Chapter 1: Introduction

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Fujiwara *et al.* (2017a) have published a shortened version of this chapter.

1.1 Motivation and goals

An atmospheric reanalysis system consists of a global forecast model, input observations, and an assimilation scheme, which are used in combination to produce best estimates (analyses) of past atmospheric states. Whereas operational analysis systems are continuously updated with the intention of improving numerical weather predictions, reanalysis systems are (typically) fixed throughout their lifetime. Using a fixed assimilation–forecast model system to produce analyses of observational data previously analysed in the context of operational forecasting (the "re" in "reanalysis") helps to prevent the introduction of inhomogeneities in the analysed fields due to changing assimilation-forecast model systems (*Trenberth and Olson,* 1988; *Bengtsson and Shukla,* 1988; see also *Fujiwara et al.*, 2017a), although artificial changes still arise from other sources (especially from changes in the quality and/or quantity of the input observational data).

The Stratosphere-troposphere Processes And their Role in Climate (SPARC) project is one of the four core projects of the World Climate Research Programme (WCRP). Researchers interested in SPARC use global atmospheric reanalysis products (**Table 1.1**) (1) to understand a wide range of processes and variability in the atmosphere, (2) to validate chemistry climate models, and (3) to investigate and identify climate change (e.g., *SPARC,* 2010; *Randel et al.,* 2004; *SPARC*, 2002, and references therein). Even for more recent reanalyses, however, different results may be obtained for the same diagnostic due to the different methodologies used to construct the reanalysis data sets (see, *e.g.*, *Fujiwara et al.*, 2017a for examples). There is a need, therefore, 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 use of reanalysis products in scientific studies, particularly those of relevance to SPARC. Forecasting and research centres that produce reanalyses also benefit from coordinated user feedback, which helps to drive improvements in the next generation of reanalysis products.

Table 1.1: *Global atmospheric reanalysis data sets available as of July 2018. See end of chapter 1 for abbreviations.*

Reanalysis Centre	Name of the Reanalysis Product
ECMWF	ERA-40, ERA-Interim, ERA-20C, CERA-20C, ERA5 [1]
JMA	JRA-25/JCDAS, JRA-55
NASA	MERRA, MERRA-2
NOAA/NCEP	NCEP-NCAR R1, NCEP-DOE R2, CFSR/CFSv2 [2]
NOAA and Univ. Colorado	20CR

[1] *Some ERA5 data have been available since July 2018, ERA5 data from 1979 onward have been available since January 2019, and a preliminary version of ERA5 1950-1978 data have been available since November 2020. Because most of the studies in this report were finalized before ERA5 was readily available, full evaluation of ERA5 has not been made. However, Chapter 2 includes information on the ERA5 system, and some chapters show some ERA5 results.*

[2] *CFSR is for the period from January 1979 to December 2010, and CFSv2 is for the period from January 2011 to present. We strongly recommend explicitly referring to the combination "CFSR/CFSv2" in documenting any study that uses these products across the 2010-2011 transition.*

The SPARC Reanalysis Intercomparison Project (S-RIP) was initiated in 2011 and officially started in 2013 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:

i. To create a communication platform between SPARC-related researchers and the reanalysis centres;

ii. To better understand the differences among current reanalysis products and their underlying causes and to contribute to future reanalysis improvements; and

iii. To provide guidance to reanalysis data users by documenting the results of this reanalysis intercomparison in peer reviewed papers and this S-RIP report.

