Shell Chukchi Sea Exploration Plan
Revision 2
Environmental Impact Assessment
Attachment C
Air Quality Technical Report
Offshore Subsistence Area

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Acronyms, Abbreviations, and Definitions

Note that in this section and throughout the rest of this report there are active hyperlinks that will jump to the referenced material or section. General hyperlinks are formatted like this. Hyperlinks for tables and figures are highlighted like **this**.

Air quality standard .... Health-based standard representing a pollutant concentration in the ambient air usually over some averaging period (e.g. 1-hour), intended to protect the health and welfare of people with a margin of safety.

Ambient air .... the air in outdoor locations to which the public has ready access

Area source .... an emission source type defined in CALPUFF. Area source emissions are released from two-dimensional four-sided areas

Attainment/Nonattainment ..... a determination and classification made by EPA indicating whether ambient air quality in an area complies with (i.e., attains) or fails to meet (i.e., nonattainment) the requirements of one or more **NAAQS**

Averaging time .... a specific period of time (e.g., 1 hour, 24-hours, 1 year) over which concentrations of an air pollutant are measured or model-calculated. Note that some NAAQSs are also based on multi-year averages of certain percentiles of measured or calculated concentrations.

BACT .... Best Available Control Technology

BOEM .... Bureau of Ocean Energy Management, the regulatory agency with air quality authority in portions of the Outer Continental Shelf, part of the Department of Interior.

CALPUFF .... Air quality dispersion modeling system used in this analysis. The CALPUFF modeling system consists of pre-processors, a dispersion model and post-processors. The meteorological preprocessor (CALMET) was not used to provide meteorological information. Instead meteorological data was provided by the Weather Research and Forecasting Model (WRF) and prepared for CALPUFF input using a specially designed program called the Mesoscale Model InterFace (MMIF).

CO .... carbon monoxide, a criteria air pollutant

CO_2 .... carbon dioxide

CO_2e .... Carbon dioxide equivalents (emissions of all GHGs expressed in terms of their "global warning potential")

Criteria air pollutant .... an air pollutant specifically governed by the Federal Clean Air Act for which ambient air quality standards have been set. Criteria air pollutants include carbon monoxide, particulate matter, sulfur dioxide, nitrogen dioxide, ozone, and lead.

Dispersion model................... A computerized calculation tool used to estimate pollutant concentrations in the ambient air based on numeric simulations that consider the locations and rates of pollutant emissions and the effects of meteorological conditions, usually over specific averaging times (e.g., 8-hours)

EPA .... US Environmental Protection Agency

hp .... horsepower

Meteorological data set........... a compilation of meteorological data representing conditions over some period of time and including such things as wind speed and wind direction, and formatted as required by the dispersion model being used. This analysis used a meteorological data set covering 5 years.

Micrometer/Micron .... one millionth of a meter; typically used to distinguish particle size; typical human hair is 100 about microns in diameter

MLC .... Mud Line Cellar, an excavation below the level of the sea floor to protect drilling equipment from moving ice floes.

MCL ROV System .... A remotely operated submersible excavation unit proposed for establishing MLCs.

MLC ROV System Vessel...... A support vessel used to operate and support the MLC ROV System.

Modeling domain .... the area included in the **dispersion-modeling** analysis

Modeling receptor .... a theoretical (i.e., often non-specific) location used in computer modeling at which air pollutant concentrations are calculated. Modeling may also use site-specific receptors representing individual locations.

NAAQS .... National Ambient Air Quality Standard

NSPS .... New Source Performance Standard; rules that pertain to air pollution emission sources subject to air quality permits and newly manufactured equipment

NO_2 .... nitrogen dioxide, a **criteria** air pollutant

NO_X .... oxides of nitrogen, a general class of air pollutant without a specific air quality standard but used in monitoring air quality

Particulate matter (PM) .... air pollutant comprised of solid or liquid particles; PM is usually characterized based on the particle size. See also PM10 and PM2.5.

PM_{10} .... "Coarse" inhalable particulate matter with an aerodynamic size less than or equal to 10 micrometers (**microns**)

$PM_{2.5}$ .... "Fine" inhalable particulate matter with an aerodynamic size less than or equal to 2.5 micrometers (**microns**)

Point source .... an emission source type defined in AERMOD. Point source emissions are released from a single location.

ppm .... parts per million (a metric used in quantifying concentrations of air pollutants)

Receptor................................. See modeling receptor.

Release height......................... a CALPUFF term defining the height above ground at which source emissions are released

SO_2 .... Sulfur dioxide, a **criteria air pollutant**

tpy .... tons per year, an estimate of annual emissions μg/m^3 .... micrograms per cubic meter (a metric used in quantifying concentrations of air pollutants)

Preface

Shell Gulf of Mexico Inc. (Shell) has requested authorization from the United States Department of the Interior, Bureau of Ocean Energy Management (BOEM), to drill exploration wells in the Chukchi Sea beyond the 3-mile seaward boundary of Alaska. Exploration drilling will consist of the operation of two drilling units with support vessels on the Outer Continental Shelf (OCS) of the Chukchi Sea. Shell already has an approved Exploration Plan (EP) for drilling in the Chukchi Sea at the Burger Prospect (EP for Revision 1), but is making changes to that approved EP.

This report was developed for Shell's EP Revision 2 and its supporting Environmental Impact Assessment (EIA), for exploration drilling operations for Shell's future seasons of operations. This Air Quality Technical Report presents the analytical methods and results of an analysis to estimate offshore air pollutant concentrations in subsistence use areas that may result from the drilling units and their support vessels.

BOEM implements its authority to protect air quality under 30 CFR Part 550 Subpart C. This program is referred to as the BOEM Air Quality Regulatory Program (AQRP). BOEM also has the responsibility to evaluate potential impacts of the exploration drilling program pursuant to the National Environmental Policy Act (NEPA). BOEM Alaska indicates that air quality modeling is required to evaluate potential impacts under NEPA.[1]

This report is in response to a specific request by BOEM to evaluate potential air quality impacts of the exploration program in certain offshore areas that are used by native communities for subsistence activities. The basic assumptions, methods and analyses used in this report are identical to those in Attachment B (the onshore analysis) of the EIA for EP Revision 2, with the following exceptions:

- The locations of predicted concentrations are offshore in a specific area defined as the Subsistence Use Area.
- The criteria used for evaluation of these impacts are based on occupational criteria rather than the ambient air quality standards that are designed to protect sensitive populations such as the elderly, sick or very young.

Much of the detail in this report is identical to the onshore assessment but has been repeated here for the convenience of the reader.

[1] Meeting between BOEM and Shell, May 15, 2013, held in BOEM office, Anchorage, Alaska

1 Summary

This air quality analysis of the Shell OCS Exploration Program described in Shell's EP Revision 2 identifies air pollutant emissions and onshore concentrations that may result from the air emissions from the exploration program.

The air quality assessment of the exploration drilling program, as described in EP Revision 2, includes development of detailed emission inventories based on spatially and temporally distributed emissions from the following emissions units:

Offshore Drilling Program

- Two drilling units, including
    - Main generators
    - Propulsion engines
    - Various internal-combustion engines
    - Heaters and boilers
    - On-board incinerators
- Ice-management vessels (includes anchor handlers), including
    - Propulsion and generator engines
    - Boilers
    - Incinerators
- Oil spill response vessels
- Offshore supply vessels
- Support Tugs
- Oil storage tanker
- Science vessels
- MLC ROV System vessel

Emissions from these units and activities were evaluated with air quality dispersion modeling. The air quality analysis considered emissions and concentrations of "criteria" air pollutants, including oxides of nitrogen, oxides of sulfur, particulate matter and carbon monoxide. The air quality analysis indicates emissions from the exploration drilling program, including all offshore activities, would not result in any subsistence area air pollutant concentrations above the proposed significance criteria.

2 Project Description

2.1 Exploration Program Activity Area

Shell proposes to continue the exploration drilling program in the Chukchi Sea, Alaska, that began in the 2012 drilling season and is detailed in EP Revision 1. Shell's proposed exploration drilling operations will take place on federal OCS leases in the vast Chukchi Sea, an area of approximately 230,000 square miles (mi^2). Shell's EP Revision 2 proposes to conduct exploration drilling activities on six lease blocks all located within what is known as the Burger Prospect, acquired in federal OCS Lease Sale 193. The drill sites are remote from any infrastructure or human habitation and are located more than 60 miles offshore in Arctic waters that are inaccessible for eight months or more of the year due to pack ice. Shell's seasonal exploration drilling operations would begin on or about July 1st and extend no later than October 31st. The sites are identified "Burger" A, F, J, R, S and V in **Table 1**. The general location is depicted in **Figure 1**.

