Appendix F

Offshore Emissions Impacts on Onshore Air Quality

OFFSHORE EMISSIONS IMPACTS ON ONSHORE AIR QUALITY

The transport of air pollution over long distances and between air basins is well established. The emissions from ocean-going vessels (OCVs or vessels) can travel great distances and numerous studies have shown local, regional, and global impacts on air quality. (Endresen, 2003; Jonson, 2000; Corbett and Fishbeck, 1997; Streets, D.G., 2000; Saxe, H. and Larsen, T., 2004) Ocean-going vessels emit large quantities of several pollutants, however, the impacts of nitrogen oxides (NOx) and sulfur oxides (SOx) are the most often studied using various air quality models. In a recent study, using a bottom-up estimate of fuel consumption and vessel activity for internationally registered fleets, annual emissions from vessels worldwide were estimated to be significantly greater that previously considered. This study estimated that the global NOx from vessels is actually more than doubled from previous estimates. This study also suggests that near shore emissions impacts may be much larger than previously estimated. (Corbett and Koehler, 2003) Other studies indicate that vessel emissions can be a dominant contributor to sulfur dioxide concentrations over much of the oceans and in many coastal regions. (Capaldo, 1999) However, NOx and SOx are not the only pollutants of concern, as additional studies show coastal ozone and particulate matter impacts from OCV emissions. (Marmer and Langmann, 2005; Lawerence and Crutzen, 1999; Fagerli and Tarrasson, 2001; Eastern Research Group and Starcrest Consulting Group, 2003)

A study for the International Maritime Organization concludes that at any given time, most vessels are near a shore and that approximately 80 percent of the emissions are emitted near the coast, including the west coast of the United States. (International Maritime Organization, 2000) In California, ship emissions are becoming an increasingly important source of emissions as their relative contributions to the total amount of pollution is increasing as land based sources become more stringently controlled. For example, the Santa Barbara County Air Pollution Control District estimates that by 2015, NOx emissions from ships will comprise more than 60 percent of their total NOx inventory. (Murphy)

The issue of onshore impacts of offshore emissions has been a concern in California for several decades. Tracer studies, analysis of meteorological data and ambient monitoring data, and air quality modeling, are approaches used to determine the extent to which emissions released offshore can impact onshore areas.

Tracer Studies

Tracer studies have been conducted off the California coast to determine characteristics of pollutant transport in California's coastal areas and they provide evidence of onshore impacts from offshore emissions. A tracer study involves the release of a known amount of a non-toxic, inert gas from either a moving or fixed point offshore and the subsequent sampling the of the atmosphere for concentrations of that gas at sites onshore. Brief descriptions of three such studies, from which we can infer that pollutants emitted from offshore ships can be transported to onshore areas and be available to participate in onshore atmospheric processes, are given below.

In 1977, a dual tracer study was conducted from a naval research vessel traveling 8 to 20 miles offshore. (ARB, 1983) The two tracers, sulfur hexafluoride and bromotrifluromethane were released as the ship moved from the Long Beach area to the Santa Barbara channel. Twenty-nine onshore sites were established to monitor for the two tracers. The results showed both tracer gases were detected at sampling stations along the entire length of the network that ran from Ventura to Long Beach.

Another tracer study involving the Santa Barbara Channel conducted in 1980 was performed to collect data to be used in an air quality model and again showed pollutants emitted offshore were detected onshore. (ARB 1982; ARB 1984) This study used sulfur hexafluoride in six tracer experiments emitted offshore and at Point Conception. Over 10,000 samples were gathered from on-shore sites and also from boats and airplanes to determine offshore transport paths. The results showed that pollutants emitted in the Santa Barbara Channel will be transported onshore and that very little dispersion occurs over water, and as a consequence, the pollutant concentration downwind can be elevated.

