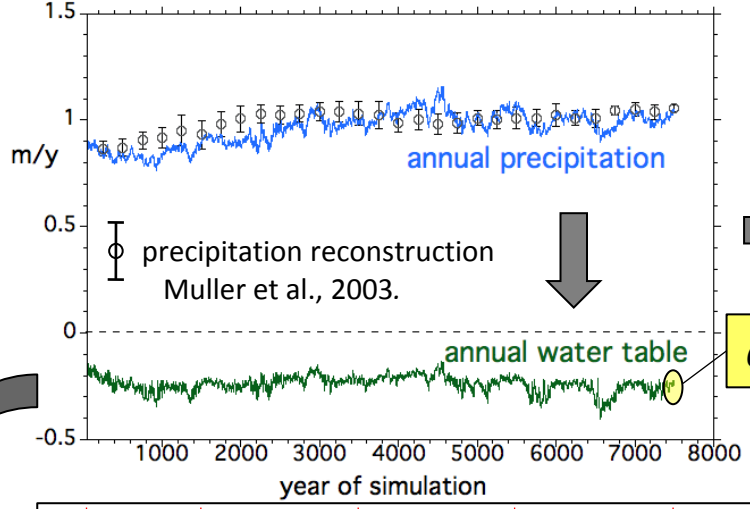
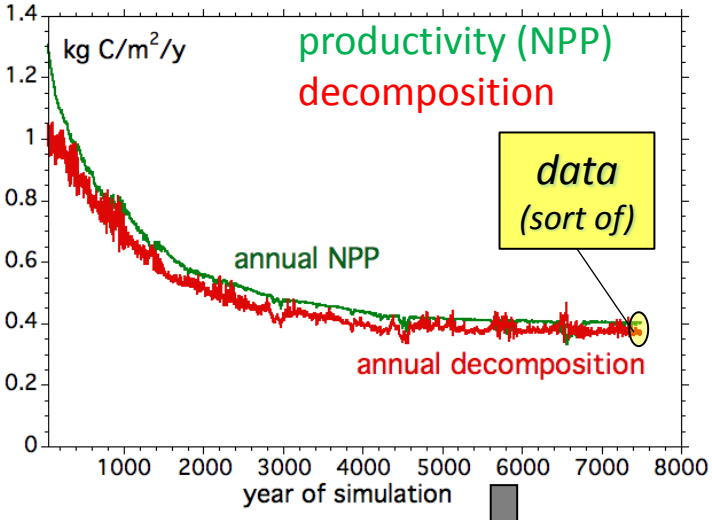
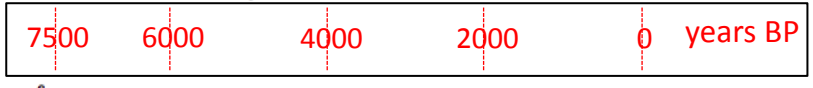
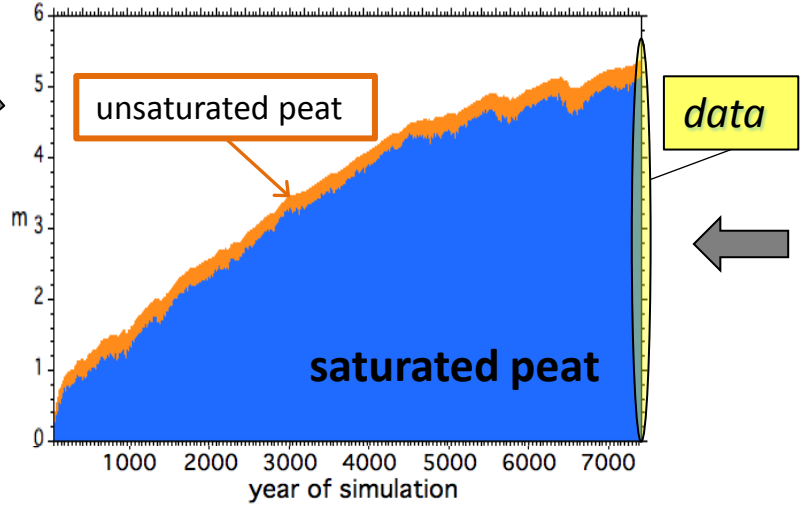


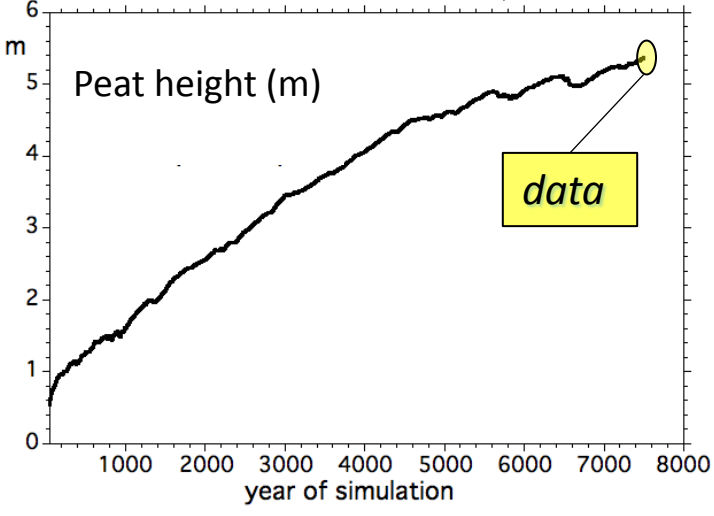
data







data



Temperate bog (Mer Bleue, Ontario) simulation

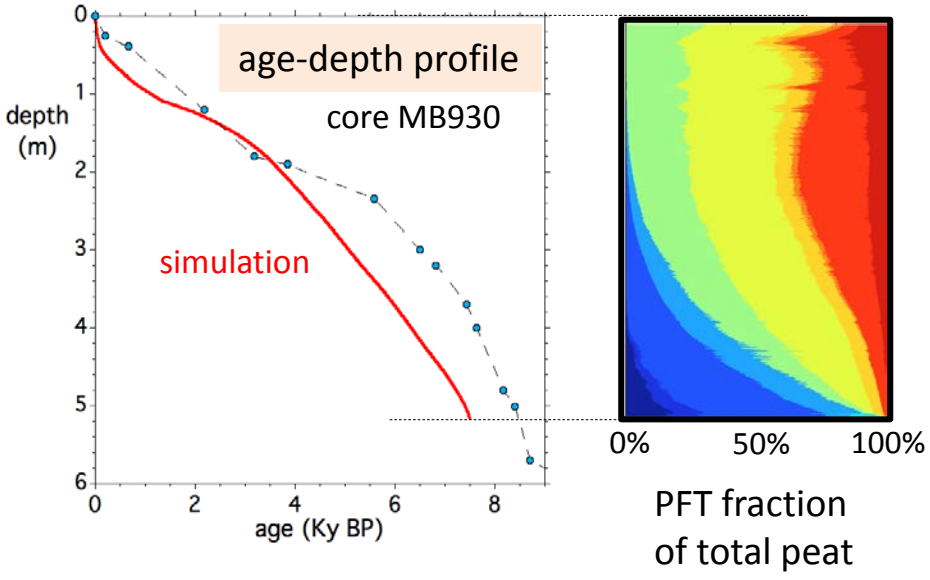


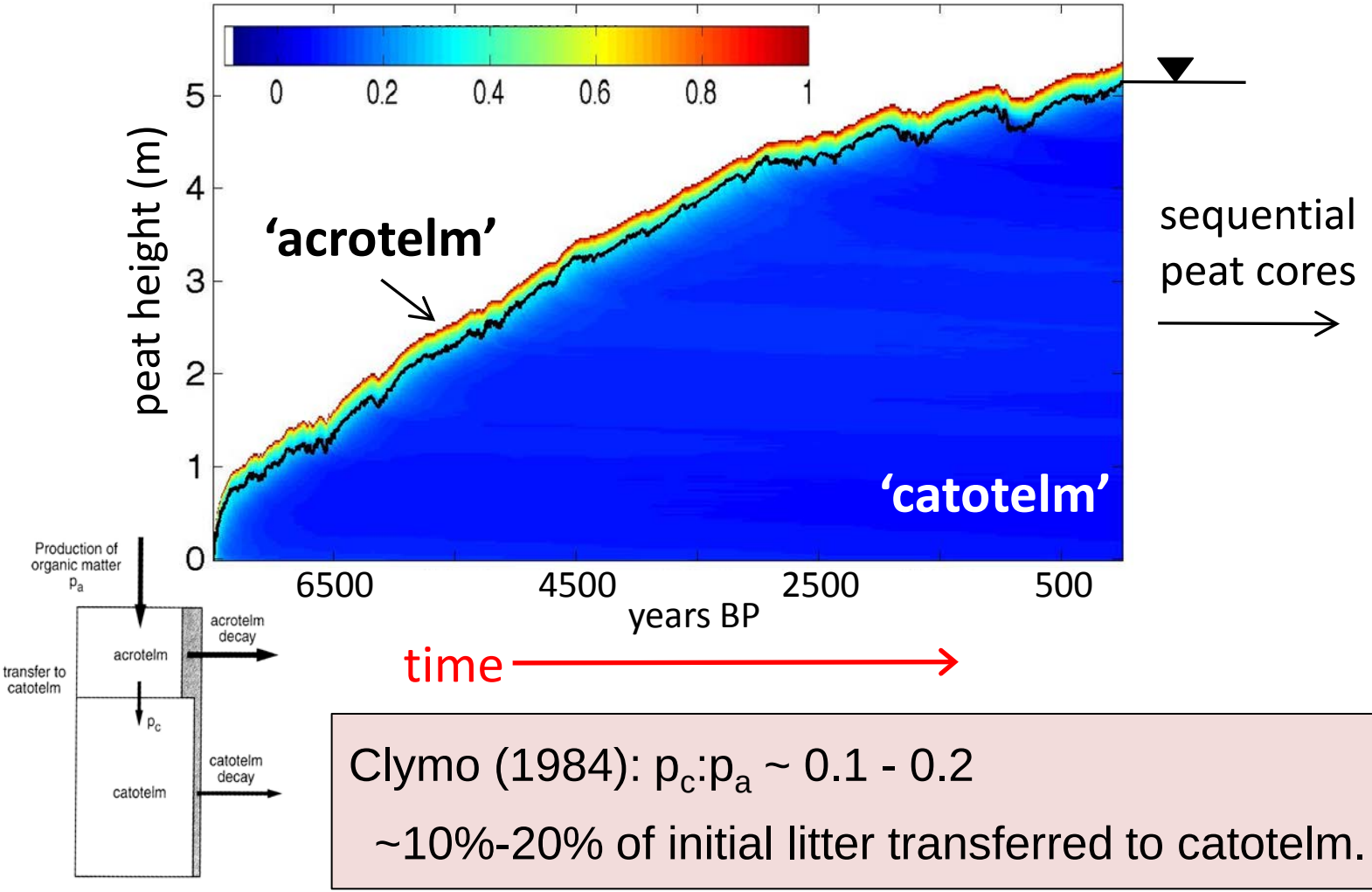
Photo: TR Moore

Final simulated 'core' can be compared to contemporary peat cores:

- age-depth profile.
- macrofossil composition profile.

