“Pulling the Trigger” on Storm Mobilization

A decision-analytic approach to Emergency Management

Discussion document

Presented at the Infocast Conference on
Emergency Preparedness and Service Restoration for Utilities

New Orleans, Louisiana
March 28, 2007

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Consultants to the Utility Industry

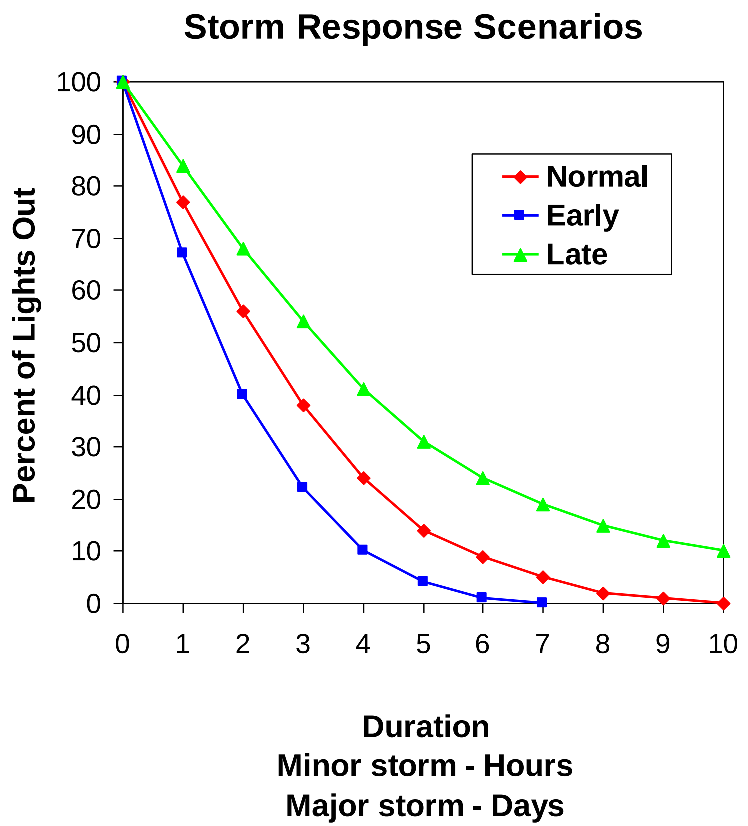
Agenda

- The problem in a nutshell
- A decision-analytic approach
- Observations and Key Questions

Early mobilization is the key to timely storm restoration…

With early prediction you can:

- Identify needed resources
  - Get them called out and rolling
  - In time to travel to the area
  - And be there when the trouble starts
- To get the feeders back up quickly
  - Restoring the most customers early
  - So you can find the taps that are out
  - And get working on the single no-lights
- And communicate more accurately
  - To give advanced notice and initial ERTs
  - To customers, media, and governments
  - To instill confidence and show leadership



"If only I could have known I needed that many crews,
I would have got them there right from the start"

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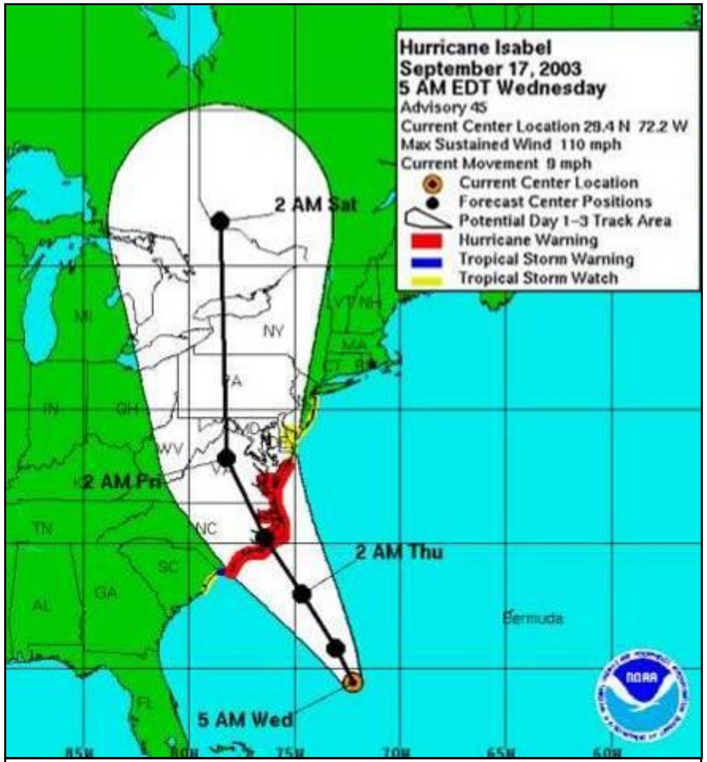
…But 'pulling the trigger' can be difficult…

Barriers to mobilization include:

- Mobilization is <u>expensive</u>
  - Overtime for your own crews
  - Costs for contractors and foreign crews
  - Logistics costs (reservations, meals, etc.)
- Mutual assistance is <u>not</u> automatic
  - Other companies want you to be sure
  - 'False alarms' cause future problems
  - All companies in the area may have needs
- Inadequate information causes <u>indecision</u>
  - Will the weather really be bad?
  - Will the damage be as bad as the weather?
  - Will we have resources standing idle?



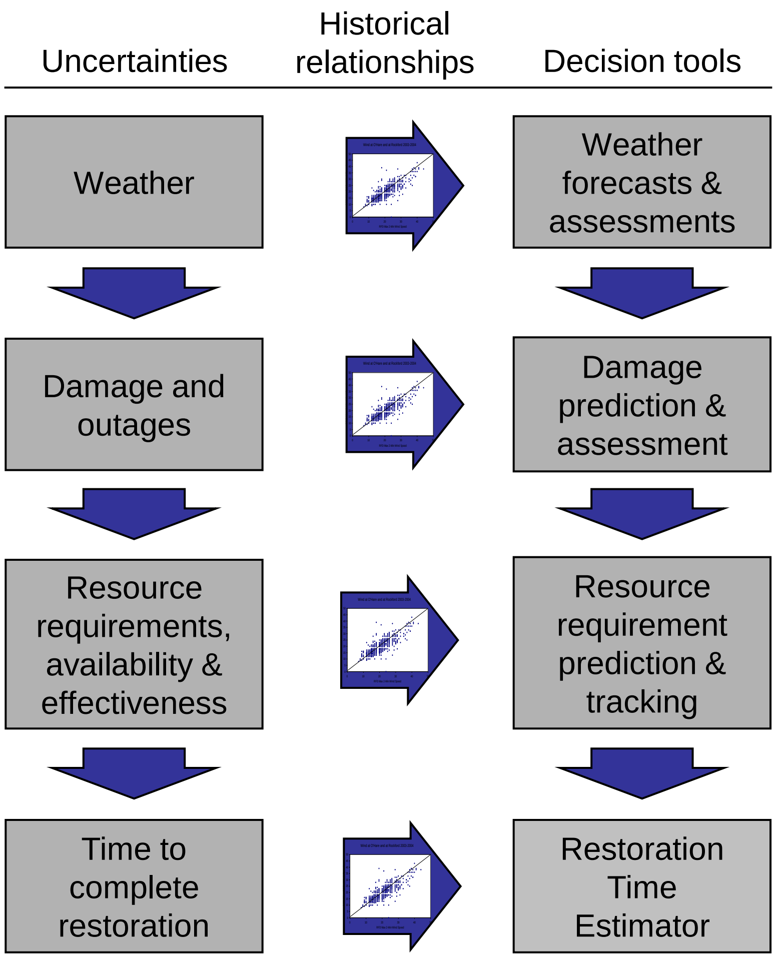
Uncertainty and inadequate information cause indecision and poor storm response

<u>Before</u> the storm, there is not enough information.
<u>After</u> the storm, there is no shortage of second-guessers

…So, better decision tools are needed

Better decision tools are needed and available:

- Weather models and measures
  - Utility-oriented forecast models
  - Ensemble forecasts for risk assessment
  - More detailed grid measurements
- Storm mobilization models
  - Relate weather to damages/outages
  - Relate damage to resource requirements
  - Relate resource requirement, availability and effectiveness to initial and ongoing Estimated Restoration Times (ERTs)



With better decision tools, emergency managers can more effectively 'pull the trigger' to make and communicate mobilization decisions

