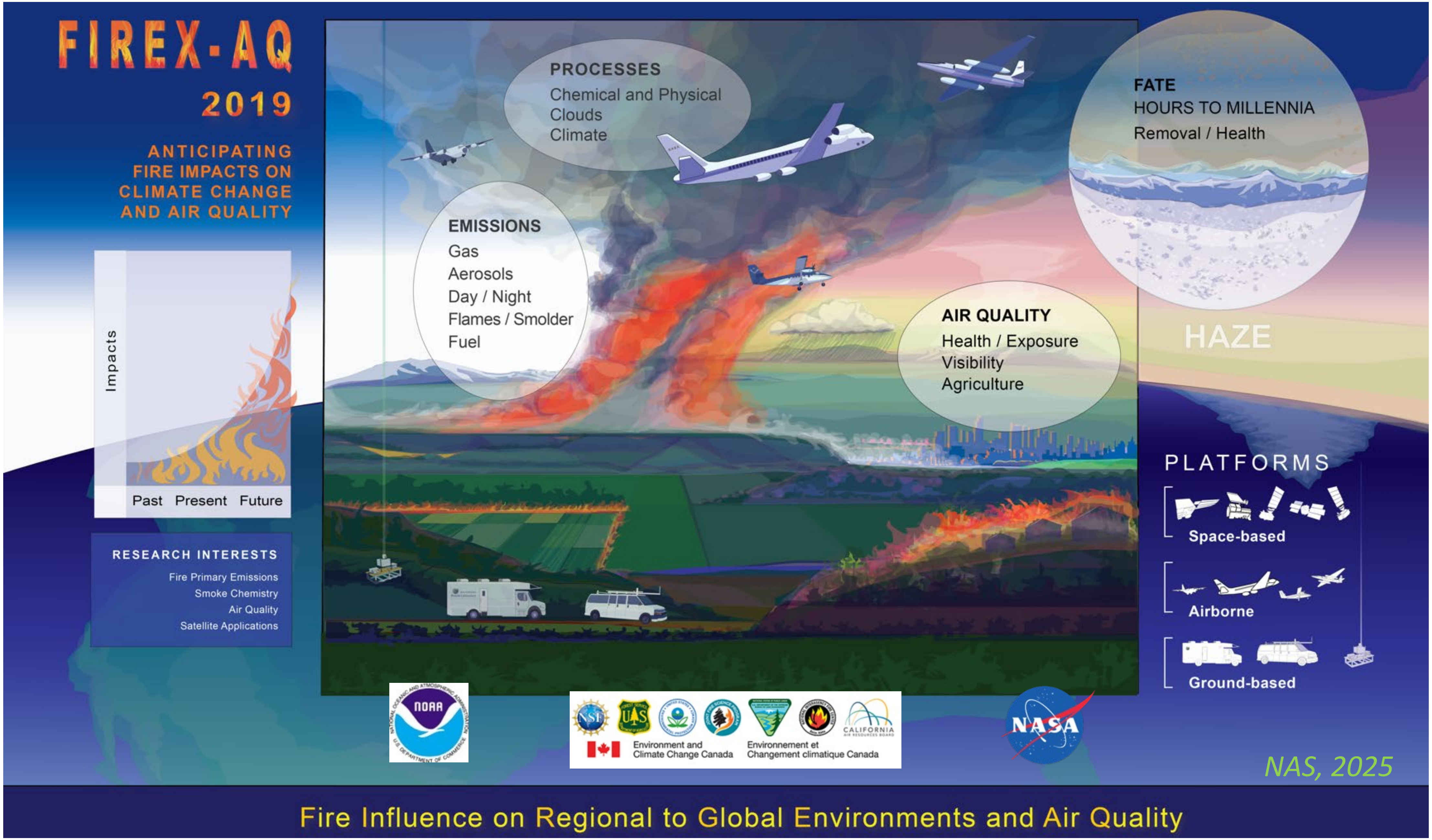
Investigating smoke from wild-, prescribed-, and agricultural fires



