Automatic Pixel-by-pixel Contrail Cloud Detections

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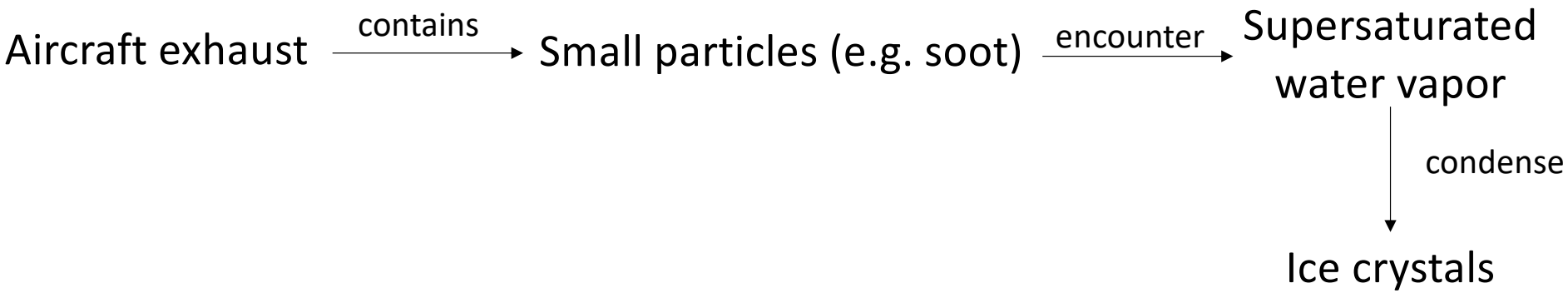
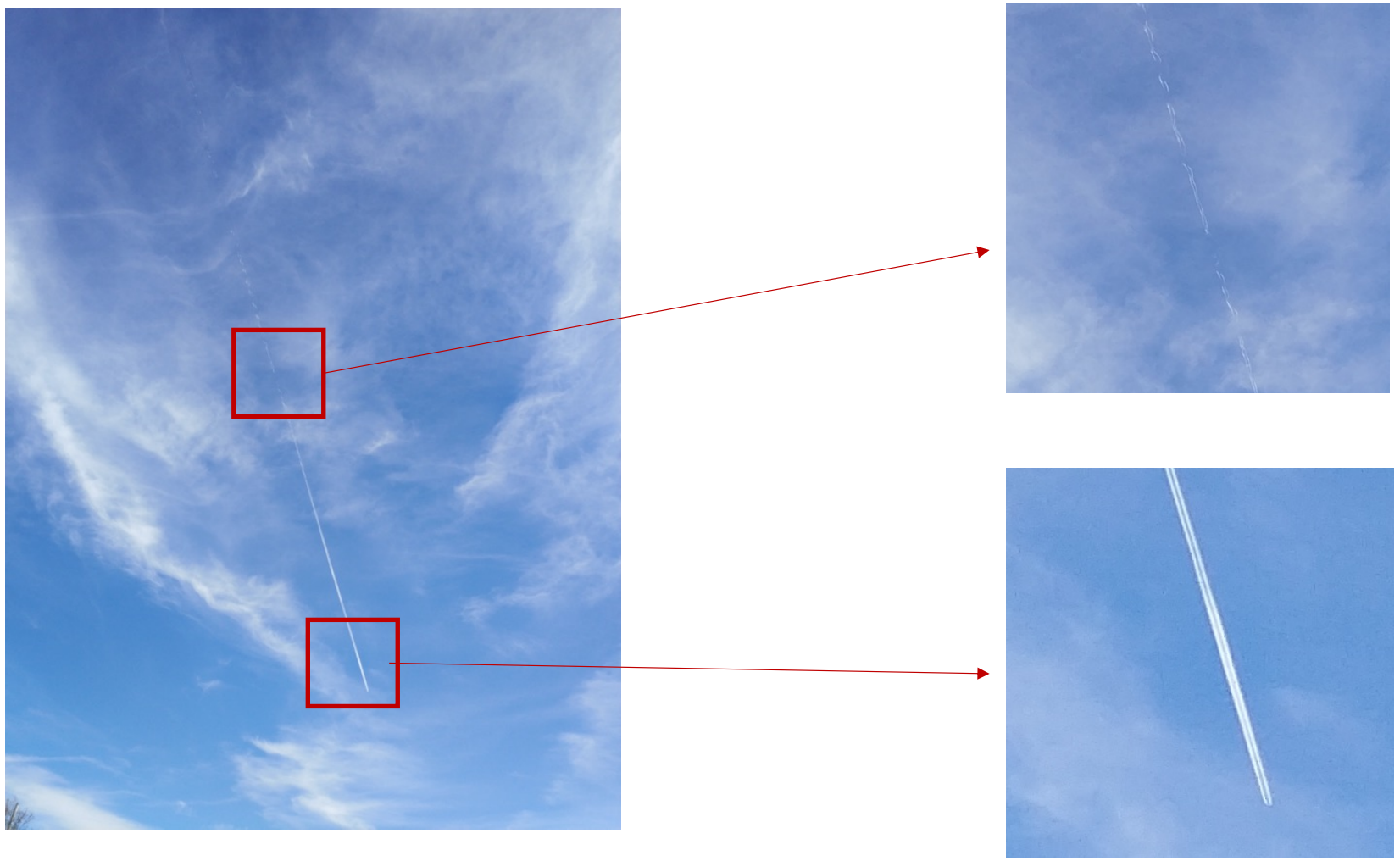
Contrail cloud



Compared with other ice clouds, contrail clouds

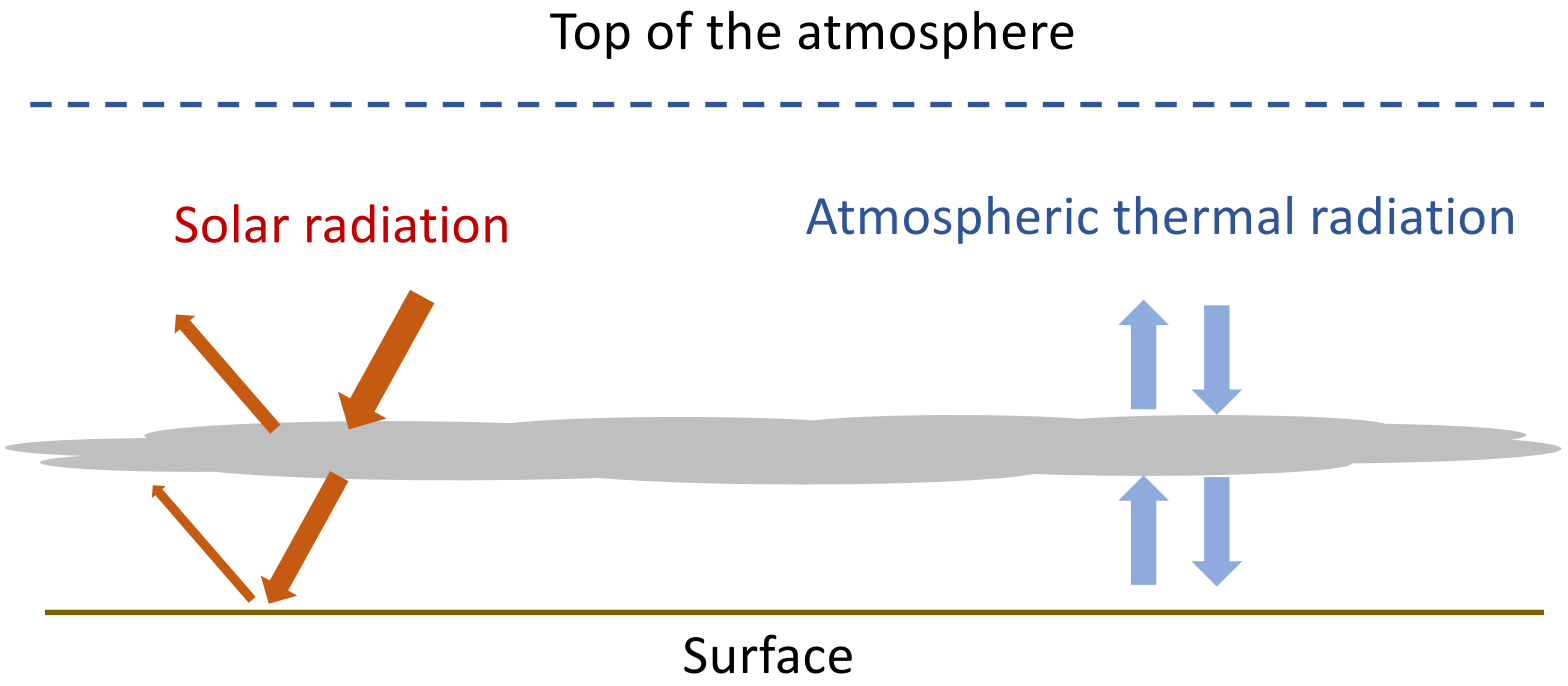
- have line or strip-like shapes;
- are formed in a more consistent altitude range;
- are optically thin.