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 activity focuses predominantly on reanalyses, although some chapters include diagnostics from operational analyses when appropriate. Available reanalysis data sets (as of July 2018) are listed in **Table 1.1**. The guidelines for the choice of reanalysis data sets are detailed below. 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). The ERA5 reanalysis, which was released during the latter stages of the activity, is not fully evaluated but is included in some intercomparisons. Selected long-term reanalyses that assimilate only surface meteorological observations (*e.g.*, NOAA-CIRES 20CR, ERA-20C, and CERA-20C) are also evaluated where appropriate. Some chapters include comparisons with older reanalyses (NCEP-NCAR R1, NCEP-DOE R2, ERA-40, and JRA-25/JCDAS), because these products have been extensively 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 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 (*e.g.*, pressures less than 10 hPa) 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 minimum intercomparison period is 1980 - 2010. This period starts with the availability of MERRA-2 shortly after the advent of high-frequency remotely sensed data in late 1978 and ends with the transition between CFSR and CFSv2. Some chapters also consider the pre-satellite era before 1979 and/or include results for more recent years. Some chapters use shorter intercomparison periods for some diagnostics due to limitations in the observational record available for comparison and/or computational resources.

1.3 Outline of this report

Summarised below are the components of this S-RIP report (see also **Figure 1.1**). On initiation of the project in 2013, it was planned to publish an interim report containing preliminary versions of Chapters 1 - 4 prior to the completion of the full report. However, following the publication of three papers covering the material in the planned interim report (*Fujiwara et al.*, 2017a; *Long et al.*, 2017; *Davis et al.*, 2017), it was decided in early 2018 that preparing a separate report was unnecessary, and the interim report was cancelled in favor of focusing on the full report. *Chapters 1 and 2* are introductory chapters. *Chapters 3 and 4* are overview chapters, for major dynamical variables in the former and for ozone and water vapour in the latter. *Chapters 5 - 11* are more process-oriented chapters, and are arranged according to, and focus on, different regions or processes within the atmosphere. It is noted that stratosphere-troposphere exchange processes are primarily evaluated in *Chapter 7* (Extratropical upper troposphere and lower stratosphere), while *Chapter 5* (Brewer-Dobson circulation) primarily evaluates the mass transport within the stratosphere. Also, *Chapter 6* (Extratropical stratosphere-troposphere coupling) deals with dynamical coupling, not transport processes. Furthermore, the processes in the upper troposphere and lower stratosphere (UTLS) are discussed separately in *Chapters 7* (Extratropical UTLS) and *8* (Tropical Tropopause Layer, TTL); *Chapter 7* begins with an introduction to these two UTLS chapters, and explains the distinction between the two UTLS regions while identifying key processes and common diagnostics used to study these processes in each region. Some important topics, such as gravity wave drag and transport processes, are sufficiently pervasive that related aspects are distributed amongst several chapters. *Chapter 12* synthesizes the findings and recommendations.

In the summary sections of *Chapters 3 - 11* and in *Chapter 12*, we use the following terms to provide context to our recommendations for each diagnostic:

- **Demonstrated suitable**: the reanalysis product could be directly validated using observational or physical constraints and was found to be in close agreement with expectations

- **Suitable with limitations**: the reanalysis product could be directly validated using observational or physical constraints and exhibited limited agreement; or, appropriate constraints were unavailable but reanalysis products were consistent beyond specific limitations as described in the text

- **Use with caution**: the reanalysis system contains all elements necessary to provide a useful representation of this variable or process, but that representation has evident red flags (*e.g.*, disagreement with available observations; meaningful disagreements among reanalyses that cannot be resolved at this point)

- **Demonstrated unsuitable**: the reanalysis product has been flagged as unable to represent processes that are key for this diagnostic as assessed in this report or by previous studies. This category is reserved for situations where the reanalysis is missing something fundamental in its structure (*e.g.*, a model top at 3 hPa means NCEP-NCAR R1 is 'demonstrated unsuitable' for studying processes in the Upper Stratosphere and Lower Mesosphere (USLM))

- **Unevaluated**: the performance of the reanalysis product with respect to this diagnostic or variable has not been examined in this report or by previous studies

It is noted that many figures in this report use the S-RIP colour definitions for reanalysis datasets (see *Appendix A*). Note, however, that some figures use different colours; thus, the readers should always refer to the legends of the figures to distinguish reanalyses by colours.

