Contrails versus Contrail Cirrus From a Satellite Perspective

Patrick Minnis
NASA Langley Research Center, Hampton, VA USA

David. P. Duda, Thad L. Chee, Kirk Ayers, Sarah K. Bedka, Konstantin Khlopenkov, Douglas A. Spangenberg, Rabindra Palikonda, Kristopher T. Bedka, Robyn Boeke
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Objectives

- Estimate ratio of contrail cover to contrail cirrus (ConCi) for subset of contrail cirrus – how does it relate to a particular mask

  - definition of linear contrail?

- Determine differences in microphysical properties of contrails & ConCi
- Explore saturation effects of ConCi on linear contrail detectability or formation
- Provide a dataset for testing contrail/ConCi formation models

  - e.g., CoCiP

Approach

- Select scenes that appear to contain contrail cirrus using GEOSat & LEOSat imagery – time tracking
- Perform linear contrail analysis for each LEOSat image during day
- Perform standard cloud retrievals for each LEOSat image during day

  - assume all cirrus in scene is contrails or contrail cirrus

  - assume no retrievals are thin cirrus (upper bound of ConCi)

- Compute statistics for each LEOSat overpass & relate to flight density & meteorology

Data

Satellites

Terra MODIS: 1-km, ~1030 LST

Aqua MODIS: 1-km, ~1330 LST

NOAA 17 AVHRR: 1-km, ~1040 LST

NOAA 18 AVHRR: 1-km, ~1330 LST

NOAA 19 AVHRR: 1 km, ~1330 LST

GOES-E/W: 4 km, half hourly

Auxiliary Data

NASA LaRC Contrail Predictor: 40 km, hourly

- based on hourly Rapid Update Cycle (RUC) forecasts

Volpe Air Traffic Data, 2006

Methodology

Contrail Detection

MODIS: Duda methods (A-conservative, B-sensitive, C-ultrasensitive)

Duda et al., TAC-3

AVHRR: Mannstein technique *Mannstein et al., IJRS, 1999*

Cloud Retrievals

Visible Infrared Shortwave Infrared Technique (VISST)

Minnis et al., TGRS, 2011

=> Phase, tau, De, Tcld

Contrail Retrievals

VISST (AVHRR)

SIST (MODIS) *Bedka et al., TAC-3*

=> Con tau, De, Tcon

Subjective Scene Selection & Filtering

- Review LEOSat 11-12 BTD and RGB images for cases with outbreaks of contrails seemingly in otherwise clear UT air, (i.e., no natural cirrus)

  => *initial cases, both large and small outbreaks*

- Use GEOSat data to determine time sequence of cirrus formation
  - does it coincide with contrail formation?
  - is it free of other cirrus apparently unassociated with contrails?
  - portion seen by LEOSat variable & cirrus may move into scene

  => *irregular box shapes and sizes, some ambiguity*

- Contrails may form over low clouds and clear scenes

  => *use only pixels having COD < 2.0*

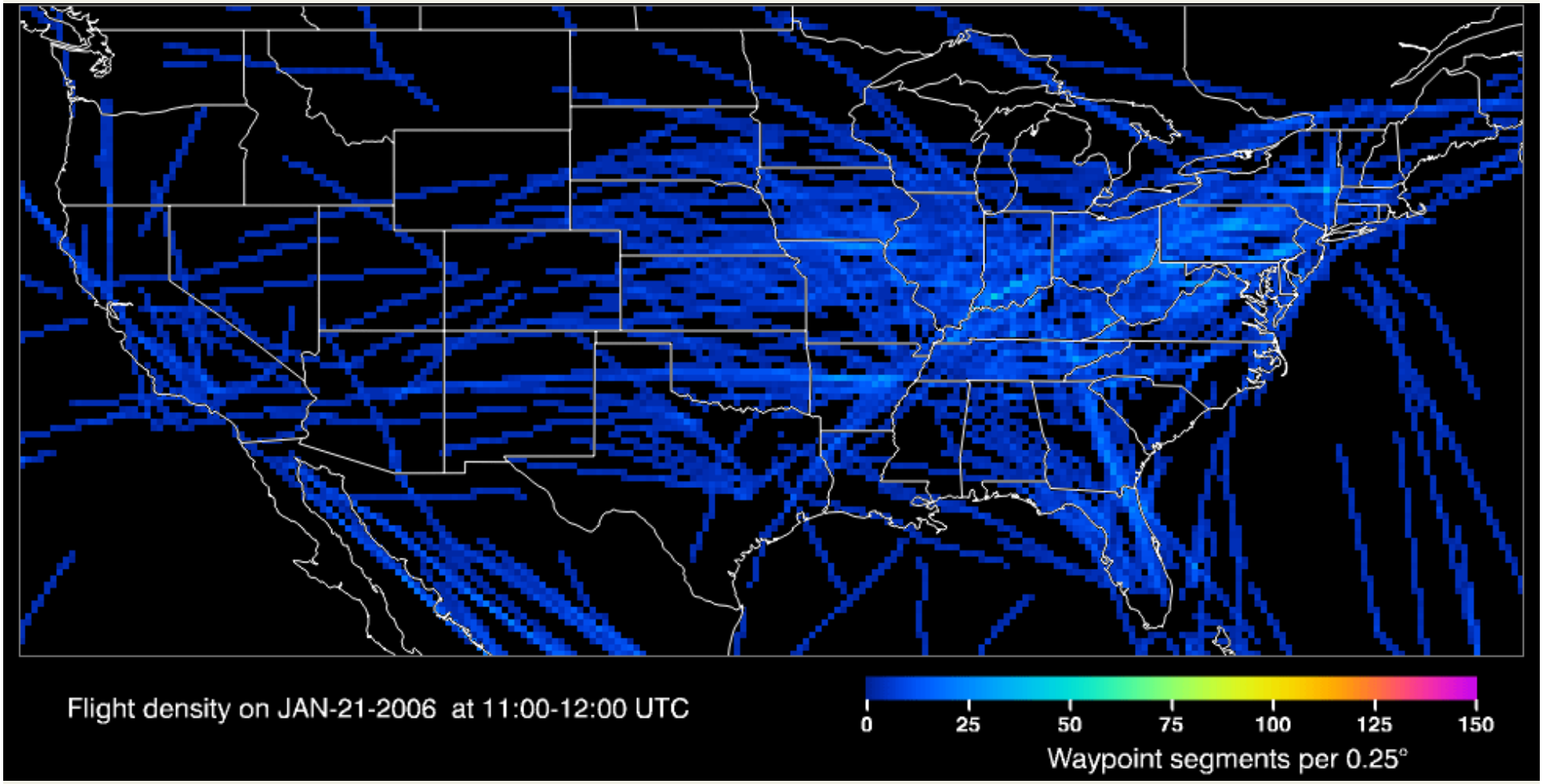
10 Selected Scenes

- 21 Jan 2006: Central US, large
- 13 Feb 2006: Central US, small
- 4 Nov 2006: Northern Mexico, large
- 5 Nov 2006: Northern Mexico, small
- 5 Nov 2006: Southeast US: small
- 6 Nov 2006: Southeast US: large
- 26 Dec 2006: Central US, small
- 28 Dec 2006: Midwest US, medium
- 31 Dec 2006: Southwest US, small
- 29 Dec 2010: Southeast US, large