Contrail cloud

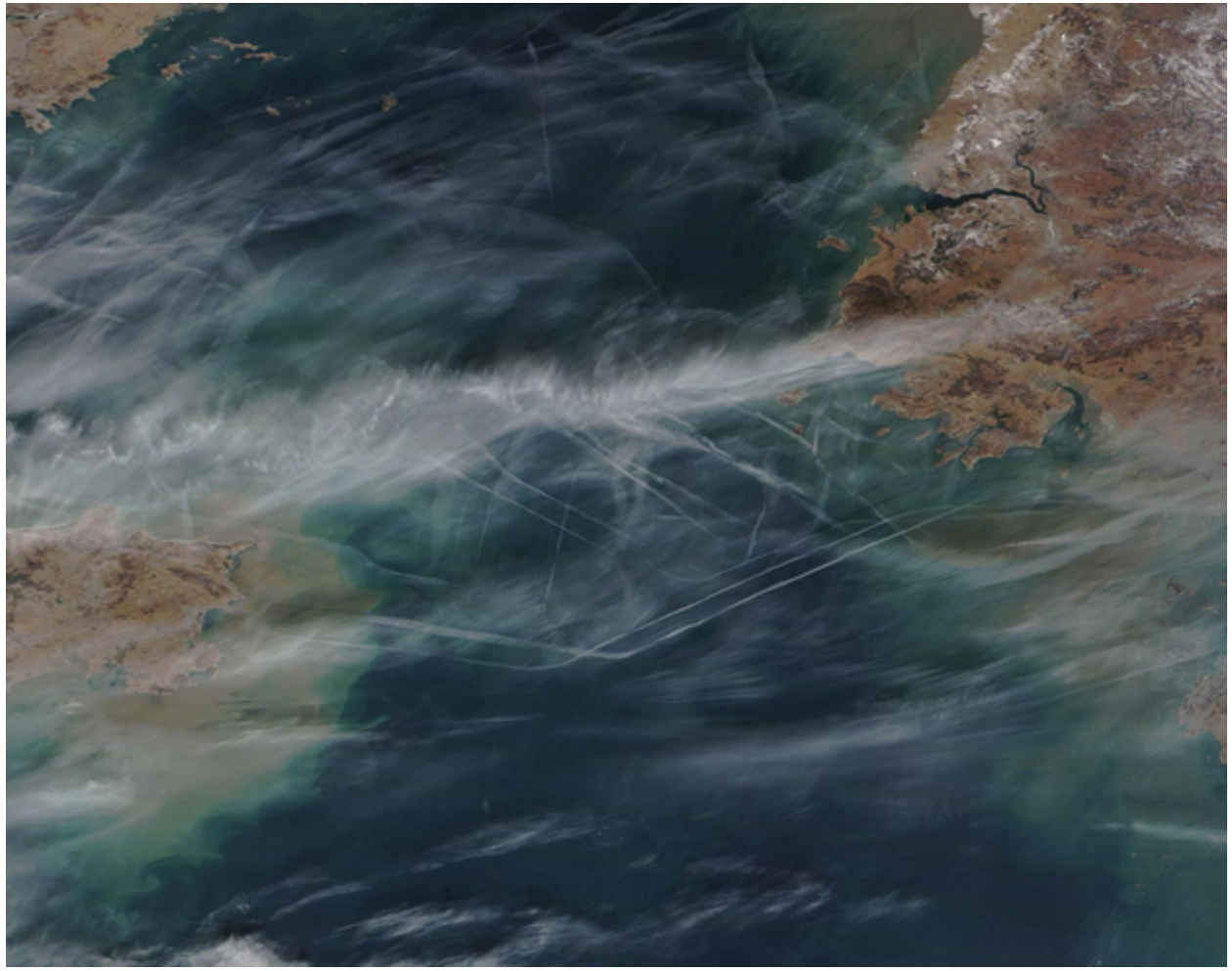


A contrail in College Station, November 19, 2017

Contrail radiative effect

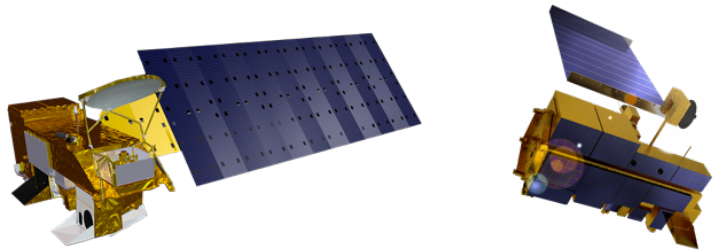


Contrails viewed from the space



Taken by NASA Terra MODIS over the Yellow Sea, Jan. 24 2020

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

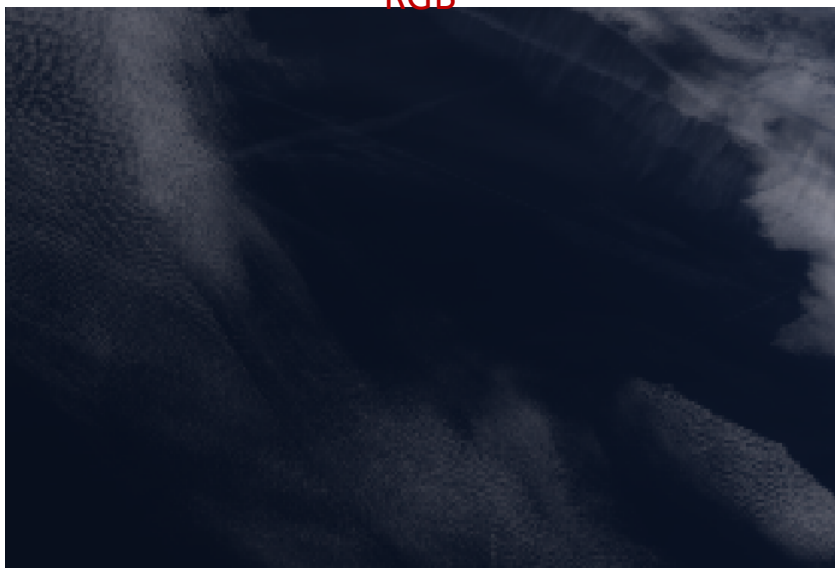


Aqua Terra

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

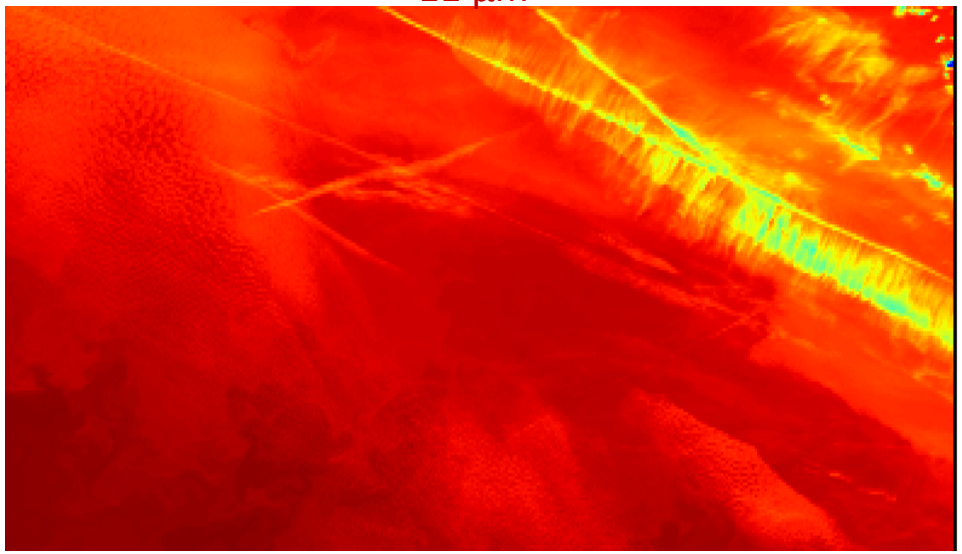
Contrails viewed from different spectral bands

