Introduction to Reanalysis and JRA

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Outline

1. Introduction to Reanalysis

1.1 Required dataset for climate monitoring

1.2 Approaches for producing climate dataset

1.3 Reanalysis for climate monitoring

2. Introduction to JRA-55 reanalysis

2.1 Data assimilation system and forecast model

2.2 Basic performance

3. JMA's next reanalysis: JRA-3Q

4. Other topics

4.1 JRA-55 family: JRA-55C and JRA-55AMIP

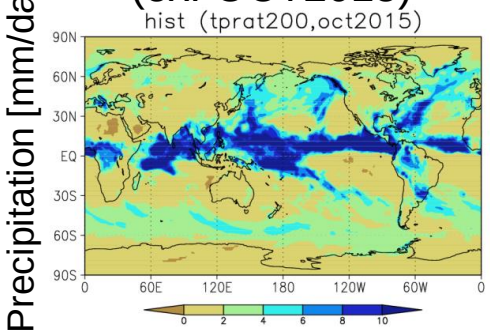
4.2 JRA-55 homepage and Atlas

1.1 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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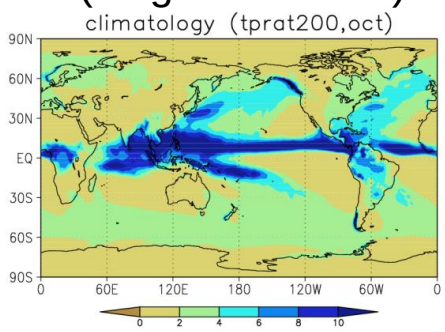
Climatology
(long-term mean)



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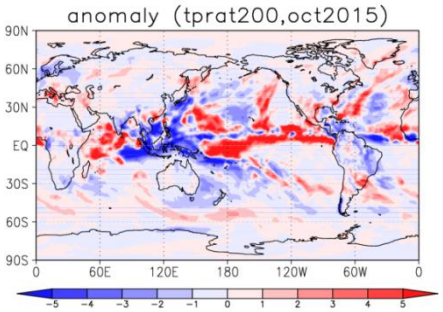
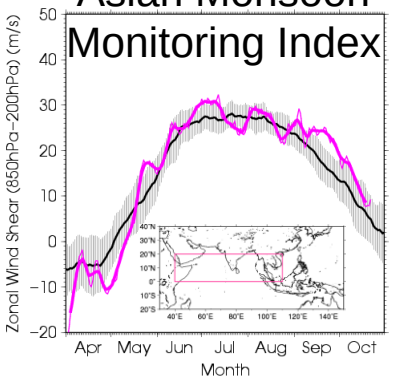
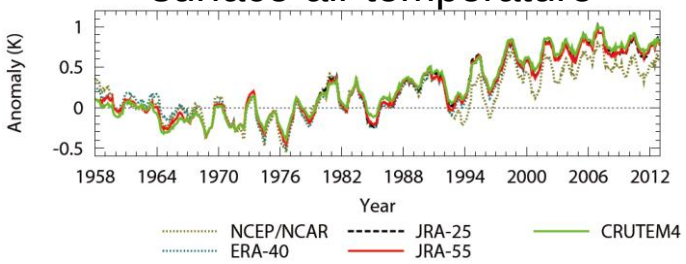
Anomaly
(deviation from the climatology)



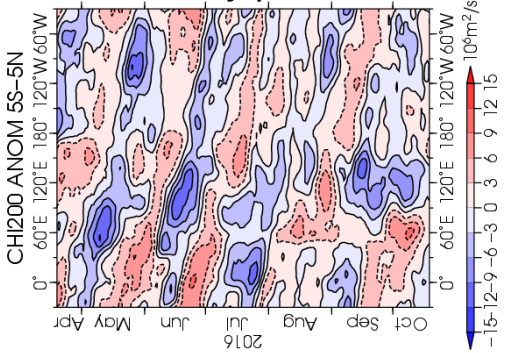
Asian Monsoon
Monitoring Index



Long-term variations of
surface-air temperature



Time-longitude section of
200hPa velocity potential anomaly



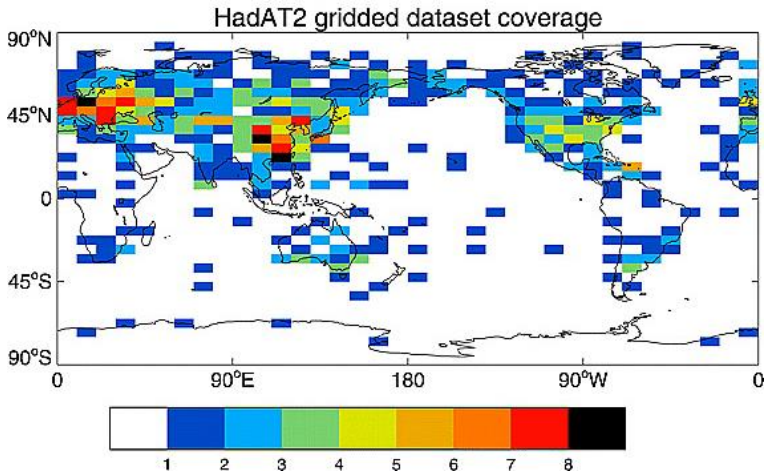
1.2 Approaches for producing climate dataset (1/4)

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…

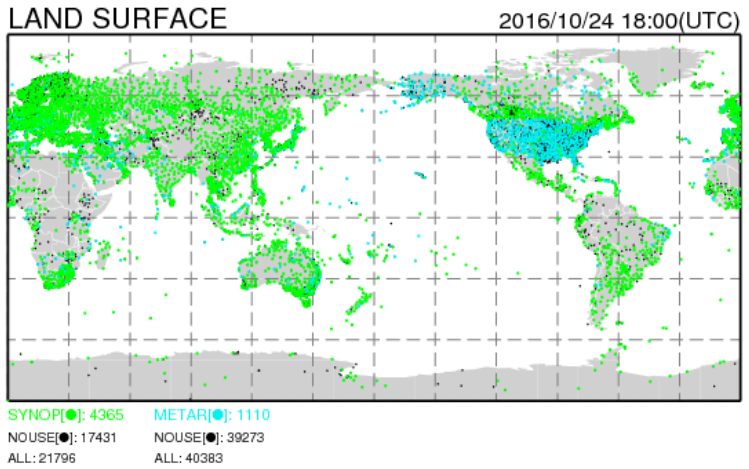
➔Observation-alone is not suitable for (general) climate monitoring (though it is useful for some specific purposes)

Radiosonde data number for each grid



Thorne et al. 2005

Distribution of surface obsevation (example)



1.2 Approaches for producing climate dataset (2/4)

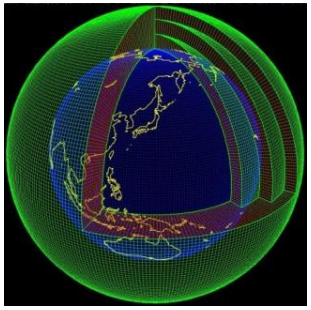
Approach (2): Using Global Circulation Model (GCM)

- Numerical integration of the basic equations of atmosphere using GCM and supercomputer
  - Grid Point Values (GPVs) 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…

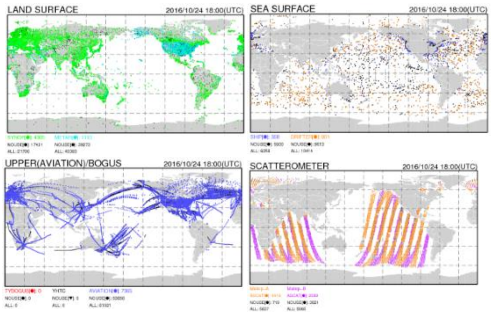
➔Modification of the model outputs by observational data is needed (this process is called “Data Assimilation(DA)”, a part of **operational analysis cycle** to estimate the initial condition for short-range NWP)

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

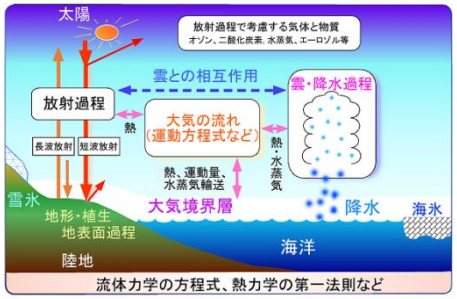
Distribution of grid points



Observational data (ex.)



Schematics of the atmospheric process

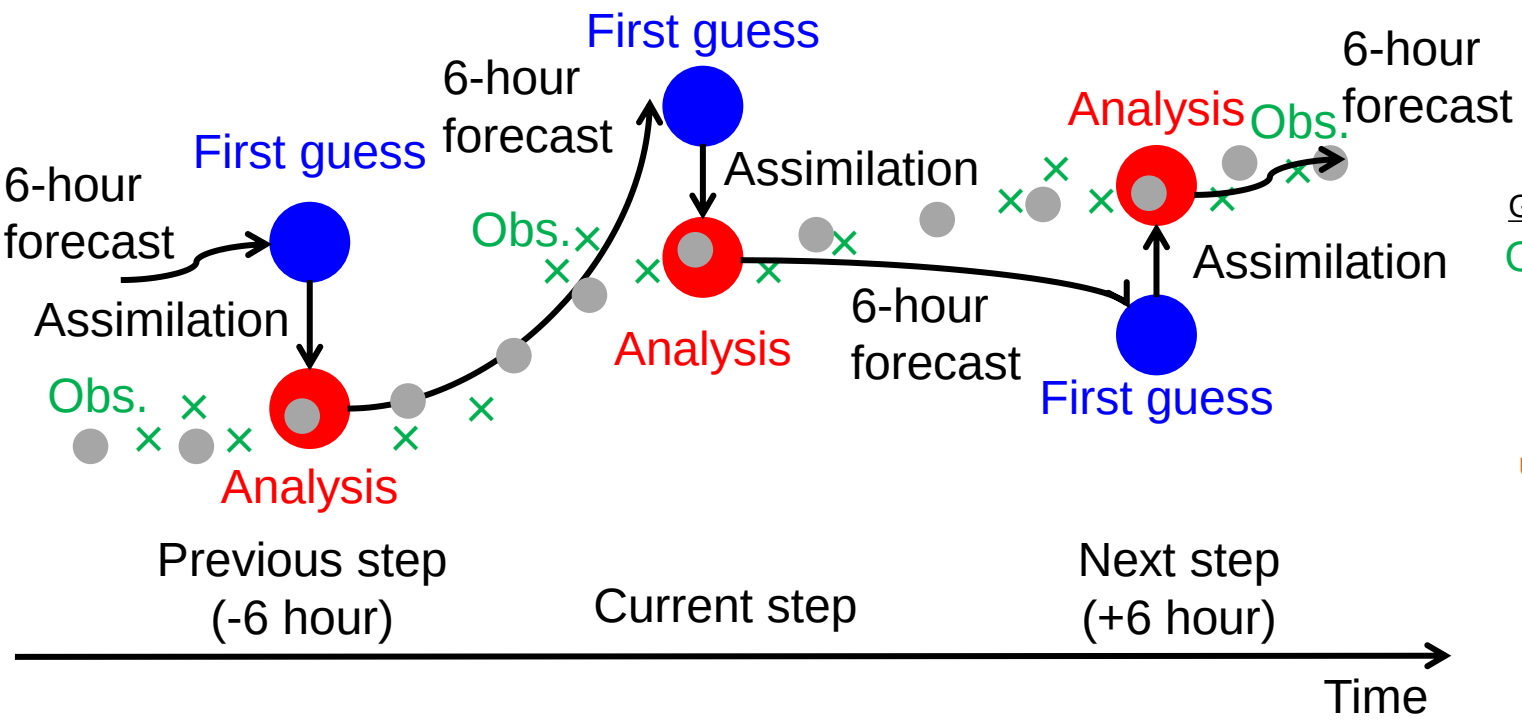


Dynamics
Radiation
Cloud etc.