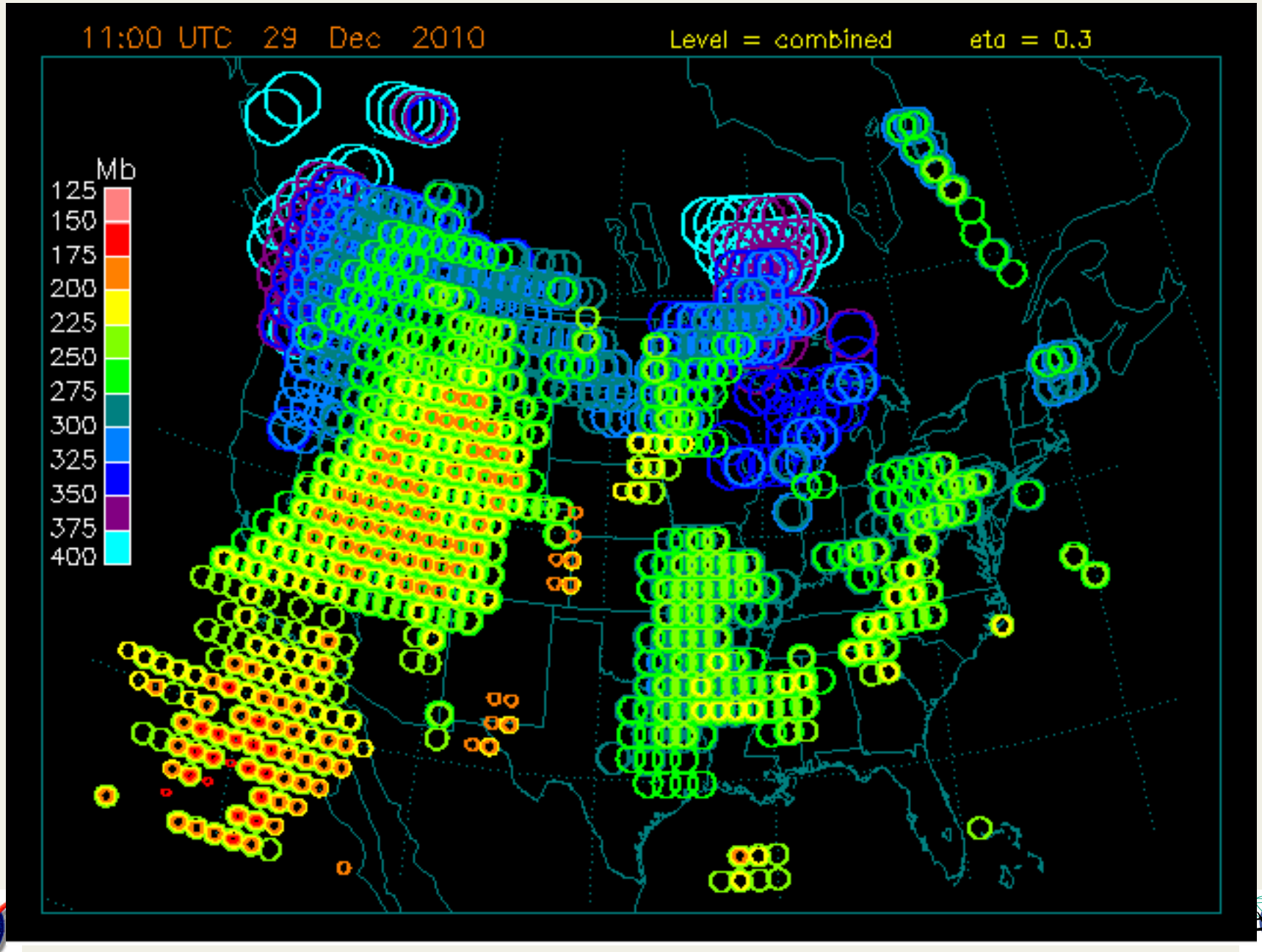
large > 40,000 cirrus pixels

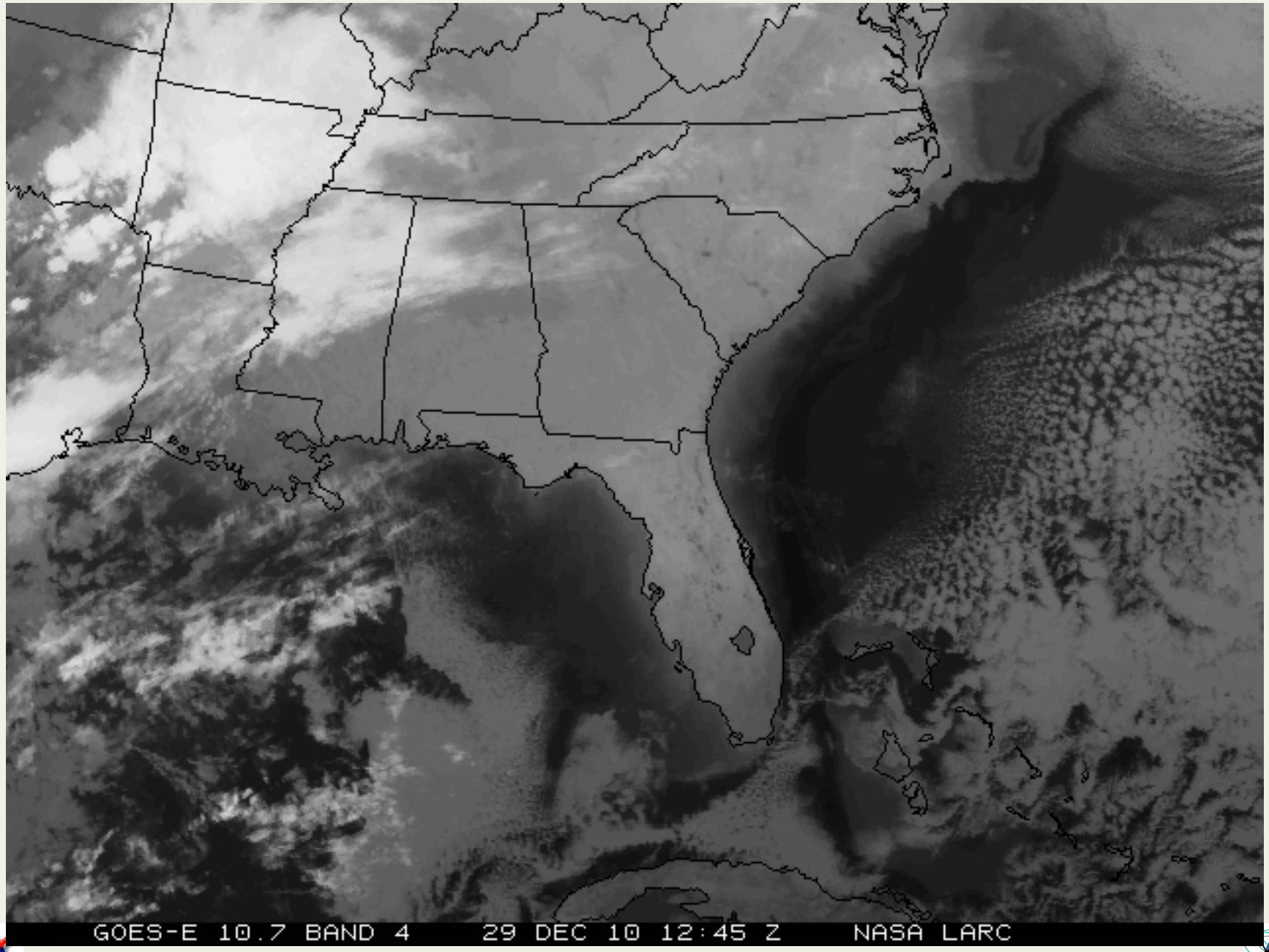
small $\leq$ 40,000 cirrus pixels

Typical Flight Density Over USA, 11- 23 UTC



Contrail Potential from RUC, 29 December 2010, 11-23 UTC

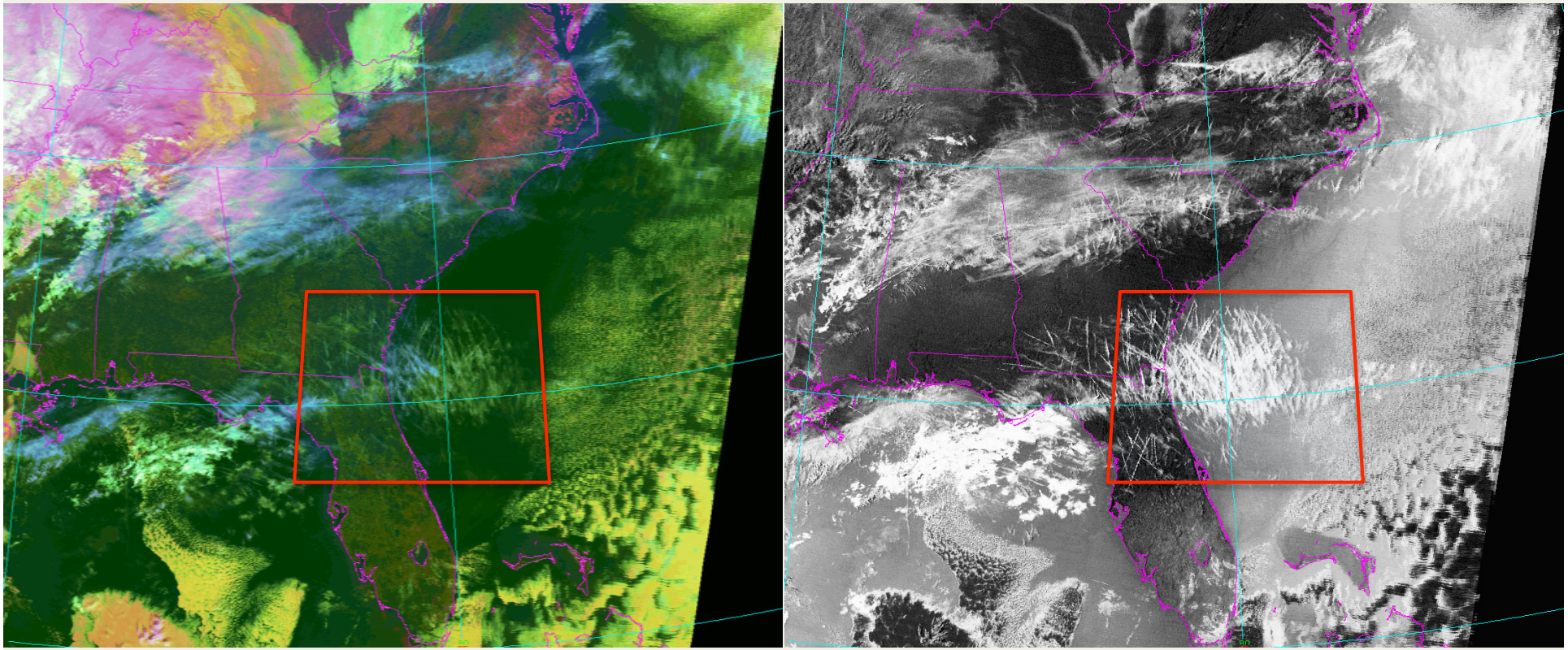



