Overview of the Deep Convective Clouds and Chemistry (DC3) Field Campaign

Mary Barth, William Brune,

Christopher Cantrell, Steven Rutledge

Jim Crawford, Frank Flocke, Heidi Huntrieser

and the over 200 participants including > 100 students and 30 post-doctoral scientists

DC3 is sponsored by the National Science Foundation (NSF), NASA, NOAA, and DLR

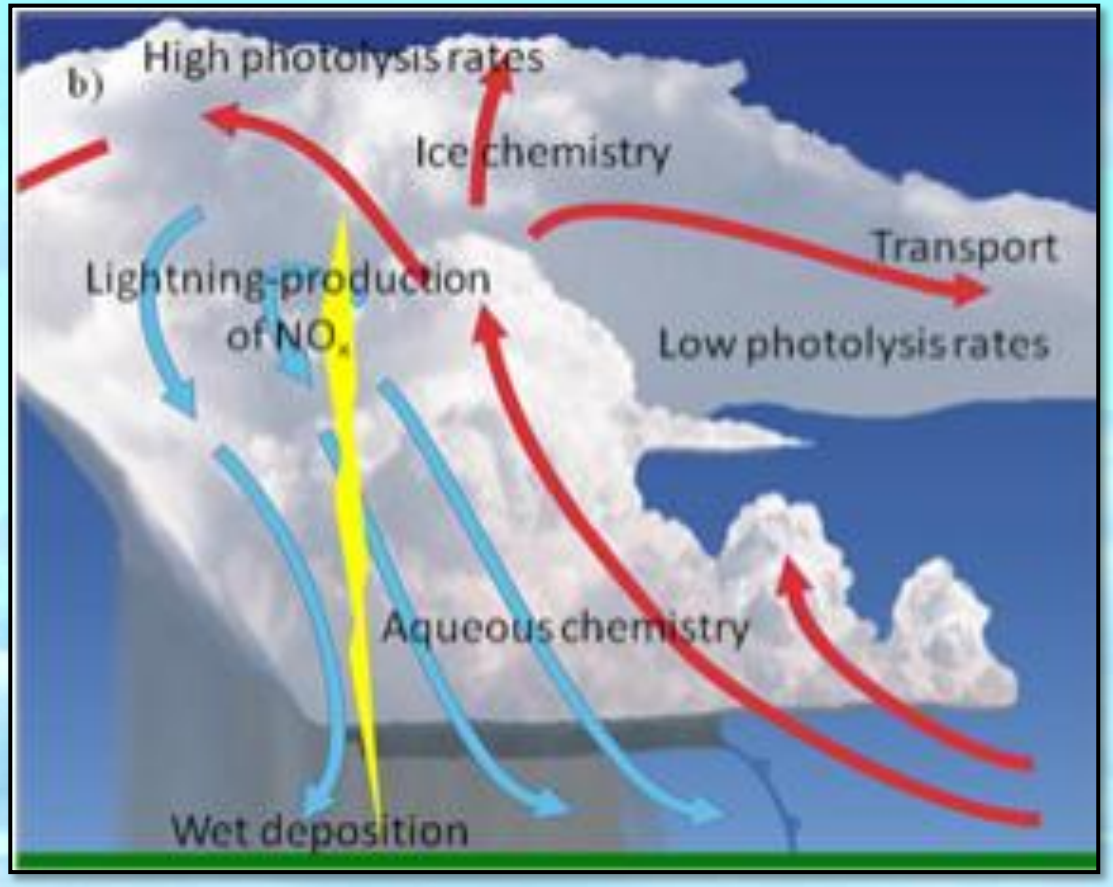
Motivation

- Deep convection alters the composition of the UTLS region
  - Transport of BL species (NO_x, VOCs, CO, H_2O) to the UT $\rightarrow$ BL-like photochemistry and production of free radicals (OH, HO_2, RO_2)
  - Transport efficiency varies with species
  - Lightning production of nitrogen oxides (NO_x)
  - $HO_x + NO_x \rightarrow$ ozone (O_3) as cloud outflow ages
- Ozone has climate impacts and affects UV radiation reaching the surface
- Previous studies involving sampling of mid-latitude UTLS region indicate significant convective influence

Goals of the DC3 Field Campaign

1. To characterize thunderstorms and examine how they process chemical compounds that are ingested into the storm (transport, scavenging, lightning, chemistry)

2. To quantify the chemical changes in the storm outflow over the following 24 hours (chemical aging)



DC3 Platforms

Aircraft: NSF/NCAR GV, NASA DC-8, DLR Falcon

NASA DC-8

NSF/NCAR GV

DLR Falcon-20

GV: NO_x, O_3, CO, CO_2, CH_4, CH_2O, VOCs, OVOCs, peroxides, SO_2, HNO_3, HNO_4, radiation, particle size distributions, cloud particle images, H_2O, CN

DC-8: O_3, O_3 & aerosol profiles, NO_x, HNO_3, NO_y, PANs, ∑ANs, ∑PNs, HNO_4, CH_2O, CO, CO_2, CH_4, VOCs, OVOCs, peroxides, HO_x, radiation, H_2O, SO_2, CN, particle size distributions, BC, f(RH), particle composition, aerosol optical properties

Falcon: O_3, NO, NO_y, CO, CO_2, CH_4, VOCs, SO_2, $j(NO_2)$, particle size distributions and number, aerosol absorption, BC

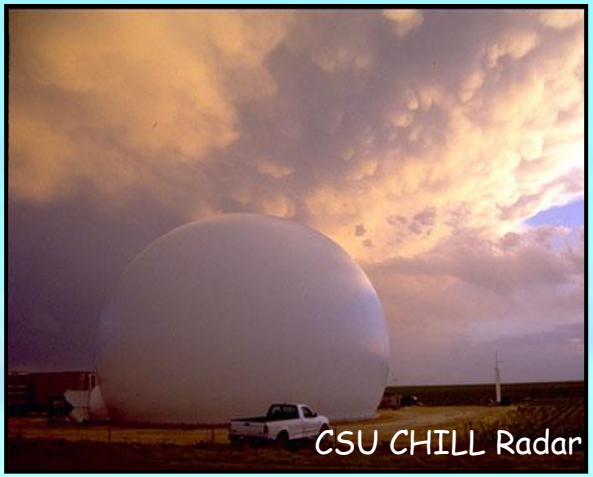
DC3 Facilities – Cloud Characterization

At each of the three study regions:

RADAR: Fixed and mobile multi-Doppler polarimetric radars

LMA networks: used to derive lightning properties

Sondes: pre-storm and storm penetrating profiles


CSU CHILL Radar


UA-H ARMOR Radar


NMT Lightning Antenna


OU SMART Radar


Weather Balloon Launch

DC3 Study Regions – Cloud Characterization

When: May-June 2012

Where: Aircraft based in Salina, KS

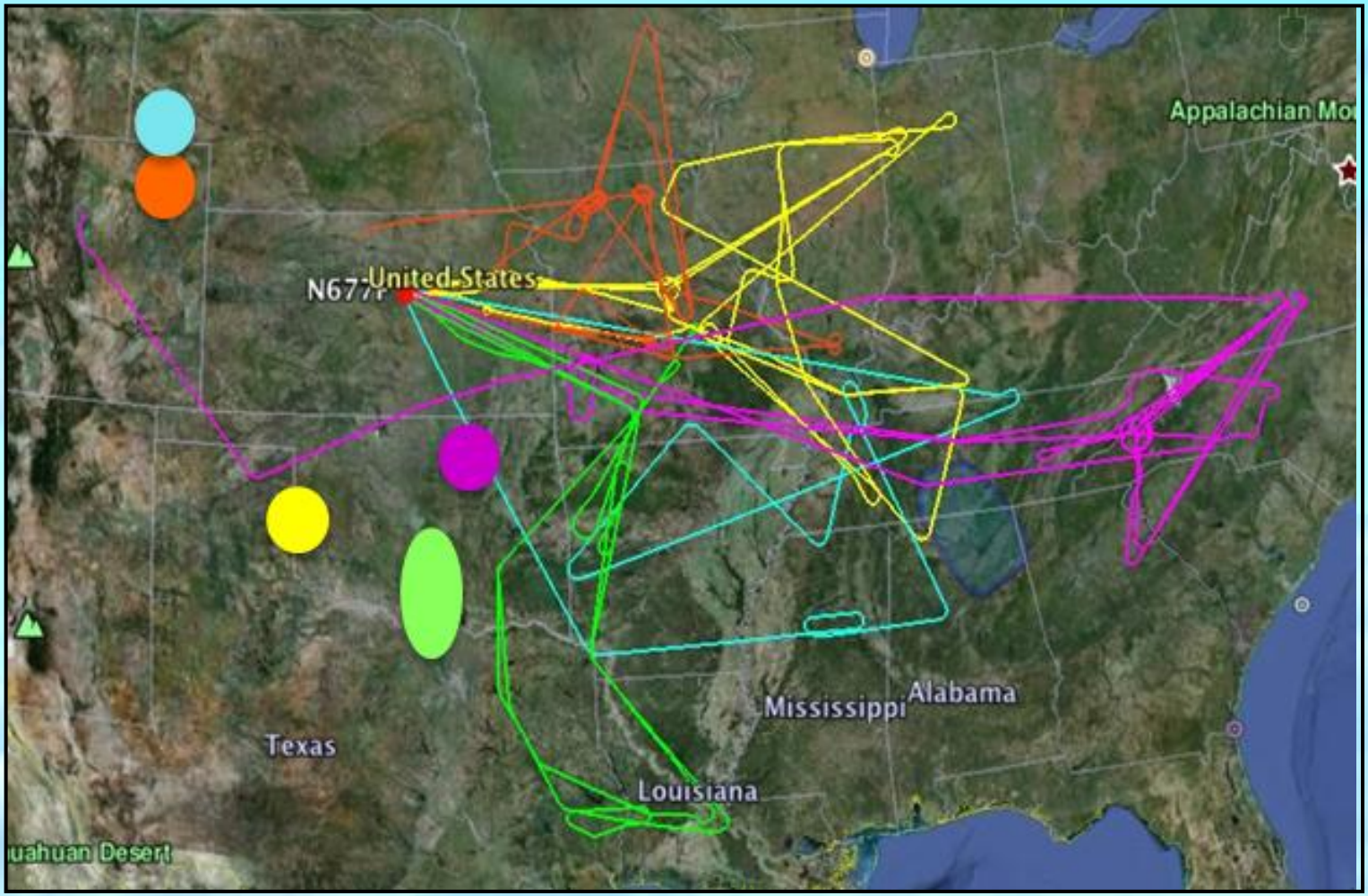
Sampled storms in:

- **NE Colorado**
- **W Texas to central Oklahoma**
- **N Alabama**

DC3 Study Regions – Outflow Aging

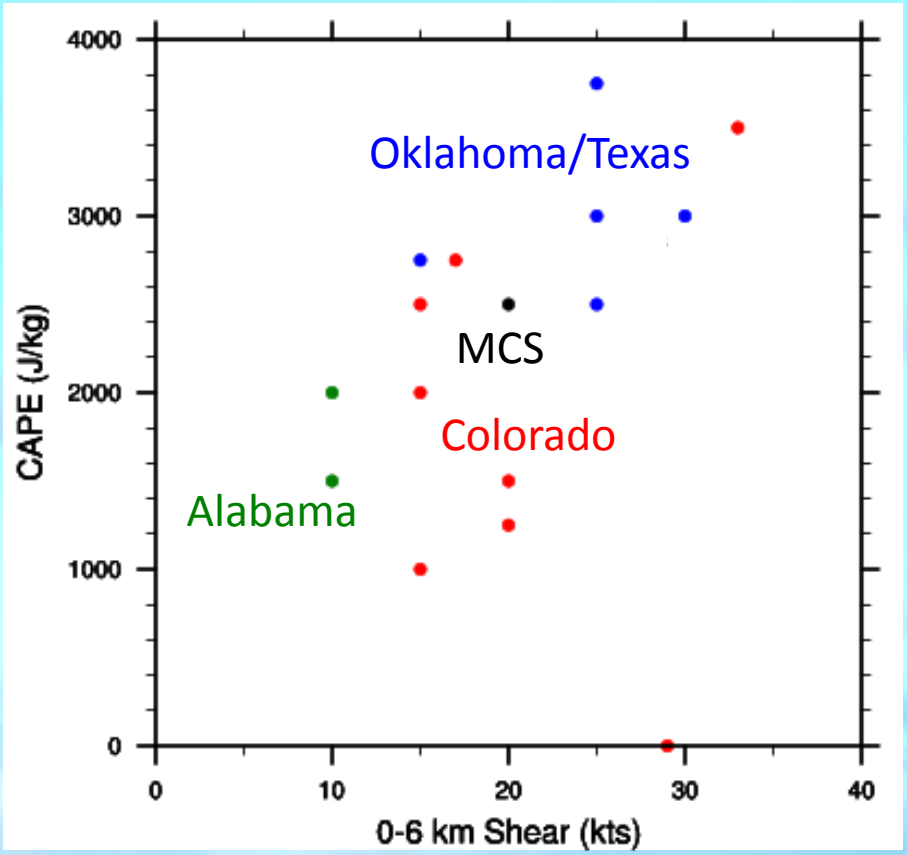
Where: Sampled photochemical aging of convective outflow in the central to eastern U.S.

May 25, 26
May 29, 30
June 6, 7
June 16, 17
June 22, 23



DC3 Storm Cases

NCAR WRF forecast CAPE and 0-6 km shear ~1 hour before convection (Weisman, Barth, Manning, Wang, Bela)



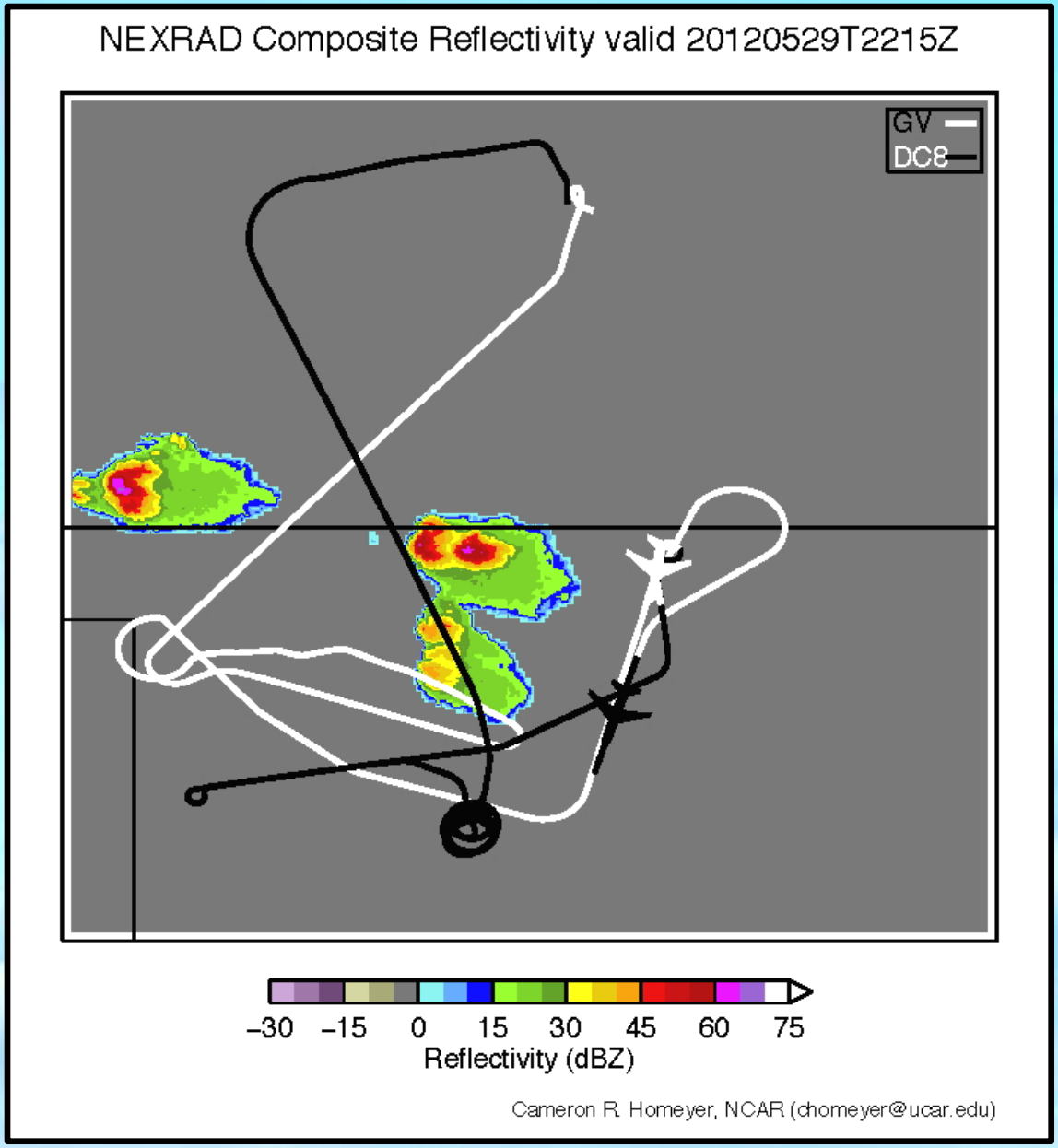
***Colorado storms**: high shear and high cloud bases resulting in ice-dominated storms.*

***Central Oklahoma and West Texas**: shear-driven thunderstorms with large CAPE producing strong, severe storms.*

***Northern Alabama storms**: low shear with moderate CAPE creating short-lived storms.*

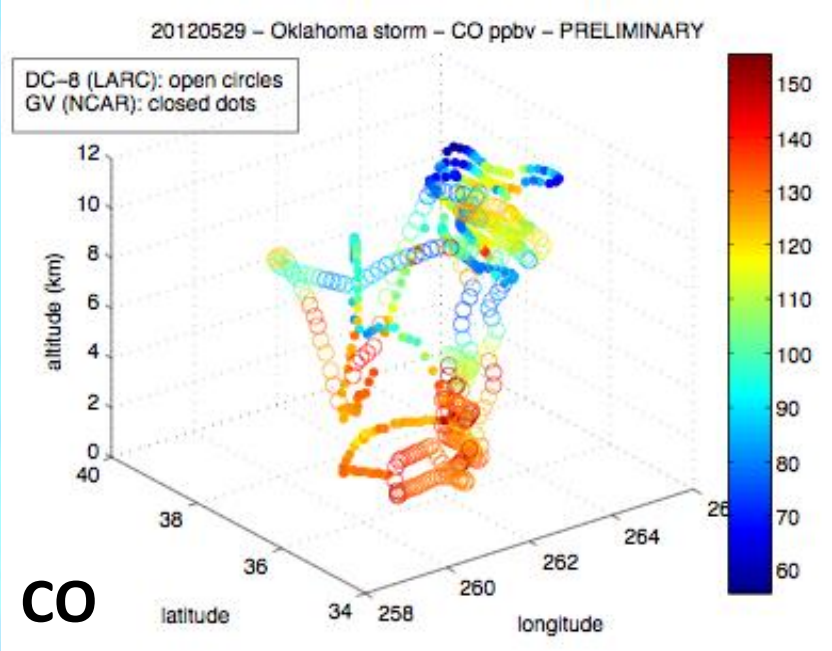
***Mesoscale Convective System** (MCS) sampled on June 11: both high shear and CAPE.*

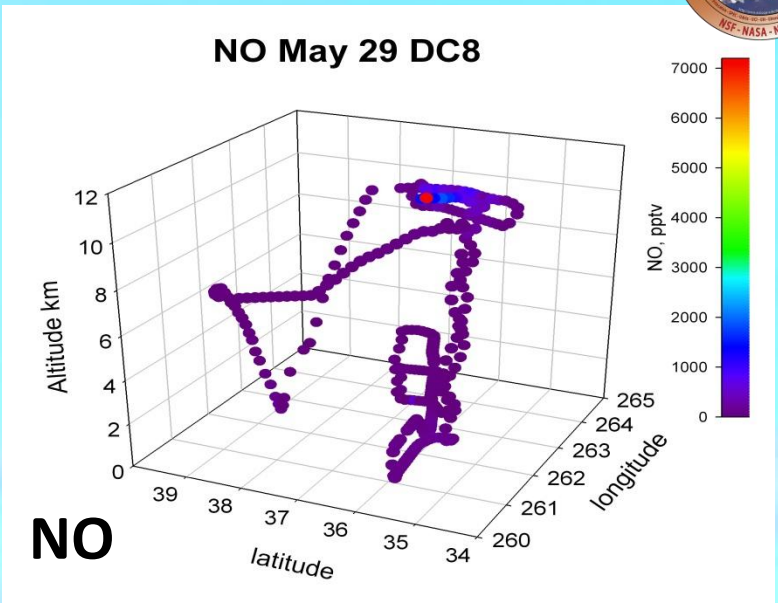
29 May 2012 Flight Tracks

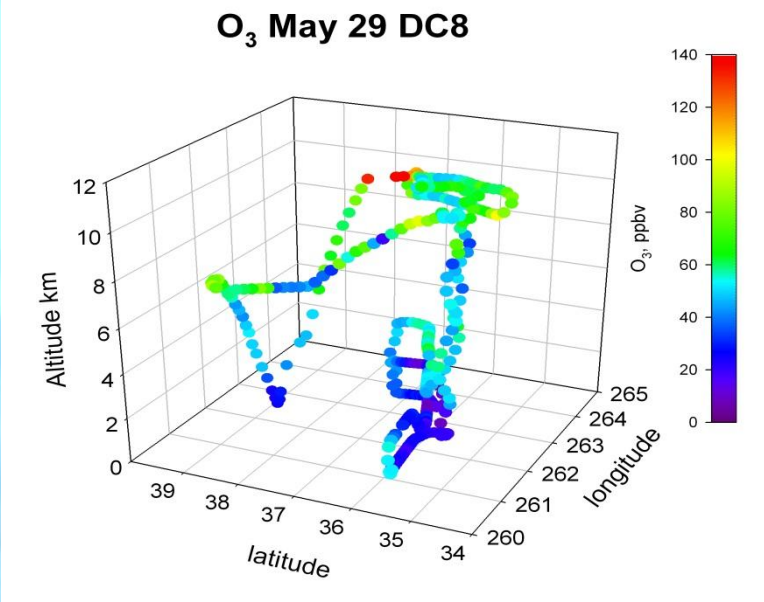


Cameron Homeyer (NCAR/ASP/ACD) produced movie.

29 May 2012 – Evidence of Transport and LNO_x







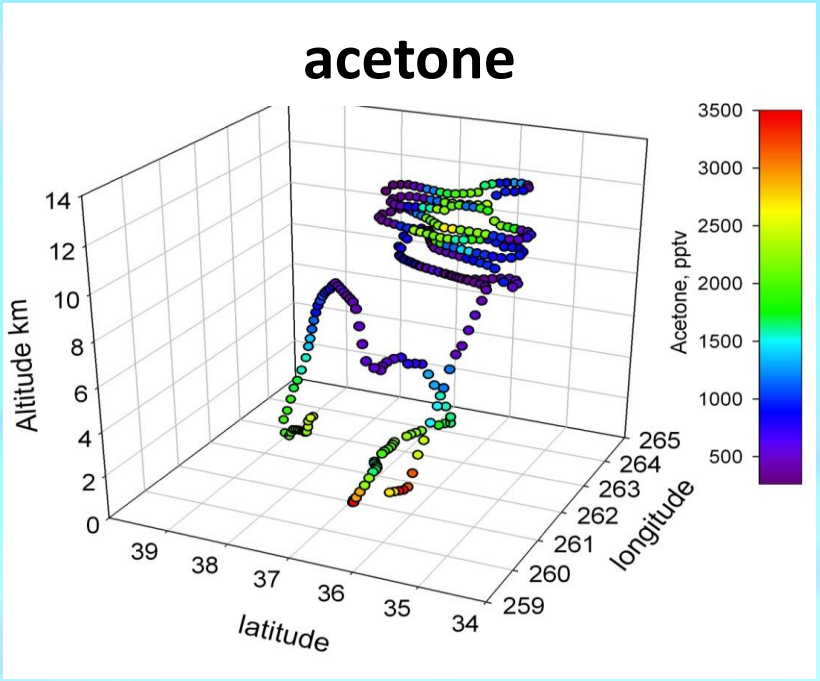
***** Preliminary Data *****

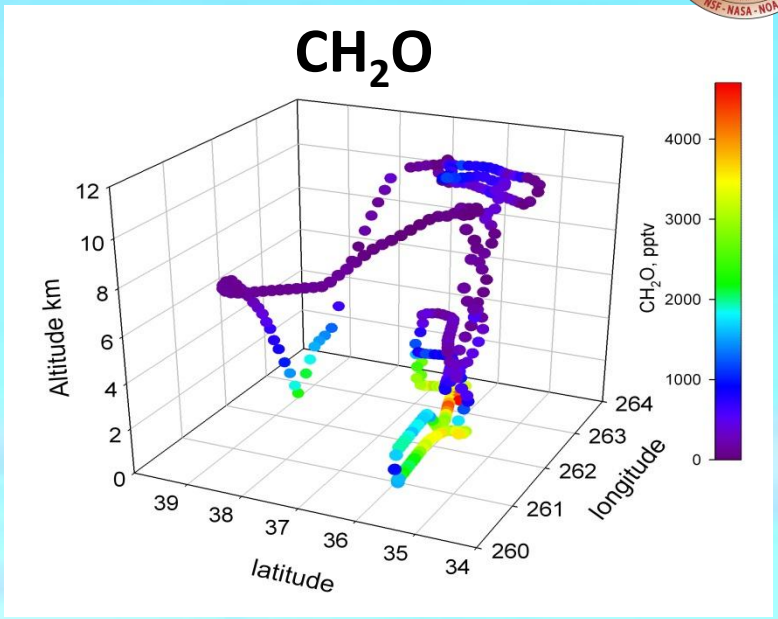
GV data: Weinheimer, Campos, Flocke, Knapp, Montzka (NCAR)

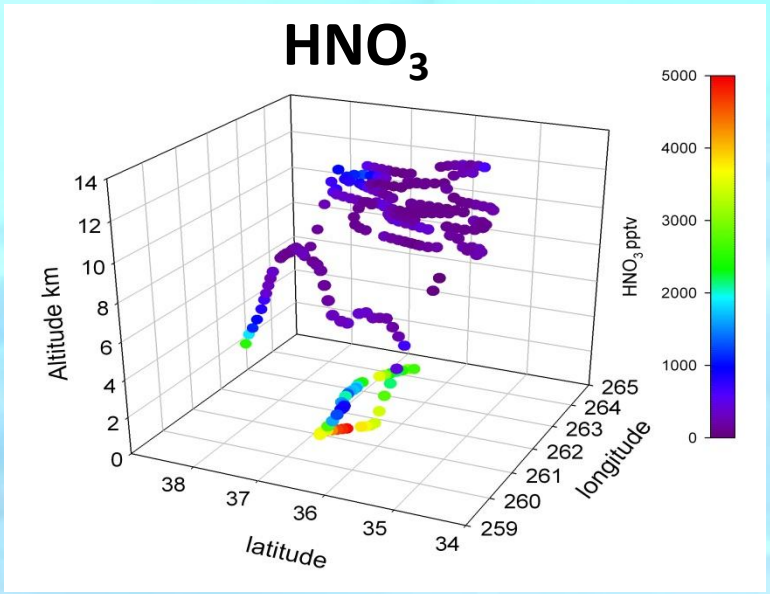
DC-8 data: Ryerson, Pollack, Peischl (NOAA/ESRL), Diskin, Sachse (NASA-Langley)

Plots courtesy Bill Brune (PSU)

29 May 2012 – Evidence of Scavenging







Comparison of scavenging effects on soluble species (from Eric Apel).

