Challenges and Opportunities for Short-Range Fire Weather Forecasting

CIWRO Fire Weather Workshop, Norman, OK, February 13, 2024

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Importance of Fire Weather Forecasting

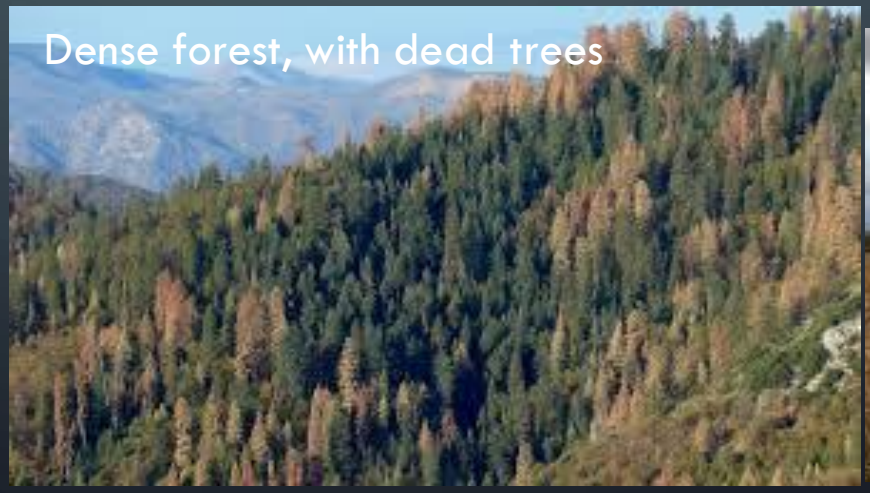
- Wildland fires are considered to be a form of high impact weather
- Short-term forecasts of these impacts are a useful too for various decision makers
  - Forecast products include environmental conditions such as wind and humidity, smoke concentrations, air quality, visibility, fire intensity and spread, and feedbacks between fire and the surrounding environment
  - Combinations of these forecast products can be used to aid in mitigating fire impacts
- Many tools exist to generate these forecasts at various spatial and temporal scales
  - Each with its own advantages and disadvantages
- Fire weather forecasting can be thought of in 3 phases:
  - **Pre-Fire, Active-Fire,** and **Post-Fire**
  - Focus here is on sub-daily forecasts (minutes to hours)

Three phases of Fire Weather Forecasting

- **Pre-Fire:**
  - Forecasting environmental and land surface conditions favorable for the initial and rapid spread of wildfires
- **Active Fire:**
  - Forecasting smoke aerosol generation and spread
  - Movement and evolution of the fire itself
  - Environmental impacts such as pyro-Cu
- **Post Fire:**
  - Impacts from heavy precipitation over recently burned land are often more significant owing to land cover changes
  - Combining precipitation forecasts with recent fire information could mitigate these impacts

Pre-Fire

- **Challenges:**
  - Determining where future environmental conditions are favorable for wildfire initiation and spread requires high resolution observations of the environment as well as land surface conditions and fuel types
  - These observations are not always readily available and what observations do exist can have high uncertainty values
- **Examples:**



Active Fire

- **Challenges:**
  - High temporal and spatial resolution fire observations are required. Often derived from satellite data, but various satellite platforms have different observation characteristics
  - Understanding how a new fire will evolve is difficult given the uncertainties in land surface and environmental observations. There is also the human factor to take into account.
  - Converting observed fire information into particulate matter (PM) concentrations for NWP also contains many uncertainties and assumptions
  - Atmospheric interactions between fire characteristics, PM concentrations, and the surrounding environmental conditions are very difficult forecast
    - Many interdependent links that are not easily modeled.

Active Fire

- Examples:


Grass Fire


Forest Fire


Smoke Plume


Pyro-Cu

Post Fire

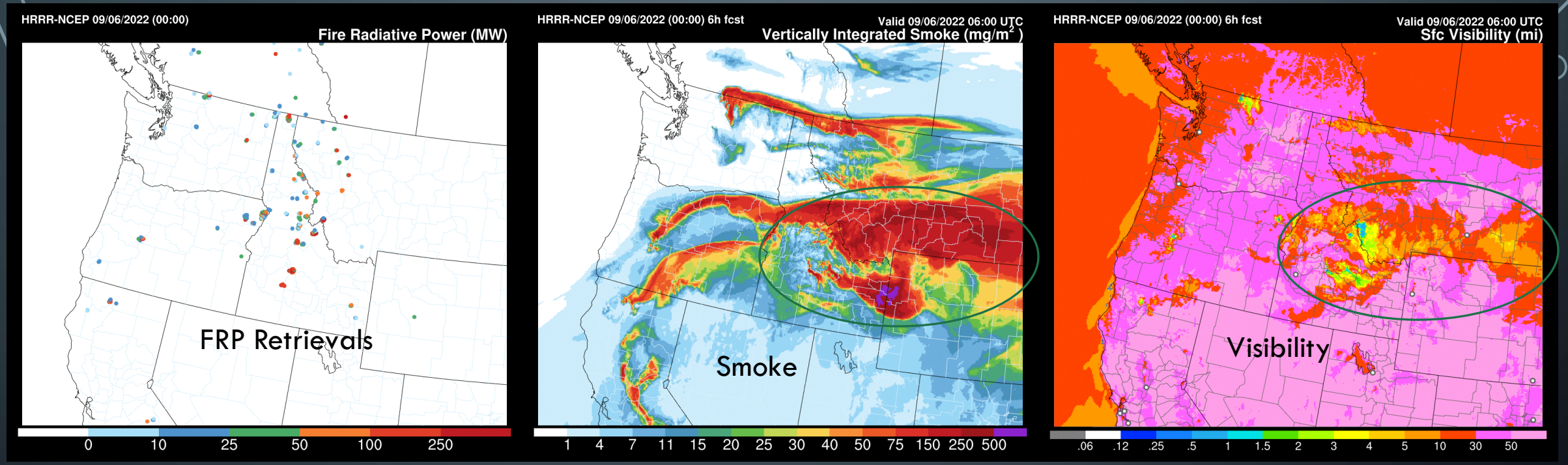
- **Challenges:**
  - Once fires have ended, they leave a lasting impact on the land surface conditions
    - Reduced vegetation, soil moisture, and albedo changes
    - All impact NWP at various scales
    - For very new fires, observations of these modified surface conditions are difficult
  - Changes in surface conditions can result in land more susceptible for flash flooding and land slides.
    - Less precipitation needed to cause severe impacts than would otherwise be the case
  - Need rapidly updated fire perimeter information in NWP systems combined with high resolution precipitation forecasts.

Current Forecast Tools (HRRR)

- **The most commonly used short-term forecast tool for all three phases is the High Resolution Rapid Refresh (HRRR) model.**
  - Version 4 which become operational in late 2020 includes a smoke aerosol forecasting ability
  - Generates 48* hour forecasts of environmental and smoke conditions at hourly intervals with new forecasts initialized every hour
  - 3 km horizontal grid spacing
  - Fire data used to generate smoke plumes is derived from polar-orbiting weather satellites.
  - Forecast output at hourly intervals (some products available at 15 minute intervals)
- **HRRR-Smoke products include:**
  - Environmental conditions (temperature, moisture, wind, cloud cover, precipitation)
  - Smoke aerosol (PM2.5) concentration (total column and individual levels)
  - Air quality and visibility

* Only 0,6,12,18 UTC initiation times go out to 48 h. Others out to 18 h

Example HRRR Forecast Products



- HRRR-Smoke 6 hour forecasts for September 6, 2020
  - Noticeable decrease in forecast visibility associated with large smoke plume

Warn-on-Forecast System

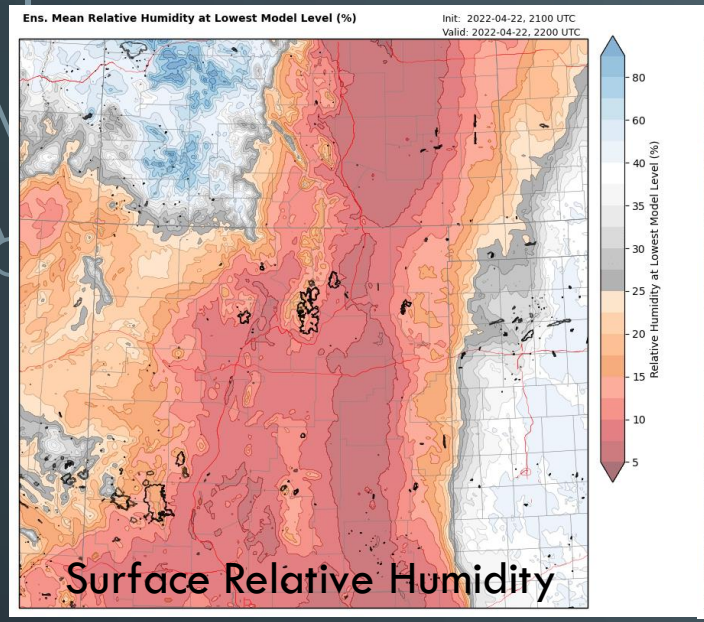
- **Based on the current realtime (WoFS)**
  - *15 minute cycling,* assimilates radar, satellite, and conventional observations
  - Generates up to 0-6 hour probabilistic forecasts of smoke and related parameters, with *5 minute* forecast output
  - Regional domain selected based on the location of expected wildfires for a particular day

