Role of Satellites in Climate Prediction using Computer Models

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Abstract*--With the introduction of computers models in the weather and climate information infrastructure in 1954, it instantly became a part of intrinsic methodology of research. In spite of early weaknesses, computer models were perceived as superior technique as it brought with it a voracious appetite for data. Starting out with regional models, they switched to hemispheric models and global model by decade's end. As scales grew, these models needed increasingly vast quantity of data demanding technological and institutional innovation. With the onset of satellite technology during the same period, the two forms often complemented each other in various ways. The data from satellite is often passed through various data analysis model before being used as an input in computer model. This paper is a humble effort in exploring the two different platforms to study the impact of increase in concentration of carbon dioxide in the atmosphere on various parameters of climate such as temperature, evaporation, rainfall, ice cover etc. The data from satellite "AQUA" NASA Earth Science satellite mission is used as an input for the model calculations from a period of 2002 to 2032. The study involves comparison of two scenarios-a control scenario, wherein the concentration of carbon dioxide are kept at the 2002 levels to set as a benchmark for comparison, that will give us the result of a hypothetical situation in which all of the carbon dioxide emission ceases from both natural and man-made sources. Another scenario involves, using the concentration of carbon dioxide and setting a linear increase trend as recorded by "AQUA satellite". Both results are compared; analyzed and potential conclusions are reported. Various shortcomings of methods are discussed along with flaws made in generalizing some specific assumptions. Future improvements and further potential studies are explored briefly.

***Keywords*--Computer models; satellite; collaboration, comparison,**

I. INTRODUCTION

A. CLIMATE MODEL

World Meteorological Organization put the definition of climate models in a single sentence, "Climate models are mathematical representation of climate". They are computer programs that simulate how climate has changed in past and how it will change in the future. It is a prediction tool that incorporates the physics and chemistry of atmosphere, ocean, various factors that can have impact on climate varying from tilt in the earth's axis, to incoming solar radiation, to the type of vegetation distributed around the globe along with others. To give an analogy: if provided with time and distance of a moving body, an academic is able to predict the speed of the body at different intervals of time. This becomes possible because of the mathematical equations describing the nature of motion of body. Similarly, a model describing the nature of environment in mathematical equation is able to predict various factors of environment at different intervals of time. However the main difference between both the situations lies in the fact that those equations describing motions are linear while those describing the environment are non-linear. Another major difference is in the scale of two scenarios. Motion of body involved 1 dimensional motion of an object, while climate model incorporates atmosphere and oceans on 3 dimensional global scales. To accomplish this speed, a large number of simplifying assumptions are made and huge number of calculations is performed, and several processes are parameterized. Another difference is in the scale of two scenarios, one covering a few units of one dimensional distance, and other involving a global three dimensional scale. Non-linear systems are susceptible to chaos theory, producing a variation in results for a minute change in initial conditions. The challenge for climate model is to run forward in time much faster than the real atmosphere that act at a scale much smaller than the characteristic grid interval like cloud dynamics and wind turbulence. And if complete physics of these processes are computed explicitly at each time step and at every grid point huge amount of data produced will affect computational abilities and time required for computation. On the other hand these processes are too important to be eliminated. Hence simplifying equations are developed to represent gross effect of many small scale processes within a grid cell as accurately as possible. There is a lot of research going on to device better and more effective ways for incorporating these small scale processes into climate models. This process is known as parameterization. To encompass the global scale of the study, the models divide earth, ocean and atmosphere into a grid. The values of predicted variables, such as surface pressure, wind, temperature, humidity and rainfall are calculated at each grid point over time, to predict their future values. Time taken in order to compute such variables directly depends inversely on the resolution of the model. Resolutions are defined on the quantitative size of the grid, smaller the grid, finer the resolution and vice versa-larger the grid, coarser the resolution. Finer resolution models take up more time to compute due to increase in number of grid point, coarser resolution with fewer grid points take comparatively less time. Choice of resolution is based on the nature and scale of study.

