Reliability of the future climate change forecast

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One of the main questions arising in the modeling of future climate change is the question about reliability of these forecasts or how the model results will represent actual climate change. The comprehensive answer on this question is not possible until the direct measurements will show the validity of the forecast. Nevertheless, it is a natural thing that one wants to estimate the reliability of future climate change forecast right now. It is possible to state about the reliability of the forecast if one know how the model reproduces the modern climate and also its change during the last century. In addition it is possible to obtain climate forecast, if one have information about future climate forcings. It is well-known that main forcing, which determines the climate change in the next century is considered to be an increasing of concentrations of greenhouse gases due to human activity and first of all carbon dioxide concentration. So the crucial factor for the climate change forecast is how the concentrations of these gases will grow with time. But the last factor depends on the amount of fossil fuel which will be burned due to the human activity. In accordance with estimates of IPCC experts for different scenarios of human activity it is expected to be burned about 1.0-2.5 thousands Gt of fuel, in carbon equivalent. One should remind that total amount of explored fossil fuel reserves is estimated as 5 thousands Gt of carbon. Therefore it is accepted to consider a few different scenarios of greenhouse gases emissions. In this work we consider three scenarios: A2, A1B, B1 in accordance with them it will be burn out about 1.9, 1.6 and 1.0 of thousands Gt of carbon respectively. However not only emissions are necessary to know carbon dioxide concentration in the atmosphere because of major part of these emissions is absorbed by ocean and land ecosystems. This absorbing capability depends from climate itself and its changes. Therefore the concentration of carbon dioxide is determined very approximately for the given emission scenario. In accordance with comparison experiment of 10 climate models with carbon cycle incorporated, which results was published in 4^{th} IPCC report, for A1B scenario by 2100 from 42% to 72% of emission carbon dioxide will stay in the atmosphere and remaining part will be absorbed by the ocean and land ecosystems. We have a little knowledge about sources and sinks of other greenhouse gases, therefore the relative uncertainty of its concentrations forecasts are even larger.

Moreover, even in the case of exact knowledge of scenario of greenhouse and other gases concentrations, different models give different forecast of climate change for given scenario. Therefore, an ensemble of models is used to predict climate change. For this reason the coupled model inter-comparison projects (CMIP) are held. Last such experiment was held in 2004-2005. About 20 models participated in it. The results of comparison are prepared to be published in the 4^{th} IPCC report and some figures in this article, were taken from this report. Mainly on these figures are shown results from other models to compare them with results from INM model.

The standard method to estimate model sensitivity is a test to doubling of CO_2 concentration from modern or pre-industrial levels. Two experiments are possible: in the first, the simulations are held long enough to reach quasi-stationary response. In the second, one looks for the non-stationary response on CO_2 doubling, when the concentration of CO_2 is increasing monotonically with rate of 1% per year, to reach double value in 70 years. On fig. 1 is shown stationary and non-stationary response of models, participating in CMIP project, on CO_2 doubling, in globally averaged surface temperature. Stationary response is between 1.8 and 4.5K. Non-stationary response due to the heating ocean response is smaller and changes between 1.4 and 2.8K. For INM model stationary response is 2.1K, and non-stationary is 1.6K. It means that the sensitivity of INM model to CO_2 doubling is smaller than the mean sensitivity, but it is inside inter-model variability.

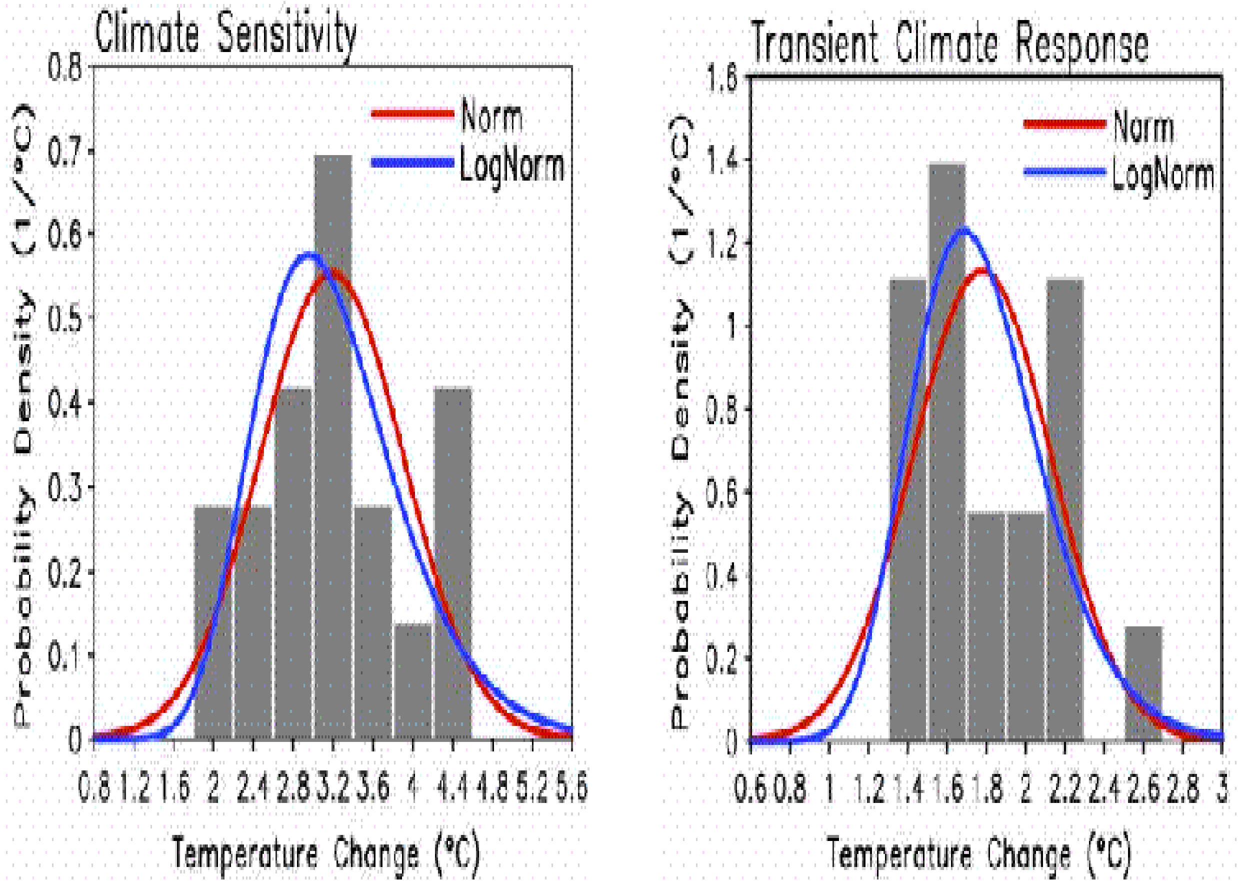

Fig.1. Histogram of surface temperature change for stationary(left) and non-stationary(right) response in model experiment with CO_2 doubling. By red and blue line is shown normal and log-normal distributions with the same mean value and dispersion.

One of the main reasons for the difference in model results is the different cloud response on global warming. The models in which total cloudiness is decreasing in response to the global warming, predict larger warming effect, than the models in which amount of cloudiness is increasing. Changes in cloudiness are accepted to characterize by its radiative forcing on the upper boundary of the atmosphere, i.e. changing of radiative balance due to cloudiness change providing that the others atmospheric parameters are the same. The changes in cloud radiative forcing in 2080-2099 relative to the 1980-1999 are depicted on the fig. 2. In the 11 models change in cloud radiative forcing is negative and in 5 it is positive. In the INM model the change of cloud radiative forcing is -1.3W/m^2, which value is slightly less than the mean value over all models. Just because the sensitivity of the INM model to CO_2 doubling is less than average value.

