# Introduction of Reanalysis and JRA-55

Yuki KOSAKA (Climate Prediction Division, JMA)

## 1. Reanalysis

Reanalysis aims at producing a high-quality homogeneous climate dataset. It can produce a dataset for numerous types of meteorological variables, including those for which observations are sparse, in a physically consistent, spatiotemporally regular manner. Reanalysis have been widely used for research into the mechanisms of the earth's climate system, the study of predictability, and climate monitoring. Continued improvement of reanalysis is crucial to advance climate research and improve climate services.

Reanalysis is different from so-called "analysis" a process to produce initial conditions for operational numerical weather prediction (NWP) by using data assimilation (DA) system and observation data available, in two points: First, the reanalysis utilizes a constant state-of-the-art NWP model and DA system for a long period, while those of the "analysis" are generally upgraded with time. Second, the reanalysis integrates all available observation data including those not available at the time of operational analysis; e.g., delayed observation and reprocessed satellite data. These characteristics of the reanalysis enable us to obtain high-quality and homogeneous dataset for various meteorological variables covering the last several decades, thereby support climate services such as climate monitoring and seasonal forecasting.

Reanalysis: "analysis of the past atmospheric conditions using a constant, state-of-the-art NWP model and data assimilation system with the latest observation to produce a high-quality, spatially and temporally consistent dataset"

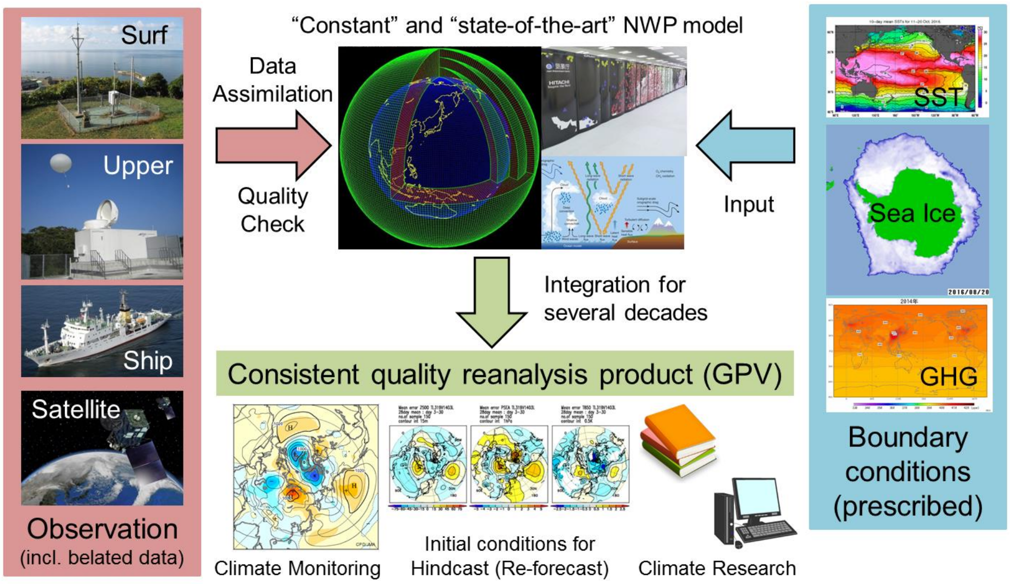

**Fig. 1.** Schematic diagram of reanalysis.

## 2. Reanalysis at JMA

Reanalysis has been conducted at a number of major NWP center. In Japan, the Japan Meteorological Agency (JMA) and the Central Research Institute of Electric Power Industry (CRIEPI) jointly produced the Japanese 25-year Reanalysis (JRA-25; Onogi et al. 2007) which covers from 1978 to 2004. In the second reanalysis by JMA called the Japanese 55-year Reanalysis (JRA-55; Kobayashi et al. 2015), updated DA system and newly prepared observations since the JRA-25 are used to improve the quality of dataset. The JRA-55 covers from 1958 to present and currently used as a basic dataset for climate services at JMA.

