

# Optical Remote Sensing with Differential Asorption Lidar (DIAL)

## Part 2: System Design and Applications

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<http://www.esrl.noaa.gov/csd/groups/csd3/>

Guest lecture for ASEN-6365 Lidar Remote Sensing  
CU Boulder

April 22, 2016

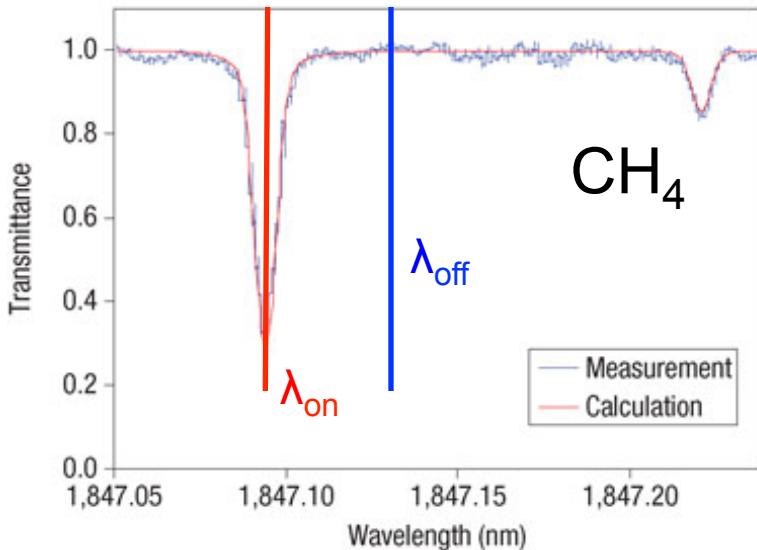
# Outline

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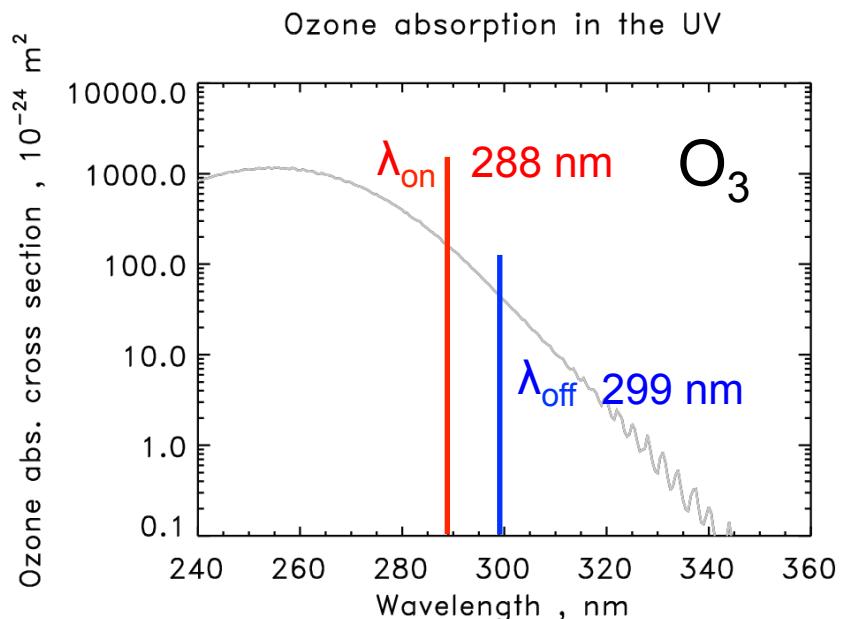
- DIAL system components
- DIAL instruments at NOAA/ESRL
- Applications of NOAA's ozone DIAL

# DIAL system components: Transmitter (1)

## Narrow absorption line



## Broad absorption feature



- $\Delta\lambda \approx 50 \text{ pm}$
- No correction for differential backscatter or extinction needed
- Transmit laser needs to be tunable
- High frequency stability, narrow bandwidth, high spectral purity

- $\Delta\lambda = \text{several nm}$
- Correction for differential backscatter or extinction necessary
- Fixed wavelength lasers OK
- High frequency stability, narrow bandwidth, high spectral purity not needed

## DIAL system components: Transmitter (2)

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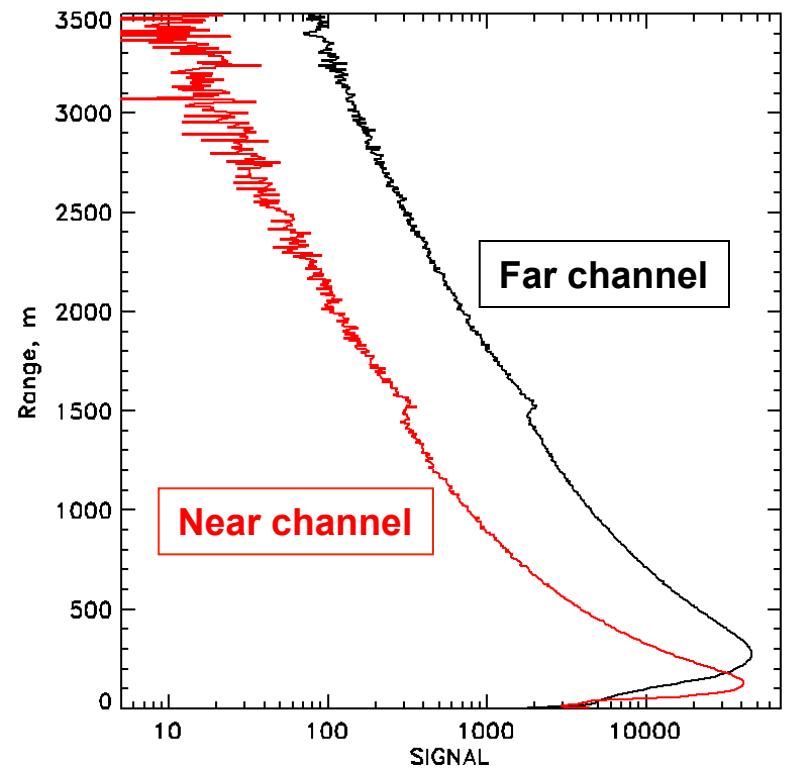
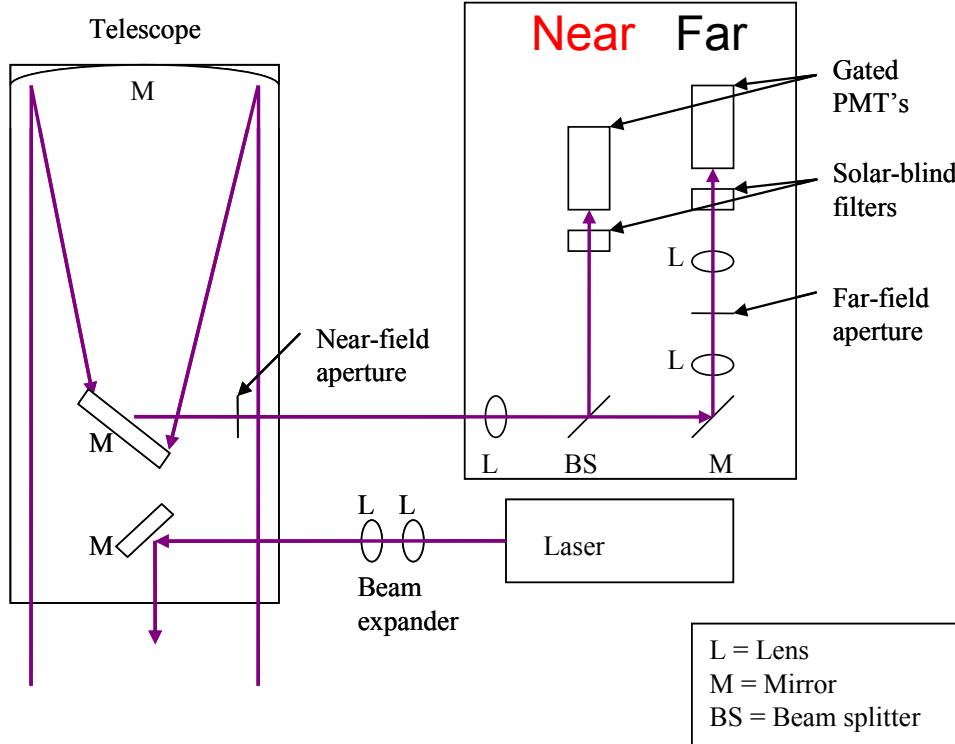
- High laser power (high pulse energy or lower pulse energy & high rep rate)
- Tunable laser or appropriate fixed frequencies

