SPARC contributions to implementation of the WCRP (COPES) Strategic Framework

1. Major challenges

1.1 Present and near future overarching themes

SPARC is organized under three interlinked overarching themes which serve to consolidate its contributions to the WCRP Strategic Framework. Each of the themes addresses some broad questions which aim to identify primary foci for SPARC activities for the present and future:

(a) 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?

(b) 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?

(c) Stratosphere-troposphere coupling

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

To address the scientific questions of the three SPARC themes, underpinning activities have been, and continue to be, developed within general topic areas such as modelling, process studies and supporting data analysis, and archiving. In many cases, facilitating these activities has led to the setting-up of targeted working groups, with specific bite-sized objectives. This modus operandi has worked well for SPARC in the past and it is expected to work in the future.

1.2 SPARC overarching activities that should be maintained beyond 2013

(a) Chemistry-Climate Model Validation Activity (CCMVal)

To coordinate the ongoing contribution of stratosphere-resolving Chemistry-Climate and Earth System Models to the WMO/UNEP Ozone Assessment and IPCC Assessment Reports, and push ahead the quantification of model uncertainties towards improving projections of stratospheric ozone and chemistry climate connections through the 21st century.

(b) ***Assessments of key uncertainties in measurements***
To provide expertise and resources in order to keep track of latent or scrutinize emerging uncertainties in measurements relevant for the stratosphere and upper troposphere (as has in the past led to SPARC Reports, and recently to the laboratory-based AquaVIT hygrometer intercomparison).

(c) ***Linking various scientific communities***
To facilitate communication between the measurement and modeling communities, providing guidance to the measurement community on modeling needs and in turn providing observational databases from the measurement community for use by modelers; furthermore to provide a channel of communication between the stratospheric research community and the climate modeling (as in IPCC) community; finally, to support the increased coordination of and synergy between various organizations such as WCRP, IGBP, WCP, etc.

While these three topics define overarching activities of indisputable importance, there are currently a large number of specialized projects through which the themes and overarching activities are realized and which are described in some more detail below. Needless to say that attempts to sharpen strategic focus in the future WCRP and SPARC might require shifts in emphasis and thus also to de-emphasize projects that are presently in the focus.

At the same time it should not be underestimated that a lot of the success of SPARC to date is based on the blossoming richness of the many small projects based on voluntary work by many scientist and interacting with each other in a bottom-up self-organizing manner. The ability of SPARC to foster such small-scale projects will also in the future be a major cornerstone for continued success of SPARC science.

2. Detailed Science Objectives

2.1 Detailed Objectives to 2013

(a) *Chemistry and Climate*

- A major current and ongoing focus of SPARC is quantifying the evolution of stratospheric ozone and its interaction with climate change.
- SPARC, in association with IGAC leads the WCRP-IGBP cross-cutting activity on atmospheric chemistry and climate (AC&C) .
- The SPARC Chemistry Climate Model Validation Activity (CCMVal) is the main underpinning modeling support for AC&C. CCMVal provides strategic modeling support to the WMO/UNEP Ozone Assessment process that is mandated under the Montreal Protocol.
- The SPARC Initiative on Halogen Chemistry will clarify recent laboratory results concerning the role of key interactions in ozone depletion and provide direct input to the 2010 WMO/UNEP Ozone Assessment
- Ongoing activities within the scope of the SPARC Chemistry and Climate theme contribute to the IPCC Assessment process. Among the substantive contributions to the IPCC AR5 will be comprehensive ozone data sets and projections for use in climate predictions.