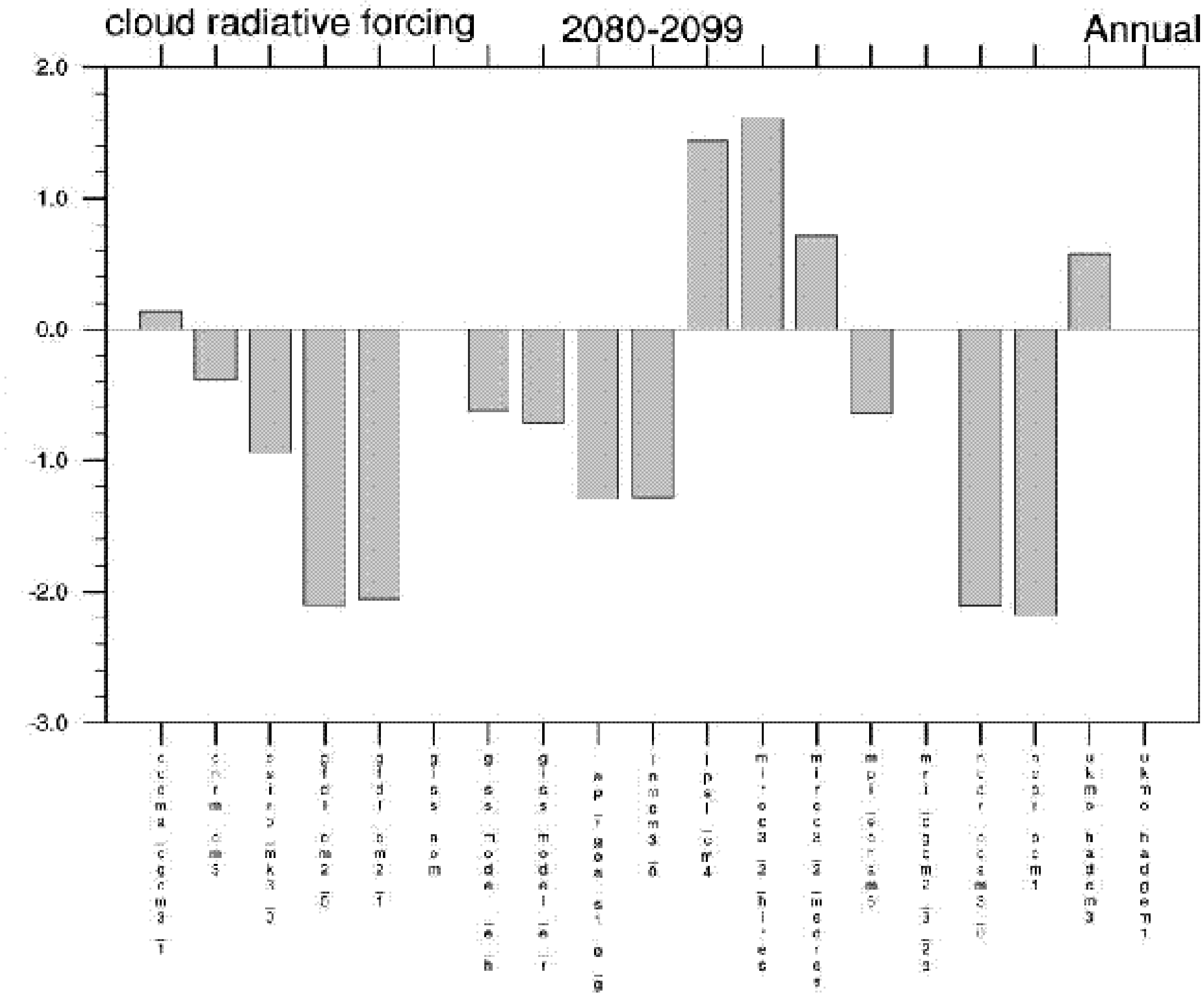

Fig.2. Change in cloud radiative forcing (W/m^2) in 2080-2099 years over 1980-1999 years for A1B scenario.

One can compare reconstruction of the globally-averaged temperature changes in 20th century with observations and model data (fig.3-4).

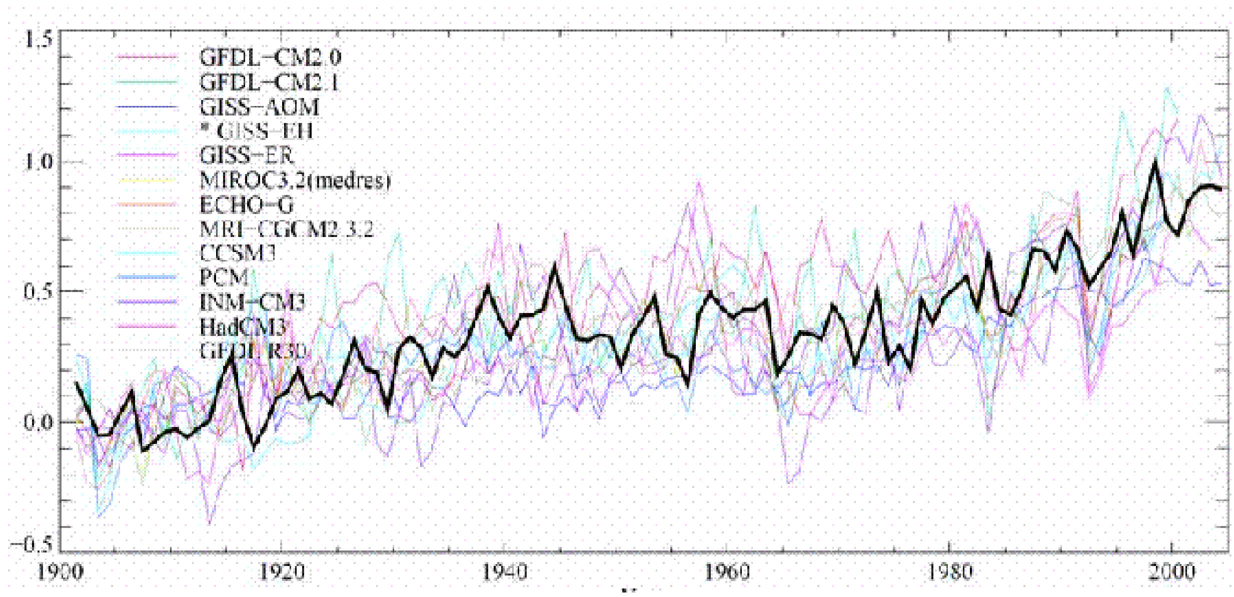

Fig.3. Time evolution of globally-averaged temperature (degrees) in 1900-2000 from observations (black solid line) and model data (colored lines).

