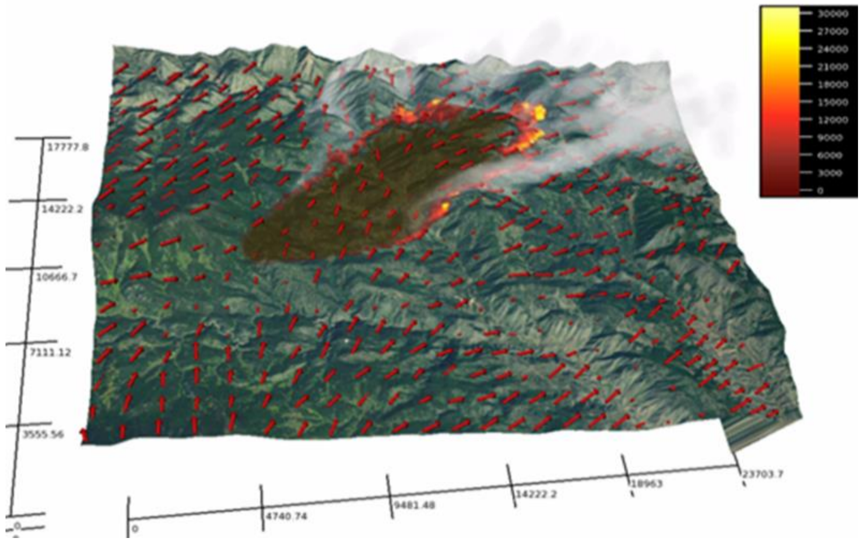
Coupled Weather and Wildland Fire Spread Model



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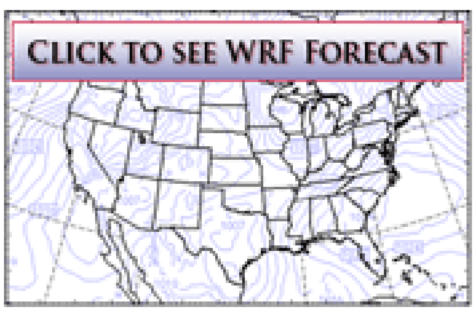
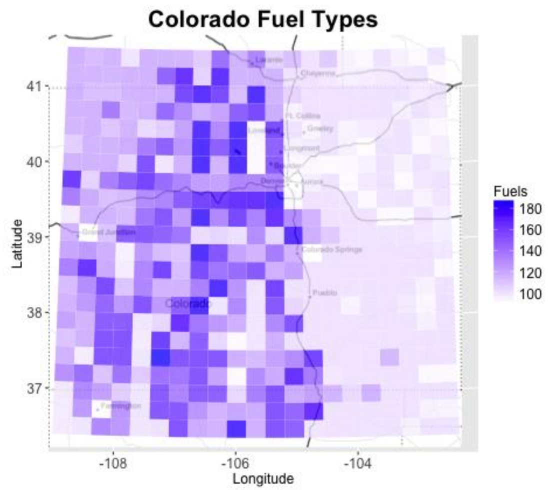
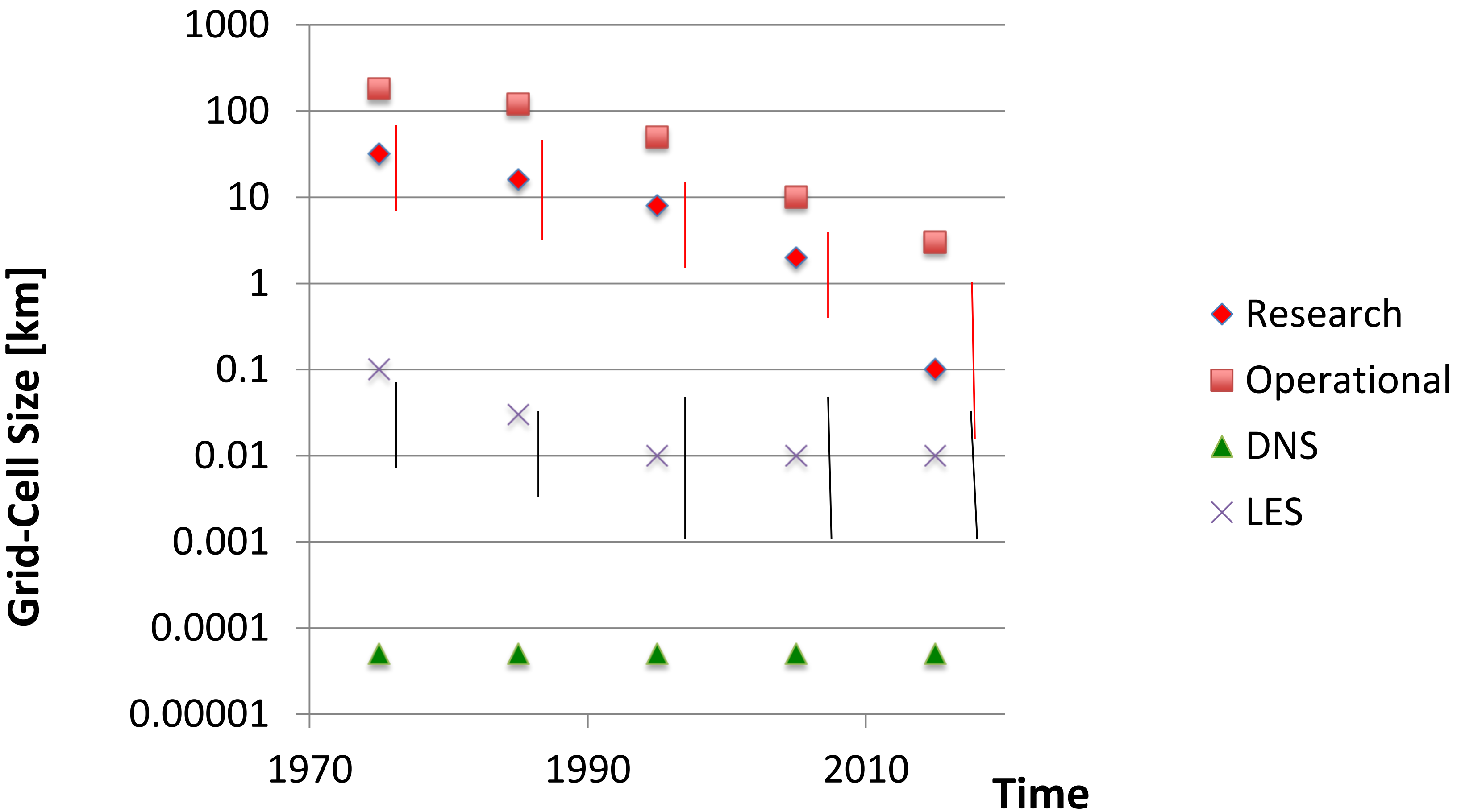
Why Operational Coupled Weather and Wildland Fire Spread Model Now?

- Models exist and they are already coupled
- Data are available
- Computational resources are available





Gap Between Grid-Cell Size in Mesoscale and Microscale Simulations is Diminishing



Multiscale simulations are now possible

Adapted from Wyngaard

The goal is to develop a fire behavior model coupled with a weather model

We are building on the open source, modular, numerical weather prediction (NWP) model the Weathere Research and Forecasting (WRF) model

- Unlike currently used fire spread models a coupled, NWP model accounts for atmospheric stability and physics and weather related events
- WRF includes multiscale modeling capabilities (from global to turbulence resolving)
- WRF has been used to a wide range of applications, dispersion, wind energy applications, solar forecasting, hydrological modeling, etc.
- WRF is widely used for weather forecasting

Coupled model enables simulation of fire weather phenomena

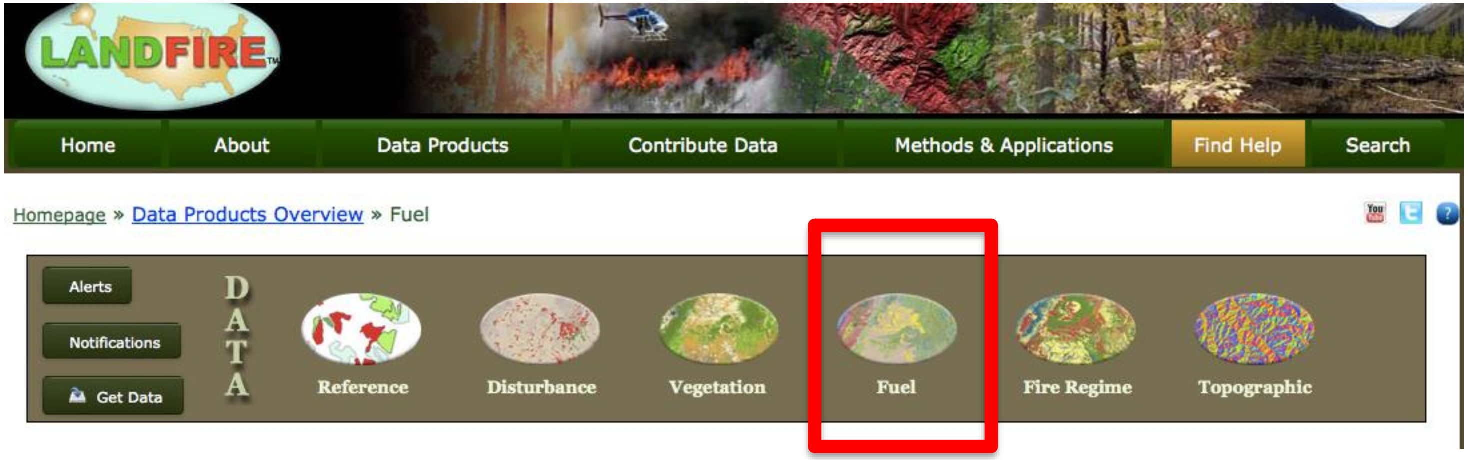
The wind (i.e. atmosphere) affects the rate of spread and direction of fire as well as fuel moisture (which determines weather and how intensely a fire burns).

Burning fuel and releases heat and water vapor into the atmosphere, causing updrafts and changing the winds

Coupled Wildland Fire Spread and Weather Model

- Coupled atmosphere wildland fire spread model is based on the WFR model and elements of NCAR's Coupled Atmosphere Wind and Fire Environment Model (CAWFE®) included in WRF-Fire model
- Surface fire spread model parameterized using Rothermel (1972) model
- Fire and burn area perimeter modeled using a level set method
- Currently using Anderson (1982) fuel model
- Fuel burnout calibrated based on Albini et al. (1995)

WRF-Fire Uses LANDFIRE Fuel Data



Fuel parameters required by WRF-Fire are:

- Surface fuel load [kg/m^2]
- Fuel load decrease weighting parameter [s]
- Surface area to volume ratio [1/m]
- Fuel depth [m]
- Fuel moisture content of extinction
- Canopy fuel load [kg/m^2]
- Canopy fuel burnout time [s]

Fire Behavior Module Is Coupled With NWP Model

Fire behavior module tracks interface between burnt and non-burning regions or a fire front. Fire front is represented using a level set method.

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Rate of spread of flaming front is computed as function of fire-affected fuel, wind, and slope using Rothermel (1972) model (semi-empirical).

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Through heat, water vapor, and smoke that are released by the fire into lowest layers of atmospheric model, fire affects atmospheric flow.

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Surface fire heats and dries the canopy.
If the surface fire heat flux exceed the empirical threshold fire transitions into the canopy.

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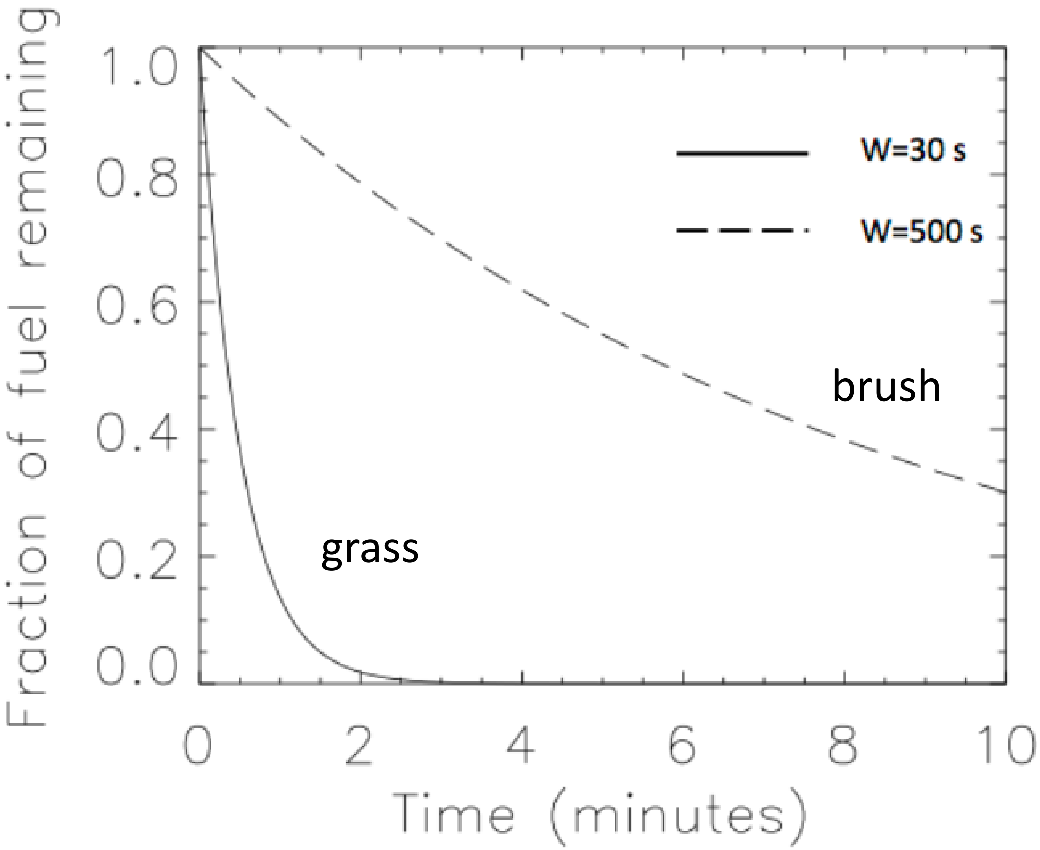
Rate of spread of the crown fire is calculated using empirical relationships to surface fire rate of spread.

Coupled Wildland Fire Spread and Weather Model

- Assimilated Multi Measurement Aircraft data (and VIIRS) for burn area perimeter and fire front data
- Optimized model performance for the operational implementation
- Fire and burn area perimeter modeled using an improved higher order level set method (5th order)
- Implementing Scott and Burgan (2005) fuel model
  - Fuel burnout calibration for Scott and Burgan model is not available for some fuel types
- Implementing more advanced crown fire model

Fuel Burnout Is Determined Empirically

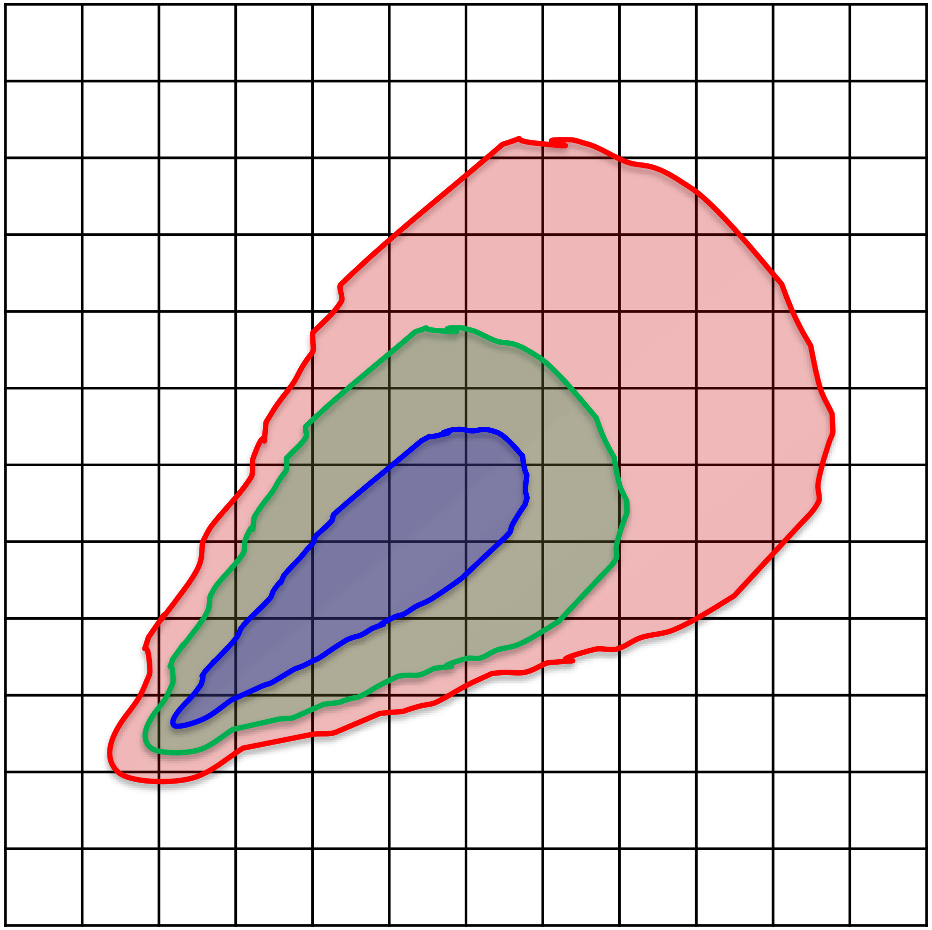


Fuel load decrease wighting parameter, W [s], was determined empirically by Albini (1995) for Anderson (1982) fuel model.

