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Совместное моделирование биотического круговорота и процессов в торфяной залежи для болотных ландшафтов южной тайги Западной Сибири с помощью комплексной модели болотных ландшафтов КОМБОЛА

Combined modeling of biotic turnover and peat deposit processes for peatland landscapes of southern taiga in Western Siberia with Complex Bog Landscape Model COMBOLA

ENVIROMIS-2018

Томск, 05 - 11 июля 2018

Поддержано проектом РФФИ № 16-07-0201-а

Болотные экосистемы и ландщафты бореальной зоны

Экосистемы торфяных болот и заболоченных земель:

-занимают около **3-5%** от поверхности мировой суши, сосредотачивая значительные запасы углерода в виде торфяных залежей **120 - 455 ПгС** (Gorham 1991; Вомперский 1994);

- по данным Botch et al. (1995) запасы углерода в болотах России равны **215 ПгС**;

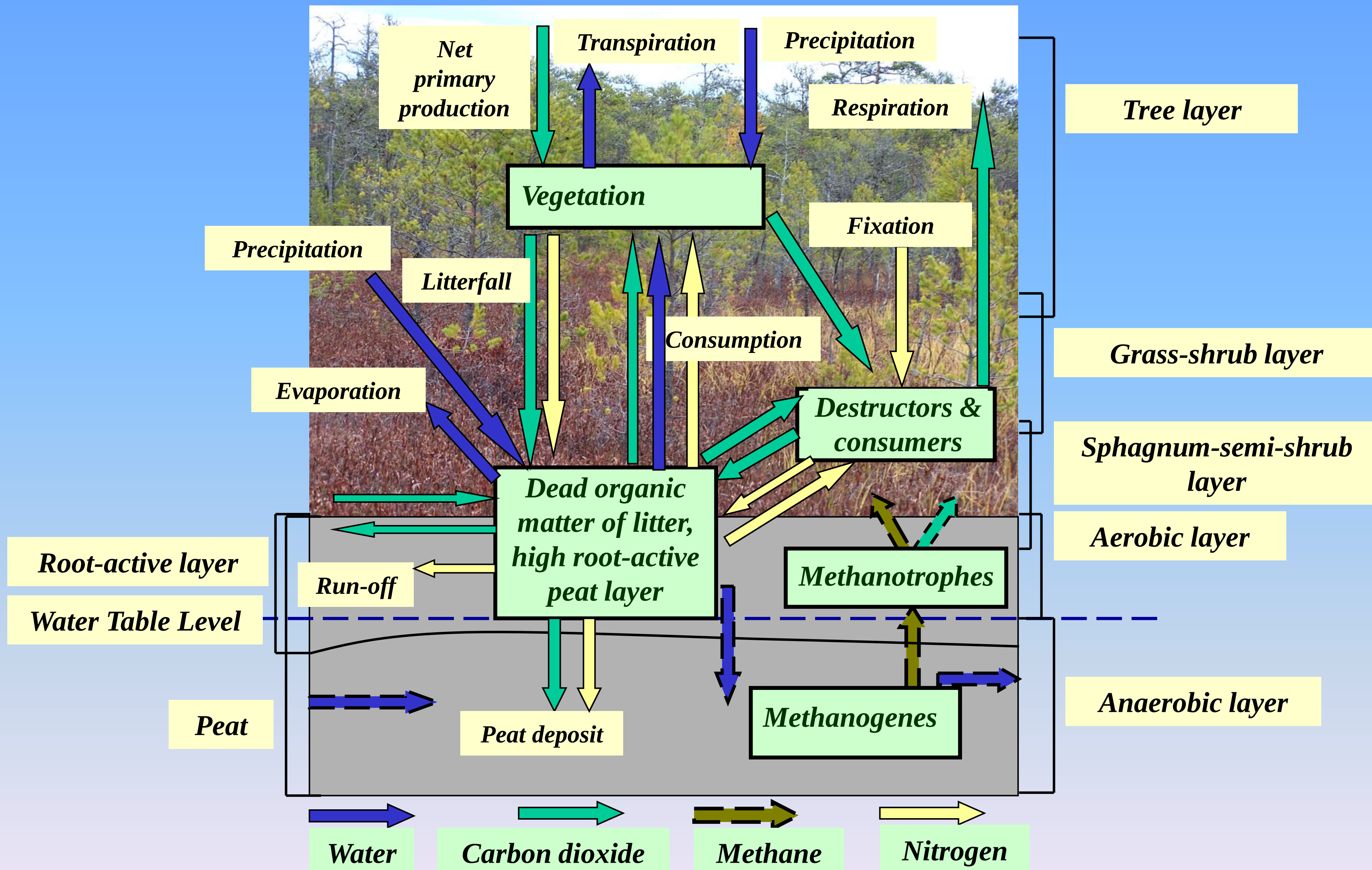
- площадь болотных экосистем Западной Сибири составляет **42%** от площади болот России, при этом в торфяниках Западной Сибири содержится около **36%** от общего пула почвенного углерода России (Вомперский, 1994; Ефремов, 1994; Титлянова, 1998);

-занимают согласно современным оценкам, **8,1**% территории России (Вомперский и др., 2005);

- могут быть как источниками, так и стоками углерод-содержащих газов при изменениях климата и антропогенных воздействиях;

- из-за большей трудности исследования и сложности функционирования хуже учитываются в расчетах и прогнозах углеродного баланса, чем леса.

Complexity of a biotic turnover and biogeochemical processes in peatland ecosystems