The JRA-55 has been based on the TL319 version of JMA's operational NWP system as of December 2009 (JMA 2013). Both the DA system and forecast model (Global spectral model; GSM) have been extensively improved since the JRA-25. Observations used in JRA-55 primarily consist of those used in ERA-40 (Uppala et al. 2005) and those archived at JMA. Observations after 1979 are basically the same as those used in JRA-25, but newly available observation data were collected and introduced whenever possible. Detailed list of the DA system, NWP model, and observation data are shown in tables 1, 2, and 3 of Appendix, respectively.

## 3. Basic performance of JRA-55

Kobayashi et al. (2015) examined performance of JRA-55 in the aspect of reproducing temporal and spatial variability of basic variables such as temperature, precipitation, and sea-level pressure. Harada et al. (2016) extended their investigation to include stratospheric circulation, tropical cyclones, the Madden-Julian oscillation, and mid-latitude storm tracks. Both studies concluded that quality of the JRA-55 improved significantly compared with that of the JRA-25. Some examples from these studies are introduced in this section.

### 3.1 Two-day forecast scores

To evaluate the temporal consistency of the product, short-range forecast was carried out in JRA-55. Figure 2 shows time series of root-mean-square (RMS) errors in 2-day forecasts at a geopotential height of 500hPa averaged over the extratropical northern and southern hemisphere from JRA-25, JRA-55, and the JMA operational system, as verified against their own analyses. The scores from JRA-55 and JRA-25 are temporally steady compared with that of the operational system, indicating that quality of the operational system strongly depends on frequent upgrades of the system. It is also found that the scores of the JRA-55 improved significantly from those of the JRA-25, which reflects updates of the system and observations since JRA-25. The improvement is particularly significant in the southern hemisphere, probably due to the availability of new satellite observations as well as to the improvement of the DA system.

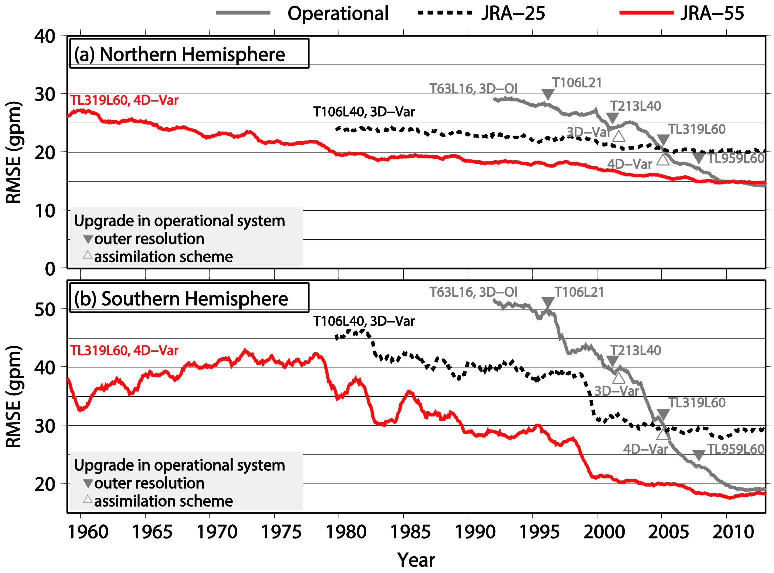

**Fig. 2.** RMS errors of 2-day forecasts at a geopotential height of 500hPa averaged over the extratropics of the (a) Northern and (b) Southern Hemispheres from JRA-25, JRA-55 and JMA operational system, verified against their own analyses. Changes in the assimilation scheme and resolution of the outer model are also noted. Each value represents the average for the last 12 months.

