A MODIS-based Contrail Climatology of Coverage and Cloud Properties

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OBJECTIVE & APPROACH

Develop Northern Hemisphere contrail climatology to

- Provide consistent empirical estimate of contrail radiative forcing & properties for model improvement & validation

by

- Refining contrail detection & retrieval algorithms
- Retrieving NH contrail & cloud properties from Terra & Aqua MODIS data
- Developing improved radiative forcing estimation methods

- Make results available to modelers in accessible formats

Modified Mannstein et al. CDA

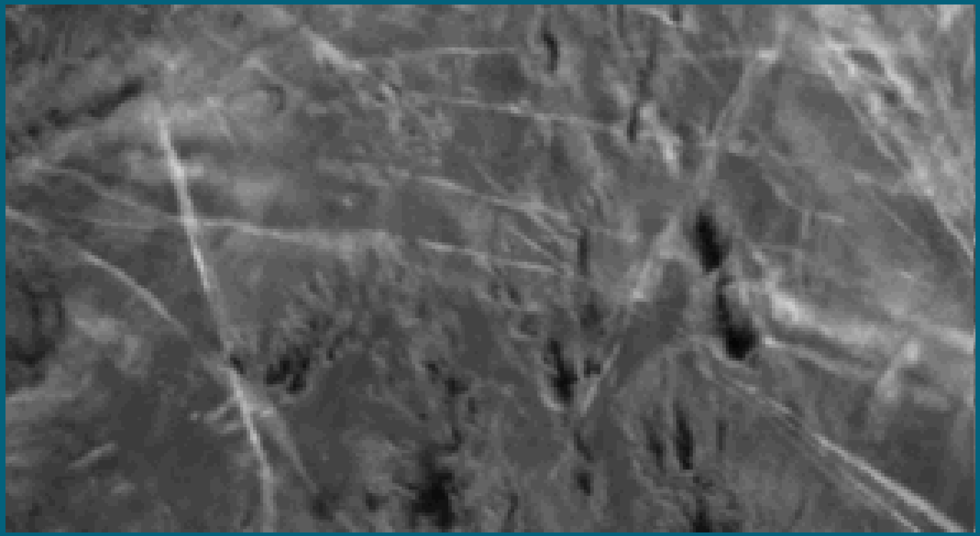
- Mannstein et al. (1999) developed automated 2-channel contrail detection algorithm (CDA) to detect linear contrails in AVHRR IR imagery

- Contrails appear as bright lines in 11 minus 12 µm brightness temperature difference (BTD) images

- Requires only brightness temperatures, T_{11} & T_{12}; no ancillary information

Cloud Detection Algorithm (CDA)

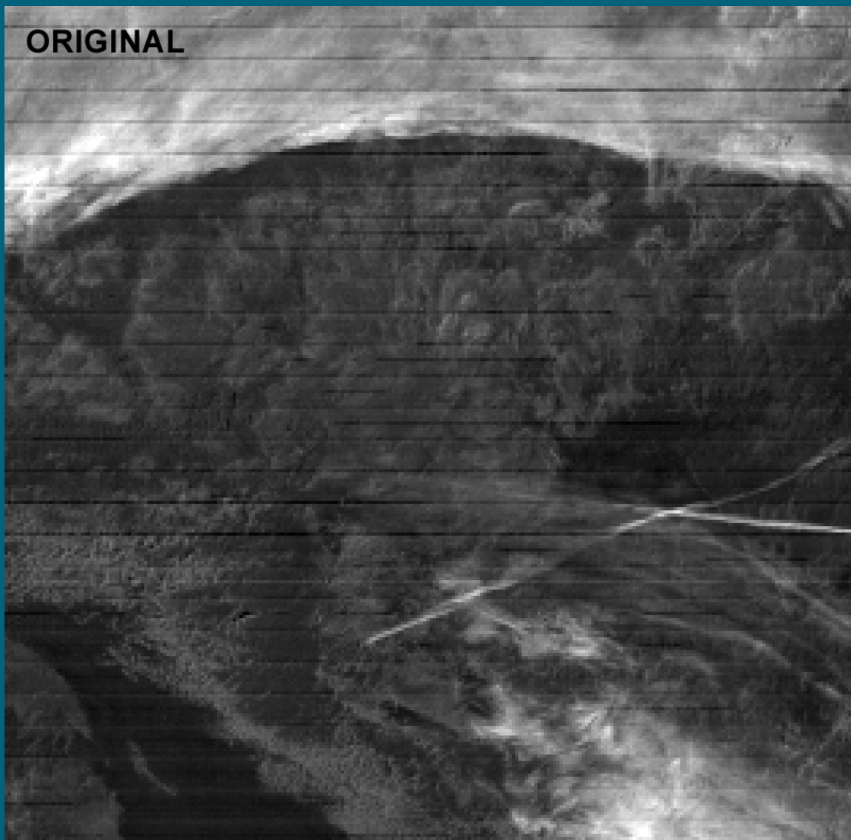
- To reduce false detections, additional IR channels (6.7, 8.6, 13.3 μm) available on MODIS are added



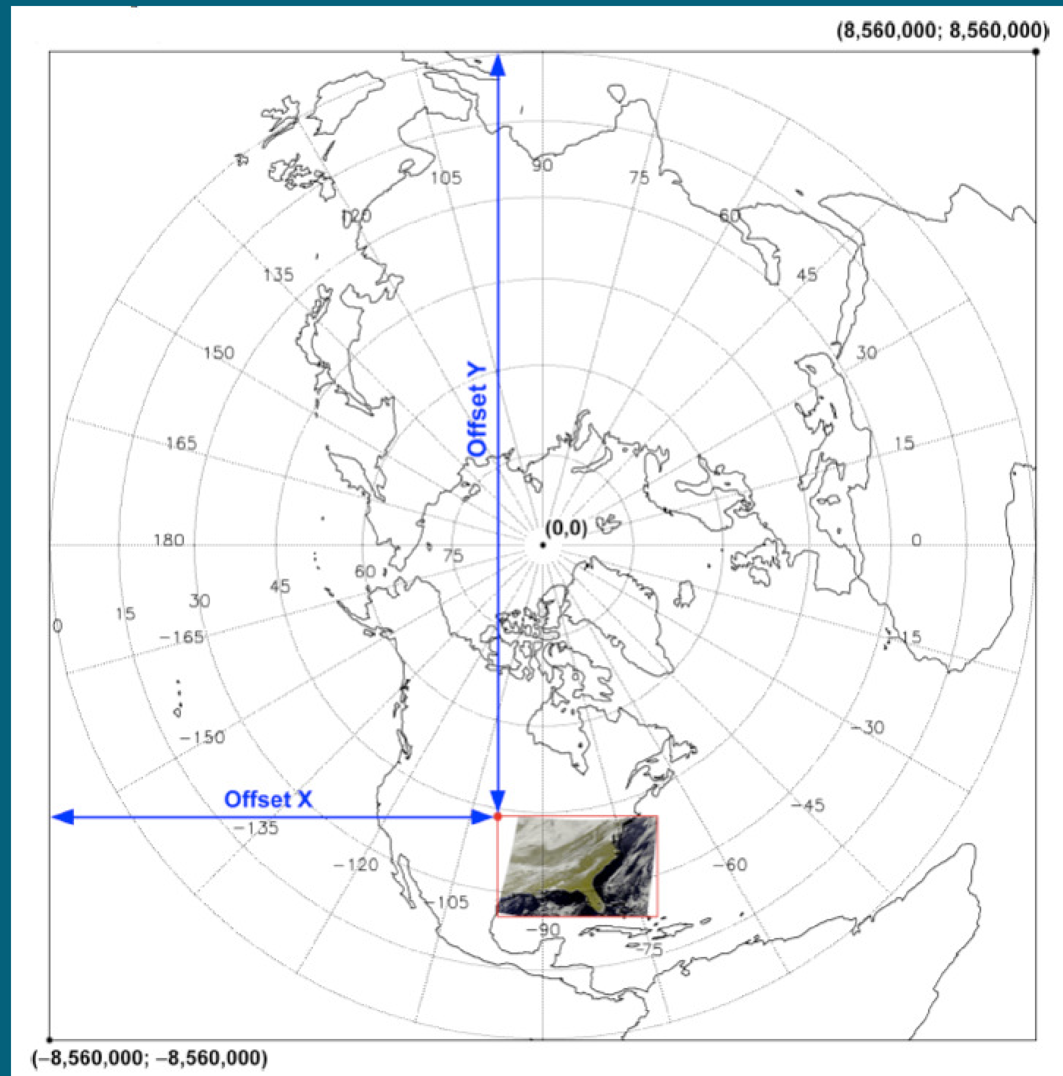
- Additional channels sometimes allow better discrimination of contrails than $BTD_{11\text{-}12}$

$BTD_{11\text{-}12}$ $BTD_{11\text{-}12} + BTD_{8.6\text{-}12} + BTD_{8.6\text{-}13.3}$

Quality Control of MODIS imagery



DESTRIPING by combination of interpolation and FFT filtering suppresses striping noise but preserves contrails.



