A Brief Introduction to the Annular Modes and Annular Mode Research  
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The following text is designed to introduce scientists from outside the climate dynamics community to the annular modes and current topics in annular mode research. The text is updated and improved regularly. In the interest of being inclusive, I have not cited individual papers, but rather refer broadly to the most relevant subset(s) of papers contained on this site. Please send any comments to David W. J. Thompson ([davet@atmos.colostate.edu](mailto:davet@atmos.colostate.edu))

***What are the annular modes?***

The annular modes are hemispheric scale patterns of climate variability. Another more popular example of a large scale pattern of climate variability is the El-Nino/Southern Oscillation (ENSO). But whereas ENSO owes its existence to coupled ocean/atmosphere interactions in the tropical Pacific, the annular modes owe their existence to internal atmospheric dynamics in the middle latitudes. ENSO is the most important (in terms of variance explained) pattern of large scale climate variability in the tropics; the annular modes are the most important patterns of climate variability in the Northern and Southern Hemisphere middle and high latitudes.

There are two annular modes in Earth's atmosphere: a Northern annular mode (NAM) and a Southern annular mode (SAM). Both annular modes explain more of the week-to-week, month-to-month, and year-to-year variance in the extratropical atmospheric flow than any other climate phenomenon. For example: the NAM and SAM explain on the order of ~20-30% of the total variance in the geopotential height and wind fields of their respective hemispheres, depending on the level and timescale considered.

The annular modes describe variability in the "anomalous" atmospheric flow, that is, variability not associated with the seasonal cycle. In the pressure field, the annular modes are characterized by north-south shifts in atmospheric mass between the polar regions and the middle latitudes. In the wind field, the annular modes describe north-south vacillations in the extratropical zonal wind with centers of action located ~55-60 and ~30-35 degrees latitude. By convention, the high index polarity of the annular modes is defined as lower than normal pressures over the polar regions and westerly wind anomalies along ~55-60 degrees latitude.

To first order, the time series of the annular modes are consistent with a normally distributed red-noise process with an e-folding timescale of ~10 days. This means that: 1) the annular modes vary on timescales as fast as weeks; and 2) the high and low index polarities of the annular modes do not reflect two distinct states of the climate system, but rather the wings of a normally distributed frequency distribution. However, not all aspects of the time series of the annular modes are consistent with a red-noise process with a 10 day timescale: e.g., the annular modes exhibit enhanced variability on monthly timescales during seasons of rigorous stratosphere/troposphere coupling (see section on Stratosphere/troposphere coupling, below); and both annular modes have exhibited trends over the past few decades towards their high index polarities (see section on Climate Change, below).

*(For more on the above subject, see the relevant papers listed under General and Wave-mean flow interaction)*

***Why do we care about the annular modes?***

One reason we care about the annular modes is that they impact climate throughout much of their respective hemispheres. To name just a few of the climate impacts of the annular modes: the NAM is associated with large anomalies in surface temperatures and precipitation across North American and Eurasia, in the distribution of sea-ice throughout the Arctic, in sea-surface temperatures over the North Atlantic, and in the spatial distribution ozone in the lower stratosphere. Similarly, the SAM is linked to variations in temperatures over Antarctica, sea-surface temperatures throughout the Southern Ocean, and the distribution of sea-ice around the perimeter of Antarctica.

Understanding the climate impacts of the annular modes has played a role in helping the climate community interpret of the structure of recent climate change, as discussed below. But the fact the annular modes are associated with various climate impacts does not imply causality. For example: it doesn't make sense to state that the high index polarity of the NAM causes a northward shift in the midlatitude jet since the high index polarity of the NAM is defined by the northward shift in the jet in the first place. Also note that the climate impacts of the annular modes are only as predictable as the annular modes themselves (see section on predictability, below).

*(For more on the above subject, see the relevant papers listed under Impacts, Arctic/Antarctic, Atmosphere-ocean interaction)*

***Are the annular modes predictable?***

Numerous studies have examined the predictability of the annular modes, and most of these studies focus on the impact of a relative slowly evolving boundary condition on the amplitude of the NAM or the SAM. As of this writing, there is observational and modeling evidence that: 1) both annular modes are sensitive to month-to-month and year-to-year variability in the stratospheric flow (see section on Stratosphere/troposphere coupling, below); 2) both annular modes have exhibited long term trends which may reflect the impact of stratospheric ozone depletion and/or increased greenhouse gases (see section on Climate Change, below); and 3) the NAM responds to changes in the distribution of sea-ice over the North Atlantic sector. To what extent changes in other external forcings (e.g., midlatitude sea-surface temperature anomalies, solar variability, etc.) impact the annular modes is less clear.

