SPARC

Stratospheric Processes And their Role in Climate

A project of the World Climate Research Programme

SPARC is a research project established in 1992 by the Joint Scientific Committee of the WCRP (World Climate Research Programme), who recognized the role played by the stratosphere in the climate system. While intense research was and continues to be carried out on stratospheric ozone depletion, there were important areas that were not receiving sufficient attention, notably those concerning the role of the stratosphere in a changing climate and the feedback of climate change on the stratosphere. The mandate of SPARC is to stimulate research in those areas that require its attention.

SPARC deals with the role of stratospheric dynamical, chemical and radiative processes in the global climate of the troposphere-stratosphere system. The key scientific issues has been identified as follows: the influence of the stratosphere on climate, the physics and chemistry associated with stratospheric ozone decreases, stratospheric variability and its monitoring, and UV irradiation changes.

THE SPARC PROJECT
(Stratospheric Processes And their Role in Climate)

The SPARC's activities have been structured within the three following themes::

- Stratospheric indicators of climate change,
- Stratospheric processes and their relation to climate, and
- Modelling stratospheric effects on climate.

❖ The SPARC Initiatives

Stratospheric Indicators of Climate Change

The stratosphere-troposphere system is changing due to both natural and anthropogenic factors, and the challenge is to understand the system sufficiently well to predict future scenarios. The test of this understanding lies in explaining past changes, but these changes need to be adequately quantified. To this end, SPARC has conducted three major assessments on temperature, ozone, and water vapour. These results have been used in the Scientific Assessment of Ozone Depletion 1999, and in the IPCC-Third Assessment Report 2001. Trends in dynamical activity would also be crucial to determine the overall climate effects of stratospheric changes.

Stratospheric Processes and their Relation to Climate

The dynamical, chemical and radiative processes which occur in the stratosphere all influence climate. An assessment of the current knowledge of these processes has shown that research is needed to better understand the following important topics:

- Upper troposphere/lower stratosphere processes,
- Gravity wave processes and the parameterisation of the effects of unresolved internal gravity waves in global numerical atmospheric models,
- Dynamical coupling between the stratosphere and the troposphere

Modelling Stratospheric Effects on Climate

In order to verify our current understanding of the role of the stratosphere in climate and to better assess future climate change, general circulation models including a detailed representation of the stratosphere are essential. SPARC through GRIPS (GCM-Reality Intercomparison Project for SPARC) has studied how well the current generation of these models simulates the current climate and its variability. In order to make a meaningful comparison with data, a comprehensive observed climatology of the means and variability of basic stratospheric parameters has been assembled.

❖ Co-ordination with other Programmes and Activities

SPARC maintains strong links with the other WCRP projects concerned with different aspects of the climate system, as well as with IGBP and IHDP projects, as the expert community on the atmosphere in the vicinity of the tropopause and above. Particularly noteworthy is the co-operation with IGAC (International Global Atmospheric Chemistry) project of the IGBP as some of the research interests of SPARC on the upper troposphere-lower stratosphere region overlap with those of IGAC.

SPARC FUTURE DEVELOPMENTS

The activity foreseen for SPARC in the future will aim to understand the observed stratospheric trends of temperature, ozone and water vapour, and solar effects, through modelling studies. These would be particularly aimed at elucidating UT/LS variability and its role in the overall climate system by building on the modelling work carried out in the stratospheric temperature trends study and GRIPS. New SPARC initiatives on stratospheric data assimilation and UV radiation penetration will be undertaken. Within this framework described in more detail below, the main priority for SPARC is to continue to facilitate research on stratospheric processes and their role in climate by providing a forum or umbrella for international co-operation and encouraging inter-disciplinary exchanges.

AN INTEGRATED RESEARCH FOCUS ON STRATOSPHERIC CLIMATE CHANGE

With the availability now of a sizeable body of information on the parameters of relevance describing stratospheric changes over the last two decades, it is appropriate to ask the following scientific questions:

- Are the different observed variations providing a consistent picture of stratospheric climate variations, including the possibility of a trend over the past two decades, upon which shorter time scale variations are superposed?
- Can model simulations, employing the known forcings that have acted upon the system over the past two decades, be used in conjunction with the observed data to reproduce the changes in the observed parameters, and thereby lead to identification of the causes of these changes?
- Do conditions and processes in the stratosphere have an effect on tropospheric climate down to the surface ?

The principal motivation arises from the fact that, over the period from the late 1970s to 2000, a number of changes, some dramatic, have been witnessed in the stratospheric climate: changes in ozone that are not the same from one decade to the next; aerosols from two volcanic eruptions perturbing the chemical and radiative budgets; water vapour data that indicate changes of various sorts depending on the times considered; pronounced temperature changes but with varying trends over the low and the middle and high latitudes, punctuated by sharp transient warmings in the aftermath of the volcanic eruptions; solar irradiance changes conforming to the 11-year cycle variations; variations in stratospheric circulation; and climate changes in the Arctic and Antarctic stratospheres especially during the winter-spring seasons.

Additional motivation arises from the fact that the coupling of the stratospheric and tropospheric climatic states is gathering increasing interest. The possibility that the tropospheric modes of variability may be related to stratospheric ones, and vice versa, is of considerable significance for climate change in the overall Earth system. Thus, a SPARC-centred focus on understanding stratospheric change could have a direct bearing on changes from the upper troposphere down to the surface.

The answers to these questions would also constitute useful inputs to the IPCC and WMO assessments. SPARC is uniquely placed to tackle the questions.

