기후예측시스템의 이해

김유진
예측운영과 예측팀
APEC 기후센터

기후예측

과거에서 기대할 수 있는 날씨 특성에 비해 원하는 시점의 날씨 특성이 어떠할 것인지에 대한 과학적인 설명

네이버 내일 온도 예보

네이버 월간 온도 예보

평년=기후평균값
AN, NN, BN
주평균 and 월평균

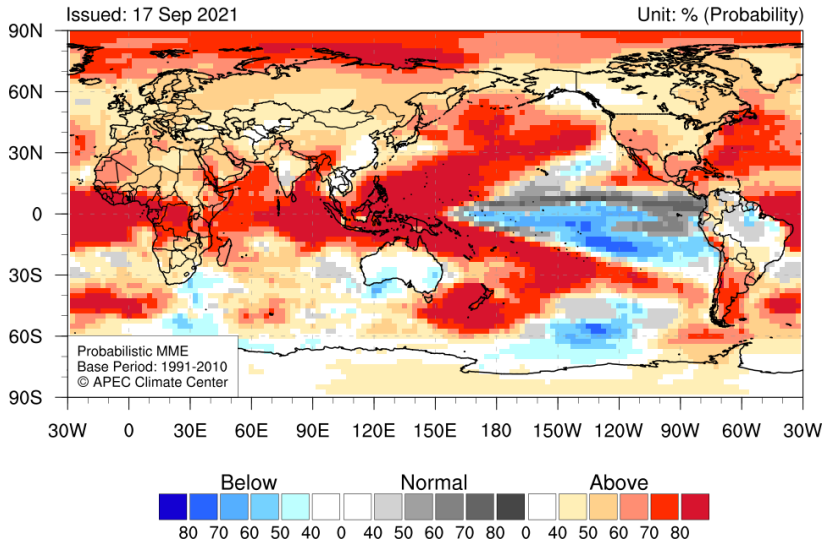
기후예측 장기예보 장기전망
계절 예측 계절내 예측

전구 온도/강수 계절 예측

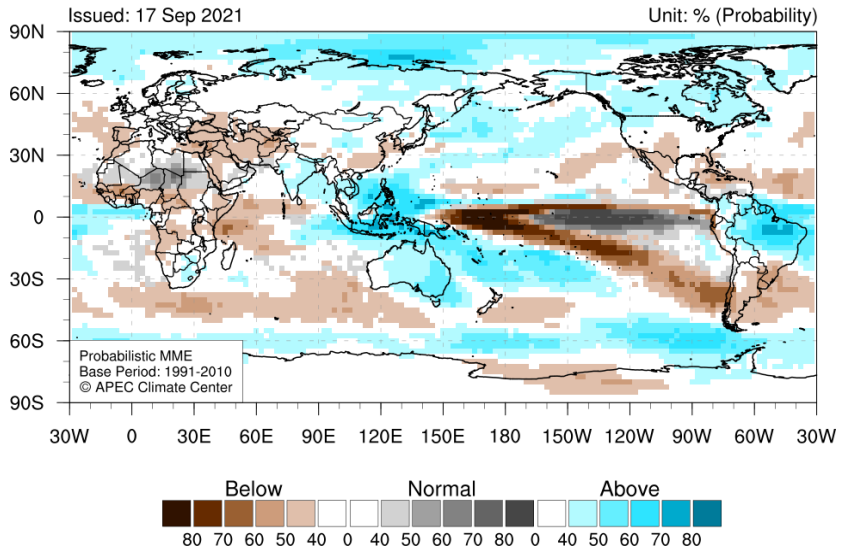
- **3개월 평균 기후 확률 예측 from APCC MME (multi model ensemble)**

9월 ➡ 10-11-12 예보

Temperature at 2m for October-December 2021



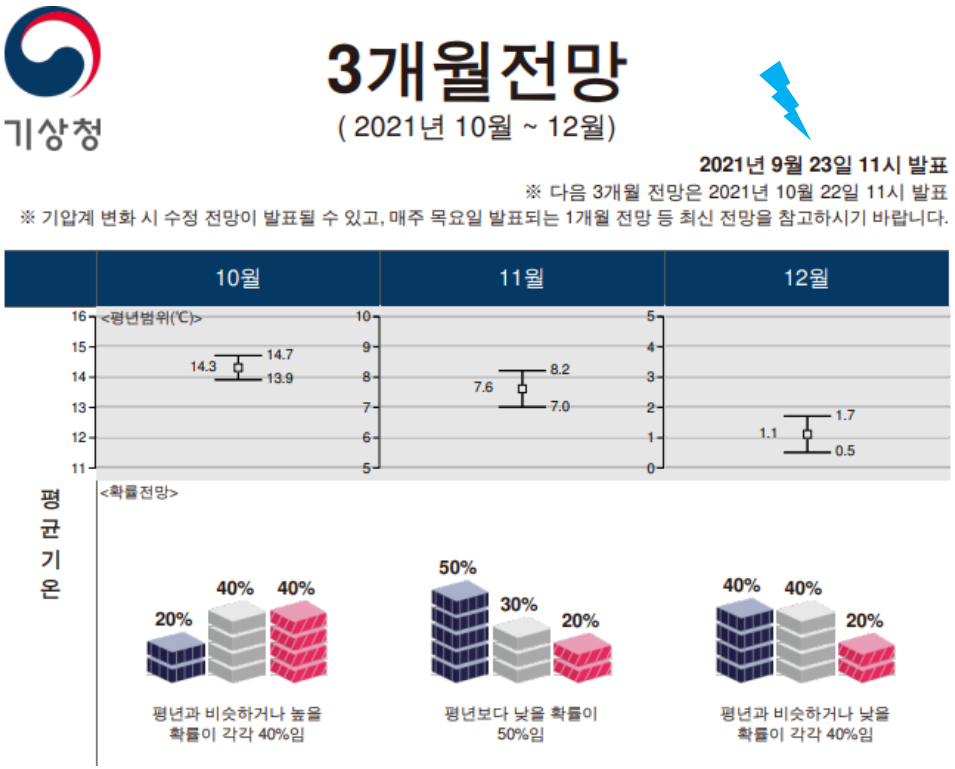
Precipitation for October-December 2021



APEC Climate Center:
https://apcc21.org/ser/outlook.do?lang=en
평년 기후(과거 20년: 1991-2010)에 대한 3개 범주(BN, NN, AN)로 분류,
향후 3개월 동안 각 범주가 될 확률 예측