Developments of WRF/CAWFE fire model

Basics of the spread model

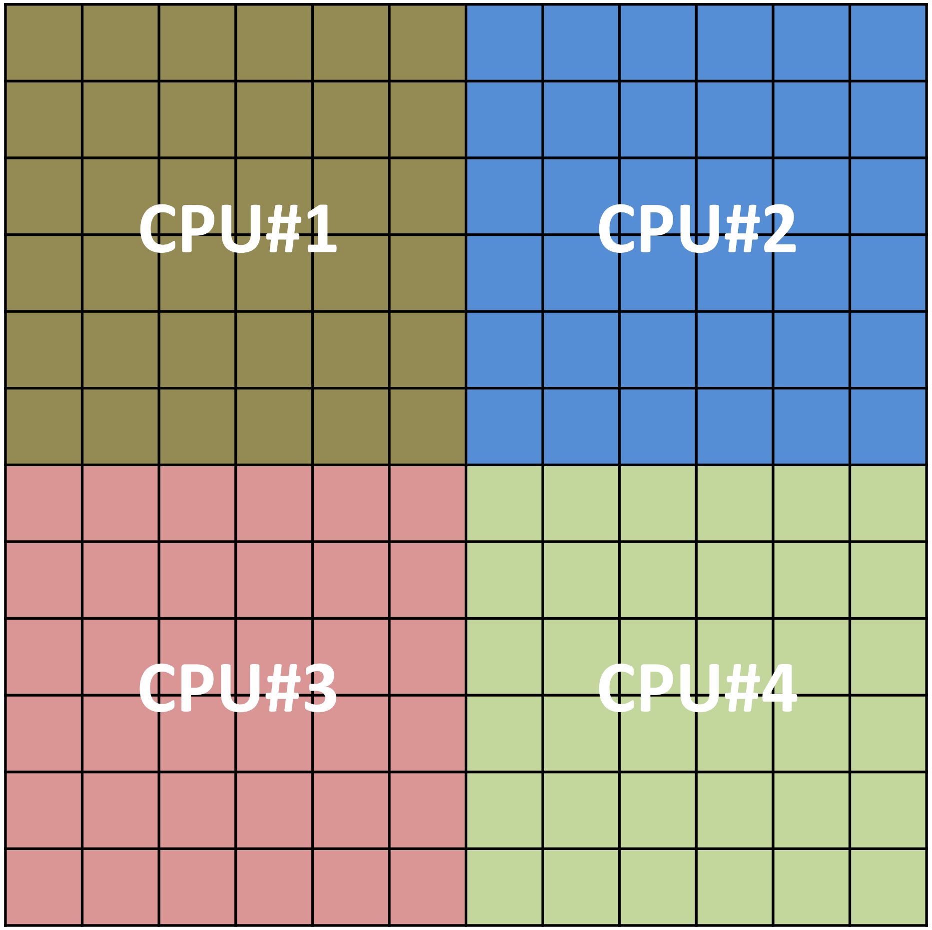
- Fire spread model is based on Rothermel 1972
- Rate of spread (ROS) calculated at each grid point and used to propagate fire line forward in time
- This mathematically done using the 'level-set method'



Developments of WRF/CAWFE fire model

<u>Parallel computing</u>

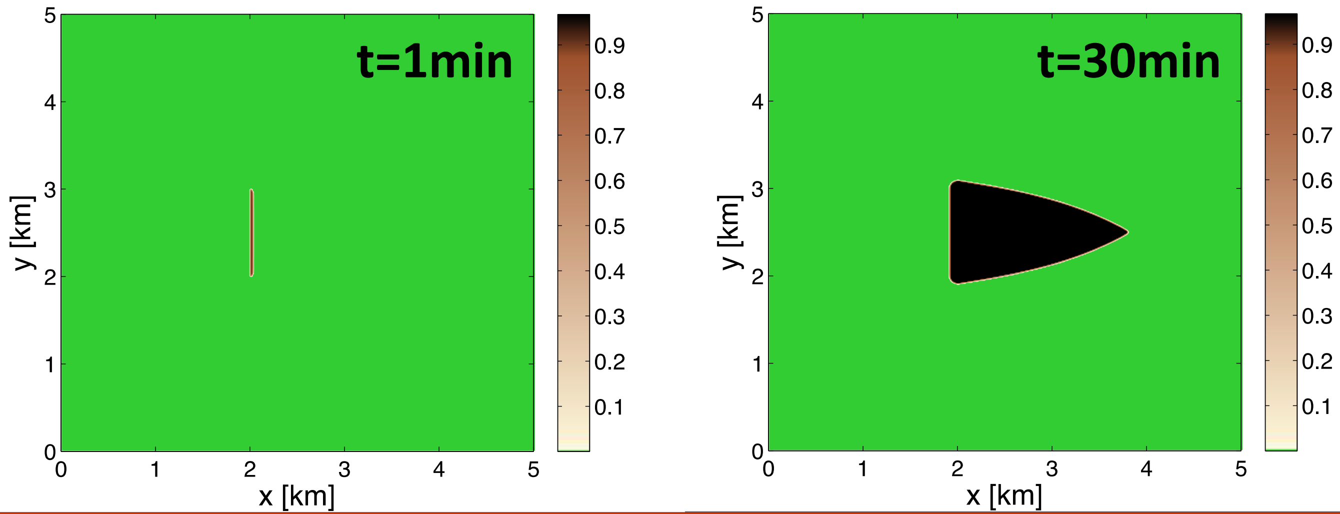
- Code rewritten to take maximum advantage of parallel computing
- Redundant calculations removed
- Increase in speed of the model -> the model runs faster



Developments of WRF/CAWFE fire model

Solution convergence (I)

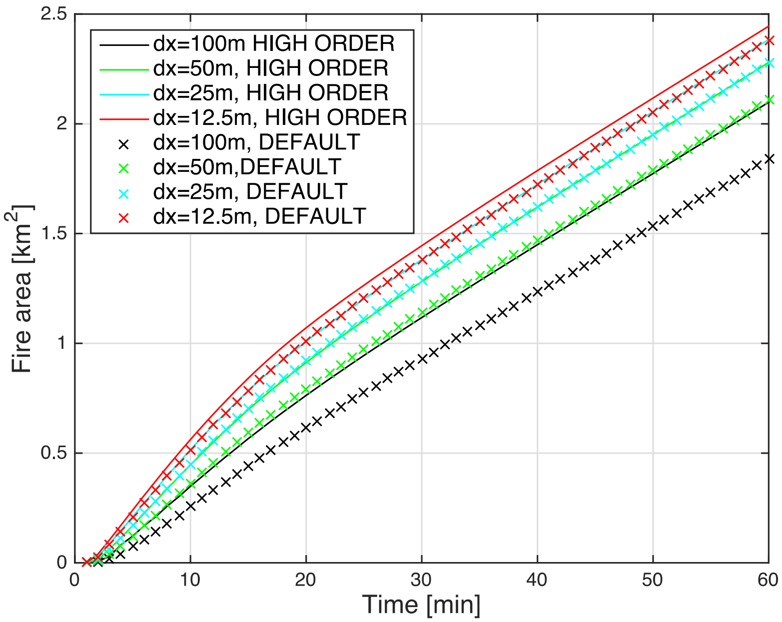
- We need to discretize the level-set equation
- How much do we need to refine the grid to reach convergence on the fire propagation/perimeter?
  - "Idealized fire": uniform wind (U = 5 ms^{-1}), flat terrain, uniform fuel (short grass), no feedback to the atmosphere (uncoupled mode) [initial fire line of 1 km length]



Developments of WRF/CAWFE fire model

<u>Solution convergence (II)</u>

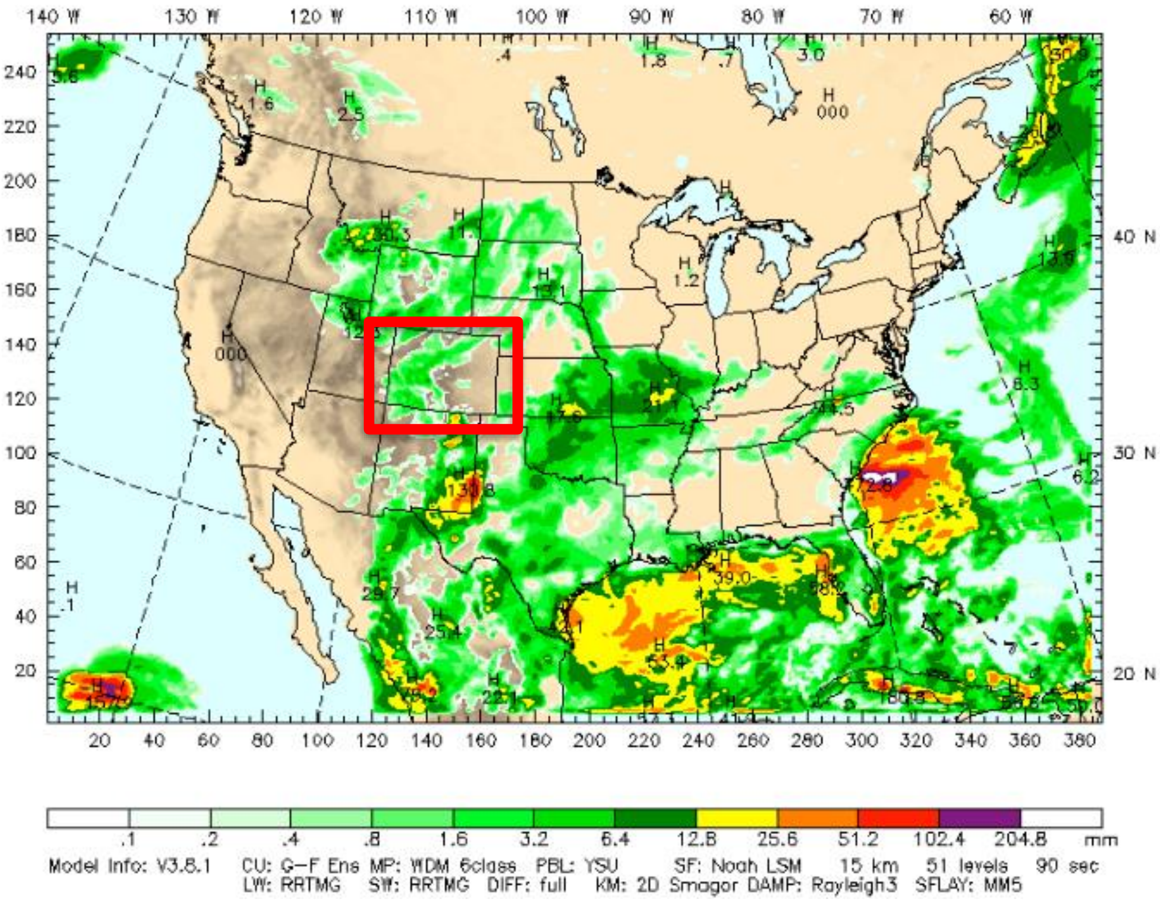
- We have implemented high-order (=more accurate) solutions for the fire propagation model and reinitialization of a level set function
- Using higher-order numerical schemes -> half the resolution is needed, 4 times faster



The goal is to develop an operational coupled atmosphere wildland fire spread model

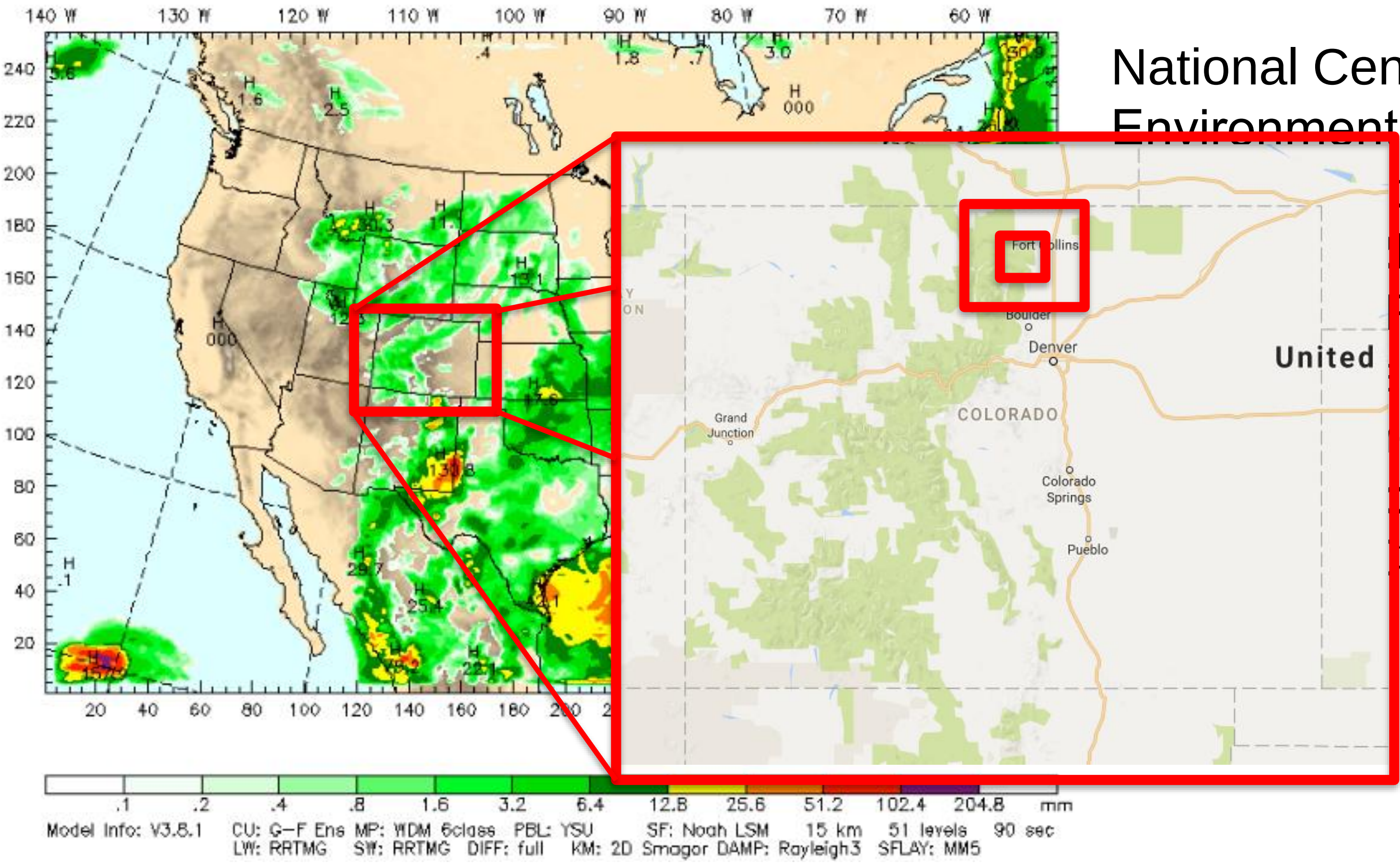
- Assimilate as much real-time, quality controlled data as available (meteorological variables, fuel types, fuel moisture content, etc.)
- Use as high-resolution simulations as possible to resolve flow, terrain, and fuel characteristics (at present large-eddy simulation at 110 m over 13 km x 13 km domain)
- Balance the speed and fidelity to produce useful, actionable information (18 h forecast in ~4 hours on 24 cores)
- Develop a nowcasting capability (3 h forecast in less than 10 min on 24 cores) using coarser simulations at 1 km over 117 km x 117 km domain

We are downscaling HRRR forecasting system output



National Center for Environmental Prediction's High Resolution Rapid Refresh (HRRR) model is based on WRF and covers CONUS. We use CAWFE® to downscale from HRRR output and focus on the area of interest (Colorado).

