EARLY WARNING AND RISK MITIGATION SYSTEMS FOR PRAIRIE TORNADOES

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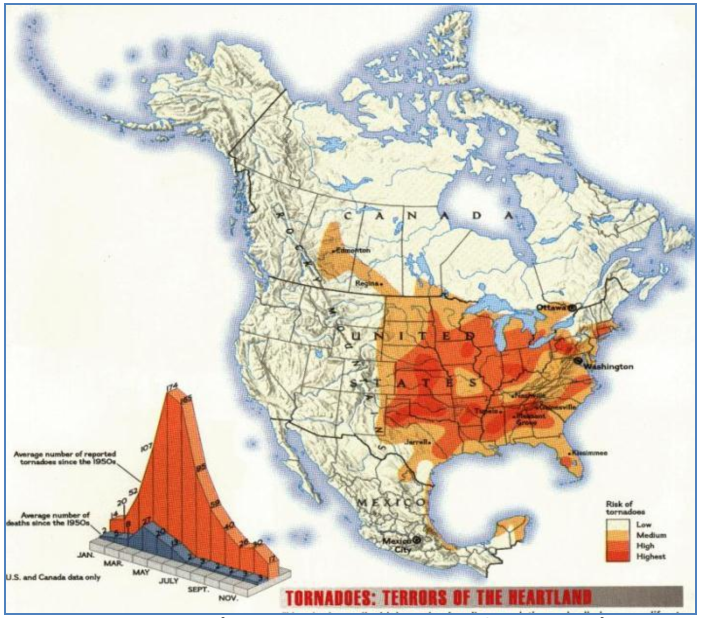
Disaster Mitigation

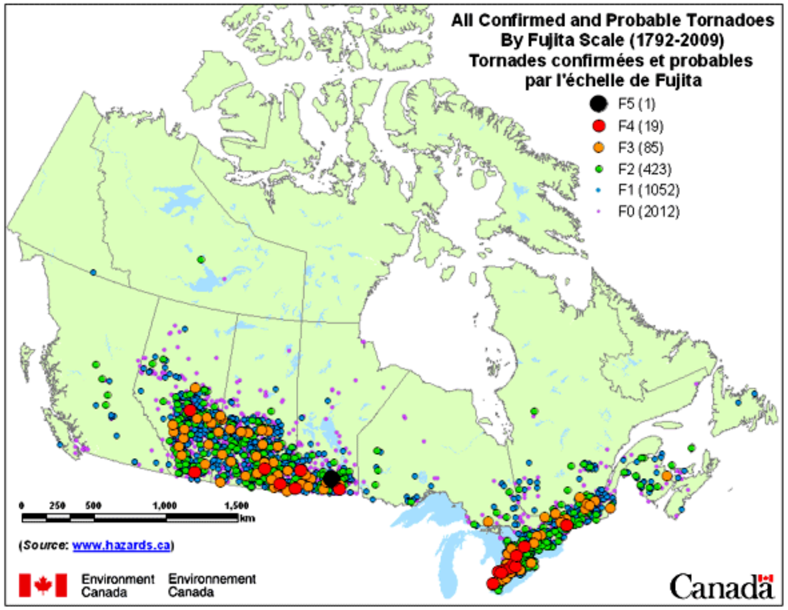
- In Canada, approximately 80% of disasters are due to extreme weather events such as tornadoes, hurricanes, hail storms etc (Hwacha, 2005).
- Canada is gradually shifting from the ways governments have historically approached disasters, through response and recovery methods, to mitigation strategies (Emergency Management Act c.15, 2007).
- Canada's National Disaster Mitigation Strategy (PSC, 2010) highlights the need to "apply and promote scientific and engineering best practices in order to build a knowledge base for sustainable, cost-effective mitigation decisions that contribute to community resiliency".

