Northern Hemisphere Stationary Waves in Future Climate Projections

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ABSTRACT

The response of the atmospheric large-scale circulation to an enhanced greenhouse gas (GHG) forcing varies among coupled global climate model (CGCM) simulations. In this study, 16 CGCM simulations of the response of the climate system to a 1% yr\(^{-1}\) increase in the atmospheric CO\(_2\) concentration to quadrupling are analyzed with focus on Northern Hemisphere winter. A common signal in 14 out of the 16 simulations is an increased or unchanged stationary wave amplitude.

A majority of the simulations may be categorized into one of three groups based on the GHG-induced changes in the atmospheric stationary waves. The response of the zonal mean barotropic wind is similar within each group. Fifty percent of the simulations belong to the first group, which is categorized by a stationary wave with five waves encompassing the entire NH and a strengthening of the zonal mean barotropic wind. The second and third groups, respectively consisting of three and two simulations, are characterized by a broadening and a northward shift of the zonal mean barotropic wind, respectively. A linear model of barotropic vorticity is employed to study the importance of these mean flow changes to the stationary wave response. The linear calculations indicate that the GHG-induced mean wind changes explain 50%, 4%, and 37% of the stationary wave changes in each group, respectively. Thus, for the majority of simulations the zonal mean wind changes do significantly explain the stationary wave response.

1. Introduction

The model-projected increase in the global mean surface temperature during 2090–99 relative to 1980–99 in response to enhanced anthropogenic forcing varies in the range of 1.1°–6.4°C (Solomon et al. 2007). Much of the uncertainty derives from a range of future socioeconomic scenarios, which combine different developments for the emission of anthropogenic greenhouse gases and aerosols; however, even when using the same greenhouse gas forcing the intermodel differences are large. The corresponding model-projected increase in the global mean surface temperature in response to a doubling of the atmospheric CO\(_2\) concentration varies in the range from 2.1° to 4.4°C (Solomon et al. 2007). The model-projected regional climate response to enhanced anthropogenic forcing varies even more than the global response (e.g., van Ulden and van Oldenburg 2006; Déqué et al. 2007). This regional response is of great societal importance.

Atmospheric stationary waves are closely linked to regional climate, and therefore play a key role in regional climate change. The purpose of this study is to investigate the dynamics of Northern Hemisphere (NH) winter stationary waves in response to the enhanced greenhouse gas (GHG) forcing in coupled global climate model (CGCM) simulations. Because aerosols are treated very differently in the models (Kiehl 2007), we restrict this study to the apparently more consistent GHG changes. Large-scale atmospheric waves are forced by the longitudinally varying topography, diabatic heating, and transient eddies; further, the propagation of the large-scale waves is influenced by the large-scale mean flow. In this article the importance of GHG-induced changes in the zonal mean flow for the NH winter stationary waves is analyzed.

Stephenson and Held (1993) published one of the
first studies on the response of stationary waves to an enhanced GHG forcing. They analyze the NH winter response of the Geophysical Fluid Dynamics Laboratory (GFDL) R15 resolution (equivalent grid spacing about 4.5° latitude × 7.5° longitude), CGCM to an enhanced GHG forcing and conclude that transients and diabatic heating appear to be the major forcing terms for the response in the stationary waves, while changes in the mean basic state and topographic forcing play only a small role. The zonal mean wind changes in the CGCM analyzed by Stephenson and Held (1993) is, however, relatively small. These results were contradicted by Joseph et al. (2004) who analyze the stationary wave response of the GFDL R30 CGCM [i.e., the same model as that of Stephenson and Held (1993), but with a higher resolution]. They conclude that at least as much of the climate change response is accounted for by the change in the zonal mean basic state as by the change in the zonally asymmetric forcings, such as diabatic heating and transient eddy fluxes.

