Planning and Proposal for Phase 2 of the SPARC-Reanalysis Intercomparison Project (S-RIP)

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The first phase of the SPARC-Reanalysis Intercomparison Project (S-RIP) culminated with the publication of the S-RIP final report in January 2022 (SPARC, 2022). In addition to overview chapters on "Temperatures and Winds" and "Ozone and Water Vapour", the report contained seven chapters summarising intercomparisons of process-oriented diagnostics for reanalyses that were available for sufficient time before completion of the report; these chapters covered major processes in the upper troposphere through the middle atmosphere (illustrated in Figure 3) comprising: the Brewer-Dobson Circulation, Extratropical Stratosphere-Troposphere Coupling, Extratropical Upper Troposphere and Lower Stratosphere, Tropical Tropopause Layer, Quasi-Biennial Oscillation, Polar Processes, and Upper Stratosphere and Lower Mesosphere. Many of the results summarised in these chapters were also reported in the peer-reviewed literature, including 53 (at this writing) papers in the ACP/ESSD S-RIP Special Issue. Broad conclusions and recommendations from S-RIP include:

- More recent reanalyses generally outperform earlier products, with some earlier reanalyses (*e.g.*, NCEP-NCAR R1 and NCEP-DOE R2) being deprecated as unsuitable for most diagnostics.
- Conventional-input and pre-satellite (*i.e.*, before 1979) reanalyses are useful for many diagnostics but should be carefully validated against full-input satellite era products.
- All reanalyses show temporal discontinuities; trends and climate shifts identified in reanalysis products should be carefully validated and justified.
- Reanalysis products on model levels should be used for all studies when sharp vertical gradients or fine-scale vertical features are involved.
- Several quantities are handled and reported differently by different reanalyses.

And, most critically for looking forward, studies relying on reanalysis products should use multiple reanalyses whenever possible. If there is a single most critical lesson we have learned from S-RIP it is that the need for systematic reanalysis intercomparisons is ongoing. S-RIP has also been extremely successful in fostering communications between users and providers / developers of reanalyses – which is critical not only to ensuring that reanalysis products are used appropriately but also to continuing the cycle of improving reanalyses. It is because of the great success of S-RIP that a new phase of this activity is clearly needed. As the first phase of S-RIP was concluding, we therefore began planning and gathering input for a new phase of this SPARC activity. Below, we summarise planning activities to date and present a proposal for S-RIP Phase 2 (S-RIP2).

S-RIP Phase 2 Planning Meetings

In addition to polling current S-RIP participants (particularly chapter co-leads for the S-RIP report) and soliciting input in S-RIP overview talks in the past couple of years, three 1 - 2 hour sessions were organised in fall 2022 in time zones friendly to the Americas (hybrid side meeting during the SPARC General Assembly), Asia (online, 10 Nov 2022, 4 - 5UTC), and Europe (online, 10 Nov 2022, 13 - 14UTC). These inquiries and meetings included a summary of S-RIP so far, updates on new products from the reanalysis centres (see below for further information), and discussion of ideas for S-RIP Phase 2. The sections below give an overview of S-RIP2 plans based on the synthesis of these discussions.

S-RIP Phase 2 Proposal – Organisation & Structure

The consensus of input from the discussions mentioned above reflects the belief that the large amount of time spent in preparing a report like SPARC (2022) might be better spent on conducting studies, enhancing communications on shorter timescales through online activities, building an enhanced web presence, and providing summary reports annually (or more often, if needed) on published papers and new results.

Therefore, we plan to organise S-RIP2 around "focus topics" rather than "chapters", with the organisation of these being similar to that of the chapters for the S-RIP report, that is, 2 - 3 topical co-leads who entrain numerous participants as contributors and coordinate efforts and foster communications among people focusing on those topics. Several chapters of the S-RIP Report were co-led by one senior scientist and one early career scientist (ECS), and we hope to continue this model in S-RIP2 by building topical leadership teams containing senior scientists and ECS.

