TCC Training Seminar on
One-month Forecast

12 – 16 November 2018

Tokyo, Japan

Tokyo Climate Center
Japan Meteorological Agency

TCC Training Seminar on One-month Forecast

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Contents

Schedule
and
List of Participants

TCC Training Seminar on
One-month Forecast
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Schedule

Day 1 - Monday, 12 November		
10:00-10:30	1. Opening - Welcome Address - Self-introduction by participants - Group photo shooting - Courtesy call on JMA's Director-General	
10:30-10:45	Coffee Break	
10:45-11:00	2. Introduction: Outline and scope of the Training Seminar, and Introduction of the Tokyo Climate Center (TCC)	
11:00-12:30	3. Lecture: "Introduction to Climatology" for experts on one-month forecasting	
12:30-14:00	Lunch	
14:00-15:30	3. Lecture: "Introduction to Climatology" for experts on one-month forecasting (cont.)	
15:30-15:45	Coffee Break	
15:45-16:15	4. Lecture: Introduction of reanalysis and JRA-55	
16:15-18:00	5. Exercise: Introduction and operation of iTacs (Basic)	
18:30-20:00	Reception	at KKR Hotel Tokyo
Day 2 - Tuesday, 13 November		
09:30-10:30	6. Lecture: One-month Forecast	
10:30-11:00	7. Lecture: Introduction of climate monitoring and analysis products for one-month forecast	
11:00-11:15	Coffee Break	
11:15-12:05	8. Lecture: Introduction of global ensemble prediction system for one-month forecast	
12:05-12:30	9. Lecture: Introduction of numerical prediction products for one-month forecast	
12:30-14:00	Lunch	
14:00-16:30	10. Exercise: Introduction and operation of iTacs (Advanced)	
16:30-16:45	Coffee Break	
16:45-18:00	11. Lecture: Introduction of one-month forecast guidance	
Day 3 - Wednesday, 14 November		
9:30-11:00	12. Exercise: One-month forecast - Producing one-month guidance forecast and verification	
11:00-11:15	Coffee Break	
11:15-12:30	12. Exercise: One-month forecast (cont.) - Producing one-month guidance forecast and verification	
12:30-14:00	Lunch	
14:00-15:45	12. Exercise: One-month forecast (cont.) - Producing one-month guidance forecast and verification	
15:45-16:00	Coffee Break	
16:00-17:00	12. Exercise: One-month forecast (cont.) - Producing one-month guidance forecast and verification	
17:00-18:00	13. Lecture: Interpretation of guidance, verification result and outputs from Numerical Prediction System (NWP)	
Day 4 - Thursday, 15 November		
9:30-11:00	14. Exercise: Generating one-month forecast for your country - Preparation for presentation	
11:00-11:15	Coffee Break	
11:15-12:30	14. Exercise: Generating one-month forecast for your country (cont.) - Preparation for presentation	
12:30-14:00	Lunch	
14:00-15:00	14. Exercise: Generating one-month forecast for your country (cont.) - Preparation for presentation	
15:00-16:00	15. Presentation by participants	Presentation (15 min.) followed by Q&A (5 min.)
16:00-16:20	Coffee Break	
16:20-18:00	15. Presentation by participants (cont.)	
Day 5 - Friday, 16 November		
09:30-10:50	15. Presentation by participants (cont.)	
10:50-11:10	Coffee Break	
11:10-12:10	15. Presentation by participants (cont.)	
12:10-12:30	16. Wrap up and Closing	
12:30-14:00	Lunch	
14:00-18:30	Technical Tour	

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"Introduction to Climatology"
for experts on One-month Forecasting

"Introduction to Climatology" for experts on One-month Forecasting

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1. Climate and Climate system

According to WMO website, "on the simplest level the weather is what is happening to the atmosphere at any given time. Climate, in a narrow sense, can be considered as the 'average weather,' or in a more scientifically accurate way, it can be defined as 'the statistical description in terms of the mean and variability of relevant quantities over a period of time.'" Although climate is the synthesis of the weather, climate is not maintained only by atmosphere itself but is formed in the interactions among many components of the Earth. This system is named as a climate system. The global climate system consists of atmosphere including its composition and circulation, the ocean, hydrosphere, land surface, biosphere, snow and ice, solar and volcanic activities (Fig.1). These components interact on various spatial and temporal scales through the exchanges of heat, momentum, radiation, water and other materials.

The purpose of the lecture is to know how climate is formed and its variability is caused. In the lecture, anthropogenic "climate change" defined by United Nations Framework Convention on Climate Change (UNFCCC) is also included.

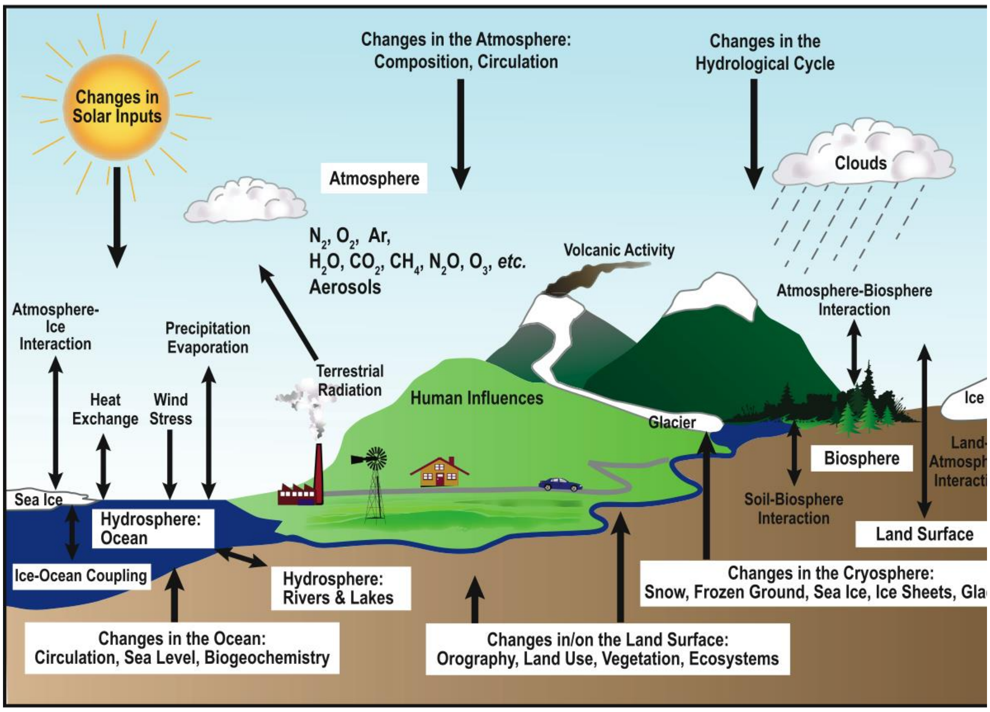


Fig. 1. Schematic view of the components of the climate system, there processes and interactions. From IPCC (2007).

2. Global mean temperature and Radiative balance

Global mean temperature of planets, which is the temperature "observed from space", is estimated by global radiation balance between absorbed solar radiation and terrestrial emission from the planet. Incoming solar radiation is reflected back to space by a fraction of the planetary albedo. For the Earth, the observed mean ground temperature (15°C) is warmer by 34°C than the estimated temperature (-19°C). The reason is suggested by comparing other planet cases. The mean ground temperature for Mars with thin atmosphere is warmer only by 1°C than the estimated temperature. For Venus with thick atmosphere, the difference is 503°C. Radiative absorption by greenhouse gas in atmosphere is an important factor to determine mean ground temperature as well as planetary albedo.

The Earth's atmosphere has different characteristics for shortwave and longwave radiations (Fig.2). It is transparent (about 50%) for shortwave radiative flux from the sun as an approximation except for the reflection due to clouds (about 20%). On the other hand, the longwave radiation flux emitted from the Earth's ground is absorbed (about 90%) once in the atmosphere approximately and then mostly emitted back to the ground (greenhouse effect). Upper cold atmosphere and clouds emit less longwave flux to space than the ground emits. As a net, surface ground is heated by shortwave radiation from the sun, and atmosphere is cooled by longwave emission to space. The vertical contrast of the heating between ground and atmosphere creates thermal instability, which is compensated by vertical transport processes of sensible and latent heat energy due to turbulences, convections and waves.

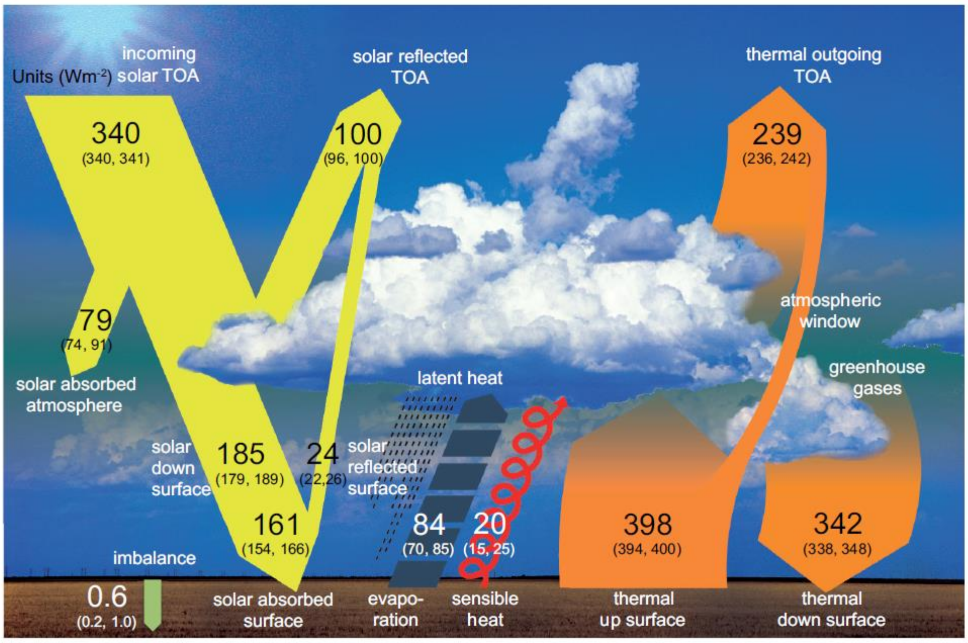


Fig. 2. Schematic diagram of the global mean energy balance of the Earth. Numbers indicate best estimates for the magnitudes of the globally averaged energy balance components together with their uncertainty ranges, representing present day climate conditions at the beginning of the twenty first century. Units W/m^2. From IPCC (2014).

3. Annual mean circulation and Horizontal heating contrast

Longitudinal contrast of radiative heating is created between day and night (Fig.3). But, generally, as compared with the annual cycle, the diurnal heating contrast does not produce significant temperature differences between day and night and related global circulations because a relaxation time to a radiative equilibrium is estimated as 30 days for the Earth (James, 1995), which is much longer than a day scale. Latitudinal heating contrast on the Earth is created on seasonal time-scale by the different incoming shortwave radiation between near the poles and the tropics (Fig.3). Local surface temperature determining outgoing longwave radiation is not adjusted instantly enough to compensate for the shortwave radiation contrast. A part of absorbed radiative energy in low latitudes is transported poleward by meridional circulations and waves in atmosphere and ocean, and these heat transports keep high-latitudes warmer than the radiative equilibrium.

Poleward/equatorward air motions form westerly/easterly wind in the upper/lower subtropics (Fig.4) through Coriolis force due to the rotation of the Earth (or the angular momentum conservation about the Earth's rotation axis). Extra-tropical waves are also responsible for creating mid- to high latitude's westerly jets.

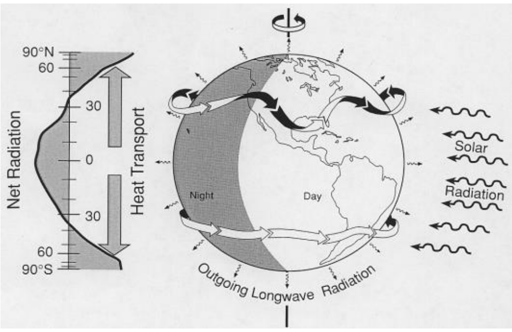


Fig. 3. Horizontal radiative imbalance and energy transport by the atmosphere and ocean. From IPCC (1995).

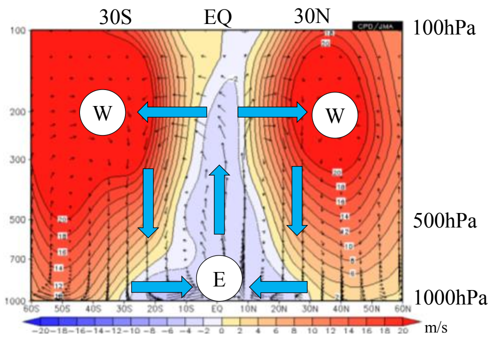


Fig. 4. Annual and zonal mean wind. Shade: zonal wind, and arrow: meridional and vertical wind.

4. Seasonal change and Heat capacity

Seasonal change is definitely produced by the seasonally changing solar incidence with its maxima at the South Pole in December and at the North Pole in June. However, zonally averaged features of temperature are not drastically changed in the troposphere (lower than about 100hPa) through the whole year, hot tropics and cold poles (Fig.5). This fact is attributed to basically unchanged distribution of sea surface temperature (SST) due to large heat capacity of the oceans; in the Earth, heat capacity of the ocean is about 1,000 times of that of the atmosphere. SSTs roughly determine the location of deep cumulus occurrences, which leads to vertical energy mixing in the troposphere and drives global circulations (Webster, 1994). Stratospheric climate above 100hPa varies following the seasonal march of the sun (Fig.5) because of the seasonal change of ozone-related shortwave heating and small heat capacity of thin stratospheric atmosphere; cold around a winter pole, warm around a summer pole. Atmospheric circulations also contribute to the stratospheric climate; a cold tropopause in the tropics is steadily created by upward motion.

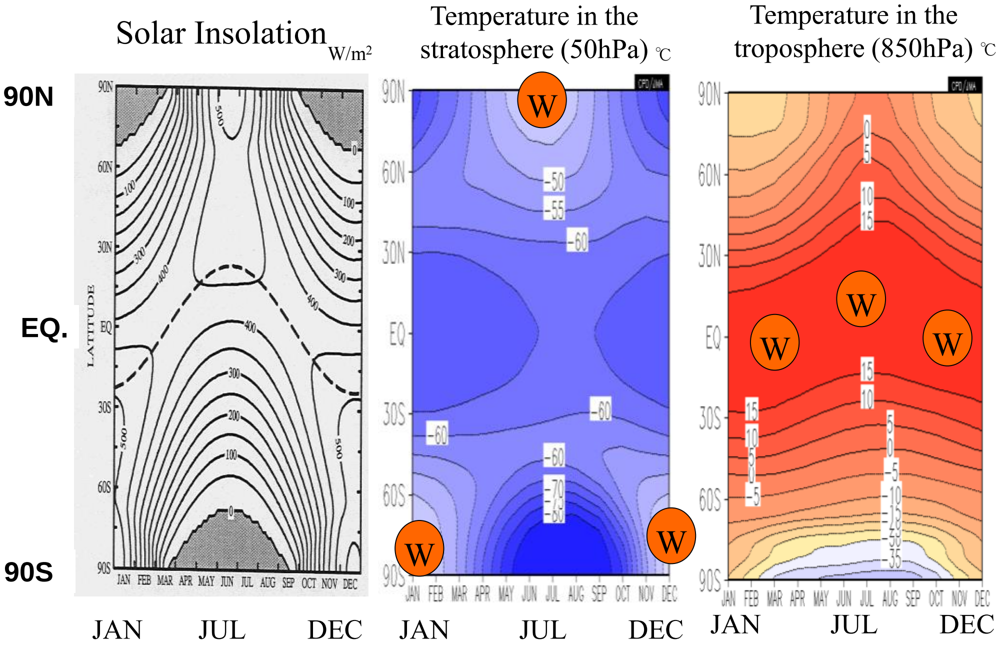


Fig. 5. Seasonal change of (left)solar insolation, zonally averaged temperature (middle) at 50hPa and (right) at 850hPa. The figure for solar insolation is from IPCC (1995).

Heat capacity of land surface is small as compared with that of the oceans. Surface air temperature over the northern continents is much higher than SSTs at the same latitudes in the northern summer (especially in daytime) and much colder in the northern winter (Fig.6). The large contrasts of surface air temperature between continents and the oceans add a significant feature to regional seasonal changes of rainfall and wind around the continents in low and mid-latitudes, which is named as monsoon. A concentrated subtropical rainfall forms a typical summer monsoon system consisting of an upper-level anti-cyclonic circulation, a monsoon trough, a low-level jet, a subtropical rainfall band expanding north eastward (south eastward) and extensive downward motions causing dry region in the north westward (south westward) area of the Northern (Southern) Hemisphere (Rodwell and Hoskins, 1996), as shown in the Asian region of Fig.6 and Fig. 7.

Jan-Jul contrast of surface temperature/precipitation

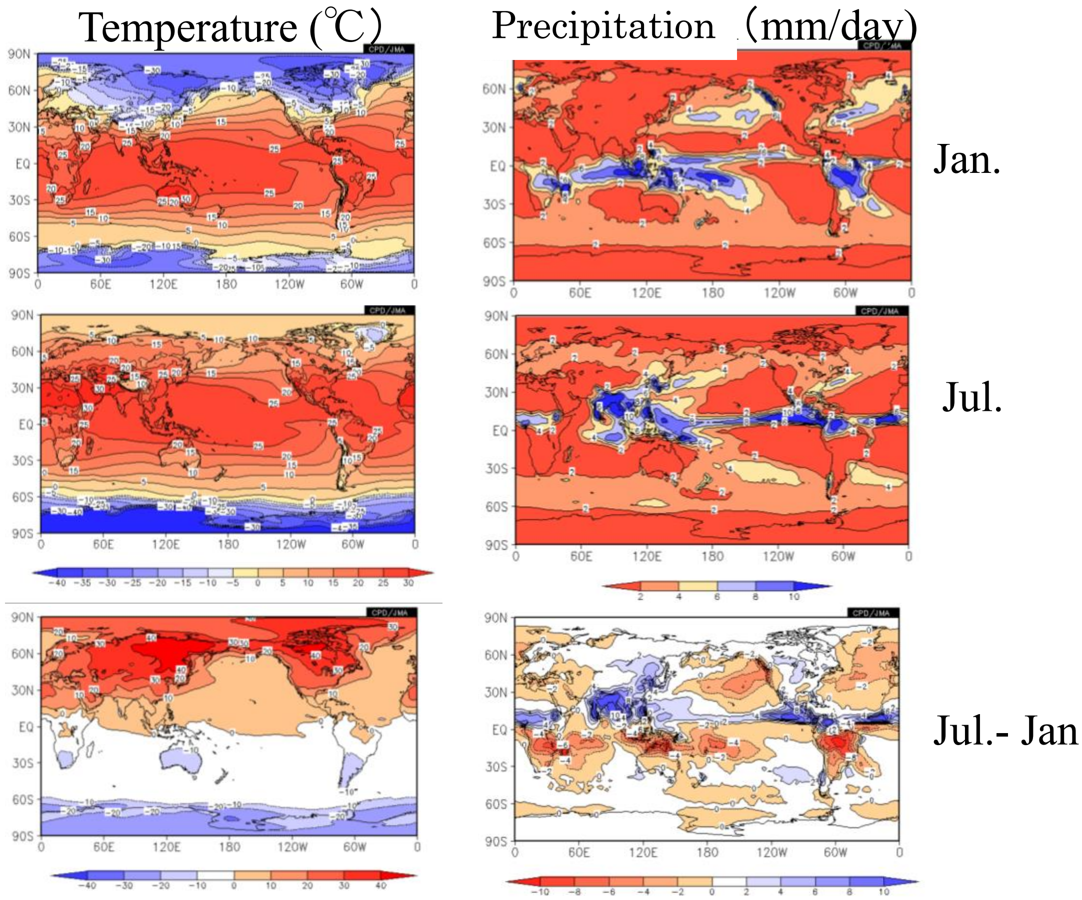


Fig. 6. (Left) surface are temperature and (right) precipitation in (upper) January, (middle) July, and (bottom) difference between the two months.

Northern Summer Monsoon circulation

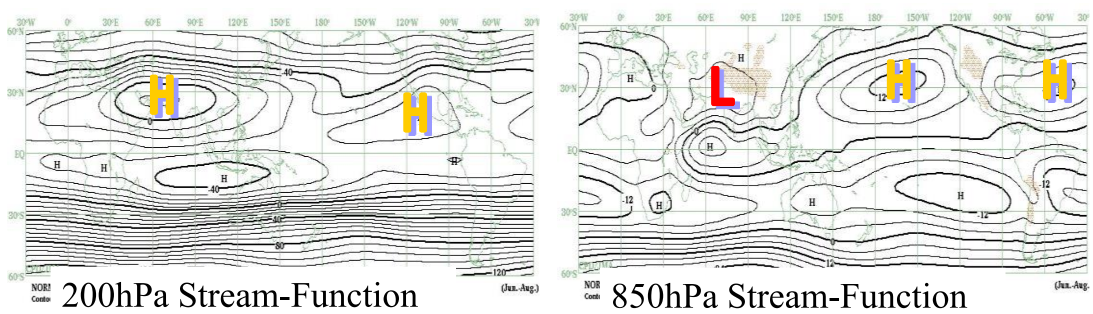


Fig. 7. (Left) 200hPa stream function and (right) 850hPa stream function in JJA.

Mountains have also impact on seasonal changes in local climate through thermal and dynamical processes. A good way to understand climate system is to modify or remove some elements of the climate system (Fig. 1). It is not easy to modify a real climate system of the Earth by changing the Earth orbit or removing mountains. Instead, we can easily modify virtual climate systems simulated numerically in climate models based on physics and other fundamental sciences. From the comparison between with/without mountain model experiments (Fig. 8), we can see that mountains would be responsible for the real world climate of humid summer and somewhat cold winter in the eastern parts of the continents.

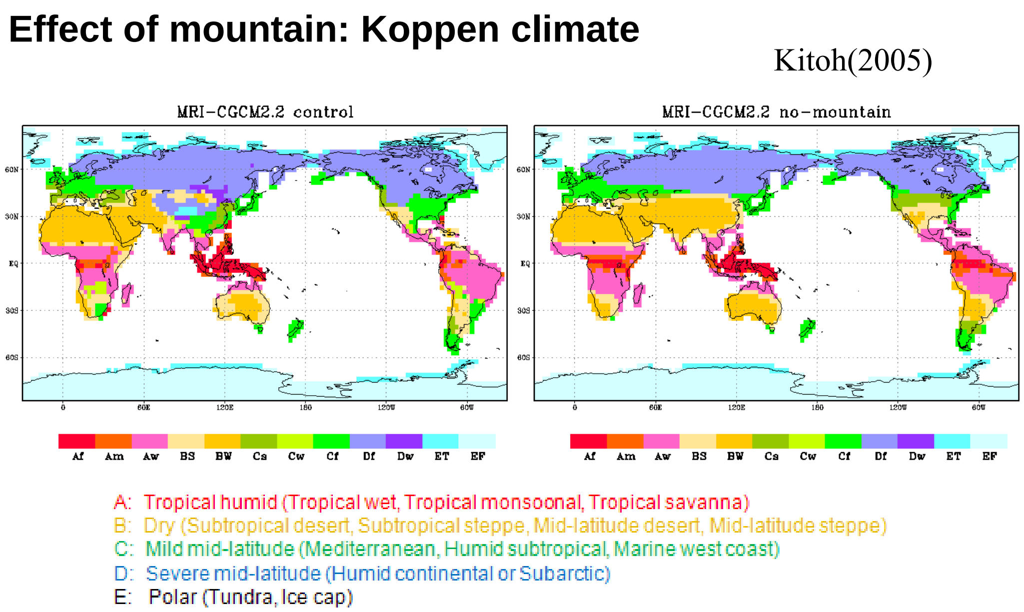


Fig. 8. Koppen climate maps simulated by a climate model (left) with mountains and (right) without mountains. From Kitoh (2005) in Japanese.

5. Intra-seasonal to Interannual variability

Climate varies naturally with time. Atmosphere itself includes internal instability mechanisms, typically the baroclinic instability around the extratropical westerly jets (Vallis, 2006). Therefore, atmosphere itself is considered as chaotic or unpredictable beyond a few weeks. However, there are some long-lived phenomena useful for one-month prediction. Blockings, large meanders of westerly jet in the mid-latitudes (Fig. 9), are maintained during a few days even to more than one week by the wave-mean flow interaction (Shutts, 1983), Some atmospheric low-frequency (>10days) teleconnections are analyzed such as wave patterns along the westerly jet waveguides (Fig. 10), which are consistent with the Rossby-wave propagation theory. Numerical ensemble predictions from many disturbed atmospheric initials are a reasonable tool to capture mean weathers in next few weeks.