Table 1. Candidate Drilling Sites[1]

Prospect	Well	Area	Lease Number	Lease Block	Latitude	Longitude	UTM Coordinates[3] X(m)	UTM Coordinates[3] Y(m)
Burger	A[2]	Posey	OCS-Y-2280	6764	N71° 18' 30.92"	W163° 12' 43.17"	563945	7912759
Burger	F	Posey	OCS-Y-2267	6714	N71° 20' 13.96"	W163° 12' 21.75"	564063	7915957
Burger	J	Posey	OCS-Y-2321	6912	N71° 10' 24.03"	W163° 28' 18.52"	555036	7897424
Burger	R	Posey	OCS-Y-2294	6812	N71° 16' 06.57"	W163° 30' 39.44"	553366	7907999
Burger	S	Posey	OCS-Y-2278	6762	N71° 19' 25.79"	W163° 28' 40.84"	554391	7914199
Burger	V	Posey	OCS-Y-2324	6915	N71° 10' 33.39"	W163° 04' 21.23"	569401	7898125

[1] Identified under Table 1.a-1 of Chukchi Sea EP Revision 2.

[2] Burger A drill site where a partial well was begun in 2012.

[3] The Universal Transverse Mercator (UTM) coordinate system quoted here is from BOEM's OCS Official Protraction Diagram and are based on the North American Datum 1983 (NAD-83), zone 3. The actual coordinates shown are the expected drill locations within each block.

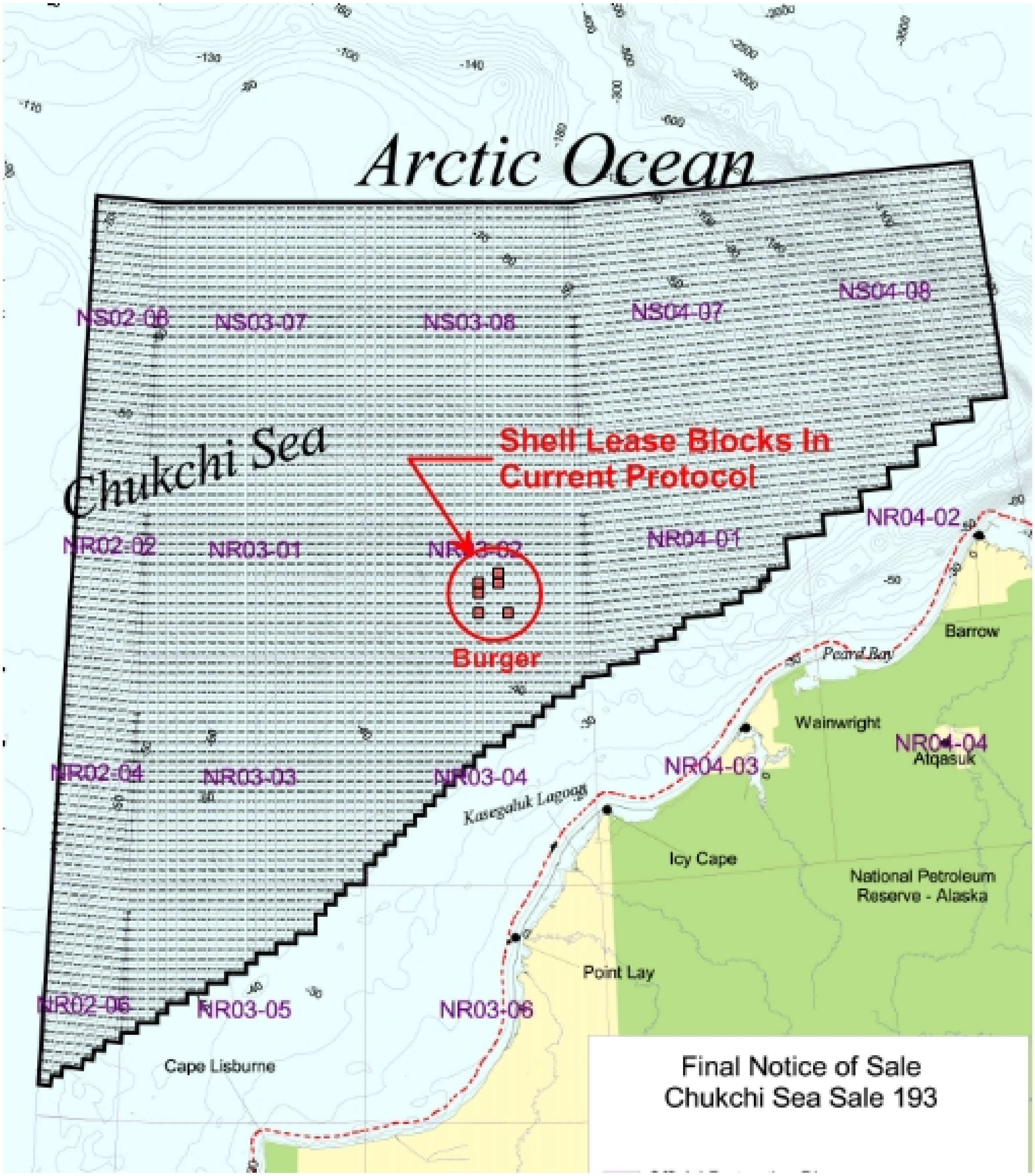


Figure 1. Project Vicinity Map

2.2 Offshore Drilling Program Activities and Emissions Units

The offshore drilling program will be conducted by two drilling units, the *M/V Noble Discoverer* (*Discoverer*) and the *Transocean Polar Pioneer* (*Polar Pioneer*), with support from ice management vessels, anchor handlers, oil-spill response (OSR) vessels, offshore supply vessels (OSVs), tugs, tankers, science vessels, MLC ROV System vessel, and aerial transport. For the drilling units, the *Discoverer* and *Polar Pioneer*, the actual vessel to be used and the types of emission units on board are defined. Support vessels are contracted on a yearly basis and multiple vessels are able to meet the duty requirements for the needed tasks. As such, it is not certain that the support vessels currently considered for the exploration program will be available. Therefore, for the support vessels, a candidate vessel and the anticipated emission units are identified.

The *Discoverer* is a turret-moored drilling unit that underwent significant upgrades in 2007 and 2013 so that it could operate in the Arctic. The *Discoverer* has its own propulsion engine for self-transport. The *Discoverer* is equipped with electrically powered thrusters, engine-driven electrical generators for the drilling motors, and other self-powered equipment such as hydraulic pumps, cranes, boilers, an incinerator, and other (mostly emergency-related) small sources. There will be no flares and no hydrocarbon-venting sources except for minor amounts associated with the drill cuttings.

The *Polar Pioneer* is a semisubmersible vessel designed to operate in the arctic environment. The *Polar Pioneer* is transported by a towing vessel. The *Polar Pioneer* operates main generator engines, heaters and an incinerator. There will be no flares and no hydrocarbon-venting sources except for minor amounts associated with the drill cuttings.

The support vessels are equipped with diesel-fueled primary and emergency power generation engines, and in some cases incinerators and/or diesel-fueled boilers.

Ice management vessels and anchor handlers will assist with management of the drilling unit anchors, bow washing of any ice buildup on the drilling units, and some ice floe fragmenting in support of the ice management vessel. One anchor handler and one ice management vessel provide primary close support for each drilling unit with regard to these tasks. The ice management vessels are needed when there are ice features that require disruption in their path or fragmentation in order to provide protection for the drilling units, or other assets critical to the safety of the exploration drilling program (i.e., mooring buoys, etc.). Up to two ice management vessels may be tasked to fragment any manageable ice flows so that the ice will flow around the drilling units. These ice management vessels may work at distances of 25 miles or more upwind of the drilling unit to monitor the leading edge of any ice floe of possible concern. These activities are necessary for managing ice at distances that provide adequate response time for drilling units to get off a well and anchor in case of encroaching ice that cannot be managed. These response times may vary depending on the drilling stage of the well hole. Furthermore, the anchor handlers and ice management vessels may have other tasks to conduct beyond 25 miles of the drilling units. This operation is accounted for in the fuel consumption limits used to calculate emissions, but ENVIRON has assumed they will be within 25 miles for the entire season. As discussed below, this assumption is conservative and tends to over-predict concentrations.

