National Aeronautics and Space Administration

Characterization of fire emission processes from high-altitude hyper-spectral observations of smoke plumes, ammonia, and fuel loadings

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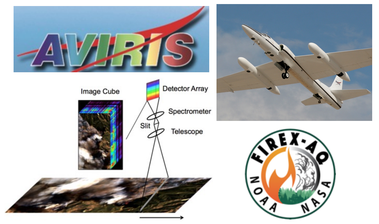
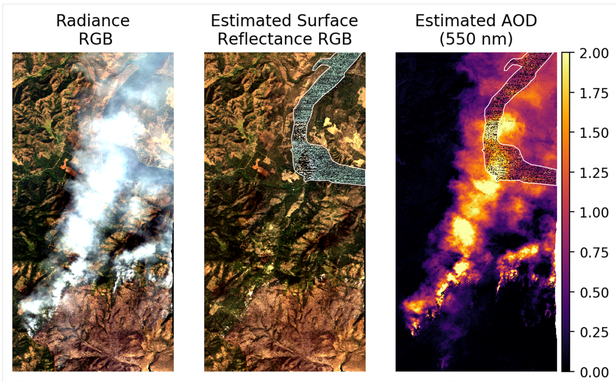
Program: FY21 R&TD Topics **Strategic Focus Area: Atmospheric composition and dynamics**

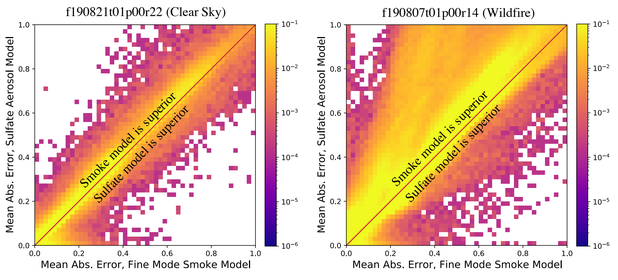
AVIRIS Aerosol Characterization – FIREX-AQ

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





Simultaneous Spectroscopic Surface and Atmosphere Retrieval from AVIRIS-C using Maximum A Posteriori (MAP) Estimation: A) The Williams Flats Fire, Aug. 6, 2019, observed in visible radiance channels; B) Visible channels of estimated surface reflectance spectrum; C) Estimated Aerosol Optical Depth (550 nm); Adopted from [B]



Histogram density of radiance residuals for smoke and sulfate aerosol models, for clear sky and wildfire flight lines

We developed an aerosol optical depth (AOD) retrieval algorithm for the AVIRIS-C instrument, quantified relevant uncertainties, and validated the results using datasets collected during the NASA/NOAA Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ) campaign.

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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 (NH3) – 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 2018-2020 join flights.

Our specific objectives:

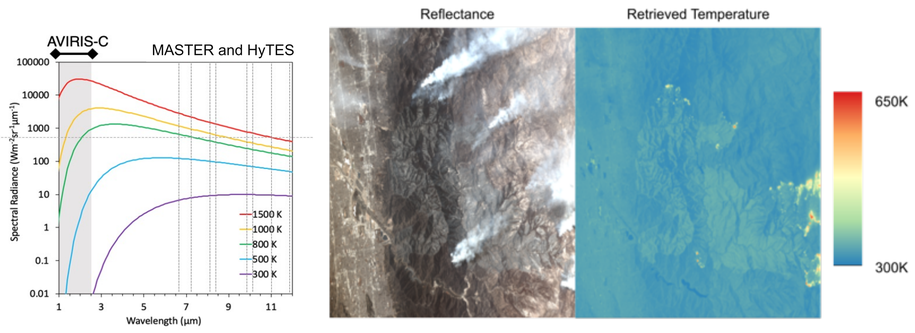
(a) Determine NH3 enhancements over various point sources;

(b) Determine AVIRIS retrieval sensitivity to different aerosol components;

(c) Establish relations between fire temperature and/or combustion phase, AOD, NH3 fire emissions, and ambient conditions;

(d) Formulate requirements and quantify uncertainties for fire emission remote sensing for PM air quality.

