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Биотический круговорот в болотных ландшафтах южной и средней тайги Западной Сибири при изменениях климата и хозяйственных воздействиях

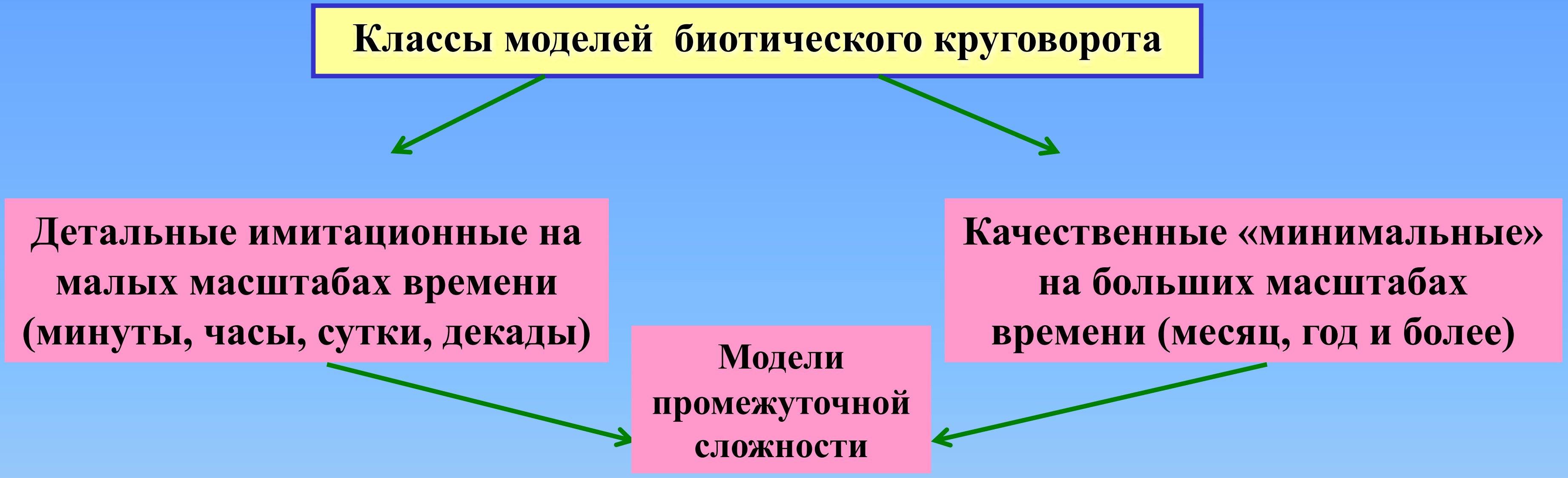
Biotic turnover in peatland landscapes of southern and middle taiga in Western Siberia under climate and anthropogenic changes

ENVIROMIS-2016

Томск, 11 - 16 июля 2016

Поддержано проектом РФФИ № 16-07-0201-а

Классы моделей биотического круговорота в экосистемах

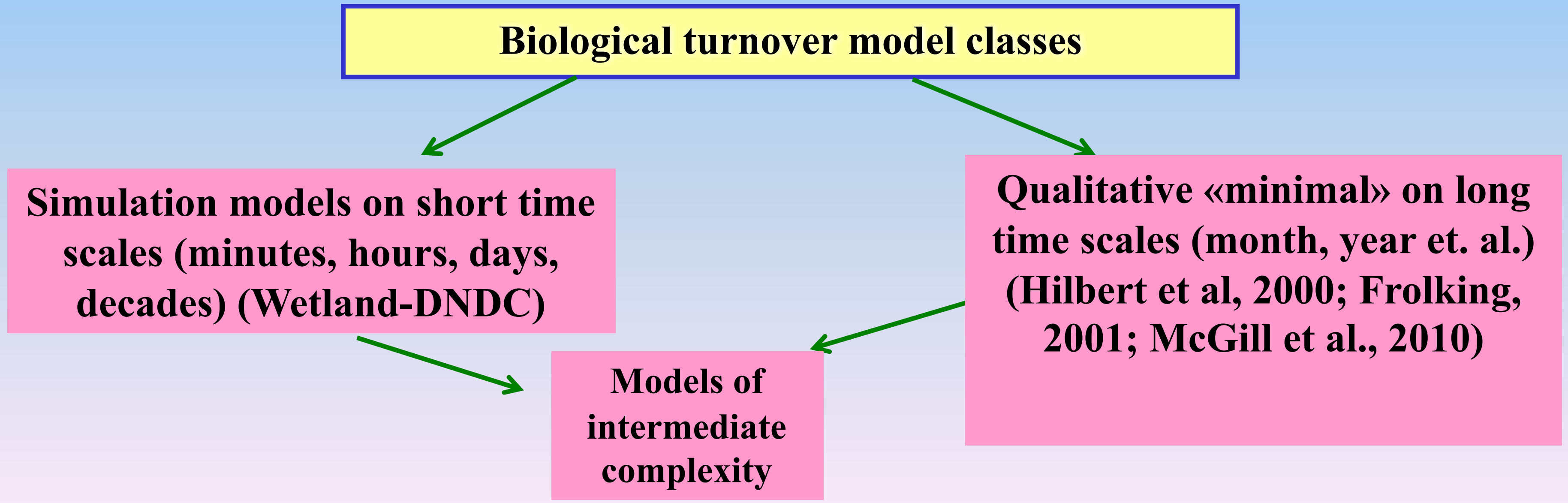


Классы моделей биотического круговорота

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

Качественные «минимальные» на больших масштабах времени (месяц, год и более)

Модели промежуточной сложности



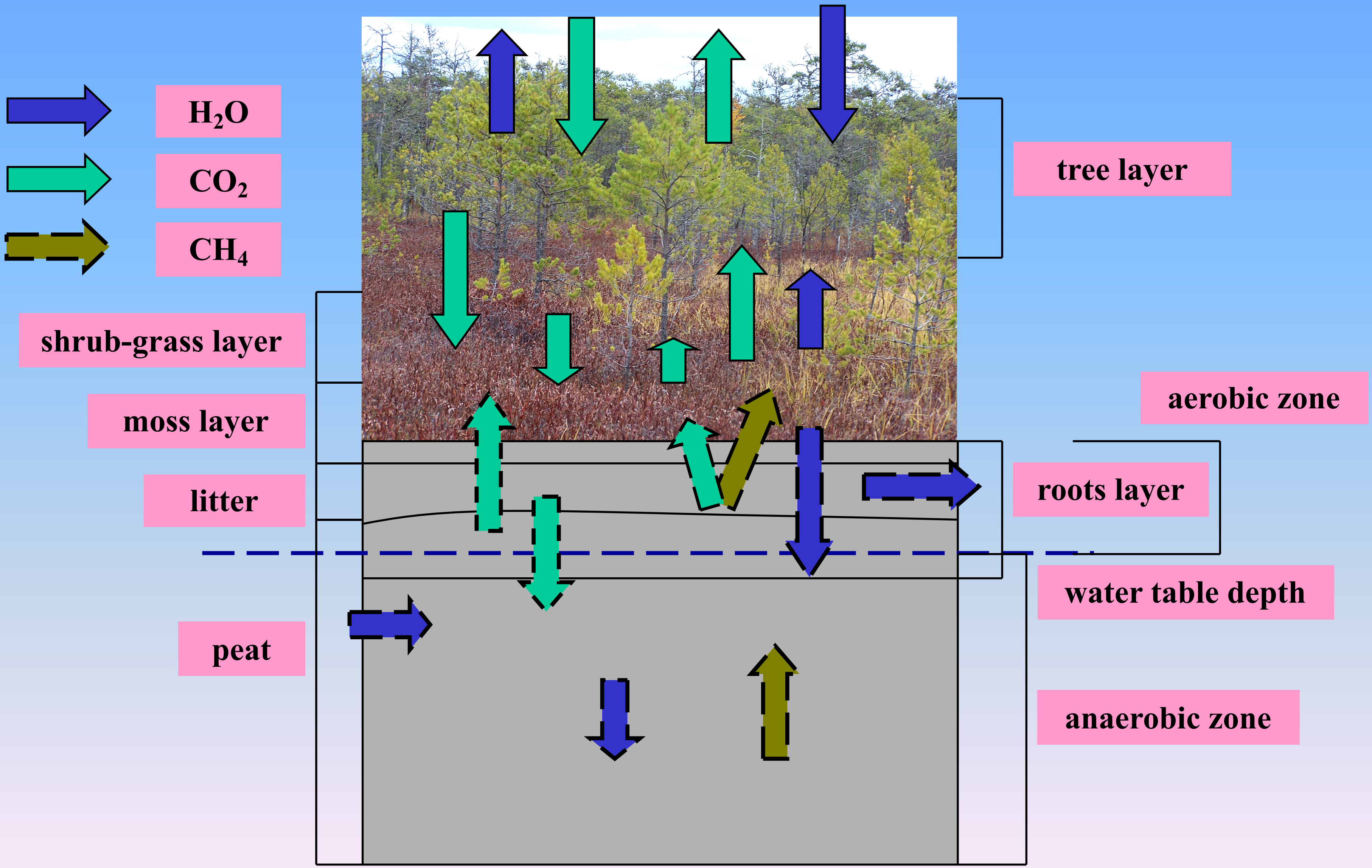
Biological turnover model classes

Simulation models on short time scales (minutes, hours, days, decades) (Wetland-DNDC)

