DC3 Science Team Meeting

February 25-28, 2013

Overview of the Deep Convective Clouds and Chemistry (DC3) Experiment

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

May 25, 2012 OK/TX storm; Photograph by Chris Cantrell

Motivation

In the upper troposphere, ozone is a GHG

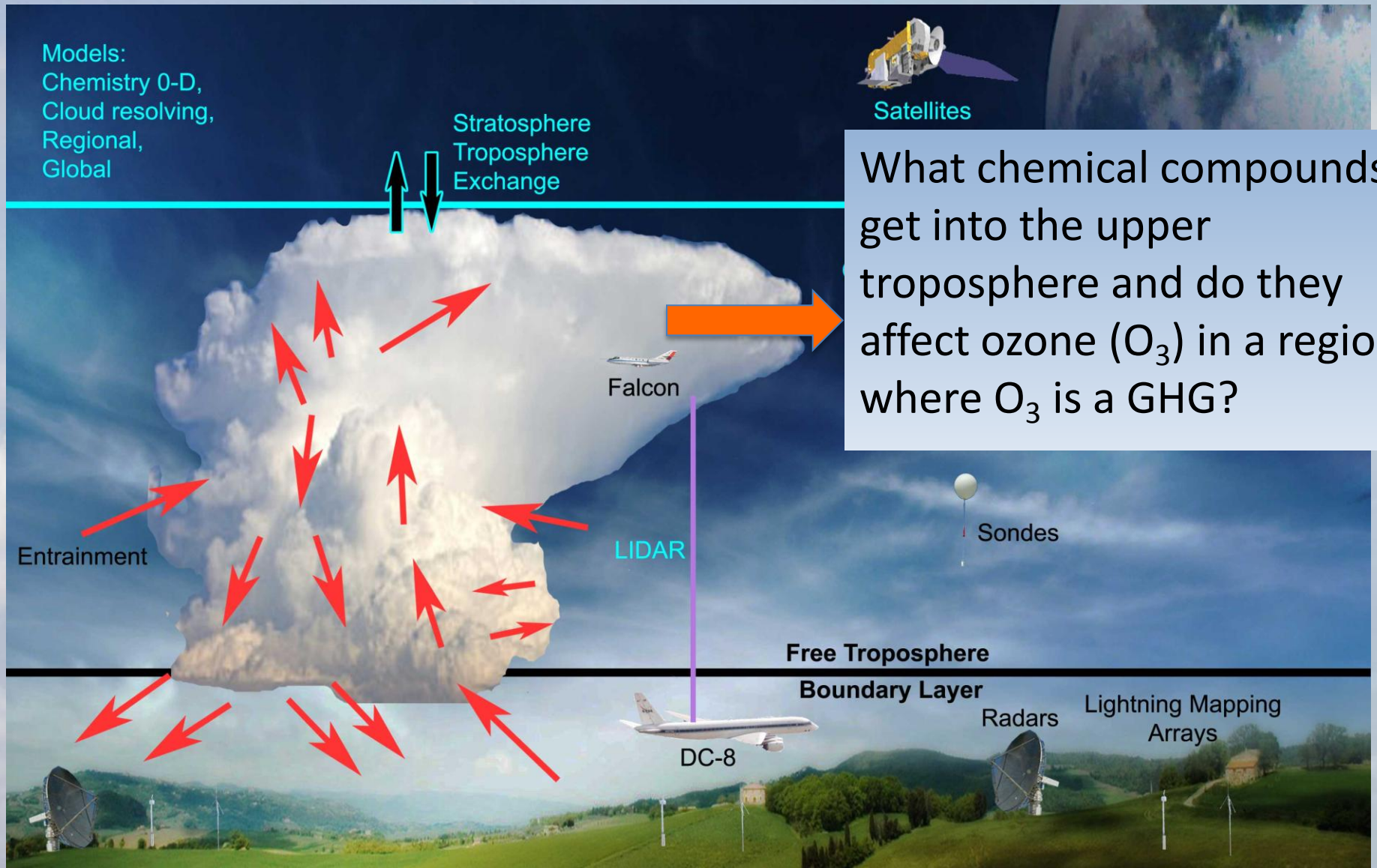
→ important for climate change

What chemical compounds get into the upper troposphere and do they produce or destroy ozone?

What role do thunderstorms have in affecting the UTLS composition and chemistry?

UTLS = upper troposphere & lower stratosphere

Motivation



What chemical compounds get into the upper troposphere and do they affect ozone (O_3) in a region where O_3 is a GHG?

Previous Field Studies
good storm information, limited chemistry

- STERAO (1996, northeast Colorado)
- EULINOX (1998, Europe)
- TROCCINOX (2004; 2005, Brazil)
- SCOUT-O3 (2005, Darwin, Australia)
- STEPS (2000, Colorado-Kansas border)

- Good storm and kinematic data
- Limited number of chemical species measured by aircraft

STERAO (northeast Colorado)

- Two aircraft, airborne and ground-based radar, ONERA lightning detection network
- Findings from July 10, 1996 storm:
  - Intracloud lightning flashes can be a major contributor to NOx
  - Lightning occurred primarily in moderate updrafts and weak downdrafts
  - Cloud-scale modeling reasonably represents transport and redistribution of trace gases; unknown how well they represent transport and scavenging of soluble gases
  - Production of NO from lightning estimated to be 330 moles/flash

Dye et al., 2000, JGR; Barth et al., 2007, JGR

STEPS (Colorado-Kansas border)

- Findings :
  - Related storm parameters to lightning flash rate
  - Provided first of the kind dynamical, microphysical and electrical observations of inverted storms and normal polarity storms
  - Positive CG lightning linked to mid-level positive charge in inverted tripole storms
  - Low Precipitation supercells characterized by inverted dipoles with no lower negative charge; no CG lightning
  - Positive CG producing storms found to be more intense, containing strong, broad updrafts

Wiens et al., 2005; Tessendorf et al., 2007a,b

Previous Field Studies
good chemistry information, limited storm data

- INTEX-A (2004, continental US)
- TRACE-P (2001), ARCTAS (2008)

- Limited cloud and no kinematic data
- Nice suite of chemical species measured by aircraft

INTEX-NA Findings

- Bertram et al., 2007, Science
  - Substantial influence of deep convection on UT composition
  - Estimate 17% of PBL air is in fresh convective outflow; 54% of UT air influenced by convection that occurred during the previous 2 days
  - Convective turnover rate between 0.1 and 0.2/day
  - Use of chemical clock as coordinate for UT chemistry
- Snow et al., 2007, JGR
  - Convectively influenced air enhanced in CH_3OOH, CH_2O, CO, NO, and NO_2, and depleted in H_2O_2 and HNO_3

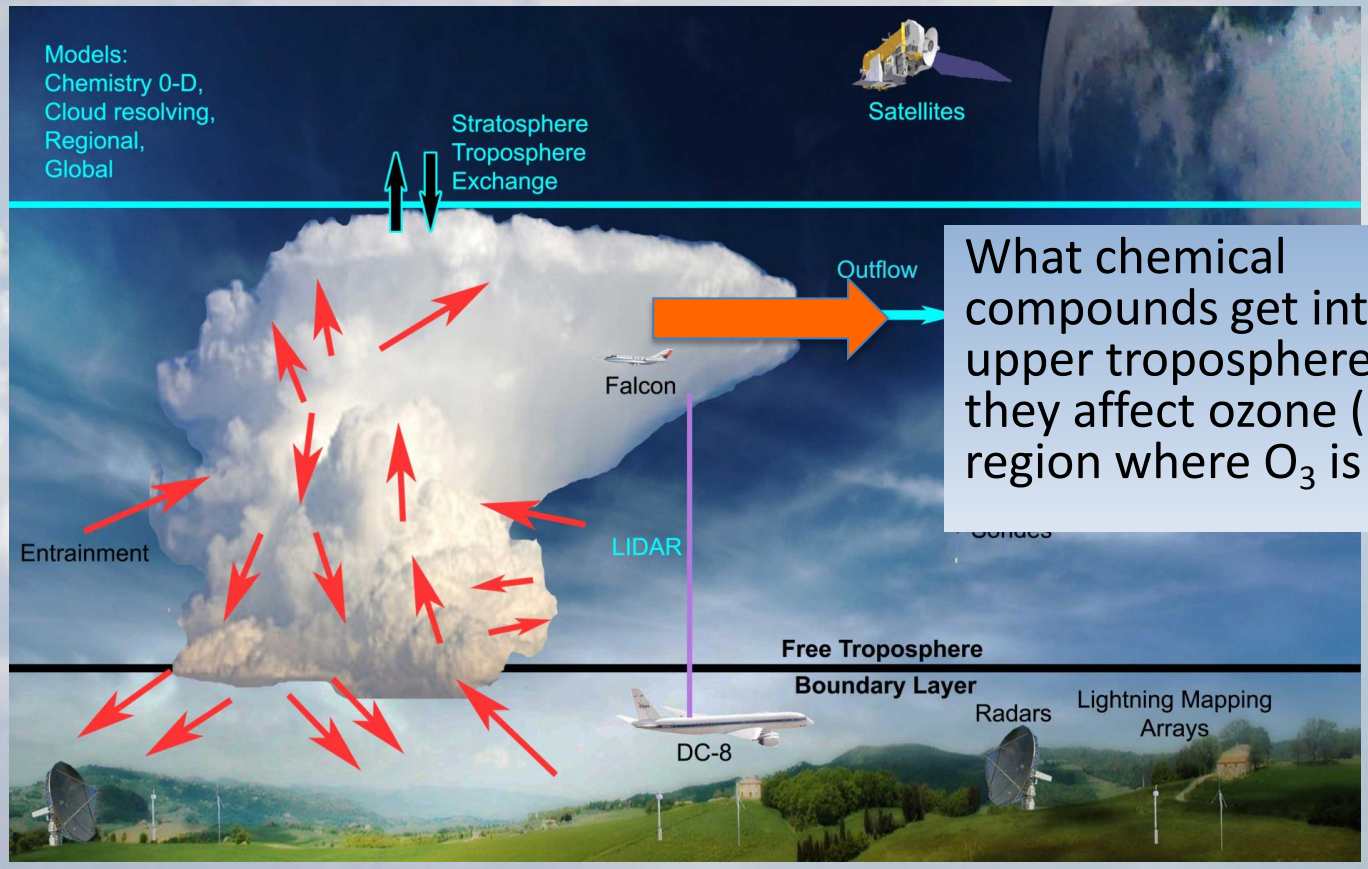
ARCTAS Findings

- Apel et al., 2012, ACP (storms in Canada)
  - Transport of isoprene to UT
  - Impact of lightning-NOx on UT OH in presence of isoprene
    - Low O3 production without lightning-NOx
    - Substantial O3 production with lightning-NOx AND isoprene