GOES-E 10.7 BAND 4 29 DEC 10 12:45 Z NASA LARC

Terra MODIS Imagery, 1626 UTC 29 Dec 2010

RGB

BTD11-12

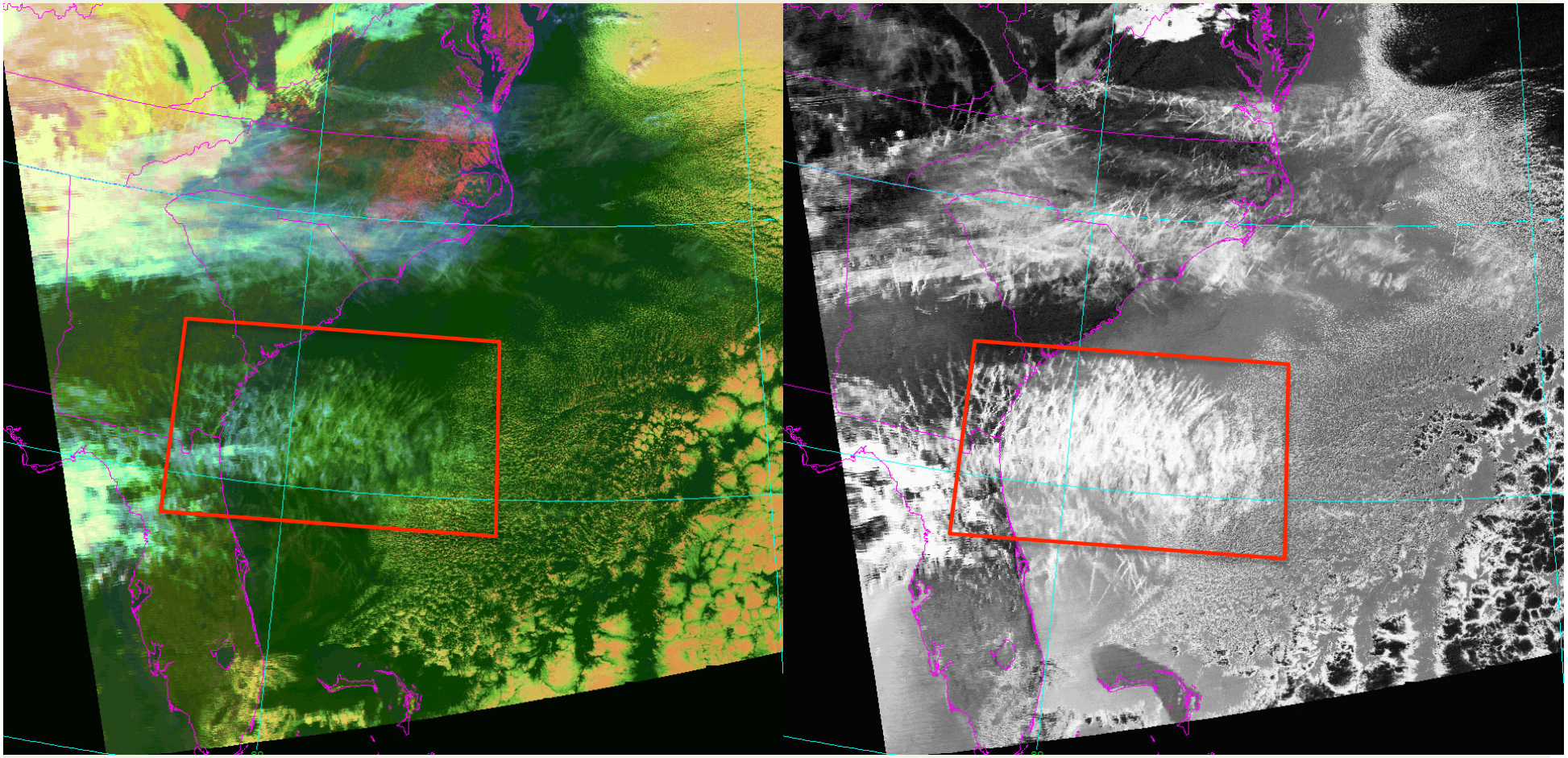


- Contrails forming in expected areas, but earlier than predicted
  - Florida, Georgia, S & N Carolina, Virginia

Aqua MODIS Imagery, 1626 UTC 29 Dec 2010