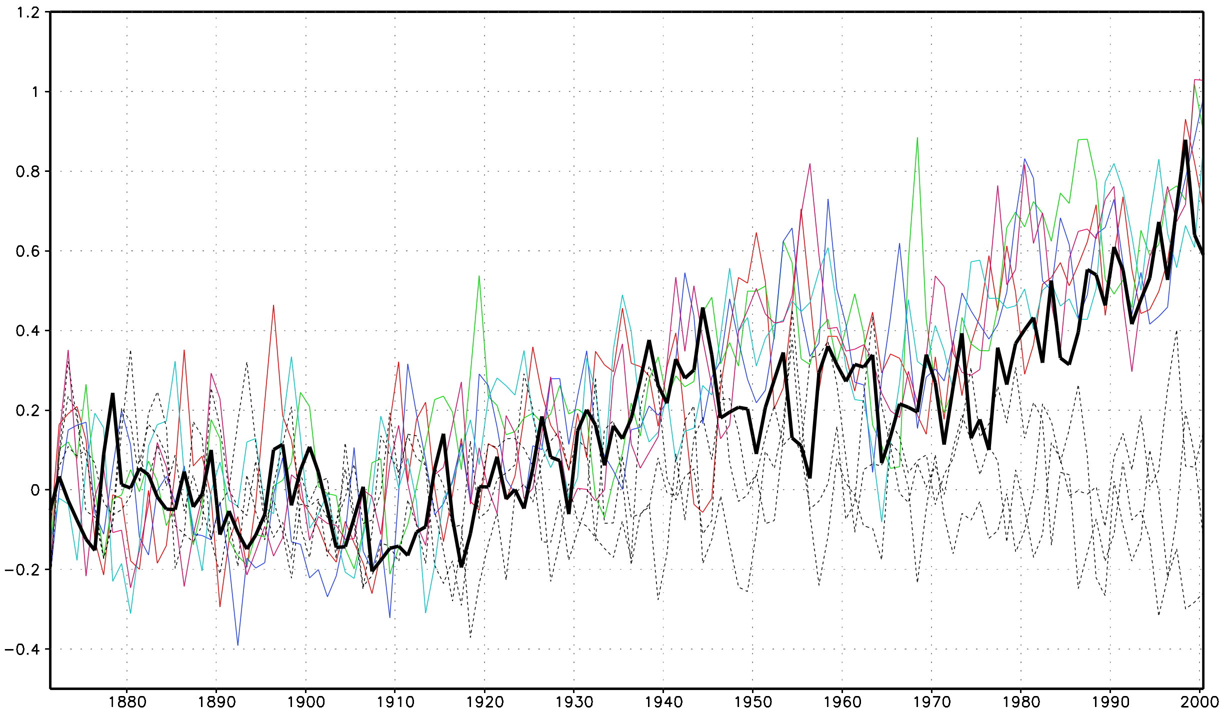

Fig.4. Times evolution of globally averaged temperature in 1871-2000 from observations (black solid line), INM model data from experiments with observed forcings (colored lines) and with forcings fixed at the level of 1871 year (black dotted line).

From observations the warming in the 20^{th} century is about 0.7K. A similar value obtained by averaging of model results, it is estimated from 0.5 to 1.0K by year 2000. In most models in 40^{th} - 50^{th} a warming is greater than in the 60^{th} - 70^{th} . An ensemble forecast composed from 5 INM model runs gives an estimate for warming between 0.7K and 1K, which is corresponding to the observations or somewhat larger. For comparison here are presented results of three model runs with concentrations of all radiationally active gases fixed at the level of 1871. There is no meaningful trend of temperature in all experiments. In the INM model we also have a warming in 40^{th}-50^{th} and a weaker warming in 60^{th} of 20^{th} century. One can conclude that the simulated time evolution of globally-averaged temperature is close to the observed.

Let us compare forecasts of globally-averaged temperature and precipitation for different scenarios of all models and INM model (fig.5-6). As it follows from figures, by year 2100 for scenario A2 the warming amounts between 2.3 and 3.9K. An average value of warming is about 3.4K, which is close to the forecast value from INM model. For scenario A1B the warming is between 1.9K and more than 4K. An average value is about 2.7K and for INM model it is 2.6K. For scenario B1 the warming is between 1.0 and 3.3K. An average value is 1.8K, for INM model it is 2.0K. Therefore a warming value predicted by INM model is close to the average value composed from all model forecasts.

An apparent contradiction between the fact, that sensitivity of the INM model to the CO_2 doubling is lower than average, can be resolved by taking in mind that in every scenario, besides greenhouse gases, also sulfate aerosols are considered. But in INM model an indirect effect of sulfate aerosols is not included, which may lead to increasing of the value of global warming. One can verify this most prominently during the first part of the 21^{st} century, when according to all scenarios, a concentration of the sulfate aerosols will reach its maximum. During these years the temperature anomaly over 1980-1999 is one of the largest in the INM model among other models. Another reason for higher warming rate in the INM model, than it could be expected from sensitivity experiment, is slightly weaker heating of the ocean in the INM model than in the average over all models. The last suggestion will be further investigated.

Under global warming all models also predict an increasing in the precipitation rate. For A2 scenario an increasing is about 2-8% by year 2100, an averaged value is about 5% and INM model gives an increasing is about 6%. For A1B scenario an increasing is about 1.5-7%, an averaged value is about 4.3% and INM model gives an increasing is about 4.7%. For B1 scenario an increasing is about 1.5-5.5%, an averaged value is about 3% and INM model gives an increasing about 3.5%. Therefore, for all scenarios an increasing of precipitation in INM model slightly larger than average value, but confine itself in deviation range obtained from all models.

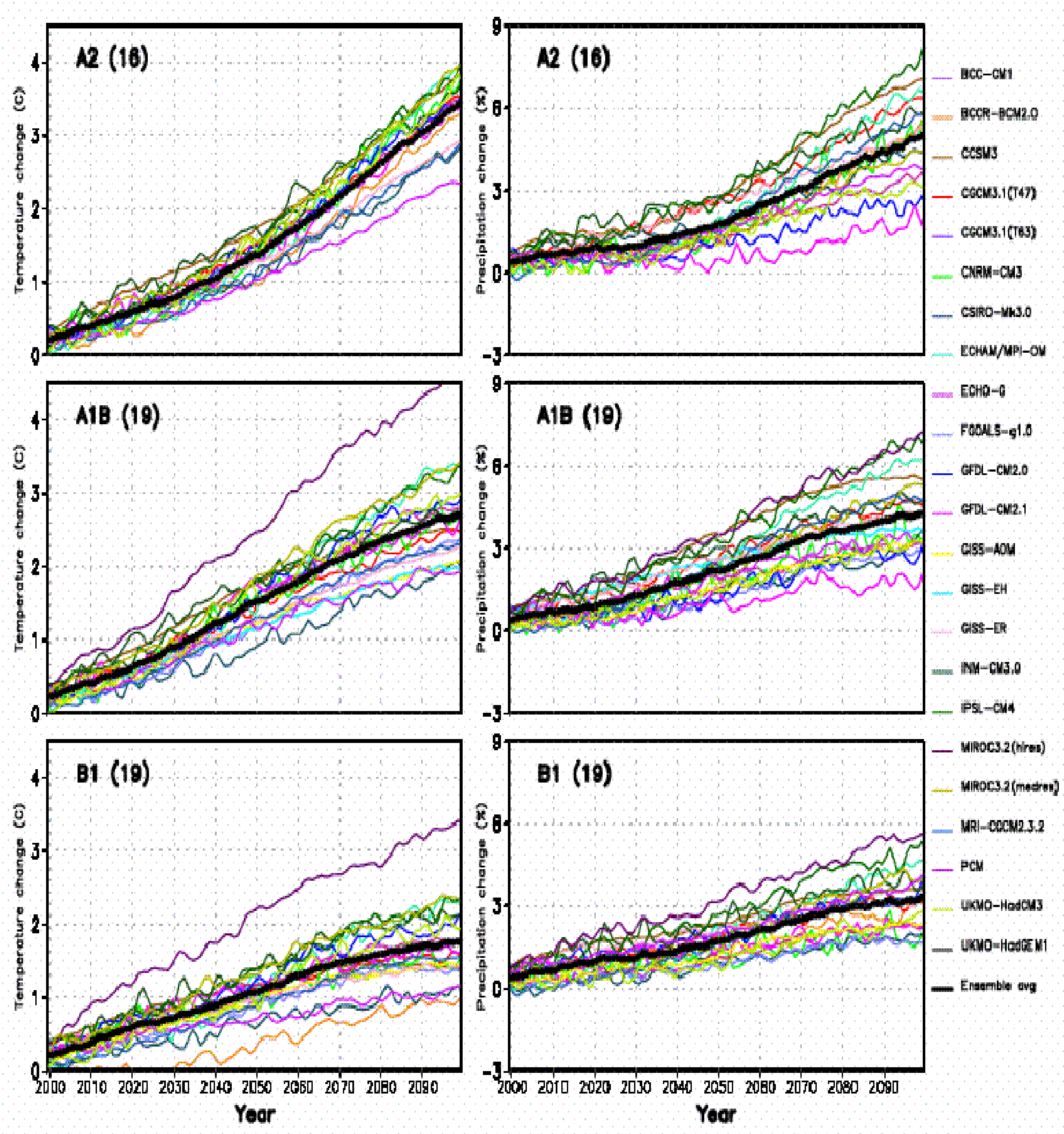

Fig.5. Anomaly of globally-averaged surface temperature in degrees (left) and precipitation in percent (right) for A2 scenario(top row), A1B(middle row) and B1(bottom row) in 2000-2100 over 1980-1999 for all models participating in CMIP project.