(b) Detection, attribution and prediction of stratospheric changes

- Quantification of Stratospheric temperature changes is an ongoing current SPARC activity. The activity has succeeded in identifying sources of uncertainty in both the radiosonde and satellite records of stratospheric temperatures. This has enabled quantification of temperature trends that are consistent across data sets.
- The recently initiated WAVAS-2 activity will update the SPARC Water Vapour Assessment to include more recent measurements, and provide a consolidated evaluation of current understanding concerning processes affecting stratospheric water vapour and its evolution.
- Documenting the state of the polar vortices during the IPY period is the central goal of SPARC-IPY. Activities contributing to this include
  - (i) collection, archiving, and intercomparisoin of objective analysis products from the major research and prediction centers that are able to produce stratospheric analyses during the IPY period .
  - (ii) collection, analysis, and intercomparison of ground-based lidar observations from a network of Arctic observing stations during the IPY period.
- Determining the magnitude of natural variability of key variables in the stratosphere is critical to detection and attribution of long-term change. Evaluating the full range of natural variability from the observational record alone is difficult because of the existence of significant long-term variability. Evaluating the probability of rare events with the aid of ensembles of long simulations using global climate models has been demonstrated to be

possible using idealized dynamical GCMs. Confidence in prediction and attribution requires statistically significant results based on ensembles of integrations with numerical models, as is now happening within CCMVal.
- Evaluating and understanding solar influences on climate is the main focus of the SOLARIS (Solar Influence study for SPARC) activity.

(c) Stratosphere-troposphere dynamical coupling

- Analyses of downward propagation of dynamical anomalies from the stratosphere into the troposphere suggests that knowledge of the state of the stratosphere can enhance our ability to predict aspects of the large-scale evolution of the troposphere, which would be of practical value for weather forecasting and climate prediction. Correspondingly, weather forecast centres have started to extend operational forcasts deep into the stratosphere.

- The central focus of the SPARC DynVar Activity is to evaluate the ability of GCMs to represent the large-scale dynamical coupling between the stratosphere and troposphere on a wide range of time scales and assess its importance for climate prediction.
- Improving GCMs, e.g. their ability to reproduce the QBO and other modes of natural variability in the stratosphere (and the significance of their absence in climate prediction), is an overarching theme of the DynVar Activity. Use of data assimilation as tool for evaluating model biases in is being addressed in the SPARC Data Assimilation Working Group (SPARC-DAWG).

2.2 Key Science Questions Beyond 2013 as far as Currently Conceivable

- *Quantify the interaction between ozone recovery and climate change*
  Ozone recovery will be affected by climate change, and will itself affect climate over the next half-century (especially in the high latitude southern hemisphere). Understanding these linkages is important for policy reasons – in fact the Parties to the Montreal Protocol are specifically asking for answers to these questions. Yet the linkages themselves are complex and in many cases not well understood, in particular the dynamical coupling to high-latitude surface climate found in observations and models.

- *Foster stratospheric science in climate accountability, mitigation and adaptation*
  The climate science of mitigation and adaptation are key cross-cutting issues which require a higher level of accuracy than the attribution work that has so far dominated climate research. As a part of the climate system, it is imperative to know the influence of changes – wanted, unwanted, or human engineered – on the stratosphere (e.g., concerning the effect of biofuels on stratospheric ozone).

- *Investigate air quality aspects of the troposphere-stratosphere system*
  The interactions between atmospheric chemistry and climate will be a principal driver for changes in air quality given the potential (and realized) changes in middle atmospheric chemistry, transport and dynamics which result in changes in tropospheric chemical composition, in particular in the tropospheric ozone background. This topic intermingles with key societal issues that need stratospheric attention – air traffic being a major one for the existing fleet that is expanding and other kinds of air transportation that will emerge in the coming decades.

- *Quantify the impact of solar variability (on all time scales) on climate*
  In order to detect and attribute anthropogenic effects on climate, and to predict future climate, it is necessary to properly account for all sources of natural variability. Solar variability is a major such source, and the dominant mechanisms involve changes in upper stratospheric ozone. This includes not only the well-known 11-year solar cycle, but also a host of shorter-term variations (e.g. solar proton events) whose significance has only been recently appreciated. Yet the dynamical mechanisms for how these variations propagate down into the lower atmosphere remain unclear.