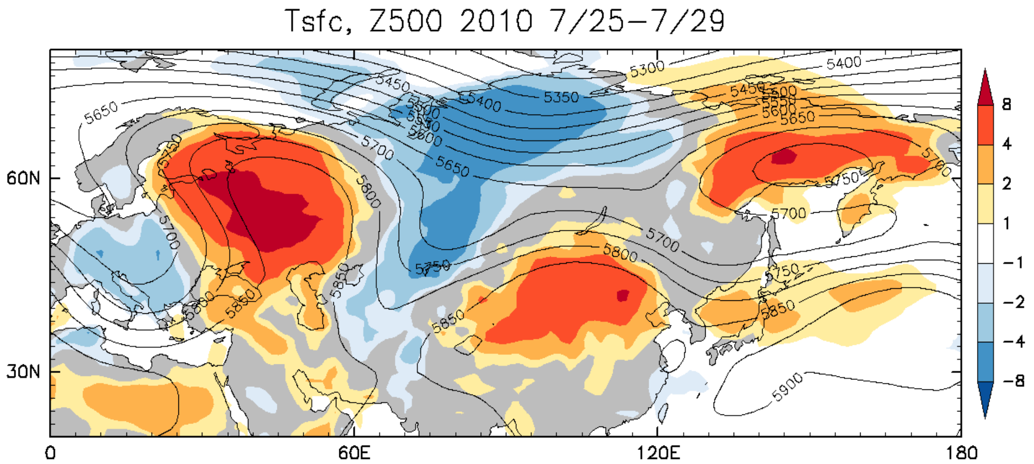


Fig. 9. Surface temperature anomalies (colors; Unit is K) and 500hPa geopotential height (contours; Unit is gpm) averaged during July 25 – 29 in 2010.

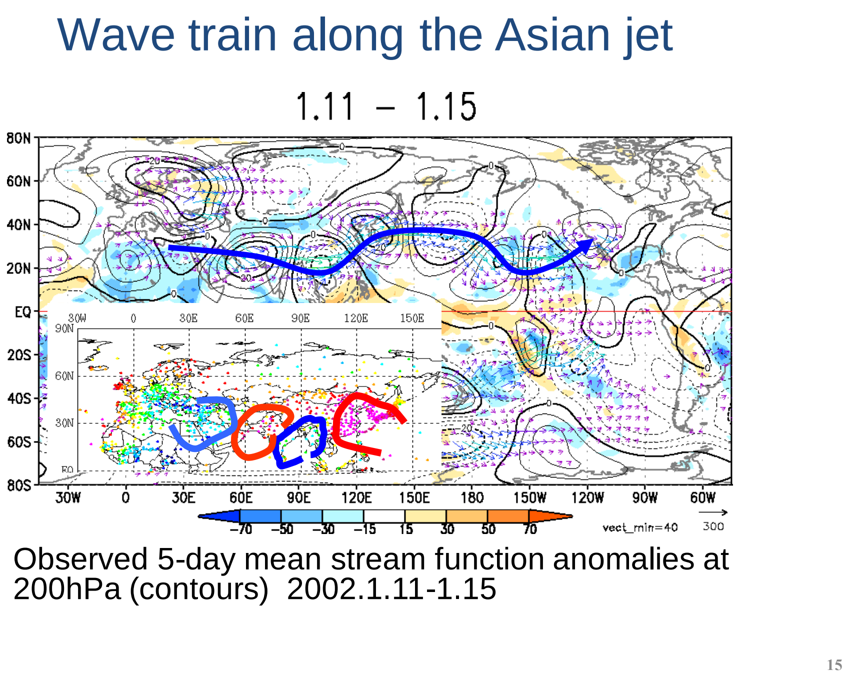
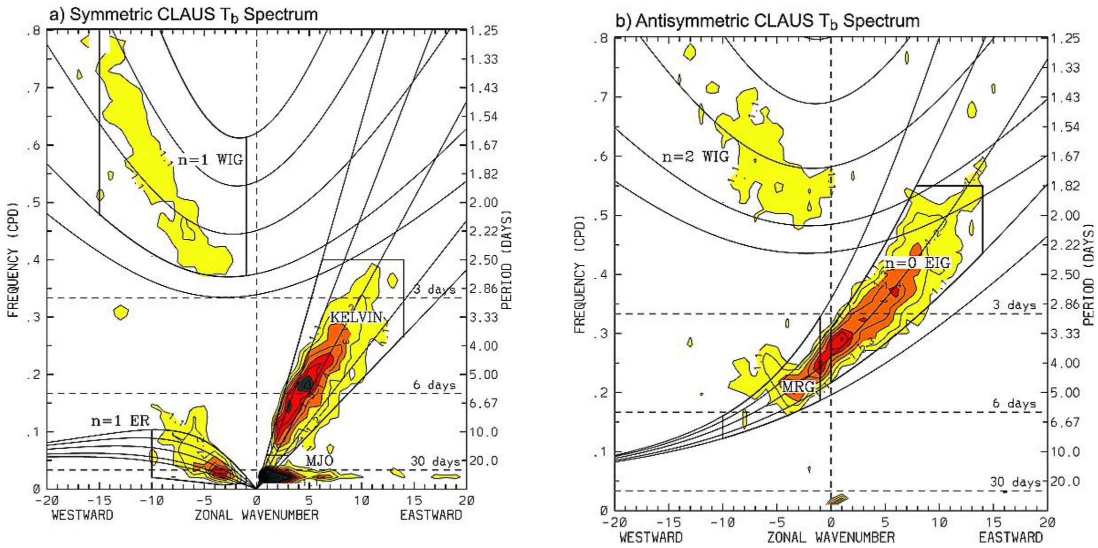


Fig. 10. (Larger) Observed 5-day mean stream function anomalies at 200hPa during Jan. 11-15 in 2002 (contours). Contour intervals are every 5 m^2 s^{-1}. (Smaller) Observed surface temperature anomalies during the same period.

In the tropics, some peaks in spatial and temporal power-spectrums, indicating organized atmospheric variability coupled with convective activity, are imbedded in red noise backgrounds. Weekly to intra-seasonal variabilities of outgoing longwave radiation (OLR) associated with equatorial waves, such as Kelvin waves, equatorial Rossby waves (ER) and mixed Rossby-Gravity waves (MRG), can be detected in Fig. 11 as well as the Madden-Julian Oscillation (MJO).



Wave number–frequency power spectrum of the (a) symmetric and (b) antisymmetric component of Cloud Archive User Services (CLAUS) T_b for July 1983 to June 2005, summed from 15° N to 15° S, plotted as the ratio between raw T_b power and the power in a smoothed red noise background spectrum (see WK99 for details). Contour interval is 0.1, and contours and shading begin at 1.1, where the signal is significant at greater than the 95% level. Dispersion curves for the Kelvin, $n = 1$ equatorial Rossby (ER), $n = 1$ and $n = 2$ westward inertio-gravity (WIG), $n = 0$ eastward inertio-gravity (EIG), and mixed Rossby-gravity (MRG) waves are plotted for equivalent depths of 8, 12, 25, 50, and 90 m. Heavy solid boxes represents regions of wave number–frequency filtering

Fig. 11. Spatial and temporal power-spectrums in the tropics of (left) symmetric and (right) asymmetric cloud variability about the equator. (From Kiladis et al. 2009)

The Madden-Julian Oscillation (MJO) is an eastward-moving oscillation of surface pressure, precipitation (or cloud) and winds along the equator with the period of 30-60 days and planetary scale wavenumbers (Fig. 11). Monitoring MJO or watching OLR and velocity potential anomalies may be very helpful for intra-seasonal prediction in the tropics to the subtropics and even in the mid-latitudes (Fig. 12). Improvement of MJO prediction skill is one of key topics for operational numerical prediction centers in the world.

The MJO and related OLR or convection anomalies are symmetry around the equator for the northern winter (Fig. 12 left) whereas those migrate northward toward Asian monsoon regions over the Indian Ocean and the western Pacific for the northern summer (Fig. 12 right).

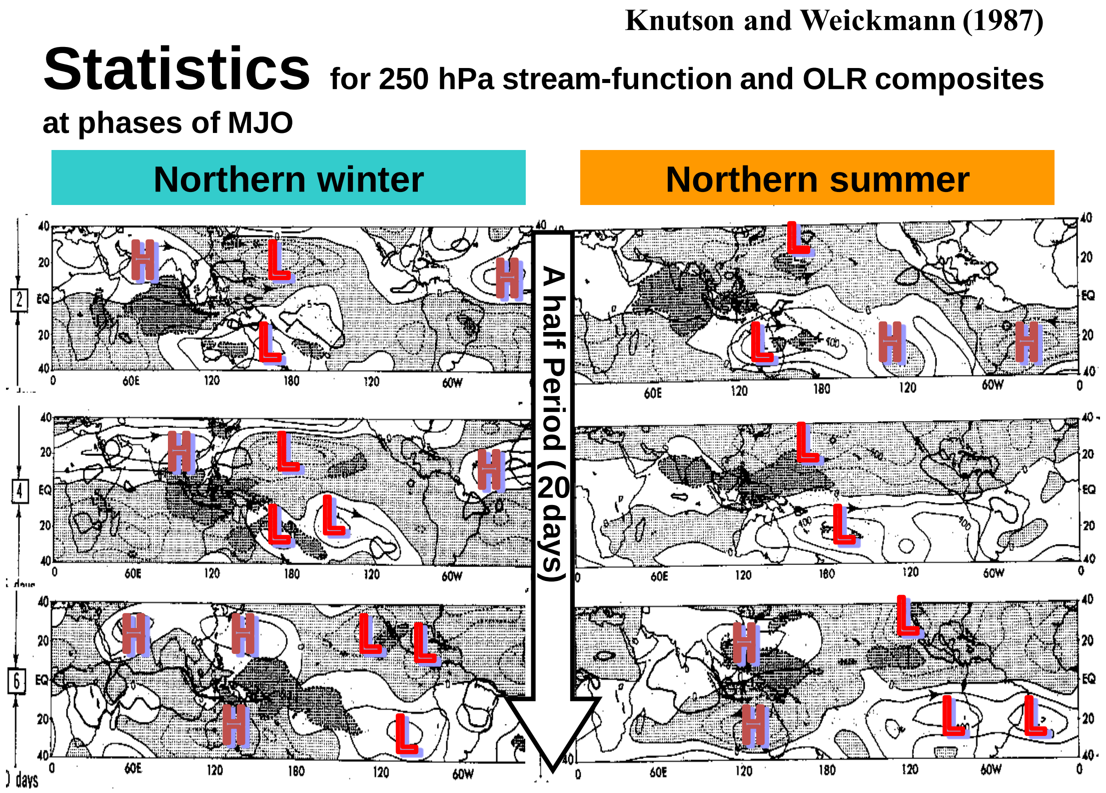


Fig. 12. Composite maps of OLR (shades) and 250hPa stream function anomaly (contours) at MJO phases (Left) for the norther winter and (right) for the northern summer (from Knutson and Weickmann 1987).

Atmosphere-ocean interactions are able to produce longer time-scale natural variability in atmosphere with periods beyond months up to several and decadal years. A typical example is ENSO (El Niño / Southern Oscillation) with the period of 2-7 years, which is the most dominant interannual climate variability in the climate system and has huge sociological and economic impacts globally. El Niño events themselves, and related surface air temperature and precipitation anomalies are predicted successfully on seasonal to inter-annual scales (Fig.13). The SST anomalies with El Niño tend to keep seasonally steady precipitation (heating) anomalies over the equatorial central Pacific. The response of the upper and lower-level tropical atmosphere to these steady heating anomalies can be explained based on forced equatorial waves or the Gill-pattern (or Matsuno-Gill pattern) (Fig. 14). These anomalous steady heating in the tropics forces modification of Walker circulation and occurrence of stationary Rossby waves in the tropics, which propagate to mid-latitudes and tend to cause extratropical teleconnection patterns such as the Pacific North America (PNA) pattern and the Western Pacific (WP) pattern.

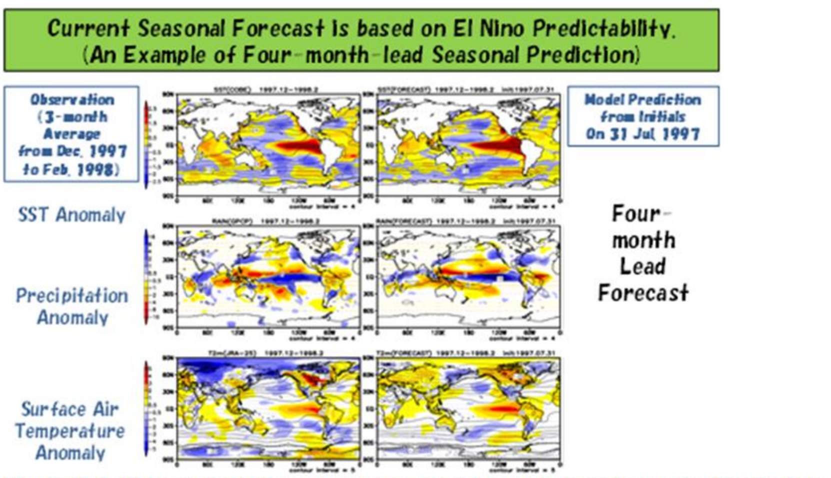


Fig. 13. (Left) observed SST, precipitation and surface air temperature anomalies for DJF 1997-98. (Right) the same except for four-month lead prediction.

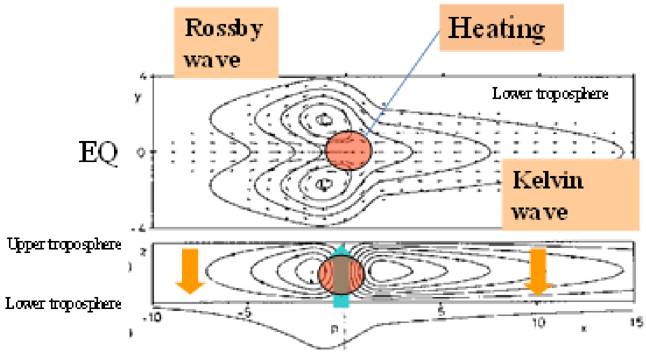


Fig. 14. Tropical atmospheric responses to equatorially symmetric heating anomalies. (from Gill 1980).

Recently, terms of “El Niño Modoki” or “Central Pacific (CP)-El Niño” are used to distinguish them from normal El Niño events or Eastern Pacific (EP)-El Niño. They consist of the equatorial Pacific phenomena with warm SST anomalies and enhanced precipitation in the central Pacific, and cold SST anomalies and suppressed precipitation in the eastern Pacific, on contrast. The remote effect of El Niño during the mature stage is stored in the Indian Ocean capacity and still influential to the Indo-western Pacific climate even during summer following the ENSO (Fig.15). A dipole mode with an east-west SST anomaly contrast sometimes occurs around September and October in the tropical Indian Ocean, which is at least partially independent from ENSO events (Fig. 16). Occurrence of this mode affects climate over various regions including tropical eastern Africa and the maritime continent.

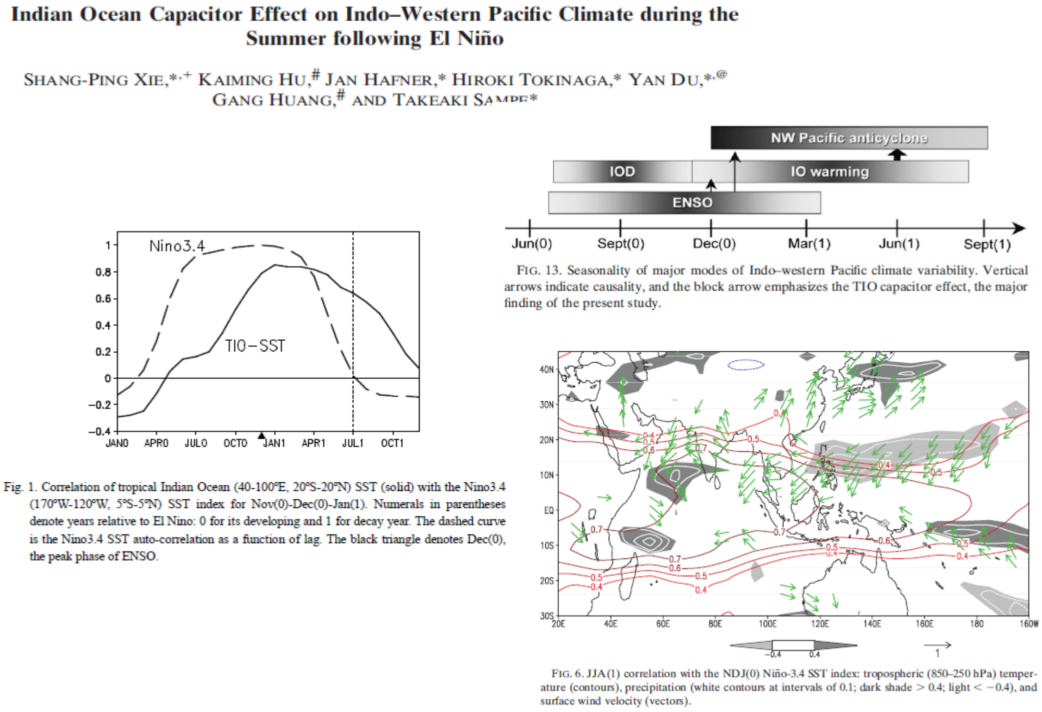


Fig. 15. Indian Ocean capacitor effect. (Left) lagged correlation of tropical Indian Ocean SST with Nino 3.4 SST for Nov(0)-Dec(0)-Jan(1). (Upper-right) seasonality of major modes. (Lower-right) correlation of the Nov(0)-Dec(0)-Jan(1) Nino3.4 SST with the following Jun(1)-July(1)-Aug(1) tropospheric temperature (contours), precipitation (shades) and surface wind (vectors). From Xie et al. (2009).

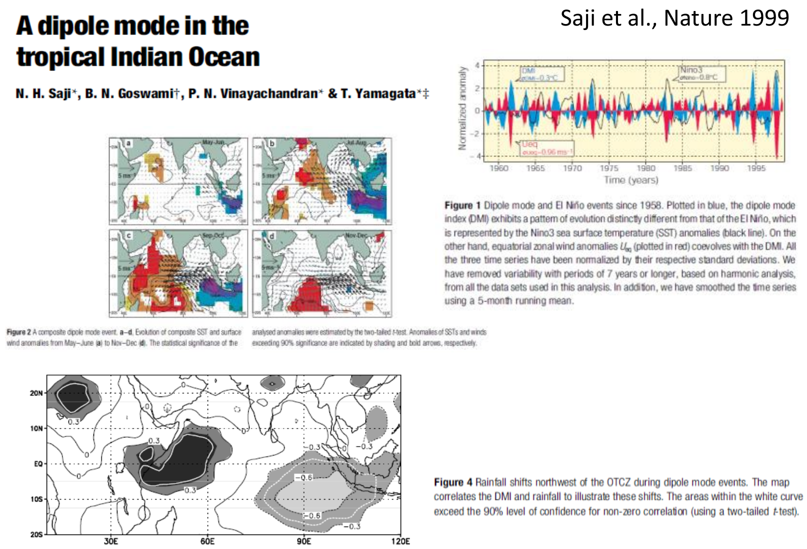
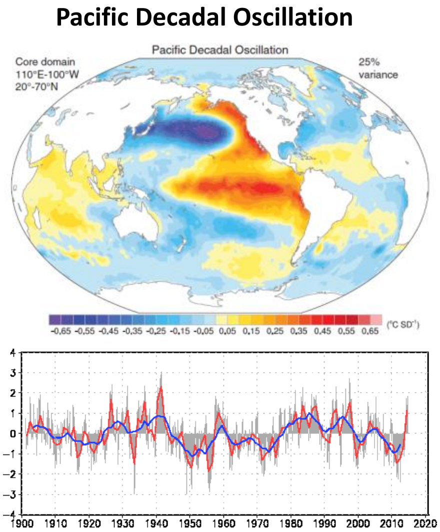


Fig. 16. A dipole mode in the tropical Indian Ocean. (Upper-left) time-evolution of the dipole mode SST anomaly, (lower-left) rainfall shift during the dipole mode, (right) historical records for dipole mode and El Niño events. From Saji et al. (1999).

6. Decadal variability

One of decadal variabilities is found in SST anomaly from the North Pacific to the tropics (Fig. 17) which is named Pacific Decadal Oscillation (PDO) or Interdecadal Pacific Oscillation (IPO). A possible mechanism of PDO is the subduction hypothesis; high latitudes' cold surface water is subducted in the North Pacific and flows into the subtropical deeper ocean along the surfaces of constant density, and then emerges again to the surface of the equatorial Pacific by upwelling (Deser et al. 1996).



Trenberth and Fasullo (2013)

PDO index (From JMA HP)

Fig. 17. (Upper) SST anomaly pattern in the positive phase of Pacific Decadal Oscillation (PDO)(from Trenberth and Fasullo, 2013) and (lower) PDO index (from http://ds.data.jma.go.jp/tcc/tcc/products/elnino/decadal/pdo.html).

This is consistent with the analysis showing that the decadal SST variability in the central North Pacific spreads into the deep ocean. PDO has impact on ENSO characteristics and regional climate on decadal scales. Several studies indicated that the negative phase of PDO played the major role in the slowdown of the global averaged surface air temperature raise in recent years (Meehl, 2015).

7. Global warming

Human activity also changes external conditions of the climate system, typically the increase of greenhouse gases which lead to warmer climate. The influences of global warming appear not only in global mean temperature but also in local precipitation, sea-level, tropical cyclones and weather extremes including extreme precipitation rate and consecutive dry days (Fig.18).

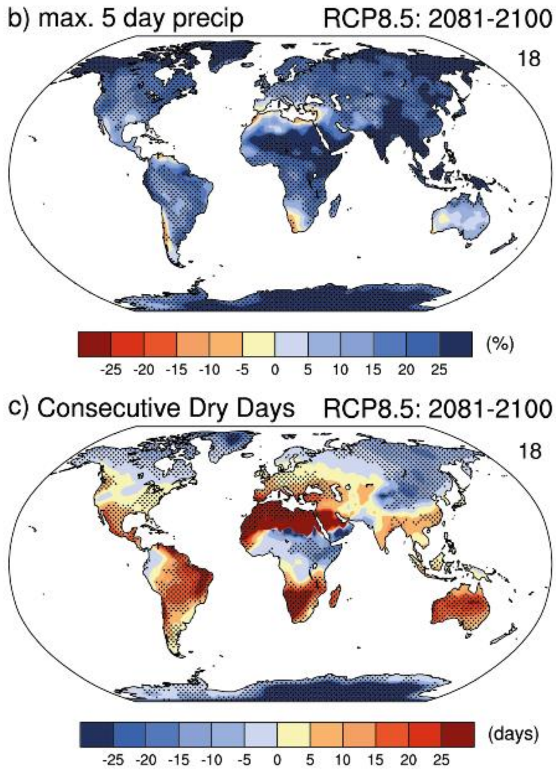


Fig. 18. (Upper) projected percent changes of the annual maximum five-day precipitation accumulation over the 2081-2100 in the RCP8.5 scenario relative to the 1981-2000 from the CMIP5 models and (lower) the same as the upper figure expect for the annual maximum number of consecutive dry days when precipitation is less than 1 mm/day. Stippling indicates gridpoints with changes that are significant at 5% level using a Wilcoxon signed-ranked test. (From WGI_AR5_Fig12-26b and c).

8. Summary

Unusual weather and climate are attributed to unusual atmospheric flows, storms and convective disturbance. Diagnostic analysis shows that those disturbances are often related to atmospheric intrinsic waves and phenomena. Numerical ensemble predictions from many disturbed atmospheric initials are a reasonable tool to capture mean weathers in next few weeks.

However, atmospheric environment is maintained and influenced by other elements consisting of the climate system. Unusual and steady convective activity is sometimes connected to long-term SST anomalies related to ocean variability. Numerical ensemble atmosphere-ocean simulations starting from many disturbed atmospheric and oceanic initials are a reasonable tool to capture the mean state of weathers and climate in a timescale from weeks to seasons.

Radiative processes including longwave absorption by greenhouse gases and shortwave reflection by snow, ice, clouds and aerosols determine the local Earth's ground temperature. The distribution of ground temperature is influential to vertical and horizontal atmospheric and oceanic stabilities, the amount of water vapor and the speed of water cycle. Then, those can affect atmospheric and oceanic flows, the features of storms and convections and eventually our daily lives. Therefore, we need to continue careful watches and diagnostics for global and local climate systems (Fig.1), as well as its decadal to historical predictions using the Earth or climate system models starting from many disturbed oceanic initials.

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One-month Forecast

One-month Forecast

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Tokyo Climate Center (TCC)/
Climate Prediction Division of
Japan Meteorological Agency (JMA)

Outline

- Introduction
- Predictability and Ensemble Prediction
- Signal for 1-month Forecast
- Seasonal Forecast in Japan
- Procedure of 1-month Forecast

Introduction

Classification of Meteorological Forecasting
(WMO GDPFS Manual)

	Forecasting target period
Nowcasting	Up to 2 hours
Very short-range weather forecasting	Up to 12 hours
Short-range forecasting	Beyond 12 hours and up to 72 hours
Medium-range weather forecasting	Beyond 72 hours and up to 240 hours
Extended-range weather forecasting	Beyond 10 days and up to 30 days
Long-range forecasting	Beyond 30 days up to two years
Climate forecasting	Beyond two years

Target of this seminar

Manual on the Global Data-processing and Forecasting System, Appendix I-4
(https://www.wmo.int/pages/prog/www/DPFS/documents/485_Vol_I_en_colour.pdf)

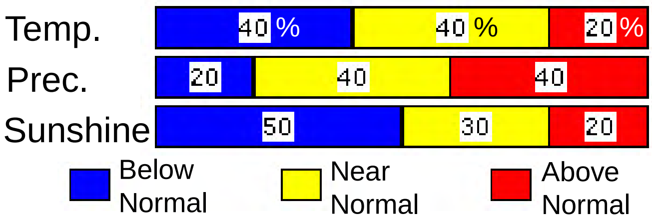
Short/Long Range Forecasts

Short range forecast

Date	30 Tue	31 Wed	1 Thu	2 Fri	3 Sat	4 Sun	5 Mon
Tokyo Daily Forecast							
Probability of precipitation (%)	0/0/20/20	20	60	60	30	10	10
Reliability	/	/	B	C	A	A	A
Tokyo High (°C)	7	7 (6 – 9)	5 (3 – 7)	6 (4 – 9)	8 (7 – 11)	8 (6 – 11)	7 (5 – 8)
Tokyo Low (°C)	0	1 (-1 – 2)	1 (-1 – 2)	2 (0 – 4)	1 (0 – 3)	1 (-1 – 2)	0 (-1 – 2)

- Forecasting the actual weather parameters (e.g., weather, temp.)
- Deterministic forecast

Seasonal forecast



Above example shows a forecast in 3 categories: **Below**, **Near** and **Above normal**.

