WILDFIRE SMOKE AND VOLCANIC ASH FORECASTING OVER NORTH AMERICA WITH THE RAP AND HRRR NWP SYSTEMS

Eric James [1,2] , Ravan Ahmadov[1,2] , Trevor Alcott[2], Georg Grell[2], and Curtis Alexander[2]

Acknowledgement: S.Benjamin[2], J. Stewart[1,2], S. Freitas[3], G. Pereira[3,4], I. Csiszar[5], M. Tsidulko[8], B. Pierce[6], S. McKeen[1,2], S. Peckham[7], A. Edman[9], M. Goldberg[10], B. Sjoberg[10]

JPSS proving ground and risk reduction program

[1] Cooperative Institute for Research in Environmental Sciences, University of Colorado at Boulder, Boulder, CO, USA

[2] Earth System Research Laboratory, NOAA, Boulder, CO, USA

[3] NASA Goddard Space Flight Center & USRA/GESTAR, Greenbelt, MD, USA

[4] Federal University of São João del-Rei, MG, Brazil

[5] Center for Satellite Applications and Research, NOAA/NESDIS, College Park, MD, USA,

[6] Advanced Satellite Products Branch, Center for Satellite Applications and Research, NOAA/NESDIS, Madison, WI, USA

[7] Cold Regions Research and Engineering Laboratory, US Army Corps of Engineers, Hanover, NH, USA

[8] I.M. Systems Group, Inc, Rockville, MD, USA

[9] National Weather Service, NOAA, USA

[10] NOAA's Joint Polar Satellite System Program Office

WRF Workshop
12 June 2018

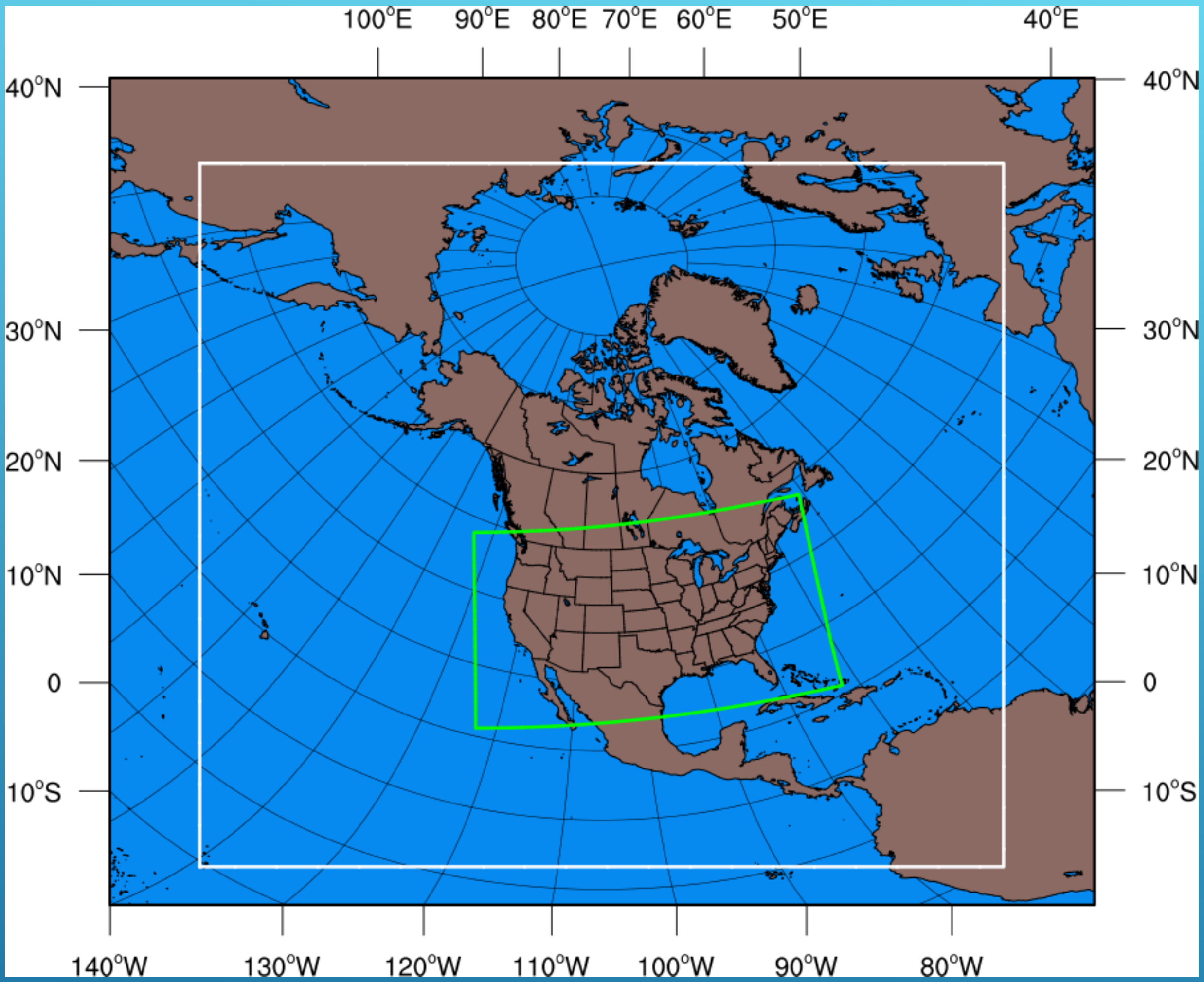
Introduction

- The Rapid Refresh (**RAP**) and High-Resolution Rapid Refresh (**HRRR**) are numerical weather prediction systems running operationally at the National Weather Service and in real time at NOAA Earth System Research Laboratory / Global Systems Division (NOAA/ESRL/GSD). The models are run with an hourly update cycle, at **13km grid spacing** for the **RAP** (covering North America) and **3km grid spacing** for the **HRRR** (over the CONUS domain).
- At present mostly offline air quality models with relatively coarser resolution are used for smoke forecasting. Some of these models do not simulate plume rise. Very few air quality models use the satellite **Fire Radiative Power (FRP)** data to estimate wildfire emissions and plume rise.
- The goal of this project "**Towards the Inclusion of VIIRS Fire Products into the HRRR Real-Time Forecasts**" funded by the JPSS PGRR program is to include the **VIIRS products like FRP data** into two coupled air quality models (**RAP-smoke** and **HRRR-Smoke**), in order to improve the numerical prediction of fire emissions and smoke dispersion in forecast models used at NOAA, and also to improve weather forecasting.
- The **RAP-smoke** and **HRRR-smoke** model configuration is based on the **RAP** and **HRRR** models with added smoke tracer emitted as fine particulate matter by biomass burning emissions (including simulation of plume rise by the model).
- The inclusion of wildfire emissions in NWP systems raises the possibility of also including volcanic ash emissions for episodic eruptions within the **HRRR** and especially the **RAP** domain.

RAP-smoke and HRRR-Smoke models

The primary advantages of the **RAP-smoke** and **HRRR-Smoke** modeling system:

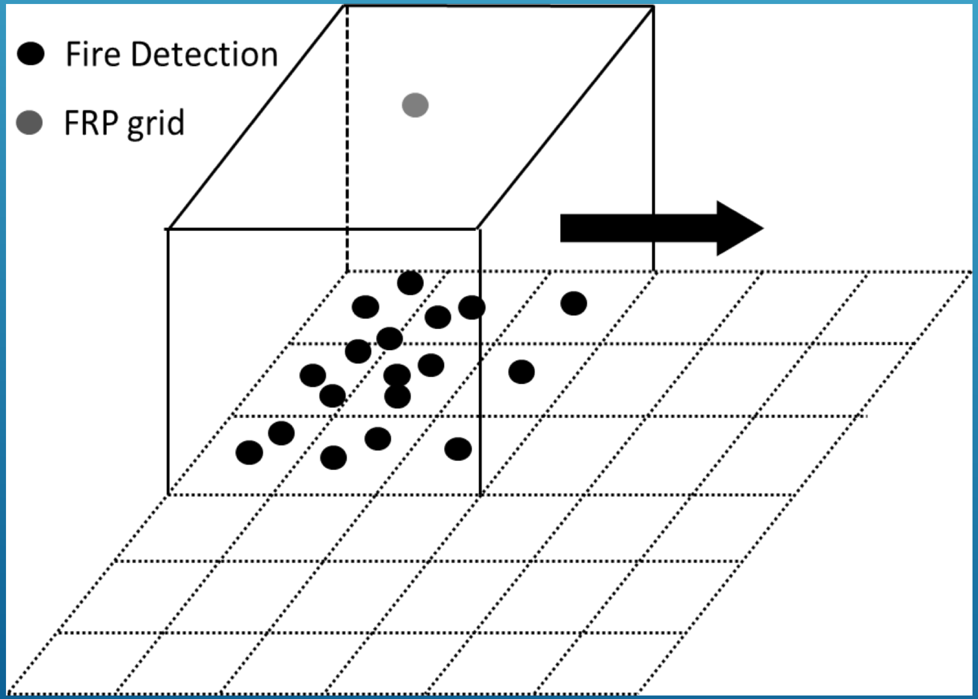
- High spatial resolution (for the **HRRR-smoke**) to allow simulation of mesoscale flows and smoke dispersion over complex terrain.
- Full coupling between meteorology and smoke: feedback of smoke on predicted radiation, cloudiness, and precipitation (using double moment microphysics).
- Biomass burning emissions and inline plume rise parameterization based on the satellite FRP data.
- A rapidly updating data assimilation cycle for meteorology.
- The forecast lead time is 36 hours (for the **HRRR-smoke**) and 48 hours (for the **RAP-smoke**), with forecasts initialized at 00, 06, 12 and 18 UTC.
- Meteorological and smoke boundary conditions for the **HRRR-smoke** are provided by the 6h old **RAP-smoke** forecast.



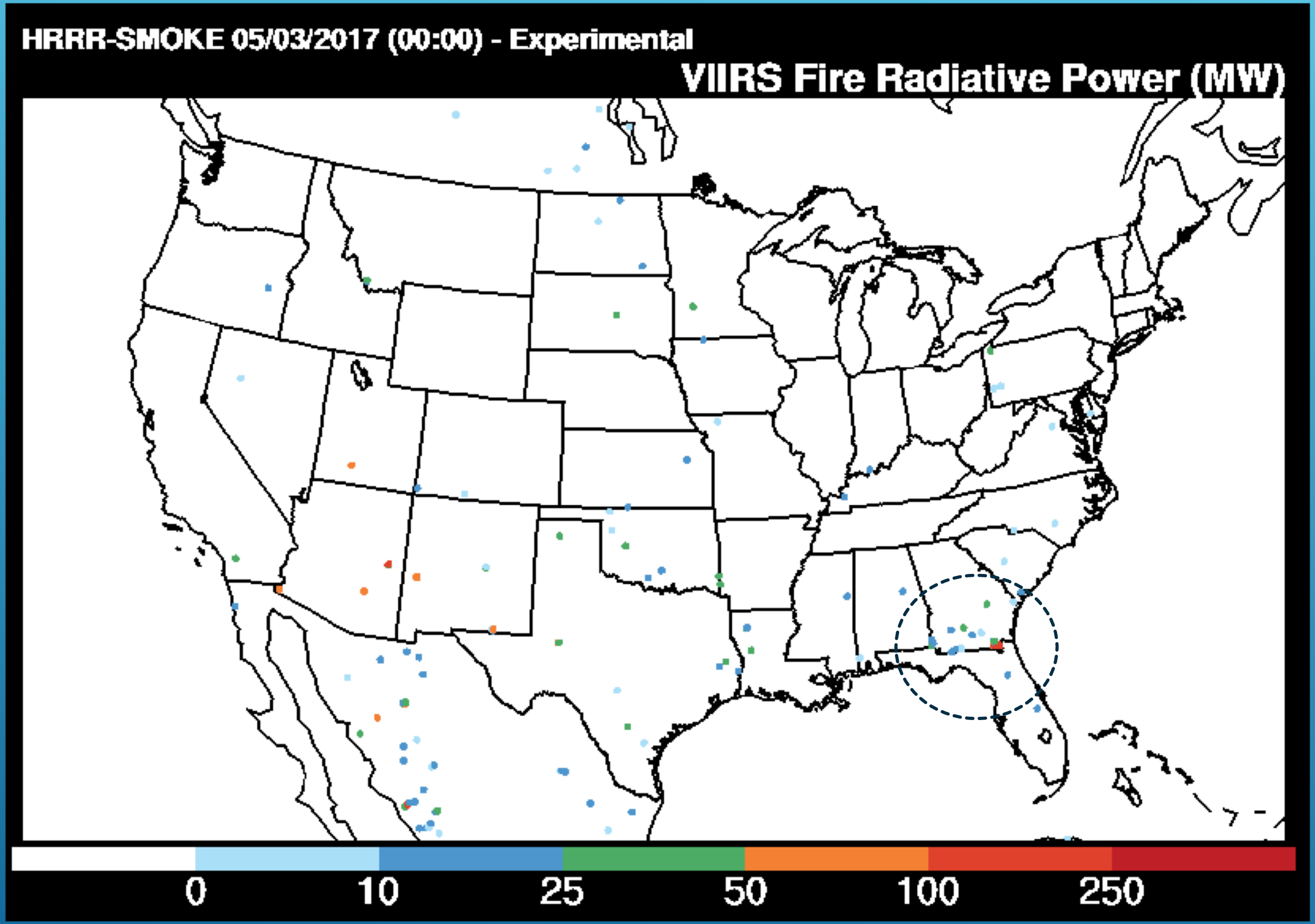
Operational weather forecast models at NWS:
RAP (white), 13km grid spacing
HRRR (green), 3km grid spacing
(https://rapidrefresh.noaa.gov/)