RGB

BTD11-12



- Contrails form in expected areas, but earlier than predicted
  - Florida, Georgia, S & N Carolina, Virginia, Atlantic
- Merging contrails producing stripy cirrus deck

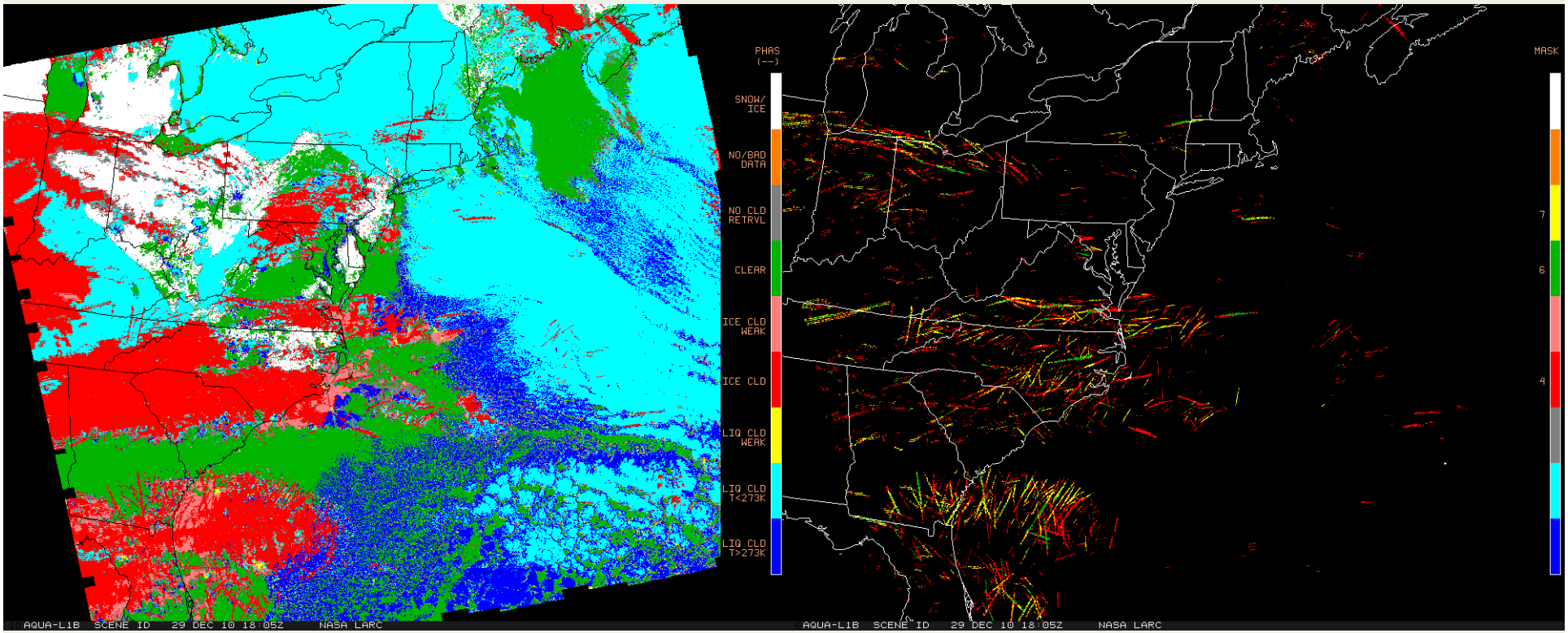
Aqua MODIS Imagery, 1626 UTC 29 Dec 2010

