2022년 APEC기후센터 기후정보서비스 사용자워크숍

기후예측 생산 및 검증

- 2022. 10. 27
- APEC 기후센터
- 이현 주
다중모델 양상별의 이해

• 양상별 예측이란?
• 다중모델 양상별
• 결정론적 예측과 확률론적 예측
수치예보

단일 수치예보의 한계

모델의 예측시간이 길어질수록 예측 편차가 커짐

모든 관측 자료 → 수퍼컴퓨터(계산) → 예측 값 생성

수치예보 모델
- 운동방정식
- 질량보존방정식
- 열역학 방정식
- 지배방정식

출처: 기상청
Our knowledge of climate model and initial condition is not never perfect!

→ Perfect forecast is impossible.
극히 작은 값의 차이가 “초기값의 민감도”에 의해 클러스터 차이를 만든다.

[에드워드 로렌츠, 결정론적 비주기 흐름, 1963]
양상블예측

Signal >> Noise : more predictable
Signal << Noise : less predictable

양상블 멤버들의 시그널(Signal, 빨간실선)과 노이즈(Noise, 검은 실선)
다중모델 양상별 예측

잡음 감소
(Random Noise)

계통오차 감소
(Systematic Error)

More samples
: Ensembles

Cancellation of errors
: Multi-Model

다중모델 양상별(MME) 기법

- 1990년대 시작: Krishnamurti 등
- 기후모델 분야의 집단지성
- APCC(2005~ , 15개 모델), WMO-LC(2009~, 14개 모델), NMME(2011~, 6개 모델), EUROSIIP(2005~, 6개 모델)
Hindcast & Forecast

- Hindcast (Retrospective forecast)
  - 평년기간, climatology

- Forecast (real-time forecast)
  - 실제 예측

Siva Reddy, 2015, A study on global ocean analysis from an Ocean Data assimilation system its sensitivity to observations and forcing fields>

Numerical Models

Hindcasting  Nowcasting  Forecasting
Past  Present  Future


\[ e_1, e_2, \ldots, e_n \]

Hindcast  Forecast

Climatology

Anomaly = Forecast - Climatology

단정 예측 vs. 확률 예측

상자에서 음료수 1개를 꺼낸다면??

단정 예측

확률 예측

출처: 기상청
다중모델 양상별 기법

[단정예측]

<table>
<thead>
<tr>
<th>SCM</th>
<th>SPM</th>
<th>MRG</th>
<th>SSE</th>
</tr>
</thead>
</table>

- Simple composite of individual forecast with equal weighting
- Calibrated MME which is obtained from the adjusted (or corrected) single-model forecasts based on a stepwise pattern projection method (Kug et al. 2008)
- Empirically weighted MME with coefficient computed by multiple linear regression (Krishnamurti et al. 2000)
- Same as MRG, but with EOF-filtered dataset (Yun et al. 2003)

\[
P = \frac{1}{M} \sum_{i} F_{i}'
\]

\[
P = \frac{1}{M} \sum_{i} \hat{F}_{i}'
\]

\[
P = \sum_{i} a_{i} \hat{F}_{i}'
\]
확률추정방법

모수화 vs. 비모수화 기법적용

비모수화(Non-Parametric Estimate)

Empirical ranking (or counting) method
각 카테고리 해당하는 양상별 수를 하여 확률을 추정하는 방법

모수화(Parametric Estimate)

Statistical fitting method
예측자료가 특정 분포물로 따른다는 가정 하에 특정 분포의 PDF로 각 카테고리의 확률을 추정하는 방법

A Gaussian fit estimate is more accurate than counting for Gaussian distributed forecast variables (Wilks 2002; Tippett et al. 2007).

Most of operational centers use a Gaussian fitting method for tercile-based categorical probabilities of global climate variables (e.g., IRI, JMA, MSC).