Agenda

- The problem in a nutshell
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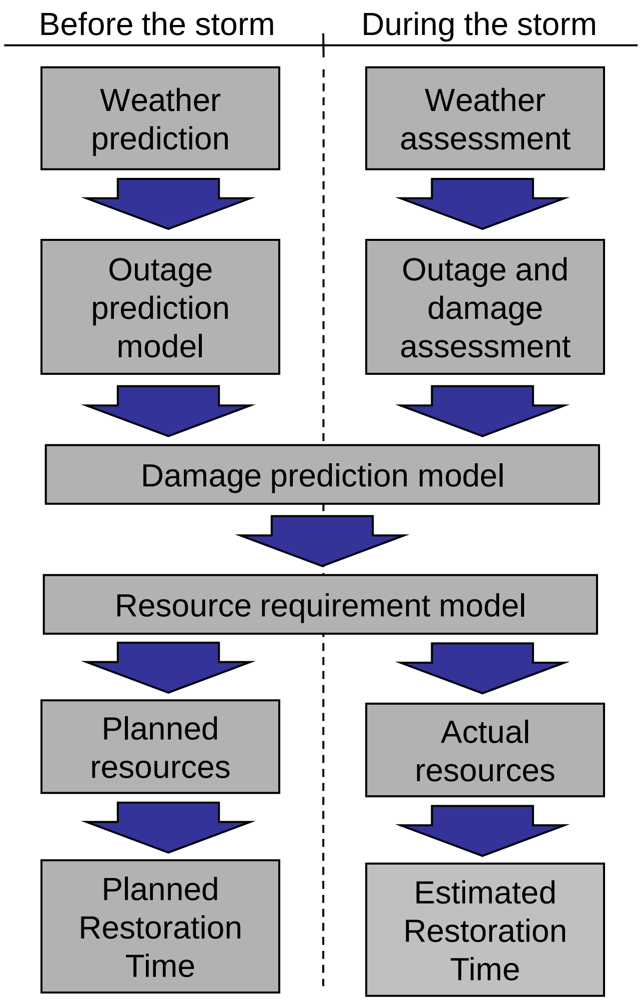
Decision models can help both before and after the storm has hit

Prediction models facilitate storm mobilization ***before the storm***

- Forecasters predict weather
- Weather drives outages
- Outages drive damage
- Damage drives resources
- Resources affect restoration time

Similar tools help manage work and ERT's ***during the storm***

- OMS and patrollers provide actual outages and damage
- Resource model uses actual outage and damage data to estimate resources
- Actual resources available versus resources needed drives estimated ERTs



With a better way to predict the resources needed, valuable time early in the storm can be saved, reaping shorter overall restoration

Most bad weather can be somewhat predicted

Outage-causing bad weather comes in various forms, all of which are at least partly predictable:

- Hurricanes are visible days in advance, *but* their exact path is uncertain
- Sustained high winds tend to be an areawide phenomenon, forecastable in advance, *but* 'micro-bursts' and tornadoes are unpredictable in force and location
- Storm fronts, and their associated lightning, wind, and rain or snow, are forecastable, *but* can vary in force and location
- Ice storms are generally anticipated, *but* the exact accumulation and location vary
- Heat waves are forecastable within the week *but* the impact on utilities depends on wind, cloud cover, humidity, and demand response

Even though some aspects of weather are unpredictable, many weather events are very predictable and allow no excuse for not mobilizing

Developing relationships to outages begins with historical weather

- Historical weather data is available online from NOAA:
  - Daily data for each month (the F6 report) can be found for local offices by clicking on the national map at: www.weather.gov/climate/index.php
- The locations with the most data are airports, e.g.,
  - Chicago-O’Hare (ORD)
  - South Bend (SBN)
  - Charleston, WV (CRW)
- The data include:
  - Temperature (Hi-Lo-Average)
  - Wind speed and direction
  - Precipitation
  - NOT lightning strokes

LOCAL CLIMATOLOGICAL DATA
NOAA, National Climatic Data Center

INTERNATIONAL AIRPORT (MSP)
Lat: 44°52' N Long: 93°13' W Elev (Ground): 834 Feet
Time Zone: CENTRAL WBAN: 14922 ISSN #:0198–2745

NOVEMBER 1996
MINNEAPOLIS–ST.PAUL, MN

	TEMPERATURE °F						DEG DAYS BASE 65°			SNOW/ICE ON GND(IN)		PRECIPITATION (INCHES)		PRESSURE (INCHES OF HG)		WIND SPEED = MPH DIR = TENS OF DEGREES			MAXIMUM				
										0600 LST	1200 LST	2400 LST	2400 LST						5–SEC		2–MIN		
DATE	MAXIMUM	MINIMUM	AVERAGE	DEP FROM NORMAL	AVERAGE DEW PT	AVERAGE WET BULB	HEATING	COOLING	WEATHER	DEPTH	WATER EQUIV	SNOW–FALL	WATER EQUIV	AVERAGE STATION	AVERAGE SEA LEVEL	RESULTANT SPEED	RES DIR	AVERAGE SPEED	SPEED	DIR	SPEED	DIR	DATE
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
01	31	19	25	-16	14	21	40	0	SN	0		T	T	29.12	30.05	11.2	31	12.0	26	31	21	32	01
02	35	17	26	-15	16	23	39	0		0		0.0	0.00	29.26	30.20	6.2	29	7.8	20	26	14	29	02
03	57*	23	40	0	26	34	25	0		0		0.0	0.00	29.05	29.97	7.6	18	8.3	18	17	16	18	03
04	46	34	40	0	38	40	25	0	RA BR	0		0.0	0.33	28.99	29.90	7.2	14	7.6	16	15	13	14	04
05	45	41	43	4	41	42	22	0	BR	0		0.0	0.00	29.09	30.00	7.6	14	7.9	16	13	14	13	05
06	47	29	38	0	38	40	27	0	RA DZ FG BR	0		0.0	0.04	28.89	29.79	4.0	22	10.7	26	29	22	28	06
07	48	29	39	1	30	34	26	0		0		0.0	0.00	28.91	29.82	6.3	25	7.9	22	31	16	31	07
08	39	30	35	-2	26	32	30	0	SN	0		T	T	29.10	30.02	12.2	31	12.4	31	33	23	34	08
09	34	25	30	-7	19	25	35	0	SN	0		T	T	29.14	30.07	14.8	32	15.0	32	32	24	31	09
10	27	23	25	-11	13	22	40	0	SN	0		T	T	29.33	30.27	11.3	34	11.8	23	36	18	36	10
11	26	13	20	-16	8	18	45	0	SN	0		T	T	29.59	30.54	8.2	33	8.6	18	31	16	32	11
12	25	9	17	-18	8	15	48	0		0		0.0	0.00	29.74	30.71	6.1	33	5.4	16	02	10	32	12
13	29	14	22	-13	9	18	43	0		0		0.0	0.00	29.75	30.71	4.3	34	3.5	11	02	8	04	13
14	29	12	21	-13	9	18	44	0	SN	0		T	T	29.66	30.62	11.4	12	12.3	36	13	29	13	14
15	38	25	32	-1	30	32	33	0	RA DZ FZRA SN PE RASNPE	1		1.7	1.58	29.14	30.07	14.0	15	14.3	36	13	28	13	15
16	52	38	45*	12	44	44	20	0	RA DZ BR	1		0.0	1.27	28.90	29.81	13.2	15	13.5	39*	16	30*	16	16
17	49	18	34	2	20	24	31	0	RA FZRA SN PE BR	0		T	0.12	29.02	29.95	16.3	25	17.3	36	22	28	26	17
18	24	16	20	-12	12	17	45	0		0		0.0	0.00	29.28	30.22	6.9	28	7.6	16	26	13	26	18
19	24	15	20	-11	13	19	45	0		0		0.0	0.00	29.22	30.16	4.8	02	5.9	14	02	9	07	19
20	25	22	24	-7	19	23	41	0	SN FG FZFG BR	4		4.4	0.46	29.13	30.07	10.1	09	10.5	18	08	16	10	20
21	29	18	24	-6	22	24	41	0	SN BR	5		0.4	0.02	29.29	30.23	5.0	32	6.8	15	34	13	32	21
22	28	15	22	-8	20	22	43	0	FZDZ SN BR	5		1.0	0.12	29.28	30.23	4.5	19	6.3	15	16	13	16	22
23	28	18	23	-6	18	21	42	0	SN PE FZFG BR	5		6.3	0.48	29.22	30.15	11.3	01	11.6	24	03	18	02	23
24	19	-4	8	-21	10	14	57	0	SN BR	10		1.1	0.05	29.43	30.38	6.7	32	7.7	18	36	14	33	24
25	15	-7	4	-24	-2	4	61	0		10		0.0	0.00	29.45	30.42	6.1	32	7.7	22	34	17	34	25
26	13	-9	2*	-25	-5	0	63	0		9		0.0	0.00	29.66	30.64	4.9	27	6.7	14	25	13	24	26
27	24	-11*	7	-20	5	9	58	0	BR	9		0.0	0.00	29.58	30.55	5.3	18	6.6	17	21	14	20	27
28	31	17	24	-2	19	23	41	0	BR HZ	9		0.0	0.00	29.15	30.08	8.5	16	9.1	17	19	15	18	28
29	36	24	30	4	29	31	35	0	RA SN PE BR HZ	9			0.56	28.86	29.78	8.2	14	8.5	17	17	15	16	29
30	33	22	28	3	26	28	37	0	SN BR	6		0.4	0.05	28.73	29.64	8.4	28	10.4	25	29	20	30	30
	32.9	17.8	25.4		19.2	23.9	39.4	0.0	< MONTHLY AVERAGES	TOTALS–>		15.3	5.08	29.23	30.17	1.6	28	9.4	<– MONTHLY AVERAGES				
	-8.1	-7.4	-7.8		<–––––––––––––– DEPARTURE FROM NORMAL ––––––––––––––>								3.53	SUNSHINE, CLOUD, & VISIBILITY TABLES ON PAGE 3									