Chapter 1 - Introduction: The S-RIP motivation, goals, rationale, and report structure are described. See also *Fujiwara et al.* (2017a).

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 execution streams and archived data products. This chapter covers much of the same material as *Fujiwara et al.* (2017a), but in more detail and with some additions and corrections included. An extended electronic-only version of *Chapter 2* (denoted Chapter 2E) is also available as an online supplement to this report (through **https://s-rip.ees.hokudai.ac.jp/** and **https://s-rip.github.io**).

Chapter 3 - Overview of temperature and winds: This chapter evaluates major dynamical variables (*e.g.*, zonal mean temperature, zonal mean wind) of all the recent and past reanalyses on standard pressure levels. This evaluation uses monthly mean and 2.5° zonal mean data sets and spans the satellite era from 1979 - 2014.

The first key plot shows the homogeneity (or in many cases inhomogeneity) of each reanalysis with respect to pressure over the time period of the reanalysis. Then, key plots of the ensemble climatological means and individual reanalysis anomalies from these means are presented. 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, rocketsondes, and non-assimilated satellite data. Additionally, the chapter presents how the more recent reanalyses have progressed over time to greater agreement among themselves, especially with the assimilation of GNSS-RO data. This chapter is an extended version of *Long et al.* (2017).

Chapter 4 - Overview 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-Biennial Oscillation (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 is covered in the later, more process-oriented 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. This chapter is an extended version of *Davis et al.* (2017).

Chapter 5 - Brewer-Dobson circulation: This chapter focuses on evaluation and comparison of the stratospheric circulation, using diagnostics based on the residual mean meridional mass streamfunction (*e.g.*, tropical upwelling), and stratospheric transport tracers such as the age-of-air (AoA). Off-line chemistry transport models in Eulerian and Lagrangian frameworks are used to compute tracer and trajectory diagnostics for more recent reanalyses. Results are compared to those from observation-based datasets derived from satellite, ground-based, balloon, and aircraft observations of long-lived tracers such as SF_6, CO_2, and N_2O. Particular attention is given to comparing past trends in AoA from the different reanalyses with several model simulations.

Chapter 6 - Extratropical stratosphere-troposphere coupling: This chapter covers the representation of dynamical coupling between the troposphere and stratosphere in the reanalyses. It focuses on the coupling between the stratospheric polar vortex and the troposphere on daily to intraseasonal time scales, and how this short-term variability is modulated on interannual time scales, *e.g.*, by El Niño Southern Oscillation (ENSO), the QBO, and stratospheric ozone loss. In particular, dynamical metrics associated with Sudden Stratospheric Warming (SSW) events are considered, including changes in heat and momentum fluxes, blocking events, the meridional circulation, and vertical coupling of the zonal mean circulation as characterized by the annular modes. In addition, alternative strategies for characterizing SSWs are considered. Reanalysis uncertainty, *i.e.*, the spread between reanalyses, is contrasted with sampling uncertainty associated with natural variability; in most cases, uncertainty in stratospheric-tropospheric coupling metrics is dominated by the latter. The utility of surface and conventional-input reanalyses is also explored.

Chapter 7 - Extratropical Upper Troposphere and Lower Stratosphere (ExUTLS): This chapter evaluates the processes in the UTLS specifically in the extratropics. Only the most recent reanalyses have resolution adequate to represent many ExUTLS processes, so older reanalyses are not analyzed. Diagnostics include characterization of the tropopause based on different definitions (including multiple tropopauses, vertical structure, comparison of temperature-gradient based tropopause characteristics with radiosonde observations, *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, assimilated UTLS ozone from the more recent reanalyses is evaluated, including diagnostics of dynamically-driven column ozone variations, evidence of STE and mixing, and the relationships of ozone diagnostics to the dynamical variability. This chapter also includes comparisons of assimilated UTLS ozone with satellite observations.