B. *EDUCATIONAL GLOBAL CLIMATE SYSTEM*

As evident from the assessment reports form “Intergovernmental Panel On Climate Change” climate change will profoundly impact both our planet’s environment and world’s economic and geopolitical landscape in coming decades. Since these impacts have the potential to affect everyone, a basic knowledge of the Earth’s climate system is critical in order to make informed judgments about climate related issues. To achieve that goal, we need to create an environment of knowledge transfer and promote methodology adopted by climate scientist. Computer models are primary tools used in climate research; however they remained elusive to public in general until recently. The lack of familiarity with such techniques has often engendered public distrust of important scientific findings based on such methodologies.

“EdGCM” provides a research based GCM with a user-friendly interface that can be run on desktop computer. It allows students such as ourselves to embrace the science behind climate change just as actual researchers do. It encourages students to participate in full scientific process of experiment design, running simulation, analyzing data, reporting on results. It can facilitate collaborations between schools, universities, national labs, and the private sector so students can understand the role of teamwork in scientific research.

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C. *AQUA SATELLITE*

The Aqua mission is a part of the NASA-centered international Earth Observing System (EOS). Aqua was formerly named EOS PM, signifying its afternoon equatorial crossing time. It has six Earth-observing instruments on board, collecting a variety of global data sets.

On May 4, 2002, a Delta-2 rocket carrying NASA's Aqua satellite was launched into space from Vandenberg Air Force Base near Lompoc, California. Aboard the satellite was an instrument designed to deliver weather and climate information of Earth's atmosphere using a technique called infrared sounding. Now in orbit the Atmospheric Infrared Sounder instrument, or AIRS for short, measures the infrared, or heat, energy emitted by Earth's surface and atmosphere. From this measurement the concentration of many of our planet's trace gases, including the greenhouse gas carbon dioxide, are extracted.

The troposphere is the lowest seven to ten mile high layer of atmosphere that begins at Earth's surface, and the AIRS instrument detects carbon dioxide best in middle of it at altitudes between 15,000 and 30,000 feet. In 2002, AIRS--which collects data around the entire globe every day--reported the average concentration of carbon dioxide in Earth's mid-troposphere to be 372 parts per million (ppm). Still going strong in 2013, AIRS reported April's average daily global concentration in this region to be 397 ppm, with peaks exceeding 400 ppm. The concentration of carbon dioxide in the mid-troposphere lags behind the concentration found at the surface due to the time it takes the gas to be transported to this height. But when compared against the historic record which began in 1958 at Hawaii's Mauna Loa Observatory, the measurements made using AIRS data agree unequivocally that atmospheric carbon dioxide is consistently increasing by about 2 parts per million, year after year, over the entire Earth.

II. METHODS

A. *DEFINING INPUTS OF RUN*

If we propose that the climate is changing implies that we know what it used to be under normal circumstance. We are comparing present with some period in past. We would like to know details and the trends overtime. Since we are focusing on climate we need a long period ideally more than 30 years. Keeping in mind the time constraints and the scale of study we decided to select a period of thirty years from 2002-2032. Runs carried out in this time period will give a vision of where we stand in terms of our ecological footprint in the first 3 decades of 21st century.

Two runs are carried out and the input data is fed such that it mimics the scenarios planned and thus a proper comparison can be analyzed between the two. In the first scenario, concentration of greenhouse gases are set at the levels of those observed during the year 2002 and no trend is set for increase or decrease in concentration.

In the second scenario the concentration of greenhouse gases are initially kept at 2002 levels and then a linear increase of carbon dioxide are observed of 2 ppm per year all across the globe as is evident from the data provided by aqua satellite. Rest all other parameters are set at default so that the results can depict the impact due to carbon dioxide alone.

B. EXPECTATIONS

It is now widely established fact that increase in the concentration of greenhouse gases increases the global average temperature. Increase in temperature kick starts a positive feedback that leads to increase in precipitation. With more surface runoff and high temperature, we should expect an increase in evaporation. Changes in sea, ice or snow cover could be highly unpredictable since their state is often determined by multiple factors like oceanic chemistry. The results should be as close to the reported value of IPCC as possible for them to be realistic.