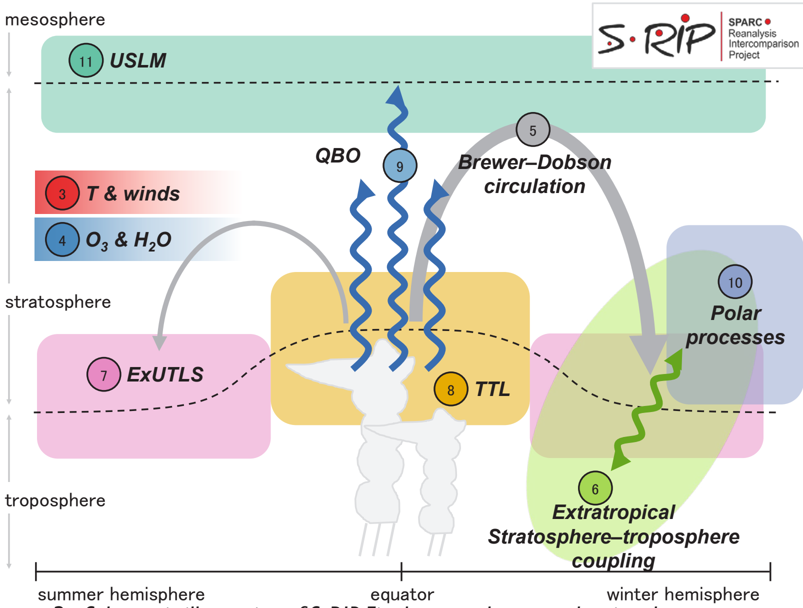

***Figure 3:** Schematic illustration of S-RIP Final report chapters, showing the processes and regions covered in Chapters 5 through 11. Other chapters include the Introduction (Chap. 1), Description of the Reanalysis Systems (Chap. 2), and Synthesis Summary (Chap. 12). From Figure 1.1 of SPARC (2022)*

S-RIP leadership will continue to be organised with a few activity co-leads coordinating the topical co-leads and taking the lead on communications with the SPARC office, organising workshops and seminars, providing regular "S-RIP News" reports, and in general coordinating all activities of the S-RIP community. Currently, Jonathon Wright is expected to be an ongoing project co-lead for Phase 2, with Masatomo Fujiwara and Gloria Manney gradually (likely over a period of up to a few years) phasing out their leadership roles as additional new co-leads are entrained. Because the scope of S-RIP2 will be even larger than that of the first phase, we anticipate a more formal division of responsibilities among the co-leads; for example, overseeing tasks such as communications with the S-RIP community, overseeing development and maintenance of web-based activities, coordinating between linked/overlapping focus topics, and coordinating joint work with other SPARC activities are some of the tasks that may be assigned to different co-leads for primary responsibility to spread the workload. As this new phase of S-RIP develops, we may find that more than three co-leads are ideal.

A particular focus of S-RIP2 will be an enhanced online presence; based on the discussions so far this may include:

- Detailed information on the reanalysis systems and models, such as that in Chapter 2 of SPARC (2022), will be moved online. This will allow us to provide much more complete information and to update/add information on new reanalyses quickly.
- In addition to linking to the special issue papers, the website will feature highlights of recently published S-RIP2-related papers (including those in the special issue and in other journals).
- We plan to organise regular webinars, with a wide variety of topics including talks on recent papers, discussions/panels on general S-RIP2 planning and progress, talks describing new or upcoming reanalysis systems, talks by/discussions with representatives of related SPARC activities, *etc.*
- To further define what our "web-base" should look like, we will be forming a task team to develop a detailed plan.

Because we are not working towards a single final report, the journal special issue for S-RIP2 (as well as peer-reviewed papers in other journals) will be one of the primary sources of detailed information on intercomparison studies and an organising focus for the activity. The ACP and WCD (with ESSD expected to be added) special issue "The SPARC Reanalysis Intercomparison Project (S-RIP) Phase 2" opened for submissions on 1 January 2023.

Because there are continually studies being submitted/published focusing on new reanalysis evaluations and intercomparisons, we have opened this special issue in advance of ramping up all activities for S-RIP2, and expect to see submissions during the transition to the new phase.

