Biases in Model Forecasts of Environmental Fields Related to the Subseasonal Prediction of Tropical Cyclone Activity

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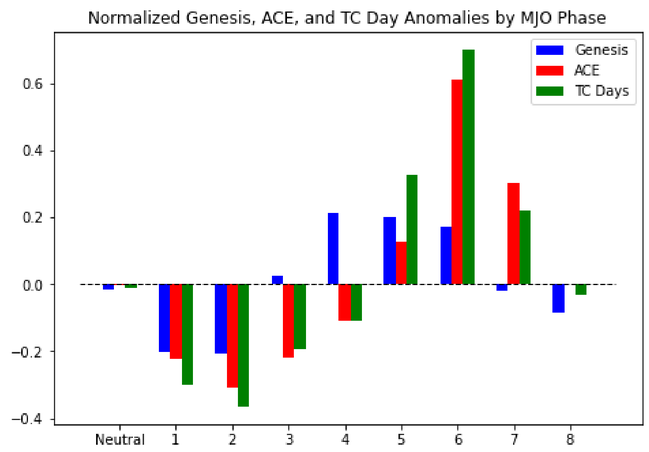
Introduction

Subseasonal and extended range prediction of tropical cyclones (TCs) have many potential applications in energy, emergency response, and defense sectors; however, subseasonal TC prediction remains a challenge due to biases in both large-scale conditions and TCs in coupled global models. Subseasonal forecasts of large-scale environmental conditions, such as vertical wind shear and OLR, are generally more skillful than forecasts of smaller scale phenomenon, such as TCs themselves. Thus, model forecasts of environmental parameters can be linked to TC activity and then be used to extend the horizon of useful skill through statistical-dynamical models.

In this study we evaluate the ECMWF model as part of the Subseasonal-to-Seasonal (S2S) database and the Navy-ESPC as part of the SubX project on their ability to capture environmental signals linked to West Pacific TC activity. To isolate the signals in TC activity associated with subseasonal variability, we examine events of anomalous TC days relative to each season's total TC activity. These events are used to create composites of the environmental conditions related to TC activity at various lead times for each of the forecast models, which are then validated against the ERA5 reanalysis. To quantify skill, we look at the evolution of the pattern correlation between the model and reanalysis composites over the tropics as a function of lead time. We also create statistical-dynamical hybrid models using ECMWF and Navy-ESPC outputs to establish the contribution of predictors such as subseasonal OLR and shear fields to model skill.

Methodology

- TC data comes from IBTrACS. We use data of West Pacific TCs during June-Nov from 1979-2020 to calculate normalized TC day anomalies which are used for composites and training/verification of the statistical-dynamical hybrid model. We also tested genesis and ACE as metrics and found TC days had the strongest ties to subseasonal variability and produced the highest skill.
- ECMWF Reanalysis Version 5
  - Hourly data, 0.25˚ grid spacing, 137 levels
  - OLR, 850hPa and 200hPa winds
  - Remove data within 500km of TC centers
- We use ECMWF forecasts as part of the S2S project.
  - Use only the deterministic model
  - 860 Forecasts from 2001-2020
  - Two forecasts per week
  - Atmosphere: 55km and 50 level resolution
  - Fully coupled, daily mean OLR
- We use Navy-ESPC forecasts as part of the SubX project.
  - 1486 forecasts from 1999-2015
  - Atmosphere: 32km and 137 level resolution
  - Fully coupled, daily mean OLR

