A Sub-Pixel-Based Calculation of Fire Radiative Power from MODIS Observations: Retrieval, Validation, and Sensitivity Analysis

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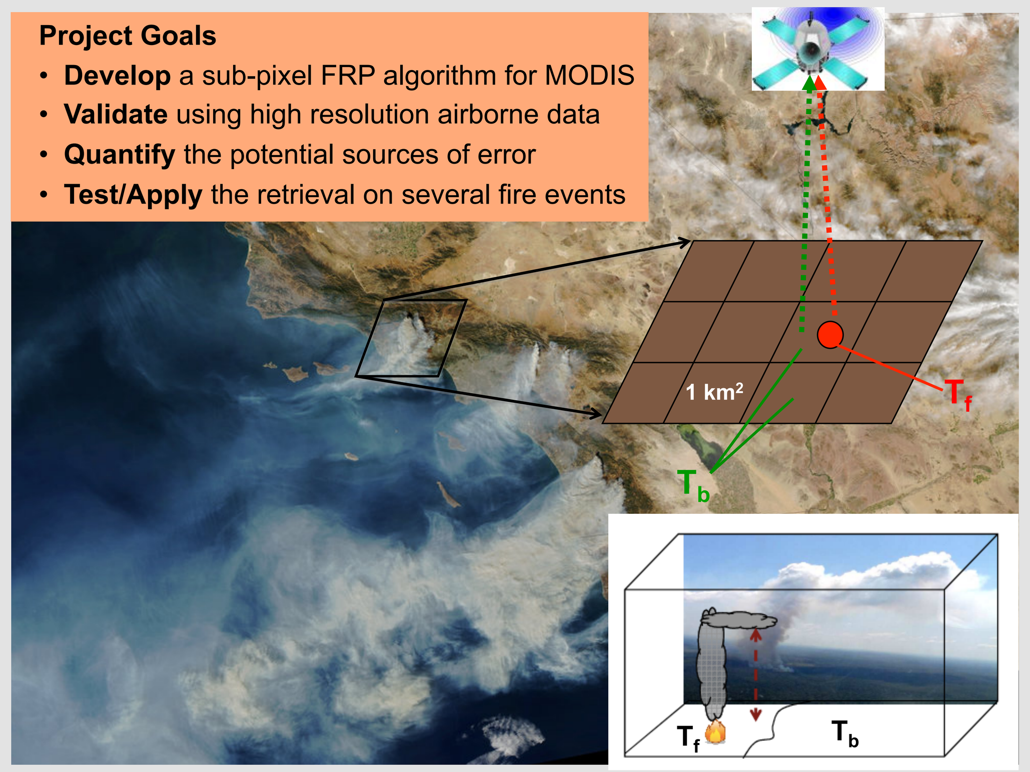
I. Introduction and Motivation

Using satellite, airborne, and meteorological data, this study develops and validates a new sub-pixel-based calculation of fire radiative power (FRP_f) for fire pixels detected at 1 km^2 nominal spatial resolution by the MODerate Resolution Imaging Spectroradiometer (MODIS) fire detection algorithm (collection 5). A two-component model (Dozier method) for retrieving sub-pixel fire area fraction and temperature has been available since 1981. However, in the current investigation, modifications are made to the retrieval to account for atmospheric effects by implementing output from a radiative transfer model at 3.96 and 11 μm (MODIS fire detection channels). In addition, two clustering techniques are implemented to mitigate errors that may exist when using individual pixels. The FRP_f, in combination with retrieved fire cluster area, allows a large fire burning at a low intensity to be separated from a small fire burning at a high intensity, which will likely improve estimates of smoke plume injection heights in modeling studies and could enhance fire-related applications using the future GOES-R and VIIRS sensors.