Probabilities of both below and near normal temp. are **40%**, and above normal temp. is **20%**.

- Forecasting deviation from the climatological normal in categories (Not actual temp. or precip.)
- Probabilistic forecast (Not forecasting which category will happen, but forecasting probabilities of occurrence for each category)

Anomaly

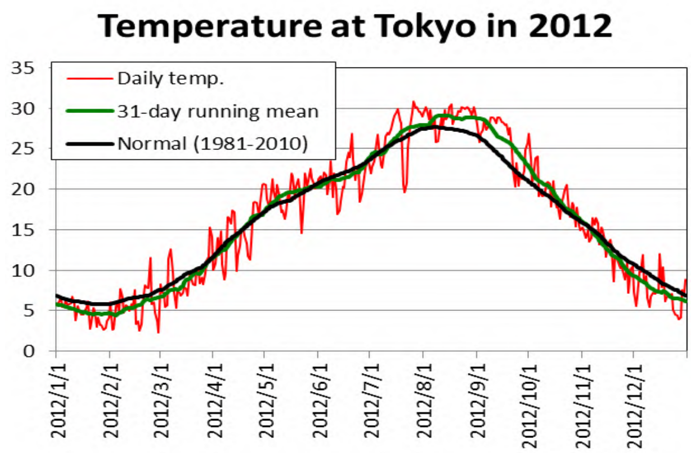
Normal: Defined as 30-year average for 1981 – 2010

Anomaly: Deviation from the normal

[Anomaly] = [Actual Value] – [Normal]

- Weather condition changes from year to year (interannual variability)
- Anomalous climate may affects the lives of society (e.g., drought, flood, and hot spell)

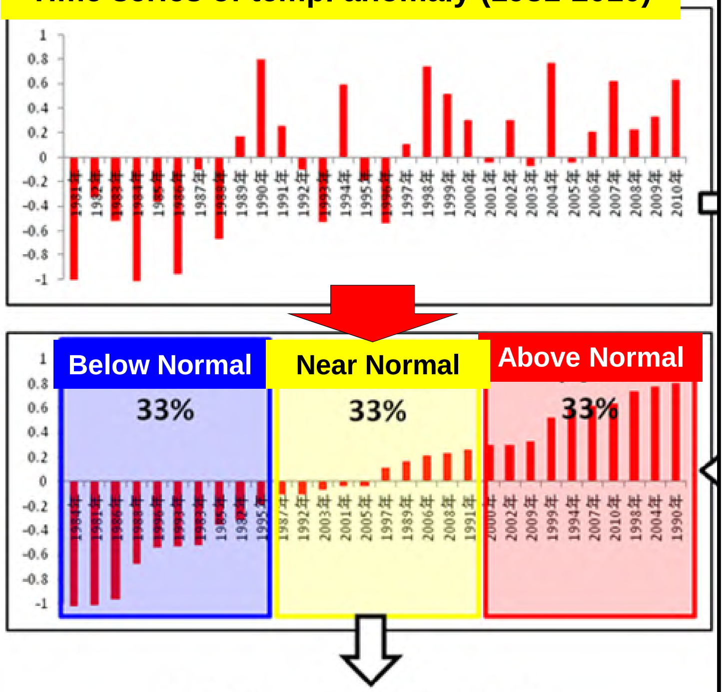
Anomaly is the target of seasonal forecasting.



Forecast Category

- JMA conducts seasonal forecast in **3 categories**: **<u>Above</u>**, **<u>Near</u>**, and **<u>Below Normal</u>**
- Arranging historical data for 30-year (e.g., 1981-2010) in ascending order,
  - 1 - 10th: **Below Normal**
  - 11 - 20th: **Near Normal**
  - 21 - 30th: **Above normal**

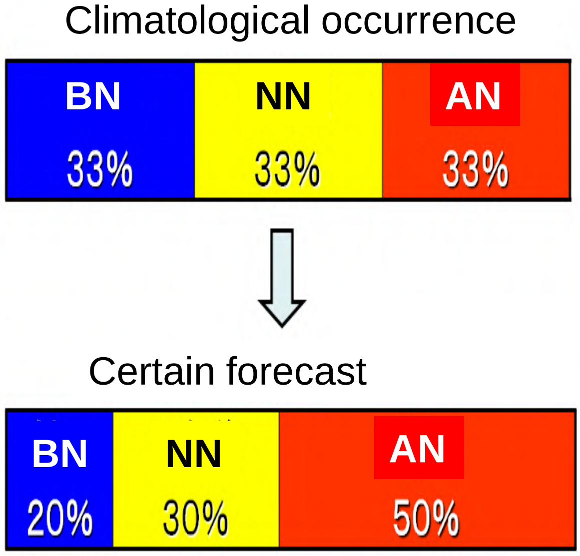
Time series of temp. anomaly (1981-2010)



Range of Near normal: -0.1 to +0.3 ℃

3-category Probabilistic Forecast

- In the seasonal forecast probability for each category is predicted.
- Occurrence rate for each category is expected 33% in climatology.
- In certain forecasting, deviation from the climatological occurrence is important.

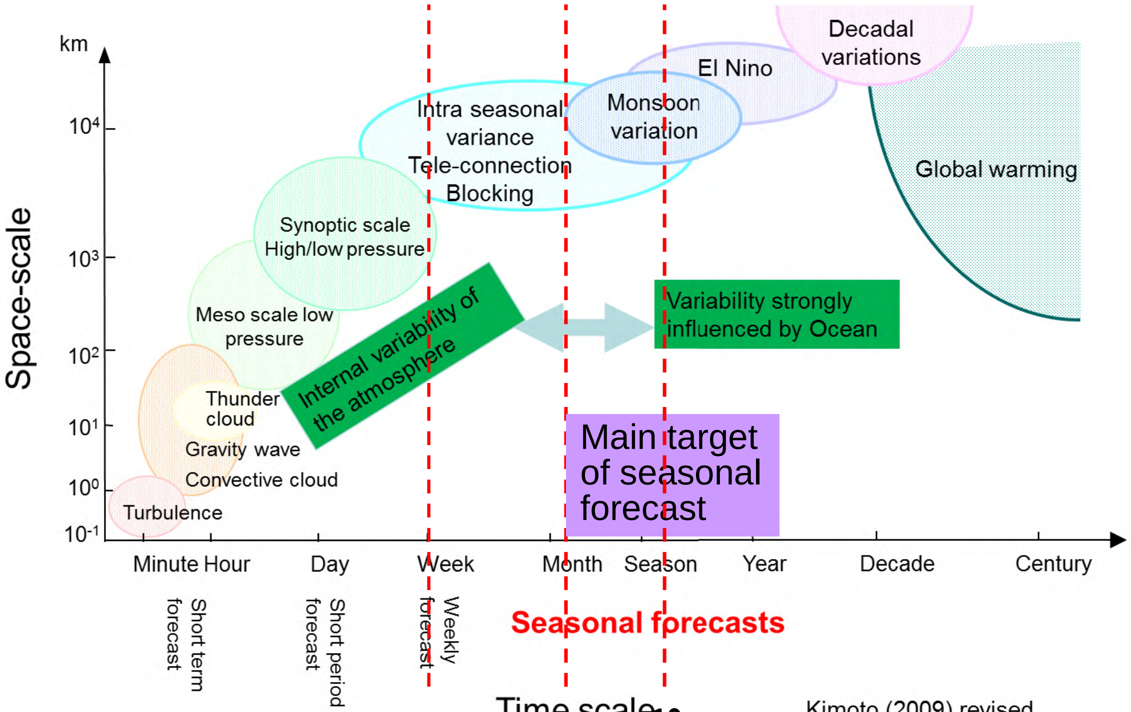


This forecast shows that above normal is ***more likely*** (50%), and below normal is ***less likely*** (20%) to occur than expected in climatology (33%).

Predictability and Ensemble Prediction

Multiple Structure of Atmospheric Phenomena

- Variations in atmosphere consist various space- and time-scale phenomena.
- Targets for seasonal prediction are phenomena with large time- and space-scale (over about a week).



Kimoto (2009) revised

Signal and Noise for Each Kind of Forecast

Green boxes show signal for short-range forecast and noise for one-month forecast

Kind of forecast	**Signal**	**Noise**
Medium-range (One-week forecast)	Shortwave disturbance dominating over daily variations of weather	
Extended –range (One-month forecast)	Low-frequency variation of atmosphere (meanderings of the jet, blocking, AO, MJO and so on)	Transient eddies (moving high, low)
Long-range (Three-month, Warm/Cold season forecast)	Low-frequency variation of tropical ocean and its influence, such as ENSO and Indian Ocean variation	Low-frequency variation of atmosphere

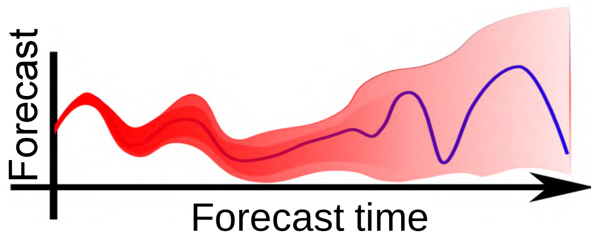
Blue box shows signal for seasonal forecast

Red boxes show signal for one-month forecast and noise for seasonal forecast

Noise can be reduced by time average (e.g., 1-month mean)

Chaos in Atmosphere

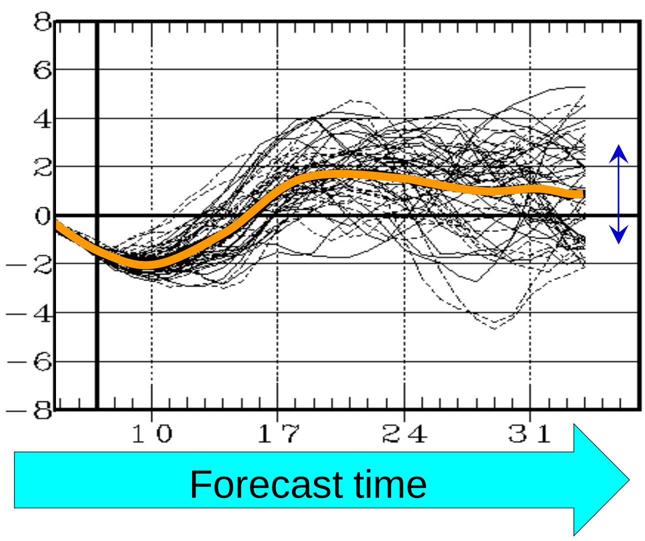
- Due to chaotic behavior of atmosphere, errors rapidly grow during period of prediction.



- To address this issue, ensemble prediction is essential for long-range forecasting.

Ensemble Prediction

In **ensemble prediction**, the model is run many times from very slightly different initial conditions.



Ensemble Member = Individual solutions

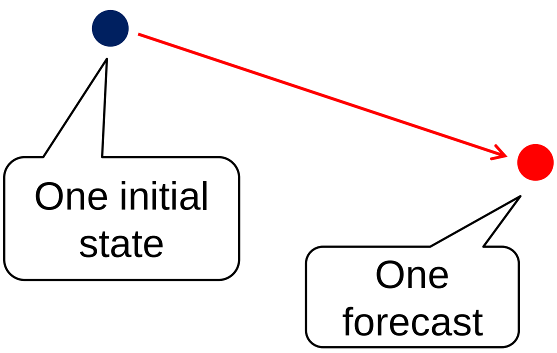
Ensemble spread = Standard dev. among members, suggesting degree of **uncertainty**

Ensemble mean = Average of ensemble members, suggesting degree of **signal**

- Ensemble mean is statistically better than each member.
- The more the number of members is, the better the prediction is.

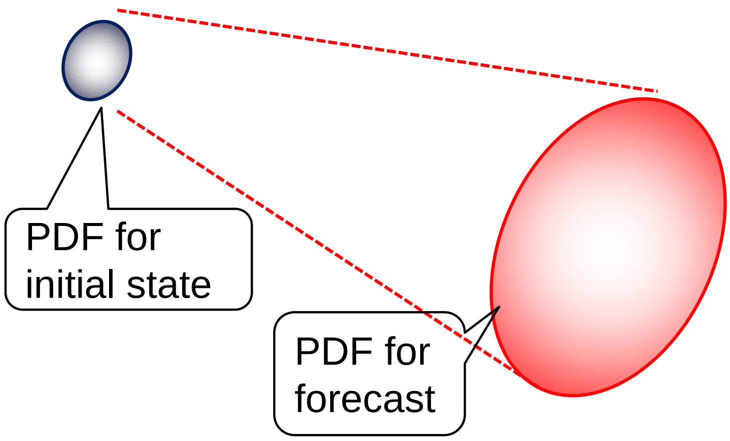
Deterministic and Probabilistic Forecast

Deterministic forecast



Calculate one forecast using one initial state

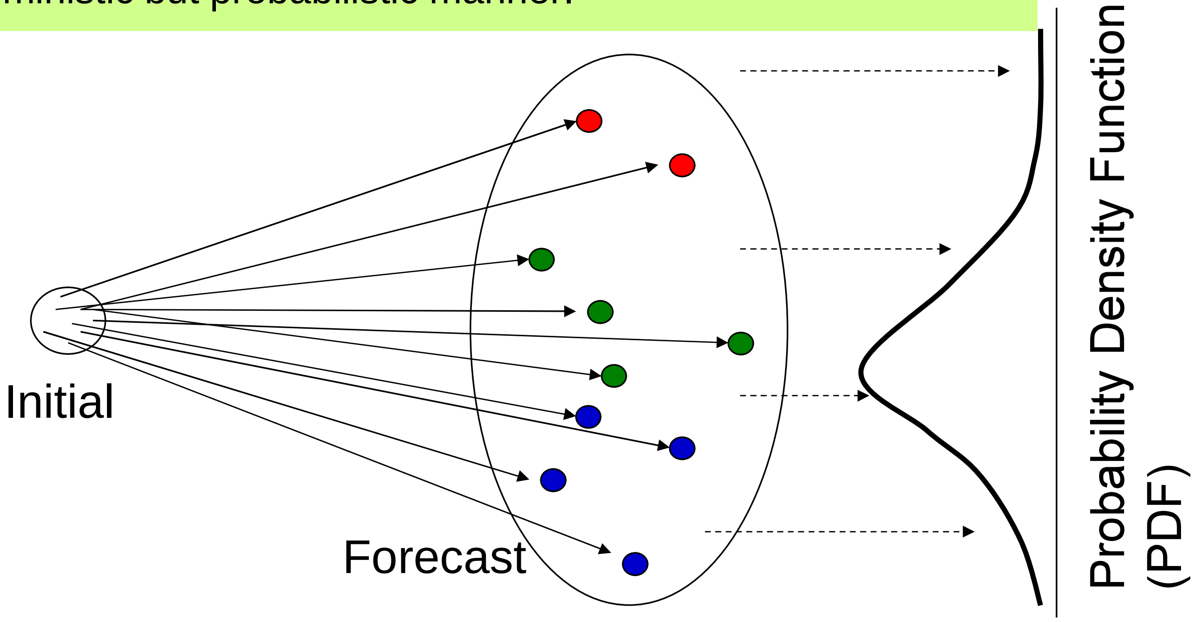
Probabilistic forecast



- EPS derives PDF for forecast.
  - ➢Possible to predict probability of the targeted phenomena, which add degree of reliability to deterministic forecasting.

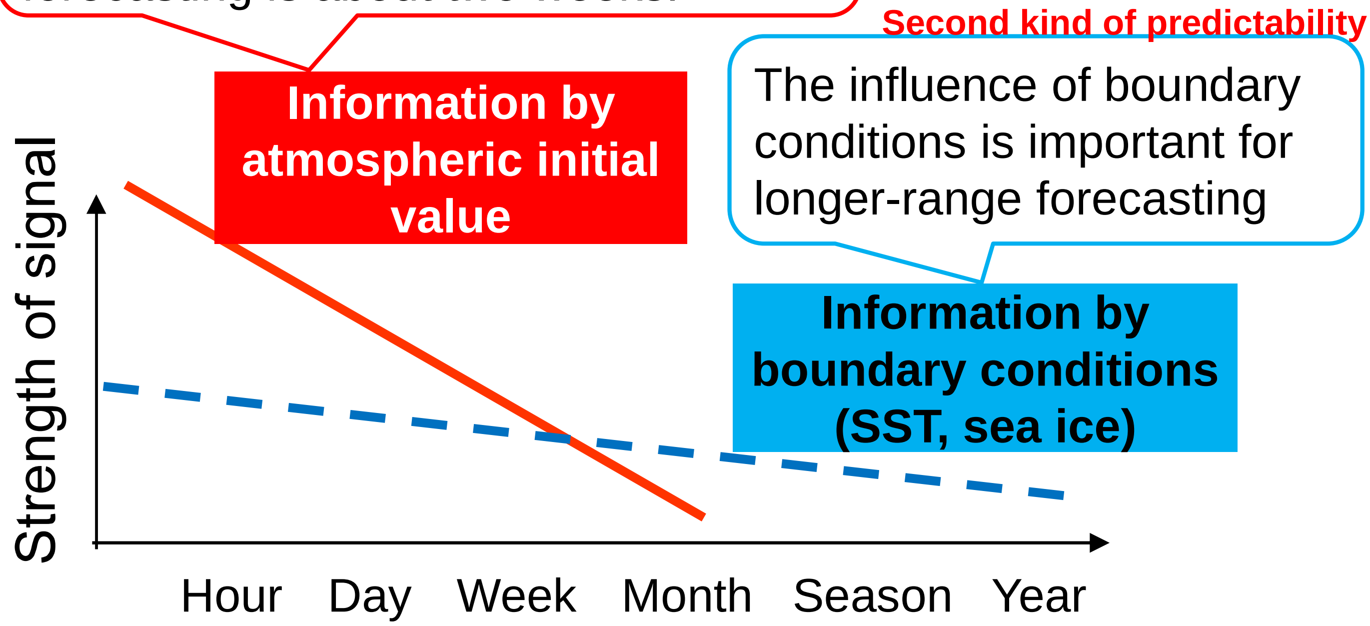
Probabilistic Forecast

- Ensemble prediction system (EPS) enables to derive PDF from the distribution of individual members.
- This denotes that long-range forecast is possible with not deterministic but probabilistic manner.



Initial and Boundary Condition

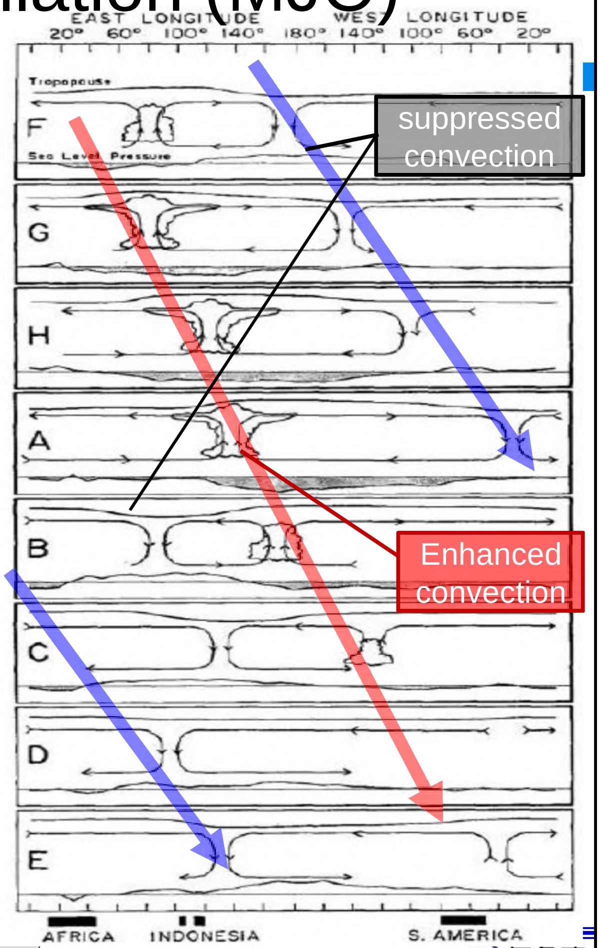
Due to the chaotic nature of the atmosphere, the limit for deterministic forecasting is about two weeks.



Signal for One-month Forecast

Madden-Julian Oscillation (MJO)

- Most dominant mode over the tropics in extended range timescale
- MJO propagates eastward along the equator with periods of 30 – 60 days
- A large-scale coupled pattern between deep convection and atmospheric circulation
- Clear signal of convection is seen over the Indian Ocean and the western Pacific
- Its convective activity makes an impact on mid-high latitude through the meandering of the jet stream
- MJO is monitored with 200hPa velocity potential (upper-level divergence) field
- Possible to predict its evolution up to 2-3 weeks (Important signal for 1-month forecast)

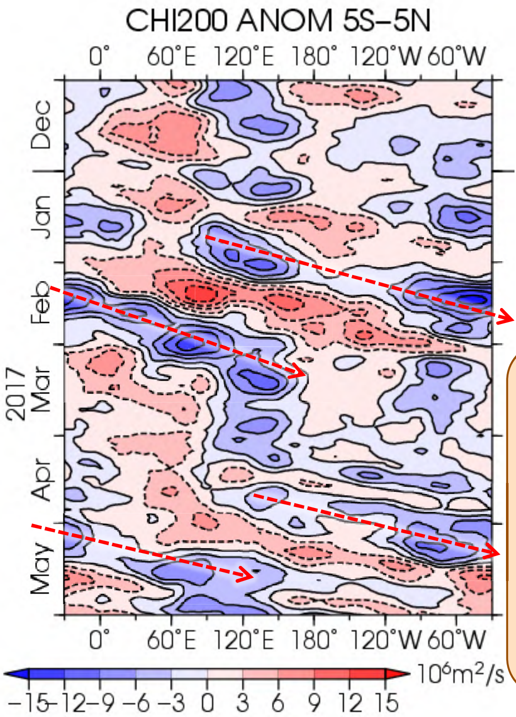


Original; Madden and Julian (1972) Fig.16

Monitoring of MJO

http://ds.data.jma.go.jp/tcc/tcc/products/clisys/mjo/moni_mjo.html

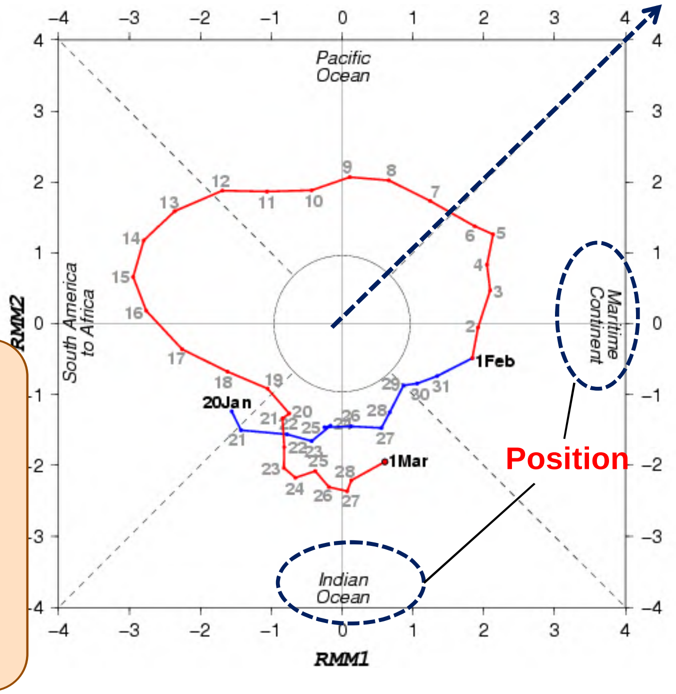
Time-longitude section of **chi200** anomaly along the EQ.



Blue: Upper-level Divergent anomaly
Red: Convergent anomaly

MJO's phase and amplitude diagram

Amplitude: distance from the center

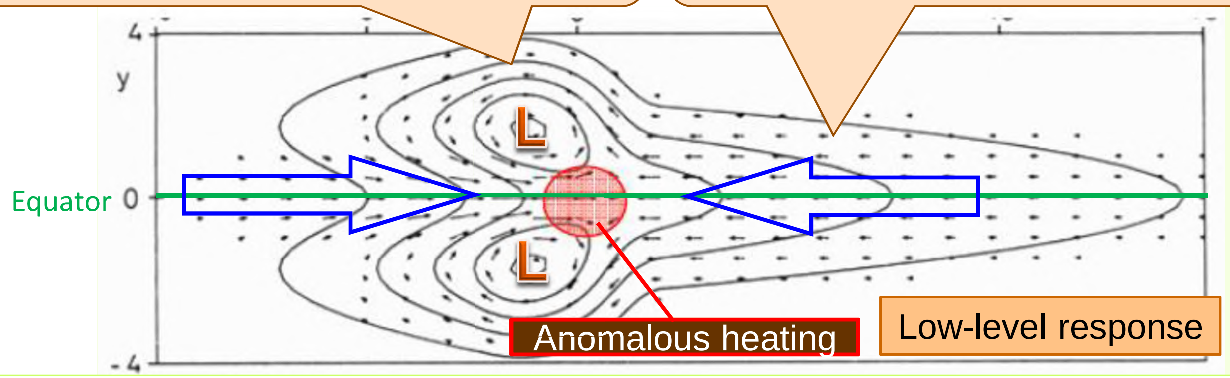


Matsuno-Gill pattern

Basic features of the response of the tropical atmosphere to convective activity (heating).