The SPARC Scientific Steering Group

Co-Chairs
M. Geller (USA), A. O'Neill (UK)

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P. Canziani (Argentina), C. Granier (France),
K. Hamilton (USA), D. Karoly (Australia),
T. Peter (Germany), A.R. Ravishankara (USA),
U. Schmidt (Germany), T. Shepherd (Canada)
S. Yoden (Japan), V. Yushkov (Russia)

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WMO/GAW : J. Miller, M. Proffitt (Switzerland)
COSPAR : J. Gille (USA)
SCOSTEP : R. Vincent (Australia)
IGAC : S. Penkett (UK)
NDSC: M. Kurylo (USA)

The SPARC Data Center

The SPARC Data Center was opened in June 1999 at SUNY, Stony Brook (USA) and is archiving the SPARC-relevant data to facilitate data exchanges between participating scientists.
Manager: P. Udelhofen
http://www.sparc.sunysb.edu/

The SPARC Office

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The SPARC Publications (available on request from the SPARC Office)

SPARC Newsletter
The SPARC Office publishes a newsletter every six months containing reports on SPARC and related activities, and a calendar of meetings

SPARC Reports
- SPARC Science Plan, WCRP Report N°83, WMO/TD-N°582 (December 1993)
- SPARC Implementation Plan, WCRP Report N°105, WMO/TD-N°914 (June 1998)
- SPARC Report N°1: SPARC-IOC Assessment of Trends in the Vertical Distribution of Ozone, WMO Report N°43 (May 1998)
- SPARC Report N°2: SPARC Assessment of Upper Tropospheric and Stratospheric Water Vapour, WCRP Report N°113,WMO/TD-N°1043 (December 2000)
- SPARC Report N°3: Assessment of Stratospheric Temperature Trends (under preparation)
- SPARC Report N°4: Intercomparison of Middle Atmosphere Climatologies (under preparation)

The SPARC General Assemblies

- The 1st SPARC General Assembly, Melbourne, Australia, 2-6 December 1996
- The 2nd SPARC General Assembly, Mar del Plata, Argentina, 6-10 November 2000

Prepared by The SPARC Office

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STRATOSPHERIC PROCESSES AND THEIR RELATION TO CLIMATE

UPPER TROPOSPHERIC AND LOWER STRATOSPHERIC PROCESSES

Co-Chairs: A.R. Ravishankara (USA) and T. Shepherd (Canada)

Objectives

It is in the upper troposphere and lower stratosphere (UT/LS) that the role of chemistry in climate comes into greatest prominence, and SPARC expects to play a key role in developing the science in this area through carefully targeted workshops and review papers.

Scientific motivation

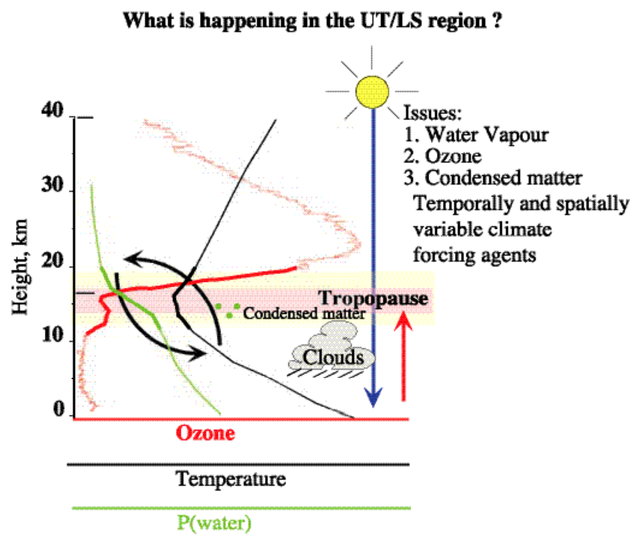
The UT/LS is a critical region for climatesensitivity. Chemical and radiative timescales are relatively long, which means that dynamical forcings (chemical transport and adiabatic warming or cooling) play a particularly strong role in controlling the structure of the region. But equally, this means that chemical concentrations and temperature are highly sensitive to changes in rates of chemical and radiative processes. Transport of ozone through the UT/LS region plays a key role in determining chemical abundances in the troposphere as a whole. Low temperatures also imply the importance of condensed matter (liquid and solid clouds and aerosols) in this region, and, therefore, of heterogeneous and multiphase chemical reactions. Finally, the tropical tropopause controls the amount of stratospheric water vapour through the freeze drying mechanism.

Activity within SPARC

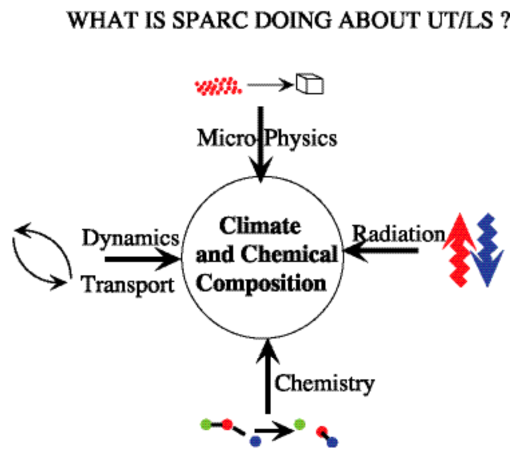
Given the need for an interdisciplinary understanding of climate science in the UT/LS region, SPARC has brought together scientists with different expertise (chemistry, microphysics, radiation, dynamics, transport) and methodology (theory, modelling, measurement, laboratory studies). Special workshops organized in collaboration with IGAC have focused on particular gaps in understanding and led to key papers reducing the uncertainty of photochemistry of ozone and rates of peroxy radical reactions that affect ozone in the UT/LS region. A recent workshop in Bad Tölz, Germany led to a new understanding of the UT/LS region as a transition region between the troposphere and stratosphere. A review paper is expected to result. A recent workshop on nitrogen oxides in the atmosphere and their partitioning in the UT/LS region was held in Heidelberg, Germany. The next workshop on the current state of gas phase reactions in the UT/LS region is scheduled for July 22-27, 2001 in Breckenridge, Colorado.

Future Plans

The goal is to continue to bring together the tropospheric and stratospheric climate modelling communities, as well as the radiative-dynamical and chemical communities.



The stratosphere is characterized by high ozone and low water vapour, and the troposphere by low ozone and high water vapour. The transition between the two regions occurs over a layer of finite thickness corresponding to a minimum in temperature, which may be called the tropopause layer. Climate chemistry is highly dependent on the OH radical, whose production is proportional to the product of ozone and water vapour and so is large in the UT/LS region. [Courtesy of A.R. Ravishankara.]



The UT/LS region involves a complex interplay between dynamics, transport, radiation, chemistry, and microphysics. Dynamics and radiation lead to the low temperatures that form condensed matter through microphysical processes; microphysics in turn affects chemistry, as do temperatures, solar radiation, and transport of chemical species; chemistry in turn feeds back onto climate through radiation. [Courtesy of A.R. Ravishankara.]

STRATOSPHERIC PROCESSES AND THEIR RELATION TO CLIMATE

GRAVITY WAVE PROCESSES AND PARAMETERIZATION

Co-chairs: K. Hamilton (USA) and R. Vincent (Australia)

The Gravity Wave Processes and Parameterisation (GWPP) initiative of SPARC is coordinating international projects aimed at understanding the internal gravity wave field in the stratosphere and its interaction with the large-scale circulation and climate. Thus far, most of the effort has gone into projects designed to improve the empirical database for characterizing and understanding the gravity wave field.