• 기술적으로 간단하며, 계산시간이 빠르며, 점근적인 분포에서 정확도가 높다(예 기온의 Gaussian PDF)
"Probabilistic Multi-Model Ensemble"

\[
P(E) = \sum_{i=1}^{M} P(\text{Model}_i) \times P(E \mid \text{Model}_i)
\]

- Uncalibrated multi-model ensemble, with model weights proportional to the square root of ensemble size of individual models
**Chi-square Test**

\[ \chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \]

- **k**: number of categories
- **O**: observed frequencies in forecast
- **E**: expected frequencies

If differences are not significant at 5% sig. level.

→ **UNCERTAINTY!!!!**
Temperature at 850hPa for 2006 JJA
APCC 다중모델양상별 계절예측

통어시아 계절예측

전지구 계절예측

계절내 진동예측

11개국 15개 기관
예측자료 실시간 입수

분석, 평가 및 최적 예측값 산출
(매달 향후 1~6개월 예측)

APEC기후센터 홈페이지를 통한
온라인 예측 정보 및 데이터 제공
(매월 700여 수신처)

“The quality of one-month MME forecast is very good and that is hugely important”
(Dr. Quang Nguyen, VietNam)

### APCC 다중모델양상별 계절예측

#### [APCC MME 참여 모델 현황 (2022년 5월 기준)]

<table>
<thead>
<tr>
<th>#</th>
<th>Institute</th>
<th>Model Name</th>
<th>SST Specification (H/F)</th>
<th>Masking/OLR</th>
<th>Ens. (H/F)</th>
<th>Forecast Period</th>
<th>Hindcast Period</th>
<th>Resolution</th>
<th>File Type</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>APCC</td>
<td>SCOPS</td>
<td>Predicted/Predicted</td>
<td>O / olr</td>
<td>10/10</td>
<td>6-month</td>
<td>1982-2013</td>
<td>T159, L31</td>
<td>NetCDF</td>
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<tr>
<td>2</td>
<td>BCC</td>
<td>CSM1.1m</td>
<td>Predicted/Predicted</td>
<td>O</td>
<td>24/24</td>
<td>6-month</td>
<td>1991-2015</td>
<td>T106, L26</td>
<td>NetCDF</td>
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<td>3</td>
<td>BoM</td>
<td>ACCESS-S2</td>
<td>Predicted/Predicted</td>
<td>O / olr</td>
<td>27/11</td>
<td>5-month</td>
<td>1981-2018</td>
<td>N216(~60km), L85</td>
<td>NetCDF</td>
</tr>
<tr>
<td>4</td>
<td>CMCC</td>
<td>SPS3.5</td>
<td>Predicted/Predicted</td>
<td>O / f: olr, h: -</td>
<td>40/50</td>
<td>5-month</td>
<td>1993-2016</td>
<td>~0.5x0.5o, 46L</td>
<td>NetCDF</td>
</tr>
<tr>
<td>5</td>
<td>CWB</td>
<td>TCWB1Tv1.1</td>
<td>Predicted/Predicted</td>
<td>X / olr</td>
<td>30/30</td>
<td>6-month</td>
<td>1982-2019</td>
<td>T119, L40</td>
<td>GRIB1</td>
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<tr>
<td>6</td>
<td>ECCC</td>
<td>CANSIMpV2.1</td>
<td>Predicted/Predicted</td>
<td>X</td>
<td>20/20</td>
<td>11-month</td>
<td>1980-2020</td>
<td>T63, L35, 10x10, L85</td>
<td>GRIB2</td>
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<tr>
<td>7</td>
<td>HMC</td>
<td>SL-AV</td>
<td>Observed/Persistent</td>
<td>-</td>
<td>10/20</td>
<td>3-month</td>
<td>1990-2015</td>
<td>1.125x1.40625, L28</td>
<td>GRIB2</td>
</tr>
<tr>
<td>8</td>
<td>JMA</td>
<td>JMA/MRI-CPS3</td>
<td>Predicted/Predicted</td>
<td>O</td>
<td>10/50</td>
<td>6-month</td>
<td>1991-2020</td>
<td>T319, L100</td>
<td>GRIB2, f: Binary</td>
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<tr>
<td>9</td>
<td>KMA</td>
<td>GLOSEA6GC3.2</td>
<td>Predicted/Predicted</td>
<td>X</td>
<td>12/42</td>
<td>6-month</td>
<td>1993-2016</td>
<td>N216, L85</td>
<td>GRIB2</td>
</tr>
<tr>
<td>10</td>
<td>MetFR</td>
<td>SYS 8</td>
<td>Predicted/Predicted</td>
<td>O</td>
<td>25/51</td>
<td>5-month</td>
<td>1993-2016</td>
<td>T359, L127</td>
<td>GRIB1</td>
</tr>
<tr>
<td>11</td>
<td>NASA</td>
<td>GEOS-S2S-2.1</td>
<td>Predicted/Predicted</td>
<td>O / olr</td>
<td>4/10</td>
<td>8-month</td>
<td>1981-2016</td>
<td>288x181, L72</td>
<td>NetCDF</td>
</tr>
<tr>
<td>12</td>
<td>NCEP</td>
<td>CFSv2</td>
<td>Predicted/Predicted</td>
<td>X / olr</td>
<td>20/20</td>
<td>6-month</td>
<td>1982-2010</td>
<td>T126, L64</td>
<td>GRIB1</td>
</tr>
<tr>
<td>13</td>
<td>PNU</td>
<td>CGCMv2.0</td>
<td>Predicted/Predicted</td>
<td>O</td>
<td>35/35</td>
<td>6-month</td>
<td>1980-present</td>
<td>T42, L18</td>
<td>Binary</td>
</tr>
<tr>
<td>14</td>
<td>UKMO</td>
<td>GLOSEA6</td>
<td>Predicted/Predicted</td>
<td>X</td>
<td>28/42</td>
<td>5-month</td>
<td>1993-2016</td>
<td>N216, L85</td>
<td>NetCDF</td>
</tr>
<tr>
<td>15</td>
<td>MGO</td>
<td>MGOAM-2</td>
<td>Persistent/Persistent</td>
<td>f: O, h: - / olr</td>
<td>6/10</td>
<td>3-month</td>
<td>1979-2004</td>
<td>T42, L14</td>
<td>f: GRIB1, h: NetCDF</td>
</tr>
</tbody>
</table>

