The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

1968-3

Conference on Teleconnections in the Atmosphere and Oceans

17 - 20 November 2008

Global Teleconnections via the Tropospheric Subtropical Waveguide

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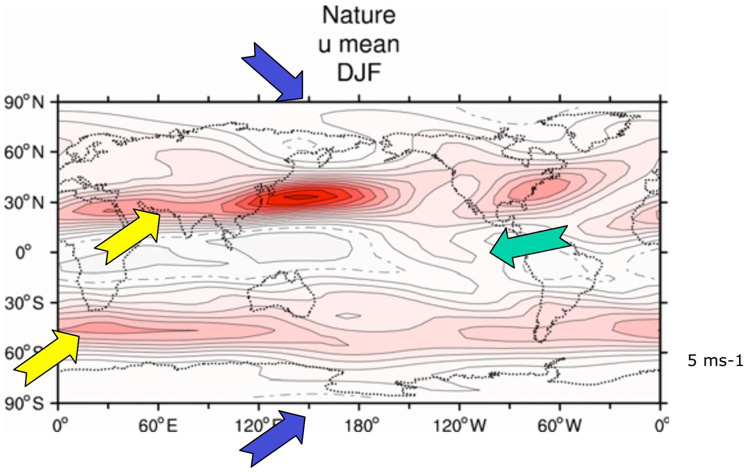
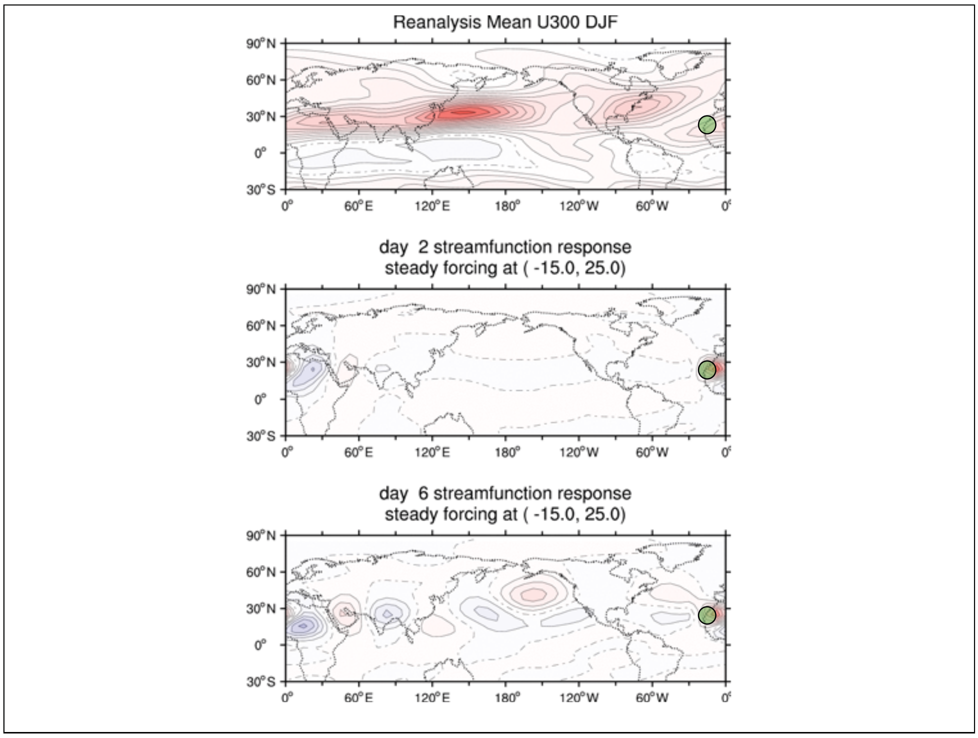
Though it is generally accepted that variability at widely separated regions is connected, most of the teleconnections that have been carefully documented are associated with teleconnection patterns that are regional. In this talk an example of teleconnections that reach completely around the globe will be considered.

