Radiative Forcing Efficiency of the Fourmile Canyon Fire Smoke Plume--A Near-Perfect Ad Hoc Experiment

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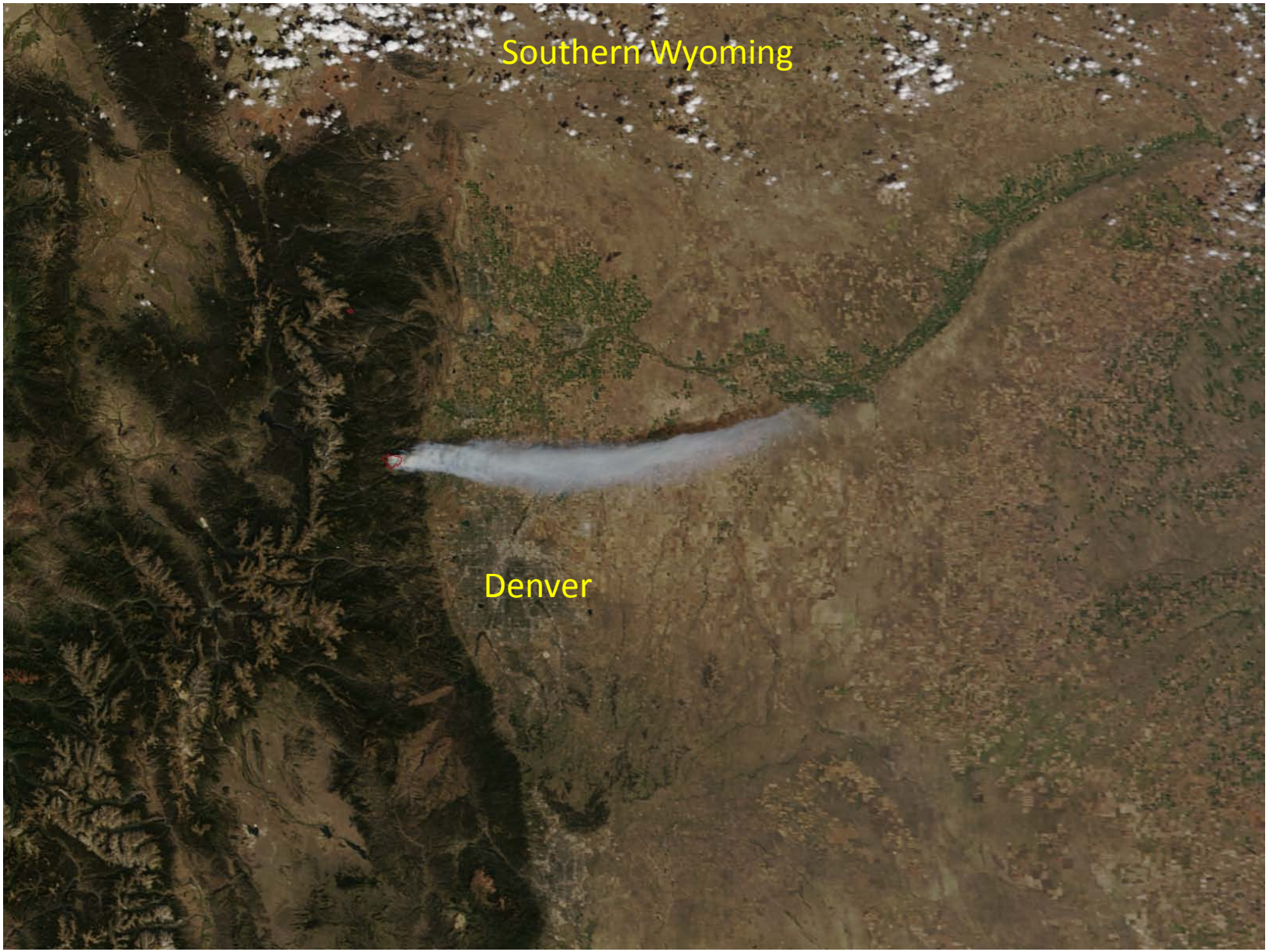
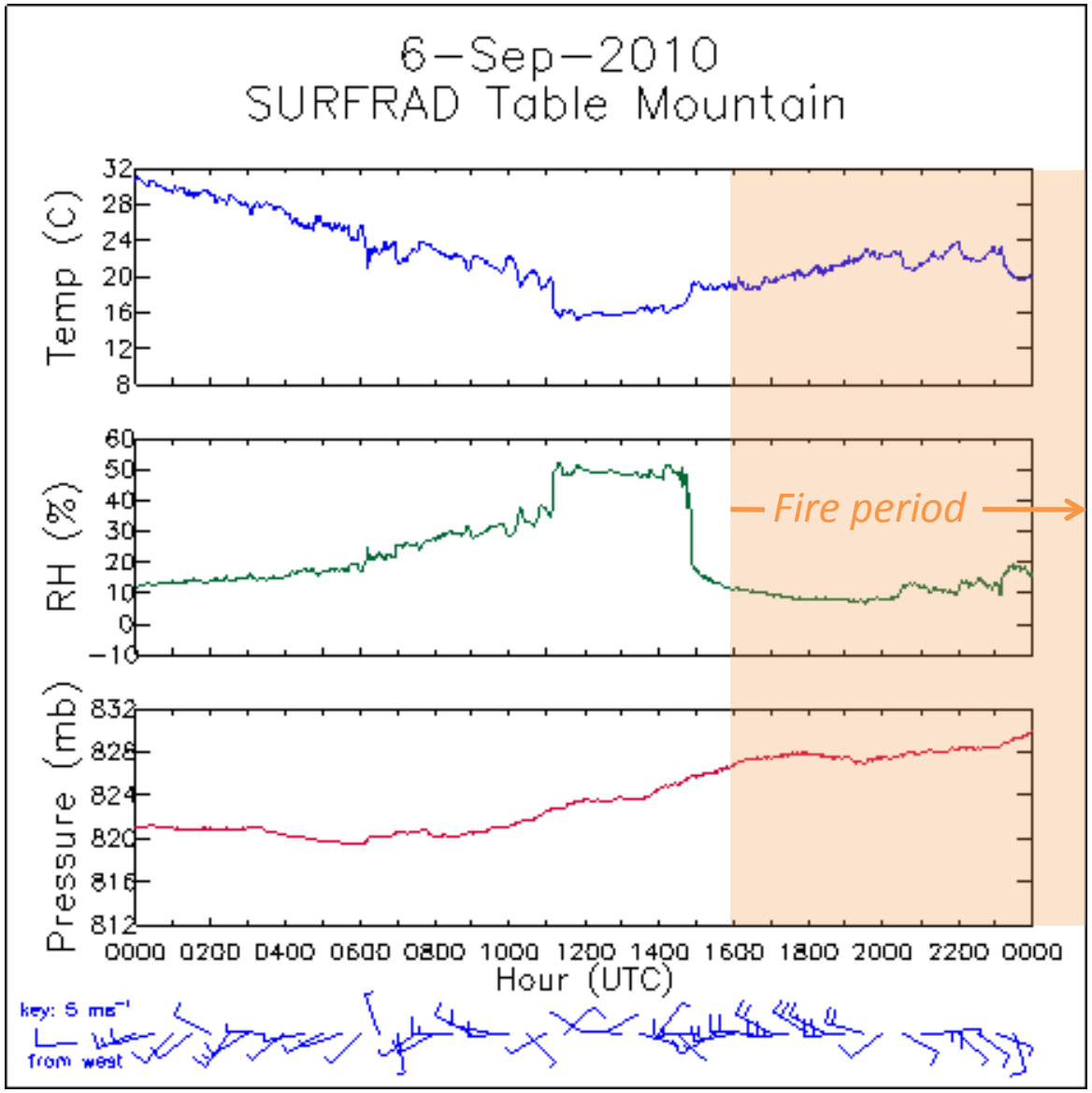
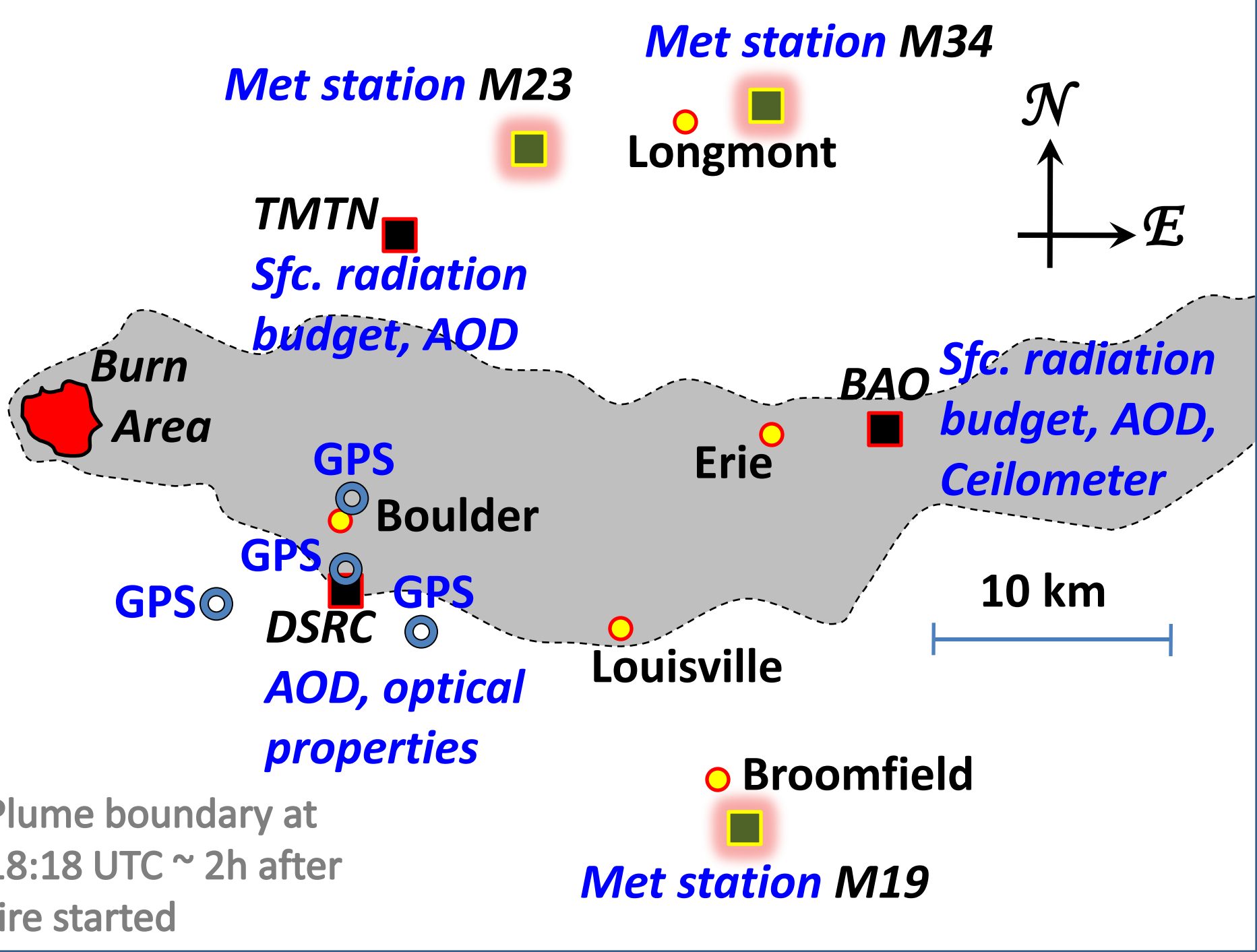
Plume from the perspective of NASA MODIS

