The Boulder Atmospheric Observatory: More than just a Tall Tower!

Daniel E Wolfe
NOAA/ESRL/PSD
CU/CIRES

Outline:

- History
- Tower Specs and Facts
- Tower and Site Description
- Instrumentation/Data
- Web Site (*near real-time data*)
- Past Experiments (*BAO Reports*)
- Long Term Research Programs (*GMD*)
- Recent Experiments
- Unique Events
- Fun Photos

AGENDA

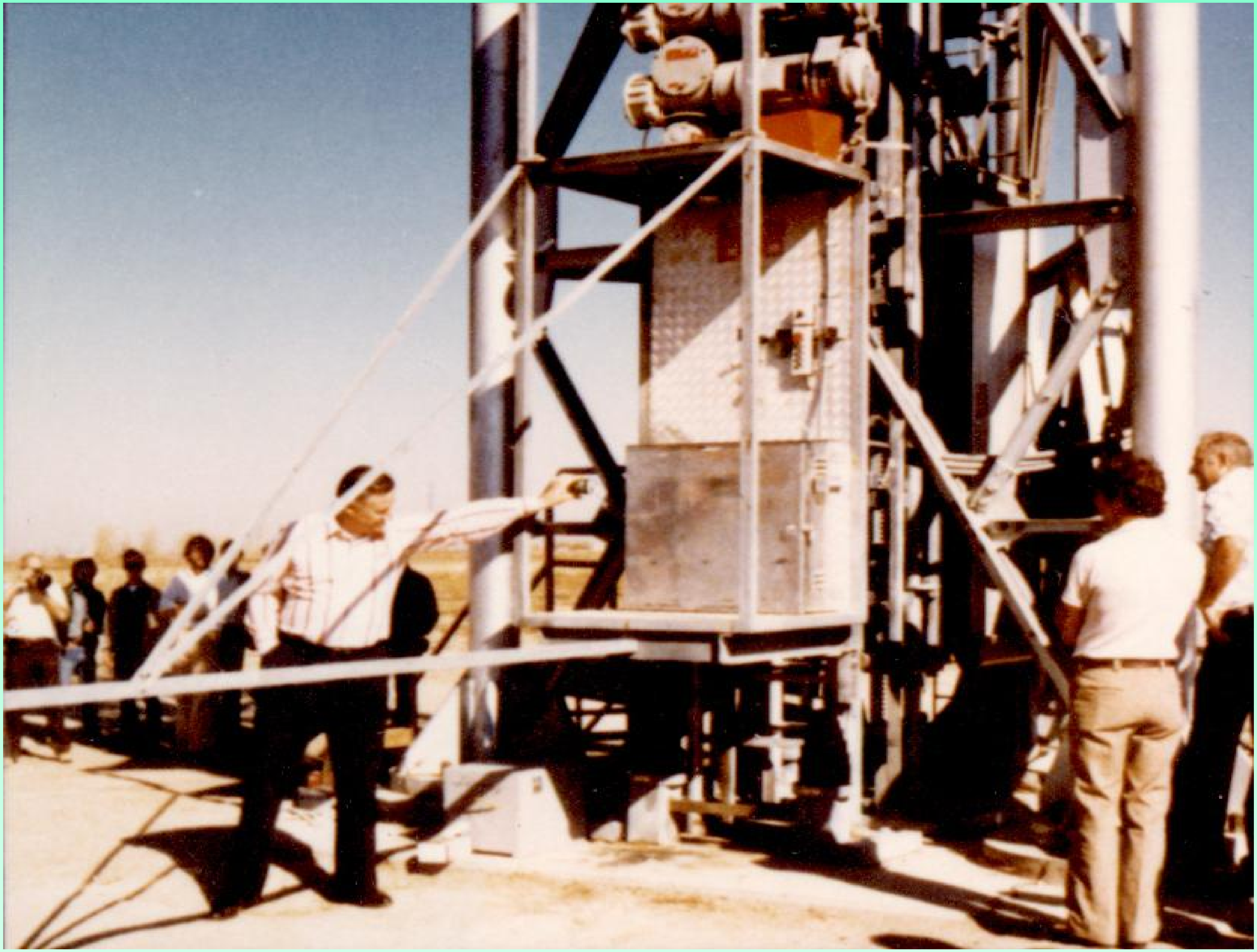
WORKSHOP ON PROPOSED NOAA/NCAR/CIRES

JOINT METEOROLOGICAL OBSERVATORY

(J. M. O.)

February 4, 1974

30 AM	Key atmospheric science problems, and the role of the proposed meteorological observatory	J. Businger
)0 AM	WPL's Remote Sensing Mission and the J. M. O.	
	Introduction	C. G. Little
10 AM	Laser Beam Remote Sensing	R. S. Lawrence
30 AM	Lidar Remote Sensing	V. E. Derr
50 AM	Coffee Break	
10 AM	Microwave Radiometry	M. T. Decker
30 AM	Meteorological Radar	E. E. Gossard
50 AM	Geoacoustics	W. H. Hooke
10 AM	Acoustic Echosounding	F. F. Hall
30 AM	WPL's Need for a Meteorological Observatory	C. G. Little
50 AM	Lunch	
)0 PM	NOAA's Office of Weather Modification and the J. M. O.	E. Bollay
15 PM	Atmospheric Physics and Chemistry Laboratory and the J. M. O.	H. K. Weickmann
30 PM	CIRES and the Joint Meteorological Observatory	G. Chimonas
45 PM	NCAR Aircraft Measurements and the J. M. O.	D. Lenschow
:00 PM	NCAR Field Observing Facility and the J. M. O.	R. J. Serafin
15 PM	Research Opportunities Represented by the J. M. O.	D. Atlas



Tower Christening

Oct 1977

Background

The Boulder Atmospheric Observatory (BAO) tower was constructed in 1977 at a cost of approximately $1.5M.

Tower instrumentation and data acquisition system originally came from Air Force Cambridge Research Laboratories, MA (Kaimal, Wyngaard, Haugen). Responsible for the Kansas and Minnesota boundary layer experiments (1968, 1973)

It sits on 180 acres (1/4 section) of land about 25 miles east of Rocky Mountains near Boulder, CO.

NOAA leases 100 acres from the Colorado State Land Board.

The tower is 300m high and has 8 levels with instrument booms.

A 3-person elevator provides access to all heights.

The tower includes a mobile instrument carriage with a boom for profiling studies

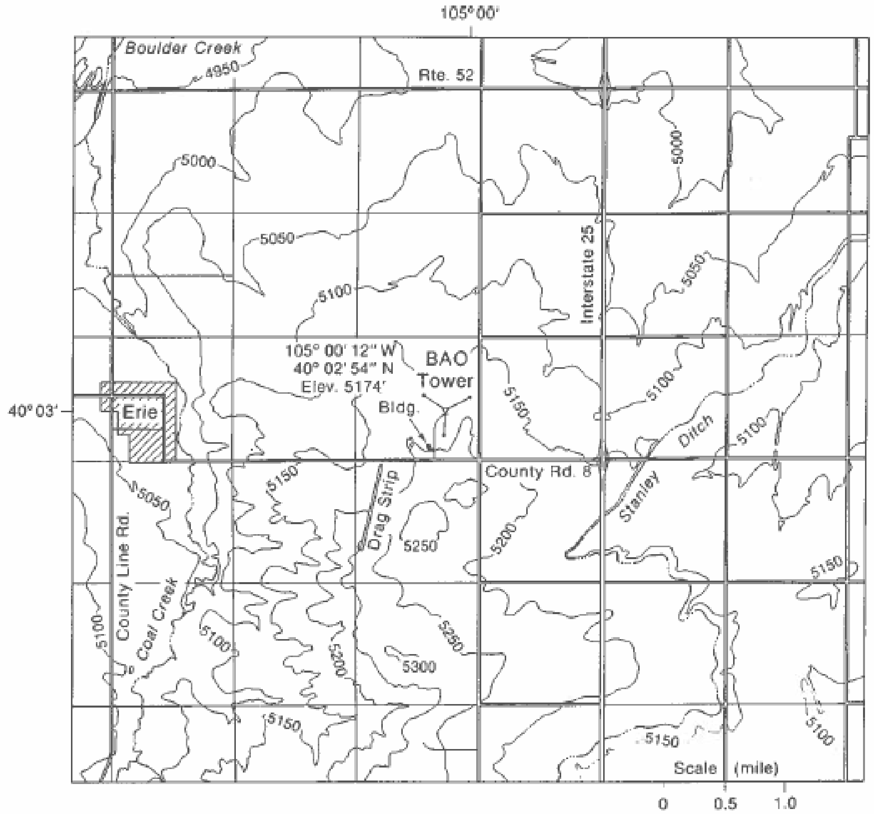
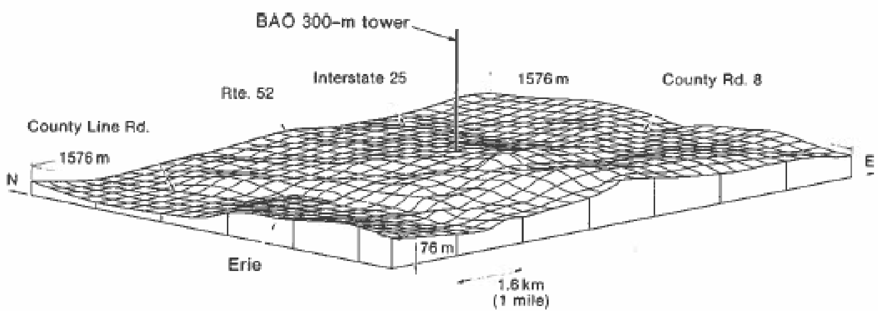
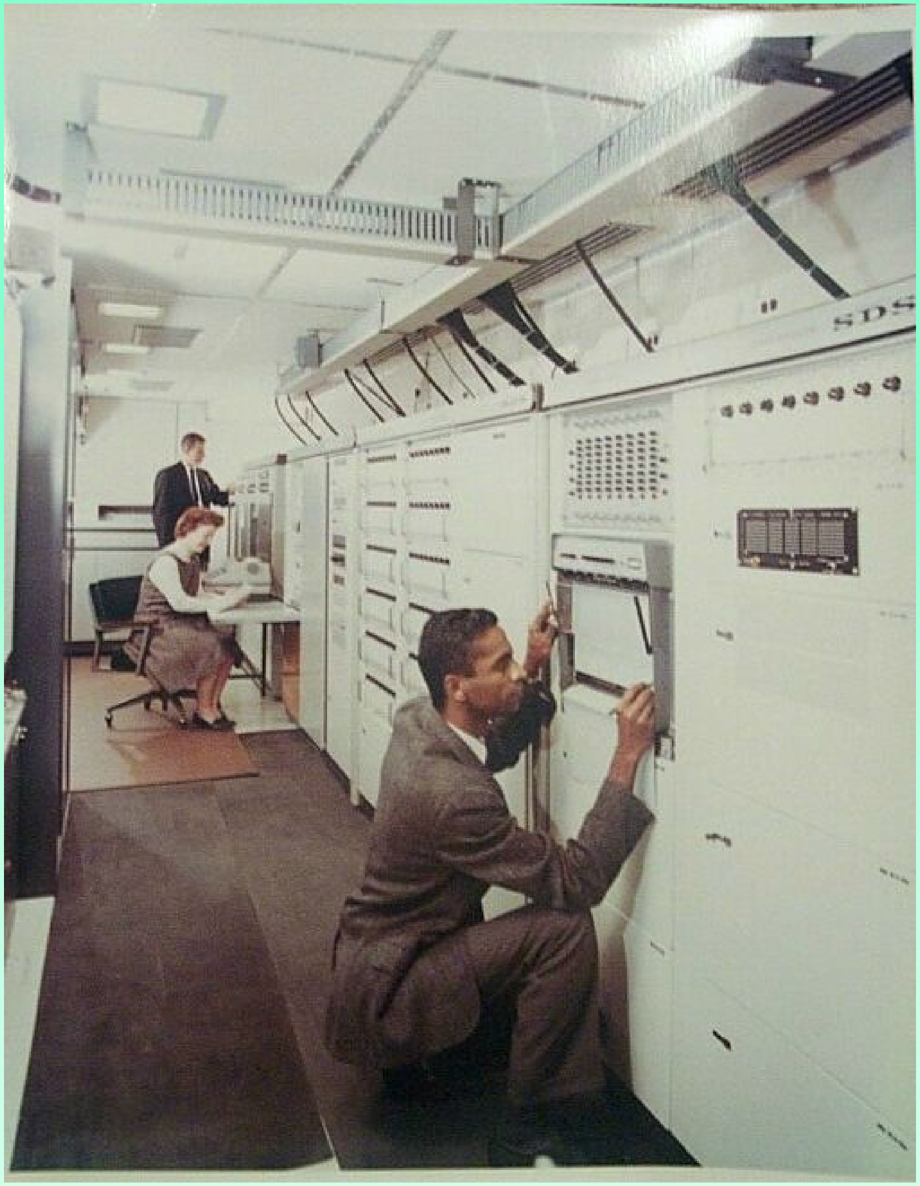


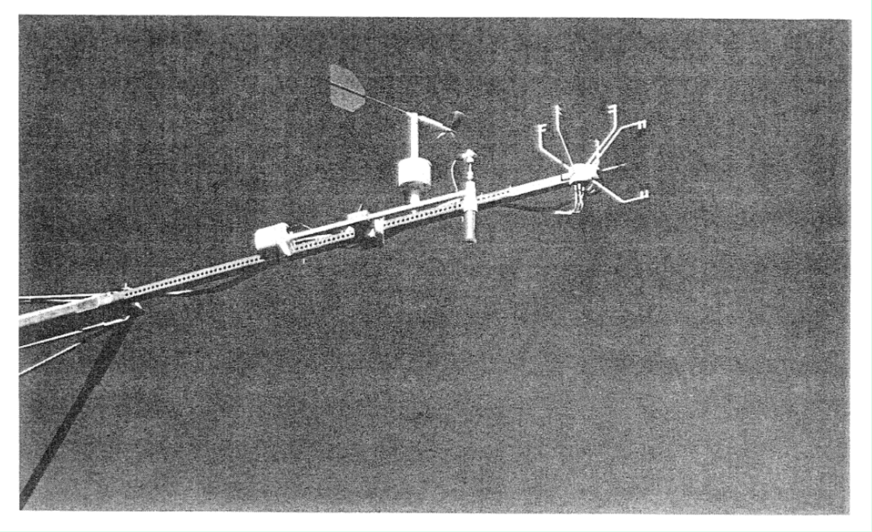
Figure 2.2a.--A conventional contour map of the immediate BAO terrain.



PHOENIX 1978



System's Trailer
Dr. Chandran Kaimal



Original Joint facilities/computer buildings

BOULDER ATMOSPHERIC OBSERVATORY DATA SUMMARY

AVERAGING PERIOD= 20.00 MIN

5 SEP 79 10 20 MST

Z[M]	VWES	VSOU	U	V	W	VH	AZ	FVS	FVD	T	TD	L
10	-3.22	-3.46	-1.69	4.41	-0.18	4.73	43.	4.42	55.	28.19	1.30	-25.77
22	-3.37	-3.95	-2.07	4.76	-0.10	5.19	41.	4.88	54.	27.64	0.63	-30.21
50	-3.44	-4.00	-2.16	4.88	-0.18	5.33	40.	4.98	51.	27.12	0.43	-63.04
100	-3.82	-4.07	-1.98	5.22	-0.08	5.58	43.	5.05	54.	26.59	0.40	-80.50
150	-3.96	-3.76	-1.64	5.20	-0.16	5.46	46.	5.24	54.	26.06	-0.20	999.99
200	-3.94	-3.33	-1.27	5.00	-0.05	5.15	50.	5.23	56.	25.48	-0.49	999.99
250	-4.11	-3.65	-1.48	5.30	-0.11	5.50	48.	5.24	53.	25.06	-0.99	999.99
300	-4.00	-3.88	-1.73	5.29	-0.11	5.57	46.	5.50	53.	24.56	-1.34	999.99

Z[M]	UU	VV	WW	TT	UV	VW	UT	VT	UW	WT
10	1.4315	0.9045	0.2380	0.3675	-0.4158	-0.0337	-0.2360	-0.0999	-0.1314	0.1623
22	1.2687	0.7045	0.3757	0.1983	-0.3042	-0.0682	-0.1432	-0.0811	-0.1500	0.1685
50	1.0214	0.5257	0.6504	0.0778	-0.2340	-0.0809	-0.0946	-0.0239	-0.2118	0.1352
100	0.7430	0.6420	0.7717	0.0548	-0.0233	-0.0877	-0.0856	-0.0195	-0.2118	0.1057
150	0.8567	0.7280	0.7761	0.0285	0.0889	-0.0716	-0.0697	-0.0186	-0.1297	0.0727
200	0.9299	0.7570	0.6753	0.0211	-0.0354	-0.0859	-0.0658	-0.0391	-0.1253	0.0454
250	1.1671	0.8311	0.7471	0.0284	0.0294	-0.0433	-0.0650	-0.0707	-0.2243	0.0325
300	0.8392	0.8532	0.5918	0.0264	-0.1268	0.0473	-0.0126	-0.0631	-0.0995	-0.0086

Optical Triangle

V [M/SEC]	AZ [DEG]	CONV [1/SEC]	LOG10(CN2)
1.25	13.	0.01118	-13.14339161

Micro-barograph array

STN 1	STN 2	STN 3	STN 4	STN 5
6.461	7.832	6.597	19.247	8.690

PRESSURE[MB]

842.25

SOLAR RAD[LY/MIN]

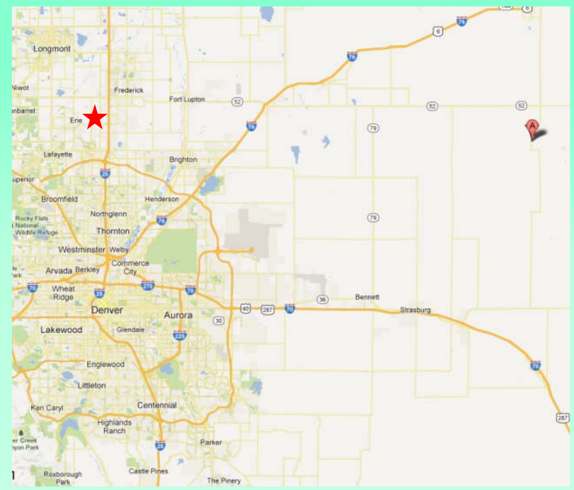
1.07

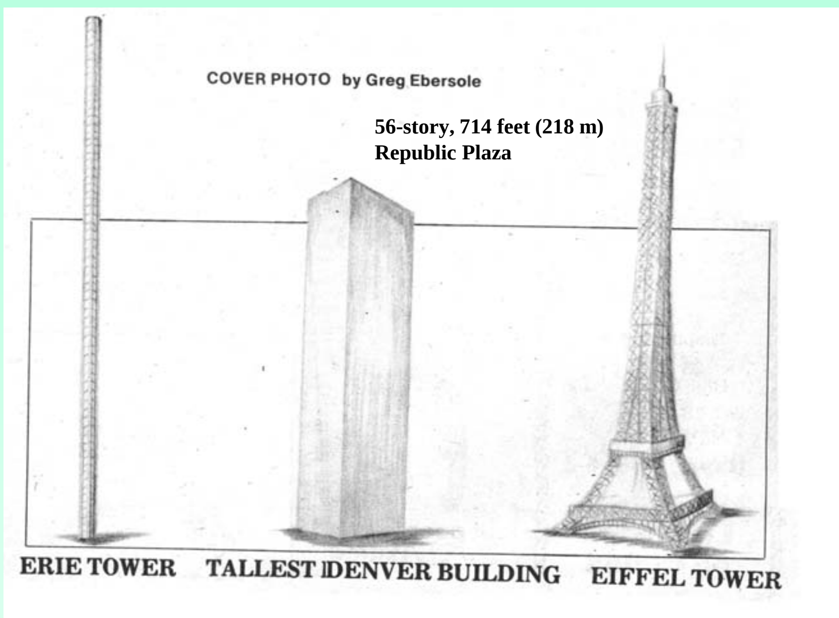
Original computer printout
20 min summary

Category	Structure	Country	City	Height (metres)	Height (feet)	Year Built
Skyscraper	Burj Khalifa	United Arab Emirates	Dubai	829.8	2,722	2010
Self supporting tower	Tokyo Sky Tree	Japan	Tokyo	634	2,080	2011
Guyed Mast	KVLY-TV mast	United States	Blanchard	628.8	2,063	1963
Clock building	Abraj Al Bait Towers	Saudi Arabia	Mecca	601	1,972	2011
Mast radiator	Lualualei VLF transmitter	United States	Lualualei	458	1,503	1962

Colorado

- Radio communications tower: KJHM, KDHT
  - Height: 1,996 ft (608 m)
  - Hoyt (39°55′22″N 103°58′18″W)
  - Year built: 2003





More Facts

10’ on a side triangular structure.

9 ½”- 4 ¾” solid steel galvanized legs (largest rolled steel at the time)

60’ deep pylons under each leg

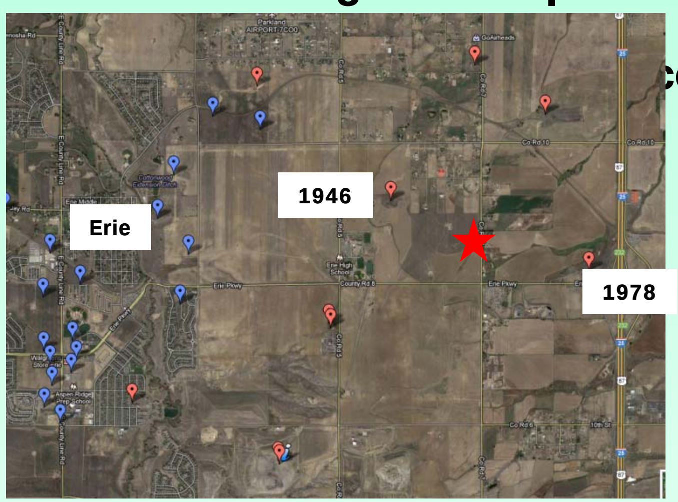
6 guy wires/leg (18 total) connected to 50’ deep anchors. Inner guys are 4400’ and outer guys 800’ from the base of the tower

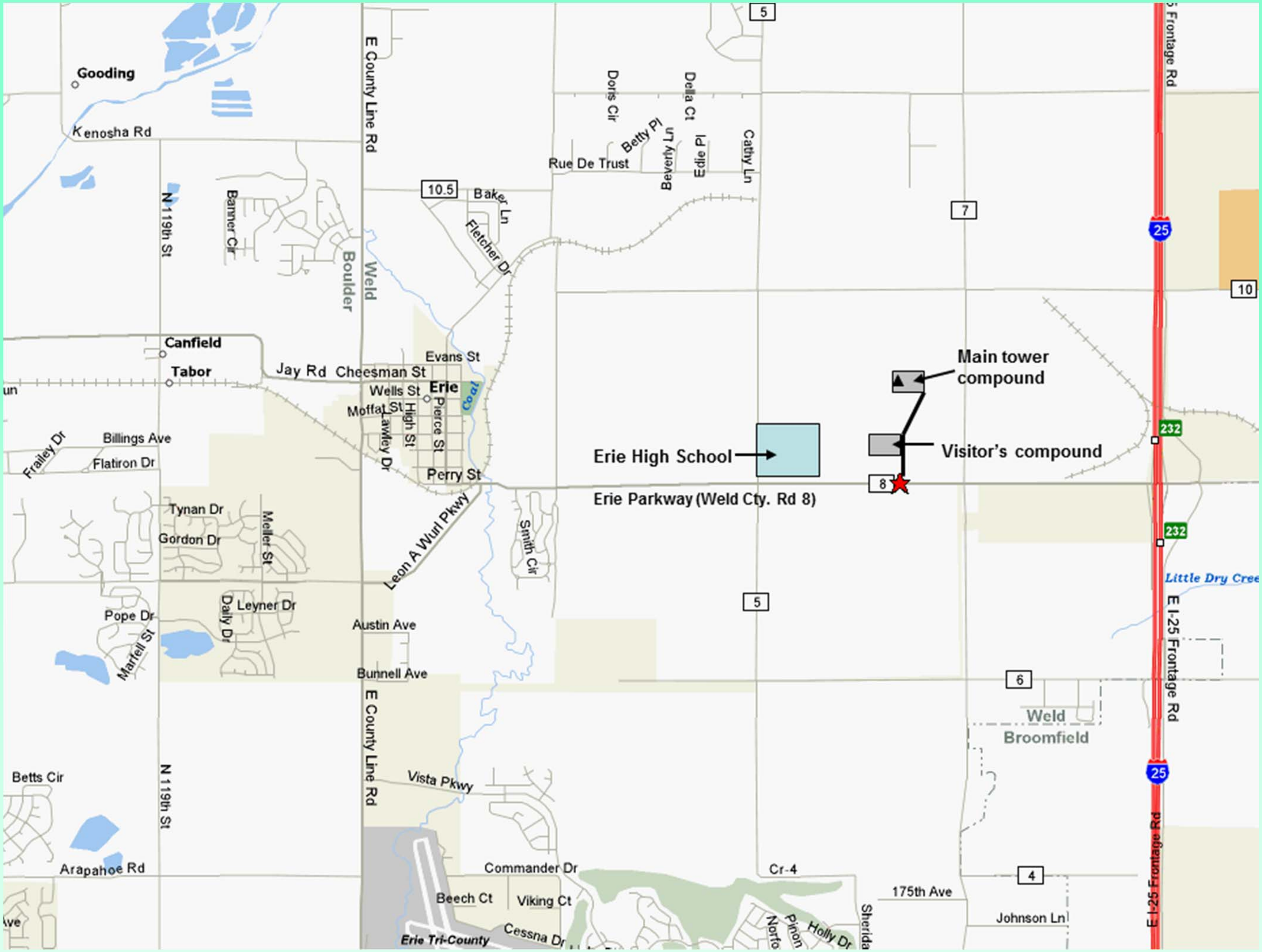
3 levels of aircraft warning lights on 3 sides (480 VDC)