Классы биогеофизических моделей болотных экосистем

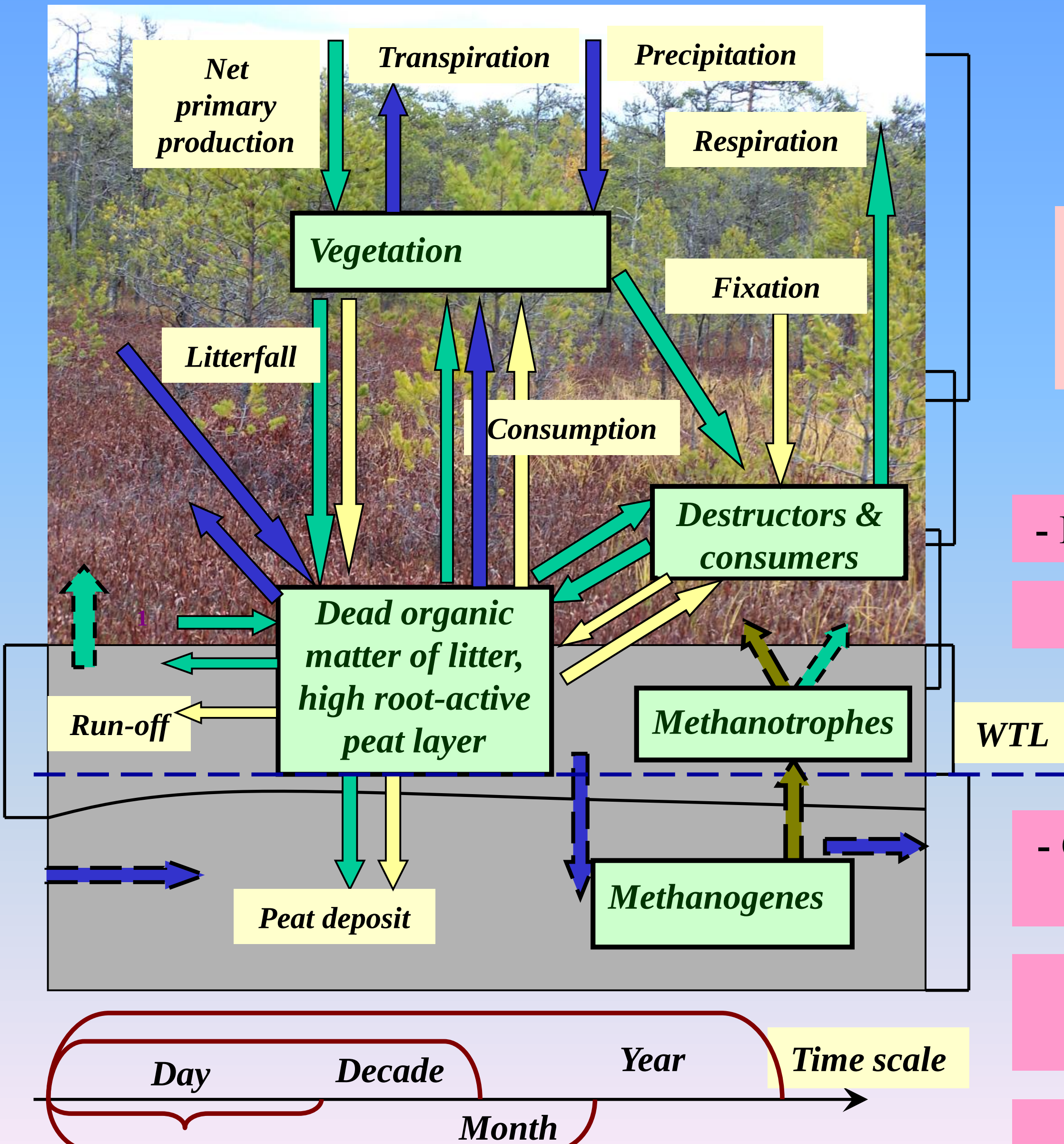
Классы моделей биотического круговорота и эмиссии газов с поверхности болот

Детальные имитационные на малых масштабах времени (минуты, часы, сутки, декады)

(Wetland-DNDC, Li et al., 2002; Лавров и др., 2005; Калюжный и др., 2005)

Качественные «минимальные» на больших масштабах времени (месяц, год и более) (Hilbert et al, 2000; Frolking, 2001; McGill et al., 2010)

Model system COMBOLA: layer-module structure
(COmplex MOdel of BOg LAndscapes)



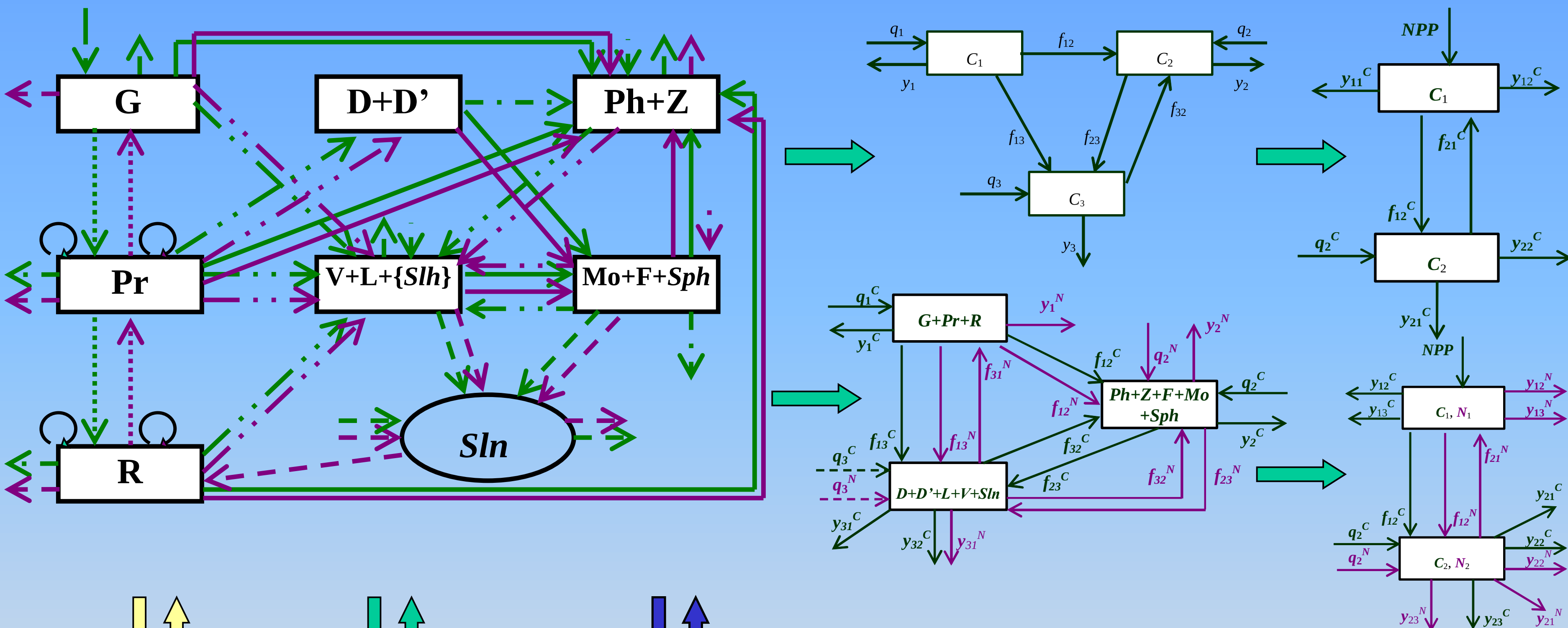
Model layer – a set of the same objects and processes on all time and space scales

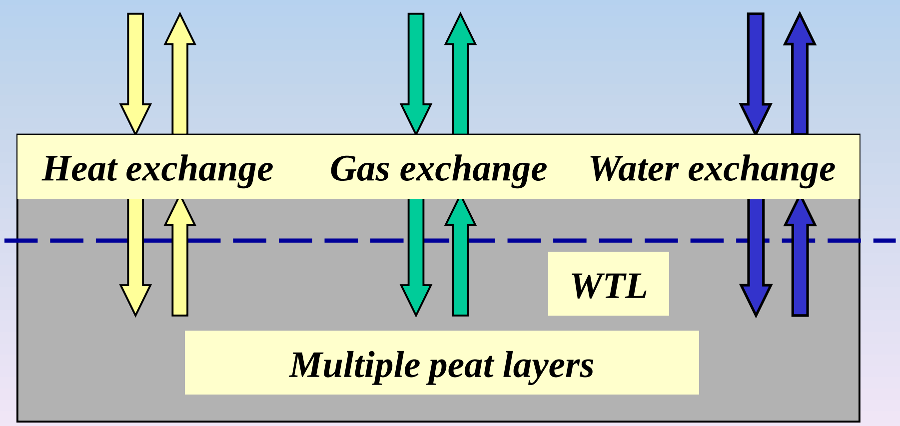
Model module – part of the layer for selected time scale combined with parts of other layers