Activities

Routine balloon soundings of wind and temperature contain valuable information about the gravity wave field, although much of this information is lost when these data are archived only at the usual mandatory and significant levels, as is the standard practice in most countries. Modern radiosonde systems actually record data at quite high vertical resolution (~100 m). The SPARC GWPP initiative has coordinated the accumulation and analysis of these "raw" high-resolution data. This has been done primarily by involving scientists from a number of countries who have interacted with their own national meteorological services to obtain, save and analyse the high resolution data. Routine data have now been obtained from the meteorological services of 12 countries (Australia, Canada, Finland, France, Germany, Iceland, Japan, Korea, New Zealand, Switzerland, UK and USA). The data provided by the US include some from Caribbean locations as well as from US territories in the western Pacific. Limited amounts of temperature data from the special SHADOZ campaign of ozonesonde profiles have also been obtained for several stations, including some in tropical Africa and South America. The data are now being analysed to characterize aspects of the wave climatology in the lower stratosphere. Another project being coordinated by the SPARC GWPP initiative (in collaboration with SCOSTEP) is an international field experiment to be held in late 2001 in the Australian-Indonesian region. This Darwin Area Wave Experiment (DAWEX) will study the waves in the stratosphere and higher altitudes in relation to strong diurnal convection observed just north of Darwin, Australia.

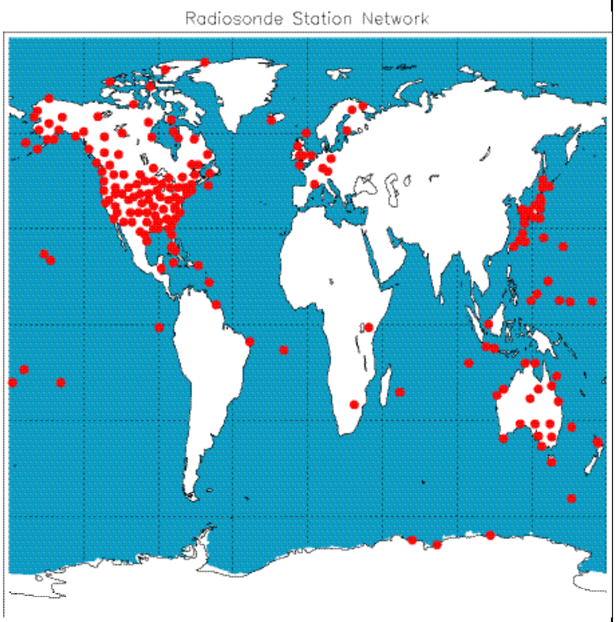
Future Plans

The SPARC GWPP initiative in the future will:

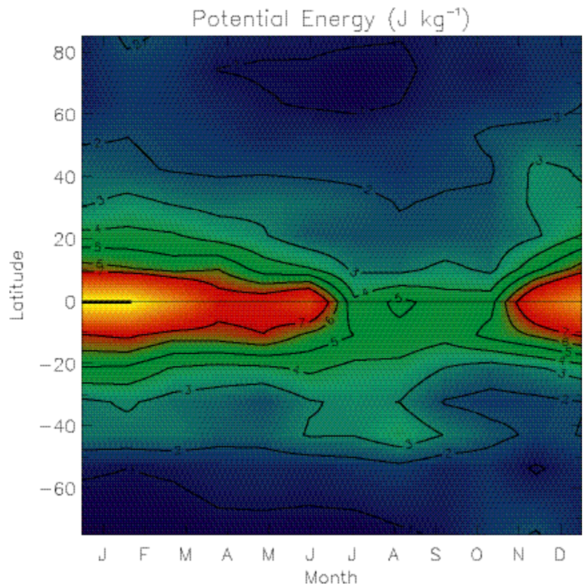
· Coordinate the continuing analysis of the global high-resolution data set. It is hoped that most of the high-resolution soundings used in this project will be archived at the SPARC Data Center,

· Build on the DAWEX experience to organize an even more ambitious field experiment in 2003 or later. This Effects of Tropical Convection Experiment (ETCE) will examine the role of deep convection on the dynamical, chemical and microphysical aspects of the tropical upper troposphere and stratosphere.

· Coordinate modelling work designed to formulate practical parameterisations of gravity wave effects in global climate models.



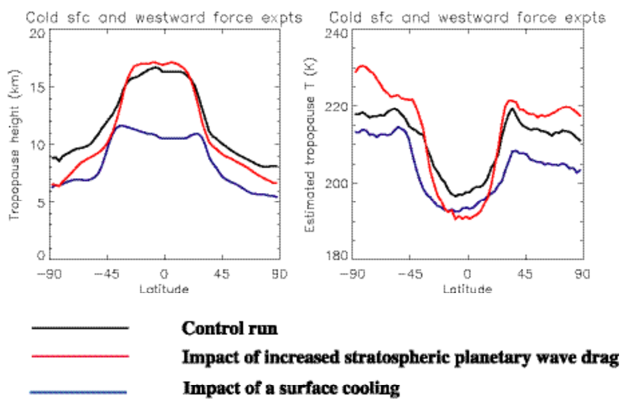
The locations of all the stations from which there have been some high-resolution wind or temperature data contributed to the SPARC GWPP initiative.



Meridional and seasonal dependence of the potential energy associated with gravity waves in the lower stratosphere determined from the high-resolution data acquired and analysed by the scientists in the SPARC GWPP initiative. The contour labels are in J/kg.

