Ozonesonde and aircraft measurements during CALNEX, 2010

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Measurement of western U.S. baseline ozone from the surface to the tropopause and assessment of downwind impact regions

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Received 11 April 2011; revised 13 September 2011; accepted 15 September 2011; published 18 November 2011.

[1] Since 1997, baseline ozone monitoring from the surface to the tropopause along the U.S. west coast has been limited to the weekly ozonesondes from Trinidad Head, California. To explore baseline ozone at other latitudes, an ozonesonde network was implemented during spring 2010, including four launch sites along the California coast. Modeling indicated that North American pollution plumes impacted the California coast primarily below 3 km, but had no measurable impact on the average coastal ozone profiles. Vertical and latitudinal variation in free tropospheric baseline ozone appears to be partly explained by polluted and stratospheric air masses that descend isentropically along the west coast. Above 3 km, the dominant sources of ozone precursors were China and international shipping, while international shipping was the greatest source below 2 km. Approximately 8–10% of the baseline ozone that enters California in the 0–6 km range impacts the surface of the USA, but very little reaches the eastern USA. Within California, the major impact of baseline ozone above 2 km is on the high elevation terrain of eastern California. Baseline ozone below 2 km has its strongest impact on the low elevation sites throughout the state. To quantify ozone production within California we compared inland ozone measurements to baseline measurements. For average daytime conditions, we found no enhancements of lower tropospheric ozone in the northern Central Valley, but enhancements of 12–23% were found in the southern Central Valley. Enhancements above Joshua Tree were greater, 33–41%, while the greatest enhancements occurred over the LA Basin, 32–63%.

Tropospheric ozone monitoring in western North America

Routine in situ ozone measurements from Earth’s surface to the tropopause are made at only 5 ozonesonde sites in western North America.

Only Trinidad Head on the west coast is representative of baseline ozone.

Baseline ozone - ozone measured at a location with no recent influence from local pollution sources [*TF HTAP definition*].

Science Questions:

1) Is Trinidad Head representative of baseline ozone at other coastal sites?

2) Once baseline ozone comes ashore, where does it go?
IONS ozonesonde networks  
(Intercontinental Chemical Transport Experiment Ozonesonde Network Study)

<table>
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<th>Experiment</th>
<th>Season</th>
<th>Location</th>
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<td>Summer</td>
<td>eastern N. America</td>
<td>A. M. Thompson et al., JGR 2007</td>
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<td>western N. America</td>
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IONS-2010 ozonesonde network

Near daily ozonesondes were launched from 7 sites between May 10 - June 19, 2010.

A total of 230 sondes were launched, the most in any western North America field campaign.

Funding, operations and support provided by:

NOAA ESRL Health of the Atmosphere Program
NASA Tropospheric Chemistry Program
U. S. Navy
Environment Canada
NOAA National Weather Service
National Park Service
California State Parks
Naval Postgraduate School (Monterey)
Federal Aviation Administration
California’s coastal topography affects ozone transport:

Coastal mountains impede the transport of marine boundary layer air into California at Trinidad Head and Pt. Sur [Parrish et al., 2010].

Relatively low topography allows air at Pt. Reyes to enter the Central Valley in the vicinity of The Carquinez Strait [Bao et al., 2008].


Figure produced by Tom Ryerson, NOAA ESRL
Comparison of 4 inland sites to Trinidad Head of mass of ozone (DU 100 hPa⁻¹) from 0 - 6 km a.s.l for 2004-2009:

KE = +1%
SP = -2%
BL = +6%
BO = +20%
Percent difference in total mass of ozone below 1km, for southern sites compared to Trinidad Head.
Baseline ozone determined by removing all measurements with a 5-day North America NO\textsubscript{x} tracer > 280 pptv.

Decrease in baseline ozone is calculated in units of: DU 100 hPa\textsuperscript{-1}.
Percent difference in total mass of ozone per km (DU 100 hPa^{-1}), for inland sites in comparison to coastal sites at similar latitude.
Percent difference in total mass of ozone (DU 100 hPa^{-1}) for:
LA Basin and Joshua Tree compared to San Nicolas Island.
To look at the situation another way....

Baseline ozone is equal to more than 80% of the ozone measured above the Central Valley and Shasta.

