"GLOBAL WARMING": OBSERVED VARIATIONS AND CHANGES

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ABSTRACT

There are several parameters of fundamental importance with respect to understanding why the climate is or is not changing, especially as related to the "greenhouse effect". These parameters include integrated changes of temperature (horizontal and vertical), precipitation (horizontal) and water vapor (horizontal and vertical). It is also of fundamental importance however to determine how these parameters respond to an enhanced anthropic greenhouse. This includes knowledge about temporal and spatial the details of climate variations. The details of how they are expected to change is often of fundamental importance with respect to the impact on socio-economic, biochemical, and geophysical systems. This implies that we must understand both why and how the climate may change. Monitoring and analysis for why the climate is changing is not synonymous with having how the climate has or will change.

UNDERSTANDING WHY TEMPERATURES HAVE INCREASED

The most pervasive consequence of an enhanced greenhouse effect is the projected increase of global average temperatures. For this reason there has been considerable effort expended in obtaining accurate representations of the instrumented and proxy thermometric record (Jones et al., 1986a; Jones et al 1986b; Jones, 1988; Hansen and Lebedeff, 1987; Hansen and Lebedeff, 1988; Vinnikov et al., 1990; Cook et al., 1991; Bradley and Jones, 1992; Folland et al., 1990). At present, the best estimates of the observed change in global mean temperatures over the past 100 years is in the range of 0.3 to 0.6°C (IPCC, 1990, 1992). The rather wide confidence interval stems from a variety of monitoring problems including: 1) changes of observing methods, 2) incomplete global monitoring, and 3) the separation of local micro- and meso- scale climate variations (including urban heat island effects) from large-scale changes.

Over the past 100 years increases of anthropic greenhouse gases such as CO_2, N_2O, CH_4, O_3, and CFCs have lead to an enhanced greenhouse effect. This has resulted in increases in the radiative forcing at the top of the troposphere. Using the physics from radiative transfer models the IPCC (1990) estimates this increase close to 2 W/m^2 when averaged over the globe. This is equivalent to about a 1.5 increase in equivalent CO_2 forcing.

The sensitivity of the climate system to this forcing at the earth's surface is of critical importance. There are many indirect effects, such as ancillary changes in clouds and water vapor, that can occur with an increase of global mean temperature which affect the sensitivity of the climate system to increases in greenhouse gases. For this reason, comparison of actual changes of surface temperature with projected changes of temperature from General Circulation Models (GCMs) has taken on special importance. The GCMs include many, but not all, of the indirect forcing functions. Assuming all other forcing functions are near zero, such comparisons yield estimates of climate sensitivity to a doubling of equivalent CO_2 in the range of 1° to 2°C using an observed 100-year warming rate of 0.5°C. If a lower estimate of observed warming (0.3°C) is used the sensitivity is less than 1°C, but if the high end (0.6°C) is used the sensitivity is about 2°C.

It may be overly simplistic to simply compare the greenhouse induced climate change with the observed record. The instrumented climate record may be affected by other important forcing functions besides greenhouse forcings. For example, atmosphere/ocean GCMs (AOGCMs) have indicated that the climate system could have internal chaotic variations of the order of several tenths of °C over periods as short as a Century (Hansen et al., 1988; Manabe et al., 1991; Manabe et al., 1992). Proxy records of global temperature suggest that the climate has fluctuated by at least several tenths of degrees over the past several Centuries (Bradley and Jones, 1992). On shorter time-scales volcanic forcing will clearly lead to a cooling effect at the surface (Hansen et al., 1991). Additionally, recent evidence suggests that manmade sulfate aerosol forcing (Charlson et al., 1992) and biomass burning may have significantly altered the radiative balance (-1 W/m^2) of the planet, partially offsetting the greenhouse effect.