Project Goals

- **Develop** a sub-pixel FRP algorithm for MODIS
- **Validate** using high resolution airborne data
- **Quantify** the potential sources of error
- **Test/Apply** the retrieval on several fire events



MODIS Fire Radiative Power (FRP)

Advantages

- Quantitative indicator of fire intensity
- Proportional to amount of biomass consumed
- Proportional to amount of smoke released
- Related to the smoke plume height

Current FRP Limitation (collection 5)
FRP per 1 km²

These pixels have equal FRP?

MODIS Pixel #1	MODIS Pixel #2
High fire temp.	Cooler fire temp.
Small fire area	Large fire area

We need FRP per fire area!

Fig. 1. Schematics showing the potential issues caused by sub-pixel fire characteristics for the current version of the MODIS fire detection algorithm.

II. MODIS Sub-Pixel Retrieval and Case Study Specifics

Calculations per MODIS fire pixel (orange in flow chart):

$$L_4 = PB(\lambda_4, T_f) + e_{4b}(1-P)L_{4b}$$

$$L_{11} = PB(\lambda_{11}, T_f) + e_{11b}(1-P)L_{11b}$$

where L = radiance, B = IR Planck Function, P = fire area fraction, T_f = fire temperature, L_b = background radiance, and e_b = assumed background emissivity.