- *Improve climate models via data assimilation*
  Stratospheric climate models exhibit strong climate biases which are believed to be mainly due to their representation of gravity-wave drag. Gravity-wave drag is also believed to be critical for simulating the quasi-biennial oscillation, a key feature of natural variability, in climate models. Yet gravity-wave drag parameterizations are poorly constrained by observations. By testing climate models in data assimilation mode, errors in gravity-wave drag parameterizations should be easier to identify.

- *Improve climate models via use of mesoscale/cloud-resolving models*
  The upper part of the tropical troposphere, called the tropical tropopause layer (TTL), plays a key role in chemical climate as it sets the chemical boundary conditions (including water vapour) of the stratosphere. Yet the action happens over a shallow layer of ~5 km depth, and involves convective processes. This implies the need for high vertical resolution and well parameterized convective processes. Both of these requirements present challenges for climate models. It is hoped that the use of mesoscale/cloud-resolving models could help constrain parameterizations and evaluate climate models in this region. These models could also be useful for representing convective sources of gravity waves and evaluating gravity-wave parameterizations.

- *Quantify the impact of vertical domain and resolution in the middle atmosphere in climate modelling*

Operational climate models such as those that have been used for the IPCC Assessments typically have domains that do not extend far above the stratopause and limited vertical resolution in the stratosphere. There is compelling evidence of the dynamical impact of the stratosphere on the tropospheric circulation on a wide range of time scales. Even for high-lid models, it has become clear that high vertical resolution in the stratosphere is fundamental to simulating the equatorial quasi-biennial oscillation, a key source of stratospheric variability with tropospheric imprints. Yet little is known or understood about the impact of limited vertical domain or vertical resolution on tropospheric climate: to what extent does this compromise our predictive capabilities?

- *Improve decadal stratospheric ozone predictability*
  The stratosphere exhibits significant decadal variability associated with solar variability and the decadal time scale of changes in chlorine loading. The wintertime Arctic also exhibits decadal variability which is presumably associated with forcing from sea-surface temperatures, and there is the potential for multi-year memory in stratospheric tropical zonal winds. All these factors make decadal predictability of stratospheric ozone a viable possibility, and the role of the stratosphere (and stratospheric ozone) in decadal predictability a cutting-edge research topic.

- *Improve seasonal climate predictability*
  The stratosphere possesses many mechanisms for both intraseasonal and interseasonal memory — the long radiative timescale of the lower stratosphere, the seasonal persistence of stratospheric ozone anomalies, the quasi-biennial oscillation in tropical stratospheric winds, the long time scale of polar vortex anomalies — and there is accumulating evidence that the stratosphere provides a source of seasonal predictability in the troposphere. Yet seasonal prediction systems do not currently include full representations of the stratosphere or stratospheric ozone. There is an opportunity here to make a significant advance in seasonal climate predictions.

- *Improve understanding of climate variability in the stratosphere*
  Stratospheric variability, in particular that of the winter polar vortex in both hemispheres, is highly nonlinear, so that the frequency distribution of a physical quantity is far from a normal distribution. The predictability of fluctuations and short-term trends in such a system is a scientifically interesting problem with important applications; the concept of deterministic predictability is no longer adequate and development of a probabilistic approach to climate prediction is probably required. A related question is the separation of the response of the stratosphere to an external forcing (e.g., anthropogenic linear trend) from finite-amplitude natural variations of a non-Gaussian nature.

- *Improve chemistry-climate coupling in the stratosphere-troposphere system*
  In climate modeling, self-consistency of the dynamical and radiative fields is key. Because ozone is highly variable both spatially and temporally, especially in the vicinity of the tropopause and the polar vortex edge, imposing the ozone distribution externally will inevitably lead to radiative-dynamical inconsistencies. This must also compromise the fidelity of stratosphere-troposphere dynamical coupling. It is therefore important to move towards fully coupled chemistry-climate modeling and to implement detailed sub-models, or components, of the stratosphere and atmospheric chemistry in Earth System Models.

