SPARC
New Initiatives

SPARC Scientific Themes and Associated Key Questions

SPARC has been a successfully running project within the WCRP programme during its 12 years of existence. In response to new issues recently emerged about the role of the atmosphere in climate, the SPARC community felt the need to address and include further initiatives that correspond to the ongoing progress in both scientific research and technological evolution.

The following themes are meant to encapsulate, in brief, SPARC's future programme. The associated questions posed within each theme are certainly not exhaustive; they aim to identify primary foci for our activities, at least in the immediate future.

1. Stratosphere-Troposphere Coupling

- What is the role of dynamical and radiative coupling with the stratosphere in extended range tropospheric weather forecasting?
- What is the role of dynamical and radiative coupling with the stratosphere in determining long-term trends in tropospheric climate?
- By what mechanisms do the stratosphere and troposphere act as a coupled system?

2. Detection, Attribution and Prediction of Stratospheric Changes

- What are the past changes and variations in the stratosphere?
- How well can we explain past changes in terms of natural and anthropogenic effects?
- How do we expect the stratosphere to evolve in the future and what confidence do we have in those predictions?

3. Stratospheric Chemistry and Climate

- How will stratospheric ozone and other constituents evolve?
- How will changes in stratospheric composition affect climate?
- What are the links between changes in stratospheric ozone, UV radiation and tropospheric chemistry?

The above themes will lean on the following on-going activities, including Model Development, Process Studies and Data Support.

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Stratosphere-Troposphere Dynamical Coupling

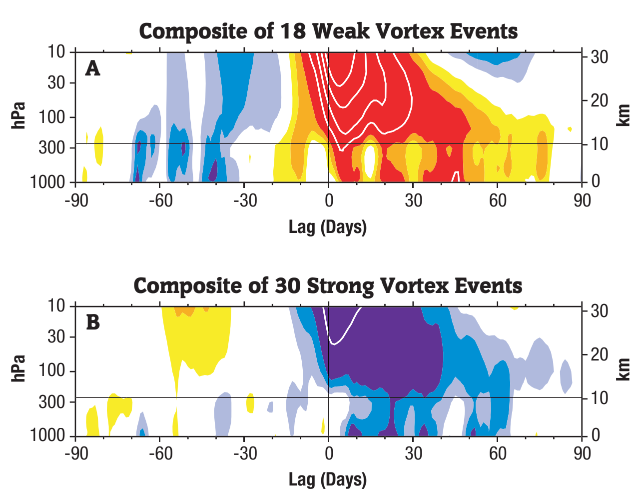

Figure 1. Weather from above. A weakening (red) or strengthening (blue) stratospheric vortex can alter circulation down to the surface. The diagrams show composites of the NAM index. (A) Composite of 18 weak vortex events and (B) 30 strong vortex events. The thin horizontal line indicates the approximate tropopause (Baldwin and Dunkerton, 2001).

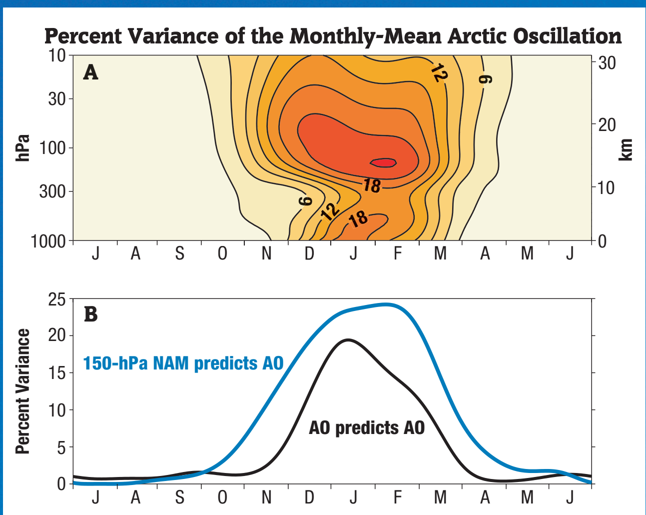

Figure 2. (A) Statistical predictability of the monthly-mean 1000-hPa NAM after a 10-day lead. The diagram shows that predictability is greatest during winter, and that the stratosphere provides better predictability than the troposphere. (B) Cross sections through (A) at 1000 and 150 hPa. (Baldwin *et al.*, 2003).

