Wildfire Applications and Emergency Response

Presenter: **Hyun Cheol Kim**

Other Team Members: **Tianfeng Chai, Daniel Tong, Yunyao Li**

NOAA Air Resources Laboratory

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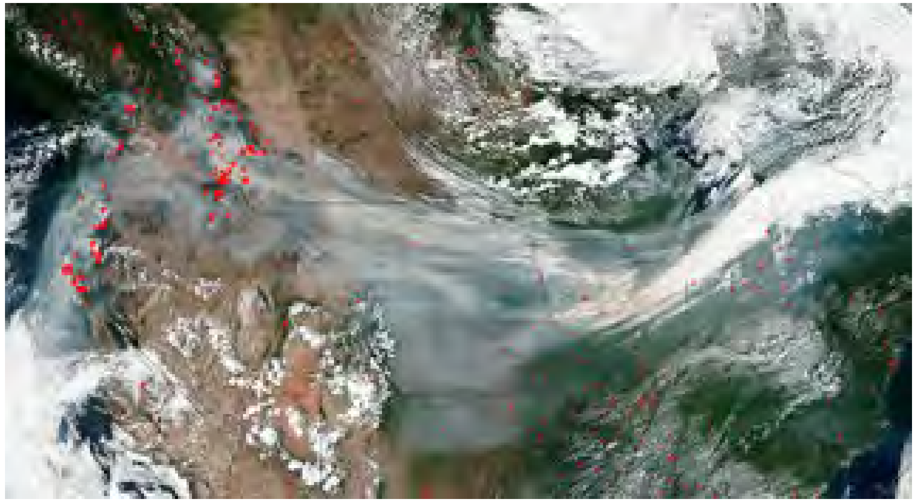
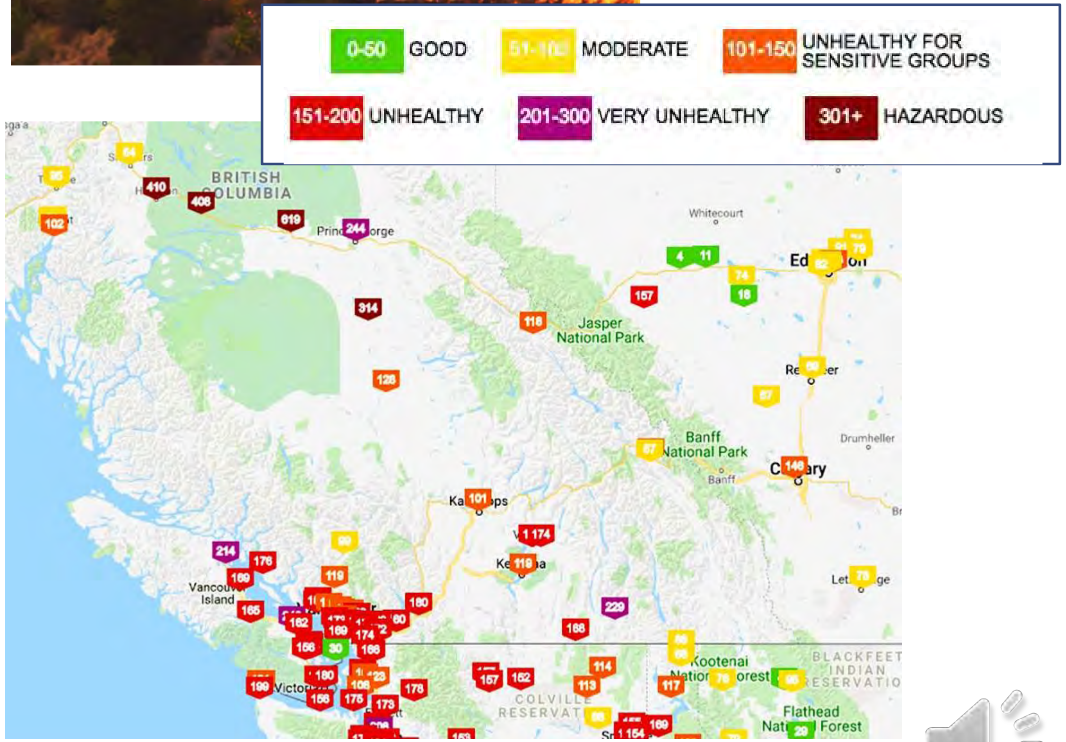
Wildfire Applications and Emergency Response

