Broadening Systematic Reanalysis Intercomparisons in the SPARC-Reanalysis Intercomparison Project Phase 2 (S-RIP2): Chemical Reanalyses & Air Quality, Tropospheric Circulation, Extreme Events, and More

Sean M Davis, Gloria L Manney, Jonathon S Wright, Masatomo Fujiwara, Krzysztof Wargan, Mohamadou Diallo, Felix Plöger, K Emma Knowland, Brad Weir, and the S-RIP Team

S-RIP Phase 1 Overview

S-RIP is a SPARC Activity to:
- Compare reanalysis data sets for key diagnostics
- Identify and understand differences among reanalyses
- Provide guidance for using reanalyses in scientific studies
- Foster collaborations between reanalysis centers and the scientific community
- Contribute to future improvements in reanalyses

The S-RIP Phase 1 final report was published in January 2022: https://www.sparc-climate.org/sparc-report-no-10/

The S-RIP Special Issue of ACP and ESSD: https://www.atmos-chem-phys.net/special_issue829.html contains 53 papers with S-RIP Phase 1 results

Phase 1 Focused primarily on the upper troposphere and stratosphere (Figure 1, Table 1)

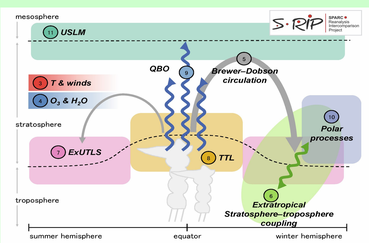

Figure 1: Schematic of S-RIP Final Report Chapters

	Chapter Title	Chapter Co-leads
1	Introduction	Masatomo Fujiwara, Gloria Manney, Lesley Gray
2	Description of the Reanalysis Systems	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	Thomas Birner, Beatriz Monge-Sanz
6	Extratropical Stratosphere-Troposphere Coupling	Edwin Gerber, Patrick Martineau
7	Extratropical UTLS	Cameron Homeyer, Gloria Manney
8	Tropical Tropopause Layer	Susann Tegtmeier, Kirstin Krüger
9	QBO	James Anstey, Lesley Gray
10	Polar Processes	Michelle Santee, Alyn Lambert, Gloria Manney
11	Upper Stratosphere Lower Mesosphere	Lynn Harvey, John Knox
12	Synthesis Summary	Fujiwara, Manney, Gray

Table 1: S-RIP Final Report Chapters and Chapter Co-leads

Among other key outcomes (see Chapter 12 of S-RIP Report), Phase 1 of S-RIP demonstrated that:
- Studies relying on reanalyses products should use multiple reanalyses whenever possible (especially for diagnostics that cannot be compared directly with observations)
- All reanalyses show discontinuities – trends derived from reanalysis products should be carefully validated and justified (eg, consistency among reanalyses and with physical expectations)
- Homogenized and continuing data records are essential for reanalysis production and evaluation
- **These and other recommendations argue strongly for an ongoing need for continuing and extending reanalysis comparisons**

S-RIP Phase 1 Examples -- Ozone

Reanalysis Ozone Overview

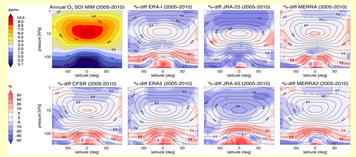

Figure 2, from Chapter 4: Comparison of annual zonal mean reanalysis ozone with the SPARC Data Initiative Multi-Instrument Mean. Recent reanalyses (especially ERA5, MERRA-2, CFSR) capture well the broad aspects of observed ozone distributions.

Tropical Tape Recorder from Reanalysis Winds

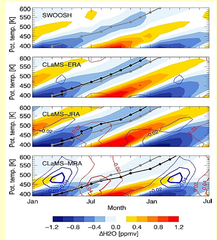

Figure 3, from Chapter 5: Signature of stratospheric "tape recorder" signal in water vapour in the SWOOSH multi-instrument data set, and based on simulations from the Lagrangian CLaMs model driven with ERA-Interim, JRA-55, and MERRA-2 winds. Reanalyses show significant differences in both the intensity and upward propagation of the tape recorder signal.

