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Prediction of Atmospheric Carbon Dioxide Radiative Transfer Model based on Machine Learning

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Abstract: Global warming is caused by the increasing amount of greenhouse gases in the atmosphere. The Kyoto Protocol to the United Nations Framework Convention on Climate Change defines carbon dioxide (CO), methane (CH:), nitrous oxide (N0) fluorocarbons (HFC), holocarbon (PFC), and sulfur hexafluoride (SF.) Six gases are divided into the main greenhouse gases, of which CO, the largest proportion of emissions, is an important man-made greenhouse gas." As the main gas affecting the global greenhouse effect (75%), the amount of CO in the atmosphere has increased from 315 ppm in 1958 to 417 ppm in 2022, and global annual CO emissions have increased from 27 Pg to 49 Pg% over the past 40 years. Therefore, under the background of deep reinforcement learning, it is a problem that all countries pay more attention to predict the concentration emission of carbon dioxide to cope with the severe situation of climate warming. In order to obtain the radiative forcing value under the influence of carbon dioxide concentration, a simplified net radiative flux model is established. Based on the radiative transfer equation, this model can calculate the net radiative flux and radiative forcing of each layer of the atmosphere due to changes in carbon dioxide concentration. The results are compared with the RRTMG-LW long-wave radiative transfer model of American Center for Atmospheric and Environmental Research (AER) under the same factor, and the error is less than 1%.

Keywords: Machine Learning; The Atmosphere; Radiation Transfer; Carbon Dioxide Model.

1. Introduction

Since the Industrial Revolution 100 years ago, the average global temperature has increased (0.74 soil 0.18)C, which is caused by the root cause of the greenhouse gas concentration caused by human activities. Due to the rapid development of human production and social activities, the volume fraction of greenhouse gases such as HO, CO2, CH,N00 and fluorine chlorine in the earth's atmosphere is increasing, and the volume fraction of CO is increasing most significantly[2-3]. According to the IPCC report, the atmospheric CO2 volume fraction has increased from 280X10-6 before the Industrial Revolution to 379x10-6 in 2009. The key to the effect of carbon emissions and radiation transfer control policy is the monitoring of atmospheric CO, the existing monitoring methods mainly lie in the countries through the preparation of greenhouse gas inventories to understand the impact of emission reduction, increase in sinks and other measures on global warming, but this method faces the shortcomings of data lag and inconsistency, information opacity and other drawbacks, there is a difficult to adapt to the application of the problem." As a long-term, cyclic and global atmospheric CO observation technology, satellite remote sensing has the potential to eliminate the deviation of global carbon budget accounting, which is an important reason why atmospheric CO remote sensing technology has been paid more and more attention. At present, the radiative transfer model RF is used to characterize the climate effect of greenhouse gases, indicating the general trend of climate change. When RF>0, it will warm the ground and troposphere, and when RF0, it will cool the ground and troposphere[4]. 1 In terms of radiative forcing methods for calculating CO, the internationally recognized and widely used atmospheric radiation models are AER's atmospheric radiation model Fu-Liou model MODTRAN5, SBDART, SHDOM, etc.

Therefore, under the background of machine deep learning and the development of digital economy at the present stage, the radiation model in the atmosphere is considered by many complex factors such as climate and meteorology, and the calculation is complicated. By simplifying the one-dimensional radiation transfer equation, the author has made the following calculations[5]: The greenhouse effect of CO2 is considered from the perspective of radiative heat transfer, and the net radiative flux and radiative forcing of each layer are calculated and analyzed. In order to verify the reliability of the simplified model, the RRTM-LW long-wave radiative transfer model of the American Center for Atmospheric and Environmental Research (AER) is cited for comparative analysis.

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2. RELATED WORK

2.1. RRTMG Calculation Model

Compared to RRTM, RRTMG is faster and more accurate in the cyclic model [7]. Compared to the RRTM Long-Wave Radiation Scheme (RRTM LW), the RRTMG Long-Wave Radiation Scheme (RRTMG LW) contains a number of modifications :(1) a computationally more efficient radiative transfer calculation method is adopted, and the radiative efficiency of all atmospheric gases is included; (2) Absorption and scattering of liquids, ice clouds, and aerosols are considered :(3) Monte Carlo independent line approximation McICA is added to represent random subgrid cloud change rates, maximum random subgrid cloud change rates, and maximum cloud overlay options. RRTMG(Rapid Radiative

Transfer Model) radiation software is developed by the U.S. Center for Atmospheric Environmental Research, has been widely used to calculate atmospheric radiation. The development of this model is based on LBLRTM, mainly using the relevant k distribution mode, and improving the accuracy and efficiency of the operation as much as possible [6-8].

