Fleets of UAVs for wildfire monitoring

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LAAS-CNRS

10/07/2018

The Fire-RS project

Provide fire responders an automated tool for wildfire remote monitoring.

Universidade Vigo

Design and construction of a communication CubeSat & deployment of ground fire sensors

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

Fixed-wing UAV deployment and operation

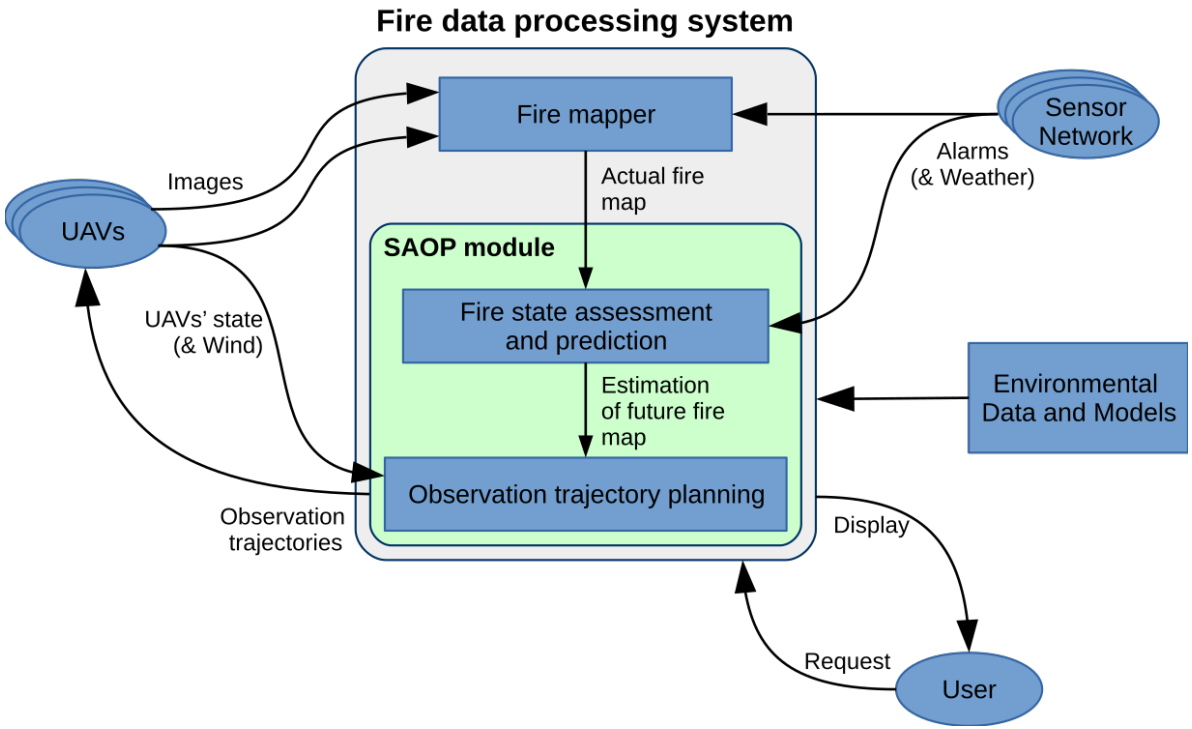
LAAS CNRS

Situation assessment and observation planning (SAOP)

Situation Assessment and Observation Planning

An active perception machine:

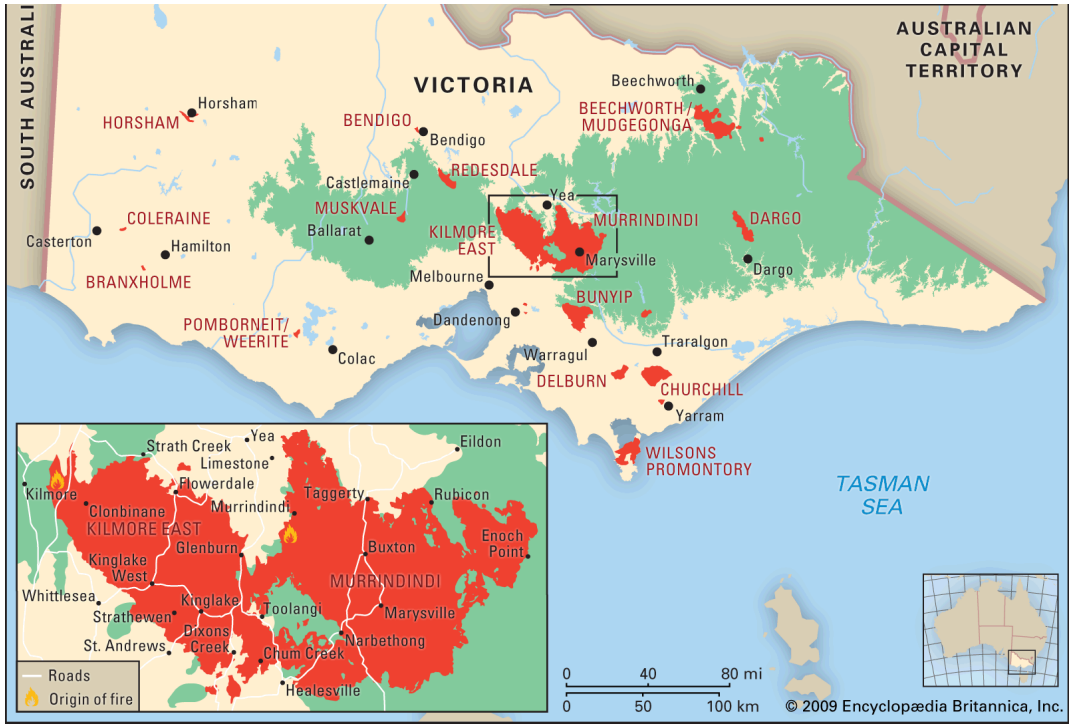
- Build a map of the observed phenomenon
- Plan observations for a fleet of UAVs.



