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POLYTECHNIQUE MONTRÉAL

# Use of UAVs in Post-Disaster Response

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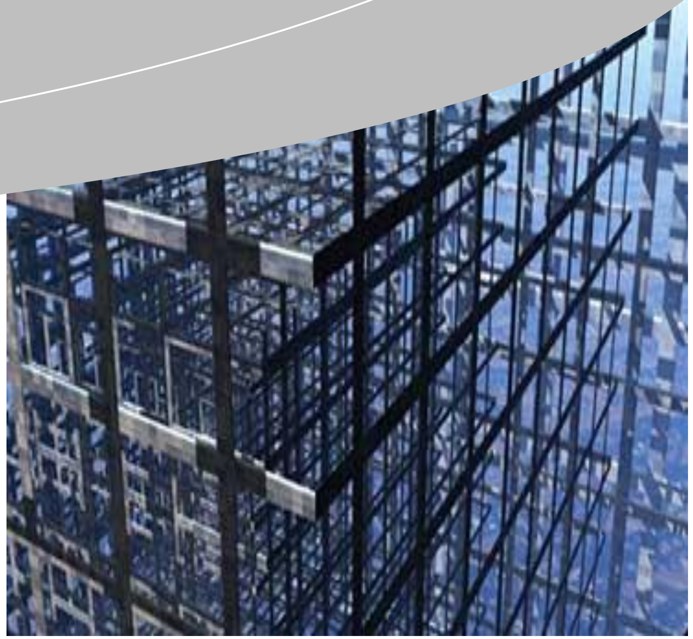

# Overview

- Context, introduction, and literature review
- Problem description
- Problem formulation
- Potential use in practice
- Conclusions and future work

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# Context

- In the aftermath of a disaster, often rescuers are tasked with locating victims trapped and in need of aid:
  - Most search and rescue procedures are incredibly manual with rescuers approaching collapsed structures.
  - After a disaster, human rescuers using tools such as dogs, acoustic sensors, and snake cameras to locate people.
- Explosion of cell phone usage around the world:
  - Cellphones emit a host of signals by virtue of being on and active.
  - Research has begun to explore the ability to passively or actively detect or interact with these signals.

FEMA Urban Search and Rescue team members search house to house for survivors in tornado devastated neighborhood in Moore, Oklahoma. Andrea Booher for FEMA

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# Introduction

- Some organizations and research institutions are adding a new dimension to their search and rescue operations by using UAVs and drones;
- Drones have an obvious utility with the ability to fly over a disaster area;
- Attaching a wireless sensor, a device to detect cell phones, to the done can allow the drone to locate cell phone users in a region;
- Drones have a hard endurance constraint (flight time) and cannot usually cover the entire search area alone.
- There is the potential but underexplored use of drones to be used in urban search and rescue operations.

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# Literature Review (1/3)

- When cross referencing the use of UAVs and Drones, USAR operations, and using wireless sensors; Few papers are yielded
- Some of the authors attempt to demonstrate using drones to help establish wireless networks using software on cellphones
- Most wireless sensor analysis or feasibility occurs in the Wilderness SAR context,
  - That is, attempting to find one person or a group of people missing in a search area,
  - Literature does deem the technology feasible (locate device).
- If a disaster is cited, usually an earthquake versus a meteorological event.

# Literature Review (2/3)

- Since few are in a USAR context, there is an opportunity to explore this tool to assist rescuers in locating victims and potential victims.
- One of the best demonstration studies on the matter was from Beck, et al (2018) where the authors propose a system for assisting in locating people in need of aid after the Haitian earthquake in 2010
- Authors outline a method of how drones can survey the island to identify the location of people

Beck, Zoltan, et al. "Collaborative Online Planning for Automated Victim Search in Disaster Response." *Robotics and Autonomous Systems*, vol. 100, 2018, pp. 251–266., doi:10.1016/j.robot.2017.09.014.

# Literature Review (3/3)

- As most literature is in a WiSAR context, most applications envision an unconstrained search area,
- Therefore, most applications do not account for a constrained search area.
- In addition, WiSAR operations usually are tasked with finding a singular person or group that is missing, rather than accounting for people who might not be in need of aid.

