Final Report

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NWS Offices:	Pendleton, Pueblo, Sterling, and Tallahassee
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Project Title:	Development and Evaluation of Mesoscale Lightning Threat Guidance for Operational Use at NWS Forecast Offices
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Section 1: Project Objectives

The **objectives** of this COMET research were to:

- Develop statistical lightning guidance algorithms for at least one domain within each of the four contiguous NWS regions—Eastern, Central, Southern, and Western. The procedure was developed and tested in Florida by Shafer and Fuelberg (2008). The current research establishes the usefulness of the algorithms around the nation.

- For each selected domain, develop the algorithms for as many months or seasons that are necessary to achieve optimum results. This will determine the effectiveness of the approach during the entire year, not just the warm season that was studied over Florida.

- Develop procedures so that results of the algorithms can be used within the GFE environment of IFPS. This will facilitate easy use of the algorithm's output by the NWS. The scale of our forecasts (10 km resolution) is comparable to that used within IFPS/GFE.

Shafer, P.E., and H.E. Fuelberg, 2008: A perfect prognosis scheme for forecasting warm season lightning over Florida. Mon. Wea. Rev., 136, 1817-1846.

Section 2: Project Accomplishments and Findings

The first step was to select three regions for which to develop the lightning guidance products. The goal was to select areas that had different land forms, land-sea interfaces, and lightning climatologies. We selected the areas of:

- Washington D.C.—the western region is mountainous while the eastern portion consists of flatter terrain that contains complex sea-land interfaces (e.g., Chesapeake Bay).

- Pueblo CO—the area mostly is very mountainous, but there is a flatter area to the east

- Pendleton OR—the coastal plain is relatively flat, as is the Columbia Basin, but there is a coastal mountain range and complex high terrain elsewhere. This region experiences much less lightning than the other two.

One of the major aspects of our statistical approach was to include "map type parameters" that would locate small scale climatological regions of enhanced or reduced lightning that would not be adequately depicted in most operational models. Five map types were developed for each region for each 3 h forecast period. The map types were determined from low-level geopotential height fields. Type A was the most common height pattern for each region, Type B the second most common, etc. An example of Type A in the Oregon region, along with the lightning occurring for that flow type is given in Fig. 1.