REMAPPING of imagery reduces effects of image distortion at large viewing angles.

Contrail Detection Algorithm (CDA) Development

- MODIS spectral data used to enhance Mannstein CDA
    - Six sensitivity levels developed to reduce large false alarm rate (FAR)

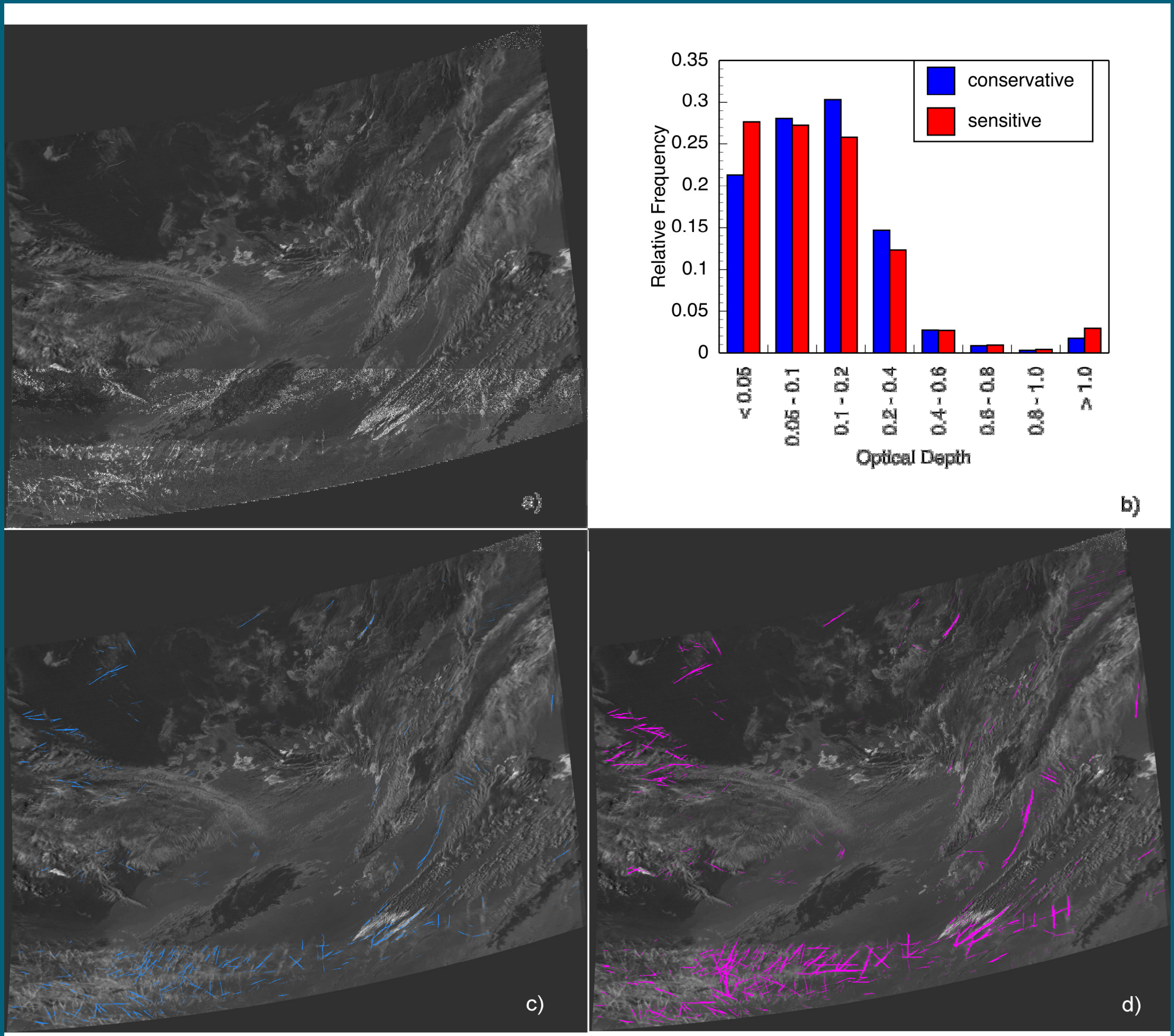
Contrail detection & retrieval for MODIS image, eastern USA, 1530 UTC, 1 Jan 2006

(a) BTD11-12 image

(b) PDF of retrieved contrail optical depths (COD)

(c) conservative CDA

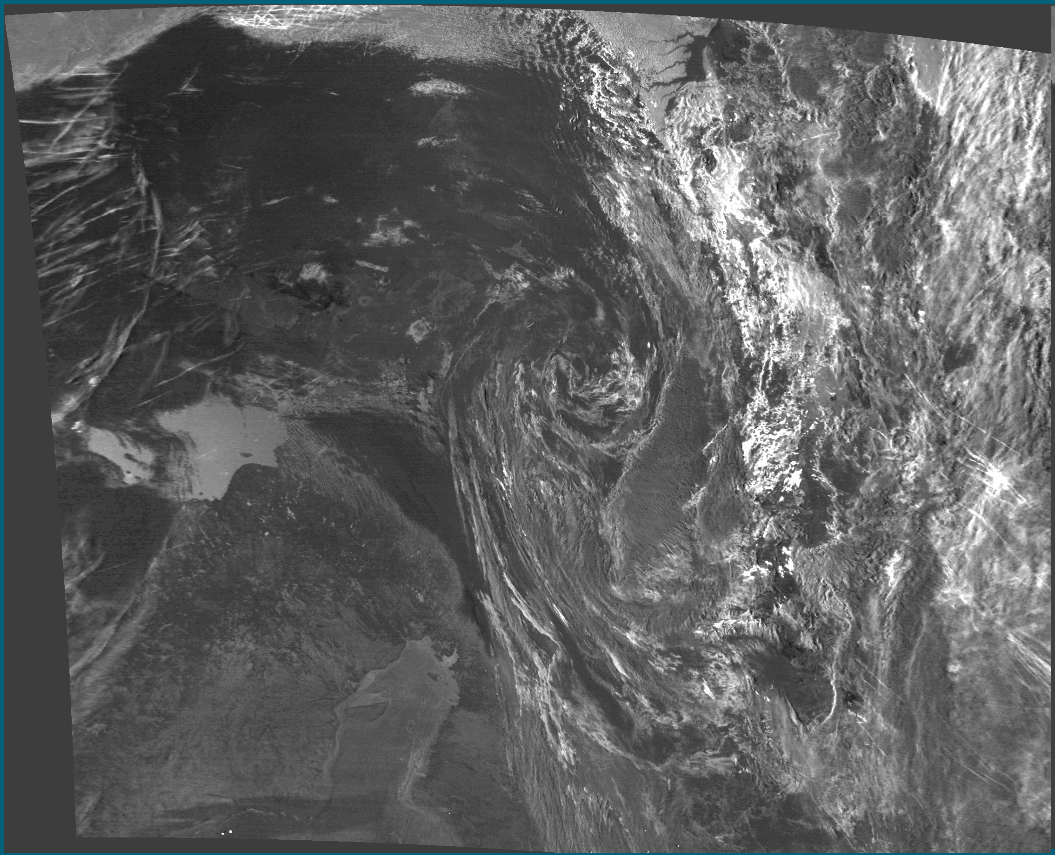
(d) sensitive CDA, detects more & wider contrails, COD range increase



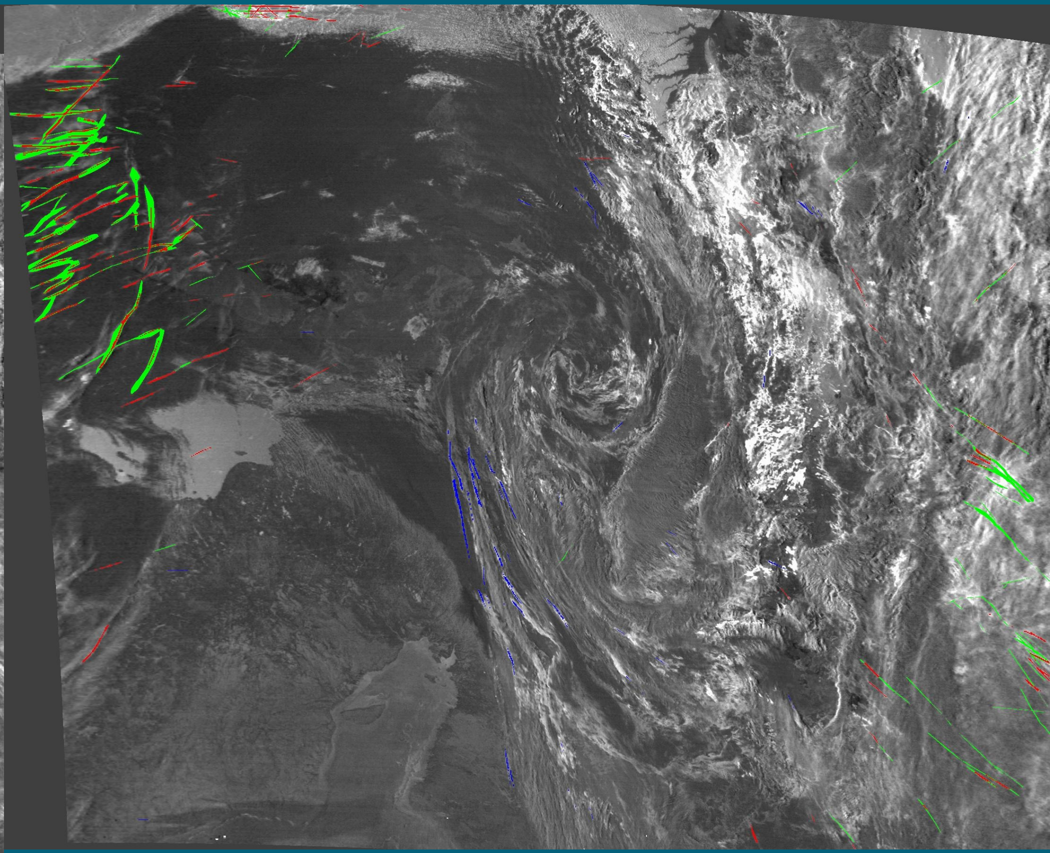
CDA Error Analysis Using of Bio-optical Method

