Assessing NMME Models in Forecasting ENSO Onset During Last 30-years

Sungjoon Park[1], Muhammad Azhar Ehsan[2,3,4]

1) Department of Computer Science, Columbia College of Columbia University
2) Center for Climate Systems Research, Columbia Climate School
3) NASA Goddard Institute for Space Studies
4) International Research Institute for Climate and Society, Columbia Climate School

sp4050@columbia.edu | (917) 673-1361

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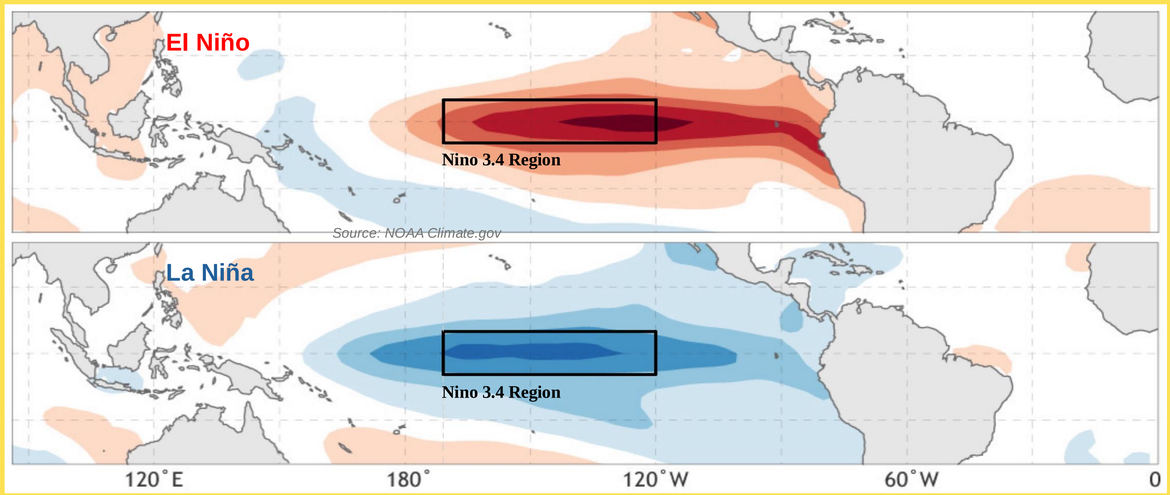
1. Introduction

- **ENSO** is a major driver of **global climate variability**, affecting weather patterns worldwide.
- **ENSO Onset** is the **transition** from an ENSO-neutral state to a **cold (La Niña)** or **warm (El Niño)** phase in the center-east equatorial Pacific Ocean (Niño 3.4 Region, 5N-5S, 170W-120W)



- **NMME Models** underpin CPC and IRI's **ENSO forecasts** used by policymakers and meteorological agencies worldwide to plan for & respond to seasonal anomalies in precipitation and temperature.
- Assessing **NMME Models' performance** at **ENSO Onset prediction** provides feedback for model development, helping models achieve more accurate predictions.

2. Methods

- **Data Sets**
  - **Niño 3.4 Region SSTs**, Base Period of 1991-2020
  1. **Monthly Observed** data from **CPC ERSSTv5**
  2. **Model Hindcast** data from **IRI Data Library**
- **Analyses** (Observed vs Models)
  - Seasonal (Onset Seasons: AMJ-OND)
  1. **SST Mean and Variance for all seasons**
  2. Lead-dependent Variance for Onset Seasons
  3. **Anomaly Correlation for Onset Seasons**
  - Event-specific for each ENSO Onset
  1. Anomaly Error
  2. **Squared Error Skill Score (SESS)**
  3. Lead-dependent SESS
- **ENSO Phase and Onset**

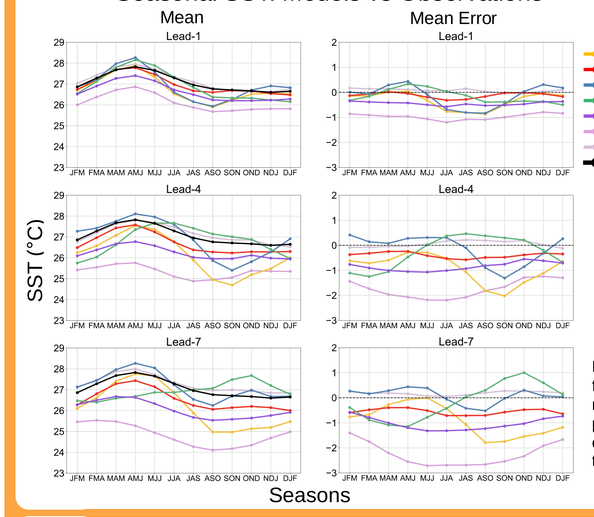
Seasonal Niño 3.4 Anomalies (Niño 3.4 Index) → CPC NOAA Threshold → 18 ENSO Phases Identified