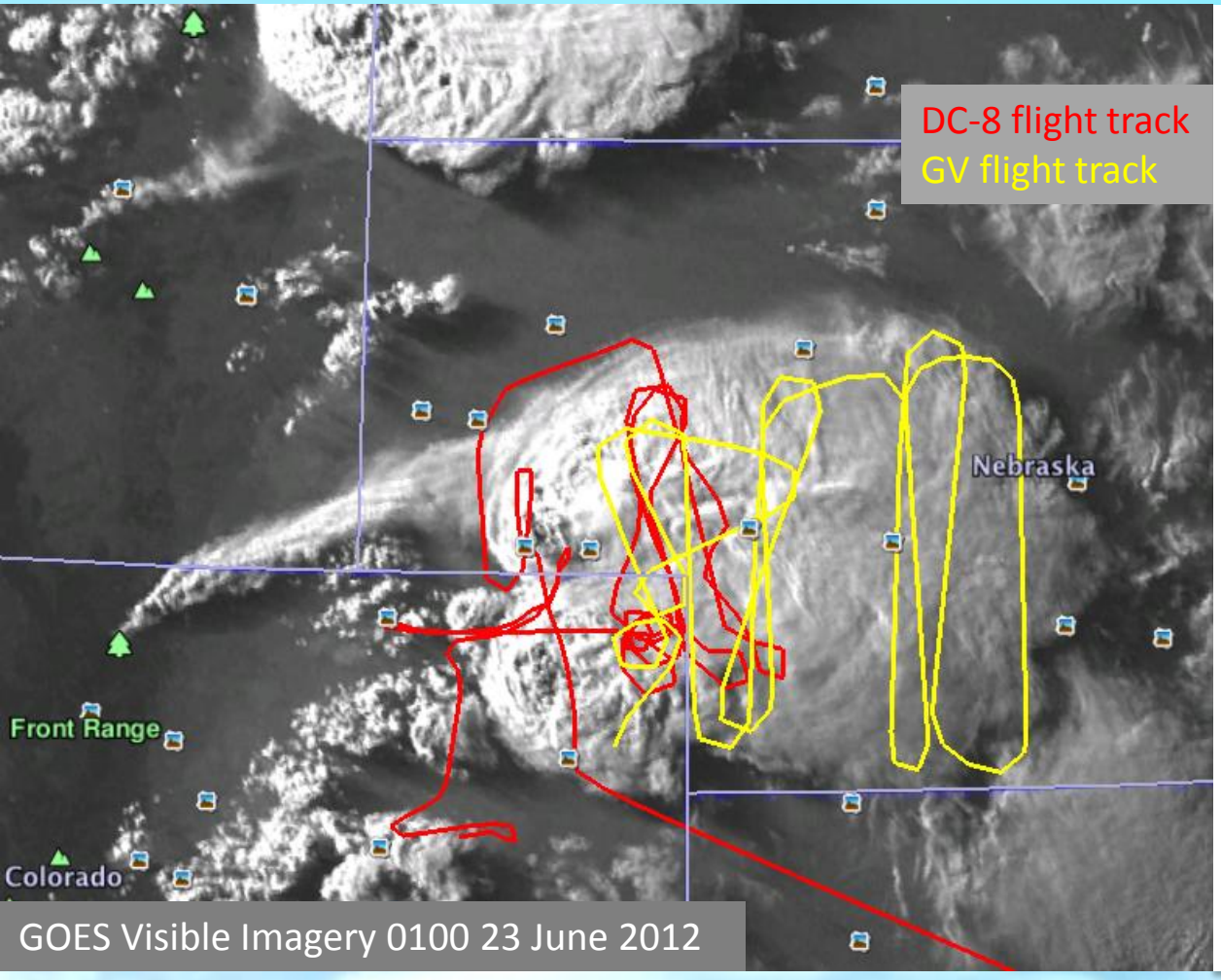
***** Preliminary Data *****

HNO_3 data: Greg Huey (Georgia Tech)

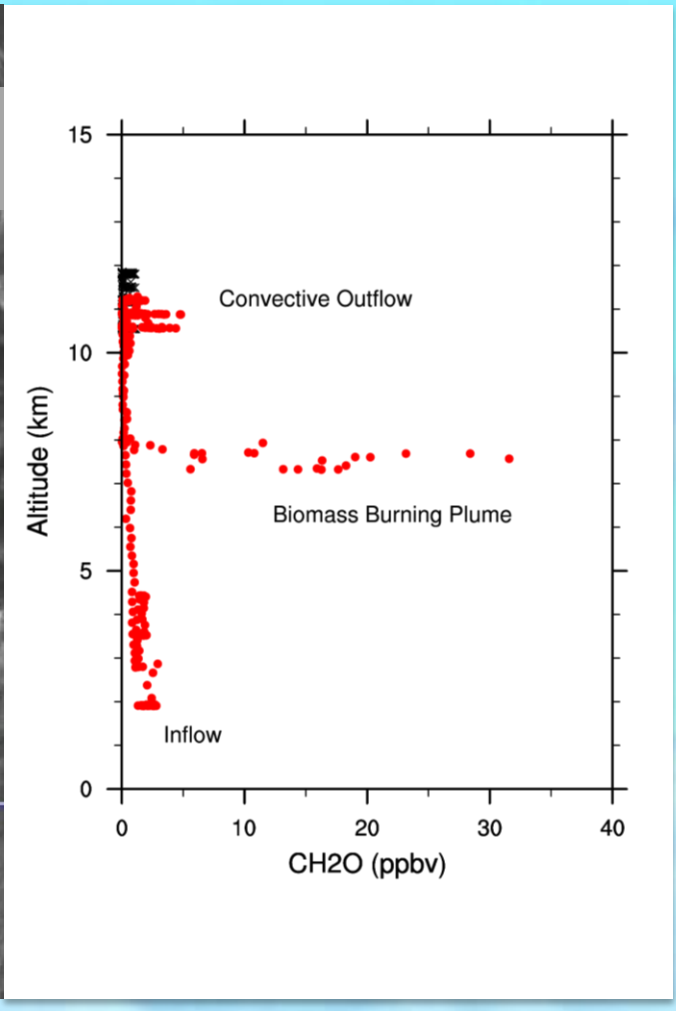
TOGA data: Eric Apel, R. Hornbrook, A. Hills (NCAR) ; Dan Riemer (U. Miami)

CH_2O data: Alan Fried, J. Walega (now at U. Colorado)

Smoke Plume Entrained into Storm: 22 June 2012



GOES Visible Imagery 0100 23 June 2012

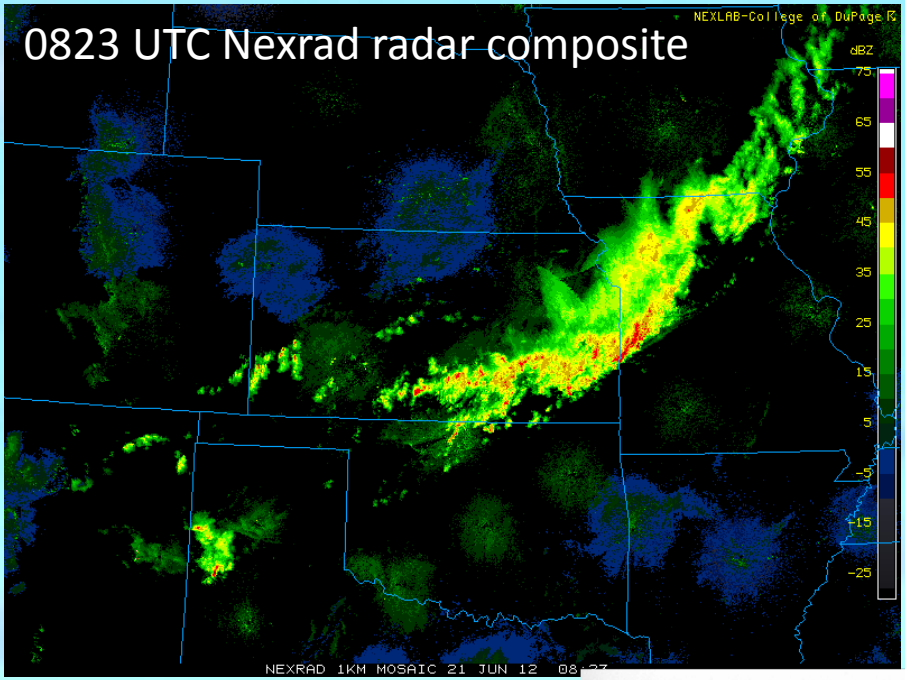


*** **Preliminary Data** ***

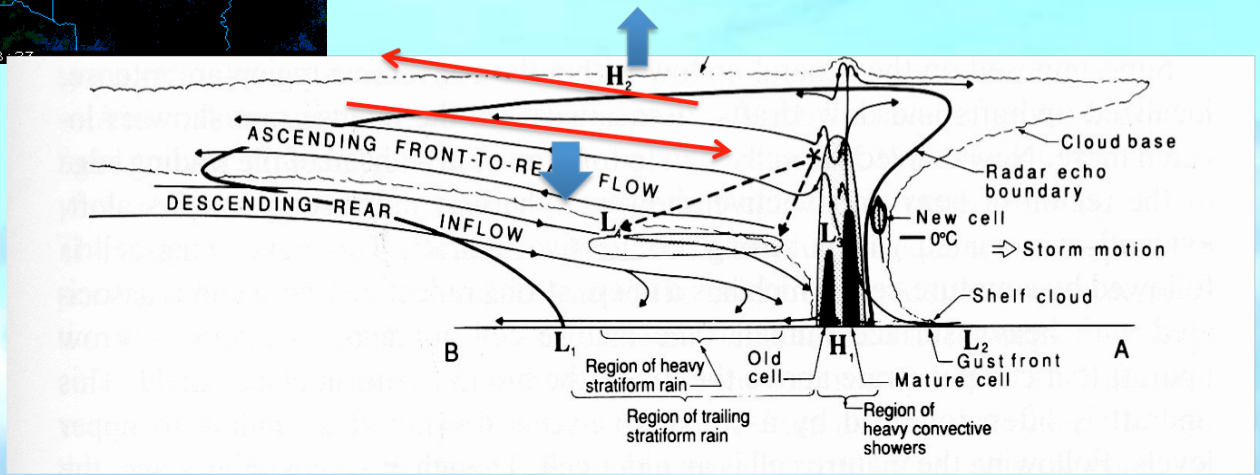
DC-8 data: A. Fried, J. Walega (U. Colorado); T. Hanisco (NASA/GSFC)

GV data: D. Richter, P. Weibring (U. Colorado)

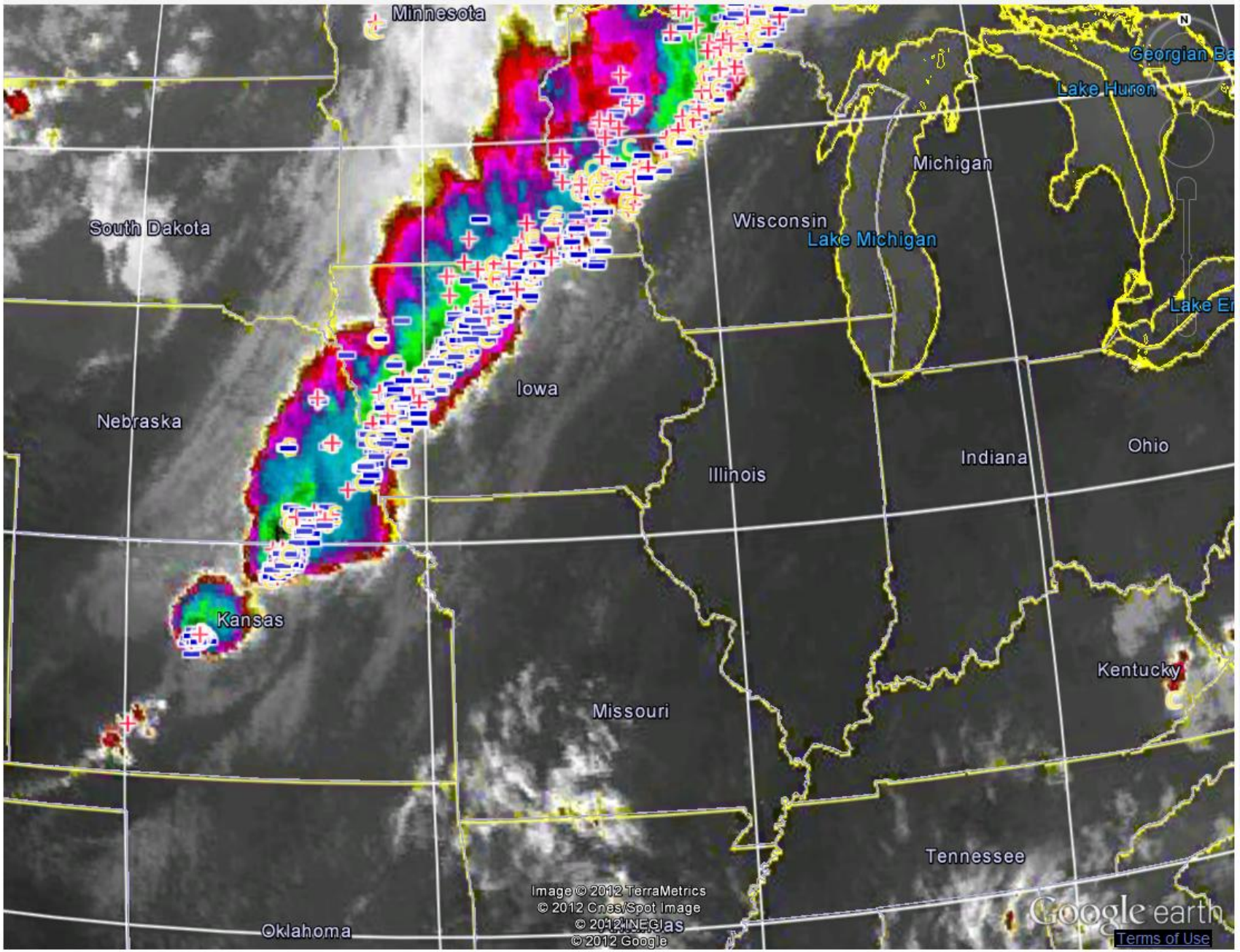
Photochemical Aging Case: 21 June 2012



Mesoscale Convective System



Houze, Rutledge, Biggerstaff and Smull (1989), BAMS



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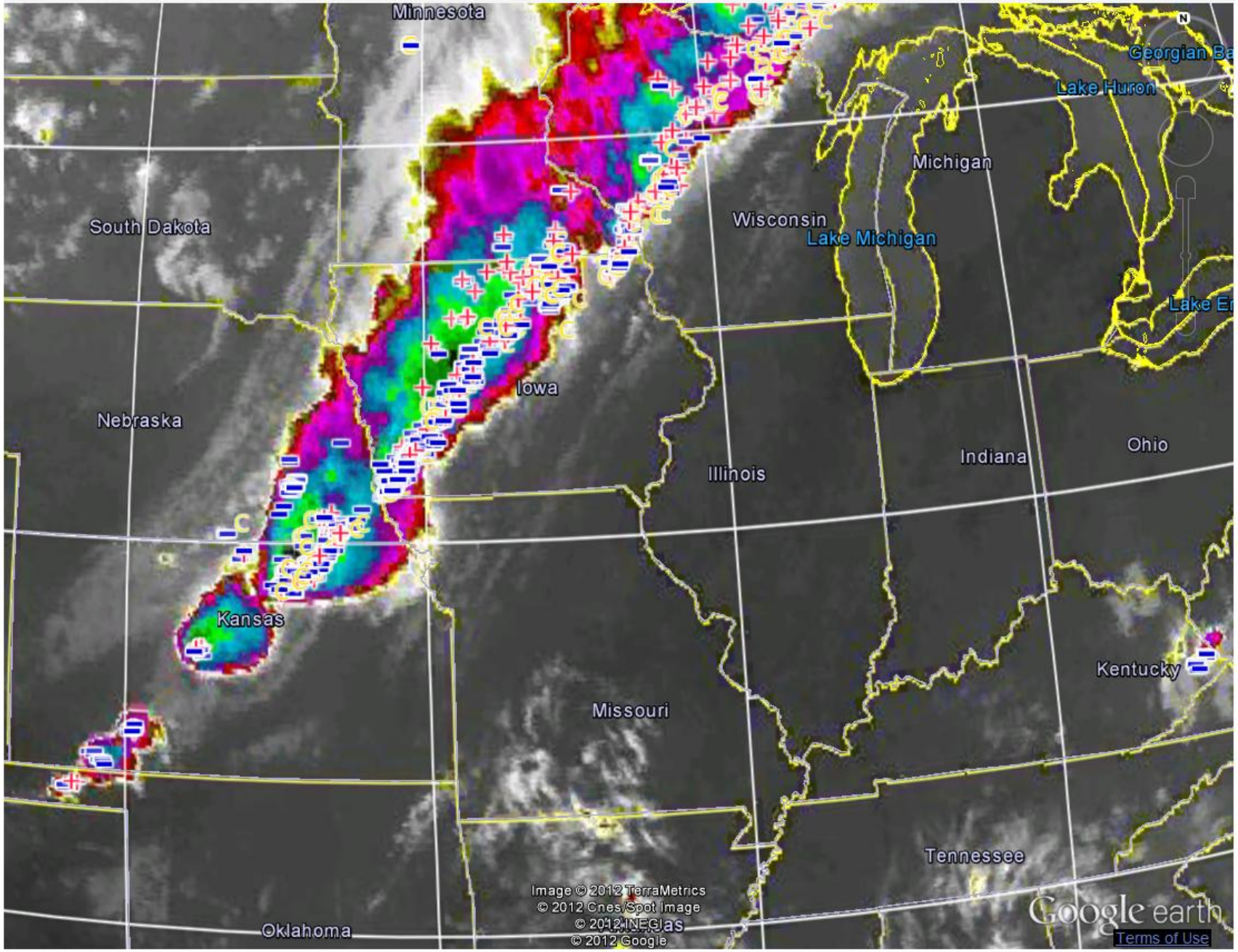

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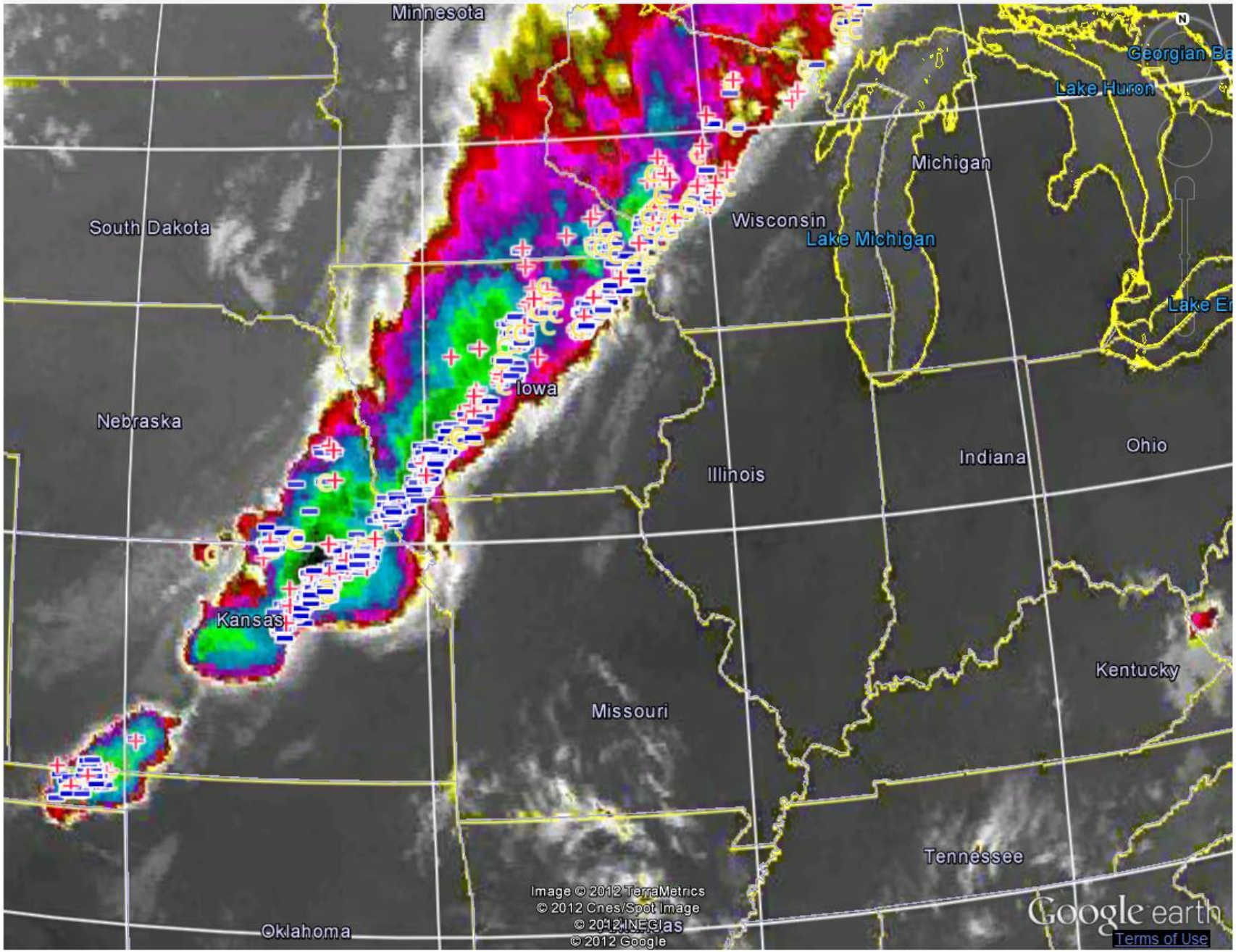

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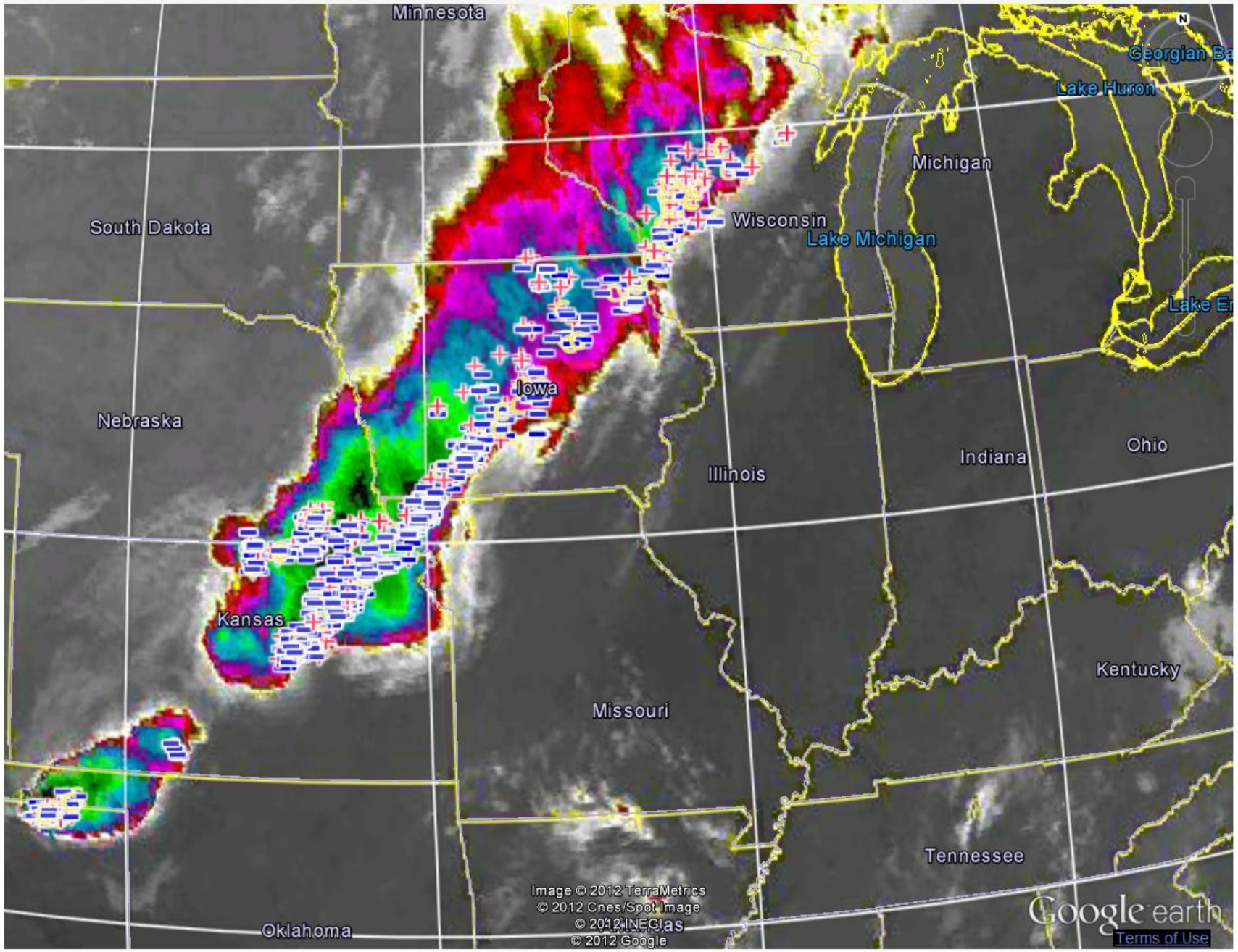

