Simulating North American Heat Waves and Large scale Weather Regimes in climate models: Circulation Characteristics and synoptic-scale activity

Tianyu Jiang*, K. J. Evans, V. Anantharaj, R. Archibald, D. Bader, M. Branstetter, J. Hack, P. Jones, S. Mahajan, M. Maltrud, J. McClean, M Taylor, P. Worley

Introduction

In many regions of the U.S., the summer season is marked by the occurrence of extremely hot episodes that persist for more than several days, and often referred to as "heat waves". These surface thermal extremes are usually accompanied by prominent large scale circulation patterns, so called "atmospheric blocking".

Atmospheric blocking is a large-scale quasi-stationary extratropical flow regime. It is commonly referred to as the situation when the midlatitude westerly jet and synoptic systems are interrupted by strong and persistent meridional flow. Simulation of atmospheric blocking in most climate models is still very challenging. It has been suggested that the representation of blocking frequency in numerical models depends on many factors, including the mean state of the subtropical jet, orography and eddy forcing.

Data and Methodology

This study uses the NCEP-NCAR reanalysis datasets as the primary "observation" reference. Model simulations are conducted with the NCAR-DOE CCSM4. The CCSM4 as configured for this study is composed of an active global spectral atmosphere model (CAM4) for two different horizontal resolutions T85 and T341, which correspond to approximately 1.4° and 0.3° grid spacing, respectively. The climate is strongly constrained by the ocean data (prescribed), which is also another way to isolate the impact of resolving the smaller scales in T341 as compared to the ocean behavior differences of the two models.

The active regions for U.S. heat wave events are identified through a classis EOF analysis following (Lau and Nath, 2012), the corresponding regression is based on the corresponding principle components.

The blocking detection metrics employed here include a hybrid method that combines the 2-D statistics of blocking highs on 500 hPa and the associated meridional gradient characteristics [Dunn-Sigouin et al, 2013]. It can provide both the spatial and the temporal information of blocking events at the mid-troposphere.

U.S. Heat Waves: Key Regions

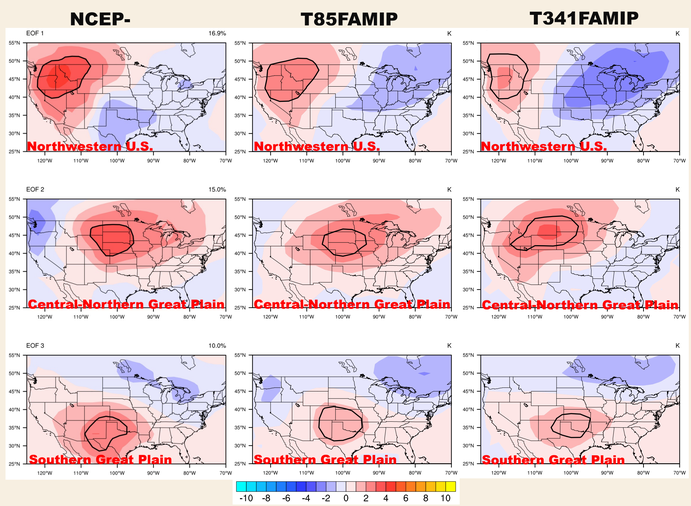

Fig. 1 The most active modes for U.S. heat waves identified through classic EOF analysis of DAILY T_{max} in summer. The black circles indicate the key regions selected to define the events (unit: K).

Surface Characteristics Associated With U.S. Heat Waves

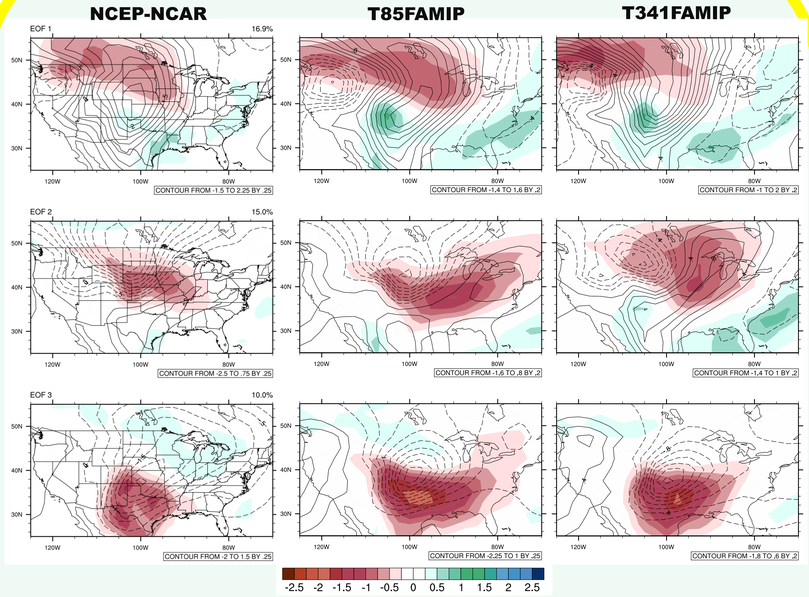

Fig. 2 Surface anomalies associated with heat waves by Regressing precipitation (color shading, unit: mm/day) and SLP (contour interval: 0.25 hPa) on to the corresponding principle components from Fig. 1.

