MME Seasonal Prediction & its Localization using CLIK
Climate Variability
Climate Prediction & Verification
Localization

&

Generating Seasonal Outlook

CIK
Climate Information Toolkit
Climate Prediction 101

Yun-Young Lee
CLIMATE?
Weather is what we get,
Climate is what we expect!
Weather summary = Climate

Expectation=
mean condition of atmosphere (temp. & Prcp.)
Climate = Expectation
Climate Change = Expectation Should be changed!
Climate Prediction = Expectation of Expectation

How uncertain!
Prediction

a rigorous (often quantitative,) statement forecasting what will happen under specific conditions

(in meteorology)

- What: atmospheric state (weather)

- Conditions: current state, physical rules, external forcing factors

Atmosphere is dynamical system!

\[
\frac{d\vec{X}}{dt} = F(\vec{X},a)
\]

\[
\vec{X}(t_0 + \tau) = \vec{X}(t_0) + \int_0^\tau F(\vec{X}(t),a(t)) dt
\]
Determinism

Perfect prediction is possible when we have knowledge of all necessary “conditions”

\[
\frac{d\vec{X}}{dt} = F(\vec{X}, a)
\]

Chaos

Small difference in the initial state cause huge difference later in the deterministic nonlinear system.

Our knowledge is never perfect!

→ perfect forecast is impossible...
Predictability

Depends on **what to predict**

**Lead time** ($\tau$)
- Temperature of this room tomorrow
- Temperature of this room in 30 days later
- Temperature of this room in 30 years later

**Location**
- Temperature of Busan (Korea)
- Temperature of Antofagast (Chile)
- Temperature of Villa Las Estrellas (Antarctica)

**Physical variables**
- Temperature
- Rainfall
- Wind speed

**Time-scale of predictand**
- Mean Temperature during a day
- Mean Temperature during a month
- Mean Temperature during a century
Signal & Noise

Two scales

• **Fast and small** scale processes:  **noise**
  – Weather by tropical cyclone etc.

• **Slow and large** processes:  **signal**
  – Climate by ENSO, ITCZ, monsoon, MJO and so forth

• What is the **Signal**? (How we can “see”?)
  – Tendency of weather that has to be physically caused by **slow varying processes**
Potential predictability

Matter of 

Signal & Noise

\[ X = X_s + X_n \]

Measured by relative magnitude (variance) of signal and noise

Signal >> Noise : more predictable

Signal << Noise : less predictable
Climate prediction

How long (time domain)?

Time mean of weather

Subseasonal forecast

Climate prediction
Weather statistics

Primary seasonal weather statistics: seasonal **mean**
2002 summer (JJA) rainfall

Monthly prec. Anomaly (Aug)

Summer mean prec. anomaly

Typhoon “RUSA” passed at 8/31 (1000mm a day)
Methods

- Statistical (Empirical)
  - Use observed relationship of climate system to predict future
  - Linear

- Dynamical
  - Based on “physical law” of climate system and expect to mimic “the memory”
  - Nonlinear
Pros/Cons

**Statistical/Empirical**
- Simple and cheap
- Based on (observation) data
- Short observing history. Do we have enough?
- Unprecedented events predictable ????

**Dynamical**
- Complex and expensive
- Based on Law
- Is our understanding accurate?
Statistical forecasting

(0) Climatology
- Baseline of seasonal forecasting
- “Nothing particular, Sir.”
  \[ x(t + 1) = \bar{x} \]
  - Rainfall amount will be similar to 30 year average.
  - I don’t know? (33%:33%:33%) or Near Normal?

(1) Persistence
- Assume that future will be the same as it is now.
  \[ x'(t + 1) = x'(t) \]
  - Often Close to people’s expectation.
  - Effective when the autocorrelation is large (e.g. ENSO forecast)

(2) Regression
- The most popular method and many variations
  \[ x'(t + 1) = ay(t) + b \]
  - \( x \): predictand (e.g. rainfall at a station)
  - \( y \): predictor (e.g. NINO3.4 SST)
Regression based forecast

Question #1: Predictor selection
- How to define predictor (y)?
- By definition, predictor should cause some changes in variation of predictand.

