# Summary and Highlights of the SPARC-Reanalysis Intercomparison Project

S·RIP — SPARC Reanalysis Intercomparison Project

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SPARC — Stratosphere-troposphere Processes And their Role in Climate

## The S-RIP Project: Overview and Outlook

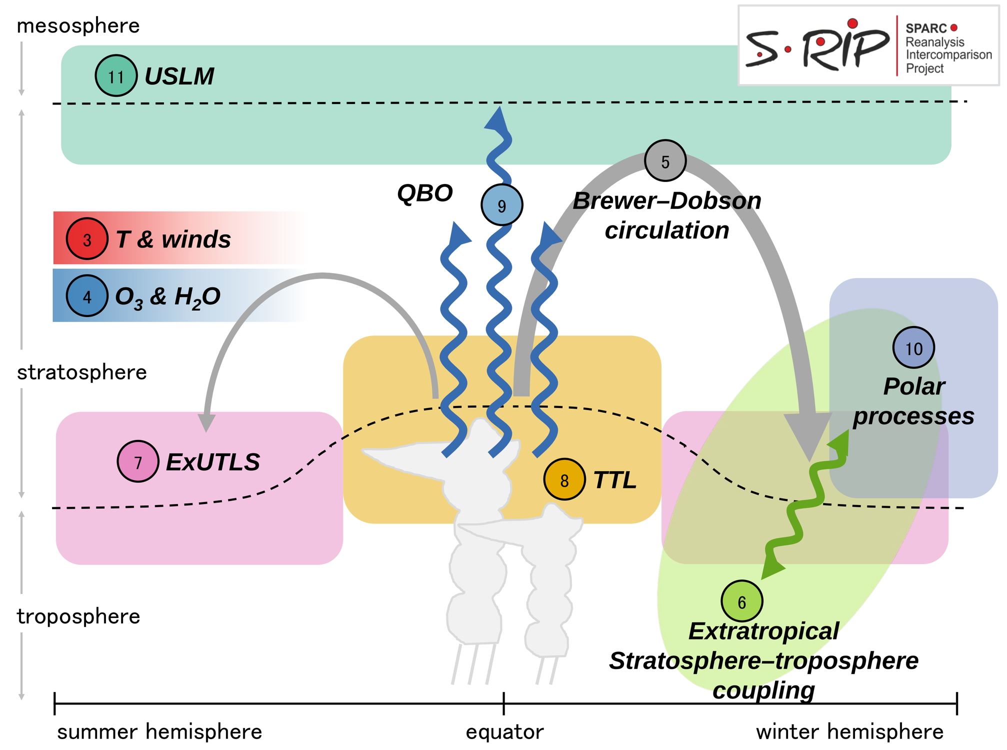


**Figure 1:** S-RIP Chapter Schematic

S-RIP is a coordinated SPARC-supported activity to:

- Compare reanalysis data sets for key diagnostics (emphasizing most recent reanalyses).
- Identify and understand the causes of differences amongst reanalyses.
- Provide guidance on the appropriate usage of various reanalysis products in scientific studies.
- Establish and foster collaborative links between reanalysis centres and the SPARC community.
- Contribute to future improvements in reanalysis products.

The S-RIP project is nearing completion, with the final report being readied for review in early 2019. Figure 2 lists the chapters and their lead authors:

| | 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 |

**Figure 2:** S-RIP Chapters and Lead Authors

The S-RIP project overview and details of reanalysis systems are found in:

Fujiwara, M., and Coauthors, 2017: Introduction to the SPARC Reanalysis Intercomparison Project (S-RIP) and overview of the reanalysis systems. *Atmos. Chem. Phys.*, **17**, 1417–1452, doi:10.5194/acp-17-1417-2017, URL `www.atmos-chem-phys.net/17/1417/2017/`.

Approximately 30 (and rising!) S-RIP related papers are published or in review in the S-RIP Special Issue of ACP and ESSD:
https://www.atmos-chem-phys.net/special_issue829.html

The following panels show highlights / key findings from each of the diagnostic chapters (Chapters 3 through 11).

S-RIP is facilitating communications between reanalysis centers and the user community. We not only provide the atmospheric science community with comprehensive information and guidelines for using the reanalyses for many types of process-oriented studies, but also provide the reanalysis centers information that is critical to improving future reanalysis products. With the current S-RIP project reaching fruition, we are planning to extend this project to comprehensively evaluate the next generation of reanalyses that are expected to be released in 2019 to 2022.

