# Stratosphere-Troposphere Coupling: Characterizing intraseasonal variability with the Annular Modes

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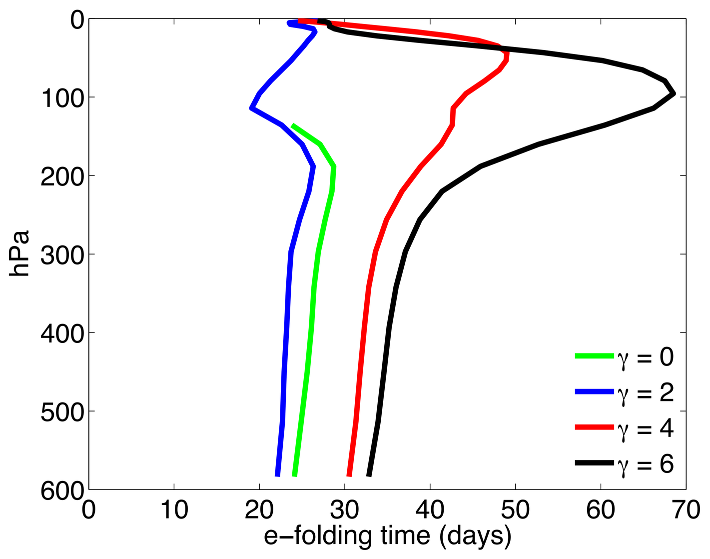
## 1. Introduction

- ✦ The annular modes (AMs) characterize coupled variability between the tropospheric jets and the stratospheric polar vortex *[e.g. Thompson & Wallace 2000, Baldwin & Dunkerton 2001]*.
- ✦ The ability of models to accurately capture intraseasonal variability may be related to there sensitivity to climate change *[e.g. Kidston and Gerber 2010]*.
- ✦ Climate trends projects onto annular modes [e.g. Miller et al. 2006], and can lead to confusion between internal variability and externally forced changes *[Gerber et al. 2010]*.

In this poster, we consider three questions:

1. How well do CMIP3, CCMVal2, and CMIP5 models capture the variability of the annular modes?
2. What is the impact of stratosphere-troposphere coupling on tropospheric variability?
3. For purposes of model intercomparison, is a simpler definition of the annular mode based on polar cap average geopotential height sufficient?

## 2. Background




*Gerber and Polvani [2009]* find that enhanced stratospheric variability in a idealized GCM can increase the persistence of the tropospheric annular modes.

Figure 1 The annular mode time scale as a function of pressure in four integrations with an idealized GCM. They differ only in the thermal forcing of the stratosphere, set by γ, the lapse rate (K/km) of the equilibrium temperature profile; larger values lead to a colder polar vortex. Simulations with γ=4 and 6 exhibit more variability in the lower stratosphere, which increases the persistence of the tropospheric AM.

- ✦ CMIP3 models capture the gross features of the AMs *[Gerber et al 2008]*
- ✦ Southern Hemisphere (SH) time scales are too long in DJF
- ✦ Northern Hemisphere (NH) seasonal cycle delayed and weak