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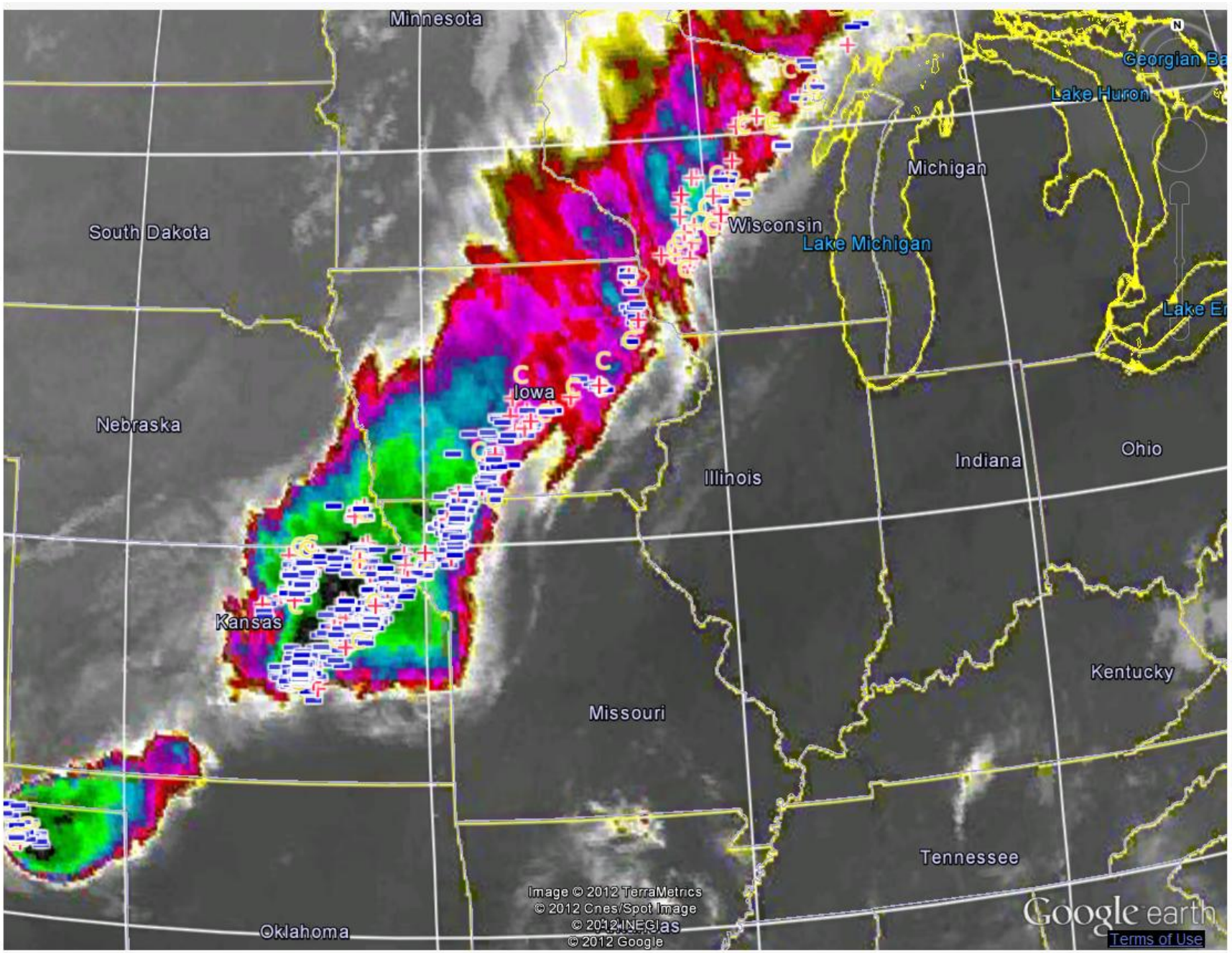

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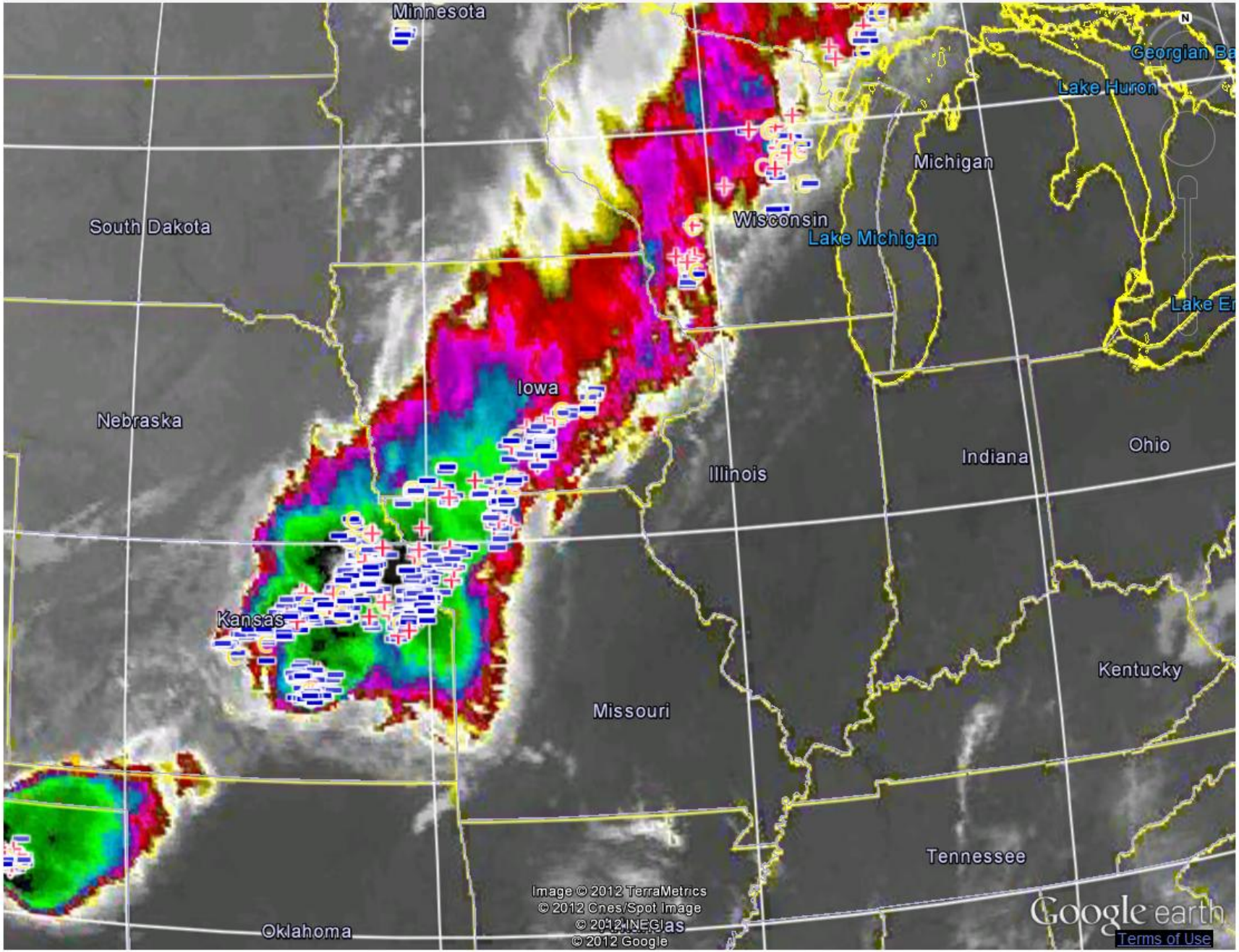

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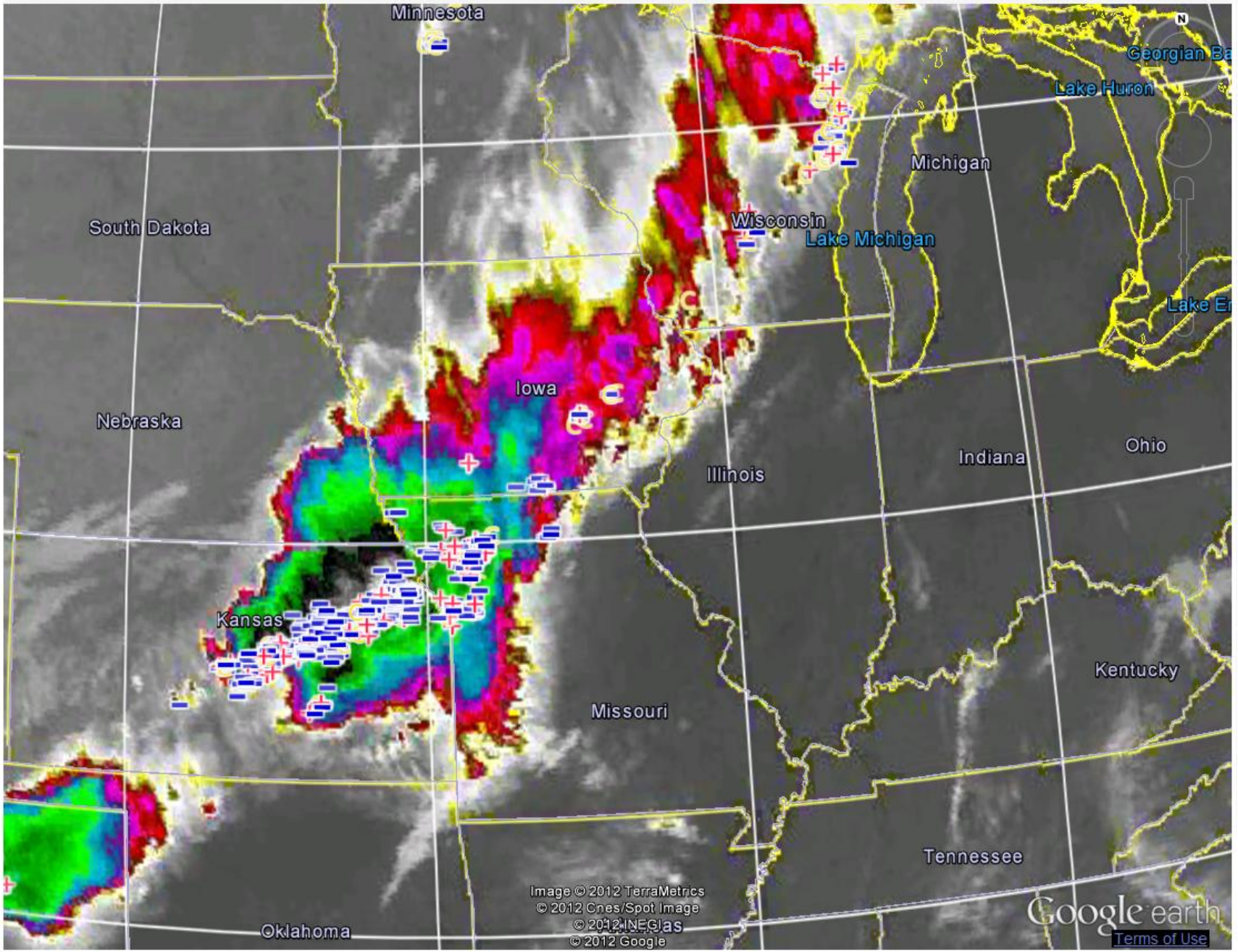

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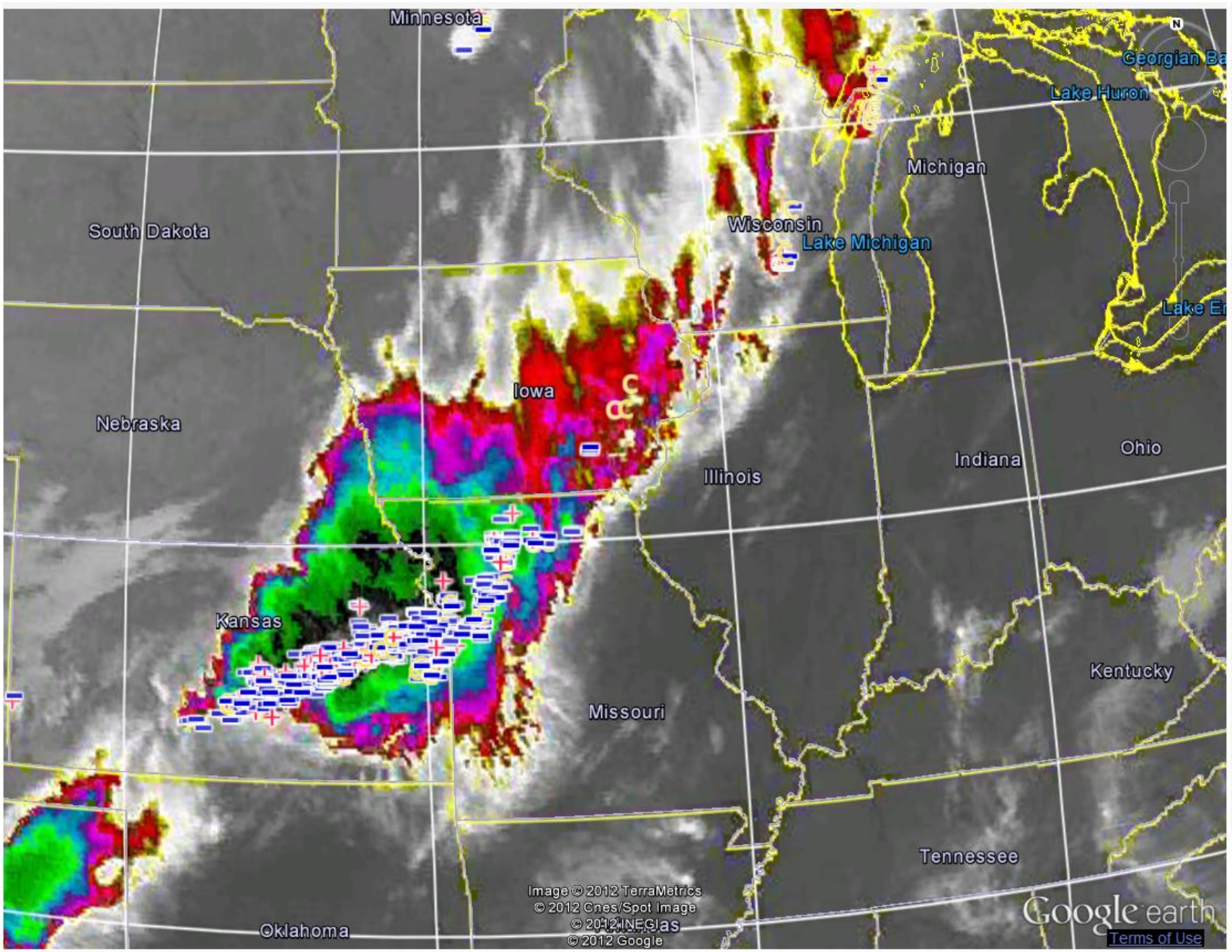

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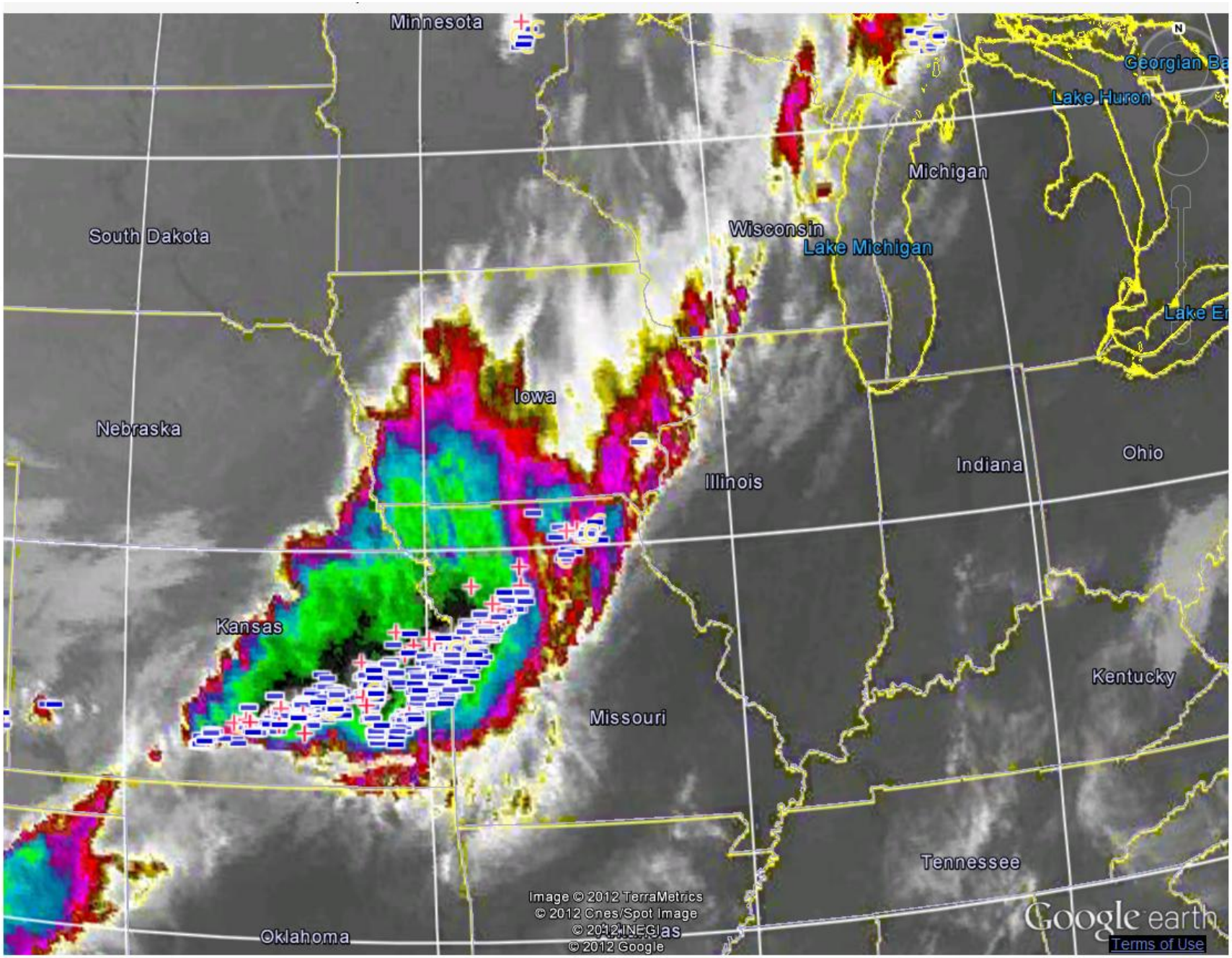

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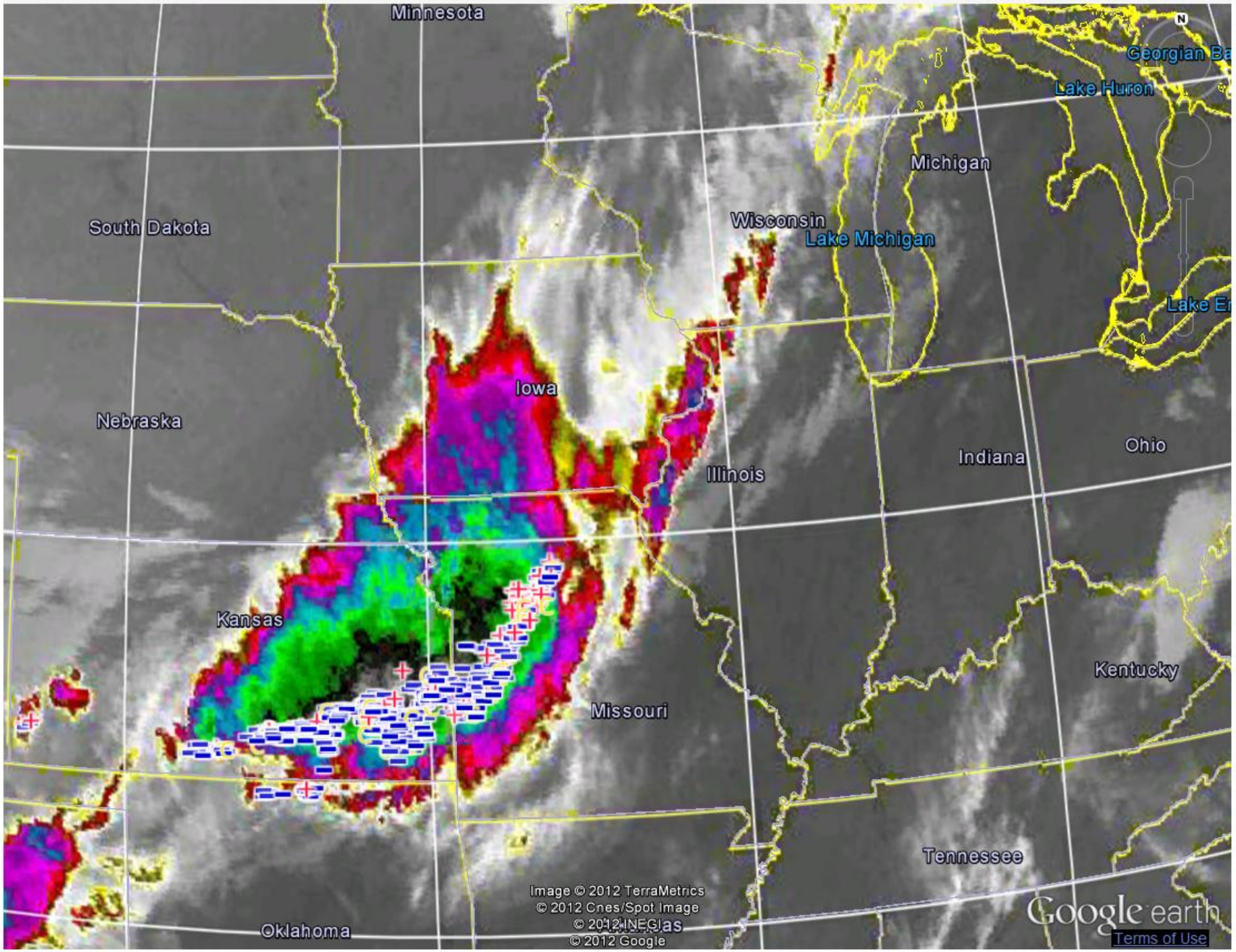

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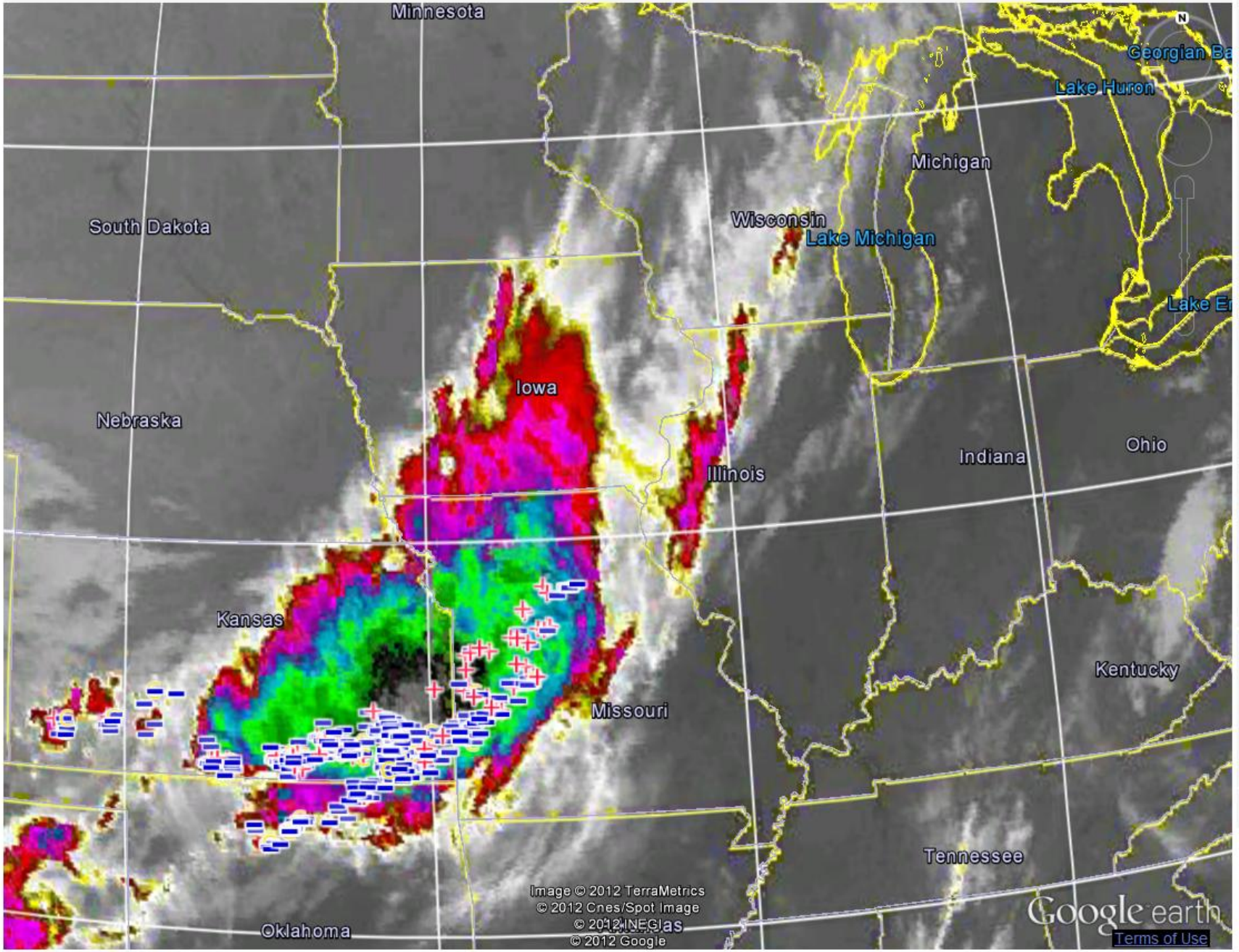

