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A proposal of the SPARC Reanalysis/Analysis Intercomparison Project

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Introduction

Meteorological analysis data sets are constructed as a best estimate of the state of the atmosphere using atmospheric observations with an assimilation scheme and a global forecast model. The assimilation schemes and forecast models used for operational weather forecasts are routinely updated as improvements are made, and the changes in the system produce artificial changes in the analysed fields. The term "reanalysis" is used for an analysis data set that is produced using a single version of a model and assimilation scheme for a long-term (typically multi-decadal) period in the past (*e.g.*, Trenberth *et al.*, 2008). Note, however, that the observational data inputs still vary over the period of the reanalysis. The SPARC community has used reanalysis and analysis data sets to understand atmospheric processes, variability of the stratosphere and upper troposphere, and to validate chemistry-climate models (*e.g.*, SPARC CCMVal, 2010).

There are currently eight global reanalysis data sets available worldwide (see **Table 1**). In the near future, at least three new global reanalysis data sets will be available; namely ERA-20C, CFSR-Lite, and JRA-55. Some analysis data sets are also available and used for middle atmosphere science (*e.g.*, UKMO stratospheric assimilated data originally prepared for the Upper Air Research Satellite project, operational ECMWF analyses, and NASA's GEOS-5) and for mesosphere and lower thermosphere science (*e.g.*, Navy Operational Global Atmospheric Prediction System - Advanced Level Physics and High Altitude (NOGAPS-ALPHA; Eckermann *et al.*, 2009). Studies comparing some of these reanalysis/analysis products have shown that different data sets give different results for the same diagnostic, such as the global energy budget and hydrological cycle (Trenberth *et al.*, 2011), the Brewer-Dobson circulation (Iwasaki *et al.*, 2009), the stratospheric vortex weakening and intensification events (Martineau and Son, 2010), large-scale wave activity at the tropical tropopause (Fujiwara *et al.*, 2011), diurnal migrating tides (Sakazaki et al., 2011), and temperature trends (Randel *et al.*, 2009; Xu and Powell, 2011a, 2011b), as well as the climatology of the middle atmosphere (*e.g.*, Randel *et al.*, 2002; Kishore *et al.*, 2009). Depending on the diagnostic, the different results may be due to differences either in the observational data assimilated, the assimilation scheme or forecast model, or any combination of these.

With the availability of several global reanalysis data sets, we think that now is the time to start a coordinated activity to compare all (or some of the newer) reanalysis data sets for various key diagnostics, to understand the causes of the differences, to use the results to provide guidance on appropriate usage of various reanalysis products in scientific studies, and to connect such activities with future improvements of the reanalysis products. The data assimilation community, including reanalysis centres, will benefit from coordinated user feedback. Such feedback can lead to improvements in the next generation of reanalysis products. The "key" diagnostics include both those for the middle atmosphere science and those with large impact on the reanalysis improvements. For these purposes, it is critical to have a close collaboration between the data users and the reanalysis centres. The SPARC community consists of many active scientists who study the full range of middle atmosphere science, and has produced several successful, coordinated studies such as the SPARC Intercomparison of Middle Atmosphere Climatologies (Randel *et al.*, 2002) and the Chemistry-Climate Model Validation project (SPARC CCMVal, 2010). Although the reanalysis data sets extend to the surface (and even the subsurface for some data sets), a project focusing on the middle atmosphere (including the Upper Troposphere Lower Stratosphere (UTLS), stratosphere, and mesosphere) by the SPARC community would be able to produce a rather concise but very meaningful summary for the reanalysis intercomparison. Therefore, we here propose the SPARC Reanalysis/Analysis Intercomparison Project (S-RIP). (The idea of S-RIP was first discussed at the 8th SPARC Data Assimilation Workshop in June 2011; see the report in this issue.)

S-RIP will be in part an update of the previous climatology intercomparison by SPARC (Randel *et al.*, 2002) but with a much wider perspective, covering all the major middle atmosphere diagnostics. Also, some of the aspects of S-RIP would be quite similar to those of CCMVal project and SPARC DynVar project (**http://www.sparcdynvar.org/**). We can thus utilise the experience and knowledge obtained from these previous activities. One clear difference from CCMVal is the fact that the reanalysis centres are largely independent of the SPARC community, having connections with other weather prediction, climate and atmospheric-science communities. We thus need to establish a collaborative link between the reanalysis centres and the SPARC community. The collaboration will include the discussion and interpretation of the analysis results, and the preparation of the final report.

Possible Diagnostics Focusing on the Middle Atmosphere

Possible "key" diagnostics are discussed here. Our current thinking is that the scientific working group will discuss and suggest the "key" diagnostics and that individual researchers will determine the actual diagnostics and data sets to be analysed (see the next section for our current ideas on the project organisation).