NAS, 2025

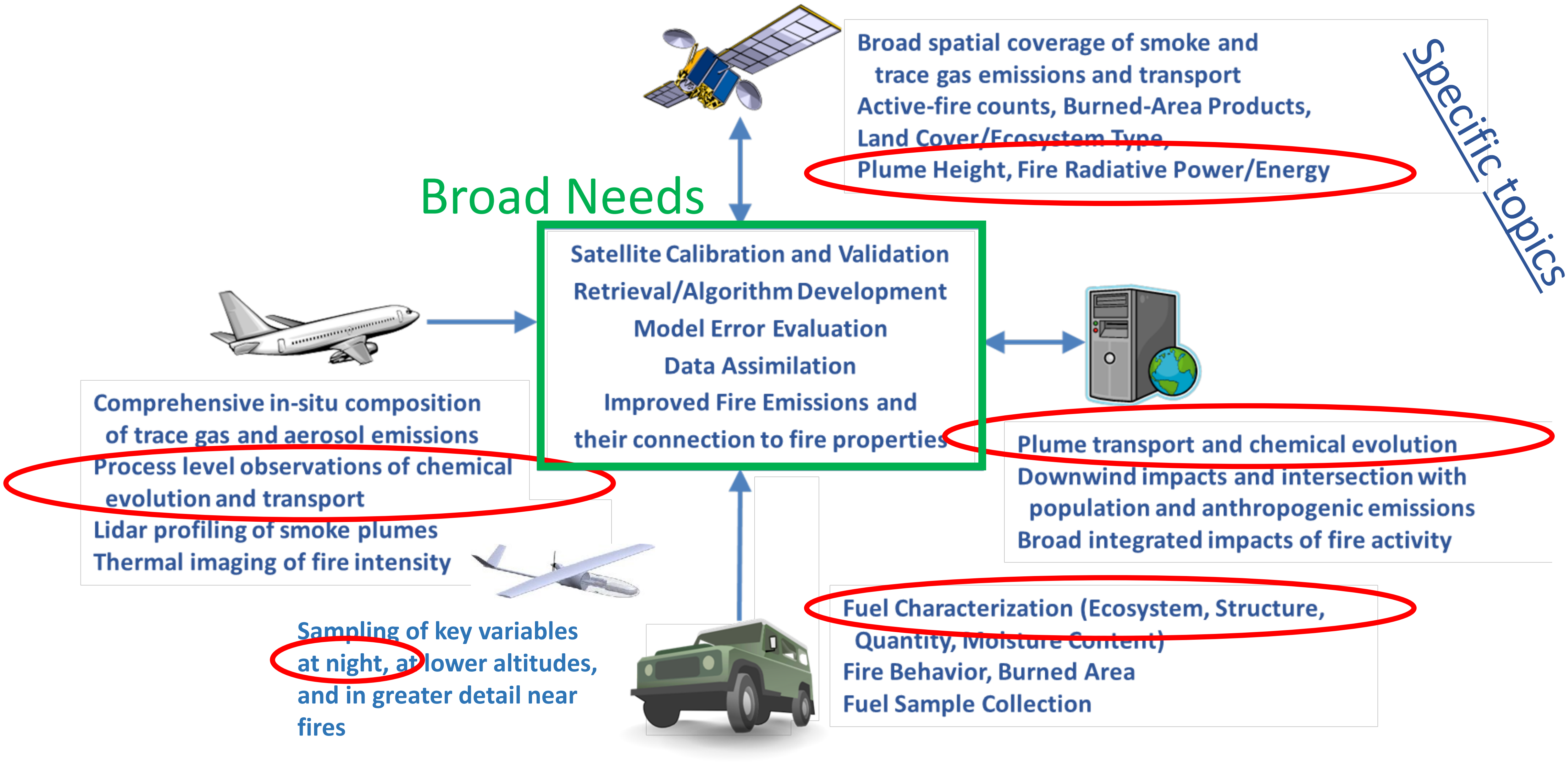
Outline

1) FIREX-AQ 2019 Intensive Overview: scientific goals, technical approaches, temporal and physical scope, data outputs, and methods of analysis.