VISST Scene Type

- Blue, liq water
- white, snow
- Red, ice
- green, clear

Contrail Mask

- Red, C only
- green, B+C
- Yellow, A+B+C



- Most contrail pixels classified as ice, those not classified as ice are re-phased
- Many pixels off Florida & Virginia classified as cirrus, not contrails

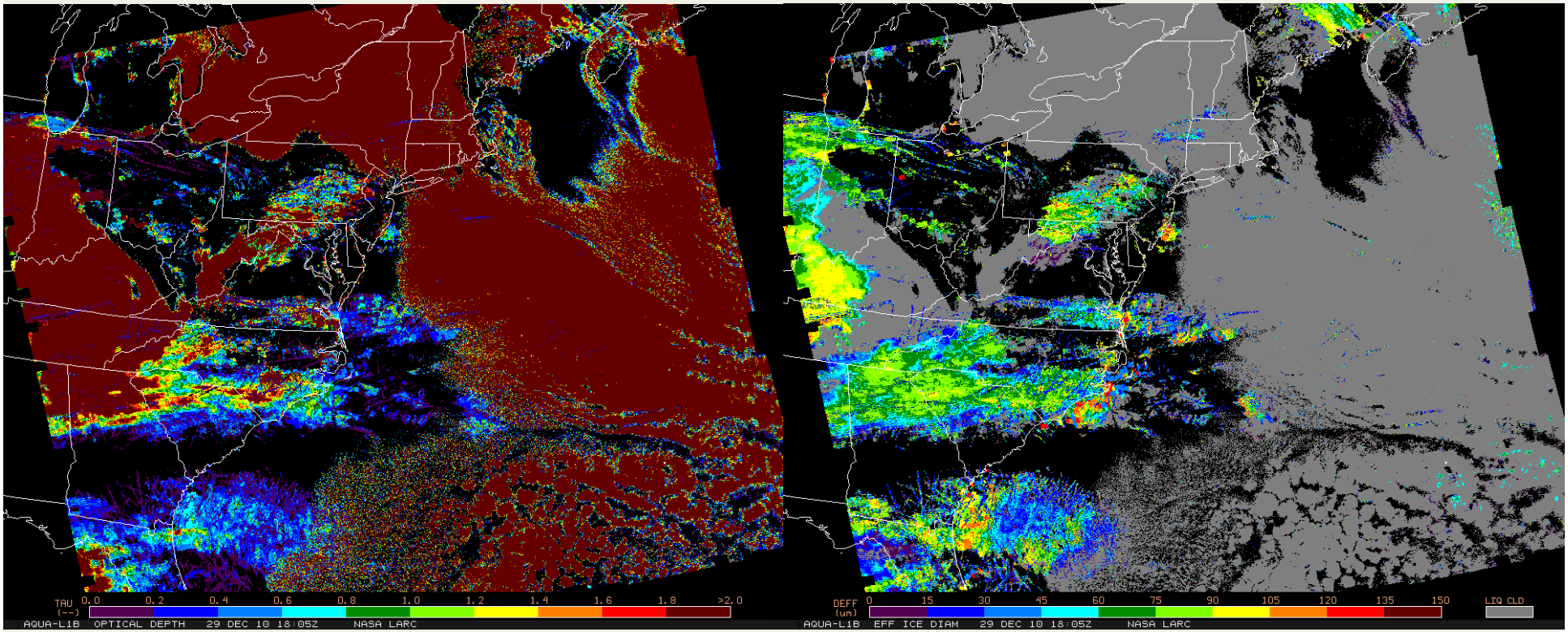
Aqua MODIS VISST Retrievals, 1804 UTC 29 Dec 2010

Optical Depth

- Blue, tau < 0.8
- Red, tau > 1.8

Effective Ice Diameter (μm)

