Re-analyses as predictability tools

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Outline

- Introduction
- Overview of JRA-25 Re-analysis
- Applications using reanalysis data and its benefit
  - Monthly to Decadal Forecasting
    - One-month forecasts
    - El Niño & seasonal outlook
    - Decadal forecasts
  - Climate system monitoring
  - Climate information based on reanalysis
- Reanalysis as a tool for research and studies
- Status of JRA-55
- Summary

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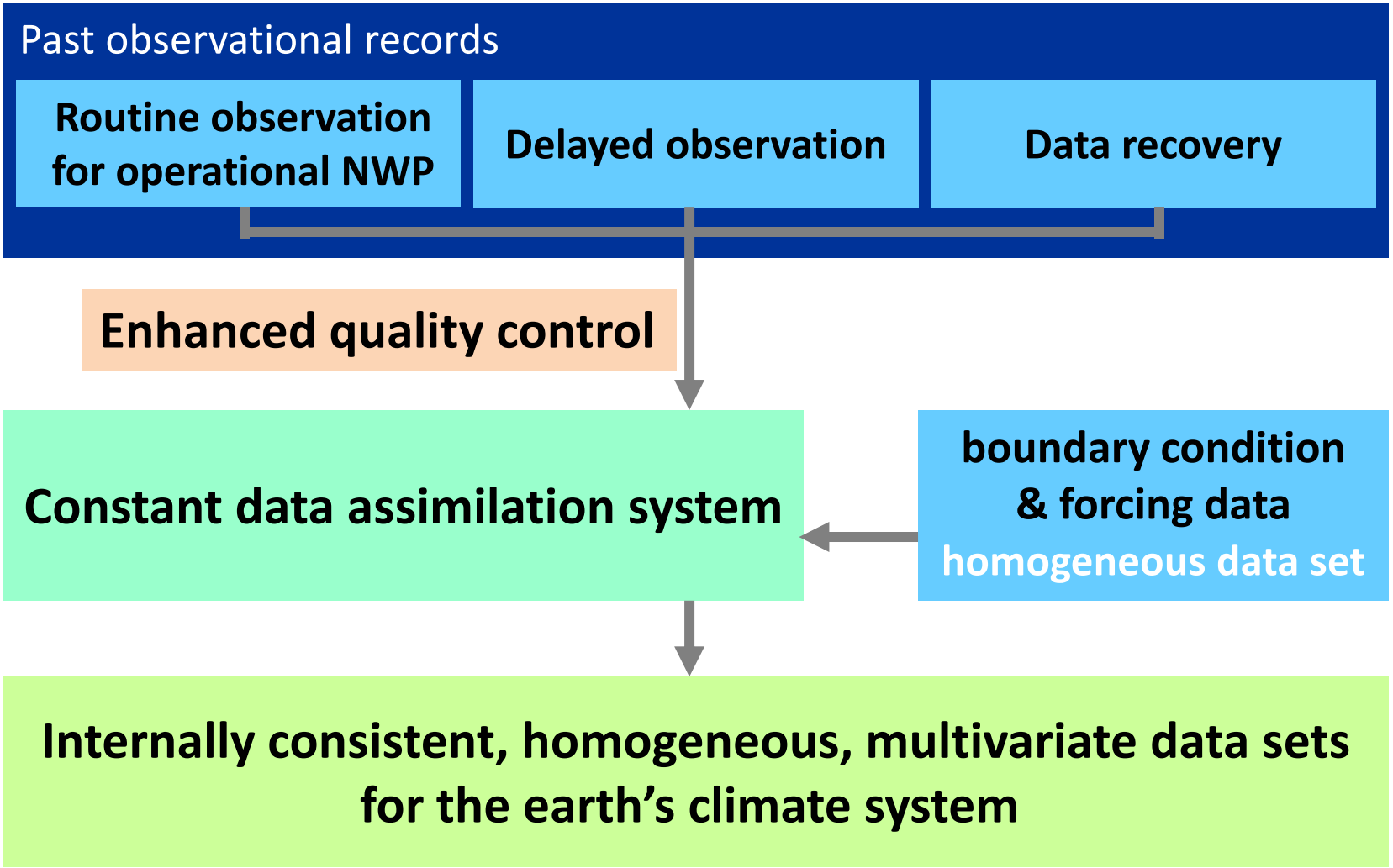
What is Re-analysis?



History of Re-analyses

Reanalysis	Producer	Period	Resolution	Assimilation
NASA/DAO	NASA/DAO	1980-1995	2x2.5L20	3D-OI +IAU
ERA-15	ECMWF	1979-1993	T106L31	3D-OI
NCEP-NCAR	NCEP-NCAR	1948-present	T62L28	3D-Var SSI
NCEP-DOE	NCEP-DOE	1979-present	T62L28	3D-Var SSI
ERA-40	ECMWF	1957.9-2002.8	T_L159L60	3D-Var
JRA-25/JCDAS	JMA-CRIEPI	1979-present	T106L40	3D-Var
ERA-Interim	ECMWF	1989-present	T_L255L60	4D-Var
CFSR	NCEP	1979-present	T382L64	3D-Var GSI
MERRA	NASA	1979-2010	1/2x1/2deg	3D-Var GSI
20th Century Reanalysis	NOAA-CIRES	1871-2008	T62L28	EnKF
JRA-55 (ongoing)	JMA	1957.12-2012	T_L319L60	4D-Var
ERA-??? (planned)	ECMWF	Extending back at least to 1938	T_L511	Weak-constraint 4D-Var

Re-analysis: an essential tool to know predictability and to assess long-range weather forecast

- Predictability
  - How much skill do our forecast systems have?
  - How predictable are certain phenomena?
- Predictability-tools
  - Measure the **real predictability** (forecast verification)
  - We need to know the **truth** (or best estimate) to assess the forecasts: Observational data or **Re-analysis** data
  - Provide a tool to investigate the **potential predictability** under a perfect model assumption with homogeneous datasets.

The re-analyses are essential products for operational weather centres.

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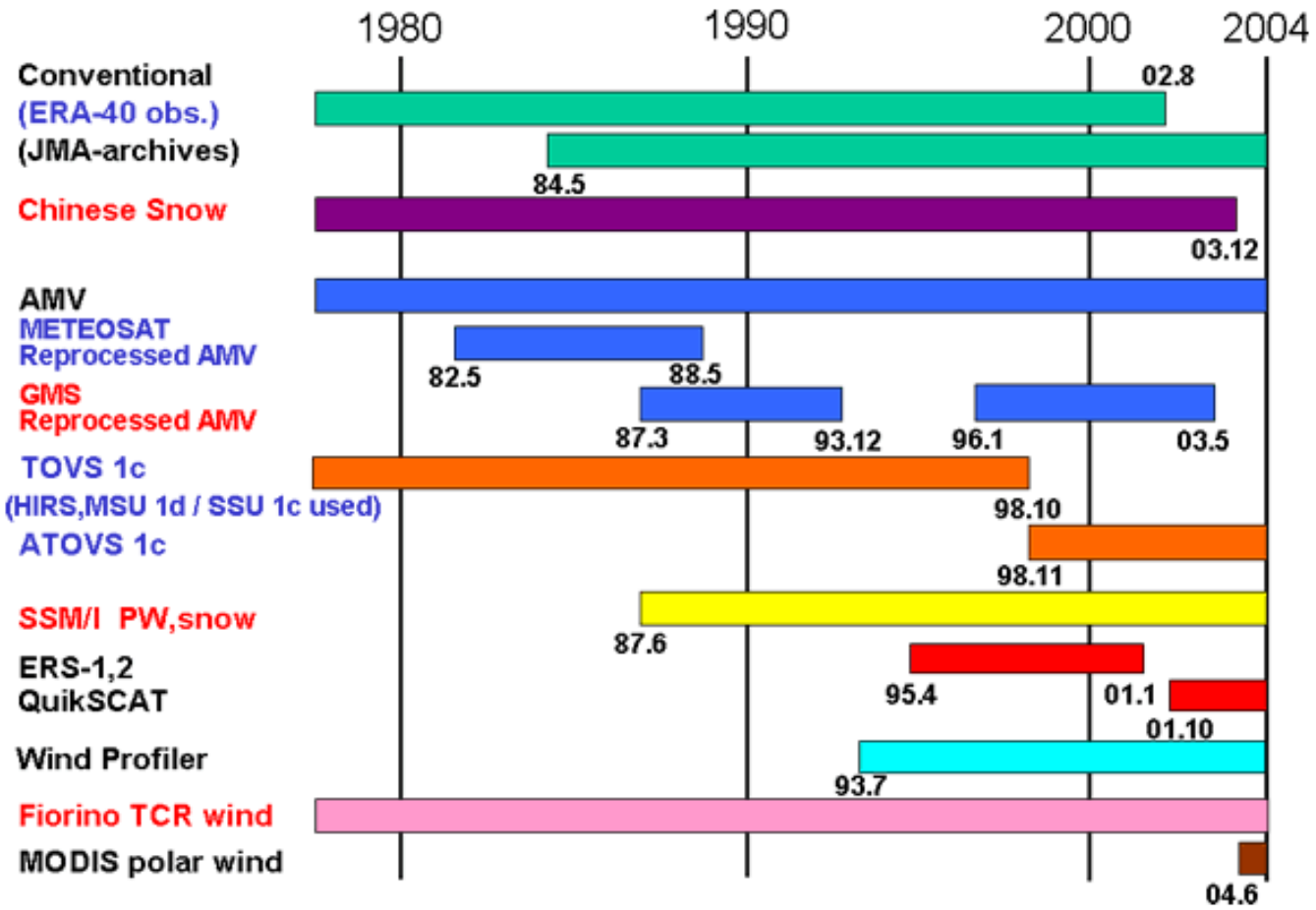
Status of JMA Reanalysis

- **JRA-25 (1979-2004)**
  - completed in 2006
  - jointly conducted by JMA and Central Research Institute of Electric Power Industry (CRIEPI)
  - based on JMA forecast system as of 2004
  - **freely available for research purposes**
    - http://jra.kishou.go.jp/JRA-25/index_en.html
  - A full copy of the JRA-25 data also available from the NCAR data archive: http://dss.ucar.edu/datasets/ds625.0/
  - **Over 1,700 registered users and 100 cited references** as of Aug 2010
    - The JRA-25 description paper (**Onogi *et al.*, 2007, *JMSJ*)**
- **JCDAS (2005-present)**
  - Near real-time operational climate analysis with the JRA-25 system.
- **JRA-55 (1958-2012)**
  - **New JMA reanalysis project is on-going (2008-2012).**

JRA-25 overview

- Assimilation system : JMA operational system as of April 2004
- Global model resolution : T106L40 (model top: 0.4hPa)
- Data assimilation : 3D-Var
- Assimilated satellite data:
  - ✓SSM/I precipitable water retrievals
  - ✓ TOVS/ATOVS radiances (level 1d: HIRS/MSU, level 1c: SSU/AMSU-A/AMSU-B)
- JRA-25 original boundary/forcing data:
  - ✓Daily COBE SST and sea ice (Ishii et al. 2005, *Int. J. Clim.*)
  - ✓ daily 3D-ozone profile
- JRA-25 was the first reanalysis using the observational data outlined below.
  - ✓Wind profile retrievals surrounding tropical cyclones
  - ✓ SSM/I snow coverage
  - ✓digitized Chinese snow depth data
  - ✓reprocessed GMS-AMV

Observation data used for JRA-25



Datasets written in red are used for the first time in reanalyses.

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Overview of JMA monthly to seasonal forecast systems

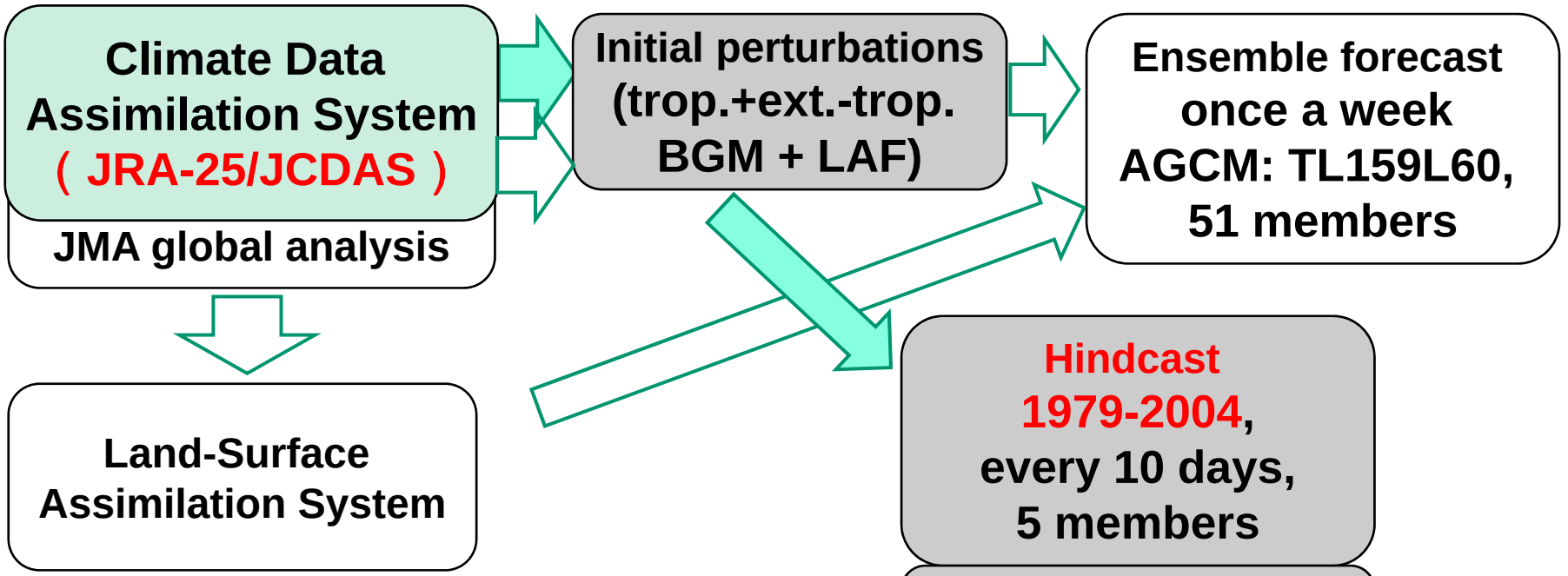
Forecast systems	periods	descriptions
1-month ensemble forecast	34 days	JMA-GSM (AGCM), T_L159L60, BGM+LAF (50 mem), Prescribed SST anomaly, Land surface analysis
3-month, seasonal ensemble forecast	max. 210 days	JMA/MRI-CGCM (2008.03- present for ENSO outlook, 2010,02-present for seansonal forecasts) AGCM: T_L95L40, LAF+BGM (trop)+prtb. Ocean analysis (51 mem/1 month) OGCM: 0.3-1 deg x 1 deg 51 vertical levels
ENSO forecast	7 months	

Monthly to Seasonal Forecasting

- Roles of re-analyses
  - **Long-term** (>20 yrs) analyses for re-forecasts
  - Atmospheric analysis (initial conditions)
  - Ocean analysis (initial conditions)
  - Land surface analysis (initial conditions)

  – Needs of high quality (homogeneity, more data, advanced quality control, state-of-the-art assimilation system) analysis data for **re-forecasts** (hindcasts)

