DC3 Highlights from the Perspective of the German DLR Falcon Aircraft

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DLR
Deutsches Zentrum für Luft- und Raumfahrt

Motivation of the German DLR Falcon team to participate in DC3 – *Deep Convective Clouds and Chemistry Experiment*

- Quantification of lightning-produced NO_x (LNOx) (fresh and aged) including tracer transport and O_3 production

- Aerosol characterization (fresh and aged) in thunderstorm inflow/outflow and in biomass burning (BB) plumes

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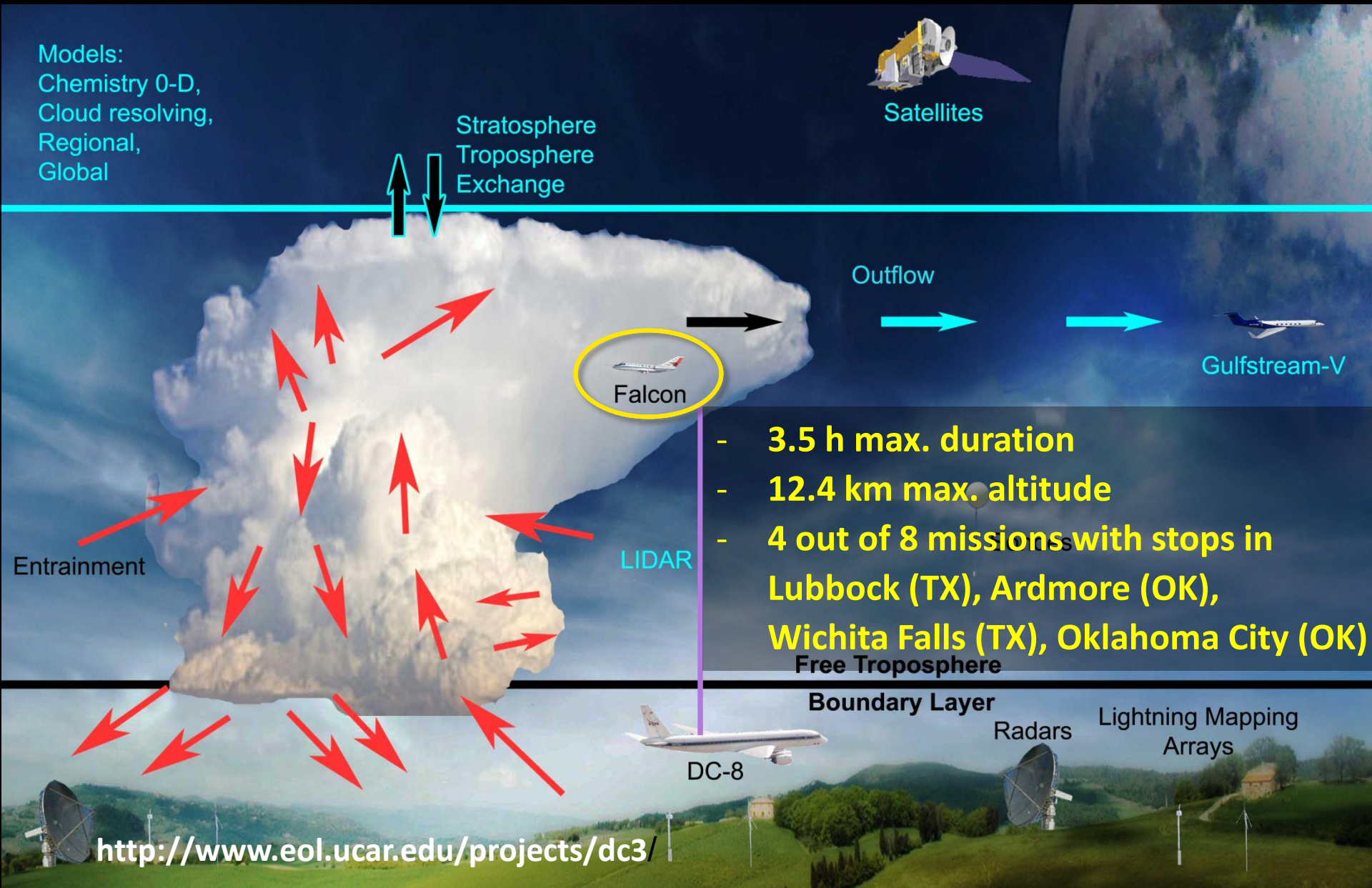
1. DC3 Field experiment design:
   - role of the German DLR Falcon
   - Falcon flight tracks
   - Falcon instrumentation
2. Falcon mission flights in summer 2012 (KS):
   - general overview
   - selected flights:

     8 June "aged CO-LNOx"+ UT/LS-O_3
     11 June "fresh MO-LNOx"+ BB-CO
     12 June "fresh KS-LNOx"+Asian-CO

     T 17 June "aged LNOx"+ BB-CO
     +UT/LS-O_3
3. Summary and Outlook

DC3 field experiment design



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

Instrumentation on the German DLR Falcon during DC3
Aircraft base in Salina (KS)

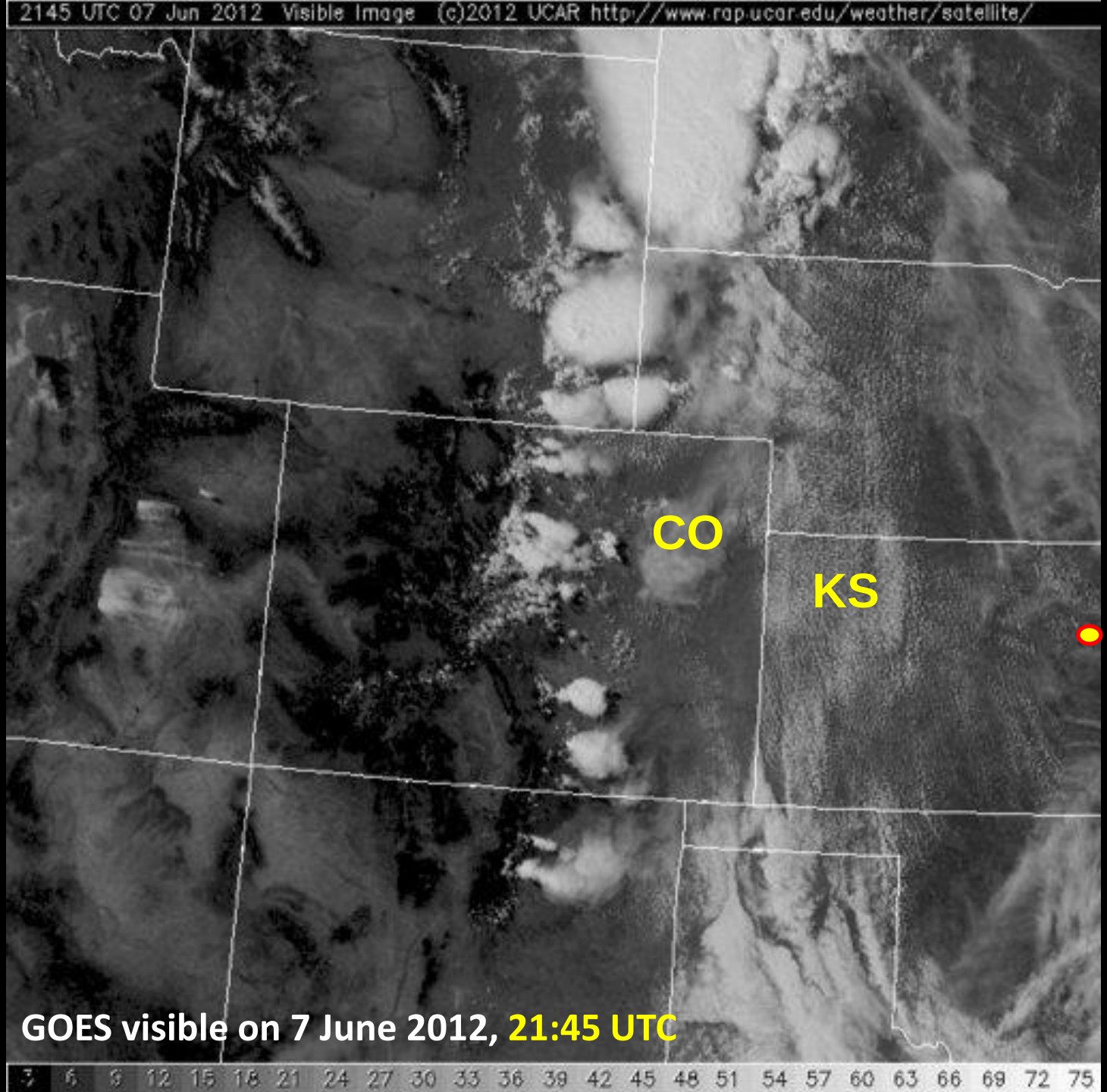
Overview talk by B. Weinzierl: Biomass burning studies

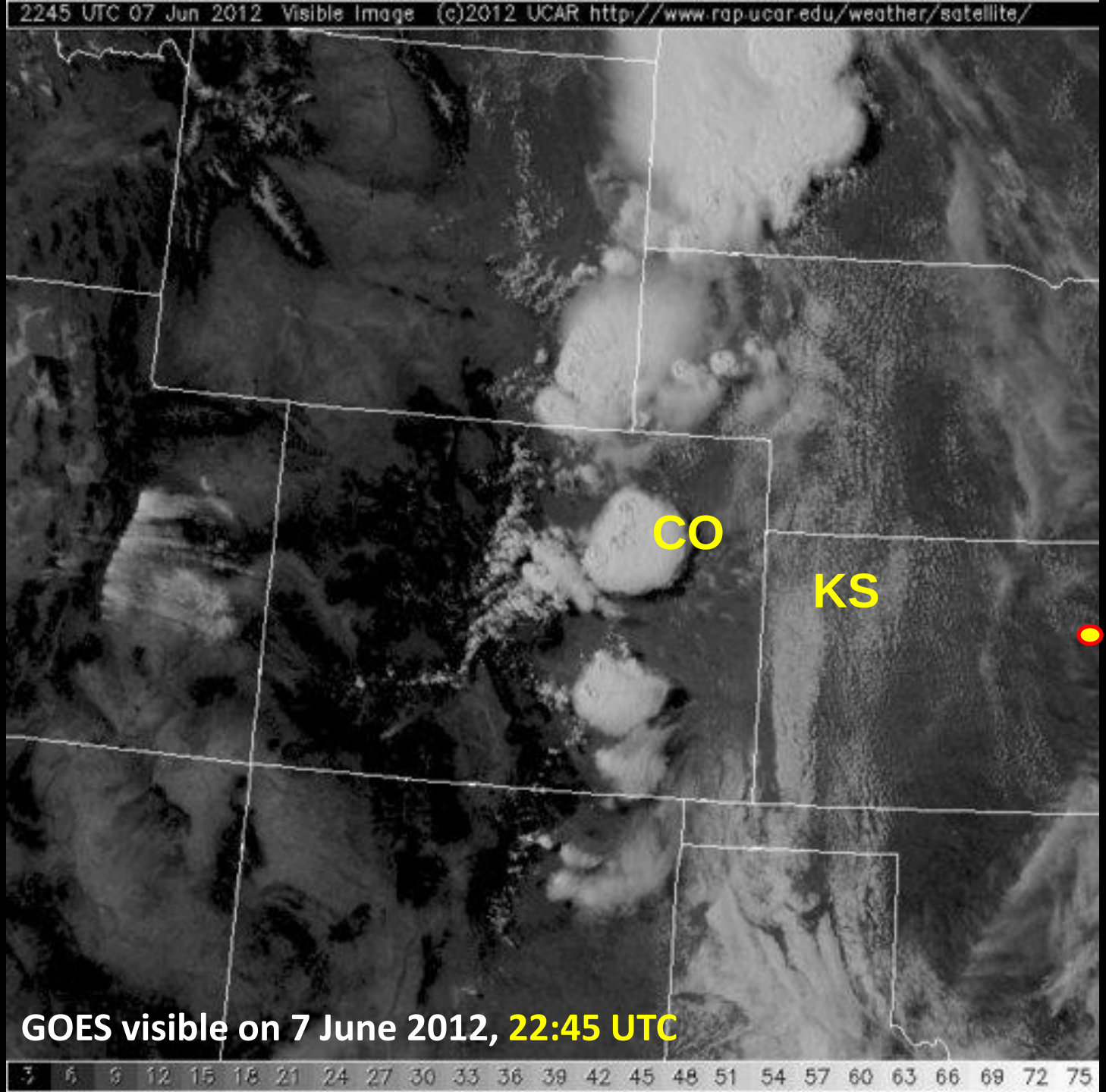
2 posters by K. Heimerl and D. Fütterer (DLR)

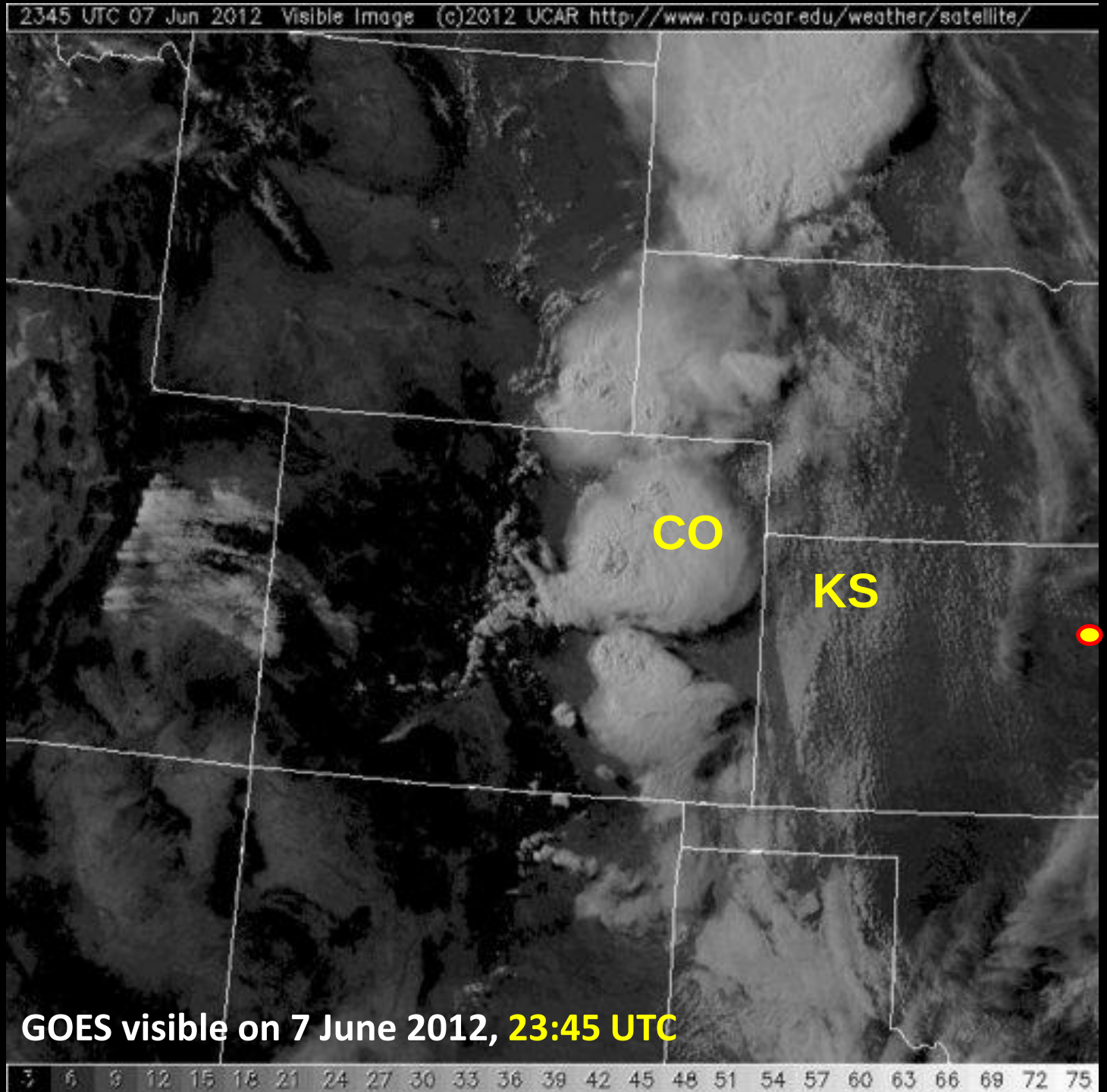
„It´s a challenge to be at the right place at the right time and you need brilliant pilots“

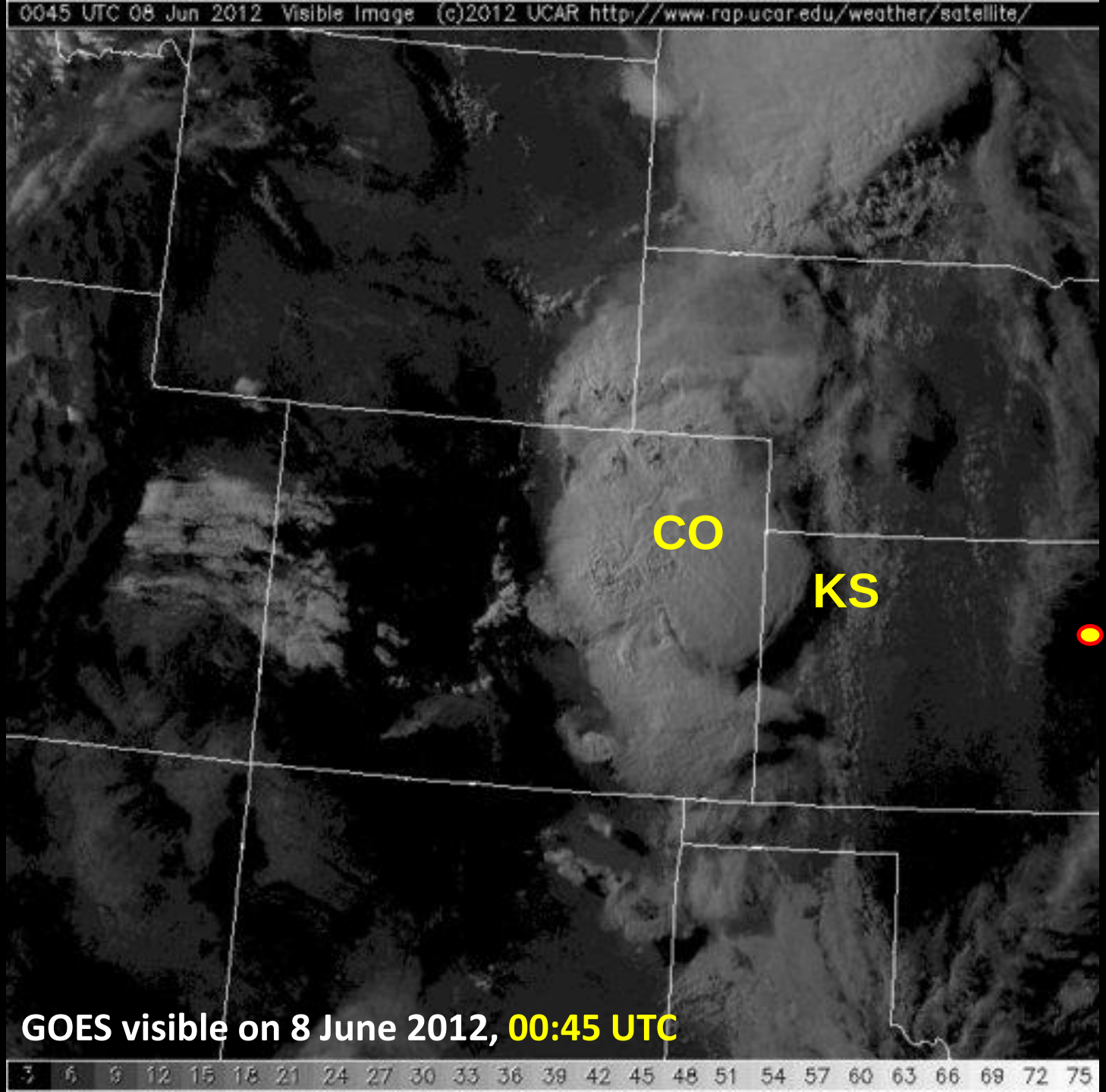
Date 2012	Fresh LNOx (KS) squall line	Fresh LNOx (CO) squall line	Fresh LNOx (WY) squall line	Fresh LNOx (NE) squall line	Fresh LNOx (MO) MCS	Fresh LNOx (AR) MCS	Fresh LNOx (OK) MCS MCC MCV	Fresh LNOx (TX) isolated-supercell MCV
29 May (2x)							**X** DC8 GV	
30 May (2x)							**X**	**X** (3 NO)
5 June (2x)							**X**	**X**
6 June **(flash)**			**X** (no NO) DC8 GV	**X** (no NO) DC8 GV				
8 June (2x)								
11 June (2x)					**X** (5 NO) DC8 GV	**X** (5 NO) DC8 GV		
12 June	**X** (3 NO)	**X** (3 NO)						
14 June								

