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Did atmospheric waves get wavier?

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Abstract

Have you ever seen those wavy lines on a weather map? Those lines are called isohypses (similar to isobars) and those large waves have a big impact on our weather. Bigger waves mean more strange temperature extremes, like long heat waves, or long periods of freezing weather. If the waves are really large, you can have a day where Ohio is colder than Alaska! We wanted to know how wavy those waves are, and if the waviness is changing over time. To find out, we developed a way to count the waviest waves and then compared data for the last thirty years. Climate change might actually make the waves wavier. And that might lead to more extreme weather—heat waves and cold snaps—in the future.

Introduction

Wavy lines on a weather map (called *isohypses*) tell us where the atmospheric pressure is changing (Fig. 1). These waves are called Rossby waves: they are large meanders in high-altitude winds which can have a big impact on our weather by moving cold air towards the equator and warm air toward the poles. When there are large waves, crazy things can happen, like warm days in Alaska at the same time it's freezing in Kansas (Fig.2)! These temperature extremes have a big effect on our weather, so it is important to understand the waves that cause them. We wondered, have these waves changed as the atmosphere warms due to climate change? To find out, we developed a new index for waviness and tested it on upper atmospheric data collected between 1979 and 2015.

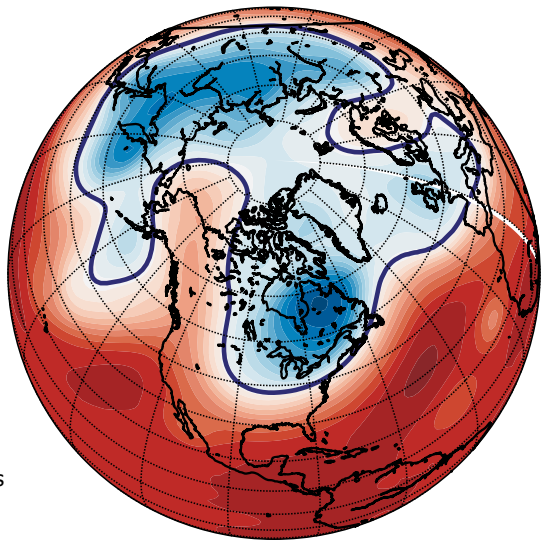

Figure 1:
On the 27th of January 2014, the isohypse was particularly "wavy"! (This is the solid blue line marking the border between areas of high and low atmospheric pressure.) This resulted in anomalously low temperatures over the north-east United States (See figure 2).

Figure 2:
Loaders clear Summit Avenue of snow in Union City, New Jersey the evening of February 15, 2014.

Methods

First we needed to find a way to visualize the waves we saw in the atmosphere each day and describe the degree of waviness. To do this, we developed an index (a number that is based on a calculation incorporating several variables) based on the shape of each wave. We called our index the Meandering Index ("M" for short), named after the curves in the isohypses, which are called meanders.

This method was new; other scientists have studied waves before, but have only considered the *size* (North-South extent) of the waves, not the *shape*. The data we used was a combination of observed and model data called a reanalysis. We chose the reanalysis because it provides data that is uniformly distributed in space and time. This makes it easy to study with a computer.

Once we had all the M's calculated, we divided the dataset into two time periods (1979-1999 and 2000-2015) and then into seasons: fall, winter, spring, and summer. We looked at data for three regions of the world: the whole northern hemisphere, Eurasia and North America. To compare the M's for each of those datasets, we created a distribution of M's for each one. A distribution is like a histogram but continuous, which shows how many of each index occurred in each dataset. We were especially curious about how the highest M's might have changed from one period to the next because large values of M, or a very wavy atmosphere, lead to extreme hot and extreme cold weather events.

Results

The data for the northern hemisphere showed us that the shape of the distribution for M was similar for each of the four seasons. This means that there isn't much change in the shape of the waves throughout the year.

However, we saw a significant increasing trend toward more strongly meandering patterns with time (Fig. 3). The most pronounced changes were in the Northern Hemisphere and Eurasian datasets and for autumn-early winter. The strongest trend in the North American dataset was an increasing trend in M in the summer months. This means that in the last few decades, there have been larger and curvier waves in our atmosphere.

We also considered the altitude and latitude at which the waves had been observed in each dataset. After some analysis we found that the average altitude of the waves with the most meanders increased by about five or ten meters every decade. This shows the thermal expansion of the lower troposphere due to global warming. And in autumn the latitude increased by about 0.3 degrees/decade too, meaning that the maximum waviness activity moved northward.

The changes in M over the last three decades along with the changes in position (latitude and altitude) tell us that something important is changing in the way the atmosphere behaves.

Please see page 3, Figure 3

Discussion

Large waves in the atmosphere lead to temperature extremes like heat waves and cold snaps. These weather phenomena have increased in the latest decades, likely even the cold extremes despite global warming.

Why would cold snaps increase in a warming climate? Very large, very curvy waves can move air great distances, until you have air that originated near Mexico causing toasty conditions in Alaska and air that started out chilling in Fairbanks, Alaska causing freezing conditions in New Orleans. If these waves are getting larger and curvier, that means an increase in this kind of wild weather.

In this study we developed an index to describe the meandering of a wave then used that index to see if the meandering is increasing over time. We found significant increasing trends in M in all three of our study locations—the whole northern hemisphere, Eurasia, and North America.

Increases in the northern hemisphere and Eurasia were in the autumn and early winter. We know that high meandering index patterns in autumn and early winter can lead to prolonged cold snaps.

We didn't study why this increase is occurring, but other scientists have suggested things like changes in ocean temperatures near the equator and up at the poles are changing the way our atmosphere works. Understanding how these things will change in a warming climate is important in understanding how many heat waves and cold snaps we might expect in a warming climate.