Tornadoes in Canada

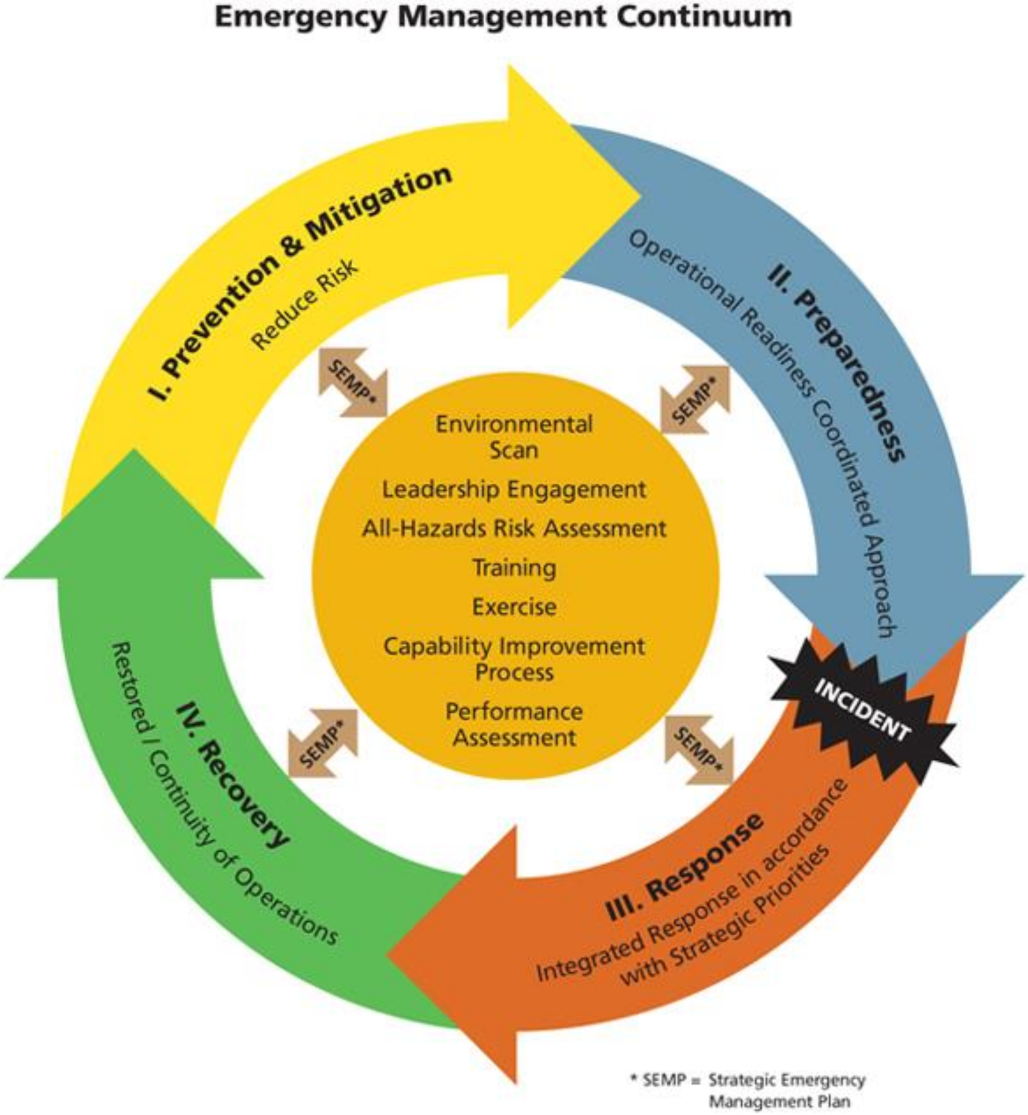
- According to Environment Canada (EC), which is the authority responsible for tornado detection and warning, an average of 43 tornadoes per year occur across the prairies provinces and about 17 occur across Ontario and Quebec.



Source: (Grosvenor et al, 1998)



Mitigation of the Impact of Tornadoes



Picture Courtesy: Public Safety Canada

Pre-disaster Stage

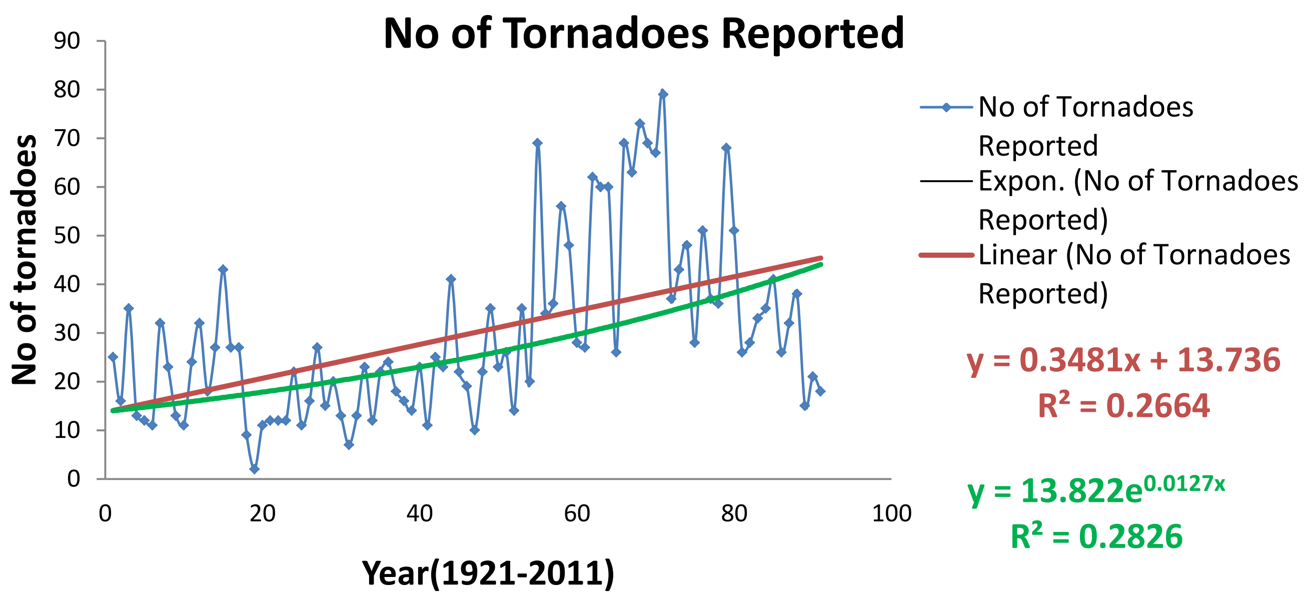
Deaths and injuries could be minimized by taking appropriate actions at the pre-touch down phase of a tornado.