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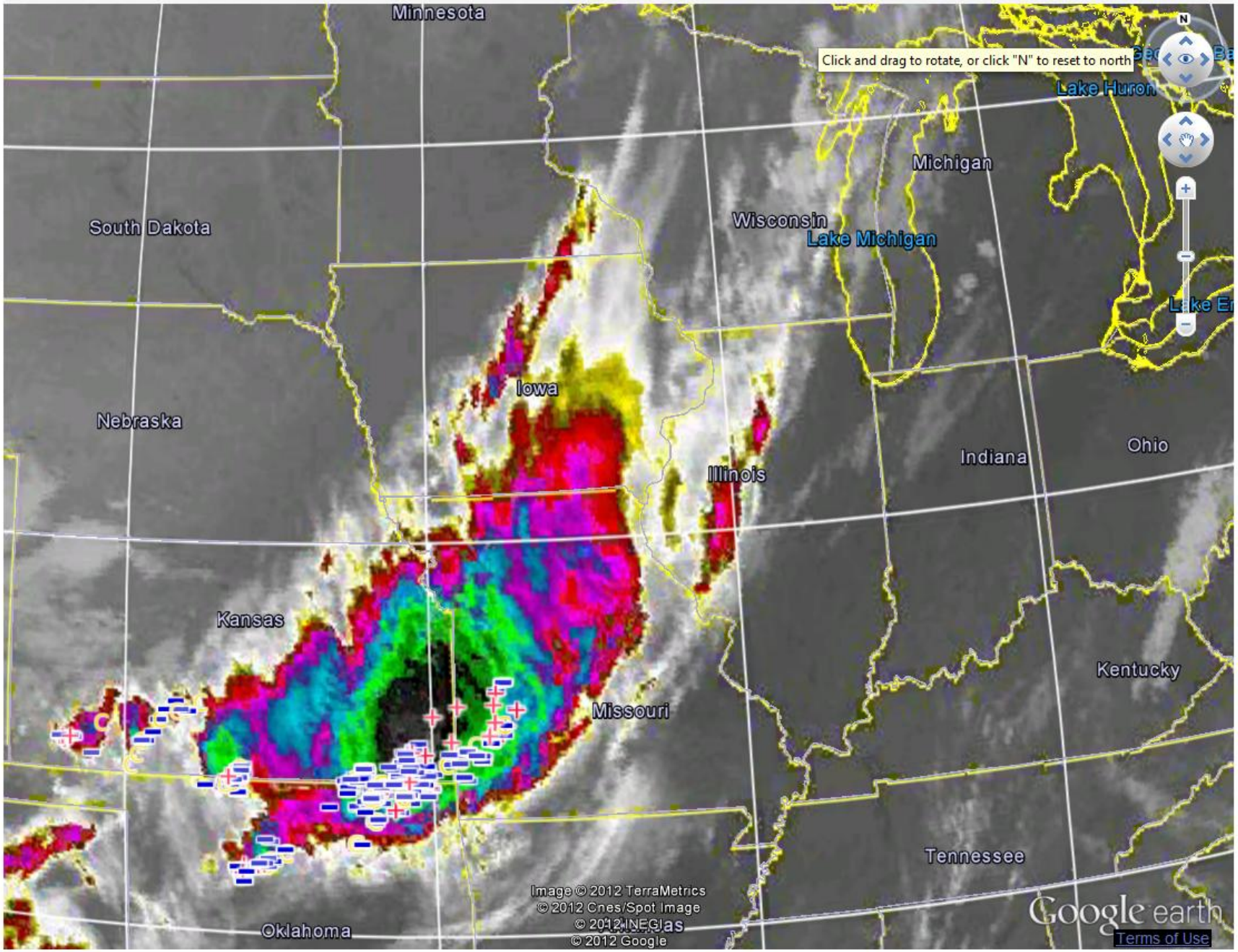

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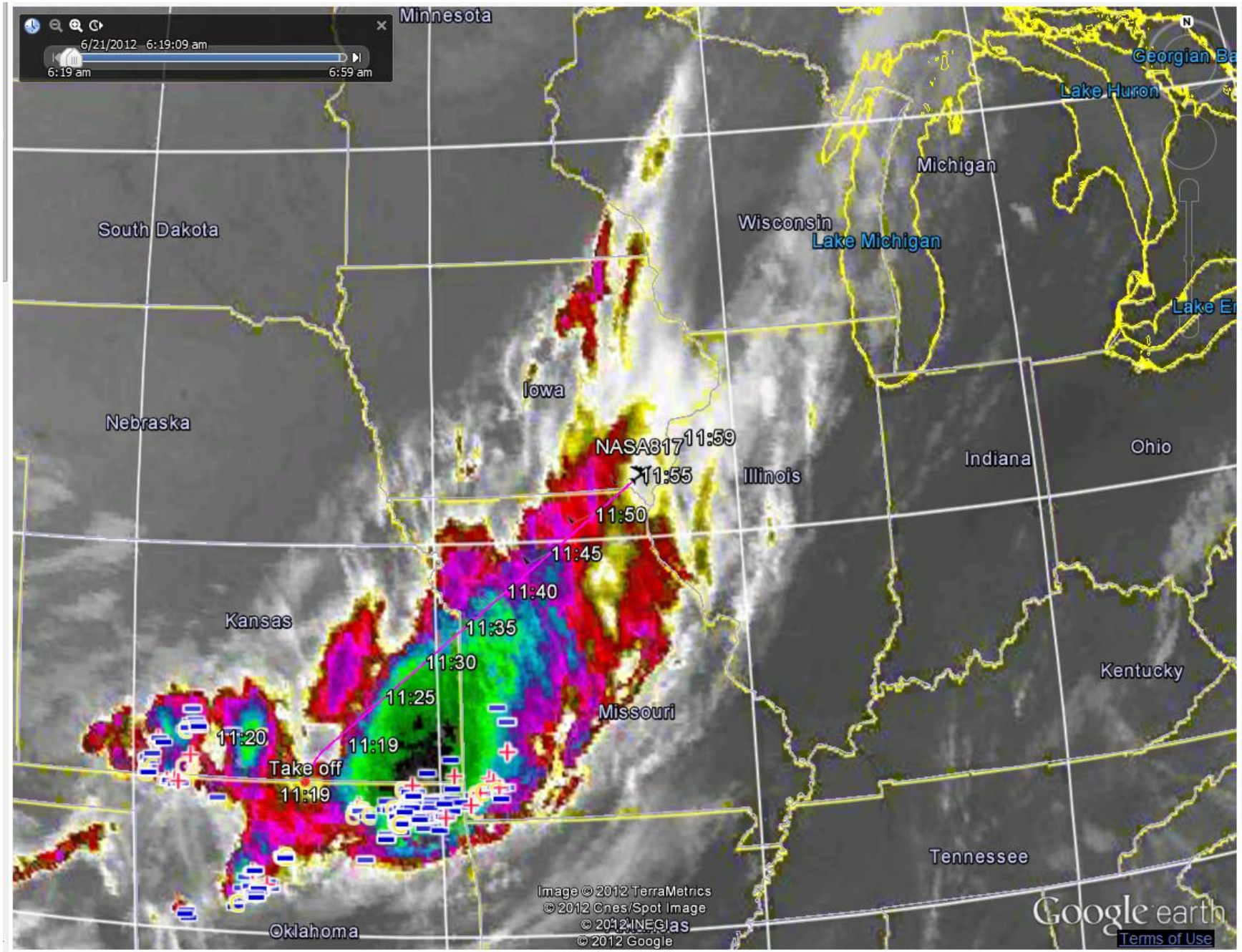

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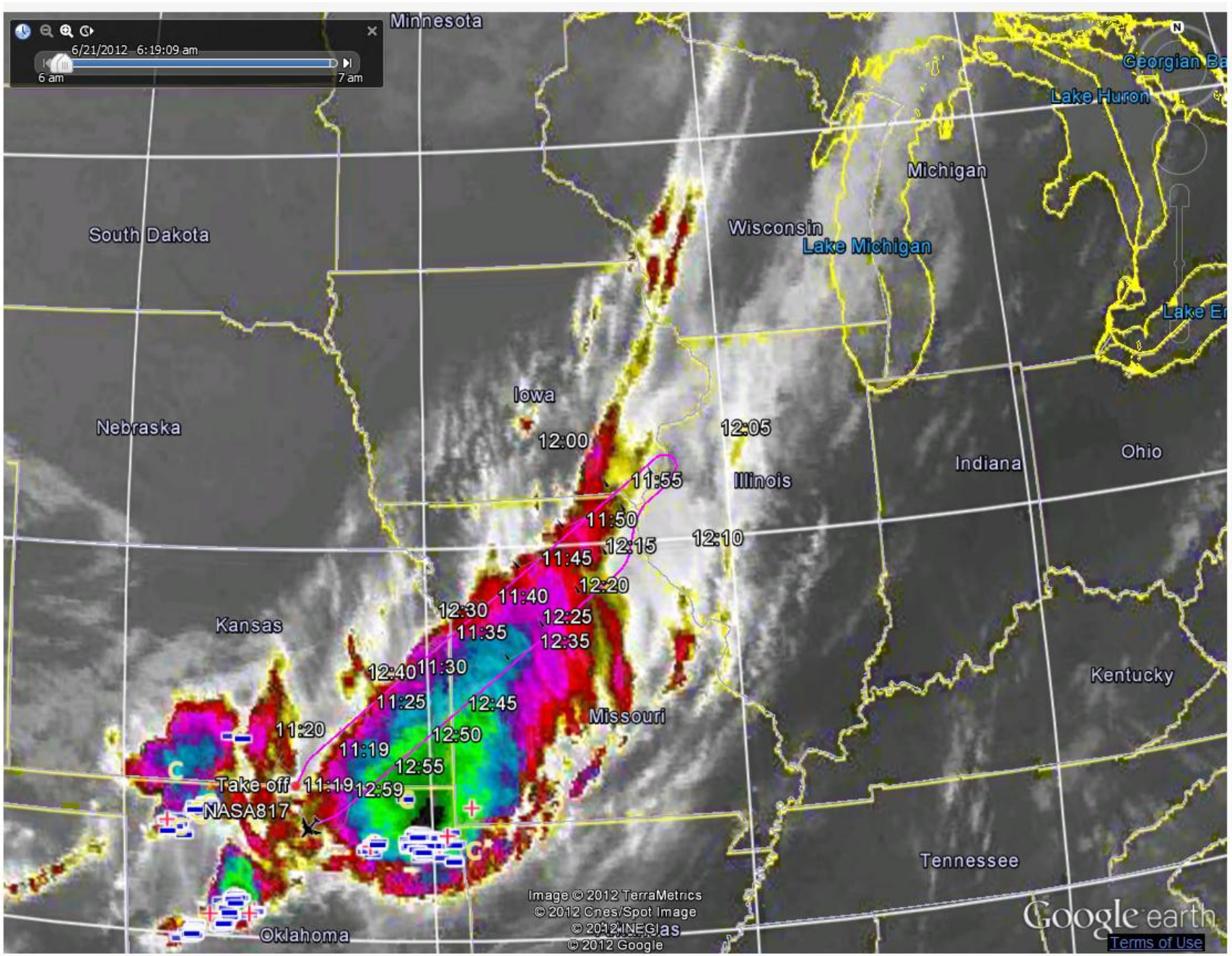

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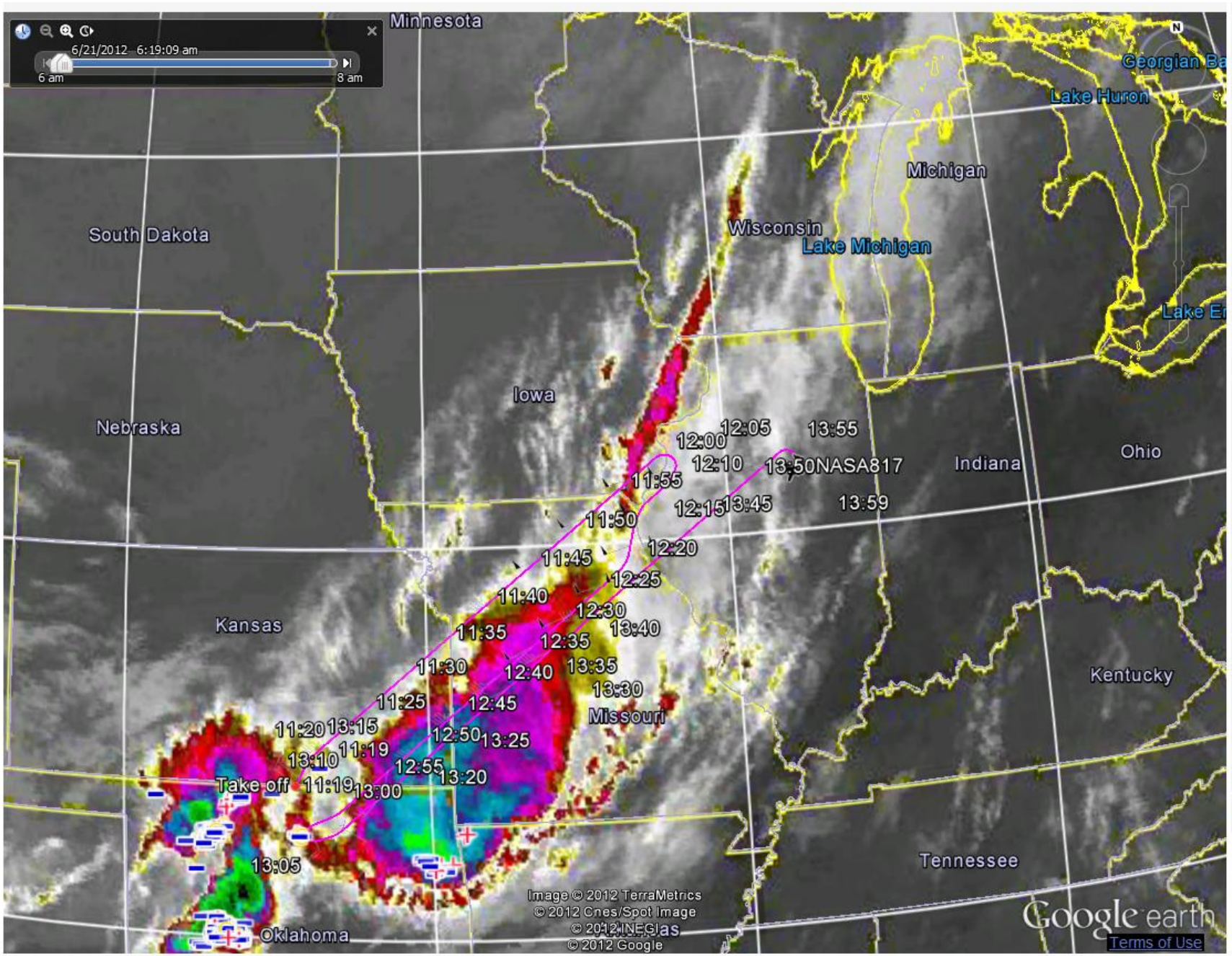

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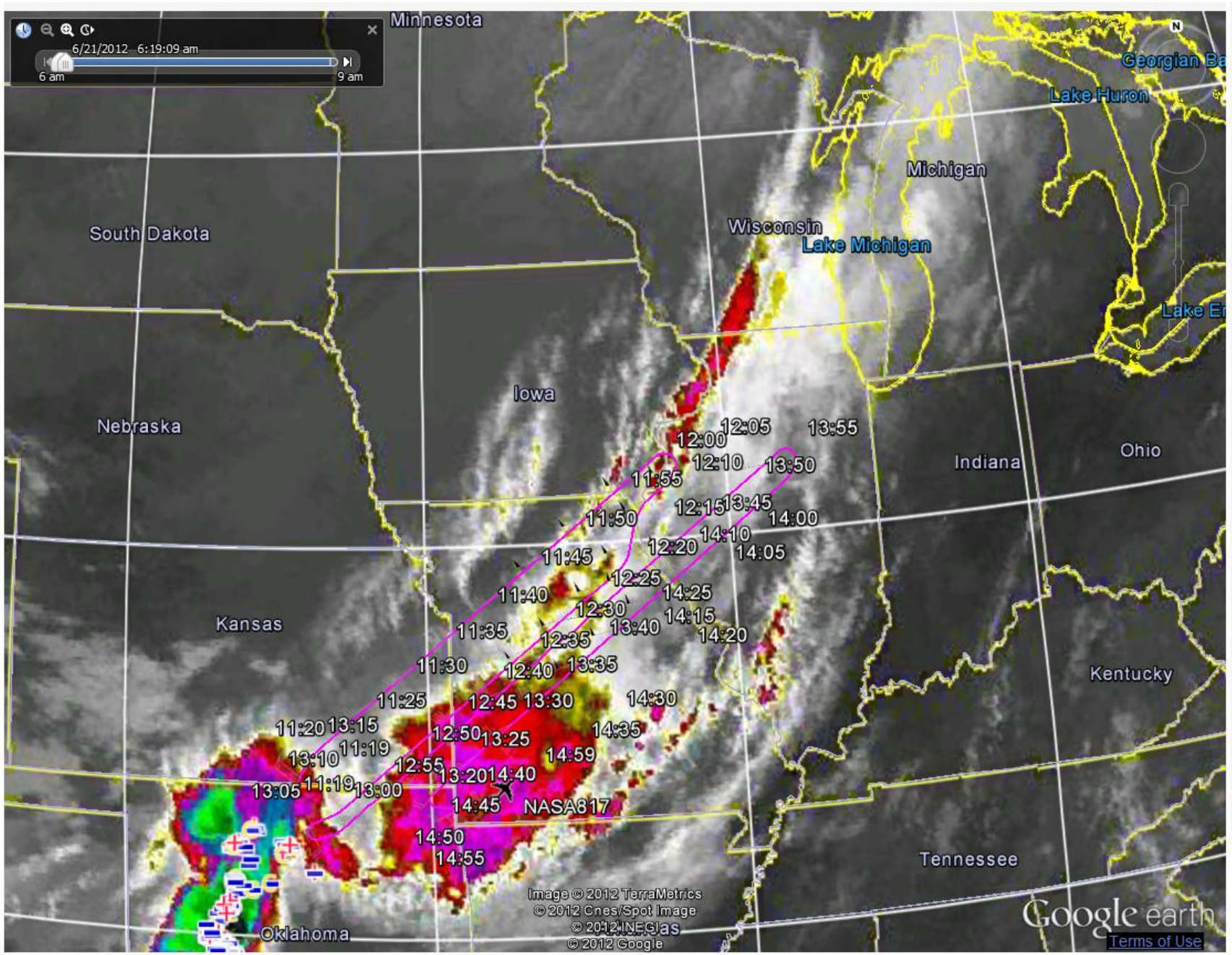

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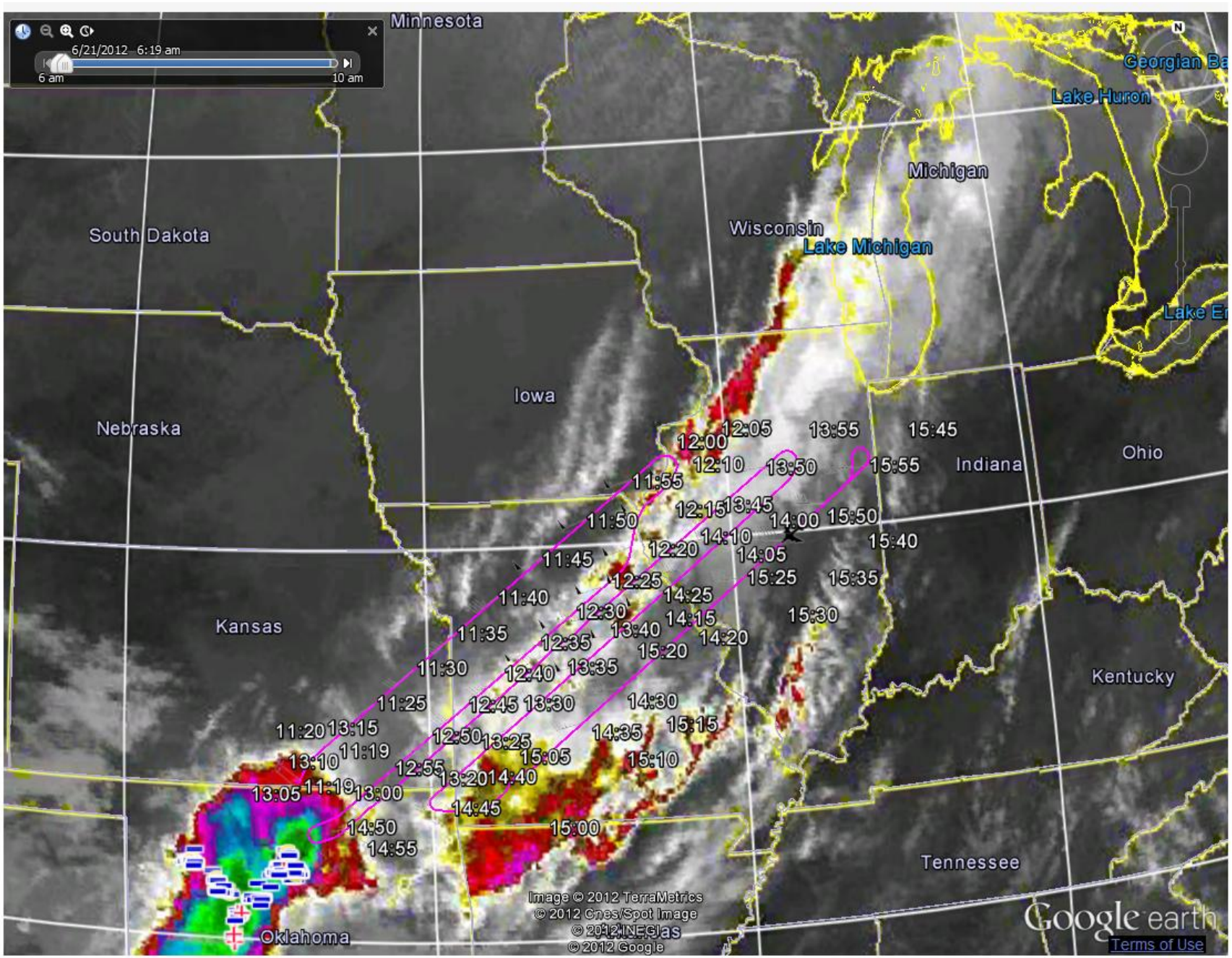

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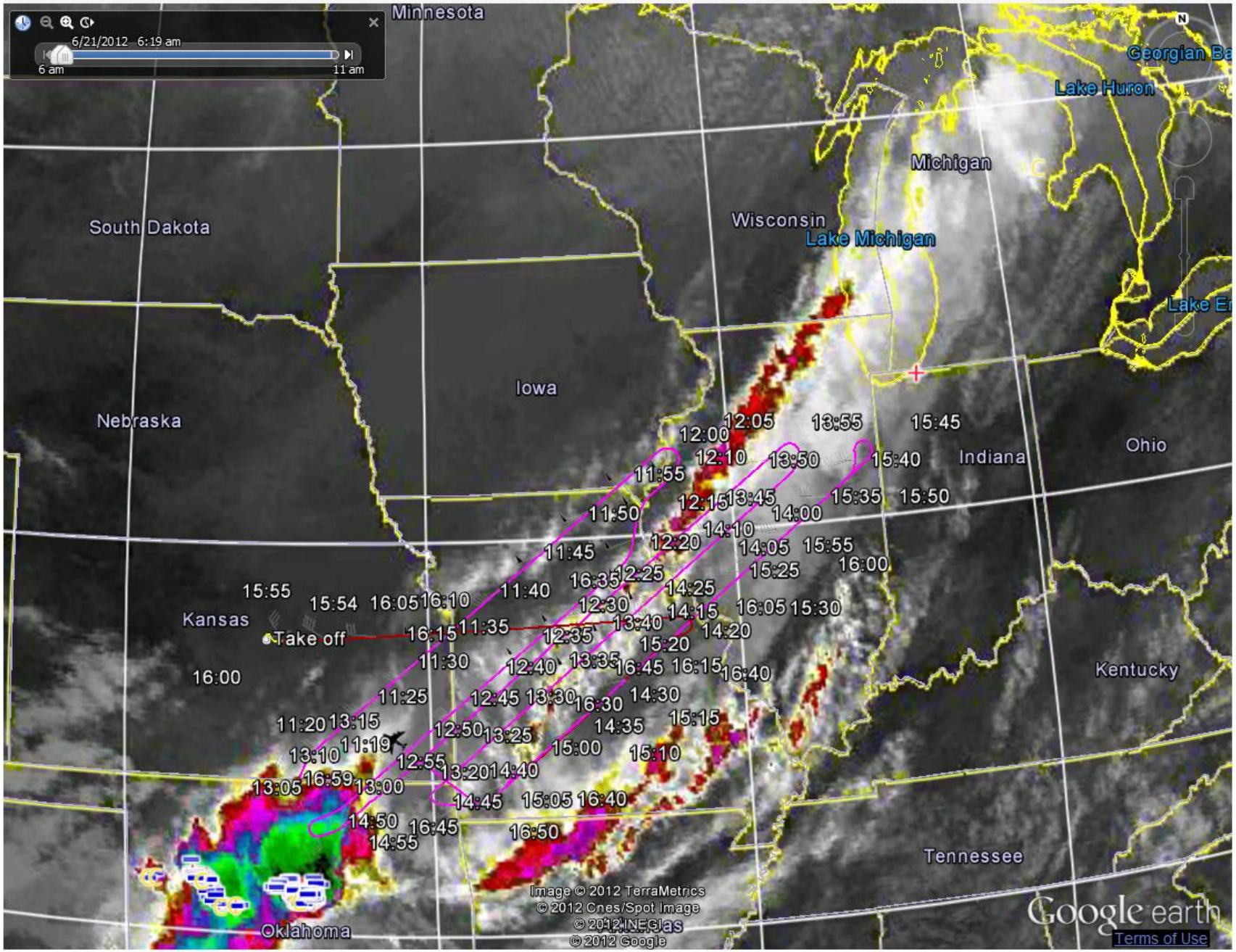