Mapping the VIIRS FRP data to the HRRR-Smoke CONUS grid

The clustering procedure performs a combination of all detected fires from VIIRS according to the model spatial resolution and grid configuration.

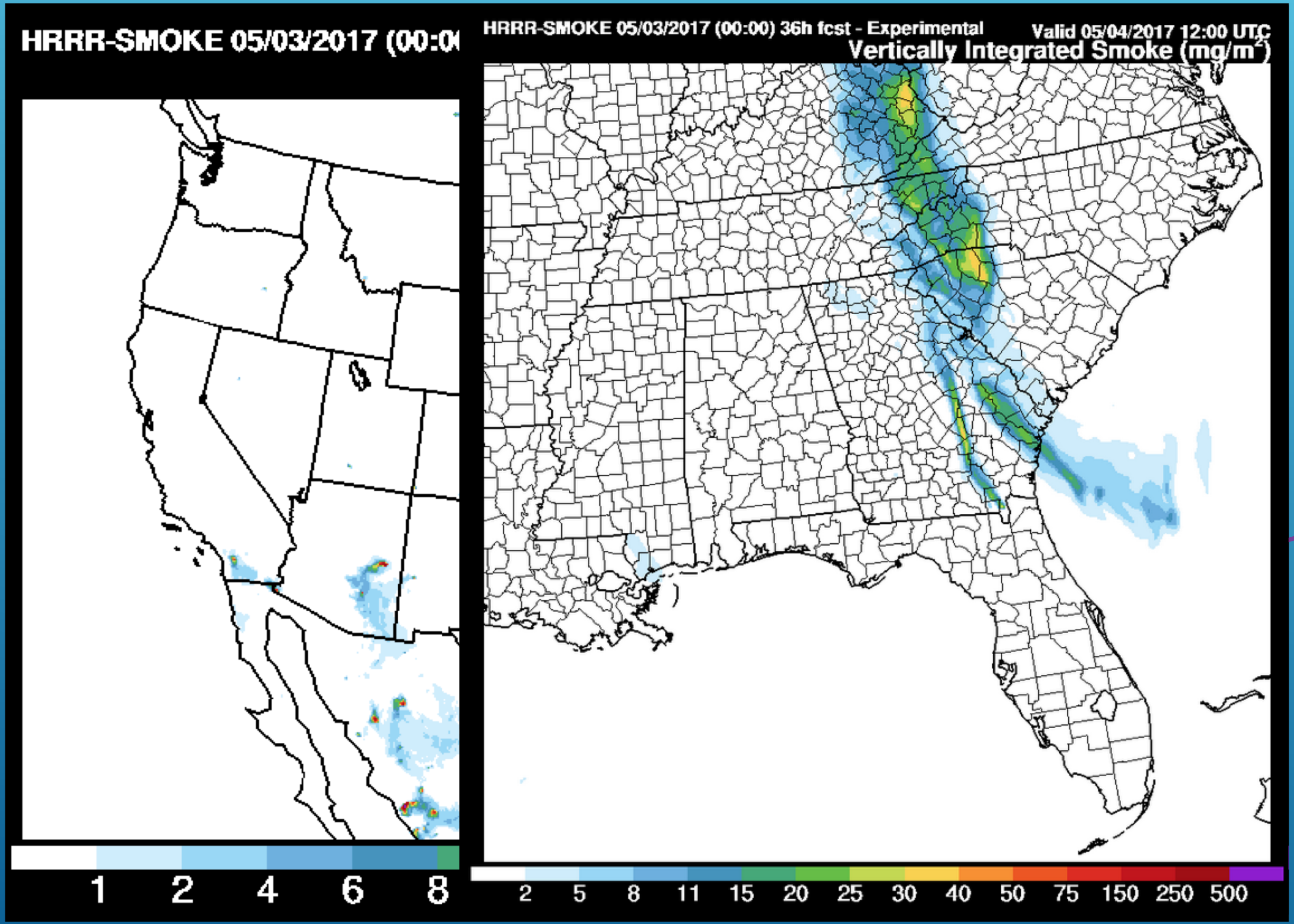


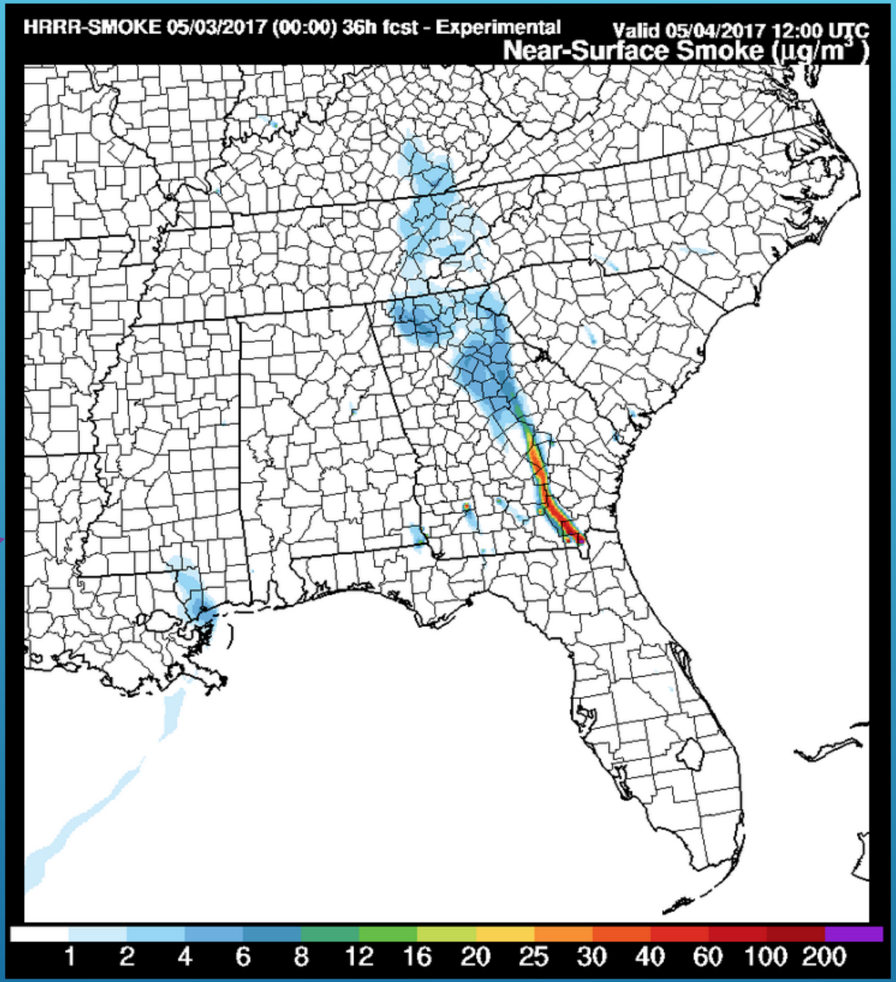
Averaged VIIRS FRP data mapped over 3x3km HRRR CONUS grid pixels for May 3, 2017



Smoke forecast for May 4, 2017 (rapidrefresh.noaa.gov/hrrr/HRRRsmoke/)

This plot shows simulated fire emitted fine particulate matter (PM2.5 or fire smoke) concentrations at the first model level (~8m above ground). The following plot shows forecast of near-surface fire smoke for May 4, 8am EDT over the CONUS and its subdomain. This forecast is based on the model simulation of 36 hours from the model initialization time, which is 8pm EDT, May 2, 2017.





The real-time HRRR-Smoke web-site for public access (rapidrefresh.noaa.gov/hrrr/HRRRsmoke/)

U.S. Department of Commerce I National Oceanic & Atmospheric Administration I NOAA Research

Earth System Research Laboratory
High Resolution Rapid Refresh (HRRR)

Earth Modeling Branch (EMB) | Projects | GSD Home | ESRL Home

HRRR Home Info Page

Current and Forecast Graphics

Operational NCEP HRRR:
- NCEP HRRR CONUS Hourly
- NCEP HRRR CONUS Subhourly

Experimental HRRR Products:

Deterministic
- HRRR CONUS Hourly
- HRRR CONUS Subhourly
- HRRR CONUS Smoke
- HRRR Alaska
- HRRR Hawaii
- HRRR Caribbean
- HRRR PacNW 750m Nest
- HRRR Soundings
- HRRR Reflectivity Matrix
- HRRR Aviation Fields Hourly
- HRRR Aviation Fields Sub-hrly

Ensemble/Probabilistic
- HRRRE (HRRR Ensemble)
- HRRRE Control Member
- HRRR-TLE (Time-Lagged Ens)

Analysis/Nowcast
- HRRR RTMA 3D
- HRRR RTMA subhourly

Other NOAA HRRR graphics:
- **New HRRR Product Browser**
- Operational HRRR from NCEP
- Operational HRRR from SPC

HRRR Documentation

Operational Configuration:
- NCEP HRRR Config Files

GRIB2 Tables
- NCEP HRRR 2-D Hourly
- NCEP HRRR 2-D Sub-hrly
- NCEP HRRR 3-D Native Level
- NCEP HRRR 3-D Isobaric Level

Experimental Configuration:
- HRRR Config Files

HRRR-Smoke Model Fields - Experimental

Model: HRRR-smoke (Experimental)   Area: Full   Date: 11 Jun 2018 - 12Z

*** Experimental forecast, use at your own risk *** - see description.   RAP-Smoke (North America domain, 13.5 km resolution)