An oil-spill response vessel or vessels will be anchored nearby, typically between the two drilling units. During season, these vessels will primarily be used during refueling operations to protect against possible spills and will be located near the refueling Arctic oil fuel storage tanker. The OSR vessels are expected to be used in the unplanned and unlikely event of an oil discharge to the water. These vessels will be available to both the *Discoverer* and the *Polar Pioneer*.

Other support vessels include those for resupply and material transfer to shore. The OSVs would travel to the drilling units, then “park” in dynamic positioning (DP) mode beside the drilling unit for material or personnel transfer. The OSVs may operate in DP mode beside the drilling unit and would remain there for approximately one day.

It is anticipated that up to two vessels similar to the OSVs will be primarily used to monitor discharges from each drilling unit as required by the National Pollutant Discharge Elimination System (NPDES) General Permit. These vessels may remain within a few miles of each drilling unit for these sampling periods or conduct secondary tasks, as needed.

Two tugs will be operated in standby mode on-location in case the *Polar Pioneer* must leave location quickly because of encroaching ice. Another tug will escort the *Discoverer* to the drill site, assist during mooring, and depart the season to conduct other activities outside the Chukchi Sea.

A fuel and oil tanker is expected to be located in an area between the two drilling units to resupply the drilling units and support vessels.

During the 2012 drilling season, mudline cellars (MLC) were excavated with large drills aboard the *Discoverer*. As described in Shell's EP Revision 2, an MLC may also be excavated by a separate vessel (MLC ROV System vessel) supporting a specially designed subsurface excavator. This MLC operation may proceed ahead of the *Discoverer* and *Polar Pioneer* to future well sites within the same lease blocks identified in **Table 1**.

If the ice management vessels or OSVs travel beyond 25 miles from the drilling units, air emissions would be dispersed to a greater extent than when the vessels are closer to the drilling units. Because the dispersion modeling conducted in this analysis concentrates all ice management and OSV emissions within 25 miles of the drilling units, it results in predictions that are higher than those expected if some vessels venture outside the 25 mile radius. Consequently, additional modeling of that scenario is not warranted.

2.3 Spatial and Temporal Relationships of Offshore Drilling Program Emission Units

For air impact analysis purposes, there are three emission unit groups: the drilling units, the on-location support vessel support, and the onshore activities. Emissions units that are physically close together can have additive impacts, whereas, if the same emissions units are located over a large area, the impacts will be smaller at any one location (and distributed over a larger area).

The emission units on the *Discoverer* and *Polar Pioneer* are concentrated on each drilling unit. The support vessels will be spread over a 25 mile radius of the *Discoverer* and *Polar Pioneer*; therefore, emissions will be dispersed over this large area and will not be concentrated. At large distances from the drilling units, of up to 50 miles, the collective emissions will be well dispersed.

The *Discoverer* and the *Polar Pioneer* will operate in separate lease blocks. Based on **Table 1**, the distance between drill sites varies from 3 kilometers to 21 kilometers, depending on the two drill sites that are active at any given time. In order to evaluate the greatest potential onshore impact from the exploration activities, it is assumed that the drilling units are operating at the two lease blocks closest to the subsistence use area (see Figure 3.11.6-11 of EIA for EP Revision 2), which are blocks J and V. This assumption will result in an analysis of the greatest potential impacts to subsistence activities because at distances larger than a few miles where there is no elevated terrain, air quality concentrations are inversely proportional to the distance between the emission unit and the receptor. In this instance, the two drilling units are approximately 14 kilometers apart.

As discussed, the support vessels operate in different locations and operate in different ways over large areas. The anchor handler and ice management vessels will operate in areas determined by the drilling unit locations. When they are managing or scouting ice, they may typically be 25 miles or more upwind of the drilling unit. When these vessels are not working they could be anchored in warm-stack mode, transitioning or working in support of activities inside or outside of the OCS program area.

The OSR vessels will normally be in an area between the *Discoverer* and the *Polar Pioneer*. These vessels will be in a stand-by mode or supporting refueling operations associated with exploration program.

Some emissions units may not operate concurrently. Only emissions units that operate concurrently can have additive short-term (1-hour and 24-hour) concentrations. Those that do not operate concurrently will not have additive short-term concentrations, although all will contribute to concentrations averaged over the season. Drilling and use of the drilling units' smaller internal combustion (IC) engines will take place only after the drilling unit is fully anchored and connected to its anchors. The *Discoverer*'s propulsion engine will only be used intermittently once it is anchored. The cementing and logging equipment will only be used when setting casing or logging a well when the drilling unit is anchored at a drill site. None of the smaller diesels are operated during ship transit to and from the drill site. None of the smaller IC engines are used more than occasionally. However, since the precise times when individual emission units are expected to operate are not known at present, all units have been conservatively assumed to be operating concurrently in the air quality analysis.

3 Affected Environment

3.1 Evaluation Criteria

Air quality is generally assessed in terms of whether concentrations of air pollutants are higher or lower than prescribed criteria. As discussed in Attachment A of the EIA for EP Revision 2, national ambient air quality standards (NAAQS), which are established at levels determined to protect human health with a margin of safety, including the health of sensitive individuals like asthmatics, the elderly, the chronically ill, and the very young, are not appropriate criteria for offshore locations because the area is not readily accessible to the public and those who are able to reach the area are more apt to be healthy individuals capable of hunting, fishing, or working on commercial vessels. These individuals are present, if at all, only for limited periods of time and are comparatively healthier than the more susceptible population that NAAQS are designed to protect. See Attachment A of the EIA for EP Revision 2. In addition, under the clean air act, NAAQS are only implemented in air quality control regions, which do not extend beyond the State's 3-mile seaward boundary. The criteria applied in the current evaluation have been selected to protect subsistence area users in offshore locations and are more protective than Occupational Safety and Health Administration's (OSHA) exposure standards, and thus have a built-in margin of safety . These criteria are presented in **Table 2**.

Table 2. Evaluation Criteria for Offshore Subsistence Area Users

Pollutant	Averaging Time	Offshore Subsistence Area Criteria (μg/m^3)
Nitrogen Dioxide (NO_2)	1-hour	3,760
Particulate Matter (PM_{10} and $PM_{2.5}$)	1-hour	500
Carbon Monoxide (CO)	1-hour	55,000
Sulfur Dioxide (SO_2)	1-hour	5,200

3.2 Existing Air Quality Conditions

There are no existing sources of air pollution near the Chukchi Sea lease area because it is more than 60 miles from land and there are no other oil exploration or development sources in the Chukchi Sea at this time. In the absence of sources of emissions, the air quality in the project area is expected to be good. The points of land nearest the proposed drill sites are in the remote parts of the Arctic coast of Alaska, and are mostly uninhabited except for occasional subsistence hunting and fishing. The nearest native villages are at Wainwright and Point Lay, approximately 66 and 86 nautical miles away, respectively.

Because the drill site location will be far from the Alaska shoreline and away from significant sources of pollution, existing air quality concentrations can be represented with a regional value. According to the EPA's *Guideline on Air Quality Models* (40 CFR 51, Appendix W, Section 8.2.2c), a "regional site" may be used to determine background concentrations if there are no monitors located in the vicinity of the source. A "regional site" is one that is located away from the area of interest, but is impacted by similar natural and distant man-made sources. The majority of the air quality data on the North Slope have been collected by various industrial developments associated with the oil and gas resources of the area.

Shell and ConocoPhillips began monitoring NO_2, $PM_{2.5}$, PM_{10}, SO_2, CO, and O_3 concentrations at Wainwright, Alaska in November 2008 and Point Lay, Alaska in June 2010. Both monitoring stations are remotely located (minimal influence of industry and other human activities) and are the most representative "regional sites" on the North Slope for estimating offshore pollutant concentrations in the Chukchi Sea. However, both monitoring sites are located onshore and are located adjacent to villages and therefore may be exposed to high concentrations of pollutants from nearby combustion or unpaved road dust from vehicles. Consequently, it is expected that the measured concentrations of pollutants at these stations are higher than the concentrations that actually occur offshore because the combustion and dust sources are not present on the open sea. A map of the ambient monitoring stations on the North Slope is provided in **Figure 2**.