Chapter 8 - Tropical Tropopause Layer (TTL): This chapter evaluates 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 vertical temperature profile, tropopause levels, and the level of zero radiative heating, is analysed. Diagnostics related to clouds and convection in the TTL include cloud fraction, cloud water content, and outgoing longwave radiation. The chapter takes 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 the South Asian Summer Monsoon in the reanalyses are evaluated.

Chapter 9 - Quasi-Biennial Oscillation (QBO): The diagnostics in this chapter include analysis of the tropical QBO in zonal wind and temperature, tropical waves and the QBO zonal momentum budget, and extra-tropical teleconnections of the QBO. Observations used for validation include operational and campaign radiosondes, and satellite observations from GNSS-RO, HIRDLS, SABER, COSMIC and AIRS.

Chapter 10 - Polar processes: This chapter focuses on microphysical and chemical processes in the winter polar lower stratosphere, such as polar stratospheric cloud (PSC) formation; denitrification and dehydration; heterogeneous chlorine activation and deactivation; and chemical ozone loss. These are "threshold" phenomena that depend critically on meteorological conditions.

A range of diagnostics is examined to quantify differences between reanalyses and their impact on polar process studies, including minimum lower stratospheric temperatures, area and volume of stratospheric air cold enough to support PSC formation, maximum latitudinal gradients in potential vorticity (a measure of the strength of the winter polar vortex), area of the vortex exposed to sunlight each day, vortex break-up dates, and polar cap average diabatic heating rates. For such diagnostics, the degree of agreement between reanalyses is an important direct indicator of the systems' inherent uncertainties, and comparisons to independent measurements are frequently not feasible. For other diagnostics, however, comparisons with atmospheric observations are very valuable. The representation of small-scale temperature and horizontal wind fluctuations and the fidelity of Lagrangian trajectory calculations are evaluated using observations obtained during long-duration superpressure balloon flights launched from Antarctica. Comparisons with satellite measurements of various trace gases and PSCs are made to assess the thermodynamic consistency between reanalysis temperatures and theoretical PSC equilibrium curves. Finally, to explore how the spatially and temporally varying differences between reanalyses interact to affect the conclusions of typical polar processing studies, simulated fields of nitric acid, water vapour, several chlorine species, nitrous oxide, and ozone from a chemistry-transport model driven by the different reanalyses for specific Arctic and Antarctic winters are compared to satellite measurements.

Chapter 11 - Upper Stratosphere and Lower Mesosphere (USLM): This chapter focuses on the uppermost levels in the reanalyses, where assimilated data sources are most sparse. The first part of the chapter includes a brief discussion of the effects of the model top and physical parameterizations relevant to the USLM. Long-term signatures of discontinuities in data assimilation and variability among reanalyses are then presented. A climatology of the basic state variables of temperature, horizontal winds, and residual circulation velocities is given. The climatology includes estimates of variability among the reanalyses. Annual cycles highlight the dependence of reanalysis difference on time of year. We then document dominant modes of variability in the reanalyses in the tropical regions and at high latitudes, and longer-term variability including solar cycle, volcanic, ENSO, and QBO signals. The tropical Semi-Annual Oscillation (SAO), the middle-atmosphere Hadley circulation, and the occurrence of inertial instability are compared among the reanalyses. High latitude processes considered include polar vortex variability and extreme disruptions therein observed during "elevated stratopause" events. Planetary wave amplitudes are quantified and compared to observations. The chapter ends with a comparison of solar atmospheric tides, 2-day wave amplitudes, and 5-day wave amplitudes in the USLM.

Chapter 12 - Synthesis summary: This chapter summarizes the key findings and the common patterns across the report, and provides suggestions as to the appropriateness of individual reanalyses for studies of particular atmospheric processes. It provides 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; **Figure 1.2**), 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; **Figure 1.2**), 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.