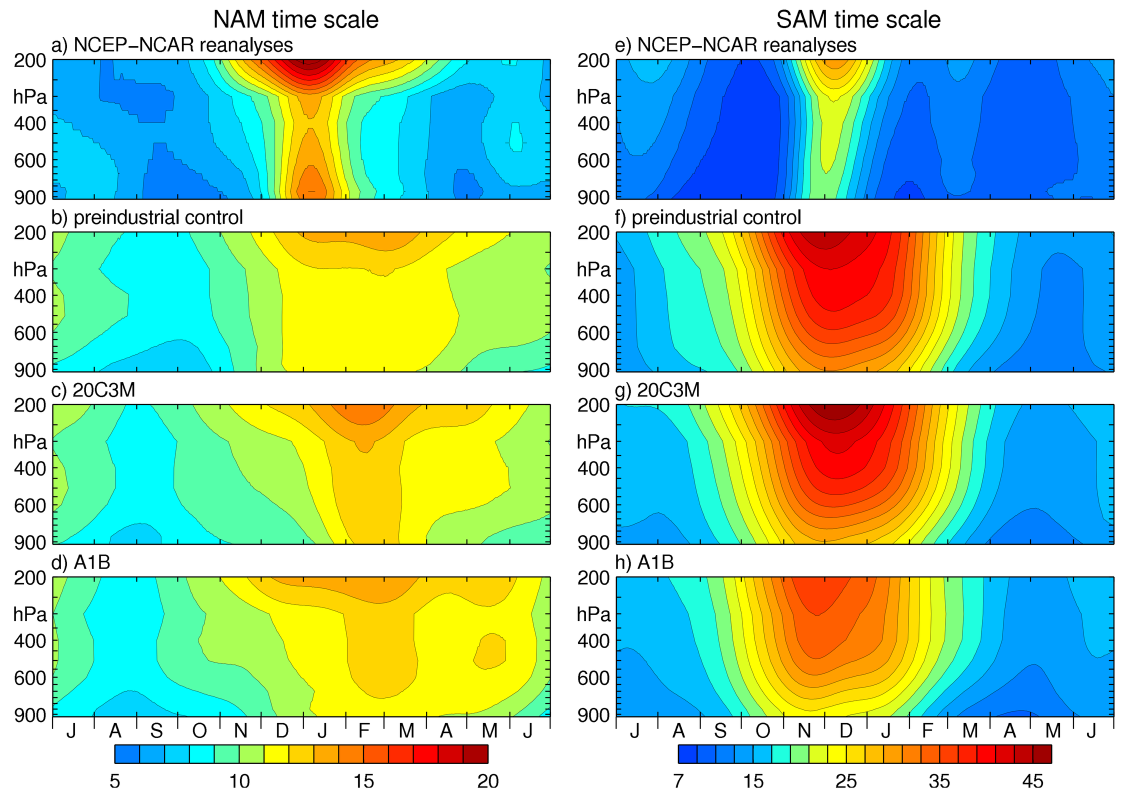



Figure 2 The time scale of the annular mode as a function of height and season in the CMIP3 models. At top, results from NCEP-NCAR reanalyses from 1958-2008 and 1979-2008 in the NH and SH, respectively (analyses based on ERA-40 are nearly identical). The three lower panels show the time scales for the preindustrial control, 20C3M historical, and A1B scenario integrations.

## 3. Methods

We compare the method of *Gerber et al. [2010]* with a simpler annular mode recipe, as suggested by *Baldwin and Thompson [2009]*. The new method is quite straightforward:

1. Use daily, zonal mean geopotential height, *Z(ϕ,p)*.
2. For each day and pressure level, remove the global mean *Z*. This focusses AM on north-south variations in mass/momentum.
3. Define "simple" NAM/SAM time series to be the latitude weighted average geopotential height from 65º N/S to the pole.
4. For each calendar day, remove the time mean and linear trends from time series. (This removes seasonal cycle.)
5. Multiply time series by -1, to keep sign convention of AM.

- ✦ Steps (2) and (4) help prevent climate trends from aliasing onto the internal variability.

## 4. Results

- ✦ Figs. 3-5 show results based on Chemistry Climate Models in the CCMVal2 intercomparison project *[Gerber et al 2010]*. These models have a relatively well represented stratosphere, compared to CMIP3 models.
- ✦ Fig. 6 suggests that the simple polar cap average geopotential height strategy captures most of the AM variability.
- ✦ Figs. 7-9 show tentative results based on coupled climate model simulations in the CMIP5 intercomparison project.