Date 2012	Aged LNOx (CO)	BB Whitewater-Baldy (NM)	BB Little Bear (NM)	BB High Park (CO)	BB Canada	Aged LNOx (OK/TX)	Asian-CO
29 May (2x)		**X** (no CO, 80 O3)					
30 May (2x)		**X** (500 CO, 80 O3)					
5 June (2x)	**(X)** (110 CO, 80-100 O3)						
6 June (flash)							
8 June (2x)	**X** (**1 NO**, 110 CO, 80-110 O3)					**X** (150 CO, 100 O3)	
11 June (2x)			**X** (700 CO, 80 O3)	**X** (130 CO, 60 O3)	**(X)**		
12 June			**(X)**	**X** (140 CO, 60 O3)			**X** (160 CO, 120 O3)
14 June				**X** (130 CO, 90 O3)			


2145 UTC 07 Jun 2012 Visible Image (c)2012 UCAR http://www.rap.ucar.edu/weather/satellite/
CO
KS
Salina
GOES visible on 7 June 2012, 21:45 UTC
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75


2245 UTC 07 Jun 2012 Visible Image (c)2012 UCAR http://www.rap.ucar.edu/weather/satellite/
CO
KS
Salina
GOES visible on 7 June 2012, 22:45 UTC
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75

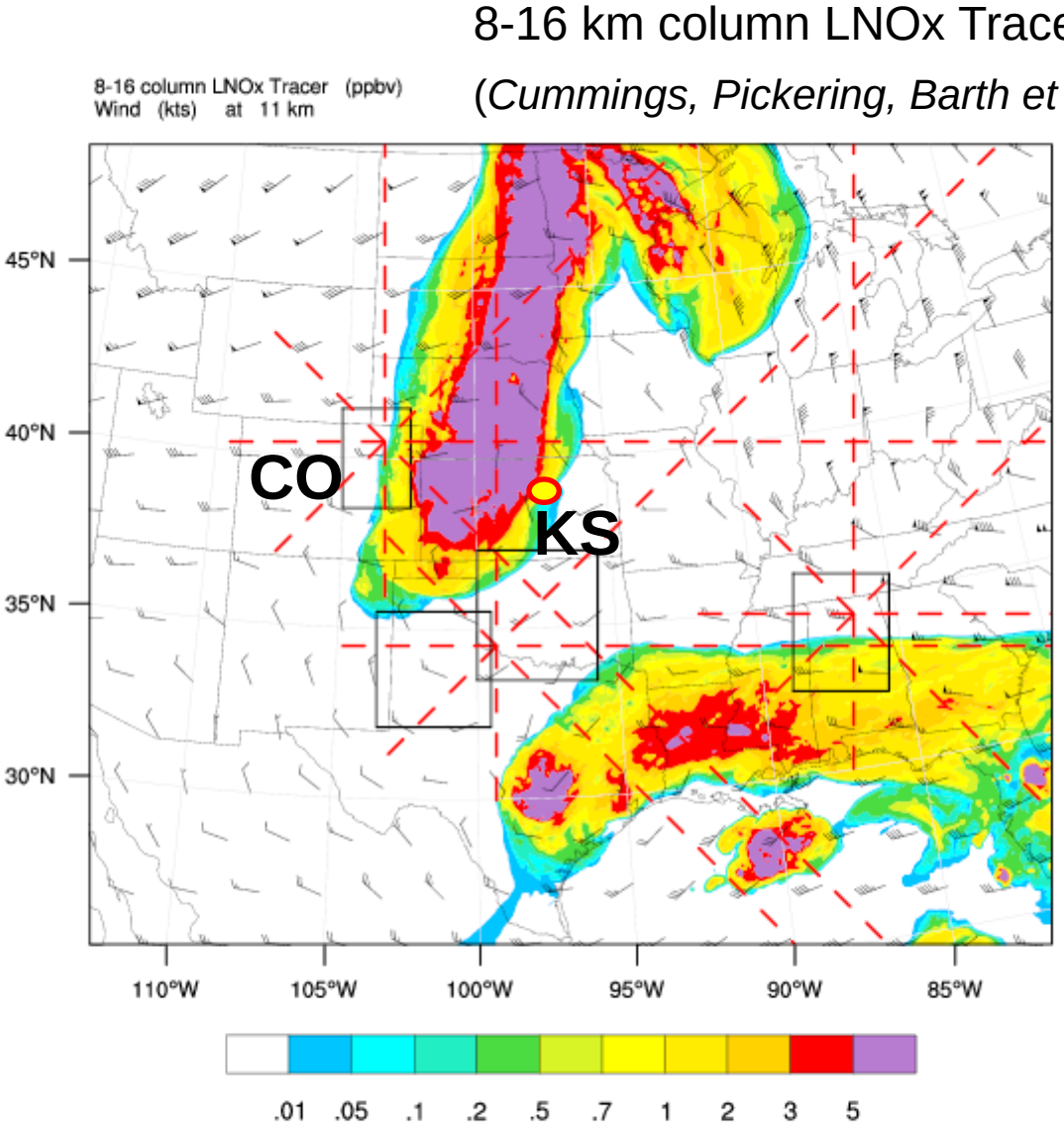

2345 UTC 07 Jun 2012 Visible Image (c)2012 UCAR http://www.rap.ucar.edu/weather/satellite/
CO
KS
Salina
GOES visible on 7 June 2012, 23:45 UTC
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75


0045 UTC 08 Jun 2012 Visible Image (c)2012 UCAR http://www.rap.ucar.edu/weather/satellite/
CO
KS
Salina
GOES visible on 8 June 2012, 00:45 UTC
3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48 51 54 57 60 63 66 69 72 75

NCAR WRF ARW Forecast (Δx=3 km)

8-16 km column LNOx Tracer (ppbv)

(*Cummings, Pickering, Barth et al.*)



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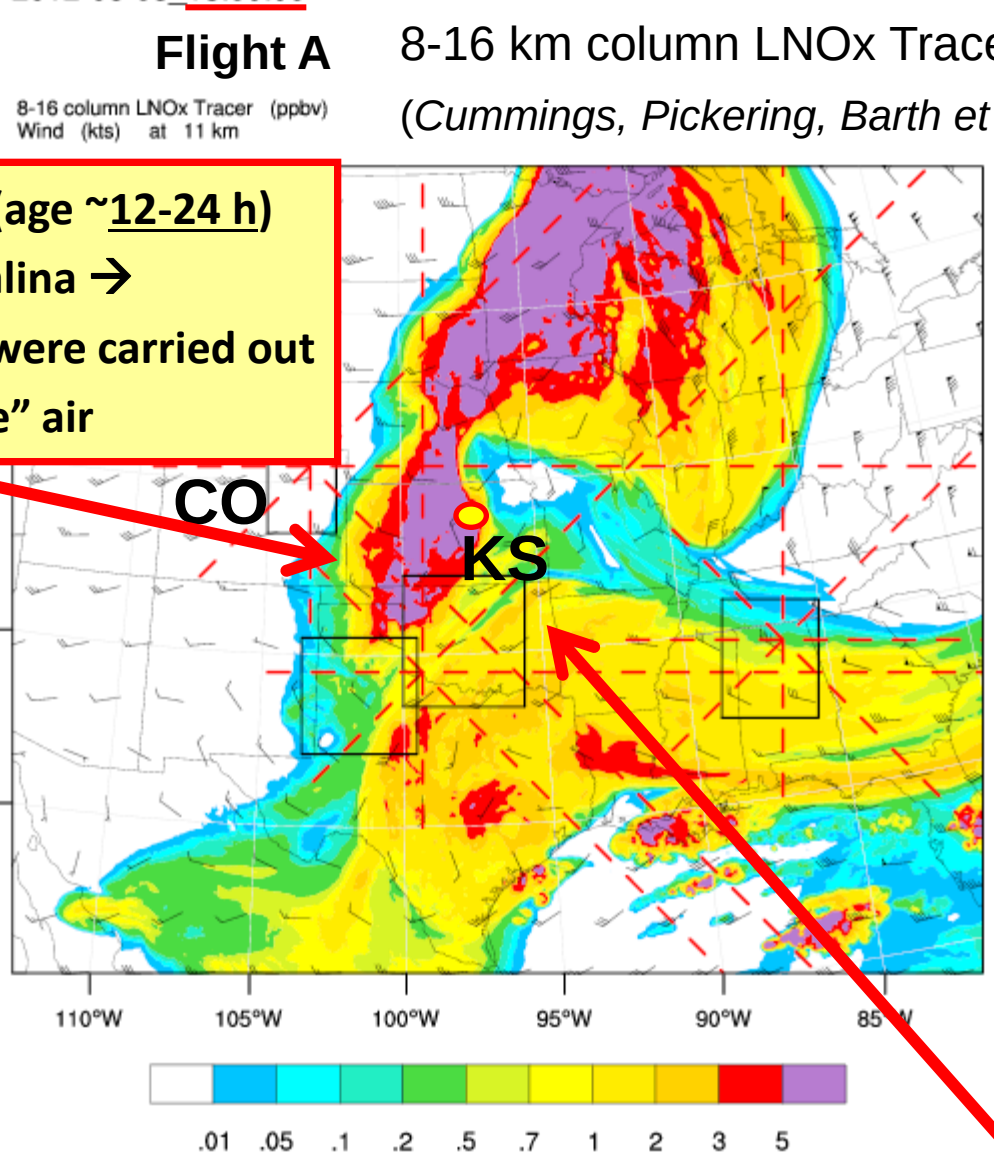


LNOx plume from CO (age ~12-24 h) directly over Salina →

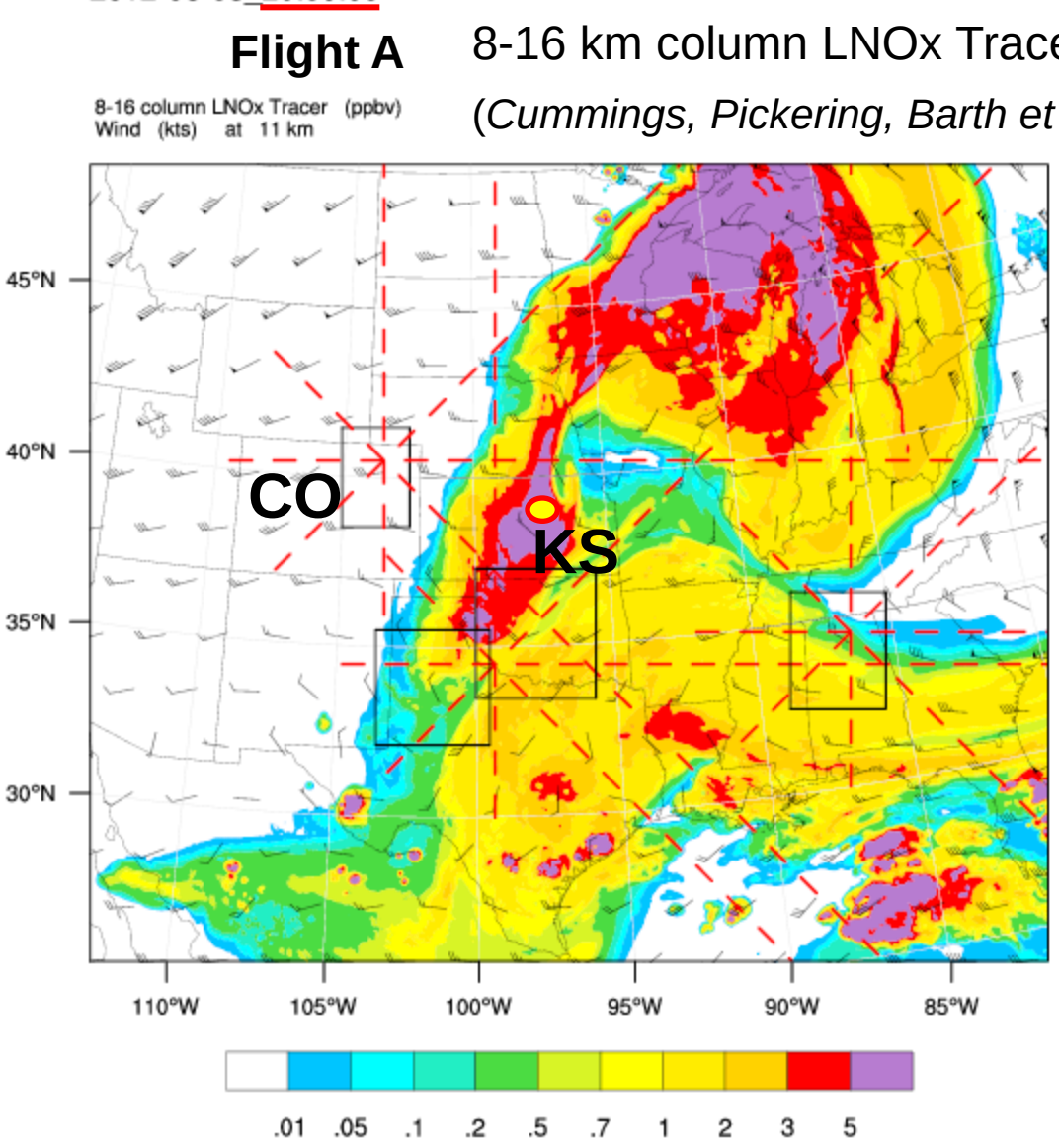
2 Falcon mission flights were carried out in "cloud-free" air

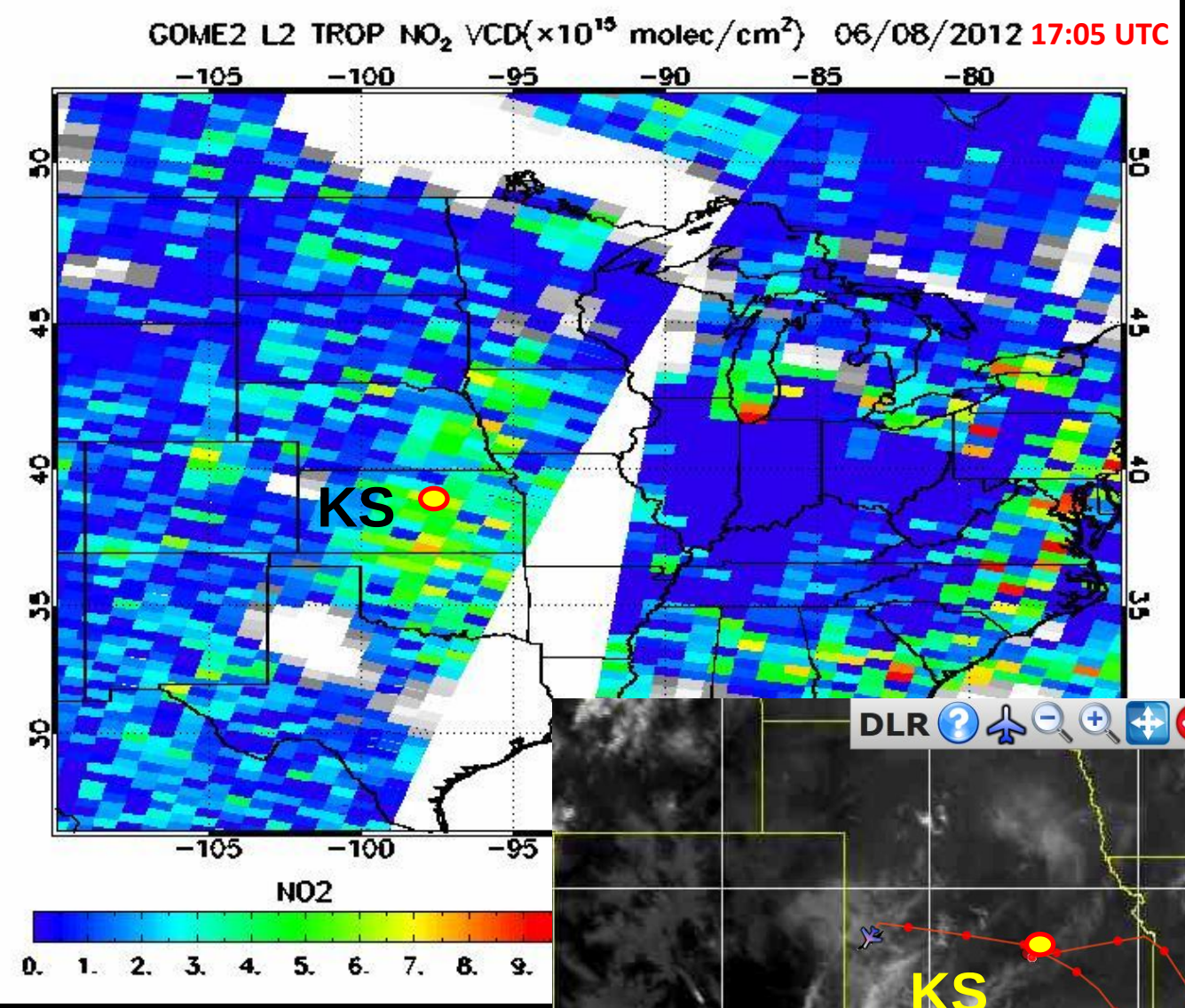
LNOx plume from OK/TX (age ~24-48 h) over SE Kansas

NCAR WRF ARW Forecast (Δx=3 km)

8-16 km column LNOx Tracer (ppbv)

(*Cummings, Pickering, Barth et al.*)



