THE PRINCIPLE OF THE WORST SCENARIO IN MODELLING BIOSPHERE-CLIMATE DYNAMICS

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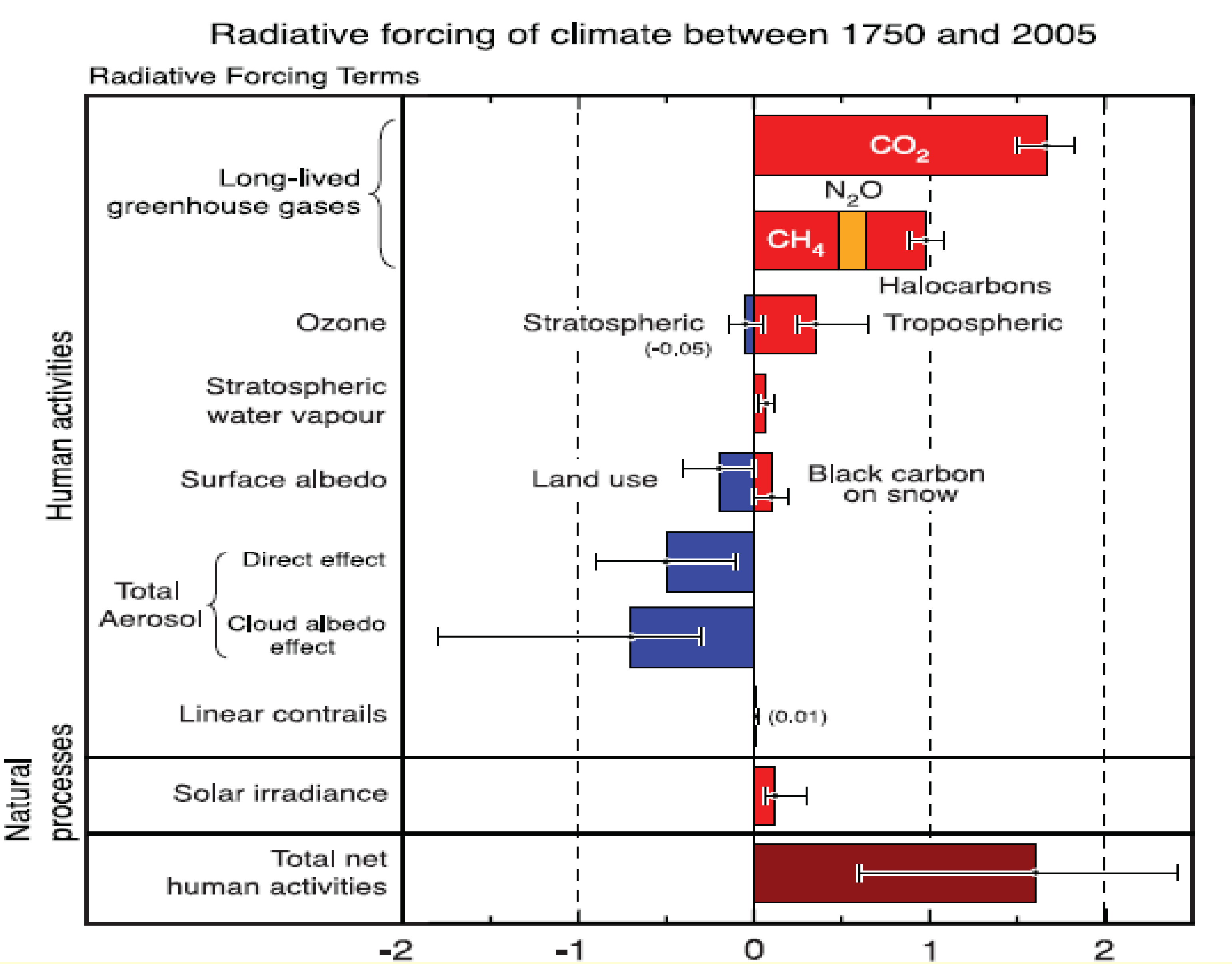
Belolipetsky P.V.

Abstract

- As a rule, developers of climate and biosphere models aim at predicting the most probable scenario. Thus, they have to take into account the maximum possible number of various, frequently mutually compensating, interactions of the components of these systems.

- However, assessment of the contribution of any climatic or biospheric process has finite accuracy and is represented by a confidence interval. So there are possible much large climatic and biosphere changes than in most probable scenario.

- For the estimating probability of catastrophic changes we can seek not most probable scenario but just take parameters from the confidence intervals. (It is the idea of the principle of the worst scenario).



Forster, P., et al., 2007: Changes in atmospheric constituents and in radiative forcing, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge Univ. Press, Cambridge, U. K.

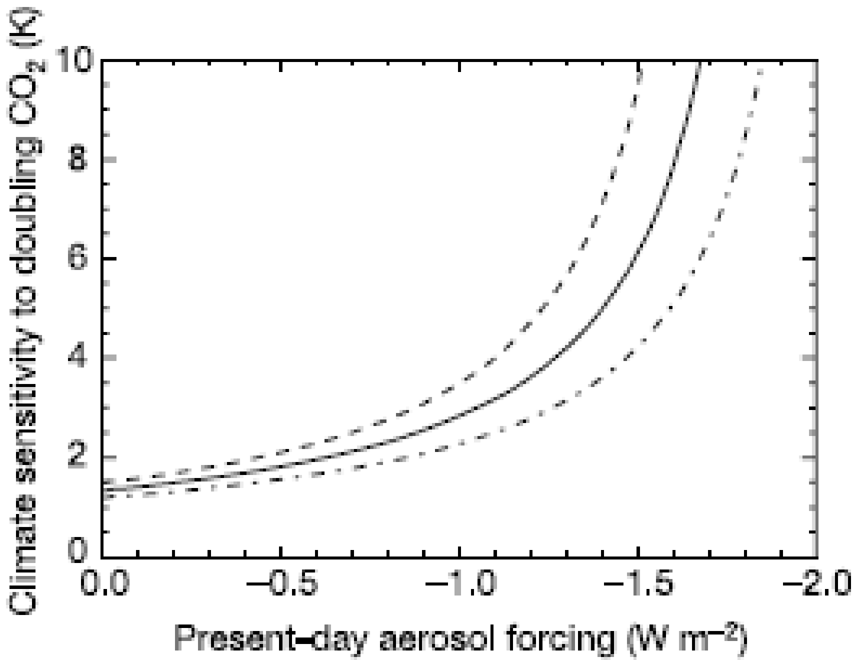
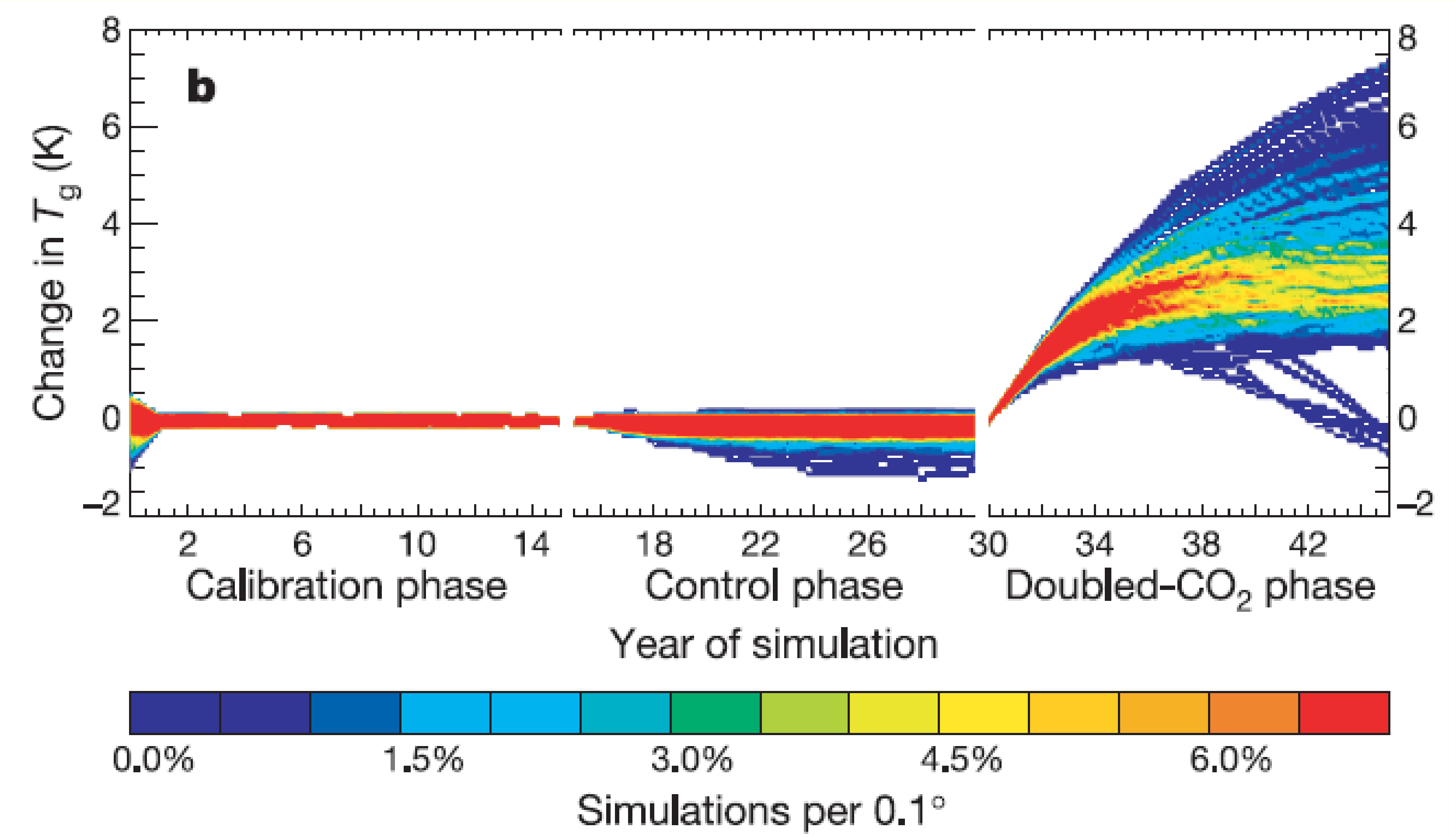


