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The global climate change and forest prediction in China

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Abstract— The climate change prediction in China based on OCU model as well as summary analyses of GFDL, GISS, NCAR, OCU and UKMO models are used for discussing the approaches to predict the response of the forest in China under double concentration of atmospheric carbon dioxide after about 2020. The growth, production and distribution boundary of Chinese fir (*Cunninghamia lanceolata*), the tree composition and their growth in cold temperate Daxingan Mountain region, and potential forest zones in China are discussed in this paper as example.

Keywords: global climate change; forest in China; prediction.

1 Introduction

The global climate change and its effects on the human being has become one of the main environmental problems all over the world. With regard to the ralationship between global climate change and the forest, specialists believe that one of the main reasons for the increase of CO_2 concentration in the air, which results in a "greenhouse effect", lies to a great extent, in the damage and reduction of forests. Some foretists have even begun to consider the effects on the distribution and growth of forests of the global climate change. At present, it seems that there are three tasks in the research of the relationship between global climate change and the forest. Firstly, how forest reduction in the world affects the global climate change. Secondly, how the global climate change affects the forest and forestry of the world or individual countries, and whether we can predict it or not and find out the solution.Thirdly, how the function and scale of forests are established and what are the functions for the comprehensive strategy to prevent the global climate from getting warmer. According to international researches, some data for the first have been collected and recognized as consistent, but thorough and detailed research should be carried out for further illumination. As regards the second, specialists in a few countries, such as the United States, New Zealand and so on have made some predictions and discussions. With regard to the third, the question has been put forward, but no specific discussion has taken place.

This paper puts emphasis on the necessity for research on how global climate change affects the forest in China, and discusses its prediction approaches with a view to arouse the attention of the forestry authorities to making further researches.

2 International general evaluation on global climate change

Scientists agreed with the following points of view: because human activities affect the balance of geosphere and biosphere, the increase in contents of CO_2, CH_4 in atmosphere causes greenhouse effect which makes global climate warmer. During the last one hundred years (1890－1990) CO_2 concentration was increased from 270 ppm to 345 ppm. From 1960 to 1984, its average annual increase rate was 1.64 ppm. According to this trend, it will be increased from 340 ppm to 355 ppm by the end of this century. It is expected to become 660 ppm in the middle of 21 century. One of the main reasons for CO_2 concentration increase is the declination of a large number of forests as well as the increase of fossil fuel used by the human being, and the proportion of the former item is expected to be 30%－50% of the whole.

By the next century the temperature of the global surface is expected to increase 3℃±5℃ (Fig.1) as predicted by different models. But the extent of increase is different according to different regions. In the high latitude region rising will be more

