

Contrail Coverage and Radiative Forcing Over the USA Derived from Satellite Data

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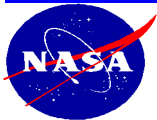
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Atmospheric Effects of Aviation Conference 2000

Snowmass, Colorado, June 2000



CONTRAIL COVERAGE

- Global coverage of persistent contrails is expected to increase with increasing jet air traffic.

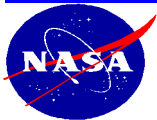
Current: near 0.1% (approximately 4.6×10^5 km²)

- based on limited satellite studies over Europe & N. Atlantic projected with tuned model calculations with current traffic from Sausen et al. (1998)

Future projections (2050): 0.38 to 0.47 %

- based on tuned models with projected flight traffic

Need: Verification and/or improvement of the modeled coverage



Radiative Effects of Contrail-Cirrus

Shortwave (SW) Forcing: $CRF_{sw} = E_0(\delta) [\alpha_{clr} - \alpha_{cld}]$

Longwave (LW) Forcing: $CRF_{lw} = F \uparrow_{clr} - F \uparrow_{cld}$

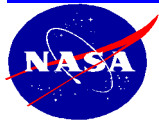
Net Forcing: $CRF_{net} = CRF_{lw} + CRF_{sw}$

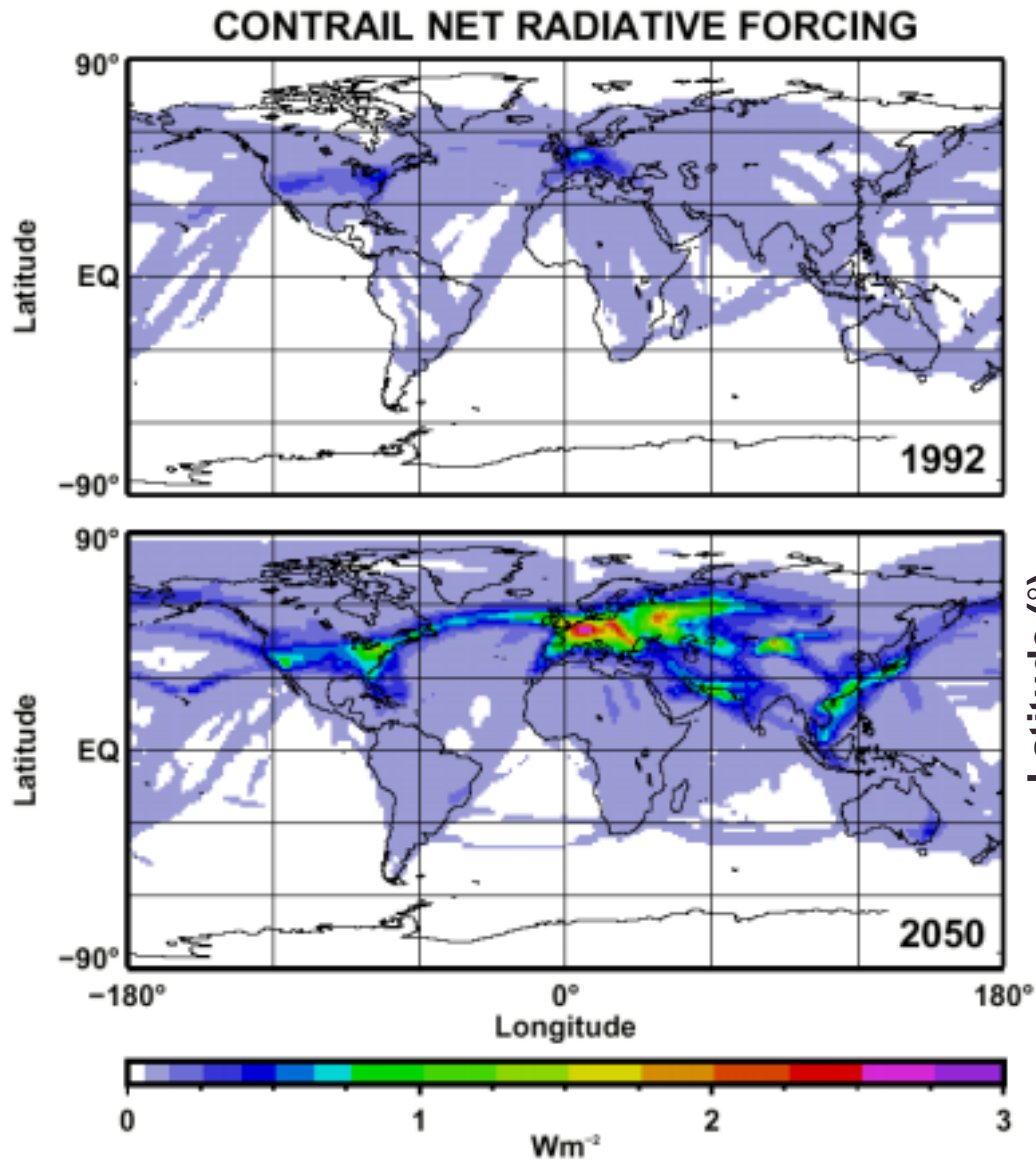
- Best estimate of current annual mean CRF_{net} : **0.02 W m⁻²**

- *calculated using RTM with contrail coverage, assumed diurnal cycle, random overlap with mean cloud cover; $\tau = 0.3$, $D = 24 \mu m$*

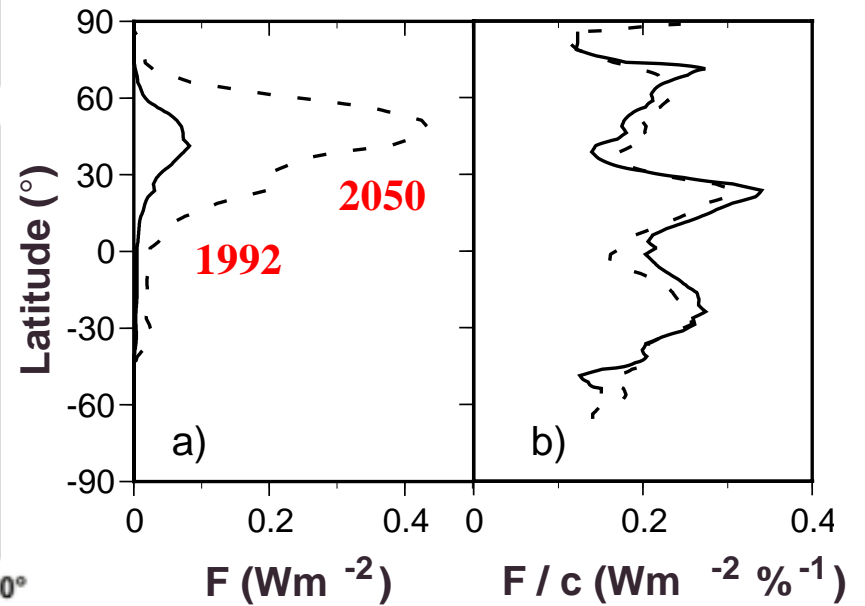
- Future projections (2050): **0.10 W m⁻²**

Need: Verify or improve τ , D , overlap, diurnal cycle (lifetimes), RTM calculations





Current Estimates of contrail radiative forcing



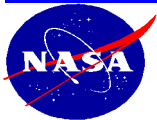
OBJECTIVES

- **CONTRAIL COVERAGE**

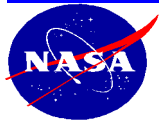
- Derive linear contrail coverage from 1-km AVHRR data
- Estimate lifetimes, growth rates and spreading factors from geostationary imager (4-km) data

- **CONTRAIL RADIATIVE FORCING**

- Estimate CRF directly from imager data
- Estimate particle size, optical depth, IWP for RTM calcs using multispectral satellite data



LINEAR CONTRAIL COVERAGE

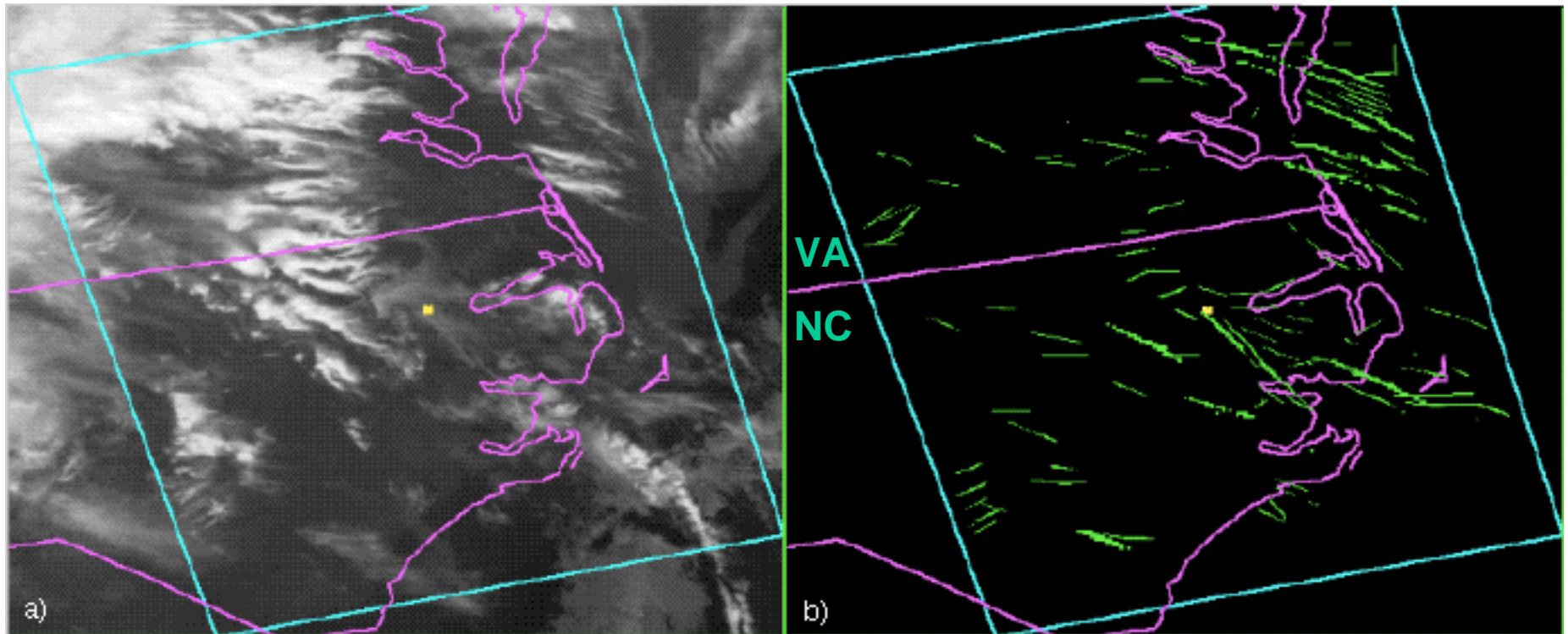


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Contrail-coverage & radiative forcing over the USA

Automated Contrail Detection

NOAA-12 AVHRR, April 1997



10.8- μ m image

detected contrails

methodology from Mannstein et al. 1999

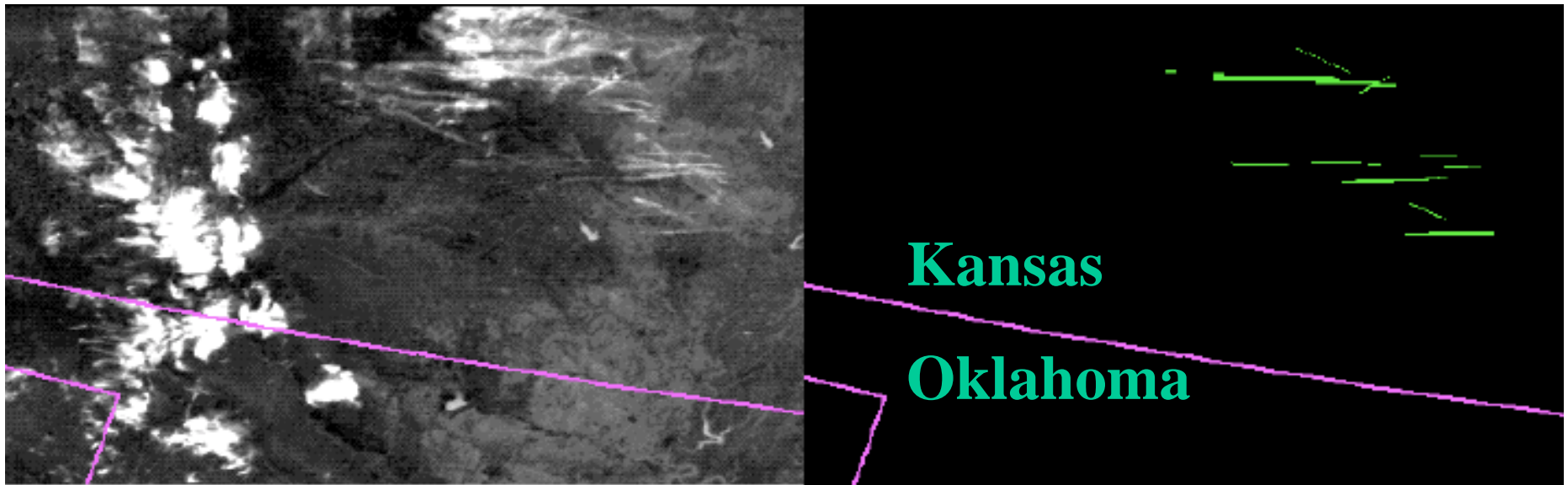


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Contrail-coverage & radiative forcing over the USA

Automated Contrail Detection

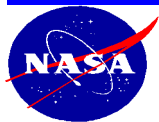
NOAA-14 AVHRR, September 30, 1996



10.8- μm image

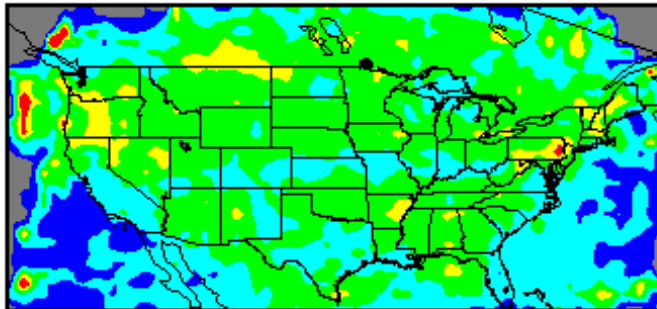
detected contrails

underestimation of contrails!