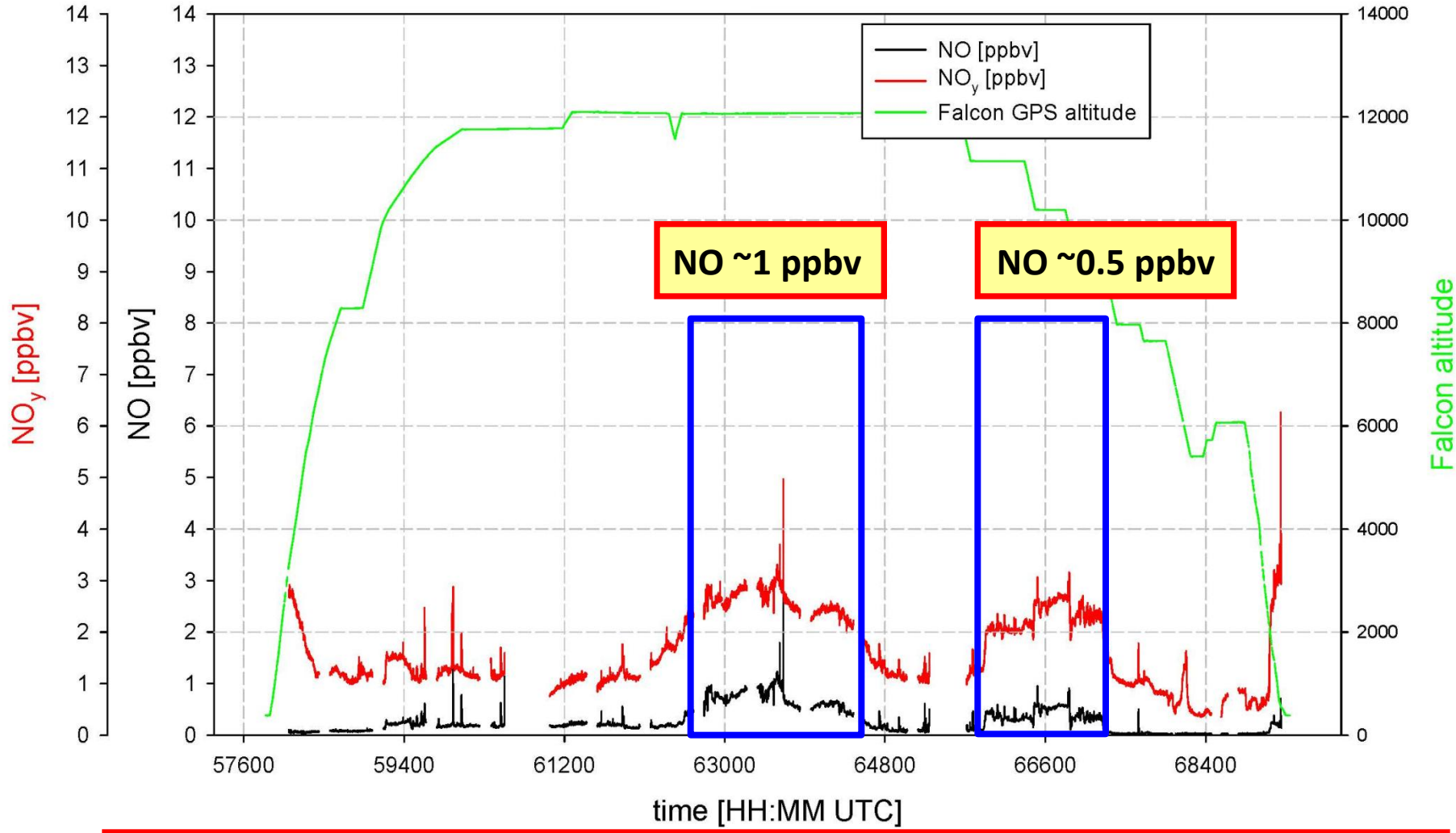

GOME2 L2 TROP NO2 VCD(×10^15 molec/cm^2) 06/08/2012 17:05 UTC
−105
−100
−95
−90
−85
−80
50
45
40
35
30
KS
NO2
0. 1. 2. 3. 4. 5. 6. 7. 8. 9.


DLR
KS
06/08/2012 1739 UTC GOES-13 IR Ch4
06/08/2012 1739 UTC GOES-13 VIS Ch1

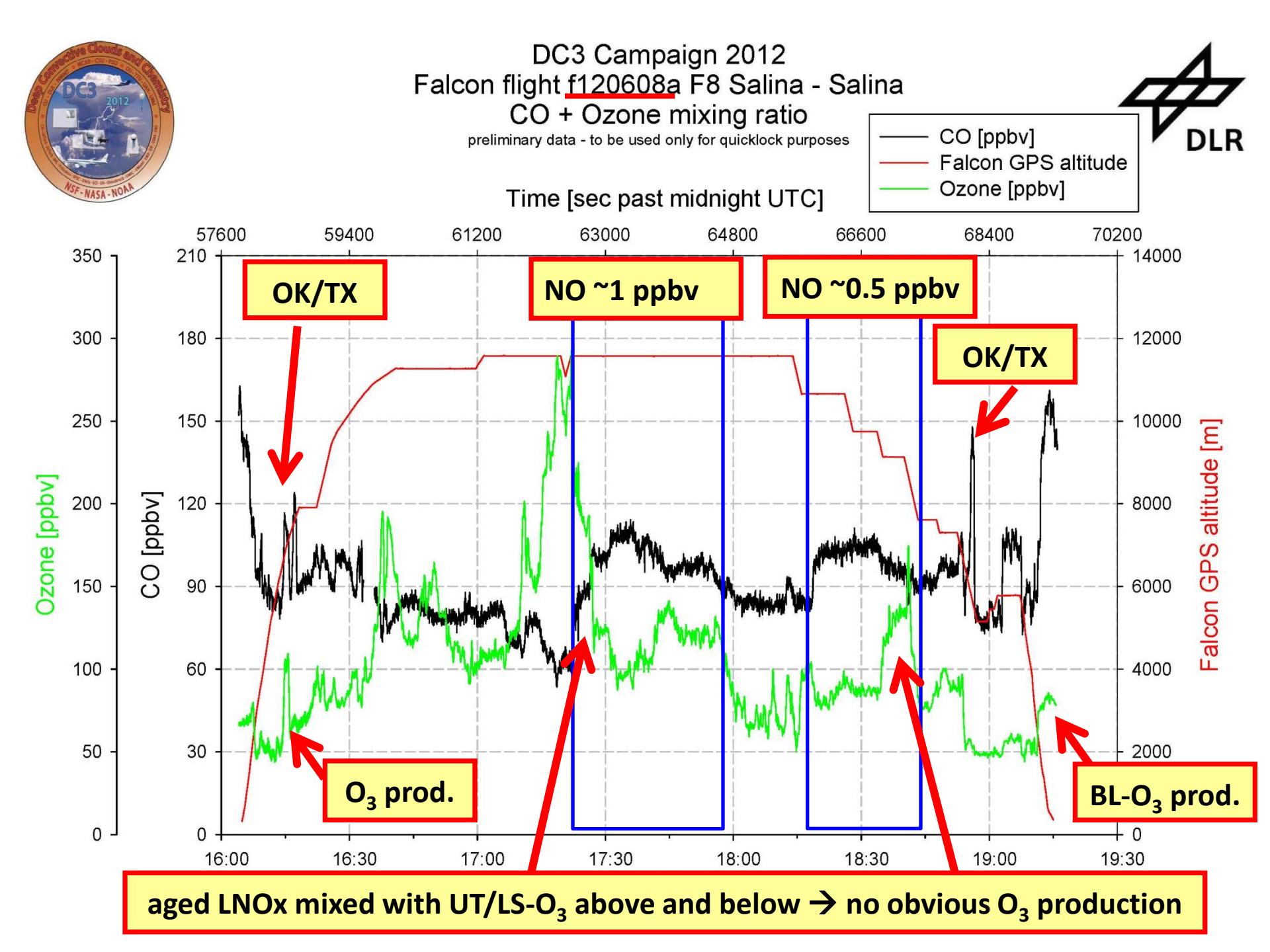
DC3 Campaign 2012
Falcon flight f120608a F8 Salina - Salina
NO + NO_y mixing ratio

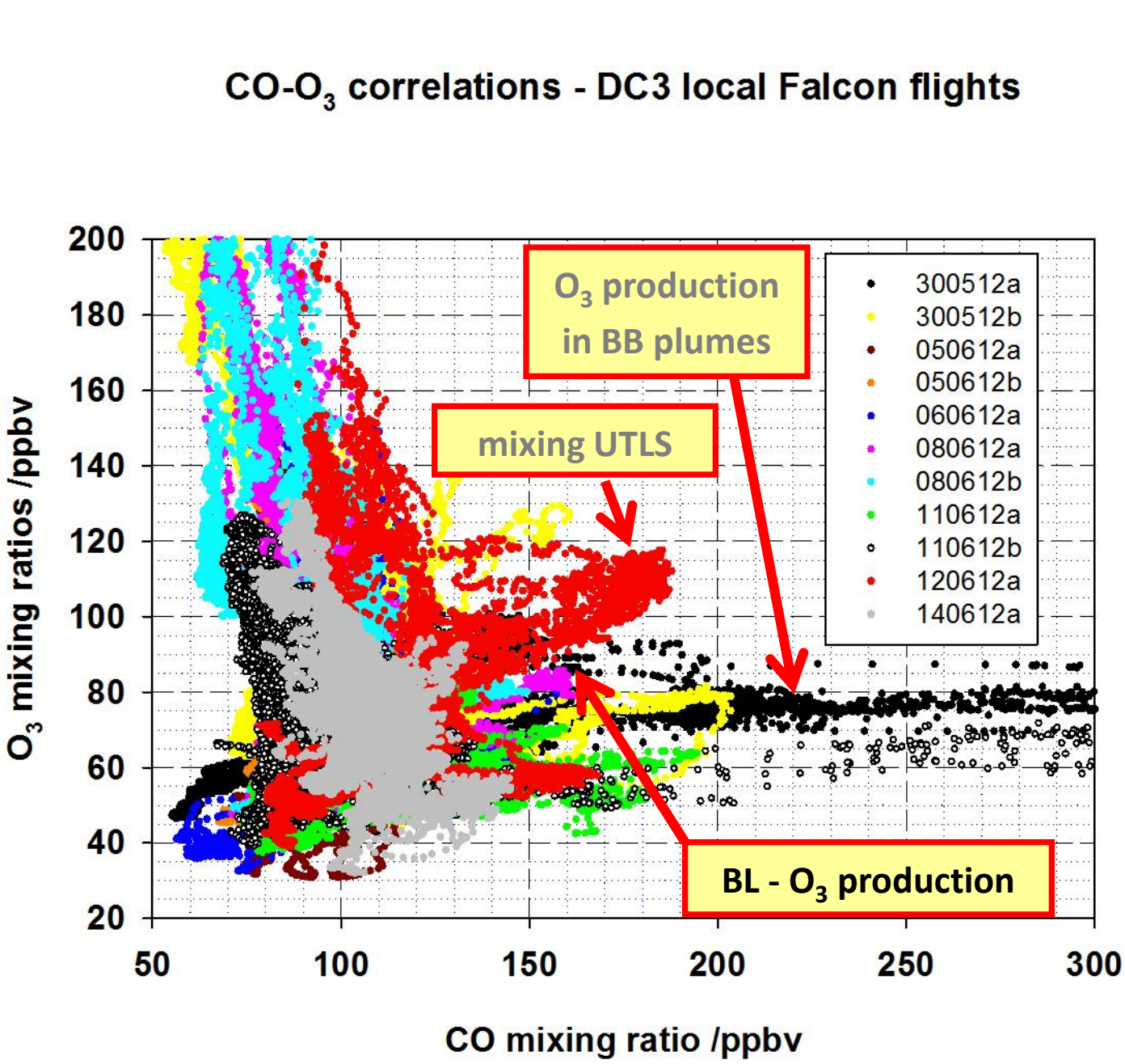
preliminary data - to be used only for quicklook purposes

DLR

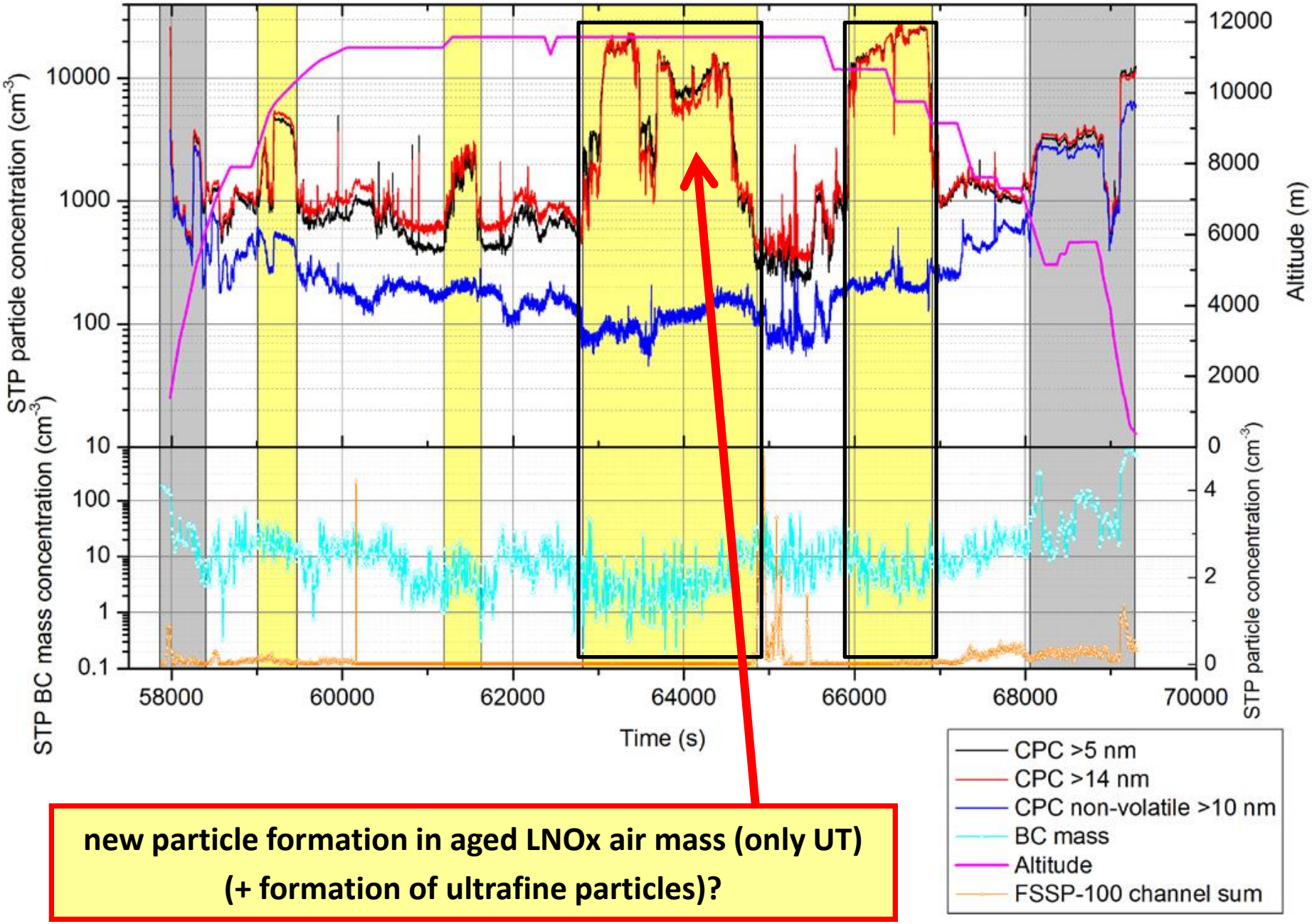


aged LNOx probed above ~9 km (up to 12 km) for ~1 h during each of the 2 flights


DC3 Campaign 2012
Falcon flight f120608a F8 Salina - Salina
CO + Ozone mixing ratio
preliminary data - to be used only for quicklock purposes
DLR
CO [ppbv]
Falcon GPS altitude
Ozone [ppbv]
Time [sec past midnight UTC]
57600
59400
61200
63000
64800
66600
68400
70200
Ozone [ppbv]
CO [ppbv]
Falcon GPS altitude [m]
OK/TX
NO ~1 ppbv
NO ~0.5 ppbv
OK/TX
O3 prod.
BL-O3 prod.
16:00
16:30
17:00
17:30
18:00
18:30
19:00
19:30
aged LNOx mixed with UT/LS-O3 above and below → no obvious O3 production


CO-O3 correlations - DC3 local Falcon flights
O3 production in BB plumes
mixing UTLS
BL - O3 production
300512a
300512b
050612a
050612b
060612a
080612a
080612b
110612a
110612b
120612a
140612a
O3 mixing ratios /ppbv
CO mixing ratio /ppbv
200
180
160
140
120
100
80
60
40
20
50
100
150
200
250
300

F#8 – 120608a – Salina-Salina

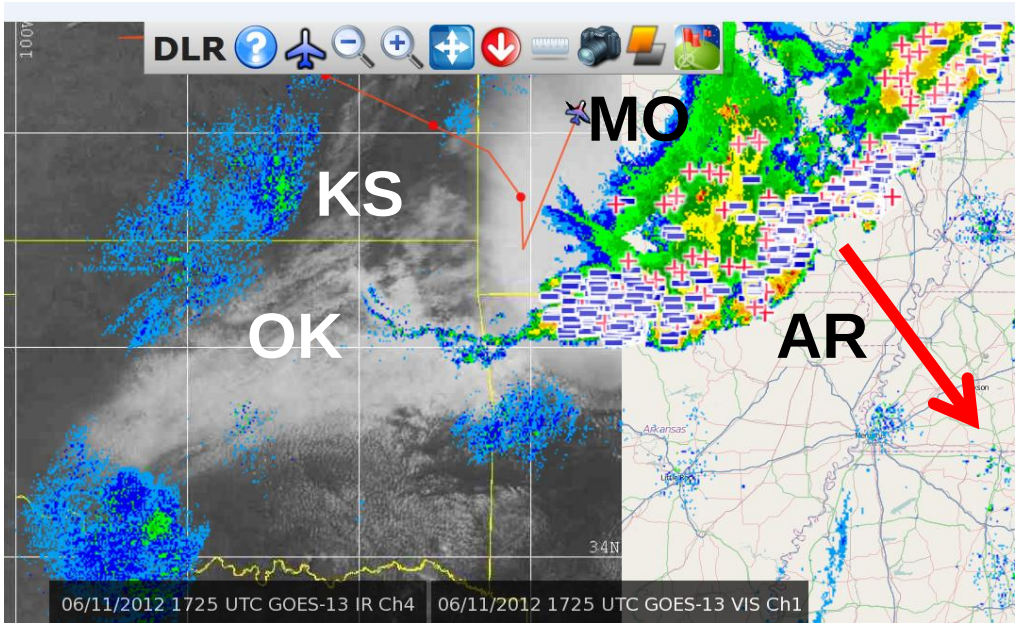


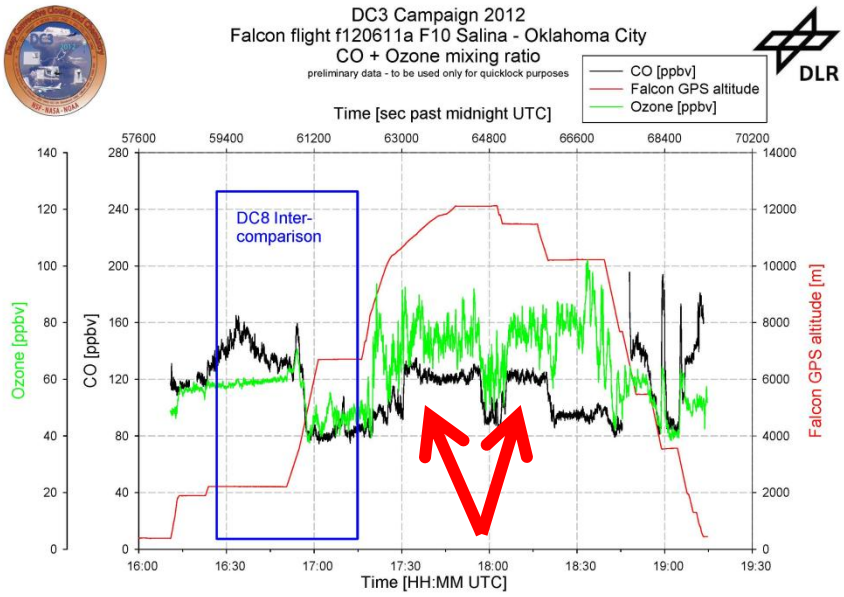
new particle formation in aged LNOx air mass (only UT)

(+ formation of ultrafine particles)?