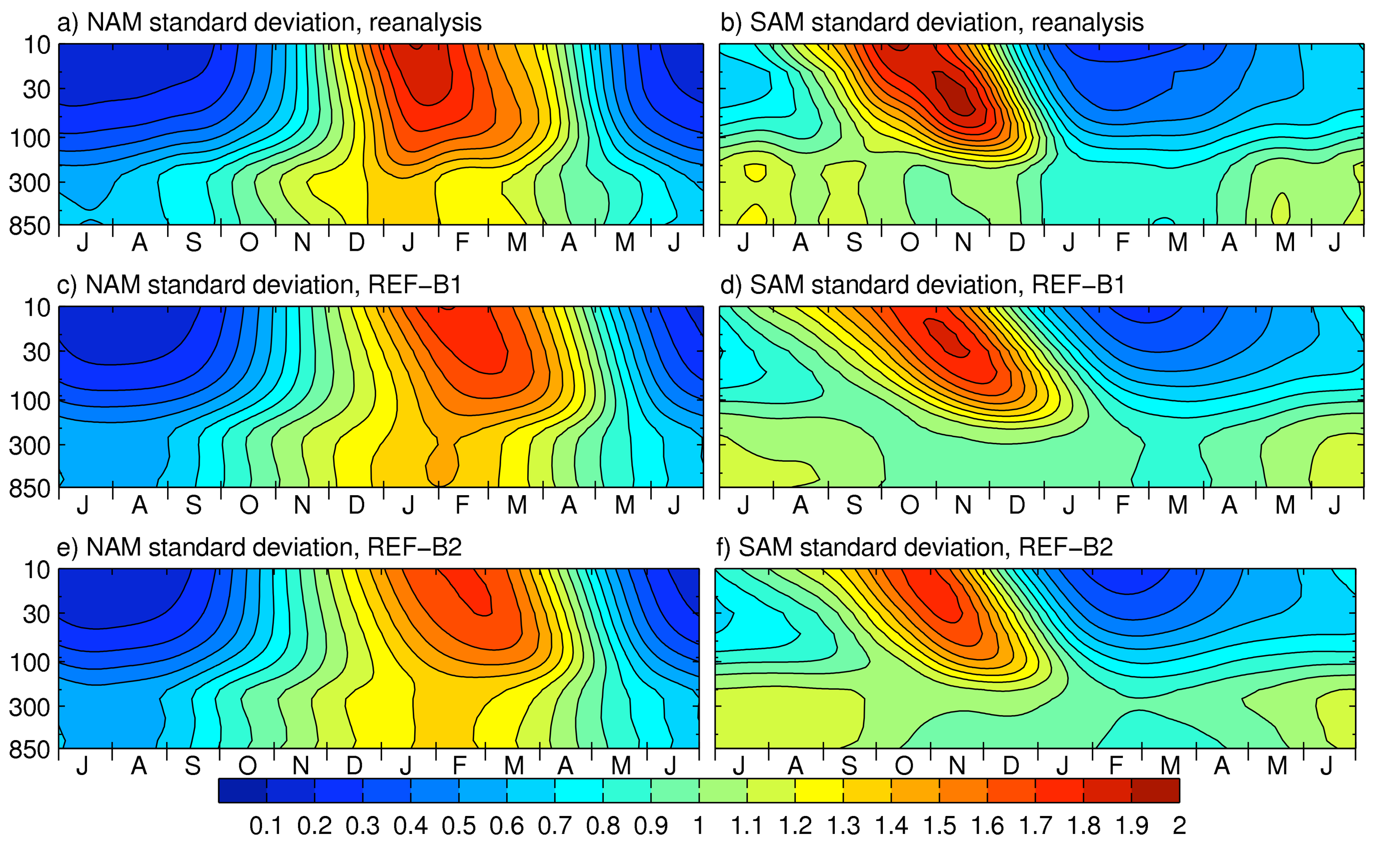



Figure 3 The standard deviation of the annular mode time series as a function of pressure and season, as in *Baldwin et al 2003*. The top panels are based on ECMWF reanalyses from 1958-2008 and 1979-2008 in the NH and SH, respectively. In the lower panels, we show the multimodel ensemble mean statistics based on 9 Chemistry Climate Models' REF-B1 (1960-2006) and REF-B2 (2054-2099) integrations.

