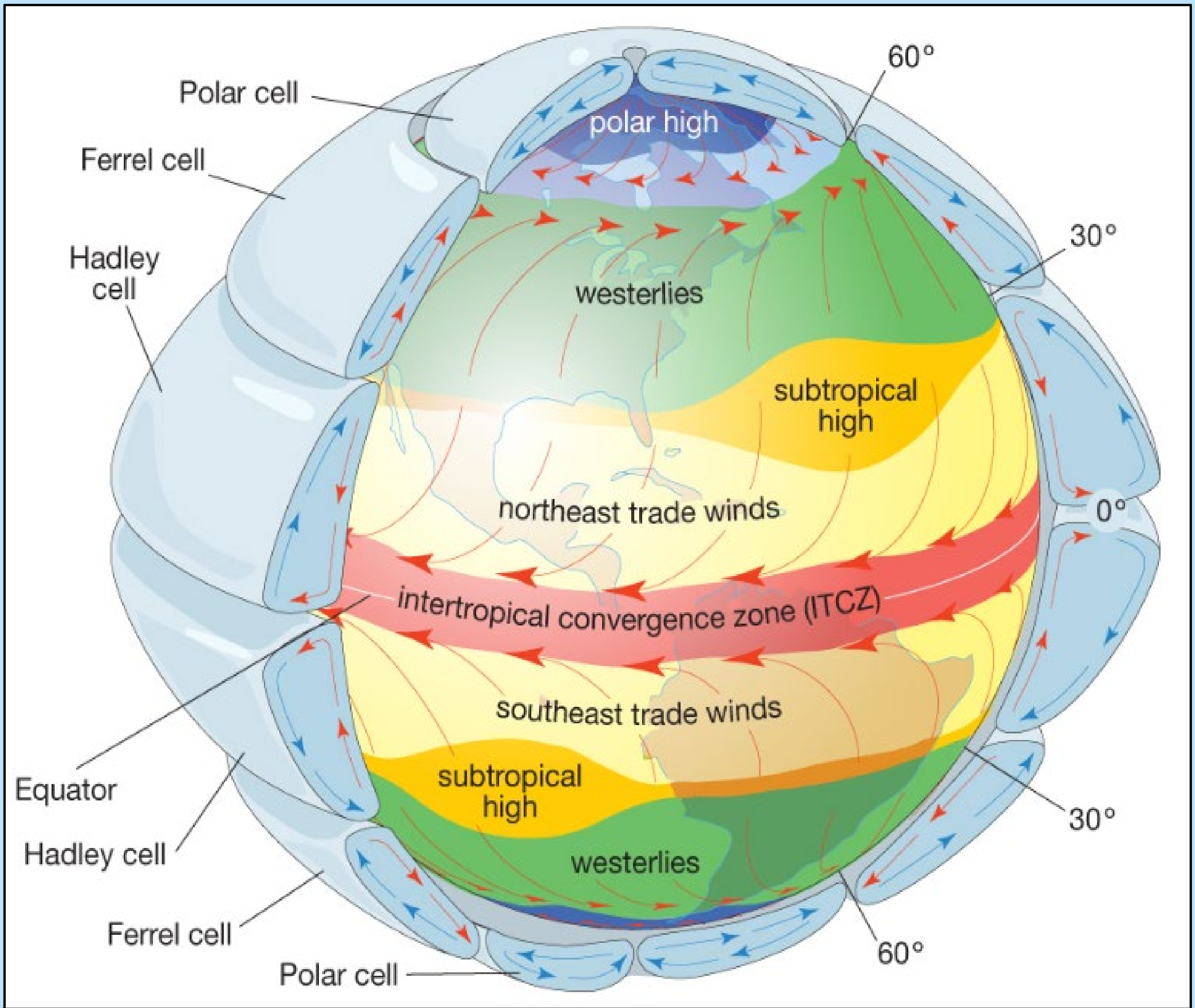
Climate, Climate Change, and the General Circulation

Introduction

Climate change is one of the pre-eminent issues that is driving agricultural, private sector, and governmental decision making on the time scale of a few years to a few decades. There is little disagreement among scientists that climate does change on a variety of timescales both preferred (e.g. cyclical) and extemporaneous. Climate has changed over time since the Earth has had an atmosphere and ocean. Climate scientists agree that climate change is primarily reflected as regional inhomogeneities versus being globally uniform. However, there is some disagreement regarding whether climate change in primarily driven by external factors versus the internal dynamics of the Earth-Atmosphere (EA) system.