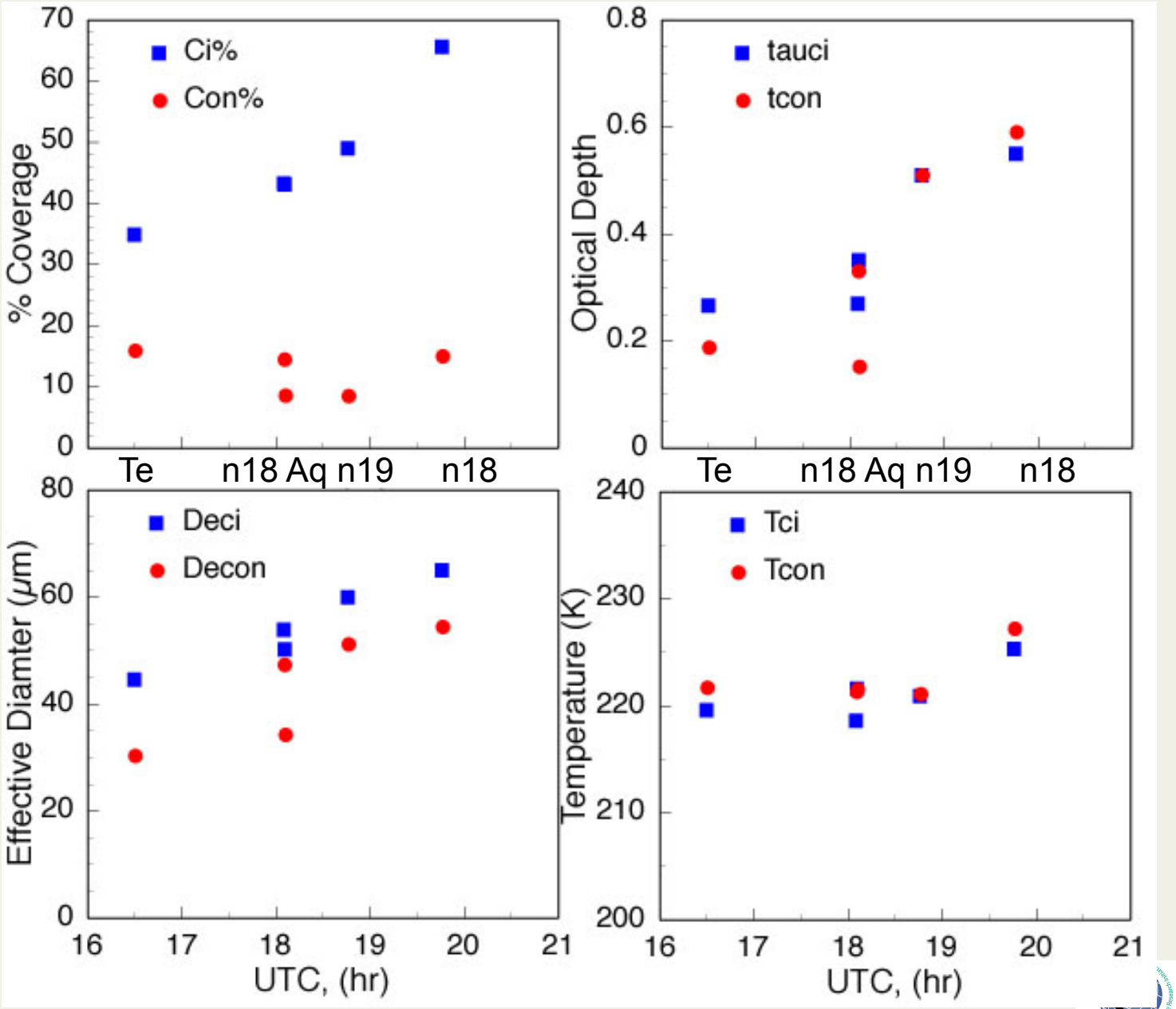
- Blue, De < 60 μm
- Green, De = 60-90 μm



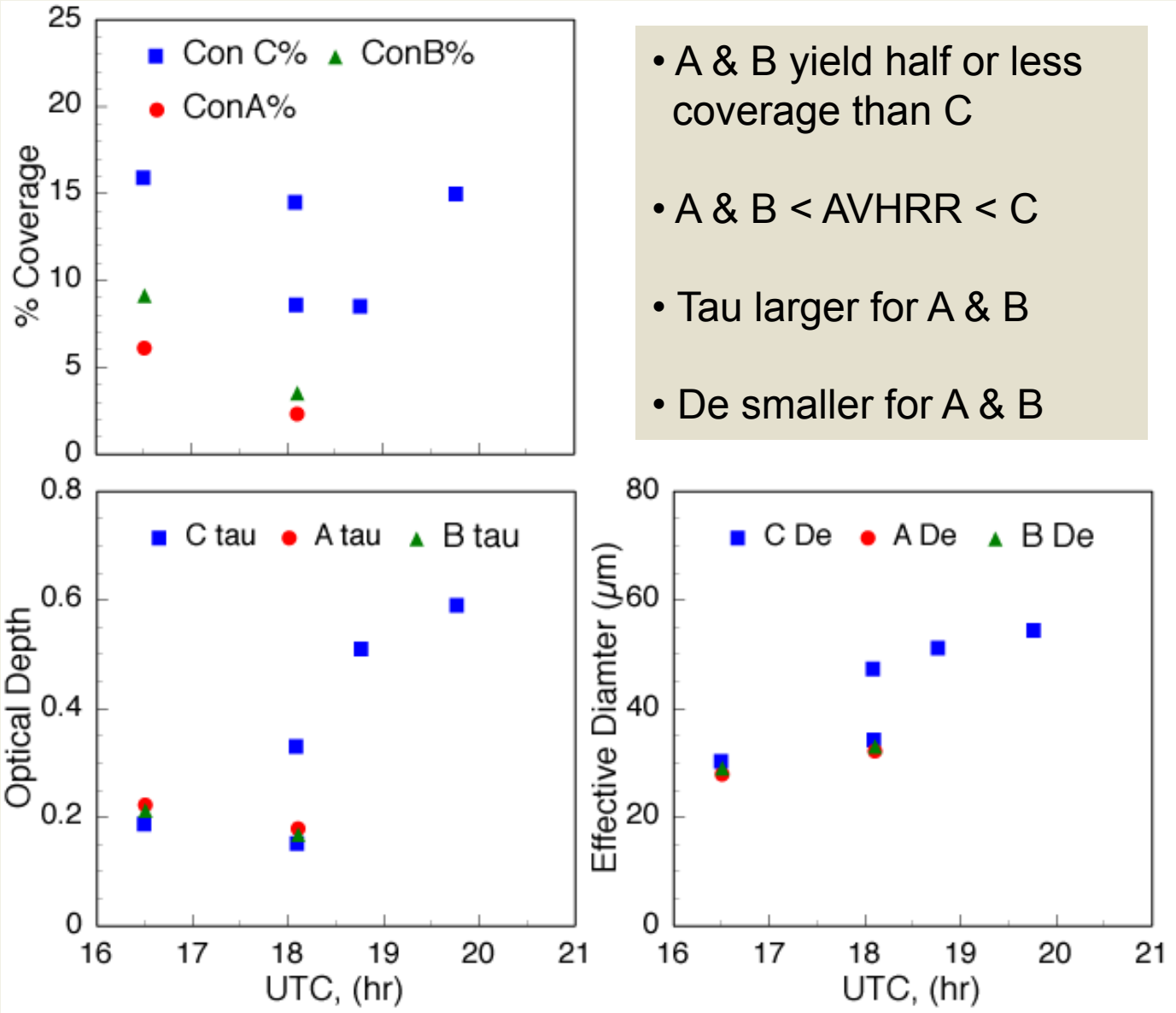
- Most contrails and ConCi with no lower clouds have tau < 1
  - many < 0.2 (purple)
- SIST results replace VISST for most contrails