The troposphere influences the stratosphere mainly through a variety of atmospheric waves that propagate upward. Recent evidence shows that the stratosphere organises this chaotic wave forcing from below to create long-lived changes in the stratospheric circulation. These stratospheric changes can feed back to affect weather and climate in the troposphere. In the Northern Hemisphere, the connection can be described as a link between the strength of the stratospheric polar vortex and the dominant pattern of surface weather variability, the Northern Annular Mode (NAM).

When the NAM is positive, pressures are lower than normal over the polar cap but higher at low latitudes, with stronger westerlies at mid-latitudes, especially across the Atlantic. Northern Europe and much of the United States are warmer and wetter than average, and Southern Europe is drier than average. The NAM is very similar to the North Atlantic Oscillation (NAO). Variations in the strength of the polar vortex appear to induce changes to the surface NAM (Figure 1), but the dynamical processes are not well understood.

However, it may be possible to use stratospheric information to improve weather forecasts beyond the seven- to ten-day limit of weather prediction models (Figure 2). SPARC is also working toward improved seasonal weather forecasts through the WCRP's Task Force on Seasonal Prediction.

How will changes in stratospheric greenhouse gas concentrations and composition affect climate? Coupling to the stratosphere has the potential to alter patterns of surface climate change, and the surface response depends on whether the stratospheric vortex becomes stronger or weaker. At present, climate models do not agree as to how the stratospheric vortex will evolve with increasing greenhouse gas concentrations.

In addition to weather and climate, the stratosphere may also play a role in long-term variations in the polar ice pack, sea surface temperatures and deep ocean circulation, because the mid- and high-latitude oceans are sensitive to persistent changes in the NAM. The most pressing issue in stratosphere-troposphere coupling is to better understand the dynamical processes by which the tropospheric circulation responds to changes in the stratosphere.

A better understanding of stratosphere-troposphere coupling may help to better predict not only weather on monthly and seasonal time scales, but also the climatic effects of greenhouse gas increases, stratospheric ozone depletion, solar changes and volcanoes.

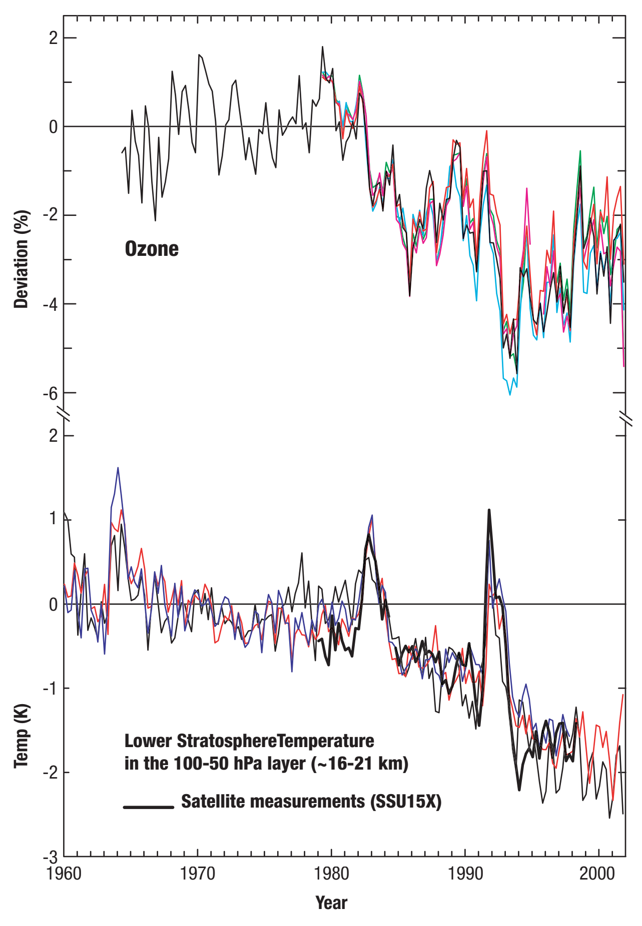

Figure 1. Time series of globally averaged changes in column ozone (top) and lower stratospheric temperatures (bottom) for the period 1960-2000. The ozone observations show results derived from a number of ground-based and satellite data sets, from Fioletov *et al.* (2002); the light lines show results derived from several radiosonde data sets (described in Seidel *et al.*, 2004). Both the ozone and temperature time series have been deseasonalized and changes are expressed with respect to a reference period of 1960-1980.