AMMA (2006, western Africa)

- Variety of facilities (radar, LINET, multiple aircraft)
- Borbon et al. (2012) JGR:
  - CH_2O scavenged by storms to some extent (4-39%)
  - After convection, 60% of CH_2O is due to photochemical production rather than direct transport
- Huntrieser et al. (2011) ACP
  - Study of 2 MCS → 70-180 moles NO/flash
  - Lower lightning-NOx production similar to findings from other tropical studies (TROCCINOX, SCOUT-O3), but smaller than the 300-500 moles/flash estimated for midlatitudes (STERAO, CRYSTAL-FACE, EULINOX)

DC3



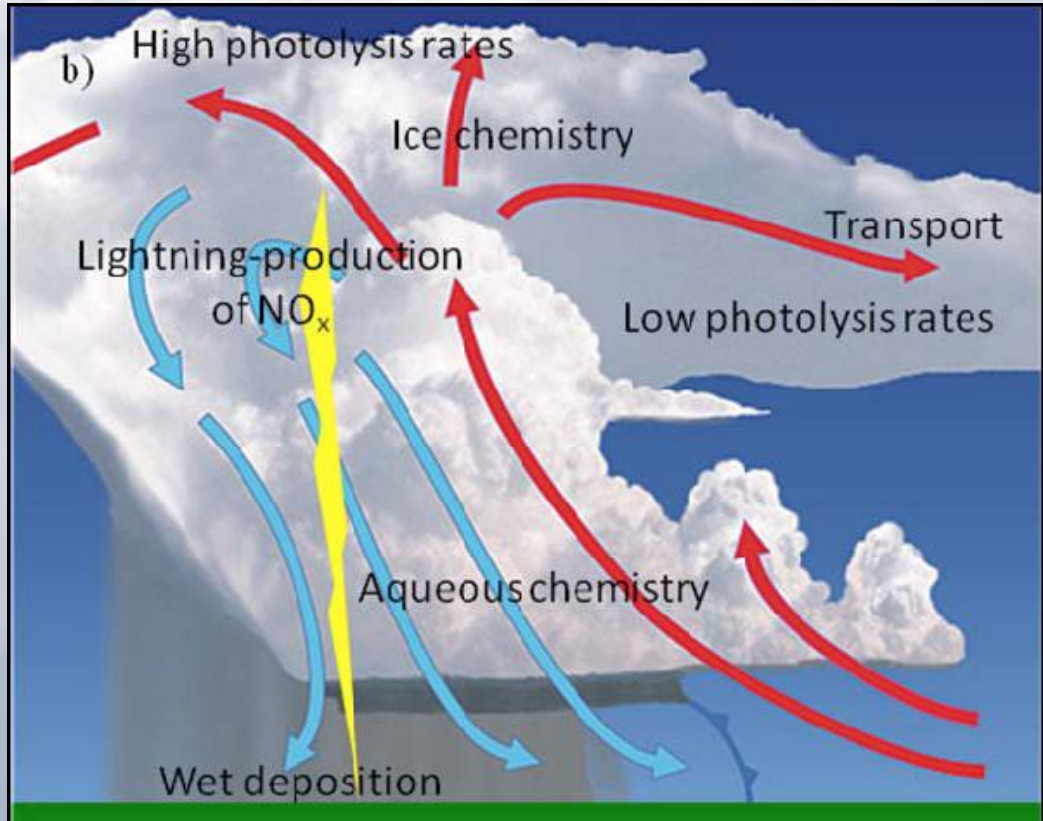
What chemical compounds get into the upper troposphere and do they affect ozone (O_3) in a region where O_3 is a GHG?

Goals of the DC3 Field Campaign

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

2. ***To learn how the air that exits the storm in the upper troposphere (UT) changes chemically during the next day*** (chemical aging)

Additional topics: aerosols, halogens



Setting for the DC3 Field Campaign

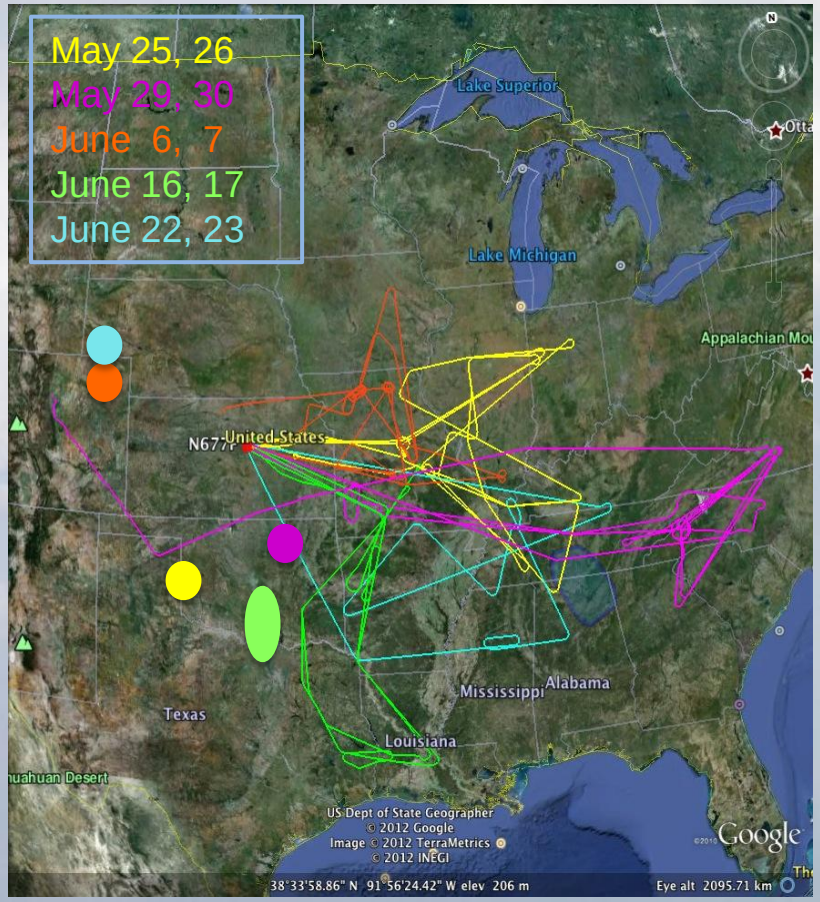
When: May – June 2012

Where: Based Salina, Kansas

Sampled storms in NE Colorado, W Texas to central Oklahoma, and N Alabama

Downwind Flights

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



Aircraft Facilities

3 aircraft equipped with chemistry, aerosol, and cloud physics probes.

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**

Cantrell: Summary of GV Measurements

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**

Brune: Summary of DC-8 Measurements

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**

Huntrieser: Summary of Falcon Measurements

Aircraft Flights

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

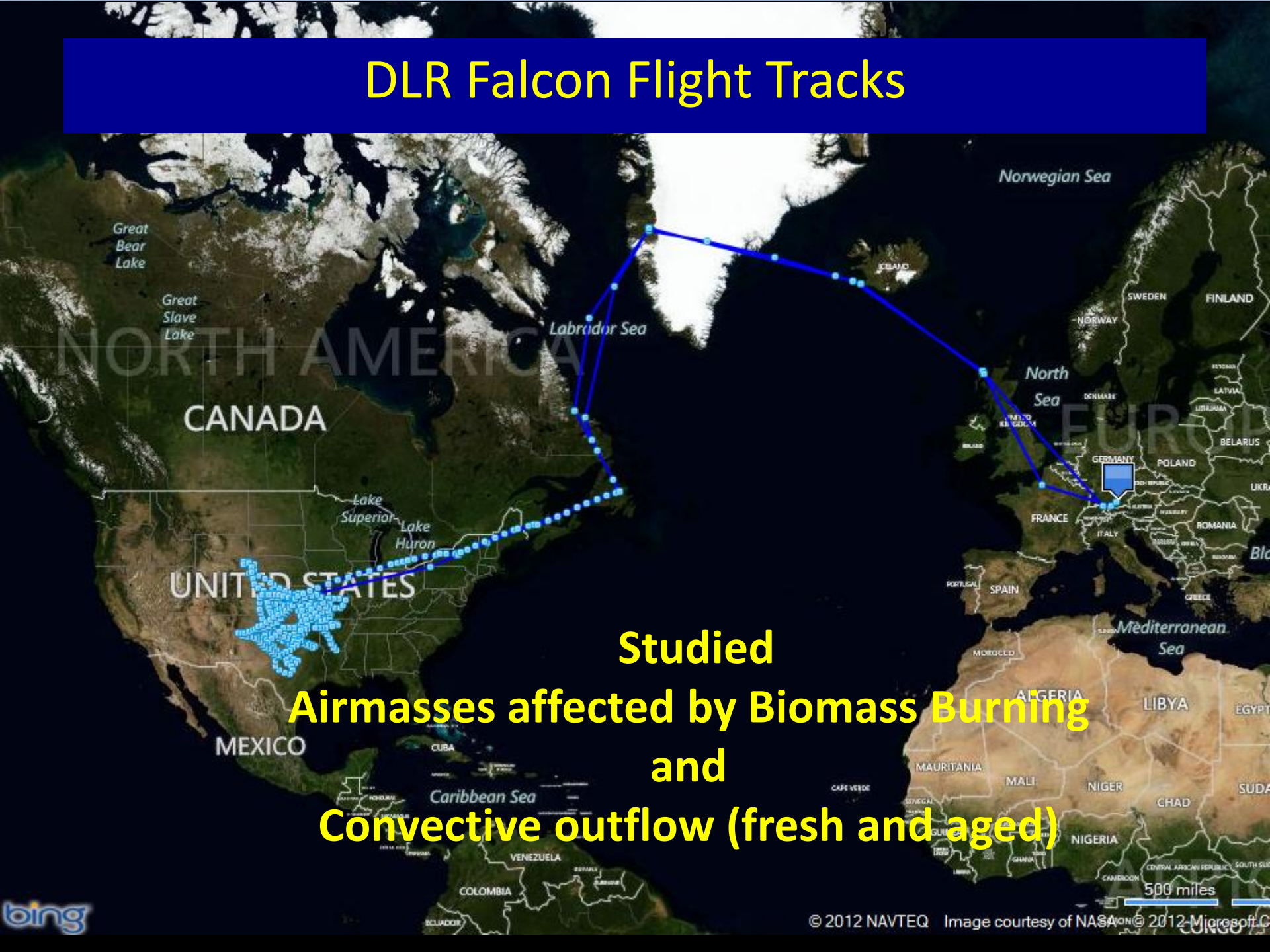
Green = Alabama storm
Orange = OK/TX storm
Blue = Colorado storm
Purple = Chemistry focus

