CHAPTER 1

Introduction

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CHAPTER 1

INTRODUCTION

Contents

1.1. MOTIVATION AND GOALS

The Stratosphere-troposphere Processes And their Role in Climate (SPARC) community uses reanalysis data sets to understand a wide range of processes and variability in the atmosphere, to validate chemistry climate models, and to investigate and identify climate change (e.g., SPARC, 2002; Randel et al., 2004; SPARC, 2010, and references therein). Even for more recent reanalyses, however, different results may be obtained for the same diagnostic due to different technical details of the reanalysis systems (see, e.g., Fujiwara et al., 2016 for a list of many examples). There is thus a need for a coordinated intercomparison of reanalysis data sets with respect to key diagnostics that can help to clarify the causes of these differences. The results can then be used to provide guidance on the appropriate usage of reanalysis products in scientific studies, particularly those of relevance to SPARC. The reanalysis community also benefits from coordinated user feedback, which helps to drive improvements in the next generation of reanalysis products. The SPARC Reanalysis Intercomparison Project (S-RIP) was initiated in 2011 to conduct a coordinated intercomparison of all major global atmospheric reanalysis data sets. While the focus is on the stratosphere, the intercomparison also encompasses the troposphere and lower mesosphere where appropriate.

The goals of S-RIP are as follows:

(1) To create a communication platform between the SPARC community and the reanalysis centres;
(2) To better understand the differences among current reanalysis products and their underlying causes and to contribute to future reanalysis improvements; and
(3) To provide guidance to reanalysis data users by documenting the results of this reanalysis intercomparison in peer reviewed papers and two SPARC S-RIP reports.

This Chapter discusses the scope and plans of S-RIP based on the S-RIP Implementation Plan (February 2014) and updated information.

1.2. SCOPE

The S-RIP project focuses predominantly on reanalyses, although some chapters include diagnostics from operational analyses when appropriate. Available and soon to be available reanalysis data sets (as of this writing in August 2016) are listed in Table 1-1. The guidelines for the choice of reanalysis datasets are as follows. Many of the chapters focus primarily on newer reanalysis systems that assimilate upper-air measurements and produce data at relatively high resolution (i.e., ERA-Interim, JRA-55, MERRA, MERRA-2, and CFSR). We also intend to include forthcoming reanalyses (e.g., ERA5) when they become available, and long-term reanalyses that assimilate only surface meteorological observations (e.g., NOAA-CIRES 20CR and ERA-20C) where appropriate. Some chapters will include comparisons with older reanalyses (NCEP-NCAR R1, NCEP-DOE R2, ERA-40, and JRA-25/JCDAS), because these products have been heavily used in the past and are still being used for some studies, and because such comparisons can provide insight into the potential shortcomings of past research results. Other chapters will only include a subset of these reanalysis data sets, since some reanalyses have already been shown to perform poorly for certain diagnostics or do not extend high enough in the atmosphere. At the beginning of each chapter an explanation is given as to why specific reanalysis data sets were included or excluded. The intercomparison period common to all chapters is 1979–2012. This period starts with the advent of high-frequency remotely sensed data (the “satellite era”) and ends with the starting year of the S-RIP activity. Some chapters will also consider the pre-satellite era before 1979 and/or include results for more recent years. Given the wide use of ERA-40 (which only extends to August 2002), separate intercomparisons for 1979—2002 are also considered for selected diagnostics.

Table 1-1. Global atmospheric reanalysis data sets available or soon to become available (the latter in square brackets) as of November 2016. See Chapter 2 for the reanalysis data sets considered in this report.