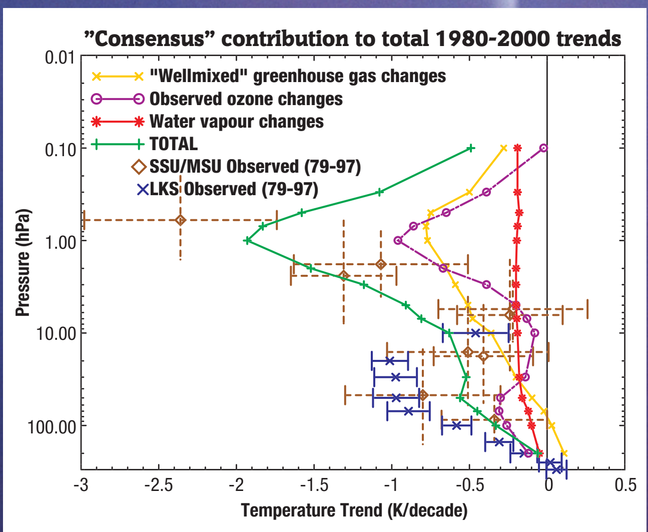

Figure 2. Global and annual mean temperature trends for the period approximately 1980-2000, from an average of model results using observed changes in ozone and greenhouse gases, and idealized water vapour trends. Observed temperature trends derived from satellite and radiosonde data sets are indicated by the symbols, and the error bars give the two-sigma trend uncertainties (from Shine *et al.*, 2003).

Detection, Attribution and Prediction of Stratospheric Changes

The composition and circulation of the stratosphere has changed substantially during the past four decades, and these changes have had a sizeable impact on the global climate system. Reliable observational records for global stratospheric ozone and lower stratospheric temperature, which extend back to the late 1950's, show significant changes during the most recent decades (Figure 1). Stratospheric changes occur as a result of both natural and anthropogenic causes, for example by volcanic or solar cycle effects, and by variations in greenhouse gases and ozone depleting substances. The stratosphere also exhibits substantial unforced natural variability, which is not well quantified. In order to predict the future evolution of the stratosphere, and quantify uncertainties in such predictions, it is important to understand past stratospheric changes, and in particular develop global models capable of simulating the observed record within the natural variability. Detection and attribution of past stratospheric changes go hand-in-hand with developing an ability to *predict* future evolution.

Past activities of SPARC have focused on quantifying the historical variations (and uncertainties) in stratospheric ozone, temperature, water vapour and aerosols, and ongoing work is aimed at assuring continued high quality 'climate' temperature data sets for the stratosphere. A key question is how the temperature and constituent observations fit together within the current understanding of the stratospheric climate system. This question is addressed by comparing past observations with a hierarchy of model simulations of varying complexity. For example, in a globally and seasonally averaged sense (which substantially reduces the effects of natural variability),the observed vertical structure of decadal stratospheric cooling over 1980-2000 is in reasonable agreement with changes calculated from decreasing ozone and increasing greenhouse gases (Figure 2).

However, more detailed comparisons show that the magnitude of the observed cooling in the Northern Hemisphere extratropical lower stratosphere is much larger than that calculated. This suggests that either additional processes need to be included in the model simulations (a plausible candidate is an increase in stratospheric water vapour over this time period), or the models do not properly represent the dynamical feedback to the forcing, or the observed cooling includes a large component of unforced natural variability. While examining linear trends is instructive, future attribution work will focus on simulating the full variability of the historical record, including effects such as volcanic eruptions, solar variability and stratosphere-troposphere dynamical coupling.

Detection, Attribution and Prediction of Stratospheric Changes

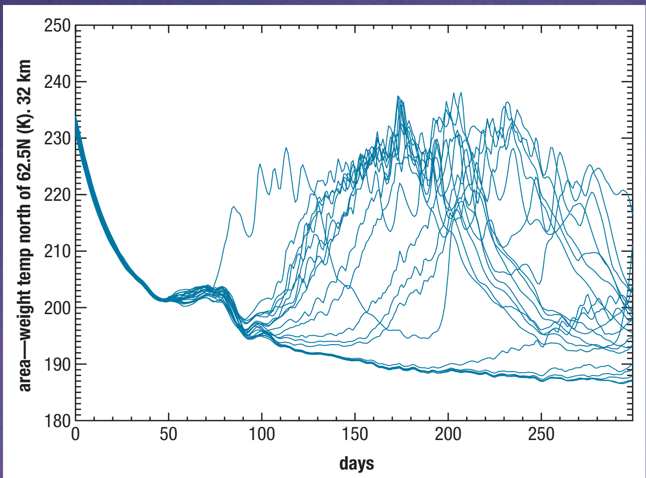

Figure 3. An ensemble of time series of temperature in the middle stratosphere over the polar cap, as simulated by a numerical model of the stratosphere and mesosphere, starting from slightly different initial conditions in August. (Courtesy Lesley Gray, University of Reading).

