Introduction to Reanalysis and JRA-55

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1. Introduction to Reanalysis
   - Basic dataset for climate services
   - Operational analysis
   - Comparison b/w operational analysis and reanalysis

2. Introduction to JRA-55 reanalysis
   - Data assimilation system and forecast model
   - Basic performance
   - JRA-55 homepage and user application

3. JMA’s next reanalysis: JRA-3Q
1. Introduction to reanalysis

- For operational climate monitoring, we need dataset of...
  1. covering the globe for several decades
  2. including as many meteorological variables as possible
  3. spatially and temporally consistent and highly qualified

- In general, observation-alone is not enough to satisfy such conditions because the regions and variables are limited.

- However, dynamically and physically consistent GPVs with various variables could be produced by incorporating observation data into the state of numerical weather prediction (NWP) model.
  - This process, “Data Assimilation (DA)”, is a part of operational analysis cycle to estimate initial conditions for weather forecast.
  - Can dataset produced by long-term DA cycle satisfy the third condition??

Observation (example)  Grid point and physical processes of NWP model

Bauer et al. (2015)
Operational analysis cycle

Schematic diagram of the operational analysis cycle

- Actual state of the atmosphere (unknown, but we want to know)

Observations (example)
- Surface
- Radiosonde
- Ship
- Satellite

Boundary conditions (example)
- SST
- GHG (CO2)

Forecast model

Grid points of the model

Supercomputer

Used for the analysis at

First guess

6-hour forecast

Analysis

Assimilation

Obs.

Previous step (-6 hour)

Current step

Next step (+6 hour)

Time

6-hour forecast

First guess

Analysis

Assimilation

Obs.

Obs.
I. Un-uniformly distributed observations
II. The hatched area surrounding observations are analyzed with high quality. The high quality area extends thorough forecast.
III. In the next data assimilation, the deep colored area surrounding observations are analyzed with much higher accuracy. The higher quality area extended further by the next forecast.
IV. The repetition of data assimilation and forecast is called “Data Assimilation cycle”. DA cycle plays very important role to keep a certain level of high quality even in the area with no/less observational data.
## Operational analysis and Reanalysis

### Comparison of the operational analysis and reanalysis

<table>
<thead>
<tr>
<th></th>
<th>Operational analysis</th>
<th>“Re” analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model and DA system</strong></td>
<td>Occasionally changes (to improve forecast skills)</td>
<td>Constant and the latest* (to assure consistency and accuracy)</td>
</tr>
<tr>
<td><strong>Observation data</strong></td>
<td>Belated data are not used (because time for operational NWP is limited)</td>
<td>Belated data can be included (which may lead to improve the quality)</td>
</tr>
<tr>
<td><strong>Period</strong></td>
<td>The same as that of the model (not covering long-period)</td>
<td>Can be extended to past (depends on the obs. availability)</td>
</tr>
</tbody>
</table>

RMSE of forecast errors for Z500 in the northern hemisphere (with information of model improvements)

![Graph showing RMSE of forecast errors](image)

Obs. available at the time of operational analysis

![Diagram showing observation availability](image)

**Provided by Mr. Yoshiaki SATO (CPD/JMA)**

**Used for the analysis at**
Summary of section 1 (reanalysis)

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”

“Constant” and “state-of-the-art” NWP model

Data Assimilation

Quality Check

Integration for several decades

Consistent quality reanalysis product (GPV)

Input

Surf

Upper

Ship

Satellite

Observation (incl. belated data)

SST

Sea Ice

GHG

Boundary conditions (prescribed)

Climate Monitoring

Initial conditions for Hindcast (Re-forecast)

Climate Research
2. Introduction to JRA-55

- **1st JRA-25** (Onogi et al. 2007)
  - By JMA and CRIEPI* (1979-2004)
    *Central Research Institute for Electric Power Industry
  - Near real-time extension using the same system (JCDAS) was conducted by JMA and terminated in February 2014

- **2nd JRA-55** (Kobayashi et al. 2015)
  - By JMA (1958-2012)
  - The first reanalysis which covers more than 50 years since 1958 with 4D-VAR data assimilation system
  - Real time analysis after 2013 to present

*In Japanese, “5” is pronounced as “Go”.*
# JRA-55 Reanalysis System

JRA-55 reanalysis system was extensively improved since JRA-25.

