Diurnal cycle of linear contrails, cirrus, and outgoing longwave radiation in the North Atlantic from MODIS, MSG and models

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Abstract

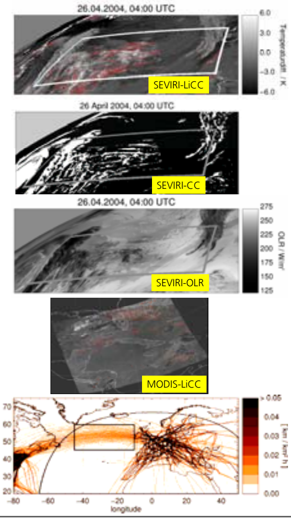
Cloud cover from linear contrails, cirrus cloud cover, and outgoing longwave radiation (OLR) at top of the atmosphere were derived from MSG SEVIRI in a North Atlantic region (NAR) for a period of eight years (Febr 2004- Jan 2012) with 15 min time resolution. The aviation induced contributions to cirrus coverage and OLR in the NAR flight corridor were derived from these data assuming linear response of cirrus and OLR changes to air traffic density and cirrus/OLR background without aviation assumed either constant of as observed in the corresponding South Atlantic region (SAR). Global results were obtained by extrapolating the regional results with global models [Graf et al., 2012; Schumann and Graf, 2013].

Here, the results are compared with linear contrail coverage values derived from MODIS aboard the LEO satellites Terra and Aqua [Duda, Minnis et al., 2013] . The global observations revealed surprisingly high contrail cover in the North Atlantic region. Terra and Aqua overpass times in the NAR are limited to four narrow time intervals and hence cannot resolve the full diurnal cycle.

The results are also compared with predictions of contrail cover and OLR forecast by the Contrail and Cirrus Prediction tool CoCiP. CoCiP computes the cirrus and OLR changes for given meteorology and given air traffic.

The comparisons show that the LEO observations tend to overestimate the daily mean aviation effects in the NAR because the observations times coincide with times of traffic peaks in the NAR.

Datasets – Cirrus Coverage and Air Traffic Density



Linear contrail coverage, cirrus coverage, and outgoing longwave radiation are derived from infrared Meteosat-SEVIRI data. The contrail detection algorithm CDA-MSG identifies linear cirrus cloud structures. The cirrus detection algorithm MeCiDA2 flags cirrus cloud pixels based on several morphological and brightness temperature tests. The outgoing longwave radiation is derived by a state of the art narrowband-to-broadband conversion method applied to the IR channels of SEVIRI [Mannstein et al., 2012].

The linear contrail cover MODIS-LiCC is derived from MODIS on Aqua and Terra applying a contrail detection algorithm [Duda et al., 2013].

EUROCONTROL provided a dataset of air traffic density (ATD) for the region shown in the figure. An animated version representing the diurnal cycle can be found following this QR code:

Results

The annual-mean diurnal cycle of airtraffic (black line) in the North Atlantic region (NAR, 45°-55°N, 10°-45°W) exhibits two peaks in early morning and afternoon with different peak times in the western and eastern parts of the NAR, corresponding to maxima in westbound/ eastbound air traffic.

The vertical lines indicate the overpass times of the Aqua and Terra satellite with MODIS instruments in NAR, the shaded areas indicate a time period of 4 h before the respective overpass.

Correction for annual mean background

$$\mathrm{LiCC}'(x,y,t_i) = \mathrm{LiCC}(x,y,t_i) - \langle \mathrm{LiCC}(x,y,t_i)\rangle_{t_i} + \langle\langle\langle \mathrm{LiCC}(x,y,t_i)\rangle\rangle\rangle_{x,y,t_i}$$