### 3.2 Temperature

Figure 3 compares monthly mean land-surface air temperature anomalies from the Climatic Research Unit (CRU) temperature database (CRUTEM4, Jones et al. 2012), the NCEP/National Center for Atmospheric Research (NCAR) reanalysis, ERA-40, JRA-25, and JRA-55, averaged over the globe. The low-frequency variability of 2-m temperature anomalies over land is fairly similar between JRA-55 and JRA-25. Compared with ERA-40, the trend reproduced in JRA-55 is closer to that in CRUTEM4 but there is a difference of less than 0.1 K between CRUTEM4 and JRA-55 after the 1990s.

The difference might be related to a difference in how observations are used between CRUTEM4 and JRA-55. In JRA-55, observations on islands and the coast are not used in the screen-level analysis of JRA-55 and analysis in those areas could be affected by observations in coastal waters such as reports of surface observation from sea stations (SHIP) and buoy observations (BUOY), and by Sea Surface Temperature (SST) through background fields. On the other hand, CRUTEM4 is based on observations over land only, which include those on islands and on the coast.

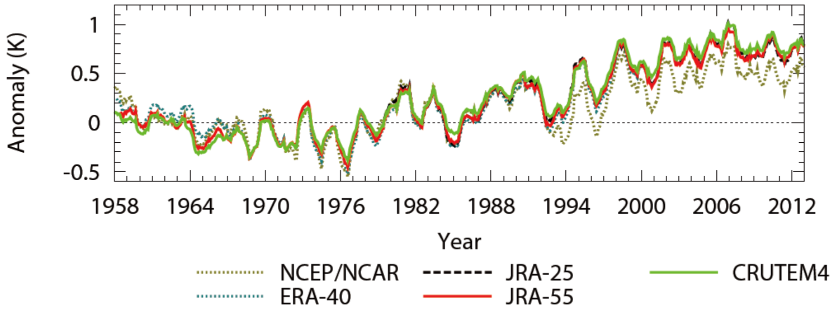

**Fig. 3.** Twelve-month running mean land-surface air temperature anomalies from CRUTEM4, the NCEP/NCAR reanalysis, ERA-40, JRA-25, and JRA-55, averaged over the globe. Anomalies for each dataset were defined relative to their own climatological monthly means over 1961–1990, except JRA-25, for which anomalies were first computed relative to its own climatological monthly means over 1981–2010 and then adjusted so that their average over 1979–1990 gave the same value as that of JRA-55. Reanalyses are sampled with the same spatial and temporal coverage as CRUTEM4.

### 3.3 Precipitation

Figure 4 shows the climatology of precipitation distribution in JRA-55, JRA-25, ERA-Interim (Dee et al. 2011), ERA-40, the Modern-Era Retrospective Analysis for Research and Applications (MERRA, Rienecker et al. 2011), and the Global Precipitation Climatology Project (GPCP) version 2.2 (Adler et al. 2003) as an observational dataset. While precipitation in middle and high latitudes are underestimated in most reanalysis, JRA-55 well reproduce these feature, especially in the Pacific and Atlantic Oceans north of 30°N. On the other hand, JRA-55 overestimates precipitation in the tropics compared with GPCP. The regions where JRA-55 overestimates precipitation tend to exhibit the spin-down problem[1] (not shown). Therefore, the excessive precipitation in the tropics in JRA-55 is most likely related to the dry bias and the spin-down problem of the forecast model in regions of deep convection.

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[1] Precipitation is excessive immediately after the start of forecasts and then gradually decreases.