Contrails and flight tracks from Terra MODIS over United States
1605 UTC, 1 April 2006

BTD 11- 12 µm



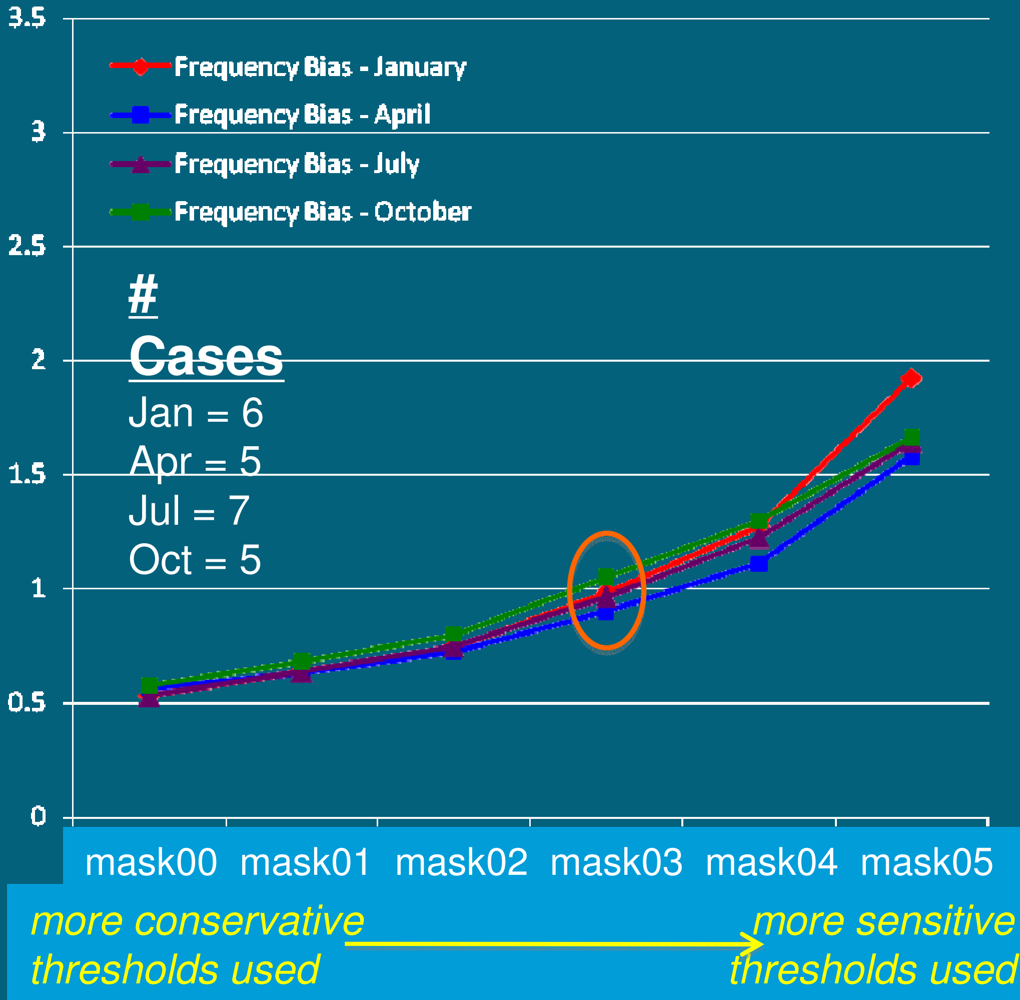
Composite mask



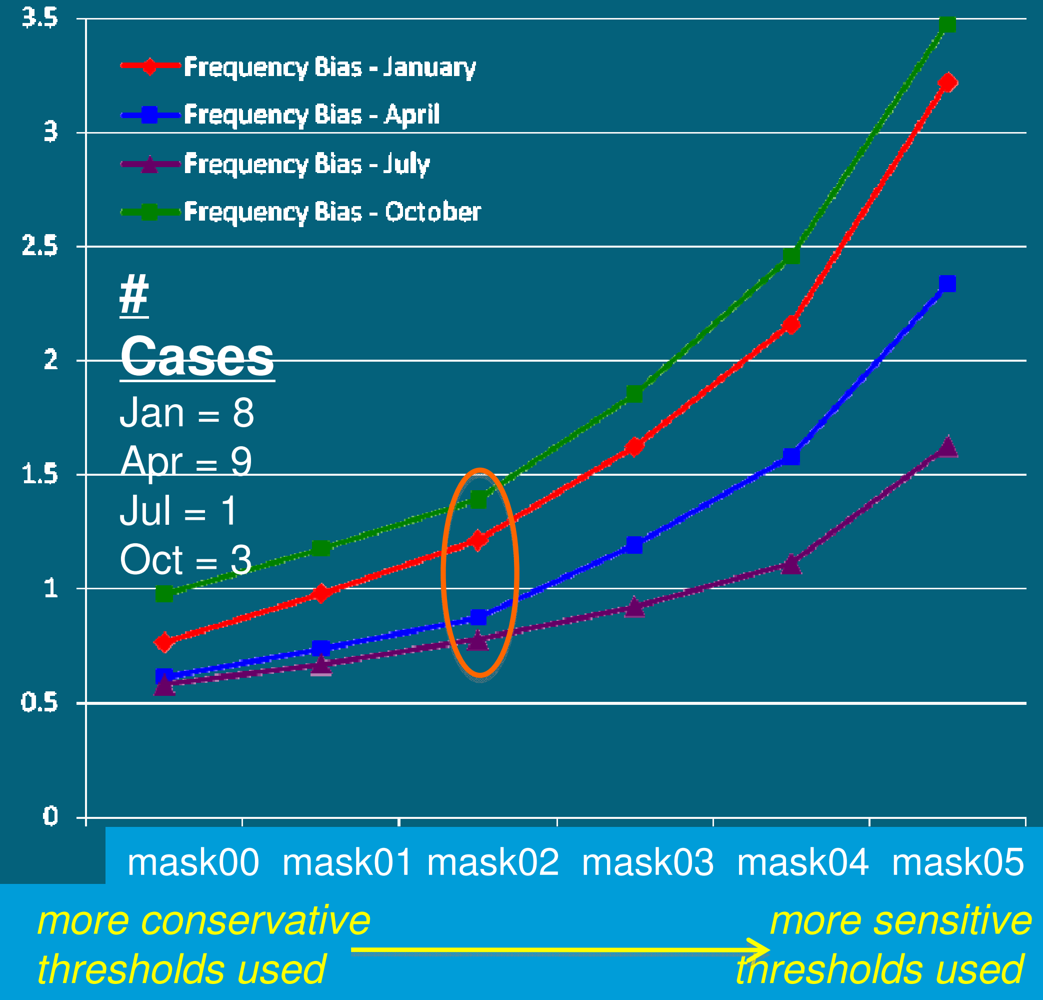
- CDA contrails overlaid BTD image in red
- contrails added by analyst in green
- contrails deleted by analyst in blue