AVIRIS + HyTES + MASTER Fire Energetics



Fire temperature retrieval using combined spectra approach applied to AVIRIS, HyTES, and MASTER data collected over Bobcat Fire on 9/17/20 at 20:32 UTC.

Significance/Benefits to JPL and NASA:

This project is a pathfinder towards airborne and spaceborne characterization of the critical linkages between fire energetics and PM from BB emissions by the analysis of combined data from JPL's imaging spectrometers – AVIRIS and HyTES – for studies of atmospheric pollution.

This project increases the diversity of JPL projects, with a clear goal of future use of NASA products from imaging spectrometers by regulatory agencies (CARB, EPA, etc.). The deliverables resulting from this proposed work will enable us to apply for external funding through the CARB for ammonia characterization in California from fires and feedlots (per discussions with Toshihiro Kuwayama, Manager, Atmospheric Processes Research Section, CARB). The project is also helping to establish a potential for synergetic science investigations for NASA's AOS and SBG decadal missions as described in [C].

Ultimately this effort sets the stage for robust planned EV proposals. In particular, EVI FINEX concept that would quantify fire combustion phases for improving BB emission estimates is being developed through advancements in JPL technologies (NASA IIP concept: Compact Fire Infrared Radiance Spectral Tracker (c-FIRST) is submitted in 2021). The results of the project were used for the science justification on MWIR technology developments.

Our project demonstrates the joint capabilities of AVIRIS and HyTES for improving 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." 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's AOS, 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.

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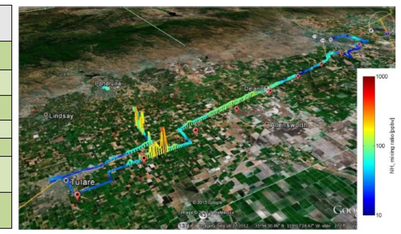
HyTES Characterization of Ammonia from Biomass Burning Emissions

Instrument Characteristic	HyTES
Number of pixels x track	512
Number of bands	256
Spectral Range	7.5-12 um
Integration time	30 ms
Total Field of View	50 degrees
Pixel size at 2000 m flight altitude	3.64 m
Pixel size at 20,000 m flight altitude	36.4 m



NH_3 from an open path Quantum Cascade Laser (QCL) on a moving platform in the San Joaquin Valley during DISCOVER-AQ 2013.

NH_3 is
- highly reactive
- highly variable in space and time

In-situ measurements are sparse

IR satellite sensors can provide much better coverage but …
- NH_3 is concentrated mostly in the boundary layer, where IR sensor sensitivity is often low
- High spatial variability leads to intra-pixel inhomogeneity in a single 15-50 km satellite pixel