Reanalysis Centre	**Name of the Reanalysis Product**
ECMWF	ERA-40, ERA-Interim, ERA-20C, [ERA5]
JMA	JRA-25/JCDAS, JRA-55
NASA	MERRA, MERRA-2
NOAA/NCEP	NCEP/NCAR (R-1), NCEP/DOE (R-2), CFSR
NOAA and Univ. Colorado	20CR

1.3. OUTLINE PLAN FOR S-RIP REPORTS

Summarised below are the plans for the S-RIP’s two reports: an interim report to be published in 2016 (this report) and a full report to be published in 2018. The report consists of two parts. Chapters 1–4 are designated as “basic” chapters that constitute this 2016 interim report and will be updated and included in the 2018 full report. Chapters 5–12 are designated as “advanced” chapters that will only be included in the 2018 full report. The advanced chapters are arranged according to, and focus on, different regions or processes within the atmosphere. Some important topics, such as gravity waves and transport processes, are sufficiently pervasive that related aspects are distributed amongst several chapters.

PART I. Basic Chapters:

Chapter 1. Introduction: The S-RIP motivation, goals, rationale, and report structure are described.

Chapter 2. Description of the reanalysis systems: This chapter includes detailed descriptions of the forecast model, assimilation scheme, and observational data assimilated for each reanalysis. It also provides information on processing streams and data products and resolutions that are available.

Chapter 3. Climatology and interannual variability of dynamical variables: This chapter centers around climatologies of major dynamical variables (e.g., zonal mean temperature, zonal mean wind) created for the period 1979–2012 from an ensemble of the newer reanalyses on standard pressure levels. The sub-period 1979–2002, allowing comparison with ERA-40, is included in an appendix. Key plots of the ensemble climatological means and individual reanalysis anomalies from these means are presented in this report, with more complete plots in an accompanying online atlas. Inter-reanalysis variations are quantified. The validation of this climatology is based on independent observations (i.e., those not used in the reanalyses) such as non-assimilated radiosondes, lidars, rocketsondes, and non-assimilated satellite data.

Chapter 4. Climatology and interannual variability of ozone and water vapour: This chapter includes a detailed evaluation of ozone and water vapour in the reanalyses, using a range of observational data sets obtained from both nadir and limb satellite instruments. The diagnostics considered include climatological evaluations such as monthly zonal mean cross-sections and altitude profiles, seasonal cycles, and interannual variability. Some more advanced diagnostics, such as the Quasi-Biennal Osciallation (QBO) and equivalent latitude timeseries, are used to better understand the differences in the climatological evaluations, while a detailed investigation of the transport processes resulting in these distributions will be covered in the "advanced" chapters. In addition, this chapter includes some summary information on the assimilated observations and on the modelling of ozone and water vapour in each reanalysis system.

PART II. Advanced Chapters:

Chapter 5. Brewer-Dobson circulation: This chapter will focus on evaluation and comparison of the stratospheric circulation in the more recent reanalyses, using diagnostics such as the residual mean meridional streamfunction, age-of-air (AoA), and measures of mixing. Off-line chemistry transport models in Eulerian and Lagrangian frameworks will be used. Results will be validated against satellite, ground-based, balloon, and aircraft observations of long-lived tracers such as SF_6, CO_2, and N_2O. Particular attention will be given to comparing past trends in AoA from the different reanalyses, as well as to comparing reanalysis-based trends with those obtained from models.

Chapter 6. Stratosphere-troposphere coupling: This chapter will cover the representation of two-way coupling between the troposphere and stratosphere in the reanalyses. It will focus in particular on extra-tropical coupling on daily to intraseasonal time scales, and how this shorter-term variability is modulated on interannual time scales (e.g., by El Niño Southern Oscillation (ENSO), volcanic eruptions, and stratospheric ozone loss). The chapter will synthesize and compare established approaches with more recent metrics to characterize planetary wave coupling and blocking, it will examine vertical coupling of the zonal mean flow (e.g., the annular modes), and diagnostics relevant to proposed mechanism(s) connecting the stratosphere and troposphere (e.g., changes in tropopause height). It will also take into account the recent discussion on how to best characterize Sudden Stratospheric Warmings (SSWs), exploring how the established and alternative definitions of SSWs impact diagnostics of stratosphere-troposphere coupling.

