Modifications to the Objective Lightning Probability Forecast Tool at Kennedy Space Center/Cape Canaveral Air Force Station, Florida

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The 45th Weather Squadron (45 WS) provides weather support to Cape Canaveral Air Force Station (CCAFS) and Kennedy Space Center (KSC) in Florida. This weather support includes daily 24-Hour and Weekly Planning Forecasts, both of which include the probability of lightning occurrence. This information is used for general planning of operations at CCAFS/KSC and begins the process of issuing lightning advisories during the day. During the summer lightning season, the 45 WS relies heavily on the objective lightning probability forecast tool developed by the Applied Meteorology Unit (AMU).

The current AMU lightning probability forecast tool was developed in phases. The core of the tool is a set of logistic regression equations that calculate the probability of lightning occurrence for the day on KSC/CCAFS during the warm season months of May–September. The predictors were selected for each month from a set of skew-T indices, the probability of lightning based on seven Florida peninsula flow regimes, the climatological lightning probability for each day, and one-day persistence. In Phase I, the period of record (POR) was the warm seasons in the 15-year period 1989–2003. These equations outperformed several standard forecast methods that were in operational use at the time and provided 48% better skill than the previous objective tool. In Phase II, five modifications were made to the equations to improve their performance even further: 1) increase the POR by 2 years (1989–2005), 2) add the CCAFS 1000 UTC sounding to the Florida 1200 UTC soundings to determine the daily flow regime, 3) determine the optimal relative humidity (RH) layer, 4) use a new smoother for the daily lightning climatology curve, and 5) refine the forecast valid area to only include locations of 45 WS forecast responsibility. Their performance was tested against that of the Phase I equations and several other forecast benchmarks. Results showed that the new equations produced an 8% increase in skill over the Phase I equations. They also showed more reliability, an improved ability to distinguish between non-lightning and lightning days, and improvement in other performance metrics. The new equations were transitioned into operations, replacing the Phase I equations.

Given the success of these lightning probability equations and opportunities for further incremental improvement, the AMU began Phase III of this project. Three more warm seasons were added, resulting in a 20-year POR (1989–2008). The same candidate predictor variables from Phase II were used plus a new one: the mean speed in the flow regime layer (1000–700 mb). Previously, the mean wind directions in this layer at the various sounding sites determined the flow regime across the Florida peninsula, but the speed was not considered. The original objective tool used by 45 WS prior to Phase I showed that the wind speed near this layer had a small but not insignificant effect on the probability of lightning occurrence: increasing speed produced increasing probability up to a certain threshold, then decreasing probability at higher speeds. The warm season was also expanded to include October since the daily climatology showed the lightning season continued into that month. The data will be stratified by the natural transitions found in the daily lightning probability climatology curve as opposed to the monthly stratification. This stratification method is defined by the physical attributes contributing to thunderstorm formation as opposed to arbitrary calendar dates. Five sub-seasons are evident in the daily lightning climatology:

1) Pre-season (~1–13 May),
2) Ramp-up (~14 May–22 June),
3) Lightning season (~23 June–12 August),
4) Ramp-down (~13 August–12 October), and
5) Post-season (~13–31 October).

The dates are approximate because they are based on the 20-year daily climatology. The actual dates vary among the individual years. To stratify the data properly, an objective method using observed data will be used to determine the start date of each sub-season. This method must use data available to the forecasters and must be able to make the sub-season start date determination on the day it happens, not a post-analysis. Once stratified, the data will be separated into development and verification data sets and the equations developed using the same methods employed in the previous phases. Their performance against the Phase II equations will be tested, and the best method will be used in operations. This presentation will focus on the new lightning season stratification method, the equation development, final predictors, and how well the new equations perform compared to those in current operational use.

MODIFICATIONS TO THE OBJECTIVE LIGHTNING PROBABILITY FORECAST TOOL AT KENNEDY SPACE CENTER / CAPE CANAVERAL AIR FORCE STATION, FLORIDA

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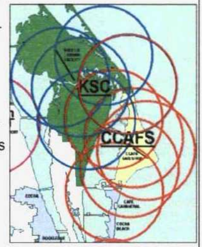
BACKGROUND



The 45th Weather Squadron (45 WS) at Cape Canaveral Air Force Station (CCAFS) includes the probability of lightning occurrence in their 24-Hour and Weekly Planning Forecasts, briefed at 0700 EDT for daily operations planning on Kennedy Space Center (KSC) and CCAFS.