RGB

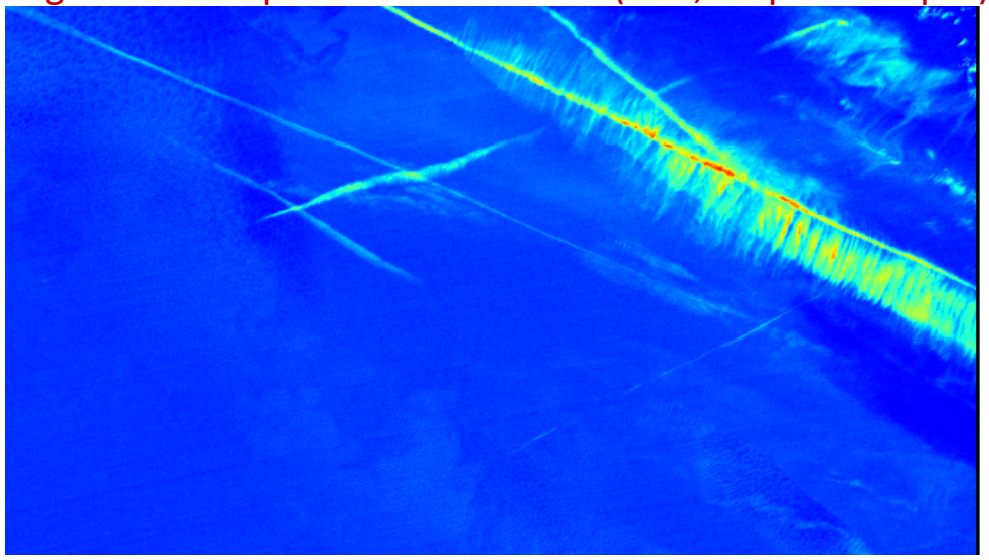


1.38 µm

11 µm

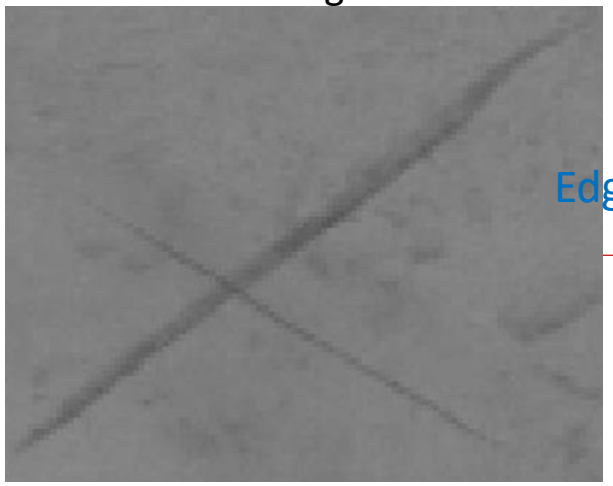


Brightness Temperature Difference (BTD, 12 µm – 11 µm)

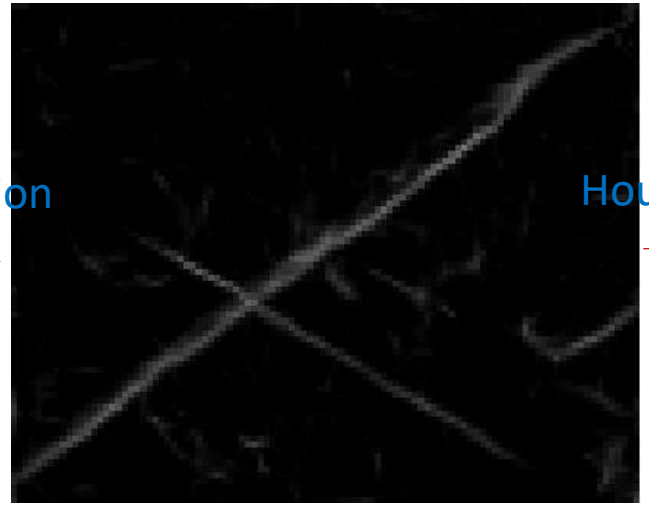


Contrail detection based on pattern recognition

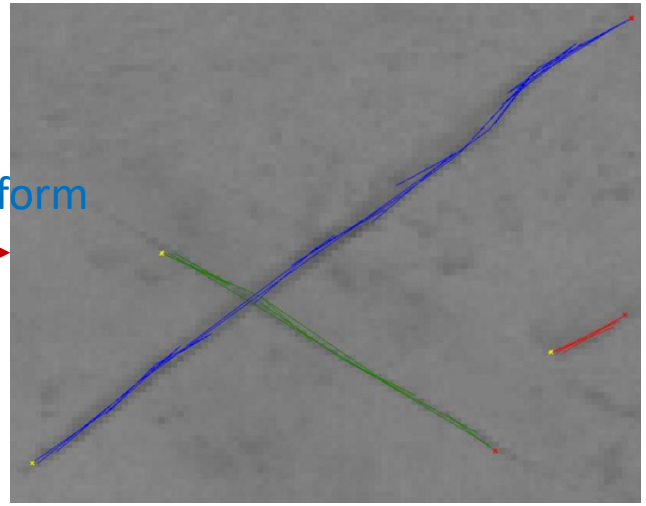
BTD image



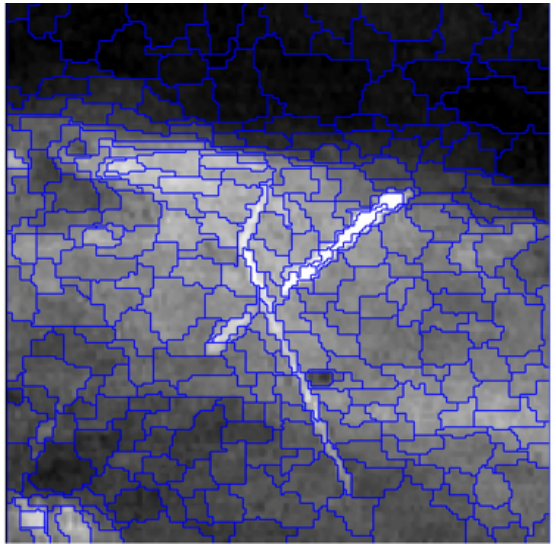
Edge detection



Hough transform



Padmanabhan et al. (2014)



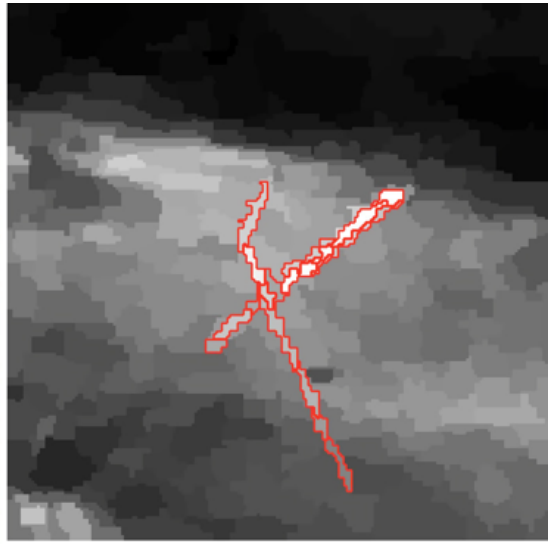
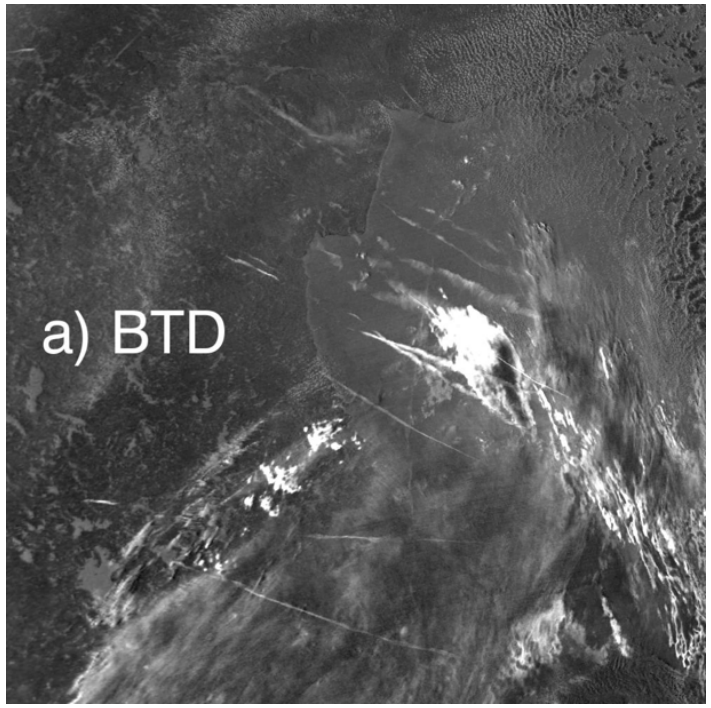
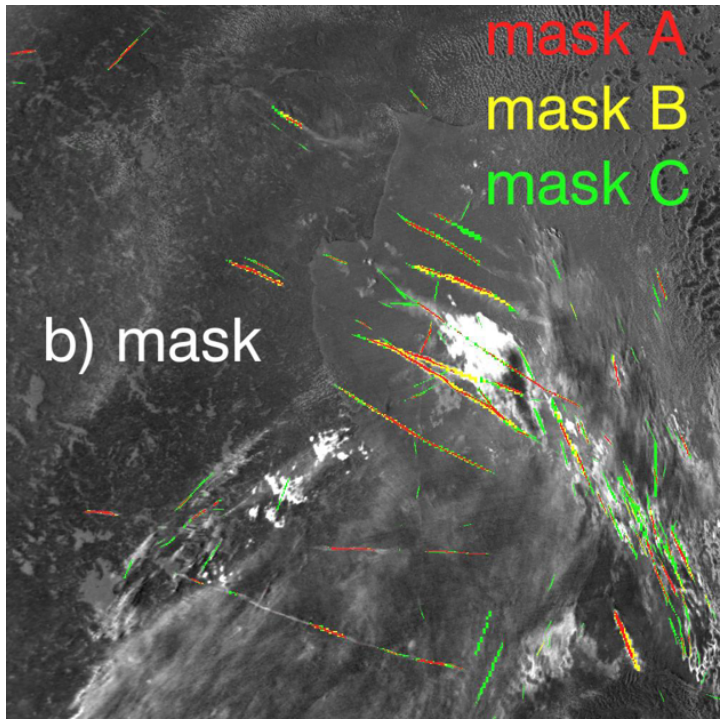