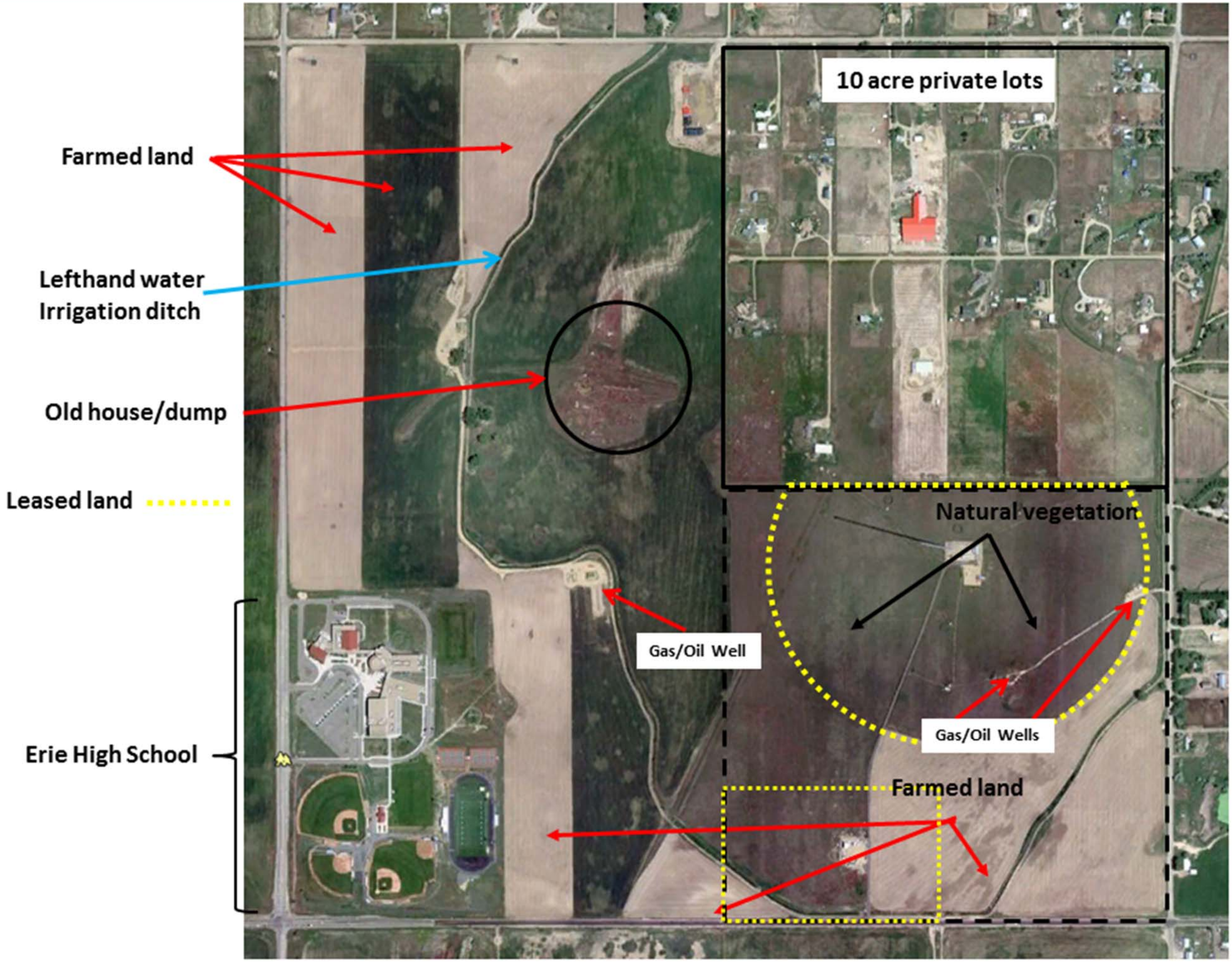
Elevator and Instrument carriage are cog driven (480 VDC)

It takes the inside elevator 6 mins to get the top

The tower is located coal mines.

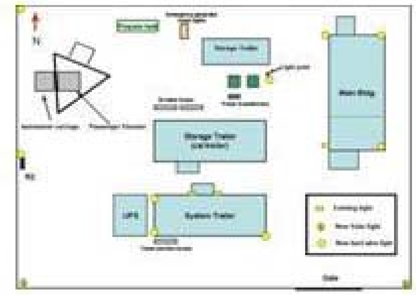



Main tower compound
Visitor's compound
Erie High School
Erie Parkway (Weld Cty. Rd 8)
Gooding
Kenosha Rd
Canfield
Tabor
Jay Rd
Cheesman St
Evans St
Wells St
Erie
Moffat St
Lawley Dr
High St
Pierce St
Perry St
Billings Ave
Flatiron Dr
Frailey Dr
Tynan Dr
Gordon Dr
Meller St
Leyner Dr
Daily Dr
Pope Dr
Marfell St
Austin Ave
Bunnell Ave
Leon A Wurl Pkwy
Smith Cir
E County Line Rd
N 119th St
Banner Cir
Boulder
Weld
Coal
Baker Ln
Fletcher Dr
Rue De Trust
Doris Cir
Della Ct
Betty Pl
Beverly Ln
Edie Pl
Cathy Ln
Vista Pkwy
Betts Cir
Arapahoe Rd
Commander Dr
Beech Ct
Viking Ct
Cessna Dr
Erie Tri-County
Cr-4
175th Ave
Johnson Ln
Broomfield
Little Dry Cree
E I-25 Frontage Rd
25
232
5
7
8
6
4
10
10.5


10 acre private lots
Farmed land
Lefthand water
Irrigation ditch
Old house/dump
Leased land
Natural vegetation
Gas/Oil Well
Gas/Oil Wells
Erie High School
Farmed land

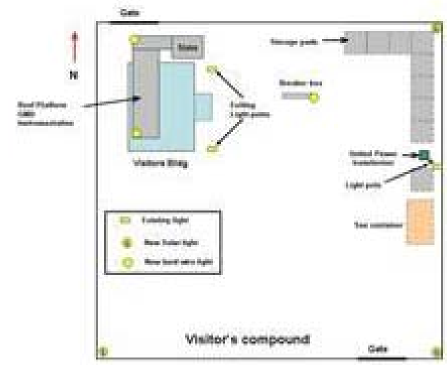
County Rd 10

County Rd 8 or
Leon A. Whurl Pkwy
or Erie Parkway



Tower Compound

Visitor Compound

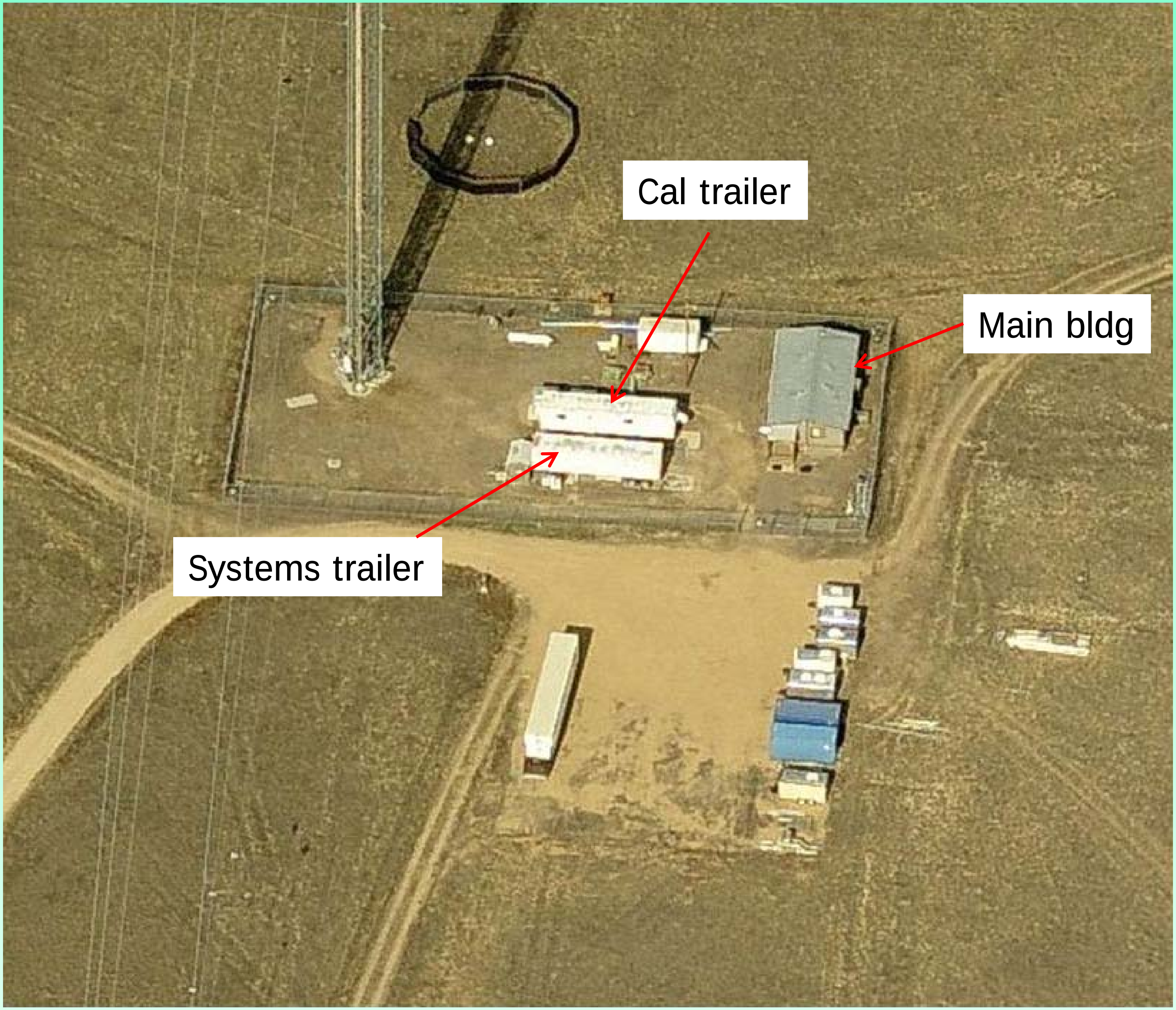


County Rd 5

Main Entrance

County Rd 7

Main Tower Compound



Visitor Compound

Current BAO Configuration/Instrumentation

8 Instrument booms: 10, 22, 50, 100, 150, 200, 250, 300m NW and SE w/power
Fiber Optic cable: 10, 50, 100, 300m



Primary levels
Sfc, 10, 100, 300 meters
Sfc Pressure, precipitation
10m T, RH, Wind Speed and Direction (prop-vane)
100m T, RH, Wind Speed and Direction (prop-vane)
300m T, RH, Wind Speed and Direction (2-D sonic)

Secondary levels:
50, 150, 200 meters
50m T, Wind Speed (cups NW/SE) Direction (vane NW)
150m T, Wind Speed (cups NW/SE) Direction (vane NW)
200m T, Wind Speed (cups NW/SE) Direction (vane NW)

Remote Sensors:
Sodar, CL31 Ceilometer, *Microwave radiometer (VC)*

Data Access

FTP
ftp1.esrl.noaa.gov
anonymous
guest
cd psd3/bao/Tower/Processed/daily (Daily processed files)

BAO_SFC_YYYYDDD.dat YYYY = Year DDD = Year day
BAO_300_YYYYDDD.dat
BAO_010_YYYYDDD.dat
BAO_100_YYYYDDD.dat

cd psd3/bao/Tower/Processed/daily (Monthly processed files)

BAO_SFC_YYYYMM.dat YYYY = Year MM = Month
BAO_300_YYYYMM.dat
BAO_010_YYYYMM.dat
BAO_100_YYYYMM.dat

All times are UTC

You are at: PSD » Observing Systems » BAO

The Boulder Atmospheric Observatory (BAO)

For more details contact Dan Wolfe, 303-497-6204
In Case of Emergency (including tower light outage), contact Security Dispatch Center: 303-497-3530.

The BAO is research facility in Erie, Colorado maintained by the Physical Sciences Division, which is used for studying the planetary boundary layer and for testing and calibrating atmospheric sensors. Ongoing measurements include solar radiation and greenhouse gases. The centerpiece of the facility is a 300-m tower instrumented at multiple levels with slow-response temperature, relative humidity and wind sensors, a profiling instrument carriage, a variety of remote sensing systems, and a real-time processing and display capability that greatly reduces analysis time for scientists. The BAO has been the host of several large national and international experiments and numerous smaller ones.


News


Web Cam

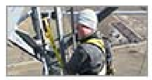
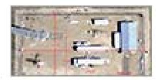


Photo Gallery

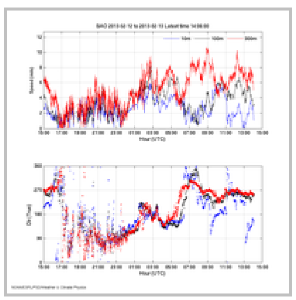

Site Information

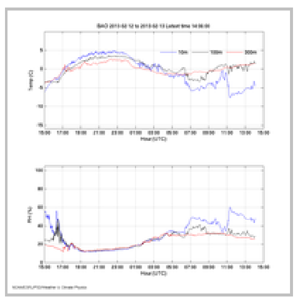

Site Images

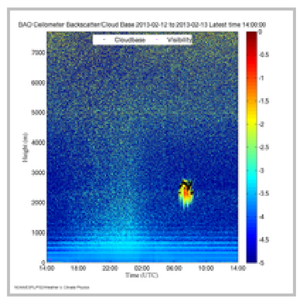
Data

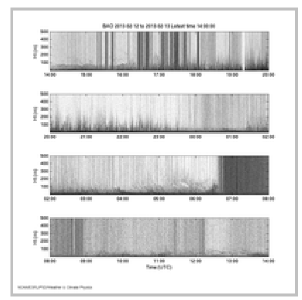
Current Data Plots

Compare Plots


Wind Speed & Direction

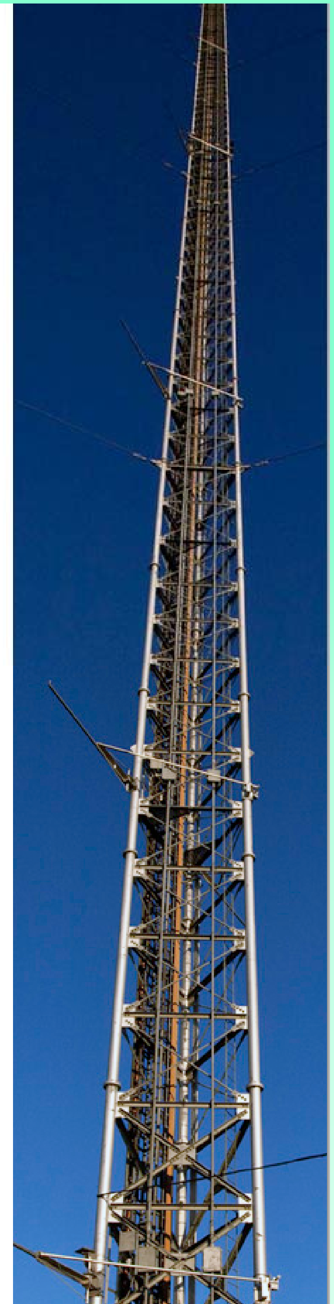

Temperature & Relative Humidity

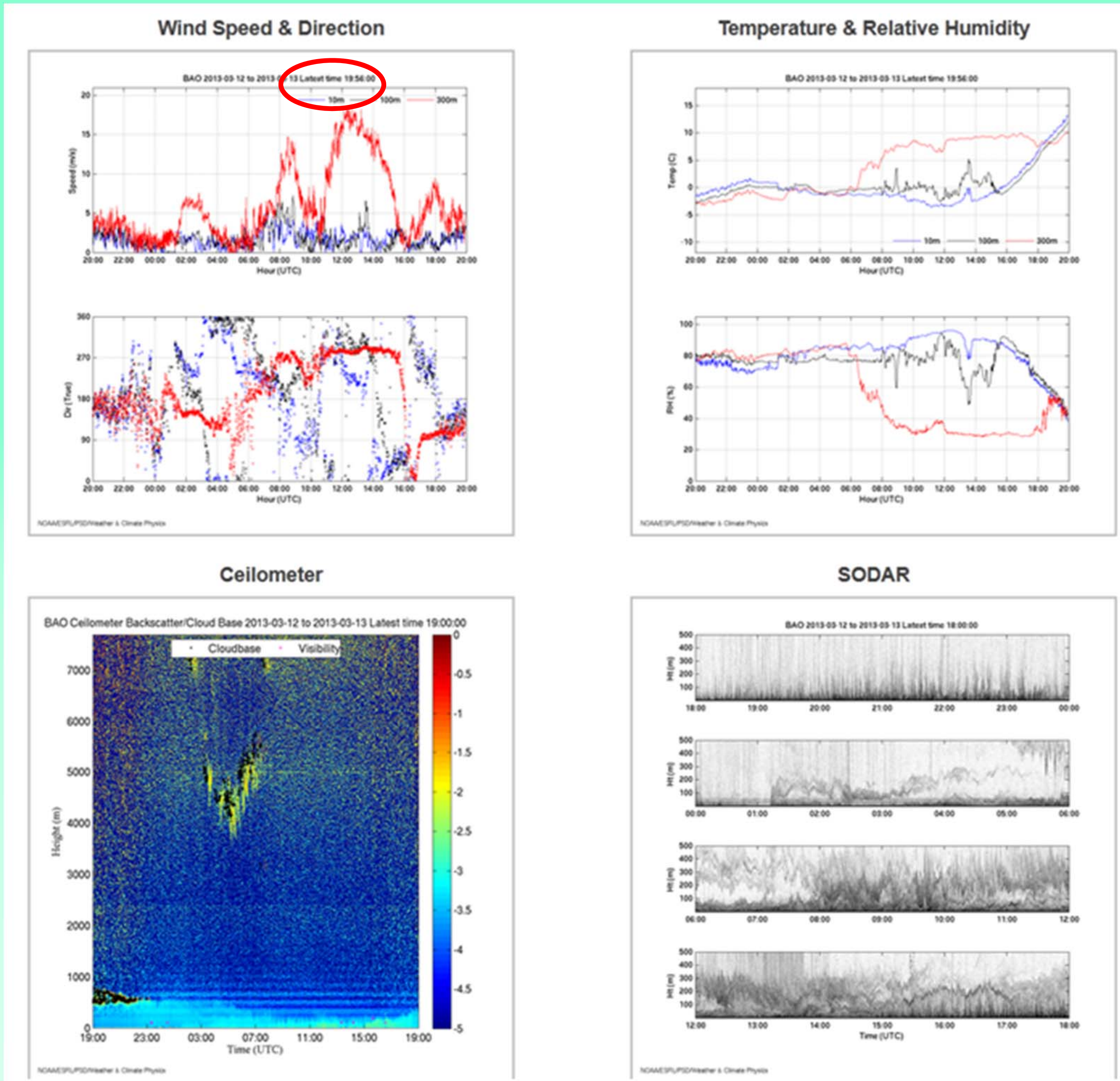

Ceilometer


SODAR

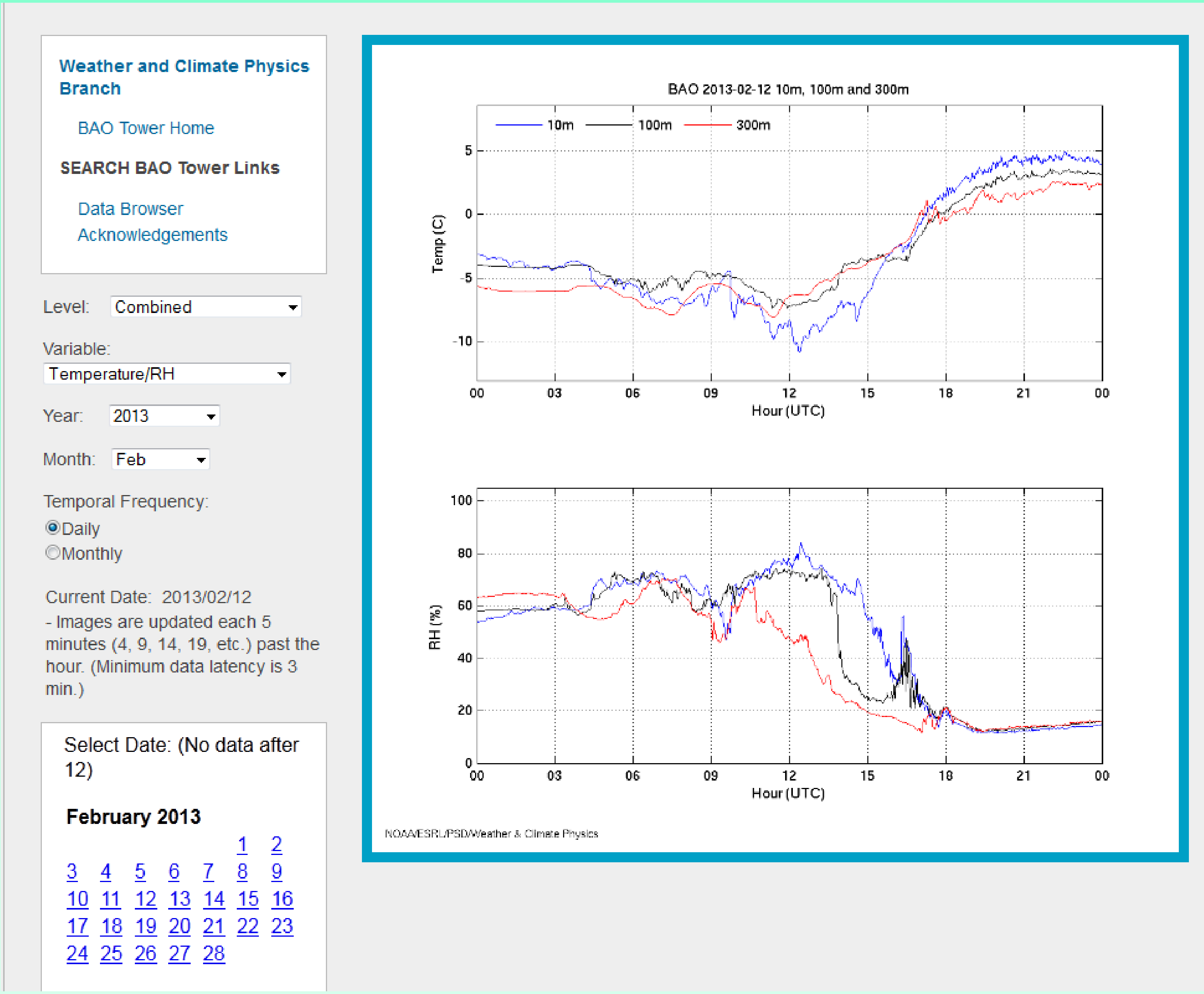
More Data

- » Data Browser for BAO Tower Data
- » FTP Site for BAO Tower Data
- » ESRL/GMD Tall Towers CO_2 Monitoring
- » ESRL/GMD Solar & Thermal Atmospheric Radiation
- » ESRL/GMD Surface Met

