
# Virtual Research Presentation Conference

## Characterization of fire emission processes from high-altitude imaging remote sensing

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**Program: (RTD Topical Concept**)

Jet Propulsion Laboratory
California Institute of Technology

Assigned Presentation # RPC-045

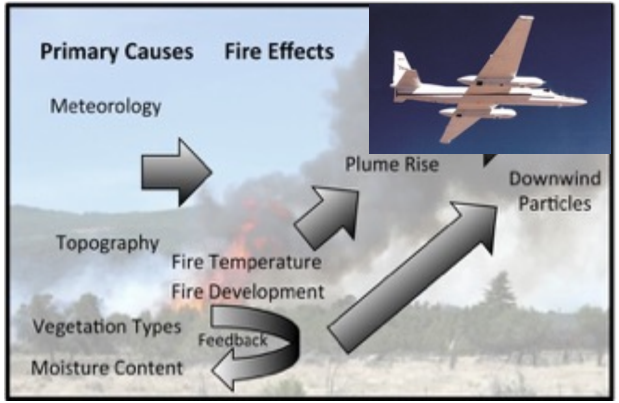
# Characterization of Fire Emission Processes

***Problem being solved:***

How can a combination of JPL's spectrometers be used to improve assessments of biomass burning (BB) emissions from fires for air quality applications?


**Abstract**

Biomass burning (BB) emissions are a significant global air pollution source, and the gases and particles emitted from fires can directly and indirectly affect climate, air quality, and human health. This project aims to improve our understanding of particulate matter (PM)-relevant BB emissions, with an emphasis on ammonia ($NH_3$) – a secondary aerosol precursor – as a function of combustion phase (flaming/smoldering) through the use of the combined capabilities of JPL's remote sensing imaging spectrometers, AVIRIS and HyTES, onboard NASA's ER-2 aircraft, and datasets from the 2019 FIREX-AQ field campaign and the 2018/2019 HyspIRI flights.

# Characterization of fire emission processes

a) **Why this problem and why now:**

- In recent years, the number of landscape fires, the acreage burned by both wildfires and prescribed burning, and the length of the "fire season" in the United States have all increased dramatically leading to PM exceedances.
- Understanding the PM component of BB emissions as a function of combustion conditions (flaming vs. smoldering) is an increasingly visible research focus that has grown out of laboratory experiments, in-situ observations, and chemical transport models, and cannot be fully addressed with existing satellite datasets due to saturation issues and the relatively coarse spatial resolution of satellite instruments.

a) **Advancement over current state-of-the-art:**

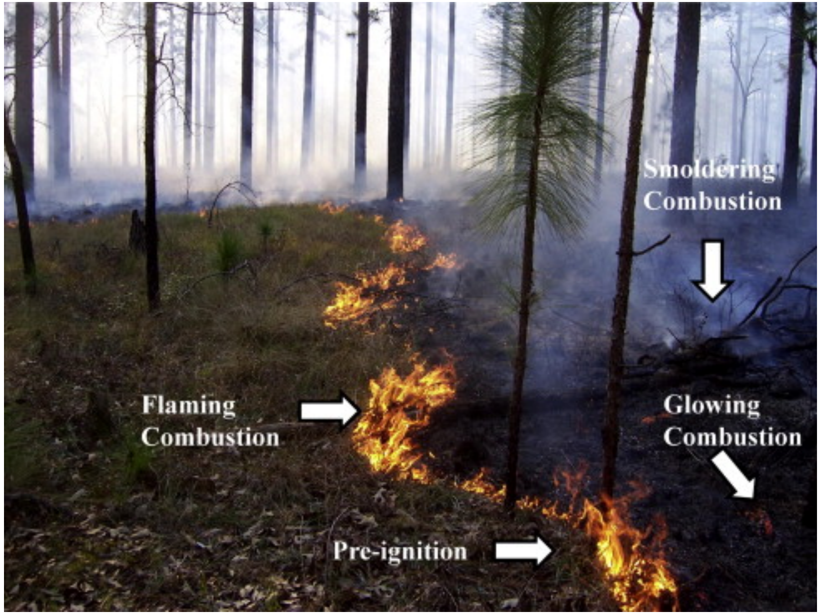
- At present, no investigations have been done utilizing JPL's imaging spectrometers on the ER-2 aircraft to characterize the relationships between fire combustion phase and aerosol properties. This has been primarily due to lack of relevant observations, which are now available from the 2018/2019 HyspIRI field campaign.

a) **Relevance to NASA and JPL:**

- Our concept will improve our understanding of PM emission processes from fires in an effort that is directly aligned with one of the 2017 DS's "most important" objectives, which is to quantify "processes that determine the spatio-temporal structure of important air pollutants."
- Combining the capabilities of JPL's airborne imaging spectrometers will demonstrate applications of JPL technologies.
- Will help to strengthen JPL partnership with CARB for air quality monitoring and regulation.
- This effort sets the stage and will help formulate observational requirements for robust planned EV suborbital and mission proposals.