Image segmentation and convolutional neural network (CNN); Zhang et al. (2018)

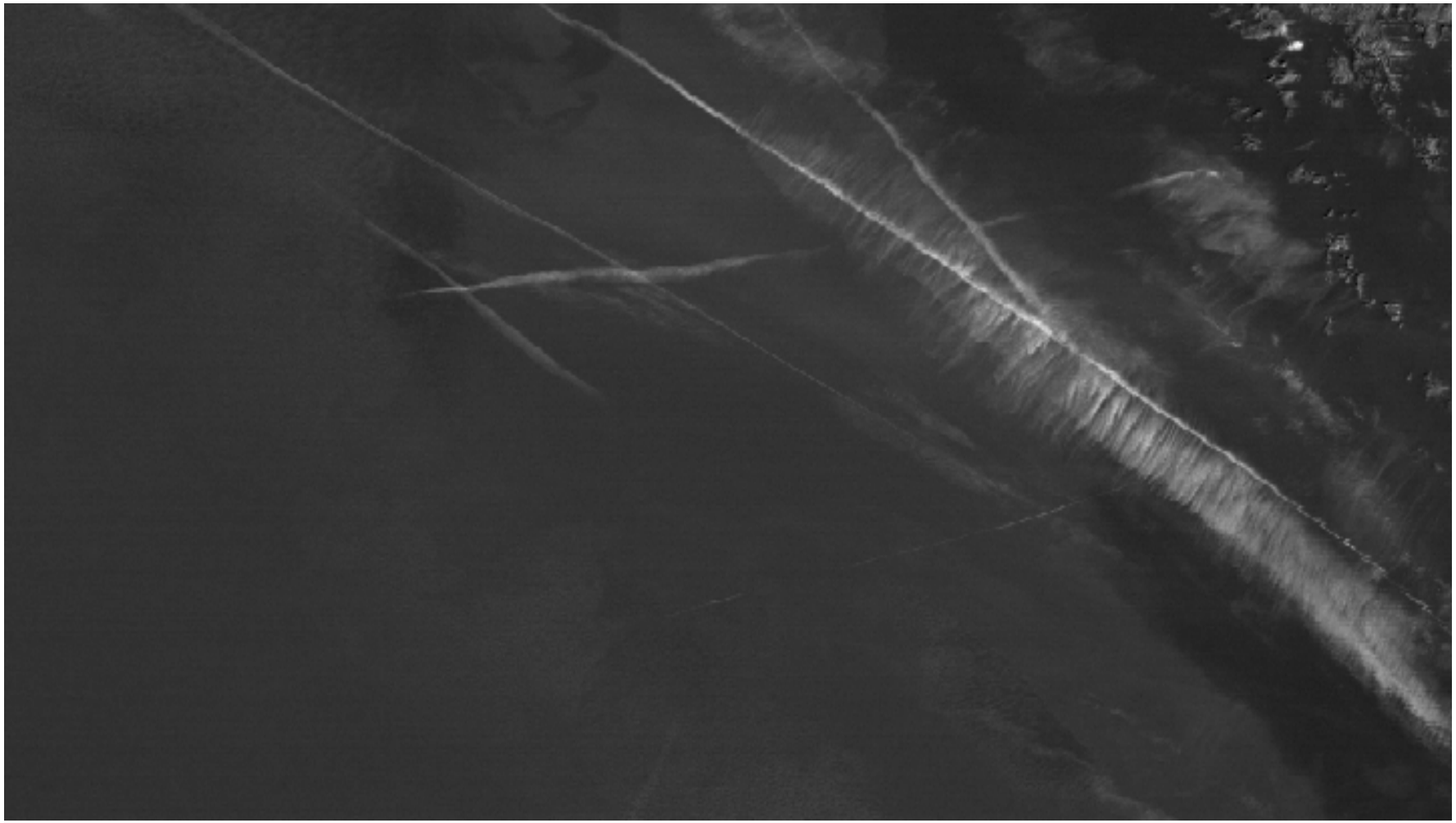
Contrail detection based on pixel signals





Mannstein et al. (1999); Duda et al. (2013), (2019)

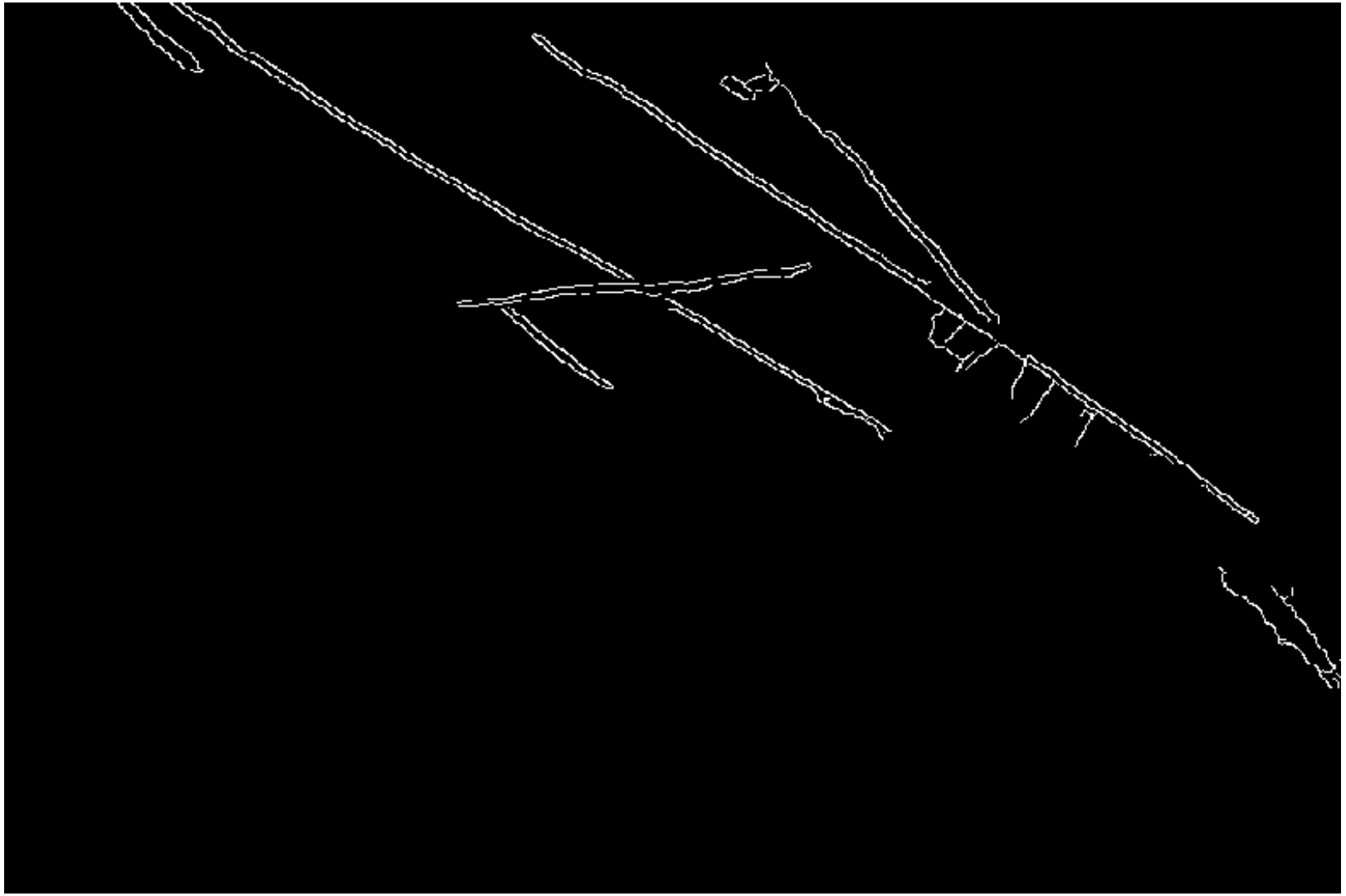
1. Obtain brightness temperature difference image



