The role of (aircraft) field campaigns in air quality research

Frank Flocke, ACOM

Thanks to
Gabi Pfister and Becky Hornbrook, ACOM
Christoph Knote (U Munich)
The FRAPPÉ and DISCOVER-AQ Science Teams
NASA, CDPHE
NOAA CSD

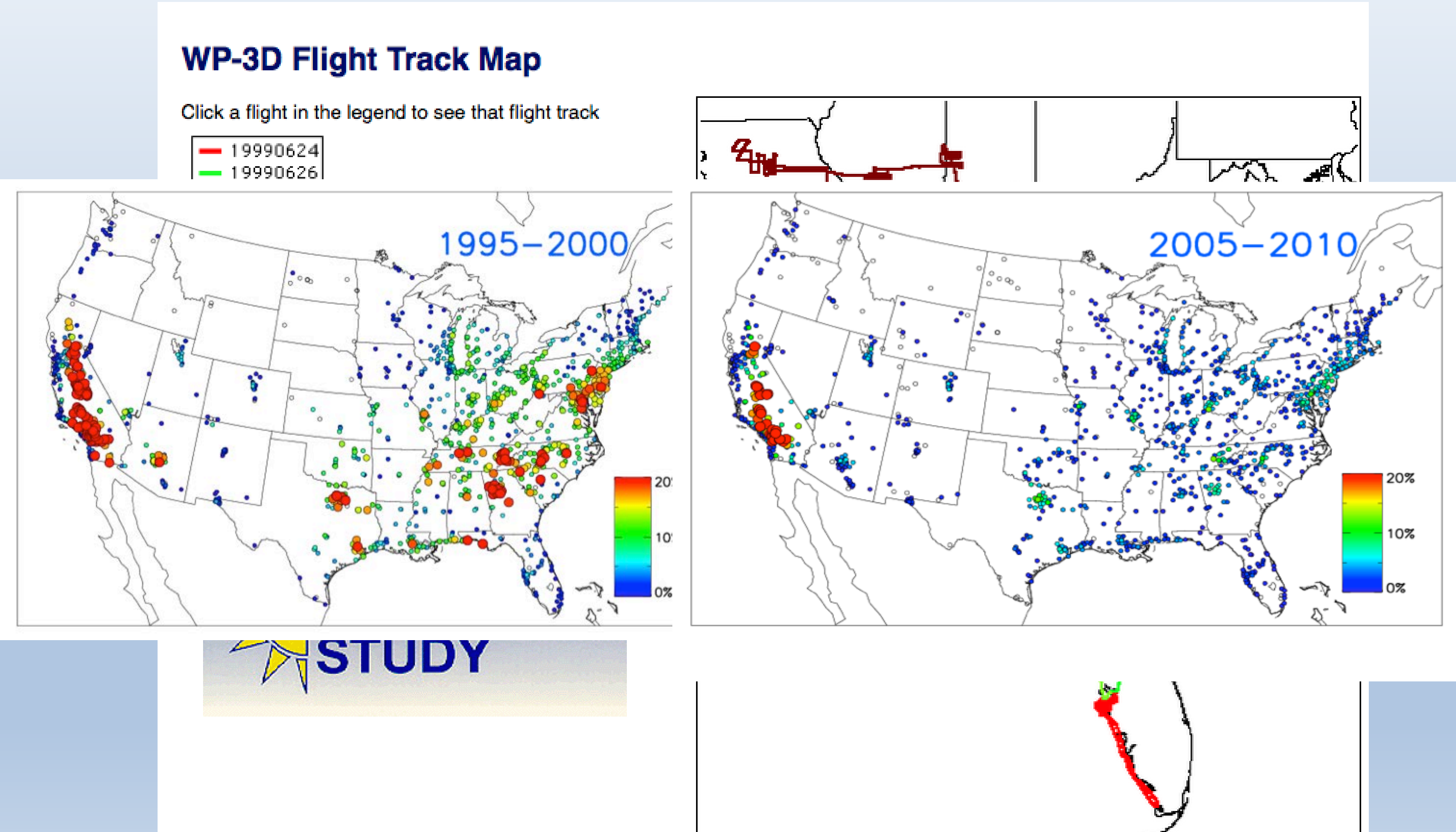
The role of (aircraft) field campaigns in air quality research

- They are absolutely **essential** and we should have **more** of them.

The role of (aircraft) field campaigns in air quality research

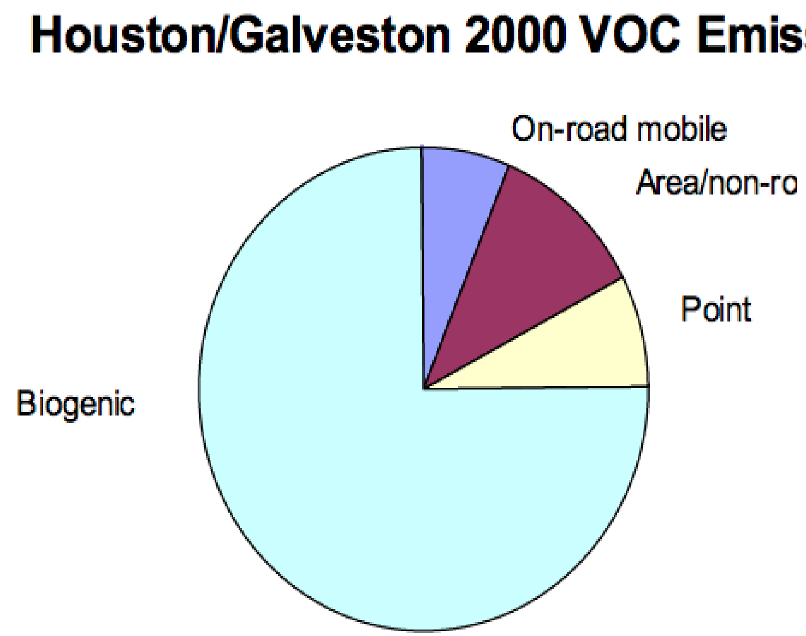
- They are absolutely **essential** and we should have **more** of them, because…
- It’s difficult to compile emission inventories and even more difficult to verify them with (typically sparse) ground based monitoring (of few species).
- It’s difficult to measure vertical distributions of many tracers from the ground.
- It’s impossible to assess chemical processing when only ground-based data for some criteria pollutants is available
- One can’t adequately model ground level ozone and develop pollution control strategies without comprehensive observations

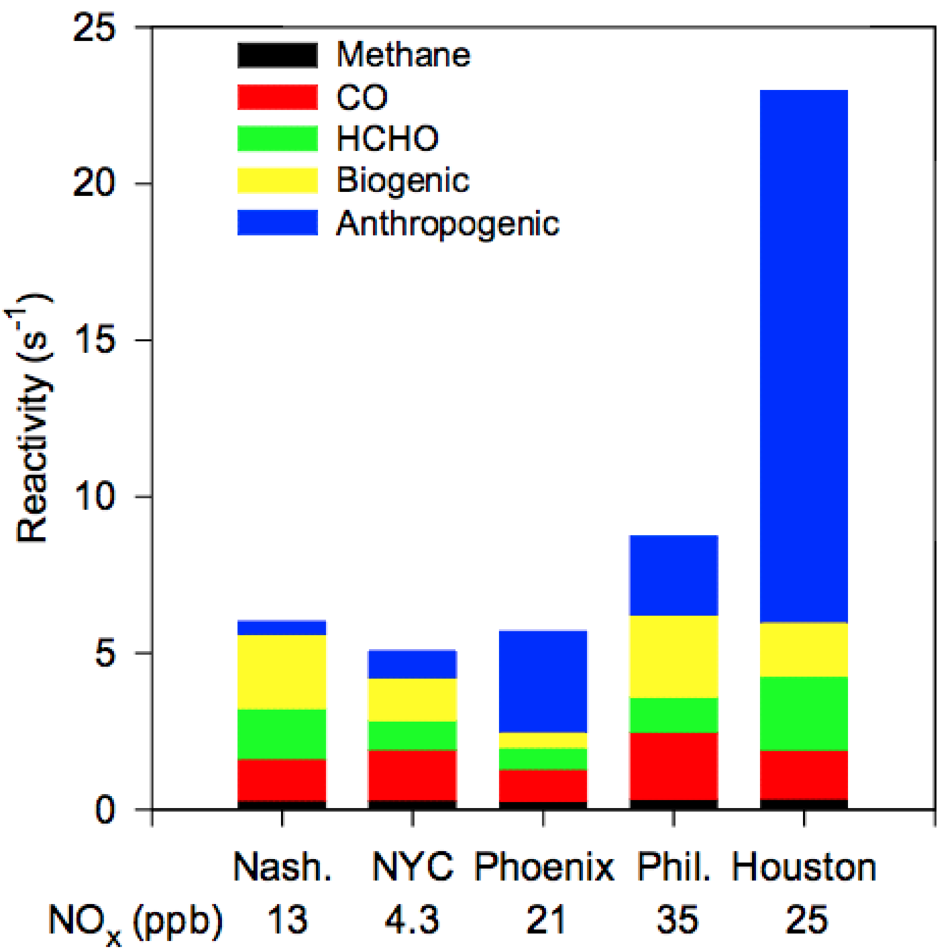
NOAA’s SOS field campaigns (1990s)



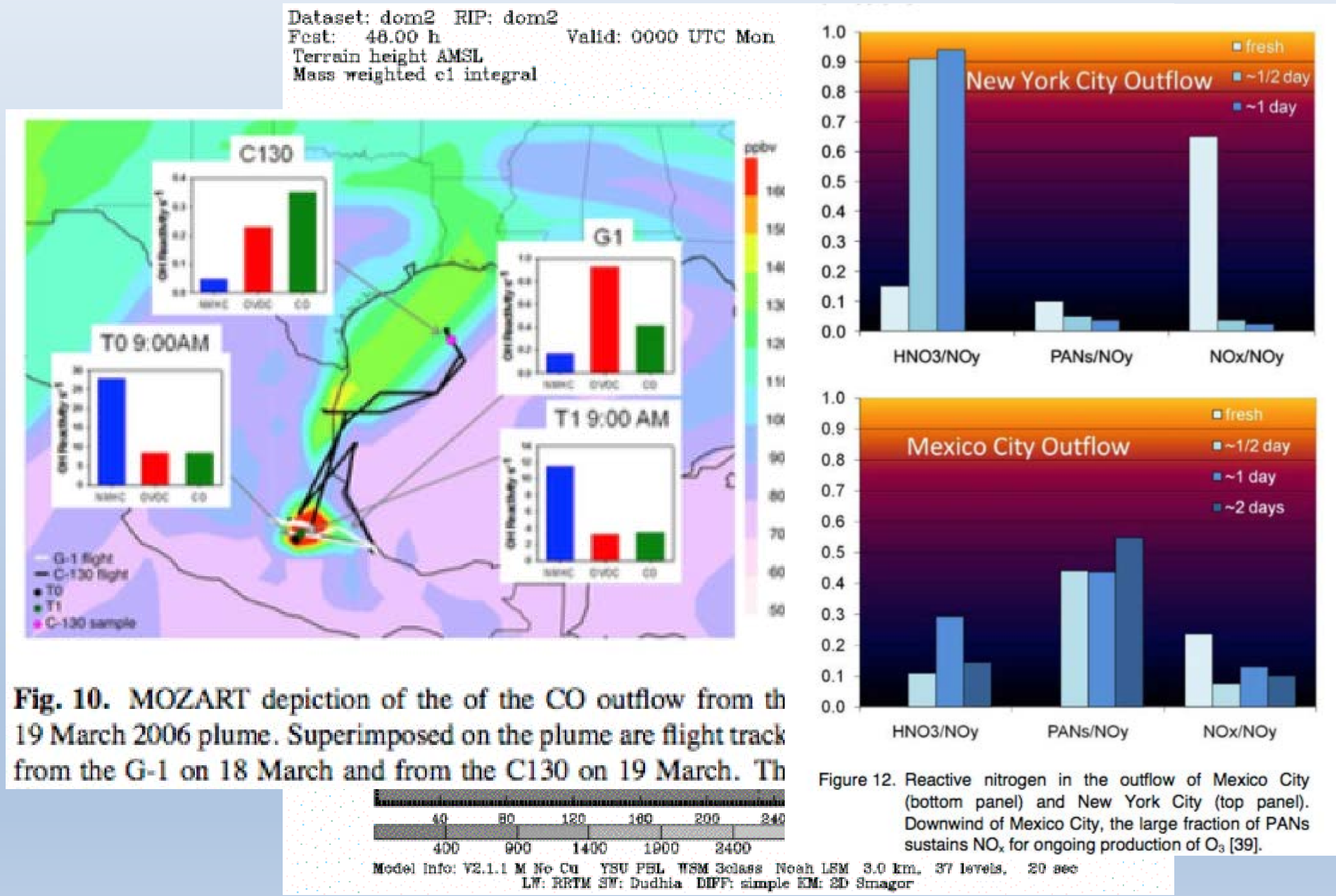
Source: NOAA ESRL

NOAA's TexAQS field campaigns





NCAR’s MIRAGE-Mex Field Campaign



The role of (aircraft) field campaigns in air quality research

- Aircraft field measurements deliver:
  - High resolution 3-D pictures of tracer distributions and the state of the atmosphere
    - Air mass evolution (‘Lagrangian’ approach)
    - Vertical profiles to provide link with satellite and other remote sensing data
  - Payloads typically include measurements of highly speciated primary and secondary pollutants, including intermediates and products.
    - FRAPPÉ payload

The role of (aircraft) field campaigns in air quality research

- Aircraft field measurements deliver:
  - The best tool for model evaluation
    - Emissions (plus ground observations of point sources)
    - Source “fingerprinting”
    - Area and point source integration
    - Ground truth for Meteorology / transport
    - Chemistry and physical transformations
  - Aircraft data can be used for ground monitor evaluation
    - Provide validation for existing ground monitoring network
    - Provide input for optimal monitor placement

The role of (aircraft) field campaigns in air quality research

- Aircraft field measurements don’t deliver:
  - Long term monitoring
    - Typically weak statistics
    - →Satellites, long term ground monitoring
  - Smaller point source characterization
    - →Simultaneous ground measurements
  - Measurements very close to the ground (in populated areas and complex terrain)
    - →Missed approaches can help with this in select areas