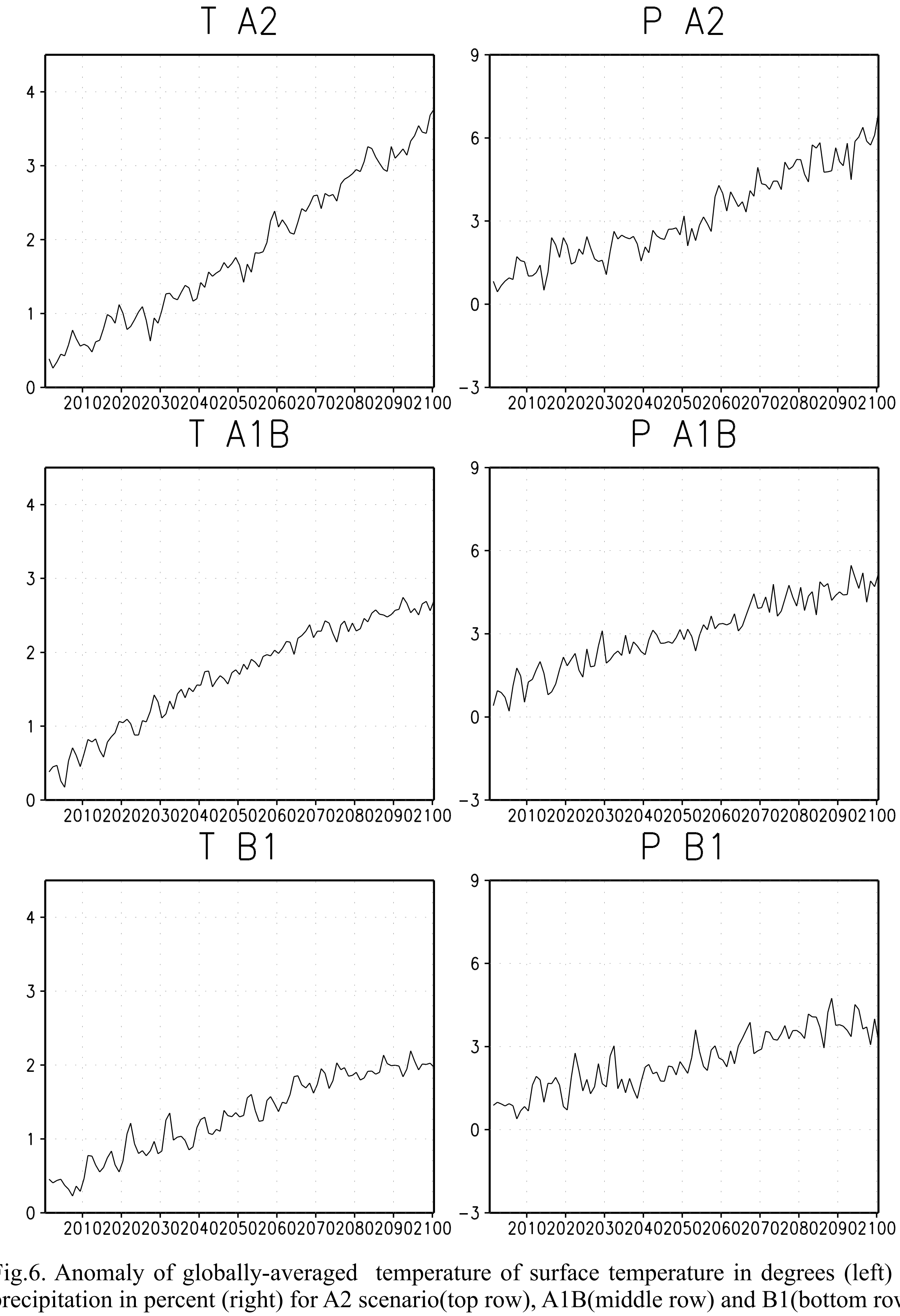

Fig.6. Anomaly of globally-averaged temperature of surface temperature in degrees (left) and precipitation in percent (right) for A2 scenario(top row), A1B(middle row) and B1(bottom row) in 2000-2100 over 1980-1999 for INM model.

One can consider a geographical distribution of climate changes due to the global warming in INM model and other models. On fig.7 are shown changes in precipitation, soil moisture, river runoff and precipitation in 2080-2099 for A1B scenario relatively to 1980-1999. Data are averaged over ensemble of 19 models participating in CMIP project. On the fig.8 are shown similar data but for INM model. In general we have a good agreement as well as qualitative and quantitative between the results of INM model and all other models. According to the data of INM model and other models the precipitation increases in the middle and high latitudes on 0.2-0.4 mm/day, and mostly decreases in the subtropics, including the area close to Mediterranean Sea. Also we have an increasing of precipitation near Ecuador and especially in tropics over the most part of Indian and Pacific oceans. Over the tropics in Atlantic ocean and central America we have a decrease in precipitation. Such changes in precipitation determine the changes in river runoff. The river runoff increases in the middle and high latitudes of Eurasia and Northern America and decreases in Central America and in the vicinity of the Mediterranean Sea according to INM model and other models data. The difference between model results are in South-Eastern Asia, where according to INM data it should be some increasing in precipitation but according to the data of all other models – some decreasing.

At global warming the evaporation increases over the most part of the oceans, excepting region south from Greenland, surroundings of Antarctica and some other regions according to the data both of INM model and all other models. Over the land the evaporation increases in the middle latitudes of Eurasia and Northern America. The changes in soil moisture are positive in some regions of middle latitudes of Eurasia and Northern America, and near Equator. Over rest part of the land the changes in soil moisture are negative or close to zero according to the data both of INM model and all other models. Therefore the results of INM model for these physical quantities are quite comparable with results averaged over all models.