Performing the MODIS Retrieval
(Peterson et al., Submitted)

LOOKUP TABLES (4 and 11 μm)
- SBDART Radiative Transfer Model (Ricchiazzi et al., 1998)
- Account for atmospheric effects
- Vary the potential geometries
- Vary the surface temp. (bottom of atmosphere)

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MODIS INPUTS
- Geolocation data (solar/sensor zenith, azimuth)
- Level 1B pixel radiances
- **Fire product background temps.**

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Match MODIS inputs to lookup tables

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PIXEL LEVEL RETRIEVAL | **CLUSTERING RETRIEVALS**
- Single Retrieval via Averages
- General Summation Method

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OUTPUTS
- **Fire area fraction and pixel area**
- **Actual (surface) fire temp.**

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Sub-Pixel-Based FRP_f

$$FRP_f = \sigma(T_f^4 - T_{4b}^4)A_f$$

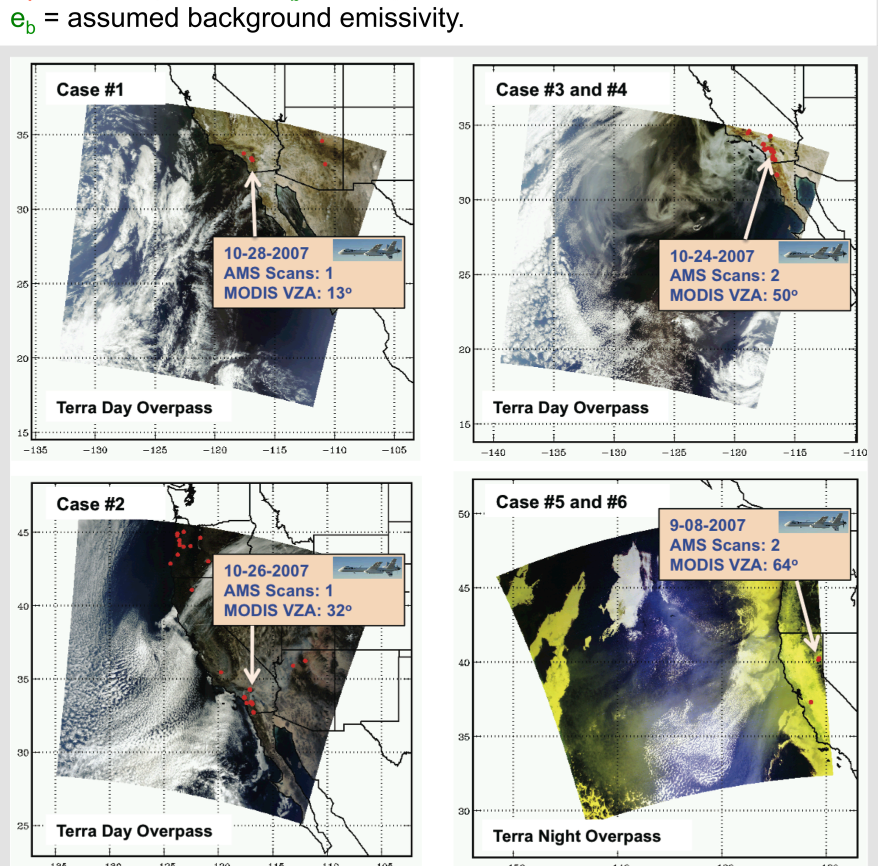
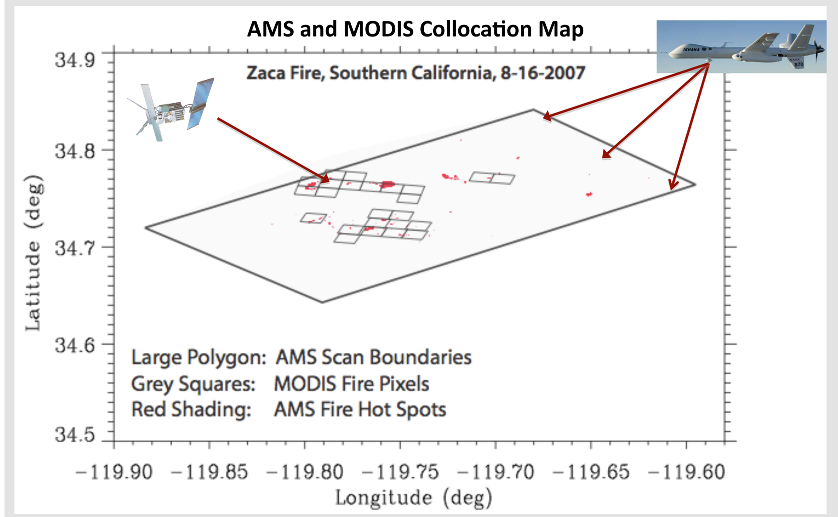