SPECIFIC TOPICS ON STRATOSPHERIC PROCESSES AND THEIR RELATION TO CLIMATE

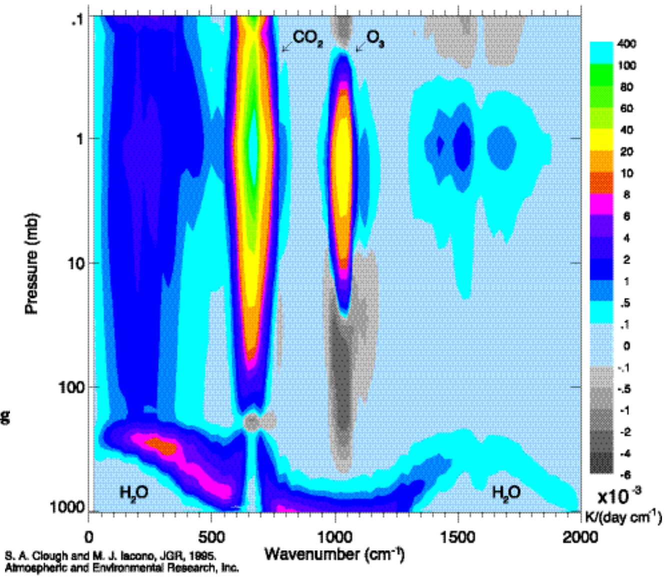
Sensitivity of the height and temperature of the tropopause



Reference: Thuburn and Craig (J. Atmos. Sci., 1997, 2000)

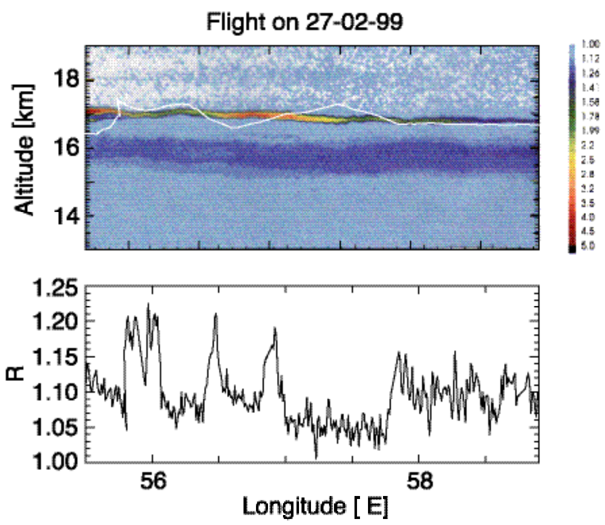
Sensitivity of the height and temperature of the tropopause to idealized changes in a general circulation model. The dark curves show the control case. The red curves show the impact of increased stratospheric planetary wave drag, which acts to raise and cool the tropopause in the tropics and to lower and warm it in the extratropics. The blue curves show the impact of a surface cooling, which acts to lower and cool the tropopause everywhere. The different character of the response to dynamical and radiative changes is a useful fingerprint for attribution of observed changes. [Courtesy of J. Thuburn, Reading Univ.]

Spectral Cooling Rates for the Mid-Latitude Summer Atmosphere Including Water Vapor, Carbon Dioxide, and Ozone



Thermal infrared cooling rates for H_2O, CO_2 (355 ppm), and O_3 as a function of wavenumber and pressure for midlatitude summer conditions. Colour scale x 10^{-3} is in units of K d^{-1} $(cm^{-1})^{-1}$. The figure demonstrates the special nature of the UT/LS region in the atmosphere's radiative balance. The band centred at 667 cm^{-1} is dominated by CO_2, and exhibits strong stratospheric cooling (explaining why a CO_2 increase leads to stratospheric cooling) but a local warming at the tropopause. The band around 1043 cm^{-1} is dominated by O_3 and exhibits warming throughout the lower stratosphere. Water vapour makes a strong contribution to upper tropospheric cooling near 300 cm^{-1}, although its effects are moderated by CO_2. In the UT/LS region the thermal infrared warming and cooling effects tend to largely cancel, implying a strong radiative sensitivity to greenhouse gas changes. [Courtesy of M. Iacono, AER.]

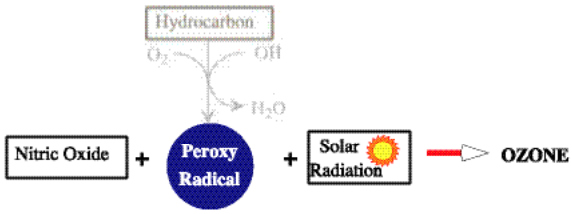
Ultrathin tropical tropopause cloud (UTTC) at 17 km altitude



Ultrathin tropical tropopause cloud at 10°S and 17 km altitude, located about 300 m below the tropical tropopause, detected through backscatter ratio R at 1064 nm measured by OLEX on the German research aircraft Falcon during the APE-THESEO experiment in February 1999 (top panel). *In situ* measurements of backscatter ratio at 532 nm measured by the aerosol sonde MAS on board the Russian high-altitude research aircraft Geophysica, whose flight track is indicated by the white line in the top panel, are shown in the bottom panel. The cloud is only about 200-300 m thick and has an optical density of about 10^{-4}, 300 times lower than that required for visibility from the ground. The low temperatures of the tropical tropopause region lead to the formation of cirrus clouds, which might be important for chemistry via heterogeneous reactions and possibly also for scavenging (e.g. of HNO_3). They also provide useful constraints on dehydration mechanisms. These results suggest that subvisible cirrus clouds may be far more prevalent than has previously been imagined. [Courtesy of DLR/Oberpfaffenhofen, CNR/Rome, and the APE-THESEO community.]

SPARC/IGAC ACTIVITY ON STRATOSPHERIC PROCESSES AND THEIR RELATION TO CLIMATE

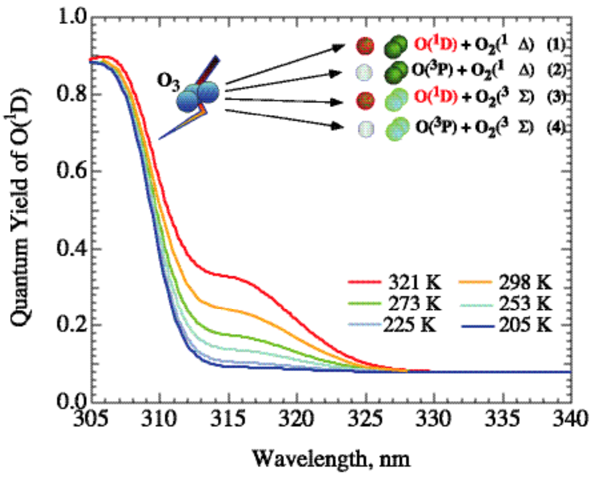
The chemistry of peroxy radicals - a SPARC/IGAC activity



Ozone is a key trace constituent in the troposphere because it is a greenhouse gas, initiates chemistry that controls greenhouse gases, and is toxic to the biological system. The chemistry by which ozone is photochemically produced in the troposphere is inherently different from the chemistry that pervades ozone generation in the stratosphere. Peroxy radicals, produced by the oxidation of hydrocarbons in the presence of oxygen, play a central role in the photochemical production of ozone in the troposphere. Quantification of the ozone production rate and the abundance of ozone in the troposphere requires accurate information about the mechanism of chemical reactions of the peroxy radical and the rates of their processes in the atmosphere. [Courtesy of A.R. Ravishankara.]

