Radiative forcing of a small-scale wildfire smoke plume at the surface, atmosphere, and TOA from surface and satellite observations

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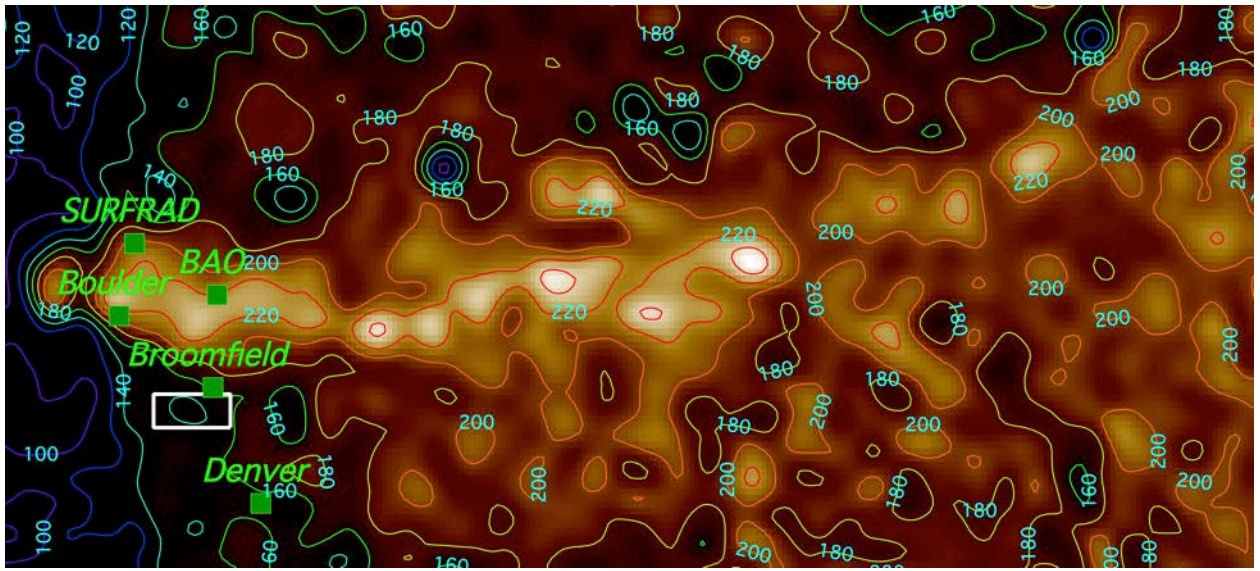

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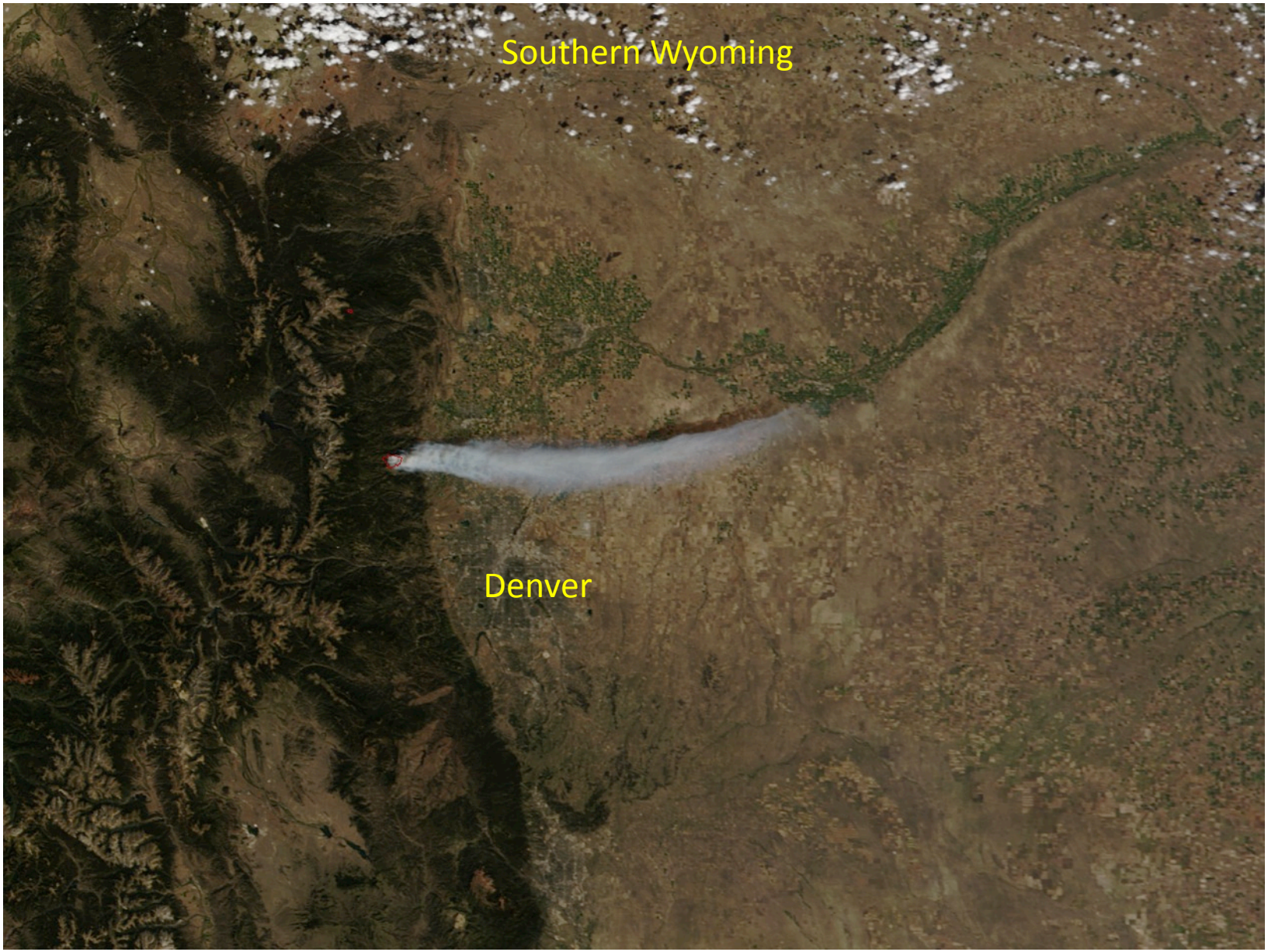
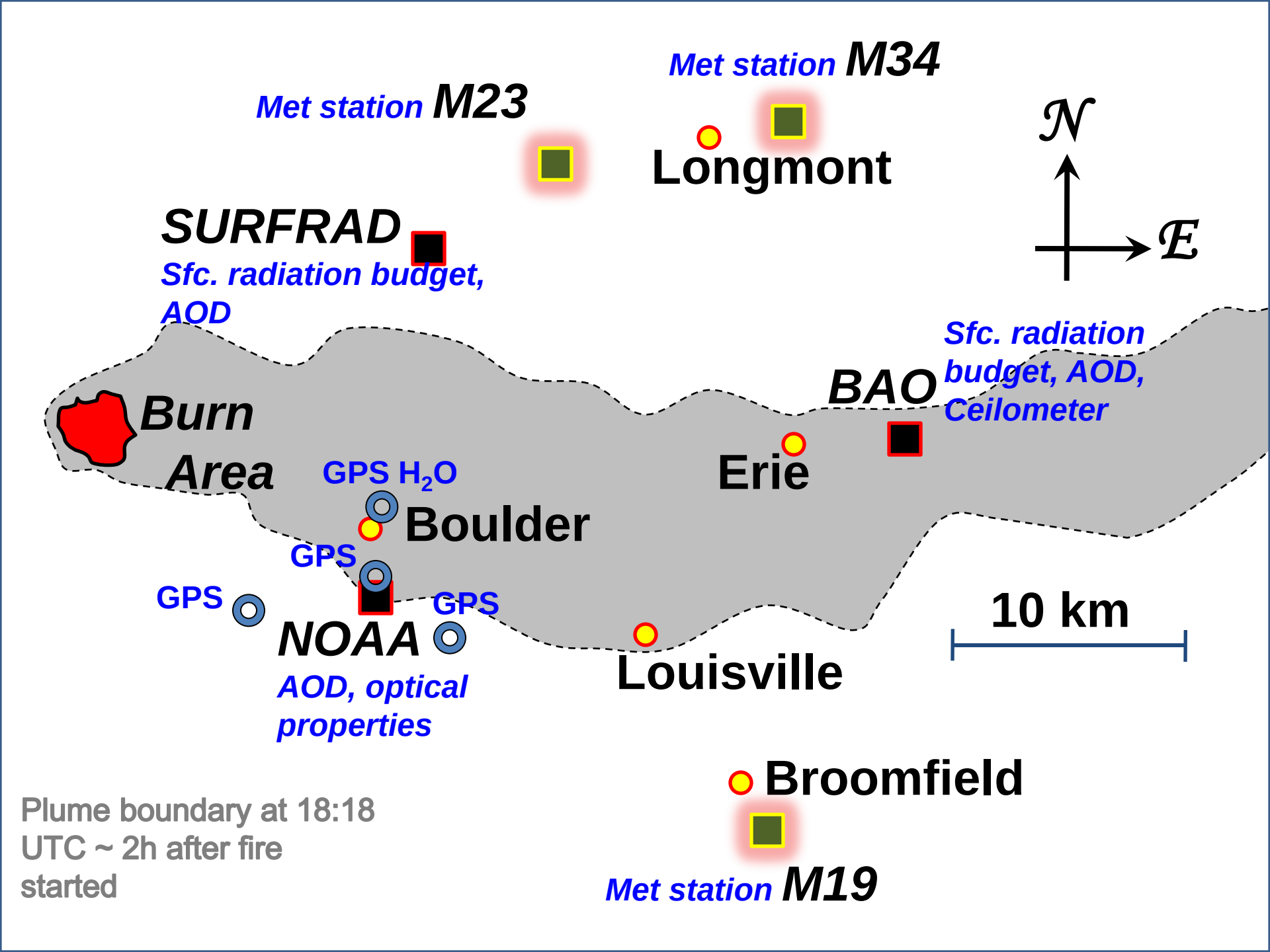
NASA Terra MODIS imager