Species	Laser transmitter	Wavelengths
O <sub>3</sub>	4x Nd:YAG / Excimer + Raman shift OPO, CeLiCAF, 3x Ti:Sapphire	Fixed: 266 – 359 nm Tunable: 280 – 320 nm
H <sub>2</sub> O	Ti:Sapphire, Alexandrite, OPO, Fiber laser	720 – 940 nm, 1.5 μm
CH <sub>4</sub>	OPO	1.67 μm, 3.3 μm
CO <sub>2</sub>	Fiber laser, OPO, Tm:Ho:YLF	1.57 μm, 2.05 μm
VOCS	Dye lasers	Mid-IR @ several μm
NH <sub>3</sub>	Dye laser, CO <sub>2</sub> laser	208 nm, 9 – 10 μm

OPO = Optical Parametric Oscillator

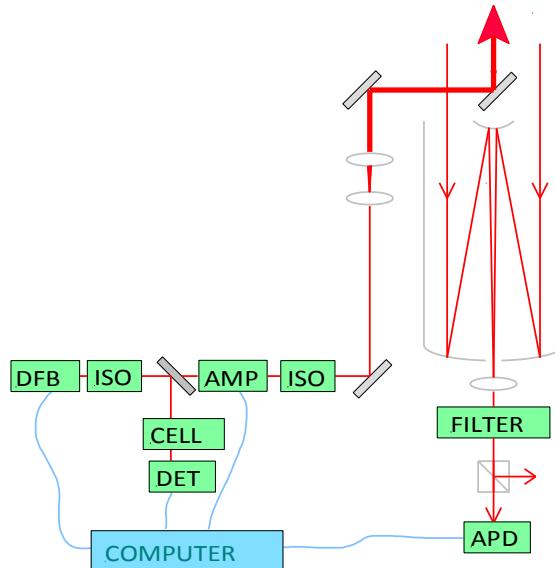
# DIAL system components: Receiver

- Large telescope
- Narrow field of view to suppress background light
- Combination of near and far channels to compress large dynamic range

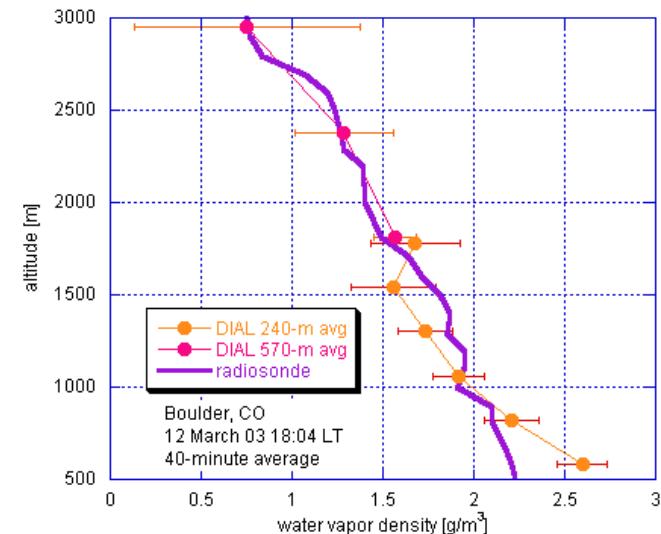


# DIALs at NOAA/ESRL/CSD: Water Vapor

CODI = COmpact DIAL (prototype of small, autonomous H<sub>2</sub>O DIAL system)



wavelength	823 nm
output pulse energy	~0.15 µJ
pulse duration	600 ns
pulse repetition freq.	8 – 10 kHz
telescope diameter	34 cm
field-of-view	180 µRad

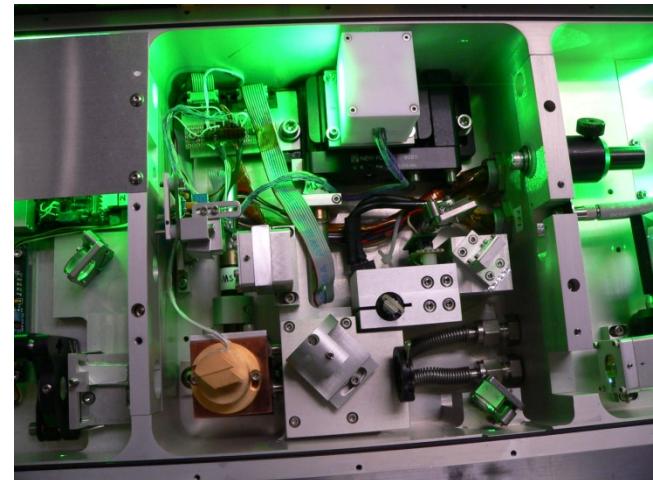
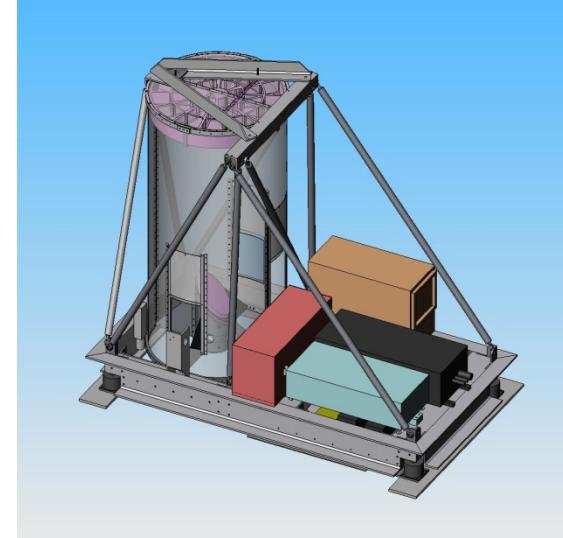