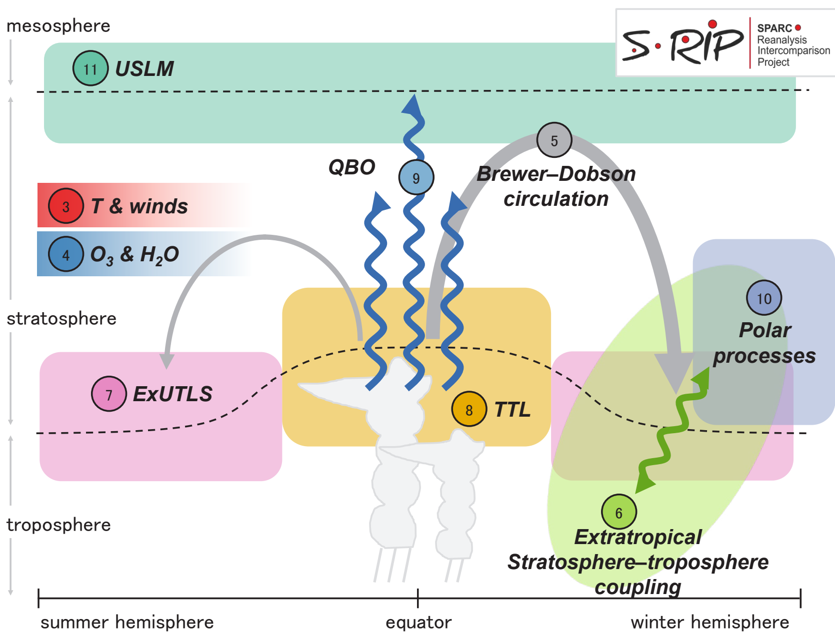

Figure 1.1: *Schematic illustration of the atmosphere showing the processes and regions that are covered in this report. The numbers are the chapter numbers. Domains approximate the main focus areas of each chapter and should not be interpreted as strict boundaries. Chapters 3 and 4 cover the entire domain. (Updated from Fujiwara et al., 2017a.)*

Figure 1.2: *Photographs from (left) the 8th SPARC Data Assimilation Workshop at Brussels in 2011 and (right) the 9th SPARC Data Assimilation workshop at Socorro in 2012.*

The 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; **Figure 1.3**). 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, two side meetings were held during the SPARC General Assemblies (Queenstown, New Zealand, in January 2014; and Kyoto, Japan, in October 2018), and four annual workshops were held (**Figure 1.4**). 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 (*Fujiwara et al.*, 2017b). The 2017 workshop was hosted by Beatriz Monge-Sanz and Rossana Dragani at the ECMWF, Reading, UK in October 2017 (*McCormack et al.*, 2018). The 2014, 2015, 2016, and 2017 workshops were co-organized with Quentin Errera (and John McCormack for the 2017 one) and were held at the same place in the same week as the SPARC Data Assimilation workshops, with a one-day joint session. In June 2018, an S-RIP chapter-lead meeting was hosted by Gloria Manney and held at the NorthWest Research Associates (NWRA), Boulder, USA (**Figure 1.5**).

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. In October 2015, Jonathon Wright was assigned as a co-editor of the S-RIP Report 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, now in Germany), Simon Chabrillat (Belgium), Sean Davis (USA), Yulia Zyulyaeva (Russia; until October 2014), Michaela Hegglin (UK), Kirstin Krüger (Germany, now in Norway), Craig Long (USA), Susann Tegtmeier (Germany, now in Canada), Gloria Manney (USA), Lesley Gray (UK; since November 2015), and Masatomo Fujiwara (Japan).

Each reanalysis centre also has designated a contact who is involved in S-RIP and whose presence is vital to ensure the two-way flow of knowledge between researchers participating in S-RIP 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).