DEGREE DAYS

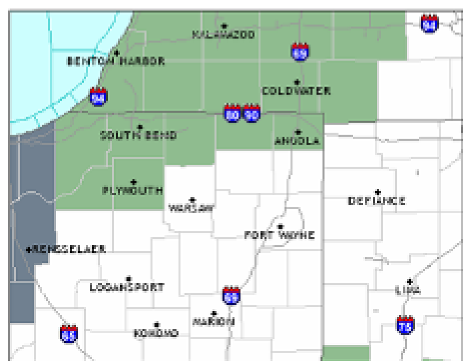
	MONTHLY TOTAL	MONTHLY DEPARTURE	SEASON TO DATE TOTAL	SEASON TO DATE DEPARTURE
HEATING:	1182	228	1854	198
COOLING:	0	0	602	–80

GREATEST 24– HR PRECIPATATION: 1.71 DATE : 15–16
GREATEST 24– HR SNOWFALL: 6.3 DATE : 23
GREATEST SNOW DEPTH: 10 DATE : 25+

SEA LEVEL PRESSURE		DATE	TIME
MAXIMUM :	30.76	13	1011
MINIMUM :	29.54	30	0536

NUMBER OF DAYS WITH →

MAXIMUM TEMP ≥ 90: 0
MAXIMUM TEMP ≤ 32 : 17
THUNDERSTORMS : 0
MINIMUM TEMP ≤ 32 : 27
MINIMUM TEMP ≤ 0 : 4
HEAVY FOG : 0
PRECIPITATION ≥ 0.01 INCH : 12
PRECIPITATION ≥ 0.10 INCH : 8
SNOWFALL ≥ 1.0 INCH : 5



New sources of historical weather data can be even more detailed in terms of time, place, and type of weather

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NWS Storm Event records can supplement F6 data

The National Weather Service has a special service as part of NOAA's NCDC (National Climatic Data Center). It produces an entry for all storm events, and can be searched by state, county, and date range.

Typical data includes the wind speed for 'Tstm (Thunderstorm) Wind' events, property damage, and text describing such things as 'trees down', 'power lines down', etc.

Event Record Details

Event: **Tstm Wind** State: **West Virginia**
Begin Date: **10 Jul 2003, 04:44:00 PM EST** County: **Kanawha**

Begin Location: **Yeager Arpt (CRW)**

Begin LAT/LON: **38°22'N / 81°36'W**

End Date: **10 Jul 2003, 04:44:00 PM EST**

End Location: **Yeager Arpt (CRW)**

End LAT/LON: **38°22'N / 81°36'W**

Magnitude: **50**

Fatalities: **0**

Injuries: **0**

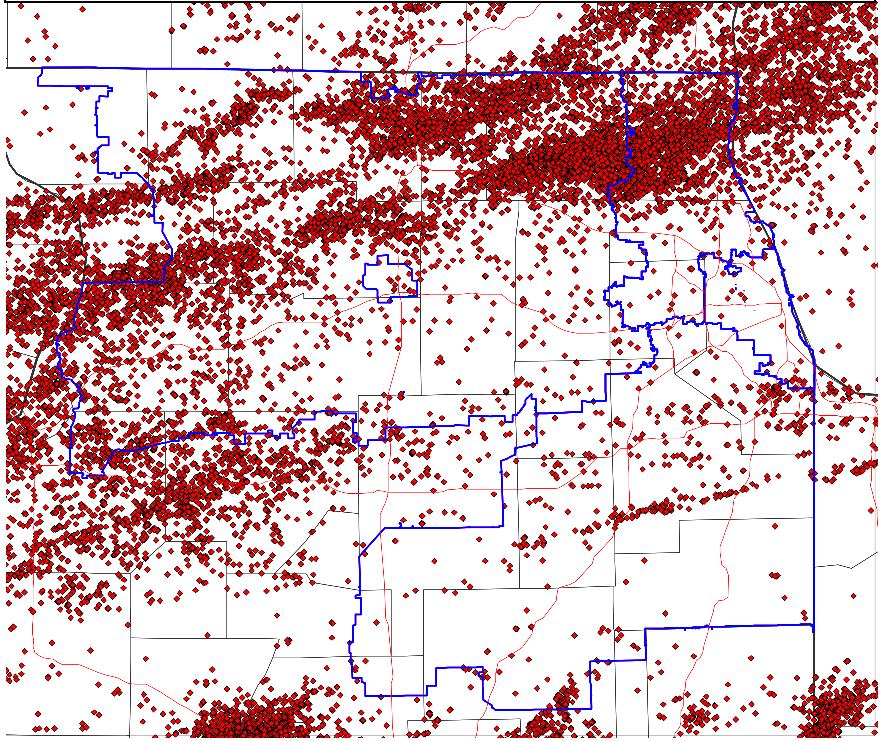
Property Damage: **$ 0.0**

Crop Damage: **$ 0.0**

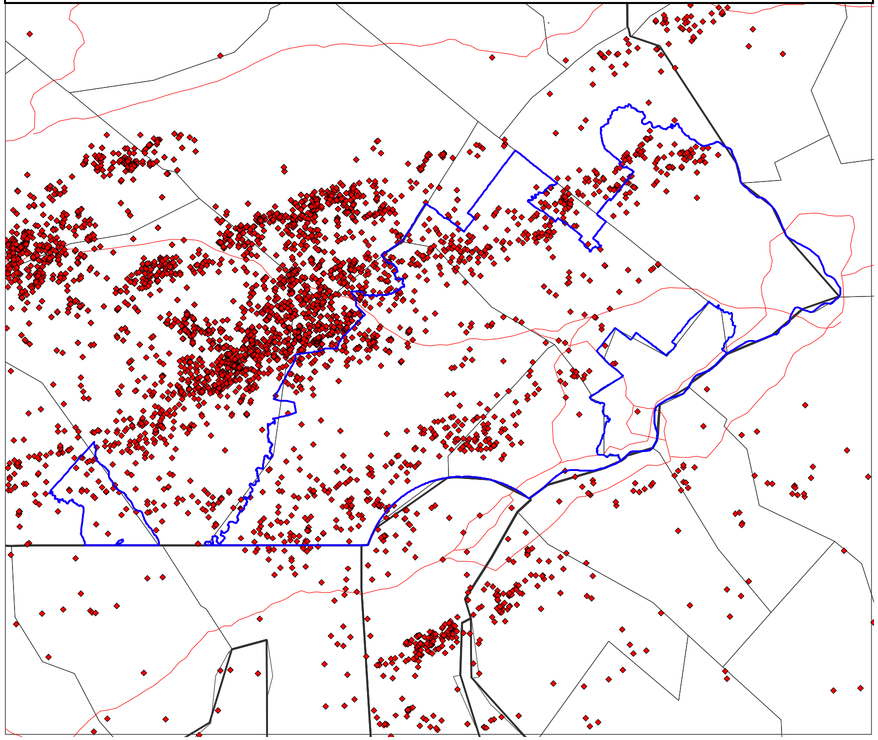
Description:
A potent squall line developed during the early afternoon across central Ohio, on southwest to central Kentucky. This was along a prefrontal surface boundary, and well out ahead of a strong cold front. The atmosphere warmed into the 80s with surface dew points in the 70 to 75 degree range. Additional thunderstorms formed into a broken west to east line across West Virginia, ahead of the squall line. This caused flooding problems. After 1500E, the squall line accelerated eastward, moving near 50 mph. As a result of this event, a few more counties, such as Ritchie and Harrison, were added to FEMA's disaster declaration number 1474. This federal disaster was initiated during the month of June.