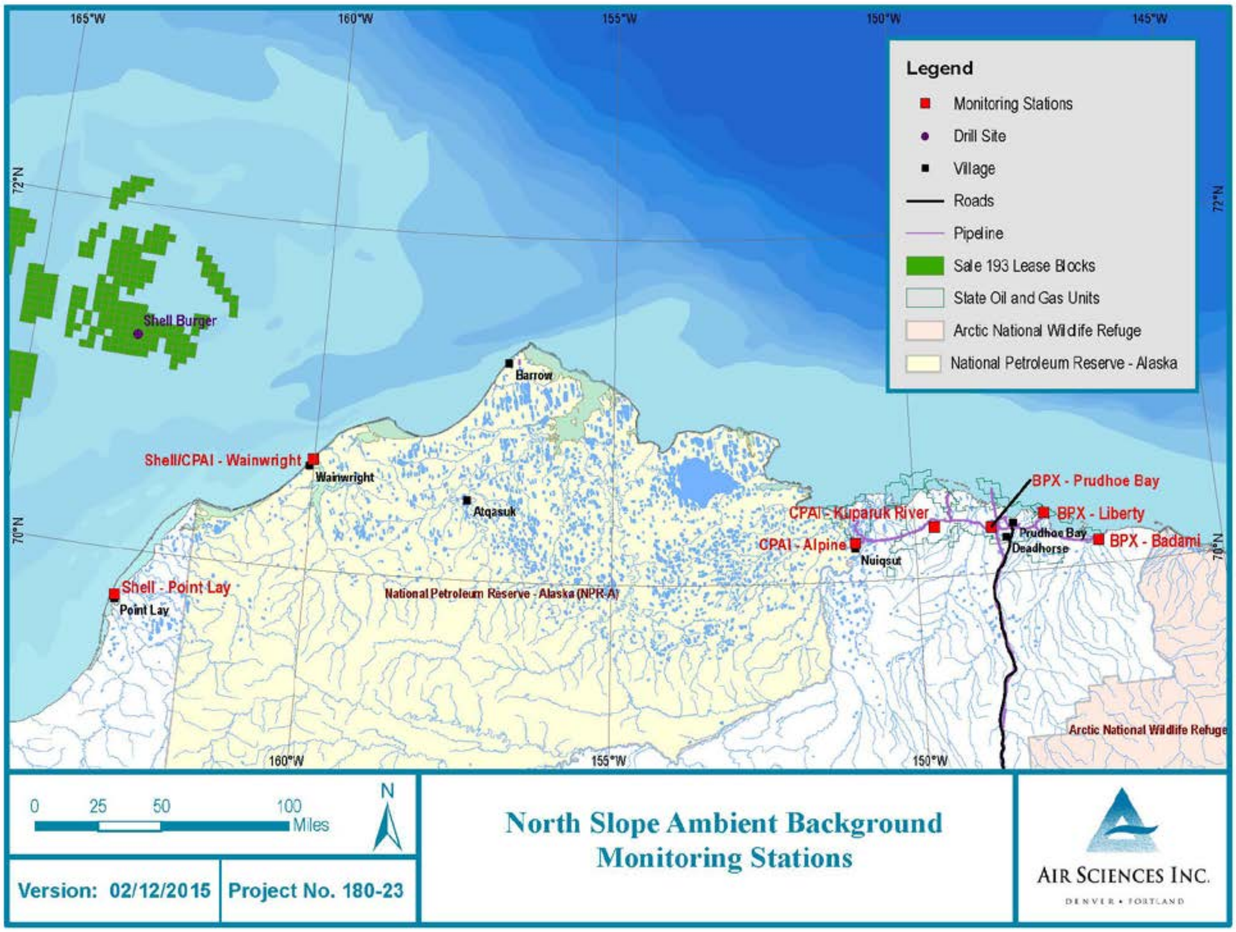


Figure 2. Regional Air Quality Monitoring Site Locations

Table 3 summarizes the background pollutant concentrations measured at the Wainwright and Point Lay monitoring stations during the drilling seasons (July 1 – Nov. 3).Note that annual concentrations best represent the average concentrations onshore, and likely overstate concentrations in the subsistence area because the onshore areas adjacent to developed areas with local sources of air pollution as opposed to the undeveloped environment of the Arctic Ocean.

Table 3. Maximum Existing Ambient Air Concentrations

Pollutant	Averaging Period	How standard is applied	Wainwright Maximum Measured Concentration [b] (µg/m³)	Pt. Lay Maximum Measured Concentration [c] (µg/m³)	NAAQS (µg/m³)
NO_2	1-hour	3-year average of 98th percentile daily maximum 1-hour averages	40.1	43.8	188
	Annual	Maximum arithmetic average	1.4	1.4	100
$PM_{2.5}$	24-hour	3-year average of 98th percentile daily averages	10.7	5.5	35
	Annual	3-year average of annual arithmetic averages	2.9	2.0	12
PM_{10}	24-hour	Not to be exceeded more than once per year (2nd highs), averaged over 3 years	73.0	23.6	150
	Annual[d]	--	16.6	6.2	--
SO_2	1-hour	3-year average of 99th percentile daily maximum 1-hour averages	8.1	11.6	190
	3-hour	Not to be exceeded more than once per year (2nd high)	12.8	14.1	1,300
	24-hour	Not to be exceeded more than once per year (2nd high)	2.2	13.4	365
	Annual	Maximum arithmetic average	0.4	4.8	80
CO	1-hour	Not to be exceeded more than once per year (2nd high)	953	1490	40,000
	8-hour	Not to be exceeded more than once per year (2nd high)	946	1280	10,000

[a] Maximum background ambient air concentrations are calculated for the July 1st- Nov. 30th "drill season" period, using the most recent available data from Wainwright and Point Lay monitoring stations.
[b] Maximum concentrations measured at Wainwright from 2009 through 2012, as calculated according to the method described in "how standard is applied" column
[c] Maximum concentrations measured at Point Lay monitoring site from 2011 through 2013, as calculated according to the method described in "how standard is applied" column.
[d] There is currently no NAAQS for annual PM_{10}

The criteria that have been identified in Table 2 all refer to a one-hour average concentration. Comparison of the 1-hour concentrations in Table 3 (NO_2, SO_2, and CO) all show measured concentrations well below the criteria. There are no 1-hour ambient standards for either designation of particulate matter (PM_{10} or $PM_{2.5}$), therefore, the 24-hour values are adjusted by the persistence ratio of 24-hour to 1-hour concentration of 0.4 from the SCREEN3 model. In this comparison, Point Lay PM backgrounds were deemed more representative to use. Wainwright particulate matter backgrounds were not considered representative because of contamination from road dust from the adjacent unpaved road discussed in SLR (2011) and SLR (2012). Thus for PM_{10} the peak measured 24-hour concentration from Table 3 of 24 µg/m3 is multiplied by 2.5 to get 60 µg/m3 while for $PM_{2.5}$ the peak measured 24-hour concentration of 5.5 µg/m3 is multiplied by 2.5 to get 14 µg/m3. Both of these values are well below the 1-hour criteria in Table 2 of 500 µg/m³.