We are downscaling HRRR forecasting system output



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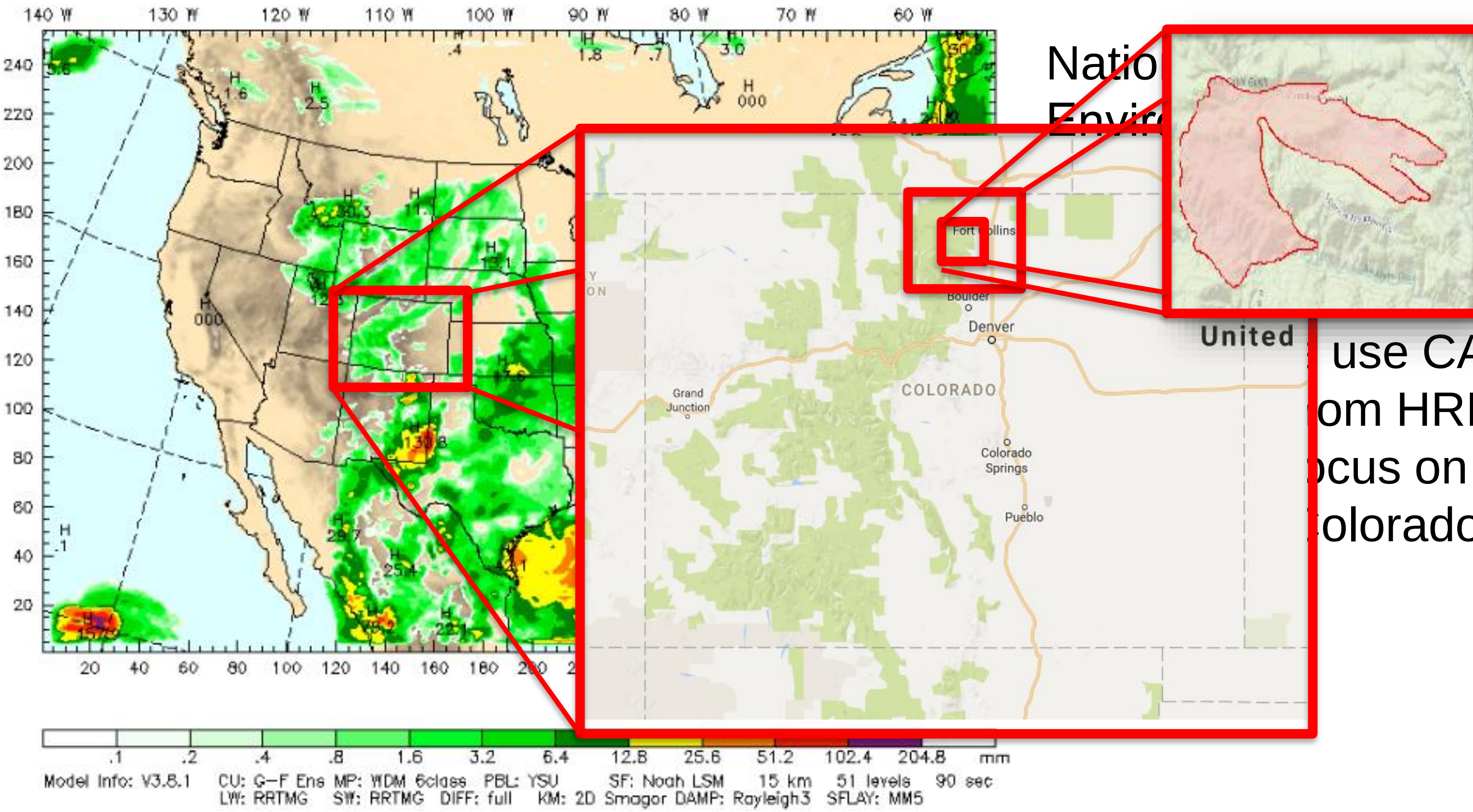

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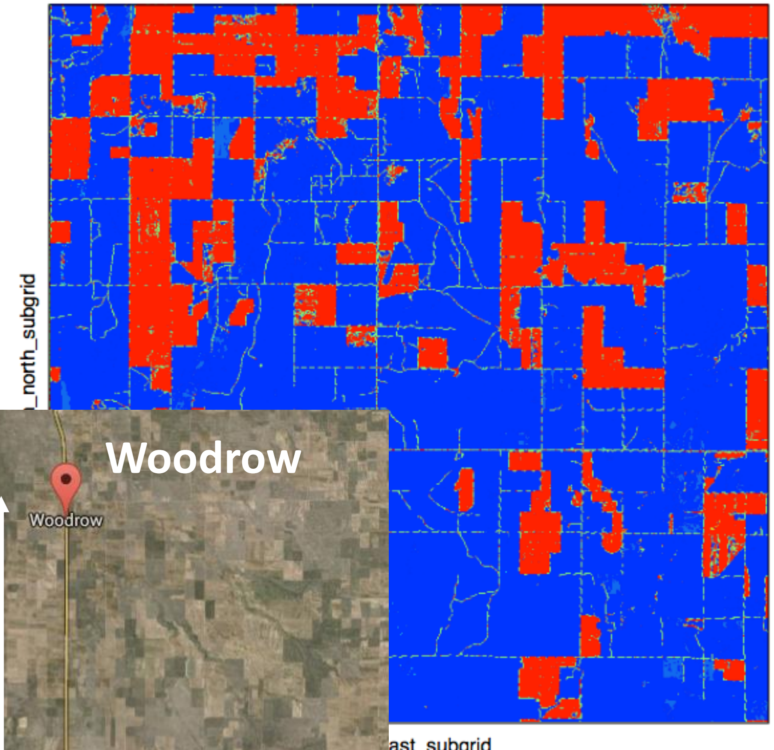
Last Chance, CO, Fire

- Grassland fire
- Fire started Monday, June 25, 2012, south of Last Chance, CO, Washington County
- Strong southerly winds
- 45,000 acres burned – second largest wildfire in Colorado in
- 11 structures burned, including four houses
- The fire was fully contained by Tuesday evening, June 26
- Cause of fire -sparks an automobile wheel following a tire blowout (Wikipedia)



Fuel:
Red – no fuel
Blue – grass

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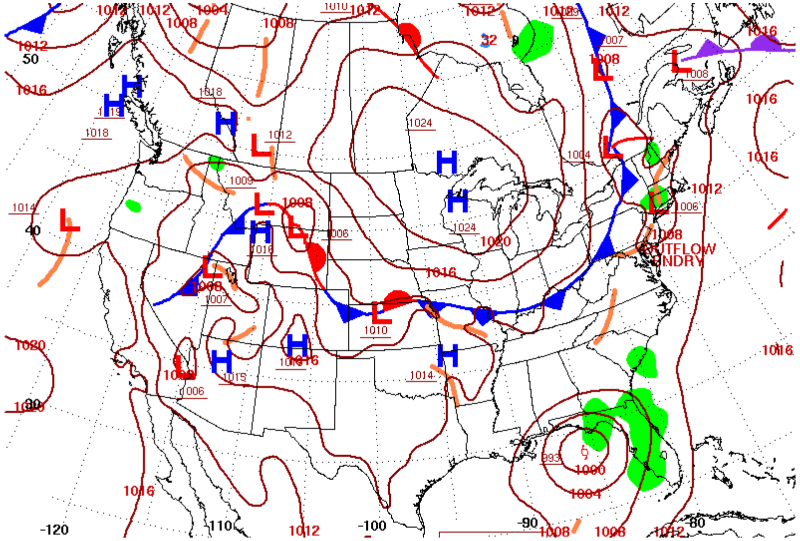
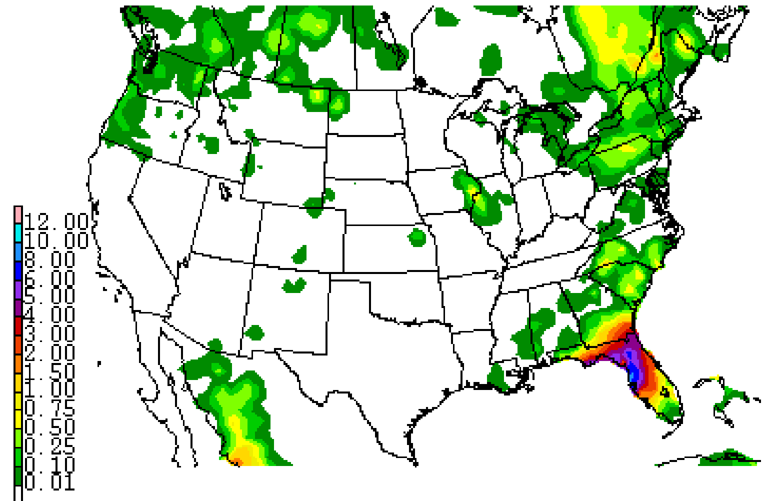
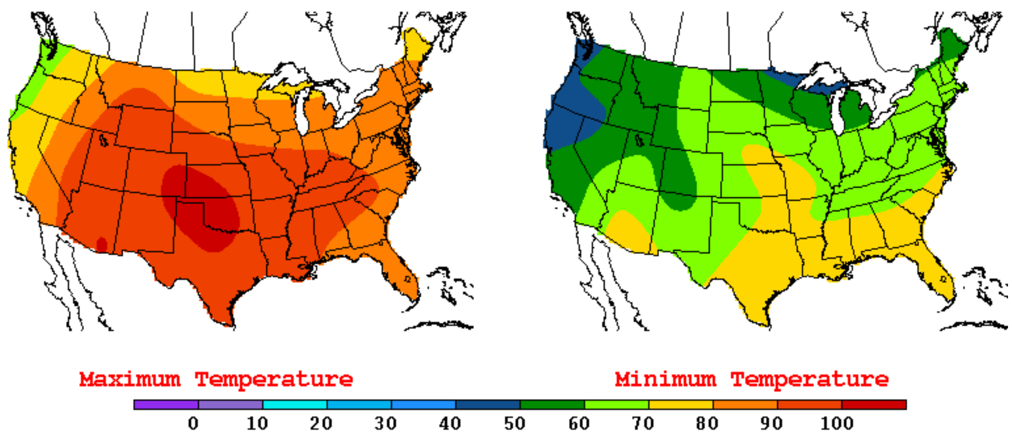


Surface Weather Map at 7:00 A.M. E.S.T.

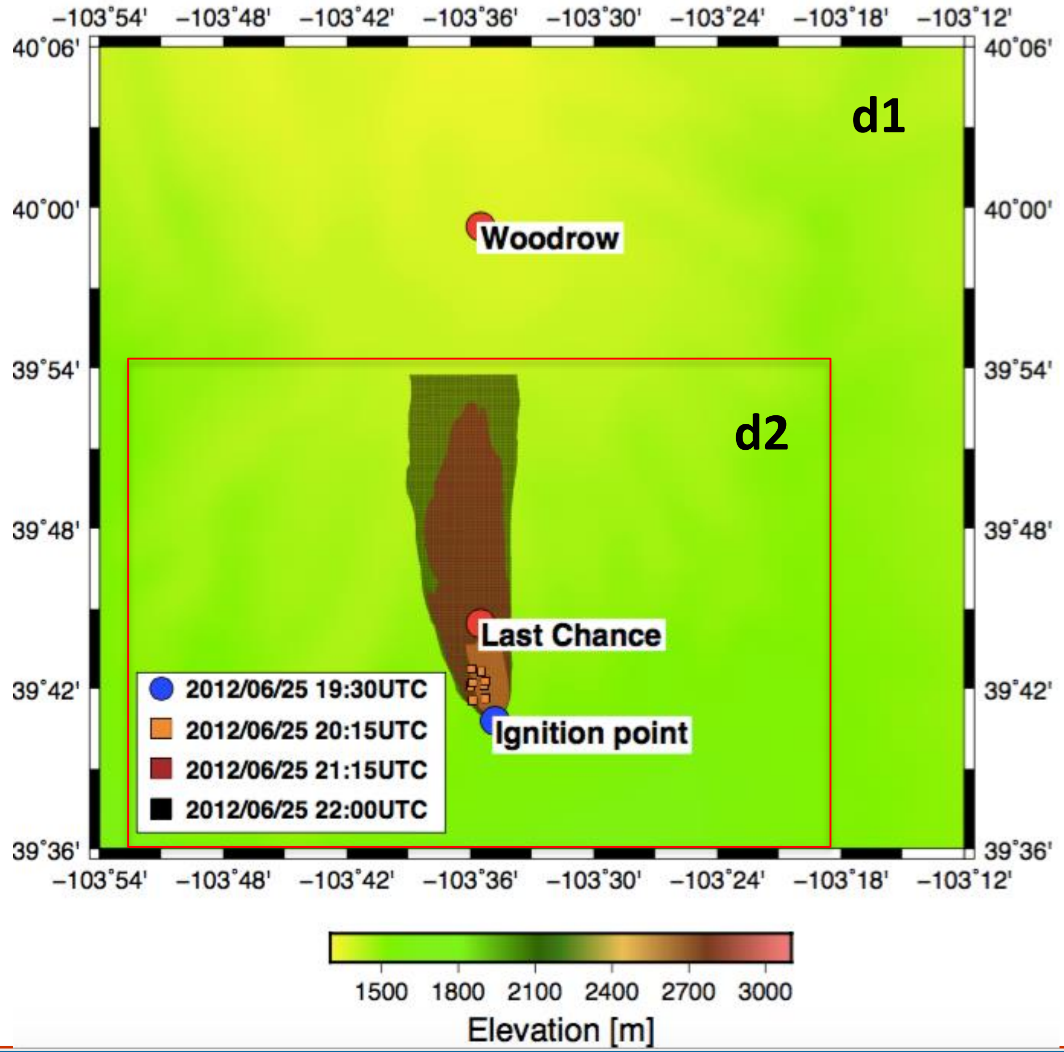


24-hr Precipitation (in.) Ending at 7:00 A.M. E.S.T.