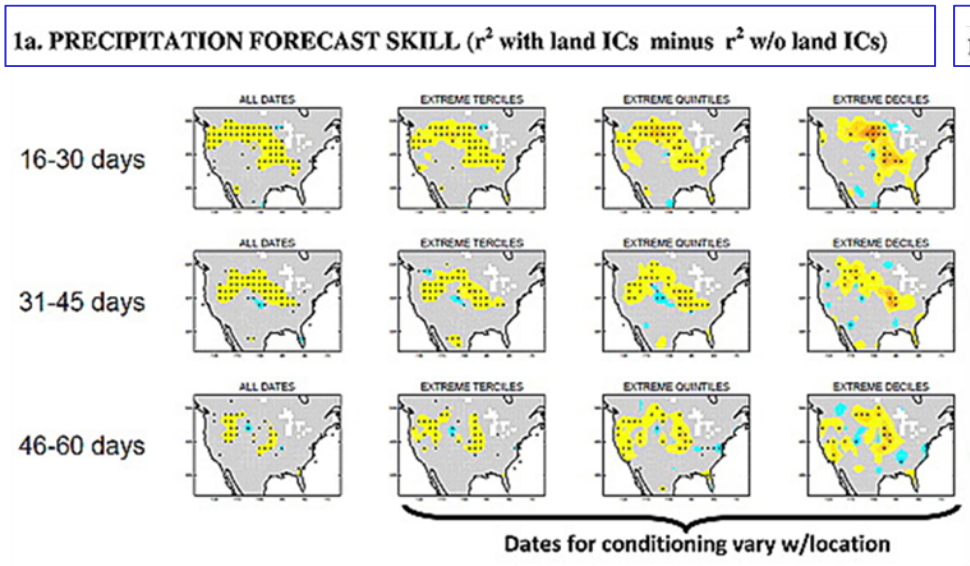
JMA Monthly Forecast System

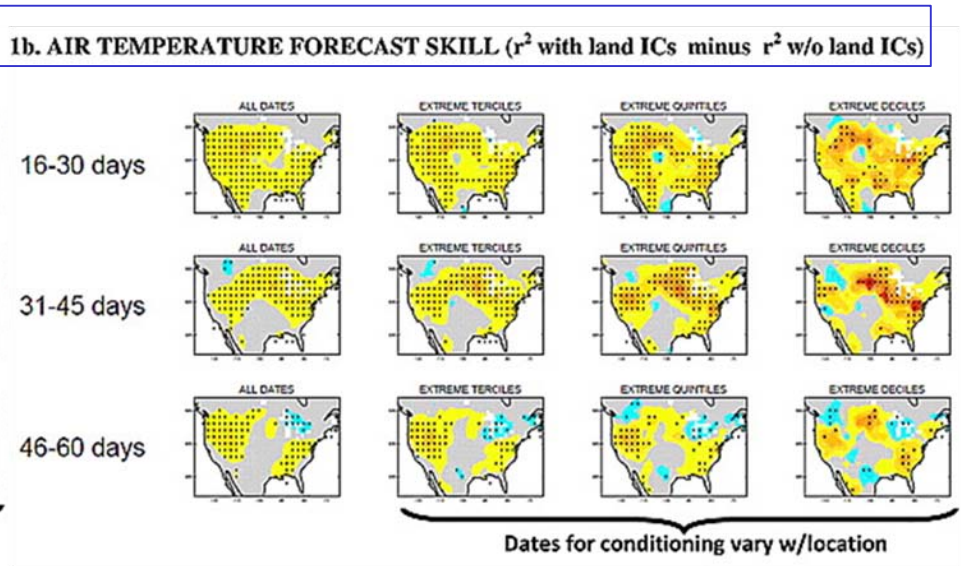


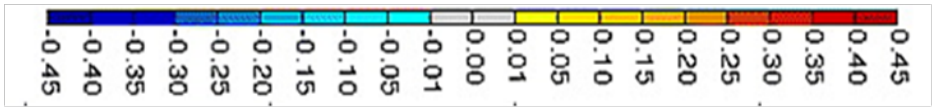
The re-analysis for hindcast is an essential part of JMA monthly forecast system.

White boxes and arrows show the routine forecast system.

Benefit of Reanalysis in Land surface analysis







Results from GLACE 2 project , Koster et al. 2010 *GRL*

Atmospheric Reanalysis → Realistic land surface initialization → Better forecasts

Global Land Surface Analysis System in JMA

for initial conditions of land surface parameters

Global Atmospheric Assimilation System (Re-analysis for re-forecast period)

Atmospheric Forcing (00 06 12 18UTC)

Input

Simple Biosphere Model (TL159)

Land Surface Assimilation

(00 06 12 18UTC)

Snow Depth

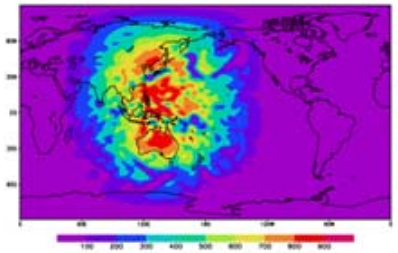
Ground Surface/Soil Temperature

Soil Wetness

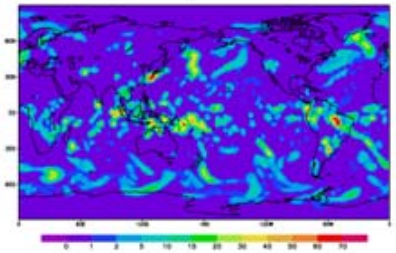
Land Surface Model Initials

1-month forecast model

Shortwave Radiation



Precipitation



Input

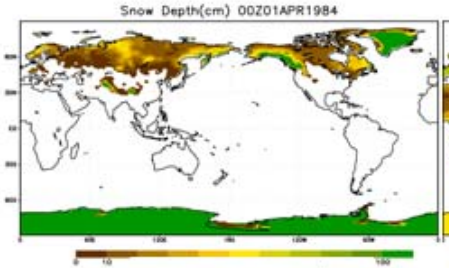
Snow (00UTC)

Snow-Depth Analysis

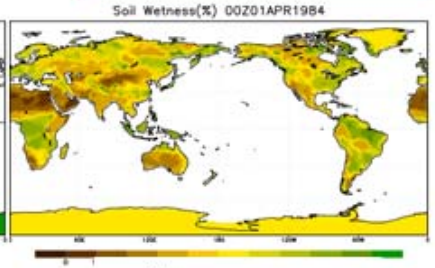
First Guess

SYNOP Snow Depth

SSM/I Snow Cover



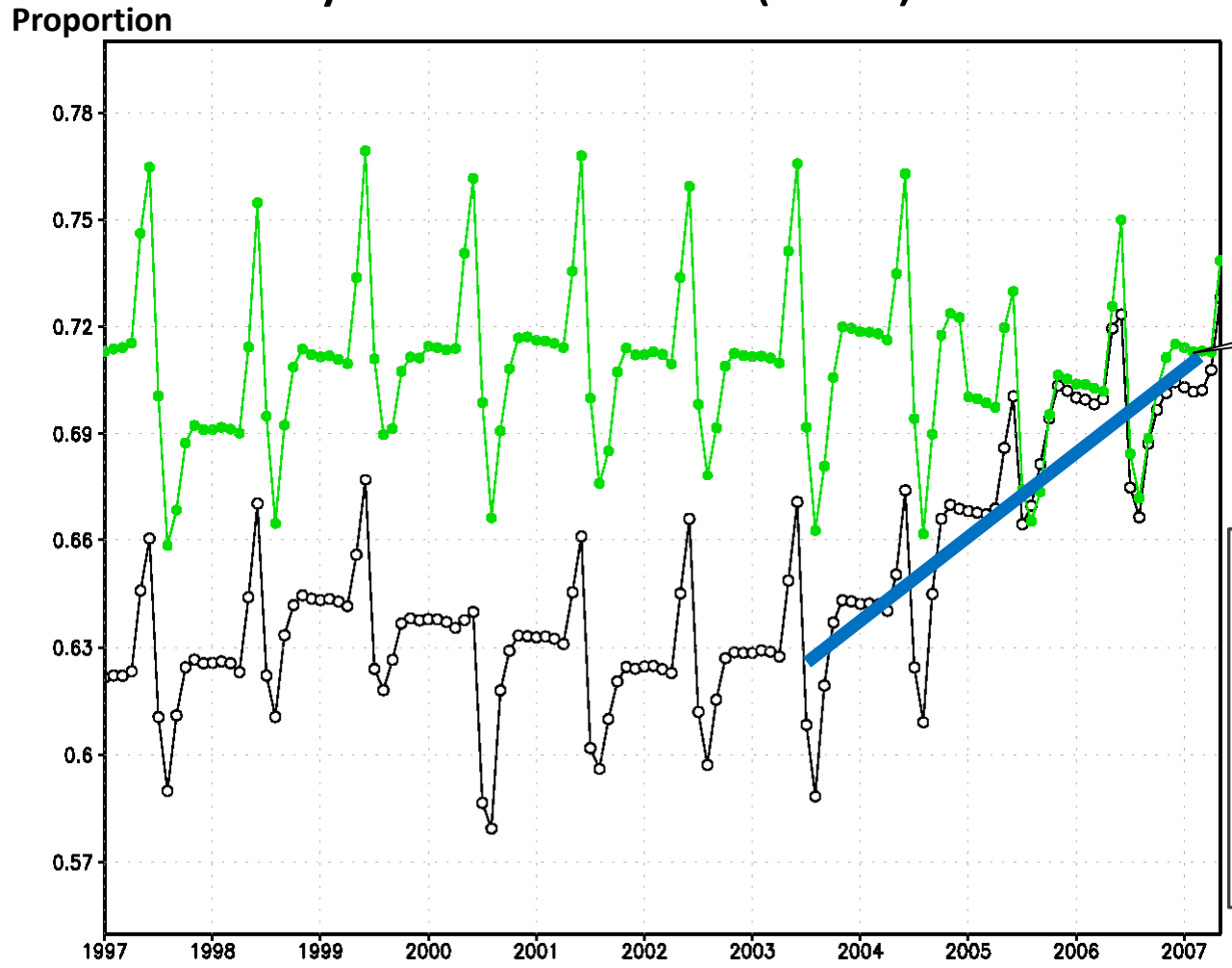
Snow Depth



Soil Wetness

Benefit of Reanalysis in Land surface analysis
Impact for soil wetness

Monthly Soil Wetness (root) 90N-60N

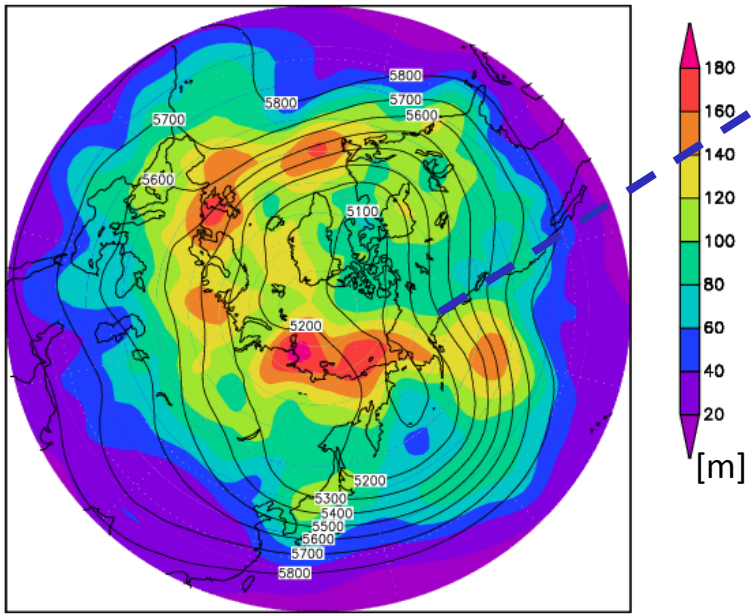


Due to a change in the quality of precipitation from the JMA operational analysis

- Forced by atmospheric data from JRA-25
- Forced by atmospheric data from the JMA operational analysis

Flow-dependent predictability in monthly forecast system '**spread**'

Larger spread	**Smaller spread**
• Larger uncertainty	• Smaller uncertainty



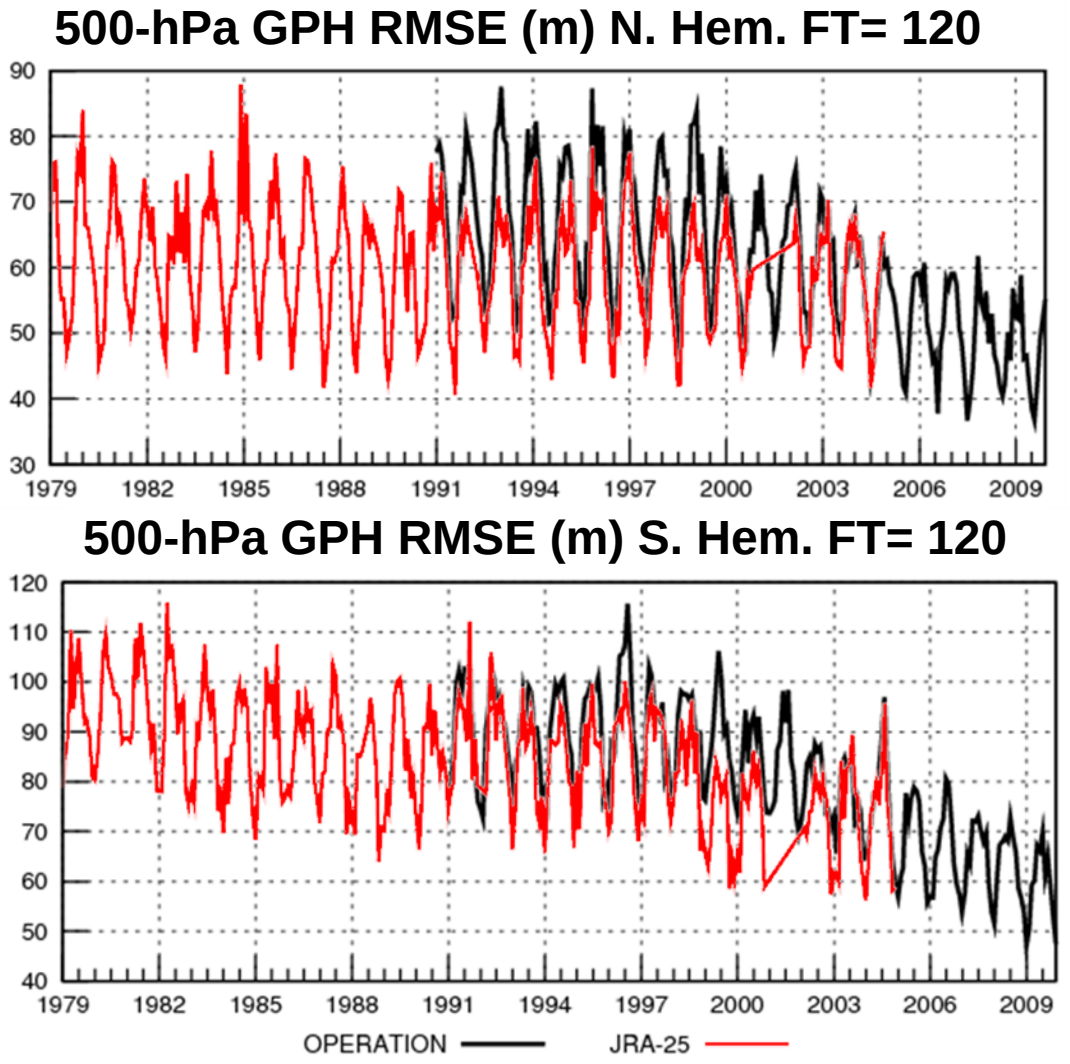
Large spread associated with a blocking event

(Shade) Spread of 500-hPa GPH at day 10 for 25-member ensemble forecasts starting from 2007/11/28.

The time-dependent predictability would be obtained with long-period re-forecasts and re-analyses.