In addition, it can also be directly used in the calculation of multi-directional scattering, and it is accurate in the calculation of flux and cooling rate. It is the rapid radiation transfer model used in the numerical Prediction model of Global/Regional Assimilationand Prediction Enhanced System (GRAPES) in our country, which is used to simulate the radiation of the meteorological satellite sensor to the earth observation. In essence, RRTMG is a fast radiative transfer mode based on statistics, with fast calculation speed and high accuracy. However, in the infrared water vapor band, due to the interference of linear absorption, continuous absorption and other gas absorption, the absorption characteristics are complex, and the calculation accuracy of RRTMG is relatively low. Machine learning usually outperforms traditional statistical methods in solving nonlinear statistical problems. Therefore, this paper uses machine learning methods to establish the transmission efficiency of nuclear radiation in atmospheric stratification of satellite channels.

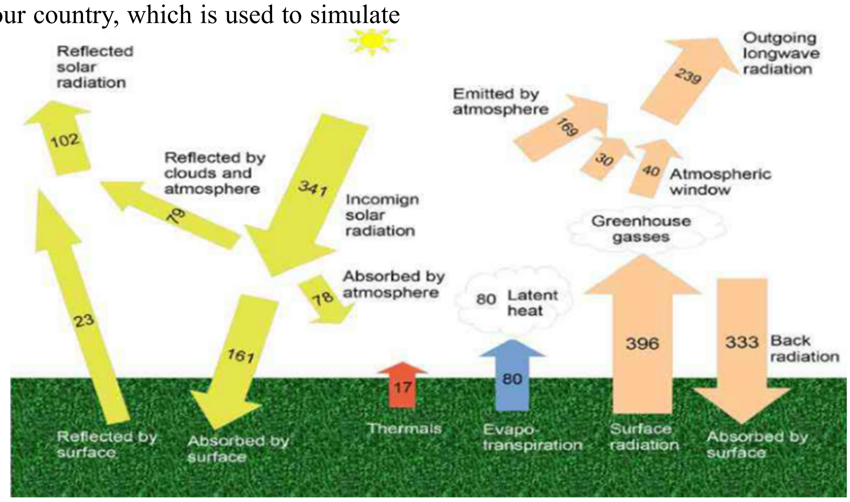

Figure 1. Physical model of long wave radiation transmission

At the same time, RRTMG radiative transmission algorithm has relatively weak data dependence. Therefore, in order to further improve the computational efficiency of RRTMG, it is very necessary to adopt GPU technology to accelerate RRTMG. This paper focuses on the following two aspects of the long-wave radiation model RRTMG LW:

(1)RRTMG LW one-dimensional, two-dimensional and three-dimensional regional agent division GPU acceleration algorithms are proposed respectively, and the GPU version G-RRTMG LW is implemented based on CUDA Fortran. In the RRTMG LW 3D GPU acceleration algorithm, the acceleration method of "parallel first, then accumulation" is proposed for the subroutine rtrnmc, which realizes the improvement of the rtrmc parallel algorithm and improves the parallel computing efficiency of rtrnmc[9]. The experimental results show that compared with the calculation of single CPU core on a single GPU, The RRTMG LW achieves up to 30.98x acceleration.

The parametric calculation of atmospheric radiation transfer is mainly achieved by calculating radiation flux and heating/cooling rate. The calculation of these two parts is introduced below. The average amount of spectral emitted radiation from the atmosphere can be expressed as:

$$I_v(u) = \frac{1}{v_2-v_1}\int_{v1}^{v2} dv \left\{ I_0(v) + \int_{T_v}^{1} \left[B\left(v,\ \theta(T_v')\right) - I_0(v) \right] dT' \right\} \quad (1)$$

If we make two assumptions: 1. The Planck function changes linearly along the absorption path in the layer; 2. The pressure, temperature and substance in the layer are evenly distributed, and the absorption coefficient is characteristic:

$$I_v(u,\ \varphi) = \frac{1}{v_2-v_1}\int_{v1}^{v2} dv \left\{ B_{eff}(v,\ T_v) + [I_0(v) - B_{eff}(v,T_v)] exp\left[-k(v,P,\theta)\frac{\rho\Delta z}{\cos\varphi}\right] \right\} \quad (2)$$

(2) G-RRTMG LW was successfully applied to the Earth system model CAS-ESM. Aiming at the characteristics of multi-node and multi-GPU in large-scale heterogeneous supercomputing system, RRTMG LW multi-node and multi-GPU acceleration algorithm based on MPI+CUDA Fortran hybrid programming mode is proposed to realize the fast calculation of CAS-ESM. The experimental results show that RRTMG LW achieves 78.12x acceleration on 16 K20Gpus. This paper combines mechanical engineering and computer science to advance logistics automation by focusing on precise robot control based on accurate positional data. It provides a practical basis for the research of heterogeneous computing algorithms for other physical processes. Beyond logistics automation, this interdisciplinary research highlights the potential of collaborative efforts in tackling challenges related to handling intricate sensor data[10].

