Introduction to Reanalysis and JRA-3Q

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Outline

1. Introduction to Reanalysis

- Basic dataset for climate services
- Comparison b/w operational analysis and reanalysis

2. Introduction to JRA-3Q

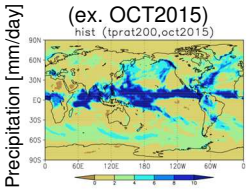
- Data assimilation system and forecast model
- Basic performance

Required dataset for climate monitoring

- **As basis for climate monitoring, climate dataset should be…**
  1. Covering the globe for several decades
  2. Including as many variables and time scales as possible
  3. Spatially and temporally consistent and highly qualified

Examples of climate monitoring

Raw Value (ex. OCT2015)



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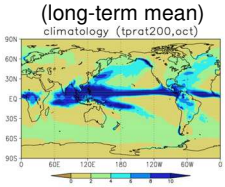
Climatology (long-term mean)



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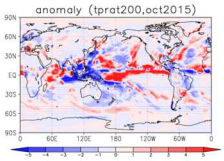
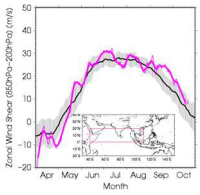
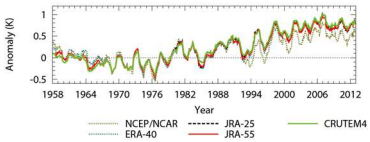
Anomaly (deviation from the climatology)



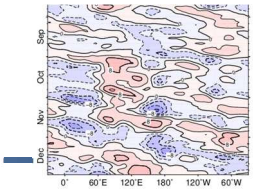
Asian Monsoon Monitoring Index



Long-term variations of surface-air temperature



Time-longitude section of 200hPa velocity potential anomaly



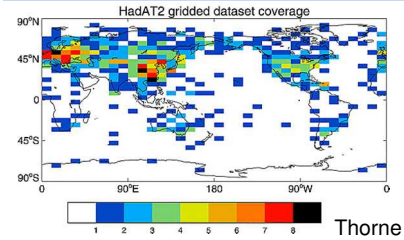
Approaches for producing climate dataset

Approach (1): Using observational data only

- Historical in-situ surface and upper observational data have been accumulated for several decades or a century in many organizations
  - ☐ High quality climate dataset can be generated at the observation station and surrounding region
  - ☐ However, the regions and variables are limited…

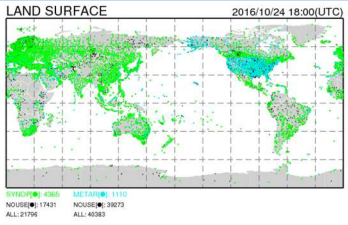
➔ Observation-alone is not suitable for (general) climate monitoring (though it is useful for some specific purposes)

Radiosonde data number for each grid



Thorne et al. 2005

Distribution of surface observation (example)



Approaches for producing climate dataset

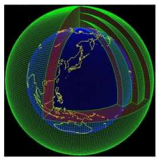
Approach (2): Using Global Circulation Model (GCM)

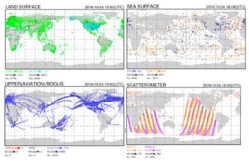
- Numerical integration of the basic equations of atmosphere using GCM and supercomputer
  - Gridded data with many kind of variables are generated based on consistent dynamics and physics of the model
  - However, calculation by model-alone is not enough to produce dataset with high accuracy…

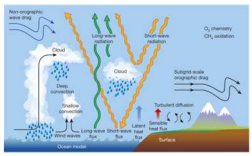
➔ Modification of the model outputs by observational data is needed (this process is called “Data Assimilation(DA)”, a part of **operational analysis cycle** to estimate the initial condition for short-range NWP)

➔ Climate dataset can be produced by long-term DA cycle??