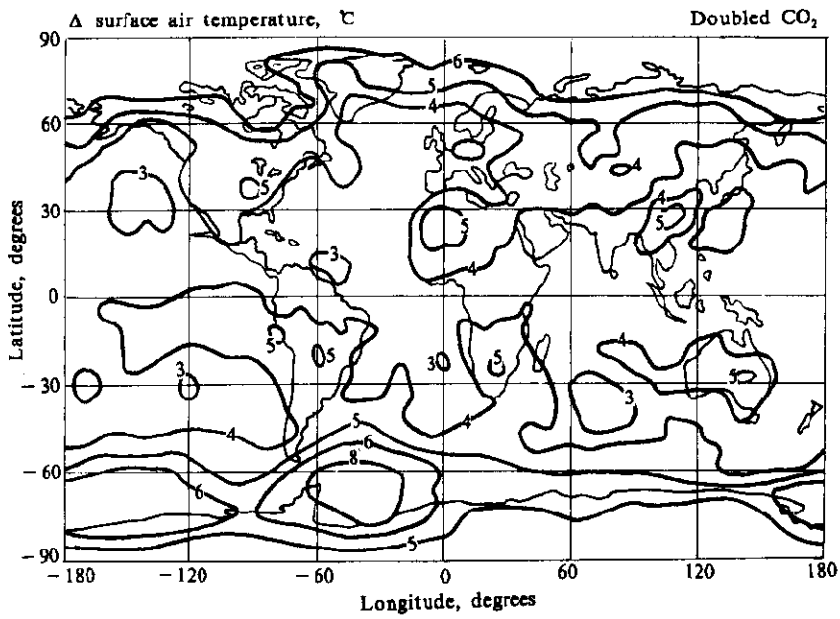

Fig.1 Global warming in 3-D model for doubled CO_2

distinct than that in the equator region. In the region of North and South Poles the extent of rising will be higher, so that the upper layer of glacier will melt, and the tundra belt will be moved backward. The oceans will be enlarged because of melting of glaciers. The models predicated that cities along the seashore, such as New York, Los Angeles, London, Veness, Shanghai and so on will be submerged. Greenhouse effect will also influence the global water circulation. Rainfall and snowfall will increase from 7% to 15% in total. Intensity and distribution pattern of raining will change. The most changes range from the region of the tropic ocean to the forest region in the mid latitudes. In some areas water efficiency will be improved, but in other areas it will be reduced because of seasonal changes. In the region of mid latitudes it may be wetter in spring and drier in summer. The soil moisture in the growth season will not be enough. But some uncertain factors and negative feedback factors in biosphere-geosphere can not be predicted altogether. So the description for this prospect is only sketchy, somebody thinks that the temperature increase of 0.5 ℃ by the year 2000 will not cause serious ecological imbalance.

3 Greenhouse effect influences world forests

Hoffman, an American specialist, pointed out that some participants of an International Conference of US Scienctific Association thought that the going up of CO_2 concentration affected plants as follows: (1) individual photosynthesis is speeded up; (2) individuals make use of moisture more effectively; (3) other changes for the plant growth will affect its economic productivity and ecological relationship; (4) because some factors in a certain range will restrict the growth of plants, ecosystems with non-management may not improve their net productivity, but ecosystems with management, such as forests and plantations, may gradually improve their net productivity. He thought that greenhouse effect brought about by CO_2 concentration increase might decrease productivity of sensitive species and disadvantages to insect and bring about fire damage. So the advantages and disadvantages of greenhouse effect brought about by CO_2 concentration increase on the world forestry may beak even. It may bring us neither advantage nor calamity. But it may deeply change and affect forests in specific regions. It will either affect forest distribution and management model or make request of new gene for human being. He was in charge of the prediction research for American forestry. The forestists in New Zealand also predicate the forest changes according to the data of increasing temperature in the year of 2030 and 2052. He also thought that the results were both good and bad through estimate research to the change of annual produc-

tion, wood properties, and salinization because of the ocean surface going up and wind, frost, snow and so on.

4 The prediction problem of the global climate change and forests in China

4.1 The prediction of the greenhouse effect on the climate in China

Based on the integrated analysis for the prediction of GFDL, GISS, NCAR, OSU and UKMO models by Zhao Zongci (Zhao, 1989), it is predicted that due to the increase of CO_2 concentration in the atmosphere, the temperature in our country will get warmer, and when CO_2 doubles in the year 2020, the temperature will increase. 3.1－5.1 ℃ in winter and 1.8－5.1 ℃ in summer. Most of the models showed that in winter the temperature will increase more than 4 ℃ in northeast China, West Inner Mongolia, North China Plain, and upper reaches of Yangtze River and Huaihe River, lower than 4 ℃ in south and southeast China. The temperature will increase less than 4 ℃ in most parts of the country in summer. The rate of rainfall also will obviously change both in winter and summer. Most models showed that in winter the rainfall would decrease along the coast of Bohai and in south China, and increase in other areas. Particularly in most of the western parts of west and northeast China the possibility for increasing rainfall is very high. In most areas of China except the areas of upper and lower reaches of Yellow River and near Wuhan, it will increase. In most areas of south China in winter the soil moisture will decrease. The meaning is that the soil is becoming drier. But it will get wetter in most areas of north China. The soil of the mid areas of China will get drier in large scale in summer. It is quite possible to get dry within and near Hetao region and in north China (Zhao, 1989).