Question #2: appropriate Function
- How to define a and b?
- Your choice: linear, nonlinear, single, multi....complex ones are not necessarily better.

\[ x'(t + 1) = ay(t) + b \]

Predictand: my mood in the morning
Predictor? Relationship?

- Should be based on Physical relationship between predictors and predictands
- Predictor cannot be tiny signal in the seasonal forecast
- Keep “doubt” on the possibility of selection by chance
- Selected predictor should be validated with separate data

✓ If they give similar results, the simpler is the better!
Dynamical forecast

- Use GCM: Global Climate Model
- It used to be called “General Circulation Model”
Dynamical forecast

- Governing Equations ➔ Written as computer program code (NWP)

\[
\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla) \mathbf{u} = \nabla \Phi - 2\Omega \times \mathbf{u} - \frac{1}{\rho} \nabla p + \mathbf{f}
\]

\[
\frac{\partial \rho}{\partial t} + \nabla (\rho \mathbf{u}) = 0 \quad \iff \quad \frac{D \rho}{Dt} = -\rho \nabla \cdot \mathbf{u}
\]

\[
\frac{\partial \theta}{\partial t} + \mathbf{u} \cdot \nabla \theta = l
\]
GCMs

- Coupled GCM
  - Atmosphere
  - Ocean
  - Sea-Ice
  - Land surface
  - Chemistry
  - Biosphere
Numerical modeling

**Issue**

- Digitization (physical variable is continuous, but computer needs digitization”)
  - Resolution, subgrid-scale parameterization
- Unknown processes, tunable parameters
- Initialization (for forecasting)

**NOT the same with NATURE**
**NO perfect GCM**
Initialization
Estimating Current status of climate system

- Preparing the beginning climate state of GCM with available observation
  - Balance between Wrong GCM vs Wrong OBS.
  - Balance between components (Atm, Ocn)
Ensemble Forecasting

- Run many times
  - Starts from slightly different initial conditions
Multi Model Ensemble Forecasting

- Run with many models

Which one??
Use all!

A way to **reduce prediction uncertainties** generated when any single model is selected (to avoid extremely wrong forecast), in the end, to **improve overall prediction skill**!
Collection of Dynamic ensemble seasonal prediction data from NMHS and research institutes (14 operations/institutions from 10 countries)
<table>
<thead>
<tr>
<th>Nation</th>
<th>Organization</th>
<th>Acronym</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Bureau of Meteorology</td>
<td>BoM</td>
</tr>
<tr>
<td>Canada</td>
<td>Meteorological Service of Canada</td>
<td>MSC</td>
</tr>
<tr>
<td>China</td>
<td>Beijing Climate Center, China Meteorological Administration</td>
<td>BCC</td>
</tr>
<tr>
<td>Chinese Taipei</td>
<td>Central Weather Bureau</td>
<td>CWB</td>
</tr>
<tr>
<td>Italy</td>
<td>Centro Euro-Mediterraneo sui Cambiamenti Climatici</td>
<td>CMCC</td>
</tr>
<tr>
<td>Japan</td>
<td>Japan Meteorological Agency</td>
<td>JMA</td>
</tr>
<tr>
<td>Korea</td>
<td>APEC (Asia-Pacific Economic Cooperation) Climate Center</td>
<td>APCC</td>
</tr>
<tr>
<td></td>
<td>Korea Meteorological Administration</td>
<td>KMA</td>
</tr>
<tr>
<td></td>
<td>Pusan National University</td>
<td>PNU</td>
</tr>
<tr>
<td>Russia</td>
<td>Hydrometeorological Centre of Russia</td>
<td>HMC</td>
</tr>
<tr>
<td></td>
<td>Main Geophysical Observatory</td>
<td>MGO</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>United Kingdom Met Office</td>
<td>UKMO</td>
</tr>
<tr>
<td>USA</td>
<td>National Centers for Environmental Prediction, NOAA</td>
<td>NCEP</td>
</tr>
<tr>
<td></td>
<td>National Aeronautics and Space Administration</td>
<td>NASA</td>
</tr>
</tbody>
</table>
APCC operational forecast