Table 1: Examples of global reanalysis systems to be evaluated in S-RIP Phase 2

Reanalysis System	Period	Source	Focus	Grid
JRA-3Q	1947–	Japan (JMA)	global atmosphere	40km, 0.01hPa top
CRA-40	1979–2018	China (CMA)	global atmosphere	34km, 0.27hPa top
R21C	1998–2025	USA (NASA)	global atmosphere	25km, 0.01hPa top
CORe (ensemble, conventional observations)	1950–	USA (NOAA)	global atmosphere	70km, 0.2hPa top
CAFE60 (ensemble)	1960–	Australia (CSIRO)	global atmosphere + ocean	200km, ~3hPa top

Table 2: Examples of chemical reanalysis systems to be evaluated in S-RIP Phase 2

Reanalysis	Period	Source	Focus	Grid
CAMS-EAC4	2003–	ECMWF	whole atmosphere	0.75deg, 60L
BRAM2	2004–2019	BIRA-IASB	stratosphere/ UTLS	2.5x3.75deg, 37L
M2_SCREAM	2004–	NASA/ GMAO	stratosphere/ UTLS	~50km, 72L
TCR2	2005–2019	NASA/ JPL	troposphere	1.1deg, 32L
R21C-CHEM	1998–2025	NASA/ GMAO	whole atmosphere	25km, 72L

S-RIP Phase 2 Proposal – Reanalyses

Most of the reanalysis centres whose products were evaluated in S-RIP have new reanalyses that have started production. ECMWF's ERA5 reanalysis became available late in the process of the first phase of S-RIP, so only a small subset of the diagnostics were evaluated for ERA5. Thus, one focus of S-RIP2 will be to fully evaluate ERA5. This will be especially informative for diagnostics (*e.g.*, for the UTLS, gravity waves, and mixing processes) of smaller (sub-synoptic or fine vertical scale) processes given the improved resolution (horizontal, vertical, and temporal) of ERA5 over the previous generation of reanalyses. Table 1 lists several of the other global reanalyses that are either in production or starting production very soon that will be evaluated in S-RIP2.

Chemical reanalyses have become much more mature since the start of S-RIP, and there are now several that are publicly available and widely used. One new focus of S-RIP2 will thus be evaluation of these and other upcoming chemical reanalyses. Table 2 lists several of the current chemical reanalyses and those starting production soon that will be evaluated in S-RIP2; the current CAMS-EAC4, BRAM2, TCR-2, and M2-SCREAM reanalyses are described by Inness *et al.* (2019), Errera *et al.* (2019), Miyazaki *et al.* (2020), and Wargan *et al.* (2023), respectively. We also plan to evaluate other planned chemical reanalyses as they become available. In particular, BRAM2 and TCR-2 were run using ERA-Interim for the meteorological fields, and thus end with August 2019 when ERA-Interim was discontinued. The groups producing both of these plan new versions to (along with other improvements) be driven with ERA5.

In addition to these reanalyses, there is currently much work on very high-resolution regional reanalyses for studying sub-mesoscale to synoptic-scale processes in greater detail. As more regional reanalyses become available, systematic evaluation and intercomparison of these will become important, as will comparison with global reanalyses to understand how adequate or inadequate the global reanalyses' representation of these smaller scale processes is.

As in the first phase, in S-RIP2 we will produce systematic documentation for all the reanalyses evaluated; moving this to an online platform for S-RIP2 will allow us to link in more comprehensive information on features of the reanalyses that may be of interest for specific diagnostics, and will facilitate maintaining "living" documentation that can be updated in near real time.

S-RIP Phase 2 Proposal – Continuing and New Focus Topics

All of the S-RIP report chapters evaluating process-oriented diagnostics (Chapters 5 through 11 described above) focus on topics for which evaluation of new and upcoming reanalyses will be critical to inform scientific studies. Most immediately, as noted above, ERA5 has not been fully evaluated for most of these diagnostics because of the timing of its release with respect to the schedule for completing the S-RIP Report.

Many of those chapters (as well as Chapter 4, Overview of Ozone and Water Vapour) evaluated diagnostics for which it will be helpful to include the chemical reanalyses, including Chapter 5 (BDC), Chapter 7 (ExUTLS), Chapter 8 (TTL), and Chapter 10 (Polar Processes). In addition, several new focus topics have been proposed and are expected to be included in S-RIP2. A partial list of topics to be included follows, with notes on relationships to S-RIP Report chapters:

- Stratospheric Polar Vortex: This topic would build on Chapter 10 of the S-RIP Report but also include diagnostics related to the general evolution of the stratospheric polar vortex (dynamics) and wintertime polar transport in relation to the vortex throughout the stratosphere.