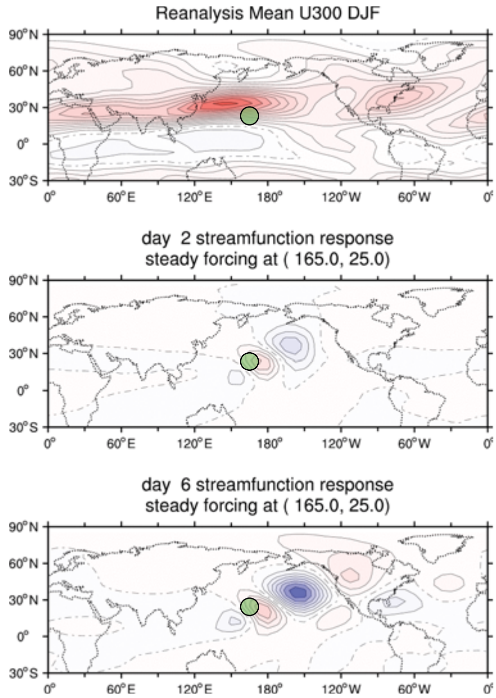
Waveguides



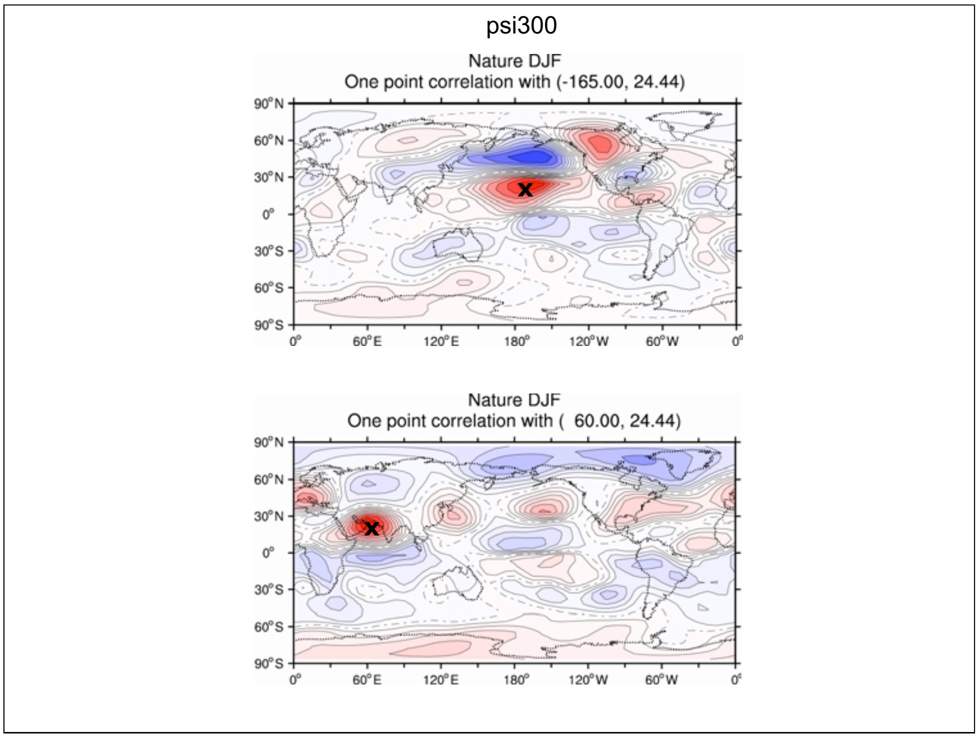
To understand how circumglobal teleconnections can occur it is useful to think of the concept of a waveguide. Two waveguides that are often invoked are that produced at the poles by the reflection of stationary Rossby waves and that in the eastern tropical Pacific where mean westerlies make it possible for planetary waves to propagate between the hemispheres. A third waveguide is the one we will concentrate on, namely that produced by the mean subtropical westerly jet in the troposphere. Simple linear theory indicates this jet will trap waves of intermediate wavelength. These distrubances will have strong easterly group velocities making it possible for events in one region to influence circulation anomalies in distant regions.



This behavior is seen in this calculation with the linear barotropic vorticity equation where forcing at the upstream end of the African/Asian jet produces a string of disturbances that nearly circle the hemisphere within 6 days of being switched on.

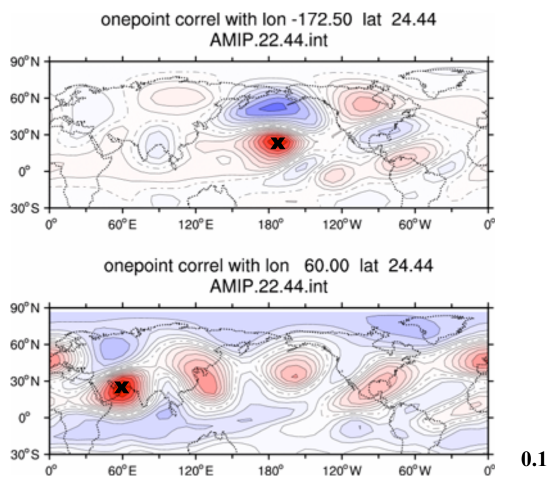


By contrast a forcing at the downstream end of the jet produces a wavetrain with more of a meridional orientation which covers only about a third of the NH after 6 days.

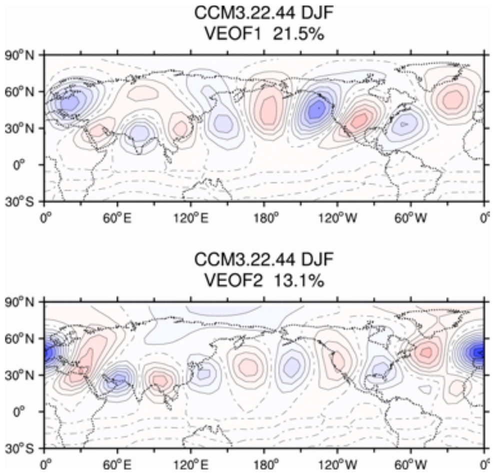


That such distinctions in propagation characteristics occur in nature is seen when we look at one point correlation plots of upper tropospheric streamfunction. When the master point is in the North Pacific an arching pattern is produced that is longitudinally confined. On the other hand, points in the subtropical waveguide co-vary with points at a sequence of locations that encircle the globe.