1820 UTC, ~ 2 hours after the fire started




Met station M34
Met station M23
Longmont
N
E
SURFRAD
Sfc. radiation budget, AOD
Sfc. radiation budget, AOD, Ceilometer
BAO
Burn Area
GPS H_2O
Erie
Boulder
GPS
GPS
GPS
NOAA
AOD, optical properties
Louisville
10 km
Broomfield
Met station M19
Plume boundary at 18:18 UTC ~ 2h after fire started

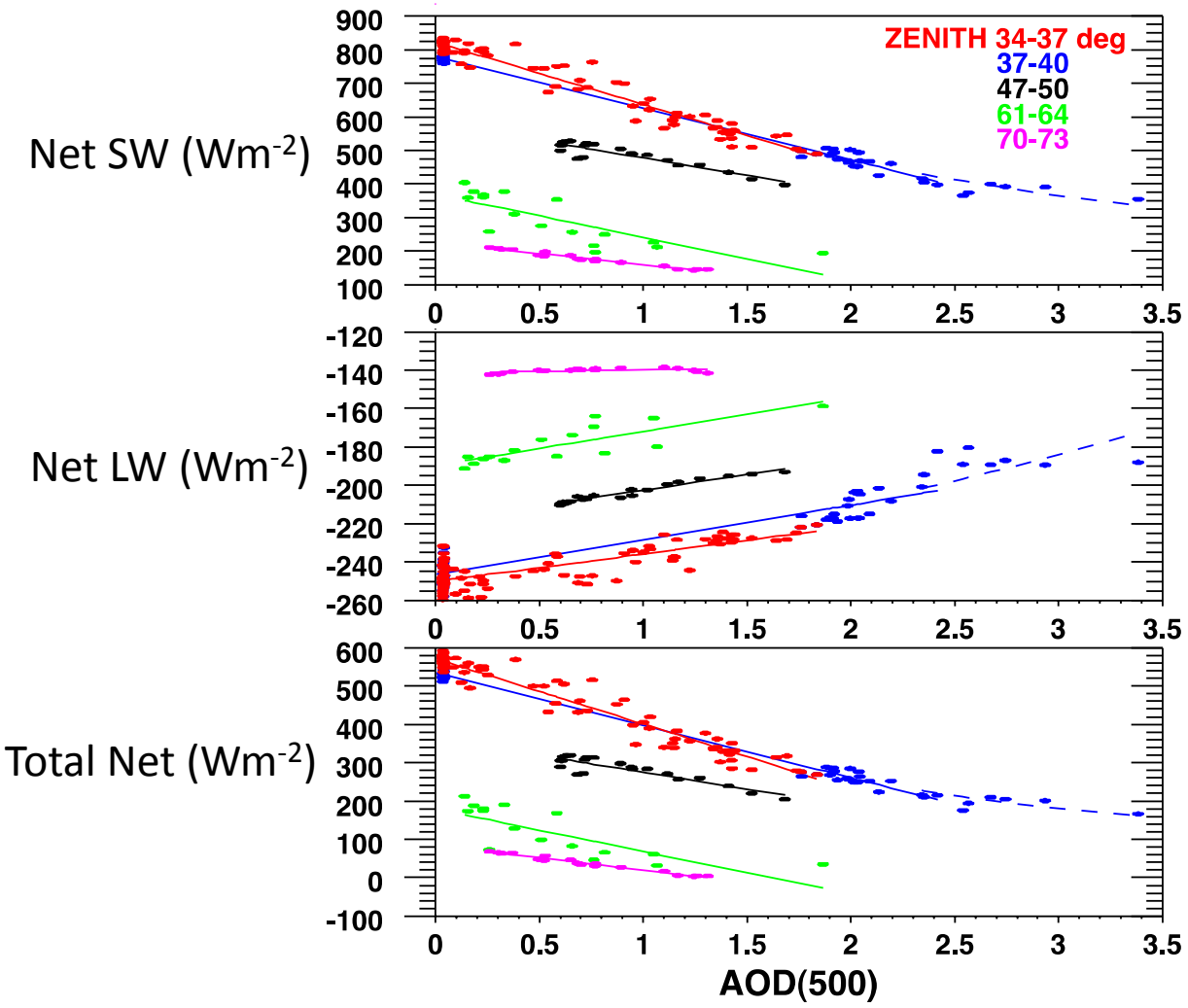
Our focus is to compute the total Radiative Forcing (RF) and Efficiency (RFE) of the smoke aerosol at the surface, atmosphere, and TOA