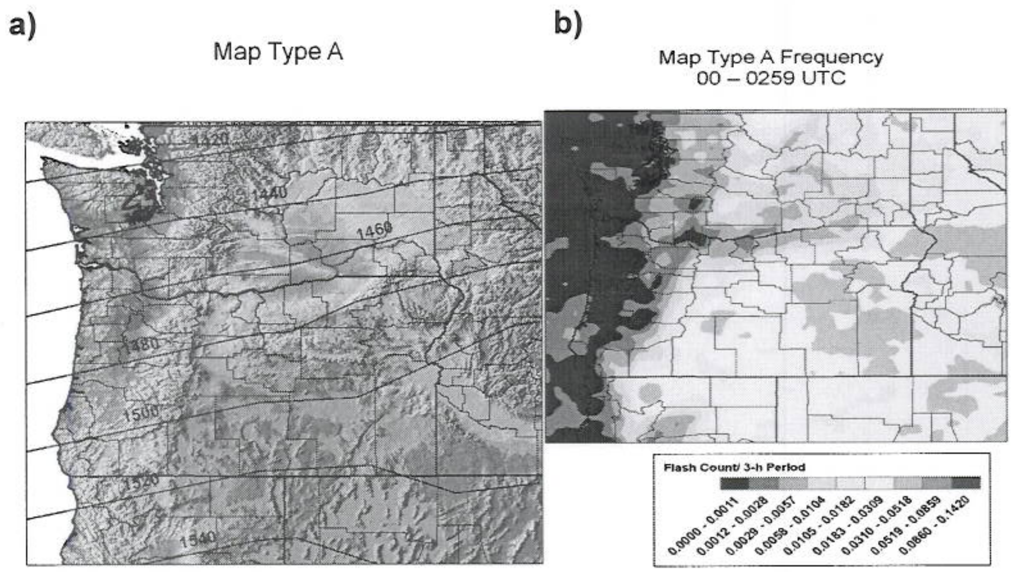


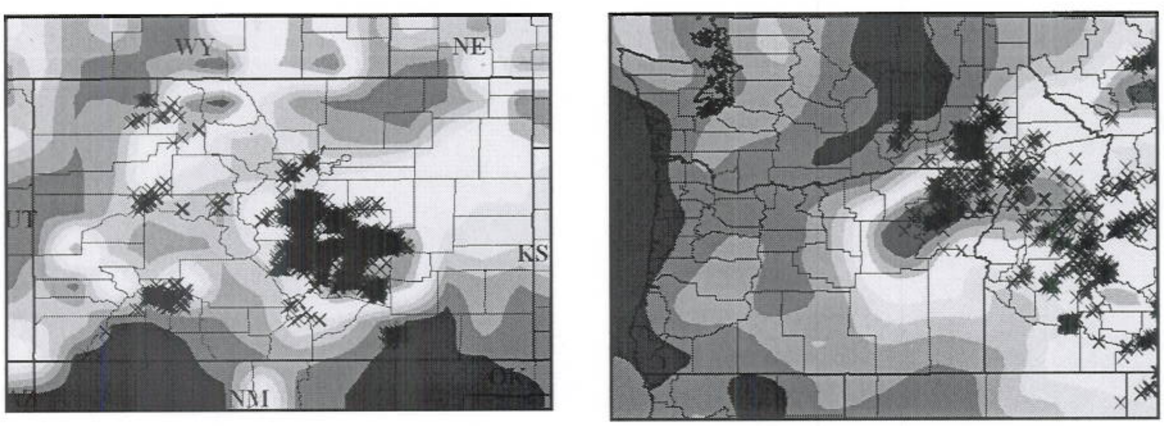
Figure 1. a) Geopotential heights at 850 mb that correspond to the most common warm season flow pattern in the Oregon/Washington domain. The pattern exhibits high pressure (weak ridging) to the south over northern California/NW Nevada and relatively strong southwesterly flow across the region. b) Locations of lightning that occur during a Type A flow pattern (panel a). The image is for the period 0000-0259 UTC. Separate lightning distributions were prepared for each 3 h interval and for the Sterling VA and Pueblo CO areas.

We developed two types of guidance products for each of the three regions for each 3 h period.

- The probability of at least one cloud-to-ground (CG) flash occurring within each 10 × 10 km grid box encompassing each area.

- If at least one flash would occur, what is the probability that the grid box would experience an amount of CG lightning corresponding to the 50th, 75th, 90th, and 95th percentiles of occurrence during that 3 h period.

We used the perfect prognosis (perfect prog approach) to develop the lightning guidance products. Thus, the RUC data that were used to calculate the various predictors were assumed to be "perfect". This approach is advantageous in that the guidance equations do not need to be re-derived as new or improved forecast models are developed. Binary logistic regression was used to develop the "yes or no" lightning product, and negative binomial regression was used to forecast the amount of lightning. In addition to the map type parameters, a host of potential meteorological predictors was provided to the selection scheme, covering all aspects of stability, moisture, and vertical motion. Four seasons of data (through 2008) were used as training. The selection process then picked the combination of predictors that best forecast the lightning in each of the three regions for each 3 h period. Map type was selected for every forecast equation. We were careful that these final predictors were not highly inter-correlated since this would produce undesirable results.



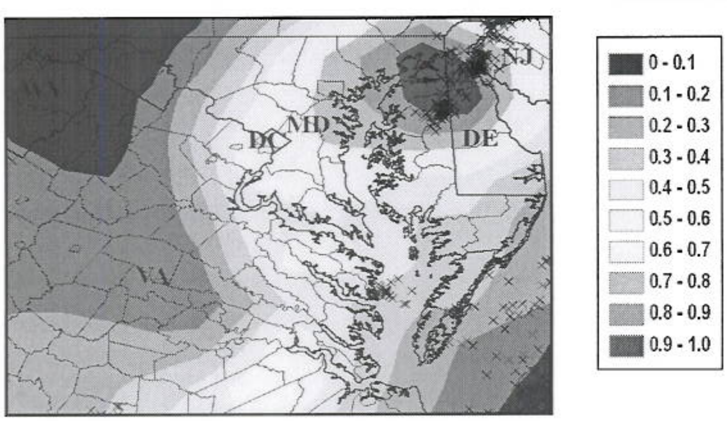


Fig. 2. Examples of the probability of one or more CG flashes in a 3 h period (colors) along with the observed CG flashes in the same period (X's). RUC data served as input. The examples are for three different days.