Last Chance, CO, Fire

- d1 – 127 km x 127 km (1km grid cell)
- d2 – 28 km x 28 km (111m grid cell)
- Squares – VIIRS data
- Contours – CAWFE simulation



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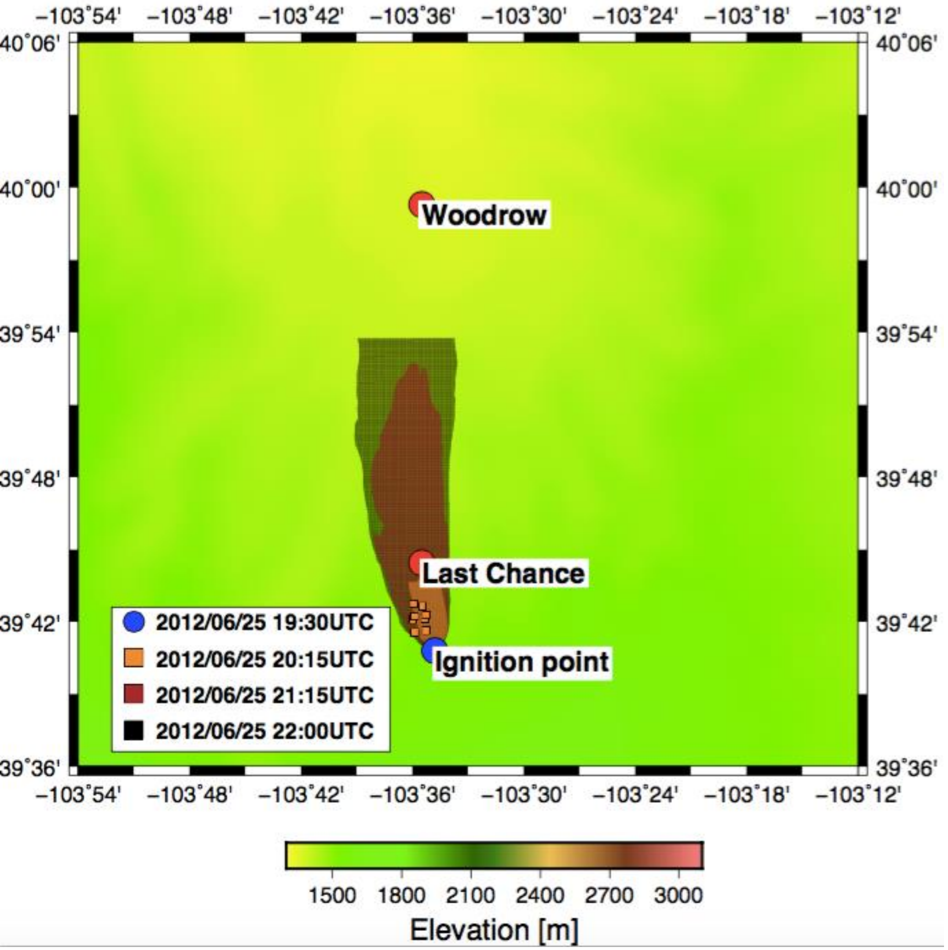

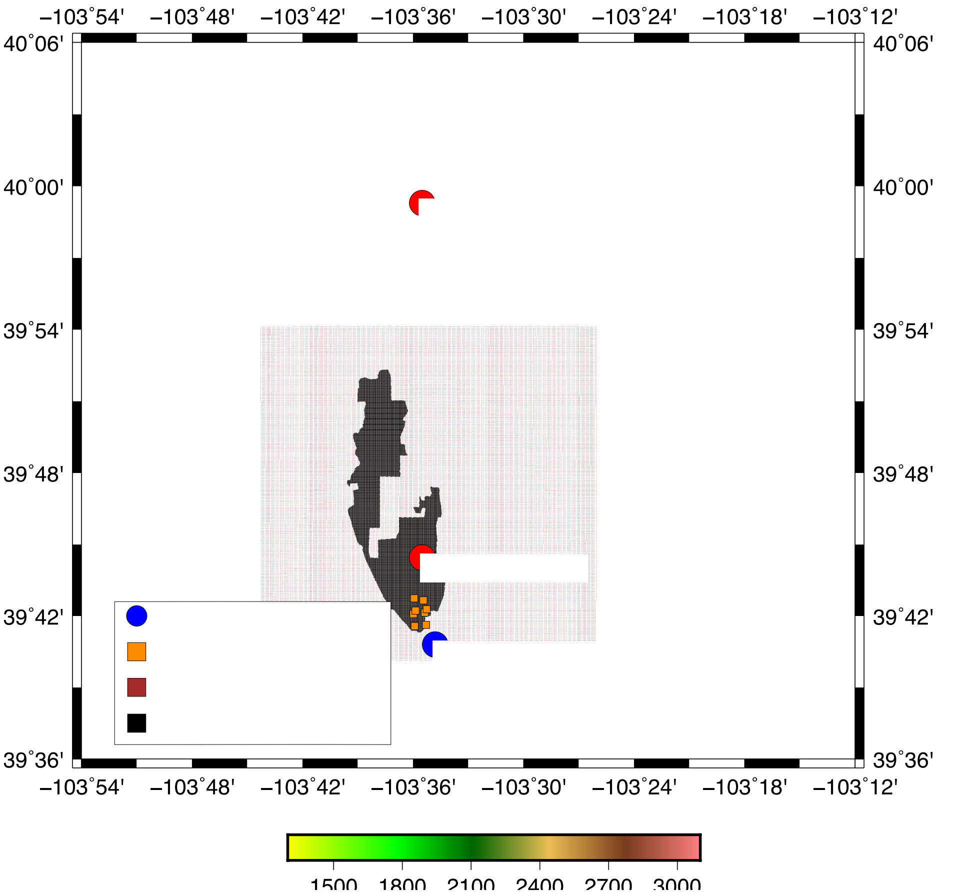

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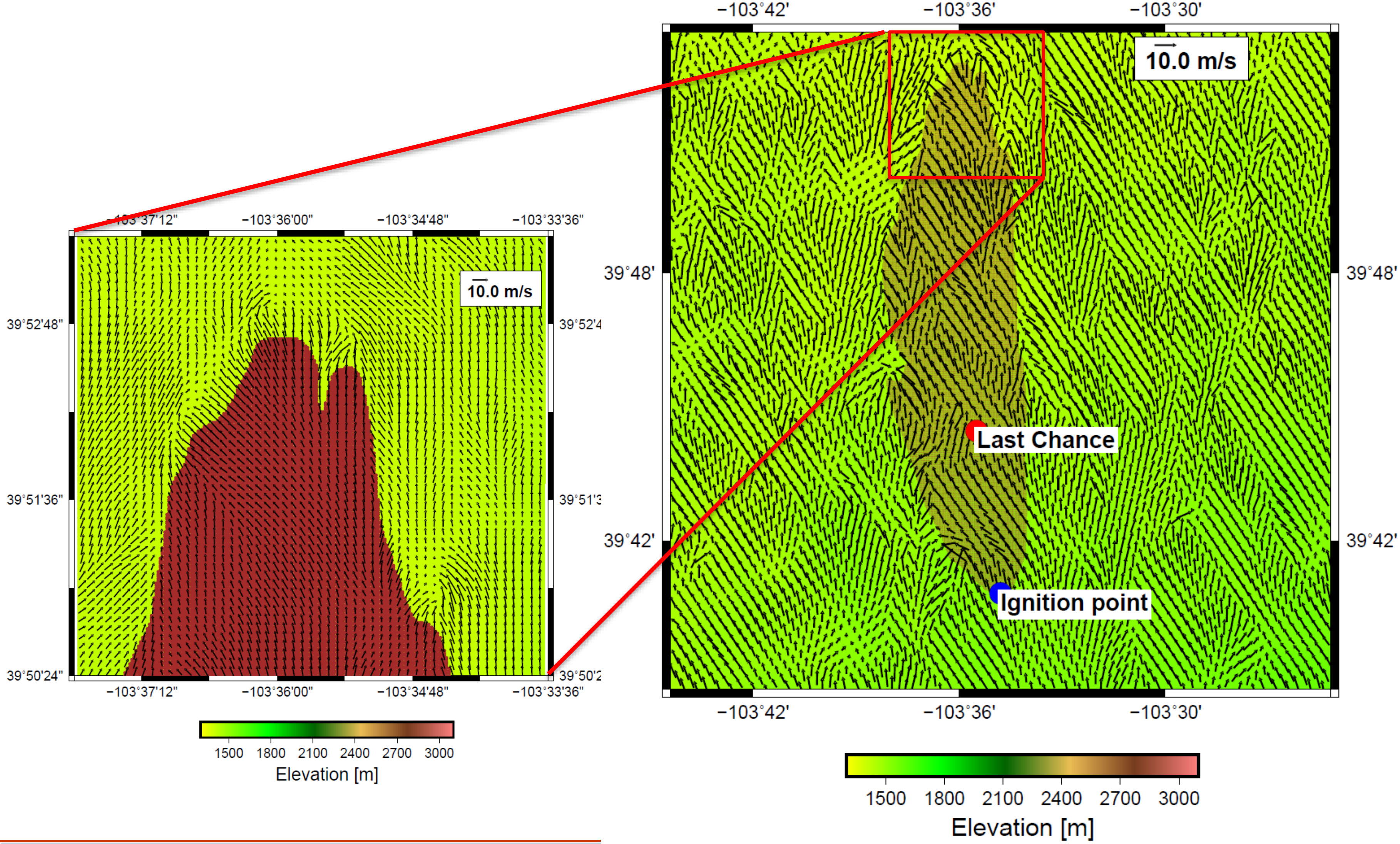
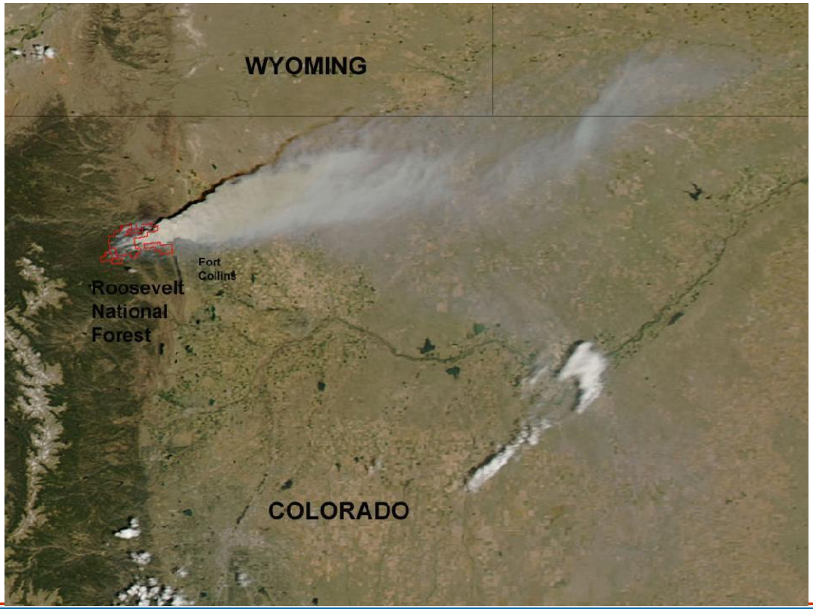


High Park, CO, Fire

- A wildfire in the mountains.
- Fire started Monday, June 9th, 2012, West of Fort Collins, CO, Larimer County.
- Southwesterly winds
- The hot and dry conditions (fire danger extreme) led to a rapid intensification of the fire.
- 87,000 acres burned – third largest wildfire in Colorado history by burned area.
- 259 homes burned.
- The fire was fully contained by June 30th.
- Caused by lightning.



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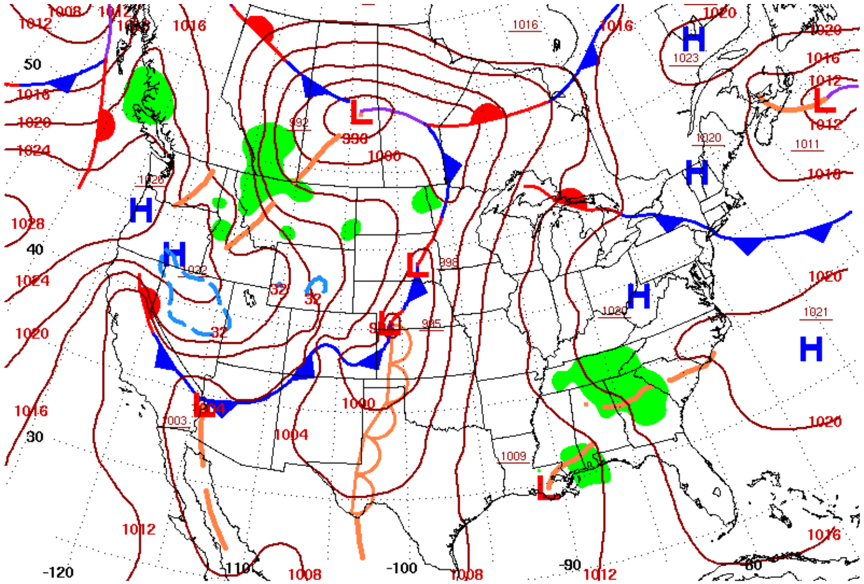

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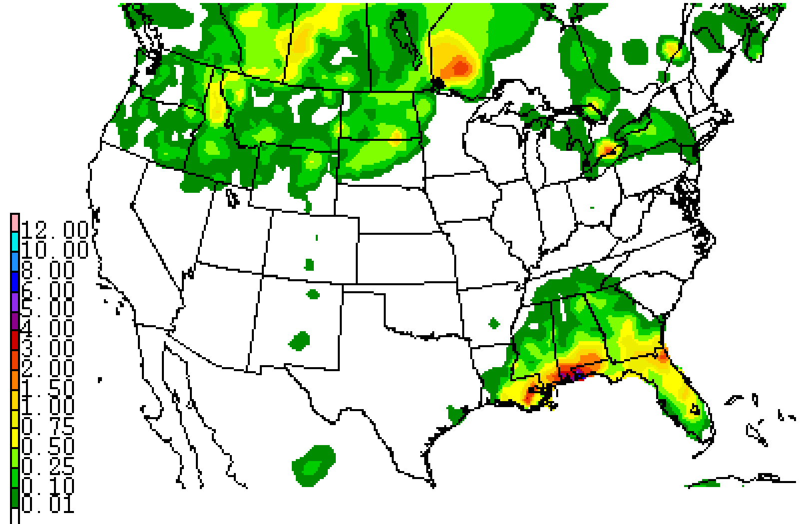

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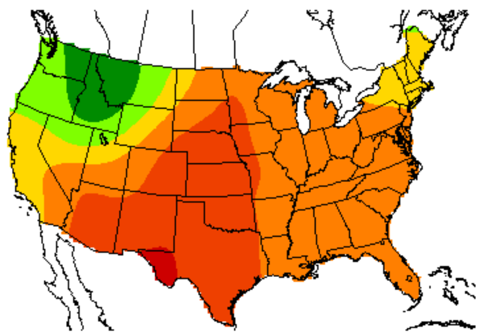
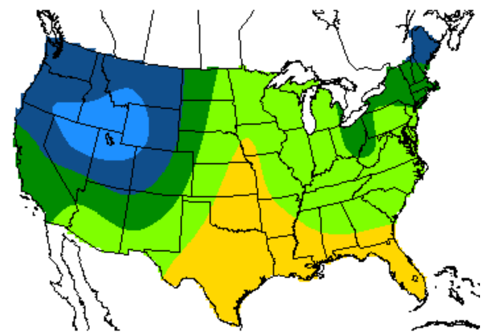
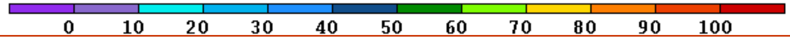




Maximum Temperature

Minimum Temperature



High Park, CO, Fire

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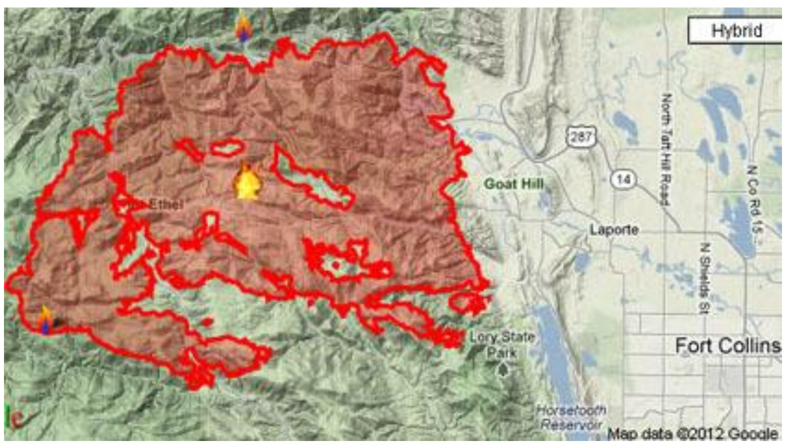
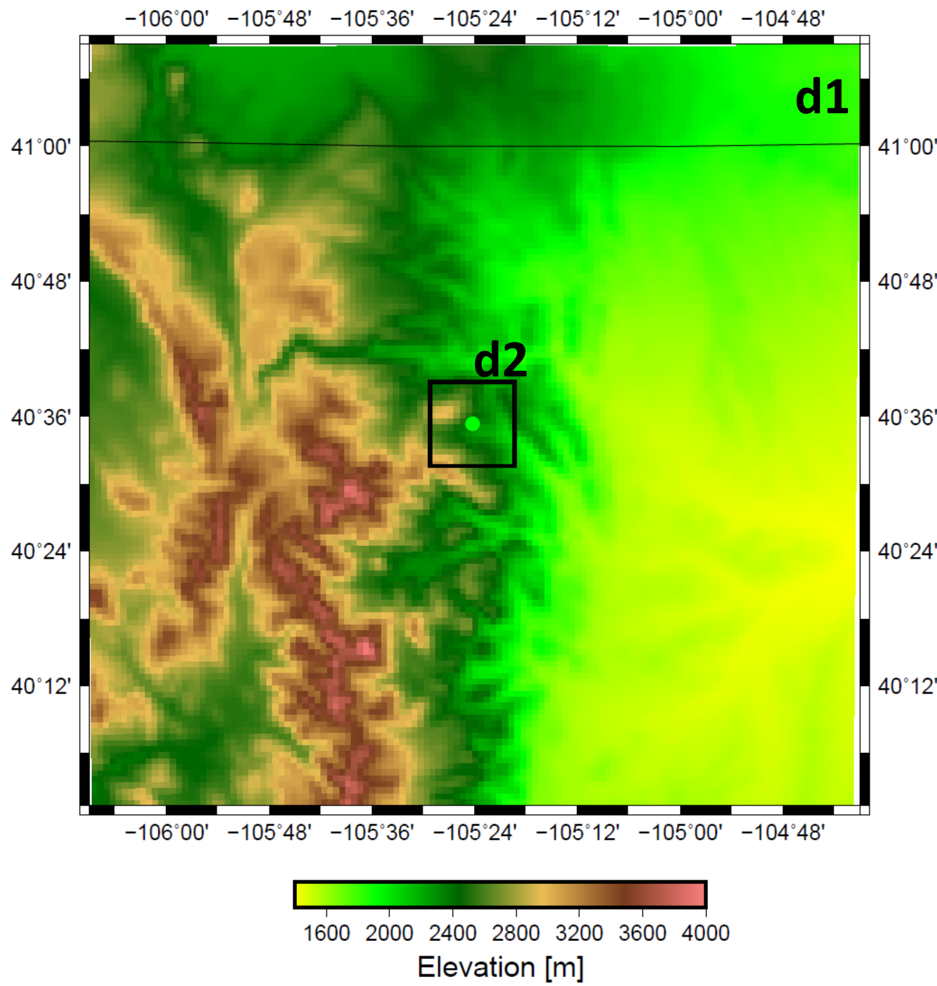
- d2 – 14 km x 14 km (111m grid cell)





