Airborne measurements of direct aerosol radiative forcing in INTEX/ITCT, 2004

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Methodology for studying aerosol radiative forcing from an airborne platform - the aerosol gradient method

1) Measure simultaneous change in spectral aerosol optical depth (AATS-14) and spectral net irradiance (SSFR) across AOD gradient.

2) Slope of the regression of F_{net} vs. AOD yields

$\Delta F_{net} / \Delta AOD$ = aerosol radiative forcing efficiency

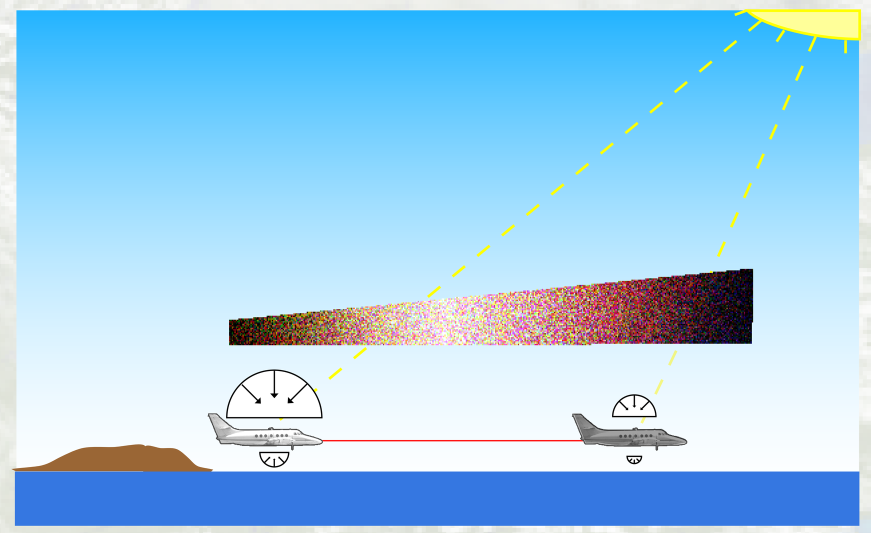
3) This constitutes an observationally-based estimate of aerosol radiative effects.

4) Advantage over ground-based methods = quasi-instantaneous, because of short horizontal distances.

5) Need to consider (and correct for) effects of changing solar zenith angle and changing column water vapor contents during low-level leg.

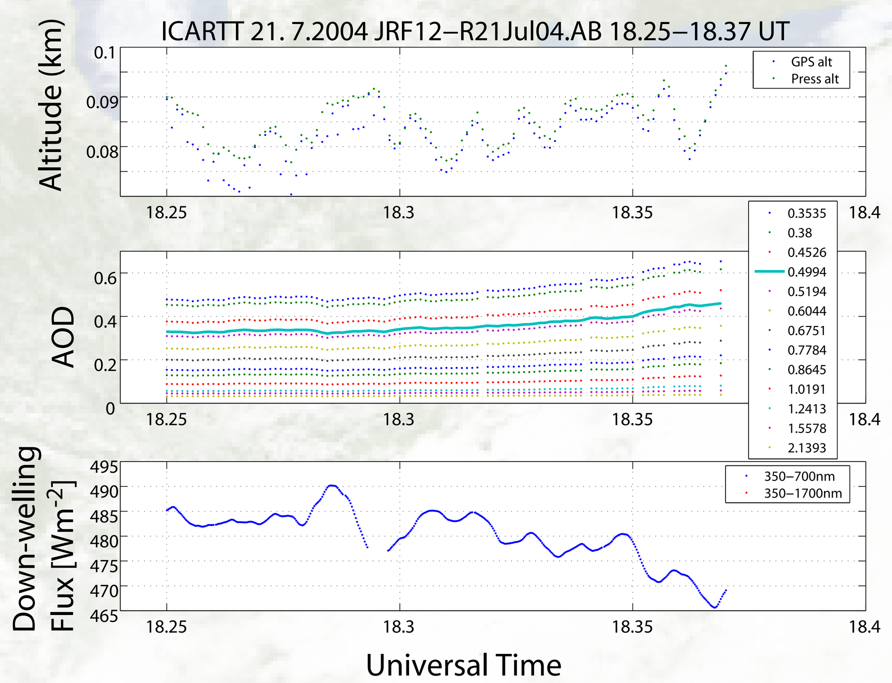
Left: AATS-14 measures spectral AOD at 13 wave-lengths, 354-2139nm

