Atmospheric Rivers: A global climatology based on reanalysis and the Community Atmosphere Model (CAM)

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Introduction

Atmospheric Rivers are long, thin horizontal filaments of elevated moisture transport, that are usually found extending from the tropics up through the subtropics and into the midlatitudes. They are known to produce heavy precipitation and flooding in the Western United States (i.e., Ralph et. al., 2006) and elsewhere (Stohl et. al., 2008). One question concerning these rivers is what the their global average characteristics are, and can an IPCC-class global climate model accurately simulate these characteristics? Knowing this could help improve the forecasting of atmospheric rivers, including how they might change due to global warming. It can also provide a chance to examine one of the quantitative methods used to define an atmospheric river.

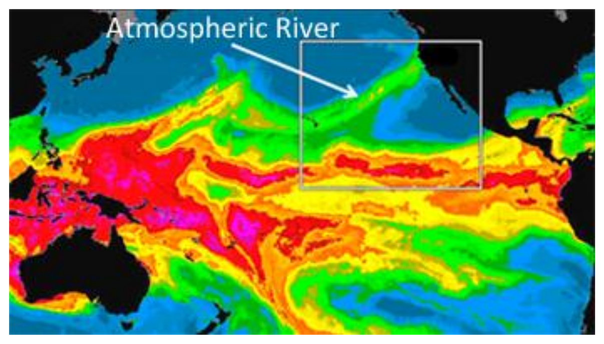


Image of an atmospheric river from NOAA

Methods

The data used to generate the climatology comes from the MERRA reanalysis [Reinecker et. al., 2011], while the model used to generate the comparisons is the Community Atmosphere Model version 5 (CAM5) [Neale et. al., 2010]. Three different model simulations were computed for this study, all with year 2000 boundary conditions. The first run had a 1.9° latitude x 2.5° longitude resolution with a finite volume core. The second run had a T42 horizontal resolution with an Eulerian spectral dynamical core. The third run also has a finite volume dynamical core, but with a 0.9° latitude x 1.25° longitude horizontal resolution. This will help determine how the simulation of atmospheric rivers might depend on the mode's dynamical core and the horizontal resolution.

The technique used in this study to define atmospheric rivers in gridded data was originally developed in Zhu & Newell, 1998. The first step is to create a vertically-integrated moisture flux vector, shown below:

$$\vec{Q} = \mathbf{i}\left(\frac{1}{g}\int_{ps}^{300hPa} q\vec{u}\,dp\right) + \mathbf{j}\left(\frac{1}{g}\int_{ps}^{300hPa} q\vec{v}\,dp\right)$$

Where q is the specific humidity, u is the zonal velocity, v is the meridional velocity, ps is the surface pressure, and g is the acceleration due to gravity. Once this moisture transport vector is defined, it is then run through the detection algorithm, shown below:

$$|Q| \ge |Q_{mean}| + 0.3\left(|Q_{\max}| - |Q_{mean}|\right)$$

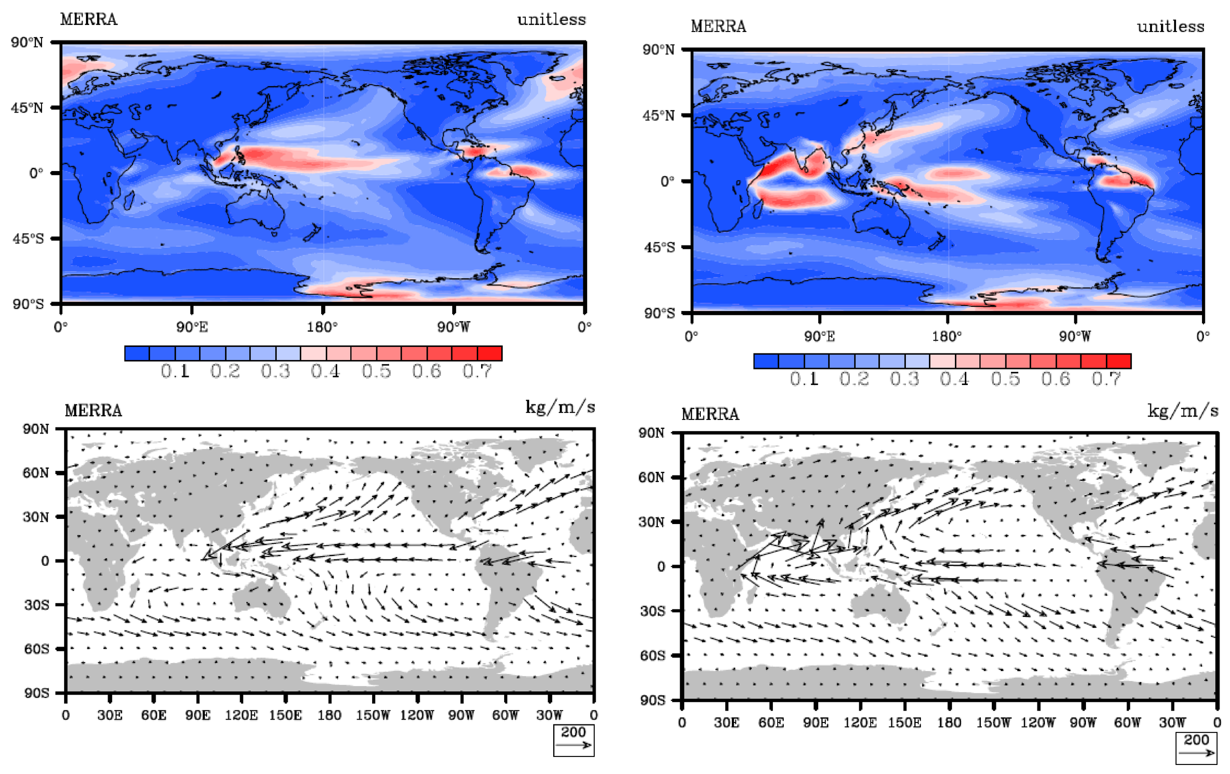
Where Q_{mean} is the zonally averaged vertically-integrated moisture flux, and Q_{max} is the maximum vertically-integrated moisture flux at the particular latitude. If at a particular grid point the inequality is true, then that grid point is marked to contain an atmospheric river, and the moisture flux present at that grid point is marked as atmospheric river moisture flux.

Note on maps at right:

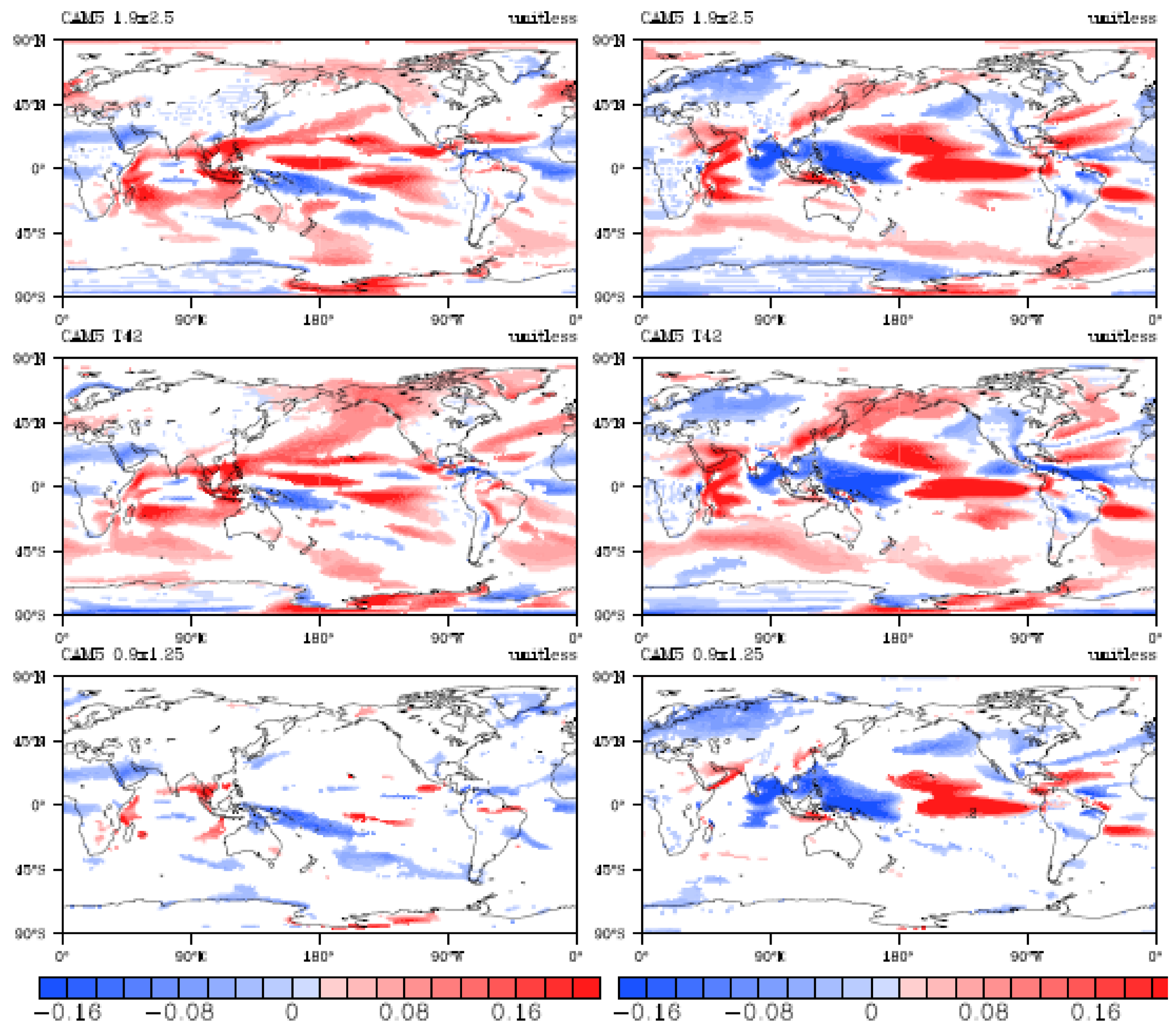
The contour maps to the right show the probability of an atmospheric river being in that particular location for any given six-hour interval. Also note that some of the locations in bright-red might have a higher probability then what the label bar shows.