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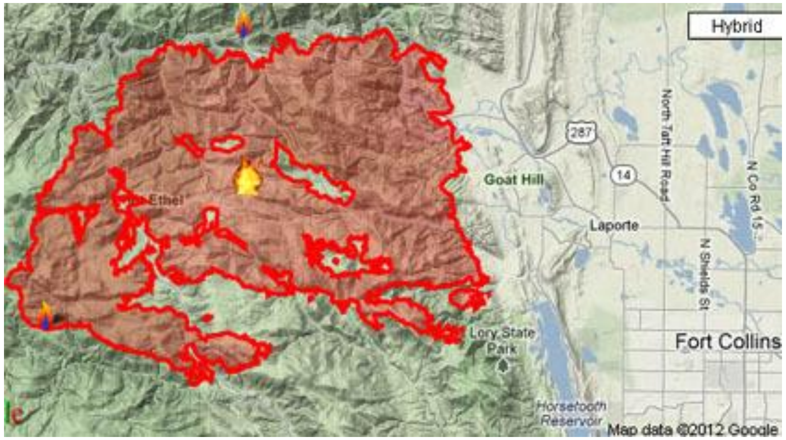

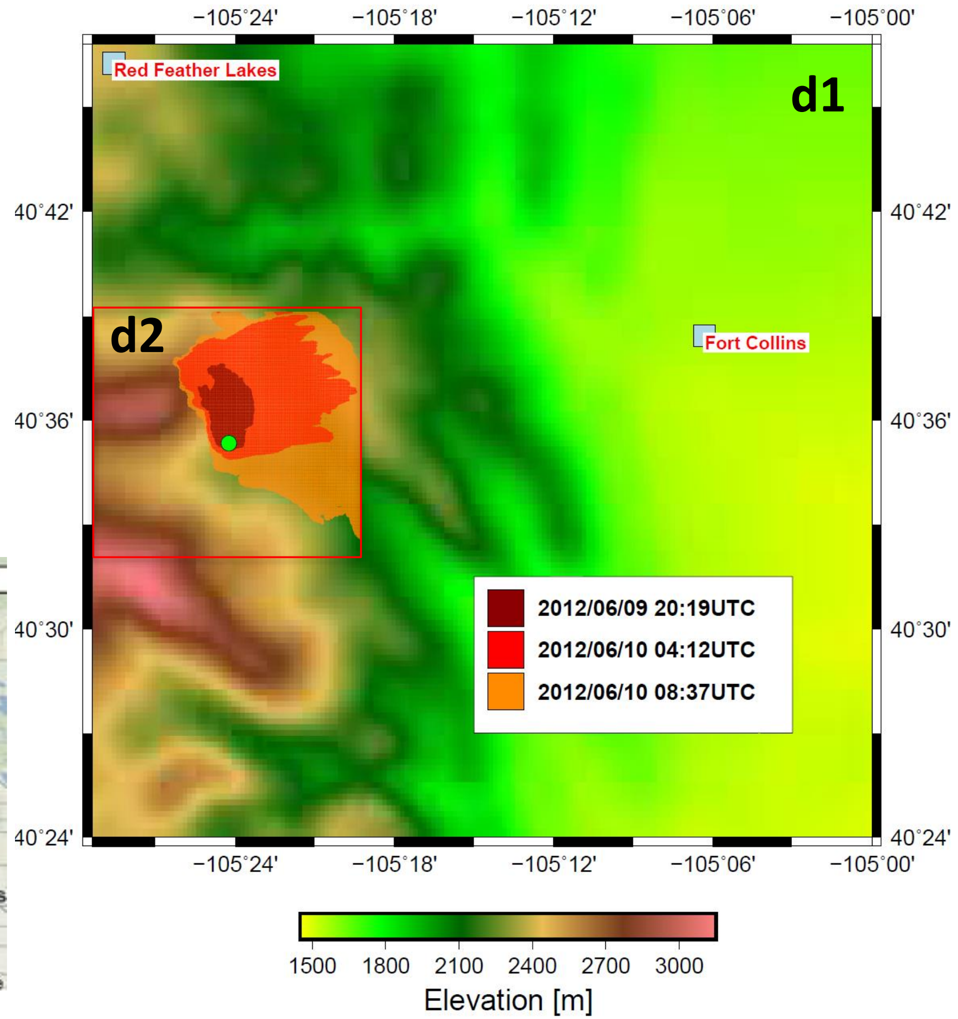

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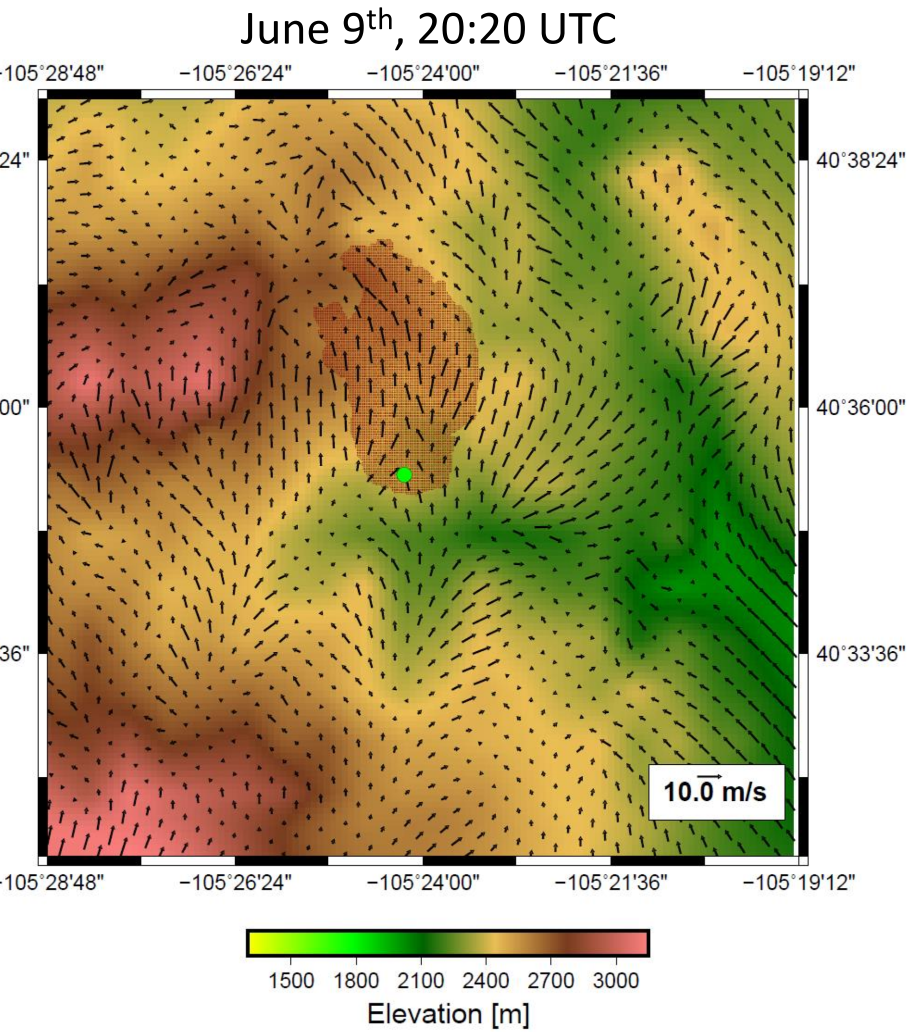
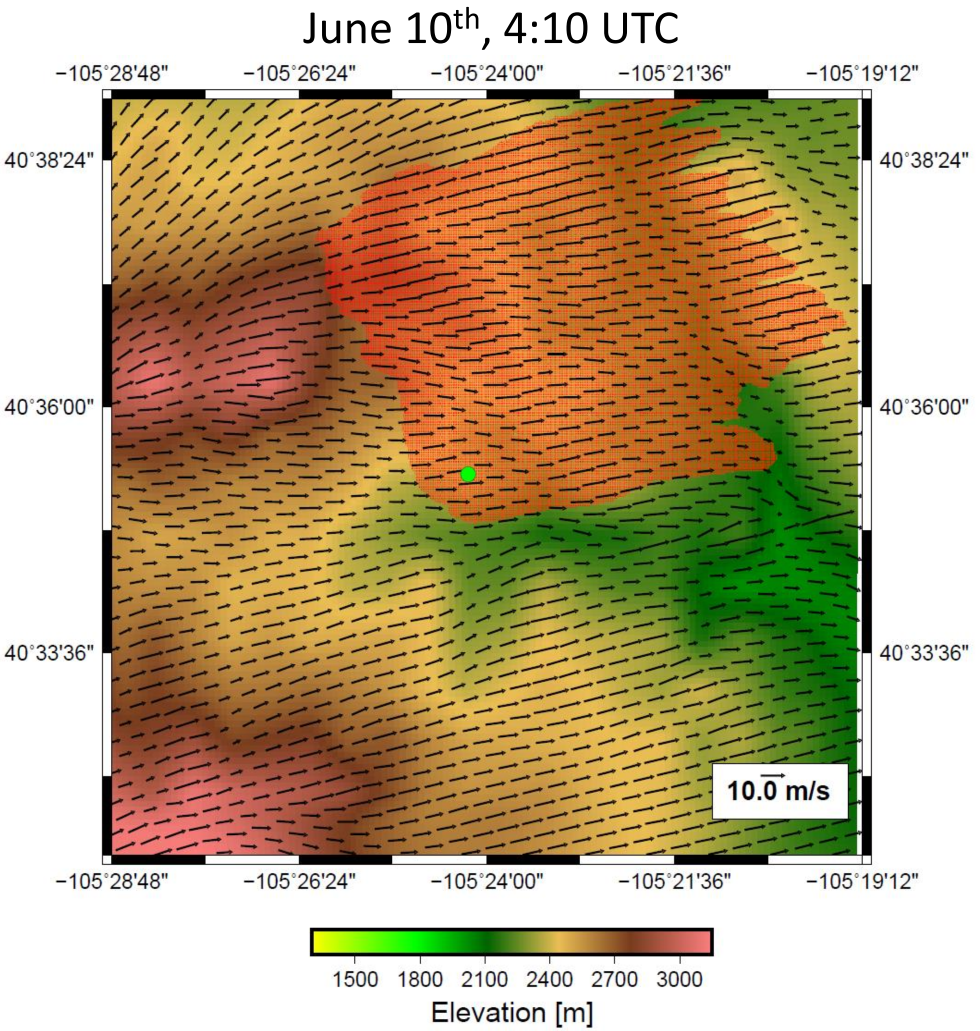




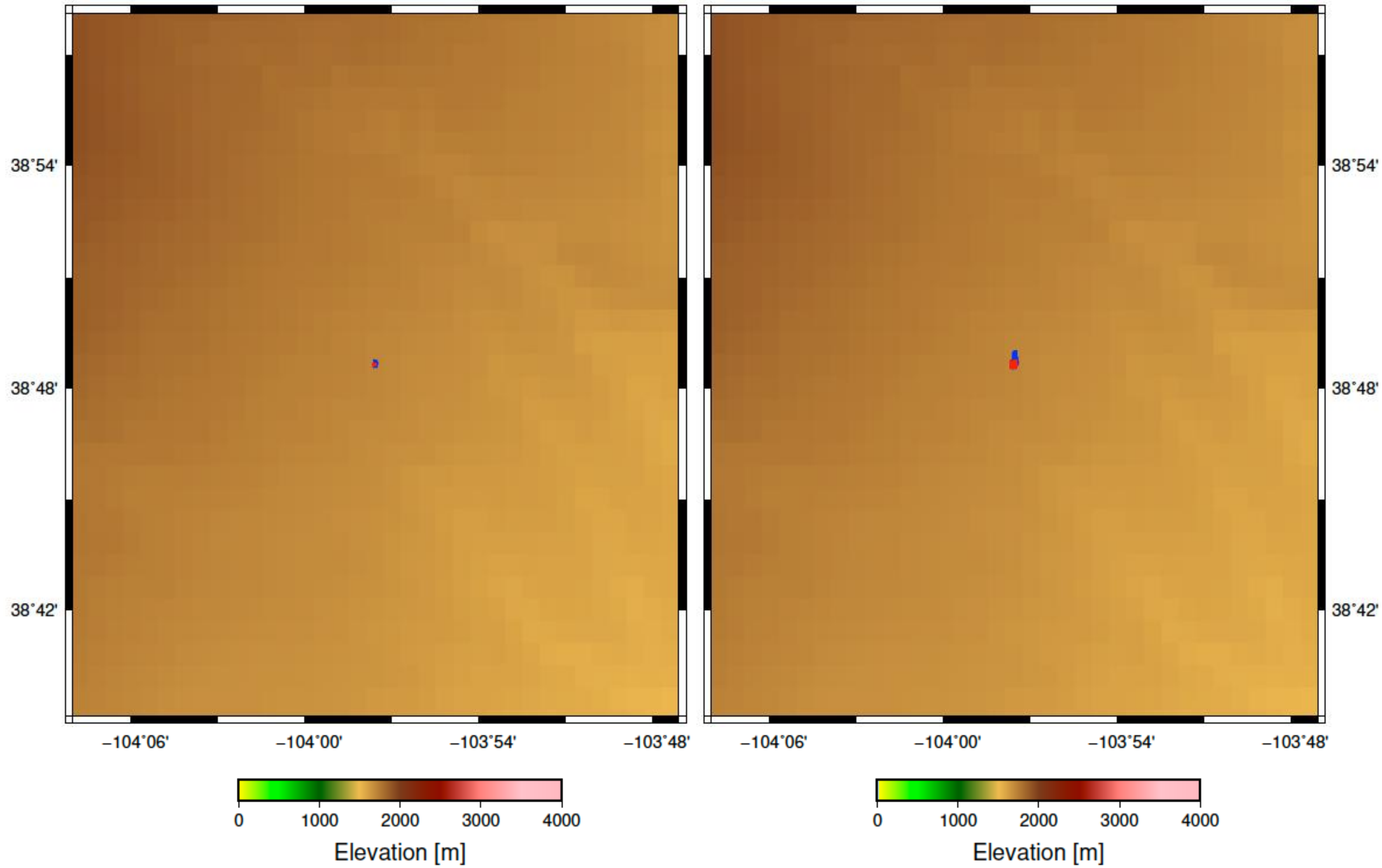
For Short-Term Forecasting We Explored a Possible Nowcasting System

- The goal is to provide a short-term forecast (~3-hour lead time) as fast as possible
- Currently 3-hour lead time high-resolution forecast with 110 m grid cell size takes 40-50 minutes
- Coarser resolution, 1 km grid cell size, can produce 3-hour lead time forecast in about 5 minutes.
- The domain with 1km grid cell size is the same as outer domain used in the CO-FPS operational system:
  - 117 km x 117 km centered on the ignition location