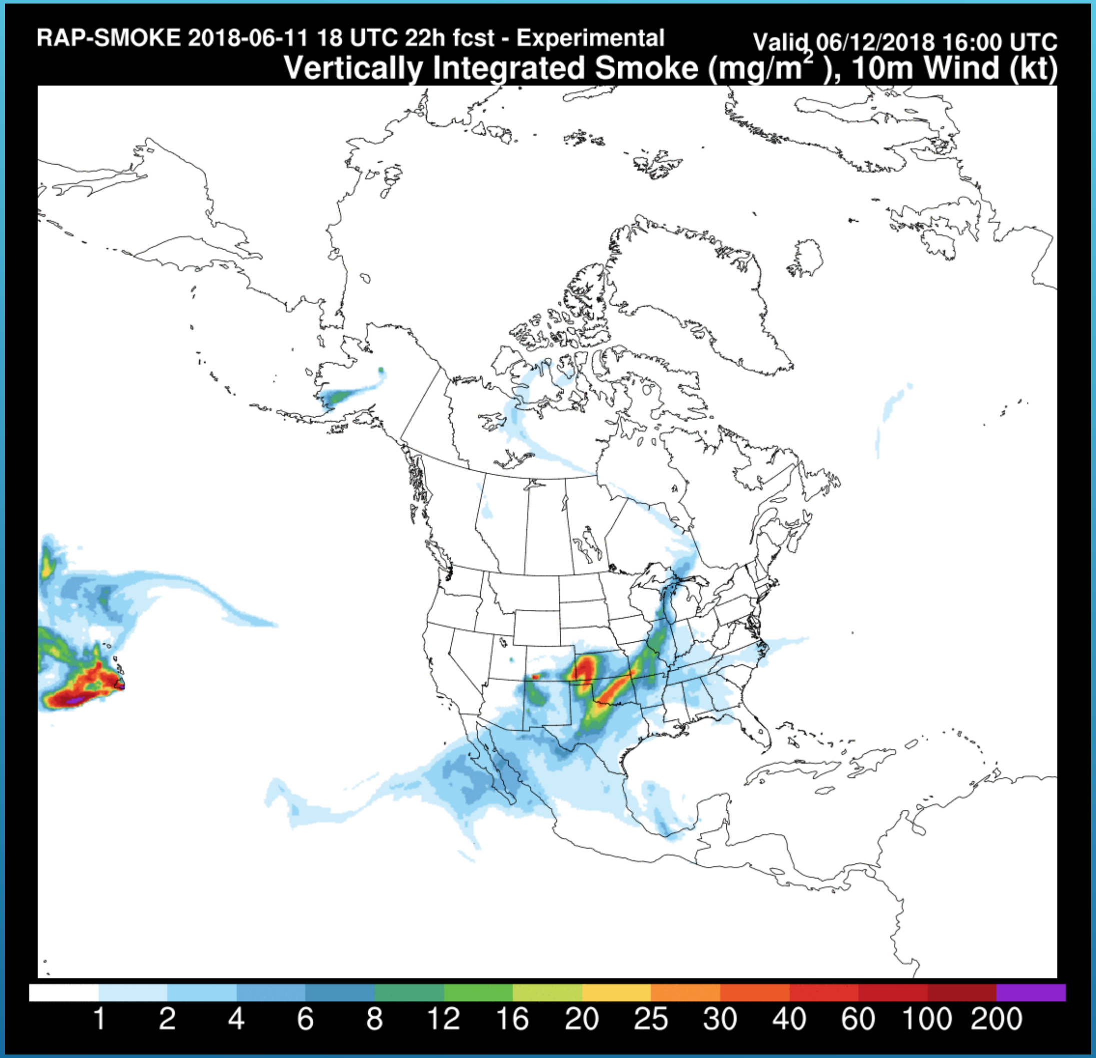
Visualization on Interactive Map

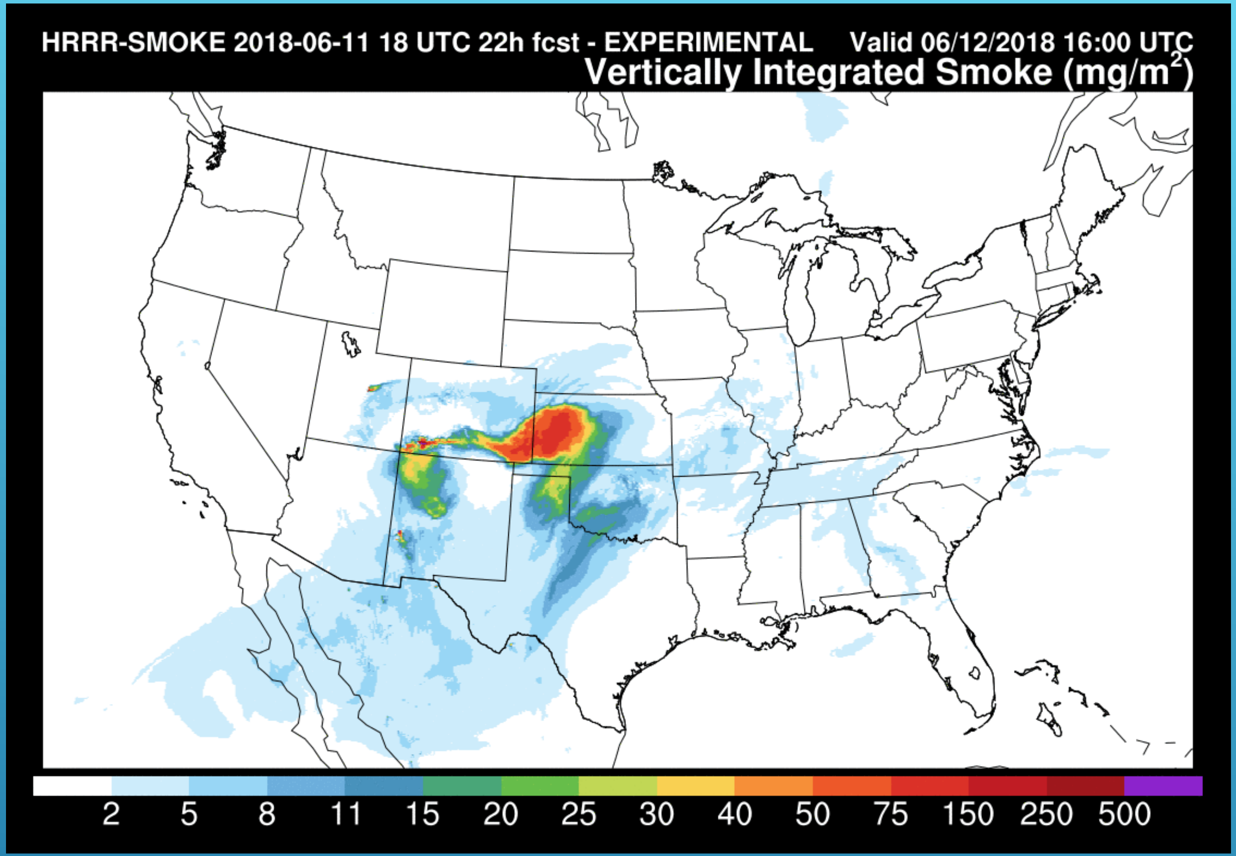
VIIRS Active fire quick guide

Model: HRRR-smoke (Experimental)   **Domain:** ✓ Full / NW / NC / NE / SW / SC / SE / Seattle-Portland / Central CA / Southern CA / WECAN   **Date:** 11 Jun 2018 - 12Z

Valid Time	All times	Loop	Mon 12				Mon 16	Mon 17	Mon 18	Mon 19	Mon 20	Mon 21	Mon 22	Mon 23	Tue 00	Tue 01	Tue 02	Tue 03	Tue 04	Tue 05	Tue 06	Tue 07	Tue 08	Tue 09	Tue 10	Tue 11	Tue 12	Tue 13	Tue 14
Forecast			00				04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
all fields			00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
fire radiative power	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
near-surface smoke	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1000 ft AGL smoke	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
vertically integrated smoke	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
10m wind	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1h precip	✔	✔		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
2m temperature	✔	✔	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

RAP-smoke and HRRR-smoke (based on WRF-chem)