Temperate bog (Mer Bleue, Ontario) simulation

Fraction of initial litter mass remaining as peat

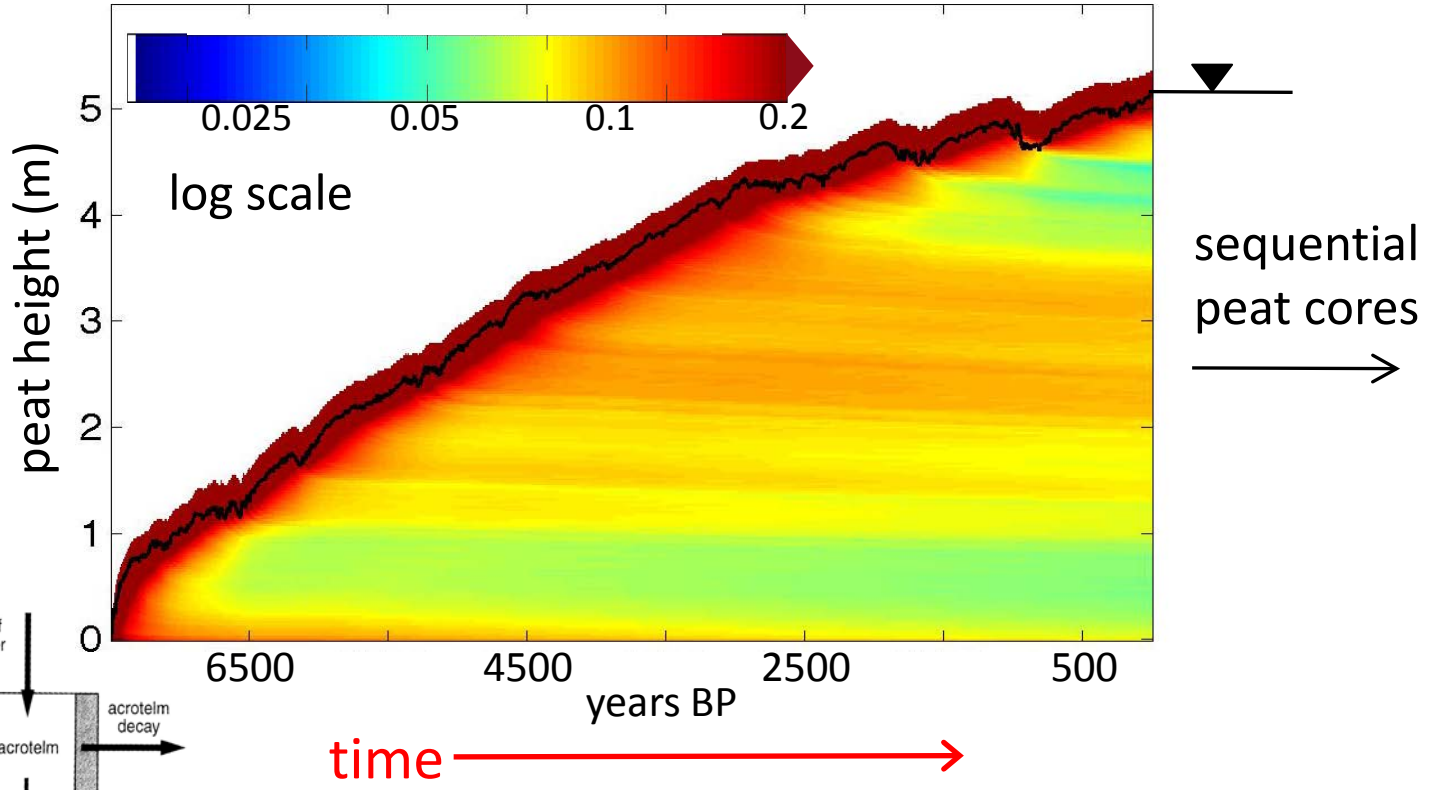


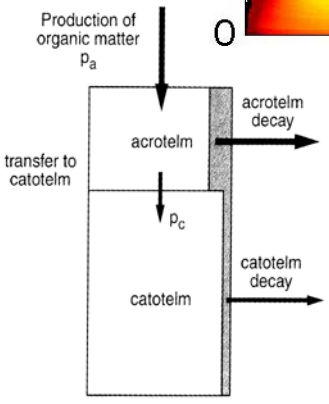
Clymo (1984): p_c:p_a ~ 0.1 - 0.2

~10%-20% of initial litter transferred to catotelm.

Temperate bog (Mer Bleue, Ontario) simulation

Fraction of initial litter mass remaining as peat





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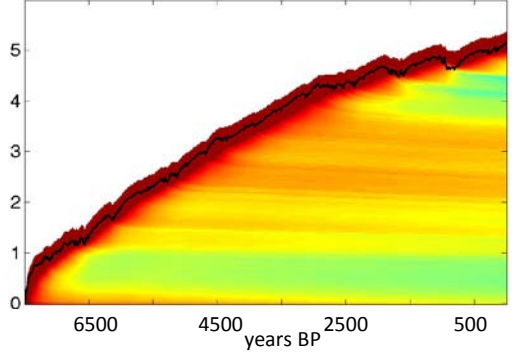
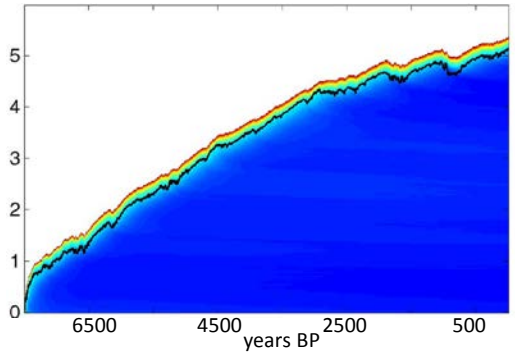
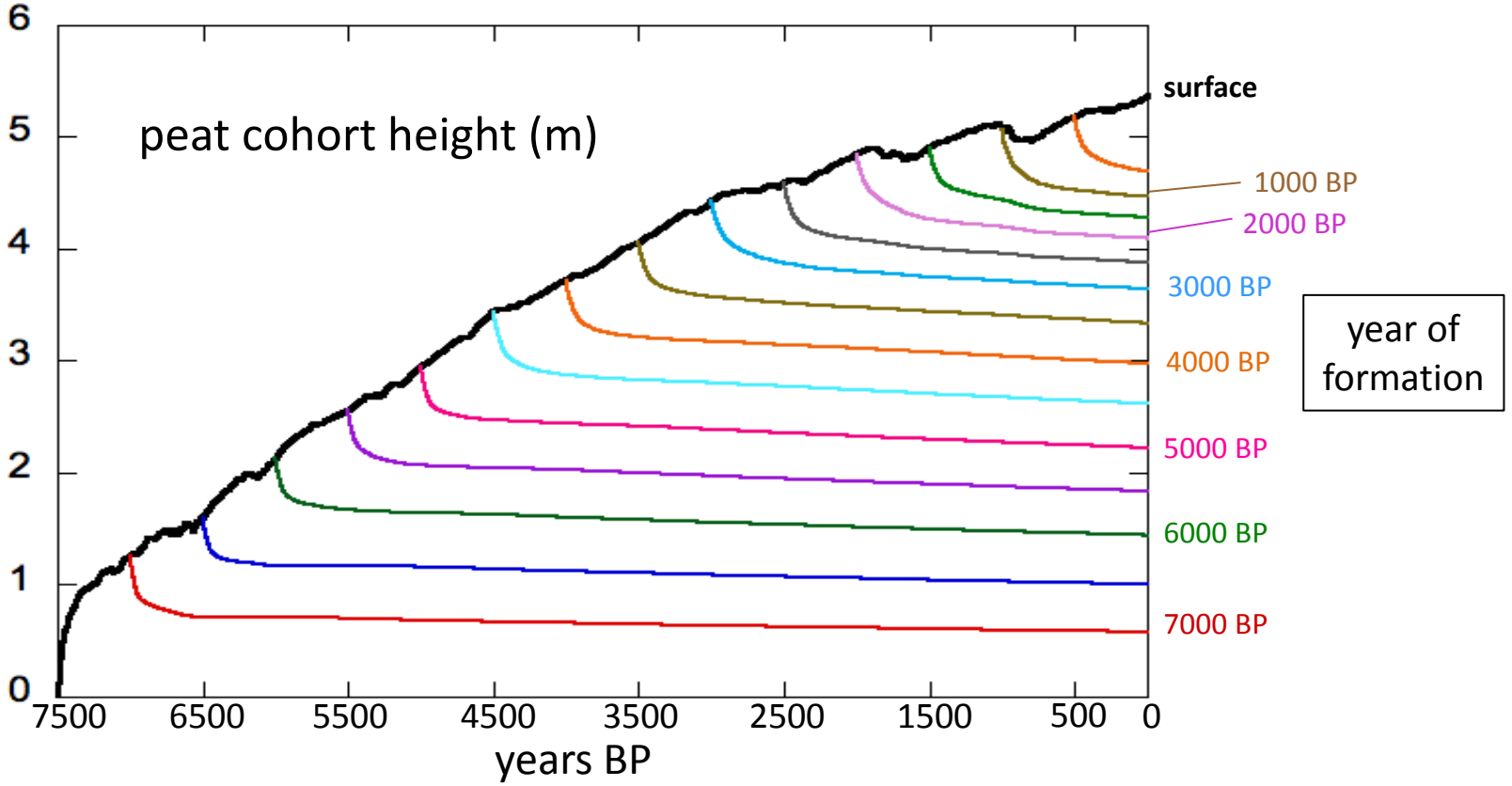


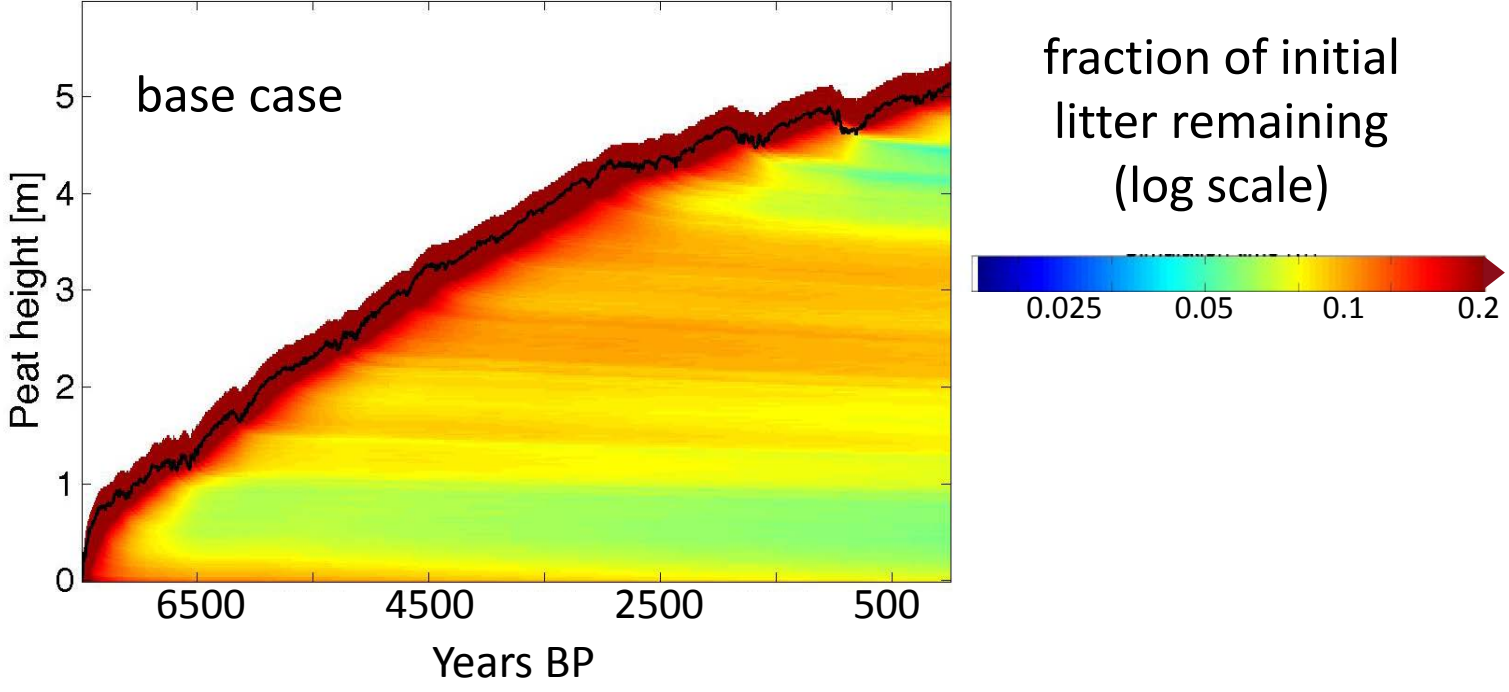
Annual cohort depth trajectories through time, in 500 yr intervals.

