5-th Korea-Russia Joint Workshop on Climate Change
and Variability in Eurasian Continent

Modeling climate change in Eurasia with coupled Climate - Global Vegetation Model

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OUTLINE

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- Study Aim
- Modelling surface processes and Vegetation
- Experimental Design
- Future changes in Siberian region
- Results
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Summary

Background

The biosphere, which includes the surface air layer, the vegetation layer (ecosystems and biomes), soil, and the hydrosphere, has a noticeable influence on atmospheric climate through the mechanisms of exchange of energy, moisture, momentum, greenhouse gases, and aerosol.

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Climatology of surface CO_2 fluxes in coupled model of the general circulation of an atmosphere — vegetation -soil: a case with prescribed vegetation. - Proceeding of international conference " Numerical mathematics and mathematical modelling ", devoted to the 75 anniversary to academician G.I.Marchuka and the 20 anniversary of Institute of numerical mathematics of the Russian Academy of Science,// Moscow, Russia, on June, 19-22th, 2000, m. II, c. 97-112.

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Study Aim

To tests the ability of LSM and Dynamic Global Vegetation Model are coupled to a CM3/INM(RAS) General Circulation Model and intermediate complexity climate system model (Planet Simulator) , and run into the future for Special Report Emission Scenarios (SRES): A2.

Modelling of surface processes and vegetation

SiB , LSM, ISBA, CLM, CLM2, CLM3.5, NOAH,..., LSM/INM-RAS

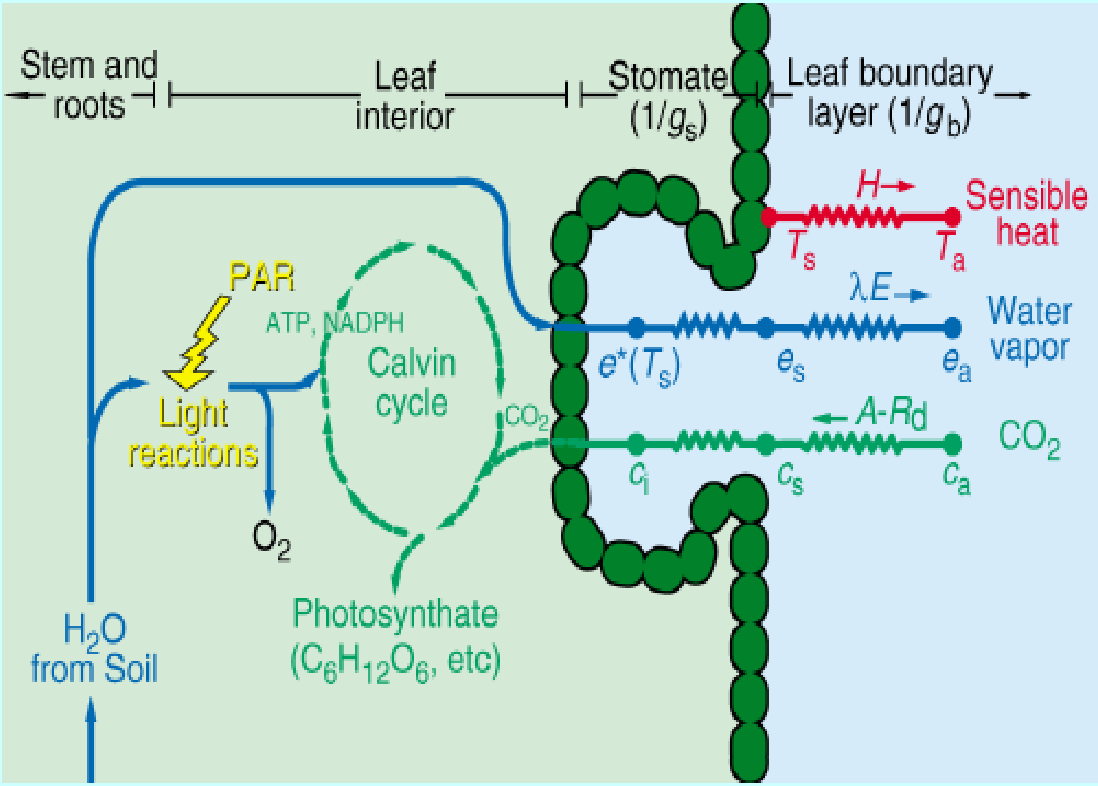
Exchanges between atmosphere and surface of :
Heat
Water
Radiation
Momentum
Biophysical consistency

Biogeochemistry, particularly as it affects atmospheric CO2
Treatment of human land use (e.g., agriculture) and land-use change

Vegetation distribution changes consistently with climate

Scalability (grid independence?)

Leaf Physiology in SiB model

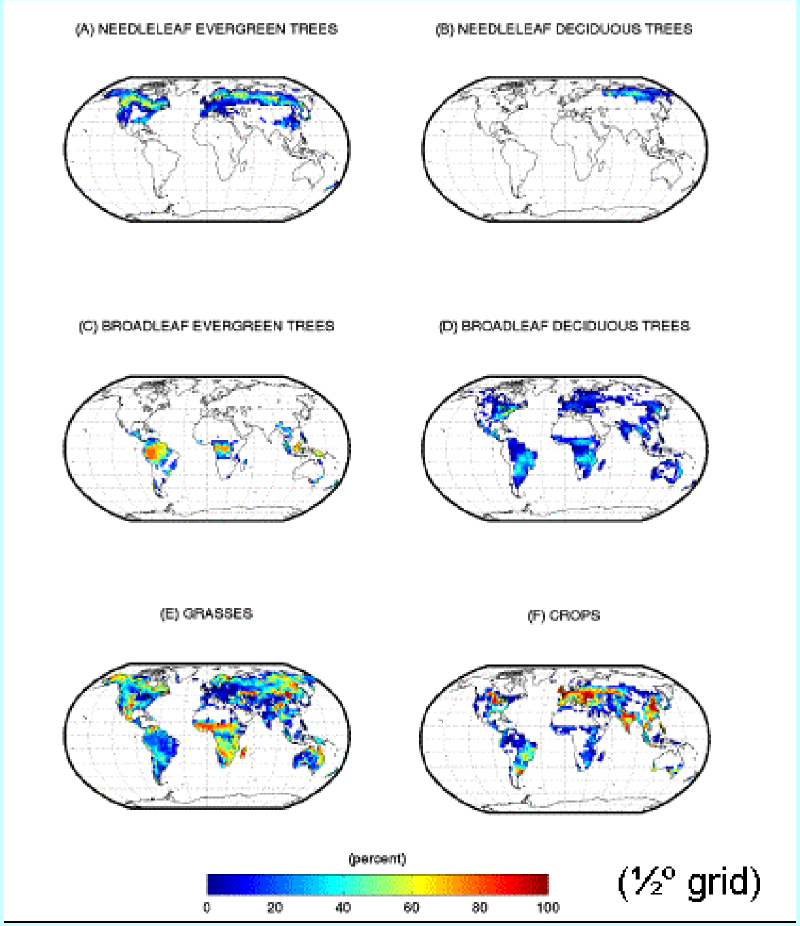


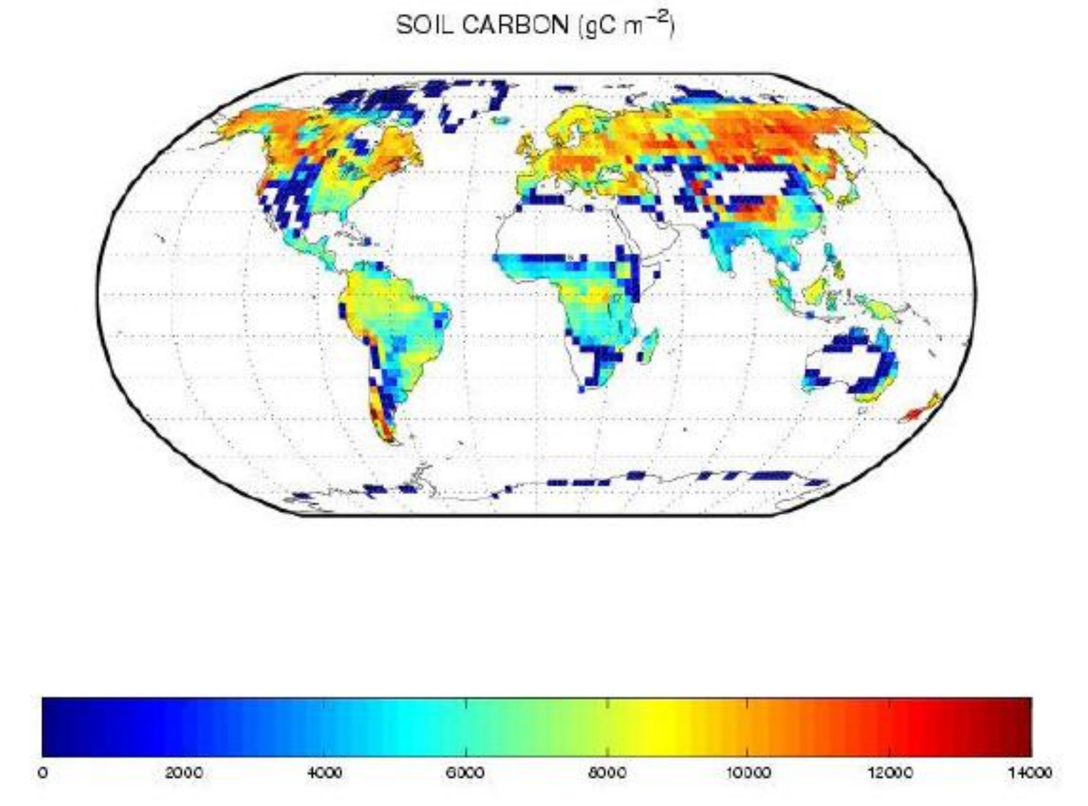
Community Land Model (CLM2) in CCSM

- SiB-like photosynthesis and transpiration
- 10-layer soil with variable root uptake
- 0-5 layer snowpack accomodates strong temperature gradients (insulation)
- Subgrid-scale tiling of “plant functional types”

Fractional coverage by evergreen trees, deciduous trees, grass, crops, bare ground, etc.