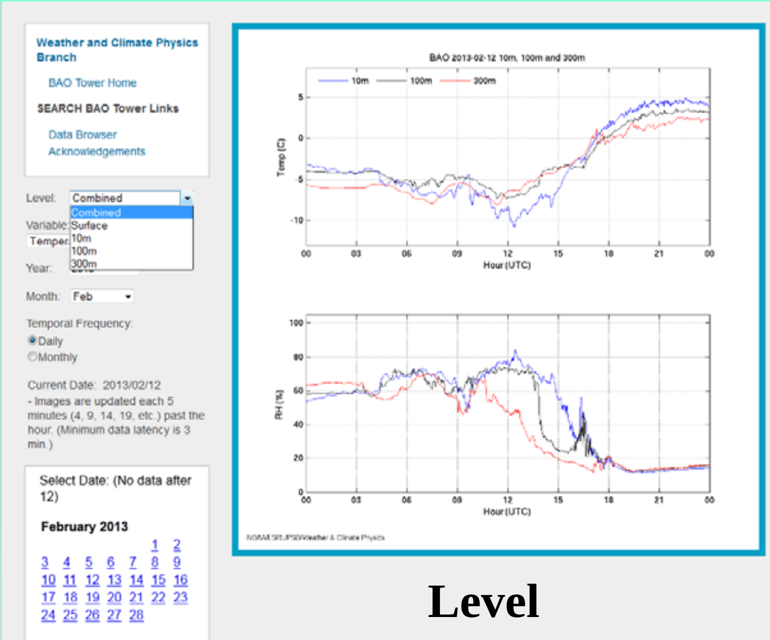




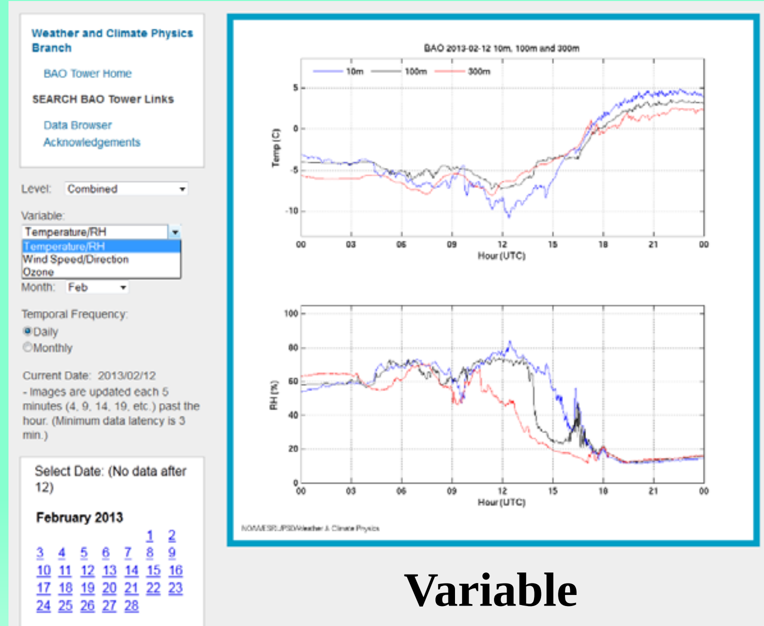
Near Real-Time Data



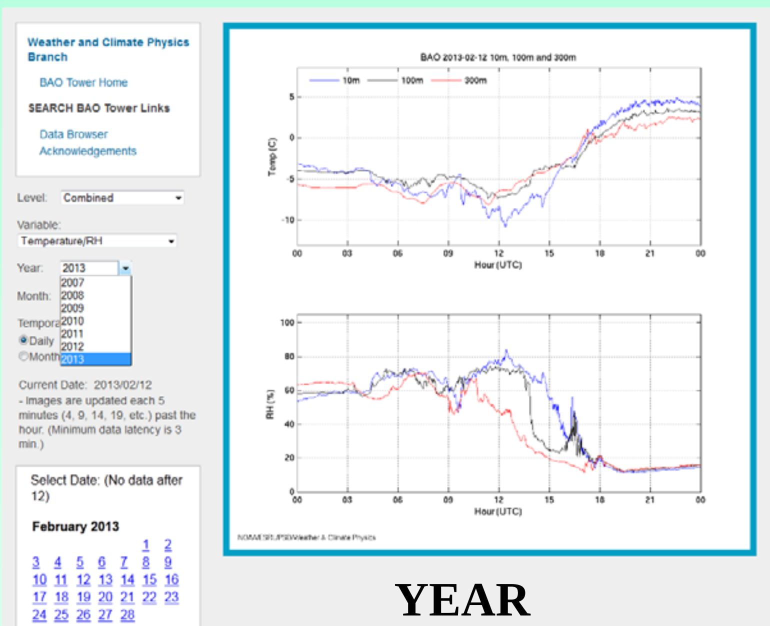
Data Browser



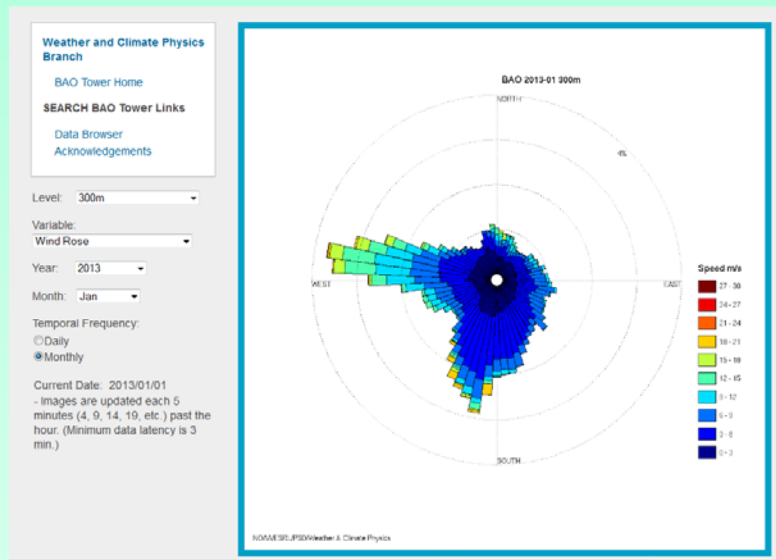
Level



Variable



YEAR

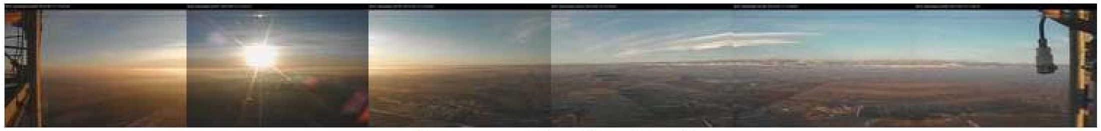


Month

T/RH Histograms, Ozone, wind rose, time series

BAO Tower Web Cam

NE 34°T	South Denver	NW 334°T



Panorama Looking South

Click thumbnails for higher resolution images:

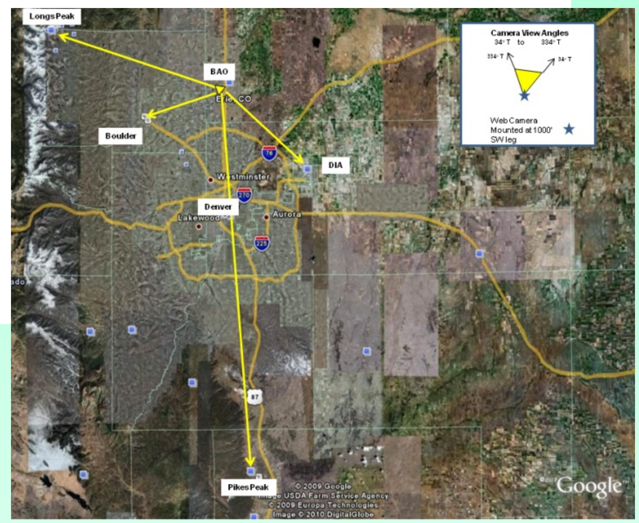
Boulder

Denver

Denver Zoom

DIA

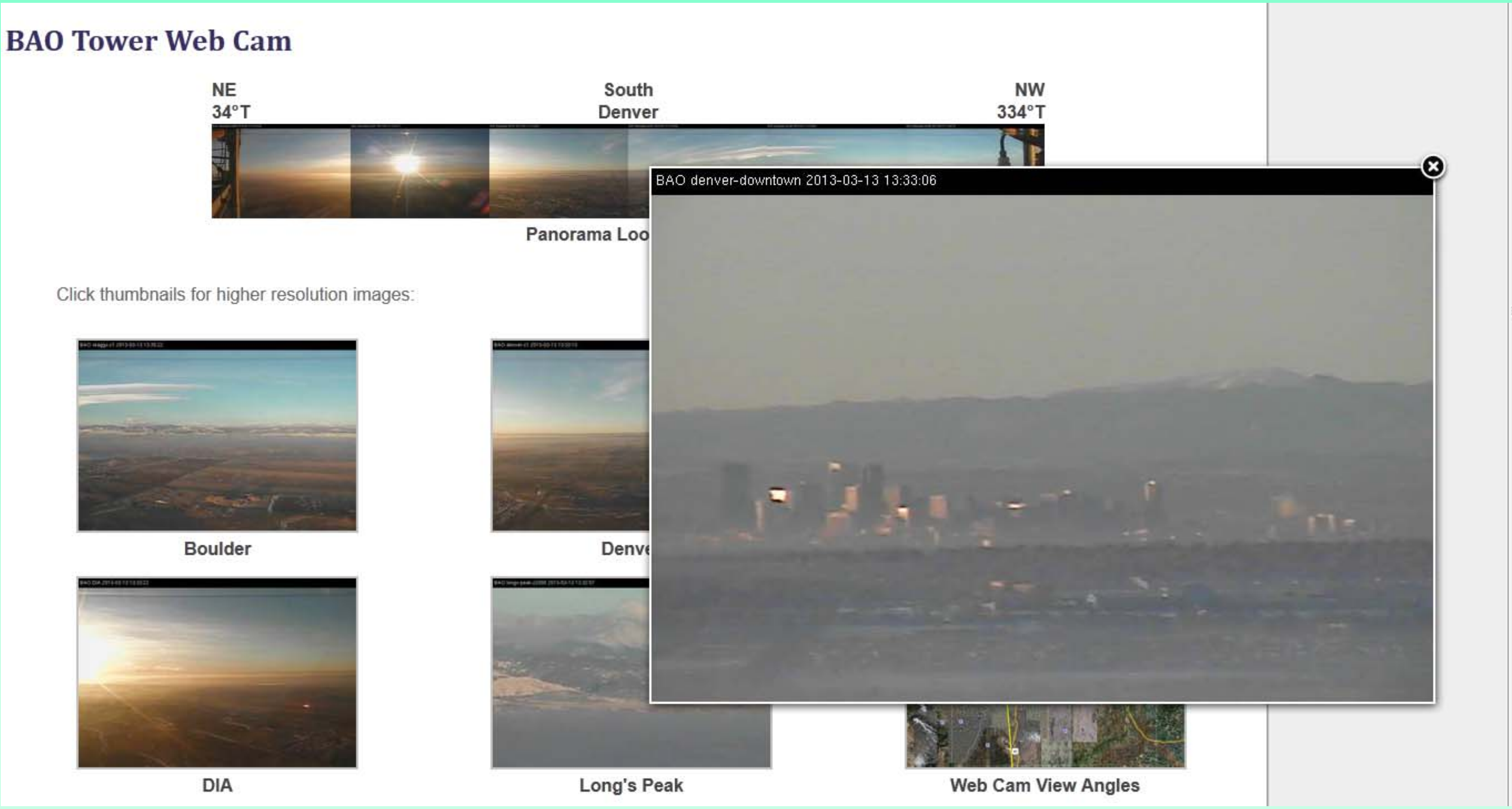
Long's Peak



BAO Web Camera

Hourly updates

http://www.esrl.noaa.gov/psd/technology/bao/



BAO Web Camera

Hourly updates

http://www.esrl.noaa.gov/psd/technology/bao/

BAO Reports

BAO Report 1:	Project Phoenix The September 1978 Field Report	Dec 1979
BAO Report 2:	The Boulder Low-level Intercomparison Experiment (Preprint of WMO Report)	Jun 1980
BAO Report 3:	Turbulence Statistics for Design of Wind Turbine Generators (Preprint of Report to DOE)	Dec 1980
BAO Report 4:	Studies of Nocturnal Stable Layers at BAO	Jan 1983
BAO Report 5:	An Evaluation of Wind Measurements by Four Doppler Sodars	Jul 1984
BAO Report 6:	A Field Comparison of IN SITU Meteorological Sensors	Dec 1985
BAO Report 7:	Project CONDORS Convective Diffusion Observed by Remote Sensors	Jul 1986

Past Field Programs and Studies

The BAO tower has served as a validation site for a wide variety of ground-based radar, lidar, sodar, infrasonic and radiometric remote sensing systems, and fixed, aircraft-, balloon-, and satellite-borne sensors.

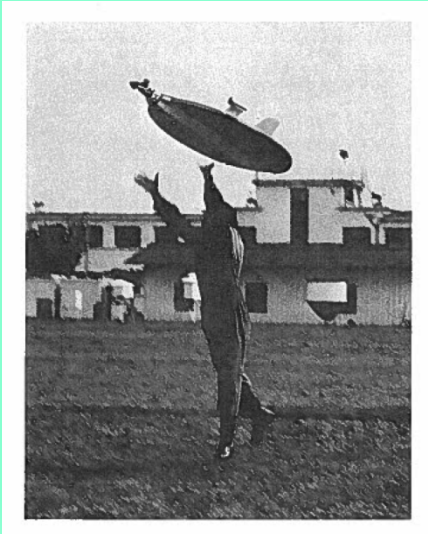
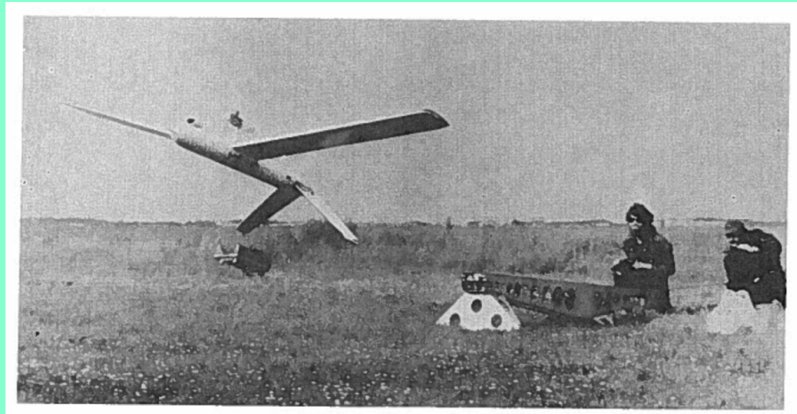
It has been featured in a number of investigations of fundamental boundary layer processes, such as convective mixing, wave and turbulence activity, and microbursts.

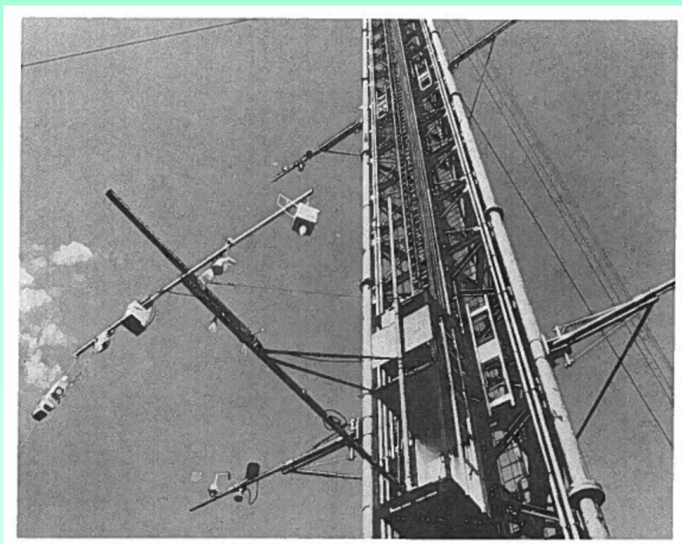
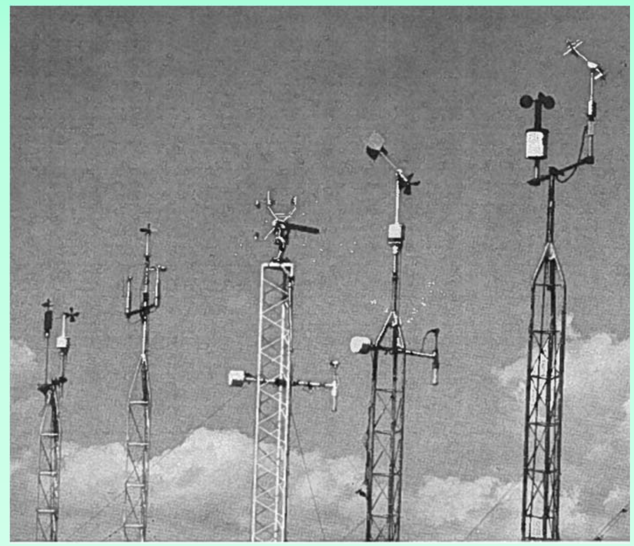
The BAO has been part of several mesocscale studies looking into the structure of passing cold fronts, convergence lines, wind shear, gust fronts, and mountain waves.

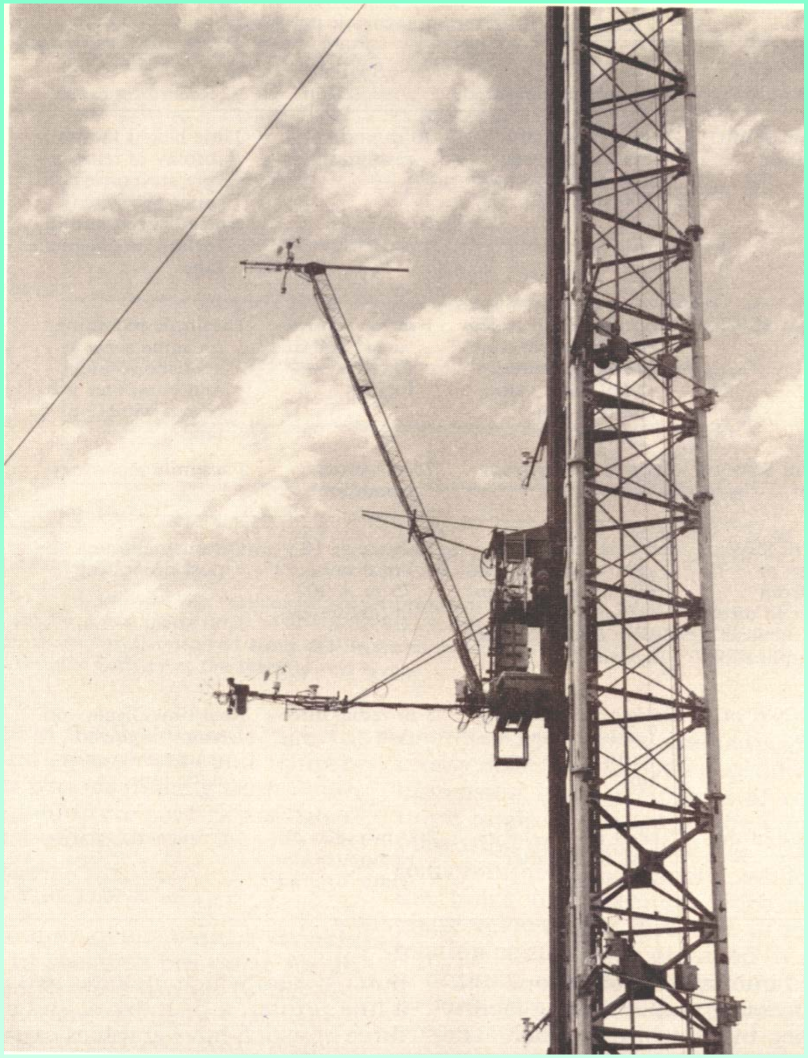
It has also been the centerpiece in a number of dispersion and air quality studies.

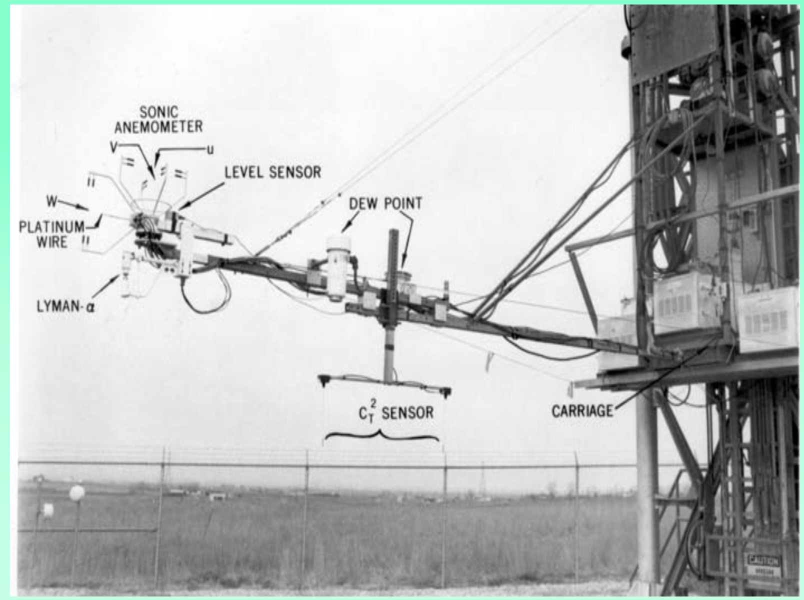
The BAO has hosted solar and IR radiation instruments for over 25 years. Measurements have been used to validate satellite retrievals and global climate models, in addition to serving as a climate record.

The BAO tower has been part of over 40 field programs, both large and small, resulting in **over 200 citations in refereed Journals.**





SONIC
ANEMOMETER
V
u
LEVEL SENSOR
W
PLATINUM
WIRE
DEW POINT
LYMAN-α
C_T^2 SENSOR
CARRIAGE

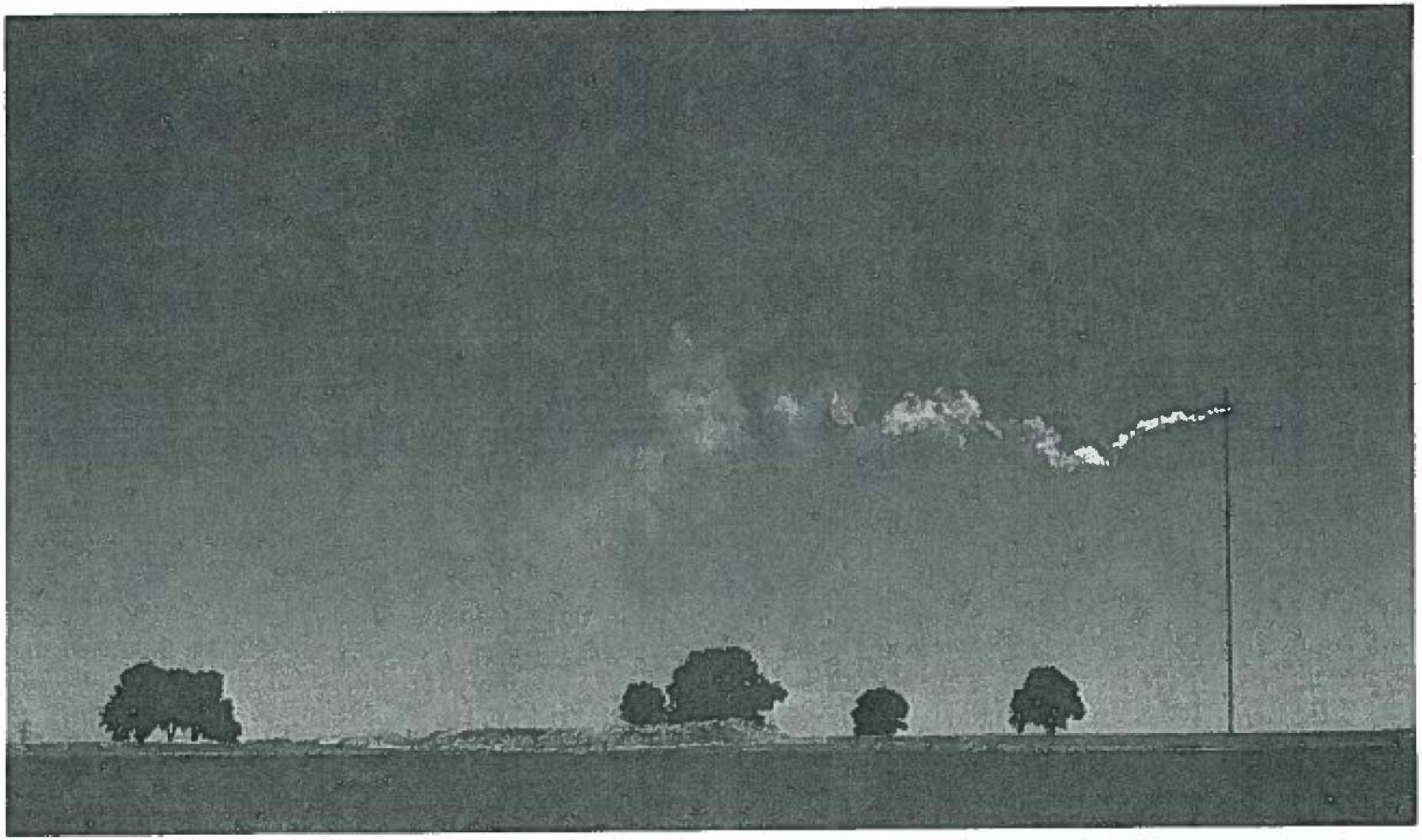


Fig. 1.1. Oil fog plume released from the 280 m level on the BAO tower during CONDORS 83. Aluminized chaff was also released simultaneously from a chaff cutter at the same level on the tower and tracked by radar.