An example of a final 3 h forecast and its verification for each domain is given in Fig. 2. Similar guidance maps were prepared to show whether that period would be in the 50th, 75th, 90th, and 95th percentiles of occurrence

Two points should be emphasized: 1) Although the lightning guidance was developed using RUC analyses, the input from any model can be used operationally. We examined the use of RUC 13 and NAM 12 on the independent data set. However, output from any other model, including local mesoscale models could be used. 2) Although the algorithms were developed from analyses, forecast data can be input, e.g., using 12 h RUC or NAM forecast data would yield a 12 lightning forecast. One does not need to merely input analyses.

The examples in Fig. 2 show relatively good agreements between the forecast CG lightning and what was actually observed. Of course, not all forecasts are this good. It was important to compute quantitative verification statistics for each region. We selected several statistical parameters with which to evaluate the forecasts using an independent data set—the warm season of 2009:

- Relative Operating Characteristic (ROC) curves plot the true positive rate versus the false positive rate.

- Brier Scores for our schemes versus those based on a combination of persistence and climatology. Brier scores are widely used to evaluate probabilistic forecasts such as ours.

- Brier Skill Scores that assess the degree to which our procedures out perform or underperform those based on climatology and persistence.

- Reliability diagrams are a measure of the accuracy of a probabilistic forecast, indicating the relationship between the probabilities and the observed frequency of the predictand. The diagrams indicate whether the scheme is over forecasting or under forecasting at any particular value of probability.

Results for Colorado showed that the lightning forecast models for predicting one or more flashes generally exhibited positive Brier skill scores relative to climatology. In fact, skill for the region exceeded that of the other two domains. Skill for both the RUC13 and NAM12 was positive for every time projection except the 3-6 h (2100-2359 UTC) projection. However, skill generally deteriorated for each subsequent projection, likely due to errors in the NWP model forecasts that increase with time. The models also showed Brier score improvement over persistence when forecasting events in the 75th or greater percentiles, with more limited skill for events in the 90th and 95th percentiles. Reliability generally was good for forecasting one or more flashes, although some over forecasting was indicated. The RUC13 model was more skillful than the NAM12. Conversely, the reliability diagrams indicated great difficulty in forecasting the amount of lightning in Colorado.

Our lightning guidance product for the Washington, D.C. area also showed positive Brier skill scores relative to its respective climatology model through the 2100-2359 UTC period. Brier scores for forecasting one or more flashes using RUC13 were positive for each time projection. However, the skill deteriorated sharply during the 3-6 h projection, and then more gradually for future forecast projections. Lightning forecasts based on the NAM12 model performed similar to the RUC13, but showed no skill during the last projection (12-15 h). When forecasting events in the 75th or greater percentiles, the models were superior to persistence/climatology, with more limited Brier skill for events in the 90th and 95th percentiles. The reliability of forecasting one or more flashes generally was good, but with some under forecasting of the lower probabilities. Similar to the Colorado region, however, the reliability of forecasting the amount of lightning was poor because model probabilities were too low.

The forecast models for one or more flashes in the Oregon region exhibited good Brier skill scores compared to persistence. However, results showed that Oregon was the most difficult region to forecast. Brier scores of the RUC13 data were positive for each forecast projection, with a gradual decrease in skill throughout. Results for the NAM12 model generally were good, but showed negative skill compared to persistence/ climatology during the 3-6 h projection. Forecasts of the amount of lightning from both the RUC13 and the NAM12 models showed good Brier skill scores, especially during the first three projections. The models exhibited good reliability for forecasting one or more flashes, although some slight over forecasting was indicated. Similar to the other two regions, forecasting the amount of lightning exhibited poor reliability due to the small forecast probabilities, and the Brier scores showed no skill compared to persistence/ climatology.

To summarize, the lightning guidance algorithms for each region do show improvements over persistence and climatology, i.e., they exhibit skill. Results for Colorado were best, and those for Oregon were worst. However, none of the results were as good as those found earlier for Florida. This is expected since Florida's warm season thunderstorms mostly are triggered by the sea breeze, which is a rather well behaved phenomenon. Nonetheless, we believe that our guidance products will be a useful addition to those already in use.

The algorithms now are ready for operational testing at the NWS offices in Sterling, VA, Pendleton, OR, and Pueblo, OR. The original plan was for NWS Tallahassee to develop procedures to implement the equations in the GFE environment. Unfortunately, staffing issues and other critical needs prevent them from doing so immediately. We hope that can be accomplished over the next few months. Therefore, we are about to begin making the calculations at FSU each day and placing the results (e.g., Fig. 2) on our web site for access by the NWS offices. This web site is almost ready.