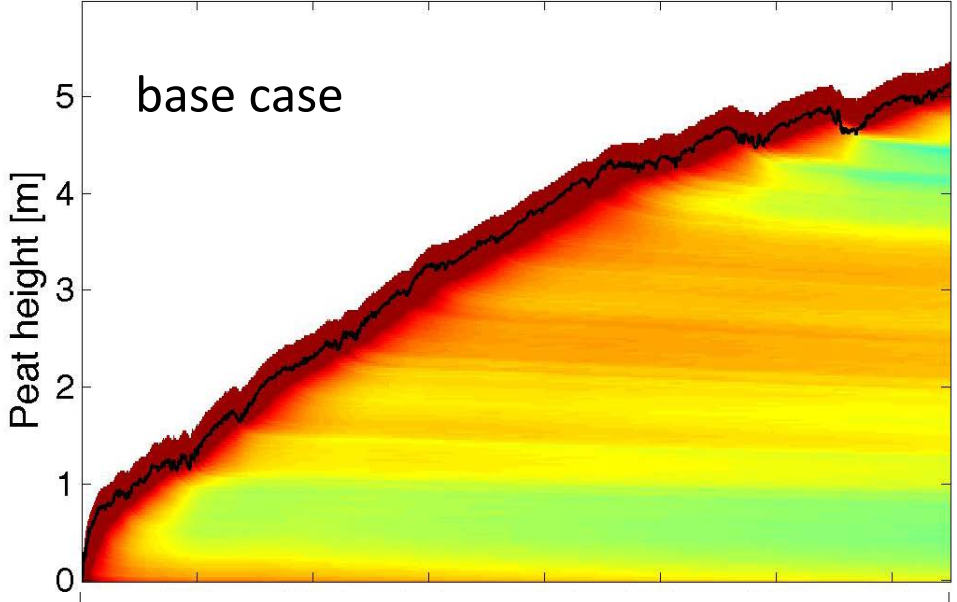


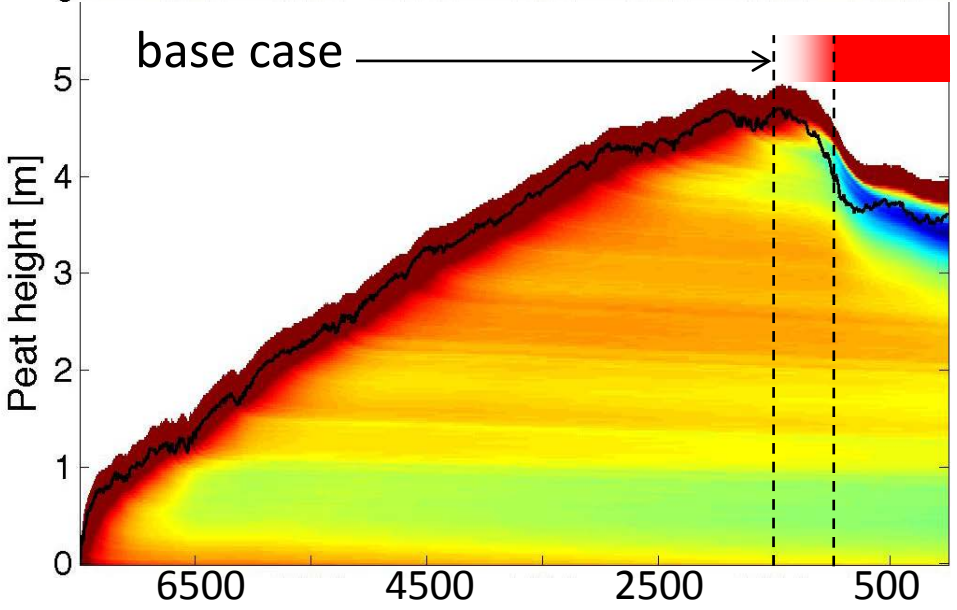


Simulate the impact of a major drying or ditching

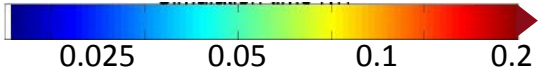
- on the peat profile
- on the net carbon balance over time
- on the apparent carbon accumulation rate over time


base case
Peat height [m]
0
1
2
3
4
5
6500
4500
2500
500
Years BP
fraction of initial
litter remaining
(log scale)
0.025
0.05
0.1
0.2



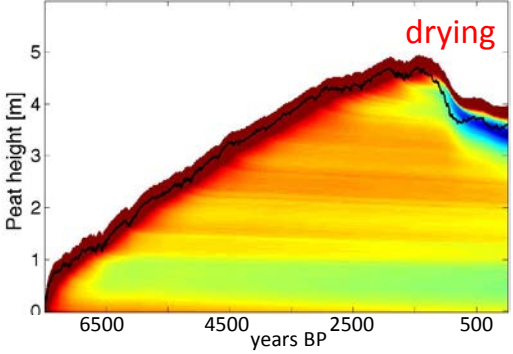


fraction of initial litter remaining (log scale)

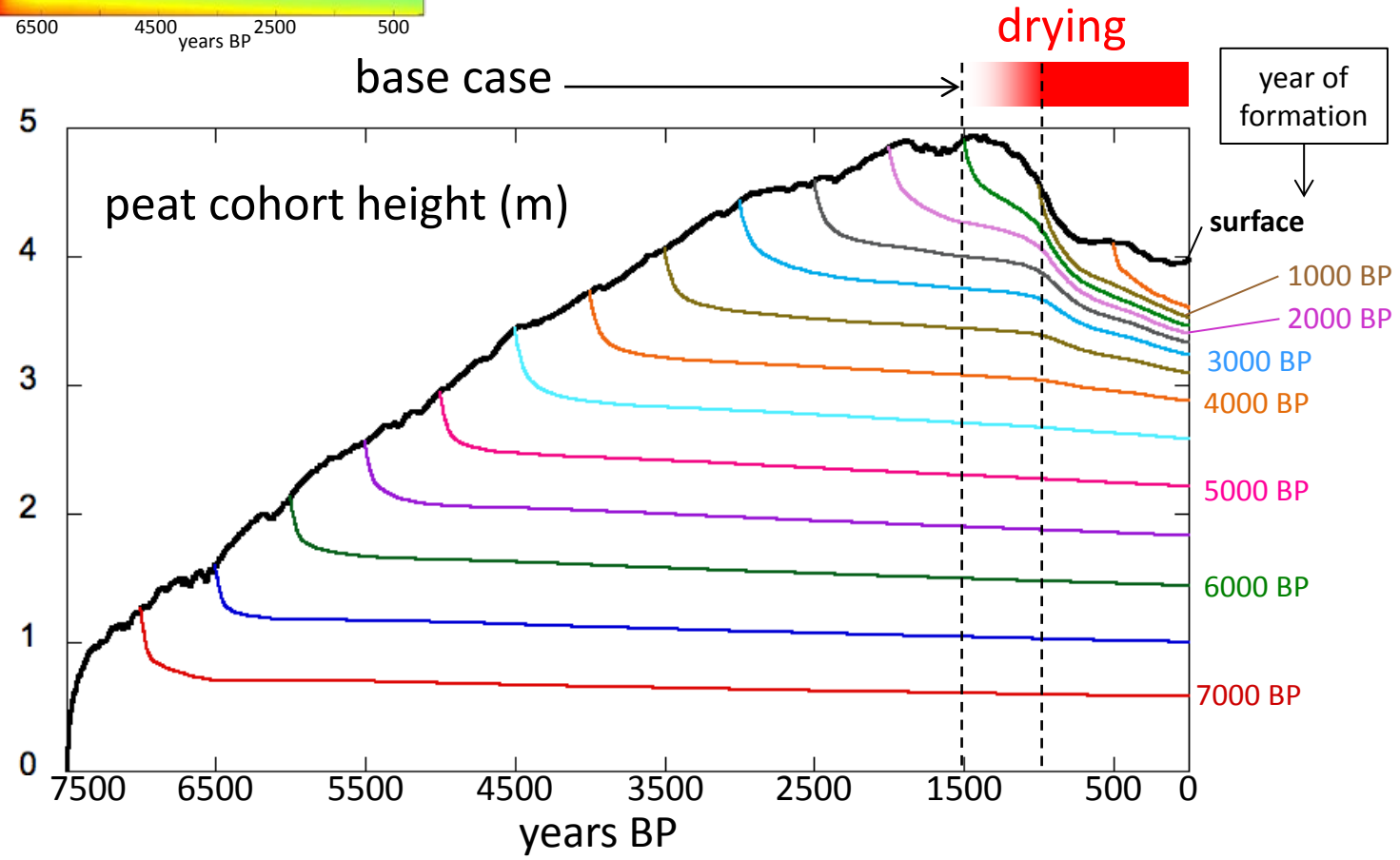


New model scenario – DRYING

ET_0 increased linearly by 0.66% per decade from 1500 to 1000 BP (net 33% increase), then held constant.



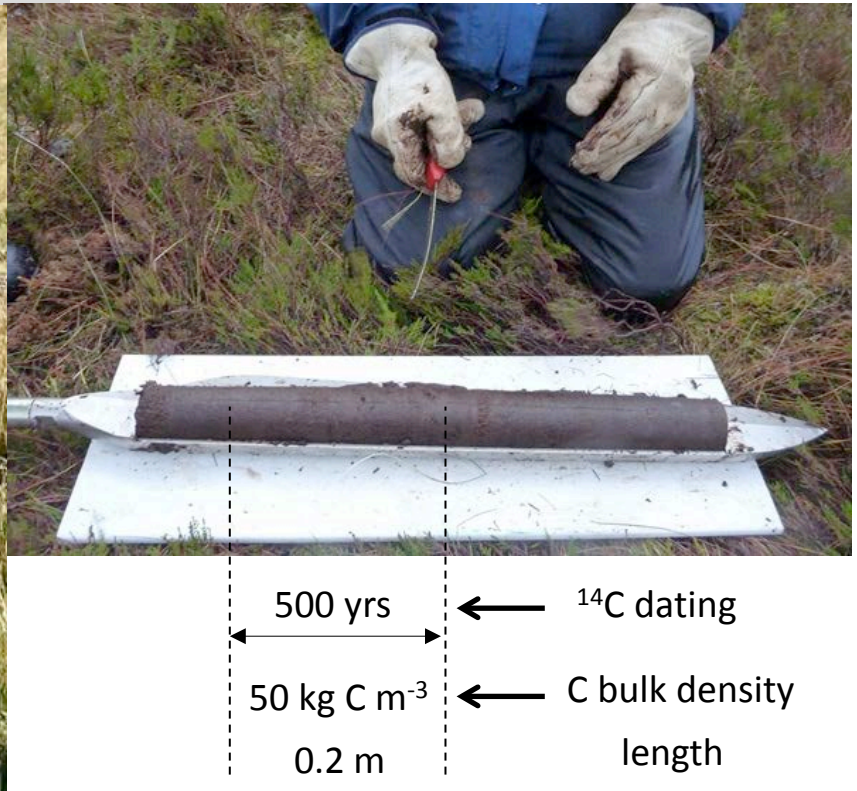
DRYING – ET_0 increased linearly 0.66% decade^{-1} 1500-1000 BP (net 33% increase), then constant.