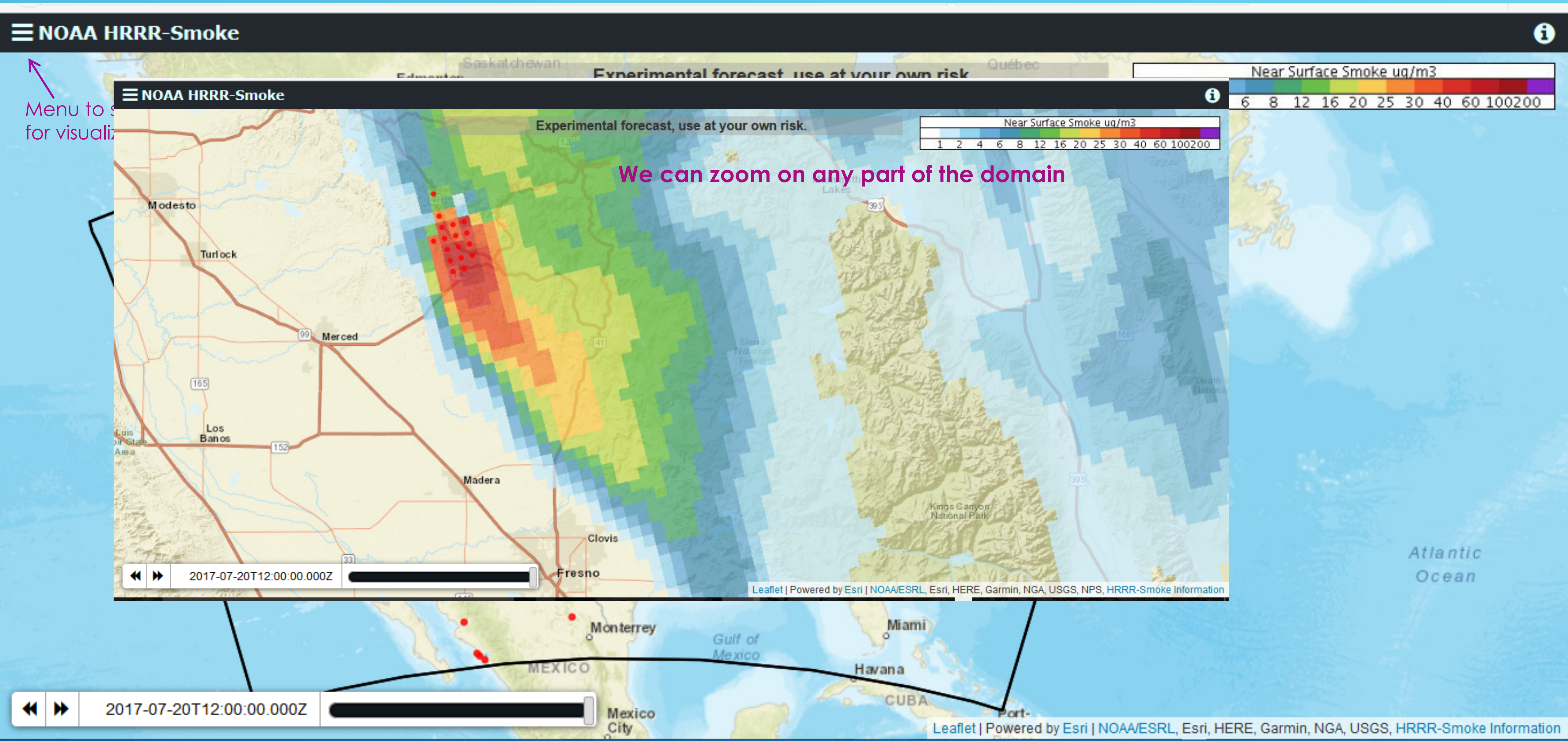




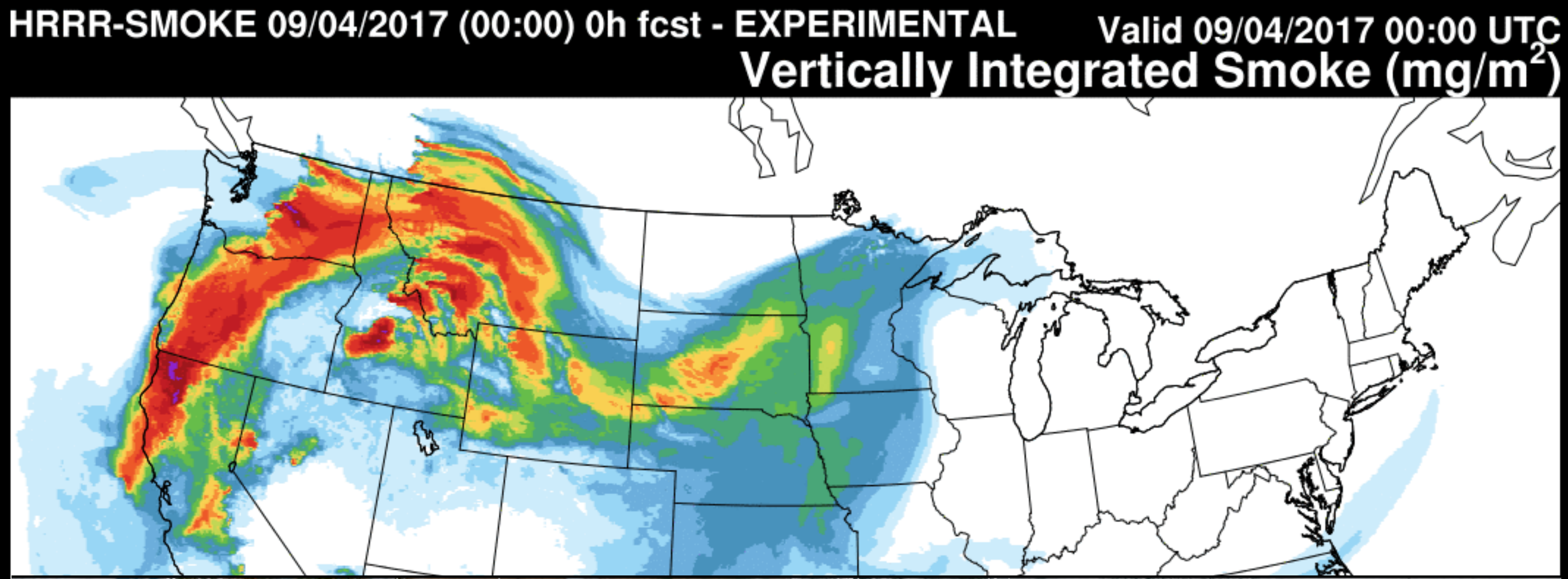
https://rapidrefresh.noaa.gov/RAPsmoke
https://rapidrefresh.noaa.gov/hrrr/HRRRsmoke

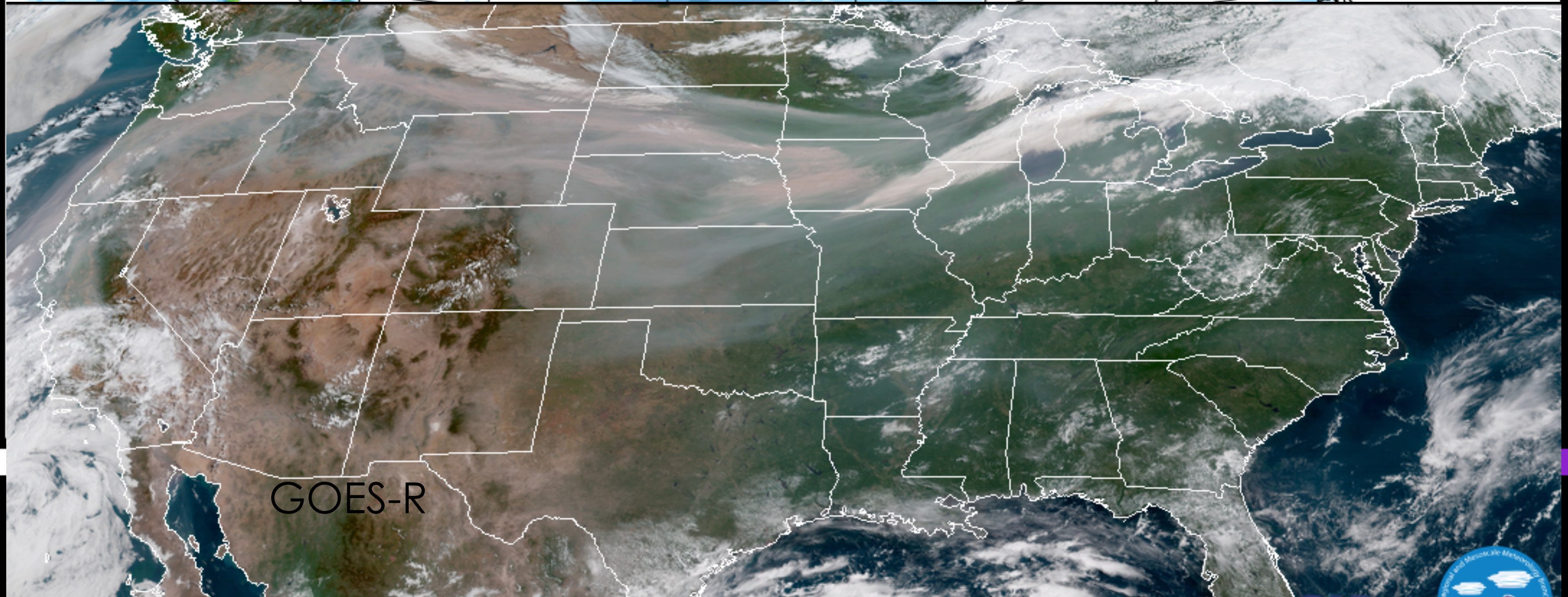
22h forecasts valid at 16 UTC 12 June 2018

Visualization of HRRR-Smoke forecast over zoomable map

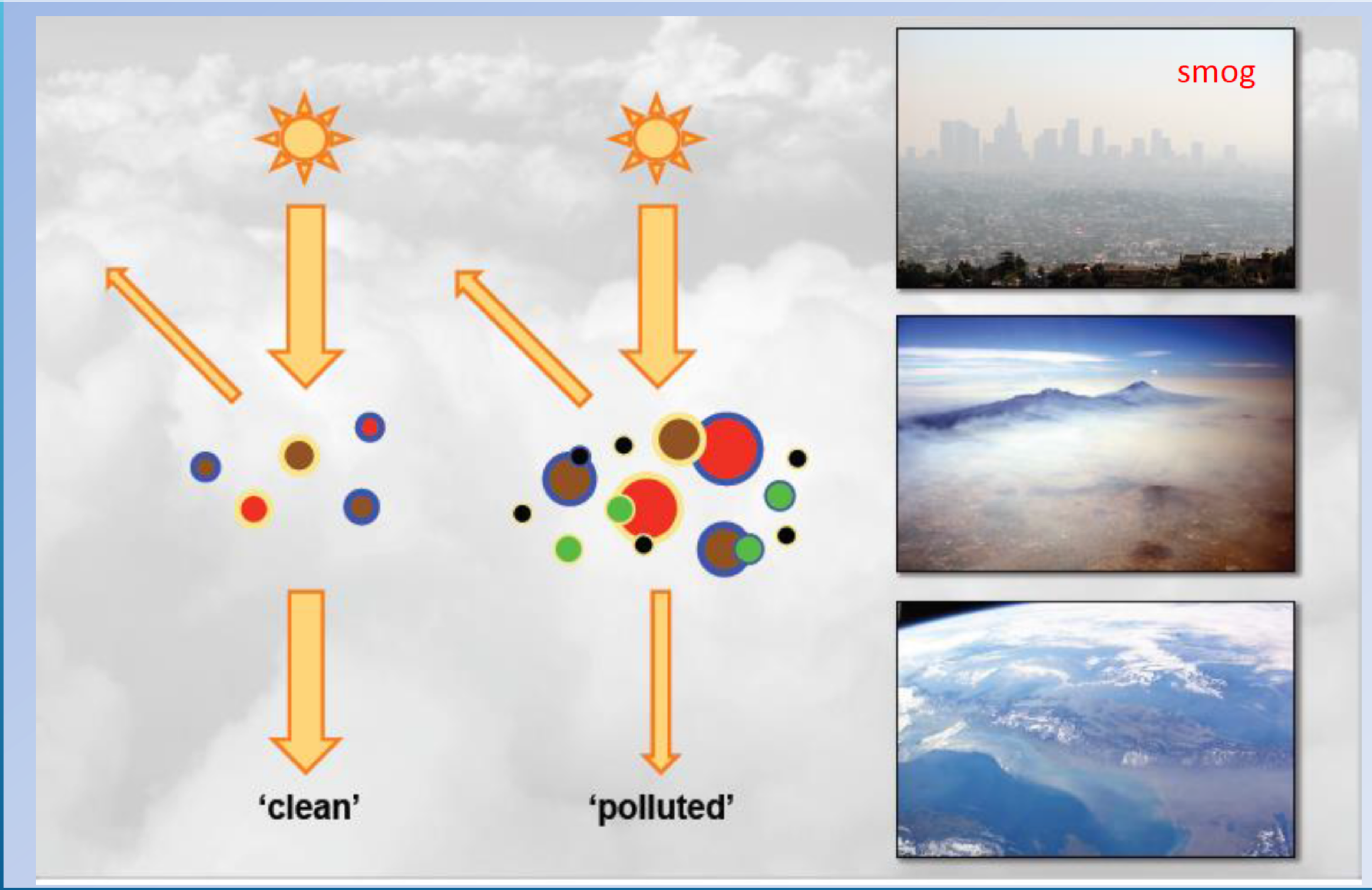


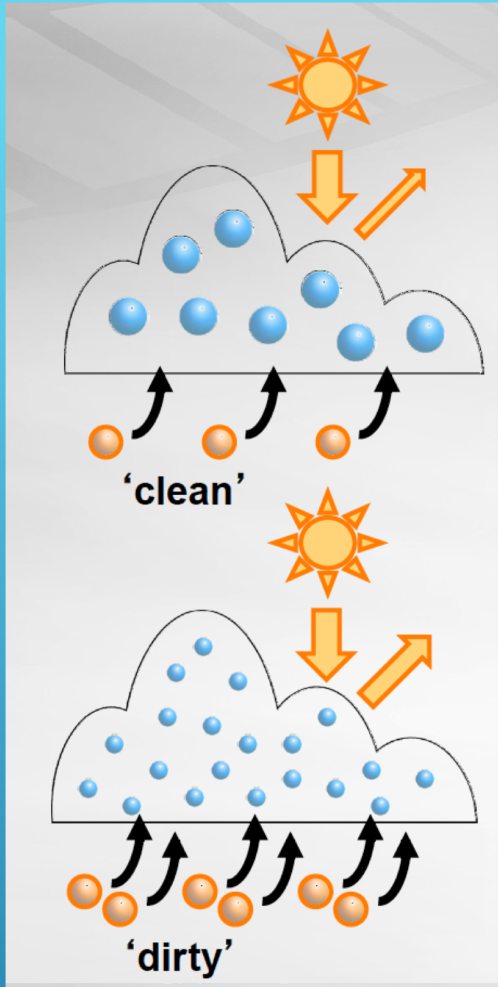
https://hwp-viz.gsd.esrl.noaa.gov/smoke/index.html https://rapidrefresh.noaa.gov/hrrr/HRRRsmoke/