## Why Simultaneously Map Wildfire Temperature and Emissions?

- Oxygen and temperature determine combustion efficiency, which determines trace gas, organic compound, and aerosol emissions
  - Flaming combustion: > 800 K
  - Glowing combustion (high oxygen): 500-800 K
  - Smoldering combustion (low oxygen): 500-800 K




*Ottmar, 2014*

Mass flux measurements show that $CO_2$, CO, $CH_4$ and $\mathbf{NH_3}$ are the four most predominant gas species emitted in the steady stage of smoldering combustion at low temperatures (peak ~550–650°C).

$NH_3$ is the major precursor responsible for the formation of particulate ammonium, sulfate, and nitrate.

# AVIRIS-C

(PI: R. Green - JPL)

Airborne Visible Infrared Imaging Spectrometer

| Instrument Characteristic | AVIRIS-C |
|---|---|
| Spectral range | 0.37-2.55 μm |
| Spectral resolution | 9.8 nm |
| Swath | 11 km |
| Pixel size | 20 m |

| Relevant fields |
|---|
| **Fire temperature** (K) |
| $CO_2$ (ppm-m) |
| $CH_4$ (ppm-m) |
| Water vapor (column precipitable cm) |
| $O_2$ pressure altitude |
| AOD - research |

# HyTES

(PI: S. Hook - JPL)

Hyperspectral Thermal Emission Spectrometer

| Instrument Characteristic | HyTES |
|---|---|
| Spectral Range | 7.5-12 μm |
| Spectral resolution | ~7 nm |
| Swath | 18.6 km |
| Pixel size | 36.4 m |

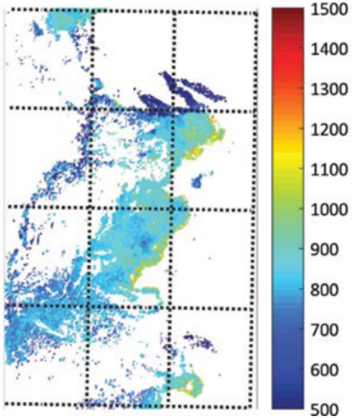
| Relevant fields |
|---|
| **Land Surface Temperature (LST)** (including hot targets) |
| Spectral Emissivity at 256 bands (7.4-12 mm) |
| $SO_2$ and $CH_4$ - validated |
| **$NH_3$** and $NO_2$ - research |
| $O_3$ (in development) |

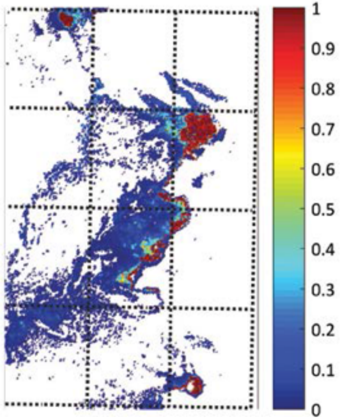
Fire temperature could explain around 85% of the variability of the volatile organic compound (VOC) emissions. VOCs released from low temperature burns have properties that make them more likely to form aerosols in the fire plumes.