Reference: G. S. Tyndall, *et al*., The Atmospheric Chemistry of Small Organic Peroxy Radicals, J. Geophys. Res., in press, 2001.

Photochemistry of O_3 - a SPARC/IGAC activity



The photochemical decomposition of ozone to yield $O(^1D)$, the first electronically excited state of the oxygen atom, is a key process in the troposphere and the stratosphere. The reaction of $O(^1D)$ with H_2O is the major sources of OH radicals, which are the essential species for the initiation of chemistry in the atmosphere. The reaction of $O(^1D)$ with N_2O is the major source of nitrogen oxides in the stratosphere. Therefore, knowing how much $O(^1D)$ is produced in the photodissociation of ozone is essential. A panel of experts was collected as a part of the SPARC/IGAC joint activity to evaluate the quantum yield for $O(^1D)$, i.e., the number of $O(^1D)$ atoms produced for a photon absorbed by ozone, which led to a revision of the previous picture of ozone photolysis. The final obtained result shows that the quantum yield varies as a function of wavelength and temperature. [Courtesy of A.R. Ravishankara.]

Reference: Y. Matsumi, *et al*., Quantum yields for production of $O(^1D)$ in the ultraviolet photolysis of ozone : Recommendation based on evaluation of laboratory data, J. Geophys. Res., submitted, 2001.

INDICATORS OF CLIMATE CHANGE

STRATOSPHERIC TEMPERATURE TRENDS

Chair: V. Ramaswamy (USA)

Objectives

The objectives are to

· Inter-compare and assess the stratospheric temperature variations and changes, available from observational datasets, and

· Use model simulations and measurements to understand the causes of the observed changes, in particular the role of natural and anthropogenic causes.

Key findings

The first phase of the assessment has been completed (see Ramaswamy *et al.*, Reviews of Geophysics). The results have also been reported in the recently released WMO (1999) and IPCC (2001) scientific assessments.

Inter-comparison of the observations over the 1979-1994 period reveals an annual-mean cooling of the global lower stratosphere (Figure 1), with the trends being statistically significant mainly in the midlatitudes of the Northern Hemisphere. There is a remarkable coherence amongst the various observational datasets. The global-mean, annual-mean cooling is estimated from the various datasets to be about 0.6 K/decade. Over the longer period 1966-1994, the global-mean, annual-mean cooling is estimated to be about 0.35 K/decade. Substantial cooling (~3-4 K/decade) is observed in the lower polar stratosphere during late winter/spring in both hemispheres. However, in the Arctic, the dynamical variability is large, and this introduces difficulties in establishing a statistical significance of the trends there.

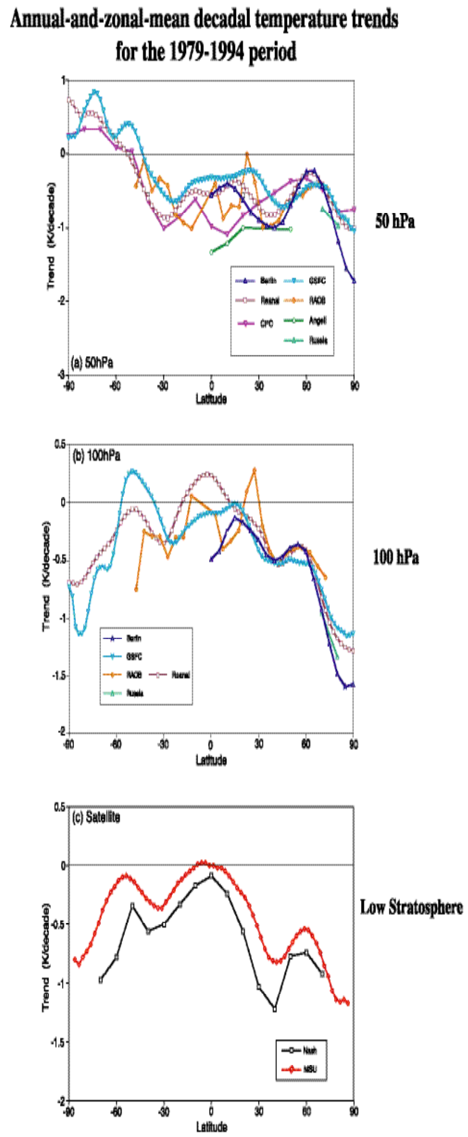


Figure 1: Anuual-and-zonal-mean decadal temperature trends for the 1979-1994 period, as obtained from different datasets.

The vertical profile of the annual-mean stratosphere change observed in the Northern Hemisphere midlatitudes (45°N) is quite robust among the different observations (Figure 2). The mean trend consists of a ~0.75K/ decade cooling in the 20-35 km range, with the cooling trend increasing with height above. Model simulations indicate that changes in trace gas concentrations are major contributors to the observed cooling of the global-mean stratosphere. The trace gas changes identified are:

· Increases in the well-mixed greenhouse gases (CO_2, CH_4, N_2O and CFCs),

· Depletion of stratospheric ozone (see Figure 3), and

· Increases in water vapour (see Figure 4).

The cooling trend of the global stratosphere has been punctuated by transient warmings (1-2 years) following the El Chichon (1982) and Mt Pinatubo (1991) volcanic eruptions, when temporary enhancementsin stratospheric aerosol concentrations induced a radiative heating.