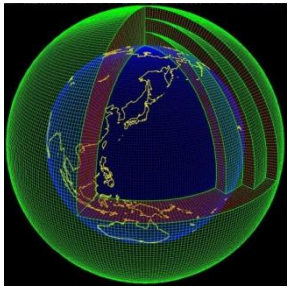
1.2 Approaches for producing climate dataset (3/4)

Schematic diagram of the operational analysis cycle

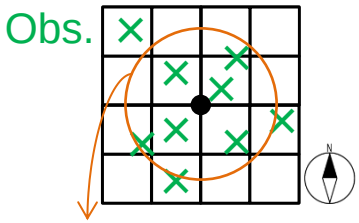
● Actual state of the atmosphere (unknown, but we want to know)



Forecast model



Grid points of the model



Supercomputer

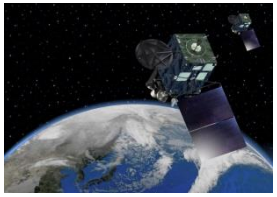
Observations (example)

Surface

Radiosonde

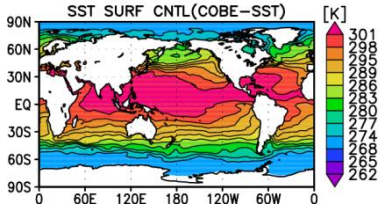
Ship

Satellite

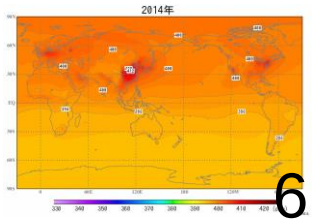


Boundary conditions (example)

SST

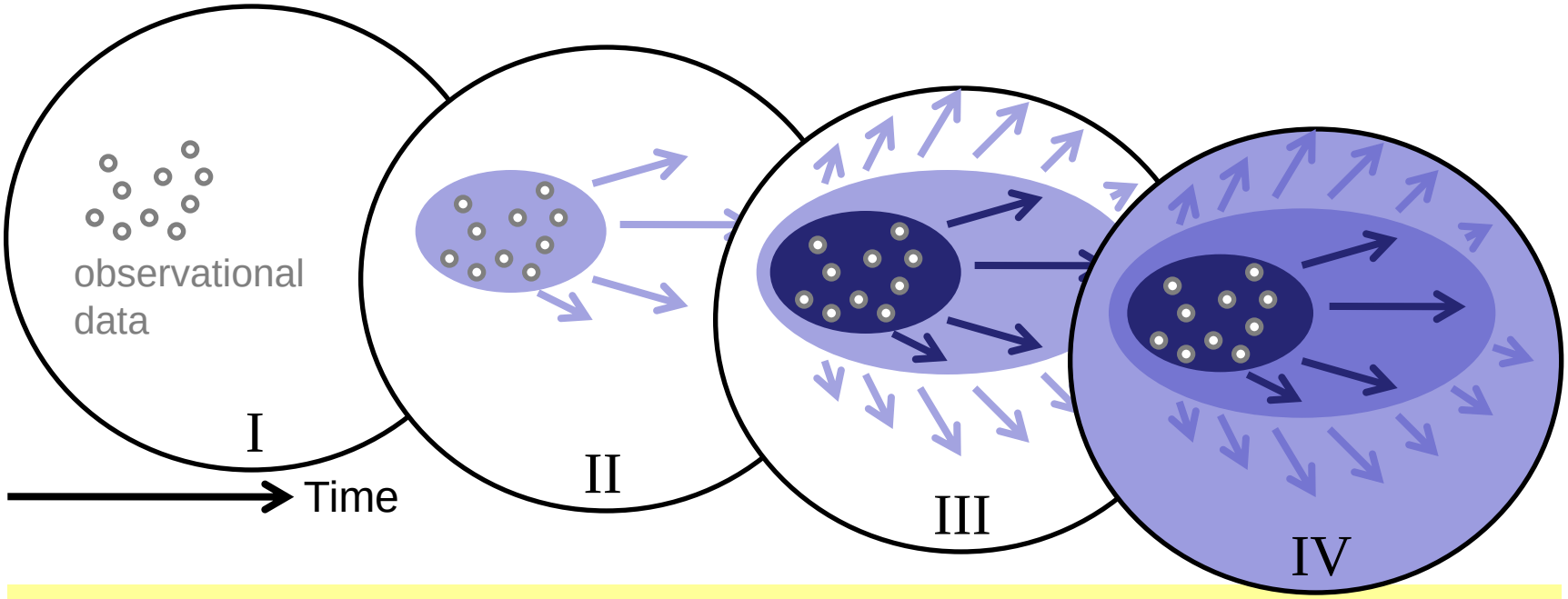


GHG (CO2)



1.2 Approaches for producing climate dataset (4/4)

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 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.

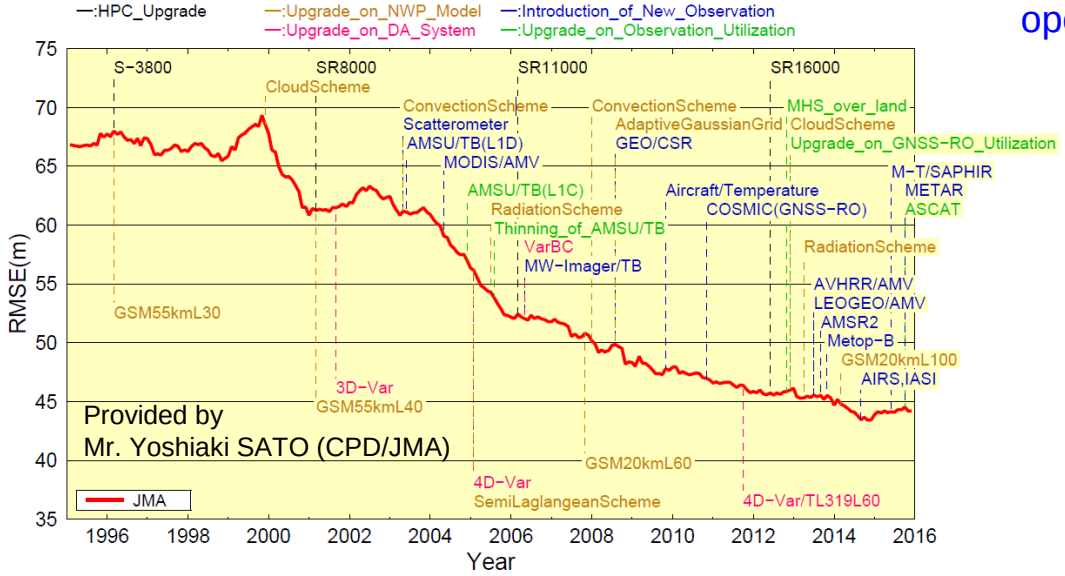
1.3 Reanalysis for climate monitoring (1/2)

Comparison of the operational analysis and reanalysis

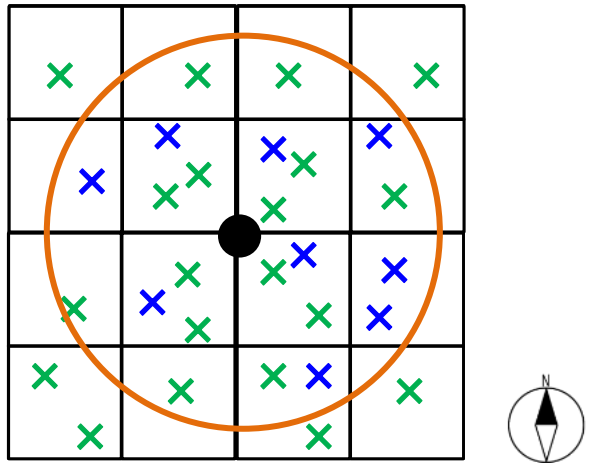
* as possible

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

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



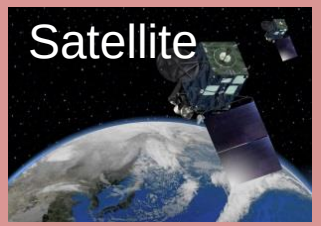
Obs. available at the time of operational analysis
Obs. which become available after the time of operational analysis (belated data)



Used for the analysis at ●

1.3 Reanalysis for climate monitoring (2/2)

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"

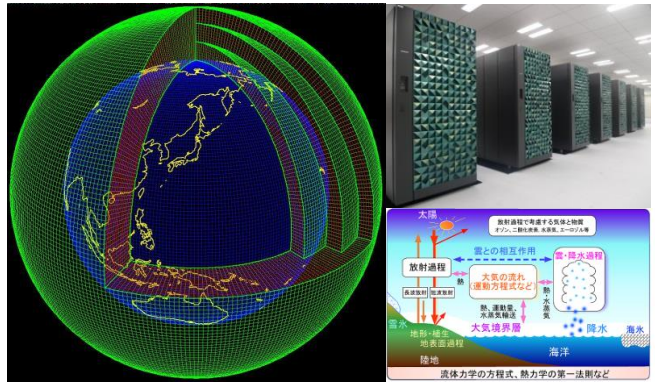


Observation
(incl. belated data)

"Constant" and "state-of-the-art" NWP model

Data Assimilation

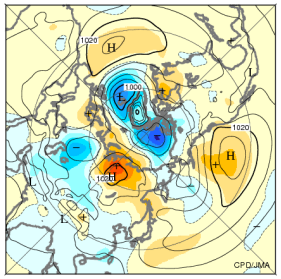
Quality Check



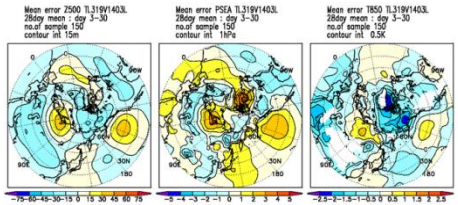
Input

Integration for several decades

Consistent quality reanalysis product (GPV)

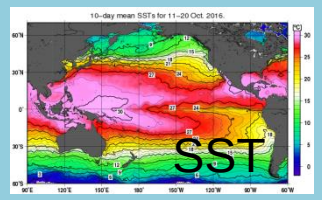


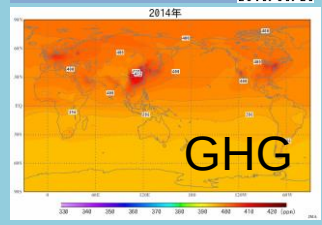
Climate Monitoring



Initial conditions for Hindcast (Re-forecast)

Climate Research





Boundary conditions (prescribed)

2. Introduction to JRA-55 reanalysis

- 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

JRA Go! Go!