*Sekimoto et al., ACP, 2018*

AVIRIS-C; <u>Flaming fires</u>

T ~ 1200K



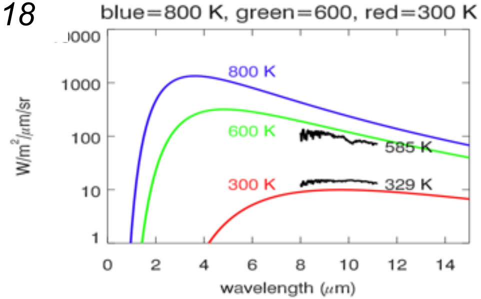



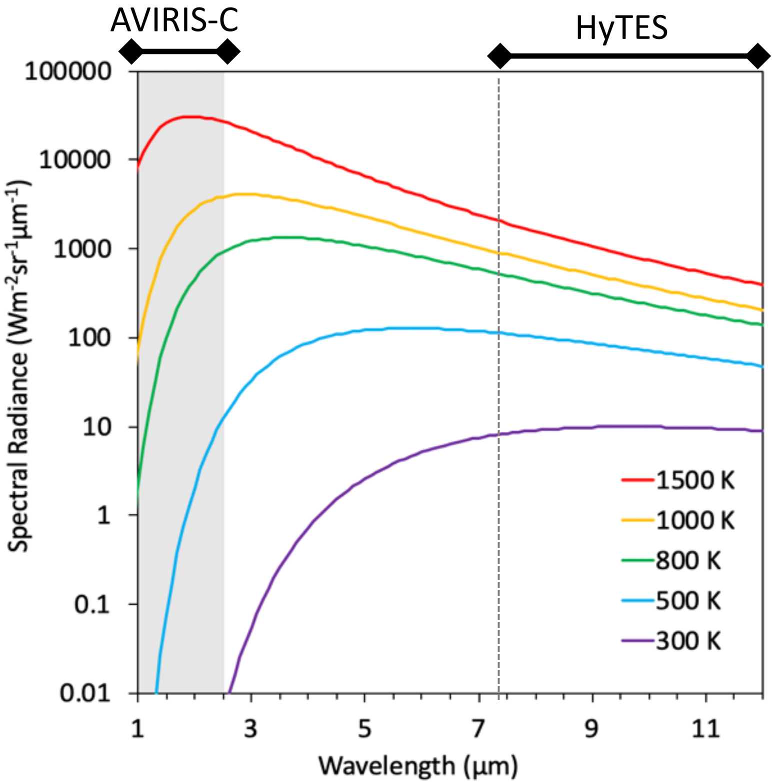

*Veraverbeke et al., RSE, 2018*

HyTES; <u>Smoldering fires</u>