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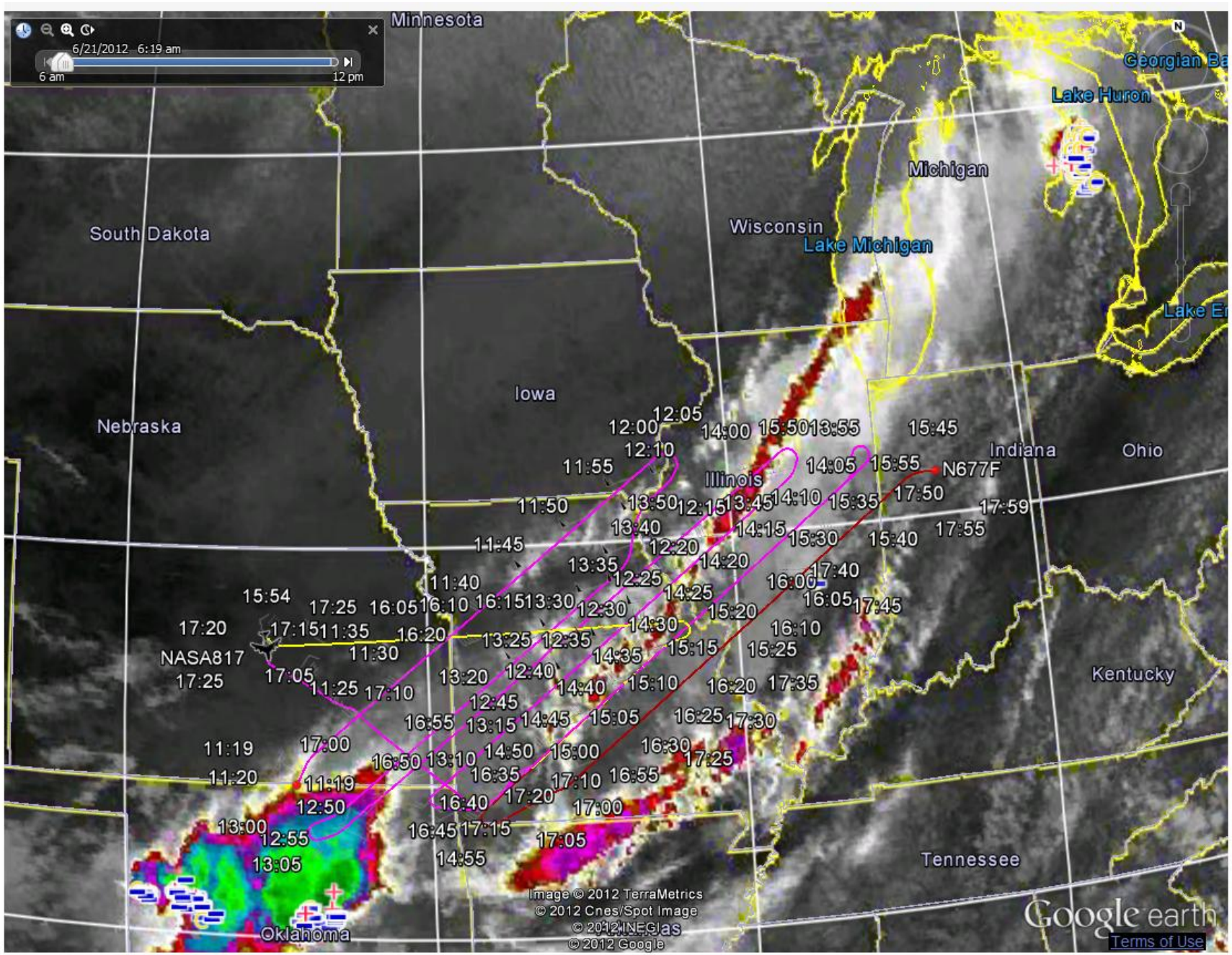

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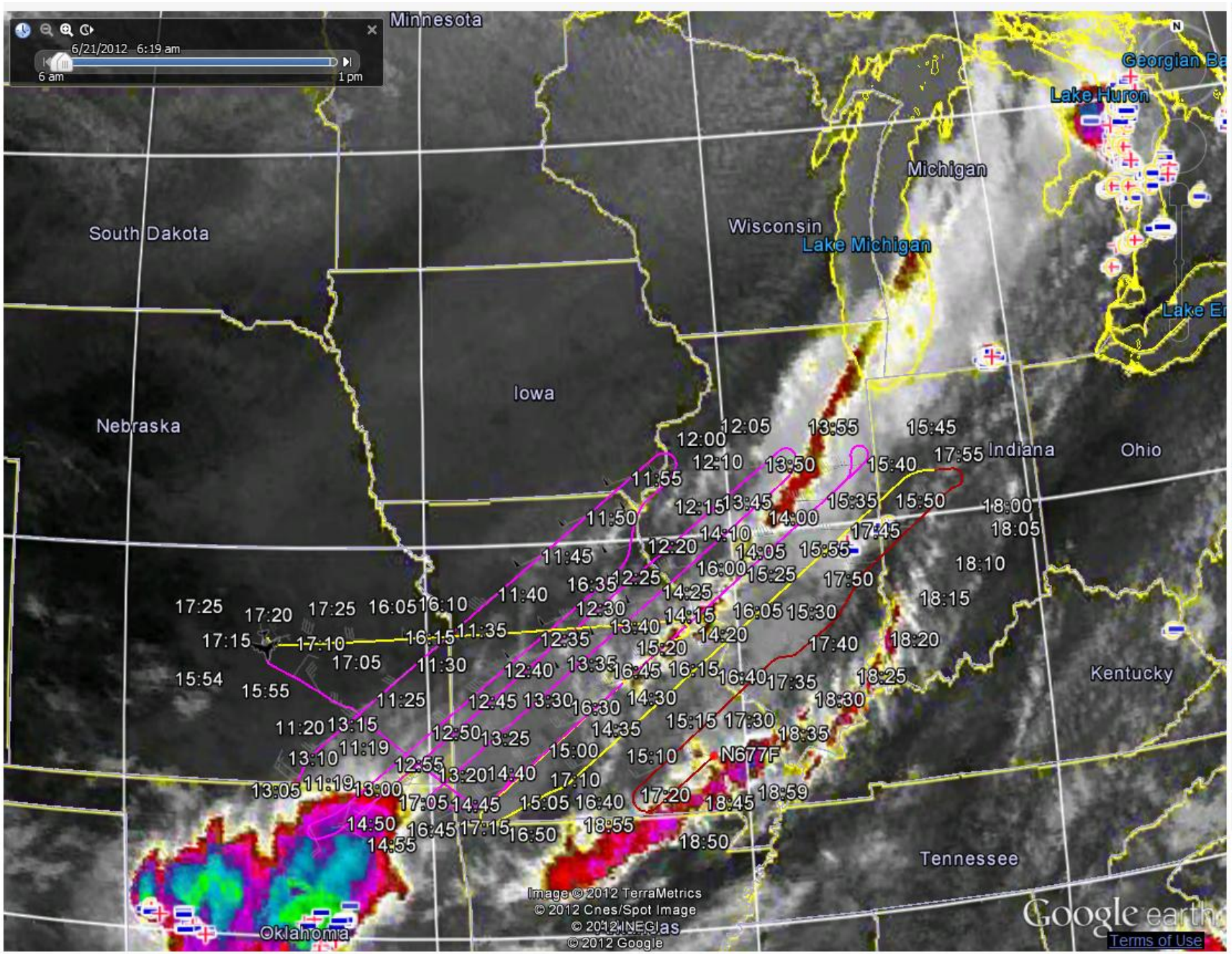

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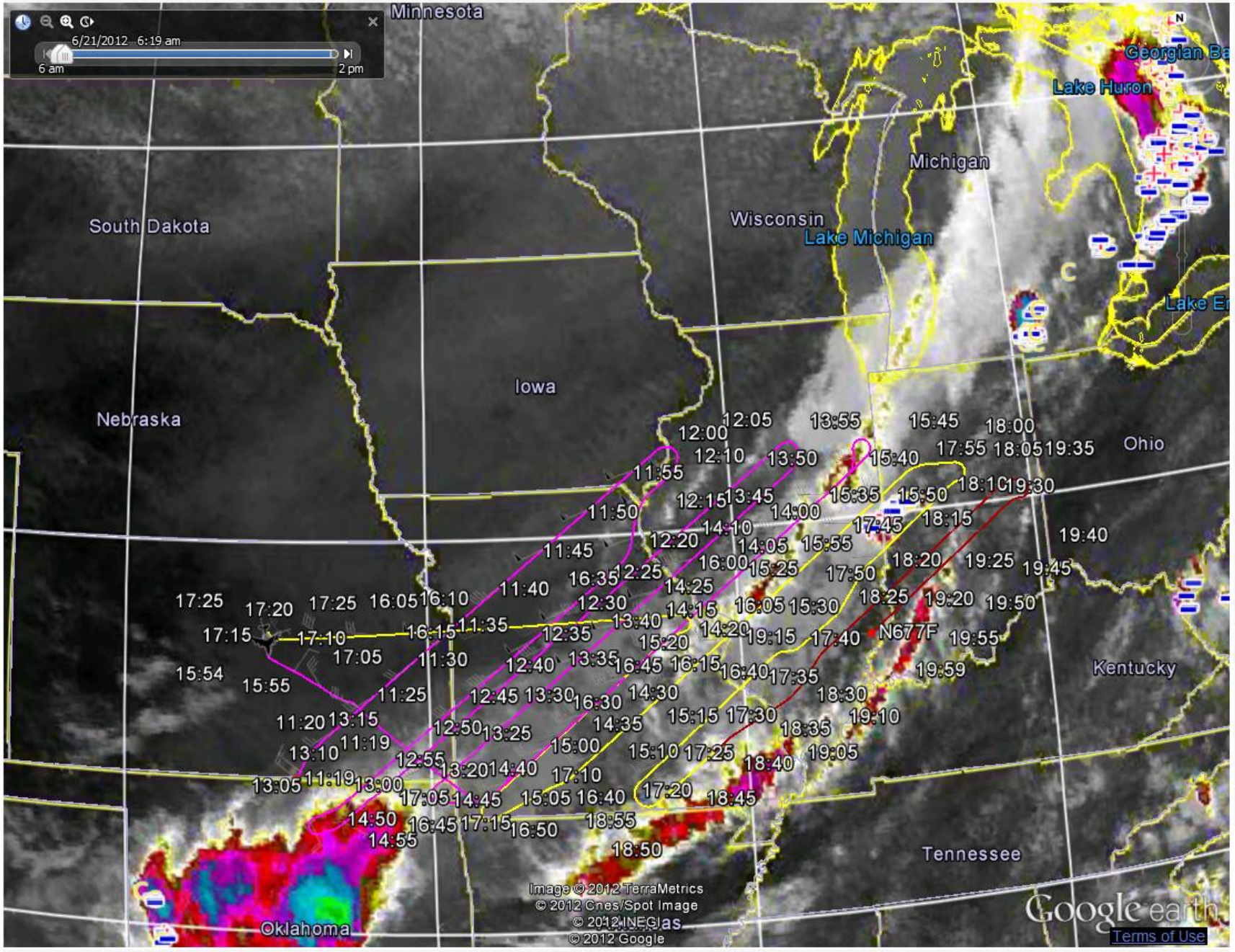

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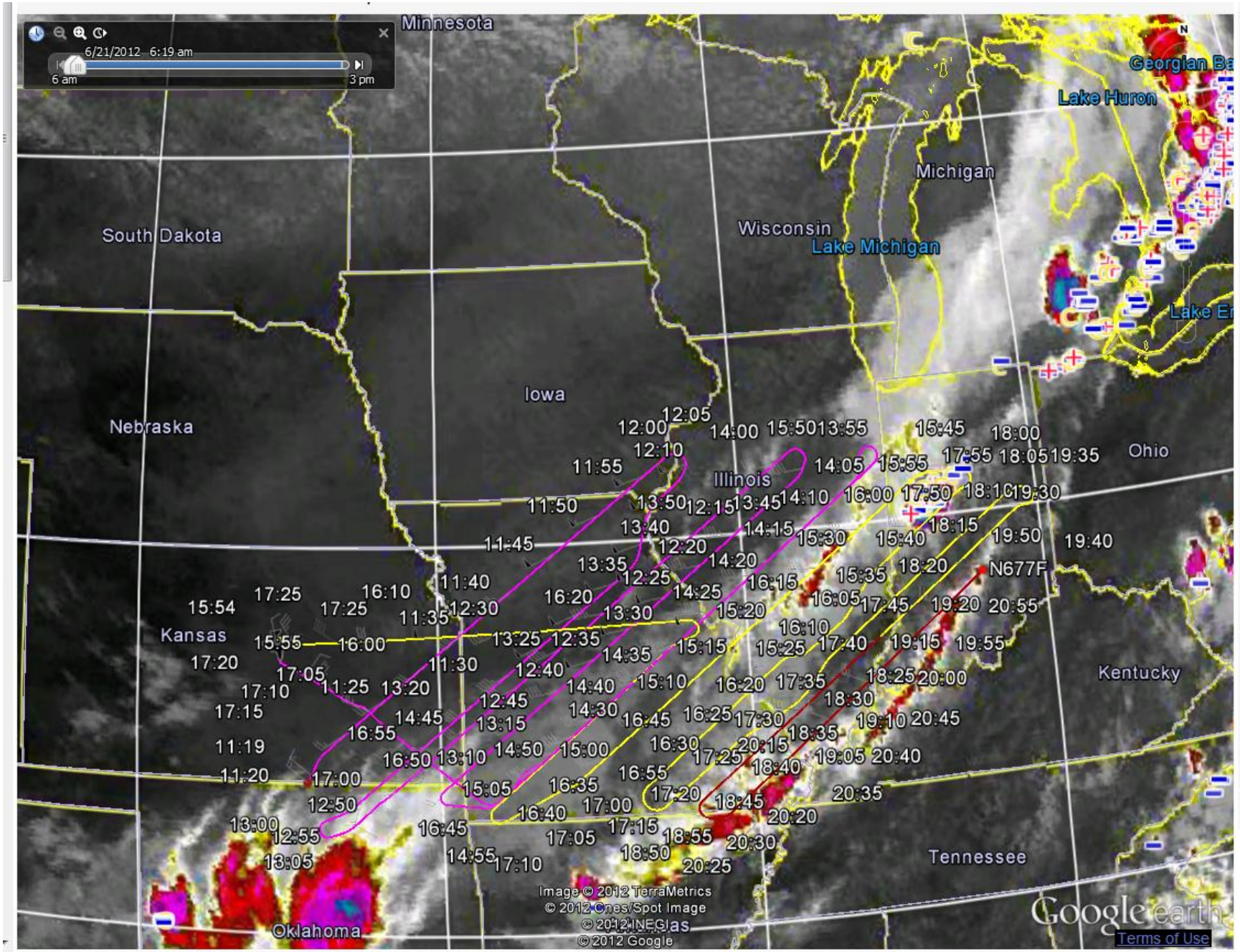

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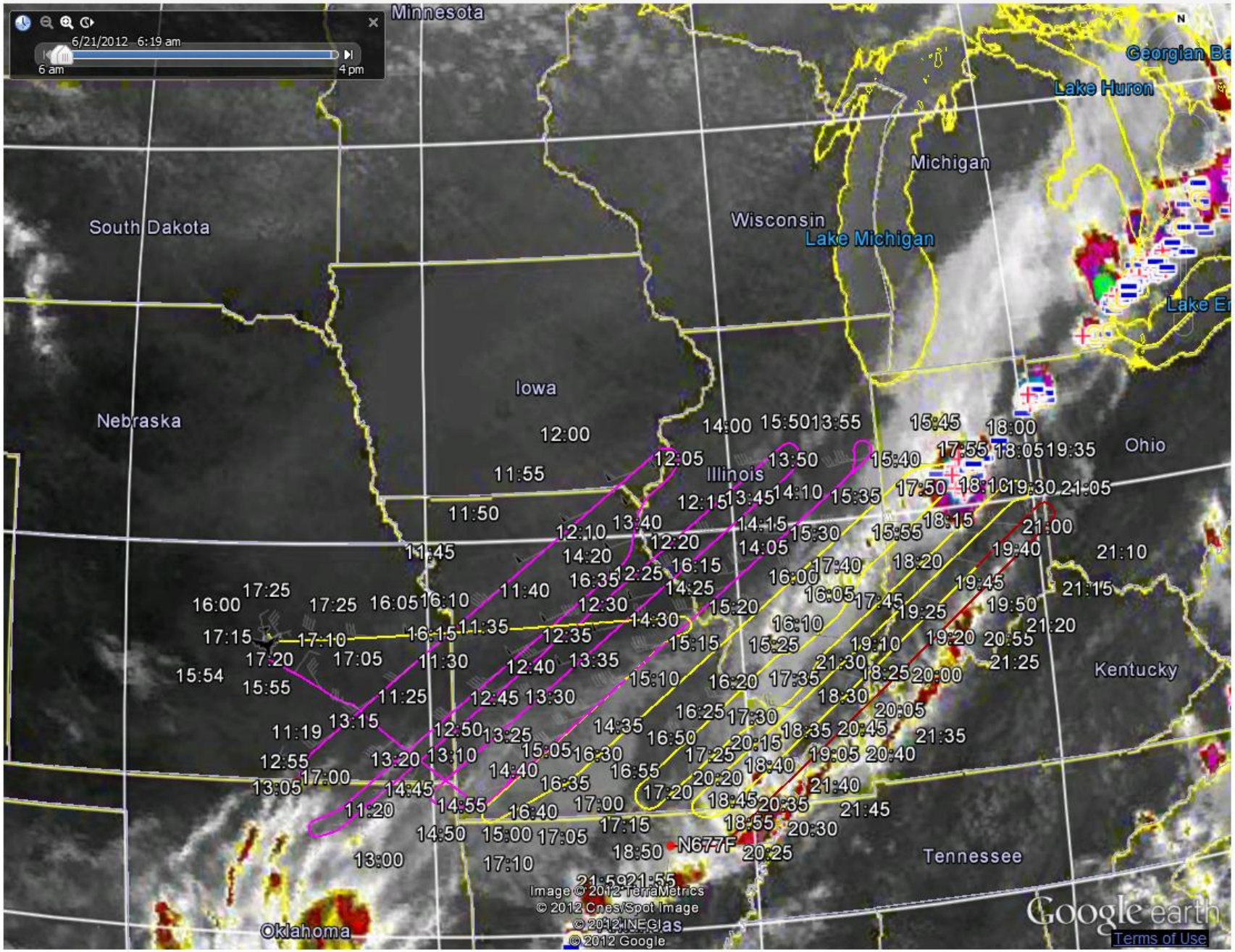

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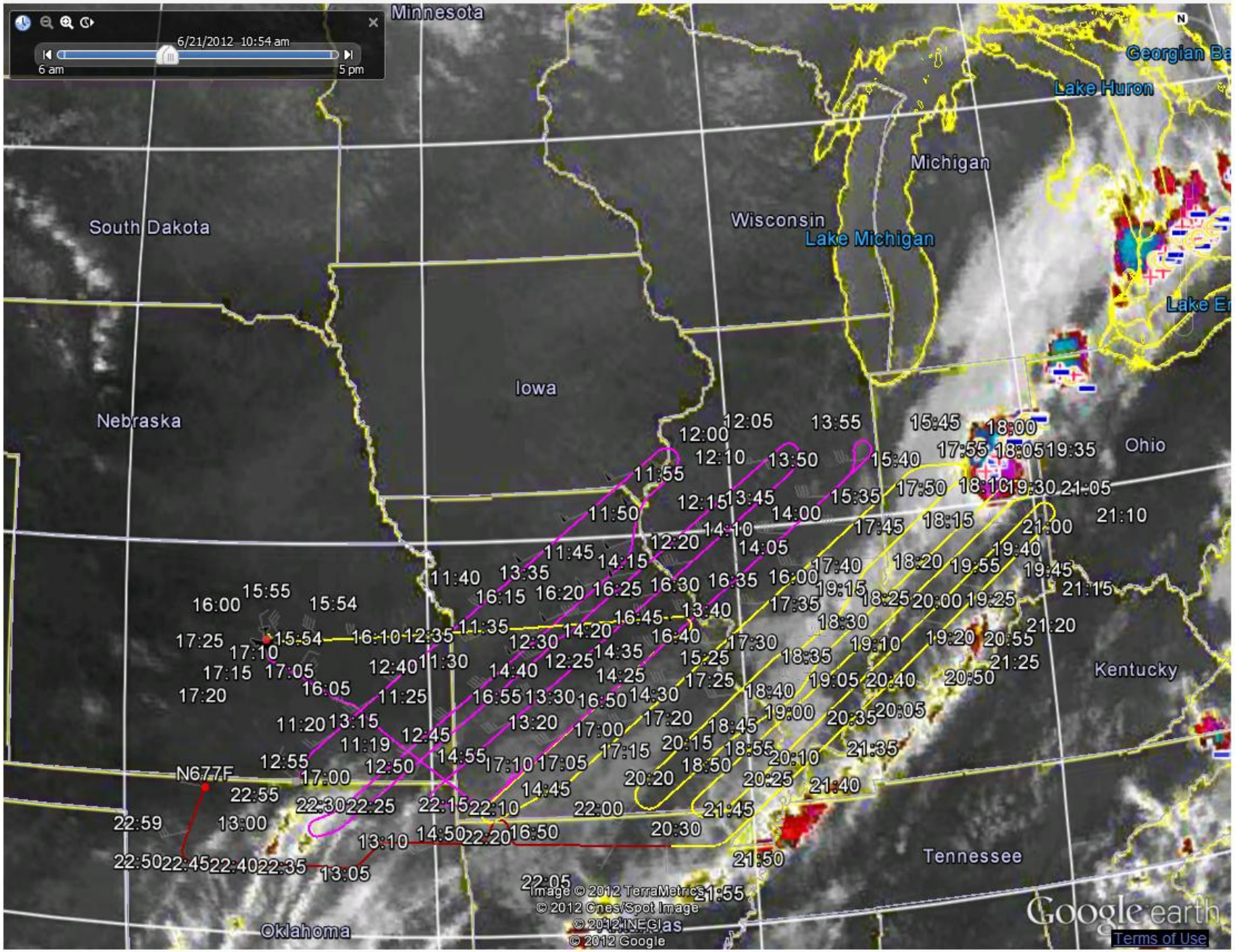

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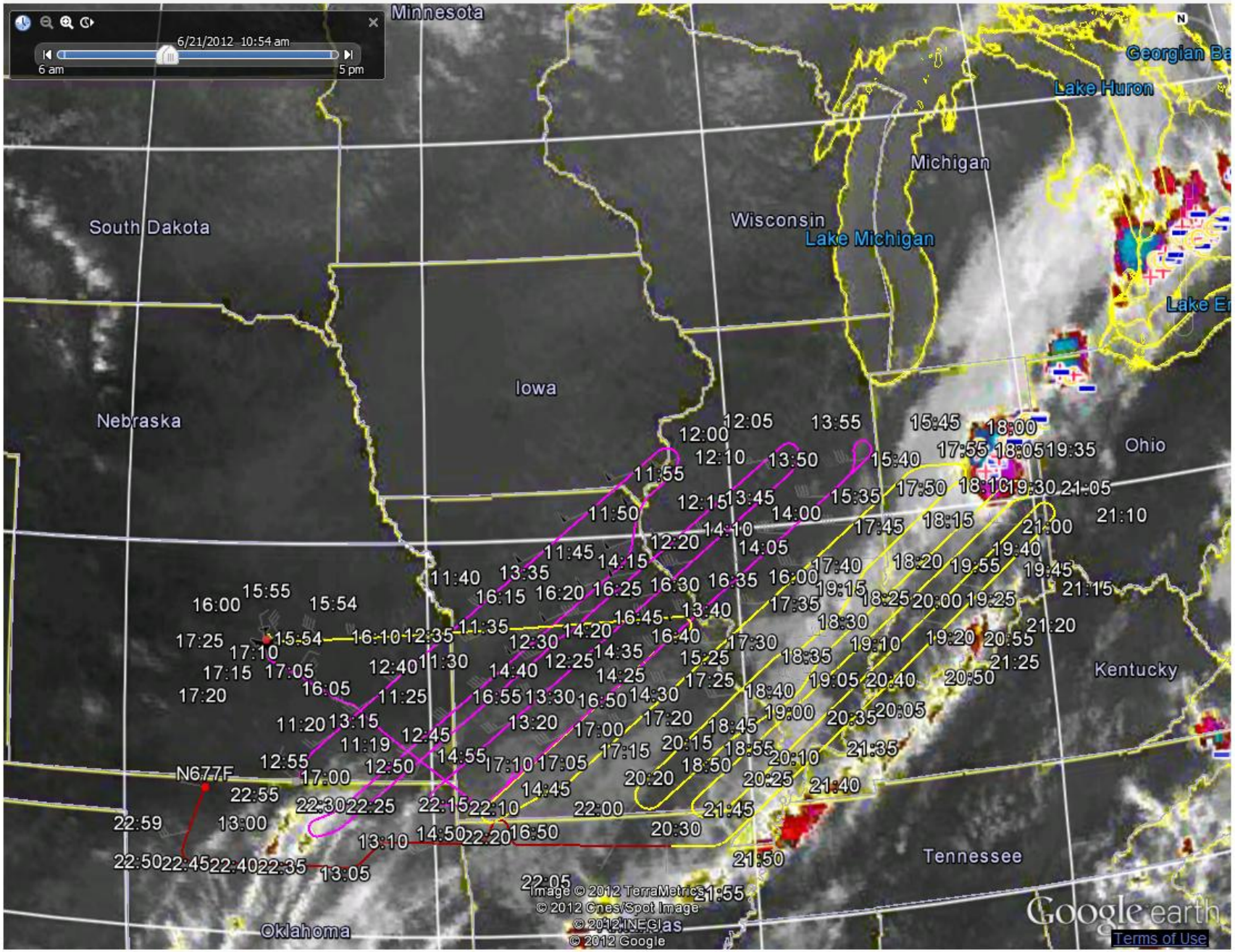