Lightning stroke data are available from the NLDN

May 17, 2004: Strokes hitting ComEd territory: 11,300



May 18, 2004: Strokes hitting PECO territory: 737



- Lightning stroke data are available from the National Lightning Detection Network in Tucson, AZ
- Many companies have been using lightning stroke data for years
- Data can be integrated with territory maps to get accurate counts of strokes by region
- The maps shown are of Northern Illinois and Eastern Pennsylvania (Exelon territory).

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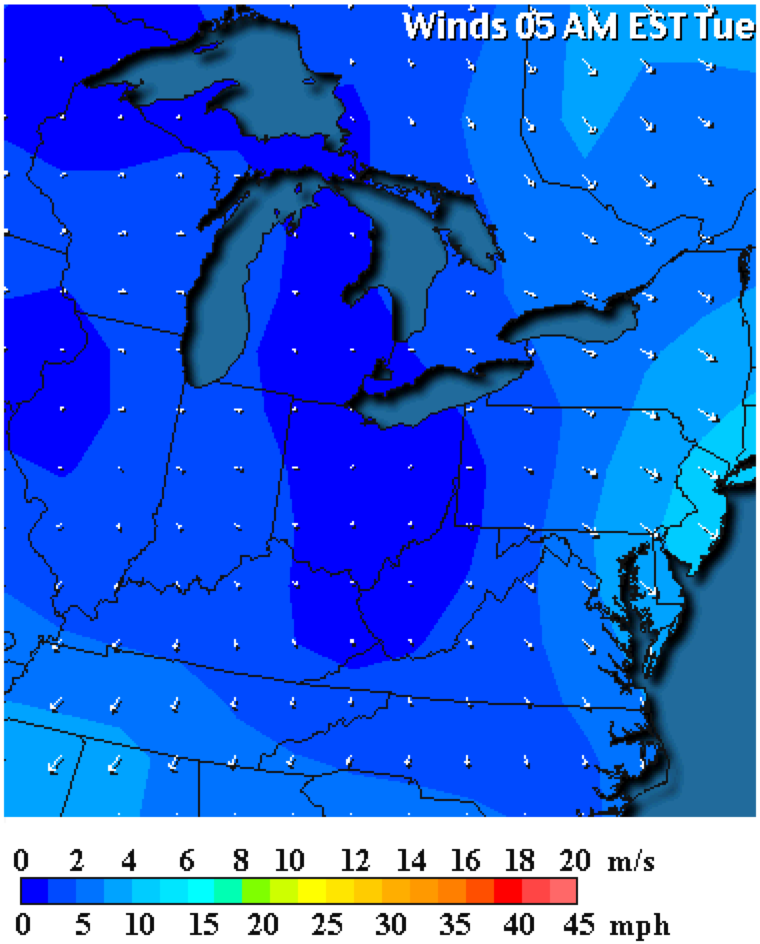
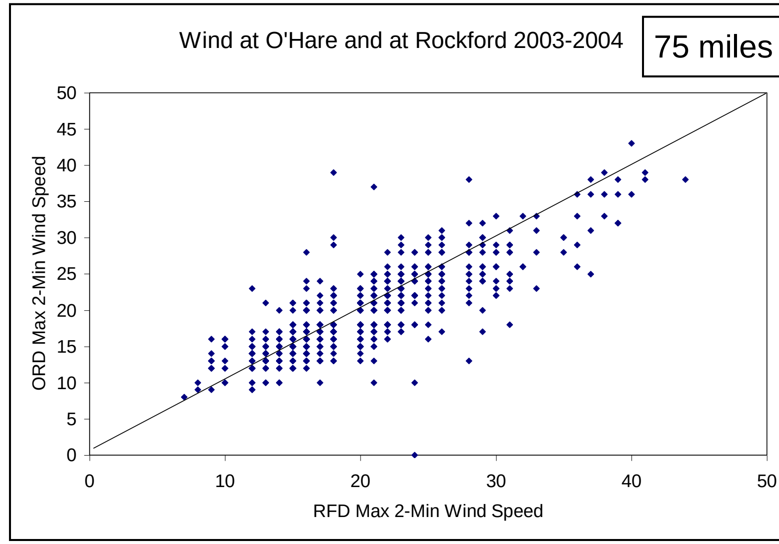
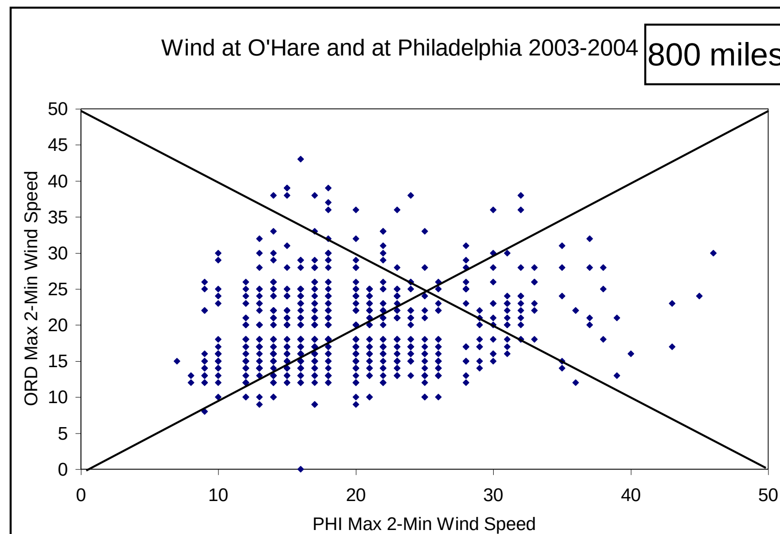
Sustained wind speed tends to be a regional phenomenon

Sustained wind speed differences of more than 5 mph normally span 100's of miles







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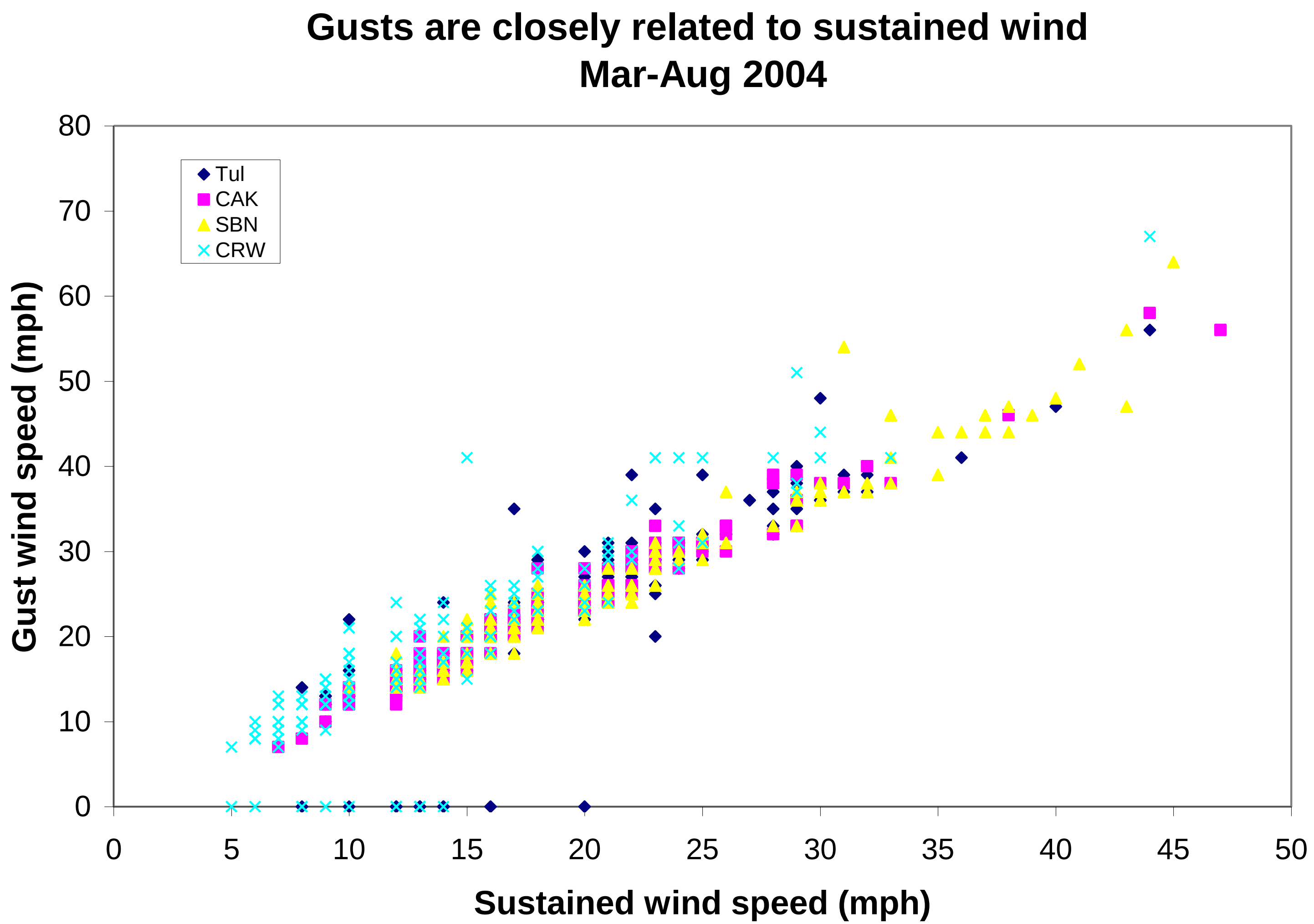
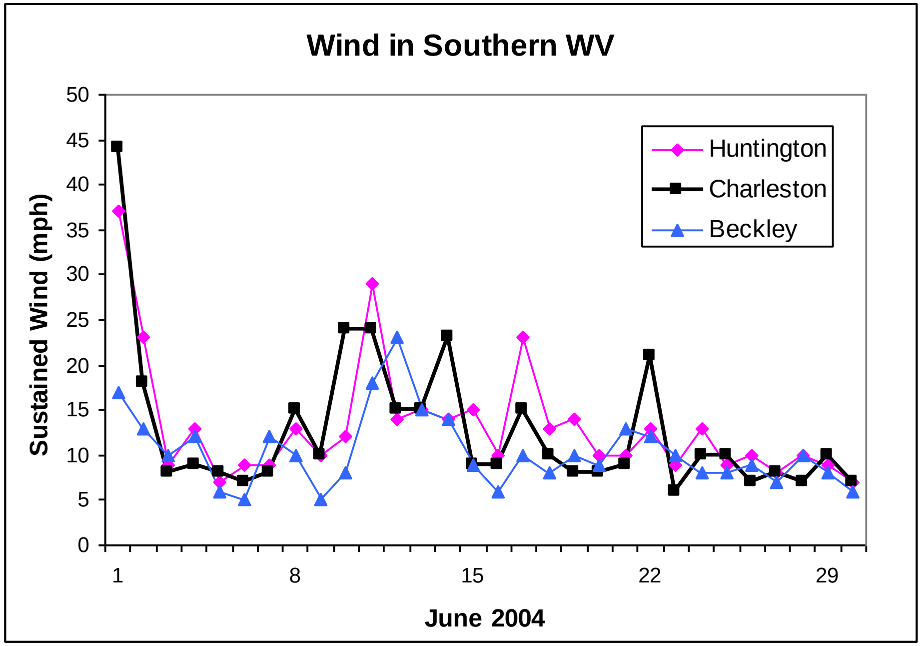
Gusts (5-sec) are closely related to sustained wind (2-min)