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
MAY 13	Shakedown AL 14	15	16	17	CO storm 18	OK storm 19
20	AL storm 21	22	23	24	OK storm 25	Downwind 26
		OK storm 29	Downwind 30	31	CO sources & TX storm 1	CO storm 2
JUNE 3	4	CO storm 5	CO storm 6	Downwind 7	8	9
10	AL & MCS 11	12	13	14	CO storm 15	OK storm 16
Downwind 17	18	19	20	MCS aging 21	CO storm 22	Downwind 23
24	UT survey 25	26	CO storm 27	CO storm 28	29	TX sources 30

DLR Falcon Flight Tracks

13 DLR Falcon DC3 missions from
29 May – 14 June 2012
~40 local flight hours

DLR Falcon Flight Tracks



Studied
Airmasses affected by Biomass Burning
and
Convective outflow (fresh and aged)

Green = Alabama storm
Orange = OK/TX storm
Blue = Colorado storm
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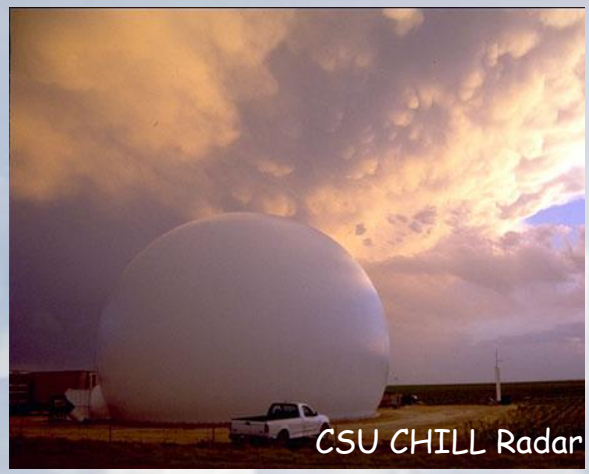
Ground Facilities

What: Ground-based radars, lightning mapping arrays, and weather soundings in all three sampling regions


CSU CHILL Radar


UA-H ARMOR Radar


NMT Lightning Antenna


OU SMART Radar


Weather Balloon Launch

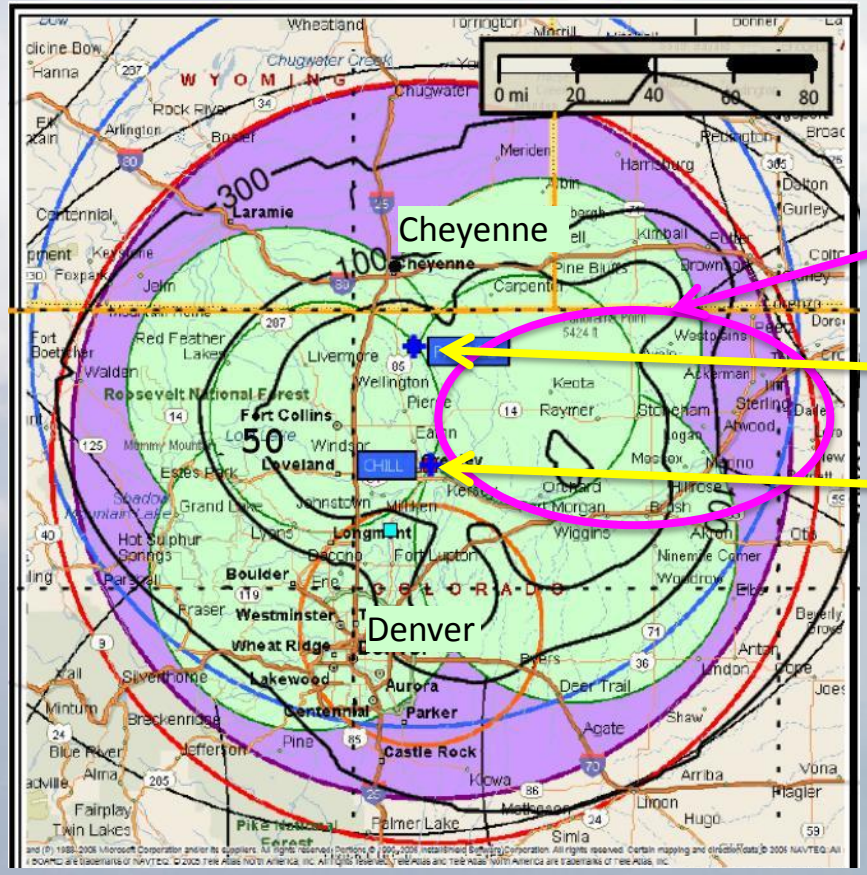
Colorado Ground-based Operations

Colorado Ground Facilities:

LMA and radars operated throughout campaign

16 cases in total including 4 days of scanning electrified fire plumes

Rutledge: Highlights of Colorado Operations



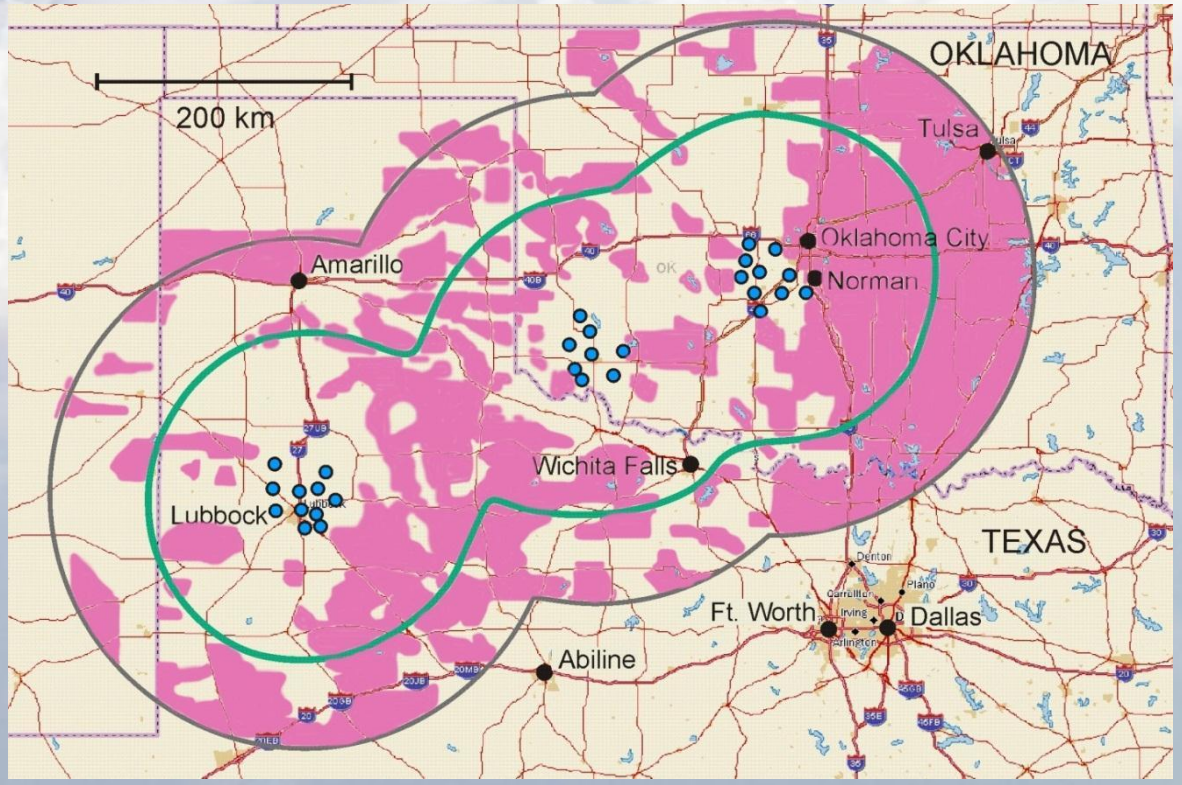
Oklahoma-Texas Ground-based Operations

West Texas to Central Oklahoma Facilities:

LMA operated throughout campaign

Radars and soundings operated on 13 days; 7 days of in-storm EFM sdgs

MacGorman: Highlights of Oklahoma-Texas Operations



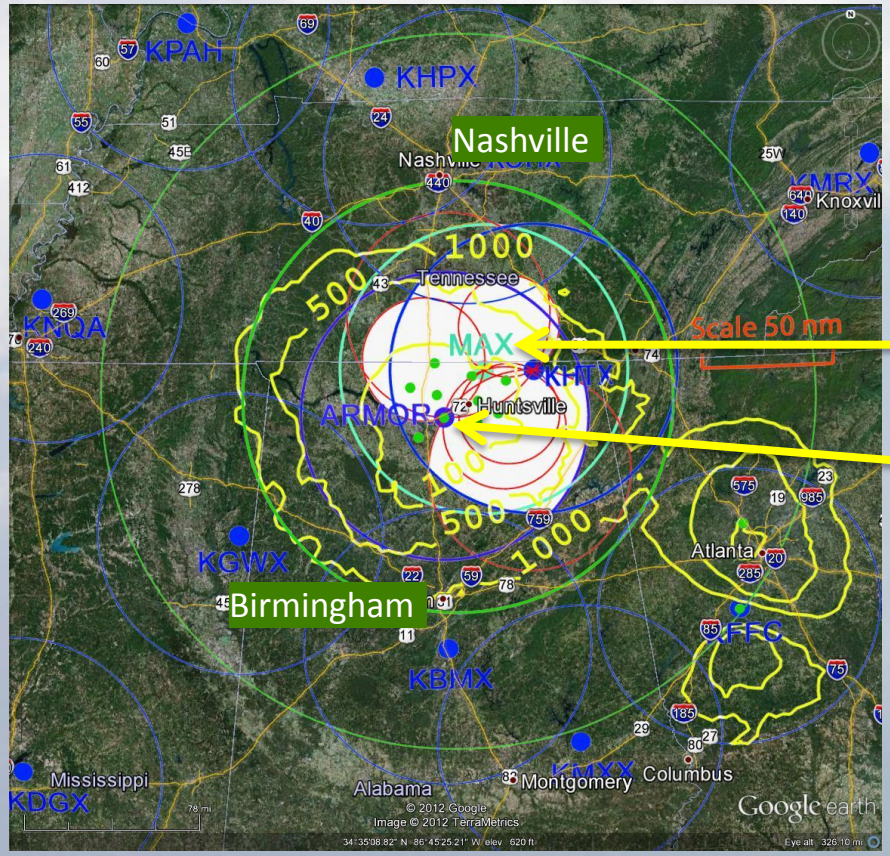
Alabama Ground-based Operations

Alabama Ground Facilities:

LMA and radars operated throughout campaign

12 cases of a variety of thunderstorms observed

Carey: Highlights of Alabama Operations

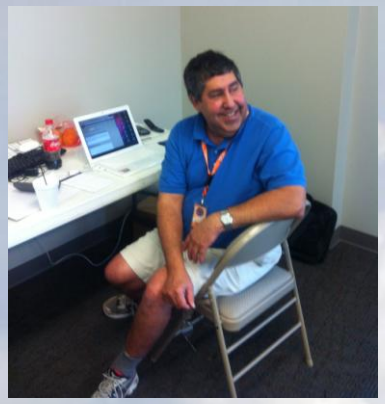


MAX radar

ARMOR radar

Forecasting for the DC3 Field Campaign

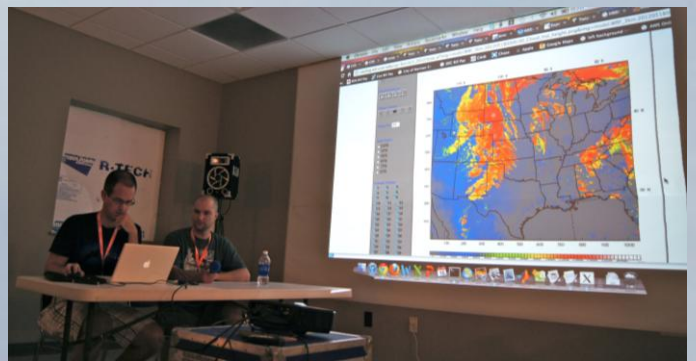
Expert forecasting used to predict if/when storms would occur in the DC3 sampling regions



Salina, Kansas
Lead Forecaster
Nowcasters

Regional Forecasters

NE Colorado	**Oklahoma/Texas**	**Alabama**
CSU	NOAA/NSSL	UAH



Synoptic Meteorology over U.S.

Characterized by troughs and ridges advecting from west to east across U.S., typical for mid-latitudes

Southern U.S. dried out during June and went into drought conditions

Wildfires were predominant over the Rocky Mountains, beginning in New Mexico and moving northward into Colorado, Wyoming, and Montana/Idaho/Washington later in the summer

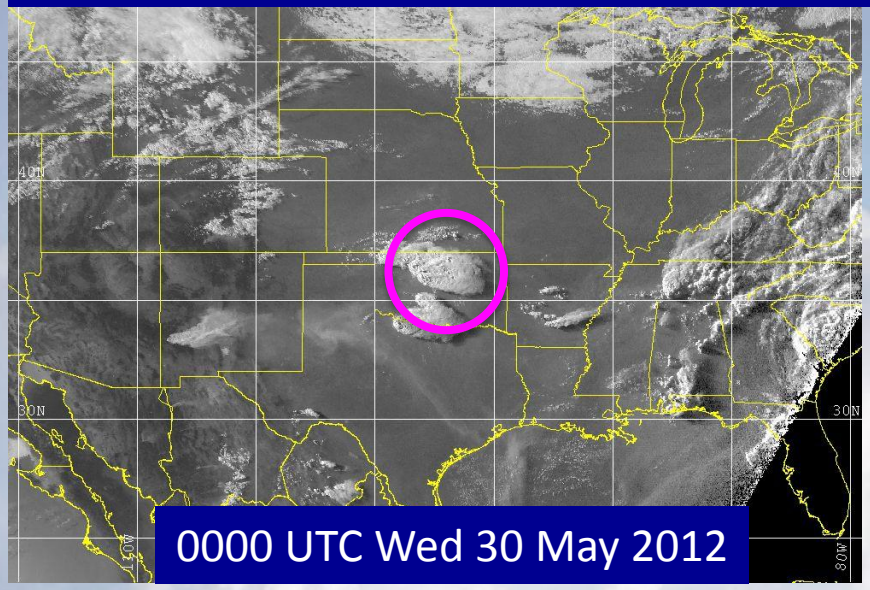
Water Vapor Imagery

See water vapor movie file

Courtesy Owen Cooper

Visible Satellite / Radar

MCS over Kansas
profile behind storm by DC8 + transport into stratosphere



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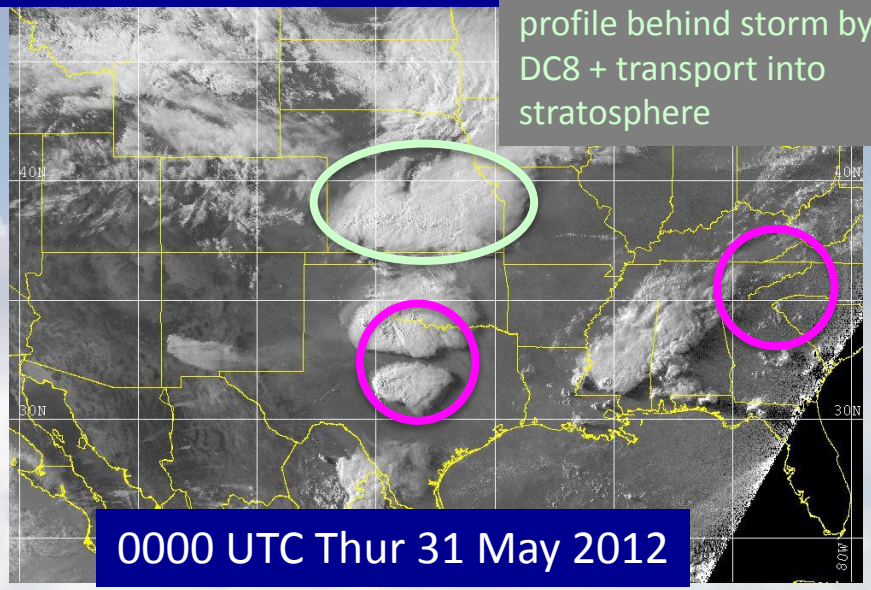

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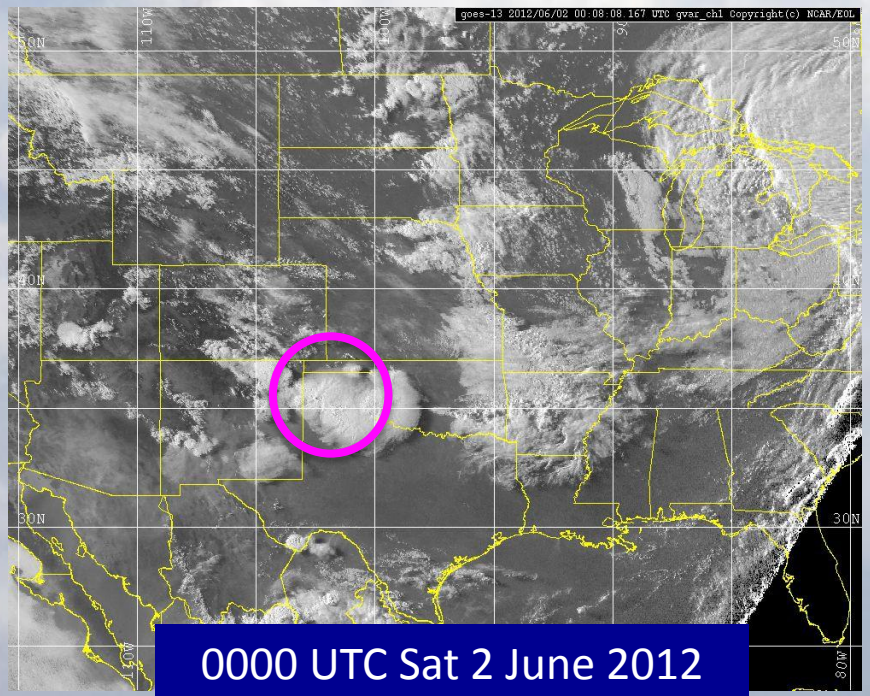
Flight Region