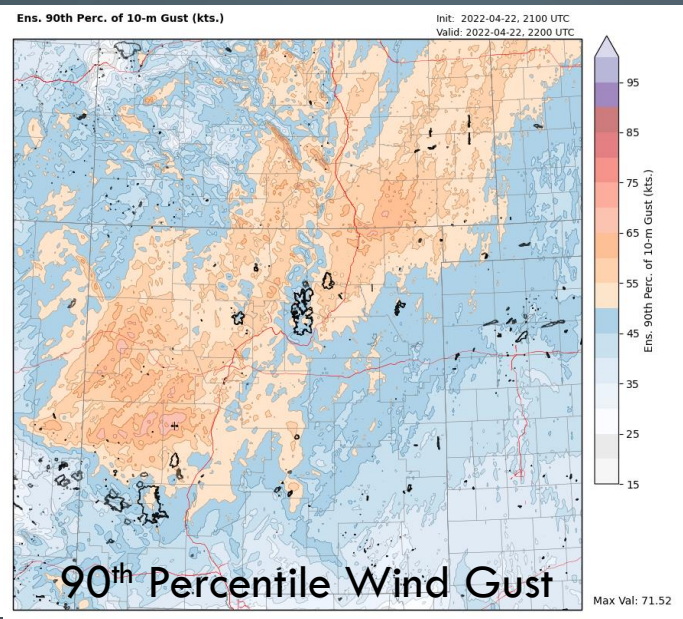
    Uses GSL WRF version 3.9.1 (both HRRR and WoFS-Smoke use the same code-base)
  - Baseline configuration 3 km grid spacing, plans to reduce to ~1 km grid spacing

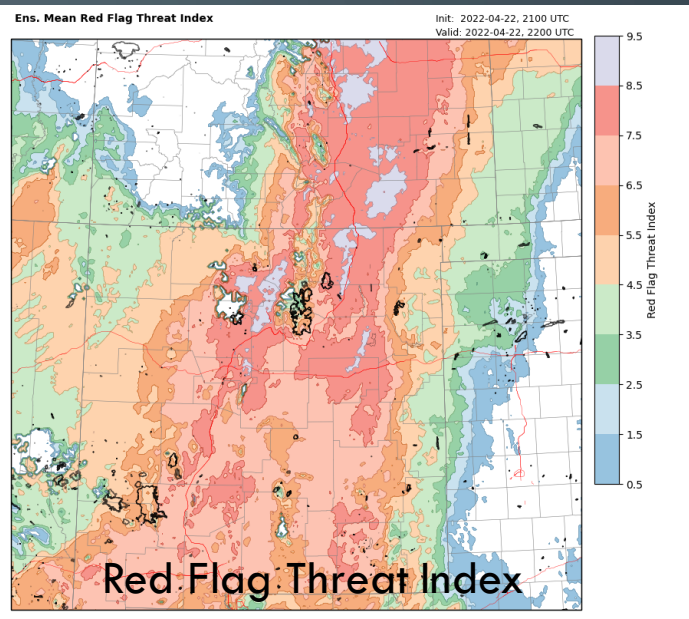
- **Key differences from basic WoFS:**
  - Change to all members to RRTMG radiation to enable radiation– smoke feedback in the system.
  - Smoke and fire initial and boundary conditions are taken from the operational HRRR forecast initiated at 1200 UTC and translated into the WoFS domain. 5% random noise added to smoke variable in each ensemble member
  - Fire radiative power retrievals from GOES-16/18 are updated at 15 minutes intervals so that fires which initiate or dissipate during the cycling are analyzed
  - HRRR-Smoke only uses polar-orbiting satellite data that cannot sample rapidly changing wildfire characteristics (RRFS uses GOES data at hourly intervals)
  - Smoke variable added to the model state to allow AOD assimilation (Smoke = $PM_{2.5}$ in this system). Not yet used