300mb streamfunction

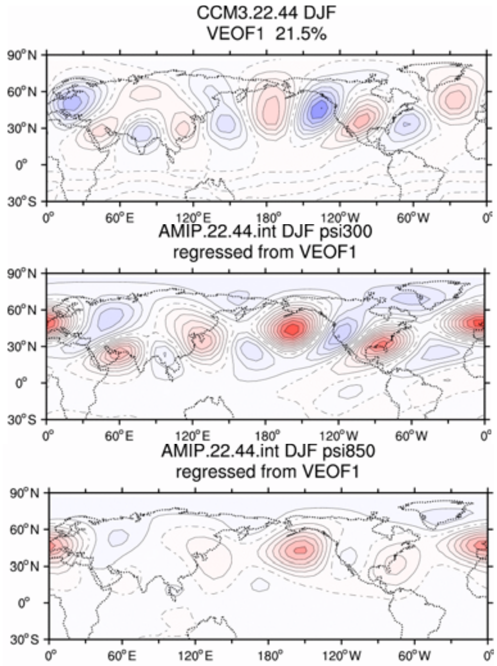


This distinction is seen a little more clearly in AGCMs. In addition to having larger samples than nature, AGCM experiments allow one to see that the effect of the waveguide is not related to any particular external forcing but is an intrinsic property of atmospheric variability. In these examples, an ensemble of experiments is analyzed in such a way that the effects of year to year variability in SST does not influence the analysis.

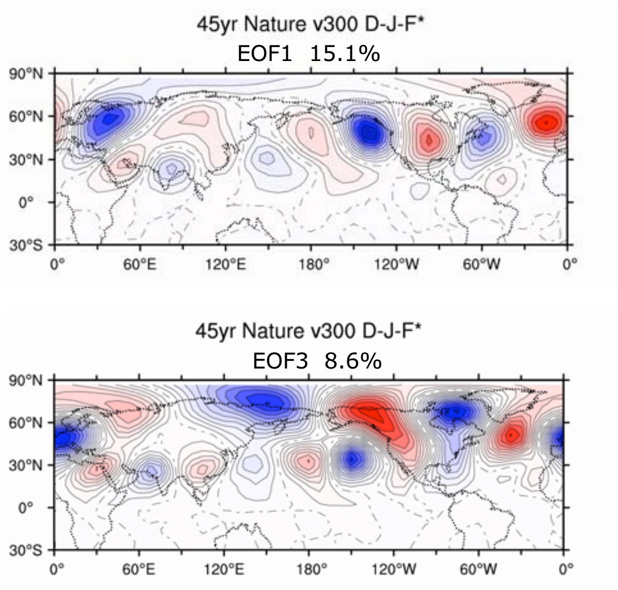


It turns out that an effective way to isolate variability associated with the waveguide is to consider upper tropospheric meridional winds. This serves as a natural filter that emphasizes the scales that are trapped in the subtropical waveguide. As a result, EOF analysis of DJF meridional winds in the AGCM lead to two patterns associated with waveguide variability. The prominence of zonal wave 5 is obvious. Together these two patterns represent a family of waveguide patterns.

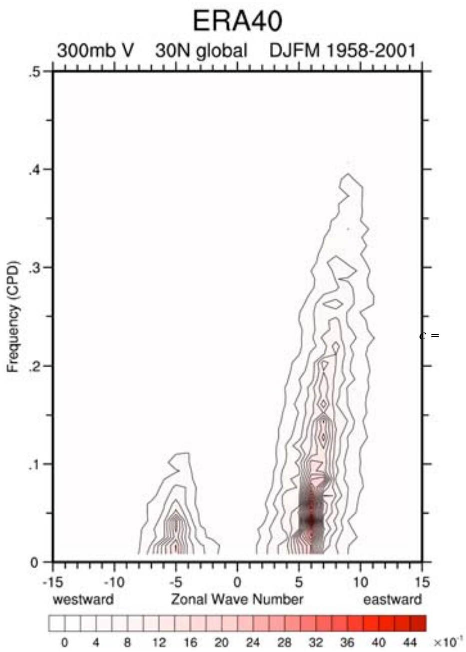
Circumglobal Waveguide Pattern



The AGCM's leading vEOF explains considerably more variance than the second indicating a preferred phase of waveguide variability. I refer to the leading pattern as the Circumglobal Waveguide Pattern. Using regression one sees it is associated with a distinctive Northern Hemisphere-wide circulation pattern in the upper troposphere. This pattern extends to the surface over the northern ocean basins but not elsewhere.