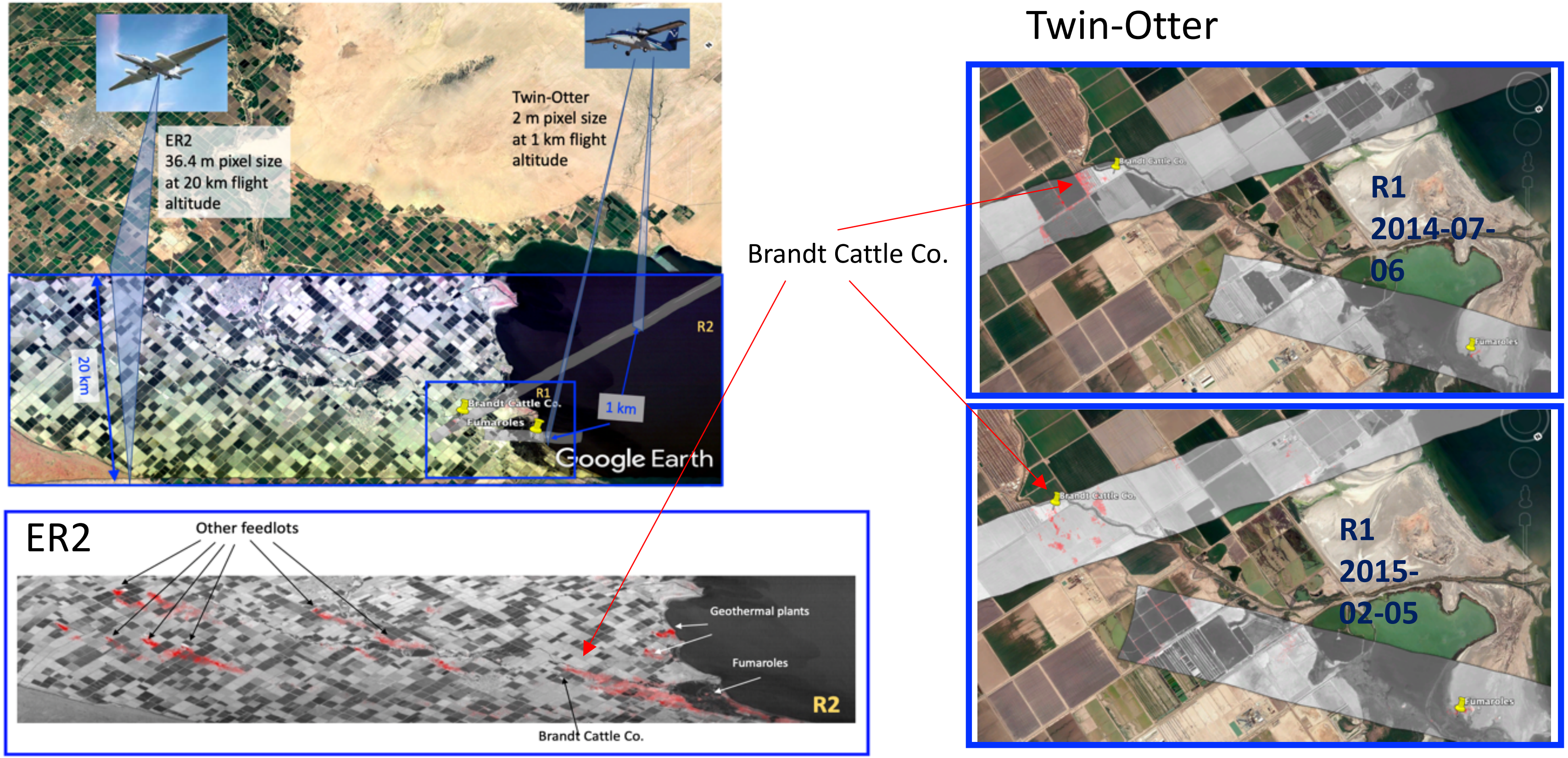
For T below ~600 K

*Kuai et al, JSTARS, 2019*

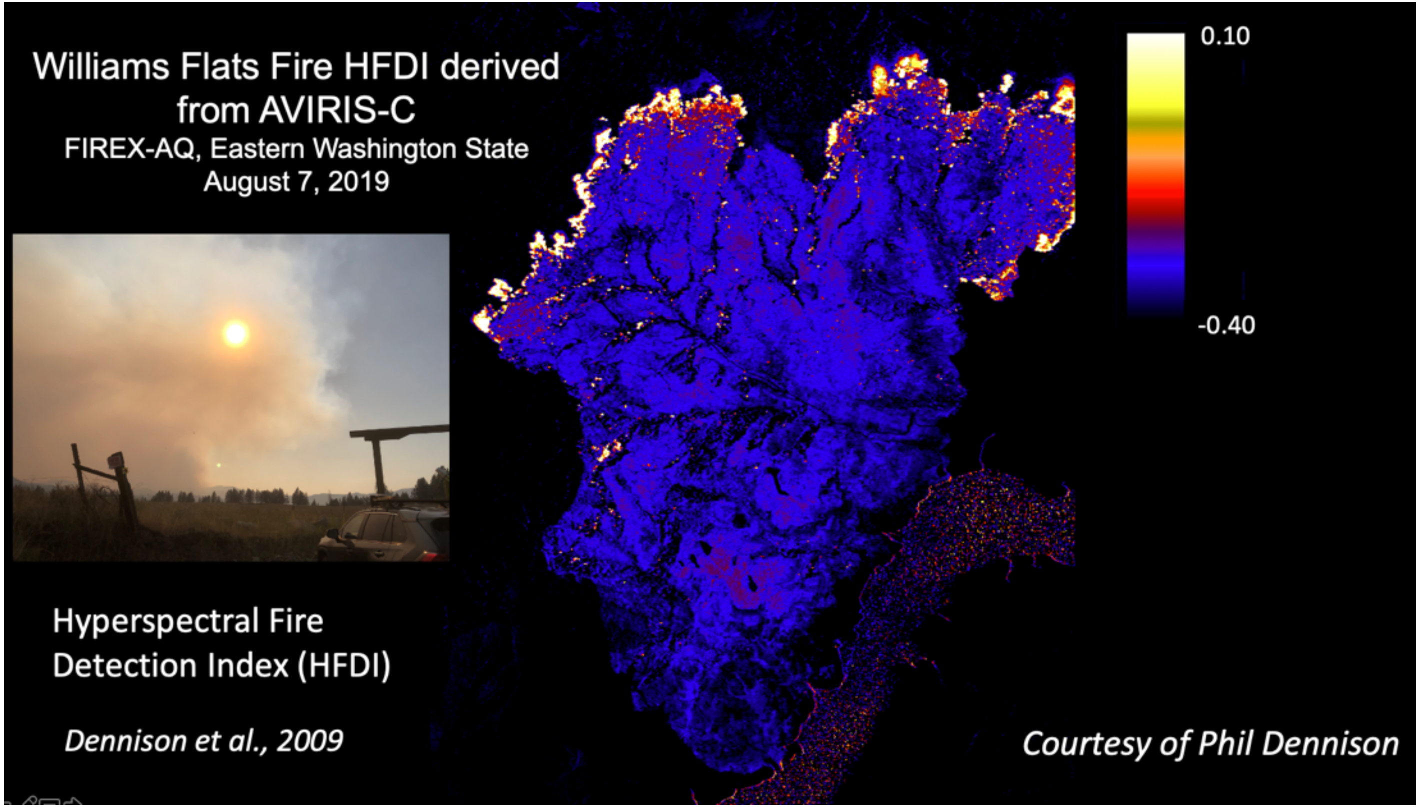


# HyTES Surveys in California



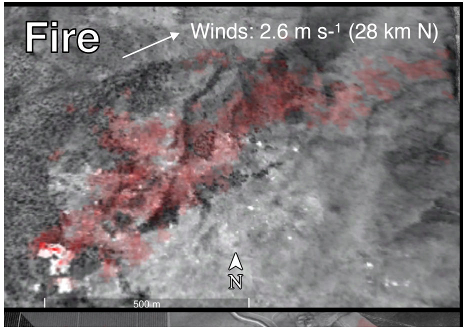
# AVIRIS Observations of Fires during FIREX-AQ 2019