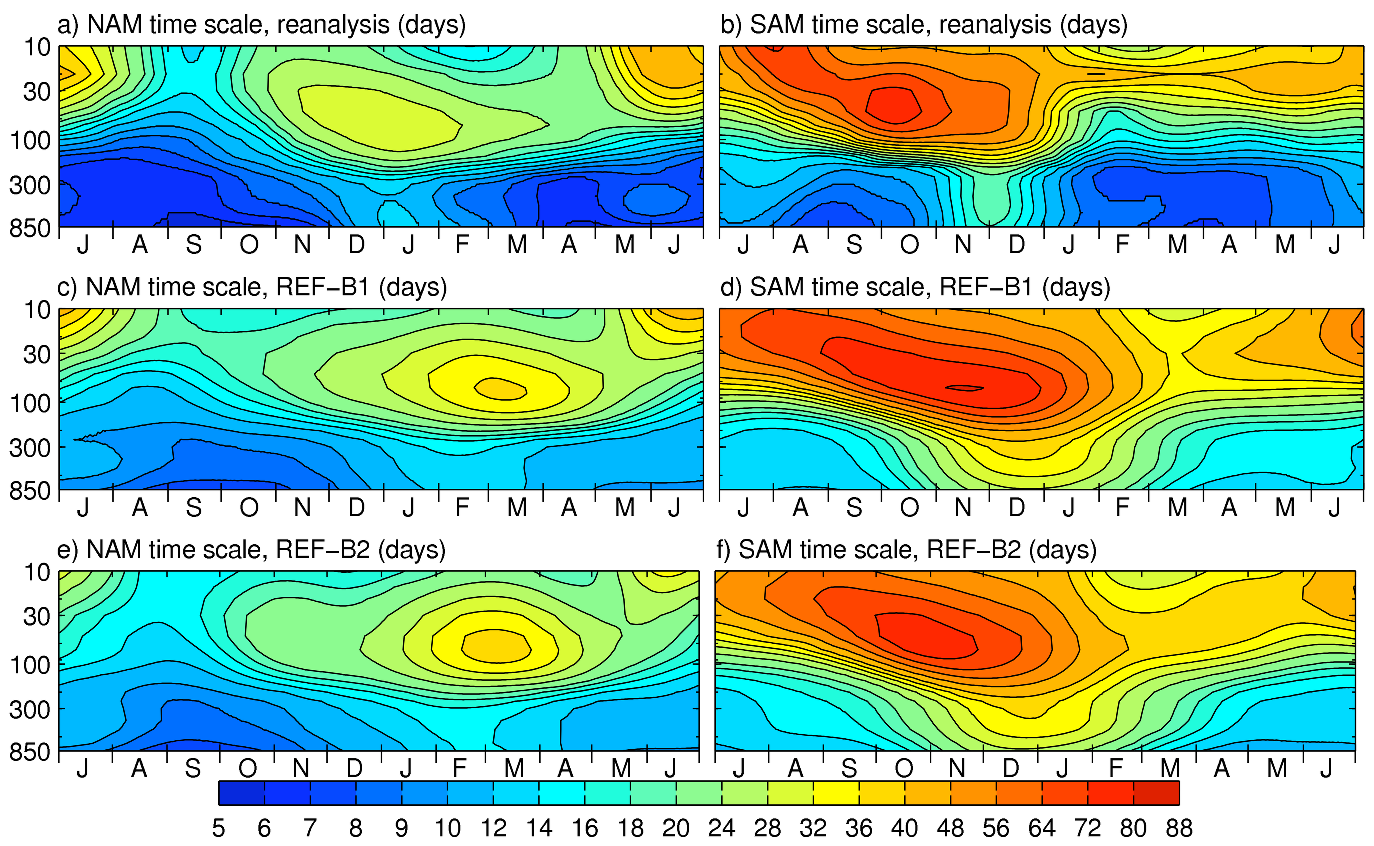



Figure 4 The same as in Figure 3, but the e-folding time scale of the annular mode autocorrelation function, as in *Baldwin et al. 2003*. This time scale provides a measure of the persistence of the annular mode index. Note the asymmetries between the hemispheres. The models capture the basic structure, but there are systematics biases in the seasonal cycle (particularly in the NH) and overall amplitude (particularly in the SH).