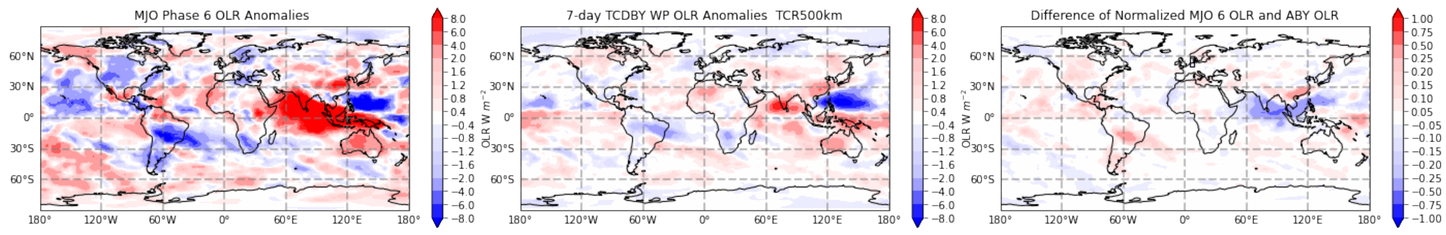


Normalized anomalies of WPAC TC Days, ACE, and genesis by MJO phase

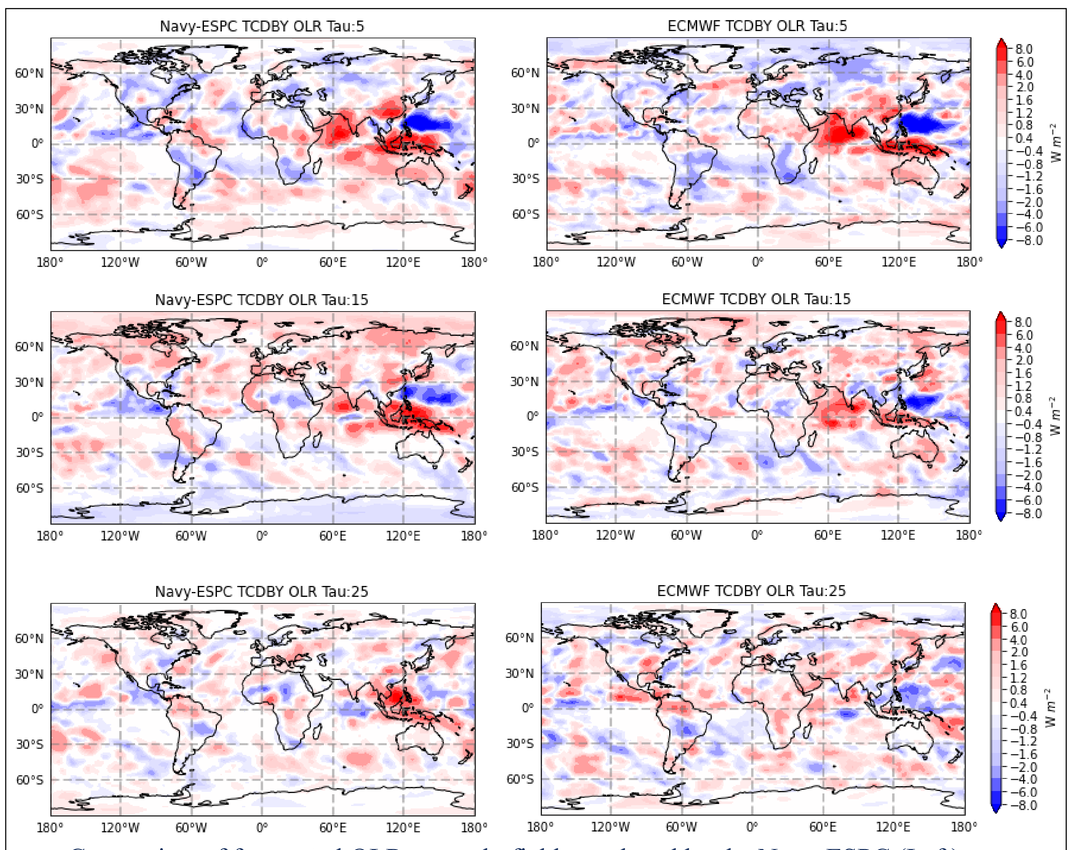
- MJO is quantified using Real-Time OLR MJO index (ROMI) from Kiladis 2014 both for forecasts and reanalysis.
- Subseasonal composites are created by taking the top third of normalized 7-day running mean TC day anomalies for each given year. This is based off of the ABY method from Hansen et al. (2020).
- Statistical Dynamical Hybrid models are created by inputting forecasted fields or metrics (such as MJO PCs) and feeding them into a logistic regression scheme. The logistic regression is trained on yearly out of sample model forecast data. Verification is done for 2001-2015 period for consistency.

Results: Subseasonal Composite

- Subseasonal composites (TCDBY) of many fields do not have clear signals in association with West Pacific TC activity
  - This includes genesis potential index as well as 200hPa divergence, RH, PI, and Vorticity
- Shear is found to increase over the WPAC during periods of heightened subseasonal TC activity
  - Increased shear primarily occurs over the Philippines and is related to increased low level westerly flow
  - Likely tied to MJO
  - There is also a signal in meridional winds that extends over Eurasia but it is relatively weak.
- Decreased OLR over the West Pacific and increased OLR over the Indian Ocean are an environmental signal for increased WPAC TC activity
  - Environment within 500km of TCs are removed but negative OLR anomalies in the WPAC may indicate incipient disturbances or favorable conditions for convective activity
  - Positive OLR anomalies over the Indian Ocean is likely the composite picking up on the MJO signal. MJO phases 6 being most favorable for TC activity in the WPAC
- The OLR pattern in the subseasonal composite is similar to the MJO phase 6 OLR pattern with key differences
  - There is decreased OLR over the equatorial Indian Ocean and WPAC
  - Positive OLR over coastal China



Left: OLR composite during subseasonally active WPAC TC Day periods (TCBDY), Middle: OLR composite during MJO phase 6, Right: The difference between MJO and TCBDY composite normalized by maximum amplitude of anomalies



Composites of forecasted OLR anomaly fields produced by the Navy-ESPC (Left) and ECMWF (Right) verifying during periods of increased subseasonal TC activity as defined by the TCDBY composite method. Top plots show 5-day forecasts, middle: 15-day, and bottom 25-day forecasts.