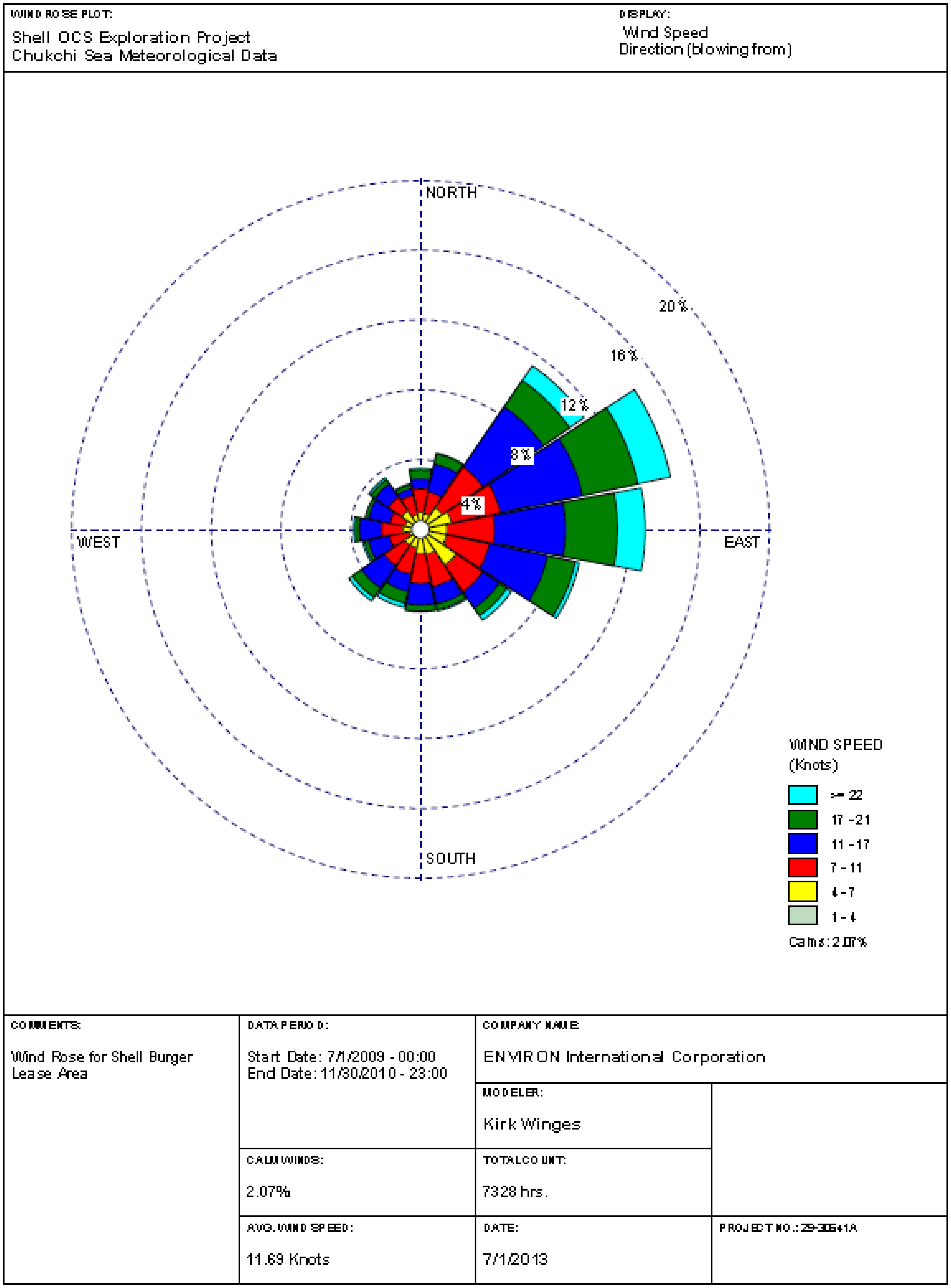
3.3 Meteorological Conditions and Climate

Climate in the project study area is unique to the polar region. The climate is dominated by severe cold temperatures during winter and a brief period of warming in late summer and early fall.

From an air pollution perspective, the most important meteorological parameters are wind speed and direction because they determine the transport and dispersion of airborne contaminants. Wind conditions are commonly represented by a figure known as a wind rose. **Figure 3** depicts a wind rose figure constructed from the meteorological data used in the current analysis. The figure has a series of bars emanating from the center of the drawing. The bars represent the relative frequency of wind directions with the length of each bar representing the relative frequency of the wind direction. In this case it shows the most frequent wind directions at the Burger Lease are coming from the east-northeast.

The colors in the figure illustrate the relative frequencies of wind speeds at the project site. The color code in the figure can be used to interpret the wind speeds.

Wind roses are indicative of dominant wind directions and thus also, the most frequent transport directions of air pollutants. Due to the higher transport frequencies, in many cases peak long-term average concentrations can be found downwind in these directions, because they occur more often and when averaged over a longer period of time can typically have higher average concentrations. This is not always the case, as other factors can contribute to the determination of peak downwind concentrations, such as the presence or absence of receptors in each downwind direction, terrain elevations in the downwind directions, wind speeds associated with each wind direction and air turbulence associated with each wind direction. Thus wind roses are useful when interpreting long-term average concentrations, with the above qualifiers. However, the wind rose gives little information on the peak short-term (e.g., hourly or daily) concentrations. Short-term concentrations can occur in any wind direction, regardless of how common or frequent the wind direction is. As a result, it is common for peak short-term impacts to be in different locations than the peak long-term concentrations, and the peak short term concentrations are not necessarily aligned with the most common wind directions.



WRPLOT View - Lakes Environmental Software

Figure 3. Wind Rose for Shell Burger Lease Area 2009-2010

4 Offshore Exploration Program Analytical Methods

An air quality impact analysis includes two basic steps: (1) development of an emission inventory that identifies short-term and annual emissions related to the exploration drilling program, and (2) dispersion modeling to estimate resulting air contaminant concentrations in the ambient air. Appendix K of EP Revision 2 provides detailed documentation of projected emissions, including the basis for all calculations, attributable to the exploration activities described in EP Revision 2. Please refer to Appendix K of EP Revision 2 for further details. The following sections discuss the methods employed and the critical assumptions involved in the dispersion modeling analysis, which are based on the information provided in Appendix K of EP Revision 2.

4.1 Model Configuration of Emission Units

All of the emission units associated with the exploration drilling program are to some extent mobile. The most stationary of the units are those on the drilling units. During the drilling of any individual well, the drilling unit remains fixed over the well. However, the *Discoverer* rotates about the drilling stem, placing the bow of the ship in the direction of the oncoming wind, which is usually also the direction any moving ice would come from. The *Discoverer* does not rotate as a result of the wind acting on it, but rather is moved by a cranking system aboard the *Discoverer*. As the vessel is rotated, the locations of many or all the emission units on the drilling unit are moved. The *Polar Pioneer* does not rotate with the wind.

Although the *Discoverer* emission units are mobile, for purposes of the modeling study, both drilling units are assumed to be point sources at a fixed location. Given that the nearest onshore receptors are more than 100 kilometers from the *Discoverer*, the effect of the actual rotation of the ship is insignificant in the modeled concentrations. Hence the drilling unit is assumed to be pointing in the direction of the prevailing wind for the entire drill season. The prevailing wind direction was assumed to be coming from 60 degrees measured clockwise from north based on buoy measurements taken at the Burger site during July to November 2009.

In contrast to the drilling units, the support vessel emissions units are much more mobile. Section 2.4 describes the various types of movement and operation from each type of support vessel.

Given the highly mobile nature of these support vessels it is inappropriate to model them as fixed point sources, but rather as area sources where emissions are distributed over an area. For the ice management vessels, the area source is modeled as a large triangular area approximately 25 miles long and located upwind of the drilling unit. For the other vessels, a square area source, 2 kilometers on each side, is assumed to represent the remaining emission units. It is recognized that ice management vessels may be located further from the drilling units when managing ice, but the dimensions and locations used for these vessels have been selected to conservatively represent the spatial extent of their emissions.

Figure 4 is a schematic drawing that shows the location of these point and area sources. Note that the large triangular areas are intended to represent the ice management vessel emissions. The four smaller square areas shown in the figure are used to represent the support vessels. One of these square areas is used to represent the MLC ROV System and its associated MLC ROV System vessel. The two areas shown directly downwind of the *Discoverer* and *Polar Pioneer* represent the close support vessels including the science vessel and any tugs dedicated to the drilling unit. The central area source, located between the two drilling units is the common fleet, including the Oil Spill Recovery vessels and the oil supply tanker.