*(For more on the above subject, see the relevant papers listed under Forecasting the annular modes, Atmosphere-ocean interaction, Arctic/Antarctic, Stratosphere/troposphere interaction, Trends)*

***Why do the annular modes exist?***

At this point, we don't have a definitive answer as to why the annular modes exist. We do know that variations in the annular modes are driven by changes in the north-south flux of westerly momentum by waves in the midlatitude upper troposphere. And there is good evidence that the annular modes would not exist in the absence of positive feedbacks between the induced changes in the zonal wind and the wave fluxes. But there is still no single widely accepted theory as to why annular modes are so predominant in Earth's atmosphere. In fact, a few studies question whether the annular modes are truly dynamical structures in the first place, and suggest they may be artifacts of EOF analysis.

*(For more on the above subject, see the relevant papers listed under General and Wave-mean flow interaction)*

***What's the difference between the NAM, the Arctic Oscillation, and the North Atlantic Oscillation? And what's the difference between the SAM, the Antarctic Oscillation, and the high-latitude mode?***

The short answers : none and none.

Through most of the 20th century, the NAM was referred to exclusively as the North Atlantic Oscillation. That's because both the data coverage and the amplitude of the NAM are largest over the Atlantic sector of the hemisphere. When the polar scale of the northern pressure center of the NAO was identified in the late 1990s, the name Arctic Oscillation was introduced to highlight the fact that the pressure anomalies associated with the NAO span most of the Arctic. But 'oscillation' is something of a misnomer, as neither the northern or southern annular modes oscillate regularly in time (see text on What are the annular modes?, above). For this reason, in recent years the NAO/AO nomenclature has been increasingly supplanted in the dynamical literature by the phrase Northern Annular Mode (NAM). Annular denotes the longitudinal scale of the pattern, and annular mode suggests the NAM reflects dynamical processes that transcend a particular hemisphere or, for that matter, planet.

Likewise, the leading mode of variability in the Southern Hemisphere has been referred to as the High Latitude Mode and the Antarctic Oscillation, but is most commonly labeled the Southern Annular Mode in the recent literature.

*(For more on the above subject, see the relevant papers listed under General)*

***Stratosphere/troposphere coupling and the annular modes***

The annular modes are coupled with annular variability in the stratospheric flow during the winter season in the Northern Hemisphere and the spring season in the Southern Hemisphere. For decades, the prevailing wisdom was that stratospheric processes respond to but do not impact the tropospheric flow. But recent observations and model results done in the context of the annular modes suggest the coupling is two-way.

The recently discovered two-way nature of stratosphere/troposphere coupling is important for a number or reasons, not least the fact that the timescale of variability in the stratosphere is generally longer than the ~10 day timescale of variability in the extratropical troposphere. Recent numerical simulations suggest the coupling between the stratospheric and tropospheric circulations has practical applications for weather forecasting and also implications for tropospheric climate change (see text on Climate Change, below). The mechanisms whereby changes in the stratospheric flow impact the troposphere are currently under investigation.

*(For more on the above subject, see the relevant papers listed under Stratosphere/troposphere coupling)*

***Atmosphere/ocean interaction and the annular modes***

Both annular modes have large impacts on the sea surface temperature fields of their respective hemispheres. The changes in sea-surface temperatures are consistent with the impact of the annular modes on the surface fluxes of latent and sensible heat, and also on the flux of heat by the anomalous Ekman flow. The literature on atmosphere/ocean interaction and the annular modes is heavily skewed towards the Northern Hemisphere: there are hundreds of studies on the impact of the NAM on the North Atlantic Ocean but still only a handful of studies on the impact of the SAM on the Southern Ocean. This will undoubtedly change in the next few years.

To first order, observations of atmosphere/ocean interaction in the context of the annular modes are consistent with the passive response of the ocean to changes in the atmospheric flow. The impact of midlatitude sea surface temperature anomalies on the annular modes is thought to be small, at least on intraseasonal suggest interannual timescales. That said, recent evidence suggests that changes in sea-ice extent may drive variability in the annular modes.

*(For more on the above subject, see the relevant papers listed under Atmosphere-ocean interaction)*

***What is the role of the annular modes in climate change?***

Observations and numerical experiments suggest the annular modes have played and will continue to play a role in climate change. Both annular modes have exhibited trends towards their high index polarities over the past few decades: The trend in the NAM is largest during NH winter, is most pronounced from the middle 1960s to the late 1990s, and has relaxed somewhat in the past decade. We likely need at least another decade of data to know whether the trend in the NAM is, in fact, continuing. The trend in the SAM is largest in the SH summer season. The trend in the NAM helps explain the spatial structure of recent trends in NH climate and several ecosystems over the past few decades. The trend in the SAM helps explain the pattern of recent temperature trends over Antarctica.

Why have the annular modes exhibited trends over the past few decades? We still don't know for sure. But observations and model results suggest the trend in the SAM is at least partially driven by Antarctic ozone depletion. Climate models forced with increasing greenhouse gases consistently simulate a trend towards the high index polarity of the SAM. Climate models do not simulate a consistent trend in the NAM in response to either increasing greenhouse gases or stratospheric ozone depletion.

*(For more on the above subject, see the relevant papers listed under Impacts and Trends)*