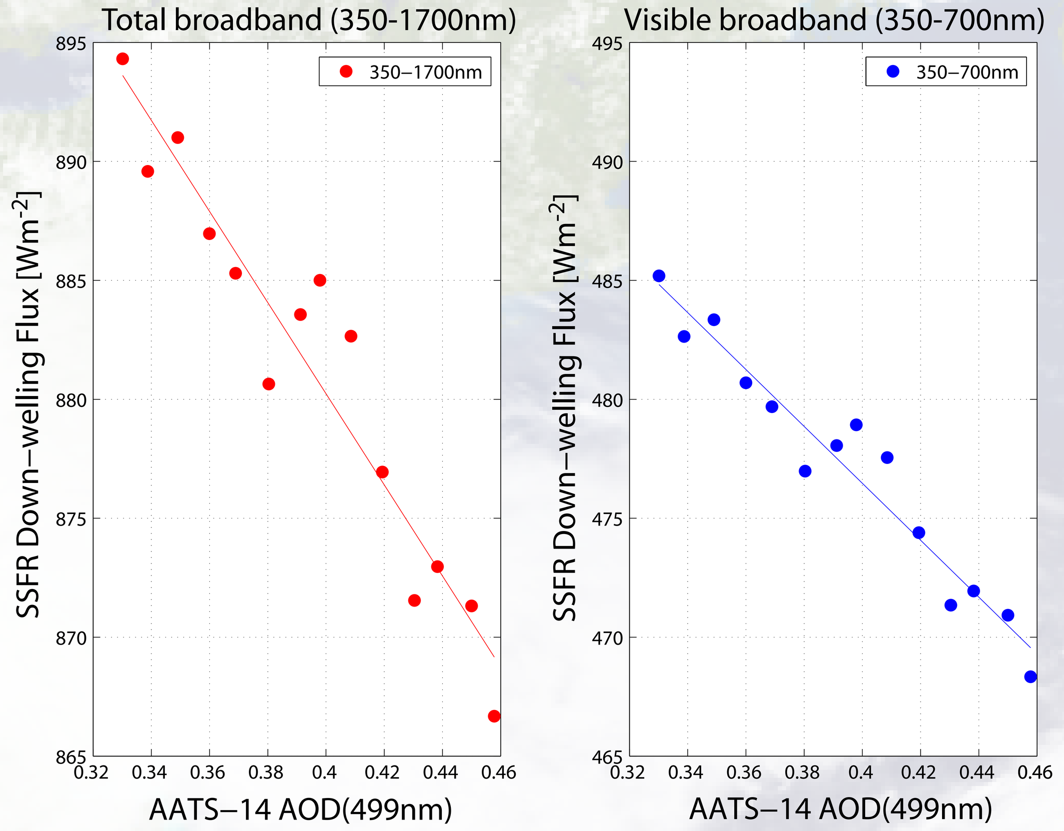
Right: SSFR measures spectral irradiance 300-1700nm, ~8-12nm resolution



Example

Time-series (below) of spectral AOD and down-welling broadband solar flux across AOD gradient encountered on July21, 2004. Regression plot (right) of down-welling flux vs. midvisible AOD; slope yields the direct aerosol forcing efficiency (defined per unit AOD).