Plant Functional Type Geography




SOIL CARBON (gC m^{-2})
0
2000
4000
6000
8000
10000
12000
14000

Prognostic Canopy Air Space

temp

$$\rho c_p \Delta z \frac{\partial T_a}{\partial t} = H_c + H_g + H_s + H_m$$

canopy, ground, snow, turbulence

vapor

$$\frac{\rho c_p \Delta z}{\gamma} \frac{\partial e_a}{\partial t} = \lambda E_c + \lambda E_g + \lambda E_s + \lambda E_m$$

CO_2

$$\rho \Delta z \frac{\partial C_a}{\partial t} = R_g - A_n - \frac{C_a - C_m}{r_a}$$

respiration, photosynthesis, turbulence

Experimental Design

with Climate model CM3/INM/RAS

(V.Alexeev, V. Galin, V. Dymnikov, V. Lykosov, E.Volodin, N. Diansky)

Model Description

- Atmospheric core of model

- LSM/ICMMG SB RAS - biophysical and biochemical surface model

- Lund-Potsdam-Jena dynamic global vegetation model

Atmospheric core of CM3/INM model

- Terrain-following vertical coordinate (21 σ-levels)
- Semi-implicit formulation of integration in time
- Energy conservation finite-difference schemes (5x 4) (Arakawa-Lamb,1981)
- Convection (deep, middle, shallow)
- Radiation (H_2O, CO_2, O_3, CH_4, N_2O, O_2; 18 spectral bands for SR and 10 spectral bands for LR)
- PBL (5 σ-levels)
- Gravity wave drag over irregular terrain

Land Surface Model (ICM&MG/SB RAS):

- Vegetation composition, structure
- Radiative fluxes
- Momentum and energy fluxes
- Vegetation and ground temperature
- Soil and lake temperature
- Surface hydrology (snow, runoff, soil water, canopy water etc.)

- **CO2 emissions from terrestrial vegetation (photosynthesis, respiration)**

$$\frac{1}{r_s} = m \frac{A}{c_s} \frac{e_s}{e_i} P_a + b$$

$$A = \min(w_c, w_j, w_e)$$

$$R_m = [L R_l f(N) + B_s R_s + B_r R_r] e^{\frac{T_v - 25}{10} a_m}$$

$$R_g = 0.25(A^{sun} L^{sun} + A^{sha} L^{sha})$$

$$\Delta NPP = (A^{sun} L^{sun} + A^{sha} L^{sha} - R_m - R_g) \Delta t$$

- **CH4 emissions from natural wetlands**

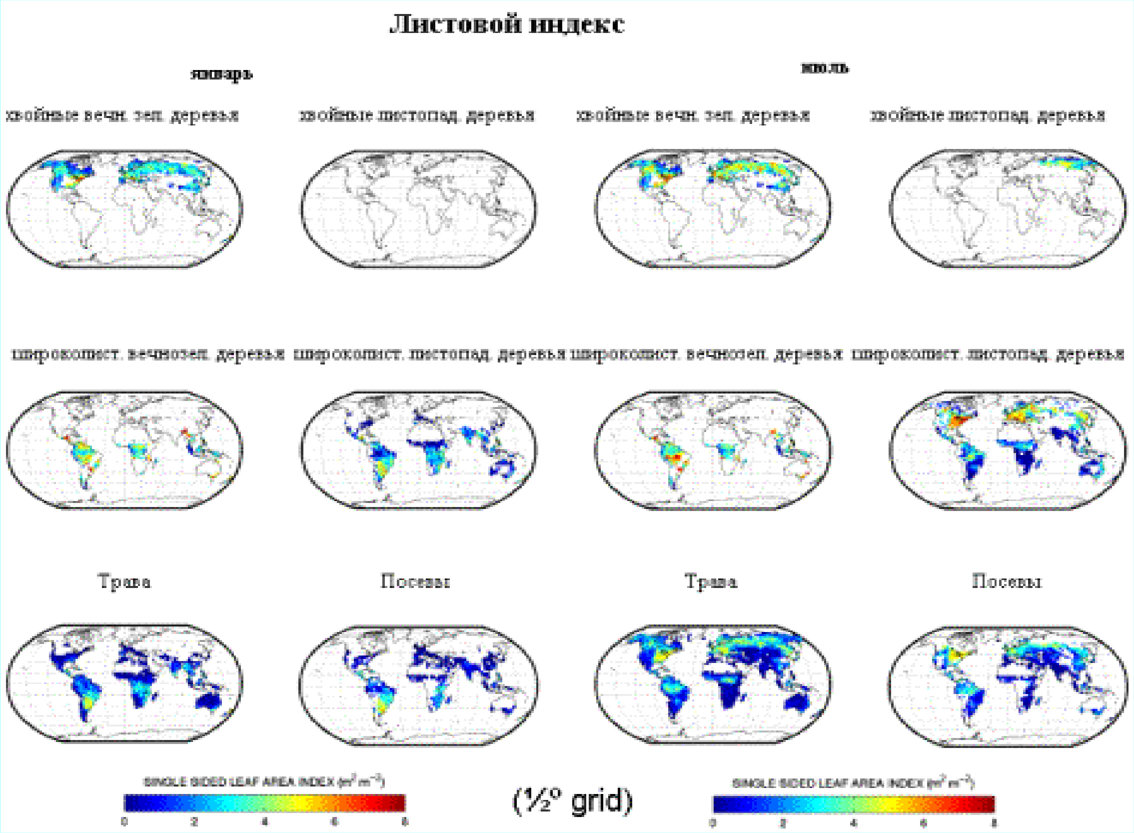
$$R_{prod} = R_0 \cdot f(NPP) \cdot f(T) \cdot Q_{10}^{\frac{T - T_{mean}}{10}}$$

$$R_{oxid} = - \frac{V_{\max} \cdot C_{CH4}}{K_m + C_{CH4}} \cdot Q_{10}^{\frac{T - T_{mean}}{10}}$$

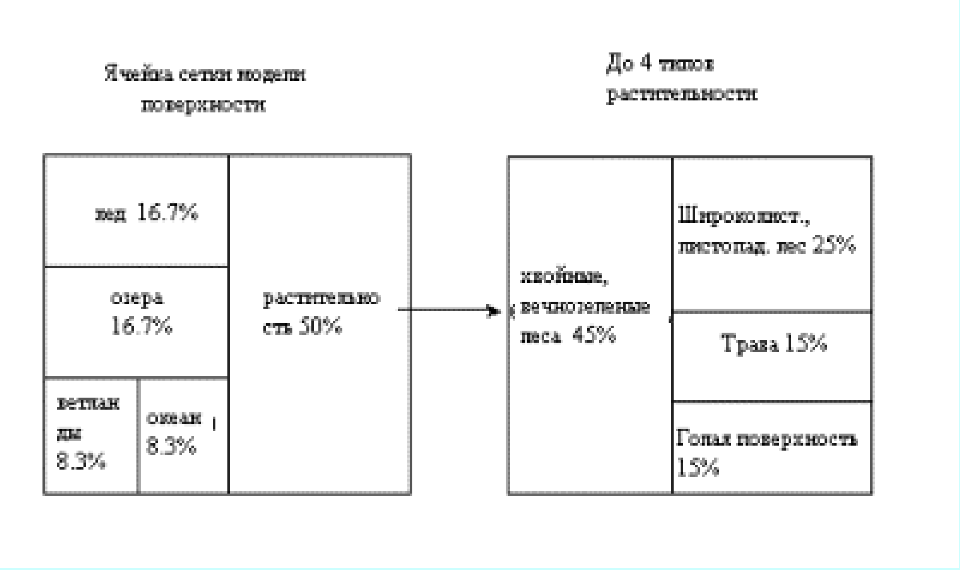
$$Q_e = f(C_{CH4}) \cdot (C_{CH4} - C_{thresh})$$