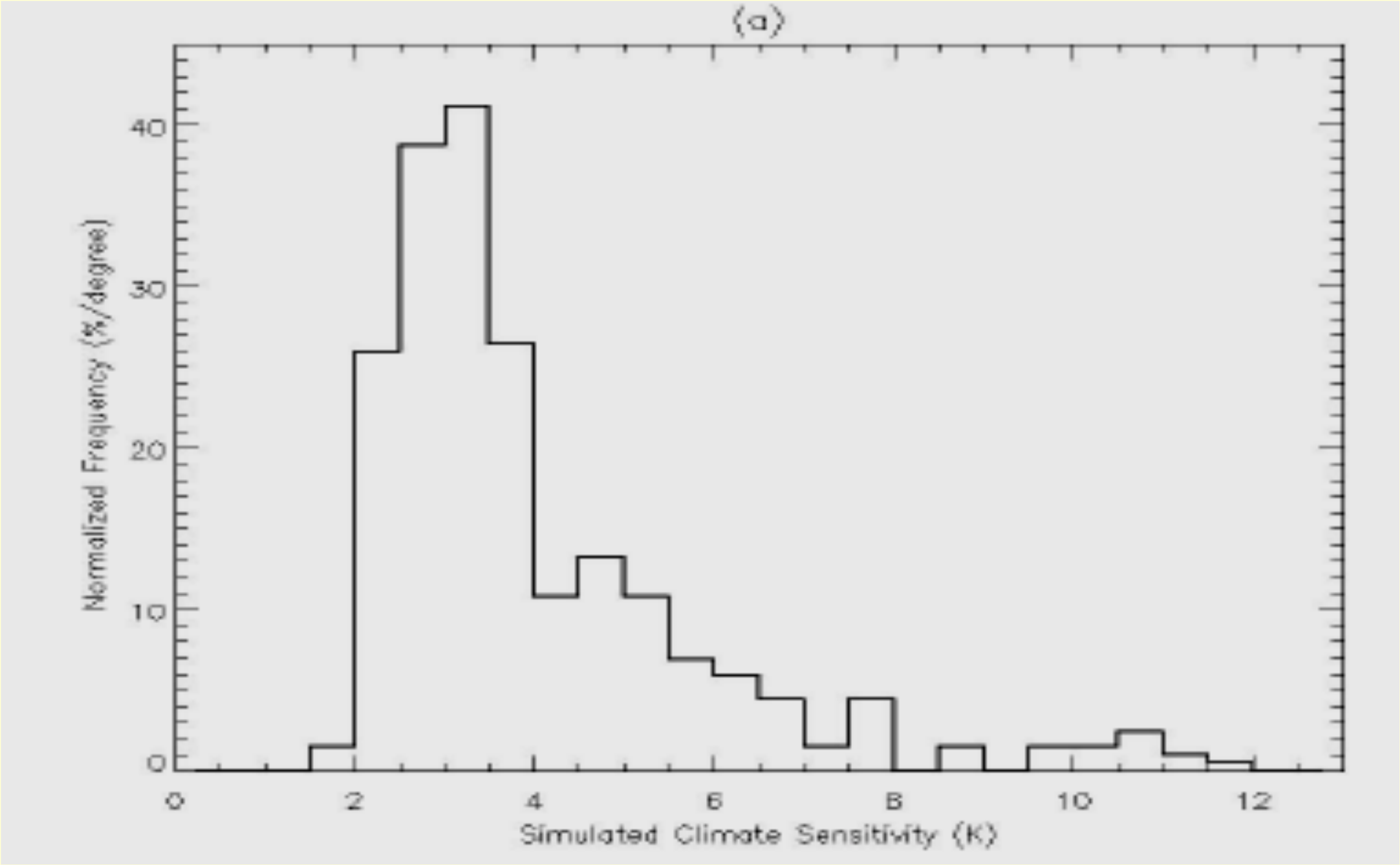
Figure 1 | Climate sensitivity required to explain the observed 1940–2000 warming as a function of the strength of aerosol radiative cooling. The solid line represents results using the central estimate of heat capacity (1.1 ± 0.5 GJ m^{-2} K^{-1}) from Levitus *et al.*[24], and the dashed (dot-dashed) lines represent the higher (lower) limit of this heat capacity. More details of the model are given in Box 3.

M.O. Andreae, C.D. Jones, P.M. Cox. 2005. Strong present day aerosol cooling implies a hot future. *Nature.*, **435**, 1187-1190.



Frequency distributions of T g (colours indicate density of trajectories per 0.1 K interval) through the three phases of the simulation

D. A. Stainforth, T. Aina, C. Christensen, M. Collins, N. Faull, D. J. Frame, J. A. Kettleborough, S. Knight, A. Martin, J. M. Murphy, C. Piani, D. Sexton, L. A. Smith, R. A. Spicer, A. J. Thorpe & M. R. Allen Nature.-2005.-V.433.