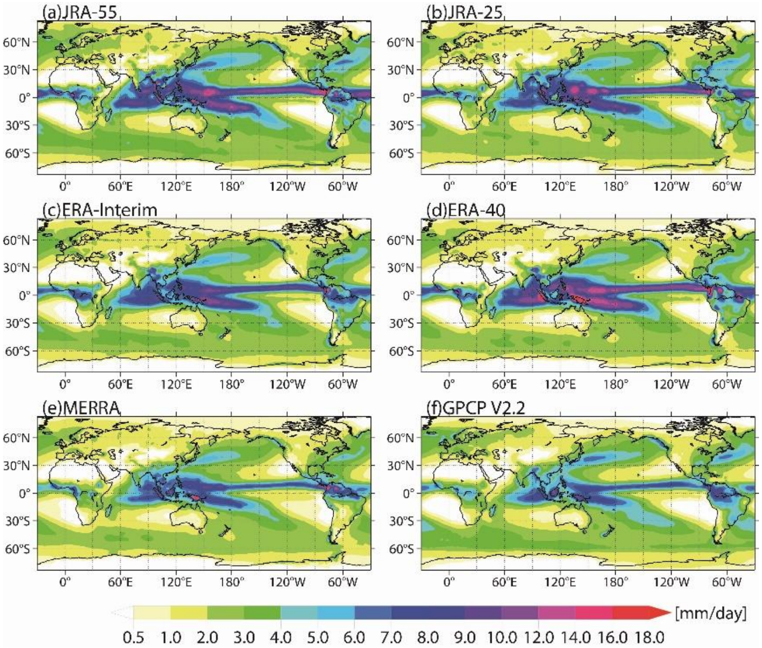

**Fig. 4.** Climatological annual mean precipitations in (a) JRA-55, (b) JRA-25, (c) ERA-Interim, (d) ERA-40, (e) MERRA, and (f) GPCP V2.2, averaged over 1980–2001.

## 4. JRA-55 user application and homepage

The JRA-55 data are available from the JMA Data Dissemination System (JDDS) for registered users. Application for JRA-55 data access can be made via the JRA-55 homepage by filling in necessary information such as name, affiliation, and purpose of use. The dataset is also available from the Data Integration and Analysis System (DIAS) managed by the University of Tokyo, the Center for Computational Sciences (CCS) of University of Tsukuba, NCAR in the U.S.A., and the Earth System Grid Federation (ESGF) at the National Aeronautics and Space Administration (NASA). Note that registration at the JRA-55 homepage is valid only at JDDS and separate registration is required for downloading from these collaborative organizations.

The JRA-55 homepage also provides detailed information on JRA-55 data (JRA-55 Product User's Handbook) and its quality issues. In addition, the homepage displays climate maps for a variety of meteorological variables ranging from basic metrics to technical considerations for climate research (JRA-55 Atlas). It is expected to be widely useful in research and education.

**JRA-55 homepage:** http://jra.kishou.go.jp/JRA-55/index_en.html
**JRA-55 Atlas:** http://ds.data.jma.go.jp/gmd/jra/atlas/en/index.html

## 5. Next Japanese reanalysis: JRA-3Q

JMA is currently planning to conduct the third Japanese reanalysis called JRA-3Q (Japanese Reanalysis for Three Quarters of a century), which covers over 75 years from 1947 to present.

The JRA-3Q will be produced by utilizing the latest NWP system as of 2018, as well as newly added observation since the JRA-55, to update quality of the reanalysis products. The production of JRA-3Q will be started in the first quarter of 2019 and ended by the end of 2021. Detail of the provisional plan and schedule will be presented in the lecture.

## Appendix: Detail of the DA system, NWP model, and observation data for JRA-25 and JRA-55.

**Table 1.** Data assimilation systems used for JRA-25 and JRA-55.

| | **JRA-25** | **JRA-55** |
|---|---|---|
| Basic system | JMA's operational system as of March 2004 (JMA 2002) | JMA's operational system as of December 2009 (JMA 2007, 2013b) |
| Horizontal grid system | Gaussian | Reduced Gaussian |
| Horizontal resolution | T106 (~110 km) | TL319 (~55 km) |
| **Atmospheric analysis** | | |
| Vertical levels | Surface and 40 levels up to 0.4 hPa | Surface and 60 levels up to 0.1 hPa (Iwamura and Kitagawa 2008; Nakagawa 2009) |
| Analysis scheme | 3D-Var with the T106 inner resolution | 4D-Var with the T106 inner resolution |
| Background error covariances | Static | Static with the simple inflation factor of 1.8 applied before 1972 |
| Bias correction for satellite radiances | *TOVS*<br>Adaptive scheme using 1D-Var analysis departures (Sakamoto and Christy 2009)<br>*ATOVS*<br>Static (until July 2009) and adaptive (thereafter) schemes using radiosonde and supplemental background fields (Kazumori et al. 2004) | VarBC (Derber and Wu 1998; Dee and Uppala 2009; JMA 2013) |
| Radiative transfer model for satellite radiances | *TOVS:* RTTOV-6<br>*ATOVS:* RTTOV-7 | RTTOV-9.3 |
| **Surface analysis** | | |
| Screen-level analysis | 2D-OI | 2D-OI with the FGAT approach |
| Land surface analysis | Offline SiB with 6-hourly atmospheric forcing | Offline SiB with 3-hourly atmospheric forcing |
| Snow depth analysis | 2D-OI | 2D-OI |