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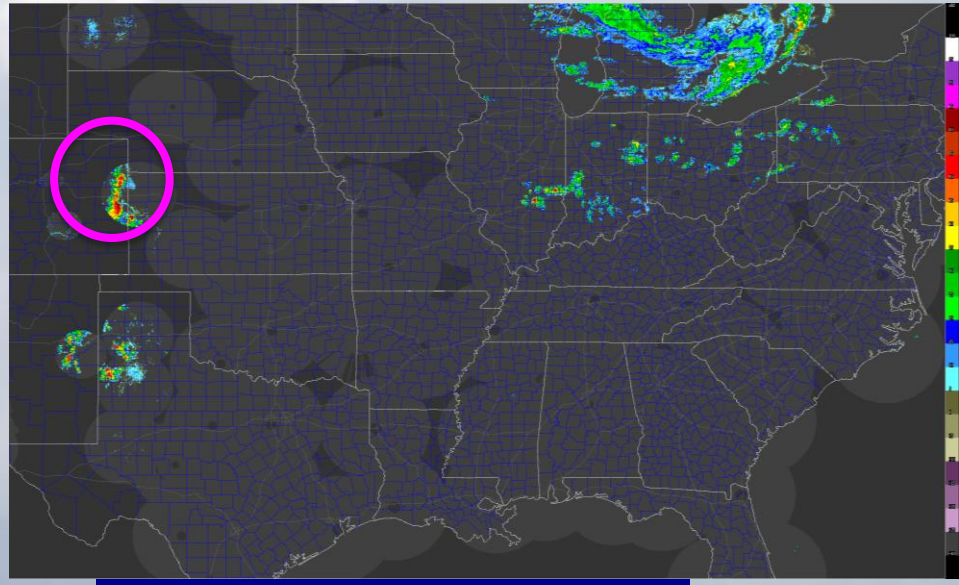

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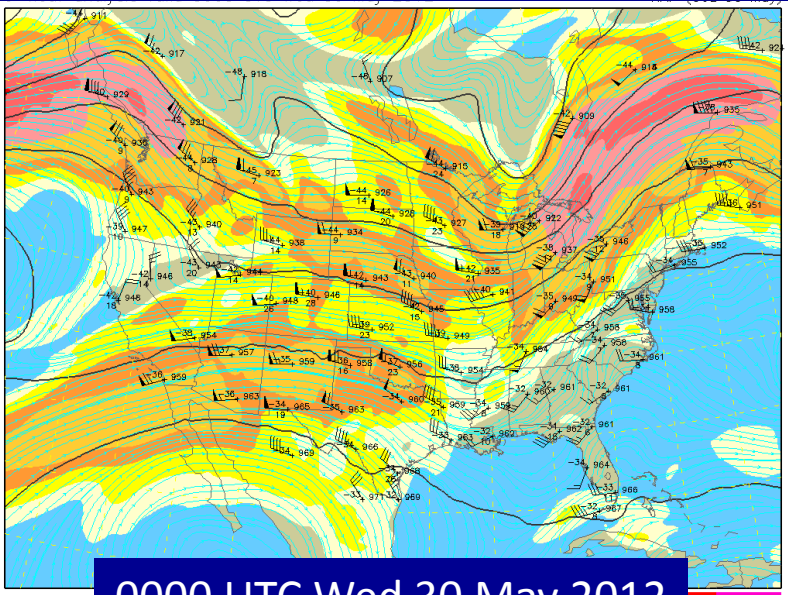
300 mb Heights / Isotachs



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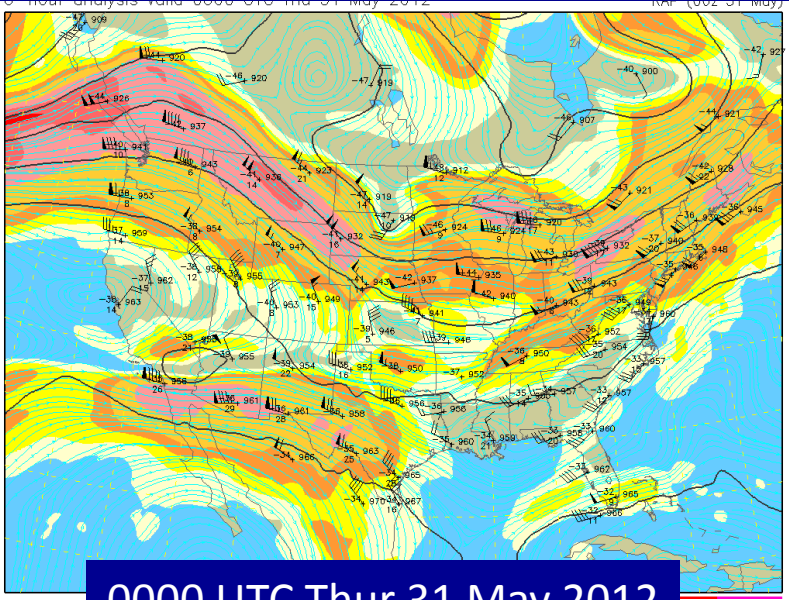

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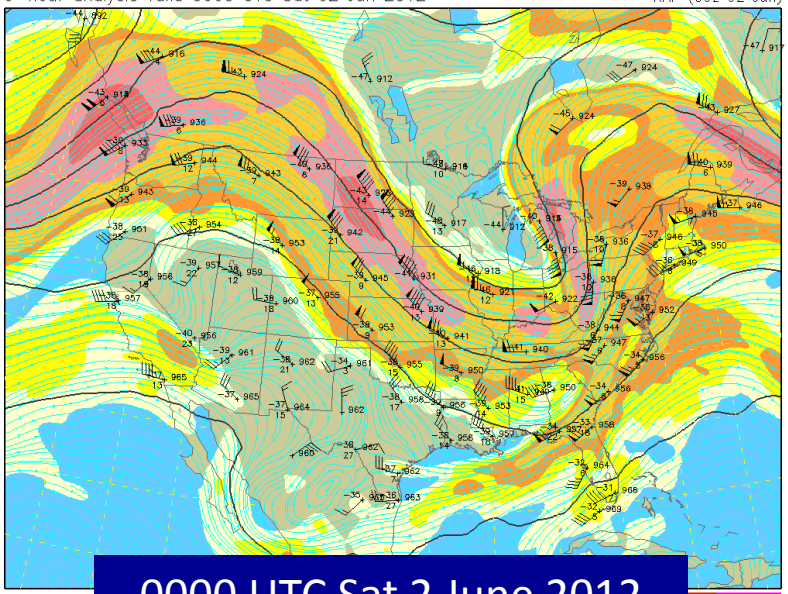
300 mb Heights (dm) / Isotachs (knots)



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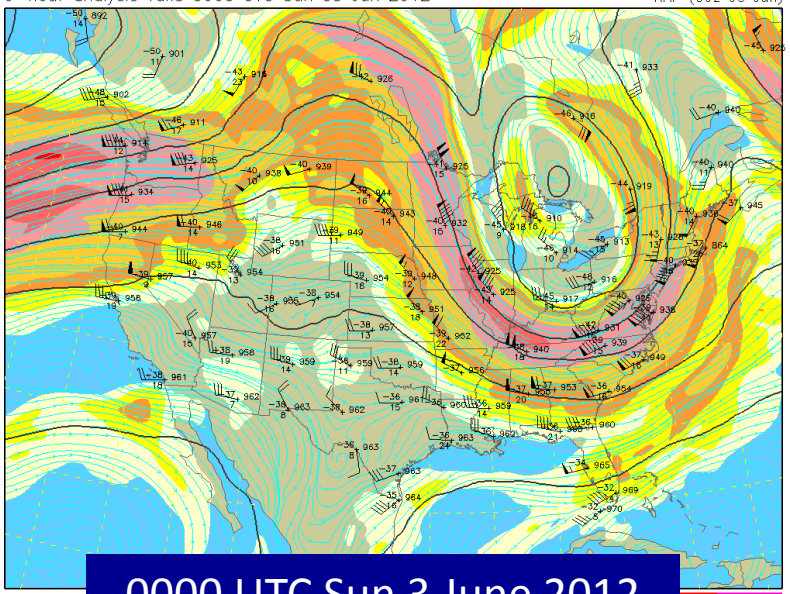
300 mb Heights (dm) / Isotachs (knots)



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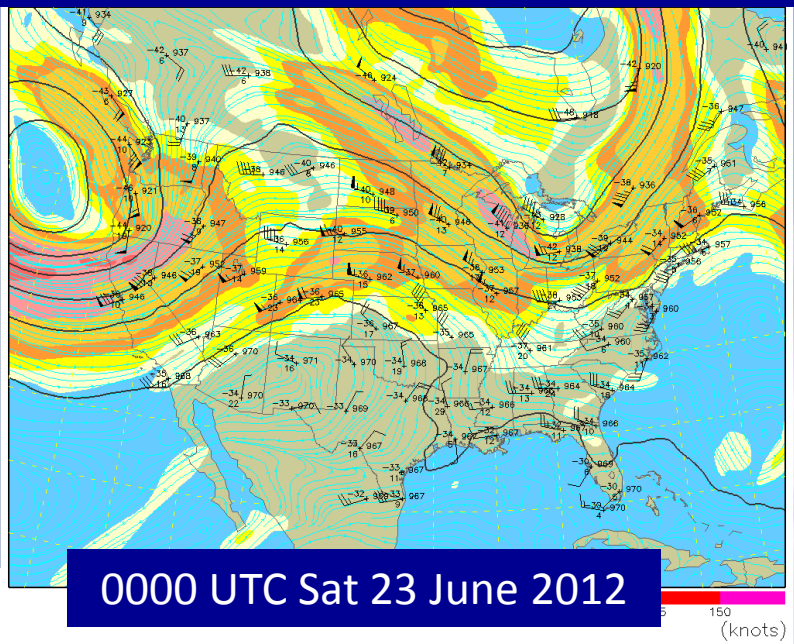
300 mb Heights / Isotachs