Date 2012	Fresh LNOx (KS) squall line	Fresh LNOx (CO) squall line	Fresh LNOx (WY) squall line	Fresh LNOx (NE) squall line	Fresh LNOx (MO) MCS	Fresh LNOx (AR) MCS	Fresh LNOx (OK) MCS MCC MCV	Fresh LNOx (TX) isolated-supercell MCV
29 May (2x)							**X** DC8 GV	
30 May (2x)							**X**	**X** (3 NO)
5 June (2x)							**X**	**X**
6 June **(flash)**			**X** (no NO) DC8 GV	**X** (no NO) DC8 GV				
8 June (2x)								
11 June (2x)					**X** (5 NO) DC8 GV	**X** (5 NO) DC8 GV		
12 June	**X** (3 NO)	**X** (3 NO)						
14 June								

Falcon A-flight on 11 June 2012: Widespread MCS over Missouri and Arkansas





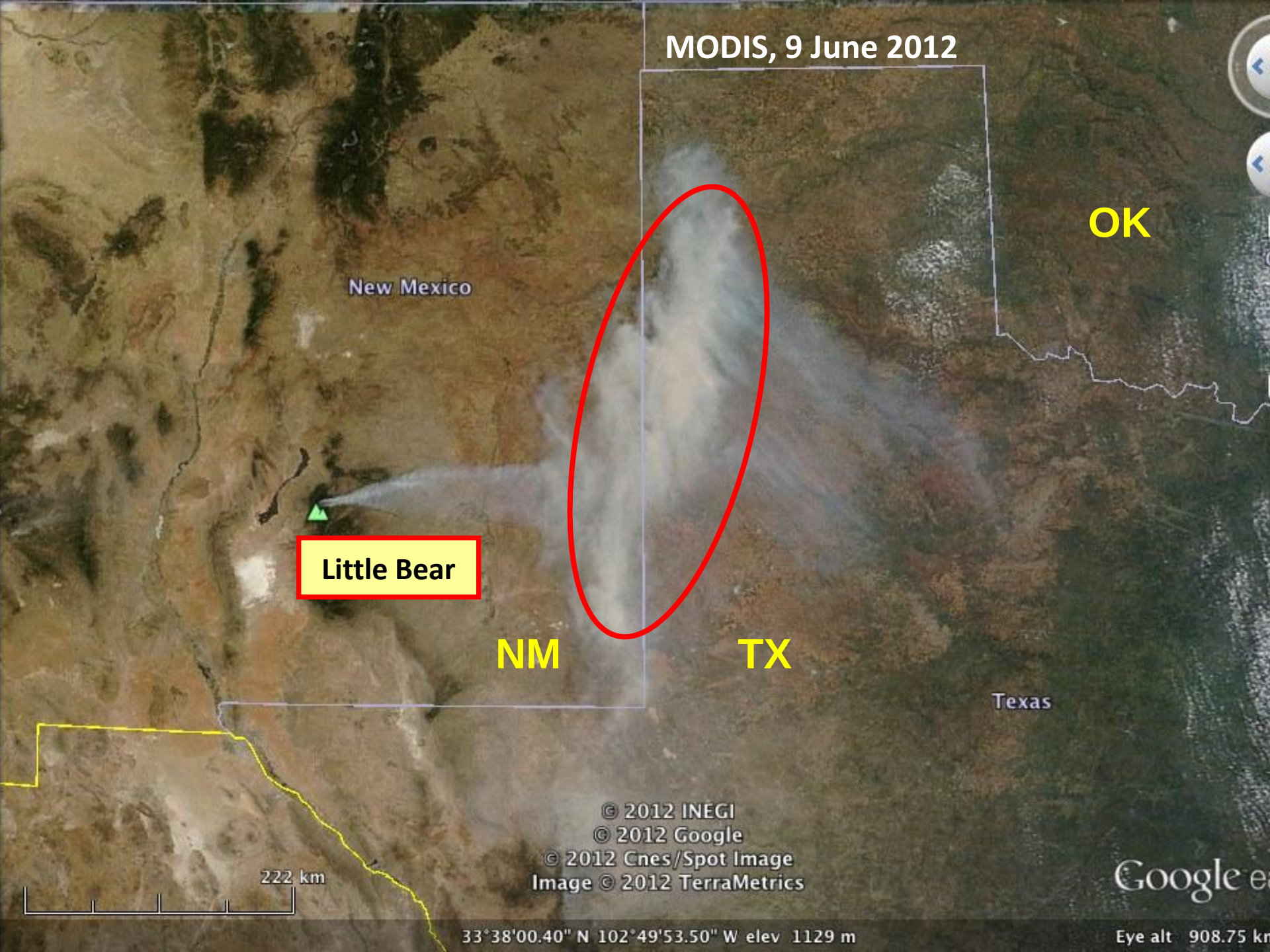
Flight on 11 June 2012 to Oklahoma City:

Flight A: 5 transects in anvil outflow ~10-12 km during ~1 h

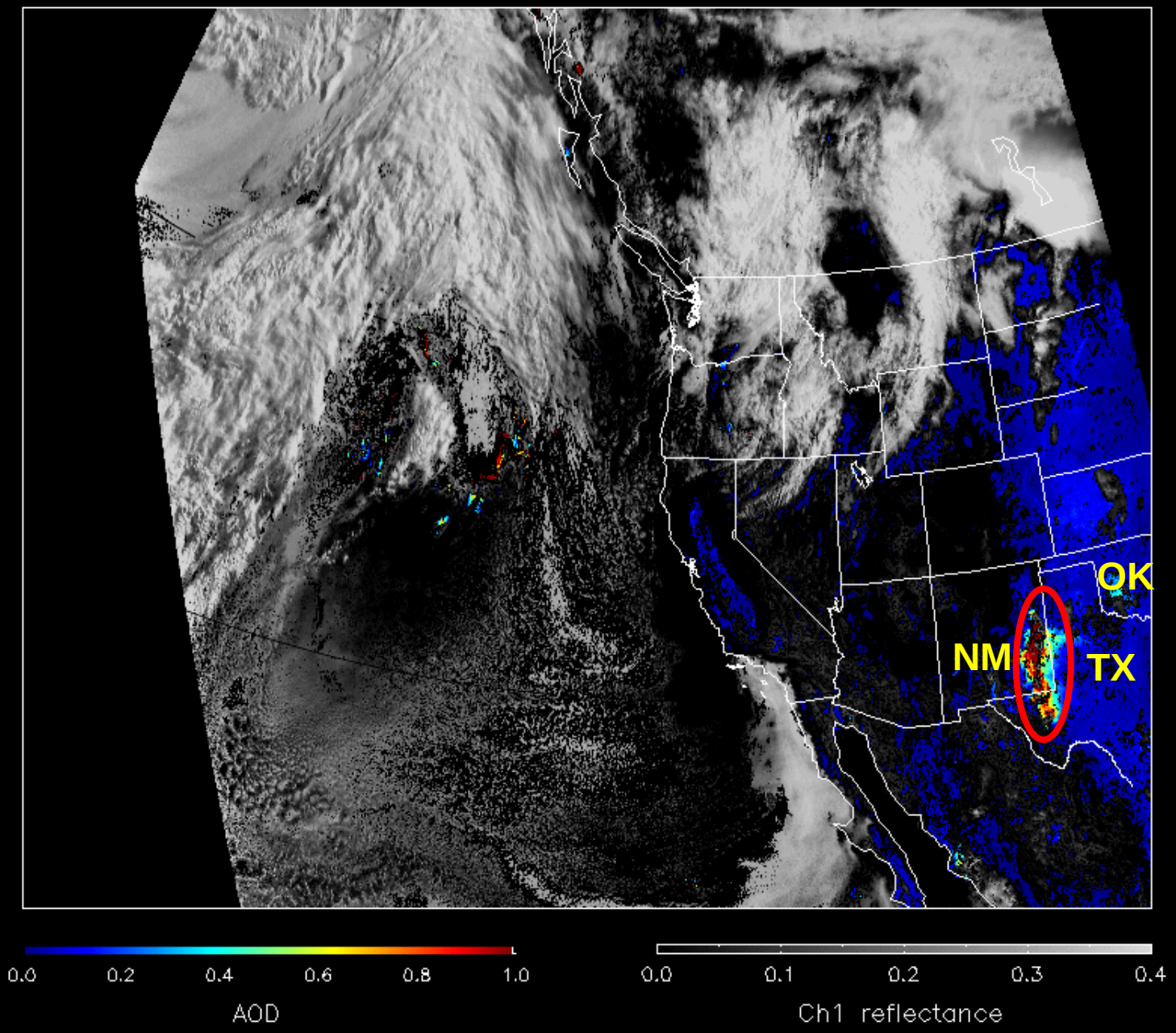
Flight B: 2 transects in anvil outflow ~11-12 km during ~0.5 h

- **high negative cloud-to-ground flash rate**

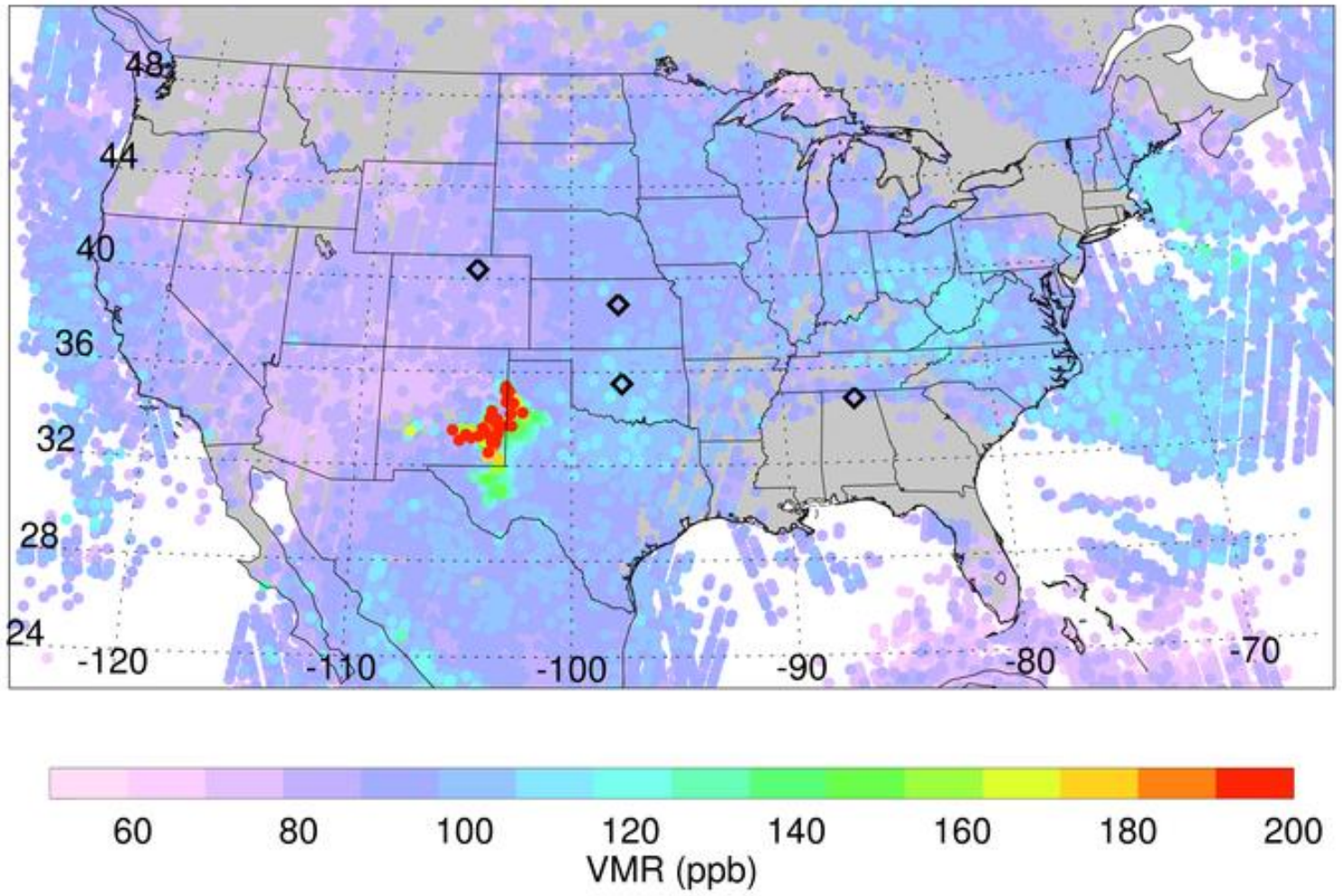
Date 2012	Aged LNOx (CO)	BB Whitewater-Baldy (NM)	BB Little Bear (NM)	BB High Park (CO)	BB Canada	Aged LNOx (OK/TX)	Asian-CO
29 May (2x)		**X** (no CO, 80 O3)					
30 May (2x)		**X** (500 CO, 80 O3)					
5 June (2x)	**(X)** (110 CO, 80-100 O3)						
6 June (flash)							
8 June (2x)	**X** (1 NO, 110 CO, 80-110 O3)					**X** (150 CO, 100 O3)	
11 June (2x)			**X** (**700 CO**, 80 O3)	**X** (130 CO, 60 O3)	**(X)**		
12 June			**(X)**	**X** (140 CO, 60 O3)			**X** (160 CO, 120 O3)
14 June				**X** (130 CO, 90 O3)			

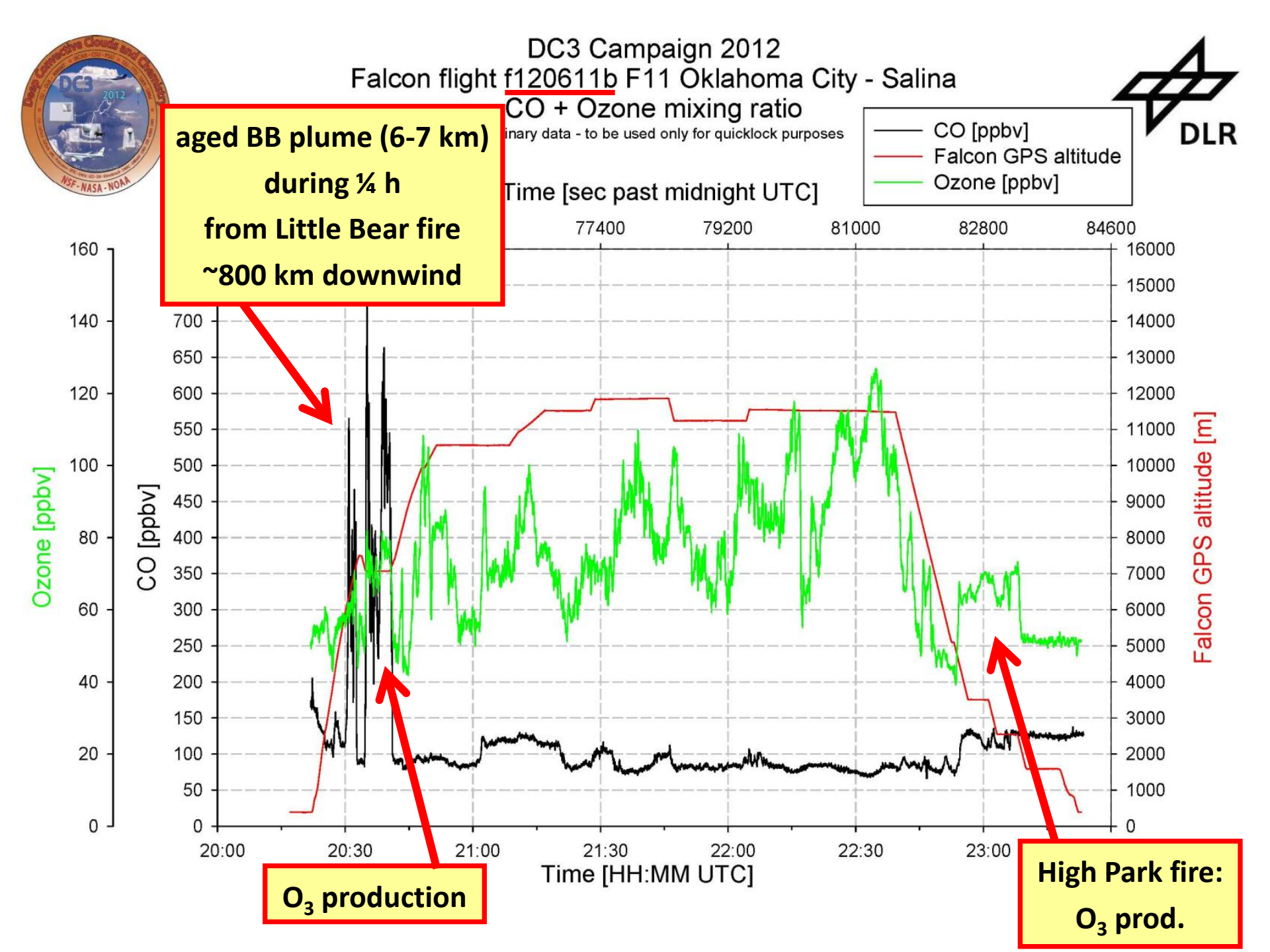

MODIS, 9 June 2012
OK
New Mexico
Little Bear
NM
TX
Texas
© 2012 INEGI
© 2012 Google
© 2012 Cnes/Spot Image
Image © 2012 TerraMetrics
222 km
33°38'00.40" N 102°49'53.50" W elev 1129 m
Eye alt 908.75 km