In Japanese, "5" is pronounced as "Go".

2.1 JRA-55 reanalysis system

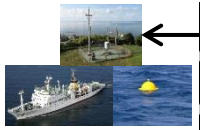
JRA-55 reanalysis system was extensively improved since JRA-25

	JRA-25	JRA-55
Period	1979-2004 (26 years)	**1958-2012 (55 years)**
NWP system	As of Mar. 2004	As of Dec. 2009
Resolution	T106L40 (~110km) *(top layer at 0.4 hPa)*	**TL319L60 (~55km)** ***(top layer at 0.1 hPa)***
Advection scheme	Eulerian	**Semi-Lagrangian**
Assimilation scheme	3D-Var	**4D-Var** ***(with T106 inner model)***
Bias correction (satellite radiance)	Adaptive method (Sakamoto et al. 2009)	Variational Bias Correction (Dee et al. 2009)
GHG concentrations	Constant at 375 ppmv (CO_2)	Annual mean data are interpolated to daily data (CO2,CH4,N2O)

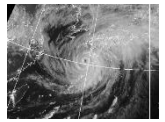
2.2 Observational Data for JRA-55 (1/2)

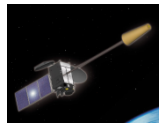
Newly available and improved past observations are included in JRA-55

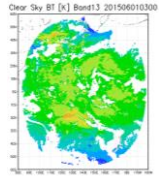
(image)

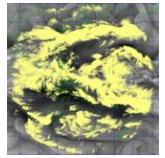


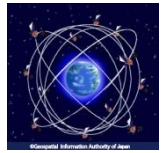
(image)











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**

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*

Conventional

Satellite radiances

AMV

New types of sat obs

** First time for reanalyses

* Improved from or added to JRA-25

1960 1970 1980 1990 2000 2010

Year

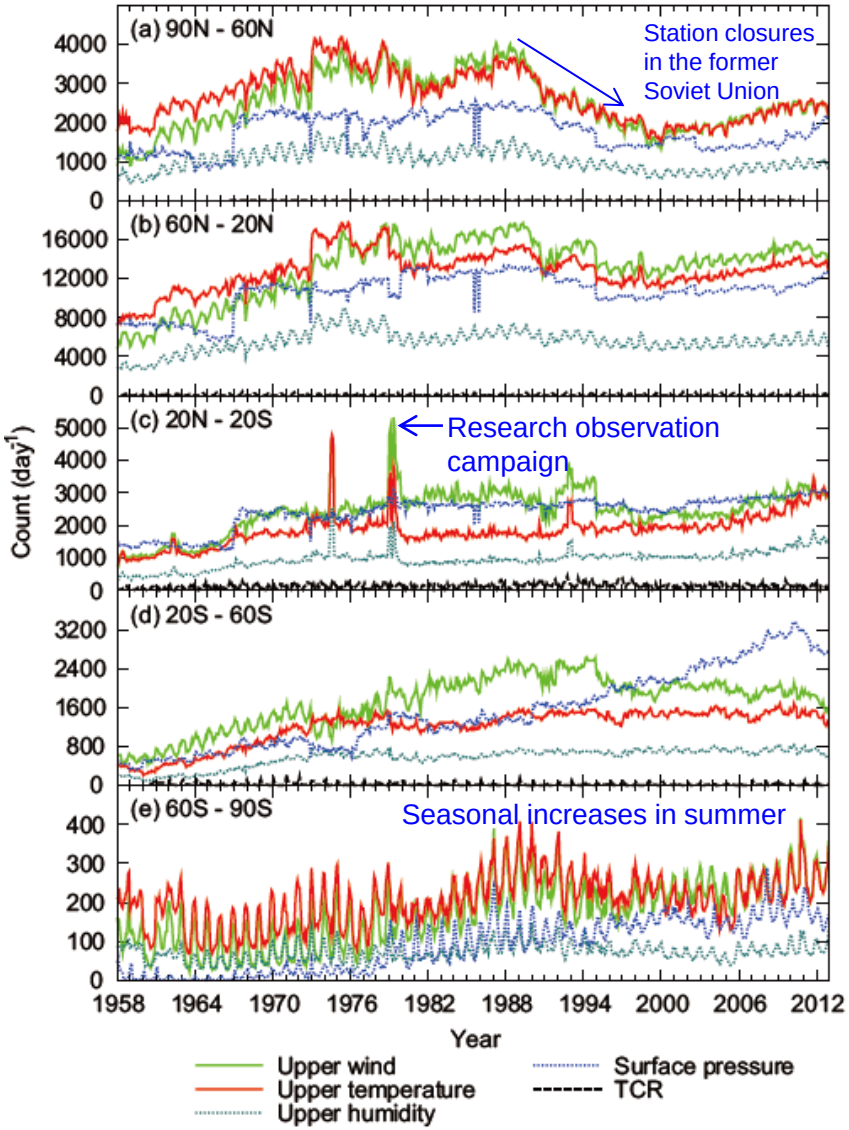
AMV: Atmospheric Motion Vectors

GNSS: Global Navigation Satellite System

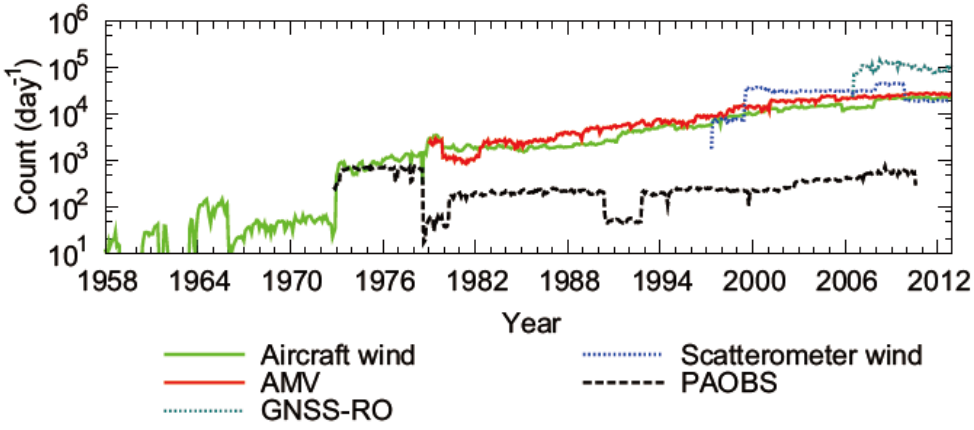
2.2 Observation data for JRA-55 (2/2)

Number of observations assimilated in JRA55 is continuously increasing

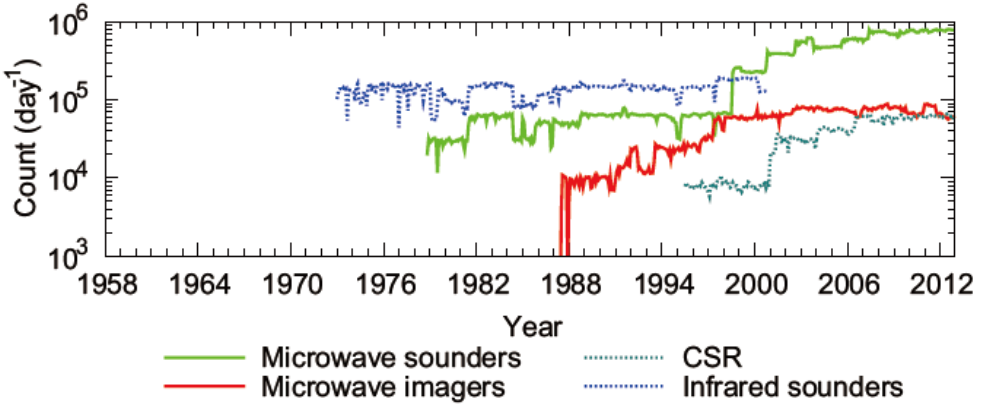
Conventional observation and TCRs



Aircraft an satellite winds, PABOS, and GNSS-RO



Various types of satellite radiances



Kobayashi et al. (2015, JMSJ)