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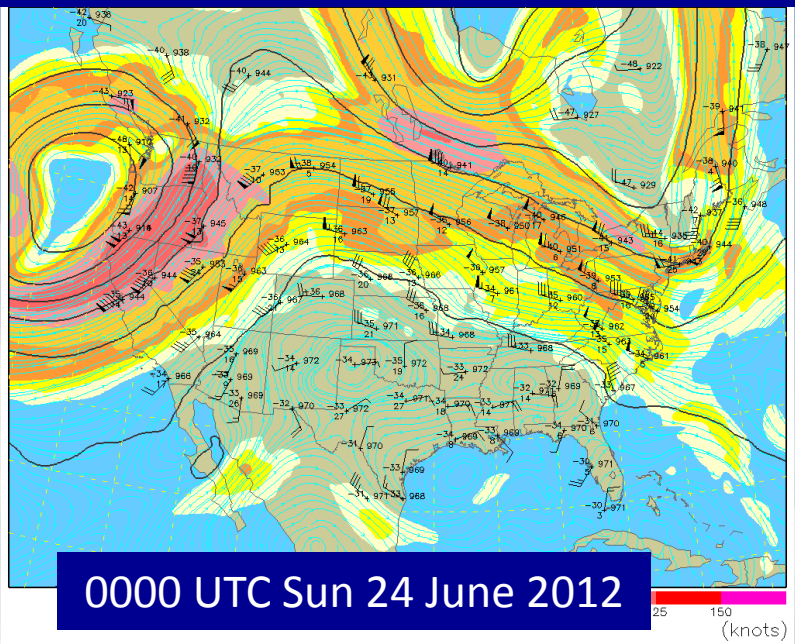

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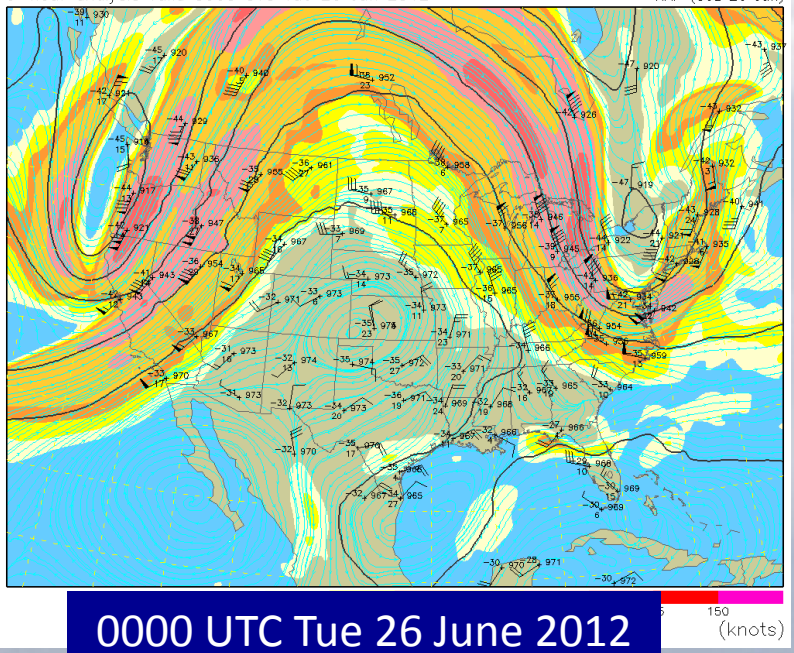

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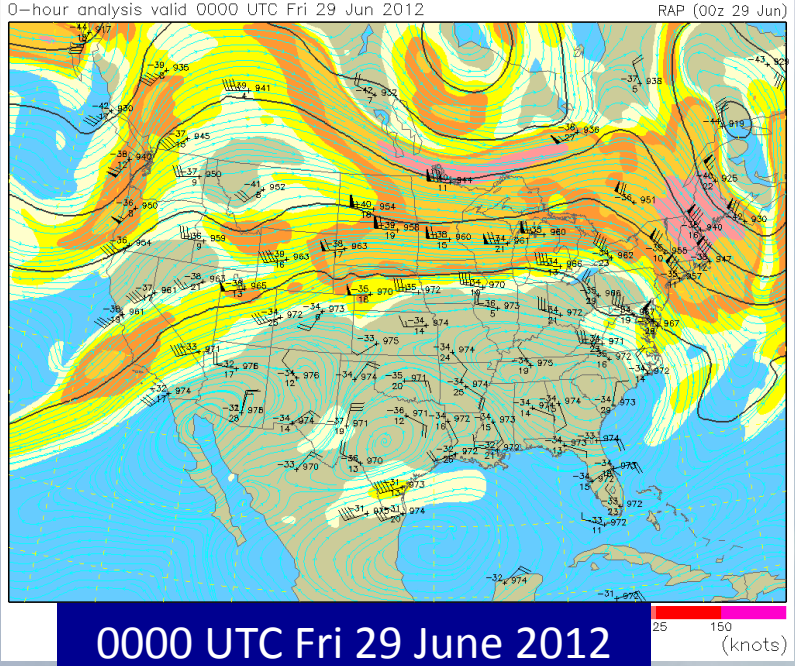
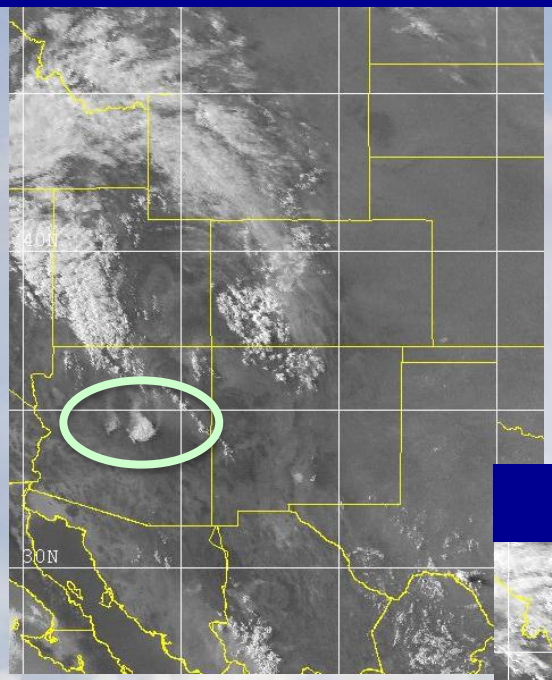


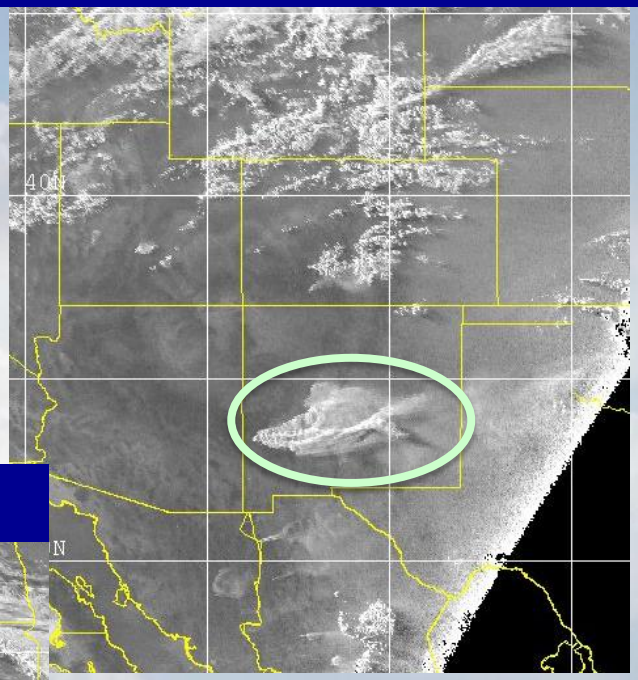
0000 UTC Fri 29 June 2012

Wildfires

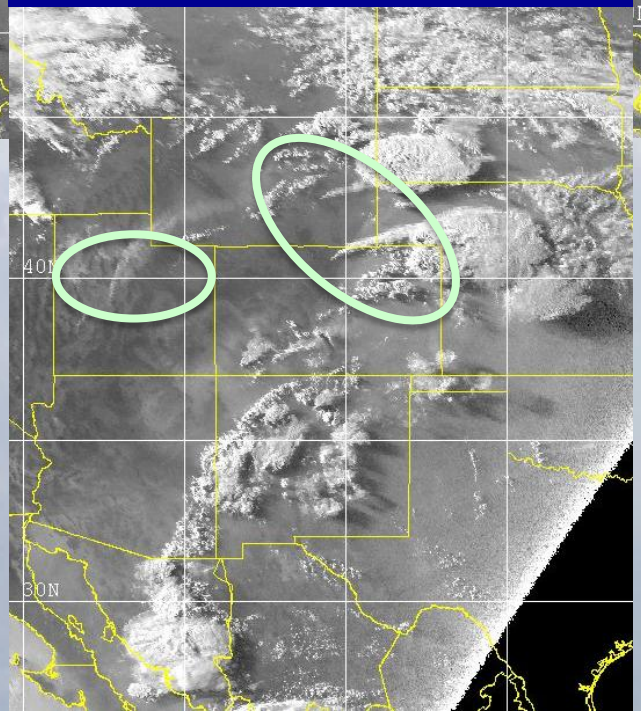
16 May 0030 UTC



29 May 0130 UTC



23 June 0130 UTC



Synoptic Meteorology over U.S.

Characterized by troughs and ridges advecting from west to east across U.S., typical for mid-latitudes

Southern U.S. dried out during June and went into drought conditions

Wildfires were predominant over the Rocky Mountains, beginning in New Mexico and moving northward into Colorado, Wyoming, and Montana/Idaho/Washington later in the summer

Meteorology of DC3 Storm Sampling Regions

The three regions have different types of thunderstorms.

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

Central Oklahoma and West Texas: shear-driven thunderstorms with large convective available potential energy (CAPE) producing strong, severe storms.