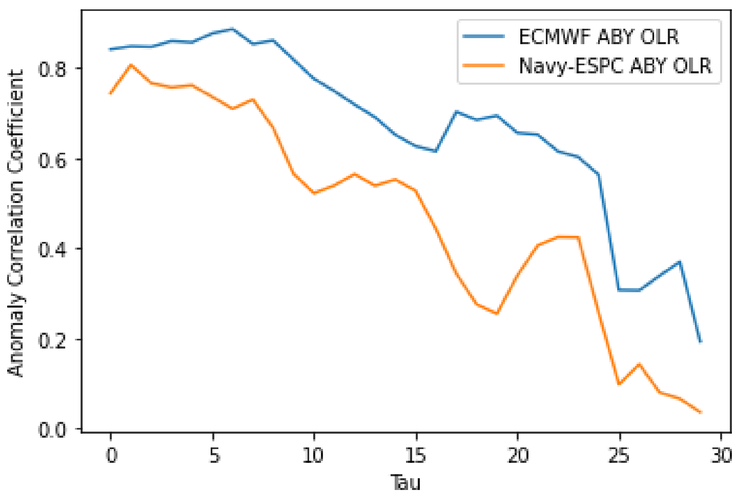
Results: Reproducing Subseasonal Signal

Subseasonal composites of ECMWF and Navy-ESPC OLR forecasts are taken based on the observed TC activity and as a function of lead time.

For short lead times both models are good at reproducing the subseasonal OLR signal and even appear to capture distinctive features such as the decreased OLR over equatorial Indian Ocean.

The Navy-ESPC quickly loses the subseasonal pattern and by day 25 has lost the pattern completely. At 25 day lead-times the Navy-ESPC predicts anomalously high OLR over the WPAC during periods that verified having above average TC activity.

The ECMWF is better at resolving the OLR pattern associated with subseasonal WPAC TC activity.



Spatial correlation coefficient between reanalysis OLR TCDBY composites and ECMWF and Navy-ESPC TCDBY composites as a function of lead time.

Results: Model Skill

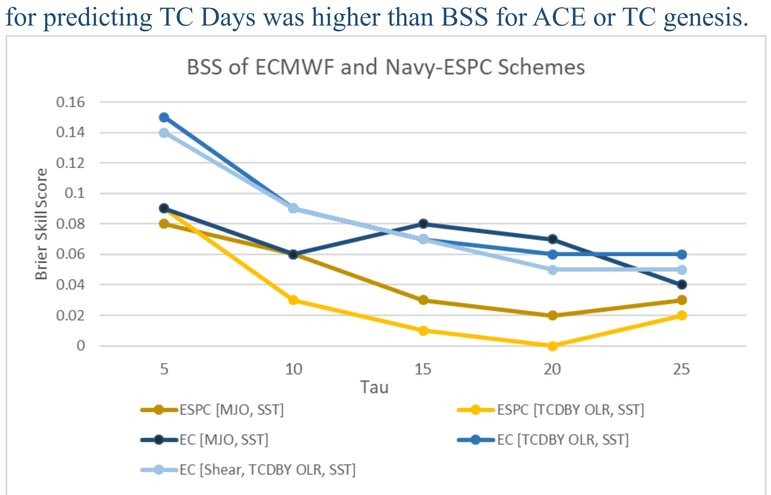
The statistical-dynamical schemes use persistence forecasts of SSTs in the Indian Ocean, WPAC and Nino 3.4 region, as well as model forecasts of either MJO PCs, or the correlation coefficient of forecasted OLR anomalies with the reanalysis TCBDY OLR composite. Other fields were also tested such as the correlation coefficient of 850hPa zonal winds or vertical wind shear magnitude with their respective TCBDY composites.

The ECMWF scheme that incorporates correlation coefficients of OLR TCBDY composites performs better at most lead times (at all lead times when assessing 2001-2020 skill) than the scheme that uses the MJO PCs.

The Navy-ESPC, does not see an improvement in skill by incorporating OLR TCBDY forecasts suggesting it is only drawing predictability from the MJO and SSTs.

Various predictive measures of shear and low-level zonal wind were not found to improve the skill when added to a scheme that contained an OLR component.

BSS for predicting TC Days was higher than BSS for ACE or TC genesis.



The brier skill score of various statistical dynamical schemes. The key identifies the dynamical model used and the forecasted parameters that are fed into the logistic regression model.

Conclusions

- For extended range and subseasonal prediction, anomalous TC days in the West Pacific has the strongest connection to the MJO and is the best predicted metric for the statistical-dynamical hybrid models.
- Increased vertical wind shear and associated low level inflow into the West Pacific are environmental signals that are associated with increased subseasonal TC activity. However, these appear to be connected to the MJO. Using these fields as predictors of TC activity does not result in an additional improvement in skill.
- The OLR pattern associated with enhanced WPAC TC activity is similar to but distinct from the OLR pattern for MJO phases 6. The discrepancy between these points to an environmental phenomenon (perhaps the Mei-Yu front or SE Asian Monsoon) that may provide a source of predictability for subseasonal TC prediction.
- The ECMWF is able to capture the subseasonal OLR signal better than the Navy-ESPC.
- The ECMWF, as a part of a statistical-dynamical hybrid model, sees an increase in skill when incorporating the spatial OLR pattern as compared to using the MJO PCs. The Navy-ESPC sees a slight decrease in skill when incorporating the spatial OLR pattern.

Acknowledgements:

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