우리나라 기상청의 장기전망

- 우리나라 온도 3개월 전망

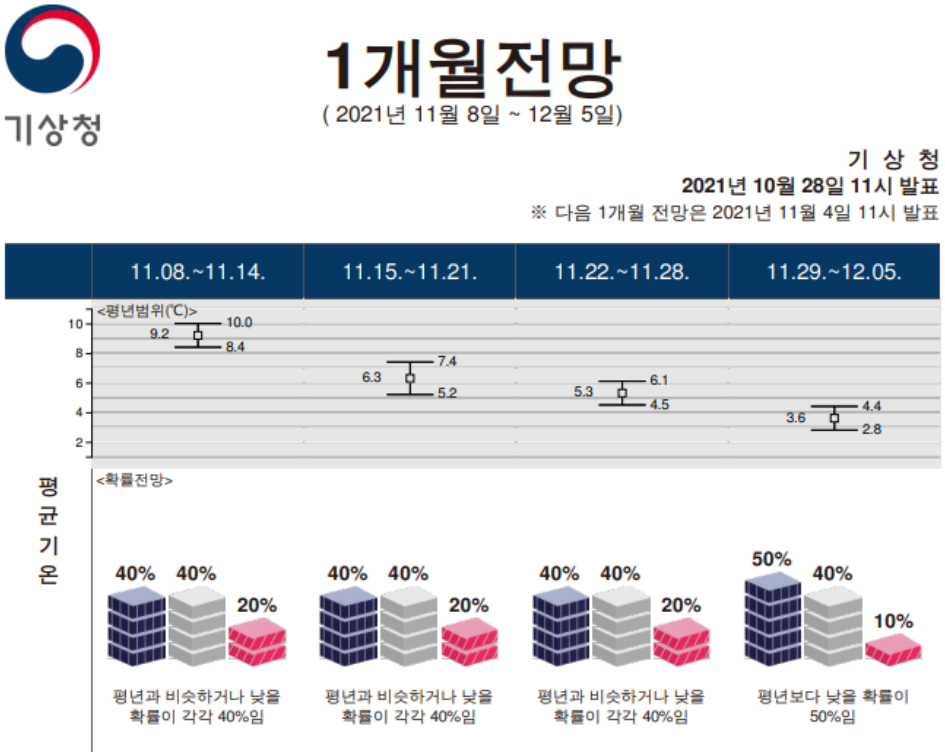


Seasonal outlook
계절예측
1개월 후 1-3개월
월별 and 계절별 평균

https://www.weather.go.kr/w/weather/long_term/month3.do

우리나라 기상청의 장기전망

- 우리나라 온도 1개월 전망



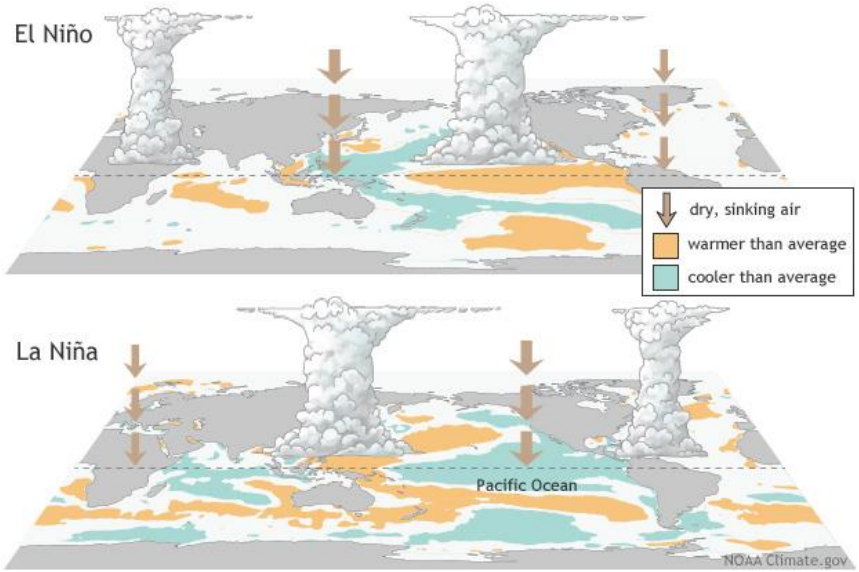
Subeasonal to seasonal (S2S)
계절내 예측
10일 후 1개월 이내
주별 평균

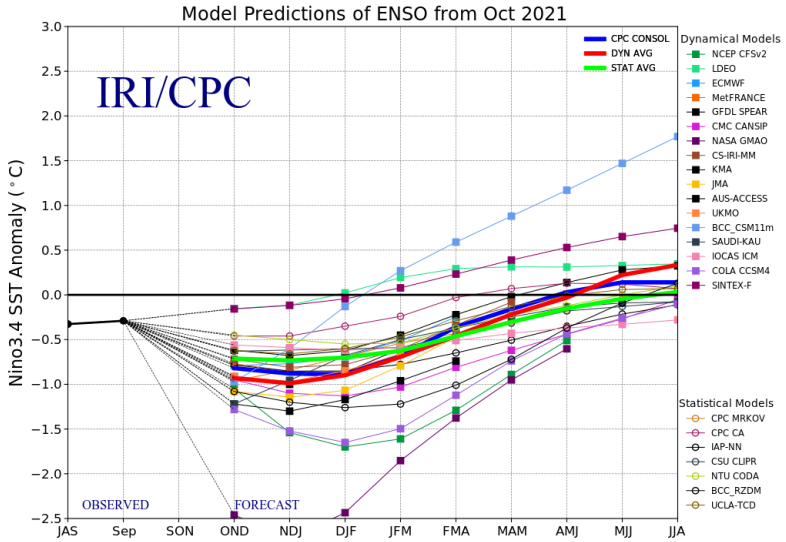
비교적 최근에 예보 시작

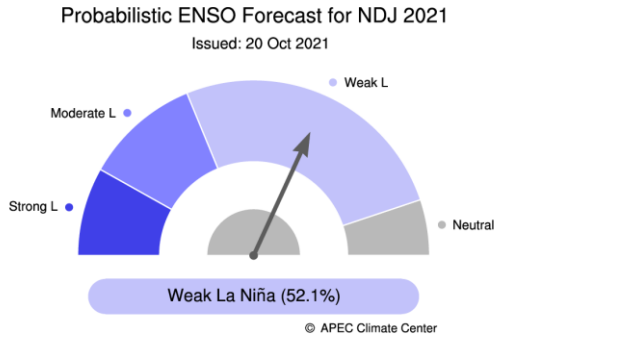
https://www.weather.go.kr/w/weather/long-term/month1.do

ENSO 예측

El Niño & La Niña (El Niño-Southern Oscillation) 전지구적, 장기적 영향







https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/?enso-sst_table
https://apcc21.org/ser/eastasia/outlook.do?lang=ko

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   - 통계모델
   - 우리나라 장기예보의 과정

3. 기후예측 정보의 이해
   - 앙상블 예측
   - 결정론적 예측, 확률론적 예측
   - Hindcast/Forecast
   - 검증 정보

기후예측 시스템 개론

- 역학 모델
- 통계 모델
- 우리나라 장기예보의 과정

역학 모델 vs. 통계모델

Dynamical model

Use complex dynamical numerical models of the main Earth system component

Statistical model

Use historical relationship between regional physical variables and climate phenomena

- 통계모델은 1800년대 후반부터 사용 역학모델은 상대적으로 최근에 도입
- 역학적 기후예보는 상대적으로 최근에 도입되었지만 빠르게 성장

역학 모델 (수치모델)

- 역학모델을 이용한 날씨 예보는 1950년대부터... (Troccoli, 2010)
- 역학모델은 해양-육지-대기가 충분히 결합되어 물리 법칙(heat, momentum, water fluxes)이 격자 단위로 계산

- 계절예보에 역학적 수치예보모델이 사용된 것은 상대적으로 늦음 (90년대 중반)
- 최초: NOAA's CPC CFS, ECMWF's SEAS systems
- 날씨예보와 많은 부분을 공유할 수 있어, 급속도로 발달
- APCC MME(2008), WMO LC MME 다중역학모델

- But, 비용이 많이 들고 운영이 상대적으로 어려움(통계모델)
- 우리나라 대학 PNU-CGCM, SNU-GCM
- 모델 격자와 실제 예측지점과의 괴리: Downscale, 통계적 후처리

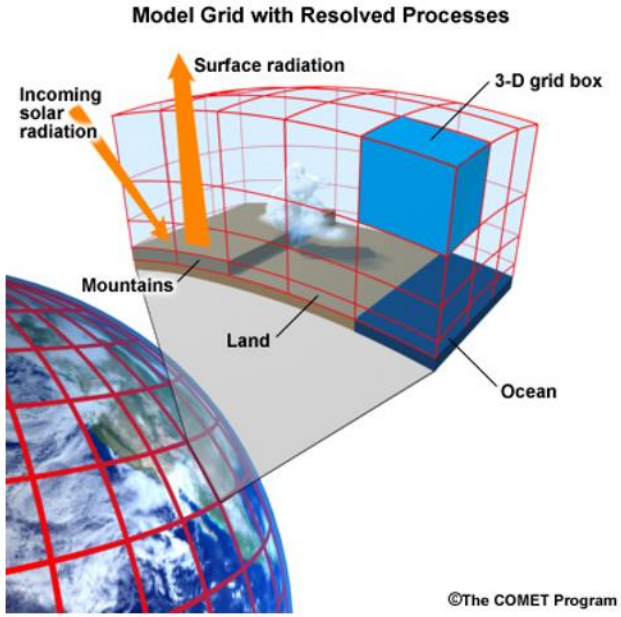
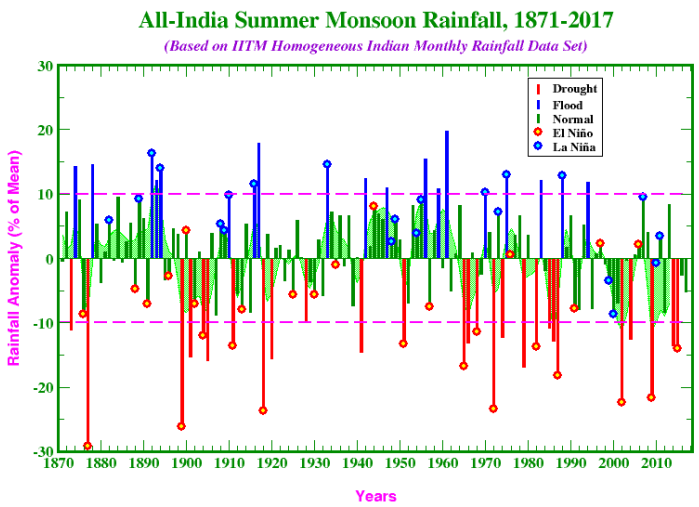


