

Short Term Lightning Hazard Predictions

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ABSTRACT: Thunderstorms and lightning pose a safety risk to people spending time outdoors for professional or recreational purposes and are potentially hazardous to machinery and equipment operated outdoors. Thus, entities such as airports, sports venues and military operations employ safety procedures that include timely warnings and observations of the onset and duration of lightning hazards. These procedures, while crucial to ensure people safety, can have substantial impacts on the efficiency of operations, and thus may vary greatly depending on a particular application. NCAR has been working with the Army Test and Evaluation Command (ATEC) to develop capabilities that enable timely warnings of lightning threats for people and material involved in outdoor testing at the Army test ranges. In addition, working with the Federal Aviation Administration (FAA) enabled exploring a different lightning prediction application, focused on lightning safety for ramp and airport grounds maintenance workers. Notable improvements have been made recently to the previously developed lightning monitoring and prediction capabilities to capture all phases of lightning evolution (i.e., initiation, mature cores, and anvil) and to provide longer lead times and higher update rates. Comparisons of the lightning detection and prediction capability for different applications and impacts on safety vs. efficiency are discussed in this paper.

INTRODUCTION

Lightning poses a serious threat to the safety of people pursuing recreational outdoor activities and those working outdoors at airports, test sites, or sports events, etc. Lightning may also be hazardous to equipment and materials used or tested outdoors. It is important, therefore, to establish relevant procedures that help ensure the safety of people exposed to the potential hazards of nearby thunderstorms and lightning. The most simple safety procedures may rely on sky observations, while advanced procedures make use of lightning and radar observations in various ways.

The National Center for Atmospheric Science (NCAR) has developed a short-term lightning monitoring and nowcasting capability, initially aimed as guidance to forecasters at test ranges of the U.S. Army Test and Evaluation Command (ATEC). It has since been modified for use with other applications as well, such as providing guidance to airport operations or sports events. In the following, the lightning monitoring and prediction capability is described and recent changes are discussed that have been made to it. The lightning alert capability is explored in further detail using the example of airline and airport operations, and air traffic data are utilized to quantify impacts of the safety-related downtime on the

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operational efficiency.

LIGHTNING NOWCAST CAPABILITY

The current NCAR nowcast capability enables lightning alerts with short lead times of <30 minutes, yet improvements are underway to extend the lead time toward 60 minutes. The lightning monitoring includes a real-time display of lightning information that consists of data from 1) Continental United States (CONUS) lightning detection networks, such as Vaisala's National Lightning Detection Network, NLDN), WSI's United States Precision Network (USPLN) or Earth Networks Total Lightning Network (ENTLN), and/or 2) regional high precision, high detection efficiency total lightning information, such as obtainable by a Lightning Mapping Array (LMA; Thomas et al. [2004]). It also includes relevant storm information derived from volumetric radar data, such as intensity, organization, and motion. The NCAR lightning nowcast capability builds on a fuzzy-logic approach that relates radar reflectivity characteristics observed by the NWS Weather Surveillance Radar 1988 – Doppler (WSR-88D) to lightning potential forecasts [Saxen et al. 2008, Deierling et al. 2009].