III. RESULTS AND DISCUSSION

Several factors that are essential in defining our climate systems are analyzed namely temperature, precipitation, evaporation, soil moisture, maximum surface air temperature, net heat surface, snow cover, snow fall, and snow depth.

A. MAXIMUM SURFACE AIR TEMPERATURE

Observation (Fig.1): There is an interesting contrast in the observation of surface temperature. In the northern hemisphere, the increase in temperature is positive and higher. Some regions around Russia and Europe saw an increase in temperature by 1.8ºC, which is in close proximity to the range provided by Intergovernmental Panel on Climate Change (2.5- 5 º C). However parts of southern hemisphere saw a decrease in surface temperature of almost an equal magnitude of
-1.8 º C.
Analysis: Such pattern of higher heating in northern hemisphere may be accounted to the fact that most of the continents on planets are located in the northern hemisphere including major greenhouse gas producer like U.S, China, and Europe. Since greenhouse gases play a vital role in increasing temperatures, the distribution of increase in temperature can be based on this fact. This is also a key data that pinpoints to the argument that human population is a cause of increase in temperature.

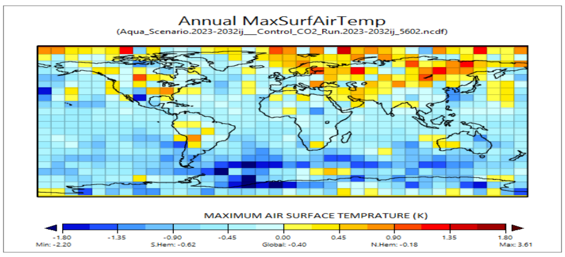

Fig.1

B. EVAPORATION

Observation (Fig.2): The comparison between the two scenarios shows an increase in annual evaporation throughout the planet. However increase in northern hemisphere and in equatorial region is more predominant reaching a maximum of 0.39 mm/day.
Analysis: Increase in surface air temperature in the northern hemisphere might have triggered increase in evaporation rates. Equatorial region is a region receiving highest solar radiation and is normally a region experiencing highest evaporation rates.

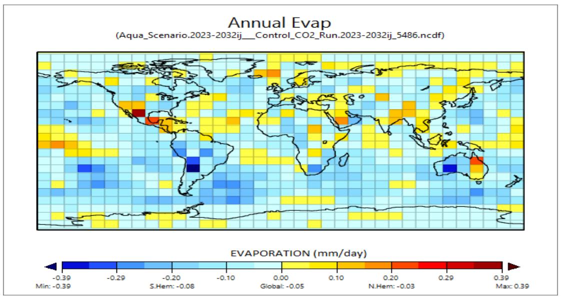

Fig.2

B. ANNUAL NET HEAT AT SURFACE

Observation (Fig.3): There is a uniform increase in the annual surface heat in both the hemisphere. In most regions the increase is as high as 3.71 (W/m^2). Most of this increase is localized over water masses.
Analysis: The basic greenhouse effect explains that carbon dioxide has a capacity to entrap the reflected radiation preventing their escape to outer space. This leads to increase in the surface temperature that accounts for such magnitudes of increase in annual heat.

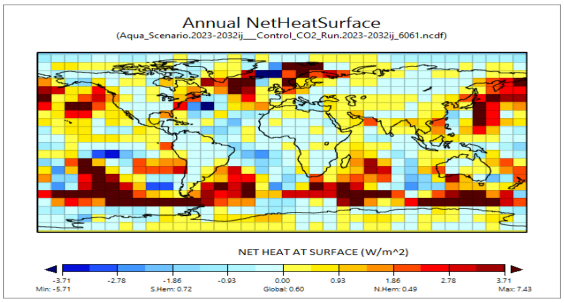

Fig. 3

C. PRECIPITATION

Observation (Fig.4): Overall, large scale global increase in annual precipitation is evident. In most regions the increase is more than 0.30 mm/day, reaching 0.60 mm/day in some regions.
Analysis: Variation in precipitation is directly proportional to variation in temperature.