Figure 1. Schematic of a dynamical model used for seasonal climate prediction courtesy of UCAR COMET Program.1

https://climateai.medium.com/a-very-brief-history-of-seasonal-climate-forecasting-for-agriculture-8948736748ac
<Troccoli, 2010: Review Seasonal climate forecasting. Meteorol. Appl. 17:252-268.>

통계 모델

- 운영이 상대적으로 용이, 계산자원 비용 이점
- 1870s, Indian Monsoon prediction fail (1877-1878) – Indian famines – Research carried out the the Indian Meteorological Department (IMD) (Troccoli 2010)
- Southern Oscillation (SO) – pressure over South Pacific and the Indonesian region (Walker, 1924)

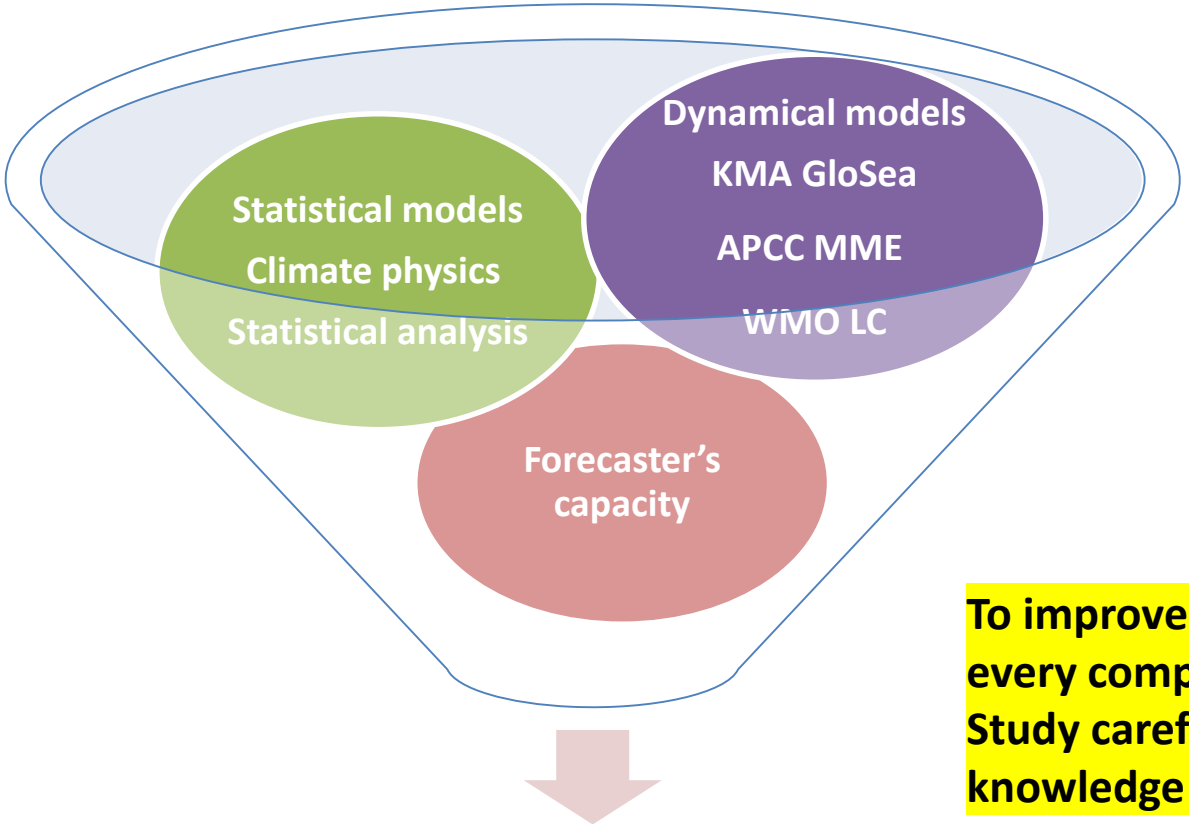


- 1970s, relationship between SO and El Nino, an inter-annual warming of SST along the equatorial Pacific South American coast is used to seasonal prediction (Harrison et al. 2008)
- Statistical models:
- Relationships between relatively stationary climate phenomena and regional atmospheric variables
- Changes of 'relationships' in longer-period

<Troccoli, 2010: Review Seasonal climate forecasting. *Meteorol. Appl.* 17:252-268.>
<Walker, 1924: Correlation in seasonal variations of weather. IX. A further study of world weather. *Memories of the Indian Meteorological Department* 24(9): 275-332.>
<Harrison et al., 2008: Seasonal forecasts in decision making. *In Seasonal Climate: Forecasting and Managing Risk, NATO Science Series*. Springer Academic Publishers: Dordrecht, Netherlands;13-42.>

우리나라의 장기 예보

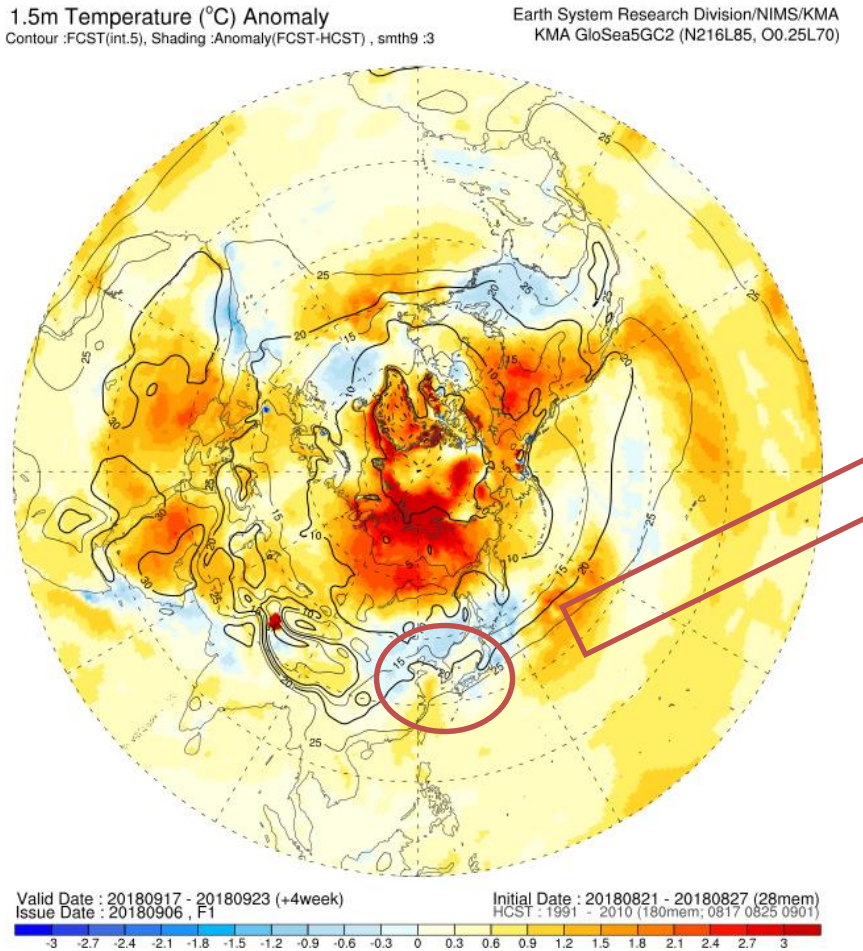
- **Component of operational climate prediction**



