Dynamic global vegetation models and their integration with remote sensing data

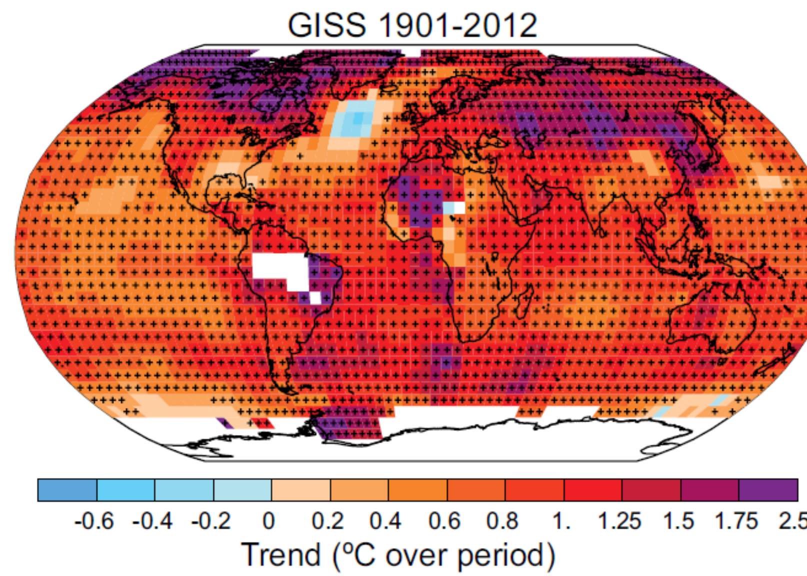
Khvostikov S.A.
khvostikov@d902.iki.rssi.ru
Space Research institute of
Russian Academy of Science

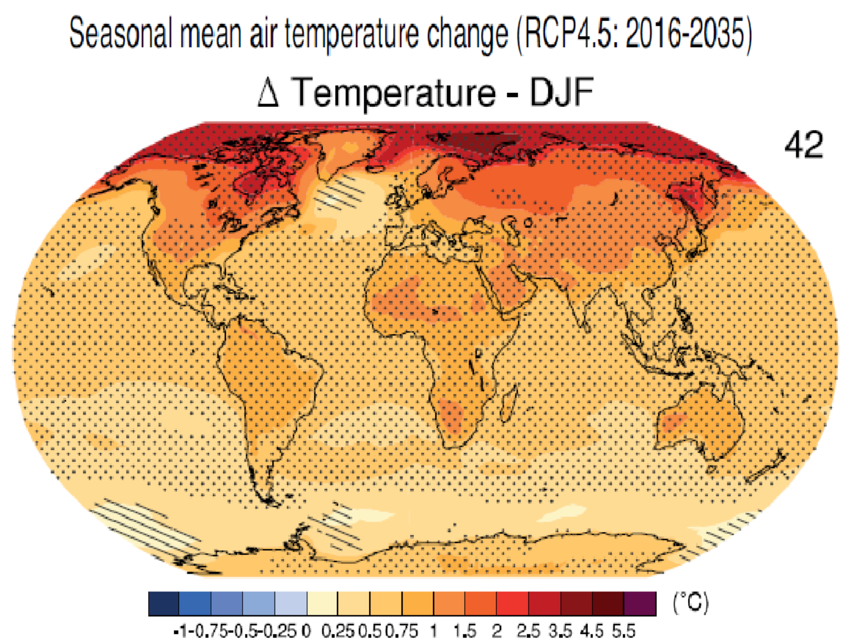
Global climate change

Observations and forecasts show significant changes in global climate.

Those changes are especially prominent in boreal areas.

To predict this change Earth System models are necessary.

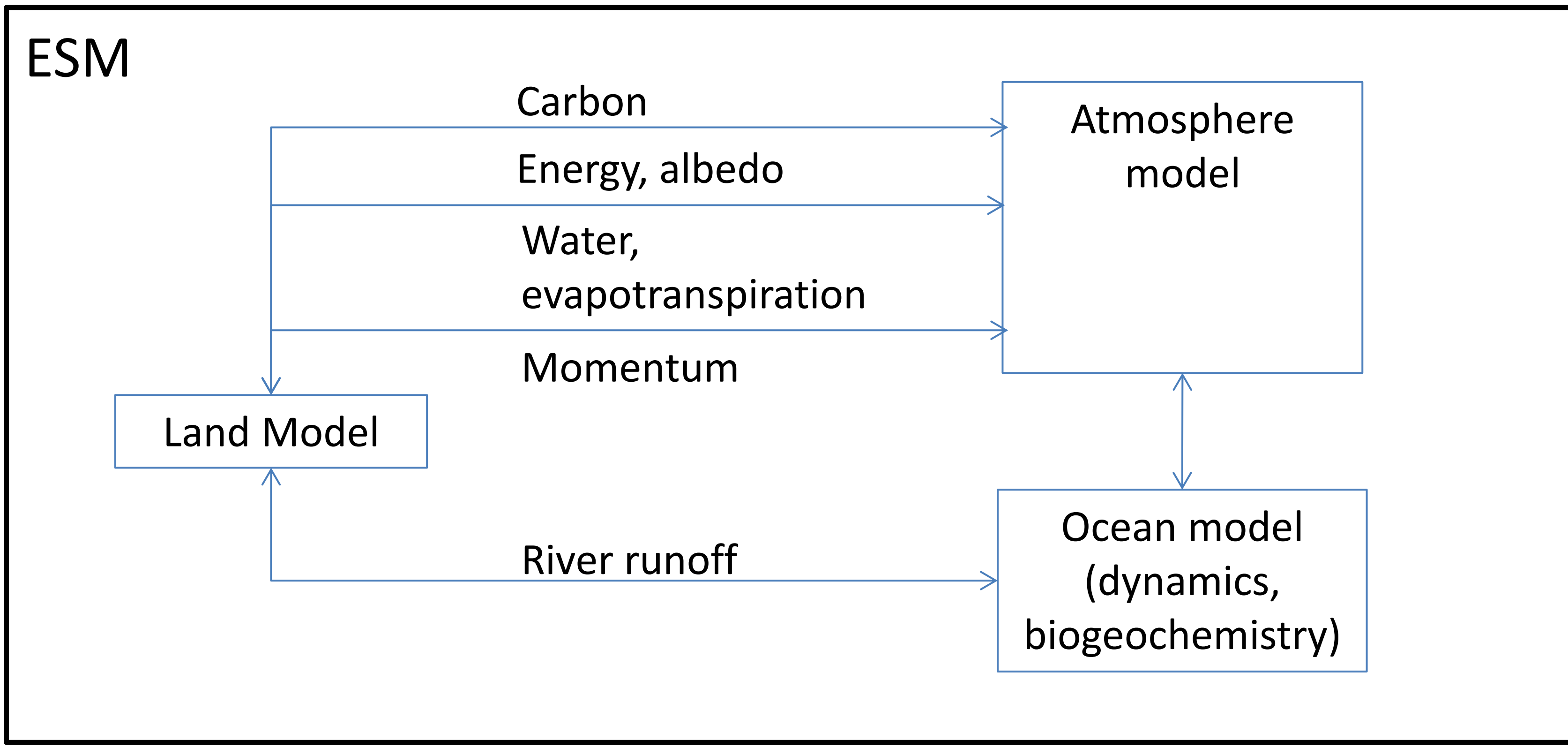




Stocker T. (ed.). Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. – Cambridge University Press, 2014.

Earth System Models

Earth system models have to account for all major (interconnected) components: atmosphere, ocean and land.