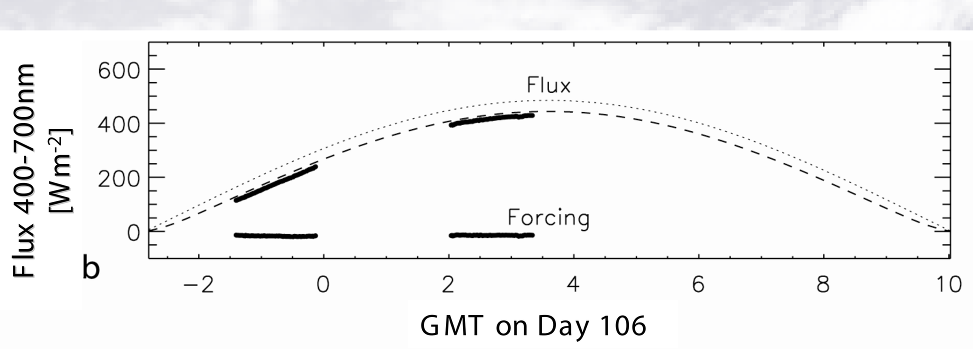


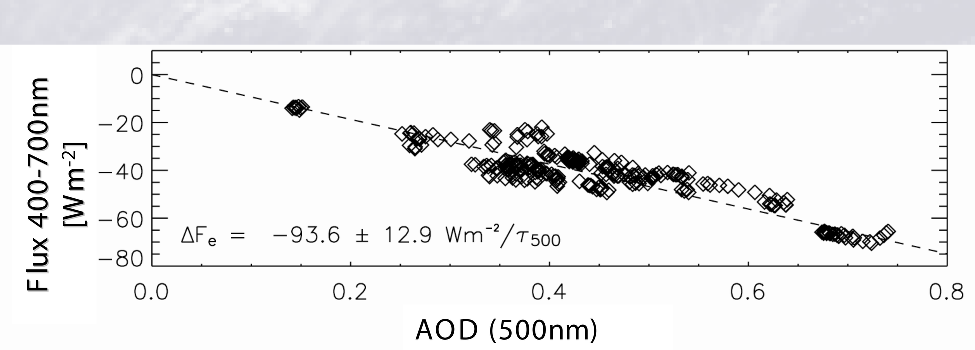
Background

As part of the INTEX-NA (INtercontinental chemical Transport EXperiment-North America) and ITCT (Intercontinental Transport and Chemical Transformation of anthropogenic pollution) field studies, the NASA Ames 14-channel Airborne Tracking Sunphotometer (AATS-14) and a set of Solar Spectral Flux Radiometers (SSFR) took measurements from aboard a Jetstream 31 (J31) aircraft during 19 science flights (~53 flight hours) over the Gulf of Maine during 12 July – 8 August 2004.

AATS-14 measures the direct solar beam transmission at 14 discrete wavelengths (354-2138 nm), yielding aerosol optical depth (AOD) spectra and water vapor column content. The SSFR system consists of separate nadir- and zenith-viewing hemispheric optical collectors and respective grating spectrometers that yield measurements of down- and upwelling, solar irradiances at a spectral resolution of ~8-12 nm over the wavelength range 300-1700 nm. Among the overall goals of the J31-based measurements of spectral AOD and irradiances are to assess spectral direct and indirect radiative effects of aerosol particles advecting from North America over the northwestern Atlantic Ocean.