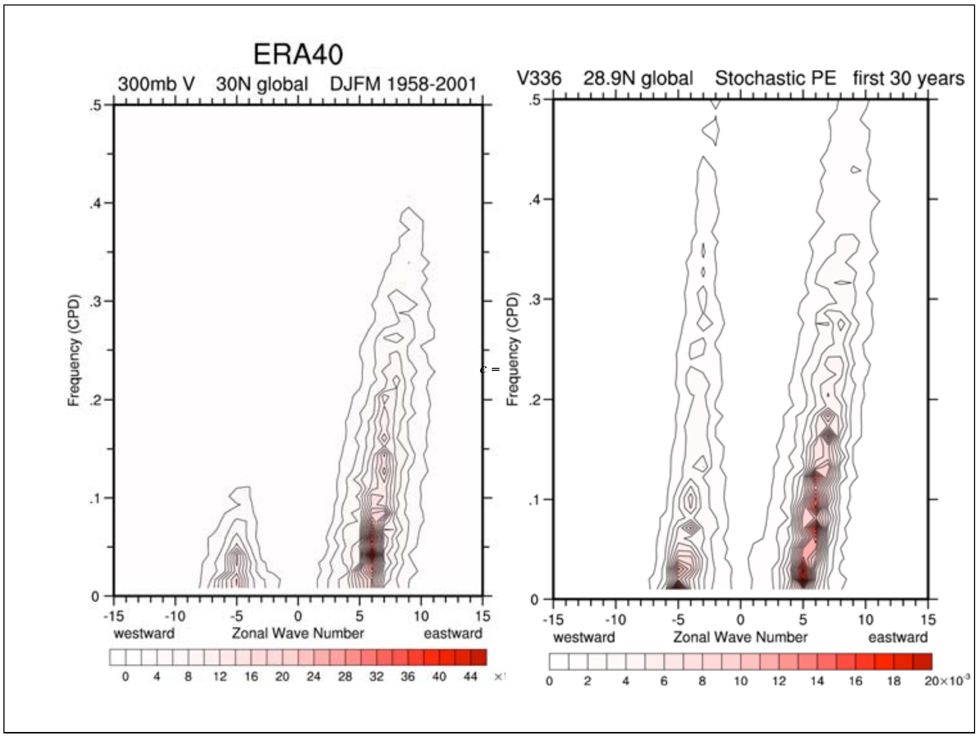


Two of the three leading vEOFs at 300 hPa in nature also are dominated by waveguide activity with a prominent zonal wave 5 structure.

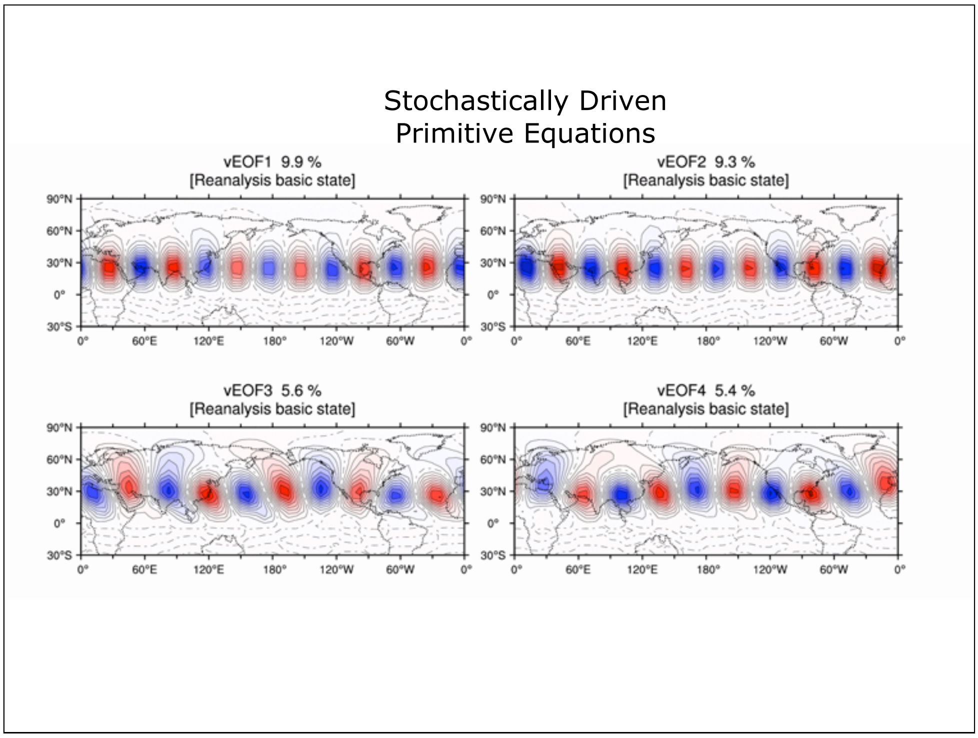


$$\omega = \left\{ \overline{u} - \frac{\beta}{(k^2 + l^2)} \right\} k$$

That zonally elongated variability in the subtropical waveguide might be expected was anticipated by linear ideas. We now explore in more detail whether this is the appropriate interpretation of these features. From linear ideas we expect large-scale disturbances to adhere to a simple dispersion relationship between scale and frequency. Looking at variability at 30N (more or less in the waveguide), we see that indeed such a relationship does hold. Interestingly this space-time analysis suggestions that wave 5 tends to have a frequency near zero, consistent with our finding that this is the dominant scale for monthly and seasonal anomalies in the waveguide.