Mean Retrieval Results for December 29, 2010, Florida

- Mask C used for MODIS
- SIST yields smaller tau & De than VISST
- AVHHR con results represent con + ConCi
- Con De < ConCi De



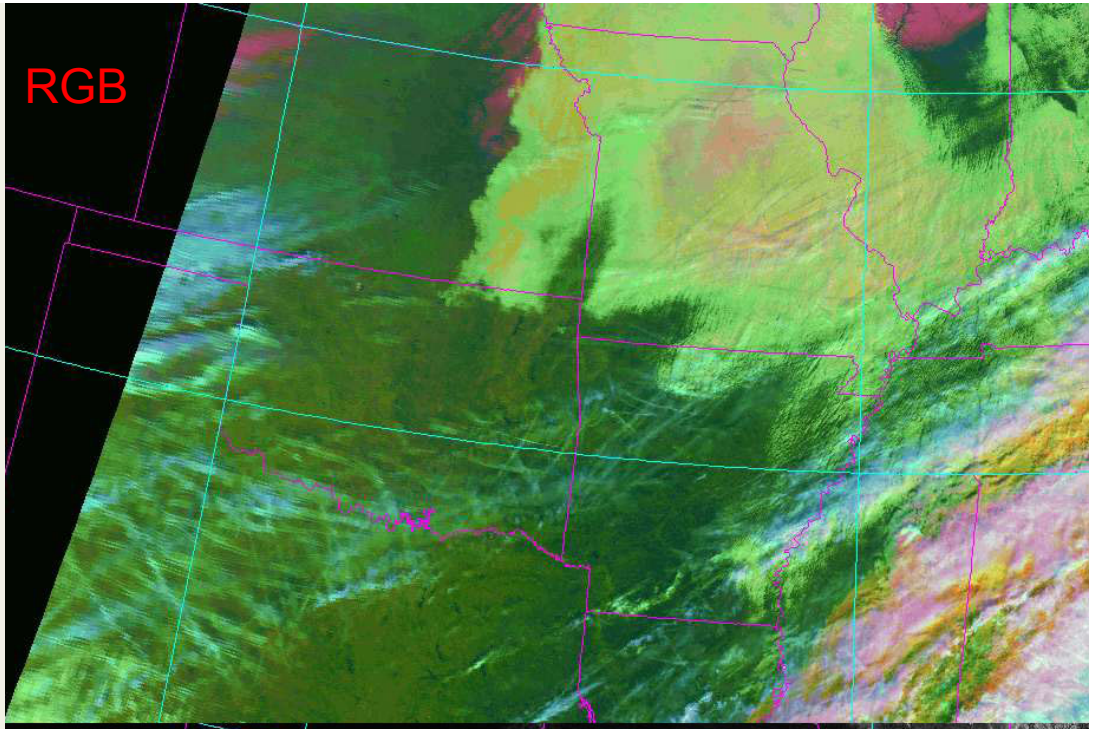
Mean Contrail Mask Results for December 29, 2010

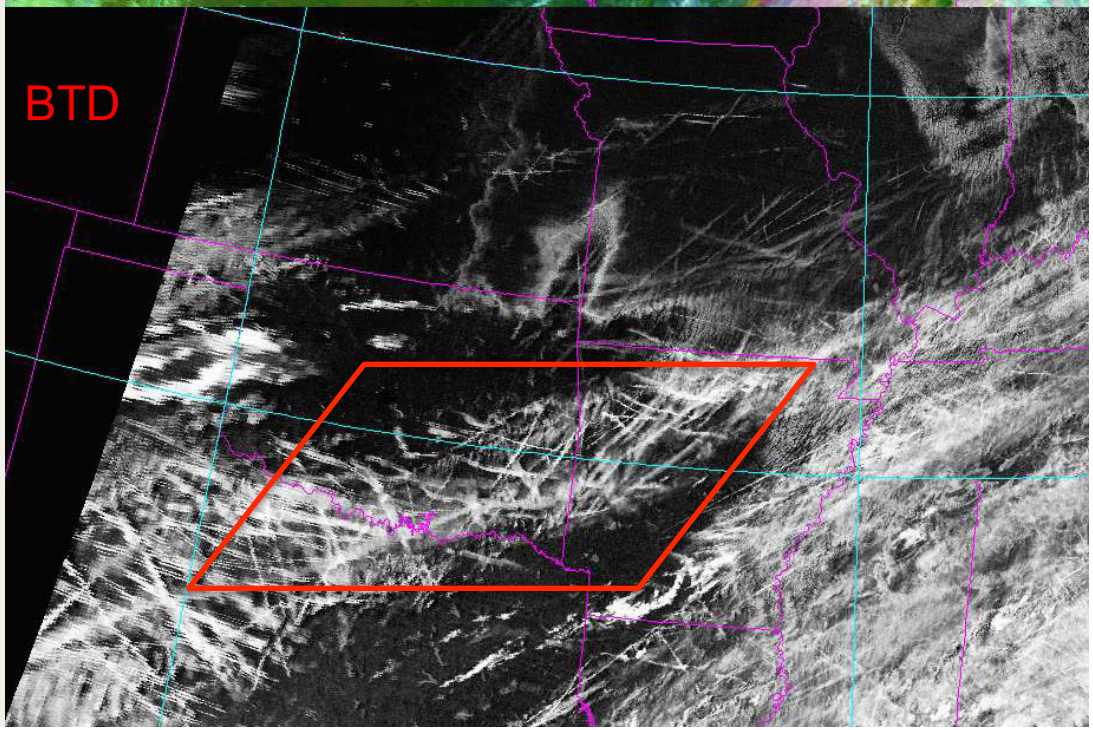


- A & B yield half or less coverage than C
- A & B < AVHRR < C
- Tau larger for A & B
- De smaller for A & B

Terra MODIS Imagery
21 Jan 2006, 1630 UTC

- Outbreak over clear & low clouds with snow
- Developed throughout the day
- Fast moving