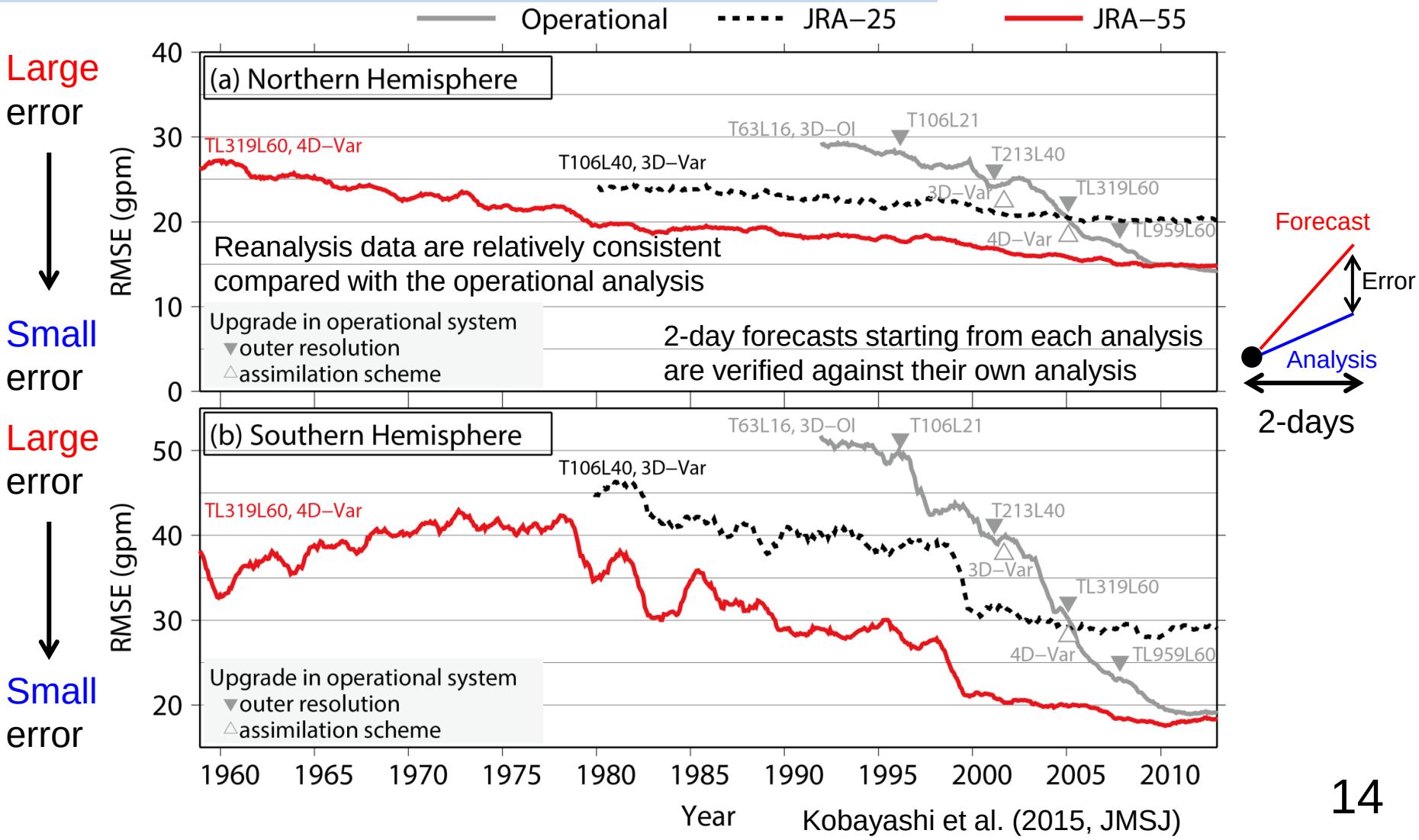
Unit: 1/day [Monthly mean counts]

2.2 Basic performance (1/6)

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

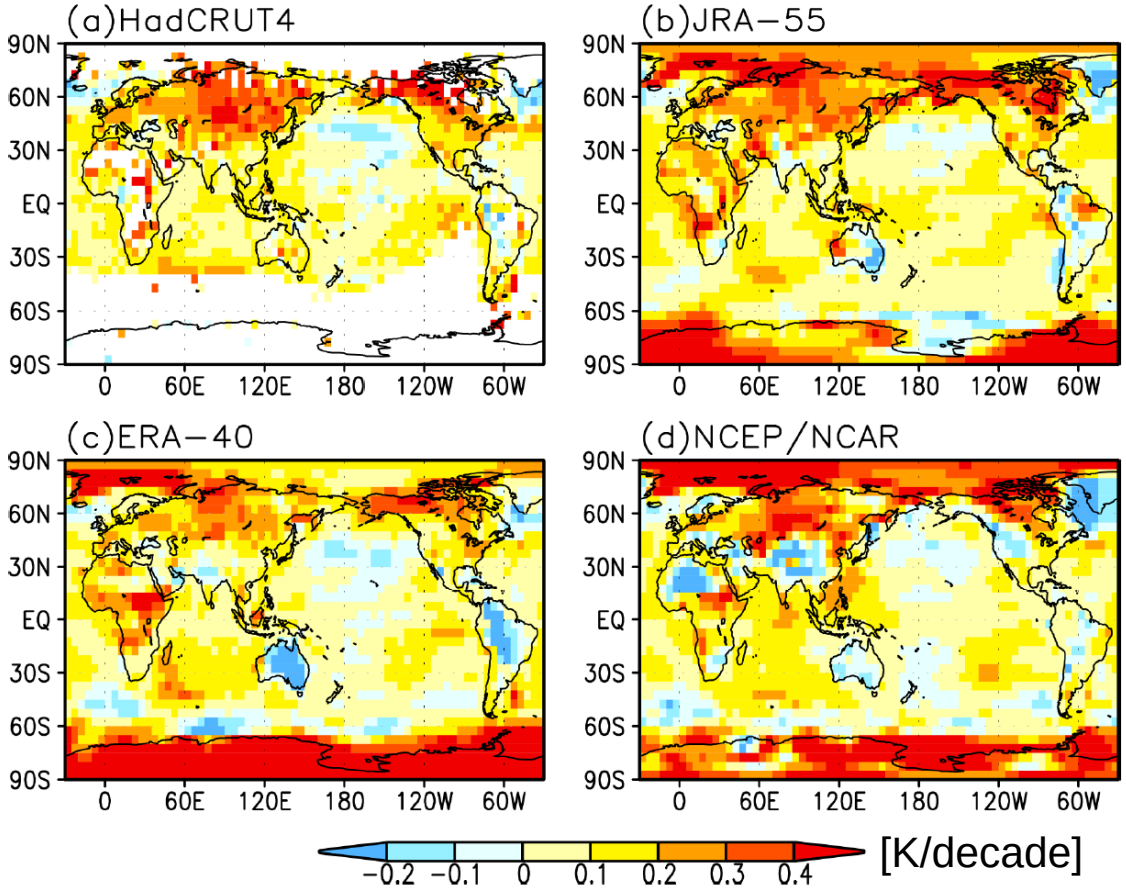


Kobayashi et al. (2015, JMSJ)

2.2 Basic Performance (2/6): Temperature in the troposphere

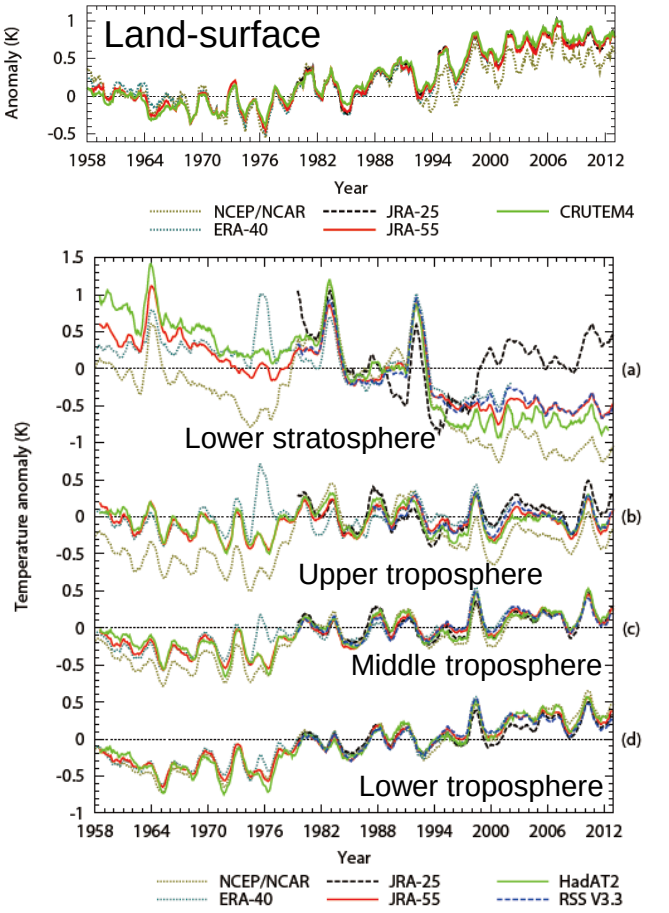
Long-term trends and variation of temperature in the land-surface and troposphere are well reproduced by JRA-55 reanalysis