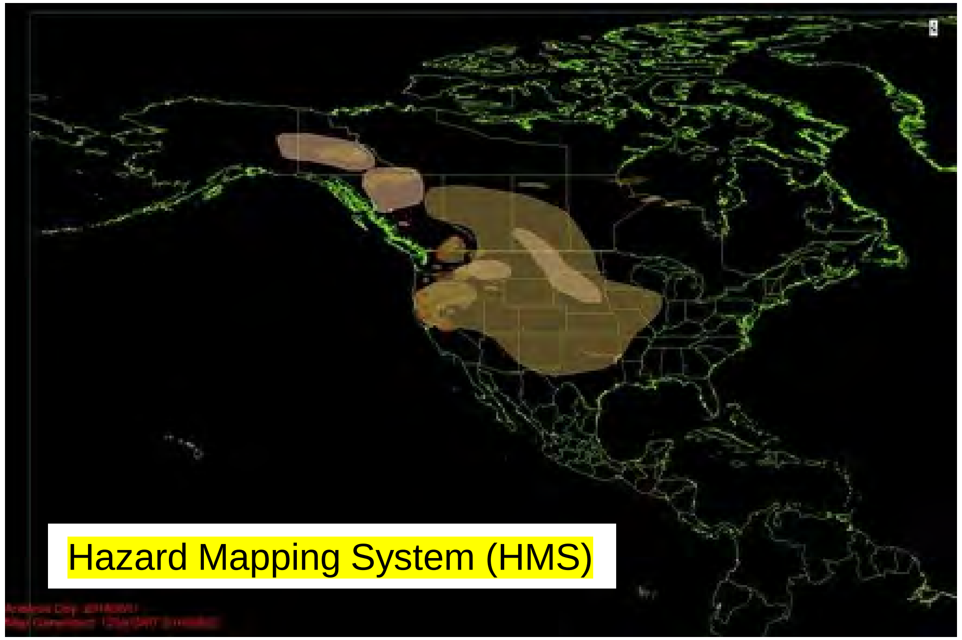
- **Smoke from wildfires can have significant negative impacts on public health;**
- **Air quality forecast accuracy is greatly hindered by large uncertainties in wildfire emission estimates;**
- **Our goals are to objectively and optimally estimate wildfire emissions based on observations of the fire plumes (satellite and other) and to provide robust air quality forecasts of wildfire air quality impacts.**

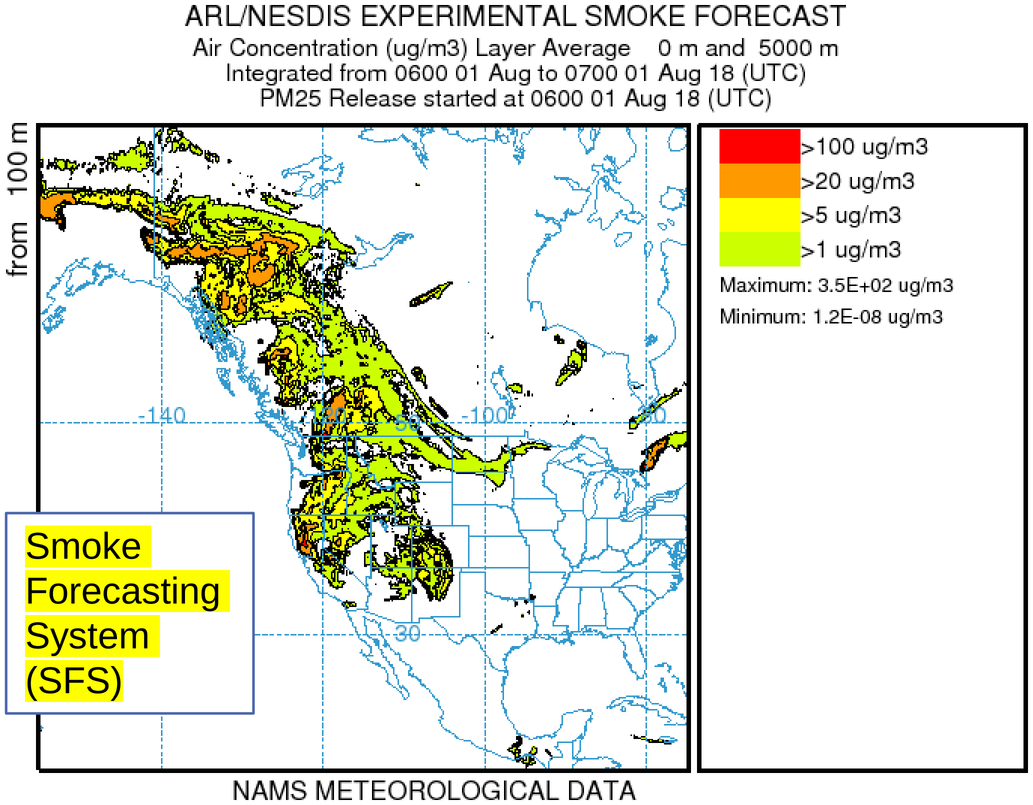




Relevance - "Make forecasts better, and detect changes in the atmosphere"

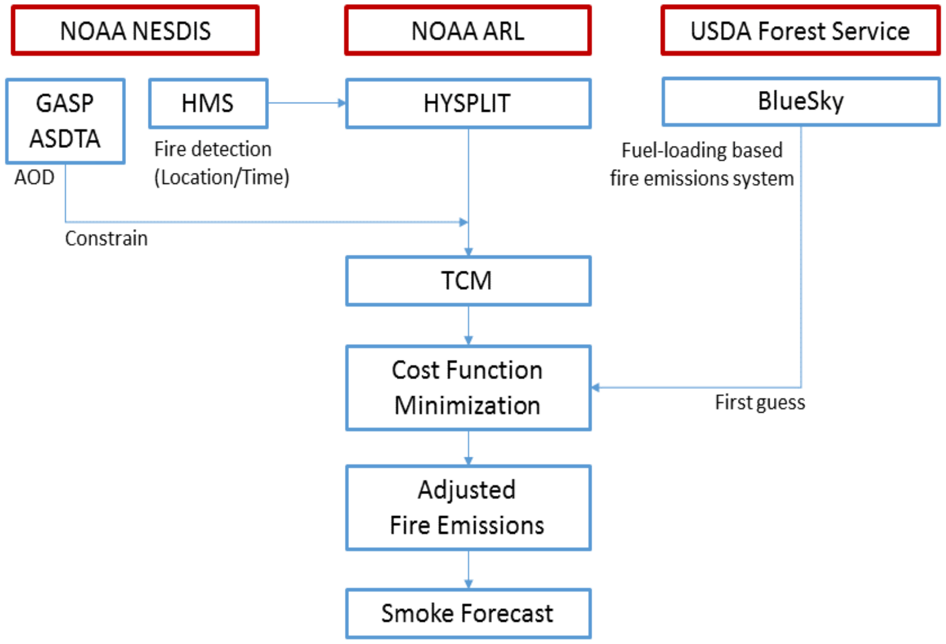
- The Smoke Forecasting System (SFS), based on HYSPLIT, USFS Blue Sky emissions model, and the NOAA-NWS Hazard Mapping System, has been operated since 2007.
- Continuing to improving fire emissions estimates and forecast smoke air quality impacts remains an important goal.