Results

- Con: 42,375 px
  ConCi: 97,820 px
- tau

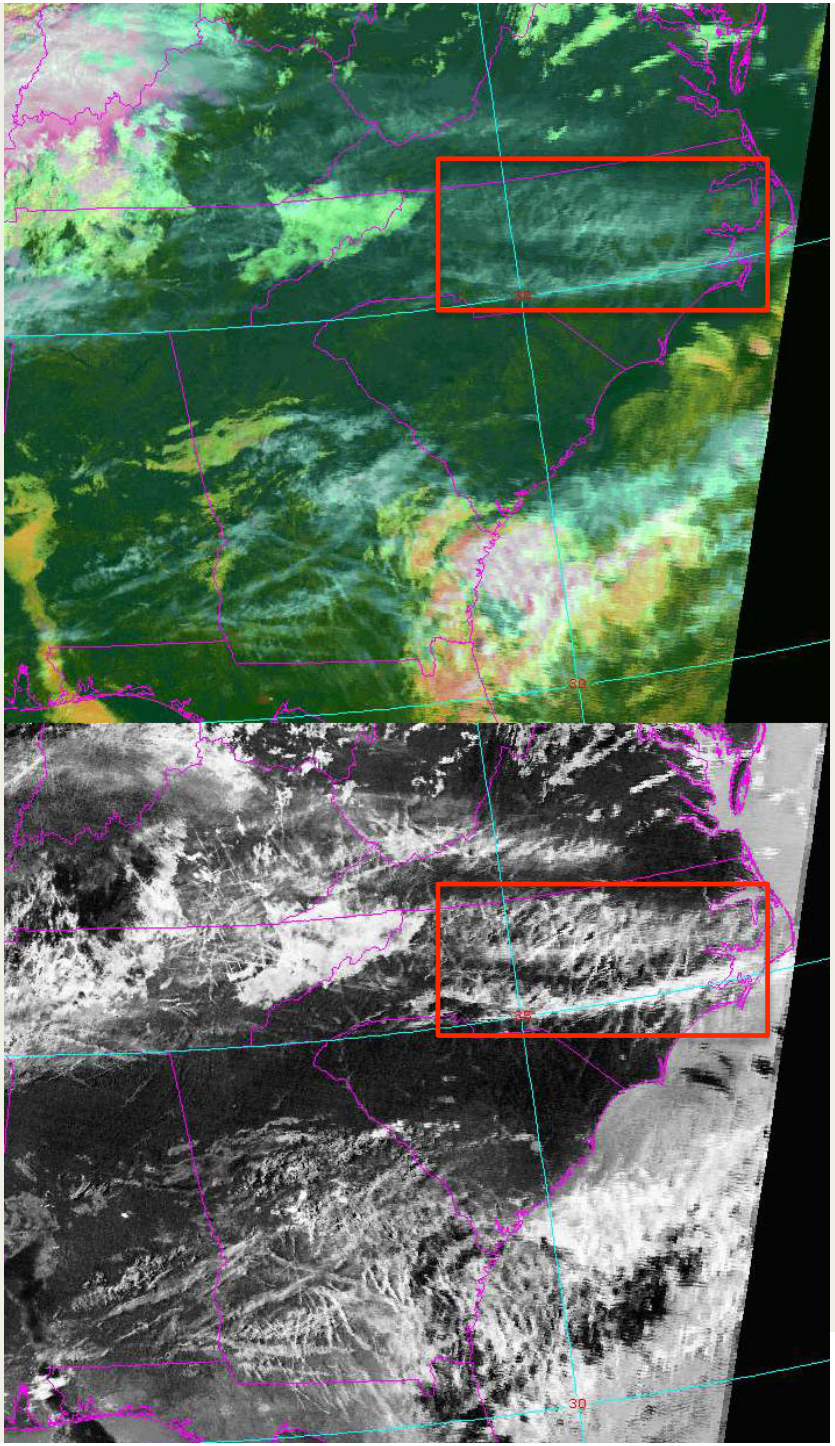
ConCi	A	B	C
0.36	0.19	0.18	0.16

- De

ConCi	A	B	C
37.5	27.1	28.3	29.1

Terra MODIS Imagery
5 Nov 2006, 1647 UTC

- Outbreak over clear
- Developed throughout the day
- Fast moving



Results

- C Con: 6,375 px
  ConCi: 24,922 px
- tau

ConCi	A	B	C
0.49	0.20	0.19	0.18

- De

ConCi	A	B	C
55.7	37.8	39.5	39.7

Average Statistics for Contrails & Contrail Cirrus

MODIS: 19 cases AVHRR: 10 cases

Area covered ~ 1.5 * Npix

	Con%	Con Npix	*Ci / Con	*Nci/ Con	Ci tau	Con tau	Ci De (μm)	Con De (μm)
A	3.1	4.67 k	6.5	8.3	0.36	0.17	41.8	27.2
B	4.9	7.48 k	4.7	5.8	0.39	0.16	42.9	28.8
C	9.3	14.2 k	2.5	3.0	0.48	0.14	46.5	30.2
AVHRR	6.3	10.9 k	4.3	5.0	0.56	0.55	56.7	44.4

** ratio = (Ci pix +Con pix) / (Con pix)*

- Avg MODIS Con tau < general average, impact of background?
- AVHRR tau too high, VISST overestimates tau for thin cirrus
- AVHRR Con tau = Con + ConCi; MODIS Con tau = Con only
- Ratio of total cirrus to linear contrail ranges from 2.5 to 8.3

Summary & Conclusions

- Developed initial methods to study linear contrails & ConCi
  - generated preliminary results
- MODIS analysis yields typical linear contrail tau & De
  - contrails separated from background
- AVHRR analysis yields larger values of tau & De for both contrails & ConCi
  - contrails include background
- Contrail cirrus coverage varies from 1.5 to 8 X Con coverage depending on the mask
  - mask defines linear contrails; how to compare with models?
- ConCi optical depth 2 – 3.5 X Con tau depending on mask
- ConCi crystal size ~ 1.5 X Con De (AVHRR different)
- Only considered ConCi in absence of natural cirrus

Future Efforts

- Refine methods to analyze linear contrails & ConCi in imagery
  - flexible box shape
  - eliminate dependence on visible channel (WV, CO2)
  - try flight track matching to obtain degree of overlap
- Adjust AVHRR analysis to be more like MODIS technique
  - same approach to retrievals
  - analyze more cases (contrail aging)
- Modify MODIS retrievals to compute tau/De for both contrail & background
  - help study saturation effects
  - yields total contrail impact
- Relate results to meteorology
  - T, RH, v, du/dz, etc.
  - may aid parameterizations
- Work with in situ and active remote obs to validate
  - e.g., CONCERT
- Collaborate with modelers to validate models
  - may be only way to address natural vs ConCi ambiguity