Surface air temperature trends from 1958 to 2001



Reanalysis data were re-gridded to 5x5 resolution

Monthly temperature anomalies averaged over the globe



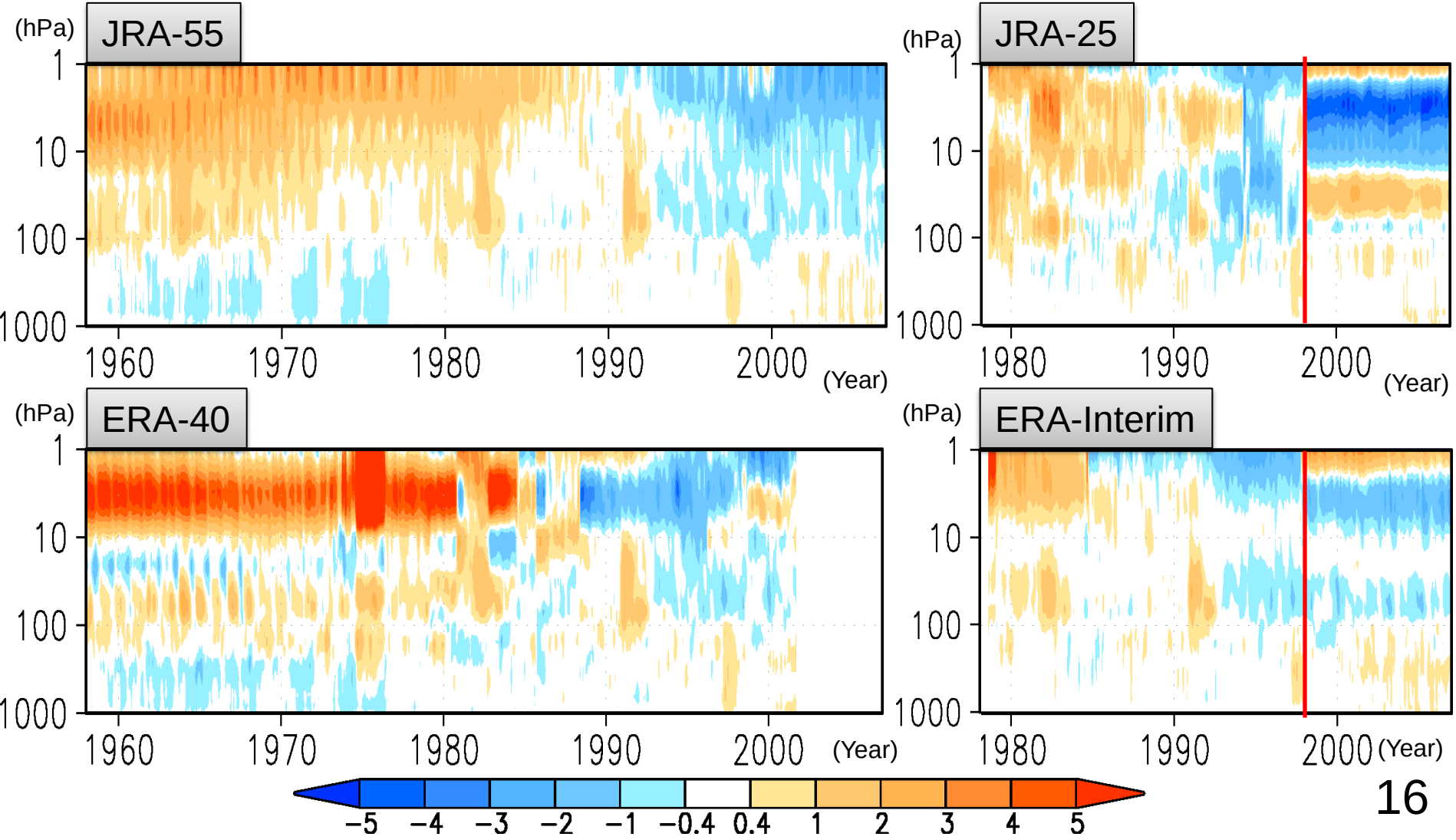
12-month running mean

Harada et al. (2016,JMSJ) and Kobayashi et al. (2015, JMSJ)

2.2 Basic Performance (3/6): Temperature in the stratosphere

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

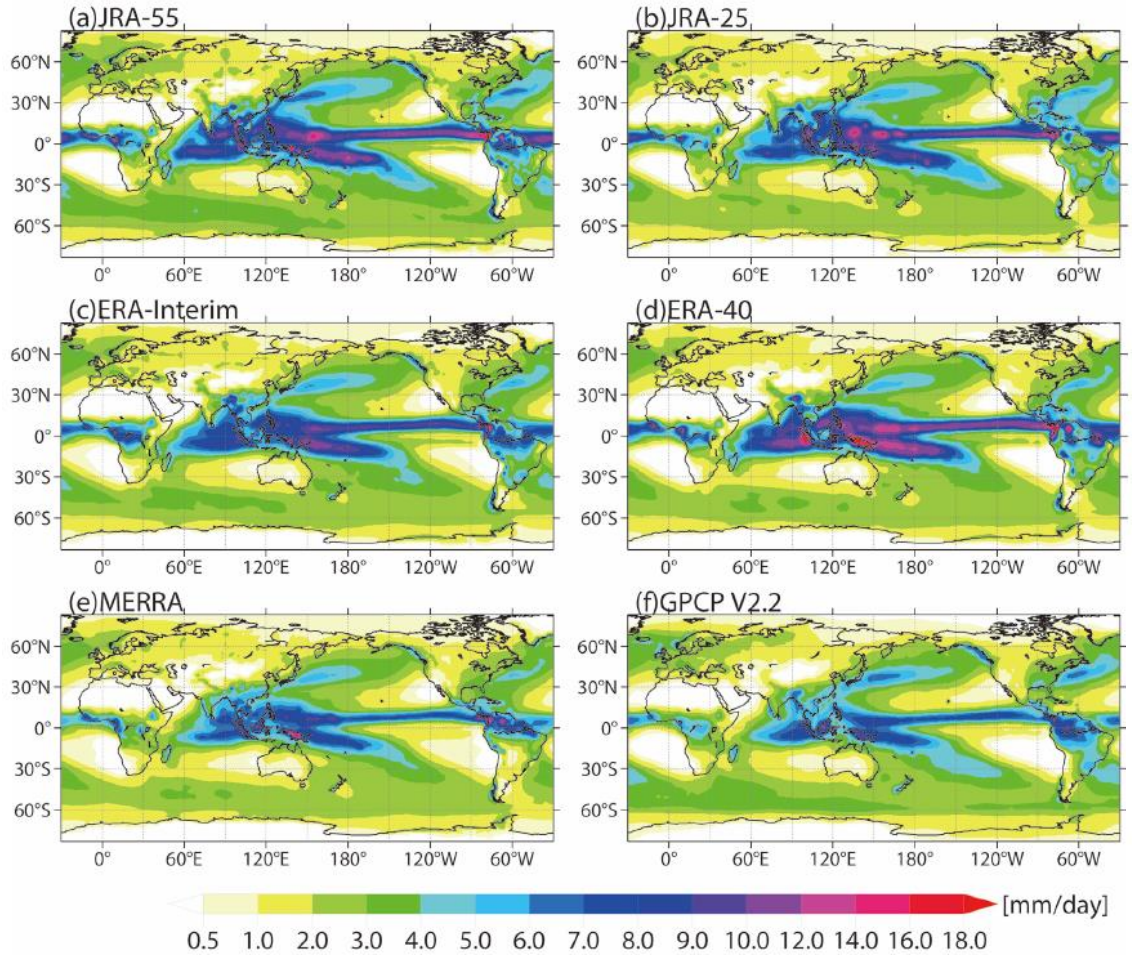
Time-height sections of global mean temperature anomalies (1980-2001 mean)



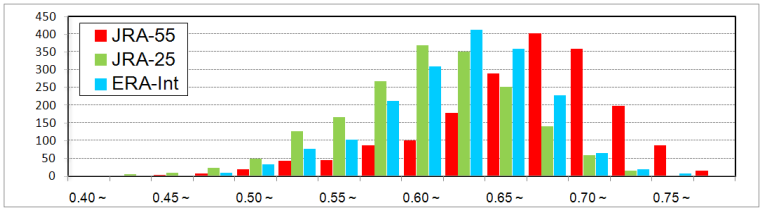
2.2 Basic Performance (4/6): Precipitation

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



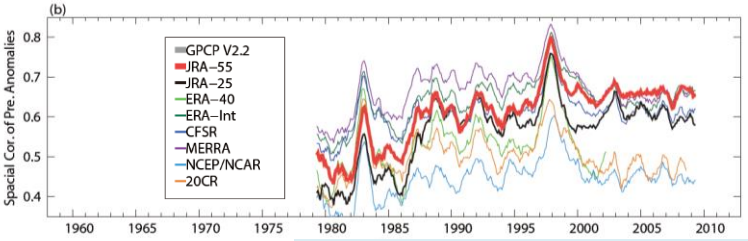
Frequency of spatial correlation of daily precipitation against TRMM



Small Correlation Large

Region: 22S-22N
Period: 1998-2009, May-Sep.

Spatial correlation of monthly precipitation anomaly against GPCP



Year

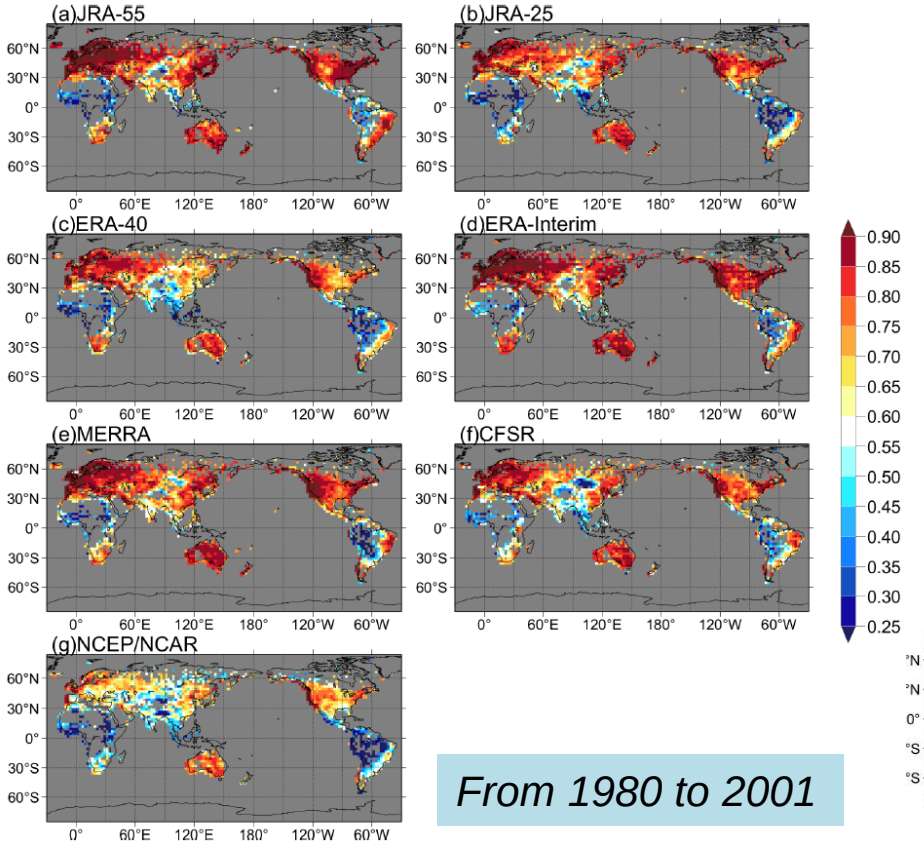
Region: Global
12-month running mean

Kobayashi et al. (2015, JMSJ)

2.2 Basic performance (5/6): Precipitation over land

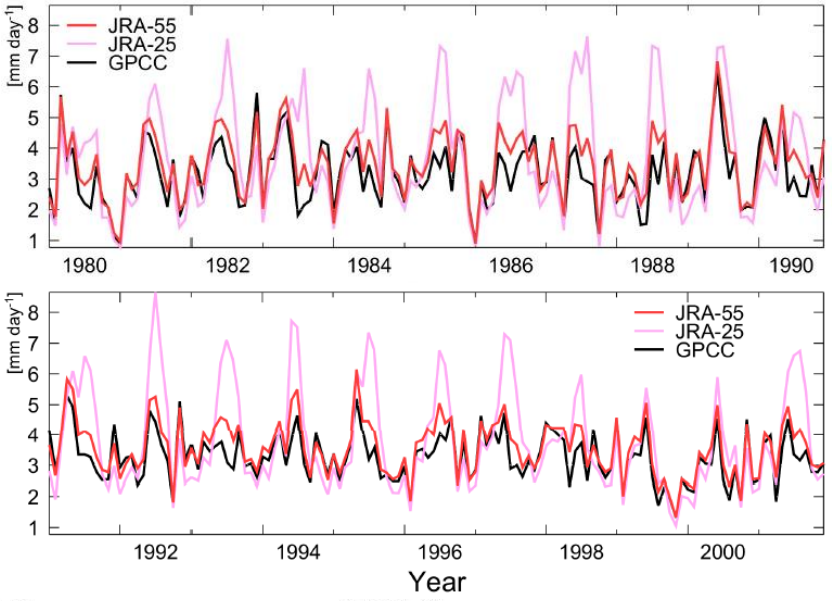
Precipitation estimated by JRA-55 is consistent with the GPCC results. Representation of precipitation over extra-tropical land is of high quality throughout the reanalysis period.