Warn-on-Forecast System: Forecast Examples

22 April 2022

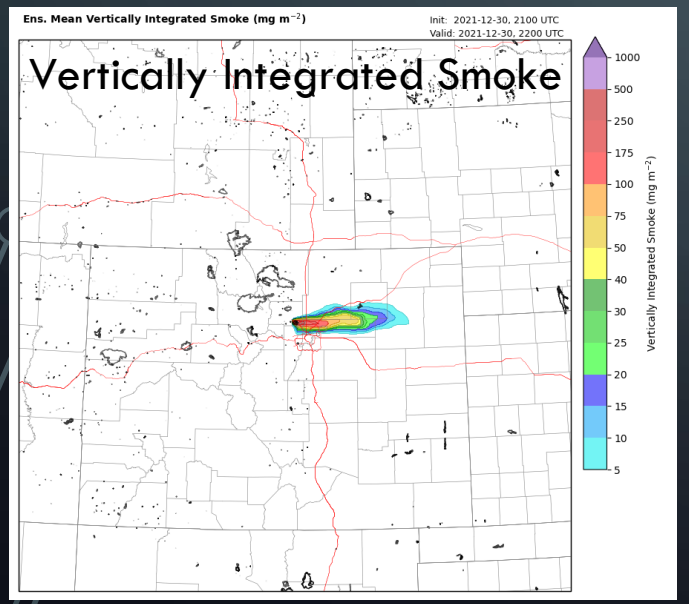


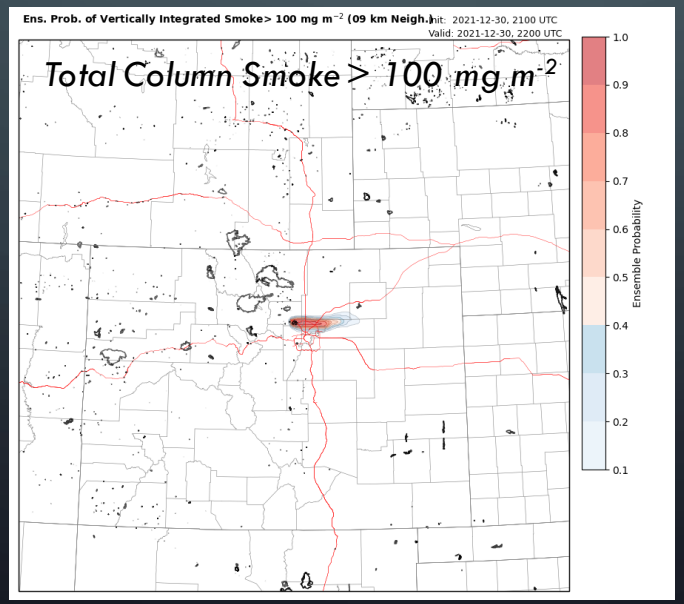


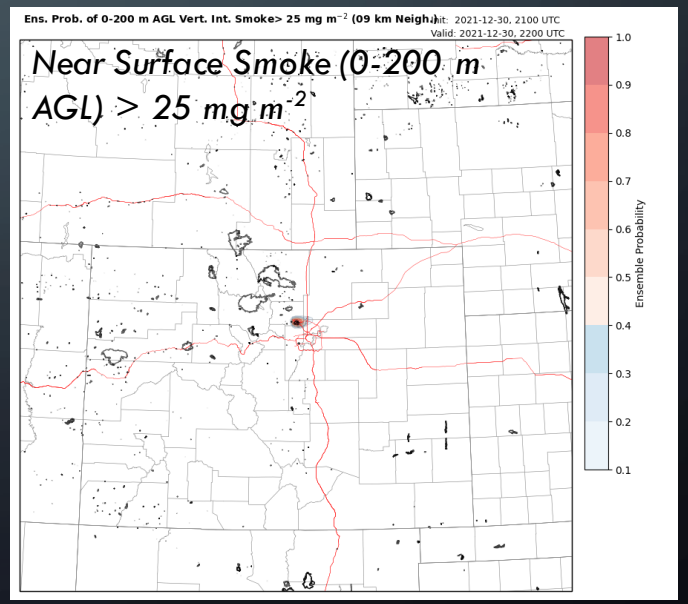


0: Non critical
1-2: Elevated
3-4: Critical Low
5-6: Critical High
7-8: Extremely Critical
9-10: Historic