- *Quantify the role of the polar regions in global climate*
  Dynamical variability in the polar vortex represents a key mechanism of stratosphere-troposphere coupling. Because the polar regions also exhibit the largest ozone depletion, chemical-dynamical coupling is highly nonlinear in this region. For the same reasons, the polar regions exhibit the strongest feedback of ozone depletion on climate. The rapid melting of Arctic sea ice points to the major differences between the response of the two polar regions to climate change, and has potential ramifications in terms of stratosphere-troposphere coupling. There is strengthening evidence of tropical-polar coupling within the stratosphere, and even evidence of inter-hemispheric coupling. Thus, the polar regions represent key elements within the global climate system, with highly nonlinear aspects involving strong chemical-climate coupling.

- *Quantify effects of future stratospheric change on the global carbon cycle*
  Changes in the radiative balance of the Antarctic stratosphere, as a result of ozone recovery and increased greenhouse gas loading, will strongly affect the future evolution of the southern annular mode. Since the southern annular mode influences surface wind speeds over the southern ocean, and hence the exchange of CO_2 between the atmosphere and ocean (which depends on the square of the wind speed), stratospheric change in the Antarctic is likely to be relevant to global carbon cycling in the future and to the ability of the ocean to take up a significant fraction of anthropogenic emissions of CO_2.

- *Critically assess Geoengineering*
  Global surface temperature is observed to decrease following volcanic eruptions, which increase atmospheric albedo. This has led to a recent suggestion that releasing large amounts of sulphate aerosol in the stratosphere could be a temporary measure to slow global warming. But the sulphate aerosol arising from the Mt Pinatubo volcanic eruption is also believed to have increased ozone depletion. Thus the possible negative consequences on the stratospheric ozone layer and the associated impacts through surface ultraviolet radiation and changes in climate would need to

be thoroughly assessed with appropriate well-evaluated models that include a fully resolved stratosphere (including chemistry) and a coupled ocean to consider the various feedbacks before such a geoengineering experiment could be contemplated.

3. Detailed Contributions to Unifying COPES Themes

(a) Modelling

- CCMVal: Chemistry-Climate model validation. Process oriented validation of comprehensive chemistry-climate models (CCMs). Definition of reference CCM simulations for assessments.
  The overarching goal of CCMVal is to improve understanding of the performance of Chemistry-Climate Models (CCMs) and their underlying GCMs (General Circulation Models) through process-oriented evaluation, along with coordinated analysis of science results. Achieving these goals will involve comparing CCM constituent distributions with (robust) relationships between constituent variables as found in observations. This effort is both a model-model and model-data comparison exercise. Key diagnostics with respect to radiation, dynamics, transport, and stratospheric chemistry and microphysics are defined in the CCMVal Evaluation Table. Modelers may decide (based on their own priorities and resources) which diagnostics to examine in any particular area.

  Benefits: The organized and coordinated CCM modeling within the CCMVal activity helps to (a) provide the maximum amount of useful scientific information for WMO/UNEP and IPCC assessments (b) improve chemistry-climate models through process oriented diagnostics and evaluation.

- Dynamics and Variability Activity (DynVar): Modelling dynamical coupling between stratosphere and troposphere over a wide range of time scales using a range of modelling approaches.
  The SPARC DynVar project aims to study the dynamical influence of the stratosphere on the troposphere using “high-top” atmospheric general circulation models (AGCMs) with good stratospheric representation. The project’s long-term goal is to determine the dependence of the mean climate, climate variability, and climate sensitivity on the stratospheric general circulation as represented in AGCMs. It aims to answer the thematic questions:

1. How does the stratospheric circulation (as represented in climate models) affect the tropospheric general circulation?
2. How does the stratosphere influence climate variability on all time scales?