Avalanches

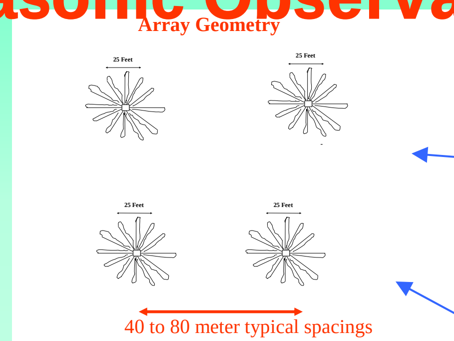
Ocean waves

Meteors ***

Severe Weather

Fires

Infrasonic Observatory



Tornadoes

Earthquakes

TLE's

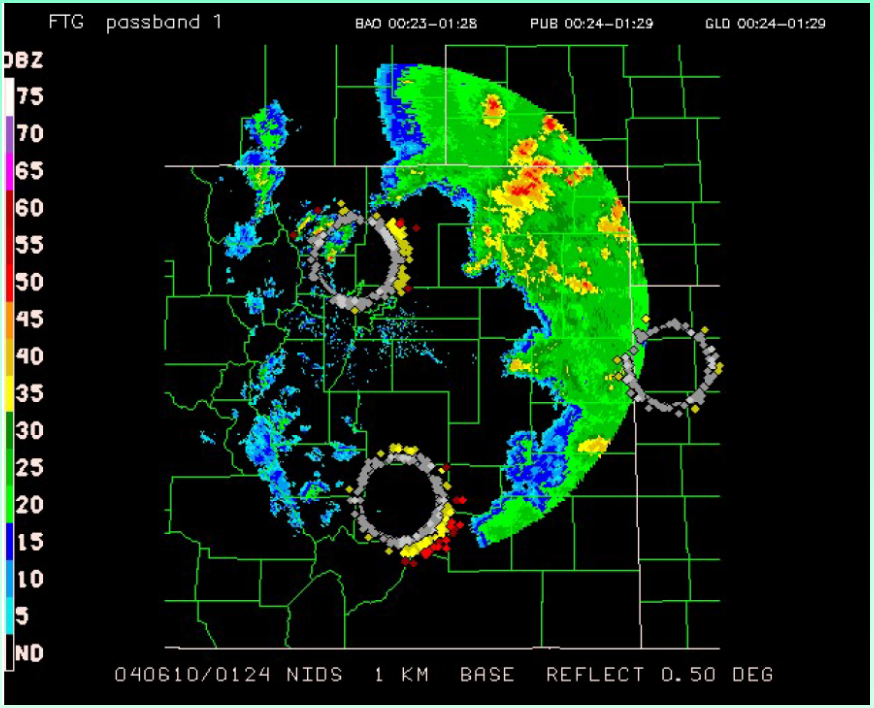
Explosions

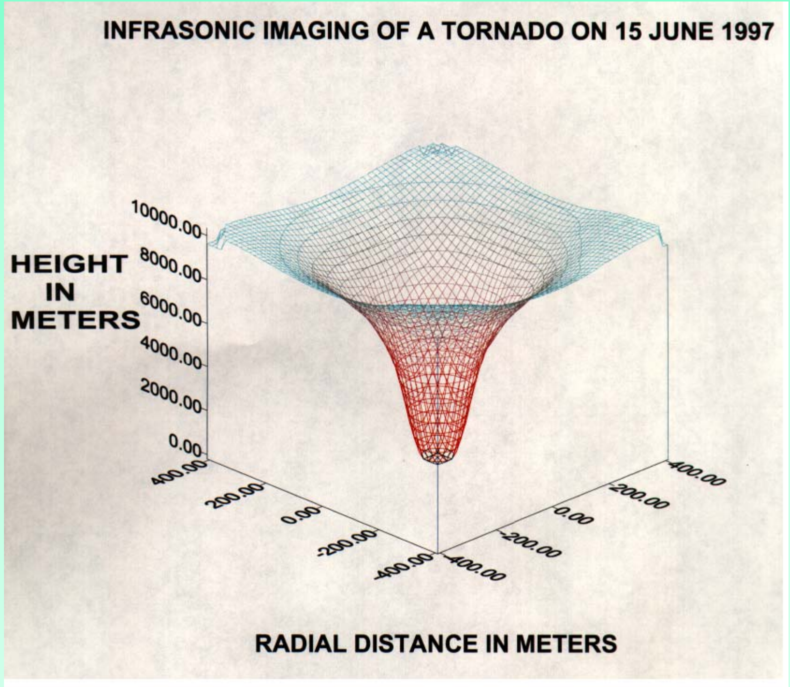
Volcanoes

Other??

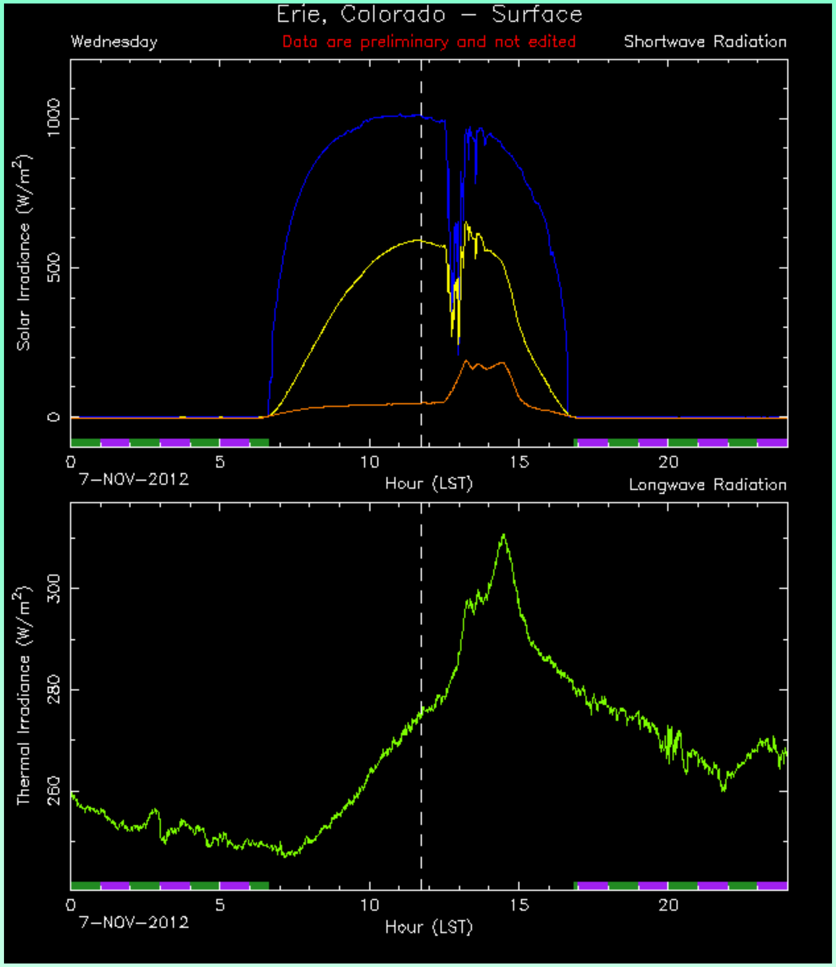
Turbulence

Infrasound
(Bedard et al.)





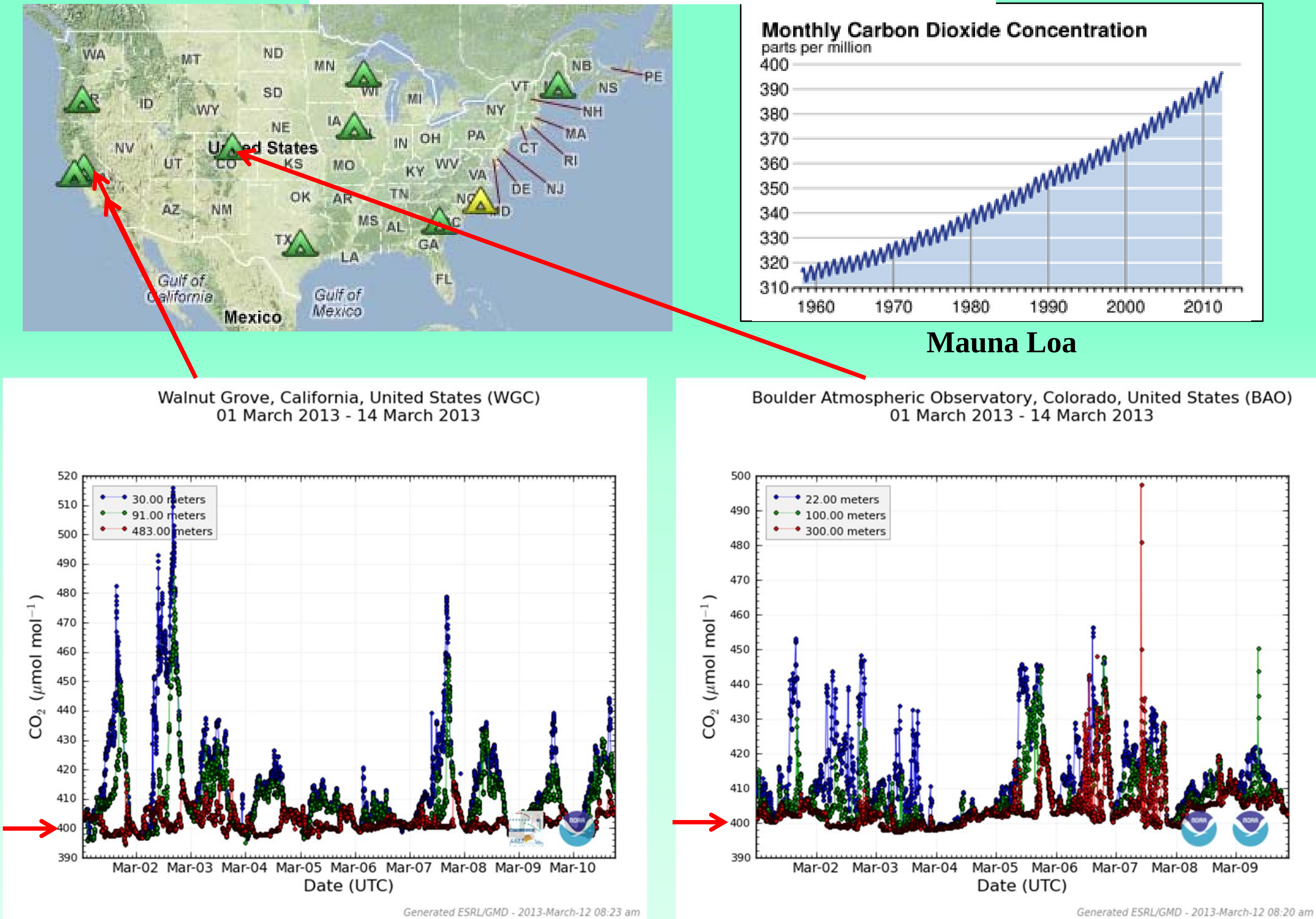
Infrasonic Observations
(Bedard et al.)

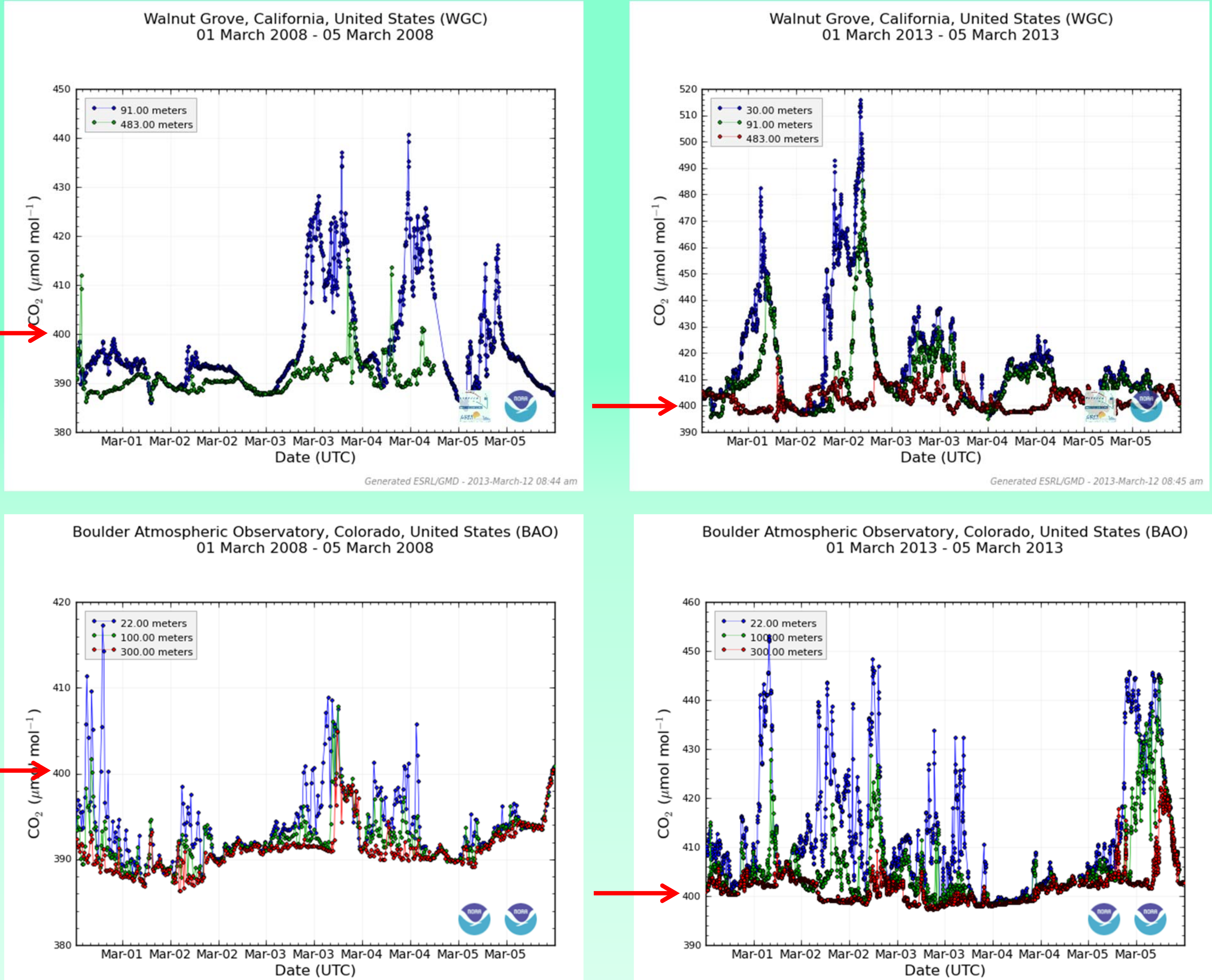


Up and down facing long- and short wave radiometers
Sun tracker (diffuse)
Sunphotometer (NASA)

NOAA / ESRL / GMD Radiation Group
BSRN Site

NOAA/ESRL/GMD Tall Tower Network

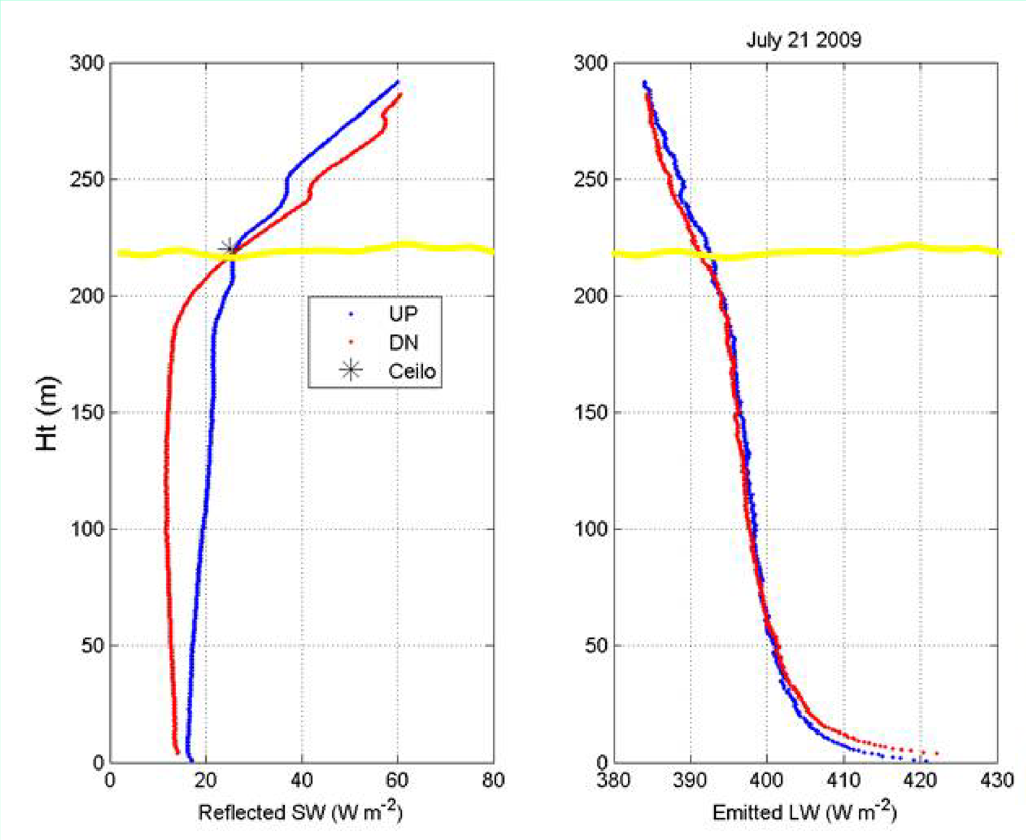




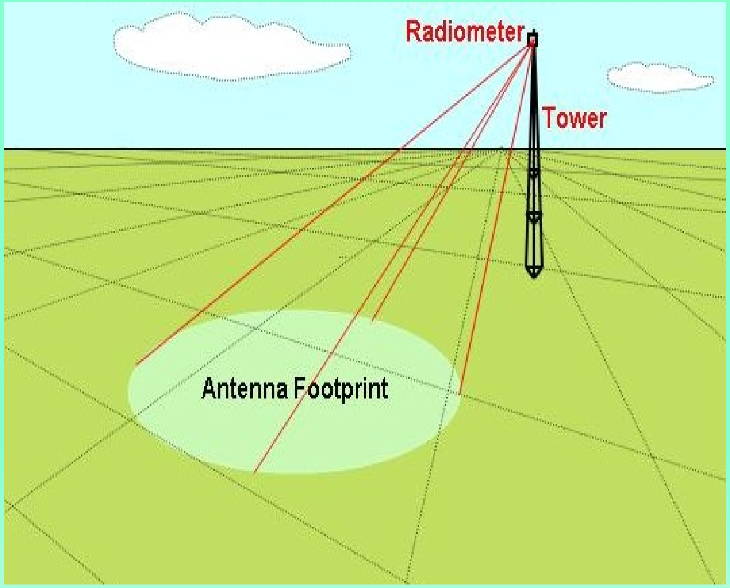
NOAA / ESRL / GMD Tall Tower Network

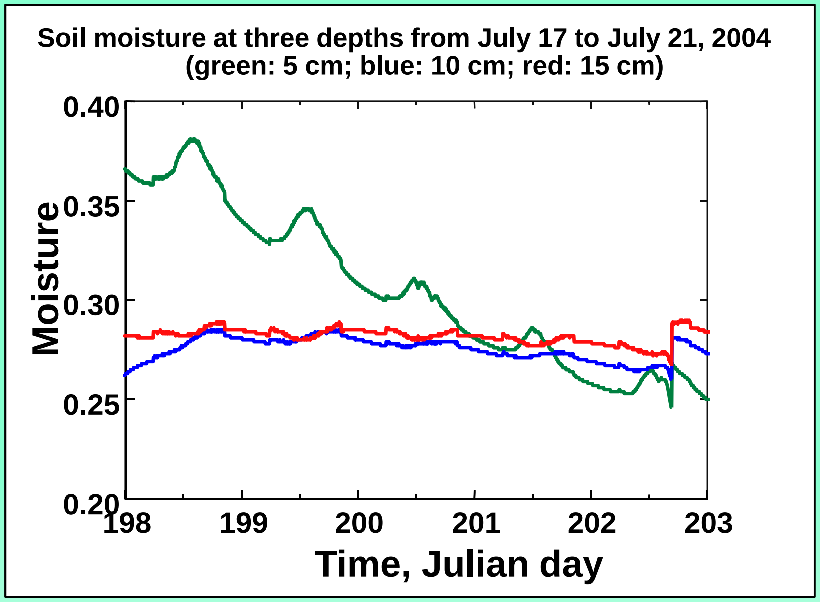
CU Aerospace Senior Projects

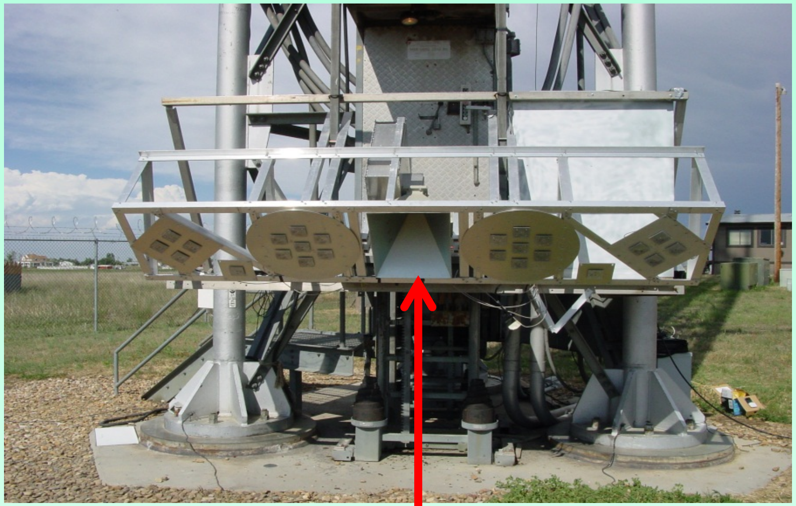
NCAR dropsonde



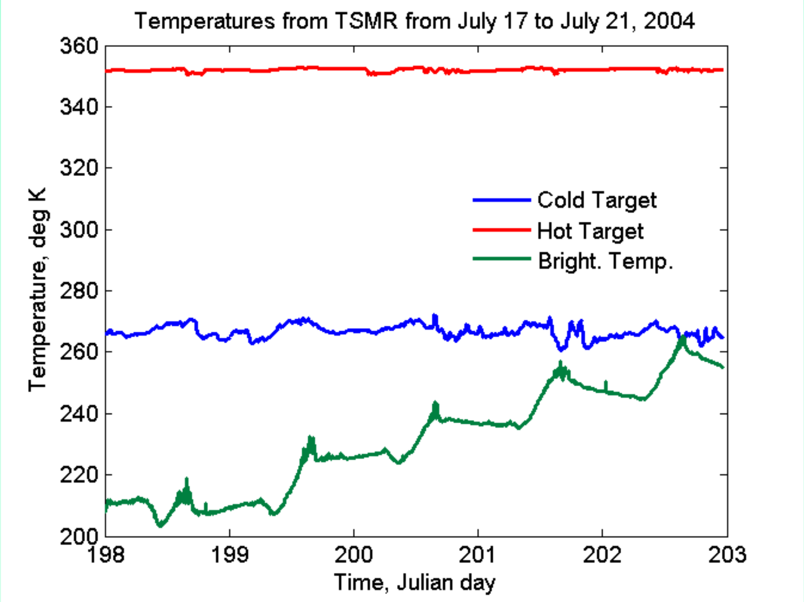
Teacher in the Lab
Dr. Peter Blanken (Geography)