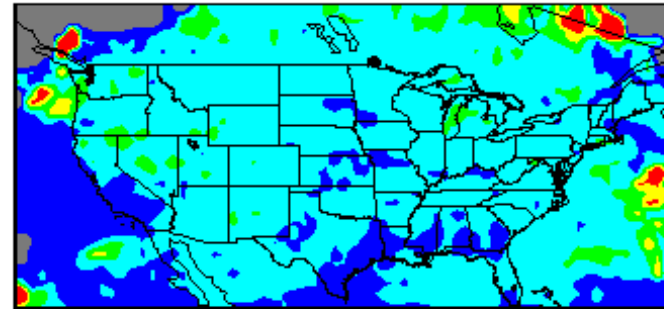


CONTRAIL AMOUNT OVER CONTINENTAL USA FROM AVHRR DATA

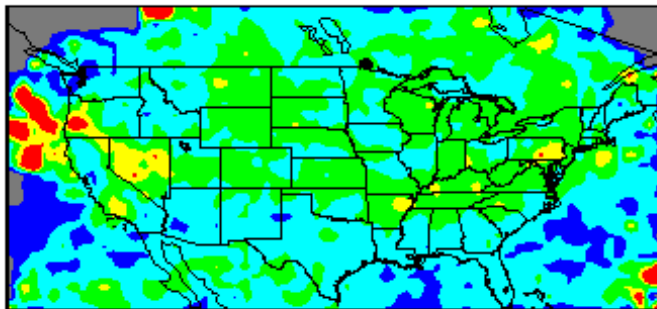
APRIL '93



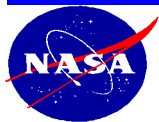
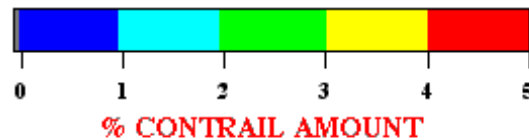
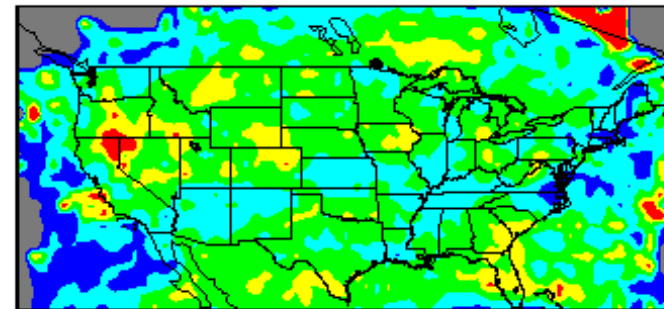
JULY '93



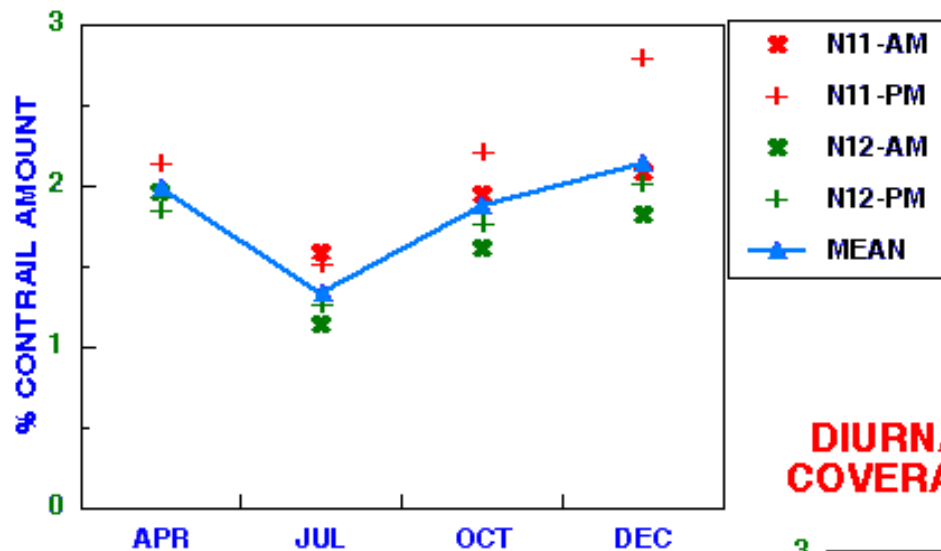
OCTOBER '93



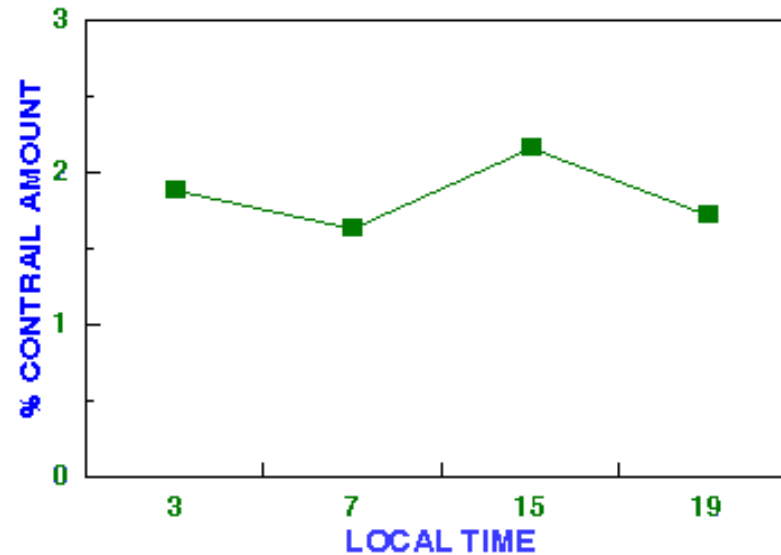
DECEMBER '93



SEASONAL VARIATION OF CONTRAIL COVERAGE OVER CONTINENTAL USA



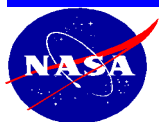
DIURNAL VARIATION OF CONTRAIL COVERAGE OVER CONTINENTAL USA



ERROR ESTIMATE

NOAA-11/12: 30% BIAS

NOAA-14: -200% BIAS



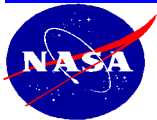
COMPARISON OF PERCENTAGE CONTRAIL CLOUD AMOUNT OVER THE CONTINENTAL USA, %

MONTH	THEORY	OBSERVATION
April	1.36	1.98
July	0.40	1.33
October	1.04	1.87
December	1.08	2.14
Annual	0.97	1.83

Using underestimate of 30% for NOAA-11/12 contrails:

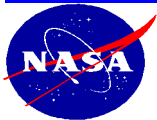
The observed annual mean would be **1.28%.**

Thus, the theoretical results are within **25% of the observed.**

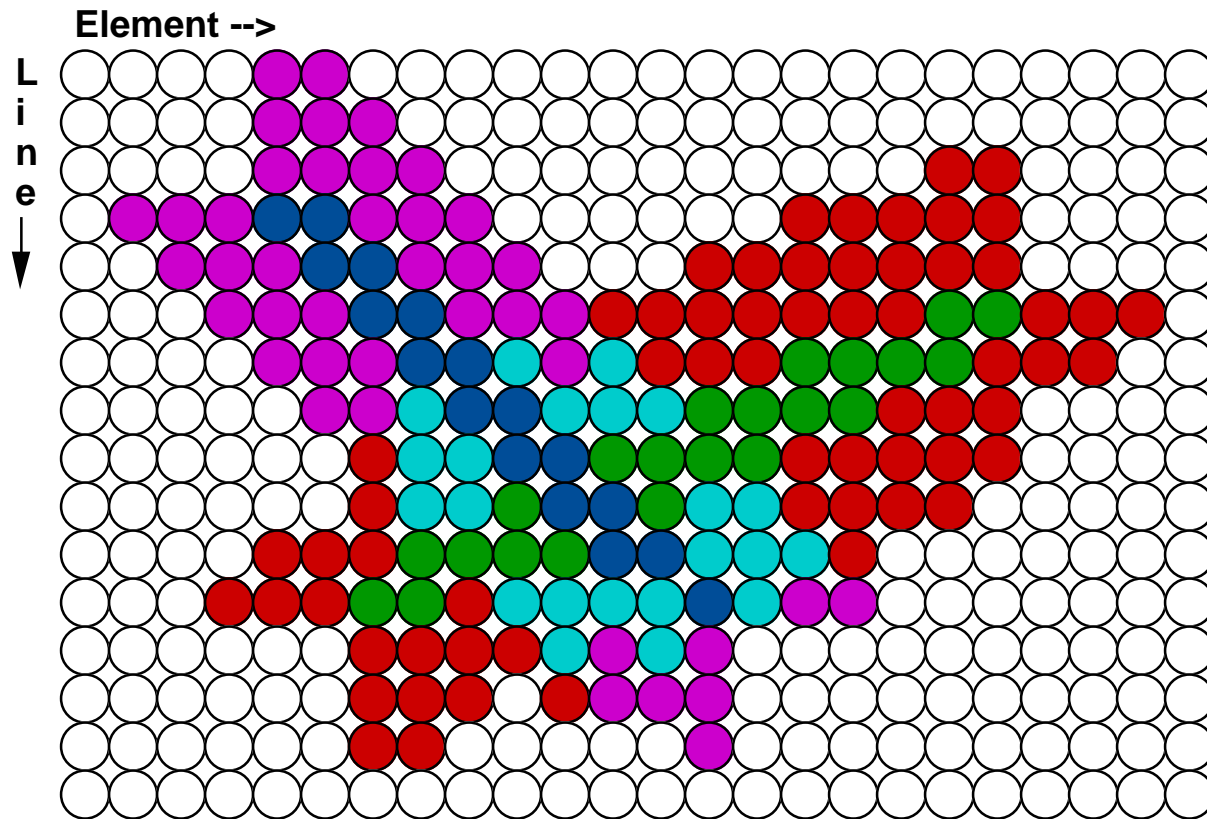


Methodology to Compute CRF Directly

- **Empirical correlations between GOES and ERBE data**
 - VIS reflectances → broadband (0.2 - 5 μm) solar albedo
 - IR temperatures → broadband (5 - 50 μm) longwave flux
- **Use nominal ERBE anisotropic correction models to convert to albedo and flux from the observed radiances**
 - contrails are optically thin, models correspond to $\tau \sim 10$



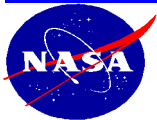
Computing instantaneous CRF directly



$$\text{CRF1}_{lw} = LW1 - \text{avg}(LW + LW)$$

$$\text{CRF2}_{lw} = LW2 - \text{avg}(LW + LW)$$

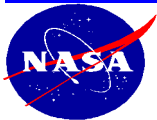
$$\text{CRF}_{lw} = \sum (\text{CRFn}_{lw} * N_{cn}) / N$$



COMPARISON OF CONTRAIL LONG WAVE FORCING OVER THE CONTINENTAL USA, Wm^{-2}

MONTH	THEORY	OBSERVATION
April	0.35	0.58
July	0.24	0.57
October	0.36	0.54
December	0.40	0.56
Annual	0.34	0.56

Accounting for contrail overestimate by NOAA-11/12
yields corrected observation of **0.39**
Thus, calculations would be within **15%** of observed.



LINEAR CONTRAIL MICROPHYSICAL PROPERTIES

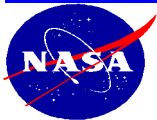


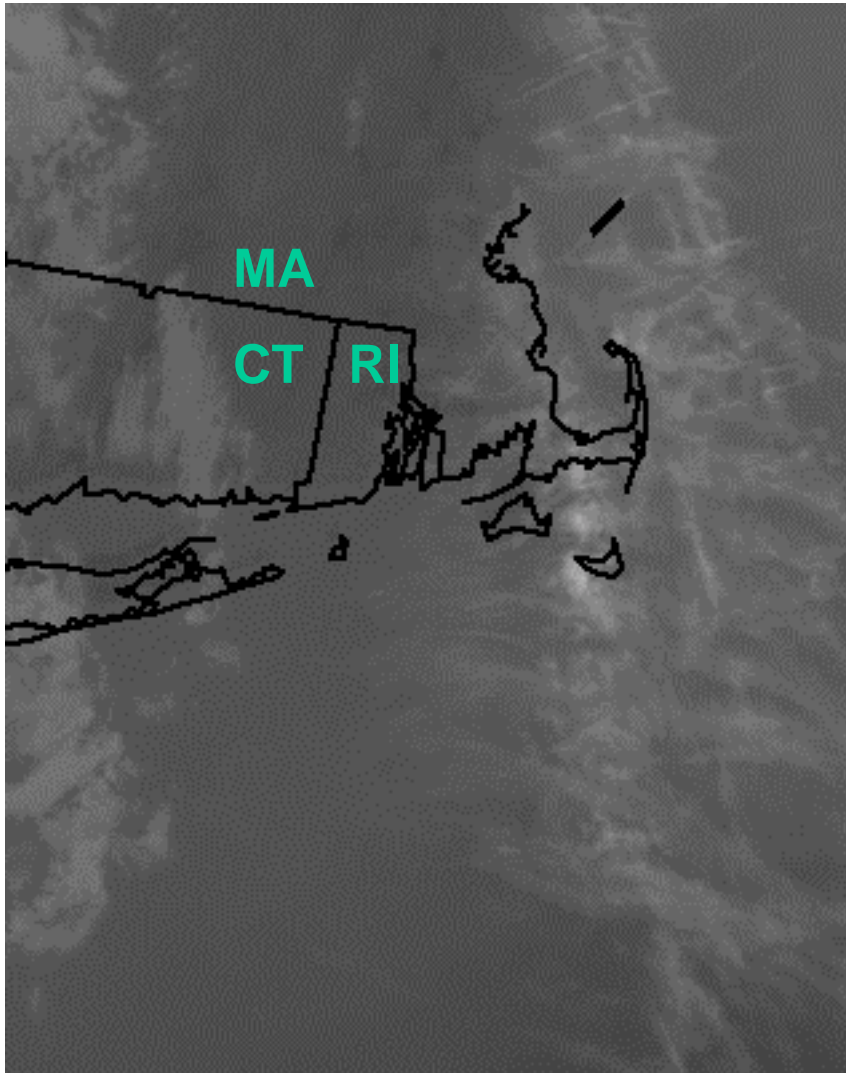
Langley Research Center

Contrail-coverage & radiative forcing over the USA

Methodology

- Layer Bispectral Threshold Method (LTBM)
 - To discriminate between clear and cloudy sky
 - VIS (ch 1: 0.65 μm) and IR (ch 4: 10.7 μm) thresholds
- VIS-IR-SI technique (VIST):
 - Cloud microphysical properties are derived from observed VIS (channel 1: 0.65 μm) reflectance, SI (channel 5: 12.0 μm) and IR (channel 4: 10.7 μm) brightness temperatures
 - Iterative technique to determine cloud particle size, VIS optical depth, and cloud temperature