A pair of cyclonic circulation straddling the equator on the western side of the heating (equatorial Rossby wave).

Low pressure and easterly winds along the equator east of the heating (equatorial Kelvin wave).

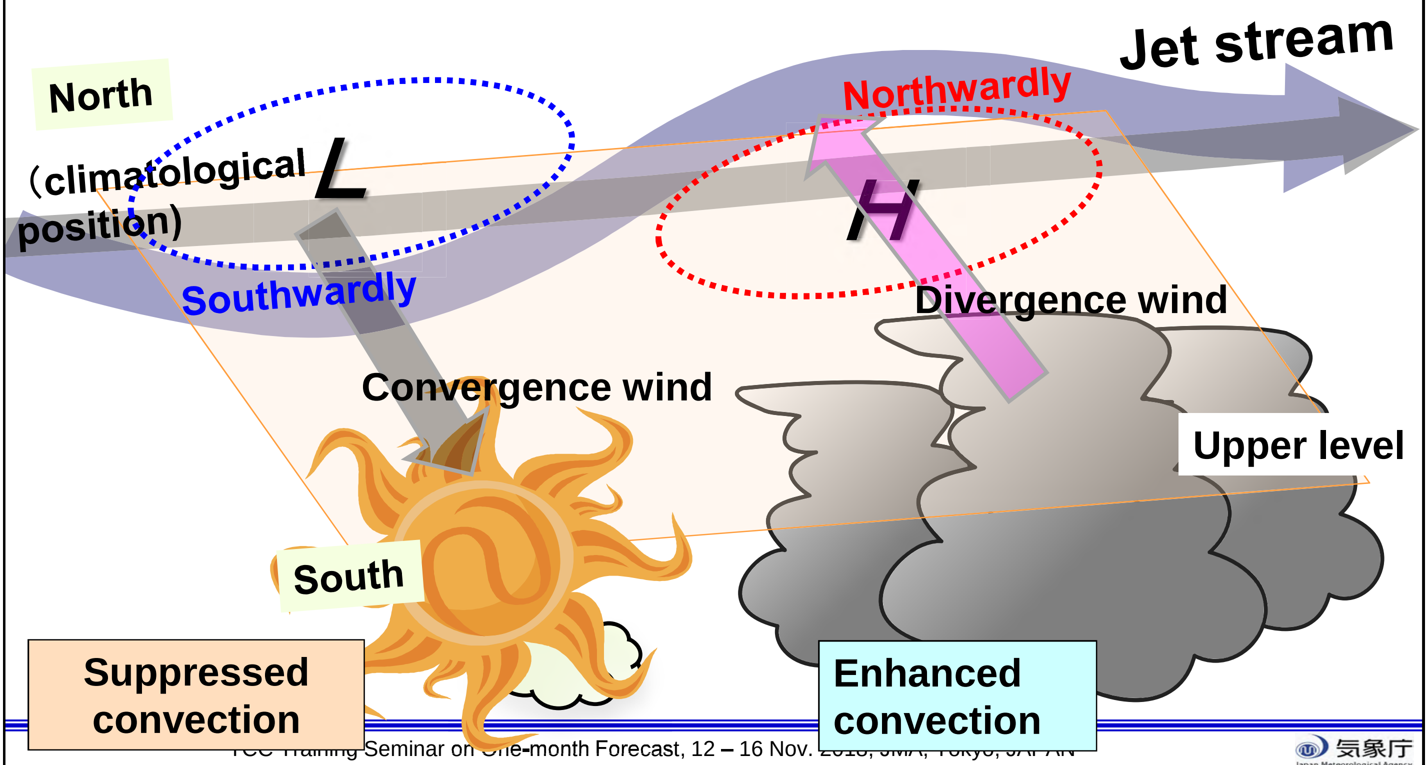


Atmospheric response in the lower troposphere to the heating symmetric about the equator
Contours indicate perturbation pressure, and vectors denote velocity field.
Red circle indicates the position of the heating. (Source: Gill 1980)

Upper-level response shows the reverse of the low-level response.

Meanderings of jet stream by anomalous convections

Shifted **northwardly** (north side of enhanced convections)
Shifted **southwardly** (north side of suppressed convections)



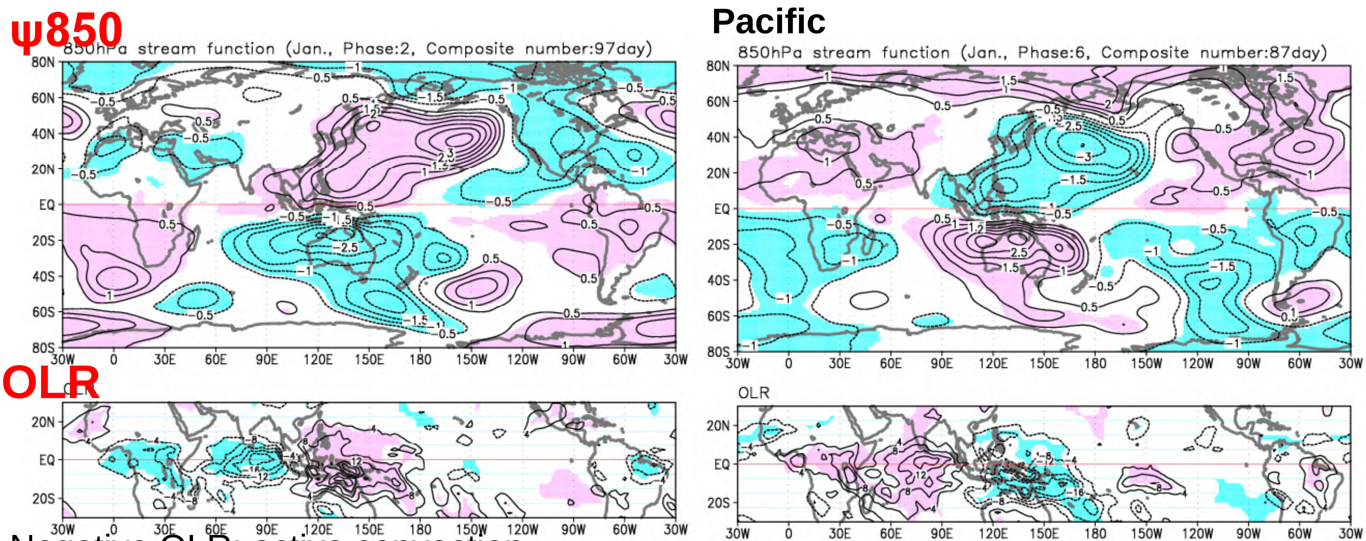
Atmospheric Response to MJO

http://ds.data.jma.go.jp/tcc/tcc/products/clisys/mjo/composite.html

Composite maps for each MJO phase in January

Phase 2: Active in the Indian Ocean

Phase 6: Active in MC – the western Pacific



Negative OLR: active convection

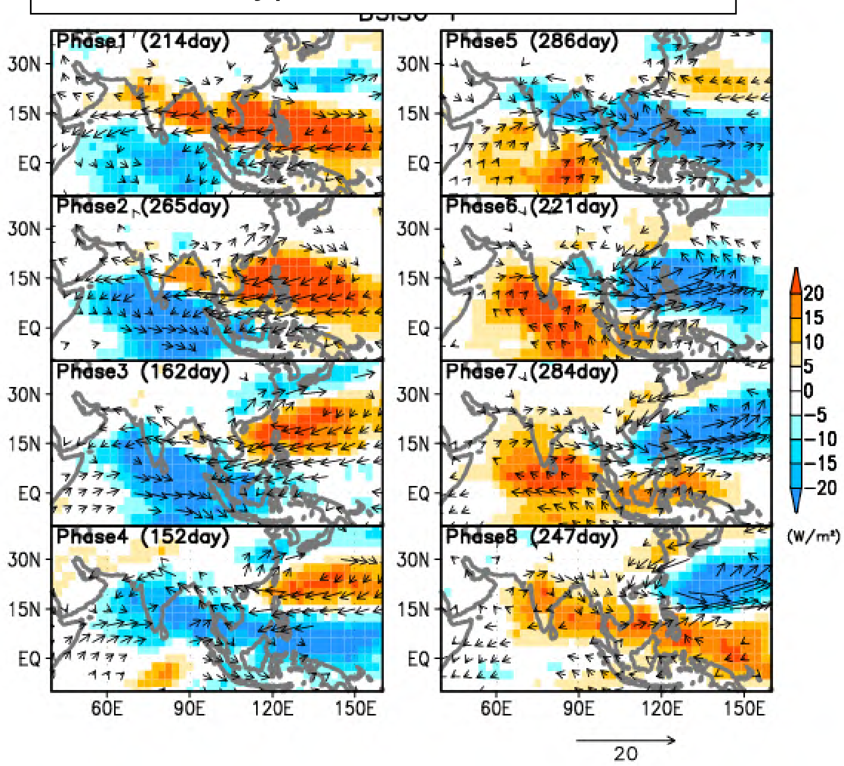
Response is dependent on season and the position of MJO

BSISO

- In boreal summer, northward propagation is also seen over the Indian Ocean and the western Pacific
- BSISO hugely affects the Asian monsoon activity

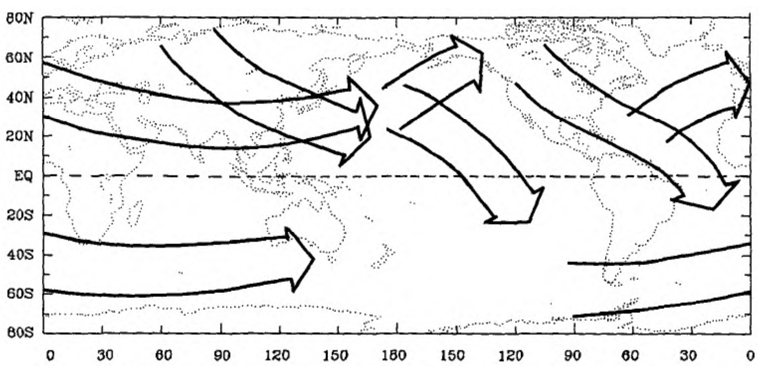
Blue: Negative OLR (active convection)
Red: Positive OLR (inactive convection)
Arrows: 850-hPa wind

One of the typical evolutions of BSISO



Quasi-stationary Rossby Wave

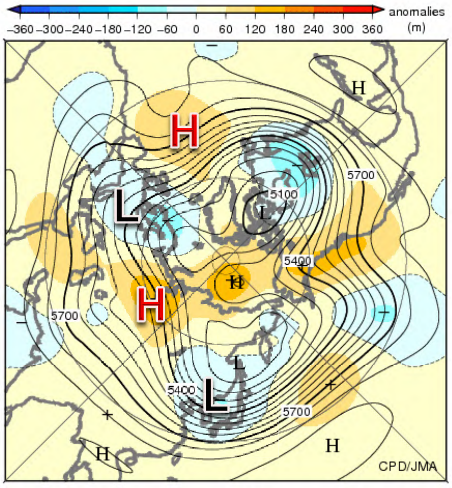
- Meandering of the westerly wind often persists for more than a week due to (quasi-)stationary Rossby wave.
- Stationary Rossby wave often causes extreme weather (ex. hot/cold spell, drought…)
- The wave energy propagates eastward often along the sub-tropical and polar front jet streams (teleconnection).
- Stationary Rossby wave is one of the important phenomena in 1-month forecast.



Typical path of Rossby wave energy propagation

(Hsu and Lin, 1992)

Quasi-stationary Rossby Wave

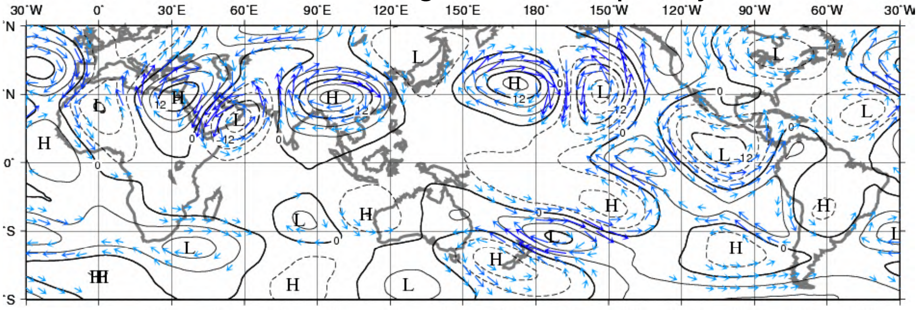


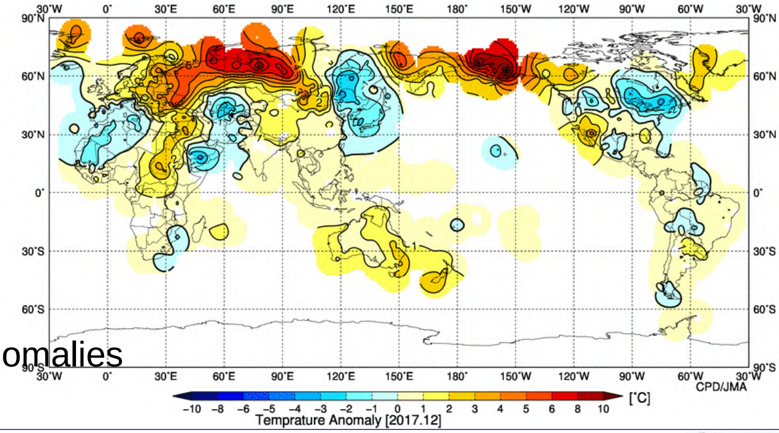
Z500 in Dec. 2017

Rossby wave trains are seen along the polar front jet stream

200-hPa stream function anomaly in Dec. 2017

Wave trains are seen along the sub-tropical jet stream



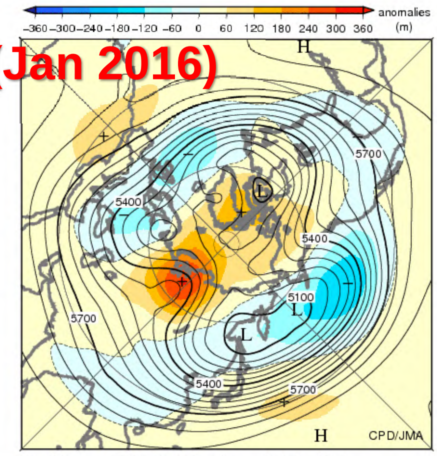


Monthly mean temperature anomalies in Dec. 2017

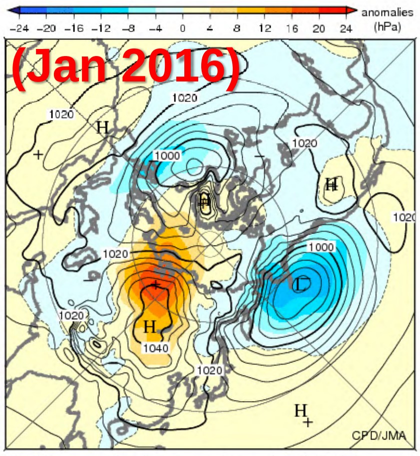
Eurasia (EU) Pattern

- The EU pattern is shown as a Rossby wave train along the polar front jet stream.
- The positive EU pattern is associated with an enhanced ridge over Siberia and intensification of the Siberian High.
- Hence the positive EU is often connected to a cold air outbreak and leads to an unusually freezing episode over East Asia and sometimes Southeast Asia as well.

Z500 (Jan 2016)



SLP (Jan 2016)

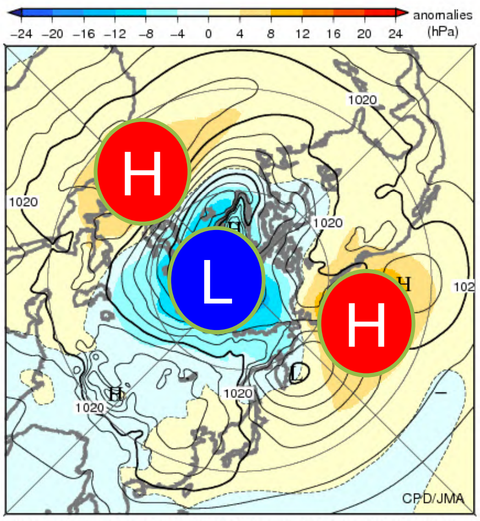


Arctic Oscillation (AO)

- Meridionally asymmetric anomalies pattern of pressure (temperature) between arctic and mid-latitudes
- most dominant variations in the boreal winter
- ➢ Once the AO happens, it may persist and its influence may become large.

SLP anomalies (1988/89 DJF)

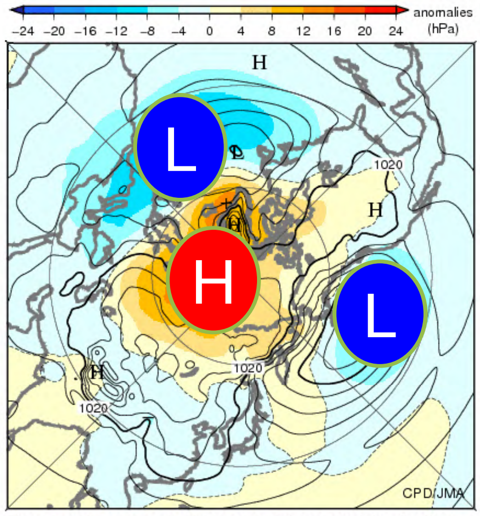
+AO



Three month mean sea level pressure and anomaly in the Northern Hemisphere (Dec.1988–Feb.1989)
The contours show sea level pressure at intervals of 4 hPa.
The shading indicates sea level pressure anomalies.

SLP anomalies (2009/10 DJF)

-AO



Three month mean sea level pressure and anomaly in the Northern Hemisphere (Dec.2009–Feb.2010)
The contours show sea level pressure at intervals of 4 hPa.
The shading indicates sea level pressure anomalies.

One-month Forecasts in Japan

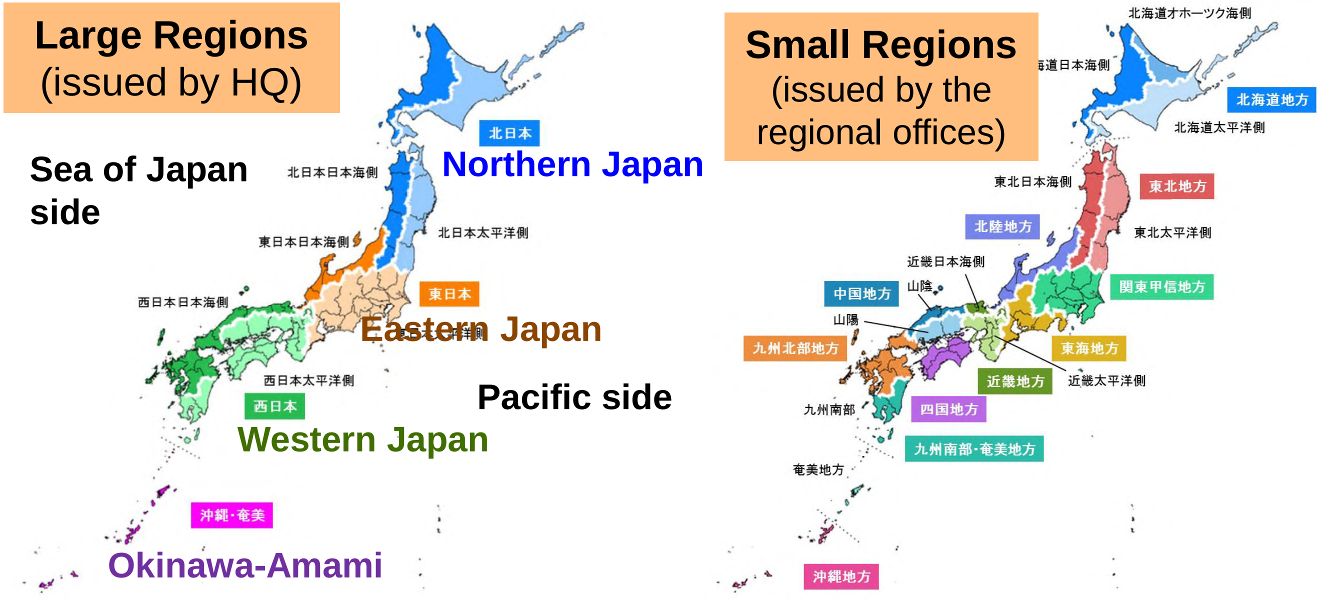
Japan's seasonal forecast started in 1942 for the purpose to reduce agricultural damages associated with cooler summers.

Seasonal Forecast at JMA

	Date of issue	Forecast Period	Forecast Item
1-month Forecast	Every Thursday	1-month mean	Temperature, Precipitation, Sunshine, Snowfall
		Weekly mean (1st, 2nd, 3rd-4th week)	Temperature
3-month Forecast	Around 25th of every month	3-month mean,	Temperature, Precipitation, Snowfall
		Monthly mean (1st, 2nd, 3rd month)	Temperature, Precipitation
Warm Season Forecast	Around 25 Feb.	3-month mean (Jun. – Aug.)	Temperature, Precipitation
		Rainy season (Jun. – Jul.)	Precipitation
Cold Season Forecast	Around 25 Sep.	3-month mean (Dec. – Feb.)	Temperature, Precipitation, Snowfall

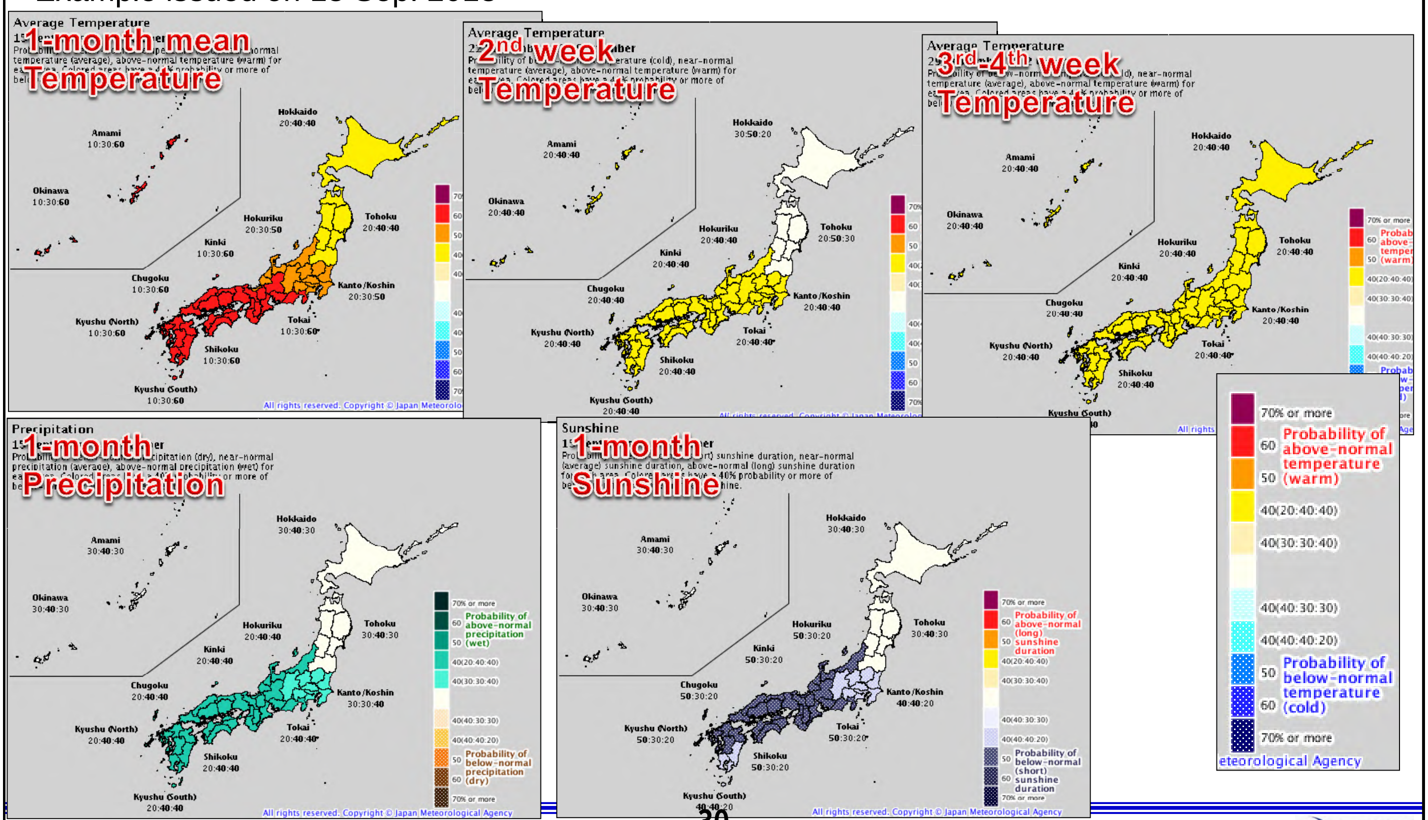
Forecast Region

- Forecast is issued for sub-regions divided based on the climate characteristics.