<table>
<thead>
<tr>
<th></th>
<th><strong>JRA-25</strong></th>
<th><strong>JRA-55</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Period</strong></td>
<td>1979-2004 (26 years)</td>
<td>1958-2012 (55 years)</td>
</tr>
<tr>
<td><strong>NWP system</strong></td>
<td>As of Mar. 2004</td>
<td>As of Dec. 2009</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>T106L40 (~110km) ( (\text{top layer at 0.4 (hPa))} )</td>
<td>TL319L60 (~55km) ( (\text{top layer at 0.1 (hPa))} )</td>
</tr>
<tr>
<td><strong>Advection scheme</strong></td>
<td>Eulerian</td>
<td>Semi-Lagrangian</td>
</tr>
<tr>
<td><strong>Assimilation scheme</strong></td>
<td>3D-Var</td>
<td>4D-Var ( \text{(with T106 inner model)} )</td>
</tr>
<tr>
<td><strong>Bias correction (satellite radiance)</strong></td>
<td>Adaptive method ( \text{(Sakamoto et al. 2009)} )</td>
<td>Variational Bias Correction ( \text{(Dee et al. 2009)} )</td>
</tr>
<tr>
<td><strong>GHG concentrations</strong></td>
<td>Constant at 375 ppmv ( \text{(CO}_2 ) )</td>
<td>Annual mean data are interpolated to daily data ( \text{(CO}_2,\text{CH}_4,\text{N}_2\text{O)} )</td>
</tr>
</tbody>
</table>
Newly available and improved past observations are included in JRA-55

- **GNSS**: Global Navigation Satellite System
- **AMV**: Atmospheric Motion Vectors

**Observational data for JRA-55 (1)**

- **SYNOP**, **SHIP** and **BUOY**
- Snow depth over Russia, Mongol and USA**
- Digitized snow depth over China**
- Radiosondes, pilot balloons and wind profilers
- Tropical cyclone wind retrievals**

**Timeline**

- Aircraft
- **PAOBS**
- **IR sounders***
- **MW sounders**
- **MW imagers***
- **GOES***
- **METEOSAT***
- **GMS and MTSAT (reprocessed)****
- **GOES***
- **METEOSAT (reprocessed)***
- **GMS and MTSAT (reprocessed)****
- **MODIS**
- **Scatterometers***
- **GNSS RO***

**Legend**

- Conventional
- Satellite radiances
- AMV
- New types of sat obs

**Notes**

- **First time for reanalyses**
- * Improved from or added to JRA-25

**Years**


**Acronyms**

- AMV: Atmospheric Motion Vectors
- GNSS: Global Navigation Satellite System
Observation data for JRA-55 (2)

Number of observations assimilated in JRA55 is continuously increasing

Conventional observation and TCRs

(a) 90N - 60N  
(b) 60N - 20N  
(c) 20N - 20S  
(d) 20S - 60S  
(e) 60S - 90S

Station closures in the former Soviet Union
Research observation campaign
Seasonal increases in summer

Aircraft an satellite winds, PABOS, and GNSS-RO

Various types of satellite radiances

Unit: 1/day [Monthly mean counts]
The forecast scores of the JRA-55 system are considerably better than those of the JRA-25 due to new observational data and improvements of the DA system.

**RMSEs of 2-day forecasts of the geopotential height at 500hPa**

*Average over the extratropics

Reanalysis data are relatively consistent compared with the operational analysis.

2-day forecasts starting from each analysis are verified against their own analysis.

Upgrade in operational system
- outer resolution
- assimilation scheme

Upgrade in operational system
- outer resolution
- assimilation scheme
Basic performance (2): Tropospheric temperature

Long-term trends and variation of temperature in the land-surface and troposphere are well reproduced by JRA-55 reanalysis.

Surface air temperature trends from 1958 to 2001

Monthly temperature anomalies averaged over the globe

Reanalysis data were re-gridded to 5x5 resolution

12-month running mean
Basic performance (3): Stratospheric temperature

Cold bias in the stratosphere, one of the major problems of JRA-25, is extensively reduced in JRA-55 due to the revision of longwave radiation scheme.

Time-height sections of global mean temperature anomalies (1980-2001 mean)
Basic performance (4): Precipitation

JRA-55 well reproduce the precipitation in middle and high latitude. Spatial pattern of daily precipitation in the tropics are well reproduced by JRA-55.

**Annual mean precipitation averaged over 1980-2001**

![Maps showing precipitation patterns](image)

**Spatial correlation of monthly precipitation anomaly against GPCP**

- **Region:** Global
- **Period:** 1998-2009, May-Sep.

**Frequency of spatial correlation of daily precipitation against TRMM**

- **Small Correlation**
- **Large Correlation**

**Year**

- **Region:** Global
- **12-month running mean**
Basic performance (5): Tropical cyclones

Spatial pattern and intensity of TCs are well represented by JRA-55. However, artificial decreasing trends were detected due to bugs in TCRs…

**RMSE of TC position with respect to the best track**

**Global detection rates of tropical cyclones**

Artificial decreasing trends of JRA-55 due to TCRs bug??