Firstly, the "key" diagnostics addressed in the intercomparison should include all the major diagnostics for the middle atmosphere sciences (*e.g.*, those covered by the CCMVal). Intercomparison between different reanalysis/analysis data sets would give us information on the current technological level of the reanalyses. Where possible, evaluations will be made using independent or original observational data sets. Second, in order to gain a deeper understanding of the reanalysis system and to contribute to future improvements in the reanalysis products, we may need further data analyses. For example, it would be useful to clarify how each part of the reanalysis system (*e.g.*, satellite observations, radiosonde observations, resolved wave drag, parameterized wave drag) contributes to each of the diagnostics. In other words, we want to understand how much the observations constrain a specific diagnostic and how much the model components and the assimilation scheme control that diagnostic. Third, there could be some diagnostics or data analyses that are directly relevant to finding flaws in the reanalysis system or improving the system, especially from the reanalysis-centre perspective.

Examples of possible areas of interest are listed below:

- Middle atmosphere climatology (*e.g.*, Randel *et al.*, 2002; Kishore *et al.*, 2009): These diagnostics can be calculated using the CCMVal diagnostic tool (Gettelman *et al.*, 2012, manuscript in preparation)
- Brewer-Dobson circulation (*e.g.*, Iwasaki *et al.*, 2009; Okamoto *et al.*, 2011; Butchart *et al.*, 2010, 2011): More emphasis should be placed on contributions of sub-grid scale momentum fluxes and momentum deposition, and of orographic and non-orographic gravity wave drag.
- Heat budget of the middle atmosphere (*e.g.*, Fueglistaler *et al.*, 2009)
- Atmospheric energetics and balance by using the normal-mode function expansion - the role of large-scale inertio-gravity waves in the tropics (Žagar *et al.*, 2009a, 2009b)
- Quasi-Biennial Oscillation including its influence on the extratropics, and Semi-Annual Oscillation
- Polar stratosphere issues including lower-stratospheric wintertime temperature evolution (which determines the degree of polar processing and chemical ozone loss) (*e.g.*, Manney *et al.*, 2003, 2005), Sudden Stratospheric Warmings (SSWs) (*e.g.*, Charlton and Polvani, 2007) and stratosphere-troposphere dynamical coupling (*e.g.*, Martineau and Son, 2010; Nishii *et al.*, 2011).
- Upper troposphere and lower stratosphere (UTLS) issues (Gettelman *et al.*, 2010; Hegglin *et al.*, 2010) including the tropical width (*e.g.*, Davis and Rosenlof, 2011), advection dehydration calculations (*e.g.*, Liu *et al.*, 2010; Schoeberl and Dessler, 2011), effective diffusivity (*e.g.*, Shuckburgh *et al.*, 2009), and wave activity (*e.g.*, Suzuki *et al.*, 2010; Fujiwara *et al.*, 2011)
- Dynamics of the upper stratosphere and lower mesosphere/stratopause region where observations are limited (*e.g.*, Sakazaki *et al.*, 2011). This may be helpful in assessing differences in the underlying forecast models.
- Various trajectory calculations such as, *e.g.*, age of air, and UTLS transport for ozone and water vapour budget (*e.g.*, Liu *et al.*, 2010; Schoeberl and Dessler, 2011)
- Tracer distributions (ozone and water vapour; *cf.* SPARC Data Initiative by Hegglin and Tegtmeier, 2011)
- The mass conservation (by comparing with free-running model simulations)
- Radiative flux and heating/cooling rate profiles
- Variability at various interannual time scales in association with, *e.g.*, the Annular Modes, El Niño Southern Oscillation (*e.g.*, Trenberth and Smith, 2006, 2009), solar cycle (*e.g.*, Powell and Xu, 2010), and volcanoes eruptions
- Trends (*e.g.*, Randel *et al.*, 2009; Xu and Powell, 2011b; SPARC Stratospheric Temperature Trends Working Group)
- Other diagnostics that can answer the question, "how can we use operational polar orbiting satellite data better in future reanalyses?" If additional resources are available at the reanalysis centres, investigating the analysis increment data and Observation minus Forecast (OmF) data, and performing an Observing System Experiment (OSE) may be very useful. Note that the analysis increment data can be a good proxy for the gravity wave drag.

Finally, note that some basic diagnostics have already been investigated at the reanalysis centres. See, for example:

- Dee, ERA-Interim data products and plans for future ECMWF reanalyses, presented at the 8th SPARC Data Assimilation Workshop, 2011
- Long *et al.*, Evaluation of the stratosphere in recent reanalyses, presented at the 8th SPARC Data Assimilation Workshop, 2011

The electronic files for the above two presentations are available at **http://www.atmosp.physics.utoronto.ca/SPARC/sparc_daworkshop/scientificprogram.html**. Therefore, the SPARC community needs to contribute to the investigation of advanced and unique diagnostics.