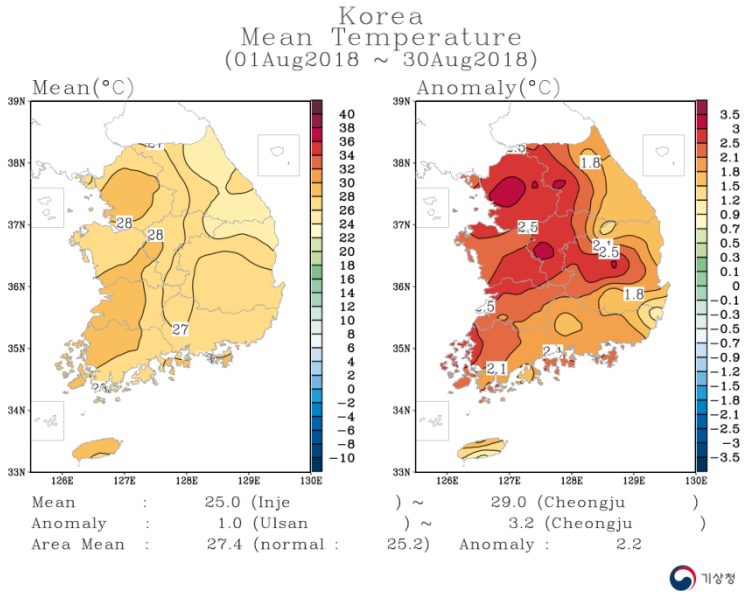
To improve forecast skill, every components are important. Study carefully and expand your knowledge on climate forecast.

Operational dynamical model

- **KMA running model for Korean operational forecast**



South Korea

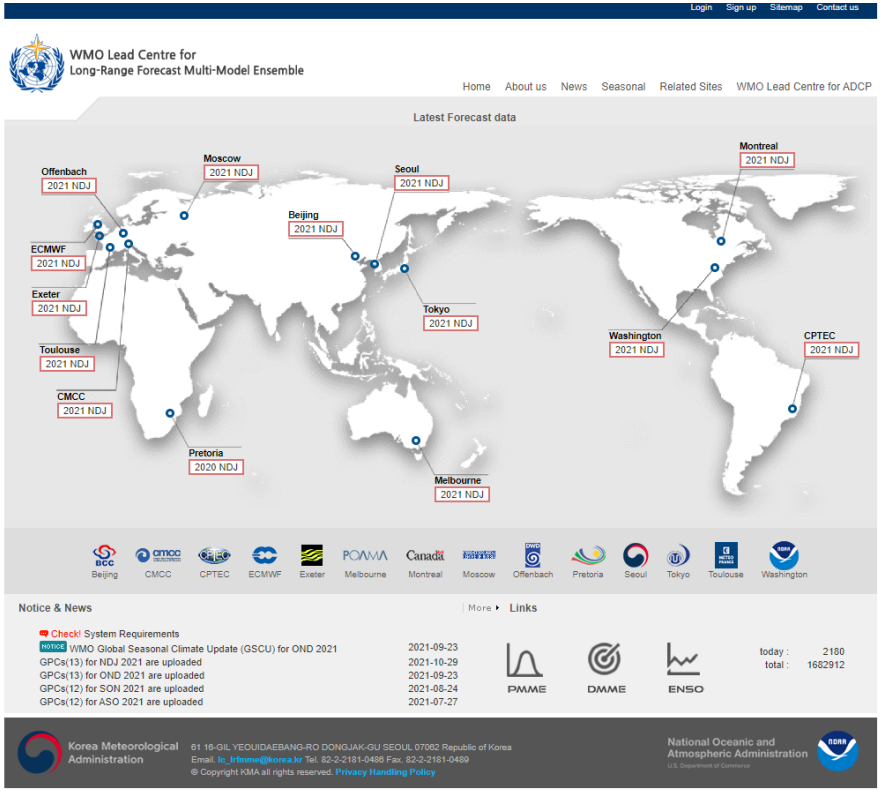


KMA GloSea5GC2
2018 Aug 27 Issue
17 Sep – 23 Sep

Operational dynamical model

APCC MME

WMO LC MME



다중모델앙상블
여러 역학수치모델 사용, 객관적 예측정보

Statistical Model

- 지역기후현상과 물리변수들의 상관관계(원격상관관계)
- 통계기후예측모델 - equation
- Statistical model to predict Northeast Asia summer precipitation
- Practically considered in the real operation by KMA

NCEP 계절예측시스템과 정준상관분석을 이용한
북동아시아 여름철 강수의 예측

권민호* · 이강진

한국해양과학기술원 해양순환기후연구부, 426-744, 경기도 안산시 상록구 해안로 787

A Prediction of Northeast Asian Summer Precipitation Using the NCE
Climate Forecast System and Canonical Correlation Analysis

MinHo Kwon* and Kang-Jin Lee

Ocean Circulation and Climate Research Division,
Korea Institute of Ocean Sciences and Technology, Gyeonggi 426-744, Korea

Abstract: The seasonal predictability of the intensity of the Northeast Asian summer monsoon is low while that c
western North subtropical high variability is, when state-of-the-art general circulation models are used, relatively high
western North Pacific subtropical high dominates the climate anomalies in the western North Pacific-East Asian re
This study discusses the predictability of the western North Pacific subtropical High variability in the National Cente
Environmental Prediction Climate Forecast System (NCEP CFS). The interannual variability of the Northeast
summer monsoon is highly correlated with one of the western North Pacific subtropical Highs. Based on this relatio
we suggest a seasonal prediction model using NCEP CFS and canonical correlation analysis for Northeast Asian su
precipitation anomalies and assess the predictability of the prediction model. This methodology provides significant skill in
the seasonal prediction of the Northeast Asian summer rainfall anomalies.

Keywords: monsoon, seasonal prediction, the western North Pacific subtropical high, canonical correlation analysis

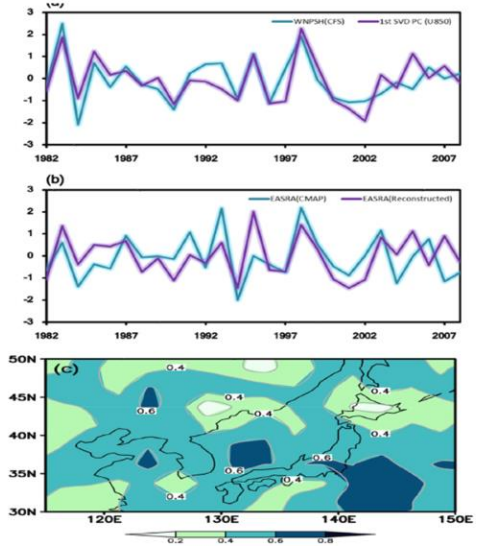


Fig. 3. (a) WNPSH predicted by NCEP CFS (blue line) and time series corresponding to the leading SVD mode of 850 hPa zonal winds (purple line). (b) EASRA from CMAP (blue line) and EASRA predicted by the CCA model (purple line). (c) Maps of the point by point correlation coefficients between JJA precipitation anomalies from CMAP and the CCA model for the

Statistical Model

- Statistical forecast model for Changma (Korean summer rainy season)
- Considered in the real operational forecast by KMA
- Changma phenomena, limitation of period

The Development of a Statistical Forecast Model for Changma

SEUNG-EON LEE AND KYONG-HWAN SEO

Division of Earth Environmental System, Department of Atmospheric Sciences, Pusan National University, Busan, South Korea

(Manuscript received 1 January 2013, in final form 14 July 2013)

ABSTRACT

Forecasting year-to-year variations in East Asian summer monsoon (EASM) precipitation is one of the most challenging tasks in climate prediction because the predictors are not sufficiently well known and the forecast skill of the numerical models is poor. In this paper, a statistical forecast model for changma (the Korean portion of the EASM system) precipitation is proposed that was constructed with t based predictors. A forward-stepwise regression was used to select the predictors that inclu temperature (SST) anomalies over the North Pacific, the North Atlantic, and the tropical Seasonal predictions with this model showed high forecasting capabilities that had a Gerri ~0.82. The dynamical processes associated with the predictors were examined prior to their diction scheme. All predictors tended to induce an anticyclonic anomaly to the east or sout which was responsible for transporting a large amount of moisture to the southern Korean predictor in the North Pacific formed an SST front to the east of Japan during the sum maintained a lower-tropospheric baroclinicity. The North Atlantic SST anomaly induced do propagation in the upper troposphere, developing anticyclonic activity east of Japan. Fo tropical Pacific SST anomaly triggered a cyclonic anomaly over the South China Sea, which wa atmosphere–ocean interactions and induced an anticyclonic anomaly via northward Rossby tion. Overall, the model used for forecasting changma precipitation performed well ($R = 0.8$ predicted information for 16 out of 19 yr of observational data.