2. Remove background

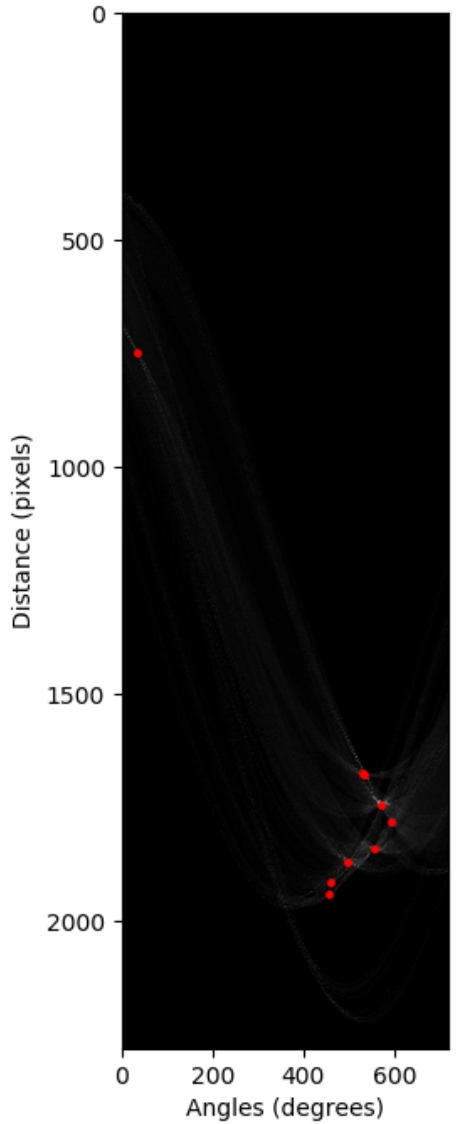
3. Edge detection

4. Remove non-contrail features

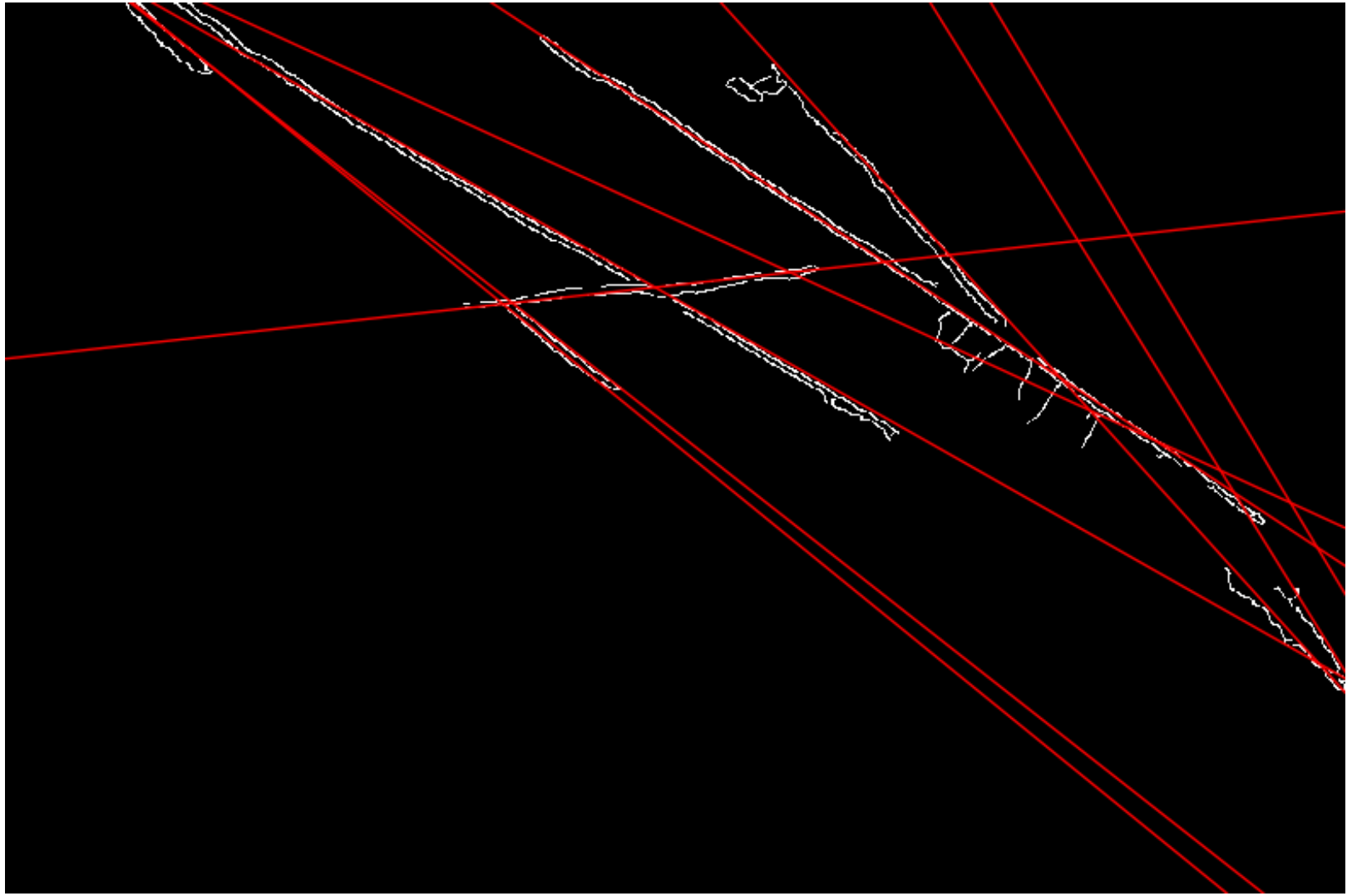


5. Line detection

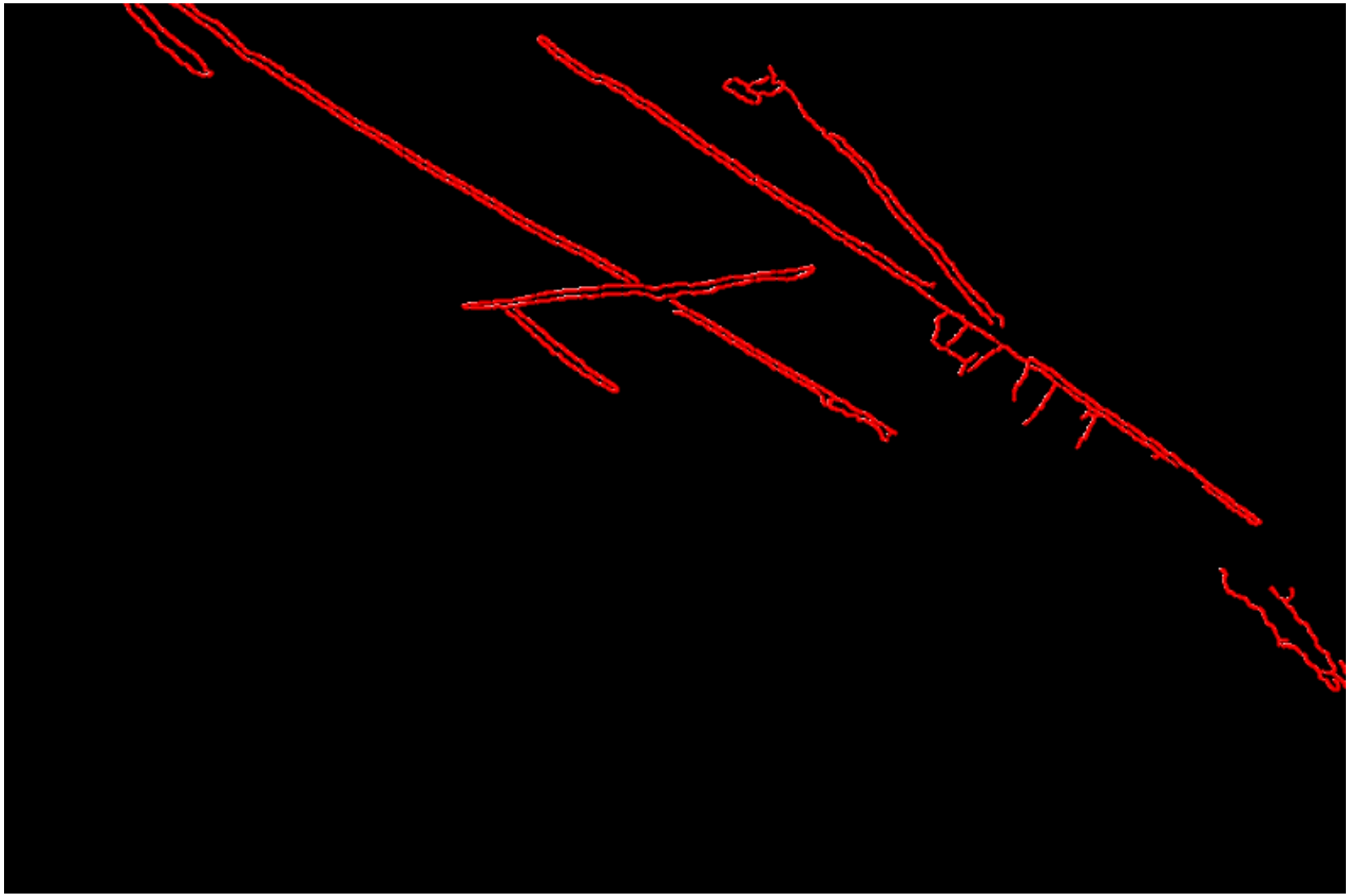
