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Involvement of the Brewer-Dobson circulation in changes of northern hemisphere ozone

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The decline of Northern Hemisphere ozone during the 1980s and early 1990s and its rebound during subsequent years involve systematic changes of total ozone. Such changes are shown to have a close relationship to random interannual changes. These two components of interannual variability share a common structure. In it, ozone changes at high latitudes of the winter hemisphere are compensated at low latitudes and in the summer hemisphere by coherent changes of opposite sign. In particular, the downward trend over the winter hemisphere is accompanied over the tropics and summer hemisphere by an upward trend. The out-of-phase structure of ozone changes is shown to vary coherently with anomalous forcing of the residual mean circulation of the stratosphere, the so-called Brewer-Dobson circulation. Analogous behavior is exhibited by temperature.

The residual circulation is also reflected in the seasonality of systematic changes. Compensating trends at high and low latitudes amplify simultaneously – during winter, when the polar-night vortex is disturbed by planetary waves that force residual motion. After the final warming, the residual circulation collapses. The compensating trends at high and low latitudes then reverse, gradually erasing anomalies that developed during the disturbed season. Restoring ozone to climatological-mean conditions, this reversal leaves little memory by the time the next disturbed season begins. As a result, systematic changes of ozone depend only upon conditions during individual winters, not upon preceding winters. They must therefore involve the same mechanisms that operate in random interannual changes.

The ozone trend shares major features with the climate sensitivity of ozone, which has been derived from random changes over a large population of winters. The climate sensitivity has the same structure as the Arctic Oscillation, which evolves similarly during the period. Each reflects a change of wintertime downwelling, compensated at low latitudes by changes of upwelling and of the tropical tropopause.

The correspondence between systematic and random changes of ozone implies a major involvement of the residual circulation. Such changes involve anomalous dynamics, as well as anomalous photochemistry. About a third of the trend in the Northern Hemisphere average is accounted for directly by changes of chlorine and aerosol loading, independently of the residual circulation. The remainder, which operates coherently with the residual circulation, may also depend on changes of chemical composition, but indirectly. External momentum forcing of the stratosphere by planetary waves is determined chiefly by the tropospheric circulation. However, changes of equatorial wind (reflecting internal forcing) can follow from anomalous radiative heating in the stratosphere, through changes of ozone or CO_2.

Isolating individual contributions from transport and photochemistry will be essential to meaningfully interpret systematic changes of ozone and temperature. The climate sensitivity of those properties may afford a more reliable means of doing so than is available from conventional trend analysis. Because it follows from random changes over a large population of winters, the climate sensitivity can be related to coherent changes of dynamical and chemical structure. This contrasts with the "trend", which can no longer be regarded as even monotonic (let alone linear), rendering its definition ambiguous.