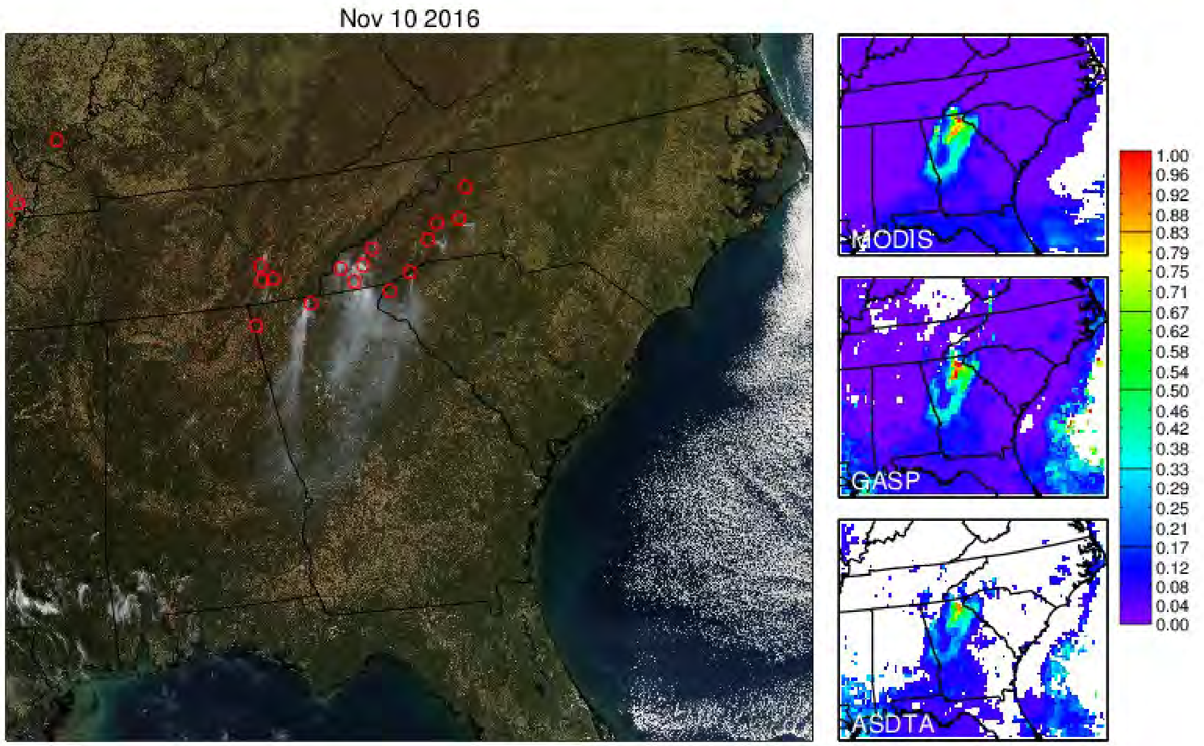


HYSPLIT-based Emission Inverse Modeling System for wildfires

- **The HEIMS-fire system has been developed to estimate wildfire emissions constrained by space-born satellite observations**



Schematic diagram of the HYSPLIT-based Fire Emission Inverse Modeling System.



Detection of fires over the southeastern region of the United States on November 10, 2016. True-color image from MODIS (left), MODIS AOD (top right), GASP AOD (middle right), and ASDTA AOD (bottom right) are shown.

Inverse modeling of fire emissions

- **An independent HYSPLIT simulation starting at each HMS fire location with given starting time and duration is run with a unit source, at several possible release height to generate a *Transfer Coefficient Matrix (TCM)*.**