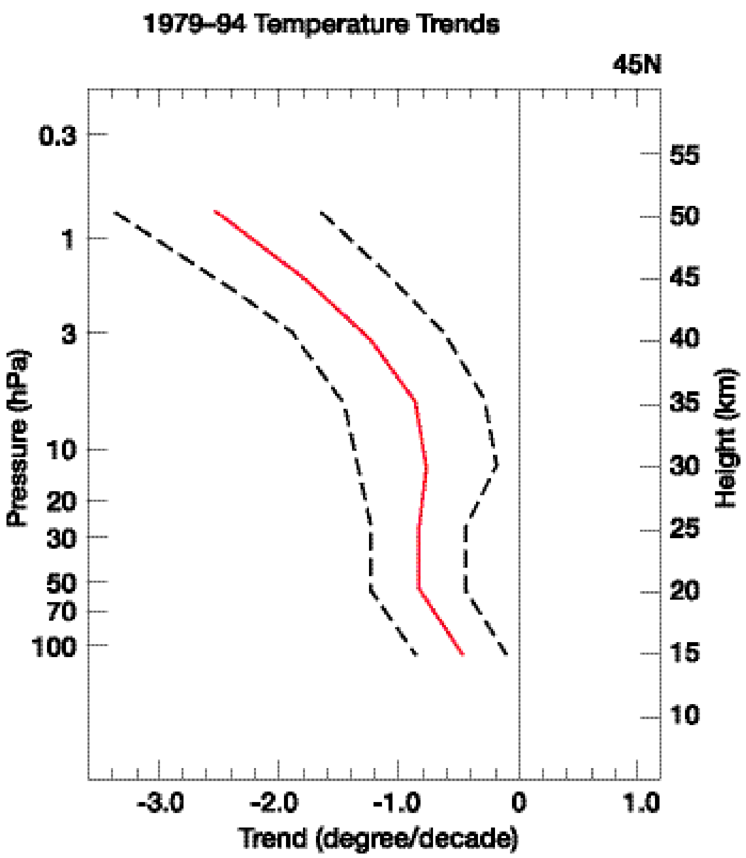


Figure 2: Mean vertical profile of the temperature trend over the 1979-1994 period in the stratosphere at 45°N, as compiled using radiosonde, satellite and analysed datasets. The solid red line indicates the trend estimate while the dashed lines denote the uncertainty at the 2-σ level.

Future Plans

Further analyses of observations and model simulations will continue to advance the understanding of the variation and trends in the stratospheric thermal state.

Activities planned include:

· Ensuring continuity, updating and consistency checks on the observed temperature time series to the end of the last decade.

· Extension of the analyses to cover the observed seasonal trends.

· Assessing the temperature variations on finer time and space scales e.g., interannual variations, zonal-mean trends.

· Ascertaining causes of the observed features on the different space-time scales: trace gases, aerosols, SST variations, solar cycle, quasi-biennial oscillation and dynamical variations.

The plans call for providing inputs into the next scientific assessment of stratospheric ozone (WMO, 2002), which is already underway.

Reference: V. Ramaswamy, M-L. Chanin, *et al.*, Stratospheric temperature trends: Observations and model simulations, Reviews of Geophysics, 39, 71-122, 2001.

INDICATORS OF CLIMATE CHANGE

UNDERSTANDING OZONE TRENDS

Chair: N. Harris (UK)

Objectives

The objective is to improve the understanding of the past changes in ozone. This work involves assessing the quality of existing data records and understanding past ozone trends in the light of the suggested mechanisms.

Achievements

On-going assessment of the quality of ozone measurements by ground-based and satellite instruments is coordinated by the World Meteorological Organisation's Global Atmospheric Watch (WMO-GAW) programme. The main activity of the SPARC Ozone Trend working group has been to enhance the routine quality assessment through the organisation of the international 'Assessment of Trends in the Vertical Distribution of Ozone' in conjunction with the International Ozone commission and WMO-GAW. This was published as SPARC Report N°1. The main conclusion is that the trends derived from the measurements made by a number of techniques above 20 km altitude are consistent (see Figure 3).

Future Plans

There have been an increasing number of studies investigating how decadal changes in dynamics affect the observed long-term ozone trends. Downward trends in mid-latitude ozone have been partly caused by changes in atmospheric dynamics. Changes in regional dynamic phenomena over the last 30 years such as the Arctic Oscillation are linked with reduced ozone amounts over much of Europe. Accurate quantification of the role of dynamics, vis à vis, that of chemical processes, remains unresolved.

A new joint SPARC/IOC initiative to assess their relative importance started with a workshop in March 2001 organised in cooperation with the WMO-UNEP assessment co-chairs. In conjunction with this, continuing discussions are being held within SPARC to see how progress can be made toward a comprehensive description of past stratospheric changes.

Reference: SPARC Report N°1, Assessment of Trends in Vertical Distribution of Ozone, May 1998.

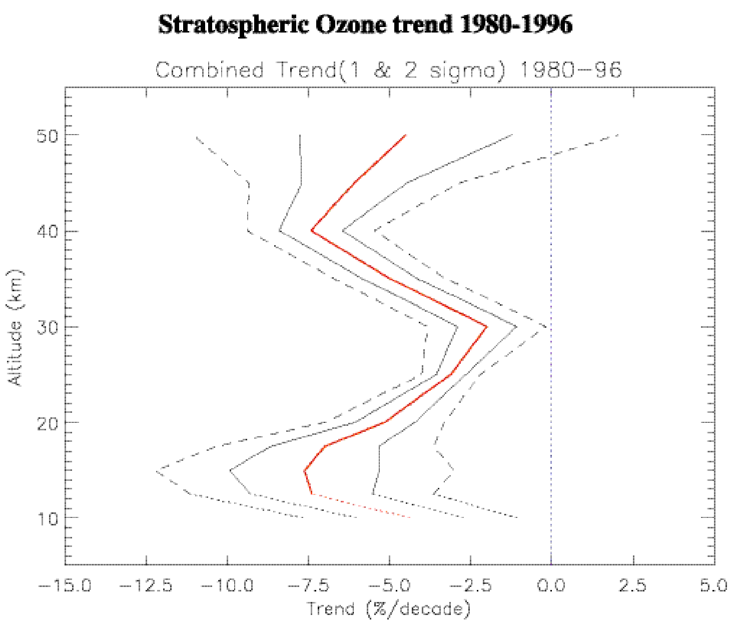


Figure 3: Mean trend in the vertical distribution of ozone over northern mid-latitudes for 1980-1996 (heavy solid line) calculated using the trends derived from SAGE I-II, ozonesondes, SBUV and Umkehr measurements. Combined uncertainties are shown as 1σ (light solid lines) and 2σ (dashed lines). The combined trends and uncertainties are extended down to 10 km as shown by the light dotted lines but the results below 15 km should be viewed with caution.

INDICATORS OF CLIMATE CHANGE

ASSESSMENT OF UPPER TROPOSPHERIC AND STRATOSPHERIC WATER VAPOUR

Co-chairs: D. Kley (Germany) and J.M. Russell III (USA)

Objectives

The overall goal was to provide an assessment of the state of knowledge of the water vapour distribution, variability and long-term changes. Accurate knowledge of the water vapour concentration in the atmosphere and its changes is critical for understanding and predicting long-term temperature changes both at the surface and throughout the atmosphere.