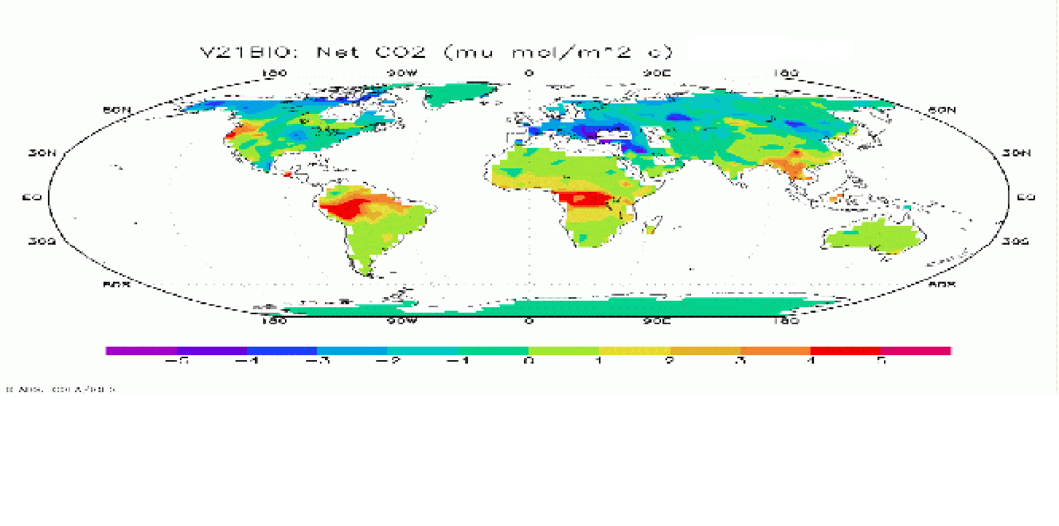
$$F = F_{diff} + F_e + F_{plant},$$

Leaf area index

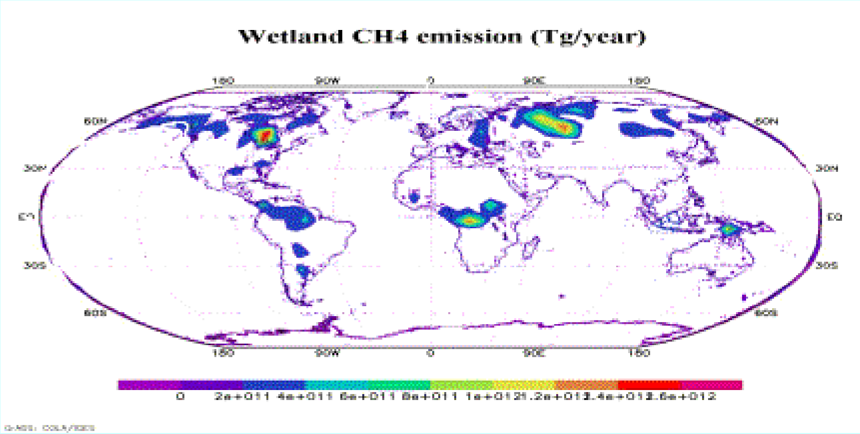


Grid structure in land surface model

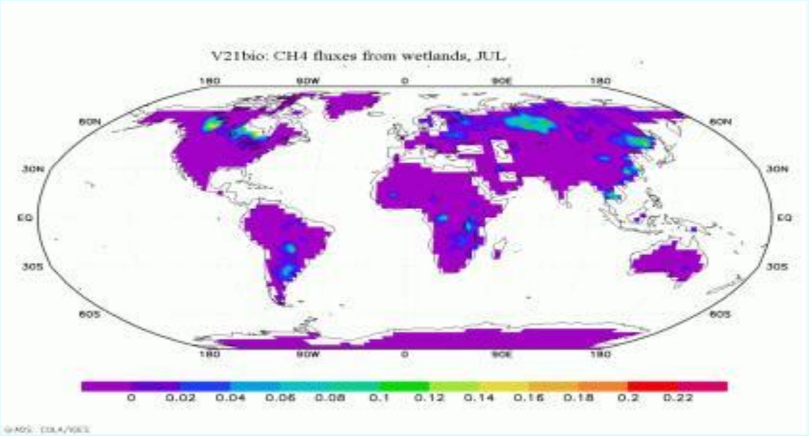




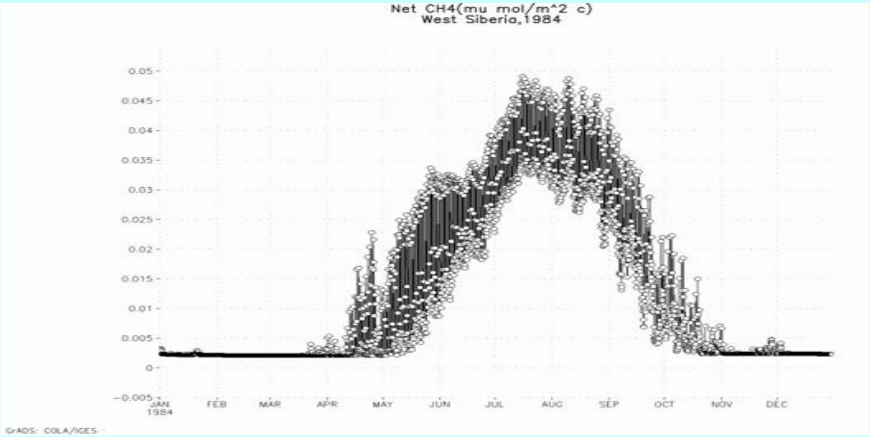
Global Net CO2 fluxes (mmol CO2/m^2 c), coupled simulation, JUL)



CH4 fluxes from wetlands: observations [Muller J.F., 1992];

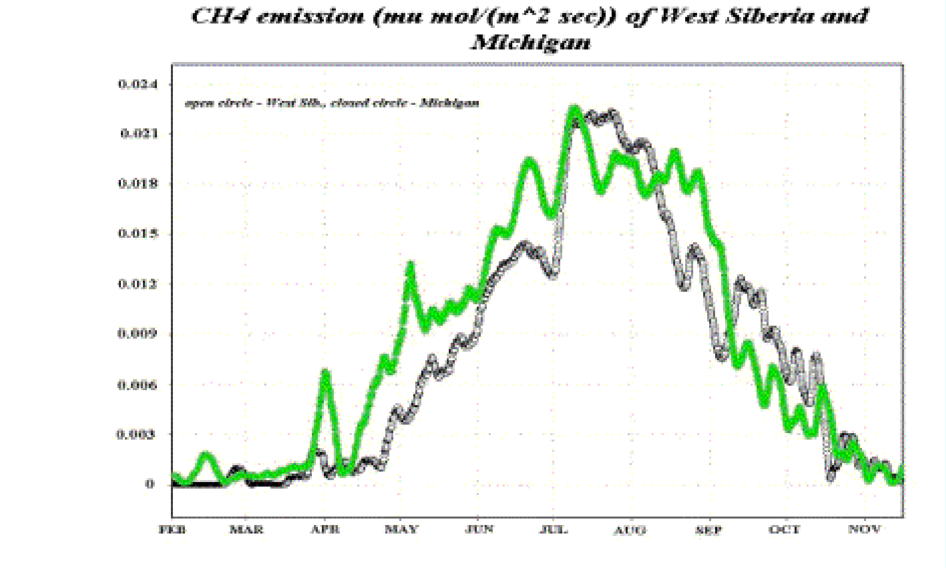


CH4 fluxes (mmol CH4(m^2 c) coupled simulation



CH4 emissions from natural wetlands (coupled framework)
West Siberia

Seasonal variation of CH4 fluxes for Western Siberia and Michigan



Integratated Dynamics Global Vegetation Models(DGVM)

The BIOME4 Global Vegetation Model (Haxeltine and Prentice ,1996).

- *Lund – Potsdam –Jena (LPJ) – intermediate complexity model with broad rang of applications to global climate dynamics (S. Sitch et al, 2003)*

- The Community Land Model + Dynamic Global Vegetation Model *(S.Levis, G. Bonan, M. Vertenstein, and K. Oleson, 2004)*

- *HyLand (HYL) model (Levy et al., 2004);*

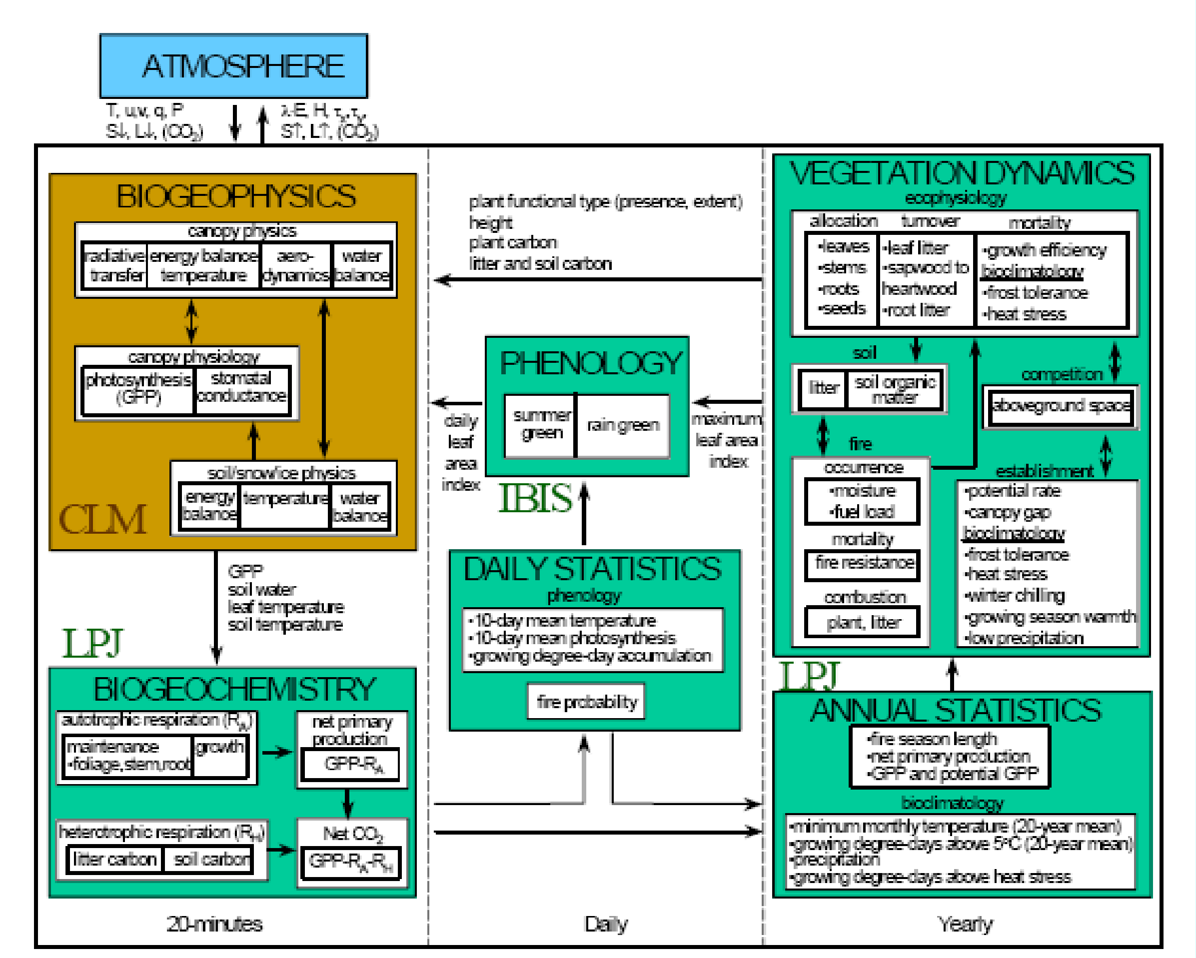
- *ORCHIDEE (ORC) model (Krinner et al., 2005);*