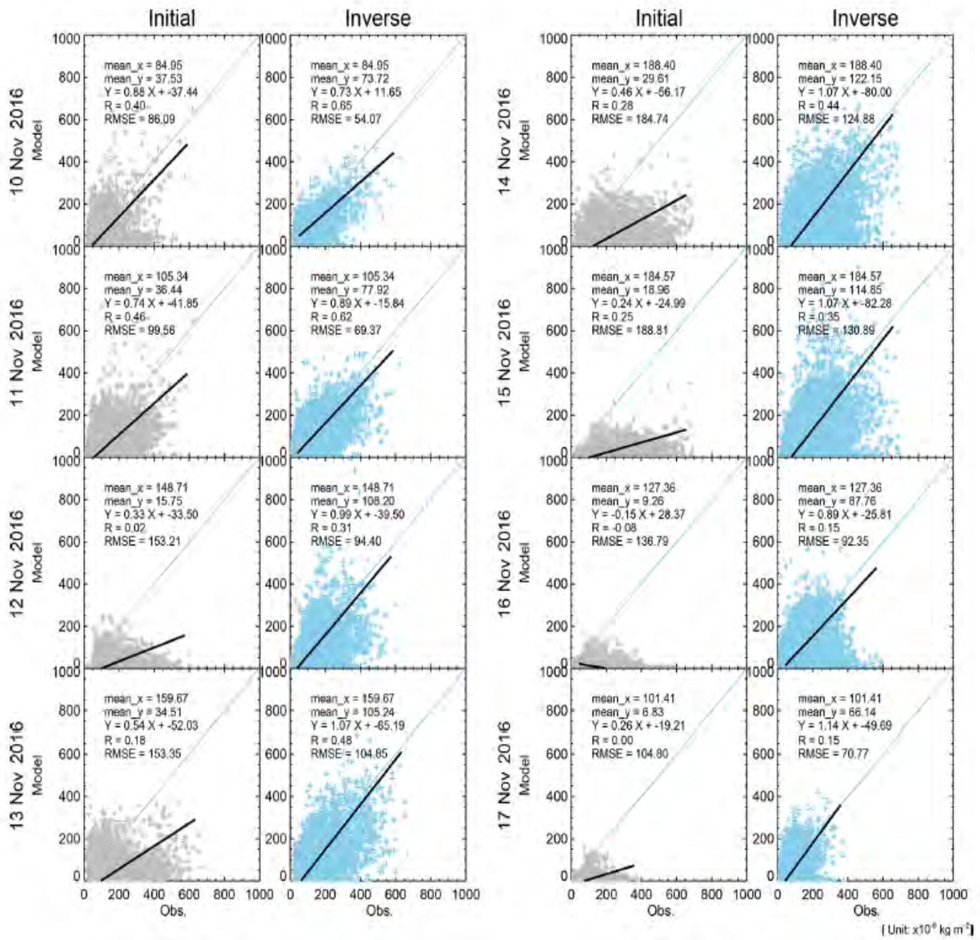
- **Source terms are solved by minimizing a cost function based primarily on the differences between model predictions and observations, following a general data assimilation approach.**

$$\mathcal{F} = \frac{1}{2}\sum_{i=1}^{N}\sum_{k=1}^{Z}\frac{(q_{ik} - q_{ik}^{b})^2}{\sigma_{ik}^2} + \frac{1}{2}\sum_{m=1}^{M}\frac{(c_m^h - c_m^o)^2}{\epsilon_m^2} + \mathcal{F}_{other}$$