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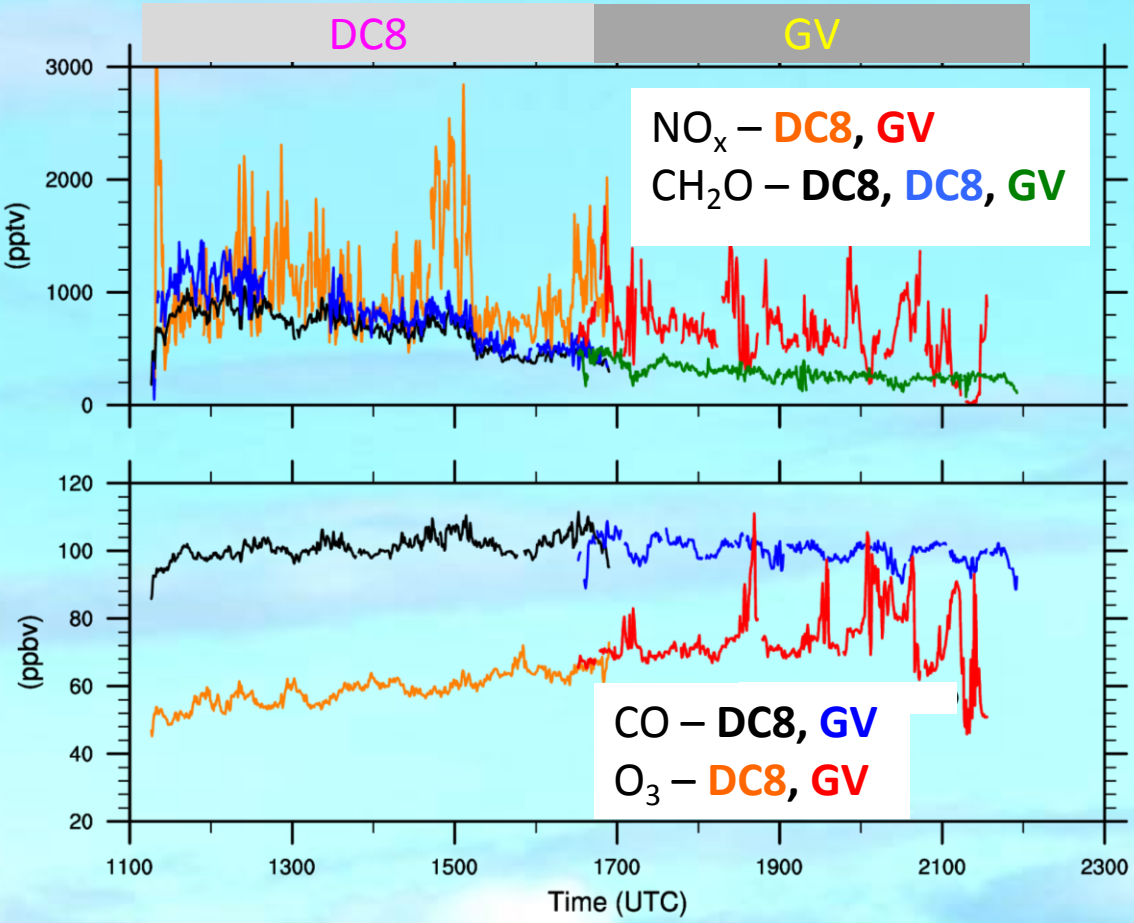
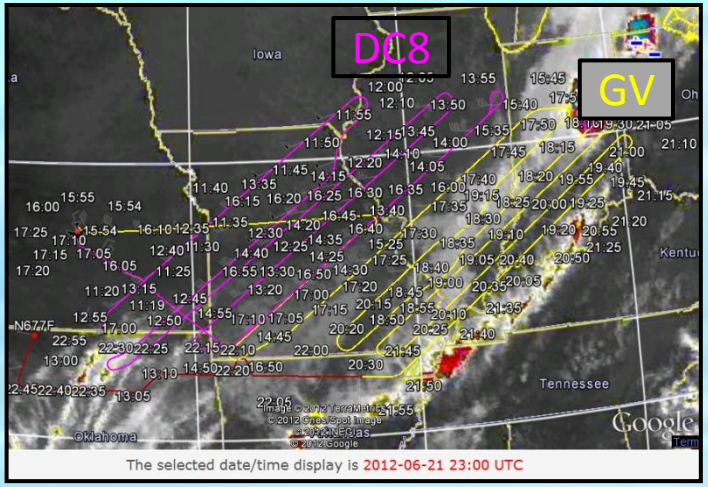
Photochemical Aging Case: 21 June 2012



- Decrease of NO_x and CH_2O
- CO fairly constant
- Increase of O_3 by 10-15 ppbv
- Data need to be put in the context of the airflow to properly analyze the photochemical aging



***** Preliminary Data *****

DC-8 data: T. Ryerson, I. Pollack, J. Peischl (NOAA/ESRL); T. Hanisco (NASA/GSFC); A. Fried, J. Walega (now at U. Colorado); G. Diskin, G. Sachse (NASA/LaRC)

GV data: A. Weinheimer, F. Flocke, T. Campos, D. Knapp, D. Montzka (NCAR); D. Richter, P. Weibring (now at U. Colorado)

DC3 Schedule and Summary

1 January 2013	Preliminary Data Due
1 July 2013	Final Data Due, Data publicly available
25-28 February 2013	DC3 Science Team Meeting

DC3 Dataset

- Extensive: aircraft, radar, lightning, soundings
- Improve knowledge on thunderstorms and how storms affect the composition and chemistry of the atmosphere
- Apply that knowledge to weather and climate models

DC3-Related Oral Presentations and Posters

Oral:

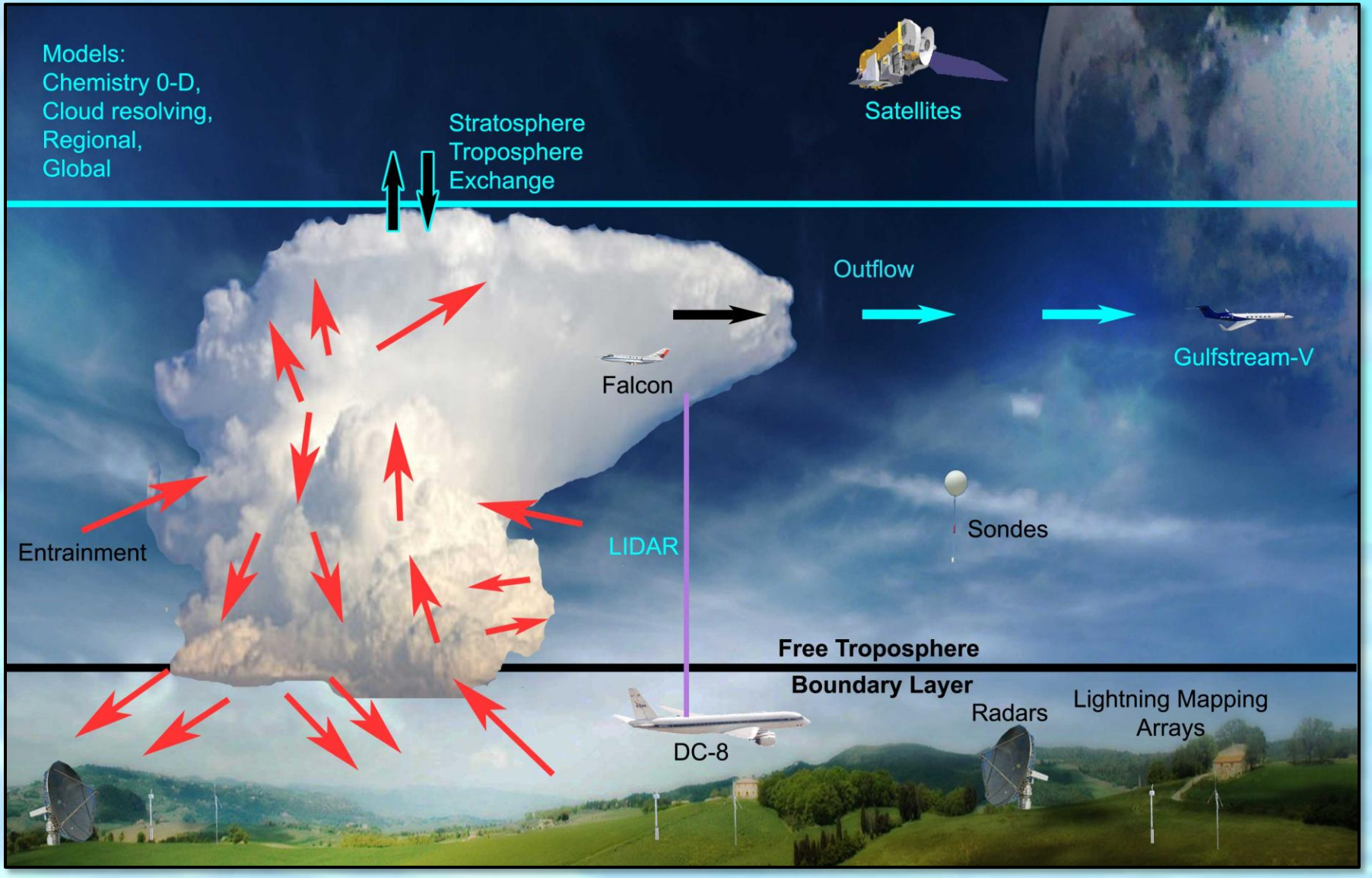
A12E-02. Vertical transport of formaldehyde by thunderstorms…, *Tom Hanisco et al.*
A12E-03. Airborne quantification of upper tropospheric …, *Ilana B. Pollack et al.*
A12E-04. Aircraft observations of biomass burning emissions…, *David J. Knapp et al.*
A12E-05. Variability in deep convective mass transport…, *Gretchen Mullendore et al.*
AE12A-02. An Overview of the lightning – atmospheric chem…, *Kenneth E. Pickering et al.*
AE12A-03. Fractal-based lightning channel length estimation…, *Eric Bruning & R. J. Thomas*
AE12A-04. Lightning in Colorado forest fire smoke plumes…, *Tim Lang et al.*
AE12A-05. Lightning mapping observations during DC3…, *Paul R. Krehbiel et al.*

Posters:

A11A-0016. Continuous Measurement of Particle Hygroscopicity…, *Chuck A. Brock et al.*
A21H-0152. Tracer and chemistry modeling of thunderstorms…, *Mary C. Barth et al.*
A21H-0153. Particle size distribution measurements…, *John Ortega et al.*
A21H-0154. In situ airborne measurement of formaldehyde…, *Heather Arkinson et al.*
A21H-0155. Submicron aerosol transport and aging…, *Pedro Campuzano-Jost et al.*
A21H-0156. Convective entrainment deduced from biomass…, *Thomas B. Ryerson et al.*
A21H-0158. Constraints on transport pathways…water vapor…, *Anthony O'Brien et al.*
A31E-0078. Calibration and Field Deployment …VCSEL Hygrometer…, *Josh P. DiGangi et al.*
A33C-0167. Ground based spectral radiance and irradiance…, *Samuel E. Leblanc et al.*
A51B-0042. Airborne measurements of single particle…, *Milos Z. Markovic et al.*
A51E-0116. Actinic flux measurements and photolysis…, *Samuel R. Hall et al.*

Extra Slides

Diagram of DC3 Convective Cloud Studies



DC3 Aircraft Sampling

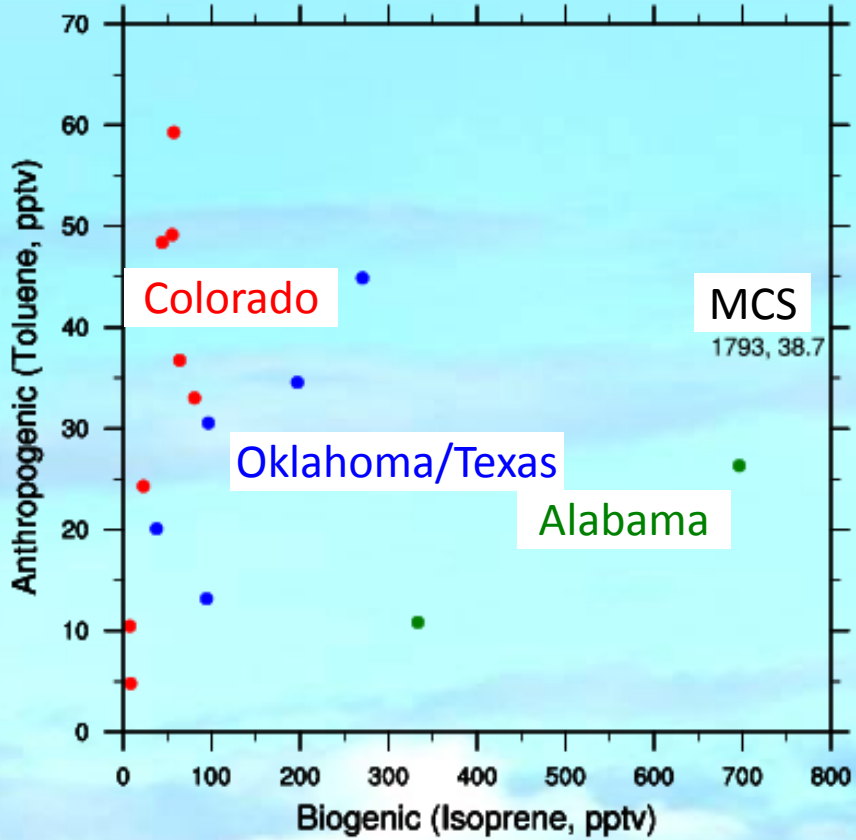
Using the 3 aircraft, DC3 sampled:
19 cases of active thunderstorms; >6 cases of photochemical aging

NSF/NCAR GV and NASA DC-8 flew 17 coordinated flights
8 storms in northeast Colorado
5 storms in West Texas to central Oklahoma
2 storms in Alabama & Mesoscale Convective System (MCS) over Missouri

3 cases of photochemical aging from TX/OK storms
2 cases of photochemical aging from NE Colo. Storms
1 case of chemical aging of the 0-12 hr dissipating MCS outflow

DC3 Study Regions – Cloud Characterization

Preliminary data of average concentrations within 2 km of the ground color coded by the sampling region. All points are from DC-8 data except the June 27, 28 storms.



→ General separation of anthropogenic and biogenic influences among regions

→ The MCS occurred over a region with very high isoprene emissions

*** **Preliminary Data** ***

PTR-MS – Proton Transfer Reaction Mass Spectrometry: A. Wisthaler (U. Innsbruck)

TOGA – Trace Organic Gas Analyzer: E. Apel (NCAR) and D. Riemer (U. Miami), R. Hornbrook, A. Hills (NCAR)

DC3 Decision Making

Daily Science Team meetings

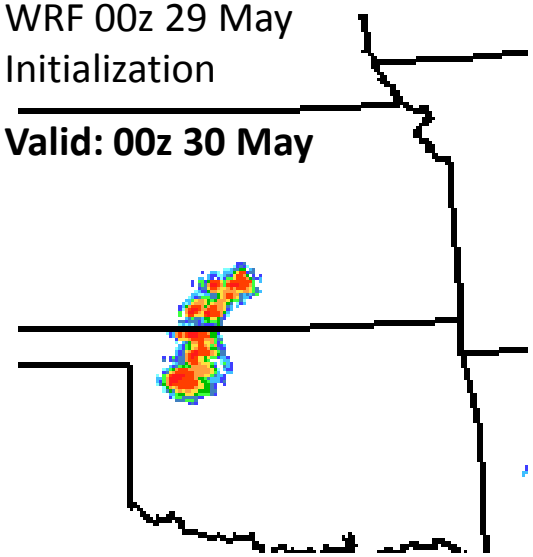
weather forecasts (overview & regional) – included WRF 3-4 km simulations twice/day

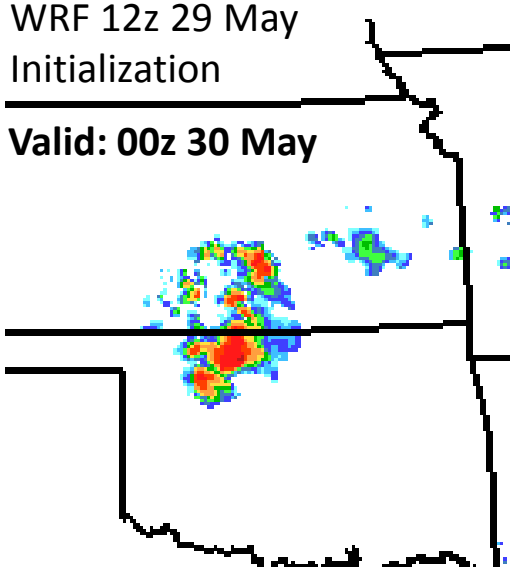
tracer forecasts

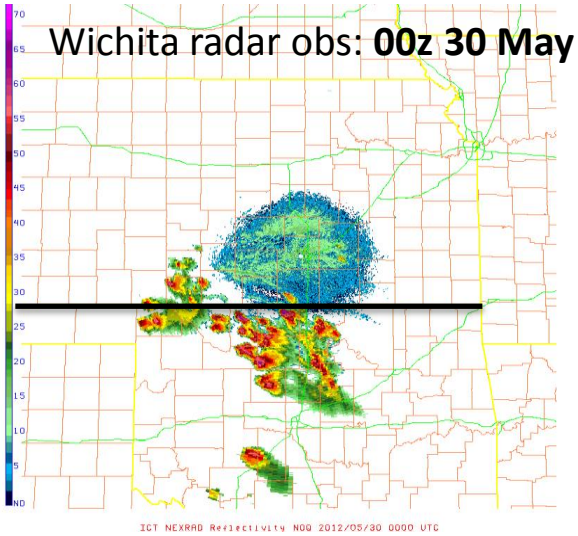
platform readiness

instrument readiness

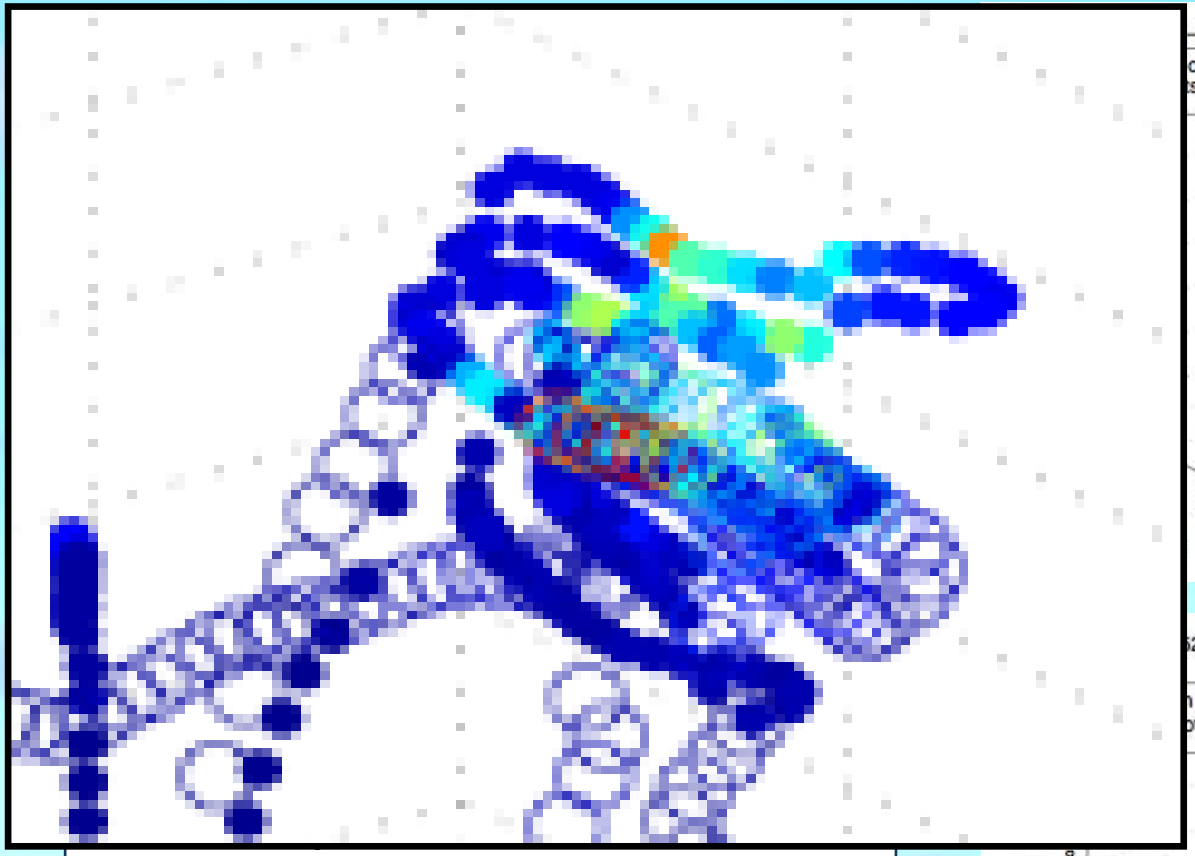
Decision on whether to fly, type of flights, locations of flights