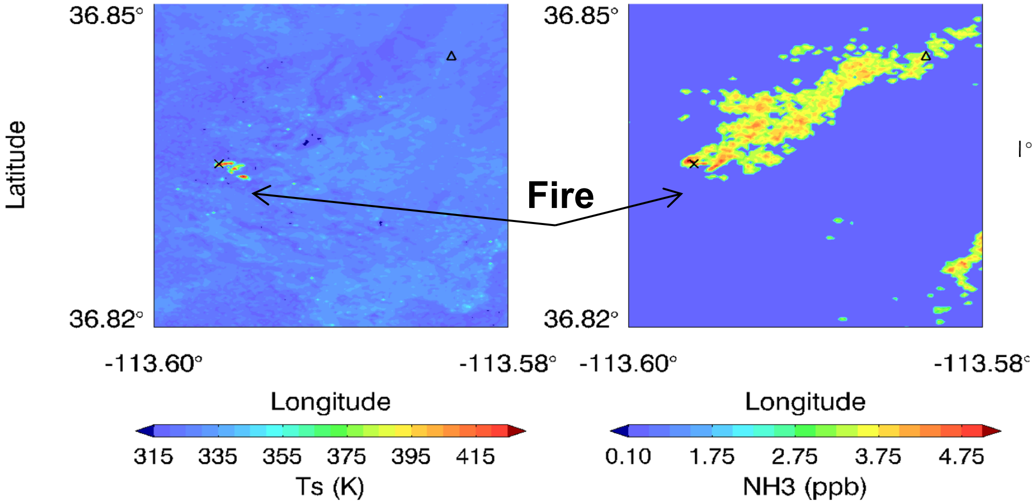
# RESULTS

In Year 1, $NH_3$ retrievals from HyTES data and aerosol retrievals in smoke conditions from AVIRIS-C data were developed, assessed, validated, and compared with in situ and satellite observations.

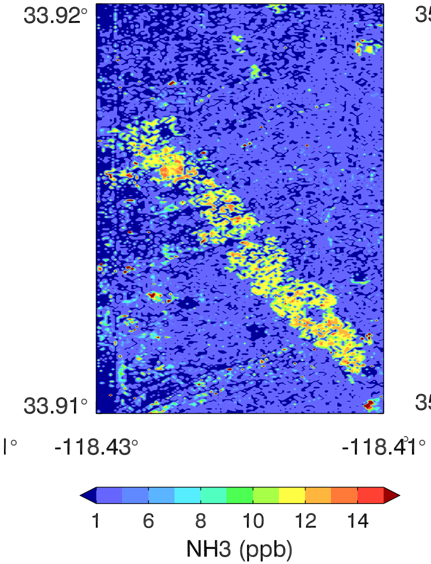
## Gulch Fire (Smoldering)



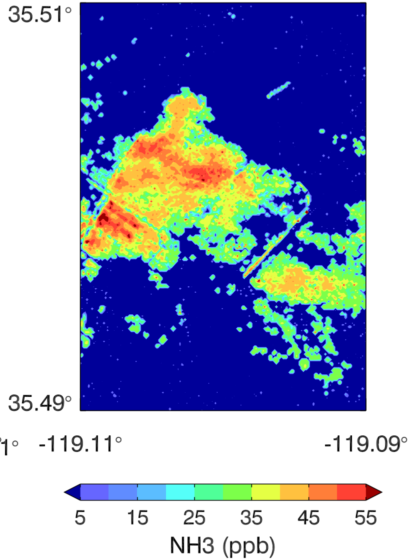

Simultaneous retrievals of surface temperature and $NH_3$ enhancements from HYTES observations