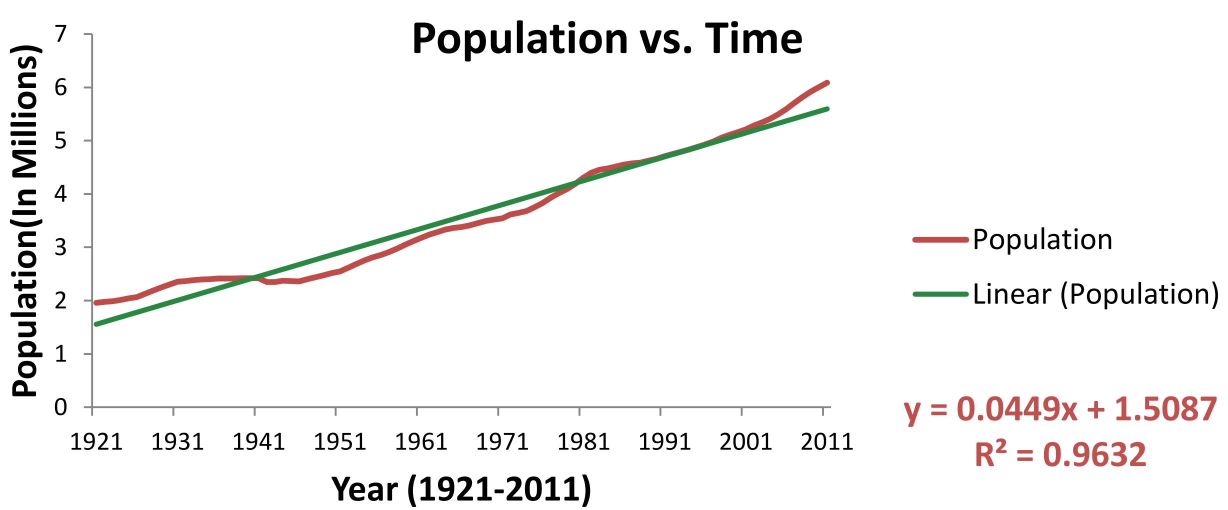
Research Objective

To study, analyze, model, simulate and propose improvements to plans and systems to mitigate the impacts of tornadoes in the Canadian Prairies

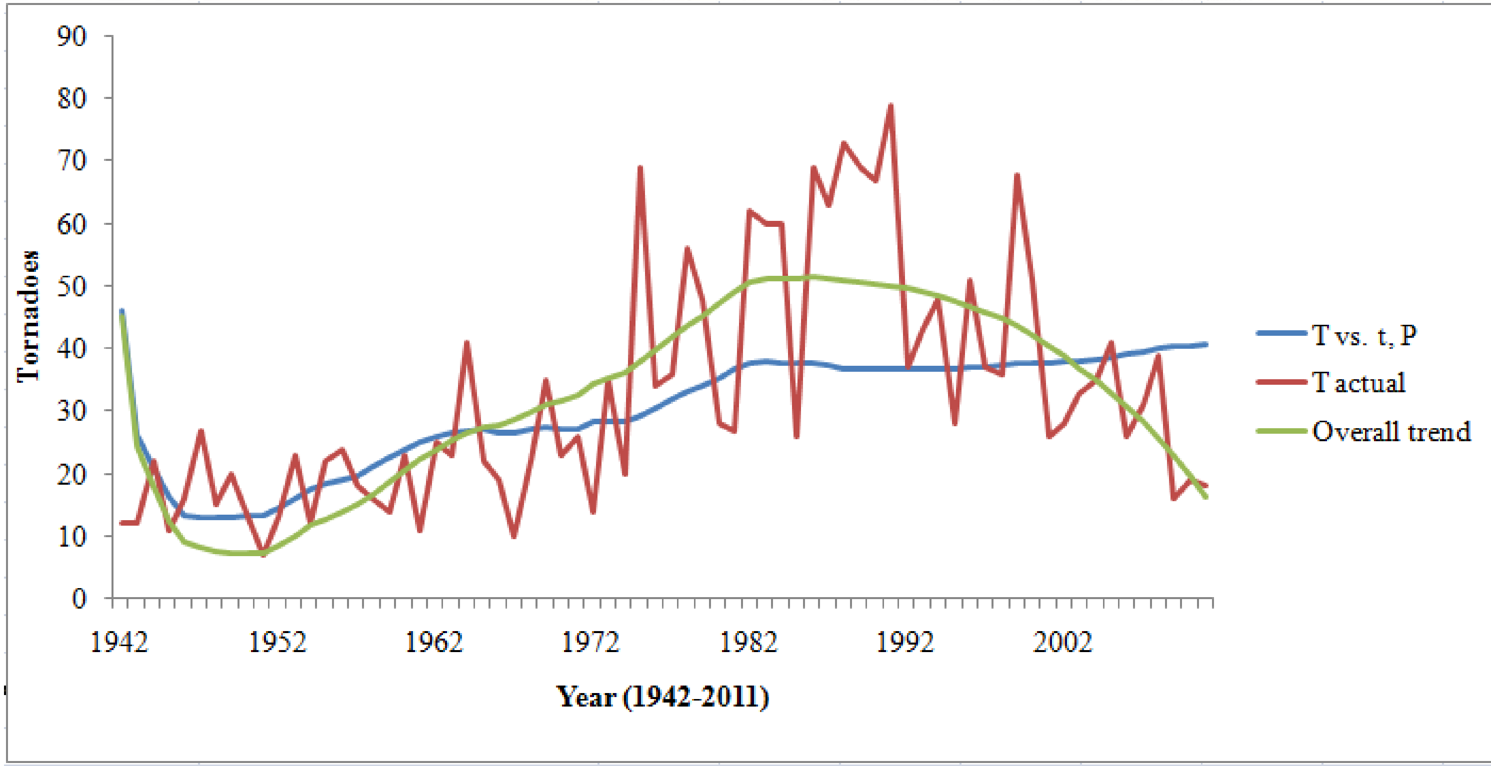
- Statistical analysis of historical Canadian Prairie data on tornadoes
- Network modeling and simulation of the tornado detection, warning and communication (TDWC)network
- Stated preference analysis of how Calgary households and vehicle-drivers will evacuate (or not) in response to tornado warnings
- Analysis of the total time consumption for warning, communication and evacuation
- Analysis of false warning and missed events in the Canadian Prairies
- Recommendations for the stakeholders involved in the TDWC process

1. STATISTICAL ANALYSIS OF THE TORNADO DATABASE





Model Development for the Tornado Time Trend



Regression Model $$T_o(t) = 1987.2\, e^{-22.6P^{-2.1}} t^{-0.796}$$

+

Time Series Model $$T_u = 0.1935 - 1.267t + 0.074t^2 - 0.00087t^3$$

A cyclic nature for the observed tornado frequency with a period of around 65 years.