Many scientists state that external forcing drives the climate. This is primarily expressed in the idea of examining the balance of energy leaving our EA system versus that coming into the EA system. In this view, carbon dioxide is like a control knob that regulates the balance of incoming versus outgoing radiation. In other words, current changes in climate have been driven by atmospheric changes in carbon dioxide concentration, and the forcing is amplified by positive feedbacks. Other scientists state that the EA system is a complex physical system in which internal dynamics and their complicated behaviors will cause climate to change on discrete timescales. They believe climate is not static and that the influence of carbon-dioxide is either relatively small compared to natural cycles or projects onto the internal dynamics.

Weather is the day-to-day state of the atmosphere and can be represented by measurements taken instantaneously. Climate, on the other hand, is the time mean state of the atmosphere along with higher order statistics that measure variability. The most common time interval used for global climate is 30 years. Climate change is simply the change in the statistical character of climate over a period greater than 30 years. The general circulation is defined as the large-scale structure of the atmosphere over time scales of 15 days to less than 10 years. Thus, like climate, the general circulation can be viewed as the statistical compilation of the weather. Also, like climate, the general circulation is driven largely by the character of the underlying surface. In turn, the character of the general circulation can influence the predominant weather of a given location on the time scale of two weeks to a few years.



Schematic of the general circulation (from the Encyclopedia Britannica).

Since the middle of the 19th century, most sources cite that annual global mean surface temperature has increased by approximately 1°C (1.8°F). Much of this increase has occurred over two time periods, from approximately 1910–1945 and 1975–2000. However, these changes have not been globally uniform and have been associated with changes in the general circulation. Here, we will survey important aspects of the current state of general circulation along with recent changes, and likely changes in the future.

The Tropics

Most studies show little trend overall in tropical precipitation since the mid-20th century. But many have shown the western Pacific and Indian Ocean monsoonal circulations have weakened over the past 50 years as well as decreases in land-based precipitation and surface wind speeds. Over the same period, there is no consistent signal in the strength of the Hadley circulations because the results of many studies are dependent on the data set used and the time period analyzed. But studies agree that there is interannual and interdecadal variability in the strength of the Hadley and Walker circulations, and these are as strong or stronger than observed trends. There have been suggestions that the width of the Hadley regime has increased significantly over the last few decades[1].

Relatively uniform observations of global tropical cyclone activity have only been available since about 1980 and most studies demonstrate no statistically significant increase in overall activity worldwide, despite interannual and interdecadal variations. The last few decades have shown an increase in tropical storms versus weaker hurricanes, but a statistically significant increase in stronger hurricanes. Regionally, the strongest increases in tropical cyclone activity have occurred over the Atlantic while the Pacific region has observed static (Eastern) or decreasing (Western) activity at all intensity levels[2]. These trends in Atlantic and West Pacific tropical cyclone activity were manifest strongly in the observations of the 2020 tropical season.

The consensus of model projections in future tropical cyclone activity suggest that this activity will remain like today, but the proportion of stronger storms may increase and be associated with greater precipitation amounts. The confidence in these projections is low and uncertain since even higher resolution models continue to struggle with capturing the occurrence and strength of tropical cyclones and the associated convection[3].

El Nino and Southern Oscillation (ENSO) is an irregular (every 2 to 7 years) warming of the sea surface temperatures in the central and eastern tropical Pacific. This phenomenon has an impact on the general circulation and weather worldwide by altering the distribution of surface heating in the Pacific Ocean and in the atmosphere. In turn, the configuration of the mid-latitude jet-stream is altered, and this often results in anomalous temperature and precipitation regimes for certain areas including North and South America, which are impacted the greatest. Agriculture on both continents is quite sensitive to the phase and strength of ENSO. Paleoclimate studies show ENSO is not new but has been around for thousands of years and longer.