Very brief introduction to wildfires

- Wildland areas
- Often concomitant
- Size: Up to 1000 km^2
- Propagation speed:

  Typically from 1 km/h to 10 km/h



- Propagation speed and direction is dynamic
  - Wind speed and direction
  - Terrain slope
  - Fuelbed

Wildfire propagation models

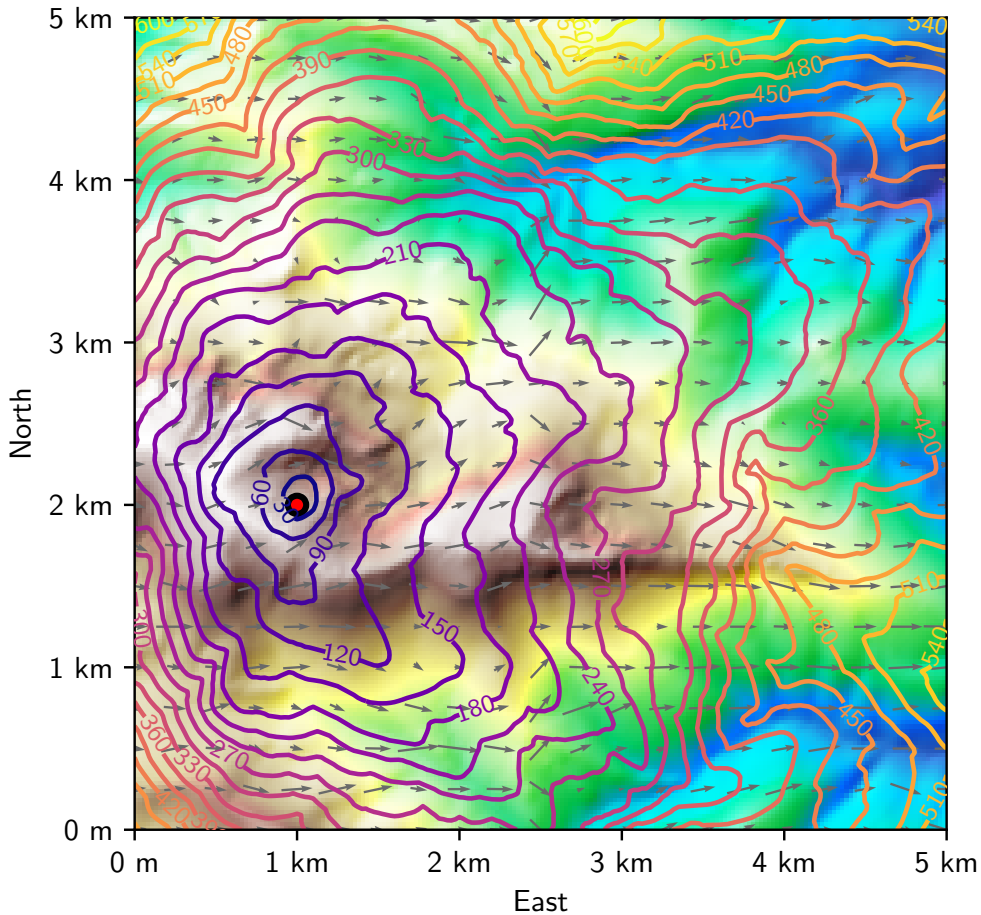
Inputs:

- Elevation map
- Fuel map
- Coarse wind forecast

Tools:

- Ground level wind simulation
- Wildfire simulator

Wildfire forecast



Fire mapping

Establish a relation between every pixel in a geo-tagged image and its corresponding location in the world

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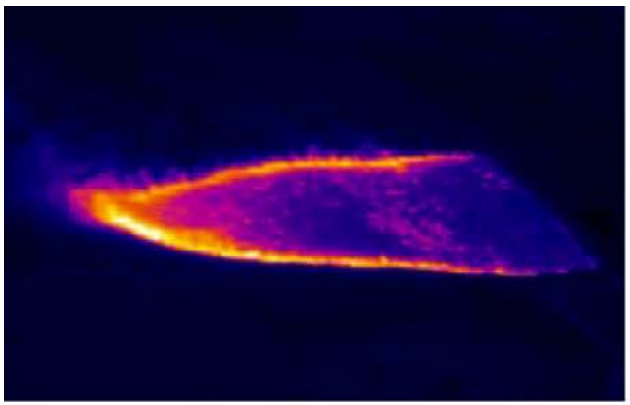
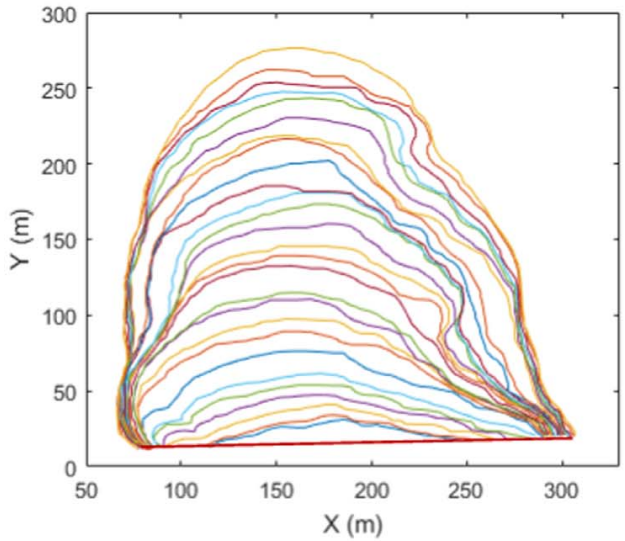
+ GPS position & elevation
+ Camera pose
+ Digital Terrain Map (DTM)