Gao Suhua (Gao, 1990) quoted OSU models to predict how it affected the agriculture in China and estimated the possibility of climate change in China: annual mean temperature will increase 2.69 ℃ . The extent of temperature increase will be the highest, which will reach 3.04 ℃ in southwest China, while the extent of temperature increase in south China will be the lowest, which will reach 2.42 ℃ . The increase in temperature will be higher in winter than in summer, the annual average rainfall will increase in the whole country. In south China the rainfall increase the most, which is about 251.5 mm, but in northwest China it increases the least, which is about 77mm. In the whole country the average rainfall will increase 146.4mm. The extent of increasing rainfall will be higher in summer than that in winter. The change of the soil moisture is very complex, which tends to decrease in most parts of north China,

and tends to increase in the north Yangtze River. Decreasing soil moisture looks more significant in North China Plain. Zhang Jiancheng pointed out, due to summer wind activities becoming stronger, the monsoon area would extend to the north and west. The annual rainfall will increase in the region of eastern parts of northwest China and north China where the marginal region of present monsoon exists through the rainfall in summer may be reduced there.

4.2 How the possible climate changes caused by greenhouse effect affecting the forest in China

According to different range of effected time, three kinds of response models of greenhouse effect caused by increasing CO_2 concentration are as follows: (1) instant response; (2) response after a medium period; (3) response after a long period.

4.2.1 Instant response

CO_2 concentration, increasing temperature and related moisture conditions can directly cause physiological change of trees, including changes for exchange process between leaf surface and water, heat or air. Increasing CO_2 will cause stomata opening shrink and evaporation decrease. It advantageous to the photosynthesis. And the temperature moderately going up is good to enhance metabolism. The kind of instant response model do not directly play a role on significance to predict forest changes caused by greenhouse effect. Only through the accumulation of instant response for quite a long time, can greenhouse effect affect the forest productivity. Therefore, in order to reach the prediction objective as required, medium period response models should be adopted directly.

4.2.2 Response after medium period

The continuing effect of the increase of CO_2 concentration and greenhouse effect on climate changes for a period from more than ten years to several decades will bring about unfavorable changes on the productivity of forests and the ability of forest species in adjusting themselves to the environmental changes, and the changes of tree species and forest distributions often show the tendency of forest productivity difference, the state of insect pests, the changes of the distinction of distribution area (migration of horizontal distribution distinction, the changes of vertical distribution and so on). These changes will undoubtedly and greatly affect forestry.

4.2.3 Response during a long period

The long term response is defined as a kind of response model in which the global climate change in a long period (several hundred years) causes changes of forest distribution. This kind of response took place several times while the climate changed during the geological period. As to the long term response, although the response of plant vegetation is faster than that of the soil, it is still very slow,

especially for the forest. It will take several hundred years in the cold region to improve soil conditions after the changes of forest take place. The stability of new pattern of forest vegetation distribution is based on the pattern of regulation of soil properties. At present, greenhouse effect predicting distribution pattern of forest is the only direction. In fact, the objective is to predict the tendency of living ability of distribution migration. Thus greenhouse effect which influences the forest can be emphasized on the prediction of response during more than ten years to several decades.

The approaches for detailed prediction on all kinds of medium period responses are as follows: concerning for prediction for forest productivity changes, we should first determined the correlation between main climatic elements which affect forest productivity and forest meteorological productivity. The meteorological production of the forest is a kind of production difference for certain forests or three species under the conditions of the same site and due to the difference of climate conditions. It could be found by analyzing forest production with different water and heat conditions on different latitude or with obvious differences in water and heat conditions in the same place in various years. The effects on people's management level should be picked out in consideration. Therefore, it can be beneficial to get a large quantity of long-term statistic data. The climate elements are different according to requirement for prediction precision and possibility, e. g. annual mean temperature, average temperature in the coldest and hottest months, annual total radiation, effective accumulated temperature, annual total rainfall and rainfall in the growing season, and so on. The data for meteorological production in agriculture was well collected. Although there have been data for some forests in the sample plot, it is seldom scientists undertook research on forest meteorological production.

$$\text{Suppose: } \hat{Y}=f(\overline{T},\ P,\ \Sigma 10\cdots), \tag{1}$$

There is a functional relationship between Y (meteorological production) and annual mean temperature, annual rainfall, $\geqslant 10$ ℃ accumulated temperature, or other meteorological elements. The production caused by CO_2 double concentration are current average production plus meteorological production under the climate conditions at that time.

$$Y_{2\times co_2}=\overline{Y}_{1\times co_2}+\overline{Y}. \tag{2}$$

If the loss of forest production brought out by the harmfulness of insect pest and the other meteorological harmfulness, for example, typhoon and fire, are also considered, damage of insect pests (generation, happening times, and degree, and its correlation with concerned climate elements) should be obtained at first, and then further prediction model.