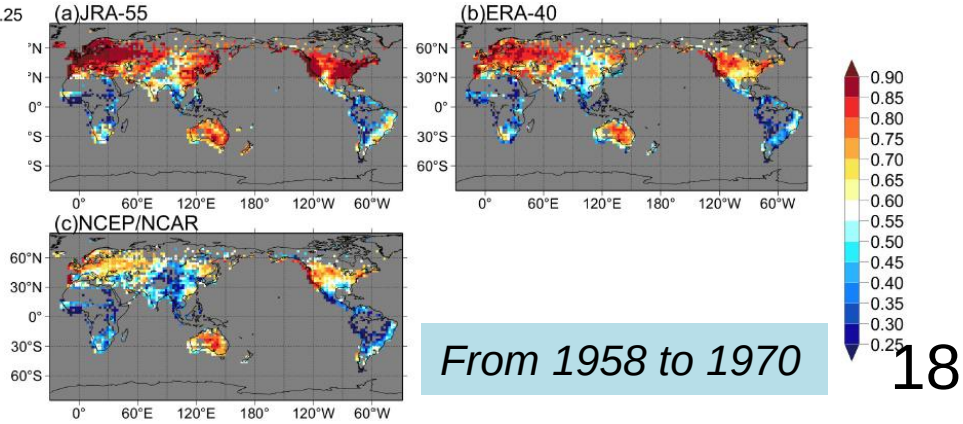
Temporal correlation coefficients of monthly precipitation anomaly with GPCC



From 1980 to 2001

Time series of monthly mean precipitation averaged over 30-40N, 80-100W





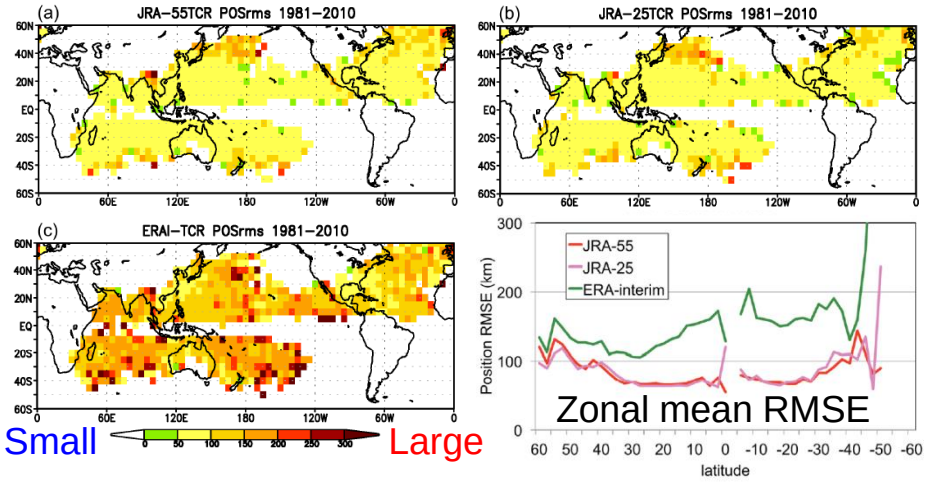
From 1958 to 1970

Harada et al. (2016, JMSJ)

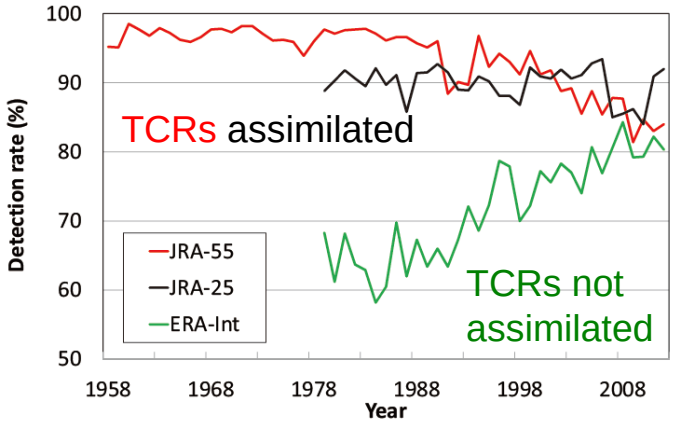
2.2 Basic Performance (6/6): Tropical cyclones

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



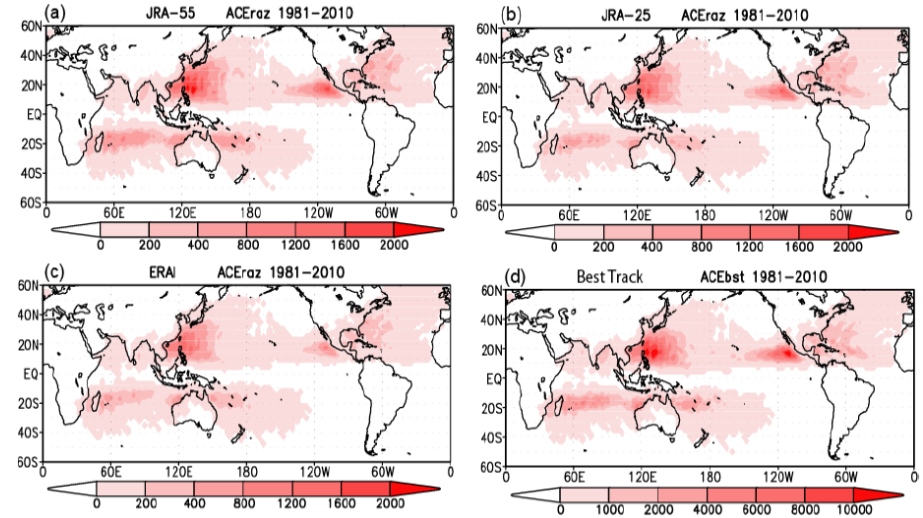
Global detection rates of tropical cyclones



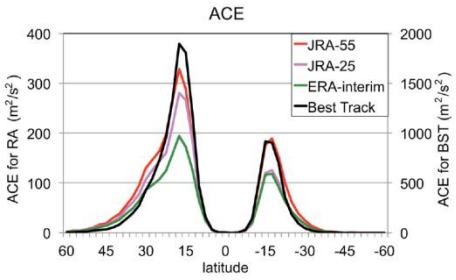
Artificial decreasing trends of JRA-55 due to TCRs bug??

Case study of individual TC: OK
Analysis of long-term TC trends: NG

Accumulated cyclone energy (ACE)



Zonal mean ACE



Kobayashi et al. (2015, JMSJ)

Summary of 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 improved from JRA-25. For example…**
  - 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