Hough transform



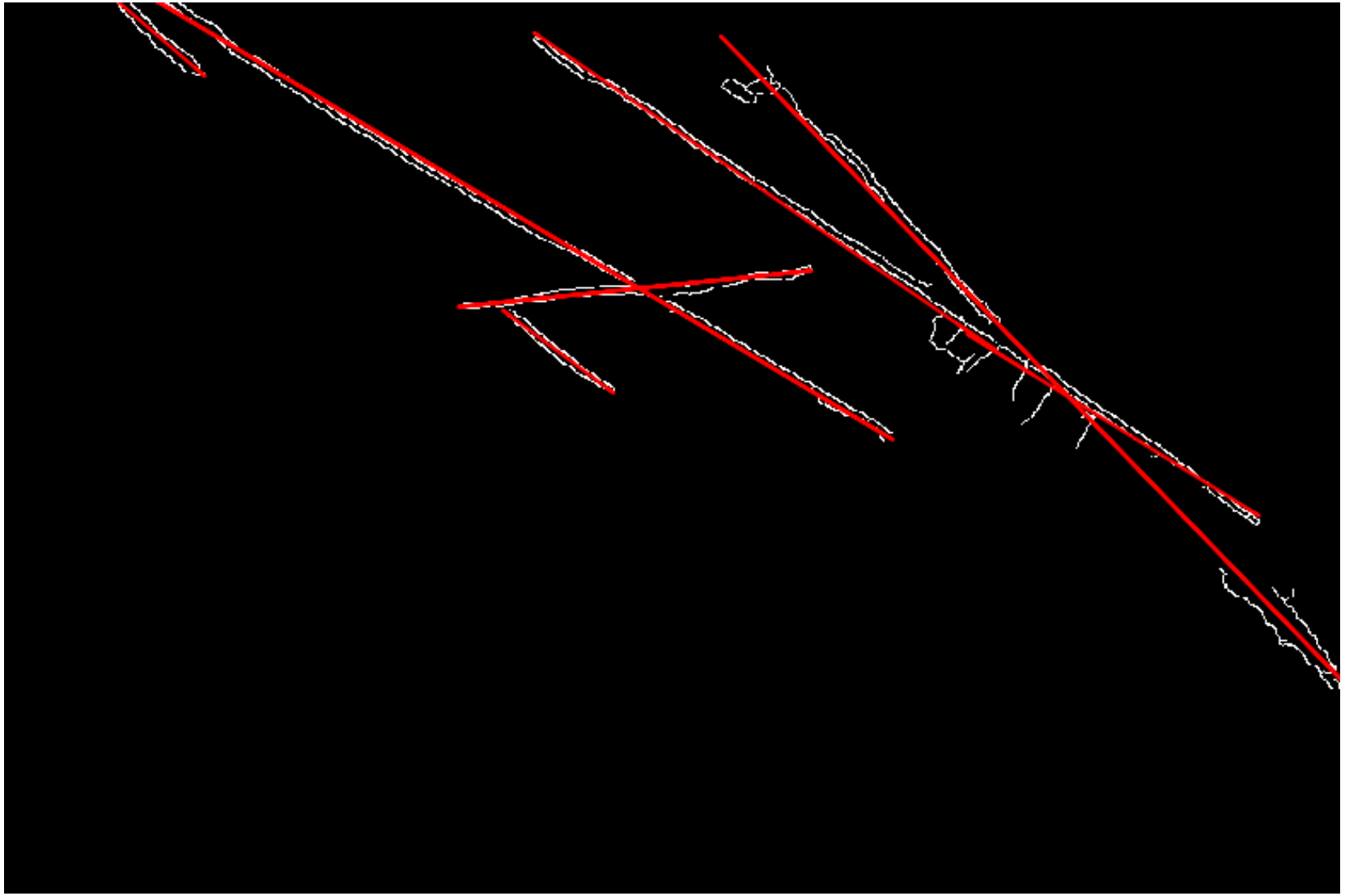
Hough inverse transform



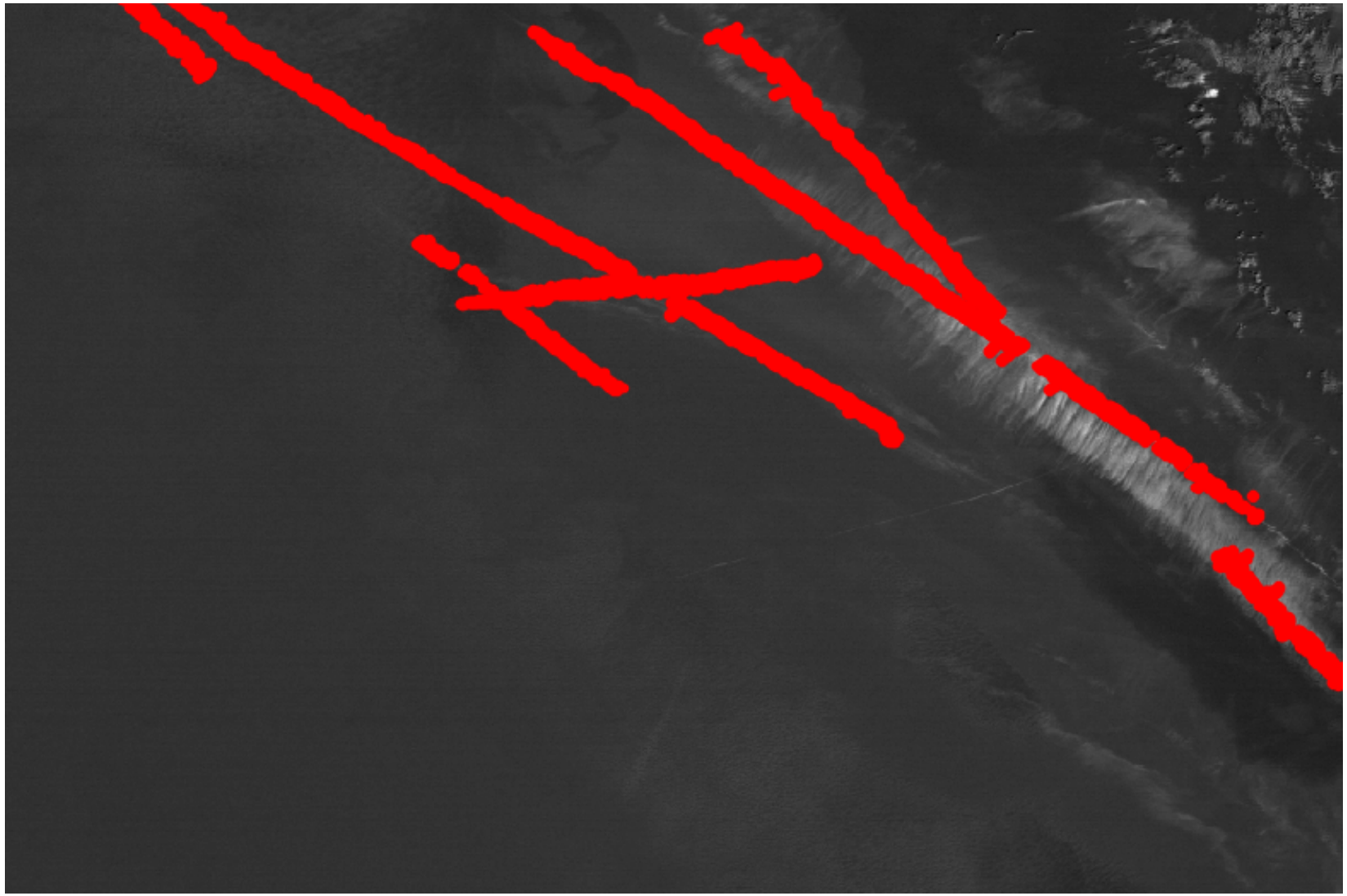
6. Determine edges associated with each detected line