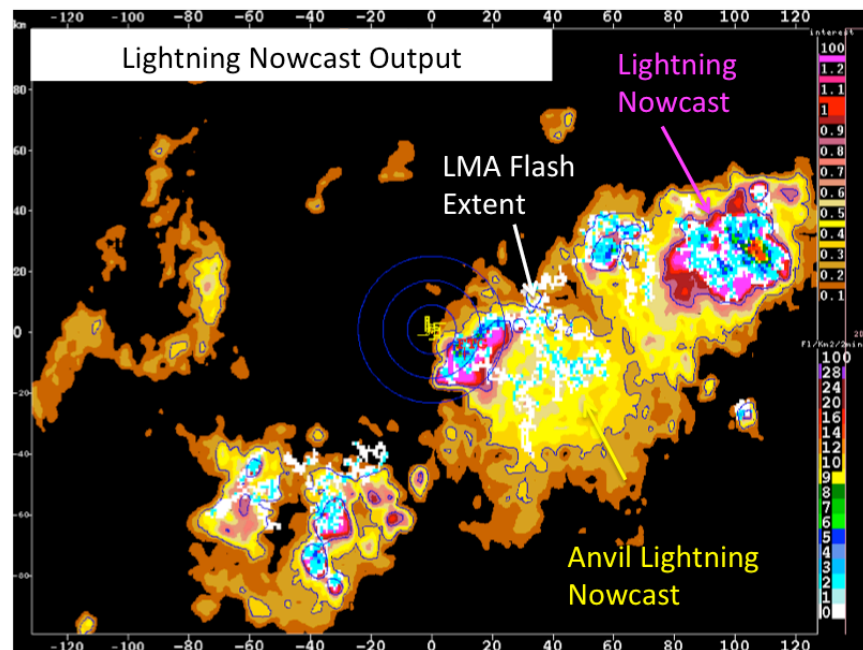


Figure 1. Example of a lightning potential nowcast from the enhanced lightning prediction capability that includes storm cores (magenta shading) and anvil (yellow shading), with contemporaneous LMA data overlaid. Two color-scales are shown to the right. The upper scale is for the lightning potential with warmer colors showing higher potential for lightning to occur. The lower scale is for the lightning flash extent (i.e., horizontal footprint) as depicted by the Lightning Mapping Array (LMA).

Recently, several new predictor fields have been evaluated that have shown skill in previous studies to identify lightning and anvil lightning. Based on a careful selection process, a new combination of lightning predictor fields (still using fuzzy logic) has been developed to better capture lightning from all

phases of thunderstorm evolution (i.e., initiation, mature cores, and anvil) and provide longer lead times. The new capability (Figure 1) enables defining areas of higher lightning frequency and probability (magenta areas; lightning produced within storm cores) and areas of less likely but still possible lightning (yellow; e.g., lightning produced within anvil clouds). The output is scaled between 0.1 and 1.6 where areas of lower lightning potential thresholds are associated with storm anvils and storm initiation (yellow areas in Figure 1). Areas of higher lightning potential thresholds are related to lightning in thunderstorm cores (pink areas in Figure 1). Using tunable thresholds the lightning potential nowcasts can be adapted to reflect specific user needs (e.g., lower thresholds yield longer lightning alert lead time, longer operational downtimes, but increased safety).

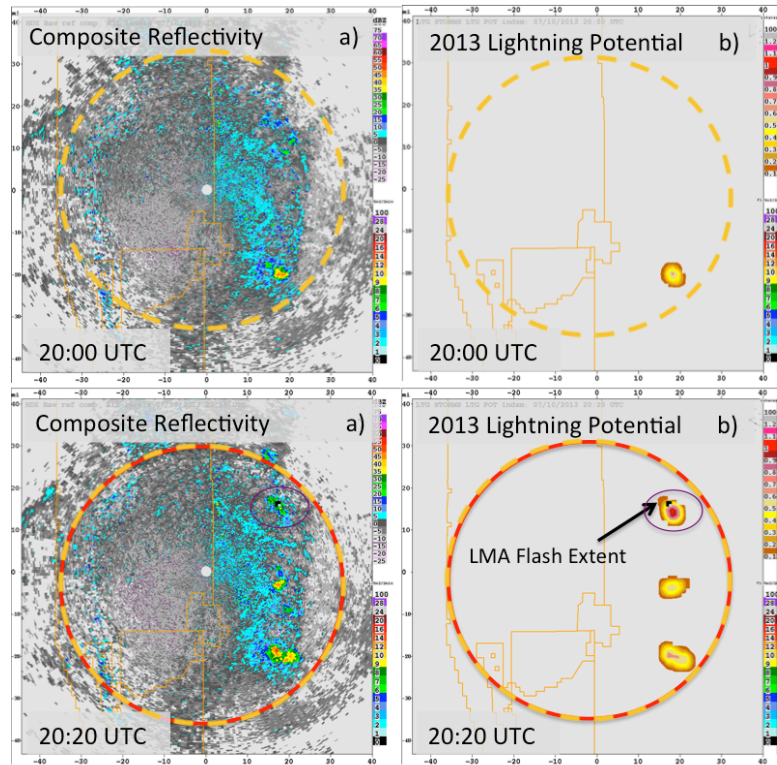


Figure 2: Lightning alert circles with customized 35 mile radius. Observed KHDX NEXRAD radar reflectivity composite (a) and the current NCAR (labeled 2013) lightning prediction capability (b) is shown. Observed LMA lightning activity is indicated by the black pixel. Based on a particular lightning potential threshold (0.4, yellow area), the orange alert circle triggered 20 minutes before lightning was observed within the circles. The key to interpreting the alert circles is shown in Figure 3.

