# The Japanese 55-year Reanalysis "JRA-55": An Interim Report

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## Abstract

The Japan Meteorological Agency (JMA) started the second Japanese global atmospheric reanalysis project named the Japanese 55-year Reanalysis (JRA-55). It covers 55 years, extending back to 1958, when the global radiosonde observing system was established. Many of the deficiencies found in the first Japanese reanalysis, the Japanese 25-year Reanalysis (JRA-25), have been improved. It aims at providing a comprehensive atmospheric dataset that is suitable for studies of climate change or multi-decadal variability, by producing a more time-consistent dataset for a longer period than JRA-25.

Production of JRA-55 started in 2010, and computations for more than 16 years have been completed as of August 2011. The entire JRA-55 production will be completed in early 2013 and thereafter JRA-55 will be continued as a new JCDAS on real time basis. This paper is a brief report to introduce the JRA-55 reanalysis project. The data assimilation and prediction (DA) system used in JRA-55 is introduced and compared to that used in JRA-25. Early results of JRA-55 are presented and discussed, showing general improvements.

## 1. Introduction

It is a crucially important requirement to estimate the climate features of the global atmosphere with high accuracy in terms of both quality and quantity for climate studies and monitoring. Reanalysis of past observations with a fixed, state-of-the-art numerical weather prediction (NWP*) system is a powerful approach to fulfill such a requirement.

Global reanalyses have been conducted at major NWP centers such as the NCEP/NCAR reanalysis (Kalnay et al. 1996; Kistler et al. 2001), NCEP/DOE renalaysis (Kanamitsu et al. 2002) and ERA-40 (Uppala et al. 2005) by ECMWF. JMA and CRIEPI also completed the JRA-25 reanalysis (Onogi et al. 2007), and thereafter JMA has been operating the JMA Climate Data Assimilation System (JCDAS), to continue producing consistent climate data on real time basis. These reanalyses have been providing fundamental data sets for climate monitoring and researches. However, to extend the range of application, further improvement is needed. In particular, neither data availability nor long-term consistency in data quality is sufficient for detecting and examining long-term climate trends and/or multi-decadal climate variability (Trenberth et al. 2008). This clearly shows the need for updating a reanalysis dataset with a state-of-the-art system and recently new reanalyses have become available from ECMWF (Dee et al. 2011), NASA (Rienecker et al. 2011), NCEP (Saha et al. 2010) and NOAA-CIRES (Compo et al. 2011).

Since the time of the JRA-25 production, the JMA operational NWP system achieved some major updates, including increase of resolution, introduction of a new radiation scheme to the forecast model, and four-dimensional variational data assimilation (4D-Var) with Variational Bias Correction (VarBC). With these updates, the current system is able to handle satellite radiances better and to produce less-biased analysis fields compared to the JRA-25 system, and expected to overcome the deficiencies in the stratospheric temperature analysis such as negative bias in JRA-25.

To address the issues identified in JRA-25, we started the second Japanese reanalysis project, JRA-55, in which the analysis period is extended substantially from that for JRA-25 with the more advanced DA system. In this paper, we report an overview of the JRA-55 project and progress as of August 2011. In Section 2, the models used in JRA-55 are outlined and compared with those used in JRA-25. In Section 3, several early results of JRA-55 are introduced and compared with the results of JRA-25. In Section 4, advantages and remaining deficiencies in JRA-55 are summarized, and future plans are presented.

## 2. Data assimilation and prediction system

Table 1 summarizes the DA system and boundary conditions of JRA-55 together with those of JRA-25 for comparison. It is based on the JMA operational NWP system as of December 2009 (JMA 2007), into which many improvements have been implemented since the time of the JRA-25 production, including higher spatial resolution, introduction of the new radiation scheme, and 4D-Var with VarBC for satellite radiances. Long term quality of JRA-55 is expected to be improved by introduction of green house gases with time varying concentrations.

Observational data being used in JRA-55 are listed with their available period in Fig. 1. In addition to the data assimilated into JRA-25, many kinds of newly obtained observational data are assimilated. Atmospheric Motion Vector (AMV) data from GMS, MTSAT and METEOSAT are newly reprocessed after JRA-25. Clear Sky Radiance (CSR) data from GMS and MTSAT reprocessed at MSC/JMA will be used for the first time in reanalyses.

The production is being executed with three separate streams (Fig. 1). Stream A covers old years with few satellite data. Stream B covers the period from 1980 to 2002, with AMV from geostationary satellites, radiances from vertical sounders (TOVS and ATOVS) and microwave imagers (SSM/I), and ocean surface winds from microwave scatterometers (ERS and QuikSCAT) onboard polar orbiter satellites. Stream C covers recent years from 2003 with many kinds of satellite data. Streams A and B are being calculated as of August 2011.