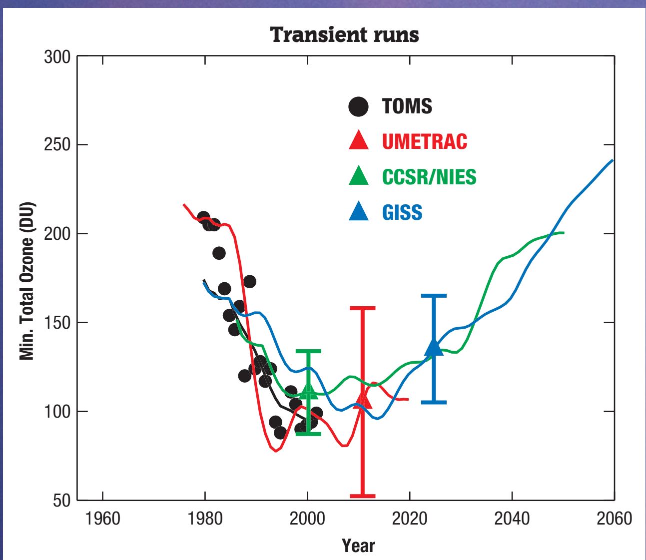

Figure 4. Time series of minimum Antarctic total ozone from TOMS observations (for 1979-2001) and results from several 3D chemistry climate model transient simulations for the period ~1980-2050.
(Details can be found in Austin *et al.*, 2003).

A key aspect of attribution is the development and refinement of global models to include more complex and realistic physical processes. The current research community involves a number of groups with General Circulation Models (GCM's) that include a realistic middle atmosphere, and work is progressing to develop and use fully coupled chemistry-climate models. While, overall, these models have substantially improved their climate simulations with time, there are still chronic problems in many models, including persistent temperature and zonal wind biases, and a lack of realistic tropical zonal wind oscillations. The GCM-Reality Intercomparison Project for SPARC (GRIPS) is aimed at intercomparing and improving model behaviour, with current and planned topics including:

1) Comparisons of model responses to specified forcings, such as volcanic and solar cycle variability.
2) Intercomparisons of radiation codes, stratospheric transport diagnostics and winter polar ozone loss simulations.
3) Improved quantification of gravity wave parameterisation effects, sensitivities and uncertainties.
4) Better understanding of dynamical feedbacks and stratosphere-troposphere coupling.
5) Improved UTLS physics, especially aerosol and cloud microphysics.

One further aspect of understanding decadal-scale changes in stratospheric climate is the probabilistic nature of the problem. Large dynamic variability within the stratosphere (especially in winter and spring) makes the detailed evolution sensitive to initial conditions (as illustrated in Figure 3). This behaviour requires the use of ensemble runs and long control simulations to properly distinguish signal and (climate) noise for both past and future changes. It also mandates the use of multiple models, given current uncertainties in model formulations and dynamical feedbacks.

Figure 4 shows an example of chemistry-climate model predictions of Antarctic ozone changes to 2060 (from Austin *et al.*, 2003). Although the models are driven by the same imposed forcing changes, there are substantial differences in both time evolution and interannual variability among the models, and the reasons for these differences are poorly understood. Evaluating the reasons for such model sensitivities (in particular for coupled chemistry-climate models) is a crucial step forward for predicting future stratospheric changes.

Climate-Chemistry Interactions

Many agents force Earth's climate. Changes in these agents can perturb the climate significantly. Atmospheric chemistry plays a critical role in the perturbation of climate by controlling the magnitudes and distributions of a large number of important climate forcing agents. For example, abundances and distributions of water vapour and ozone in the stratosphere depend critically on the atmospheric chemistry. Similarly, the abundances of methane and tropospheric ozone also depend on atmospheric chemical processes.

According to IPCC (2001), methane and ozone are the second and third most important greenhouse gases that have increased due to anthropogenic activities since the industrial revolution. Changes in tropospheric composition alters the stratospheric composition via changes in the input to the stratosphere. Similarly, changes in the stratosphere affects the troposphere *via* changes in the input of UV radiation and also of ozone from the stratosphere (Figure 1).