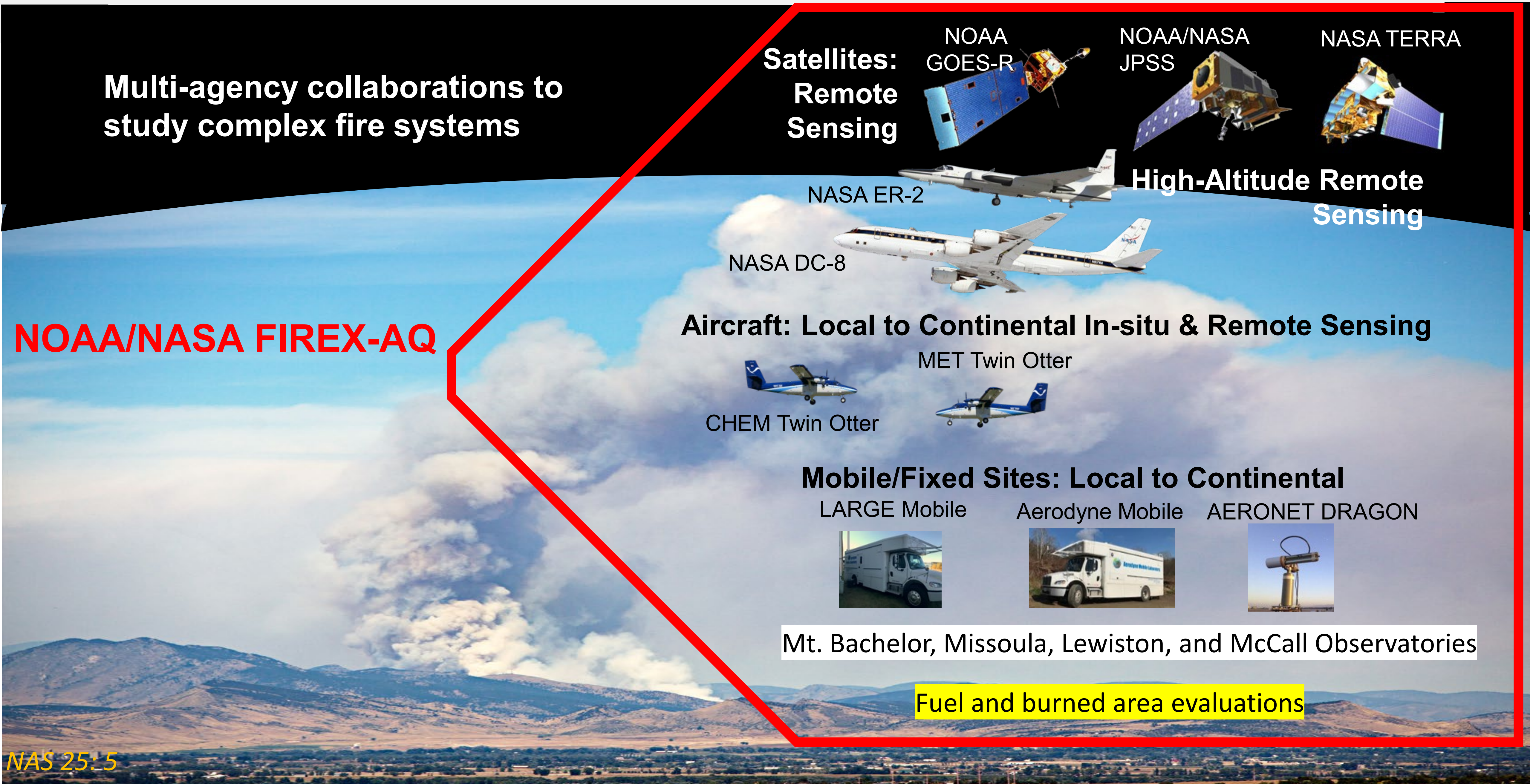
2) FIREX-AQ outputs, lessons learned about data collection, analysis, and modeling of wildland fire and smoke behavior, the capability of current models to capture relevant variables and interactions, other strengths and weaknesses of the models