1. Collecting model data
2. Preprocessing (data reconstruction, QC and so forth)
3. Calculation & visualization (MME & verification)
4. Issuing prediction (& graphics)

- Middle of month (-1)
- Second half of month (-1)
- First half of month (0)
- Middle of month (0)
APCC Climate Information

Seasonal outlook (global)  ENSO & IOD prediction

Climate Outlook for April - September 2019

(Dated: 29 Mar 2019)
During February 2019, El Niño conditions were strengthened with positive sea surface temperature anomalies across the equatorial Pacific Ocean. The updated APCC ENSO outlook suggests a greater than 55% probability for moderate El Niño during April – June, and a greater than 80% probability for El Niño conditions during July – September 2019. Positive temperature anomalies are likely to prevail over the tropical Pacific, subtropical South Pacific, northern North Pacific, maritime continent, tropical Atlantic, western and central Indian Ocean, southern Africa, northern South America for April – September 2019. Below normal precipitation anomalies are expected for the central off-equatorial Pacific and the seas off the north coast of Australia, and above normal precipitation anomalies are expected for the equatorial Pacific for April – September 2019.

Temperature and Precipitation Outlook:

1. Forecast for April – June 2019

Strongly enhanced probability for above normal temperatures is predicted for the tropical Pacific, northwestern and northern North Pacific, subtropical South Pacific, maritime continent, tropical and subtropical Atlantic, northern South America, southern Africa, and the Indian Ocean (excluding the eastern part). Enhanced probability for above normal temperatures is expected for the Arctic, Canada, Australia, and north Africa. Enhanced probability for below normal temperatures is predicted for the southern Indian Ocean near Australia and the Antarctic Ocean near South America. Strongly enhanced probability for above normal precipitation is expected for the equatorial Pacific. Strongly enhanced probability for below normal precipitation is predicted for the Philippines, Philippine Sea, and the central off-equatorial North Pacific. Enhanced probability for above normal precipitation is expected for the seas off the north coast of Australia, Bay of Bengal, Arabian Sea, Caribbean Sea, and the tropical Atlantic.

Temperature at 2m for April-June 2019

Fig. 3. Multi-model ensemble (MME) forecasts of SST anomalies for April – June 2019 (top) and July – September 2019 (bottom). Anomalies are computed with respect to the common base period of participating models in the APCC MME prediction (1983-2010).

Fig. 4. Probabilistic MME forecasts of the status and intensity based on 3-month mean Niño3.4 index for four overlapping 3-month mean periods. Anomalies are computed with respect to the common base period of participating models in the APCC MME prediction (1983-2010).
APCC MME skill improvement

More skillful compared to WMO & NMME

By YM Min (APCC)

Hindcast Skill: ACC

it keeps improving!

RT Forecast Skill: T850, ACC
Evaluation of Seasonal Prediction

Yun-Young Lee
How GOOD?

- Evaluation of forecast : verification
Verification

- Evaluation: measure of **closeness**
Verification

- Evaluation: depends on Dimension/Viewpoint
Deterministic continuous forecast

**Various measures**

- **MSE** (Mean Square Error), **RMSE** (Root MSE)
  \[
  MSE = \frac{1}{N} \sum_{i} (F_i - O_i)^2
  \]

- **MSSS** (Mean Square Skill Score)
  - Conventional form of “skill score”
  - \( 1 - \frac{MSE}{MSE_c} \), MSE : error/penalty, MSE_c : error of climatology forecast

- **TCC** (Temporal Correlation Coefficient), **ACC** (Anomaly Correlation Coefficient)
  \[
  ACC = \frac{\sum_{i=1}^{N} w_i (f_i - \bar{f})(o_i - \bar{o})}{\sqrt{\sum_{i=1}^{N} w_i (f_i - \bar{f})^2 \sum_{i=1}^{N} w_i (o_i - \bar{o})^2}}
  \]

\[skill \ score = \frac{SCORE_{forecast} - SCORE_{reference}}{SCORE_{perfect \ forecast} - SCORE_{reference}}\]