Figure 1.3: *Figure 1.3. Photograph from the S-RIP Planning Meeting at Exeter in 2013.*

Figure 1.4: *Photographs from (top left) the 2014 S-RIP workshop at NOAA at College Park in the USA, (top right) the 2015 workshop at Paris, France, (bottom left) the 2016 workshop at Victoria, Canada, and (bottom right) the 2017 workshop at ECMWF at Reading, UK. These four workshops were held jointly with the SPARC Data Assimilation workshops, and these photographs were taken on the joint-session day.*

Each chapter of the report selected co-leads who organised the production of relevant diagnostics and the chapter writing, along with several contributors. The chapter co-leads are listed in **Table 1.2**.

The project has been monitored by the S-RIP co-leads via email communications with the chapter co-leads. Full S-RIP workshops have been held annually (see *Section 1.4*) to discuss emerging scientific results, the current status of each chapter, planning of evaluations, writing of papers, and completion of chapters. Individual chapter workshops were also held, usually jointly with other relevant workshops and conferences. The latest project information has been disseminated through the S-RIP website (at **https://s-rip.ees.hokudai.ac.jp**; being migrated to **https://s-rip.github.io**), 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 1.6**). A virtual machine for data processing and a group workspace for storing data have been provided by the British Atmospheric Data Centre (BADC) of the UK Centre for Environmental Data Analysis (CEDA), as negotiated by James Anstey and Lesley Gray. S-RIP common grid files have been archived at a zenodo site (**https://zenodo.org/record/3754753**; **https://doi.org/10.5281/zenodo.3754753**). A CFSR/CFSv2 model level data set has been converted to netCDF format using the High Resolution Initial Conditions (HIC) binary files and forecast files that are archived by NOAA's NCEI (**https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/climate-forecast-system-version2-cfsv2**; the converted data files are available upon request from Sean M. Davis and Karen H. Rosenlof at NOAA). Zonal-mean data sets prepared for S-RIP are archived at the CEDA (Martineau *et al.*, 2018). These include dynamical variables and derived quantities prepared by Patrick Martineau (**https://doi.org/10.5285/b241a7f536a244749662360bd7839312**) as well as heating rates prepared by Jonathon Wright (**https://doi.org/10.5285/70146c789eda4296a3c3ab6706931d56**).

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 (EGU).

Figure 1.5: *Photograph from the 2018 S-RIP chapter-lead meeting at NWRA at Boulder, USA.*

***Table 1.2:** Chapter titles and co-leads.*

	Title	Co-leads
1	Introduction	Masatomo Fujiwara, Gloria Manney, Lesley Gray, Jonathon Wright
2	Description of the Reanalysis System	Jonathon Wright, Masatomo Fujiwara, Craig Long
3	Overview of Temperature and Winds	Craig Long, Masatomo Fujiwara
4	Overview of Ozone and Water Vapour	Michaela Hegglin, Sean Davis
5	Brewer-Dobson Circulation	Beatriz Monge-Sanz, Thomas Birner
6	Extratropical 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)	James Anstey, Lesley Gray
10	Polar Processes	Michelle Santee, Alyn Lambert, Gloria Manney
11	Upper Stratosphere and Lower Mesosphere (USLM)	V. Lynn Harvey, John Knox
12	Synthesis Summary	Masatomo Fujiwara, Gloria Manney, Lesley Gray, Jonathon Wright

The editors of this special issue are Peter Haynes, Gabriele Stiller, and William Lahoz. Later (in January 2017), this special issue was extended to an inter-journal special issue in ACP and Earth System Science Data (ESSD), another journal produced by the EGU. Gabriele Stiller is the special-issue editor for ESSD. This special issue is one of the ways to encourage researchers to publish S-RIP related works. As of 9 November 2021, there are 48 published papers in this special issue.

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 Dynamical Variability (DynVar), the SPARC QBO initiative (QBOi), and the Observed Composition Trends and Variability in the UTLS (OCTAV-UTLS) activities. 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 several 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 S-RIP report, thus enhancing opportunities for coordination and collaboration.