$$RFE_{(sfc\ or\ TOA)} = \Delta net\ Rad_{(sfc\ or\ TOA)} / \tau_{500nm}$$

$$RFE_{atmos} = RFE_{TOA} - RFE_{sfc}$$

- Computed for SW, LW, and all-wave
- RFE_{SW} dependent on solar zenith angle and surface albedo
- RFE_{LW} dependent on the thermal structure of the atmosphere, water vapor, and skin temperature

Clear-sky surface measurements throughout the day allowed direct calculation of RFE_{sfc}



Satellite data is necessary to compute aerosol radiative forcing at TOA

- CERES broadband imagers (20 km res.) could not resolve the Fourmile Canyon fire smoke plume

- MODIS spectral imagers (1 km res.) could resolve the plume, but NASA does not do a narrowband-to-broadband conversion

MODIS Spectral radiance to broadband conversion

SW: Tang et al. [2006], *Remote Sensing Environment*

$$r = b_0 + \rho_1 b_1 + \rho_2 b_2 + \rho_3 b_3 + \rho_4 b_4 + \rho_5 b_5 + \rho_6 b_6 + \rho_7 b_7$$

r = broadband shortwave reflectance

$b_i = c1_i + [c2_i/(1+\exp((1/\cos(VZA)-c3_i/c4_i))$

$\rho_i = \pi L_i d^2/Eo_i \cos(SZA)$

L_i upwelling radiance for MODIS channel i

RMS error = 0.01

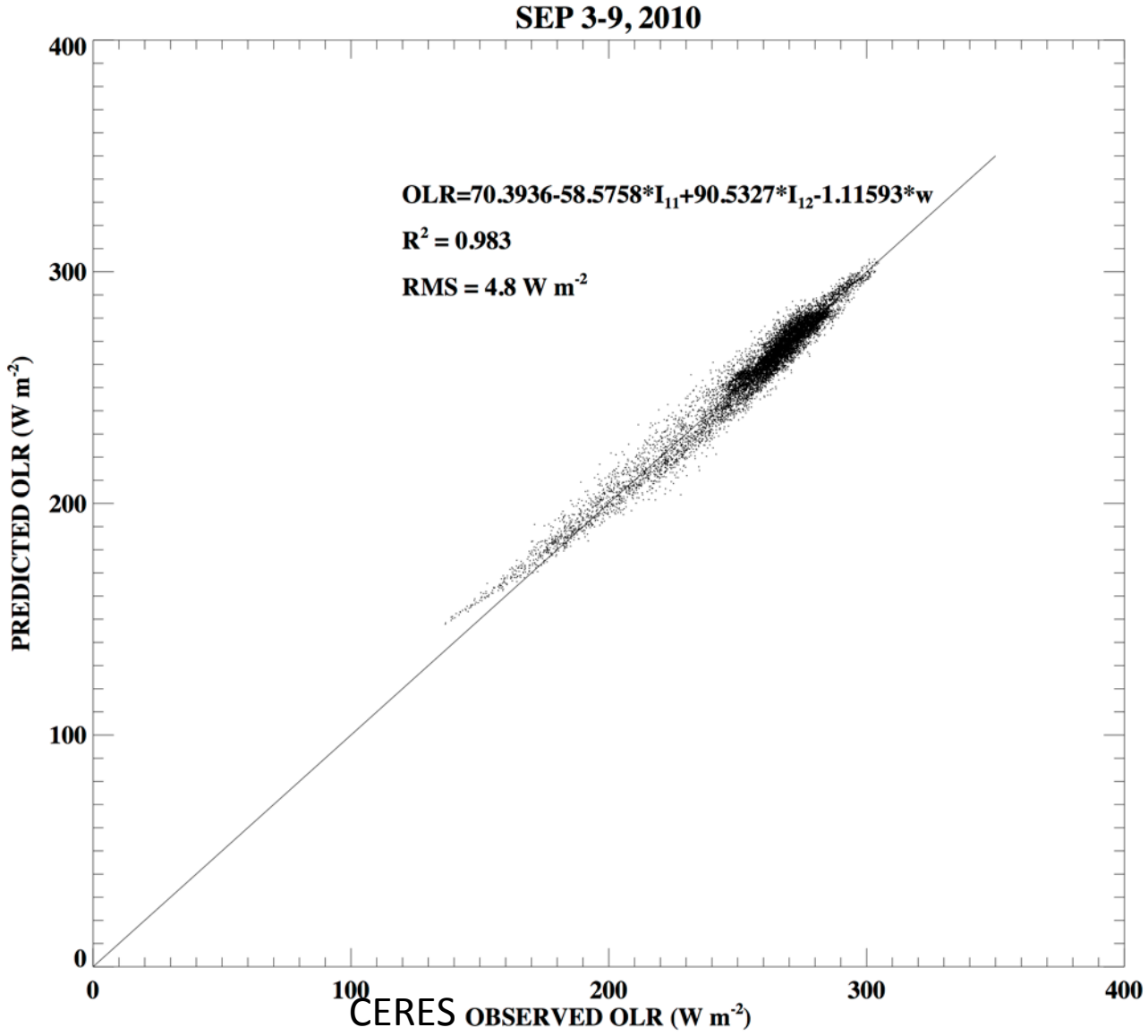
LW: Inamdar and French [2009], *AMS Conference*