Activity

A large number of tropospheric and stratospheric water vapour measurements have been reported over the past 50 years. Instrumentation has evolved from *in situ* to satellite instrumentation but only a small number of measurements have records longer than 10 years. The objective was to gather the largest possible number of independent water vapour observations in the lower stratosphere and upper troposphere, to validate accuracy and uncertainty of the data sets, to look for consistencies between the data sets and to reach conclusions about observed changes.

Key findings

Taken together, ground-based, balloon, aircraft, and satellite measurements reveal a global stratospheric water vapour increase of ~2 parts per million by volume (ppmv) over the past 45 years or ~0.05 ppmv per year. This increase of over 75% has significant climate implications. Modeling studies by scientists from the University of Reading (UK) show that since 1980 the stratospheric water vapour increase has produced a surface temperature rise of about one half of that due to the increase of carbon dioxide alone. The reasons for this water vapour increase are unknown. One possible contributing factor is methane that has increased in the atmosphere since the 1950's, but this can only account for at most one half of the increase in stratospheric water vapour mixing ratio over this time period.

Upper tropospheric humidity (UTH), i.e. ~9 to 16 km above the earth's surface, has been measured by several consecutive generations of instruments on operational satellites. The satellite record shows a 2% increase over the last 20 years in the equatorial region. However, the uncertainty in this determination is too large to allow a clear conclusion as to whether this is a result of climate change. The combined uncertainty of the tropospheric relative humidity and temperature data sets is too large to allow definite conclusions to be drawn about long-term changes of upper tropospheric water vapour mixing ratio.

Future plans

Since recent publications show that the long-term change of upper tropospheric temperature and tropospheric cold-point temperature are negative, the increase of the stratospheric water vapour mixing ratio is incompatible with the simple Brewer freeze drying mechanism. The trend minimum near 100 hPa also awaits analysis and explanation. Future research is needed both in chemistry and dynamics to attempt to explain these observations. The water vapour data used in the SPARC study are available upon request at the SPARC Data Center (http://www.sparc.sunysb.edu).

Reference: SPARC Report N°2, SPARC Assessment of Upper Tropospheric and Stratospheric Water Vapour, December 2000.

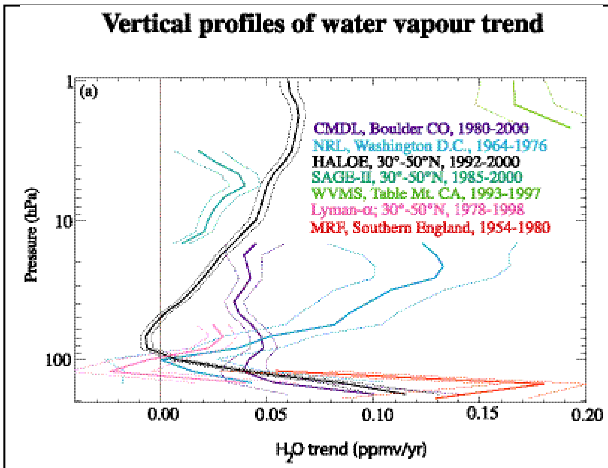


Figure 4: Vertical profiles of the estimated linear trends for data sets from *in-situ*, satellite and ground-based observations between 30º-50ºN. Colors and valid years are annotated on the inset. [Courtesy of K. Rosenlof.]

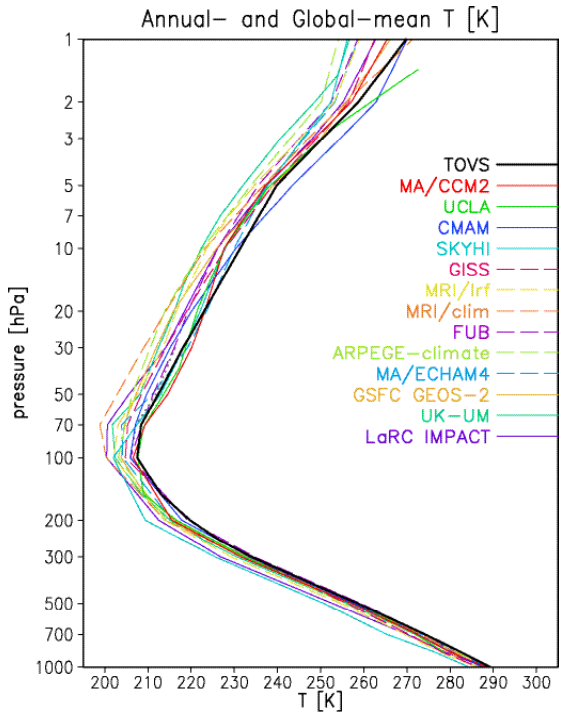
MODELLING STRATOSPHERIC EFFECTS ON CLIMATE

INTERCOMPARISON OF MIDDLE ATMOSPHERE CLIMATE MODELS: THE GRIPS (GCM-Reality Intercomparison Project for SPARC) INITIATIVE

Co-chairs: S. Pawson (USA) and K. Kodera (Japan)

Objectives

GRIPS aims to understand how well we can represent the coupled troposphere-middle atmosphere system in middle atmosphere climate models. These models are general circulation models that extend from the surface to the stratosphere or beyond, which attempt to represent all processes that impact the atmospheric circulation and structure. GRIPS has three concurrent 'phases' each of which poses specific questions: Phase 1 asks how well the different models perform; Phase 2 examines some of the model components in detail; Phase 3 compares the response of the models to perturbations in the physical forcing mechanisms (such as volcanic aerosol loading, solar variability, and ozone changes). A very important question, motivating the Phase-3 studies, is how well can models represent climate variability over the past two decades?



Global, annual mean temperature from the models and observations (black line). (S. Pawson *et al*., B.A.M.S., 2000)

Key findings

Many of the activities in Phase 1 of GRIPS are complete or are nearing completion. It was shown that most models have a cold bias at all levels (Figure) and this has prompted an investigation of the performance of radiation schemes. The models display considerable differences in their ability to simulate the quasi-stationary wave structure in the troposphere and stratosphere. To understand the interannual variability, at least 20 years of integration are required, which is just becoming possible for many of the participating models. Travelling waves in the tropics differ vastly between the models, a result partly due to different representation of convective processes and partly due to model formulation. The models show very different spectra of resolved gravity waves, which have an important impact on what we attempt to parameterise.