First guess

HYSPLIT

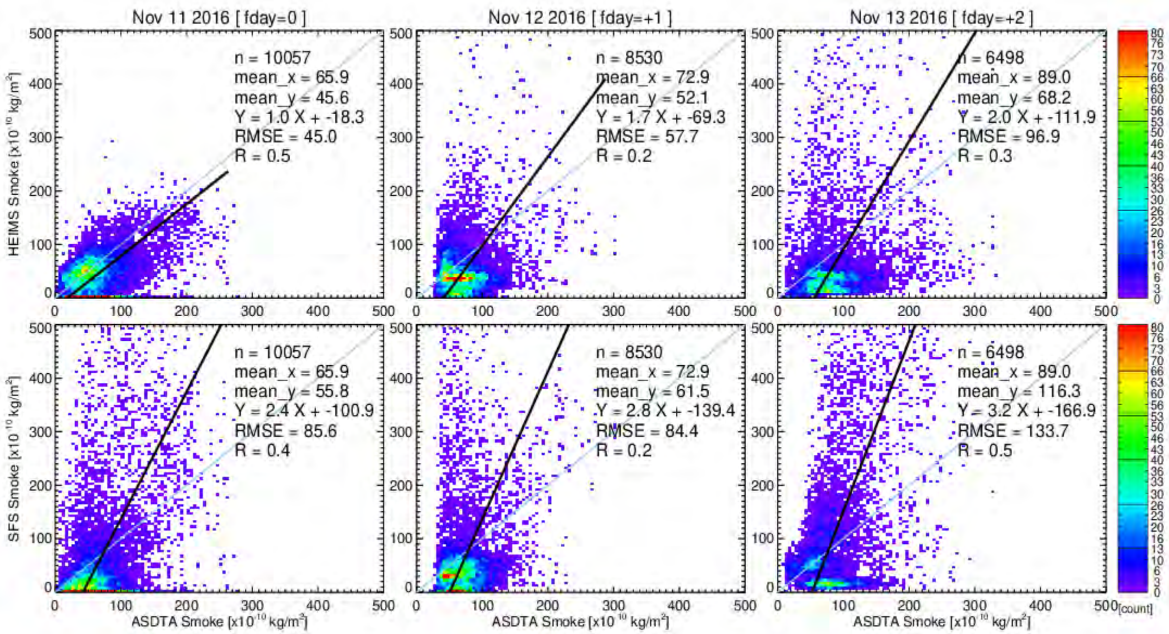
GASP



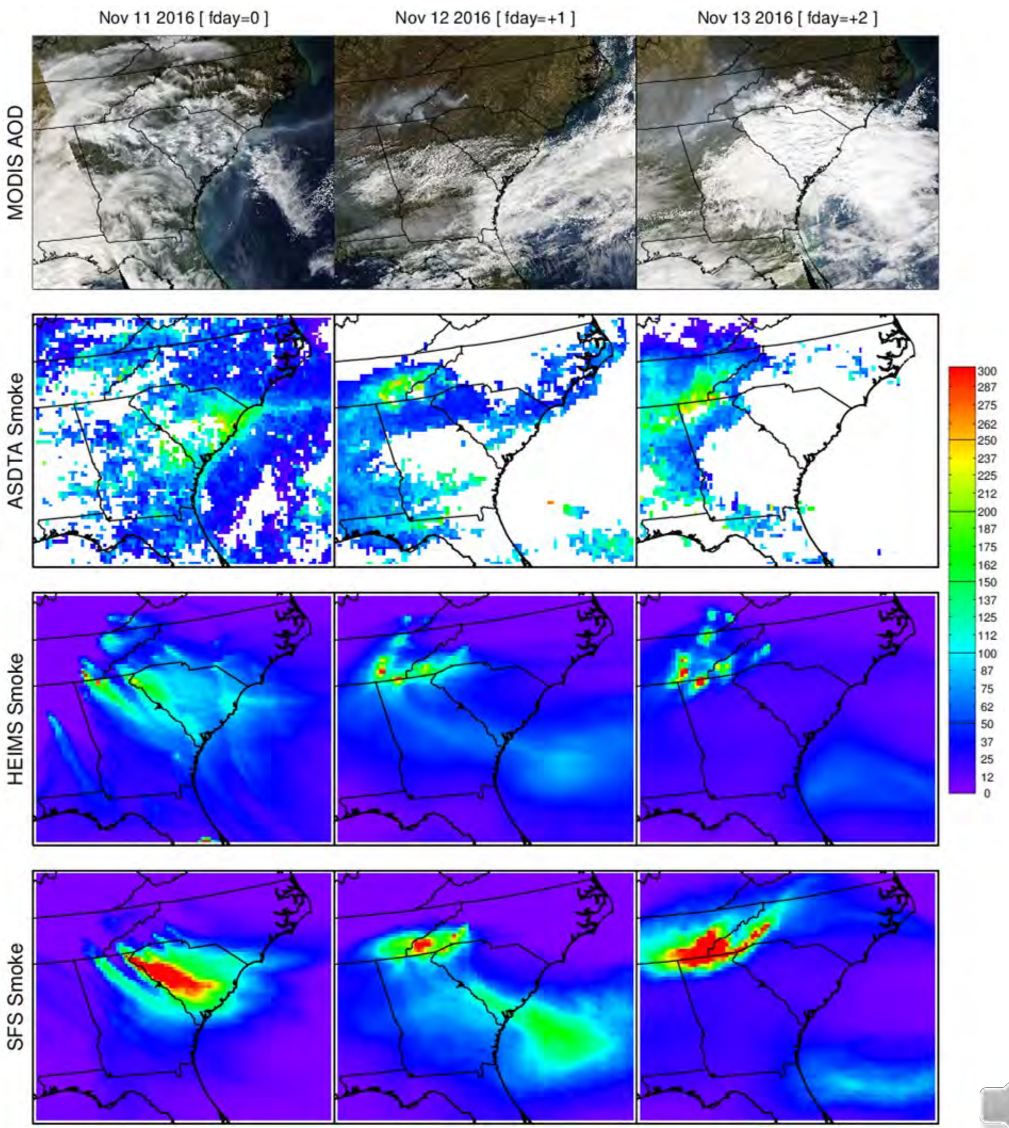
Scatterplot comparison between initial and assimilated smoke mass loading using adjusted fire emissions.

Improved smoke forecast/hindcast using HEIMS-f

- Compared with currently operational BlueSky emission predictions, emission estimates from HEIMS-f outperform in both reanalysis and hindcast modes compared with satellite observed smoke mass loadings.