$$LW_{TOA} = a_0 + a_1 L_{11} + a_2 L_{12} + a_3 w$$

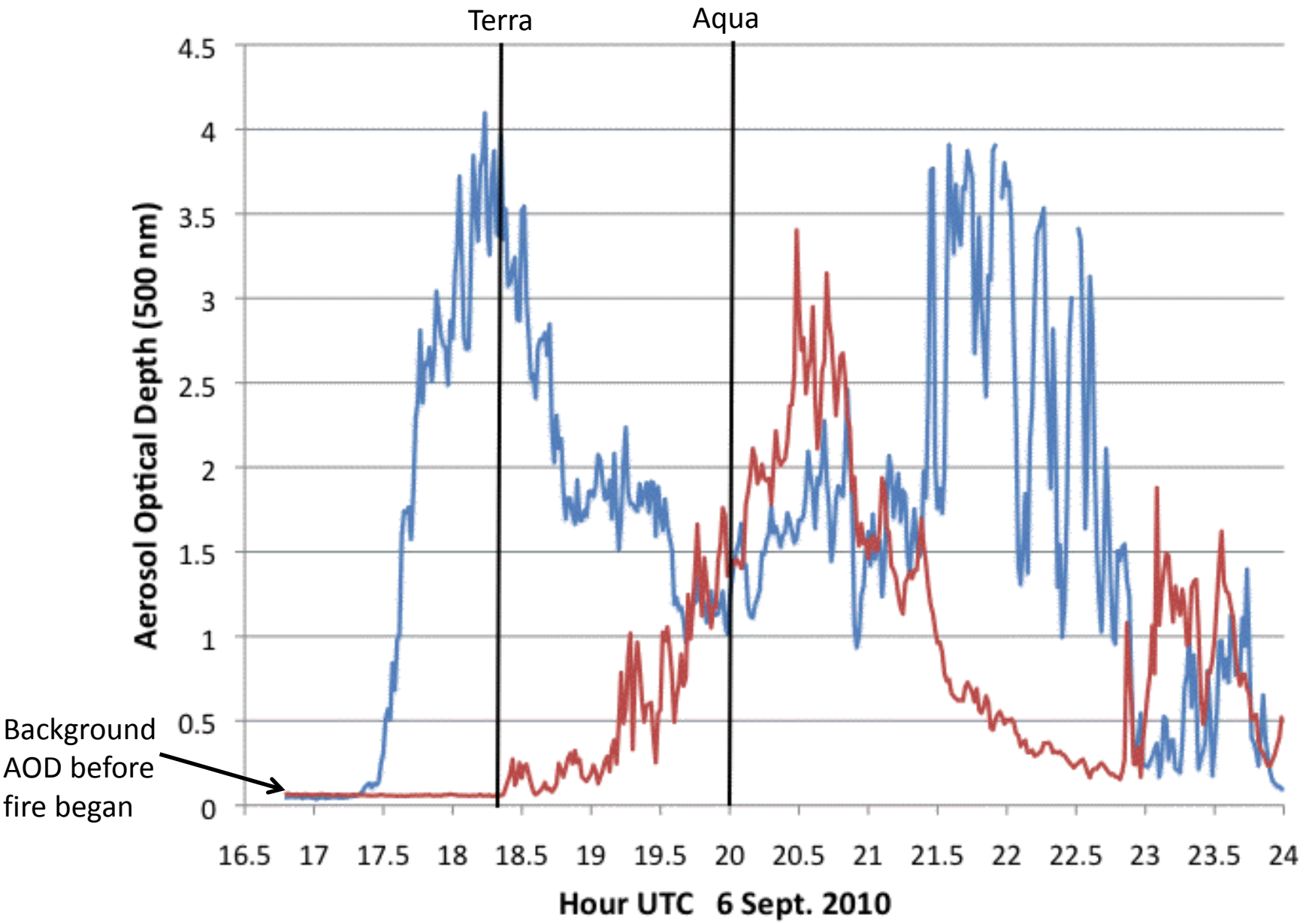
L_{11} and L_{12} are MODIS 11 and 12μm radiance

w is the MODIS integrated water vapor product

LW narrowband to broadband model calibrated to CERES data for one week surrounding the event