Mountainous areas are less predictable than level plains

Although Huntington is only
50 mi W of CRW
and Beckley is only
50 mi SE of CRW,
on the windiest days
the sustained wind can differ by as much as 10-25 mph



Because of the terrain around Charleston and Southern WV, the usual similarity of sustained wind at nearby locations is not as valid. As a result, the model needed to use data from three locations: Charleston, Huntington, and Beckley

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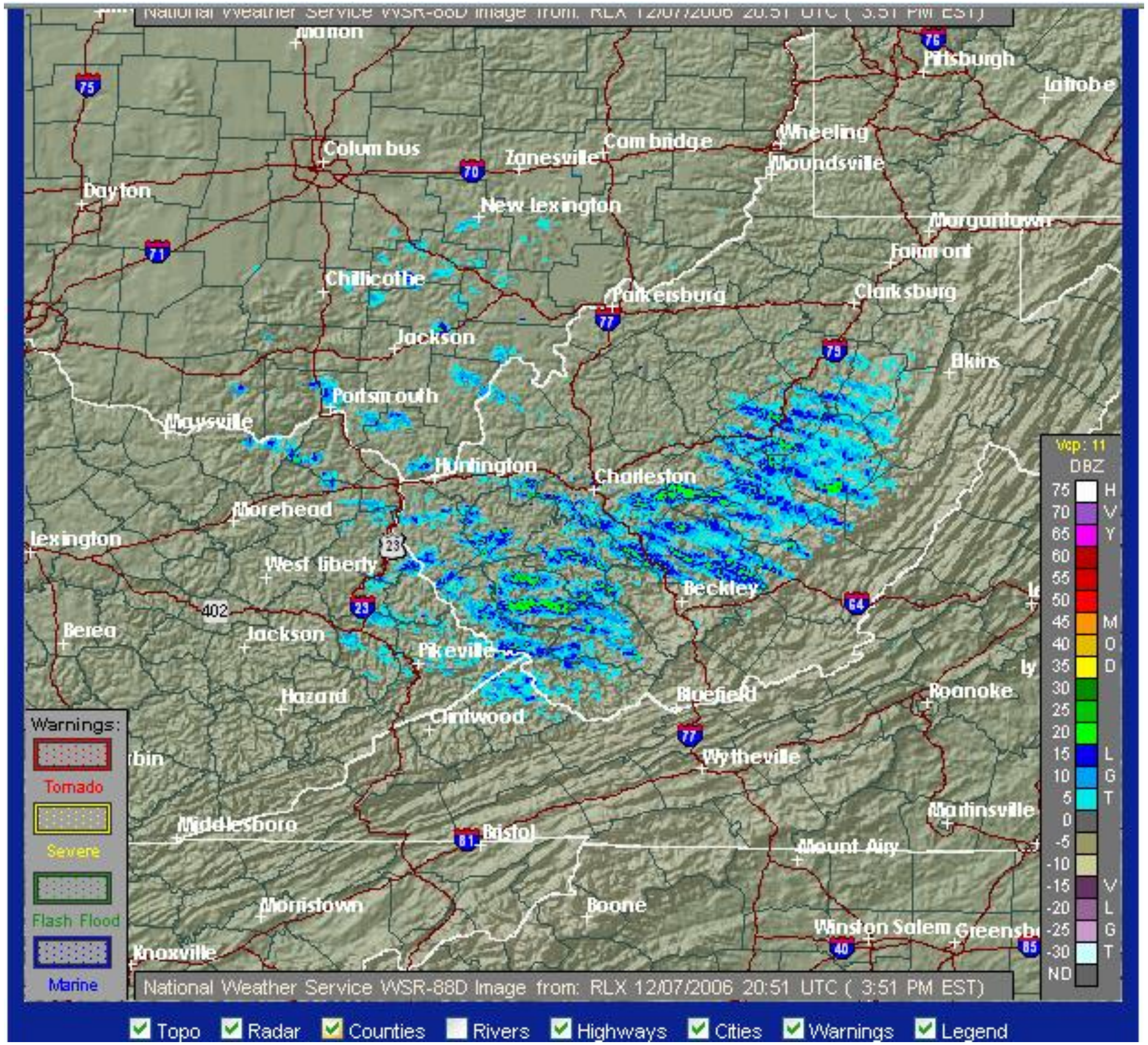
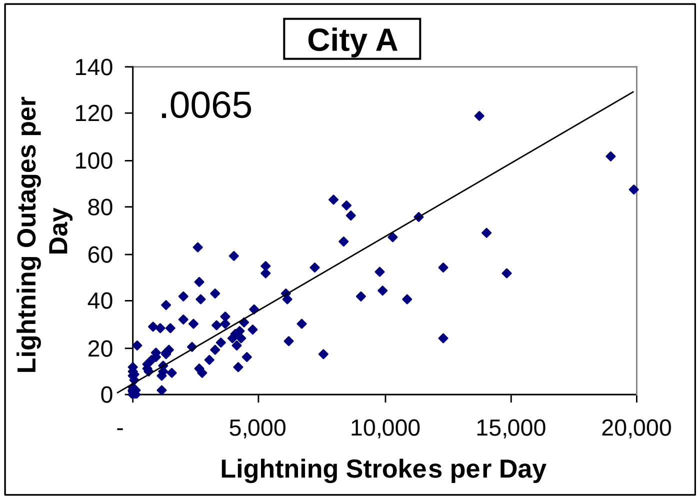
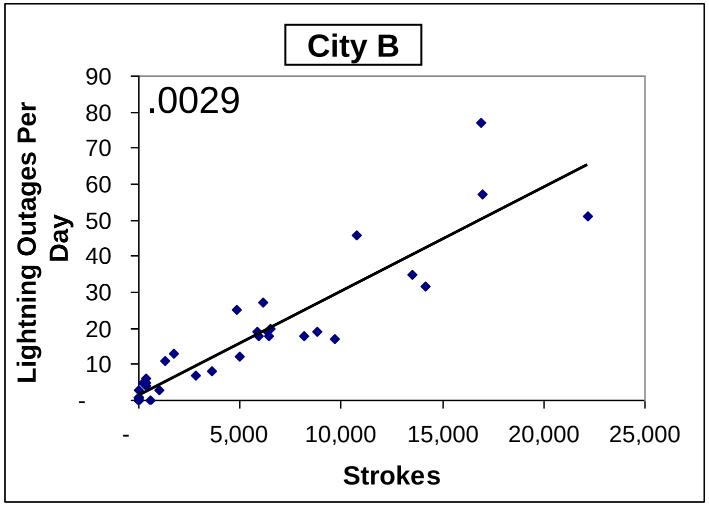
Significant terrain features can complicate weather patterns