6 Sept. 2010, 12:15 MDT, ~ 2 hours after the fire started



Good weather conditions for a wildfire




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

Our focus was the Radiative Forcing Efficiency (RFE) of the smoke aerosol

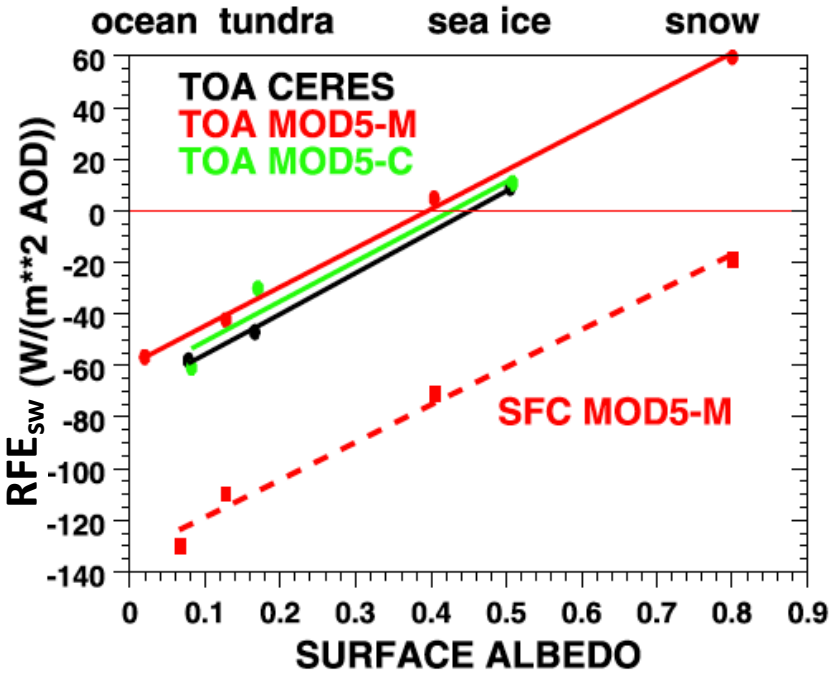
RFE = ΔTotal Net Sfc. Rad./unit AOD_{500}

RFE_{sw} (direct effect of aerosol)

RFE_{lw} (enhanced emission by the smoke layer)

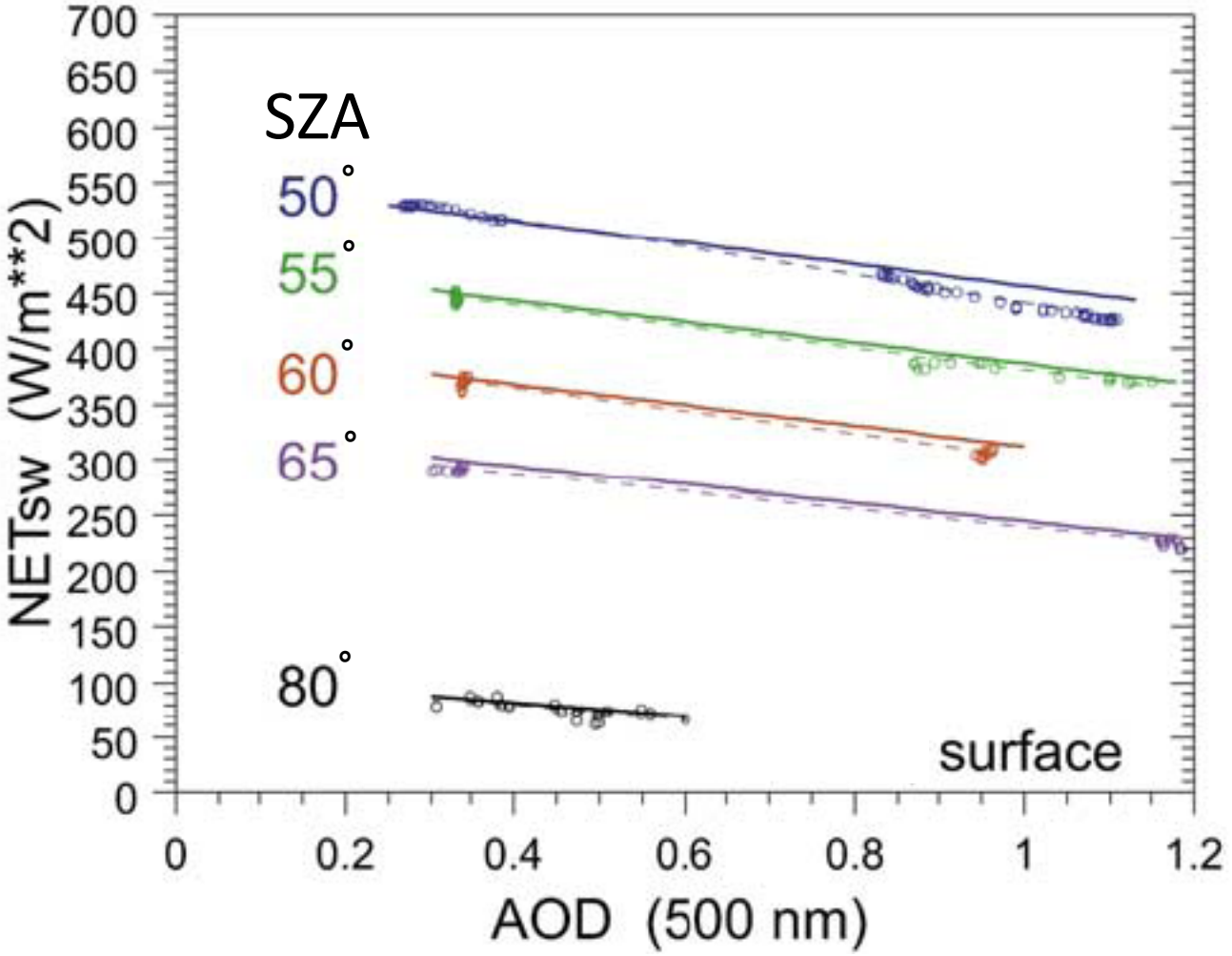
Measurements Needed:

- Net SW
- Net LW
- Surface albedo
- AOD (500nm)



From *JGR*, Stone et al. 2008

RFE_{sw} also depends strongly on the solar zenith angle (SZA)



From *JGR*, Stone et al. 2008

Ideal measurement set for RFE

- Two state-of-the-art surface radiation budget stations under smoke plume – *SW, LW, and Albedo*
- AOD measurements at three sites – *large range of AOD sampled*
- Cloud-free skies all day – *uninhibited AOD calculations, large range of solar zenith angles*
- Many ancillary measurements – *Optical properties of aerosol, TSI, GPS integrated water vapor, wind, temp., RH*
- Very few similar published studies have such a complete set of measurements
- Others have used model calculations, MODIS AOD, distant albedo measurements, only downwelling radiation, estimate upwelling SW using albedo, etc.

AOD (500nm)

Angstrom Exponent (412/675)

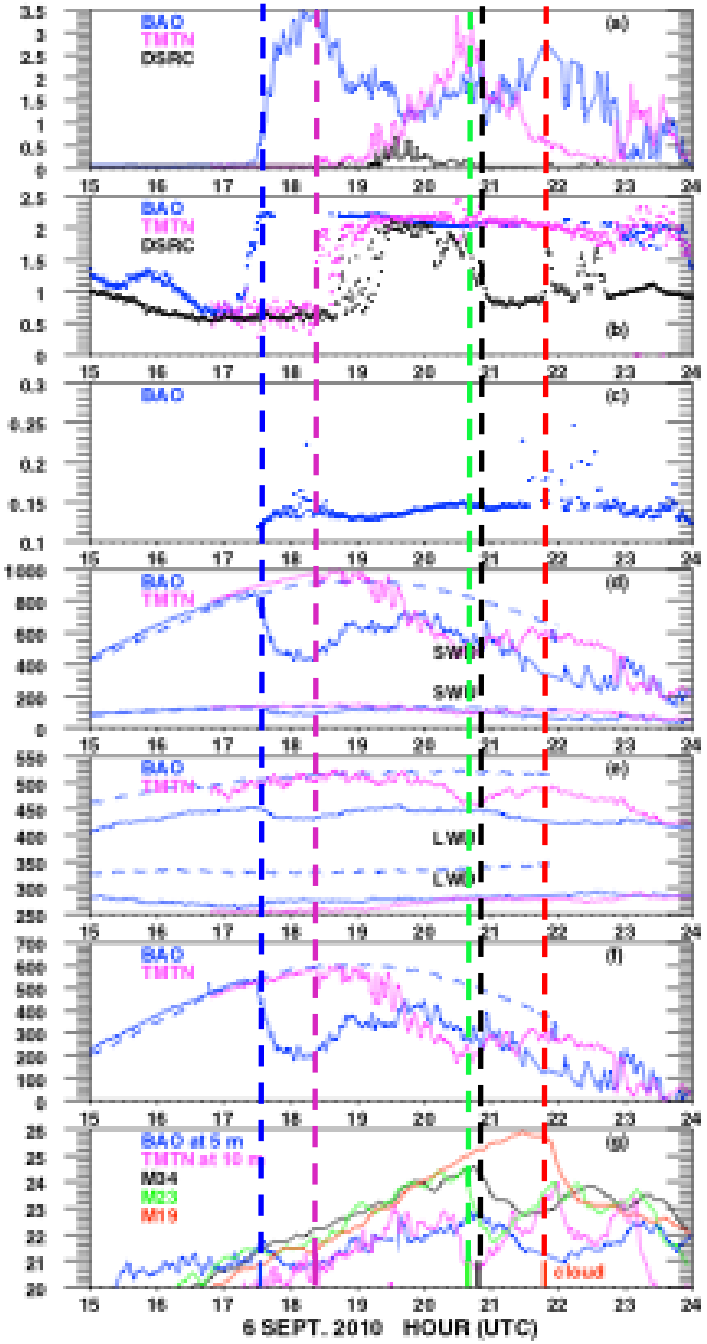
Fine mode Effective Radius (μm)