In a study of the response of the Southern Hemisphere (SH) atmospheric circulation to an enhanced radiative GHG forcing in the ECHAM4/Ocean Isopycnal Model 3 (OPYC3) CGCM, Brandefelt and Källén (2004) find that the SH stationary wave response is associated with a strengthening of the zonal mean waveguide for barotropic Rossby waves. The spatial patterns of the leading modes of SH variability are also found to change, consistent with the strengthening of the zonal mean waveguide. The NH winter stationary wave response in this CGCM is also accompanied by a change in the spatial patterns of the leading modes of variability (Brandefelt 2006). The zonal mean upper-level wind is strengthened in this CGCM simulation; the zonal mean propagation conditions, however, are not altered by the enhanced GHG forcing.

The increase in the zonal mean upper-level wind, and the associated increased pole-to-equator temperature gradient at upper levels, found in the simulations analyzed by Stephenson and Held (1993), Joseph et al. (2004), and Brandefelt (2006), is a common signature in CGCM simulations of the response to an enhanced GHG forcing (Räisänen 2003). This increase in the upper-level temperature gradient is a result of increases in GHG concentrations and decreases in stratospheric ozone, which are expected to result in a heating of the troposphere and a cooling of the stratosphere (Hoskins 2003). Because the tropopause height decreases from the subtropics to high latitudes, the temperature gradient at a particular pressure level is expected to increase due to these changes in the vertical structure. As a further result, a lifting of the tropopause during the twenty-first century is expected (Santer et al. 2003). Increases in tropopause height are also identified in observations over the past decade (Hoinka 1998; Seidel et al. 2001; Randel and Gaffen 2000; Highwood et al. 2000). The importance of this increase in the zonal mean flow for the NH winter stationary waves is analyzed in this article.

To interpret the barotropic response of the stationary waves in the CGCM simulations, a linear model of the barotropic stationary waves is applied. Linear theory has proven useful in understanding the response of stationary waves to changes in the zonal mean circulation. This process has been interpreted by Rossby et al. (1939) through a dispersion relation for stationary waves. Using a linear baroclinic model of stationary waves, the longitudinal structures of NH variability patterns may be derived as linear responses to meridional displacements of the zonal mean jet (Ting et al. 1996; DeWeaver and Nigam 2000; Körnich et al. 2006). The main mechanism behind it is the so-called zonal-eddy coupling, where the anomalous zonal mean wind affects the linear propagation of the stationary waves and thus produces an anomaly in the stationary waves.

Concerning climate change scenarios, linear models allow exploration of how stationary waves in future climate projections are affected by changes either in the zonal mean background or in the longitudinally dependent stationary wave forcings, such as heating or transient eddies.

In the present study, the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4) ensembles of CGCMs are analyzed. Compared with previous versions of these CGCMs, many of these models contain improved physical parameterizations and increased resolution. In section 2 the CGCM simulations are described. The simulated unperturbed NH winter stationary waves are described and compared to the reanalysis. In section 3 the linear barotropic model is described. In section 4 the changes in the NH winter stationary waves in response to the enhanced GHG forcing are described. It is shown that the simulations can be divided into a few groups based on their barotropic stationary wave response. The associated change in the zonal mean barotropic wind is also described. In section 5 the linear model is applied to investigate the importance of the zonal mean background flow changes for the stationary wave response. The study is summarized in section 6.

2. Stationary waves in IPCC simulations

Because aerosol forcing is a major uncertainty in future climate projections (Kiehl 2007), we choose to analyze the response of the system to changes in the GHG
forcing only. All available simulations with a 1% yr\(^{-1}\) increase in the atmospheric CO\(_2\) concentration to quadrupling (approximately 140 yr) within the World Climate Research Program’s (WCRP’s) Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset are analyzed. This limits our study to 16 simulations with 14 different CGCMs. The simulations are listed in Table 1. Abbreviations for each simulation, which will be used throughout the article, are also listed. There is one simulation available for each of these CGCMs, with the exception of the Model for Interdisciplinary Research on Climate (MIROC) for which an ensemble of three simulations is available. Thus, both a multimodel ensemble and an initial value ensemble are available for the study, enabling an investigation of the relative importance of internal variability and intermodel differences for the response to the same GHG forcing.