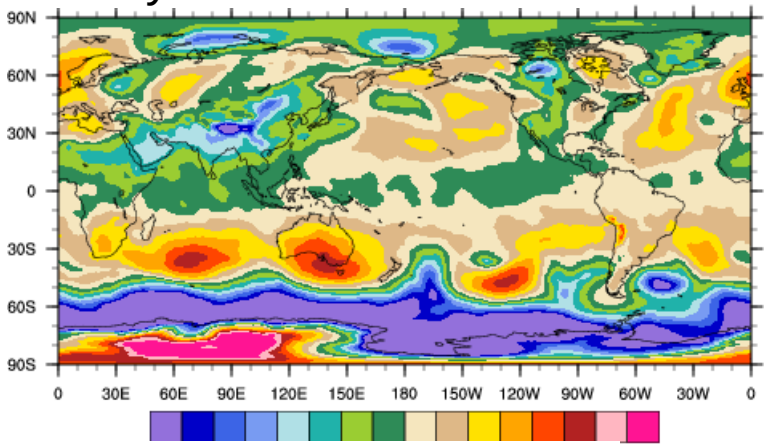
Interannual variability of the inherent predictability in general circulation

- Forecasts in reanalysis may give information about the time-dependent predictability.
- The year-to-year variability of the inherent predictability in the general circulation can be seen in the forecast scores.

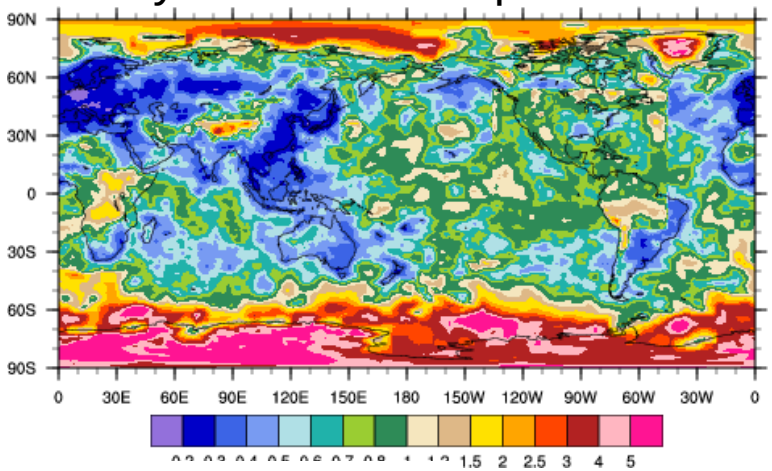


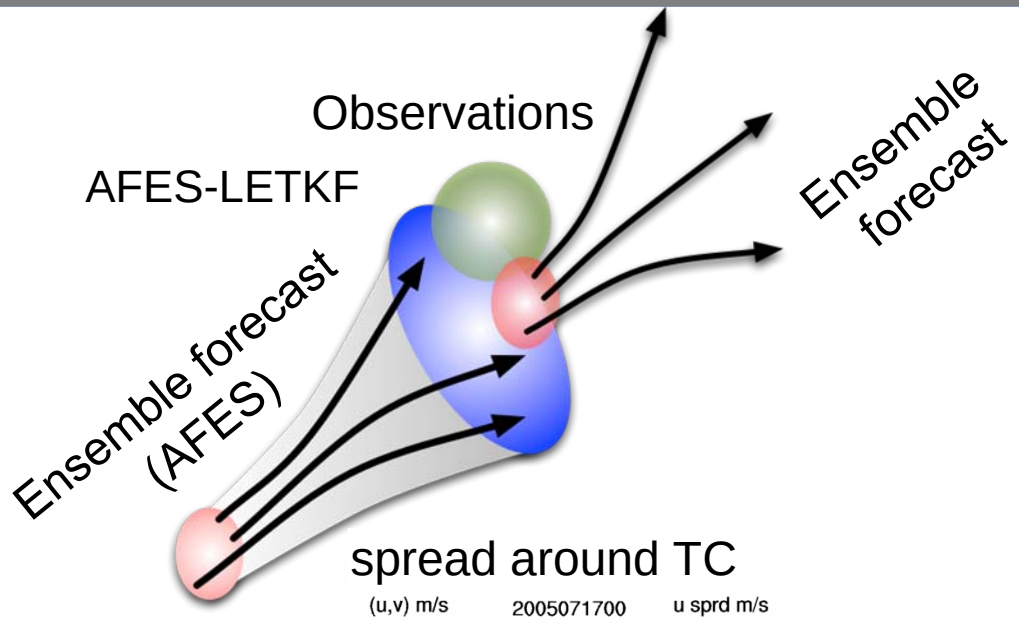
Predictability with Ensemble Kalman Filter technique
AFES-LETKF experimental ensemble reanalysis ALERA

analysis ensemble mean

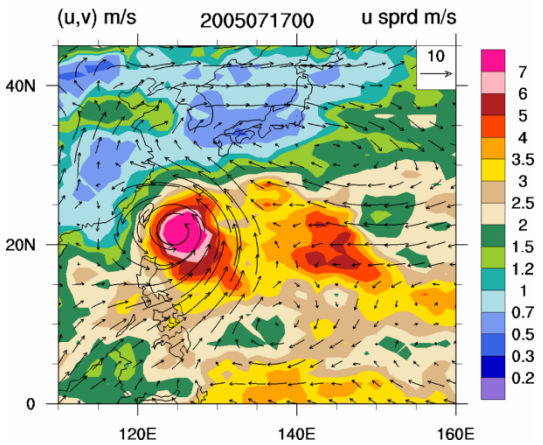


analysis ensemble spread





spread around TC

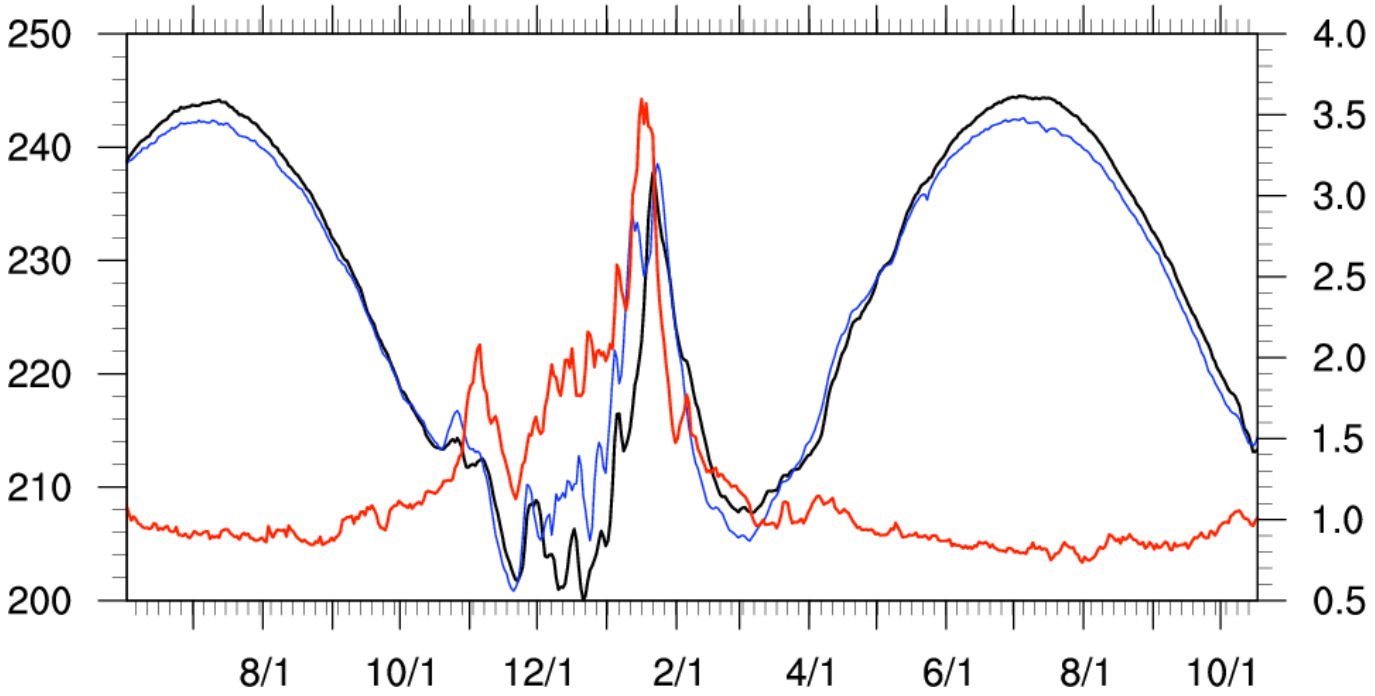


Miyoshi et al. (2007)

ALERA: Collaboration among JMA, JAMSTEC and Chiba Institute of Science
http://www.jamstec.go.jp/esc/afes/alera/

Uncertainty (predictability) seen in some weather extreme events with experimental (short-term) reanalysis
Stratospheric sudden warming

Temperature at 10-hPa (65N-90N)
20050601-20061017

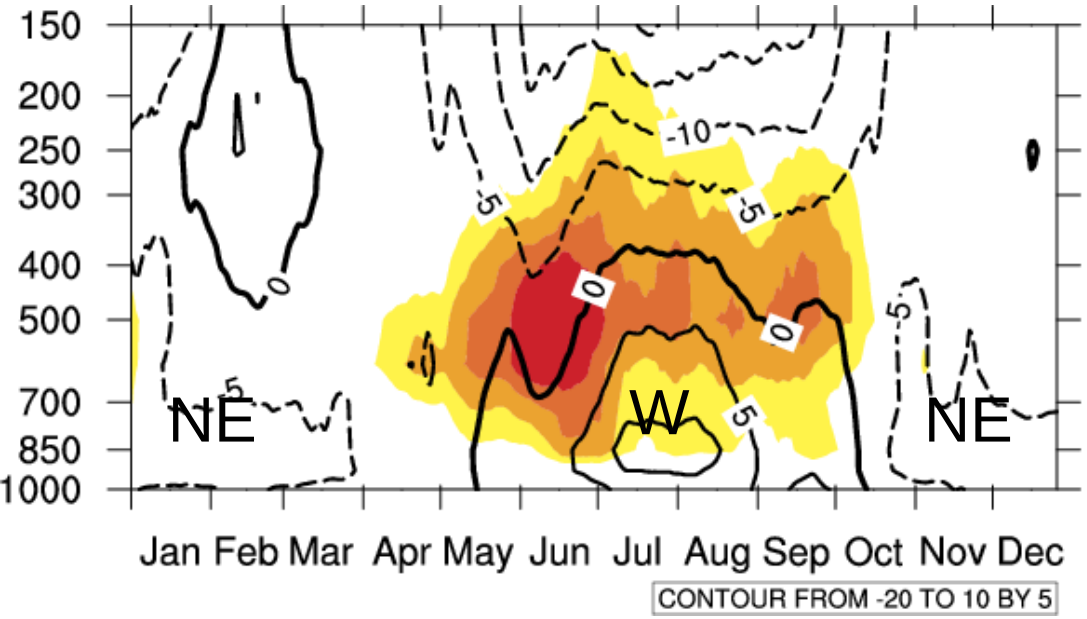


- ALERA mean
- ALERA spread
- CDAS

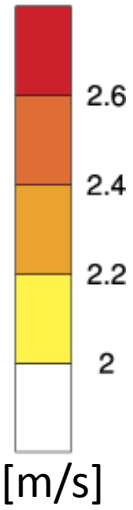
Enomoto et al. (2010), *GRL*

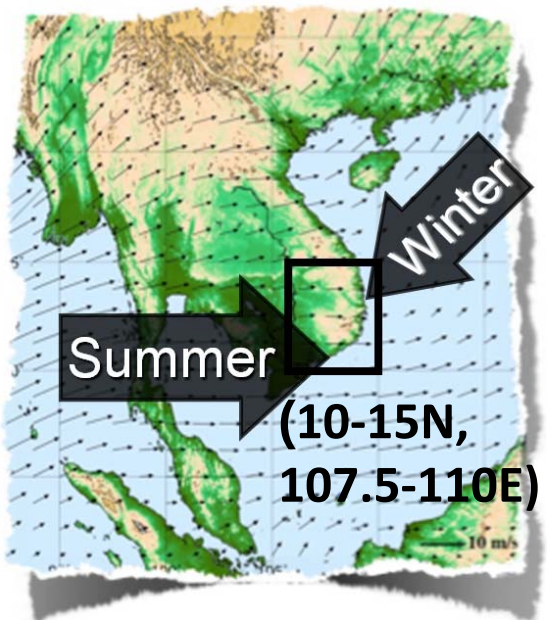
Uncertainty (Predictability) seen in some extreme events. Monsoon onset in Vietnam

U 850-hPa (contour) and its analysis ensemble spread (shade) 30-day running mean (10-15N, 107.5-110E)



Increase of ensemble spread prior to monsoon westerly

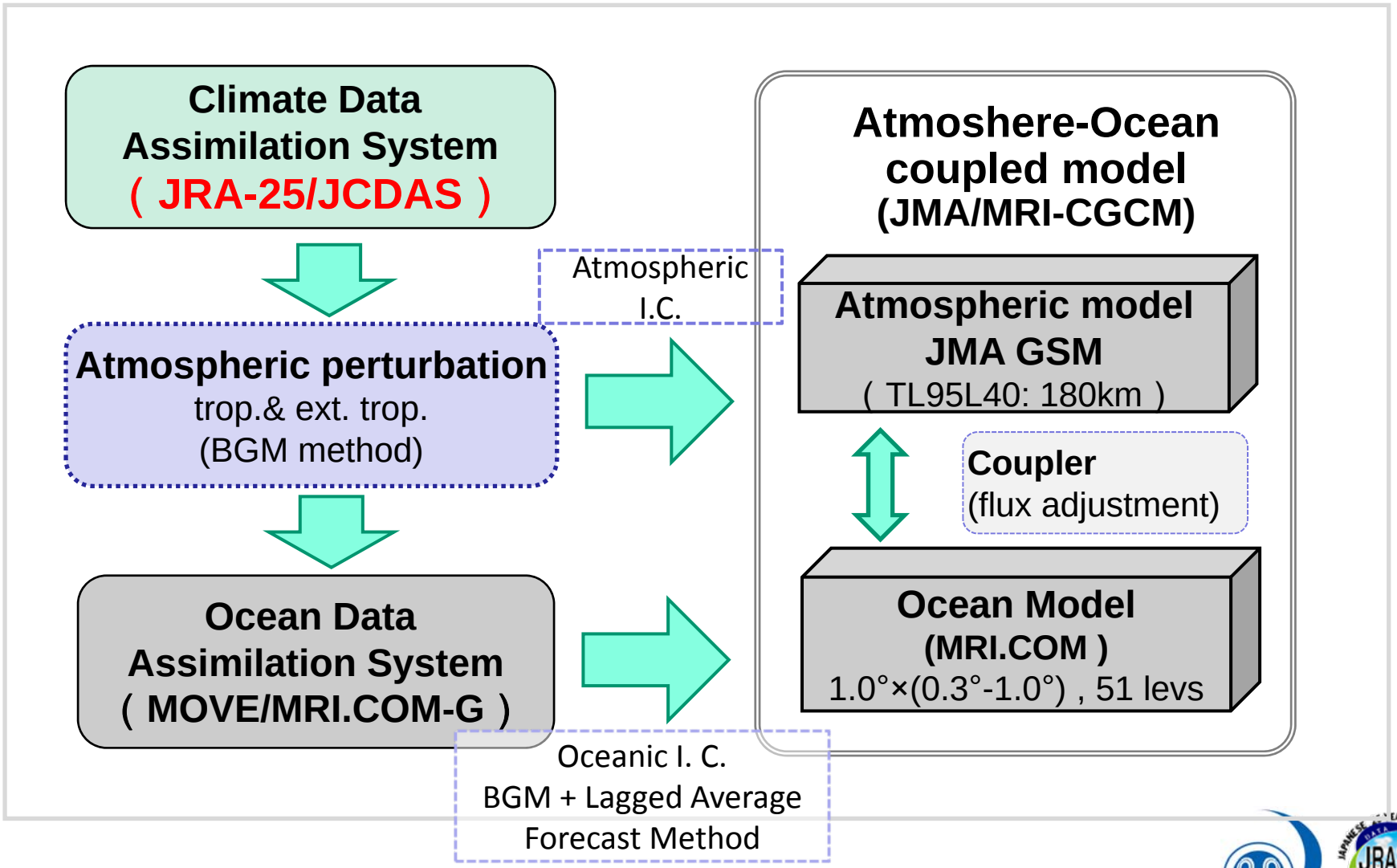




M. Hattori

Enomoto et al. (2010), GRL

Seasonal Forecast System with JRA-25/JCDAS



El Niño monitoring and forecasting with JRA-25/JCDAS

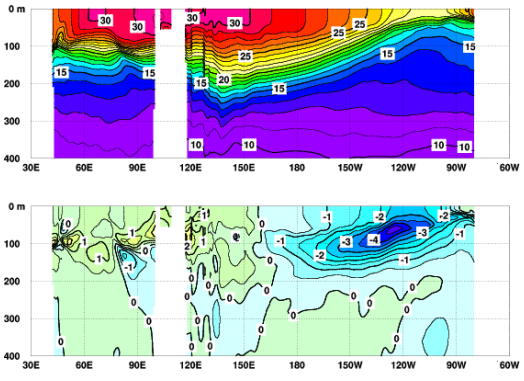
JCDAS (operational)