Main model layers

- **Biological turnover (carbon, nitrogen, …)**
- **Water cycle and WTL calculation**
- **thermo- and water exchange in peat deposit**
- **Gas exchange (CO_2, CH_4) in peat deposit with a number of layers**
- **Calibration of flow coefficients and biophysical parameters**
- **Climatic and human impact scenarios**

Biotic turnover and peat layer processes in peatland landscapes as keystones of model system COMBOLA

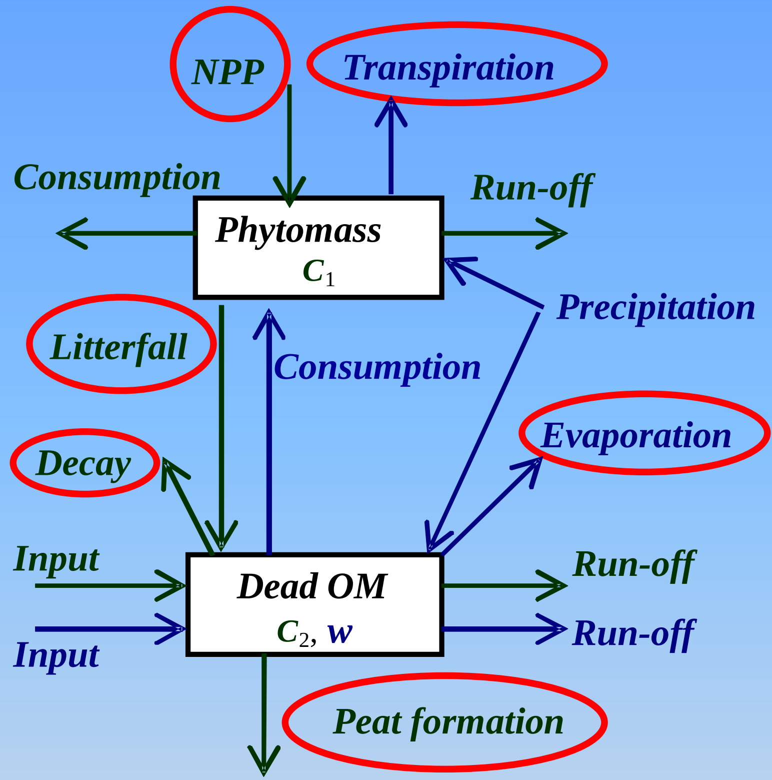




The main goal of model system COMBOLA:

Multi-component modeling of biotic turnover + biogeophysical processes inside peat layers over different time scales

Bog carbon cycle model with a water balance on an annual time scale



Flow functional form accounting water:

$$NPP = C_1\varphi_1(C_1)\varphi_2(w)\, f(T_a)$$

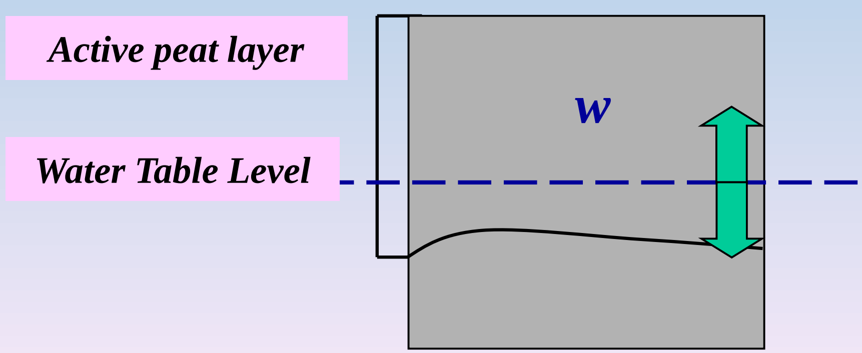
where $\varphi_2(w) = \dfrac{g_1 w}{1+g_2 w^2}$

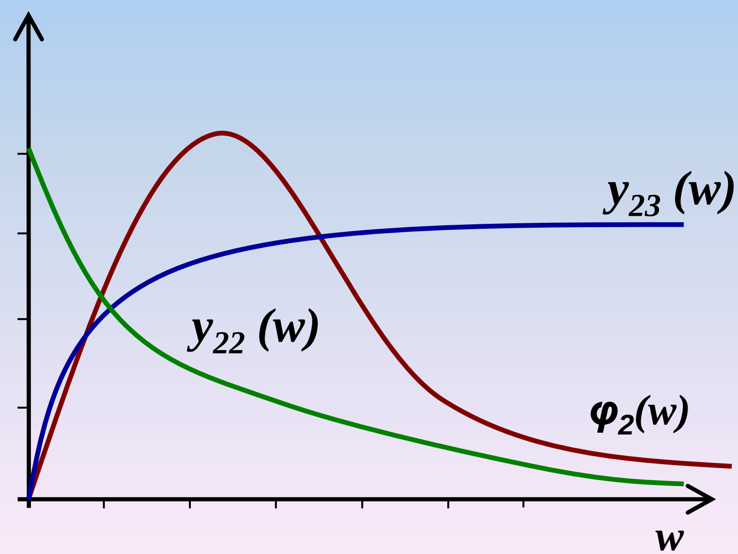
$$E_T = \frac{E_0 w C_1}{1+d_0 w}$$ - evapotranspiration

$m_1 C_1$ - phytomass consumption, $\alpha_{12} C_1$ – litterfall,

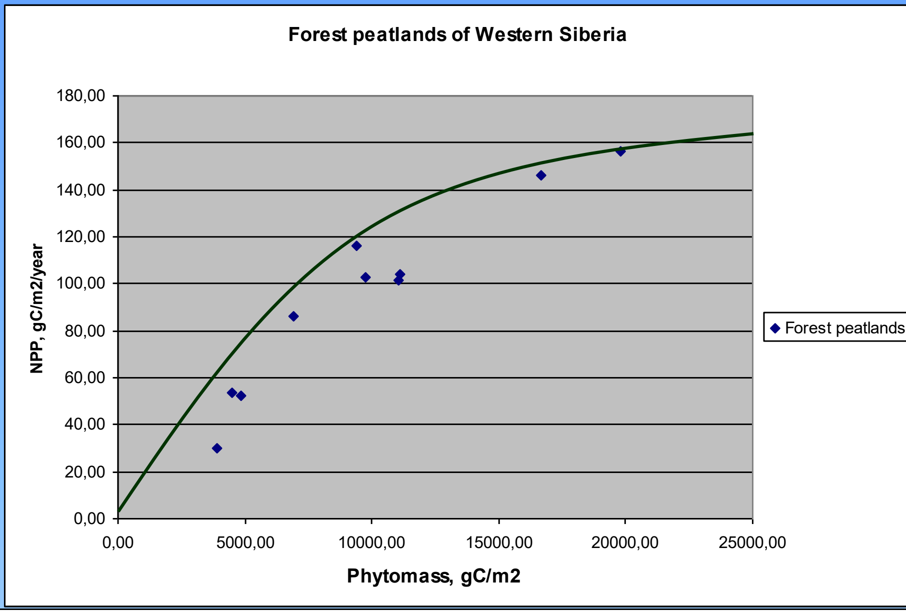
$$y_{23} = \frac{d_p w C_2}{1+d_0 w}$$ - peat deposit

