Quantifying global contrail-cirrus

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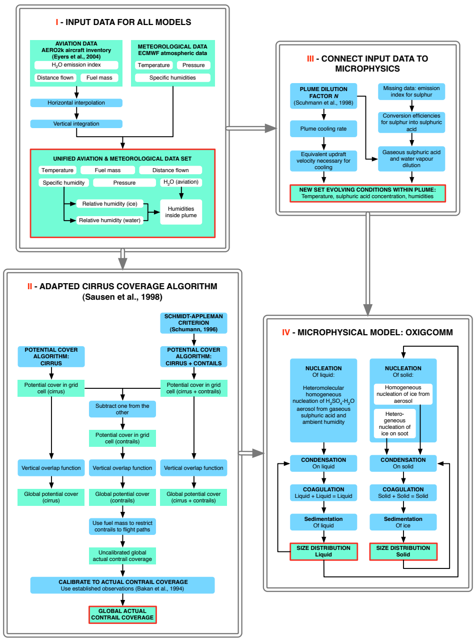
Introduction

Contrail-cirrus is indistinguishable from natural cirrus [Unterstrasser, 2008]. We therefore aim to:

A) Quantify global contrail-cirrus produced by aviation.

B) Investigate the properties (size, number concentration, etc.) of ice particles formed in contrail-cirrus.

Persistent contrail occurrence and coverage can be predicted by the Schmidt-Appleman criterion and a modified cloud coverage algorithm [Schumann, 1996, Sausen, 1998]. More detailed information on the number and nature of ice particles formed from the exhaust is found by microphysically simulating ice crystal growth. Both of these modelling approaches require the best possible input data.



I - INPUT DATA FOR ALL MODELS

AVIATION DATA
AERO2k aircraft inventory
(Eyers et al., 2004)
H_2O emission index
Distance flown
Fuel mass

METEOROLOGICAL DATA
ECMWF atmospheric data
Temperature
Pressure
Specific humidities

Horizontal interpolation

Vertical integration

UNIFIED AVIATION & METEOROLOGICAL DATA SET
Temperature
Fuel mass
Distance flown
Specific humidity
Pressure
H_2O (aviation)
Relative humidity (ice)
Relative humidity (water)
Humidities inside plume

II - ADAPTED CIRRUS COVERAGE ALGORITHM
(Sausen et al., 1998)

SCHMIDT-APPLEMAN CRITERION
(Schumann, 1996)

POTENTIAL COVER ALGORITHM: CIRRUS

POTENTIAL COVER ALGORITHM: CIRRUS + CONTAILS

Potential cover in grid cell (cirrus)

Potential cover in grid cell (cirrus + contrails)

Subtract one from the other

Potential cover in grid cell (contrails)

Vertical overlap function

Vertical overlap function

Vertical overlap function

Global potential cover (cirrus)

Global potential cover (contrails)

Global potential cover (cirrus + contrails)

Use fuel mass to restrict contrails to flight paths

Uncalibrated global actual contrail coverage

CALIBRATE TO ACTUAL CONTRAIL COVERAGE
Use established observations (Bakan et al., 1994)

GLOBAL ACTUAL CONTRAIL COVERAGE

III - CONNECT INPUT DATA TO MICROPHYSICS

PLUME DILUTION FACTOR *N*
(Scuhmann et al., 1998)

Plume cooling rate

Equivalent updraft velocity necessary for cooling

Missing data: emission index for sulphur

Conversion efficiencies for sulphur into sulphuric acid

Gaseous sulphuric acid and water vapour dilution

NEW SET EVOLVING CONDITIONS WITHIN PLUME:
Temperature, sulphuric acid concentration, humidities

IV - MICROPHYSICAL MODEL: OXIGCOMM

NUCLEATION
Of liquid:
Heteromolecular homogeneous nucleation of H_2SO_4-H_2O aerosol from gaseous sulphuric acid and ambient humidity

NUCLEATION
Of solid:
Homogeneous nucleation of ice from aerosol
Hetero-geneous nucleation of ice on soot

CONDENSATION
On liquid

CONDENSATION
On solid

COAGULATION
Liquid + Liquid = Liquid

COAGULATION
Solid + Solid = Solid

Sedimentation
Of liquid

Sedimentation
Of ice

SIZE DISTRIBUTION
Liquid

SIZE DISTRIBUTION
Solid

Figure 1 (right). Schematic of modelling processes used. Expounded further below.

I. Input data

Two sets are needed for contrail-cirrus coverage and subsequent microphysical modelling:

- Flight paths and fuel emission information can be found from aircraft inventories: we have used the AERO2k data set [Eyers et al., 2004] which covers 2002 (Figure 2).

- Physical parameters (temperature, humidity and pressure) are available from ECMWF ERA40 data sets (Figure 3).

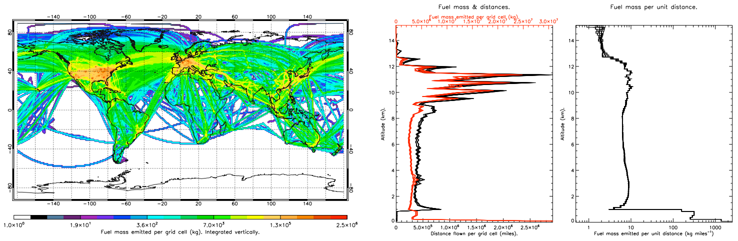


Figure 2. From the AERO2k aviation inventory for January, 2000. Left: vertically integrated fuel mass emitted. Right: vertical profiles of fuel emitted and distances flown. The majority of aviation takes place at cruise altitudes between 9 and 12 km (around 250 hPa).