Land component of Earth Models

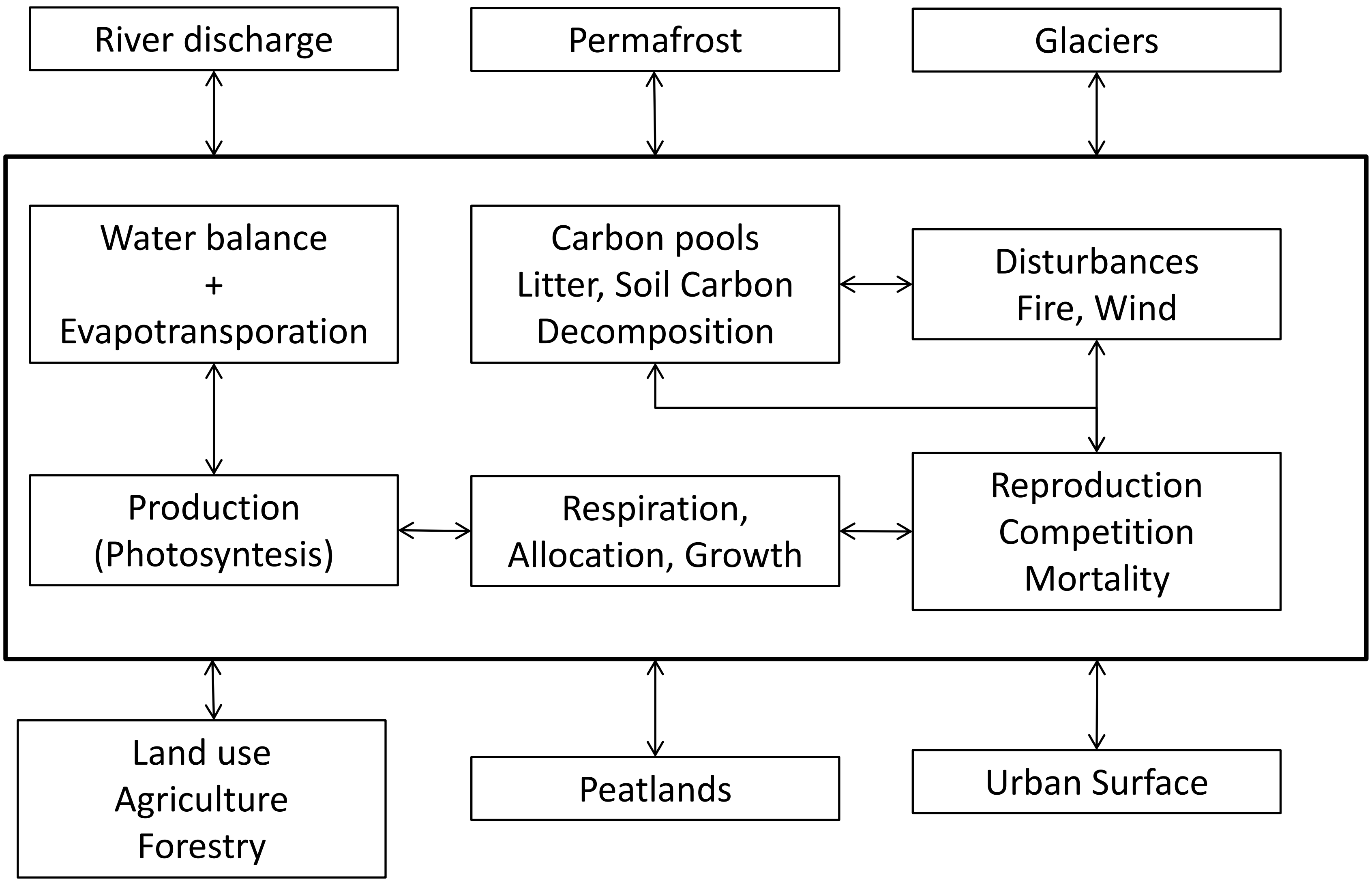
Many Earth System Models include sophisticated land surface models.

Lecture plan:

1. Land surface models. Dynamic global vegetation models.
2. Evaluation of DGVM with remote sensing data. Tuning of DGVM
3. DGVM in IKI

Land surface model	Earth system model	Institution	Country
ORCHIDEE	IPSL-CM6	IPSL	France
JSBACH	MPI-ESM	Max Planck Institute for Meteorology	Germany
	NESM (v.3)	NUIST	China
CLM (Community Land Model)	CESM		USA
	CMCC ESM	CMCC	Italy
	FGOALS		China
SEIB-DGVM	MIROC-ESM	MIROC	Japan
LPJ-GUESS	EC-Earth	SMHI + 26 institutes	Sweden + 9 European countries

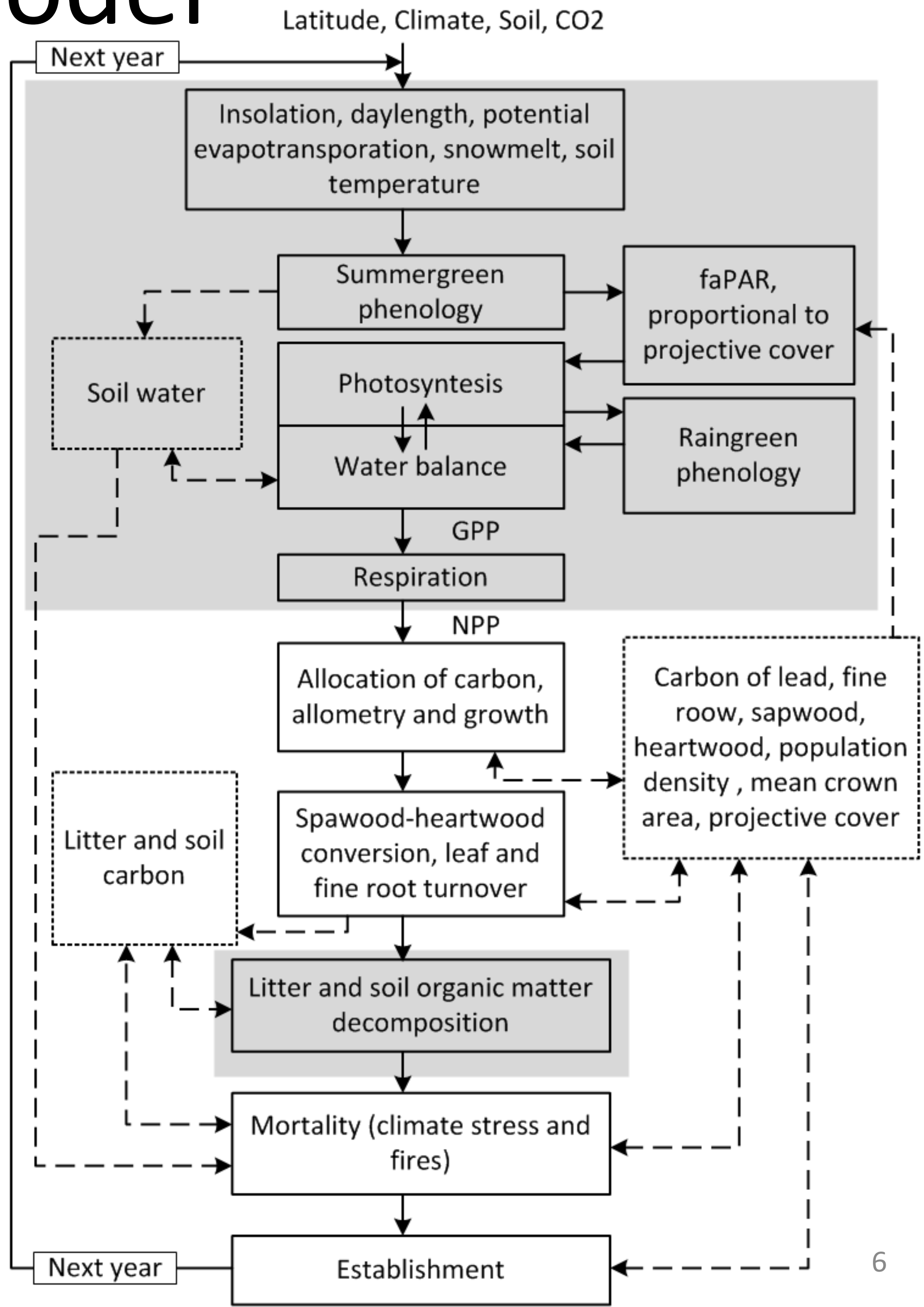
Land surface models



LPJ model

LPJ model will be used as an example of dynamic global vegetation model. Many other LSM imitate vegetation in similar way.