## Power plant

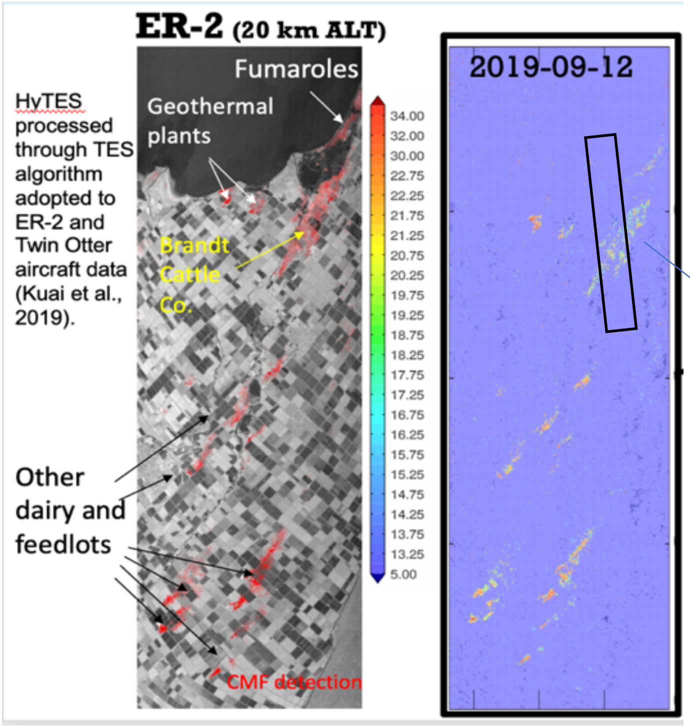



## Feedlot

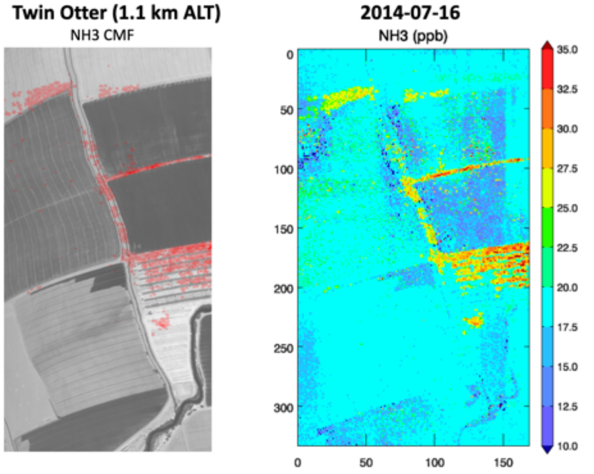



*Kuai et al., JSTARS, 2019*

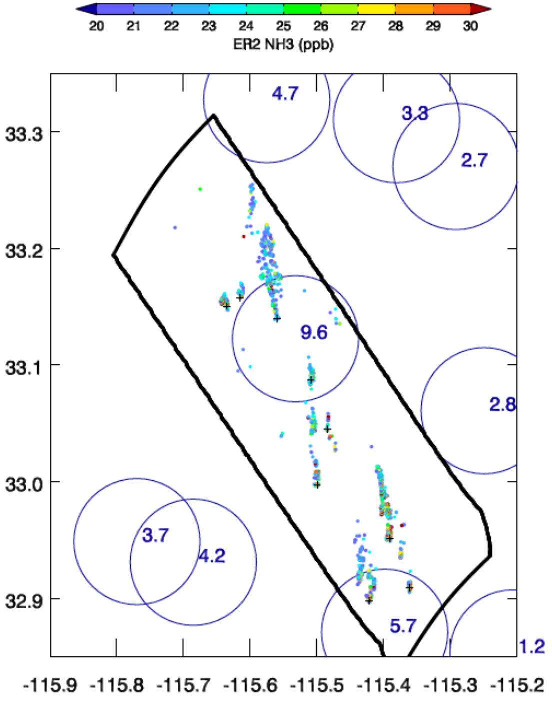
# Quantitative Comparison of Retrieved ER-2 $NH_3$ to Twin Otter $NH_3$




- Both observed enhancement at Brandt Cattle Company
- Enhancement in plume:
  - Twin-Otter: >30 ppb, ER2 >20 ppb
  - Higher enhancement in Twin-Otter low flight measurements
- Background level
  - Twin-Otter: 10-20 ppb
  - ER2: 5-15 ppb



# ER2 $NH_3$ Comparison to CrIS and Model Simulations



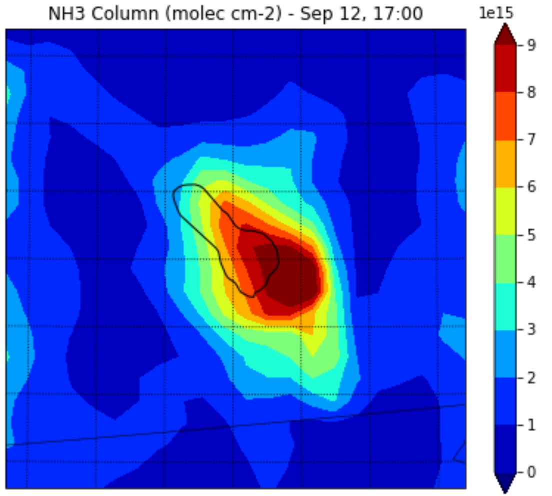

ER2 data:

- Located 9 sources for the plumes
- 20-30 ppb level

CrIS data:

- 15 km footprint
- One target covers more than one plume
- Matched two collocated targets (~10 and ~6 ppb level)
- Measure integrated enhancement