SW down, SW up (Wm^{-2})

LW up, LW down (Wm^{-2})

Total Sfc. Net radiation (Wm^{-2})

Air temp. (°C)

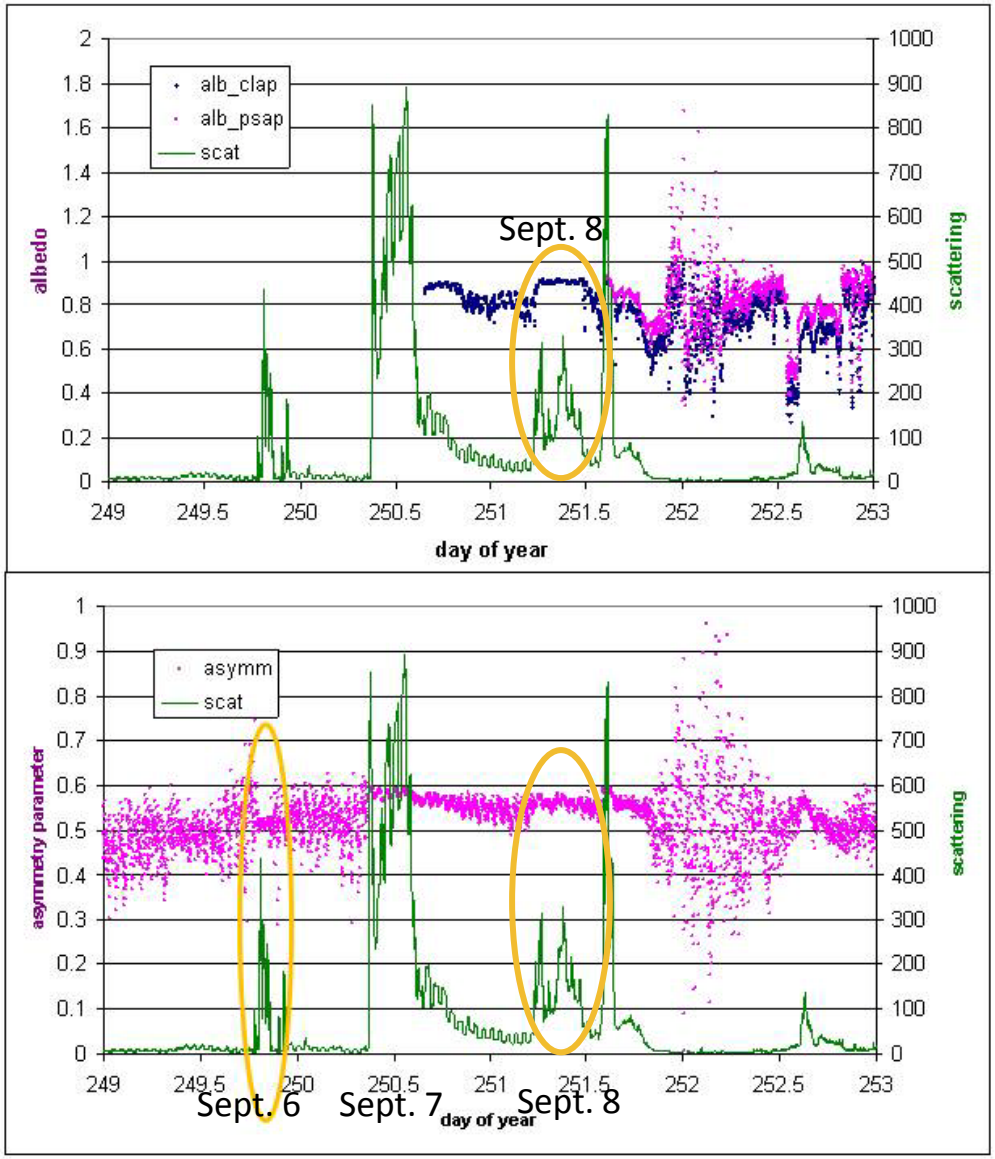


Plume skirting Table Mt. at 1732 UTC -- the time it arrived at BAO

2°- 5°C reduction under plume

Measured optical properties at the DSRC

(courtesy of Betsy Andrews and John Ogren)



Single scattering albedo

Unfortunately we didn't have an absorption instrument on in the lab before mid-DOY250.

For DOY 250.5-251.5, SSA ranges between 0.65-0.91, with the lower values occurring when scattering was also low.