Distribution of grid points | *Observational data (ex.)* | *Schematics of the atmospheric process*



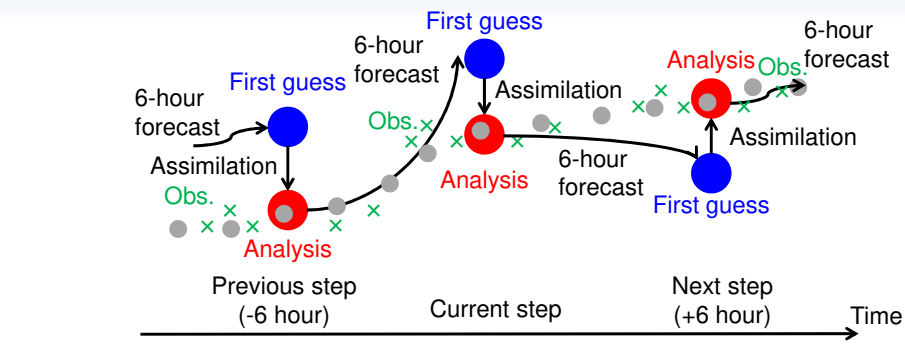




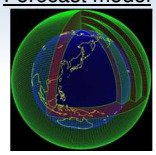
Bauer et al. (2015)

Data assimilation

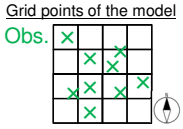
Schematic diagram of the data assimilation cycle



Forecast model



Grid points of the model



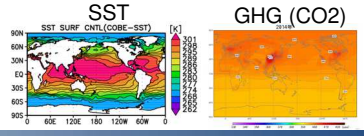
Supercomputer

Observations (example)

Surface | Radiosonde | Ship | Satellite

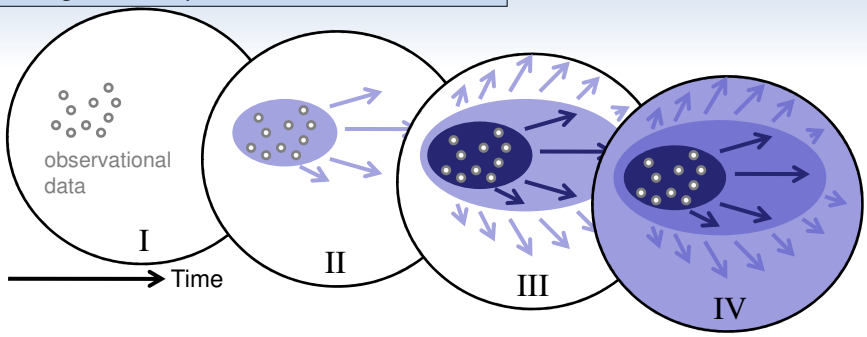
Boundary conditions (example)

SST | GHG (CO2)



Impacts of data assimilation

Schematic diagram of impacts of data assimilation



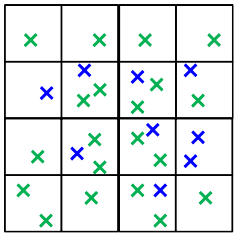
I. Un-uniformly distributed observations
II. The hatched area surrounding observations are analyzed with high quality. The high quality area extends through forecast.
III. In the next data assimilation, the deep colored area surrounding observations are analyzed with much higher accuracy. The higher 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

	Operational analysis	Reanalysis
Model and DA system	Upgraded with time (to improve forecast skills)	Constant and the latest* (to assure consistency and accuracy)
Observation data	Delayed data can't be used (because time for operational NWP is limited)	Delayed data are included (which may lead to improve the quality)