Increase in temperature triggers higher evaporation leading to greater quantity of vapor in air leading to higher precipitation.

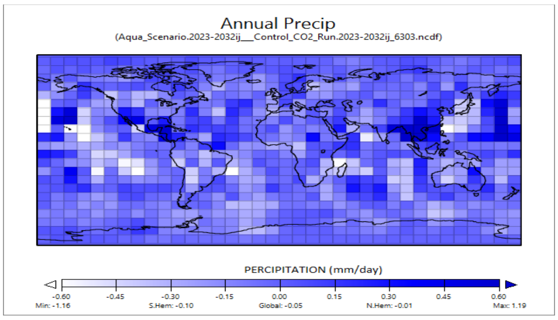

Fig.4

D. SOIL MOISTURE

Observation (Fig. 5): Pattern of soil moisture follows almost a similar pattern as precipitation. Soil moisture increase overall is 8.16 mm/day, with China, and Norway experiencing increase as high as 32.65 mm/day.

Analysis: Soil moisture increase is directly related to the amount of precipitation since the source of this moisture is precipitation. This fact is many times cited as one of the few advantages of global warming which might promote vegetation growth and agriculture. 2012 saw a dramatic reforestation in China.

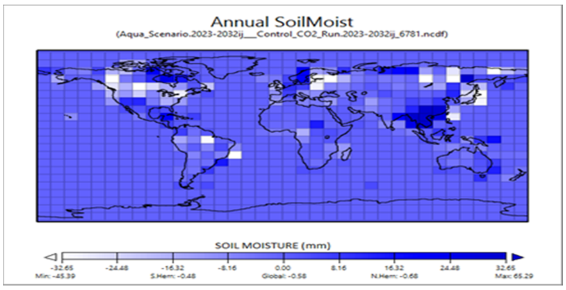

Fig. 5

E. SNOW FALL

Observation (Fig. 6): The data suggests a minor decrease in snowfall in the northern hemisphere. Southern hemisphere saw an increase in snow fall in the northern region of Antarctica however it was quickly followed by a decrease in southern end.

Analysis**:** The behavior in the northern hemisphere of decreasing snowfall can be attributed to increase in surface air temperature. There could be several possible explanations for behavior in southern atmosphere. One of the explanations could be, the role of wind and cloud. However the increase and decrease is insignificant only 0.17%.

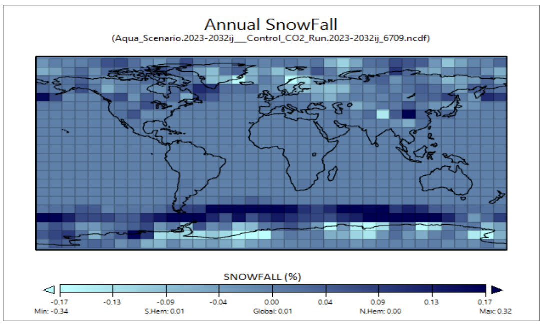

Fig. 6

F. SNOW DEPTH

Observation (Fig.7)**:** The data suggests similar patterns between snow depth and snowfall with depth increasing up to 6.90 mm H2O near Antarctica. A contrasting decrease is observed in the northern regions of Europe and Russia.

Analysis**:** Very difficult to point out the source of this change, as stated above.

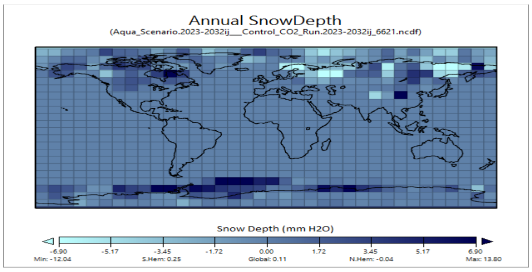

Fig. 7

G. SNOW COVER

Observation (Fig.8)**:** Increase in cover of snow is significant only near the vicinity of Antarctica where it increases by 12.19%.

Analysis **:** It might be difficult to account such observation however data on snow cover, snow depth, and snow fall suggests that there is a large mass of frozen ice trying to push itself northward, away from south pole.