Frequency Bias

Daytime Observations Only

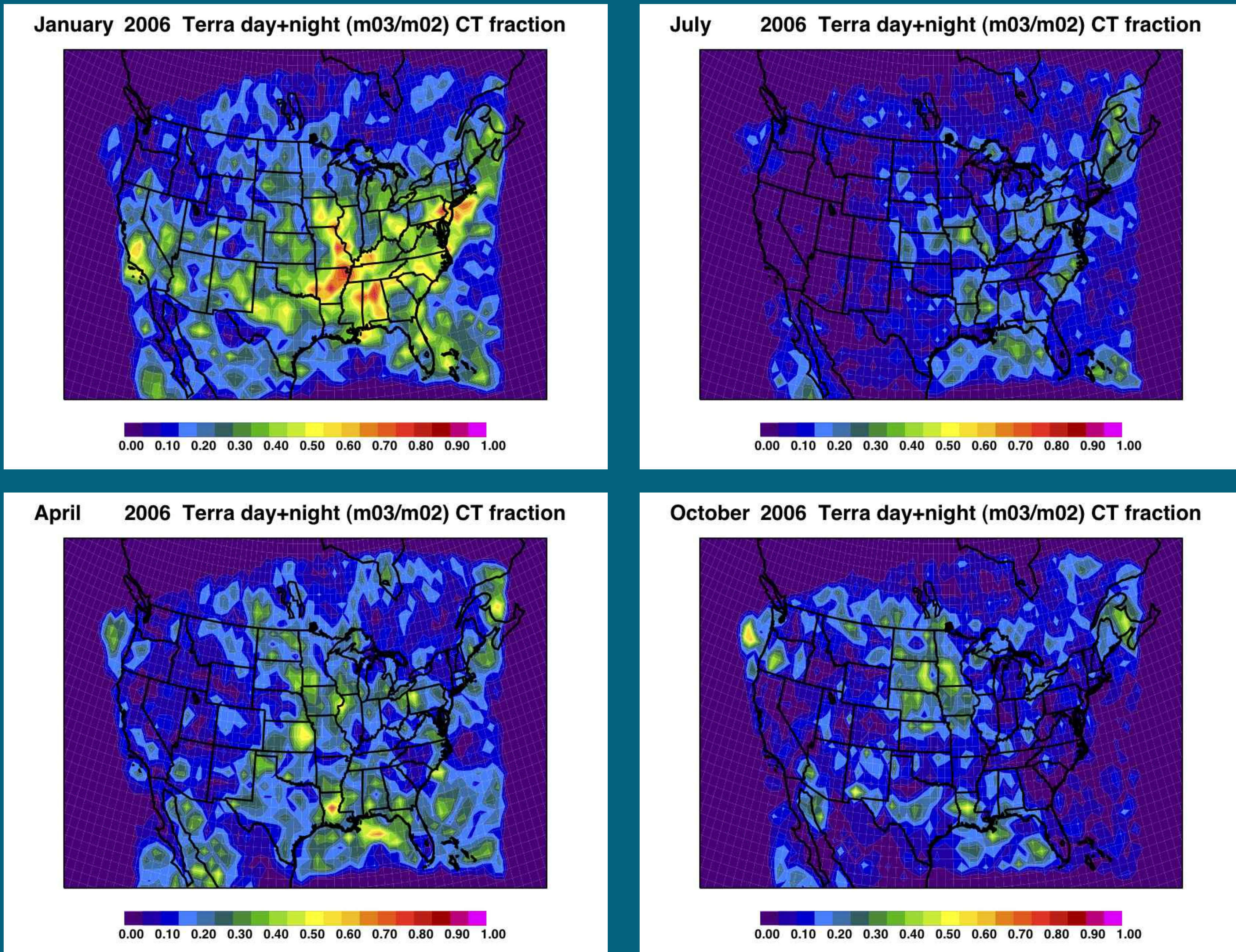


Nighttime Observations Only



A frequency bias of 1 indicates that the mask neither overestimates nor underestimates the number of contrails.

CONUS – CT fraction (in percent)

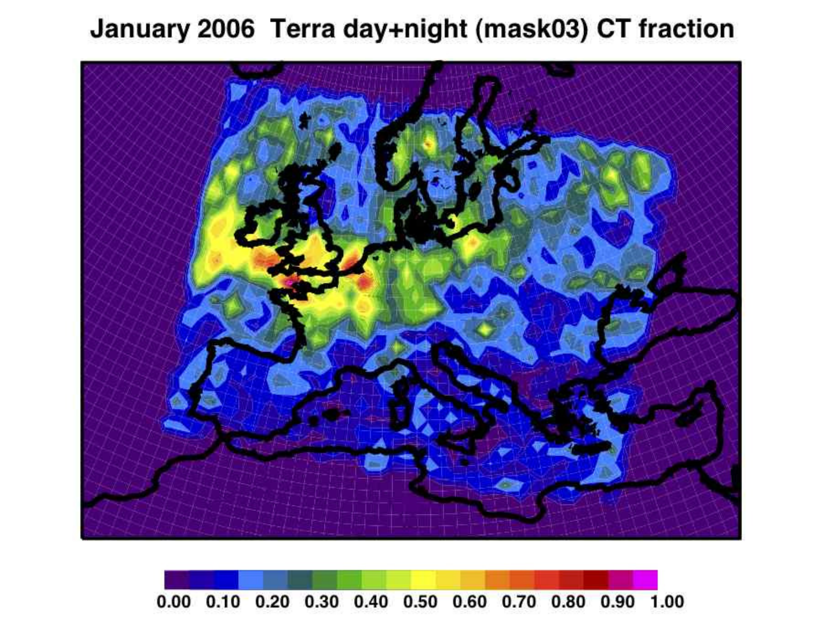


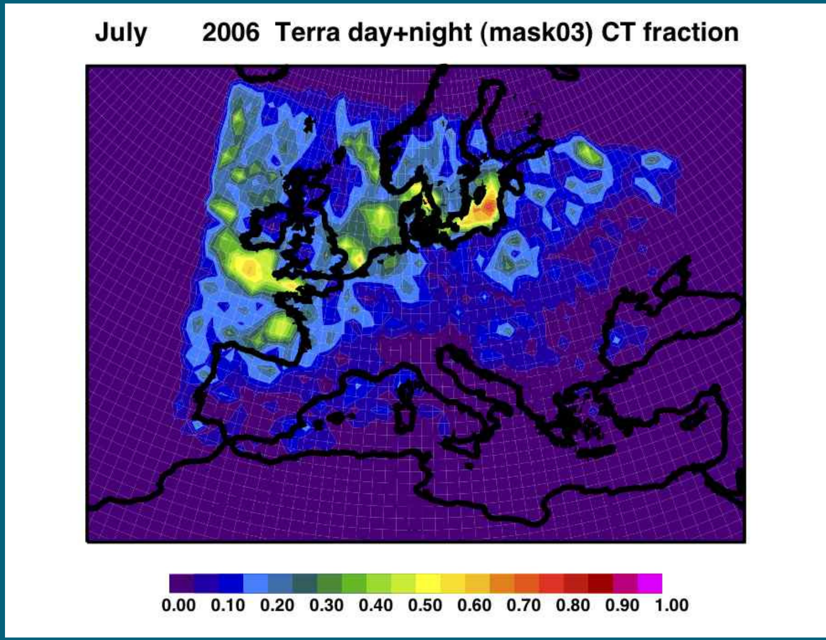
- JAJO (Jan, Apr, Jul, Oct) mean contrail fraction:

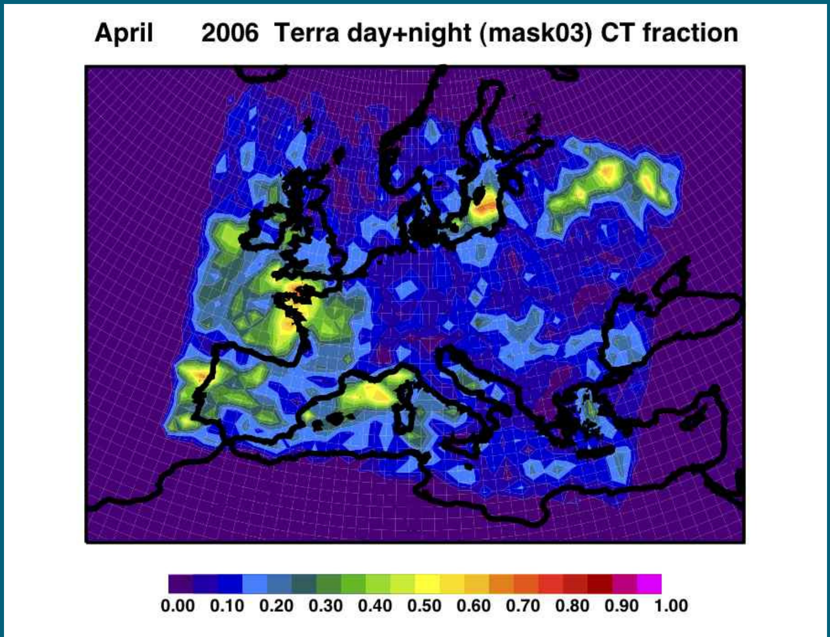
0.15 %

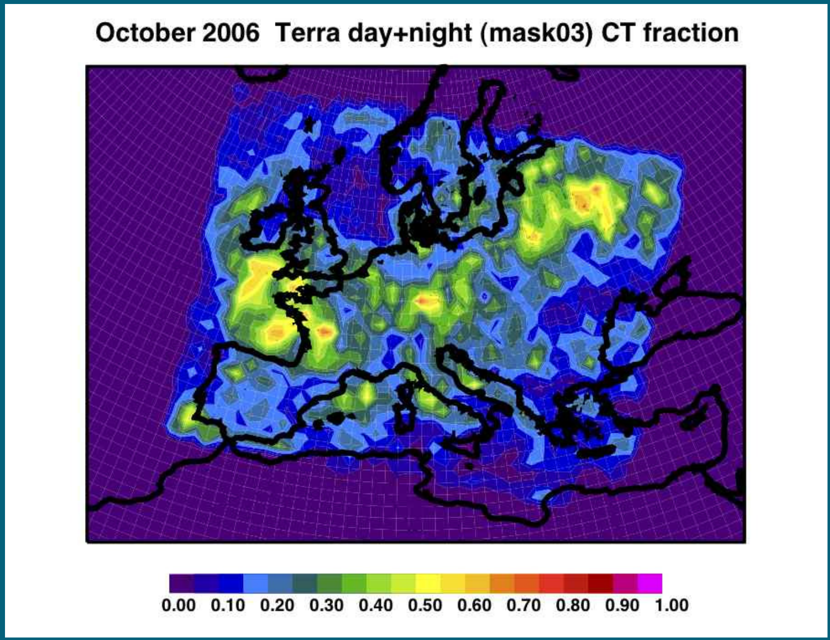
(≈2X smaller than 2001 AVHRR study)