The simulations analyzed are started from preindustrial or present-day conditions (see Table 2). This information has been included to facilitate a test of the importance of the initial state for the response to the enhanced forcing. The horizontal resolution of the atmospheric components of each CGCM varies in the range of 5° latitude \(\times\) 1.4° longitude. This information has also been included in Table 2 to test the importance of the horizontal resolution. For the analysis in this article, all the fields from the different simulations have been interpolated to a common Gaussian grid with triangular truncation at wavenumber 21.

The atmospheric stationary waves are defined as the departure from the climatological and zonal mean. The response of the large-scale circulation is largely equivalent.
lent barotropic, which is why the response in the barotropic streamfunction is studied. The barotropic mean is determined as the pressure-weighted vertical mean (for pressure levels of 850–100 hPa). The use of the barotropic mean enables a comparison of the CGCM-simulated circulation with barotropic theory.

The simulated NH winter (December–February) barotropic stationary waves are displayed in Fig. 1 for the years of 3–32 of each simulation. This period is chosen to represent an unperturbed climate, even though the atmospheric concentration of CO₂ increases by 35% during this period.

The spatial pattern correlation of the unperturbed barotropic stationary waves in each simulation with the barotropic stationary waves in data from the 45-yr European Centre for Medium-Range Weather Forecasts
(ECMWF) Re-Analysis (ERA-40; Uppala et al. 2005) for the years of 1979–2002 is displayed in the top-right corner of each panel. The spatial pattern correlation is calculated with area weighting. The pattern correlation with ERA-40 varies in the range of 0.69–0.96. With the exception of the Beijing Climate Center (BCC), the pattern correlations with ERA-40 exceed 0.88.

The unperturbed barotropic zonal mean wind is displayed in Fig. 2 for each simulation. The simulations are grouped based on their respective stationary wave responses to the enhanced GHG forcing. This will be described further in section 4. For comparison, the barotropic zonal mean wind in ERA-40 is also displayed in Fig. 2 (lower-left panel). The simulated wind is comparable in amplitude and shape to the reanalysis in all models. BCC is an exception, with a 9 m s$^{-1}$ weaker jet maximum than in ERA-40.

3. The linear barotropic stationary wave model

To interpret the stationary wave responses in the different simulations, a linear barotropic vorticity model is constructed. The starting point is the barotropic vorticity equation,

$$\frac{d}{dt} \left( \nabla^2 \psi + f \right) = \mathcal{F}(\psi) + r(\psi),$$

with the total derivative $d/dt$, the Laplace operator $\nabla^2$, and the Coriolis parameter $f$. The streamfunction is defined by

$$\frac{\partial \psi}{\partial x} = v; \quad \frac{\partial \psi}{\partial y} = -u,$$

where $u$ and $v$ are the eastward and northward wind components, respectively, and the vorticity $\xi$ is ex-
pressed in terms of streamfunction $\psi$ as $\xi = \nabla^2 \psi$. The term $f_0$ on the rhs of (1) represents mechanical and thermal forcing, for example, by orography and latent heat release. Finally, $r(\psi)$ is the friction.

First, we separate the streamfunction into the time mean component $\Psi$ and deviations from the time mean $\psi'$. Taking the time mean of (1) we obtain

$$- \frac{\partial \Psi}{\partial y} \frac{\partial \nabla^2 \Psi}{\partial x} + \frac{\partial \Psi}{\partial x} \frac{\partial \nabla^2 \Psi}{\partial y} + \frac{\partial \Psi}{\partial y} \frac{\partial f_r}{\partial y} = T(\psi') + r(\psi) + T(\psi),$$

(3)

where $T(\psi')$ represents the terms describing transient processes.