# DIALs at NOAA/ESRL/CSD: Ozone

TOPAZ = Tunable Optical Profiler of Aerosol and oZone

- Tunable, all-solid state, compact O<sub>3</sub> DIAL
- Replaced previous fixed-wavelength O<sub>3</sub> lidar in 2006
- Size & weight were reduced significantly

TOPAZ Specifications	
Wavelengths	3
Wavelength tuning range	285-310 nm
Pulse energy	0.2-0.8 mJ/pulse
Pulse rate	1 kHz with pulse-to-pulse tuning capability
Minimum/maximum range	0.3 km / 5 km
Eye-safe range	~150 m
System weight	~800 lbs (including chiller and control electronics)
Output	Ozone and aerosol backscatter profiles
Vertical/horizontal resolution (O <sub>3</sub> )	90 m / 600 m ( $\Delta t = 10$ s)
Precision (O <sub>3</sub> )	3 - 15 ppbv



# TOPAZ Ozone Lidar

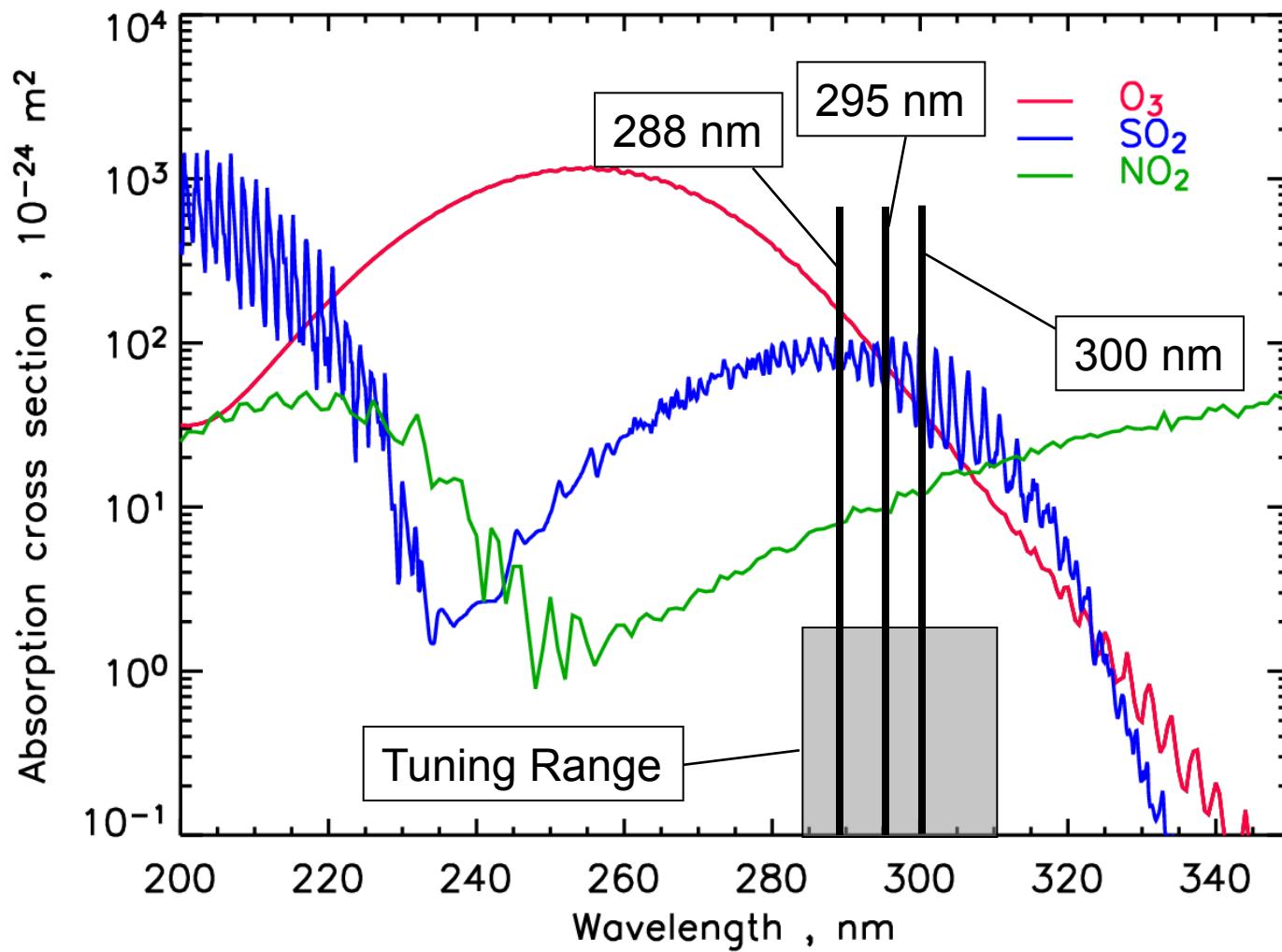
2006 – 2011: Airborne deployments on NOAA Twin Otter



2012: Conversion to truck-based, scanning instrument



## TOPAZ wavelengths & tuning range



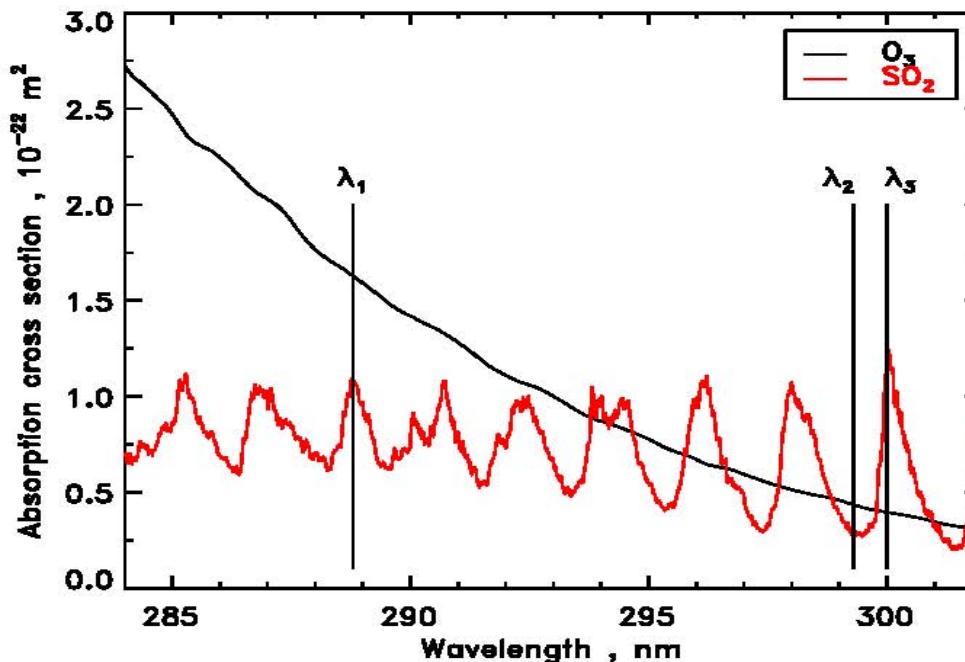
# TOPAZ is a tunable, multi-wavelength DIAL system