Asymmetry parameter

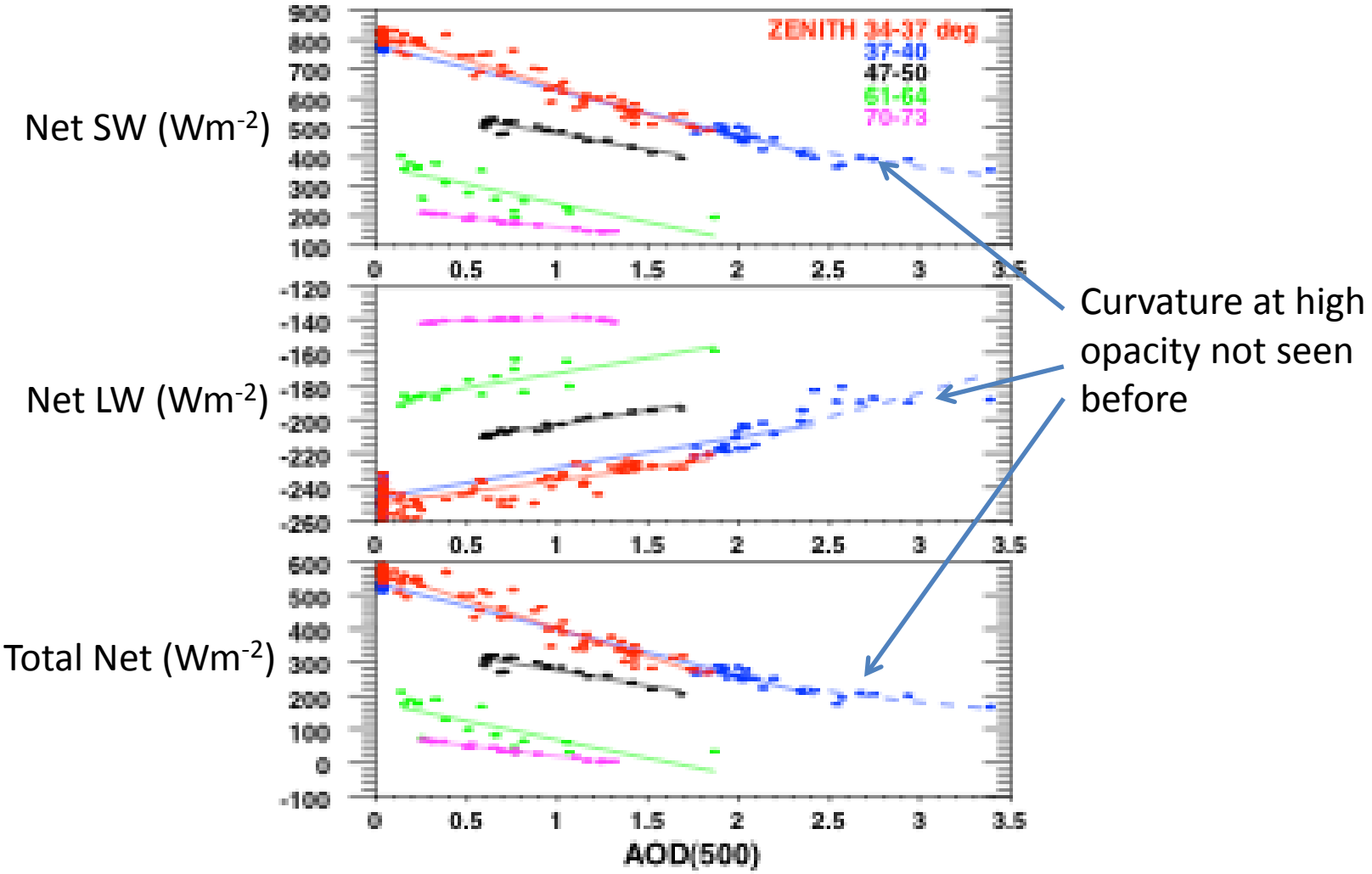
~0.52 (dry, sub-10 um)

Range 0.52-0.59 for date range 250.5-251.5

Surface net radiation vs. AOD yields RFE

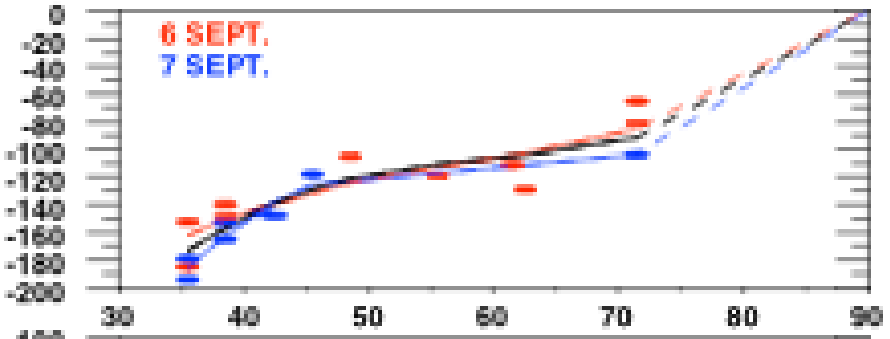
Large range of solar zenith angles

Combined TMTN and BAO data; albedo=0.15 at both sites



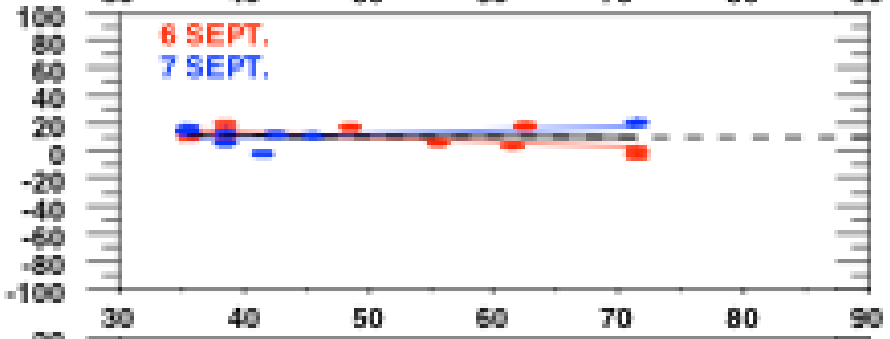
Radiative Forcing Efficiency (RFE_x) as a function of solar zenith angle, valid for sfc. Albedo of 0.15