# Problem Description (1/2)

- Envision the search area discretized in into scanning areas,
- A drone with a wireless sensor, and others, attached will fly to and scan a scanning area,
- Drones have a hard *endurance constraint*, flight time,
- Drones will consume flight time along the route *and* at each scanning site.

# Problem Description (2/2)

- Formulation envisioned as a distance-constrained capacity vehicle routing problem (DCVRP).
- Began with formulation from Kek, et al (2008) and modified to suit the problem here,
- Notable change: the DCVRP is usually outlined as having a different resource consumed at the nodes (customers) and on the arc (enroute).
- In a post-disaster context: time windows less important than overall service time.

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# Problem Formulation and Constraints (1/2)

## Sets:

| | |
|---|---|
| $i \in N$ | Set of customers |
| $i \in H$ | Set of hubs (where drones depart) |
| $i \in V = N \cup H$ | Set of hubs and customers |
| $k \in K$ | Set of Drones available |

## Parameters:

| | |
|---|---|
| $c_{ij}$ | Cost (time) of going from $i$ to $j$ |
| $d_i$ | Demand (time) of scanning at site $i$ |
| $Q$ | The upper limit of time a drone can fly (endurance) |
| $K$ | The upper limit on the number of drones available |
| $M$ | Big ass number, specifically $Q + \max_j [d_j]$ |

## Variables:

| | |
|---|---|
| $x_{ijk} \in \{0,1\}$ | Arc $i$ to $j$ is traveled by drone route $k$ |
| $y_k \in \{0,1\}$ | Indicator variable that drone route $k$ is used |
| $z_{ik} \geq 0$ | Load variables specifying the total load serviced by vehicle since its last visit to a depot by the time it reaches customer node. Read as maximum load on route k. |
| $q_k^R \geq 0$ | Amount of endurance consumed by routes |
| $q_k^S \geq 0$ | Amount of endurance consumed by scanning |

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# Problem Formulation and Constraints (2/2)

$$\min \sum_{i\in V}\sum_{j\in V}\sum_{k\in K} c_{ij}x_{ijk} + \sum_{i\in N}\sum_{k\in K} d_i x_{ij} \qquad (1)$$

$$\sum_{\substack{j\in V\\ j\neq i}}\sum_{k\in K} x_{ijk} \le 1 \qquad i \in N \qquad (2)$$

$$\sum_{i\in H}\sum_{j\in N} x_{ijk} = y_k \qquad k \in K \qquad (3)$$

$$\sum_{\substack{i\in V\\ i\neq j}} x_{ijk} - \sum_{\substack{j\in V\\ j\neq i}} x_{jik} = 0 \qquad k \in K,\ j \in V \qquad (4)$$

$$z_{ik} = 0 \qquad i \in H,\ k \in N \qquad (5)$$

$$\left(z_{ik} + d_j - z_{jk}\right) \le M\left(1 - x_{ijk}\right) \qquad i \in V,\ j \in N,\ k \in K,\ i \neq j \qquad (6)$$

$$\left(z_{ik} + d_j - z_{jk}\right) \ge -M\left(1 - x_{ijk}\right) \qquad i \in V,\ j \in N,\ k \in K,\ i \neq j \qquad (7)$$

$$z_{ik} \le q_k^S \qquad k \in K \qquad (8)$$

$$\sum_{i\in V}\sum_{j\in V} c_{ij}x_{ijk} + \sum_{i\in V}\sum_{j\in V} d_i x_{ijk} \le q_k^R \qquad k \in K \qquad (9)$$

$$q_k^s + q_k^R \le Q \qquad k \in K \qquad (10)$$

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# Problem Formulation and Constraints (2/2)

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$$\mathbf{z_{ik} \le q_k^S} \qquad \mathbf{k \in K} \qquad \textbf{(8)}$$

$$\mathbf{\sum_{i\in V}\sum_{j\in V} c_{ij}x_{ijk} + \sum_{i\in V}\sum_{j\in V} d_i x_{ijk} \le q_k^R} \qquad \mathbf{k \in K} \qquad \textbf{(9)}$$

$$\mathbf{q_k^s + q_k^R \le Q} \qquad \mathbf{k \in K} \qquad \textbf{(10)}$$

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# Potential use in practice

On May 20, 2013, a EF-5 tornado struck central Oklahoma causing extensive damage to communities of Newcastle, Oklahoma City, and Moore

FEMA Urban Search and Rescue team members search house to house for survivors in tornado devastated neighborhood in Moore, Oklahoma. Andrea Booher for FEMA

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# Why tornadoes and Moore-Newcastle?