FRONT RANGE AIR POLLUTION AND PHOTOCHEMISTRY ÉXPERIMENT

PIs: Gabriele Pfister and Frank Flocke

NCAR / ACOM

Joint with NASA DISCOVER-AQ

PI: James Crawford

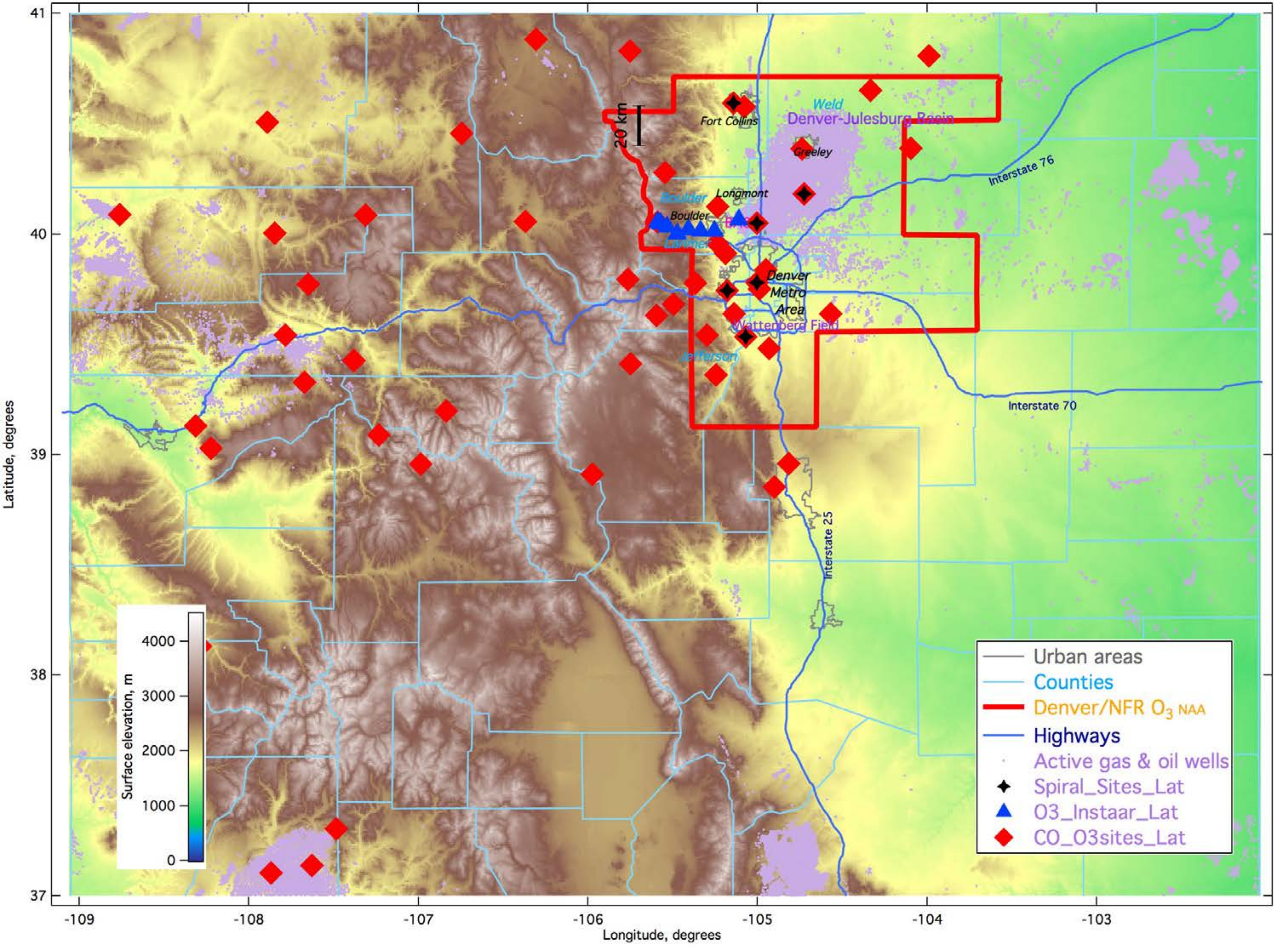
Northern Front Range Metro Area (NFRMA)

July 15 - August 18, 2014

http://www2.acd.ucar.edu/frappe

FRAPPÉ was funded by State of Colorado & National Science Foundation

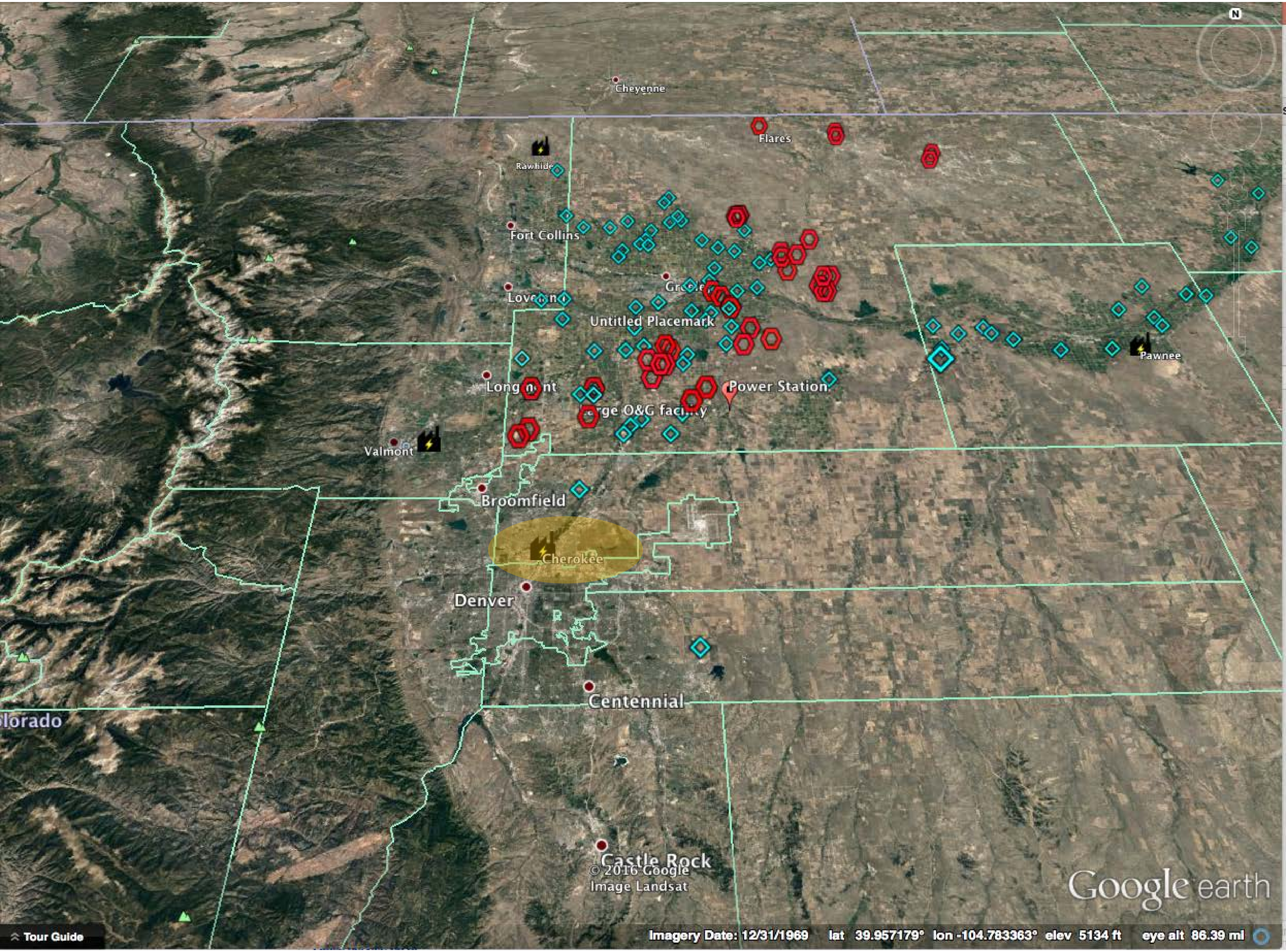
National Center for Atmospheric Research (NCAR), NASA Airborne Science Program
Colorado Department for Health and Environment (CDPHE), Colorado State University (CSU),
University of Colorado Boulder, Environmental Protection Agency (**EPA**) Region 8,
National Oceanic and Atmospheric Administration (**NOAA**), National Park Service (**NPS**),
Regional Air Quality Council (RAQC), UC Berkeley, UC Irvine, UC Riverside, US Naval Academy,
U of Wisconsin, U of Rhode Island, U of Cincinnati, Georgia Tech, GO3 Project, Aerodyne Inc.,
and others



Fort Collins
Weld
Denver-Julesburg Basin
Greeley
20 km
Interstate 76
Boulder
Longmont
Boulder
Larimer
Denver
Metro
Area
Wattenberg Field
Jefferson
Interstate 70
Interstate 25
Surface elevation, m
4000
3000
2000
1000
0
Urban areas
Counties
Denver/NFR O_3 NAA
Highways
Active gas & oil wells
Spiral_Sites_Lat
O3_Instaar_Lat
CO_O3sites_Lat
Latitude, degrees
Longitude, degrees
41
40
39
38
37
-109
-108
-107
-106
-105
-104
-103

Front Range

- **Very diverse Sources of air pollution**
  - Somewhat separated spatially in some cases, co-located in other cases
  - Different expectations of future growth
  - Emissions difficult to assess

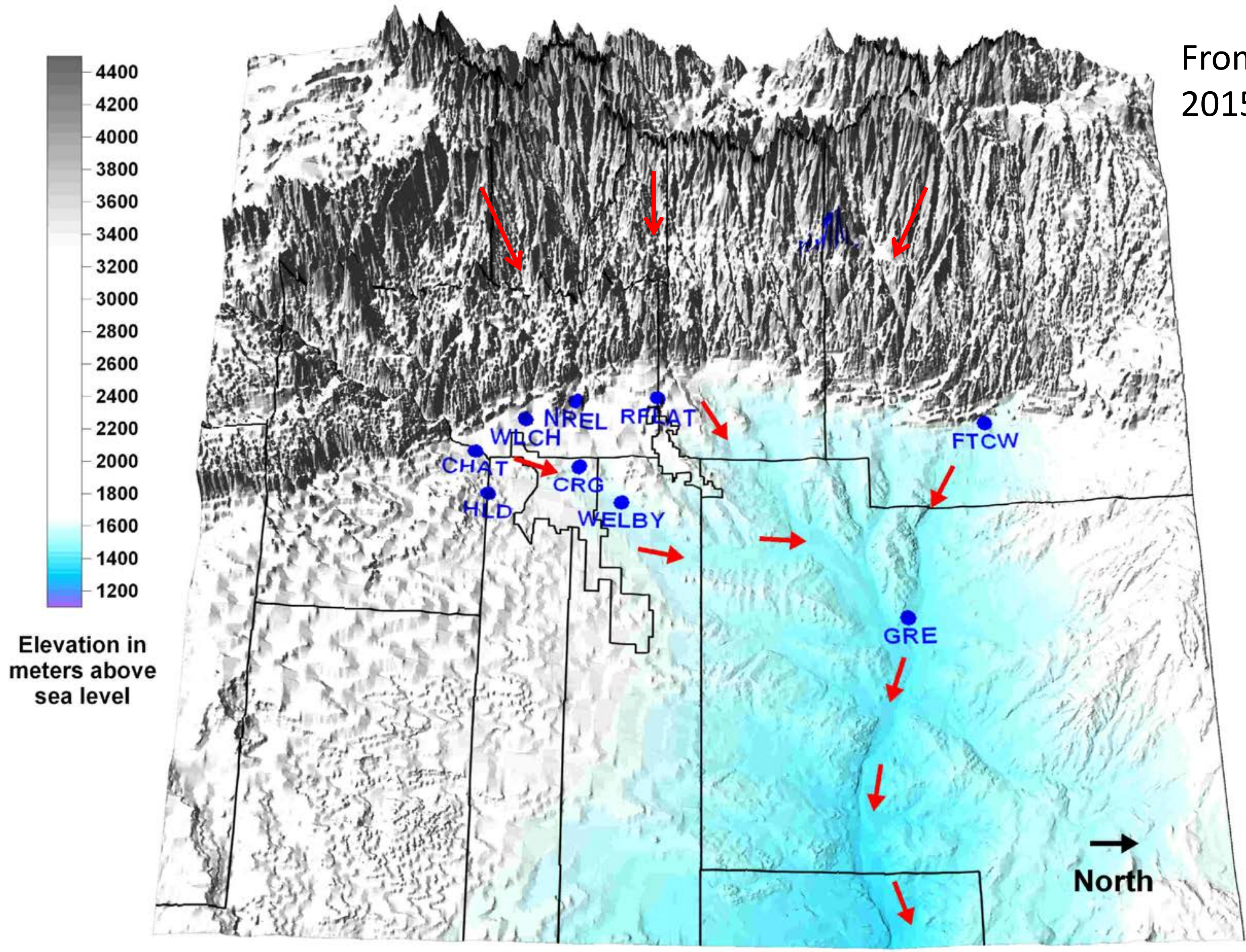


Cheyenne
Flares
Rawhide
Fort Collins
Greeley
Loveland
Untitled Placemark
Longmont
Power Station
Large O&G facility
Valmont
Pawnee
Broomfield
Cherokee
Denver
Centennial
Colorado
Castle Rock
© 2016 Google
Image Landsat
Google earth
Tour Guide
Imagery Date: 12/31/1969 lat 39.957179° lon -104.783363° elev 5134 ft eye alt 86.39 mi

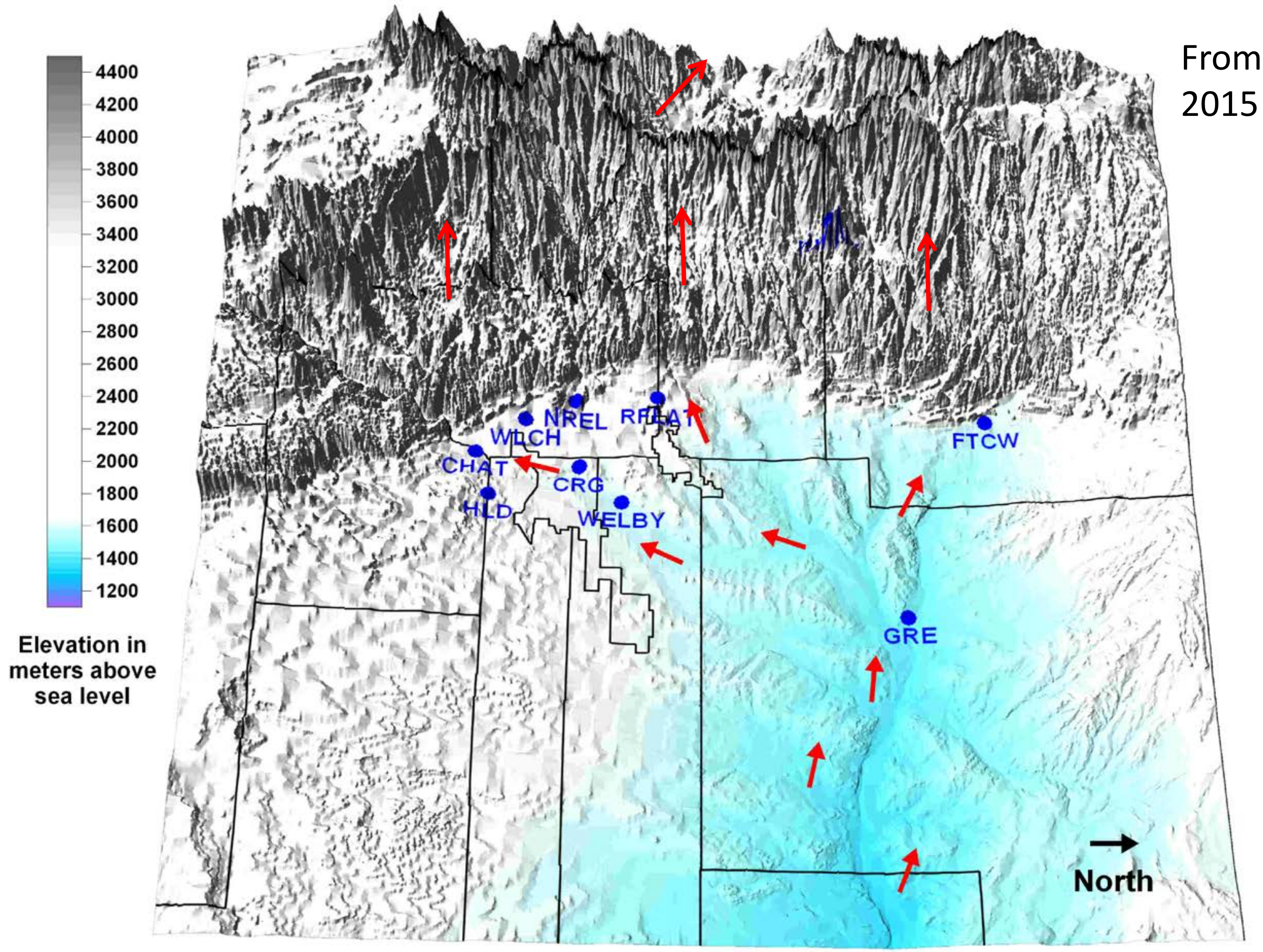
Front Range

- **Very diverse Sources of air pollution**
  - Somewhat separated spatially in some cases, co-located in other cases
  - Different expectations of future growth
  - Emissions difficult to assess
- **Unique, mountain-driven local meteorology**
  - Drives local mixing and transport
  - Recirculation
  - Difficult to simulate

