California Baseline Ozone Transport Study (CABOTS) Ozonesonde Measurements: Summer 2016

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1. Introduction

Despite dramatic improvements in California's air quality, the State must continue to achieve significant reductions in ozone (O_3) precursor emissions. For non-attainment (NA) areas, the State Implementation Plan (SIP) must show how new controls will reduce ground-level ambient O_3 to levels below the health-based standards. While recent health research has led the EPA to propose a new, lower 8-h O_3 standard to 70 ppb from 75 ppb, increasing Asian industrialization has led to increased baseline O_3 concentrations entering the State from the west [Jaffe et al., 2003; Cooper et al., 2010]. Short term field studies have documented instances of elevated O_3 concentrations aloft [Neuman et al., 2012] that could potentially be relevant to ground level exceedances. While these measurements have provided infrequent information about O_3 aloft, these isolated efforts do not provide sufficient information to fully understand the spatial and temporal variations in baseline O_3 concentrations entering California, and the processes by which baseline O_3 aloft may mix down and contribute to surface O_3 exceedances in the San Joaquin Valley (SJV).

Therefore, California Baseline Ozone Transport Study (CABOTS) was organized by the California Air Resources Board (CARB) to investigate difficult policy-relevant questions of the magnitude and daily variability of vertical O_3 as it enters California from the Pacific during the spring and summer of 2016. It also seeks to determine the extent to which trans-Pacific long-range transported O_3 mixes down to surface sites across the state, especially in the SJV. To help meet these goals, SJSU launched near-daily ozonesondes along the northern California coast. Other organizations involved in CABOTS include UC Davis, NOAA/ESRL, NASA, EPA, and the Bay Area Air Quality Management District (BAAQMD).

2. Ozonesonde Launches

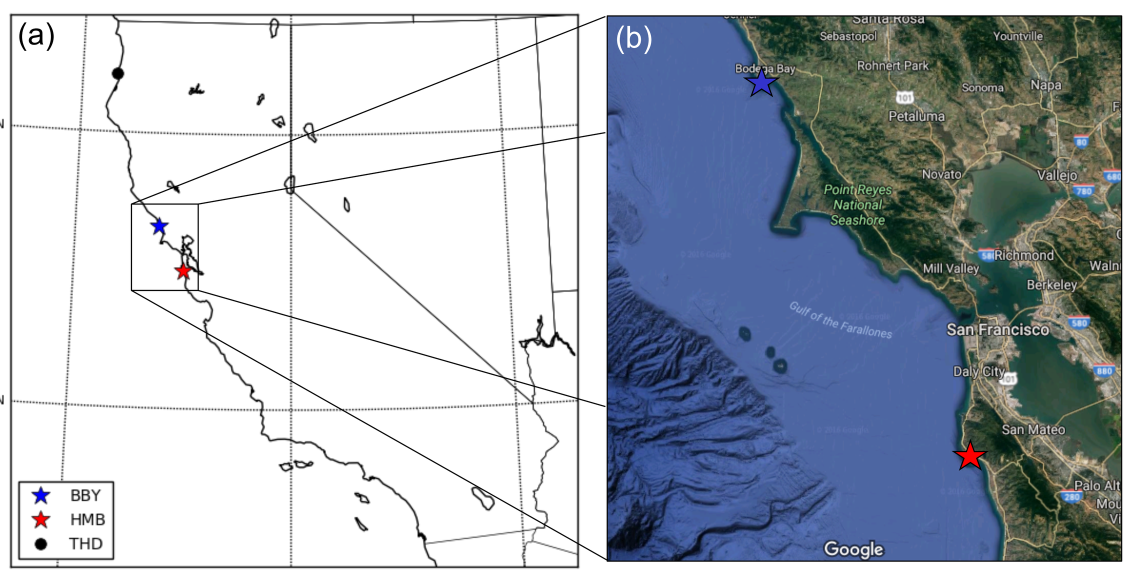

Figure 1. (a-b) Locations of CABOTS ozonesonde site locations Bodega Bay (BBY) and Half Moon Bay (HMB) in relation to NOAA/ESRL's Trinidad Head (THD) regular ozonesonde launch site in northwestern CA. (c) An ozonesonde launch in Bodega Bay, CA.