JRA-55 covers the period from pre-satellite era to recent years with many kinds of varying satellite data as shown in Fig. 1. It is recognized that analysis quality largely depends on the background error covariance matrix (B-matrix) when/where the number of observational data is small (Whitaker et al. 2009). Therefore, for years before 1972 with no satellite data, the B-matrix specified in the data assimilation system needs to be adjusted. We estimated an appropriate scaling factor for the B-matrix used in the pre-satellite era to be 1.8 from departure statistics of a set of assimilation experiments with and without satellite data. Figure 2 shows bias and RMS difference between radiosonde temperature measurements and the background and analyzed values from assimilation experiments for the extratropical southern hemisphere. It can be seen that covariance scaling gives a positive impact in reducing RMS of background departures.

In JRA-25, land surface in the Amazon basin has a dry bias due to unrealistically high pressure area formed in the lower troposphere. A similar problem occurred in preliminary experiments

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*All acronyms are defined in Table S-1 of the supplement.

Table 1*. Comparison of the DA systems, and boundary conditions between JRA-55 and JRA-25.

| | JRA-25 | JRA-55 |
|---|---|---|
| Years | 26 years (1979−2004) | 55 years (1958−2012) |
| Model version | as of Mar. 2004 operational | as of Dec. 2009 operational |
| Resolution | T106L40 (~120 km) (top layer at 0.4 hPa) | TL319L60 (~60 km) (top layer at 0.1 hPa) |
| Time integration | Eulerian | Semi-Lagrangian |
| Long-wave radiation | *Line absorption* Statistical band model *Water vapor continuum* e-type | *Line absorption* Table lookup + K-distribution *Water vapor continuum* e-type + P-type |
| Assimilation scheme | 3D-Var (with T106 resolution) | 4D-Var (with T106 inner model) |
| Background error covariance | Constant | Simple inflation factor (× 1.8) applied before 1972 |
| Bias correction (radiosonde) | Andrae et al. (2004) | RAOBCORE v1.4 (Haimberger 2007) |
| Bias correction (satellite radiance) | Sakamoto and Christy (2009) | VarBC (Dee 2005) |
| Land surface analysis | Offline SiB (6 hourly atmospheric forcing) | Offline SiB (3 hourly atmospheric forcing) |
| Green house gases | $CO_2$ (constant at 375 ppmv) | $CO_2$, $CH_4$, $N_2O$, CFC-11, CFC-12, HCFC-22 (daily interpolation of annual values) |
| Ozone | Daily 3-D ozone (MRI-CCM1; T42L45) (Shibata et al. 2005) | (−1978) Monthly climatology (1979−) New daily 3-D ozone (MRI-CCM1; T42L68) (Shibata et al. 2005) |
| Aerosol | Annual climatology for continental and maritime | *Optical depth* Monthly 2-D climatology *Optical properties, vertical profile* Annual climatology for continental and maritime |
| SST / sea ice | COBE SST (Ishii et al. 2005) | COBE SST (Ishii et al. 2005) |

with a prototype version of the JRA-55 system, and we found that this problem stemmed from a mismatch between surface pressure observations and the background values. The cause of the mismatch has not been fully understood, but is likely related to mis-specified station height, bias in observations and deficiencies in the diurnal cycle reproduced by the forecast model. While this problem needs further investigation, we simply discard surface pressure observations around the Amazon basin to prevent this problem.

## 3. Quality of JRA-55 early results

Computations for more than 16 years have been completed as of August 2011. We describe some early results of JRA-55 in which deficiencies in JRA-25 have been removed or reduced significantly.

Figure 3 shows vertical profiles of global mean bias and RMS differences between radiosonde temperature measurements and the background and analyzed values from JRA-55 and JRA-25. Both bias and RMS difference of JRA-55 are reduced from those of JRA-25. In particular, large negative biases (note that ‘OBS minus BG/AN’ are drawn) found in the lower stratosphere of JRA-25 have been removed. This improvement is due to the introduction of the new radiation scheme, which was implemented into the operational system in December 2004.