## Chapter 3: Overview of Temperatures and Winds

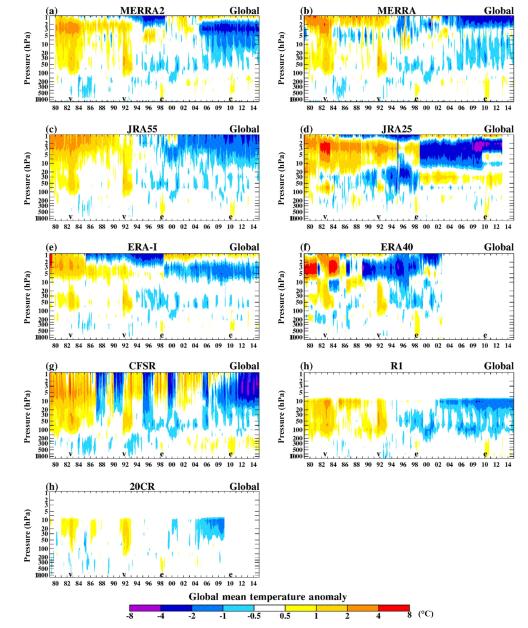

**Figure 3:** Zonal mean reanalysis temperature differences from a reanalysis ensemble mean (REM).

Chapter 3 provides an overview of reanalysis zonal mean temperature and winds differences. Some key findings are:

- Extreme caution is advised in using reanalyses to estimate trends since irregularities in long-term time series may occur because of changes in available data sources (especially in the upper stratosphere, at pressures below ~10 hPa).
- Reanalyses do not capture QBO wind transitions or longitudinal variations well, especially before 1998.
- Before 2005 (when GNSS-RO observations were first assimilated, large temperature biases between reanalyses were seem in the UTLS.
- Antarctic temperatures for some reanalyses show oscillations with height prior to 1998.

## Chapter 4: Overview of Ozone and Water Vapour

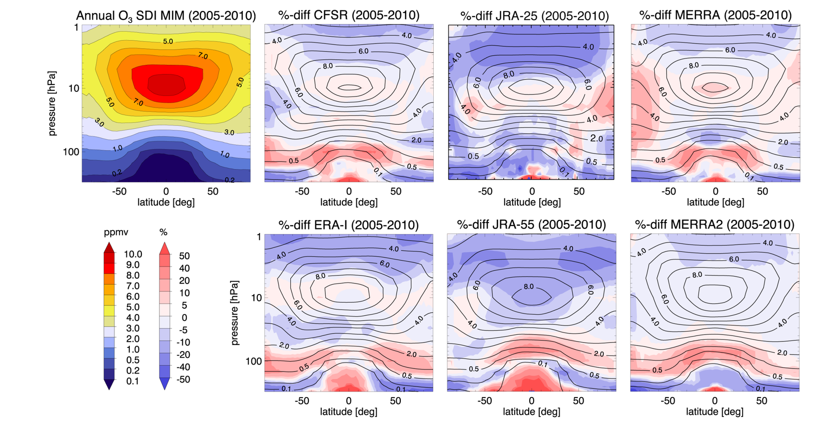

**Figure 4:** Reanalysis ozone compared with SPARC Data Initiative Climatology.

Chapter 4 gives an overview of reanalysis ozone and water vapor fields. Key findings include:

- Ozone climatologies, annual cycles, and interannual variability typically agree well with observations.
- Total column ozone is largely captured by reanalyses, with some limitations (e.g., no column ozone data during polar night).
- The ozone vertical distribution is weakly constrained by data assimilation, so mean biases in ozone products vary with height (from ~10 to 50% in the stratosphere).
- Stratospheric water vapour products from current reanalyses are generally not recommended for use in scientific studies.