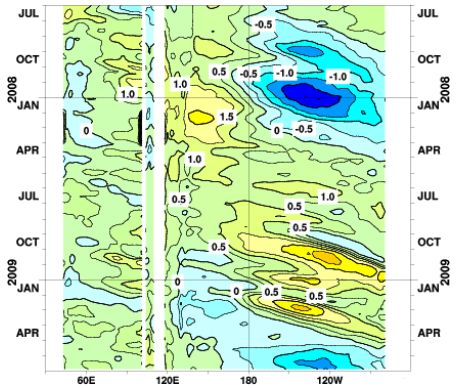
Ocean Data Assimilation

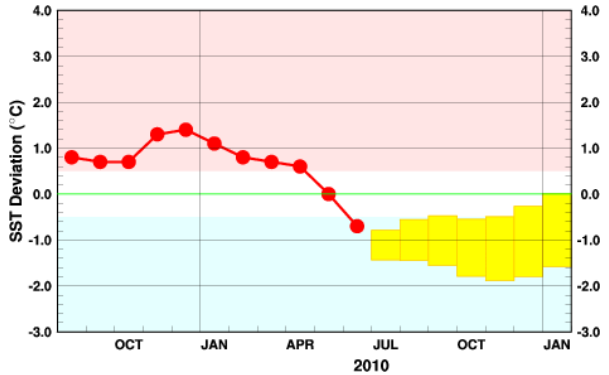
Seasonal and ENSO prediction with CGCM

Subsurface ocean data for ENSO monitoring

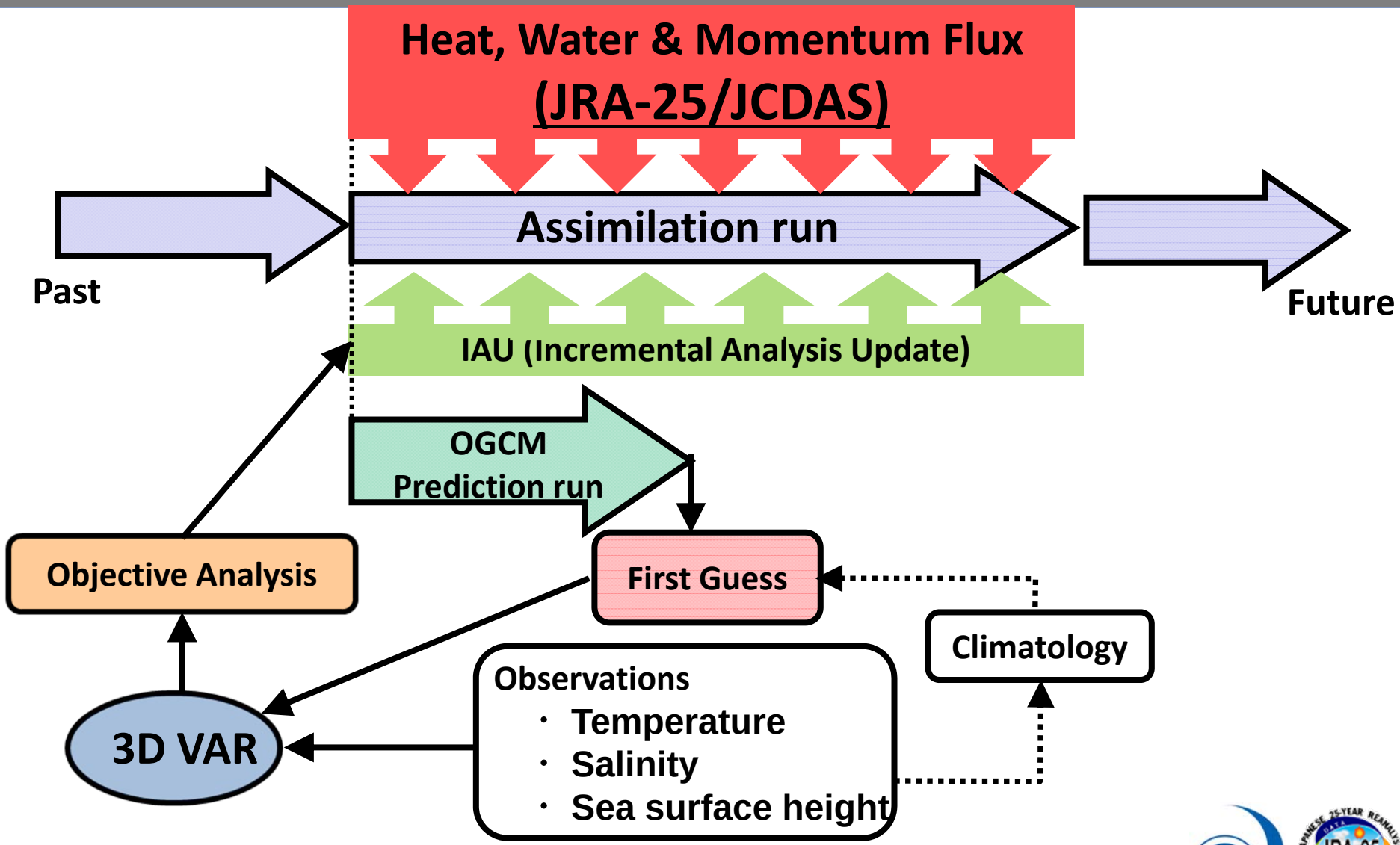
ENSO outlook



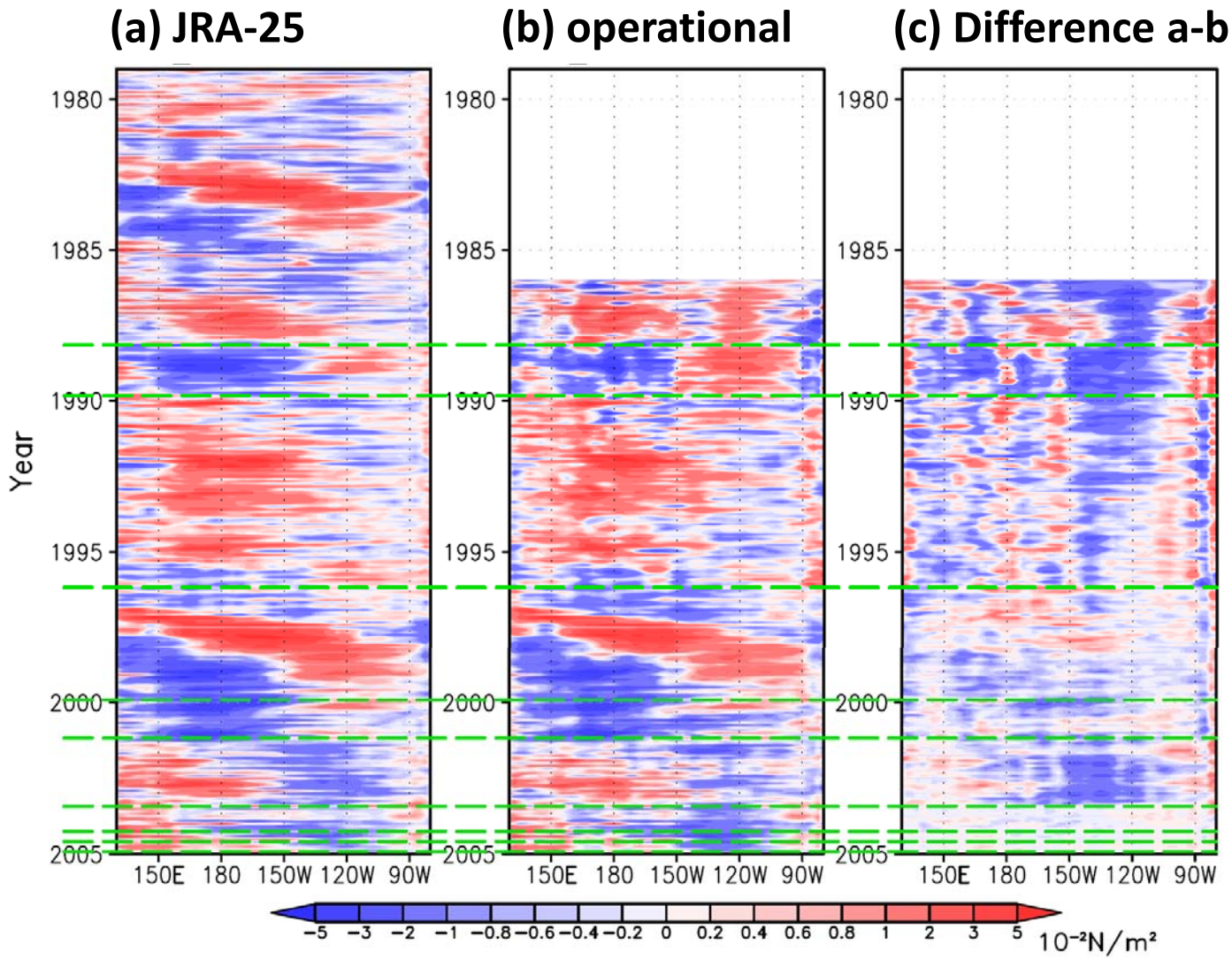




Ocean Data Assimilation (MOVE/MRI.COM-G)



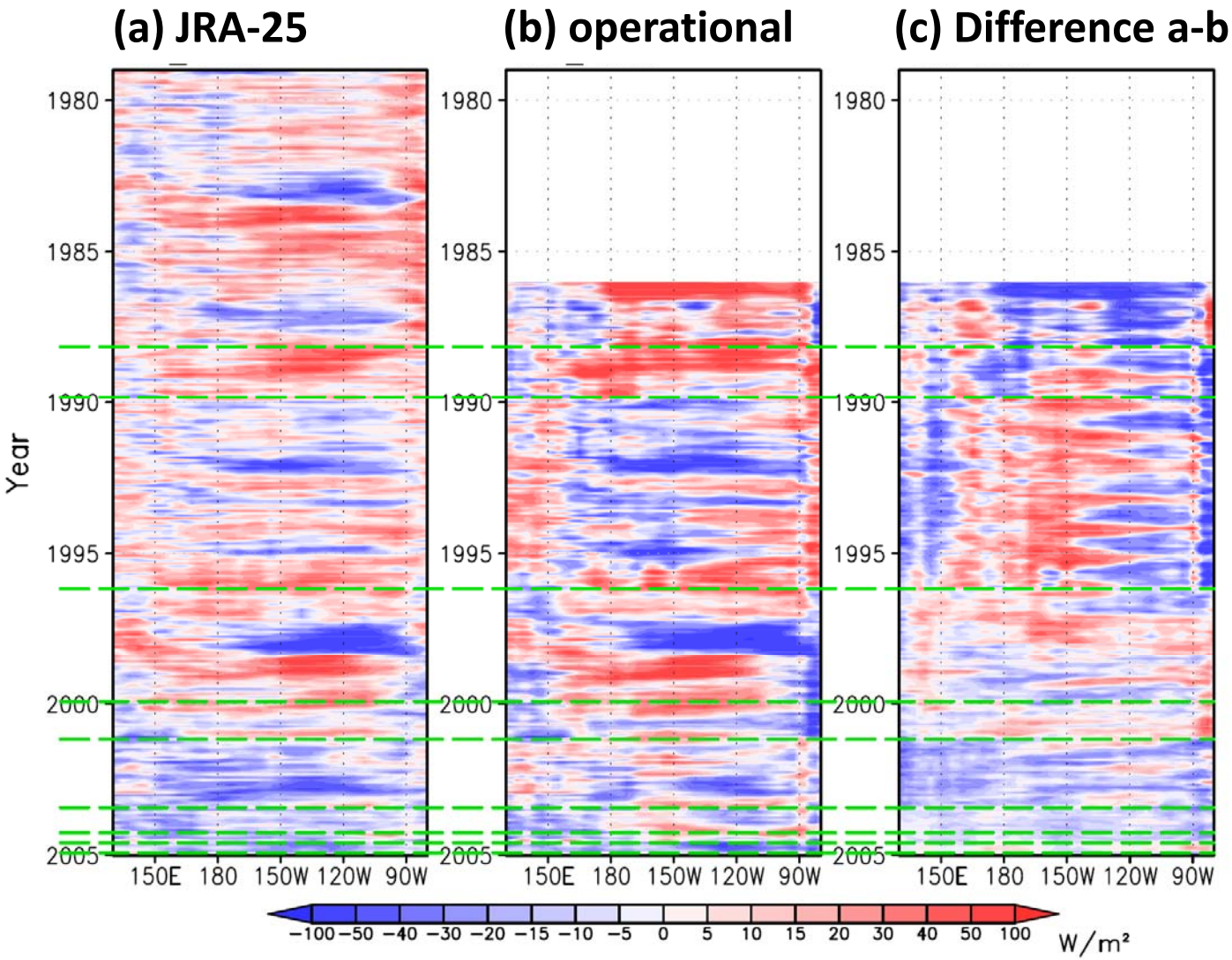
Benefit of Reanalysis in Ocean Data Assimilation



Zonal wind stress anomalies along the equator (5S-5N) with (a) JRA-25, (b) JMA realtime operational analysis, (c) difference btw (a) and (b) .

Dashed green lines indicate major change of physics/assimilation in JMA realtime systems.