Which is designed to give an answer for the question “What is the relative improvement of the forecast over some reference forecast?”
Verification

- Evaluation: depends on **Dimension/Viewpoint**
Examples

\[ F(t) = O(t) + 100 \]

RMSE?
But, Temporal Correlation?
Probabilistic forecast

- **Brier score (BS)**
  - MSE of prob. forecast
  \[ BS = \frac{1}{N} \sum_i (F_i - O_i)^2 \]
  \( F = \) probability (forecast),
  \( O = 1/0 \) (actual outcome of instance)
  Eg. Binary events such as “rain” or “no rain”
  Range: 0 to 1, Perfect score = 0
  **Intuitively**, Higher score = Better skill?

- **Brier Skill Score (BSS)**
  \[ \text{BSS} = 1 - \frac{BS}{BS_c} \]
  \( BS \): error/penalty,
  \( BS_c \): BS of climatology forecast
  Range: -infinity to 1
  Perfect score = 1

**Skill score** = \[
\frac{\text{SCORE}_{\text{forecast}} - \text{SCORE}_{\text{reference}}}{\text{SCORE}_{\text{perfect forecast}} - \text{SCORE}_{\text{reference}}}
\]
Which is designed to give an answer for the question “What is the relative improvement of the forecast over some reference forecast?”
Probabilistic forecast (Categorical)

<table>
<thead>
<tr>
<th></th>
<th>“rain”</th>
<th>“no rain”</th>
</tr>
</thead>
<tbody>
<tr>
<td>F O Yes</td>
<td>False Alarm (F)</td>
<td>Hit (H)</td>
</tr>
<tr>
<td>Yes</td>
<td></td>
<td>False Alarm (F)</td>
</tr>
<tr>
<td>No</td>
<td></td>
<td>Correct Rejection (C)</td>
</tr>
</tbody>
</table>

**Correct forecast**

**SR (Success Rate)**
\[
SR = \frac{H+C}{H+M+F+C}
\]

0 to 1  
Perfect score = 1

**bias**
\[
bias = \frac{H+F}{H+M}
\]

0 to ∞  
Perfect score = 1

**TR (Threat Score)**
\[
TR = \frac{H}{H+M+F}
\]

0 to 1  
Perfect score = 1

**HR (Hit Rate)**
\[
HR = \frac{H}{H+M}
\]

0 to 1  
Perfect score = 1

**FAR (False Alarm Rate)**
\[
FAR = \frac{F}{F+C}
\]

0 to 1  
Perfect score = 0

Good forecast: **HR↑, FAR ↓**
Probabilistic forecast (Categorical)

- **ROC (Relative Operating Characteristics)**


**ROC score**

- Area Under ROC curve

Range: 0 to 1
- perfect: ROC score = 1
- no skill: ROC score = 0.5 (no added value)
Probabilistic forecast (Categorical)

- **ROC (Relative Operating Characteristics)**

ROC Score:
- **Perfect**: ROC score = 1
- **No Skill**: ROC score = 0.5 (no added value)


ROC scores:
- AN: 0.70
- NN: 0.59
- BN: 0.68

ROC score = Area of ROC curve

Range: 0 to 1
- perfect: ROC score = 1
- no skill: ROC score = 0.5 (no added value)
Probabilistic forecast (Categorical)

- ROC (Relative Operating Characteristics)


- Biased forecast with high ROC score
- A measure of potential usefulness

**ROC score**

= Area of ROC curve

Range: 0 to 1

- perfect: ROC score = 1
- no skill: ROC score = 0.5 (no added value)
Probabilistic forecast (Categorical)

- **HSS (Heidke Skill Score)**

  "What was the accuracy of the forecast in predicting the correct category, relative to that of random chance?"  