Correction for background + satellite zenith angle sensitivity cirrus cover

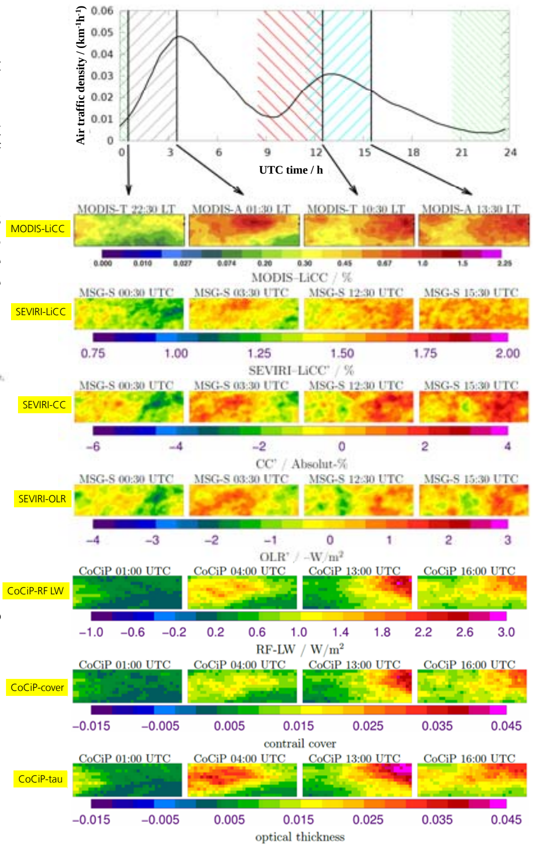
$$\begin{aligned}\mathrm{CC}'(x,y,t_i) &= \mathrm{CC}(x,y,t_i) - \mathrm{CC}(x,y',t_i)_{\mathrm{SAR}} \\ &\quad - \langle\langle\langle \mathrm{CC}(x,y,t_i) - \mathrm{CC}(x,y',t_i)_{\mathrm{SAR}}\rangle\rangle\rangle_{x,y,t_i}\end{aligned}$$

same for outgoing longwave radiation

$$\begin{aligned}\mathrm{OLR}'(x,y,t_i) &= \mathrm{OLR}(x,y,t_i) - \mathrm{OLR}(x,y',t_i)_{\mathrm{SAR}} \\ &\quad - \langle\langle\langle \mathrm{OLR}(x,y,t_i) - \mathrm{OLR}(x,y',t_i)_{\mathrm{SAR}}\rangle\rangle\rangle_{x,y,t_i}\end{aligned}$$

The Contrail and Cirrus Prediction tool CoCiP was applied for the year 2006 using numerical weather prediction data from ECMWF and air traffic waypoint data from FAA-ACCRI.

The figure shows the computed annual mean contrail optical thickness (5th row), mean contrail cover (6th row) and optical depth (bottom) for 01:00, 04:00, 13:00, and 16:00 UTC (from left to right).



The mean diurnal cycle of air traffic density (ATD) has a distinctive pattern with two peaks in the North Atlantic region (NAR) – a peak from eastbound traffic at 03:45 UTC and a peak of westbound traffic at 13:00 UTC. On average over the NAR, the maximum (0.05, in km^{-1} h^{-1}) occurring at 03:45 UTC is 2.3 times larger than the 24-h mean (0.021). The minimum (0.0037) at 22:45 UTC is 5.5 time smaller than the mean.

The linear contrail cover (LiCC) derived from MODIS is analyzed separately for the four overpasses at about 23:30 LT, 01:30 LT, 10:30 LT, and 13:30 LT (first row). The mean values and the spatial distribution of MODIS-LiCC is consistent with the air traffic occurrence in NAR. For example, the 22:30 LT overpass of MODIS Terra samples contrails in the NAR with low air traffic in the recent 4 h period. Only in the most eastern part, air traffic took place shortly before this overpass.

Meteosat-SEVIRI results are shown for universal times 00:30 UTC, 03:30 UTC, 12:30 UTC, and 15:30 UTC, corresponding to the MODIS LT observations in the NAR center.

The temporal, but also the spatial pattern and cover values of MODIS LiCC is highly consistent with LiCC (2nd row), CC(3rd row), and OLR (4th row) from Meteosat-SEVIRI, despite of the coarser spatial resolution of SEVIRI.

The spatial and temporal patterns of longwave radiative forcing (RW-LW changes in OLR), contrail cover and contrail solar optical depth (tau) computed with CoCiP are in good agreement with the observations. The model shows that the 24 h mean contrail cover is lower than the mean at the MODIS overflight times. Hence, the high contrail cover found from MODIS in the North Atlantic is partially a consequence of incidental agreement of observation times with air traffic peaks.

Conclusions

- MODIS linear contrail cover results agree well with linear contrail, cirrus and outgoing longwave radiation results derived from Meteosat SEVIRI, and with corresponding CoCiP model results.
- The agreement supports our previous hypothesis of aviation induced contributions to MSG observations of cirrus cover and OLR in the North Atlantic (Graf et al. 2012; Schumann and Graf 2013).
- The contrail cover from MODIS in the Atlantic region is higher than the daily mean because of coincidence of observation times with air traffic peaks.

References

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