$$y_{22} = \frac{d_c C_2}{1+d_0 w}$$ - dead organic matter decay





NPP - phytomass relation in peatland ecosystems

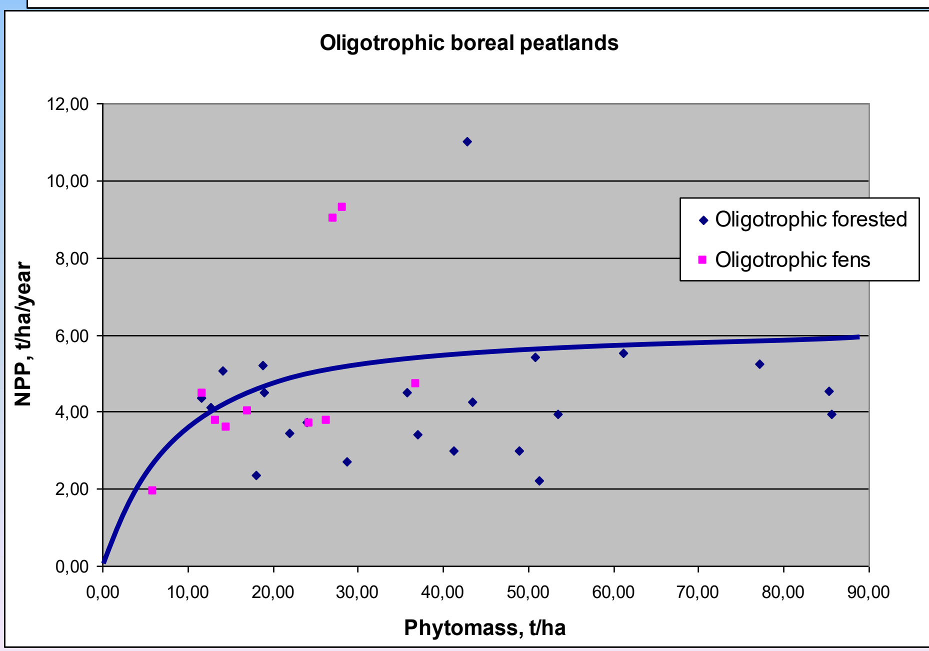


Forest peatlands of Western Siberia: $R^2 = 0.8937$

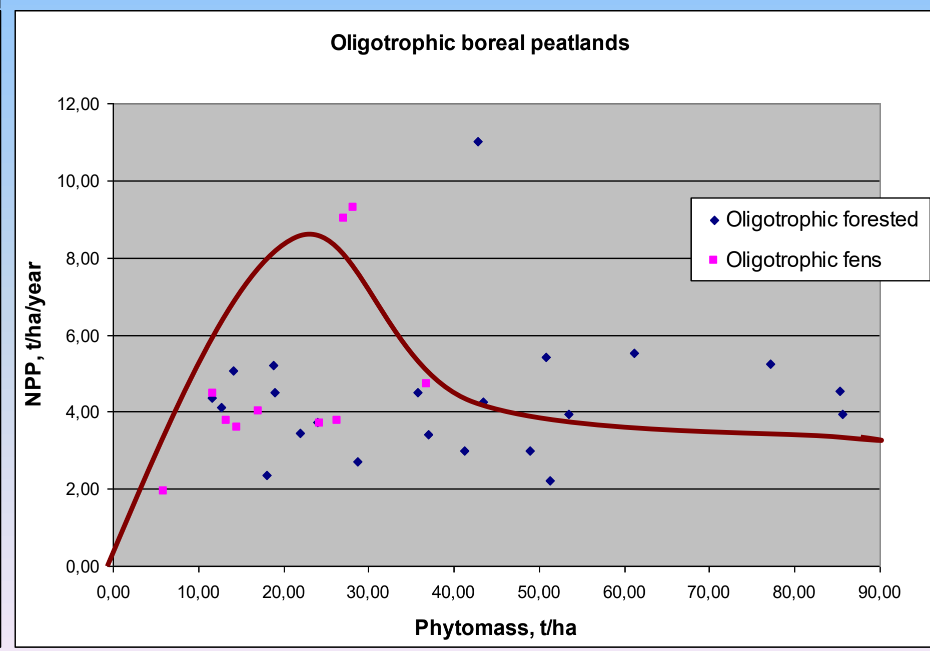
NPP functional form:

a) $$NPP = C_1 \frac{p_0}{1 + p_1 C_1} = C_1 \varphi_1(C_1)$$

б) $$NPP = C_1 \frac{p_0 C_1}{1 + p_1 C_1 + p_2 C_1^2} = C_1 \varphi_2(C_1)$$

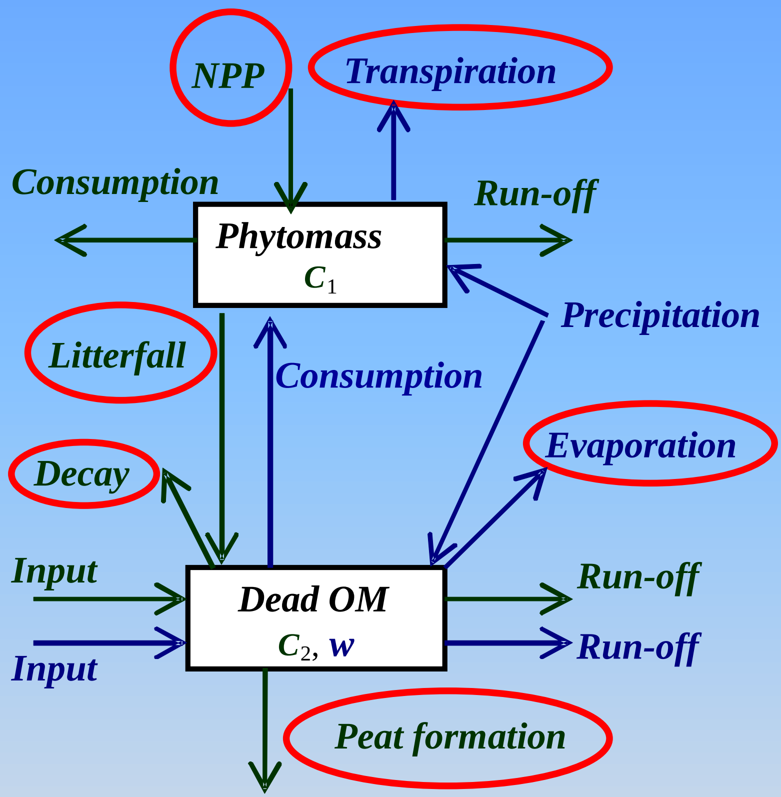


Oligotrophic bogs of Nothern Euroasia: $R^2 = 0.69$



Oligotrophic bogs of Nothern Euroasia: $R^2 = 0.6531$

Simplest carbon cycle model with a water balance in a peatland landscape



Dynamic model for two-component carbon cycle scheme with water balance :

1) $$dC_1 / dt = C_1(\varphi_1(C_1)\varphi_2(w) - m_1 - \alpha_{12})$$

2) $$dC_2 / dt = q_2 - m_2 C_2 + \alpha_{12} C_1 - \frac{d_p w C_2}{1 + d_0 w} - \frac{d_c C_2}{1 + d_0 w}$$

3) $$dw / dt = P + q_w - d_1 w - \frac{E_0 w C_1}{1 + d_0 w}$$

1) One elementary equilibrium – in-peatland lake:

$$C_1^{(1)} = 0, w^{(1)} = (P + q_w) / d_1, C_2^{(1)} = q_2 / (m_2 + \frac{d_c + d_p w^{(1)}}{1 + d_0 w^{(1)}})$$