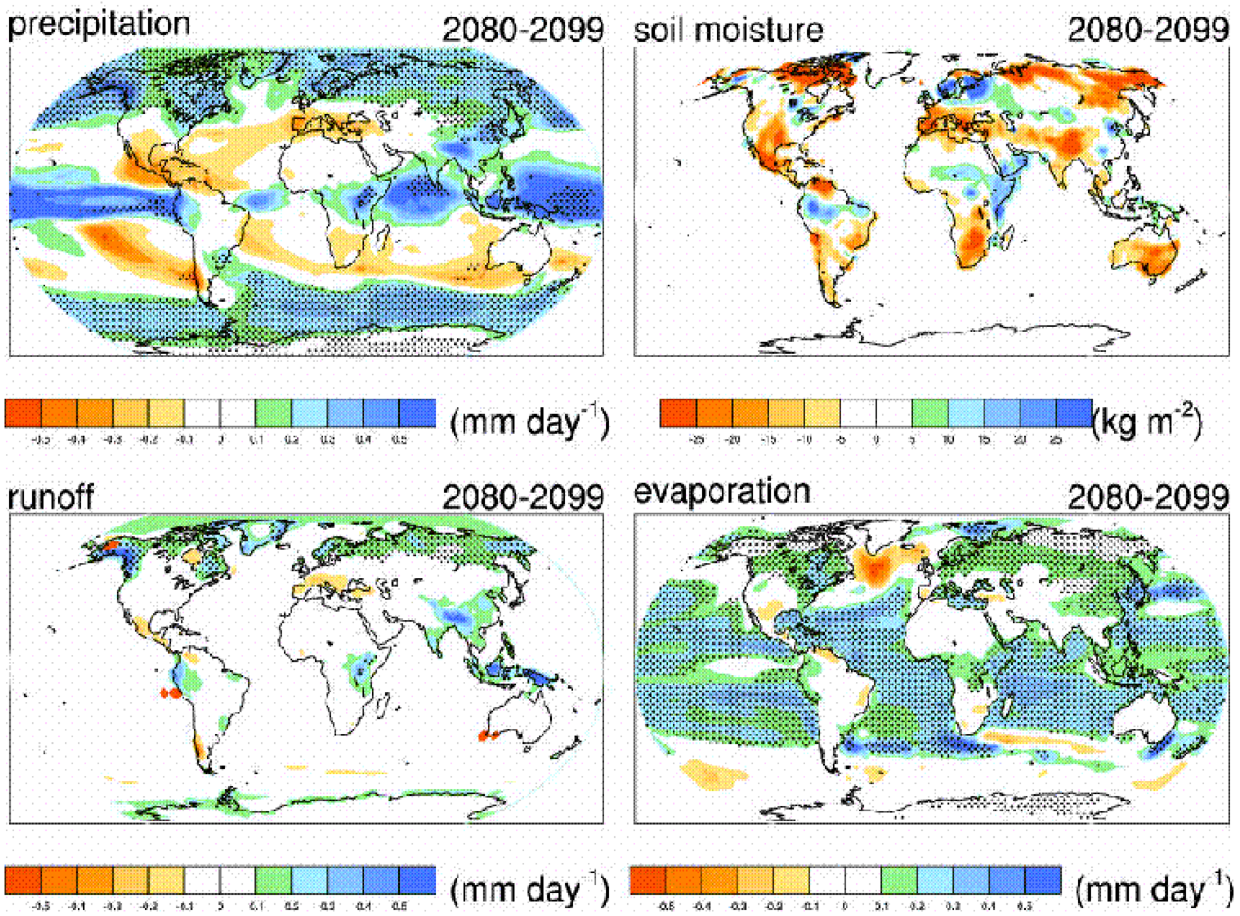

Fig.7. Differences in precipitation, mm/day (top left), soil moisture in upper 1m layer, kg/m^2 (top right), river runoff, mm/day (bottom left) and evaporation, mm/day (bottom right) in 2080-2099 for A1B scenario over 1980-1999 according to the all models data.

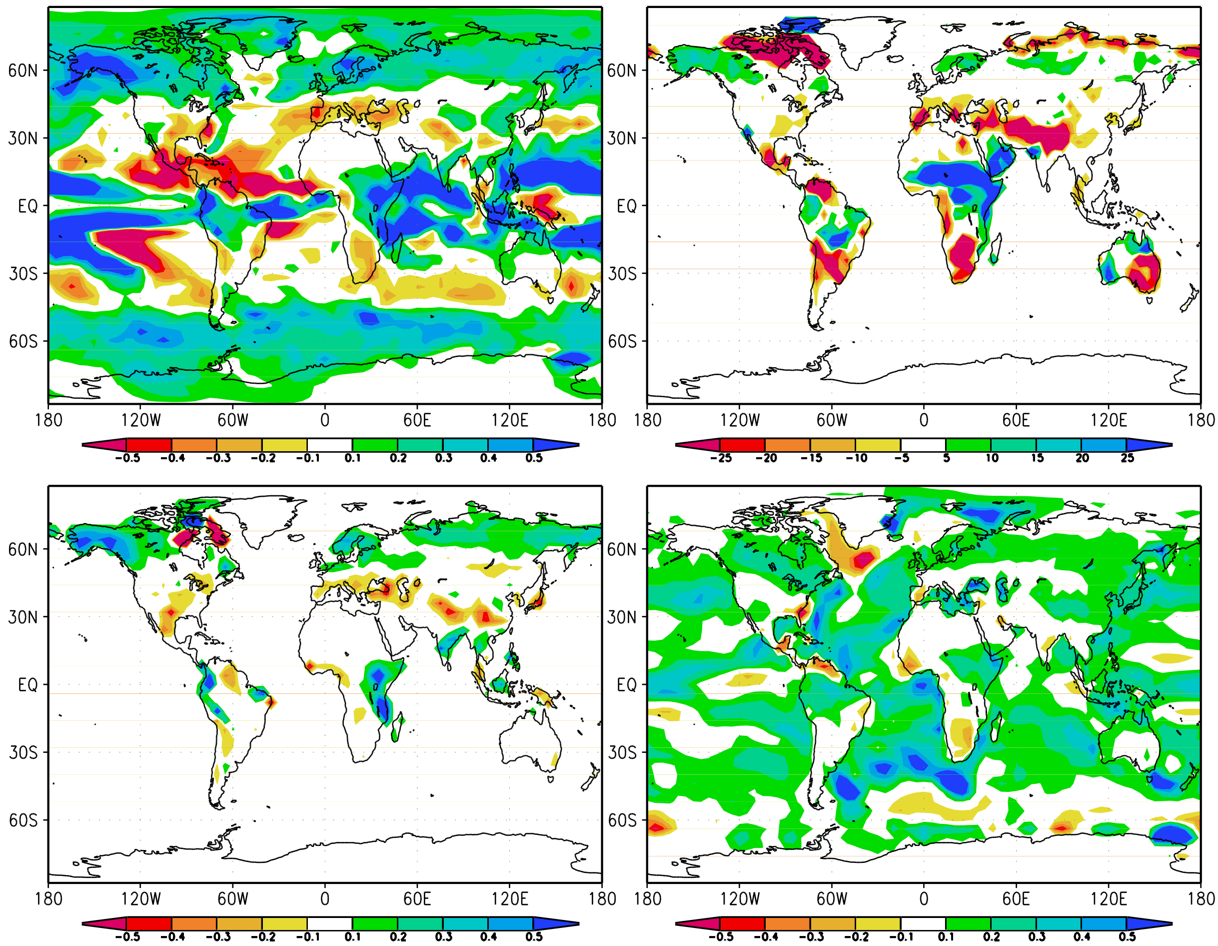

Fig.8. Differences in precipitation, mm/day (top left), soil moisture in upper 1m layer, kg/m^2 (top right), river runoff, mm/day (bottom left) and evaporation, mm/day (bottom right) in 2080-2099 for A1B scenario over 1980-1999 according to INM model data.