- Availability of data; the disaster occurred in 2013 and there is an availability of digitized and public data for the disaster.
- Relative to an earthquake or hurricane, Tornadoes have destruction area which is physically smaller in area.
- Predictability of  tornado is greater than that of an earthquake, and a tornado will dissipate quicker than a hurricane (i.e. allow for a timely rescue operation)
- The number of tornado incidents in the United States is approximately 1200 with approximately 37 EF-3 to EF-5 tornadoes occurring *in the United Sates* each year.
- The standardization and use of the Enhanced Fujita Scale which accounts for both tornado damage can aid in understanding the effectiveness of the tool over time.

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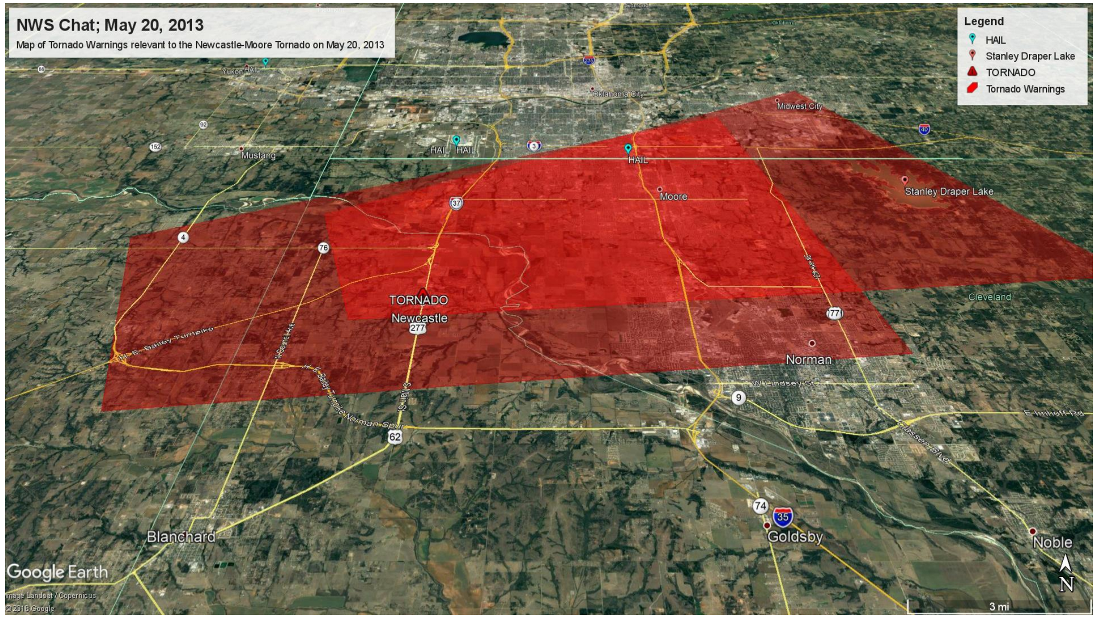
# Potential use in practice (1/2)

- Anticipate the use of Meteorologists and remote sensing technology to track the occurrence of tornados
- Meteorologists at the NWS and SPC typically delineate various severe weather watches and warnings
- Actual sightings can trigger which polygons to begin searching