3) Future needs – perspectives of the FIREX-AQ team

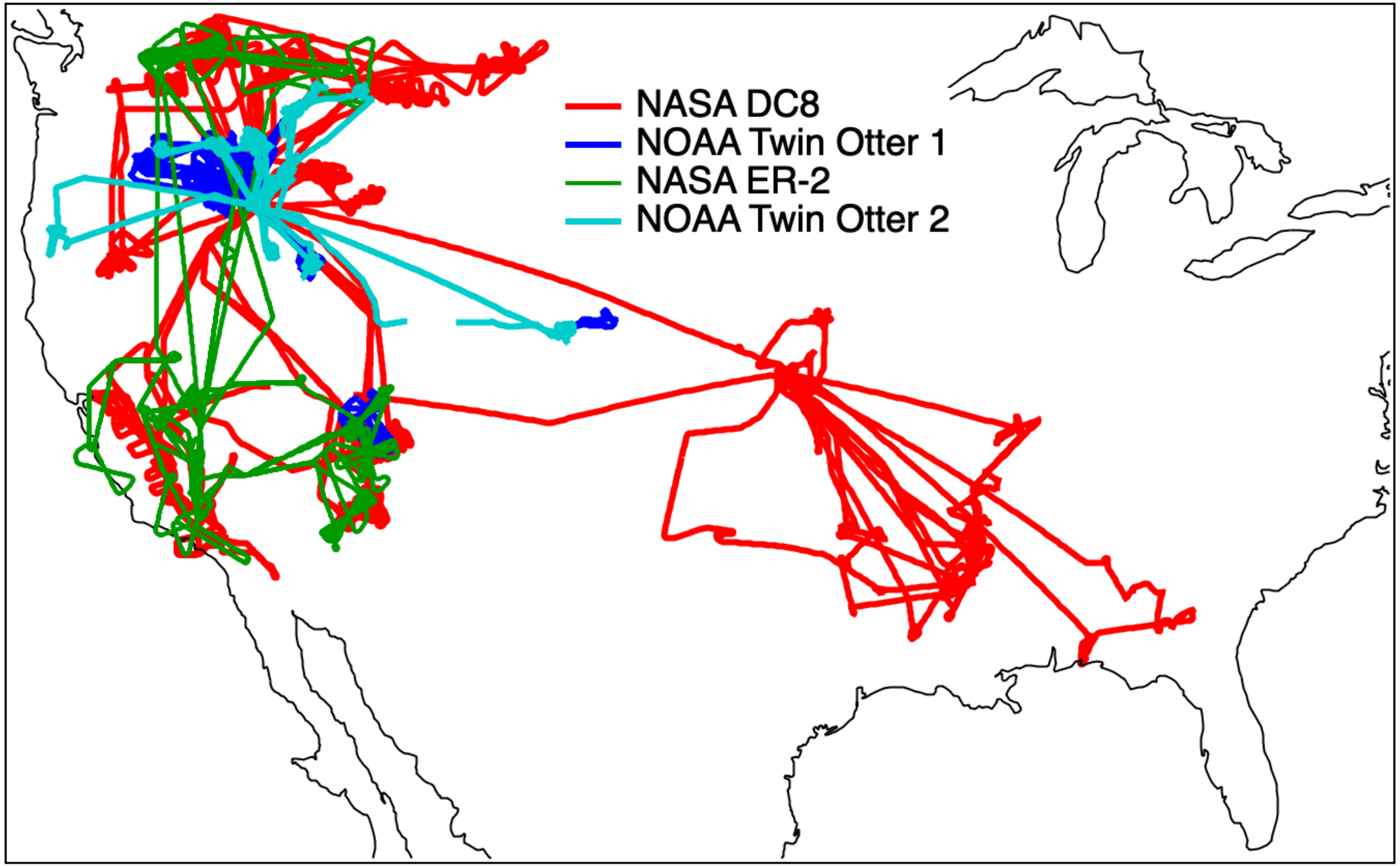
Integrated Observing Strategies to address science needs