From Reddy et al, 2015

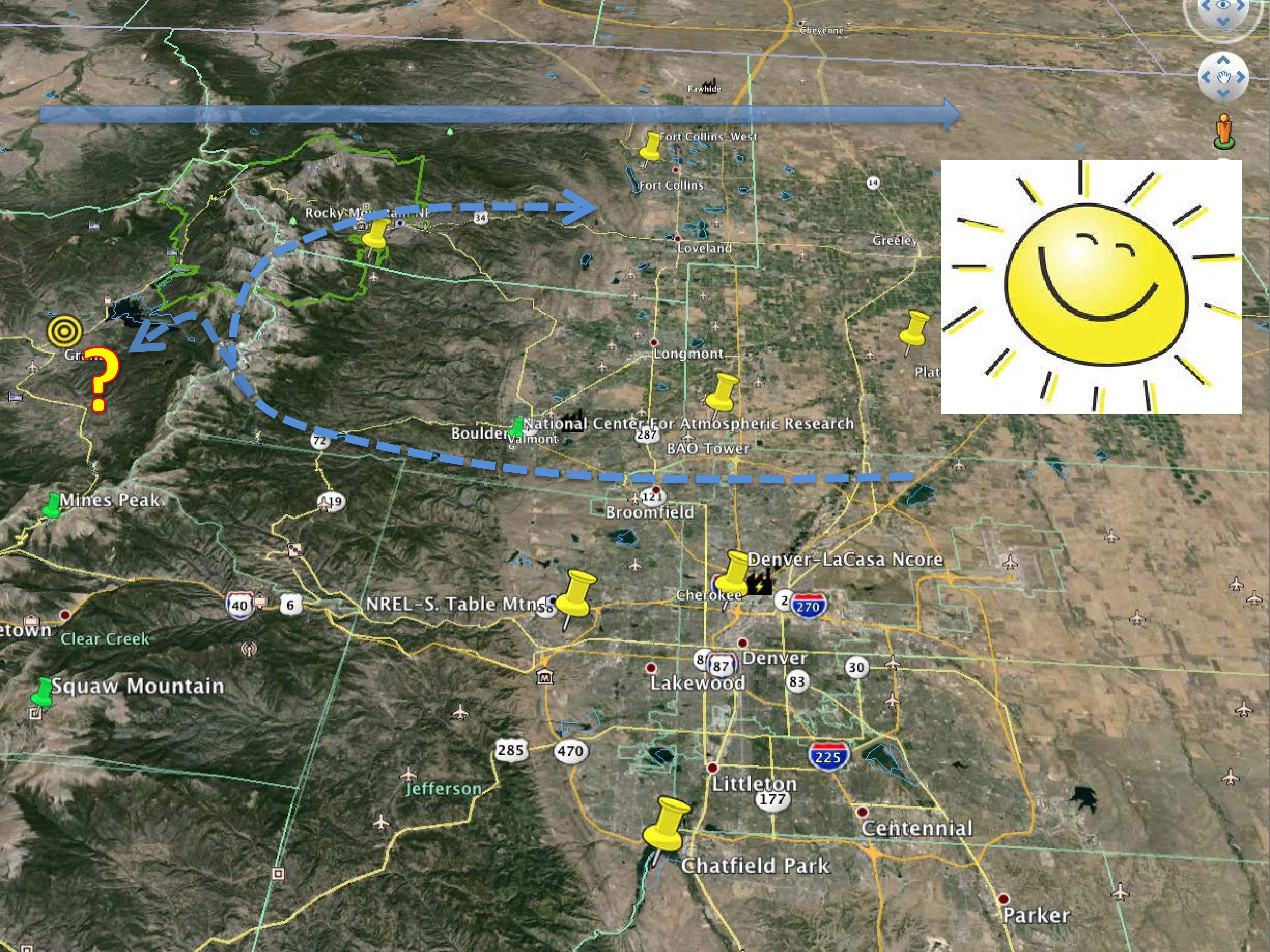


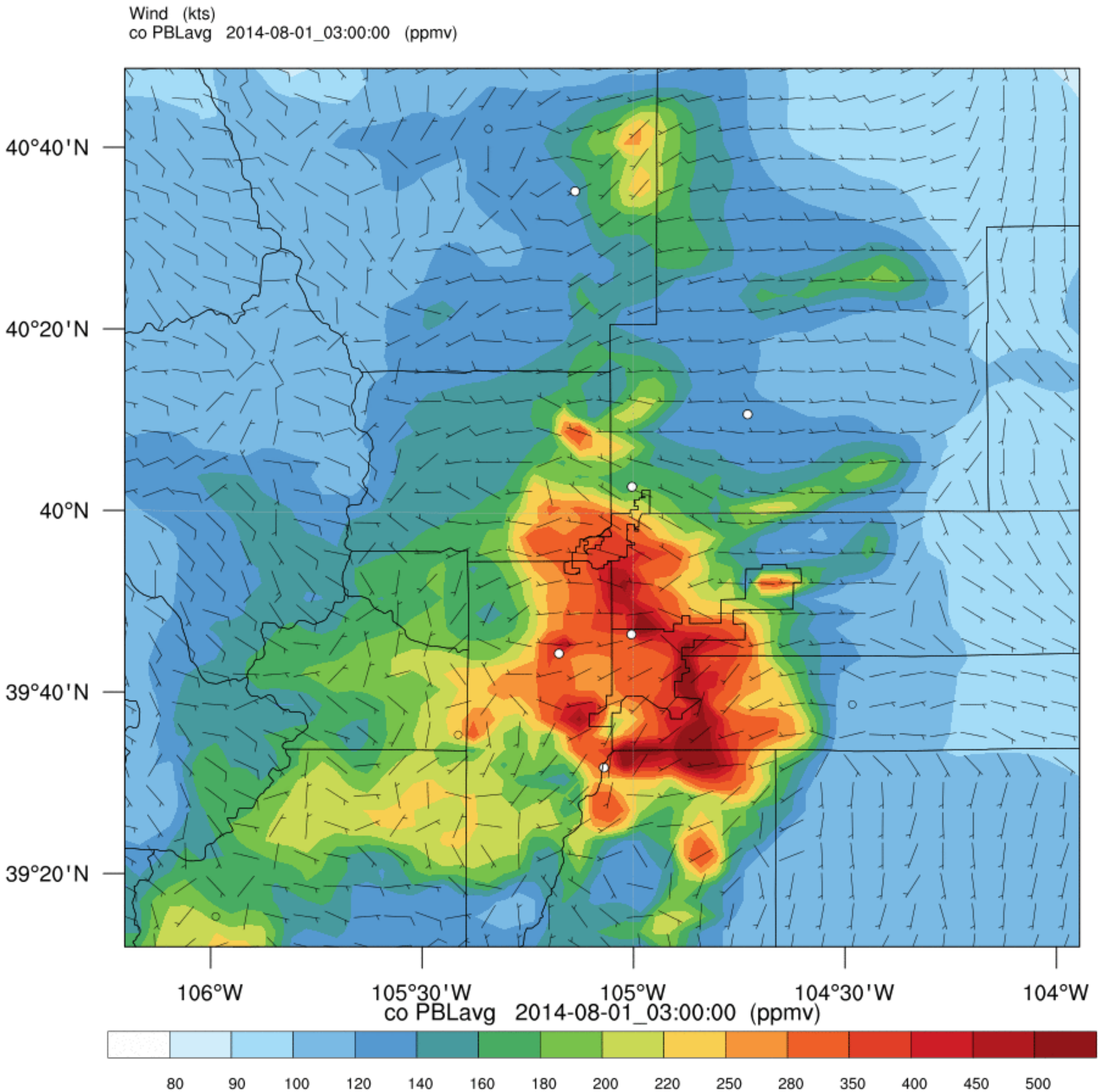
Nighttime drainage winds move cooler air into the low terrain (blue) where it pools within an inversion. Looking west towards Front Range.



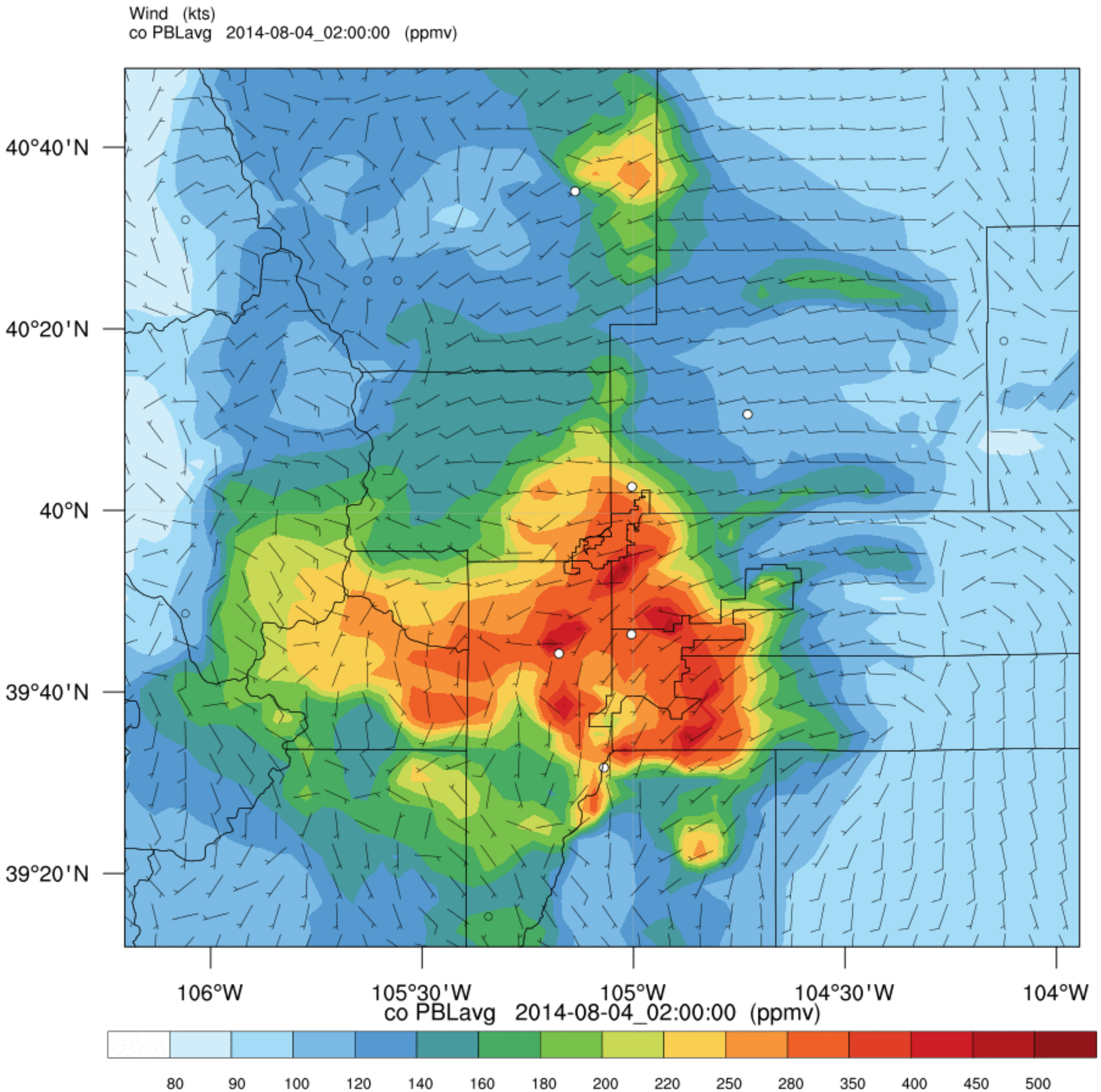
From Reddy et al, 2015

Heating of the higher terrain pulls air and emissions from the lower terrain up-valley during the late morning and afternoon. View to the west.


Cheyenne
Rawhide
Fort Collins-West
Fort Collins
Rocky Mountain NP
Loveland
Greeley
Longmont
Boulder
Valmont
National Center For Atmospheric Research
BAO Tower
Broomfield
Mines Peak
Denver-LaCasa Ncore
Cherokee
NREL-S. Table Mtns
Clear Creek
Squaw Mountain
Denver
Lakewood
Jefferson
Littleton
Centennial
Chatfield Park
Parker