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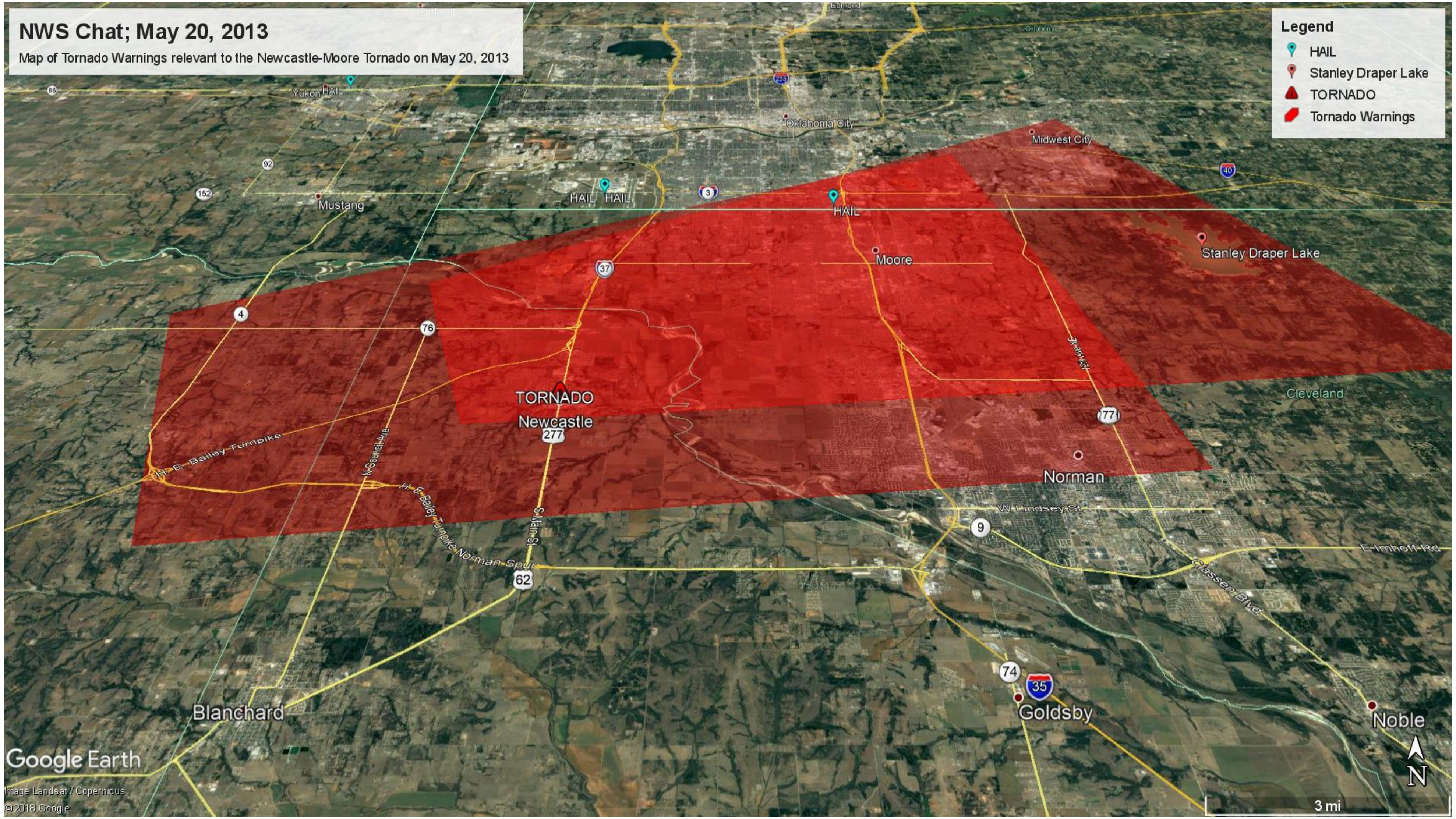
# Potential use in practice (2/2)