Instead of, or in addition to, showing the lightning potential field in Figure 1, short-term lightning nowcasts can also be visualized as elliptical markers highlighting storms capable of producing lightning in the very near term [Saxen et al. 2008]. Additionally, the system can be set up to generate site-specific color-coded alert circles around key locations based on the short-term lightning potential forecast and real-time lightning observations (Figures 2 and 3). As an example, Figure 2 shows the composite radar reflectivity from the Holloman Air Force Base (KHDX) NEXRAD radar at White Sands Missile Range

(a), and the current lightning prediction capability (b) at 20 UTC and 20:20 UTC, which for this case was the time of the first lightning strike within a 35-mile radius of the center of White Sands Missile Range. The alert circles can be customized to specific safety needs (e.g., specific distance criteria) of a user. Lightning alert circles appear dashed orange if any grid point within that circle exhibits a lightning potential. The circle becomes orange and red dashed, if both there is a lightning potential and actual lightning has occurred within this range. If lightning is observed without being predicted, then the alert circle is displayed in dashed red. In normal operations the circles should light up in orange first and then shift to orange-red as the lightning develops or moves into the area.

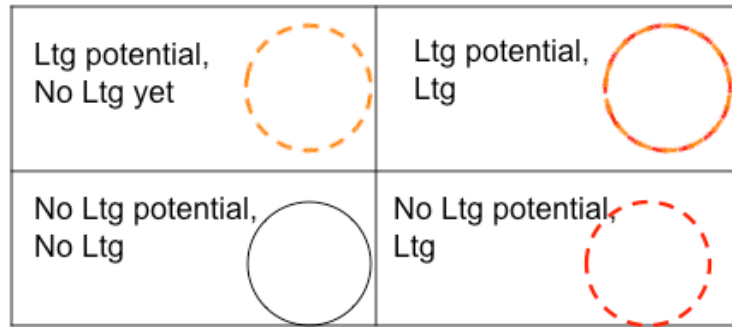


Figure 3: State of the lightning alert circles.

Lead times of the current lightning detection system verified against LMA lightning data can be notably longer depending on the setting of the lightning prediction thresholds. This is exemplified in Figure 4 (the same event as shown in Figure 2) with the maximum lightning potential within a 35-mile radius of White Sands Missile Range based on the initial (labeled as 2012) NCAR lightning prediction capability [Saxen et al. 2008] and the new (labeled as 2013) NCAR lightning prediction capability. It can be seen that the current capability provides increased safety buffers around the periods of lightning activity (e.g., a longer lead time for the onset of lightning within a 35-mile radius).

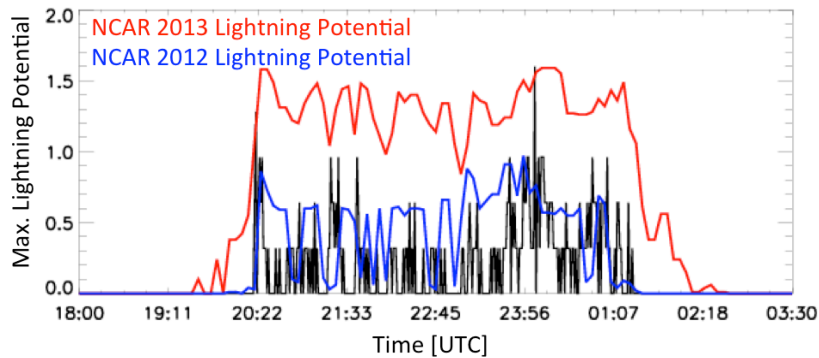


Figure 4. The black line represents the maximum lightning activity measured by the LMA normalized to scale with the maximum lightning potential output based on Saxen et al. [2008] (blue line) and updated current (red line) NCAR lightning potential output within 35 miles of White Sands Missile Range.