## Chapter 5: Brewer-Dobson Circulation

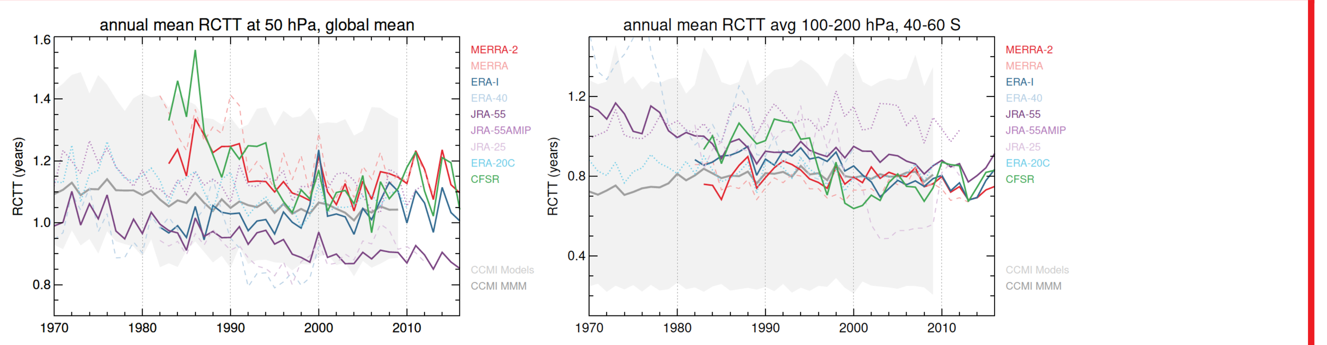

**Figure 5:** Residual circulation transit time (RCTT) from reanalyses compared with range from Chemistry Climate Model Initiative models.

Chapter 5 compares measure of the Brewer-Dobson circulation (BDC) calculated from reanalysis fields. Figure 5 shows an example comparing transit times in the deep and shallow branches of the BDC from 1979 through 2015 for reanalyses and chemistry climate models:

- Overall strengthened BDC at 50 hPa, mostly consistent between. models and reanalyses (except for ERA-Interim; CFSR shows questionable variability).
- Robust strengthening of the SH shallow circulation branch (negative RCTT trend in all recent RA products, even in ERA-Interim), but models show very large spread and opposite trend.

## Chapter 6: Extratropical Strat-Trop Coupling

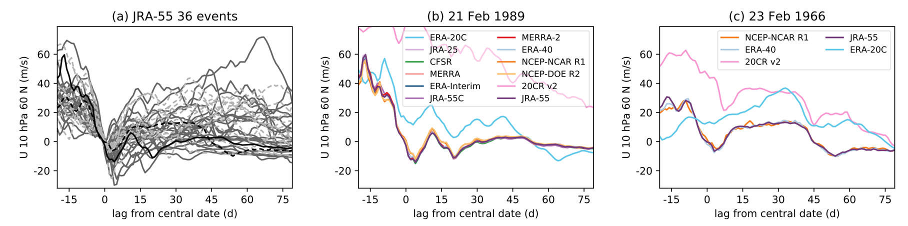

**Figure 6:** Pre- and post-satellite era Sudden Stratospheric Warmings. (a) Winds from JRA-55 for 36 sudden warmings in satellite era (dark grey) and radiosonde era (light grey, dashed lines) and for one (b) satellite-era and one (c) radiosonde era event for all reanalyses (shown as black line solid and dashed lines, respectively, in (a).

Chapter 6 examines stratosphere-troposphere (S-T) dynamical coupling in reanalyses. Key chapter findings include:

- Reanalyses are vital for evaluating extratropical stratosphere-troposphere coupling.
- In satellite era, large scale circulation is very consistent across reanalyses, and uncertainty in S-T coupling is therefore limited by sampling (i,e., by natural variability).
- Pre-satellite era reanalyses of NH appear of good quality, and can reduce sampling uncertainty, while pre-satellite era reanalyses of SH are generally of poor quality.

## Chapter 7: Extratropical UTLS

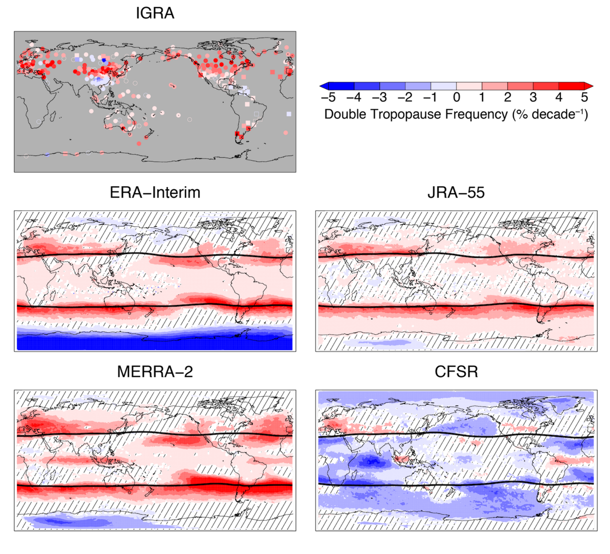


**Figure 7:** Double tropopause tendencies from radiosonde data and four reanalyses for 1980 through 2015.

Chapter 7 compares diagnostics of extratropical UTLS dynamics and transport, including trends and climatology of tropopause and jet characteristics. Figure 7 shows an examples comparison of double tropopause trends:

- Double tropopauses frequencies have increased during the past 35 years throughout the subtropics and midlatitudes of each hemisphere.
- Most modern reanalyses broadly reproduce patterns of observed trends, but do not capture the extent of poleward expansion of multiple tropopause occurrence.
- Increasing double tropopause frequency indicates more frequent poleward transport of tropical upper tropospheric air into the extratropical lower stratosphere over time.