Ozone Evolution in the Lowermost Stratosphere

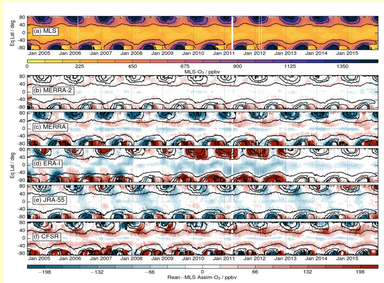

Figure 4, from Chapter 7: Microwave Limb Sounder (MLS) ozone in the lowermost stratosphere (390K isentropic surface) as a function of equivalent latitude and time, and differences between that and recent reanalyses. Only MERRA-2 and ERA-Interim assimilate MLS ozone, and ERA-Interim did so inconsistently (eg, none before 2008, a version not recommended for scientific use from mid-2009 through 2012). Even in the lowermost stratosphere shown here, largest differences among reanalyses arise from the reanalyses poorly representing Antarctic ozone depletion (which depends strongly on each model's parameterized heterogeneous chemistry).

Ozone in the Asian Summer Monsoon Circulation

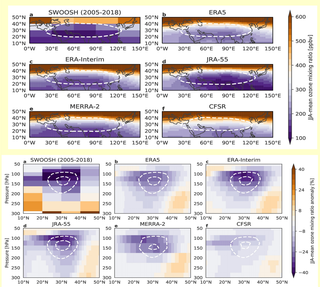

Figure 5, from Chapter 8: JJA ozone mixing ratios in the region of the Asian summer monsoon (ASM) anticyclone from the SWOOSH data set compared with that from recent reanalyses; top: maps at 100hPa; bottom: latitude/pressure cross-sections averaged over the 30–120E longitude region, covering the primary ASM region. None of the current reanalyses, even those assimilating MLS data, fully captures the ozone decrease in the ASM region.

S-RIP Phase 1 Examples -- Dynamics

Sudden Stratospheric Warmings

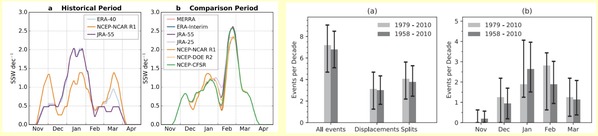

Figure 6, from Chapter 6: Frequency of sudden stratospheric warmings (SSWs), comparing satellite period (after 1979) with longer "historical" period. Pre-satellite era analysis from recent / current DAS are generally of good quality for large scale motions and can be used to reduce sampling uncertainty in measures of stratosphere-troposphere coupling.

Temperature and Wind Responses to Ozone Depletion

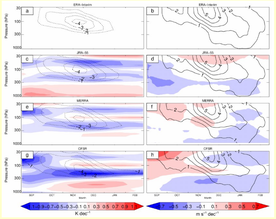

Figure 7, from Chapter 6: (left) Zonal mean temperature trends averaged over 60-90S for 4 reanalyses (dashed lines); shading shows differences of other reanalyses from ERA-Interim. (Right) Zonal mean zonal wind trends (contours); shading shows differences of other reanalyses from ERA-Interim. Large differences among reanalyses arise from poor representations of Antarctic ozone depletion, which depends strongly on parameterized heterogeneous chemistry.

ENSO Impact on Stratosphere-Troposphere Coupling

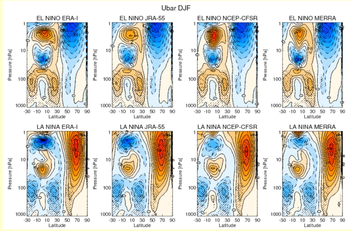

Figure 8, from Chapter 6: Composites of DJF average of monthly mean zonal mean zonal wind anomalies for (top) El Niño and (bottom) La Niña. Stippling indicates 95% significance level. Generally good agreement across reanalyses is found for El Niño and La Niña polar stratospheric responses, despite some differences in the tropics.

Trends in Upper Tropospheric Jets

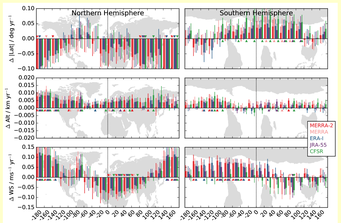

Figure 9, from Chapter 7: Bar charts of global polar jet and polar/subtropical jet separation trends as a function of longitude in 20-degree bins, showing five reanalyses for DJF. Bars show slopes of fits, error bars show the 1-σ uncertainty in slopes. Absolute value of latitude is used, so positive slopes indicate a poleward shift in both hemispheres. Triangles show cases where the slope is significant at the 95 % confidence level.