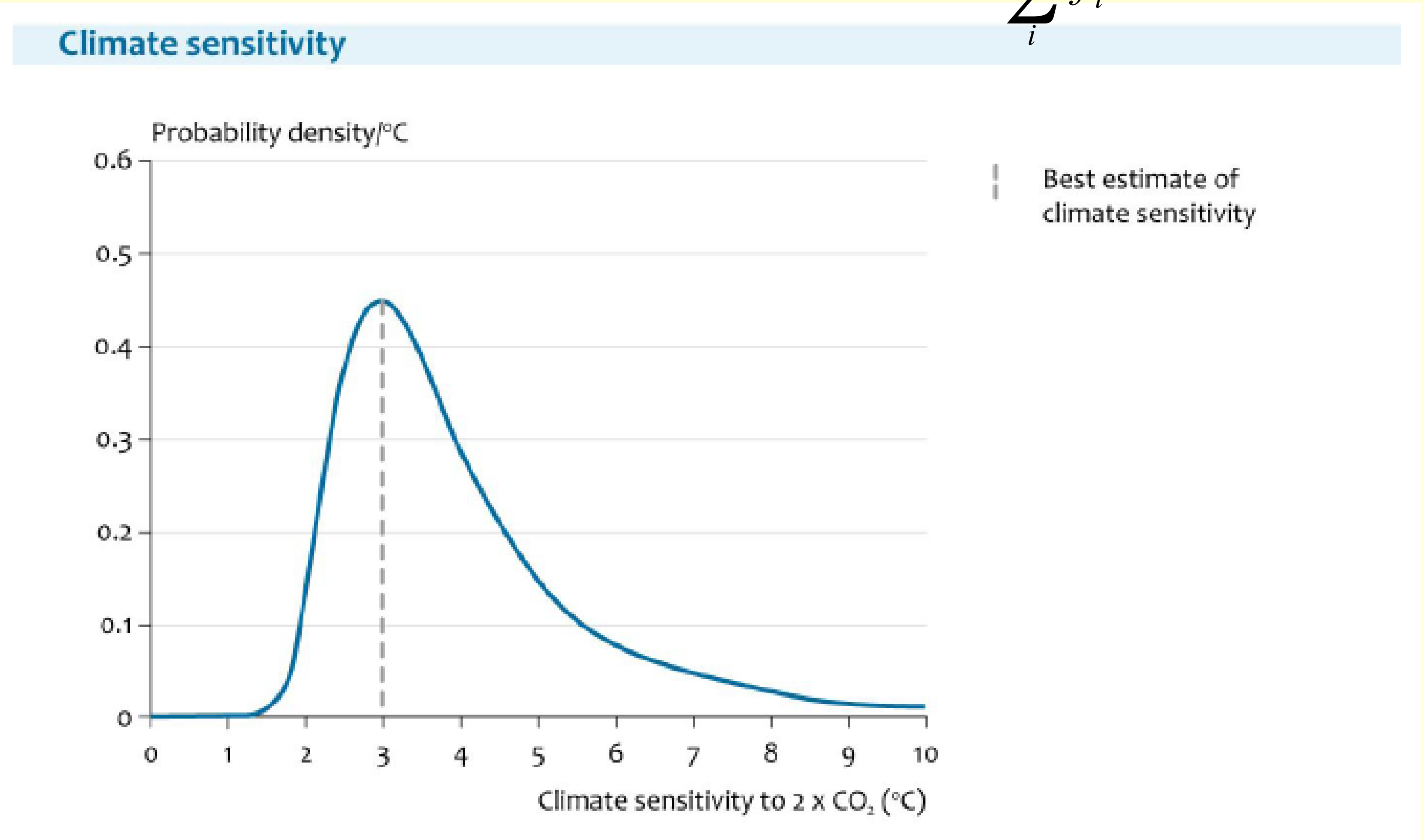


Probability (%) of corresponding climate sensitivity.

D. A. Stainforth, T. Aina, C. Christensen, M. Collins, N. Faull, D. J. Frame, J. A. Kettleborough, S. Knight, A. Martin, J. M. Murphy, C. Piani, D. Sexton, L. A. Smith, R. A. Spicer, A. J. Thorpe & M. R. Allen
Nature.-2005.-V.433.

$$C\frac{d\Delta T}{dt} = \Delta R_f + \sum_i f_i \Delta T$$

$$\Delta T = -\frac{\Delta R_f}{\sum_i f_i}$$



Roe and Baker. 2007. Why is climate sensitivity so unpredictable? Science, 318, 629–632.

$$\Delta T = -\frac{\Delta R_f}{\sum_i f_i}$$

$$\Delta R_f = 4\,W \cdot m^{-2}$$

$f_I = -3.2\,W \cdot m^{-2} \cdot {}^{o}C^{-1}$ longwave insolation feedback

$f_{VW} = 1.8 \pm 0.18\,W \cdot m^{-2} \cdot {}^{o}C^{-1}$ water vapour feedback

$f_A = 0.26 \pm 0.08\,W \cdot m^{-2} \cdot {}^{o}C^{-1}$ surface albedo feedback

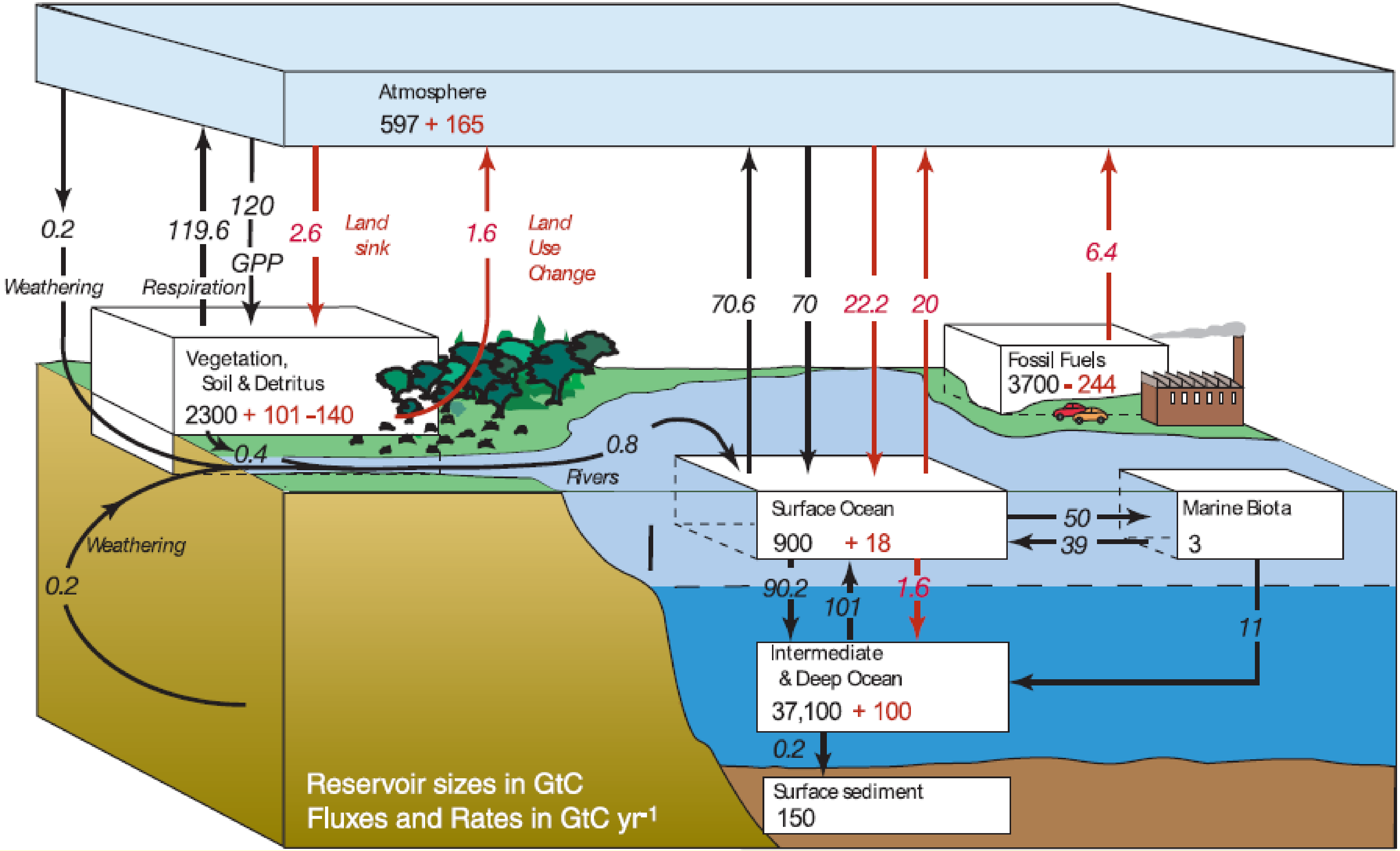
$f_C = 0.69 \pm 0.38\,W \cdot m^{-2} \cdot {}^{o}C^{-1}$ cloud feedback