2. EVALUATION OF THE WARNING COMMUNICATION AND EVACUATION SYSTEM

Objective:

- To compare the total time consumption for warning, communication and evacuation with the warning lead time

Warning issuance to the warning receipt point

(Network Simulation)

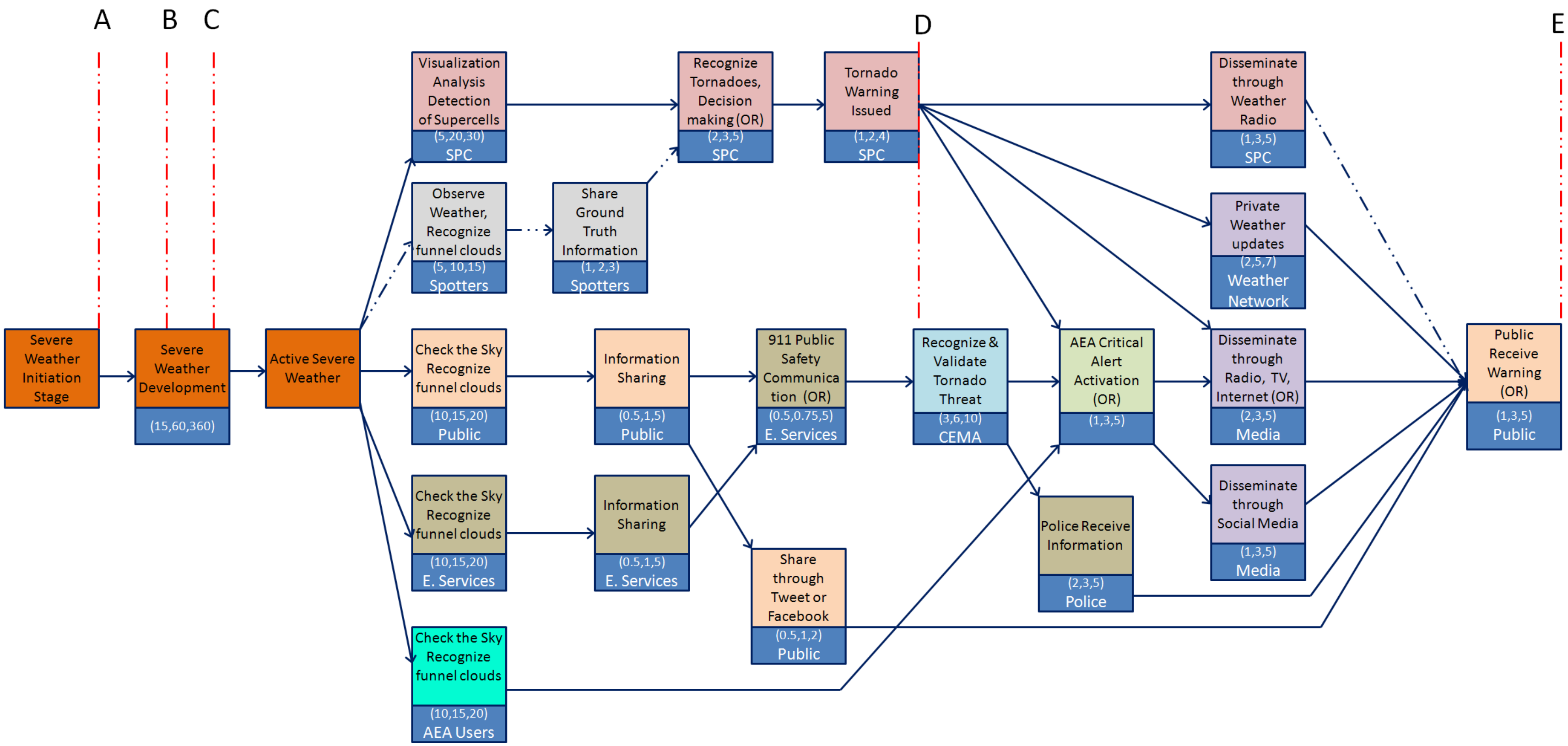
+

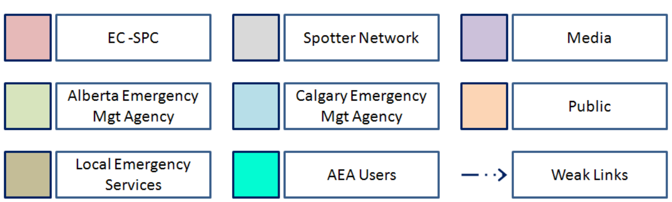
Warning receipt point to the evacuation completion point

(Tornado Survey)

- Curve fitting procedures required for this analysis used EasyFit software

Tornado Detection, Warning and Communication Network





A - Conditions are favourable for severe weather development
Severe Thunderstorm Watch issued
B -Recognize Severe Thunderstorm triggers (Tornado may be possible)
Severe Thunderstorm Warning Issued / Public -Activate Preparedness Plan
C - Conditions are favourable for tornado development
Tornado Watch is issued
D - Tornado may be probable, imminent or immediately occurring
Tornado Warning is issued
E - Public Receive Warning / Act Immediately