3. How does the stratosphere influence climate change?

   Benefits: understanding the role of the stratosphere in the climate system; understanding and characterizing the role of the stratosphere in dynamical prediction; Characterizing stratospheric variability and its role in detection of climate change.

- The SPARC Solar Influence (SOLARIS) Activity. Part of a SPARC-CAWSES collaboration. Understanding and modelling solar influences on climate through stratospheric chemical and dynamical processes. In collaboration with Working Group 1 of the SCOSTEP CAWSES (Climate and Weather of the Sun-Earth System) program.
  The SOLARIS activity is complementary to both the CCMVal and the DynVar activities. Its goals are to answer such key questions as (a) What is the mechanism for solar influence on climate, specifically the dynamical and chemical response in the middle atmosphere (stratosphere and mesosphere) and its propagation down to the Earth's surface? (b) How do the solar cycle and the stratospheric quasi-biennial oscillation (QBO) interact and what are the mechanisms? (c) What is the spatial structure of the solar signal in ozone and temperature? Coordinated GCM and mechanistic model studies are used to understand discrepancies between different observations and model experiments.

  Benefits: quantifying solar influences on climate and climate change.

(b) Observations (including some cross-cutting with modeling)

- Evaluating and updating stratospheric trends (SPARC temperature trends activity, stratospheric H_2O trends as part of the WAVAS-2 activity)

  Benefits: Understanding and resolving uncertainties and quantifying stratospheric trends, validating chemistry-climate models, direct input to both IPCC and WMO/UNEP assessments, e.g. by (a) defining what is meant by ozone recovery, thereby developing and improving the framework for the WMO/UNEP Ozone assessments, (b) addressing disparities in specifying past ozone forcing in the models that contributed to IPCC assessments.

- Evaluating stratosphere-troposphere coupling of modes of variability (e.g. annular modes, Arctic Oscillations).

  Benefits: characterizing coupled variability from observations and its role in tropospheric weather.

- Stratospheric Data Assimilation (SPARC-DA working group). Focus on middle atmosphere data assimilation issues.

  Benefits: improving assimilation techniques to deal with DA problems that are more pronounced in the stratosphere than in the troposphere, such as high variability and error accumulation over long time scales.

- SPARC-IPY Archive: a well-organized data archive of measurements and analyses of the polar stratosphere during the IPY period. Archiving of analyses from major centres during the IPY period is being carried out under the auspices of the SPARC-DA activity.

- SPARC Data Center: Archiving of special-purpose data sets and reference data sets (e.g. high resolution radiosonde observations). Access portal for archives in other centres that are developed through SPARC activities (e.g. IPY archive).

(c) Climate System Science (including some cross-cutting with modeling and observations)

(i) Science Activities

- CCMVal: Major underpinning for the WCRP-IGBP Atmospheric Chemistry and Climate Initiative (AC&C).

  Benefits: Provides motivation, methodology, and context for observational and process modelling activities directed toward improved understanding of chemistry-climate coupling and climate prediction throughout the atmosphere.

- SPARC Dynamics and Variability Activity

  Benefits: Improved understanding and prediction of dynamical variability in the stratosphere and mesosphere, its coupling with tropospheric processes, its role in prediction on all time scales and in detection and attribution of climate change.

- The Tropopause Inititive and SPARC-GEWEX-IGAC collaborative activities on modelling the role of deep convection in stratosphere-troposphere coupling and exchange, particularly in the region of the tropical tropopause.

  Benefits: The tropopause region (including both the tropical and extratropical tropopause layers, TTL and the ExtTL) is the location of major exchanges of radiatively and chemically active species (e.g. water vapour, methane, ozone depleting substances, ozone itself, and other radiatively important species) between the troposphere and stratosphere. Understanding the physical and dynamical processes governing and constraining this region (e.g. processes determining the location and magnitude of the cold-point temperature) are critical to evaluating and modelling climate sensitivity as well as for modelling critical processes such as lifetimes of very short-lived species (VSLS).