Was developed in a cooperation between 3 institutes in Lund, Postdam, Jena. Two major versions – LPJ-GUESS and LPJml4 (and many other modifications).



Schaphoff S. et al. LPJmL4–a dynamic global vegetation model with managed land–Part 1: Model description //Geoscientific Model Development. – 2018. – Т. 11. – №. 4. – С. 1343-1375.

Sitch S, Smith B, Prentice IC, Arneth A, Bondeau A, Cramer W, и др. Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model. Global Change Biology. 2003 г.;9(2):161–185.

LPJ model

Modelling is performed on the level of grid cells, with resolution of half degree (50 kilometers).

Models one individual plant of each Plant Functional Type (PFT) - boreal broadleaf forest, evergreen needle-leafed forest, herbaceous grasses etc.

Starts with bare soil, plant a bit of every PFT in each cell, perform spin-up for hundreds of years with historical climate.

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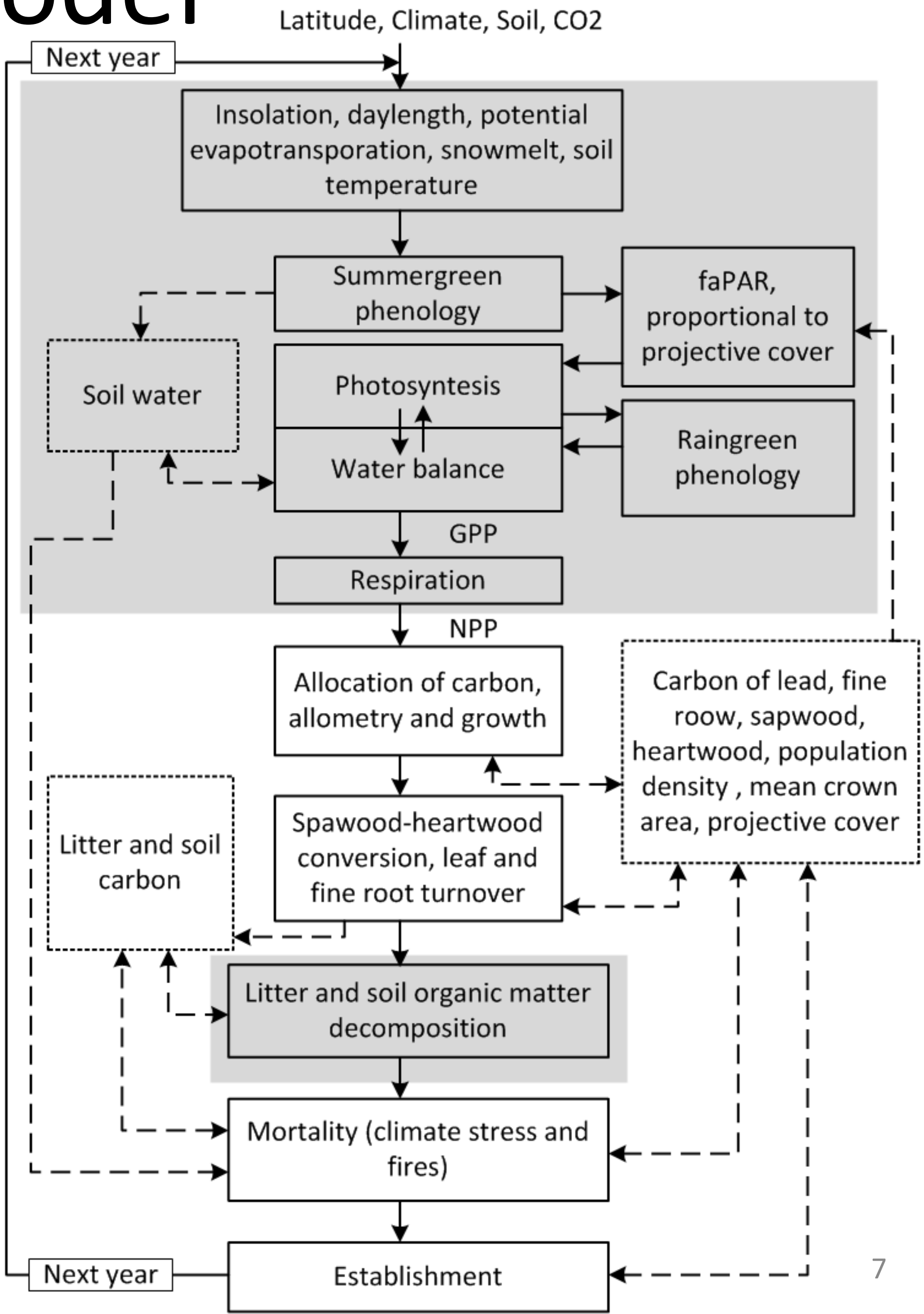
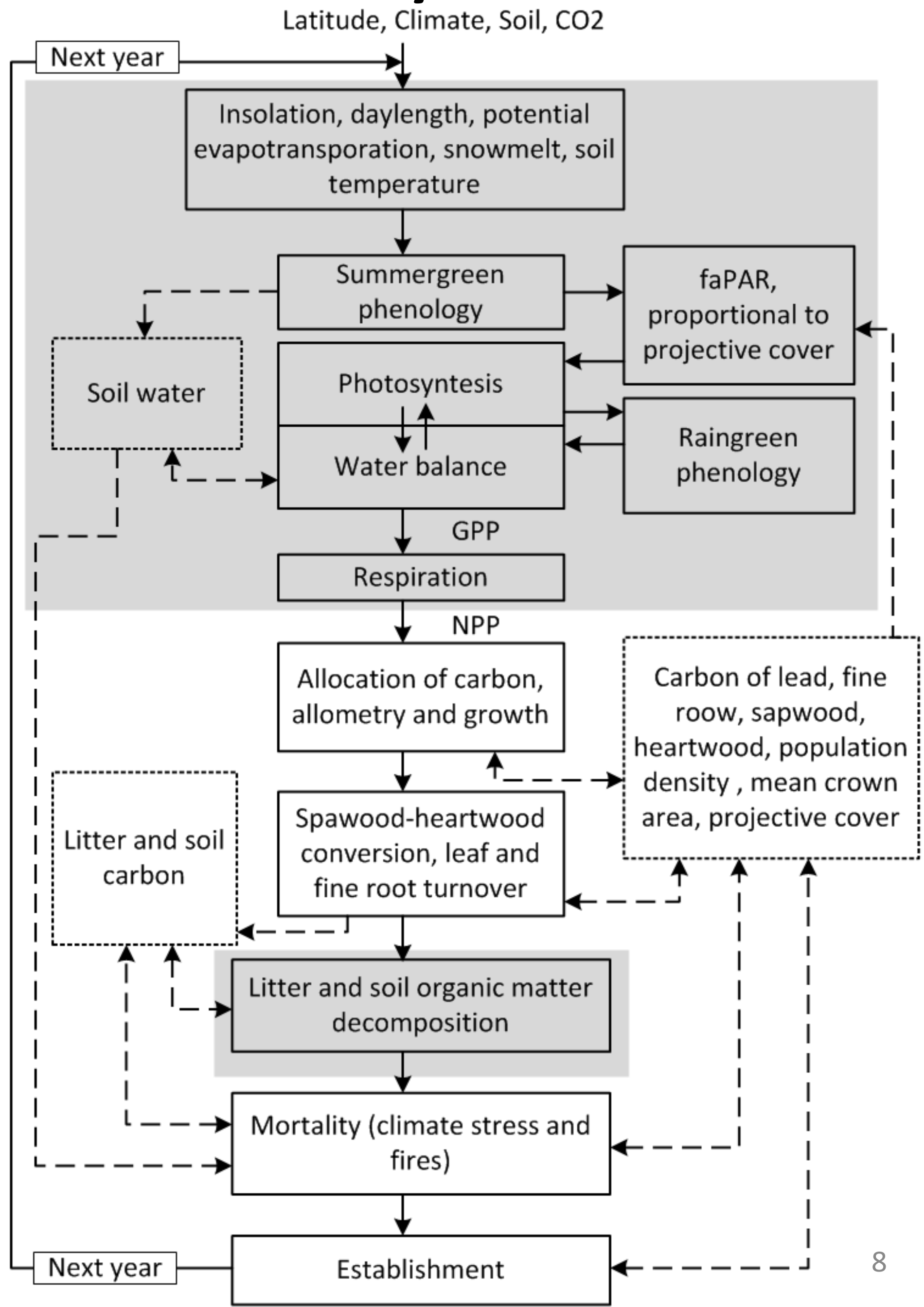