MME | 3(6)-month | 1991-2010 | 2.5°x2.5°, 1.0°x1.0° |

모델 자체 SST masking 있음: O, 없음: X, f: forecast, h: hindcast

(빨간색: 변경 모델 / 녹색: MME 참여 X)
APCC 다중모델양상별 계절예측

현업스케줄

MME 운영체계 및 일정

Data Collection
- FTP
- Model data (Hindcast/Forecast)
- Observation
- Pre-processing

Quality Check
- Communication with model holders
- Decision on model set

MME Prediction (DMME, PMME)
- Verification (Previous forecast, hindcast)
- Graphic (Individual model, MME)
- Application (Index forecast, CLIK, etc)

Outlook
- Interpretation & description of prediction
- Dissemination

Participating Institutions

APEC Climate Center

APEC Member Economies
기후예측 검증

• 검증이 무엇이고, 왜 필요한가?
• 결정론적 예측 검증방법
• 확률론적 예측 검증방법
Verification

• What is verification?
  - **Verification** is the process of comparing forecasts to relevant observations
    - Verification is one aspect of measuring forecast **goodness**
  - Verification measures the **quality** of forecasts
  - For many purposes a more appropriate term is “**evaluation**”

• Why verify?
  - **Administrative purpose**
    - Monitoring performance
    - Choice of model or model configuration (has the model improved?)
  - **Scientific purpose**
    - Identifying and correcting model flaws
    - Forecast improvement
  - **Economic purpose**
    - Improved decision making
    - “Feeding” decision models or decision support systems
Verification Skill Score

- **Skill Score**
  - **Non-categorical forecast**
    - Root Mean Square Error (RMSE)
    - Anomaly Pattern Correlation Coefficient (ACC)
    - Temporal Correlation Coefficient (TCC)
    - Mean Square Skill Score (MSSS)
    - Gilbert Skill Score (GSS)
  - **Categorical forecast**
    - Relative Operating Characteristic (ROC) score map
    - ROC Curve and Score
    - Reliability Diagram
    - Brier skill Score