The most recent of the tracer studies discussed here was conducted as part of the 1997 Southern California Ozone Study. (ARB, 2000) The objectives of this tracer study were two-fold. The primary objective was to obtain direct evidence regarding the trajectory of emissions from vessels transiting the coast and the impact on onshore air quality from two proposed shipping lanes. The secondary objective was to assess the ability of models to simulate the relevant physical processes that take place during transport of emissions offshore from the shipping lanes to onshore. A total of 51 onshore sampling site locations were selected from Santa Barbara to Oceanside, going inland as far as Santa Clarita Valley and the Rubidoux air monitoring station. Five perfluorocarbon (PFTs) tracers were used in this study. The tracer gases were released from both a fixed point offshore and from vessels moving simultaneously along two shipping lanes for a specified period of time. The results of the study showed that the tracer gases were detected on-shore and suggested that meteorology strongly influences the direction and magnitude of dispersion of the pollutants.

Meteorology/Climatology

Another source of information regarding onshore impacts is to examine the meteorology/climatology near the coast. In the early 1980's, based on a investigation of meteorological data, the Air Resources Board established the California Coastal Waters (CCW) as a boundary within which emissions that are released, are transported on-shore. In addition, ARB meteorology staff recently reviewed available data to determine if California meteorological and climatology support the transport of offshore emissions to coastal air basins. A brief discussion on the development of the CCW and the more recent data review is presented below.

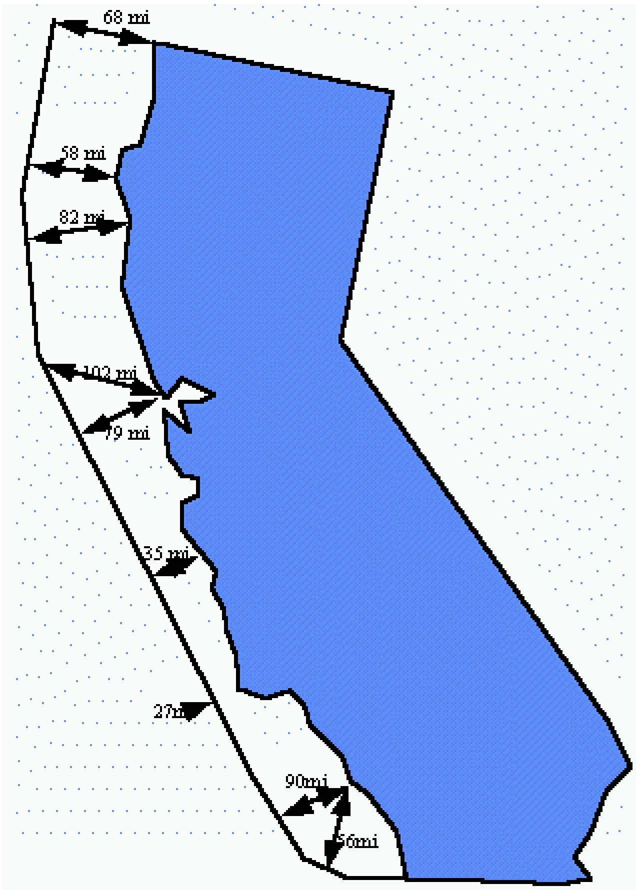
California Coastal Water Boundary: Previous studies by the ARB have demonstrated that pollutants released off California's coast can be transported to inland areas due to the meteorological conditions off the coast. In 1983, in the Report to the Legislature on Air Pollutant Emissions from Marine Vessels, the ARB established a boundary based on coastal meteorology within which pollutants released offshore would be transported onshore (ARB, 1983; ARB, 1984). The development of the boundary defined as the California Coastal Waters (CCW) is based on over 500,000 island, shipboard, and coastal observations from a variety of records, including those from the U.S. Weather Bureau, Coast Guard, Navy, Air Force, Marine Corps, and Army Air Force. (ARB, 1984) The area within the CCW boundary is defined as that area between the California coastline and a line starting at the California Oregon border at the Pacific Ocean. The California Coastal Waters are shown in Figure 2. This boundary ranges from about 25 miles off the coast at the narrowest to just over 100 miles at the widest.

Figure 2: California Coastal Waters

"California Coastal Waters" means that area between the California Coastline and a line starting at the California-Oregon border at the Pacific Ocean

thence to 42.0°N 125.5°W
thence to 41.0°N 125.5°W
thence to 40.0°N 125.5°W
thence to 39.0°N 125.0°W
thence to 38.0°N 124.5°W
thence to 37.0°N 123.5°W
thence to 36.0°N 122.5°W
thence to 35.0°N 121.5°W
thence to 34.0°N 120.5°W
thence to 33.0°N 119.5°W
thence to 32.5°N 118.5°W

and ending at the California-Mexico border at the Pacific Ocean. Coordinates shown above are exact. Distances of California Coastal Waters boundary from coast are rough



approximations.