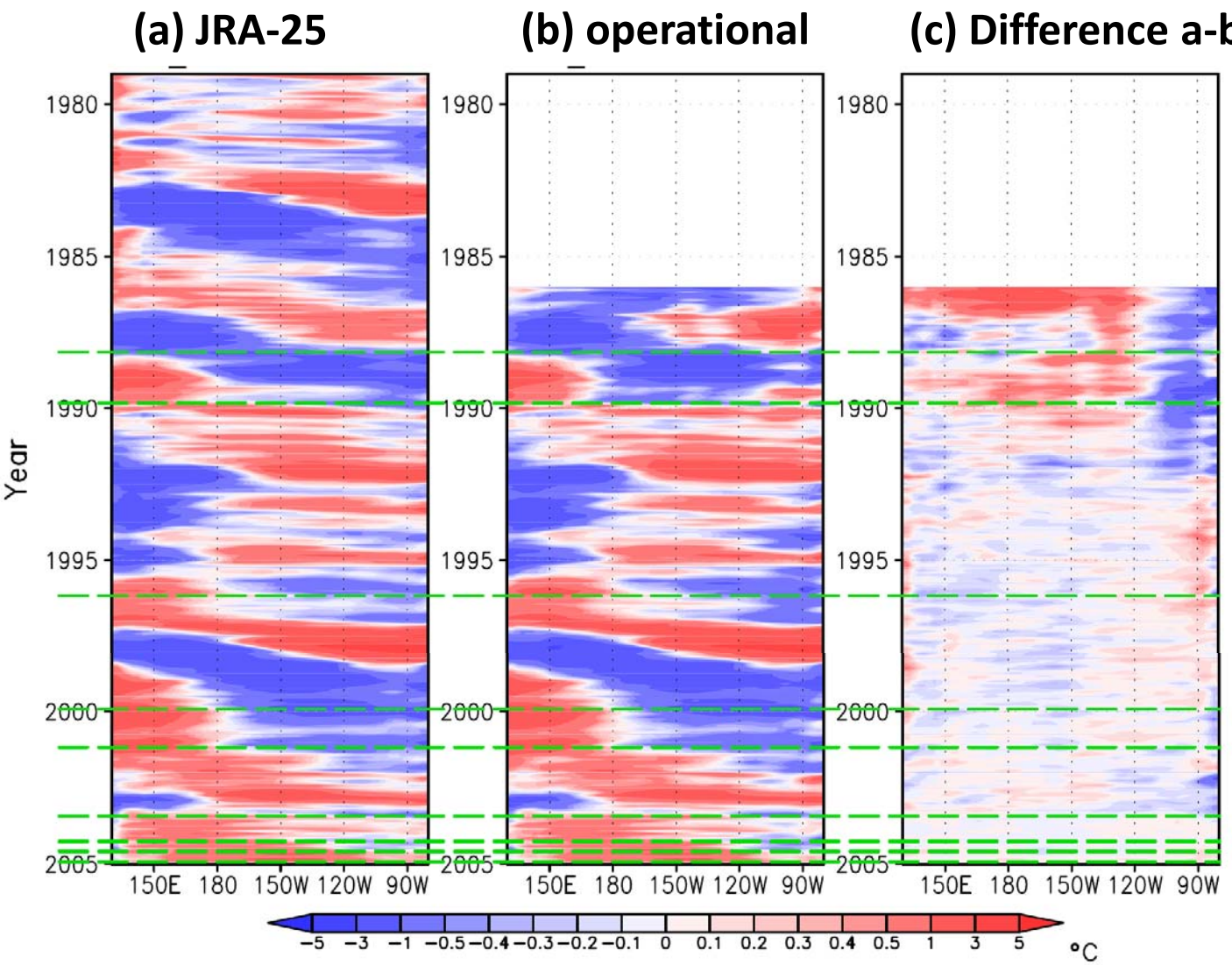
Benefit of Reanalysis in Ocean Data Assimilation



Net heat flux (heat and radiation) anomalies along the equator (5S-5N) with (a) JRA-25, (b) JMA old operational analysis, (c) difference btw (a) and (b) .

Dashed green lines indicate major change of physics/assimilation in JMA realtime systems.

Benefit of Reanalysis in Ocean Data Assimilation



Ocean Heat Content (averaged subsurface temperature) anomalies along the equator (5S-5N) analysed with (a) JRA-25, (b) JMA operational analysis, (c) difference btw (a) and (b) .

Dashed green lines indicate major change of physics/assimilation in JMA realtime systems.

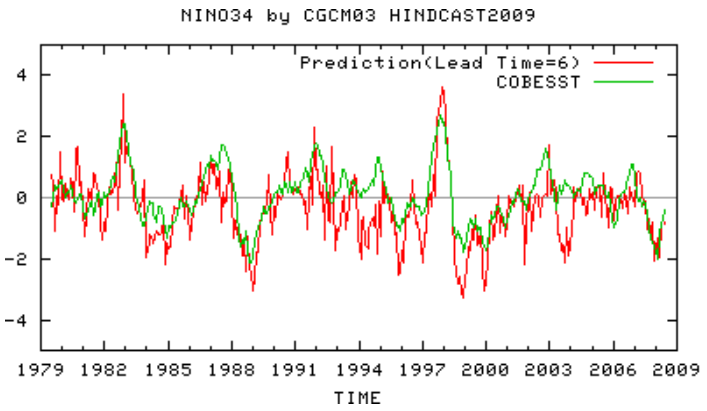
For ENSO prediction

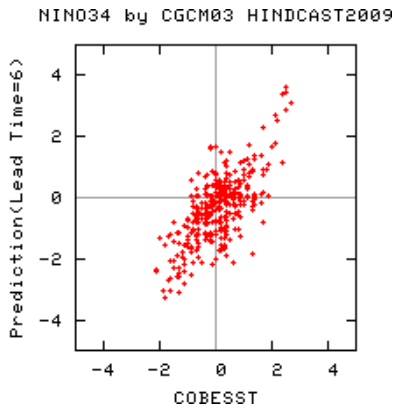
JRA-25/JCDAS

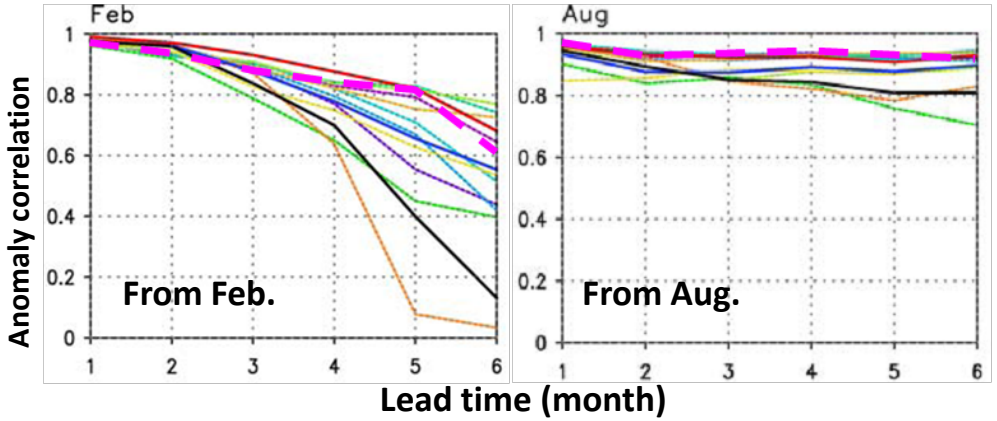
Ocean Data Assimilation

CGCM hindcast

Estimations for forecast skills and systematic errors





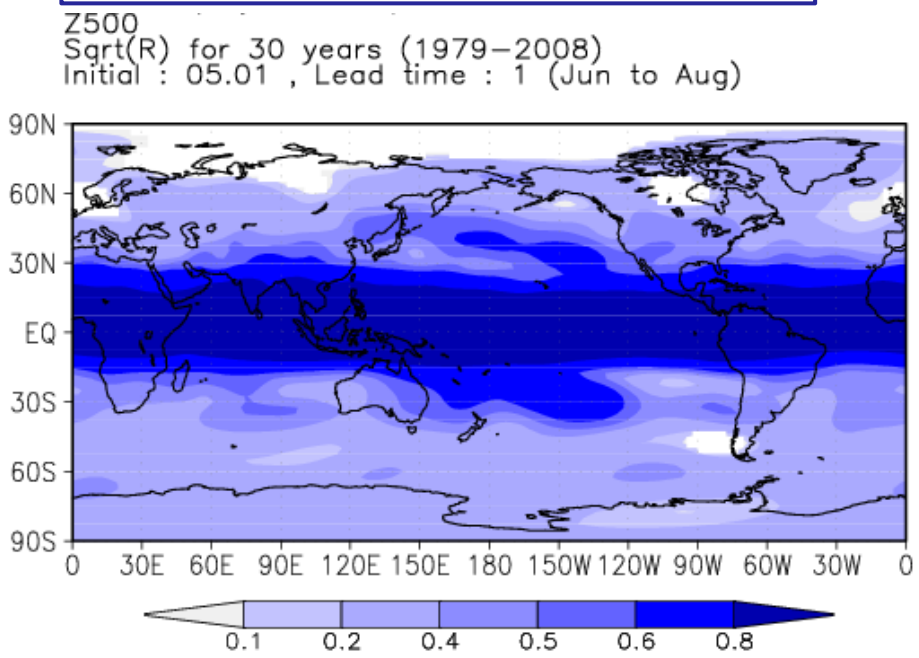


Originally,
Jin et al. 2008
Clim. Dyn.

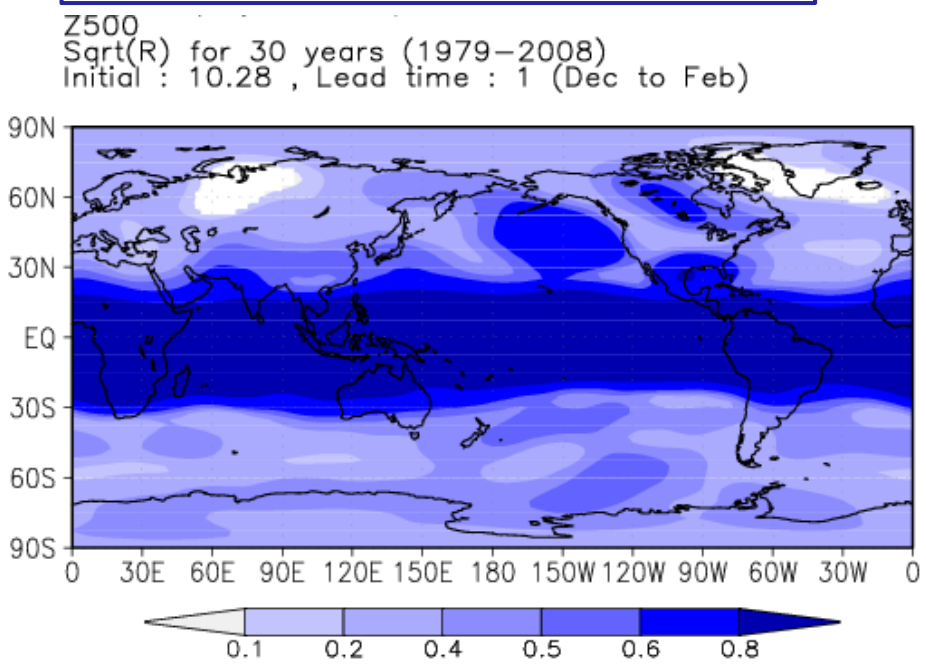
Base period:
1980-2001

Assessment of potential predictability with long period re-analysis and hindcast

500-hPa GPH Boreal Summer (JJA)



500-hPa GPH Boreal Winter (DJF)



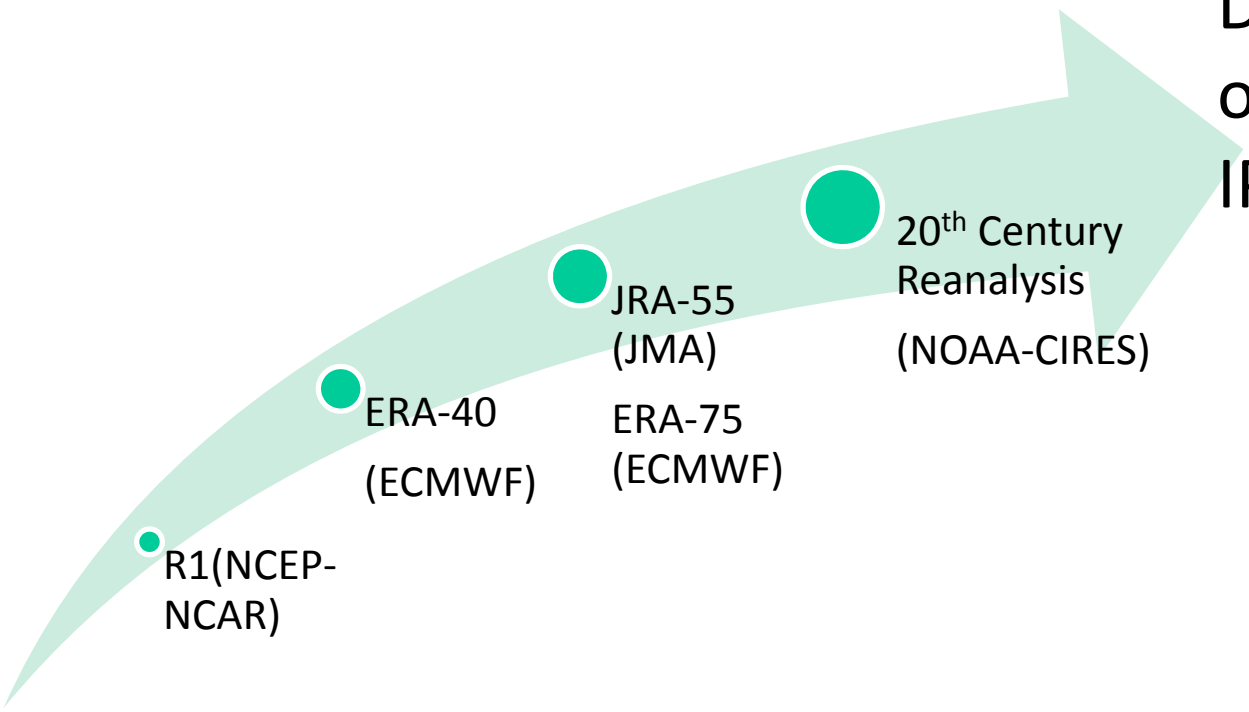
$$R = \frac{S^2}{S^2 + N^2}$$

$$N^2 = \frac{1}{m(n-1)} \sum_{i=1}^{m} \sum_{j=1}^{n} (x_{ij} - \overline{x_i})^2 \qquad \sigma_{em}{}^2 = \frac{1}{m-1} \sum_{i=1}^{m} (\overline{x_i} - \overline{\overline{x}})^2$$

$$S^2 = \sigma_{em}{}^2 - \frac{1}{n} N^2$$

cf. Rowell *et al.* 1995 *QJRMS*
Sugi *et al.* 1997 *JMSJ*

Reanalysis for Decadal predictability



Decadal f
orecasting
IPCC AR5

IPCC
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
WMO UNEP

Long-period reanalysis is necessary for research of the decadal variability.

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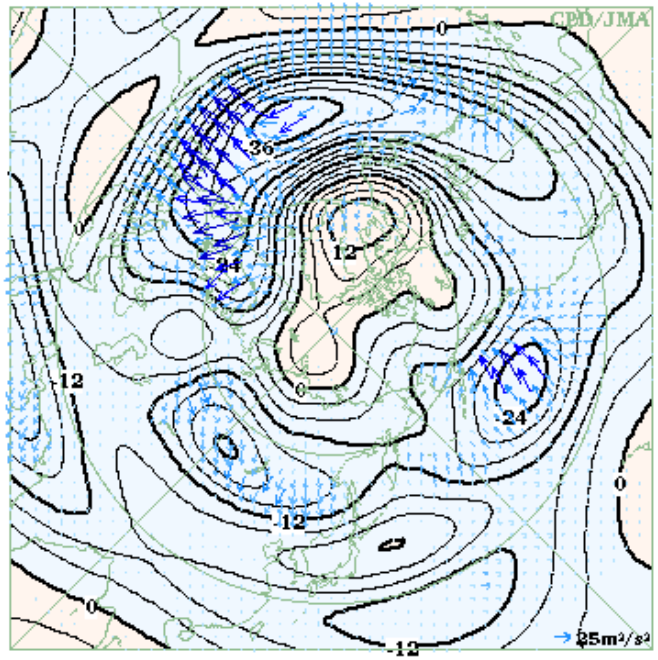
Reanalysis for climate system monitoring

- JMA operational climate monitoring utilizes JRA-25/JCDAS, JMA sea surface temperature analysis data (COBE-SST), OLR data (provided by courtesy of NOAA)…
- JMA as well as CPC/NOAA etc. routinely issue climate monitoring reports focusing on global atmospheric circulation, Asian monsoon, ENSO, AO, teleconnections…



MONTHLY MEAN WAVE ACTIVITY FLUX AT 300hPa
IN THE NORTHERN HEMISPHERE (Feb. 2010)
Arrows show horizontal component of wave activity flux.
(Takaya and Nakamura 2001, J.Atmos.Sci., 58, 608-627)
Contours show stream function anomalies in an interval of $4\times10^{**}6m^2/s$. Negative anomaly area is shaded.
Base period for normal is 1979-2004.