Fig. 2. Projections of the four MODIS scenes containing the six case studies with available validation data in 2007.

III. Validation of Retrieved Fire Area

Incorporate the high-resolution data (3-50 meters) obtained from the Autonomous Modular Sensor (AMS), flown aboard NASA's Ikhana Unmanned Airborne System (UAS).



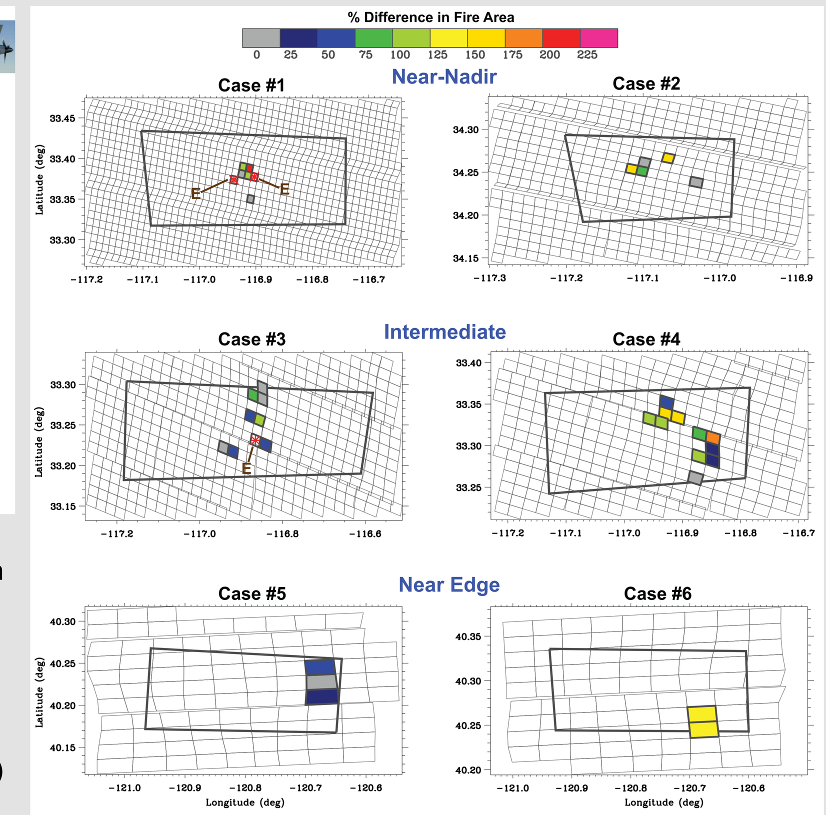


Fig. 3. (Top) an example AMS and MODIS collocation map. (Right) Spatial representation of all six colocation case studies in California. The large black polygons denote the boundaries of the AMS scan and smaller grey polygons represent the MODIS pixel mesh. The three MODIS pixels containing a red asterisk and brown "E" indicate where the MODIS background temperature was higher than the mean pixel temperature (retrieval error, see Section VII). The viewing zenith angle (VZA) increases from case #1 (13°) to case #5 and #6 (64°).

IV. Indirect Effects on Retrieved Fire Area

AMS and MODIS fire area comparisons have shown promise for a fire area greater than ~0.001 km^2 (1000 m^2), but the accuracy of the retrieval is affected by the scan characteristics and sub-pixel fire properties.

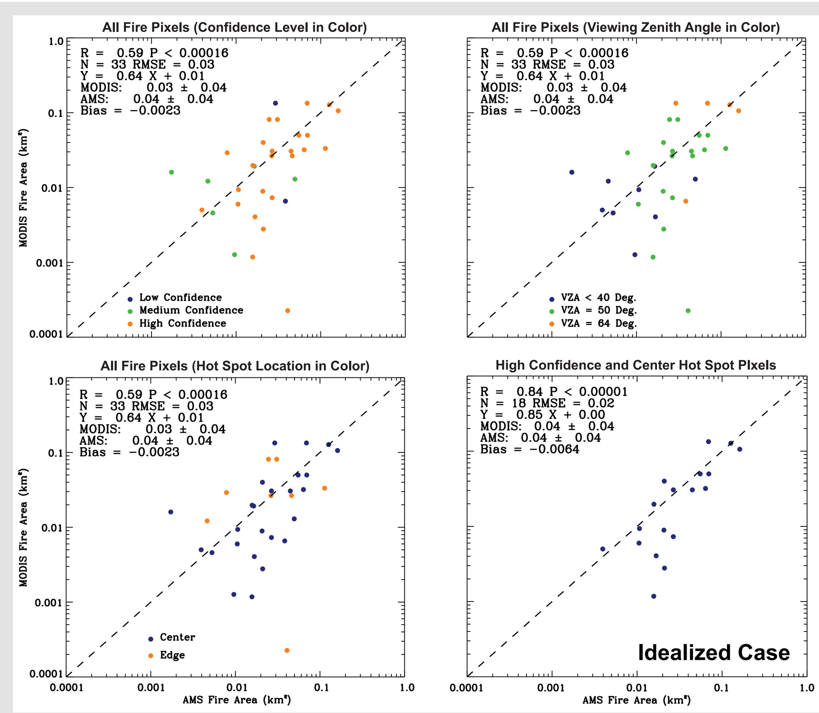


Fig. 4. Pixel-level comparisons between retrieved MODIS fire area and AMS observed fire area from all six collocated cases.