Lead and lag times of lightning alerts also depend on the scale for which lightning warnings are performed as well as on the lightning data used for monitoring (and verification). While longer lead times (and as a consequence downtimes) have the benefit of increased safety and are applicable for some operations, such as at the Army test ranges, other applications like airports may have operational (and economic) pressures that require shorter downtimes. To illustrate the tradeoff between safety and efficiency (longer versus shorter downtimes) the following section contrasts downtimes incurred by an LMA system and lightning measured by several CONUS lightning detection networks with downtimes derived from different thresholds of the current NCAR lightning potential nowcast output for several safety rules in the context of airport operations.

BALANCING LIGHTNING SAFETY VERSUS OPERATIONAL EFFICIENCY

Airline and airport stakeholders employ safety rules that are reactive to a first lightning strike within a critical distance to halt outdoor work and start a waiting period. Each subsequent lightning strike within that critical distance will reset the clock for the waiting period. Outdoor work may resume after there have been no further lightning strikes within that critical distance and designated timespan. Steiner et al. [2014] have shown that such ramp closures can cause noticeable impacts on terminal air traffic.

The subsequent analyses are based on safety rules that utilize various sources of lightning and lightning potential information to gauge impact on air traffic in and out of airports. Three safety rules were used in this study, as listed in Table 1. They represent a range of typically observed procedures, varying from a very aggressive Rule 1 that some airline stakeholders with advanced decision support tools employ to a more conservative Rule 3 used when little support is available and stakeholders are primarily relying on direct sky observations. Many airlines have been relying on something close to Rule 1 or 2.

Table 1. *Three commonly used lightning safety rules.*

<i>Rule</i>	<i>Critical Distance (miles)</i>	<i>Waiting Period (minutes)</i>
1	3	6
2	5	15
3	6	30

To assess the lightning potential nowcasts in the context of impacts related to air traffic at airports, the above safety rules were used to translate time-series of lightning and lightning potential data into time-series of nominal ramp closures, assuming a perfect implementation of safety procedures by the operators. In reality, this is not quite the case, as Steiner et al. [2013] highlighted, but it provides for a meaningful basis to quantify the magnitude of the traffic impacts caused by lightning-induced ramp closures. Note, that lightning potential data exceeding thresholds of 0.1, 0.2 up to 1.5 were translated into nominal ramp closures by applying the rules listed in Table 1. All combinations of lightning data sources, lightning potential output and safety rules were explored in our analyses. In order to preserve anonymity,

we label them as Rules 1 – 3 and lightning Sources A – D, respectively. Air traffic data used herein were obtained from the Research and Innovation Technology Administration (RITA) Bureau of Transportation Statistics (BTS). This dataset contains detailed information about departure and arrival statistics, such as scheduled and actual gate departure/arrival times, departure/arrival delay, wheels-off / touchdown time, and taxi-out / taxi-in time by airport and airline, including airborne time, cancellation and diversion, and other related information.

Nominal ramp closures were computed first for case studies and subsequently compared to air traffic data. Figure 5 illustrates a case study of nominal ramp closures from lightning Sources A – D in comparison to nominal ramp closures of lightning potential nowcasts exceeding thresholds of 0.6 (threshold 1 in Figure 5) and 1.1 (threshold 2 in Figure 5), respectively, with regard to arrival and departure delays. The nominal ramp closure start and stop times derived from the lightning potential threshold 1 are equivalent to those of lightning Source A which is the most complete lightning source that also captures anvil lightning. Similarly the ramp closure start and stop times for a higher threshold 2 match well those derived from commercial lightning detection Sources B – D that are mostly associated with lightning in thunderstorm cores. Lower and higher thresholds of the lightning potential nowcast are able to depict areas of anvil and core lightning.