Review of Available Meteorological and Climatological Data: As previously documented in reports by the ARB (ARB, 1983; ARB 1984) the lower atmosphere is the medium in which air pollution is carried from one surface or near-surface pollution source to a surface based receptor. In this medium, the direction of pollution transport and the dispersion of air pollutants are largely dependent upon the wind and the vertical temperature distributions (stability).

The wind and the stability along the coast of California are largely affected by the North Pacific high pressure cell, particularly during the summer. It is a semi-permanent feature of the Northern Hemispheric large scale atmospheric circulation pattern, and it produces a predominantly northwesterly flow of maritime air over the California coastal waters. This circulation pattern is modified to more westerly flow by continental influences as the air approaches the coast of California.

Another California weather characteristic that results from the location of the Pacific high is the steady flow of air from the northwest during the summer that helps drive the California Current of the Pacific Ocean. The California Current sweeps southward almost parallel to the California coastline. However, since the mean drift is slightly offshore, there is a band of upwelling immediately off the coast as water from deeper layers is drawn into the surface circulation. The water from below the surface is colder than the semi-permanent band of cold water just offshore, which ranges from 25 to 50 miles in width.

The temperature of water reaching the surface from deeper levels is as much as 10° colder during the summer than is the water 200-300 miles farther west. Comparatively warm, moist Pacific air masses drifting over this band of cold water form a bank of fog which is often swept inland by the prevailing northwest winds out of the high pressure center. In general, heat is added to the air as it moves inland during these summer months, and the fog quickly lifts to form a deck of low clouds that extend inland only a short distance before evaporating completely. Characteristically, this deck of clouds extends inland further during the night and then recedes to the vicinity of the coast during the day. This layer of maritime air is usually from 1,000 to 2,000 feet deep, while above this layer the air is relatively warm, dry, and cloudless.

Additionally, the air flowing around the Pacific high at upper levels is sinking (subsiding) and consequently warming due to compression. This warm air above the cool coastal marine air produces a strong, persistent vertical temperature inversion which limits the vertical mixing of pollutants.

As stated above, the North Pacific high pressure cell produces a predominantly northwesterly flow of marine air over California Coastal Waters and, generally, this flow becomes more westerly as the air approaches the coast of California.

Numerous climatological studies which describe the air flow patterns along the California coast clearly show this. Table 1 presents a summary of the wind flow direction frequencies measured at various locations along the California coast as shown in previous ARB reports. The table shows that onshore wind flow predominates during the spring and summer at all five locations, and during the fall at four out of the five sites. The table also shows that, on an annual basis, onshore winds are about twice as common as offshore winds at those given locations. The data in Table 1 are based on a relatively large data set. Because the data set covers multiple years, these wind flow percentages are not expected to change significantly over time. However, data from a more recent analysis are provided in Table 2 to show the consistency in wind flow patterns through the years. Table 2 shows the predominant wind flow at various coastal sites in California. The directions that are shaded correspond to onshore conditions. All coastal sites depicted in this table are dominated by onshore conditions and each site has at least eight months where onshore flow is the dominant wind direction. The data in Table 2, although depicted slightly different, are consistent with the data in Table 1.

Table 1: Wind Flow Direction Frequencies in Coastal Areas of California[1]

Station	Wind Direction	Seasonal Frequency[2] (%)				
		Spring	Summer	Fall	Winter	Annual
Oakland	Onshore	75	83	62	47	67
	Offshore	20	13	27	42	25
	Calm	5	4	11	11	8
Vandenberg AFB	Onshore	64	69	48	34	54
	Offshore	24	9	32	53	29
	Calm	12	22	20	13	17
Santa Barbara	Onshore	50	62	44	32	47
	Offshore	26	21	29	24	25
	Calm	24	17	27	44	28
Point Mugu NAS	Onshore	57	59	41	31	47
	Offshore	28	21	41	54	36
	Calm	15	20	18	15	17
Los Angeles	Onshore	68	81	60	43	63
	Offshore	30	16	36	53	34
	Calm	2	3	4	4	3