Apparent peat C accumulation rate

www.northpennines.org.uk/Pages/Research.aspx

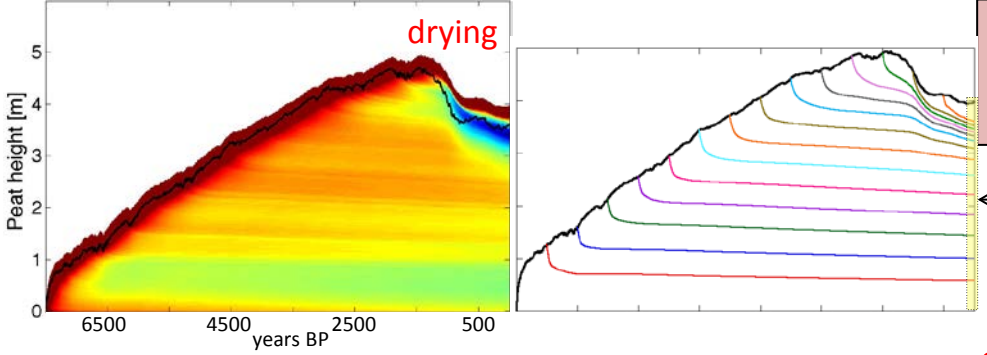
www.plymouth.ac.uk/pages/view.asp?page=33117



So, during that interval, the apparent CAR is

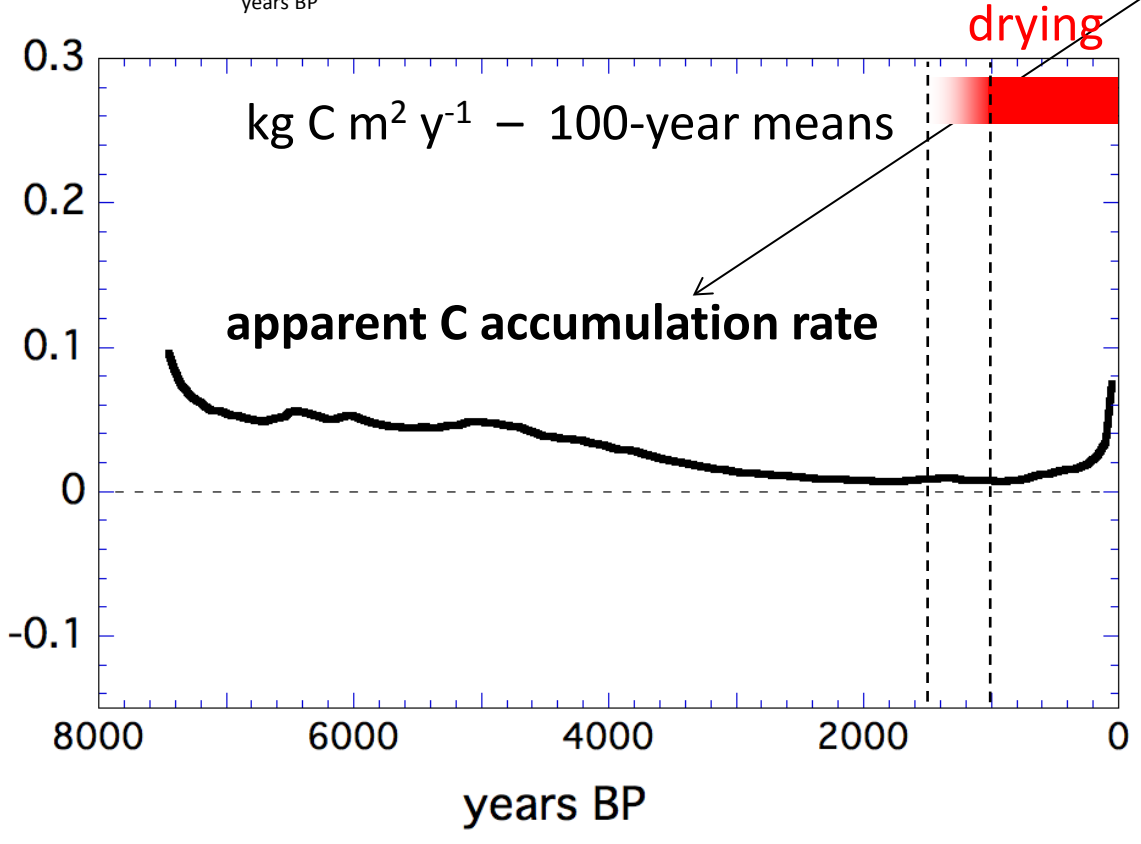
CAR: carbon accumulation rate

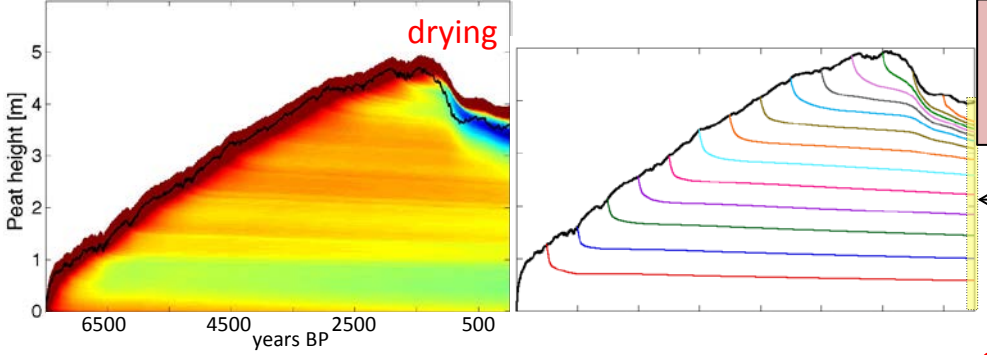
$$CAR_1 = \frac{50\ kg\ C\ m^{-3} \cdot 0.2\ m}{500\ yr} = 20\ g\ C\ m^{-2}\ yr^{-}$$



DRYING – ET_0 increased 0.66% $dec.^{-1}$ for 1500-1000 BP, then constant.

contemporary peat core





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contemporary peat core

drying

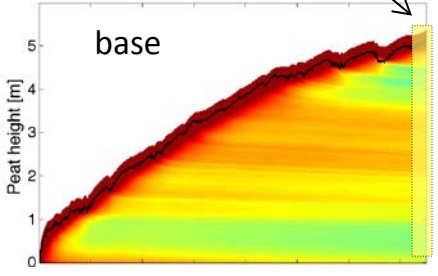
kg C m^2 y^{-1} – 100-year means

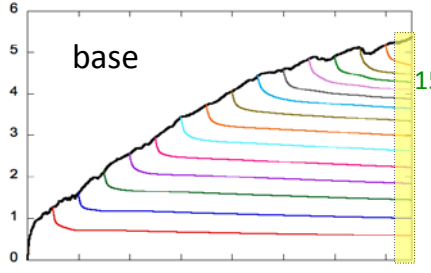
apparent C accumulation rate

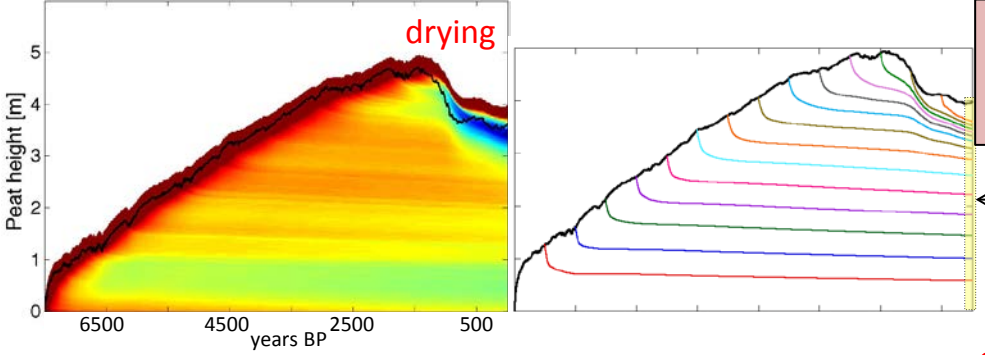
base run to 1500 BP

base run had identical carbon balance to drying run up to 1500 BP, but very different apparent CAR in a contemporary core.

0.3
0.2
0.1
0
-0.1
8000
6000
4000
2000
0
years BP







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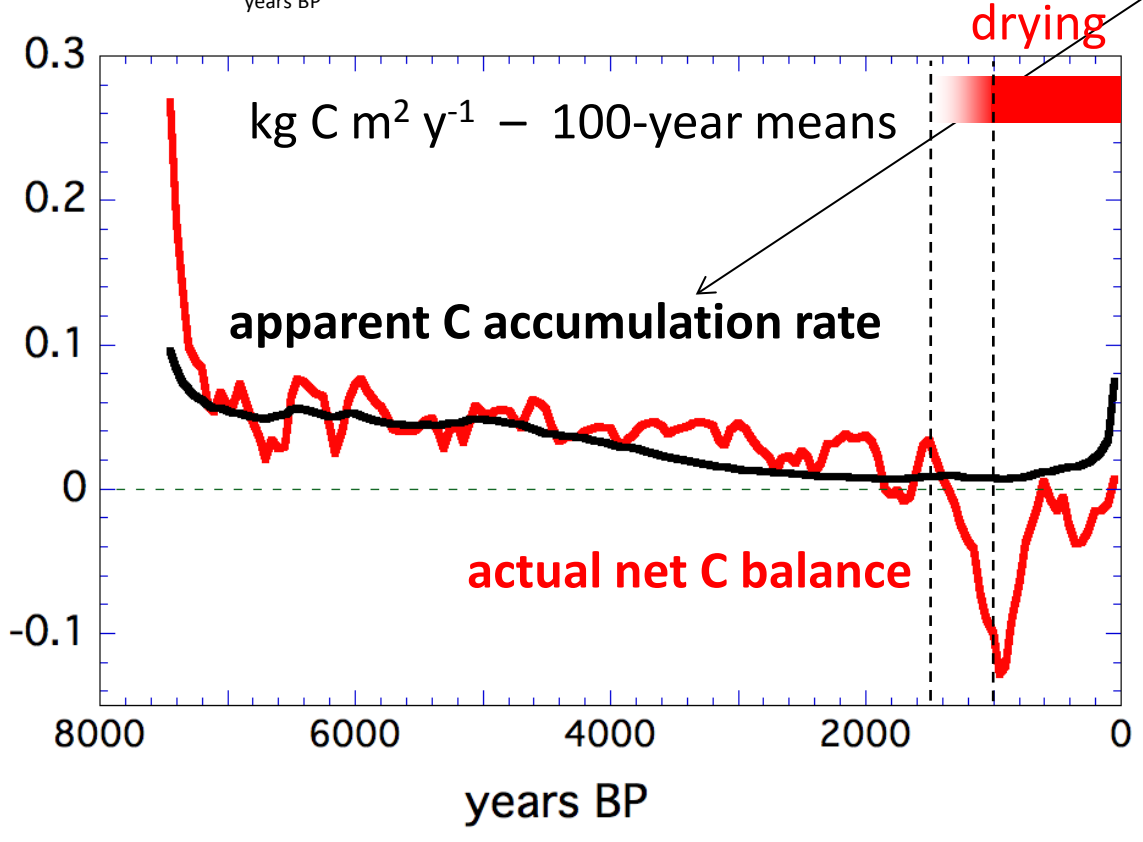
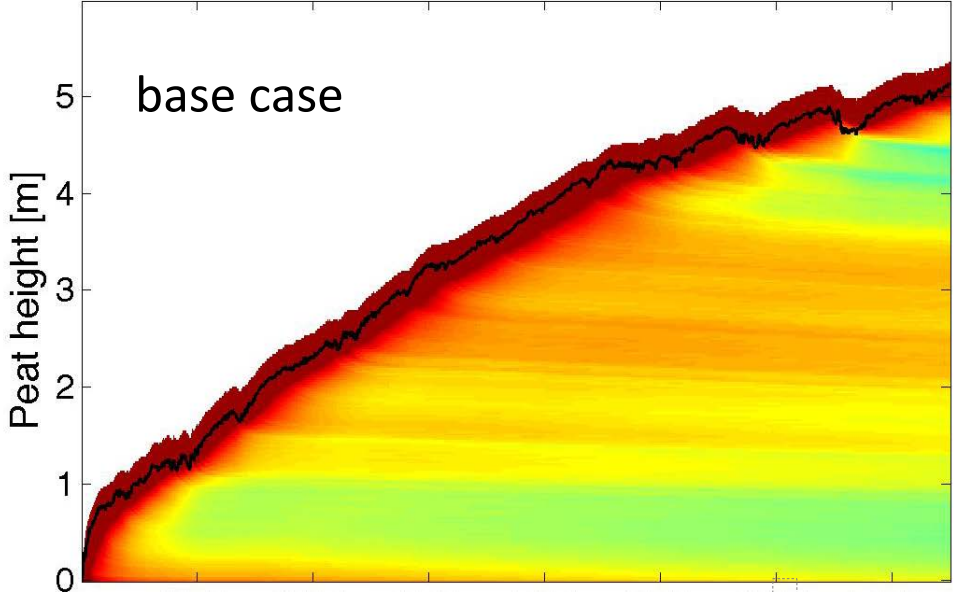
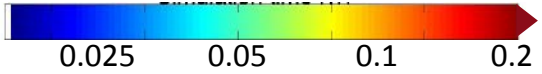