Across the polluted regions of southern California, baseline ozone is equal to 63–76% of the measured ozone above Joshua Tree and the LA Basin.
Impact of baseline ozone on the surface of the United States
Impact of baseline ozone on the surface of the United States
Impact of baseline ozone on the surface of the United States

Measured ozone (blue), ppbv and sample size (white)

O3 transported to surface (g/cell) averaged over all forward plumes

avg O3 mass (g/15000 km²) from each level transported to surface based on maximum daily value over 5 days
Free tropospheric ozone trend above western North America

Ozone measurement locations: April-May, 1984-2008, 3000-8000 m

Ozonesondes, 1995-2008
- Trinidad Head, CA
- Boulder, CO
- Kelowna, BC
- Edmonton/Stoneyplain, AB
- Vanscoy, SA
- Bratt's Lake, SA

MOZAIC, 1995-2008
- Portland, OR
- San Francisco, A
- Los Angeles, BC
- Phoenix, AZ
- Denver, CO
- Dallas, TX
- Houston, TX

Aircraft missions
- CITE 1-C 1984
- STRAT NO DATA
- SUCCESS 1995
- POLARIS 1996
- WAM 1997
- PEM-TROPICS B 1998
- TOPSE 2000
- TRACE-P 2001
- ITCT 2002
- INTEX-B 2006
- PACDEX 2007
- ARCPAC 2008
- START08 2008

Lidar, 2003-2008
- Table Mountain, CA
Tropospheric NO$_2$ column data from the GOME and SCIAMACHY sensors were freely downloaded from: www.temis.nl
For methodology see:
Boersma, K. F., et al. (2004), Error analysis for tropospheric NO2 retrieval from space, J. Geophys. Res., 109, D04311,
Richter, A., et al.(2005), Increase in tropospheric nitrogen dioxide over China observed from space, Nature, 437

CO$_2$ data from US Energy Information Agency
Free tropospheric ozone trend above western North America

All available data above western North America, regardless of transport history.
Free tropospheric ozone trend above western North America


All available data above western North America, regardless of transport history.
Will free tropospheric ozone above western North America continue to increase, or will it level off?

Maybe, maybe not......
Tropospheric O\(_3\), 2000


Current legislation emissions, 2030
Anthropogenic NO\(_x\): +18%

Strongly increased emissions, 2030
Anthropogenic NO\(_x\): +96%

Historic (1850-2000) global and regional anthropogenic NO\textsubscript{x} emissions, with future RCP scenarios (2000-2050).

The outlook:

- large regional changes in ozone precursors are ongoing,
- but global NO$_x$ emissions are expected to change by no more than
  +/- 10% over the next 10 years.

Therefore, enhanced baseline ozone along the US west coast appears to be “here to stay”, at least for the near term.
Outlook for free tropospheric ozone profiles in 2013-2014

To ensure we have at least 50 profiles per April-May period we need supplemental sondes from Trinidad Head and Boulder: ~ $50,000/year
Passive 20-day anthropogenic NOx tracers above the individual coastal sites.

Retroplume release altitude = 0 - 8 km

Column: T. Head, n=1384
Column: Pt. Reyes, n=1270
Column: Pt. Sur, n=1451
Column: San Nic. Is., n=912

Footprint: T. Head, n=1384
Footprint: Pt. Reyes, n=1270
Footprint: Pt. Sur, n=1451
Footprint: San Nic. Is., n=912

ozone (ppbv): blue
RH (%): green
% from strat.: yellow
sample size: white

Total: black
N. America: yellow
China: red
Jap/Kor: blue
SE Asia: green
India: cyan
Europe: magenta
NH shipping: white
FLEXPART Lagrangian Particle Dispersion Model

FLEXPART was used to identify air mass sources and receptor regions associated with each ozone measurement

GFS wind fields: 0.5° x 0.5° horizontal resolution, 26 vertical levels

one retroplume and one forward plume were calculated every 200 m along every ozonesonde profile

The quantity of a 20-day passive anthropogenic NO\textsubscript{x} tracer transported to the ozonesonde measurement locations was calculated

EDGAR 2005 anthropogenic NO\textsubscript{x} emission inventory with University of Delaware 2001 international shipping NO\textsubscript{x} emissions (J. Corbett)
Median profiles at all sites, May - June 19, 2010

- TH-clim
- HI-clim
- TH
- RY
- PS
- SN
- KE
- SH
- JT

Altitude, m

O3, ppbv

Sample size