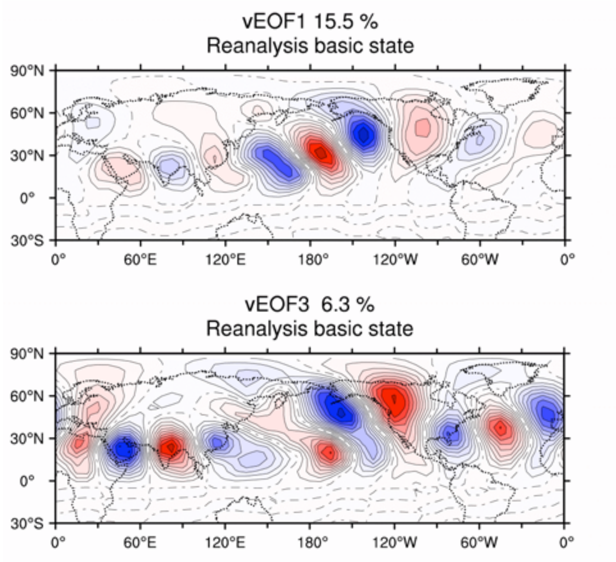


Further confirmation of the linear origin of the relationships seen in the space-time spectrum is produced when we linearize the primitive equations about the mean winter state from nature and then stochastically excite them with vorticity sources that are white in space and time.

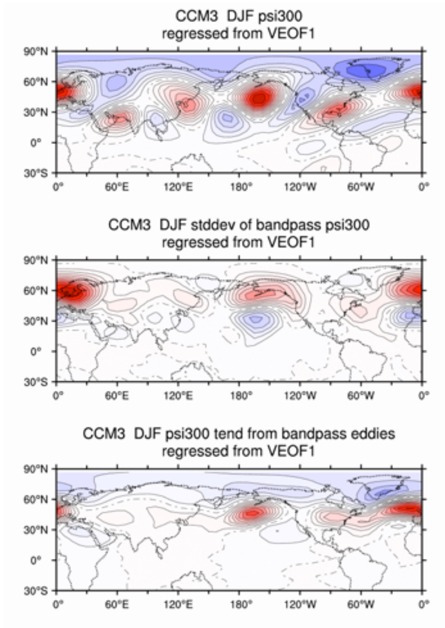


That the mechanisms that give preference for low-frequency variability trapped in the waveguide is primarily a result of the meridional structure of the mean state is seen in this experiment where the linear model is linearized about the zonally symmetric component of the DJF climatology from nature. Monthly mean variability is confined to the waveguide though zonal wave 6 is more prevalent than wave 5.

Stochastically Driven Primitive Equations

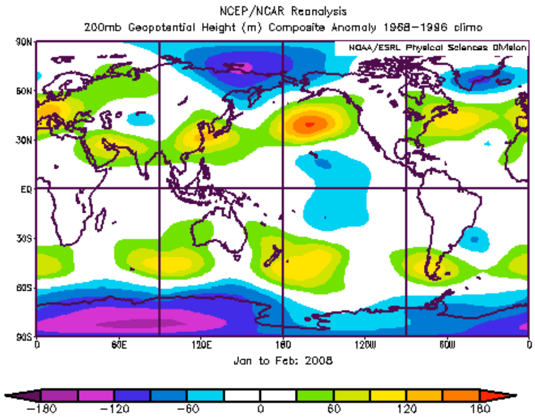


Switching to a basic state that includes the zonal asymmetries in the climatological state we see that wave 5 becomes dominant. So perhaps those asymmetries have an influence on the preference for wave 5 variability.