**Table 2.** Forecast models used for JRA-25 and JRA-55.

| | **JRA-25** | **JRA-55** |
|---|---|---|
| Base model | JMA GSM as of March 2004 (JMA 2002) | JMA GSM as of December 2009 (JMA 2007, 2013b) |
| Horizontal resolution | T106 (~110 km) | TL319 (~55 km) |
| Vertical levels | Surface and 40 levels up to 0.4 hPa | Surface and 60 levels up to 0.1 hPa (Iwamura and Kitagawa 2008; Nakagawa 2009) |
| **Dynamics** | | |
| Horizontal grid system | Gaussian | Reduced Gaussian |
| Advection scheme | Euralian | Semi-Lagrangian |
| **Radiation** | | |
| Longwave radiation | *Line absorptions*<br>Random band model of Goody (1952)<br>*Water vapor continuum (e-type)* | *Line absorptions*<br>Pre-computed transmittance tables and *k*-distribution (Chou et al. 2001)<br>*Water vapor continuum (e-type and p-type)* |

| | | |
|---|---|---|
| | Roberts et al. (1976)<br>*Radiatively active gases*<br>$H_2O$, $O_3$ and<br>$CO_2$ (constant at 375 ppmv) | Zhong and Haigh (1995) with MK_CKD (Clough et al. 2005)<br>*Radiatively active gases*<br>$H_2O$, $O_3$, $CO_2$, $CH_4$, $N_2O$, CFC-11, CFC-12 and HCFC-22 |
| Shortwave radiation | *Absorptions by $H_2O$, $O_2$, $O_3$ and $CO_2$*<br>Briegleb (1992) | *Absorptions by $H_2O$*<br>Briegleb (1992)<br>*Absorptions by $O_2$, $O_3$ and $CO_2$*<br>Freidenreich and Ramaswamy (1999) |
| Cloud radiation | *Longwave*<br>Maximum-random overlap<br>*Shortwave*<br>Random overlap | *Longwave*<br>Maximum-random overlap with the method of Räisänen (1998)<br>*Shortwave*<br>Random overlap |
| Aerosols | Atmospheric aerosol profiles from WMO (1986) (CONT-I over land and MAR-I over sea) | Atmospheric aerosol profiles from WMO (1986) (CONT-I over land and MAR-I over sea) with optical depths adjusted to 2-dimensional monthly climatology |
| **Cumulus convection** | Prognostic Arakawa-Schubert | Prognostic Arakawa-Schubert with DCAPE |
| **Initialization** | Nonlinear normal mode initialization | Not used |
| **Boundary conditions and forcing fields** | | |
| SST and sea ice | COBE-SST (Ishii et al. 2005) | COBE-SST (Ishii et al. 2005) |
| Ozone | T42L45 version of MRI-CCM1 (Shibata et al. 2005) | *Until 1978:* Climatology<br>*From 1979 onward:*<br>T42L68 version of MRI-CCM1 (Shibata et al. 2005) |

**Table 3.** Observational data sources for JRA-55. Observations shown in plain cells were added or reprocessed after JRA-25, whereas those in shaded cells are the same as those used in JRA-25. Acronyms in this table are summarized in Appendix B. of Kobayashi et al. (2015).