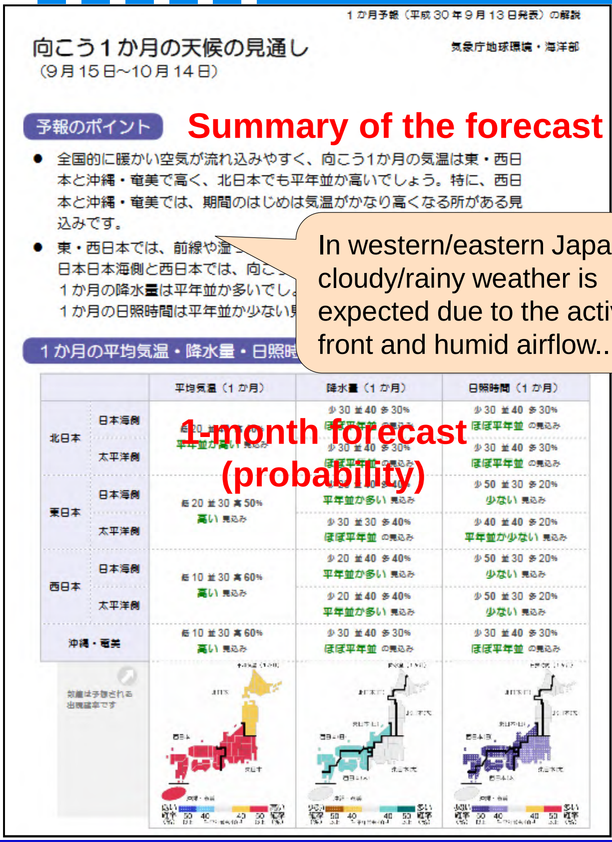
One-month Forecast

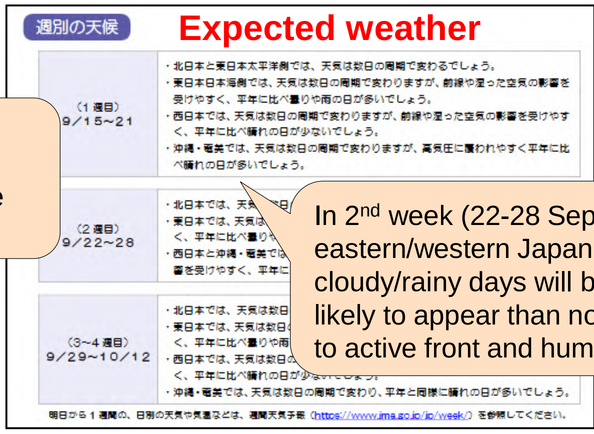
Example issued on 13 Sep. 2018

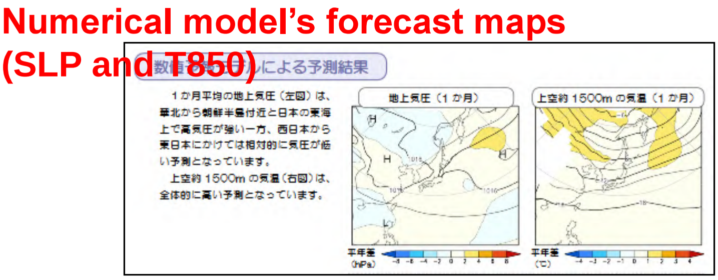


Commentary on One-month Forecast

Commentary material is also provided from JMA HP

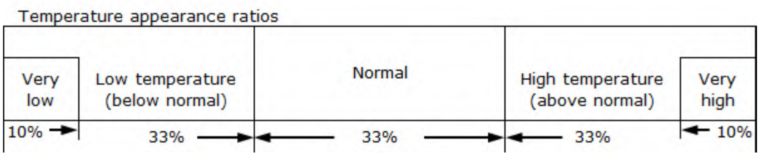




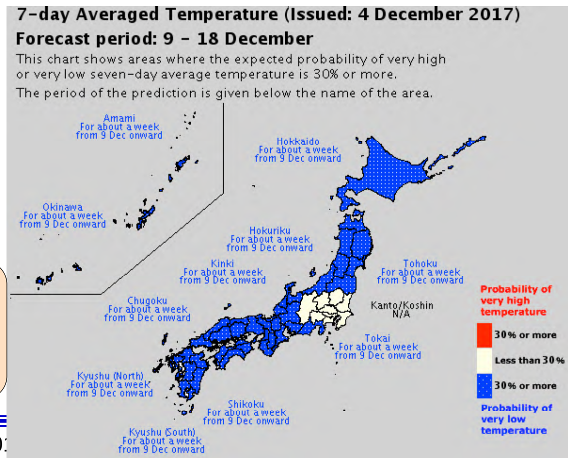


Early Warning Information for Extreme Weather

- **<u>Objective</u>:** Mitigation of the adverse impacts from extreme weather events (hot/cold spell, heavy snow) on socio-economic activities such as agriculture and disaster prevention in early stage (1-2-week ahead).
- **<u>Targeted event</u>:** An extreme 7-day averaged temperature or 7-day snowfall amounts event which appears once per decade in climatology (i.e., 10%).
- **<u>Timing of issuing</u>:** When targeted event is expected to happen 5-14-day ahead with the probability of 30% or more (i.e., 3 times more likely to happen than normal).



In this example, information for significantly cold weather from 9 Dec. onward was issued on 4 Dec.



2-week Temperature Forecast

- From June 2019, new information of temperature outlook for the next 2-week will be provided.
- On JMA-HP, observation data for the past week and forecast for the next 2-week are summarized in one page so that users can easily check the temporal change of temperature.

August

Nagoya	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22 (20-24)	23 (21-25)	24 (22-26)	25 (23-27)	26 (24-28)
(Maximum)	29.5	32.4	34.4	34.2	30.1	33.0	33.3	当日	30	30	32	32	33	32	32	33	34	34	34	33
(Minimum)	25.4	24.1	25.6	25.7	25.4	25.3	24.1	当日	25	25	25	25	25	25	25	25	25	26	26	25

Past 7-day (Observation) | 1st week (Daily forecast) | 2nd week (5-day mean forecast)

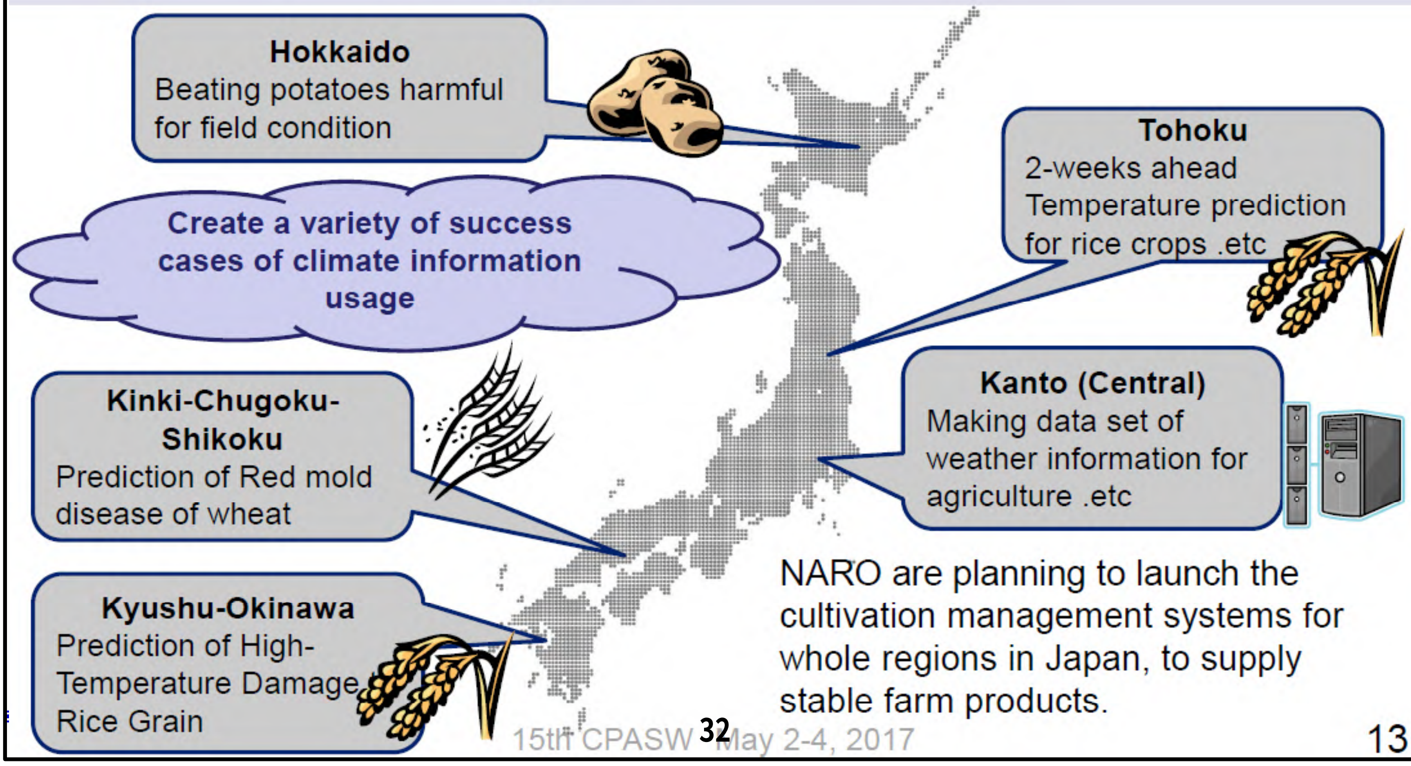
Category
- Very High
- High
- Near Normal
- Low
- Very Low

Example issued on 14 Aug.

http://www.data.jma.go.jp/gmd/risk/en

Utilization of Seasonal Forecast

JMA conducted joint researches with agricultural research Institutes（NARO）all over Japan.



NARO are planning to launch the cultivation management systems for whole regions in Japan, to supply stable farm products.

Future issues for practical use

Expansion is one of future issues for practical use

JMA makes effort to continue dialogue with local agricultural organization to promote a use of climate information in agricultural decision-making.

Meteorological Office

Climate Services

- Dialogue & Sharing knowledge
- Joint technology development

local agricultural organization (research center and government agricultural association)

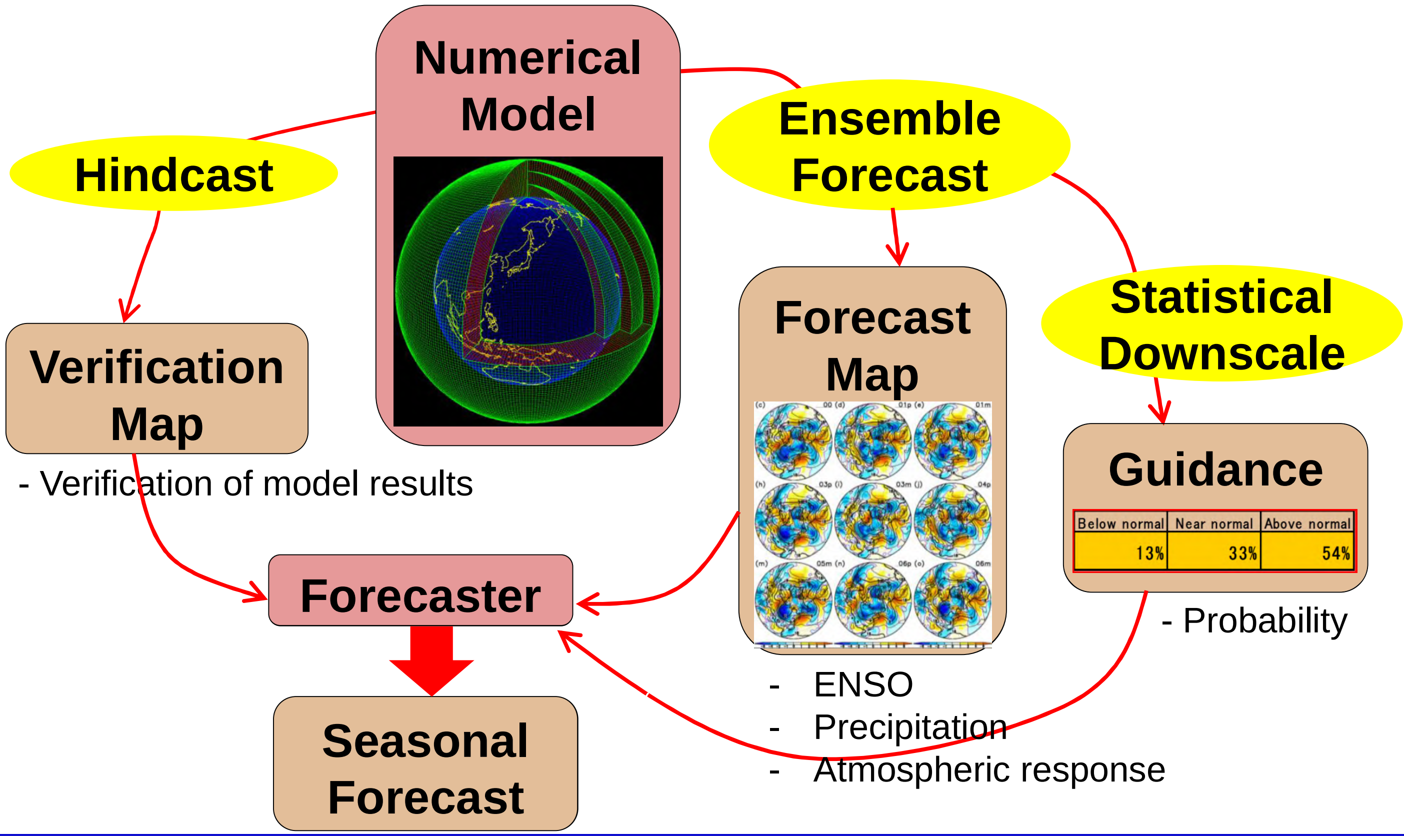
They usually have close contact with farmers in their territory

Farming information with agromet Advisories

Farmers

Procedure of One-month Forecast

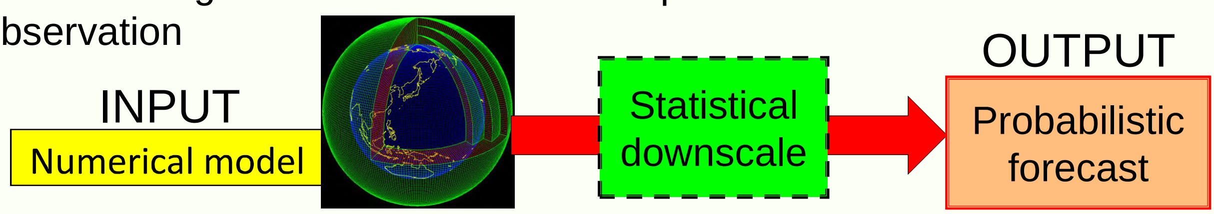
Flow of Making One-month Forecast



Procedure of One-month Forecast

1. Understand the current status of ocean and atmosphere
2. Check the numerical model results **Lecture on Wednesday**
   – Convective activity (Precipitation)
   – Atmospheric circulation (response to the convection)
3. Check the prediction skill of the numerical model
4. Check the **guidance** to estimate probability **Exercise on Wednesday**
5. Decide forecast **Goal of this seminar**

Guidance is an application to translate model output values into target of forecasting with statistical relationship between forecast and observation



Introduction of climate monitoring and analysis products for One-month Forecast

Introduction of climate monitoring and analysis products for One-month Forecast

It is important for seasonal forecast to figure out current condition of atmospheric condition and convective activity. On the TCC website, various products for climate system monitoring are available for understanding seasonal forecast. In this document, we introduce the following 6 products (Fig.1).

1. Animation Maps
2. Asian Monsoon Monitoring Indices (daily)
3. Time-Longitude Cross Section
4. Madden-Julian Oscillation (MJO) Phase and Amplitude monitor
5. Composite map for El Niño / La Niña events
6. Sea Surface Temperature

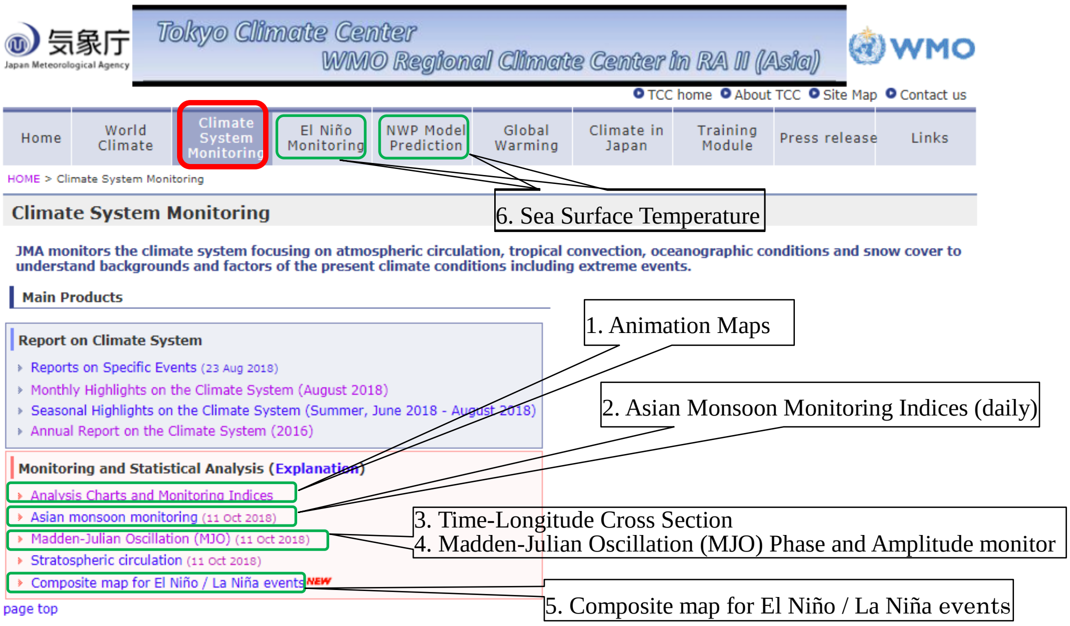


Fig. 1. Climate System Monitoring web page on the TCC website (https://ds.data.jma.go.jp/tcc/tcc/products/clisys/index.html)

1. Animation Maps

Animation Maps is available from Analysis Charts and Monitoring Indices page on the TCC website (fig.2).

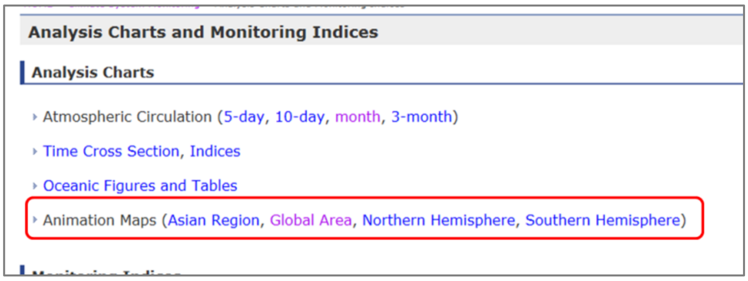


Fig. 2. Analysis Charts and Monitoring Indices page on the TCC website (https://ds.data.jma.go.jp/tcc/tcc/products/clisys/acmi.html)

The Animation Maps web pages are useful to analyze the time evolution of atmospheric circulation and tropical convective activity.

The web pages cover four areas: the Asian Region (fig.3), the Northern Hemisphere, the Southern Hemisphere and the Global Area (fig.4). Data on major elements for use in monitoring extratropical circulation (such as sea level pressure, 500-hPa geopotential height and 850-hPa temperature) shown on polar stereographic charts are available on the Northern Hemisphere and Southern Hemisphere pages, and data for use in monitoring tropical convective activity and circulation (such as outgoing longwave radiation (OLR), velocity potential and stream function) are available on the Asian Region and Global Area pages. Daily (1-day), 5-day, 7-day, 10-day and 30-day average charts are available for all elements. The Animation Maps are available for the period from 1958 to two days prior, and are updated every day.

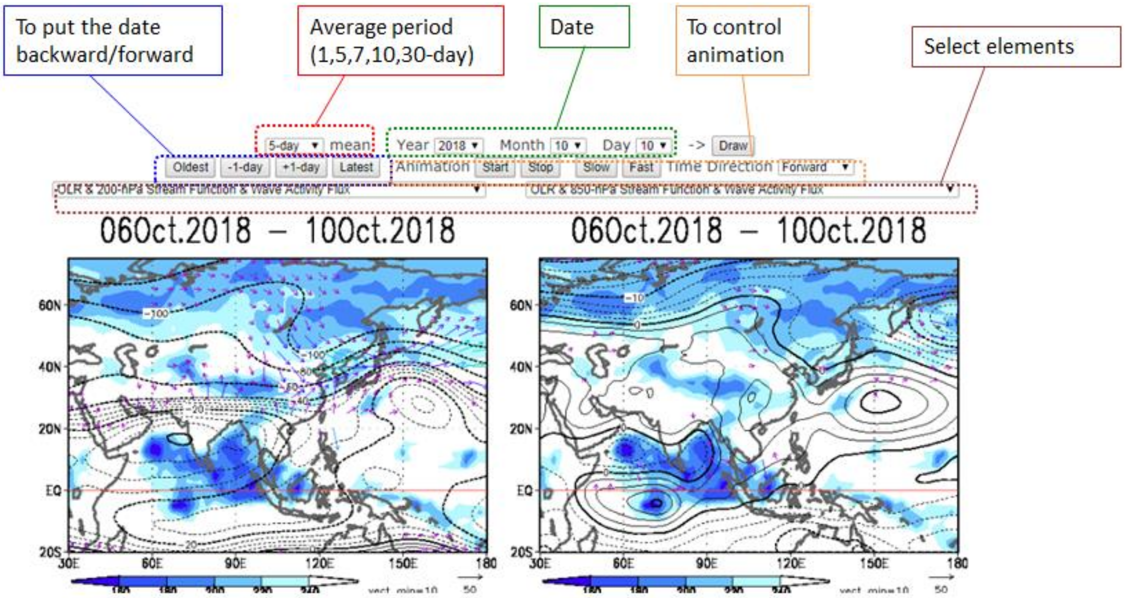


Fig. 3. Animation Map page layout (Asian region)

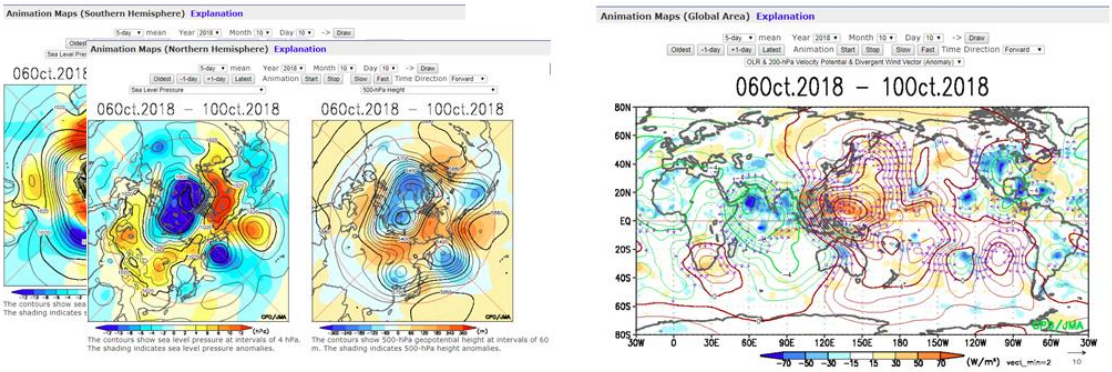


Fig. 4. Animation Map page layout

(Left: Northern and Southern Hemisphere, Right: Global Area)

2. Asian Monsoon Monitoring Indices (daily)

This web page provides the daily time series of Asian Monsoon Monitoring Indices (such as area averaged vertical zonal wind shear (Webster and Yang 1992) and OLR (Wang and Fan 1999) (fig.5). These indices are useful in monitoring the strength and expansion of the Asian summer monsoon, and are updated every day.