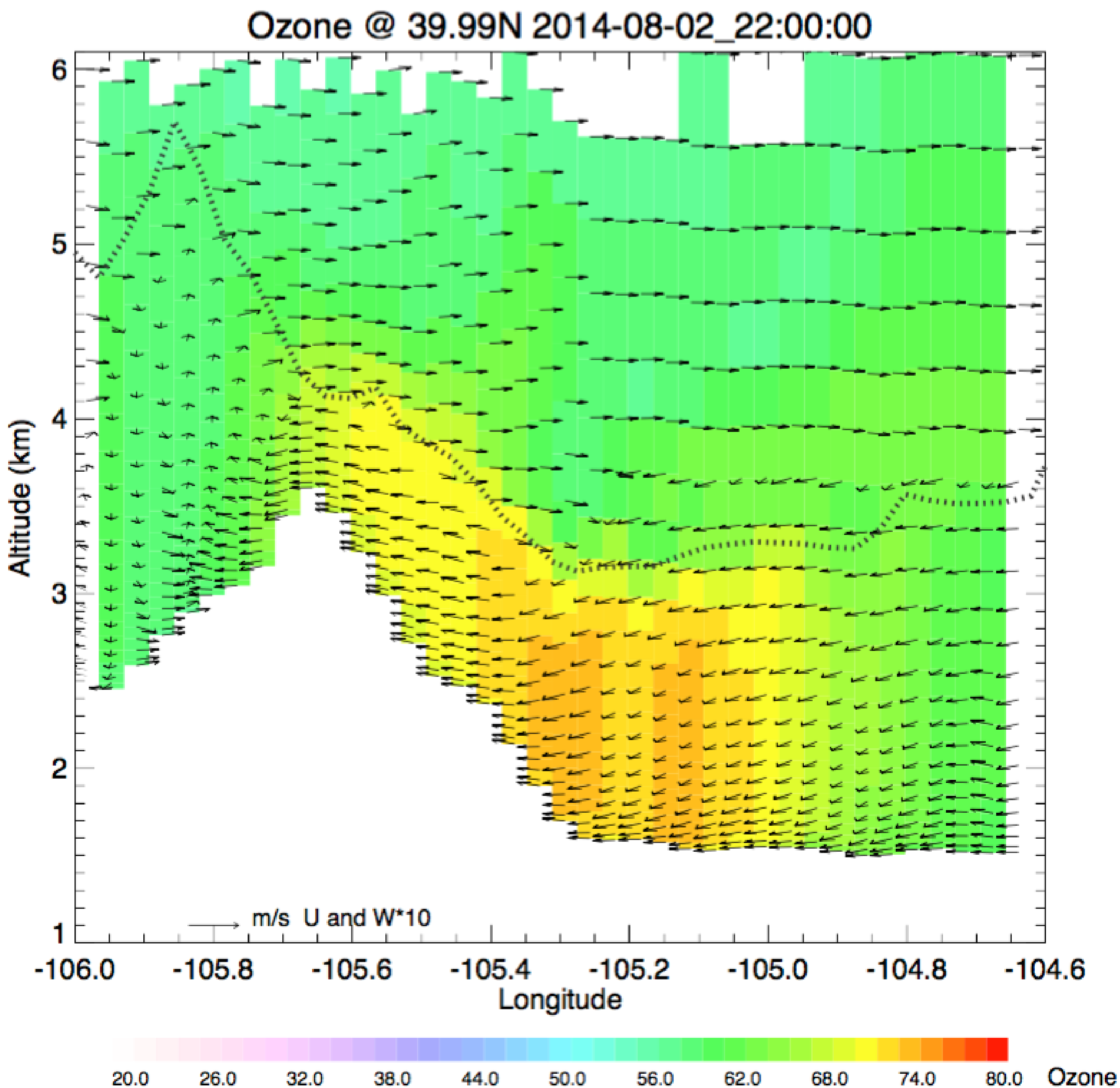


Gabi Pfister, ACOM

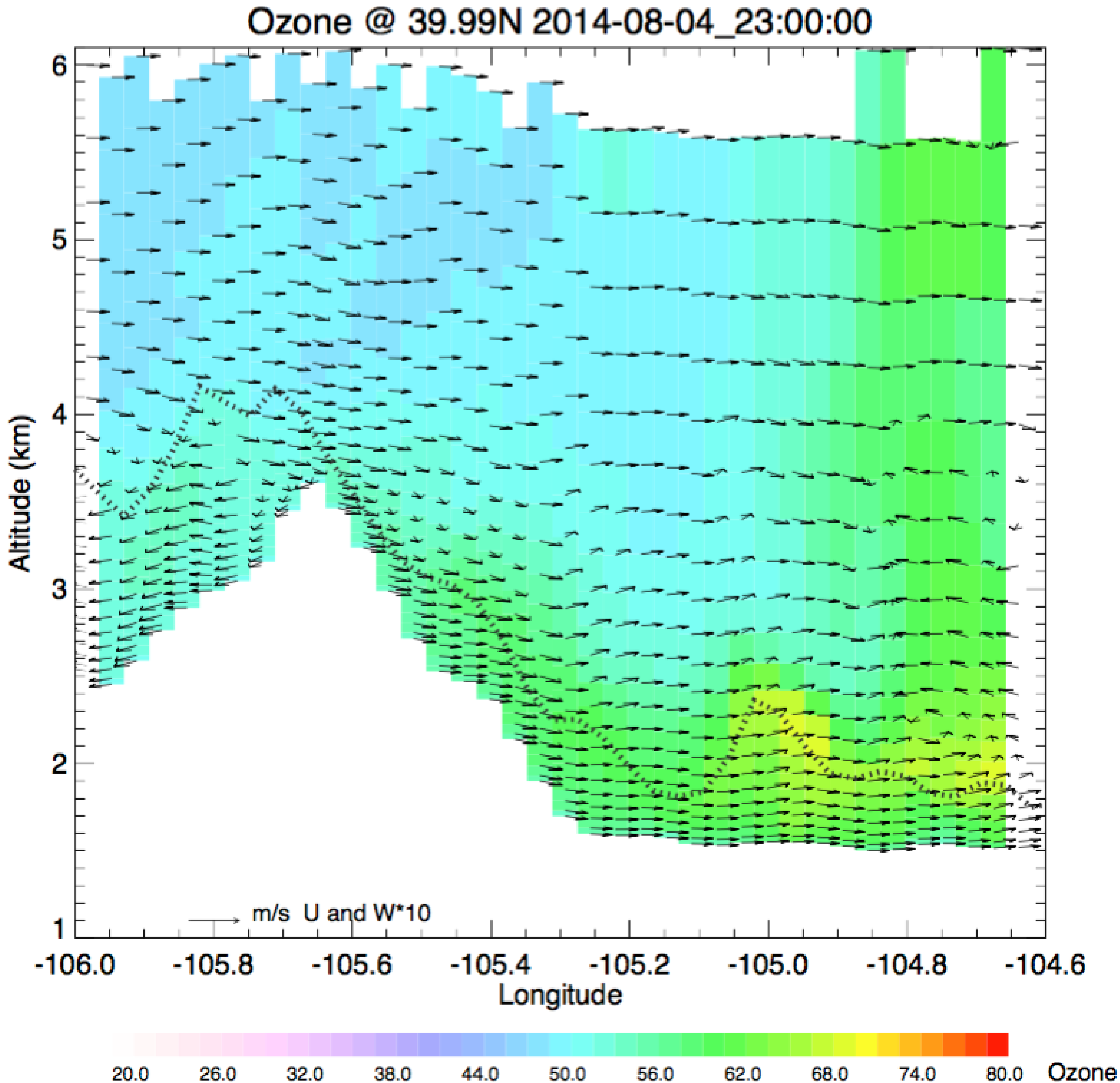


Gabi Pfister, ACOM

Gabi Pfister, ACOM



Gabi Pfister, ACOM



Modeling AQ (in the Front Range)

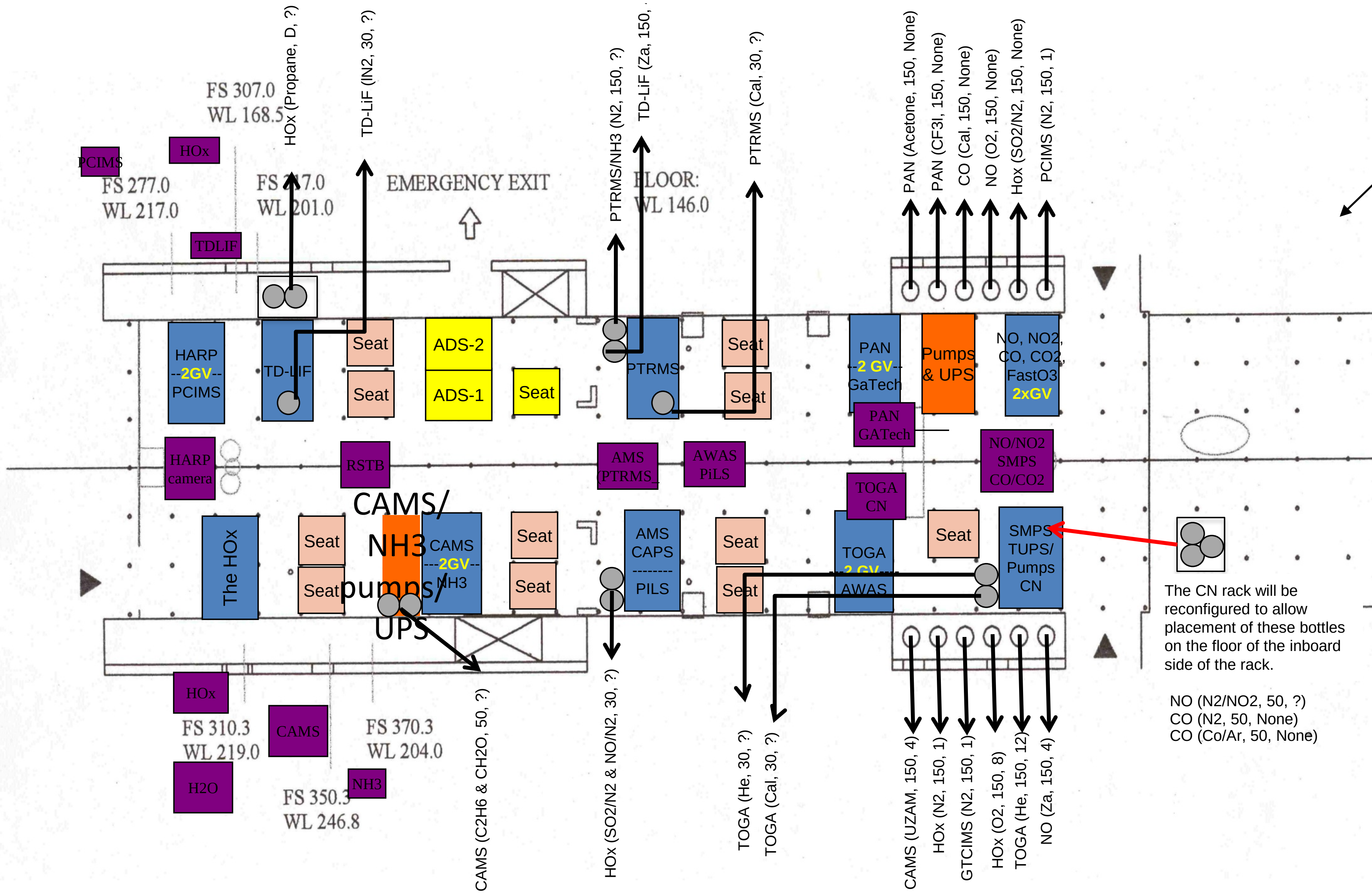
- **In order to adequately simulate Front Range ozone and accurately predict outcomes of possible control strategies, the model must:**
  - Use accurate emissions
  - With accurate diurnal and seasonal variability
  - Distribute these emissions into an accurate boundary layer
  - Predict wind direction and speed, horizontal dispersion and mixing and vertical mixing/dilution with accurate background air
  - Accurately compute the chemical reactions and physical transformations

FRAPPÉ Measurements/Modeling

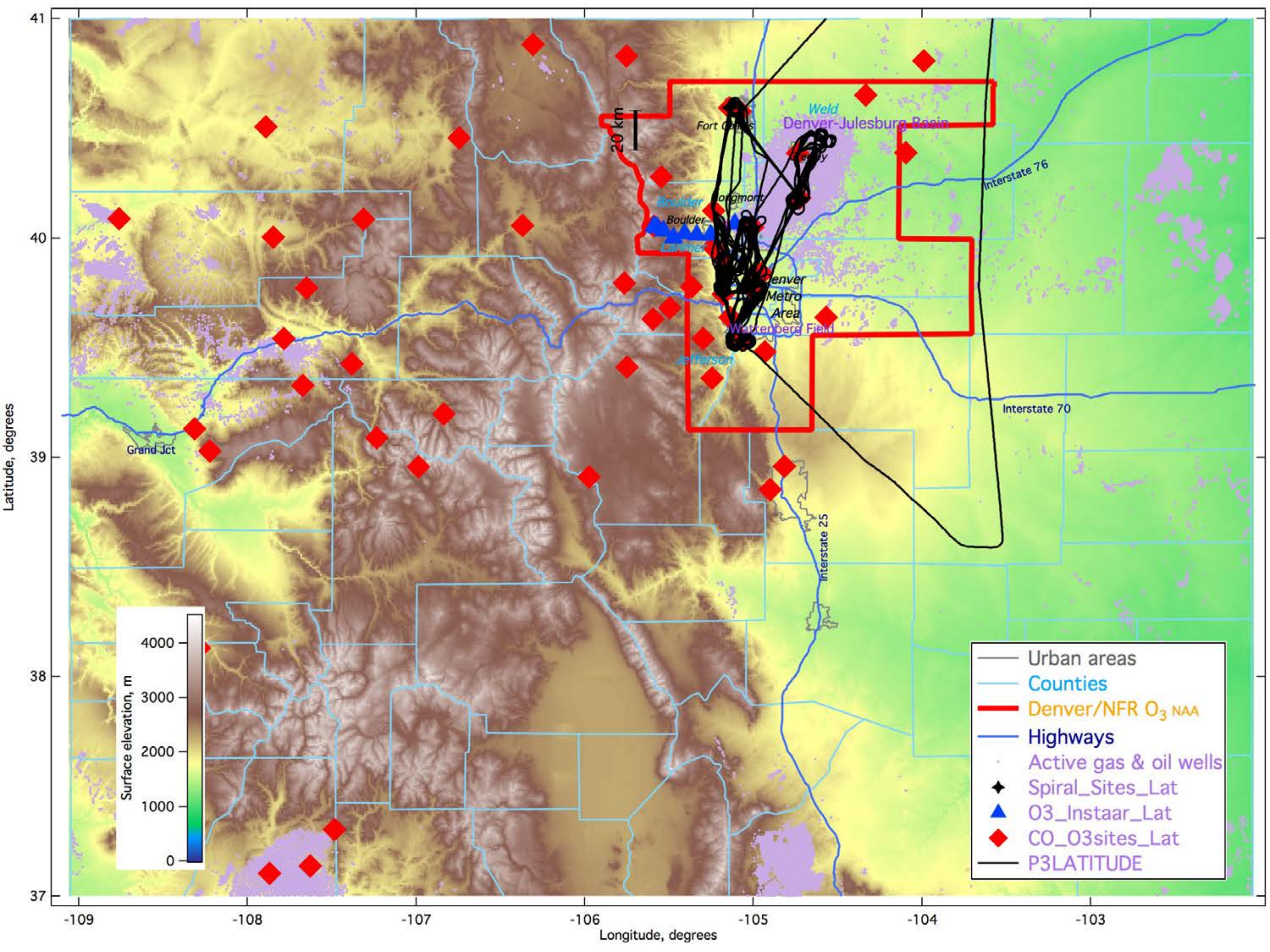
- Aircraft: Ozone, NO, NO_2, HNO_3, HNO_4, PANs, alkyl nitrates, peroxy nitrates, CO, SO_2, CO_2, methane, methane isotopes, NH_3, C_2-C_{10} alkanes, alkenes, alkynes, CH_2O, aldehydes, other oxygenates (over 100 VOC species), CH3CN, HCN, OH, HO_2 and RO_2 radicals, halogenated tracers, particles: number and size distr., type, chemical composition, physical parameters, CN, met. and aircraft state parameters, UV/Vis actinic flux measurements.
- Aircraft with remote sensing instruments
- Satellite data
- Surface Sites/Mobile: Photochemical tracers (depends on site), mobile vans with photochemical and emission tracers, vertical profiles (Erie Tower), column integrated measurements of aerosol parameters, O_3, NO_2, vertically resolved measurements of ozone, particles (LIDAR).
- Modeling: CMAQ and RAQMS, WRF-tracer, WRF-Chem, CAM-Chem, MOZART-4, FlexPart, NOAA HRRR, RAPChem

Key:
Instrument (Gas Type, Cylinder Size, # of Flights Before Changed)