RFE_{sw}
Wm^{-2}/AOD_{500}



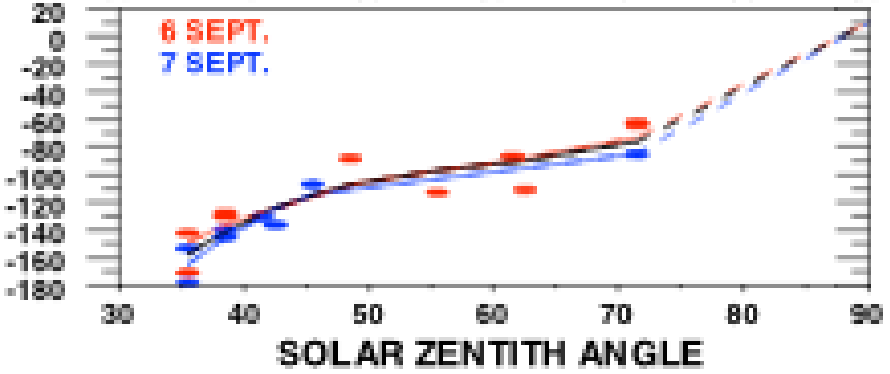
-194 to 0 Wm^{-2}/AOD_{500}
In the daytime

RFE_{Lw}
Wm^{-2}/AOD_{500}



+10 Wm^{-2}/AOD_{500}
Day and night

$RFE_{all\ wave}$
Wm^{-2}/AOD_{500}



Integrated effect

Because RFE varies nonlinearly with solar zenith angle, a daily integral is more useful for assessing the climatic impact of smoke aerosols

Daily Integrated results for the Fourmile Canyon fire:

RFE_{sw}: -61.5 Wm^{-2}/AOD_{500}

RFE_{lw}: +10.0 Wm^{-2}/AOD_{500}

RFE_{total}: -51.5 Wm^{-2}/AOD_{500}

This implies that the surface radiative forcing of a widely dispersed smoke aerosol averaging an AOD of only 0.1 would be about -5 Wm^{-2}

Conclusions

- Maximum cooling due to shortwave attenuation is about 20 times greater than warming by enhanced thermal emission by the smoke layer

- Our computed Radiative Forcing Efficiency of the Fourmile fire plume of -51.5 Wm^{-2}/AOD_{500} is valid for surface albedo of 0.15

- Cooling under smoke plume during the day was as much as 5°C

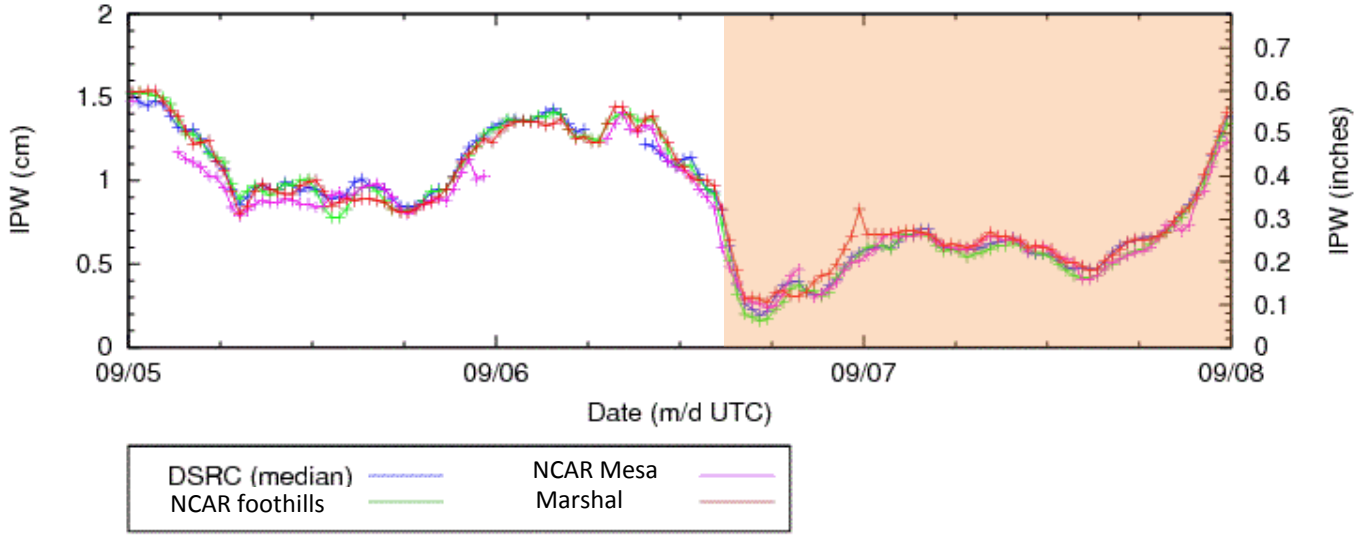
- Studies have shown that pyrocumulus from wildfires injects smoke aerosol into the stratosphere where it can reside for months