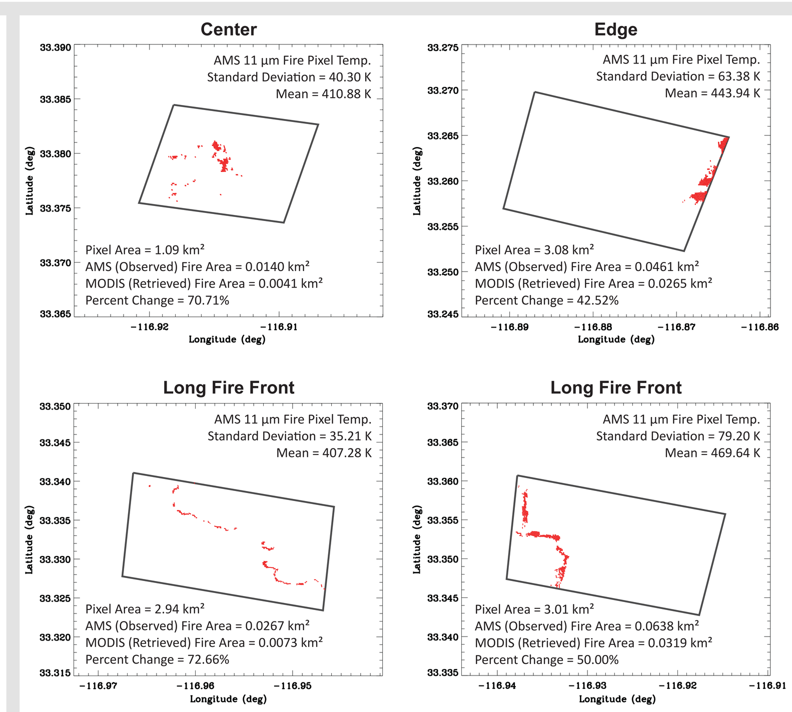


Fig. 5. Spatial display of the sub-pixel fire region (via AMS) within four MODIS fire pixels.

V. Clustering-Level Comparisons

- The clustering-level results highlight the importance of averaging to reduce the random errors highlighted in Section IV, such as the distribution of sub-pixel fires, point-spread-function effects, and coregistration errors.
- The sum of pixel-level retrievals method may be more advantageous because the definition of a cluster can be changed as needed, but isolated, small fires will not benefit.

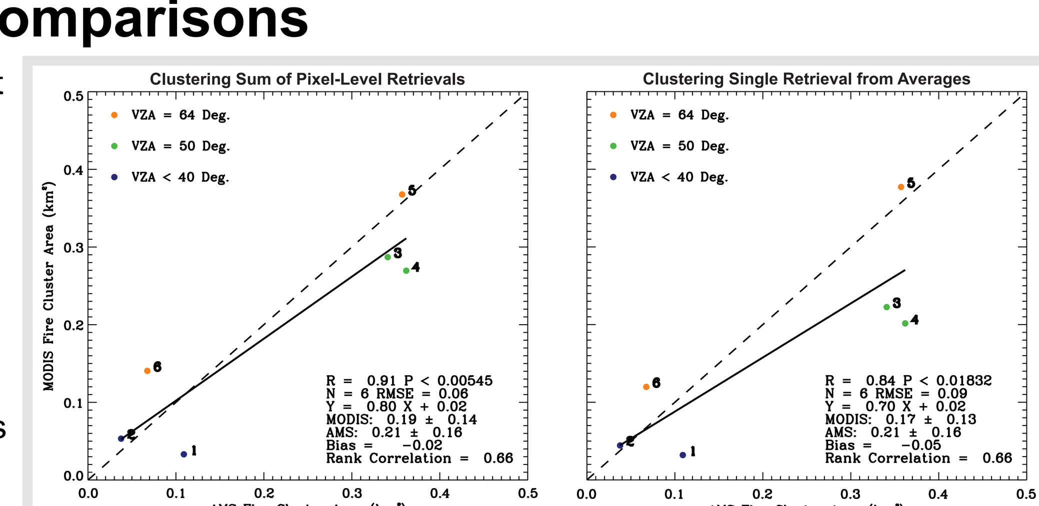


Fig. 6. Cluster-level comparisons between retrieved MODIS fire area and AMS.

