CROSS SEASON MEMORY OF OCEAN-ATMOSPHERE SYSTEM

-- A NEW SEASONAL HURRICANE FORECAST MODEL FOR THE NORTH ATLANTIC BASIN[1]

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1. Introduction

In this work, a new seasonal forecast model will be introduced based on clustering analysis of tropical storms in the North Atlantic basin (Kossin et. al., 2010, Kossin2010 hereafter). This model just includes one predictor but can make skillful forecast for Atlantic storms activity as early as the end of last hurricane season. So its skillful seasonal forecast can cross Spring Barrier.

2. The Forecast Model

Kossin2010 applied the Atlantic best tack data in 1950-2007 in their clustering analysis. In this work Kossin2010's analysis is redone by using best track data in 1851-2012. By doing this more data can be included in the analysis. We believe the missing data issue in the early years is not a problem in clustering analysis, since in which only the structure of a storm track is considered, but its date does not matter. North Atlantic tropical storms and hurricanes can be classified into four distinguishable clusters. Figure 1 illustrates the patterns of the storms in each of the clusters, including storm genesis points, storm track patterns, and prevailing U.S. landfall locations. It is clear that different clusters have different genesis, track patterns, and favorite landfall regions. For instance, Cluster 1 storms prefer the landfalls in West Florida and in the US East Coast, Cluster 2 storms tend to have Gulf of Mexico landfalls while Cluster 3 storms are more like to have the U.S. East Coast landfalls and Cluster 4 more likely to have Gulf of Mexico landfalls.

This sole predictor we identified for the new seasonal Atlantic storm forecast model is the cluster information of the last **named** storm from the last season (named it as CLSLS). Hence we name this approach as CLS (Clustering from Last Season) forecast model. It turns out that the CLS model can obtain skillful forecast with a longer lead time than most statistical and dynamical models. The last named storm from the last season could be any tropical storm and above storm in the North Atlantic basin and it does not necessarily have to be a U.S. landfall storm.

For time period 1935-2014, the impact of CLSLS is calculated and summarized in Table 1 for tropical storm above storms. If the annual mean storm count associating with a CLSLS is assumed to be the forecasted mean storm count for a year having the same CLSLS, then CLSLS information could be used to make seasonal storm forecast. Similar summary for hurricanes and major hurricane can be developed in a similar way as Table 1. The CLS forecast model is developed using CLSLS as the sole predictor. In this model, the historical average of storm counts with different CLSLS is applied as the forecasted mean value of the storms this season. For instance, if the CLSLS is a Cluster 2 storm, it is predicted that this season will be a quiet or below average season with 9.93 named storms basin-wide, 2.87 named U.S. landfall storms respectively.

Table 1: The Impact of CLSLS to tropical storm and above storm activity of upcoming season (1935-2014)

CLSLS	Average US LF storm counts	Average basin-wide storm counts
Cluster 1 Mean	2.89	9.71
Cluster 2 Mean	2.87	9.93
Cluster 3 Mean	4.83	13.75
Cluster 4 Mean	3.22	12.44
Overall Mean	3.25	10.98
Overall Std	1.79	4.08
1935-2014 RMSE	1.66	3.80
1984-2001 RMSE	1.79	3.26

Table 2: RMSE Comparison between Gray's Model forecast and CLS model forecast (1984-2001)

model types	named storms	hurricanes	major hurricane
Gray June Forecast	4.00	3.30	2.30
Gray August Forecast	3.00	2.40	1.80
CLS Model Forecast	3.26	2.42	1.70

(Courtesy to Brian Owens and Christopher Landsea)

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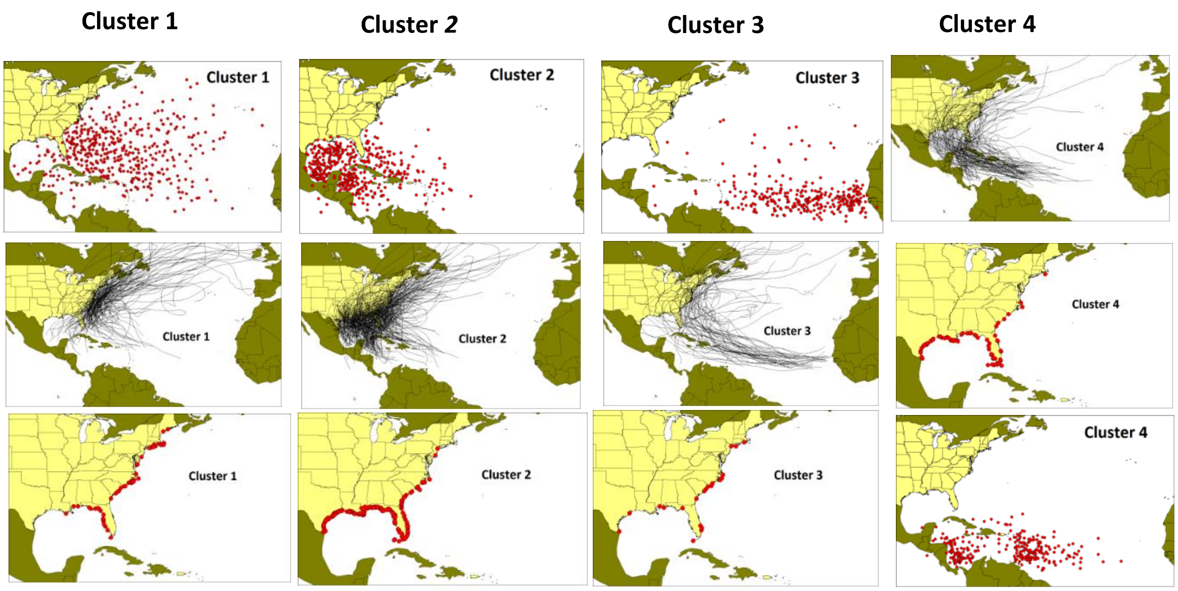

Figure 1: Clustering Features of US Landfall/Bypass Events
(repeating Kossin2010 for data in 1851-2012)

As a common practice in the seasonal forecast community, RMSE (Root Mean Square Error) was used to measure the forecast skill.