## Advantages of tunability:

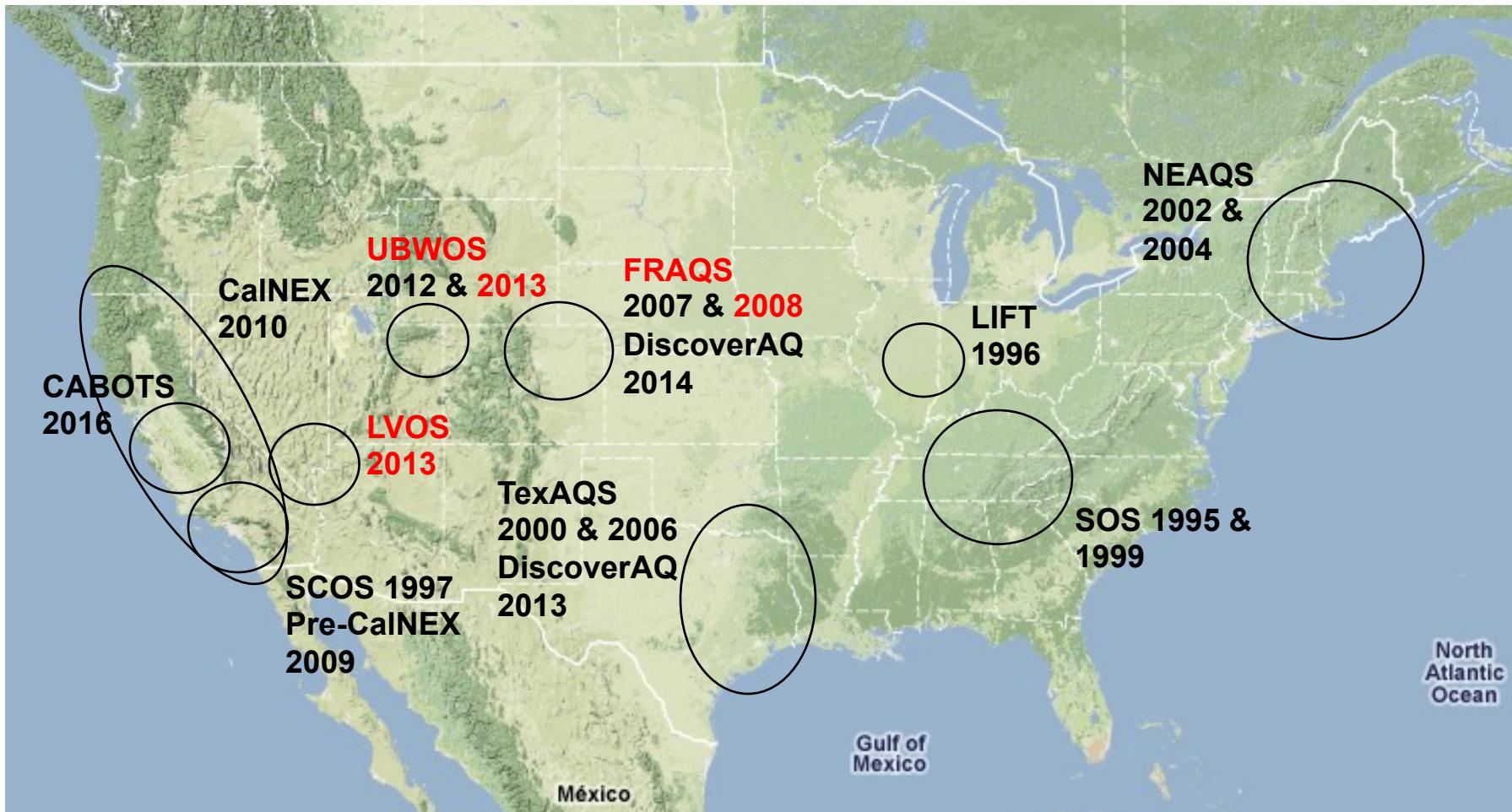
- Wavelengths can be optimized for given atmospheric ozone loading
- Minimize interference from other trace gases, e.g. SO<sub>2</sub>

## Advantages of multi-wavelength capability:

- Allows simultaneous measurement of 2 species (O<sub>3</sub> & SO<sub>2</sub>)
- Dual-DIAL application to minimize uncertainties due to aerosol backscatter and extinction corrections