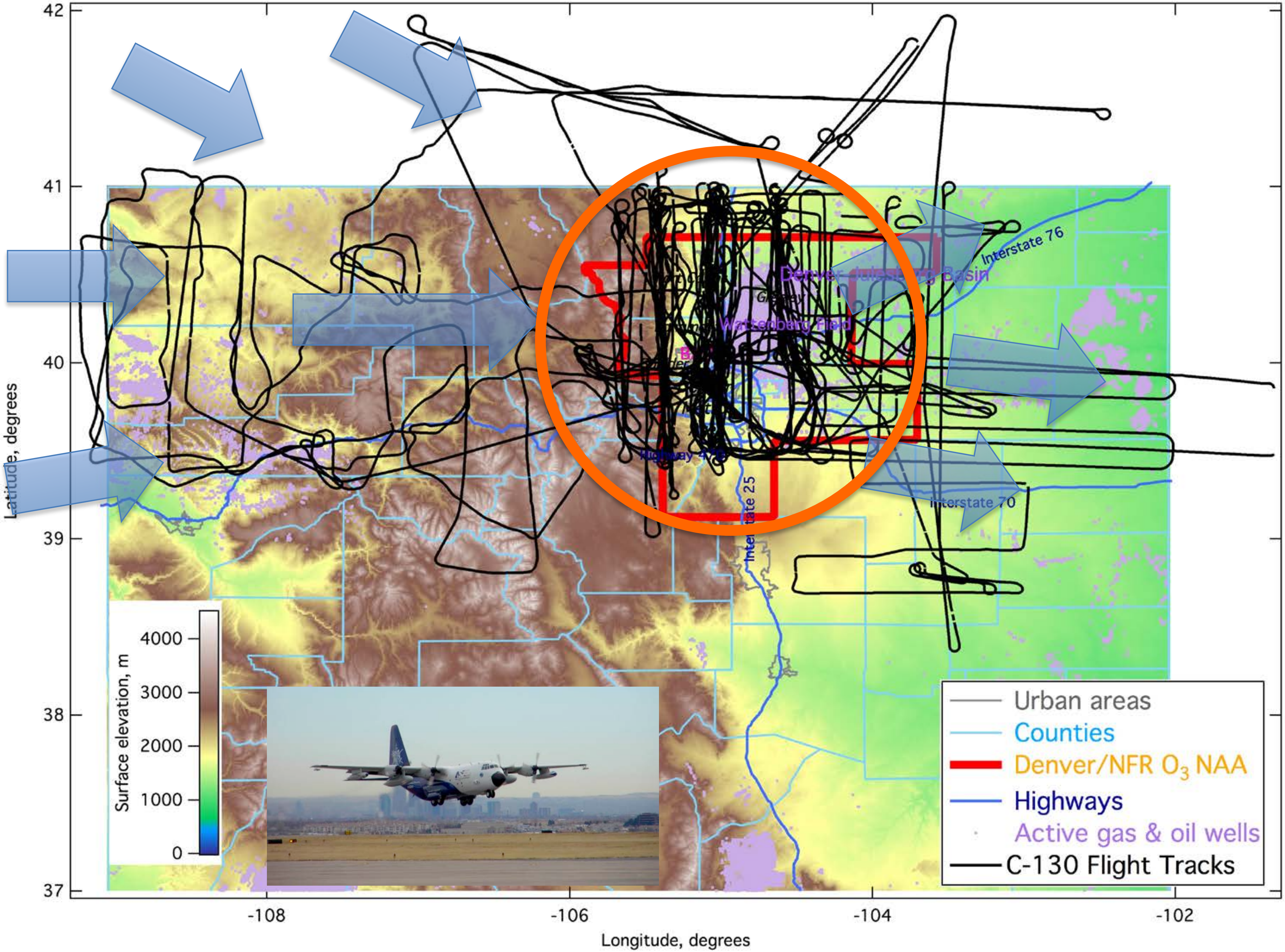
TD-LiF and PTRMS will have small bottles mounted to the tops of their racks.



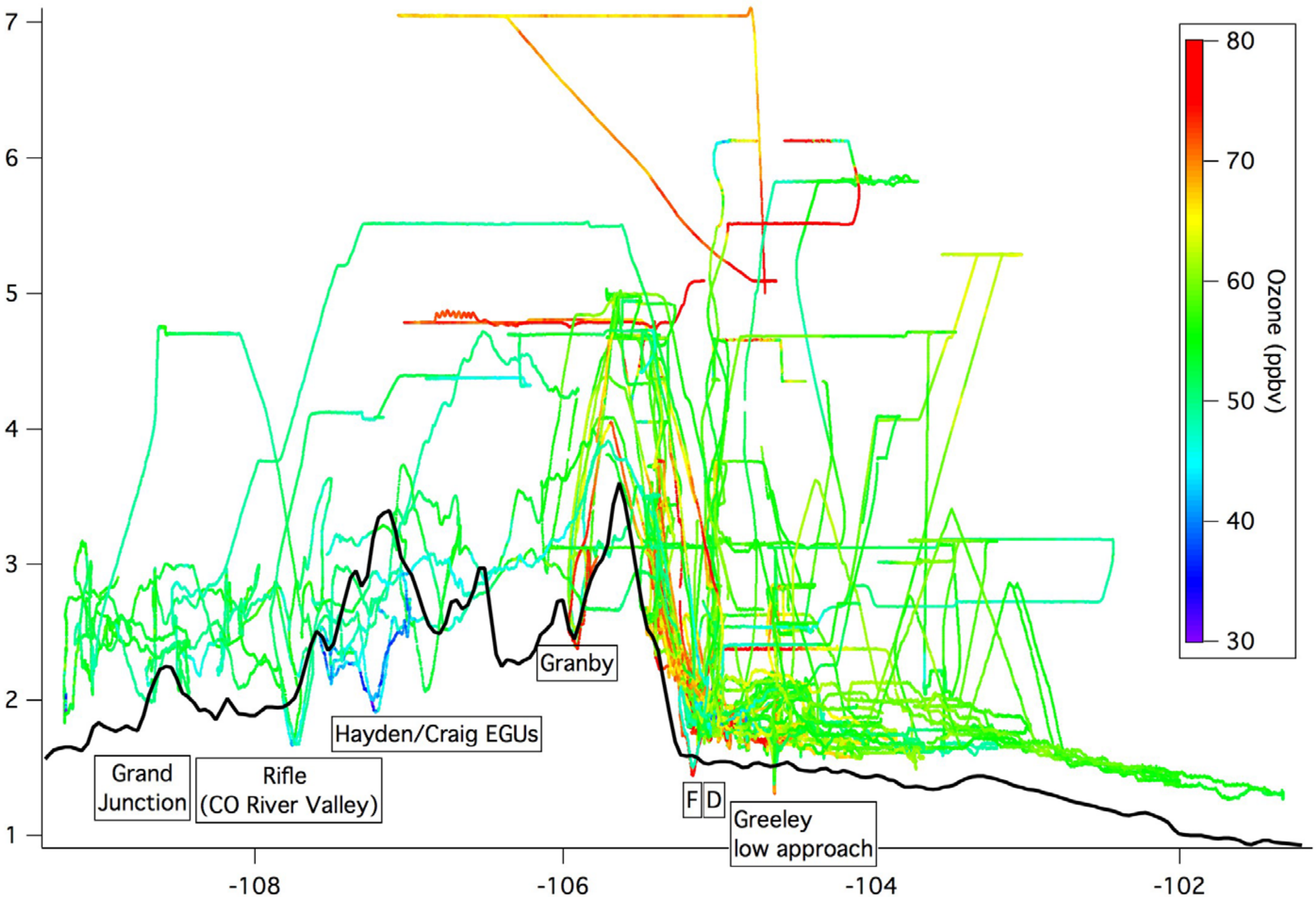
C-130 Payload



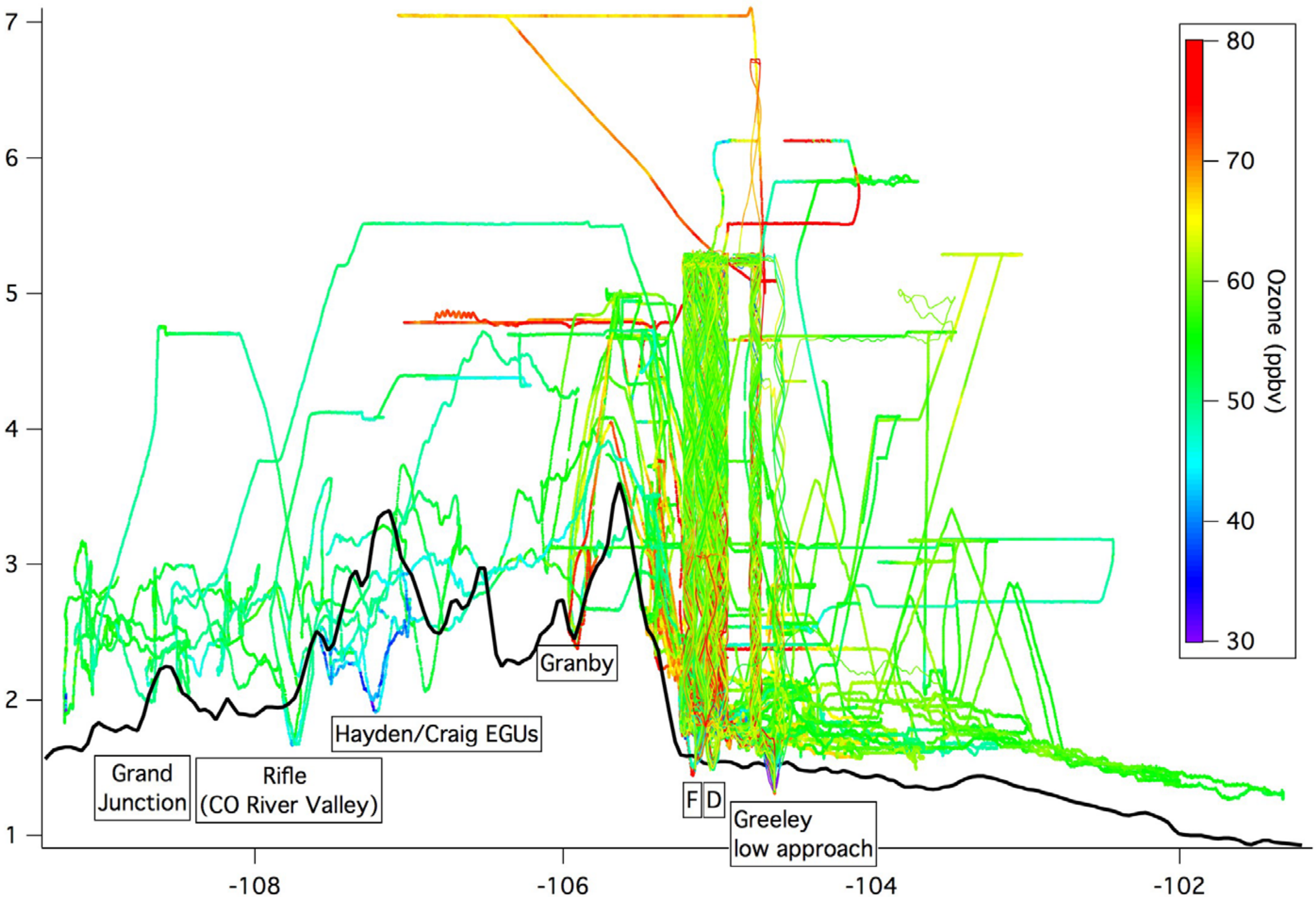
41
40
39
38
37
-109
-108
-107
-106
-105
-104
-103
Latitude, degrees
Longitude, degrees
20 km
Fort Collins
Weld
Denver-Julesburg Basin
Greeley
Interstate 76
Boulder
Longmont
Boulder
Larimer
Denver
Metro
Area
Wattenberg Field
Jefferson
Interstate 70
Grand Jct
Interstate 25
Surface elevation, m
4000
3000
2000
1000
0
Urban areas
Counties
Denver/NFR O3 NAA
Highways
Active gas & oil wells
Spiral_Sites_Lat
O3_Instaar_Lat
CO_O3sites_Lat
P3LATITUDE



42
41
40
39
38
37
Latitude, degrees
-108
-106
-104
-102
Longitude, degrees
Interstate 76
Denver-Julesburg Basin
Greeley
Wattenberg Field
Highway 470
Interstate 25
Interstate 70
Surface elevation, m
4000
3000
2000
1000
0
Urban areas
Counties
Denver/NFR O_3 NAA
Highways
Active gas & oil wells
C-130 Flight Tracks



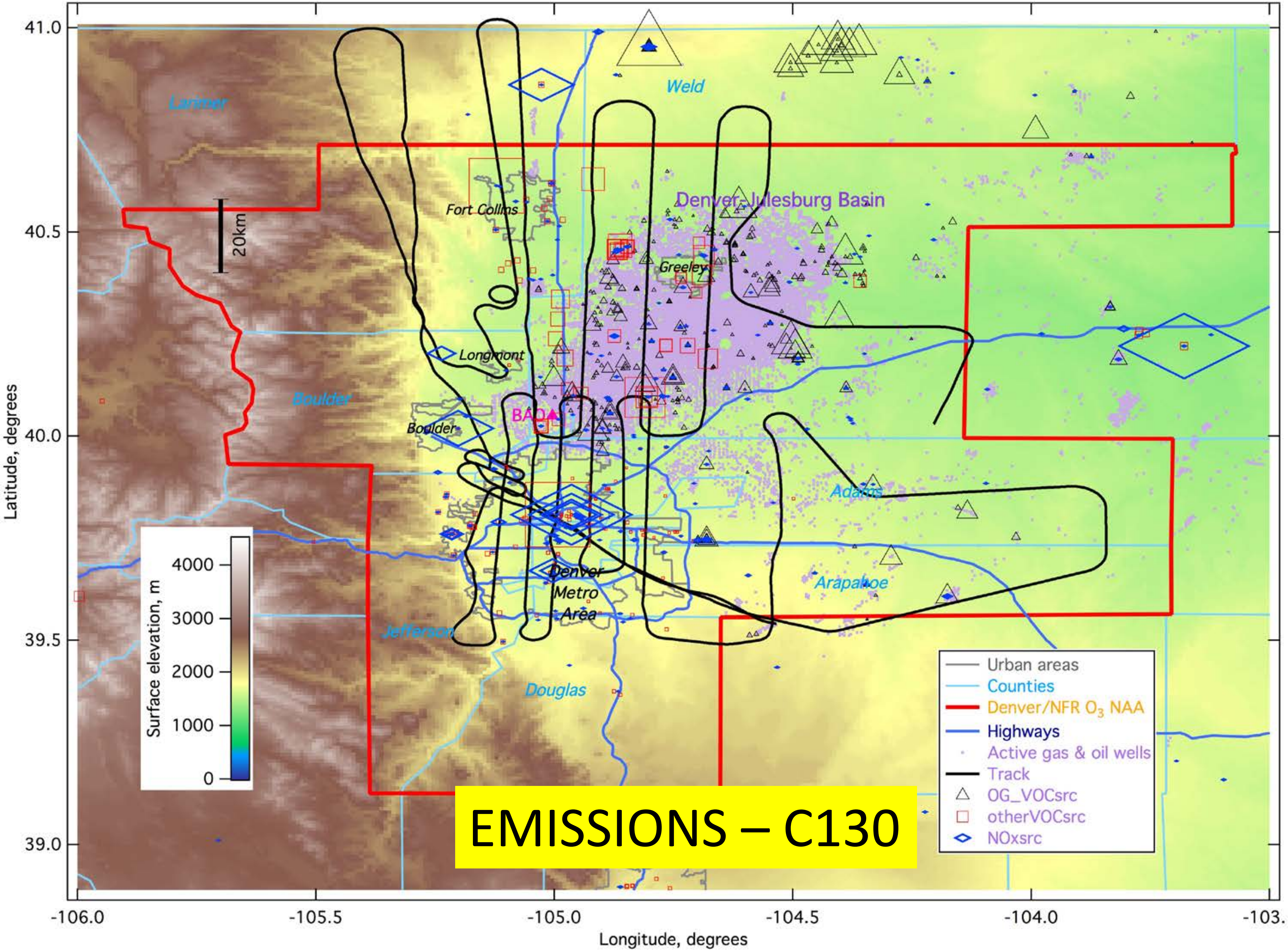
7
6
5
4
3
2
1
-108
-106
-104
-102
80
70
60
50
40
30
Ozone (ppbv)
Granby
Hayden/Craig EGUs
Grand Junction
Rifle (CO River Valley)
F
D
Greeley low approach