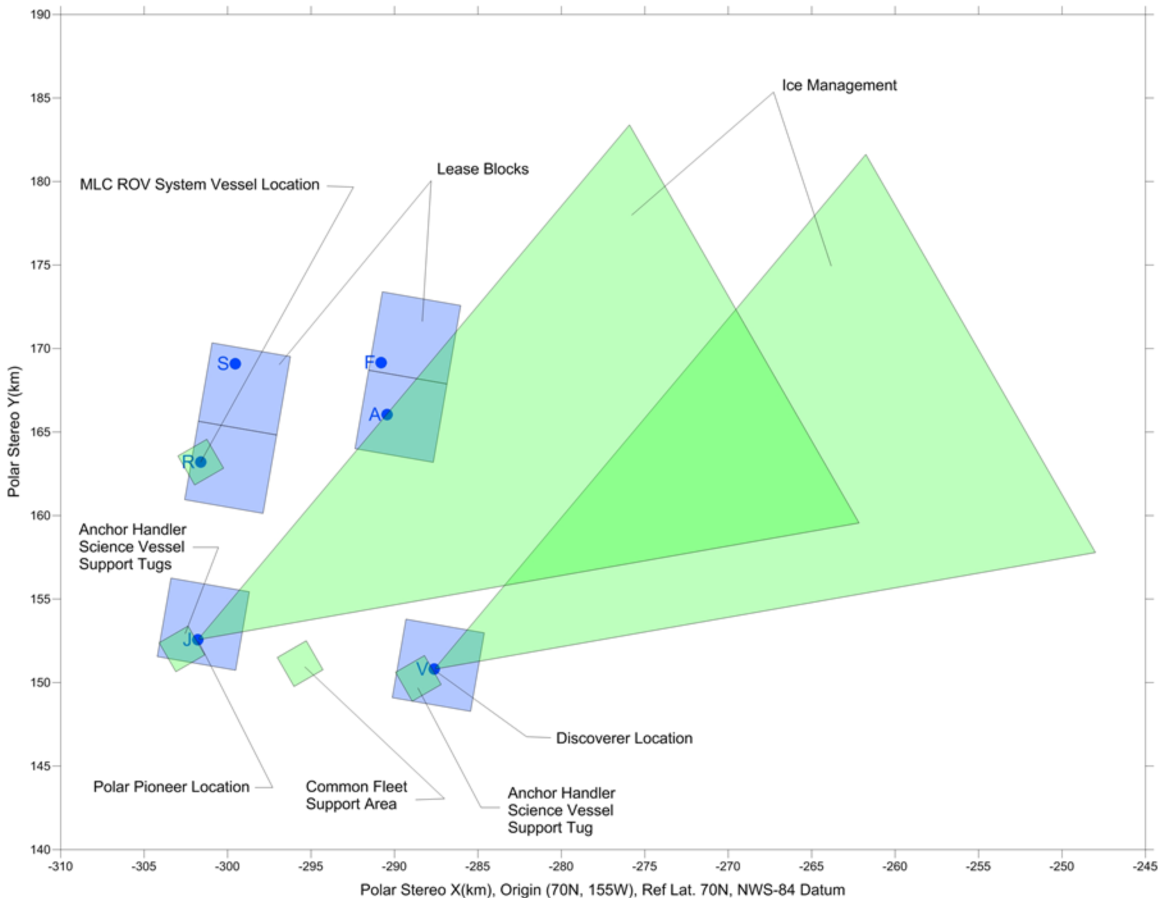


Figure 4. Orientation of Model Emissions Sources

4.2 Dispersion Modeling

ENVIRON International Corporation (ENVIRON) used air quality dispersion modeling simulations to estimate ambient concentrations attributable to emission units associated with the exploration program. This section discusses the methods used to develop these simulations.

Air quality models are computer programs designed to mathematically represent atmospheric transport and dispersion of airborne contaminants. The purpose of the proposed air quality modeling in this impact analysis is to provide estimates of ambient concentrations of air pollutants emitted by the various engines boilers, and other emission units that are part of the exploratory drilling program described in EP Revision 2.

4.2.1 Dispersion Model Selection

The two air quality models most commonly recommended in the Guideline for industrial sources of emissions are the AERMOD model and the CALPUFF model. The AERMOD model is recommended by EPA for computation of concentrations within 50 kilometers of a source, while the CALPUFF model is recommended for locations farther than 50 kilometers from a source. Discussions with BOEM[2] indicated

[2] Meeting between Shell and BOEM held on May 15, 2013 at BOEM's offices in Anchorage Alaska.

the agency's intention to follow EPA's Guideline on Air Quality Models. While the Guideline provides no specific guidance on modeling offshore vessels, the guidance does suggest that when source-receptor distances are more than 50 kilometers, CALPUFF should be used.

BOEM requires a demonstration that emissions from the exploration program will not exceed certain levels onshore. For that analysis, provided in Attachment B to the EIA, BOEM has indicated to Shell that the CALPUFF modeling system is appropriate. For this special analysis of offshore impacts in the subsistence area, the same logic is used. Because the nearest subsistence area is located more than 70 kilometers from the closest candidate drilling location, the CALPUFF model is the appropriate model to use.

ENVIRON applied CALPUFF to predict pollutant concentrations from emissions associated with Shell's offshore drilling program in the Chukchi Sea. The CALPUFF predictions were used to display potential regional pollutant concentrations, and to assess compliance with the subsistence area criteria. The remainder of this section describes the long-range transport dispersion modeling techniques.

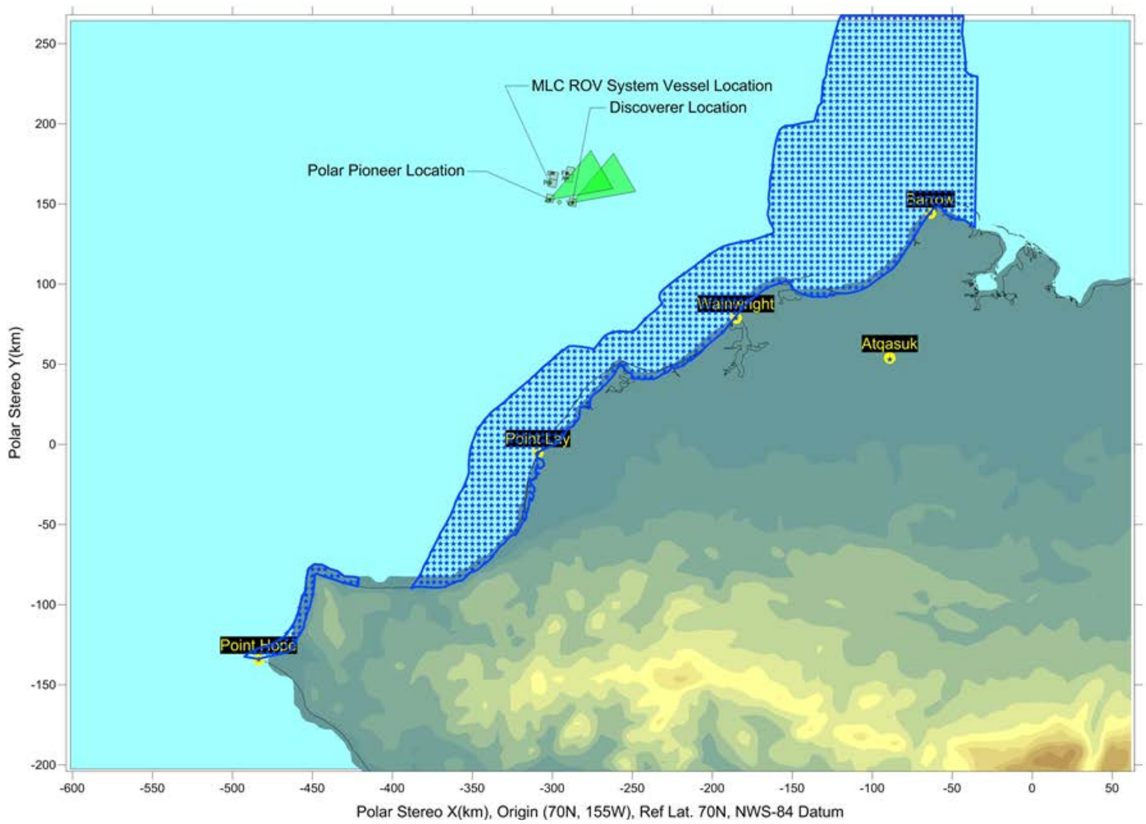
4.2.2 Methods

ENVIRON applied the regulatory version of the CALPUFF modeling system to simulate emissions from the offshore drilling program described in EP Revision 2. CALPUFF (Version 5.8) is the EPA recommended dispersion model for long-range transport analyses and source-to-receptor distances beyond 50 km.[3] For the application of CALPUFF, Shell followed the techniques recommended by the Federal Land Managers for Class I area assessments with a few modifications for Arctic conditions and available datasets. The simulations were performed based on a representative set of meteorological conditions from July to November 2007, 2008, and 2009, so as to best reflect drilling season conditions. EPA and ADEC practice is to accept data sets less than 10 years old for use with modeling. Shell considers this data set to be representative because meteorology does not change dramatically on short time scales. The methods used to prepare the meteorological fields and perform the dispersion model analysis are described below.