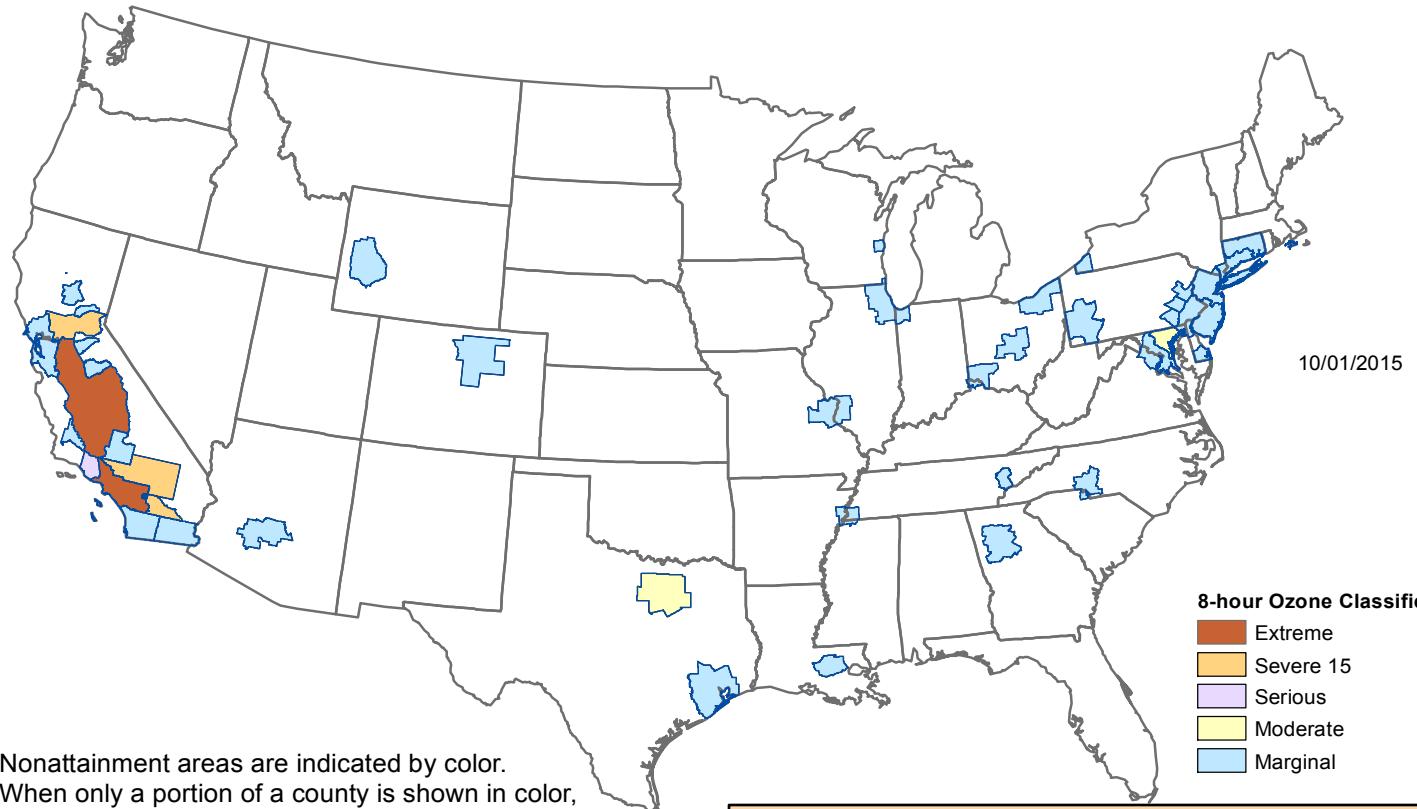


# Ozone DIAL Application: Regional Air Quality



# Ozone non-attainment areas in the US

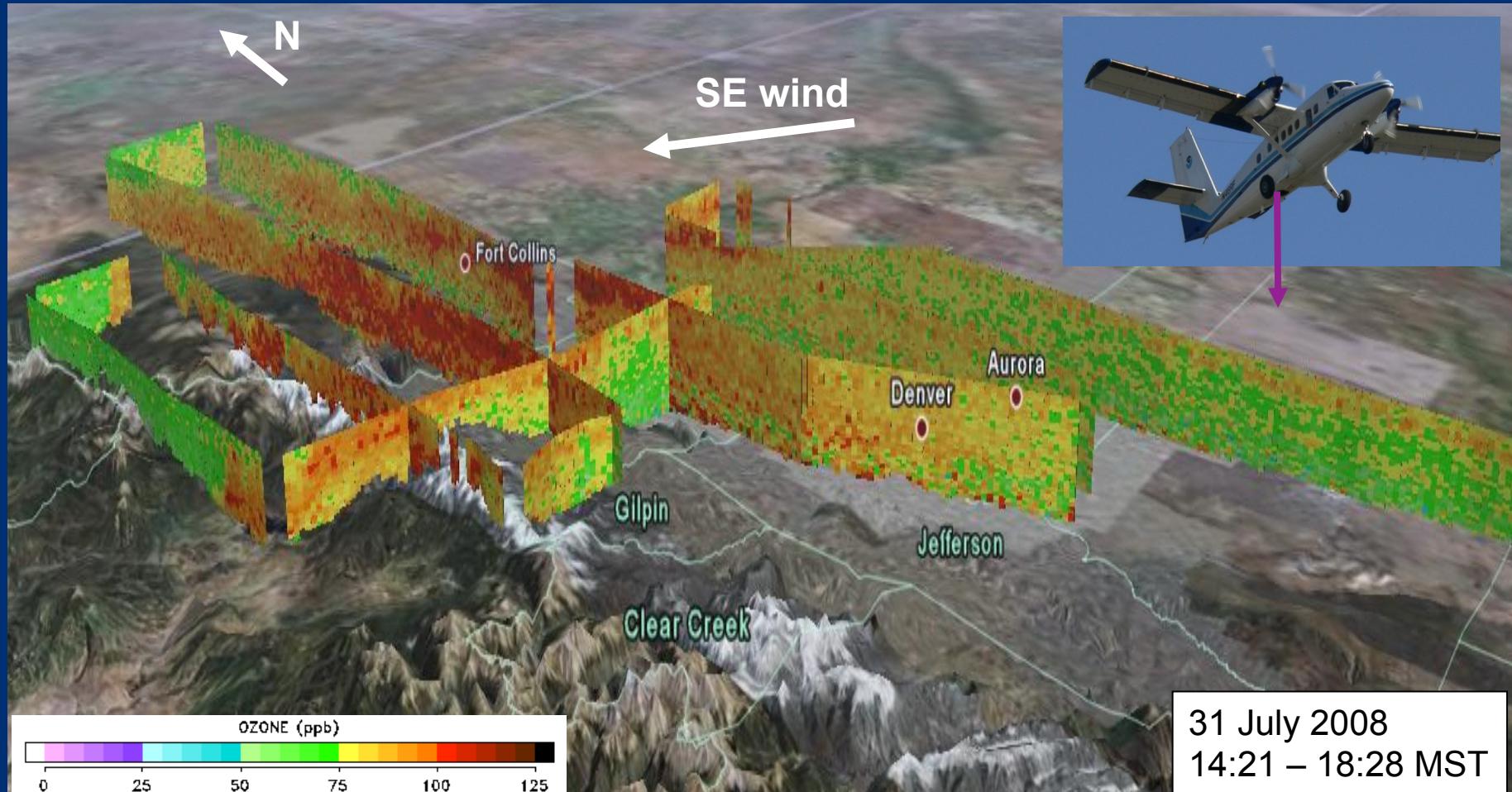
United States 8-hour O<sub>3</sub> standard (2008): 75 ppbv



An area is in non-attainment if the 3-year average of the annual 4<sup>th</sup> highest daily maximum 8-hr ozone concentration exceeds the standard.

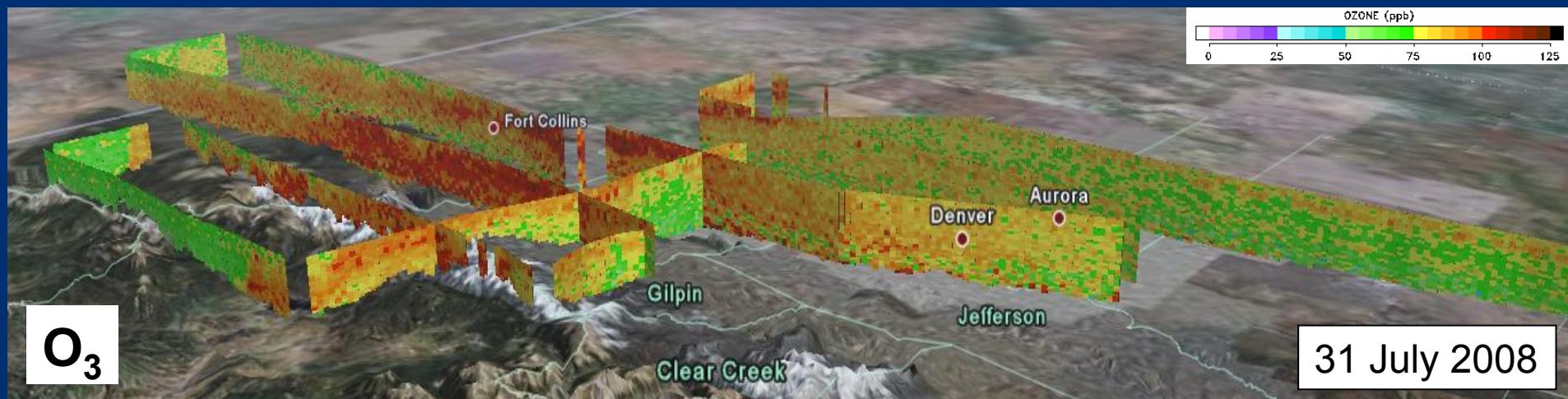
# Front Range Air Quality Study: Jul/Aug 2008