SJSU conducted the CABOTS near-daily ozonesondes 50 mi. NW of San Francisco in Bodega Bay, CA (BBY) from May 6th – August 17th (Fig. 1a). BBY is approximately 250 mi. SSE of NOAA/ESRL's Trinidad Head ozonesonde launch site. Additional support from the EPA allowed for a second coastal ozonesonde launch location 60 mi SE in Half Moon Bay, CA later during the study. There is a total of 108 ozonesonde profiles (84 in BBY and 24 in HMB) over 104 days. Electrochemical cell (ECC) ozonesondes (model 2z-V7) were used with i-Met radiosondes. The ECC ozonesondes have a general uncertainty of ±10 %. Ozonesondes were launched at both locations near 2:00 pm local time.

	Bodega Bay	Half Moon Bay
Time period	5/6-8/17	7/15-8/17
Number of ozonesondes	84	24

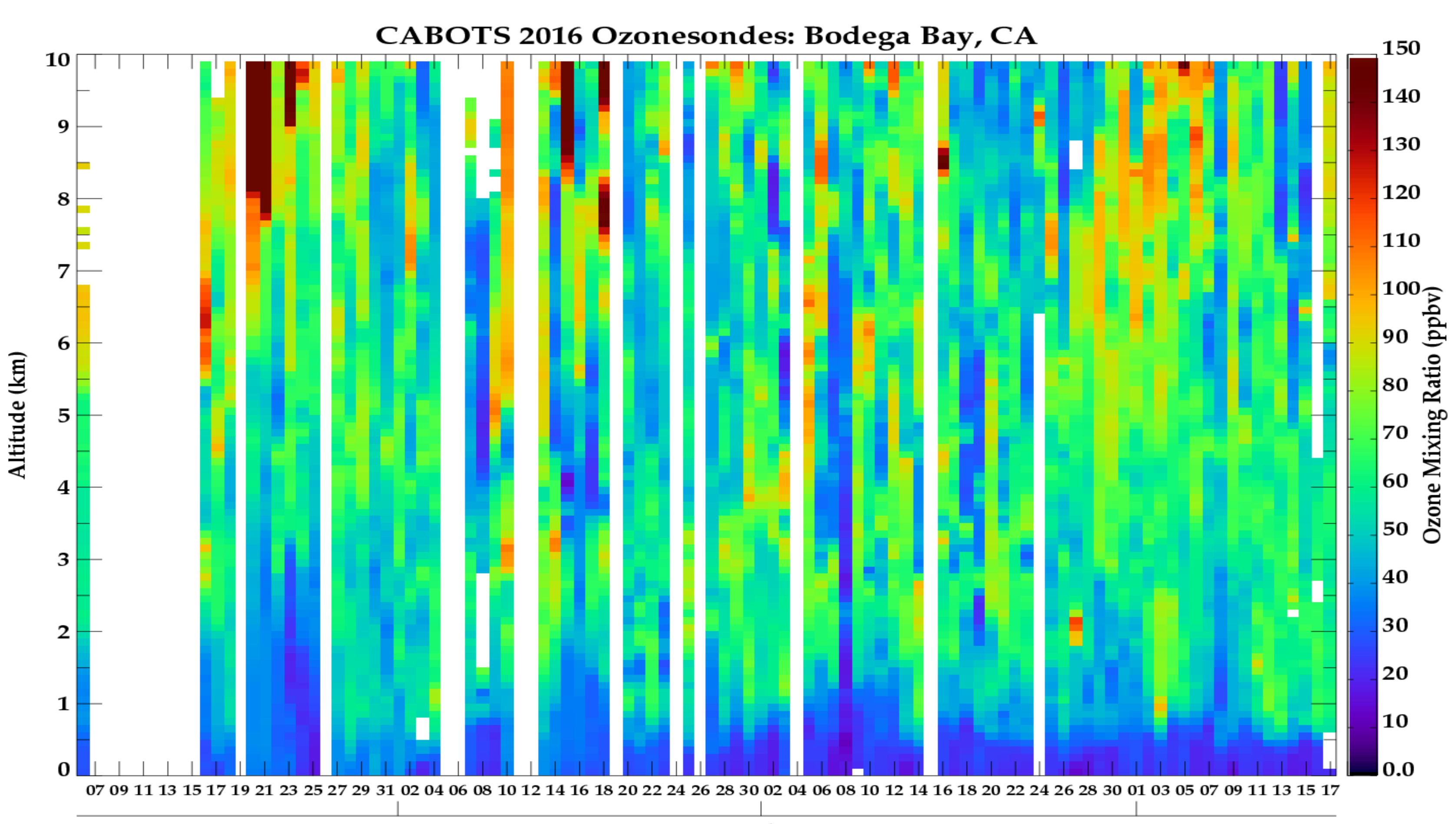

Figure 2. CABOTS vertical O_3 measurements at Bodega Bay during the entire CABOTS period.

The daily upper air ozone measurements demonstrate very complex spatial and temporal variability throughout the entire CABOTS time period (Figs. 2 and 3). There were a few cases of stratospheric air transport into the upper troposphere in mid-May and in the first half of June. There are also distinct layers of high O_3 in the lower troposphere (≤ 3 km) as well, especially during late July and August.