Temporal variability of the stratospheric temperature analysis was assessed using microwave sounder measurements processed

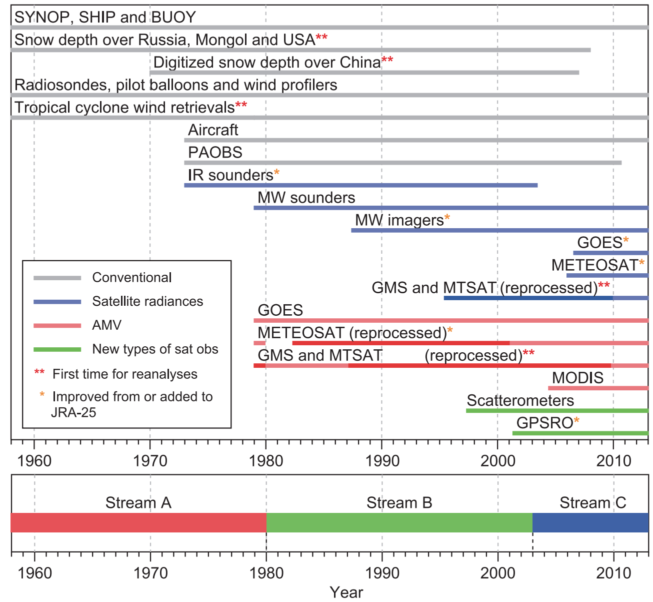


Fig. 1*. List of observational data available for JRA-55 with their period (top) and streams of JRA-55 production (bottom). 55 years are separated into three parts of years depending on availability of satellite data type. Note that the final list is subject to change depending on progress in development.

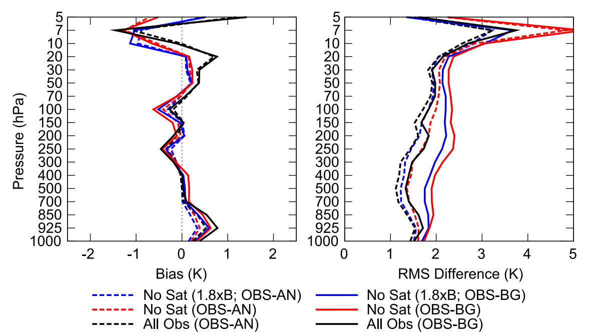


Fig. 2. Bias and RMS difference between radiosonde temperature measurements and the background (solid lines) and analyzed values (dotted lines) from experiments with all observations (black), no satellite (red) and no satellite with covariance scaling (blue) for the extratropical southern hemisphere for August 1990.

by RSS (Mears and Wentz 2009). The result for 11 years from 1980 showed that the trend of JRA-55 is in better agreement with that of RSS compared to that of JRA-25, and that unrealistic variation seen in the time series for JRA-25 was reduced significantly in JRA-55 (Fig. 4). These improvements are primarily due to the introduction of VarBC (Dee 2005) and indicate an improved performance in handling satellite radiances.

Figure 5 shows the time series for (a) precipitation, (b) evaporation, (c) runoff, and (d) soil wetness at the root level averaged over the Amazon basin. As mentioned in Section 2, JRA-25 has a dry bias over the Amazon basin and the time series for precipitation from JRA-25 shows a clear underestimation (Fig. 5a) compared to the GPCP Ver. 2.1 (Adler et al. 2003). The time series for precipitation from JRA-55 shows a better agreement with GPCP, and the time series for other hydrological variables also demonstrate an improved seasonal cycle compared to that of JRA-25 (Figs. 5b, c, d). Although verification with independent observations is needed, the water cycle of the Amazon basin is expected to be represented more realistically in JRA-55.

Precipitation from reanalyses was assessed by Bosilovich et al. (2008) using Taylor diagrams and it was demonstrated that the

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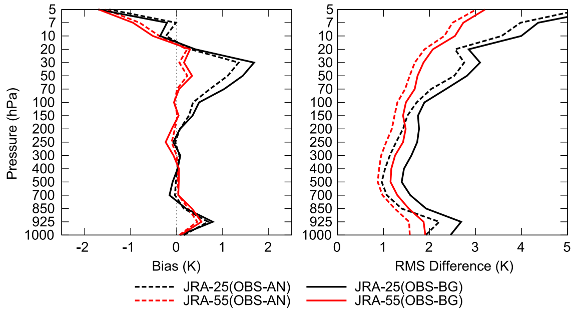


Fig. 3. Vertical profiles of global mean bias and RMS difference between radiosonde temperature measurements and the background (solid lines) and analyzed values (dotted lines) from JRA-25 (black) and JRA-55 (red) for January 1981.