Europe – CT fraction (in percent)









- JAJO (Jan, Apr, Jul, Oct) mean contrail fraction:

0.17 %

Central Europe

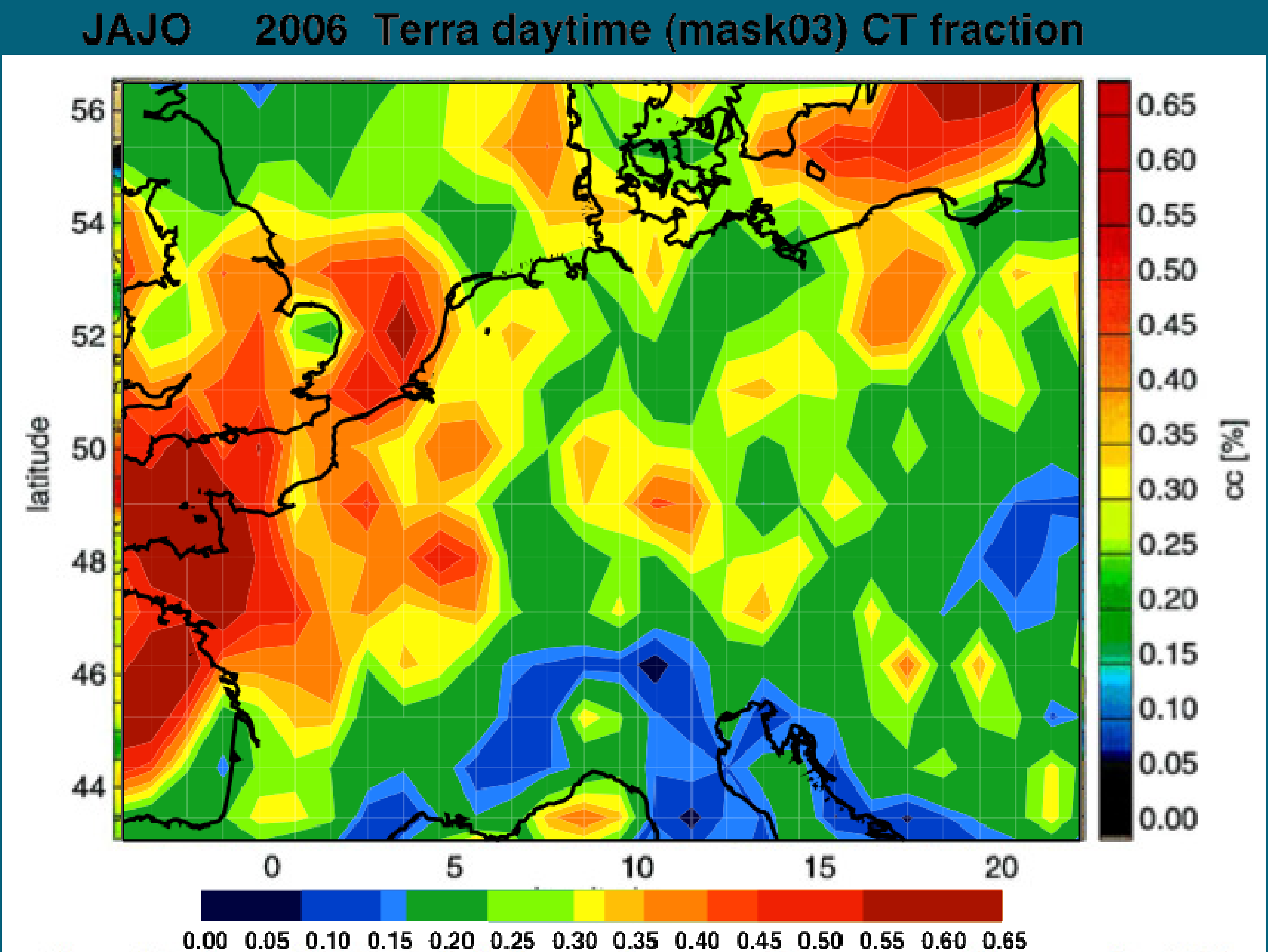


Figure 14. Annual AVHRR-derived contrail coverage (cc, uncorrected) at noon for 1996.

Mannstein et al. (1999)

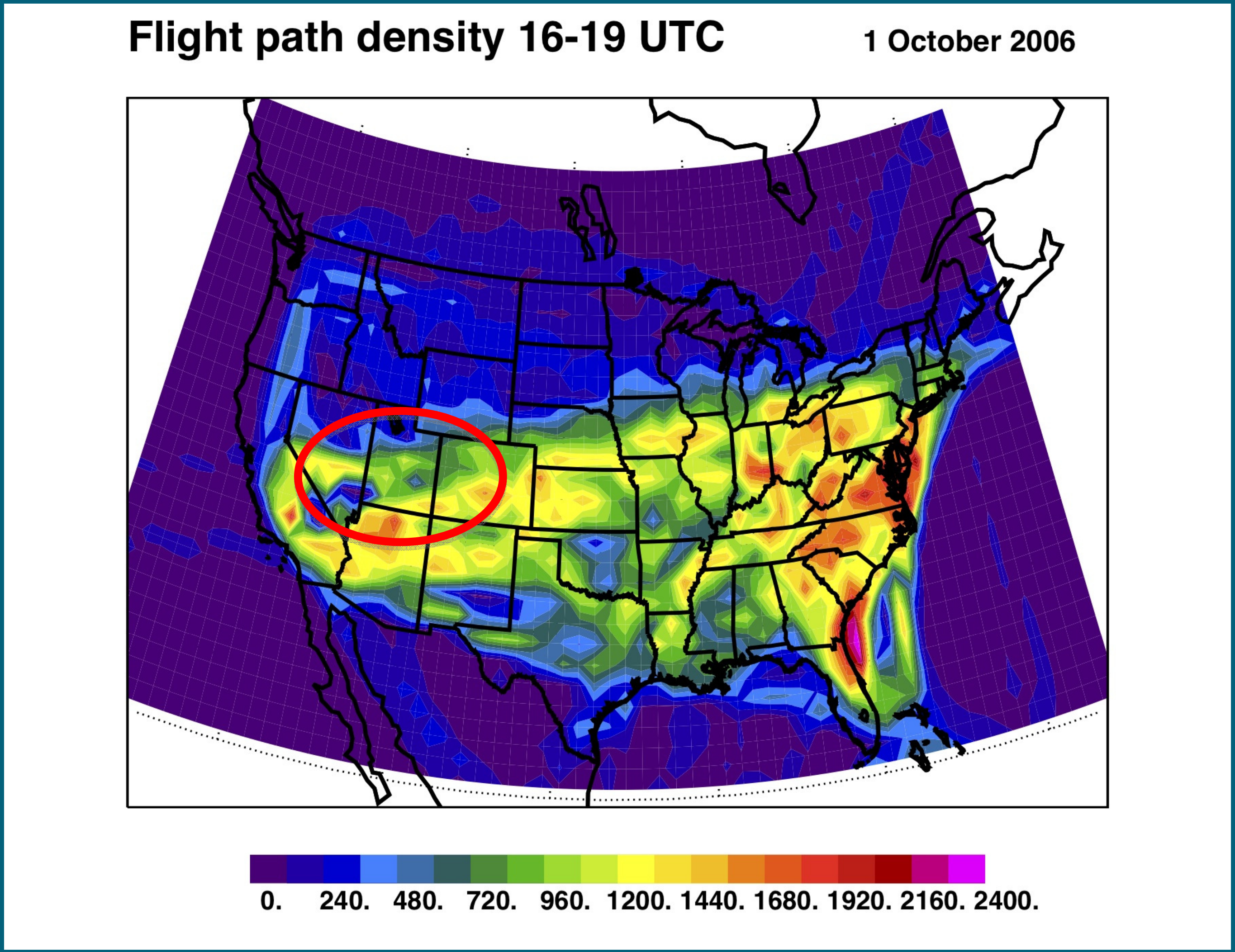
≈ 0.23 %

(1200 LT Annual 1996)