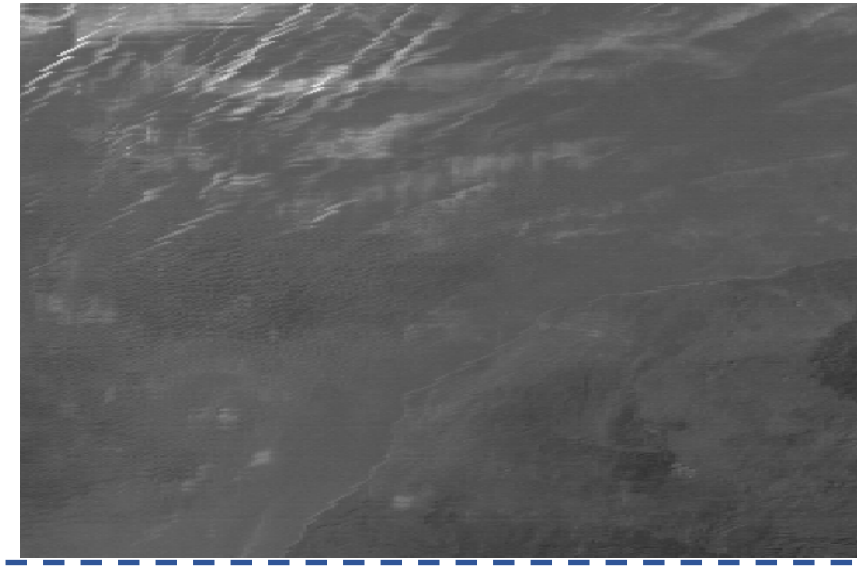
7. Obtain skeletons of contrails

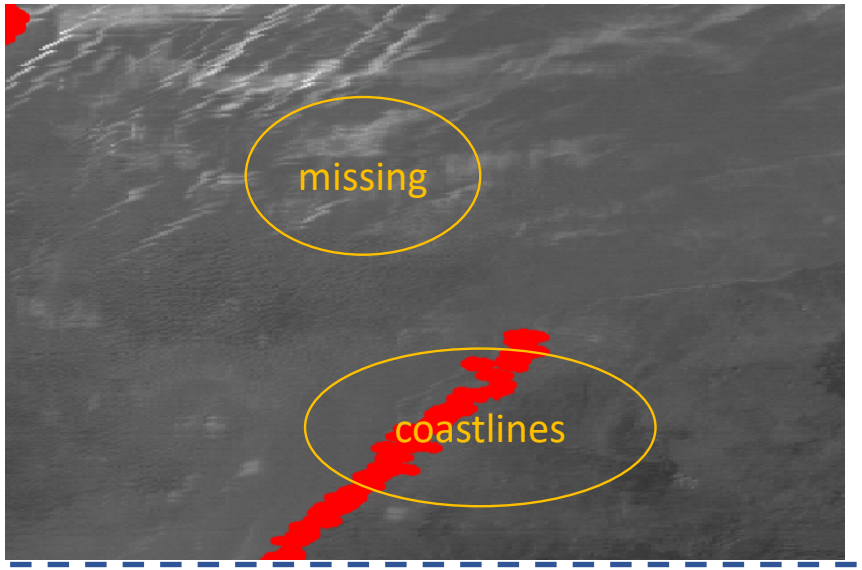


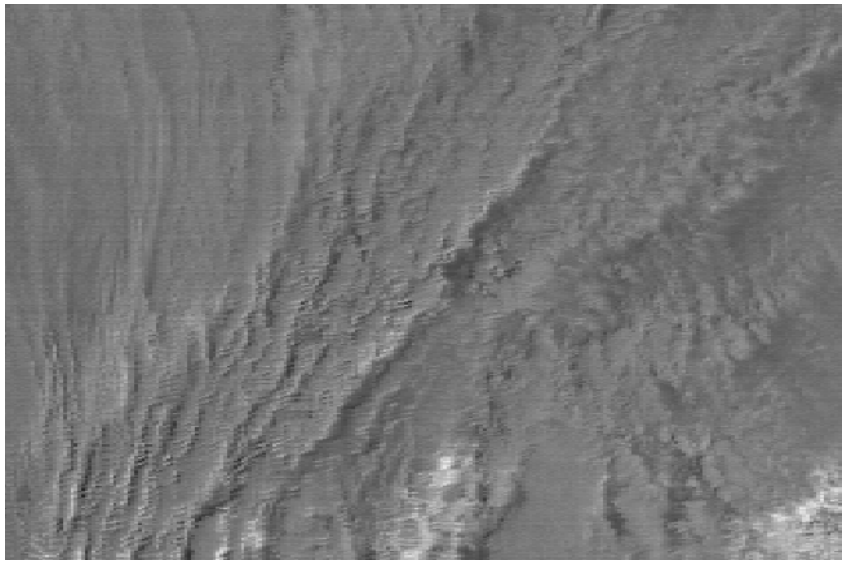
8. Obtain contrail pixels around the skeletons

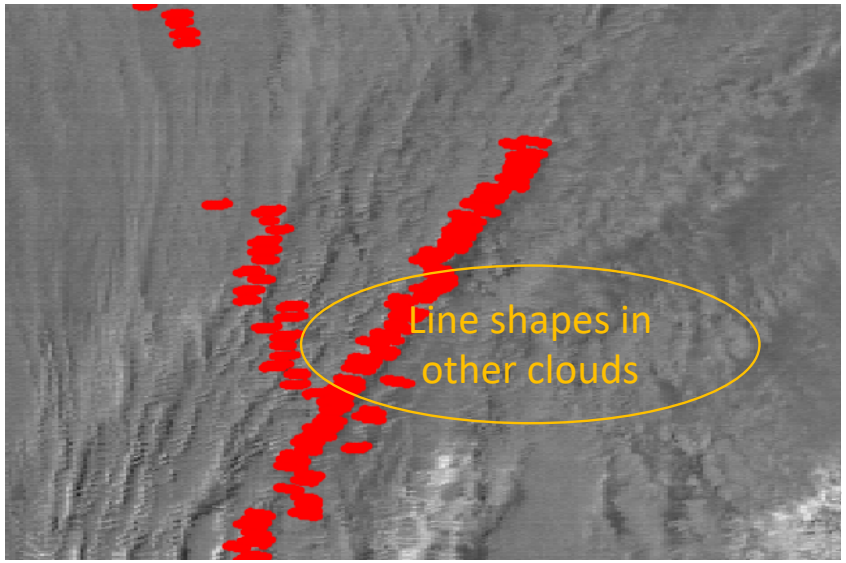


Problems





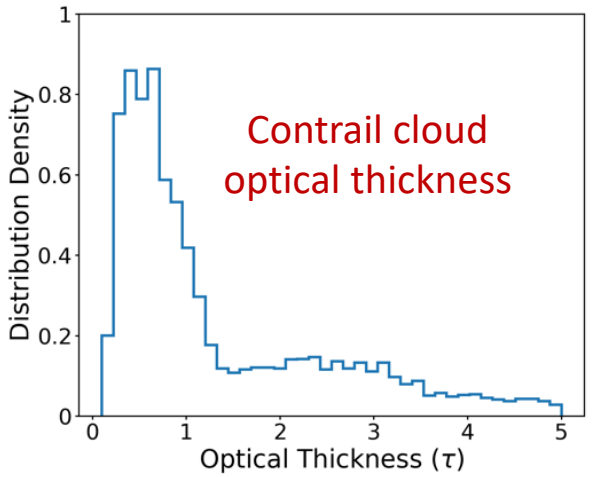


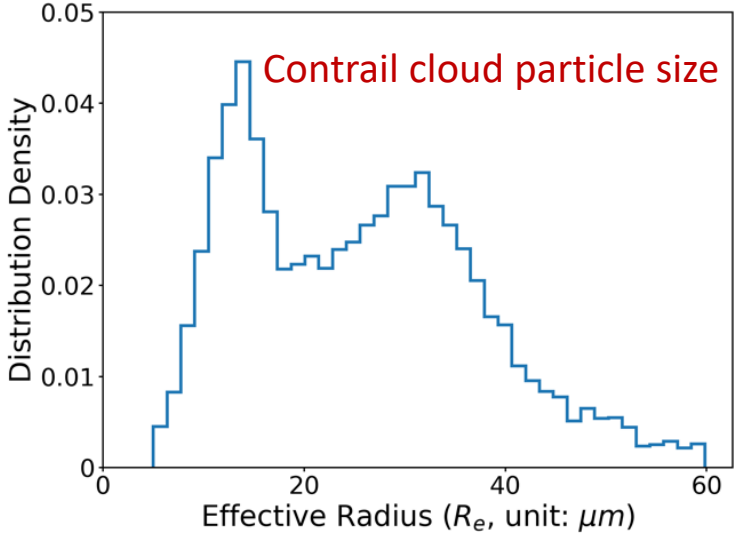


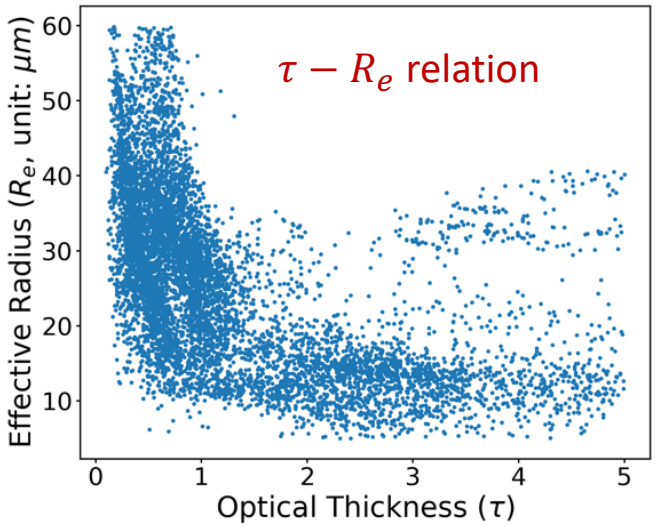
Possible solutions

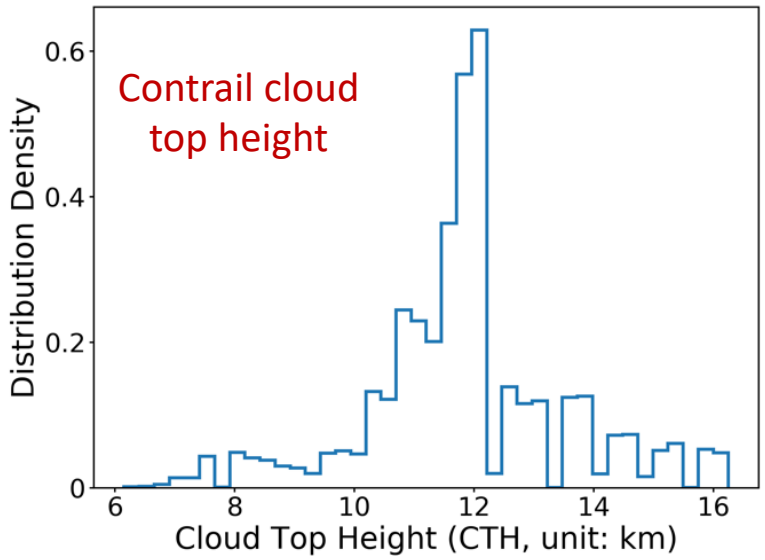
- Using multi-band signal to improve signal-to-noise ratio of BTD image;
- Using coastline information and flight traffic information to filter contrail detection results;
- Using CNN to determine contrail pixels based on detected contrail skeleton;
- …