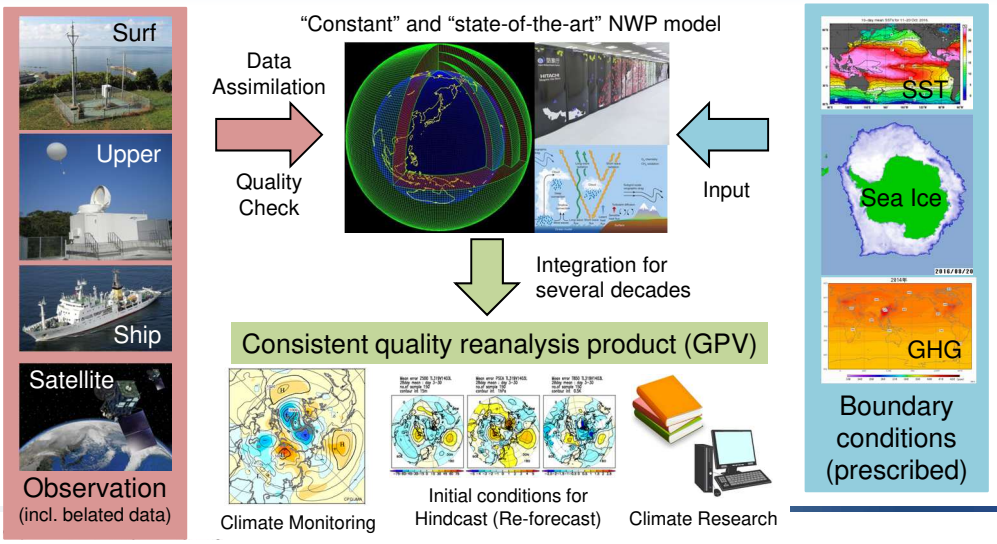
* as possible



Obs. available at the time of operational analysis
Obs. which become available after the time of operational analysis (delayed data)

Reanalysis

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



2. Introduction to JRA-3Q

- 1st **JRA-25** (Onogi et al. 2007)
  - Conducted 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)
  - Conducted by JMA (From 1958 to January 2024)
  - Update of the near real-time JRA-55 will be terminated at the end of January 2024.
- 3rd **JRA-3Q** (Kosaka et al. 2024)
  The Japanese Reanalysis for Three Quarters of a Century
  - Conducted by JMA (From September 1947 onward)

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

Reanalysis projects at JMA

	JRA-25	JRA-55	JRA-3Q
Analysis period	From 1979 to 2014	From 1958 to January 2024	From September 1947 onward
Data assimilation system	JMA operational system as of March 2004	JMA operational system as of December 2009	JMA operational system as of December 2018
Horizontal resolution	T106 (~110 km)	T_L319 (~55 km)	T_L479 (~40 km)
Vertical levels	40 levels up to 0.4 hPa	60 levels up to 0.1 hPa	100 levels up to 0.01 hPa
Analysis scheme	3D-Var (T106 inner resolution)	4D-Var (T106 inner resolution)	4D-Var (T_L319 inner resolution)
Radiative transfer model for satellite radiances	TOVS: RTTOV-6 ATOVS: RTTOV-7	RTTOV-9.3	RTTOV-10.2 • Improved accuracy • Inclusion of GHGs variations
SST and sea ice	COBE-SST: 1-degree	COBE-SST: 1-degree	Until May 1985: COBE-SST2 (1-degree) From June 1985 onward: MGDSST (0.25-degree)
Ozone	MRI-CCM1 (T42L45)	Until 1978: Climatology From 1979 onward: MRI-CCM1 (T42L68)	MRI-CCM2(T_L159L64) • Produced with the new model for the whole period

Specifications of JRA-3Q

- Extending the reanalysis period back in time
  - Atmospheric reanalysis from September 1947 to present
- Higher resolution: T_L319L60 -> T_L479L100
  - 40 km in horizontal, 100 layers up to 0.01 hPa in vertical
- Incorporating many improvements from the operational NWP system
  - Overall upgrade of physical processes
  - New types of observation
- Improved boundary conditions and forcing fields
  - COBE-SST2 (1 deg., until May 1985)
  - MGDSST (0.25 deg. from June 1985 onward)
- Improved observations
  - Observations newly rescued and digitized by ERA-CLIM et al.
  - Improved satellite observations through reprocessing
  - JMA's own tropical cyclone bogus