- Continued efforts to evaluate and understand trends in stratospheric observations, remove observing system biases, resolve apparent inconsistencies.

  Benefits: These activities are fundamental for detection of stratospheric changes.

- Continued to understanding and modelling of solar influences on climate, and their coupling with stratospheric dynamical and chemical processes.

  Benefits: Quantifying the variability of solar forcing of the troposphere.

- In the context of SPARC-IPY quantification of the structure and evolution of the stratospheric polar vortices and their links to the troposphere during the IPY period. This involves models, observations, data assimilation. Hence a cross-cut between modelling and observations.

  Benefits: Will leave a legacy of a comprehensive data set documenting state the polar atmosphere in the IPY period and associated analyses.

(ii) Toward Seamless Prediction

- Through dynamical modelling and data assimilation, characterization and quantification of stratospheric variability on times scales from days to decades, and vertical coupling throughout the atmosphere (tropospheric to mesosphere).

  Benefits: Improved observational analyses and prediction.

- Through CCMVal and associated observational and process studies enhanced understanding and prediction of chemistry-weather-climate interactions.

  Benefits: Improved understanding, quantification, and prediction of the role of chemistry in weather, climate, and air quality including effects of human influences (ACC) and mitigation initiatives (ozone recovery).

- Through data assimilation, an identification of model errors (e.g. in gravity-wave drag) through errors in short-term forecasts.

  Benefits: Improvement in the physical parameterizations of both weather and climate models in the stratosphere.

- Updating the SPARC ozone data sets, provision of an ozone forcing data set for the IPCC

4. Contributions to Implementing COPES Cross-cutting Initiatives (including overlapping with COPES themes)

Atmospheric Chemistry and Climate (AC&C)

The AC&C cross-cutting initiative is a joint collaboration between WCRP and IGBP, led by SPARC and IGAC.

> An important issue is how the changes in the tropospheric abundances of ODSs translate to changes in the ozone-depleting active chemicals in the stratosphere. Dynamical processes that control transport and dynamical issues related to vortex formation and maintenance need to be carefully taken into consideration when predicting the long-term evolution of polar ozone. The influences of the changes in stratospheric ozone and composition on the Earth’s climate that need to be evaluated include those that can influence the composition of the troposphere.
>
> *Benefits:* Enhanced understanding of the coupling between chemistry, weather, and climate. Improved ability to model and predict “chemical” weather and climate through the entire active region of the atmosphere (surface to mesopause). Contributions to WMO/UNEP Ozone assessment and IPCC. In addition to the scientific benefits, the task of assessments of the ozone layer, required by the Montreal Protocol every four years, relies on the “footwork” of organizations such as WCRP and IGBP through their projects. It provides the basis for assessments and the pool of scientists to carry out the assessments.

Anthropogenic Climate Change

The cross-cutting issues of atmospheric chemistry and climate and anthropogenic climate change are closely linked and are both prominent in the SPARC programme. The influence of changing climate is foremost among the factors affecting the future evolution of the stratospheric ozone layer. While ODS amounts in the atmosphere have peaked and are slowly decreasing, the climate of the stratosphere is also changing. Therefore, correct attribution of the ozone changes to policy actions on ODSs as opposed to changes in stratospheric climate is a key need. Also, predicting how climate change hastens or delays ozone recovery is an important issue.