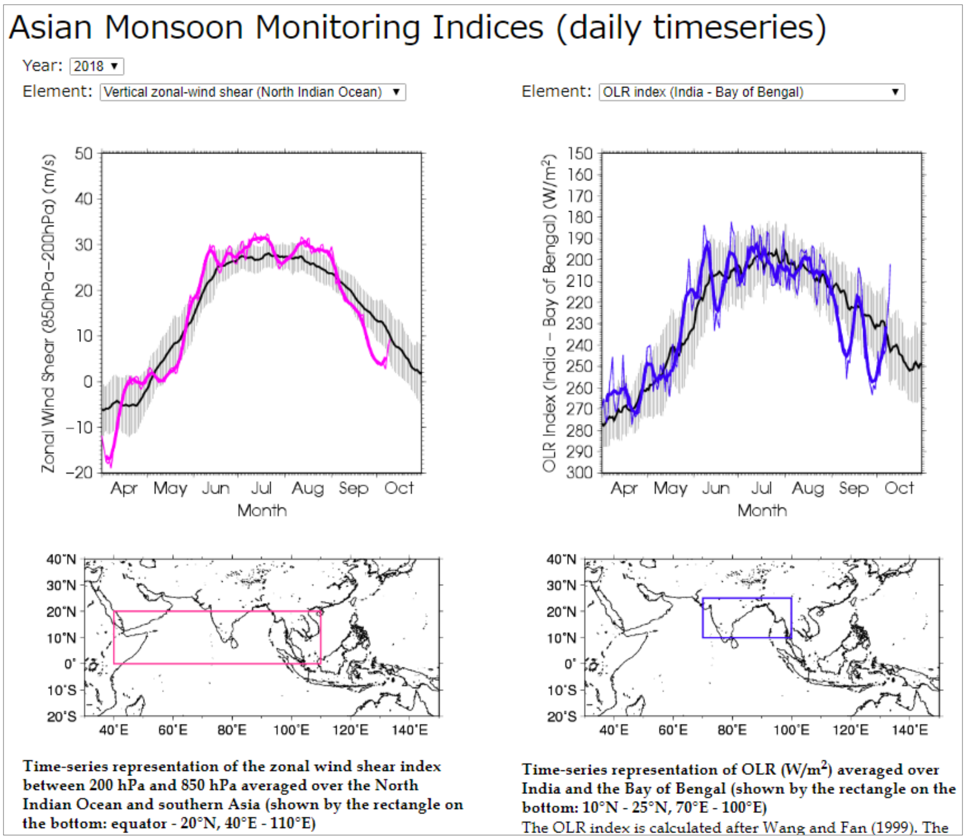


Fig. 5. Asian Monsoon Monitoring Indices (daily) page

(https://ds.data.jma.go.jp/tcc/tcc/products/clisys/ASIA_TCC/monsoon_index.html)

3. Time-Longitude Cross Section

Time-Longitude Cross Section is available from Madden-Julian Oscillation (MJO) page on the TCC website (fig.6).

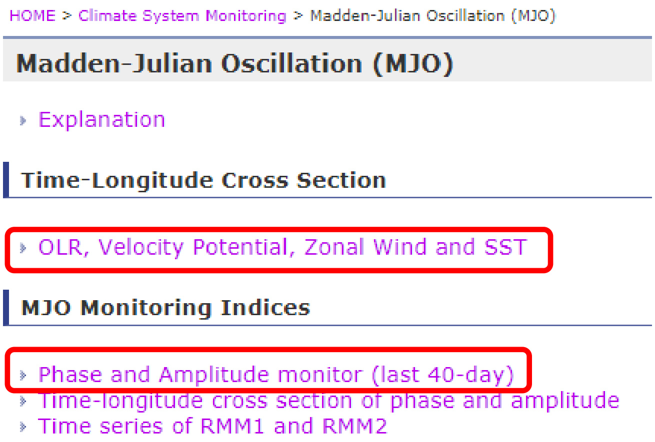


Fig. 6. Madden-Julian Oscillation (MJO) page on the TCC website (https://ds.data.jma.go.jp/tcc/tcc/products/clisys/mjo/moni_mjo.html)

This web page provides time-longitude cross sections of 3-day and 7-day mean OLR, velocity potential, zonal wind and sea surface temperature (fig.7). These charts are useful in monitoring intraseasonal oscillations such as Madden-Julian Oscillation (MJO). This web page is available for the period since 1979, and is updated every day.

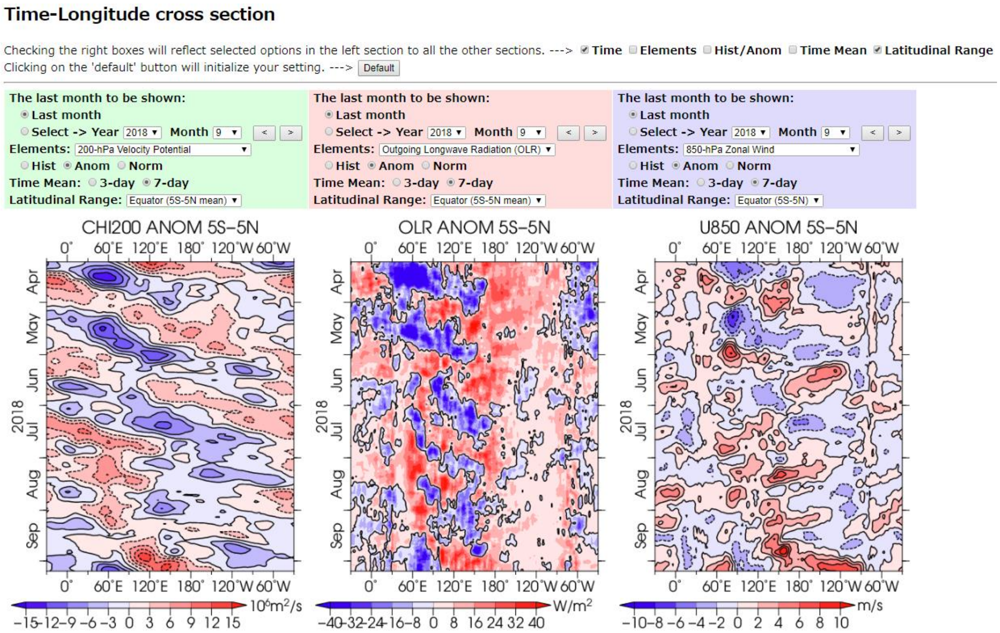


Fig. 7. Time-Longitude Cross Section page (https://ds.data.jma.go.jp/tcc/tcc/products/clisys/ASIA_TCC/mjo_cross.html)

4. MJO Phase and Amplitude monitor

MJO Phase and Amplitude monitor is available from MJO page on the TCC website (fig.8). This page provides indices for MJO monitoring defined by Wheeler and Hendon (2004). MJO Phase and Amplitude monitor (last 40-day) is convenient for MJO monitoring.

Two principal component time series from multivariate EOF of the MJO components are defined as RMM1 and RMM2. Two-dimensional phase space is defined by RMM1 and RMM2. In the phase space, the equatorial zones are divided into 8 phases and each phase indicates the active phase of the MJO propagation. In association with the eastward propagation of MJO, trajectory of RMM1 and RMM2 draws anti-clockwise circles in the phase space.

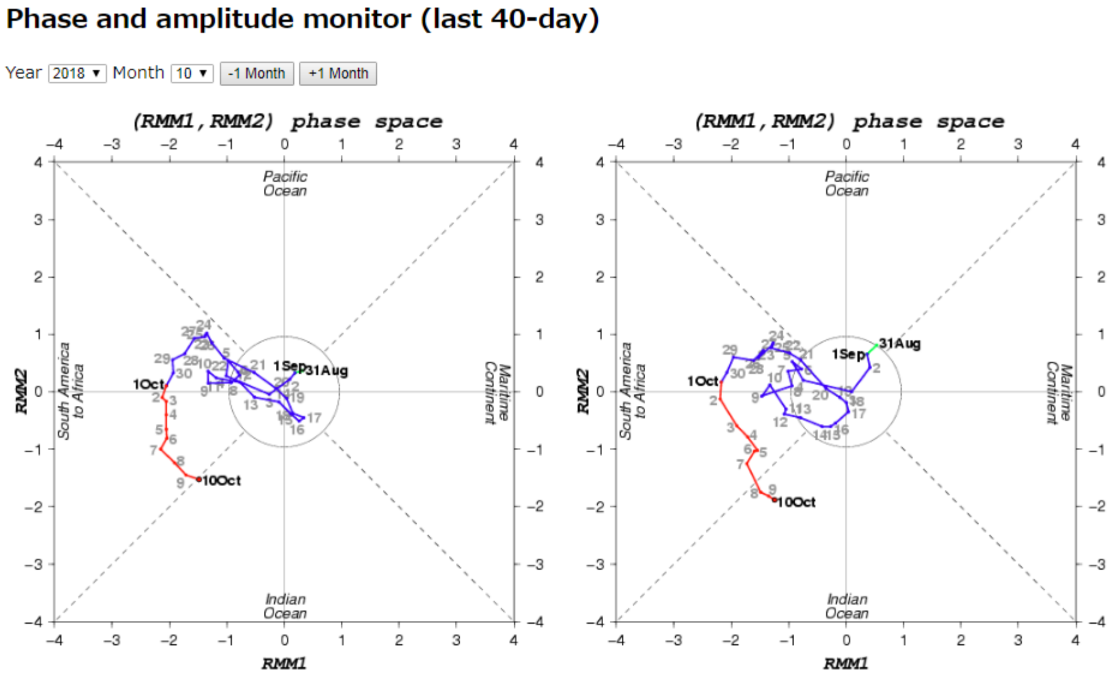


Fig. 8. MJO Phase and Amplitude monitor
(https://ds.data.jma.go.jp/tcc/tcc/products/clisys/mjo/monitor.html)

5. Composite map for El Niño / La Niña events

El Ninõ / Southern Oscillation (ENSO) events influence global atmospheric circulations and convective activities.

This web page provides the statistical analysis on the relationship between ENSO monitoring indices (such as NINO.3, NINO.WEST and IOBW) and atmospheric circulation (such as OLR, 850-hPa and 200-hPa stream function anomalies) (Fig.9). The base period for the analysis is 1958 - 2012 (except OLR: 1979 - 2012).

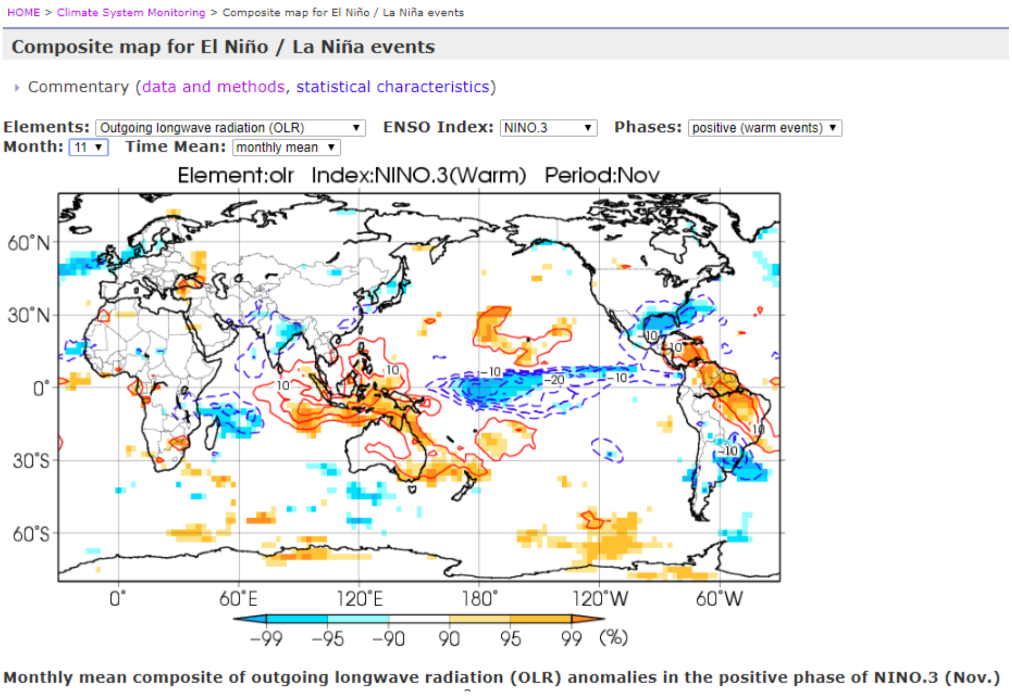


Fig. 9. Composite map for El Niño / La Niña events

(https://ds.data.jma.go.jp/tcc/tcc/products/clisys/enso_statistics/index.html)

6. Sea Surface Temperature

In this document, we introduce the following 2 web pages for oceanographic condition monitoring on the TCC website.

(1) Monthly oceanographic condition

https://ds.data.jma.go.jp/gmd/tcc/tcc/products/elnino/ocean/index_tcc.html

Various monthly charts and tables, such as sea surface temperature, ocean heat content and surface zonal wind stress, are available.

(2) Initial time sea surface temperature anomaly

https://ds.data.jma.go.jp/tcc/tcc/products/model/map/1mE/map1/zpcmap.php

Chart of initial time sea surface temperature anomaly is available in the Forecast Maps for One-month Prediction web page (Fig.10). The sea surface temperature anomaly displayed in this map is used as the lower boundary condition of ensemble prediction systems for the one-month prediction (the atmospheric general circulation model). This cheat is updated every week.

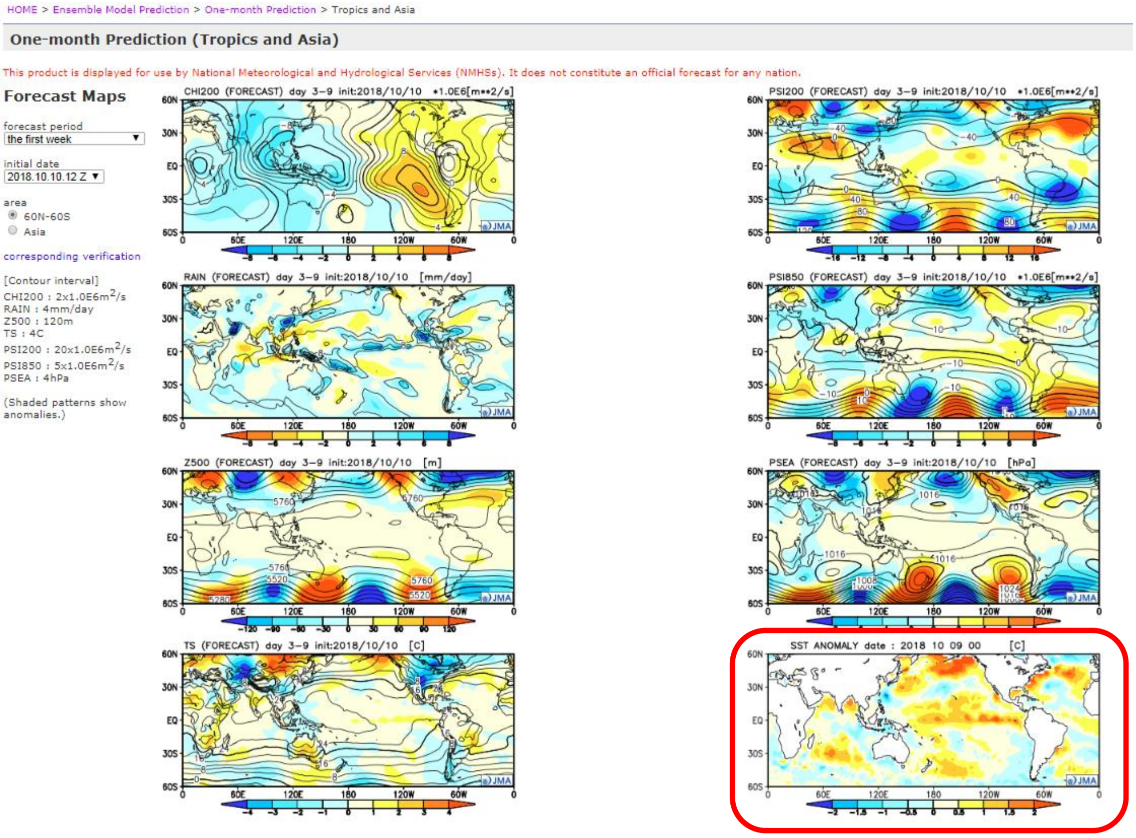


Fig. 10. Forecast Maps for One-month Prediction (Tropics and Asia) page
(Bottom right: sea surface temperature anomaly)
(https://ds.data.jma.go.jp/tcc/tcc/products/model/map/1mE/map1/zpcmap.php)

References

Wang, B. and Z. Fan, 1999: Choice of South Asian summer monsoon indices, Bull. Amer. Meteor. Soc., **80**, 629–638.

Webster, P.J. and S. Yang, 1992: Monsoon and ENSO: Selectively interactive systems. Quart. J. Roy. Meteor. Soc., **118**, 877-926.

Wheeler, M.C., and H.H. Hendon, 2004: An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction, Mon. Weather. Rev., **132**, 1917-1932.

Introduction of JMA’s
Ensemble Prediction System (EPS)
for Sub-seasonal to Seasonal Forecasting

Introduction of JMA's Ensemble Prediction System (EPS) for Sub-seasonal to Seasonal Forecasting

1. Numerical Prediction System

Figure 1 illustrates "numerical prediction system". A numerical model is made based on many kinds of physical laws, and has a large number of grids. If you input an initial atmospheric condition and boundary conditions to the numerical model, you can get to know a future atmospheric condition as an output.

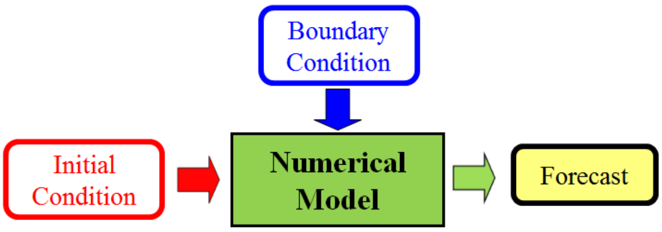


Fig. 1. Schematic of numerical prediction system

In this system, boundary conditions include many kinds of seasonal variables as natural factors except for variables such as sea surface temperatures (SSTs), sea ices and snow covers. In general, variations of boundary conditions are much slower than a variation in the atmosphere.

2. Predictability

Figure 2 shows a schematic concept of "Predictability". There are mainly 2 types of predictabilities. "Predictability of the 1st kind" depends on an initial atmospheric condition. The variation of atmosphere is so fast that information of the initial atmospheric condition can be lost rapidly. On the other hand, "Predictability of the 2nd kind" depends on boundary conditions. The slow variations of boundary conditions can make a long-range forecast possible.

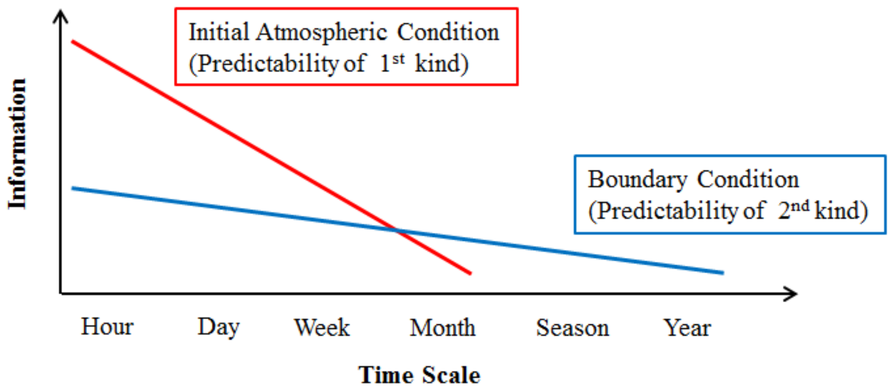


Fig. 2. Schematic concept of predictability

Phenomena in the atmosphere have their own temporal and spatial scales (Figure 3). Long-range forecasts for short-life and small-scale phenomena such as tornadoes and cyclones are practically impossible, because they are too sensitive to atmospheric initial conditions. Conversely, long-range forecasts for long-life and large-scale phenomena such as seasonal oscillations and monsoons can be expected to have predictability, because they are affected by the slowly-varying boundary conditions rather than the atmospheric initial conditions.

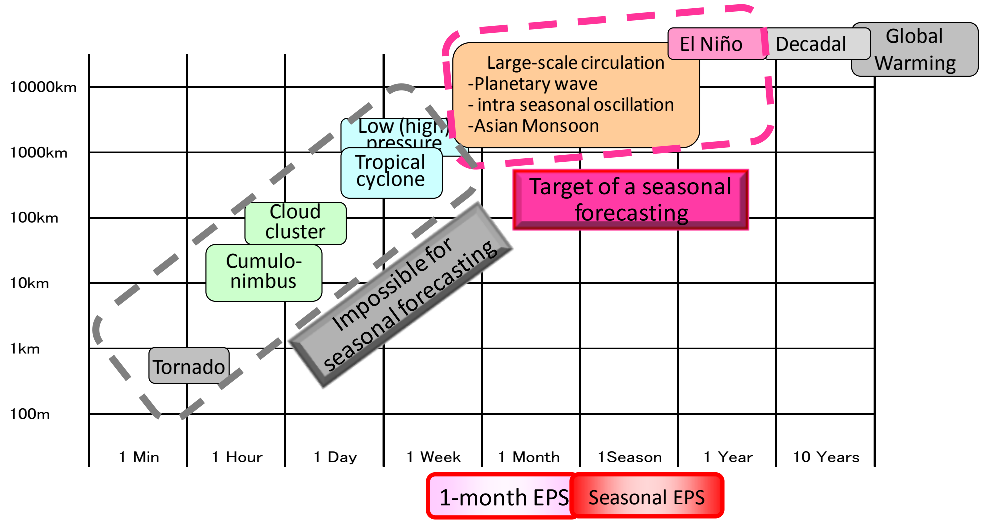


Fig. 3. Temporal and Spatial Scales of Atmospheric Phenomena

3. Uncertainty and Ensemble Prediction

Because atmosphere has chaotic nature, a small error in an initial condition grows rapidly. However, it is impossible to know a perfect initial condition even with the use of highly precise observations. Therefore, it is essential to consider uncertainty in forecasts. Ensemble prediction makes it possible to estimate uncertainty caused by initial condition errors with similar calculations from a little bit different multiple initial conditions. The individual calculated realization is called "Ensemble member" and the standard deviation among all members is called "Ensemble spread" (Figure 4).

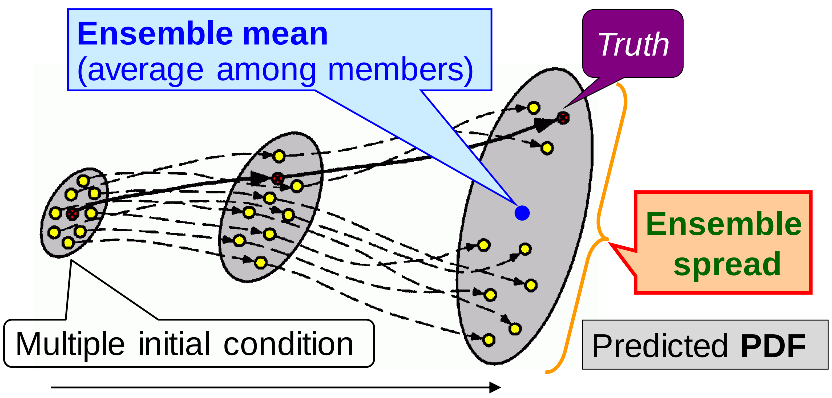


Fig. 4. Schematic of Ensemble Prediction

In order to efficiently represent initial observational errors with initial perturbations (multiple initial conditions), the Breeding of Growing Mode (BGM) and Singular Vector (SV) methods are used. The BGM method finds out the perturbation which has grown up before the initial time in its forecast and analysis cycle (Figure 5). This method is relatively simple, but necessary to keep the forecast and analysis cycle even for the time other than the initial time.

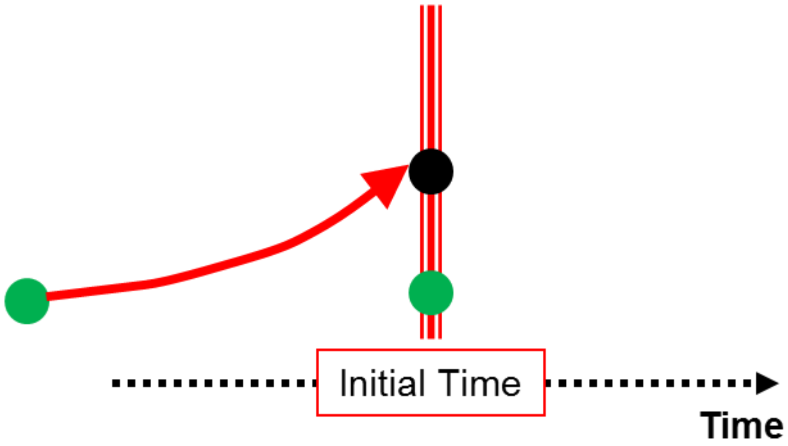


Fig. 5. Schematic of the Breeding of Growing Mode method

On the other hand, the SV method finds out the fastest growing perturbation after the initial time with the use of a tangent linear model, which is obtained by locally linearizing the original nonlinear NWP model and its adjoint model as well (Figure 6). The SV method can find potentially better growing perturbations during the evaluation time, but requires large resources for calculation and development.

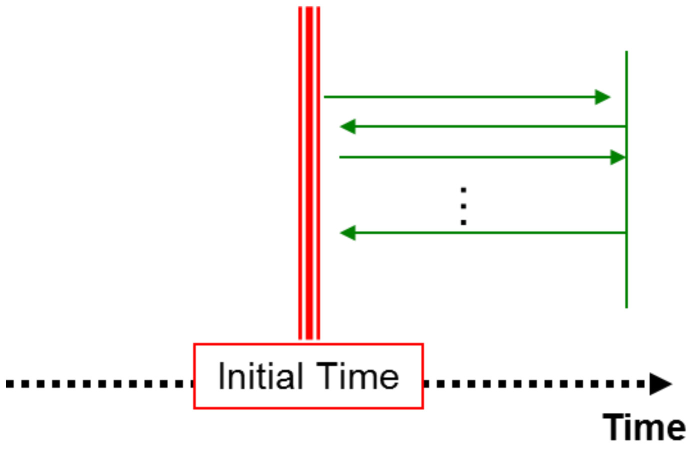


Fig. 6. Schematic of the Singular Vector method

Lagged Average Forecasting (LAF) is one of the ensemble prediction techniques. LAF ensemble prediction is calculated with the combination of ensemble predictions not only from latest initial condition but also from older initial conditions (Figure 7). LAF is an easy method for ensemble prediction and make it possible to share computer resources over several days. It is also possible to get a large ensemble spread even at initial time. However, the prediction skill from older initial conditions is generally worse than that from latest initial condition.