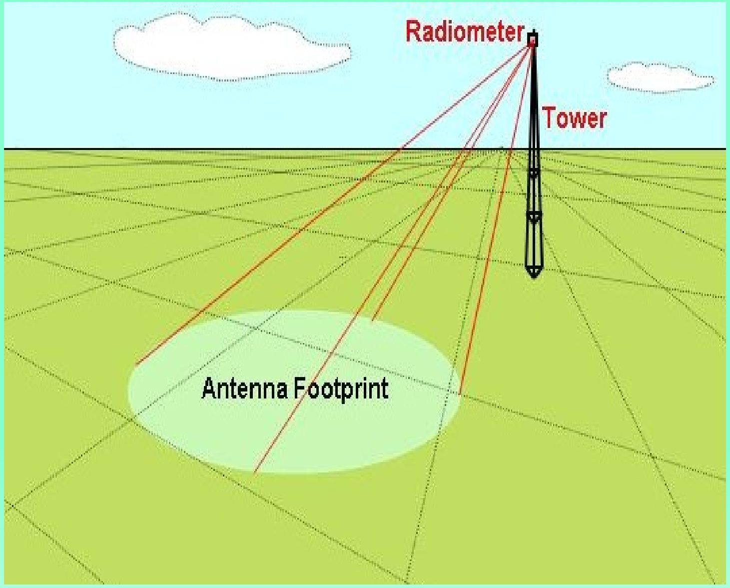


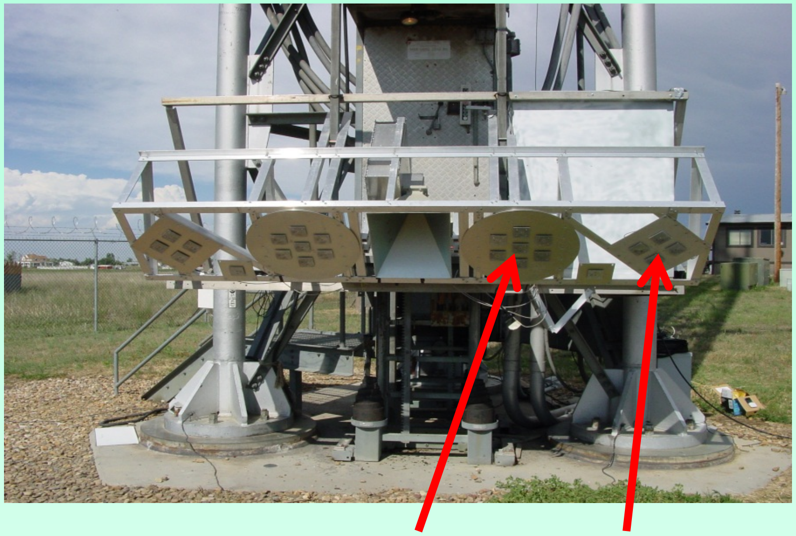
Radiometer L- Band

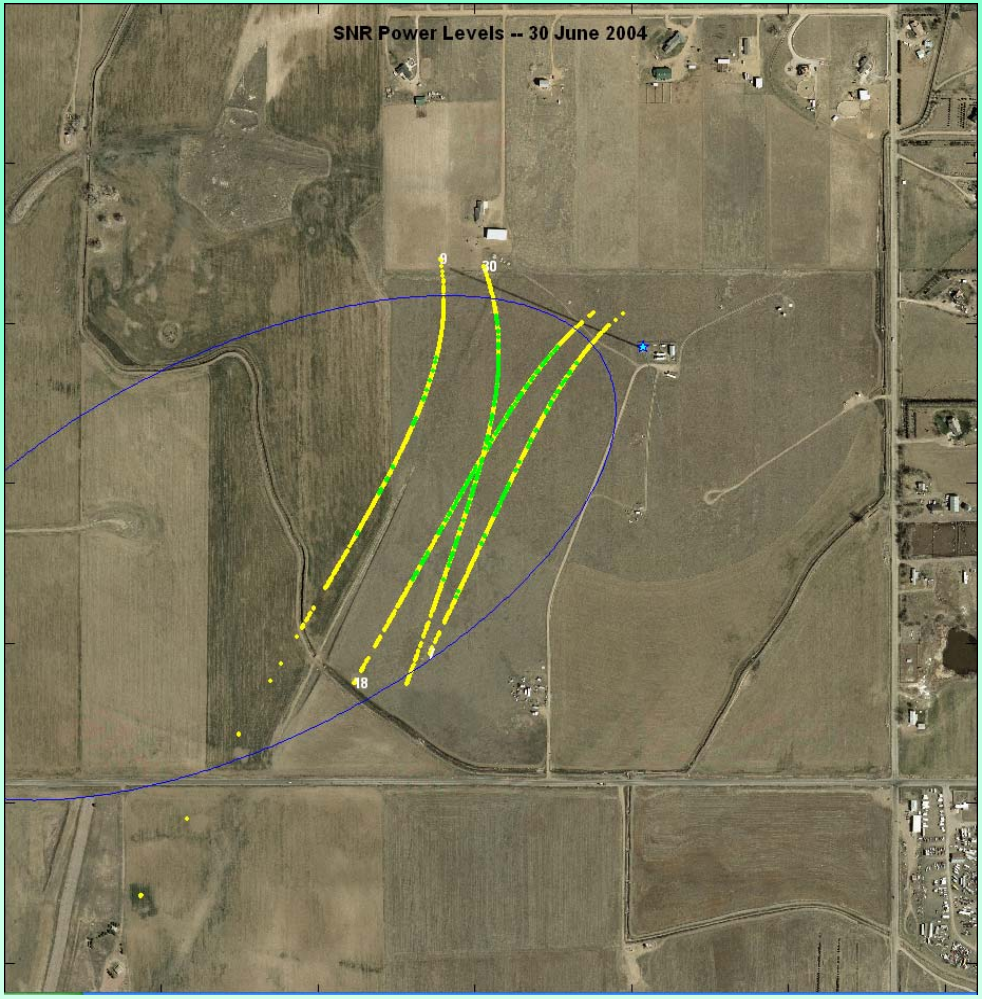


Radiometer

Zavorotny et al. 2004



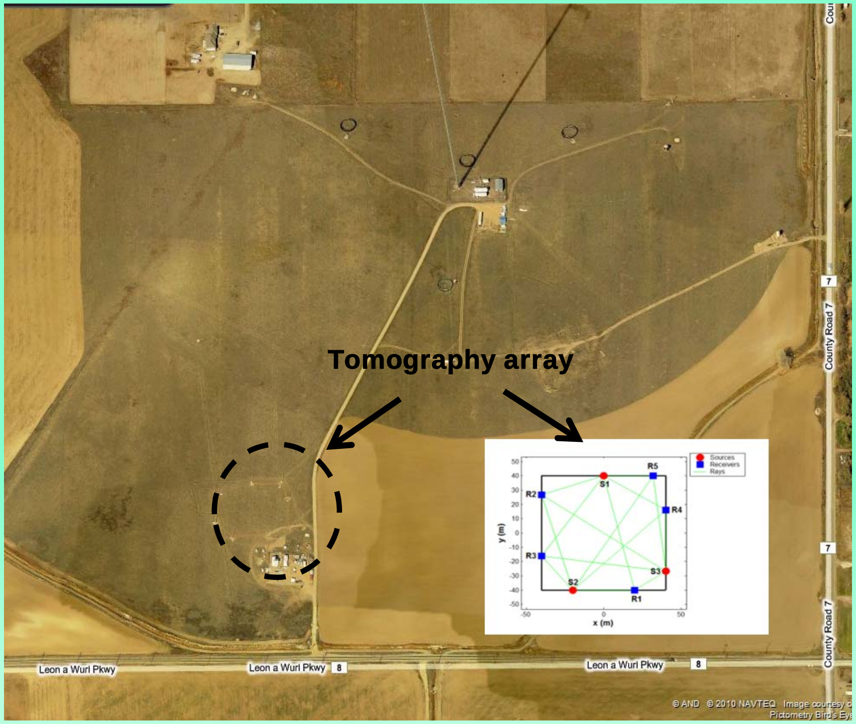


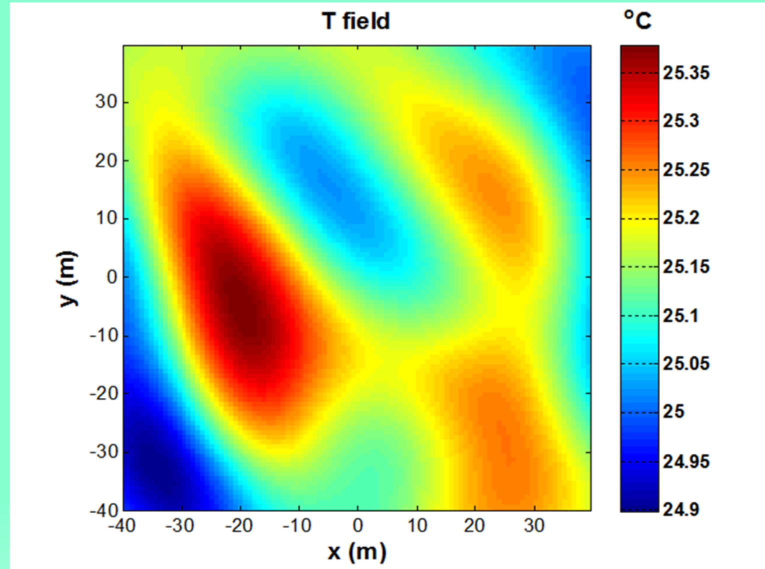


High gain Low gain

GPS Relectometry

Zavorotny et al. 2004

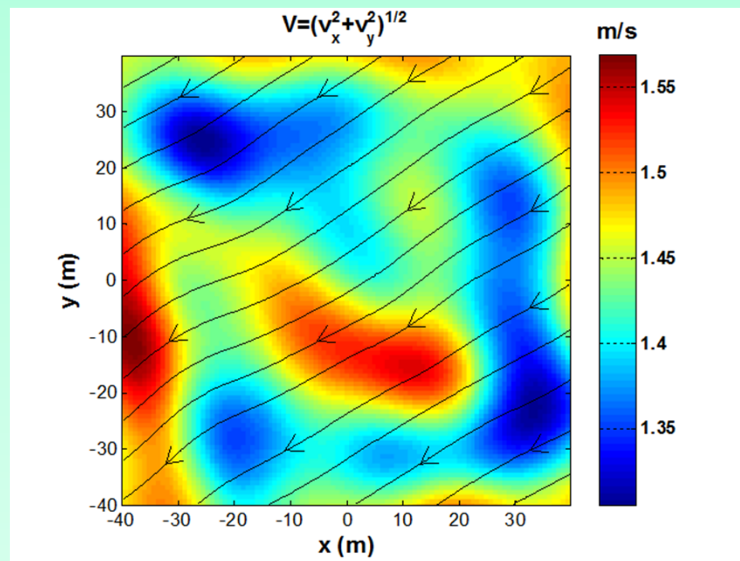




Temperature field reconstructed with TDSI July 09, 2008.

microphone

Speaker

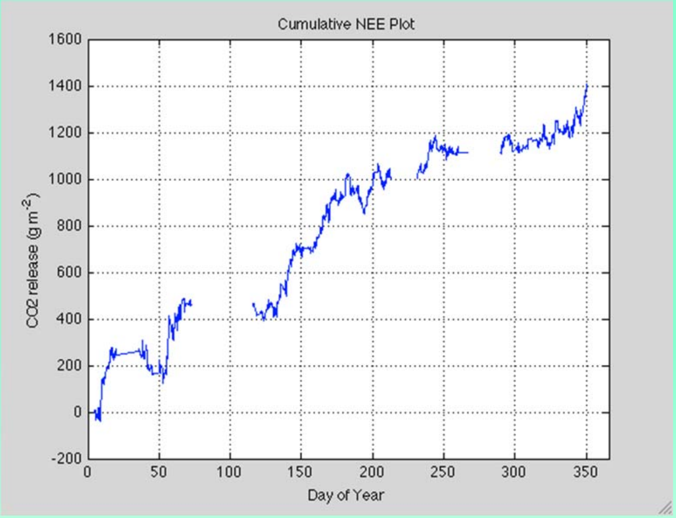


Magnitude of the wind velocity reconstructed with TDSI July 09, 2008. Arrows indicate the direction of the wind velocity vector.

Acoustic Tomography

Ostashev et al. 2008

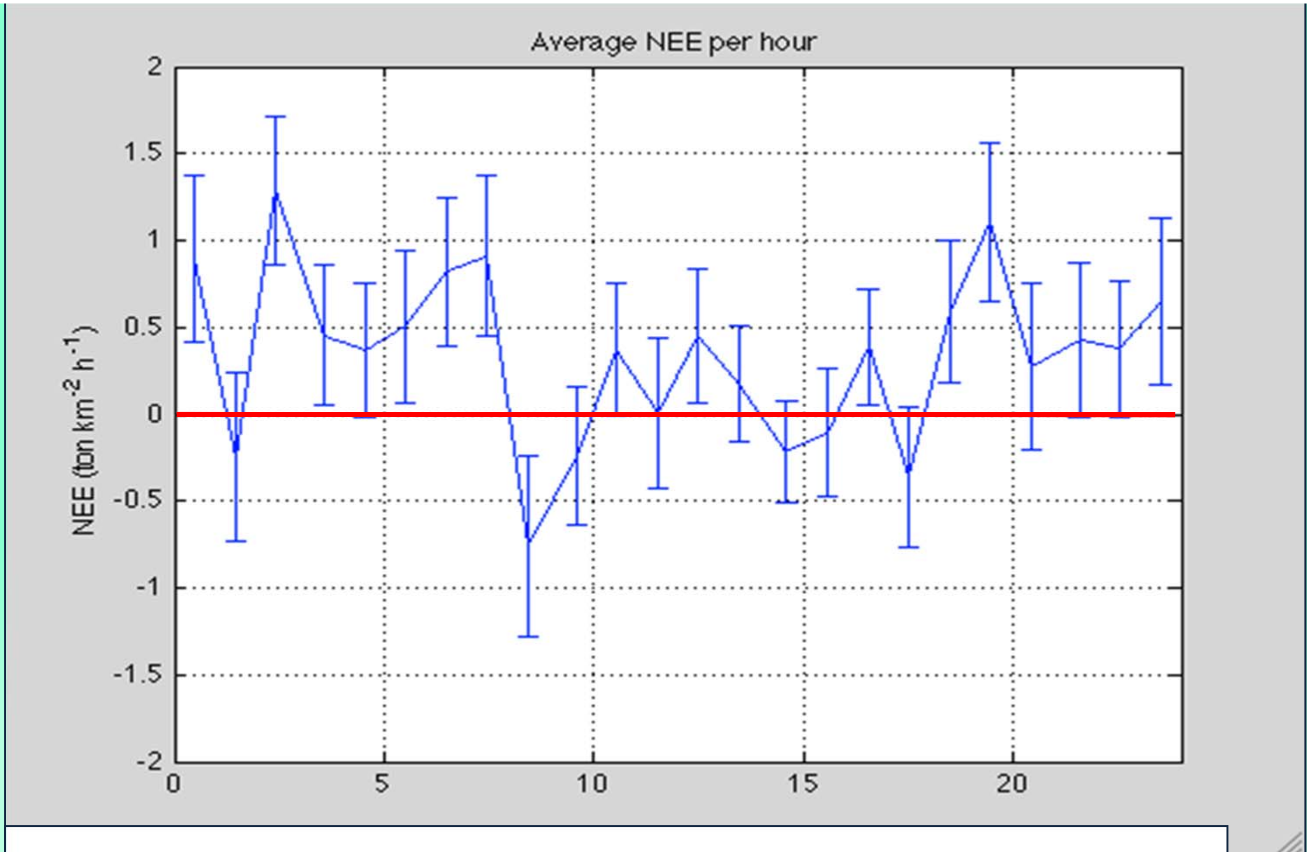
REGIONAL EDDY COVARIANCE MEASUREMENTS OF CO_2 EXCHANGE FROM A TALL TOWER NEAR BOULDER, COLORADO



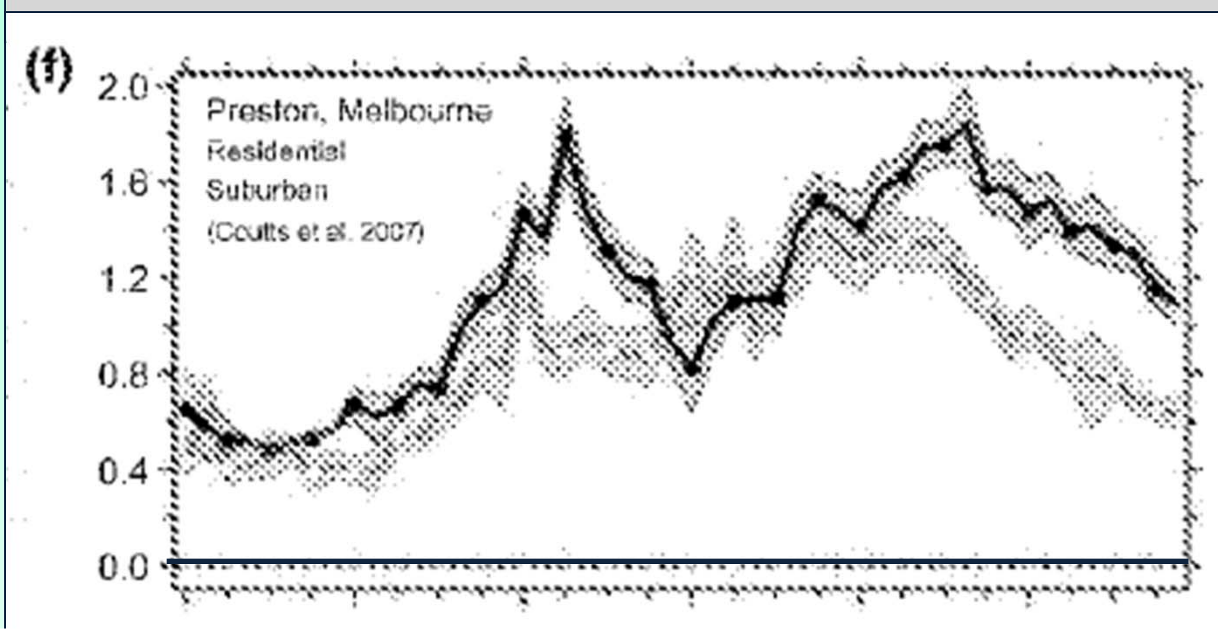
- **To derive a regional estimate of Net Ecosystem Exchange (*NEE*) from a tall tower**
- **To determine the controlling factors of *NEE* in the region**
- **To examine variations in *NEE* associated with different land uses and with seasonal land cover changes**

Emily Grahm
MS Geography 2012

Boulder Atmospheric Observatory

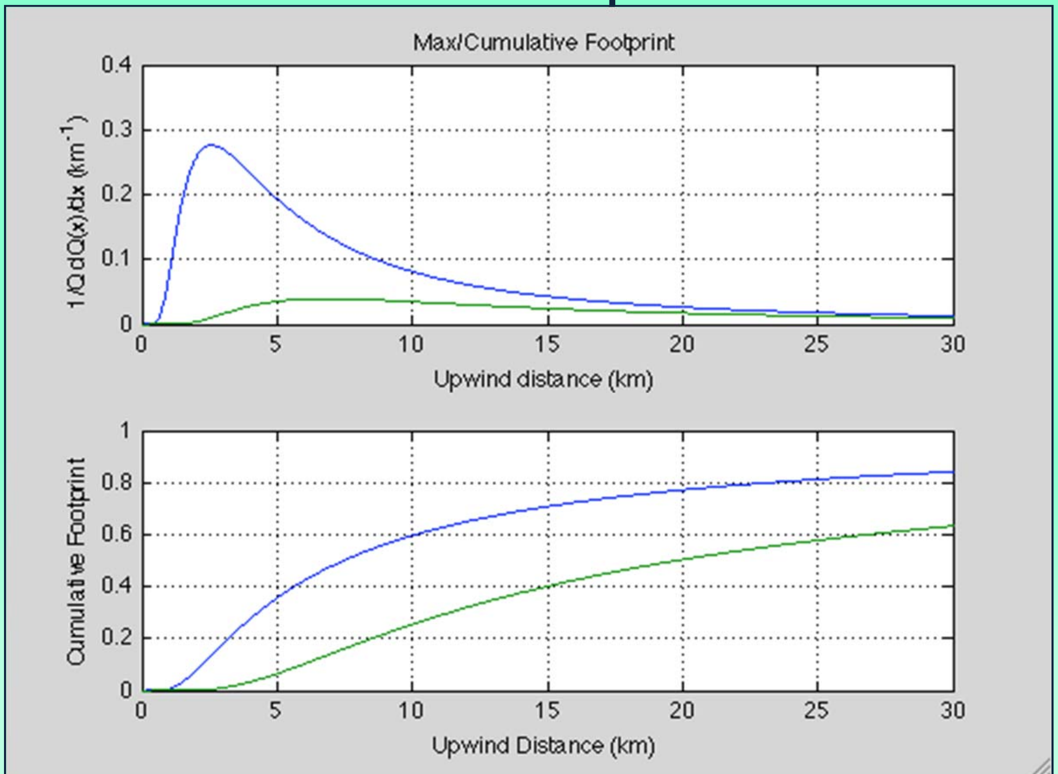


Residential Suburban, Preston, Melbourne, Australia



Graph from Velasco & Roth 2010, data from Coutts *et al.* 2007

Turbulent Flux Footprint Estimates



Time Period	Peak (km)	50% (km)	70% (km)
Daytime	2.60	7.50	14.55
Nighttime	6.87	19.80	38.55
Spring Daytime	6.86	19.80	38.50
Summer Daytime	6.76	19.50	37.95
Fall Daytime	2.43	7.03	13.65
Winter Daytime	6.83	19.70	38.30
Spring Nighttime	6.82	19.70	38.35
Summer Nighttime	7.47	215.45	419.45
Fall Nighttime	N/A	N/A	N/A
Winter Nighttime	N/A	N/A	N/A

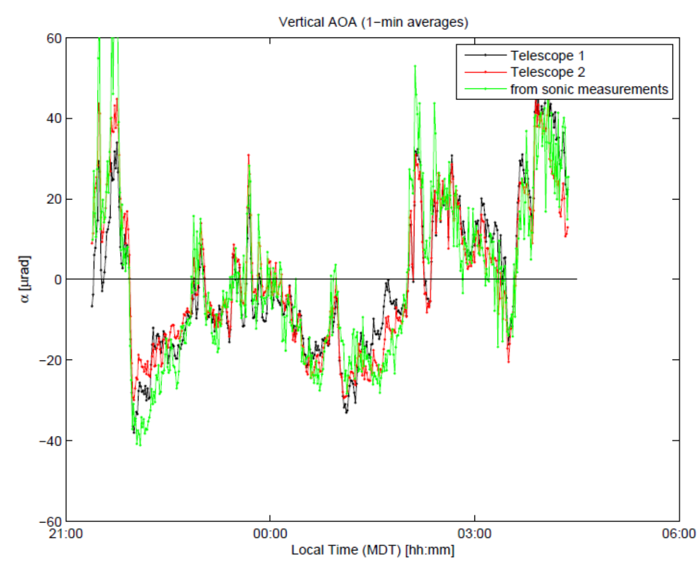


Figure 3: *1-min averages of observed and predicted vertical AOA fluctuations. Black and red: observations by means of Telescope 1 and Telescope 2, respectively. Green: predictions on the basis of vertical temperature gradients measured with two vertically spaced sonics.*

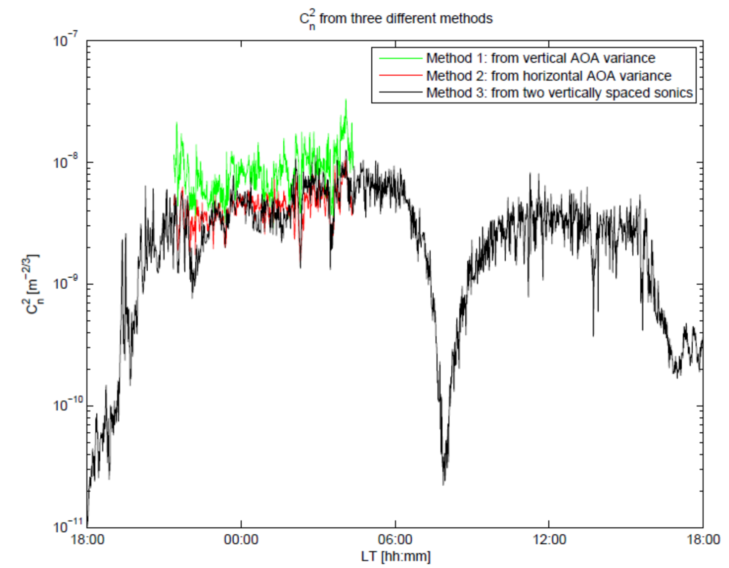


Figure 4: *Time series of C_n^2 retrieved from 1-min variances of α (green), of β (red), and of the instantaneous temperature difference measured with two vertically spaced sonics (black). The AOAs were measured with Telescope 1.*

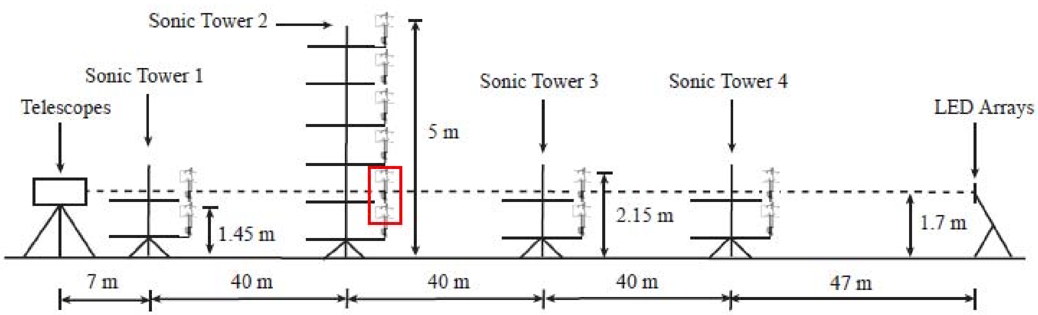
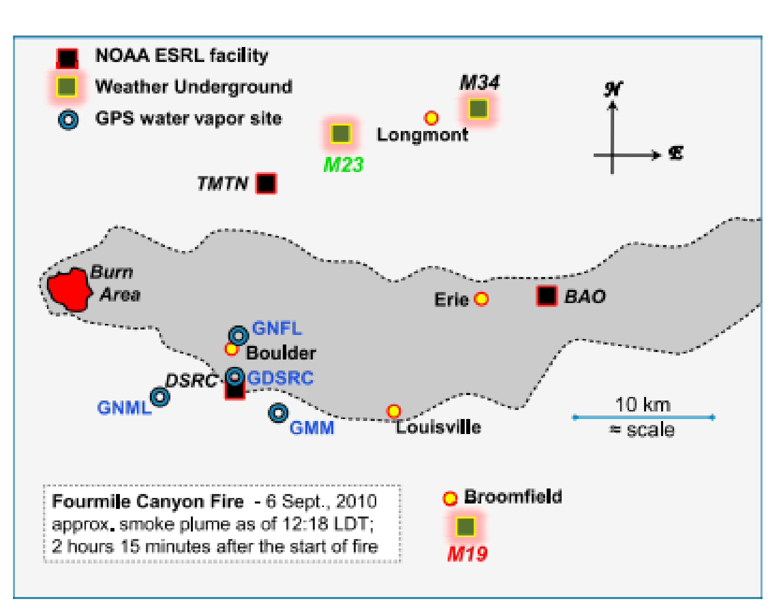


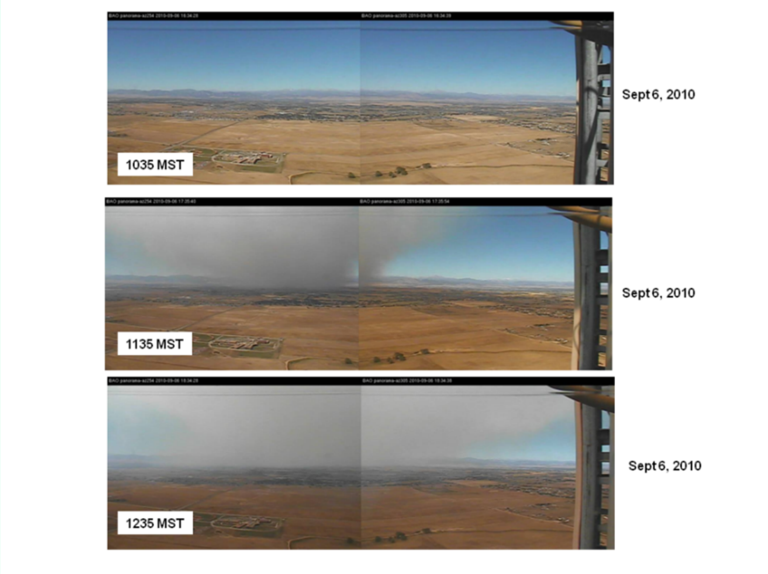
Figure 1: *Experimental setup of several optical propagation experiments conducted in August, 2012 at the Boulder Atmospheric Observatory near Erie, CO. Only data from the two sonics marked by the red box have been used for the present study.*