Some have argued (Madden and Ramanathan, 1980; Baker and Barnett, 1982; MacCracken and Moses, 1982) that the greenhouse forcings should leave a fingerprint in the climate record which could then be specifically attributed to the greenhouse effect. Such a strategy focuses around a multivariate selection of parameters to analyze. These parameter should posses high signal to noise ratios, reliable and "long" records, and appropriate time and space scales. Some of the simultaneous changes expected in the climate record include: 1) Increases of global mean temperature, 2) A reduction in the pole to equator temperature gradient in the Northern Hemisphere (primarily the cold half of the year), 3) Stratospheric cooling and tropospheric warming, 4) A Global increase of precipitation with mid-continent drying during summer, 5) Tropospheric water vapor increase, 6) A rise of sea-level, and 7) An increase of the land surface temperature relative to the sea-surface temperature. Some aspects of the observed climate record are consistent with these projected changes while others are problematic (Barnett and Schlesinger, 1987, IPCC, 1990). Nonetheless, there has been insufficient research to separate out the signature or pattern of change which might arise due to a global warming from other causes, e.g. natural variability.

UNDERSTANDING HOW TEMPERATURES HAVE INCREASED

Knowing why the climate has changed is only part of the challenge of understanding the climate system. We must also be able to project how the climate will change as it relates to man-made and natural systems on earth. As a prerequisite this means documenting and understanding the interaction between relevant climate parameters as they may affect these systems. Several examples are presented to illustrate the challenge.

Changes in the frequency of extreme temperatures is an important aspect of understanding how the recent warming has evolved over the past several decades. Many systems, both natural and man-made, are more sensitive to the tails of the distribution. To illustrate the complexity of the problem Karl et al. (1991) show that the changes in mean maximum and minimum temperatures over the past several decades have not been symmetric in the USA, the PRC, and the former USSR. The rate increase of the mean daily minimum temperature in these areas was more than three times the rate of the mean daily maximum temperature. Similarly the rate of increase of the 1-day seasonal extreme high temperatures was negligible, but an increase was apparent for the 1-day seasonal extreme minimum temperature. This has effectively lead to a decrease in variability of the extreme temperature range. It is uncertain whether this change is related to an enhanced greenhouse effect, anthropic increases in aerosols, or perhaps natural climate variability. Whatever its cause, it is a fundamental characteristic of the observed change of temperature in much of the Northern Hemisphere. It must be better understood before we can hope to confidently project the impact of any anticipated change of temperature.

The ability to project the frequency of major "weather" events is often of critical importance to many systems. Even if we could project seasonal temperature changes with perfect accuracy over relatively small space-scales, in many instances we would require still higher time resolution in order to project the impact of the changes. For example, the frequency of killing freezes which have destroyed both citrus fruit as well as citrus trees has occurred both during winters with very cold temperatures as well as during more mild winters, especially those during the mild winters of the 1980s (Figure 1). Clearly, changes in the frequency of extreme weather events is very important.

UNDERSTANDING CHANGES OF PRECIPITATION

Precipitation is arguably the most important climate parameter related to life on Earth. Unfortunately, it is very difficult to accurately document important changes of this parameter. This is related to its high frequency variability, and measurement problems. Moreover, it is exceptionally difficult to accurately project long-term regional-scale changes of this parameter. It requires detailed understanding of changes in large-scale and meso-scale thermodynamics as well as micro-scale cloud physics. Karl et al. (1991) demonstrate the problem in the central USA. They show that the IPCC (1990) projected changes of precipitation in this region (due to enhanced greenhouse gases) for summer and winter will not be detectable until well beyond the year 2030. Ironically, the magnitude of the change projected could have major impacts before we could be confident that we have detected a real change. Summer precipitation is projected to decrease by 5 to 10% and winter precipitation is projected to increase up to 15%. To make matters more complicated the observed change in the ratio of summer to winter precipitation during the Twentieth Century in the Central USA is not consistent with the projected changes, if greenhouse forcings are the only important factor.