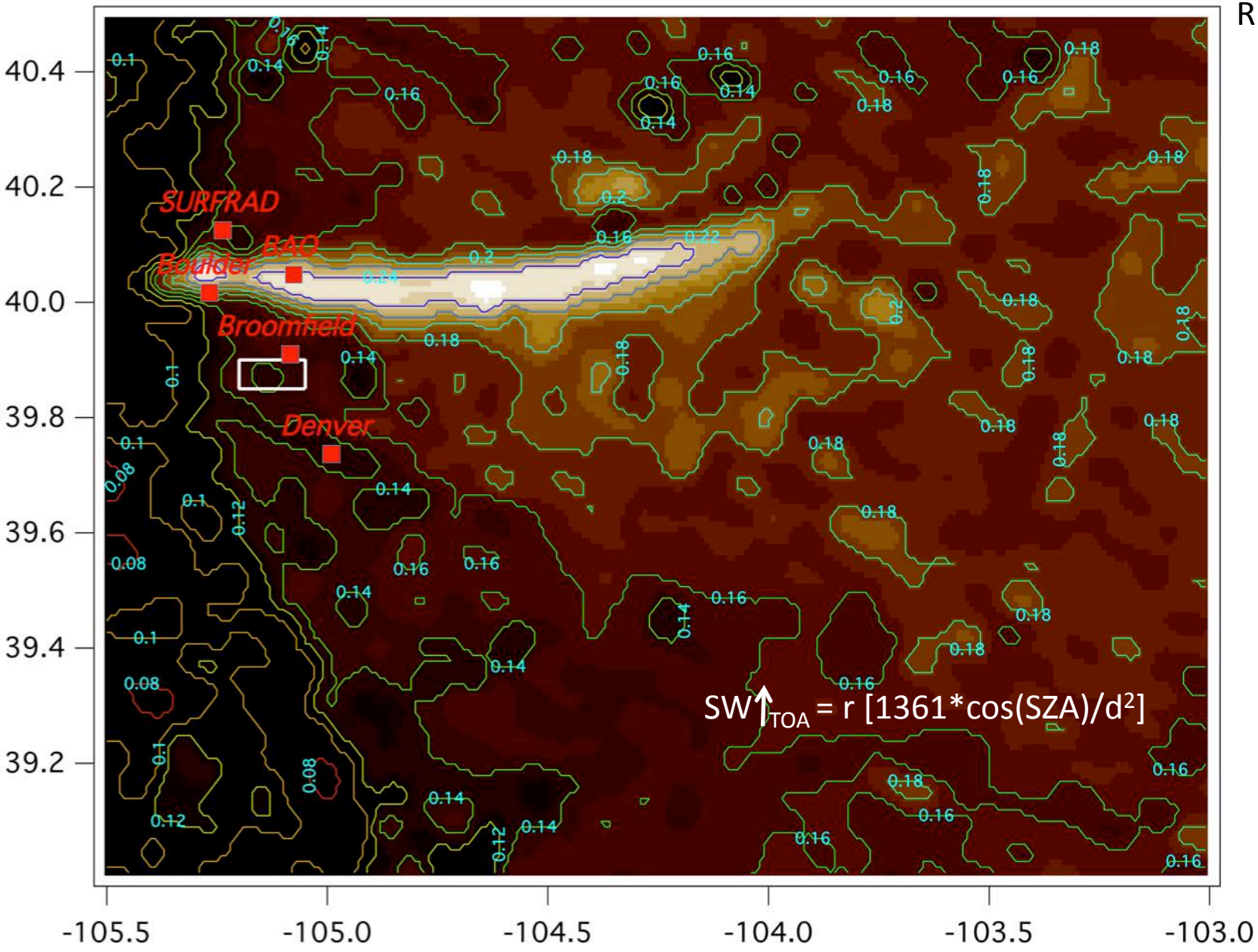


Surface AOD measurements at BAO and SURFRAD

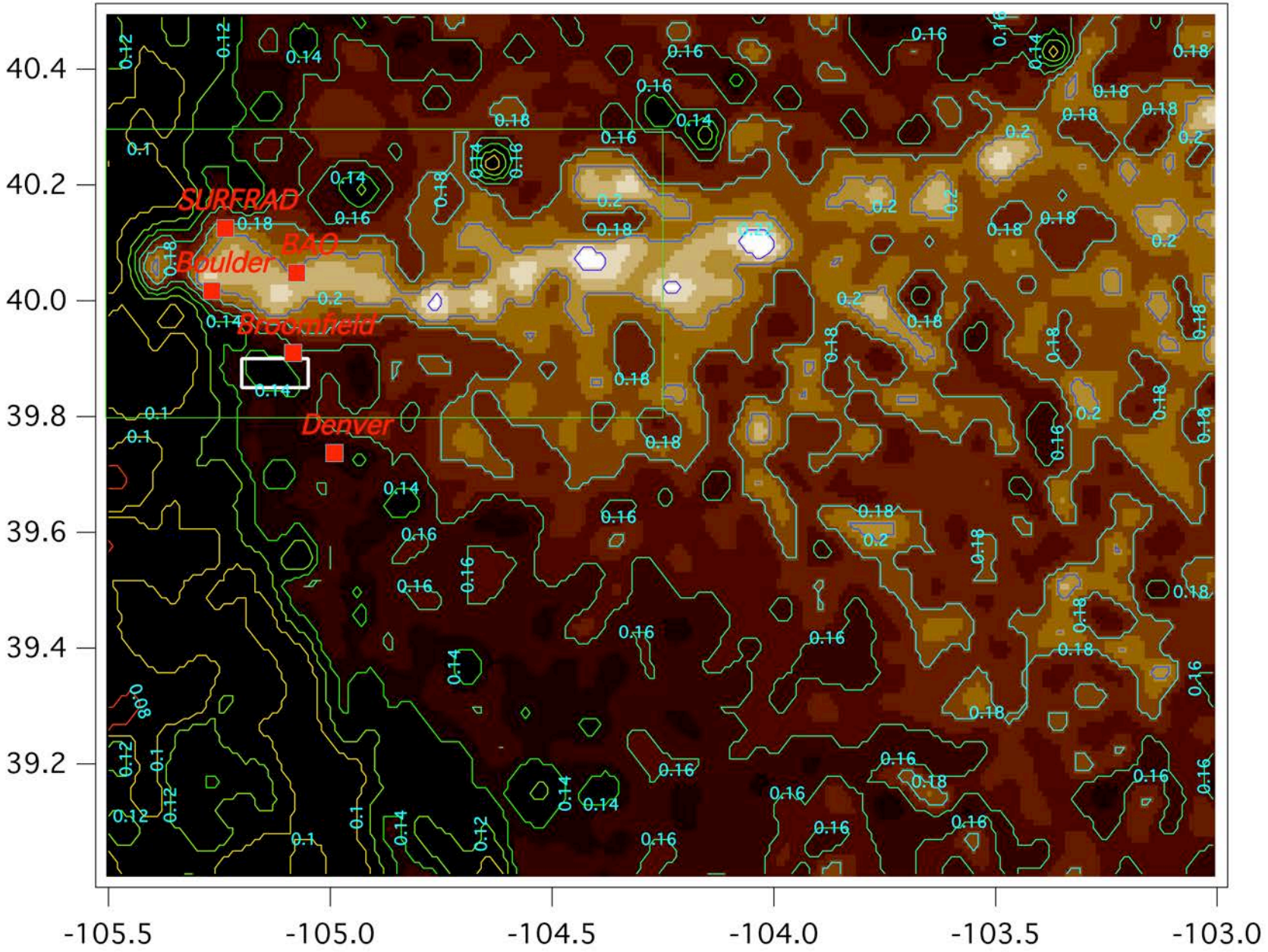


Terra SW broadband reflectance at 18:20 UTC