7
6
5
4
3
2
1
-108
-106
-104
-102
Grand Junction
Rifle (CO River Valley)
Hayden/Craig EGUs
Granby
F
D
Greeley low approach
80
70
60
50
40
30
Ozone (ppbv)

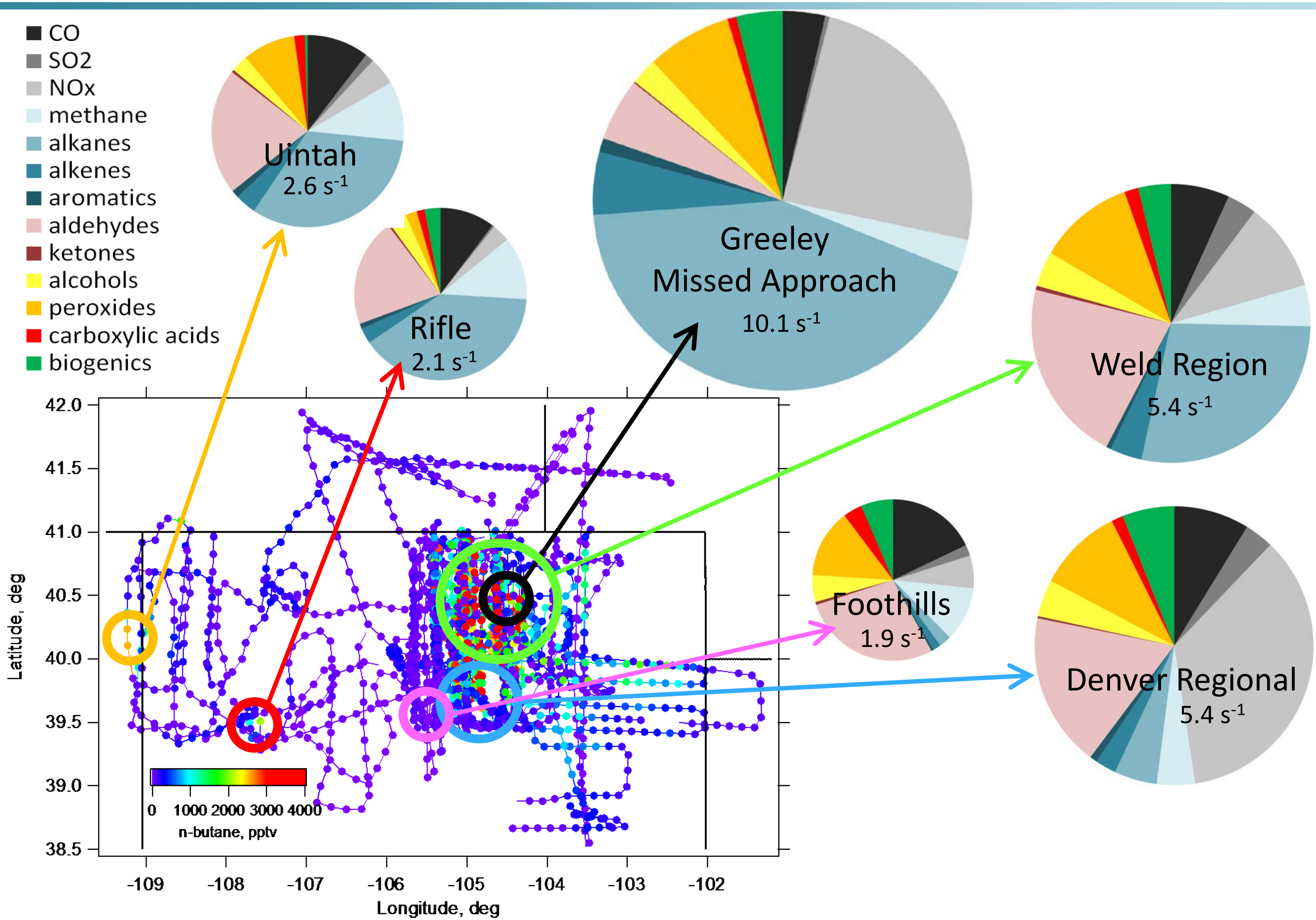
Modeling AQ (in the Front Range)

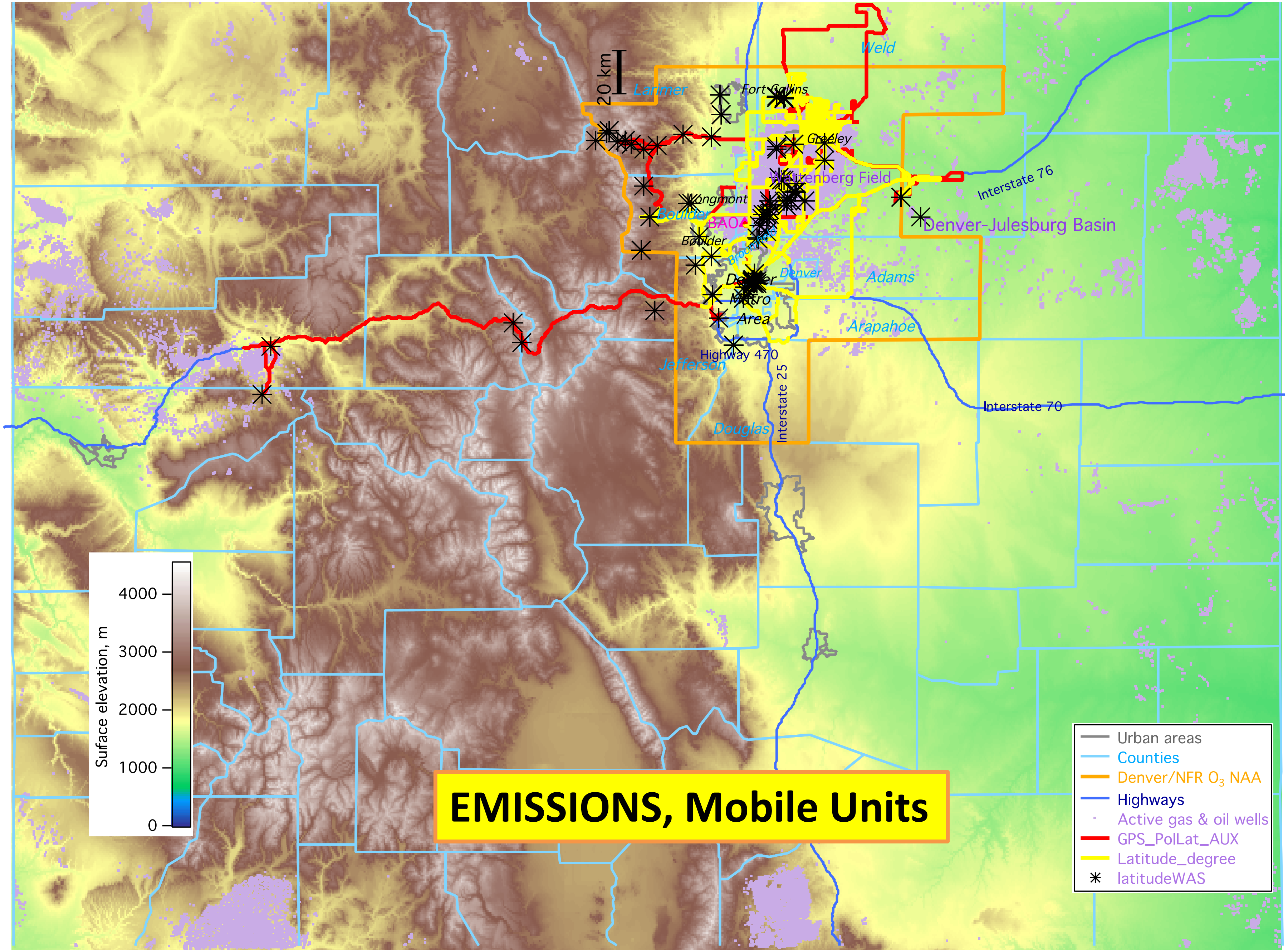
- **In order to adequately simulate Front Range ozone and accurately predict outcomes of possible control strategies, the model must:**
  - Use accurate emissions
  - With accurate diurnal and seasonal variability
  - Distribute these emissions into an accurate boundary layer
  - Predict wind direction and speed, horizontal dispersion and mixing and vertical mixing/dilution with accurate background air
  - Accurately compute the chemical reactions and physical transformations



41.0
40.5
40.0
39.5
39.0
Latitude, degrees
-106.0
-105.5
-105.0
-104.5
-104.0
-103.
Longitude, degrees
Larimer
Weld
Boulder
Jefferson
Douglas
Adams
Arapahoe
Fort Collins
Longmont
Boulder
Greeley
BAO
Denver Metro Area
Denver-Julesburg Basin
20km
Surface elevation, m
4000
3000
2000
1000
0
Urban areas
Counties
Denver/NFR O_3 NAA
Highways
Active gas & oil wells
Track
OG_VOCsrc
otherVOCsrc
NOxsrc
EMISSIONS – C130

Calculated OH Reactivity by FRAPPÉ region





EMISSIONS, Mobile Units
Weld
Larimer
20 km
Fort Collins
Greeley
Wattenberg Field
Interstate 76
Denver-Julesburg Basin
Longmont
Boulder
BAO
Boulder
Denver
Adams
Denver Metro Area
Arapahoe
Highway 470
Jefferson
Interstate 25
Interstate 70
Douglas
Suface elevation, m
4000
3000
2000
1000
0
Urban areas
Counties
Denver/NFR O_3 NAA
Highways
Active gas & oil wells
GPS_PolLat_AUX
Latitude_degree
latitudeWAS

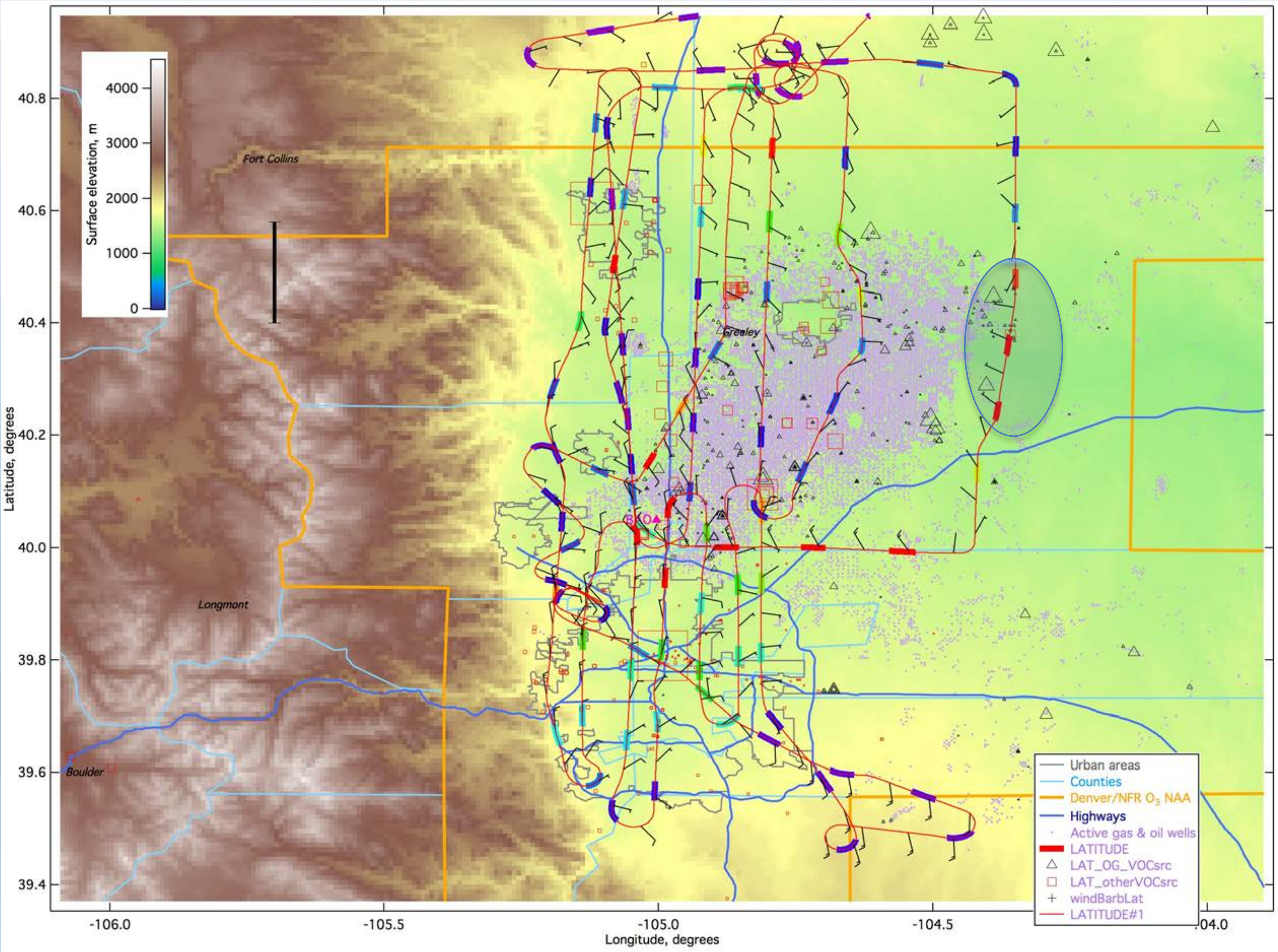
Mobile Ground Sample (Weld County)

Alkanes:
Propane 150 ppb
Butane 425 ppb
Pentanes 700 ppb
Hexanes 900+ ppb

Benzene 65 ppb

“strong smell”