= Fire perimeter map





[Valero'17]

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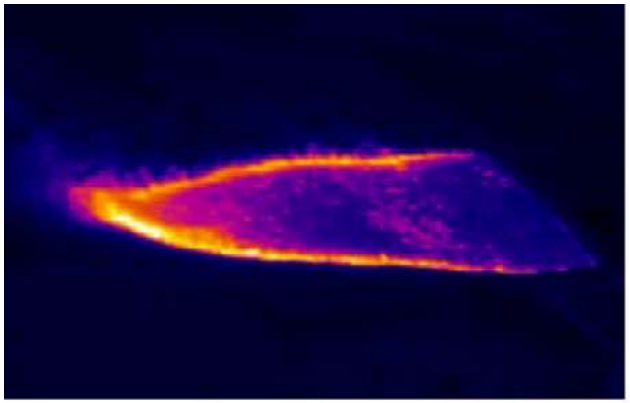
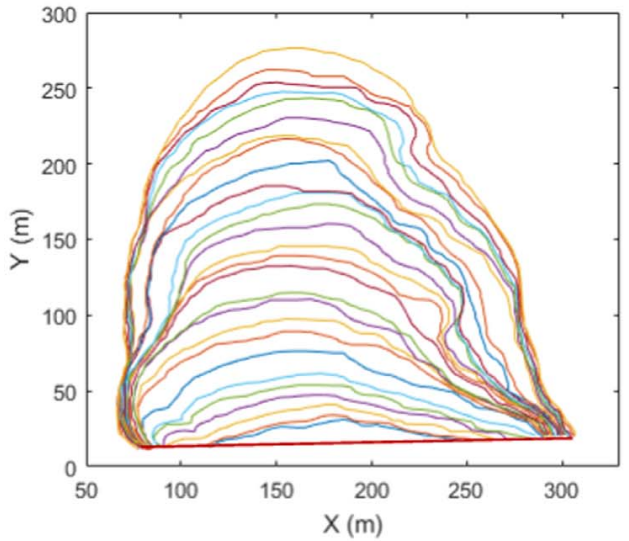
+ Data assimilation techniques
+ Evolution of the fire map
= Wildfire model parameters



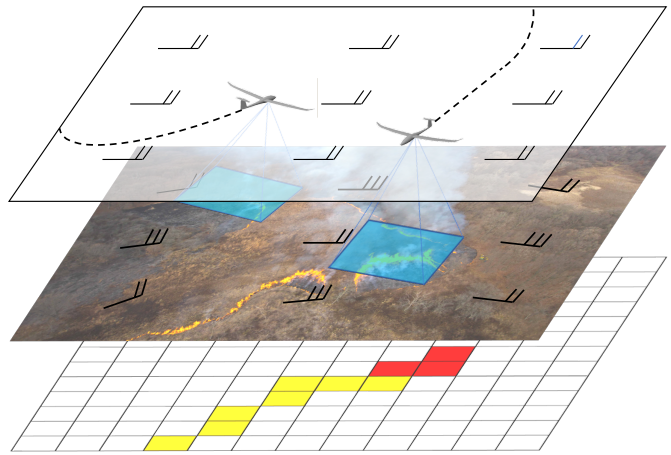


[Valero'17]

Observing wildfires: problem characteristics

Phenomenon:

- Wildfires are only observable at the fire front
- The fire front evolves with time $\rightarrow$ Observations have to be scheduled
- Highly combinatorial: Multiple UAVs $\times$ multiple fronts



UAVs: *motion and time of flight constraints*

- Round-trip
- Mountainous regions: 3D motion
- Wind drives fire ... and UAVs

A fixed-wing motion model: 2D Dubins paths

The shortest path connecting two oriented points for a vehicle...