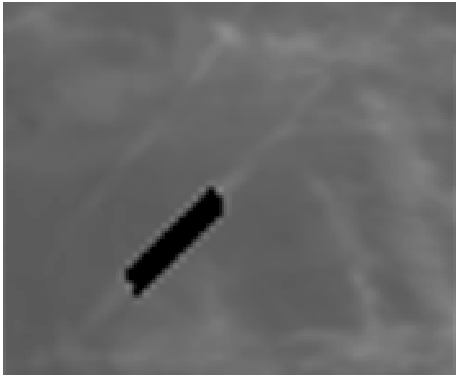




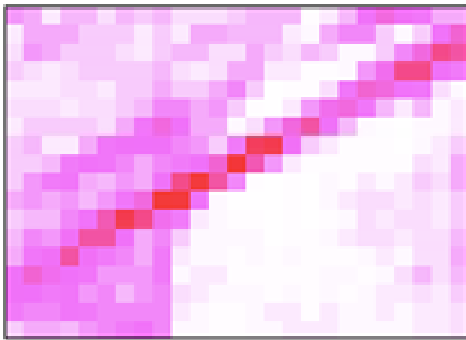
**CONTRAIL FIELD
OBSERVED IN NOAA-12
10.8- μ m IMAGE
DAY 281, 1997**



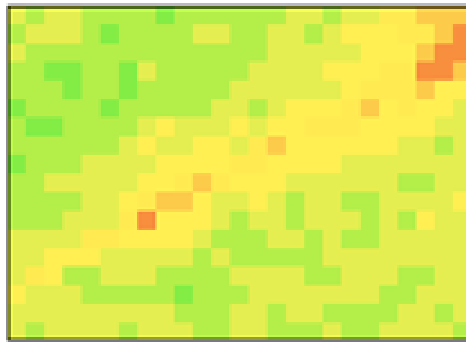
Optical property retrieval NOAA-12, day 281 1997 Off coast of New England



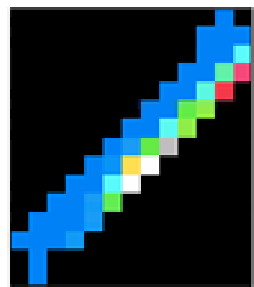
T4 - T3



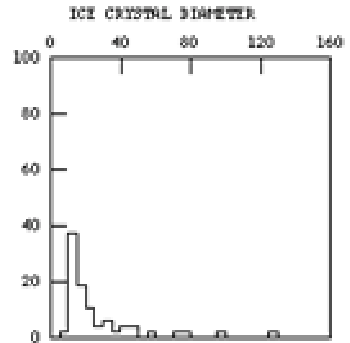
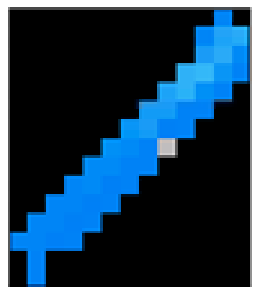
T4 - T5



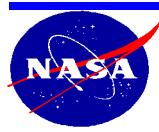
Ice Particle Diameter



Cloud Optical Depth



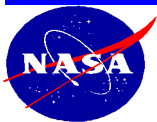
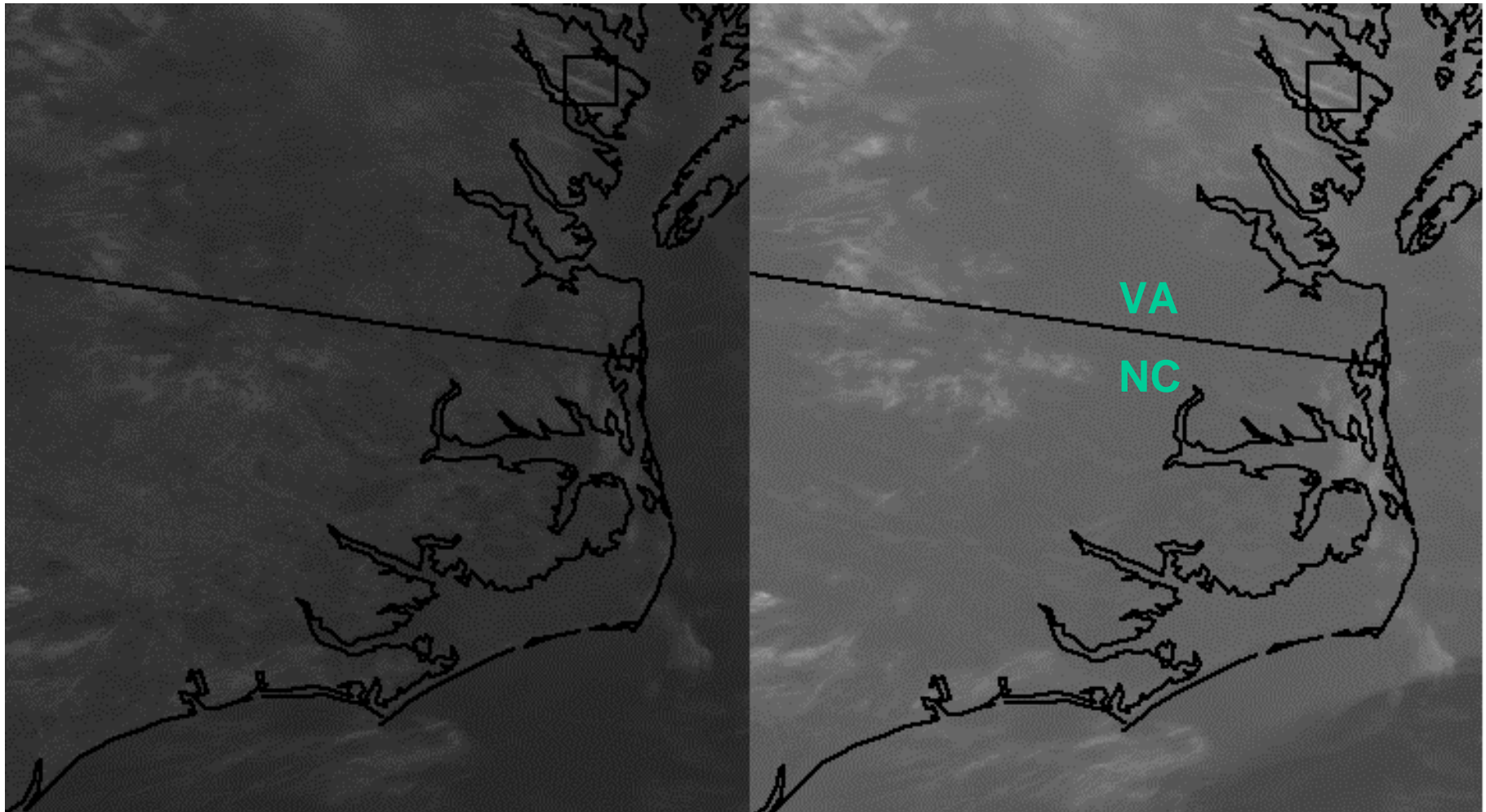
N = 60
D = 29.4 μm
 $\tau = 0.28$
IWP = 1.9 gm^{-2}



NOAA-14 Imagery, 1845 UTC, Day 345, 1996

VISIBLE

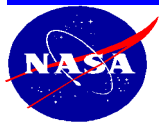
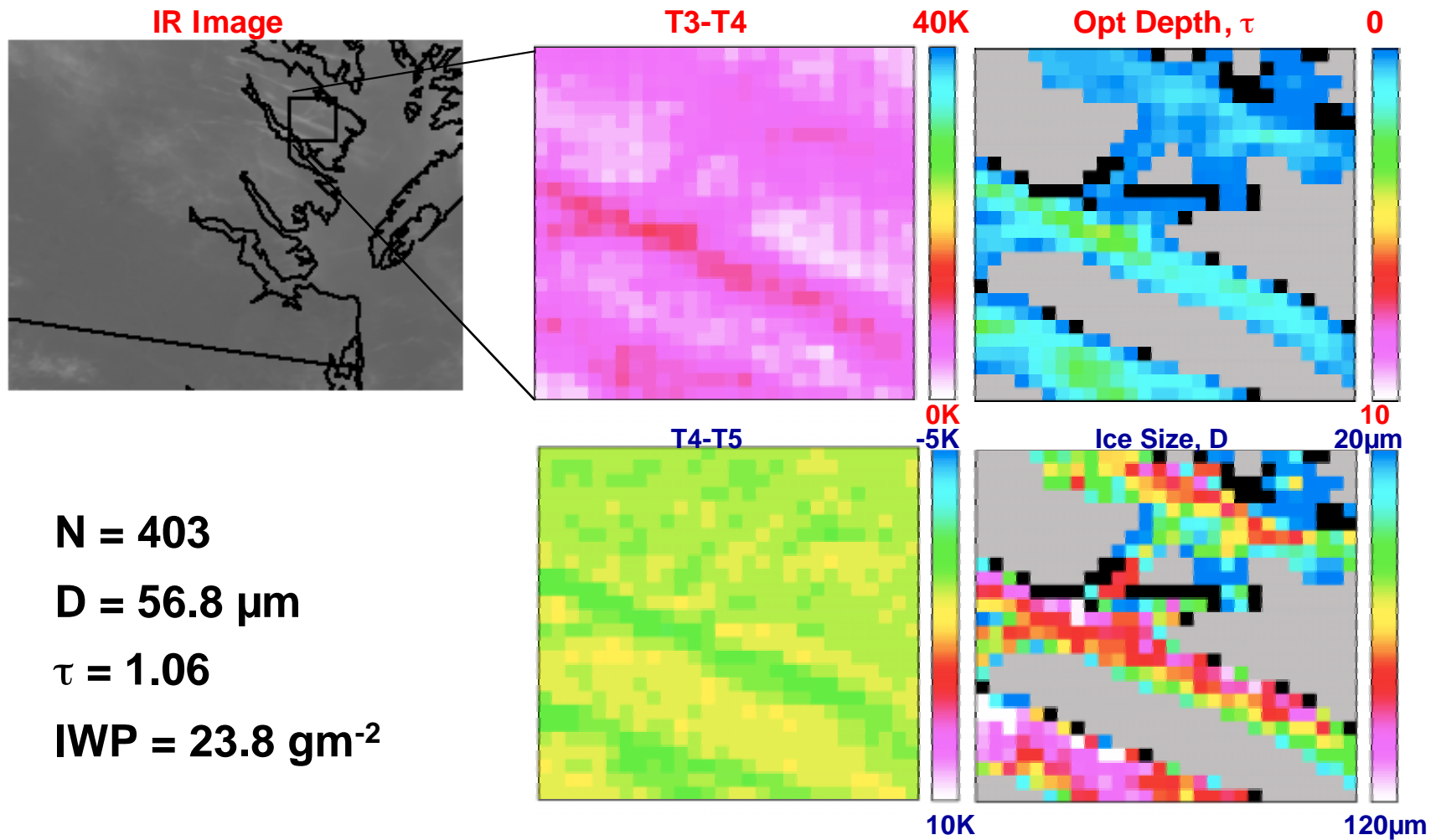
INFRARED



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Contrail-coverage & radiative forcing over the USA

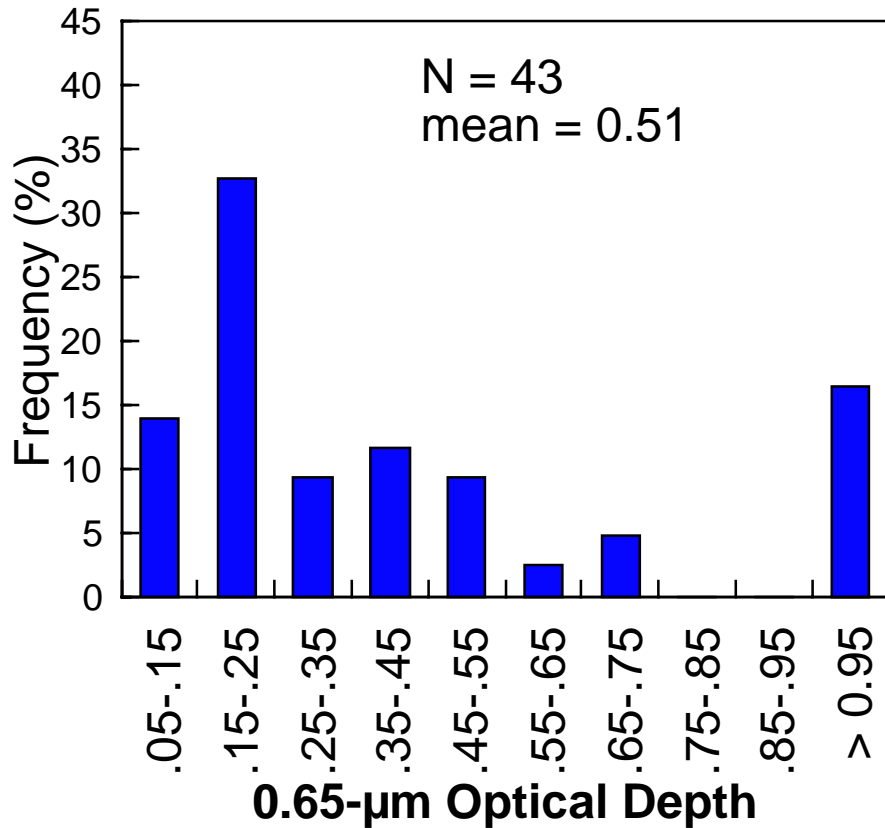
Contrail microphysical properties from NOAA-14 AVHRR 1845 UTC, Day 345, 1996