우리나라 기후 & 물리현상
-> 원격상관관계
장기예보에 있어 연구의 중요성

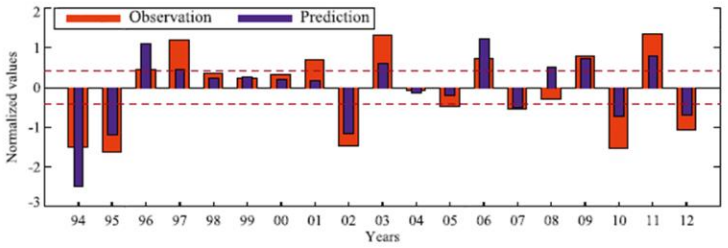


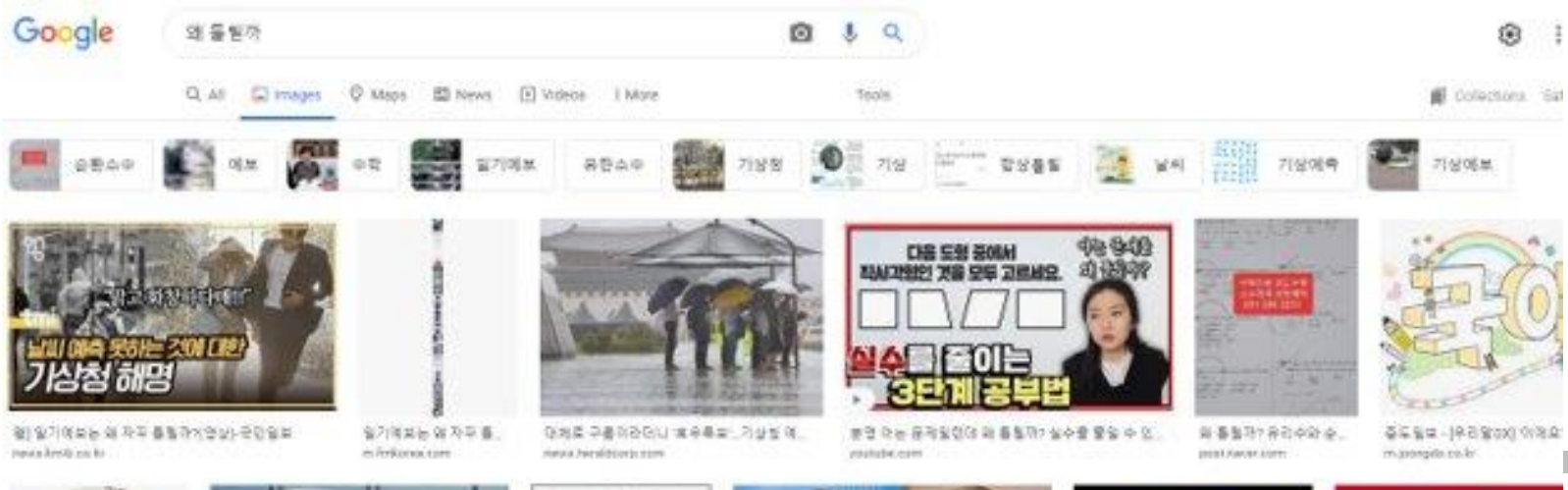
FIG. 3. Comparison of normalized precipitation predictions (blue bars) with observations (red bars). All years are cross validated (see the text for details). The dotted lines at +0.43 and −0.43 represent the threshold values for the tercile prediction. The correlation between predictions and observations was 0.85, the RMSE was 0.54, and the Gerrity score (GMSS) was 0.82.

Predictors:
North Pacific, North Atlantic, tropical Pacific SST

Operational Climate Prediction

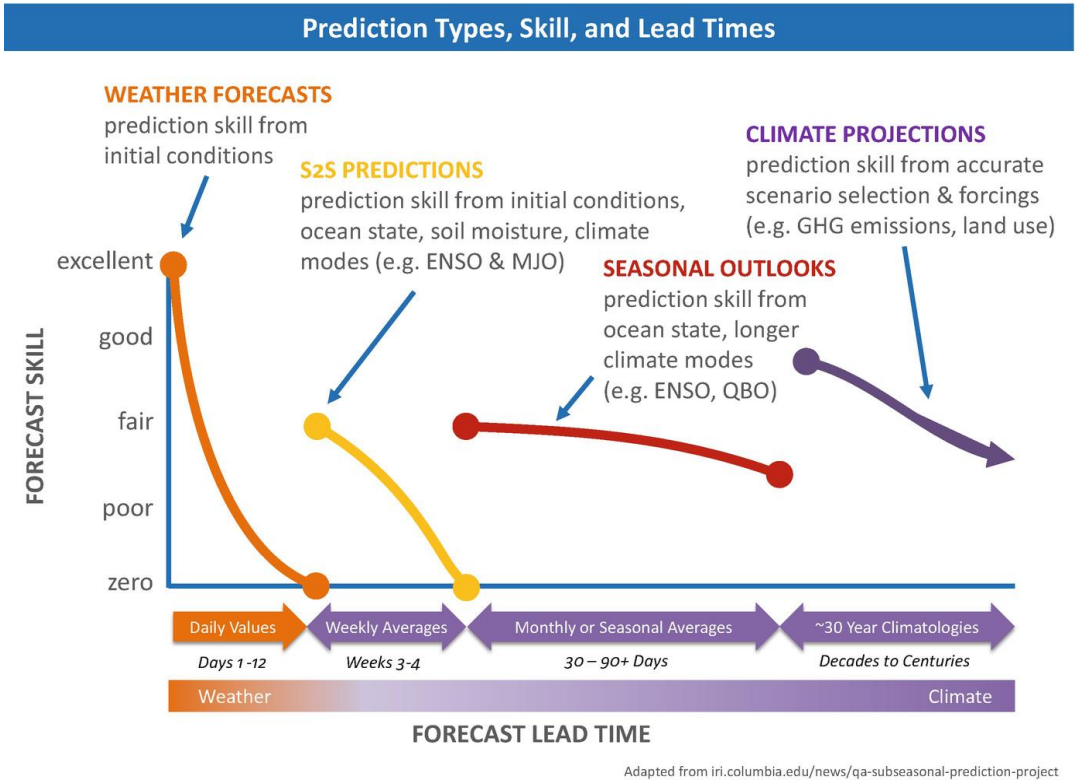
On Korean Climate

- Dynamical models
- Statistical models
- Capacity of forecasters (on climate prediction)



Forecast skill from weather to climate projections

Timescale showing the skill progression from weather and seasonal forecast to climate projections, as used in VISCA DSS.
Source: Adapted from iri.columbia.edu/news/ qa-subseasonal-prediction-project