Niño 3.4 Index: SST anomalies spatially averaged over 5S-5N, 190E-240E
ENSO Phase: Continuation of +/– 0.5 or higher SSTAs for 5 or more Seasons, as per CPC threshold
ENSO Onset: First Season of each ENSO Phase
In this study, we have identified 9 cold, 9 warm ENSO Phases (shown on the right)
Season: 3-month running average of monthly data

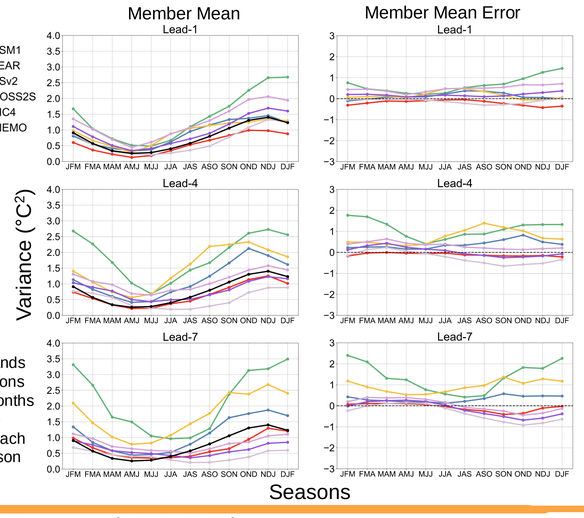
#	Year	Onset Season	Niño 3.4 Index	Duration (months)
Warm Phases (El Niño)				
1	1991	MJJ	0.5	13
2	1994	ASO	0.6	7
3	1997	AMJ	0.6	12
4	2002	MJJ	0.6	9
5	2004	JJA	0.5	8
6	2006	ASO	0.5	5
7	2009	JJA	0.5	9
8	2014	SON	0.5	19
9	2018	ASO	0.5	10
Cold Phases (La Niña)				
1	1995	JAS	-0.6	8
2	1998	JJA	-0.9	33
3	2005	OND	-0.5	5
4	2007	MJJ	-0.5	13
5	2008	OND	-0.6	5
6	2010	MJJ	-0.7	23
7	2016	JAS	-0.6	5
8	2017	SON	-0.7	7
9	2020	JAS	-0.6	30

3. Results

Seasonal SST: Models vs Observations

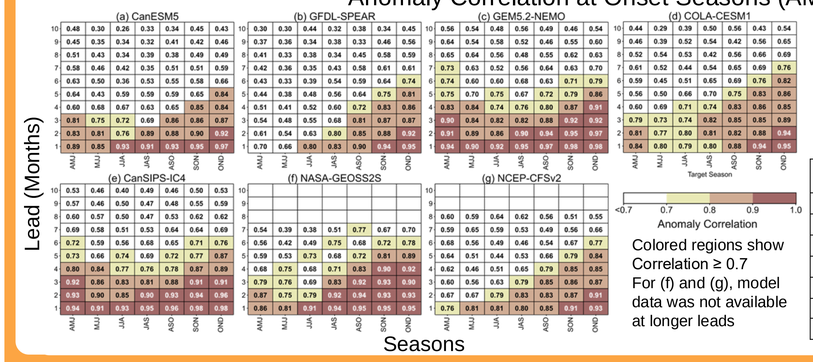


Seasonal Variance: Models vs Observations



Lead-*n* stands for predictions made *n* months prior to the center of each target season

Anomaly Correlation at Onset Seasons (AMJ-OND)