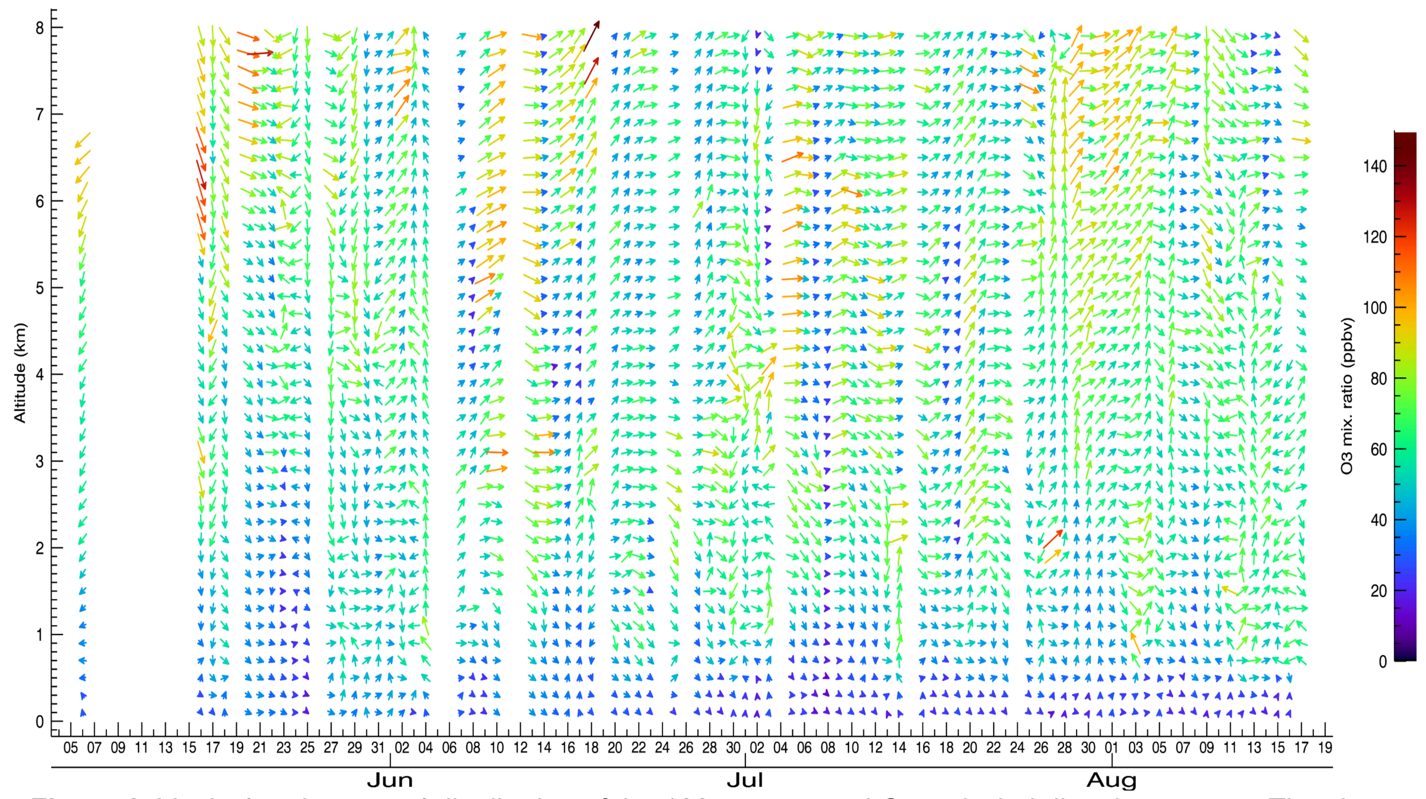

Figure 3. Vertical and temporal distribution of the 100-m averaged O_3 and wind direction vectors. The size of each vector is proportional to the O_3 mixing ratio value.