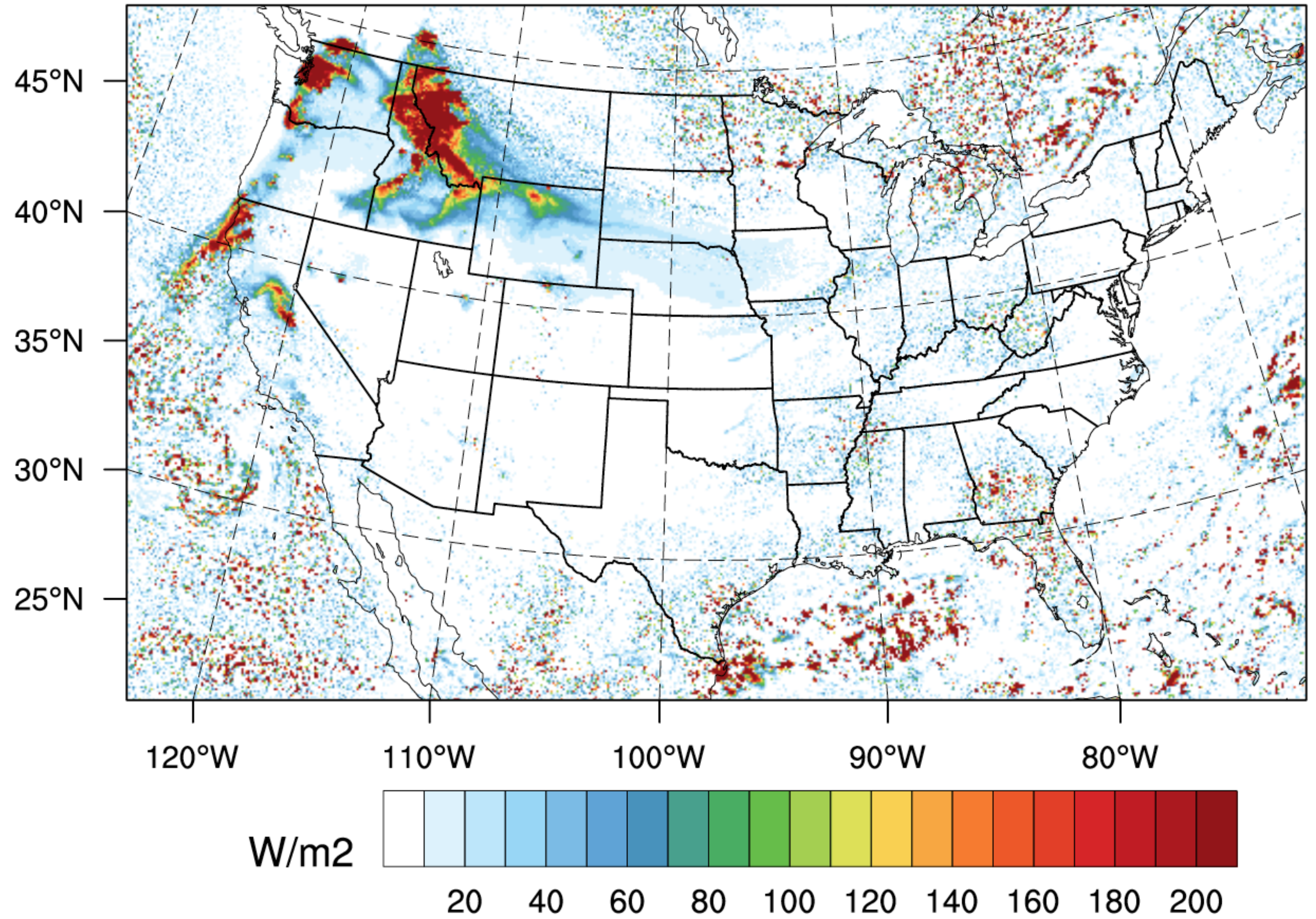
Simulating smoke feedback (direct and indirect) in HRRR-Smoke using double moment Thompson microphysics scheme



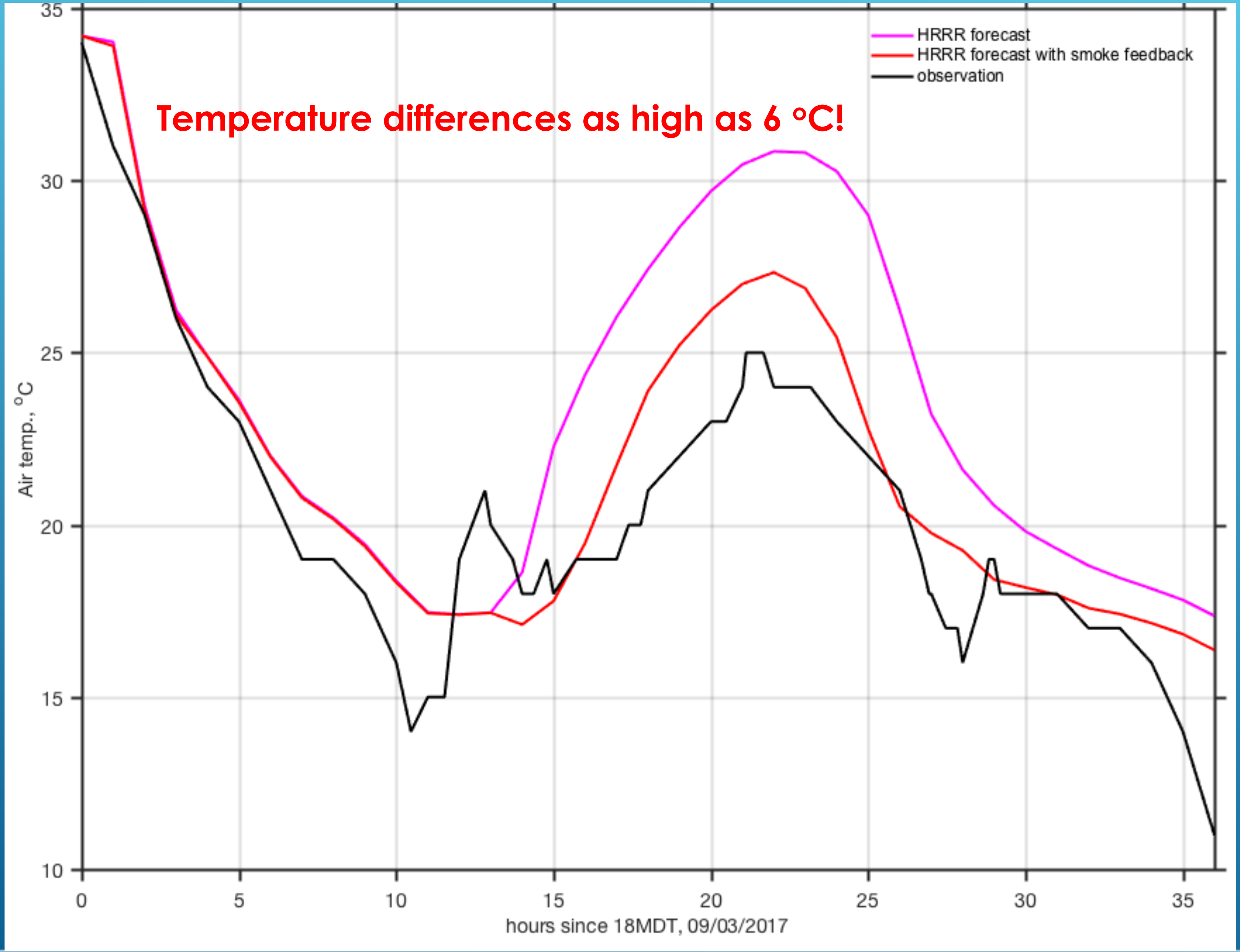


Adapted from J.Fast (WRF-Chem tutorial)

Simulated reduction in downward solar radiation, 12MDT, Sep4, 2017



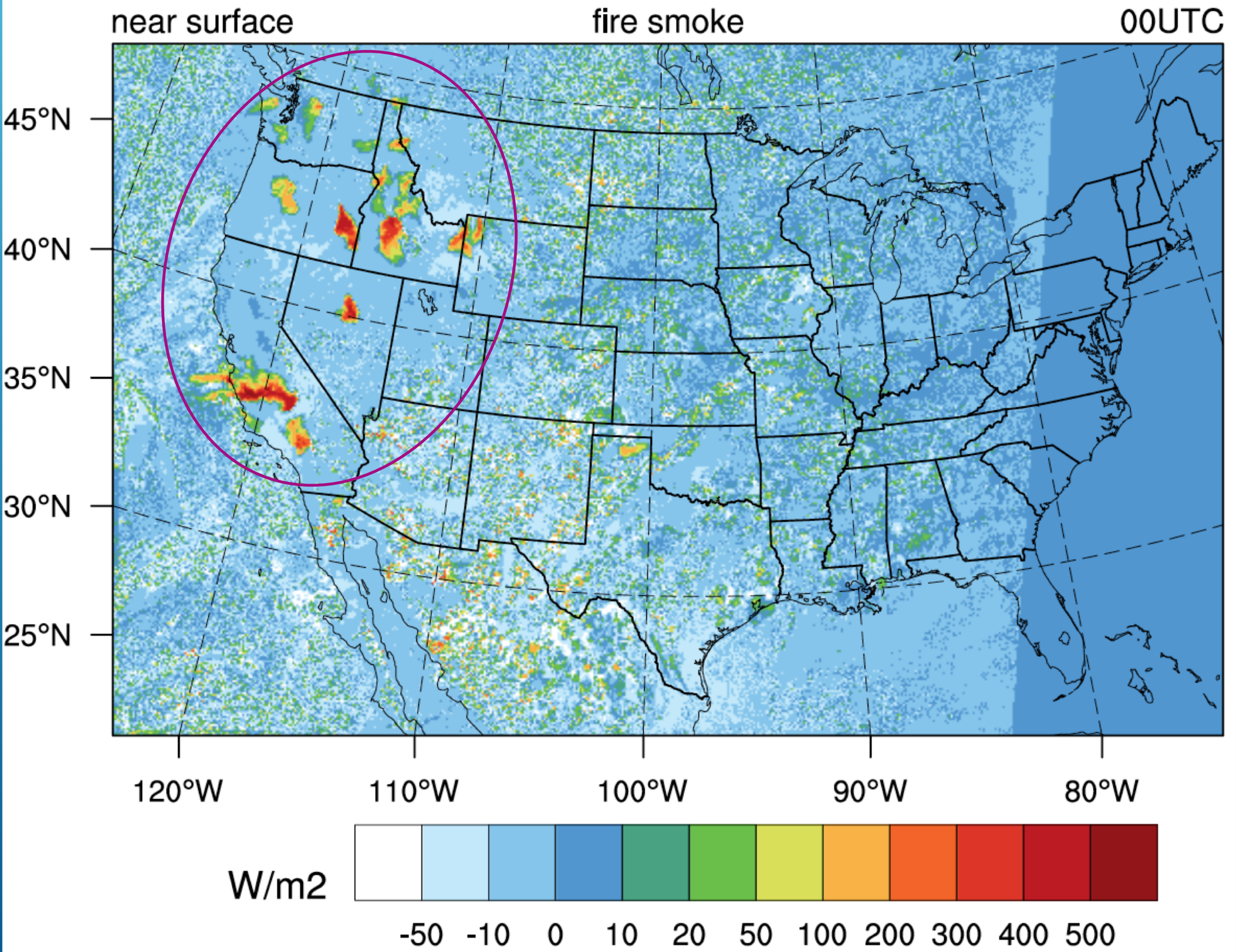
Air temperature forecast for Missoula, MT (impact of smoke)



Weather forecasting can be improved by using coupled meteorology-chemistry models like HRRR-Smoke

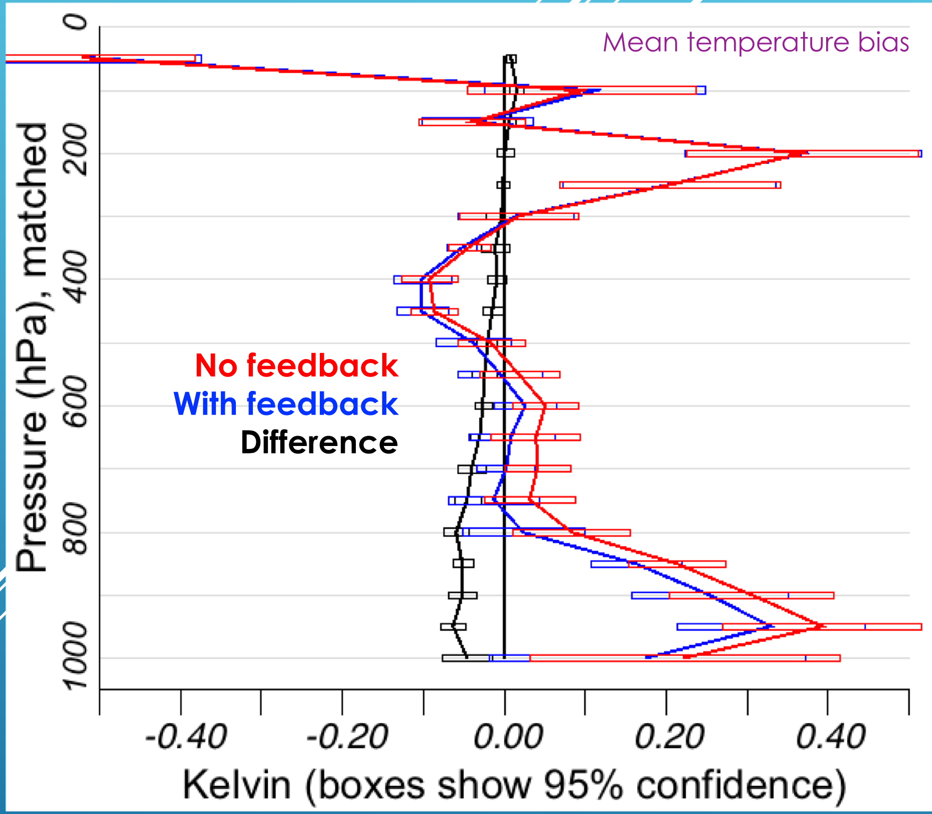
HRRR-Smoke weather prediction with and w/o smoke feedback on meteorology