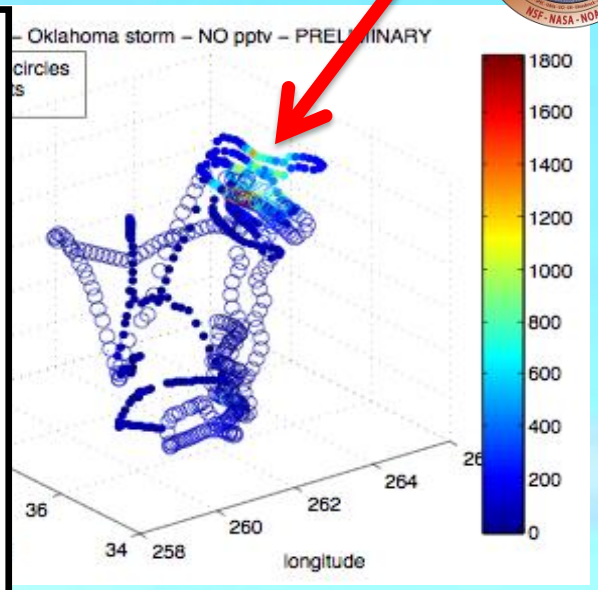


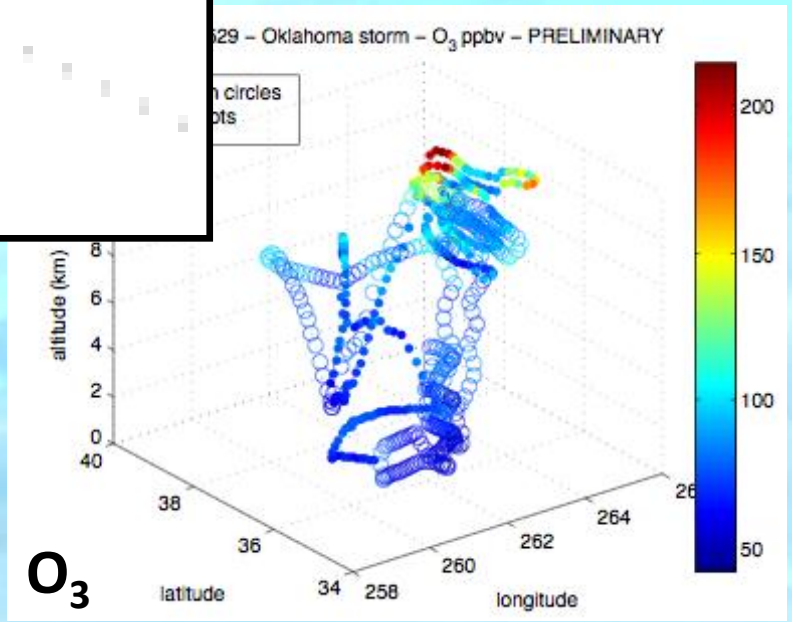




29 May 2012 – Evidence of Transport and LNO_x



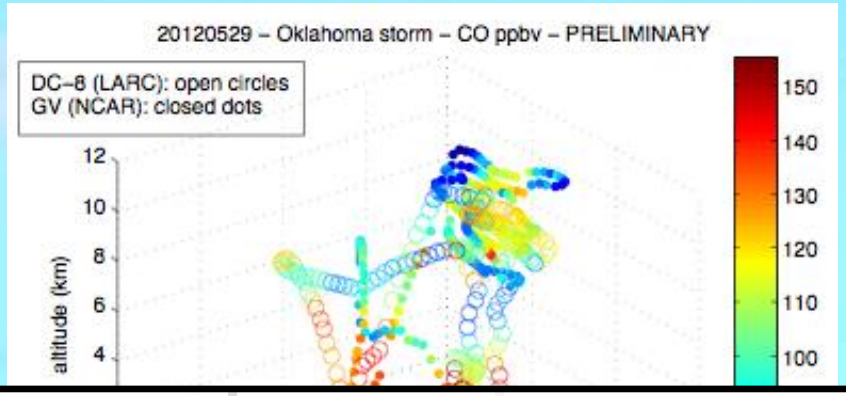


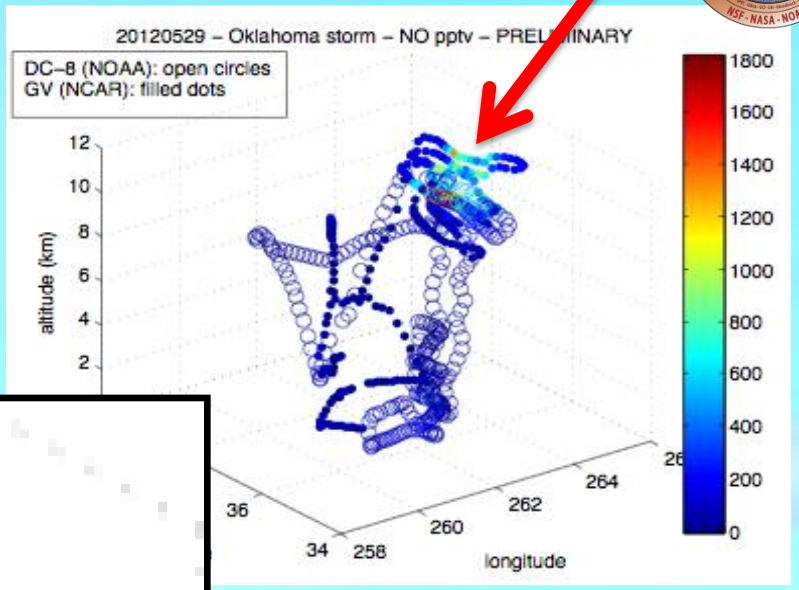


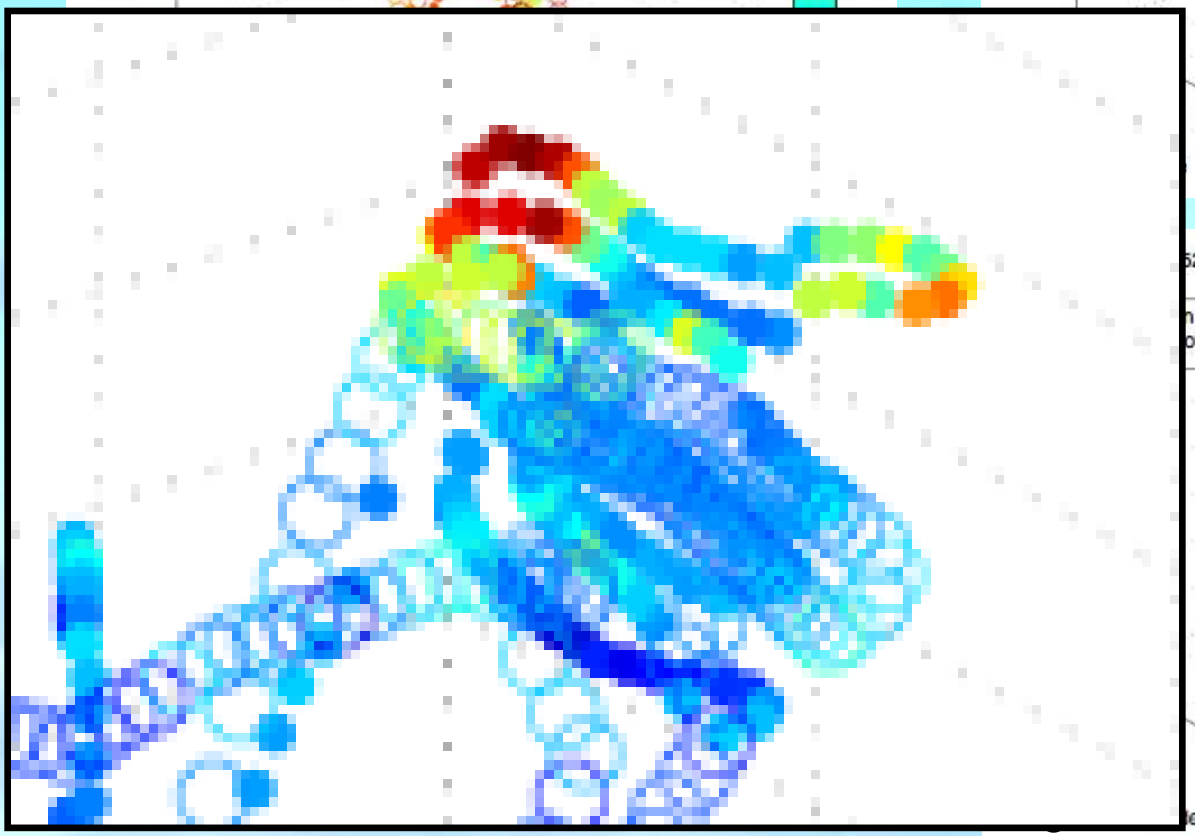
O_3

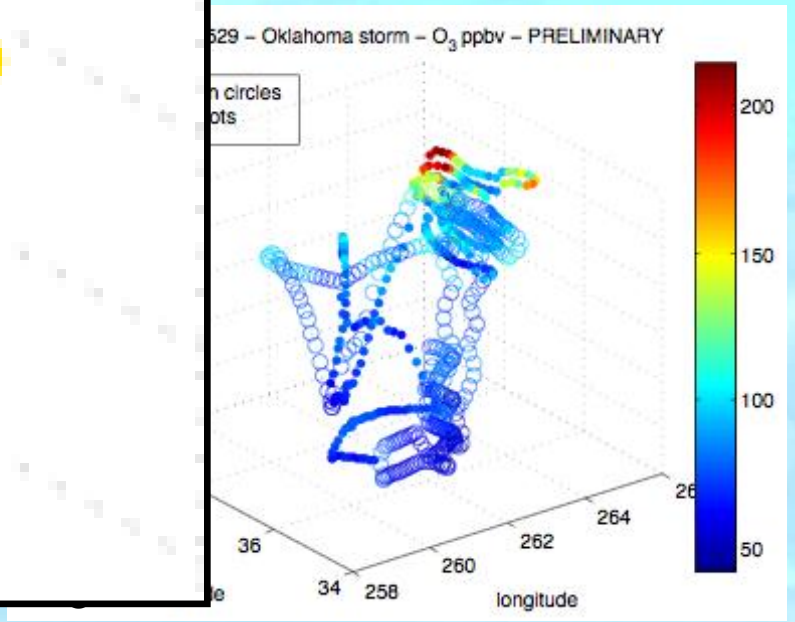
GV data: Weinheimer, Campos, Flocke, Knapp, Montzka (NCAR)
DC-8 data: Ryerson, Pollack, Peischl (NOAA/ESRL), Diskin, Sachse (NASA-Langley)
Plots courtesy Bill Brune (PSU)

29 May 2012 – Evidence of Transport and LNO_x

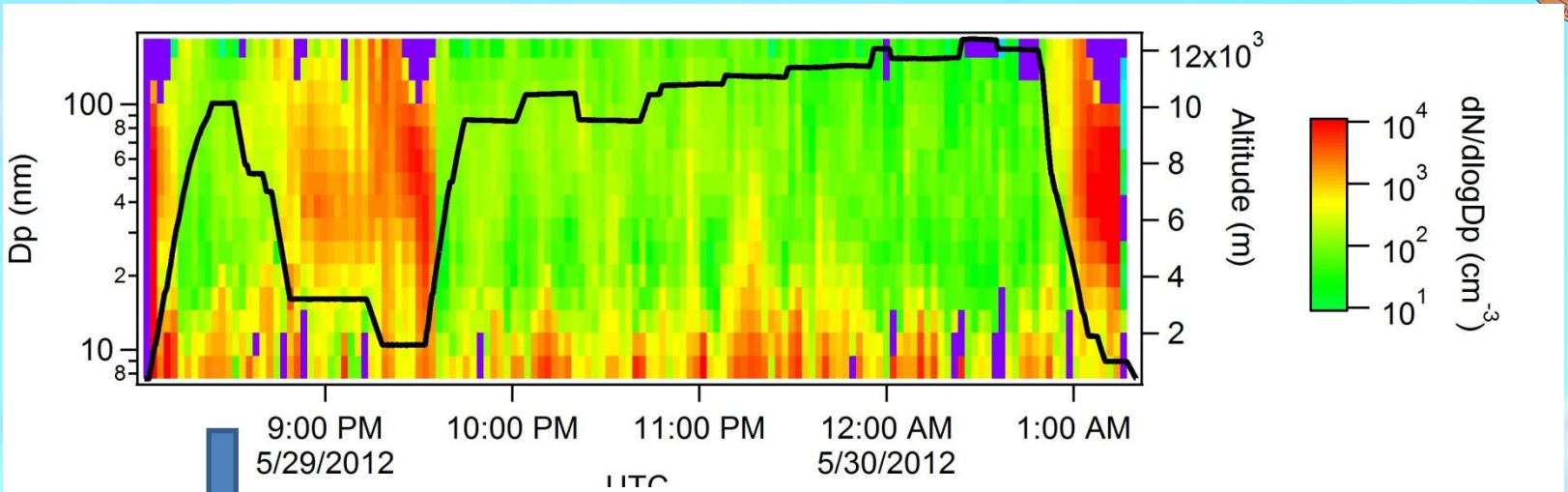




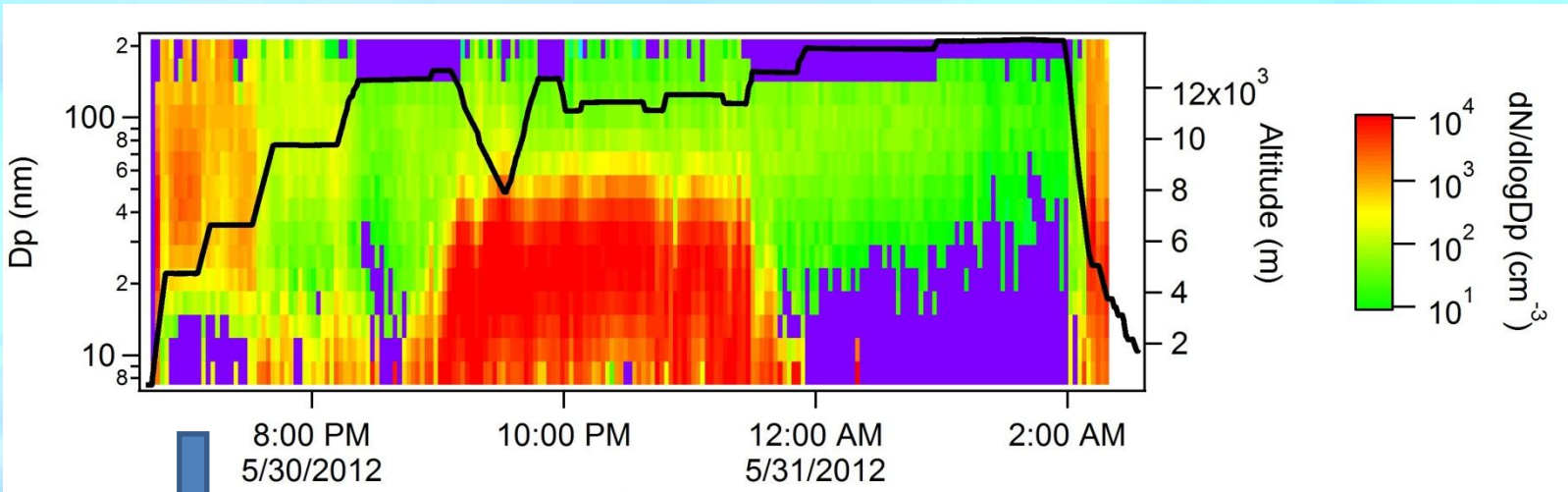




29 May 2012 – Aerosol Scavenging



Low aerosol concentrations in fresh convective outflow.

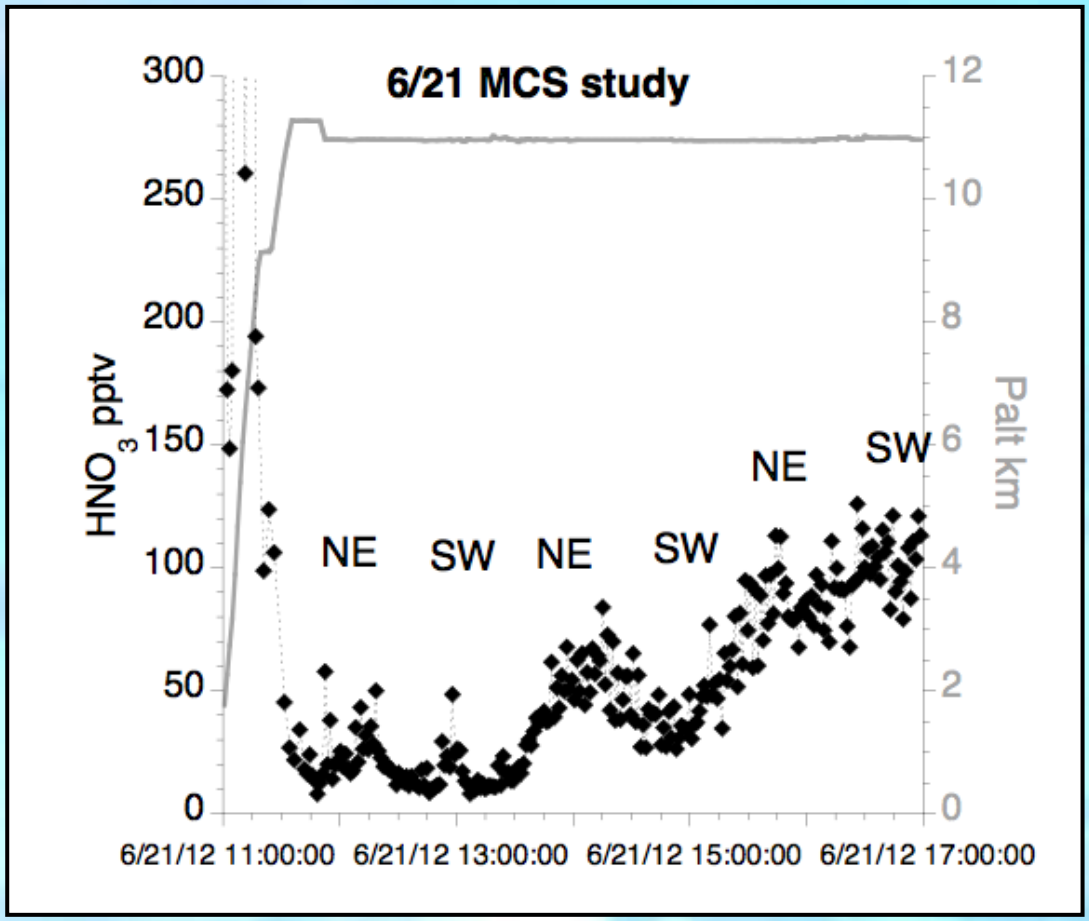


High concentrations the next day.

*** **Preliminary Data** ***

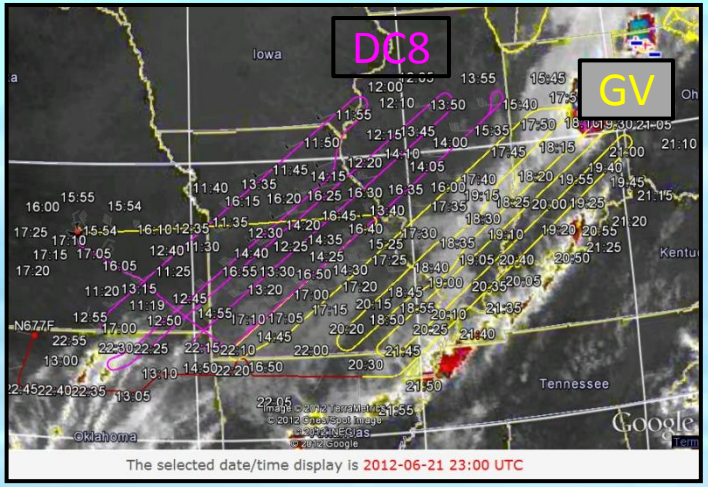
GV data: J. Smith, J. Ortega (NCAR)

Photochemical Aging Case: 21 June 2012



Nitric acid is scavenged by storms (→ near zero initially).

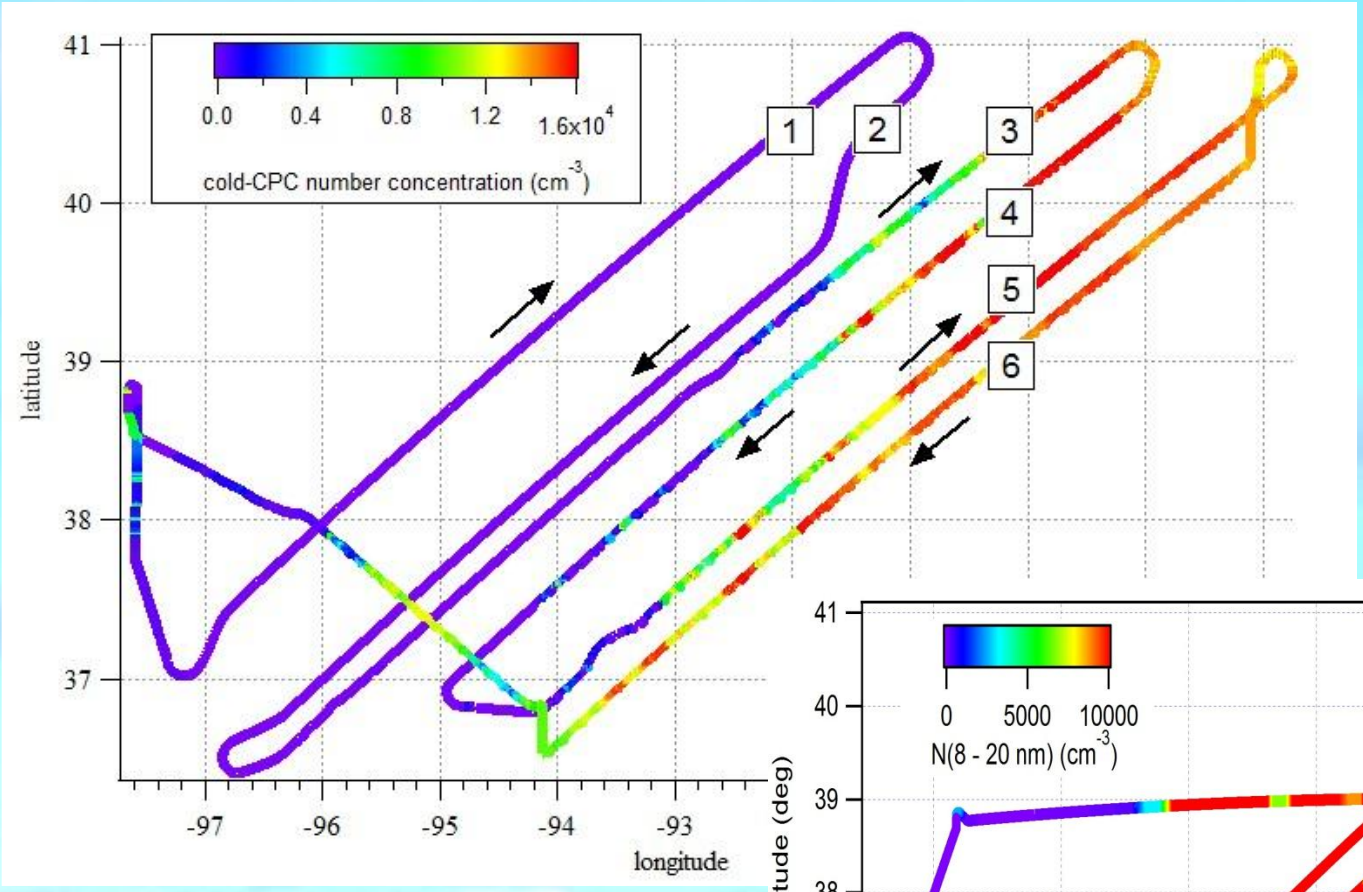
HNO_3 produced once cloud dissipates.



***** Preliminary Data *****
DC-8 data: J. Dibb (UNH)

Photochemical Aging Case: 21 June 2012

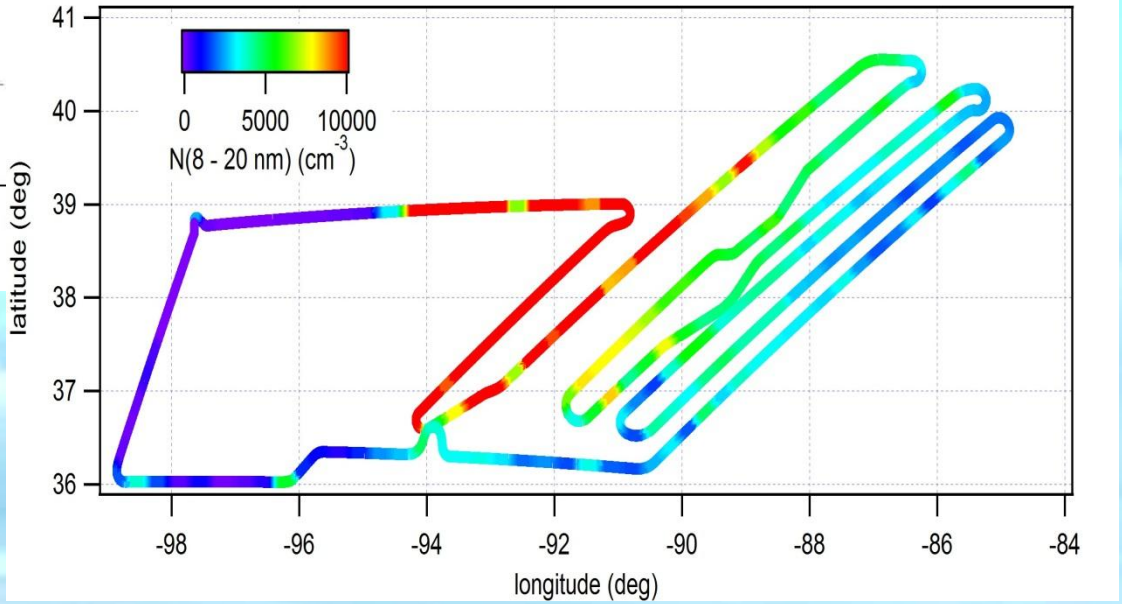
DC-8



Aerosols scavenged by storm

Aerosol production once cloud dissipates

GV



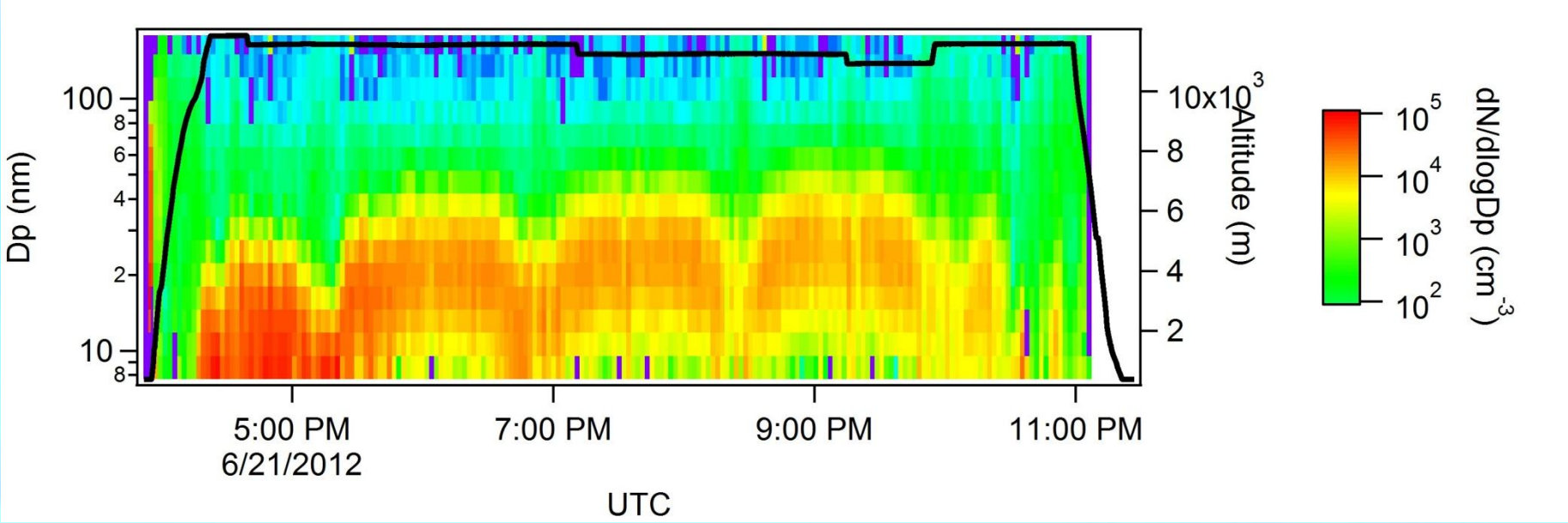
***** Preliminary Data *****

DC-8 data: L. Ziemba, B. Anderson (NASA/LaRC)

GV data: J. Smith, J. Ortega (NCAR)