This study 0.23 %

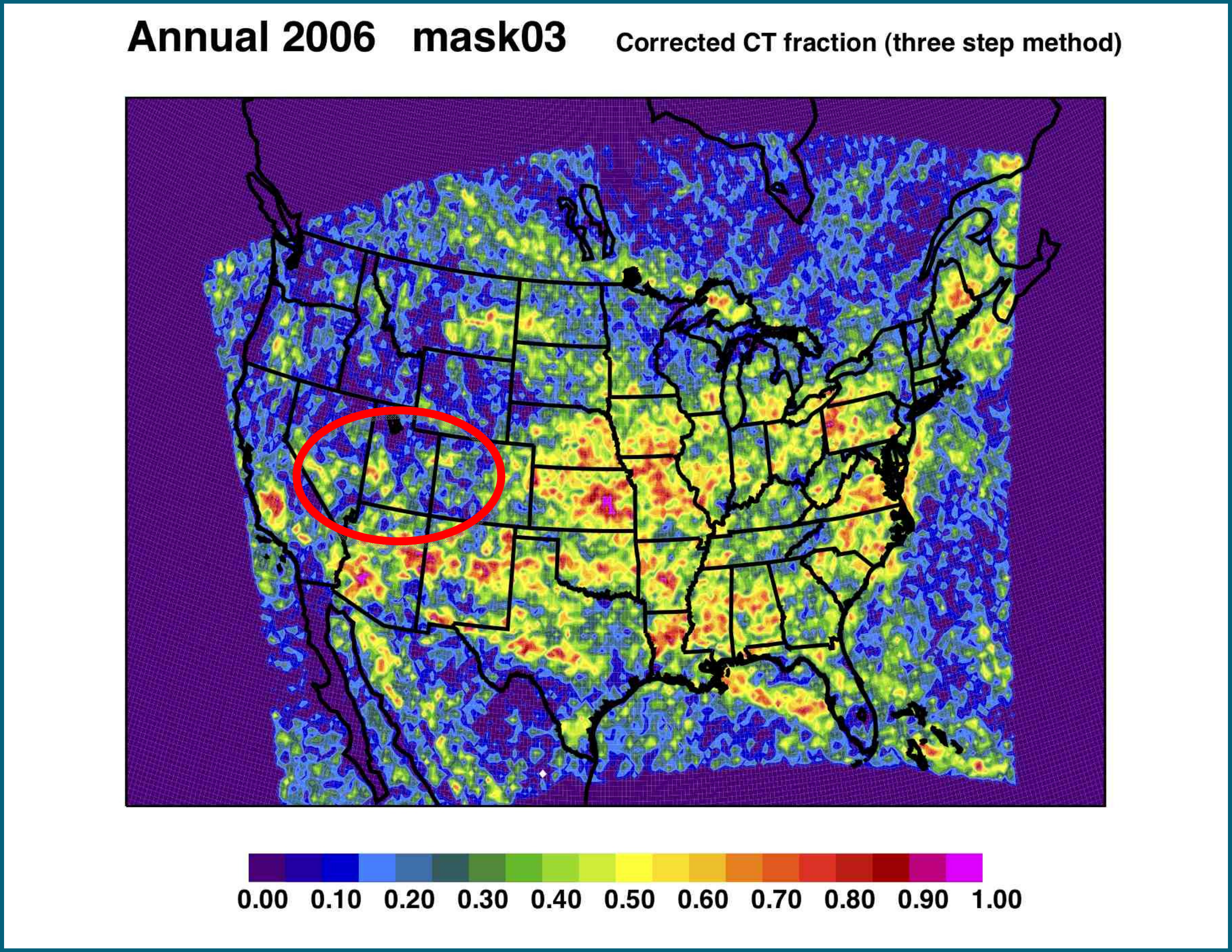
(1030 LT JAJO 2006)

Contrail coverage maps show low amounts of detected contrail coverage over parts of western US…



…when compared to air traffic density over CONUS

Compare uncorrected and corrected coverage



Uncorrected contrail amount (percent)

Contrail amount w/ one-step correction (percent)

Contrail amount w/ three-step correction (percent)

Contrail Cloud Property Calculations

- Direct method

  - Using contrail temperature, T_{con} (assumed or estimated); background temperature, T_b; observed 11-µm temperature T; and effective particle size (Re); compute emissivity ε

$$\varepsilon = \frac{\{B(T) - B(T_b)\}}{\{B(T_{con}) - B(T_b)\}}$$

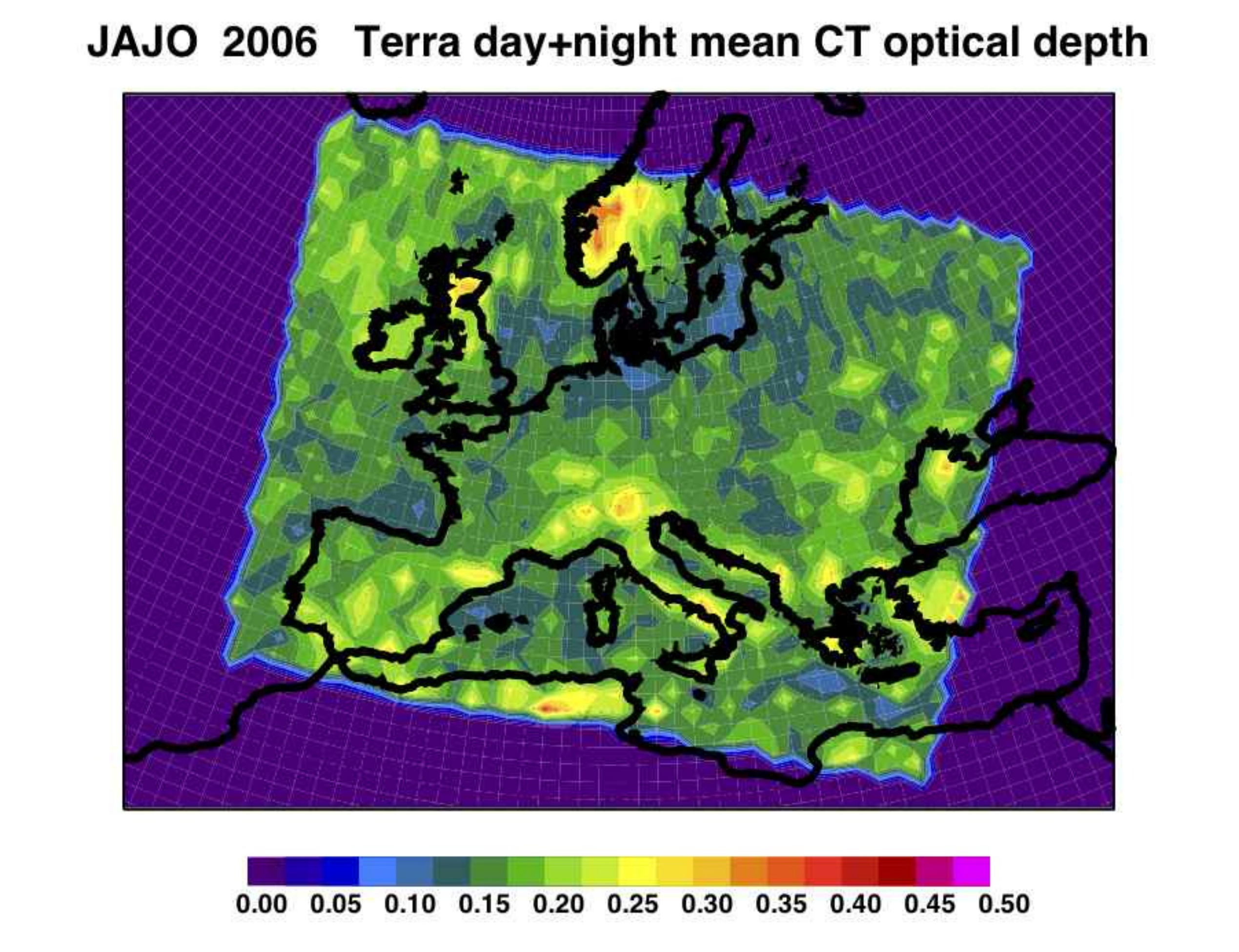
  & optical depth: $\varepsilon = 1 - \exp[\,-0.458\,(COD\,/\,\mu)^{1.033}]$

  - Estimate LW/SW RF from narrow-broadband functions, LW(T) & SW(R_v)

    - M_{LW} = LW(T) => LW CRF = LW(T) – LW(T_b)

    - M_{SW} = SW(R_v/BRDF) => SW CRF = SW(R_{vcon}) – LW(R_{vb})