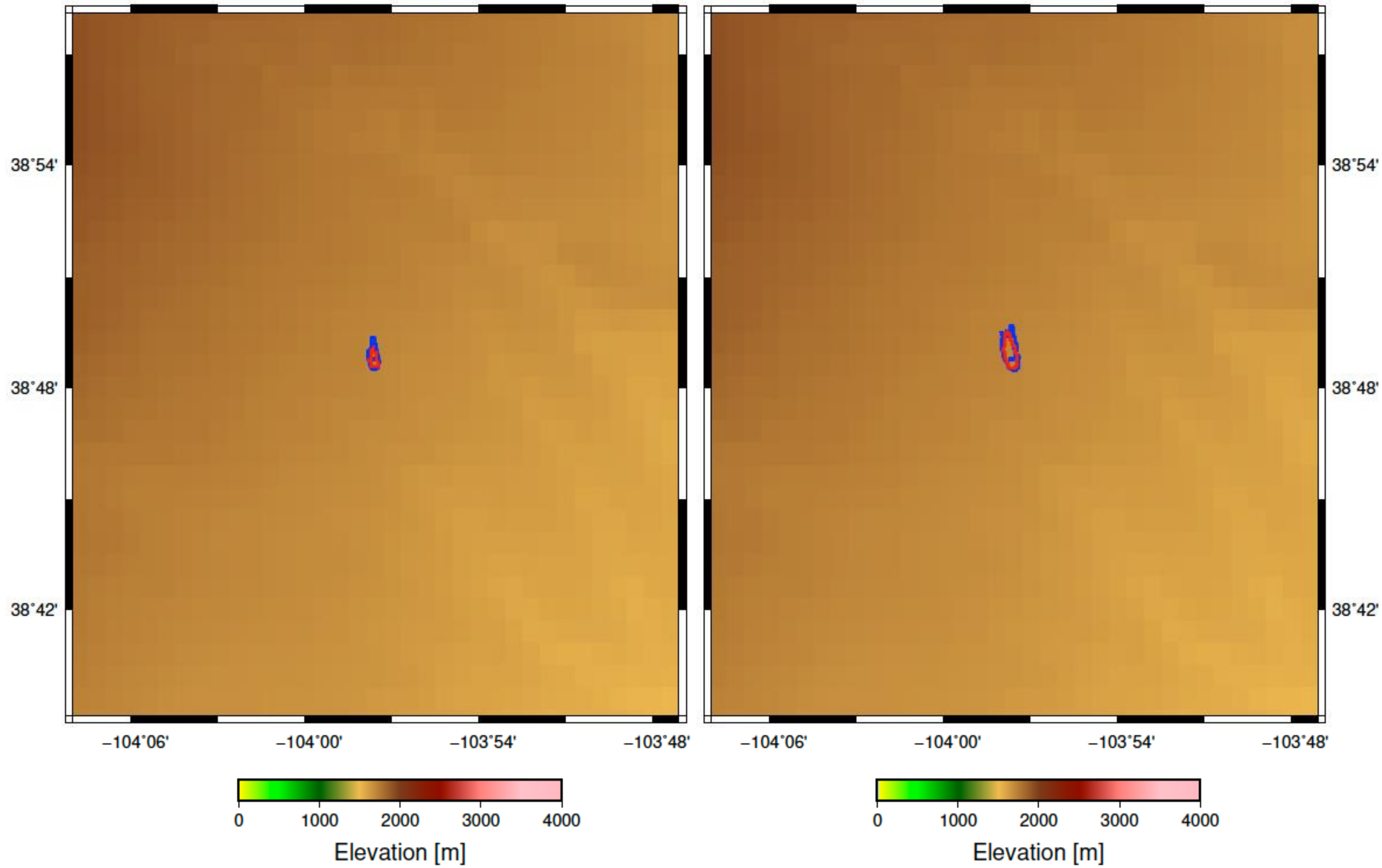
Comparison of nowcasting system forecast to high-resolution forecast

- The goal was to determine if a nowcasting system based on lower resolution forecasts could be effective
- We carried out a study to assess the differences between high-resolution forecast and lower resolution forecast
- This was model to model comparison – not a validation/verification study, results are not based on or compared to observed fires

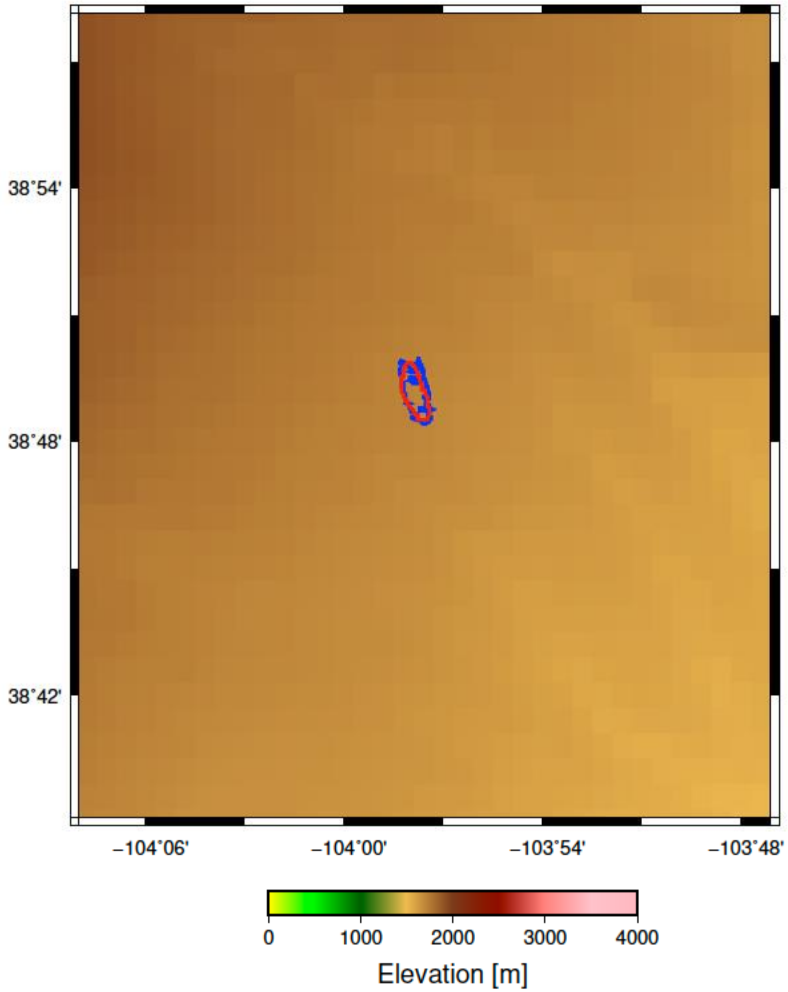
Flat Terrain – Example 1 – Hours 1 and 2

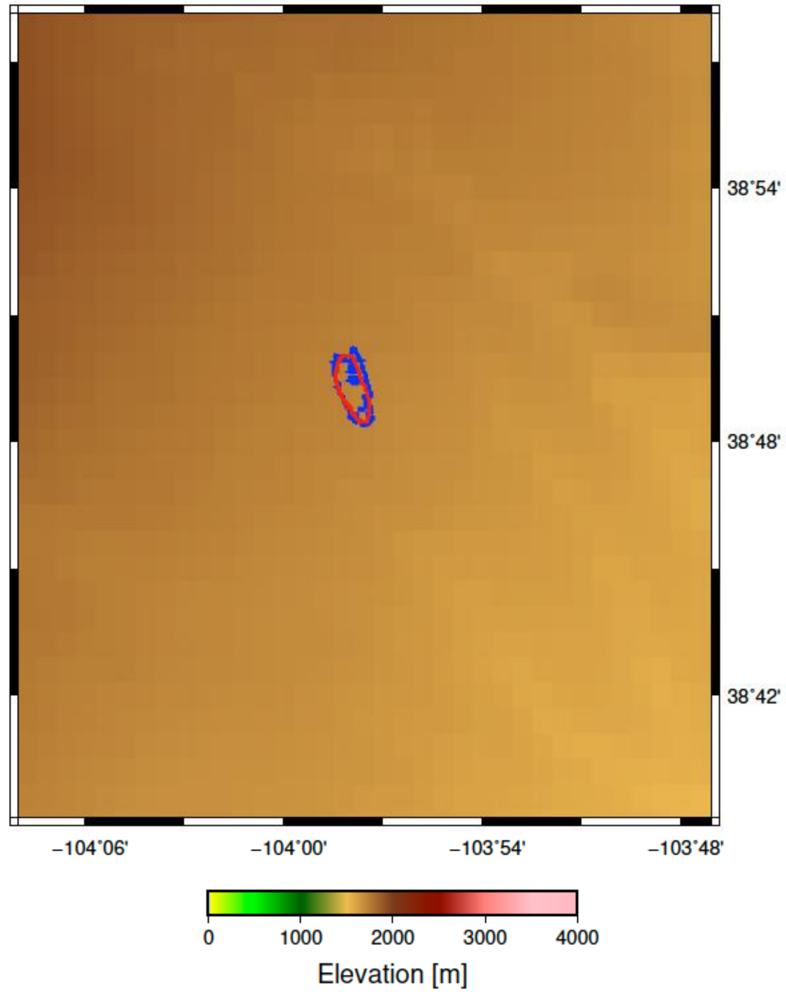


Flat Terrain – Example 1 – Hours 3 and 4

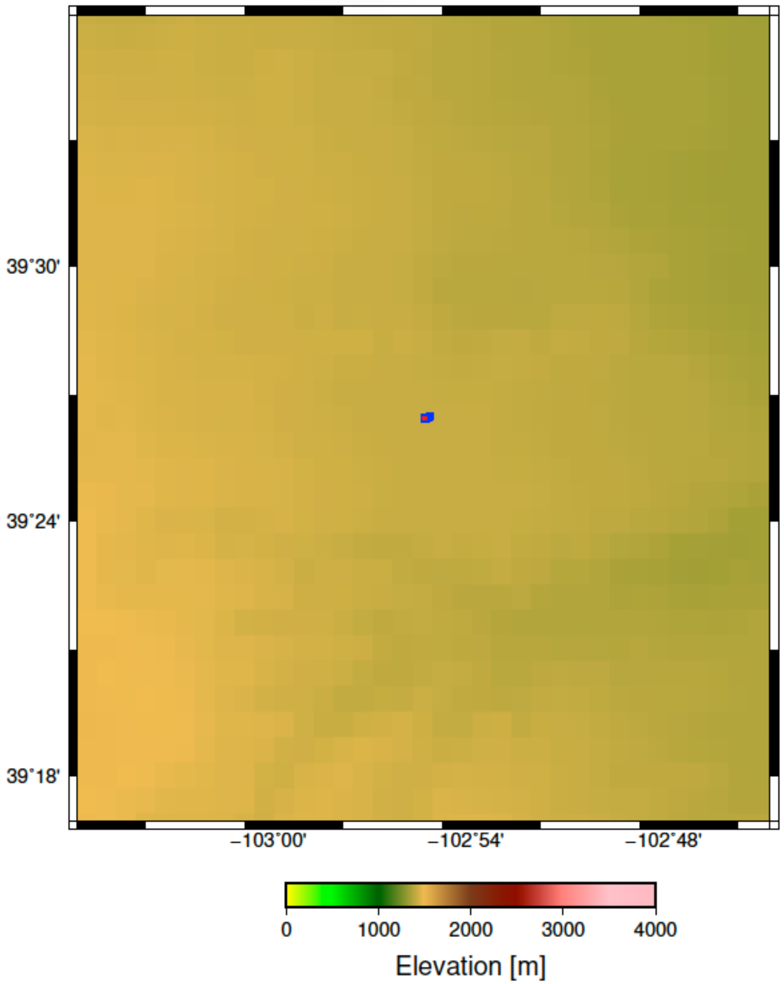


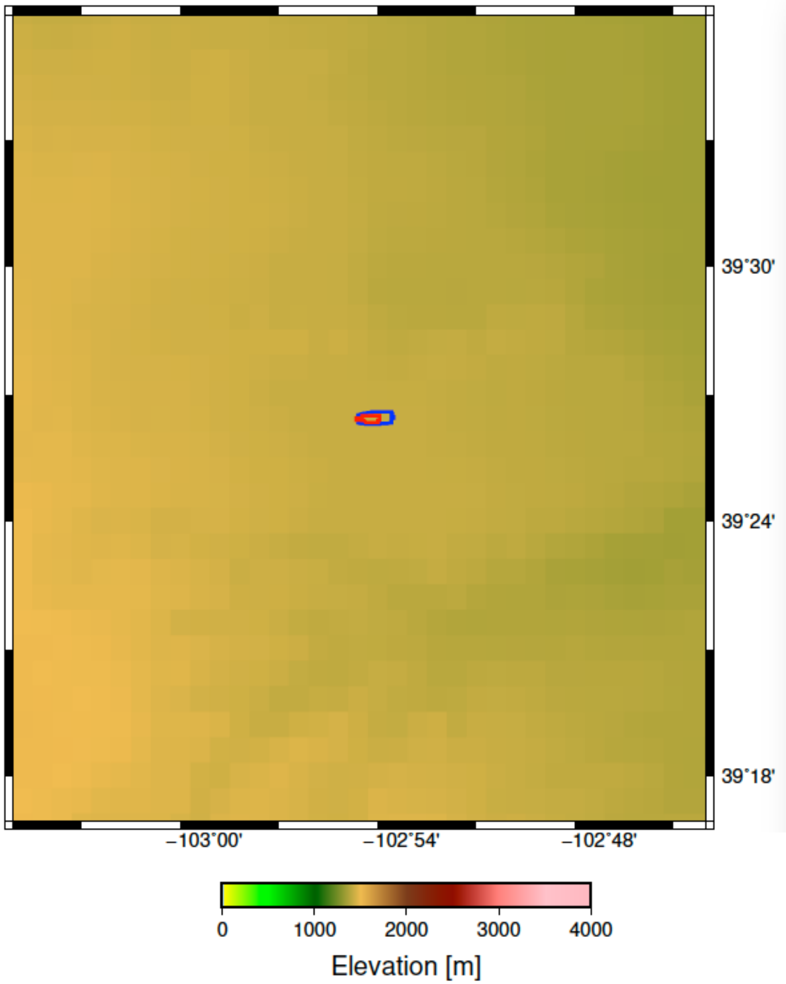
Flat Terrain – Example 1 – Hours 5 and 6