역학모델의 예측력

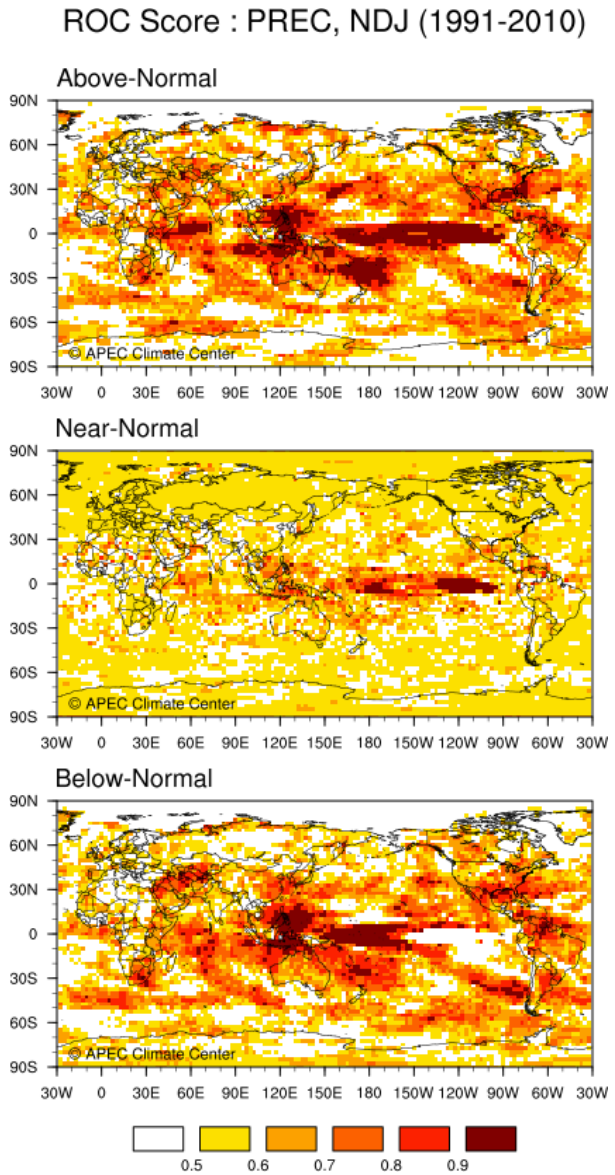
장기 예보

S2S (subseasonal to seasonal)
몇 주 내~ 1개월
주별 평균

Seasonal outlooks
1개월~ 6개월
월별, 계절별 평균

‘평균’예보, 정보의 가치

Forecast skill of seasonal forecast



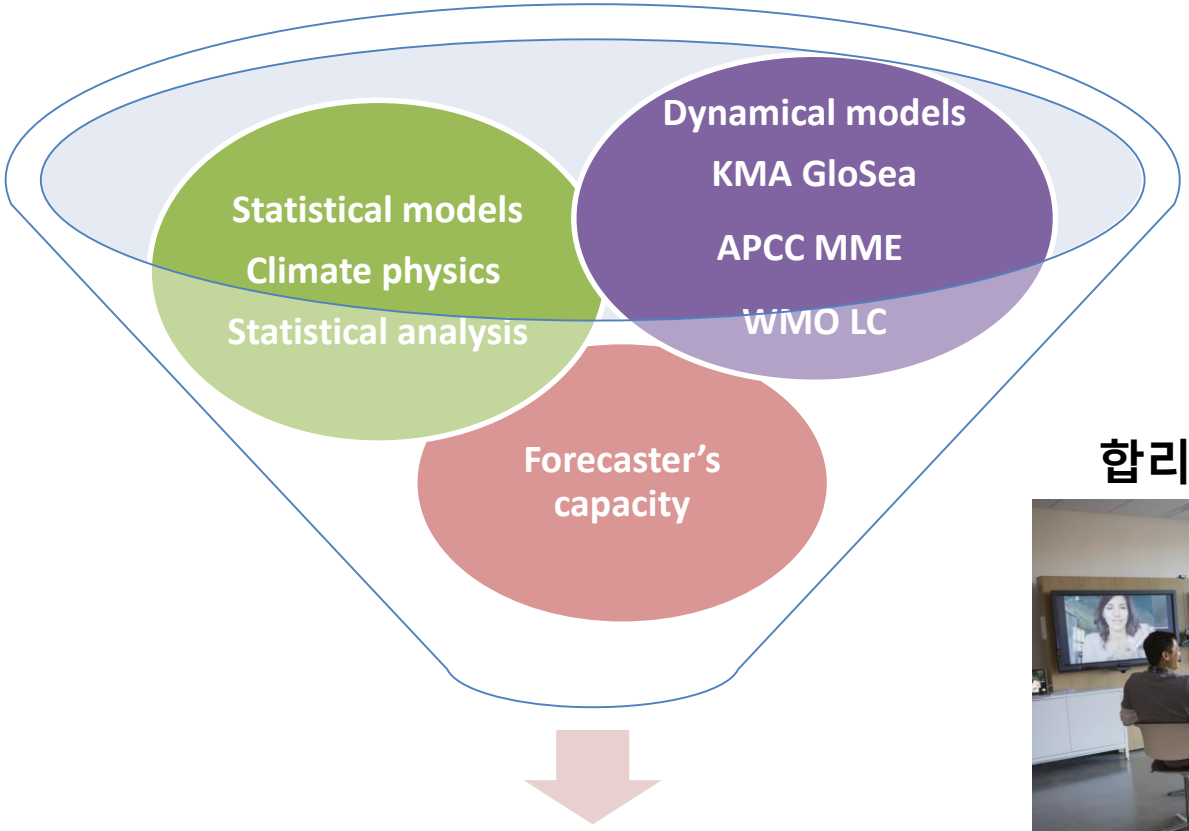
ROC score : 확률예보 검증

- 기후역학모델의 예측력 특성
- 계절별, 변수별
- 예측정보의 비판적 해석 -> 실제예보

https://www.apcc21.org/ser/hind.do;jsessionid=18FC67496AD02B65E1E4151CAF9E5EA3?lang=e

우리나라의 장기 예보

- **Component of operational climate prediction**



합리적 예보 도출!

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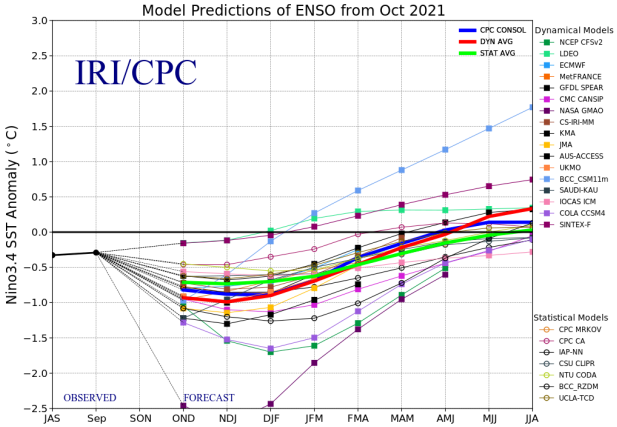
   - 결정론적 예측, 확률론적 예측
   - Hindcast/Forecast
   - 검증 정보

앙상블 예측

- 앙상블(Ensemble)
  - 전체적인 어울림이나 통일, 조화, 프랑스어. 음악
  - 통계역학 앙상블: 어떤계의 앙상블이란, 그 계와 동등한 계의 모음
  - 머신러닝 앙상블: 통계학, 기계학습. 학습 알고리즘을 따로 쓰는 경우에 비해 더 좋은 예측 성능을 얻기 위해 다수의 학습 알고리즘을 사용하는 방법.