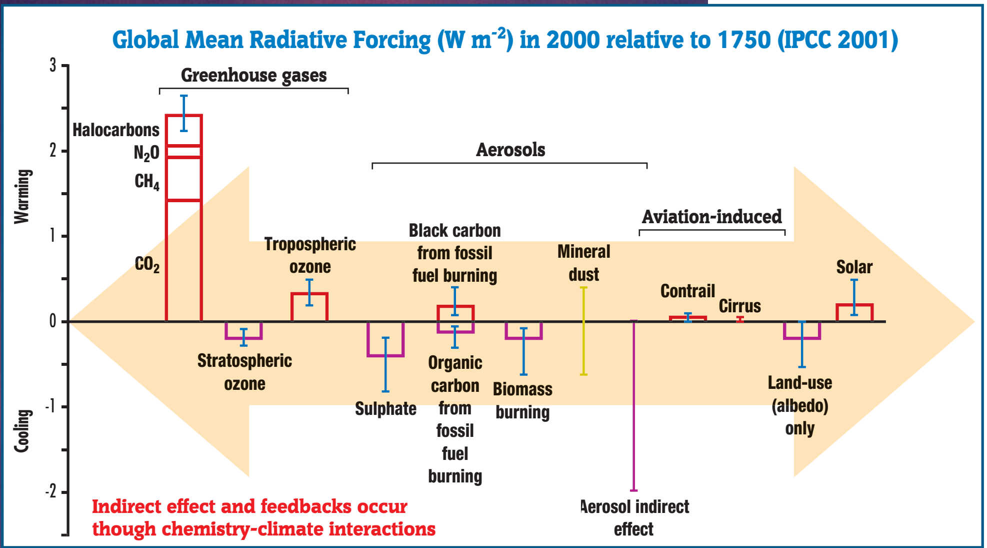

Figure 1. Coupling between forcings. The interconnections between various forcing emerge as indirect effects or feedbacks through various processes. Chemical processes are one of major pathways for the interconnections. The arrow indicates the coupling between forcing brought about by various pathways including chemical and dynamical processes. The changes in the radiative forcing, since industrialisation, shown in the figure are due to various emissions as noted by IPCC (2001). Understanding and quantifying these chemical and dynamical processes is at the heart of this theme. (From Ravishankara, 2004; adopted from IPCC 2001).

Aerosol is another climate forcing agent. Effects of anthropogenic aerosols on the climate has a potential to cancel the increased radiative forcing of greenhouse gases since industrialisation. Aerosols can perturb atmospheric radiation through a direct effect of scattering and absorption of radiation. Stratospheric aerosols greatly alter the chemistry in that region and lead to such spectacular changes as the Antarctic ozone hole, with consequences to climate. The effects of aerosols depend critically on their chemical composition and mixing state. Aerosols can also have an indirect effect *via* interaction with clouds (water, ice and cirrus clouds) by acting as Cloud Condensation Nuclei (CCN). Further, clouds can modify aerosols, their optical properties, their size distributions and their ability to act as CCN. The indirect effect, which is a strong function of chemical and physical properties of aerosols, can perturb clouds and even the hydrological cycle, two pivotal components of the climate system (Figure 2).

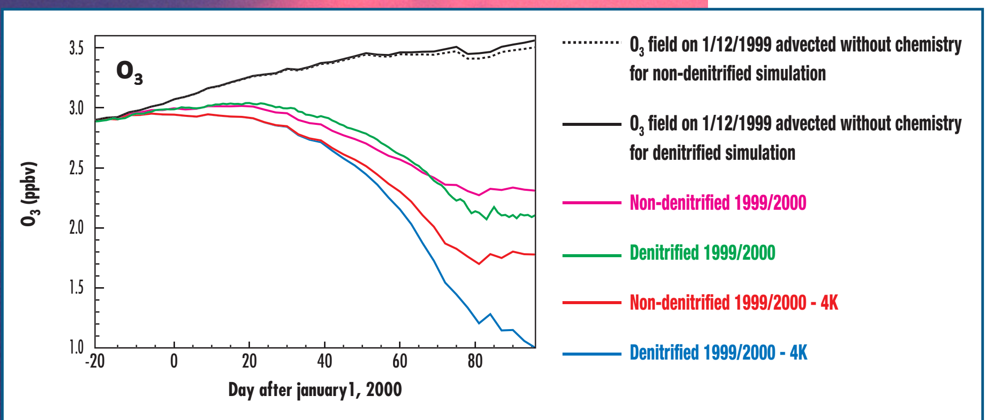

Figure 2. Change in climate alters composition. The figure shows the changes in ozone abundances as a function of time for different Arctic late-winter/early-spring conditions. These conditions, such as the PSC loading, are altered by the abundances of water vapour and nitric acid, as well as temperature. Future climate change will alter the stratospheric composition and temperature, which in turn will alter the ozone levels in this region. Understanding the impact of climate changes on composition and dynamics is another major emphasis of this theme. (From Chipperfield, 2004).