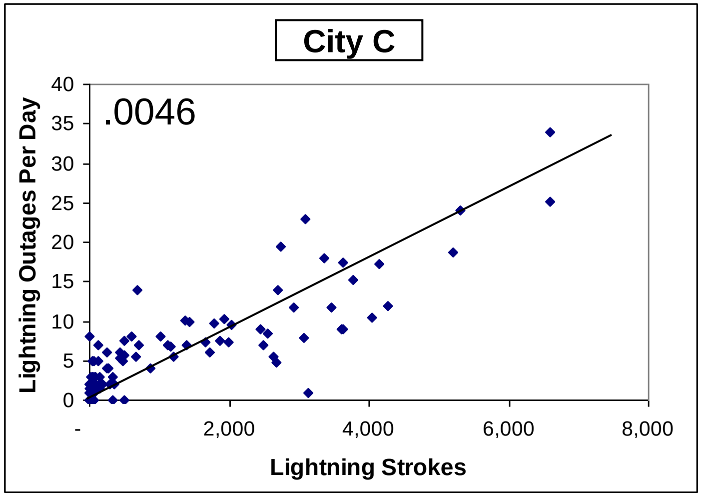
- The terrain of AEP's Appalachian Power Co. in WV is quite different than other locations in AEP (and many other companies)
- Wind does not just 'blow over' the plains and hills as it would elsewhere, but is blocked and channeled by the mountains and valleys, creating very localized weather
- Also, rain falls in abundance as clouds hit the mountains, creating flash floods as a major cause of outages

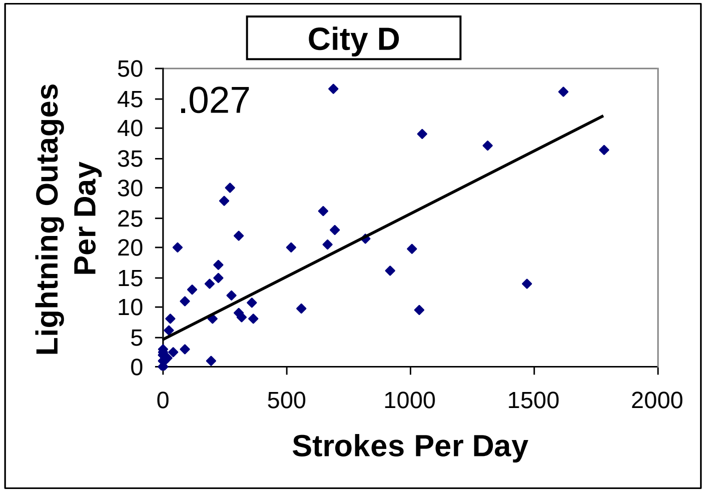


Lightning strokes drive lightning outages









The relationship is linear in the number of strokes, with slopes that are similar but vary with equipment density per square mile

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How to translate NWS lightning language into strokes for the model

This table can be used to input a stroke forecast into the model:

NWS language	Strokes per region to enter into the model			
	City A	City B	City C	City D
None	0	0	0	0
Occasional	1,000	500	1,000	1,000
Frequent	10,000	1,000	10,000	4,000
Continuous	20,000	2,000	20,000	8,000

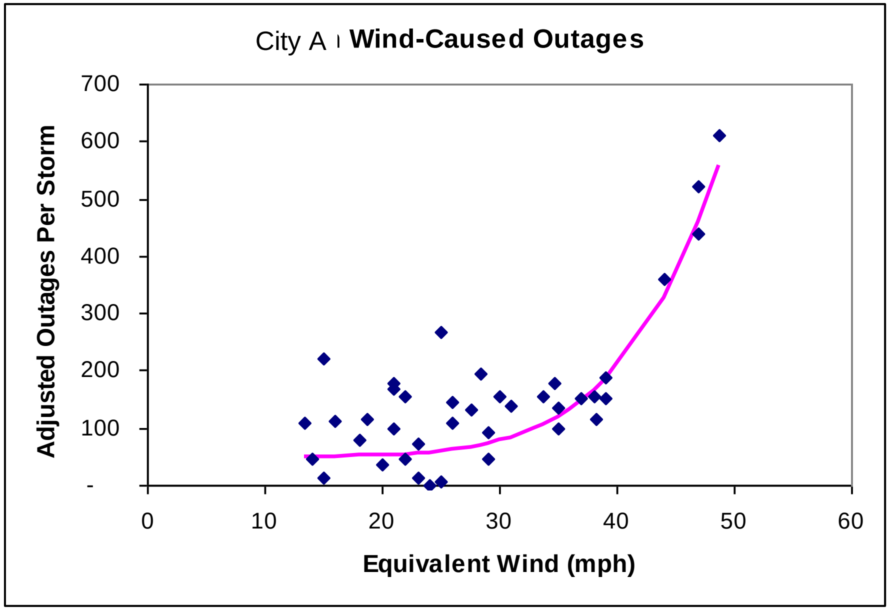
When this is done, the model will use its assumptions about outages/stroke for each region to produce a forecast of lightning-caused outages as follows (note that the coefficients are about double those for the lightning-only outages, reflecting the other outages and even non-outage calls that tend to be related to events with heavy lightning):

Outages/strokes	.0065	.035	.009	.009
Projected Outages:				
Frequent	150	35	90	36
Continuous	300	70	180	72

Lightning can usually be forecast, at least in order of magnitude, and that can help mobilize the right amount of resources for a storm.

Wind-caused outages are exponentially related to wind speed

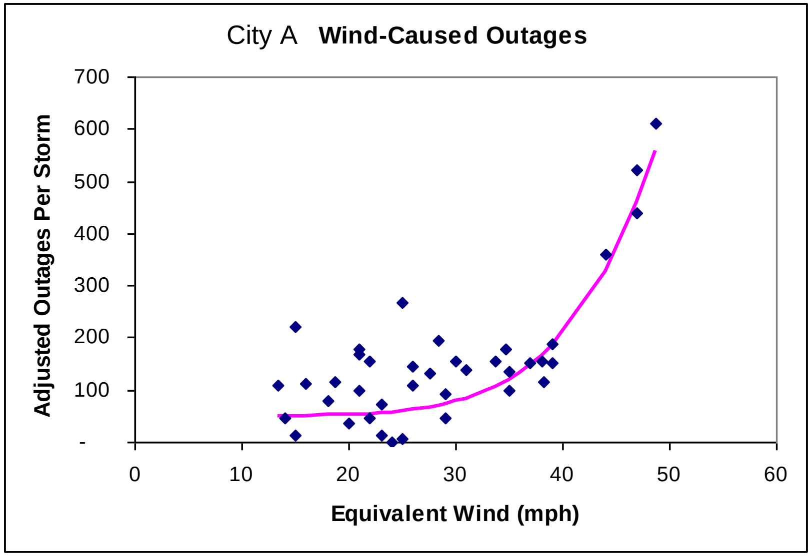
- There is an exponential relationship between wind speed and wind-caused outages, e.g.,
  - The step from 40 to 50 mph causes much more damage than from 20 to 30 mph
- The relationship is significantly affected by three other variables:
  - There is a seasonal affect due to the loss of leaves on deciduous trees from November to March
  - The duration of the wind matters, starting with emphasizing 2-min sustained wind speed over 5-sec gusts,
  - And also how many days the high-wind conditions prevail