4.2.3 Domain

The area included in the dispersion modeling analysis, CALPUFF modeling domain, is shown in **Figure 5**. This area corresponds with the known subsistence use areas documented under Figure 3.11.6-11 of the EIA of EP Revision 2. The Burger site, several villages, and a 4-km receptor grid mesh size are posted on the domain plot. The 4 kilometer grid size for receptors was selected in order to give coverage to the entire domain while still giving adequate resolution to concentrations. The analysis assumes the *Discoverer* and *Polar Pioneer* are located at the anticipated drill sites in Lease Blocks V and J, respectively. The CALPUFF domain is a rectangular 167-by-118 grid with a horizontal mesh size of 4 km and 10 vertical layers ranging geometrically from the surface to 4,000 m. A Polar Stereographic (PS) projection was used for the coordinate system with an origin at (70 N, 155 W) and standard latitude of 70 N.

[3] 40 CFR Part 51 Appendix W: Guideline on Air Quality Models



Note: Receptor locations indicated in blue.

Figure 5. Subsistence Area Receptors Used in the CALPUFF Modeling

4.2.4 Mesoscale Model Interface Format and Weather Research Forecast

The CALPUFF model requires meteorological data inputs to predict how potential emissions will behave in the specified subsistence area. This is achieved through the use of a meteorological data set and a preprocessor that prepares the information in a format that CALPUFF can accept. ENVIRON used the Weather Research Forecast (WRF) model to construct the meteorological fields and the Mesoscale Model Interface Format tool (MMIF)[4] to process and reformat the WRF output for input to CALPUFF. EPA provided ENVIRON with WRF model simulations for the Chukchi Sea, which were then processed with MMIF (Version 2.3). These WRF simulations for July to November of 2007 to 2009 supported previous ConocoPhillips permitting activities in the Chukchi Sea.[5] The WRF simulations have the three domains with grid mesh sizes of 36/12/4-km and 37 vertical levels. The boundary layer, nudging and other options

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[4] Brashers, B., and C. Emery, 2013. *Draft User's Manual: The Mesoscale Model Interface Program (MMIF), Version 2.3, 2013-4-30.* Prepared by Environ International Corp. for U.S. EPA, OAQPS, Air Quality Assessment Division, Air Quality Modeling Group, Mail Code C439-01, Research Triangle Park, NC, 27771, Accessed at http://www.epa.gov/ttn/scram/dispersion_related.htm#mmif.

[5] McNally, D. and Wilkinson, J.G., 2011. *Model Application and Evaluation – ConocoPhillips Chukchi Sea WRF Modeling* Application, Prepared by Alpine Geophysics, 7341 Poppy Way, Arvada, CO, 8007, November 21, 2011.

selected for the WRF simulations are based on comparisons to Arctic meteorological data and the results of ongoing studies sponsored by BOEM.[6]

The WRF meteorological dataset for the Chukchi Sea has been evaluated against surface and upper air observations within the model 4-km domain including analyses focused on the coastal stations as a group, and at Wainwright and Barrow individually. The WRF simulations replicated observed temperatures, mixing ratios, wind speeds, wind directions, and precipitation totals within well-established model performance benchmarks.[5] WRF also predicted the observed atmospheric structure aloft when compared to the observations at Barrow. The developers of dataset found the overall WRF model performance was better than previous datasets they evaluated for the intermountain west, Gulf Coast or eastern seaboard of the United States.[5]

ENVIRON used the following MMIF options, which follow modeling guidance, to process and reformat the WRF meteorological fields for CALPUFF:

- Use only the 4-km WRF inner domain;
- Select the *GOLDER* option for calculation of the Pasquill-Gifford stability class;
- Use layer mapping of the 37 vertical WRF levels to 10 layers with tops of 20, 40, 160, 320, 640, 1200, 2000, 3000, and 4000m;
- No recalculation of the mixing height, the WRF diagnostic output will be used directly; and
- Trim five cells along from the outer edge of the WRF 4-km mesh size domain to account for potential edge effects in the WRF simulations

ENVIRON used MMIF to prepare daily input files for CALPUFF to account for changing sea-ice coverage in the Arctic Ocean. The corresponding changes to the hourly energy fluxes and other important variables predicted by WRF governing dispersion and transport are already incorporated directly into the MMIF data provided to CALPUFF. However, several algorithms in CALPUFF (e.g. deposition velocity calculations) need to distinguish between over water and over land characteristics based on land use that is only provided at the start of each meteorological input file. Surface roughness changes from hour to hour over the water and seasonally over the land. Daily input files allow CALPUFF to consider more refined changes to land use for these algorithms. It should be noted that the surface roughness is calculated independently by WRF based on a two dimensional representation of the surface and is different for every grid cell in the surface domain.

4.2.5 Secondary Aerosols

CALPUFF incorporates algorithms to consider secondary aerosols formed from interaction and chemical transformations of emitted NO_X and SO_2. Total PM_{10} and $PM_{2.5}$ were calculated from the sum of the emitted primary species, ammonium nitrate, and ammonium sulfate. The primary PM_{10} emissions for each source were divided into six species, including: soot or elemental carbon (EC), fine soil particles (PMF), coarse particles (PMC), organic carbon (OC), sulfate (SO_4), and nitrate (NO_3). PMC fractions were calculated from the difference between PM_{10} and $PM_{2.5}$ emission rates. $PM_{2.5}$ emissions were categorized into the remaining five species using the source profiles for diesel engines and incinerators

[6] Zhang, J., Liu, F., Krieger, J., Tao, W, and X. Zhang, 1981. *Project Report for the 5-year Experimental Mesoscale Meteorology Reanalysis for the Beaufort/Chukchi Seas for Beaufort and Chukchi Mesoscale Meteorology Model Study*. Prepared for US DOI, Bureau of Ocean Energy managements, Alaska Outer Continental Shelf Region, Anchorage Alaska, Contract 0106CT39787, November 2011.

based on profiles recommended by the EPA for the Community Multi-Scale Air Quality (CMAQ) model.[7]

Reaction rates and aerosol formation in the CALPUFF chemistry algorithms are influenced by background ozone and ammonia concentrations. ENVIRON used the maximum hourly ozone observations from the NOAA Barrow Observatory and BP's Pad A monitoring site to represent background ozone concentrations in the simulations. The background ammonia concentration was assumed to be 0.5 ppb for all hours based on the Alaska Regional Haze Best Available Retrofit Technology (BART) modeling simulations.[8]

ENVIRON used the above quantitative methods to assess the contribution of emitted SO_2 and NO_X emissions to form secondary aerosols and assess $PM_{2.5}$ concentrations. Although OCS activities in the arctic are not under EPA's jurisdiction, EPA *Guidance for $PM_{2.5}$ Permit Modeling* recommends an assessment of secondary aerosols when $PM_{2.5}$ precursor emissions (NO_X and/or SO_2) emissions are greater than 40 tons per year.[9] EPA- recommended procedures include both quantitative and qualitative analyses. EPA's Guidance provides a qualitative example based on a Region 10 Office assessment of Shell's *Discoverer* drill ship and support fleet in the Chukchi Sea. EPA's qualitative assessment:

> "examined the regional background $PM_{2.5}$ monitoring data and aspects of secondary $PM_{2.5}$ formation from existing sources; the relative ratio of the combined modeled primary $PM_{2.5}$ impacts and background $PM_{2.5}$ concentrations to the level of the NAAQS; the spatial and temporal correlation of the primary and secondary $PM_{2.5}$ impacts; meteorological characteristics of the region during periods of precursor pollutant emissions; the level of conservatism associated with the modeling of the primary $PM_{2.5}$ component and other elements of conservatism built into the overall NAAQS compliance demonstration; aspects of the precursor pollutant emissions in the context of limitations of other chemical species necessary for the photochemical reactions to form secondary $PM_{2.5}$; and an additional level of NAAQS protection through a post-construction monitoring requirement."