3. Model Validation

In order to utilize the proposed model in real practice, the forecast skill of this model needs to be validated. One way to do so is to compare CLS model forecast with that from other models. Some publications need to be identified which had evaluated the forecast skill of some well-known seasonal forecast models for an extended time period. There are two papers available. One work was authored by Brian Owens and Christopher Landsea (2003, BOCL2003 hereafter) from NOAA. This paper evaluates CSU Dr. William Gray's model, by calculating the RMSE of its 18-year's (1984-2001) forecast. The comparison was performed for three basin-wide storm groups: named storms (tropical storm and above events), hurricanes, and major hurricanes. Another paper was to assess the forecast skill of a model making U.S. landfall hurricane forecast (2006). The model was developed and evaluated by James Elsner and Thomas Jagger (JETJ2006 hereafter). This section is to compare the forecast skill of CLS model and the models from these two groups. RMSE will be used as the forecast skill measure to make these comparisons.

a. Comparison with CSU Gray's model

The forecast skill (1984-2001) of Gray's model, measured by RMSE, can be obtained from BOCL2003. CSU Gray's group seasonal forecasts made inJune and August were included for named storms, hurricanes, and major hurricanes. 1984-2001 is the time period BOCL2003 applied to evaluate the forecast skill. The corresponding RMSE of CLS model is calculated in the same time period. Table 2 provides the comparison of the RMSE of the two models. It shows that CLS mode has a much smaller RMSE than Gray model's June forecast, and it has a comparable RMSE with Gray model's August forecast. However, CLS model theoretically can make the forecast right after the end of the last season. This means CLS model could have eight months more lead time than Gray's August forecast.

b. Comparison with Elsner's model

JETJ2006 divided hurricane seasons in 1851-2004 into two groups: the years with 1 or 2 U.S. landfall hurricanes, and the years with none or more than two U.S. landfall hurricanes. In JETJ2006, the RMSEs were calculated for hurricane count of these two groups respectively. The RMSE of CLS model are calculated from the forecasts of the model derived from U.S. landfall hurricane data in 1935-2014. The detailed comparison is provided in Table 3. The overall RMSE from CLS model is smaller than both of the RMSEs from

Elsner's model for two different groups of U.S. landfall hurricane. This illustrates again the better forecast skill of CLS model.

Table 3: RMSE Comparison between Elsner's and CLS U.S. landfall hurricane forecast		
Forecast Model	**Group**	**RMSE**
James Elsner(1851 -2004)	h=1 or 2	1.44
	h=0 or 3+	2.25
CLS Model forecast (1935-2014)	all landfall hurricanes	1.27

4. The Possible Mechanism

Many predictors were included in Gray's model and Elsner's model. Even though CLS model only has one predictor, comparing with these two models, it has a better forecast skill or has a comparable forecast skill but with much longer lead time. This result illustrates that CLSLS contains very rich information about future storm activity in Atlantic Ocean. Actually, it is better than any available individual climate index in storm frequency forecast in North Atlantic. BUT why does it have this forecast skill? Current climate indices represent the ocean or atmosphere conditions at a moment or an average condition over certain time period. But CLSLS includes storm genesis region, storm track information, and the information regarding how the storm moves along the track over an extended period of time. It represents an integrated ocean and atmosphere condition at the end of the last hurricane season. As we know the ocean circulation is a slower process comparing with atmosphere circulation. So the rich information of CLSLS is more likely from the ocean. But why this factor has a better forecast skill for storm activity than any other individual ocean climate index? The speculated answer could be that, the current ocean indices represent a two-dimensional ocean conditions. But CLSLS is determined by combined ocean and atmosphere conditions in an extended time period, as a result CLSLS may contain the three-dimensional or even four-dimensional ocean structure information. This structure can survive longer time than two-dimensional ocean conditions, or it can evolve following certain physical laws and across seasons. In the next season, the ocean conditions still remain favorable or unfavorable for storm activity. More importantly, these ocean conditions may have been pre-determined in a certain way by the ocean-atmosphere conditions at the end of last season. This is simply a speculation about the mechanism. Without support from detailed data, the mechanism remains unclear now. But one thing is clear that CLS model is not simply a statistical model. It actually includes the evolution history of the dynamical ocean-atmosphere system. So it is a new kind of statistical-dynamical seasonal storm prediction model.

5. Discussions

CLSLS contains very rich information about future Atlantic hurricane activity. It seems like an important physical process is showing one aspect of its mechanism to us through CLSLS. As an indicator of future storm activity, CLSLS is better than any available individual climate index. It is even better than or comparable with some complicated statistical models. The skillful forecast of CLS model can crosses Spring Barrier, so it has a much longer lead time than other seasonal storm forecast models. Currently CLSLS is used as a solely predictor in this work. We believe there is still a significant room to improve the forecast skill of CLSLS related seasonal storm forecast by applying it with other climate indices or other forecast methods.

6. References

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