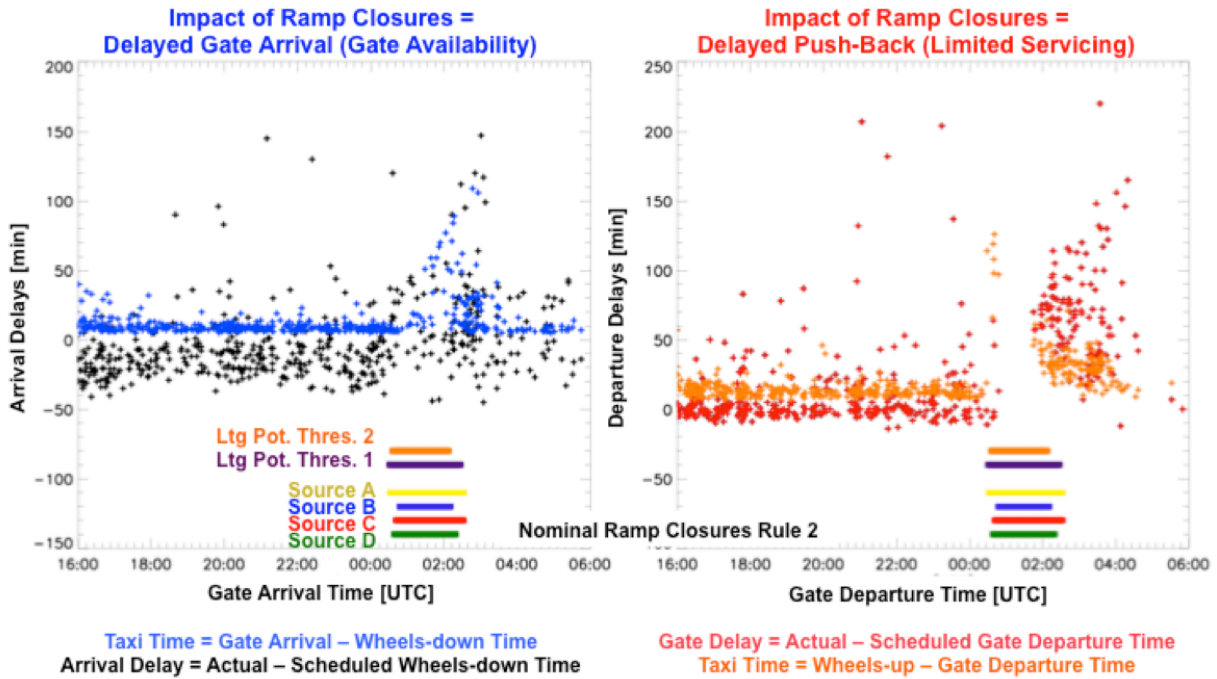


Figure 5. Impacts of ramp closures on air traffic arrivals (left) and departures (right). Nominal ramp closures were derived from lightning Sources A – D and lightning thresholds exceeding 0.6 and 1.1, respectively, and by applying Rule 2 in Table 1. They are shown on the bottom.

Table 2. Number (counts) and cumulative duration (in minutes) of nominal ramp closures for one major airport (same as used in Figures 6 and 7) based on different lightning potential thresholds (Sources B, C, and D), one regional lightning detection network (Source A), lightning potential output exceeding different thresholds and different safety rules (Table 1) for 2013. The statistics are based on times when data were available for all networks (i.e., avoiding effects of data gaps).

		Number of Ramp Closures			Duration of Ramp Closures		
		Rule 1	Rule 2	Rule 3	Rule 1	Rule 2	Rule 3
Lightning Source	A	115	99	87	2303	4467	6529
	B	59	57	58	806	2279	3579
	C	94	81	68	1435	3309	5016
	D	54	59	56	563	1812	3258
Lightning Potential Threshold	>0.1	296	304	252	14005	21646	28148
	>0.2	204	240	220	9290	15030	20550
	>0.3	150	177	176	6850	11218	15679
	>0.4	118	131	127	5065	8614	11933
	>0.5	88	109	112	3895	6806	9583
	>0.6	72	98	96	3245	5647	8169
	>0.7	66	79	85	2700	4671	6780
	>0.8	55	66	71	2265	3979	5879
	>0.9	47	61	69	1970	3509	5281
	>1.0	42	56	61	1725	3174	4579
	>1.1	40	55	54	1555	2945	4131
	>1.2	37	49	48	1340	2581	3687
	>1.3	31	46	47	1125	2224	3408
	>1.4	27	36	40	935	1834	2950
	>1.5	24	27	36	820	1523	2534