Evapotranspiration, Photosyntesis

POTENTIAL EVAPOTRANSPIRATION – evaluated from air temperature and net radiation. NET RADIATION – from temperature, albedo and cloudiness.

HYDROLOGY – models multiple soil layers, accounts for infiltrating rainfall, percolation, runoff.

PHOTOSYNTESIS – depends on absorbed PAR, temperature, daylength, canopy conductance, phenology. Provides assimilation and real evapotranspiration (accounting for soil moisture).

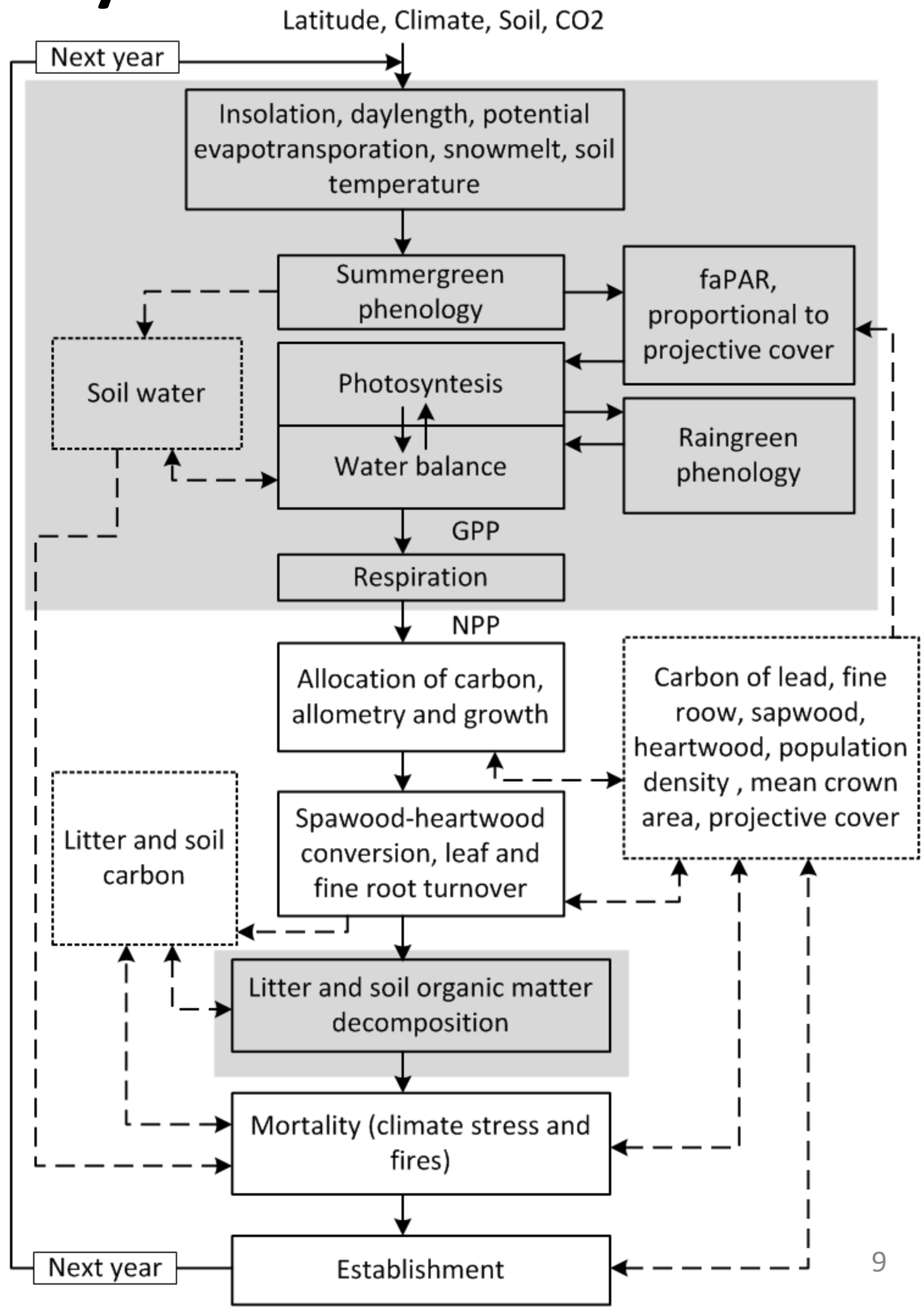


Vegetation dynamics

ALLOCATION - Each PFT has multiple tissue pools (leaves, fine roots, sapwood, heartwood). Respiration and reproduction costs are subtracted from assimilated carbon, remainder is allocated to pools according to allometric equaltions.

GROWTH – Change in pools will affect average individual, increasing its size and projective cover. Reproduction will establish new saplings each year and change density of individuals of this PFT (and decrease average pools). Total carbon and fraction in cell depends on both individual plant pools and density.

MORTALITY – Each PFT is affected by background yearly mortality, mortality from climatic stresses, or from disturbances (fires). Also part of each tissue dies off every year.