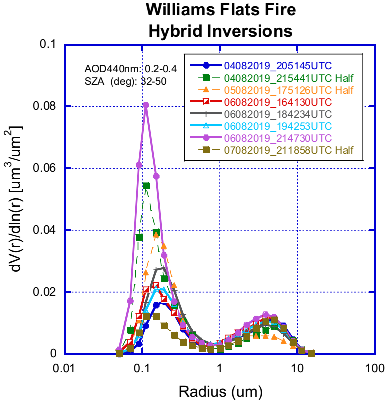
ER2: 17:05:04

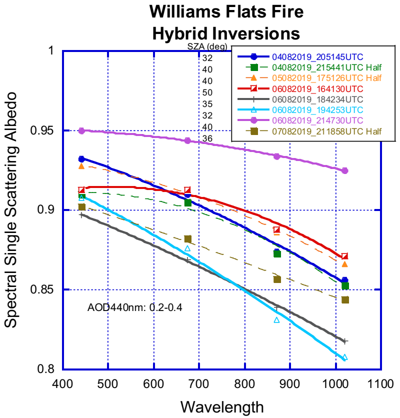


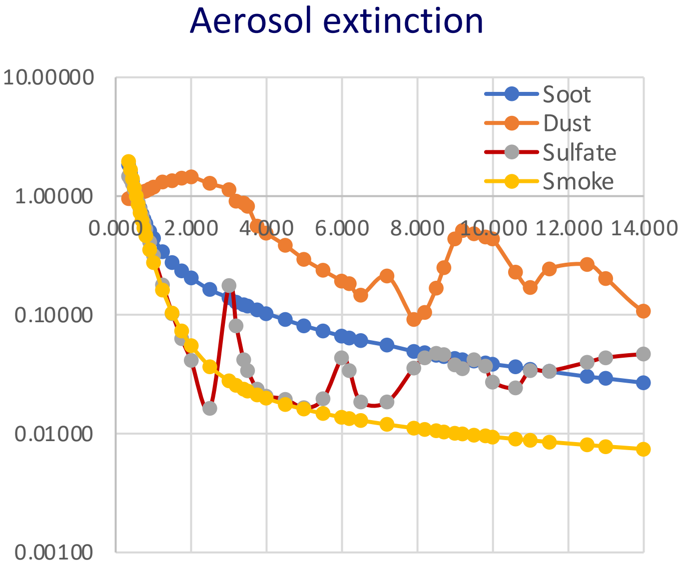

Consistency in down-wind plume tails and spatial gradient

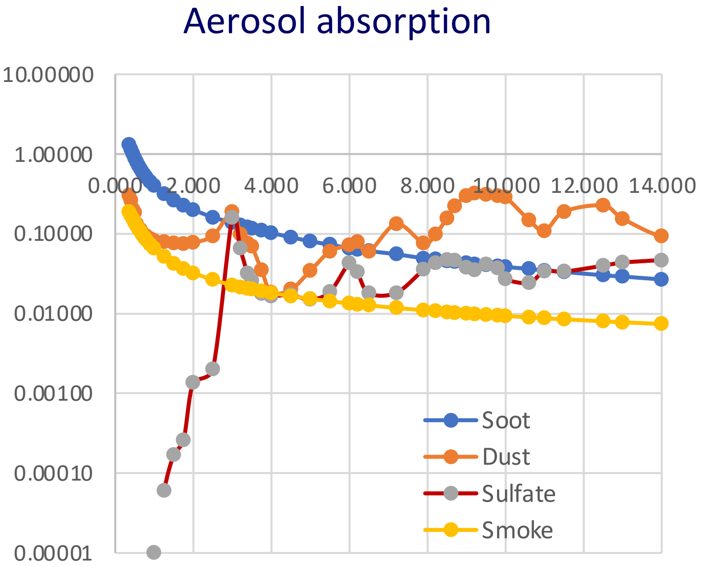
In preparation: *Kuai et al.*, Application of HyTES observations from the high-altitude ER-2 aircraft for quantification of medium-scale ammonia sources, *RSE*

# AVIRIS Aerosol Retrieval Development



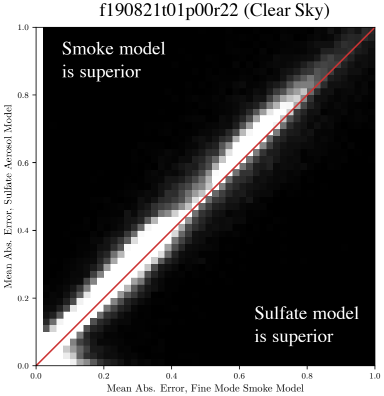



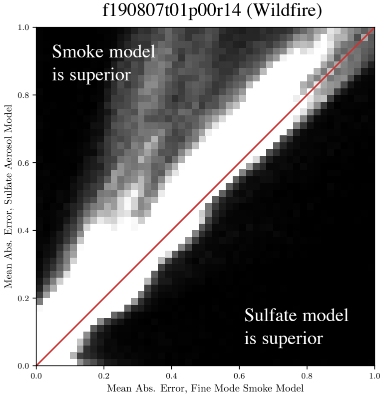



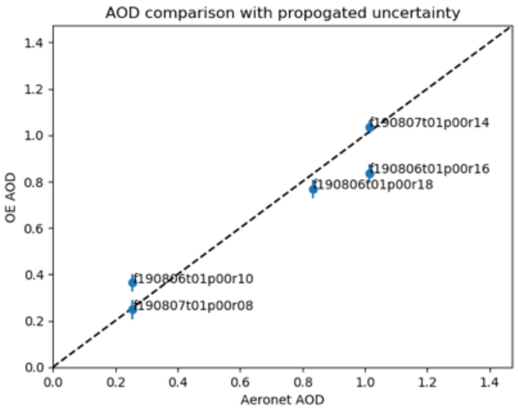

A new smoke model was derived using field observations and incorporated into the AVIRIS-C ISOFIT retrieval (the inversion of spectral surface properties, atmospheric constituents, and the instrument via Maximum A Posteriori (MAP) Estimation) using techniques from Thompson et al. (*RSE 2018, 2019).*