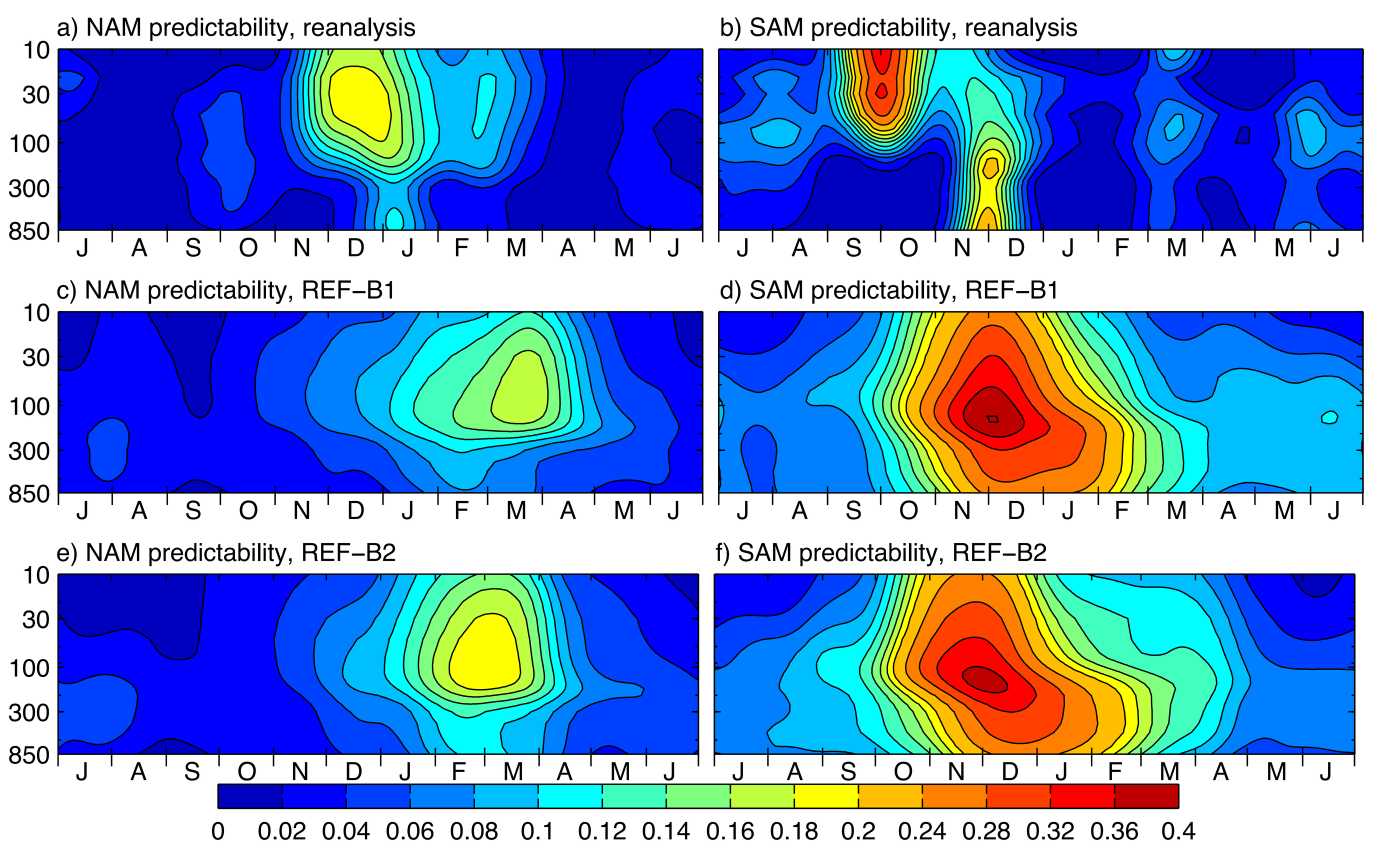



Figure 5 The same as in Figure 3, but the fraction of the variance of the *850 hPa monthly mean* annular mode index that can be predicted at 10 day lead with a persistence forecast based on the instantaneous AM at varying pressure levels (again following *Baldwin et al. 2003*). This measure suggests that knowledge of the stratospheric state of the atmosphere can sometimes carry more useful information for predicting the troposphere than the troposphere itself. CCMVal2 models capture some of the enhanced predictability available from the stratosphere in the NH, but the timing of this information is delayed. In the SH, enhanced predictability in the models arises simply from their overly persistent AM time scales.