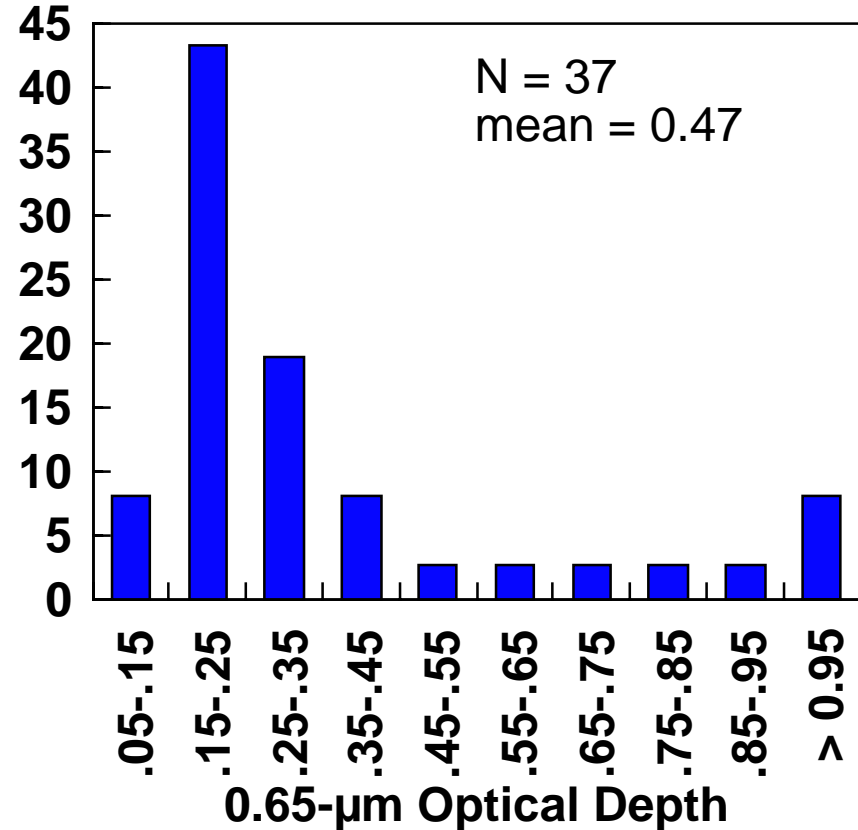
Contrail optical depths derived from AVHRR data

Preliminary results

All contrail pixels used



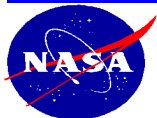
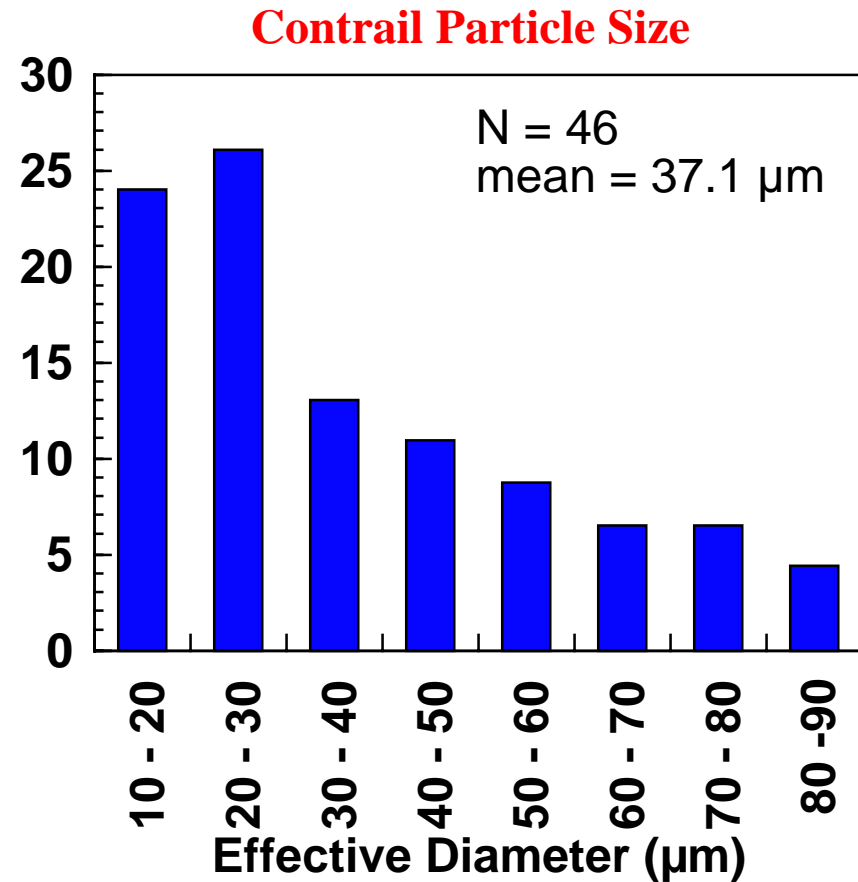
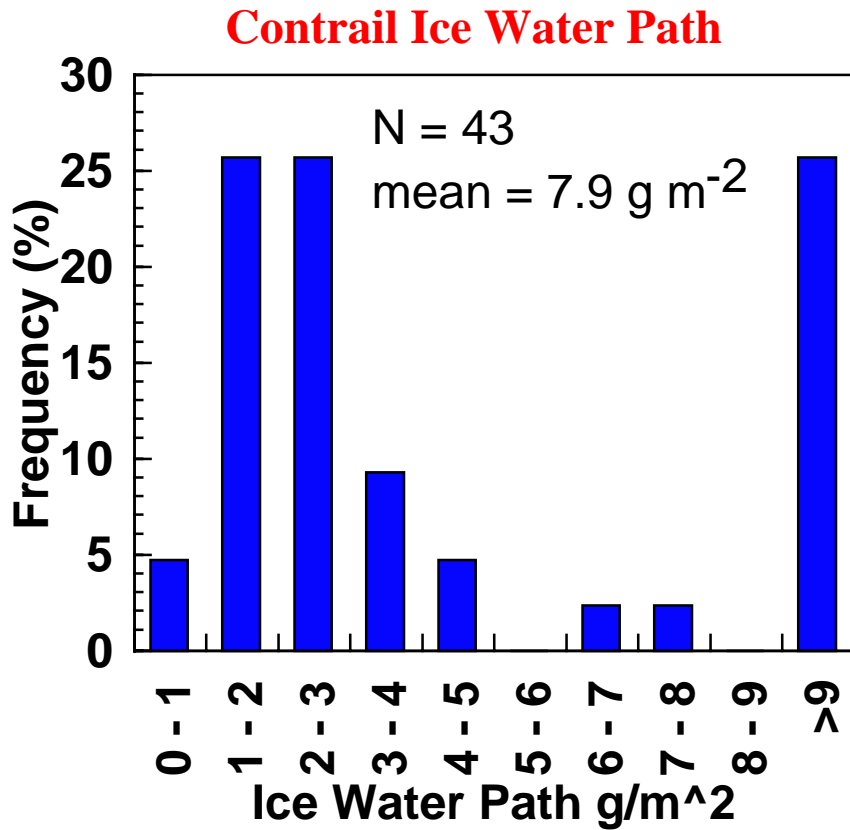
No-retrieval pixels not included



Mean value from 8 spreading contrail cases from GOES: 0.52



Linear contrail microphysical properties from AVHRR data over the USA - Preliminary results



CONTRAIL GROWTH & LIFETIMES



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Contrail-coverage & radiative forcing over the USA

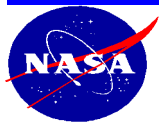
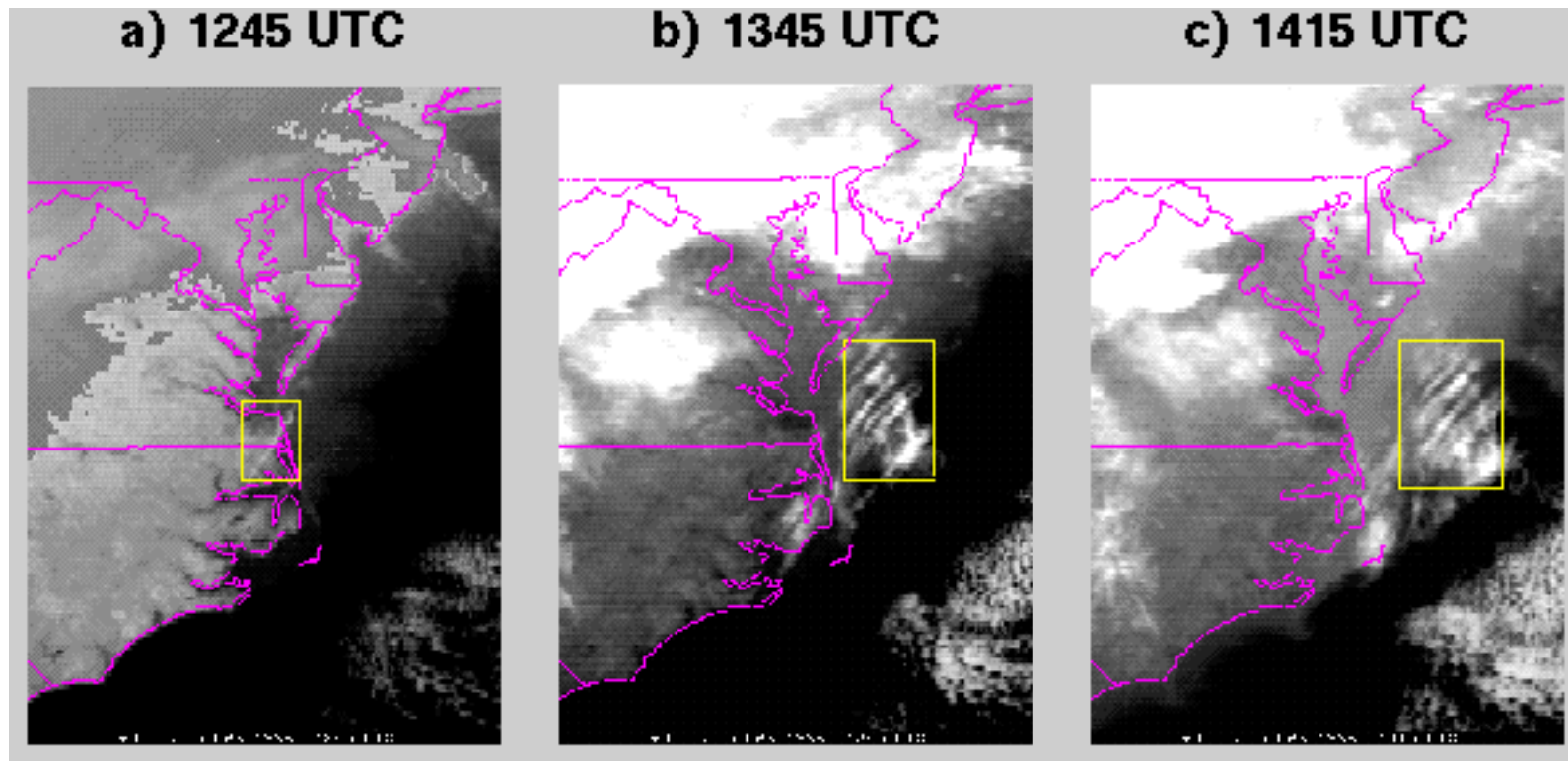
CONTRAIL SPREADING OFF EAST COAST OF USA

GOES-8 IR IMAGERY

5 MARCH 1999

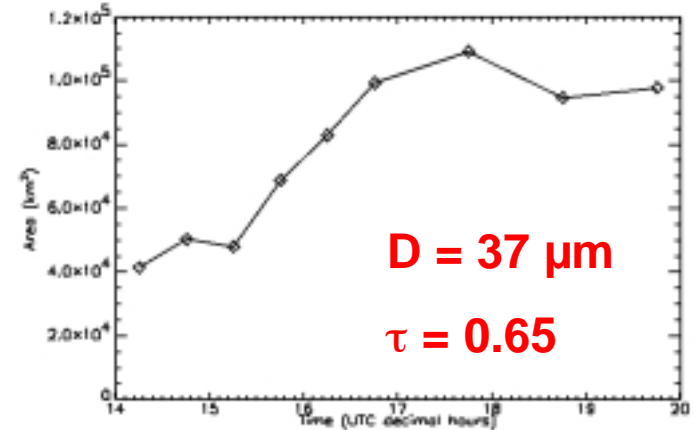
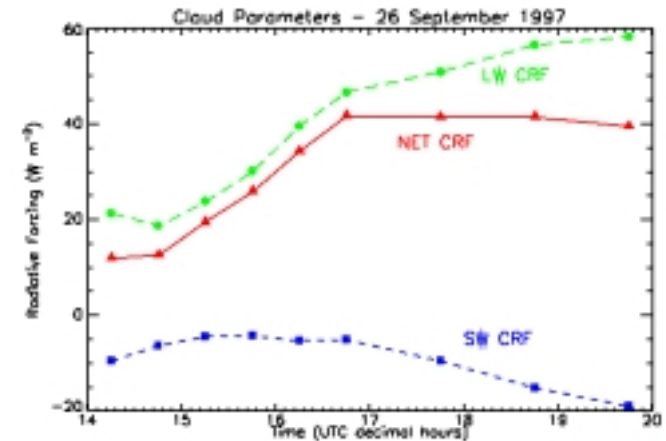
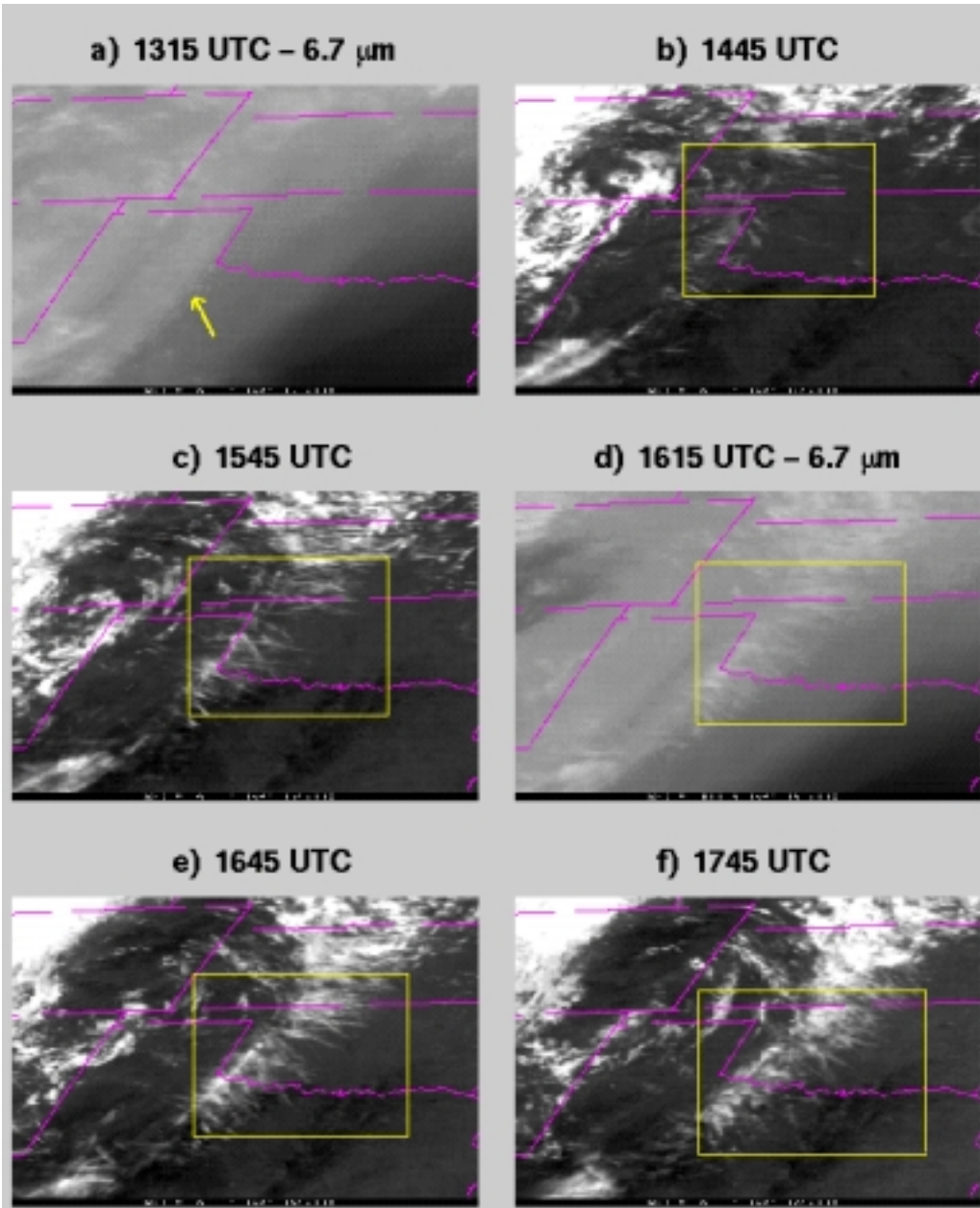
Max area = $2.2 \times 10^4 \text{ km}^2$