The formula for predicting production is:

$$Y_{2\times co_2} = \overline{Y}_{1\times co_2} + \hat{Y} - (L_1 + L_2 \cdots) \ , \tag{3}$$

The prediction for concerned meteorological elements can be gained through the prediction for concern climate. For example, Gao Suhua put forward:

$$\Sigma T_{10\ 2\times co_2} = 150.45 + 1.1266 \Sigma T_{10}. \tag{4}$$

Among which, $\Sigma T_{10\ 2\times co_2}$ is $\geqslant 10$ ℃ accumulated temperature value when CO_2 is doubled. ΣT_{10} is $\geqslant 10$ ℃ accumulated temperature value at present (compiled statistics in 1951 − 1980) and so on. The problem is that the statistic parameters of meteorological production of forest have not been carried out, even the most detailed research work on Chinese fir.

Example 1: The prediction for Chinese fir plantation areas

According to rough information on related Chinese fir which showed the relationship between meteorological conditions and the productivity in Fig. 2 (Shen, 1991), an example was given to show the change of production of Chinese fir and the change of desirable planting areas when CO_2 would be doubled in the year 2020 and continued for more than ten years (about the year 2040).

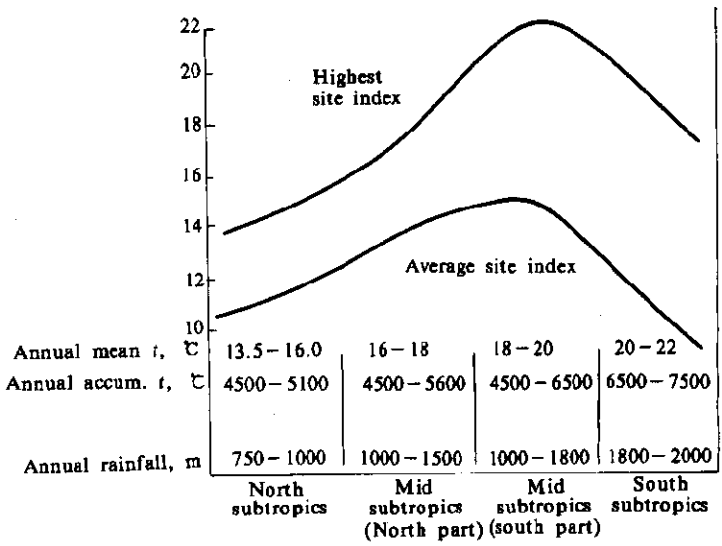

Fig.2 Influence of climate factors to tree growth of Chinese fir

As to the Chinese fir average site index, the eastern subtropical area toward north in the most suitable planting regions, the annual mean temperature decreased 1.25℃, and the annual rainfall decreased 143mm. In the same sites 20-year old Chinese fir decreased on site index degree, the meaning is that the average annual production decreased 1.5m^3 per hectare. In the south of the most suitable planting regions, Chinese fir is more sensitive to the weather getting warmer. The annual mean temperature increased 1℃. The site index is expected to decrease two (3m^3 per hectare in production). The rainfall was not affected apparently. According to the weather forecast, in the south of Chinese fir distribution region (south subtropical region), the annual mean temperature will go up 2.42℃, temperature increase in winter will be higher than that in summer, and annual rainfall will increase 251.5 mm which will concentrate in winter. Drought damage seriously affects the growth of Chinese fir in winter or trends to ease in spring. Because the temperature increase too high, and unsuitable for growing Chinese fir, its production in the south will obviously decrease. Its southern limit for distribution will be more toward the north. As regards the parameter, the distance between two places which offer an annual mean temperature difference of 1℃ in the middle and lower latitude being equal to about 100－150 kilometers of north and south change, and the conditions of geographical feature in south China, the distribution range of Chinese fir will withdraw from hilly areas along the seashore, but reach 24°N. Because the mountain areas are below 1000m sea level in the south distribution and growing area, so there is no way to move toward higher sea level. Therefore, at present the production of Chinese fir in southern areas will reduce because of its reduced productivity and growing area. The entire suitable planting areas will move north. The current temperature (15℃) in northern area will increase to ±18℃, which is equal to the heat energy condition in the present middle area. The growth season will prolong for nearly one month. The increasing temperature in summer will alleviated the effects of spring cold current on Chinese fir. Increasing rainfall will alleviated the shortage of moisture. Its annual growing production will obviously increase above 3m^3 per hectare. The vertical distribution height in the middle area suitable to Chinese fir growing will move up. Because topography are higher in the western part of this area, the vertical distribution height will go up more than 1500－2000 m, but only 500－1000 m of a few mountains in eastern part of the area, so the production between western and eastern part of the area will be different. But in general, there is going to be small changes in the average. The northern margin of distribution range may move north. At that time, planting Chinese fir will reach south of Huaihe River. Otherwise, due to increasing temperature in the forest area of Chinese fir, the insect pest will be serious, injurious insects with