Observation Data

• What is "truth" when verifying the forecast and hindcast?
  The "truth" data that we use to verify forecasts generally comes from observational data. Such as:
  - Rain gauge measurements
  - Temperature observations
  - Satellite-derived cloud cover

• Reanalysis Data
  Station observations are the best, but in the Pacific there are not enough for verification.
  Use gridded 'observational' data instead.
  - NCEP/NCAR R1 (1948~Present)
  - NCEP/NCAR R2 (1979~Present)
  - ECMWF ERA5 (1950~Present)
1) What is the average magnitude of the forecast errors?
2) How well did the forecast anomalies correspond to the observed anomalies?
Verification for Deterministic Forecast

RMSE [Root Mean Square Error]

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

\(F\): forecast  
\(O\): observation  
\(W\): weighting

What is the average magnitude of the forecast errors?

Range: 0 to \(\infty\). Perfect score: 0.
Verification for Deterministic Forecast

ACC [Anomaly Pattern Correlation Coefficient]

\[ ACC = \frac{\sum_{i=1}^{N} \omega_i (F_i - \overline{F})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^{N} \omega_i (F_i - \overline{F})^2 \sum_{i=1}^{N} \omega_i (O_i - \overline{O})^2}} \]

*Over bar means time average (climatology)*

\( F \): forecast

\( O \): observation

\( W \): weighting

How well did the forecast anomalies correspond to the observed anomalies?

Range: -1 to 1. Perfect score: 1.

WMO, 2002: Standardised verification system (SVS) for long-range forecasts LRF. Manual on the GDPS (WMO-No. 485), volume 1. >

### Verification for Probabilistic Forecast

#### The Contingency Table

<table>
<thead>
<tr>
<th>Event Forecast</th>
<th>Event observed</th>
<th>Marginal total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<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>
</tr>
<tr>
<td>Marginal total</td>
<td>H+M</td>
<td>F+C</td>
</tr>
</tbody>
</table>

- **Hit Rate** = \( \frac{H}{H+M} \)
- **False Alarm Rate** = \( \frac{F}{F+C} \)

Ex) Rainfall forecast

- **Hit**: forecast said “it will rain” and it actually rains.
- **Miss**: forecast said “it won’t rain” but it rains
- **False Alarm**: forecast said “It will rain” but it doesn’t rain
- **Correct rejection**: Forecast said “It won’t rain” and it doesn’t rain
## Verification for Probabilistic Forecast

### The Contingency Table

<table>
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<th>Event observed</th>
<th>Marginal total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Hit (H:14)</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>False Alarm (F:2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H+F</td>
</tr>
<tr>
<td>No</td>
<td>Miss (M:6)</td>
<td>Correct Rejection (C:22)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>M+C</td>
</tr>
<tr>
<td>Marginal total</td>
<td>H+M</td>
<td>F+C</td>
</tr>
</tbody>
</table>

- Hit Rate = $\frac{H}{H+M}$
- False Alarm Rate = $\frac{F}{F+C}$

**Ex) Rainfall forecast**

**Question 1)** How many times rainfall actually happened?

**Question 2)** How many times forecaster issued rainfall?
Verification for Probabilistic Forecast

**HSS [Heidke Skill Score]**

\[
HSS = \frac{(H + C) - \frac{(H + F)(H + M) + (M + C)(F + C)}{N}}{N - \frac{(H + F)(H + M) + (M + C)(F + C)}{N}}
\]

- A skill score against chance
- Relatively easy to calculate
- Range: Negative value to 1
- Perfect forecast = 1, No skill = 0
Verification for Probabilistic Forecast

ROC [Relativ Operating Characteristic] curve

- Hit Rate vs. False Alam Rate
- Hit Rate = H/(H+M)
- False Alarm Rate = F/(F+C)

What is the ability of the forecast to discriminate between events and non-events?

Range: 0 to 1. Perfect score: 1. 0.5 indicates no skill.

감사합니다.