Contrail Cloud Radiative Forcing over the Northern Hemisphere Derived from Two Years of MODIS Observations

*Douglas A. Spangenberg[1], Patrick Minnis[2], David P. Duda[1], and Sarah T. Bedka[1]

[1]Science Systems & Applications, Inc., Hampton, VA

[2]NASA-Langley Research Center, Hampton, VA

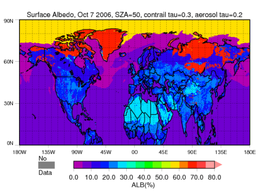
*Corresponding author email: douglas.a.spangenberg@nasa.gov

1. Introduction

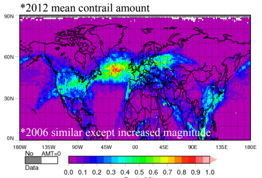
The constant presence of high-altitude air traffic across the globe influences Earth's climate through the formation of jet contrails that grow as ice-phase clouds given the right atmospheric conditions. The contrail radiative forcing (CRF) is used to assess this impact on the Earth-Atmosphere system. In this study, satellite data from Aqua and Terra MODIS is used to compute the Northern Hemisphere (NH) CRF associated with linear contrails for four seasonal months (Jan, Apr Jul, Oct) in the years 2006 and 2012. The contrail cloud properties are retrieved using the NASA-Langley infrared-only Clouds and the Earth's Radiant Energy System (CERES) algorithm. For each image pixel classified as having a linear contrail from a sensitive contrail mask, the cloud property retrievals, CERES surface albedo and emissivity, snow and ice cover, and MERRA atmospheric profiles are used in the 2-stream Fu-Liou radiative transfer model. The CRF is then derived from the model's flux output. The background scene below the contrail is considered to be either clear or filled with single layer liquid or ice clouds. The shortwave, longwave, and net CRF components are computed on a 1x1° grid for both daytime and nighttime conditions and for different background types. The CRF is derived in two ways. For the first method, radiative forcing is normalized to 100% contrail coverage to provide a measure of sensitivity to the presence of contrails. In the second method, the contrail fractions are used to get the total net forcing which indicates the actual effect on climate. By using actual observations of contrails in their environments, this study indicates the extent to which they affect Earth's radiation balance. Contrails that become nearly indistinguishable from the background cirrus, otherwise known as contrail cirrus, aren't considered here.

2. Data

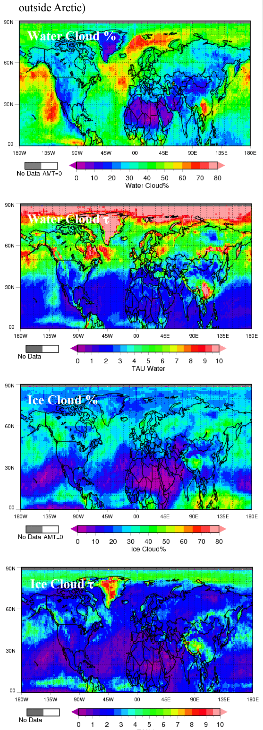
- Satellite temporal sampling: tropics, mid-latitudes sampled 2x/day at ~1:30am, 1:30pm local time (Aqua) and ~10:30am, 10:30pm local time (Terra). Greater sampling over Arctic.
- MERRA profile data: T, P, q, O_3
  - 25 mb vertical res below 700 mb; 50 mb above 700mb
  - 0.5 x 0.67° horizontal res
- CERES surface property maps: Albedo, emissivity.
- Snow and ice maps from National Snow & Ice Datacenter using the Interactive Multisensor Mapping System.
- Contrail identification from sensitive contrail mask B of Duda et al. (2013).
- Aqua and Terra MODIS 1-km pixel retrievals from CERES/NASA-LaRC algorithm including optical depth (τ), pressure, particle size, Tskin (Bedka et al., 2013). Both contrail and background cloud layer properties are used.