generation of every one year or two years, such as *Semianchis bifaciatus sinoauste,* due to shortened accumulated temperature period for growth, may mainly become one year's generation. Similarly, insect of multigeneration in one year, such as *Polychrosis cunning-hamiacola,* may mainly become four (or five) generations in one year which can increase damaging rate and extent. Because the climate trends in the Chinese fir plantation areas to become warmer, pest damage with fernga, such as *Glomerella cingulata,* can also be aggravated. Damage extent for *Lophodermium uncinatum* in the southern area may increase. In general, in the Chinese fir planation areas, when CO_2 increase at times, the change of production and desirable planting areas affected by climate will be equal in advantage and disadvantage. However, insect pest will become a serious problem to be solved.

Example 2: The prediction for Daxingan Mountain natural forest region

Daxingan Mountain lies in Northeast China. The main species are *Larix gmelini* and *Pinus sylvestris* var. *mongolia.* The region is the enlarged part of cold temperate zone of Siberian Taiga in China, which belongs to the southern border of *Larix gmelini* distribution (20, 21). When CO_2 concentration increases at times, the disadvantage to which the climate affect *Larix gmelini* will be more than advantageous. At present, annual mean temperature is about -2 ℃ which just fits into the southern border of Daxingan Mountain natural forest region. By the year 2020, the temperature will increase 3—4 ℃ , the rainfall will also increase. But the rainfall in winter will be more than that in summer. It will be relatively drier in summer. In the course of the climate change, *Larix gmelini* might have a long growth season. But when CO_2 in the atmosphere is doubled in concentration and lasts for a decade i. e. up to the year 2020, the water and heat status of the climate will be close to current temperature climate in the southern part of Daxingan Mountain. It may be possible to artificially plant *Pinus sylvestris* var. *mongolia* and *Larix gmelini,* but their natural distribution will move toward higher sea level. Because in the whole forest areas the temperature increases as well as the rainfall, but it is rather dry in summer, productivity of the whole forest area may be increased after balance of advantages and disadvantages. Meanwhile, the species component and flora will gradually change, for example, the forest types including *Laricetum-casiopinosum* may gradually disappear. The Changbai flora of the temperate zone will immigrate much. The planting area for *Picea koraiensis,* P. *jezonensis*, var. *micitsperma, Fraxinus mandshurica, Philodendron amurense, Acer* spp. and *Tilia* spp. will expand. *Larix olgensis* and L. *kaempferi* and so on may become wood-use species in certain areas. The variety in the forest areas will increase, which is useful to develop the forest areas and improve productivity. Nevertheless, because there is a long lag while the soil adjust itself to

the climate changes, the poor soil in Daxingan Mountain region will limit the forest productivity improvement. Because the depth of frozen layer of soil decreases or disappears, the marsh forming process on the lowland will intensify, marsh area will be enlarged, it will either influence the distribution and productivity of *Larix gmelini*, or affect the water balance. In general, the climate change is fairly useful for forest productivity in Daxingan Mountain region except the insect pest of *Larix gmelini* and *Pinus sylvestrss* var. *mongolica*, and elements that relate to dryness in summer and the attendant danger of fire.