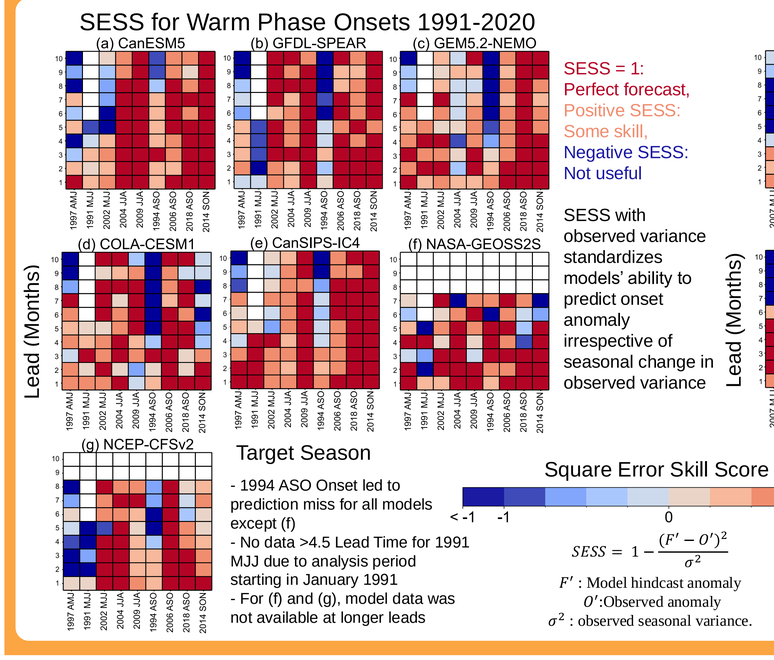


Colored regions show Correlation ≥ 0.7
For (f) and (g), model data was not available at longer leads

- Anomaly correlation evaluates model prediction of SST anomalies at cold, warm, and neutral states of ENSO
- An increase in anomaly correlation was seen in boreal fall target seasons for all models
- Table below summarizes data from Leads 1-7

Model	Spring-Early Summer Mean	Fall Mean	Total Mean and Standard Deviation	Rank
CanESM	0.669	0.760	0.703 ± 0.170	5
GFDL-SPEAR	0.534	0.780	0.639 ± 0.179	7
GEM5.2-NEMO	**0.788**	0.836	**0.802 ± 0.123**	1
COLA-CESM1	0.682	0.826	0.741± 0.128	4
CanSIPS-IC4	0.780	0.829	0.795 ± 0.129	2
NASA-GEOSS2S	0.697	**0.847**	0.757 ± 0.157	3
NCEP-CFSv2	0.637	0.779	0.694 ± 0.142	6

SESS for Warm Phase Onsets 1991-2020



SESS = 1: Perfect forecast,
Positive SESS: Some skill,
Negative SESS: Not useful

SESS with observed variance standardizes models' ability to predict onset anomaly irrespective of seasonal change in observed variance

Target Season

- 1994 ASO Onset led to prediction miss for all models except (f)
- No data >4.5 Lead Time for 1991 MJJ due to analysis period starting in January 1991
- For (f) and (g), model data was not available at longer leads

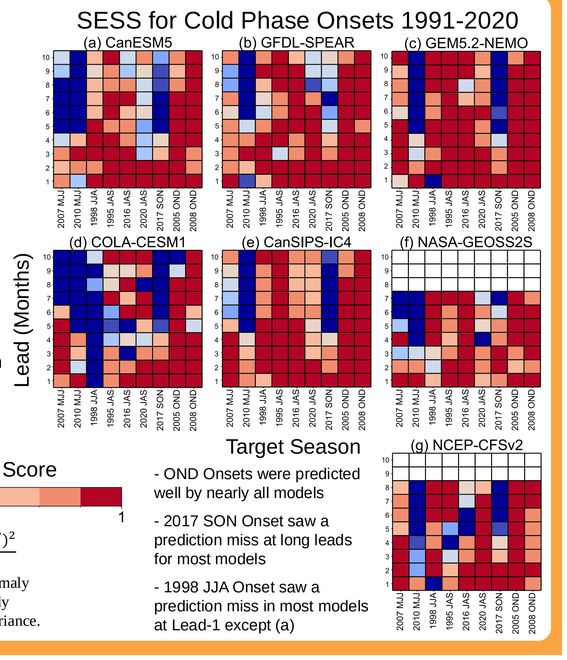
Square Error Skill Score

< -1 -1 0 1

$$SESS = 1 - \frac{(F' - O')^2}{\sigma^2}$$

F' : Model hindcast anomaly
O':Observed anomaly
σ^2 : observed seasonal variance.

SESS for Cold Phase Onsets 1991-2020



Target Season

- OND Onsets were predicted well by nearly all models
- 2017 SON Onset saw a prediction miss at long leads for most models
- 1998 JJA Onset saw a prediction miss in most models at Lead-1 except (a)

4. Discussion

1. **Seasonal Mean and Variance Analysis**
- Model behavior diverged from observations for fall target seasons, worsening for predictions made through the boreal spring
2. **Anomaly Analysis**
- Models were generally **less skillful** for boreal **spring - summer (AMJ, MJJ, JJA)** target seasons
- Conversely, models tended to show **higher correlation** for boreal **fall (ASO, SON, OND)** target seasons
- Models generally predicted **cooler-than-observed** anomalies for **warm onsets** and warmer-than-observed for cold onsets
3. **SESS Analysis**
- Prediction skill generally **increased** for **fall target seasons**, but certain onsets (1994 ASO, 2017 SON) were poorly predicted
4. **Future Directions**
- Divergent behavior in models warrants studies into **model variance**, **intra-seasonal variability**, and **model formulations**