$\text{CRF}_{\text{net}} = 3 - 25 \text{ Wm}^{-2}$



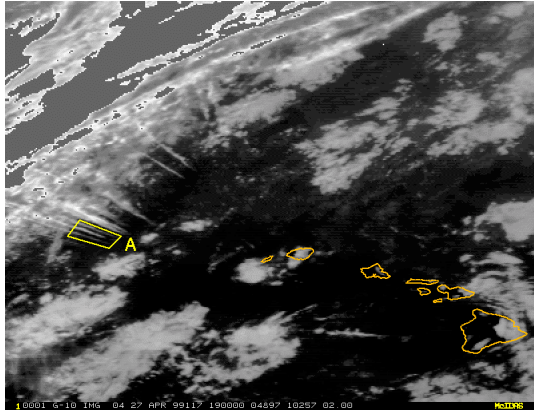
CONTRAIL OUTBREAK IN NORA MOISTURE

26 SEPT 1997

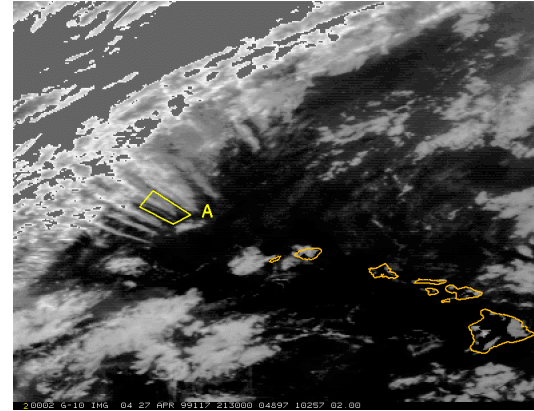


HAWAII - 27 April 1999

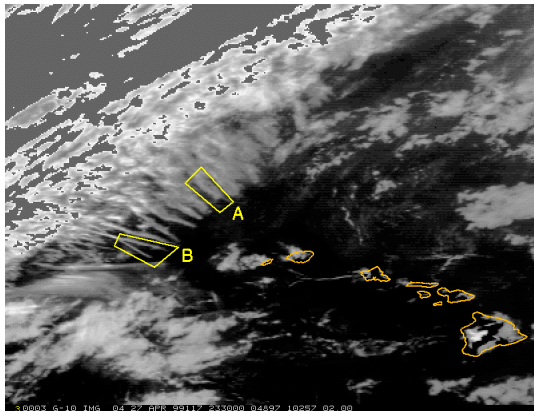
1900 UTC 27 April



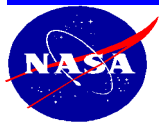
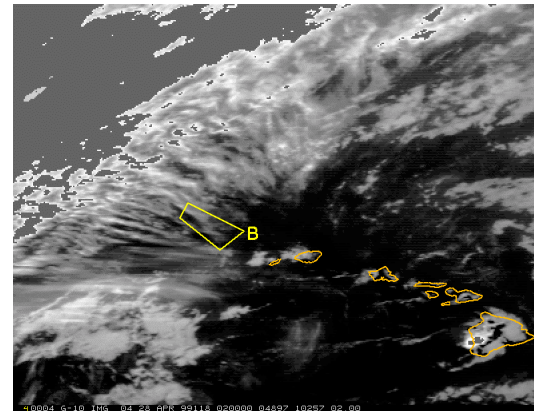
2130 UTC 27 April

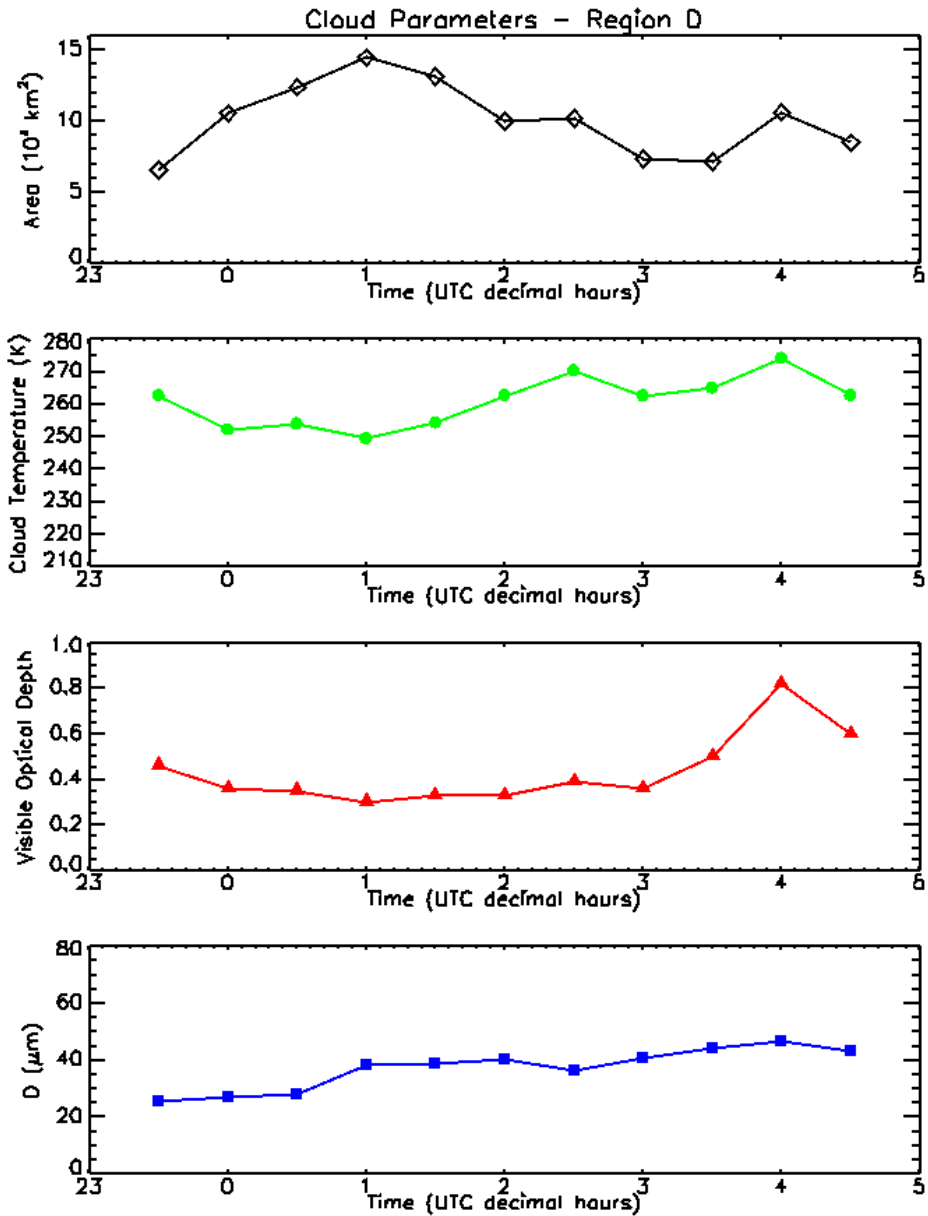


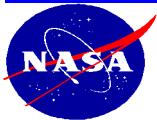
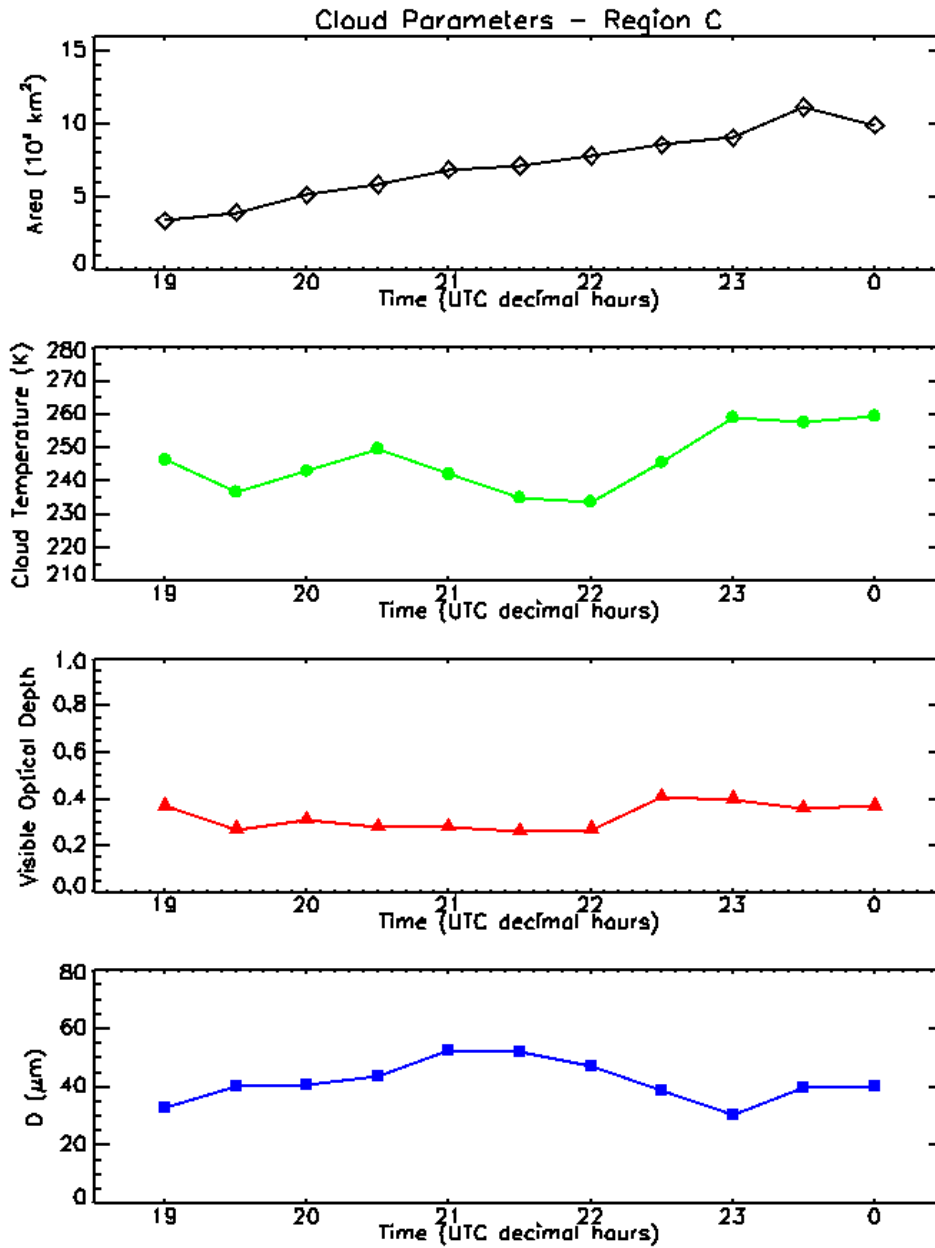
2330 UTC 27 April