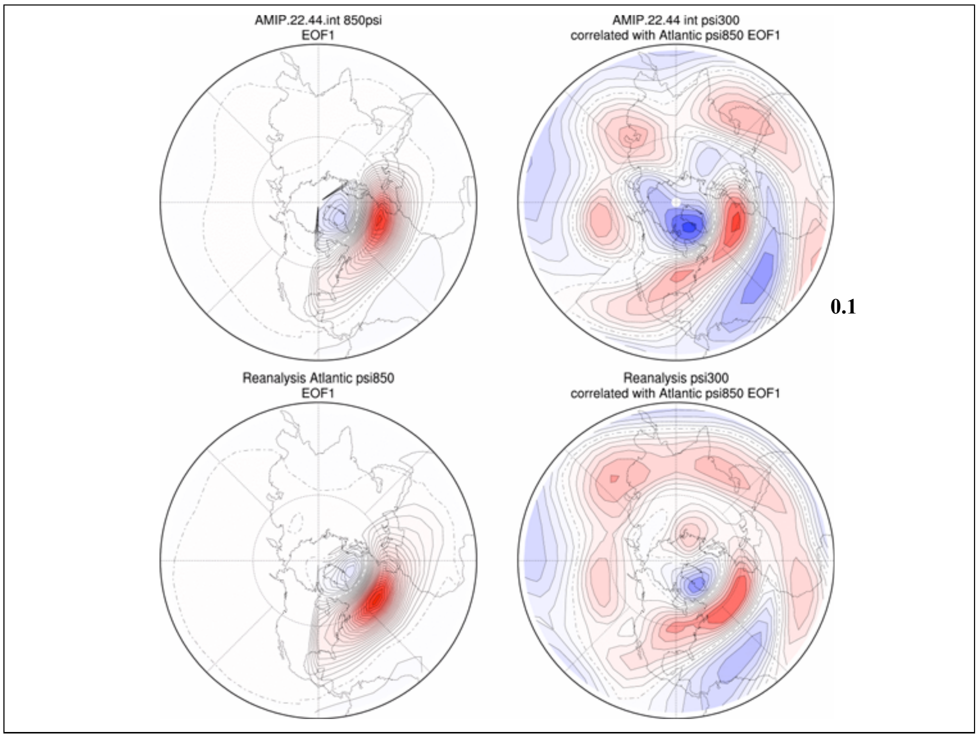


Though the interaction between low-frequency anomalies and the mean state seems to explain much of the structure of the waveguide patterns, this may not be the entire story. Notice, for example, that the linear vEOF1 is too weak east of the Atlantic. From this figure it is clear that the CWP modifies the climatological distribution of synoptic eddies in the two stormtracks. This produces a change in eddy momentum fluxes which has a positive feedback on the CWP over the N Pacific and especially over the N Atlantic -- at least in the AGCM being analyzed here. This positive feedback apparently adds to the strength of the CWP downstream of the stormtracks.

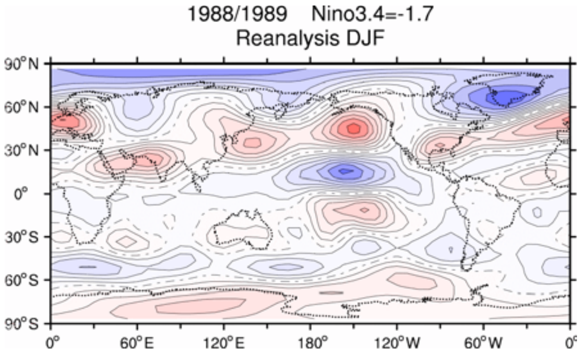
200hPa heights
Jan-Feb 2008



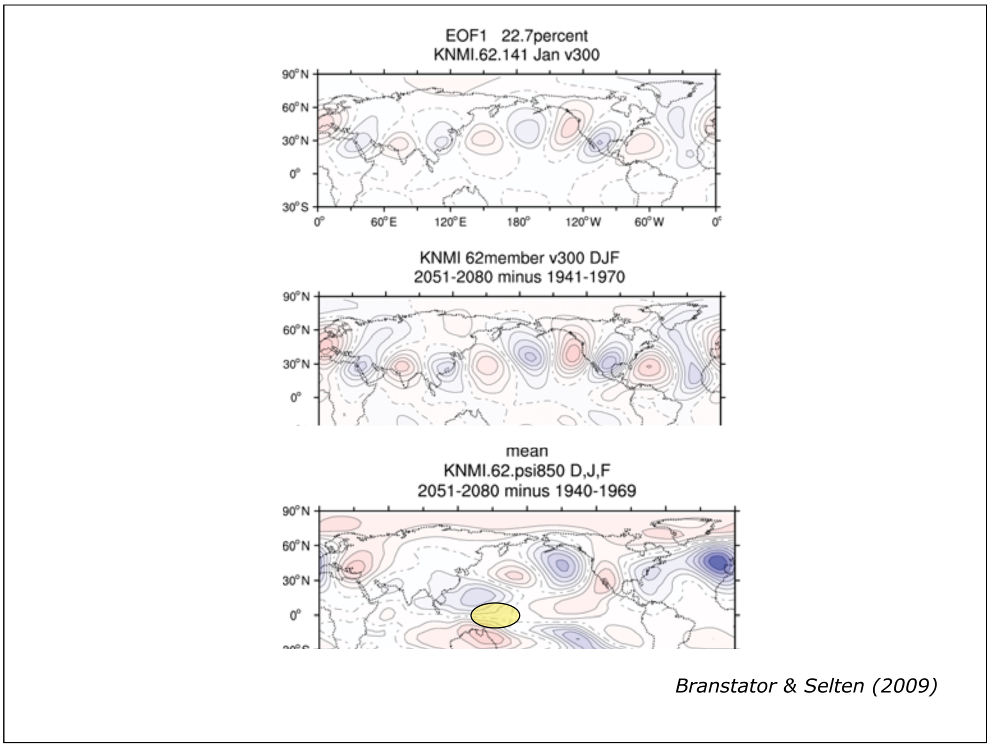
Having examined the structure of the CWP and the dynamical mechanisms that generate it, we now consider several situations where it seems to play a role. This first example demonstrates that the CWP is not just an analysis artifact. It is observable in individual maps of the observed circulation -- including the circulation that occurred last winter.