Chapter 7. Extra-tropical Upper Troposphere and Lower Stratosphere (ExUTLS): This chapter will begin with an introduction to the two UTLS chapters (Chapters 7 and 8), and will explain the distinction between the two UTLS regions while identifying key processes and common diagnostics used to study them in each region. ExUTLS processes depend critically on resolution, so the diagnostics will be produced only for the more recent reanalyses. Diagnostics will include characterization of the tropopause based on different definitions (including multiple tropopauses, vertical structure, etc.), UTLS jet characteristics and long-term changes, atmospheric transport from trajectory model calculations, and diagnostics of mixing and stratosphere-troposphere exchange (STE). In addition, UTLS ozone in the more recent reanalyses, including dynamically-driven column ozone variations, evidence of STE and mixing, and their relationships to the dynamical diagnostics, will be evaluated. This chapter will also include comparisons of assimilated UTLS ozone with satellite, balloon, and ground-based observations.

Chapter 8. Tropical Tropopause Layer (TTL): This chapter will include evaluations of the tropical transition region between the well-mixed, convective troposphere and the highly stratified stratosphere in the reanalyses. The general TTL structure as given by the cold point and lapse rate tropopause and the level of zero radiative heating will be analysed. Diagnostics related to clouds and convection in the TTL will include cloud fraction and water content, outgoing longwave radiation, and brightness temperature. The chapter will take into account the diabatic heat budget as well as dynamical characteristics of the TTL such as Lagrangian cold points, residence times, and wave activity. Finally, the width of the tropical belt based on tropical and extra-tropical diagnostics and the representation of monsoon circulations in the reanalyses will be evaluated.

Chapter 9. Quasi-Biennial Oscillation (QBO) and tropical variability: The diagnostics in this chapter will include an analysis of the tropical QBO, its extra-tropical teleconnections, other relevant teleconnections such as those with ENSO and the solar cycle, its zonal momentum budget, and spectral characteristics of tropical waves including modal analysis and equatorial wave energetics. Observations for validation will include operational and campaign radiosondes, rocketsondes, and satellite observations such as HIRDLS and SABER. Information regarding non-orographic gravity wave parameterization and analysis increments may also be utilised.

Chapter 10. Polar processes: This chapter will focus on polar processes, which are “threshold” phenomena that depend critically on meteorological conditions in the lower stratosphere. The choice of reanalysis data set can lead to substantially different results for polar process studies. A range of diagnostics based on temperatures and polar vortex structure will be examined to assess differences between reanalyses and their impact on studies of polar stratospheric cloud (PSC) formation, denitrification and dehydration, chlorine activation and deactivation, and chemical ozone loss. In addition to basic diagnostics (e.g., minimum temperatures; volume of stratospheric air cold enough to support PSC formation; size, shape, and strength of the winter polar vortex), advanced dynamical diagnostics such as trajectory-based PSC lifetimes and diabatic heating rates will be evaluated. More highly derived diagnostics, including comparisons with satellite composition and PSC measurements to assess thermodynamic consistency with theoretical PSC equilibrium curves and quantification of chemical ozone loss using a chemical transport model, will be used to explore how the spatially and temporally varying differences between reanalyses interact to affect the conclusions of case studies of specific winters.

Chapter 11. Upper Stratosphere and Lower Mesosphere (USLM): This chapter will focus on the uppermost levels in the reanalyses, where assimilated data sources are most sparse. Annual cycles of wind and temperature in the reanalyses will be compared to observations as a function of latitude and altitude. We will quantify differences in the following geophysical features and process-oriented diagnostics: the tropical Semi-Annual Oscillation (SAO), inertial instability at the tropical stratopause, the winter polar vortices, effects of SSWs on stratopause evolution and the upper stratosphere/lower mesosphere, the transformed Eulerian mean (TEM) circulation, and the 3D residual circulation. We will also present wave fluxes and planetary wave amplitudes. Comparisons will be made between the reanalyses and SABER and MLS satellite observations for validation purposes. Comparisons among reanalyses and models nudged to reanalyses in the troposphere and lower stratosphere (below the USLM) will also be used to extend our knowledge of the state of the USLM.