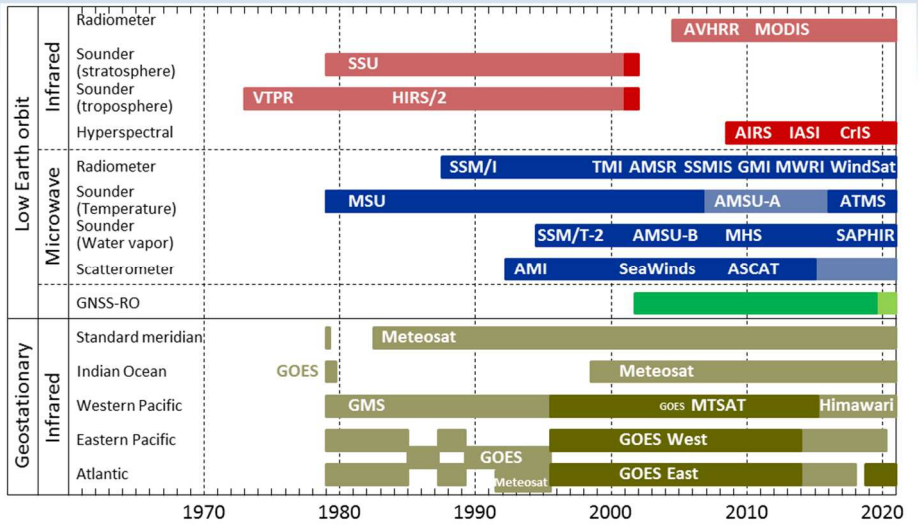
Observations used for JRA-3Q

- Building on the JRA-55 observational dataset
- Making the most of observations produced by the recent data rescue and satellite reprocessing efforts
  - Observations at surface and upper-air stations before the year 1958
  - Homogenised satellite observations through reprocessing
    - GMS/MTSAT AMVs reprocessed by JMA/MSC
- Increasing satellite humidity observations
  - Extending the period by introducing SSM/T-2 (DMSP)
  - Acquiring reprocessed microwave imager/humidity sounder data

  → Aiming at reducing the dry bias in the upper/mid troposphere
- Generating new tropical cyclone bogus data
  - Using the JMA typhoon bogus method

  → Solving the problem with tropical cyclone wind retrieval (TCR) used for JRA-55
- Introducing new types of observing system for recent years
  - Ground-based GNSS (precipitable water estimation from atmospheric delay over land)
    - Reprocessed by Dr Shoji at JMA/MRI for the period from 1994 to 2014
  - Hyperspectral infrared sounders (high vertical resolution satellite radiances)

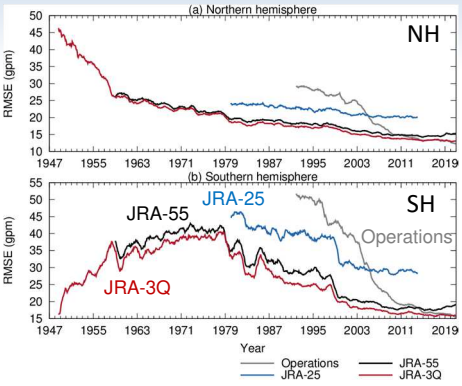
Satellite observations used in JRA-3Q



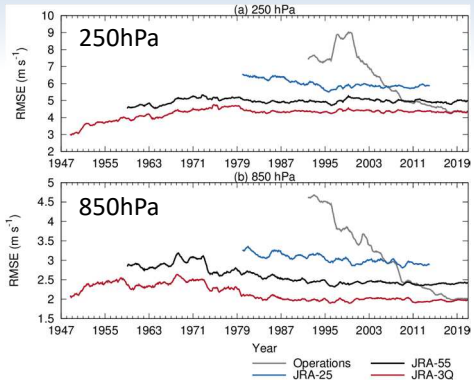
Darker shading indicates observations added, recalibrated, or reprocessed after JRA-55.