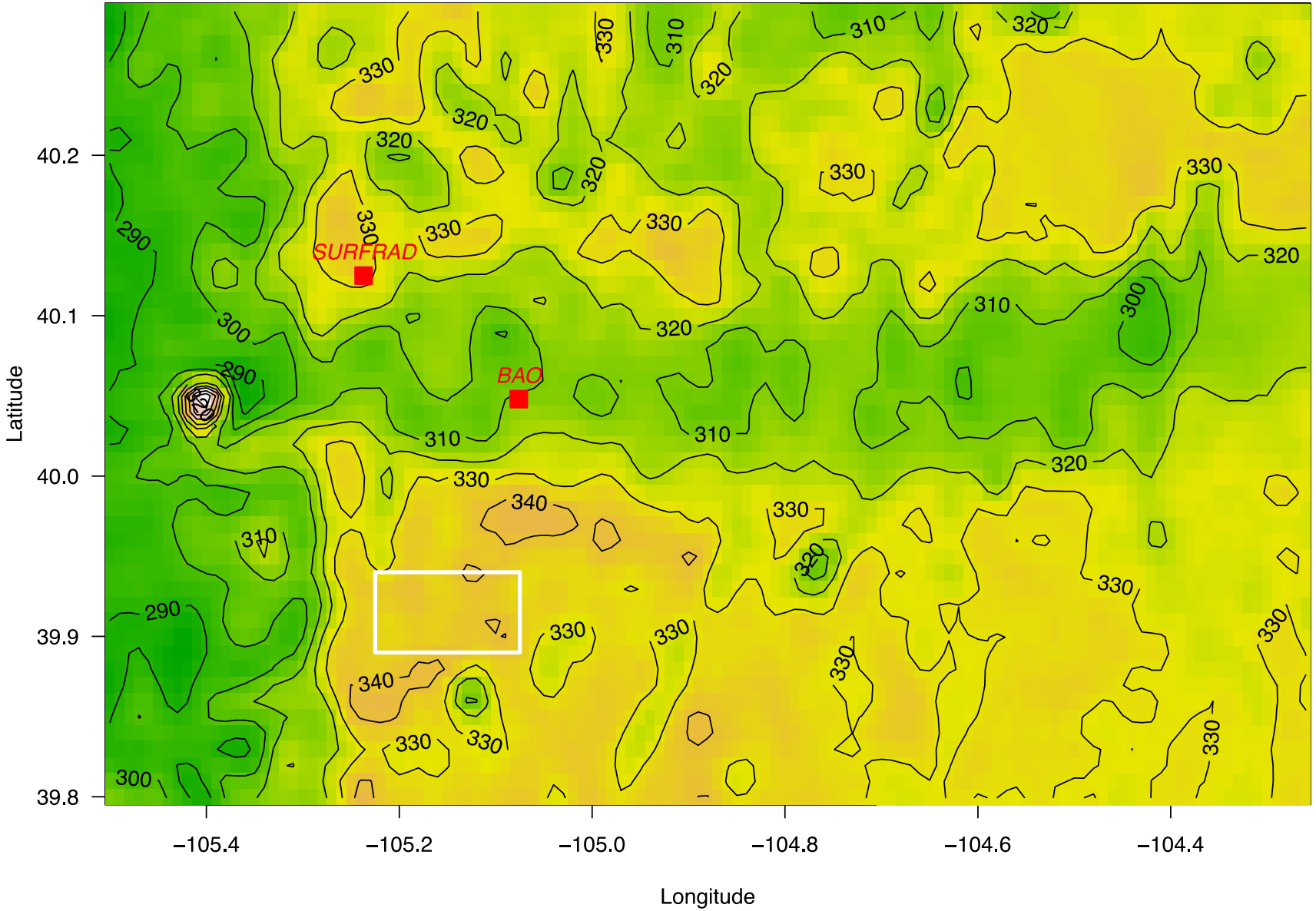
RMS=0.01



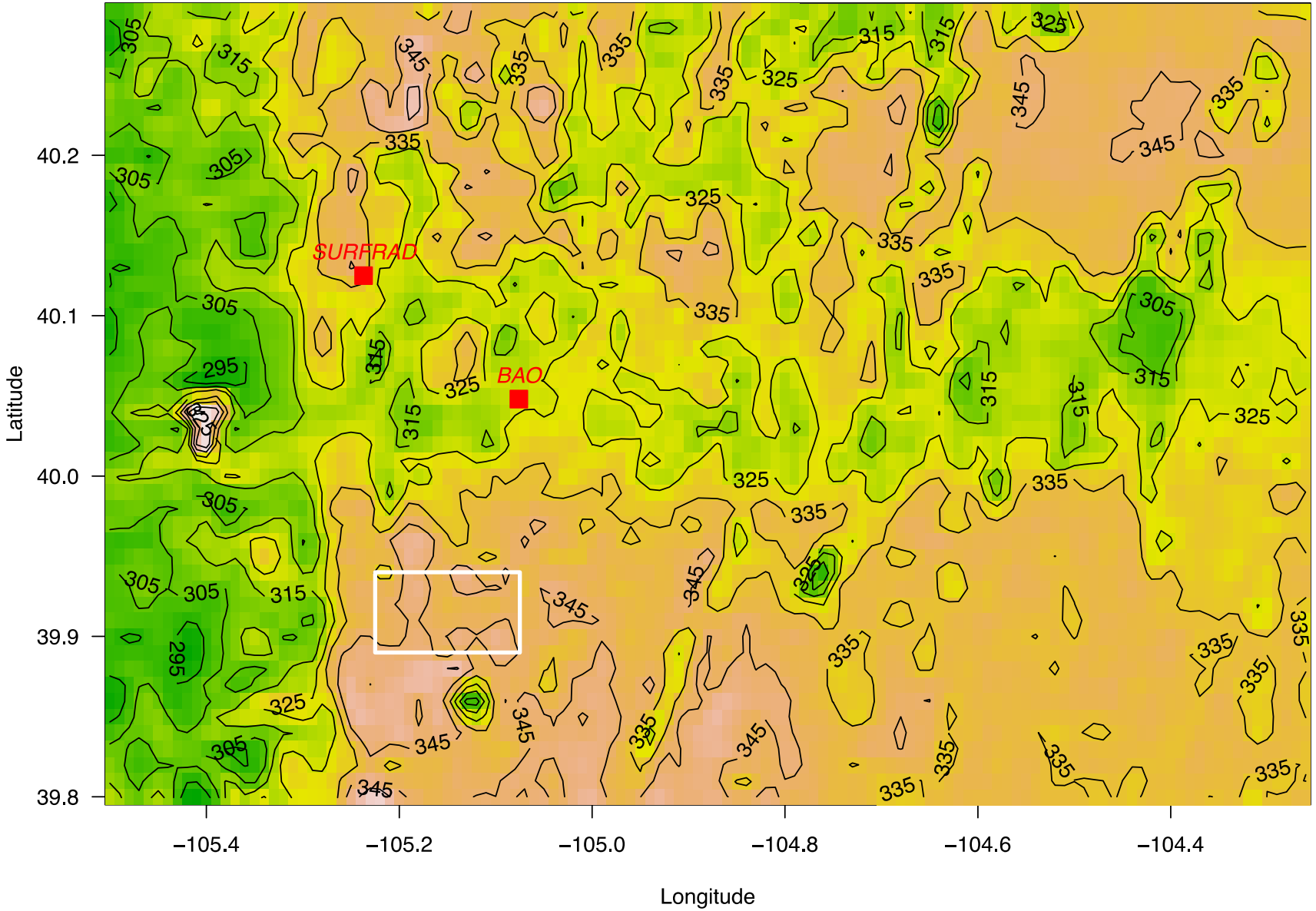
Aqua SW broadband reflectance at 20:00 UTC