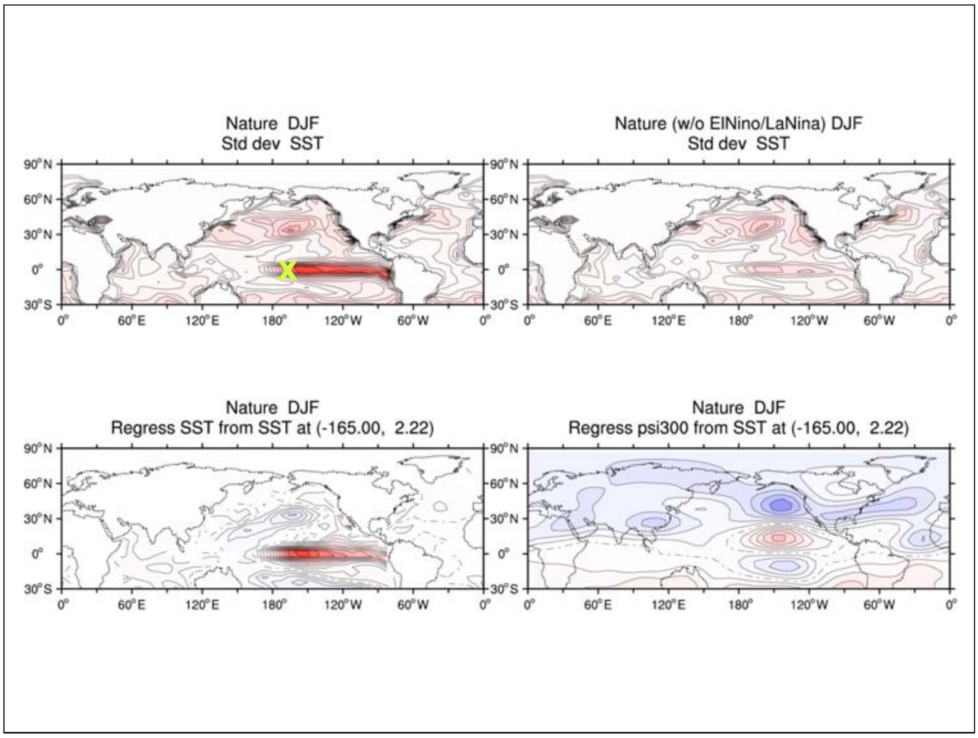
The CWP also contributes to typically analyses of the NAO. It is not clear whether the CWP and NAO are part of a common mode of variability or whether they are independent. But they have enough in common in their structure over the N Atlantic that indices that are designed to pick out the NAO also tend to have a component that matches the CWP, at least in the upper troposphere.



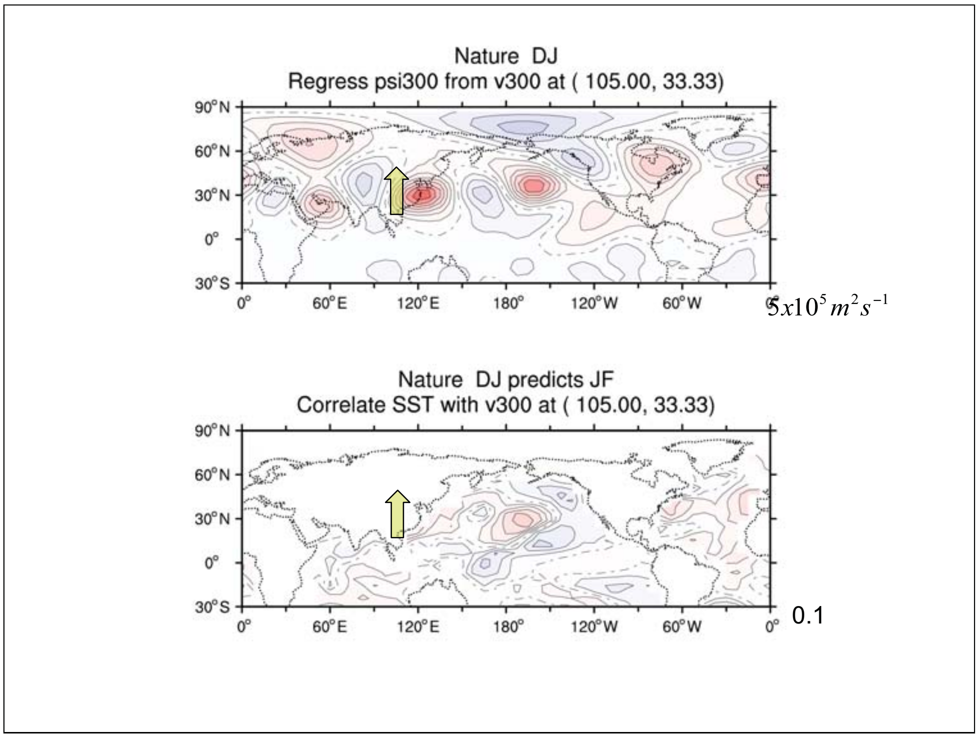
The CWP also occurs during some El Nino and La Nina episodes. What distinguishes these episodes from those when the CWP is not part of the response pattern is not completely understood.