Large Scale Circulation: Low-Frequency waves and storm tracks

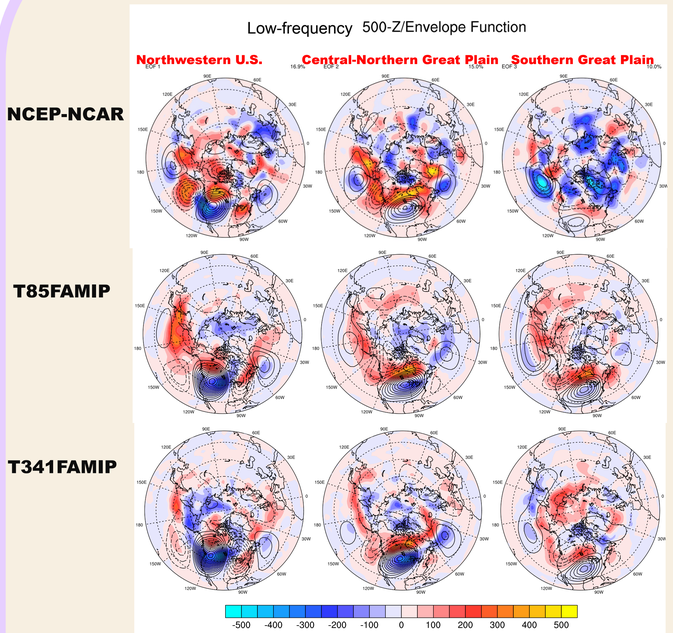

Fig. 3 Regression charts of 500-mb low-pass filtered geopotential height (contours, doubled contours for T85/ T341) and envelope function for amplitude of synoptic-scale activity (color shading).

Seasonal cycle of the NH blocking activity and midlatitude jet

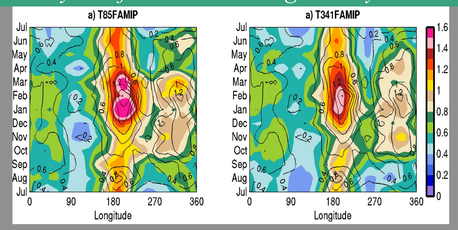

Fig. 4 blocking activity annual evolution over Northern Hemisphere. (unit: %)

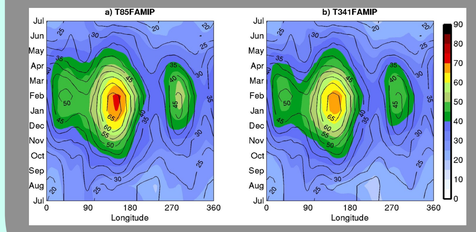

Fig. 5 Annual evolution of subtropical jet-core speed over northern hemisphere. (unit: m/s)

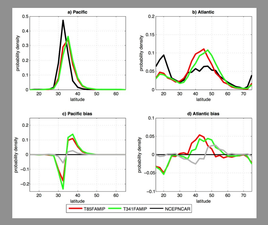

Fig. 6 Jet latitude Index (PDF, unit: %)

The Scale interaction associated with blocking development

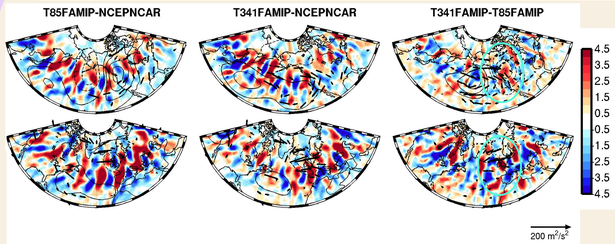

Fig. 7 Composite of E-vector (Synoptic scale) and its divergence (unit: 10^5 m/s^2) for Eastern Pacific blocking cases. the geopotential height is also shown in contours (unit: meters)

Fig. 8 Same as Fig.7, but for Atlantic blocking cases.

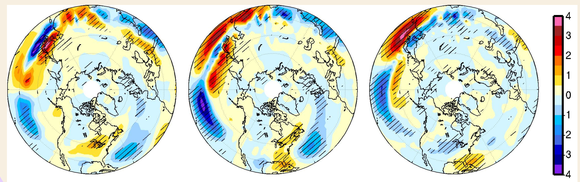

Fig. 9 Barotropic conversion from mean flow to low frequency eddies. (10^4 m^2/s^3)

Summary

In this study, the summertime heat waves in North America and the associated ridging/ blocking activity are characterized using reanalysis data and global climate models with different horizontal resolutions (~120 km / ~30 km) and ocean modules (prescribe/interactive). The typical synoptic features accompanying the heat waves are depicted. The frequency of occurrence and intensity of the upstream blockings are examined

The discrepancy between the reanalysis and the models on the heat wave characteristics as well as the upstream blocking activity is assessed by comparing the passage of synoptic-scale transients and its local reinforcement to the anticyclonic circulation. The result indicates: 1) a general agreement on the first moment of climatological distribution with different resolution; 2) the higher resolution model can improve the high-order moments of the atmosphere circulation, including the weather regimes, which is critical to a reliable simulation and projection of the climate extremes.

Reference

Dunn-Sigouin, E., and S.-W. Son (2013), Northern Hemisphere blocking frequency and duration in the CMIP5 models, J. Geophys. Res. Atmos., 118, 1179–1188, doi:10.1002/jgrd.50143.

Ngar-Cheung Lau and Mary Jo Nath, 2012: A Model Study of Heat Waves over North America: Meteorological Aspects and Projections for the Twenty-First Century. *J. Climate*, **25**, 4761–4784. doi: http://dx.doi.org/10.1175/JCLI-D-11-00575.1

*Oak Ridge National Lab, jiangt@ornl.gov