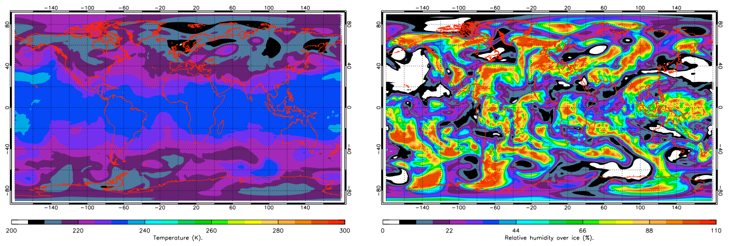


Figure 3. Temperature (left) and relative humidity over ice (right) at 250 hPa (i.e., cruise altitude, see Figure 2) from ECMWF ERA40 data at 1200 UTC, 01/01/2002.

II. Contrail-cirrus coverage

- Given temperature, pressure and humidity, the Schmidt-Appleman criterion provides a local indicator for contrail formation [Schumann, 1996].

- A cirrus coverage parameterisation can be adapted, via the Schmidt-Appleman criterion, to produce potential coverages of cirrus and contrail-cirrus+cirrus for each grid cell [Sausen, 1998].

- The difference between these is the potential coverage by contrail-cirrus (Figure 4, left). This can be calibrated via established contrail-cirrus observations (Figure 4, right) to allow actual contrail-cirrus coverage calculation over the globe (Figure 5).

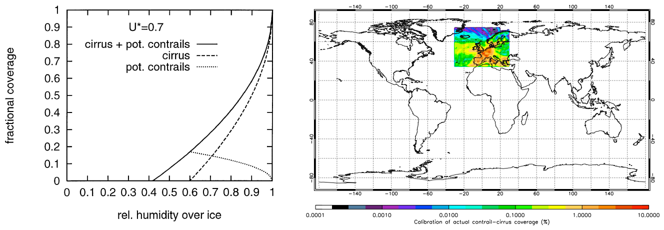


Figure 4. Left: a function of temperature, pressure and humidity provides potential converages. Right: potential coverage for contrail cirrus calibrated to 0.375% [Bakan, 1994] coverage over Western Europe for 1200 UTC, 01/01/2002.

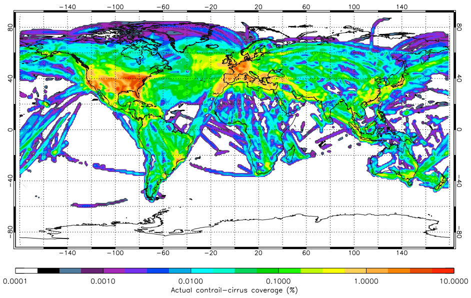


Figure 5 (right). Factor obtained via calibration in Figure 4 used over every grid cell to calculate actual contrail-cirrus coverage for 1200 UTC, 01/01/2002.

III. Connecting input data to microphysics

Schumann, 1998 have derived a bulk parameter *N* for characterising properties of the expanding plume such as temperature (Figure 6), diameter and fuel constituent concentrations. Along with certain assumptions regarding data missing from the aircraft inventory (sulphur emission index, sulphur conversion efficiencies, surviving ice crystals fractions, etc.), these dilution assumptions can be used to initialise the microphysical model.

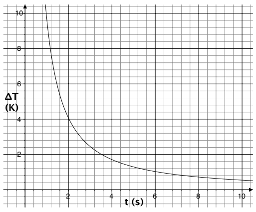


Figure 6 (right). How the temperature difference between the plume and the environment (dT) evolves via the empirically derived relation $dT = Q / (c_p N)$ where $N = 7{,}000t^{0.8}$. As can be seen, within six seconds, the plume is within 1 K of ambient temperature

IV. Microphysical model

A Stratospheric Aerosol Microphysical Model (SAMM) has previously been developed at the University of Oxford [Tripathi et al., 2004] and duly tested [Kanawade & Tripathi, 2006]. It is capable of simulating the life cycle of liquid H_2SO_4-H_2O aerosol: nucleation, condensation, coagulation and, sedimentation. SAMM is undergoing expansion, the Oxford-IITK Global Contrail Offline Microphysical Model (OXIGCOMM) has been developed to simulate:

- Oxidation of sulphur dioxide into gaseous sulphuric acid [Kazil, 2007].
- H_2SO_4-H_2O aerosol nucleation from gaseous precursors.
- Nucleation of ice particles from aerosol droplets [Ren & Mackenzie, 2005].
- Condensational growth, self-coagulation and sedimentation of each species (aerosol, ice) [Jacobson, 2002].

Conclusions

A method has been formulated to predict cirrus arising from aircraft. Whilst model development is ongoing, it is hoped that key results can eventually be compared with cirrus climatologies from remote sensing (ISCCP, HIRS, MIPAS, etc.) such that the cirrus signature from aircraft emissions can be quantified. Whilst initially developed for offline use, OXIGCOMM will be written with a view to future inclusion in a CTM.

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