Ground-based methodologies for aerosol radiative forcing studies

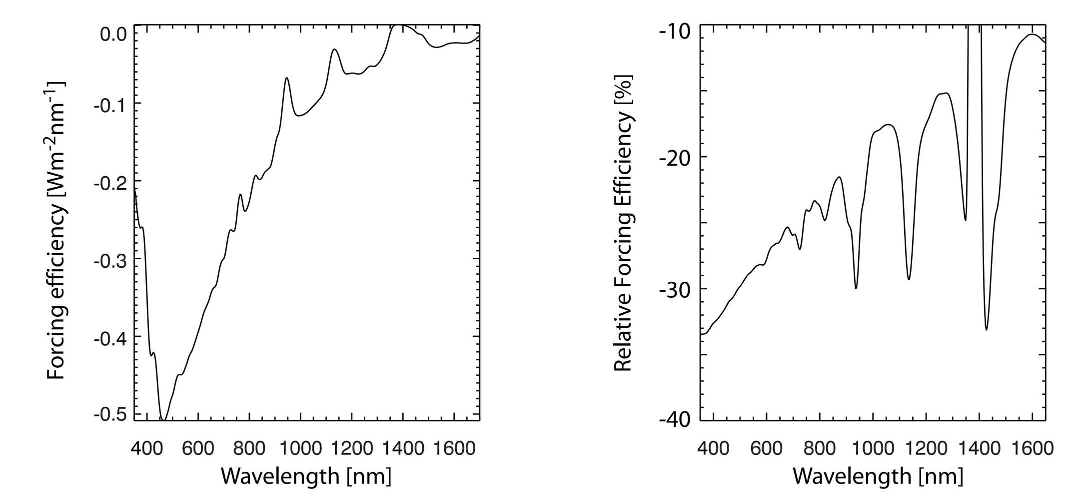




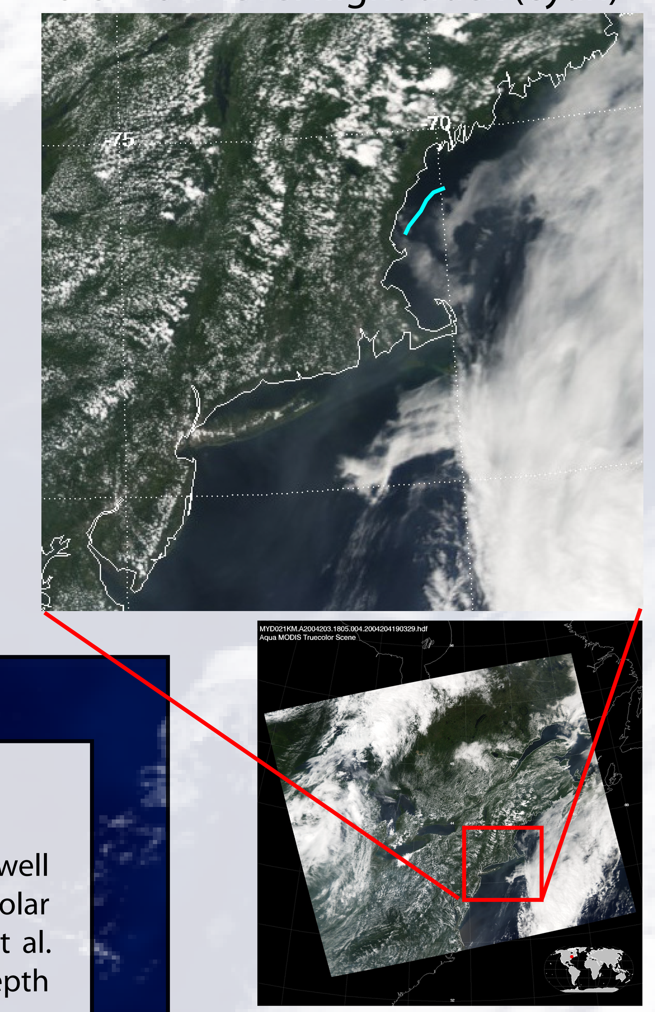
Bush and Valero, 2002 ACE-Asia

Case study applying the aerosol gradient method to smoke from Alaskan wildfires, July 21, 2004.