Accounting for the natural variability in the coupled system is critical for attributing the changes in the stratosphere. In this regard, two critical issues are being addressed within the SPARC DynVar activity:

1. *Stratospheric change as part of the attribution and detection of climate change*: Where stratospheric changes are predominantly anthropogenic and not associated with natural variability, models should be able to reproduce the changes but a key question concerns how to characterize the statistics of natural variability in the stratosphere. This is particularly challenging for the Arctic stratosphere where both observations and model results show a great deal of long-term variability, not just from year-to-year but on decadal timescales. This is similar to the timescale of the changes in ODS forcing, and also of the satellite observational record. A major modelling challenge is to characterize the variability statistics sufficiently well to enable detection and attribution of ACC in the stratosphere.
2. *Changes in the stratosphere affecting meteorological (dynamical) variability in the troposphere*: There is evidence that the state of the stratosphere can have an impact on the troposphere on a variety of timescales (medium-range, seasonal, possibly decadal). A major challenge for SPARC is to understand the nature of this stratosphere-troposphere coupling, as well as to determine the spatial (in particular, vertical) resolution needed in climate models to capture the relevant dynamical processes.

Seasonal Prediction

Time scales and memory in the stratosphere are typically longer than in the troposphere and studies have shown that circulation anomalies in the stratosphere may propagate down into the troposphere on time scales of several weeks. Current weather forecast models, even those that extend into the stratosphere, typically show systematic errors, such as underprediction of the stratospheric jet, that may be associated with inadequate resolution and modelling of stratospheric circulation anomalies and their downward influence. Addressing such issues is a focus of the DynVar activity.

Decadal Prediction

The stratosphere exhibits decadal variability associated both with internal processes (*e.g.* sudden stratospheric warmings and the quasi-biennial oscillation (QBO)) and with responses to external forcings (such as decadal-scale variations in solar irradiance, volcanic eruptions, and anthropogenic effects such as ozone depletion/recovery and increased GHG concentrations), and the relevance of tele-connection pathways that couple stratospheric and tropospheric variability is now recognised in regard to tropospheric predictability.

Modelling the role of stratosphere-troposphere coupling for decadal scale prediction poses a number of issues that SPARC is addressing. The importance of changes in atmospheric composition is central to the SPARC CCMVal activity. In addition, understanding and modelling physical and dynamical variability and its role in decadal prediction includes a range of modelling issues, such as the importance of horizontal/vertical resolution and vertical domain, and the role of parameterization of unresolved processes (*e.g*. gravity-wave drag) in modelling stratospheric variability. These issues are addressed in the context of the DynVar activity and SPARC Gravity-wave initiative.

IPY

The central goal of the SPARC-IPY programme is to document as completely as possible the dynamics and chemistry of the polar middle atmosphere during the IPY period. The collection and archiving of analyses has progressed largely as planned; data is being gathered for 6 data assimilation systems (5 with ozone, 2 with other chemical constituents, 5 with water vapour). In addition, progress has also been made on the other main components of SPARC-IPY, namely the Pan-Arctic Study, and a range of outreach activities. The Pan-Arctic Study is aimed at better understanding the middle atmospheric circulation with the help of a network of Arctic lidar measurements, satellite measurements, and meteorological soundings and analysis. Outreach activities and interactions between SPARC-IPY research activities are being coordinated at the SPARC Office

5. SPARC Legacy and Outlook beyond 2013

The “recovery” of stratospheric ozone to pre-chlorofluorocarbon levels in response to the Montreal Protocol is expected in the coming decades, with the abundances of ODSs having already peaked. At the same time the Montreal Protocol has contributed and will continue to contribute in crucial ways to limiting the release of greenhouse gases not regulated under the climate protocols. Detecting the early signs of ozone recovery, shepherding the ozone layer through the transition period, and finally seeing it through the consequences of the protocol are issues of major societal importance. SPARC has contributed in fundamental ways to addressing these issues, most prominently through the CCMVal activity as a major underpinning for both AC&C and the WMO/UNEP Ozone Assessments. The key role of SPARC in regard to these issues will continue to be needed in the coming decades. The perception of the importance of stratospheric processes in weather and climate prediction has emerged largely as a result of SPARC activities over the past decade. However, understanding and successfully modelling the key processes and characteristics of stratosphere-troposphere dynamical and chemical coupling is still emerging and will require continued focused activities similar to those within the current SPARC project.