FIREX-AQ Coordinated Measurement Activities

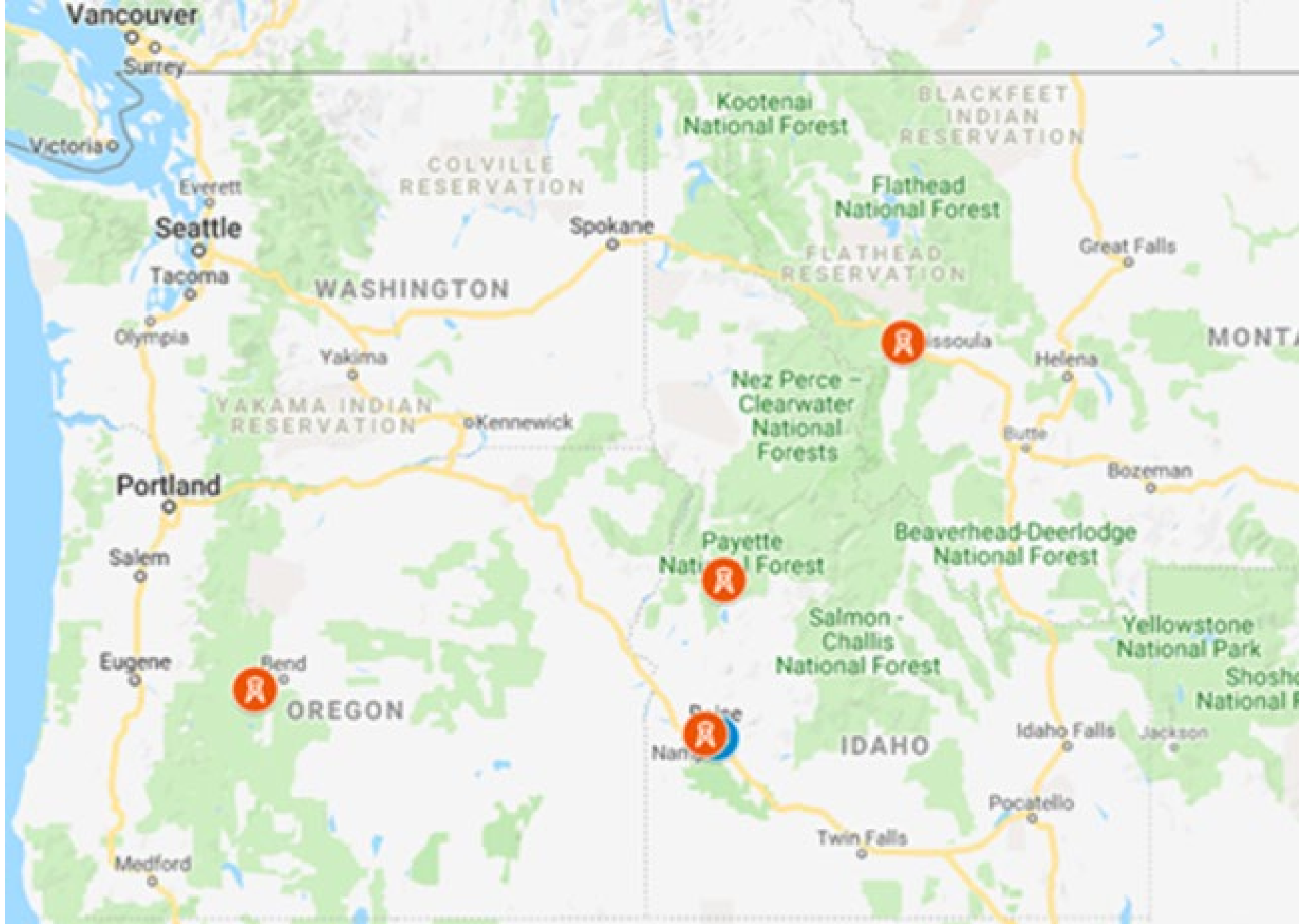


FIREX-AQ Geographic/Temporal Scope



- 7/25/25-8/19 – Western fires, DC-8, ER-2, Twin Otters, Mobile labs, Dragon
- 8/23-9/03 – DC-8 only: Agricultural and prescribed fire focus

FIREX-AQ Geographic/Temporal Scope



<u>Ground Sites:</u>

Long term observations

<u>Objectives</u>

Long range transport

O3 chemistry

Urban chemical interactions

"Suitcase" sampler

FIREX-AQ Data Outputs

In situ data from DC-8, Chem-Otter, Mobile labs

Gas phase measurement:

- **Tracers**
- **Reactive Nitrogen**
- **VOCs**
- **Hydrocarbons**
- **Oxidation Products**

Aerosol measurements:

- **Physical**
- **Optical**
- **Chemical**
- **Coarse mode**

Just the DC-8 in situ: >600 data outputs

```
  Time_Start;Time_Stop;Day_Of_Year;Latitude;Longitude;MSL_GPS_Altitude;HAE_GPS_Altitude;Pressure_Altitude;Radar_Altitude;Ground_Speed;True_Air_Speed;Indicated_Air_Speed;Mach_Number;Vertical_Speed;
True_Heading;Track_Angle;Drift_Angle;Pitch_Angle;Roll_Angle;Static_Air_Temp;Potential_Temp;Dew_Point;IR_Surf_Temp;Static_Pressure;Cabin_Pressure;Solar_Zenith_Angle;Aircraft_Sun_Elevation;Sun_Azimuth;
Aircraft_Sun_Azimuth;Mixing_Ratio;Part_Press_Water_Vapor;Sat_Vapor_Press_H2O;Sat_Vapor_Press_Ice;Relative_Humidity;U;V;W;TEDR;REYN;YAW;AOA;Smoke_flag;transect_type;fire_id;Background_flag;
transect_smoke_age;transect_smoke_MCE;transect_number;transect_plume_number;transect_mce_ODR;transect_mce_odr_chisq;fire_distance_estimate;transect_major_fuel;transect_constituent_fuel;
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HNO3_CITCIMS;PAN_GTCIMS;PPN_GTCIMS;APAN_GTCIMS;PBN_GTCIMS;NH3_UIOPTR;N2O5_NOAACIMS;N2O_LGR;CO_DACOM;CH4_DACOM;CO_LGR;CO2;C2H6_CAMS;CH2O_CAMS;CH2O_ISAF;CH2O_UIOPTR;OCS_WAS;DMS_WAS;CFC12_WAS;CFC11_WAS;
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NR_Chloride_PM1_AMSSD;worldLat;WorldLon;
```