- moving forward $V > 0$
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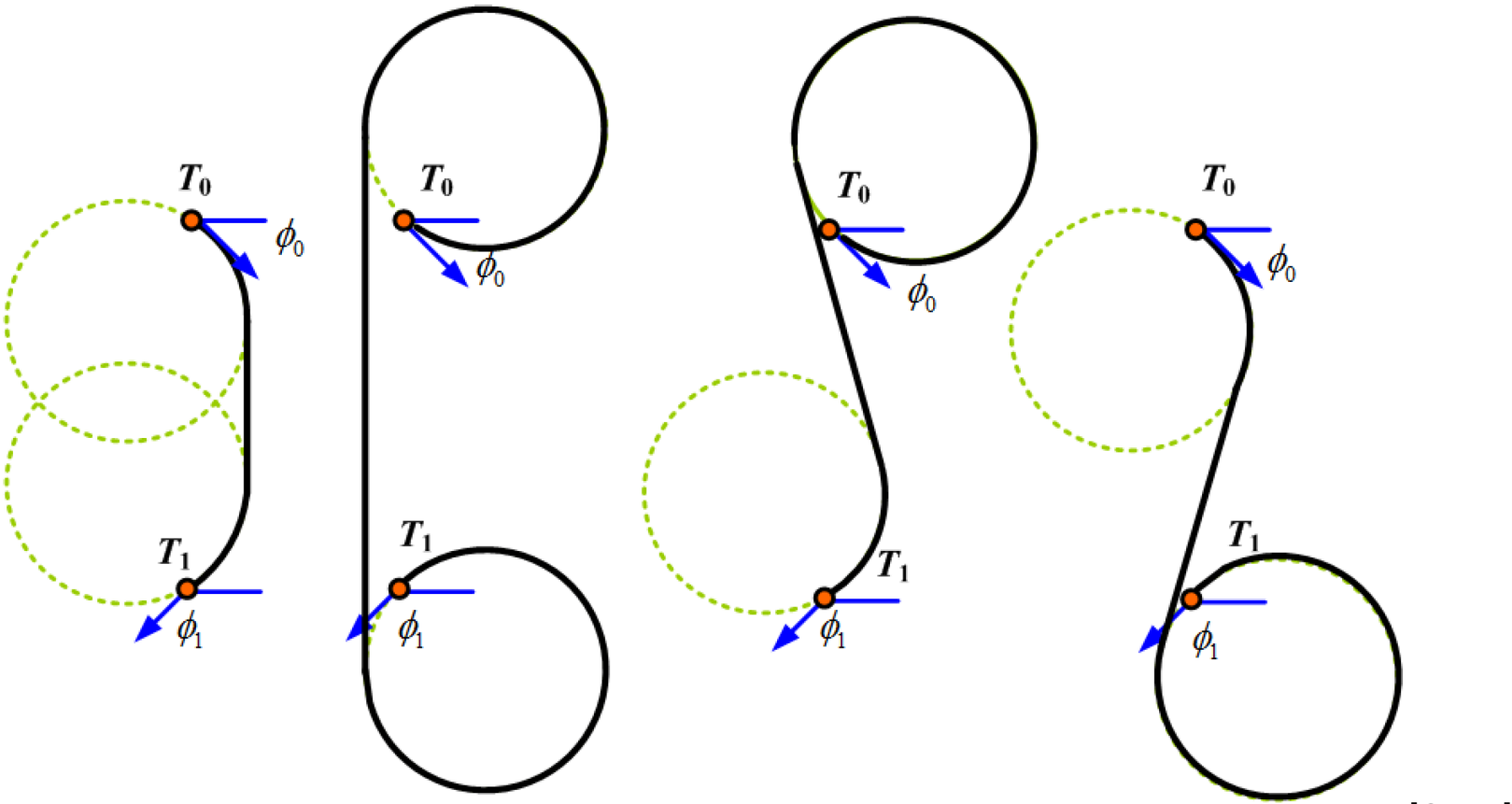
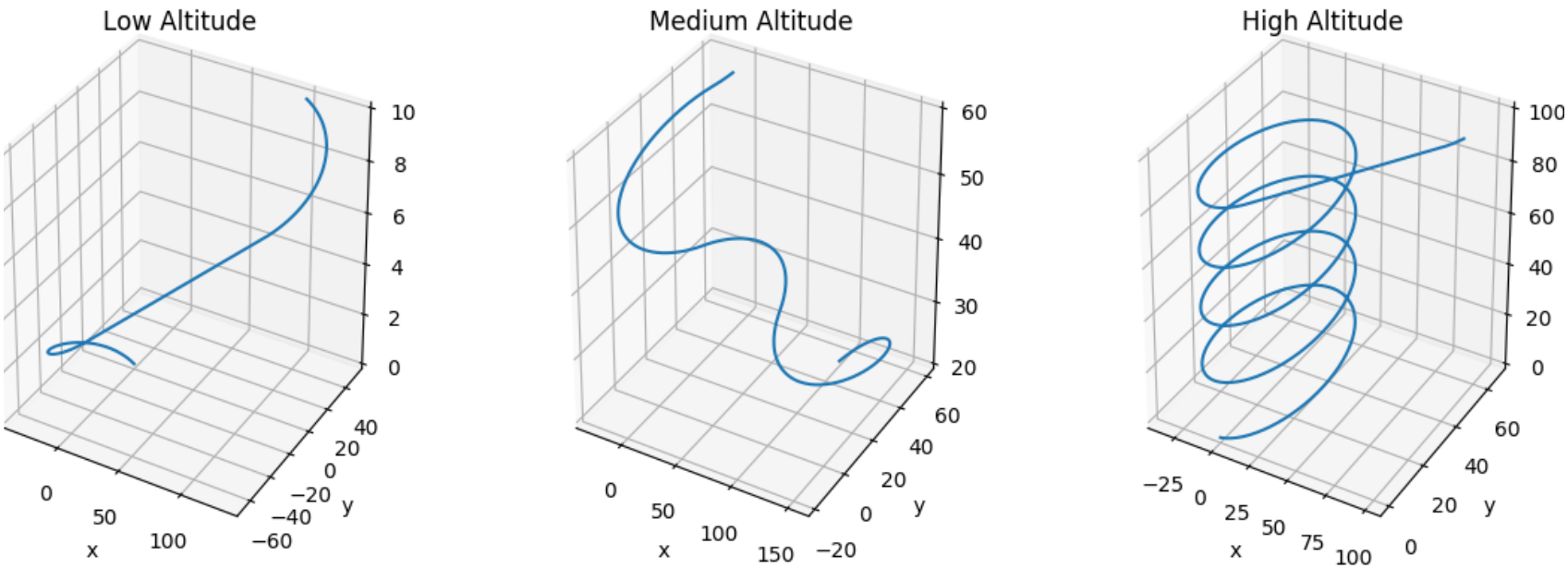