Flat Terrain – Example 2 – Hours 1 and 2





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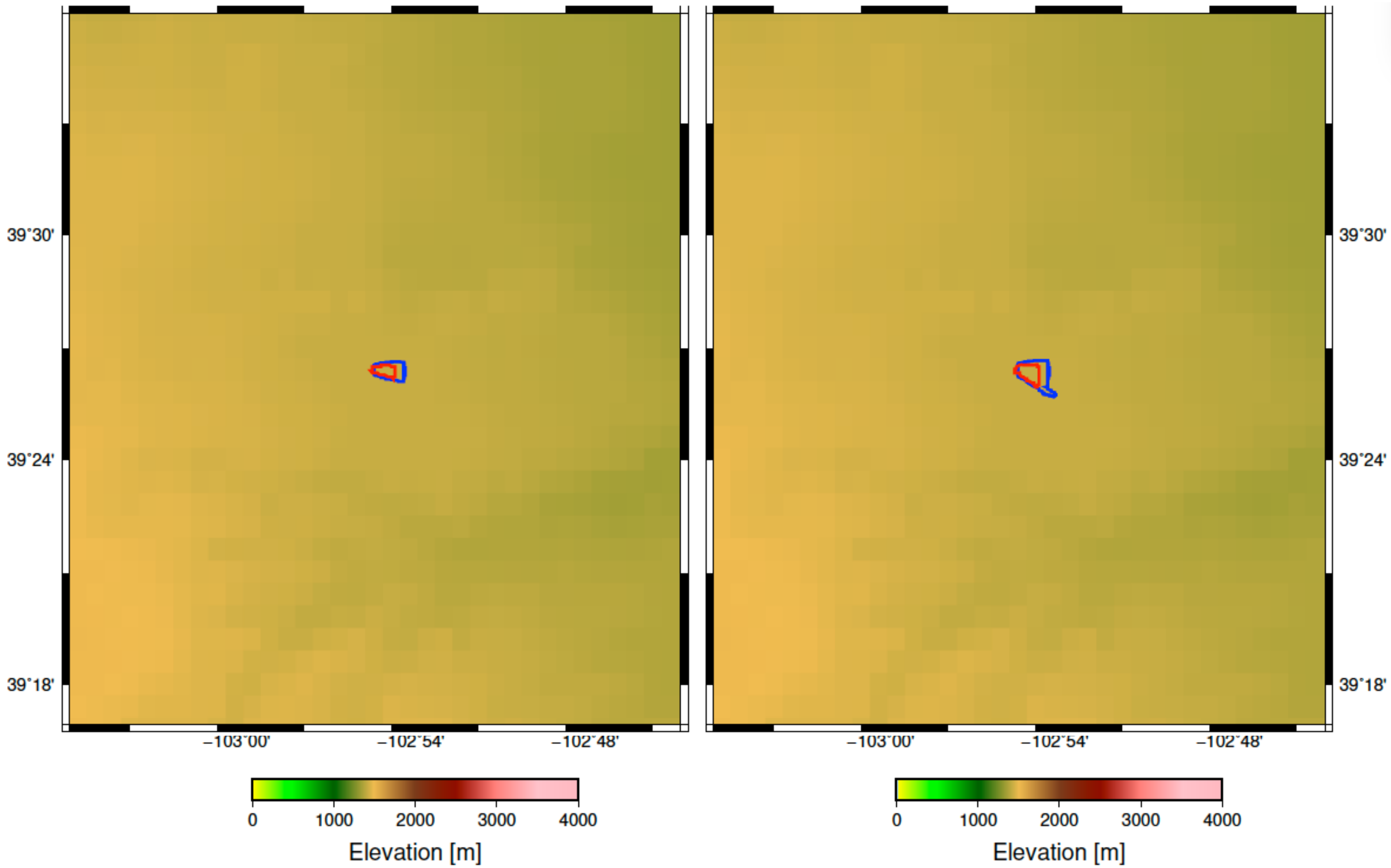

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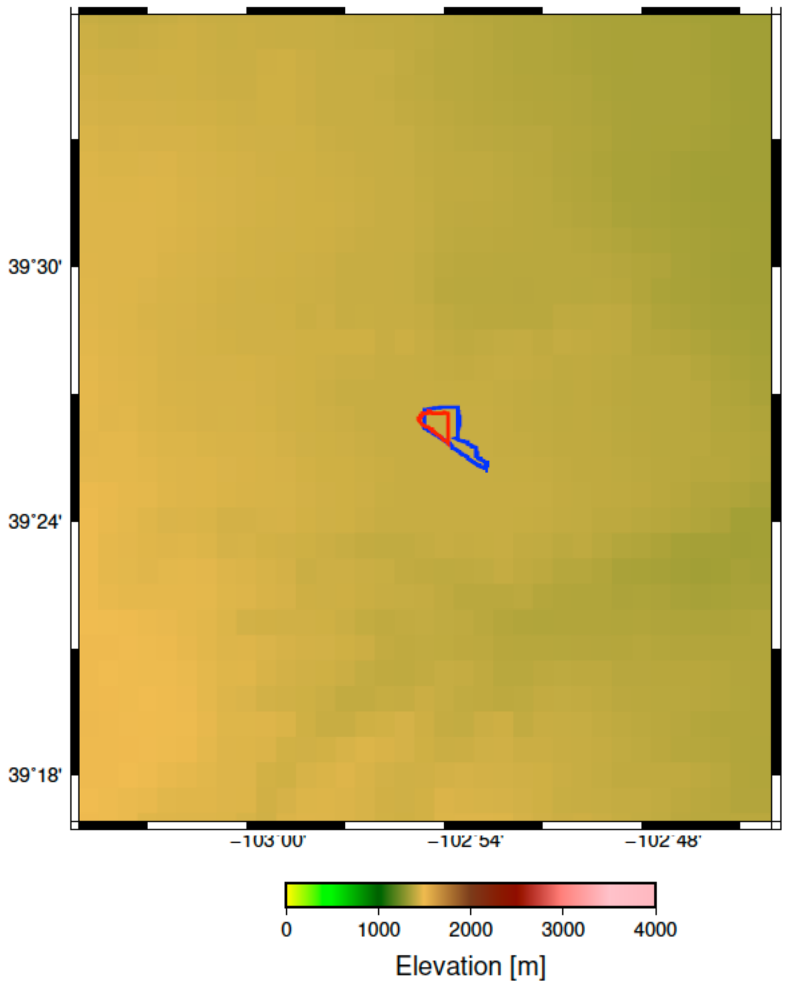
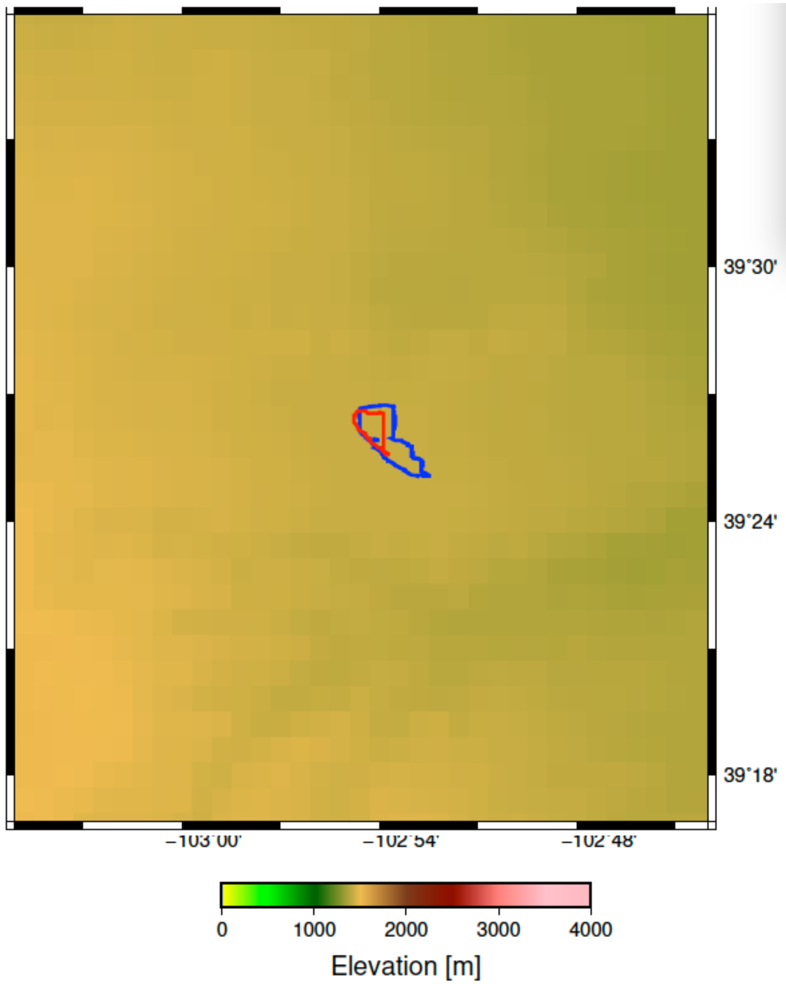
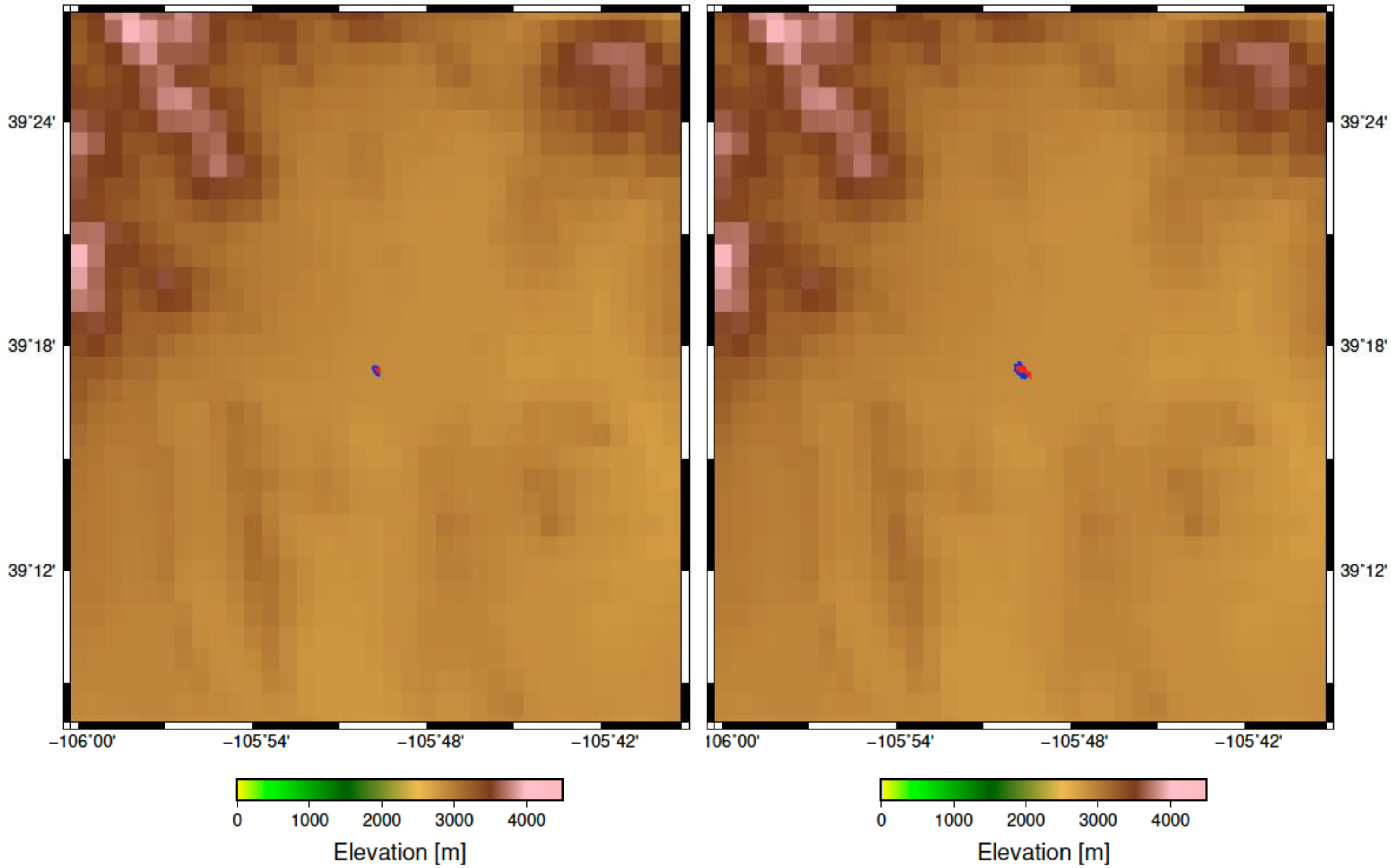
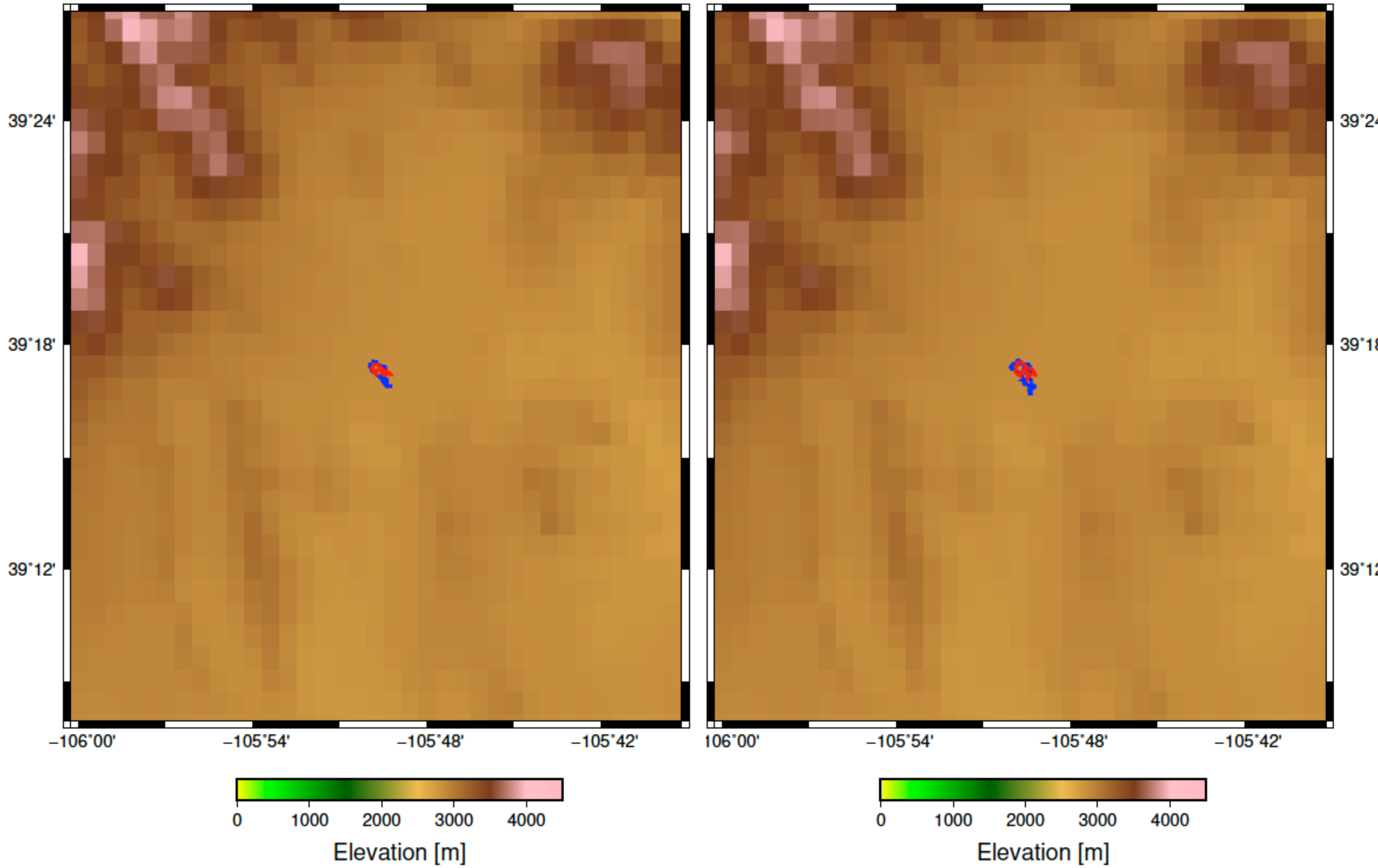