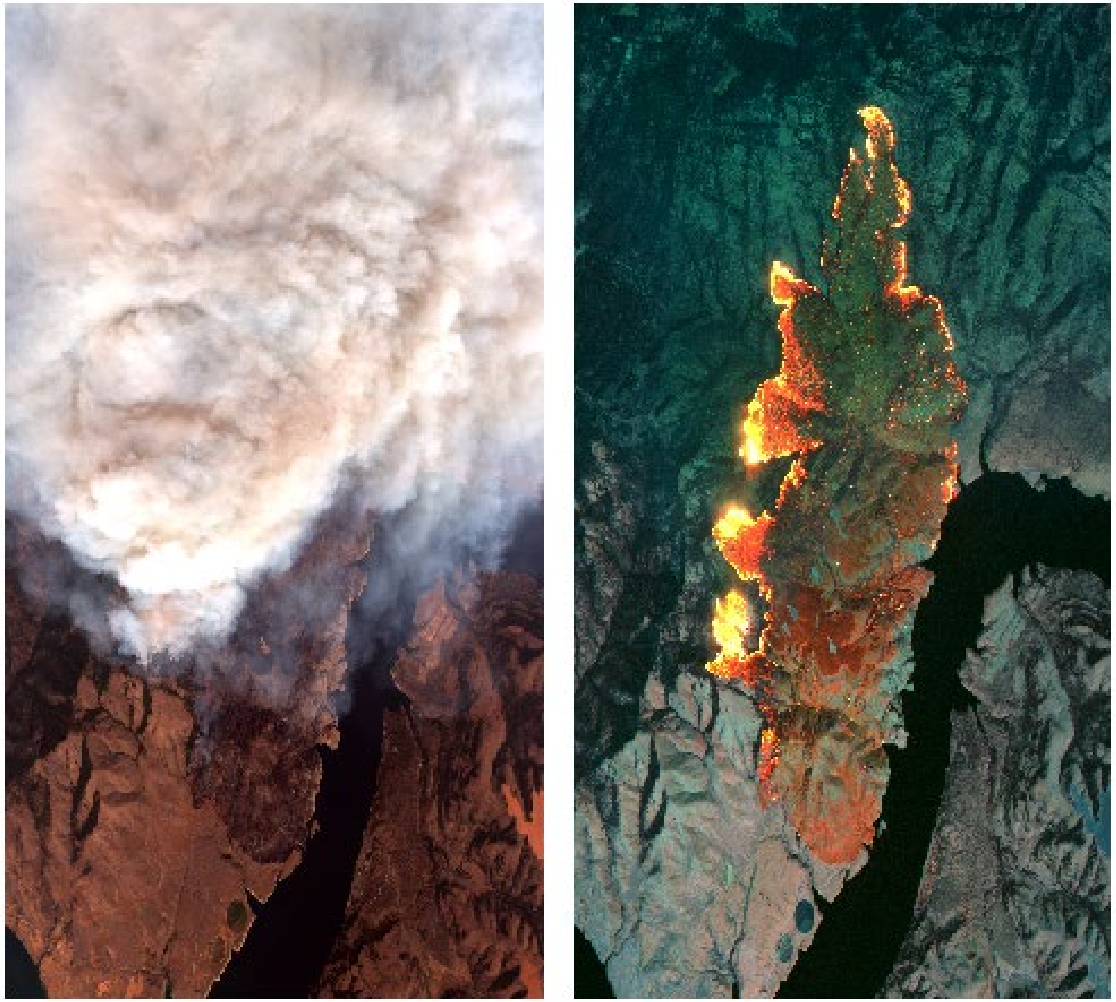
FIREX-AQ Data Outputs

Remote sensing data:

Remote sensing:

- **Active lidar – aerosol properties, 3-d winds**
- **Passive radiometer for photolysis rates**
- **scanning spectrometers for cloud properties, vegetation, trace gases, FRP**
- **Scanning IR interferometers for trace gases, thermodynamic profiles**

MASTER on DC-8



RGB (0.654um-0.546um-0.462um)   CIR (4.060um-2.210um-1.602um)

FIREX-AQ Lessons Learned

More than 85 papers published: Topics include:

1. Fire Emissions & Source Characterization

Emission Factors & Inventories: Determining emission factors for various species.

Connections between Fire Radiative Power (FRP) and emissions.

Developing and comparing emission inventories (e.g., top-down vs. bottom-up).

Investigating diurnal cycles and other parameterizations.

Primary Emitted Species: Volatile Organic Compounds (VOCs) and other trace gases.

Primary aerosols: composition and microphysical properties at the source.

2. Atmospheric Transformation & Chemistry

Aerosol Aging & Evolving Properties: Formation of SOA.

Changes in chemical composition, physical state, and optical properties during transport. Aerosol impacts on photolysis rates.

Gas-Phase Chemistry:

Chemical transformation mechanisms of VOCs and reactive organics.

Chemistry involving reactive nitrogen species and ozone formation.

FIREX-AQ Lessons Learned

More than 85 papers published: Topics include:

3. Fire & Smoke Dynamics / Meteorology

Plume Dynamics: Plume rise, heat flux, and smoke transport. Interactions with the boundary layer.

Fire-Weather Interactions: Connections between fire behavior and meteorological conditions. Smoke-weather feedbacks and impacts on cloud properties.

4. Measurement & Observation

Instrumentation: Development, evolution, and advances. Instrument calibration and validation.

Observation Techniques: Remote sensing of aerosols, gases, and fire properties. Integrating and airborne measurement campaigns.

5. Modeling, Evaluation, & Forecasting

Model Evaluation & Intercomparison: Comparing models with measurements (transport, chemistry). Case studies and multi-model comparisons.

Predictive Applications: Air quality forecasting. Machine learning for smoke and fire identification.

6. Impacts & Applications

Human Health & Air Quality: Health impacts, including specific effects of VOCs and reactive organics. Influence of wildfire smoke on indoor air quality.

Highlighting some takeaways

Statistics:

- Highly detailed and specific measurements (as possible from some prescribed fire as in FIREX-AQ) are great for advancing process-level understanding…

But we need better statistics to make more progress on larger scale modeling

Data collection:

- Match measurement approach to science goal – still can't get everything all at once
  - Example: Slow Twin otter for Lagrangian sampling, Fast DC-8 to characterize entire plume
    - (and FAA/TFR requirements…)
  - Example: DC-8 vs Mobile labs for initial smoke characterization
  - Flexibility (DC-8 for Blackwater – blackwater started early, shortened preflight…)

    (What's relevant to your interests?)