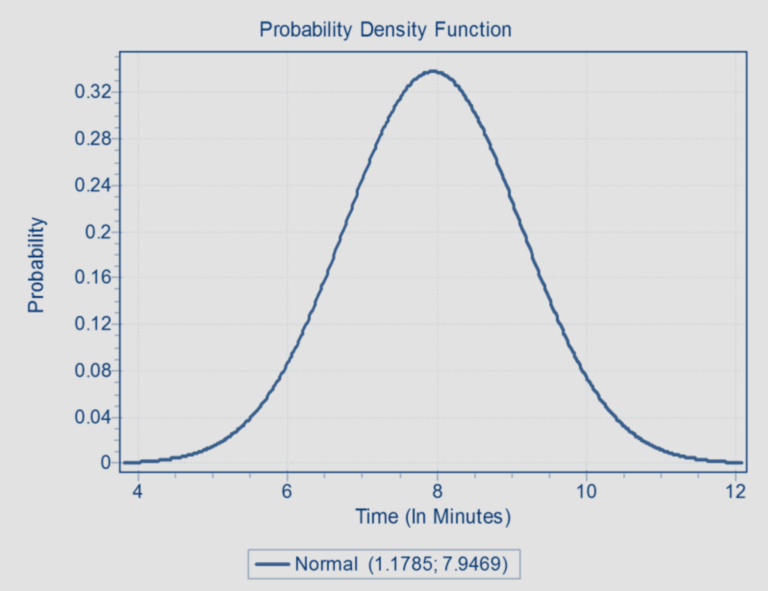
Stated Preference Survey

- Nearly 500 Calgarians took part in the online survey and provided information on how they would respond to tornado warnings after receiving them.
- The respondents were asked to assume that they received a tornado warning; and, their intended evacuation responses when at home and driving were collected separately.

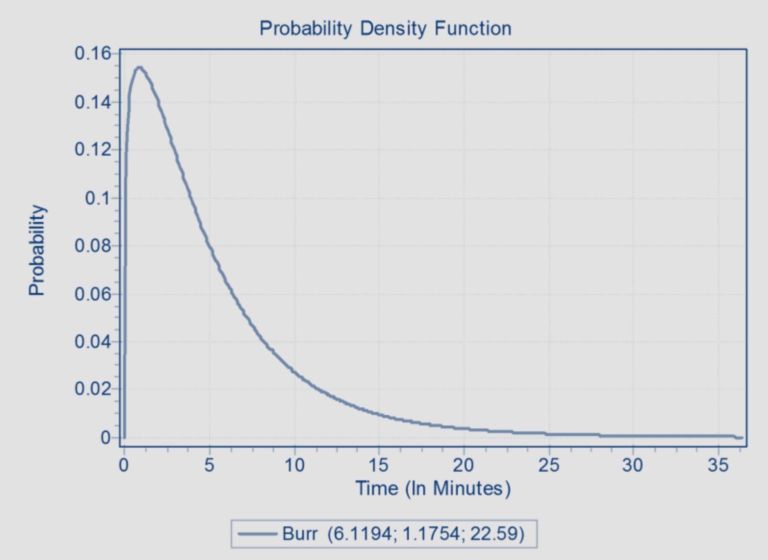
Variable	Response Categories	Percentage
Gender	Male	66.0
	Female	34.0
Age	Below 30	13.5
	Between 30 and 50	52.8
	Above 50	33.7
Dwelling Type	Single Detached Dwelling	74.6
	Other	25.4
Household Size	One	12.8
	Two	32.3
	Three or More	54.9
Presence of School Aged Children	Yes	33.5
	No	66.5
Presence of People with Reduced Mobility	Yes	6.2
	No	91.7
	Not Answered	2.1
Household Income	Less than $50,000	9.3
	$50,000 - $120,000	36.8
	Above $120,000	40.1
	Not Answered	13.8
Level of Education	Up to High School	7.1
	Training after High School	32.8
	Undergraduate Degree	38.5
	Postgraduate Degree	19.0
	Not Answered	2.6