Organisation of the Project

The project will have three major components: (1) the management team which will deal with the overall coordination including the SPARC-reanalysis centre

Table 1: Summary of available global reanalysis data sets. For further information on these reanalyses, see, e.g., http://reanalyses.org/ prepared by the reanalysis centres and http://www.cgd.ucar.edu/cas/catalog/ and http://climatedataguide.ucar.edu/ prepared by National Center for Atmospheric Research.

Product	Centre	Period	Resolution and Lid Height of the Forecast Model
NCEP-1	NCEP and NCAR	1948-present	T62, L28, 3 hPa
NCEP-2	NCEP and DOE AMIP-II	1979-present	T62, L28, 3 hPa
ERA-40	ECMWF	1958-2001	TL159 and N80 reduced Gausiian, L60, 0.1 hPa
ERA-Interim	ECMWF	1979-present	TL255 and N128 reduced Gausiian, L60, 0.1 hPa
JRA-25/JCDAS	JMA and CRIEPI	1979-present	T106, L40, 0.4 hPa
MERRA	NASA	1979-present	(2/3)x(1/2) deg., L72, 0.01 hPa
NCEP-CFSR	NCEP	1979-present	T382 (T574 for post 2010), L64, 0.266 hPa
NOAA-CIRES 20th Century Reanalysis (20CR)*	NOAA/ESRL PSD	1871-2008	T62, L28, 2.511 hPa

(*) NOAA-CIRES 20CR assimilates only surface pressure reports and uses observed monthly sea-surface temperature and sea-ice distributions as boundary conditions (Compo et al., 2011).

connection and with the data archiving, (2) the scientific working group which will suggest the diagnostics covered and has the responsibility for editing and writing the final report, and (3) all SPARC-related researchers who will perform the data analysis, write journal papers, and contribute to the final report.

More specifically, the management team, which will include Masatomo Fujiwara and David Jackson and representatives from the reanalysis centres, will be responsible for making the arrangements with the reanalysis/analysis centres, forming the scientific working group, and making the data archiving arrangements including website management. The scientific working group would be made up of 7 to 10 dedicated members and would include the management team. It would be responsible for determining the relevant diagnostics, providing guidance on specific approaches to data analyses, recruiting the researchers to contribute to the final report and work on each of the diagnostics, and editing the final report. SPARC-related researchers would perform the data analysis, write journal papers, and contribute to the S-RIP workshops and the final report.

The reanalysis data sets shown in **Table 1** are freely available from the websites prepared by individual reanalysis centres and from **http://dss.ucar.edu/**. As archiving processed data such as climatologies, diagnostics of SSWs, vortex breakdown date, *etc*., would also be useful for the community, the management team will consider this. The scientific working group would also make summary tables showing/comparing detailed and relevant technical information of the reanalyses (*e.g*., observational data usage and corrections, specifications of assimilation scheme and forecast model, *etc*.) for the interpretation of the comparison results. The project will hold two or three dedicated workshops where analysis results are discussed with the SPARC community and the reanalysis centres, and produce the final report as a SPARC report, which reviews the then past and near-future publications. The project duration is expected to be 3-5 years for the first phase. Since reanalysis centres envision a 7-year period between new generations of reanalysis products, there is scope for additional phases of this project depending upon the success of the first phase.

S-RIP will be officially proposed at the SPARC SSG meeting in February 2012. If you are interested in becoming involved, and/or if you have any sugestions, please contact Masamoto Fujiwara.

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Update on the SPARC Temperature Trends Working Group

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The SPARC Stratospheric Temperature Trends group focuses on improved understanding of long-term variability and trends in stratospheric temperatures, based on various observational data sets and model-data comparisons. The group has been relatively dormant for the past several years, but has recently been revived with the addition of a new co-chair (David Thompson, Colorado State University) (together with co-chair William Randel, NCAR), in addition to adding several new members. Details of the group membership and past activities can be found on the group website: **http://www.sparc-climate.org/activities/temperature-trends/**.

The temperature trends working group held a 2-day workshop September 20-21 in Paris, hosted by Philippe Keckhut and Chantal Claud. This meeting focused on setting group priorities and plans for the near future, and provided an opportunity for detailed discussions on revised and updated data sets (including radiosonde-based data, satellites, lidars and reanalysis data). The discussion leaders and topics are briefly highlighted below.

S. Bronniman led a discussion of long-term radiosonde data and reanalysis data sets, focusing on historical data prior to 1960 (a focus of the Comprehensive Historical Upper Air Network, CHUAN; Stickler *et al.*, 2010). **D. Seidel** discussed analysis of the seasonal and latitudinal patterns in temperature trends, and also highlighted the growing GCOS Reference Upper Air Network (GRUAN) network for climate-quality upper-air measurements. **C. Claud** showed new analysis