Chapter 12. Synthesis summary: This chapter will summarize the key findings and the common patterns across the report, and provide suggestions as to the appropriateness of individual reanalyses for studies of particular atmospheric processes. It will provide recommendations for future research and reanalysis development.

1.4. DEVELOPMENT OF THE S-RIP TEAM

The need for a coordinated reanalysis intercomparison project was proposed and discussed at the 8th SPARC Data Assimilation Workshop held at Brussels, Belgium in June 2011 (Jackson and Polavarapu, 2012), leading to the proposal of the SPARC Reanalysis Intercomparison Project (S-RIP) in January 2012 (Fujiwara et al., 2012). In February 2012, S-RIP was officially endorsed by the SPARC Scientific Steering Group (SSG) as an emerging activity of SPARC. A first S-RIP session was held at the subsequent 9th SPARC Data Assimilation workshop in Socorro, New Mexico, USA, in June 2012 (Jackson et al., 2013), followed by the formation of the scientific Working Group (11 members) and the confirmation of the reanalysis centre contacts (8 members) by August 2012. The Working Group then proceeded to discuss chapter titles, co-leads, and initial contributors to the final SPARC report, and organised an S-RIP Planning Meeting for the following year.

The first S-RIP Planning Meeting, with 39 participants, was hosted by David Jackson at the UK Met Office in Exeter, UK from 29 April to 1 May 2013 (Fujiwara and Jackson, 2013). The purpose of that meeting was to finalise the report outline, to determine the diagnostics list and observational data required for validation for each chapter, to agree on general guidelines and protocols, and to define the project timetable. The S-RIP Implementation Plan was submitted to the SSG in January 2014, at which point S-RIP was officially endorsed by the SSG as a full activity of SPARC. Since this official launch of S-RIP, one side meeting was held during the SPARC General Assembly in Queenstown, New Zealand, in January 2014, and three annual workshops were held. The 2014 workshop was hosted by Craig Long at the NOAA Center for Weather and Climate Prediction, College Park, Maryland, USA in September 2014 (Errera et al., 2015). The 2015 workshop was hosted by Bernard Legras and held at Pierre and Marie Curie University, Paris, France in October 2015 (Errera et al., 2016). The 2016 workshop was hosted by James Anstey and held at Victoria, Canada in October 2016. The 2014, 2015, and 2016 workshops were co-organized with Quentin Errera and were held at the same place in the same week as the SPARC Data Assimilation workshops, with one-day joint session.

1.5. MANAGEMENT AND COMMUNICATION

S-RIP was initially co-led by Masatomo Fujiwara (Japan) and David Jackson (UK) until April 2014 when Jackson stepped down. David Tan (UK) served as a co-lead between September 2014 and July 2015, working together with Masatomo Fujiwara. Since November 2015, S-RIP has been co-led by Masatomo Fujiwara, Gloria Manney (USA), and Lesley Gray (UK). The co-leads are members of a wider Working Group, who help steer the direction of the project and coordinate the specifics of the work. The Working Group members are David Tan (UK; until July 2015), Thomas Birner (USA), Simon Chabrillat (Belgium), Sean Davis (USA), Yulia Zyulyaeva (Russia; until October 2014), Michaela Hegglin (UK), Kirstin Krüger (Germany/Norway), Craig Long (USA), Susann Tegtmeier (Germany), Gloria Manney (USA), Lesley Gray (UK; since November 2015), and Masatomo Fujiwara (Japan).

Each reanalysis centre has also designated a contact who is involved in S-RIP and whose presence is vital to ensure the two-way flow of knowledge between the S-RIP research community and the reanalysis centres. The reanalysis centre contacts are David Tan (ECMWF; until July 2015), Rossana Dragani (ECMWF; since July 2015), Craig Long (NOAA/NCEP), Wesley Ebisuzaki (NOAA/NCEP), Kazutoshi Onogi (JMA), Yayoi Harada (JMA), Steven Pawson (NASA; until April 2016), Krzysztof Wargan (NASA; since April 2016), Gilbert Compo (NOAA and University of Colorado), and Jeffrey Whitaker (NOAA).