We now consider two equilibrium states of the atmosphere, namely, the unperturbed state $\Psi_c$ and the perturbed state $\Psi_{c+\delta}$:

$$\Psi_c = [\Psi_c] + \Psi_c^*,$$

$$\Psi_{c+\delta} = [\Psi_c] + [\Psi_{\delta}] + \Psi_{c}^* + \Psi_{\delta}^*,$$

(4)

where $[\Psi]$ and $\Psi^*$ are the zonal mean component and the deviation from the zonal mean, respectively, and the perturbation ($= \text{the difference between the two states}$) is labeled with $\delta$. In the same manner, the forcing terms $f$, $r(\Psi)$, and $T$ can be split into an unperturbed contribution and a perturbation.

Writing (3) for the perturbed and the unperturbed state and taking the difference of these two equations yields an equation for the streamfunction perturbation. This equation is linearized for small perturbations in the stationary waves $\Psi_{\delta}^*$. This yields

$$\frac{\partial}{\partial y} \left( \nabla^2 \left( [\Psi_c] + [\Psi_{\delta}] + \Psi_c^* + \Psi_{\delta}^* + f_r \right) \right) \frac{\partial \Psi_{\delta}^*}{\partial x} = - \frac{\partial \nabla^2 \Psi_c^*}{\partial x} \frac{\partial \Psi_{\delta}^*}{\partial y} - r(\Psi_{\delta}^*)$$

(6)

The thermal and transient forcing terms have been omitted in (6) (see below for a discussion).

Equation (6) describes a linear model of the barotropic stationary wave perturbation $\Psi_{\delta}^*$. The lhs of (6) consists of the linear operator times the stationary wave perturbation. The linear operator depends only on the unperturbed state $[\Psi_c]$ and $\Psi_c^*$, and the zonal mean perturbed state $[\Psi_{\delta}]$. The rhs of (6) is the forcing of the linear stationary wave perturbation by zonal eddy coupling. It connects the perturbation of the zonal mean background $[\Psi_{\delta}]$ to the unperturbed stationary wave $\Psi_c^*$. Given the unperturbed stationary wave, the unperturbed zonal mean background, and the perturbed zonal mean background, (6) can be solved by inverting the linear operator. The solution yields the stationary wave perturbation $\Psi_{\delta}^*$, and it describes the changed propagation of the unperturbed stationary wave resulting from the change in the zonal mean background.

It should be noted that changes in the thermal stationary wave forcing $f_{\delta}^*$ and changes in the transient eddy forcing have been omitted in the presented linear model. These terms would appear on the rhs of (6) and are expected to have a nonnegligible impact on the stationary wave response. However, we focus on the impact of the zonal eddy coupling, that is, the impact of a changed zonal mean background on the stationary wave response.

To apply the linear barotropic model of stationary waves from (6) on the CGCM simulations, the friction term has to be specified. This friction contains the following two contributions: the surface friction and horizontal diffusion. For the former, a Rayleigh friction with a time scale of 7 days, is chosen uniformly for all models. This friction is sufficient to produce stable solutions of the linear model. Double or half of the time scale for the Rayleigh friction only changes the amplitude of the linear response, but has little effect on the pattern. Because the linear model will be applied to ensemble means of different CGCMs that apply different diffusion schemes, the same biharmonic diffusion scheme with a damping time scale of 20 days for total wavenumber 21 is used for all linear calculations. The horizontal diffusion has negligible effect on the linear solution.

4. Stationary wave response in IPCC simulations

The simulated response of the circulation to the enhanced GHG forcing is defined as the difference between a perturbed climate and the unperturbed climate. As discussed earlier, the years of 3–32 of each simulation are chosen to represent the unperturbed climate. The perturbed climate is represented by the years of 111–140 of each simulation. The atmospheric CO$_2$ concentration increases by 35% during this period.