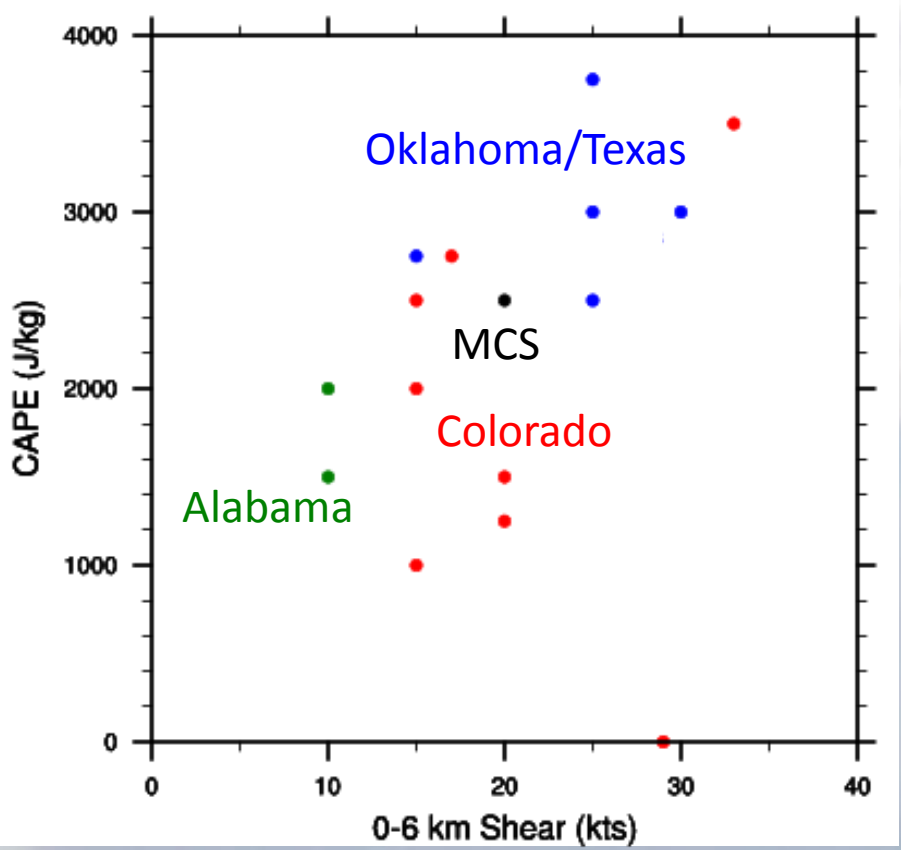
Northern Alabama storms: low shear with moderate CAPE creating short-lived storms.

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

→ Plot the 0-6 km shear vs. CAPE for each storm case

Meteorology of DC3 Storm Sampling Regions

NCAR WRF Forecasted CAPE and 0-6 km shear. Values are taken ~1 hour before convection occurred in the region. NCAR WRF forecasts by Weisman, Barth, Manning, Wang, Bela.



→ General separation of types of storms from region to region

→ The MCS lies between OK/TX and northeast CO storm environments

Chemical Environment of Sampling Regions

The three regions have different chemical environments.

Northeast Colorado:

Agricultural region +Denver plume

Isoprene and biogenic VOC emissions are low

Central Oklahoma and West Texas:

Agricultural with 100s of gas and oil wells

Influenced by Dallas – Ft. Worth and Oklahoma City plumes

Northern Alabama:

Forested region with high isoprene and biogenic VOC emissions.

Industrial activity

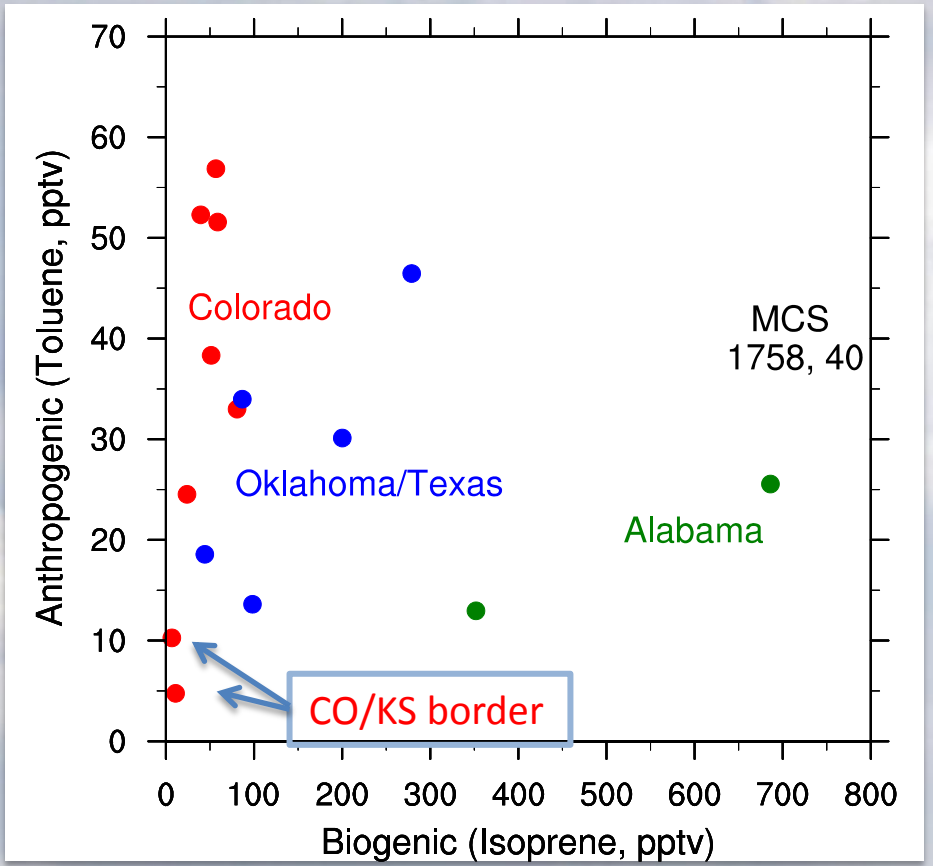
MCS in southern Missouri and Arkansas:

Mixture of high biogenic and anthropogenic air composition

→ Plot the biogenic species vs. anthropogenic species for each storm case

Chemical Environment of Sampling Regions

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

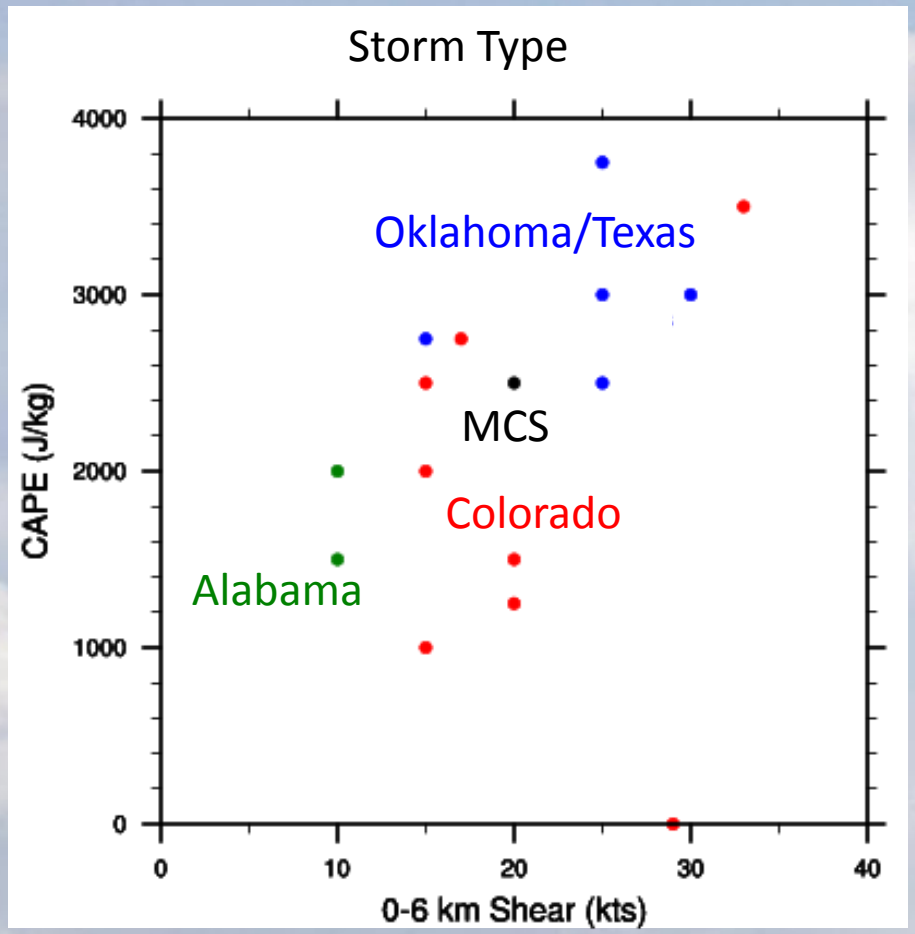
→ The MCS occurred over a region with very high isoprene emissions

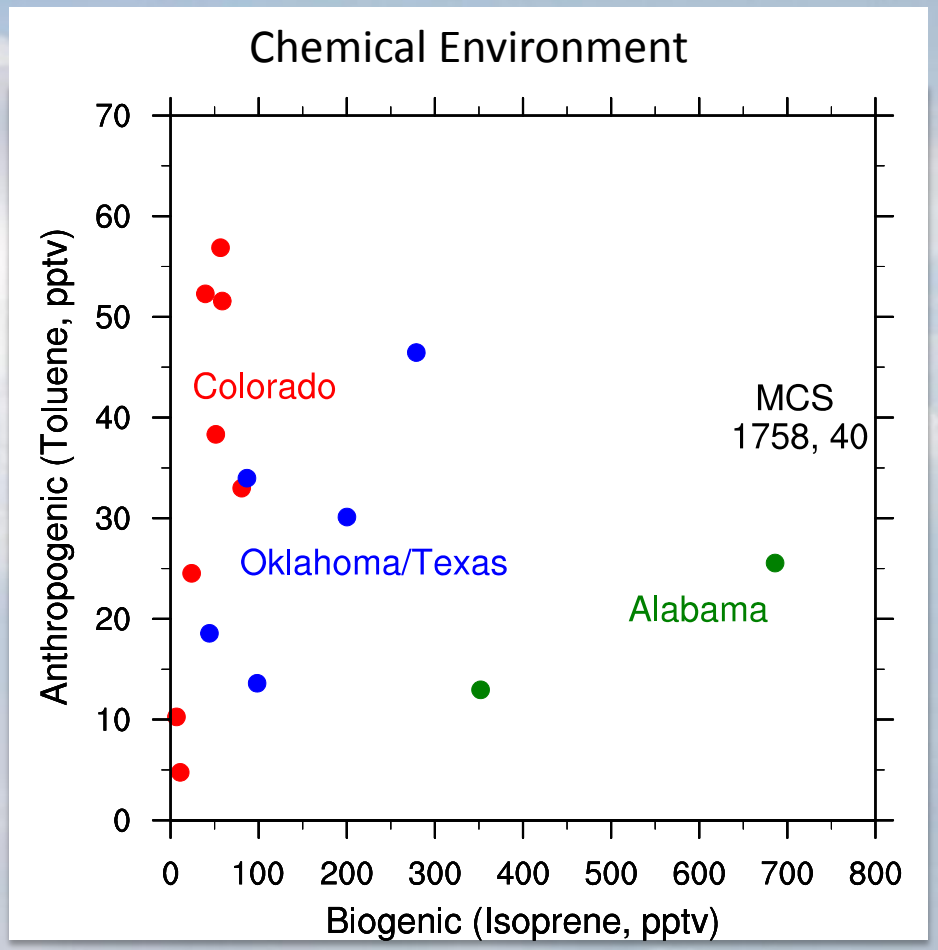
DC3 Preliminary Data provided by the following Instrument Teams:

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)

Range of types of storms and chemical environments





Outcomes of DC3 Field Experiment

Several Hypotheses and Topics to Address:

Convective Transport and UT Transport Properties

Scavenging

Lightning-generated NOx

Lightning – storm parameter relationships

Inverted lightning cases compared to normal polarity lightning

Chemistry in/near the anvil where it is bright or dark

Ozone production during the next 24 hours

Seasonal transition of the UT composition

Aerosol processing by storms, new particle formation, etc

Biomass burning studies

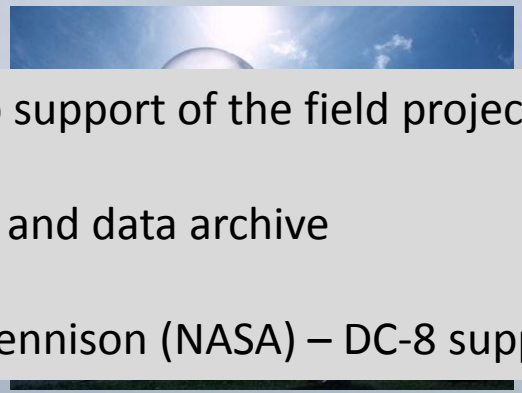
Source characterization of regions

Halogen chemistry

Outcomes of DC3 Field Experiment

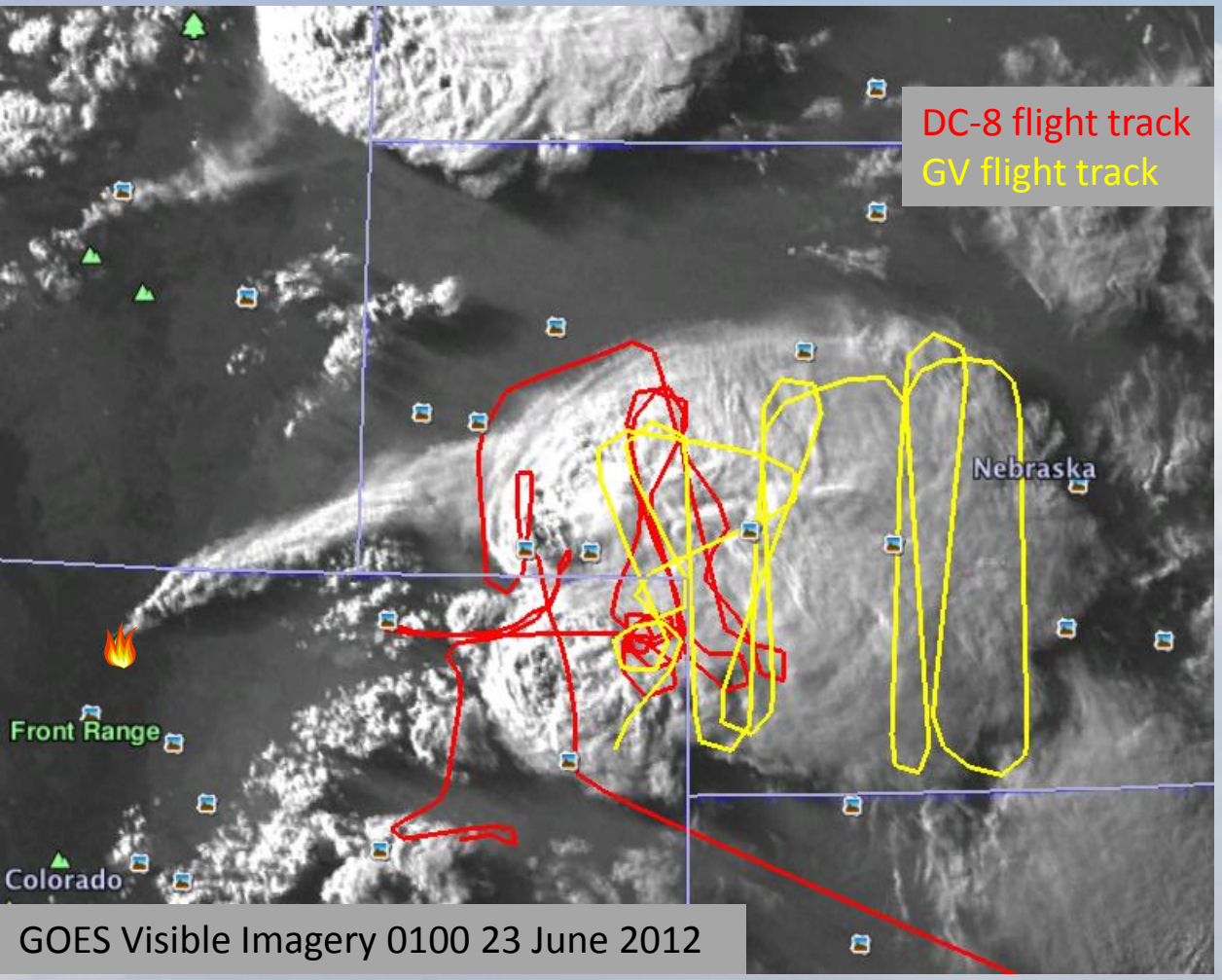
Unique dataset of measurements combining meteorological, electrical, and chemical parameters.

- Improve knowledge on thunderstorms and how storms affect the composition and chemistry of the atmosphere
- Apply that knowledge to weather and climate models


The NCAR/EOL staff are thanked for their superb support of the field project:
Vidal Salazar and Jim Moore – overall support
Greg Stossmeister, Steve Williams – field catalog and data archive
Mike Daniels and team – IT support
A. Schanot, J. Jensen – GV support; F. Cutler, C. Jennison (NASA) – DC-8 support

Smoke Plume Entrained into Thunderstorm June 22, 2012



GOES Visible Imagery 0100 23 June 2012

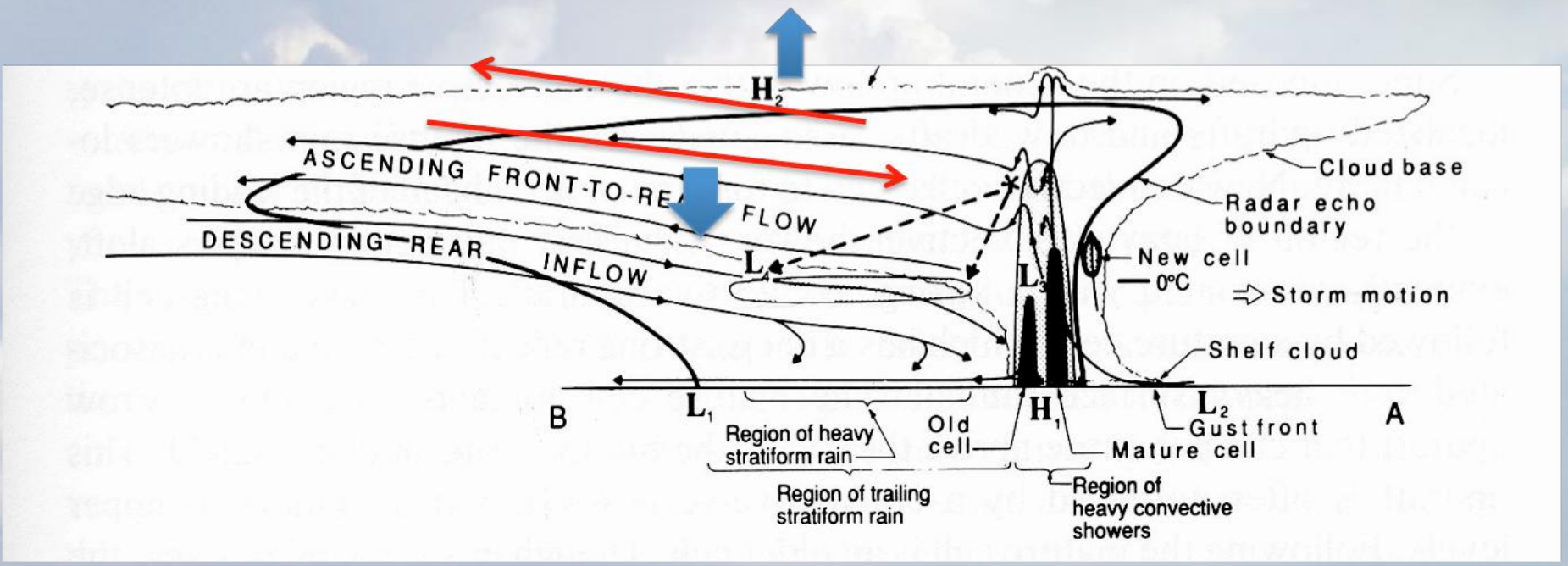
Unexpected Measurements of biomass burning and thunderstorms allow for studies on:

Entrainment from the side of storm (7 km altitude)

Effects of particles on the storm and on lightning flashes

Mesoscale Convective Systems:

May 30, 2012 – Kansas
June 11, 2012 – Missouri – Arkansas
June 21, 2012 – Missouri



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