This forecast is based on subjective analyses of model and observational data and output from an objective tool developed by the Applied Meteorology Unit (AMU). This tool was developed over two phases (Lambert and Wheeler 2005, Lambert 2007). It consists of five equations, one for each warm season month (May–Sep), that calculate the probability of lightning occurrence for the day and a graphical user interface (GUI) to display the output. The Phase I and II equations outperformed previous operational tools by a total of 56%.

Based on this success, the 45 WS tasked the AMU with Phase III to improve the tool further.

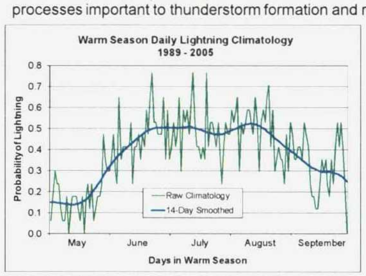
PHASE III GOALS:

The Phase III work had three goals:

1) Increase the period of record (POR) from 17 to 20 years (1989–2008),
2) Add October data to determine if lightning season continued into that month, and
3) Stratify by lightning occurrence sub-seasons instead of month for equation development.

The Phase II daily lightning climatology (below) provided the impetus for goals 2) and 3).

- The climatological probability values decrease through, but do not level off at, the end of September like at the beginning of May; the end of the season is likely in October. In addition, the values at the end of September are higher than those in most of May. If we forecast lightning probability at the beginning of May, then we should also do it for at least part of October.
- Periods of consistent climatological trends identify lightning sub-seasons. Stratifying the forecast equations by sub-seasons rather than month might capture the physical processes important to thunderstorm formation and result in better-performing equations

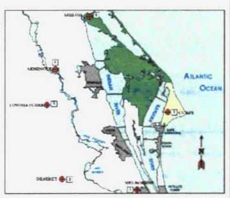


Estimated Sub-Season Dates:

1) Pre-lightning
1 – 13 May
2) Ramp-up
14 May – 22 June
3) Lightning
23 June – 12 August
4) Ramp-down
13 August – 12 October
5) Post-lightning
13 – 31 October

DATA SOURCES

Cloud-to-Ground Lightning Surveillance System (CGLSS)



Network of six sensors surrounding KSC/CCAFS

- Date and time,
- Latitude and longitude, and
- Strength and polarity of CG strikes.

These data were used to determine lightning occurrence for each day. Only one CG was required.

1200 UTC soundings at Miami, Tampa, and Jacksonville

Following Lericos et al. (2002), the mean wind directions in the 1000–700 mb layers at these stations were used to determine the flow regime for each day.

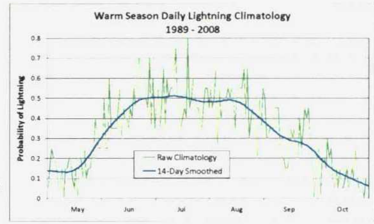
1000 UTC CCAFS sounding

Eleven parameters from this sounding were used as candidate predictors. The mean wind in the 1000–700 mb layer was used to determine the flow regime.

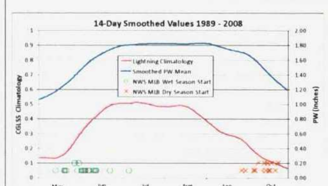
DATA PREPARATION

New 20-Year Daily Climatology

- The values in early October begin decreasing at a slower rate – could signal end to lightning season. Satisfies the second goal, October data included in analysis.
- The values at the beginning of October are higher than at the beginning of May.
- May-Sep values decreased by ~1% from Phase II values.



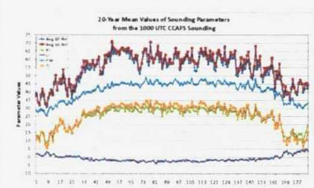
Sub-Season Ground-Truth Dates

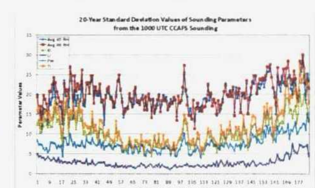


- National Weather Service Melbourne, Fla. (NWS MLB) developed method to determine wet and dry season start dates.
- These dates coincide with ramp-up (wet) and end of (dry) lightning season as defined by the daily climatology.
- These dates were used to validate objective methods that determine the start dates of the sub-seasons in each year.