Each chapter of the report has selected co-leads who organise the production of relevant diagnostics and the chapter writing, along with several contributors. The chapter co-leads are listed in Table 1-2.

Table 1-2. Chapter titles and co-leads (as of November 2016)

	Title	Co-leads
1	Introduction	Masatomo Fujiwara, Gloria Manney, Lesley Gray
2	Description of the Reanalysis System	Jonathon Wright, Masatomo Fujiwara, Craig Long
3	Climatology and Interannual Variability of Dynamical Variables	Craig Long, Masatomo Fujiwara
4	Climatology and Interannual Variability of Ozone and Water Vapour	Michaela Hegglin, Sean Davis
5	Brewer-Dobson Circulation	Thomas Birner, Beatriz Monge-Sanz
6	Stratosphere-Troposphere Coupling	Edwin Gerber, Patrick Martineau
7	Extra-tropical Upper Troposphere and Lower Stratosphere (ExUTLS)	Cameron Homeyer, Gloria Manney
8	Tropical Tropopause layer (TTL)	Susann Tegtmeier, Kirstin Krüger
9	Quasi-Biennial Oscillation (QBO) and Tropical Variability	James Anstey, Lesley Gray
10	Polar Processes	Michelle Santee, Alyn Lambert, Gloria Manney
11	Upper Stratosphere and Lower Mesosphere (USLM)	Lynn Harvey, John Knox
12	Synthesis Summary	Masatomo Fujiwara, Gloria Manney, Lesley Gray

The project is monitored via progress reports written by the chapter co-leads every 6 months (with the option of associated teleconferences for further discussion). Full S-RIP workshops are held annually to discuss the current status of each chapter, planning of evaluations, writing of papers, and completion of chapters. Individual chapter workshops are also held, usually jointly with other relevant workshops and conferences. Current project information is disseminated through the S-RIP website (http://s-rip.ees.hokudai.ac.jp/) constructed by Jonathon Wright and Masatomo Fujiwara, which includes a public section and an internal Wiki to facilitate the preparation of the report (see Figure 1-1). The processed data used to create figures and tables in the report will be stored at the British Atmospheric Data Centre (BADC) of the UK Centre for Environmental Data Analysis (CEDA), as negotiated by James Anstey and Lesley Gray. Quasi-monthly S-RIP News emails have been sent to the participants and other interested researchers to share the latest information relevant to the project and to keep the volunteer participants motivated. Following the discussion at the 2015 S-RIP workshop, in February 2016 a special issue on "The SPARC Reanalysis Intercomparison Project (S-RIP)" was launched in Atmospheric Chemistry and Physics (ACP), a journal of the European Geosciences Union. The editors of this special issue are Peter Haynes, Gabriele Stiller, and William Lahoz. This is one of the ways to encourage researchers to publish S-RIP related works by the end of 2018.