- *Sheffield -DGVM (SHE) (Woodward et al., 1995; Woodward and Lomas, 2004);*

- *TRIFFID (TRI) (Cox 2001).*

Community Land Model + Dynamic Global Vegetation Model

CLM-DGVM wire diagram, G. Bonan et al. 2003)



Dynamic Global Vegetation Models

The Processes

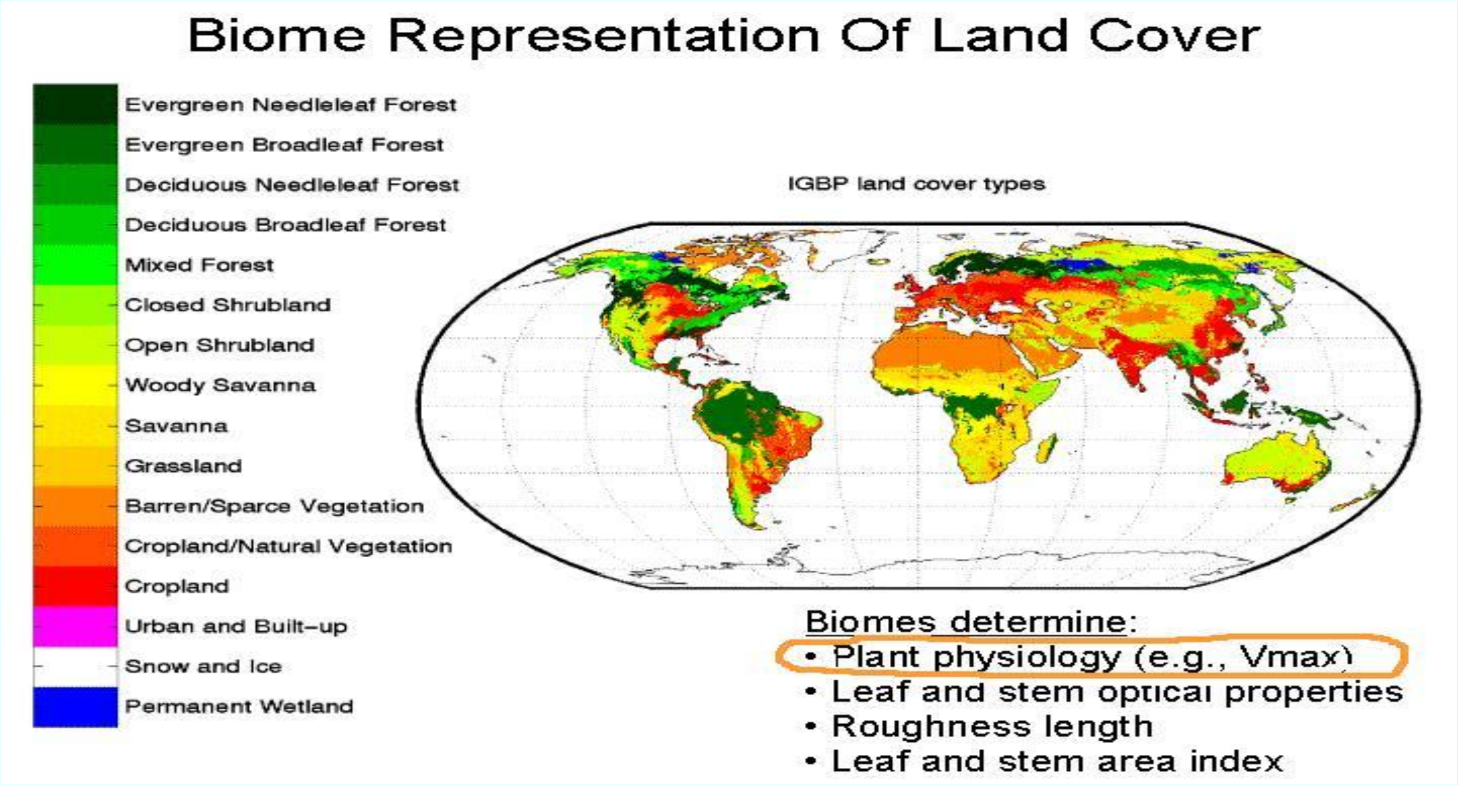
1. Net Primary Production: Linking Processes Across Time Scales
2. Competition for Water
3. Reproduction
4. Turnover
5. Mortality Due to Negative Net Primary Production
6. Allocation
7. Competition for Light
8. Background Mortality and Mortality Due to Stress
9. Mortality Due to Fire
10. Establishment and Survival
11. Phenology
12. Soil Organic Matter

Evaluation of ecosystem dynamics and terrestrial carbon cycling in LPJ dynamic global vegetation model.

Lund-Potsdam-Jena dynamic global vegetation model

- Plant functional types (10 PFT)
- Annual vegetation and carbon dynamics
- Penology
- Production
  - water availability
  - photosynthesis
  - respiration
  - reproduction
  - allocation
  - mortality
- Input data

Plant functional type

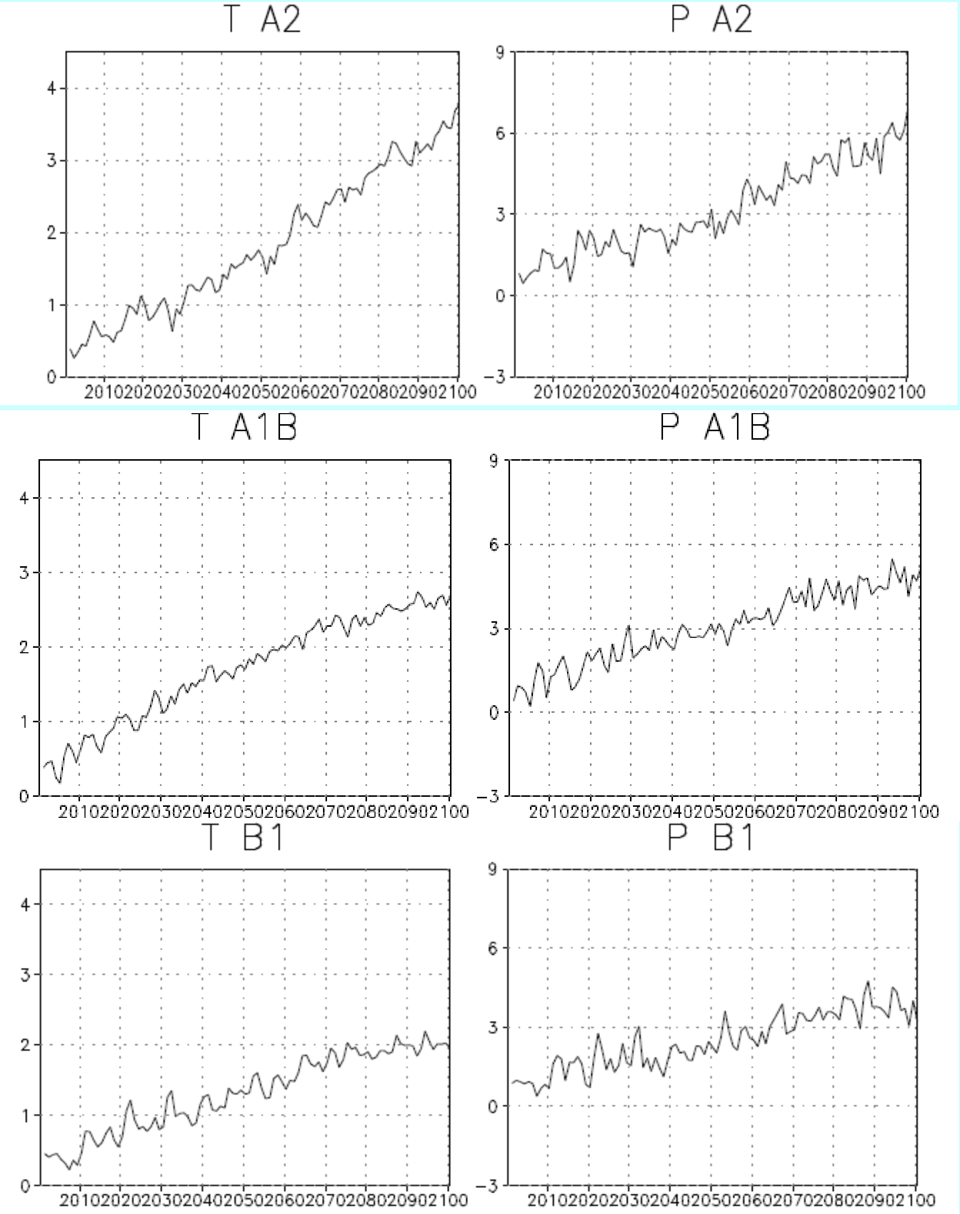


LPJ dynamic global vegetation model

- is able to reproduce carbon and water exchange with atmosphere on seasonal time scale;
- is able to simulate spatial distributions of soil, litter and vegetation pools and NPP, runoff within their accepted ranges and agree with observed patterns
- is able to reproduce global vegetation distribution in general agreement with satellite derived maps of phenology and leaf type
- is able to evaluate seasonal cycle of CO2

Table of PFT

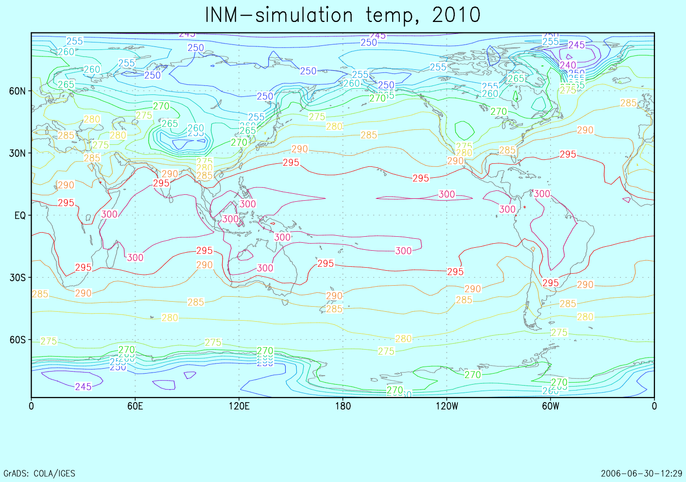
- **TrBE - tropical broad-leaved evergreen**
- **TrBR - tropical broad-leaved raingreen**
- **TeNE – temperate needle – leaved evergreen**
- **TeBE - temperate broad – leaved evergreen**
- **TeBS - temperate broad – leaved summergreen**
- **BoNE – boreal needle – leaved evergreen**
- **BoNS - boreal needle – leaved summergreen**
- **BoBS - boreal broad – leaved summergreen**
- **TeH - temperate herbaceous**
- **TrH - tropical herbaceous**