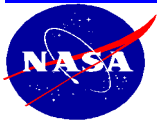
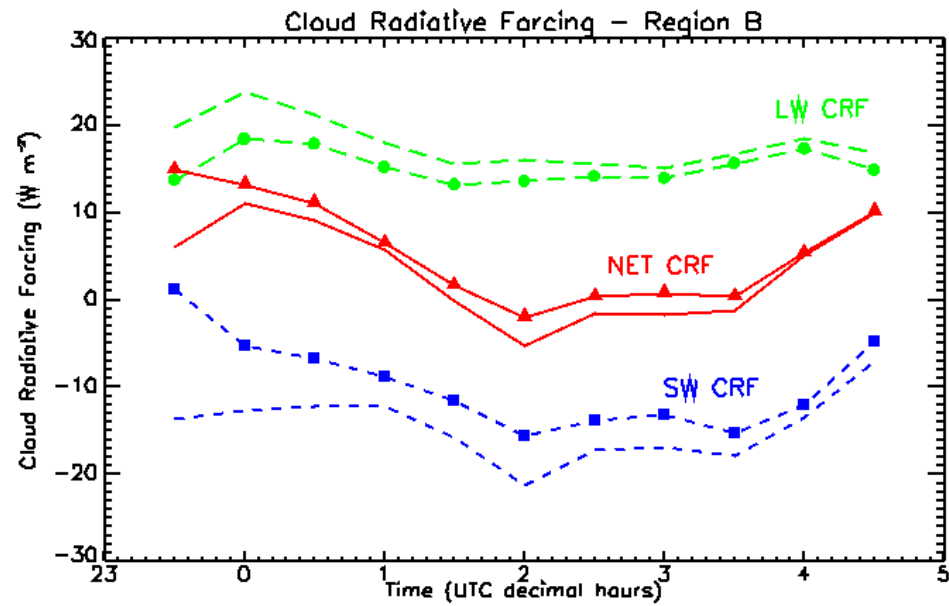
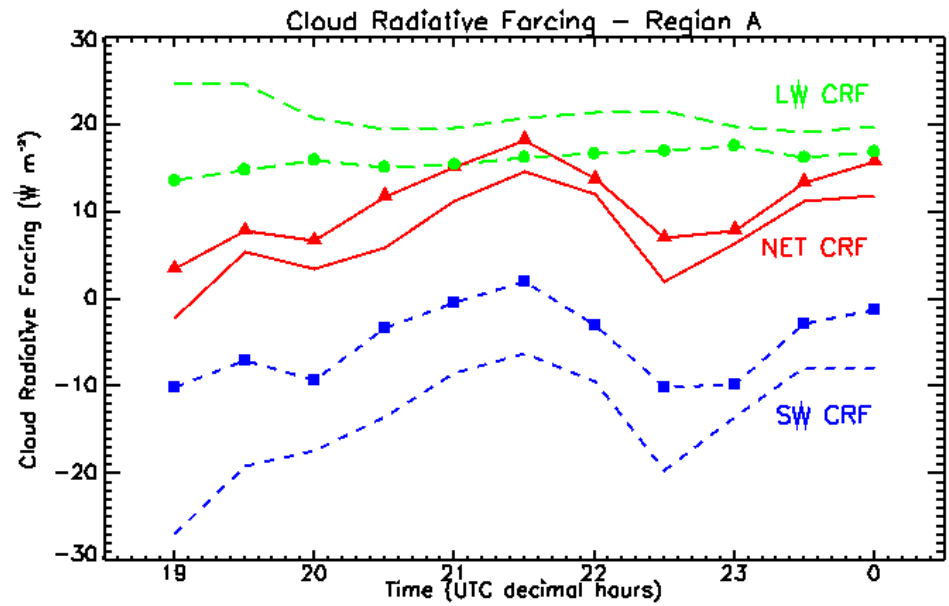


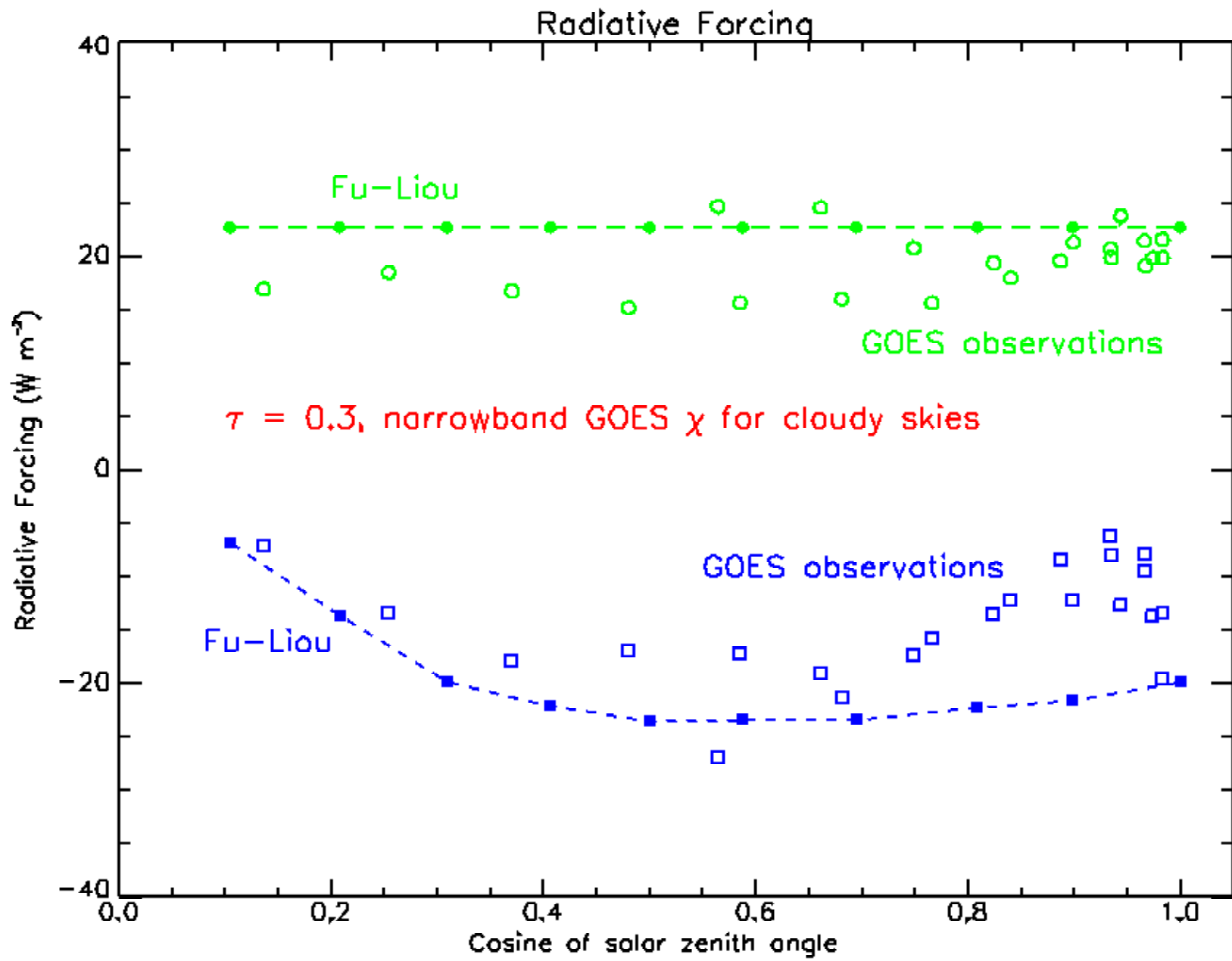
0200 UTC 28 April





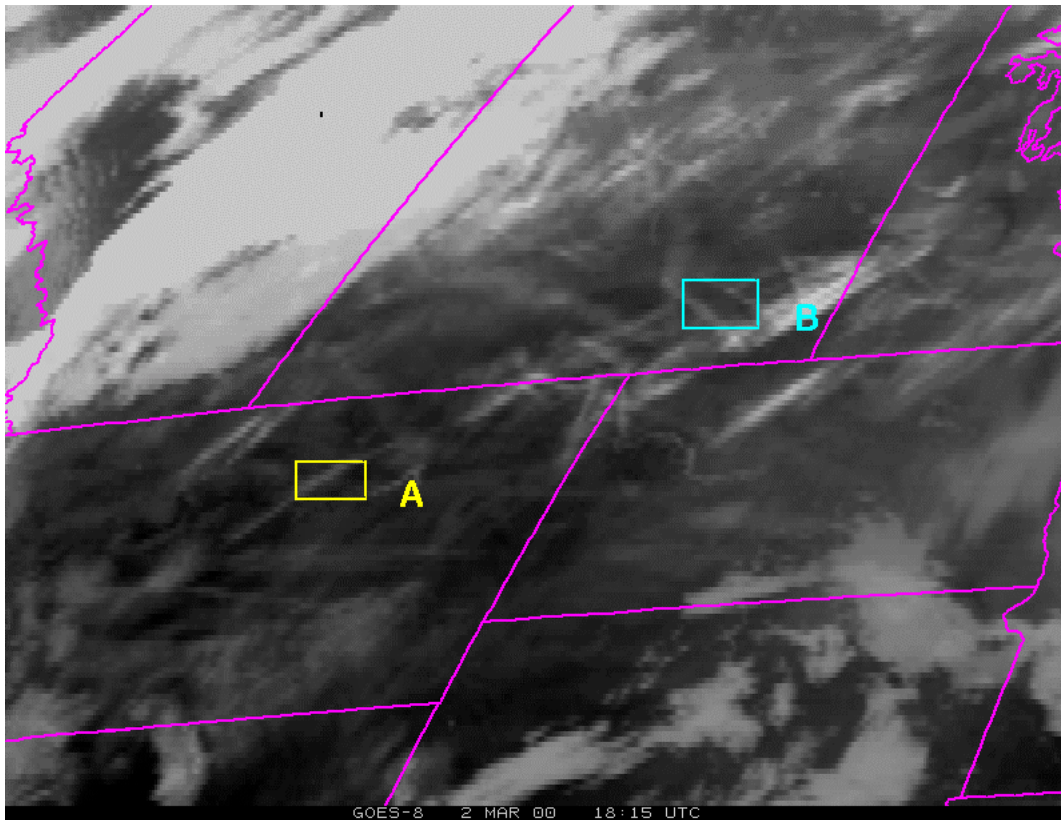






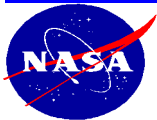
CANADA/USA - 2 March 2000

1815 UTC 2 March



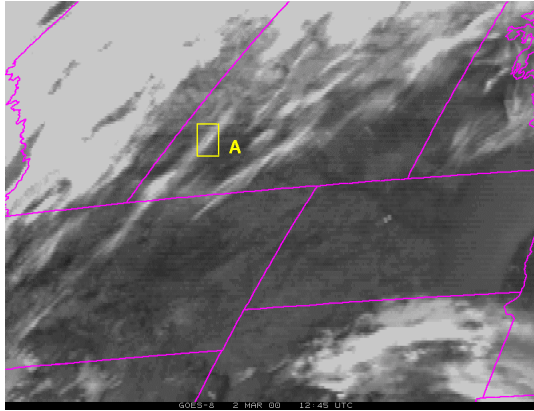
Which box contains a contrail(s), and which contains non-contrail generated cirrus?

(Both have similar particle sizes (A: 37 μm , B: 25 μm) and similar optical depths (A: 0.54 and B: 0.43).

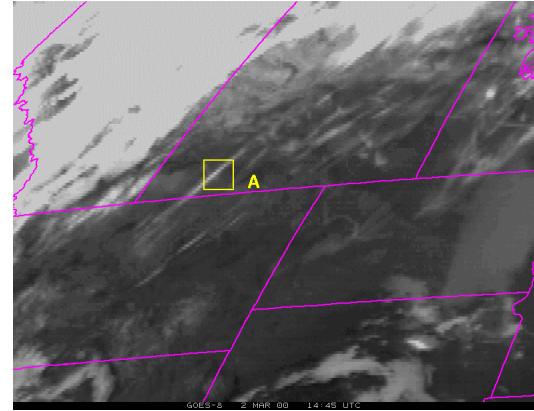


CANADA/USA - 2 March 2000 (continued)

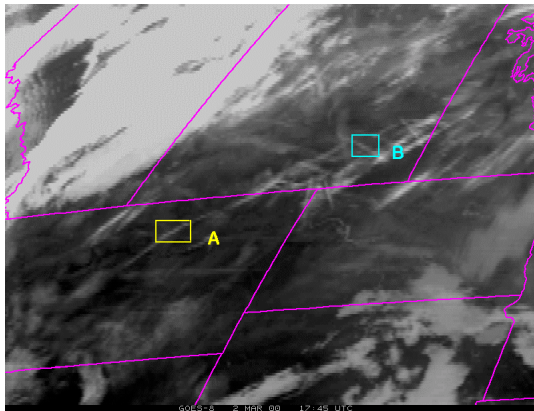
1245 UTC 2 March



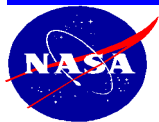
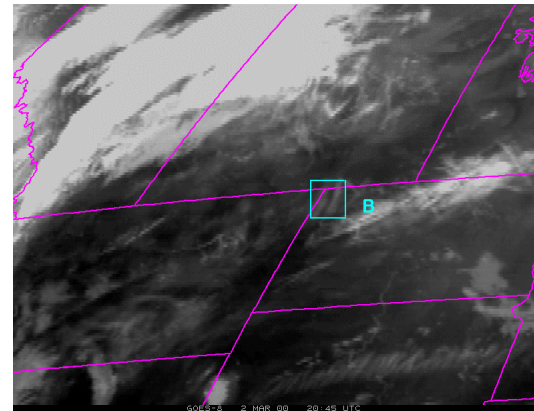
1445 UTC 2 March

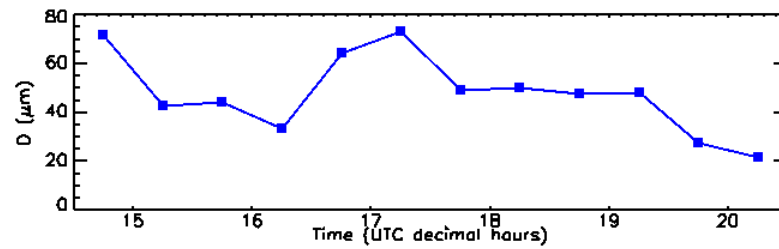
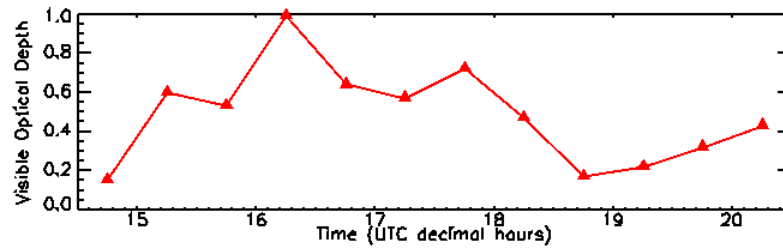
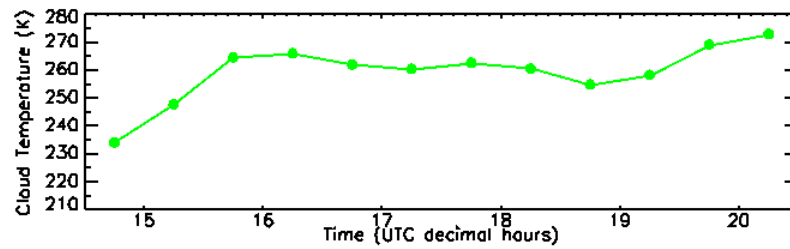
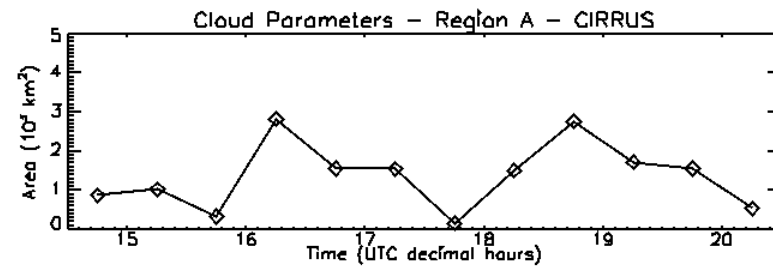