$f_{TG} = 0.84 \pm 0.26\,W \cdot m^{-2} \cdot {}^{o}C^{-1}$ Lapse rate feedback

$$\Delta T_{AVERAGE} = 3.1\ {}^{o}C$$

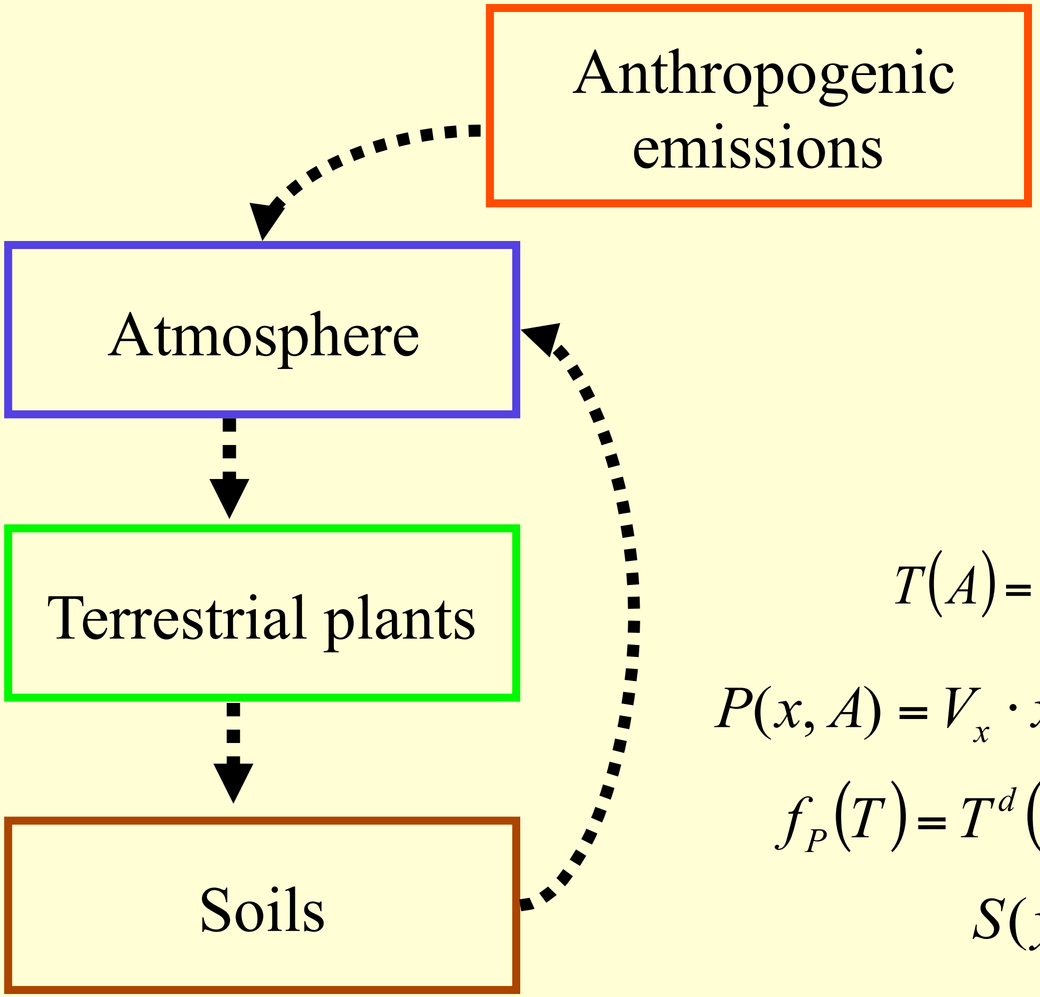
$$\Delta T_{MIN} = 1.83\ {}^{o}C \qquad \Delta T_{MAX} = 10.26\ {}^{o}C$$

Randal, D. A., et al., 2007: Climate models and their evaluation, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge Univ. Press, Cambridge, U. K.



Denman, K.L., et al., 2007: Couplings between changes in the climate system and biogeochemistry, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge Univ. Press, Cambridge, U. K.

INITIAL MINIMAL MODEL OF GLOBAL CARBON DYNAMICS



$$\begin{cases} \dfrac{dC}{dt} = fuel(t) \\ \dfrac{dx}{dt} = P(x, A, T(A)) - D(x) \\ \dfrac{dy}{dt} = D(x) - S(y, T(A)) \\ C = A + x + y \end{cases}$$

$$T(A) = T_o + T_{del} \cdot \log_2\left(\frac{A}{A_0}\right)$$

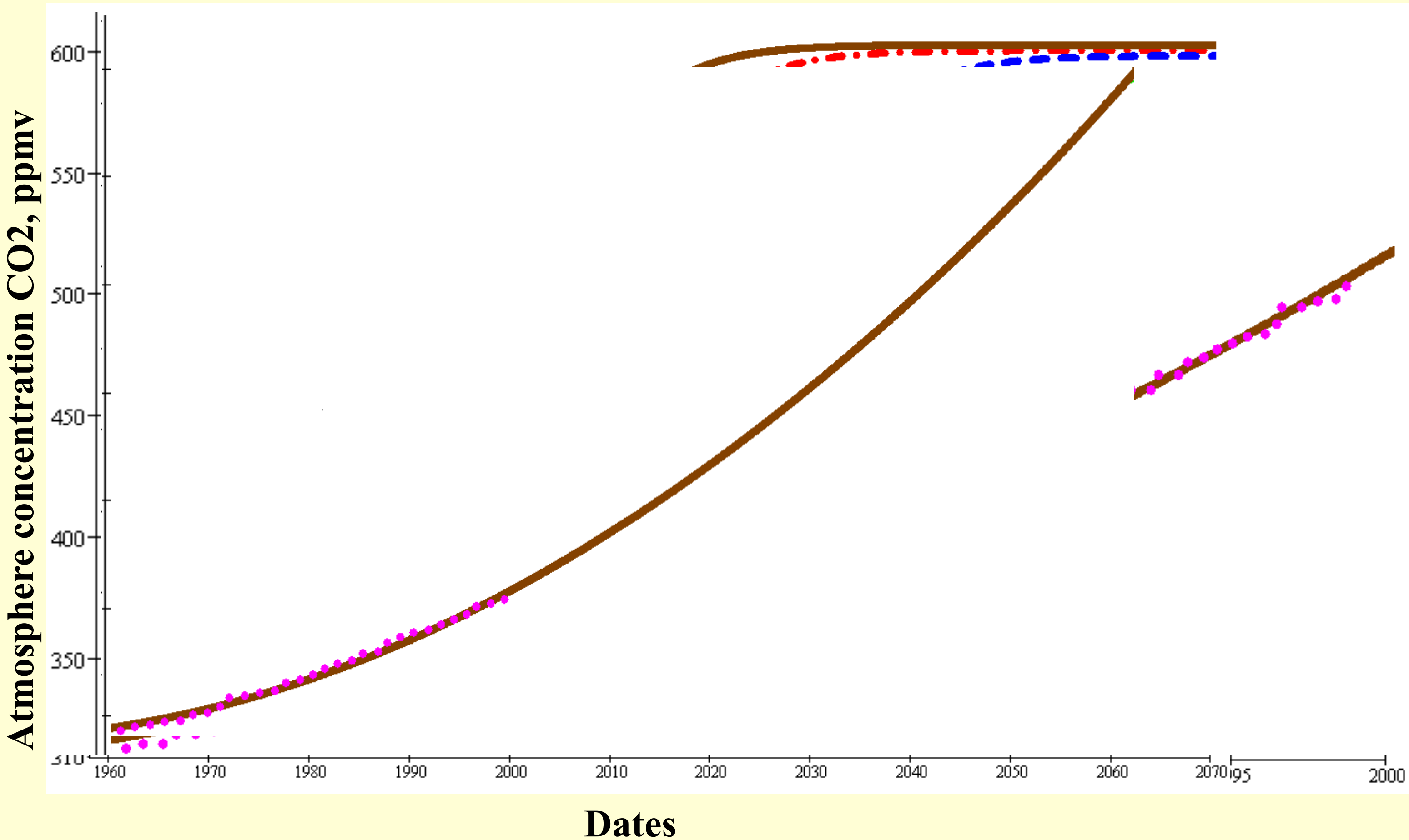
$$P(x, A) = V_x \cdot x \cdot (x_{\max} - x) \cdot V(A) \cdot f_P(T(A))$$