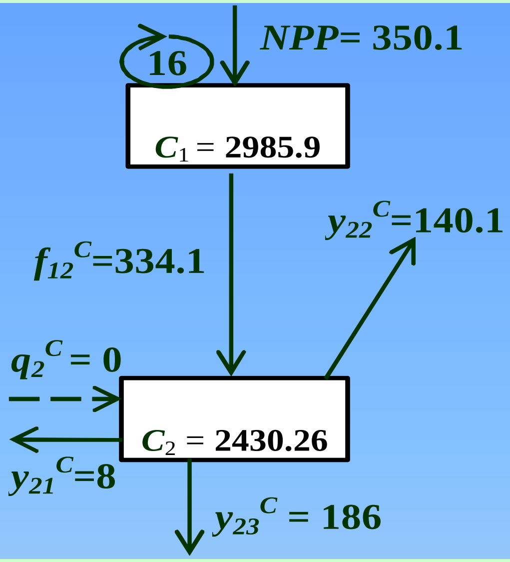
2) All other equilibria are found from the equation:

$$P + q_w - d_1 d_0 w^2 + w(d_0(P + q_w) - d_1) = E_0 w \varphi_1^{-1}\left(\frac{m_1 + \alpha_{12}}{\varphi_2(w)}\right)$$

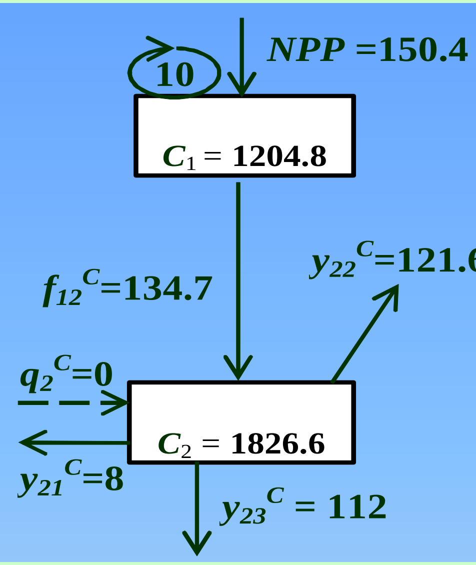
Model dynamics depends on monotonicity of factor $\varphi_1(C_1)$ and properties of water factor $\varphi_2(w)$.

Two-component static diagrams of annual carbon cycle in Western Siberian southern taiga peatland landscapes

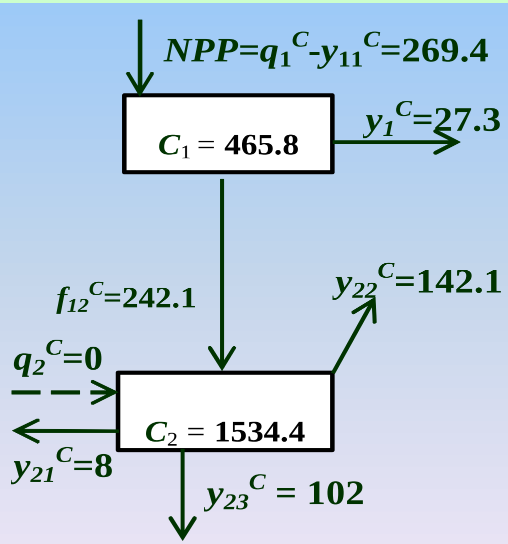
Storages - gC/m^2,
flows - gC/m^2·year.



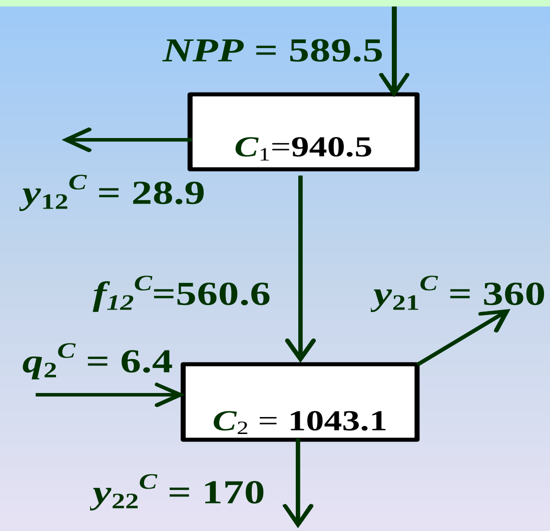
Oligotrophic pine-shrub-sphagnum bog (“tall ryam”)



Oligotrophic pine-shrub-sphagnum bog (“low ryam”)



Oligotrophic sedge-sphagnum fen



Mesotrophic shrub-sphagnum fen

Data from (Golovatskaya and Dyukarev, 2009; Golovatskaya, 2010, 2013; Valutskii and Khramov, 1977; Bazilevich and Titlyanova, 2008).

Western Siberian southern taiga landscapes

1 – pine-grass-sphagnum forested bog «tall ryam»
2 – mesotrophic sphagnum fen
3 – oligotrophic fen with lake

Stability of typical steady states in the two-component carbon cycle model

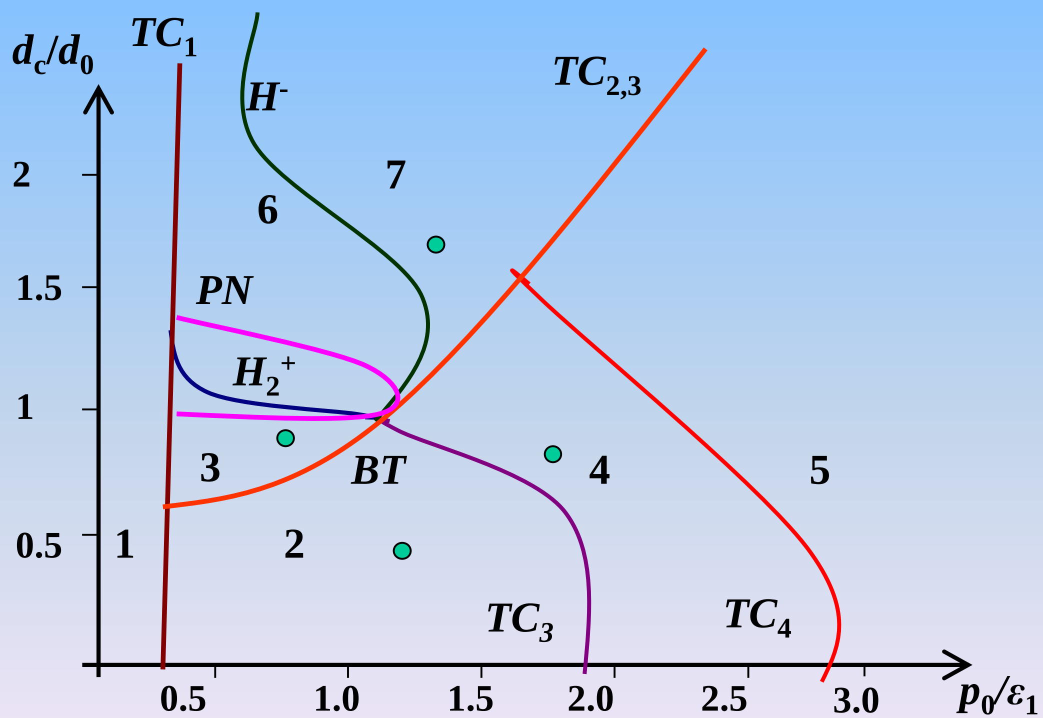
In-peatland lake equilibrium:

$$C_1^{(1)}=0,\ w^{(1)}=(P+q_w)/d_1,\ C_2^{(1)}=q_2/(m_2+\frac{d_c+d_p w^{(1)}}{1+d_0 w^{(1)}})$$