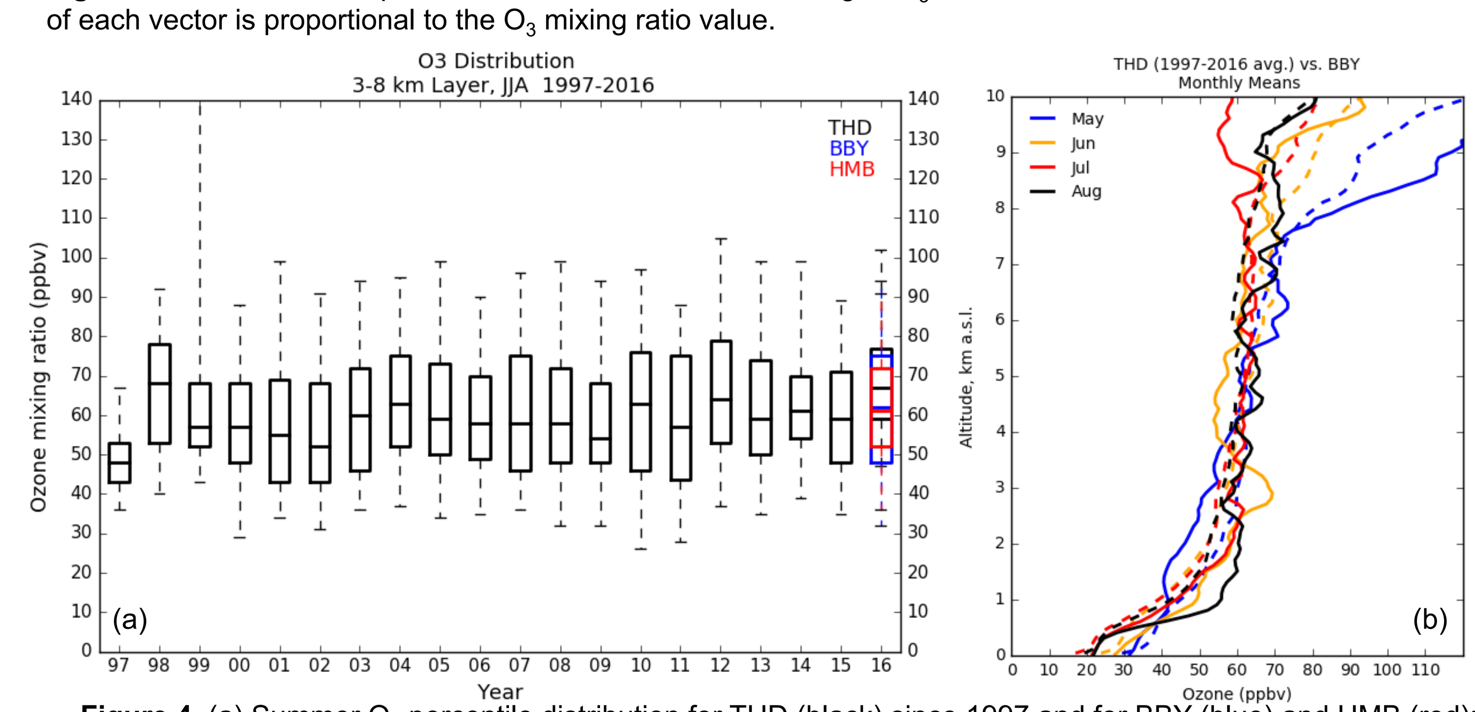

Figure 4. (a) Summer O_3 percentile distribution for THD (black) since 1997 and for BBY (blue) and HMB (red); (b) Monthly mean O_3 measurements at THD, BBY and HMB from 1997-2016.