$$f_P(T) = T^d (T_P - T) \qquad D(x) = V_d \cdot x$$

$$S(y, T) = V_s \cdot y \cdot f_M(T)$$

S.I. Bartsev, A.G. Degermendzhi, D.V. Erokhin. 2008. Principle of the worst scenario in the modelling past and future of biosphere dynamics. *Ecological modelling.* **216/2**, 160-171.

RESULTS OF INTIAL MINIMAL MODEL

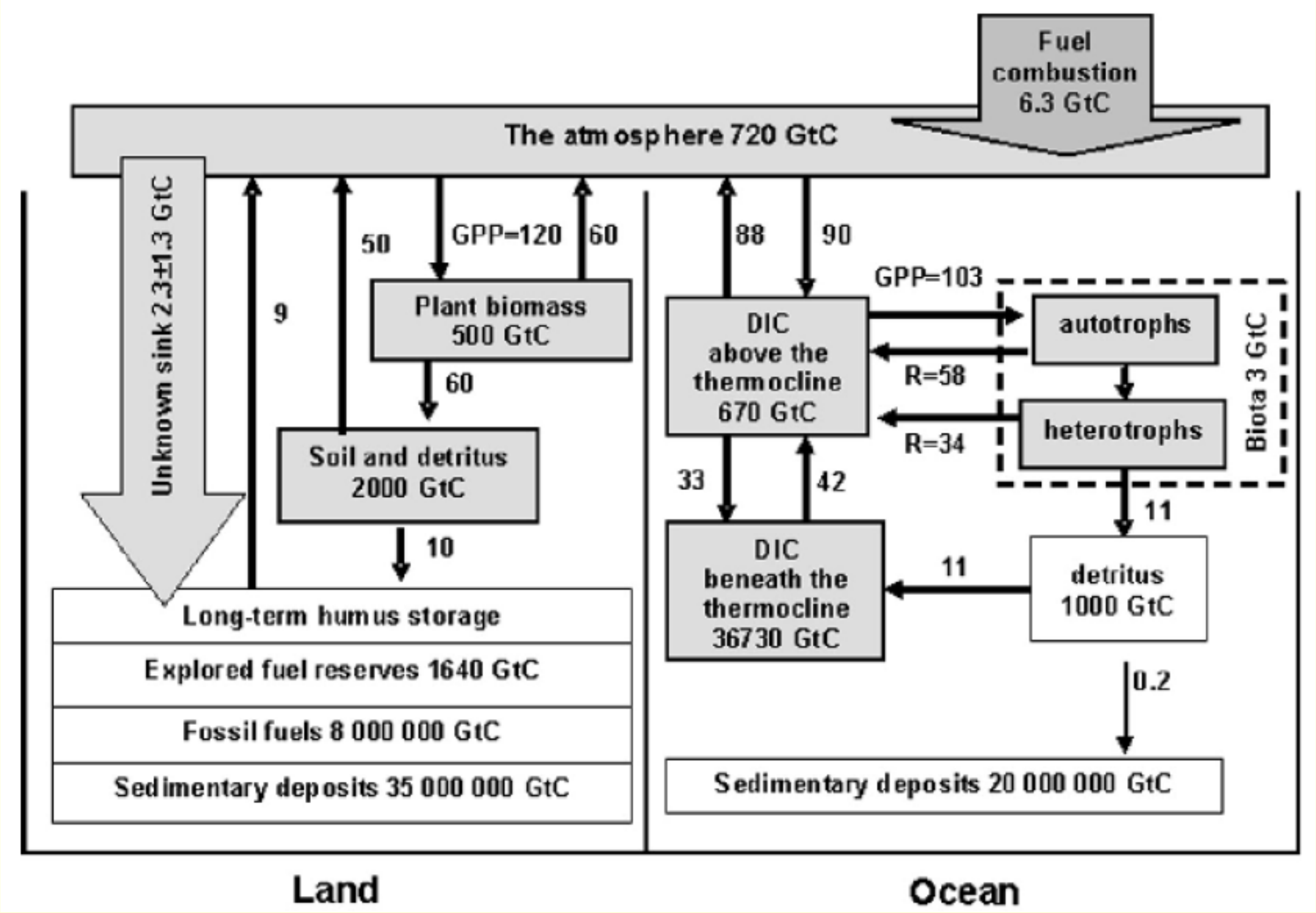


Dynamics of atmosphere CO_2 at different dates of completely stopping the emission.

- Mauna-Loa data; - 2059; - 2064; - 2070;

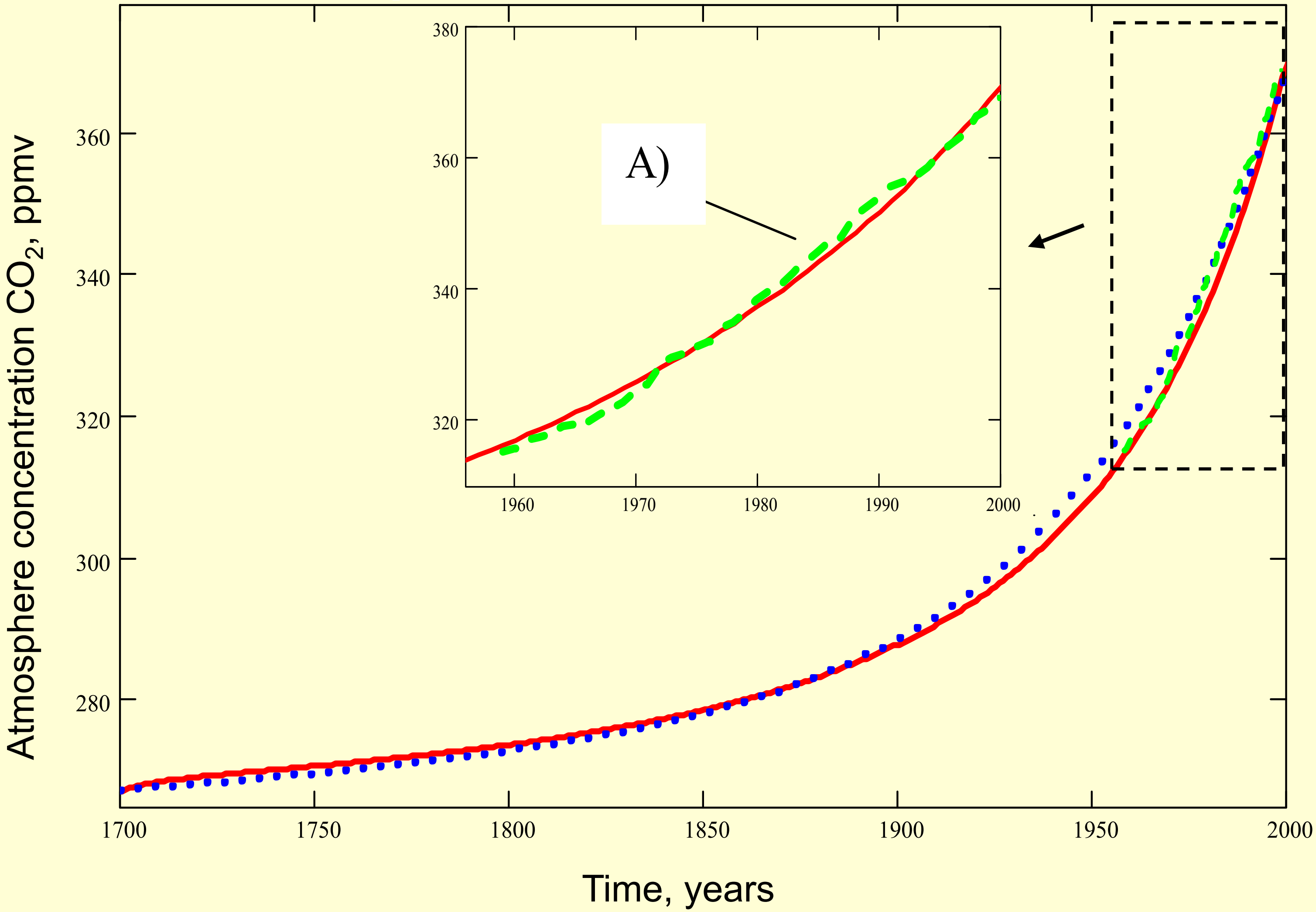
- 2080.