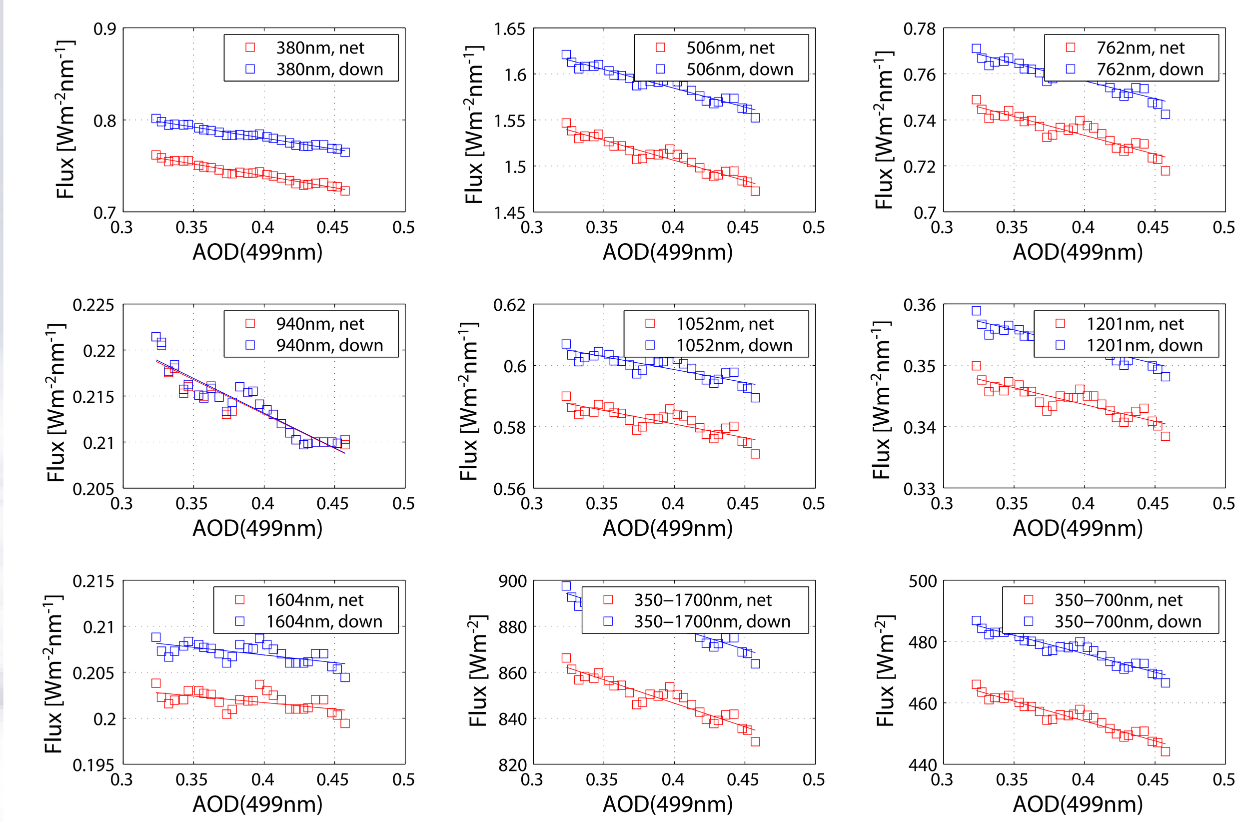
Full spectra of absolute (left) and relative (right, obtained by normalizing with down-welling flux) of the direct aerosol radiative forcing efficiency (defined per unit AOD).