30 December 2021

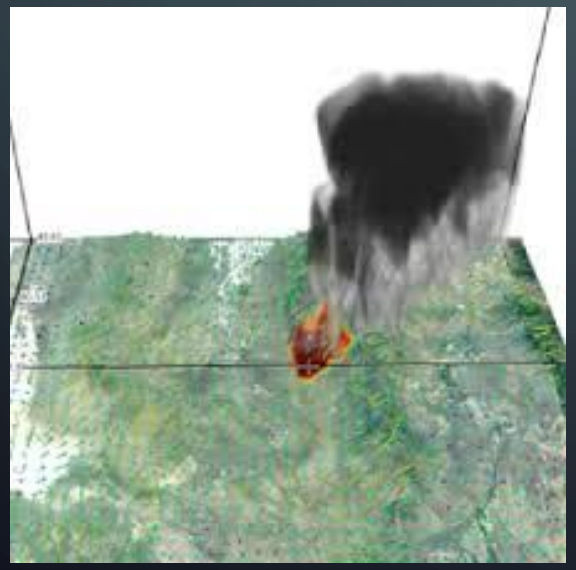


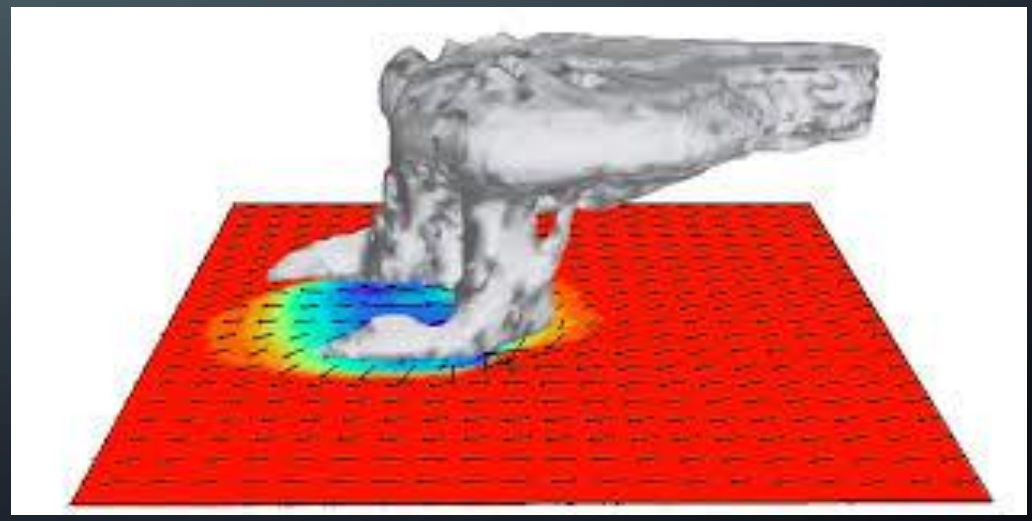




Individual Fire Prediction

- Ultra high resolution models (~100 m or less) can be used to model individual fires and their impacts
  - Generally fully coupled between land surface conditions, environment, and fire properties
  - Example: WRF-SFIRE
- Forecast impact of specific fires
  - Model domain is usually too small for multi-fire forecasts





Opportunities for the Future:

- **Observations:**
  - Satellite: Improved retrievals of fire and aerosol properties, especially from GOES satellites
  - Radar: Develop tools to extract debris and smoke characteristics from polarimetric radar data
  - UAS: Use UAS measurements to assess the pre-fire land surface conditions, active fire smoke aerosol concentrations, and post-fire land surface conditions
- **Modeling:**
  - Use improved observations as model inputs and validation
  - Continue to develop atmosphere, land, fire coupling techniques
  - More use of ensembles
- **Other:**
  - Test new observations and model developments using prescribed burns in which certain aspects of the fire can be estimated in advance.

Thank You!

- **HRRR Output:**
  - https://rapidrefresh.noaa.gov/hrrr/HRRR/
- **WoFS Output:**
  - https://cbwofs.nssl.noaa.gov
  - https://wof.nssl.noaa.gov/research/