12.3 # UNCERTAINTY ANALYSIS OF GLOBAL CLIMATE CHANGE PROJECTIONS

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1. INTRODUCTION

We use quantitative uncertainty analysis techniques to estimate the likelihoods of climate change in the twenty-first century. We use the Latin Hypercube approach to perform a Monte-Carlo simulation based on uncertainty in eight factors determining anthropogenic emissions projections and three climate system properties. Although uncertainty in the emission model's factors are assessed via expert judgment, uncertainty in the climate system properties can now be constrained by climate observations of the twentieth century. By sampling from the uncertain input distributions and running approximately 500 simulations with the MIT Integrated Global System Model (IGSM) (Prinn et al., 1999), this method produces probability distributions (pdfs) for climate variables in the twenty-first century. We present results from two cases, with and without mitigation policies, to demonstrate the effect on the pdfs of climate change. This method differs considerably from other studies (e.g., Wigley and Raper, 2001) in that the input parameters for the climate model are constrained by recent climate observations (Forest et al., 2001a,b) and pdfs were estimated for the emission scenarios (Webster et al., 2001) rather than assuming equal probability among possible scenarios.

2. METHOD

To estimate uncertainty in climate change projections, we perform Monte-Carlo simulations with the MIT IGSM by propagating uncertain input distributions for the important model parameters and emission scenarios. To reduce the number of simulations, we run 250 simulations where specified set of input parameters and emissions scenarios are obtained from a Latin Hypercube Sampling (Iman and Helton, 1988). This sampling procedure divides each input pdf into 250 equally probable bins and samples randomly from the 250 bins for each input parameter without replacement. Thus, the 250 simulations are roughly representative of the point probability distribution over the input parameters.

Several components of the MIT IGSM have been improved since Prinn et al. (1999) was published. The atmospheric chemistry and climate model (Wang et al., 1998) has incorporated a reduced-form urban air chemistry model (Mayer et al., 2000) such that atmospheric chemistry is treated separately for urban areas and then incorporated into the large scale climate system. The Terrestrial Ecosystem Model is now fully integrated and estimates the carbon uptake by land surfaces as required in the atmospheric carbon budget.

3. INPUT PDFS FOR CLIMATE MODEL PARAMETERS

In previous studies of this type (e.g., Webster and Sokolov, 2000), the probability distributions for input parameters to the climate model have been obtained from expert elicitation studies. Forest et al., (2001a,b) have now provided input distributions for three important model parameters as constrained by optimal fingerprint detection statistics obtained from observations of recent climate change and model estimates of natural variability (full description in Forest et al. 2001a). Two of the uncertain parameters (climate sensitivity (S) and the rate of heat uptake by the deep ocean given as the effective ocean diffusivity (K_v)) controls the large-scale climate system response to external forcings. The third parameter (F_{aer}) accounts for uncertainty in the total forcing via the aerosol forcing strength. Together, these act as surrogates for structural uncertainty of atmosphere-ocean general circulation models (AOGCMs). By estimating the dependence of detection statistics on these parameters, we estimate three joint probability distributions based on independent climate change diagnostics. We then combine these pdfs by using Bayes' Theorem to construct a *posterior* distribution based on multiple diagnostics.

The distributions used in this study (Figure 1) are modified from those in Forest et al. (2001b) by the inclusion of an expert prior applied to the ocean heat uptake parameter, K_v (i.e., effective ocean diffusivity.) This prior is estimated from the distribution of K_v values obtained by matching the transient response to identical forcings of the

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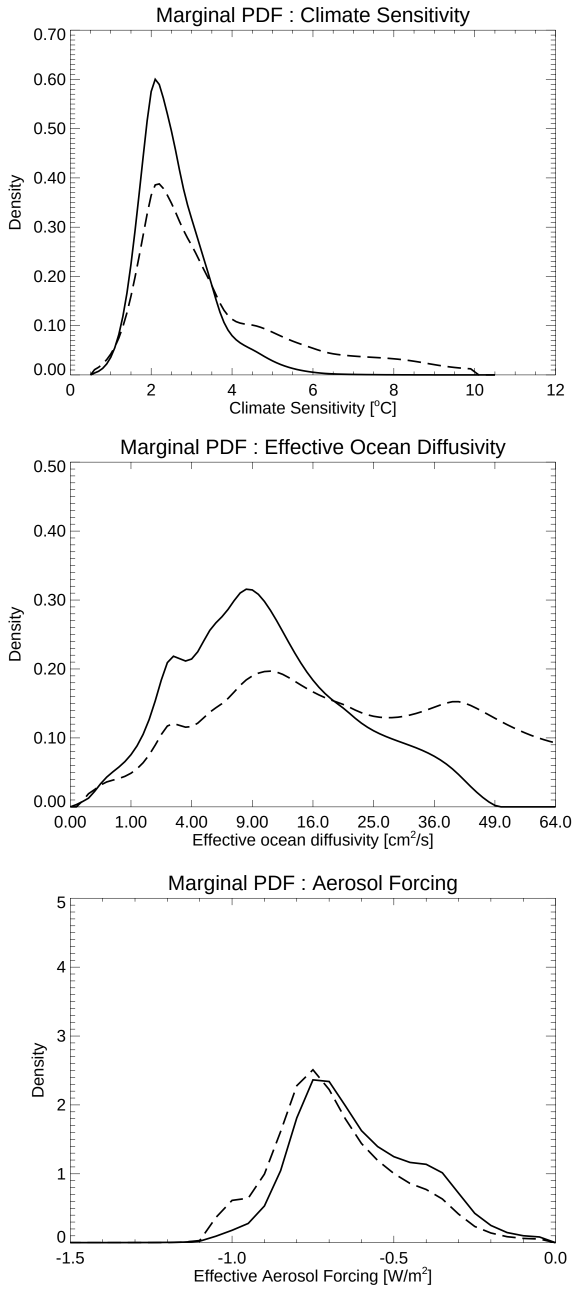