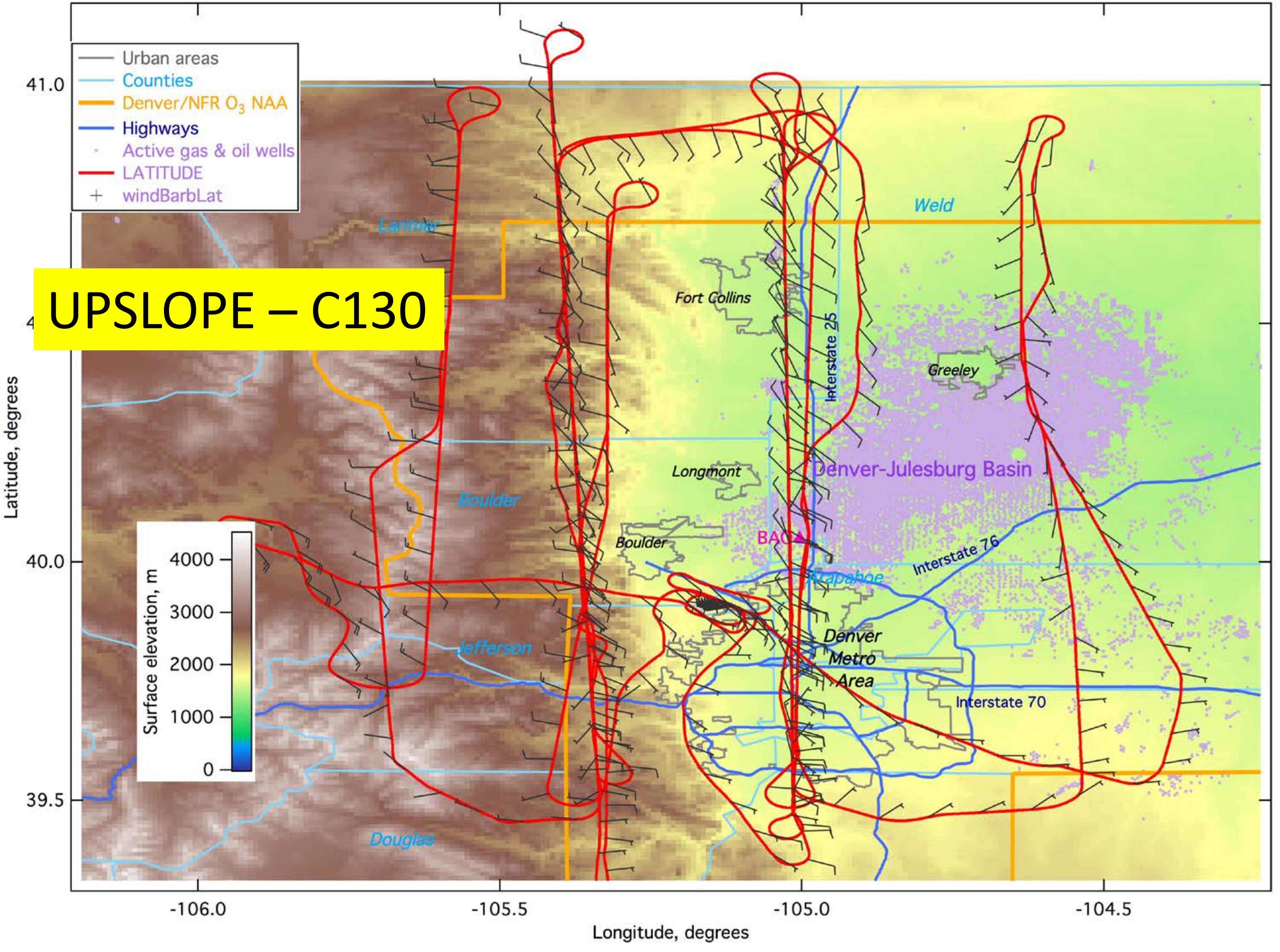
Find good model / data comparison cases

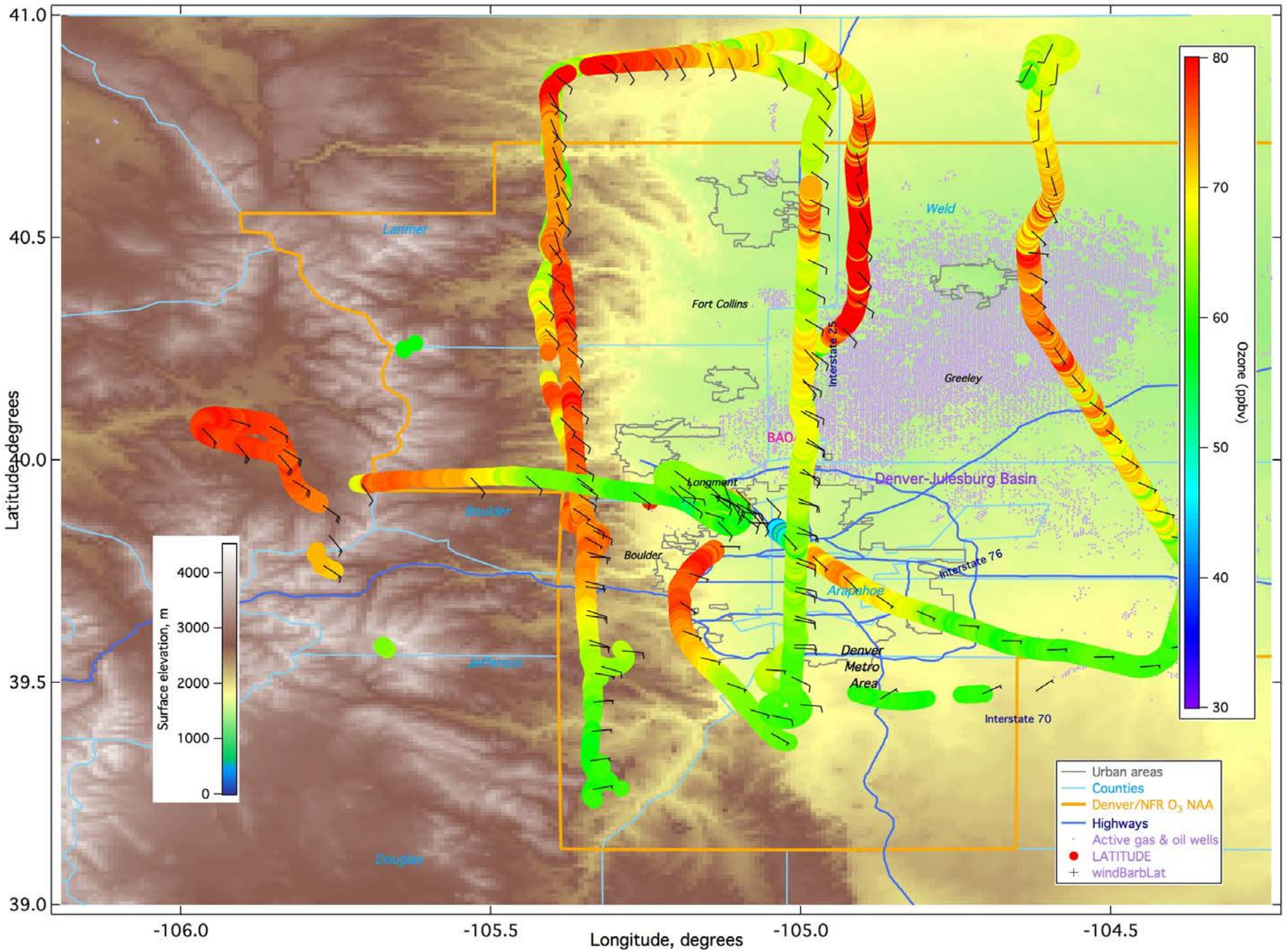


Modeling AQ (in the Front Range)

- **In order to adequately simulate Front Range ozone and accurately predict outcomes of possible control strategies, the model must:**
  - Use accurate emissions
  - With accurate diurnal and seasonal variability
  - Distribute these emissions into an accurate boundary layer
  - Predict wind direction and speed, horizontal dispersion and mixing and vertical mixing/dilution with accurate background air
  - Accurately compute the chemical reactions and physical transformations

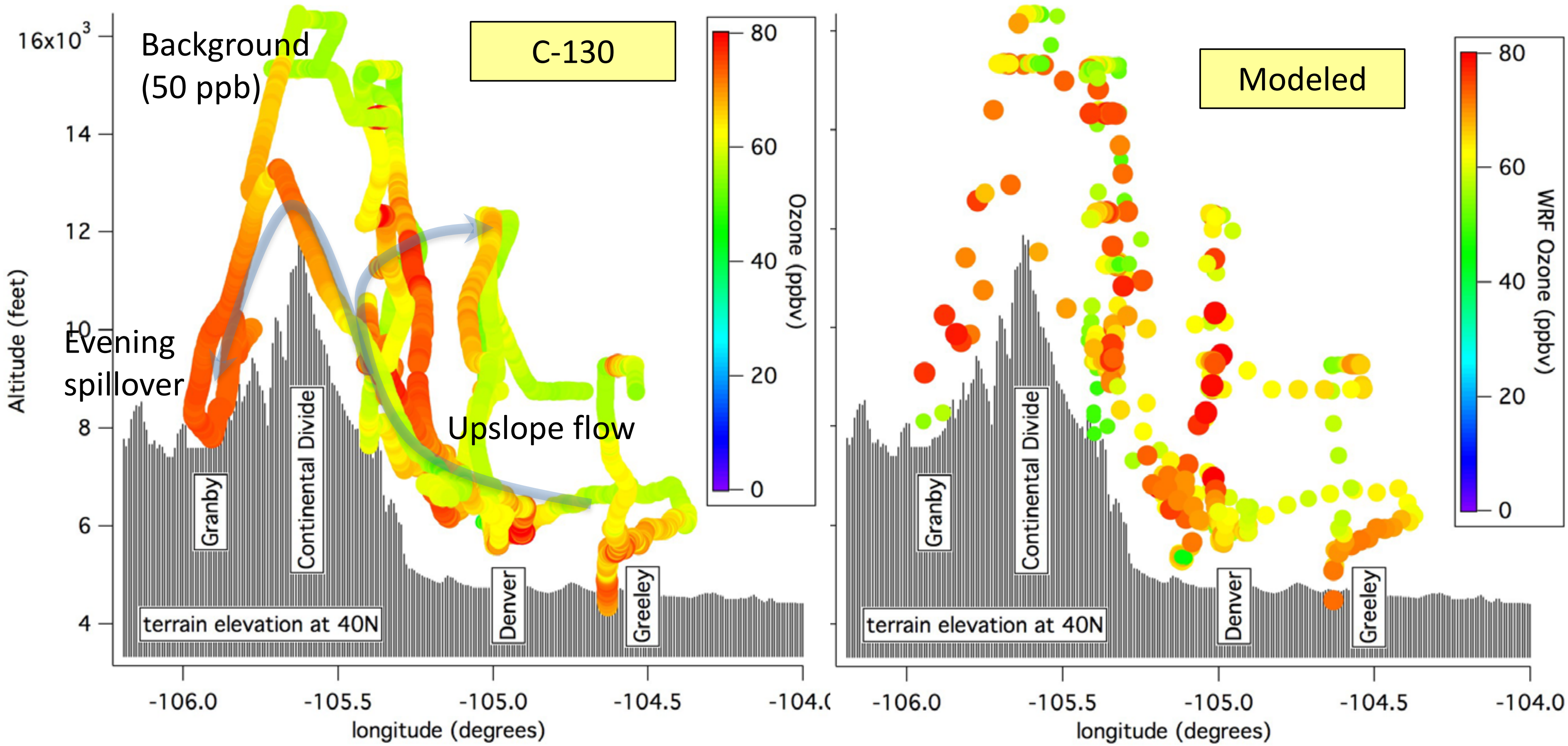
UPSLOPE – C130





41.0
40.5
40.0
39.5
39.0
Latitude, degrees
-106.0
-105.5
-105.0
-104.5
Longitude, degrees
Larimer
Weld
Fort Collins
Interstate 25
Greeley
BAO
Longmont
Denver-Julesburg Basin
Boulder
Interstate 76
Arapahoe
Jefferson
Denver
Metro
Area
Interstate 70
Douglas
Surface elevation, m
4000
3000
2000
1000
0
Ozone (ppbv)
80
70
60
50
40
30
Urban areas
Counties
Denver/NFR O_3 NAA
Highways
Active gas & oil wells
LATITUDE
windBarbLat

Ozone Transport into the Mountains



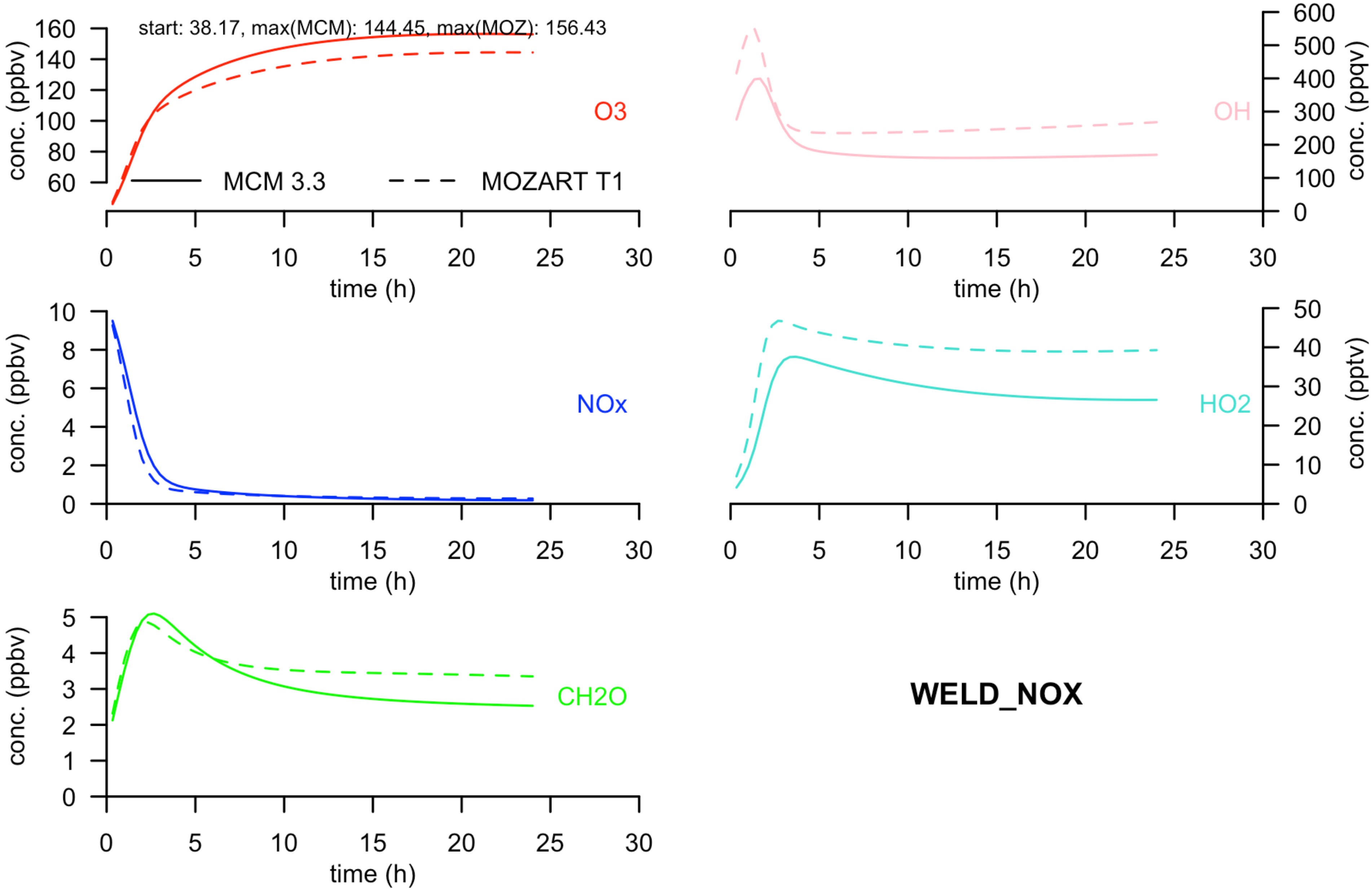
The Figures highlight the transport event for ozone - produced over the Front Range and being pushed westward into the mountains by thermally driven upslope. This demonstrates how Front Range ozone can impact remote areas up to the divide and into the adjacent valleys on the west side of the divide. WRF captures this transport nicely.