Section 3: Benefits and Lessons Learned: Operational Perspective

The need for quality lightning guidance across the State of Colorado is important for multiple reasons. Foremost; cloud to ground lightning activity is the leading cause of forest fires in the Centennial state. As I write, a major fire is burning just east of the Great Sand Dunes National Park, and this fire was started by lightning. Current lightning forecast information which Colorado NWS offices issue to the fire weather community via the Fire Weather Forecast product (Fig 3) is questionable at best. Known as the "Lightning Activity Level", or LAL, this numerical value represents the amount of lightning activity which is expected over a fire weather zone region. However, this LAL value in its' current form is simply based off of the current thunderstorm "Probability of Precipitation" (POP) value expected over that fire weather zone (Table 1). As an example, if the POP value is 40% over a given fire weather zone, than the LAL value would be 4 (40-80 lightning strikes). As can be seen, the LAL value has absolutely no relevance to physical attributes associated with electrified convection.

It is hoped that using the Lightning Threat Guidance developed by the FSU research group, that we (NWS) could have an improved lightning forecast product that would could incorporate into our Fire Weather Forecast and share with the operational Fire Weather community over Southeast and South Central Colorado. Since this technique is related to attributes associated with electrified convection, it would likely be a significant improvement over the current LAL product which is currently forecast at this time. As per the results from Mr. Saunders Thesis, the Lightning Threat Guidance showed skill over the state of Colorado.

One of the drawbacks of this project from an operational perspective was that the output from the Lightning Threat Guidance is not going to be incorporated directly into NWS Graphical Forecast Editor (GFE). Since it will not be in the GFE database, it will be physically impossible to incorporate this Lightning Threat Guidance information into the National Digital Forecast Database. I should mention, however, the forecasters at NWS Pueblo will have the opportunity to look at the Lightning Threat Guidance information via the internet, and they will be able to mention the results of the output in the "text discussion" part of the Fire Weather Forecast product. There is no guarantee, however, that this will happen.

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COZ225-231045-
SOUTHERN FRONT RANGE-
INCLUDING...LA VETA PASS...SANGRE DE CRISTO MOUNTAINS...
WET MOUNTAINS
248 PM MDT TUE JUN 22 2010

...RED FLAG WARNING IN EFFECT UNTIL 9 PM MDT THIS EVENING...

.TONIGHT...
SKY/WEATHER.........PARTLY CLOUDY(34 PERCENT).
MIN TEMPERATURE.....44-54F.
MAX HUMIDITY........29-47 PERCENT...EXCEPT 24-37 PERCENT ABOVE
                    10000 FEET.
20-FOOT WINDS.......WEST 5-10 MPH WITH GUSTS TO AROUND 30 MPH.
LAL.................1.
HAINES INDEX........6 OR HIGH POTENTIAL FOR LARGE PLUME DOMINATED
                    FIRE GROWTH.
10K FT WINDS........WEST 15-30 MPH BECOMING SOUTHWEST 10-20 MPH
                    AFTER MIDNIGHT.
MIXING HEIGHT.......11000 FT AGL UNTIL 2200. 1500 FT AGL AFTER
                    0200.
TRANSPORT WINDS.....WEST AROUND 15 MPH UNTIL 0500...THEN SOUTHEAST.
SMOKE DISPERSAL.....EXCELLENT UNTIL 2200. POOR AFTER 0500.
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.WEDNESDAY...
SKY/WEATHER.........MOSTLY SUNNY(47 PERCENT). ISOLATED
                    THUNDERSTORMS IN THE AFTERNOON.
MAX TEMPERATURE.....71-88F...EXCEPT 55-76F ABOVE 10000 FEET.
MIN HUMIDITY........10-21 PERCENT.
20-FOOT WINDS.......SOUTHEAST 5-10 MPH.
LAL.................2.
HAINES INDEX........6 OR HIGH POTENTIAL FOR LARGE PLUME DOMINATED
                    FIRE GROWTH.
10K FT WINDS........SOUTH AROUND 15 MPH.
MIXING HEIGHT.......500 FT AGL UNTIL 0800. 15000 FT AGL AFTER 0900.
TRANSPORT WINDS.....SOUTH AROUND 15 MPH.
SMOKE DISPERSAL.....POOR UNTIL 0700. EXCELLENT AFTER 0900.
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Figure 3. Text product from the NWS Pueblo Fire Weather Forecast product issued at 3 PM 22 June 2010.