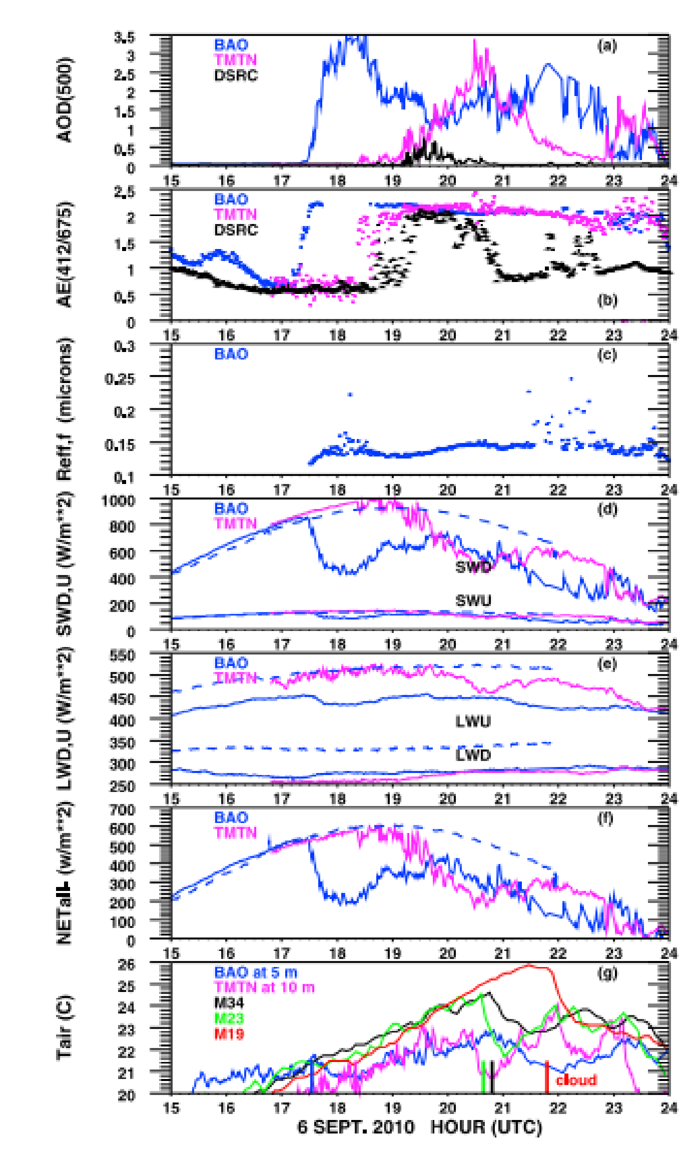
Figure 2: *The two 14-inch telescopes, spaced laterally by 2.0 m and pointing at two test-light arrays, which were also laterally spaced by 2.0 m and 174 m away from the telescopes. The propagation paths were horizontal and 1.7 m above flat ground.*

Optical Anemometry

Muschinski and Tichkule, 2012



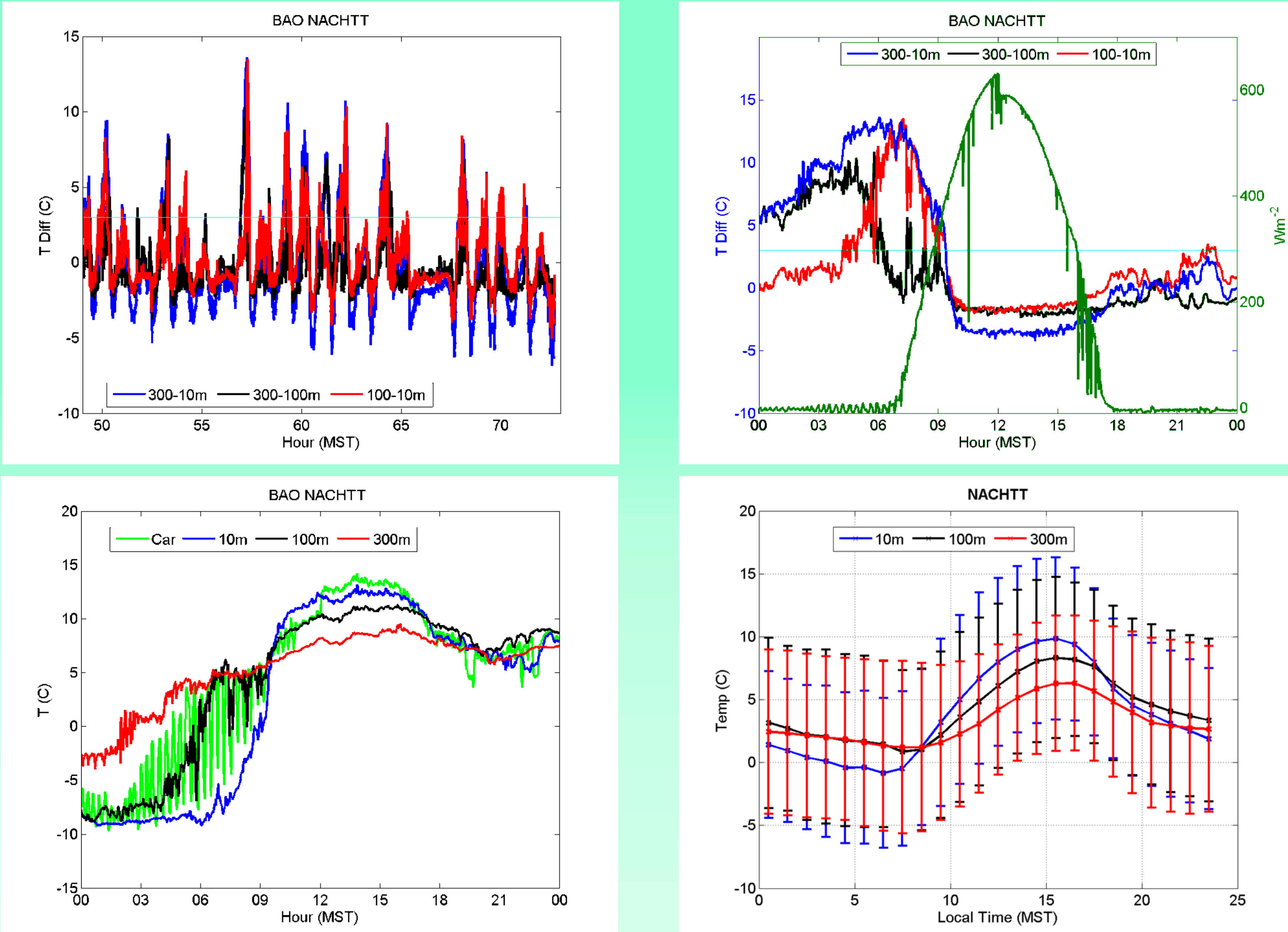




Radiative Forcing

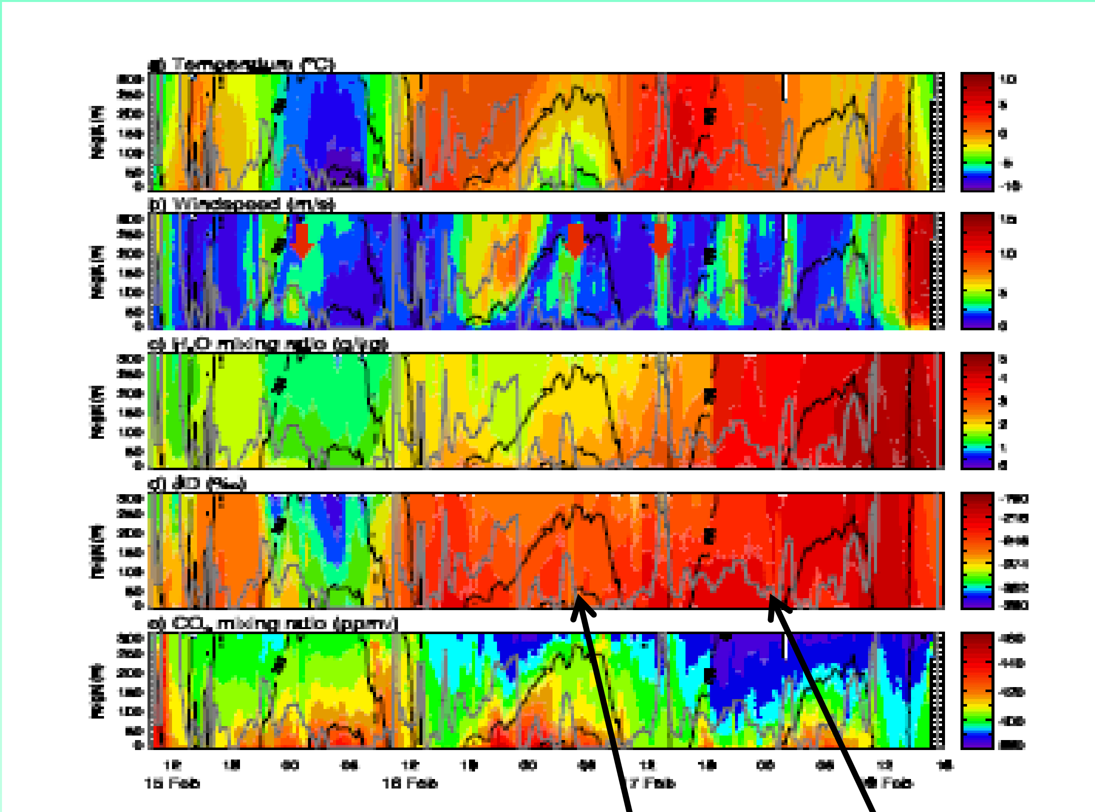
Stone et al., 2011

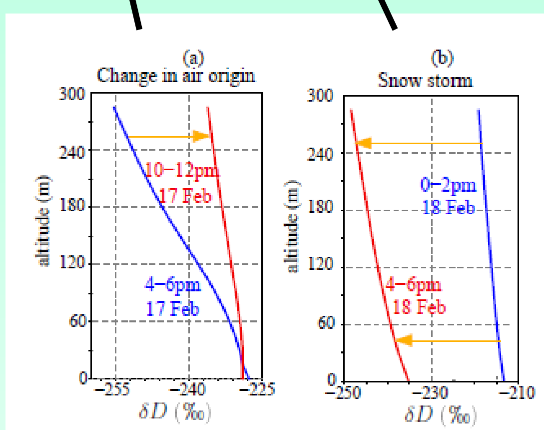
Nitrogen, Aerosol Composition, and Halogens on a Tall Tower (NACHTT 2011)



Nitrogen, Aerosol Composition, and Halogens on a Tall Tower NACHTT 2011 Wolfe et al.

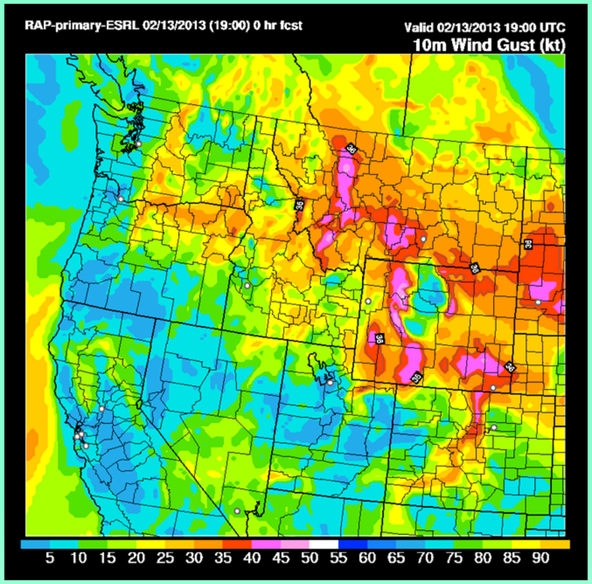
Determining water sources in the boundary layer from tall tower profiles of water vapor and surface water isotope ratios after a snowstorm in Colorado



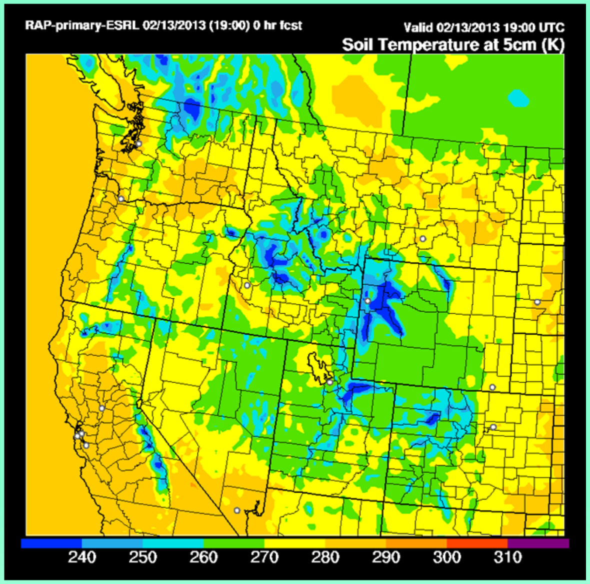


Water Vapor

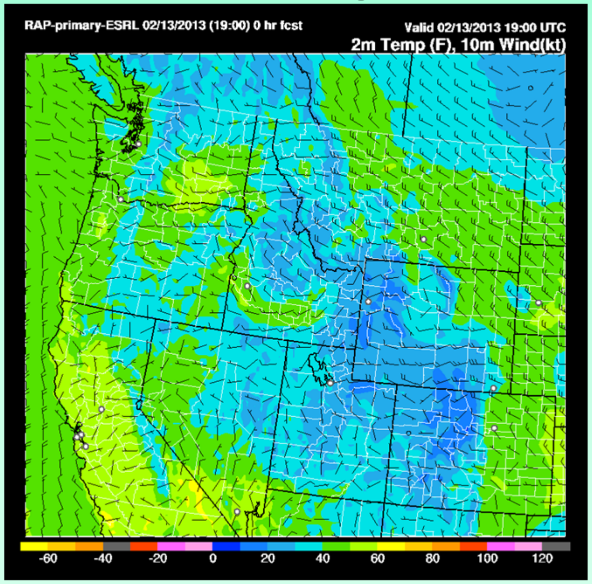
Noone et al. 2013



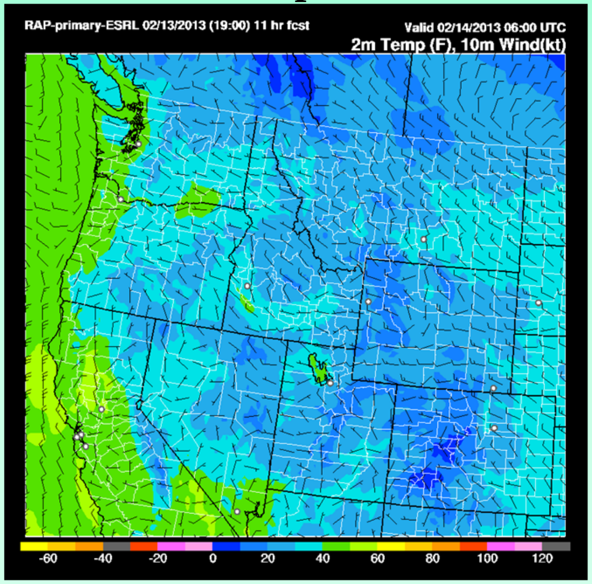
10m wind gust



Soil Temperature

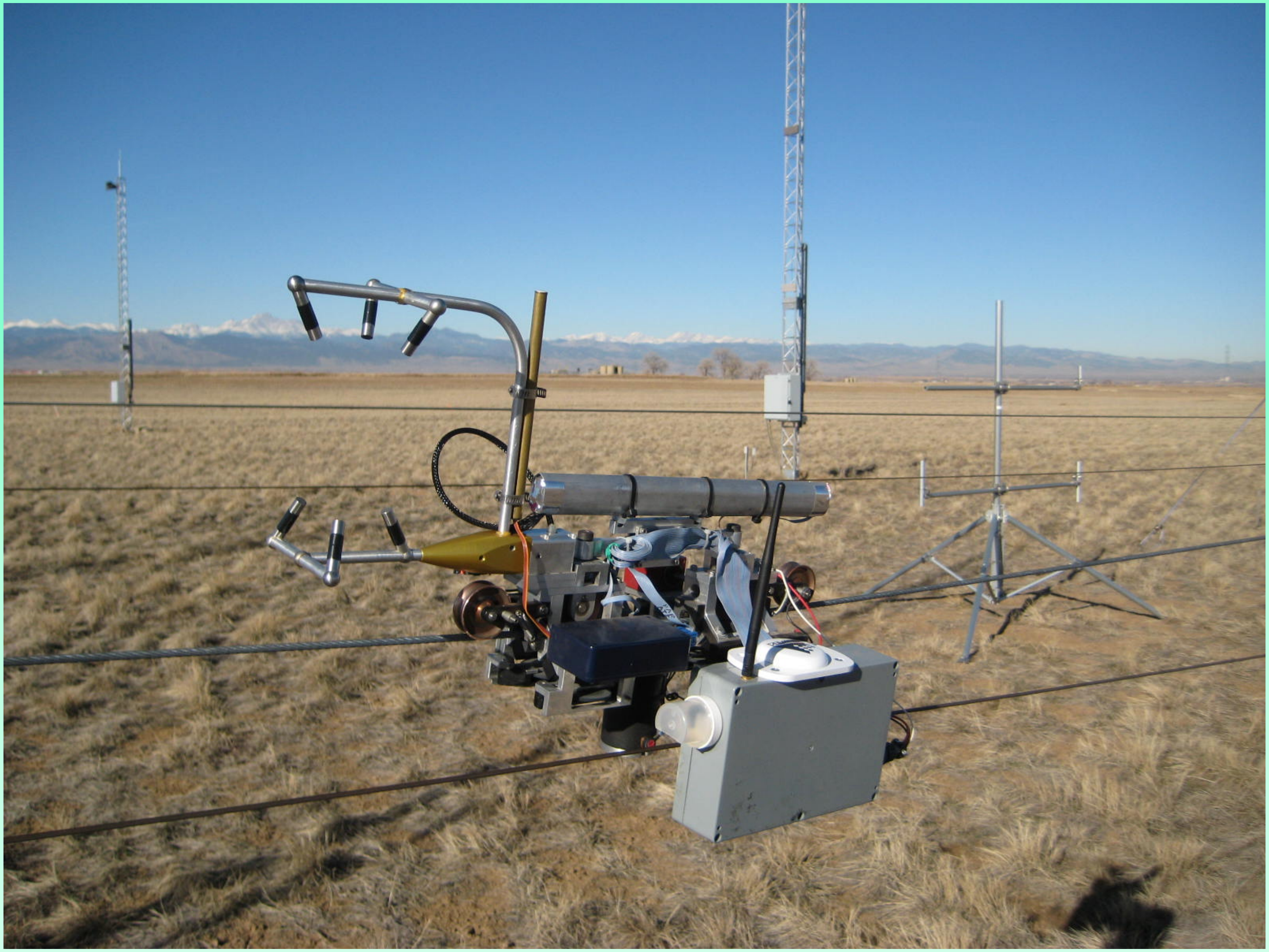


2m T and Wind valid 19Z



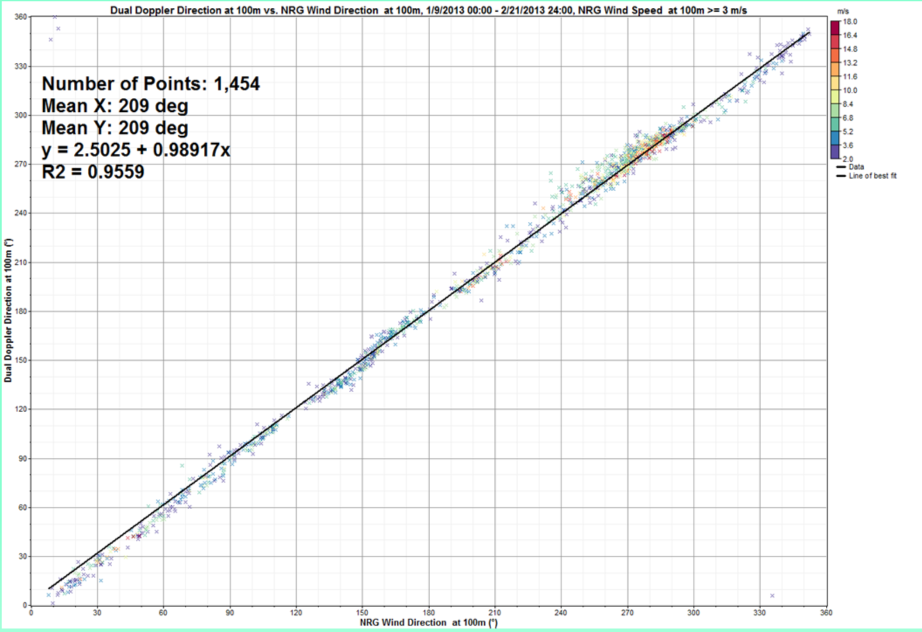
2m T and Wind valid 06Z

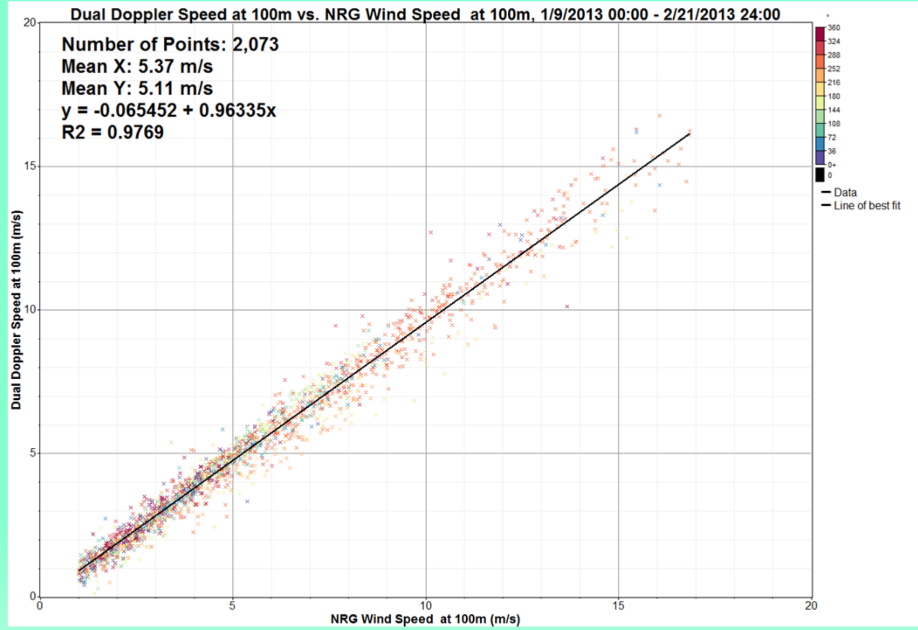
The **Rapid Refresh** (RAP) model replaced the RUC as the NOAA next-generation hourly-updated assimilation/modeling system operational at NCEP at 12z on 1 May 2012.



TRAnsect Measurement system (TRAM)
NCAR Steve Oncley

TRAnsect Measurement system (TRAM)
NCAR Steve Oncley

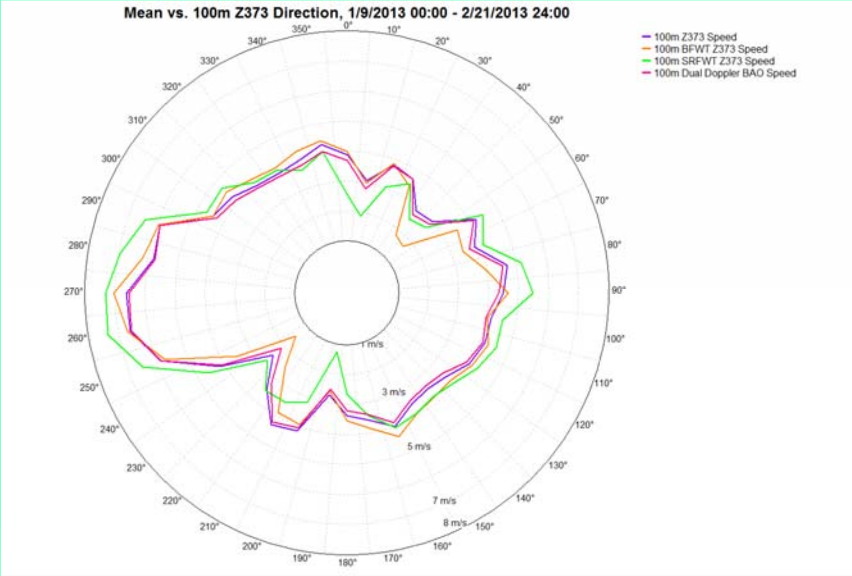


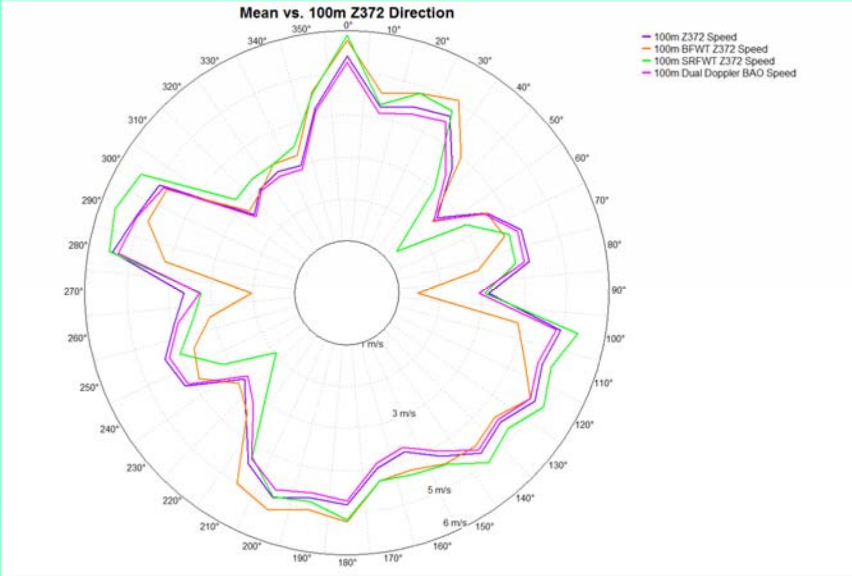


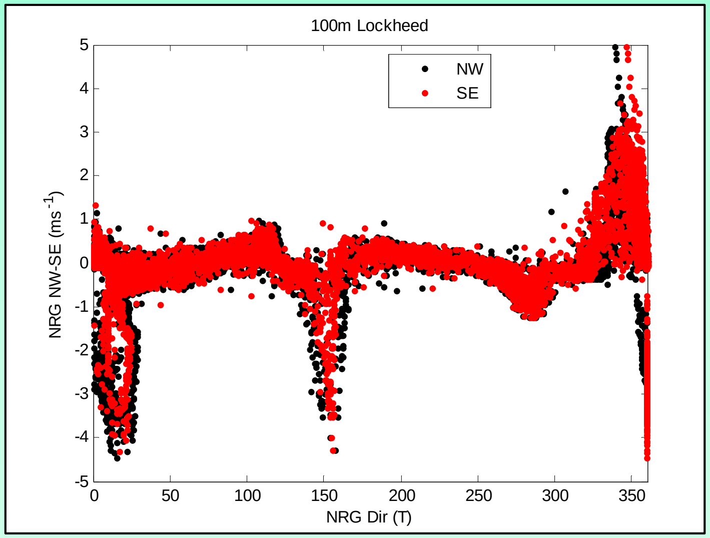
WindTracer
Scanning lidar

WINDTRACER® Lockheed Martin
(Barr et al.)