VI. Sub-Pixel MODIS FRP_f vs. the Current MOD14 FRP (FRP_p)

- FRP_f is strongly correlated to the current MODIS FRP_p (R = 0.93), but also contributes additional information.
- The combination of FRP_f and cluster fire area can be used differentiate large fires burning at a low intensities from small fires burning at a high intensities.
- FRP_f flux will likely improve estimates of initial smoke plume buoyancy and injection heights.

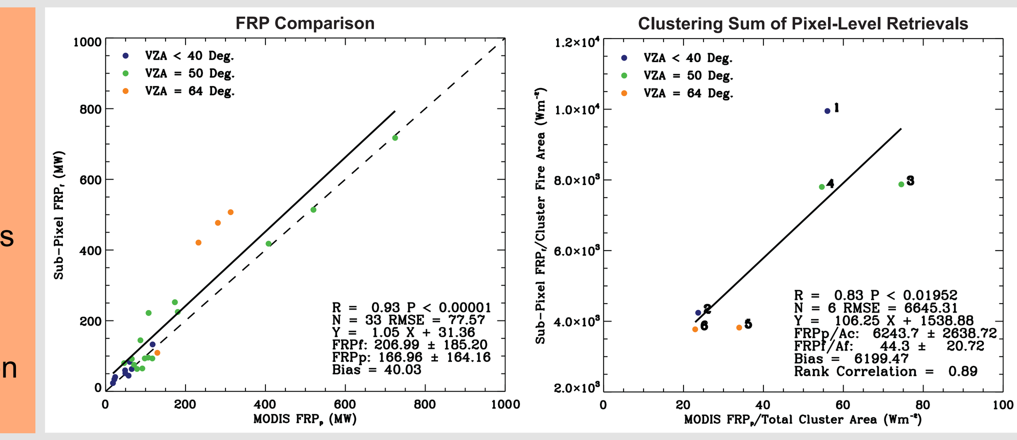
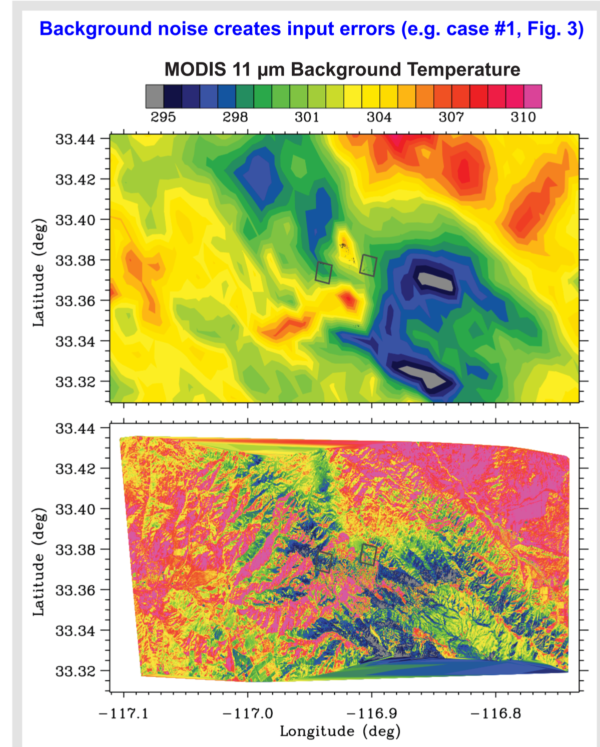


Fig. 7. (Left) Pixel-level comparison between the current MODIS FRP_p and FRP_f. (Right) Cluster-level comparison between MODIS FRP_p per cluster area and FRP_f per fire area (FRP_f flux) using the sum of pixel-level retrievals method.

VII. Sensitivity to Background Temperature

Of the many inputs, the retrieval is most sensitive to background temperature noise, primarily at 11 μm.