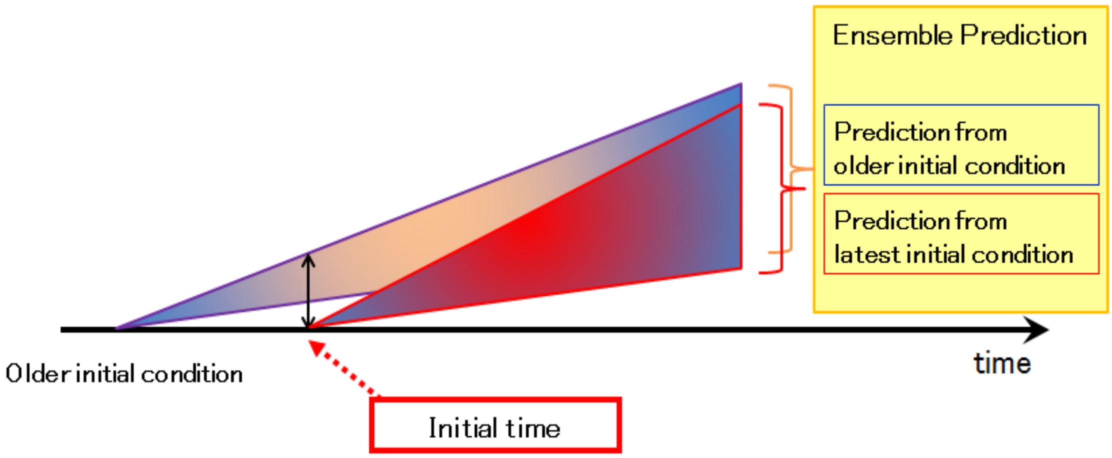


Fig. 7. Schematic of Lagged Average Forecasting (LAF)

Forecast uncertainty is caused by imperfection not only of initial conditions but also of numerical prediction models. In order to consider the uncertainty caused by imperfection of numerical prediction models, multi-model ensemble (MME) system and stochastic physics scheme are often used. The MME is an EPS using some different ensemble prediction models, and the stochastic physics scheme is a method to perturb time variations due to physics parameterization with random numbers (Figure 8).

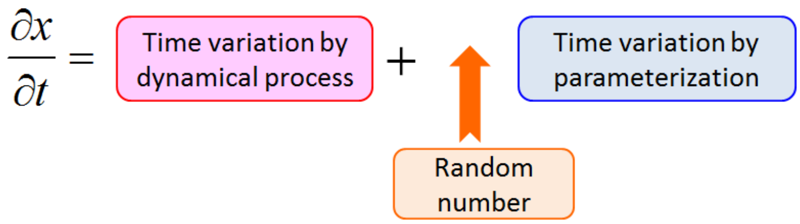


Fig. 8. Schematic representation of Stochastic Physics Scheme

4. WMO Forecast Classification

In line with "WMO's Manual on the Global Data-Processing and Forecasting System"[1], forecasts are classified by their ranges as Table 1. Sub-seasonal to seasonal forecasting, which is the main topics of the TCC seminar, corresponds to extended- and long-range forecasting (shaded in table 1).

Table 1 Definitions of meteorological forecasting range classified by WMO

	Forecasting target period
Nowcasting	Up to 2 hours
Very short-range weather forecasting	Up to 12 hours
Short-range forecasting	Beyond 12 hours and up to 72 hours
Medium-range weather forecasting	Beyond 72 hours and up to 240 hours
Extended-range weather forecasting	Beyond 10 days and up to 30 days
Long-range forecasting	Beyond 30 days up to two years
Climate forecasting	Beyond two years

5. JMA's Global and Seasonal Ensemble Prediction System

JMA uses a high-resolution atmospheric general circulation model (AGCM) named "Global EPS" for extended-range weather forecast, because predictability of the 1st kind is relatively important. JMA also uses a coupled ocean-atmosphere general circulation model (CGCM) named "Seasonal EPS" for long-range forecast, because predictability of the 2nd kind become more important. The specifications of these two EPSs are listed in Table 2. The model resolution for Seasonal EPS is lower than that for Global EPS, because CGCM requires more computer resources than AGCM due to calculation not only of atmospheric component but also of oceanic component. In order to make initial perturbations, Global EPS uses the combination of SV, LAF and LETKF[2] methods, while Seasonal EPS uses the combination of BGM and LAF methods. The both models also adopt the stochastic physics scheme to consider uncertainty caused by the models' imperfection. The last major upgrades are March 2017 for Global EPS and June 2015 for Seasonal EPS, respectively. JMA normally upgrades Global EPS every few years and Seasonal EPS every half decade.

For more detailed information, see the "Numerical Weather Prediction of JMA" website (http://www.jma.go.jp/jma/jma-eng/jma-center/nwp/nwp-top.htm).

[1] http://www.wmo.int/pages/prog/www/DPS/Publications/WMO_485_Vol_I.pdf

[2] LETKF is a Local Ensemble Transform Kalman Filter based on Hunt et al. (2007).

Table 2 Specification of the One-month and Seasonal EPS (as of November 2018)

	Global EPS	Seasonal EPS
Upgrade	Last: March 2017 Frequency: Every few years	Last: June 2015 Frequency: About every half decade
Model	AGCM (Atmospheric General Circulation Model)	CGCM (Coupled Ocean-atmosphere General Circulation Model)
Resolution	Horizontal: 40km(TL479) up to 18days 55 km (TL319) after 18 days Vertical: 100 levels up to 0.01 hPa	* Atmospheric component Horizontal: 110 km (TL159) Vertical: 60 levels up to 0.1 hPa * Oceanic component Horizontal: 1.0º longitude, 0.3–0.5º latitude (with Tri-pole grid) Vertical: 52 levels + Bottom Boundary Layer
Forecast range	Up to 34 days	7-month (initial month of Sep., Oct., Feb., Mar., Apr) 4 months (the other initial month)
Oceanic conditions	Prescribed SST perturbation Prescribed Sea Ice distribution	MRI.COM (Oceanic General Circulation Model) Interactive Sea Ice Model
Green House Gases	Constant	RCP4.5 scenario for 6 GHGs
Ensemble methods	Singular Vector (SV), Lagged Average Forecast (LAF), Local Ensemble Transform Kalman Filter (LETKF), Stochastic physics scheme	Breeding of Growing Modes (BGM), Lagged Average Forecast (LAF), Stochastic physics scheme
Ensemble size	50 (combination of 13-11 SVs & 4 initial LAF at 12 hour interval)	51 (combination of 13-12 BGMs & 4 initial LAF at 5-day interval)
Frequency of operation	Every Tuesday and Wednesday	Every 5 days
Frequency of model product creation	Once a week Every Thursday	Once a month Around 20th (no later than 22nd) of every month

6. Hindcast

Hindcasts are systematic forecast experiments for past cases. Hindcast experiments are performed using the corresponding operational model. Hindcast datasets are used not only to estimate the systematic biases and prediction skills but also to develop statistical models. In order to calculate a large number of past events, large computer resources are required. To save the computational costs, the ensemble size and the calculation frequency for hindcasts are less than those for operational forecasts. The detailed differences between hindcasts and operational forecasts are listed in Table 3. For the initial date on which no hindcast was performed, the hindcast data is created with a linear interpolation method using the data on the previous and next initial dates.

Table 3 Differences between hindcasts and operational forecasts

* Global EPS

	Hindcast	Operational system
Initial Condition	JRA-55	Global Analysis (Newer System than JRA-55)
Ensemble size	5 (5 SVs, not using LAF and LETKF)	50 (13-11 BGMs & 4 initial LAF with 12 hour interval)
Forecast range	Initial date + 40 days	2, 3, 4,...31, 32 days from the latest initial date (Wednesday)
Initial date	10th, 20th, end of month	00UTC and 12UTC on every Tuesday and Wednesday
Target period for hindcast	Available : 1981.1-2017.3 Verification: 1981.1-2010.12	–

* Seasonal EPS

	Hindcast	Operational system
Initial Condition	JRA-55	JRA-55
Ensemble size	5 (5 BGM)	51 (13-12 BGMs & 4 days LAF with 5-day interval)
Forecast range	Lead time from 0 to 6 months as shown in the correspondence table below	(4-month EPS) Lead time from 1 to 3 as shown in the correspondence table below (7-month EPS) DJF (initial month of Sep., Oct.) JJA (initial months of Feb., Mar. and Apr.)
Initial date	24 initial dates a year (16th Jan., 31th Jan., 10th Feb., 25th Feb., ,... 12th Dec. and 27th Dec.)	Once a month
Target period for hindcast	Available : 1979-2014 Verification: 1981-2010	–

Correspondance between lead times (months) and initial dates

Target Month / Initial Date	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
27-Dec, 12-Dec	0	1	2	3	4	5	6					
31-Jan, 16-Jan		0	1	2	3	4	5	6				
25-Feb, 10-Feb			0	1	2	3	4	5	6			
27-Mar, 12-Mar				0	1	2	3	4	5	6		
26-Apr, 11-Apr					0	1	2	3	4	5	6	
31-May, 16-May						0	1	2	3	4	5	6
30-Jun, 15-Jun	6						0	1	2	3	4	5
30-Jul, 15-Jul	5	6						0	1	2	3	4
29-Aug, 14-Aug	4	5	6						0	1	2	3
28-Sep, 13-Sep	3	4	5	6						0	1	2
28-Oct, 13-Oct	2	3	4	5	6						0	1
27-Nov, 12-Nov	1	2	3	4	5	6						0

7. Prediction Skills

7.1. Global EPS

The anomaly correlation coefficient (ACC) scores of the operational one-month forecasts (Figure 9) show upward trends, reflecting model improvements. However, temporary increases and decreases are sometimes seen, corresponding to major and unsettled ENSO events respectively. Compering between the stable periods in early 2000s and that in early 2010s, ACC of geo-potential height at 500hPa (Z500) for 28-day mean forecast in the Northern Hemisphere has been improved about 1.2 points.

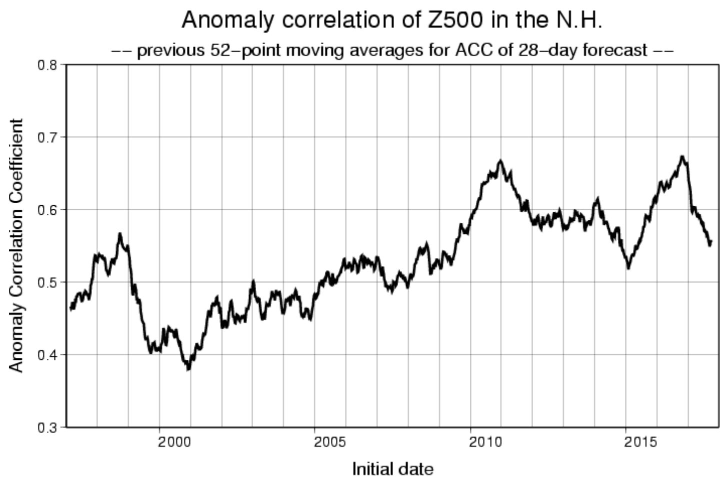
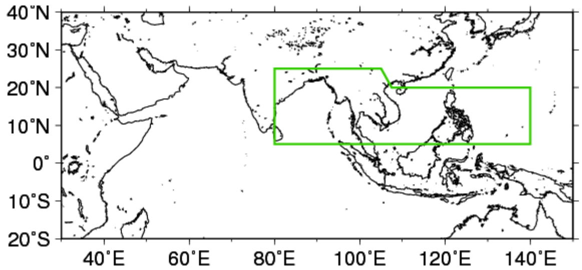


Fig. 9. Anomaly correlation of geopotential height at 500hPa for operational 28 day mean forecasts in the Northern Hemisphere

Focusing on the area-averaged daily rainfall scores in summer monsoon season, onset and offset seasons are somehow predictable, but mature season is relatively difficult to predict (Figure 10). It is assumed that seasonal oscillations such as Madden Julian Oscillation (MJO) and Boreal Summer Inter Seasonal Oscillation (BSISO) make the monsoon rainfall forecasts difficult. According to the hindcast verification, MJO is somehow predictable up to around 25 days, but velocity and amplitude biases can be seen as well.



Initial month	Daily Rainfall Correlation (28day mean)
May	0.46
June	0.09
July	0.38
August	0.30

Fig. 10. Region (left) and score (right) of a daily monsoon rainfall index for hindcast

7.2. Seasonal EPS

Figure 11 shows the prediction skill (ACC) diagrams for SST indexes. Prediction skills for NINO.3 (i.e., El Niño/La Niña) have seasonal dependencies. According to the hindcast verification, prediction skills through boreal spring season are generally low, and called "Spring Barrier". Prediction skills for NINO.WEST, IOBW and Dipole Mode Index (DMI) also have seasonal dependencies. Prediction skills for NINO.WEST are relatively low during tropical cyclone season, and those for IOBW are also relatively low for the forecast through summer monsoon season. Those for DMI can be predictable mainly in autumn season.

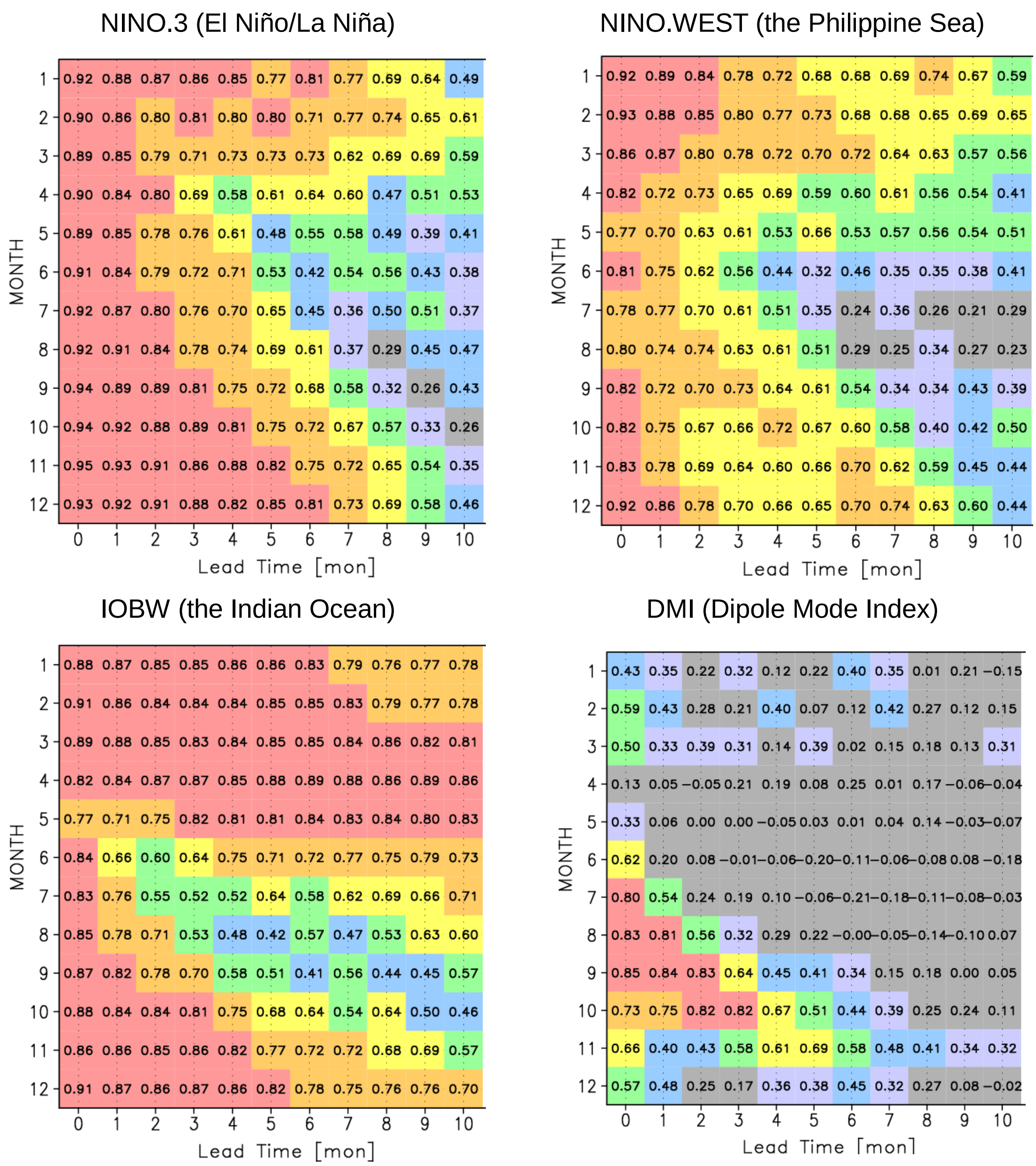


Fig. 11. Prediction skill (ACC) diagram of SST index

Although seasonal EPS considers variabilities of sea ices and 6 kinds of greenhouse gases, 2m temperature trends have relatively large bias in some regions (Figure 12). Resent cooling trends in and around Siberia and the Bering Sea during boreal winter are not seen in the hindcast results. Because forecast scores of hindcast for 2m temperature is also low in and around Siberia and the Bering Sea during boreal winter, 2m temperature forecasts in those regions should be interpreted with caution.

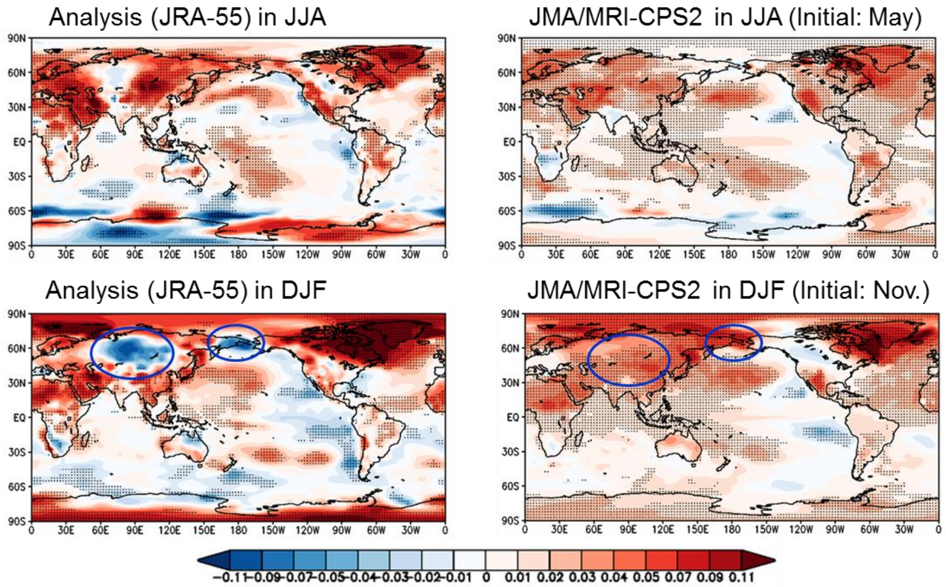
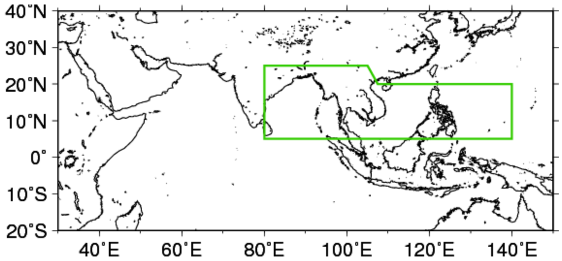


Fig. 12. Comparison between analysis and hindcast of 2m temperature trends

Focusing on the area-averaged monthly rainfall scores in summer monsoon season, the onset and offset seasons are somehow predictable, but the mature season is relatively difficult, same as Global EPS (Figure 13). It is assumed that seasonal oscillations such as MJO and BSISO can influence the performance of monsoon rainfall forecasts. However, according to hindcast verification, the MJO forecast skill is better than Global EPS especially for the amplitude.



Target Month	LAF period	
	11/26 April	16/31 May
June	0.20	0.63
July	0.08	0.21
August	0.05	-0.07
Sept.	0.45	0.30

Fig. 13. Region (left) and score (right) of a monsoon index for hindcast

8. Products

8.1. TCC Website for Numerical Model Prediction (GPC Tokyo)

Many kinds of numerical prediction model products are available on the TCC website (Figure 14). Some products such as extreme weather prediction and gridded data require authentication. These products are displayed for reference by National Meteorological and Hydrological Services (NMHSs) and not forecast for any nation.

Fig. 14. TCC's numerical weather prediction (GPC Tokyo) website
http://ds.data.jma.go.jp/tcc/tcc/products/model/index.html

(a) One-month Prediction Products

- Forecast maps
- Real-time and hindcast verification charts
- Probabilistic forecasts at station points in Southeast Asia.
- Extreme forecast index (authentication is required)
- Forecast map animation (authentication and high speed internet access are required)
- Gridded data of operational forecasts and hindcasts (authentication is required)

(b) Three month and Warm/Cold Season Products

- Forecast maps
- SST index time-series forecast (available since June 2015)
- Real-time and hindcast verification charts
- Probabilistic forecasts
- Gridded data of operational forecasts and hindcasts (authentication is required)

8.2. Forecast Maps

Various kinds of forecast maps are available on the numerical model prediction website of TCC. The period for forecast maps are 1st week, 2nd week, 3-4 week and 28 days average for one month prediction, and 1-month and 3-month average for seasonal prediction. The elements are as follows:

(a) Tropical Maps (60S-60N)

- Daily mean precipitation (RAIN)
- Velocity Potential (CHI200)
- Stream Function at 200hPa (PSI200)
- Stream Function at 850hPa (PSI850)
- Geo-potential height at 500hPa (Z500)
- Sea Level Pressure (PSEA)
- Surface Temperature (TS)
- Sea Surface Temperature (SST)
- Stream Function and wind at 850hPa (only for seasonal EPS)

(b) Northern Hemisphere Maps

- Geo-potential height at 500hPa (Z500)
- Temperature at 850hPa (T850)
- Sea Level Pressure (PSEA)

SST, RAIN and CHI200 maps are useful to understand tropical convections. PSI200, PSI850 and wind at 850hPa maps are useful to understand Rossby and Kelvin responses (i.e., Matsuno-Gill responses) associated with tropical convections. Meanwhile, Z500 map is useful to understand teleconnection patterns such as Pacific North America (PNA), Tropical Northern Hemisphere (TNH), Eurasia (EU) and West Pacific (WP) patterns. In general, predictabilities over mid- and high- latitudes are small but those for phenomena associated with topical convections are relatively high, because tropical convections are well influenced by slow variable SSTs. Also, PSEA map is useful to understand Arctic Oscillation (AO), North Atlantic Oscillation (NAO) and the strength of North Pacific High, Siberian High, Aleutian Low and so on. In addition, model output temperature maps are necessary to check statistical guidance reliability. If predicted temperatures in guidance are different from those in model, you should consider the possible reason.

8.3. Verification Scores and Maps

Various kinds of verification products are available on the numerical model prediction website of TCC. The elements are as follows:

(a) Verification products for Global EPS operational forecast

- Error maps for every forecast
- Historical and Recent scores
- Reliability diagrams for each season
- ROC curves for each season

(b) Verification products for Global EPS hindcast

- Bias maps
- Hindcast maps
- Time-series Circulation Index
- Verification Score Maps

(c) Verification products for Seasonal EPS operational forecast

- Error maps for every forecast

(d) Verification Products for Seasonal EPS hindcast

- Deterministic score Maps
- Probabilistic score Diagrams
- Probabilistic score Maps
- Time-series Circulation Index
- ENSO Index score
- ENSO Index time-series
- Hindcast Maps

Error maps and the operational scores are useful to understand the real-time operational model performance. Hindcast score maps are useful to understand the spatial distribution of model prediction skills. In the low prediction skill region, it is not recommended to use model output directly. Statistical relationships to the high skill region and calibration using past observation should be considered. Time-series circulation indexes for hindcast are useful to understand model predictabilities of various kinds of focal phenomena such as El Niño/La Niña, Indian Ocean Dipole (IOD), monsoon rainfalls and circulations. Higher skill phenomena should be used for explanation of forecast reasons.

8.4. Probabilistic forecast

JMA provides calibrated tercile probabilistic forecasts for 3-monthand warm and cold season averaged sea surface temperature, surface temperature and precipitation over the global based on the seasonal EPS (Figure 15). An ordered probit model is used to calibrate tercile probabilistic forecasts using 30-year hindcasts (1981-2010). The thresholds of tercile are determined so that the climatological chance of occurrence for each category is 33.3 % for the hindcast period from 1981 to 2010.

