3.4 DESCRIBING GLOBAL CLIMATE VARIABILITY AND CHANGE USING SIMPLE INDICES

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1. INTRODUCTION

Many studies have used global-mean surface temperature to establish the degree and significance of changes in climate over the last century. This is because global-mean temperature is expected to respond to radiative forcing changes associated with increasing greenhouse gases and because using the global average enhances the signal-to-noise ratio. Additional information is available for the attribution of climate change through the spatial patterns of surface temperature changes. Fingerprint methods which use spatial and temporal information for the attribution of climate change have been reviewed recently by the IPCC (Mitchell et al., 2001).

In this study, we use several simple indices of surface temperature patterns, including the global-mean, the land-ocean temperature contrast, the meridional temperature gradient, and the magnitude of the annual cycle, to describe global climate variability and change. These indices represent the main features of the fingerprint of greenhouse climate change but are easier to interpret. Also, they are associated with dynamical factors determining the large-scale atmospheric circulation. For natural climate variations, they contain information independent of the global mean temperature.

Preliminary results from this study were presented by Karoly and Braganza (2001) but they are extended here. We use global instrumental observations for 1881-1999 (Jones, 1994; Parker et al., 1995), paleoclimate reconstructions from proxy data for 1700-1900 (Mann et al., 1998), and long control and anthropogenic climate change simulations from 5 different coupled ocean-atmosphere climate models (CSIRO9, HadCM2, HadCM3, GFDL R30, ECHAM4). In a companion paper (Karoly and Braganza, 2002), the indices are used to evaluate the performance of control climate model simulations of natural climate variability. The variability and correlation structure of the indices on interannual and decadal timescales from control simulations with all 5 models compare well with those from detrended observational data and from proxy data. Hence, the simulation of global-scale surface temperature variability in these climate models is good.

Here, we compare the observed trends in the indices over the last 50 years (1950-99) and the last 100 years (1900-99) with the trends in the forced model simulations and the variability of the trends in long control simulations. The forced model simulations include increasing greenhouse gases and increasing sulphate aerosols from about 1860 (GS cases).

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2. DEFINING THE GLOBAL INDICES

Four simple indices based on surface temperature patterns are used. All the indices have been identified previously in studies of climate variability and change, although they have not been considered together, apart from in Karoly and Braganza (2001).

- Global-mean surface temperature (GM): The area-weighted global average of surface temperature. This has been used in many climate change detection studies.
- The contrast between land and ocean surface temperature (LO): The difference between mean surface temperature over land and mean sea surface temperature. This index has been chosen to capture the pattern of greater warming over land than ocean
- The magnitude of the annual cycle over land (AC): Calculated for each hemisphere by subtracting mean winter from mean summer temperature over land, then weighted by the fraction of land area in each hemisphere and combined into a single index.
- The mean meridional temperature gradient (MTG): Difference between two zonal bands representing the NH extra-tropics (22.5°N-37.5°N) and the NH mid to high latitudes (52.5°N-67.5°N). MTG has been chosen to represent the recent observed pattern of greater warming in high latitudes compared to the tropics

A data mask was created to exclude regions where the observations were sparse or non-existent. This mask was applied to both observations and model data. As a result of applying the mask, large regions of the Southern Ocean and Antarctica, as well as smaller regions in the high northern latitudes and over the interior of the southern continents have been omitted from the analysis.

3. TRENDS IN THE INDICES

The linear trends in each of the indices were calculated for two separate periods: 1900-1999 (last 100 years) and 1950-1999 (last 50 years) from the observational data and the forced model simulations. The uncertainty in the trends due to internal climate variability was estimated for each of the indices from the range of trends found in the long, unforced climate model simulations. The different members from an ensemble of simulations with the same forcing and model also allow the uncertainty of the trends due to the chaotic nature of climate to be estimated from the forced model simulations.

First, we identify significant observed trends by assessing whether they are significantly different from zero. Next, we compare the observed trends with those from the forced model simulations to assess whether the observed changes are consistent with the forced climate changes.

The observed trends over the period 1950-99 in all the indices (shown in Table 1) are significant and cannot be explained by natural internal climate variations (as the 90% confidence interval about zero trend from the control simulations does not include the observed trend). The observed trends over the last 100 years are similar but generally significant at lower confidence levels. The observed trends are generally consistent with those in most of the model simulations forced by increasing greenhouse gases and sulphate aerosols (as the 90% confidence interval about the observed trend includes some of the forced model trends). The observed trend in global-mean temperature is significantly smaller than simulated by the models (apart from HadCM2) but the observed reducing trend in the magnitude of the annual cycle is significantly larger than simulated by any of the models (apart from HadCM3). The trend in meridional temperature gradient simulated by the GFDL model is highly variable but the ensemble mean is not consistent with that observed, unlike the other models.

In general, the observed climate change shown by these indices is consistent with that due to human-induced climate forcing and not consistent with natural variability alone.

The observed trends over the last 100 years and over the last 50 years agree better with the simulations forced by increasing greenhouse gases and sulphate aerosols than with those forced by increasing greenhouse gases alone. The rate of change of the observed and model indices over the last 50 years is larger than over the last 100 years, suggesting an increase in the rate of climate change over the recent period.

While we have shown that there are significant changes in the indices over the last 50 years and that these changes are generally consistent with simulations forced with increasing greenhouse gases and sulphate aerosols, we have not considered any other possible climate forcings, such as changing solar irradiance. This will be considered in further work. We are also investigating other possible indices, such as the diurnal temperature range or the temperature contrast between the troposphere and the stratosphere.

Index	Observed	90% confid	CSIRO9	HadCM2	HadCM3	GFDL-R30	ECHAM4
GM	0.41	±0.19	0.65	0.47±0.13	0.63±0.06	0.61±0.10	0.57
LO	0.30	±0.18	0.37	0.28±0.19	0.39±0.08	0.20±0.06	0.49
AC	-0.50	±0.26	-0.11	-0.18±0.08	-0.28±0.11	-0.10±0.04	-0.18
MTG	0.53	±0.37	0.30	0.42±0.23	0.51±0.34	-0.04±0.48	0.26

TABLE 1. Linear trends (°C per 50 years) over the last 50 years (1950-99) in the indices from observations and anthropogenically-forced (GS) climate model simulations. The 90% confidence interval for the trends is based on the distribution of trends from the long control model simulation with HadCM2. The uncertainty for the forced model trend is the range of trends found in that model's GS ensemble with 3 or 4 members.

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