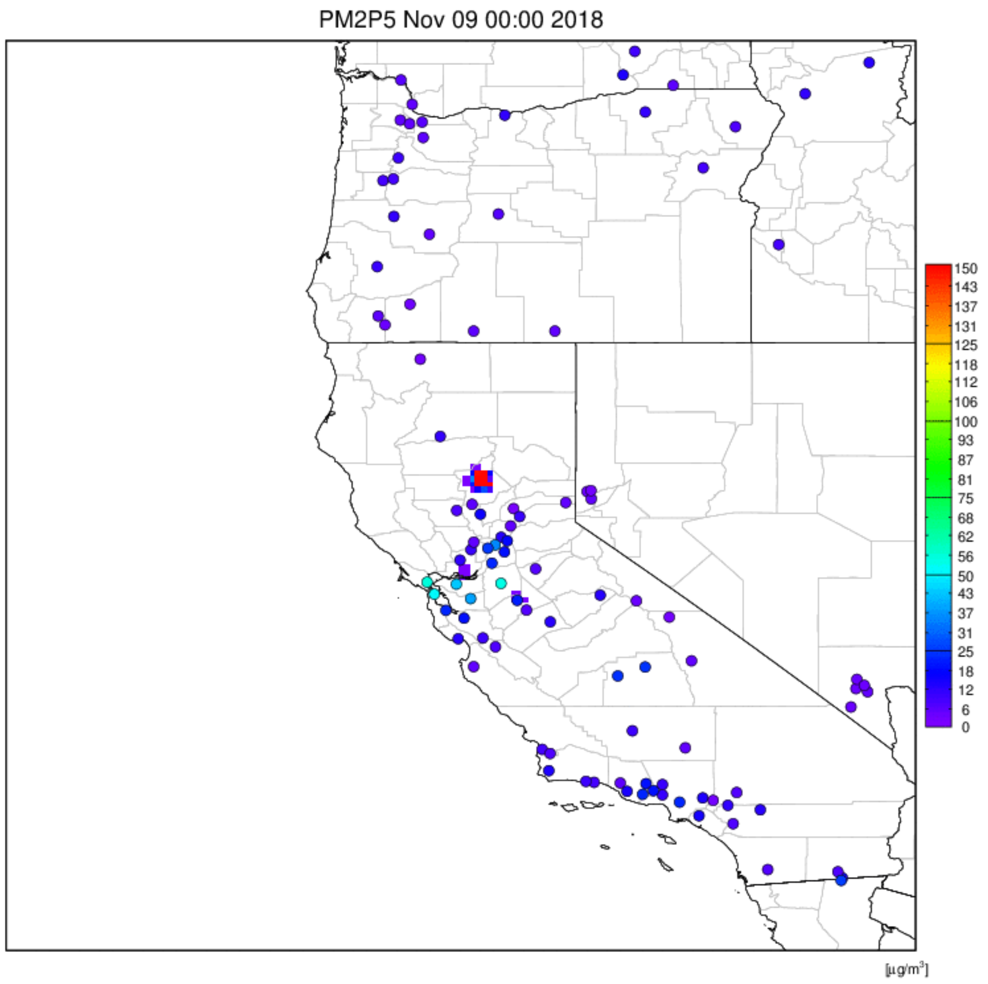


Scatter plot comparisons between ASDTA smoke and HEIMS smoke (upper) and ASDTA and SFS smoke (lower) for forecast days, fday=0, +1, +2.



Advantage of the dispersion-based top-down emissions estimation

- Fire detections from space can be limited in case of thick smoke plumes covering fire spots.
- For the Camp fire case study, the second week simulations underperform due to limited fire spot detections from satellite.
- Dispersion-based inverse modeling system can fill gaps for undetected fire locations.



Improving smoke plume rise schemes

- **Briggs schme**

$$BF = a\,HEAT$$

$$H_p = \begin{cases} b\,BF\,U^{-1}\,u_*^{-2} & \text{neutral, unstable} \\ c\,(BF\,U^{-1}\,s^{-1})^{\frac{1}{3}} & \text{stable, } U > 0.5\ \mathrm{m\,s^{-1}} \\ d\,BF^{\frac{1}{4}}\,s^{-\frac{3}{8}} & \text{stable, } U \le 0.5\ \mathrm{m\,s^{-1}} \end{cases}$$

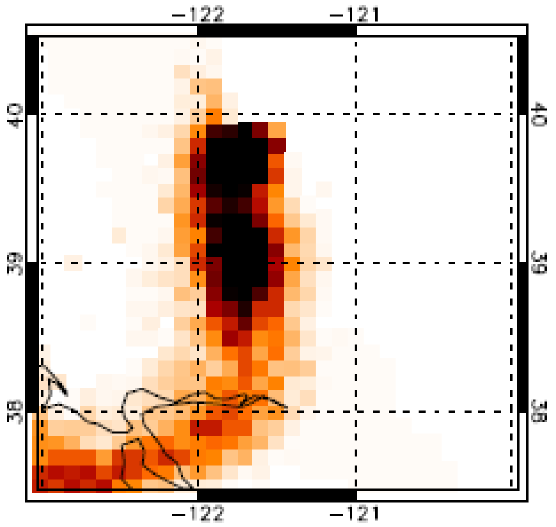
where *BF* is the buoyancy flux (m4/s3), *HEAT* is the heat released (W), *Hp* is the injection height (m), *U* is the horizontal wind speed (m/s) at 10-m elevation, *u** is the friction velocity (m/s), *s* is the static stability (1/s2), and *a*, *b*, *c*, and *d* are constants.

- **Sofiev scheme**

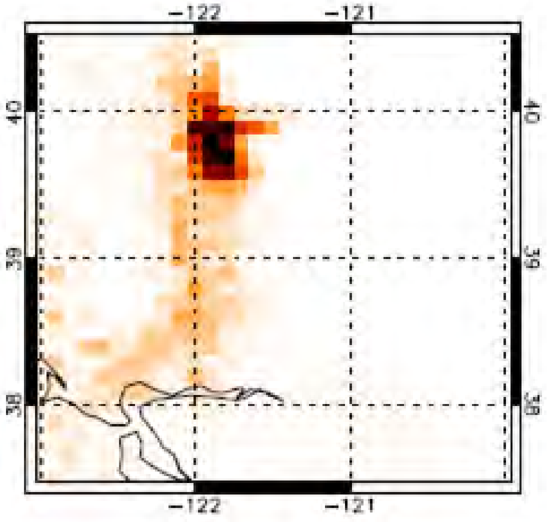
$$H_p = \alpha H_{PBL} + \beta\left(\frac{FRP}{FRP_0}\right)^{\gamma} \exp\left(-\frac{\delta BV_{FT}^2}{BV_0^2}\right)$$

HPBL is the PBL height (m), *FRP* is fire radiative power (W), *FRP*0 is the reference fire power which equals to 106 W, *BVFT* is the Brunt-Vaisala frequency in the free troposphere (FT, calculated at 500 hPa), *BV0* is the reference Brunt-Vaisala frequency which equals 2.5 × 10−4 s−2, and *α*, *β*, *γ,* and *δ* are constants.