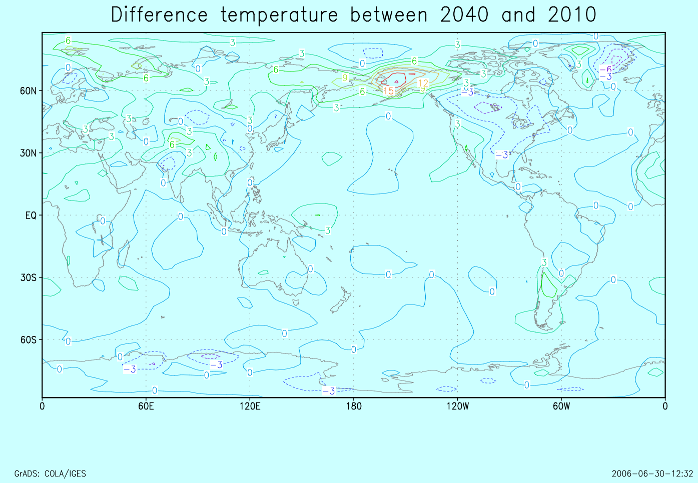


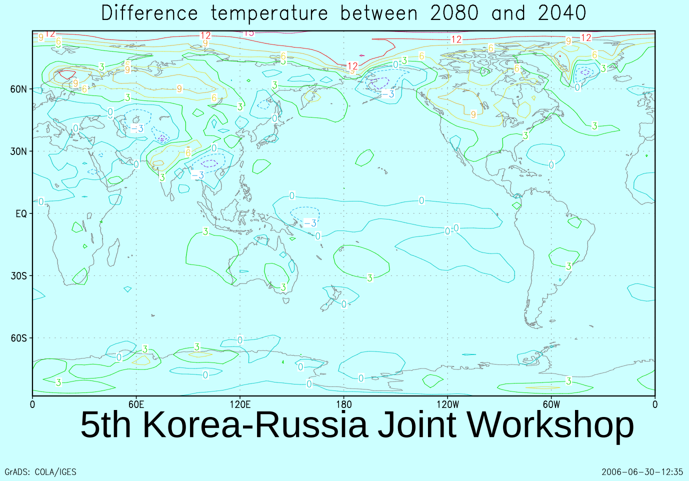
The global average temperature deviation of surface air (at the left) and precipitation (%) (on the right) for scenario A2 (above), A1B (in the middle) and B1 (below) in 2000-2100г.г. In comparison with 1980-1999г.г.

INM(CM3) model

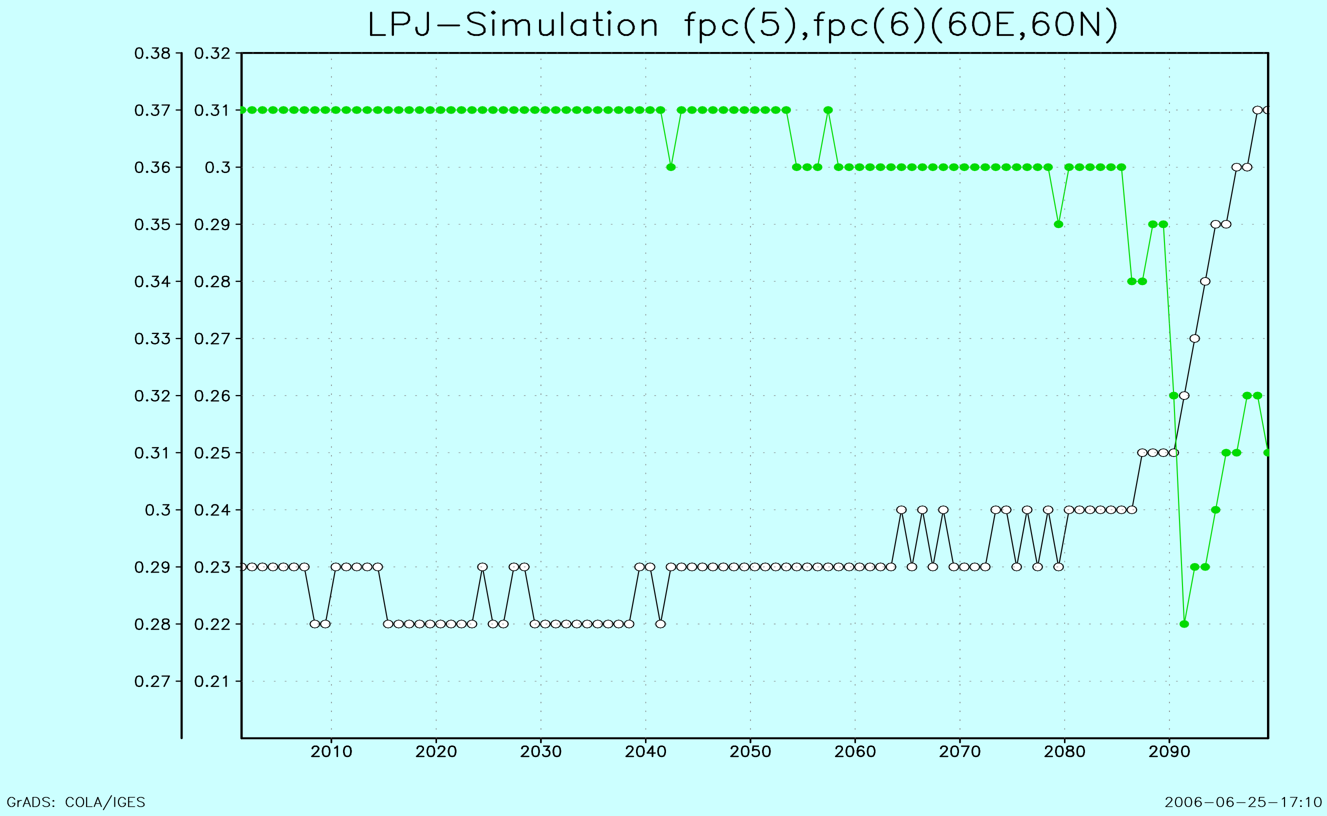
CM3/INM-simulation of temperature 2010, dTemp = T(2040) - T(2010) and dTemp = T(2080) – T(2040)