Data for Objective Method to Choose Sub-Seasons

- The method must be objective and use data readily available to forecasters.
- Comparison with the daily climatology (above) and NWS MLB study indicated precipitable water (PW) may be valuable.
- Curves in chart below (left) are similar to the daily climatology.
- PW shows low stdev values at start of season, others have values similar to their means; PW more likely to be useful.





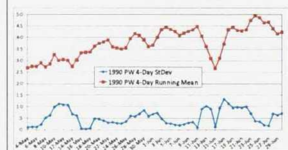
OBJECTIVE METHOD DEVELOPMENT AND TESTING

The start dates for each sub-season should be determined for each year. Three methods tested using PW to determine start of ramp-up and lightning sub-seasons: successful if ramp-up is consistent with daily climatology and lightning is within 1 week (± 7 days) of NWS MLB date.

Method 1: # Occurrences Above PW Threshold

- Ramp-up: start at 1 May, third occurrence of ≥ 1.2 in (30.5 mm)
  Median start date: 10 May (min 3 May, max 19 May), consistent with daily climatology
- Lightning: start day after ramp-up start date, 2-5 occurrences of ≥ 1.7 in-1.8 (43.2-45.7 mm)
  All combinations of # occurrences and PW values; came within 1 week 8 out of 20 years

Method 2: One-Sample t Test of PW Running Mean



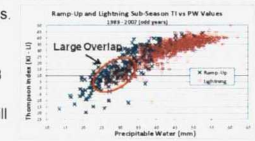
- Determine if sample mean $\bar{x}$ (4-day running mean) was drawn from population with mean μ_0

$$t = \frac{\bar{x} - \mu_0}{\left[V\hat{a}r(\bar{x})\right]^{\frac{1}{2}}} \quad \text{where} \quad V\hat{a}r(\bar{x}) = \frac{s^2}{n}$$

- Chose lightning start date within 1 week of NWS MLB date in 6 of 20 years. Sample chart for 1990, method chose 22 May, NWS MLB date 3 June

Method 3: Multiple Discriminant Analysis (MDA)

- MDA is a statistical method to discern between groups.
- Use PW and Thompson Index (KI – LI) values since PW alone was not successful.
- Chose lightning start date within 1 week of NWS MLB date in 10 of 20 years.
- Best performing method, but 50% rate of detection still not successful.



Final Method: Daily Climatology

No method successful in discerning lightning sub-season start in each year, so chose climatological dates for equations:

Pre-Lightning 1–17 May
Ramp-up 18 May – 5 June
Lightning 6 June – 16 August
Ramp-down 17 August – 11 October
Post-Lightning 12–31 October

PHASE II AND PHASE III EQUATION COMPARISON

- An equation was developed for each sub-season using the development data (16 years) , and tested on the verification data (4 years).

4 random years were chosen for each warm season day, e.g.

1 May 1996/2001/2004/2008, •••, 31 October 1997/2003/2006/2007

The remaining years were in the development data.

- The Phase II equations were also run using the verification data
- Comparison of Phase III performance over Phase II shows a degradation in the forecast

Performance of Phase III equations over Phase II equations for the warm season and each sub-season (no October equation in Phase II to compare with Post-Ltg sub-season).

Warm Season	Pre-Ltg	Ramp-Up	Lightning	Ramp-Dn
-3.6%	-12.2%	-12%	-0.6%	-4.1%

CONCLUSIONS

- The overall lightning season extends into October, therefore data from that month were included in the Ramp-Down and Post-Lightning sub-season equation development.
- None of the objective methods chose a lightning sub-season date within 1 week of the NWS MLB wet season start dates in each individual year. Therefore, sub-season start dates based on the daily lightning climatology were used to stratify the data in all years.
- The equations developed for the sub-seasons in Phase III did not improve the forecast over the Phase II monthly equations – their performance was slightly inferior to the Phase-II equations.
- The Phase II equations will remain in operational use.

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