[Cai'17]

RSR LSL LSR RSL

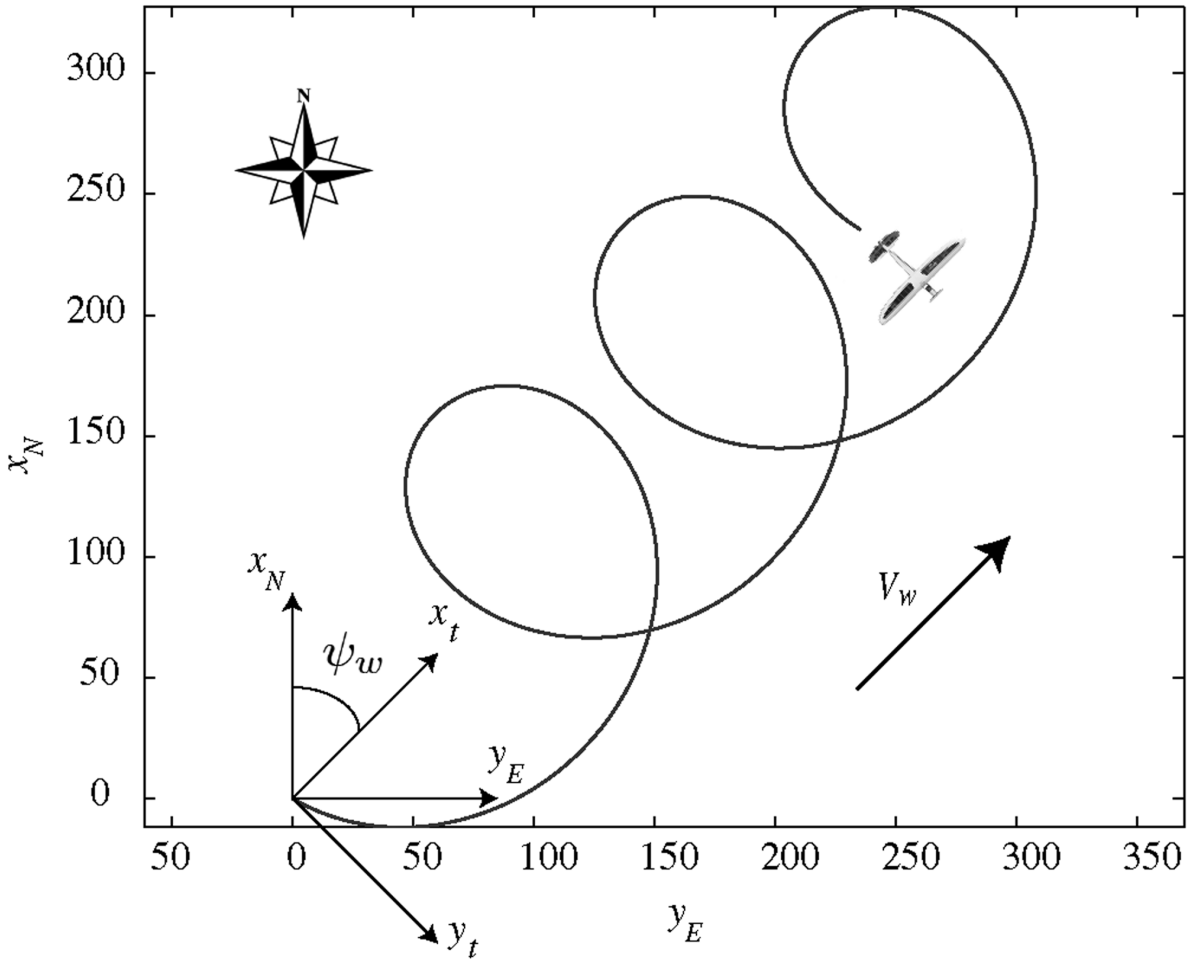
3D Dubins airplane paths

- Horizontal and vertical motions decoupled
- 3 types of paths depending on the destination altitude [Chitsaz'07]:
  - Low altitude: destination reached with $\gamma \leq |\bar{\gamma}|$
  - High altitude: Make helices with $\gamma = |\bar{\gamma}|$
  - Medium altitude: Extend the path length