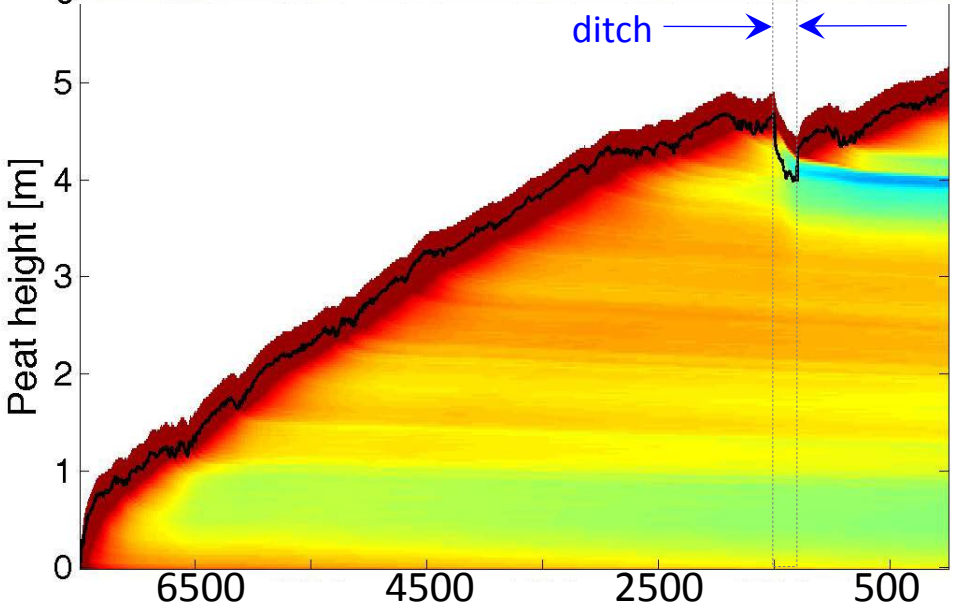
Apparent CAR – *gradual* climate change impact c. 5.0 - 2.5 kBP.

Actual Net C Balance – *abrupt* climate change impact c. 1.5 – 0.6 kBP.



fraction of initial litter remaining (log scale)



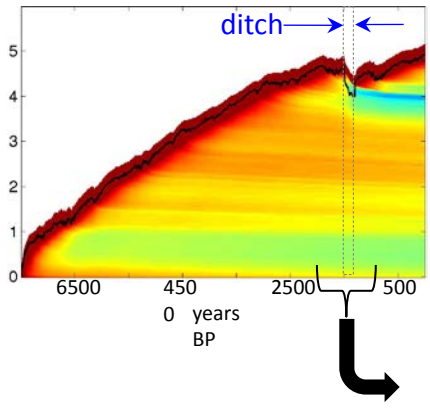


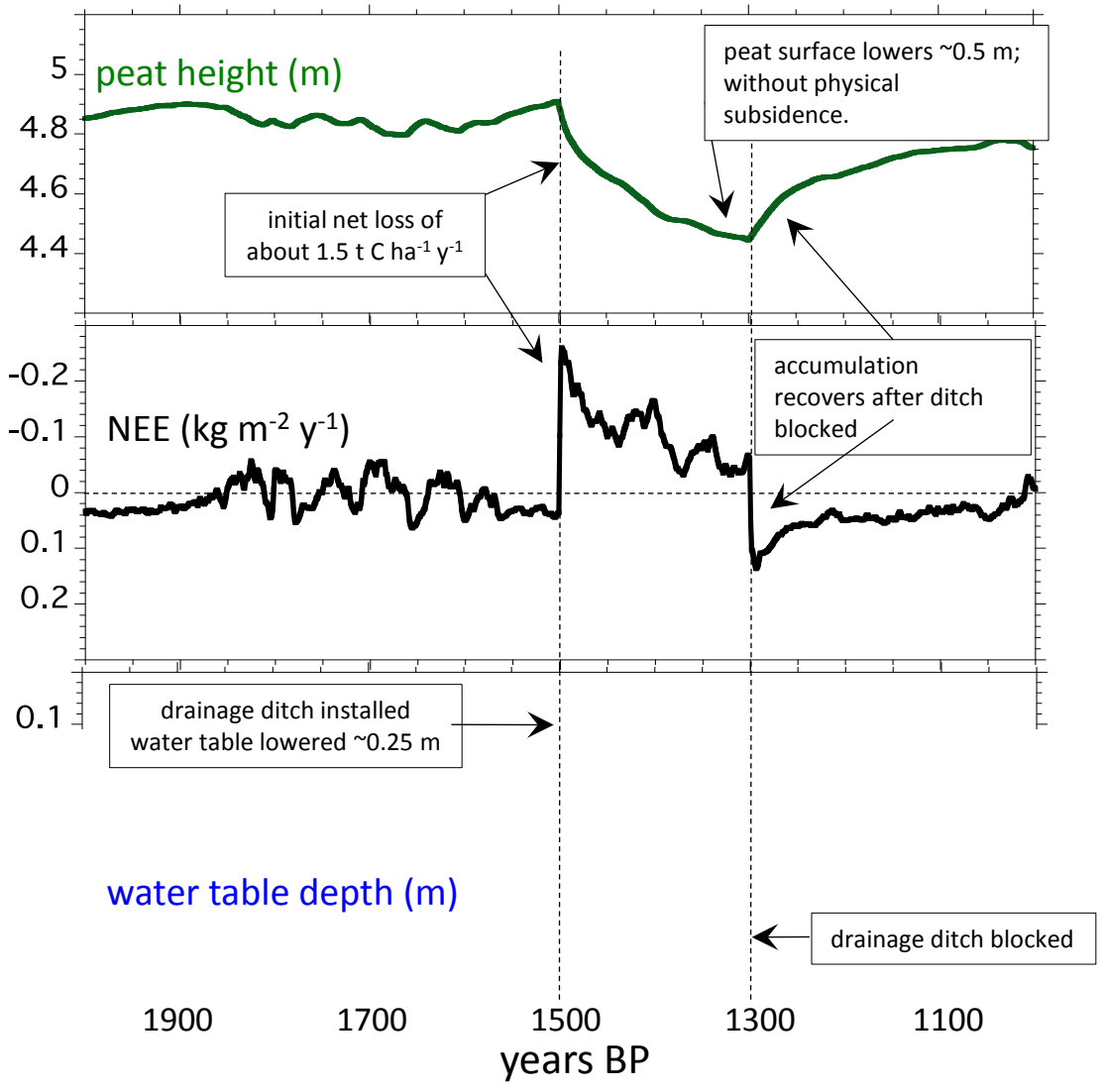
New Model Scenario –

DITCH

Water table lowered ~0.25 m for 200 yrs, then rapidly restored.

Ditch - Water table lowered at 1500 BP by ~0.25 m for 200 yrs, then rapidly restored.





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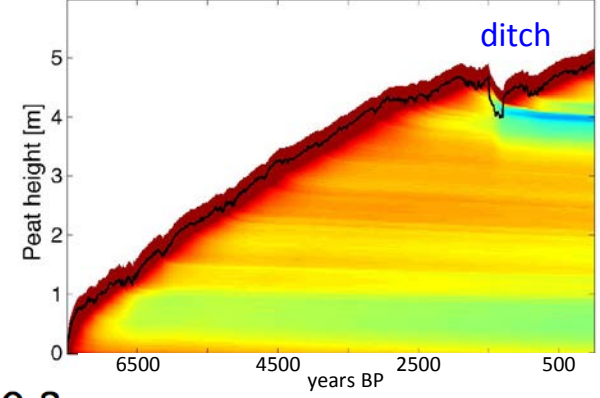
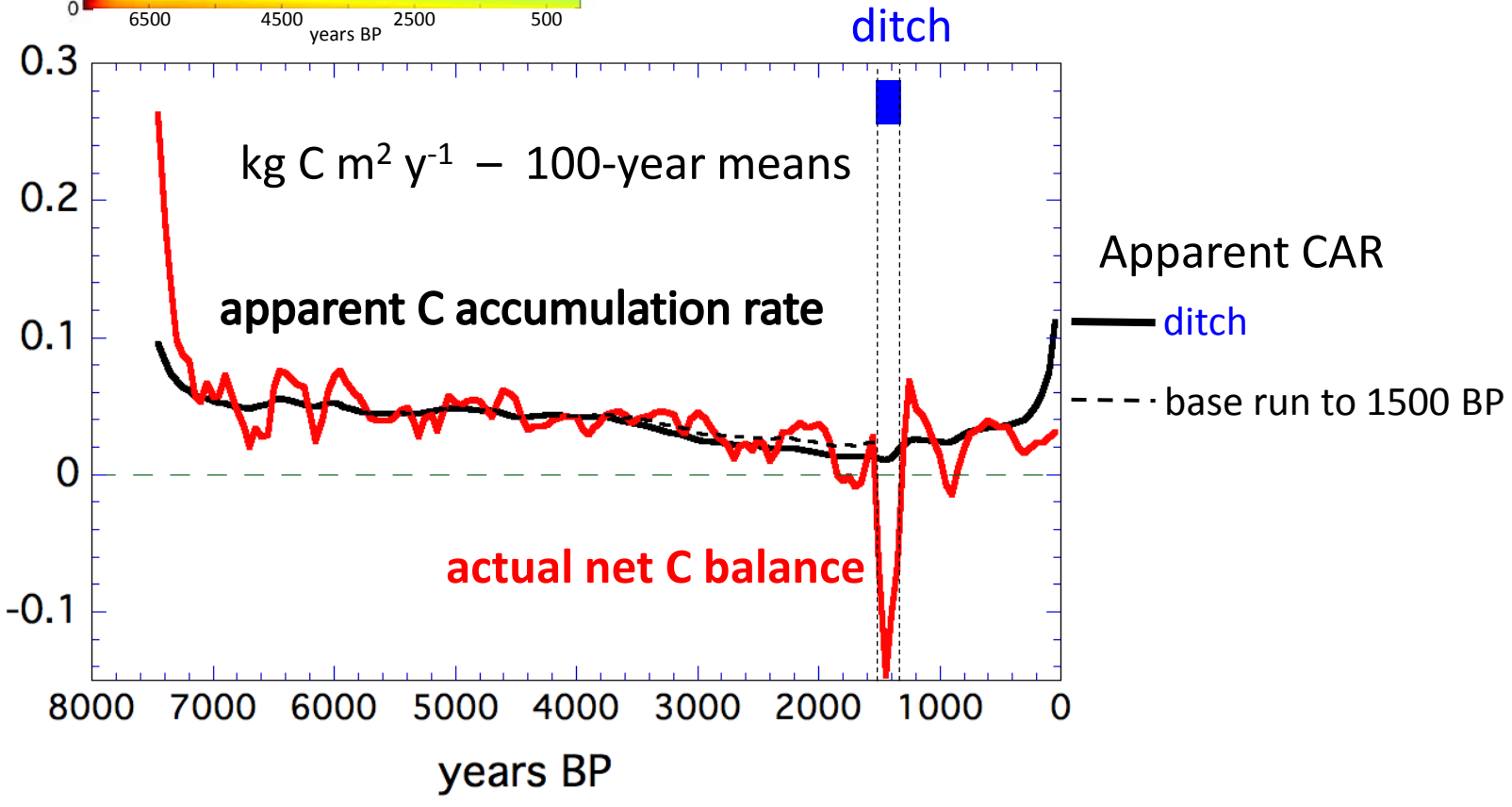
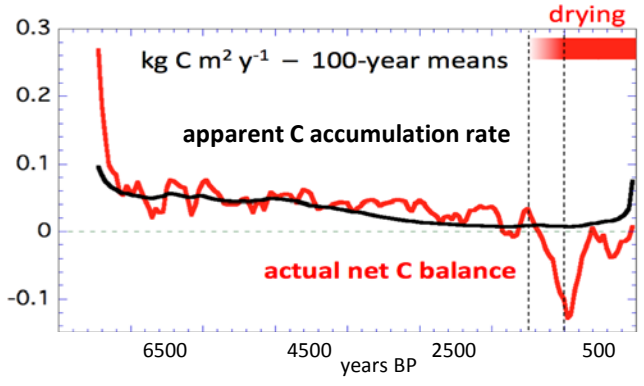