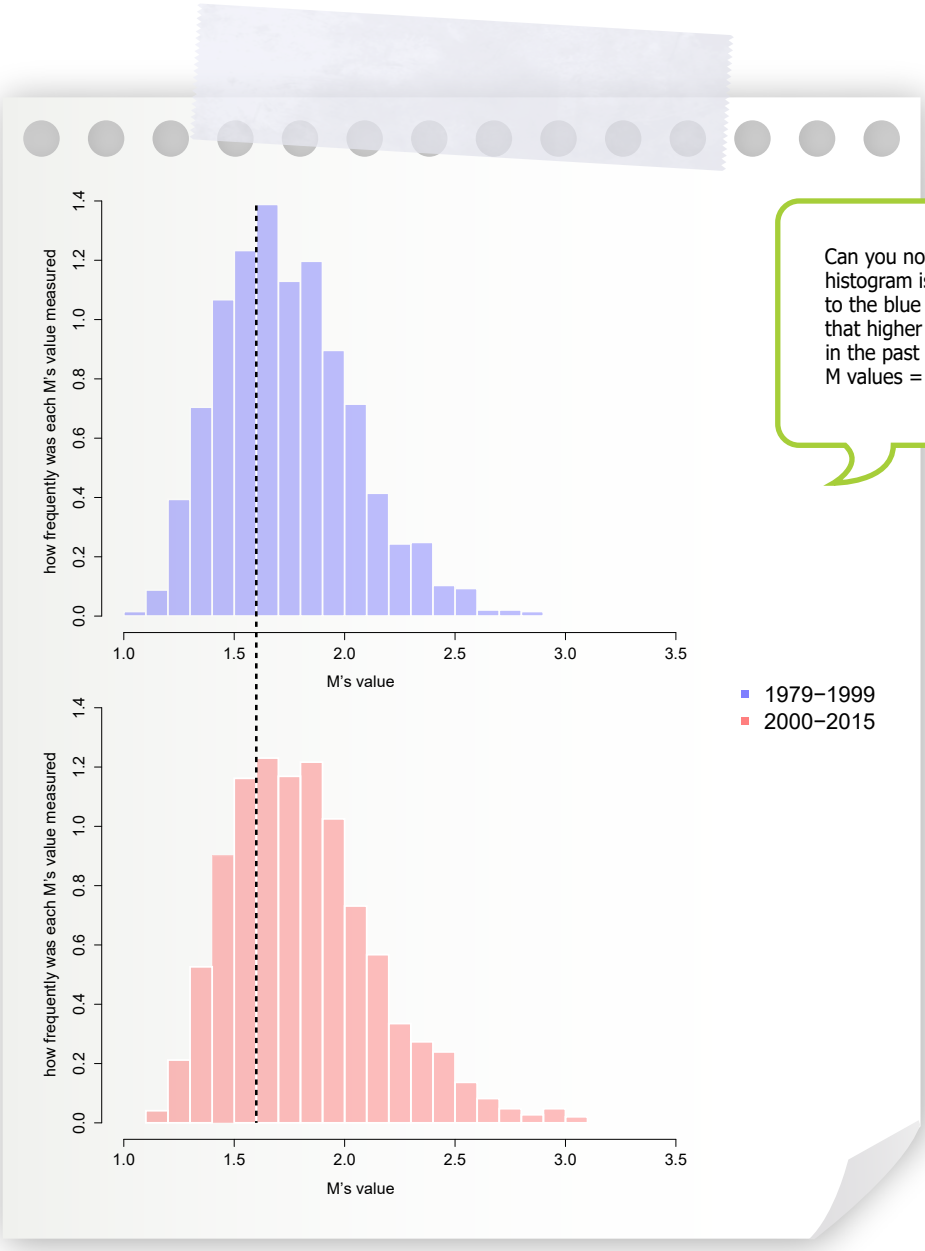

Figure 3:
A histogram showing how frequently a particular Meandering index ("M") was measured. (Note: this histogram illustrates only data from autumns in the Eurasian region.)
X-axis = M's value
Y-axis = how frequently was each M's value measured
The blue bars (top) illustrate data from the period 1979-1999. Red bars (bottom) illustrate data from 2000-2015. We also calculated the **mean M value** for each of the two periods. *How do they compare?* **1970-1999 = 1.74 vs. 2000-2015 = 1.82.**

Conclusion

Understanding how meanders in the atmospheric waves behave is just one way to better understand how the atmosphere is changing in response to climate change. We know we will experience more temperature extremes in a warming climate. Other types of weather are also affected by the same waves, like droughts and floods. The next time you are shivering in Texas on a sunny February afternoon, remember atmospheric waves.

Glossary of Key Terms

Distribution – mathematical tool that allows you to see the frequency of a given value in a large dataset.

Index – A calculation based on several different variables observed in a data set. In this case, the index was based on the curviness of the meanders in the isohypses.

Isohype – A line on a map connecting points of equal equal height at a certain pressure level. (Similar to isobar which are contour lines connecting points of equal atmospheric pressure at the same altitude.)

Check your understanding

1. Isohypses are lines on a weather map (called contour lines) that connect points of equal height at a certain pressure level. This is what usually meteorologists are looking at. They are analogous to lines on a topographic map, which connect points of constant elevation. What does it mean when lines are close together on a topographic map? What do you think it means when the isobars on a weather map are close together?

2. Have you ever experienced the passage of a cold front in your town? Where does the cold air come from?

3. Imagine you are in Boise, Idaho enjoying an unusually balmy day in mid-December. You call your friend in Baton Rouge, Louisiana who tells you "It's freezing down here!" then adds jokingly "Must be global warming!" What do you say to your friend?

4. Have you noticed any unusual weather in your town or any signs that the climate is changing?

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