2.2. Machine Learning

In fields such as machine learning, pattern recognition and data mining, building good models from data is a major job. For supervised learning with labels, numerical values are regression problems, categorical values are classification problems, and models trained with existing data can be called regressors. (Zhou,2012) In general, for one-person problems, a method is usually selected and a model is learned, while ensemble learning learns multiple models with one or more methods[11]. Then these models are combined according to certain combination strategies to complete the learning task. Under normal circumstances, the generalization performance of integrated learning is better than that of a single learner, and this advantage is particularly prominent for "weak learners". Individual learners usually use algorithms such as decision trees and neural networks. When using ensemble learning methods, you can either use a single algorithm or choose a variety of algorithms. Existing ensemble learning methods usually use the same algorithm, which is called homogeneous integration.

The basic learning used in this paper is that the calculation of atmospheric transmittance on the basis of ensemble learning is a regression problem. For the regression problem, if the input space X is divided into J disjoint regions R1,R2,... ,R, the output constant for each region is G; , then the tree is represented as follows:

$$T(x;\Theta) = \sum_{j=1}^{J} c_{mj} I\left(x \in R_{mj}\right) \quad (3)$$

Therefore, it can be seen that the combination of independent base learners can greatly improve the overall performance of the model, and it is usually hoped that the more independent the base learners are when learning the base learners. An easy way to implement this idea is to use different data sets each time, but often the data is limited and it is difficult to generate large mutually exclusive and representative data sets.

3. Methodology

The infrared thermal radiation absorbed and emitted by the earth-gas system radiates upward from the ground along the height direction, and its wavelength includes 0~120 pm. Firstly, this part of the energy transfer in a certain wavelength is analyzed. This part of the energy will be absorbed and emitted by greenhouse gases in the atmosphere during the transfer process, and the greenhouse gases are considered to be separated and calculated. Considering the effect of CO2, a greenhouse gas, on long-wave radiation alone, the energy emitted upward by each microlayer can be obtained after the heat radiation is transferred from the ground to the top of the atmosphere. In the same way, the energy distribution in the process of transmitting radiation energy from the top of the atmosphere to the ground can be calculated. The process of calculating heat radiation from the ground to the top of the atmosphere is taken as an example to illustrate the concrete implementation steps of the model calculation

3.1. Atmospheric Absorption Coefficient

According to HITRAN (High resolution Transmission Molecular Absorption Database), online data [8] can be obtained at 101325 Pa atmospheric CO content is 100%, and the corresponding wavelength of any temperature (T) is 0~120 pm every 0.1m interval spectral absorption coefficient array A is obtained by p=pRT (where R is the gas constant).

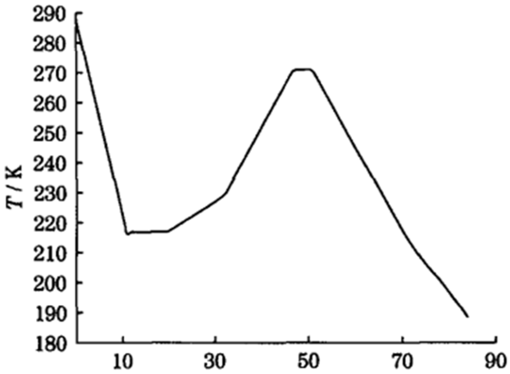

Figure 2. Changes of atmospheric temperature with height

The RRTM-LW long-wave radiative transmission model is adopted, the calculation height is the same, only the role of CO gas is considered, and the set CO volume fraction is injected under the standard atmosphere of the United States. The calculated results are compared to obtain the tropopause radiation flux results of the two, and the calculated results have certain errors: a. the influence of different absorption coefficients on the calculation accuracy of CO radiation characteristics. The absorption coefficients of RRTM-LW long-wave radiation transfer model are calculated by LBLRTM. HITRAN on the web database is used in this model, and some processing is done on it.

Considering that atmospheric transfer of radiant energy disk is a very complex process, which cannot be accurately described by mathematical model, this paper firstly performs basic calculation by simplifying the basic model of radiant transfer, and then calculates the performance of thermal imaging system based on the approximate model obtained by RRTM-LW radiant transfer model of tropopause net radiant flux. Table 1 below shows the comparison of the two models. There are some errors in the calculation results: a. The influence of different absorption coefficients on the calculation accuracy of CO radiation characteristics. The absorption coefficients of RRTM-LW long-wave radiation transmission model are calculated by LBLRTM, and HITRANon the web database is used in this model. b. Treatment of radiation transfer equation the former can deal with multiple scattering processes, and the role of scattering is ignored in this model.