Case study of individual TC: OK

Analysis of long-term TC trends: NG

**Accumulated cyclone energy (ACE)**

Zonal mean ACE
Summary of section 2 (JRA-55)

- **Forecast model and data assimilation system for JRA-55**
  - Extensively improved from those for JRA-25
    (e.g., resolution, 4D-VAR, advection scheme and physical schemes)

- **Observational data for JRA-55**
  - Improved in both quality and quantity from JRA-25
    (e.g., many reprocessed satellite data, newly available data)

- **JRA-55 has been significantly improved from JRA-25**
  - Reduction of Cold bias in the stratosphere
  - Reduction of the dry bias in the Amazon basin (not shown)
  - Increase of spatial temporal consistency

- **Problems to be addressed (The next reanalysis)**
  - Dry bias in the upper and lower troposphere
  - Warm (cold) bias in the upper (lower) troposphere
  - Unrealistic long-term trends in tropical cyclones
Basic information of JRA-55 is provided from JMA’s homepage. Registered users can download JRA-55 products from the JDDS* using FTP.


*JMA Data Dissemination System

Guides on JRA-55 products

JRA-55 and related dataset are also available from the collaborative organizations:

http://gpvjma.ccs.hpcc.jp/~jra55/index.html
http://rda.ucar.edu/datasets/ds628.0/
3. The next Japanese reanalysis: JRA-3Q

- **JRA-3Q** (Japanese Reanalysis for Three Quarters of a Century)

In Japanese, “3” is pronounced as “San”. San-Q ➔ San-kyuu ➔ Thank you ☺️

- **Provisional specifications**
  - **Higher resolution**: $T_{L319L60} \rightarrow T_{L479L100}$
    - 40 km in horizontal, 100 layers up to 0.01 hPa in vertical
  - **Extending the reanalysis period back in time**
    - Atmospheric reanalysis from 1947 to present
  - **New boundary conditions and forcing fields**
    - COBE-SST2 (1 deg., up to 1985)
    - MGDSST (0.25 deg. from 1985 onward)
  - **New observations**
    - Observations newly rescued and digitized by ERA-CLIM et al.
    - Improved satellite observations through reprocessing
    - JMA’s own tropical cyclone bogus
### Satellite observing systems for JRA-3Q (plan)

**Thin Color shadings: used for JRA-55, Others: not used**

**Thick Color shadings: will be used for JRA-3Q**

#### Low Orbit Satellite

<table>
<thead>
<tr>
<th>Infrared</th>
<th>Sounder (stratosphere)</th>
<th>Sounder (troposphere)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiometer</td>
<td>HRR</td>
<td>VTPR</td>
</tr>
<tr>
<td>Sounder</td>
<td>PMR</td>
<td>HIRS/2</td>
</tr>
<tr>
<td>Radiometer</td>
<td>SMMR</td>
<td>MSU</td>
</tr>
<tr>
<td>Sounder</td>
<td>NEMS</td>
<td>AMS</td>
</tr>
<tr>
<td>Sounder</td>
<td>SCAMS</td>
<td>SSMT</td>
</tr>
<tr>
<td>Scatterometer</td>
<td>SASS</td>
<td>SSMT2</td>
</tr>
<tr>
<td>GNSS radio occultation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Geostationary Infrared

<table>
<thead>
<tr>
<th>Standard Meridian</th>
<th>Indian Ocean</th>
<th>West Pacific</th>
<th>East Pacific</th>
<th>Atlantic</th>
</tr>
</thead>
<tbody>
<tr>
<td>METEOSAT</td>
<td>GOES</td>
<td>SMS</td>
<td>Reprocessed AMV</td>
<td>GOES West</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>GOES East</td>
</tr>
</tbody>
</table>

#### Timeline

- 1970
- 1980
- 1990
- 2000
- 2010
- 2020

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Thin Color shadings: used for JRA-55, Others: not used

Thick Color shadings: will be used for JRA-3Q
Japanese financial year (FY) runs from 1 April to 31 March
Summary

- **Reanalysis**
  - Analysis of the past atmospheric conditions using a constant, state-of-the-art NWP model and data assimilation system with the latest observation data
  - Production of a high-quality, spatially and temporally consistent dataset is vital for operational climate monitoring

- **JRA-55**: the latest reanalysis by JMA
  - Improved NWP system and newly available observational data are used to produce consistent climate dataset from 1958 onward
  - Registered users can download JRA-55 products from the JDDS

- **JMA-3Q**: the next reanalysis by JMA
  - Currently in preparation to produce higher quality and more consistent dataset for climate monitoring