Curve of stability loss for in-peatland lake: $\varphi_2(w^{(1)})\varphi_1(0)=m_1+\alpha_{12}$

Stability relations for non-zero steady states: $C_1^{(2)}=0;$

$$\frac{E_0 w^{(2)}\varphi_1(C_1^{(2)})}{1+d_0 w^{(2)}}\varphi_2'(w^{(2)})=(d_1+\frac{E_0 C_1^{(2)}}{(1+d_0 w^{(2)})^2})\varphi_2(w^{(2)})\varphi_1'(C_1^{(2)}));\quad \varphi_2(w^{(2)})C_1^{(2)}\varphi_1'(C_1^{(2)})=d_1+\frac{E_0 C_1^{(2)}}{(1+d_0 w^{(2)})^2}$$



Stability boundaries of equlibria:

1 –in-peatland lake is stable

2 – mesotrophic fen and low "ryam" are stable

3 – oligotrophic fen is stable

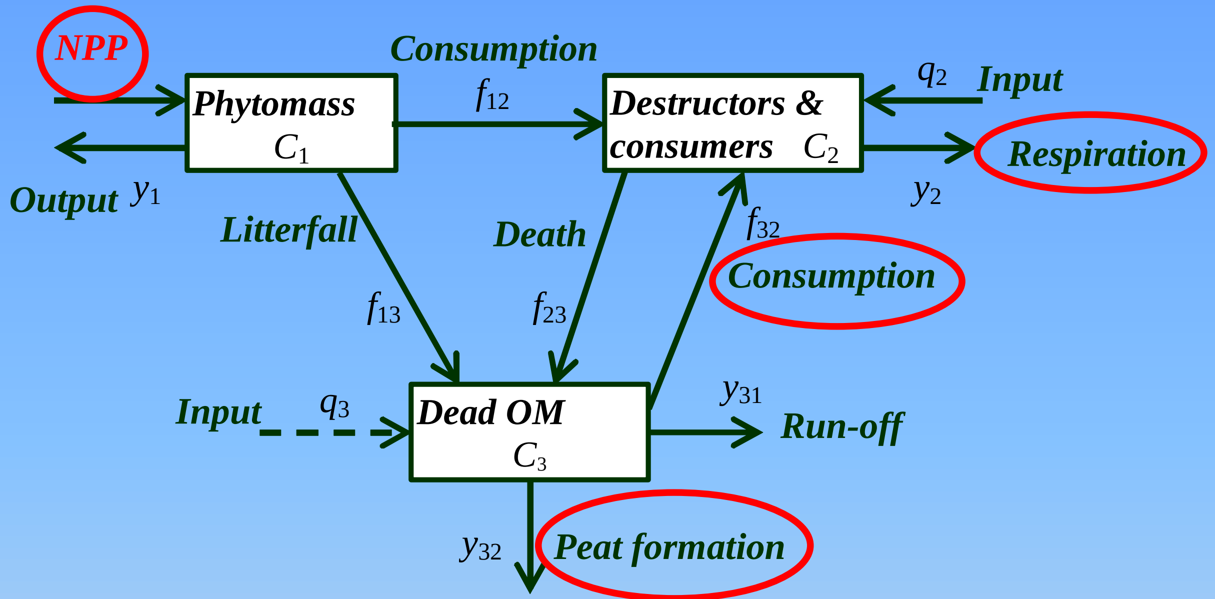
4 – tall "ryam" is stable

5 – pine forest is stable

6 – oscillatory regime

7 – mesotrophic fen is stable

Three-component simple carbon cycle model

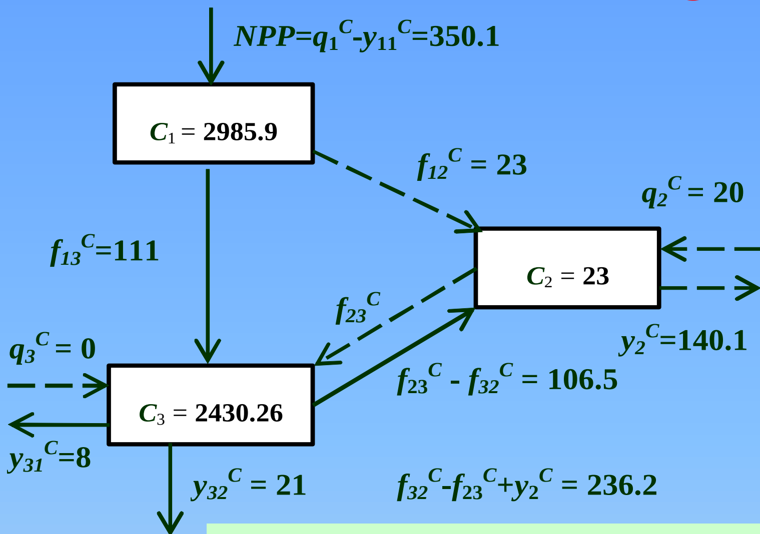


Simple dynamic model for 3-component scheme :

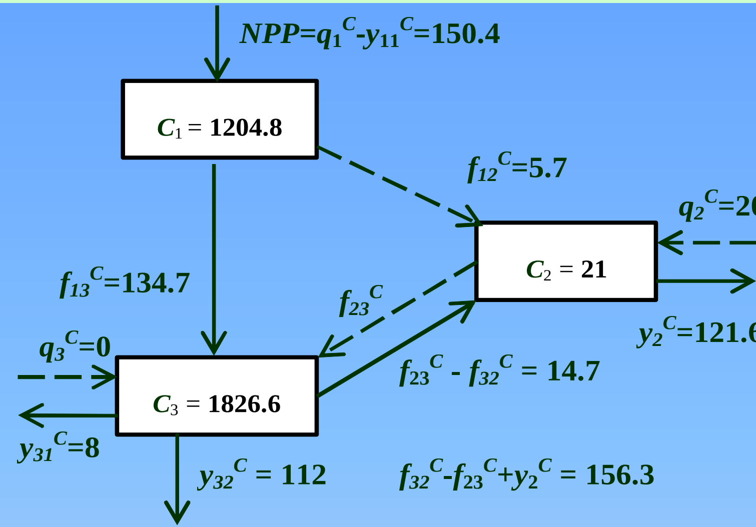
$$\begin{cases} \dfrac{dC_1}{dt} = C_1(\varphi_{1,2}(C_1) - m_1 - \alpha_{13} - \gamma_{12}C_2) \\ \dfrac{dC_2}{dt} = q_2 + \gamma_{12}C_1C_2 - m_2C_2 - \alpha_{23}C_2 + \gamma_{32}C_2C_3 \\ \dfrac{dC_3}{dt} = q_3 - m_3C_3 + \alpha_{13}C_1 - \gamma_{32}C_2C_3 + \alpha_{23}C_2 \end{cases}$$

In-peatland lake equilibrium [0;0; q_3/m_3]