Qualitative «minimal» on long time scales (month, year et. al.) (Hilbert et al, 2000; Frolking, 2001; McGill et al., 2010)

Models of intermediate complexity

“Simple” models of biological turnover in peatlands in context of the model system COMBOLA (COmplex MOdel of BOg LAndscapes)



H_2O

CO_2

CH_4

shrub-grass layer

moss layer

litter

peat

tree layer

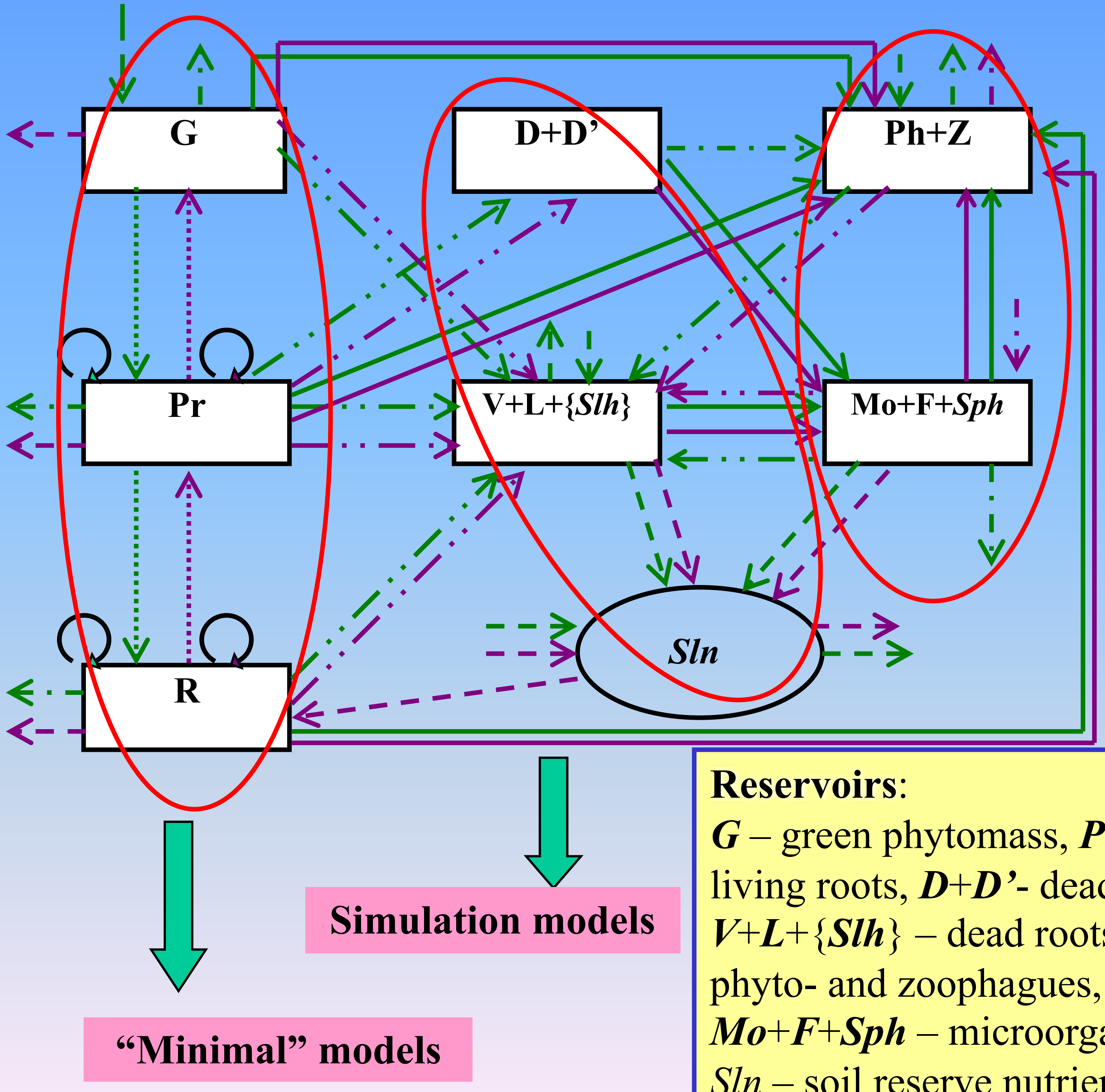
aerobic zone

roots layer

water table depth

anaerobic zone

Universal scheme of a biotic turnover in terrestrial ecosystems



Simulation models

“Minimal” models

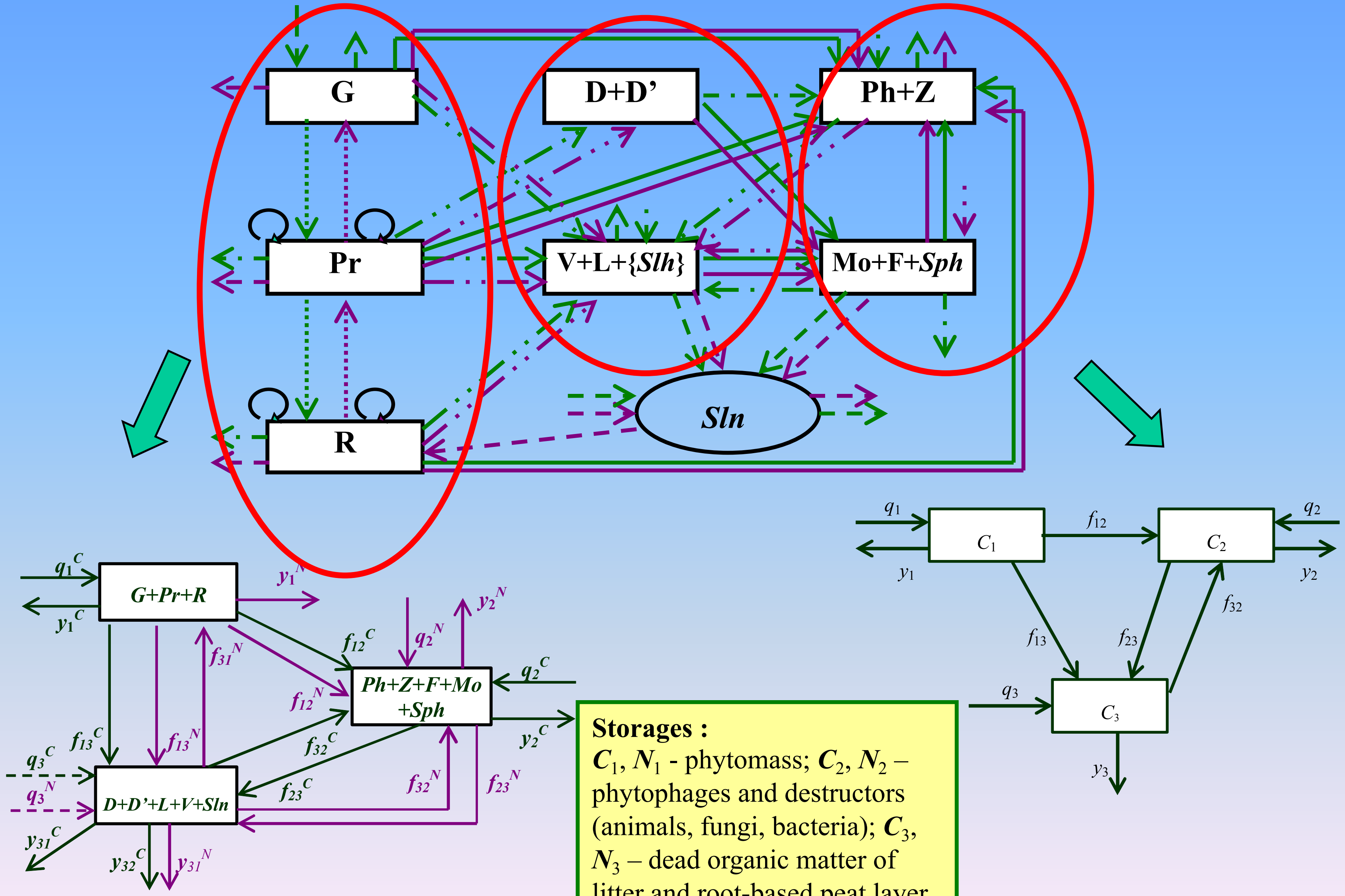
Carbon and nitrogen flows in an ecosystem:

- - → photosynthesis,
- · → respiration,
- · → denitrification and nitrogen fixation
→ consumption,
- · · → litterfall, excretion
↻ accumulation in real increment,
- - → import and export, abiotic oxidation,
······→ translocation

Reservoirs:

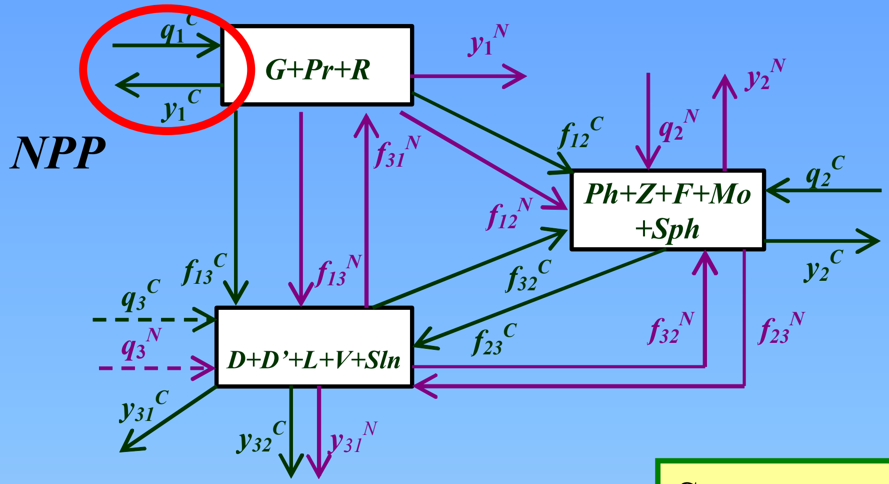
G – green phytomass, ***Pr*** – perennial phytomass, ***R*** – living roots, ***D*+*D’***- dead standing phytomass, ***V*+*L*+{*Slh*}** – dead roots + litter + {humus}, ***Ph*+*Z*** – phyto- and zoophagues, ***Mo*+*F*+*Sph*** – microorganisms+fungi+saprophages, *Sln* – soil reserve nutrients.

Aggregation of static schemes for biotic turnover schemes in minimal models



Storages :
C_1, N_1 - phytomass; C_2, N_2 – phytophages and destructors (animals, fungi, bacteria); C_3, N_3 – dead organic matter of litter and root-based peat layer

Minimal aggregated compartment schemes of particular and combined cycles in peatland ecosystems



NPP

q_1^C

y_1^C

G+Pr+R

y_1^N

f_{31}^N

f_{12}^C

q_2^N

y_2^N

q_2^C

Ph+Z+F+Mo +Sph

f_{12}^N

y_2^C

f_{13}^C

f_{13}^N

f_{32}^C

q_3^C

q_3^N

D+D'+L+V+Sln

f_{23}^C

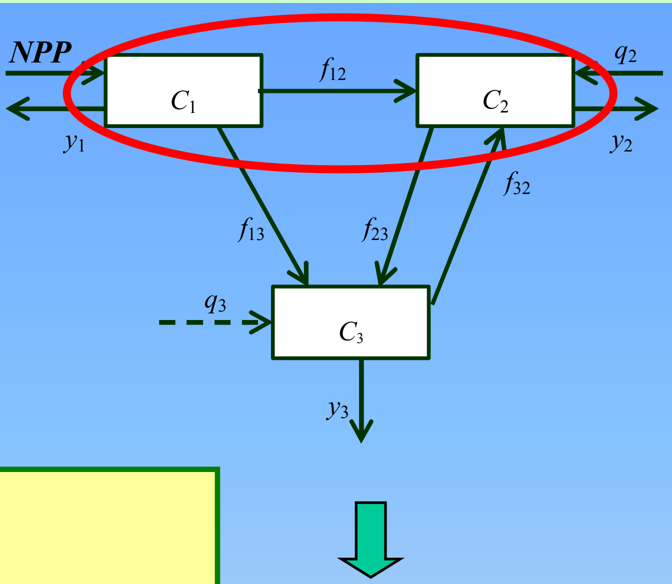
f_{32}^N

f_{23}^N

y_{31}^C

y_{32}^C

y_{31}^N



NPP

C_1

f_{12}

C_2

q_2

y_1

y_2

f_{32}

f_{13}

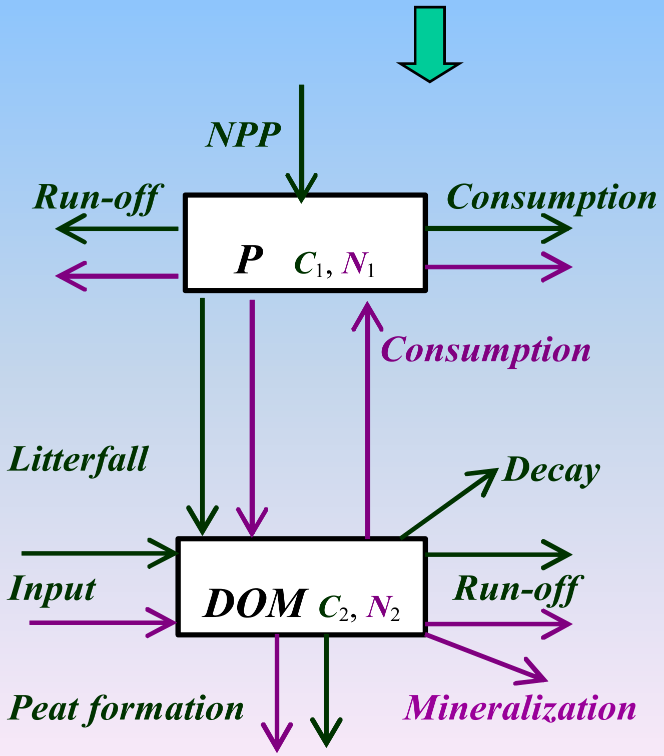
f_{23}

q_3

C_3

y_3

Storage :
C_1, N_1 – **Phytomass;**
C_2, N_2 – **Dead Organic Matter** of the root layer