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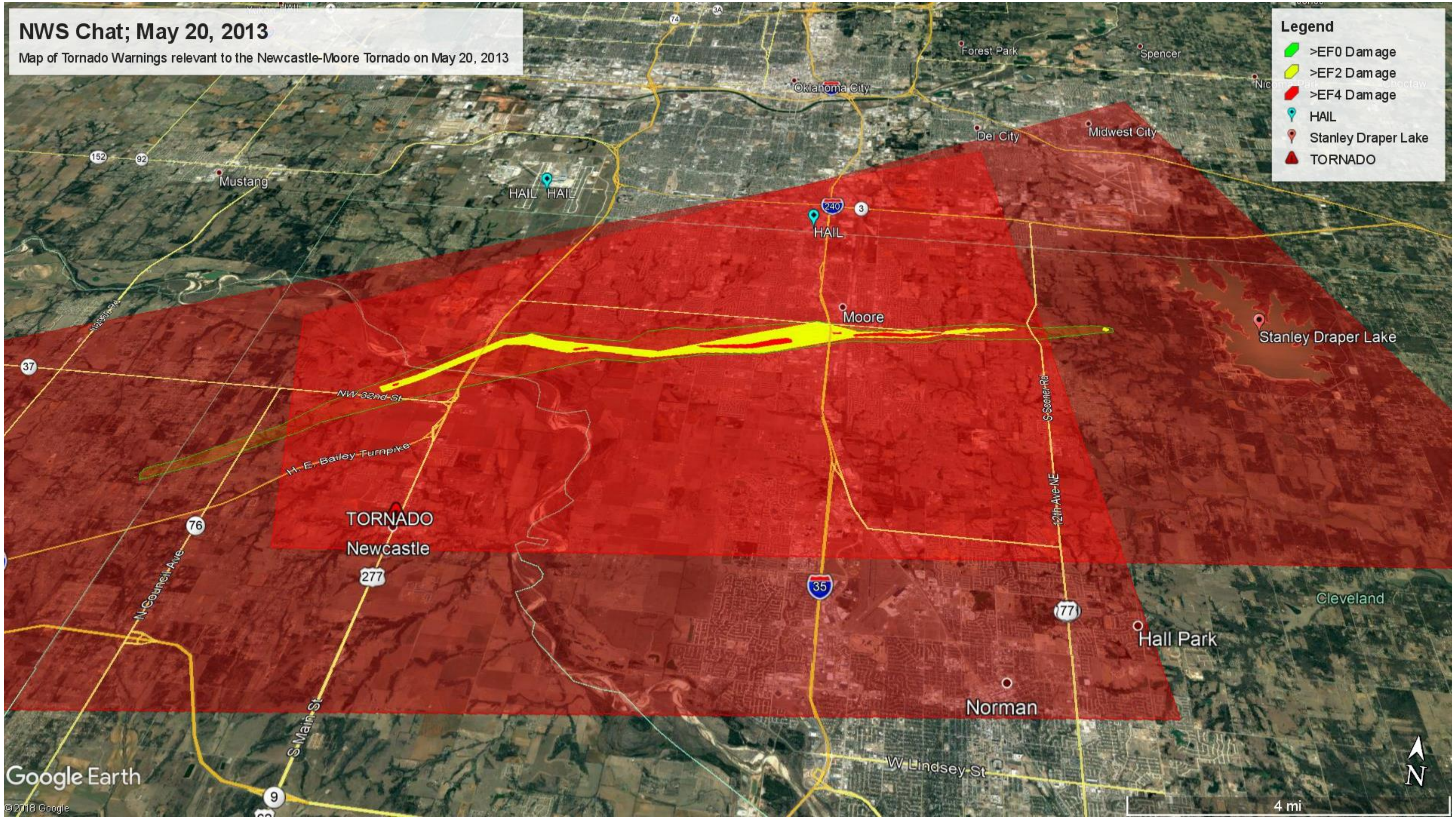
# Limitations

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# Attempts to better isolate search area

- Use roads or existing structures from OpenStreetMap as an indicator
  - Most buildings and victims would be within 300m of a road
  - Scanning cornfields is usually unnecessary
- Encourage spotters and the media better indicate bearing and direction of tornadoes
  - Note that severe weather observations are indicated where the spotter is, not the location of the tornado
- Most meteorologists during extreme weather events are tasked with updating predictions, not analyzing remote sensing data
  - Potential there to possibly use meteorologists to assist in delineating a search area.

# Conclusions and future steps

- Expand the model to incorporate priority search areas
- Incorporate a Dynamic Vehicle Routing (DVRP) into the search algorithm and incorporate damage reports as they happen to increase the priority of search area
  - Best indicator of damaged property is damaged property

# Questions?

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