GASP AOD, 9 June 2012

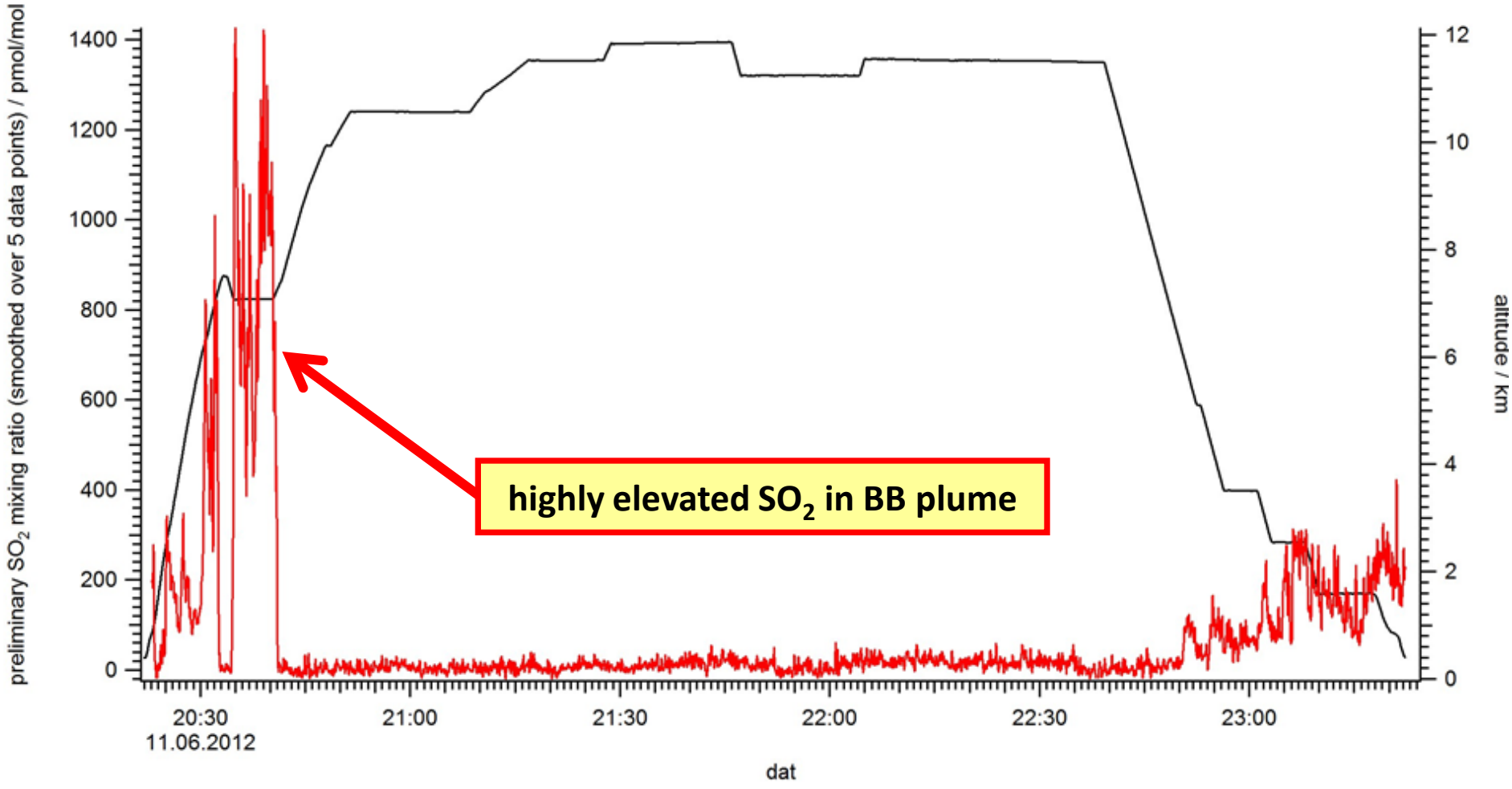


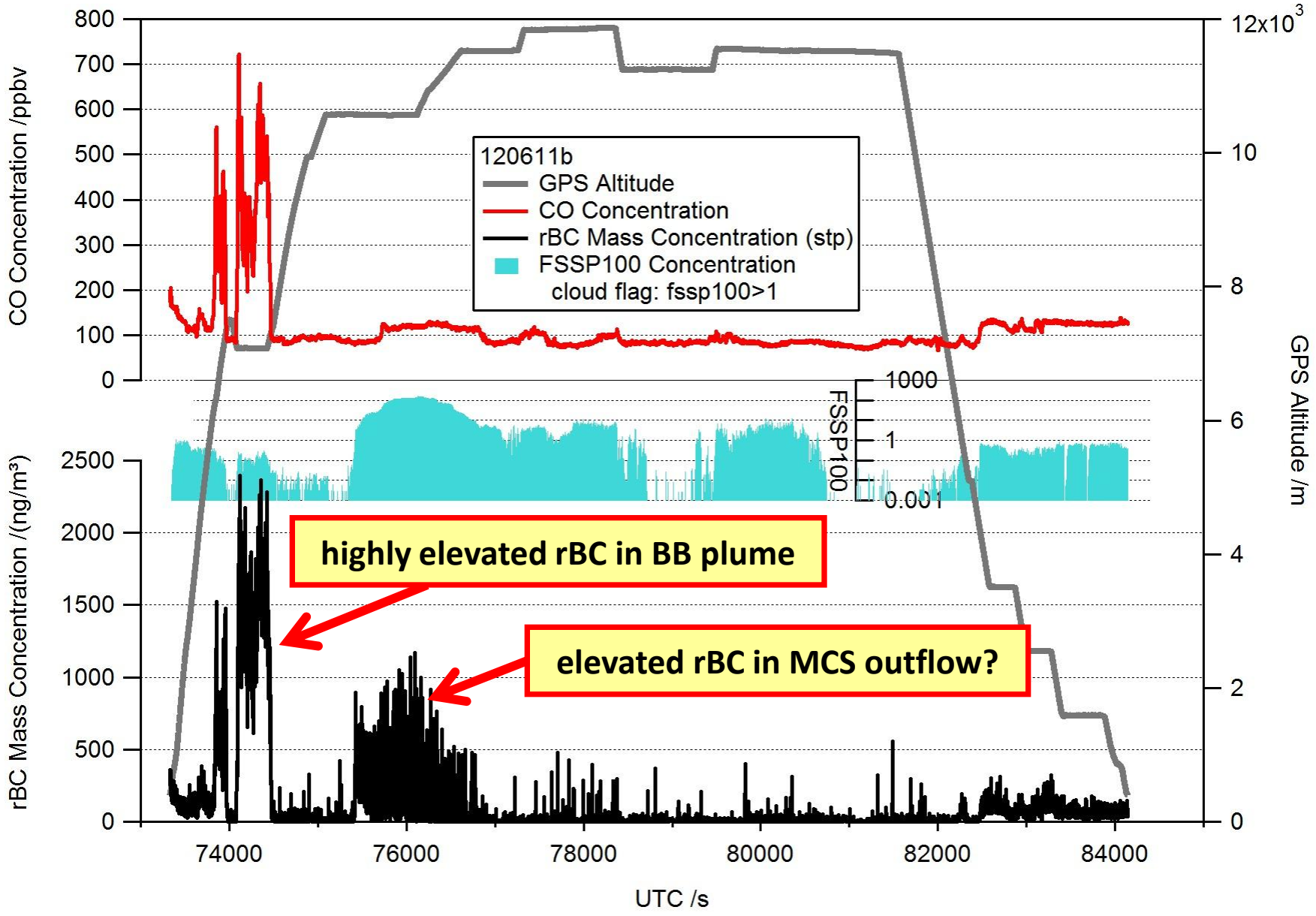
NCAR/FORLI IASI CO Total Column Effective VMR 9 Jun 2012




DC3 Campaign 2012
Falcon flight f120611b F11 Oklahoma City - Salina
CO + Ozone mixing ratio
inary data - to be used only for quicklock purposes
DLR
CO [ppbv]
Falcon GPS altitude
Ozone [ppbv]
Time [sec past midnight UTC]
77400
79200
81000
82800
84600
aged BB plume (6-7 km)
during ¼ h
from Little Bear fire
~800 km downwind
Ozone [ppbv]
CO [ppbv]
Falcon GPS altitude [m]
Time [HH:MM UTC]
20:00
20:30
21:00
21:30
22:00
22:30
23:00
O3 production
High Park fire:
O3 prod.

F120611b,
SO_2 timeseries, CI-ITMS




F120611b Oklahoma City - Salina
CO Concentration /ppbv
rBC Mass Concentration /(ng/m³)
GPS Altitude /m
12x10³
UTC /s
120611b
GPS Altitude
CO Concentration
rBC Mass Concentration (stp)
FSSP100 Concentration
cloud flag: fssp100>1
FSSP100
highly elevated rBC in BB plume
elevated rBC in MCS outflow?

DC3 Campaign 2012

Falcon flight f120611b F11 Oklahoma City - Salina

NO + NO_x mixing ratio

preliminary data - to be used only for quicklock purposes

DLR

NO [ppbv]

NO_x [ppbv]

Falcon GPS altitude

MCS outflow: NO ~4-5 ppbv

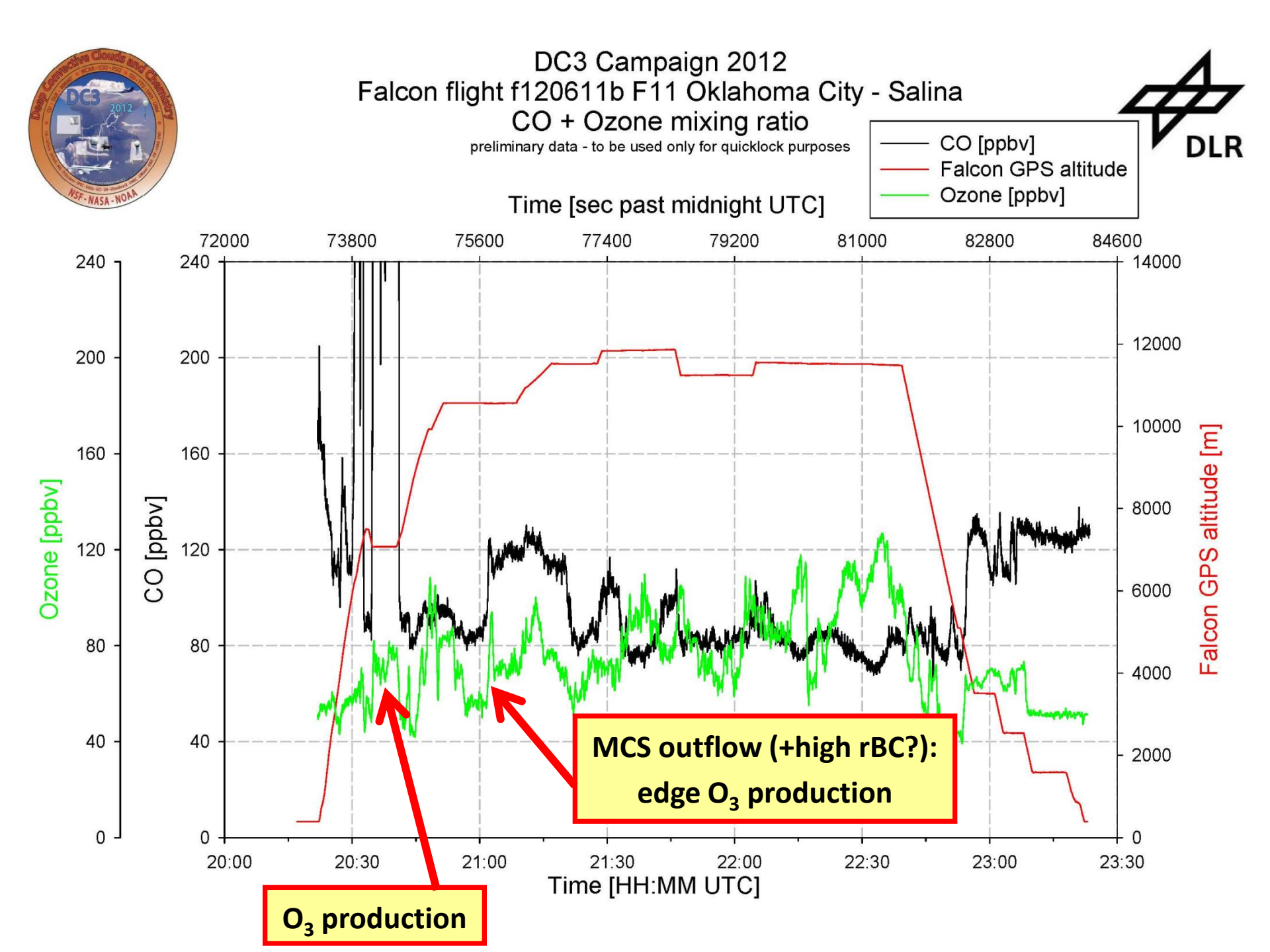
NO low in BB plume

NO_x [ppbv]

NO [ppbv]

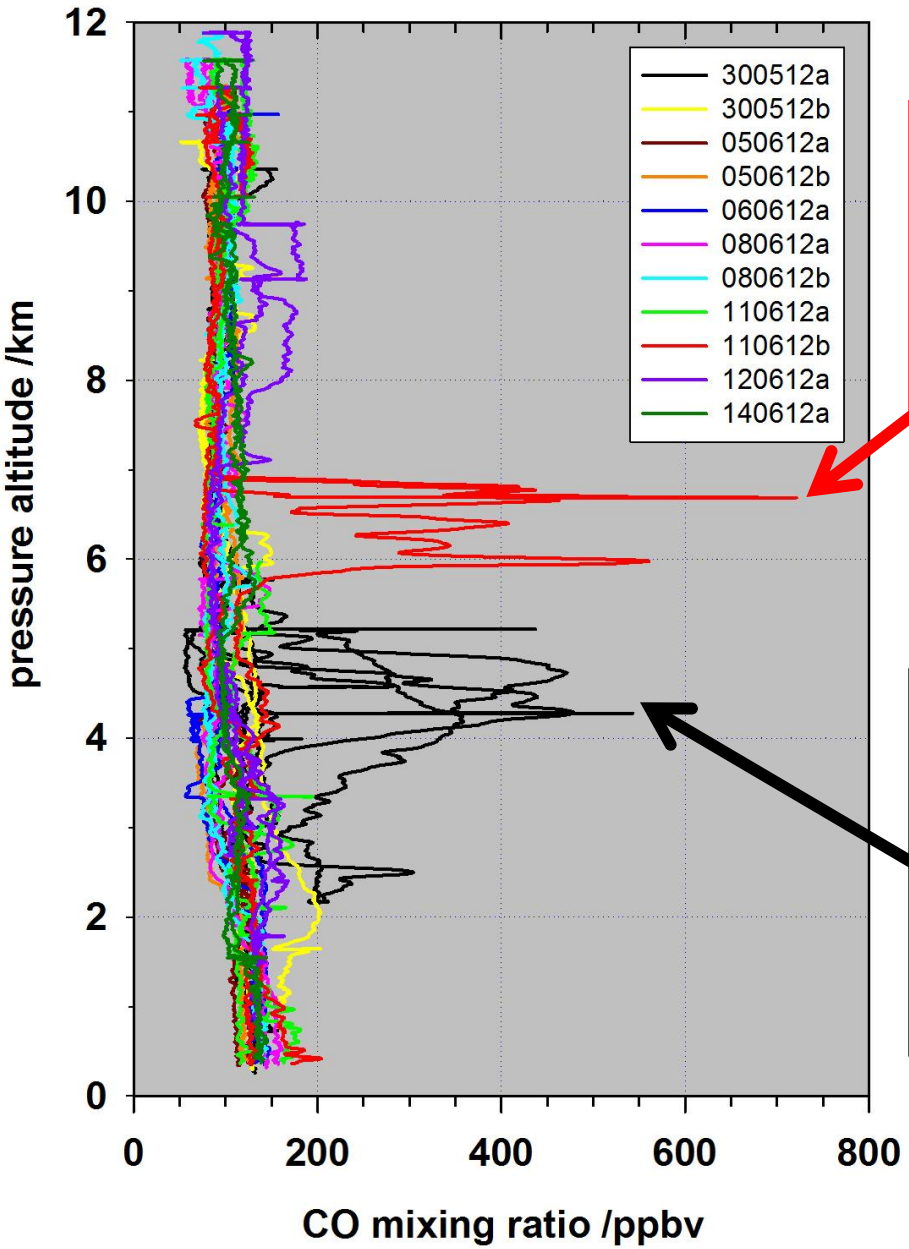
Falcon altitude

time [HH:MM UTC]


DC3 Campaign 2012
Falcon flight f120611b F11 Oklahoma City - Salina
CO + Ozone mixing ratio
preliminary data - to be used only for quicklook purposes
DLR
CO [ppbv]
Falcon GPS altitude
Ozone [ppbv]
Time [sec past midnight UTC]
72000
73800
75600
77400
79200
81000
82800
84600
Ozone [ppbv]
CO [ppbv]
Falcon GPS altitude [m]
240
200
160
120
80
40
0
14000
12000
10000
8000
6000
4000
2000
0
20:00
20:30
21:00
21:30
22:00
22:30
23:00
23:30
Time [HH:MM UTC]
MCS outflow (+high rBC?):
edge O3 production
O3 production

DLR

CO Falcon - DC3 2012 - Local

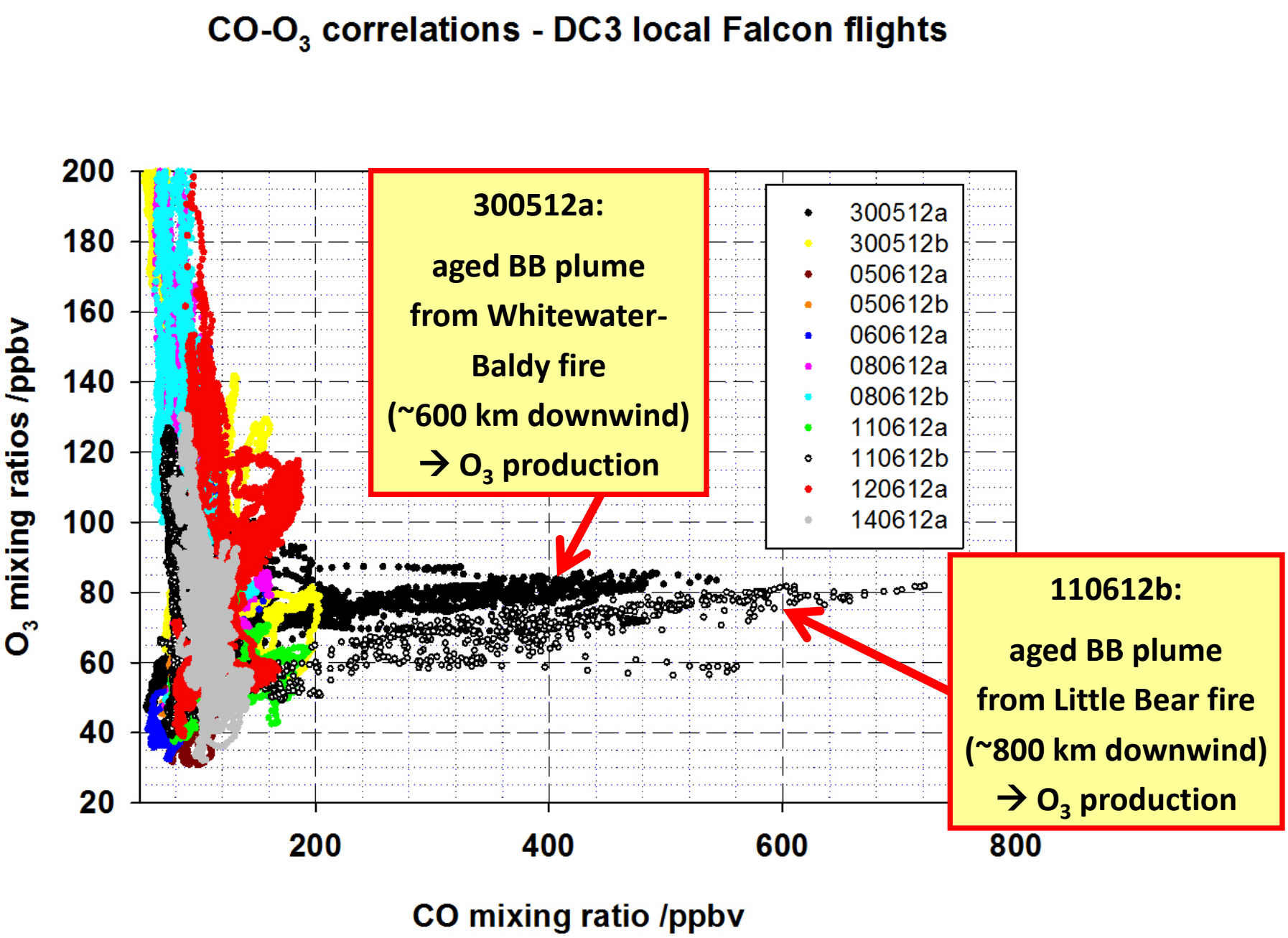


110612b:

aged BB plume (6-7 km) from Little Bear fire ~800 km downwind

300512a:

aged BB plume (3-5 km) from Whitewater-Baldy fire ~600 km downwind


CO-O3 correlations - DC3 local Falcon flights
300512a:
aged BB plume
from Whitewater-
Baldy fire
(~600 km downwind)
→ O3 production
110612b:
aged BB plume
from Little Bear fire
(~800 km downwind)
→ O3 production
300512a
300512b
050612a
050612b
060612a
080612a
080612b
110612a
110612b
120612a
140612a
O3 mixing ratios /ppbv
CO mixing ratio /ppbv
200
180
160
140
120
100
80
60
40
20
200
400
600
800