Source: National Climatic Center

1.Period of Record:
Oakland – 1965-1978
Vandenberg AFB – 1959-1977
Santa Barbara – 1960-1964
Point Mugu NAS – 1960-1972
Los Angeles International – 1960-1978

2. Spring: March, April, May;
Summer: June, July, August;
Fall: September, October, November; and
Winter: December, January, February

Table 2: Prevailing Wind Direction at California Coastal Sites[1] (1992-2002)

Station[2]	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SFO	W	W	W	W	W	W	W	W	W	W	W	W
MRY	ESE	ESE	W	WNW	W	W	W	W	W	W	ESE	ESE
SBA	WSW	W	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW
OXR	W	W	W	W	W	W	W	W	W	W	W	NE
NTD	NE	W	W	W	W	W	W	W	W	W	NE	NE
SMO	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	SW	N
LAX	E	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	E
SNA	S	S	S	S	S	SSW	SSW	SSW	SW	SW	SW	S
OKB	W	NE	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	WSW	NNE
SAN	WNW	WNW	WNW	WNW	WNW	WNW	WNW	WNW	WNW	WNW	WNW	WNW

Source: Western Region Climate Center (http://www.wrcc.dri.edu/)

[1] Prevailing wind direction is based on the hourly data from 1992-2002 and is defined as the direction with the highest percent of frequency. Wind directions that are shaded correspond to onshore flow.
[2] SFO – San Francisco International Airport; MRY – Monterey Airport; SBA – Santa Barbara Airport; OXR – Oxnard Airport; NTD – Point Mugu Naval Air Station; SMO – Santa Monica Airport; LAX – Los Angeles International Airport; SNA – Santa Ana Airport; OKB – Oceanside Municipal Airport; SAN – San Diego Lindbergh Field

As stated above, the large scale climatological wind flow along the California coast is modified by the effects of local land/sea breeze circulations. In effect, the local daytime sea breeze enhances the large-scale onshore component of the wind while the nighttime land breeze retards or occasionally reverses the flow. Table 3 presents seasonal resultant winds by time of day for San Francisco International Airport and Point Mugu Naval Air Station. The table shows the influences of the land/sea breeze circulations and shows that the onshore winds are generally stronger than offshore winds, a further indication of the transport of offshore emissions to receptor areas onshore.

Table 3: Seasonal Resultant Winds
(Degrees/MPH – Onshore Winds Shaded)

	San Francisco (International Airport)						Point Mugu NAS				
Time (PST)	Spring	Summer	Fall	Winter	Annual		Spring	Summer	Fall	Winter	Annual
0100	277/7.2	287/9.4	281/4.7	252/1.7	280/5.7		323/1	Calm	036/2	033/4	024/1
0400	272/5.7	284/8.0	278/3.7	224/1.1	276/4.5		007/1	029/1	032/2	036/4	030/2
0700	274/4.1	282/6.2	270/2.6	180/1.4	271/3.2		013/2	013/1	031/2	038/4	029/2
1000	305/4.1	306/7.2	350/2.0	084/2.1	320/2.9		230/4	235/5	210/1	052/4	230/2
1300	288/10.7	297/15.3	307/6.2	015/1.7	299/8.1		250/8	252/8	248/5	230/2	249/6
1600	281/15.0	289/17.9	293/10.4	299/3.9	288/11.7		264/9	267/8	269/6	279/3	268/7
1900	281/13.2	289/15.3	289/9.9	282/4.0	286/10.6		279/5	287/4	320/2	001/2	297/3
2200	280/9.4	289/11.5	287/6.2	266/2.6	284/7.4		297/2	291/1	002/2	022/3	340/2
All Hours	281/8.6	291/11.3	291/5.8	276/1.3	287/6.7		269/3	264/3	300/1	022/2	288/2