Complex Terrain – Example 1 – Hours 1 and 2



Complex Terrain – Example 1 – Hours 3 and 4



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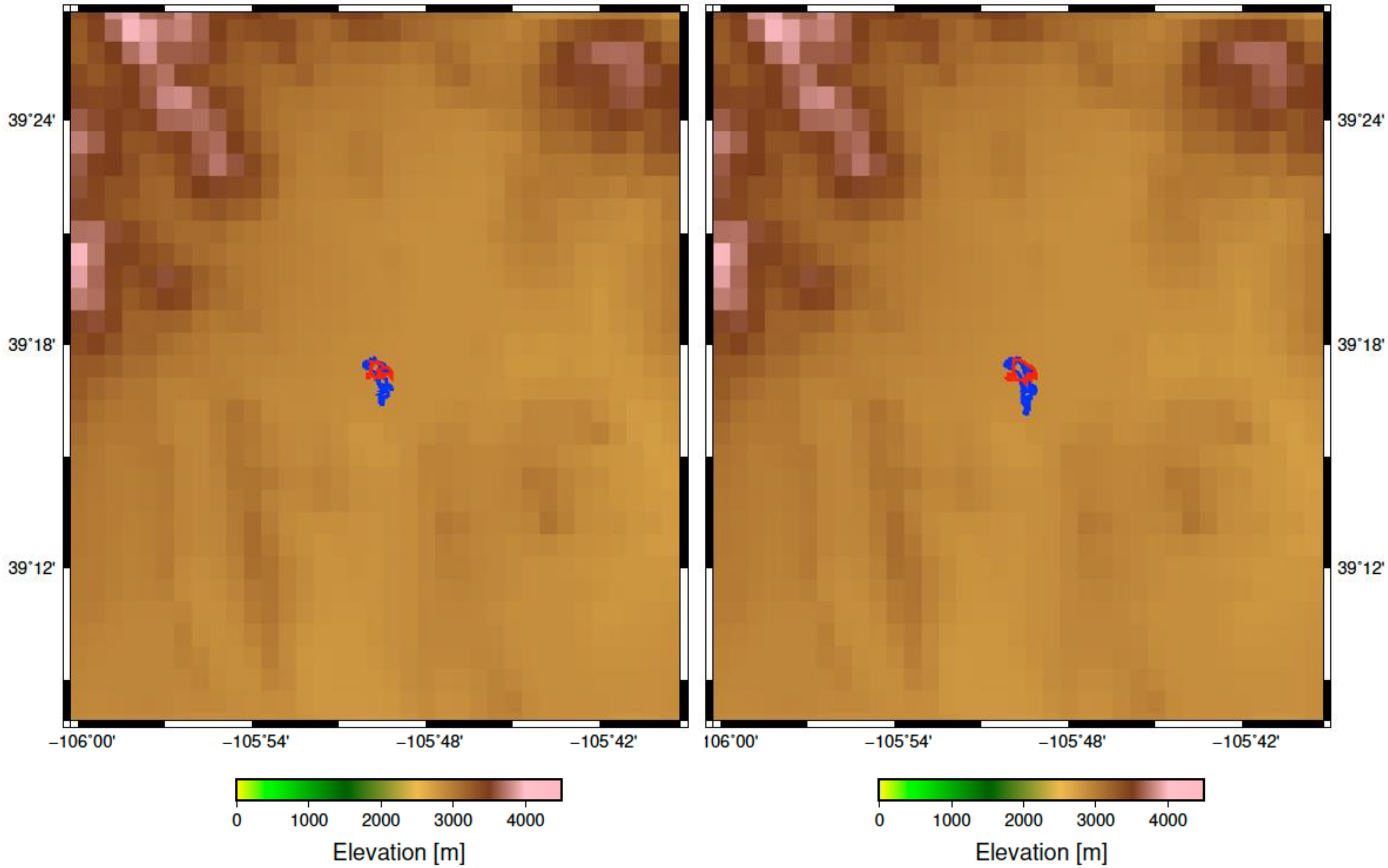
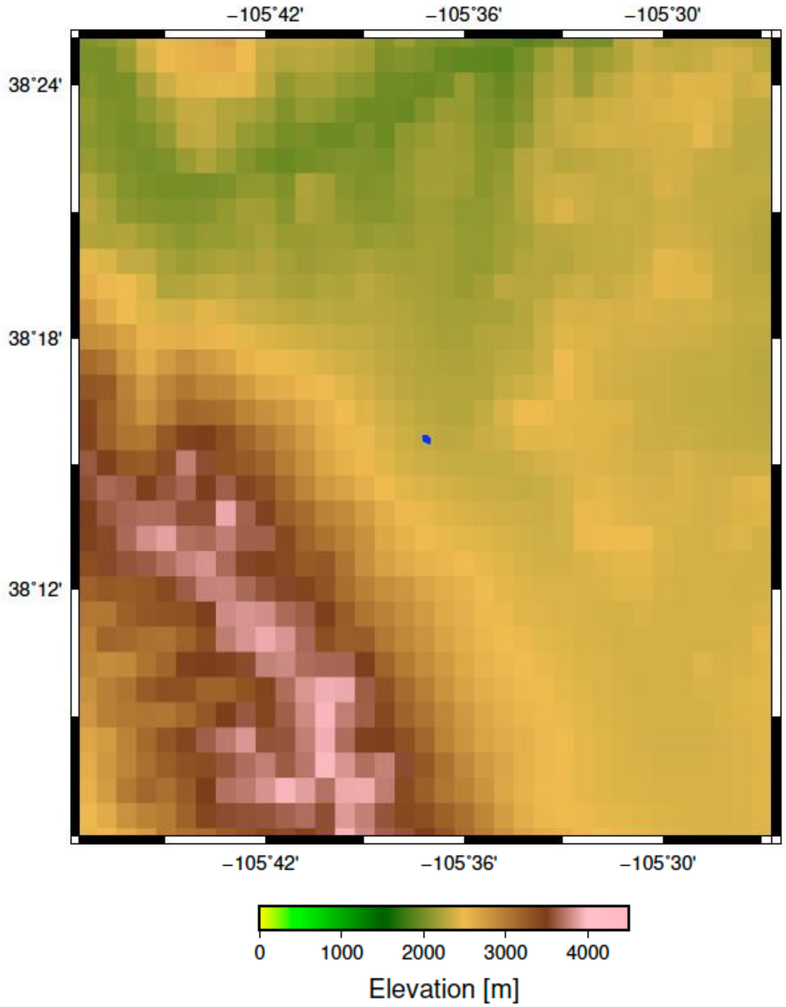
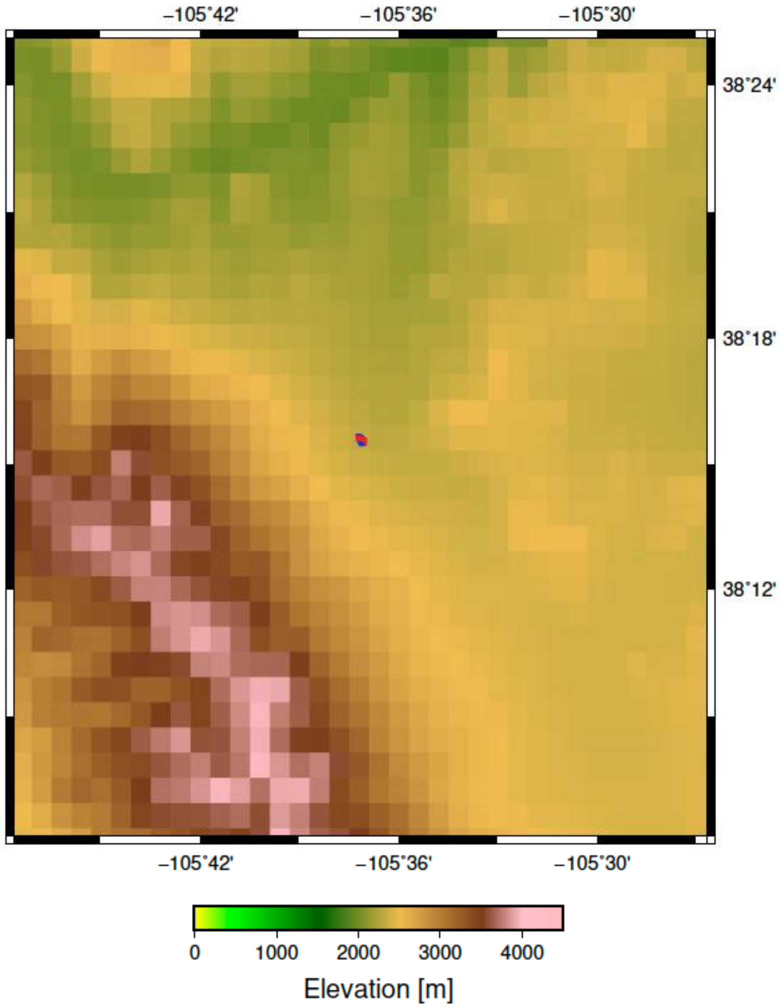


Complex Terrain – Example 2 – Hours 1 and 2





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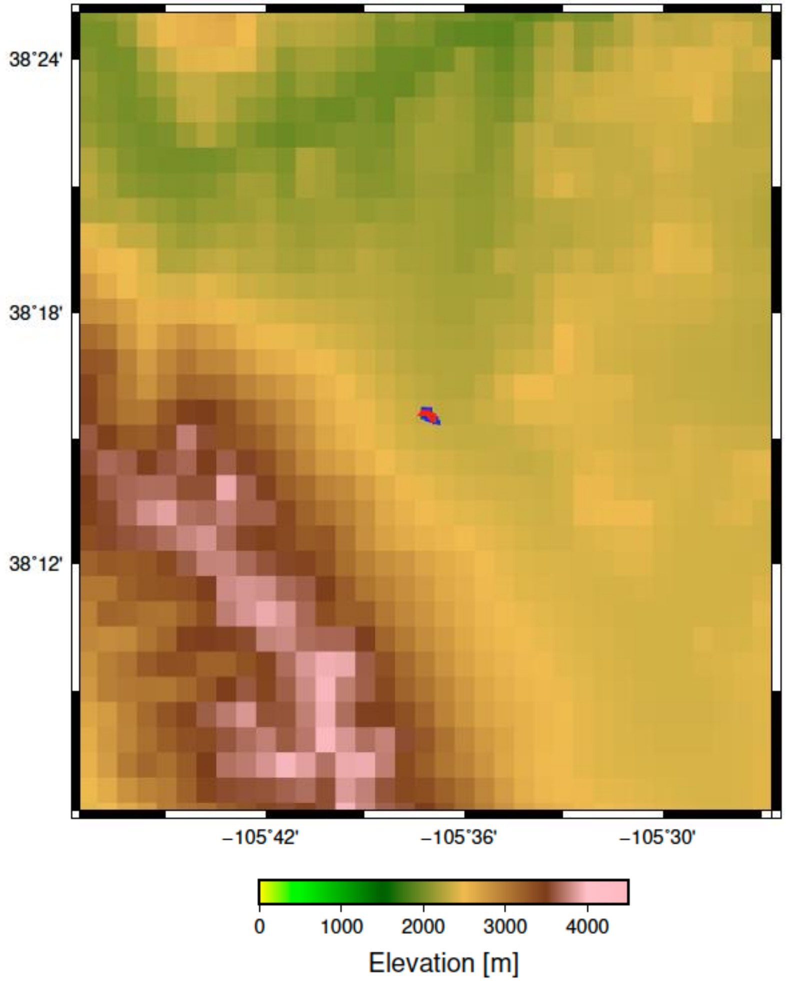
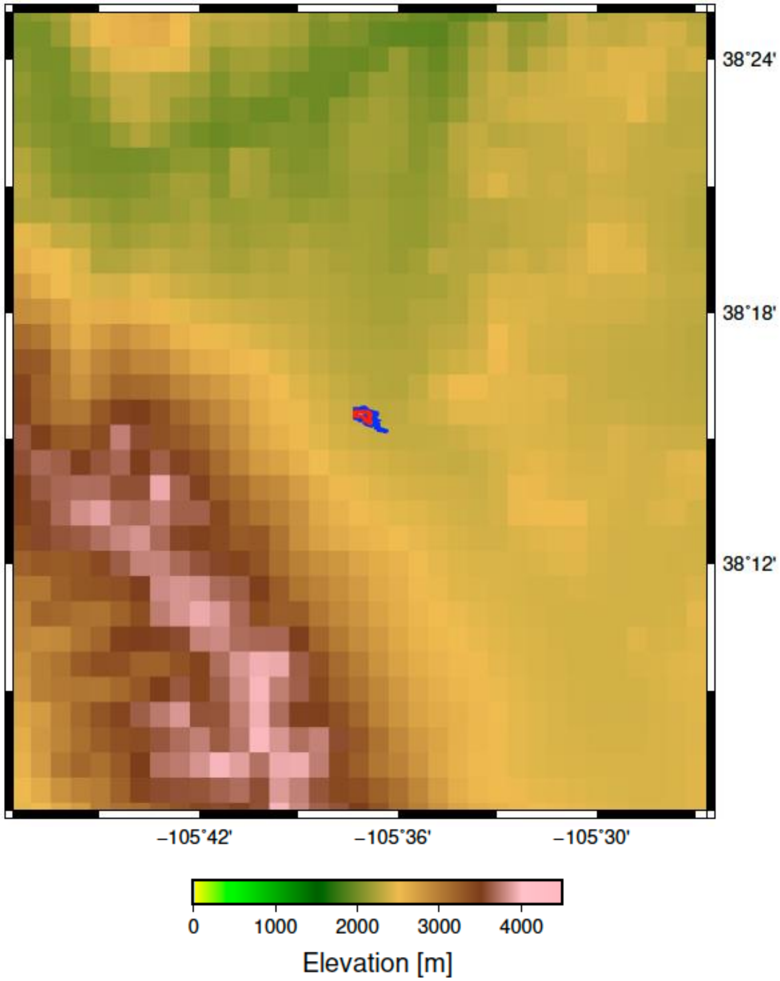
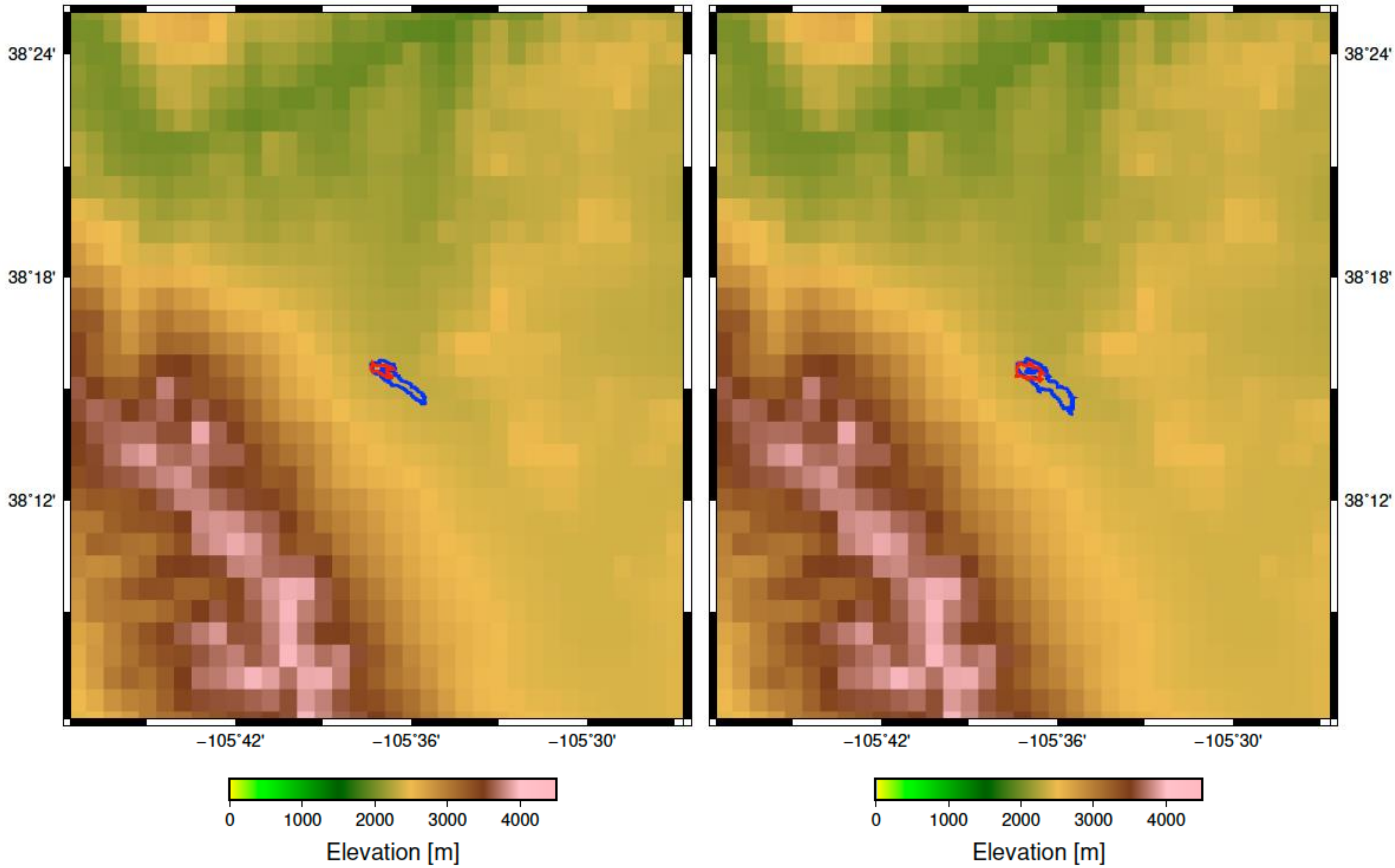




Complex Terrain – Example 2 – Hours 5 and 6



Nowcasting System - Summary

- Comparison with the high-resolution simulations shows that for the 2-3 hour lead time coarser-resolution simulations produce similar results
- In flat terrain the differences between coarser-resolution and high-resolution simulation is smaller than in complex terrain
- Coarser-resolution simulation with 1km grid cell size could be used in a nowcasting system

Thank you!

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