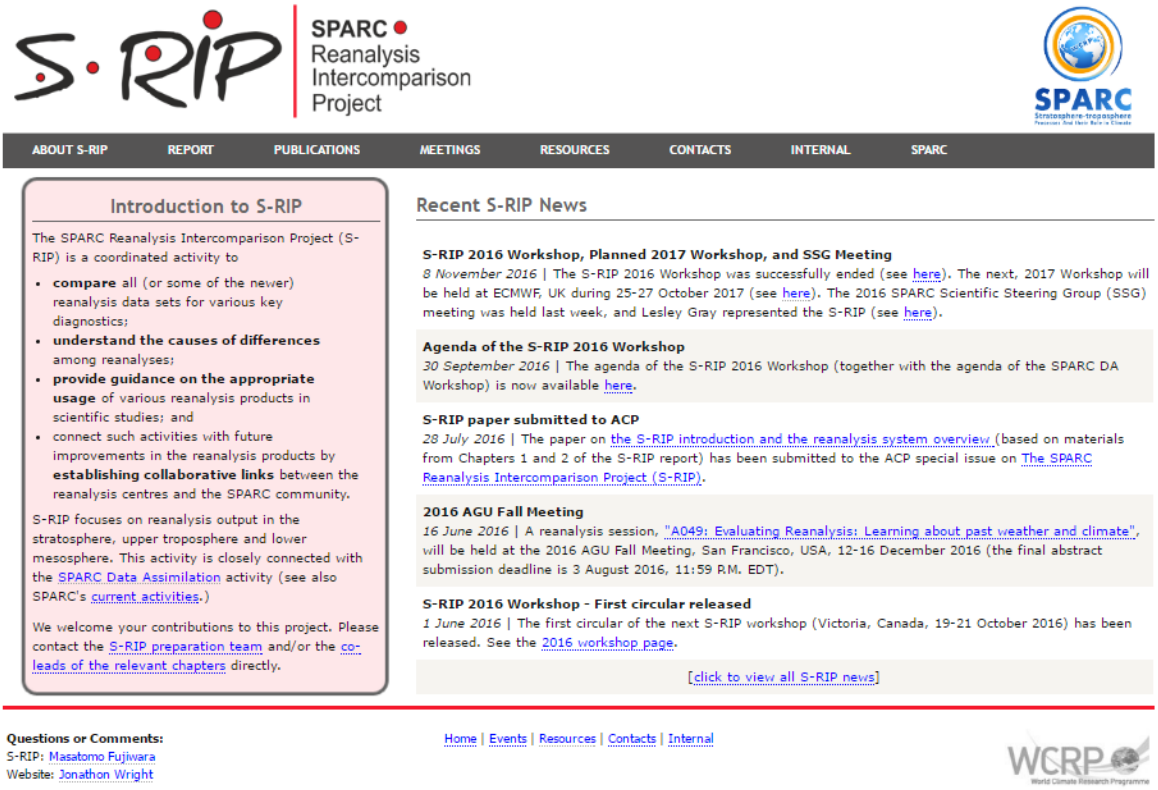

Figure 1-1. A snapshot of the front page of the S-RIP website (9 November 2016).

1.6. LINKS TO OTHER PROJECTS

S-RIP has close links to several other SPARC activities, including the SPARC Data Assimilation Working Group (SPARC-DA), the SPARC Network on Assessment of Predictability (SNAP), SPARC DynVar, and the SPARC QBOi initiative. These activities share a common focus on stratospheric analyses and, in the case of SNAP, on the impacts of these analyses on weather forecasting. The reanalyses evaluated and compared by S-RIP are widely used to validate climate models, establishing a direct connection between the activities of S-RIP and those of the Chemistry-Climate Model Initiative (CCMI). S-RIP activities also overlap with a number of other SPARC activities, such as the Temperature Changes activity, the SPARC Data Initiative, and the Gravity Waves activity. The leaders of several of these activities are also involved in the S-RIP Working Group and/or serving as chapter co-leads or contributors in the preparation of the two S-RIP reports, thus enhancing opportunities for coordination and collaboration.

S-RIP has been publicised at meetings of the WMO Working Group on Numerical Experimentation (WGNE), where the project was well received and prompted discussion about a parallel WGNE activity focused on tropospheric reanalyses. Finally, activities associated with S-RIP have the potential to be important components of the Global Framework for Climate Services.

1.7. PROSPECTS FOR THE FUTURE

S-RIP is planned to continue until 2018 (i.e., 5 years starting from the Planning Meeting in 2013). However, a fundamental goal of S-RIP is to provide well-organized feedback to the reanalysis centres, thus forming a “virtuous circle” of assessment, improvements in reanalyses, further assessment, and further improvements in reanalyses. To this end, calculations of diagnostics suited to numerous types of studies have been and are being developed for current reanalyses. These diagnostics can then be easily extended and applied to assessment of future reanalyses. Since most reanalysis centres have ongoing programmes to deliver new and improved reanalyses, it would be valuable to continue S-RIP beyond this initial period of 5 years. It will therefore be critical to review the value of S-RIP to the research community and reanalysis centres at the SPARC SSG meeting in 2018 to determine whether S-RIP should continue, and if so in what form. Some support from SPARC will be needed if the S-RIP activity is to be continued beyond 2018.