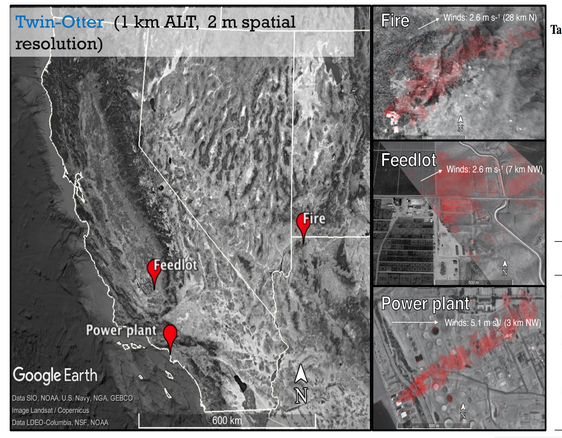
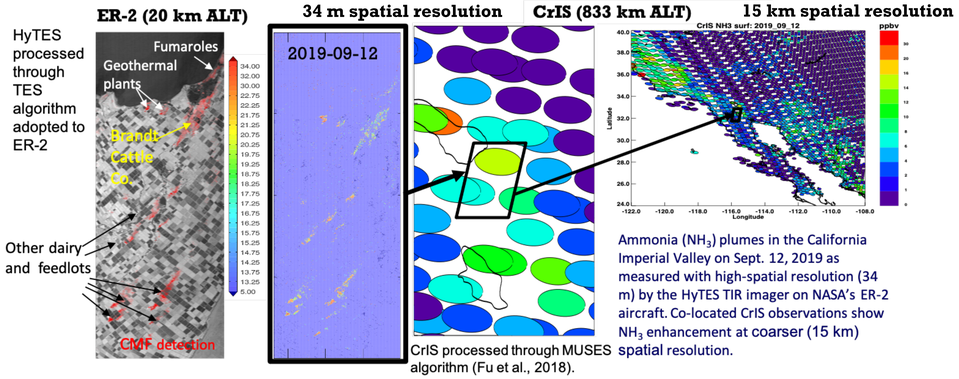


Table 1. Summary of ammonia events under investigation

	Event	Date	Location (lat/lon)
a	Fire (smoldering)	2014-07-03	Gulch Fire, Arizona 36°50'31.89"N/113°35'34.67"W
b	Power plant	2014-07-05	El Segundo, California 33°54'47.92"N/118°25'14.61"W
c	Feedlots	2015-02-09	Kern River, California 35°30'1.14"N/119°5'44.24"W

	Event	Abs (dT)	Ts (K)	E_{NH3} level
a	Fire (smoldering)	≥ 20K	310-600	Low (~ 5 ppb)
b	Power plant	10-20 K	300-330	Moderate (~0 ppb)
c	Feedlots	≤10 K	≤ 300	High (~50 ppb)



CrIS processed through MUSES algorithm (Fu et al., 2018).

Ammonia (NH_3) plumes in the California Imperial Valley on Sept. 12, 2019 as measured with high-spatial resolution (34 m) by the HyTES TIR imager on NASA's ER-2 aircraft. Co-located CrIS observations show NH_3 enhancement at coarser (15 km) spatial resolution.

We developed an optimal estimation retrieval algorithm for NH_3 from HyTES, and demonstrated that NH_3 could be quantitatively retrieved from low-altitude Twin Otter observations [A]. We also demonstrated that NH_3 retrievals with HyTES technology could be done from the ER-2 (transition to space). We adapted the NH_3 algorithm for ER-2 altitudes, performed sensitivities, quantified uncertainties, and tested with September 2019 HyspIRI datasets. Figure 3 shows the newly developed HyTES ER-2 retrievals of NH_3 over the Salton Sea in comparison with the coincident NOAA Cross-track Infrared Sounder (CrIS) NH_3 product. The paper describing the NH_3 retrieval is currently in review [D].

Publications:

[A] 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

[B] Brodrick P., D. B. Thompson, M. J. Garay, D. M. Giles, B. Holben, and O. V. Kalashnikova, Simultaneous characterization of wildfire smoke and surface properties with imaging spectroscopy during the FIREX-AQ field campaign, accepted, *JGR-Atmospheres*, August 2021

[C] Stephens G. L., O. V. Kalashnikova, P. Pilewskie, J. J Gristey, D. R. Thompson, X. Huang, M. Lebsock, S. Schmidt, The spectral nature of Earth's reflected radiation: measurement and science applications, *Frontiers Remote Sensing, V2, p11, doi:10.3389/frsen.2021.664291, 2021*

[D] Kuai L., O. V. Kalashnikova, H. Lee, K. Cady-Pereira, K. Bowman, G. Hulley, V. Payne, F. Hopkins, W. Porter, Application of HyTES observations from the high-altitude ER-2 aircraft for quantification of medium-scale ammonia sources, in review, *Remote Sens. Envir.*

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