Example 3: Effects on China's forest geographical distribution

As a long term response model, the prediction for geographical distribution pattern of the world vegetation due to climate getting warmer, which is usually based on a diagram of Holdridge's world biological zones and followed by climate classification or Lieth's model, is neither detailed nor suitable to specific conditions in China. Up to now, there is still no intergrated research on forest mathematical models of water and heat conditions and vegetation distribution made from latitude, longitude and altitude in China. Only some regional researches or works on some vegetation types (such as subalpine) have been made. Therefore, firstly the entire relative models for vegetation distribution and geographic elements should be established in China. At present, it is still very early to predict the vegetation distribution affected by climate change. However, comparing with accuracy of works in other countries, the research on it in our country has had a good foundation. "The Natural Geographic Regionalization in China" have given quite an accurate description on natural geography and vegetation features. The constants of which 1 ℃ change of annual mean temperature equals to a change of annual mean temperature of 100km and the change of 0.6 ℃ annual temperature at every 100 meters sea level, are often adopted for the prediction on movement of vegetation distribution as well as on the pattern changes of agricultural crops.

Now climate distribution zones and vegetation types in our country are as shown in Table 1.

According to a weather forecast, by the year 2020,the relationship between an accumulated temperature≥ 10 ℃ and a continuous day numbers (D_{10}) is as follows:

$$D_{10} = \frac{\Sigma T_{10}}{14.39 + 0.0013 \Sigma T_{10}} .$$

As calculation, accumulated temperature at ≥10 ℃ in the whole country are expected to increase 15%, due mostly to the increase in southwest China which will be. The formula of change rate in the growth season is as follows:

Table 1 Climate distribution zone and vegetation types in China

Natural Zones	Annual mean T, ℃	Mean T. of the coldest month, ℃	Mean T. of the hottest month, ℃	Growth season, days
Cold tmeperate	(−2.2)−(−5.5)	(−28)−(−38)	16−20	80−100
Temperate	2−8	(−2.5)−(−10)	21−24	100−180
Warm temperate	9−14	(−13)−(−2)	24−28	180−240
North subtropical	14−16	2.2−4.8	28±	250±
Mid subtropical	16−21	5−12	29±	270−300
	16±	9	20	250
South subtropical	20−22	12−14	29	365
Tropical	22−26	16−21	29	365

Natural zones	days ≥ 10 ℃	Annual accumulated T., ℃	Typical forest types
Cold temperate	<120	1100−1700	Cold temperate coniferous forest
Temperate	120−150	1600−3200	Coniferous and broad-leaved mixed forest
Warm temperate	210−270	3200−4500	Broad-leaved deciduous forest
North subtropical	220−240	4500−5000	Broad-leaved deciduous and evergreen mixed forest
	250−280	5000−6500	Evergreen broad-leaved forest (eastern China)
Mid subtropical		4000−5000	Evergreen broad-leaved forest (western China)
South subtropical	>300	6500−8000	Monsoon broad-leaved forest
Tropical		8000−9000	Monsoon rain forest Rain forest

$$\frac{dD_{10}}{d\Sigma_{10}} = \frac{14.89}{14.89 + 0.0013\Sigma_{T10}}$$

The change rate for the growth season will be larger in the north than in the south. Average growth season will be prolonged one month for the entire country.

On the basis of the above comprehensive model analysis, in recent years, changes in the tropical zone and south subtropical zone are not very clear, but the north margin in the south subtropical zone may reach Kunming, Guilin, Guangzhou and Wenzhou. The margin of mid subtropical zone will apparently move to the north, which will reach Nanjing and Wuhan. Because of the increase in both water and heat in the east of north subtropical zone in summer, the scope of moving to the north will be

bigger. The north margin might come near to Qingdao, Xuzhou, Zhengzhou, Xian and Tianshui. According to the above prediction, the changes of climate zone may show us the changes of relative forest vegetation (including wood-use plantation and economic forest). But all predictions are very rough. The predicting for forest geographic distribution in our country should be divided into several big parts and the water and heat distribution law brought about by latitude and latitude be considered carefully to set up models.

At last. the emphasis is that this article does not urgently describe how greenhouse effect influences the forest of our country when increasing CO_2 concentration is doubled after thirty years because of the lack of good basis on setting up models prediction.

This article aims at the possibility of weather-getting warmer effect on the forests in our country. It is important and necessary to try our best to study on it in this field.

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