Briggs

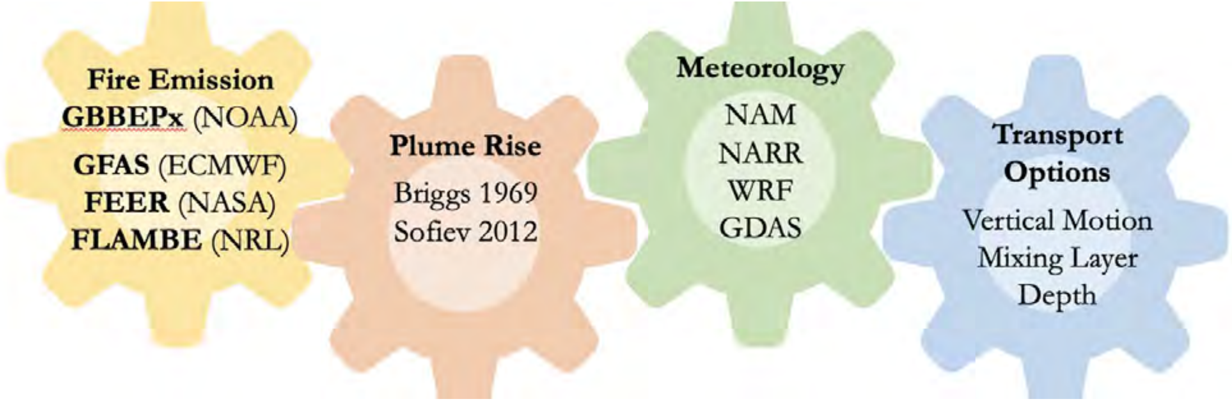


Sofiev

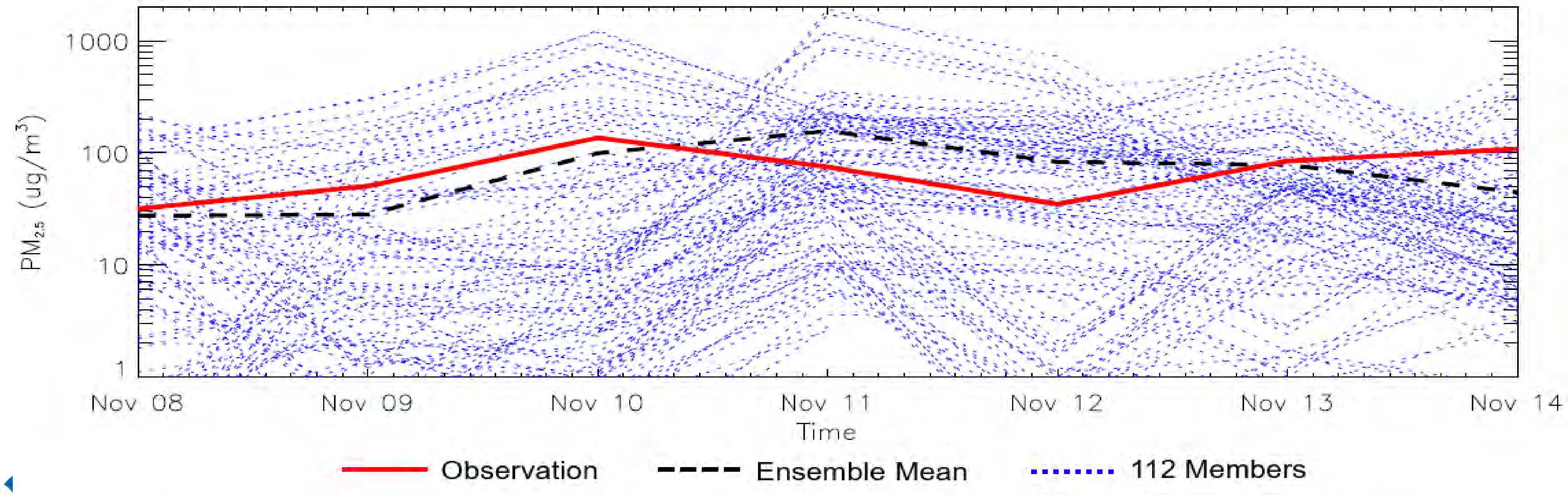


Ensemble modeling using various modeling configurations

- Constructed 112 Ensemble members using varying fire emissions, plume rise schemes, meteorological inputs, and transport physical options