## Chapter 8: Tropical Tropopause Layer

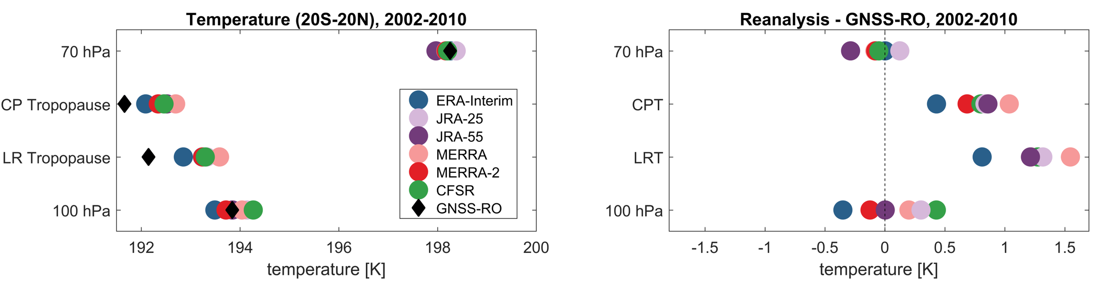

**Figure 8:** Tropical mean (20S–20N) temperature at 100 hPa, lapse rate tropopause (LRT), cold point tropopause (CPT), and 70 hPa from reanalyses: (left) comparison of radio occultation data for 2002–2010; (right) differences between the reanalyses and observations.

Chapter 8 evaluates reanalyses for use in diagnosing processes in the tropical tropopause layer. Figure 8 shows an example of reanalysis temperature comparisons in the TTL:

- Reanalyses do very well at capturing the temperature at given levels.
- They do not do as well at capturing dynamical features such as the cold point.

## Chapter 9: QBO and Tropical Variability

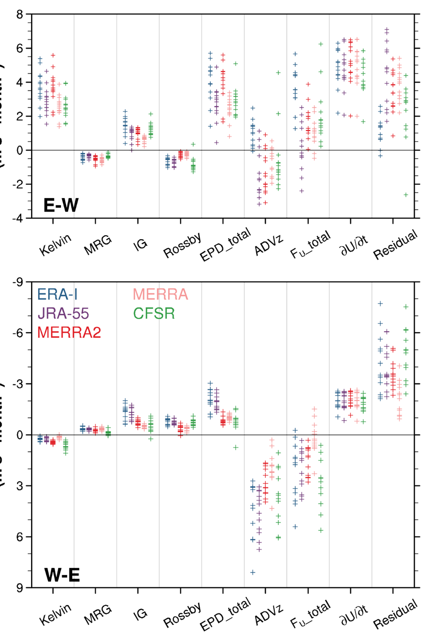

**Figure 9:** Terms in the QBO zonal-mean zonal momentum budget from 5N to 5S at 30 hPa, averaged over the easterly-to-westerly and westerly-to-easterly transitions during 1981–2010. Note that the y-axis direction is reversed in the bottom panel.

Chapter 9 focuses on the Quasi-Biennial Oscillation (QBO) reanalyses. Figure 9 shows an example comparing QBO forcing in reanalyses:

- Residual of the momentum budget is large, particularly for easterly QBO onsets.
- Residual includes contributions from small-scale gravity waves not resolved by the reanalyses, and are handled differently in different reanalyses (e.g., they are parameterized in MERRA, and the MERRA-2 forecast model was tuned to have a QBO). The non-orographic parameterized wave forcing contributes to the residual in this plot.
- Reanalyses agree fairly well on large-scale wave forcing, mainly because assimilated satellite data provide a constraint on the waves' temperature anomalies.
- Kelvin waves contribute strongly to the westerly onset, and have large natural variability.
- The vertical advection term has large natural variability, and for westerly onsets it has systematic inter-reanalysis sign differences.