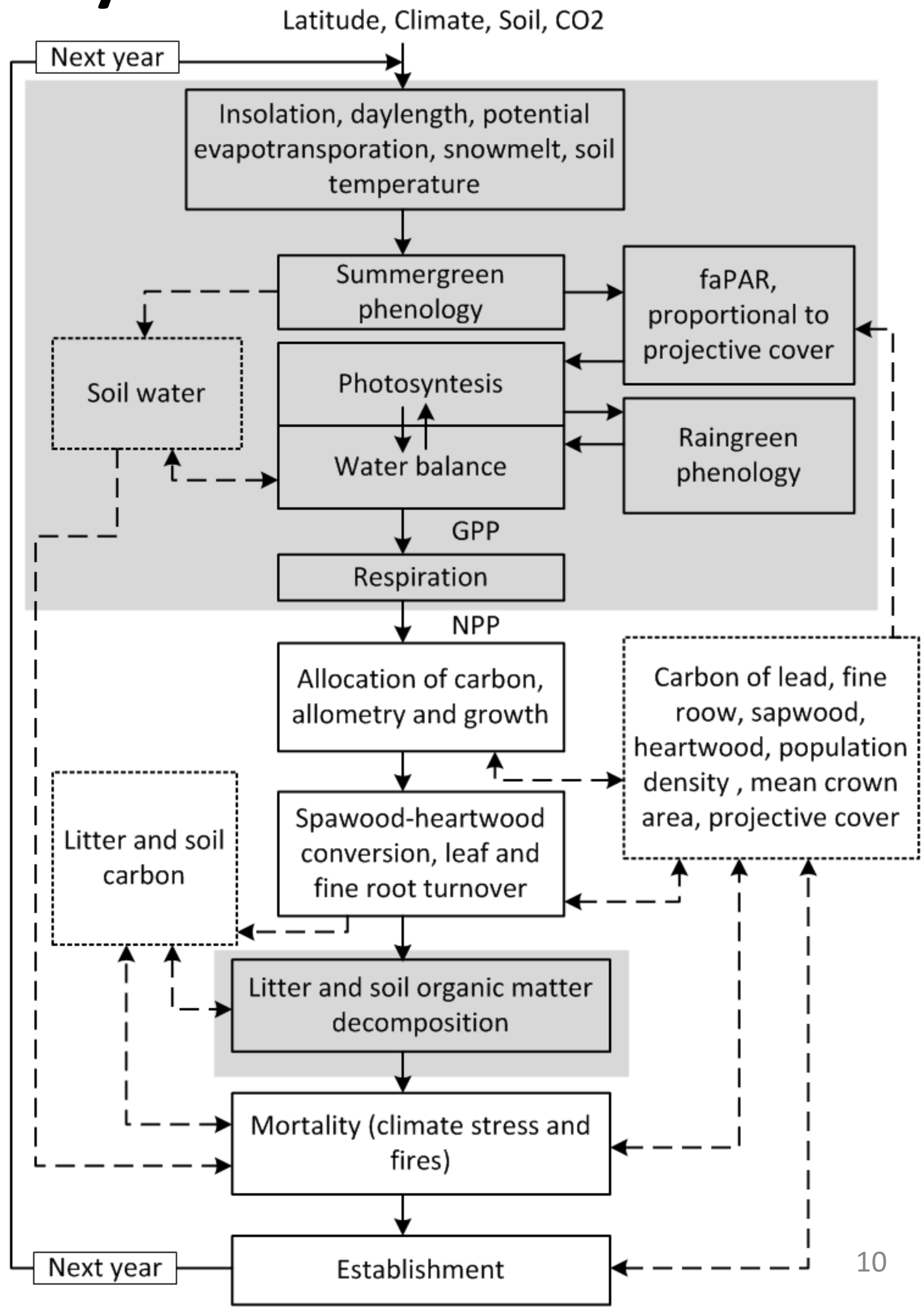


Vegetation dynamics

LITTER, DECOMPOSITION – Dead plants and tissues are added to multiple litter pools – above ground and two below ground pool. Dead matter carbon decompose and return to atmosphere, rate of decomposition depends on pool.

COMPETITION – ALL PFTs compete to claim free space in cell, more productive types have advantage in competition.

BIOCLIMATIC LIMITS - Model uses bioclimatic limits to restrain spread of PFT – limits on minimum and maximum temperatures of coldest/warmest months, limits on temperature during important stages of development etc.



Other processes

WILDFIRES – separate evaluation of fire risk, ignition, spread and effect. Remove above ground soil litter and can cause tree mortality.

LAND USE – accounts for croplands and managed forests. Prescribed part of cell taken by land use, optimal type of crop depends on climate.

OTHER PROCESSES include:

- Permafrost
- River discharge
- Irrigation and dams

Some recent developments

Attempts to move beyond bioclimatic limits – towards process based limits, that accounts for physiology of plants.

Attempts to model plants demographics. Two major approaches – modeling on the level of cohorts or individuals. Helps to better model disturbances and light competition.

Examples of models that include explicit modeling of plant demographics – CLM, LPJ-GUESS, SEIB-DGVM.

For more details:

Fisher RA, Koven CD, Anderegg WRL, Christoffersen BO, Dietze MC, Farrior CE, и др. Vegetation demographics in Earth System Models: A review of progress and priorities. Glob Change Biol. январь 2018 г.;24(1):35–54.

Validation of DGVM

DGVM produce large number of outputs, each one can be validated (using remote sensing data if available).

Methods of analysis include:

- Visual analysis, analysis of disagreement;
- Simple criteria: RMSE, correlation, bias;
- Analysis of timeseries in each cell;
- Taylor diagrams.

Output of DGVM
Fraction of PFT in cell (Land cover)
Carbon stocks, fluxes
NPP, GPP
FAPAR
LAI
Evapotranspiration
Albedo
Phenology
Soil moisture
Burnt area
River discharge
…

Tuning of DGVM

Parameters of Vegetation models can be tuned to better match observations;

Tuning can be performed by optimisation of criteria from previous slide;

One run of model can take 24 hours, tuning multiple parameters can be difficult;

Sensitivity analysis can be used to choose parameters for optimisation.

SEVER model at IKI

SEVER is one of modifications of original LPJ model.

We performed comparison and tuning of SEVER using our land cover maps.

Landcover map was converted to model PFTs. Typically it is done by so called cross-walking tables, which associate particular percentage of PFT with each land cover type.

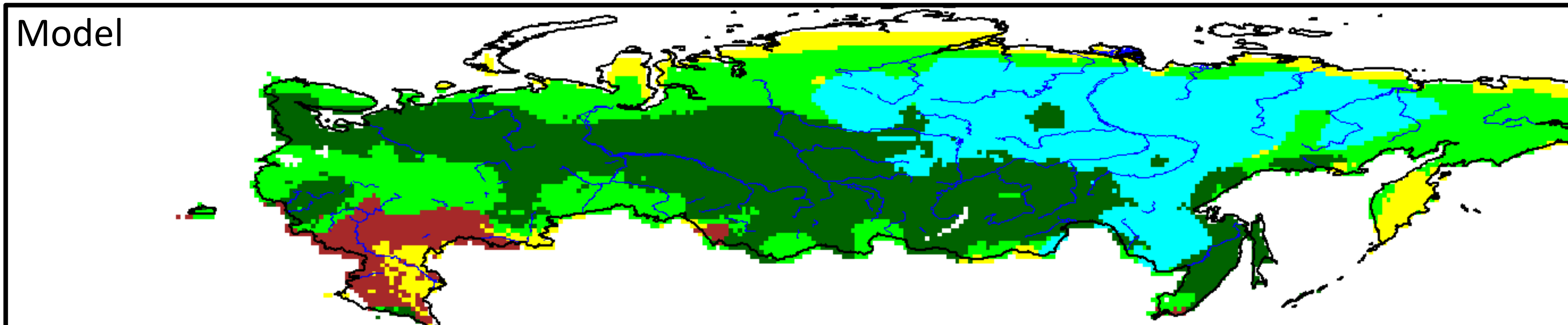
Land cover was aggregated to model resolution (0.5 degrees)

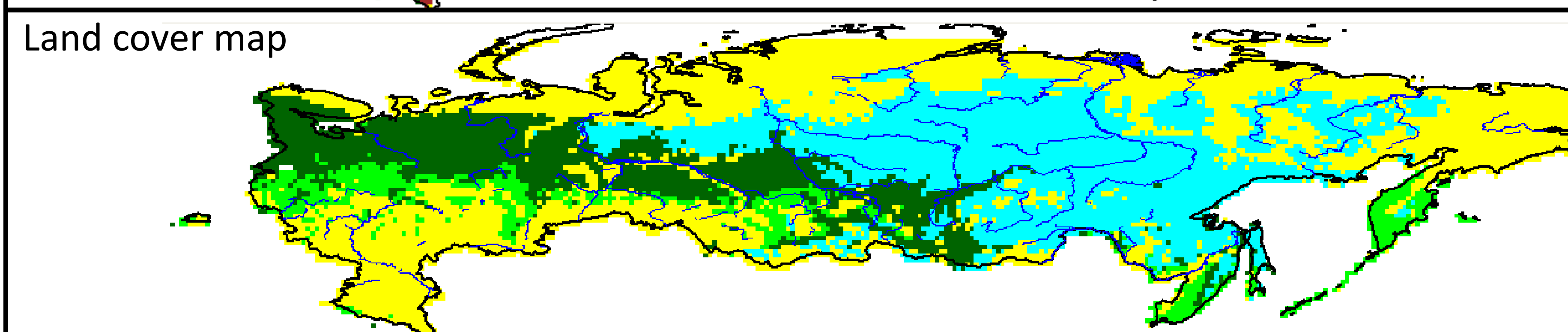
For more details:
Khvostikov S., Venevsky S., Bartalev S. Regional adaptation of a dynamic global vegetation model using a remote sensing data derived land cover map of Russia //Environmental Research Letters. – 2015. – Т. 10. – №. 12. – С. 125007.