Recent studies have demonstrated that the frequency and strength of ENSO has varied since the early 20th century and this is thought to be linked with interannual and interdecadal variability in the Pacific Ocean basin. Additionally, studies have shown that there are two variants of ENSO in which the strength and location of the primary warm sea surface temperature anomalies differ. Each variant is associated with their own weather impacts. Climate models are improving in their ability to replicate ENSO in future scenarios, and there is no consensus on future changes in the frequency, strength, or type of ENSO occurrence.

The Midlatitudes and Polar Regions

The mid-latitude jet stream and the polar front are associated with the mid-latitude storm track and are indicative of the boundary between the mid-latitude Ferrell Cell and the Polar Cell. The storm track is the composite activity of mid-latitude surface cyclones and their associated upper air waves. These cyclones are dynamically linked to the frequency, persistence, and strength of blocking anticyclones. Blocking anticyclones are persistent and quasi-stationary ridges or waves in the midlatitude jet stream. Blocking is often associated with extreme and anomalous warm and cold weather as well as wet and dry weather over very large regions of the globe.

Additionally, many studies have shown the annual precipitation amounts have increased within the Northern Hemisphere mid-latitudes since the mid-20th century. In the Southern Hemisphere mid-latitudes, precipitation has decreased in general. The former result is true for the United States in particular, and some studies have demonstrated this increase is associated with precipitation events that involve greater amounts of precipitation.

Mid-latitude cyclone activity and the associated storm tracks in most investigations has been shown to have migrated poleward since the mid-20th century. This is reflected in increases of individual cyclone activity at higher latitudes, and corresponding decreases in the mid-latitudes. A few studies have suggested winter season cyclones have increased in intensity. In is well-known that the strength and location of the storm tracks vary strongly on the interannual and interdecadal timescales. These changes in the storm track correspond to observed changes in the mid-latitude jet stream with respect to position in the Northern Hemisphere. The signal is less certain in the Southern Hemisphere. In the Northern Hemisphere, there is indication that the jet stream speeds have increased in recent decades.

An examination of the blocking anticyclone character over the last 50 years has shown that blocking was less frequent globally during the latter part of the 20th century than during the mid-20th century. However, blocking has become more frequent during the early 21st century[4]. These events have become weaker in the Northern Hemisphere with no change in duration, but in the Southern Hemisphere, they have become more persistent with little change in strength. Like mid-latitude cyclones, the interannual and interdecadal variability of blocking is significant as well.

Climate models have consistently underestimated the frequency and strength of both the mid-latitude storm tracks[5] and blocking[6] as well as the jet stream. This is due to shortfalls in the model abilities to replicate the mean flow correctly or the model construction. However, climate models are showing improvement recently in representing the storm tracks and blocking. Despite this, many studies have suggested that during the 21st century, the occurrence of storm tracks and blocking will shift poleward. But there is no consensus from the models for changes in frequency of these events due to the methods used to detect these events. Most of the studies suggest slightly fewer blocking events by the end of the 21st century. Lastly, climate models suggest that the jet stream may show stronger variability in the wind speed and less variability in the longitudinal variability[7].

Conclusion

The general circulation of the atmosphere is the compilation of weather over seasonal to interannual timescales and in turn can influence the occurrence of weather on these same timescales. The general circulation like climate is driven by the character of the underlying land and ocean surface.

During the 20th century, surface and atmospheric temperatures have warmed globally, but less so in the tropics versus the Arctic. Associated changes in the general circulation have occurred that are physically consistent with a warmer climate, such as the poleward shift of certain general circulation features. However, for other phenomena, trends in their character are difficult to identify due to a larger magnitude in interannual and interdecadal variability or differences in criterion used to identify them. For the general circulation phenomena surveyed here, there is generally low confidence and/or a weak consensus in future climate model scenarios. These are also in general consistent with the observations published by the IPCC[8].

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