Upper Stratospheric Polar Vortex

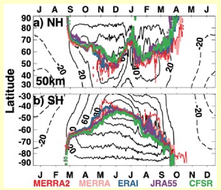

Figure 10, from Chapter 11: 2005--2015 mean polar vortex frequency (colored lines) of 50% (vortex is present 50% of the time) as a function of latitude and day of year at 1 hPa (~ 50 km) in the (a) NH and (b) SH in 5 reanalysis datasets. Months are shifted between hemispheres so that the winter is in the middle of both panels. Thin black background contours show MERRA-2 zonal mean winds every 20 m/s.

S-RIP2 Planning

S-RIP2 will extend many of the studies from Phase 1, including:
- Evaluation of new and forthcoming reanalyses (eg, complete evaluation of ERA5, evaluation of JRA-3Q)
- More comprehensive evaluation of ASM circulation and characterisation, as well at that of other monsoon regions
- More extensive comparisons of the upper stratosphere and mesosphere including newer reanalyses with higher tops

In addition, two major new / expanded focuses in S-RIP2 will extend many of the studies from Phase 1, including:
- Evaluation of tropospheric circulation (eg, blocking, Rossby-wave breaking, jets and storm tracks) in relation to both stratospheric influences and relationships to extreme weather events; this new focus extends and broadens evaluations in Chapters 6 and 7 of the S-RIP Report
- Evaluation of composition (including aerosol) reanalyses, both those focusing on upper tropospheric and stratospheric processes and those focusing on air quality (AQ) applications; this will broaden and expand evaluations from Chapters 4, 5, 7, 8, and 10 in the S-RIP report; expanded evaluations of tropospheric circulation will also be relevant to AQ studies.

Composition Reanalysis Example: M2-SCREAM

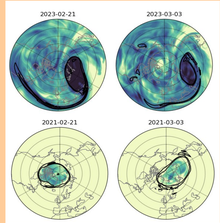

Figure 11: Middle stratospheric (700K) water vapour from the MERRA-2 Stratospheric Composition Reanalysis of Aura MLS (M2-SCREAM), on the same days of year in 2023 (top) and 2021 (bottom); both are during strong sudden stratospheric warmings (SSWs); the color range is the same in each panel – demonstrating the mixing of enhanced water vapour from the 15 January 2022 Hunga Tonga-Hunga Ha'apai eruption into the Arctic polar regions during the 2023 SSW.

Get Involved

Lesley Gray (Phase 1 Co-Lead); Masatomo Fujiwara (Phase 1&2 Co-Lead, fuji@ees.hokudai.afc.jp); Gloria Manney (Phase 1&2 Co-Lead, manney@nwra.com); Jonathon Wright (Phase 1 Report Editor & Phase 2 Co-Lead, jswright@tsinghua.edu.cn)

Some of the others also active in S-RIP2 planning:

Emma Knowland, k.e.knowland@nasa.gov
Kris Wargan, Krzysztof.Wargan-1@nasa.gov
Sean Davis, Sean.M.Davis@noaa.gov:
S-RIP2 Planning for composition reanalysis evaluations; Sean and Kris were also active in Phase 1

Felix Ploeger, f.ploeger@fz-juelich.de:
General S-RIP2 planning; UTLS dynamics and composition studies

Mohamadou Diallo, m.diallo@fz-juelich.de:
S-RIP2 Outreach & Capacity-building Coordinator; General Phase 2 planning; Brewer-Dobson Circulation Studies

We want to:

For Chemical Reanalyses:
- Gather information on existing and near-future composition reanalyses (in addition to BRAM-2/3, TCR-2/3, M2-SCREAM),
- Establish contacts with groups producing composition reanalyses and collaborate on evaluations and intercomparisons
- Entrain folks who are interested in helping evaluate chemical reanalyses

For Tropospheric Circulation Studies:
- Establish / extend collaborations with folks analyzing tropospheric circulation and extreme weather
- Entrain folks interested in reanalysis intercomparisons for such studies

Increase diversity of S-RIP2 participation, especially in the Global South, in the Southern Hemisphere, and in expanding participation of early career researchers

We invite all who are interested in any aspect of planning or participating in S-RIP2 to contact us and get involved!