The simulated response to the enhanced GHG forcing in the NH winter stationary waves is displayed in Fig. 3 for the 16 simulations. Differences between the perturbed and the unperturbed stationary waves that
are significantly different from zero at a 5% level are shaded in gray (based on a Student’s t test). The maxima and minima of the stationary wave responses are statistically significant for all simulations.

The amplitude of the changes in the stationary waves amounts to 20%–40% of the amplitude of the unperturbed stationary wave in the different simulations. To determine how the changes in the stationary waves influence the total amplitude of the waves, we compare the zonal mean of the squared streamfunction of the stationary waves in the perturbed and the unperturbed periods of each simulation. The changes in the stationary waves lead to an increased or unchanged amplitude of the stationary waves in all simulations but the Goddard Institute for Space Studies (GISS) and Meteorological Institute of the Rheinische Friedrich-Wilhelms, Universität Bonn (MIUB) simulations in group N (see group definitions below). These results are contradic-

Fig. 3. The response to the enhanced GHG forcing in the barotropic stationary waves in 16 CGCM simulations. The abbreviation for each model is shown in the top-left corner of each panel. The CI is $1 \times 10^9$ m$^2$ s$^{-1}$. Negative contours are dotted; the zero contour has been omitted. Responses that are significant at the 5% level are shaded in gray.
tory to those of Joseph et al. (2004), who find that the primary response to climate change is to zonalize the atmospheric circulation.

To quantify similarities and differences between the simulated stationary wave responses, area-weighted spatial pattern correlations of the stationary wave response in each simulation with every other simulation are calculated. The pattern correlations (displayed in Fig. 4) vary in the range from $-0.12$ to $0.85$. Pattern correlations $\geq 0.5$ are written in black and lower values are written in gray. Based on the pattern correlations, groups of simulations with similar stationary wave response are defined. The groups are defined such that each member of a group should have a relatively high correlation with each other member of the group. The threshold value for the correlation within each group is chosen based on the results displayed in Fig. 4. With a threshold value of $0.5$, three groups are formed. The mean pattern correlation within each group exceeds 0.63, indicating that 40% or more of the variance in the

![Fig. 4. The pattern correlation of the stationary wave response in each of the 16 CGCM simulations with the stationary wave response in each other CGCM. Pattern correlations below 0.50 are written in gray, pattern correlations above 0.50 are written in black. The triangles indicate groups of simulations with mutual correlations $\geq 0.5$.](image-url)
patterns is explained by the correlation. The groups consist of six, three, and two simulations. Five of the simulations are not included in any of the groups with this choice of the threshold. It may be noted that one of these simulations, the Meteorological Research Institute (MRI), has high correlations with all of the simulations but one in the first group. Because this pattern correlation between MRI and the Community Climate System Model (CCSM) is 0.46, the MRI simulation is included in the first group. This leaves four simulations that are not included in any group. The three groups are indicated with triangles in Fig. 4 and are hereafter termed S, B, and N, respectively. The simulations included in each group are listed in Table 3.

The mean stationary wave response for each group is displayed in Fig. 5. The maxima and minima in the mean response are also found in the individual responses, in approximately the same location as for the mean response, for each simulation within each group in Fig. 3.

The mean barotropic stationary wave response for group S exhibits five waves encompassing the NH. The response for this group includes the positive phase of the Pacific–North American Oscillation (PNA; Wallace and Gutzler 1981).

The mean barotropic stationary wave response for group B is similar to the mean response for group S over the North Pacific and North America, but rather different over the North Atlantic and Eurasia. Finally, the mean barotropic stationary wave response for group N is similar to the mean response for group S over the North Atlantic and Eurasia, but rather different over the North Pacific and North America. The response for group N includes the negative phase of the PNA (i.e., opposite to the response for group S) and a dipole in the North Atlantic, which is almost orthogonal to the North Atlantic Oscillation (NAO).