Transport of O<sub>3</sub> into and over the mountains



3-d distribution of O<sub>3</sub> from TOPAZ lidar

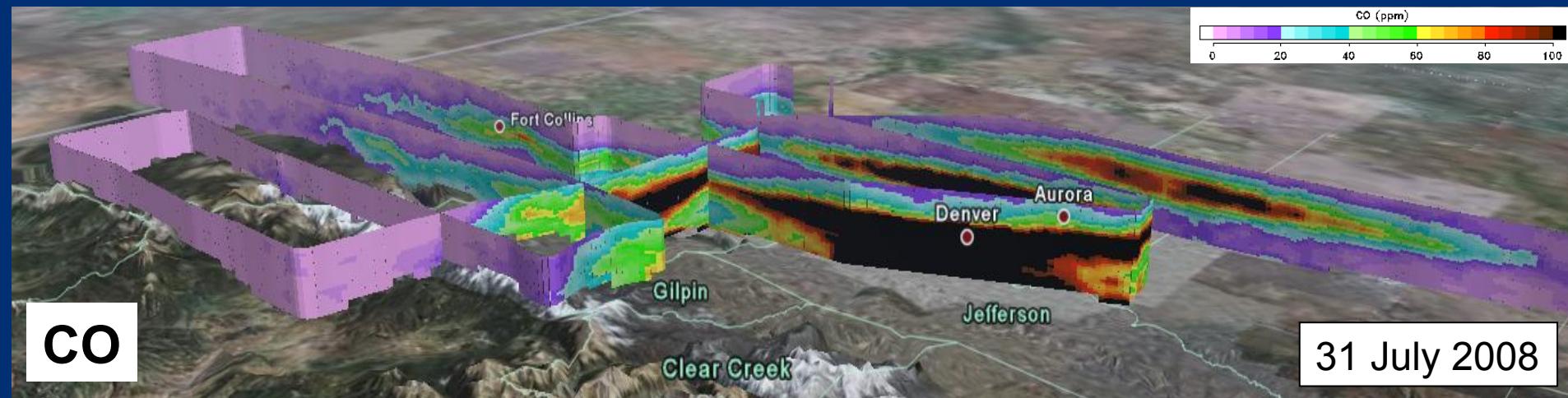
# Comparison of O<sub>3</sub> DIAL measurements with air quality model predictions



O<sub>3</sub>

31 July 2008

TOPAZ lidar measurement



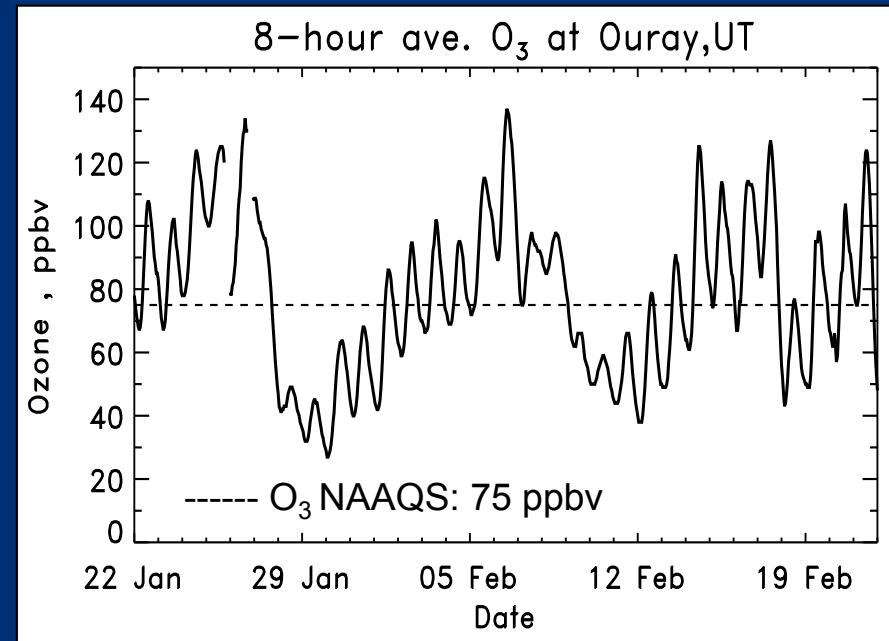
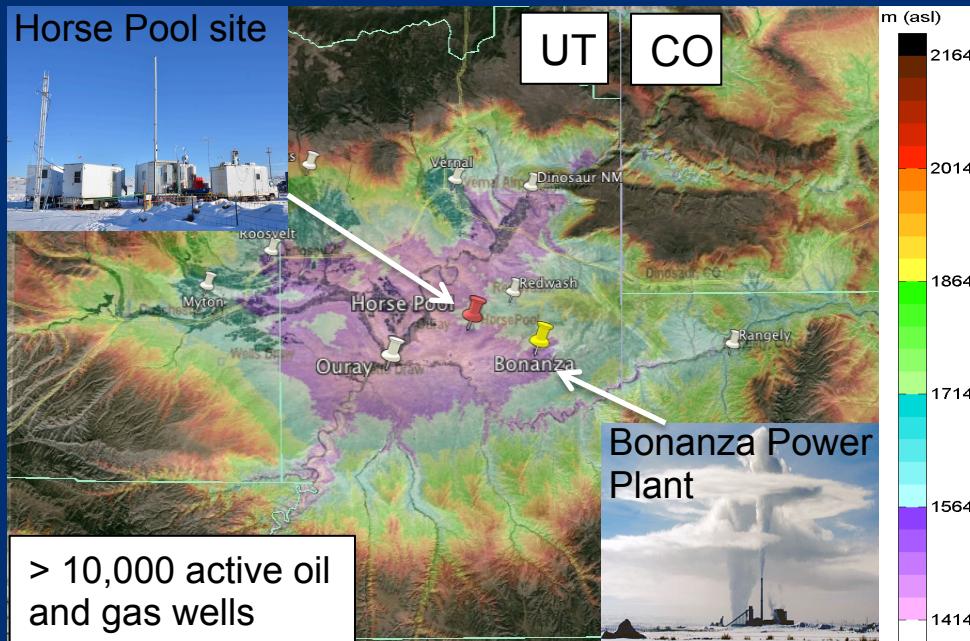
CO