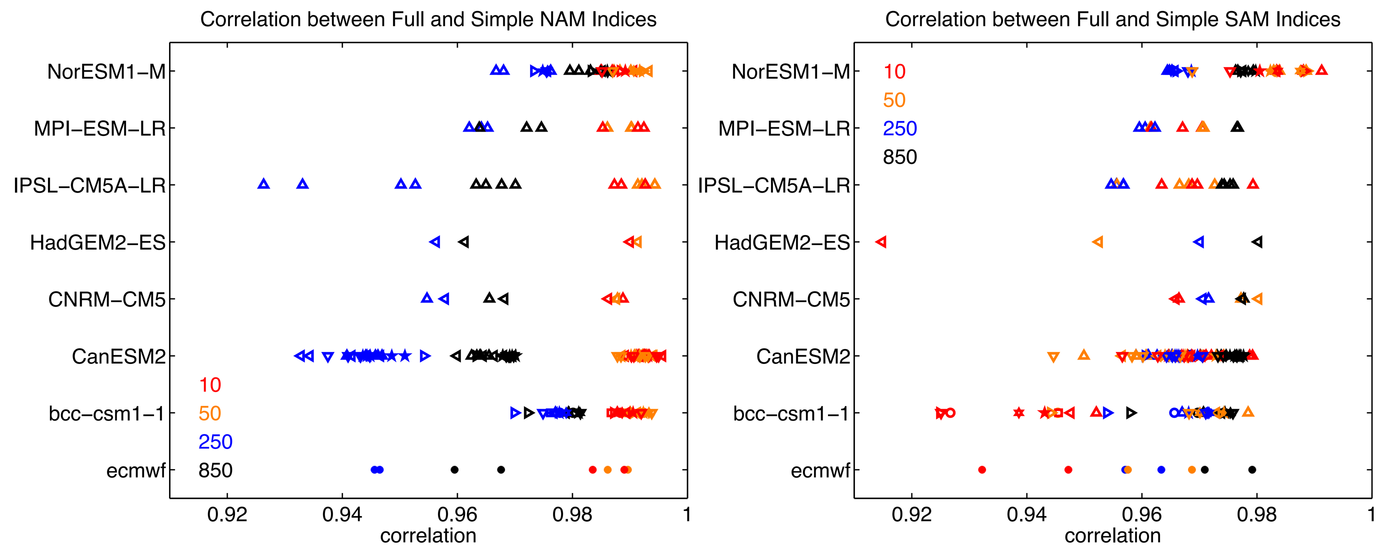



Figure 6 The correlation between the "full" AM index (as computed in *Gerber et al. [2010]*) with the "simple" polar cap average based AM index (outlined in Sec. 2) in CMIP5 integrations. Four pressure levels are considered, denoted by color. The symbols show the scenario: △= historical, ▷=preindustrial control, ◁=RCP 2.6, ☆=RCP 4.5, ✡=RCP 6.0 ▽=RCP 8.5, ▫,○=ESM scenarios.