CONCLUSIONS

- A **straightforward interpretation** of climate-carbon relations from **observed apparent carbon accumulation rates** in peat cores could be **misleading**.



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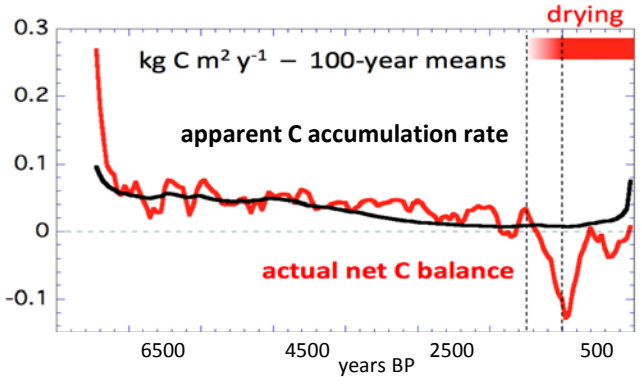
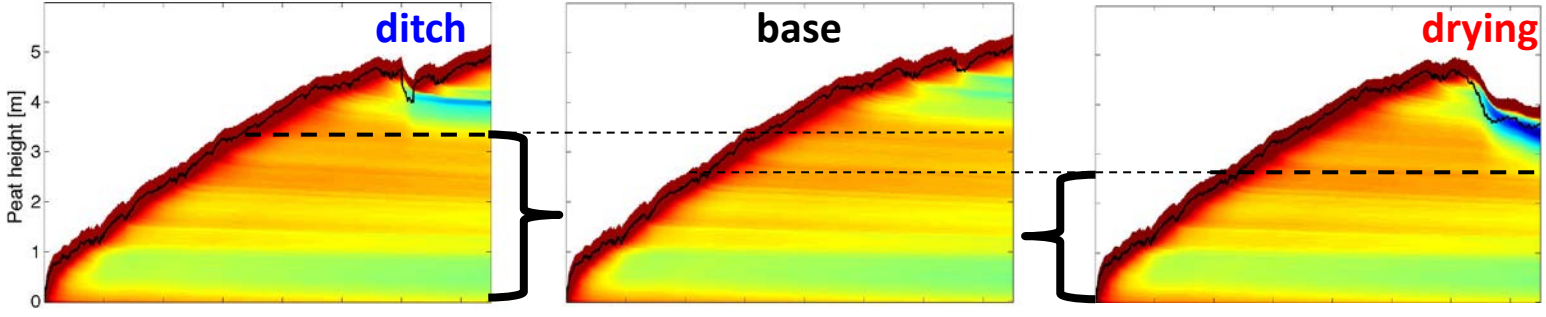
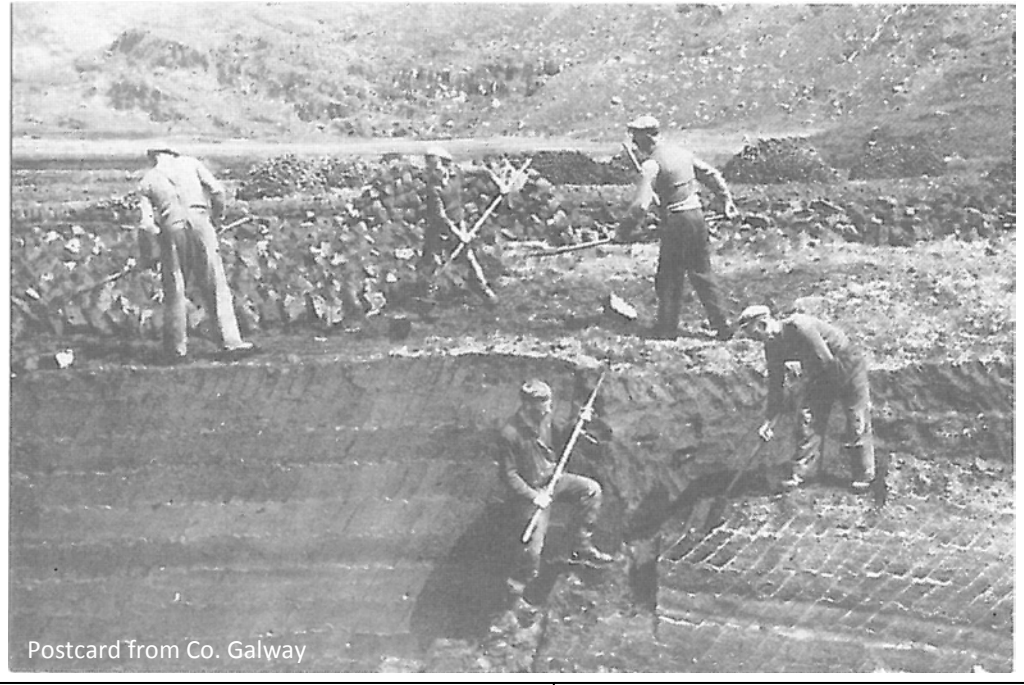


- Many climate and land-use perturbation impacts will not penetrate much more than ~1 meter into peat within 100 years, so for **estimating 21st century impacts, improved maps/models of *peatland extent* are more important than of *peat depth***.



Deeper peat unperturbed by 200-year ditch or by 1500 years of drying.

Thanks! Questions?



Special issue: Holocene peatland carbon dynamics in the circum-Arctic region

Exploring the relationship between peatland net carbon balance and apparent carbon accumulation rate at century to millennial time scales

Steve Frolking, [1] Julie Talbot [2] and Zack M Subin [3]

The Holocene
2014, Vol. 24(9) 1167–1173

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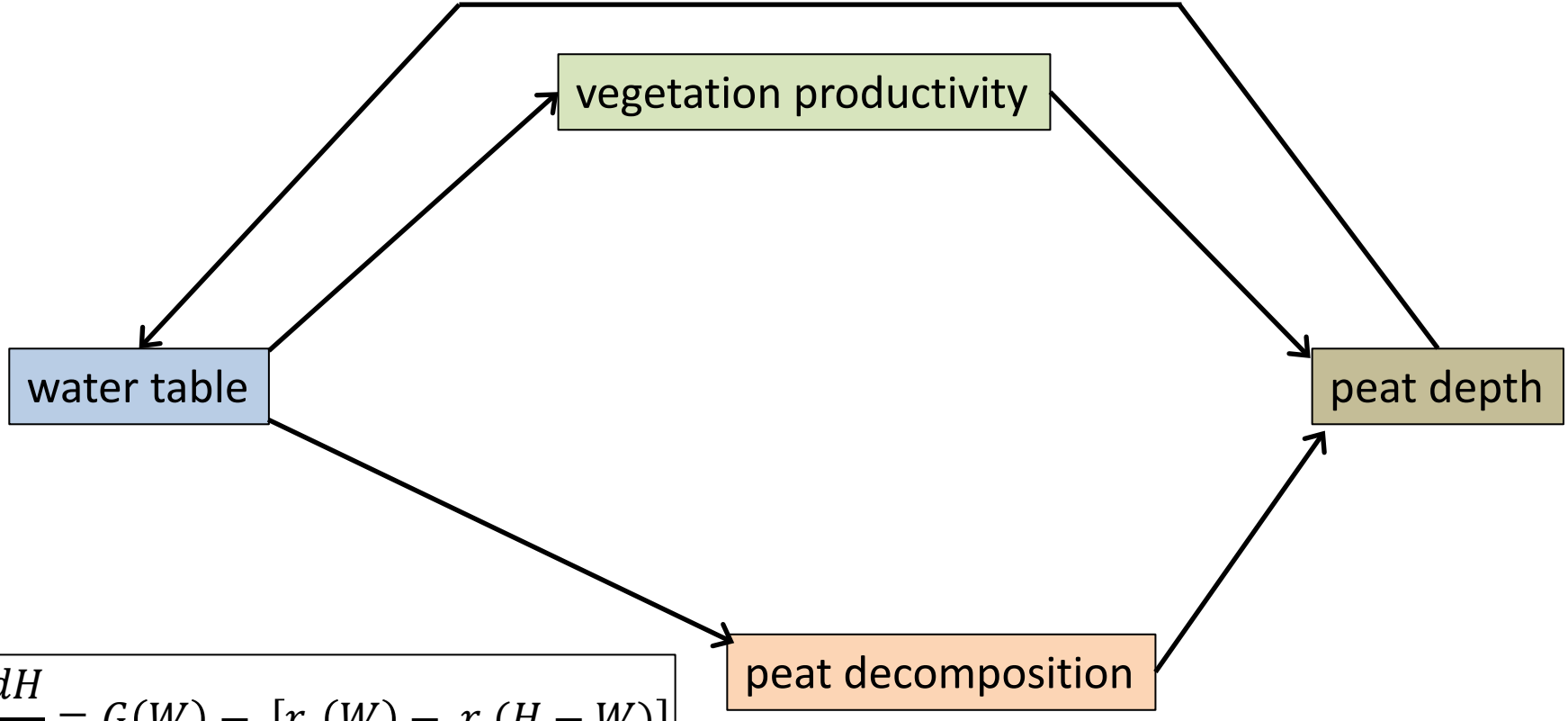
Plant-peat-water feedbacks in peat accumulation