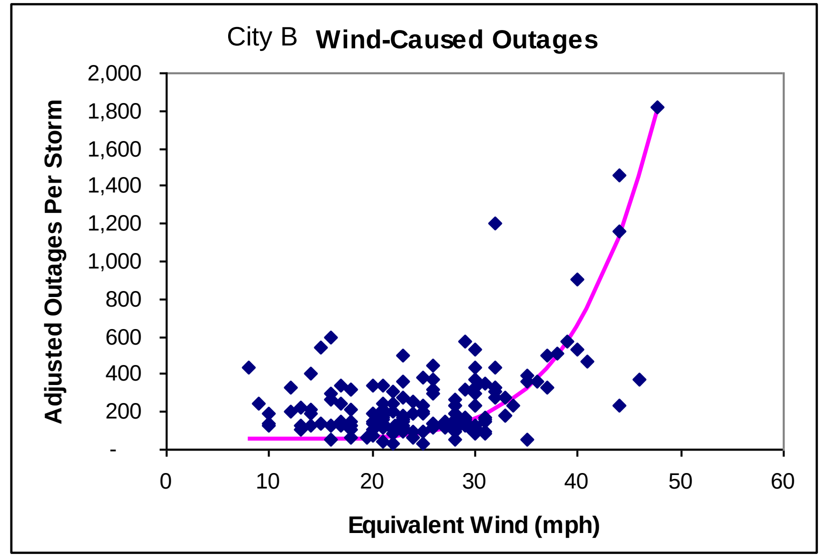


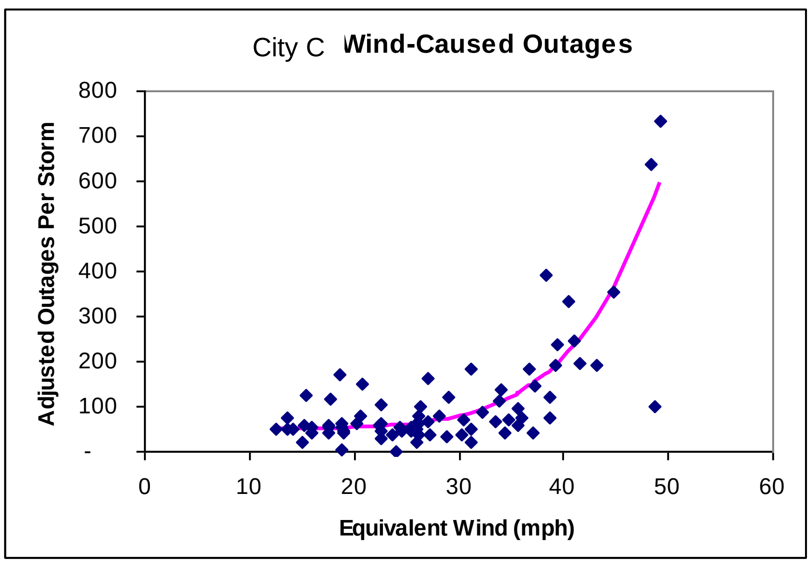
Notes: Outages are adjusted for lightning-caused outages, leaving only wind-caused and other. Ice storms are also excluded for this part of the analysis. 'Equivalent wind' adjusts the wind speed for seasonal effects and for extra duration, e.g., in winter, an actual wind speed of 35 mph is adjusted to an effective wind speed of about 31 mph, which produces half as many outages. Also, in storms in which more than one day had high winds, the effective wind speed is increased accordingly.

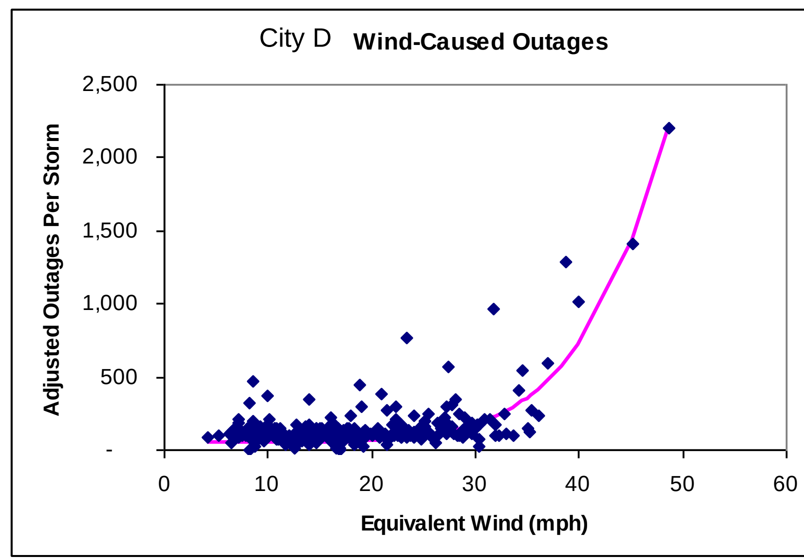
The non-linearity of the wind relationship, as well as the factors for seasonality and duration, are part of why utilities cannot rely solely on storm managers' intuition and experience. They need a model.

Similar relationships hold for different locations









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A storm mobilization model starts with the weather input…

Illustrative

	A	B	C	D	E	F	G	H
1	12/15/2006	Projected Weather						
2	Region	Wind Speed ("sustained" mph)	Wind Duration (Hours)	Lightning Strokes	Ice/snow Buildup (Inches)			Leaves on trees
3	North	40	3	1,000	0.0			1
4	South	46	3	-	0.0			1
5	West	40	3	10,000	0.0			1
6	Central	38	3	-	0.0			1
7								
8								
9								

Input value:
From the forecast "sustained winds", i.e., max 2-min sustained, not gusts

Input value:
This allows the user to reflect the duration (in hours) of the storm. In other words, how many hours you experienced the peak 2 minutes average wind speed.
Typical values are:
Normal storm: 3 Hours

Input value:
Predicted value based on lightning activity. See Table for conversion from 'moderate', etc.

Input value:
1, if the current month is April thru October for East, 0, otherwise.
This captures the 'sail' effect of deciduous trees.

As a storm approaches, forecasts can be entered into the model to drive the likely number of outages, amount of damage, and need for resources

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…then calculates outages, damages, and person-hours needed…

Based on the weather (and the historically-derived model parameters), the model estimates:

- Outages – by type
- Damages – by type of outage, since different damage types drive different resource requirements, e.g., wire-down-type outage that requires repair, versus a blown fuse
- Resources required to achieve a desired CAIDI (or you can work it the other way – tell it the resources you have and it will tell you what the restoration time will be)

12/8/2006	Outages			
Region	Wind- Caused	Lightning-Caused	Ice- Caused	Total
North	206	35	0	241
South	411	0	0	411
West	652	150	0	802
Central	718	36	0	754

12/8/2006	Damages				
	Primary		Secondary/Service		All
Region	Device Operated	Wire Down/ Structure Failure	Device Operated	Wire Down/ Structure Failure	Outages
North	119	67	34	21	241
South	185	123	62	41	411
West	408	216	110	67	802
Central	351	220	111	72	754

12/8/2006	Resource Hours Required - Total Storm					
Region	Primary Line	Service	Tree	Patroller	Wire Watcher	Runner
North	2134	279	1642	213	44	53
South	3789	524	3410	379	1812	95
West	7013	902	5131	701	5731	175
Central	6868	933	5887	687	151	172

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…to determine resources required or to predict restoration time

- With the forecast of resources required, the storm manager can consider the model's recommendation as an aid to his/her own judgment
- For a given amount of resources, the model can provide an informed early estimate of the time required to restore service
- As actual outages and damage assessments become known, they can be fed into the model for new estimates of resource requirements and expected restoration time

Model is used to determine resources needed for a given CAIDI:

12/8/2006	Persons Per Day						
Region	Primary Line	Service	Hours to Restore Primary	Hours to Restore Services	Primary CAIDI	Service CAIDI	Total CAIDI
North	90	9	23.7	31.0	356	465	356
South	160	16	23.7	32.7	355	491	356
West	296	30	23.7	30.5	355	457	356
Central	290	29	23.7	32.2	355	483	356