Date 2012	Fresh LNOx (KS) squall line	Fresh LNOx (CO) squall line	Fresh LNOx (WY) squall line	Fresh LNOx (NE) squall line	Fresh LNOx (MO) MCS	Fresh LNOx (AR) MCS	Fresh LNOx (OK) MCS MCC MCV	Fresh LNOx (TX) isolated-supercell MCV
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30 May (2x)							**X**	**X** (3 NO)
5 June (2x)							**X**	**X**
6 June **(flash)**			**X** (no NO) DC8 GV	**X** (no NO) DC8 GV				
8 June (2x)								
11 June (2x)					**X** (5 NO) DC8 GV	**X** (5 NO) DC8 GV		
12 June	**X** (3 NO)	**X** (3 NO)						
14 June								

Date 2012	Aged LNOx (CO)	BB Whitewater-Baldy (NM)	BB Little Bear (NM)	BB High Park (CO)	BB Canada	Aged LNOx (OK/TX)	Asian-CO
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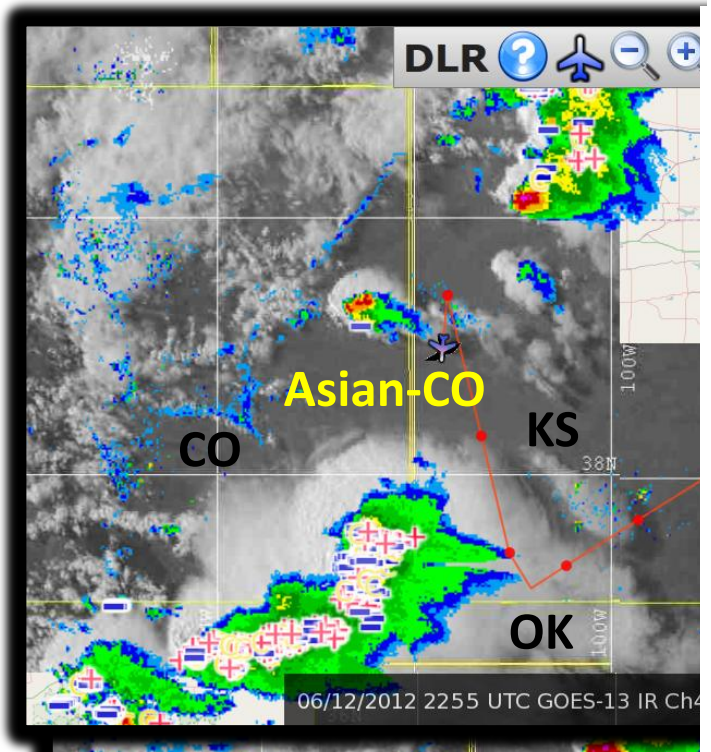
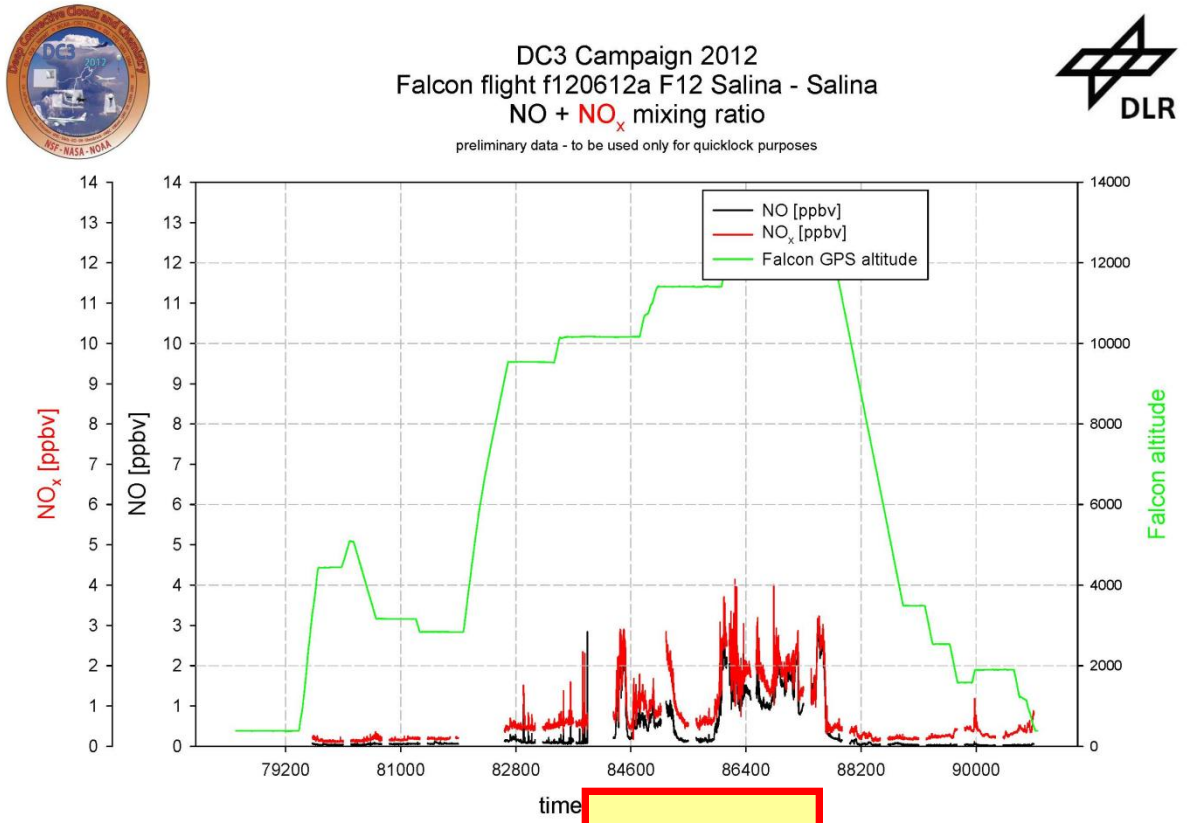
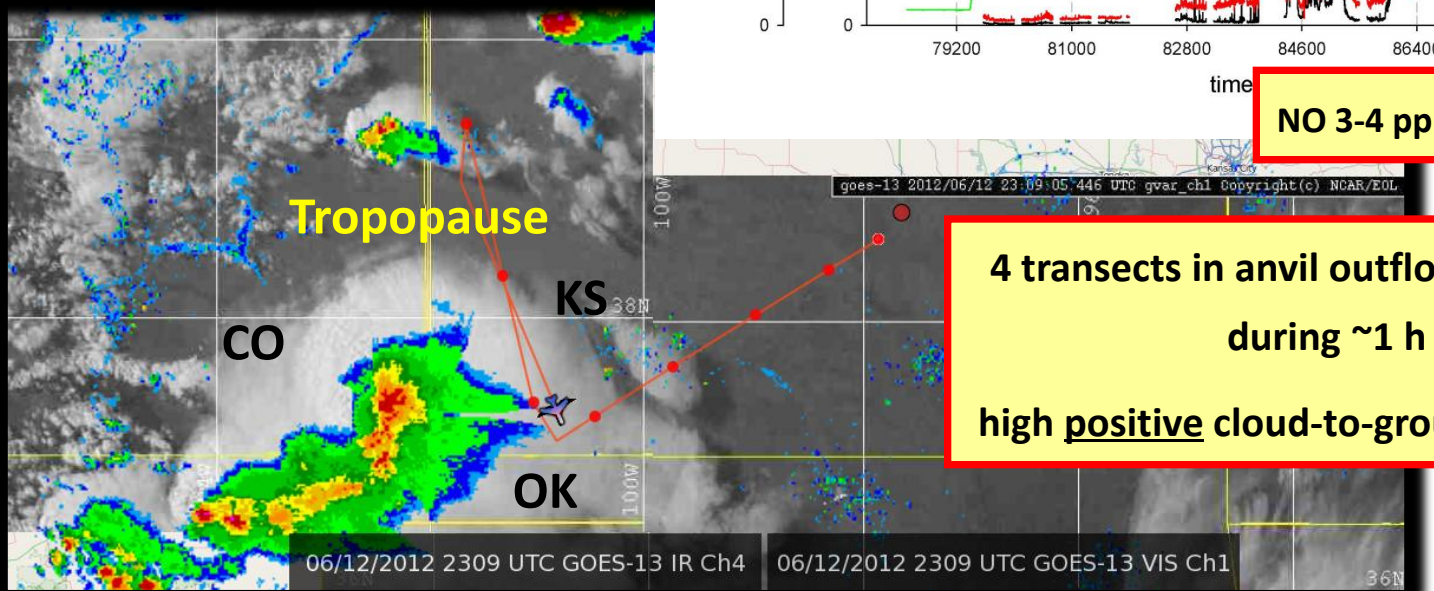
5 June (2x)	**(X)** (110 CO, 80-100 O3)						
6 June (flash)							
8 June (2x)	**X** (1 NO, 110 CO, 80-110 O3)					**X** (150 CO, 100 O3)	
11 June (2x)			**X** (700 CO, 80 O3)	**X** (130 CO, 60 O3)	**(X)**		
12 June			**(X)**	**X** (140 CO, 60 O3)			**X** (160 CO, 120 O3)
14 June				**X** (130 CO, **90 O3**)			

Falcon flight on 12 June 2012: Squall line SW Kansas



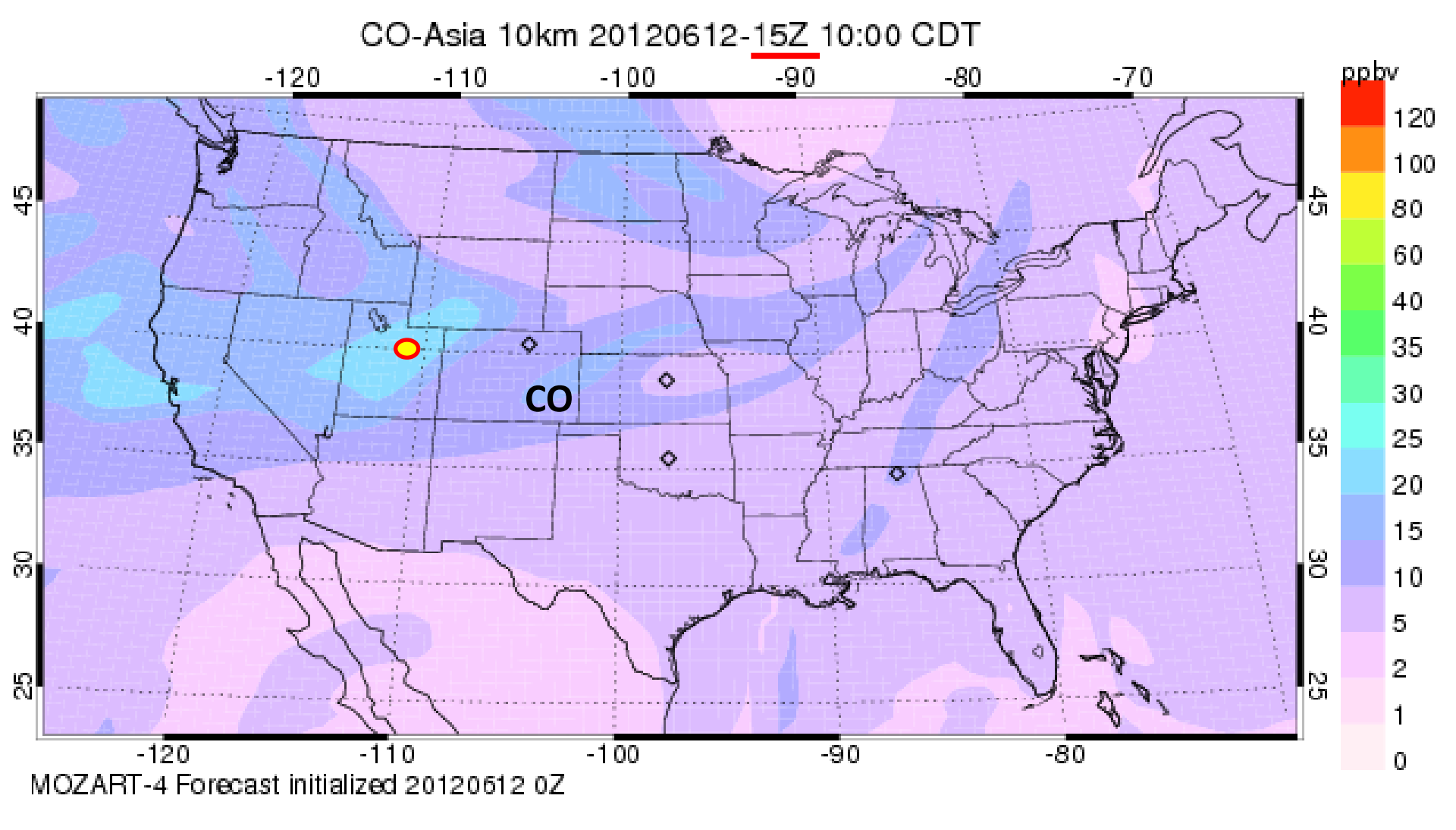


NO 3-4 ppbv

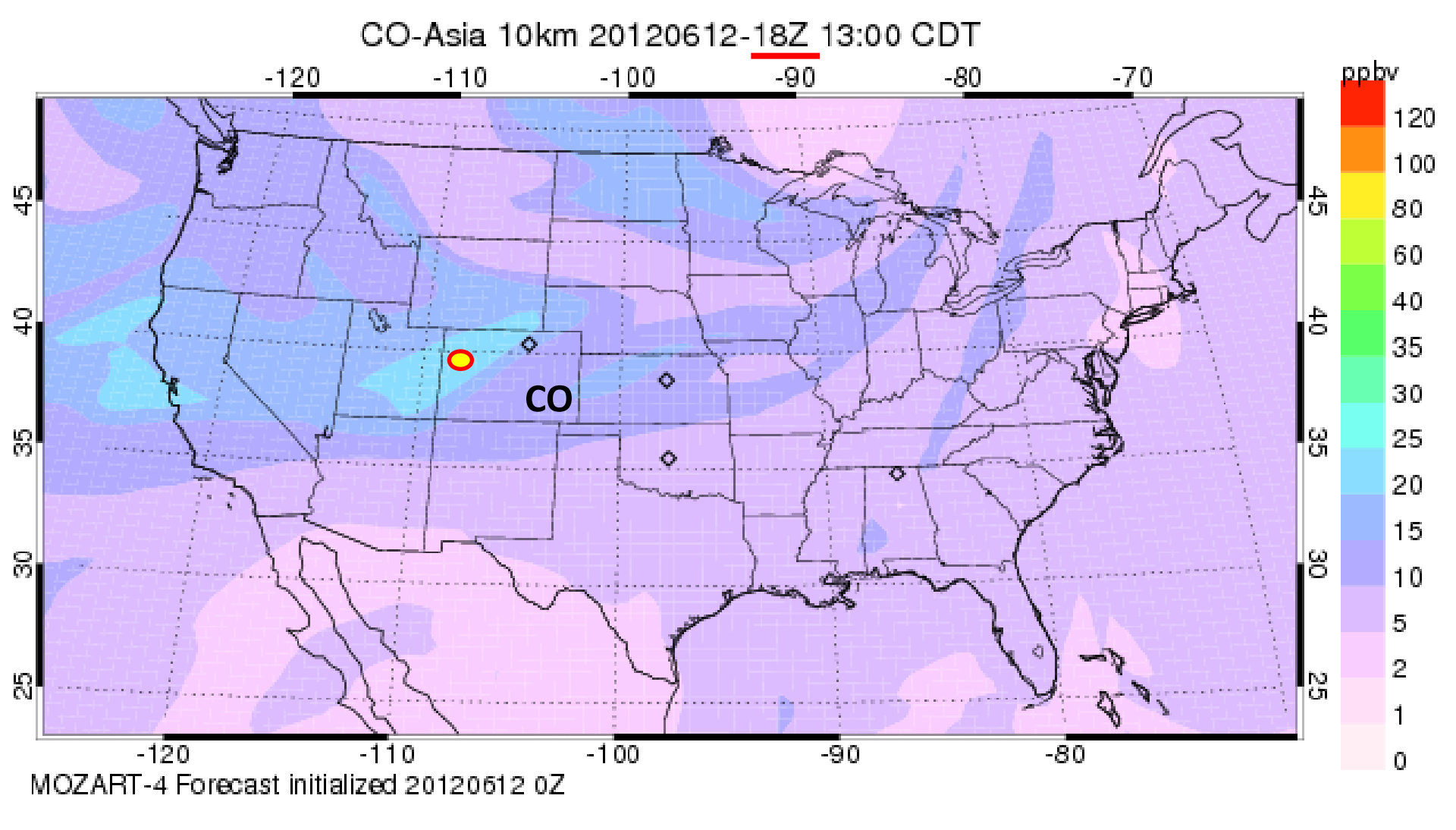


4 transects in anvil outflow ~10-12 km during ~1 h

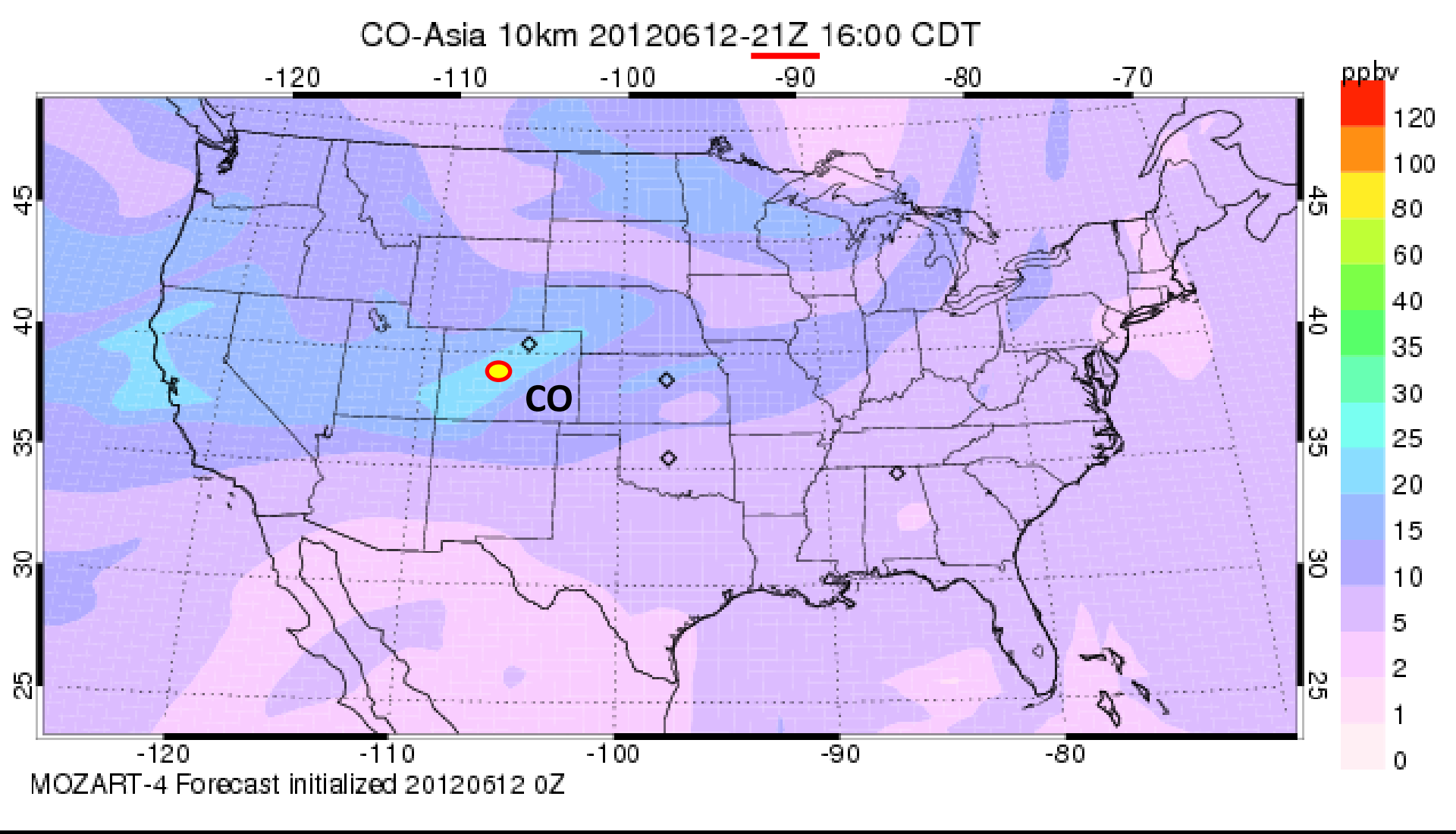
high <u>positive</u> cloud-to-ground flash rate