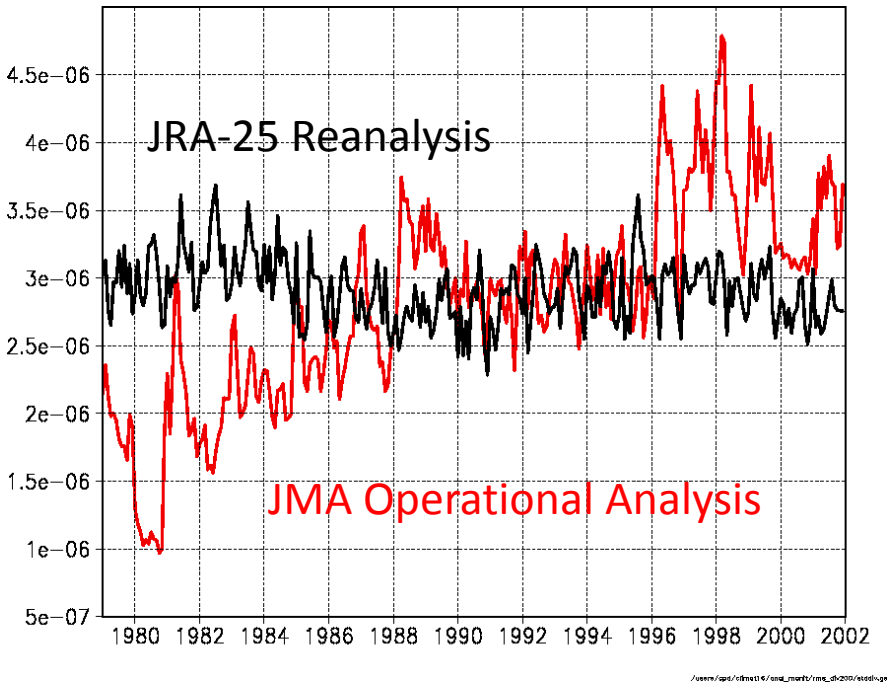
Benefit of Reanalysis for Climate Monitoring

Merit of re-analysis from a point of view of climate monitoring

- Temporal Consistency (homogeneity of records)
- Global Coverage
- Comprehensive Archive

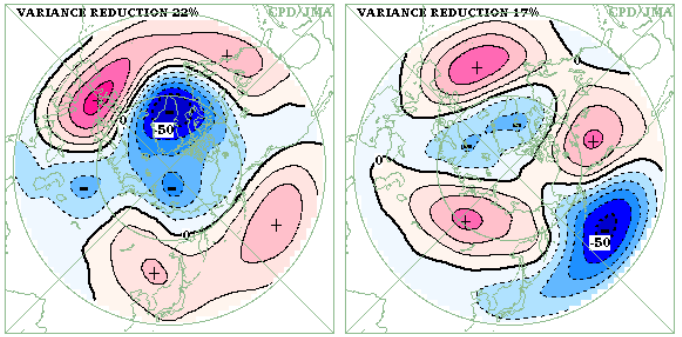
Before JRA-25, it was impossible to diagnose velocity potential (or vertical velocity) in tropics due to temporal inconsistency of atmospheric analysis.

Standard deviation of 200-hPa divergence over Tropics

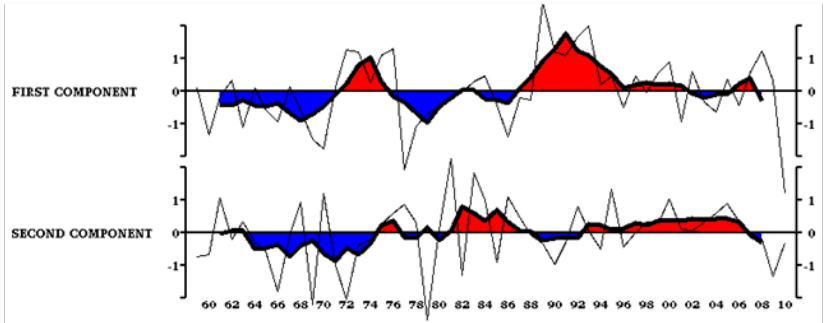


Benefit of Reanalysis for Climate Monitoring

- Homogeneous long-period dataset enable us to monitor climate system with high quality.
- Statistics of long-period data from JRA-25/JCDAS help our understanding of the atmospheric variability.



DISTRIBUTION OF EIGEN VECTOR CALCULATED FROM EOF ANALYSIS
OF SEASONAL MEAN 500hPa HEIGHT IN THE NORTHERN HEMISPHERE (WINTER)
The left and right panel show eigen vector, multiplied by root of its eigen value, of the first and second component, respectively. EOF analysis is conducted with covariance matrix for 47 samples of seasonal mean 500-hPa height from 1958 to 2004. Original data before 1979 are provided by courtesy of ECMWF.

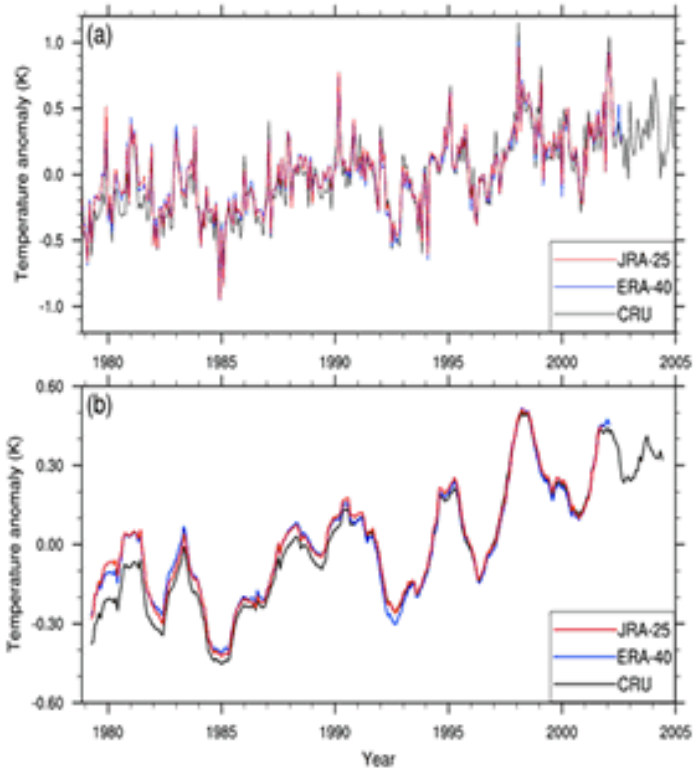


TIME SERIES OF SEASONAL MEAN EOF SCORE (WINTER)
Thin lines show normalized seasonal mean value and thick lines show their 5-year running mean values. seasonal 500-hPa height anomalies are projected onto the EOF vectors.
Base period for normal is 1958-2004. The figure '59' corresponds the season in 1958/59.

Global warming and Re-analysis

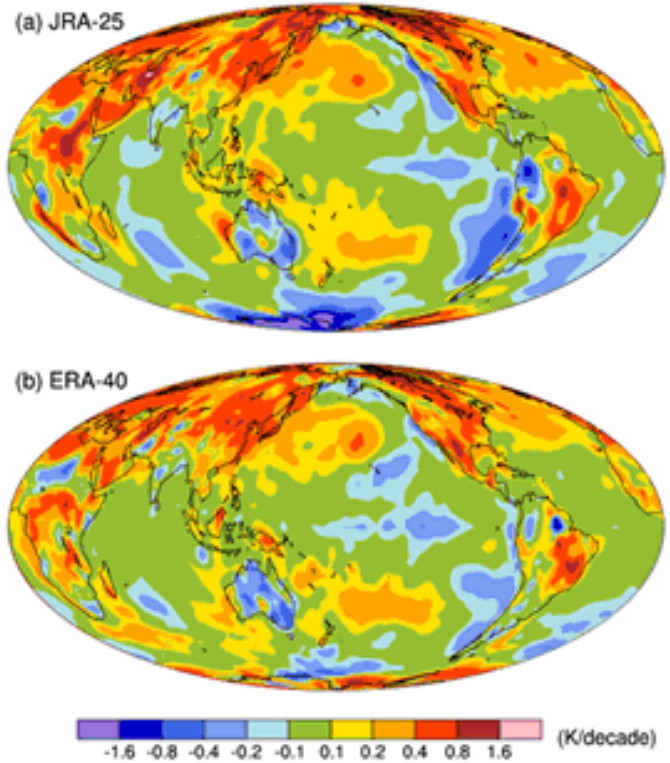
- **Surface Temperature Trends**

  The JRA-25 surface analysis employs a two-dimensional optimum interpolation scheme where various surface observations are assimilated with first-guess fields that are diagnostically obtained from upper-air first-guess fields.



Global Temperature Anomaly

Top: monthly mean, Bottom: 5-year moving average



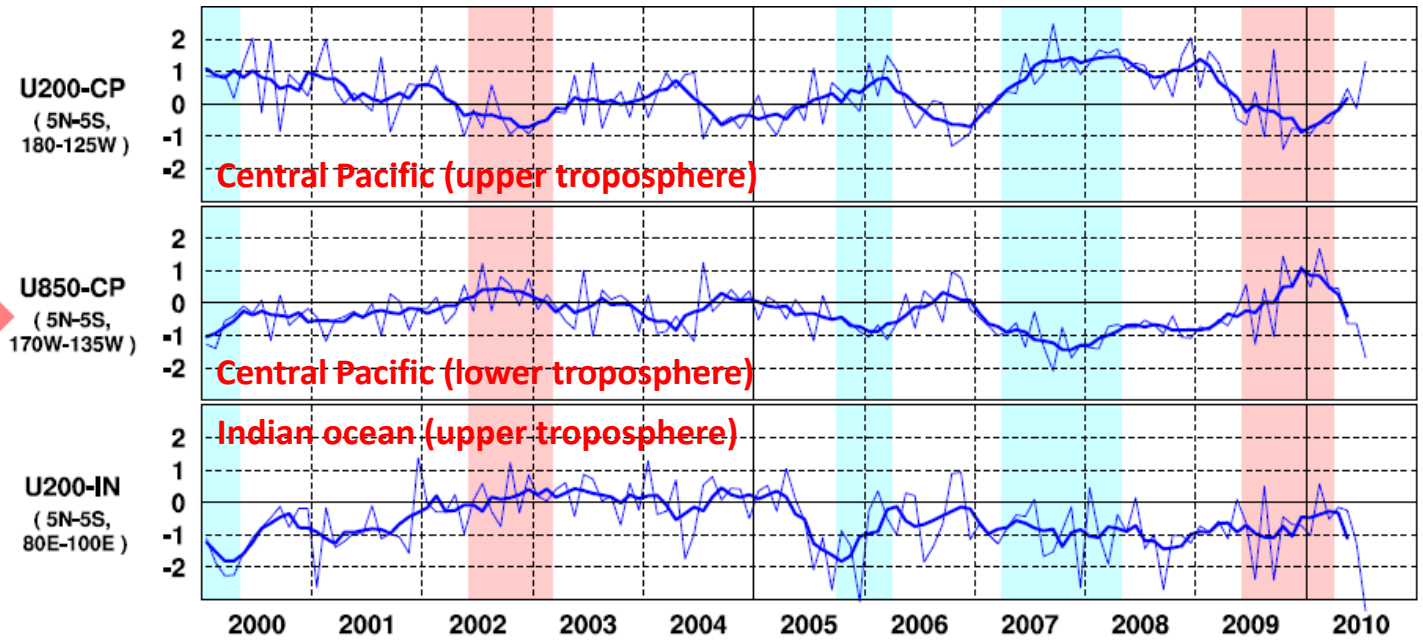
Distribution of tendency (K/decade)

See also,
Simmons et al. 2004, *JGR*
Onogi et al. 2007, *JMSJ*

ENSO Monitoring

JRA-25/JCDAS (1979-present)

Zonal wind indices over the central equatoral Pacific and the equatorial Indian Ocean

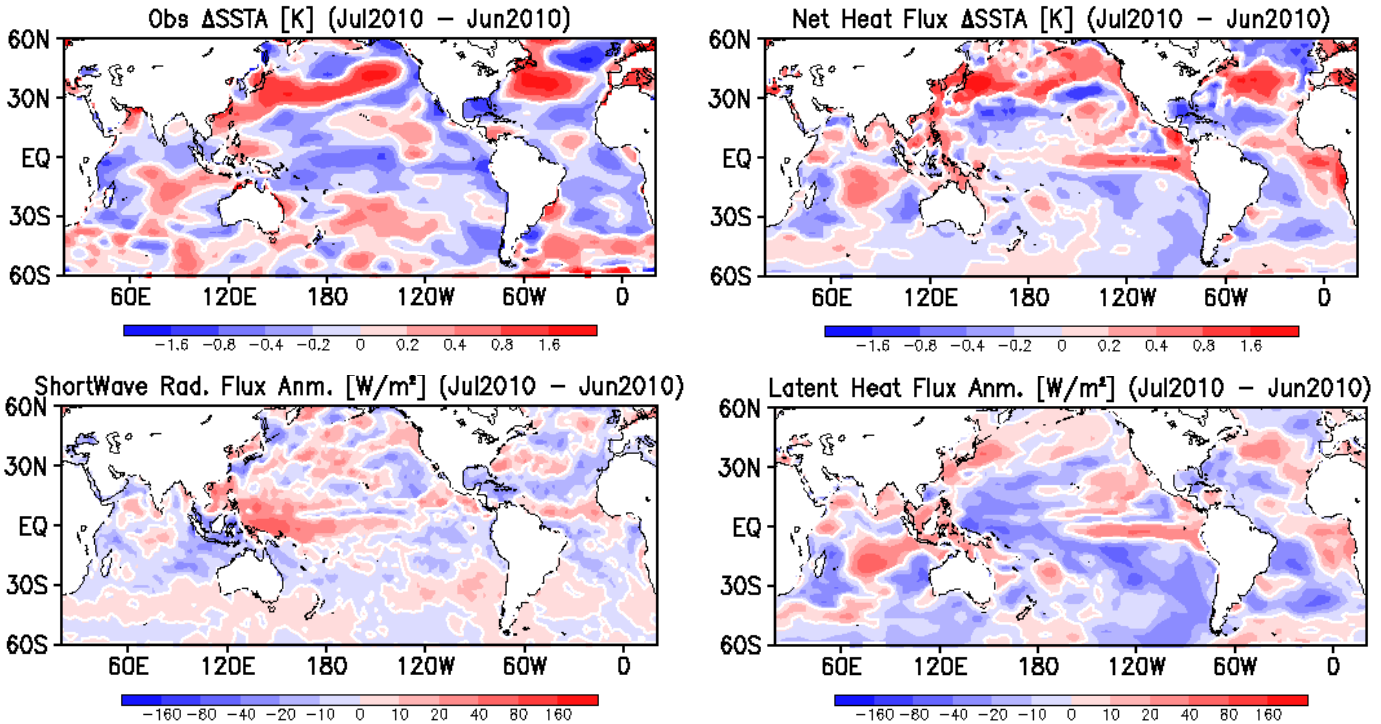


Red shades indicate El Niño periods, and blue shades indicate La Niña periods.

