PROLOG 2019

POLYTECHNIQUE MONTRÉAL

Dynamically Routing UAVs in the Aftermath of a Severe Tornado

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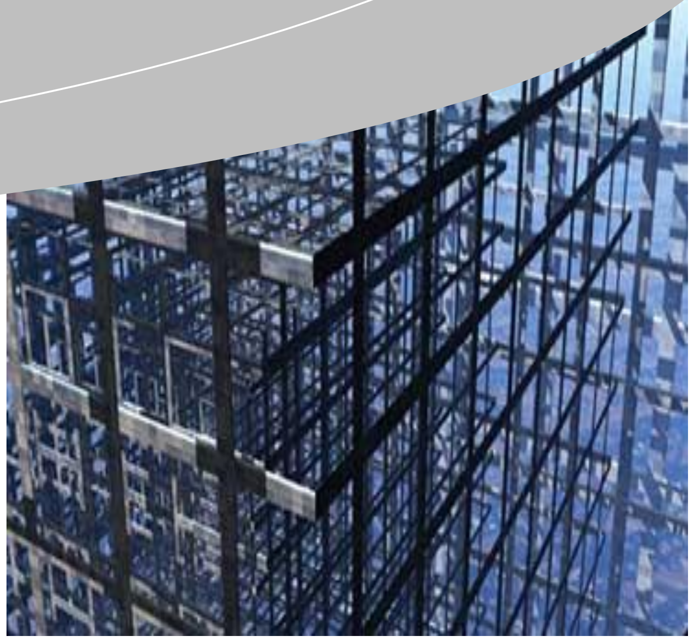

Presentation Outline

- Past work and limitations of past work
- Some relevant literature
- The new plan
- A naive policy
- Next steps

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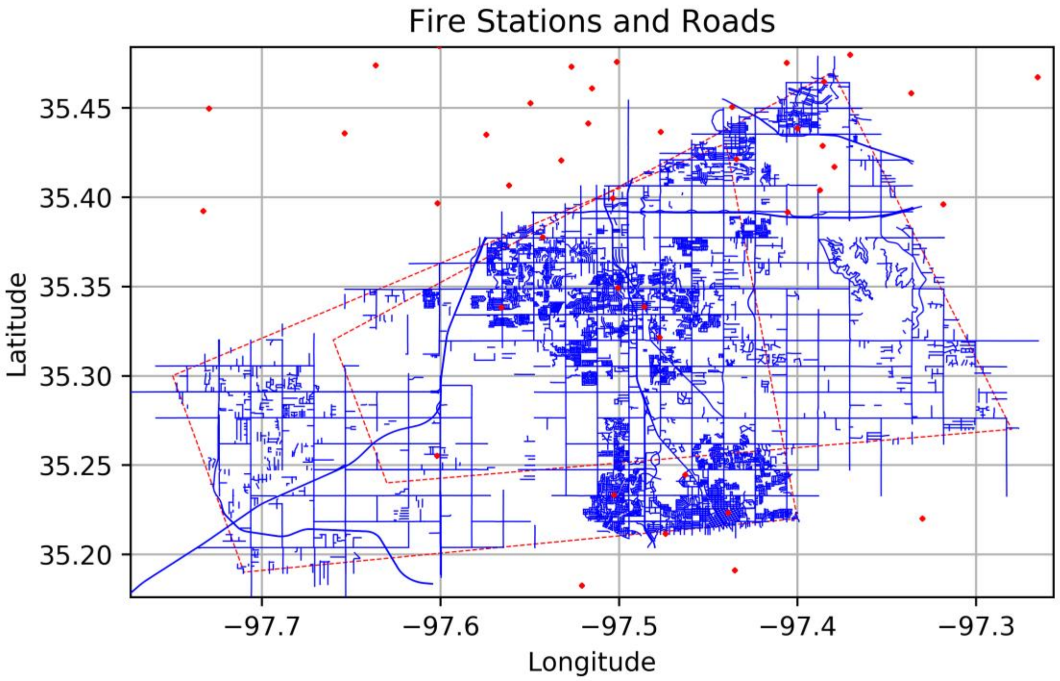
- Allocates and routes semi-autonomous UAVs with weather data and geospatial indicators
  - Weather warnings
  - Severe weather sightings
  - Roads
- Uses a fixed wing, gas-powered UAV