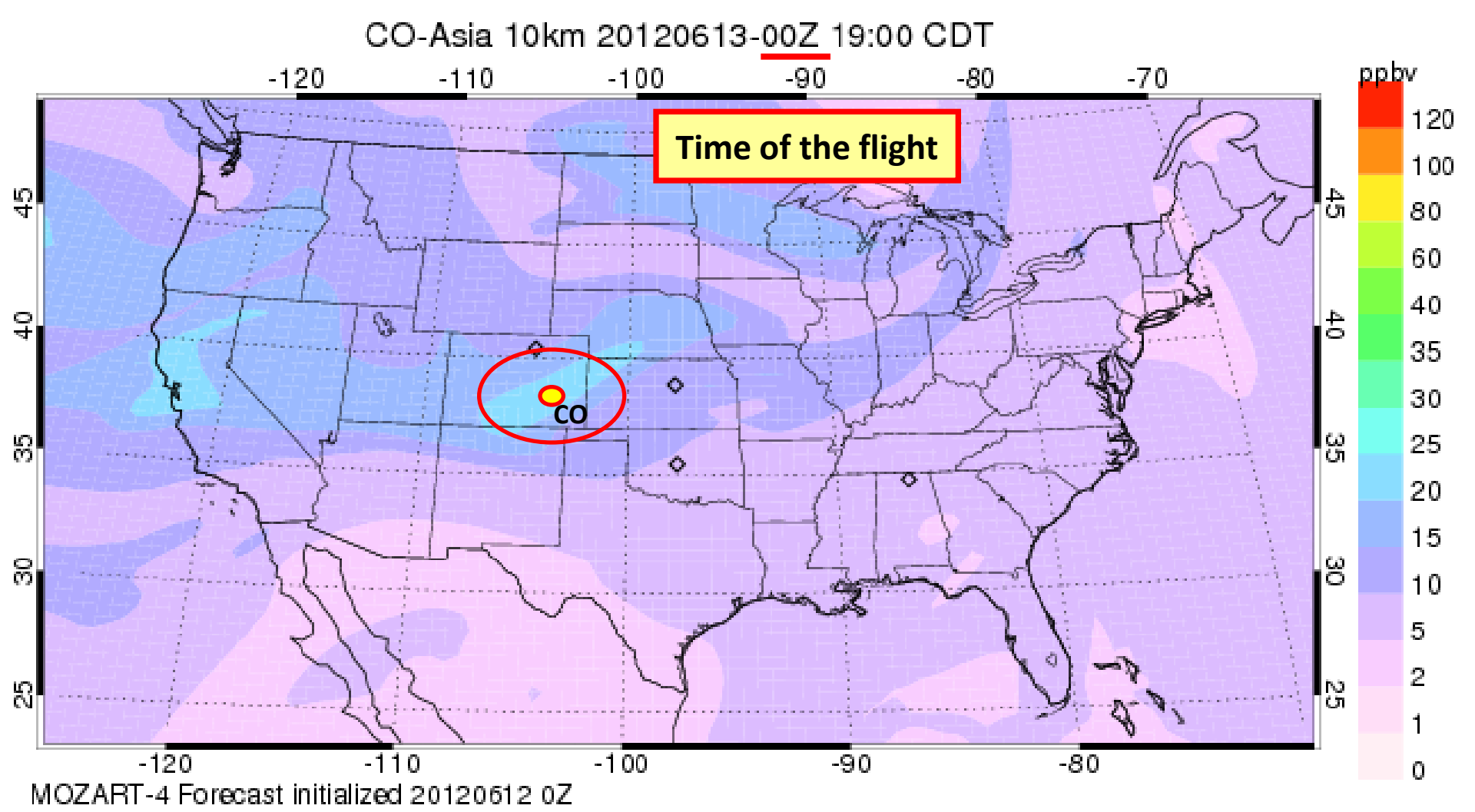
Asian-CO predicted for UT (max. ~10 km)



Asian-CO predicted for UT (max. ~10 km)



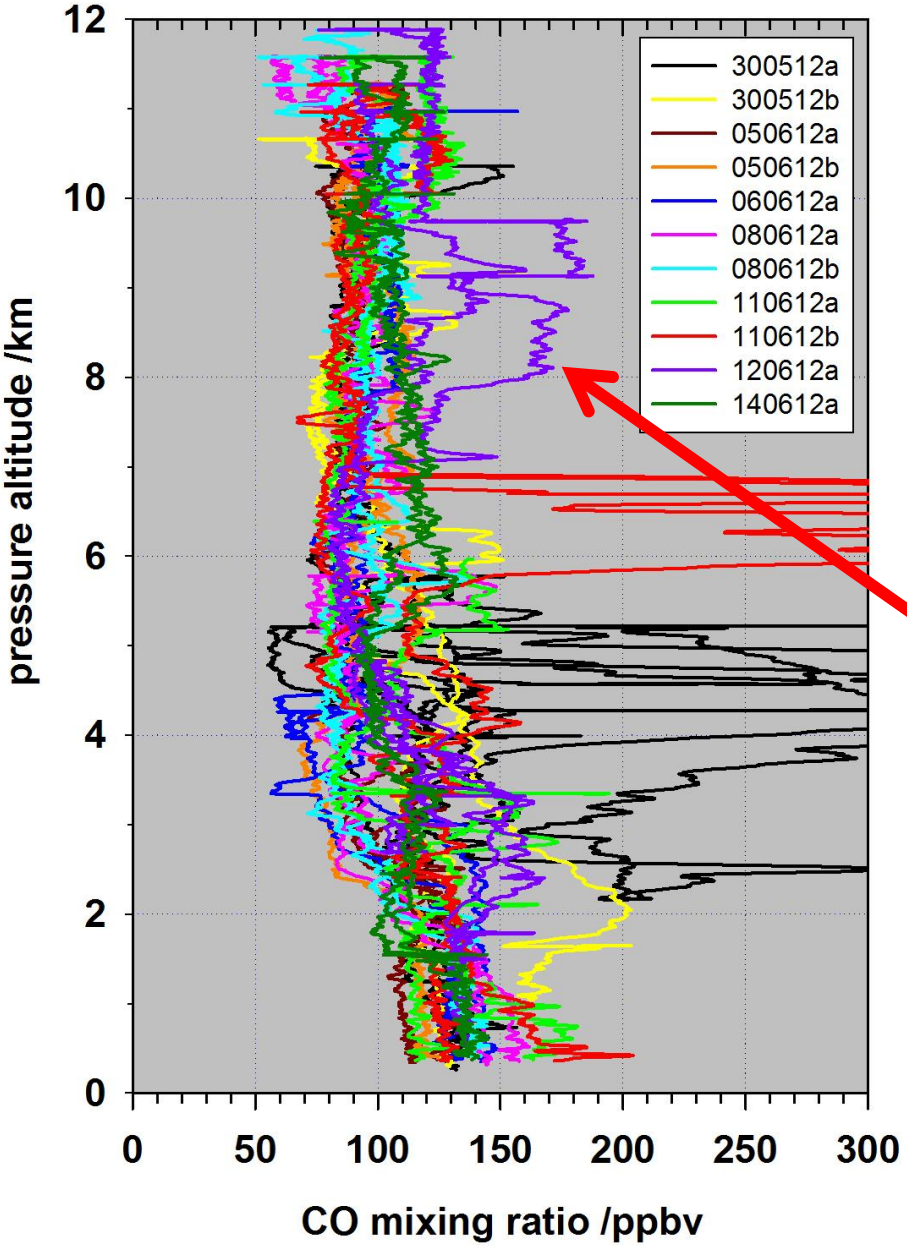
Asian-CO predicted for UT (max. ~10 km)



Asian-CO predicted for UT (max. ~10 km)

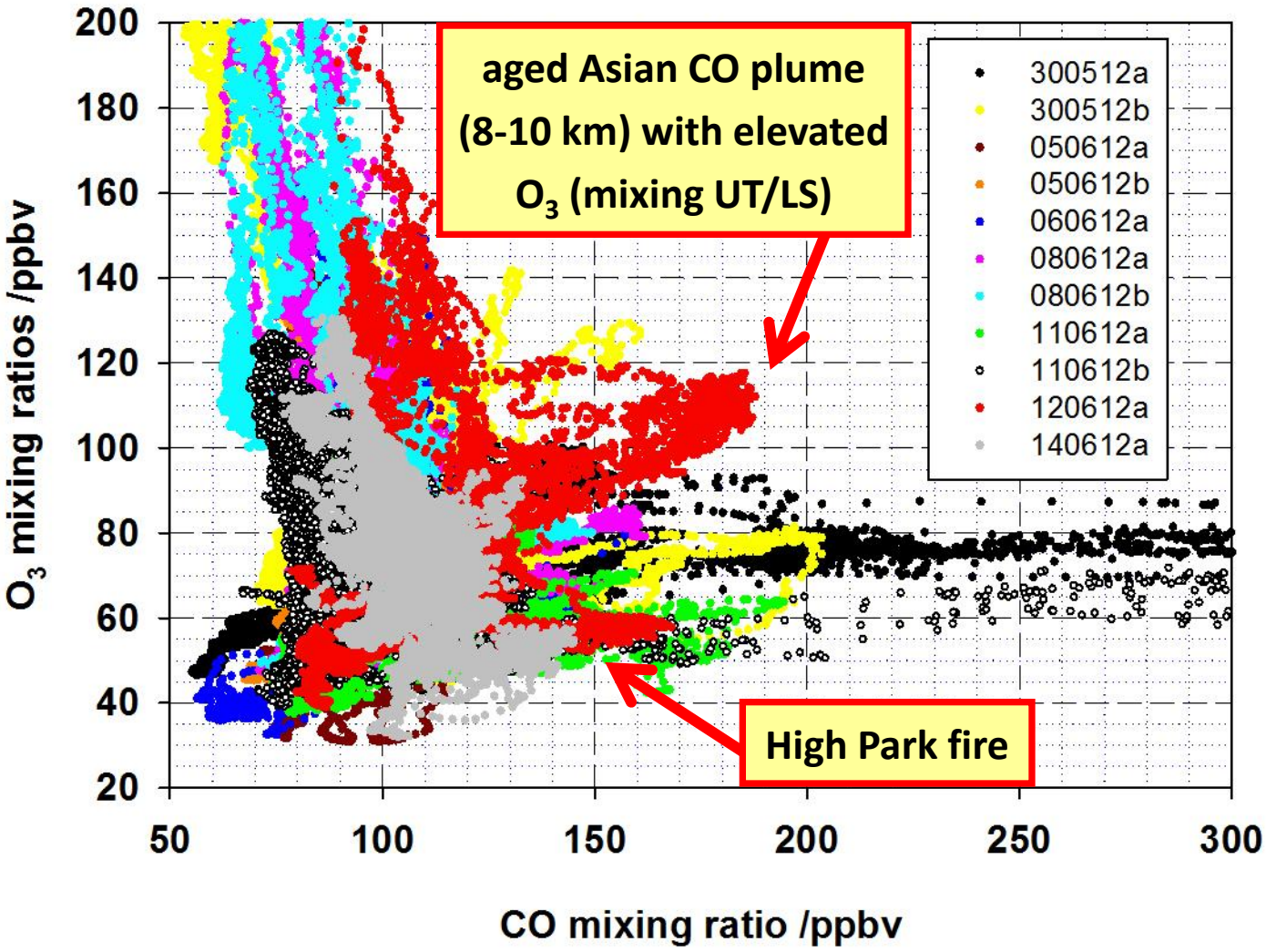
DLR

CO Falcon - DC3 2012 - Local



aged Asian CO plume (8-10 km) with elevated O_3 (mixing UT/LS)

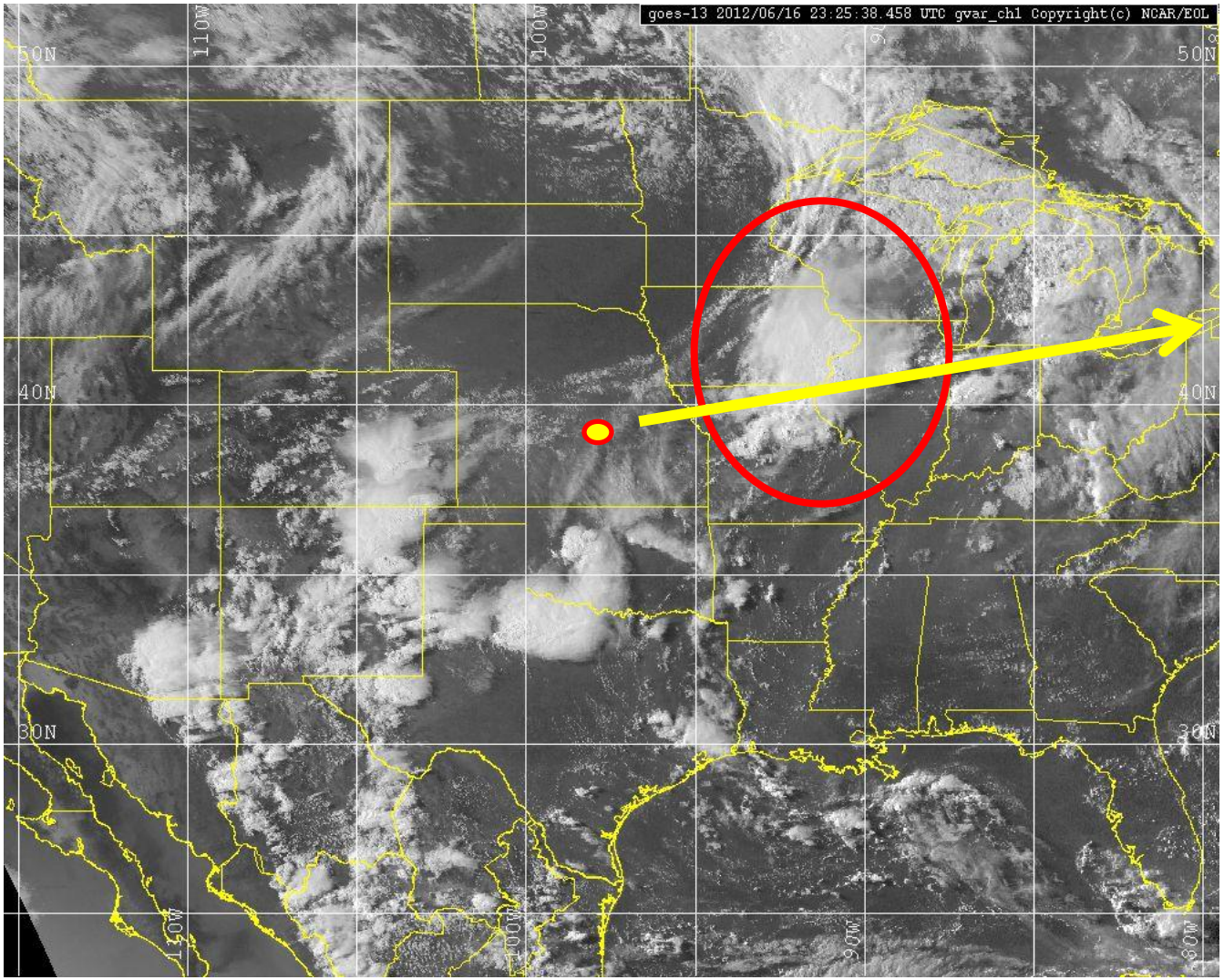
$CO\text{-}O_3$ correlations - DC3 local Falcon flights



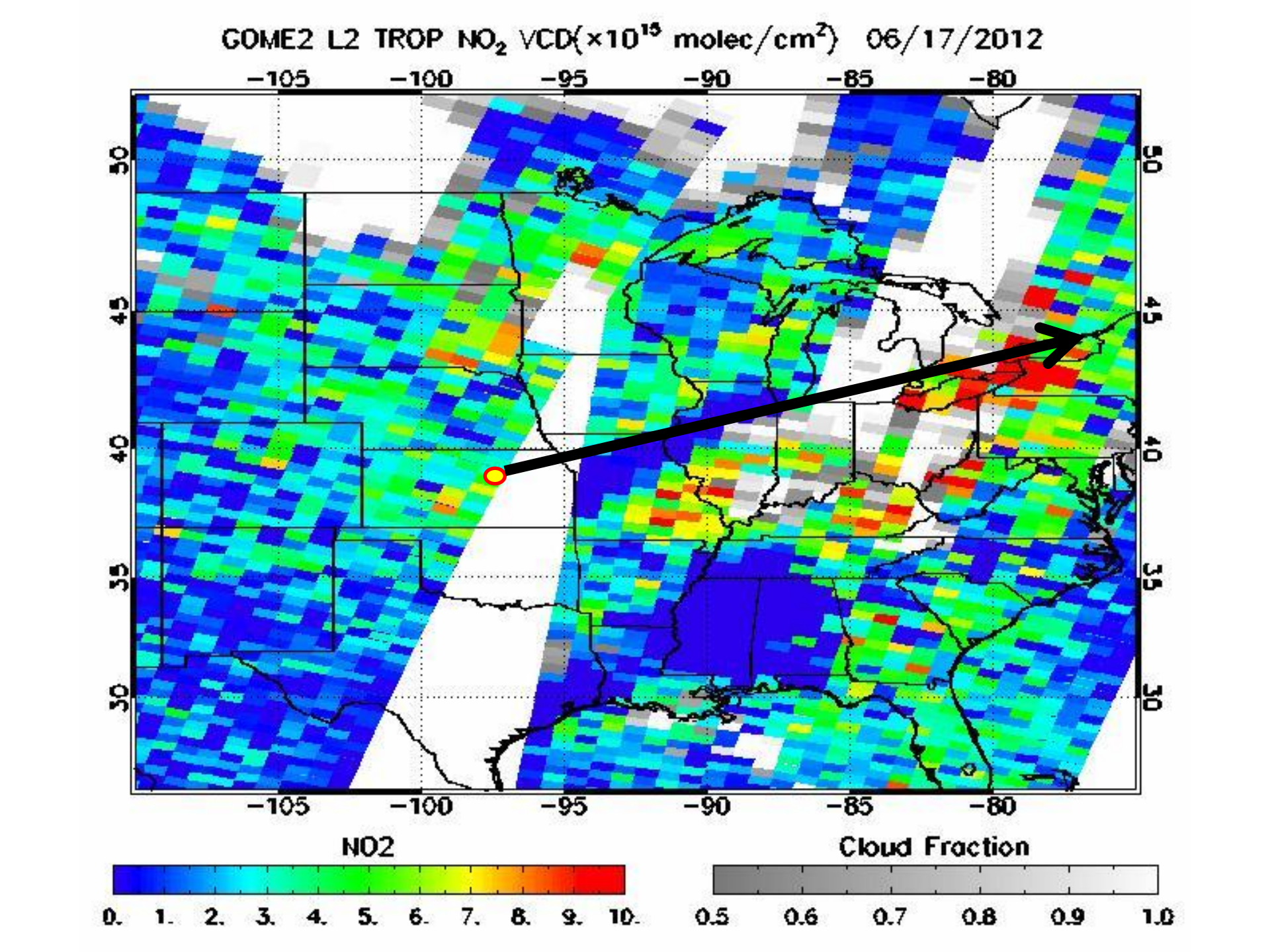
Falcon transfer flight: 17 June 2012 from Salina to Syracuse