| Data supplier | Data type and supplier's identifiers | Period | Note |
|---|---|---|---|
| **Conventional data** | | | |
| ECMWF | ▨ | Jan 1958-Aug 2002 | Uppala et al. (2005) |
| JMA | ▨ | Jan 1961- | |
| | GAME and SCSMEX | Apr 1998-Oct 1998 | |
| NCEP/NCAR | SYNOP and upper-level observation | Jan 1979-Dec 1979 | Kalnay et al. (1996)<br>Kistler et al. (2001) |
| M. Yamanaka | Radiosondes from Indonesia | Jan 1958- | Okamoto et al. (2003) |
| M. Fiorino | TCRs | Jan 1958- | Fiorino (2002) |
| RIHMI | Snow depths from Russia | Jan 1958-Dec 2008 | |
| UCAR | Snow depths from USA | Jan 1958-Aug 2011 | NCDC et al. (1981) |
| Monthly Surface Meteorological Data in China | Snow depths from China | Jan 1971-Dec 2006 | Digitized from printed matters |
| IMH | Snow depths from Mongolia | Jan 1975-Dec 2007 | |
| **Satellite radiances** | | | |
| ECMWF | VTPR | Jan 1973-Feb 1976 | Uppala et al. (2005) |
| | HIRS and SSU | Nov 1978-Dec 2000 | |
| | MSU and AMSU | Nov 1978-May 2003 | |
| NOAA/NCDC | SSM/I | Jun 1987-Dec 2004 | |
| NOAA/CLASS | AMSU and MHS | Aug 1998- | |
| | SSM/I | Jul 1987- | |
| JMA | AMSU and MHS | Jun 2003- | |
| | SSM/I and SSMIS | Mar 2006- | |
| | TMI | Dec 2011- | |
| | CSR | Jun 2005- | |
| JMA/MSC | Reprocessed CSRs from GMS-5, GOES 9 and MTSAT-1R | Jul 1995-Dec 2009 | |
| JAXA, NASA | Reprocessed TMI version 7 | Feb 1998-Dec 2011 | |

| | | | |
|---|---|---|---|
| JAXA | Reprocessed AMSR-E Version 3 | Jun 2002-Oct 2011 | |
| EUMETSAT | CSRs from the Meteosat series | Jan 2001-Aug 2009 | |
| **AMVs** | | | |
| ECMWF | GMS, Meteosat and GOES | Jan 1979-Dec 1997 | Uppala et al. (2005) |
| JMA | GMS, MTSAT, Meteosat and GOES | Dec 1979-Dec1980, Jan 1998- | |
| | MODIS | Jun 2004- | |
| JMA/MSC | Reprocessed GMS, GOES 9 and MTSAT-1R | Jan 1979-Nov 1979<br>Nar 1987-Sep 2009 | |
| EUMETSAT | Reprocessed Meteosat-2 | May 1982-Aug 1988 | van de Berg et al. (2002) |
| | Reprocessed Meteosat-3 and -7 | Jan 1989-Dec 2000<br>Aug 1988-Nov 1998 | |
| | Meteosat-5 and -7 | Jan 2001-Feb 2001 | |
| **Scatterometer ocean surface winds** | | | |
| ESA | Reprocessed AMI (ERS.ASPS20.N) | May 1997-Jan2001 | De Chiara et al. (2007) |
| Hersbach (2008) | | | |
| JPL | Reprocessed SeaWinds from QuickSCAT (QSCAT_LEVEL_2B_V2) | Jul 1999-Nov 2009 | Dunbar et al. (2006) |
| JMA | ASCAT | Jan 2008- | |
| **GNSS-RO refractivities** | | | |
| CDAAC | Reprocessed CHAMP, SAC-C, COSMIC, GRACE, Metop-A, TerraSAR-X, and C/NOFS | Jul 2006-Jun 2012 | |
| JMA | COSMIC, GRACE, Metop, TerraSAR-X, and C/NOFS | | |

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