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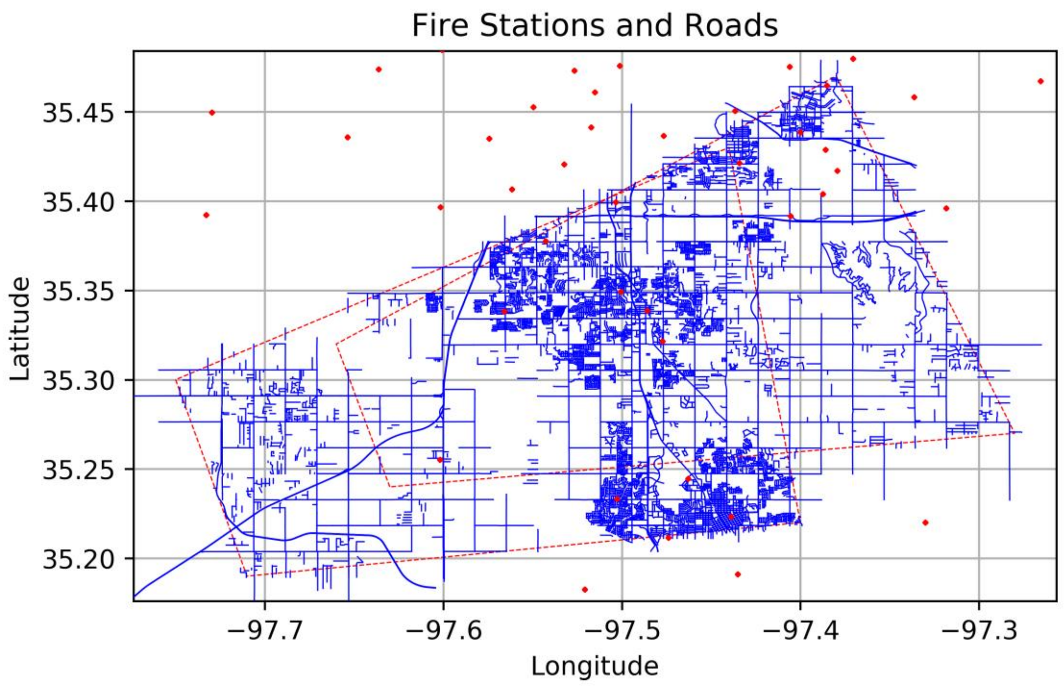
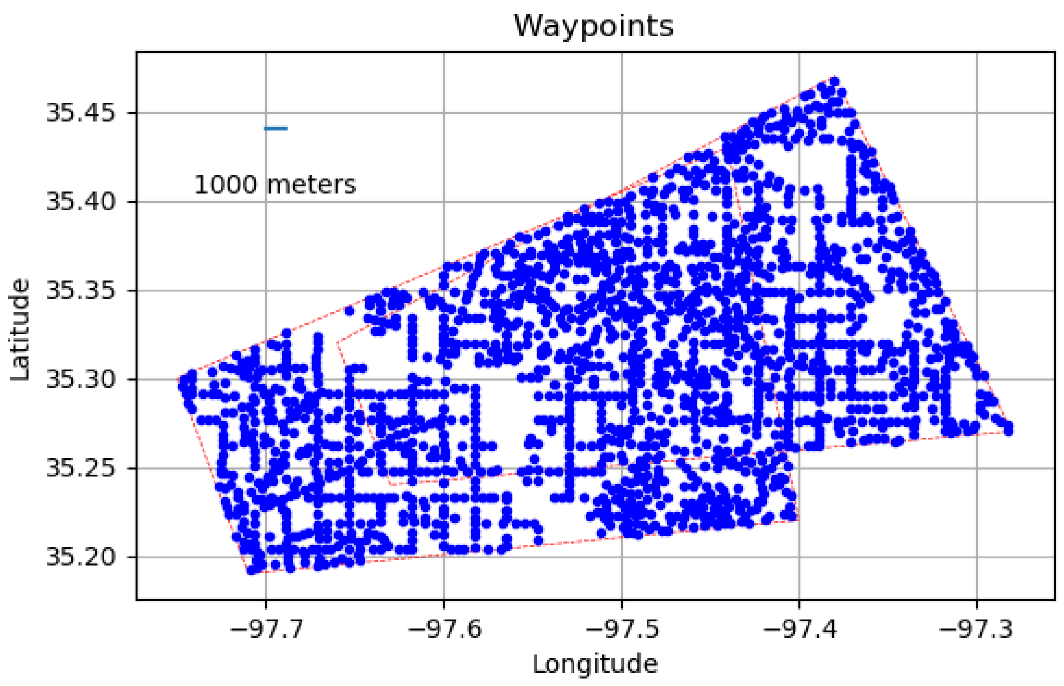
Past Work and Context : Data Generation