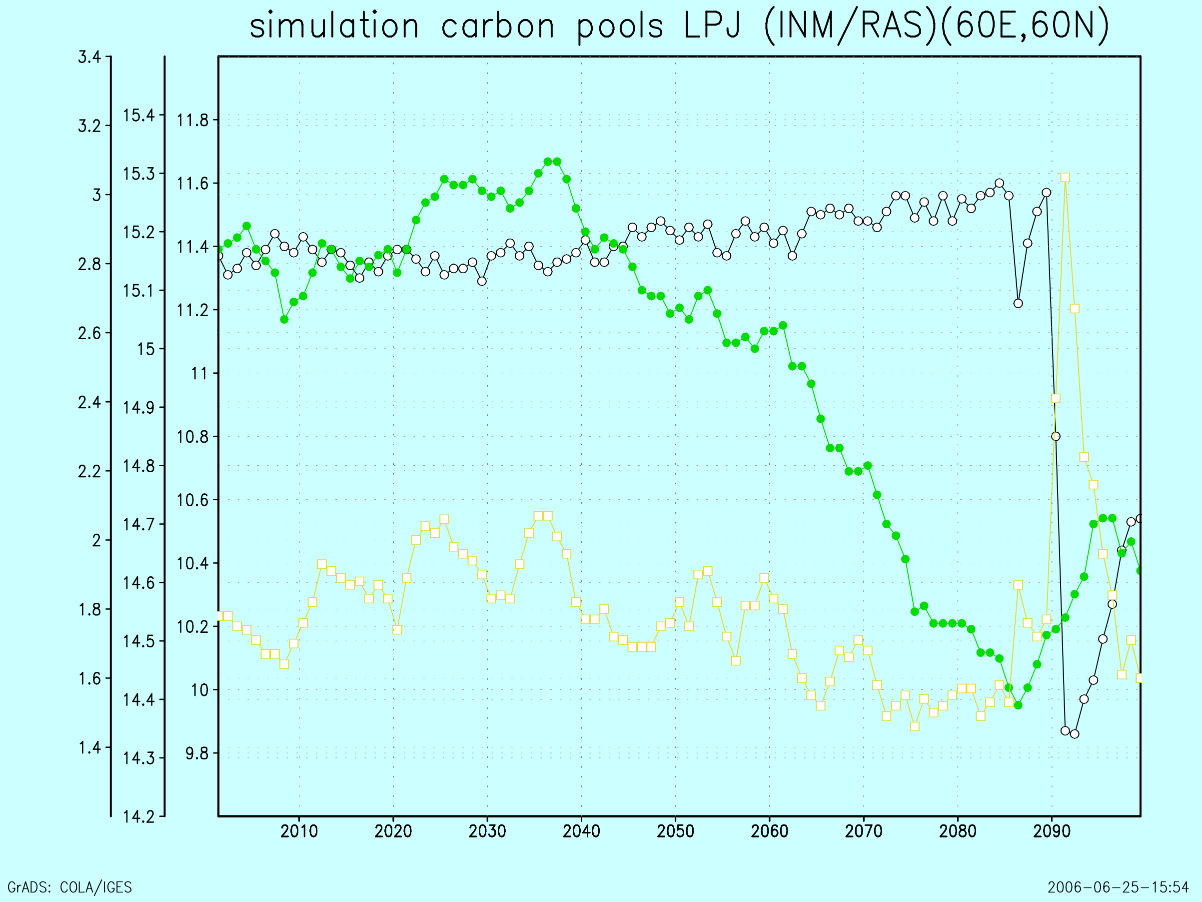




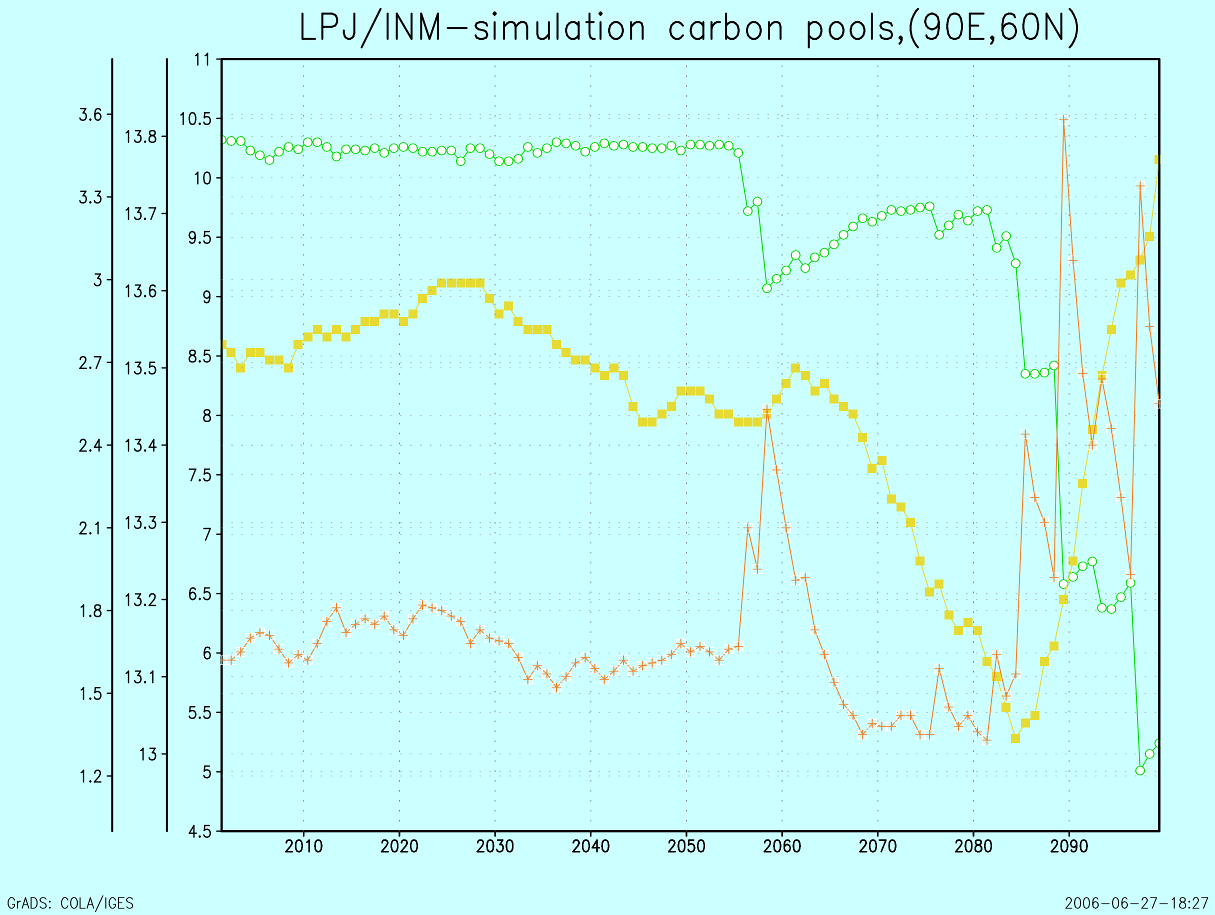
LPJ/INM(RAS)-simulation (scenario A2)
Temperate(TeBS) (black), Boreal(BoNE) (green) forest dynamics for grid cell(60E,60N)



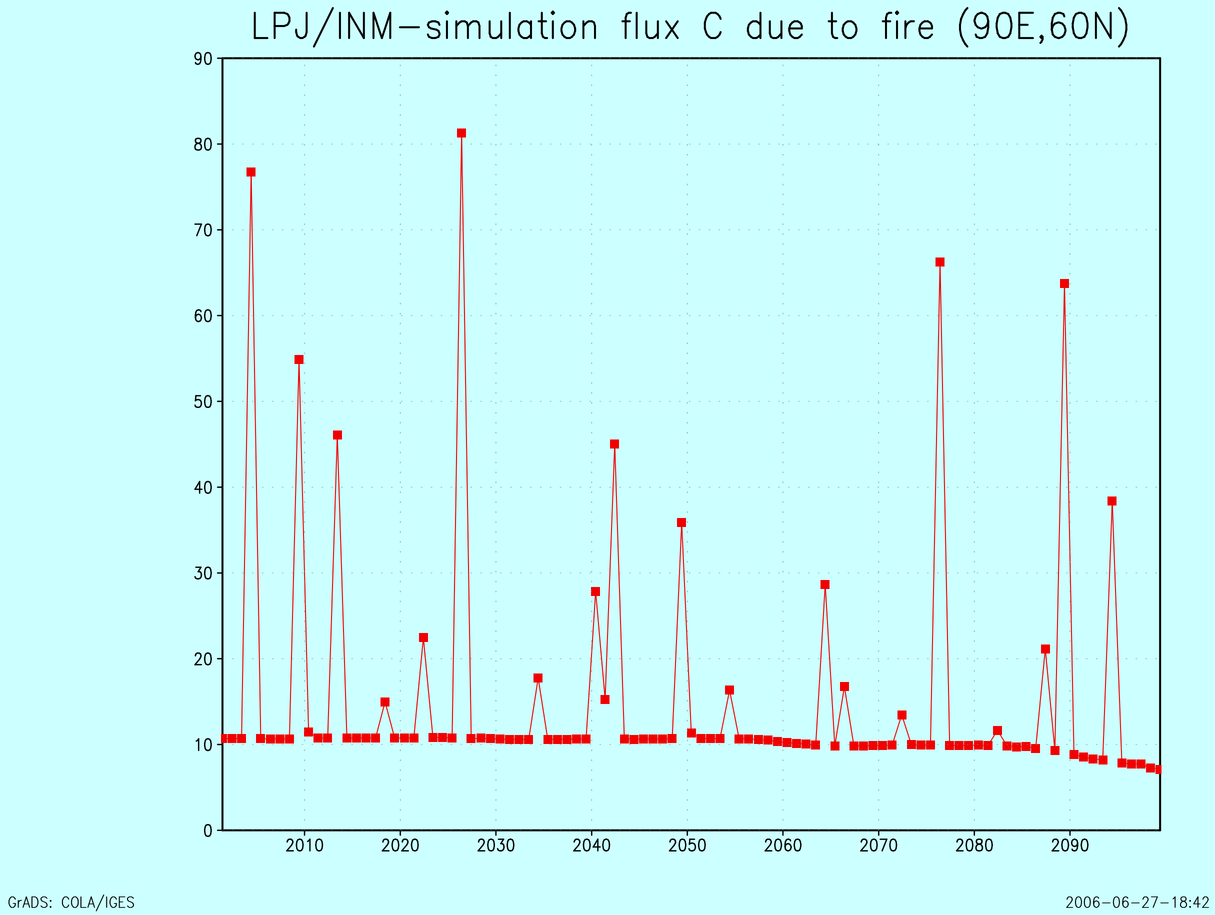
LPJ/INM(RAS)-simulation (scenario A2) of carbon pools, (60E,60N)
vegc – green, soilc – black, litterc - yellow



LPJ/INM(RAS)-simulation (scenario A2) of carbon pools(left)),(90E,60N)
vegc – green, soilc – yellow, litterc - red

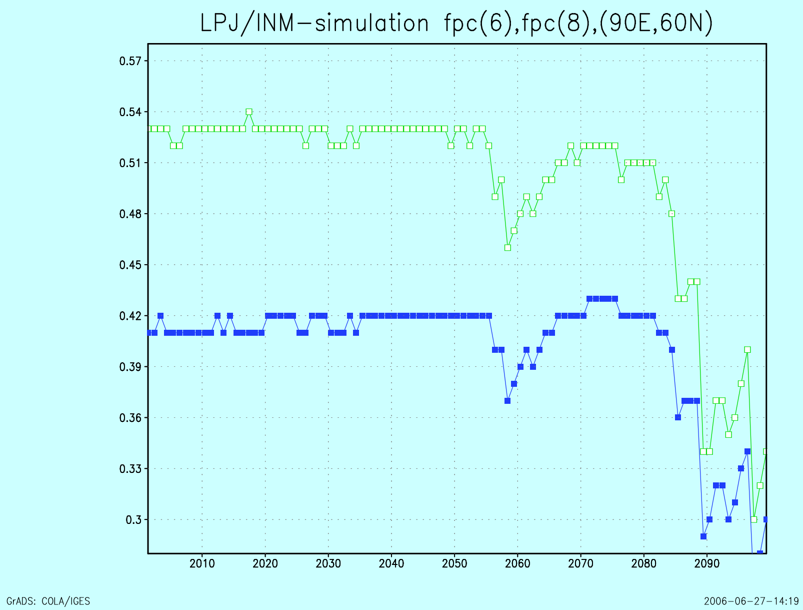


LPJ/INM(RAS)-simulation (scenario A2) flux C due to fire(gC/m^2),(90E,60N)