Analysis:

- Strong smoke heterogeneity can be normalized, simplified analysis
- Reanalysis winds – impacts on smoke physical age estimates, heterogeneity in smoke age at fixed distance from fire

Future Needs: Contributions from <u>B. Yokelson S. Brown, D. Peterson, A. Soja, J. Dibb, B. Pierce, M. Robinson, R. Ahmadov</u>

1. Linking Fire Weather, Fuels, and Emissions

Integrated Emission Prediction: Develop a deeper, quantitative understanding of how fire weather influences fuel conditions (e.g., moisture, consumption), which in turn dictates fire behavior (flaming vs. smoldering), ultimately controlling emission factors (EFs) and plume injection height.

Operational Emissions Forecasting: Transition research findings into operational air quality models by enabling them to dynamically scale emissions up or down based on projected meteorological changes.

Advanced Fuel Characterization:

- Improve the operational identification of fuel types from space (e.g., distinguishing agricultural burning from forest fires).
- Expand ground-based fuel moisture networks and integrate their data with satellite-based soil moisture retrievals for more accurate inputs to emission models.

2. Smoke Plume Dynamics and Atmospheric Transport

Plume Injection & Vertical Distribution: Improve the representation of smoke injection altitudes in models, ensuring skillful assumptions for the vertical profile and accounting for the different properties of smoke processed by pyroconvection versus that remaining in the boundary layer.

Day/Night Transitions: Conduct targeted measurements to better understand fire and smoke plume behavior during the day-to-night transition across various meteorological conditions.

Complex Terrain Meteorology: Advance the understanding and modeling of micrometeorology in mountainous terrain to improve transport predictions.

Future Needs: Contributions from B. Yokelson S. Brown, D. Peterson, J. Dibb, B. Pierce, M. Robinson, R. Ahmadov

3. Atmospheric Chemistry and Transformation

Advanced Organic Chemistry:

- **SVOCs:** Improve the identification, gas-particle partitioning, and chemical evolution of Semi-Volatile Organic Compounds (SVOCs), and effectively incorporate these complex processes into models.
- **Brown Carbon:** Better constrain the sources, secondary formation chemistry, and atmospheric lifetime of brown carbon.

Tropospheric Ozone Budget: Conduct a comprehensive evaluation of the role of biomass burning in the tropospheric ozone budget at regional to hemispheric scales, supported by aircraft and mountaintop measurements.

Cloud and Stratospheric Interactions:

- **Cloud Processing:** Obtain new measurements to improve the understanding and modeling of how clouds process smoke aerosols, affecting their properties and lifetime.
- **Stratospheric Chemistry:** Better quantify the influence of major fire emissions on stratospheric heterogeneous chemistry.

Urban Air Quality: Investigate the chemical evolution and air quality impacts that occur when wildfire smoke is transported into and mixes with polluted urban environments.

4. Observation Systems and Measurement Needs

Hi-temporal and spatial FRP: Pursue systems that provide *both* high spatial and high temporal resolution for fire detection and Fire Radiative Power (FRP), potentially through public-private partnerships and very low orbit satellite fleets and broad use of drones.

Enhanced Ground Networks: Significantly expand ground-based networks for measuring surface radiation (to evaluate model performance under smoke) and fuel moisture.

Future Needs: Contributions from B. Yokelson S. Brown, D. Peterson, J. Dibb, B. Pierce, M. Robinson, R. Ahmadov

5. Modeling, Forecasting, and Uncertainty Quantification

Advanced Ensemble Forecasting: Develop ensemble forecast systems that fully couple fire heat release with atmospheric models and include aerosol-radiation-cloud feedbacks. These systems should allow for perturbations in emissions, injection heights, and heating to better quantify forecast uncertainty.

Model Integration and Operationalization: Ensure that improved understanding of the links between fuels, weather, and emissions is fully incorporated into operational air quality and transport models.

6. Societal Impacts and Applications

Human Health Effects:

Advance the understanding of smoke health impacts beyond simple exposure, investigating metabolomics, the role of skin absorption, synergistic effects with other pollutants, and variable individual sensitivity.

Compare the health effects of prescribed fire versus wildfire smoke to inform policy and management.

Proactive Fire Management:

Quantify the benefits of prescribed fires, particularly in reducing landscape flammability in the Wildland-Urban Interface (WUI).

Devise and evaluate new methods to reduce the cost and barriers associated with conducting prescribed burns.

ACKNOWLEDGEMENTS