INTEGRATED MINIMAL MODEL OF GLOBAL CARBON DYNAMICS



S.I. Bartsev, A.G. Degermendzhi, D.V. Erokhin. 2008. Principle of the worst scenario in the modelling past and future of biosphere dynamics. *Ecological modelling.* **216/2**, 160-171.

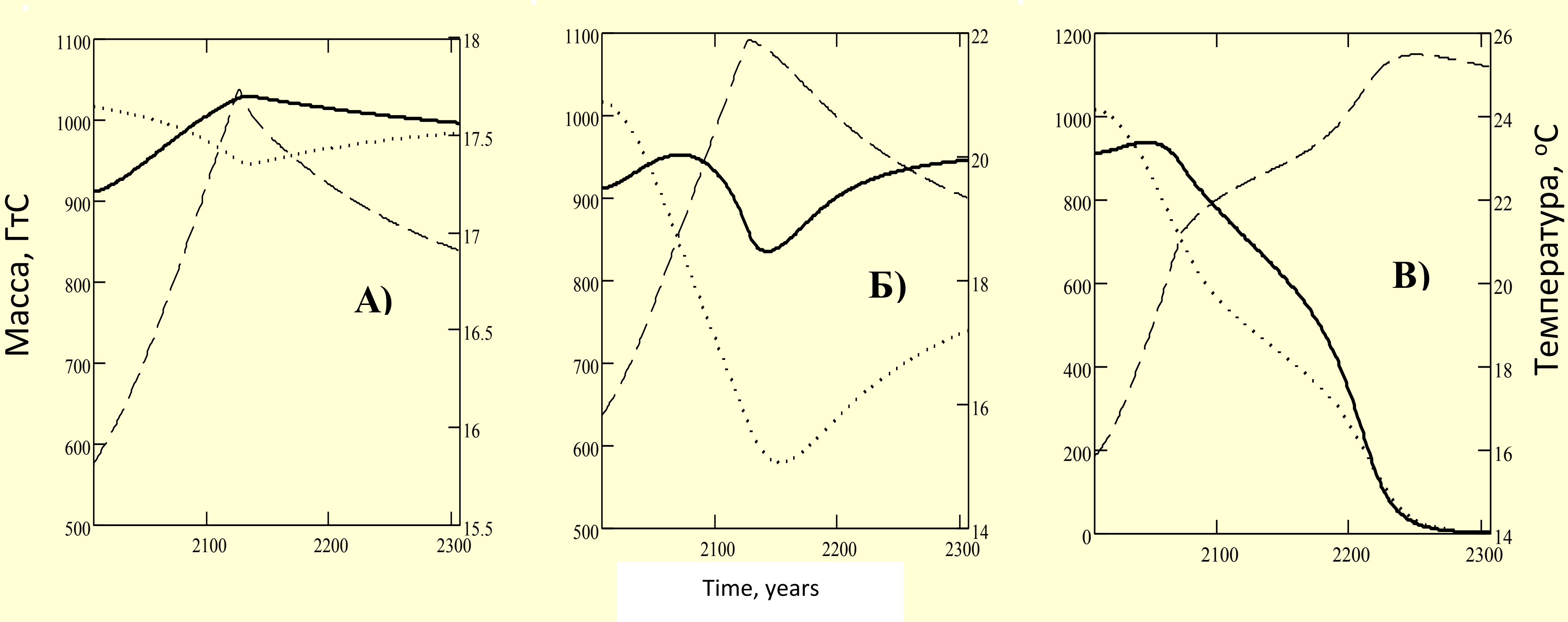
VERIFICATION OF INTEGRATED MINIMAL MODEL



Comparison of carbon dioxide dynamics by field data and numerical experiments.

A) – comparison with Mauna-Loa meseurments.