Table 1. Lightning activity table. Table taken from the NWS Pueblo Fire Weather Station Duty Manual, 22 June 2010. Note that the LAL value in the table below is simply related to the POP value.

LAL value	**Thunderstorm coverage**	**Corresponding POP value**	**Strikes/Hour**	**Total Strikes**
1	None	0%	None	None
2	Isolated	10%	<20/hr	<20
3	Isolated	20%	Up to 70/hr	20-40
4	**Scattered**	**30-50%**	**25-130/hr**	**40-80**
5	Widespread	60-100%	75-300/hr	80-160
6	DRY THUNDERSTORMS	DRY THUNDERSTORMS	Up to 70/hr	Up to 40

I am quite pleased that we will have a lightning forecast product to look at when it comes to forecasting lighting for the fire weather community. This is the first direct product that I am aware of that will explicitly forecast the location and general amount of lightning over our forecast area. I am a bit disappointed, however, that it was not made a priority to have this valuable lightning information incorporated into the GFE forecasting process. This would have been an excellent product to be ingested into the experimental Point Forecast Fire Weather product in which we (NWS Pueblo) currently issues (Figure 4).

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GREAT SAND DUNES RAWS-ALAMOSA CO
37.72N 105.51W ELEV. 8230 FT
233 PM MDT TUE JUN 22 2010

DATE               06/22/10      WED 06/23/10            THU 06/24/10            FRI
MDT 3HRLY         15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06
UTC 3HRLY         21 00 03 06 09 12 15 18 21 00 03 06 09 12 15 18 21 00 03 06 09 12

MIN/MAX                          47          81          48          80          48
TEMP              81 79 66 60 56 48 68 77 81 78 67 60 57 48 67 75 79 77 66 60 56 48
DEWPT             19 16 13 20 21 21 23 25 24 33 33 32 33 35 35 35 34 33 34 36 32 29
MAX/MIN RH                       34          12          59          19
RH                10  9 13 21 25 34 18 14 12 19 28 35 40 60 30 23 20 20 30 41 40 47
WIND DIR          SW  W  W NW SW  E  E SE  S  E  E  E  E  S SW SW SW SW SW SW  W SW
WIND SPD          24 19  9  2  1  1  4  4  6 12 13 10  4  3  8 11 11 11  9  4  4  8
WIND GUST         40                            33 23
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CLOUDS	SC	SC	SC	FW	FW	SC	SC	SC	SC	B1	B1	SC	SC	SC	SC	B1	B1	SC	SC	SC	SC	SC
POP 12HR						0				10				10				20				20
RAIN SHWRS								IS	IS	IS	IS					IS	IS	IS	IS			IS
TSTMS								IS	IS	IS	IS					IS	IS	IS	IS			IS
LAL	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1	2	3					
HAINES	5	6	6	5	5	5	5	5	6	3	3	3	3	3	3	4	5	5	3	3	3	3
10K WIND DIR	SW	W	W	W	W	SW	S	SW	SW	S	SE	S	S	SW	SW	SW	SW	SW				
10K WIND SPD	31	25	26	20	19	12	16	9	12	13	27	12	16	20	17	14	12	16				
MIX HGT	15	14	7	2	<1	<1	9	12	14	15	7	2	1	<1	6	13	15	13				
T WIND DIR	SW	SW	W	NW	W	S	S	SW	SW	S	SE	SE	S	S	SW	SW	SW	SW				
T WIND SPD	33	28	21	11	4	3	10	11	12	10	20	11	5	9	14	13	12	14				
SMOKE DISP	EX	EX	VG	PR	PR	PR	GD	VG	EX	VG	VG	PR	PR	PR	GD	EX	EX	EX				
CRTCL FWX POT	L	L	P	U	U	U	U	P	U	P	U	U	U	U	U	P	P	P	P	U	U	U
RED FLAG	W	W																				