NPP

Run-off

Consumption

P C_1, N_1

Consumption

Litterfall

Decay

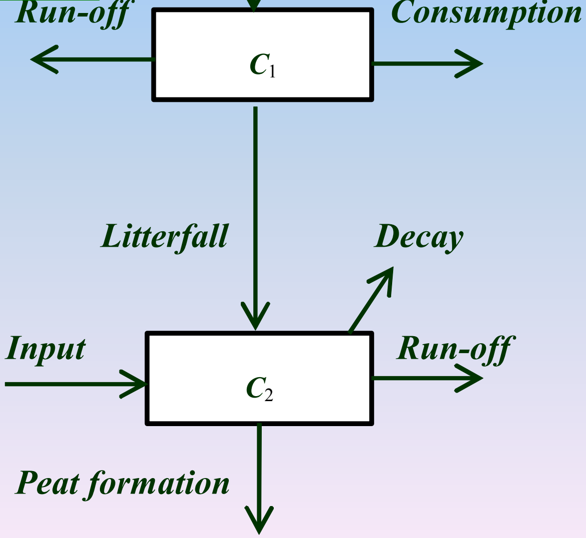
Input

DOM C_2, N_2

Run-off

Peat formation

Mineralization



NPP

Run-off

Consumption

C_1

Litterfall

Decay

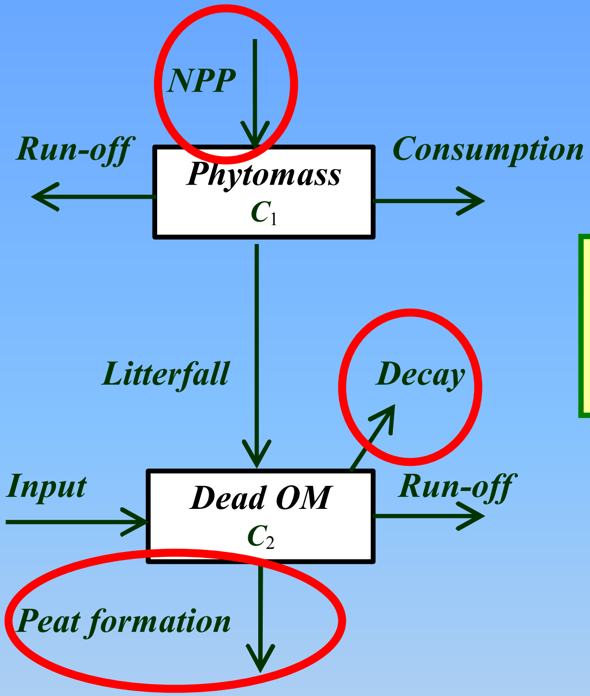
Input

C_2

Run-off

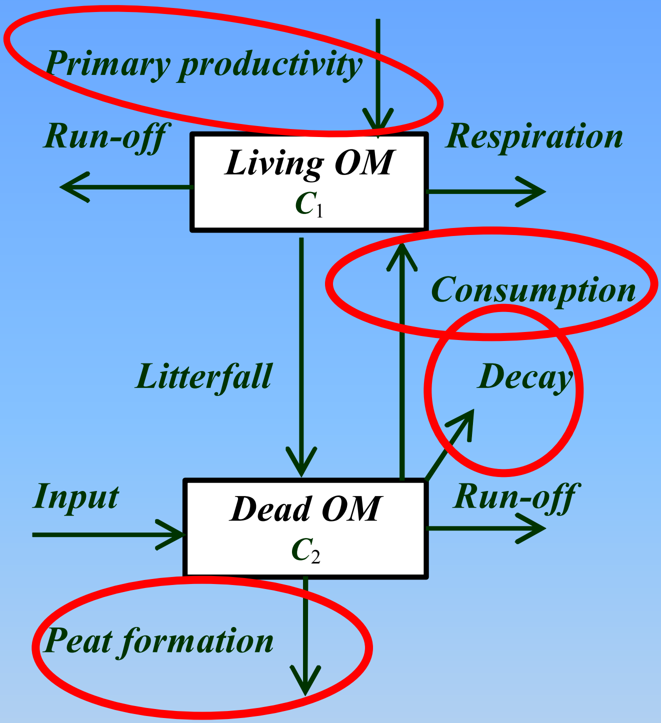
Peat formation

Simplest aggregated models of carbon cycle: feedbacks and critical flows



NPP functional form:

$$NPP = C_1 \quad (C_1)$$



Dynamic equations for the 2-component scheme:

1) $dC_1/dt = C_1 \quad (C_1) \quad m_1 C_1 \qquad {}_{12}C_1$

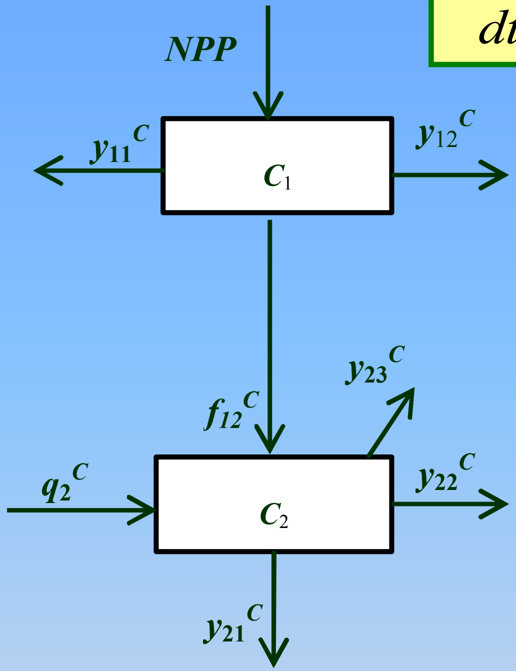
2) $dC_2/dt = q_2 \quad m_2 C_2 + \quad {}_{12}C_1$

Dynamic equations for the 2-component scheme with feedback:

1) $dC_1/dt = C_1 \quad (C_1) \quad m_1 C_1 \qquad {}_{12}C_1 + \gamma_{21} C_1 C_2$

2) $dC_2/dt = q_2 \quad m_2 C_2 + \quad {}^{C}_{12}C_1 - \gamma_{21} C_1 C_2$

NPP-phytomass relation in terrestrial ecosystems



$\frac{dC_1}{dt} = NPP \quad y_{12}^C \quad f_{12}^C \quad y_{11}^C$ - carbon balance equation for vegetation

$NPP = q_1^C \quad y_{11}^C$ - net primary productivity

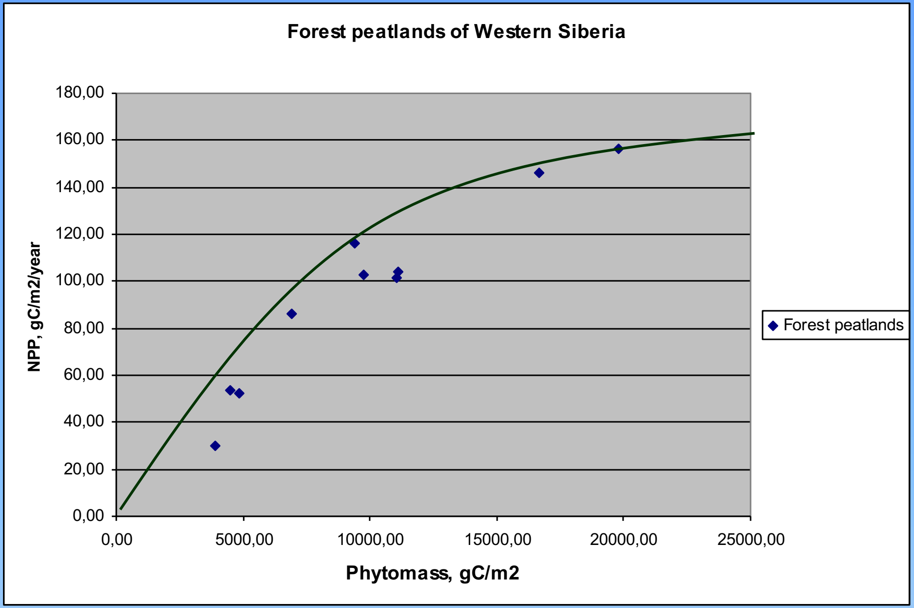
$NPP \quad const(C_1)$

$NPP \qquad {}_1C_1$

$$\lim_{C_1} NPP = const$$

In any mathematical model of biological turnover in terrestrial ecosystems on any time scale the equation for carbon balance of vegetation is strongly determined by functional form of the Net Primary Productivity - the difference between gross photosynthesis and autotrophic respiration.

NPP-phytomass relation in peatland ecosystems



Forest peatlands of Western Siberia:

Least-squared approximation by rational function in MatLab:

$$f(x) = \frac{p_0 x}{1 + r_1 x} \qquad R^2 = 0.8937$$

Peatlands of Western Siberia:

Least-squared approximation by rational function in MatLab:

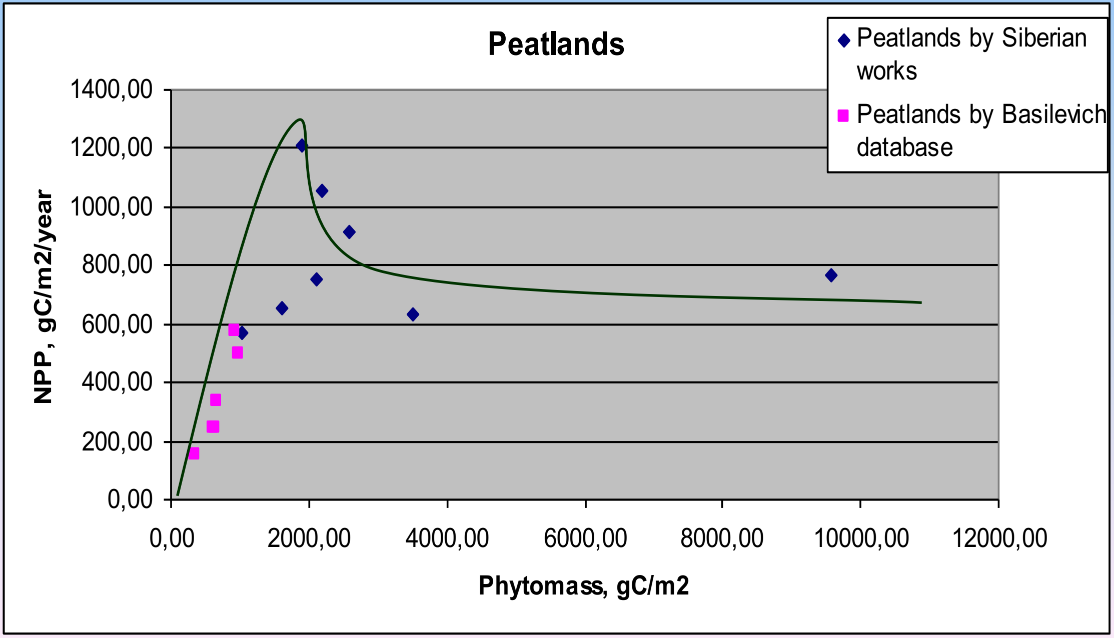
$$f(x) = \frac{x(p_0 + p_1 x)}{1 + r_1 x + r_2 x^2} \qquad R^2 = 0.7481$$

NPP functional form:

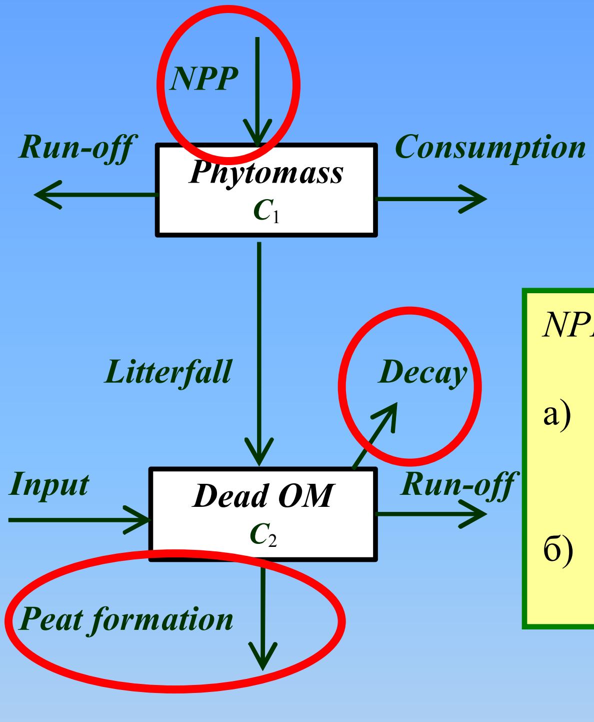
a) $$NPP = C_1 \frac{s_0}{1 + r_1 C_1} = C_1 \; {}_1(C_1)$$

б) $$NPP = C_1 \frac{s_0 + s_1 C_1}{1 + r_1 C_1 + r_2 C_1^2} = C_1 \; {}_2(C_1)$$

Data from (Efremov et al., 2007; Basilevich, Titlyanova, 2008; Golovatskaya et al., 2009; Kosykh et al., 2010).



Simplest aggregated models of carbon cycle: feedbacks and critical flows



NPP

Run-off

Phytomass
C_1

Consumption

Litterfall

Decay

Input

Dead OM
C_2

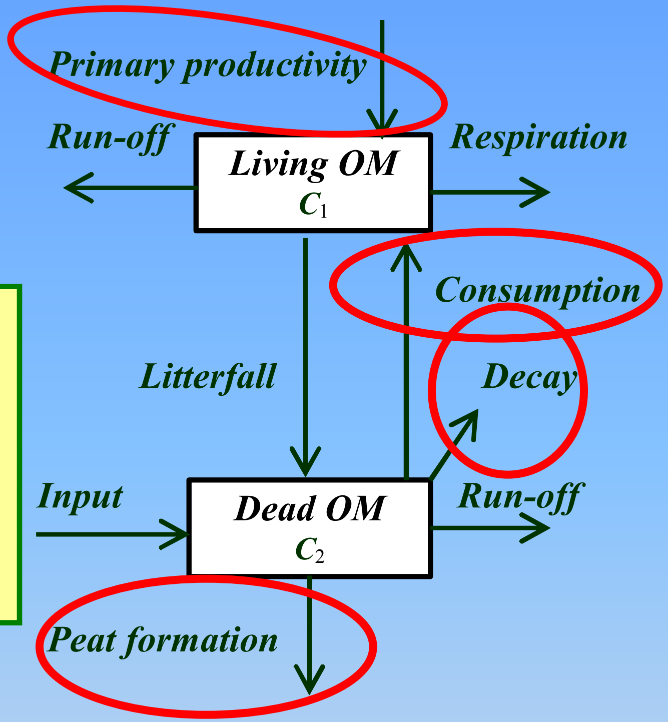
Run-off

Peat formation

NPP functional form:

а) $NPP = C_1 \frac{s_0}{1+r_1C_1} = C_1 \quad {}_1(C_1)$

б) $NPP = C_1 \frac{s_0+s_1C_1}{1+r_1C_1+r_2C_1^2} = C_1 \quad {}_2(C_1)$



Primary productivity

Run-off

Living OM
C_1

Respiration

Consumption

Litterfall

Decay

Input

Dead OM
C_2

Run-off

Peat formation

Dynamic equations for 2-component scheme:

1) $dC_1/dt = C_1 \frac{s_0}{1+r_1C_1} \quad m_1C_1 \quad {}_{12}C_1$

2) $dC_1/dt = C_1 \frac{s_0+s_1C_1}{1+r_1C_1+r_2C_1^2} \quad m_1C_1 \quad {}_{12}C_1$

$dC_2/dt = q_2 \quad m_2C_2 + \quad {}_{12}C_1$

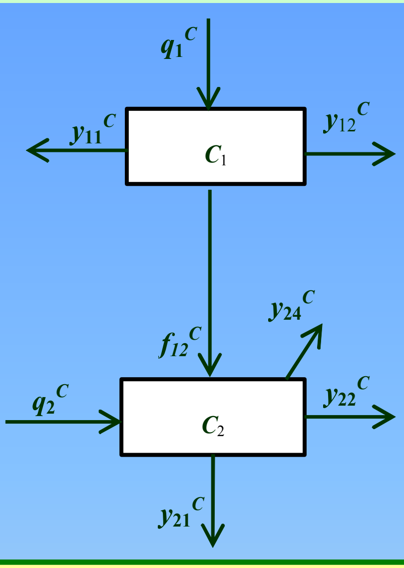
Dynamic equations for 2-component scheme with feedback:

1) $dC_1/dt = C_1 \frac{s_0}{1+r_1C_1} \quad m_1C_1 \quad {}_{12}C_1$

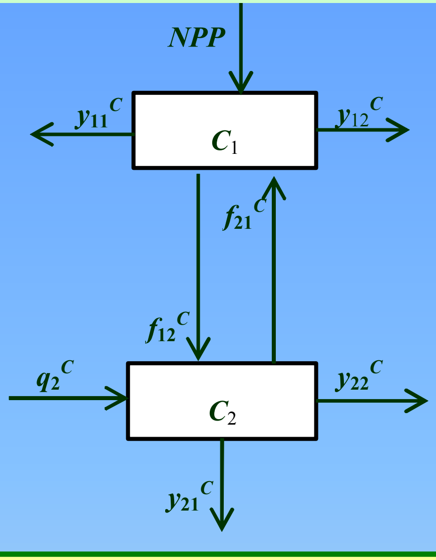
2) $dC_1/dt = C_1 \frac{s_0+s_1C_1}{1+r_1C_1+r_2C_1^2} \quad m_1C_1 \quad {}_{12}C_1$

$dC_2/dt = q_2 \quad m_2C_2 + \quad {}_{12}C_1$

Simplest aggregated models of carbon cycle: equilibria and stability



Equilibrium [0; q_2/m_2] belongs to all models



1) The only non-zero equilibrium

2) Up to two non-zero equilibria from a quadratic equation for C_1^*

1) Up to two non-zero equilibria from a quadratic equation for C_1^*

2) Up to three non-zero equilibria by qubic equation for C_1^*

Jacobi matrix for non-zero equilibria:

$$J = \begin{array}{cccc} \dfrac{NPP}{C_1} & m_1 & {}_{12} & 0 \\ & {}_{12} & & m_2 \end{array}$$

Stability condition for models 1) и 2):

$$\frac{NPP}{C_1} < m_1 + {}_{12}$$

Jacobi matrix for non-zero equilibria :

$$J = \begin{array}{cccc} \dfrac{NPP}{C_1} & m_1 & {}_{12} + {}_{12}C_1C_2 & {}_{21}C_1C_2 \\ & {}_{12} & {}_{21}C_2 & m_2 \quad {}_{21}C_1 \end{array}$$

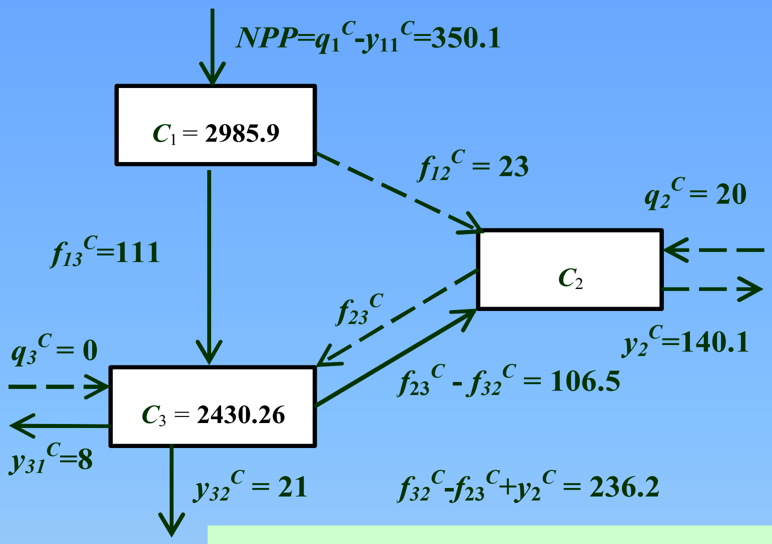
Neutrality condition (Hopf bifurcation):