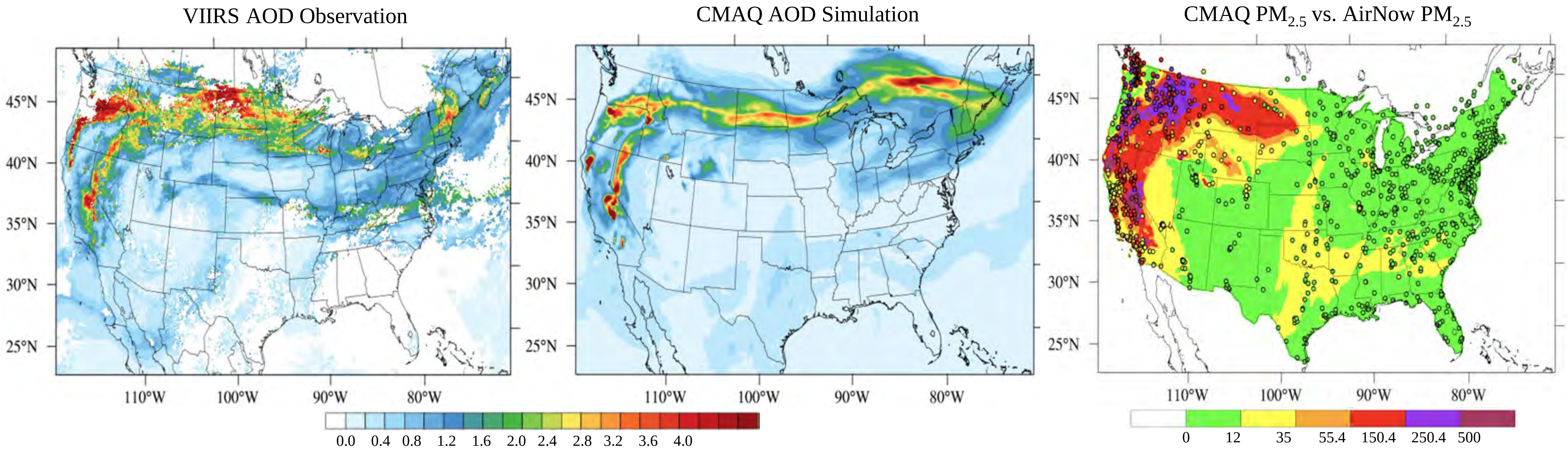


Surface $PM_{2.5}$ during 2018 Camp Fire



Feeding Chemistry Transport Model (CTM)

- Estimated fire emissions and plume rise configuration can be applied to Eulerian Chemistry Transport Model (e.g. CMAQ)
- Application for 2020 Western Wildfire case



Quality and Performance

Operational Implementations

- Providing improved fire emissions for operational smoke forecast system
- Rapid test environment of modeling configurations for operational system

Publications

- **Kim, H.C.**, **T. Chai**, **A. Stein**, and S. Kondragunta (2020), Inverse modeling of fire emissions constrained by smoke plume transport using HYSPLIT dispersion model and geostationary satellite observations, *Atmos. Chem. Phys.*, 20, 10259–10277. , doi:10.5194/acp-20-10259-2020
- **Li, Y.**, **D. Tong**, **F. Ngan**, **M. Cohen**, **A. Stein**, S. Kondragunta, et al. (2020). Ensemble PM2.5 forecasting during the 2018 Camp Fire event using the HYSPLIT transport and dispersion model. *Journal of Geophysical Research: Atmospheres*, *125*, e2020JD032768. https://doi.org/10.1029/2020JD032768
- **Li, Y.**, **D. Tong**, S. Ma, X. Zhang, S. Kondragunta, F. Li, and **R. Saylor** (2021). Dominance of wildfires impact on air quality exceedances during the 2020 record-breaking wildfire season in the United States. Geophysical Research Letters, 48, e2021GL094908. https://doi.org/10.1029/2021GL094908

Quality and Performance: *Presentations*

Presentations

- **Chai, T.,** H.C. Kim, A. Stein, and S. Kondragunta, 2019, Smoke Forecasts using HYSPLIT-based emission inverse modeling system and NOAA GOES smoke products, *2019 Joint Satellite Conference*, Boston, MA
- **Kim, H.C**., T. Chai, A. Stein, and S. Kondragunta, 2018: A HYSPLIT-based fire emission inverse modeling system for smoke forecast, *2018 AGU Fall Meeting*, Washington D.C.
- “A case study of the 2018 Camp Fire event using HYSPLIT-based emission inverse modeling system with GOES Advanced Baseline Imager (ABI) observations and other measurements for wildfire smoke forecasts", by **Chai**, **T.**, H. Kim, A. Stein, D. Tong, Y. Li, and S. Kondragunta, *EGU General Assembly 2020,* online, EGU2020-12525, https://doi.org/10.5194/egusphere-egu2020-12525, 2020.
- “Wildfire smoke forecasts using HYSPLIT-based emission inverse modeling system and GOES observations", by **Chai**, **T.**, H. Kim, A. Stein, and S. Kondragunta, *JPSS/GOES-R Proving Ground/Risk Reduction Summit,* College Park, MD, USA, February 24-28, 2020.
- “Wildfire smoke forecasts using HYSPLIT-based emission inverse modeling system and satellite observations”, by Kondragunta, S., **T. Chai**, H. Kim, and A. Stein, *2019 AGU Fall Meeting*, San Francisco, CA, USA, December 9-13, 2019.
- “Data assimilation and inverse modeling with HYSPLIT Lagrangian dispersion model and satellite data – Applications to volcanic ash and wildfire smoke predictions” by **Chai, T.**, H. Kim, A. Stein, F. Ngan, A. Crawford, B. Stunder, and M.J. Pavolonis, *2017 NOAA Satellite Conference*, New York, NY, USA, July 17-20, 2017.

Future Plans

Establish Wildfire Modeling Testbed

- Investigate fire emissions estimation methodologies
- Further development and optimization of inversion-based emissions estimates
- Investigate plume-rise estimation methodologies
- Develop probabilistic forecasts based on ensembles, including variations in emissions, model physics, and meteorology
- Comprehensive model evaluation against satellite, ground-based, and aircraft-based observations

Provide inversion-based value-added emissions estimates to other models

- National Air Quality Forecast Capability (NAQFC)
- HRRR-smoke
- UFS-based smoke forecasts