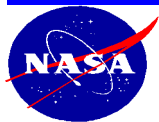
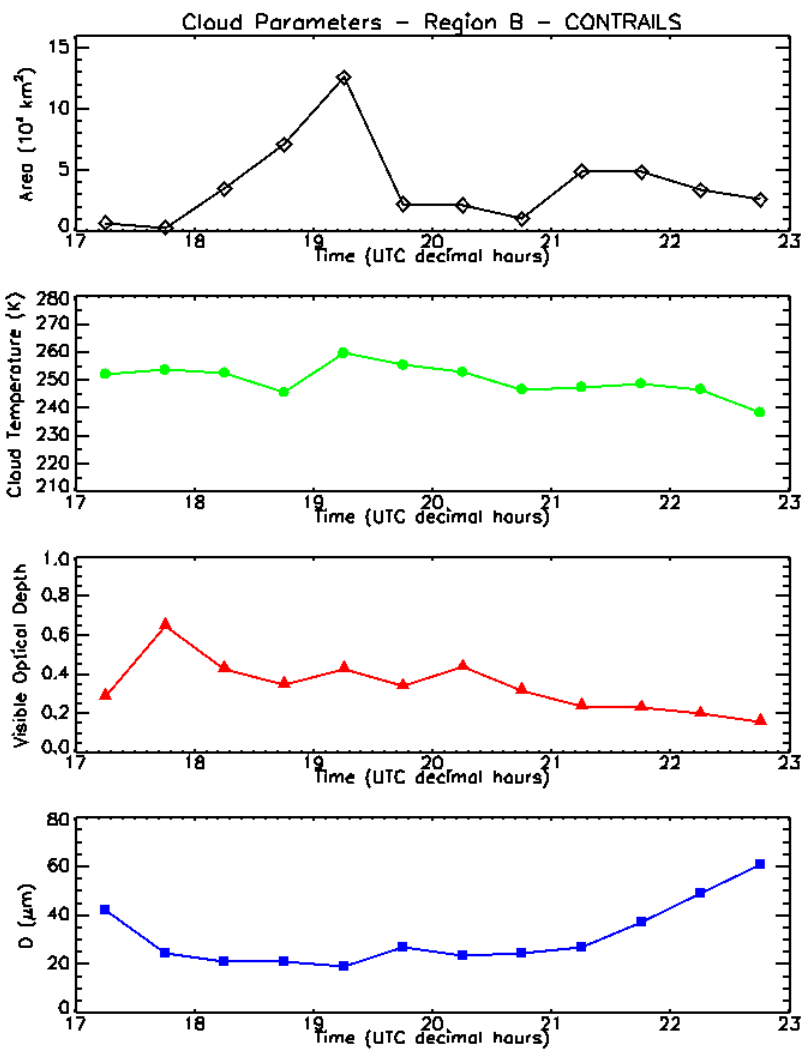
1745 UTC 2 March



2045 UTC 2 March

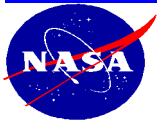






SUMMARY

- **Linear contrail coverage & LW forcing over USA is ~20% greater than estimates from tuned model studies**
 - diurnal cycle seems flat, coverage in summer >> theory
 - optical depths slightly greater than 0.3; most < 0.3
 - particle sizes slightly larger; most < 30 μm ; $D < D_{\text{cir}}$ (~56 μm)
- **Contrail spreading is easy to find, hard to analyze (few cases)**
 - D shows relatively steady growth with time; --> ~60 μm
 - spreading factor is 2 - 4 for most cases
 - some outbreaks \geq 25% of global mean!**
 - mean optical depths similar to linear contrails
 - tropical results similar to midlatitudes
 - natural cirrus can cause ambiguities as in linear cases
 - lifetimes 3 to > 14 hrs; mean > 8 hrs



FUTURE RESEARCH

- **AUTOMATE MICROPHYSICS & CRF RETRIEVALS**

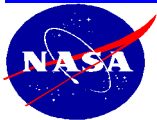
- **DEVELOP & APPLY NEW BRDF & LIMB-DARKENING MODELS;
COMPUTE CRF_{sw} , CRF_{net}**
- **VALIDATE RETRIEVALS; IMPROVE ESTIMATE OF ERROR**

- **MERGE AVHRR & MODIS WITH GOES DATA**

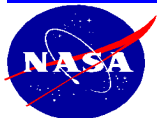
- **DETERMINE CONTRIBUTION OF LINEAR CONTRAILS TO GOES-DERIVED CONTRAIL CIRRUS**

- **MERGE FLIGHT & NWP ANALYSES WITH GOES DATA**

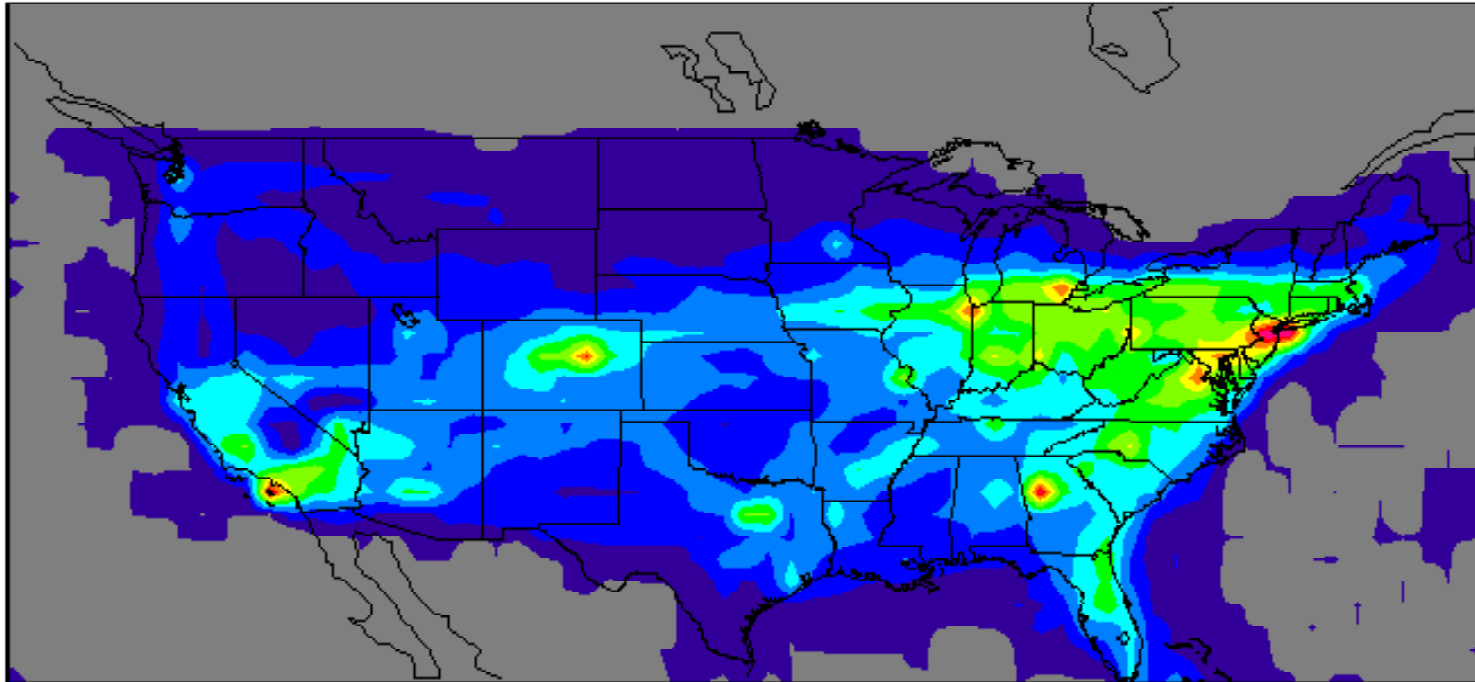
- **CREATE DATABASE OF FLIGHT DATA W/ MET & CONTRAIL DATA**
- **EXPLORE MODEL CONDITIONS PRODUCING LINEAR &
SPREADING CONTRAILS**



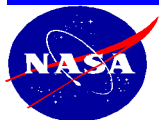
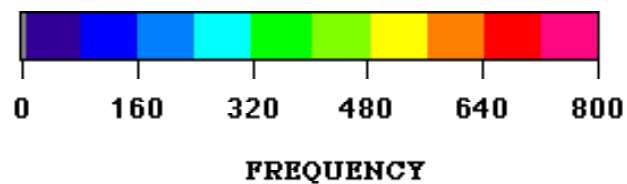
ADDITIONAL MATERIAL



FREQUENCY OF FLIGHTS OVER USA FOR AUG 15, 1999



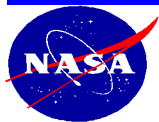
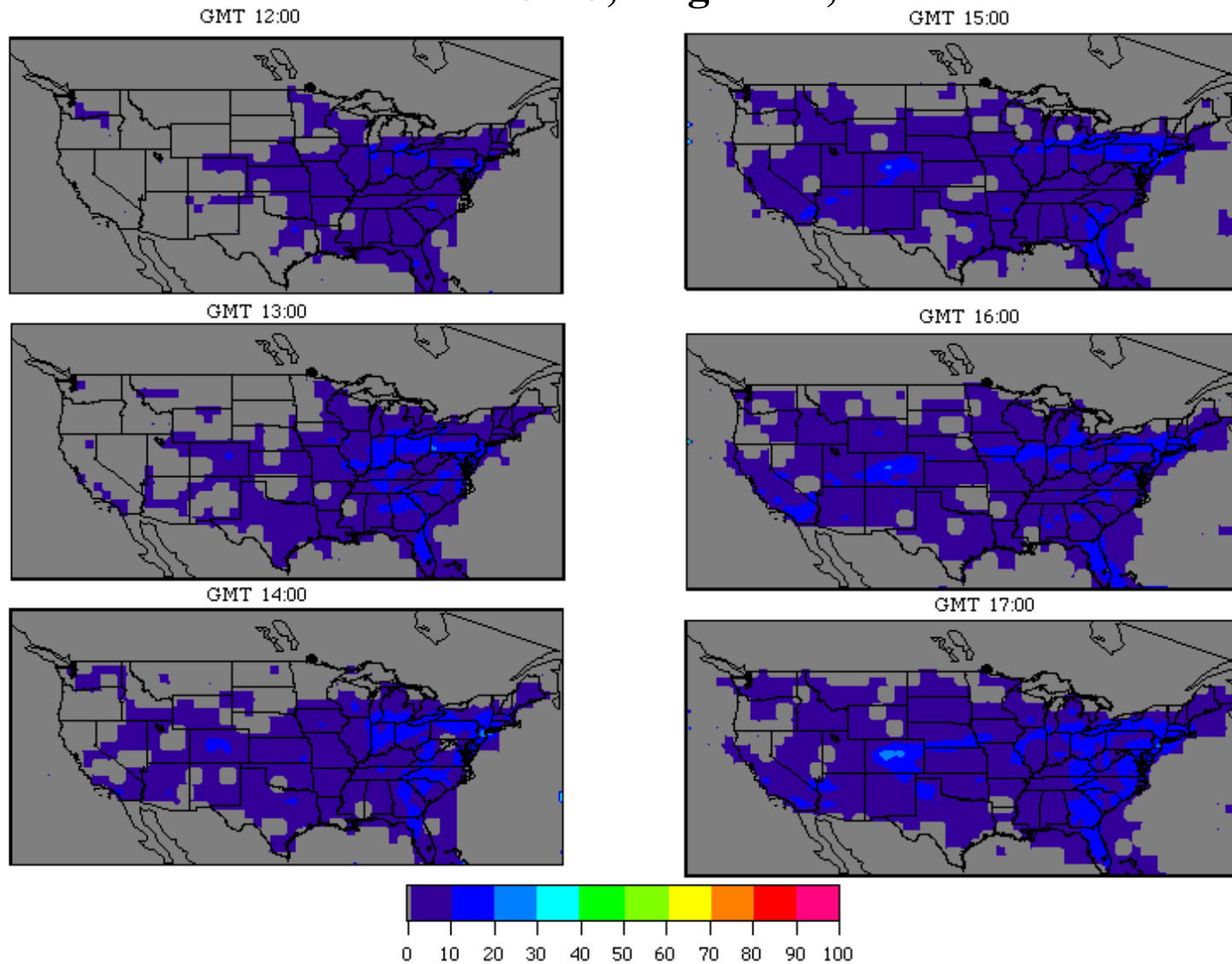
Only for flight legs above 17Kft