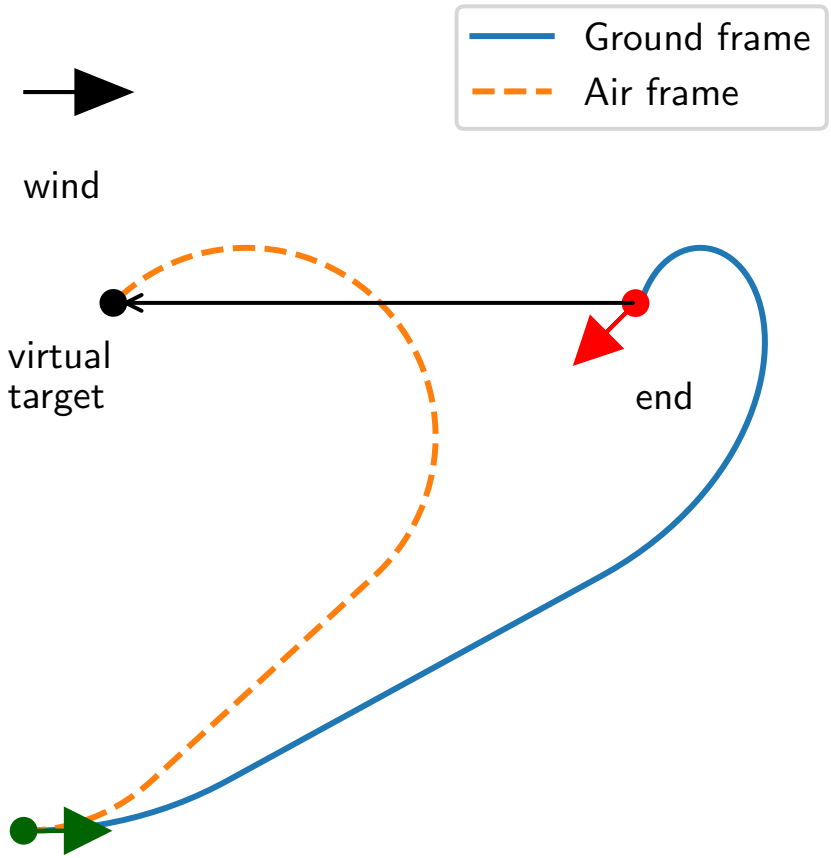
Airplane paths in windy conditions

- Dubins paths get distorted: Airspeed $\neq$ Ground speed



[Techy'09]

Dubins airplane with wind



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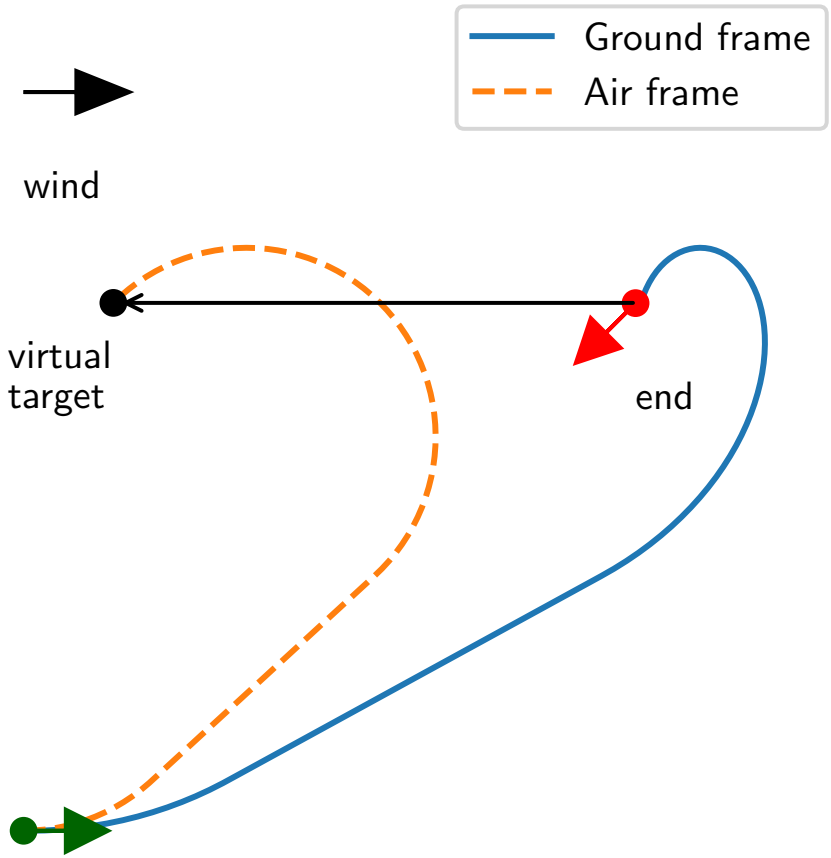

3D + wind ?

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The orienteering problem (OP)

- Extension of the traveling salesman problem (TSP)

In a graph, determine a subset of nodes to visit, and in which order, so that the total collected score is maximized and a given time budget is not exceeded
[Golden'87][Vansteenwegen'11]

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Numerous variations of the OP:

- Team orienteering Problem (TOP) [Chao'96]
- Team Orienteering Problem with Time Windows (TOPTW) [Montemanni'09]
- Dubins Orienteering Problem (DOP) [Penicka'17]

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Our problem encompasses all those extensions!