Fire Station	SBW	LSR
Where drones are launched and retrieved, aka ‘depots’	The box indicating severe weather	A sighting of severe weather





DCVRP: Problem Formulation and Constraints (1/2)

Sets:

$i, j \in W$	Set of waypoints (customers)
$s \in S$	Set of stations (depots where drones depart)
$i \in V = W \cup S$	Set of hubs and customers

Parameters:

t_{ij}	Time (cost) of going from i to j
E	The upper limit of time a drone can fly (endurance)
K	The upper limit on the number of drones available
M	Big number, specifically $\max_j [t_{ij}]$

Variables:

$x_{ijk} \in \{0,1\}$	Arc i to j is traveled by drone from depot k
$z_{ik} \in \mathbb{R}^+$	Load variables specifying the total load serviced by vehicle since its last visit to a depot by the time it reaches customer node *i*.
$\bar{\boldsymbol{t}} \in \mathbb{R}^+$	**Time it takes for the longest drone to complete it's tour**

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DCVRP: Past Problem Formulation and Constraints (2/2)

Objective Function:

$$\min \bar{t} \qquad (1)$$

Maximum tour time:

$$\boldsymbol{\sum_{i\in V}\sum_{\substack{j\in W\\ j\neq i}} t_{ij}x_{ijs} \leq \bar{t} \qquad \forall s \in S} \qquad \textbf{(2)}$$

Endurance limit:

$$\sum_{i\in V}\sum_{\substack{j\in V\\ j\neq i}} t_{ij}x_{ijs} \leq E \qquad \forall s \in S \qquad (3)$$

Drone used indicator:

$$\sum_{j\in W} x_{sjs} \leq \mathrm{K} \qquad \mathrm{s} \in S \qquad (4)$$

Flow constraints:

$$\sum_{\substack{j\in W\\ j\neq i}}\sum_{s\in S} x_{ijs} = 1 \qquad i \in V \qquad (5)$$

$$\sum_{\substack{i\in V\\ i\neq j}} x_{ijs} - \sum_{\substack{\mathrm{k}\in V\\ j\neq \mathrm{k}}} x_{j\mathrm{k}s} = 0 \qquad s \in S,\ j \in V \qquad (6)$$

Load and subtour elimination constraints:

$$z_{\mathrm{ss}} = 0 \qquad s \in S \qquad (7)$$

$$(z_{is} + t_{ij} - z_{js}) \leq M(1 - x_{ijs}) \qquad i \in V,\ j \in W,\ s \in S,\ i \neq j \qquad (8)$$

$$(z_{is} + t_{ij} - z_{js}) \geq -M(1 - x_{ijs}) \qquad i \in V,\ j \in \mathrm{W},\ \mathrm{s} \in \mathrm{S},\ i \neq j \qquad (9)$$