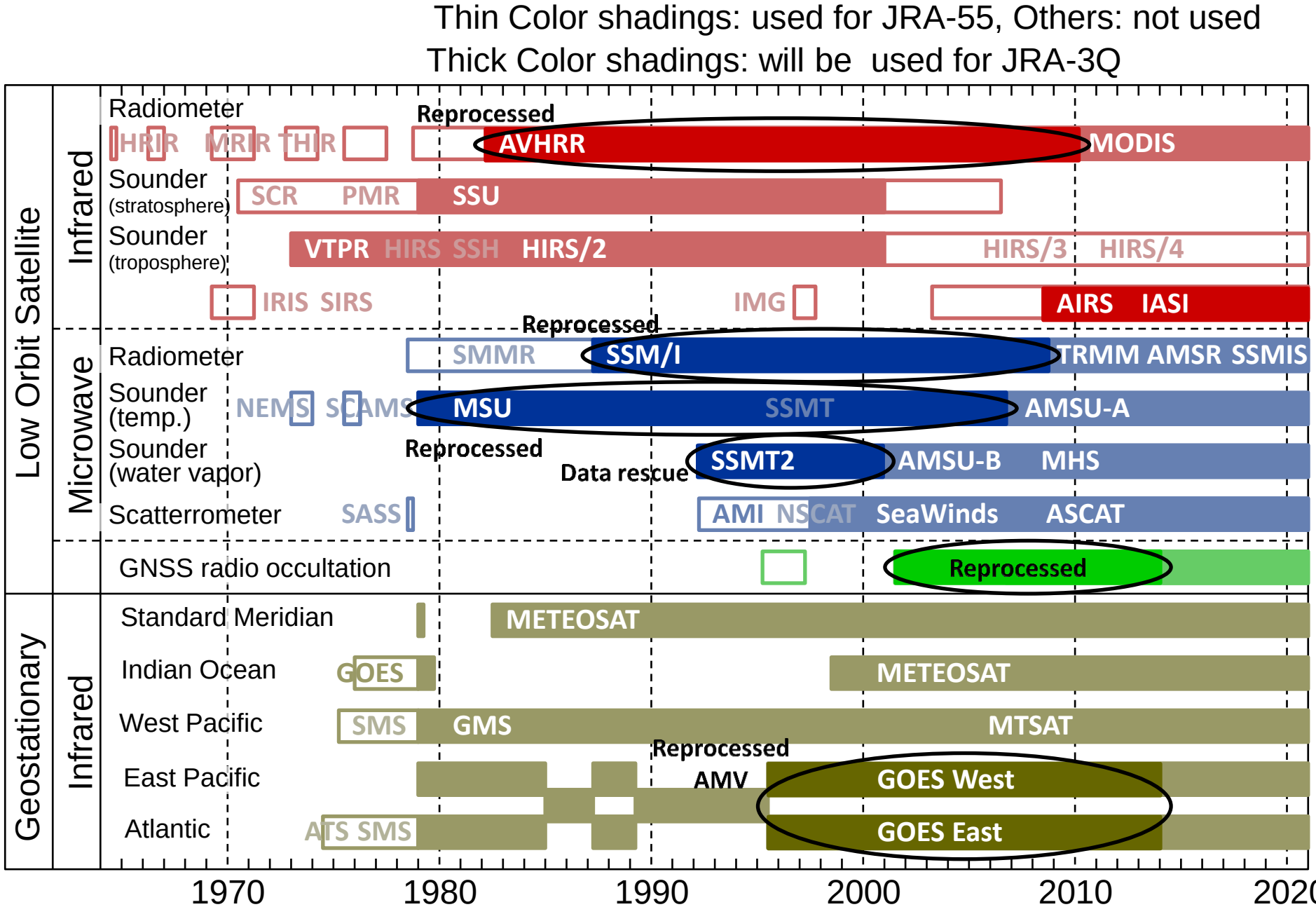
3. The next Japanese reanalysis: JRA-3Q

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

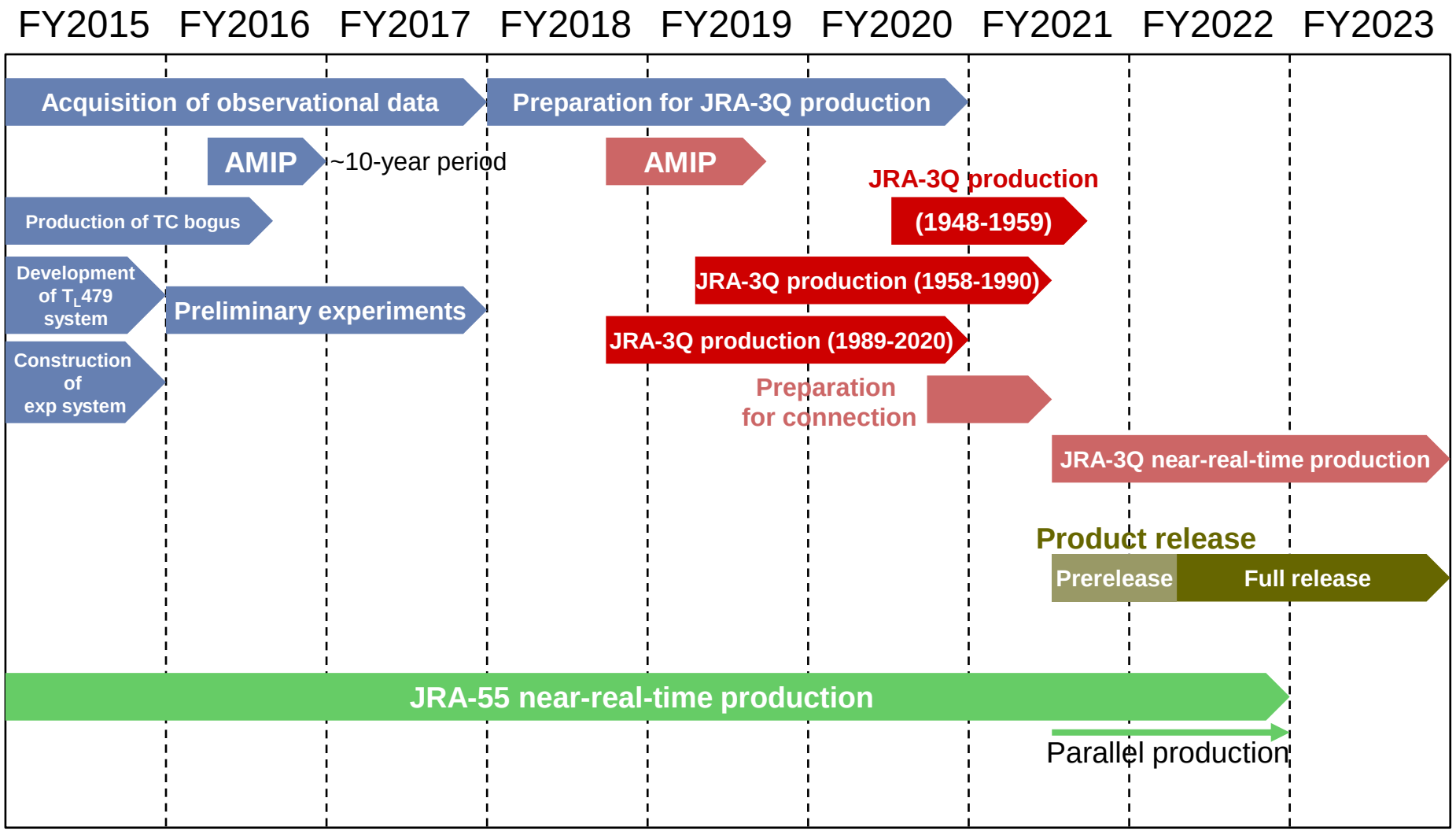
In Japanese, “3” is pronounced as “San”.
San-Q ➔ San-kyuu ➔ Thank you ☺

- **Provisional specifications**
  - Higher resolution: T_L319L60 -> 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 1948 (planned) to present
  - New boundary conditions and forcing fields
    - COBE-SST2 (from the beginning to 1981)
    - MGDSST (satellite-based SST from 1982 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)



Schedule for JRA-3Q (plan)



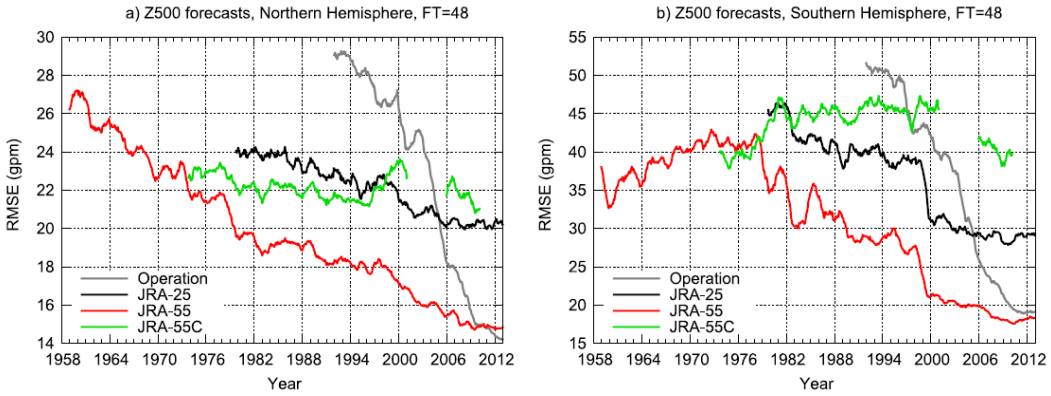
4.1 JRA-55 family

Subsets of JRA-55, JRA-55C and JRA55-AMIP, are useful for investigating impacts of changing observing systems on the quality of reanalysis

- **JRA-55** (JMA, S. Kobayashi et al. 2015)
  - Reanalysis with full observing system
- **JRA-55C** (MRI/JMA, C. Kobayashi et al. 2014)
  - Reanalysis with only conventional observations
- **JRA-55AMIP** (MRI/JMA)
  - Reanalysis without any observations

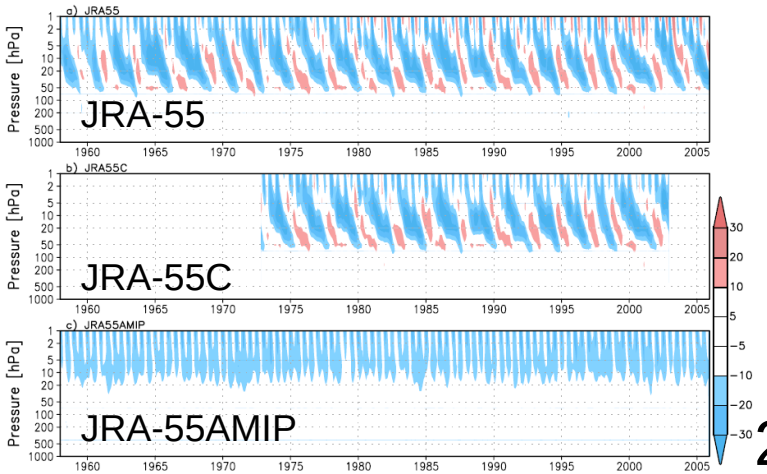
Surface
Radiosondes
TCR
Wind profilers

RMSEs of 2-day forecasts of the geopotential height at 500hPa for NH (left) and SH (right)



Kobayashi et al. (2014, SOLA)

Time-height section of equatorial (5S-5N) zonal mean zonal wind

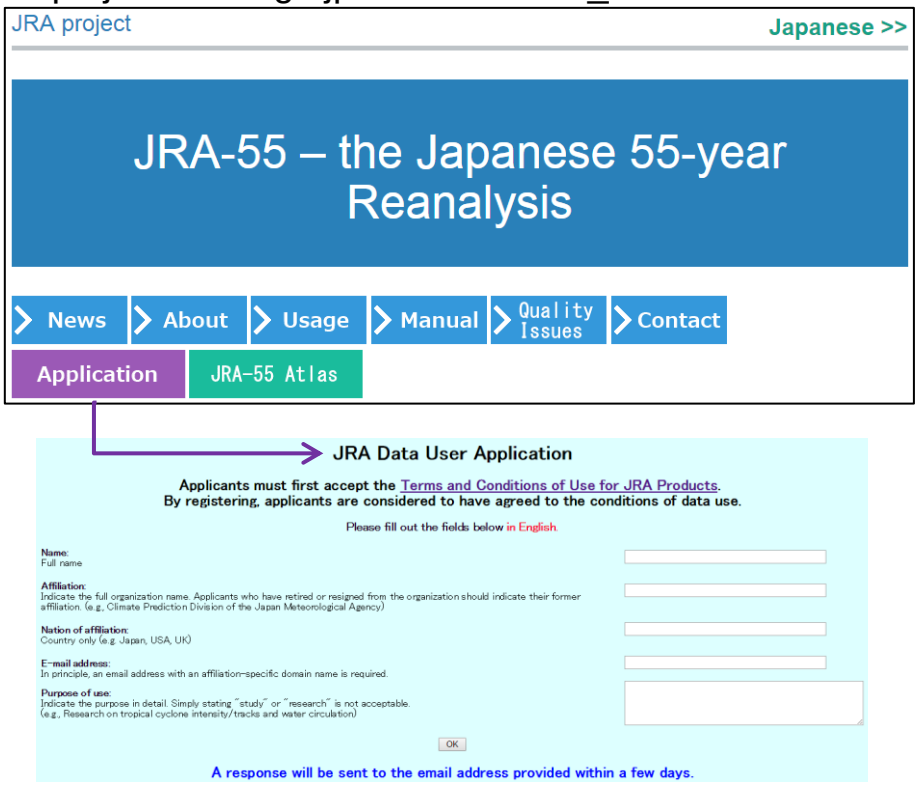


4.2 JRA-55 Homepage and Atlas (1)

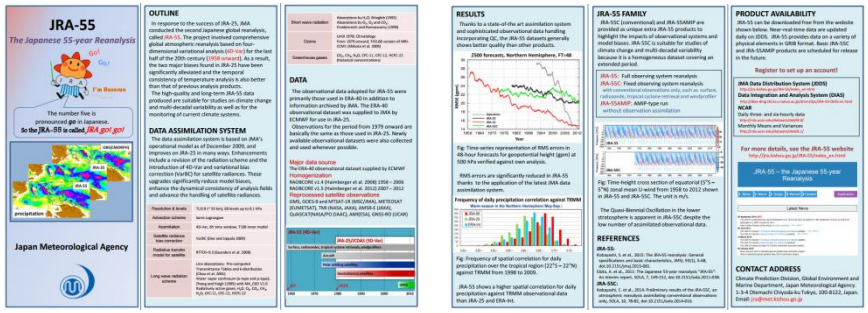
Basic information of JRA-55 is provided from JMA's homepage.
Registered users can download JRA-55 products from the JDDS*.