Two-day forecast scores (RMS errors)

Geopotential height at 500 hPa

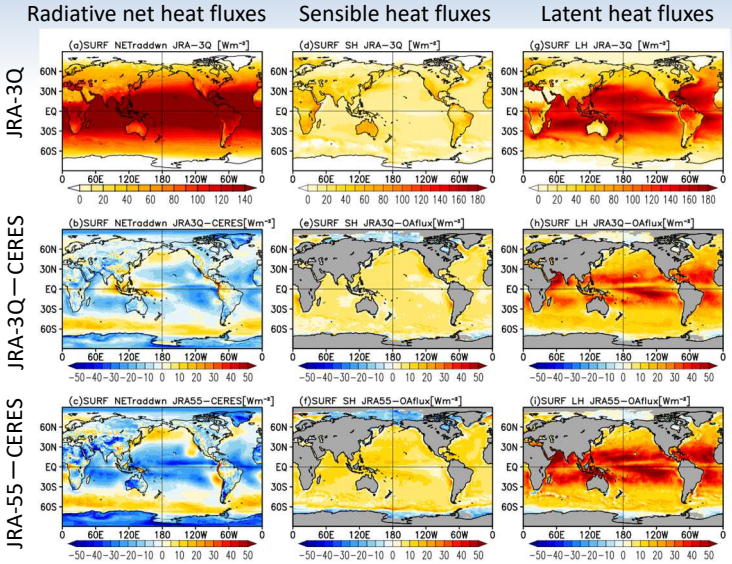


Wind vectors averaged over the tropics



- The decrease in the RMS errors from JRA-25 to JRA-55 to JRA-3Q shows that there was a steady improvement in the performance of the JMA data assimilation systems.
- During the pre-satellite period (until 1972), the forecast scores gradually deteriorated in the extratropical southern hemisphere, despite the expansion of the observing system.
  - Observations were too few to have a significant effect on data assimilation.

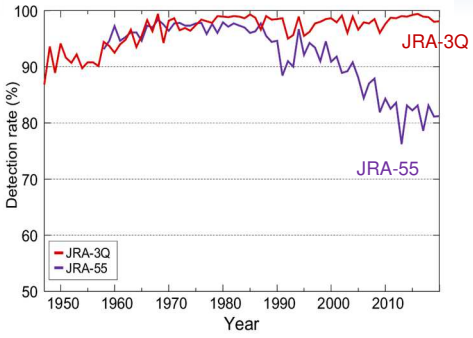
Global energy budget



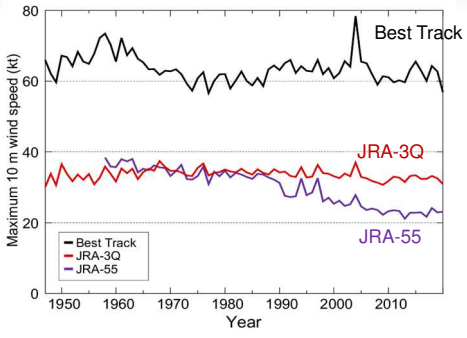
- The net energy flux over the ocean in JRA-3Q is −6.5 W m^{-2}, significantly closer to the estimate of Wild et al. (2015) (+0.8 W m^{-2}) compared with the estimate of −15.9 W m^{-2} in JRA-55.
  - This better agreement is due to overall improvements in parameterizations of physical processes.
- A reduced bias on average over the entire tropical ocean is most likely due to improved estimates of downward solar radiation associated mainly with the improved cloud radiation scheme.
- Improved net radiation fluxes in Australia, South Africa, southern South America, the western United States, and the Middle East are most likely attributable to the updated bare soil albedo.

Tropical cyclones

Global TC detection rates



Global mean of the maximum 10-m wind speed around detected TC centers

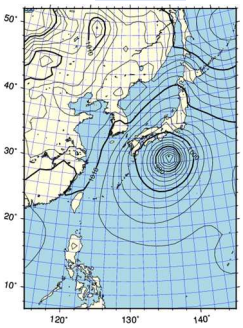


- The artificial decrease in the detection of TCs seen in JRA-55 has been resolved by the use of a TC bogus generation method based on the JMA operational system.
- JRA-3Q also assures long-term consistency in terms of maximum wind speeds, compared with JRA-55.
  However, it should be noted that the maximum wind speeds of TCs in JRA-3Q are about 50–60% of the best track wind speed, which is mainly due to difference of spatial representativeness.