$$m_2 + {}_{21}C_1^* + m_1 + {}_{12} = \frac{NPP}{C_1} + {}_{21}C_2^*$$

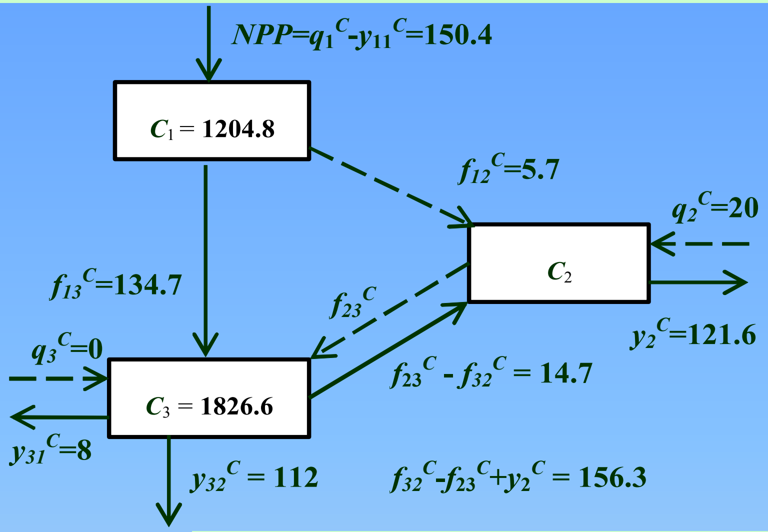
Node condition (saddle-node bifurcation):

$$(\frac{NPP}{C_1} \quad m_1 \quad {}_{12})(m_2 + {}_{21}C_2^*) = ({}_{12} \quad {}_{21}C_2^*) \; {}_{21}C_1^*$$

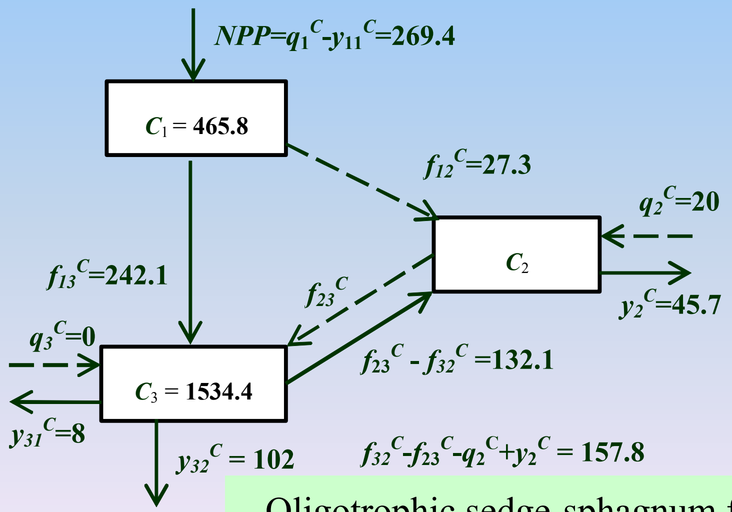
Two-component schemes of carbon cycle in peatland ecosystems of southern taiga in Western Siberia



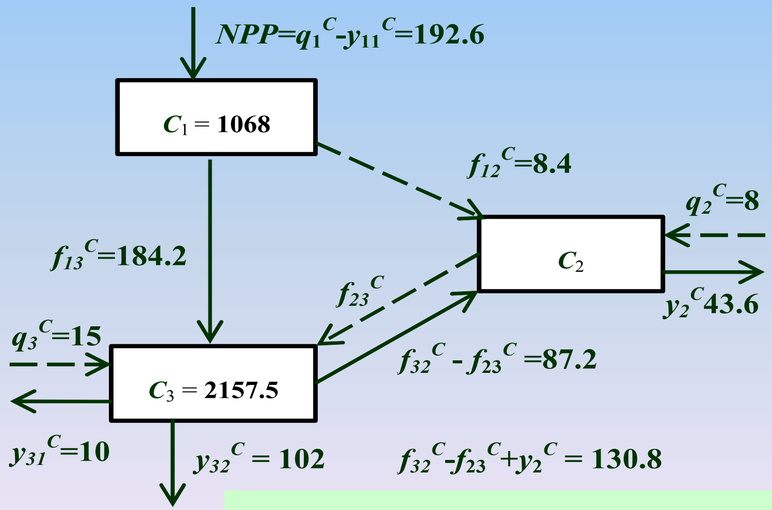
Oligotrophic pine-shrub-sphagnum



Oligotrophic low pine-shrub-sphagnum



Oligotrophic sedge-sphagnum fen

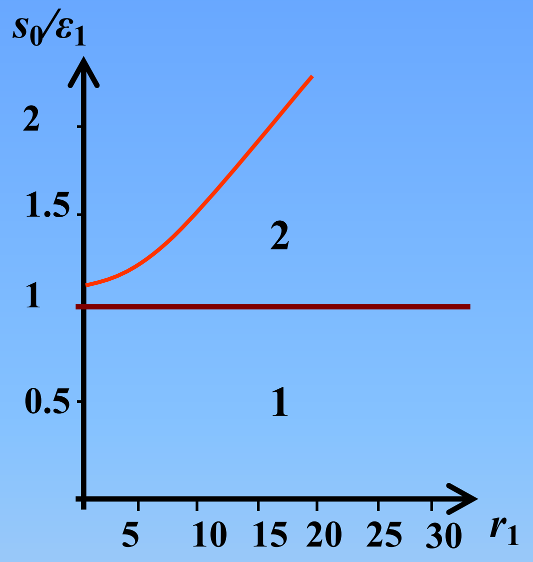


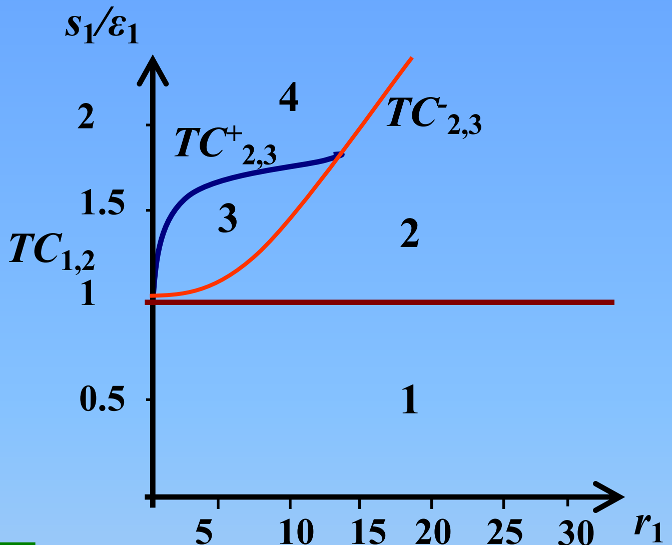
Eutrophic fen

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

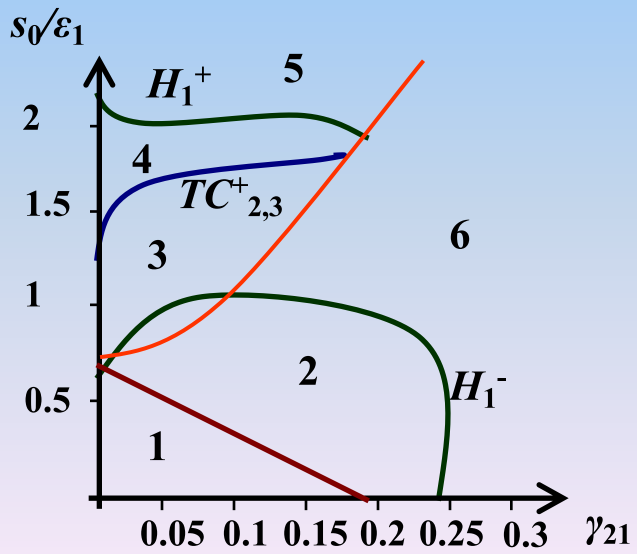
Data from (Golovatskaya, Dyukarev, 2009; Golovatskaya, 2010).