## Chapter 10: Polar Processes

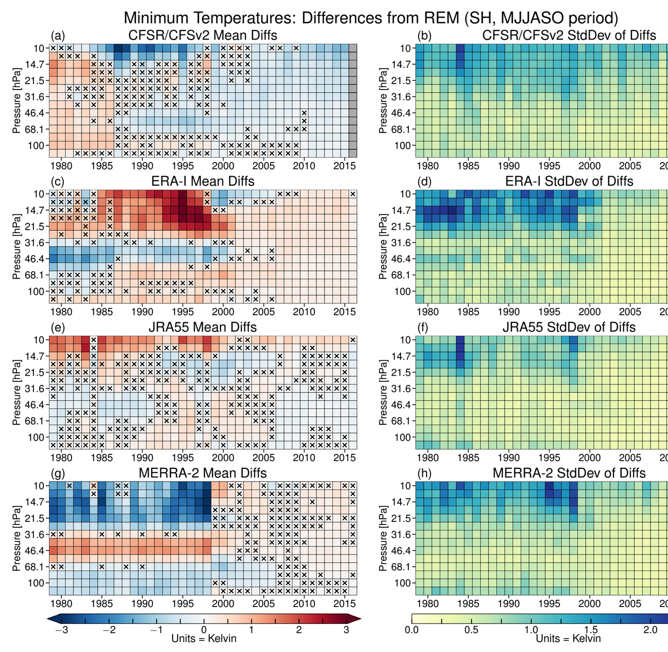

**Figure 10:** Averages (left) and standard deviations (right) of polar minimum temperature differences for each reanalysis from an REM for the 1979–2015 SH winters. X's indicate differences that are insignificant according to a bootstrapping analysis. See Lawrence et al. (2018).

Chapter 10 evaluates the performance of reanalyses in diagnostics related to lower stratospheric polar chemical processing and ozone loss. The most recent reanalyses show overall much better performance in these diagnostics that older reanalyses (many of which have been shown to be unsuitable for such studies). Figure 10 shows an example of minimum polar temperature comparisons:

- SH minimum polar temperatures converge towards much better agreement over the period compared.
- A rapid shift towards better agreement is seen around 1999, both in reanalysis differences from the REM and in the standard deviations of the differences.
- This shift is concurrent with the shift of data inputs from TOVS to ATOVS radiances (which provided better vertical resolution in the stratosphere), and is similar to shifts seen in other temperature diagnostics (e.g., see Figure 3).

## Chapter 11: Upper Stratosphere Lower Mesosphere

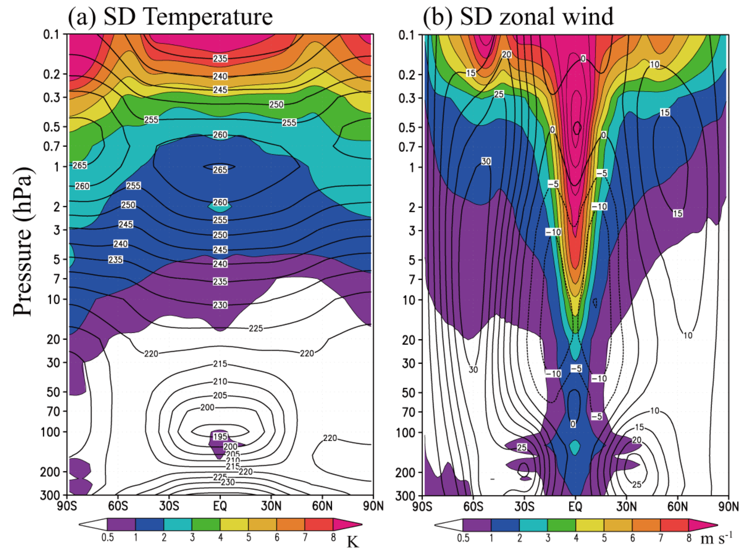

**Figure 11:** Latitude-altitude distribution of zonal mean and time mean (1980–2012) standard deviations (colors) of (a) temperature and (b) zonal winds for ERA-Interim, JRA-55, MERRA, and MERRA-2. Overlays are annually averaged (a) zonal-mean temperatures and (b) zonal winds (westerlies solid, easterlies dotted.

Chapter 11 examines reanalysis difference from the middle stratosphere up through the lower mesosphere. In this regions, reanalyses are generally not very well constrained by the data inputs. Older reanalyses in general either do not extend high enough or have issues with treatment of the model top, and thus are typically ot useful for USLM studies. Figure 11 shows an overview of temperature and wind comparisons in this region:

- Differences in temperature (zonal wind) among the reanalyses increase with height into the mesosphere at all latitudes (in the equatorial region).
- Using two or more reanalyses datasets to study phenomena (e.g., the SAO, the diurnal tide) in the tropical USLM region is recommended.
- Scientific studies using reanalyses in the USLM should make every effort to also include comparisons with independent observations.