Regardless of the future development of S-RIP, it is important that this project leaves a lasting legacy through publication of its report that helps to sustain international interest in the assessment of reanalyses. A primary goal of the project is to establish tighter links between reanalysis providers and the SPARC community. It is thus hoped that outcomes from the S-RIP assessment will facilitate and even drive future reanalysis developments in a systematic, standardised way, in place of the ad hoc approaches that have been used previously. A further legacy will be the creation of a public data archive (at BADC) of processed reanalysis data with standard formats and resolutions, which will help to enable both further intercomparisons and scientific analyses without repetition of expensive pre-processing steps. This ensemble of derived data sets will be freely available to researchers worldwide, and will is intended to be a useful tool for reanalyses assessment beyond the lifetime of the project.

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APPENDIX A: LIST OF ACRONYMS [TO BE COMBINED AND MOVED TO THE APPENDIX OF THE REPORT]

20CR: 20th Century Reanalysis
AoA: Age of Air
BDC: Brewer-Dobson Circulation
BADC: British Atmospheric Data Centre
CCMI: Chemistry-Climate Model Initiative
CEDA: Centre for Environmental Data Analysis
CIRES: Cooperative Institute for Research in Environmental Sciences (NOAA and University of Colorado Boulder)
CMAM: Canadian Middle Atmosphere Model
DOE: Department of Energy
DynVAR: Dynamical Variability
ECMWF: European Centre for Medium-Range Weather Forecasts
ENSO: El Niño Southern Oscillation
ERA-20C: ECMWF 20th century reanalysis
ERA-40: ECMWF 40-year reanalysis
ERA-Interim: ECMWF interim reanalysis
ERA5: (a planned ECWMF reanalysis for the period 1979 to present, which will replace the ERA-Interim)
ExUTLS: Extra-tropical Upper Troposphere and Lower Stratosphere
HIRDLS: HIgh Resolution Dynamics Limb Sounder
JCDAS: JMA Climate Data Assimilation System
JMA: Japan Meteorological Agency
JRA-25: Japanese 25-year Reanalysis
JRA-55: Japanese 55-year Reanalysis
MERRA: Modern Era Retrospective-Analysis for Research and Applications
MIPAS: Michelson Interferometer for Passive Atmospheric Sounding
MLS: Microwave Limb Sounder
NASA: National Aeronautics and Space Administration
NCAR: National Center for Atmospheric Research
NCEP: National Centers for Environmental Prediction of the NOAA
NCEP-CFSR: Climate Forecast System Reanalysis of the NCEP
NCEP-DOE R-2: Reanalysis 2 of the NCEP and DOE
NCEP-NCAR R-1: Reanalysis 1 of the NCEP and NCAR
NDACC: Network for the Detection of Atmospheric Composition Change
NOAA: National Oceanic and Atmospheric Administration
NOGAPS-ALPHA: Navy Operational Global Atmospheric Prediction System, the Advanced Level Physics-High Altitude version
OLR: Out-going Longwave Radiation
QBO: Quasi-Biennieal Oscillation
QBOi: QBO intercomparison
SABER: Sounding of the Atmosphere using Broadband Emission Radiometry
SAO: Semi-Annual Oscillation
SNAP: SPARC Network on Assessment of Predictability
SPARC: Stratosphere-troposphere Processes And their Role in Climate (previously, it was Stratospheric Processes And their Role in Climate)
S-RIP: SPARC Reanalysis Intercomparison Project
SSG: Scientific Steering Group

SSWs: Sudden Stratospheric Warmings
STE: Stratosphere-Troposphere Exchange
TEM: Transformed Eulerian Mean
TTL: Tropical Tropopause Layer
USLM: Upper Stratosphere and Lower Mesosphere
UTLS: Upper Troposphere and Lower Stratosphere
WGNE: WMO Working Group on Numerical Experimentation
WMO: World Meteorological Organization