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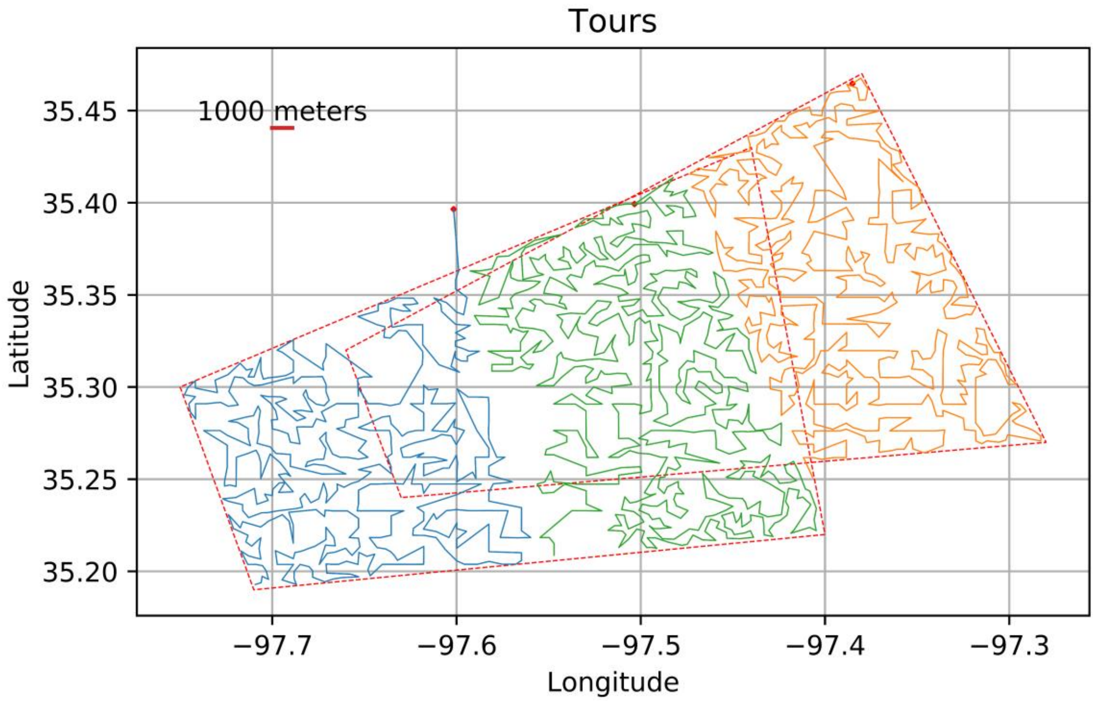
Limitations

What was done

- Demonstration of data available and its use to allocate and route UAVs
- Proposed a multi-depot VRP with an objective function that minimized the time it took to search the entire area

What are the Limits

- Do not need entire area
- Identify where damage is quickly as possible



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Relevant literature

- Reviewing literature with the following attributes:
  - Wilderness or Urban SAR or Combat Environments
  - Autonomous or semi-autonomous flying vehicles, with preference to fixed wing aircraft
  - No preference to disaster type
- Common tools are decision policies (Combat/Military) and pre-planned routes (SAR)
- Most applicable article from the literature is using a fleet UAVs in a combat environment
  - Radio silence, uses a region sharing strategy, pre-planned route, and a decision policy to react to information

Xia, Y., Batta, R., & Nagi, R. (2017). Controlling a Fleet of Unmanned Aerial Vehicles to Collect Uncertain Information in a Threat Environment. *Operations Research*, *65*(3), 674–692. https://doi.org/10.1287/opre.2017.1590