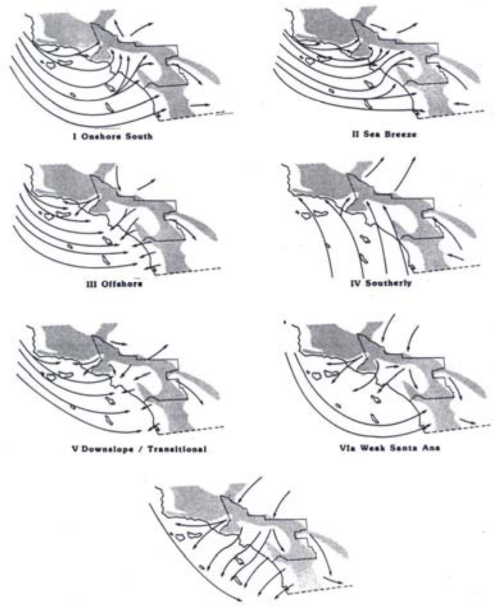
In addition, the ARB staff categorizes air flow for the four most heavily populated air basins in California: Sacramento Valley, San Joaquin Valley, San Francisco Bay Area, and the South Coast Air Basin three times a day. See Figure 1 for an example of the air flow types relevant to the San Francisco Bay Area and South Coast Air Basins.

Onshore and offshore percentages can be obtained by grouping the types appropriately. For instance, air flow types Ia, Ib, II, V, and VI would correspond to onshore conditions in the San Francisco Bay Area. Air flow types I, II, and IV would reflect onshore conditions in the South Coast Air Basin. The results are illustrated in Table 4. The onshore/offshore prevalence for these air basins based on this kind of air flow typing is consistent with the onshore/offshore frequencies of individual sites in these areas shown from prior analyses.

Figure 1

San Francisco Bay Area Air Basin

South Coast Air Basin



Period of Record: San Francisco International 1975-1979
Point Mugu NAS 1962-1977

Source: National Climatic Center

The air that flows around the Pacific high at upper levels sinks (subsides) and consequently warms due to air compression. This warm air above the cool coastal marine air produces a strong and persistent vertical temperature inversion that is a major influence on atmospheric stability. Atmospheric stability is the primary weather factor that influences the vertical dispersion of pollutants. In general, the more stable the air, the more dispersion is inhibited. An extremely stable subsidence inversion dominates the California coastal areas and effectively caps the marine layer, providing a ceiling above which pollutants cannot rise. This reduces the vertical dispersion of air pollution, particularly during the summer when the inversion is strongest and most persistent.

Table 4: Composite Surface Air Flow Types (1977-1981)

San Francisco Bay Area Air Basin					South Coast Air Basin		
Season	**Onshore**	**Offshore**	**Calm**		**Onshore**	**Offshore**	**Calm**
Winter	59	25	14		38	45	16
Spring	88	7	5		64	27	9
Summer	96	1	3		73	16	11
Fall	80	10	9		53	34	13
Yearly	81	11	8		58	30	12

Source: California Air Resources Board , California Wind Climatology (June 1984)

Table 5 is a compilation of seasonal inversion frequencies and characteristics for Oakland, Vandenberg AFB, and Point Mugu NAS. The table shows that the mean height of the base of the subsidence inversions ranges between 600 and 2200 feet above sea level (asl) and is persistent throughout the year. (Inversions are present some 90 percent of the time.) The combination of a strong, persistent inversion and the onshore winds which characterize the coastal meteorology of California is conducive to the transport of offshore emissions to coastal air basins. Offshore emissions are transported beneath or within the inversion, with little dispersion, to onshore areas.

Table 5: Atmospheric Inversion Statistics 1975-1977

Oakland					
	Spring	Summer	Fall	Winter	Annual
Mean					
Invers. Top (ft asl)	3200	2800	2900	3000	3000
Invers. Base (ft asl)	2200	1200	1700	1900	1700
Strength	6	15	8	6	9
Percentage of Occur.					
Inversion	80	98	88	80	86
Base <= 3000’ asl	58	94	71	60	71
Base <= 1000’ asl	31	47	44	43	41
Vandenberg AFB					
	Spring	Summer	Fall	Winter	Annual
Mean					
Invers. Top (ft asl)	2900	3200	2700	2600	2900
Invers. Base (ft asl)	1700	1400	1400	1600	1500
Strength	10	20	12	8	13
Percentage of Occur.					
Inversion	89	99	93	85	92
Base <= 3000’ asl	77	96	85	71	83
Base <= 1000’ asl	40	32	50	55	44