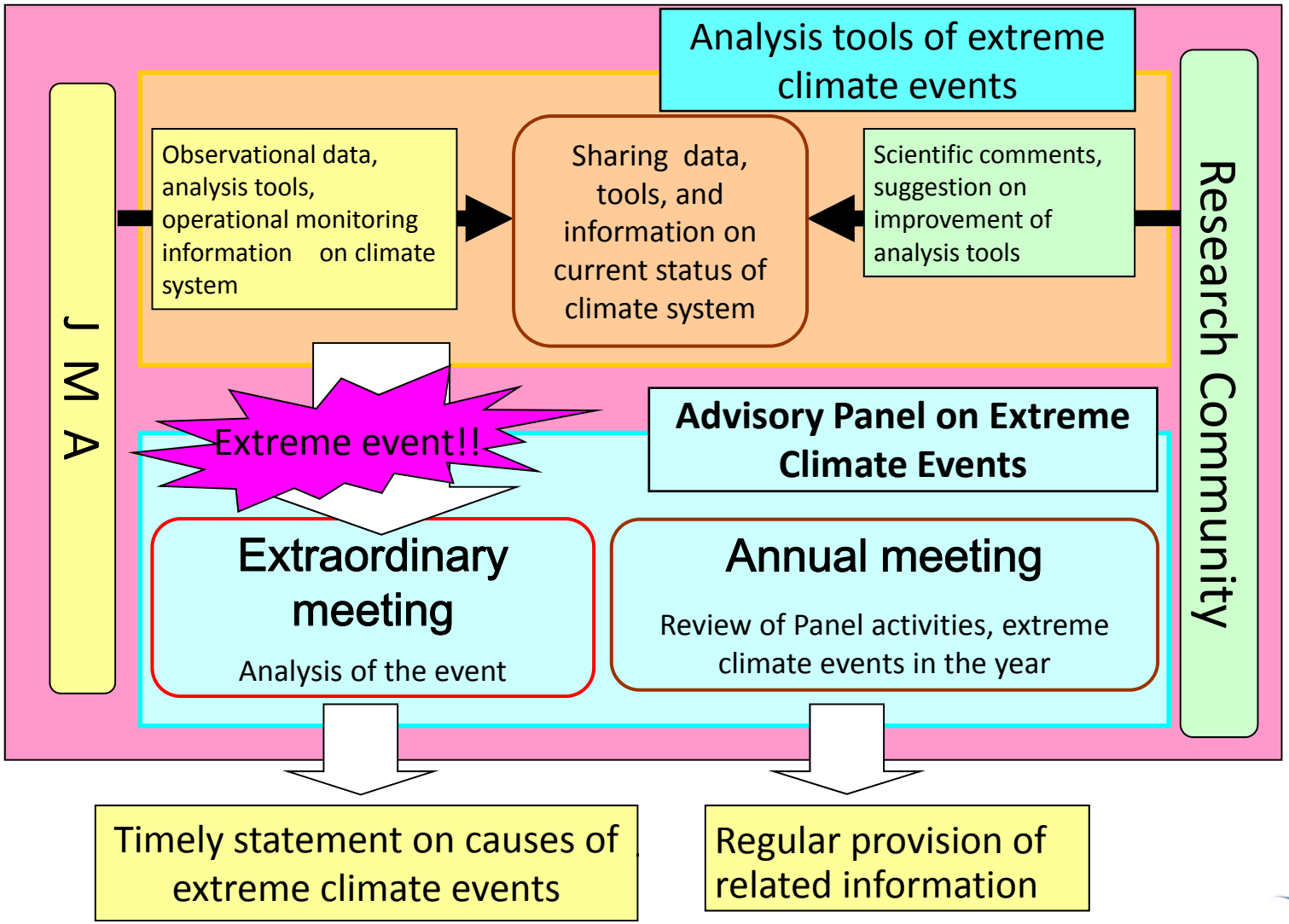
For Ocean Monitoring

Surface heat flux data from JRA-25/JCDAS are used to estimate the change rate (upper right panel) of ocean mixed layer temperature due to heat exchange at the ocean surface. This estimate can be of help to assess the attribution of factors causing SST variations.

JRA-25/JCDAS (1979-present)



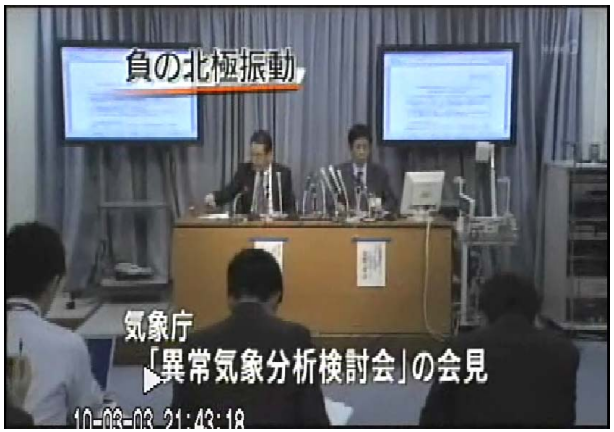
Climate monitoring service with Re-analysis data - Advisory Panel on Extreme Climate Events -



Advisory Panel on Extreme Climate Events

Discussion at Advisory Panel on Extreme Climate Events

Press release on extreme events



Briefing for press
about AO in 2009/10 winter
(broadcast news)

General public
Policy maker

Outline

- Introduction
- Overview of JRA-25 Re-analysis
- Applications using reanalysis data and its benefit
  - Monthly to Decadal Forecasting
    - One-month forecasts
    - El Niño & seasonal outlook
    - Decadal forecasts
  - Climate system monitoring
  - Climate information based on reanalysis
- Reanalysis as a tool for research and studies
- Status of JRA-55
- Summary

Reanalysis as a tool for researches and studies

- Understanding of mechanisms of the climate variability is the first step of predictions.
- Countless studies of the meteorology and climatology used reanalysis data and reveal the mechanisms.

- These are certainly great help for the operational forecast community.

Challenges in future reanalyses

Extended reanalysis period

- Data recovery, Quality Control, High quality boundary conditions, …

Better handling of changing observing system

- Adaptive tuning of error statistics
- Reanalysis using a fixed observing system as an alternative approach
- Identification of key observing system for climate monitoring

Better representation of interactions with climate subsystems (land, ocean, cryosphere)

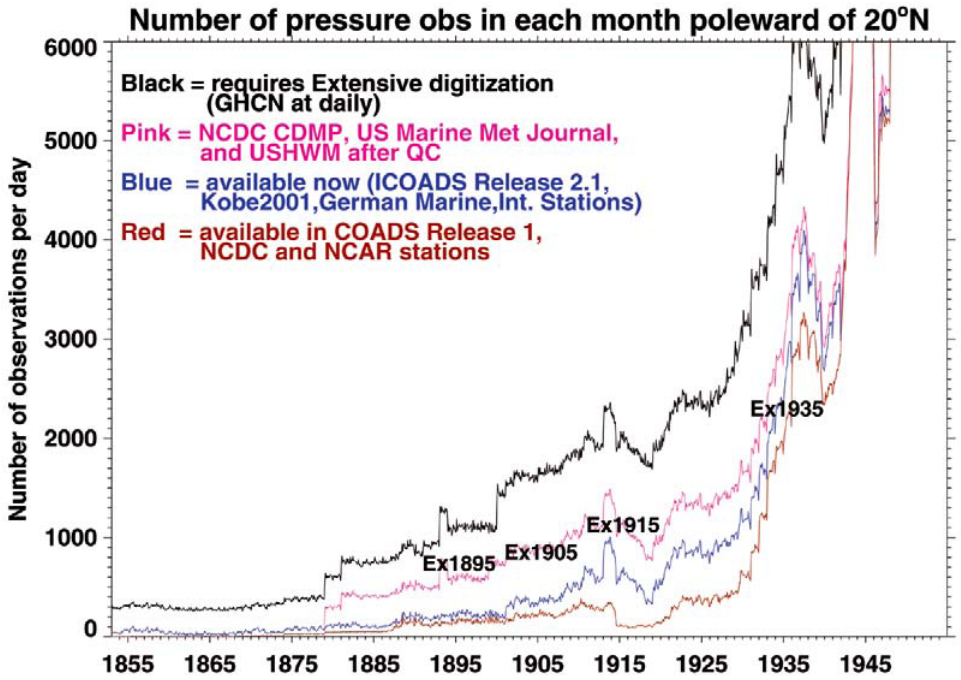
- Coupled system reanalysis

Reliable uncertainty estimates

- Ensemble-based data assimilation system (EnDA, EnKF, …)
- Comparison between available reanalysis datasets

20th century reanalysis (NOAA-CIRES)

Reanalysis period	• V1: 1908-1958 • V2: 1871-2008
Assimilation method	• Ensemble Kalman Filter (EnKF) with 56 members
Assimilation model	• NCEP'S Climate Forecast System (T62L28)
Observation (surface pressure only)	• ISPD Ver. 2 • ICOADS Ver 2.4 (1952-2006) • ICOADS Ver 2.5 (1971-1951)
Boundary condition	• HadISST



Compo *et al.*, 2006, *BAMS*

http://www.esrl.noaa.gov/psd/data/gridded/data.20thC_Rean.html

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Status of JRA-55 (1)

Global analysis

Compared with JRA-25

- Longer Period (1958-2012)
- Higher resolution
- Latest assimilation system with the latest model
- Enhanced QC
- More conventional data
- Adjustment of background error for a gap between satellite and no-satellite eras.

providing a fundamental data set for

- **researches** on climate change and decadal variability in the last half century
  → *Global Warming*
- real-time climate **monitoring**
- **verification** of seasonal forecast and climate models
- atmospheric **forcing fields** for ocean data assimilation
- chemical transport simulations
- carbon cycle simulations
- water resource management
- estimation of renewable energy resources
- severe weather risk assessment

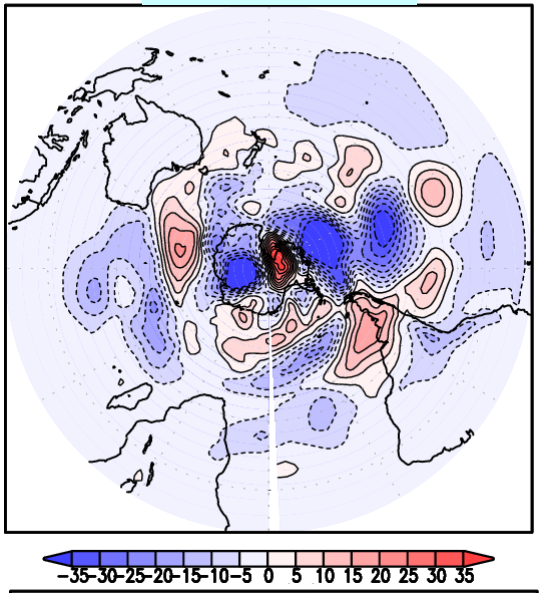
and much more

Status of JRA-55(2)

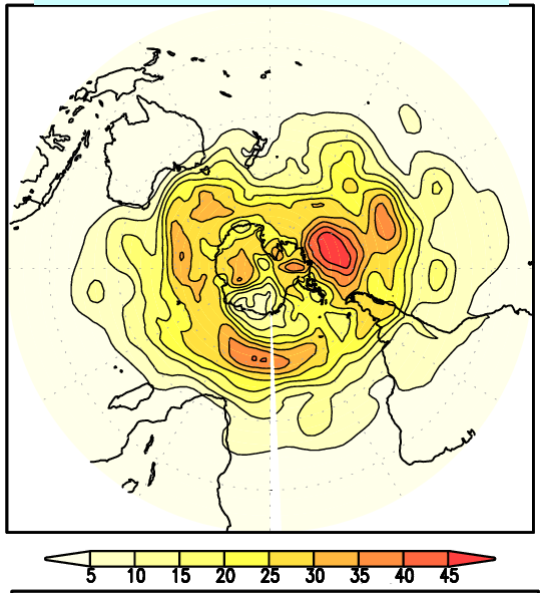
	JRA-25 (1979-2004)	JRA-55 (1958-2012)
Resolution	T106L40 (~120km) *(top layer at 0.4 hPa)*	TL319L60 (~60km) *(top layer at 0.1 hPa)*
Time integration	Eularian	Semi-Lagrangian
Assimilation scheme	3D-Var	4D-Var *(with T106 inner model)*
B matrix	Constant	Different **B** matrices for pre-satellite and satellite eras
Bias correction (radiosonde)	Radiation bias only (Andrae *et al.*, 2004)	RAOBCORE v1.4 (Haimberger, 2007, *J. Climate*)
Bias correction (radiances) For satellite	Offline	Variational Bias Correction
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

Tuning of background error covariance matrix

Z500 Bias (m)

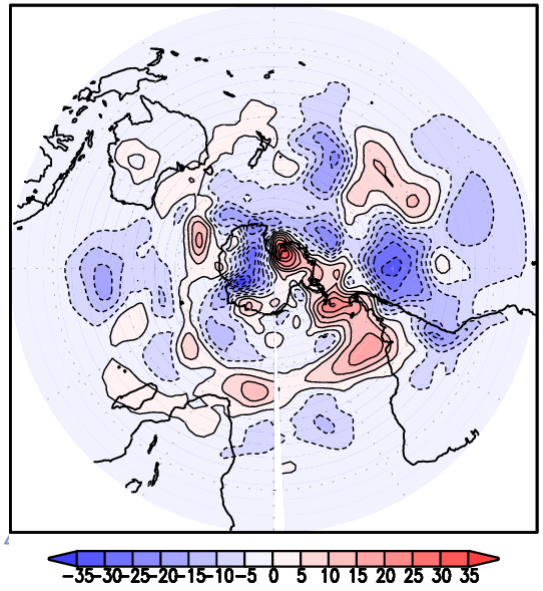


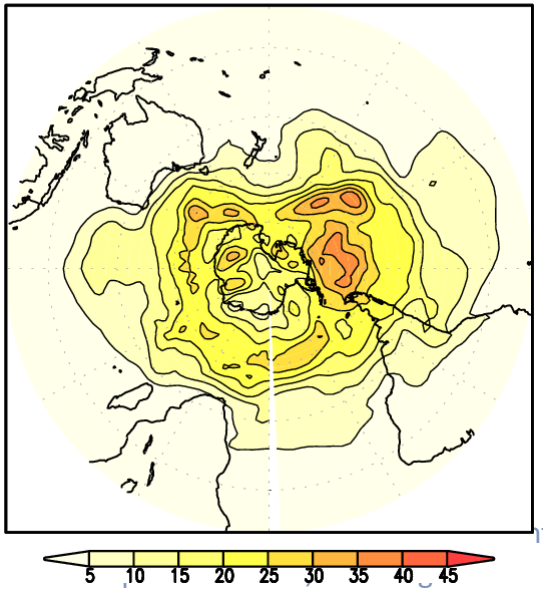
Z500 RMS Difference (m)



Difference between satellite denial experiment and control (using all available observations)