These are the findings that we conclude from this study. However it is very important to note that the results might just be a variation of non-linear solutions. There are several assumptions, and parameterization that skews the result. A detailed description is provided in next section. However the following results obtained state (at least qualitatively) correct relationship as they have also been cited by Intergovernmental Panel on Climate Change on its assessment report. The results include: observed increase in surface air temperature, surface heat, evaporation, precipitation and soil moisture.

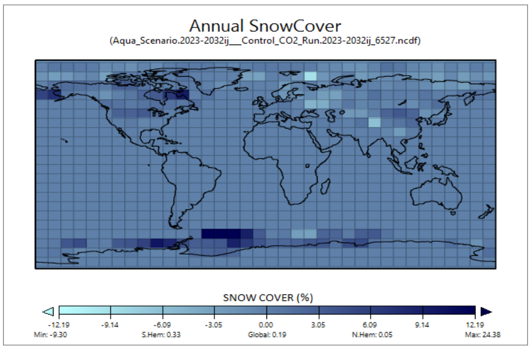

Fig. 8

H. *FLAWS IN PREDICTIONS*

Although EdGCM has enjoyed huge success among academics in particular, however it has some limitations. With its main purpose focused on outreach and compatibility across various computer platforms, the size of the software is crunched to minimum. Thus the model provided has a very coarse resolution. The value predicted in this report may be off from an actual scenario. Finer resolution models provide a more accurate picture of the ongoing change. This is the reason why the use of EdGCM has mainly be limited for educational purposes and is not very often used in major research projects requiring fine accurate details. However, EdGCM is still a very powerful tool in encompassing the changes occurring within the environmental dynamics.

In order to boost the speed and efficiency of computation, several assumptions are made regarding the factors of environments that generalize a scenario and thus the results obtained might not be applicable. Like the trend of increase in carbon dioxide is increasing linearly at 2 ppm per meter from 2002 to 2013, but it might be incorrect to assume that such increase will continue occur at such rate since the concentration might increase or decrease based on various factors.

Another disadvantage of climate models is that, although computer power continues to increase rapidly, global models currently do not resolve features smaller than about 50 miles x 50 miles. This makes it impossible to resolve smaller-scale climate features. The models also simplify or parameterize complex and often non-linear processes, such as the radiation effects of high- and low-level clouds or hydrological processes on the land.

The possible solution to the problem remains using complex, very fine resolution models at the cost of computational speed. We need to provide access to advanced capabilities for those outside the governmental and university laboratories.

I. FUTURE STUDIES

Measuring concentration of greenhouse gases is only one of the much functionality carried out by satellite. Other data like obtained by sensors, like evaporation, or change in outgoing solar radiations can also be used as an input for simulations that can be compared and then reported after careful analysis.

IV. CONCLUSION

A basic overview of the role and use climate models were analyzed, a proper methodology was adopted, using accurate data from satellites a prediction of climate was attempted using a computer model, changes were reported after a careful analysis, possible reasons were discussed, implementation and practicality of prediction was scrutinized, basic fundamental flaws were acknowledged, possible ways to overcome them were viewed, potential further studies were discussed. The main goal of the study was not as much to get accurate results as to understand and perform first-hand the activities undertaken in similar major studies carried out by climate scientists at elite institutions on supercomputers.

Year to year weather averages very naturally. No extreme event or extreme season necessarily reflects a long term climate change. Rising global average temperatures will not put an end to unusually cold winters, or ice storms, or other episodes that seems to run away from the trend. Temperature change that worries us today is an average rise of 2.5-5'C over the next 50-100 years.
In order to tackle the problem of climate change we need to understand the crux of science behind the facts. This can only be achieved by gateways tools like EdGCM that can bridge the gap between infrastructures namely climate change science and remote sensing techniques. Each of these infrastructures, in their own respect, are vast and subsequent knowledge is already in place for it. The coming years will see a unique consolidation of these infrastructures in which will be accompanied by findings emanating from gateway tools like models promoting interdisciplinary nature of study.

V. ACKNOWLEDGEMENTS

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