MODIS RGB-imagery showing J-31 low-level flight track (cyan)



Regression plots of down-welling and net irradiance in seven discrete SSFR channels, plus two broadband regions. The slope of these plots gives the instantaneous direct aerosol radiative forcing efficiency.



Conclusions

In INTEX/ITCT, we observed a total of 16 horizontal AOD gradients, with 11 gradients well suited for the aerosol gradient method presented here, because of the small changes in solar zenith angle during the gradient measurements. A companion paper by Livingston et al. (EGU05-A-05540, X148, Thu. morning) describes the comparisons of aerosol optical depth spectra to collocated MODIS and MISR measurements.

More than half of the AOD gradients (at a wavelength of 499 nm) were greater than 0.1 and extended over distances less than 40 km.

Within the 11 suitable case studies we found a high variability in the derived instantaneous aerosol forcing efficiencies (forcing per unit optical depth) for the wavelength range from 350 to 700nm, with a mean of -103Wm^{-2}. We found no dependence of the forcing efficiencies on changes in columnar water vapor (CWV), not shown here.

The instantaneous "relative" forcing efficiencies, defined as the forcing efficiencies divided by the downwelling irradiance, yielded a mean of 22% for the 11 case studies.

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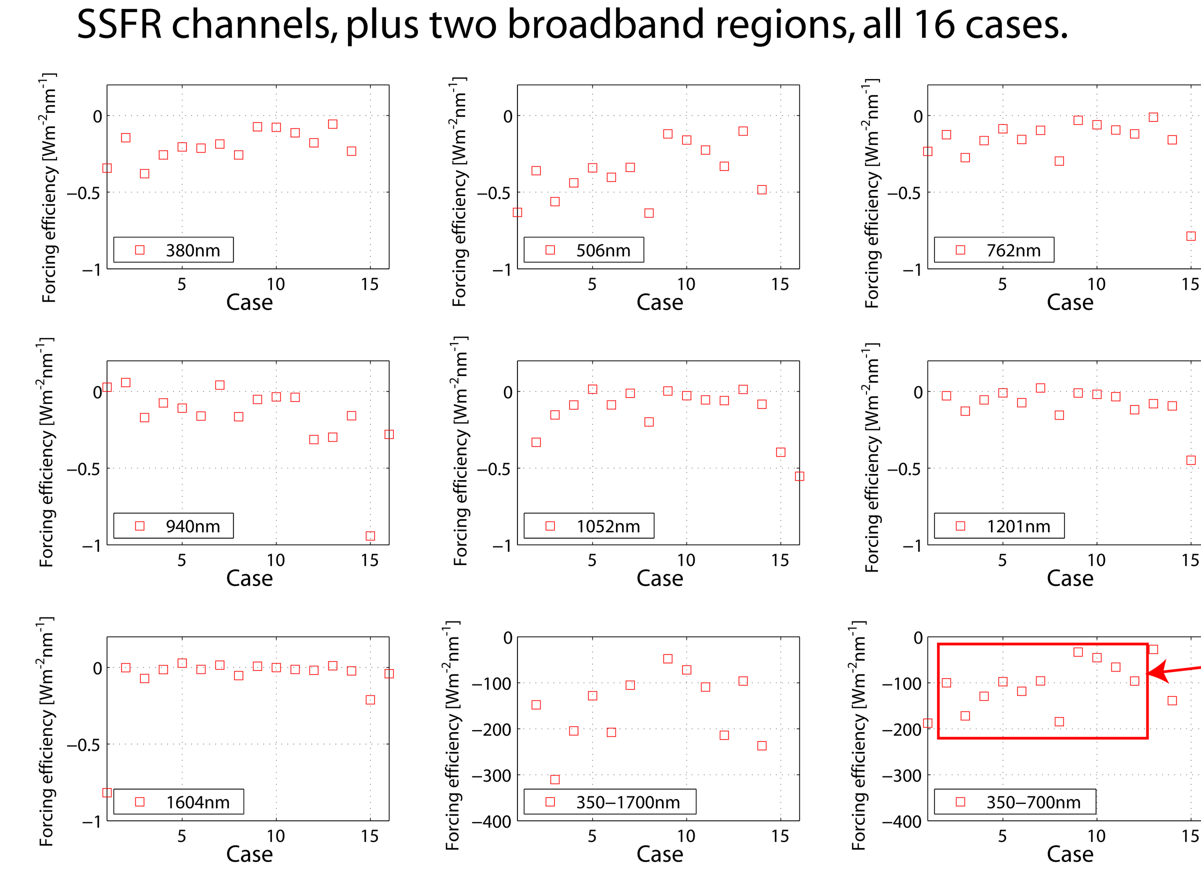
Summary of all 16 aerosol gradient forcing cases encountered in INTEX during 12 July – 8 August 2004

Date	Case Index	UT beg	UT end	AATS hours	AOD Gradient incr./decr. Distance(km)	Solar zenith angle change
07/12/04	1	18.360	18.500	0.14	↓0.17 (41.7%) / 38.4km	1.53%
07/12/04	2	19.870	19.940	0.07	↓0.09 (19.1%) / 17.5km	0.96%
07/17/04	3	14.919	14.981	0.06	↓0.04 (37.9%) / 20.0km	0.65%
07/21/04	4	18.250	18.370	0.12	↑0.14 (43.2%) / 24.7km	0.62%
07/22/04	5	15.500	15.630	0.13	↓0.10 (17.6%) / 22.4km	0.96%
07/23/04	6	17.793	17.861	0.07	↑0.21 (41.1%) / 22.5km	0.50%
07/23/04	7	17.861	17.892	0.03	↓0.07 (10.3%) / 8.1km	0.23%
07/23/04	8	18.105	18.160	0.05	↑0.05 (5.8%) / 5.2km	0.26%
07/29/04	9	15.600	15.770	0.17	↓0.46 (55.1%) / 39.9km	0.63%
07/29/04	10	15.807	15.900	0.09	↑0.38 (93.2%) / 27.7km	0.69%
07/29/04	11	16.308	16.347	0.04	↓0.18 (26.3%) / 6.1km	0.01%
08/02/04	12	15.210	15.400	0.19	↓0.25 (56.2%) / 40.6km	0.94%
08/02/04	13	15.690	15.880	0.19	↑0.23 (119.9%) / 59.5km	1.51%
08/03/04	14	20.450	20.580	0.13	↑0.10 (26.4%) / 31.9km	2.71%
08/07/04	15	14.960	15.275	0.32	↓0.03 (28.0%) / 71.5km	3.46%
08/08/04	16	17.550	17.980	0.43	↑0.04 (76.5%) / 108.9km	3.23%

Absolute aerosol radiative forcing efficiency in seven discrete SSFR channels, plus two broadband regions, all 16 cases.



The data in the red boxes of the broadband forcing plots represent those cases with small changes in solar zenith angles ($\Delta\cos(z)$<1%).

The average absolute focing for those 11 cases is -103Wm^{-2}, the corresponding average relative forcing is 22%. These are instantaneous values near the surface.

Relative aerosol radiative forcing efficiency, derived by normalizing the absolute forcing efficiencies with down-welling irradiance.