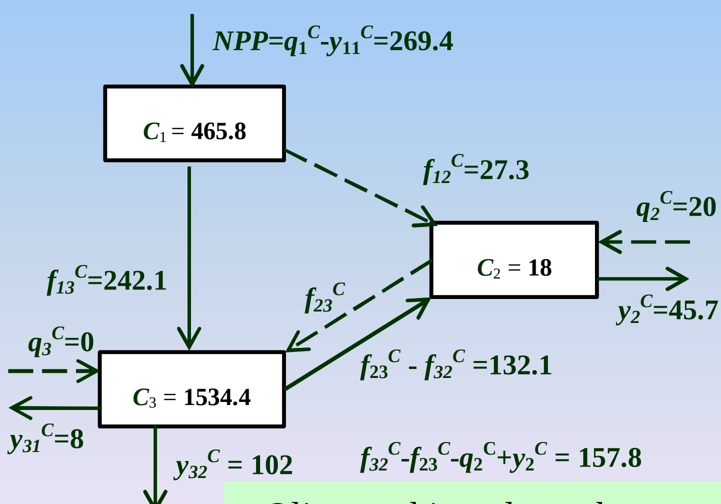
Two-component schemes of carbon cycle in peatland ecosystems of southern taiga in Western Siberia



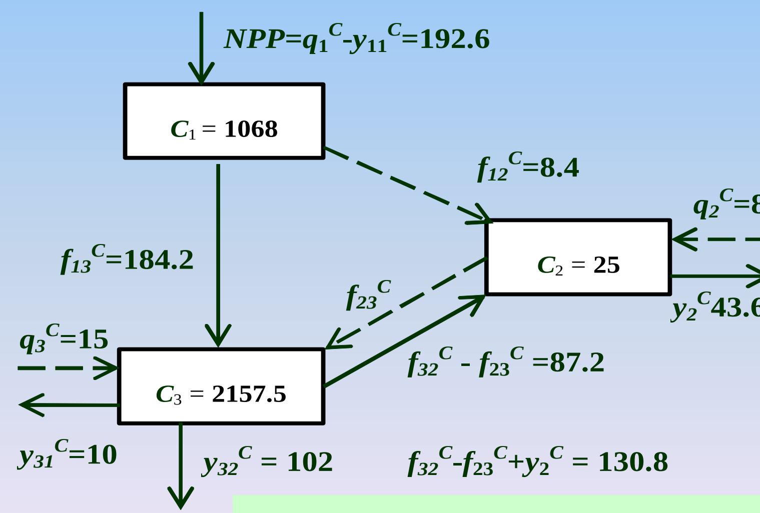
Oligotrophic pine-shrub-sphagnum



Oligotrophic low pine-shrub-sphagnum



Oligotrophic sedge-sphagnum fen

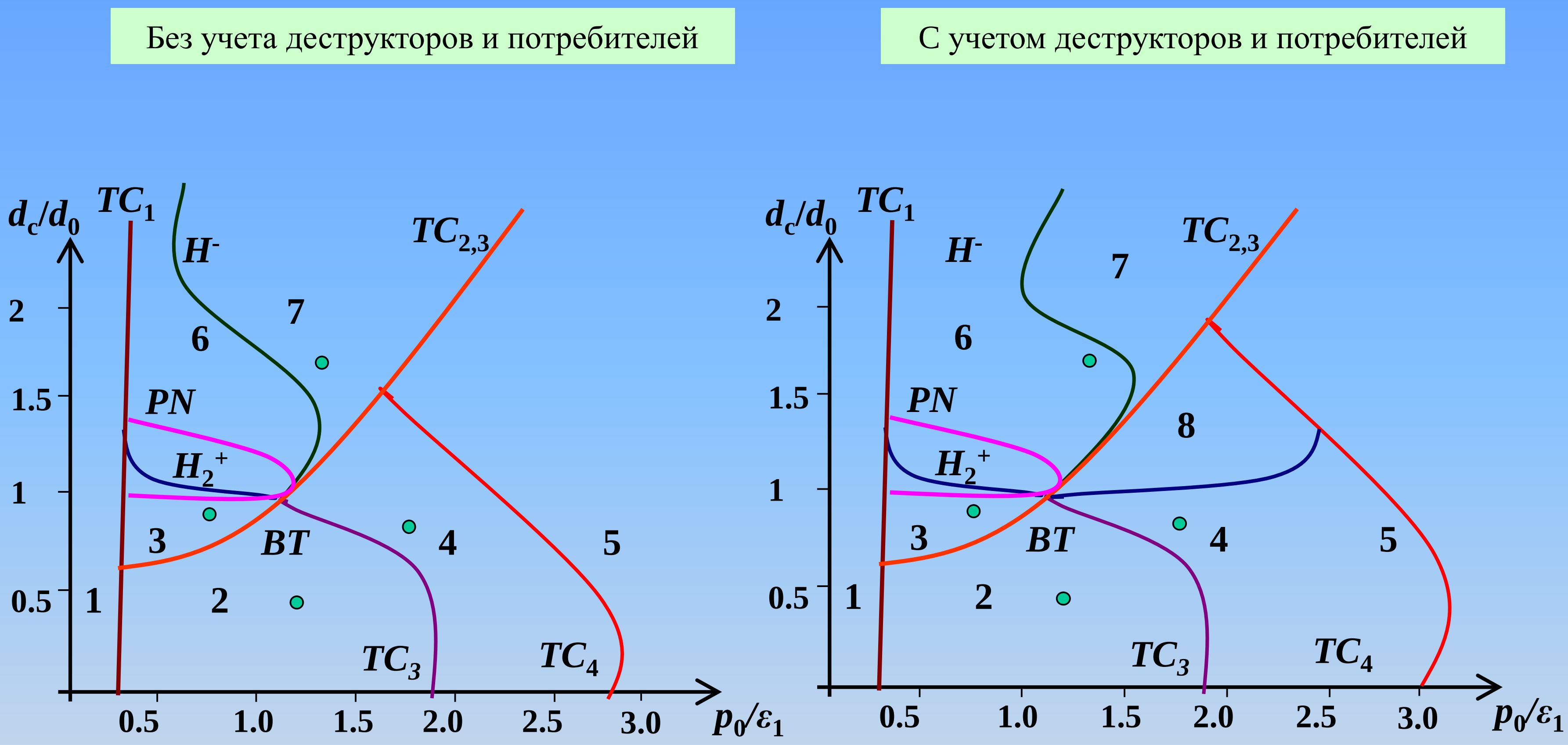


Eutrophic fen

Storages - gC/m^2, flows - gC/m^2·year.