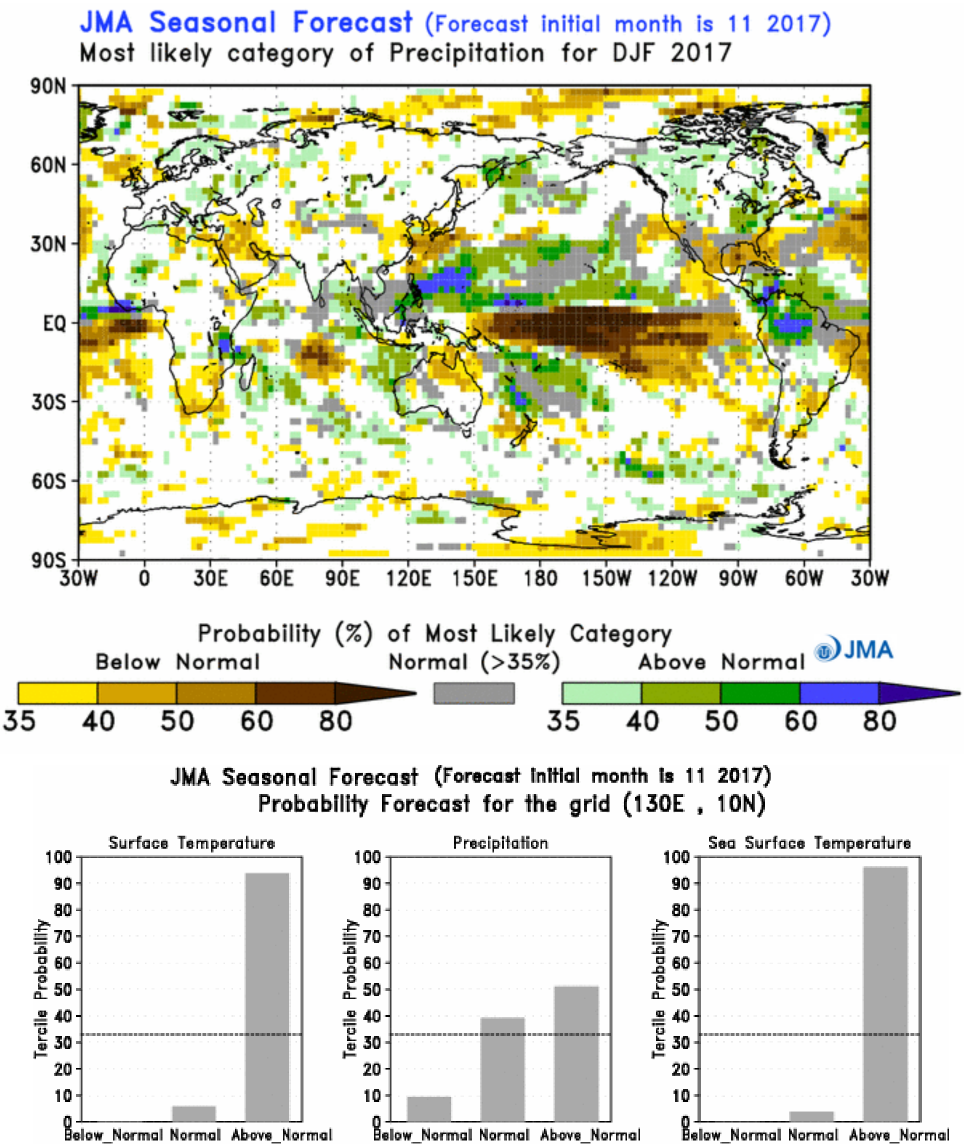


Fig. 15. Probabilistic forecast map (top) and tercile probability of a point (bottom)

http://ds.data.jma.go.jp/tcc/tcc/products/model/probfcst/3-mon/index.html

http://ds.data.jma.go.jp/tcc/tcc/products/model/probfcst/warm_cold_season/index.html

Introduction of
One-month Forecast Guidance

Introduction of One-month Forecast Guidance

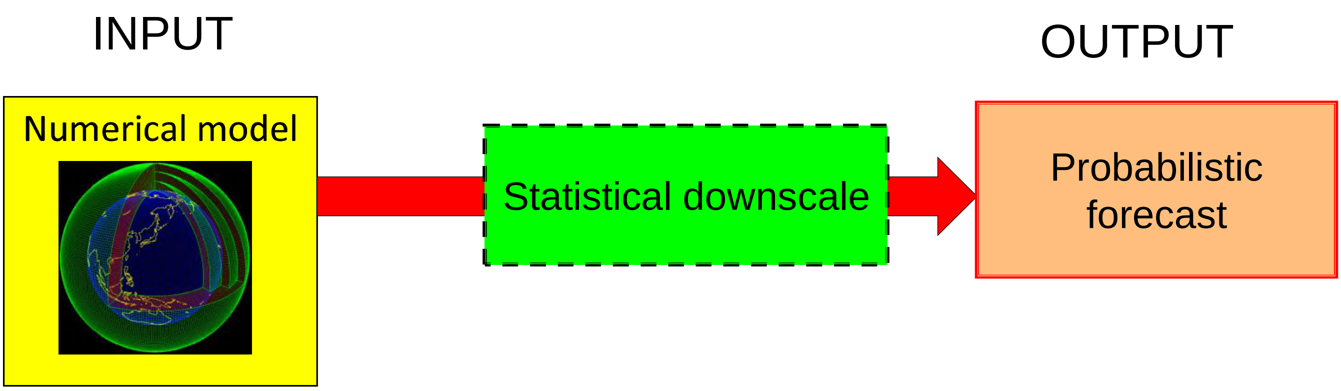
Hiroshi OHNO
Tokyo Climate Center (TCC)/
Climate Prediction Division of
Japan Meteorological Agency (JMA)

Outline

- Outline of Guidance
  - – Objective of Guidance
  - – MOS Technique
  - – Regression Model
  - – Estimation of Probability
- Verification
  - – Verification Score

Outline of Guidance

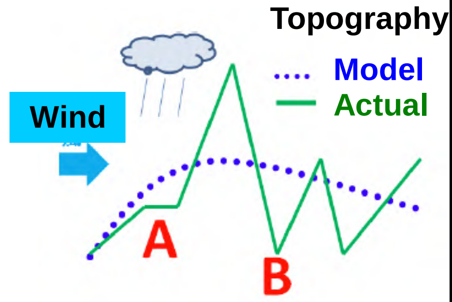
Guidance



- "Guidance" is an application to translate model output values into target of forecasting.
- Principle of guidance is based on statistical relationship using model forecasts and observation data for past cases.

Role of Guidance

- To extract effect of sub-grid scale topography
  - Model does not necessarily reproduce effect of local topography due to limited resolution.
- To reduce imperfection of the model, such as systematic error (bias error).
- To estimate degree of uncertainty, considering prediction skill



A: Upwind side
- Model may underestimate precipitation

B: Bottom of the valley
- Model may have warming bias

"Guidance" enable to improve prediction skill, compared with the direct model output.

Principle of Guidance – MOS Technique

MOS (Model Output Statistics):

To derive statistical relationship between observation and model forecast from past cases, and apply it to the real-time forecast

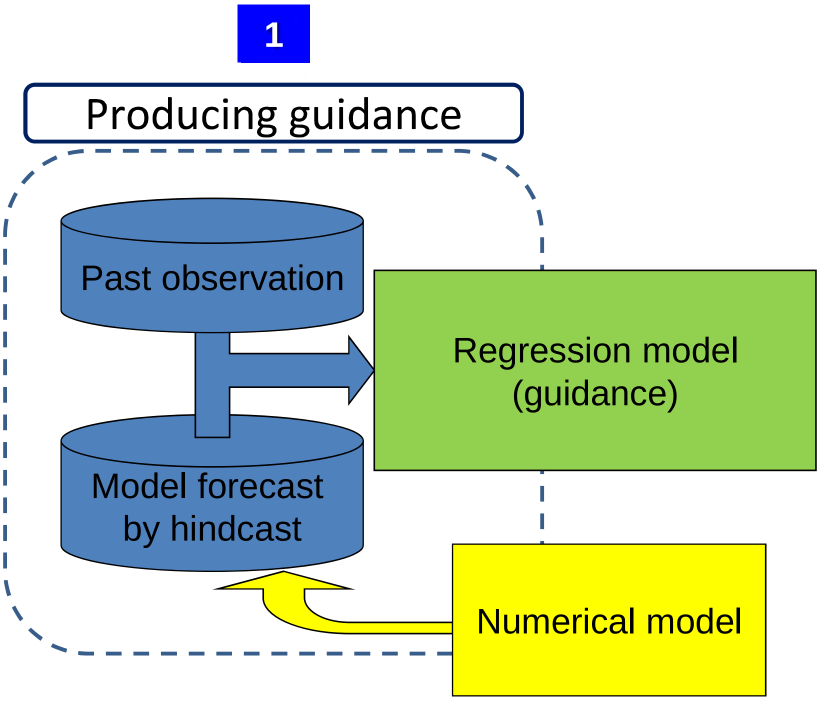
- Two types of the time series data are needed in order to produce guidance.
  - 1. Past observation (i.e., Predictands)
  - 2. Past model forecast by hindcast (i.e., Predictors)

Prepared by users

Available on TCC-HP

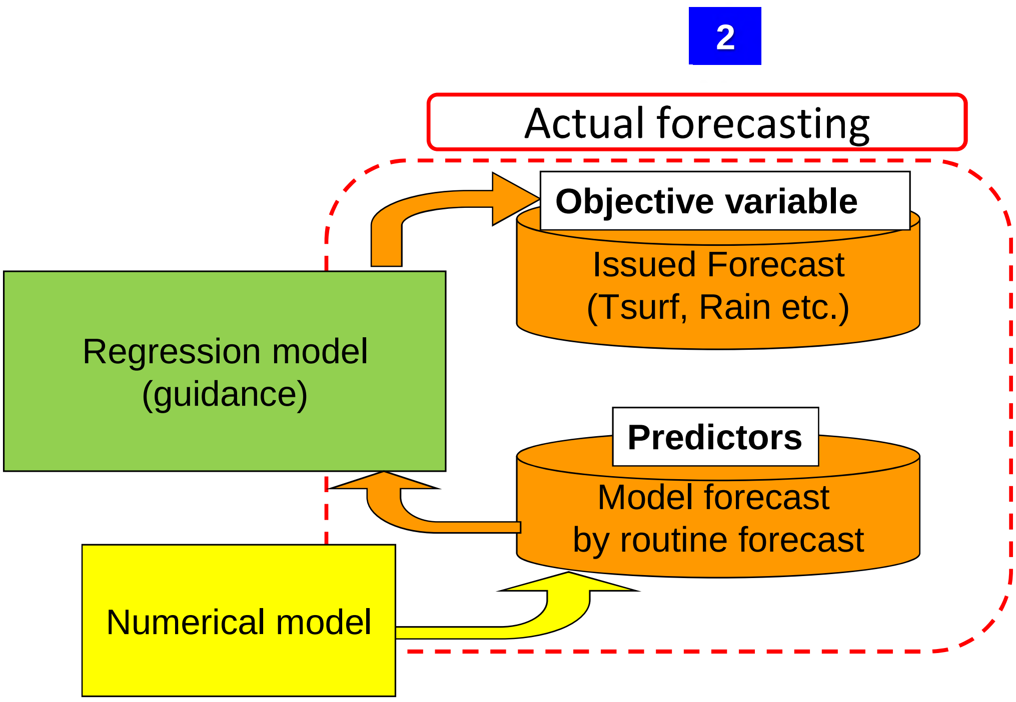
Concept of MOS Technique (1)

- **Statistical relationship** is estimated using observation and model forecast for past cases.



Concept of MOS Technique (2)

- In the real-time forecast, model results are applied to the **statistical relationship** to obtain objective variable



Single Regression

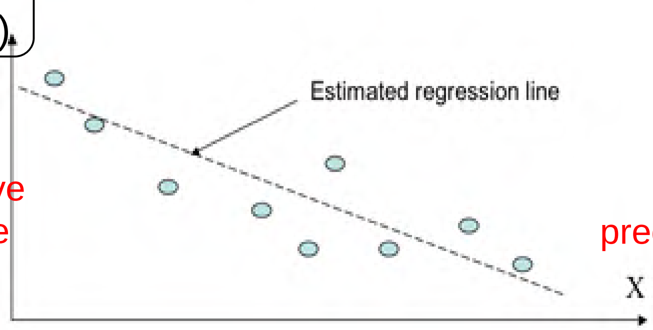
- Single regression is the relationship between **one explanatory variable** (predictors) and **objective variable** (ex. temp. rainfall).
- Single regression model is written as

$$Y = aX + b + \varepsilon$$

Y: predictand X: predictor
a: regression coefficient b: constant,
ε: error term

Predictand (e.g., temp., precipitation)

Predictor (i.e., model output)



objective variable

predictors

Multiple Regression

- More than one predictors are employed in multiple regression.
- It is assumed that the objective variable is the sum of a linear combination of predictors.

Example: **two** predictors

$$Y = a_1X_1 + a_2X_2 + b + \varepsilon$$

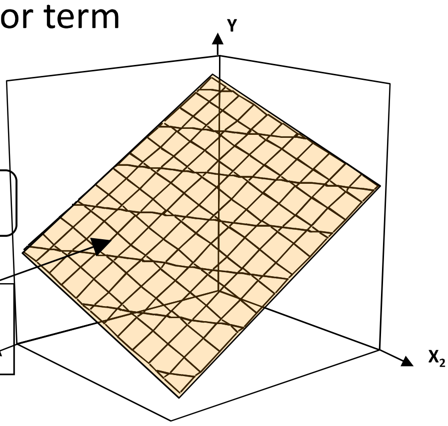
a_1, a_2: regression coefficient
b: constant
ε: error term

Predictand (e.g., temp., precipitation)

Predictor 1 (i.e., model output)

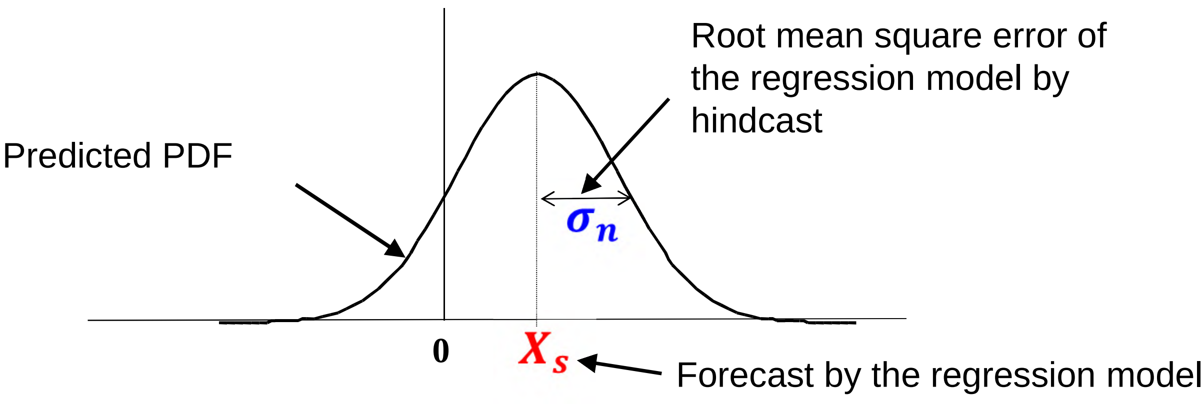
Predictor 2

Predictand will be near this plane.



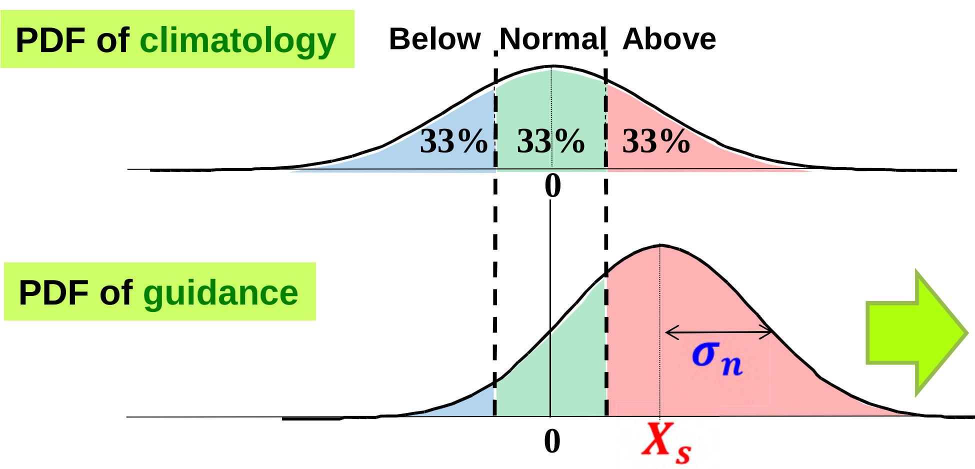
From Regression Model to Probability

- Probability Density Function (PDF) is assumed to be a **normal distribution.**
  - **Mean (x_s):** Prediction value by the regression model
  - **Standard deviation (σ_n):** RMSE of the regression model.



Estimation of Probability for 3-category

- The threshold values for 3 categories are determined from the past observation (1981 to 2010).
- Probability for each category (below-, near-, above-normal) is calculated by PDF and the threshold values.



Issued Forecast		
Below	Normal	Above
10%	30%	60%

Normalization of Precipitation Data

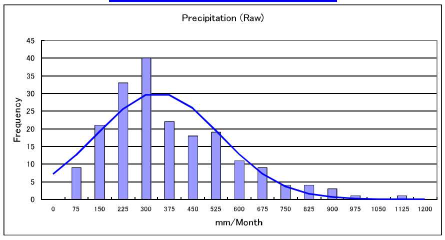
- **Normal distribution** is assumed in the regression model.
- As for temperature, its distribution is generally approximated by a normal distribution.

Meanwhile,

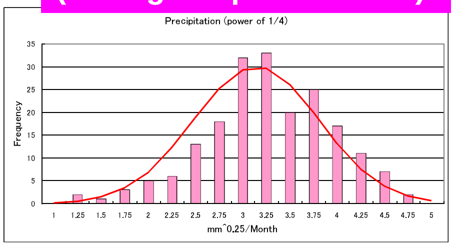
- As for precipitation, its distribution does not represent a normal distribution, and it's usually approximated by a gamma distribution.
- In order to create guidance, precipitation data need to be normalized.
- Power of 1/4 for precipitation ($RAIN^{1/4}$) is approximated by a normal distribution.

Ex. Precipitation over Japan

(Raw value)



(Taking the power of 1/4)



Verification

Verification for Deterministic Forecast

● Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - O_i)^2}$$

F_i: Forecast
O_i: Observation
C_i: Climatology
N: Sample size

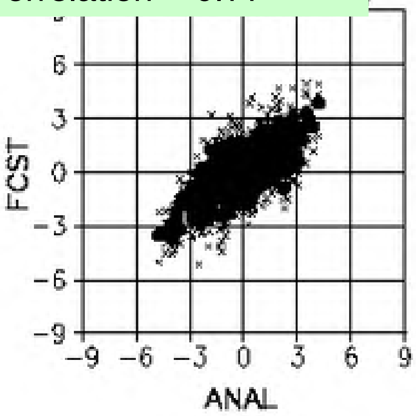
Perfect score: 0

● Anomaly Correlation Coefficient (ACC)

$$ACC = \frac{\sum_{i=1}^{N}(F_i - C_i)(O_i - C_i)}{\sqrt{\sum_{i=1}^{N}(F_i - C_i)^2}\sqrt{\sum_{i=1}^{N}(O_i - C_i)^2}}$$

Range: -1 to 1.
Perfect score: 1

Correlation=+0.77



Probabilistic forecast

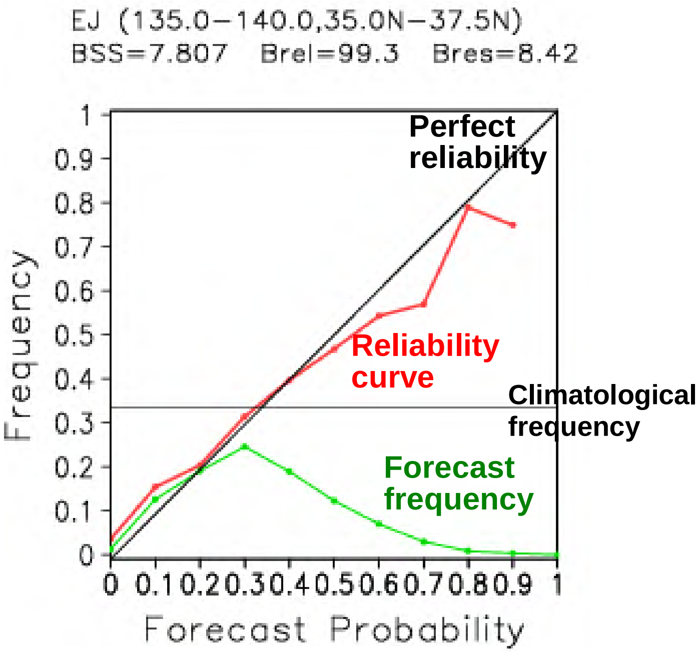
Reliability Diagram

● Red line (reliability curve);
plotted the observed frequency(Y-axis) against the forecast probability(X-axis)

Probabilistic forecast becomes better the more the reliability curve fit to 45° line (perfect reliability).

●Green line denotes forecast frequency (sharpness diagram);

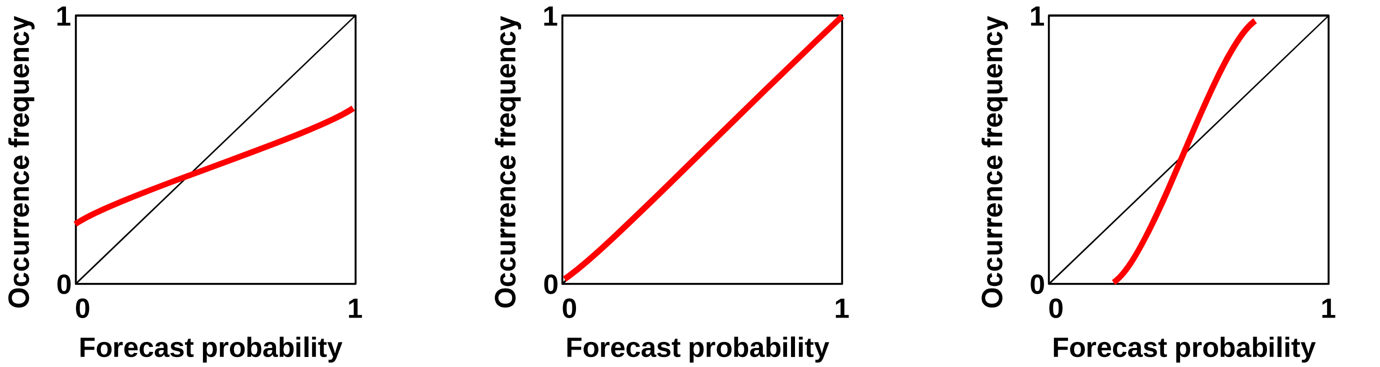
- •If most of the forecast probabilities are near the climatological frequency = unsharp
- •If probabilities near 0 and 1 (100%) are often used = sharp



Probabilistic forecast

Over/under Confidence

Over confidence | **Perfect reliability** | **Under confidence**

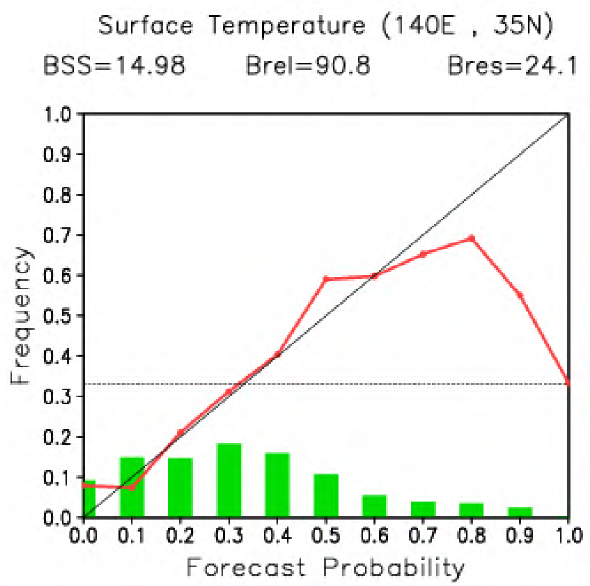


- ✓ Predicted probabilities are overestimated as compared with actual
- ✓ Predicted probabilities are underestimated as compared with actual

Probabilistic forecast

Interpretation of Reliability Diagram

Example



- The forecast is generally reliable for below 60%, while over-confident over 70%.

✓ Maximum probability should be suppressed under 60%

Probabilistic forecast

Brier Score (BS)

- Brier score is mean squared error of the probability forecasts.

$$BS = \frac{1}{2N}\sum_{i=1}^{N}\sum_{m=1}^{3}(p_i^m - o_i^m)^2$$

p_i^m : forecast probability

o_i^m : observed occurrence (0 or 1)

N : forecast frequency

m : category

Range: 0 to 1

Smaller score indicates better forecast (Perfect score: 0)

Forecast (Below, Near, Above): (0.1, 0.3, 0.6)

Observation: Above normal (0, 0, 1)

BS: $\{(0.1-0)^2+(0.3-0)^2+(0.6-1)^2\}/2 = 0.13$

Probabilistic forecast

Brier Skill Score (BSS)

- Brier skill score is ***skill*** relative to a reference forecast (usually climatology).

$$BSS = 1 - \frac{BS}{BS_{reference}}$$

$$BSr = \frac{1}{3}$$

- Perfect score: 1
- BSS>0 : better than the climatological forecast.
- BSS<0 : worse than the climatological forecast.