In addition, annual delay statistics of departures for one airport in Table 2 show that the number and cumulative duration of nominal ramp closures for a set of lower and higher lightning potential thresholds are within the range of those computed from lightning Source A and Sources B – D respectively. Furthermore, annual impacts of nominal lightning potential derived ramp closures on air traffic include the margins of nominal, lightning derived ramp closure impacts (compare Figures 6 and 7). Very low

lightning potential thresholds provide extra lead time for lightning hazards to occur. Thus, the mean time difference of total gate delays or mean gate and taxi delays in Figure 7 is larger than that derived from lightning Sources A – D (Figure 6). However, a stakeholder can use such information to prepare for the onset of a ramp closure. Such lightning potential granularity represented by these thresholds would also allow stakeholders to choose their own balance point between safe and efficient operations.



Figure 6. Departure statistics from 1 January through 31 December 2013 for one major airport. Shown are the total number of flights affected by nominal ramp closures (upper left) and associated cumulative delays (upper right), mean gate pushback delays for flights affected by ramp closures (middle left) and those not affected by ramp closures (middle right), and mean taxi-out time for flights affected by ramp closures (bottom left) and those not affected by ramp closures (bottom right). Nominal ramp closures were computed based on four sources of lightning data (color coded) and three safety rules (grouped together). The gray-shading highlights the range of uncertainty related to a choice in lightning data and safety rules.