ZephR
Profilling lidar





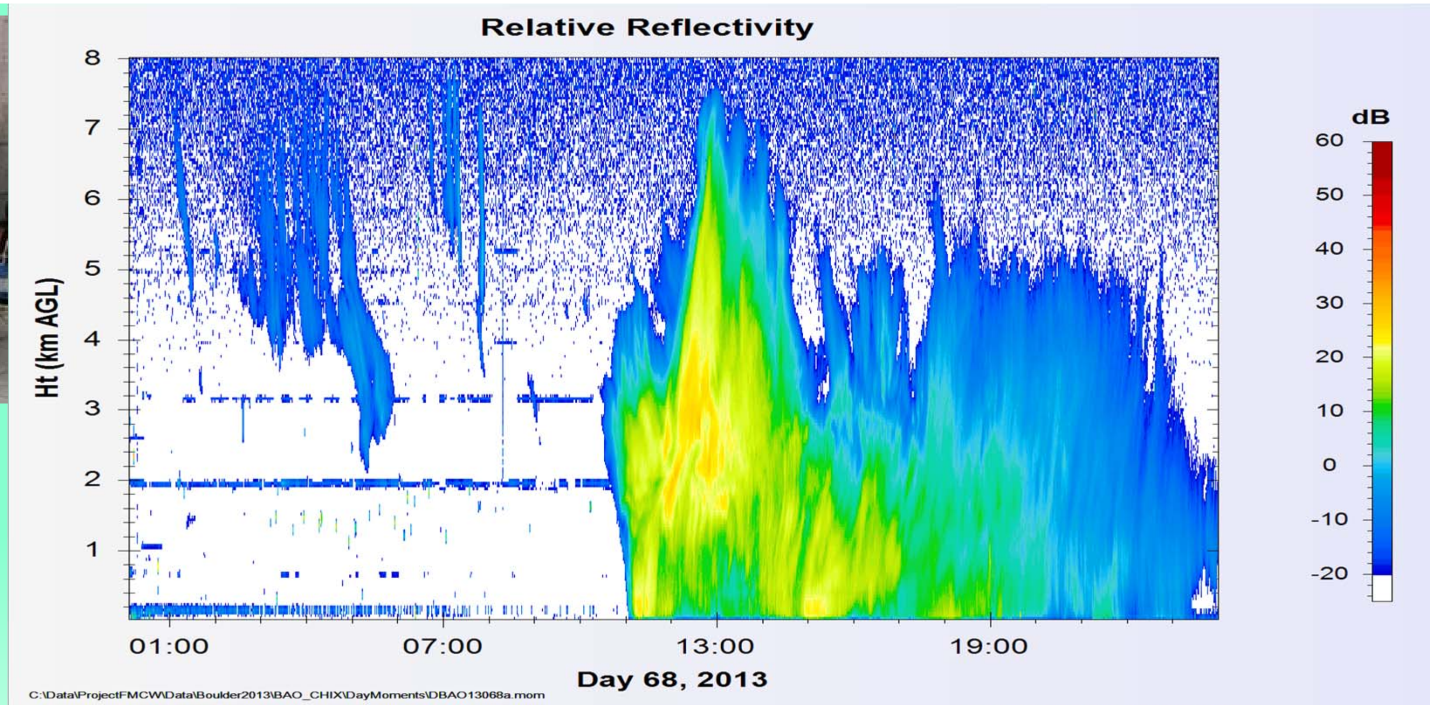


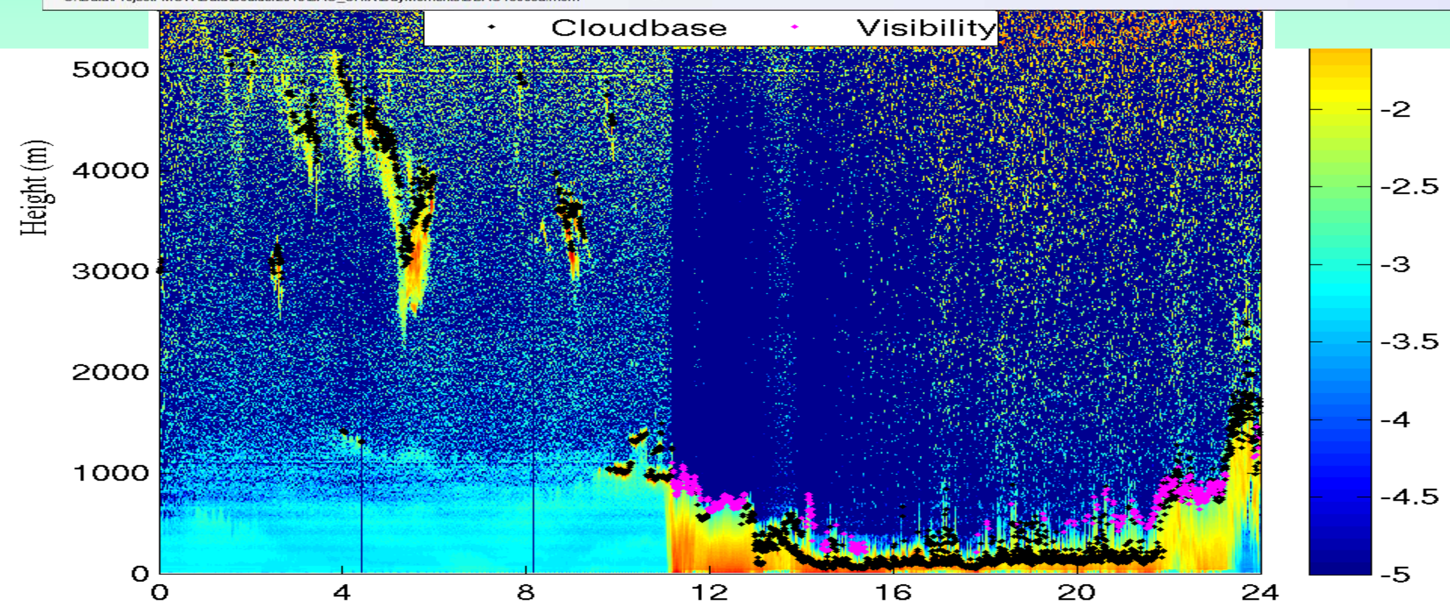
WindTracer Scanning lidar

WINDTRACER® Lockheed Martin (Barr et al.)

ZephR Profilling lidar

FMCW

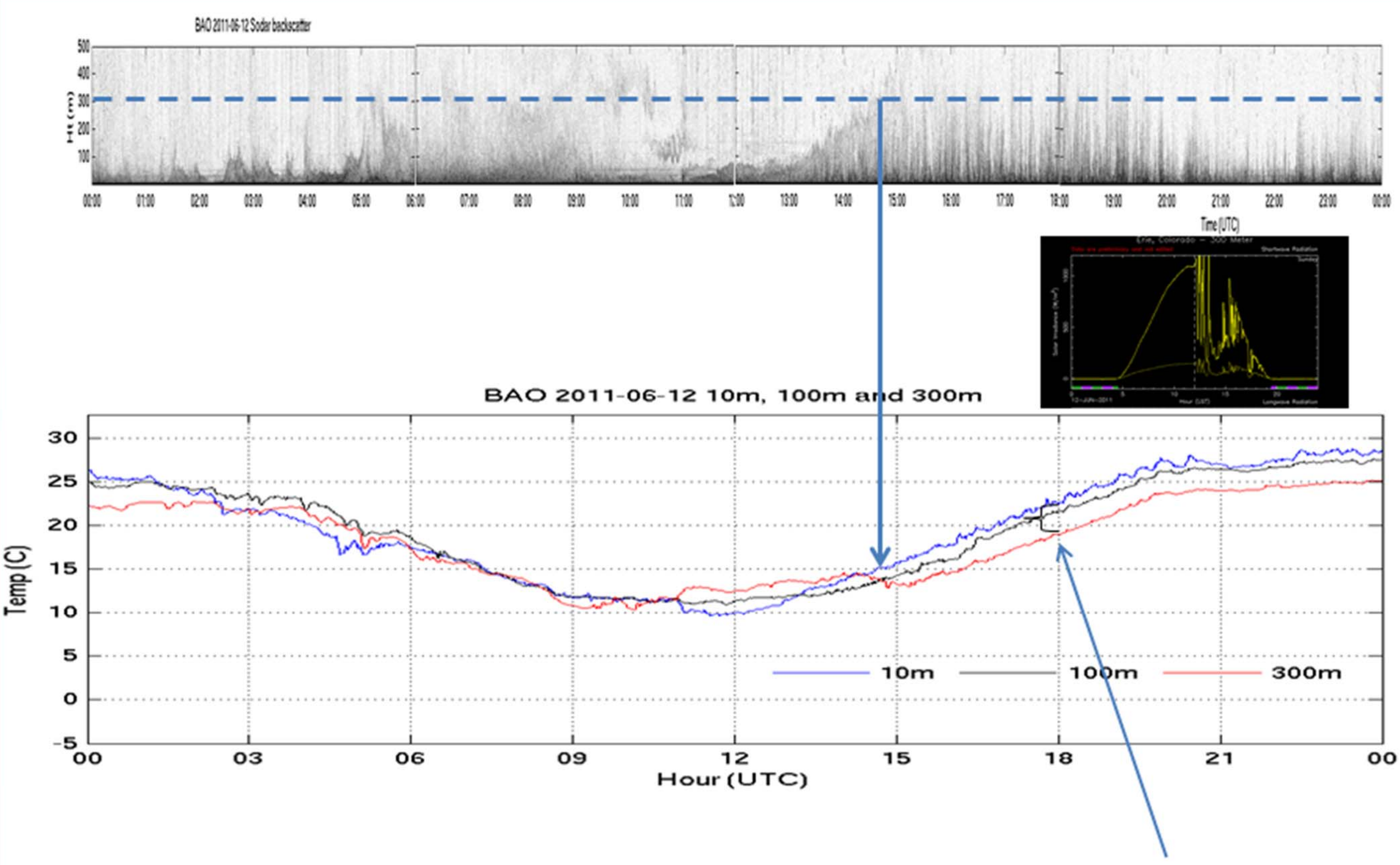




NOAA/ESR

Ceilometer and S-Band Radar
Paul Johnston

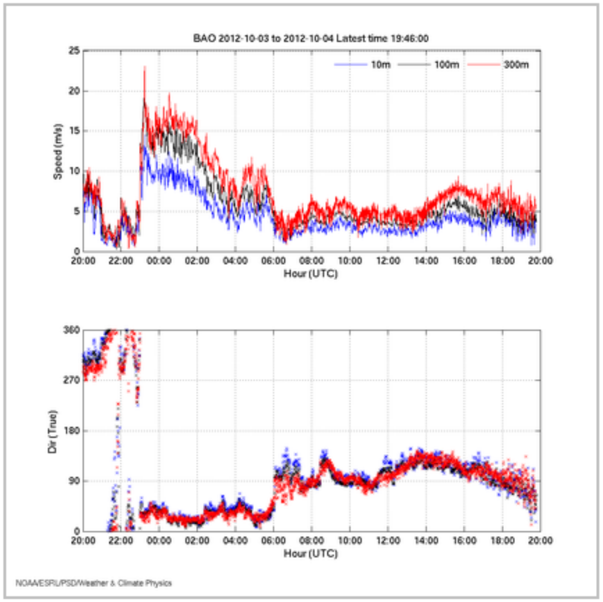
Growth of the Convective Boundary Layer



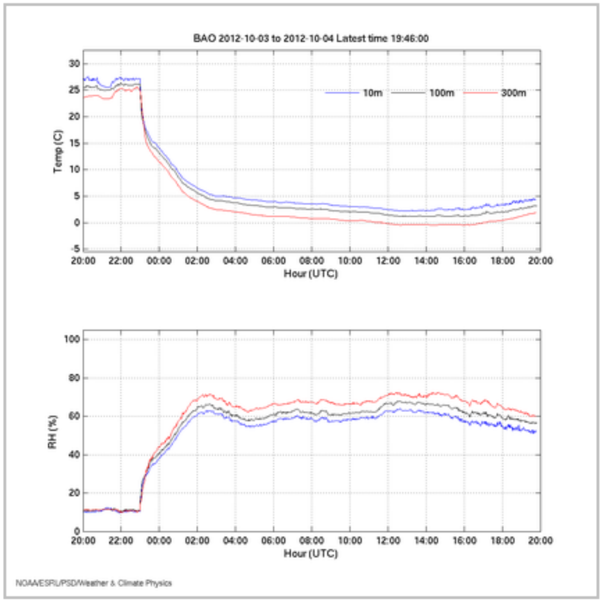
1°C per 100 meters or 5 l/2°F per 1,000 feet adiabatic or mixed = 3°C/300m