31 July 2008

WRF-FLEXPART model results

# Uintah Basin Wintertime Ozone Study (UBWOS): Jan/Feb 2013

## High wintertime $O_3$ in an oil & gas producing area

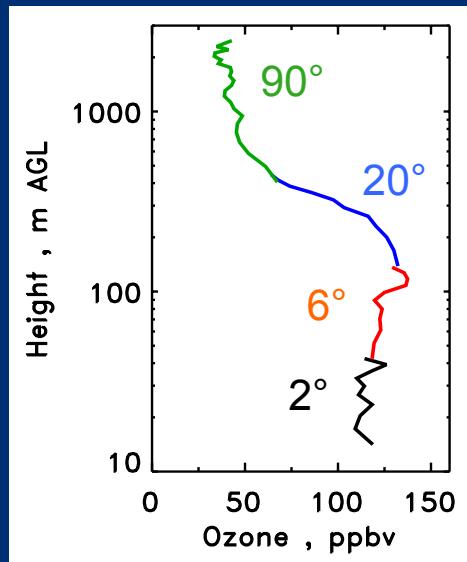
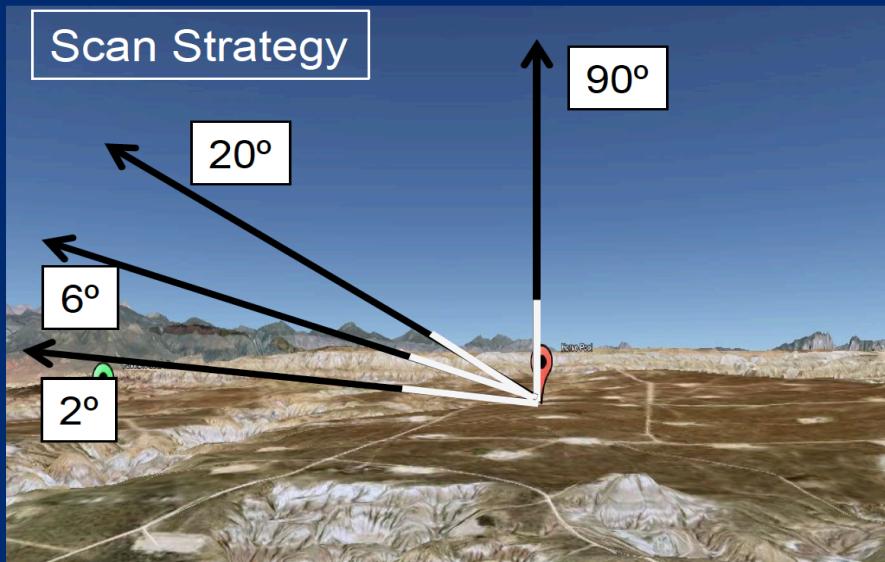


- What is the vertical extent and what are the sources of the high O<sub>3</sub> concentrations observed at the surface?