Difference in shortwave radiation between HRRR-Smoke simulations without smoke feedback and feedback included, 8pm EDT, August 20, 2016



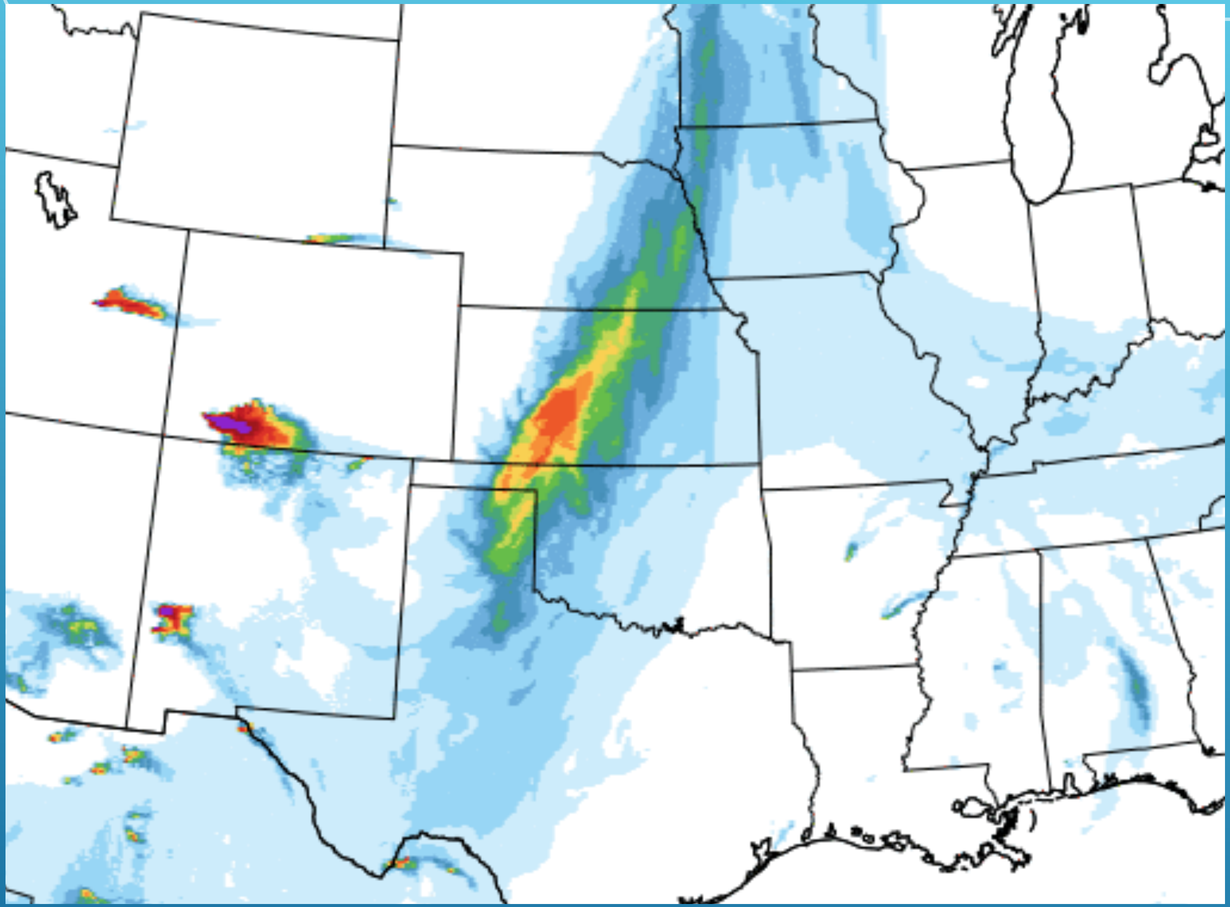
Verification study using HRRR-Smoke for August 12-20, 2016

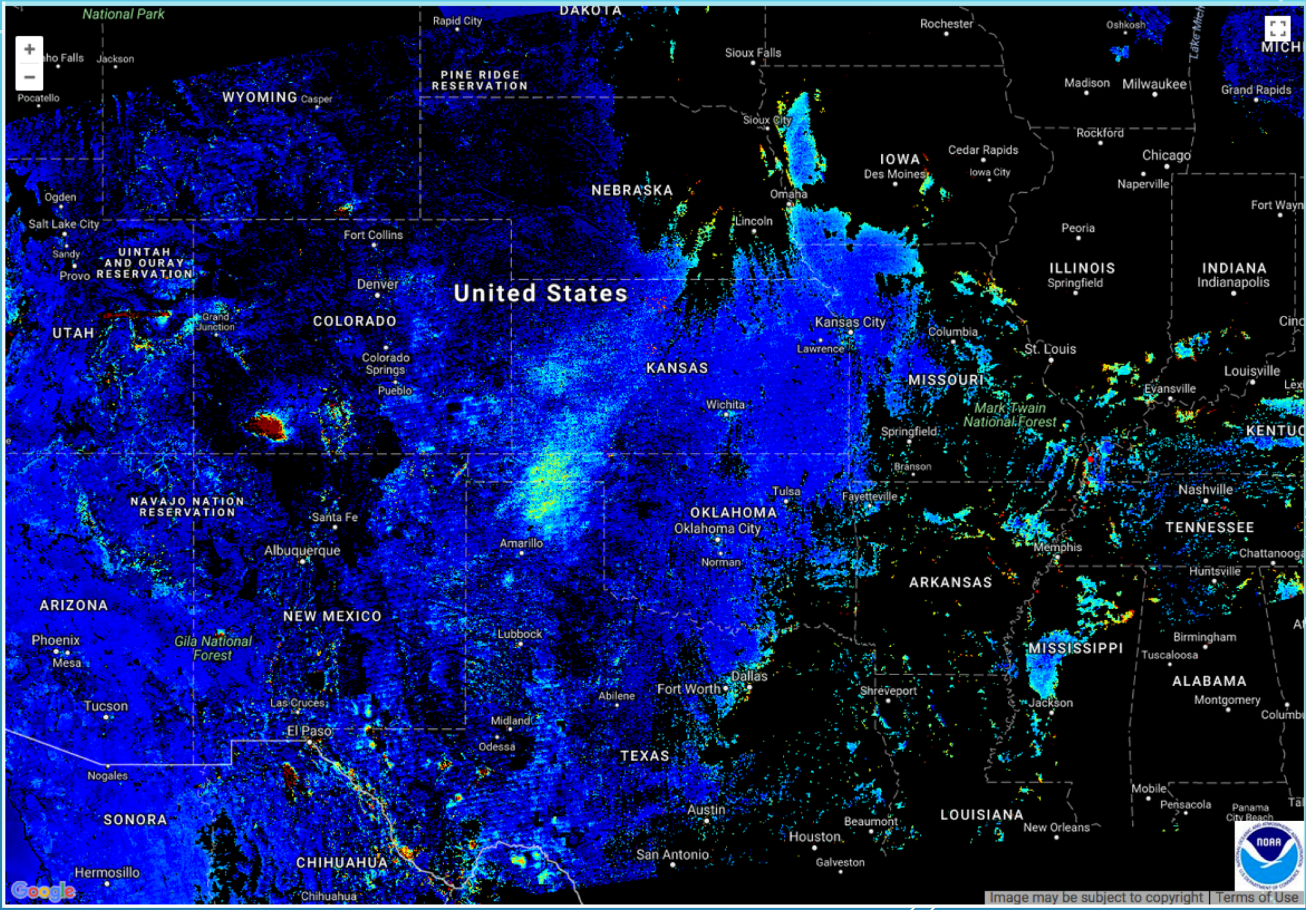
Temperature bias verification of 18 hour model forecast using radiosounding measurements in the US



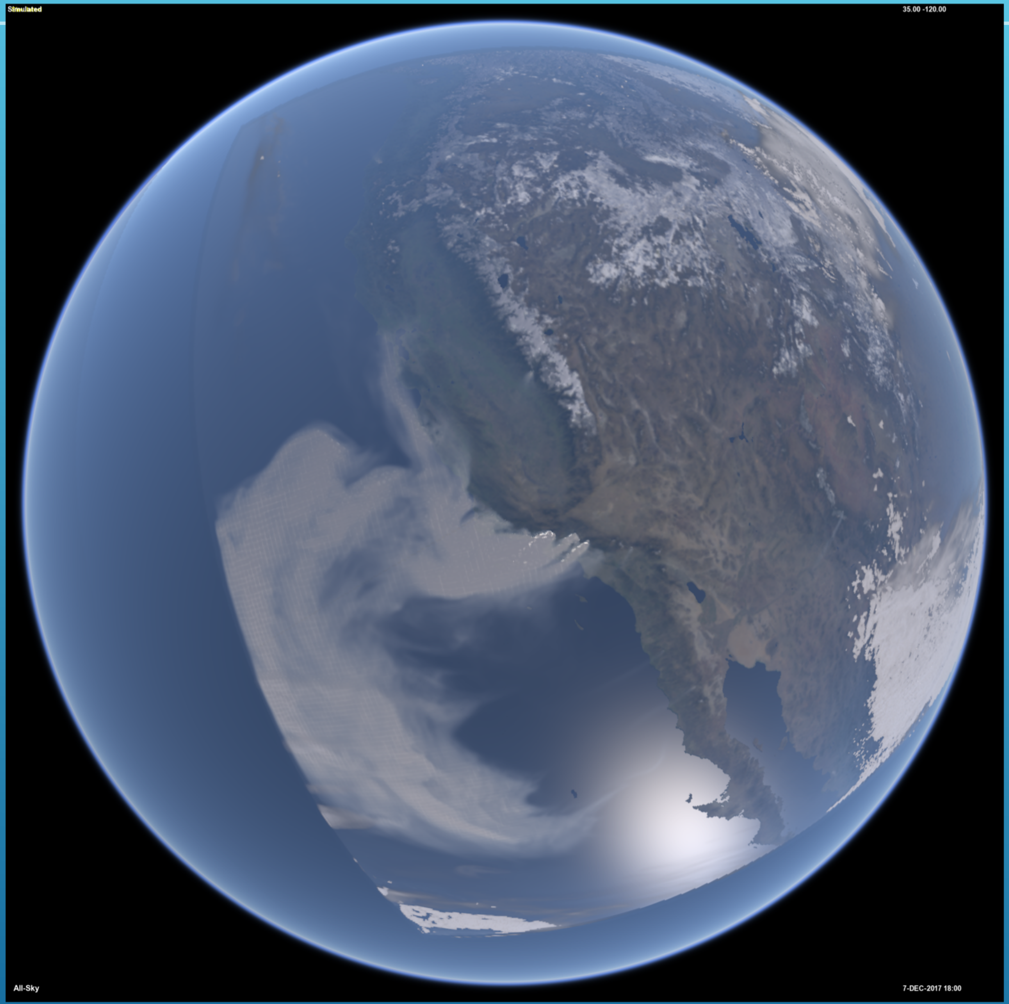
Including smoke feedback on meteorology reduces forecasted temperature bias.

