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Plane Tracks in Cirrus Clouds: An Unstudied Non-CO_2 Aviation Effect

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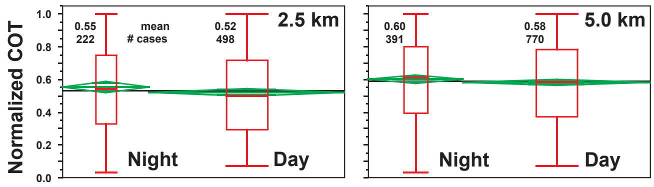
Abstract

Air traffic is known to have an immediate and noticeable effect on clouds in the upper troposphere. New clouds that form due to aircraft effluent are called contrails and known to induce cirrus in otherwise cloud-free regions of the upper troposphere. Contrails and contrail cirrus generally show low cloud optical thickness (COT). Their overall climatic effects are estimated to be minor but with very low level of scientific understanding. While optically thick cirrus clouds have a net cooling effect on surface temperature, optically thin cirrus clouds, like greenhouse gases, can have a warming effect. Aircraft emissions at cirrus altitudes have the potential to either cause optically thin cirrus clouds to form (that would have a warming effect on surface temperatures), or increase the optical thickness of existing clouds (or induce new optically thick clouds) with a net cooling effect.

Elucidating the effect of aircraft emissions on existing cirrus clouds has been more difficult. Here we combine spaceborne lidar observations with air traffic data to determine the optical thickness of cirrus clouds inside and outside flight corridors that extend from Hawaii to the west coast of the United States. Our aim is to test the hypothesis that aircraft emissions and aviation-induced clouds have no measurable effect on cirrus cloud optical properties inside and outside air traffic corridors in the upper troposphere.

CALIPSO Data Reliability: Day vs Night

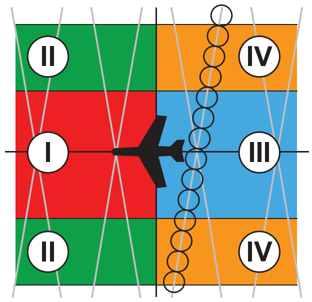
Due to the influence of daylight noise, CALIOP feature detection sensitivity is better at night than during day. We therefore examined our data for differences in day and night time CALIPSO overpasses. Examples of the mean normalized COT for cases in which the maximum cirrus geometrical cloud layer depth was 2.5 and 5.0 km show that we did not observe any significant day-night differences in normalized COT, and therefore have included both kinds of observations in our analysis.



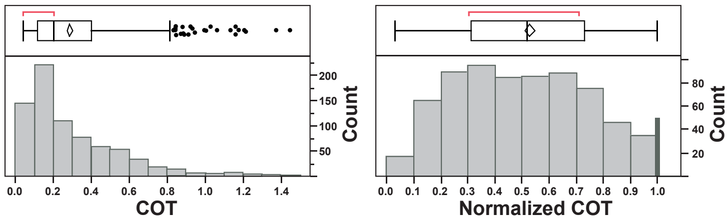
Mean normalized COT for night and day overpasses for maximum cloud layer depth of 2.5 and 5.0 km.

Approach and Quality Assurance

- ► We use actual flight tracks of commercial flights between Seattle (KSEA), San Francisco (KSFO), Los Angeles (KLAX), and Honolulu (PHNL) in the years 2010 and 2011
- ► These tracks are matched with CALIPSO overpasses in the region 15-50 °N and 120-155 °W
- ► We use the L2 5-km Cloud Layer product version 3.01 [Jan 2010 - Oct 2011] / 3.02 [Nov 2011 - Dec 2011]



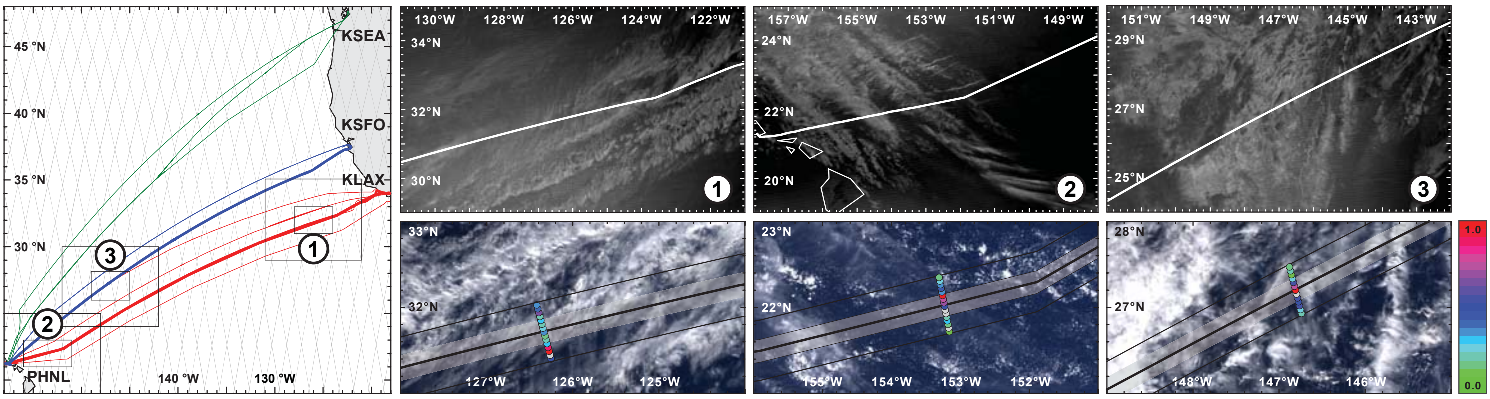
- ► Allow a maximum delay of 30 min between aircraft and CALIPSO overpass; look for cirrus at flight level
- ► We use ECMWF winds (v and dir) at the crossing point to study advection effects; extreme cases are removed
- ► Quality assurance criteria:
  - > only uppermost 2 features/layers are considered
  - > cirrus identified (feature type = cloud, sub-type = cirrus)
  - > features detected at 5-km averaging intervals
  - > Extinction_QC_Flag_532 = 0
- ► We only use the 7 points north + south of the flight track
- ► Homogeneity check: at least half of these 14 points has to show COT that fulfills the QA criteria given above
- ► The 3 points closest to the track mark the flight corridor
- ► Points 4 to 7 are outside of the flight corridor
- ► This leads to 4 categories as the CALIPSO overpass could be before or after the passage of the aircraft
- ► COT is normalized to the highest value for individual cases to account for skewness of the data