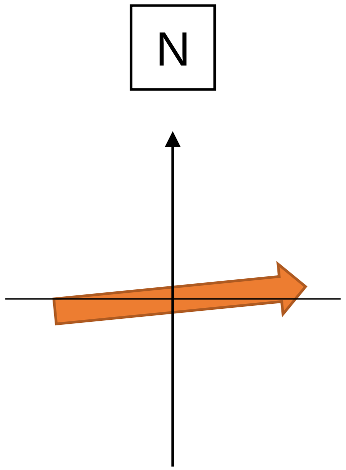
The New Plan

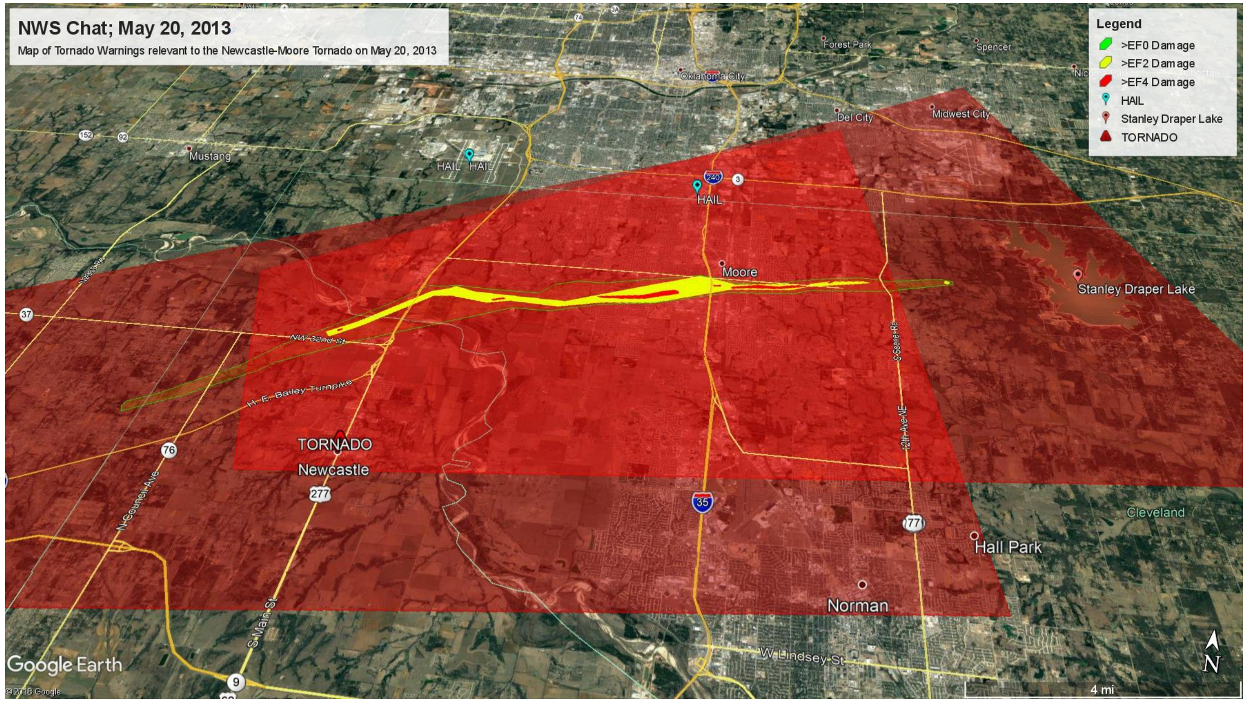
- Create an initial route as before
- **Conjecture: The best indicator of damage is damage**
- As drones search the area, operators can begin to uncover and identify damage
- Rescuers can be dispatched when damage is identified
- If damage is identified in a given area, it increases the likelihood an adjacent area(s) will have damage.

A satellite photo of Granbury, Texas before and after a 200 mph-tornado ripped through the area Wednesday night. CBS NEWS/GOOGLE MAPS