Mapping and modelling results

Dominant land cover	Boreal evergreen needleleaved	Boreal deciduous needleleaved	Boreal broadleaved	Temperate broadleaved	Herbaceous	Quality criteria (Q)
Map color						
Correlation coefficient	0,48	0,39	0,0	-	0,34	0,50

$Q = \sum_i \mathrm{corr}(X_i^{\mathrm{map}}, X_i^{\mathrm{model}})^2$ i – land cover type, correlations is weighted by cell area.





Modification of vegetation model

Following processes were modified:

Light competition

Vegetation cover should not exceed size of a cell:

$$P_{t0} + \Delta P_{t0} = P_{t1} \leq 1.0$$

Model used correction coefficient R

$$\Delta P = \sum_i R \Delta P_i \quad R = \frac{(1 - P_{t0})}{\sum_i \Delta P_i}$$

Added height of a tree $\Rightarrow$

$$\Delta P = \sum_i C \omega_i \Delta P_i$$

$$C = \frac{(1 - P_{t0})}{\sum_i \omega_i \Delta P_i}$$

$$\omega_i = A^{\frac{(h_i - \bar{h})}{\bar{h}}}$$

$$\bar{h} = \sum_{i=1}^{n} h_i / n$$

A Empirical constant

h_i Height of average individual

Tundra imitation

When following condition is met: $\Pi \geq 0,5; \; \Pi = f(x_{SNOW}) * (1 - f(x_{TEMP})) * f(x_{WIND})$

Woody vegetation in this cell removed

$$f(x) = \begin{cases} 0 & , \quad x < X_{\min} \\ \dfrac{(x - X_{\min})}{(X_{\max} - X_{\min})} & , \quad X_{\min} \leq x \leq X_{\max} \\ 1 & , \quad X_{\max} < x \end{cases}$$

Параметр	Xmin	Xmax
x_{SNOW} ,м	0	0,1
x_{TEMP} ,C°	-35,4	-12,2
x_{WIND} ,м/с	1,875	5,46

Temp-erature correction

Air temperature is corrected according to following formula

$$T_{corr} = T - 0,6 * \Delta H$$

where ΔH is a maximum elevation difference inside cell

Tuning of vegetation model

Optimisation methods were used to tune 12 model's parameters, including:

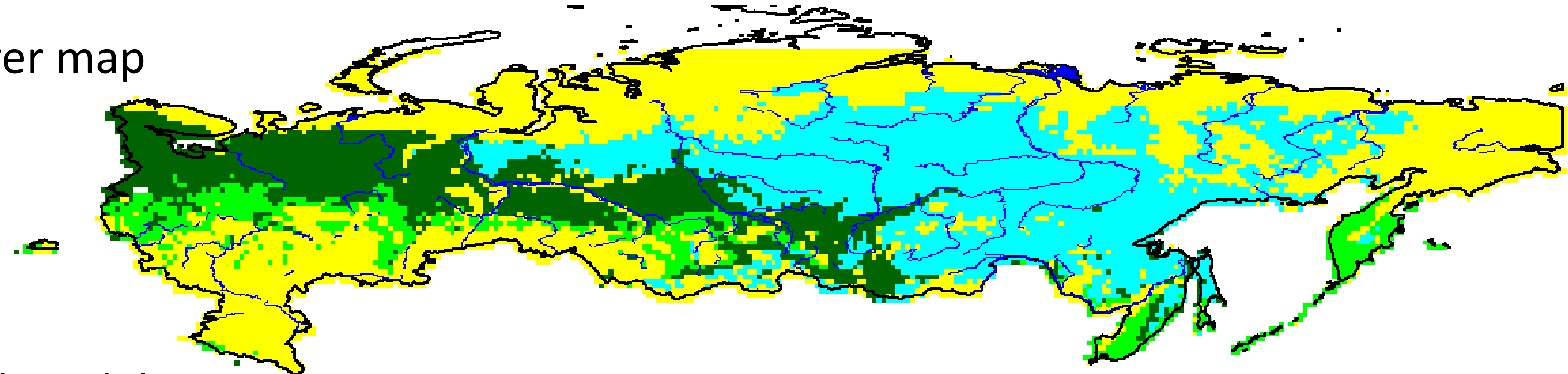
- bioclimatic limits for all major vegetation types in Russia, to tune their spatial distribution;

- empirical coefficients, introduced in model modifications.

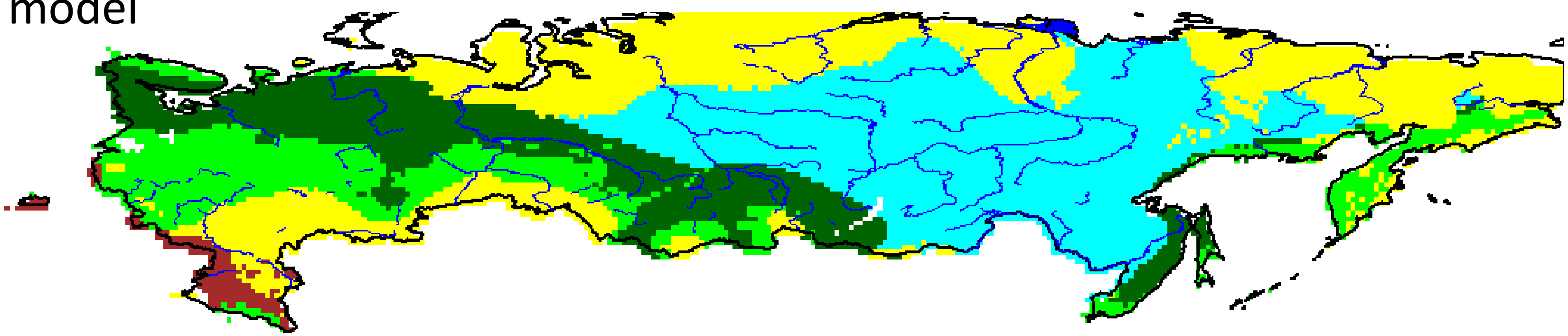
Model parameters			Original value	Tuned value
Decidious needleleaved continental index			43	36,6
Min temperature, C°	coldest month	Temperate broad-leaved	-17	-18,9
		Boreal broad-leaved	-50	-24,4
		Boreal deciduous needle-leaved	-50	-42,5
		Boreal evergreen needle-leaved	-32,5	-27,3
Max temperature, C°		Boreal evergreen needle-leaved	-2	-0,5
		Boreal broad-leaved	-2	-12,8
	hottest month	Boreal evergreen needle-leaved	23	24,5
		Boreal broad-leaved	23	22
Temperature reduction with height coefficient, C°/km			0	0,011
Light competition coefficient			1	10e4
Decidious needleleaved SLA modifier			1	0,69