<table>
<thead>
<tr>
<th></th>
<th>O</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Yes</td>
<td>Hit (H)</td>
<td>False Alarm (F)</td>
</tr>
<tr>
<td>No</td>
<td>Miss (M)</td>
<td>Correct Rejection (C)</td>
<td></td>
</tr>
</tbody>
</table>

\[
HSS = \frac{\text{SCORE}_{\text{forecast}} - \text{SCORE}_{\text{by chance}}}{\text{SCORE}_{\text{perfect forecast}} - \text{SCORE}_{\text{by chance}}}
\]

\[
= \frac{\left\{ \frac{(H + C)}{n} - \left[ \frac{(H + F)(H + M) + (F + C)(M + C)}{n^2} \right] \right\}}{\left\{ 1 - \left[ \frac{(H + F)(H + M) + (F + C)(M + C)}{n^2} \right] \right\}}
\]

Range: - infinity to 1, 0=no skill, 1=perfect skill
Probabilistic forecast (Categorical)

- Reliability curve

Accurate probability forecast system

- Reliability
- Sharpness
- Resolution

Reliability Diagram: PREC, JAS (1983-200)

- Underforecasting
- Overforecasting

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# Money Problem!

**Drought expected!**

<table>
<thead>
<tr>
<th>Preparing (reservoir)</th>
<th>Drought happens?</th>
<th>Net cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes (cost)</td>
<td>Yes or No (No money loss because of drought)</td>
<td></td>
</tr>
<tr>
<td>No (no cost)</td>
<td>Yes (money loss)</td>
<td></td>
</tr>
</tbody>
</table>

---

Money Problem!
Forecast Economic Value

\[ V = \frac{E_{cli} - E_{fore}}{E_{cli} - E_{per}} \]

V=1 : perfect forecast
V=0 : climatological forecast

E_{fore} : Expected expense of forecast
E_{per} : Expected expense of perfect forecast
E_{cli} : Expected expense of climatological forecast

\[ E_{fore} = (h + f)C + mL \]

- When the forecast is perfect, \( f = m = 0 \). and \( h = \bar{o} \). Then,
\[ E_{per} = hC = \bar{o}C \]

- When the forecast is climatology. The only one kind of action will be kept.

If we do act : \( E \rightarrow C \), otherwise \( E \rightarrow \bar{o}L \).

**Decision: action of low expense.** Thus,
\[ E_{cli} = \min(C, \bar{o}L) \]

\[ V = \frac{\min(C, \bar{o}L) - (h + f)C - mL}{\min(C, \bar{o}L) - \bar{o}C} = \frac{\min\left(\frac{C}{L}, \bar{o}\right) - (h + f)\frac{C}{L} - m}{\min\left(\frac{C}{L}, \bar{o}\right) - \bar{o}\frac{C}{L}} \]
Economic Value of Probabilistic Forecast (Above normal) : GCMs

\[
V = \frac{\min \left( \frac{C}{L}, \bar{\alpha} \right) - (h + f) \frac{C}{L} - m}{\min \left( \frac{C}{L}, \bar{\alpha} \right) - \frac{C}{L} \bar{\alpha}} = \frac{\min \left( \frac{C}{L}, \bar{\alpha} \right) - f(1 - \bar{\alpha}) \frac{C}{L} + h\bar{\alpha}(1 - \frac{C}{L}) - \bar{\alpha}}{\min \left( \frac{C}{L}, \bar{\alpha} \right) - \frac{C}{L} \bar{\alpha}}
\]

(a) Monsoon(40E-160E,20S~40N)

(b) ENSO (160E-280E,20S~20N)

Cost-Loss ratio

- Single model
- MME
Forecast Verification

- Multi aspect evaluation is preferred.
- A single verification score (e.g. $R=0.5$, explaining 25% variance) cannot tell everything.

- User oriented verification would be useful.
- If not clear, use popular one.

- Difficulties in “translating” meteorological skill score into Public wording.

- Let’s see some results!!!
APCC continuous DMME (TCC)

Rainfall (JJA)

SLP (JJA)
APCC categorical PMME

ROC Score: PREC, AMJ (1983-2010)

Above-Normal

Heidke Skill Score: PREC, AMJ (1983-2010)
Thank you.