Table 1. Comparison of the net radiation fluxes under the two models

Object	before the Industrial Revolution	Now	at a certain time	at a certain time 20 times
&/*10^{-6}	280	391	300	300
Simplified model($W \cdot m^{-2}$)	332.90	330.60	332.42	327.58
RRTM-LW model($W \cdot m^{-2}$)	333.48	330.47	332.86	324.99
Percentage difference (%)	-0.17	-0.17	-0.13	0.80

By solving one-dimensional radiation transfer equation, the influence of CO2 on the net radiation flux in each layer of the atmosphere and the radiative forcing caused by the change of CO2 volume fraction are calculated. This simplified radiative transfer equation model can calculate the net radiative flux of any layer on the one hand, and predict the radiative forcing value when the CO volume fraction changes [12]. The comparison with the results of RRTM model shows that the one-dimensional radiation transfer model proposed in this paper can accurately and quickly predict the greenhouse effect of various greenhouse gases and their effects on global temperature.

4. Conclusion

In large-scale science and engineering computing, there are often massive data processing work carried out on supercomputer systems, and high performance computing can be used to complete this work, including supercomputing and parallel computing. With the comprehensive arrival of the technology information age, the total amount of data generated by various industries is close to EB level every year, and high performance computing provides the basis for extracting useful information from these massive amounts of information. At the same time, more and more industries need to conduct more accurate simulation calculations, such as groundwater treatment needs to simulate the fluid calculation; In medicine, three-dimensional ultrasonic data needs to be converted and calculated into 3D images to provide doctors with diagnosis; and more complex numerical weather forecasting needs to simulate gas movement, radiation transmission, water vapor cycle, etc. These numerical simulation contents are the core content of climate numerical forecasting, and their calculation amount is huge. Different from other types of numerical simulation, weather forecasting requires high timeliness, so high performance computing provides an important basis for the development of weather forecasting.

The carbon dioxide concentration model of radiation transmission studied in this paper is divided into long-wave radiation and short-wave radiation. The short-wave radiation is mainly the radiation emitted by the sun, and after the Earth's surface and atmosphere absorb the solar radiation, it will emit long-wave radiation: due to the physical characteristics of long-wave radiation, only the absorption of long-wave radiation by the atmosphere is considered in most cases. To simulate climate change, the simulation of the radiative transfer of heat is critical: it is therefore important to simulate the radiative transfer accurately and quickly in all atmospheric models.

Based on the basic radiation model: Line-By-Line Radiative TransferModel (LBLRTM), the US National Center for Atmospheric Environmental Research (NCAR) developed the rapid radiative transfer model RRTMS, It simulates and calculates atmospheric radiation transfer through the parameterization of atmospheric radiation flux and heating rate. In addition, in order to better apply the radiative transfer model to the general circulation model GCMs, NCAR also developed the RRTMG scheme: Compared with RRTM, RRTMG is faster and more accurate in the circulation model. Compared to the RRTM Long-Wave Radiation Scheme (RRTM LW), the RRTMG Long-Wave Radiation Scheme (RRTMG-LW) contains a number of modifications :(1) a computationally more efficient radiative transfer calculation method is adopted, and the radiative efficiency of all atmospheric gases is included; (2) Absorption and scattering of liquids, ice clouds, and aerosols are considered :(3) Monte Carlo independent line approximation Mc ICA is added to represent random subgrid cloud change rates, maximum random subgrid cloud change rates, and maximum cloud overlay options.

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Special acknowledgment goes to the Che and his co-authors behind 'Enhancing Multimodal Understanding with CLIP-Based Image-to-Text Transformation'. This paper discusses the crucial and complex task of converting input images into corresponding textual explanations within computer vision and natural language processing domains. It introduces an innovative ensemble approach leveraging the capabilities of Contrastive Language-Image Pretraining (CLIP) models. The ensemble method involves two variations of the CLIP model, each tailored to specific nuances in the image-to-text transformation landscape. These variations include a meticulously designed multi-layer architecture and strategic utilization of CLIP's zero-shot learning potential combined with a K-Nearest Neighbors (KNN) model. The ensemble approach is rigorously evaluated using cosine similarity metrics, showcasing its superiority over standalone CLIP models, highlighting its advancements in image-to-text transformation, and emphasizing the promising prospects of ensemble learning in addressing complex multimodal tasks. Their work holds immense practical value within our field, showcasing remarkable innovation and pioneering significance. Their research not only contributes significantly to the advancement of the field but also provides invaluable insights and inspiration for our work.

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