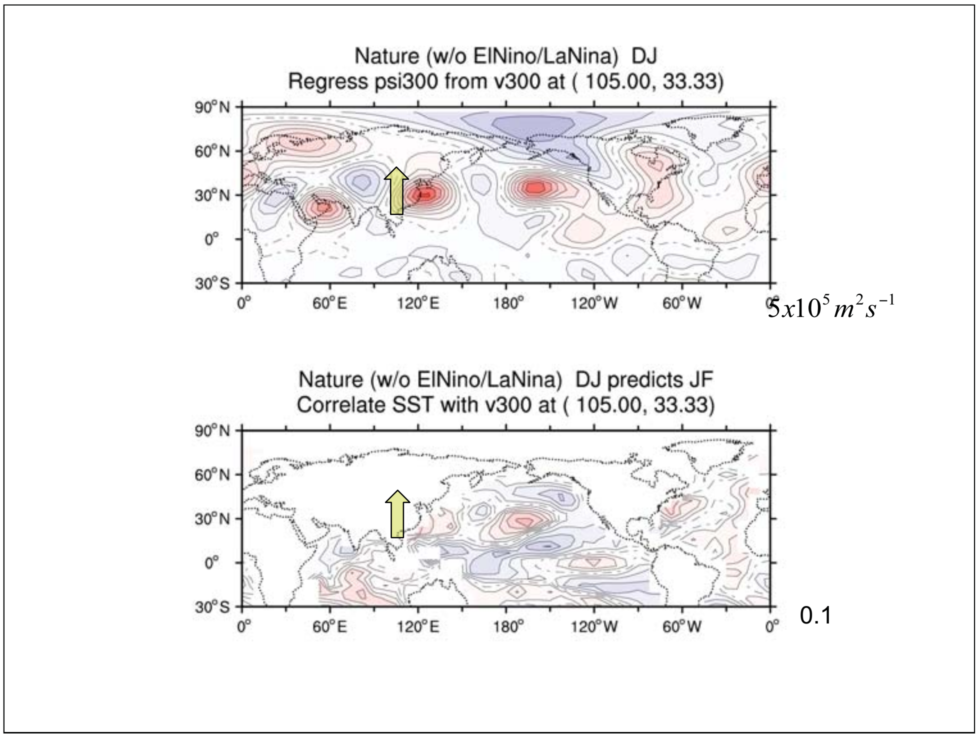
A fourth situation where the CWP also often is prevalent is global warming experiments. In most AGCMs the CWP is a prominent mode of intrinsic low-frequency variability. Thus it should be easy to excite with quasi-steady forcing anomalies. In many coupled global warming experiments a precipitation trend is generated in the central or western tropical Pacific. The associated heating can excite the CWP so that the circulation trend is similar to the CWP. Here is a striking example of such behavior as produced in an experiment with NCAR's CCSM1.4.



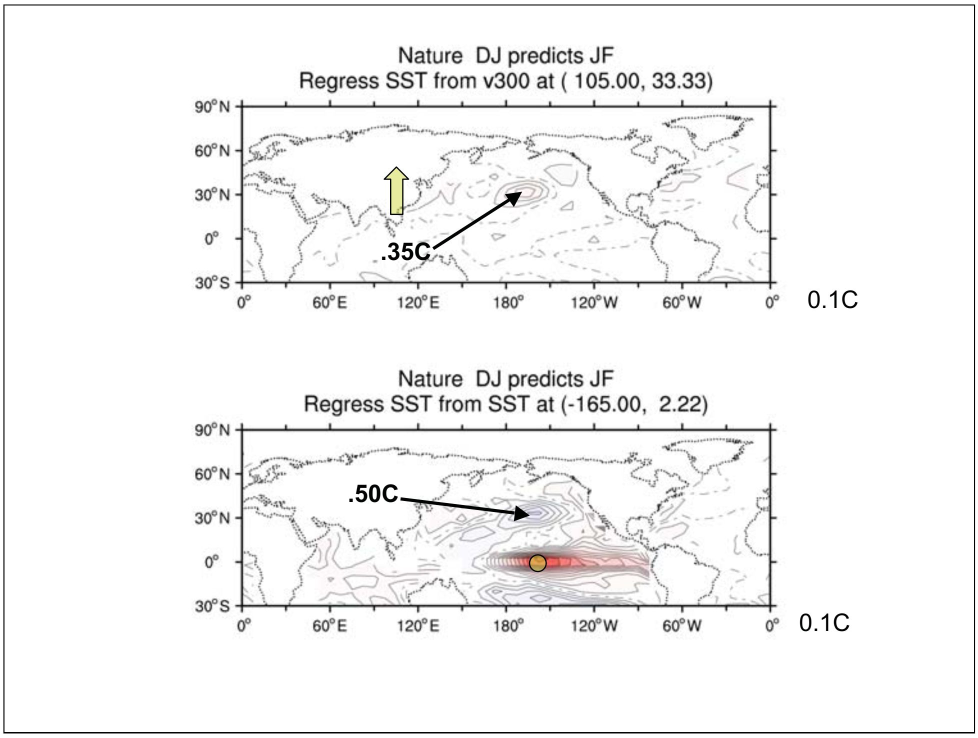
The fifth example concerns the interannual variability of N Pacific SST. It is well known that N Pacific SST variability can be initiated by tropical Pacific SST variability through the so-called atmospheric bridge. But if one excludes El Nino and La Nina events there is still significant N Pacific SST variability.



As we have seen, through the subtropical waveguide, disturbances initiated from upstream midlatitude locations can affect the circulation over the N Pacific. As seen in these diagrams, the resulting circulation can affect the underlying SSTs.



The effect of the waveguide disturbances on N Pacific SST is just as strong if one excludes El Nino and La Nina events.



It appears that the upstream influences explain roughly 2/3 as much N Pacific SST variability as is explained by tropical Pacific events. Thus there are actually two atmospheric bridges to the N Pacific.

From all these examples it is apparent that the global scale disturbances made possible by the waveguiding effect of the subtropical jet play an important part in many phenomena.