# AVIRIS Retrieval Evaluation

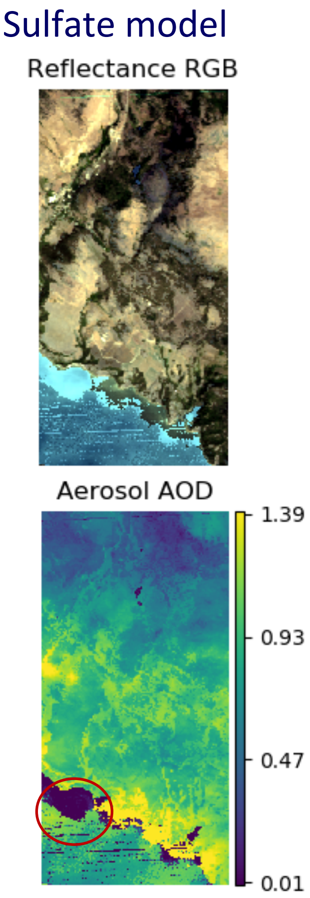


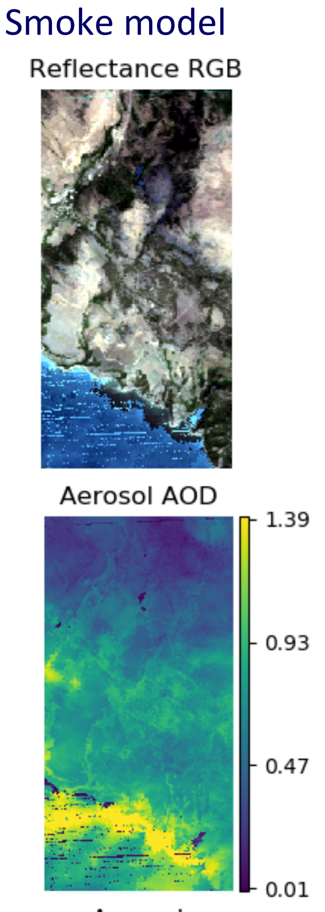




Histogram density of radiance residuals for smoke and sulfate aerosol models, for clear sky and wildfire flight ines. Bright locations have a high density of datapoints.








<u>In preparation:</u> *Brodrick et al.*, Evaluation of AVIRIS Retrievals for Fires Observed During the 2019 FIREX-AQ Campaign, to be submitted JGR

# Significance & Next steps

- Combining the capabilities of JPL's airborne imaging spectrometers is a promising tool to investigate the relationships between combustion conditions and primary/secondary aerosol emissions by quantifying $NH_3$ as an aerosol precursor.
- This research is aligned with the latest NASA and NOAA efforts to understand and characterize fire processes, which was a specific focus of the joint NASA/NOAA FIREX-AQ field campaign in 2019. AVIRIS-C was deployed in FIREX-AQ, while HyTES was flown with AVIRIS during the HyspIRI campaigns in 2018/2019 observing a variety of $NH_3$ sources, including wildfires.
- The Year 2 effort will focus on evaluating the combined capabilities of collocated observations from AVIRIS and HyTES to quantify the relationships between $NH_3$ and primary and secondary aerosols as a function of source type, fire combustion phase, and ambient atmospheric conditions.

Our long-term vision of using advanced remote sensing for determining fire energetics and monitoring BB emissions will enhance the capabilities of the upcoming NASA ACCP, EMIT, and SBG missions.

EMIT and SBG, specifically, will use imaging spectrometers to attempt to measure globally-consistent surface properties and, therefore, require improved corrections for variable atmospheric aerosols. Smoke plumes are an extreme case of challenging aerosol conditions, but the techniques developed in this project can be directly translated to EMIT and SBG.

Our investigation will help scope future BB-related airborne and satellite mission concepts, ultimately benefiting climate studies as well as air quality monitoring and regulation

# Publications and References

[1] Green R. O., et al, Imaging spectroscopy and the *Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), Remote Sens. Environ., 65*, 227–248, https://doi.org/10.1016/S0034- 4257(98)00064-9, 1998

[2] Hook S. J., W. R. Johnson, and M. J. Abrams, *NASA's Hyperspectral Thermal Emission Spectrometer (HyTES)*, pp. 93–115, Springer Netherlands, Dordrecht, 2013.

[3] Hulley G. C., et al., High spatial resolution imaging of methane and other trace gases with the airborne hyperspectral thermal emission spectrometer (HyTES), *Atmospheric Measurement Techniques*, vol. 9, no. 5, pp. 2393–2408, 2016.

[4] Kuai L., O. V. Kalashnikova, H. Lee, F. Hopkins, G. Hulley, R. Duren, J. Worden, M. J. Garay, and S. Hook, Quantification of ammonia emissions with high-resolution thermal infrared observations from the HyTES instrument: Comparison of multiple sources including a wildfire, *JSTARS*, *doi: 10.1109/JSTARS.2019.2918093*, 2019

[5] Thompson D. R., et al., Optimal Estimation of Spectral Surface Reflectance in Challenging Atmospheres, *Remote Sens. Environ.*, 232, 111258, 2019.

[6] Veraverbeke S., P. Dennison, I. Gitas, G. Hulley, O. V. Kalashnikova, T. Katagis, L. Kuai, R. Meng, Dar Roberts, and N. Stavros, Hyperspectral remote sensing of fire: State-of-the-art and future perspectives, *Remote Sens. Environ.*, 216, 105–121, 2018.