Overall Time Consumption

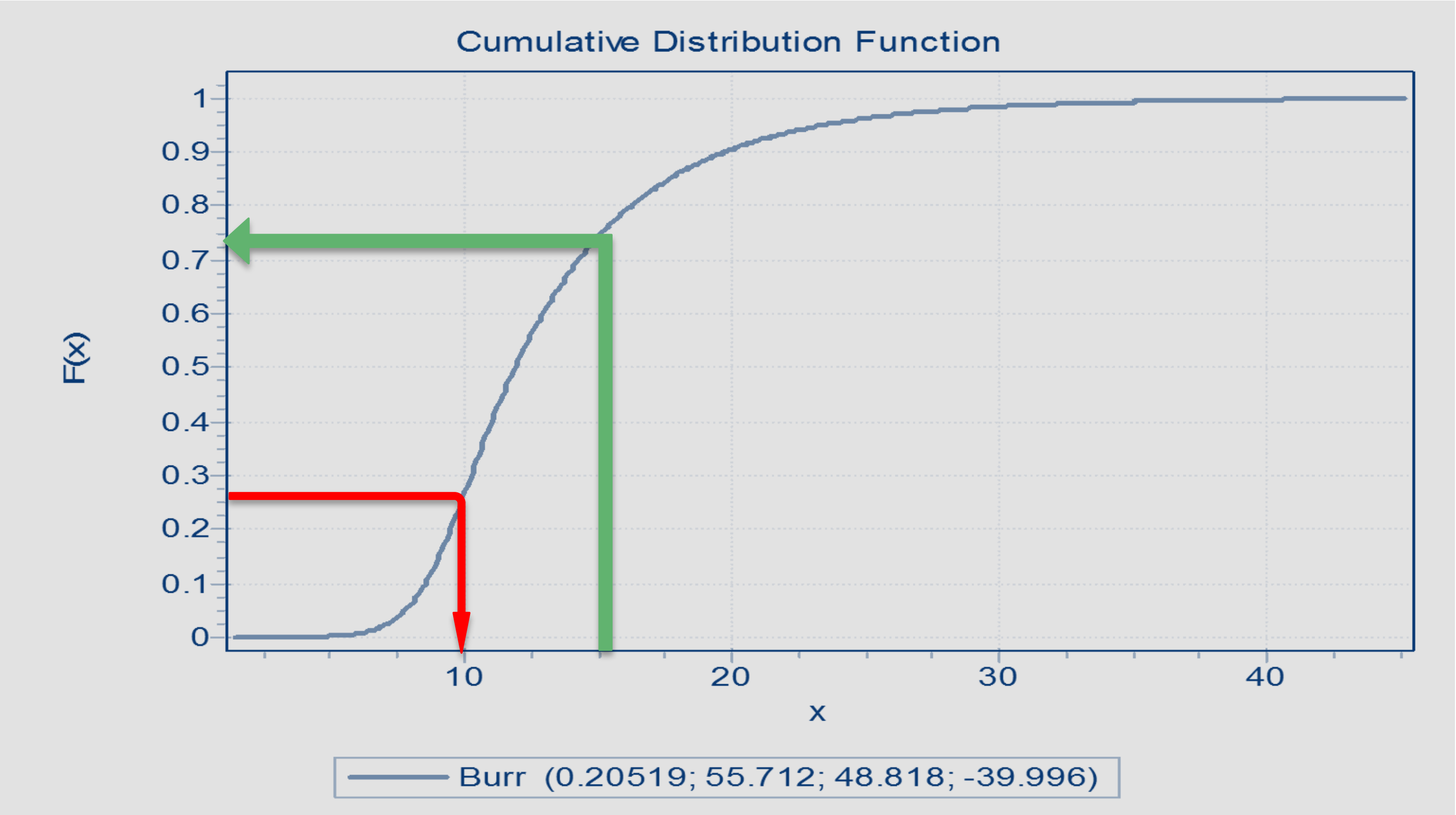
- Warning issuance to the warning receipt point



- Warning receipt point to the evacuation completion point



Overall Time Consumption



- There is around 25% chance that the evacuation can be completed by a household within 10 minutes from the warning issuance point.
- Increasing the time by 5 minutes gives more than 70% chance for a household to complete evacuation.

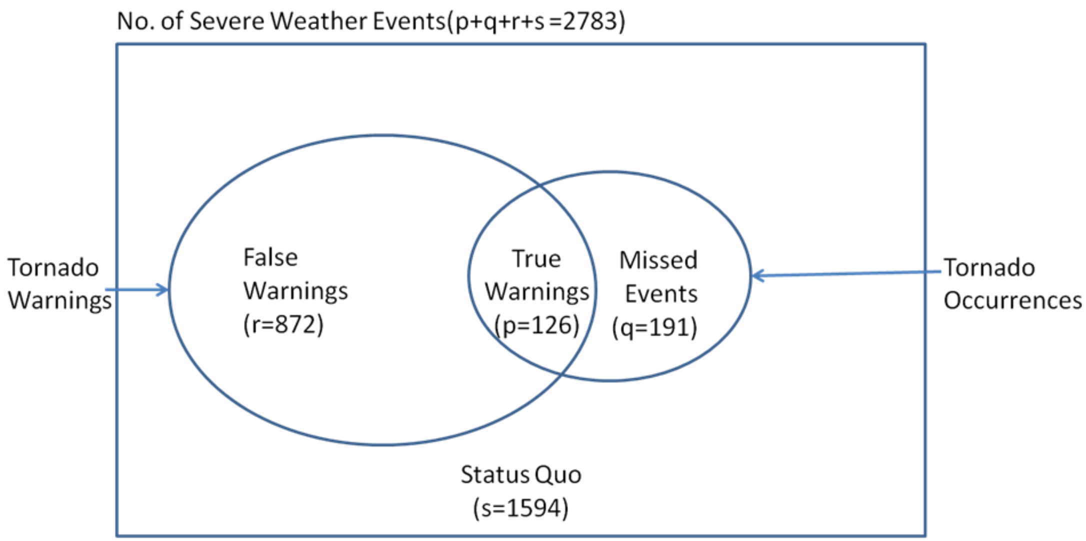
3. PRAIRIE DATA ANALYSIS

		Tornadoes Observed	
		Yes (T)	No (T′)
Tornadoes Forecasted (or Warned)	Yes (W)	**p** True Warning	**r** False Warning
	No (W′)	**q** Missed Event	**s** Status Quo

- A true warning for a tornado is a clear communication to the public to evacuate to safer places prior to an actual occurrence.
- A false warning can be considered to be a situation when the public is warned about a tornado and one actually does not occur.
- A missed event is a situation where a tornado touchdown occurred without an advance warning being issued.
- This status quo infers the correct detection of the situation that there is no tornado potential within a thunderstorm, thus, no warning is required.