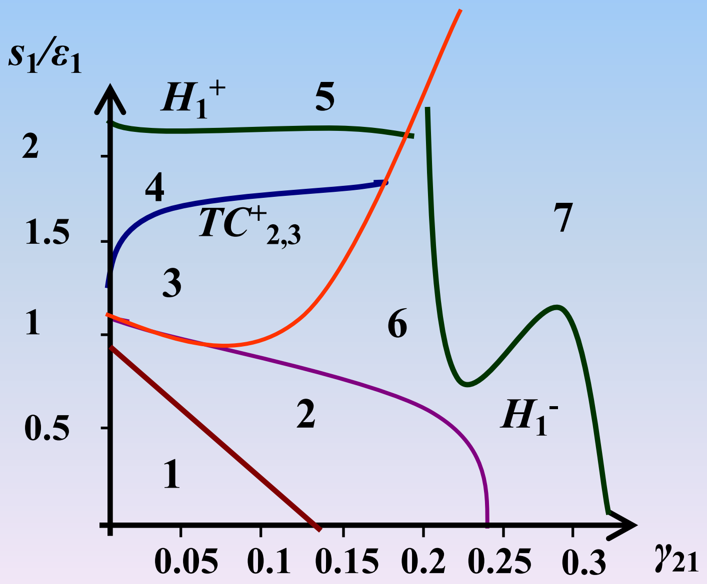
Dynamics of carbon cycle in southern taiga peatlands of Western Siberia



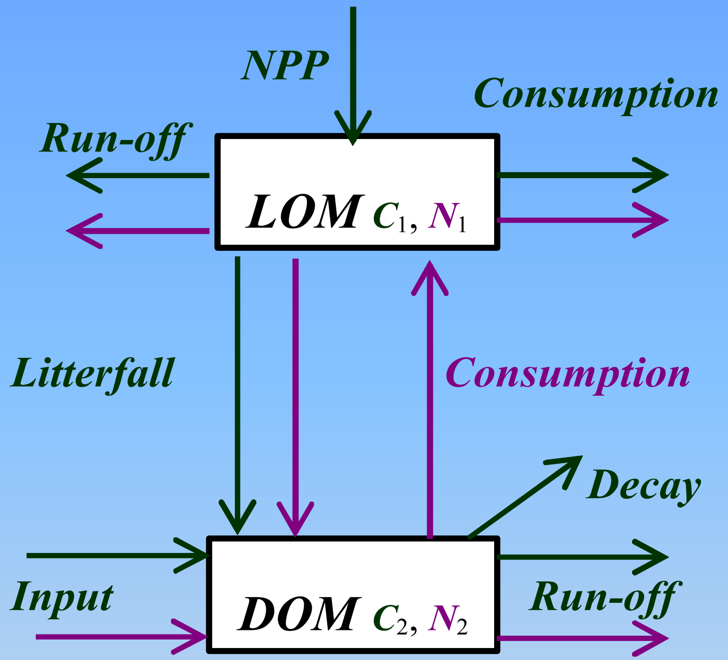


Stability domains





Modelling a combined carbon-nitrogen turnover in peatland ecosystems: biological mechanisms



LOM – living organic matter without consumers,

DOM – dead organic matter

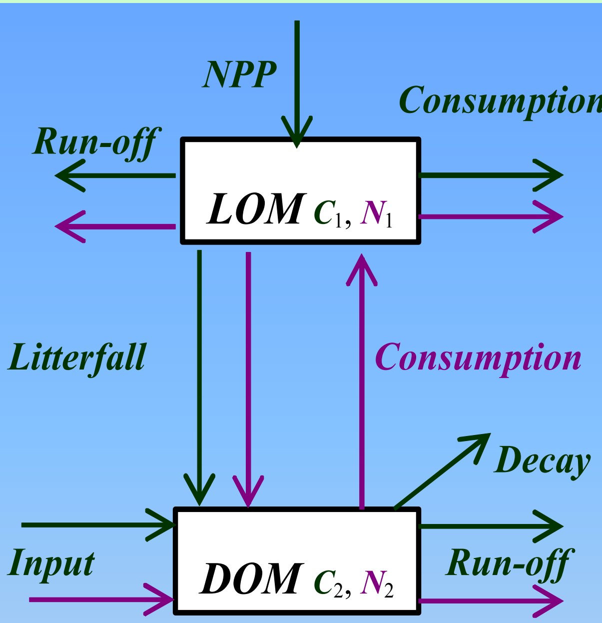
Carbon and nitrogen interaction is provided by two mechanisms

(Logofet, Alexandrov, 1984):

1) intensity of litterfall (f_{12}^C) is proportional to the C_1/N_1 ratio in the living phytomass that reflects nitrogen starvation of plants;

2) decay rate for dead organic matter decreases with the increase of C_3/N_3 ratio.

Modelling a combined carbon-nitrogen turnover in ecosystems: mathematical form



NPP

Consumption

Run-off

LOM C_1, N_1

Litterfall

Consumption

Decay

Input

DOM C_2, N_2

Run-off

Mathematical form for coupled *N-C* flows (Alexandrov et al., 1994):

1) Litterfall :

- **carbon** flow: $f_{12}^{C} = \quad {}^{C}_{12}\frac{C_1^2}{N_1}$, **nitrogen** flow: $f_{12}^{N} = \quad {}^{N}_{12}C_1$

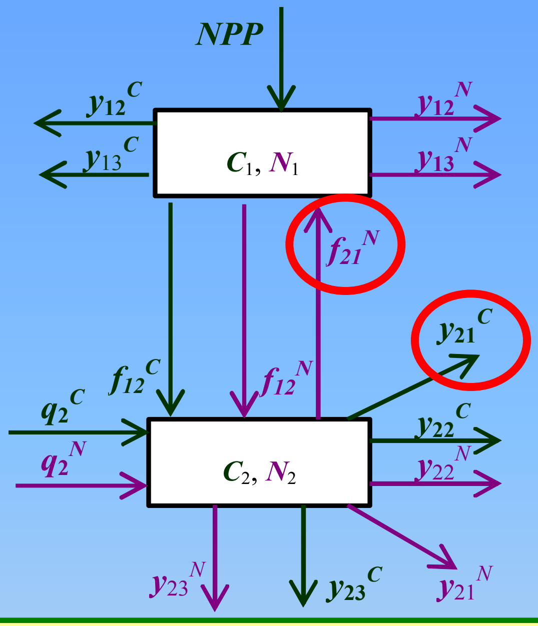
2) Decomposition of dead organic matter:

- **carbon** flow: $y_{21}^{C} = d_2^{C} N_2$, - **nitrogen** flow: $y_{21}^{N} = d_2^{N}\frac{N_2^2}{C_2}$

3) **nitrogen** uptake from soil by plants: $f_{21}^{N} = \quad {}^{N}_{21}\frac{N_2^2}{C_2}C_1$

4) NPP functional form: $NPP = C_1 \quad (C_1) f_{21}^{N}(C_2, N_2)$

Modelling a combined carbon-nitrogen turnover: dynamic equations



Dynamic model of combined carbon-nitrogen turnover :

$$dC_1 / dt = C_1 \quad (C_1) \quad {}^{N}_{21}\frac{N_2^2}{C_2} \quad {}^{C}_{13} \quad {}^{C}_{12}\frac{C_1}{N_1}$$

$$dN_1 / dt = \quad m_1^N N_1 \quad {}^{N}_{13}N_1 \quad {}^{N}_{12}C_1 + {}^{N}_{21}\frac{N_2^2}{C_2}C_1$$

$$dC_2 / dt = q_2^C \quad m_2^C C_2 \quad d_2^C N_2 + {}^{C}_{12}\frac{C_1^2}{N_1}$$

$$dN_2 / dt = q_2^N \quad m_2^N N_2 + {}^{N}_{21}C_1 \quad {}^{N}_{21}\frac{N_2^2}{C_2}C_1 \quad d_2^N \frac{N_2^2}{C_2}$$

Temperature dependent model parameters:

$NPP = NPP(C_a)$- NPP of vegetation increases under atmospheric CO_2 content C_a;

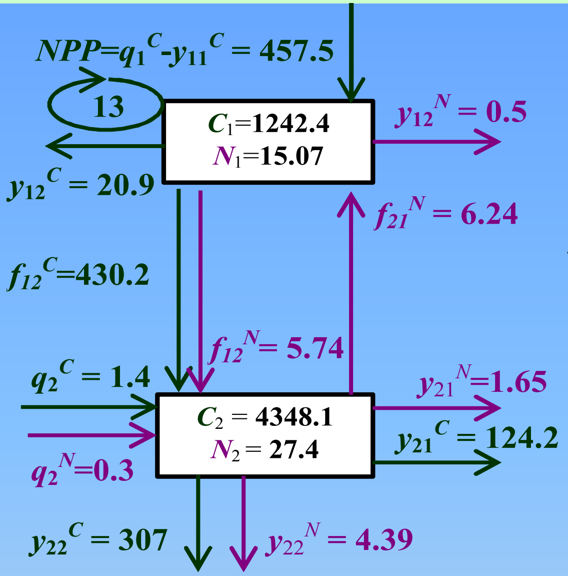
$m_2^C = m_2^C(T)$ – peat formation intensity;

$d_2^C = d_2^C(T,H)$ – 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

Two-component schemes of carbon and nitrogen cycles in peatland ecosystems of middle and southern taiga in Western Siberia