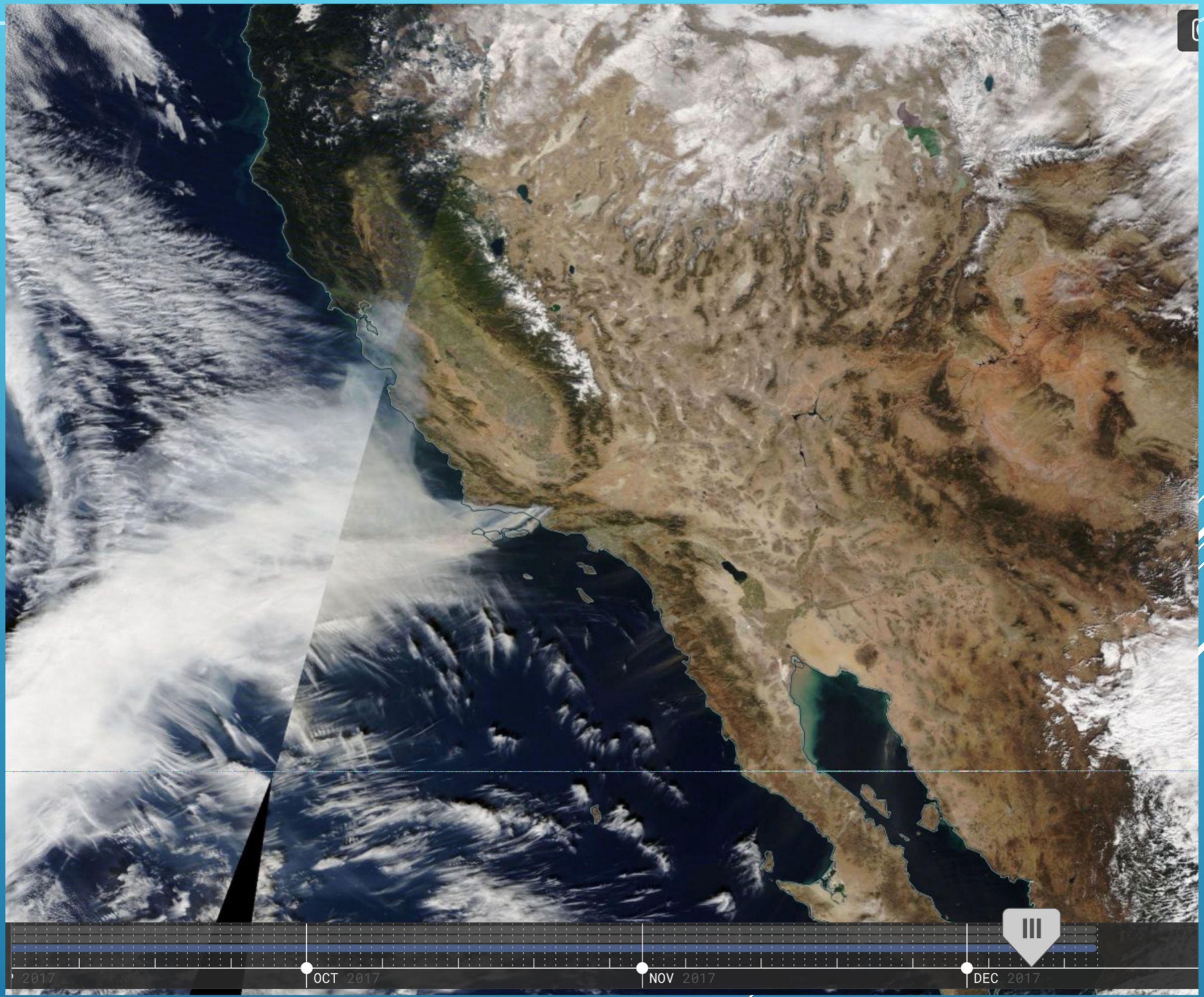
Qualitative Aerosol Optical Depth Evaluation (valid yesterday, 11 June 2018)





Recent California fires (Thomas fire), December 7, 2017





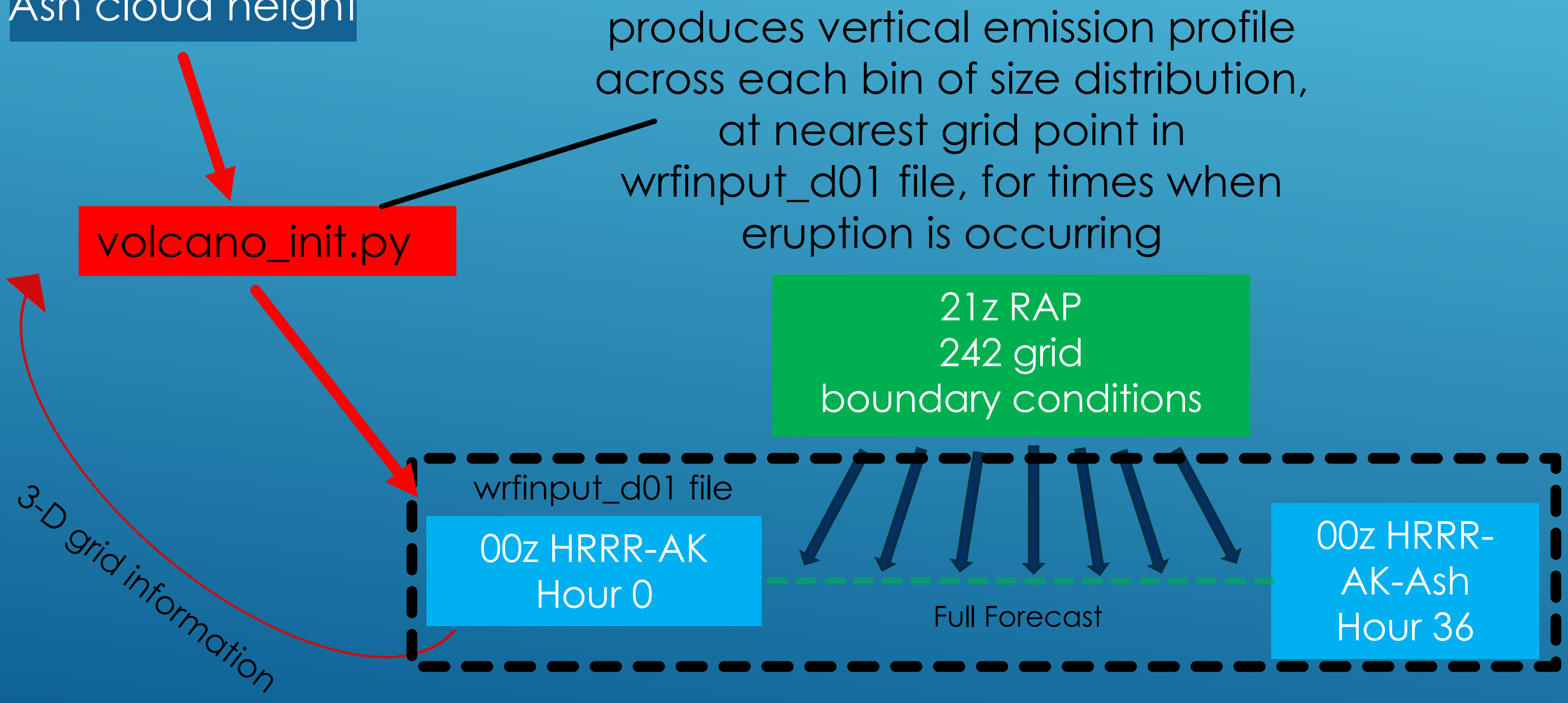
HRRR-Smoke 800km Altitude Simulated Fisheye View SoCal Fires
18UTC **Dec 7, 2017** (30 hour forecast)
3-D Hydrometeors + Aerosols
(S.Albers, CIRA)

Satellite image
worldview.earthdata.nasa.gov

Volcanic Ash Initialization

- Advisories and warnings for Alaska are issued by the Alaska Volcano Observatory.
- Advisories provide eruption time, duration, and ash cloud height.
- For real-time application, we can use climatological eruption parameters when advisories are not available.

AVO RSS Feed
Volcano name
Eruption time
Eruption duration
Ash cloud height



Volcanic Ash Initialization

```
!------------------------------------------------------------------------------------------
! Volcanoes
!------------------------------------------------------------------------------------------
!    Lat      | Long |  Elevation !Time | Eruption | Turn on/off |name
!             |      |    (m)     |Frame| Type     |  emission   |
!------------------------------------------------------------------------------------------
   50.1700,     6.8500,     600.00,   7.,   5., 1., &! ,'WESTEIFELVOLCFIELD          '&!   1
   45.7750,     2.9700,    1464.00,   7.,   1., 1., &! ,'CHAINEDESPUYS               '&!   2
   42.1700,     2.5300,     893.00,  -1.,   1., 1., &! ,'OLOTVOLCFIELD               '&!   3
   38.8700,    -4.0200,    1117.00,   7.,   1., 1., &! ,'CALATRAVAVOLCFIELD          '&!   4
   43.2500,    10.8700,     500.00,   6.,   5., 1., &! ,'LARDERELLO                  '&!   5
   42.6000,    11.9300,     800.00,   7.,   5., 1., &! ,'VULSINI                     '&!   6
   41.7300,    12.7000,     949.00,  -2.,   5., 1., &! ,'ALBANHILLS                  '&!   7
   40.8270,    14.1390,     458.00,   5.,   5., 1., &! ,'CAMPIFLEGREI                '&!   8
   40.8210,    14.4260,    1281.00,   2.,   7., 1., &! ,'VESUVIUS                    '&!   9
   40.7300,    13.8970,     789.00,   6.,   5., 1., &! ,'ISCHIA                      '&!  10
```

```
53.9300, -168.0300,    150.00,  2.,   7., 1.,  &!  ,'BOGOSLOF
```

Volcanoes are classified as several different types.

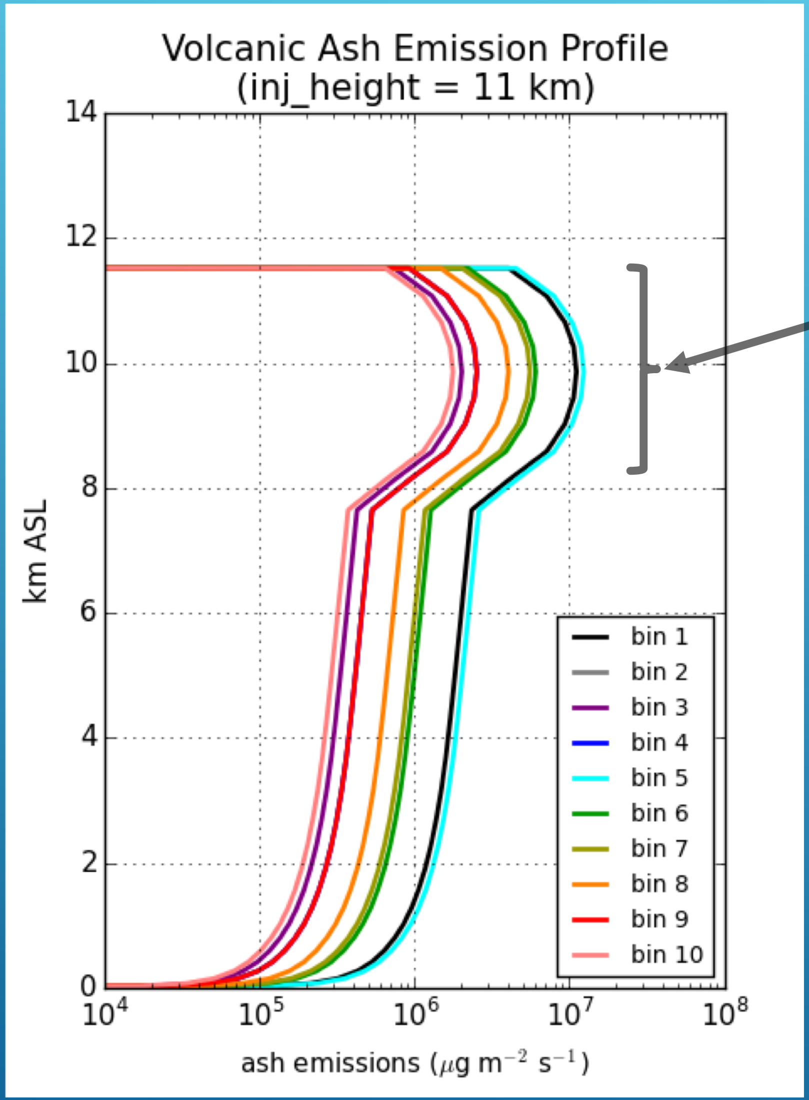
```
!-----------------------------------------------------------------------------------------
!    H km     |Duration| Eruption      | Volume      | mass fraction    | ESP     |    Type   | Example
! above vent  |  hr    | rate (kg/s)|  (km3)      | < 63 micron      |         |           |
!-----------------------------------------------------------------------------------------
      7.,        60.,     1.E+05,      0.01   ,       0.05,           &!1    M0 !Standard mafic
      2.,        100.,    5.E+03,      0.001  ,       0.02,           &!2    M1 !small mafic          !
      7.,        60.,     1.E+05,      0.01   ,       0.05,           &!3    M2 !medium mafic         !
     10.,        5.,      1.E+06,      0.17   ,       0.1 ,           &!4    M3 !large mafic          !
     11.,        3.,      4.E+06,      0.015  ,       0.4 ,           &!5    S0 !standard silicic     !
      5.,        12.,     2.E+05,      0.003  ,       0.1 ,           &!6    S1 !small silicic        !
     11.,        3.,      4.E+06,      0.015  ,       0.4 ,           &!7    S2 !medium silicic       !
     15.,        8.,      1.E+07,      0.15   ,       0.5 ,           &!8    S3 !largnvolcanoese silicic
     25.,        0.5,     1.E+08,      0.05   ,       0.5 ,           &!9    S8 !co-ignimbrite silicic!
     10.,        0.01,    3.E+06,      0.0003,        0.6 ,           &!10   S9 !Brief silicic        !
      0.,        -1.,    -1.,         -1.,           -1.              &!11   U0 !default submarine     !
```