Analysis of Tornado Warnings in the Canadian Prairies

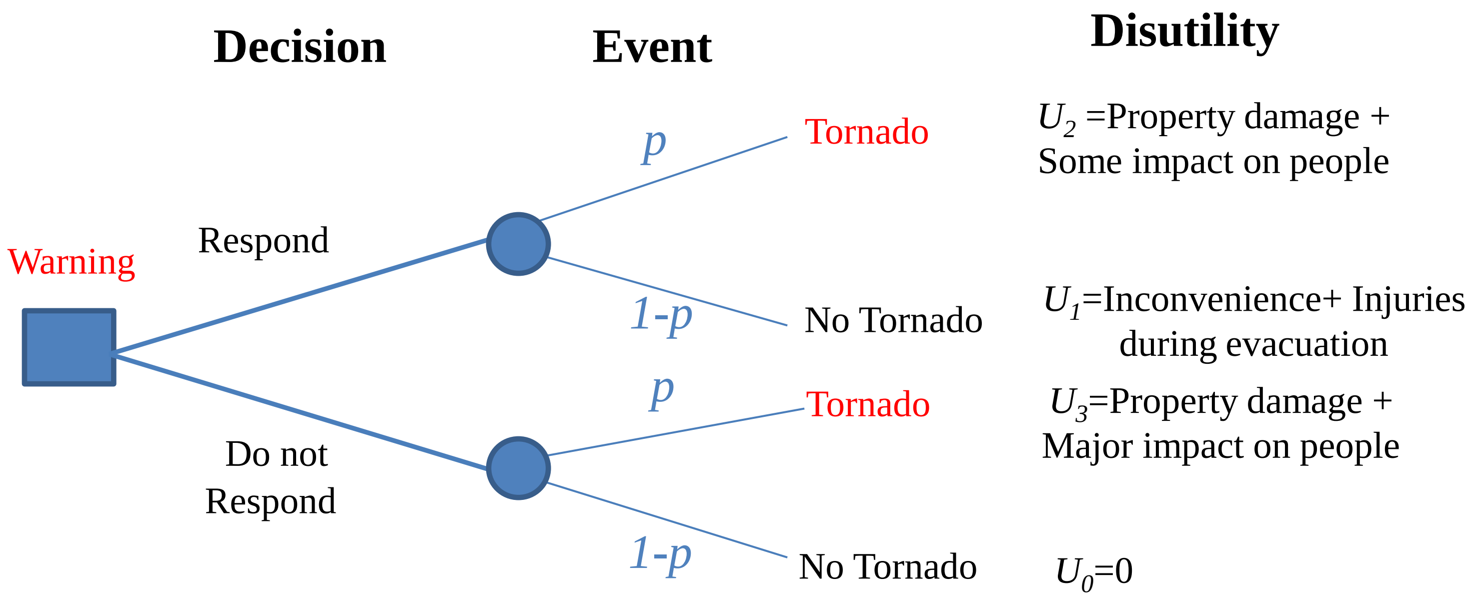
Venn Diagram of tornado warning, occurrence records from 2003 to 2012



True Warning, False warning, Detection Probabilities given a Severe Weather Bulletin

Probability of True Warning **P(T/W)**	Probability of False Warning **P(T′/W)**	Probability of Missed Event **P(T/W′)**	Probability of Detection **P(W/T)**	Probability of False Detection **P(W/T′)**
12.6%	87.4%	10.7%	39.8%	35.4%

4. HOUSEHOLD DECISION TREE FOR A TORNADO



p =Probability of a tornado given that a warning has been issued

- The expected disutility of responding to a warning E (R) = p(U_2) + (1-p)(U_1)
- The expected disutility of not responding to a warning E (R') = p(U_3)
- The household will choose to respond if E (R') >E(R)

$$p > \frac{1}{1 + \left(\frac{U_3 - U_2}{U_1}\right)}$$

Household Decision Tree for a Tornado

- Inequality

$$p > \frac{1}{1 + \left(\frac{U_3 - U_2}{U_1}\right)}$$

- $(U_3\text{-}U_2)$ - the additional disutility or the consequences of not responding to a tornado warning
- U_1 - Negative consequences of responding to a false warning

-When $(U_3\text{-}U_2)$ is higher even a low probability of a true warning *p* is sufficient to trigger evacuation response.