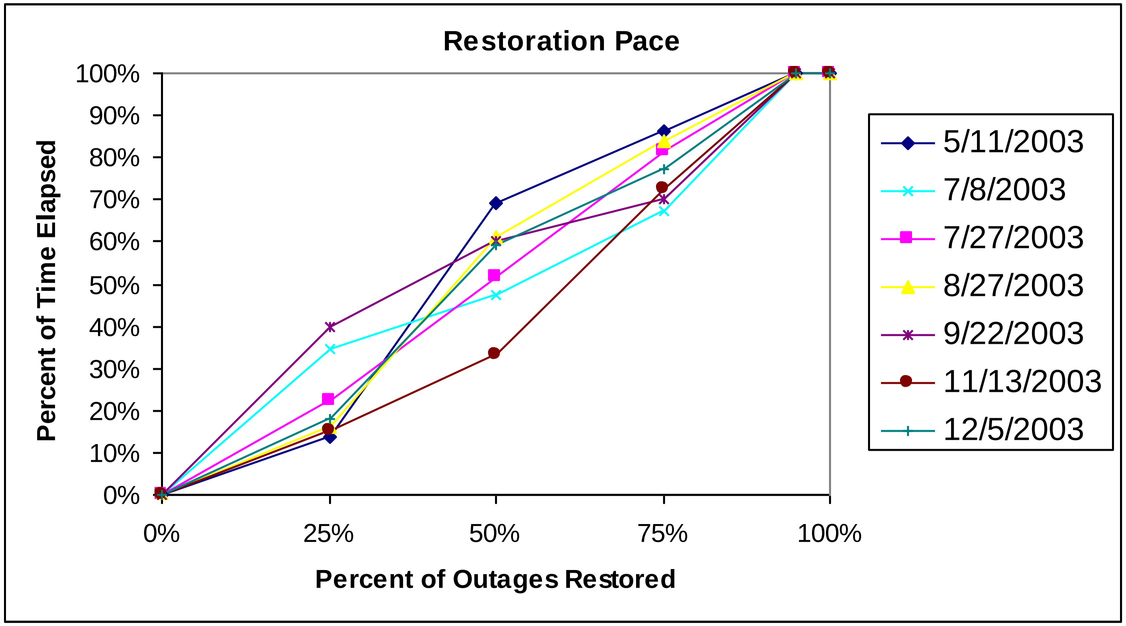
Or to predict CAIDI based on a given set of resources available:

12/8/2006	Persons Per Day						
Region	Primary Line	Service	Hours to Restore Primary	Hours to Restore Services	Primary CAIDI	Service CAIDI	Total CAIDI
North	41	4	52.0	68.1	781	1021	782
South	87	9	43.6	60.2	653	903	655
West	100	10	70.1	90.2	1052	1353	1053
Central	171	17	40.2	54.6	602	818	604

The model is a <u>tool</u> to be used to <u>enhance</u> judgment, <u>not</u> <u>replace</u> it. It aids intuition and helps make the decision to 'pull the trigger' or not

Although the pace of restoration is proportional to outages…

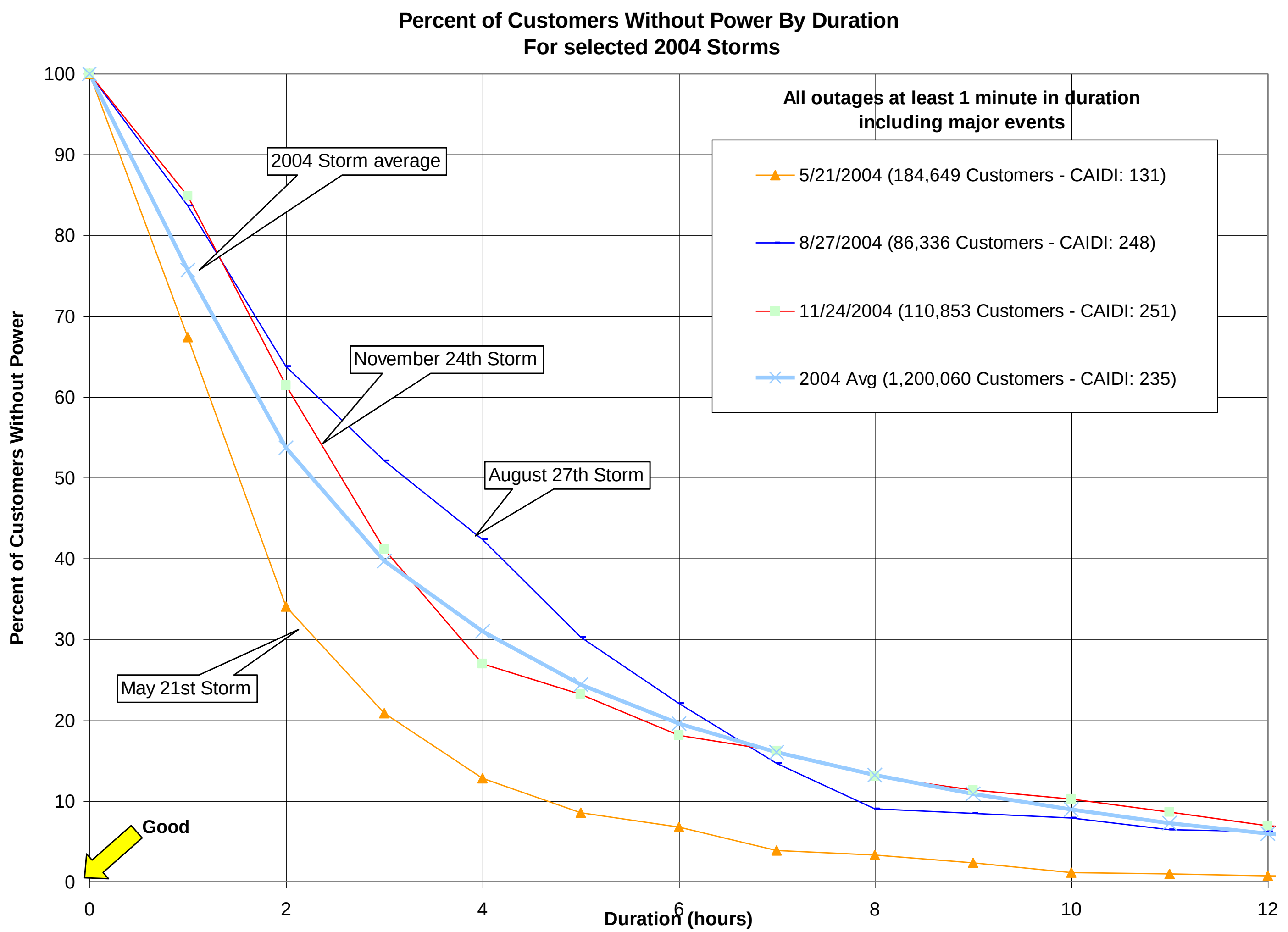
- The number of outages restored is generally proportional to the time elapsed, since it often takes the same amount of time to restore a feeder as to restore a small tap
- By contrast, Customers Interrupted are restored in a non-linear fashion, because crews are dispatched first to outages that have a large number of customers interrupted



Note: This data is from City A's 2003 storms, and, in percentage terms, is representative of the proportionality exhibited in other locations as well. The total time elapsed is the time required to restore 95% of the outages, since the definition of the 'end' of the storm can be confused with a regular day's outages otherwise.

Halfway through the restoration, only half the outages are restored, depending on whether the company got a good start, etc.

…The restoration of customers interrupted is non-linear in time



Halfway through the restoration, much greater than 50 percent of customers are restored, because of prioritization of restoration

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The model has been tested by 'backcasting' actual storms

City A 2003 Storms

Storm Date/Time		Weather		Outages		Duration	
Dates	Peak(s)	Wind	Lightning	Actual	Predicted	Actual	Predicted
Jul 27	10 PM	24	13,526	110	179	29	22
Dec 5	10 PM	21	-	117	52	22	10
Aug 26-27	4 PM	23	19,420	187	230	33	27
Sep 22	2 PM	31	-	140	84	15	15
May 11	10 PM	35	10,443	193	214	32	29
Jul 7-9	7th Noon 8th Noon	35	42,555	518	503	55	59
Nov 12-14	12th Noon 13th 5 PM	46 6 hrs	-	610	411	55	70

Notes: Wind in mph, sustained. Lightning in total strokes.

The model will not be as accurate as you would like,
but using a model like this allows you to get better with each storm

A mobilization model can benefit from continuous improvement

- Each new storm offers an opportunity to see how well the model fits, and to explore model enhancements and parameter changes if it does not
- Typical enhancements might include:
  - More detailed weather data
  - More non-linearities and special factors
    - Like effect of rain-soaked soil
  - Measuring the effect of changes in restoration methods and practices
  - Better data collection on damages incurred, resources used, etc.
- Like scientists, we advance best by “standing on the shoulders of others”

While storm managers will also benefit from practice, using a model like this will allow them to learn more and to <u>pass it on</u> to others

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Agenda

- The problem in a nutshell
- A decision-analytic approach
- Observations and Key Questions

Observations and Key Questions

Observations

- Surprisingly, most companies do not have very much sophistication in their decision support tools for storm mobilization – reliance on experience and judgment is typical
- All the evidence in decision-making processes shows that better decisions are made when supported by sound, user-friendly tools that enhance judgment without replacing it
- With a flexible tool, each application can give rise to lessons learned that enhance the capability of both the tool and the users

Key Questions

- Could you make better decisions on storm mobilization with a mobilization model?
- What would it take to put something like this in practice in your utility?

Questions?

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Doing the same thing over and over again does not lead to improvement. Measuring your decisions against a model allows learning and growth