Frontal Passage

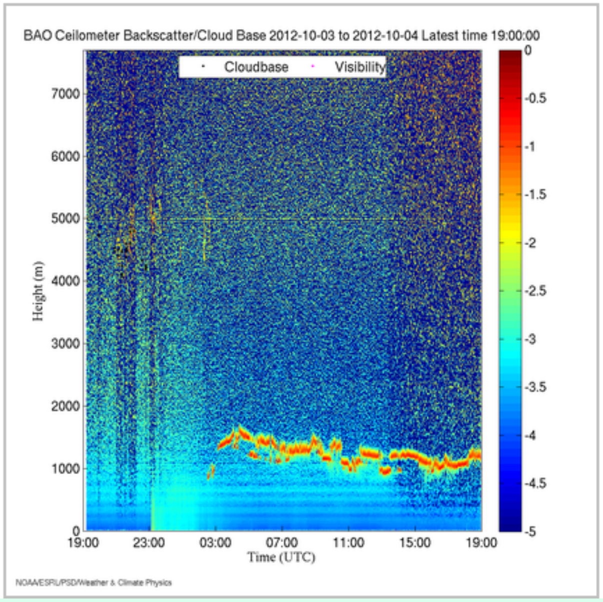
Wind Speed & Direction



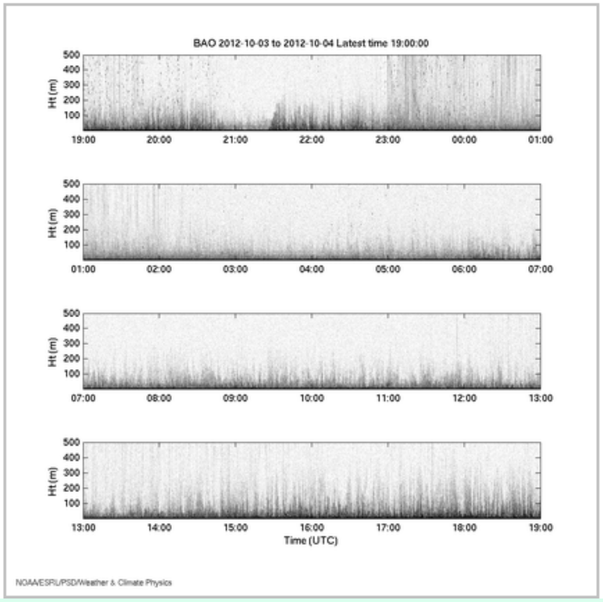
Temperature & Relative Humidity



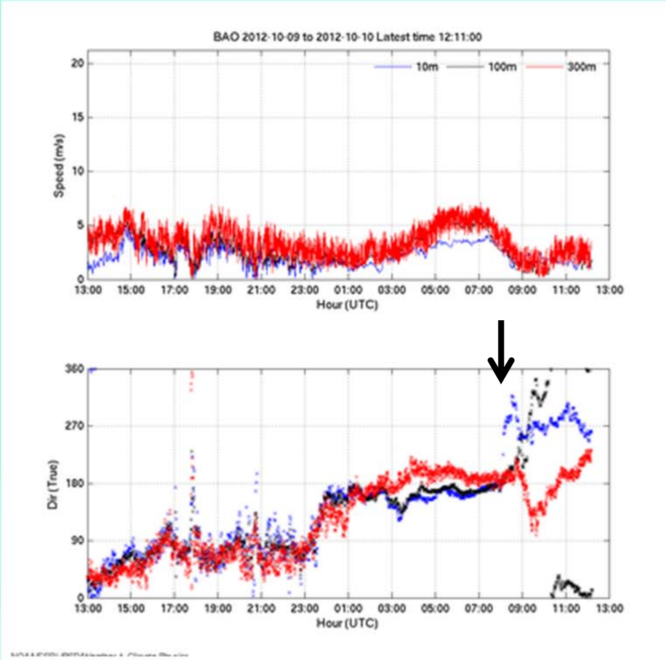
Ceilometer

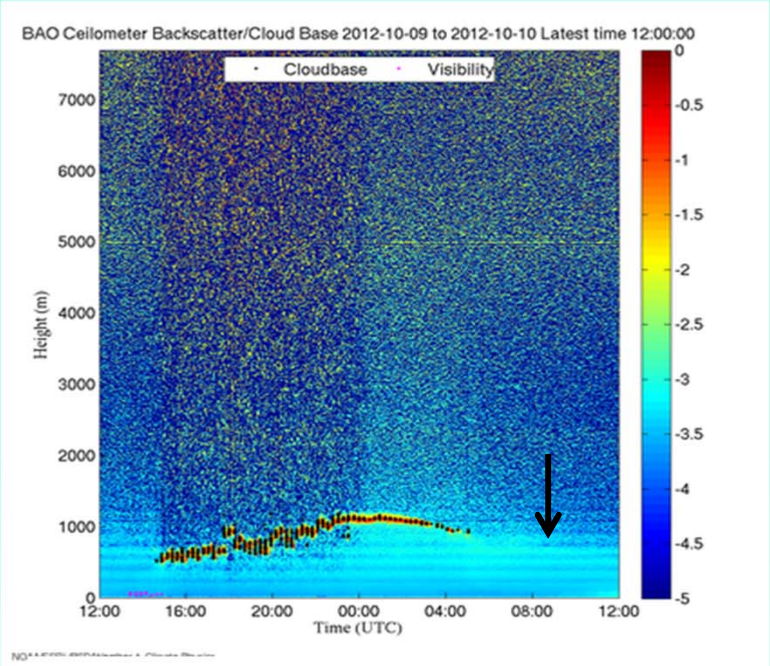


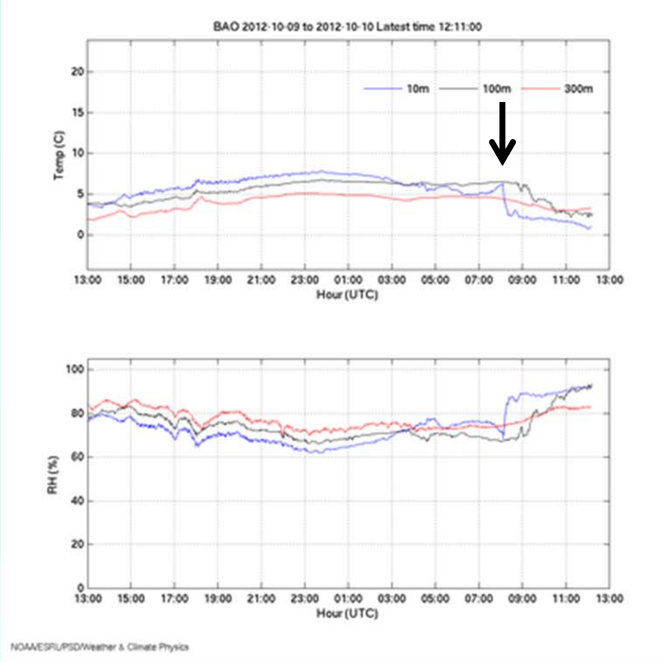
SODAR

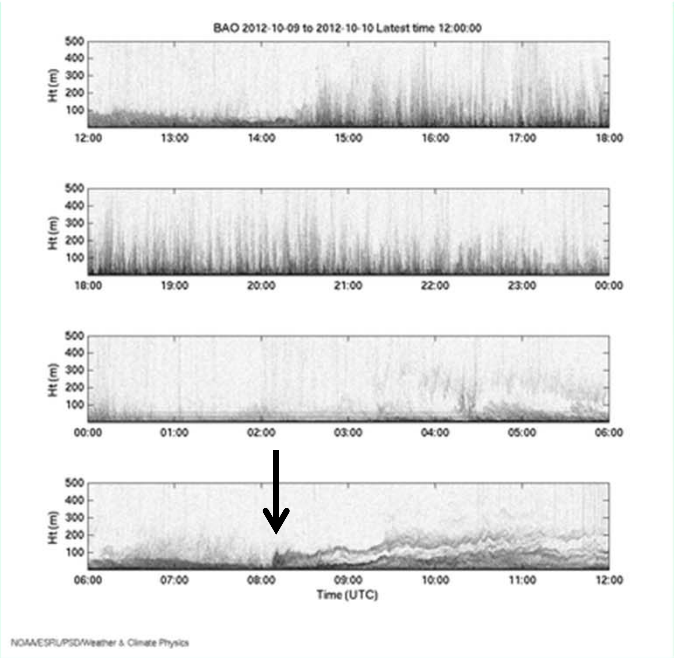


Cold Air Density Current

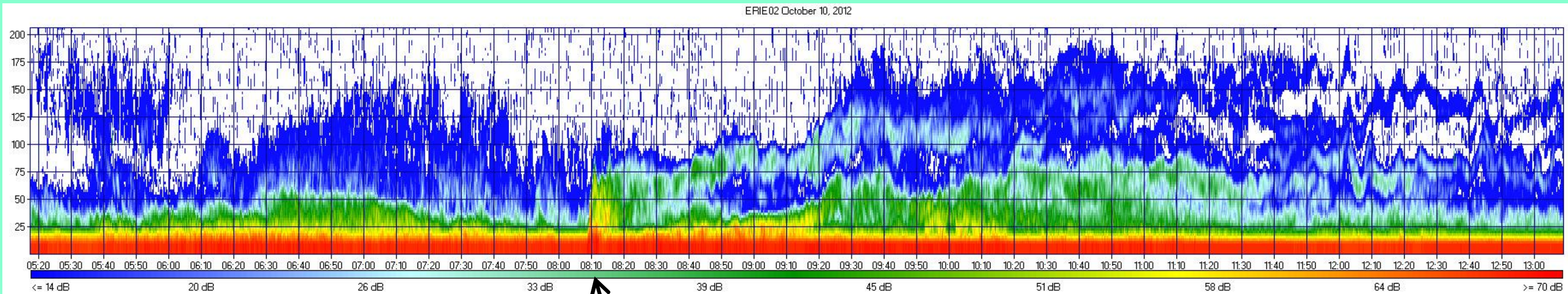


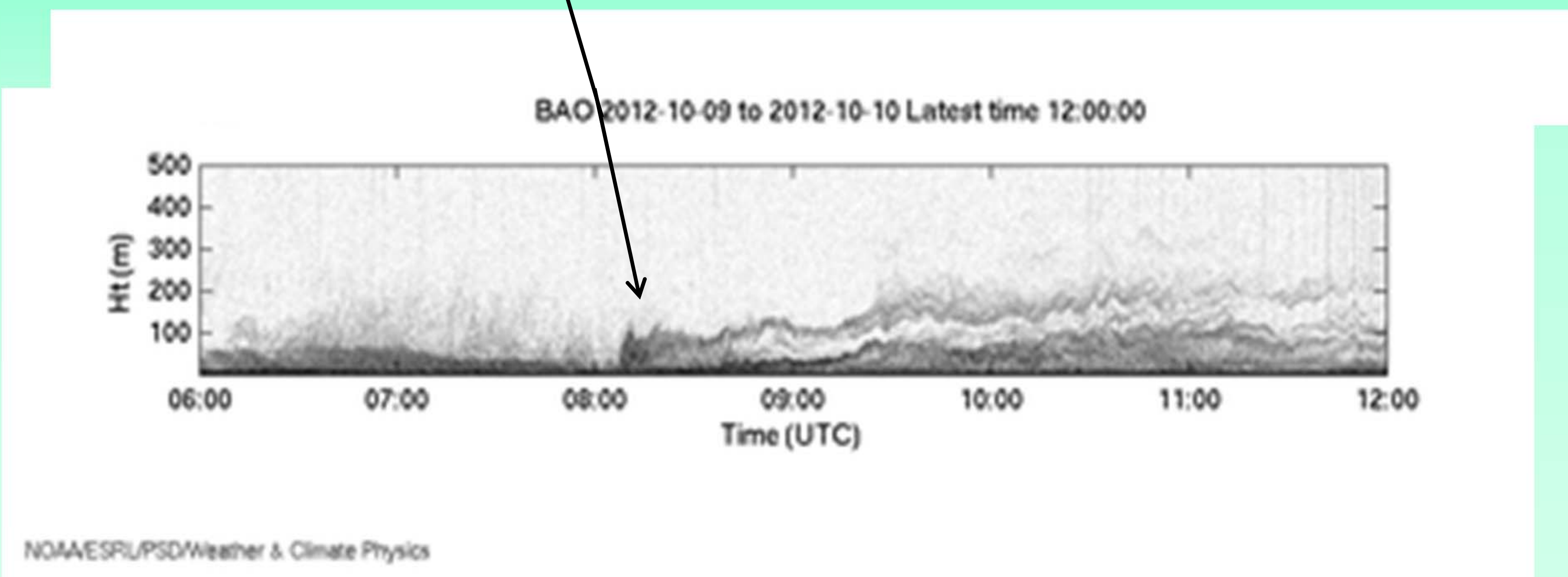


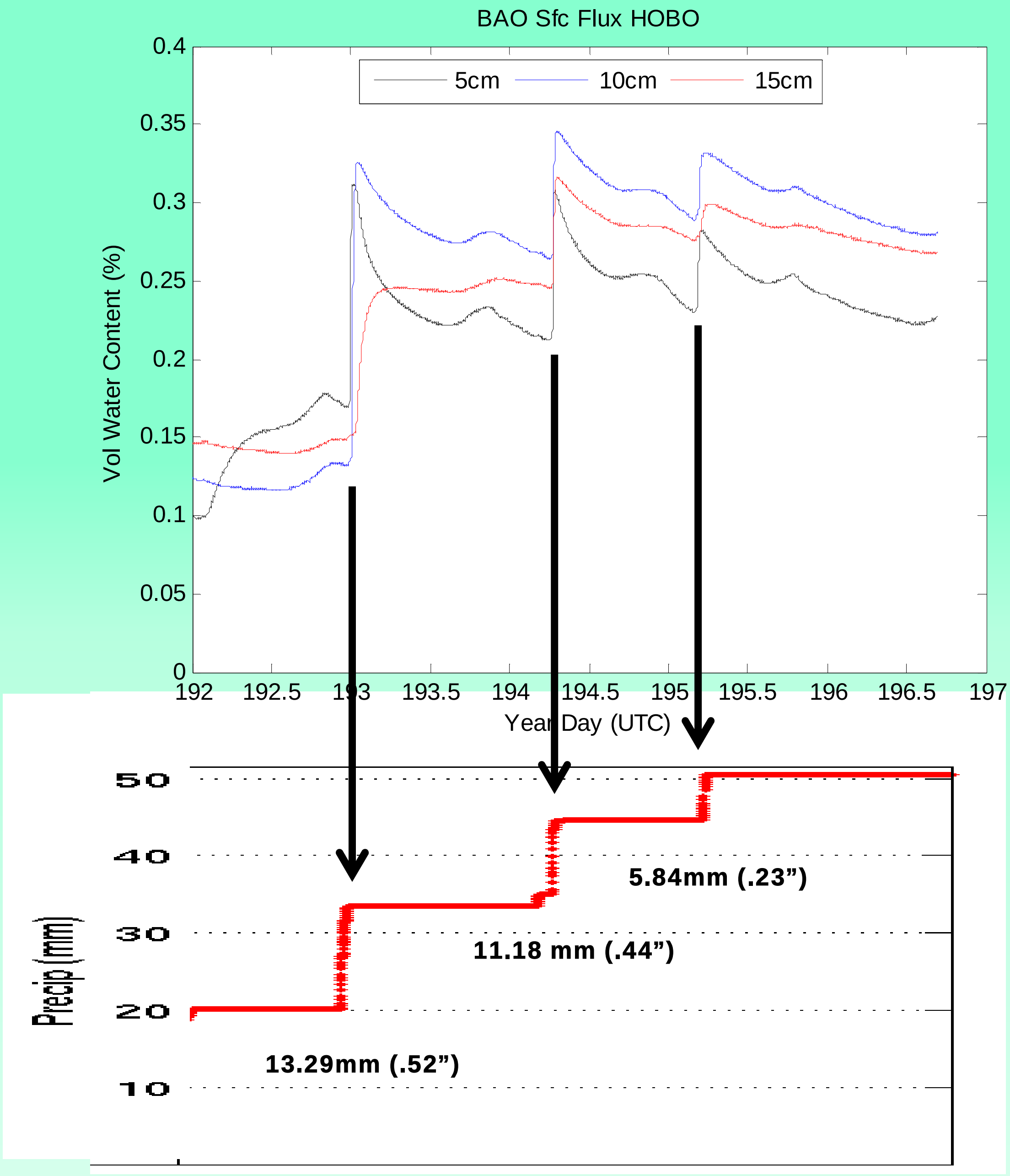




Cold Air Density Current

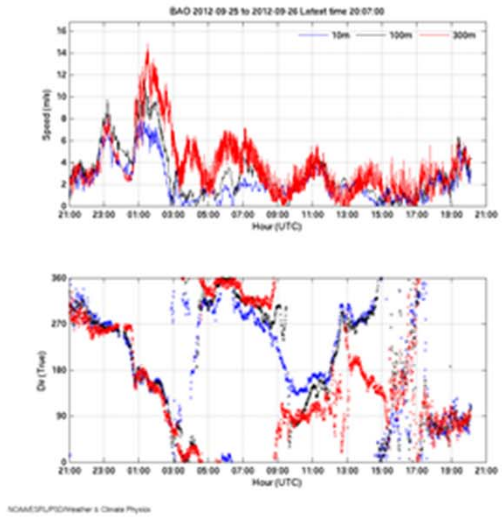




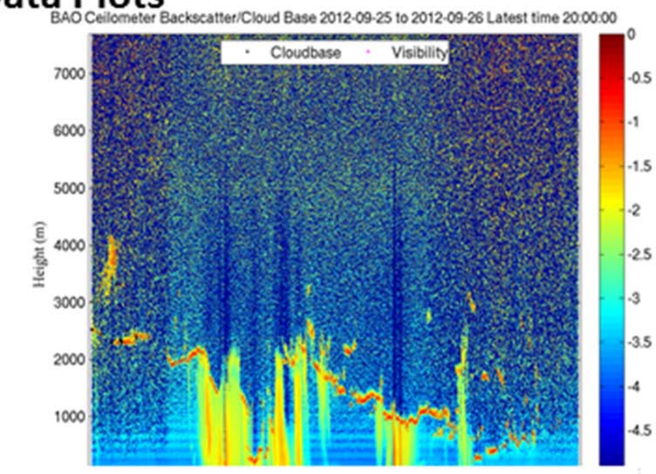


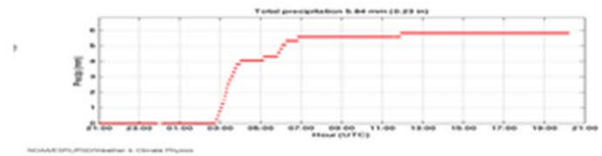
BAO Sfc Flux HOBO
5cm
10cm
15cm
Vol Water Content (%)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
192
192.5
193
193.5
194
194.5
195
195.5
196
196.5
197
Year Day (UTC)
Precip (mm)
50
40
30
20
10
5.84mm (.23”)
11.18 mm (.44”)
13.29mm (.52”)

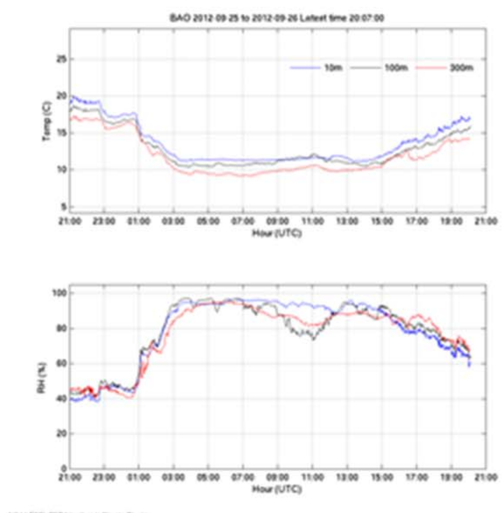
Current Data Plots



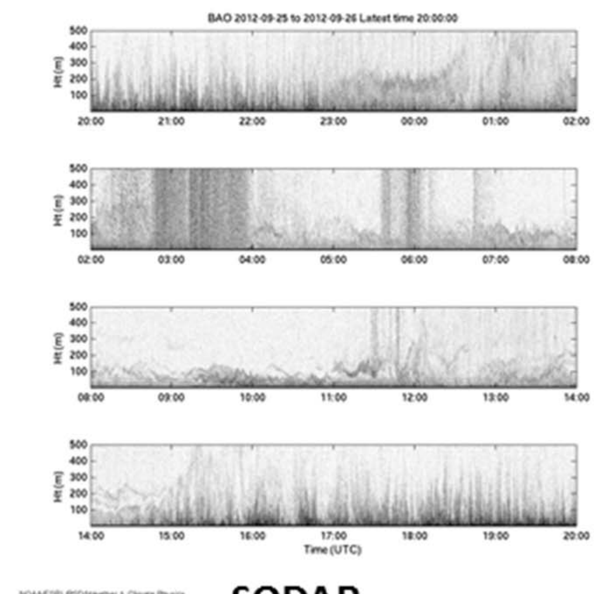
Wind Spd/Dir 10, 100, 300m







T/RH 10, 100, 300m



SODAR

Views from the Top!

Fish-eye view

Changing out radiometers

NOAA P-3

NCAR King Air

Frost

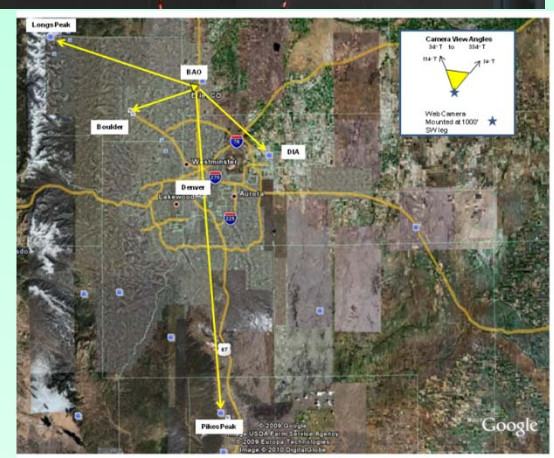
Lightning

Critters

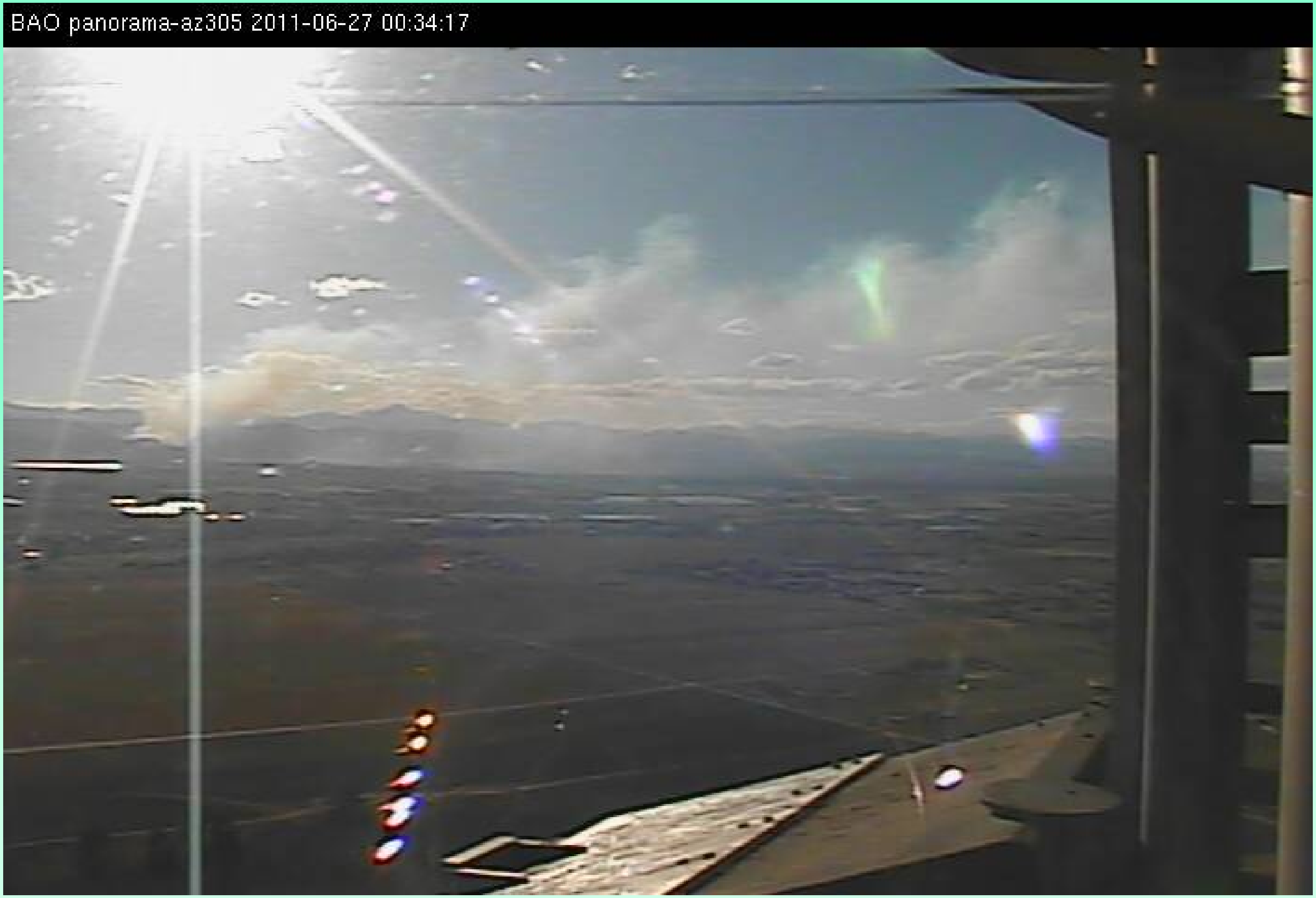
NE 34º T | Platteville | Barr Lake | DIA | Denver | Pikes Peak | Flat Irons | Longs Peak | NW 334º T

Sept 6, 2010 1135 MST

Sept 6, 2010 1735 MST



Fourmile Canyon Fire



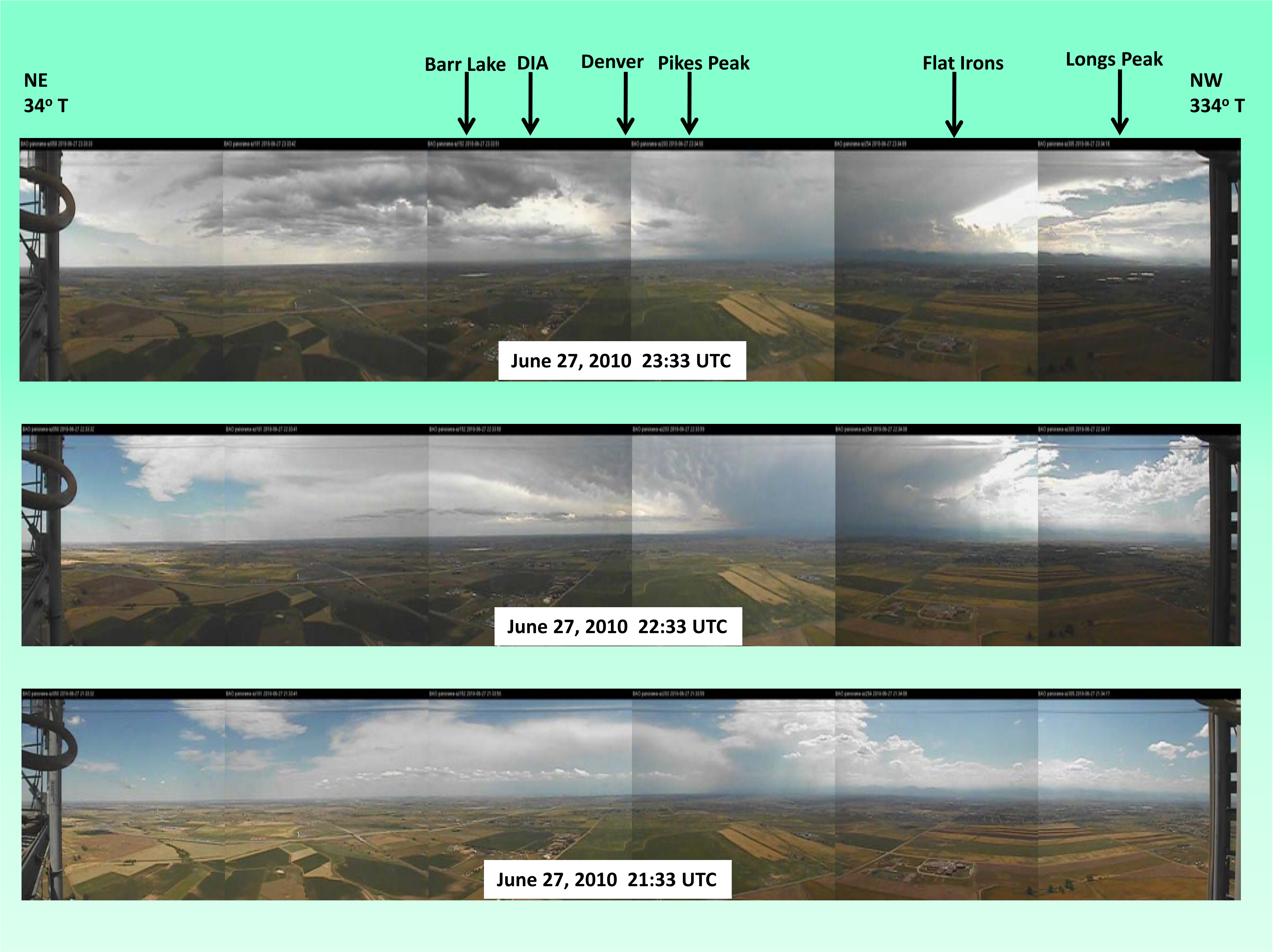
Lefthand Canyon fire June 26, 2011

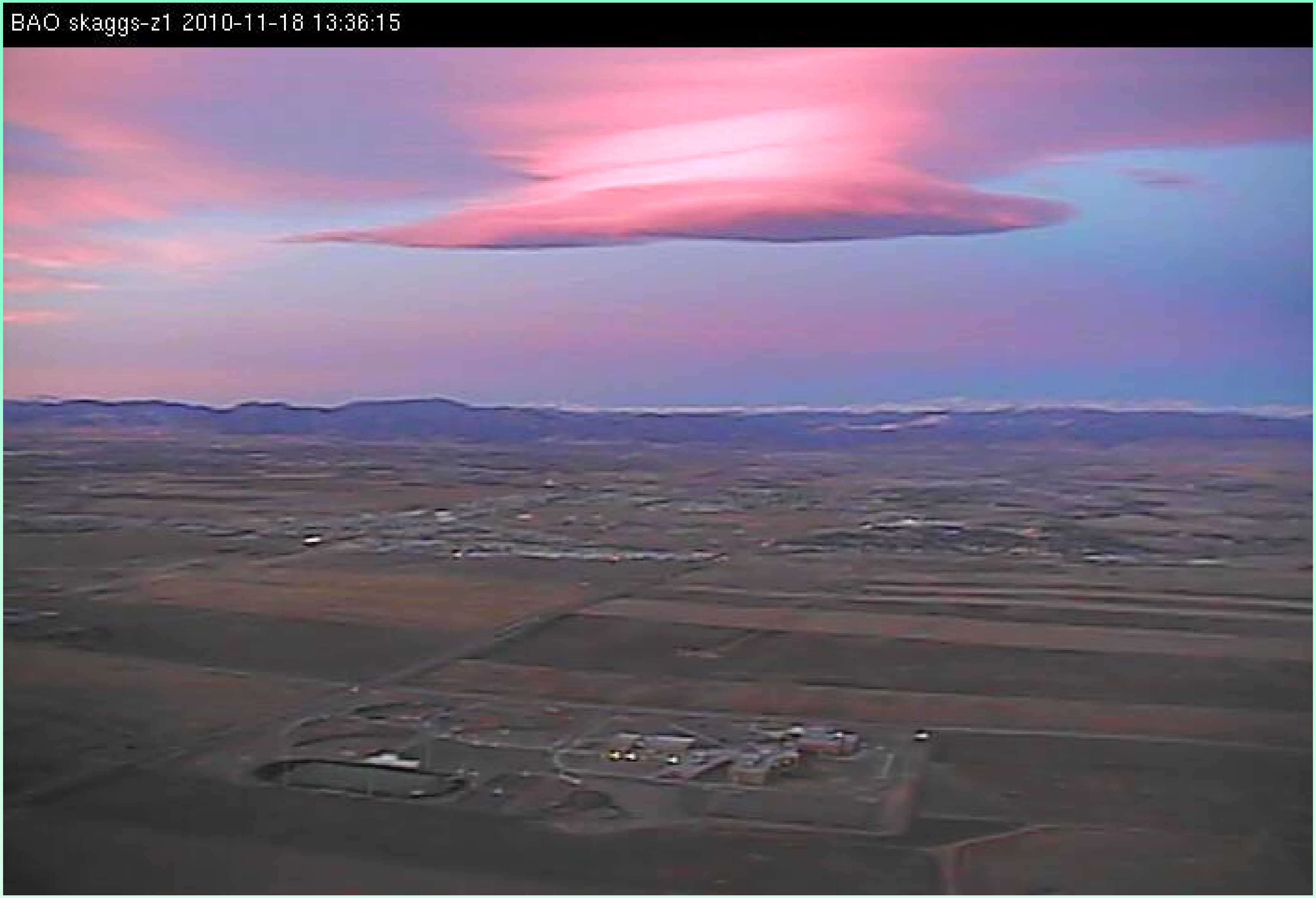
Fog layer at the BAO September 16, 2011 1330 UTC

Fog layer at the BAO September 16, 2011 1430 UTC

Fog layer at the BAO September 16, 2011 1530 UTC

Fog from the tower


NE
34º T
Barr Lake
DIA
Denver
Pikes Peak
Flat Irons
Longs Peak
NW
334º T
June 27, 2010 23:33 UTC
June 27, 2010 22:33 UTC
June 27, 2010 21:33 UTC


BAO skaggs-z1 2010-11-18 13:36:15

Thanks to:

PAST

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Wind Velocity and Convergence Measurements at the Boulder Atmospheric Observatory Using Path-Averaged Optical Wind Sensors

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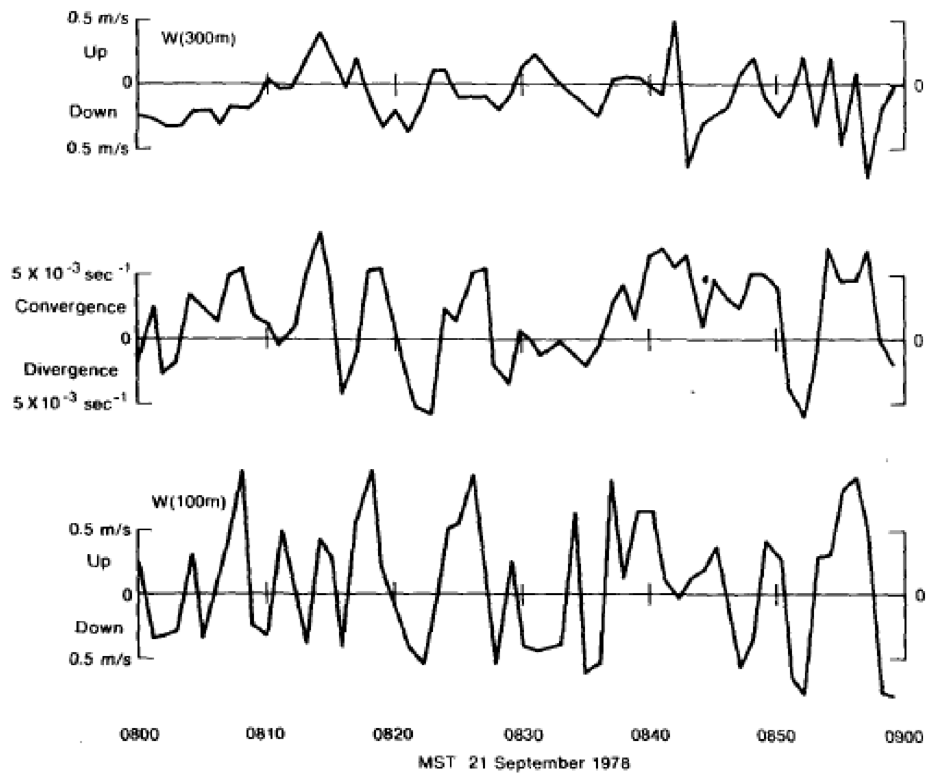

FIG. 6. The temporal variations of the optically measured convergence (middle curve) and the vertical winds at 100 and 300 m. The horizontal convergence follows the vertical wind at 100 m (below the inversion layer) better than at 300 m (above the inversion layer).