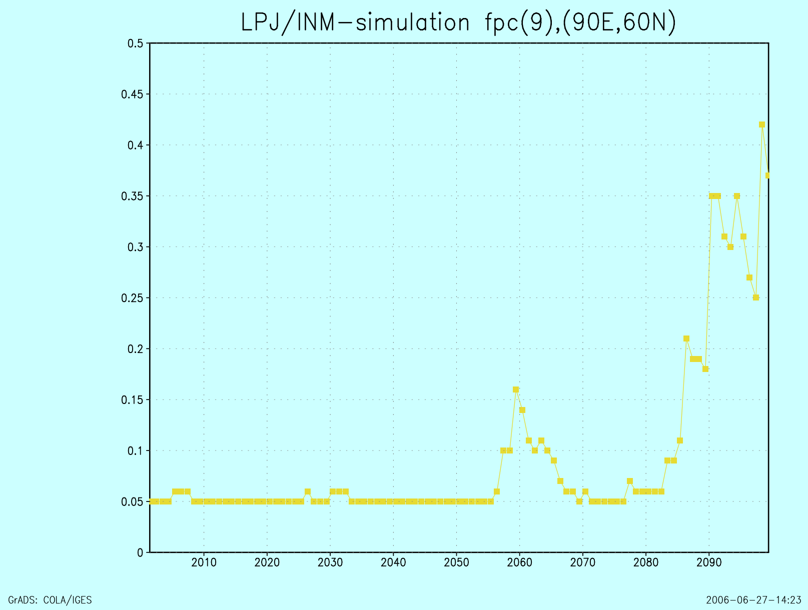


CM3/INM-LPJ simulation of FPT (scenario A2) (90E,60N)

Boreal(BoNE, BoBS) forest dynamics for grid cell



Temperate(TeH) herbaceous dynamics for grid cell



Climate system model of intermediate complexcity «Planeta Simulator»

(K. Fraedrich and H. Jansen, et al., “The Planet Simulator: Towards a User Friendly Model,”// Meteorol. Z., 2005, **14**, p. 299–304.)

A STUDY VEGETATION DYNAMICS in Northern Eurasia climate system on the base of coupled model ocean-atmosphere-vegetation-soil under global climate changes: Scenario A2.

(V. Krupchatnikov, V. Kuzin, et al.
//Izvestiya, Atmospheric and Oceanic Physics, 2009, Vol. 45, No. 1, pp. 116–136.)

Dynamical core

The spectral dynamical core of the Planet Simulator is based on the moist primitive equations representing the conservation of momentum, mass and energy. The dimensionless set of equations consists of the

– prognostic equations for the vertical component of the vorticity and the horizontal divergence
– first law of thermodynamics
– equation of state (with hydrostatic approximation)
– continuity equation
– prognostic equation for water vapour (specific humidity)

Parameterizations and subsystems

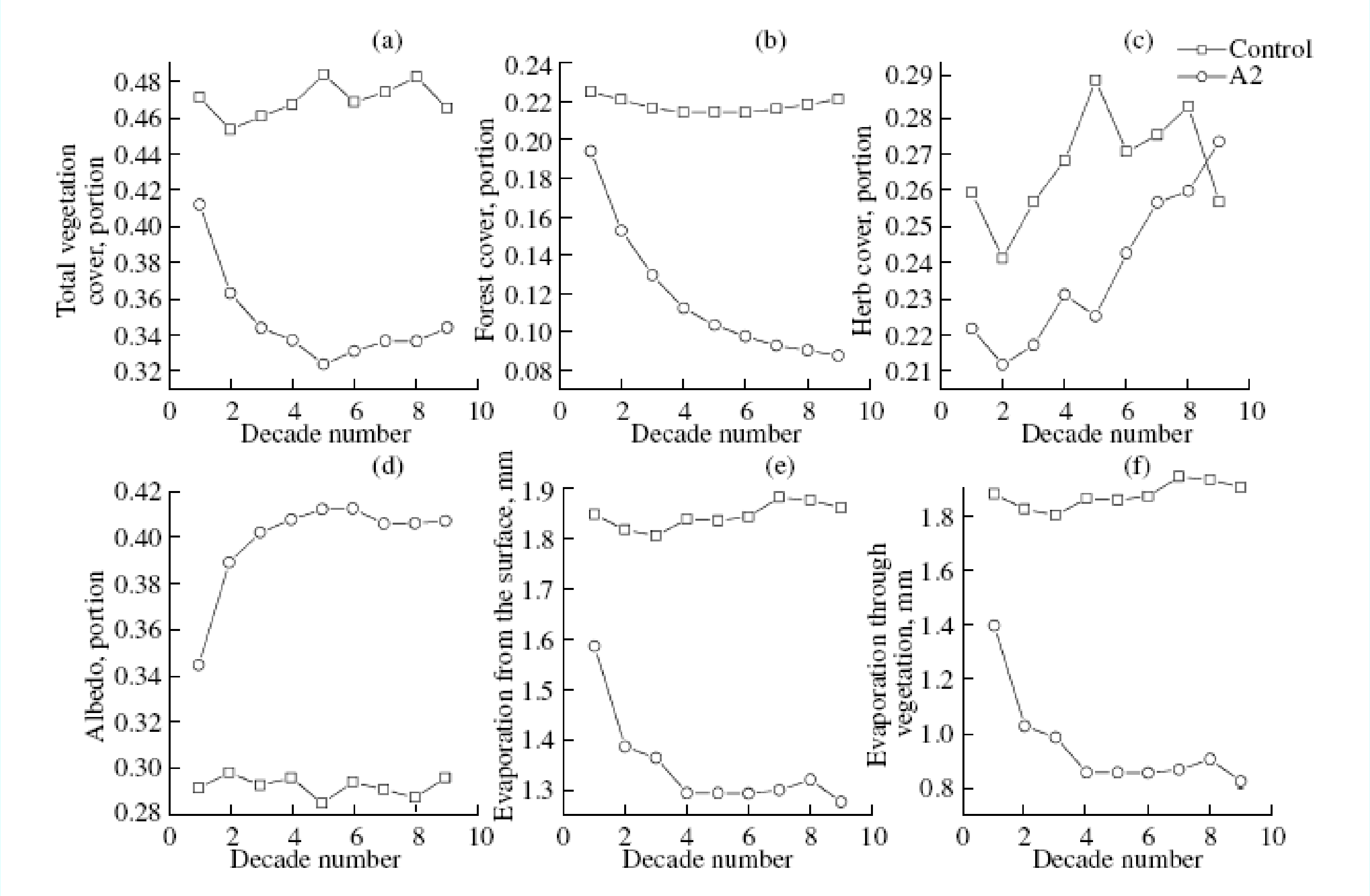
- Boundary layer and diffusion
- Radiation
- Land surface and soil
- Moist processes, clouds and dry convection
- Ocean and sea ice
- Dynamic Vegetation

Background

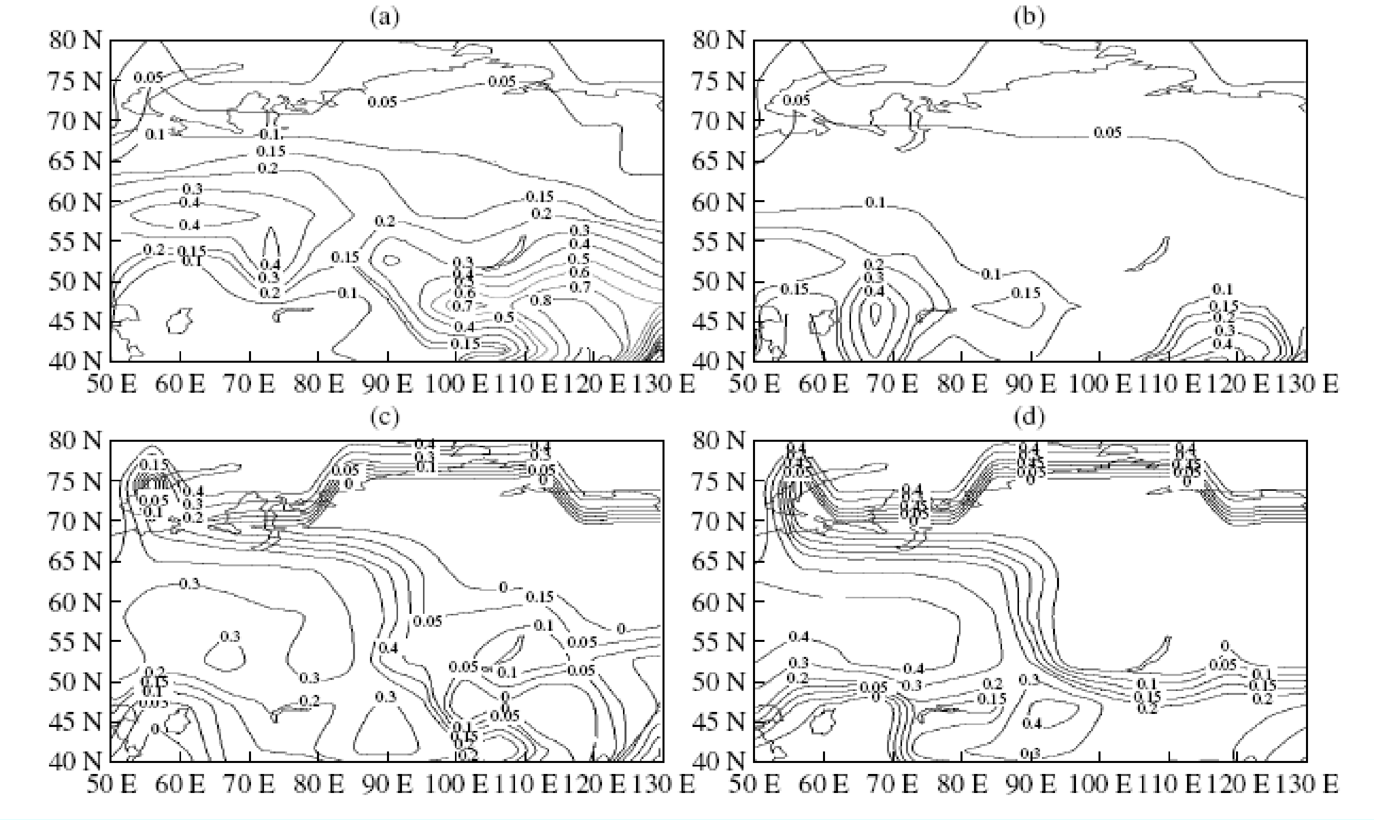
It also well established that vegetation in high latitudes have significant impact on land surface albedo and albedo feedbacks to climate system. This provides the opportunity for strong feedbacks associated with coupled snow – vegetation system. Variation of the trees line can modulate the snow cover albedo feedbacks and impact on climate (B. Cook, G. Bonan, S. Levis, H. Epstein, 2007)

Feedback of vegetation are capable to increase reaction of climatic model to change of a snow cover (Barnett T., et al, 1989; Bonnan G., et al, 1992; Ganopolsky A. et al, 1998; Claussen M. et al, 2006)

Variations in vegetation-cover parameters for the two scenarios vs. integration decade number (0–2000, 10–2100) for Siberia.