Typhoon Kathleen in 1947

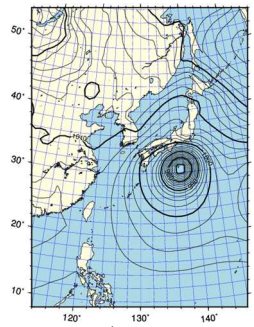
- The flooding disaster caused by Kathleen became a lesson of the history for flood control policies in the Tokyo metropolitan area.
- Typhoon Kathleen is clearly represented in JRA-3Q, and the pressure fields are generally consistent with the original weather map analyzed at that time.

JRA-3Q



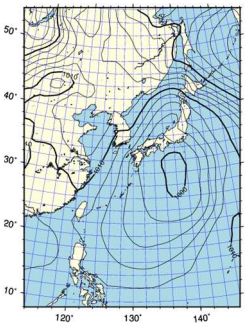
horz res 40 km, 100 levels

20CRv3



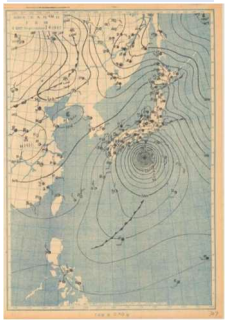
NOAA/CIRES
horz res 75 km, 64 levels

CERA-20C



ECMWF
horz res 125 km, 91 levels (atm)
horz res 110 km, 42 levels (ocn)

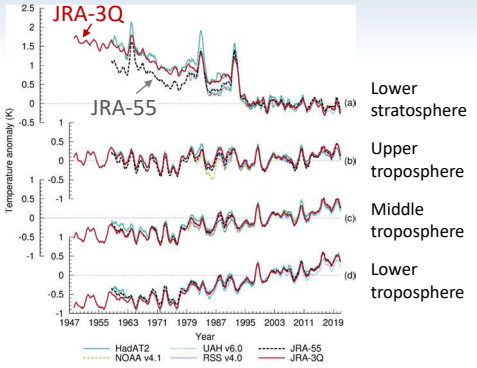
JMA weather chart



Analysis field of mean sea level pressure (hPa) at 06 UTC on 14 September 1947 and the weather map analyzed at that time

Temporal consistency of temperature analysis

Twelve-month running mean temperature anomalies averaged over the globe

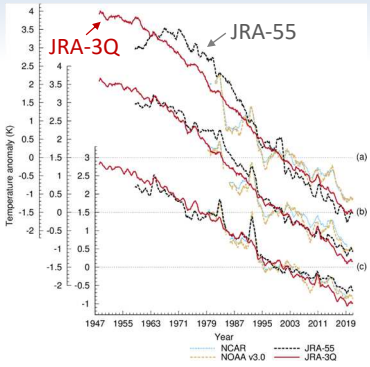


Lower stratosphere

Upper troposphere

Middle troposphere

Lower troposphere



Top stratosphere

Upper stratosphere

Middle stratosphere

- The representation of the lower-stratospheric cooling trend has been improved, most likely by the use of ozone reanalysis data generated by MRI-CCM2.1 for the entire period as well as by improved bias correction for radiosonde temperatures.
- Stratospheric warming after major volcanic eruptions is smaller than expected,
  - primarily due to the fact that the interannual variations of volcanic aerosols are not taken into account in the forecast model, and
  - the background error covariance of JRA-3Q has a shorter horizontal correlation length than that of JRA-55.

Summary

- Reanalysis
  - Analysis of the past atmospheric conditions using a constant, state-of-the-art NWP model and data assimilation system with the latest observational datasets
  - Production of a high-quality, spatially and temporally consistent dataset is vital for climate research and operational climate services.
- JRA-3Q: the latest reanalysis conducted by JMA
  - The improved NWP system and newly available observational data are used to produce a consistent climate dataset from September 1947 onward.
  - The initial quality evaluation revealed major improvements from JRA-55 in the global energy budget and representation of tropical cyclones.