12 August 2014

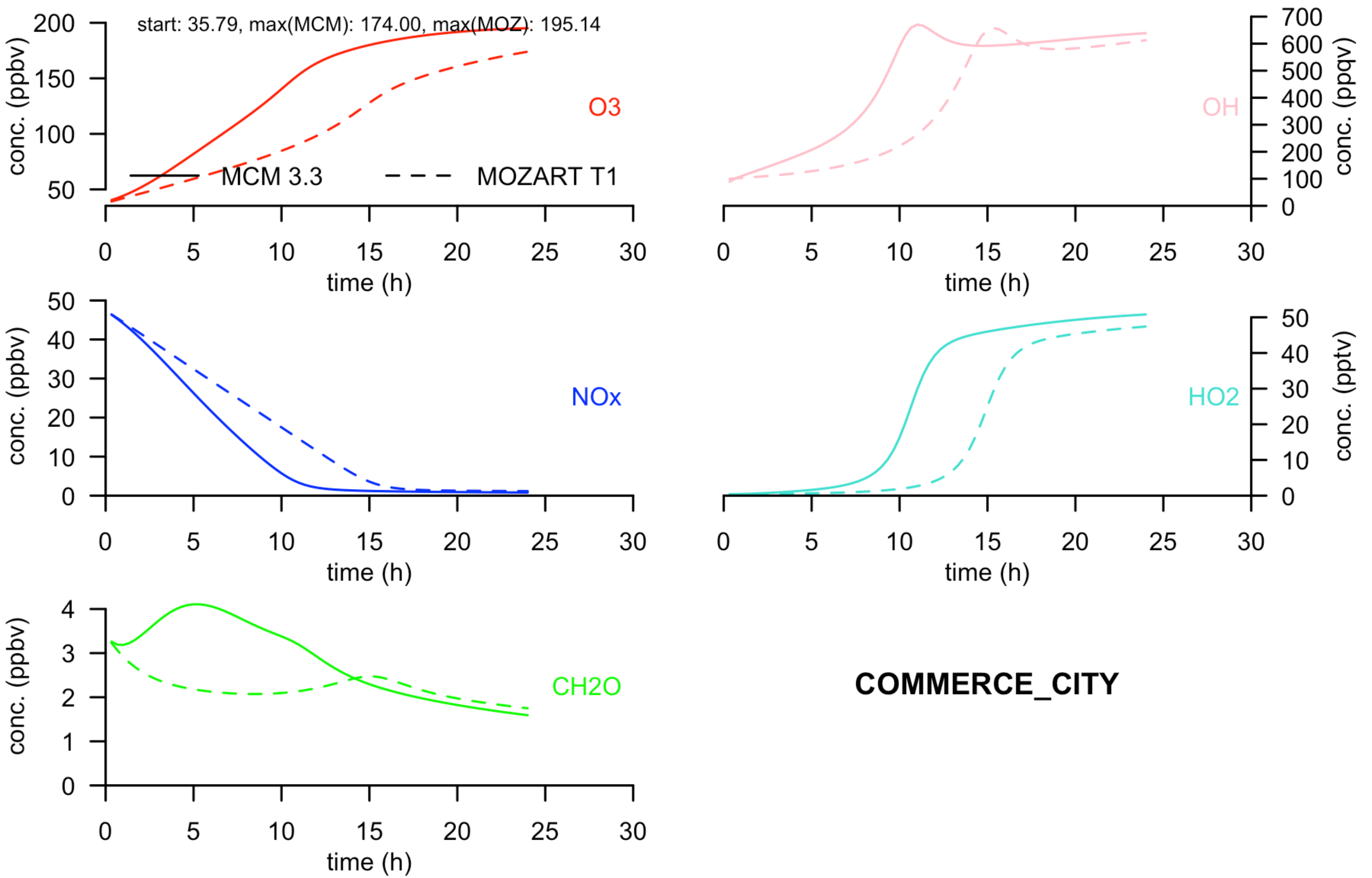
Modeling AQ (in the Front Range)

- **In order to adequately simulate Front Range ozone and accurately predict outcomes of possible control strategies, the model must:**
  - Use accurate emissions
  - With accurate diurnal and seasonal variability
  - Distribute these emissions into an accurate boundary layer
  - Predict wind direction and speed, horizontal dispersion and mixing and vertical mixing/dilution with accurate background air
  - Accurately compute the chemical reactions and physical transformations

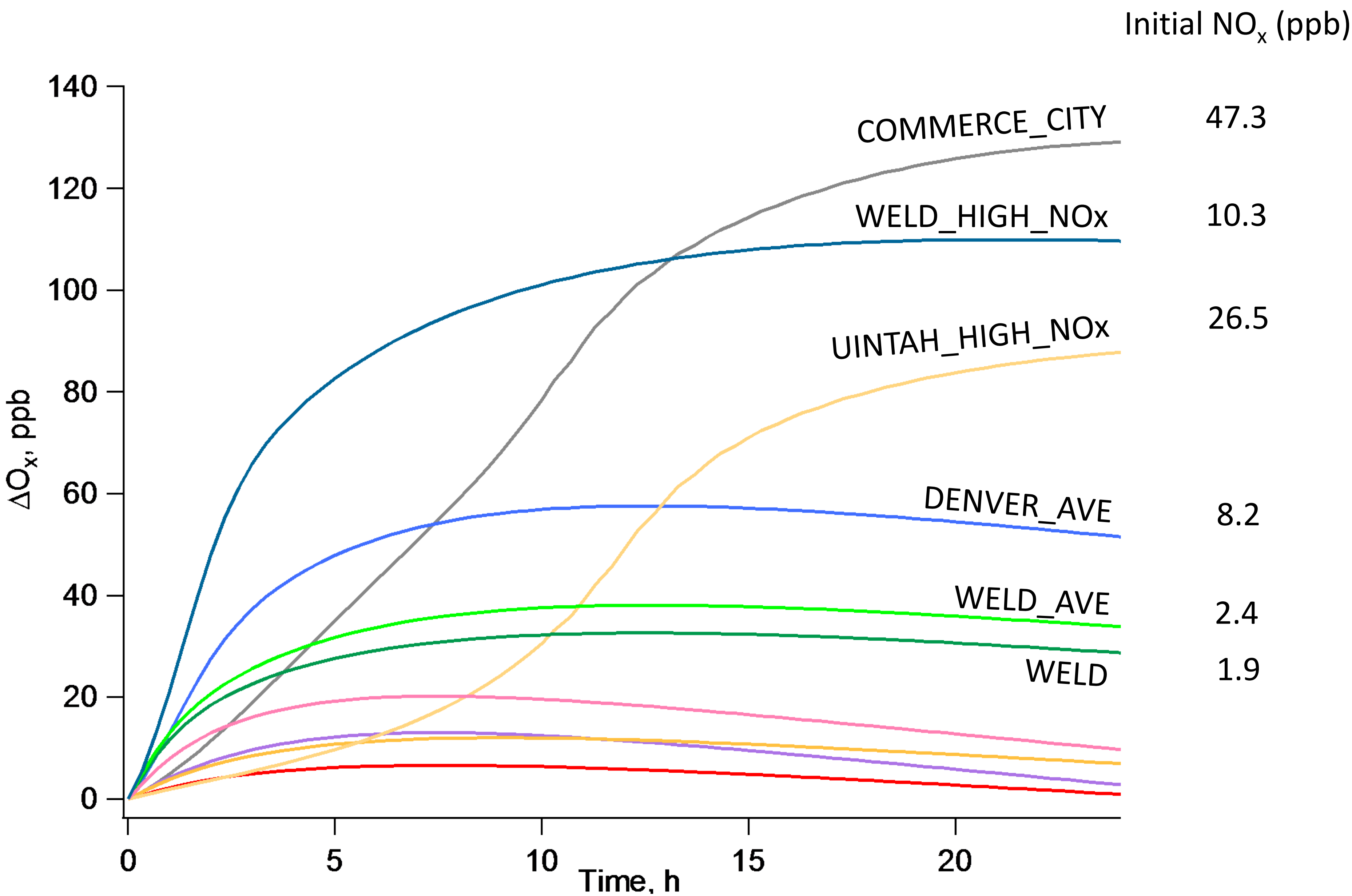
Chemical mechanism comparison - Weld County / Greeley case



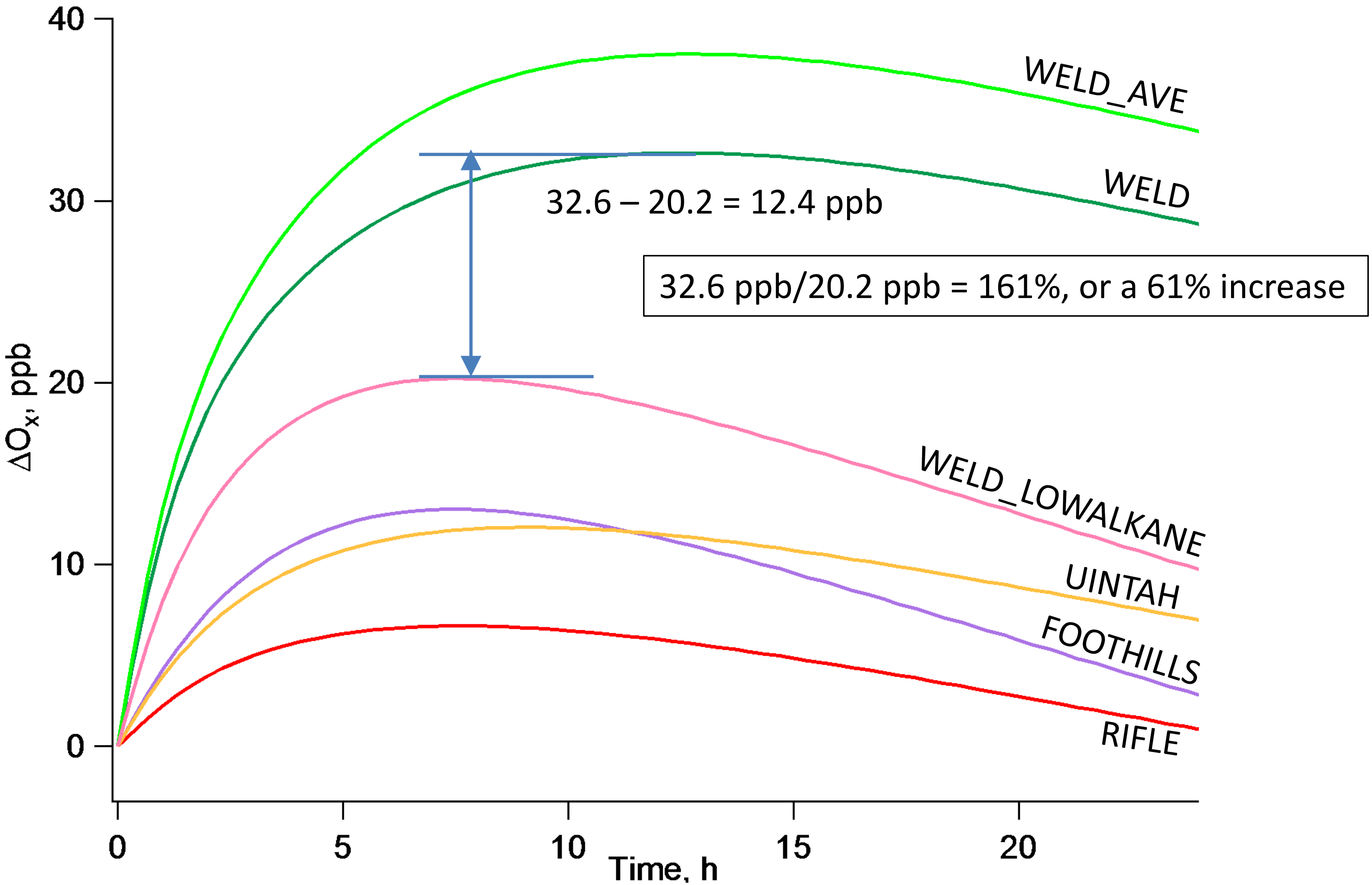
Chemical mechanism comparison – Commerce City case

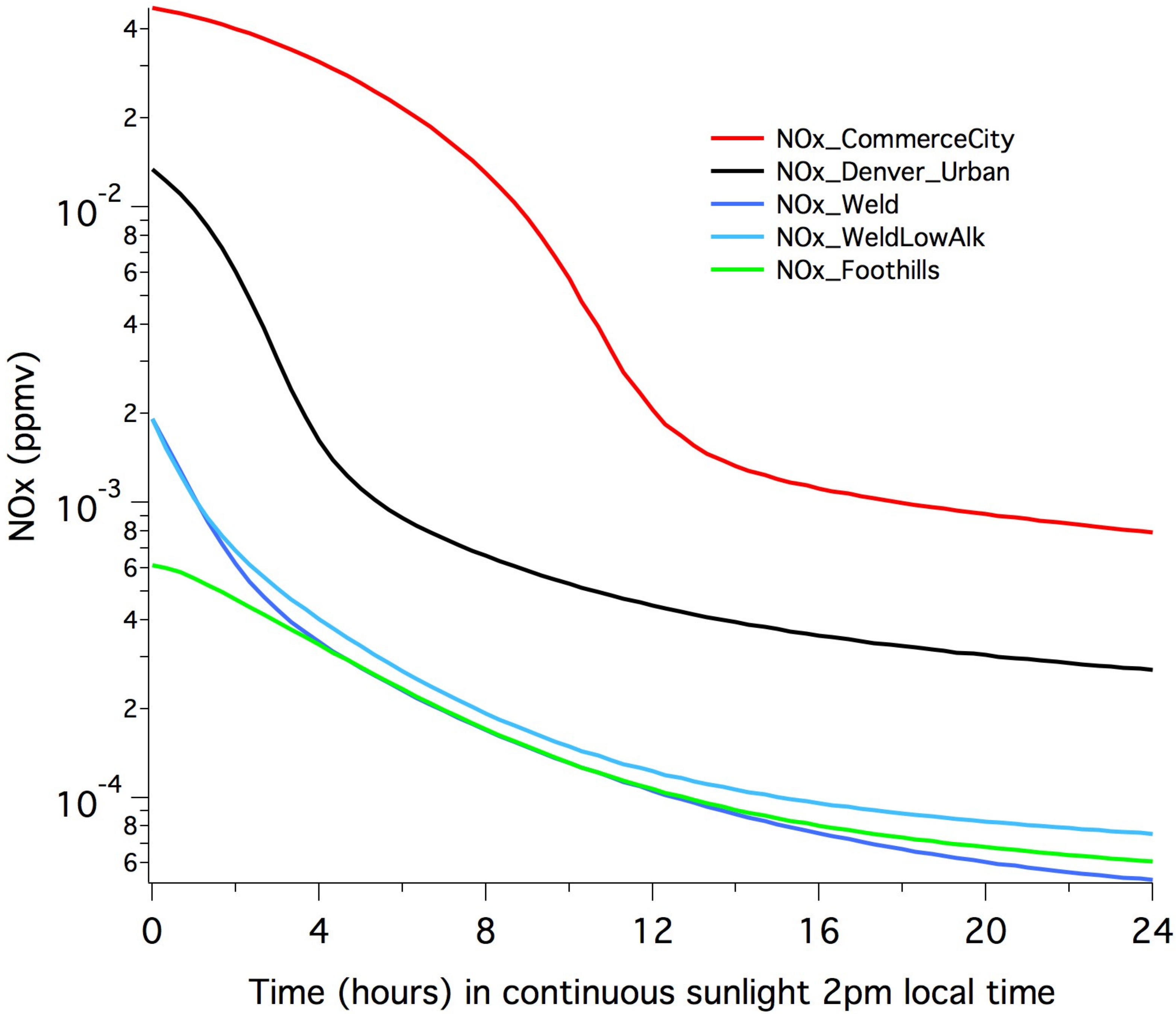


BOXMOX Model – Ozone Production Potential



BOXMOX Model – Ozone Production Potential (Low NO_x runs)





NOx_CommerceCity
NOx_Denver_Urban
NOx_Weld
NOx_WeldLowAlk
NOx_Foothills
NOx (ppmv)
4
2
10^-2
8
6
4
2
10^-3
8
6
4
2
10^-4
8
6
0
4
8
12
16
20
24
Time (hours) in continuous sunlight 2pm local time

Thank you.