*2012 mean contrail amount



MODIS 2012 daytime mean cloud phase %, optical depth (TAU) for all ice, water clouds (2006 similar outside Arctic)



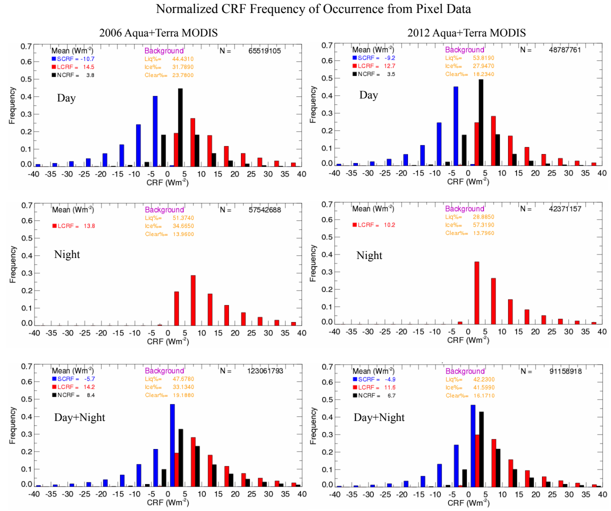
3. Methodology

- CRF calculated at pixel-level using Fu-Liou radiative transfer model (Fu and Liou 1993; Fu et al., 1998):
  - -smooth ice crystal types
  - -ice crystal aspect ratio=1.1
  - -2 streams
  - -data inputs described in section 2.
- CRF=Fconf-Fcon
  - -Fconf = Contrail free upward top-of-atmosphere SW or LW flux
  - -Fcon = Contrail covered upward top-of-atmosphere SW or LW flux
- Contrail free, contrail covered fluxes come from same satellite image pixel in Fu-Liou model.
- Mean values of CRF computed on a 1x1° grid.
- Normalized CRF: Assume 100% contrail coverage; contrail pixels only are used to get histograms and mean values. Applies to both pixel and gridded data.
- Total CRF: Uses contrail fraction weighting; takes into account all pixels, with or without contrails. Applies to gridded data.
- See Spangenberg et al. (2013) for further details.

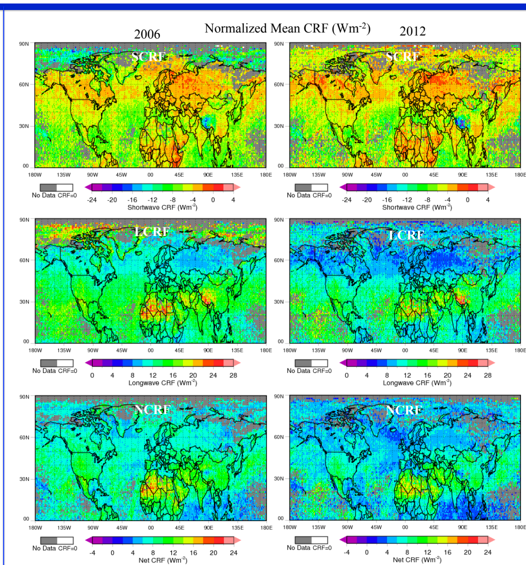
CRF Parameter	Primary Dependence
Shortwave CRF: SCRF <0 = cooling effect	-incoming solar radiation -SFC albedo -cloud albedo [cloud optical depth (τ), cloud particle size (ice=De, water=Re)]
Longwave CRF: LCRF >0 = warming effect	-SFC skin temperature -SFC emissivity -cloud τ, cloud altitude -View zenith angle
Net CRF: NCRF	SCRF + LCRF

4. Results

Normalized CRF Frequency of Occurrence from Pixel Data



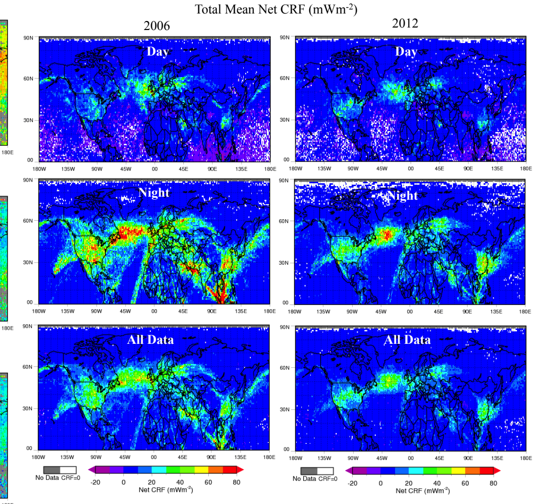
Normalized Mean CRF (Wm-2)