Each type exhibits different climatological characteristics

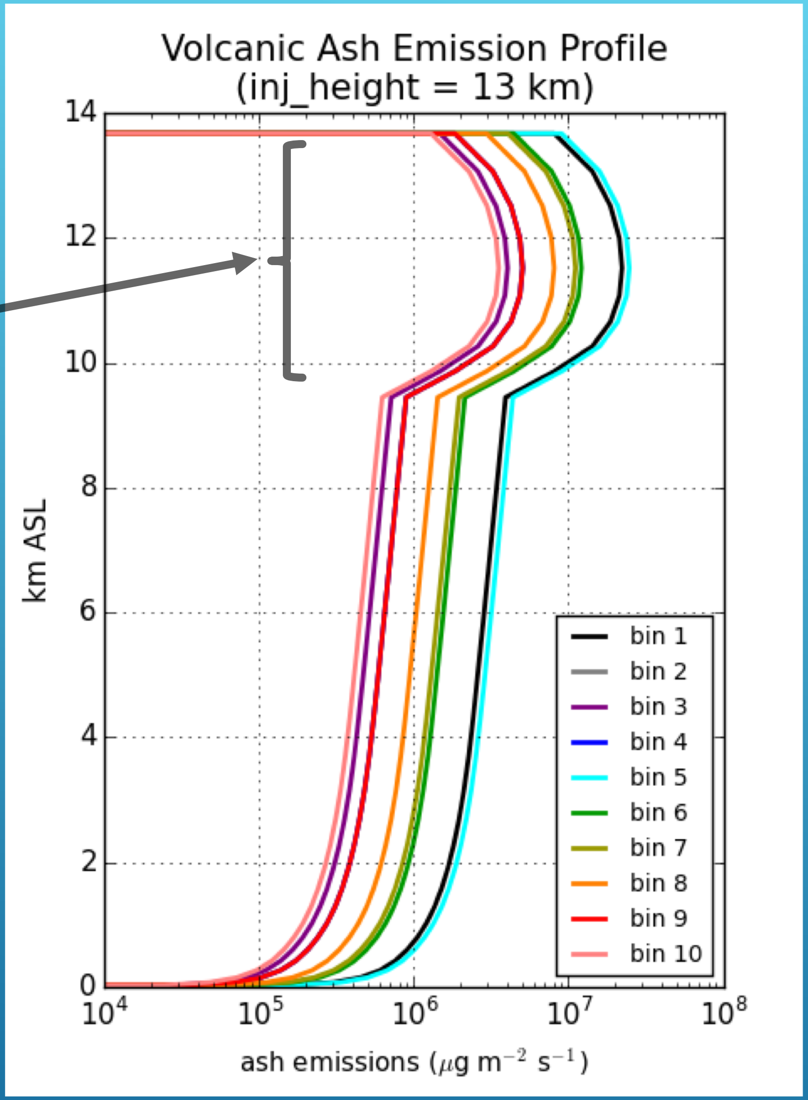
```
!----------------------------------------------------------------------------------------------------!
!                               P. Webley - size distribution
!                                                                                                    !
!Ash bin      Min       Max       phi    M0       M1       M2       M3       S0       S1       S2       S3       S8       S9       !
!          Size (um) Size (um)                                                                                                     !
!1            1000      2000      -1     6.5       0        6.5      13       22       24       22       2.92     2.92     0        !
!2            500       1000      0      12       4        12       20       5        25       5        3.55     3.55     0        !
!3            250       500       1      18.75    10       18.75    27.5     4        20       4        11.82    11.82    0        !
!4            125       250       2      36.25    50       36.25    22.5     5        12       5        8.24     8.24     9        !
!5            62.5      125       3      20.5     34       20.5     7        24.5     9        24.5     7.9      7.9      22       !
!6            31.25     62.5      4      3        2        3        4        12       4.25     12       13.02    13.02    23       !
!7            15.625    31.25     5      1.5      0        1.5      3        11       3.25     11       16.28    16.28    21       !
!8            7.8125    15.625    6      1        0        1        2        8        1.25     8        15.04    15.04    18       !
!9            3.90625   7.8125    7      0.5      0        0.5      1        5        0.75     5        10.04    10.04    7        !
!10           0         3.90625   8      0        0        0        0        3.5      0.5      3.5      11.19    11.19    0        !
!                                                                                                    !
!          Less than 63 um               6%       2%       6%       10%      40%      10%      40%      66%      66%      69%      !
!                                                                                                    !
!   Reference/notes          M0 = M2 Scollo et al 2007        Interpolated from M1 and M3       Rose et al (2007)                  !
!   Durant and Rose (2009 JVGR)      Bonadonna and Houghton 2005      Durant and Rose (2009 JVGR)                                 !
!   Durant et al 2009        Durant et al 2009        Bonadonna et al 2002                                                         !
```

Each type has ash distributed differently among 10 size bins

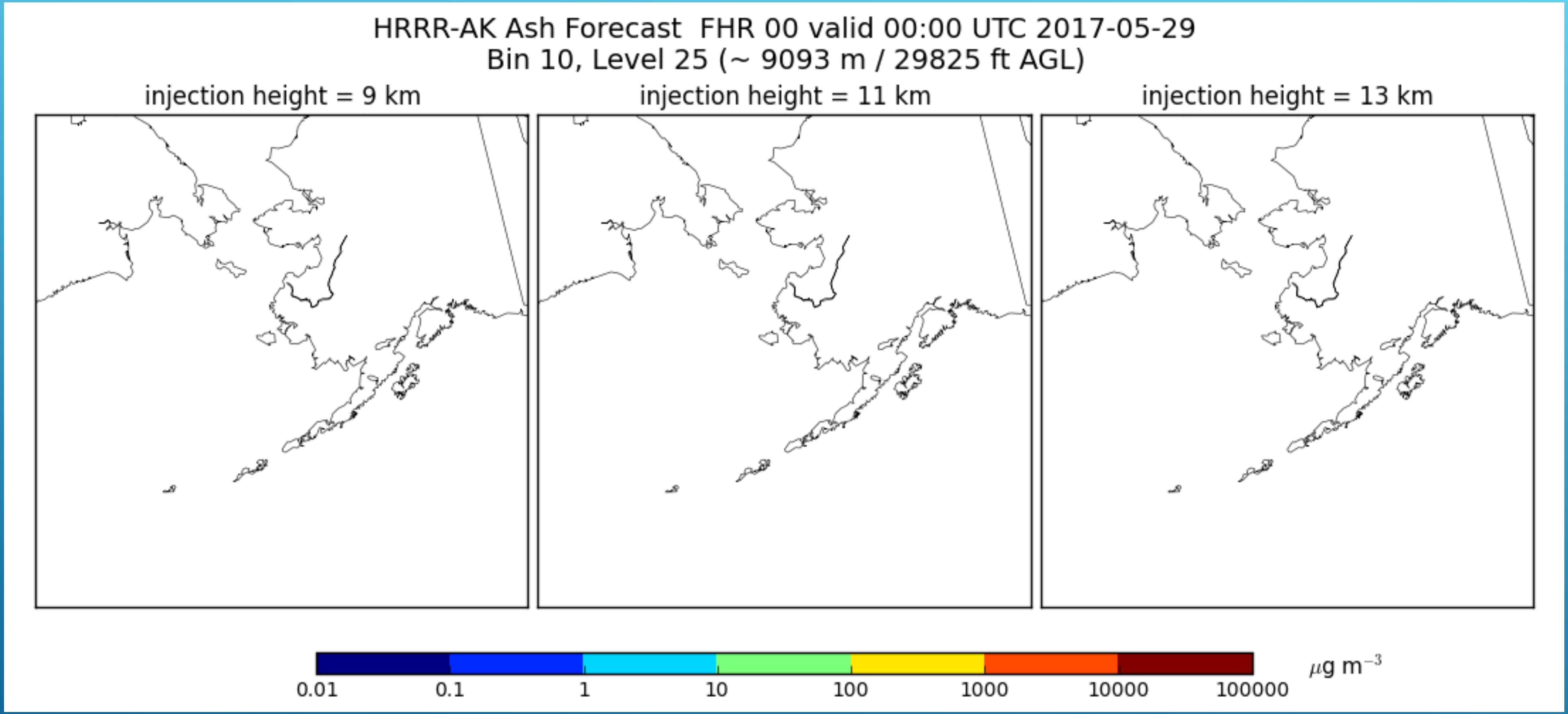
Volcanic Ash Initialization



75% of ash mass in "umbrella"



Bogoslof Eruption Case 29 May 2017



Concluding remarks and future plans

- The real-time **RAP-smoke** and **HRRR-smoke** modeling systems provide an online smoke forecasting tool, which is used by incident meteorologists, air quality agencies, researchers and the public.
- The models can help us to improve weather forecasting by including smoke feedback on meteorology.
- The real-time VIIRS provides valuable datasets for modeling fire emissions and model verification.

- *Adding visibility product to the forecast output;*
- *Transitioning **RAP-smoke** and **HRRR-smoke** to operations at NCEP*; ***RAP** and **HRRR** are already a part of the operational NWP suite at NCEP;*
- *Transitioning our smoke parameterization to NOAA's future NGGPS global modeling system*;
- *Using **HRRR-Smoke** (including NGGPS-Smoke in future) for upcoming intensive field campaigns in the US (FIREX, FIRE-Chem, WE-CAN) and further verification and refinement of the model using future aircraft measurements (e.g. parameterization of injection heights and emission factors);*
- *Assimilation of the VIIRS AOD product to improve smoke forecasting;*
- *Using high frequency GOES-R FRP data for rapid update of fire detection and emissions*; *Synergy with the GOES-R initiated fire and smoke related activities;*
- *Development of a real-time volcanic ash forecasting capability within the **RAP** and **HRRR**.*

THANK YOU FOR YOUR ATTENTION

ANY QUESTIONS OR COMMENTS ?

CONTACTS:
RAVAN.AHMADOV@NOAA.GOV
ERIC.JAMES@NOAA.GOV