Figure 1. Marginal probability density functions for climate model parameters (S, top; K_v, middle; F_{aer}, bottom) as estimated in Forest et al. (2001b). We show the *posterior* pdfs with (solid) and without (dashed) expert priors for S and K_v. When no expert prior is used, a uniform prior is assumed over the parameter space.

climate model component of the IGSM to the response of AOGCMs. A description of the matching procedure and the list of matching parameters for AOGCMs can be found in Sokolov et al. (2001) in this volume.

4. FUTURE EMISSIONS UNCERTAINTY

The uncertainty in emissions scenarios relevant to climate change has been assessed in Webster et al. (2001) and two sets of 250 scenarios were generated to force the IGSM. The scenarios were calculated using the MIT Emissions Prediction and Policy Analysis (EPPA) model (Babiker et al., 2001) which is a computable general equilibrium model for the global economy divided into 12 regions and 8 economic sectors. The model projects the major greenhouse gases (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) and other pollutants and climatically or chemically important substances including aerosols and their precursors (from SO_2, black carbon, organic carbon) and NO_x, CO, NH_3 and non-methane volatile organic compounds.

Using an expert elicitation process (detailed in Webster et al., 2001), pdfs for eight factors were estimated and a Latin Hypercube sample was drawn in order to calculate 250 unique emission scenarios under two assumptions. The first considered is a "No Policy" case in which no restrictions are placed on future economic activities to impose reductions in the emissions. A second is "Policy" case generated according to a stringent policy proposed in Reilly et al (1999). This is a severe policy scenario designed to reduce global warming significantly.

5. OUTPUT PDFs FOR CLIMATE CHANGE

Two 250-member ensembles were calculated by the IGSM according to the Policy and No Policy emission scenarios and the set of 250 combinations of the climate model parameters generated with the Latin Hypercube algorithm. (N.B. 250 simulations of the IGSM required ~30 days of computing on a 16-node cluster of 850MHz AMD Athlon computers running Linux.) From each set of simulations, pdfs for any climate change variable can be estimated. As an illustration of the approach for global mean surface temperature change and sea level rise (Figure 2), we find that, absent mitigation policies, our projections shows the mean rise in global-mean surface temperature from 1990 to 2100 is 2.5 °C, with a 95% confidence interval of 0.9 to 5.3°C. With a stringent policy applied, the 95% confidence interval is reduced to 0.7 to 3.2°C with a mean of 1.6 °C. We see similar changes in the pdfs and statistics for the projections of sea level rise.

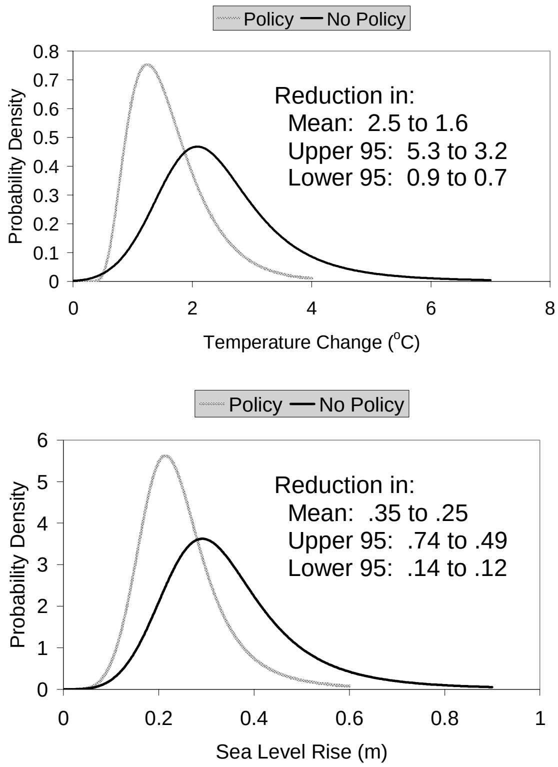

Figure 2: The probability distributions for global-mean decadal-mean surface air temperature (top) and the thermal expansion component of sea level rise (bottom) for the No Policy and Policy cases.

6. DISCUSSION

Primarily, this work serves as an example of how quantitative uncertainty analysis can be applied to the climate change problem such that we can estimate results that are relevant to the ongoing scientific and political debate. Several issues relating to these types of results should be mentioned. First, to determine meaningful probability estimates for climate change, both the economic and scientific uncertainty must be included. Taking a range of model results cannot provide probability bounds unless an analysis of this type is performed. Second, this analysis does not include uncertainty in the possible non-linear responses of the climate system such as a collapse of the thermohaline circulation or of the West Antarctic Ice Sheet. Each of these is beyond the capability of the IGSM and therefore, these results are conditioned by these assumptions. Third, the role of expert elicitation in such studies must also be considered. For example, another group of experts could choose a different set of input pdfs and therefore, alter the results. In constraining the input pdfs for the climate model parameters with climate change observations, this component of the uncertainty analysis is less susceptible to such criticism.

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