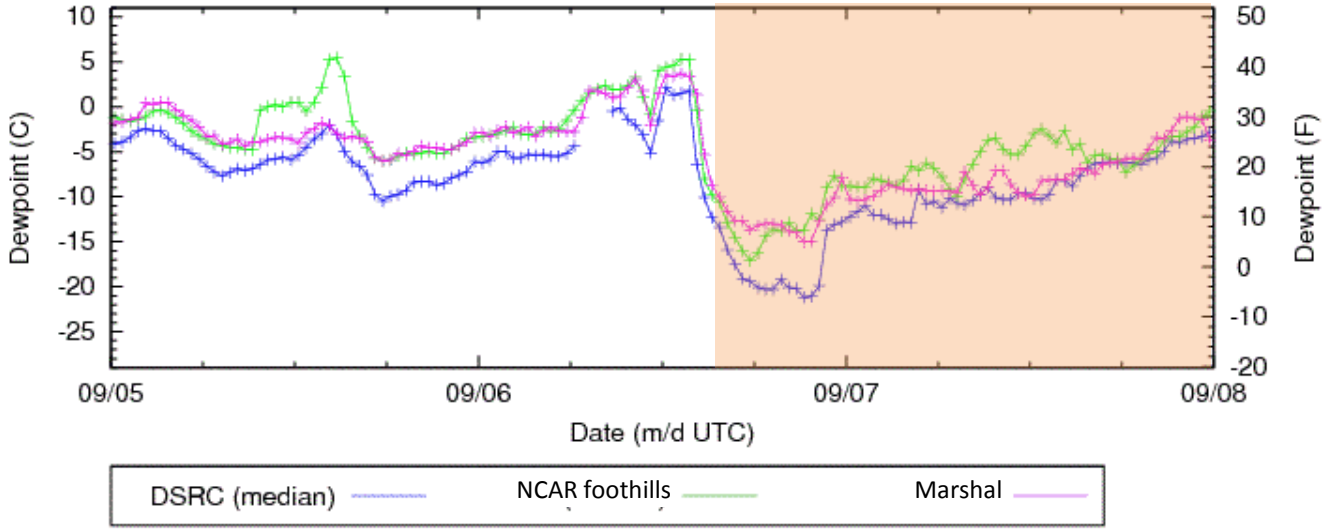
- The impact of widely dispersed smoke (0.1 AOD) can be significant; and equivalent to doubling CO_2, when in effect

- Parameterizations can be developed by extending these results to other aerosol types, sfc. albedo, RH, etc. with modeling experiments

GPS water vapor data

(Courtesy of Seth Gutman)





MODIS AOD global annual average for 2007

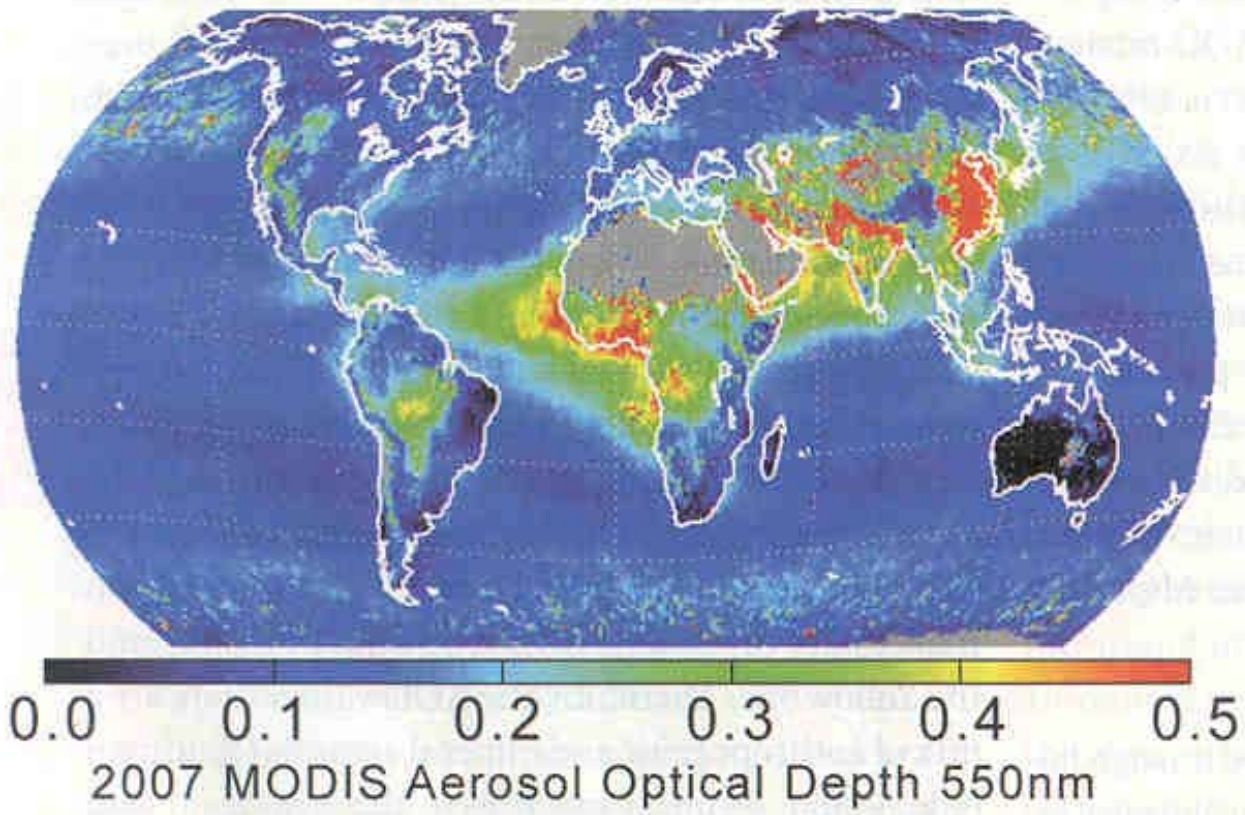


FIG. 2.22. Global map of mean AOD values at 550 nm from the MODIS *Terra* satellite.