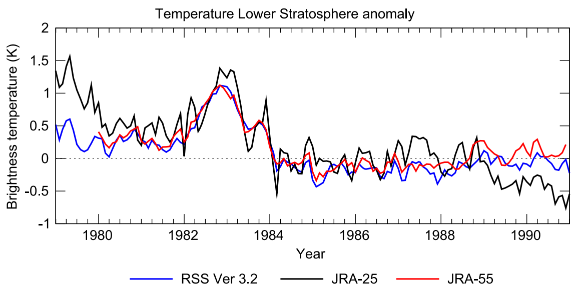


Fig. 4. Time series of global mean, monthly mean temperature anomaly at the lower stratosphere. Results are processed microwave sounder measurements (RSS Ver. 3.2; blue) and its equivalents calculated from JRA-25 (black) and JRA-55 (red). Anomalies of RSS and JRA-25 were defined relative to the 1979−1998 climatology of their own, while anomalies of JRA-55 were computed using the JRA-25 climatology and adjusted in such a way that the anomaly averaged over 1980 to 1990 was the same as that of JRA-25.

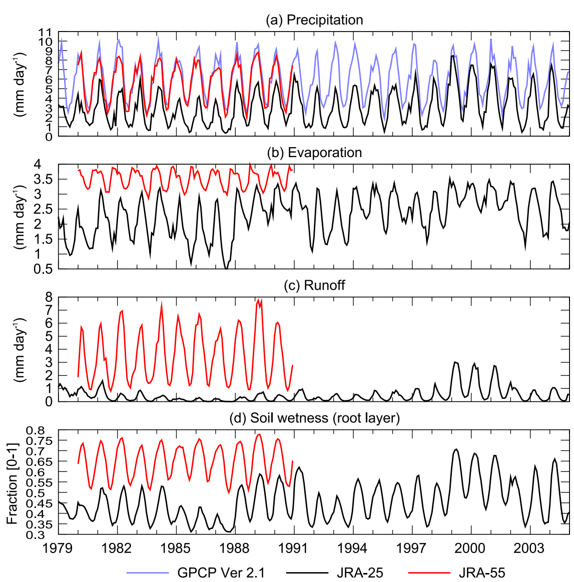


Fig. 5. Time series of surface hydrological variables in the Amazon basin; (a) precipitation, (b) evaporation, (c) runoff, and (d) soil wetness.

JRA-25 precipitation had a good correlation with GPCP. Figure 6 shows Taylor diagrams for the annual mean correlations and standard deviation of global precipitation from JRA-25 and JRA-55 with GPCP data. It can be seen that the JRA-55 precipitation, in particular over land, has an even better correlation with GPCP than that of JRA-25. However, the normalized standard deviation based on JRA-55 is slightly degraded from that based on JRA-25, as a manifestation of overestimated precipitation compared to

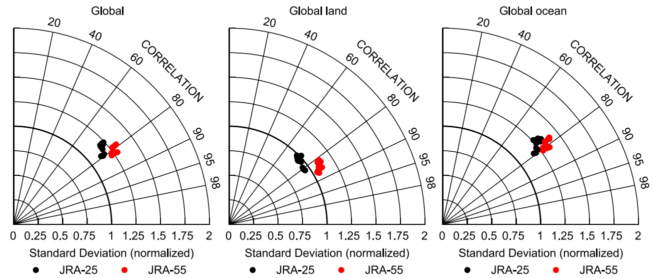


Fig. 6. Taylor diagrams for the annual mean correlations and standard deviation of precipitation from JRA-25 (black) and JRA-55 (red) with GPCP Ver 2.1 for the globe (left), global land (center) and global ocean (right). Each dot represents a 12-month average for each year, 1980−1990.

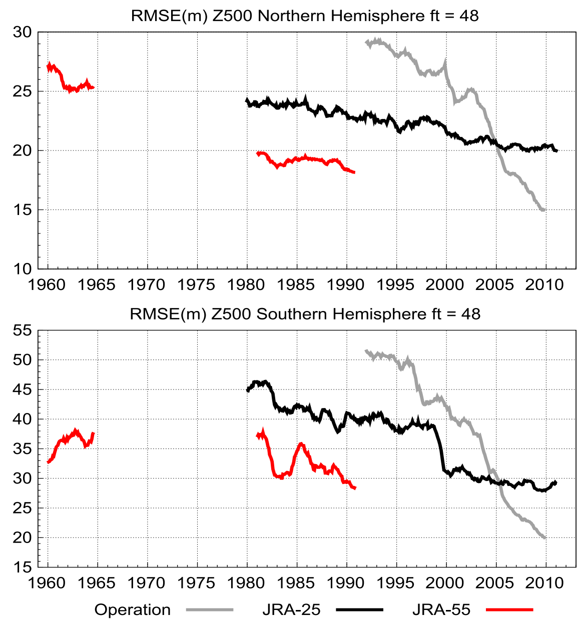


Fig. 7. Time series for the RMS error of 2-day forecast of geopotential height at 500 hPa verified against its own analysis for NH (top) and SH (bottom). Gray lines indicate the scores of operational forecast, black lines JRA-25, and red lines JRA-55. A 12-month running mean is applied for smoothing. Each forecast is started using each analysis or reanalysis data. Note that red lines are drawn only for completed years of JRA-55.