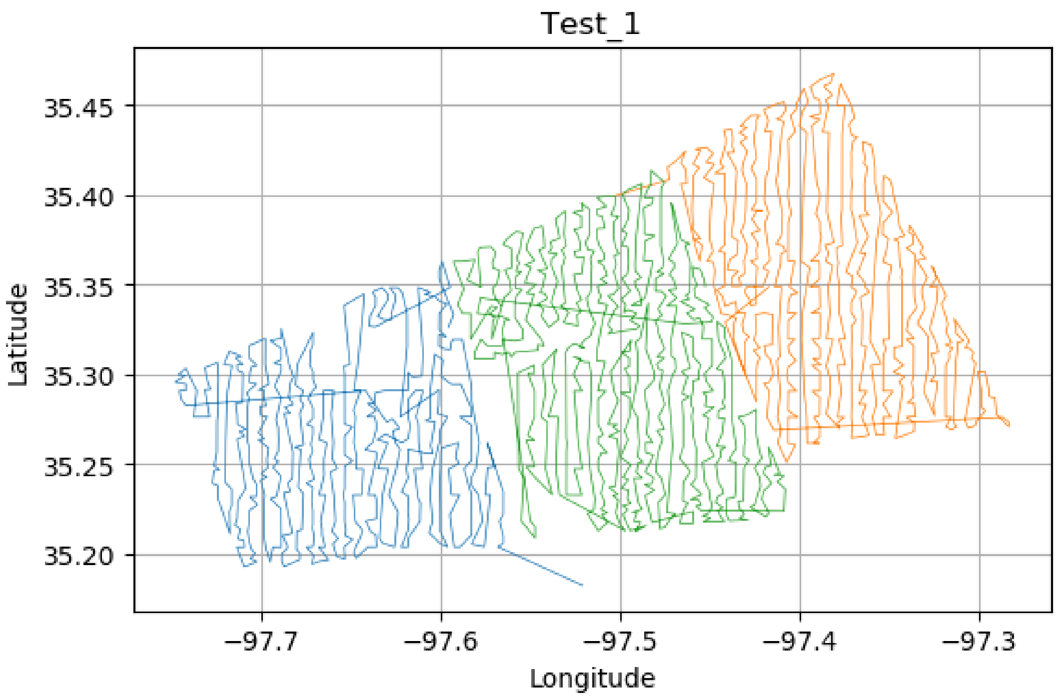
A Naive Policy

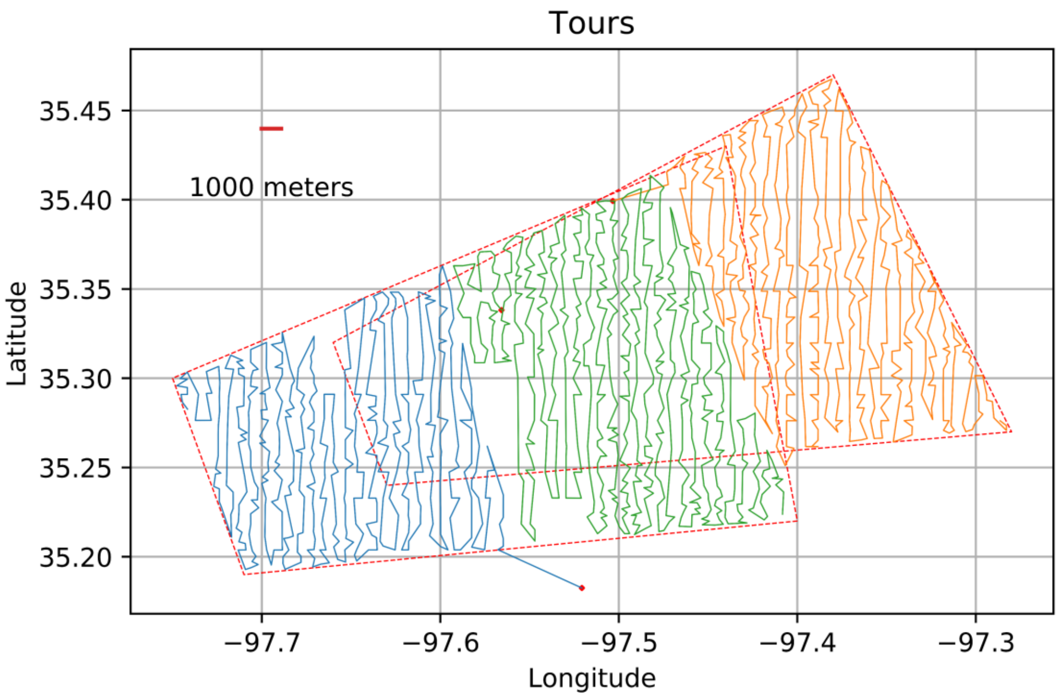
- Consider most tornadoes in the continental United States move in a *west-to-east* or *southwest-to-northeast* direction
- A naïve policy would be to fly in a north-south pattern until damage is identified, then fly east-west to uncover the extent of the damage