There are many differences between the CGCMs used to perform the simulations analyzed here. Two such differences—the horizontal resolution of the AGCM and the initial condition of the simulation—are listed in Table 2. The simulations in group S are run with varying horizontal AGCM resolutions (ranging from 1.4° to 3.75°) and varying initial conditions (preindustrial and present-day conditions). These results indicate that these two factors are not of primary importance for the response in the barotropic stationary waves to the enhanced GHG forcing. However, it is interesting to note that all but one (GFDL0) simulation in group S have spectral atmospheric components and that all but one (BCC) of the ungrouped simulations have nonspectral atmospheric components.

Group B consists of the three simulations in the MIROC ensemble. These are run with the same model and the same forcing, but start from different initial states. The pattern correlations of the ensemble members vary in the range of 0.63–0.73 (Fig. 4), and thus internal variability cannot be regarded as unimportant. The pattern correlations of the MIROC ensemble members with the other 13 simulations vary in the range from −0.12 to 0.54. From this, it may be con-

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<th>Group S</th>
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<th>Ungrouped</th>
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<td>CCCMA</td>
<td>MIROC1</td>
<td>MIUB</td>
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<td>CCSM</td>
<td>MIROC2</td>
<td>GISS</td>
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Table 3. Groups of simulations based on the stationary wave response.
cluded that internal variability and intermodel differences both play a role for the stationary wave response to the enhanced GHG forcing. The intermodel differences are of leading importance however.

The simulated response to the enhanced GHG forcing in the barotropic zonal mean wind is displayed in Fig. 6 for each simulation. The percentage of NH grid points with a response that is significantly different from zero at a 5% level (based on a Student’s $t$ test) is written in the figure next to each simulation abbreviation. As for the stationary wave response, the maxima and minima of the response are statistically significant for each simulation.

The simulations are grouped according to the previous discussion (see Table 3) and the mean response for each group is also displayed. Interestingly, the simulations in each group display similar changes in the zonal mean wind in response to the enhanced GHG forcing. The zonal mean wind response in group S is characterized by a single maximum of 1–3 m s$^{-1}$ around 35°–40°N, representing a strengthening and a slight northward shift of the jet maximum. The zonal mean wind response in group B is characterized by two maxima of 1–2 m s$^{-1}$ around 20° and 50°N, representing a broadening of the jet maximum. Finally, the zonal mean wind response in group N is characterized by a dipole with a minimum of −1 m s$^{-1}$ around 20°–35°N and a maximum of 3–3.5 m s$^{-1}$ around 45°–50°N representing a northward shift of the jet maximum.

5. Linear model results

The linear model (6) is utilized to test whether the changes in the zonal mean flow can explain the station-
The linear model is applied to the mean for each of the three groups (see Table 3), rather than to each simulation individually.

The linear stationary wave response for group S, B, and N is displayed in Fig. 7. The spatial pattern correlation of the linear stationary wave response with the corresponding CGCM response is displayed in the top-right corner of each panel.

The linear response for group S and N (Fig. 7) compare well with the respective results from the CGCM integrations (Fig. 5), although the linear model yields smaller amplitudes. The pattern correlation with the CGCM response is 0.71 and 0.61, respectively, and thus the linear model explains 50% and 37% of the CGCM response to the enhanced GHG forcing. Interestingly, the linear model captures the differences in the stationary wave responses between groups S and N over the North Pacific. This could indicate that the interaction between the topography and the zonal mean flow plays a significant role for the changes in the stationary waves in this region.

The stationary wave response of group B is of a smaller scale and lower amplitude than the responses in group S and N. The wave trains of group B are not well captured by the linear model. The pattern correlation with the CGCM response is 0.20, and thus the linear model explains only 4% of the CGCM response to the enhanced GHG forcing. These results indicate that changes in either the stationary wave forcing, that is, diabatic heating, transients, or nonlinear effects play a leading role for the changes in the stationary waves in response to the enhanced GHG forcing for this group.