No tuning



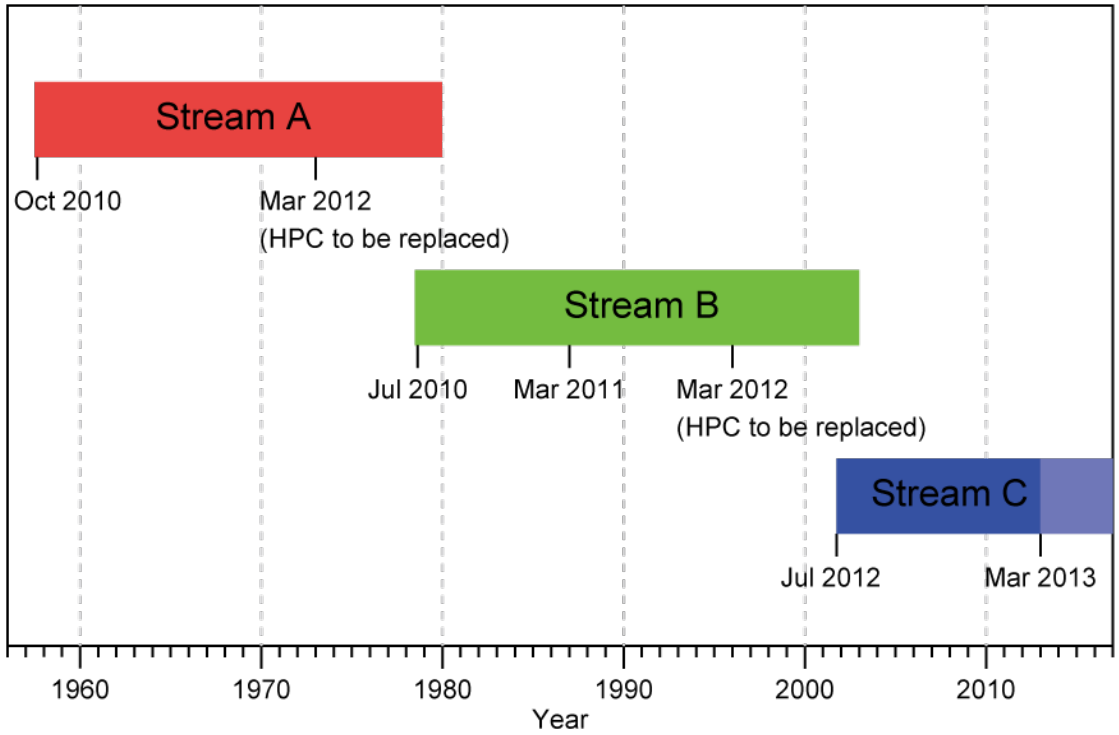


B matrix is multiplied by 1.8

Importance of B matrix in a sparse observing system

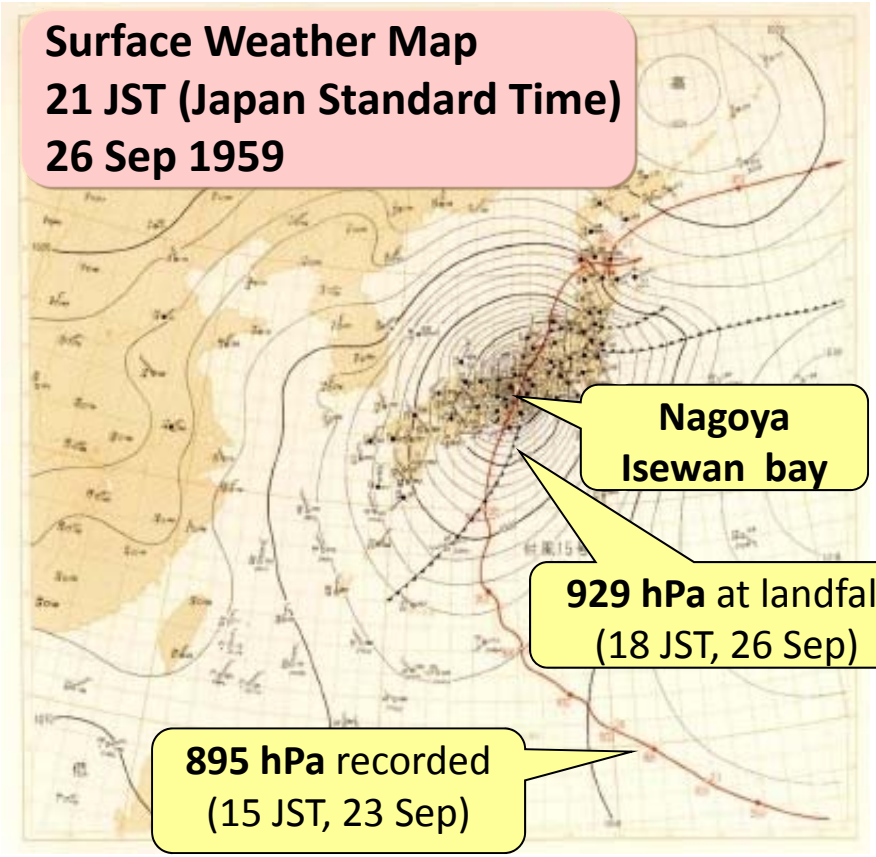
How to estimate a reliable B matrix?
EnKF, EnDA, …

JRA-55 project schedule



- Jul 2010 start of Stream B
- Oct 2010 start of Stream A
- Early 2013 completion of production
- **Mid 2013** **product release**
  - Production will be continued as a new JCDAS

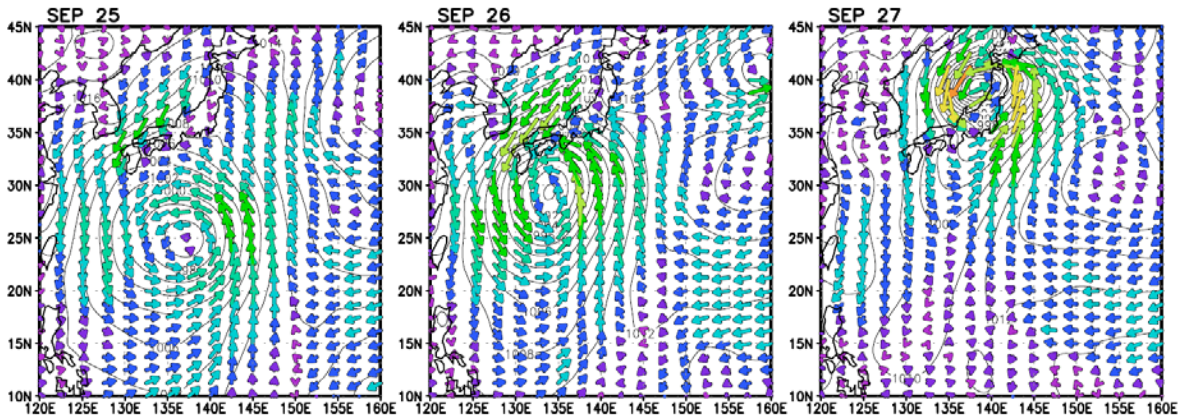
Re-examination of extreme event：
Typhoon Vera (Isewan tyhpoon) （ 1959 ） forecasts



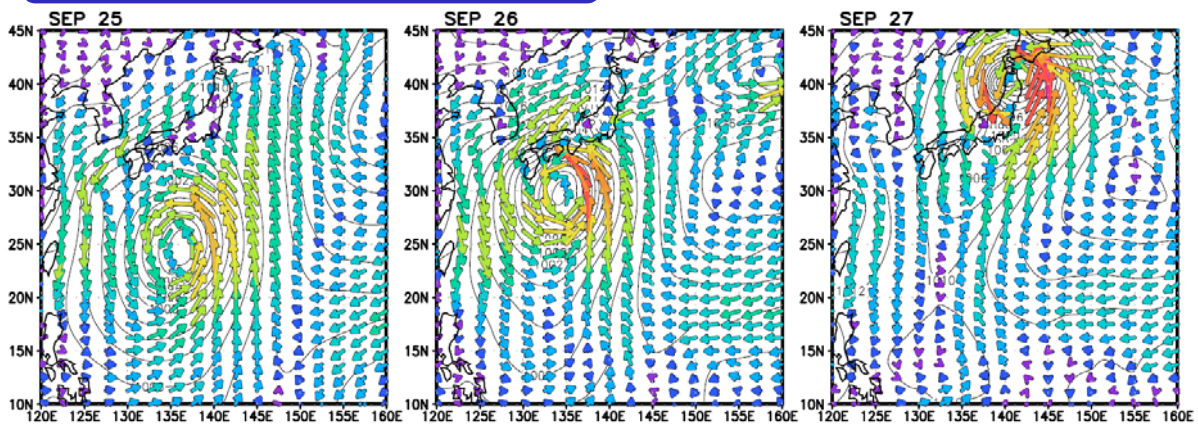
Case studies of past devastating events with reanalysis would be of great help for planning of disaster prevention, and decision making in case of disasters.

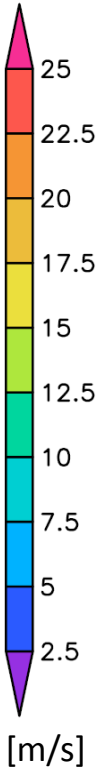
Re-analysis of Typhoon Vera 1959

ERA40 Ps, Us



JRA-55 Test Ps, Us





JRA-55 high resolution would improve representations (intensity) of typhoons in reanalysis products.

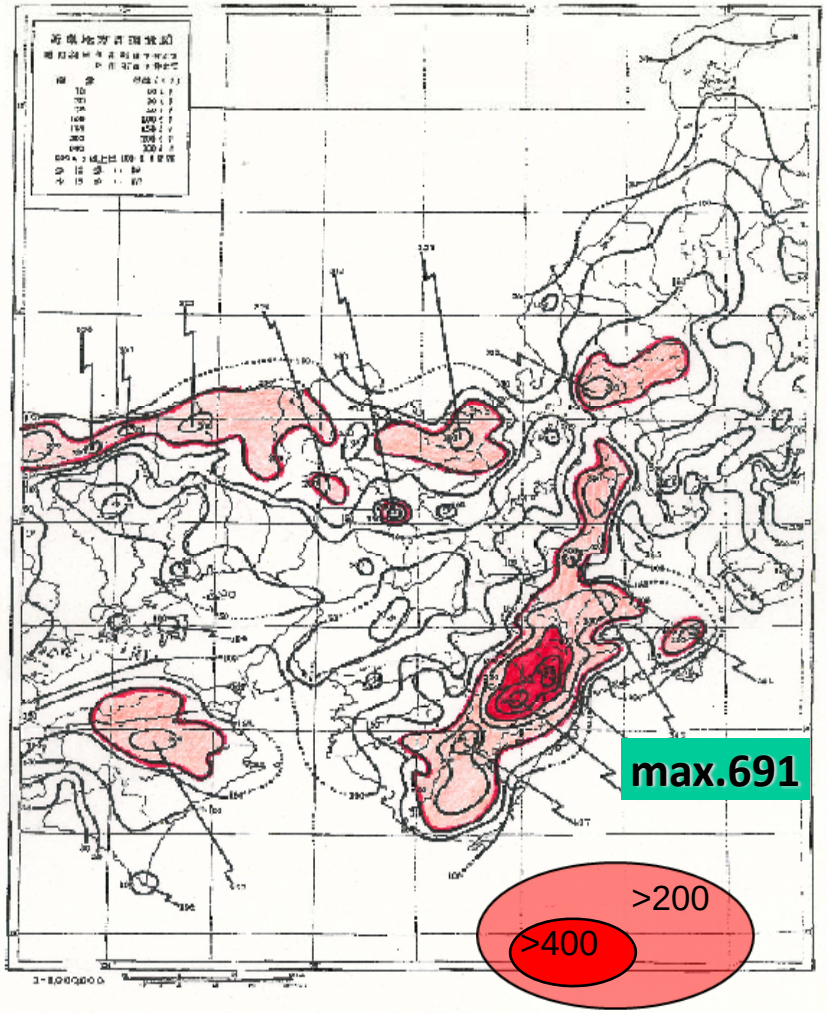
Surface pressure and wind fields in (upper) ERA-40 and (lower) JRA-55 test experiment with JRA-55 resolution. 1.25 deg data are plotted in both figures.

$\overrightarrow{15}$

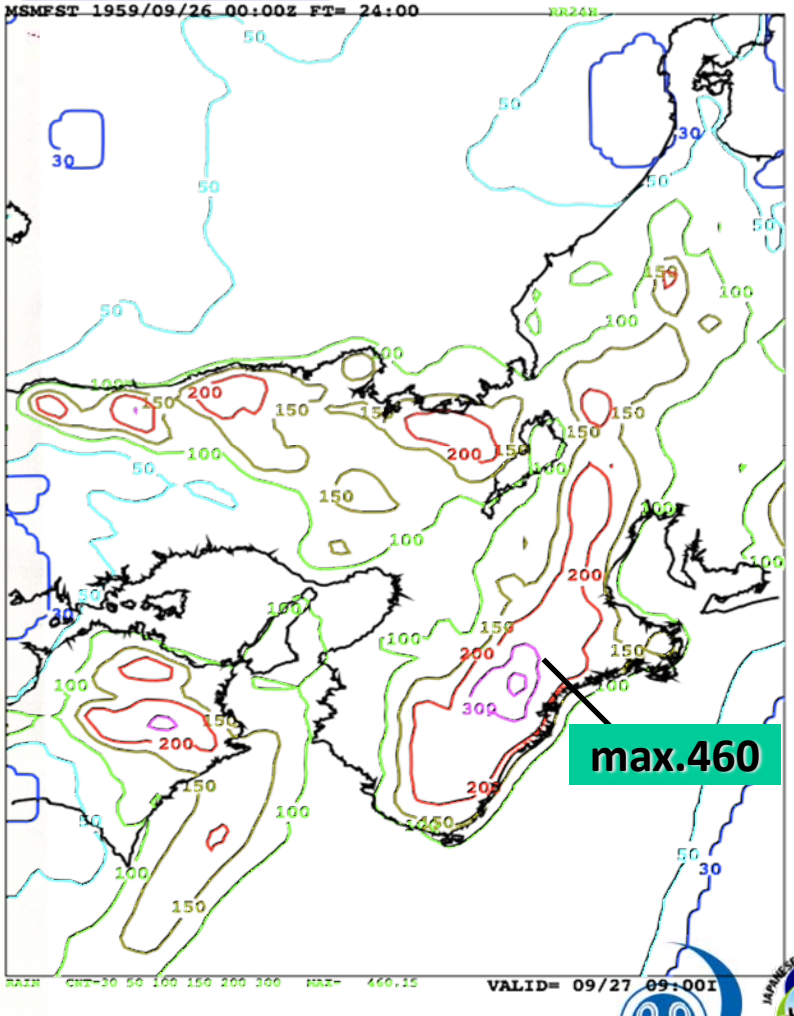
Typhoon Vera 1959 forecast with JMA non-hydrostatic model

Accumulated 24-hr Rainfall (1959.09.26,00UTC-1959.09.27,00UTC)

Observation



Forecast



Summary

- **Reanalysis**
- based on maximally available observation data with enhanced QC
- continuously produced analysis data for a long period with the latest analysis system
- **Best estimates** or **proxies of the truth** with homogenous constant quality

- **Applications of reanalysis**
  - Reanalysis is widely used with forecasting system.
  - Initials for long-range predictions and for hindcasts
  - Forcing data in ocean data assimilation
  - Verification in extended and long-range forecasts predictability
  - Inherent changes of predictability
  - Climate monitoring
  - Extreme events
  - Decadal variations and global warming

Summary -continued-

- **As tools for research**
- Interactions between production and utilization of reanalysis promote further improvements in reanalysis and research activity.

- **Future subjects**
- Flow dependency analysis
  - EnKF --- combination of reanalysis and predictability
- Reanalysis for decadal-scale variation
- JRA-55 in JMA
  - Successor of JRA-25
  - Development of predictability

assessment of predictability for extreme event , Isewan-typhoon

- Reanalysis needs to follow the advancement of forecast system
  - **Need to producing reanalysis data repeatedly**

END

Thank you for your kind attention.

And thanks to
Mr. Y. Takaya
Mr. S. Kobayashi
for preparing this material