# TOPAZ Ozone Lidar at UBWOS 2013

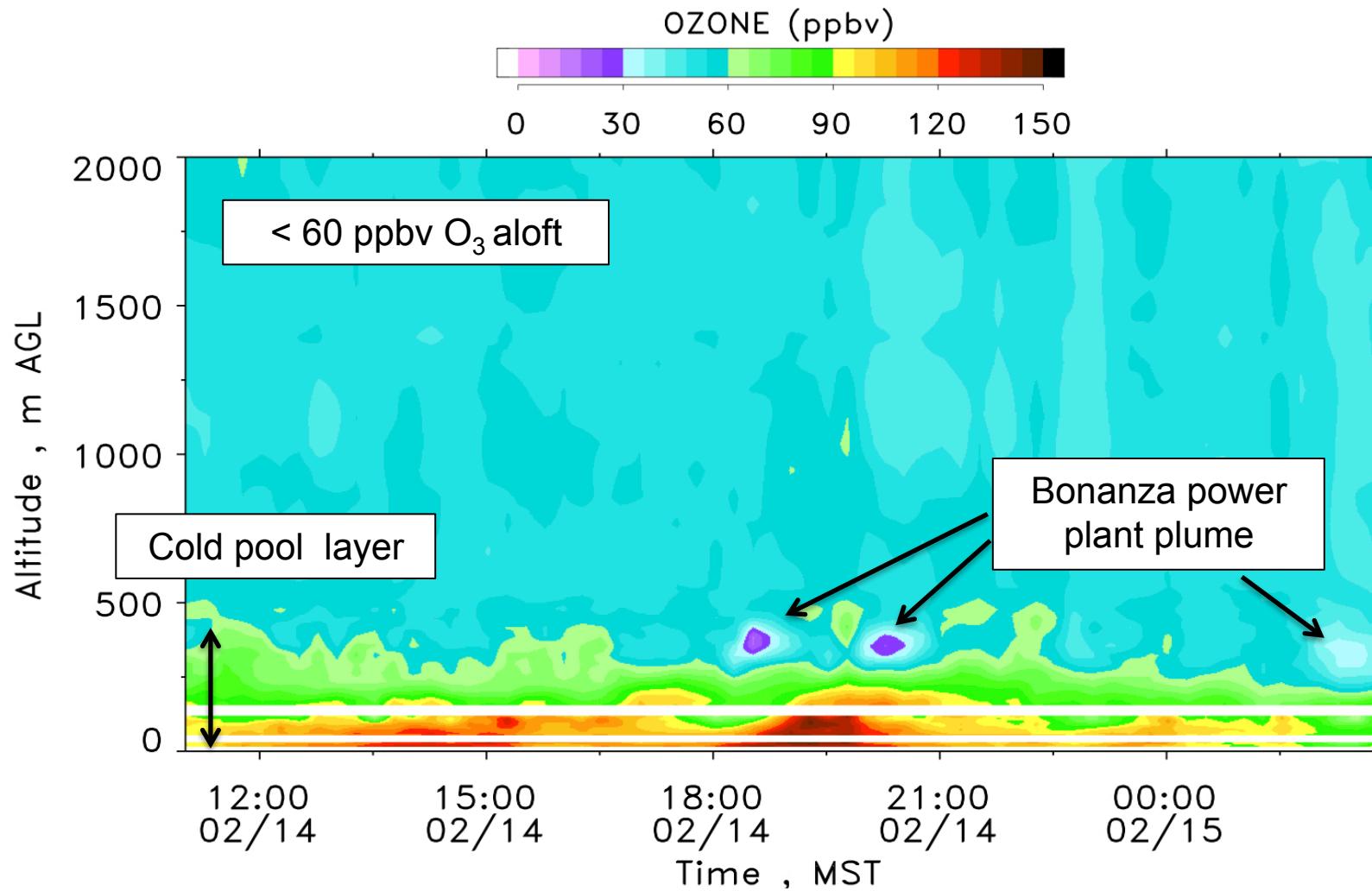


$\leq 3 \text{ km}$   
AGL  
 $\sim 15 \text{ m}$   
AGL



Composite vertical  $\text{O}_3$  and aerosol profiles every 5 min

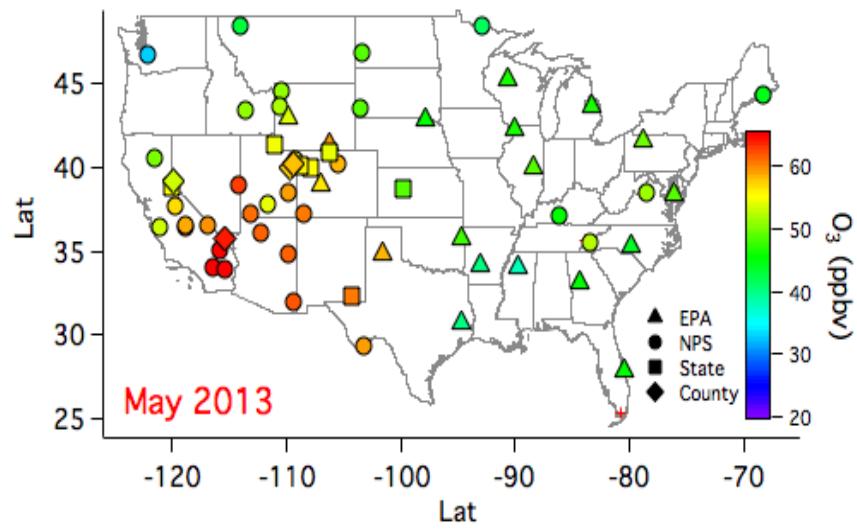
# Ozone distribution observed with TOPAZ in the Uintah Basin on 14/15 Feb 2013



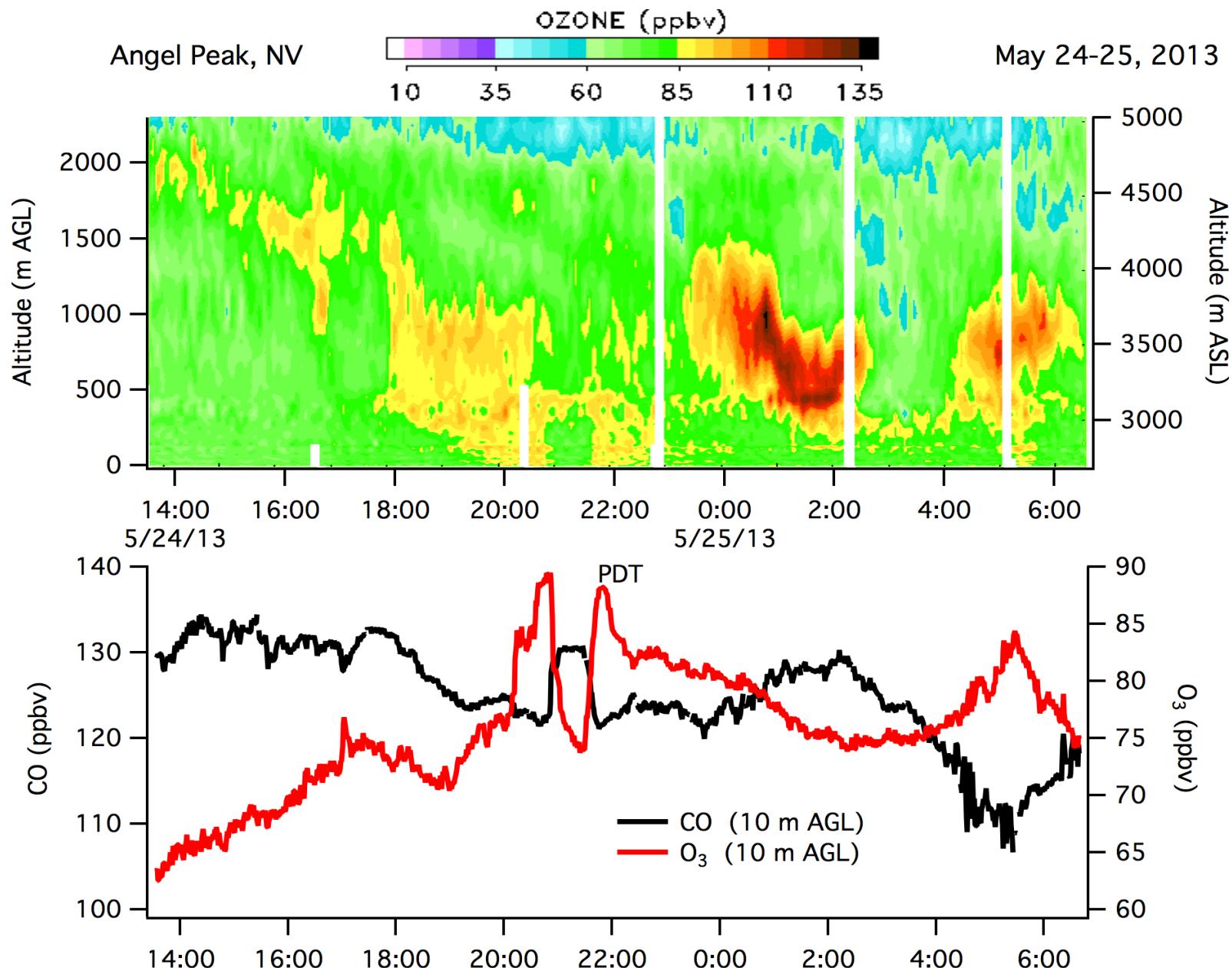
# Las Vegas Ozone Study (LVOS): May/Jun 2013

## Impact of stratospheric O<sub>3</sub> on surface air quality

Mean O<sub>3</sub> in May is greater than 60 ppbv in some remote areas (CASTNET, USNPS)



# Transport of stratospheric O<sub>3</sub> to the surface at Angel Peak



# Selected References (1)

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## DIAL transmitters (slide 4)

- Fix, A., M. Wirth, A. Meister, G. Ehret, M. Pesch, and D. Weidauer, 2002: Tunable Ultraviolet Optical Parametric Oscillator for Differential Absorption Lidar Measurements of Tropospheric Ozone, *Appl. Phys. B*, **75**, 153-163.
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## NOAA/ESRL/CSD DIAL systems (slides 6 - 10)

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## Selected References (2)

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### Ozone DIAL applications (slides 11 - 19)

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- Senff, C. J., R. J. Alvarez, II, R. M. Hardesty, R. M. Banta, and A. O. Langford (2010), Airborne lidar measurements of ozone flux downwind of Houston and Dallas, *J. Geophys. Res.*, 115, D20307, doi:10.1029/2009JD013689.
- Langford, A. O., C. J. Senff, R. J. Alvarez II, R. M. Banta, and R. M. Hardesty, 2010: Long-range transport of ozone from the Los Angeles Basin: A case study, *Geophys. Res. Lett.*, 37, L06807, doi: 10.1029/2010GL042507.
- Banta, R. M., C. J. Senff, J. Nielsen-Gammon, L. S. Darby, T. B. Ryerson, R. J. Alvarez, S. P. Sandberg, E. J. Williams, and M. Trainer, 2005, A Bad Air Day in Houston, *Bull. Amer. Meteo. Soc.*, 657-669.