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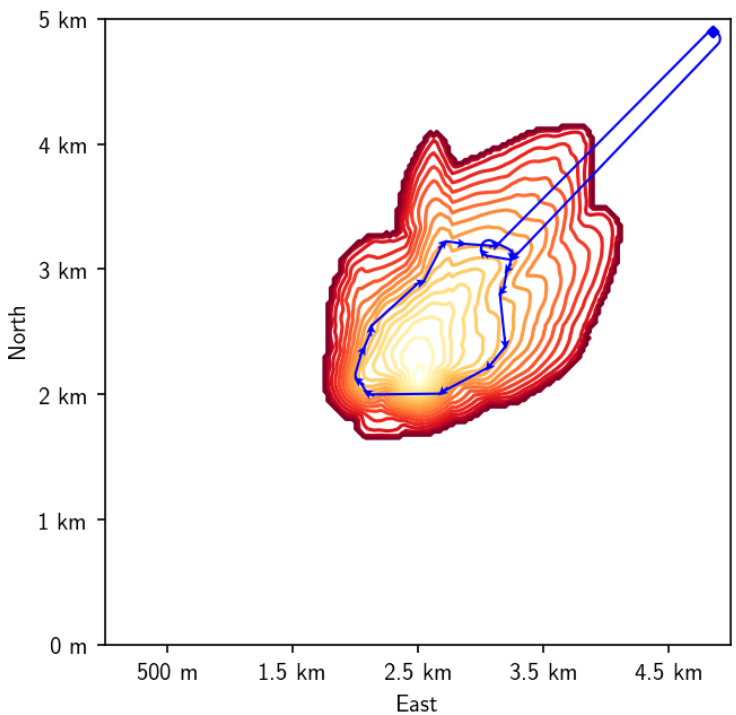
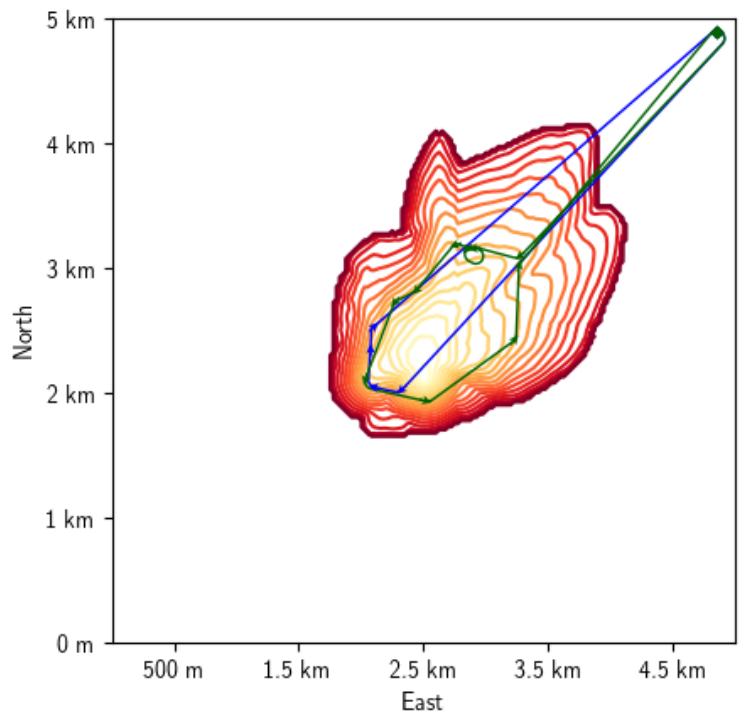
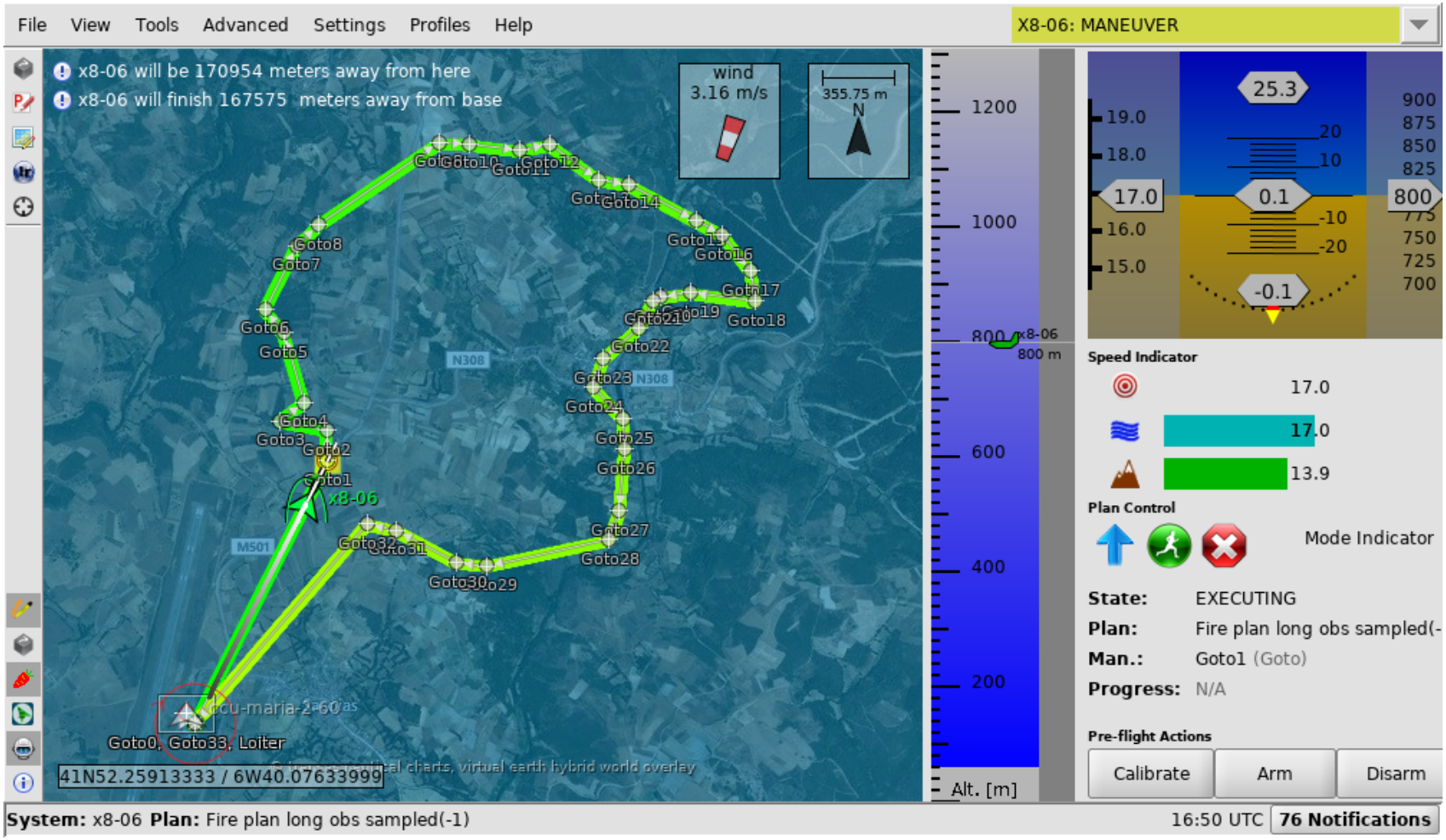
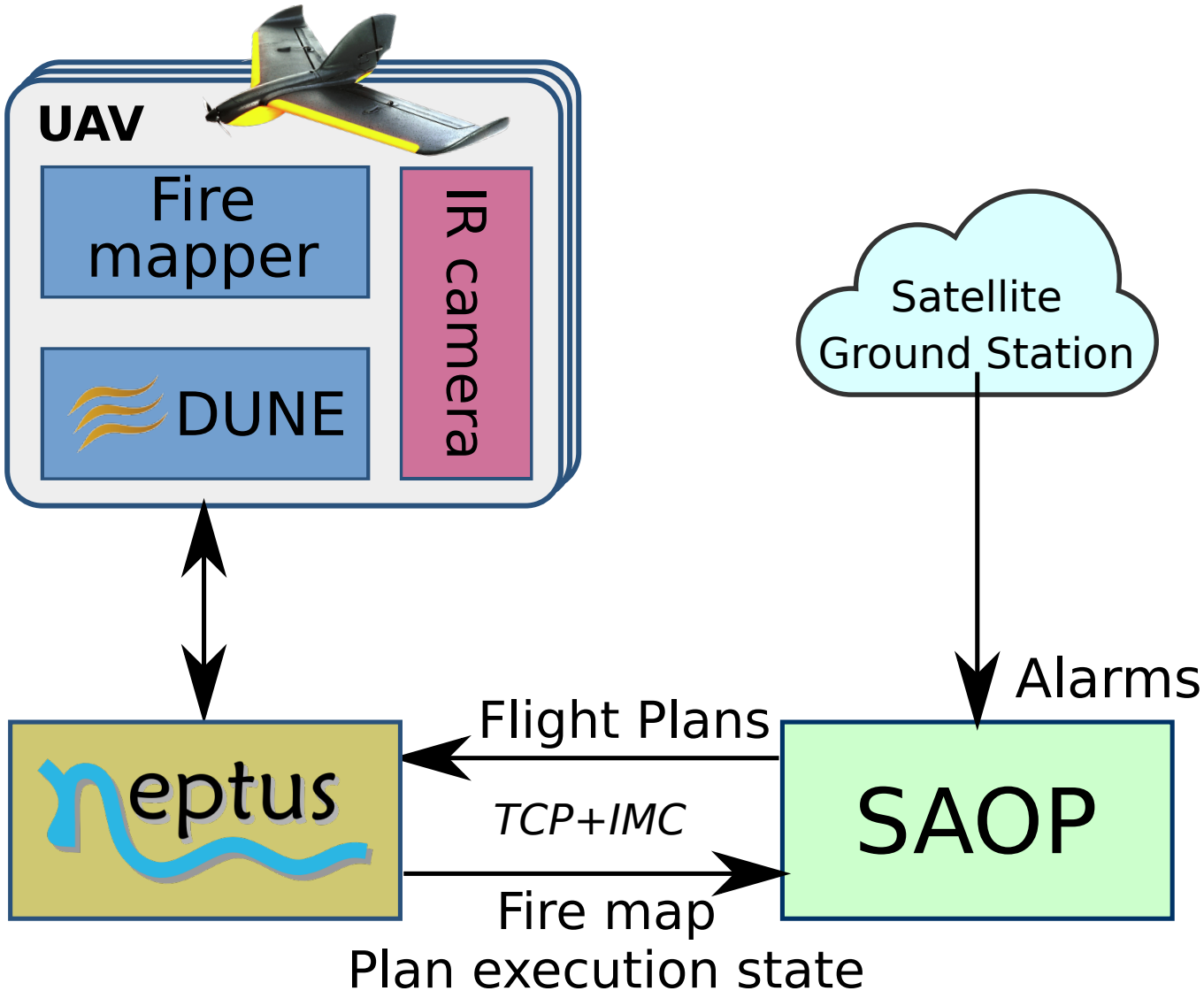




Plan execution



Integration of SAOP within Fire-RS



Upcoming work: "Fire front-driven" monitoring

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  - refining or repairing an invalid plan
- UAVs can do better than following a sequence of oriented waypoints
- Design a *"Follow fire front"* primitive:

  Give UAVs the ability of feedback on-board instead of relying solely on the global planner

Roundup

- Problem modeling:
  - Wildfire forecast
  - UAV motion models

- VNS-based observation planning

  Arthur Bit-Monnot, Rafael Bailon-Ruiz, Simon Lacroix. *A Local Search Approach to Observation Planning with Multiple UAVs*. International Conference on Automated Planning and Scheduling (ICAPS), Jun 2018, Delft, Netherlands. 9p., 2018. hal-01730655

- Plan execution