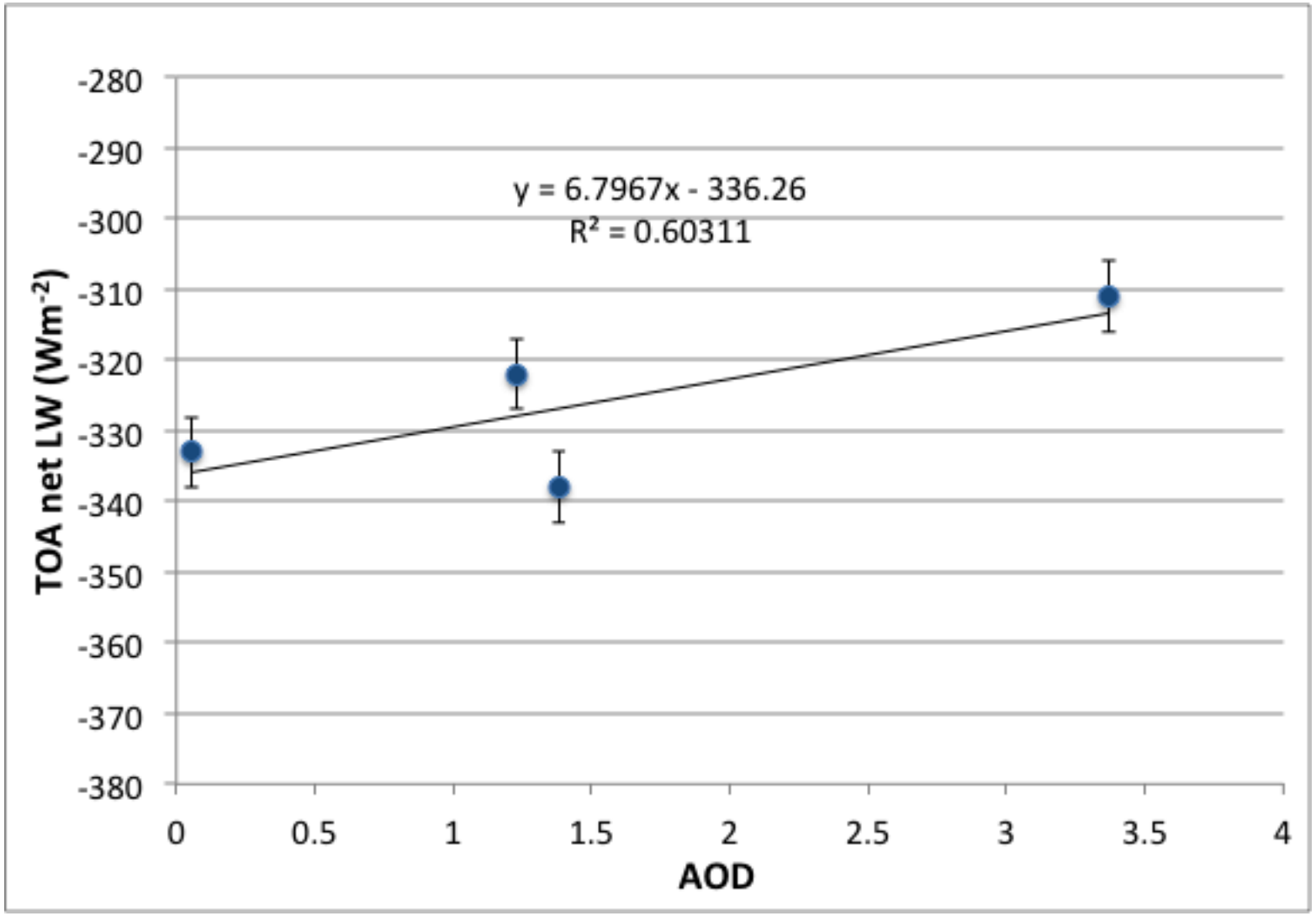
Terra broadband longwave at 18:20 UTC



Aqua broadband longwave at 20:00 UTC



LW Radiative Forcing Efficiency at TOA

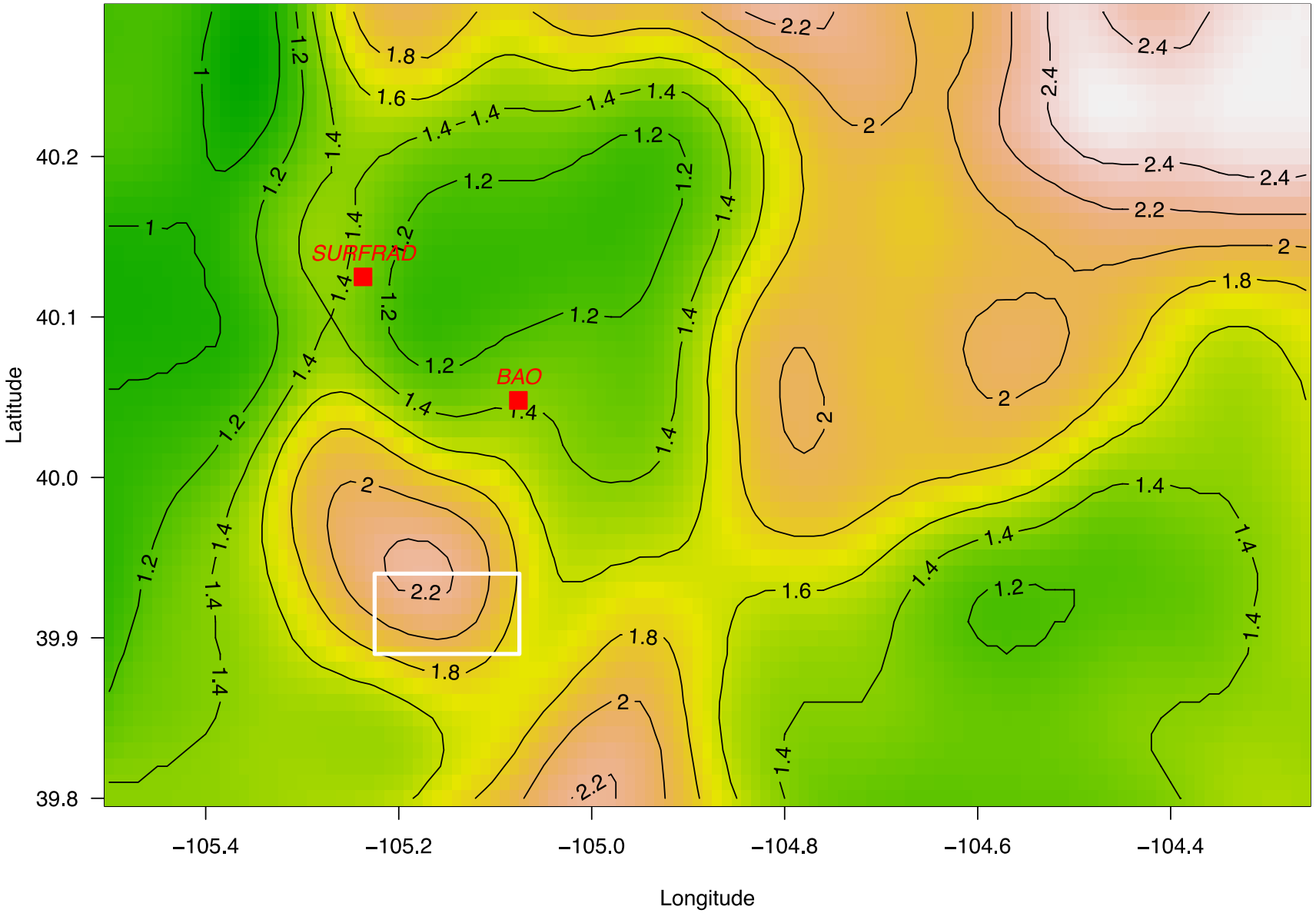


RF Results (SZA~ 35°, sfc. albedo = 0.15)