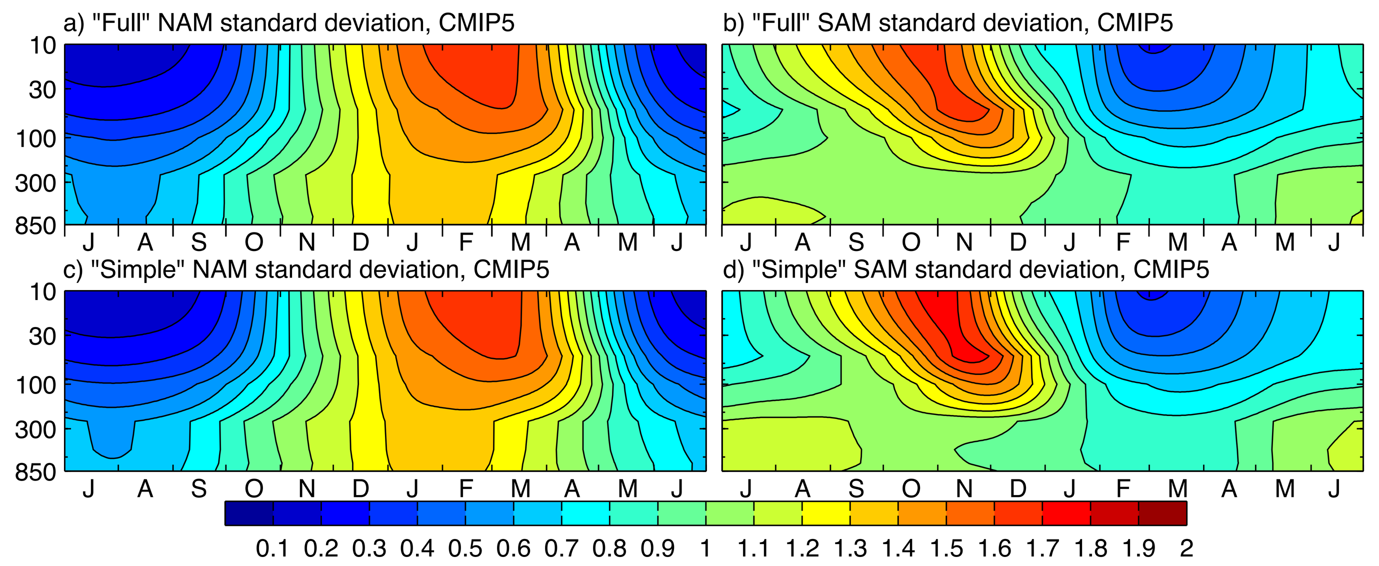



Figure 7 The same as in Fig. 3, but for the CMIP5 models. Here and in the figures below, the statistics are based only on the historical (1960-2005) simulations, available from 6 models at press. The top plots are computed from the "full" AM indices (using EOF analysis) and the lower panels are based on the "simple," geopotential height based definitions.