Testing a Naive Policy





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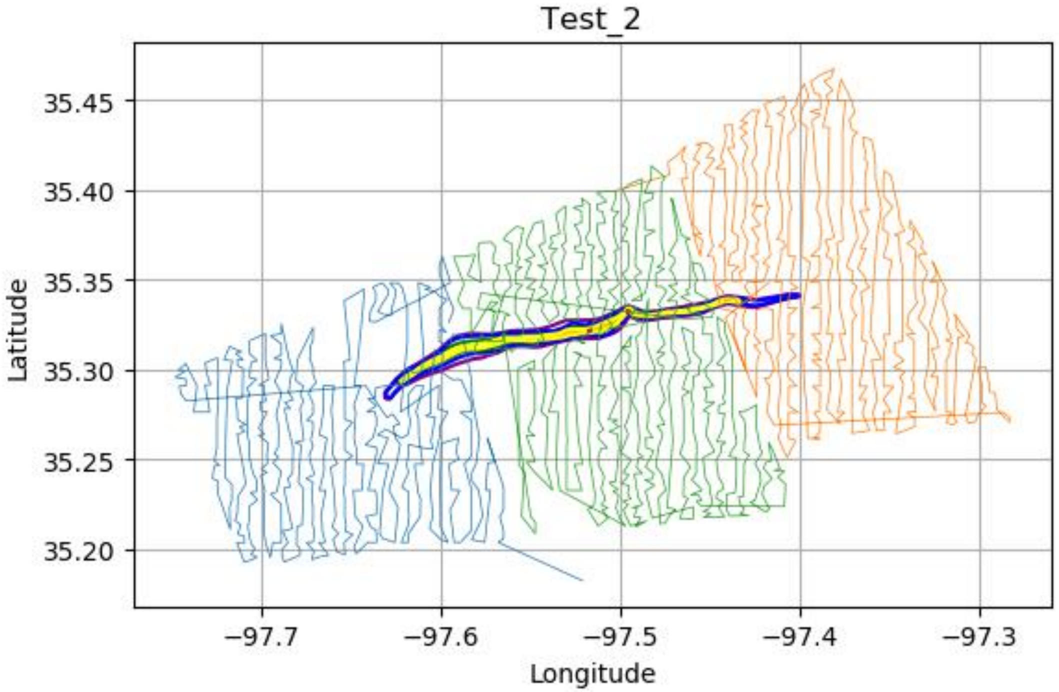
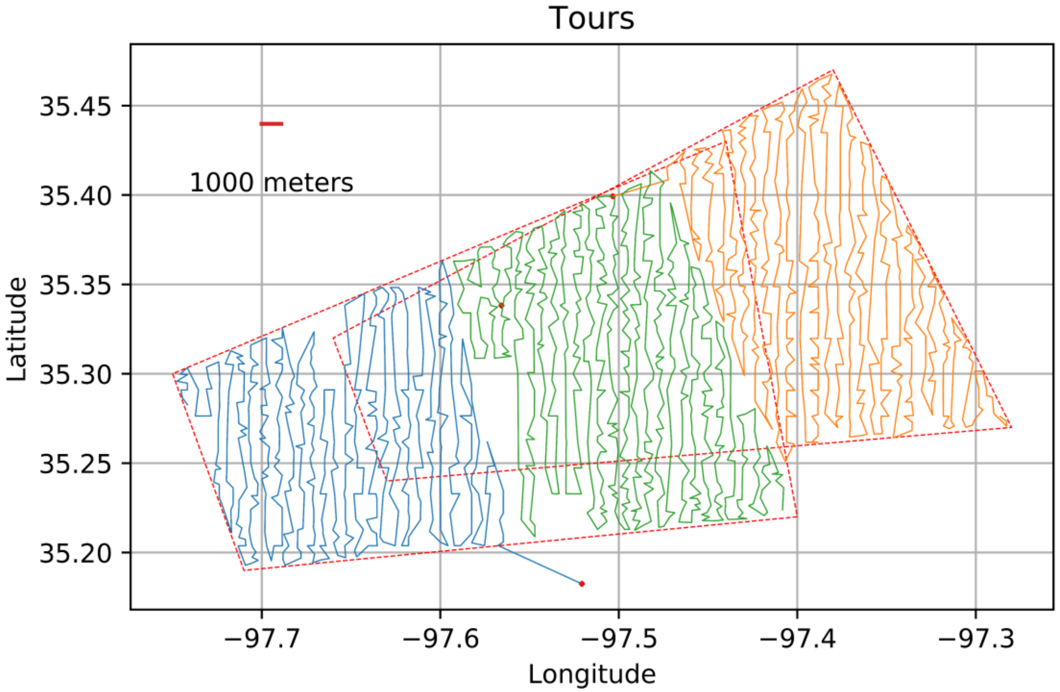