RESULTS OF INTEGRATED MINIMAL MODEL

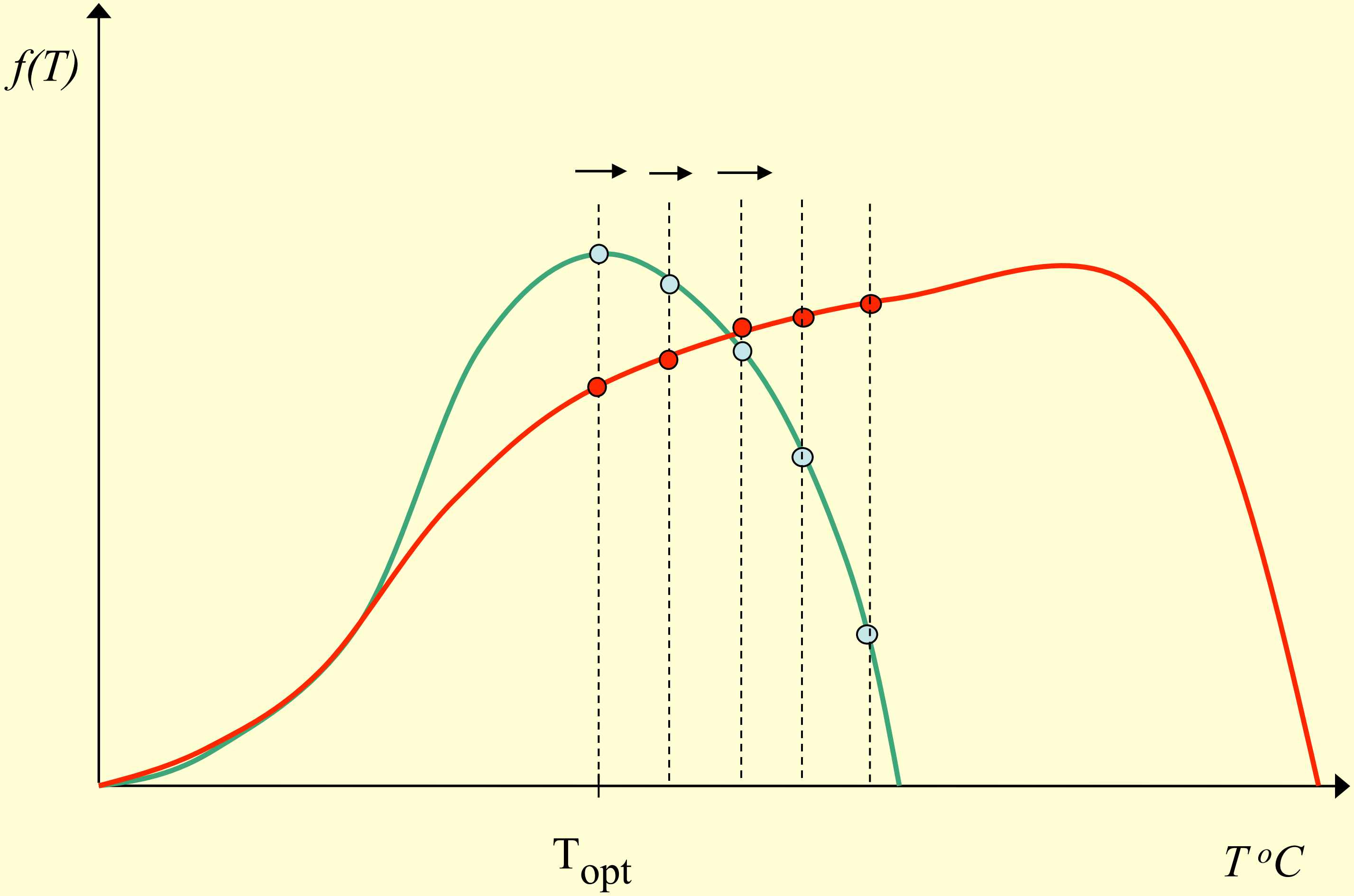


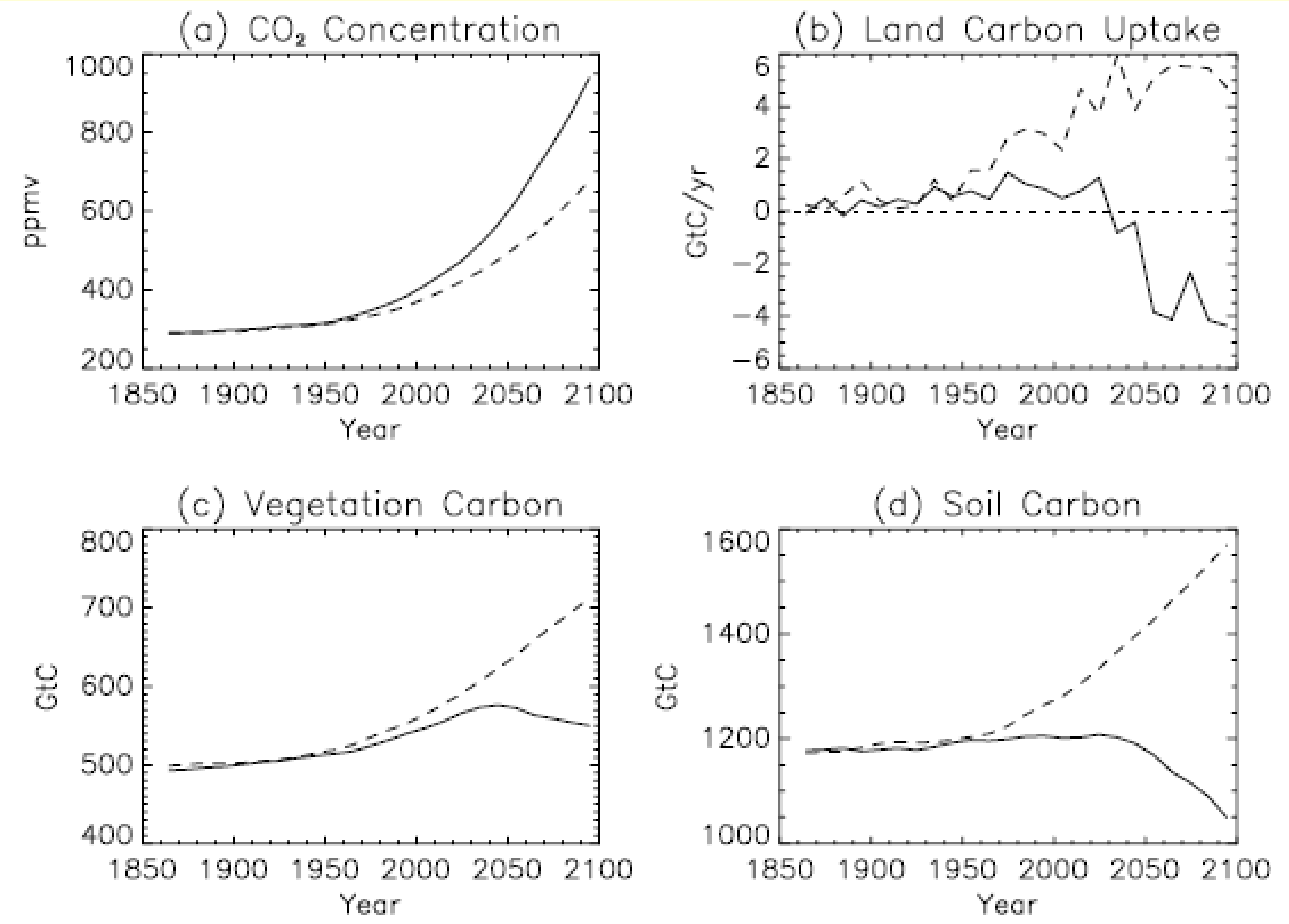
Variants of scenarios for the development of the biosphere under different values of climate sensitivity parameter T_{del}: (A) – 2°C; (Б) – 4.5°C; (B) - 6°C.

In case (B) the irreversibility date is 2073 г.

Solid line – biomass, dotted – dead organic matter, dashed – temperature.

Temperature influence on photosynthesis and soil respiration





The GCM is based on the third Hadley Centre coupled ocean-atmosphere model, HadCM3, coupled to an ocean carbon cycle model (''HadOCC'') and a dynamic global vegetation model (''TRIFFID'').

P.M. Cox, R.A. Betts, M. Collins, P.P. Harris, C. Huntingford, C.D. Jones. 2004. Amazonian forest dieback under climate-carbon cycle projections for the 21st century. *Theor. Appl. Climatol.*, **78**, 137-156.

Sufficient condition for runaway feedback

$$\frac{dC_T}{dt} = P - S$$

$$P = P_0 \cdot f_F(A) \cdot f_P(T)$$ - gross primary production (GPP)

$$S = S_0 \cdot C_T \cdot f_P(T)$$ - total respiration

$$C_T^{eq} = \frac{P_0 \cdot f_F(A) \cdot f_P(T)}{S_0 \cdot f_S(T)}$$ - equlibrium value of terrestrial carbon

$$\frac{dC_T^{eq}}{dA} = C_T^{eq}\left(\frac{1}{f_F(A)}\frac{\partial f_F(A)}{\partial A} + \frac{\partial T}{\partial A}\left(\frac{1}{f_P(T)}\frac{\partial f_P(T)}{\partial T} - \frac{1}{f_S(T)}\frac{\partial f_S(T)}{\partial T}\right)\right)$$

Sufficient condition for runaway feedback

$$\frac{dC_T^{eq}}{dA} = C_T^{eq}\left(\frac{1}{f_F(A)}\frac{\partial f_F(A)}{\partial A} + \frac{\partial T}{\partial A}\left(\frac{1}{f_P(T)}\frac{\partial f_P(T)}{\partial T} - \frac{1}{f_S(T)}\frac{\partial f_S(T)}{\partial T}\right)\right)$$

The land will tend to amplify CO2 induced climate change if terrestrial carbon decreases with increasing CO2

$$\frac{dC_T^{eq}}{dA} < 0$$

The land would self-sustaining lose carbon to atmosphere, causing runaway feedback if:

$$\frac{dC_T^{eq}}{dA} < -(1 + OceanUptake)$$

There *OceanUptake* is a fraction of any increase in atmospheric carbon that the ocean takes-up

Summary

- Mathematical models showing possibility of catastrophic changes were developed. Proposed parameterizations are not contradicting to field data, observations and experiments, parameters are from confidence intervals.

- We introduced a notion of irreversible date – then concentration of CO_2 is so, that the land would self-sustaining lose carbon to the atmosphere even in the absence of anthropogenic emissions.