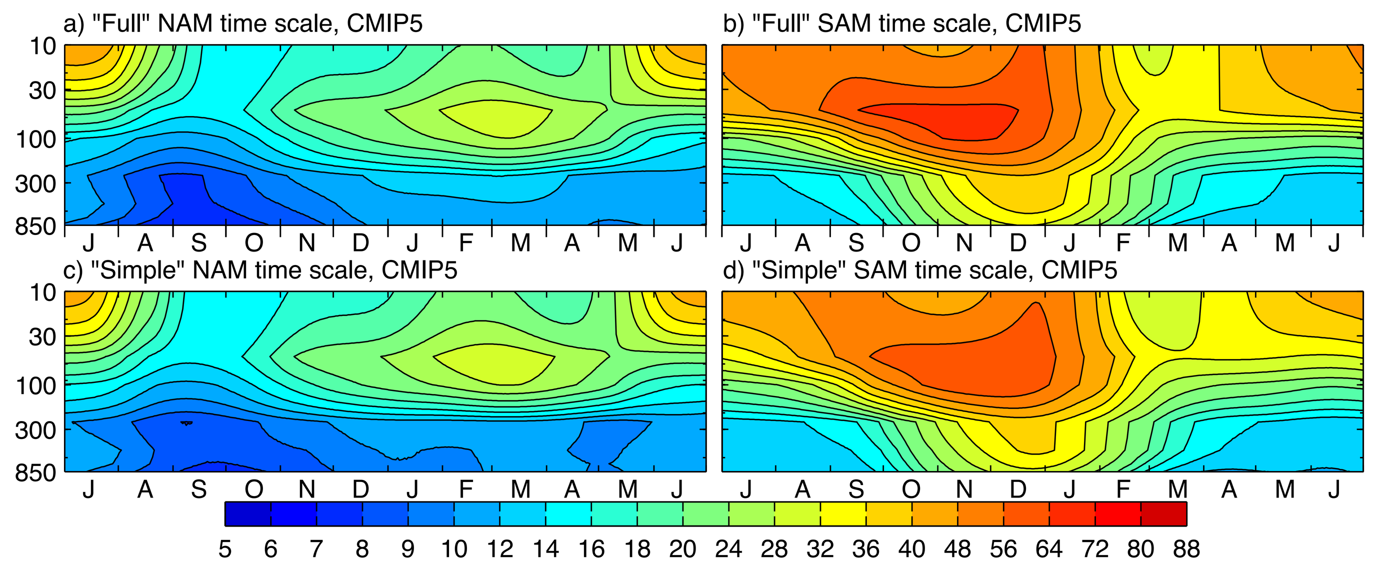



Figure 8 The same as in Fig. 4, but for the CMIP5 historical simulations.

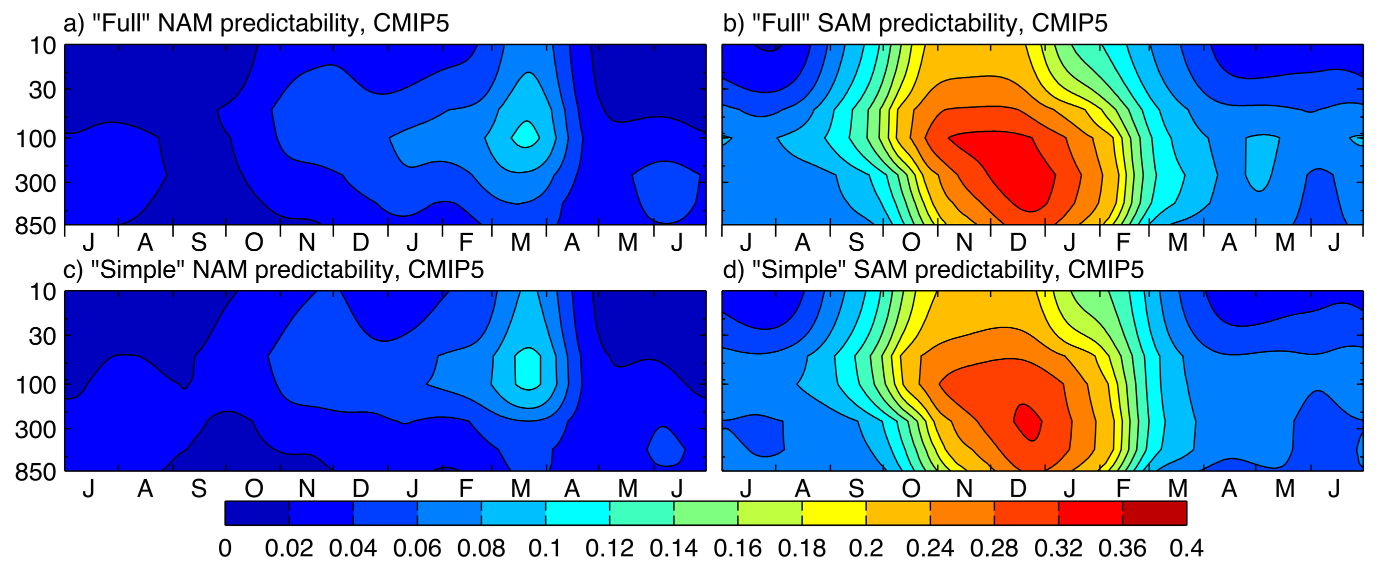



Figure 9 The same as in Fig. 5, but for the CMIP5 historical simulations.

## 5. Conclusions

1. Models capture the gross features of the annular modes, in particular the pronounced asymmetry in the seasonal cycle between the NH and SH. However, they:
   - ✦ overestimate the time scales in the SH
   - ✦ exhibit a weaker, delayed seasonal cycle in the NH

   These biases are remarkably constant across different classes of models; preliminary analysis of CMIP5 models shows little improvement.
2. Consistent delays in the seasonal cycle of the troposphere and stratosphere in the NH suggest a role for coupling between the spheres. The time scale bias in the SH is likely of tropospheric origin, and washes out any impact of stratospheric variability.
3. The simple polar cap average of geopotential height method appears sufficient for characterizing the variability of the annular modes, provided global mean geopotential height and linear trends are removed.