Conclusion and Next Steps

- The naive policy reacts to ‘seeing’ damage

Where Damage Occurred (on average)…

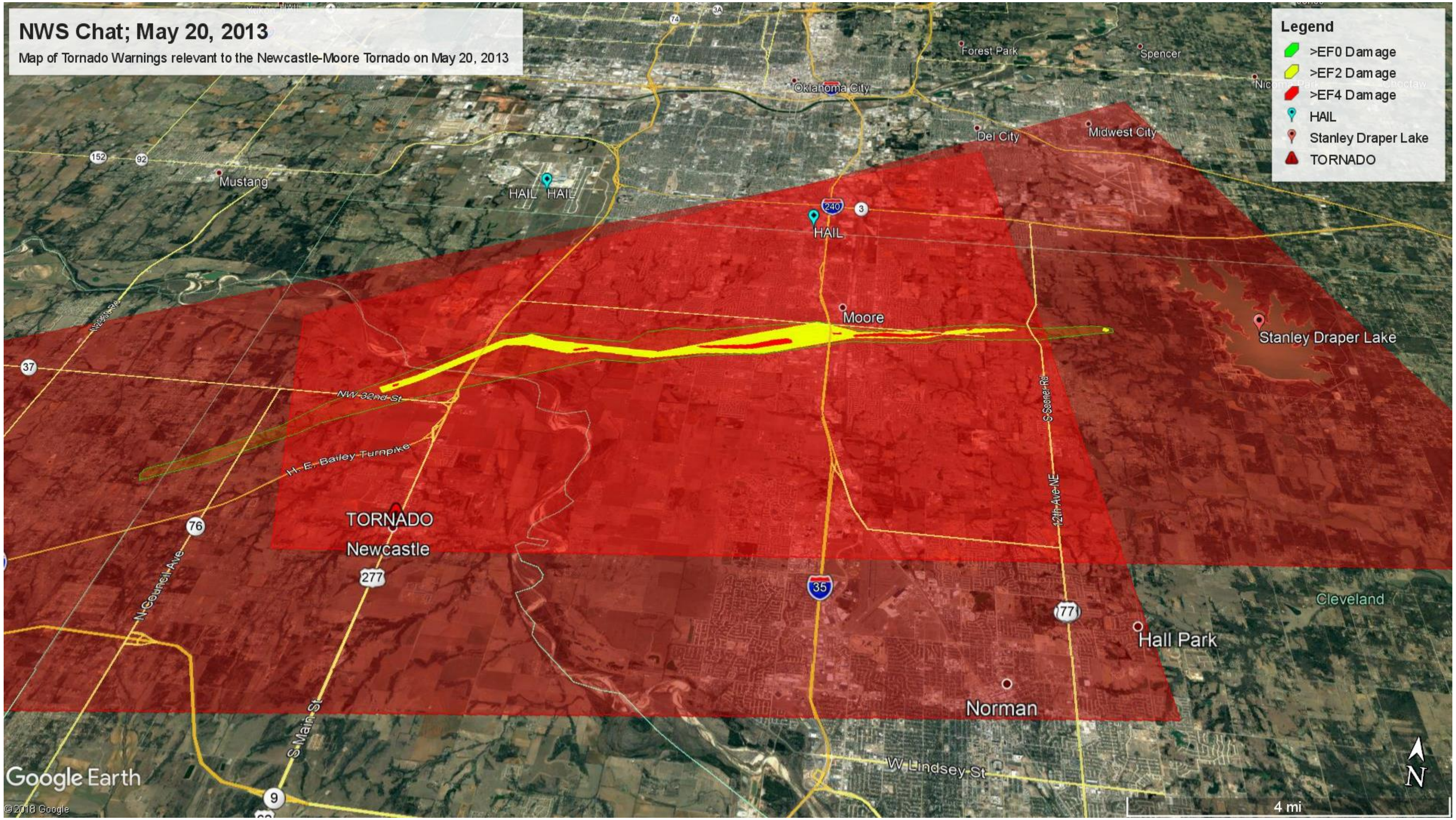
- Regions with EF5 and EF4 damage could be dispatched up to 45 mins earlier.
- EF3 was 10 mins slower, Less damage up to 30 mins later.

But we can do better!

Next Steps

- Leverage the data and expertise of how Meteorologists draw storm warnings could mean we can better dynamically route the UAVs
  - Potential to look at typical paths Tornadoes take and other patterns in the weather data
- Adjusting how the Dynamic UAV Routing works when no damage is uncovered at a waypoint
  - I.e. travel to the next possible waypoint with damage rather than returning to the north-south pattern

Thank You!



NWS Chat; May 20, 2013
Map of Tornado Warnings relevant to the Newcastle-Moore Tornado on May 20, 2013
Legend
>EF0 Damage
>EF2 Damage
>EF4 Damage
HAIL
Stanley Draper Lake
TORNADO
Forest Park
Spencer
Oklahoma City
Del City
Midwest City
Mustang
HAIL
HAIL
HAIL
Moore
Stanley Draper Lake
NW-32nd-St
H. E. Bailey Turnpike
S-Sooner-Rd
12th-Ave-NE
TORNADO
Newcastle
N-Council-Ave
Cleveland
Hall Park
Norman
S-Main-St
W Lindsey St
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