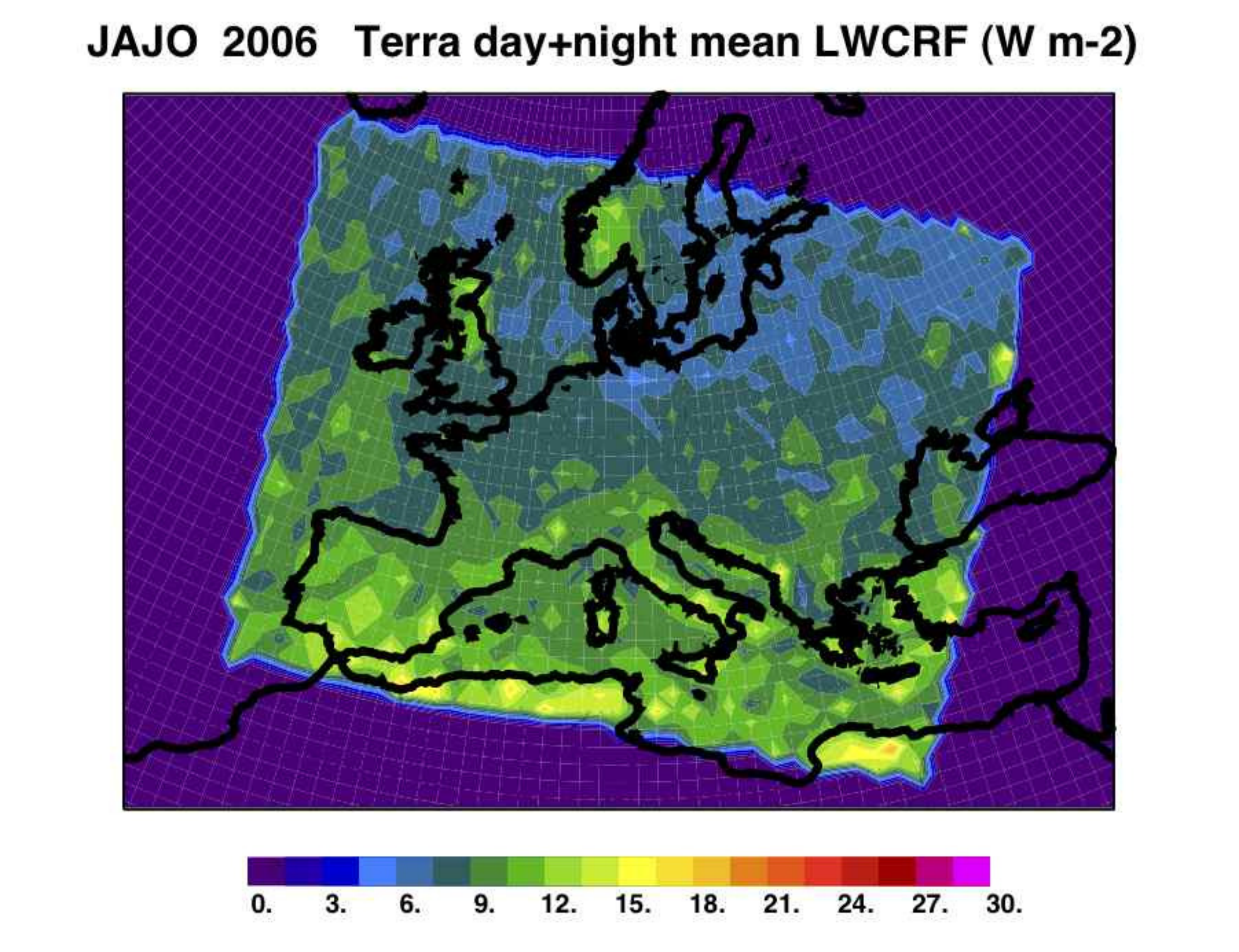
Visible Optical Depth



CONUS (JAJO mean): 0.200

Europe (JAJO mean): 0.176

LWCRF

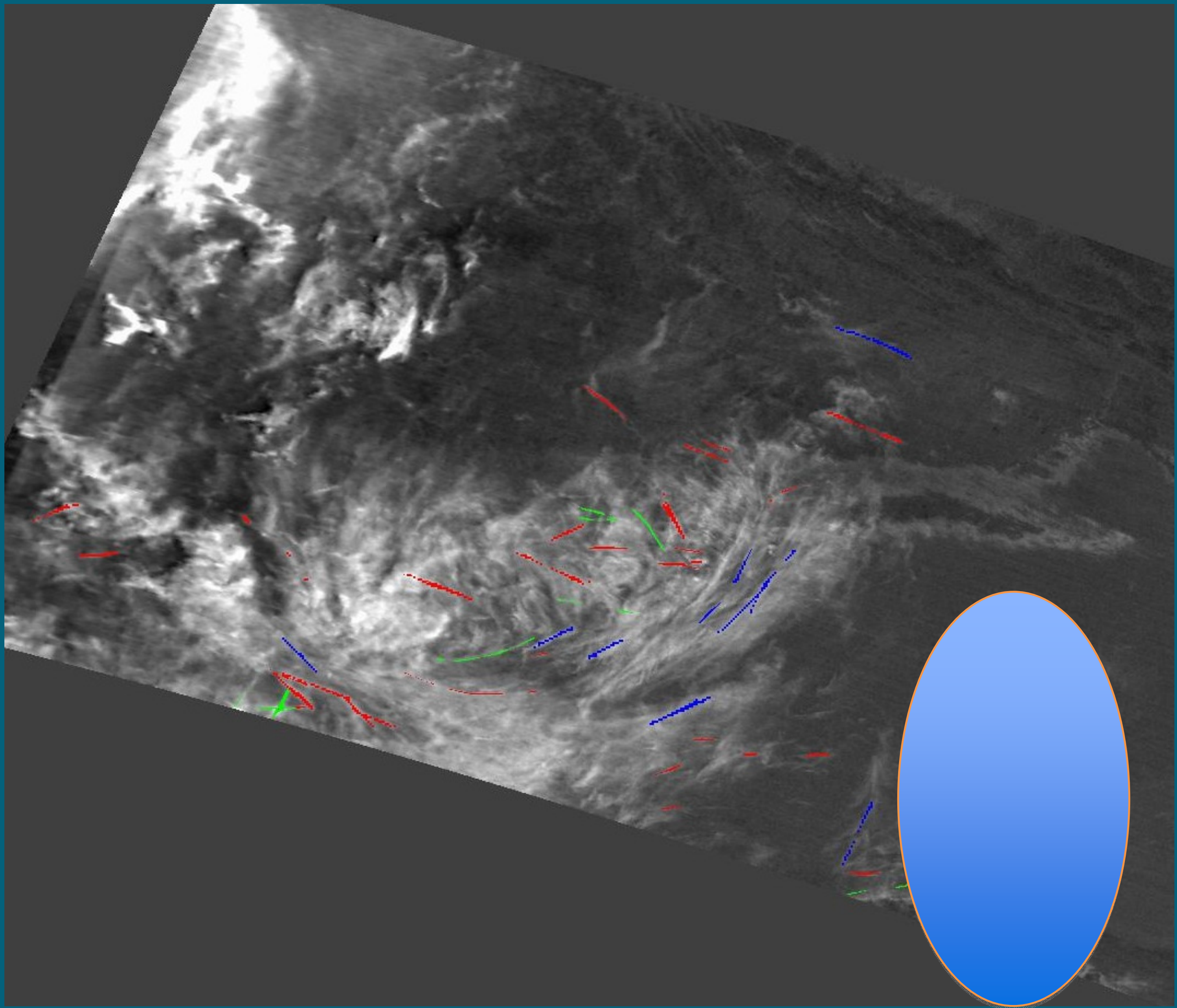


CONUS (JAJO mean): 11.2 W m^{-2}

Europe (JAJO mean): 9.0 W m^{-2}

Spreading Contrails: A Challenge for the CDA

Composite contrail analysis over eastern United States, 0312 UTC, 2 April 2006



- CDA contrails overlaid BTD image in red

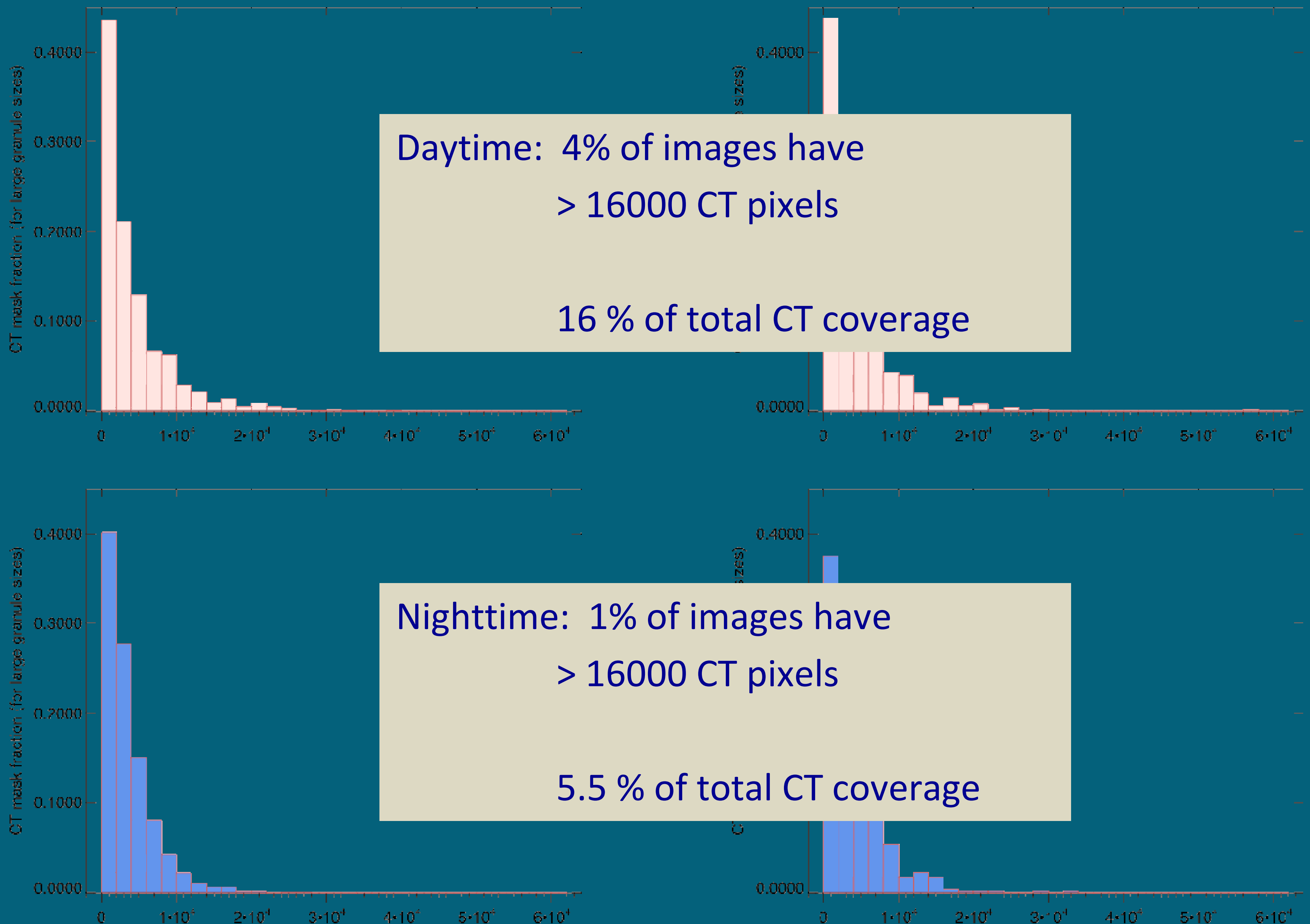
-contrails added by analyst in green

- contrails deleted by analyst in blue

Large area of spreading, overlapped contrails missed in the analysis, typical?

CT mask distribution

AQUA | TERRA



Daytime: 4% of images have
> 16000 CT pixels

16 % of total CT coverage

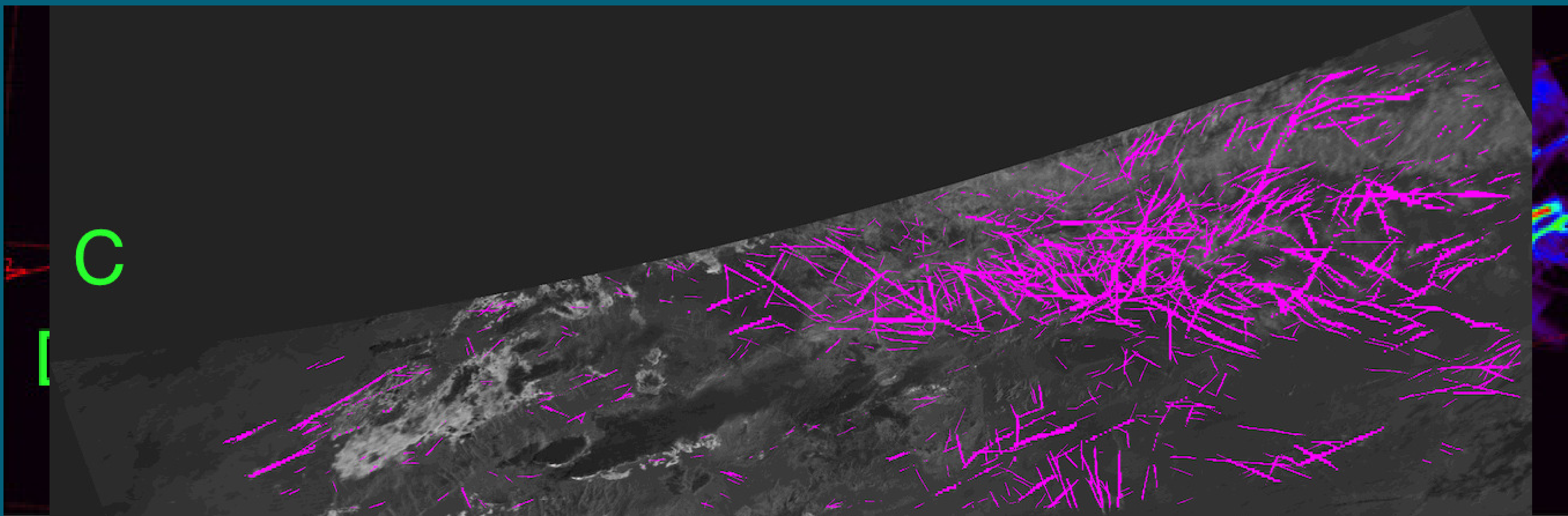
Daytime

Nighttime: 1% of images have
> 16000 CT pixels

5.5 % of total CT coverage

Nighttime

CoCIP/CDA comparison



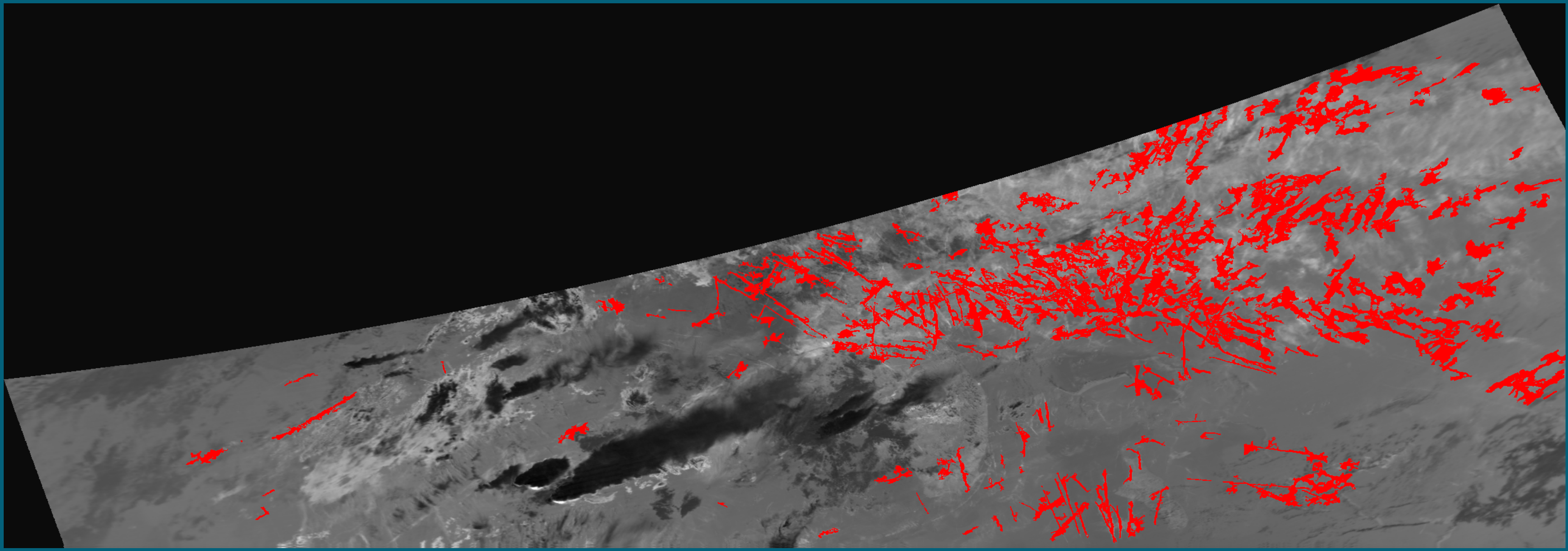
current CDA

DLR contrail model result

more sensitive CDA

even more sensitive CDA

Widening contrails



add to detected contrail pixels by comparing radiative signature of neighboring pixels

1 iteration

20 iterations

Summary

- CONUS versus Europe
  - both regions have similar amounts of coverage
  - LWCRF/optical depth slightly larger (24%/13%) over CONUS
- How to deal with missed spreading contrails?
  - increase sensitivity of CDA in outbreak areas
  - widen detected contrails by comparing neighboring pixels
- Future work (short term)
  - refine methods to widen contrails
  - use flight track data to improve false alarm rate
  - improve retrieval of contrail cloud properties and radiative forcing (RF) estimation methods
    - *Use indirect method (CERES cloud property code) for best estimate*
    - *Determine background clear and cloud properties*
    - *compute CRF using RTM => instantaneous & 24-h net CRF*