- 다중모델 앙상블(Multi Model Ensemble)
  - 여러 기관의 기후모델을 이용한 계절예측
  - APCC MME, WMO LC MME, NMME (미국), C3S(유럽)
  - 다양한 기법 존재
  - 단일모델에 비해 안정적, 예측스킬 우수



앙상블 예측

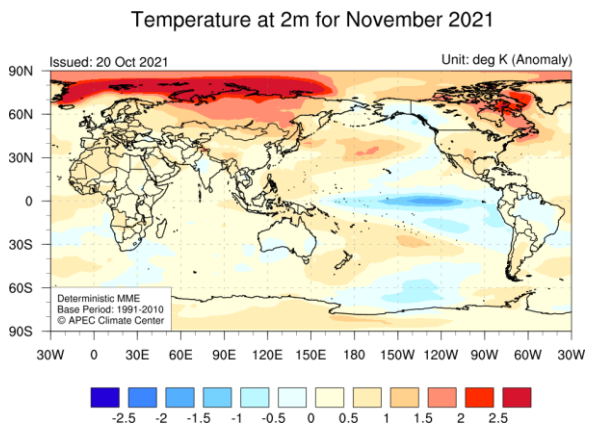
- 단일역학모델의 앙상블
  - 10-40개
  - 초기조건이 다른 날 -> model running
  - 기관마다 상이
  - 단일 앙상블에 비해 더 좋은 예측력

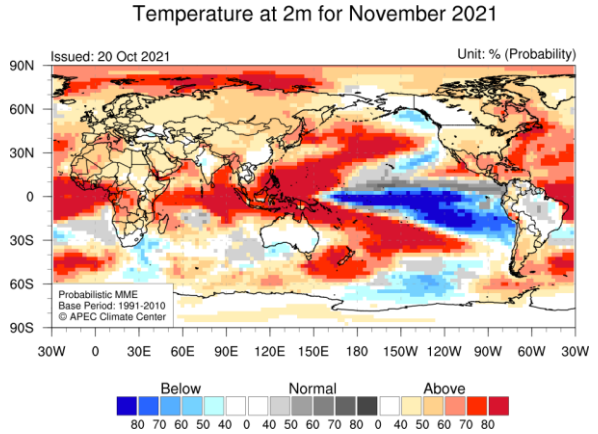
Institute	Country	Model	Resolution (Atmospheric)	Resolution (Ocean)	Ensemble (hindcast/ forecast)	Hindcast period
APCC	Korea	SCoPs	T159L31	0.3-0.5x1.0 L40	10	1982-2013
BCC	China	CSM1.1m	T119L40	1x1/3	24	1991-2015
BoM	Australia	ACCESS-S2	N216L85	0.25 L75	11	1982-2018
CMCC	Italy	SPS3.5	1x1, L46	1/4x1/4, L50	20	1993-2016
CWB	Chinese Taipei	TCWB1Tv1.1	T119L40	1x1	30	1982-2019
HMC	Russia	SL-AV	1.125x1.40625 L28		10/20	1981-2010
JMA	Japan	MRI-CPS2	TL159L60	0.3-0.5x1.0 L53	10/51	1979-2014
KMA	Korea	GloSea5GC2	N216L85	ORCA025L75	12/42	1991-2016
METFR	France	MF Sys8	TL359	0.25 L75	25/51	1993-2016
MGO*	Russia	MGOAM-2	T42L18			1979-2004
MSC	Canada	CanSIPSv2	1.4x1.4 T63L35	1.40x0.94	20	1981-2010
NASA	USA	GEOS-S2S-2.1	0.5	0.5	4-10	1982-2016
NCEP	USA	CFSv2	T126L64	0.25-0.5x0.5 L40	20	1982-2010
PNU	Korea	PNU CGCMv2.0	T42L18	2.8125	35	1990-present
UKMO	UK	GloSea5	N216L85	ORCA025L75	28/42	1993-2016

결정론적 예측, 확률론적 예측

- **Deterministic forecast (DMME)**
  - 예측값은 편차로 제공, 편차는 기후값 혹은 평년값과의 차이
  - APCC MME 평년기간은 20년 (1991-2010) : MME 참여 모델의 공통 기간
  - 개별모델의 모든 앙상블 예측값을 동일한 가중치를 부여하여 종합(SCM)

- **Probabilistic forecast (PMME)**
  - 확률값은 3분위 범주로 표현(BN, NN, AN)
  - 3분위 범주는 1991-2010 기간 hindcast 기반으로 산정
  - 개별모델의 예측확률을 각 모델별로 가중치를 부여하여 통합하는 방식

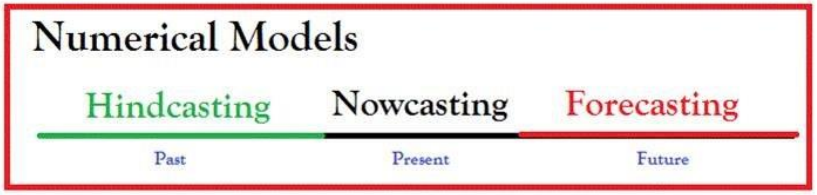




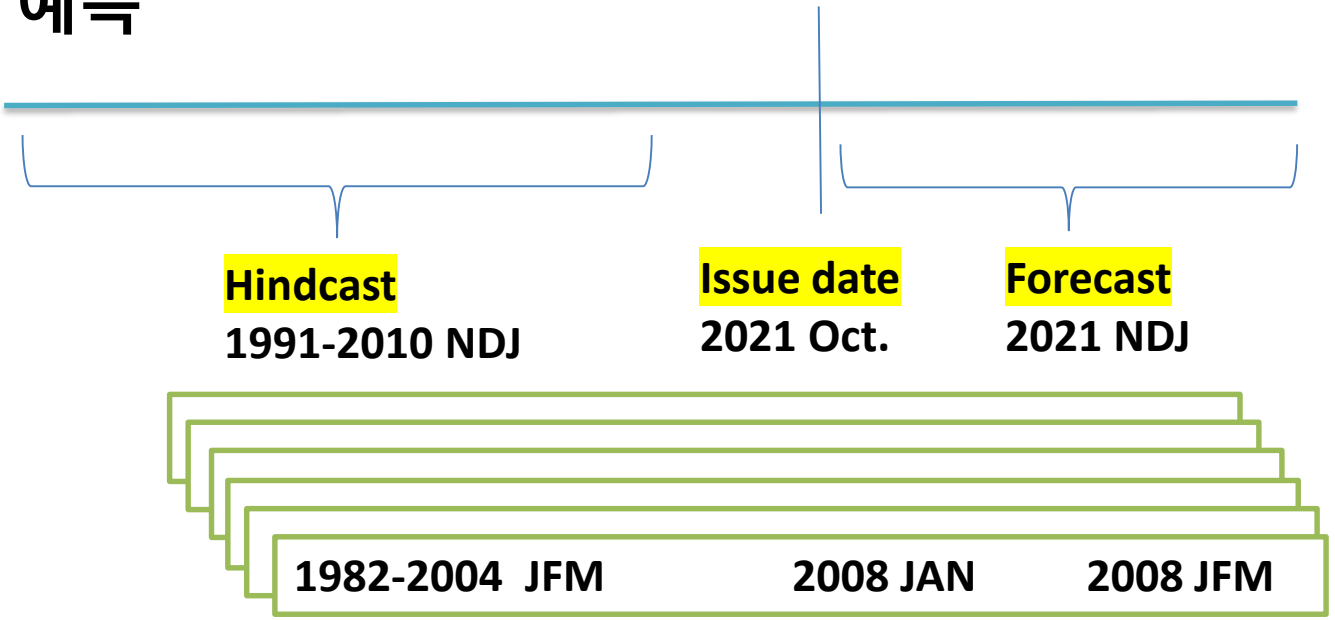
https://apcc21.org/ser/global/methodology.do?lang=ko
Min et al.(2009)

Hindcast, forecast

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



- Hindcast(Retrospective forecast)
  - 평년기간, climatology
- Forecast(real-time forecast)
  - 실제 예측

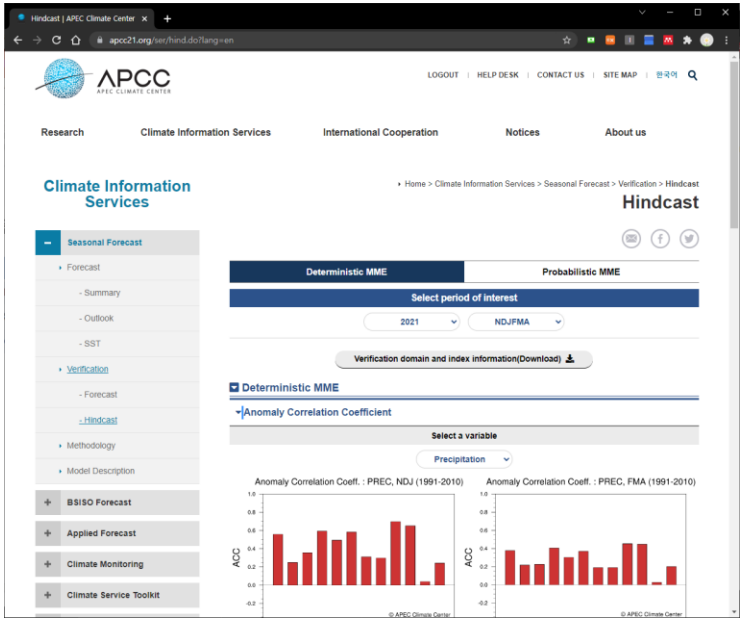


Hindcast data -> 평년기후값, 카테고리 범주(AN, NN, BN)
Hindcast : APCC-다중모델 공통기간, 개별모델별로 다름
25년까지 대부분 2020년까지 확장 계획