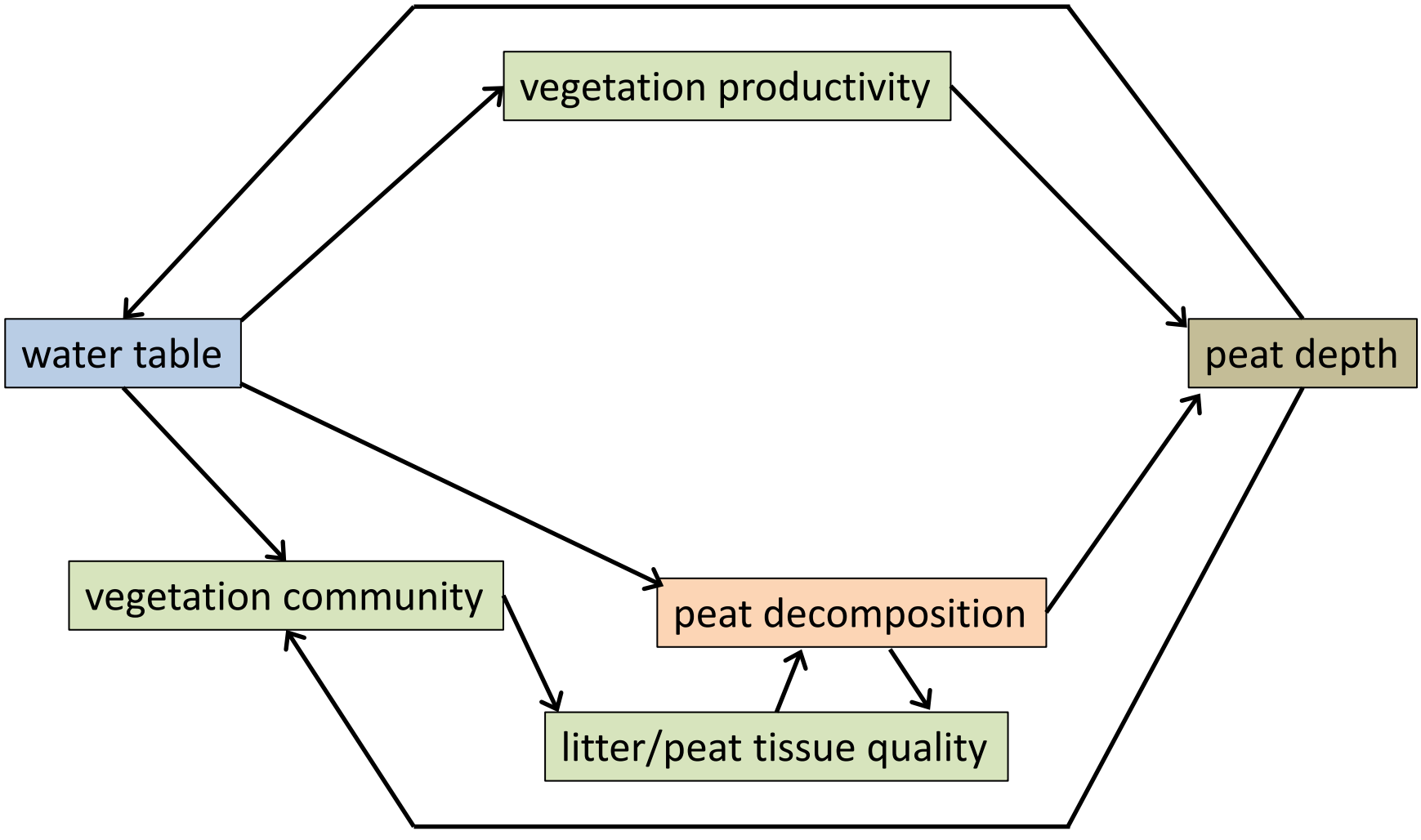


$$\frac{dH}{dt} = G(W) - [r_a(W) - r_c(H - W)]$$

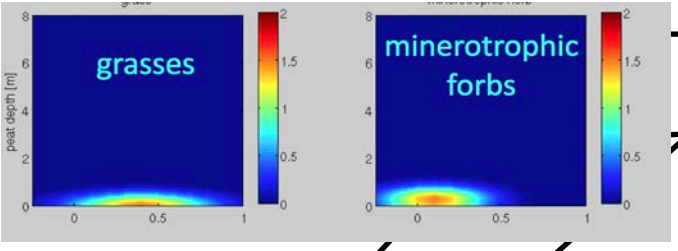
$$\frac{dW}{dt} = \frac{dH}{dt} - \left[\frac{P - E(w) - R(W)}{S}\right]$$

Hilbert et al. 2000

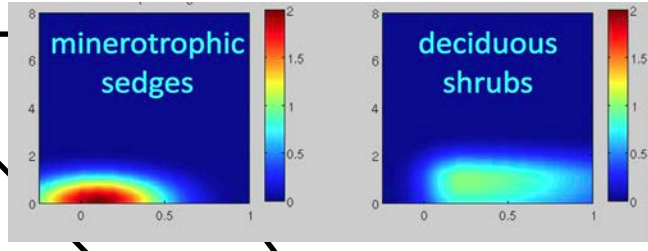
Plant-peat-water feedbacks in peat accumulation



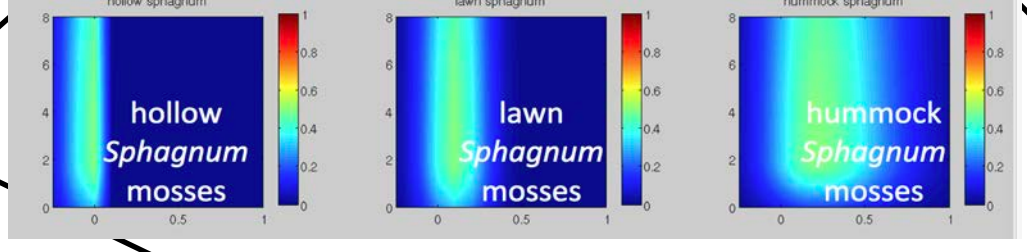
Plant-peat-water feedbacks in peat accumulation