Ongoing activities

Phase 2 research is examining the radiation schemes and the representation of gravity wave drag in the models. Off-line comparisons using identical temperature and trace gas fields reveal large differences between the radiation schemes presently used. Tests of gravity wave drag are beginning. Phase 3 studies the impacts of different forcing anomalies. Volcanic aerosols in the tropical lower stratosphere lead to perturbations to the radiative balance and induce a response in the extratropical stratosphere and troposphere in winter, an effect which is captured in some models. Changes in solar incoming radiation on 11-year timescales, coupled with their induced ozone changes, lead to a response in all models tested, but this can differ between the models.

Achievements

Two papers have appeared in the refereed literature (Koshyk *et al*, and Pawson *et al*) and several others are planned. Papers have been presented at international conferences. One of the most important achievements of GRIPS has been the success of the annual workshops, which provide a much-needed forum for informal discussion of the latest results and uncertainties of present day models.

Future plans

The main plan is to complete what we have started: Phase 1 should be wrapped up by 2002 and the scientifically relevant impact studies of Phase 3 should be studied in much more detail. To date, GRIPS has given little attention to aspects of chemistry, which will be an avenue to explore as our understanding of dynamics and physics becomes more thorough.

References: J.N. Koshyk, *et al*., The kinetic energy spectrum of horizontal motions in middle atmosphere models, J. Geophys. Res., 104, 27177-27190, 1999.

S. Pawson, K. Kodera, *et al*., The GCM-reality inter-comparison project for SPARC (GRIPS): scientific issues and initial results, B.A.M.S., 81 (4), April 2000.

MODELLING STRATOSPHERIC EFFECTS ON CLIMATE

STRATOSPHERE REFERENCE CLIMATOLOGY PROJECT

Chair: W. Randel (USA)

Objectives

In order to make a meaningful comparison of models with data, a comprehensive observed climatology of the means and variability of basic stratospheric parameters has been assembled. This work was needed for GRIPS, as well as for a number of other SPARC initiatives.

Ongoing activities

In the last few years, the SPARC Climatology group has compiled a series of monthly global climatologies of temperature, zonal winds, and various atmospheric trace constituents (N_2O, O, CH_4, H_2O, O_3, NO_2, HNO_3, etc.) which have been assembled from NCEP, UARS and other data. Monthly and daily stratospheric circulation statistics have been inferred from available stratospheric analyses or reanalyses. Other data compiled include upper-level radiosonde winds as an indicator of the phase of the QBO and statistics on tropopause height. These data sets are now accessible from the SPARC Data Centre.

Future plans

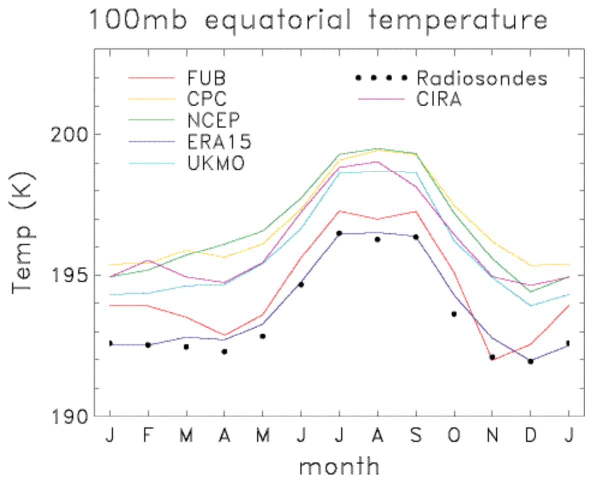
A SPARC report describing the data sets, comparing stratospheric circulation statistics, and quantifying uncertainties and interannual variability will be published in 2001. Plans for the near future are:

•to include the rocketsonde data in the data intercomparisons,

• to identify the biases in each data set,

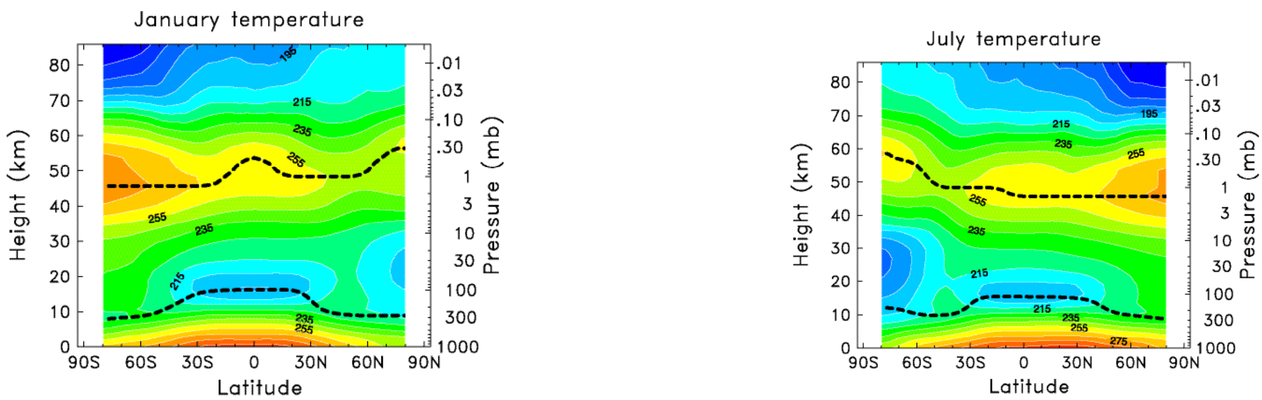
•to identify the quantities which have high uncertainty and,

•to discuss the strategies for comparison with models.



Comparison of the 100 mb zonal mean temperature at the equator obtained from 6 different stratospheric climatologies, together with a radiosonde climatology. It is to be noted that although each analysis has a reasonable annual cycle amplitude, many analyses have a mean warm bias of ~ 2-3 K (compared to the radiosonde measurements). This 100 mb tropical temperature is a particularly important quantity to be able to simulate properly in a model, if the model is to properly account for dehydration of air entering the stratosphere. [Radiosonde data are provided courtesy of D. Seidel.]

Reference: SPARC Report N°4, Intercomparison of Middle Atmosphere climatologies, to be published in 2001.



Climatological zonal mean temperature fields for January and July, derived from a combination of different UARS data sets. The dark dashed lines are the tropopause and stratopause. [Courtesy of W. Randel.]