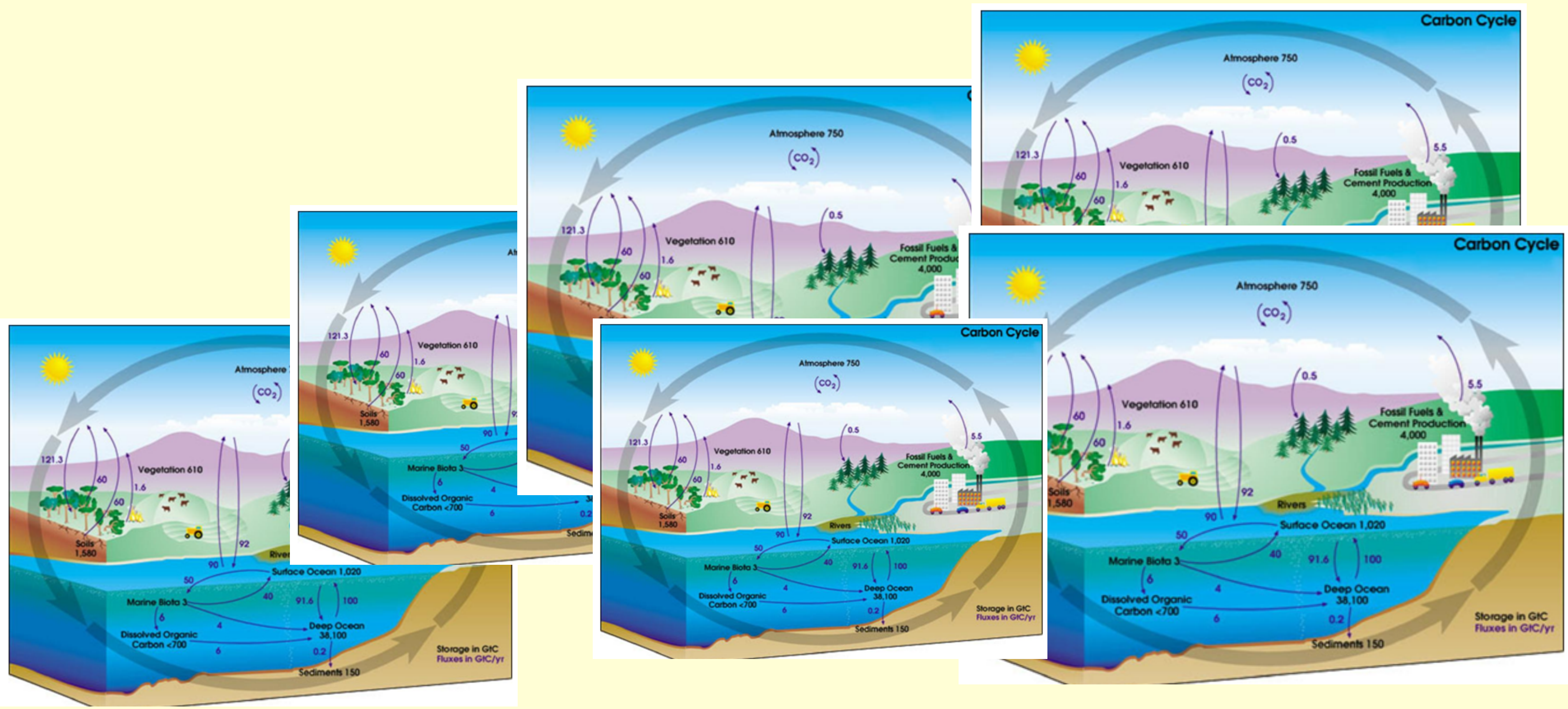
- Sufficient condition for runaway feedback was estimated.

- Experiments on closed laboratory ecosystems are carried out for investigating mechanisms used in models.

- Minimal climate model based on the principle of the worst scenario is under development. It will be coupled with minimal biosphere model

- It will be very interesting to investigate described effects using more complex models.

Thank you for attention



Эмпирическая зависимость роста среднегодовой глобально приповерхностной температуры от концентрации CO_2 (Gifford, 1993):

$$T(A) = T_o + T_{del} \cdot \log_2\left(\frac{A}{A_0}\right)$$

где ***A*** – текущее количество углерода в атмосфере;

Ao – количество углерода в атмосфере в момент измерения среднегодовой приповерхностной температуры *To*, которая равна 15.5°C в настоящее время;

T_{del} **–** чувствительность климата.

Система уравнений модели имеет следующий вид:

суша

- Изменение количества углерода в биомассе живых растений:

$$\frac{dx}{dt} = P(x, A, T(A)) - D(x)$$

- Динамика органических остатков:

$$\frac{dy}{dt} = D(x) - S(y, T(A))$$

Функция скорости роста растительной биомассы (ГтС/год) имеет вид:

$$P(x, A, T) = V_p \cdot x \cdot (x_{\max} - x) \cdot V(A) \cdot f_p(T(A))$$

- где ***x*** – количество углерода в растительной биомассе (ГтС);
- ***A*** – атмосферный углерод (ГтС);
- ***T*** – среднегодовая глобальная приповерхностная температура;
- ***Vp*** – масштабный фактор (1/(ГтС×год));
- x_{max} – предельное количество биомассы, зависящее от предельной допустимой плотности растительного покрытия (ГтС) и задается в модели как x_0G , где x_0 - количество наземной биомассы растений в настоящее время,
- ***G*** – коэффициент, характеризующий возможность растений увеличить количество биомассы.

Функция *V(A)* описывает рост биомассы в виде функции Моно:

$$V(A) = \frac{A}{K_A + A}$$

- Скорость отмирания биомассы (ГтС/год) записывается в простом виде:

$$D(x) = V_d \cdot x$$

где V_d – масштабный фактор;

x – количество углерода (Гт) в биомассе

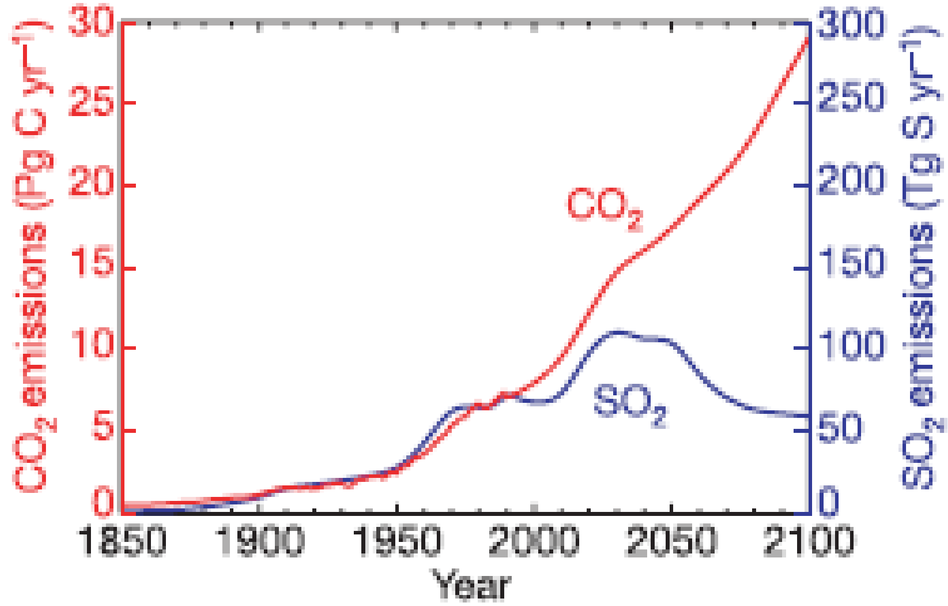
- Скорость почвенного дыхания (разложение мертвой органики) и выделения CO_2 в атмосферу:

$$S(y,T) = V_s \cdot y \cdot f_M(T)$$

где V_S - масштабный фактор;

y – количество углерода в мертвой биомассе (Гт);

$f_M(T)$ – функция типа (5) выражающая температурную зависимость почвенного дыхания, при больших значениях максимальной температуры



Box 2 Figure | Historical CO_2 and SO_2 emissions from 1850–2000, followed by projected values to the year 2100 from the SRES[25] A2 scenario.