6. Discussion and conclusions

The results presented here are encouraging: 50% of the CGCMs used for the IPCC AR4 display similar changes in the NH winter large-scale zonally asymmetric circulation in response to the enhanced GHG forcing. Further, these changes are linked to similar changes in the zonal mean circulation. The mean barotropic stationary wave response for this group (group S) exhibits five waves encompassing the NH. This pattern resembles the circumglobal wave pattern (Branstator 2002), which was found to be the dominant response pattern to an increasing GHG forcing in a 62-member ensemble of simulations for the period of 1940–2080 with an earlier version of the CCSM model (Selten et al. 2004).

The changes in the large-scale mean flow are an important driver of the stationary wave response for most simulations (groups S and N), but not for the simulations in the MIROC ensemble (group B). The behavior of the majority of the simulations contradicts the study by Stephenson and Held (1993) of the stationary wave response to global climate change in a low-resolution version of the GFDL CGCM. Using a baroclinic linear model they find that transients and diabatic heating are the major forcing terms, while changes in the zonal mean basic state play only a small role. Our results, however, confirm the study by Joseph et al. (2004) of the stationary wave response to global climate change in a higher-resolution version of the GFDL CGCM. Also using a baroclinic linear model they find that at least as much of the climate change response in the stationary waves are accounted for by the change to the zonal mean basic state as by the changes to the zonally asymmetric forcings. Joseph et al. (2004) further con-
clude that the primary response to climate change is to zonalize the atmospheric circulation. However, for the majority of the simulations analyzed here, the amplitude of the stationary waves is increased or unchanged in response to the enhanced GHG forcing.

The 14 CGCMs analyzed here do not however all simulate similar stationary wave and zonal mean wind responses to the enhanced GHG forcing, and the challenge remains in understanding the origin of these differences. Both the three-member initial value ensemble and the 14-member multimodel ensemble analyzed in this study indicate that internal variability and inter-model differences both play a role for the stationary wave response to the enhanced GHG forcing. The intermodel differences are however of leading order.

The parameterizations of cloud processes in CGCMs have been found to be of great importance for the simulated climate (Iacobellis et al. 2003). Because cloud processes are important for transient eddies and diabatic heating, differences in these parameterizations in different CGCMs are a possible source for the inter-CGCM differences in the zonal mean and stationary wave responses to GHG forcing.

Four of the simulations included in this study give stationary wave responses that cannot be categorized in any of the three groups of simulations. Three of these—the BCC, the Institute for Numerical Mathematics (INM), and L’Institut Pierre-Simon Laplace (IPSL) models—give the lowest spatial pattern correlation with the ERA-40 data for the unperturbed stationary waves. Further, the BCC and the IPSL show the largest deviations from the ERA-40 zonal mean wind. From this we hypothesize that the response in the large-scale circulation is dependent on the initial climatology, and that starting the sensitivity experiment from a state that is very different from the present-day state of the system may give the wrong answer.

In this article we attempt to answer the following question: Is it possible to predict future changes in regional climate? Specifically, we address two questions: (i) do different CGCM simulations give similar stationary wave responses, and (ii) can the changes in the zonal mean background flow explain the stationary wave response to the enhanced GHG forcing? We conclude that there are significant similarities in the stationary wave responses simulated by 50% of the different modeling groups, but the other 50% of the simulations give different changes in the stationary waves in response to the same GHG forcing. Some of the simulated stationary wave responses may be influenced by an inadequate simulation of present-day climate. However, most intermodel differences cannot be disregarded this easily.

We draw the following two main conclusions of the results presented in this article: (i) it is not possible at present to predict the stationary wave response to increasing atmospheric GHG concentrations and (ii) there is a potential for predictions of regional climate change, however, based on the finding that the change in the zonal mean wind significantly influences the stationary wave response.

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