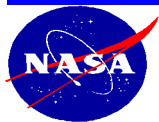
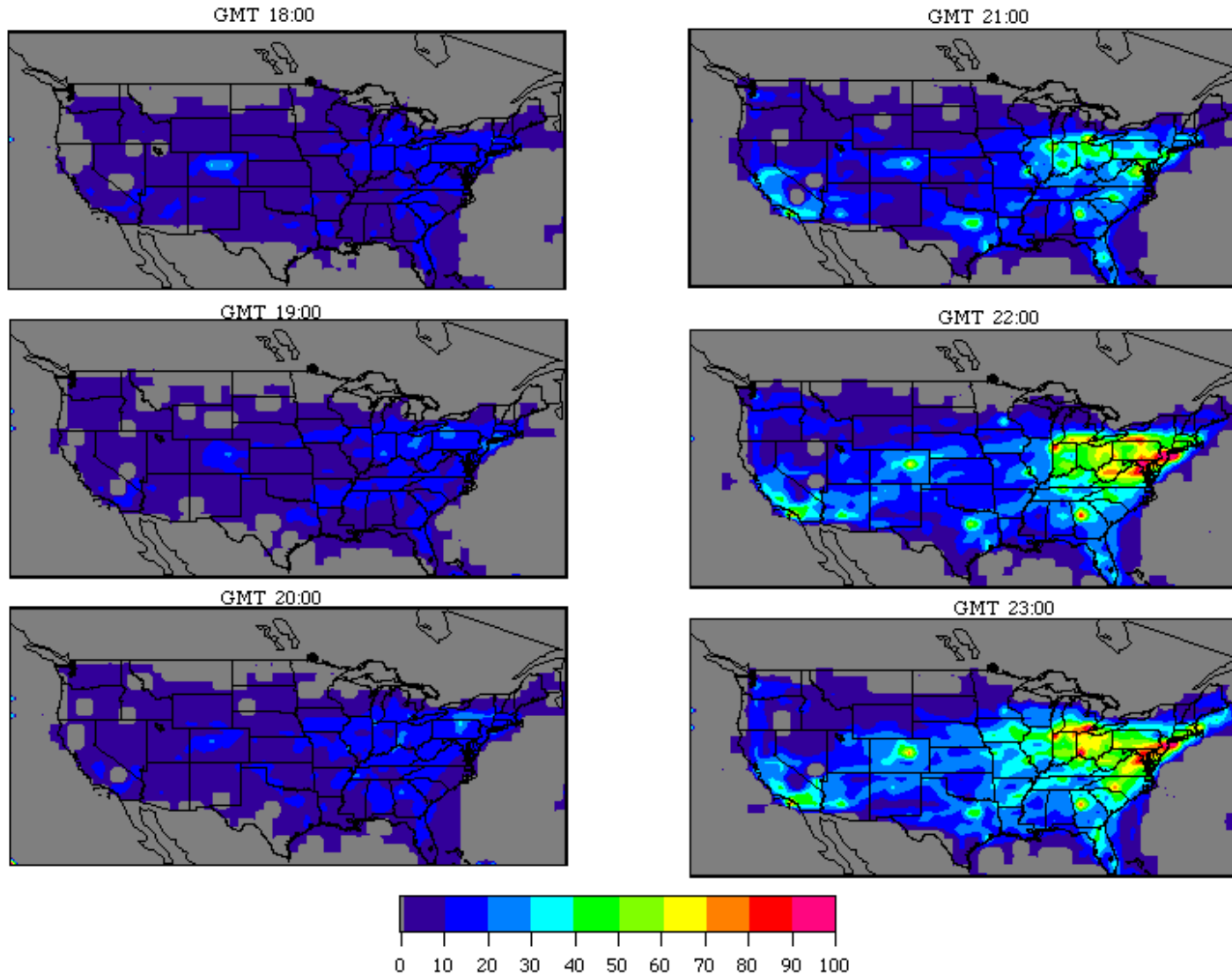
Langley Research Center

Contrail-coverage & radiative forcing over the USA

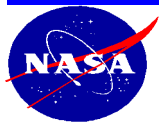
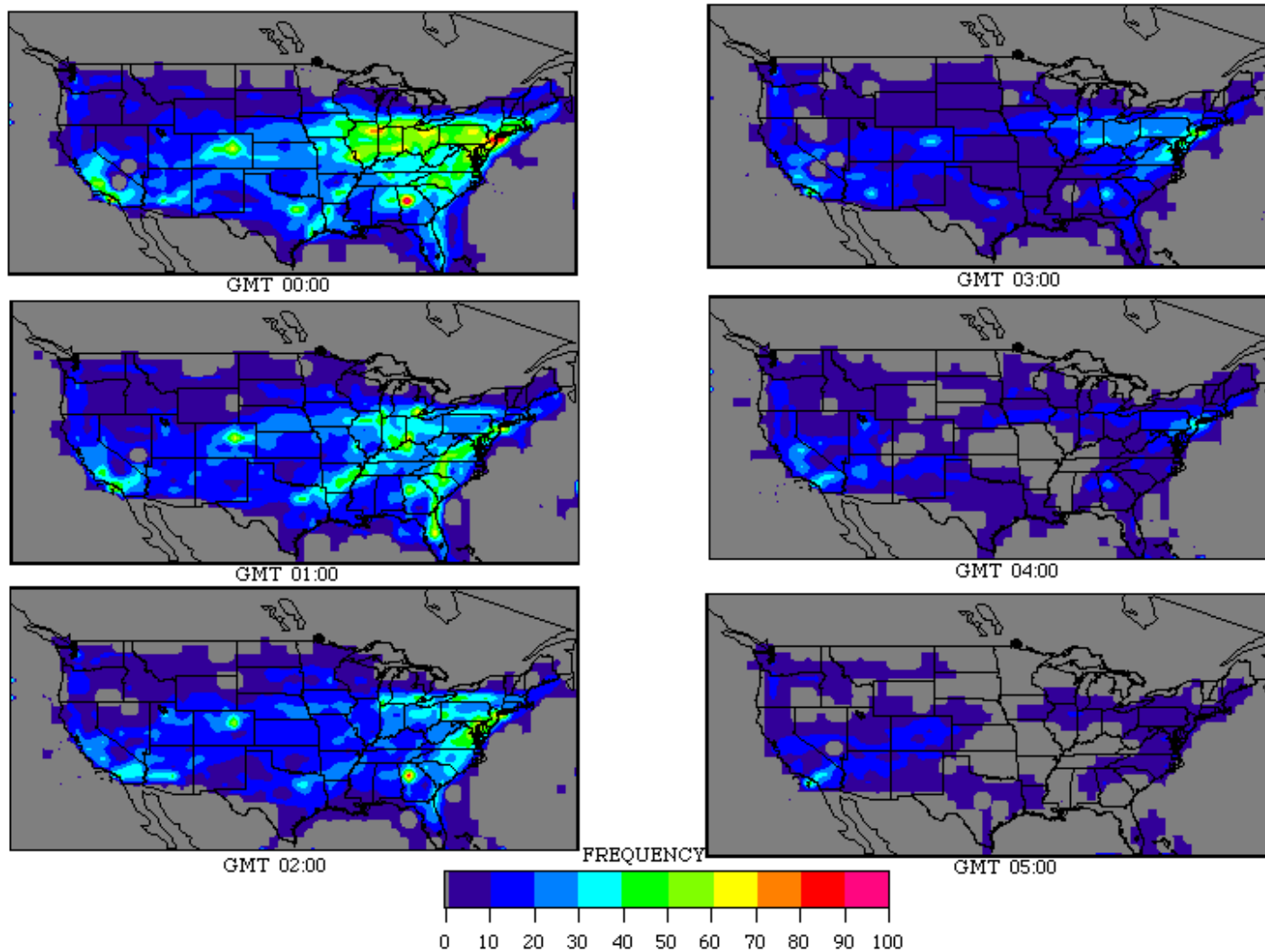
Number of flight tracks thru a 1° box above 17Kft 1200 - 1800 UTC, August 15, 1999



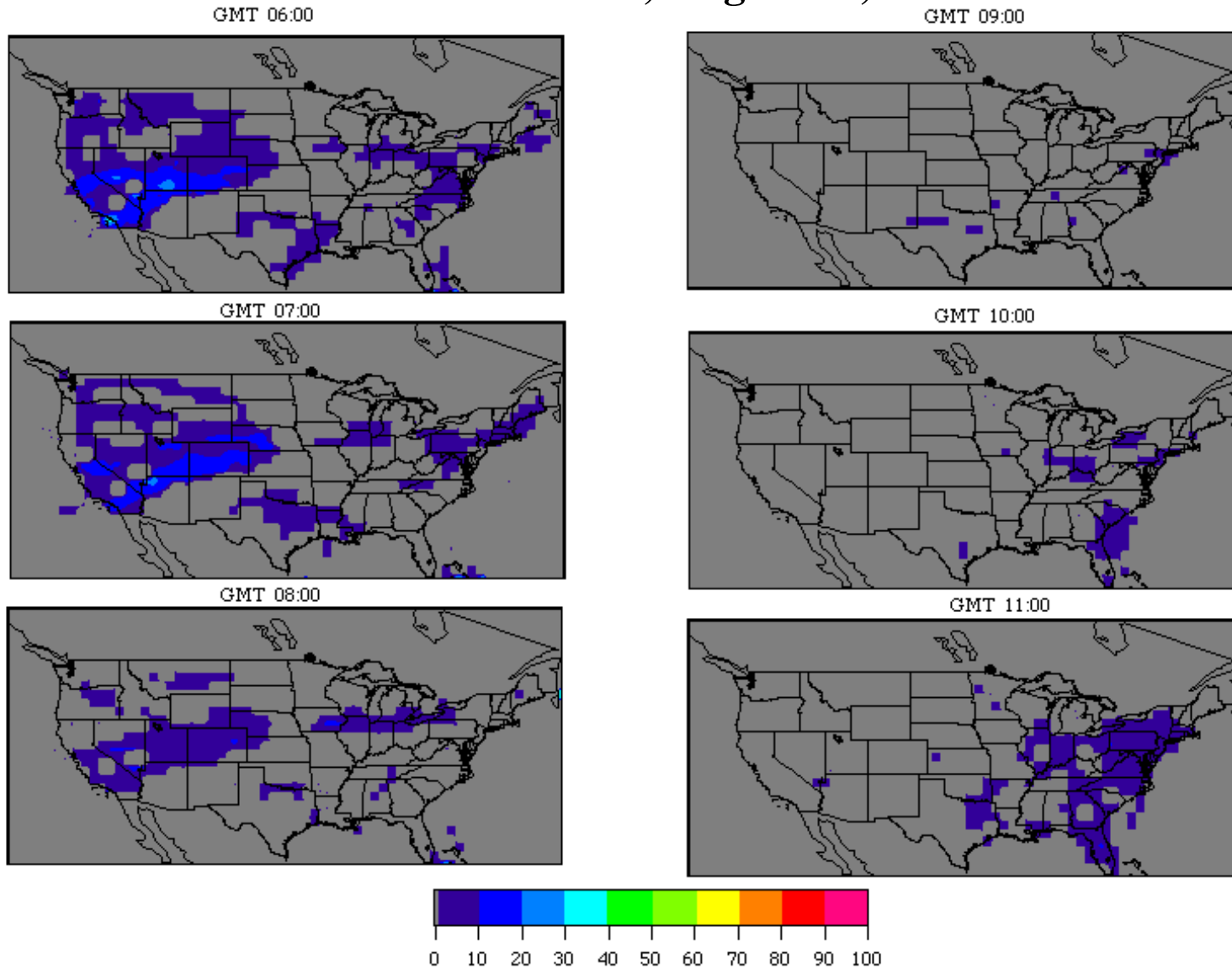
Number of flight tracks thru a 1° box above 17Kft 1800 - 2300 UTC, August 15, 1999

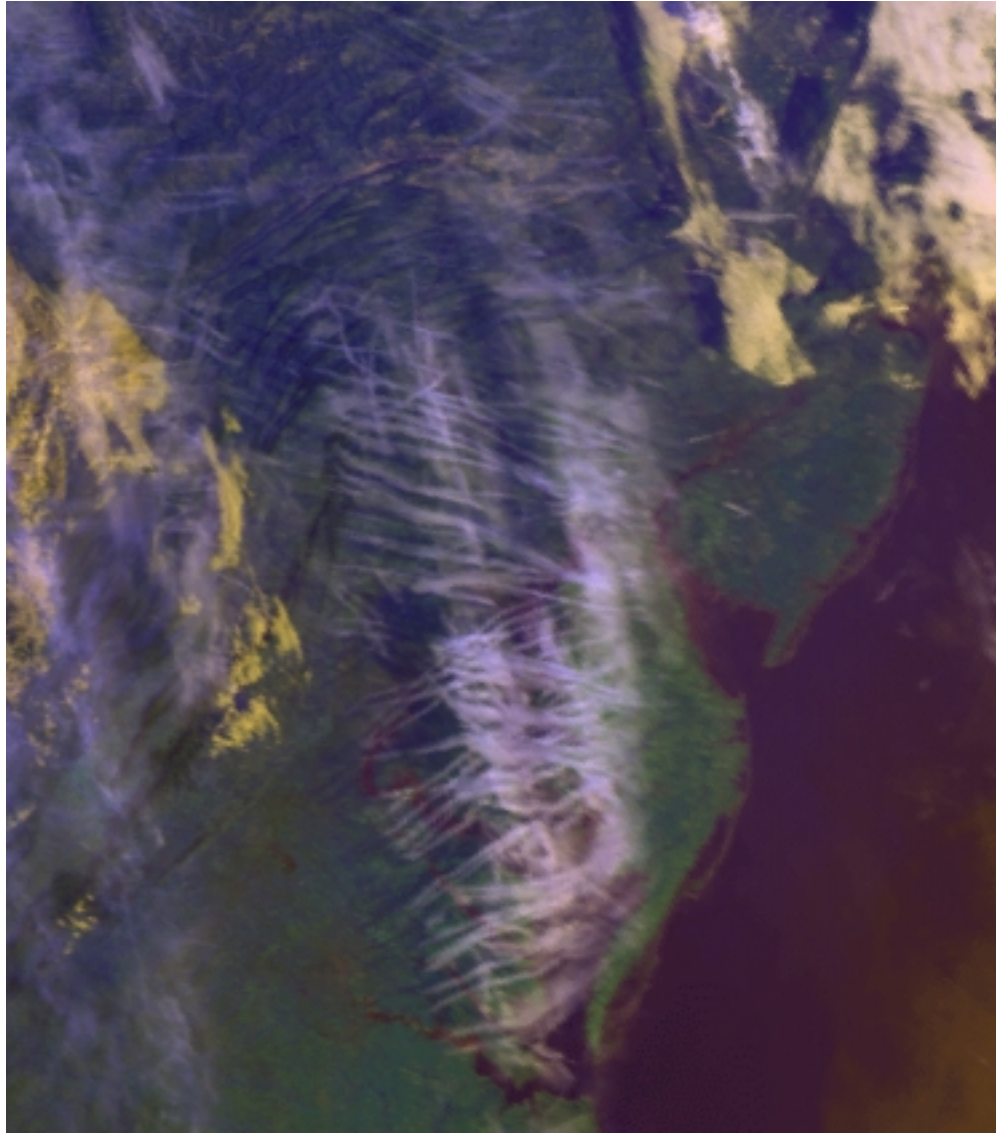


Number of flight tracks thru a 1° box above 17Kft 0000 - 1600 UTC, August 15, 1999



Number of flight tracks thru a 1° box above 17Kft 0600 - 1200 UTC, August 15, 1999





NOAA-15 AVHRR IMAGE

1313 UTC, FEB 11, 1999

**NOT ALL FLIGHTS ARE
COUNTED IN
AVAILABLE FAA DATA**

**SOME COMPENSATION
IS REQUIRED TO
RELATE FLIGHTS TO
OBSERVED CONTRAILS**