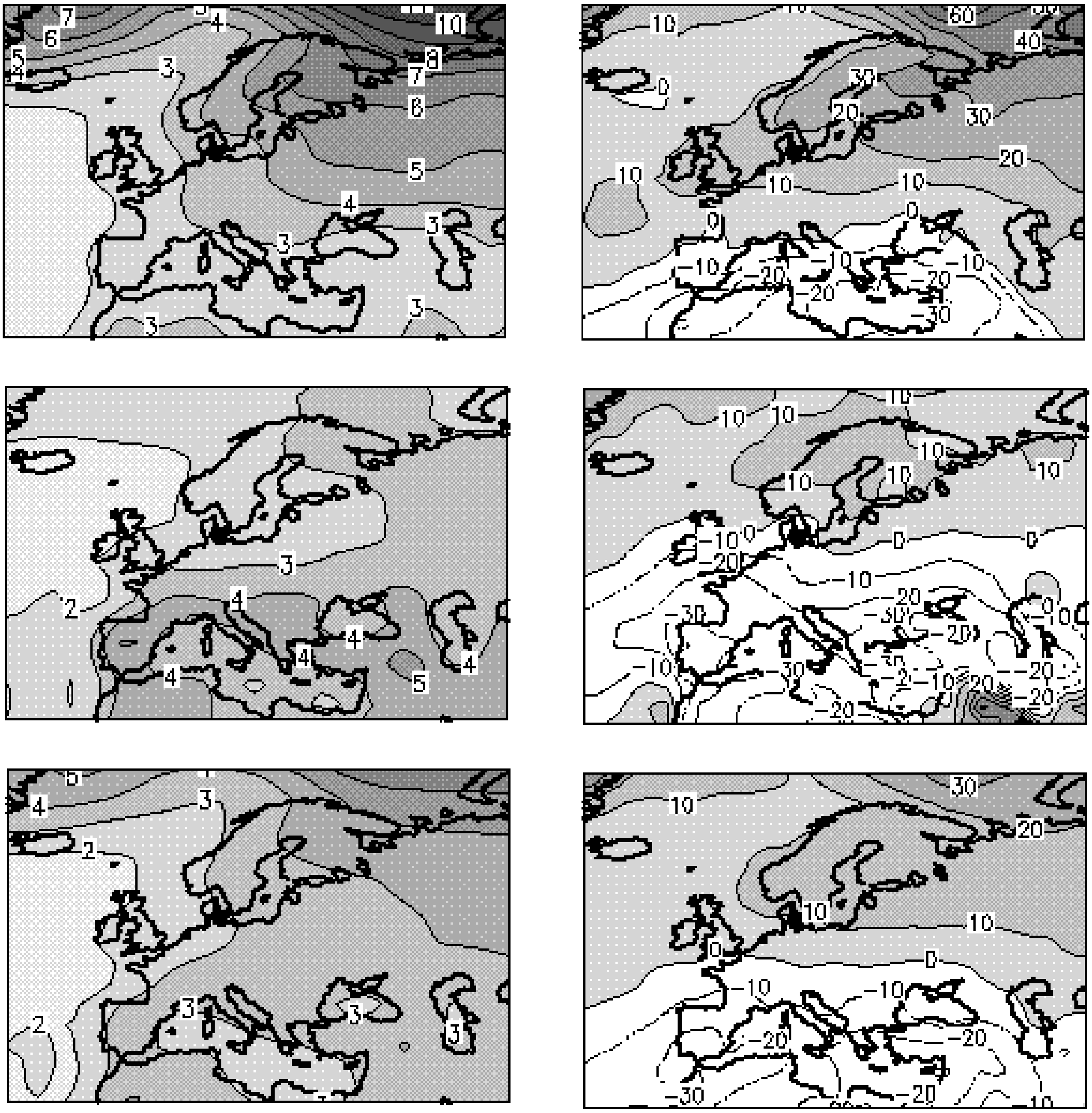

Fig.9. Surface temperature changes, degrees (left) and precipitation, percent (right) in Europe 2080-2099 relative to 1980-1999 for A1B scenario, data averaged over all models results for December-February (top row), June-August(middle row) and annual (bottom row).

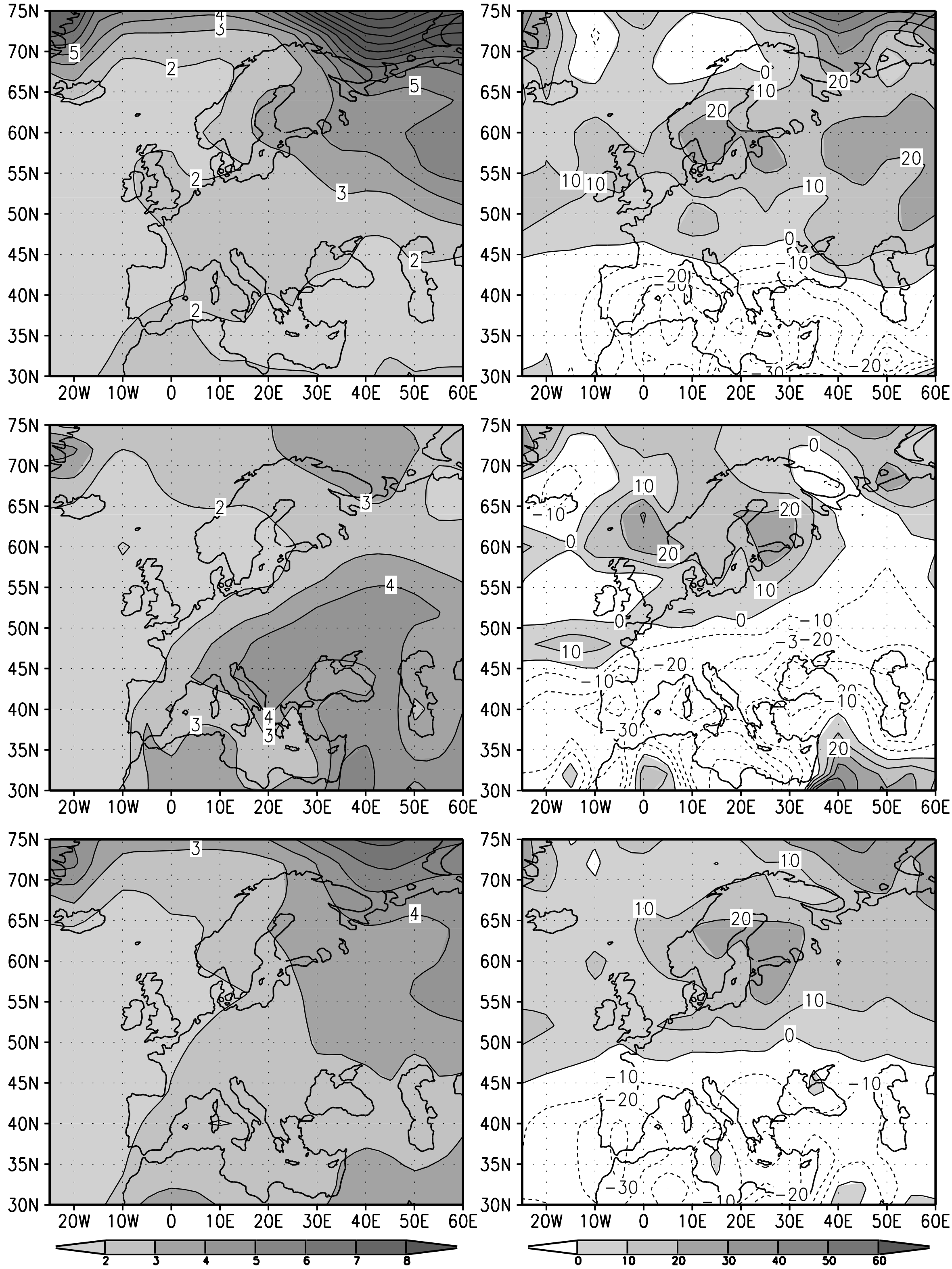

Fig.9. Surface temperature changes, degrees (left) and precipitation, percent (right) in Europe 2080-2099 relaive to 1980-1999 for A1B scenario, data from INM model in December-February(top row), June-August(middle row) and annual (bottom row).

One can compare differences in temperature and precipitation changes at global warming for data from INM model and for averaged data from all other models considering as an example climate changes in Europe (fig.9-10). During winter season the warming is strongest in Arctic, where temperature changes reach about 10 degrees, according to the data both from INM model and all other models. At the subtropics the warming is much weaker and it is about 3 degrees according to all other models, and 2-3 degrees according to INM model. In the Central European part of Russia the warming is about 3-5 degrees according to INM model and 4-6 degrees according to the all other models.

In summer the warming has a maximum about 4-5 degrees at subtropics according to the data both from INM model and all other models. Minimum of warming is over Atlantic (about 2 degrees in both cases) and also over northern part of considered region (about 3 degrees). In
In the Central European part of Russia is summer the warming is about 3 degrees for all other models and 3-4 for INM model.

Precipitation change for averaged data is positive in the northern part of considered region and reaches in winter 20-40% and in summer - 10-20%. Decrease in precipitation is most notable in the vicinity of Mediterranean Sea, where it is about 30%. The border between the regions of positive and negative precipitation changes is close to 45N in winter and to 50N in summer. All mentioned above features in precipitation changes are generally true for INM model data. Differences between averaged data and data from INM model are most pronounced in summer at the Eastern European part of Russia, where according to the INM model the precipitation slightly decreases but according to the averaged data it slightly increases.