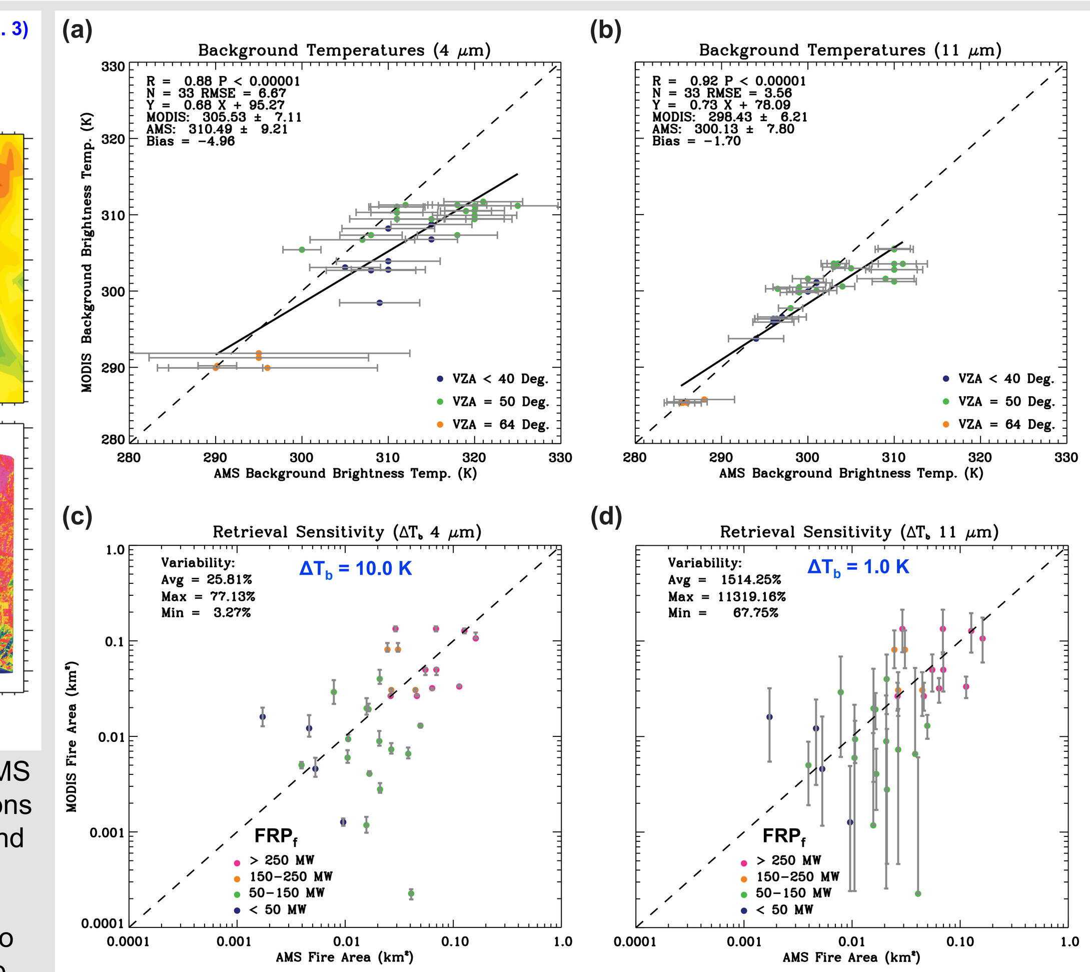


Fig. 8. (Top) Comparison of MODIS and AMS 11 μm temperature. (Right, a,b) Comparisons between the MODIS fire product background temperature and the AMS derived in-pixel background temperature at 4 and 11 μm. (Right, c,d) Pixel-level fire area sensitivity to errors in the 4 and 11 μm background temp.

VIII. Concluding Remarks

This study has developed a MODIS sub-pixel retrieval for fire area and temperature, which are used to calculate FRP_f. The retrieval was designed for any MODIS granule and a radiative transfer model was used to account for atmospheric effects. Over the next decade, the new generation of satellite sensors, such as VIIRS and GOES-R, will replace the current generation, including MODIS. Therefore, the sub-pixel algorithm is designed for easy application to these future sensors, provided the basic spectral properties are similar.

Essential References

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