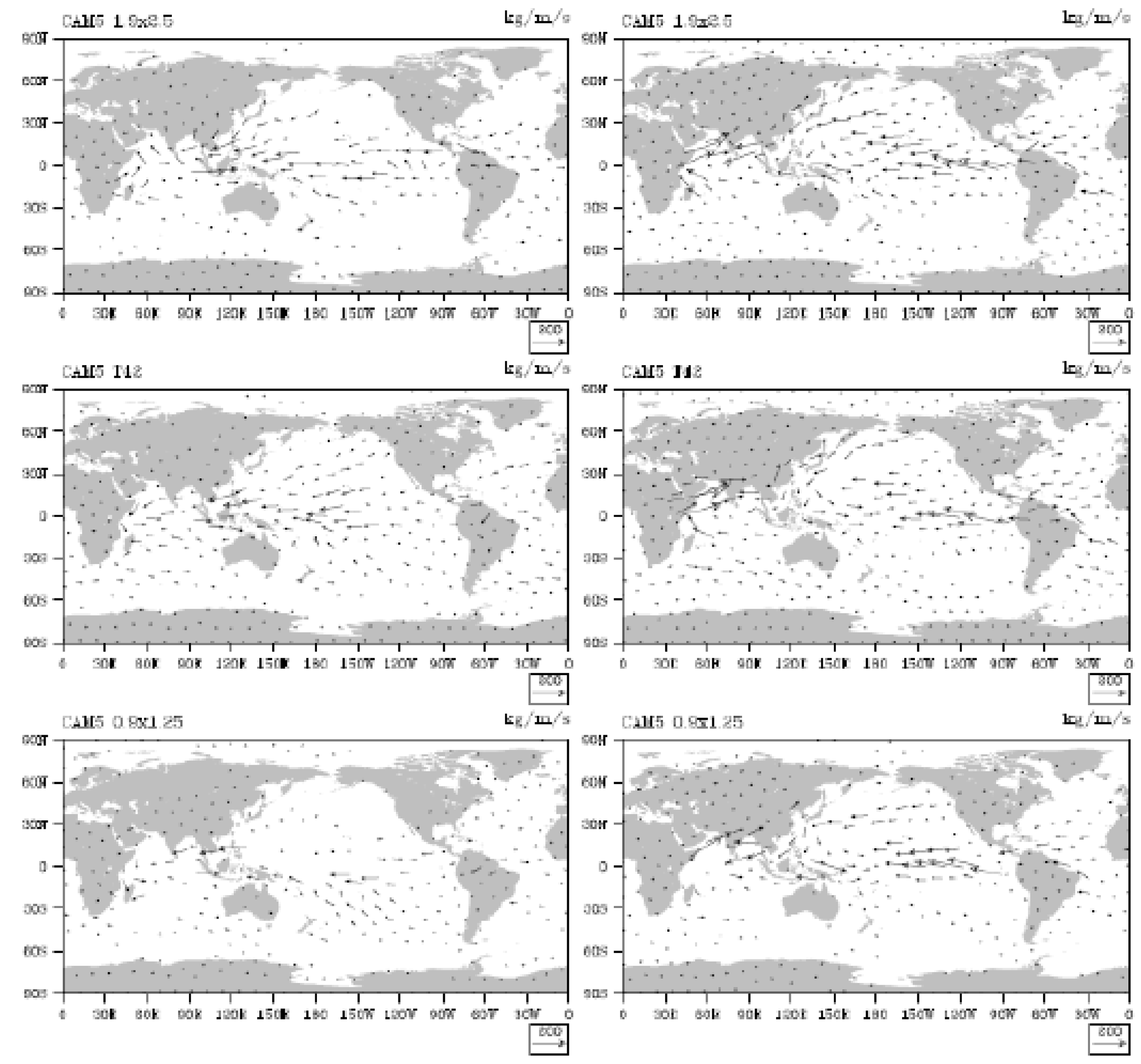
Seasonal MERRA climatology

DJF: JJA:



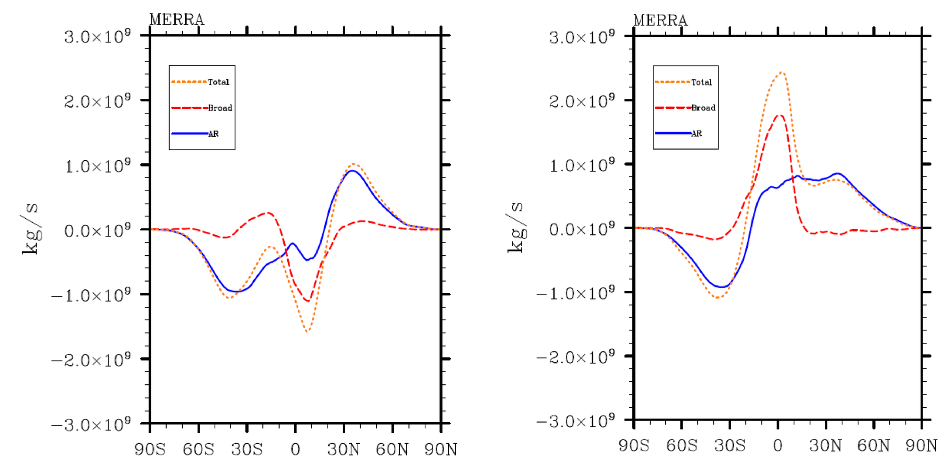
Seasonal Differences:



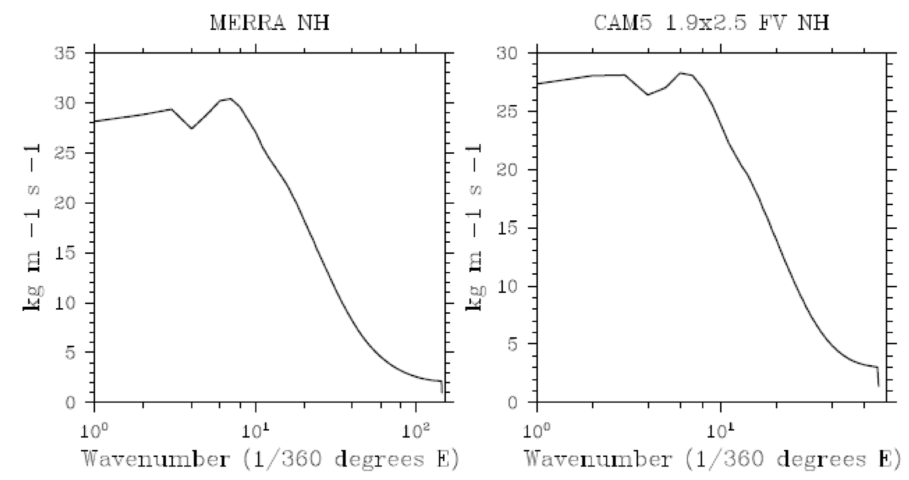


Zonal Average fluxes:

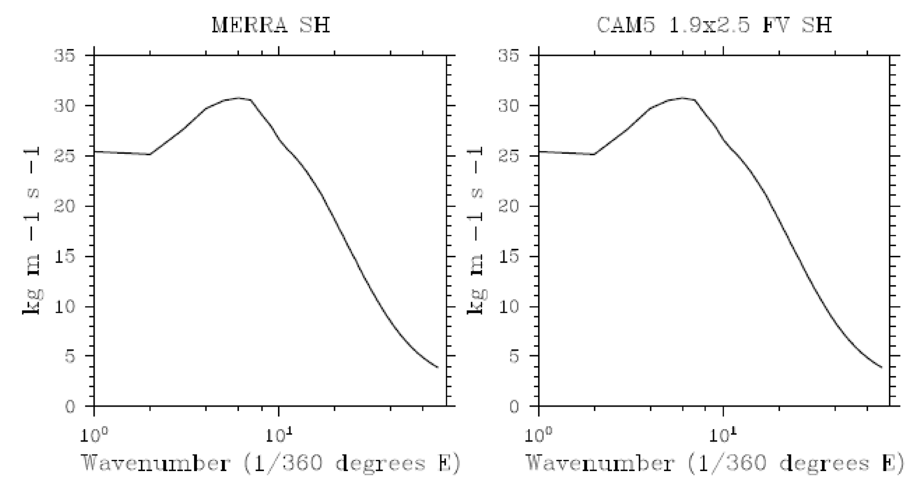
DJF: JJA:



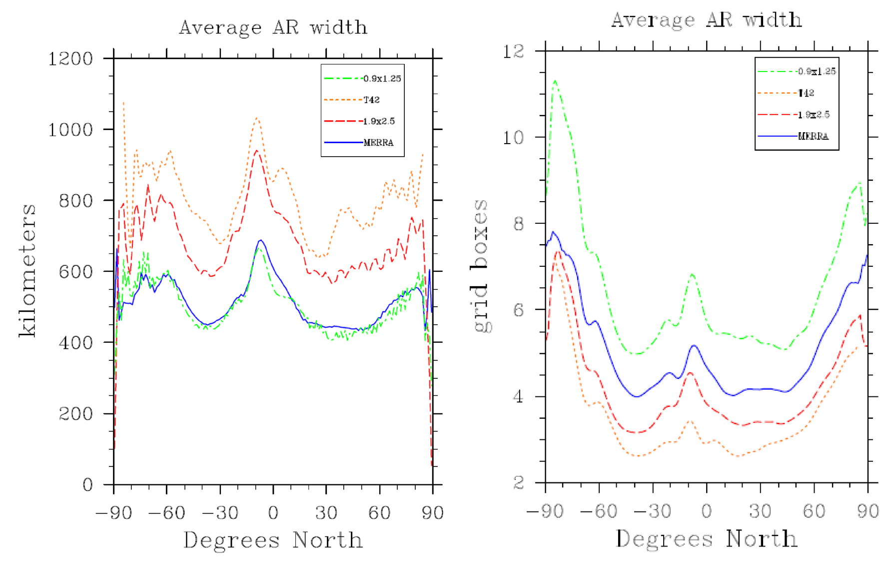
Zonal power spectrum, Northern Hemisphere:



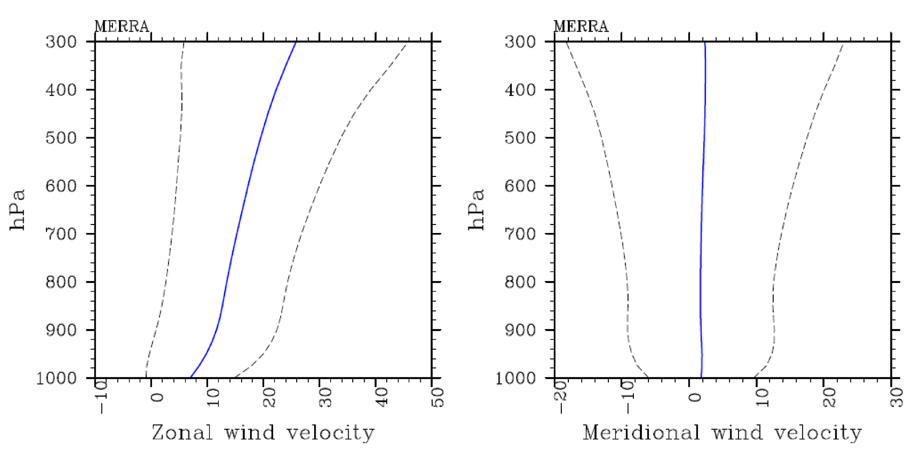
Southern Hemisphere:



Average width:



Vertical profiles of wind:



Conclusions

A general pattern of atmospheric rivers exists in the reanalysis data, which indicates that atmospheric rivers transport moisture polewards and westwards in the subtropics and midlatitudes. The climatology generated by the CAM5 runs is very similar, although statistically significant differences exist (which are all of the contoured areas in the difference plots). Still it is important to note that it is the midlatitudes where the differences between MERRA and CAM5 are smallest, which indicates that the model does in fact simulate atmospheric rivers accurately, at least in an average sense. However, neither data set captured the low-level jet present in atmospheric rivers accurately.

When examining the zonal averages, it is found that atmospheric rivers contribute the vast majority of moisture flux in the midlatitudes, for both MERRA and CAM5 (not shown). It is also found that the most important zonal wavenumber for atmospheric river moisture flux is close to wavenumber six, which indicates a possible dynamical relationship between atmospheric rivers and baroclinically unstable waves. Finally, both the width of atmospheric rivers and the global mean absolute error decreases with increasing model resolution, indicating that a higher model resolution may simulate atmospheric rivers more accurately.

Future Work

1) Perform a Reynold's decomposition on the data to help determine what features the detection method is capturing are actually atmospheric rivers.
2) Calculate correlations between atmospheric rivers and other climate phenomenon, such as ENSO.
3) Perform some more CAM5 simulations, but with different boundary conditions, to determine how sensitive the climatology is to SSTs and other surface variables.

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Funding provided by a National Science Foundation Graduate Research Fellowship.