$NPP = q_1^C - y_{11}^C = 457.5$

13

$C_1 = 1242.4$
$N_1 = 15.07$

$y_{12}^N = 0.5$

$y_{12}^C = 20.9$

$f_{21}^N = 6.24$

$f_{12}^C = 430.2$

$f_{12}^N = 5.74$

$q_2^C = 1.4$

$y_{21}^N = 1.65$

$C_2 = 4348.1$
$N_2 = 27.4$

$y_{21}^C = 124.2$

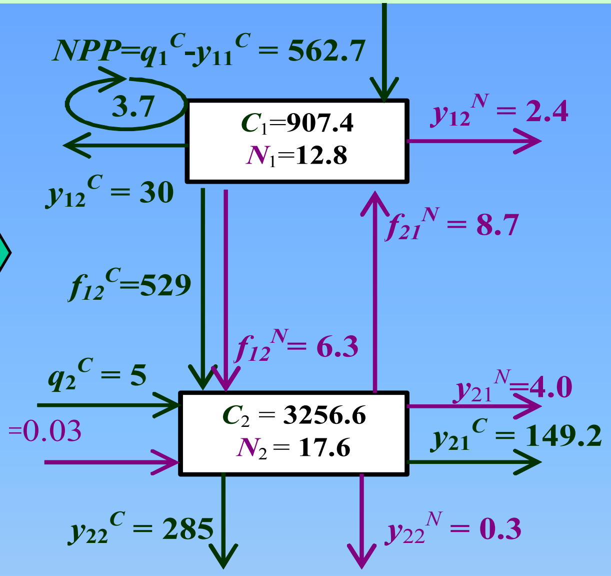
$q_2^N = 0.3$

$y_{22}^C = 307$

$y_{22}^N = 4.39$

Oligotrophic pine-shrub-sphagnum peatland (ryam)

Middle taiga



$NPP = q_1^C - y_{11}^C = 562.7$

3.7

$C_1 = 907.4$
$N_1 = 12.8$

$y_{12}^N = 2.4$

$y_{12}^C = 30$

$f_{21}^N = 8.7$

$f_{12}^C = 529$

$f_{12}^N = 6.3$

$q_2^C = 5$

$=0.03$

$y_{21}^N = 4.0$

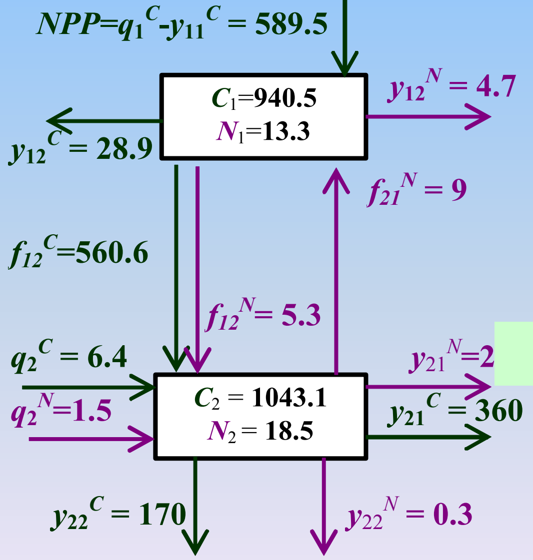
$C_2 = 3256.6$
$N_2 = 17.6$

$y_{21}^C = 149.2$

$y_{22}^C = 285$

$y_{22}^N = 0.3$

Mesotrophic sedge-sphagnum fen



$NPP = q_1^C - y_{11}^C = 589.5$

$C_1 = 940.5$
$N_1 = 13.3$

$y_{12}^N = 4.7$

$y_{12}^C = 28.9$

$f_{21}^N = 9$

$f_{12}^C = 560.6$

$f_{12}^N = 5.3$

$q_2^C = 6.4$

$y_{21}^N = 2$

$q_2^N = 1.5$

$C_2 = 1043.1$
$N_2 = 18.5$

$y_{21}^C = 360$

$y_{22}^C = 170$

$y_{22}^N = 0.3$

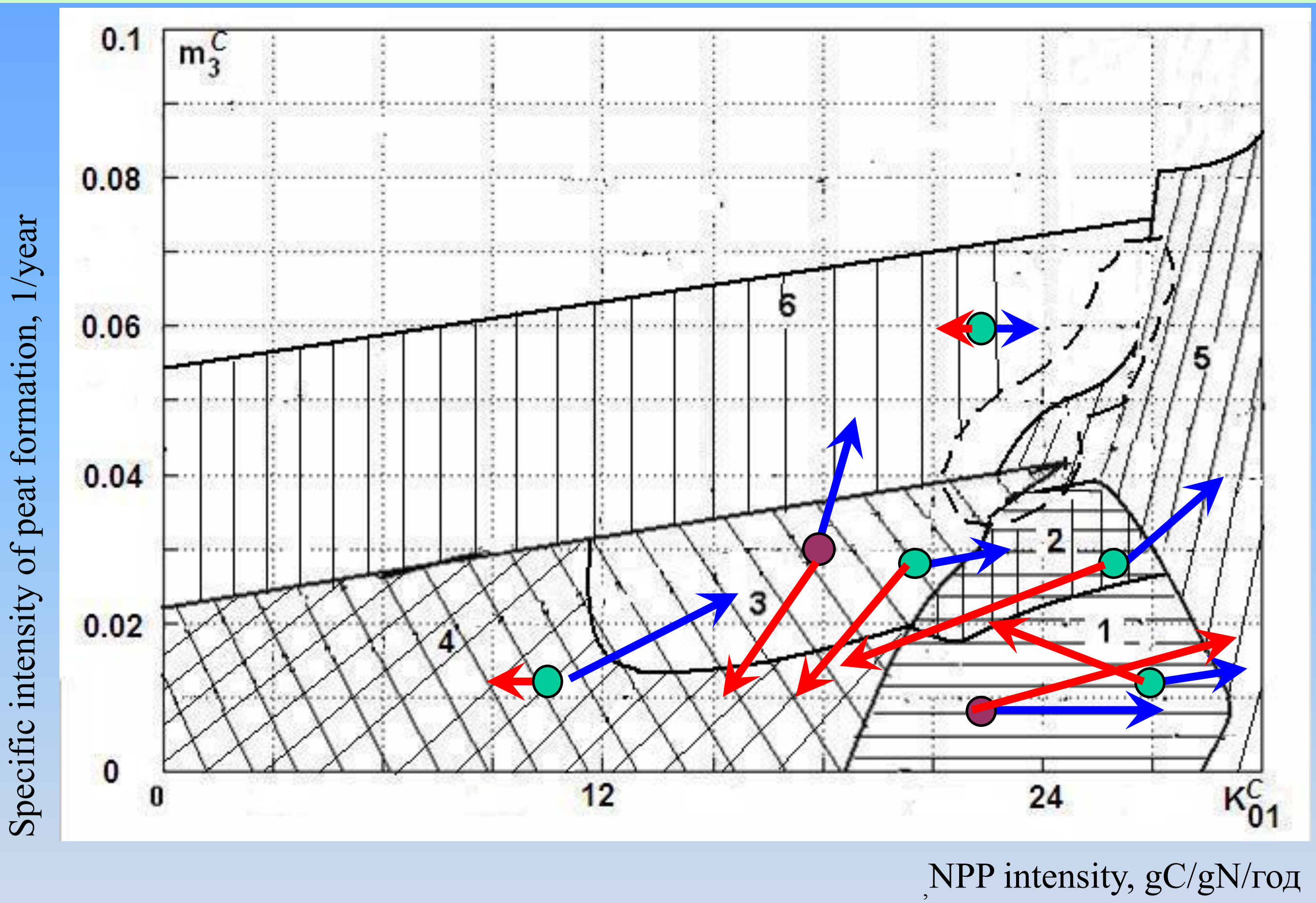
Mesotrophic sedge-shrub-sphagnum fen

Southern taiga

Storages - gC/m^2, gN/m^2,
flows - gC/m$^2\cdot$year, gN/m^{2}year.

Data from (Kosykh, Mironycheva-Tokareva, Parshina, 2010; Makhatkov, Kosykh, Romantsev, 2007; Makhatkov, Kosykh, 2010; Basilevich, Titlyanova, 2008).

Stability boundaries for steady states in models of a biotic turnover in peatlands of middle and southern taiga in Western Siberia



🟢 Southern taiga

🟣 Middle taiga

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:

1 – oligotrophic pine-shrub-sphagnum mire (“high ryam”); 2 – oligotrophic pine-shrub-sphagnum mire (“low ryam”); 3 – mesotrophic fen; 4 – oligotrophic fen; 5 – pine forest; 6 – eutrophic fen

Выводы

1) For peatlands from different regions various relations between NPP and phytomass can be obtained with equal requirements. They can be approximated by rational functions determining dynamics of the simplest two-component models of biological turnover;

2) Minimal aggregated models of separate carbon cycle can demonstrate a functional form impact for flow dependency but limited in estimation of turnover dynamics and equilibria although the model with feedback shows oscillatory dynamic regimes;

3) Nitrogen cycle inclusion even into the simplest scheme of the turnover allows to make calculation and interpretation of equilibria more effective and realize some feedbacks in the system;

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 “high ryam” of the middle taiga that can become forest due to sufficient nitrogen availability.

Спасибо за внимание !