***Figure 1.6:** A snapshot of the front page of the S-RIP website (7 May 2021).*

S-RIP has been publicised at meetings of the WMO Working Group on Numerical Experimentation (WGNE; **http://www.wmo.int/pages/prog/arep/wwrp/rescrosscut/resdept_wgne.html**; now at **http://wgne.meteoinfo.ru/**), where the project was well received and prompted discussion about a parallel WGNE activity focused on tropospheric reanalyses. In 2016, the WCRP Task Team for Intercomparison of ReAnalyses (TIRA; **https://reanalyses.org/atmosphere/wcrp-task-team-intercomparison-reanalyses-tira/**) was established under the WCRP Data Advisory Council (WDAC), and one of the S-RIP co-leads (Masatomo Fujiwara) became a member (and later, a co-lead) of TIRA as the SPARC liaison. Finally, activities associated with S-RIP have the potential to be important components of the WMO Global Framework for Climate Services (GFCS; **http://www.wmo.int/gfcs/**; now at **https://gfcs.wmo.int**).

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Appendix A: S-RIP colour definitions

Many figures in this report use the S-RIP colour definitions for reanalysis datasets shown Table A.1. Note that some figures use different colours; thus, the readers should always refer to the legends of the figures to distinguish reanalyses by colours.

Table A.1: *The S-RIP colour definitions for reanalysis and other datasets*

Reanalyses	Red, Green, Blue	Hexadecimal	Notes
MERRA-2	226, 31, 38	#E21F26	
MERRA	246, 153, 153	#F69999	
ERA-Interim	41, 95, 138	#295F8A	
ERA5	95, 152, 198	#5F98C6	
ERA-40	175, 203, 227	#AFCBE3	
JRA-55	114, 59, 122	#723B7A	
JRA-55C, JRA-55AMIP	173, 113, 181	#AD71B5	See *Chapter 2*
JRA-25/JCDAS	214, 184, 218	#D6B8DA	
NCEP-NCAR R1	245, 126, 32	#F57E20	
NCEP-DOE R2	253, 191, 110	#FDBF6E	
20CR v2c	236, 0, 140	#EC008C	See *Chapter 2*
20CR v2	247, 153, 209	#F799D1	See *Chapter 2*
CERA-20C	0, 174, 239	#00AEEF	
ERA-20C	96, 200, 232	#60C8E8	
CFSR/CFSv2	52, 160, 72	#34A048	include CFSv2 if post-2010 data are included
REM	179, 91, 40	#B35B28	reanalysis ensemble mean
Other	255, 215, 0	#FFD700	
Observations	0, 0, 0	#000000	observations - black
Other observations	119, 119, 119	#777777	observations - grey