DATE	06/25/10			SAT 06/26/10				SUN 06/27/10				MON 06/28/10				TUE 06/29/10		
MDT 6HRLY	12	18	00	06	12	18	00	06	12	18	00	06	12	18	00	06	12	18
UTC 6HRLY	18	00	06	12	18	00	06	12	18	00	06	12	18	00	06	12	18	00
MAX/MIN		78		50		79		48		80		49		82		51		82
TEMP	74	75	60	50	75	76	60	48	76	74	57	49	75	77	53	51	77	79
DEWPT	31	34	30	29	30	28	27	28	30	28	30	26	30	32	34	32	34	32
RH	20	22	32	44	19	17	28	46	18	18	35	40	19	19	48	48	21	18
PWIND DIR		SW		SW		W		N		SE		SW		SE		S		SE
WIND CHAR		<15		<15		<15		<15		<15		<15		<15		<15		<15
AVG CLOUDS	SC	B1	B1	SC	SC	SC	SC	SC	SC	SC	B1	SC	SC	B1	B1	SC	SC	SC
POP 12HR		20		20		10		5		10		10		20		20		5
RAIN SHWRS	IS	IS	IS			IS	IS			IS	IS			IS	IS			IS
SPRINKLES						IS				IS				IS				
TSTMS	IS	IS	IS			IS	IS			IS	IS			IS	IS			IS

Figure 4. Experimental point forecast fire weather product issued for the Sand Dunes National Park area which NWS Pueblo issues on a routine basis. This forecast was issued 3 pm 22 June 2010. Note that if the FSU lightning threat guidance was in the GFE database, it could easily be incorporated into this digital text database product. More information about the experimental point forecast fire weather product can be found at the following web address: **http://www.crh.noaa.gov/pub/?n=/pfw/pfwsiterequest.php**

In addition to the fire weather community, it is likely this FSU Lightning Threat Guidance product can be used when forecasting thunder over the region. Having this information available would assist the forecaster in deciding to mention thunder in one particular area or not. However, as I discussed above, it would be much easier incorporating this information into the forecast if it was included in the GFE database.

I can also envision this lightning guidance being used by search and rescue personnel when they need information about the lightning threat during a search and rescue mission.

Section 4: Benefits and Lessons Learned: University Perspective

We enjoyed this operationally related research project. Attempting to forecast the probability of whether lightning will occur in a specific 10 × 10 km grid box during a 3 h period is, and remains, a major challenge. The research emphasized the role of subtle forcing mechanisms in producing the parent thunderstorms—forcing that numerical models generally cannot resolve. In spite of the subtlety, NWS personnel must issue forecasts that incorporate this thinking. The research made us better realize the challenges that forecasters face each day.

The major problem was that the research topic was more demanding and time consuming than anticipated. It was more than most M.S. candidates can handle. As a result, the project became considerably behind schedule. FSU regrets this tardiness but hopes that the lightning guidance products will be found to be worth the wait. COMET graciously provided no-cost extensions to continue the research.

Section 5: Publications and Presentations

Fuelberg, H.E., 2009: Statistically-derived lightning forecast guidance prepared at Florida State University (Invited). 4th Conf. Meteor. Applications of Lightning Data, Amer. Meteor. Soc., Phoenix, Paper 6.1.

Rudlosky, S.D., H.E. Fuelberg, P.E. Shafer, G.T. Stano, G.A. Wagner, A.E. Hanson, H.A. Anderson, and P.A. Saunders, 2008: Lightning studies at Florida State University. 2nd International Lightning Meteorology Conference, April 24-25, Tucson, Vaisala Corp, 6 pp.

Saunders, P.A., 2010: Development and evaluation of mesoscale lightning threat guidance for operational use at NWS offices. M.S. thesis, Florida State University, Tallahassee, 68 pp. [Available from hfuelberg@fsu.edu]

Saunders, P., and H.E. Fuelberg, 2010: Development and evaluation of mesoscale lightning threat guidance for operational use at NWS forecast offices. 20th Conf. Prob. and Stat., Amer. Meteor. Soc., Atlanta, Paper 5.1, January 2010.

Section 6: Summary of University/Operational Roles

Florida State University performed most of the research related to developing the lightning guidance products. All of the data gathering, computations, and statistical evaluations were performed at FSU. The research constituted the M.S. thesis of Mr. Peter Saunders. Prof. Henry Fuelberg served as PI of the project and was Pete's major professor.

The three NWS Co-PIs (Steve Hodanish-Pueblo, Steve Zubrick-Sterling, and Jon Mittlestadt--Pendleton) generally served in an advisory capacity, helping us to select the boundaries for the study regions and serving as resources for understanding the mechanisms producing thunderstorms in their particular regions. In addition, Steve Hodanish (NWS Pueblo) previously had developed lightning climatologies for his area which he shared and discussed with us. He also was our primary "cattle prod" in a vain attempt to speed up the research