Changes in climate also affects the atmospheric chemistry, and hence the atmospheric composition, significantly. For example, a change in water vapour can perturb the oxidation capacity of the atmosphere. Changes in

Climate-Chemistry Interactions

stratospheric temperature and water vapour can alter the ozone abundance. They can for example alter the expected recovery of the ozone layer. A change in temperature or relative humidity can change the chemical and physical properties of aerosols. These interactions and feedback processes are complex and poorly understood. Therefore, a clear understanding of the processes acting in the climate system are essential. In case of short-lived species, because of their variability in space and time, even the current contributions to the climate forcings cannot be easily evaluated *via* their atmospheric observations alone but requires modeling of the relevant processes. Currently, there is a great deal of emphasis on the short-lived species because of the possibility of a quick "return" upon some policy action. Furthermore, these short-lived species are the "pollutants" that need to be addressed for human health and other concerns. Therefore, clear understanding of the processes that connect emissions (source, precursors) to abundances and the processes that connect the abundances to the climate forcings is essential for an accurate prediction of the future climate and an assessment of the impact of climate change and variations on the earth system (Figure 3).

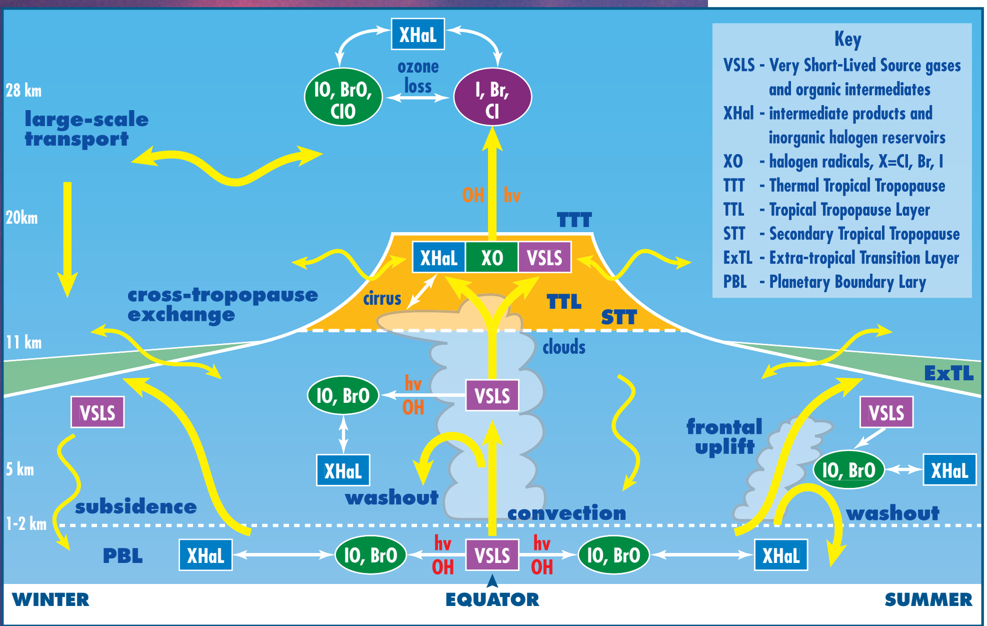

Figure 3. The key role of Tropical Tropopause Layer (TTL). This diagram depicts the various processes and regions involved in the chemistry and dynamics of TTL. Studying this region is an example of the kind of activities being undertaken in this theme. (From Cox and Haynes, 2003; from Scientific Assessment of Ozone Depletion:2002, WMO report No.47).

To assess the current state of our understanding on some of the key issues related to climate-chemistry interactions, a joint SPARC-IGAC (International Global Atmospheric Chemistry project, one of International Geosphere-Biosphere Program's (IGBP) core project) workshop was held in Giens, France, during 3-5 April 2003. The outcome of this meeting forms part of the plan for SPARC's theme on Climate-Chemistry Interactions. Examples of activities to be included in this theme are the quantification of ozone transport from the stratosphere to troposphere, chemistry and dynamics of the Tropical Tropopause Layer (TTL), and the chemical and dynamical processes that contribute to lower stratospheric ozone change.

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