Point Mugu NAS					
	Spring	Summer	Fall	Winter	Annual
Mean					
Invers. Top (ft asl)	1900	2800	2000	1400	2100
Invers. Base (ft asl)	1100	1300	1000	600	1000
Strength	7	14	10	8	10
Percentage of Occur.					
Inversion	84	99	96	87	92
Base <= 3000' asl	73	93	86	83	84
Base <= 1000' asl	57	47	66	68	59

Other Studies

Establishing the distance of how far offshore pollutants can be emitted and will have an expected onshore impact is dependent upon the models used and meteorology of the coastal area. For the development of emission inventories, U.S. EPA has investigated the extent to which emissions offshore have the potential to impact onshore air quality and taken that into consideration when developing emission inventories. Studies have also been conducted that investigate the over-water chemistry of ship emissions and how that may influence air quality models. In addition, information on the contribution of ship emissions impacts was evaluated from air monitoring data collected in Southern California during the strike of union workers at the Ports of Long Beach and Los Angeles. These are discussed briefly below.

For ocean-going vessels, the United States Environmental Protection Agency (USEPA) counts NOx emissions in their inventory if the vessel is operating within a 175 nautical mile boundary off of the United States coasts. (USEPA, 2003) As stated in the Support Document for Controlling Emissions from New Marine Engines at or above 30 liters per Cylinder, "this 175-mile area is based on the estimate of the distance a NOx molecule could travel in one day (assuming a 10 mile per hour wind traveling toward a coast, NOx molecules emitted 12 miles from the coast could reach the coast in just over one hour. NOx molecules emitted 175 miles, or 200 statue miles, could reach the coast in less than a day.)" Also mentioned in this report was a modeling study conducted by the Department of Defense That concluded that emissions released within 60 nautical miles of shore could make it back to the coast. (Eddington, 1997) In response to a request by the USEPA for comment on this 175-mile boundary, a study using 10 years of hourly surface wind data was performed to estimate the probability that offshore emissions will impact land from specified distances. (Eddington and Rosenthal, 2003) This study showed that for California, the probabilities were high (greater than 80 percent) that emissions from 50 nautical miles offshore will reach the coast within 96 hours.

There has been very little actual in-transit measurement of the pollutant emissions from ships to better understand various aspects of ship plume chemistry and reconcile differences between measurements and model predictions. However, a recent study conducted by Chen et al (Chen, 2005), where measurements of chemical species in ship plumes were taken from aircraft transecting a ship plume indicates that the NOx half-life within a ship's plume may be much shorter than predicted by photochemical models. The study demonstrated a NOx lifetime of about 1.8 hours inside the ship plume at noontime as compared to about 6.5 hours in the background marine boundary layer of the experiment. Additional studies investigating ship plume chemistry will help validate these results and help us better understand ship plume chemistry and improve the photochemical models used to investigate the impacts of ships on air quality.

Recently, a study was conducted that investigated ambient air quality data to examine contributions from ship emissions. In the fall of 2002, union workers at the ports of Los Angeles and Long Beach went on strike. The result was that the port operations shut down and about 200 ships were idling off the coast, immediately upwind of Long Beach. As part of a study in support of the University of Southern California Children's Health Study, researchers analyzed the effect of this strike on PM and gaseous pollutants at a monitoring site in Long Beach. Based on a comparison of PM and gaseous pollutant measurements from pre-, during and post-strike periods, they found statistically significant increases in particle number concentrations (60-200nm) and NOx and CO which they concluded are indicatives of contributions of emissions from the idling ships during the strike period. (ARB, 2005)

Conclusions

The transport of air pollution over long distances and between air basins has been well established. The emissions from ocean-going vessels can travel great distances and numerous studies have shown local, regional, and global impacts on air quality. Tracer studies, air quality modeling, and meteorological data analysis are typical approaches used to determine the extent to which emissions released offshore can impact onshore areas. Several studies support ARB staffs conclusion that emissions from ocean-going vessels released offshore the California Coast can impact onshore air quality.

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