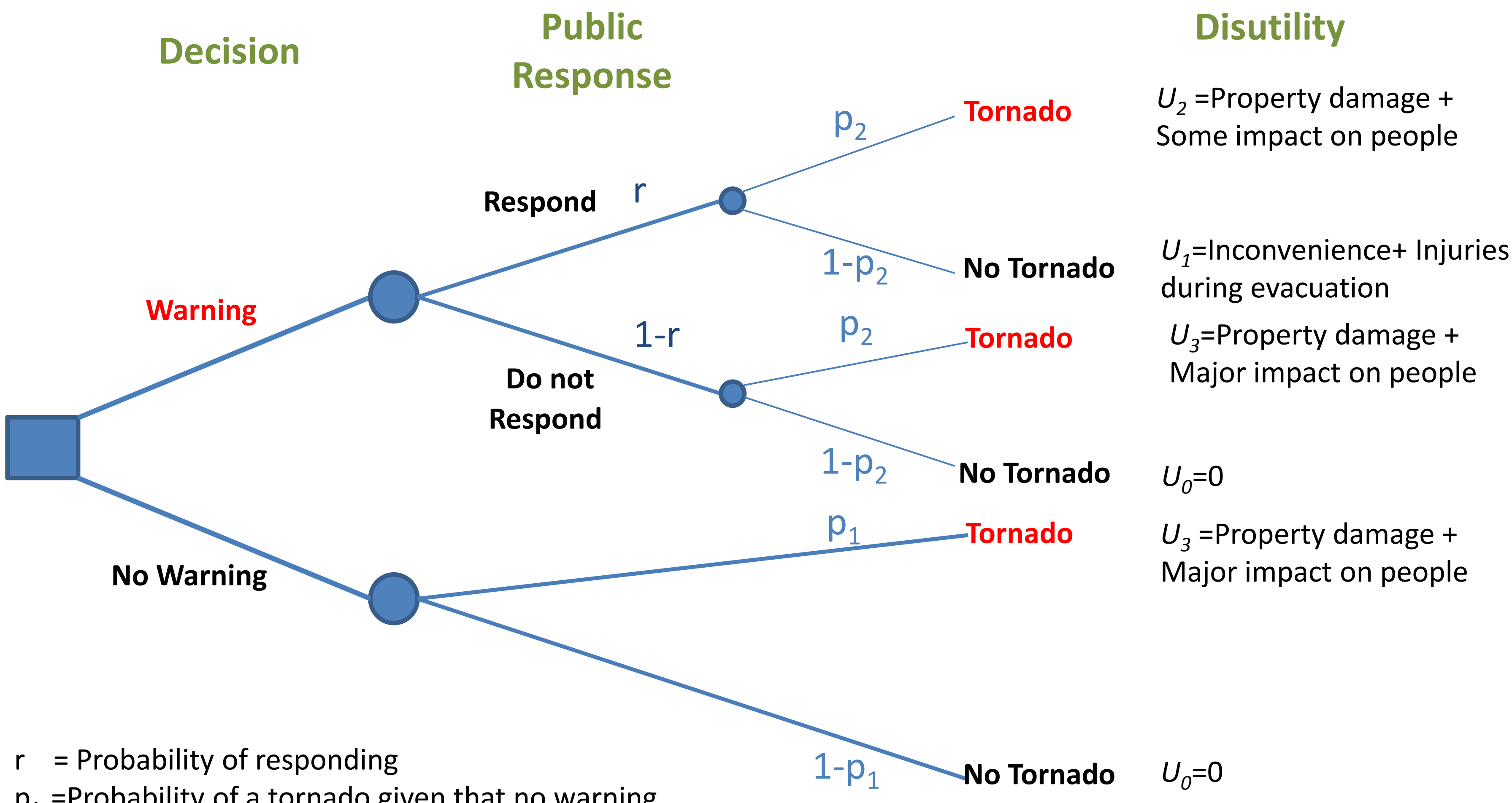
-When U_1 is higher, it is necessary to have a higher value for *p* to initiate response actions

Case (i) $(U_3\text{-}U_2) > U_1$; $\left(\frac{U_3 - U_2}{U_1}\right)$ >1 RHS of inequality < 0.5

Case (ii) $(U_3\text{-}U_2) < U_1$; $\left(\frac{U_3 - U_2}{U_1}\right)$ <1 RHS of inequality > 0.5

(Since U_1 is small and $U_3\text{-}U_2$ is high, it is unlikely that case (ii) will occur.)

5. WARNING DECISION TREE FOR A TORNADO



r = Probability of responding
p_1 =Probability of a tornado given that no warning has been issued P(T/W')
p_2 =Probability of a tornado given that a warning has been given P(T/W)

Warning Decision Tree for a Tornado

- The expected disutility of giving a tornado warning

  $E(W) = rp_2(U_2) + r(1-p_2)U_1 + (1-r)p_2(U_3)$

- The expected disutility of not giving a tornado warning is

  $E(W') = P(T/W')(U_3) = p_1(U_3)$

- The forecaster should choose to issue a warning if

  $E(W') > E(W)$

- Fundamental inequality of decision making for tornado warnings

  $\mathbf{r > \{ 1 - [P(T/W') / P(T/W)] \} / [1 - (U_2/U_3)]}$

Case (i) $P(T/W') > P(T/W)$ or (Missed event probability > True warning probability) ;

RHS is always negative since $U_2 < U_3$

No matter what response probability is expected from the public, the forecaster should choose to issue a warning.

Case (ii) $P(T/W') < P(T/W)$ or (Missed event probability < True warning probability);

RHS is positive

The response probability has to be higher than a certain positive value to justify a warning.

6. RECOMMENDATIONS

Partner	Recommendations
SPC	-Check the sufficiency and efficiency of the technological and human capacity to detect tornadoes and take remedial measures -Implementation of a group of spotters to get ground-truth information -Develop interactions with the local emergency managers Promote the use of Weatheradio application as the primary warning source
CEMA	-Conduct annual information sessions and drills to improve the awareness and preparedness at the individual level, institution level and the community level -Develop interactions with the SPC, spotters and the public to get tornado information and activate the AEA -Promote various communication media including the Internet, social media and Smartphone applications that can reach a diverse population with different preferences
AEMA	-Strengthen the AEA system to verify tornado information at the local level

RECOMMENDATIONS (cont'd)

Partner	Recommendations
Schools	-Practice evacuation drills in the Springs season -Improve the awareness of parents regarding school evacuation measures
ROC	-Initiate the use of VMS for severe weather warnings including tornadoes -Educate drivers on how to respond to a tornado emergency -Study of traffic management technologies to assist in responding to a tornado warning
Media	-Educate the public by facilitating discussions about tornado preparedness and response in the Spring and Summer seasons
Police	-Be ready to respond once a tornado touchdown is reported
Public	-Improve awareness about environmental cues of tornadoes, weather alerts, warnings and evacuation actions -Develop a family preparedness plan in responding to a tornado