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


10 AM  Laser Beam Remote Sensing  R. S. Lawrence

10 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

30 AM  Geoaustics  W. H. Hooke

10 AM  Acoustic Echo sounding  F. F. Hall

30 AM  WPL’s Need for a Meteorological Observatory  C. G. Little

50 AM  Lunch

90 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

10 PM  CIRES and the Joint Meteorological Observatory  G. Chimonas

15 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.
System's Trailer
Dr. Chandran Kaimal
Original Joint facilities/ computer buildings
**Optical Triangle**

- **V (H/SEC):** 1.25
- **AZ (DEG):** 13
- **CONV (VE/SEC):** 0.01118
- **LDC100 (CM2):** -13.143916

**Micro-barograph array**

**SUN**
- **STN 1:** 0.4961
- **STN 2:** 7.032
- **STN 3:** 8.697
- **STN 4:** 9.247
- **STN 5:** 8.690

**SOLAR RADILY/MN**
- **1.07**

---

**Original computer printout**

**20 min summary**

---

**HOUWER ATOSPHERIC OBSERVATORY DATA SUMMARY**

**AVERAGING PERIOD: 20.00 MIN**

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<th>U(U)</th>
<th>V(V)</th>
<th>W(W)</th>
<th>T(T)</th>
<th>U(V)</th>
<th>V(W)</th>
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<td>Height (feet)</td>
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<td>Elanchard</td>
<td>629.8</td>
<td>2,063</td>
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<td>Clock building</td>
<td>Abraj Al Bait Towers</td>
<td>Saudi Arabia</td>
<td>Mecca</td>
<td>601</td>
<td>1,972</td>
<td>2011</td>
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<td>Mast radiator</td>
<td>Lualualei VLF transmitter</td>
<td>United States</td>
<td>Lualualei</td>
<td>458</td>
<td>1,503</td>
<td>1962</td>
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**Colorado**

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

56-story, 714 feet (218 m)
Republic Plaza
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 in a region of underground coal mines.
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_YYYYYMM.dat       YYYY = Year MM = Month
BAO_300_YYYYYMM.dat
BAO_010_YYYYYMM.dat
BAO_100_YYYYYMM.dat

All times are UTC
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: 303-497-3630.

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.

Data

Current Data 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 CO₂ Monitoring
» ESRL/GMD Solar & Thermal Atmospheric Radiation
» ESRL/GMD Surface Met
Near Real-Time Data
Level Variable

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

YEAR

Month
BAO Tower Web Cam

Hourly updates

http://www.esrl.noaa.gov/psd/technology/bao/
BAO Tower Web Cam

Hourly updates

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


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 mesoscale 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.**
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.
25 Feet
- 25 Feet
Array Geometry

Severe Weather
Ocean waves
Tornadoes
TLE’s
Volcanoes

Avalanches
Meteors
Fires
Earthquakes
Explosions
Turbulence

Other??

Infrasonic Observatory

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

Mauna Loa
NOAA/ESRL/GMD Tall Tower Network
Teacher in the Lab
Dr. Peter Blanken (Geography)
Soil moisture at three depths from July 17 to July 21, 2004
(green: 5 cm; blue: 10 cm; red: 15 cm)

Time, Julian day

Moisture

Radiometer L-Band

Radiometer
Zavorotny et al. 2004
GPS Reflectometry
Zavorotny et al. 2004
Acoustic Tomography
Ostashev et al. 2008

Temperature field reconstructed with TDSI July 09, 2008.

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

The following table presents the peak and cumulative footprint distances for different time periods and seasons.

### Time Periods:
- Daytime
- Nighttime
- Spring Daytime
- Summer Daytime
- Fall Daytime
- Winter Daytime
- Spring Nighttime
- Summer Nighttime
- Fall Nighttime
- Winter Nighttime

### Peak and Cumulative Footprint Distances:

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<th>Time Period</th>
<th>Peak (km)</th>
<th>50% (km)</th>
<th>70% (km)</th>
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<td>2.60</td>
<td>7.50</td>
<td>14.55</td>
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<tr>
<td>Nighttime</td>
<td>6.87</td>
<td>19.80</td>
<td>38.55</td>
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<td>Spring Daytime</td>
<td>6.86</td>
<td>19.80</td>
<td>38.50</td>
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<td>Summer Daytime</td>
<td>6.76</td>
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<td>2.43</td>
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<td>Winter Daytime</td>
<td>6.83</td>
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<td>38.30</td>
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<tr>
<td>Spring Nighttime</td>
<td>6.82</td>
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<td>38.35</td>
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<td>Summer Nighttime</td>
<td>7.47</td>
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<td>Winter Nighttime</td>
<td>N/A</td>
<td>N/A</td>
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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
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

ZephR Profiling lidar

WINDTRACER® Lockheed Martin (Barr et al.)
WindTracer® Lockheed Martin
(Barr et al.)
Ceilometer and S-Band Radar
Paul Johnston

Relative Reflectivity

Cloudbase - Visibility

Ceilometer and S-Band Radar
Paul Johnston
Growth of the Convective Boundary Layer

1°C per 100 meters or 5 1/2°F per 1,000 feet adiabatic or mixed \(\square = 3^\circ\text{C}/300\text{m}\)
Frontal Passage

Wind Speed & Direction

Temperature & Relative Humidity

Ceilometer

SODAR
Cold Air Density Current
Cold Air Density Current
BAO Sfc Flux HOBO

Vol Water Content (%)

Year Day (UTC)

5cm
10cm
15cm

13.29 mm (.52")
11.18 mm (.44")
5.84 mm (.23")

50
40
30
20
10

5.84 mm (.23")
11.18 mm (.44")
13.29 mm (.52")
Views from the Top!

Fish-eye view

Changing out radiometers

NOAA P-3

NCAR King Air
Fourmile Canyon Fire

Sept 6, 2010 1135 MST

Sept 6, 2010 1735 MST
Lefthand Canyon fire June 26, 2011
Fog from the tower
Thanks to:

**PAST**
Norbert Szczepczynski, Jim Newman, Bob Krinks
Dr. Gordon Little, Dr. Freeman Hall, Dr. Chandran Kaimal
Dr. Bill Hooke, Catherine Russell, Brian Templeman

**PRESENT**
Dr. Bill Neff, Dr. Rich Lataitis, Dave Welsh, Sergio Pezoa
Bruce Bartram

Dr. Andreas Muschinski, Dr. David Noone, Dr. Peter Blanken
Dr. Michael Hannigan

Daniel.wolfe@noaa.gov  303-497-6204
http://www.esrl.noaa.gov/psd/technology/bao/

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

MU-KING TSAY,¹ TING-I WANG, R. S. LAWRENCE, G. R. OCHS AND R. B. FRITZ
NOAA/ERL/Wave Propagation Laboratory, Boulder, CO 80303

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).