vegetation productivity



water table

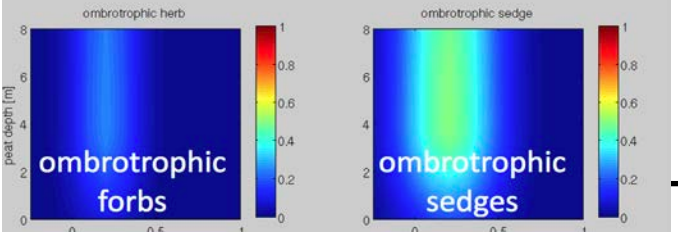


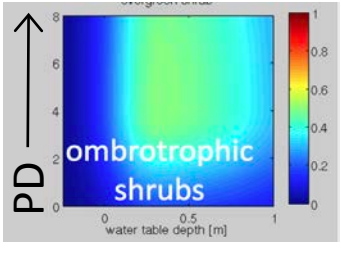
peat depth

vegetation community

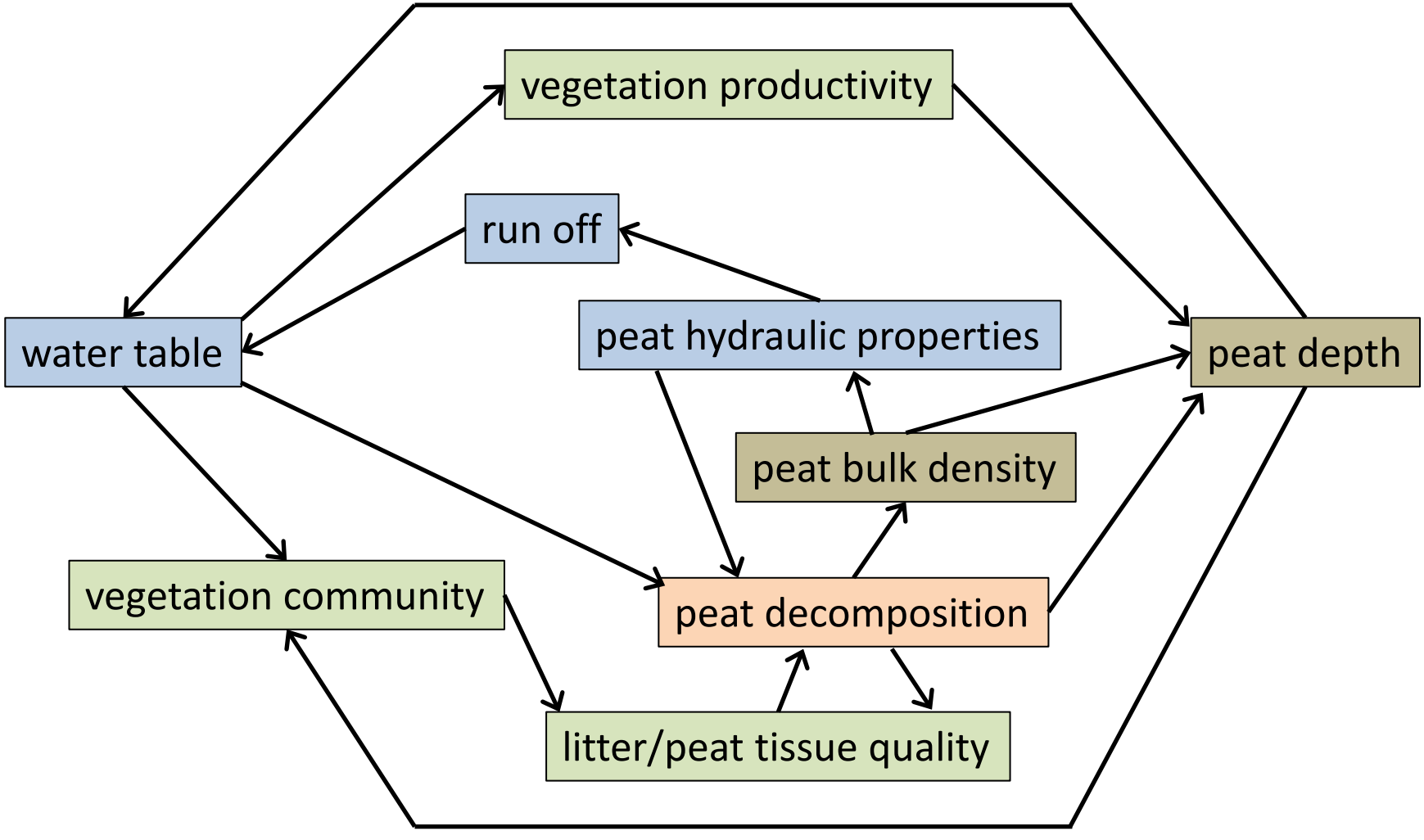
peat decomposition

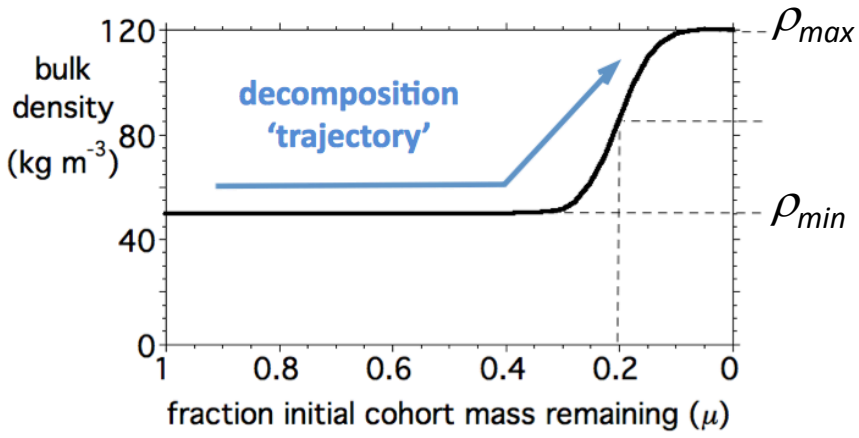
litter/peat tissue quality

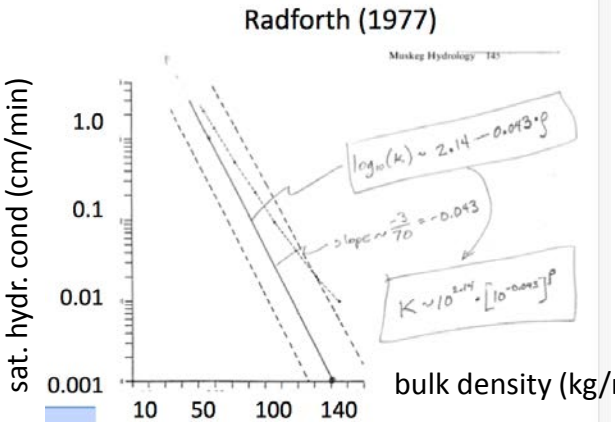




Plant-peat-water feedbacks in peat accumulation

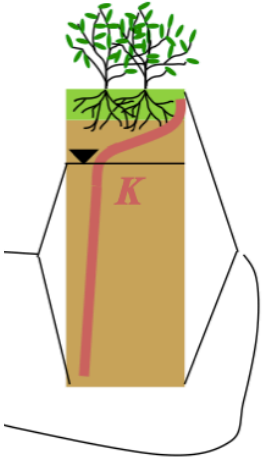


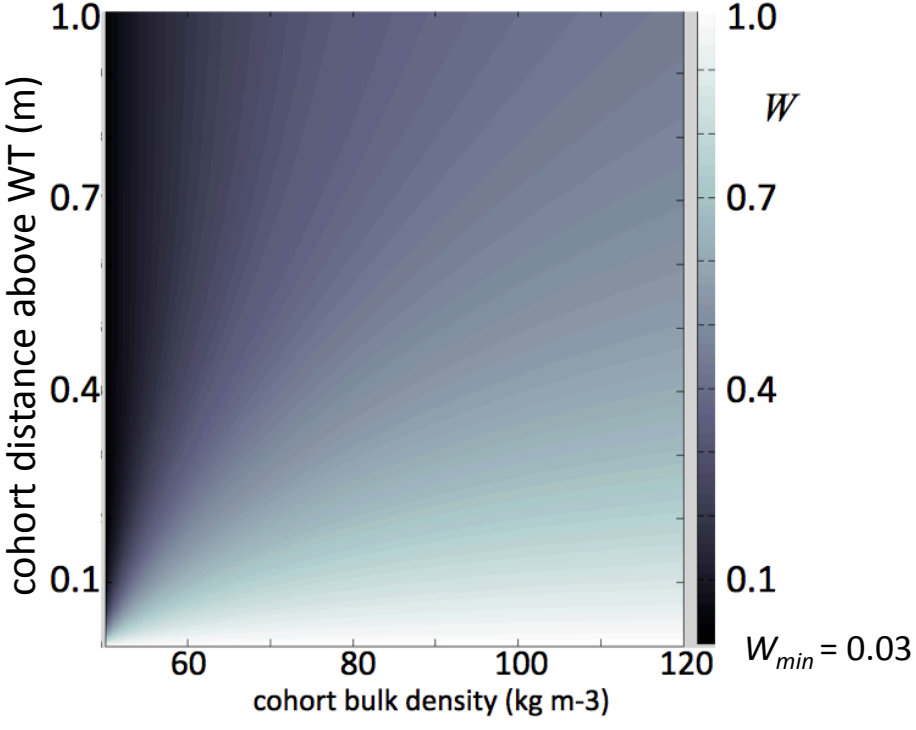




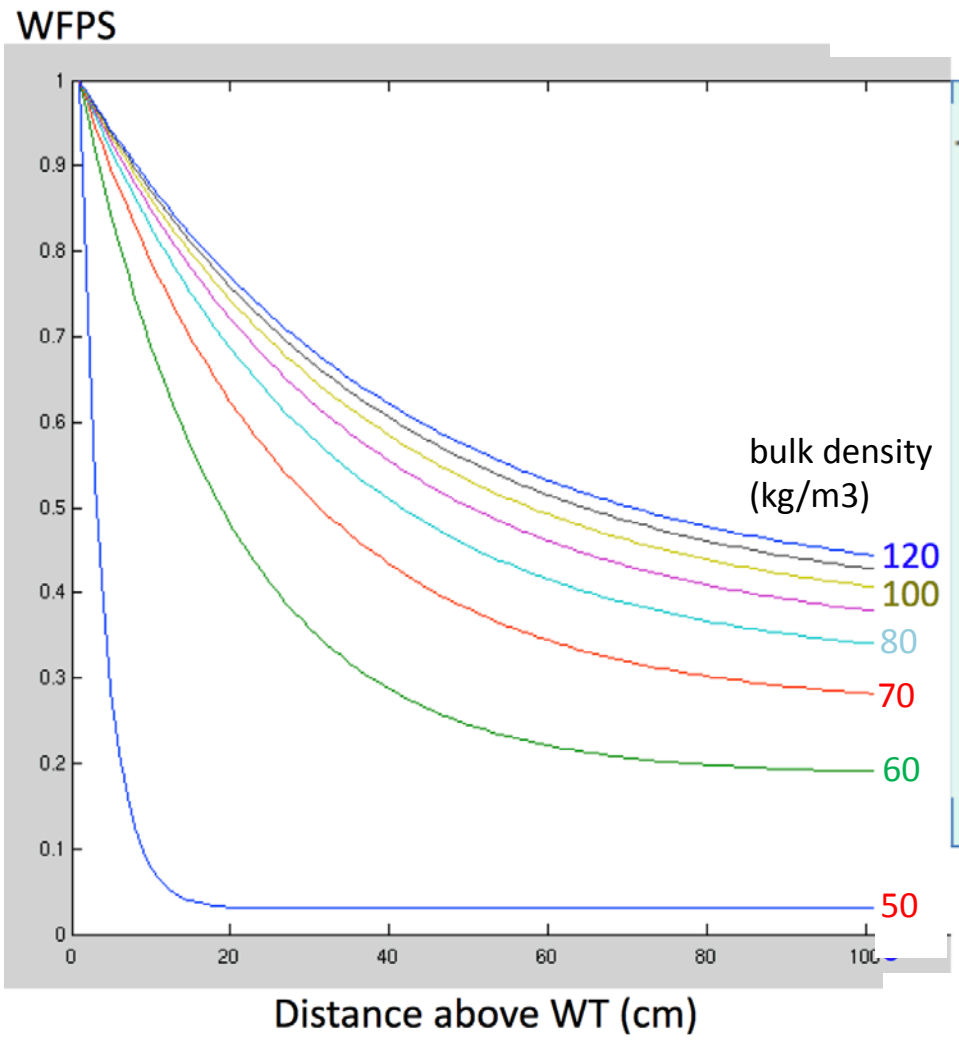
$$\sum_{i=1}^{i_{WT}} (K_i \cdot z_i)$$

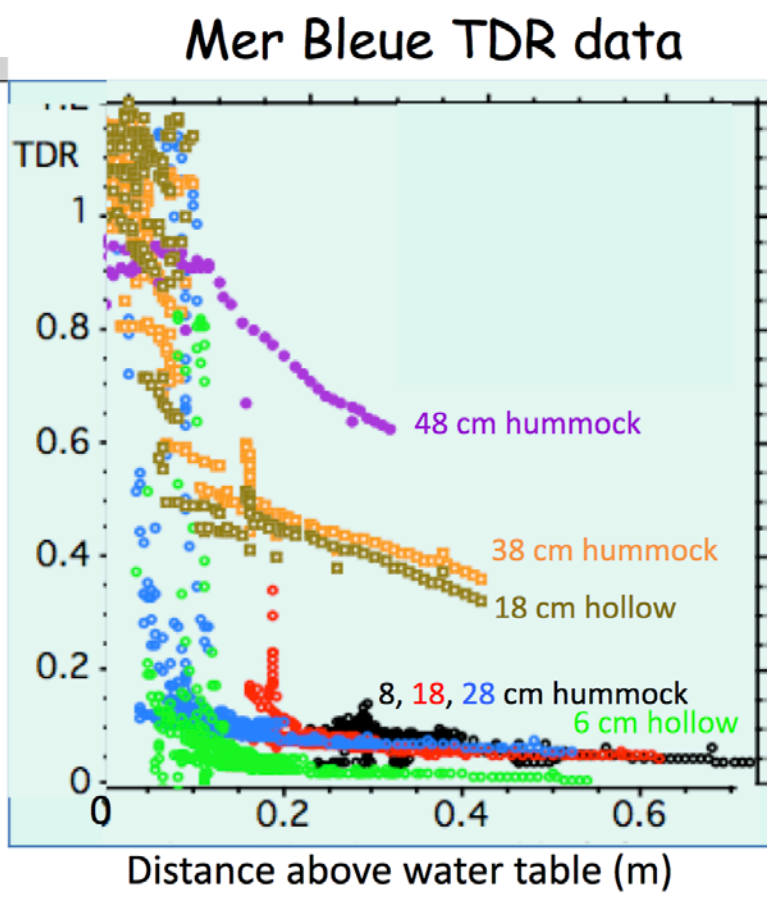
$$\sum_{i=1}^{i_{surf}} (K_i \cdot z_i)$$



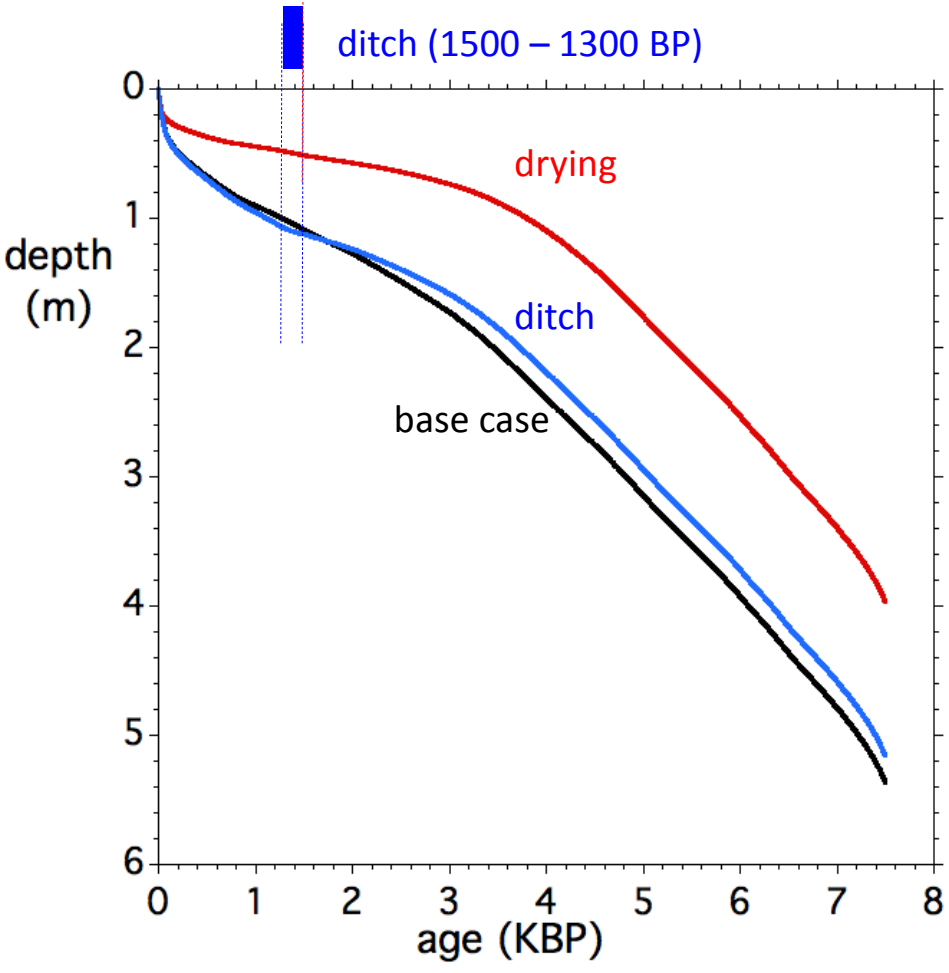


$W_{min} = 0.03$


WFPS
bulk density
(kg/m3)
120
100
80
70
60
50
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
80
Distance above WT (cm)


Mer Bleue TDR data
TDR
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
48 cm hummock
38 cm hummock
18 cm hollow
8, 18, 28 cm hummock
6 cm hollow
Distance above water table (m)

linear ET increase by 0.66% decade^{-1} (1500 – 1000 BP), then constant



fraction of initial mass remaining