One can compare the changes of sea ice cover in 2080-2099 for A1B scenario relative to 1980-1999 for data from INM model and data from all other models (fig.11-12). Without going into details of analysis of simulation of the modern sea ice cover by INM model, one should note that most significant changes occurs in summer Arctic, where sea ice cover decreases in a few times according to data from both INM model and all other models. In Antarctica as well as in summer Arctic the changes in sea ice cover are not so prominent.

On fig.13 is shown change in sea level due to the thermal heating of water. In the 20^{th} century rise of sea level in all other models is between 0 to 8 cm and in INM model it is about 4 cm. As it follows from 4^{th} IPCC report, observed sea level rise in the 20^{th} century was about 10-15 cm and more than half of this value is caused by thermal heating. Therefore in average the sea level rise due to the thermal heating is underestimated by the models. As the global warming progresses the more sea level rise is observed in the models. And it is interesting to note that the spread in model forecasts is larger for one scenario than the spread in average forecasts for all other models in three considered scenarios. Namely for A2 scenario the sea level rise by 2100 varies between models from 15 to 36 cm, for A1B scenario - from 12 to 36 cm, for B1 scenario - from 9 to 26 cm. For INM model corresponding values are 19,17 and 15 cm, therefore the data from INM model are close to the lower boundary of intermodel variability interval. This means that probably an effective ocean layer, which have enough time to be heated in INM model is slightly shallower than in average over all other models, but still inside intermodel variability interval.
This may be the reason why the non-stationary response to growing of greenhouse gases in INM model is close to the average value over all other models, but stationary response is less than in average.

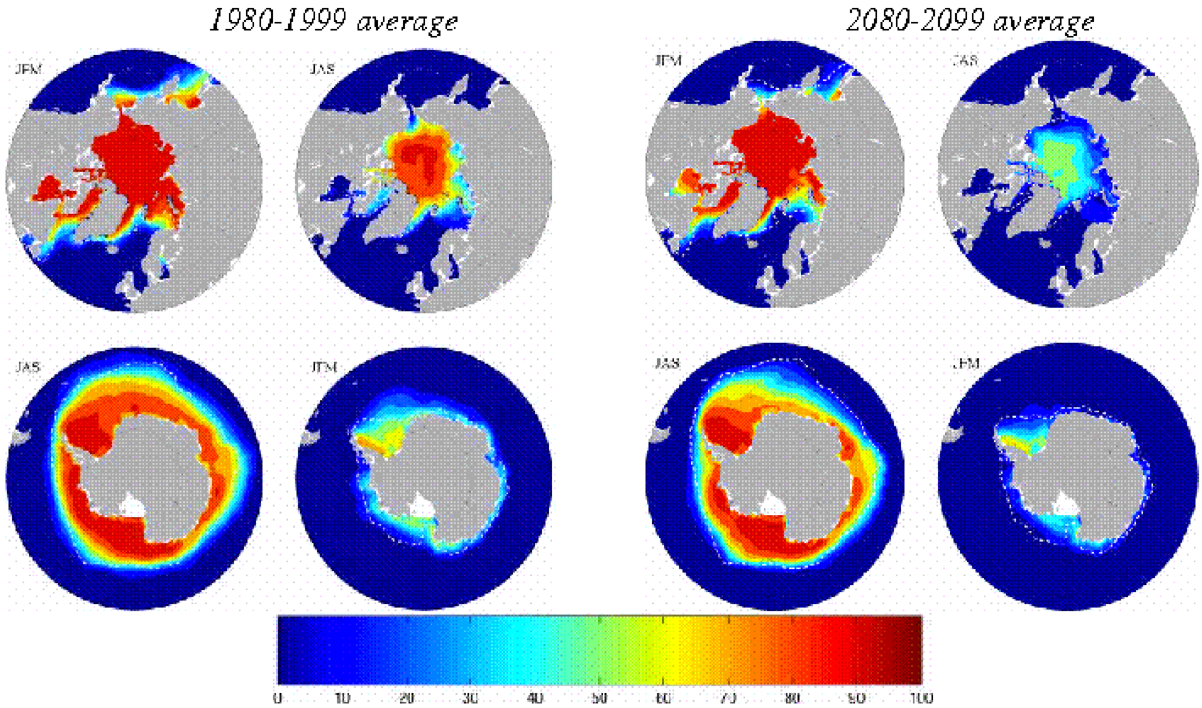

Fig.11. Concentration of sea ice (%) in Arctic and Antarctica according to the data averaged over all other models, in January-March and in Jule-September for 1980-1999 and 2080-2099.

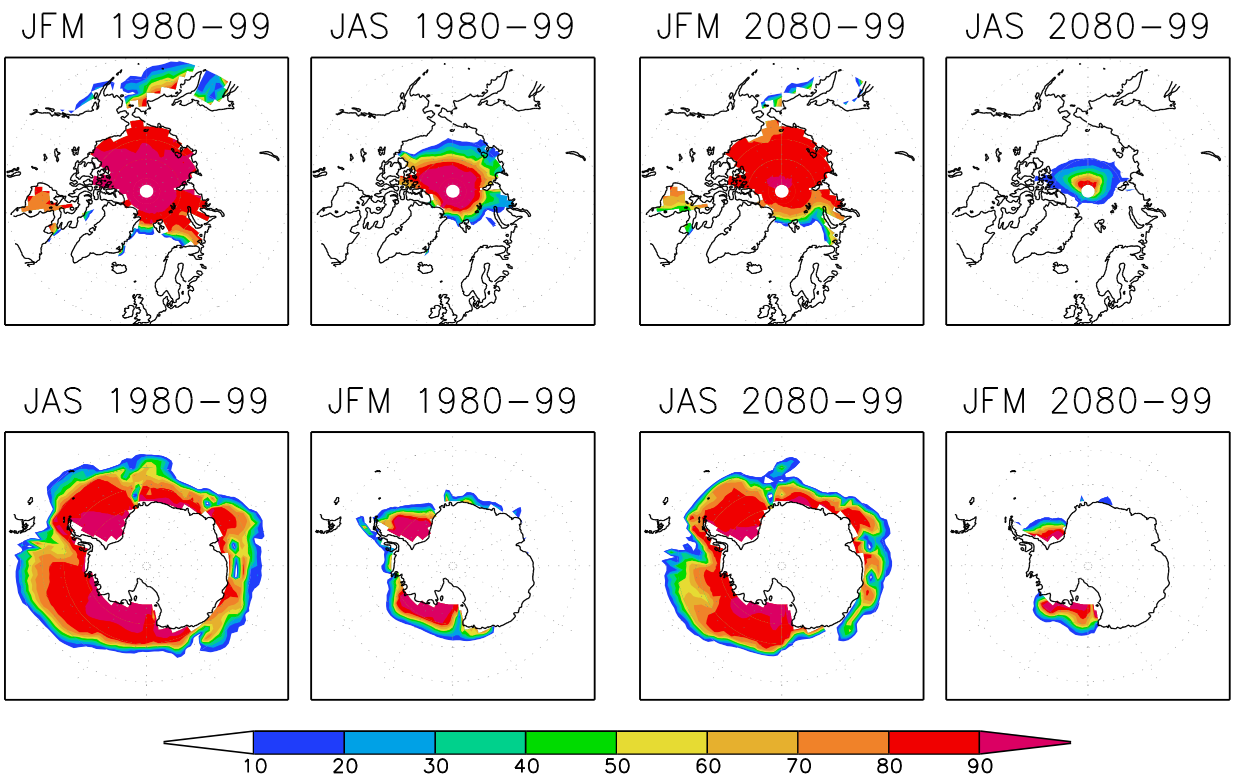

Fig.12. Concentration of sea ice (%) in Arctic and Antarctica according to the data from INM model, in January-March and in Jule-September for 1980-1999 and 2080-2099.