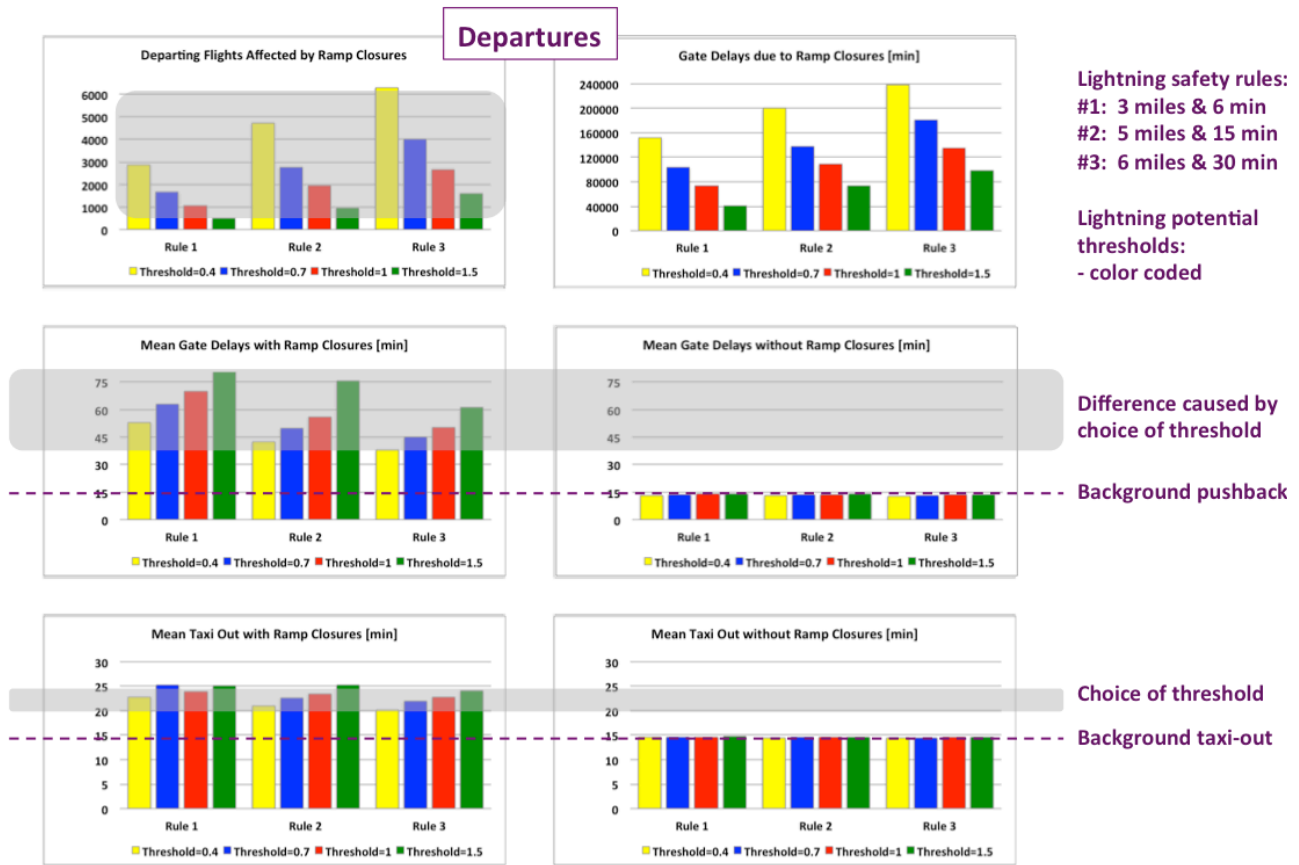


Figure 7. Similar to Figure 6, except that the lightning sources are replaced by lightning potential predictions, thresholded at four levels. Nominal ramp closures were computed based on four lightning potential thresholds (color coded) and three safety rules (grouped together).

SUMMARY

This paper provides a brief overview of NCAR's lightning alert capability. Recent enhancement of the lightning potential nowcasts have been made to capture lightning initiation and anvil lightning without compromising lightning prediction for the thunderstorm cores. These enhancements enable increased warning lead times before lightning occurs. The performance of the lightning alerts can be tuned to varied user needs. This paper illustrated different uses and implications of tuning the lightning alert capability to either provide safer yet longer downtimes (possibly allowing pro-active measures when used with sufficient warning time) or aim for shorter downtimes and thus less impact on operations as exemplified by airport operations.

The current lightning alert capability provides an assessment of the potential risk of encountering lightning strikes within a critical area. This radar-based capability yields a heads-up of looming thunderstorm-related lightning impacts, and it will be particularly beneficial to operators that have no access to other information about lightning, such as available from national or regional lightning detection

networks. The lightning potential alerts can be tuned to emulate what direct lightning observations might observe, if available, and thus help better define the lightning hazard in the vicinity of an operationally relevant area (such as an airport or test range) or recreational outdoor activities (sports event, hiking, etc.) and tune the alerts to a user's risk tolerance.

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REFERENCES

- Deierling, W., C. Kessinger, and E. Nelson, 2009: Predicting lightning potential on different time scales—A conceptual model and first results. 89th AMS Annual Meeting, Phoenix, AZ, USA, 12 – 15 January 2009.
- Saxen, T. R., C. K. Mueller, T. T. Warner, M. Steiner, E. E. Ellison, E. W. Hatfield, T. L. Betancourt, S. M. Dettling, and N. A. Oien, 2008: The operational mesogamma-scale analysis and forecast system of the U.S. Army Test and Evaluation Command. Part IV: The White Sands Missile Range auto-nowcast system. *J. Appl. Meteor. Clim.*, **47**, 1123 – 1139.
- Steiner, M., W. Deierling, and R. Bass, 2013: Balancing safety and efficiency of airport operations under lightning threats. *The Journal of Air Traffic Control*, **55**(2), 16 – 23.
- Steiner, M., W. Deierling, K. Ikeda, and R. Bass, 2014: Lightning Impacts on Departures and Arrivals, and Considerations for Balancing Operational Efficiency with Personnel Safety. *Air Traffic Control Quarterly*, submitted for publication.
- Thomas, R., P. R. Krehbiel, W. Rison, S. J. Hunyady, W. P. Winn, T. Hamlin, and J. Harlin, 2004: Accuracy of the lightning mapping array. *J. Geophys. Res.*, **109**, D14207, doi:10.1029/2004JD004549.