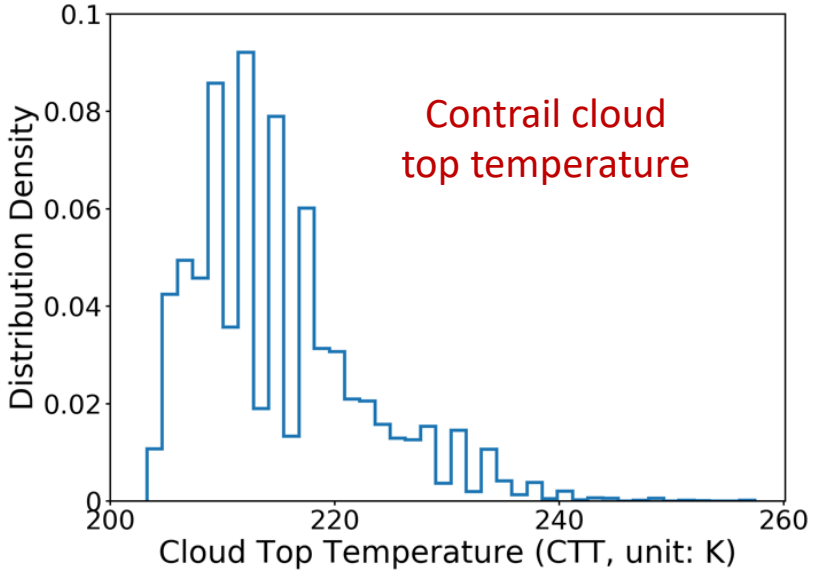
Contrail properties from **detection results** and **MODIS cloud retrieval products**



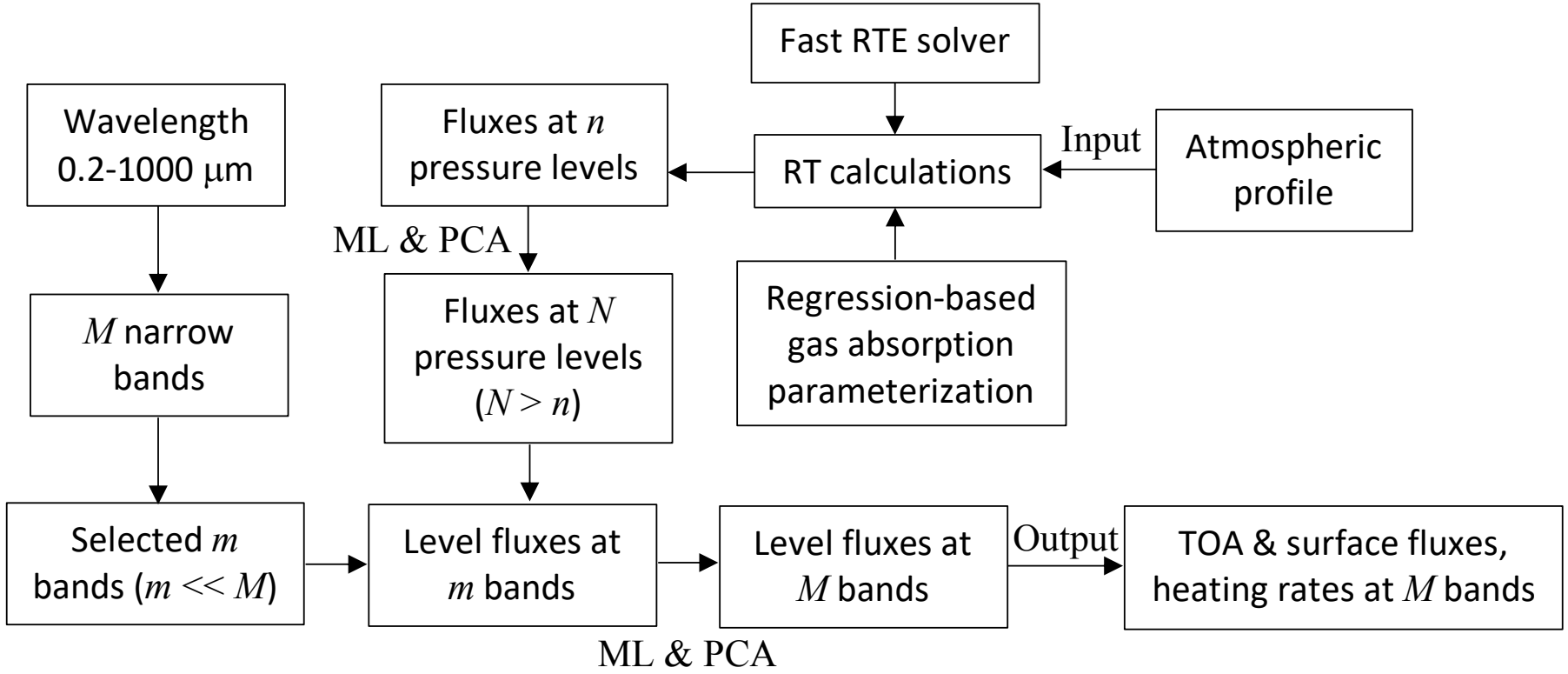








A machine learning-based fast radiative transfer model to simulate contrail radiative effect



Mapping from m bands to M bands ($m>>M$)

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

Linear mapping using principal component analysis

Nonlinear mapping using neural network

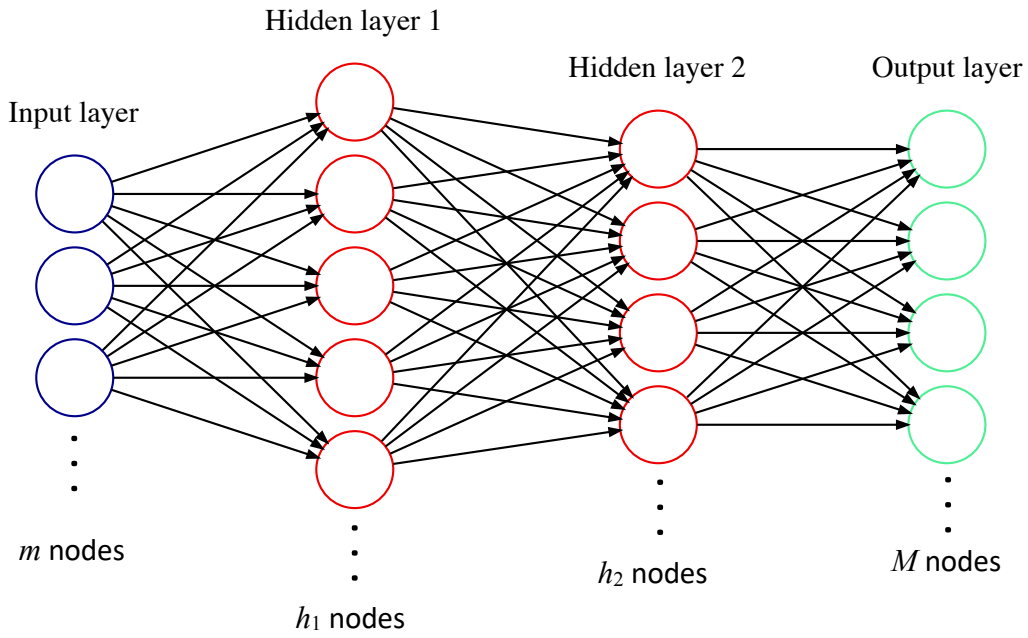
$$F_{M\times K} = P_{M\times M} C_{M\times K}$$

$$F_{M\times K} = P_{M\times s} C_{s\times K}$$

$$F_{m\times K} = P_{m\times s} C_{s\times K}$$

$$F_{M\times K} = G_{M\times m} F_{m\times K},$$

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



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.