SW	τ_{500}	Sfc RF_{SW}	TOA RF_{SW}	Atmos.RF_{SW}	Atmos. heating (°K/day)
1820 UTC					
SURFRAD	0.057		-0.6 Wm^{-2}		
BAO	3.37	-512 Wm^{-2}	-113 Wm^{-2}	+399 Wm^{-2}	+12.6 (±0.6)
2000 UTC					
SURFRAD	1.37	-255 Wm^{-2}	-58 Wm^{-2}	+197 Wm^{-2}	+8.4 (±0.6)
BAO	1.23	-187 Wm^{-2}	-75 Wm^{-2}	+112 Wm^{-2}	+6.5 (±0.6)

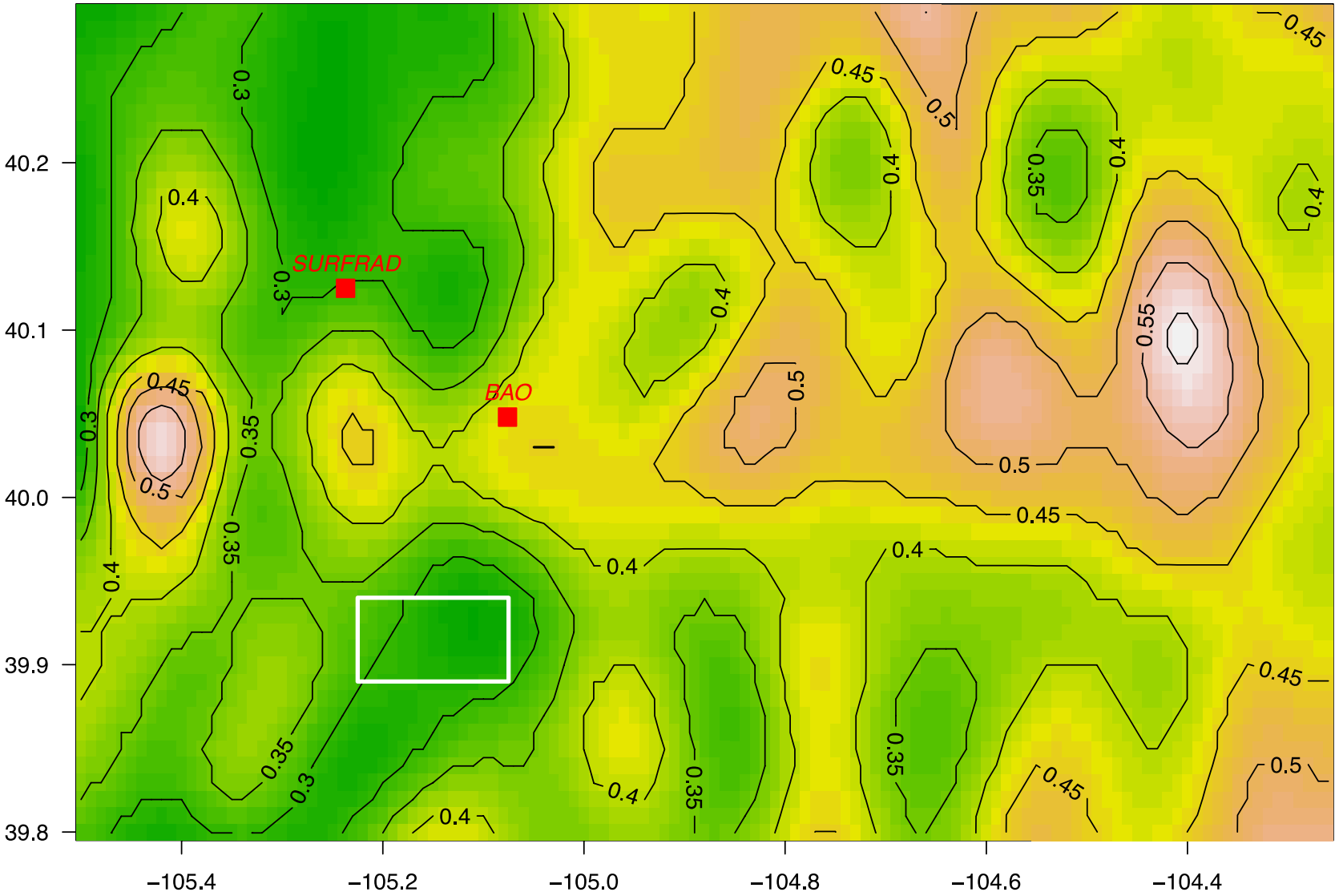
LW	τ_{500}	Sfc RF_{LW}	TOA RF_{LW}	Atmos.RF_{LW}	Atmos. heating (°K/day)
1820 UTC					
SURFRAD	0.057		+0.4 Wm^{-2}		
BAO	3.37	+34 Wm^{-2}	+24 Wm^{-2}	-10 Wm^{-2}	-4.2 (±0.3)
2000 UTC					
SURFRAD	1.37	+19 Wm^{-2}	+10 Wm^{-2}	-6 Wm^{-2}	-2.9 (±0.3)
BAO	1.23	+12 Wm^{-2}	+9 Wm^{-2}	-3 Wm^{-2}	-4.0 (±0.3)

MODIS integrated water vapor at 08:50 UTC, 6 Sept. 2010
~ 8 hours before the fire started



MODIS integrated water vapor at 20:00 UTC, 6 Sept. 2010
~ 3 hours after the fire started

Plume area shows a 1.0 – 1.5 mm increase in integrated water vapor over 3 hours due to combustion alone



Summary and Conclusions

- MODIS narrowband to broadband conversion models appear to work well for both the SW and LW
- SW cooling at the surface is 3-4 times greater than at TOA
- Smoke aerosols warm the surface in the LW, but that warming is overwhelmed by SW cooling (15 times greater in magnitude)
- At TOA, the magnitude of SW cooling is 4 to 10 times greater than the magnitude of LW heating at TOA
- Atmospheric cooling by the LW offsets the greater SW warming by about one third—thus, LW effects need to be considered when modeling the "semi-direct aerosol effect on clouds"
- Using MODIS water vapor product, we were able to quantify the increase in integrated water vapor by the burning biomass—1.0 to 1.5 mm over three hours