http://jra.kishou.go.jp/JRA-55/index_en.html

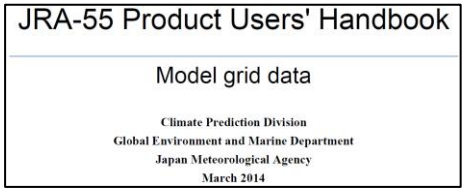
*JMA Data Dissemination System

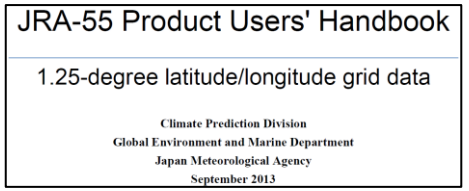


About — *Basic information of JRA-55 including background, references, and leaflets*



Manual — *Guides on JRA-55 products*





JRA-55 dataset including JRA-55 family are also available from the collaborative organizations

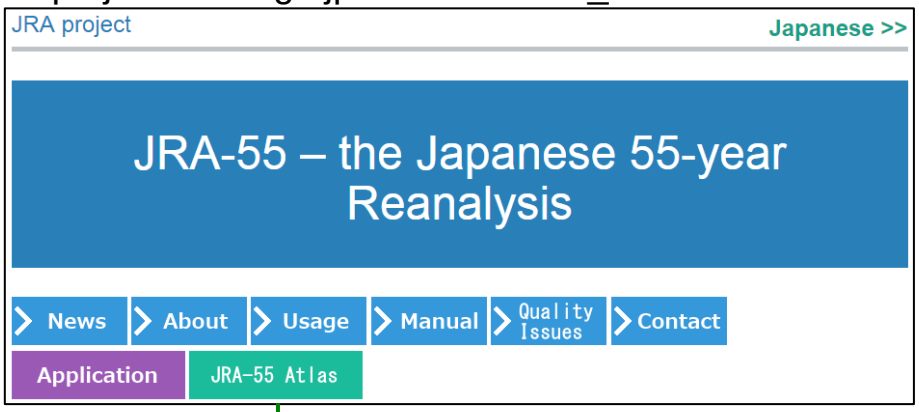
http://dias-dss.tkl.iis.u-tokyo.ac.jp/ddc/viewer?ds=JRA55&lang=en
http://gpvjma.ccs.hpcc.jp/~jra55/index.html
http://rda.ucar.edu/datasets/ds628.0/

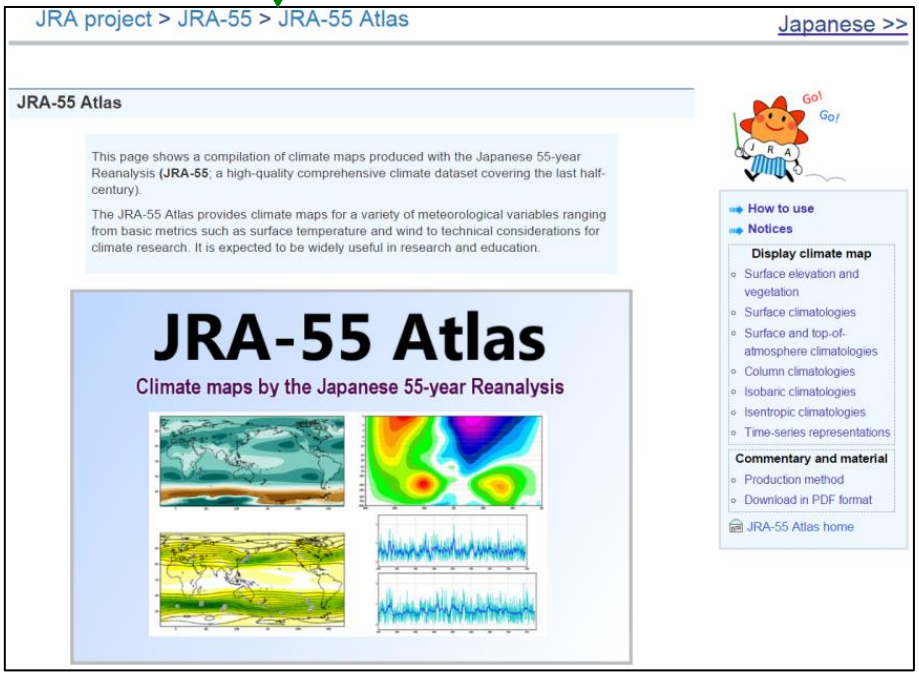
DIAS Data Integration & Analysis System
University of Tsukuba Center for Computational Sciences
NCAR UCAR Research Data Archive Computational & Information Systems Lab

4.2 JRA-55 Homepage and Atlas (2)

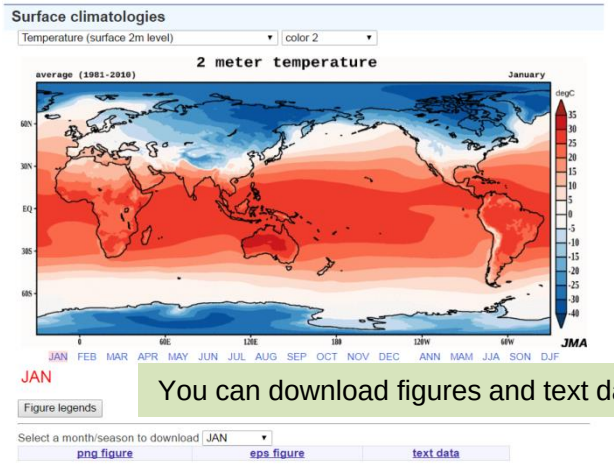
Climate maps for various meteorological variables are provided by the JRA-55 Atlas.

http://jra.kishou.go.jp/JRA-55/index_en.html



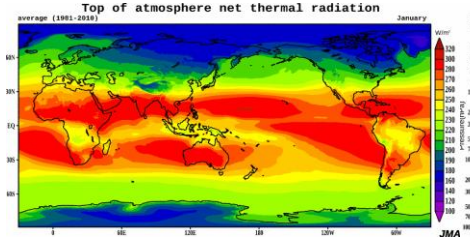


http://ds.data.jma.go.jp/gmd/jra/atlas/en/index.html

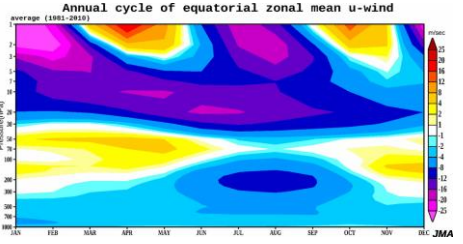


You can download figures and text data

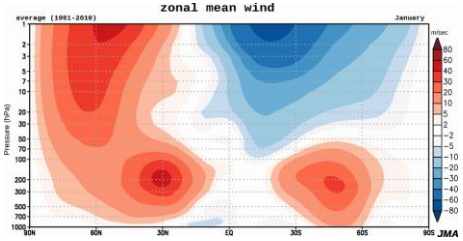
Horizontal distribution



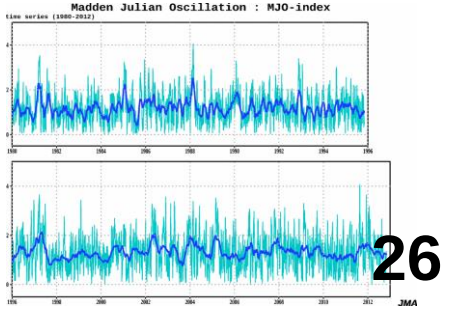
Time-height section



Latitude-height section



Time series of index



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
  - Need to produce a high-quality, spatially and temporally consistent dataset for 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
  - Spin-offs (JRA-55C and AMIP) for evaluating impacts of observation
  - Dataset and basic figures are available from the JMA's HP

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

References

- S. Kobayashi et al. (2015)
  - Kobayashi, S., Y. Ota, Y. Harada, A. Ebita, M. Moriya, H. Onoda, K. Onogi, H. Kamahori, C. Kobayashi, H. Endo, K. Miyaoka, and K. Takahashi, 2015: The JRA-55 Reanalysis: General specifications and basic characteristics. *J. Meteor. Soc. Japan*, 93, 5-48, doi:10.2151/jmsj.2015-001.
  - https://www.jstage.jst.go.jp/article/jmsj/93/1/93_2015-001/_article
- Harada et al. (2016)
  - Harada, Y., H. Kamahori, C. Kobayashi, H. Endo, S. Kobayashi, Y. Ota, H. Onoda, K. Onogi, K. Miyaoka, and K. Takahashi, 2016: The JRA-55 Reanalysis: Representation of atmospheric circulation and climate variability, *J. Meteor. Soc. Japan*, 94, 269-302, doi:10.2151/jmsj.2016-015.
  - https://www.jstage.jst.go.jp/article/jmsj/94/3/94_2016-015/_article
- C. Kobayashi et al. (2014)
  - Kobayashi, C., H. Endo, Y. Ota, S. Kobayashi, H. Onoda, Y. Harada, K. Onogi, and H. Kamahori, 2014: "Preliminary results of the JRA-55C, an atmospheric reanalysis assimilating conventional observations only", *SOLA*, **10**, 78-82, doi:10.2151/sola.2014-016
  - https://www.jstage.jst.go.jp/article/sola/10/0/10_2014-016/_article