Improvements in modeled vegetation distribution

Land cover map

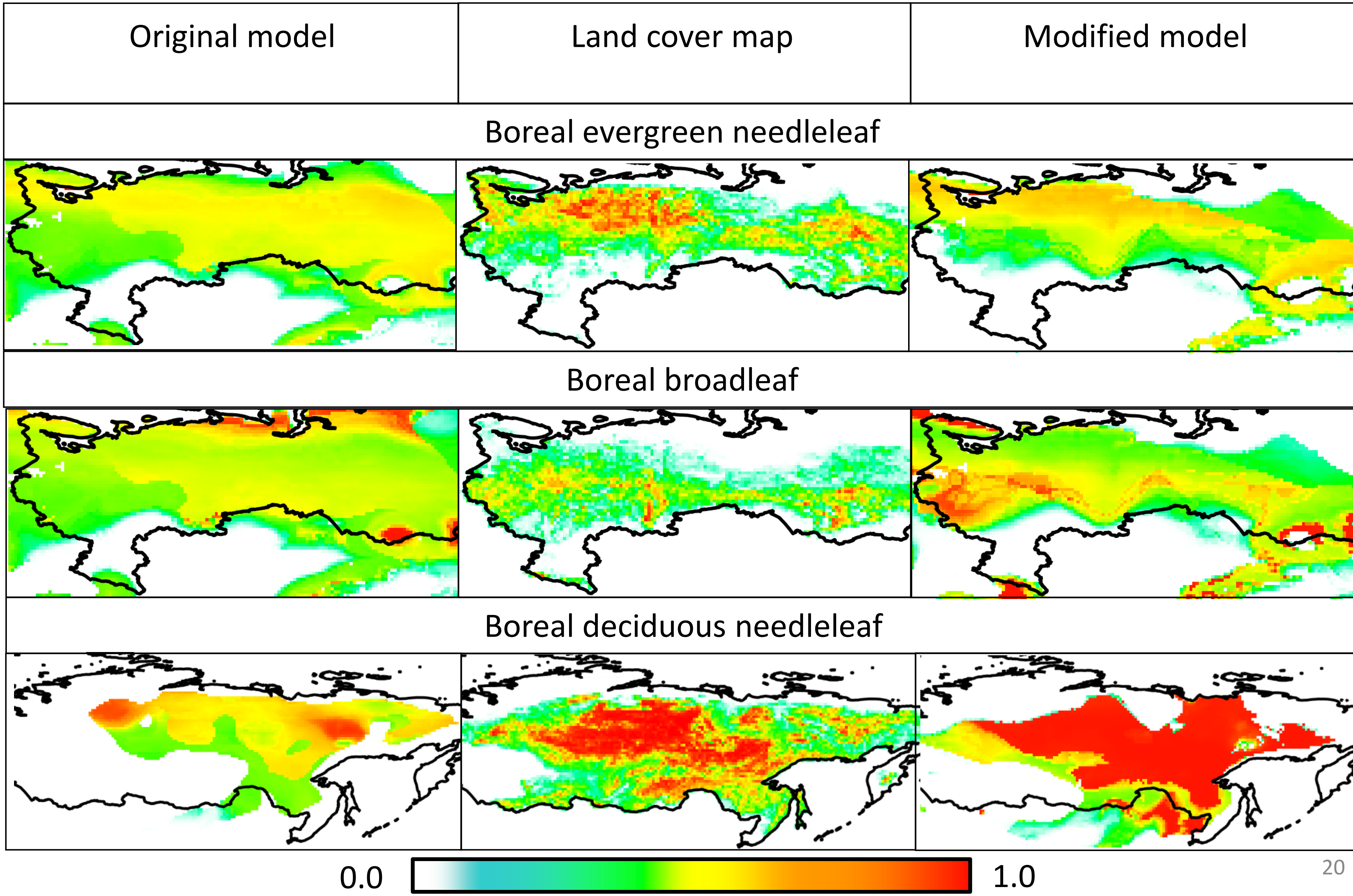


Modified model



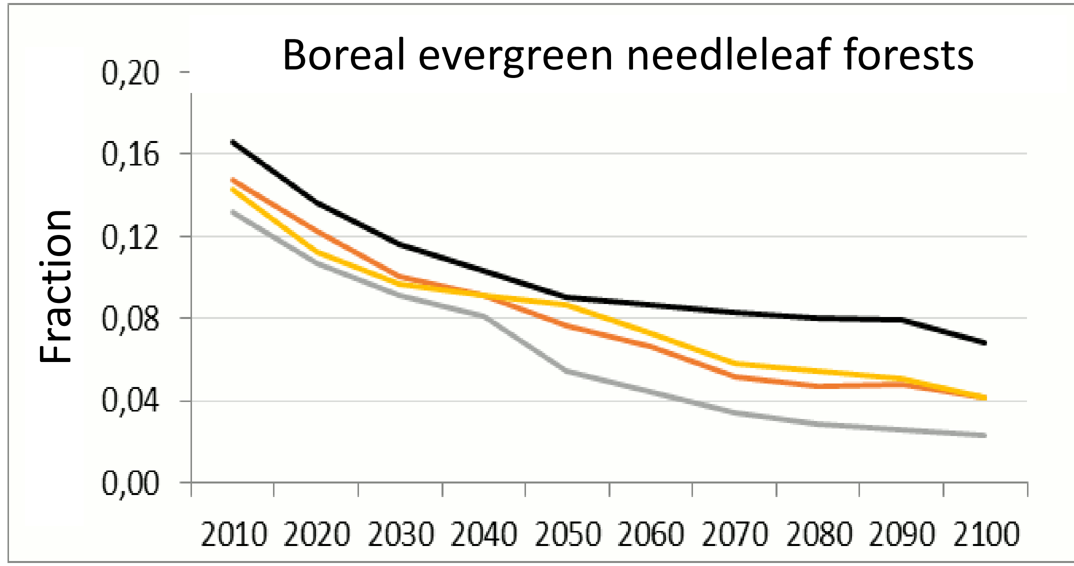
Dominant land cover	Boreal evergreen needleleaved	Boreal deciduous needleleaved	Boreal broadleaved	Temperate broadleaved	Herbaceous	Quality criteria (Q)
Land cover						
Original model, correlation	0,48	0,39	0,0	-	0,34	0,50
Modified model, correlation	0,55	0,60	0,42	-	0,50	1,09

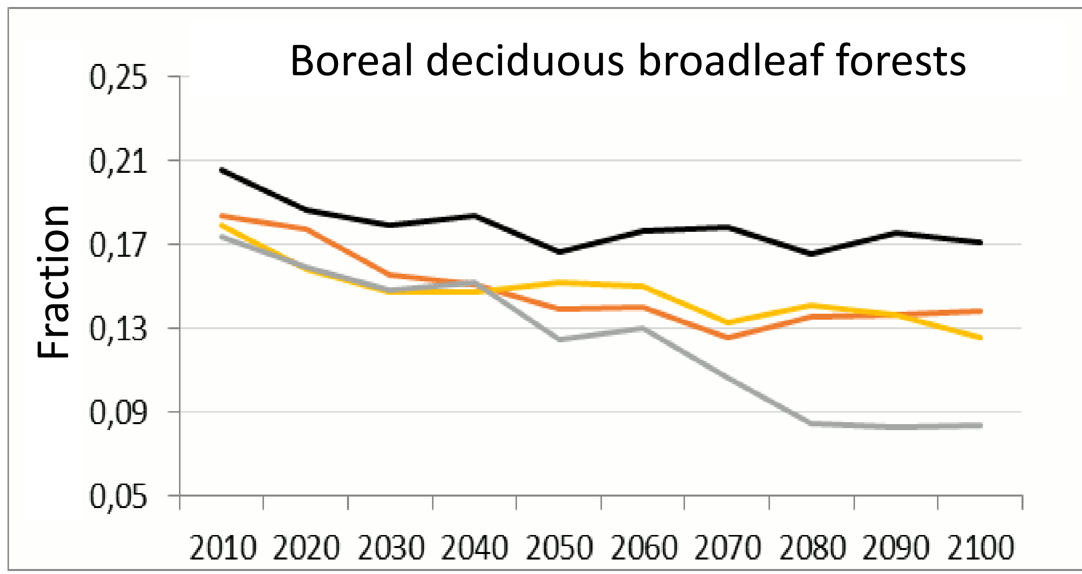
Improvements in modeled vegetation distribution

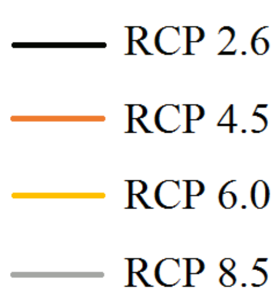


Vegetation dynamic till 2100

Forecasts show decline in area of boreal broadleaf and needleleved evergreen forests of Russia