The summer (JJA) O_3 percentile distribution for Trinidad Head (black) since 1997 and for Bodega Bay (blue) and Half Moon Bay (red) during CABOTS is shown in Fig. 4a. The whiskers represent the 5th and 95th percentiles, the box edges show the 25th and 75th percentiles, and the middle line represents the median. During JJA, the latitudinal difference in the 3-8 km layer median O_3 between THD and the CABOTS sites was about 6-7 ppb below THD's JJA median. Comparing BBY's 2016 monthly mean O_3 measurements to THD's 1997-2016 climatology (dotted lines), BBY saw above average O_3 mixing ratios in most of the lower troposphere (Fig. 4b) with BBY in August seeing about 10 ppb higher than THD's average near 1 km. BBY in June saw about 15 ppb higher than THD's June average at 3 km.

3. HMB, BBY, and the 2016 Soberanes Fire

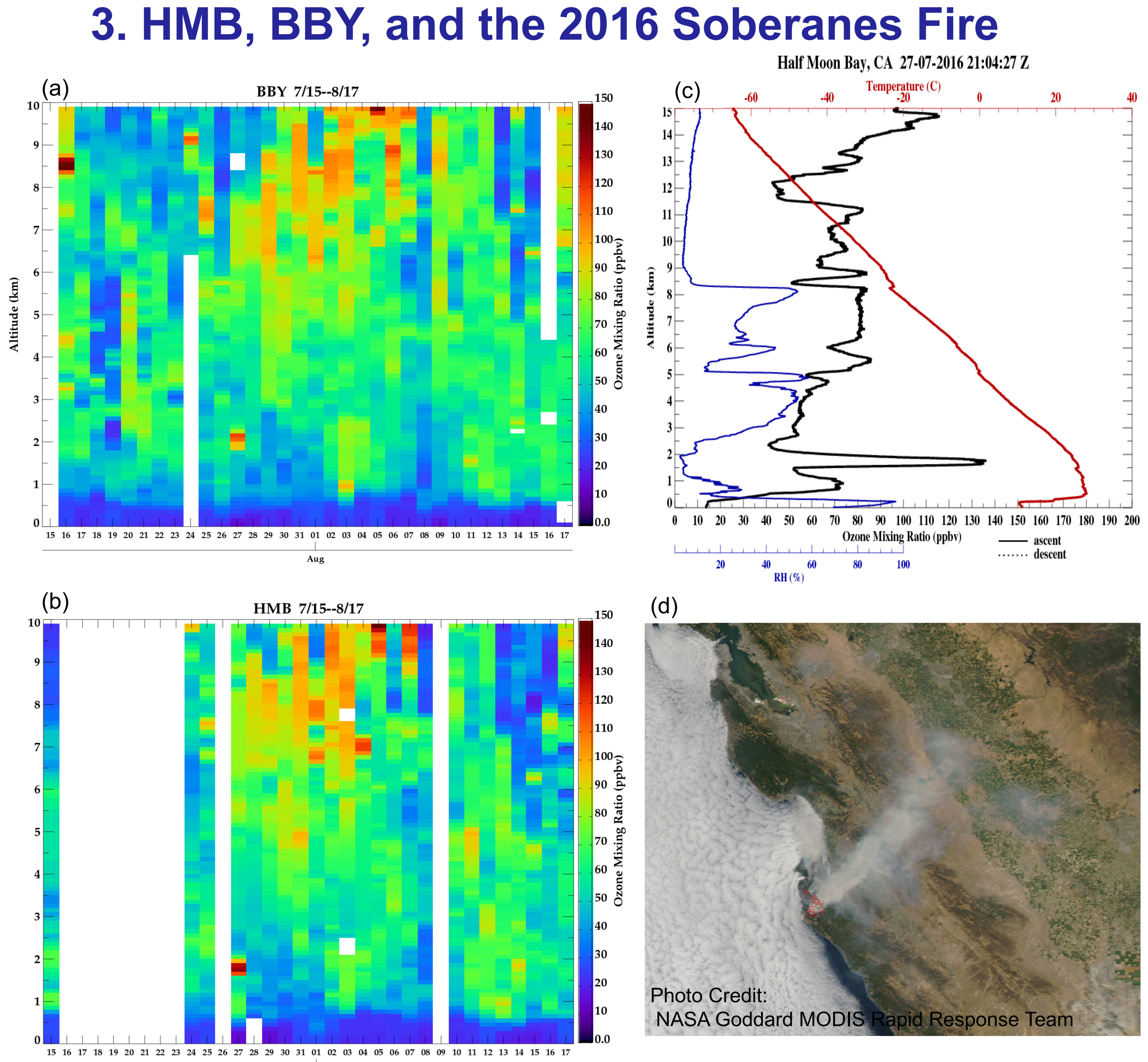

Figure 5. (a-b) BBY and HMB vertical O3 profiles From 7/15-8/17. (c) HMB ozonesonde profile for 7/27. (d) Visible Satellite image of the Soberanes Fire smoke plume on July 27th south and east of Monterey Bay.

Although HMB is 60 mi SE of BBY, there are still a considerable amount of O_3 magnitude differences, which are a result of local and/or regional influences. Nonetheless, they still agree well with one another overall spatially and temporally (Figs. 5a,b). The source for the large ozone enhancement from 6-10 km from July 26th to June 9th is being investigated. One noticeable difference and example of local influence is on July 27th. On this day, HMB's ozone profile shows an ozone concentration near 136 ppb near 2 km (Fig. 5c) and BBY measured less near 121 ppb (not shown). This low layer of elevated O_3 mixing ratios was approximately 500 m thick. The ozone-wind vector (Fig. 3) shows a southwest wind blowing onshore during this time. Visible satellite imagery from MODIS shows that on this day the main smoke plume from the large Soberanes wildfire was blowing NE, however there was some smoke drifting northward into the San Francisco Bay Area (Fig. 5d). It is certainly possible that emissions from the wildfire helped to enhance ozone in this layer. NOAA HYSPLIT backward trajectories for this day (not shown) suggest that the air below 1.5 km may have originated from off the coast of Big Sur, approximately 1.5 days before moving onshore from the southwest. Wildfires are well known to affect surface ozone values, but determining ozone production from wildfire plumes is very challenging (Jaffe et al. 2012, Lu et al. 2016). Another notable wildfire during the 2016 wildfire season that affected the Bodega Bay ozonesonde measurements was the Cold Fire on August 3rd.