Verification

- **모델의 예측력 Forecast skill – Verification**

Deterministic	Probabilistic
ACC (Anomaly Pattern Correlation Coefficient)	ROC (Relative Operating Characteristics Curve)
RMSE (Root Mean Square Error)	Reliability diagram
TCC (Temporal Correlation Coefficient)	Brier skill score



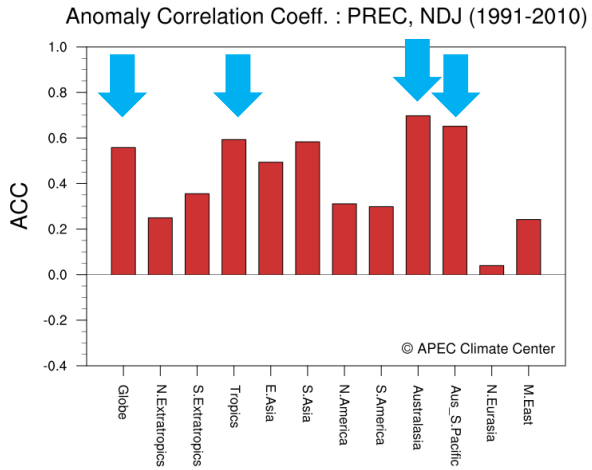
https://www.apcc21.org/ser/hind.do?lang=en

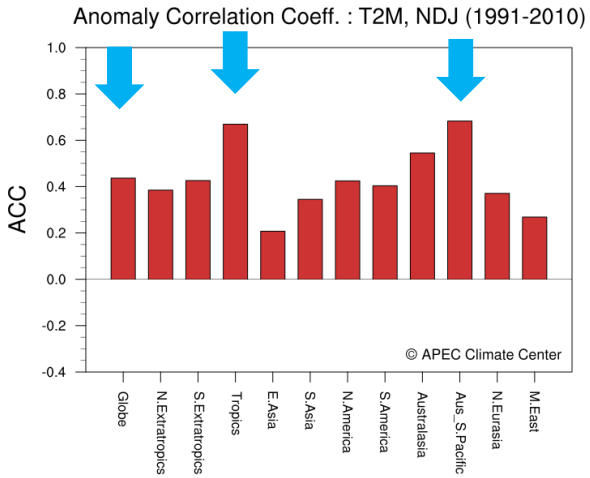
Verification for Deterministic Forecast

- **ACC (Anomaly Pattern Correlation Coefficient)**
  - 예측장과 관측장 패턴의 공간적 유사성 [-1~1]

$$ACC = \frac{\sum_{i=1}^{N} w_i (f_i - \overline{f})(o_i - \overline{o})}{\sqrt{\sum_{i=1}^{N} w_i (f_i - \overline{f})^2 \sum_{i=1}^{N} w_i (o_i - \overline{o})^2}}$$

Over bar means time average (climatology)
F: forecast
O: observation
W: weighting





<Murphy, A.H., 1988: Skill scores based on the mean square error and their relationships to the correlation coefficient. Mon. Wea. Rev. 116. 2417-2424.
WMO, 2002: Standardised verification system (SVS) for long-range forecasts LRF). Monual on the GDPS (WMO-No. 485), volume 1. >
<https://www.apcc21.org/ser/hind.do?lang=ko>

Verification for Probabilitic Forecast

- **ROC (Relative Operating Characteristic) curve**
  - **Hit Rate vs. False Alam Rate**
  - **Hit Rate (True positive rate) = TP/P**
  - **False Alarm Rate (False positive rate) = FP/N**

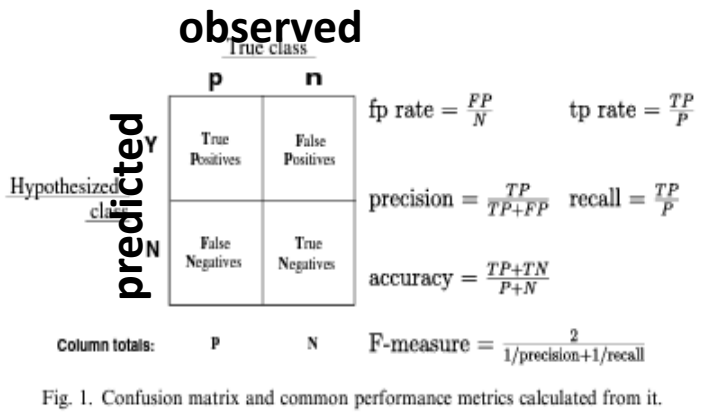
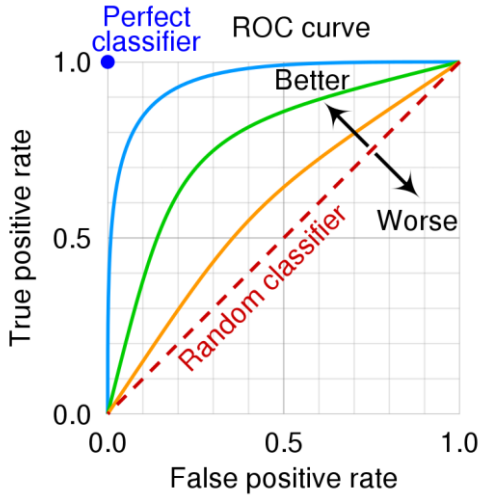
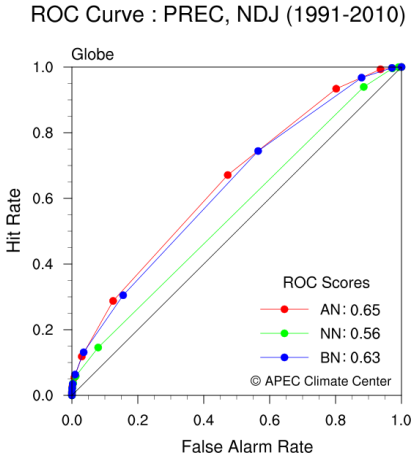
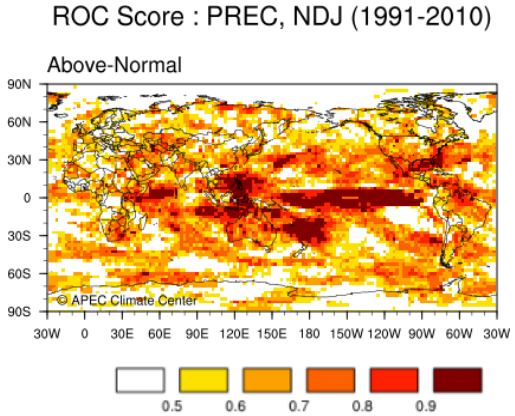


Fig. 1. Confusion matrix and common performance metrics calculated from it.

- **ROC Score (Area)**
  - **Underneath the forecast curve**
  - **0 – 1 (0.5: random forecast)**







Fawcett, Tom(2006). "An Introduction to ROC Analysis" Pattern Recognition Letters. 27 (8): 861-874.
https://www.apcc21.org/ser/hind.do?lang=ko

Summary

APCC MME 계절예측

우리나라 기상청 장기전망

IRI-CPC ENSO forecast

Ensemble prediction

Deterministic/Probabilistic

Hindcast, Forecast

Verification information

Dynamical model

Statistical model

Korean Operational Forecast

감사합니다

예측운영과 예측팀

김유진