Our ability to work with projected changes of seasonal mean precipitation that may be of the order of 5 to 10% is fraught with difficulties. First, virtually all in-situ operational measurements of precipitation, the data we use to measure climate variations, have significant measurement biases due to a number of factors, e.g. evaporation losses, aerodynamic losses around the precipitation gauge, wetting losses inside the gauge, etc. (Karl et al., 1992). These biases are exposure and weather dependent. Moreover, the biases change over time as instruments change as illustrated in Figure 2. Second, just as knowledge of a seasonal mean temperature is often insufficient to project its impact on a variety of systems, changes in the short-term temporal variability of precipitation cannot be ignored. Extreme precipitation events and their frequency determine the climatology of floods and droughts. At the present time, there is not a clear picture that emerges with respect to systematic changes of temporal precipitation variability. Projected changes appear to be model and regionally dependent (IPCC, 1992). Lastly, as the temperature warms, the form of precipitation can change. This has important implications with respect to the water balance. The source term of the water balance equation (frozen versus liquid) can significantly affect the timing and distribution of water availability, and the diurnal changes of temperature affect the evaporative losses from the soil, lakes, and reservoirs.

In order to obtain more realistic estimates of the projected changes of day-to-day precipitation variability due to increased concentrations of greenhouse gases a number of statistically-based procedures have been developed to interpret the large and local-scale state of the AOGCMs free atmosphere with respect to the precipitation received at the surface. These statistical approaches (Wigley et al., 1990; Karl et al., 1990; Von Storch et al. 1991) can improve our ability to project more realistic precipitation simulations, but they too, are limited by our ability to project the state of the atmosphere in the future as well as the bounds of the data sample used to develop the

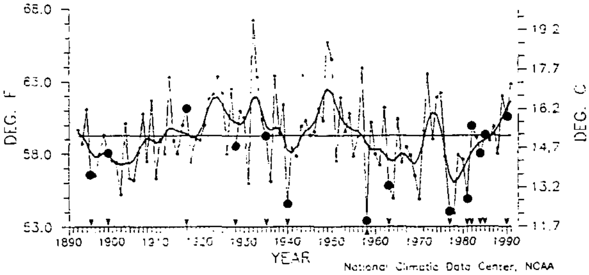

Figure 1 Mean winter temperature area-averaged over the state of Florida. Large bold dots indicate those years which had freezes so severe that extensive damage was inflicted upon both the citrus crop and the trees that bore the fruit.

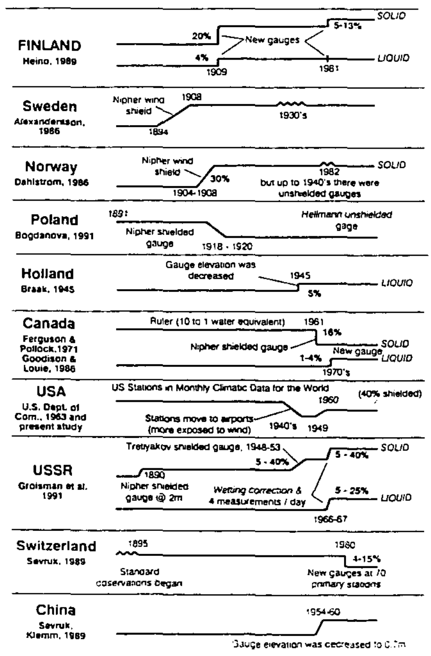

Figure 2 Changes of precipitation measurement which have led to biases in time series of precipitation data within national precipitation networks across the globe.

statistics. Because of these limitations efforts are now underway to mesh large-scale and meso-scale models to obtain a better understanding of the impact of large-scale changes at shorter time and smaller space-scales (Giorgi and Mearns, 1991).

CONCLUSIONS

Several steps need to be taken to reduce the uncertainties now associated with both understanding why and how climate has changes especially as related to the greenhouse effect.

1) Improve the reliability, continuity, and resolution of existing observations and data bases.

2) Expand the observational data base necessary to incorporate the physics necessary to include additional forcing functions, not now included in atmosphere/ocean GCMs. This includes those observations which may lead to a better understanding of anthropic and natural aerosol generation, and their subsequent interaction with water vapor, cloudiness, and the solar radiation budget.

3) Develop more sophisticated analysis techniques to assess the consistency or inconsistency of model projection with observed changes.

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