Penetration of a wide, aged LNOx area

Falcon transfer flight: 17 June 2012 from Salina to Syracuse



Cold front passage with convection the evening before the flight southwest of the Great Lakes


GOME2 L2 TROP NO2 VCD(×10^15 molec/cm^2) 06/17/2012
−105
−100
−95
−90
−85
−80
50
45
40
35
30
NO2
0. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10.
Cloud Fraction
0.5 0.6 0.7 0.8 0.9 1.0

Falcon transfer flight: 17 June 2012 from Salina to Syracuse

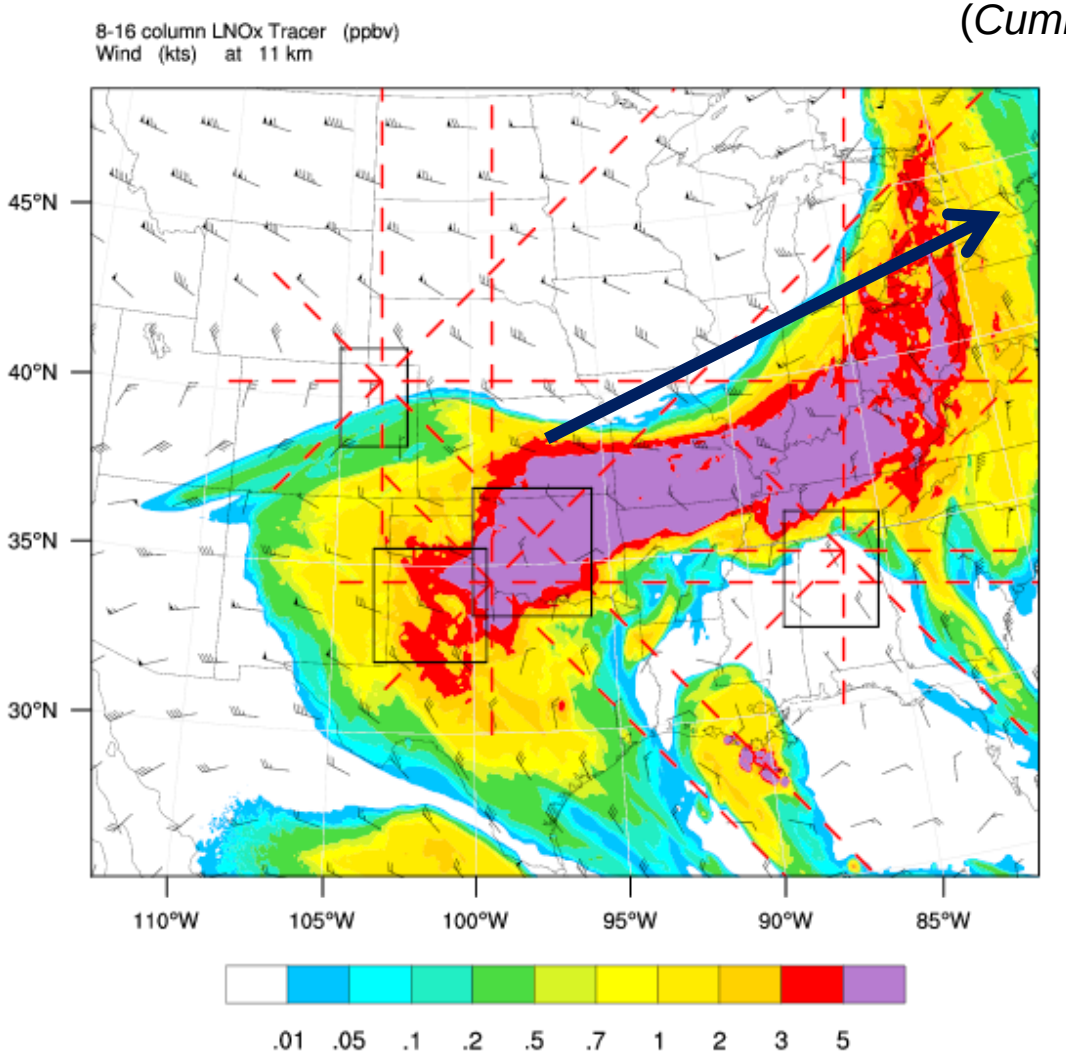
Penetration of wide LNOx area

Time of the flight

NCAR WRF ARW Forecast (Δx=3 km)

8-16 km column LNOx Tracer (ppbv)

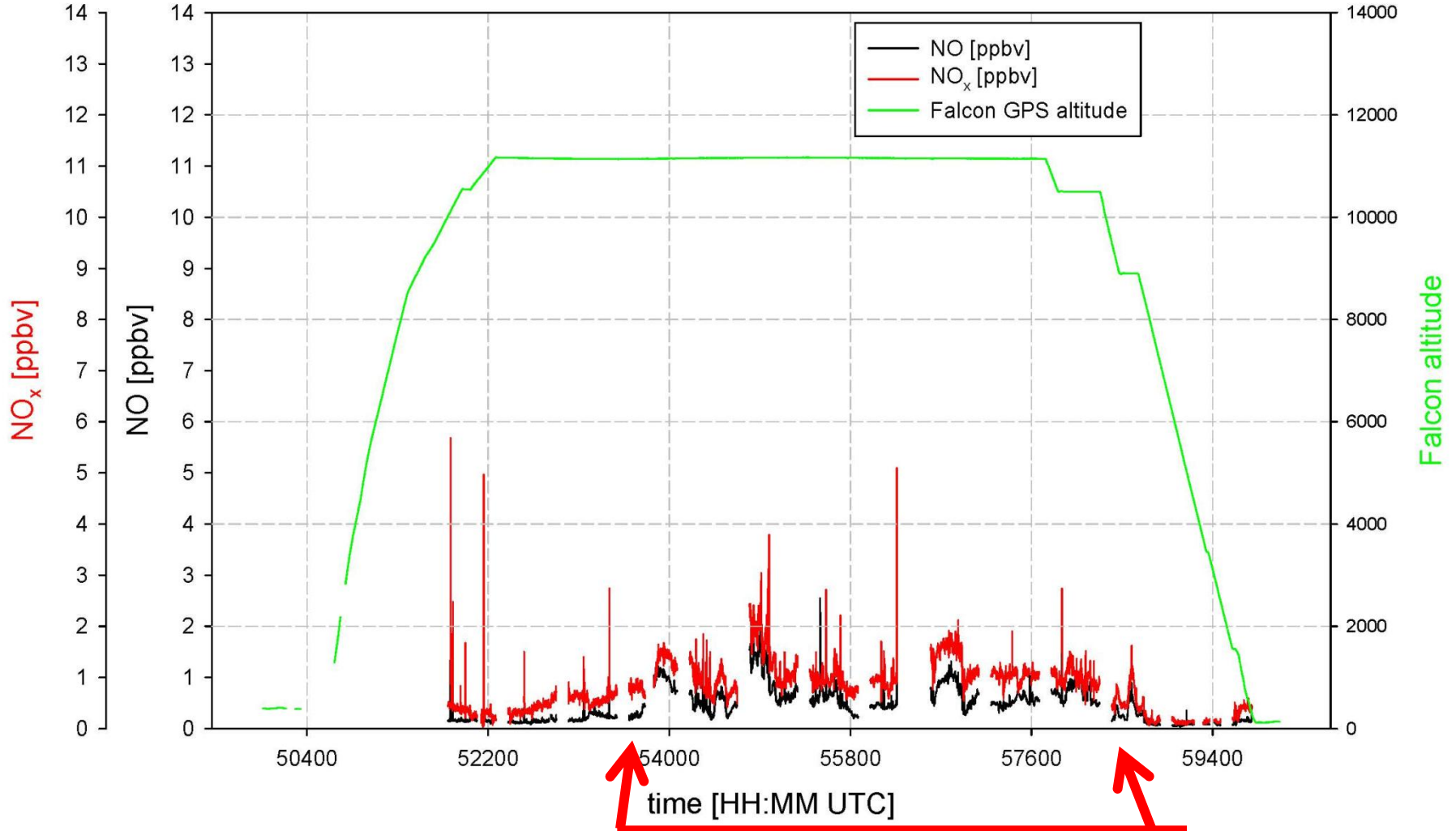
(*Cummings, Pickering, Barth et al.*)



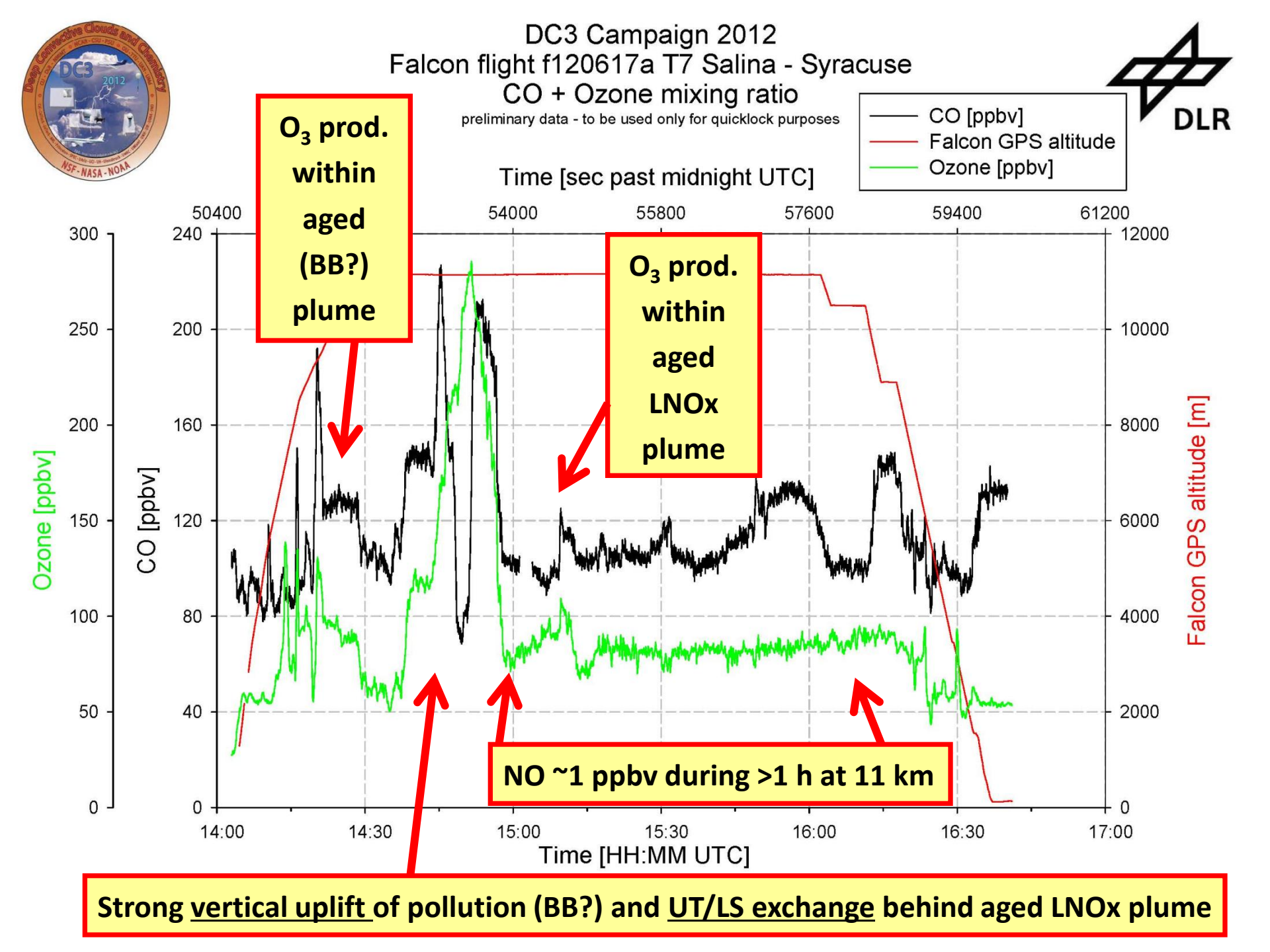
DC3 Campaign 2012
Falcon flight f120617a T7 Salina - Syracuse
NO + NO_x mixing ratio

preliminary data - to be used only for quicklock purposes

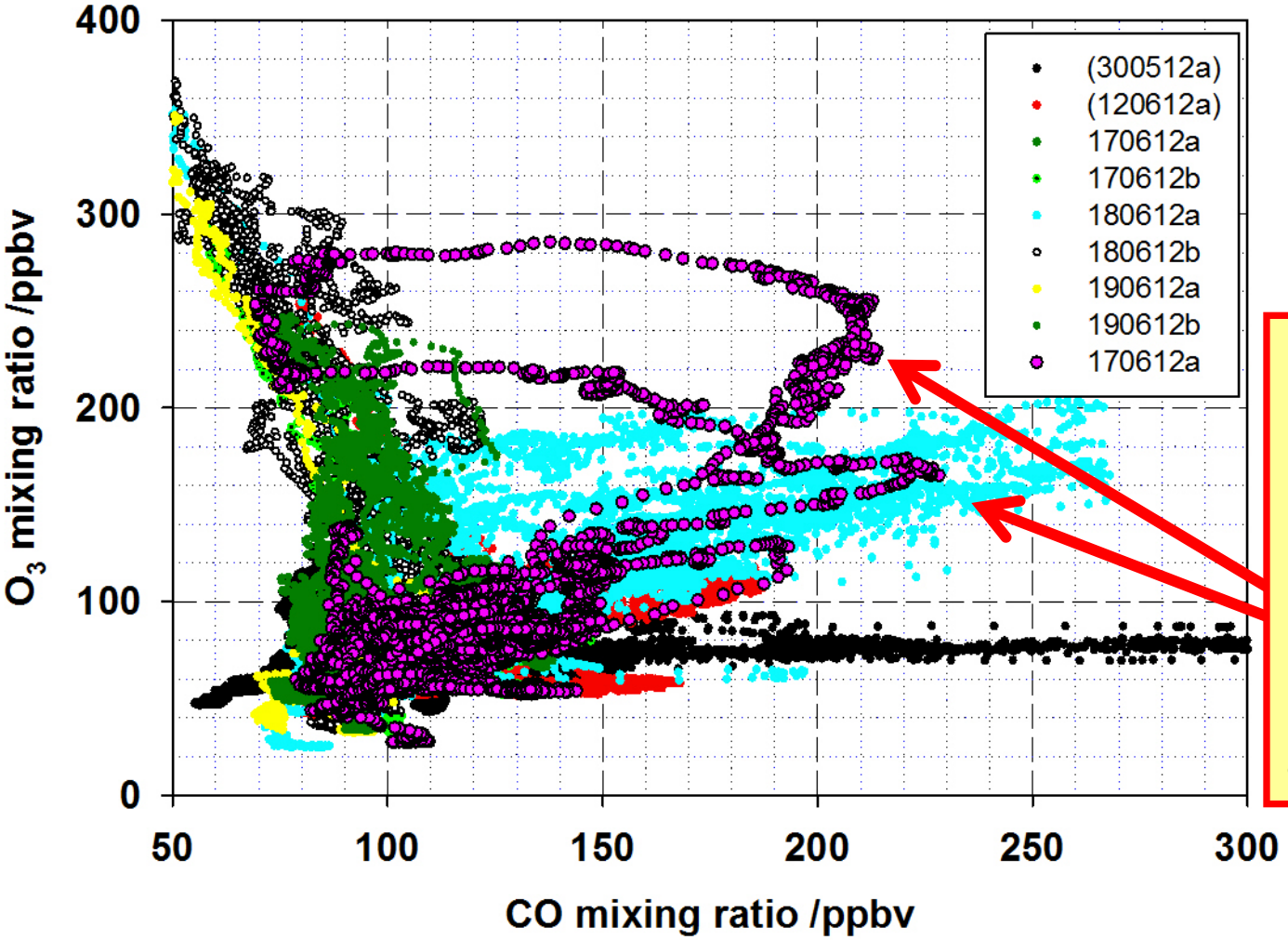
DLR



NO ~1 ppbv during >1 h at 11 km


DC3 Campaign 2012
Falcon flight f120617a T7 Salina - Syracuse
CO + Ozone mixing ratio
preliminary data - to be used only for quicklock purposes
DLR
CO [ppbv]
Falcon GPS altitude
Ozone [ppbv]
Time [sec past midnight UTC]
50400
54000
55800
57600
59400
61200
O_3 prod. within aged (BB?) plume
O_3 prod. within aged LNOx plume
Ozone [ppbv]
CO [ppbv]
Falcon GPS altitude [m]
NO ~1 ppbv during >1 h at 11 km
14:00
14:30
15:00
15:30
16:00
16:30
17:00
Time [HH:MM UTC]
Strong vertical uplift of pollution (BB?) and UT/LS exchange behind aged LNOx plume

CO-O_3 correlations - DC3 Falcon transfer flights



BB (?) pollution plumes injected into the "deep" stratosphere: pyroconvection?

T - 17 and 18 June: Salina to Greenland

Summary of the DC3 Falcon measurements

Fresh and *aged* LNOx successfully measured:

- on 30 May, *8 June*, 11 June, 12 June and *17 June* 2012
- in MCS, MCC, MCV, squall lines and isolated supercells
- repeated penetrations and long flight duration times in selected anvil outflows covering lower outflow boundaries up to 12 km
- highest NO mixing ratios (~5 ppbv) in MCS outflow on 11 June
- lightning characteristics different (high positive/negative flash rates)
- unfortunately storms mainly outside DC3-LMA domains

Interaction of anvil outflow with UT/LS-O_3 and Asian-UT-CO

Fresh and aged BB (LNOx) plumes with O_3 production successfully probed

DC3 leads: Mary Barth, Bill Brune, Chris Cantrell, Jim Crawford, Steve Rutledge - Thank you all!

„It was a pleasure for the DLR Falcon team to join the DC3 campaign!"