Photochemical Aging Case: 21 June 2012

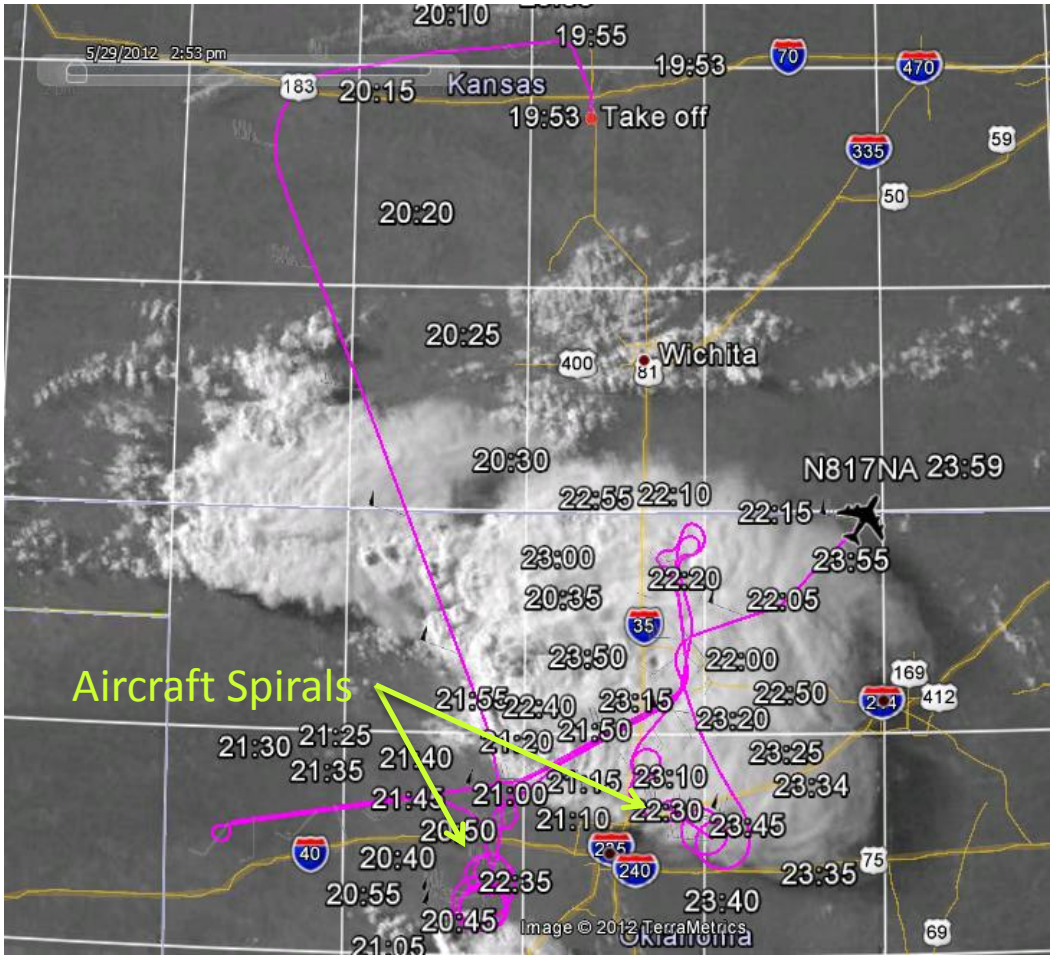
GV

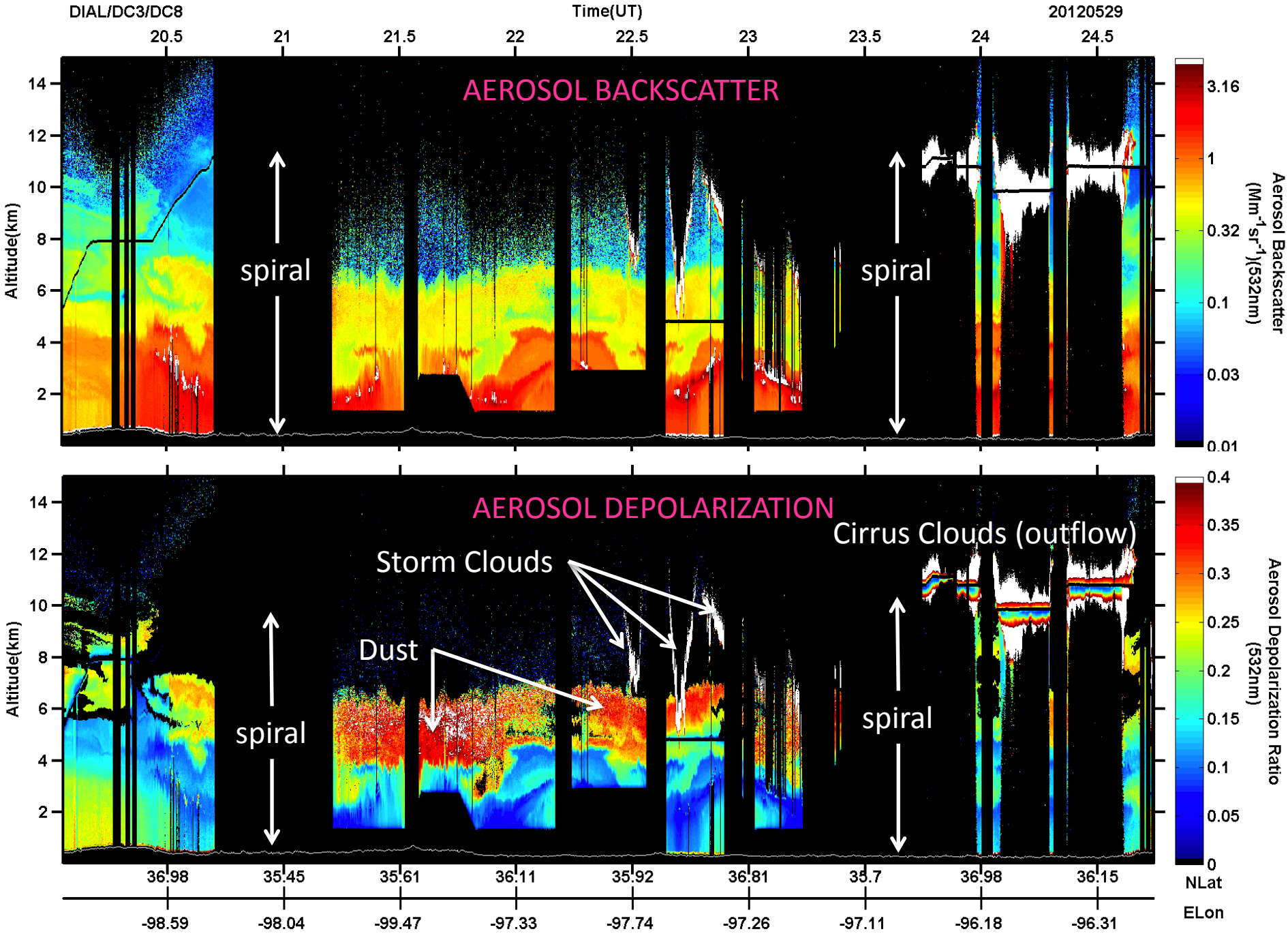


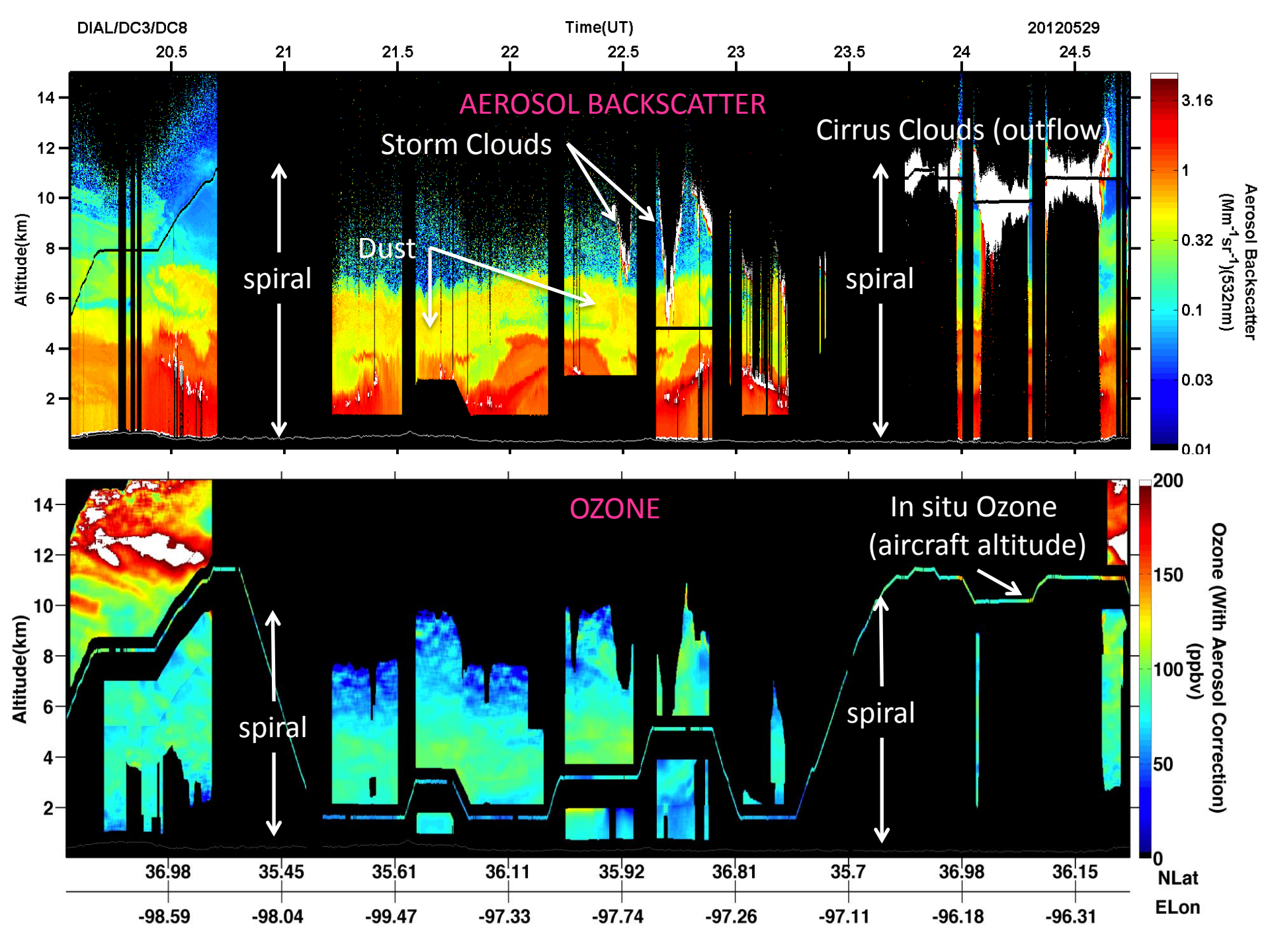
*** **Preliminary Data** ***

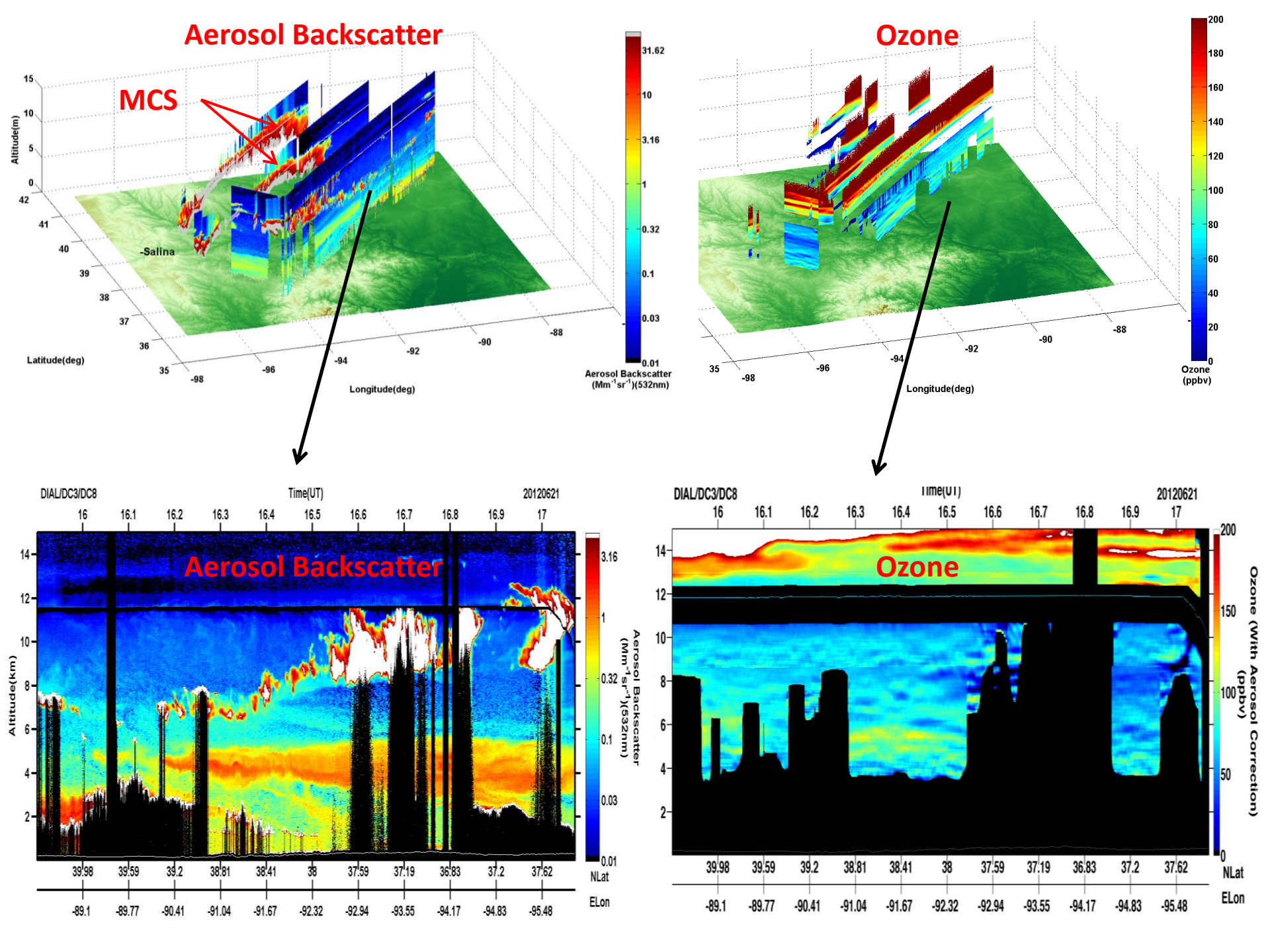
GV data: J. Smith, J. Ortega (NCAR)

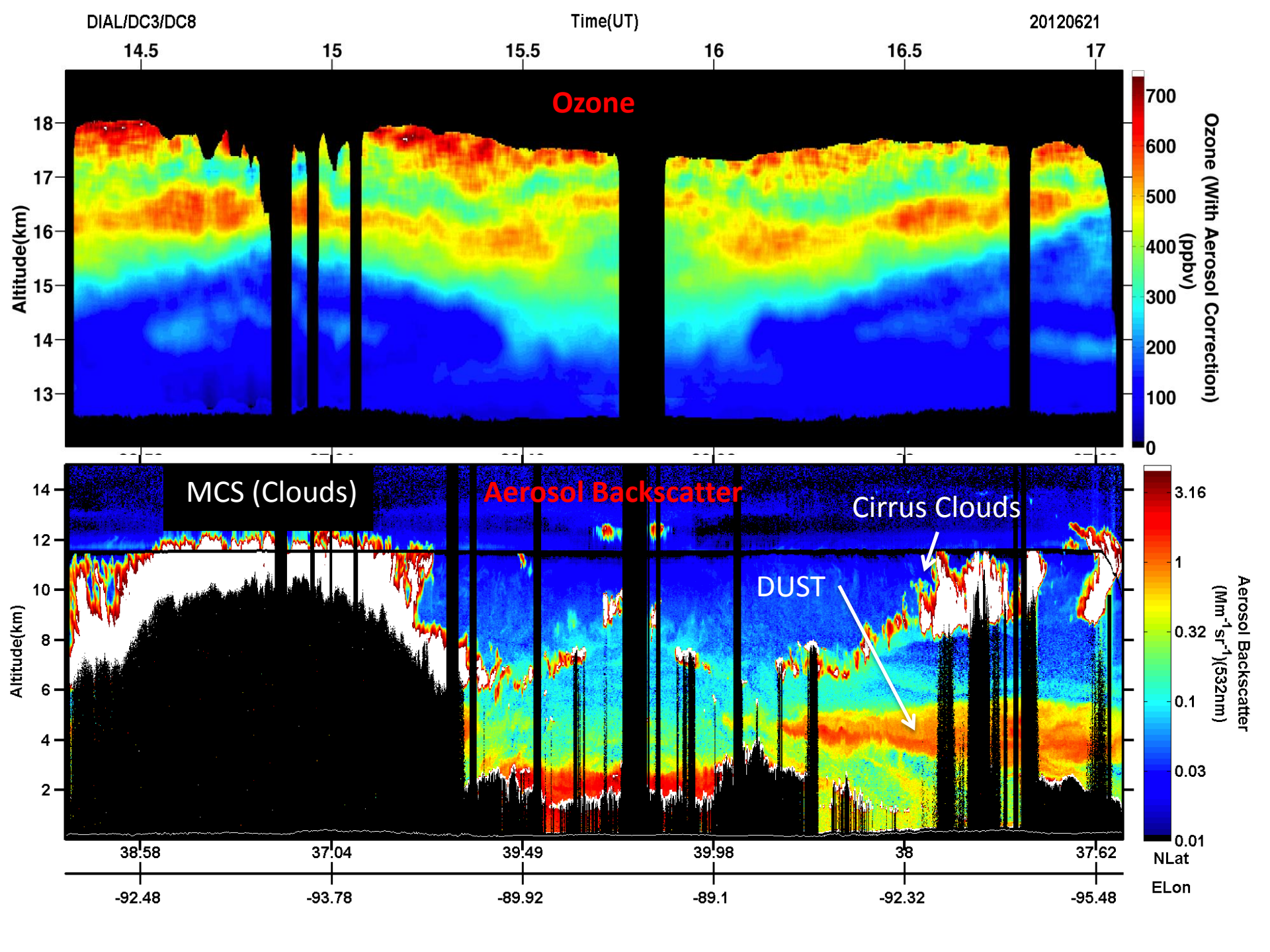
Flight Track (GOES 1km VIS)

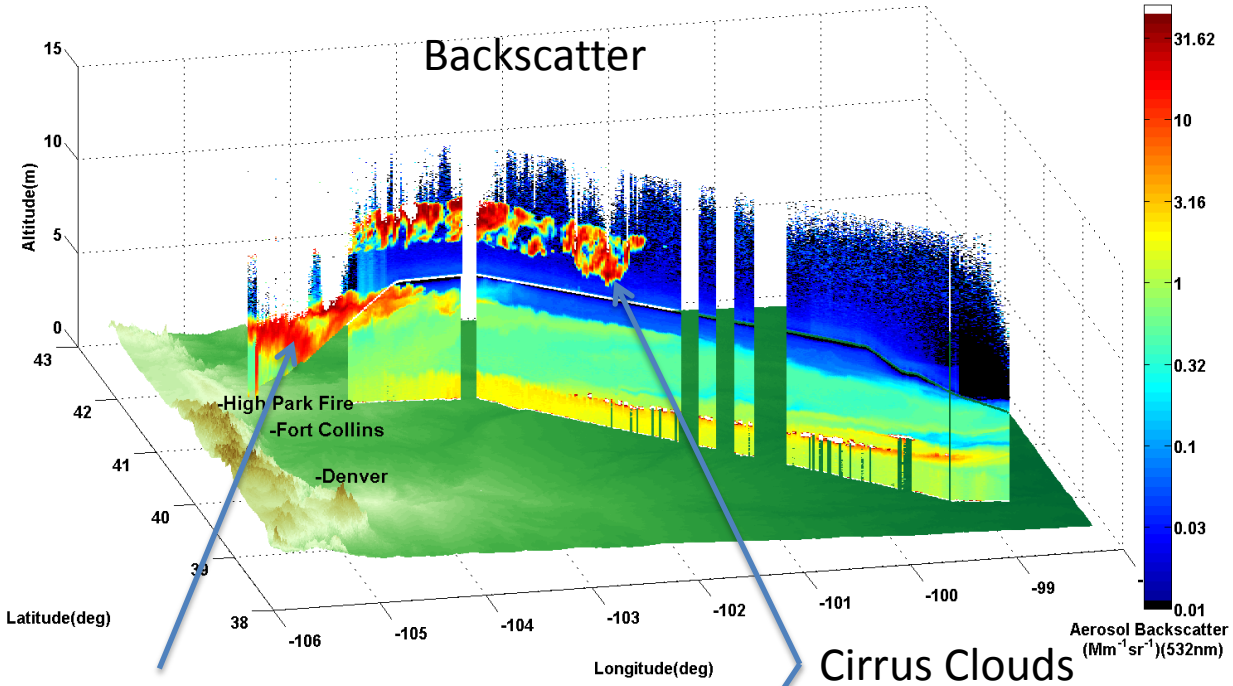



DIAL/DC3/DC8
Time(UT)
20120529
20.5
21
21.5
22
22.5
23
23.5
24
24.5
AEROSOL BACKSCATTER
Altitude(km)
14
12
10
8
6
4
2
spiral
spiral
3.16
1
0.32
0.1
0.03
0.01
Aerosol Backscatter (Mm-1sr-1)(532nm)
AEROSOL DEPOLARIZATION
Storm Clouds
Cirrus Clouds (outflow)
Dust
spiral
spiral
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Aerosol Depolarization Ratio (532nm)
36.98
35.45
35.61
36.11
35.92
36.81
35.7
36.98
36.15
NLat
-98.59
-98.04
-99.47
-97.33
-97.74
-97.26
-97.11
-96.18
-96.31
ELon


DIAL/DC3/DC8
Time(UT)
20120529
20.5
21
21.5
22
22.5
23
23.5
24
24.5
AEROSOL BACKSCATTER
Storm Clouds
Cirrus Clouds (outflow)
Dust
spiral
spiral
Altitude(km)
14
12
10
8
6
4
2
3.16
1
0.32
0.1
0.03
0.01
Aerosol Backscatter (Mm-1sr-1)(532nm)
OZONE
In situ Ozone (aircraft altitude)
spiral
spiral
200
150
100
50
0
Ozone (With Aerosol Correction) (ppbv)
36.98
35.45
35.61
36.11
35.92
36.81
35.7
36.98
36.15
NLat
-98.59
-98.04
-99.47
-97.33
-97.74
-97.26
-97.11
-96.18
-96.31
ELon

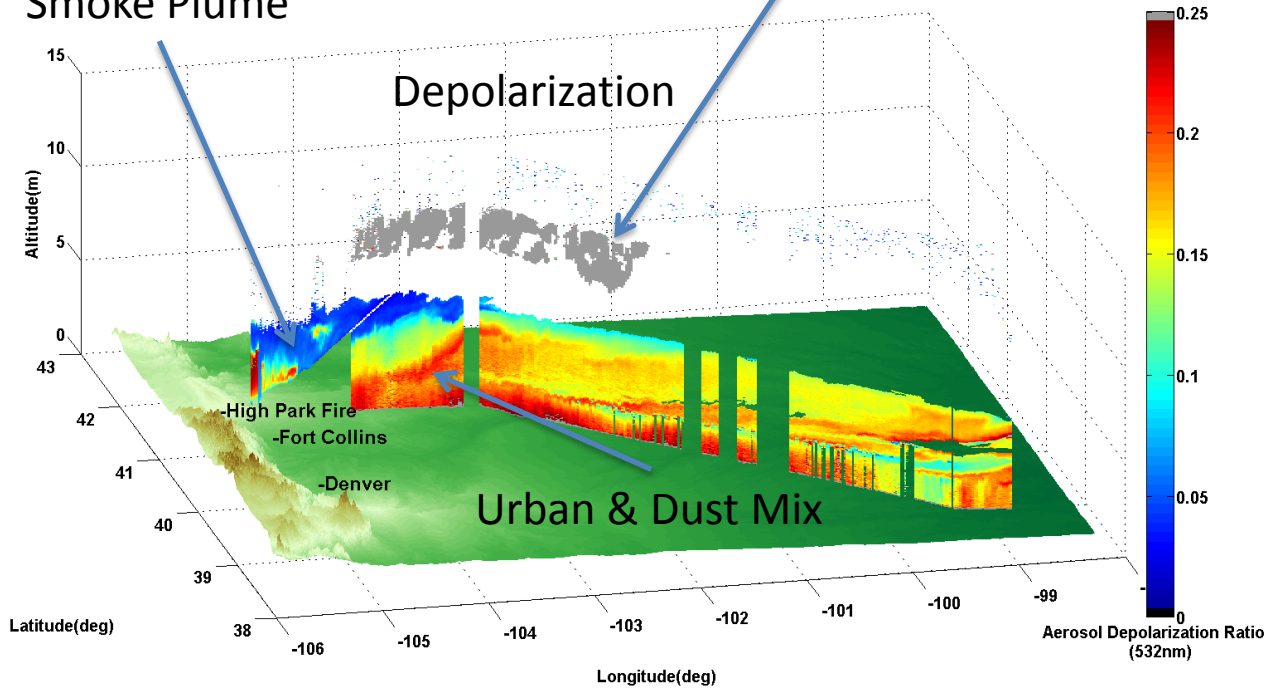

Aerosol Backscatter
MCS
Altitude(m)
Latitude(deg)
Longitude(deg)
-Salina
Aerosol Backscatter (Mm-1sr-1)(532nm)
Ozone
Ozone (ppbv)
DIAL/DC3/DC8
Time(UT)
20120621
Altitude(km)
NLat
ELon
Ozone (With Aerosol Correction) (ppbv)


DIAL/DC3/DC8
Time(UT)
20120621
14.5
15
15.5
16
16.5
17
Ozone
Altitude(km)
18
17
16
15
14
13
700
600
500
400
300
200
100
0
Ozone (With Aerosol Correction)
(ppbv)
MCS (Clouds)
Aerosol Backscatter
Cirrus Clouds
DUST
14
12
10
8
6
4
2
3.16
1
0.32
0.1
0.03
0.01
Aerosol Backscatter
(Mm-1sr-1)(532nm)
38.58
37.04
39.49
39.98
38
37.62
NLat
-92.48
-93.78
-89.92
-89.1
-92.32
-95.48
ELon



Smoke Plume

Cirrus Clouds



June 22
High Park Fire & Colorado Convective Storm

<u>Fire Plume</u>

- extinction range: 300 to >1000 Mm^{-1}
- Large contrast in the aerosol depolarization within smoke plume and regional aerosols (dust and urban)

DC-8 Flight Track