Distribution of the portions of (a) and (b) forest vegetation and (c) and (d) herb and bushes over Siberia; (a) and (c) correspond to the beginning (the first decade) of the 21st century and (b) and (d) correspond to the end (the eighth decade) of the 21st century. Scenario A2.



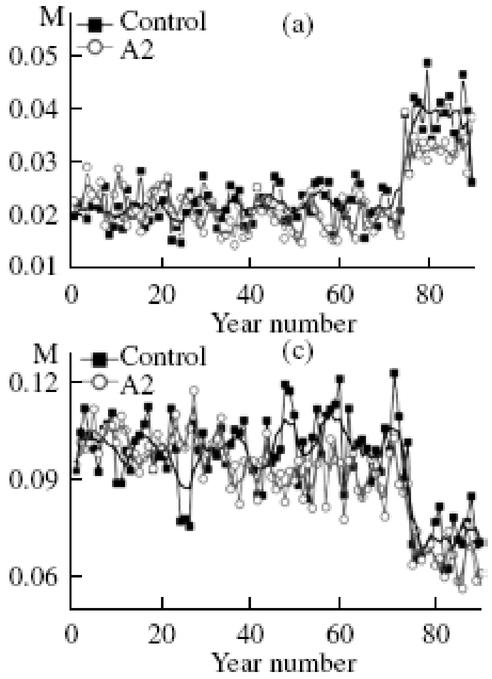


Fig. 13. Mean snow-cover depth in (a) fall, (b) winter, and (c) spring for Siberia.

Normalized NAO index

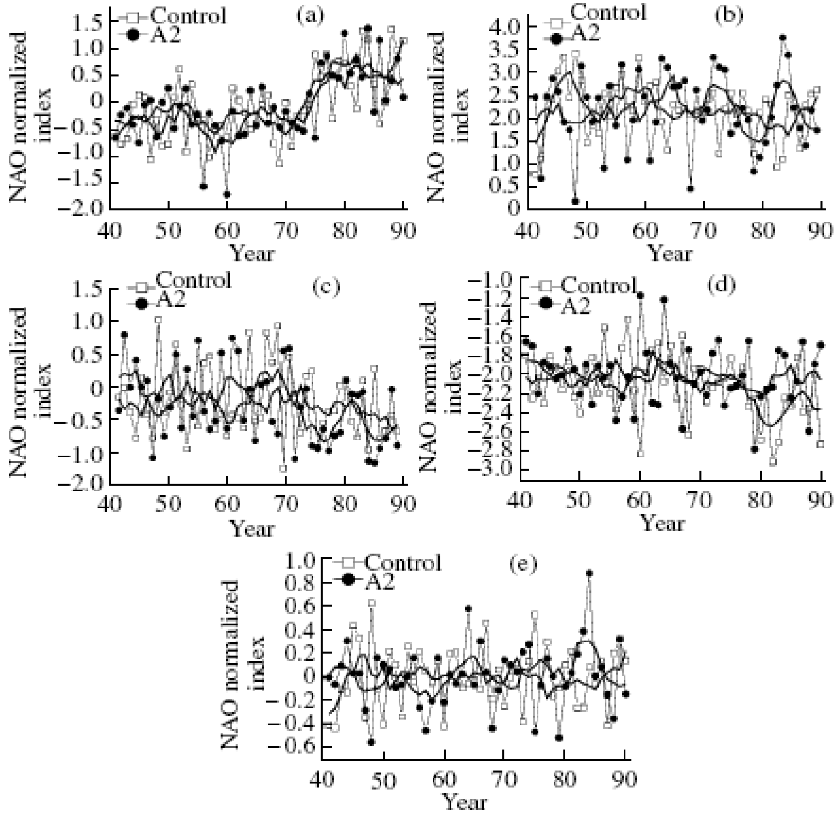
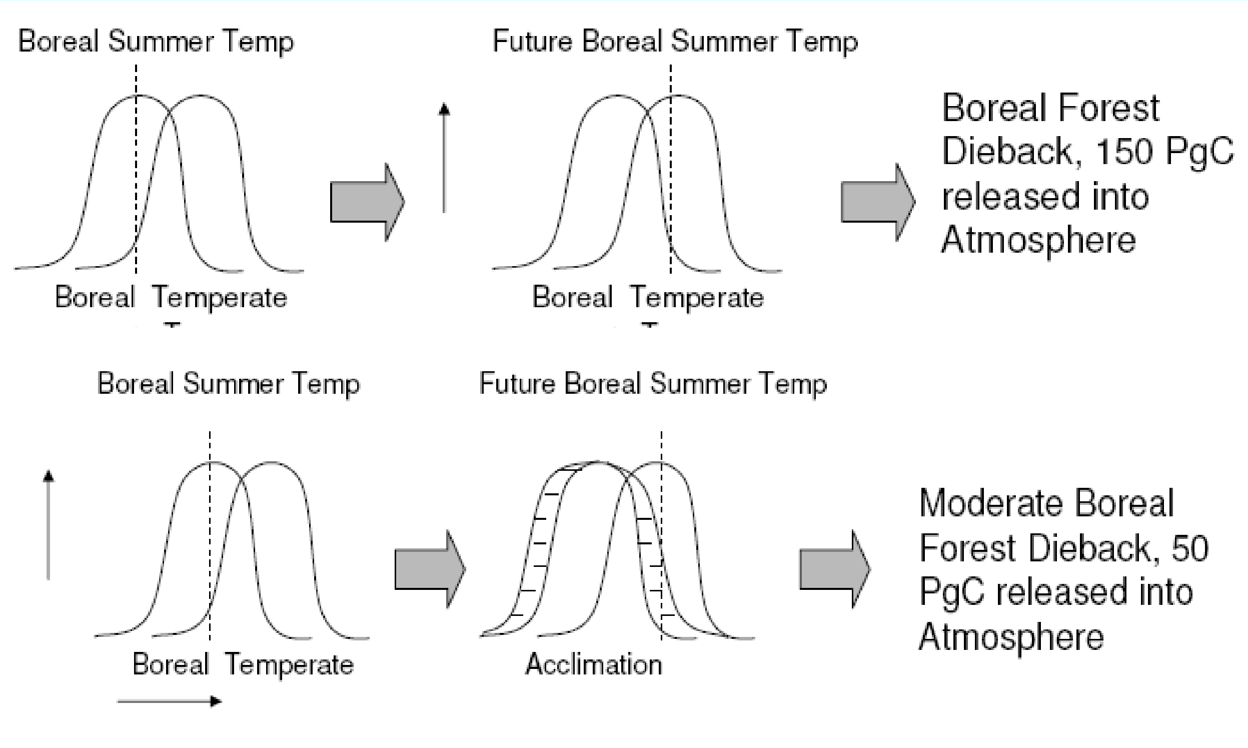


Fig. 14. Normalized index of the NAO for (a) fall, (b) winter, (c) spring, and (d) summer; (e) annual mean.



S. Sitch, et al, 2008. Evaluation of the terrestrial carbon cycle, future plant geography and climate-carbon cycle feedbacks using 5 Dynamic Global Vegetation Models (DGVMs)

Quantifying uncertainties in future land atmosphere exchange

S. Sitch[1], C. Huntingford[2], R. Betts[1], W. von Bloh[3], P. Ciais[4], P. Cox[5], P. Friedlingstein[4], N. Gedney[1], P. Levy[6], M. Lomas[7], S. Piao[4], I.C. Prentice[8], and F.I. Woodward[7]

[1]Met Office (JCHMR), Wallingford, UK.
[2] Centre of Ecology and Hydrology Wallingford, UK.
[3] Potsdam Institute for Climate Impact Research, Potsdam, Germany.
[4] Laboratoire des Sciences du Climat et de L'Environnement, Gif sur Yvette, France.
[5] Centre of Ecology and Hydrology Dorset, UK.
[6] Centre of Ecology and Hydrology Edinburgh, UK.
[7] University of Sheffield, UK.
[8] University of Bristol, UK.

Research Questions

- What is the uncertainty in the future atmospheric CO_2 concentration associated with choice of DGVM and SRES emission scenario?
- How uncertain is the Climate-Carbon feedback?
- Do DGVMs agree on their Global and Regional responses to changes in climate and atmospheric composition?
- Which key ecological processes are poorly represented in the models?

Summary I

- By 2100, atmospheric CO_2 concentrations differ by up to 285 ppm among DGVMs, equivalent to ~64% of the uncertainty associated with choice of SRES emission scenario (448 ppm).

- Simulated climate-carbon cycle feedbacks range between 40 and 355 ppm for all DGVMs and 4 SRES emission scenario combinations. The maximum range associated with choice of DGVM is 263ppm.

Summary II

- Uncertainty in future cumulative land uptake (485 PgC) associated with land processes is equivalent to ~56 years of anthropogenic emissions at the 2000 levels.

- Improving our understanding of and ability to model terrestrial biosphere processes (e.g. plant response to drought/ heat stress) is paramount to enhance our ability to predict the future development of the Earth system !

“Those who have knowledge, do not predict,
Those who predict, do not have knowledge.”

(Lao Tzu)