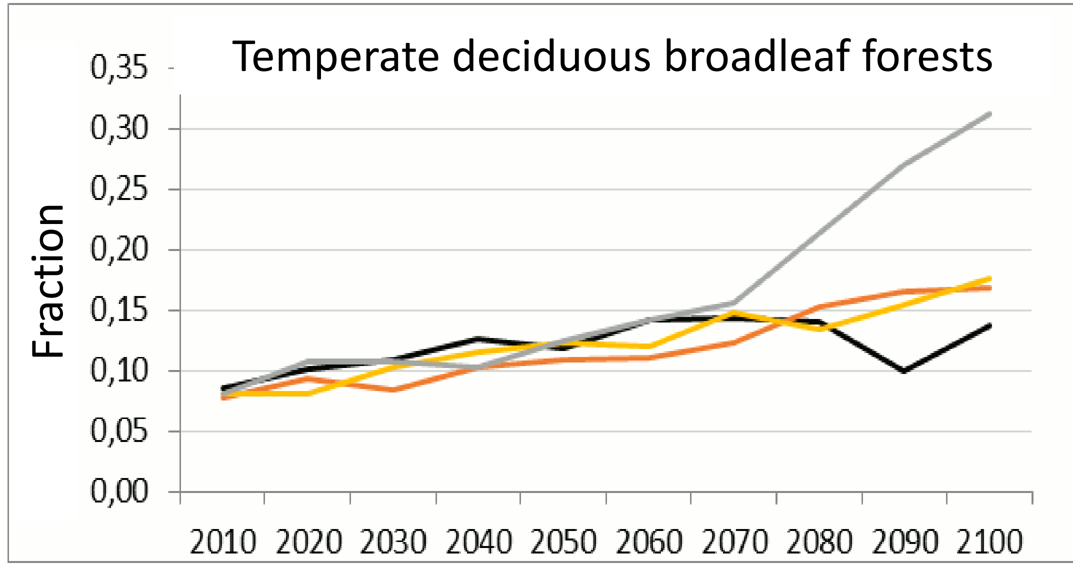


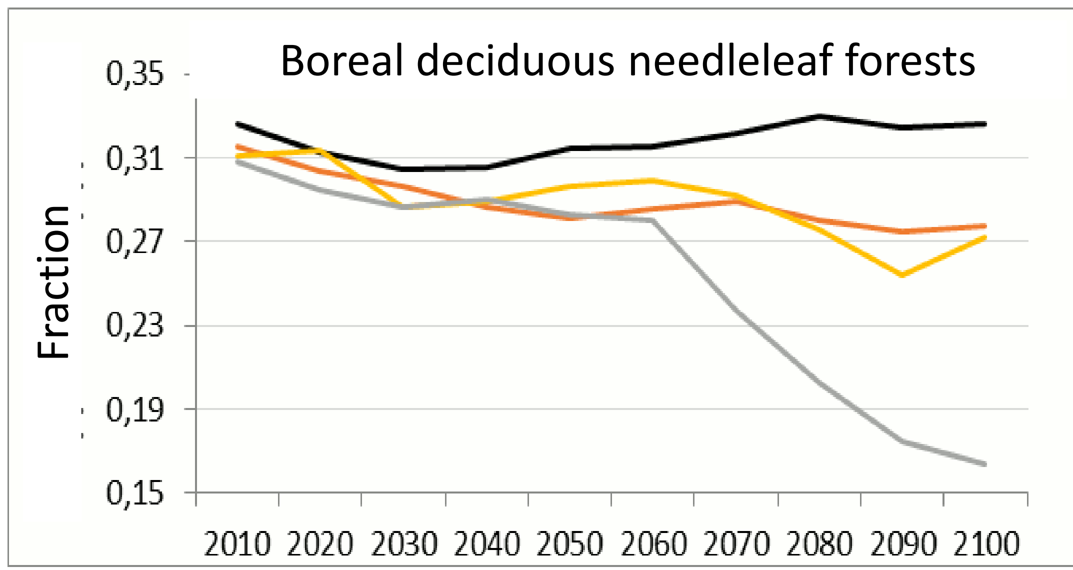


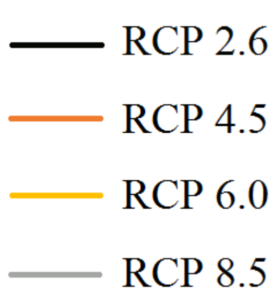
Vegetation dynamic till 2100

Boreal forests will be replaced by temperate broadleaf forests.

Also forecasts show steep decline in deciduous needleleaf forest for RCP 8.5 scenario.

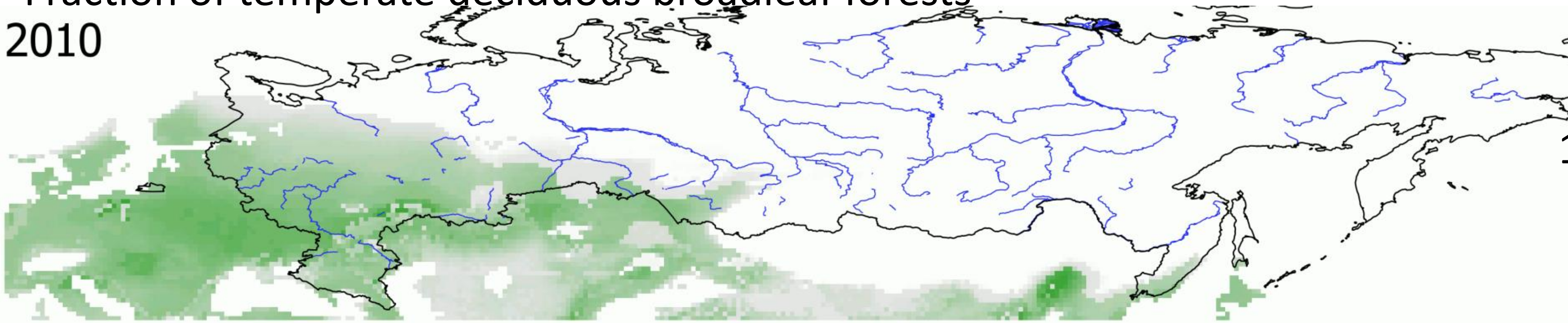




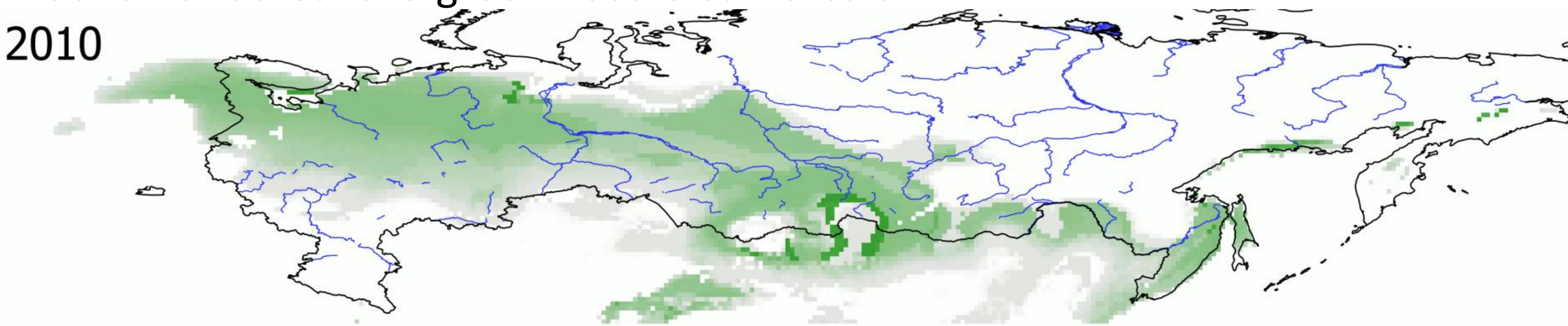


Vegetation dynamic prediction, RCP 6.0

Fraction of temperate deciduous broadleaf forests



Fraction of boreal evergreen needleleaf forests



Fraction of boreal deciduous broadleaf forests