- Stratosphere-troposphere coupling and teleconnections: This would build on Chapters 6 and 9 of the S-RIP report and has links to DynVar and SATIO-TCS. There are also many new areas of study related to teleconnections involving stratospheric pathways, e.g., interplay of tropospheric and stratospheric pathways for ENSO and MJO (*e.g.*, Lee *et al.*, 2019; Domeisen *et al.*, 2020; and references therein).

- Representations of Tropospheric Circulations, Surface Climate/Weather Extremes, and their UTLS and Middle Atmosphere Connections: There is much recent work exploring the connections of the middle atmosphere and UTLS circulation to extreme weather events at the surface, so a focus on reanalysis representation of such events (e.g., cold air outbreaks and regional variations in the triggers for these; extreme heat events such as the Pacific Northwest heat dome in 2021; extreme precipitation events). Several recent papers have compared reanalysis representation of aspects of tropospheric circulation including low level winds near Antarctica (Caton Harrison *et al.*, 2022), decadal variability of Rossby wave packets (Fragkoulidis, 2022), and signatures of heat waves in Rossby wave spectra (Strigunova *et al.*, 2022). This focus area also has links to DynVar and SNAP.

- Upper stratosphere / lower mesosphere: This will extend Chapter 11 of the S-RIP Report. For that report, there were few reanalyses available that provided data much beyond the stratopause (only MERRA and MERRA-2 had tops extending as high as 0.01hPa), but many of the new and forthcoming reanalyses (including ERA5) have higher tops, which will allow more comprehensive evaluation of representation of this region in reanalyses.

- Stratospheric and UTLS composition: This builds on Chapters 4, 7, 8, and 10 of the S-RIP report, and has links to CCMI, OCTAV-UTLS, and LOTUS.

- Monsoon Circulations: This would expand Chapter 8.8 (Asian Summer Monsoon) of the S-RIP Report to evaluate many important diagnostics and relationships related to the Asian summer monsoon, and also explore diagnostics of other monsoon circulations including the North American monsoon, Australian monsoon, and South American monsoon. This topic has links to ACAM and AeroCom.

- Brewer-Dobson circulation variability and change: This would build on Chapter 5 of the S-RIP Report.

- Gravity Waves: When S-RIP began, few reanalyses had the resolution or sophistication of parameterizations to make detailed evaluation and comparison of representation of gravity waves a priority. Since that time, some reanalyses (especially ERA5) have sufficiently fine resolution to resolve some gravity waves. Thus, the time has come for a comprehensive evaluation of reanalysis representation of gravity waves.

- Evaluations of reanalysis uses, misuses, and recommendations for model evaluation: While this is not a topic on specific atmospheric diagnostics, one of the critical roles of S-RIP was, and of S-RIP2 will be, to provide recommendations for appropriate use of reanalyses for the diagnostics in the topical focus areas, including noting reanalyses that are not generally recommended for scientific use (*e.g.*, the deprecation of NCEP-R1 and NCEP-R2 in SPARC, 2022). Because of the increasing scope of S-RIP2, having a team within the activity that focuses on tools, methods, and recommendations will facilitate fulfilment of this role. One activity planned for this topic is to evaluate and apply the Earth System Model Evaluation Tool (ESMValTool) (Weigel *et al.*, 2021, and references therein).

A particular aim of the open-source ESMValTool is to raise the standards for model evaluation by providing well documented source code, scientific background documentation of the diagnostics and metrics included, as well as a detailed description of the technical infrastructure. The motivations for developing and deploying this type of tool apply equally well to evaluation of reanalyses as they do to Earth system models.

It will be obvious that there is a good deal of overlap between many of the topics listed above, as is inevitable since the physical system we are evaluating the representation of (the Earth's atmosphere) is a single coupled system. As plans for S-RIP2 mature, we may thus find that different divisions between focus areas make sense, or that some topics are so large that they will need to be split into multiple focus areas. In addition, one of the responsibilities of one or more S-RIP co-leads will be to oversee coordination of overlapping chapters. Most of the topics listed above will benefit from the evaluation of chemical reanalyses proposed for S-RIP2.

Summary

We have presented above a summary of our planning efforts and discussions for Phase 2 of the S-RIP Activity.

As part of this proposal, we encourage people to contact us with ideas for additional topics, for extension or specific analyses related to the topics listed above, and/or to express interest in participating in (including co-leading) any of the tropics or other activities (e.g., the web-base task team) mentioned above.

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