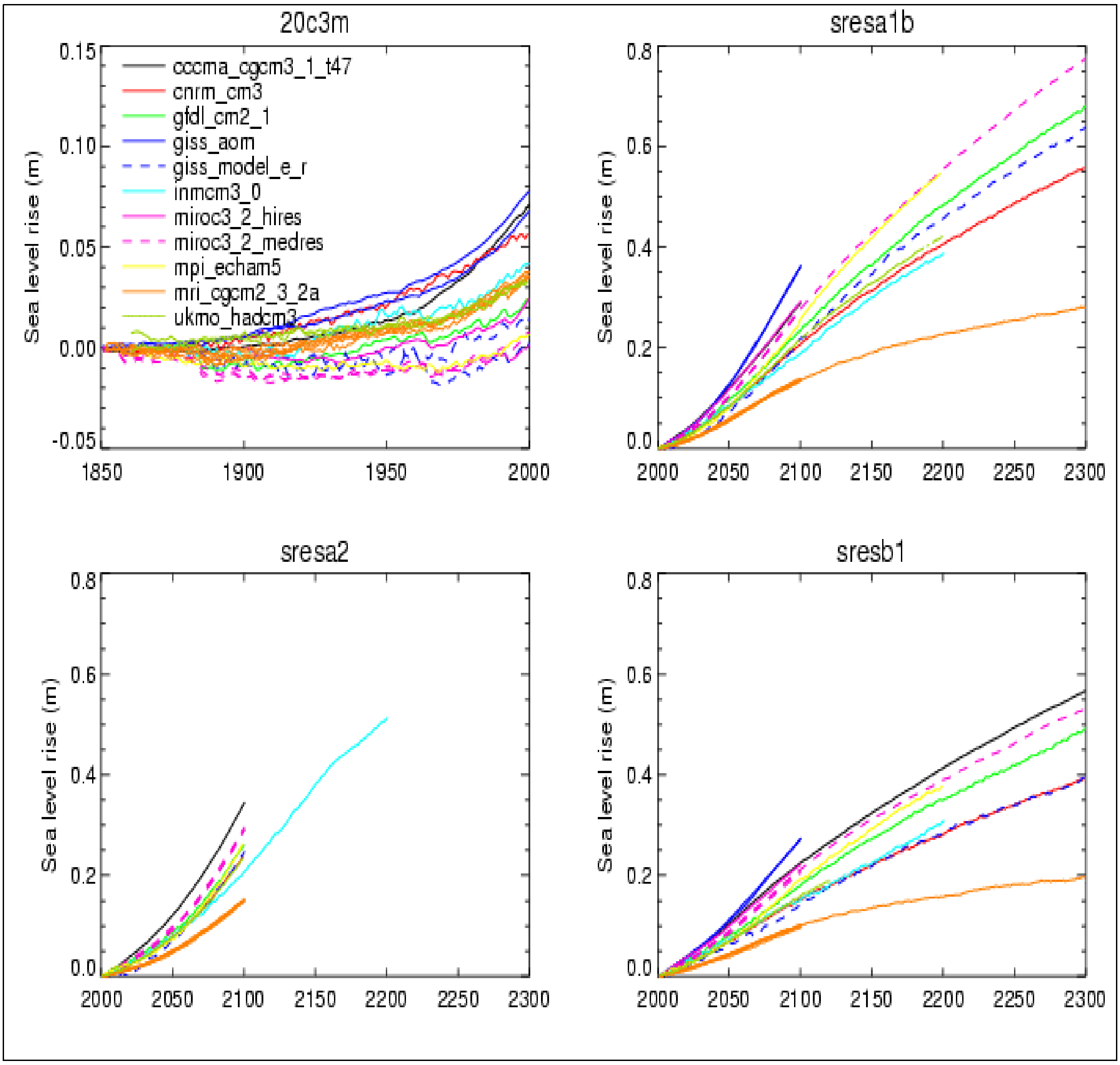

Fig.13. Sea level change (m) in different models for experiment XX (top left), A1B (top right), A2 (bottom left) and B1 (bottom right).

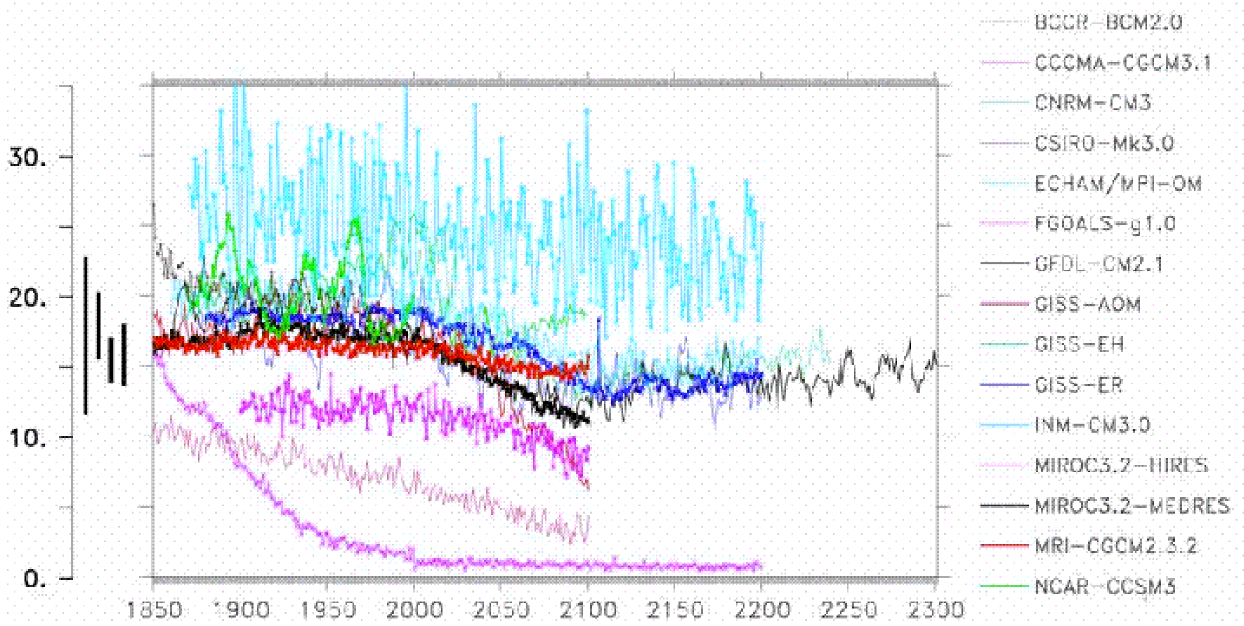

Fig.14. Time evolution of meridional streamfunction in Atlantic (Sv) at the latitute 30N for the data from different models in experiments XX and A1B. Black line on the left corresponds to the estimates from observations at the end of 20th century.

On fig.14 is shown a time evolution of meridional streamfunction in Atlantic in 1850-2300 from model data. In all models a decreasing of meridional circulation in Atlantic is observed, which is caused by weakening of convection in Northern Atlantic due to the temperature increasing and freshening of the water. This decreasing in 2100 relative to 1900 is about from 2 to 10 Sv in all other models. In INM model it is about 5 Sv. However data from INM model are distinguished from all other models, firstly by overestimated flux of fresh water in Greenland sea and secondly that the interannual variability with characteristic period of few years is largest in INM model over all other models due to the still undiscovered reasons

Finally one can conclude that results of climate change modelling in 20th - 21st centuries obtained from INM model for most climate factors are .in good agreement with average results obtained from ensemble of all other models. Thus give us possibility to state that level of predictability of future climate changes in INM model is corresponding a modern level of climate science. However, it is not possible to give the unambiguous conclusion on the degree of reliability of the model forecast due to the reasons discussed at the beginning of this article and also due to the future climate may be affected by some other still undiscovered factors.