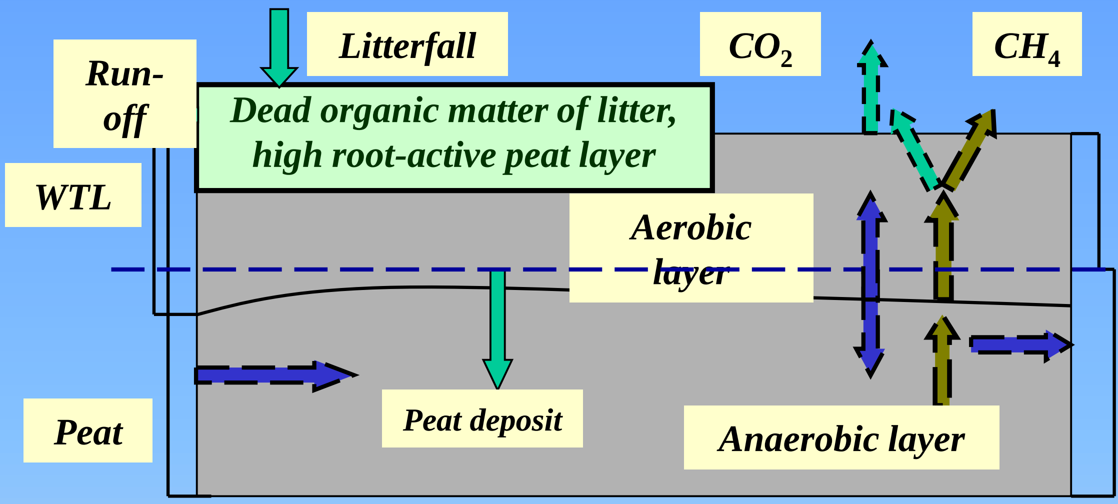
Data from (Golovatskaya, Dyukarev, 2009; Golovatskaya, 2010).

Oscillatory dynamics in the two-component carbon cycle model



Stability boundaries of equlibria:
1 –in-peatland lake is stable; **2** – mesotrophic fen and low “ryam” are stable; **3** – oligotrophic fen is stable; **4** – tall “ryam” is stable; **5** – pine forest is stable; **6** – oscillatory regime; **7** – mesotrophic fen is stable; **8** – oscillatory dynamics

Modelling peat layer processes on annual time scale



Simple dynamic model for CO_2 dynamics in peat deposit

$$\begin{cases} \dfrac{\partial C_{CO2}}{dt} = \dfrac{\partial}{\partial z}\left(D_{CO2}\dfrac{\partial C_{CO2}}{\partial z}\right) + d_2^c C_2 F(T,w) \\ c_{eff}\dfrac{\partial T}{dt} = \dfrac{\partial}{\partial z}\left(\lambda \dfrac{\partial T}{dz}\right) \end{cases}$$

Temperature dependent model parameters:
$NPP = NPP(C_a)$- NPP of vegetation increases under atmospheric CO_2 content C_a;

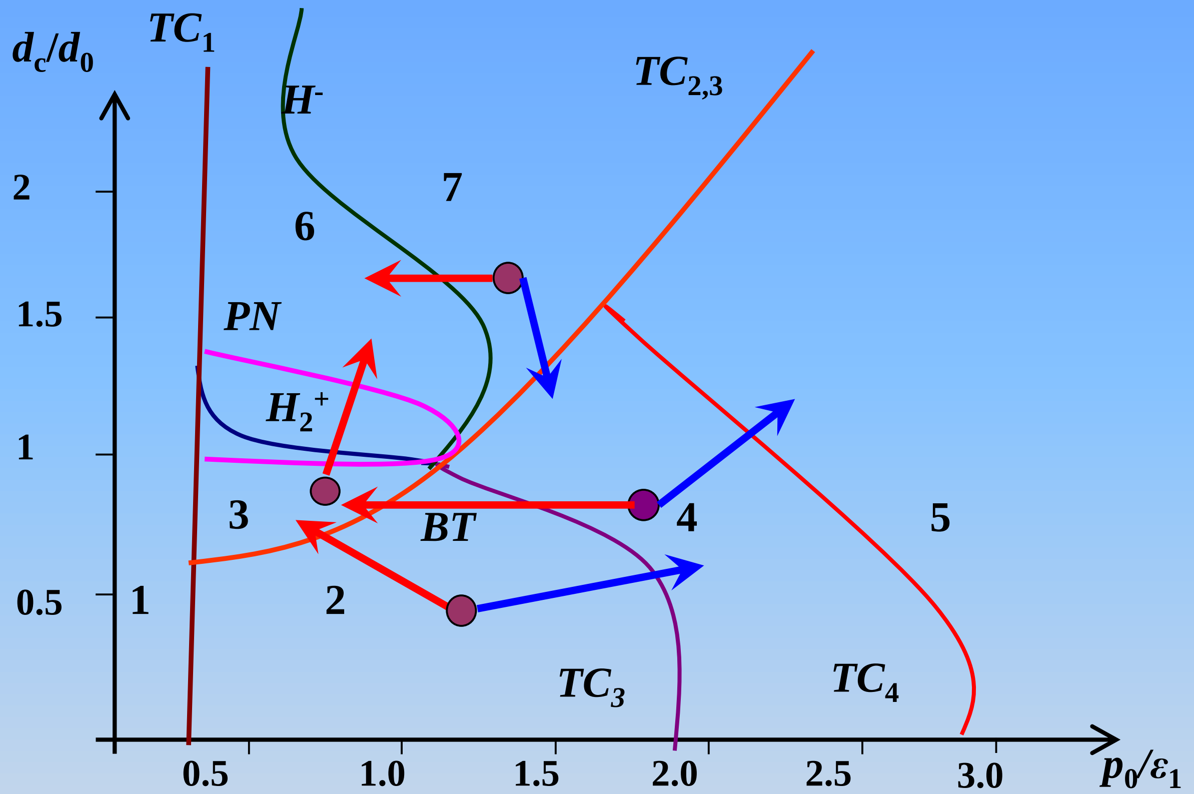
$m_2^C = m_2^C(T)$ – peat formation intensity;

$d_2^C = d_2^C(T,H)$ – intensity of decay for dead organic matter depend on the annual air temperature and total precipitation in a polynomial form.

Climate change scenarios from the global climate model IPSL (CMIP5):

RCP-2.6 (softly warm) – +0,9 … 2,3 ºC up to 2100 globally, +1,0 … 1,5 ºC locally
RCP-8.5 (extremely warm) - +3,2 … 5,4 ºC up to 2100 globally, +2,8 … 4,0 ºC locally

Combined modelling of CO_2 emission in bog landscapes with two-component carbon cycle model and peat layer processes model



Climate change by the IPSL global climate model with scenarios:
- RCP-8.5
- RCP-2.6

Stability domains of stationary dynamic regime of the biological turnover:

Stability boundaries of equlibria:
1 –in-peatland lake is stable; **2** – mesotrophic fen and low “ryam” are stable; **3** – oligotrophic fen is stable; **4** – tall “ryam” is stable; **5** – pine forest is stable; **6** – oscillatory regime; **7** – mesotrophic fen is stable

Conclusions

1) **Complexity of natural processes in peatlands can be reflected by a series of combined multi-component models of biotic turnover and thermo- and mass exchange in the peat deposit on different time scales;**

2) **Включение упрощенного водного баланса корнеобитаемого слоя торфа позволяет интерпретировать режимы круговорота с точки зрения гидрологии;**

3) **Колебательные режимы увеличивают свои области устойчивости при учете деятельности деструкторов и потребителей в биотическом круговороте олиготрофных болотных ландшафтов.**

4) **«Soft» climatic scenario RCP-2.6 of the IPSL model can transform oligo- and mesotrophic fens into forested states (“ryams”) while “ryams” can perform into forests under a century time interval;**

5) **Under the «hard» climate change scenario RCP-8.5 of the IPSL model forested oligotrophic peatlands of middle and southern taiga can be transformed into fen state due to increased precipitation except “tall ryam” that can become forest.**

Спасибо за внимание !

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