Pixel mean Aqua+Terra MODIS (normalized) CRF for 2012 (2006)

	SCRF (Wm^{-2})	LCRF (Wm^{-2})	NCRF (Wm^{-2})	N ($x10^7$)
Day+Night	-4.93 (-5.72)	11.59 (14.17)	6.66 (8.44)	9.12 (12.31)
Day	-9.21 (-10.75)	12.75 (14.50)	3.54 (3.75)	4.88 (6.55)
Night	0.0 (0.0)	10.25 (13.78)	10.25 (13.78)	4.24 (5.75)

Total Mean Net CRF (mWm-2)



Total mean Aqua+Terra MODIS CRF for 2012 (2006); contrail fraction weighting applied

	SCRF (mWm^{-2})	LCRF (mWm^{-2})	NCRF (mWm^{-2})	Contrail Coverage (%)
Day+Night	-4.79 (-7.35)	11.07 (17.92)	6.28 (10.57)	0.099 (0.132)
Day	-9.69 (-14.80)	13.06 (19.34)	3.37 (4.54)	0.106 (0.139)
Night	0.0 (0.0)	9.13 (16.53)	9.13 (16.53)	0.092 (0.124)

Pixel mean Aqua+Terra MODIS (normalized) CRF for 2012 (2006) as function of scene type underneath contrail

	Water Cloud	Ice Cloud	Clear
SCRF-Day (Wm^{-2})	-8.34 (-8.65)	-8.13 (-10.52)	-13.30 (-14.90)
LCRF-Day (Wm^{-2})	13.40 (14.33)	8.95 (11.63)	16.64 (18.65)
NCRF-Day (Wm^{-2})	5.02 (5.65)	0.82 (1.11)	3.35 (3.75)
N-Day ($x10^7$)	2.63 (2.91)	1.36 (2.08)	0.89 (1.56)
*NCRF-Night (Wm^{-2})	12.74 (14.89)	7.55 (10.96)	16.23 (16.75)
N-Night ($x10^7$)	1.22 (2.96)	2.43 (2.00)	0.59 (0.80)

* NCRF=LCRF

5. Summary

Preliminary values of MODIS-based contrail radiative forcing over the NH were presented for the seasonal months of the years 2006 and 2012. Highest normalized net CRF occurs with no cloud below the contrail at night (16-17 Wm^{-2}) whereas the least amount of net forcing occurs in conjunction with ice clouds below the contrail (0.8-1.1 Wm^{-2}). Contrails exhibited the greatest influence over the Sahara Desert with normalized net CRF values reaching 18-20 Wm^{-2}. The overall climatic effect of contrails is shown by the total net CRF; the mean NH values are 10.6 and 6.3 mWm^{-2} for 2006 and 2012, respectively with values up to 80 mWm^{-2} (2006) and 60 mWm^{-2} (2012) over the North Atlantic flight corridor. The decrease in CRF from 2006 to 2012 was primarily due to a decrease in contrail amount and a difference in background cloud properties. The differences in CRF between 2006 and 2012 are still under investigation.

6. References

Bedka, S. T., P. Minnis, D. P. Duda, R. Boeke, and R. Palikonda (2013), Contrail properties over the Northern Hemisphere from 2006 Aqua MODIS data, Geophys. Res. Lett., 40, 772-777, doi:10.1029/2012GL054363.

Duda, D. P., P. Minnis, K. Khlopenkov, R. Boeke, and R. Palikonda (2013), Estimation of 2006 Northern Hemisphere contrail coverage using MODIS data, Geophys. Res. Lett., 40, 612-617, doi:10.1002/grl.50097.

Fu, Q. and K.-N. Liou (1993), Parameterization of the radiative properties of cirrus clouds, J. Atmos. Sci., 50, 2008-2025.

Fu, Q., P. Yang, and W. B. Sun (1998), An accurate parameterization of the infrared radiative properties of cirrus clouds for climate models, J. Climate, 11, 2223-2237.

Spangenberg, D. A., P. Minnis, S. T. Bedka, R. Palikonda, D. P. Duda and F. G. Rose (2013), Contrail radiative forcing over the Northern Hemisphere from 2006 Aqua MODIS data, Geophys. Res. Lett., 40, 595–600, doi:10.1002/grl.50168.