GPCP (not shown).

The quality of reanalysis data can be assessed from the accuracy of the forecast made from a reanalysis as an initial condition. Figure 7 shows the RMS error of 500 hPa geopotential height forecasts at day 2 verified against its own analysis for JRA-55, JRA-25 and the historical JMA operational systems. Although the comparison is currently available only for the rather short period from 1980 to 1990, scores of JRA-55 are much better than those of JRA-25 in each of the hemispheres. Since the NWP system used in JRA-25 was based on the operational system as of March 2004, the scores of JRA-25 are better than those of the JMA operational analysis for the period before 2004, but the opposite is the case for 2005 and afterward. Scores of JRA-55 are expected to be comparable to the operational system around 2009 because the model used in JRA-55 is based on the operational system as of December 2009. The change in the SH of JRA-25 in 1998 is due to the replacement of TOVS to ATOVS (Onogi et al. 2007).

Wind retrievals surrounding tropical cyclones (TCR) data (Fiorino 2002) were used in JRA-25 to analyze tropical cyclones (TCs) homogeneously around the globe. Hatsushika et al. (2006) confirmed the accuracy of TC analysis in JRA-25. We can expect more accurate reanalysis of TC with a higher resolution, because TCR data are assimilated in JRA-55 as well. Bessho et al. (2010) used preliminary experimental products of JRA-55 to examine the predictability of Vera ("Isewan Typhoon" in Japanese), which landed the middle part of Japan and caused more than 5000 deaths in 1959. They performed meso-scale analysis and forecast experiments of wind, storm surge, and precipitation due to Vera using a regional model with initial and boundary conditions taken from the JRA-55 experiment. Vera was reproduced quite well with respect to position and strength, which indicates high potential applicability of the JRA-55 products to researches on extreme events such as tropical cyclones.

## 4. Summary and future plans

Early results of quality assessment have suggested that many of deficiencies in JRA-25 have been diminished or reduced in JRA-55. Specifically a large temperature bias in the lower stratosphere was significantly reduced by introduction of the new radiation scheme to the forecast model. The VarBC contributes to the diminution of unrealistic temperature variations found in the lower-stratospheric time series based on JRA-25. The dry land surface problem in the Amazon basin in JRA-25 was mitigated. Overall quality of JRA-55 is much improved as shown in forecast scores compared with those of JRA-25 for the completed years, owing to continuous development of the JMA operational NWP system as evident from the improvement in the operational scores in recent years. Global precipitation in JRA-55 is, however, still somewhat overestimated compared to GPCP as well as in JRA-25, which requires further investigation.

The entire JRA-55 production is expected to be completed in early 2013. Thereafter, JRA-55 will be continued as a new JCDAS on real time basis and replace the current JRA-25-based JCDAS. Performance of JRA-55 is monitored carefully until the completion of the production and the quality will be further investigated. A comprehensive report of the JRA-55 reanalysis will be published after the completion of the project.

While JRA-55 will use as many types and numbers of observational data as possible to give the best instantaneous field estimate, we have a plan to produce JRA-55 subset products assimilating conventional observational data only (JRA-55C), without any satellite data. It aims at retaining consistency for long years, even if its analysis quality may be inferior to JRA-55. This set of reanalyses is expected to contribute to addressing some of the issues of the current reanalyses such as impact of changing observing systems on representation of long-term climate trends and variability.

## Acknowledgements

Most of the observational data used in JRA-55 are those used in JRA-25. Additionally, newly reprocessed METEOSAT and GMS data were supplied by EUMETSAT and MSC/JMA respectively. Snow depth data over the United States, Russia and Mongolia were supplied by UCAR, RIHMI and IMH respectively. We are grateful to all the observational data providers for making their data available to JRA-55.

The JRA-55 project has been supported by a large number of the JMA staff members in many aspects including planning of the project, preparation of observational data, testing the data assimilation system, production and verification. We would like to thank all the individuals for providing us with their invaluable help and advice.

## Supplement

All acronyms are defined in Table S-1 of the supplement.

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*Manuscript received 19 July 2011, accepted 10 September 2011*
*SOLA: http://www.jstage.jst.go.jp/browse/sola*