Distribution of absolute and normalized COT for cases with a maximum cloud layer depth of 2.5 km.

Example cases

Typical aircraft flight tracks (colored lines, white and black lines for example cases), CALIPSO satellite trajectories (gray lines for 16-day cycle), and normalized cirrus optical thickness measurements (colored dots) from three example overpasses with and without contrails visible in the plots of brightness temperature difference (upper row) and visible composite (lower row). All times are given in UTC.



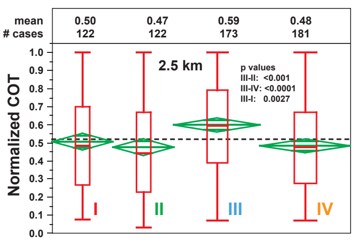
Typical flight tracks between Honolulu (PHNL) and Los Angeles (KLAX), San Francisco (KSFO), and Seattle (KSEA). Numbers mark the cases in the right panels.

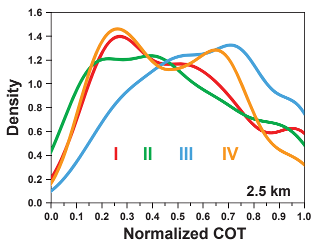
7 November 2010 - no contrails visible. aircraft: 22:18:23, CALIPSO: 21:50:35, time delay: -00:27:48, MODIS: 21:45.

20 March 2011 - contrails visible. aircraft: 23:28:53, CALIPSO: 23:47:59, time delay: +00:19:06, MODIS: 23:40.

12 January 2011 - no contrails visible. aircraft: 23:11:53, CALIPSO: 23:17:05, time delay: +00:05:12, MODIS: 23:10.

Main Results: Differences in Mean Normalized COT for the Different Categories



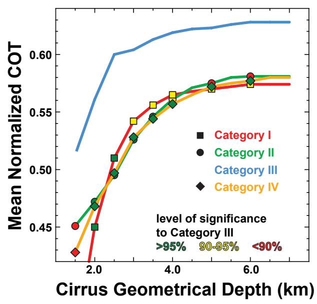


Box-and-whisker plots show the quantiles for the data in each category. Green diamonds indicate the 95% confidence intervals for the mean values of each of the categories. The dashed line shows the overall mean val ue. The same data is shown as density functions in the right panel.

The figures to the left show the investigation for a maximum geometrical cloud depth of 2.5 km. The difference in normalized COT for clouds inside and outside the flight track of the aircraft persists also for larger cirrus depth. The level of statistical significance for the difference between category III and the other categories decreases as the geometrical thickness of the clouds increases.

We have falsified our hypothesis, and observed a 22% increase in normalized COT (14% in COT) in flight corridors for cases where the aircraft was less than 30 min ahead of the satellite overpass and cloud depth was 2.5 km or less.

The effect is expected to be strongest in regions in which
(1) aircraft fly below the tropopause and at cirrus level,
(2) tropical convection is of minor influence on cloud formation (i.e., outside the ITCZ band)



Summary and Outlook

- ► We have falsified our hypothesis and observed a detectable 22% increase in normalized COT (14% in COT) in flight corridors for cases where the aircraft was 30 min or less ahead of the satellite overpass
- ► Vertically resolved lidar observations provide added value to the investigation of contrails and contrail cirrus with passive sensors and allow to also detect optically thin contrails and cirrus clouds
- ► This marks a pilot study: a larger data set is needed to investigate temporal evolution of the observed increase in cirrus optical depth; better data exploitation by using raw data instead of operational products
- ► Detailed radiative transport modelling is necessary to quantify the found effect which is expected to be a major contribution to the non-CO_2 climate effect of aviation