4. MOZART Model Evaluation

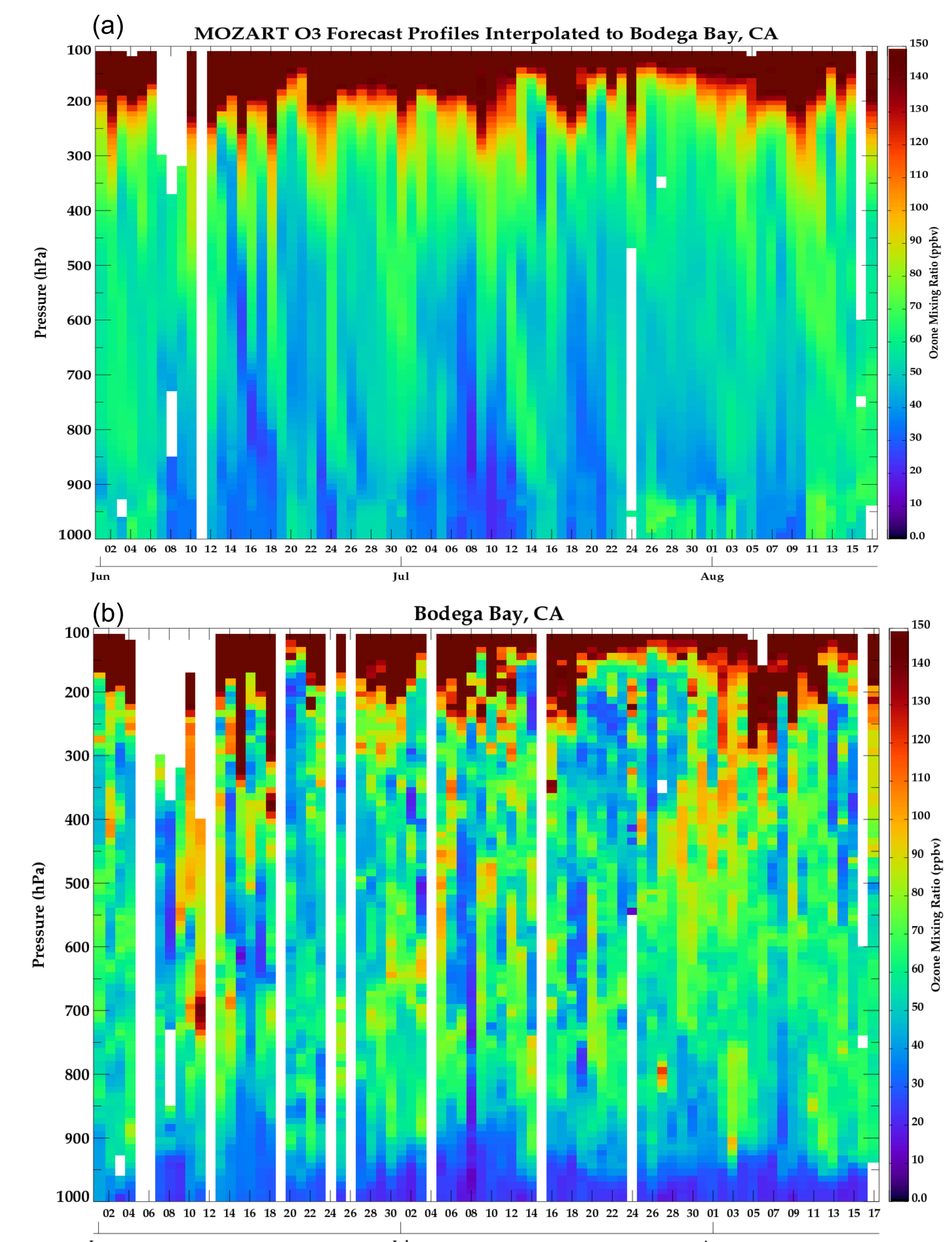

Figure 5: (a) Ozone forecast from MOZART-4; (b) ozonesondes analyses From BBY during CABOTS.

Global atmospheric chemistry forecast transport models often have very coarse resolutions, and they may not be able to capture all the fine details of local emission sources. One example is NCAR's Model for Ozone and Related Chemical Tracers (MOZART), which has a horizontal resolution of approximately 2.8 x 2.8 degrees (Emmons et al. 2010) . As shown in Figure 5, the MOZART-4's 24-h O_3 forecast product was analyzed during CABOTS for BBY in pressure height coordinates. The MOZART forecast was interpolated in time and space to BBY during the time of each launch, making most profiles roughly a 21-h forecast. The model is not able to capture most small details and features effectively, and on some days overestimates the ozone values in the lowest model levels near the surface in the boundary layer.

5. Summary

CABOTS was the first air quality field study to gather near-daily vertical O_3 profiles for any U.S. West coast site for most of the high O_3 season during both spring and summer. The O_3 measurements show large variability and complex heterogeneity spatially and temporally. These measurements will be used in future studies to determine to what extent the background O_3 can influence surface O_3 concentrations inland. There was a clear latitudinal difference in the O_3 mixing ratio values along the coast and between Trinidad Head and Bodega Bay. Bodega Bay and Half Moon Bay's median O_3 mixing ratio values in the background troposphere were almost 6-7 ppb lower than the Trinidad Head for summer 2016. Also, there was a large presence of stratospheric and California wildfire influence, particularly the Soberanes Fire, on the coastal vertical O_3 profiles.

Acknowledgements

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