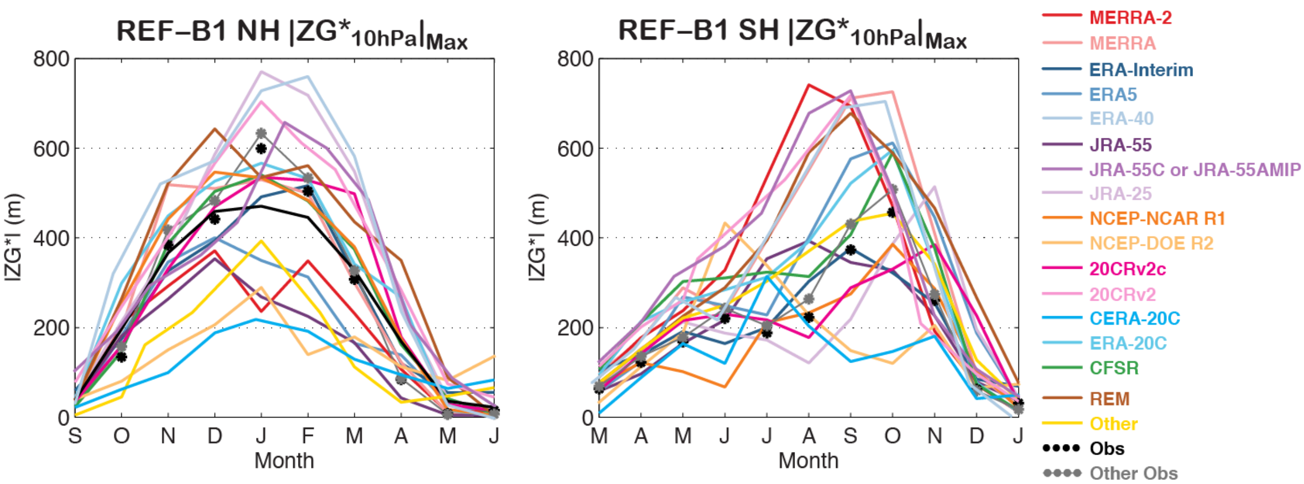

Figure A.1: *An example showing all the colours in Table A.1.*

Major abbreviations and terms

20CR	20th Century Reanalysis
AIRS	Atmospheric Infrared Sounder
AoA	Age of Air
BADC	British Atmospheric Data Centre
CCMI	Chemistry-Climate Model Initiative
CEDA	Centre for Environmental Data Analysis
CERA-20C	ECMWF 10-member ensemble of coupled climate reanalyses of the 20th century
CFSR	Climate Forecast System Reanalysis of the NCEP
CFSv2	Climate Forecast System version 2
CIRES	Cooperative Institute for Research in Environmental Sciences (NOAA and University of Colorado Boulder)
COSMIC	Constellation Observing System for Meteorology Ionosphere and Climate
DOE	Department of Energy
DynVAR	Dynamical Variability
ECMWF	European Centre for Medium-Range Weather Forecasts
EGU	European Geosciences Union
ENSO	El Niño Southern Oscillation
ERA-20C	ECMWF 20th century reanalysis
ERA-40	ECMWF 40-year reanalysis
ERA-Interim	ECMWF interim reanalysis
ERA5	the fifth major global reanalysis produced by ECMWF
ExUTLS	Extra-tropical Upper Troposphere and Lower Stratosphere
GFCS	Global Framework for Climate Services
GNSS-RO	Global Navigation Satellite System Radio Occultation
HIC	High Resolution Initial Conditions
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
JRA-55AMIP	Japanese 55-year Reanalysis based on AMIP-type simulations
JRA-55C	Japanese 55-year Reanalysis assimilating Conventional observations only
MERRA	Modern Era Retrospective-Analysis for Research and Applications
MERRA-2	Modern Era Retrospective-Analysis for Research and Applications, Version 2
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction of the NOAA
NCEP-DOE R2	Reanalysis 2 of the NCEP and DOE
NCEP-NCAR R1	Reanalysis 1 of the NCEP and NCAR
netCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
R1	Reanalysis 1 of the NCEP and NCAR
R2	Reanalysis 2 of the NCEP and DOE
OCTAV-UTLS	NorthWest Research Associates
NWRA	NorthWest Research Associates
PSC	Polar Stratospheric Cloud

QBO	Quasi-Biennieal Oscillation
QBOi	QBO initiative
REM	Reanalysis Ensemble Mean
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
SPARC-DA	SPARC Data Assimilation working group
S-RIP	SPARC Reanalysis Intercomparison Project
SSG	Scientific Steering Group
SSWs	Sudden Stratospheric Warmings
STE	Stratosphere-Troposphere Exchange
TIRA	Task Team for Intercomparison of ReAnalyses of the WCRP
TTL	Tropical Tropopause Layer
USLM	Upper Stratosphere and Lower Mesosphere
UTLS	Upper Troposphere and Lower Stratosphere
WCRP	World Climate Research Programme
WDAC	WCRP Data Advisory Council
WGNE	WMO Working Group on Numerical Experimentation
WMO	World Meteorological Organization