Automatic Pixel-by-pixel Contrail Cloud Detections

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Contrail cloud

Aircraft exhaust contains Small particles (e.g. soot) encounter Supersaturated water vapor condense Ice crystals

Compared with other ice clouds, contrail clouds

• have line or strip-like shapes;
• are formed in a more consistent altitude range;
• are optically thin.
Contrail cloud

A contrail in College Station, November 19, 2017
Contrail radiative effect

Top of the atmosphere

Solar radiation

Atmospheric thermal radiation

Surface
Contrails viewed from the space

Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the **Aqua** and **Terra** satellites

Thirty-Six spectral bands from visible to thermal IR, about 1 km spatial resolution, operating from year 2000-now

Taken by NASA Terra MODIS over the Yellow Sea, Jan. 24 2020
Contrails viewed from different spectral bands

RGB

11 µm

1.38 µm

11 µm – 11 µm

Brightness Temperature Difference (BTD, 12 µm – 11 µm)
Contrail detection based on pattern recognition

Padmanabhan et al. (2014)

BTD image → Edge detection → Hough transform

Image segmentation and convolutional neural network (CNN); Zhang et al. (2018)
Contrail detection based on pixel signals

Mannstein et al. (1999); Duda et al. (2013), (2019)
1. Obtain brightness temperature difference image
2. Remove background
3. Edge detection
4. Remove non-contrail features
5. Line detection

Hough transform

Hough inverse transform
6. Determine edges associated with each detected line
7. Obtain skeletons of contrails
8. Obtain contrail pixels around the skeletons
Problems

1. Missing coastlines
2. Line shapes in other clouds
Possible solutions

• Using multi-band signal to improve signal-to-noise ratio of BTD image;

• Using coastline information and flight traffic information to filter contrail detection results;

• Using CNN to determine contrail pixels based on detected contrail skeleton;

• ...
Contrail properties from detection results and MODIS cloud retrieval products

- Contrail cloud optical thickness
- Contrail cloud particle size
- \( \tau - R_e \) relation
- Contrail cloud top height
- Contrail cloud top temperature
A machine learning-based fast radiative transfer model to simulate contrail radiative effect.
Mapping from \(m\) bands to \(M\) bands (\(m \gg M\))

\[
F_{M \times 1} = G\left(F_{m \times 1}\right)
\]

Linear mapping using principal component analysis

\[
F_{M \times K} = P_{M \times M} C_{M \times K}
\]

\[
F_{m \times K} = P_{m \times s} C_{s \times K}
\]

Nonlinear mapping using neural network

\[
F_{M \times K} = G_{M \times m} F_{m \times K}
\]

\[
G_{M \times m} = P_{M \times s} \left[\left( P_{m \times s}^T P_{m \times s} \right)^{-1} P_{m \times s}^T \right]
\]
Summary

• We are developing an efficient and accurate contrail detection algorithm;

• The initial algorithm version has many problems needed to be fixed;

• The algorithm will be very useful for us to better understand contrail impact on the earth energy budget and ice cloud formation mechanism.