Region 10 found the formation of secondary aerosols would be limited in the Arctic and the NAAQS would be protected accounting for both the primary $PM_{2.5}$ impacts and potential contributions due the $PM_{2.5}$ precursors from the *Discoverer* and Associated Fleets.[9] These same qualitative arguments apply to the exploration activities examined in this study.

4.2.6 Downwash

The tendency for exhaust plume rise to be reduced by wind flowing across nearby structures is referred to as downwash. Because the nearest receptors are located more than 100 km from the source at the shoreline, building downwash effects will not significantly affect the modeled results. However, previous modeling analyses for the Shell exploration program have developed building downwash parameters. The modeling did use the previous downwash values developed for the Shell exploration program in the

[7] CMAQ is the preferred regulatory model for $PM_{2.5}$ and regional haze simulations. The EPA website containing PM speciation by source categories is: http://www.epa.gov/ttn/chief/emch/speciation/.

[8] The Alaska BART and Regional Haze programs are described at http://www.dec.state.ak.us/air/anpms/rh/rhhome.htm. In the original BART simulations a background of 0.1 ppb was assumed. In the more refined simulations performed by applicants seeking exemption from BART, a more conservative 0.5 ppb ammonia concentrations was assumed.

[9] EPA, 2014. *Guidance for $PM_{2.5}$ Permit Modeling.* U.S. EPA, Office of Air Quality Planning and Standards, Air Quality Assessment Division, Research Triangle Park, NC, EPA-454/B-14-001, May 2014.

CALPUFF modeling analysis for the Discoverer sources. New downwash parameters were created for the *Polar Pioneer* sources using EPA's Building Profile Input Program (BPIP).

4.2.7 CALPUFF

ENVIRON performed three CALPUFF simulations for the Chukchi Sea using short-term emissions for each July to November period of 2007 to 2009. Short-term emissions were used in the analysis to address the one-hour maximum concentrations for each pollutant in accordance with the criteria presented in **Table 2.** The respective short-term emission rates for emission units included in the simulations are discussed in Chapter 2.4 of Appendix K of EP Revision 2. It should be noted that drilling may occur between July 1 and November 30 (153 days), but each drilling season is limited to 120 days. As the critical impacts are short term ambient standards and increments, not annual averages, Shell wanted to address concerns that drilling could occur at any time during the five month window. Therefore, in order to make certain the peak meteorological scenarios were evaluated, short-term emissions were conservatively modeled to occur during all 3,672 hours in the July 1 to November 30 drilling season for each of the three years in the simulations.

It should be noted that CALPUFF addresses all pollutants in a combined single run. The interactions between pollutants, such as the secondary aerosol formation of particulate matter from gaseous oxides of nitrogen or sulfur are treated as chemical transformations in the model. These non-linear processes are modeled dynamically by CALPUFF for each hour and no aggregate or averaging methods are used.

The secondary aerosol is most commonly sulfates and nitrates, formed from sulfur dioxide and nitrogen oxides. To address secondary aerosol formation, ENVIRON applied POSTUTIL a program developed by the EPA, that converts particulate species such as sulfate and nitrate into the most common solid forms of these species, ammonium sulfate and ammonium nitrate, by converting mass to account for the difference in molecular weight between sulfate and ammonium sulfate, and nitrate and ammonium nitrate. It then sums all the particulate species to give total concentrations of PM_{10} and $PM_{2.5}$.

CALPOST (Version 6.221) was used to calculate the maximum 1-hour concentrations of each pollutant. The results used in this analysis are the maximum 1-hour values for each pollutant, without any statistical analysis to determine the 98^{th} or 99^{th} percentile that is commonly used in analyses for onshore criteria.

ENVIRON conservatively assumed all NO_X predicted at downwind receptor is NO_2 for comparisons to the criteria. A second tier approach assuming a conversion factor of 0.8 is also appropriate and could be applied in any future analyses. It should be noted, although not performed here, a Tier 3 approach can be used to limit the potential formation of NO_2 by the amount of ozone available. The Ozone Limiting Method (OLM) could be applied by post-processing the CALPUFF output files and assuming a constant NO_2/NO_X in-stack ratio, an equilibrium ratio of 0.8. The amount of NO_2 formed will be limited using the same hourly ozone input file used in the CALPUFF simulations.

5 Drilling Program Modeling Results

A total of 1,800 receptors were selected to represent the subsistence area depicted in **Figure 5**. Maximum predicted concentrations from all 1,800 receptors are presented in **Table 4** for each pollutant. All model-predicted concentrations are well below the impact criteria for offshore locations.

Table 4. Maximum Predicted Concentrations at Offshore Subsistence Area Receptors ($\mu g/m^3$)

Pollutant	Averaging Time	Maximum Modeled Concentration	Background Concentration[1]	Total Concentration	Offshore Subsistence Area Criteria
Nitrogen Dioxide (NO_2)	1-hour	52.1	40.1	92.2	3,760
Particulate Matter (PM_{10})	1-hour	24.4	60.0	84.4	500
Particulate Matter ($PM_{2.5}$)	1-hour	24.4	14.0	38.4	500
Carbon Monoxide (CO)	1-hour	16.2	953	969	55,000
Sulfur Dioxide (SO_2)	1-hour	0.1	8.1	8.2	5,200

[1] Background concentrations are documented in Table 3.1.3-1 of the EIA of EP Revision 2. It should be noted that Table 3.1.3-1 provides 1-hour background concentrations only for gaseous pollutants but for particulate matter, the 24-hour values from Table 3.1.3-1 are adjusted by the ratio of 24-hour to 1-hour concentration of 0.4 from the SCREEN3 model. Thus for PM_{10} the peak measured 24-hour concentration from Table 3 of 24 $\mu g/m^3$ is multiplied by 2.5 to get 60 $\mu g/m^3$ while for $PM_{2.5}$ the peak measured 24-hour concentration of 5.5 $\mu g/m^3$ is multiplied by 2.5 to get 14 $\mu g/m^3$

The most representative maximum background air quality values available were selected for this evaluation. These values are highly conservative, given that the monitors are located onshore and adjacent to villages containing sources of air pollutants. Maximum offshore concentrations determined by CALPUFF occur at the seaward edge of the subsistence zone west of Wainwright. The background concentrations from the nearest monitoring station to the modeled maximum concentration for each pollutant and averaging period were selected to estimate total concentrations reported in Table 4. Wainwright background concentrations were selected for all pollutants and categories except for PM, instead, Point Lay PM backgrounds were deemed more representative.

Wainwright PM backgrounds were not considered representative because of contamination from road dust from the adjacent unpaved road discussed in SLR (2011) and SLR (2012). A persistence factor was used to estimate 1-hour average maximum background values for particulate matter (24-hour values multiplied by 2.5 to estimate 1-hour values, based on persistence factors used in the EPA SCREEN3 model).

To provide further detail on the model predictions, maps of peak 1-hour model-predicted concentrations have been prepared for each of the 5 pollutants listed in **Table 2**. These figures are presented in **Figure 7, Figure 8, Figure 9, Figure 10** and **Figure 11** for NO_X, PM_{10}, $PM_{2.5}$, CO, and SO_2, respectively. These figures, called "isopleth" plots, are created by drawing contours of the peak model prediction at each location on the surface in the offshore subsistence area. As such, these do not represent conditions that occur at the same time, but rather reflect the peak potential concentration at each location, regardless of the time and date of the predicted concentrations.

These isopleth maps will not reflect the frequency of winds as seen in a wind rose, such as that in **Figure 3**, because the isopleths reflect the peak 1-hour concentration, not the annual average concentration. A wind rose shows how often a particular meteorological condition occurs, while these plots show the worst case, typically a very infrequent condition, at each location. As seen in **Figure 3**, winds most frequently come from the east, carrying emissions to the west of the drill site locations. Under these most frequent meteorological conditions, concentrations in the offshore subsistence areas are typically low. But as the wind rose also shows, on rare occasions, the wind will come from the north or northwest, carrying emissions toward the closest parts of the subsistence area. Under these infrequent conditions, the peak 1-hour concentrations are predicted and the isopleths reflect the magnitude of impact that occurs at each receptor under the most adverse conditions for that receptor location.

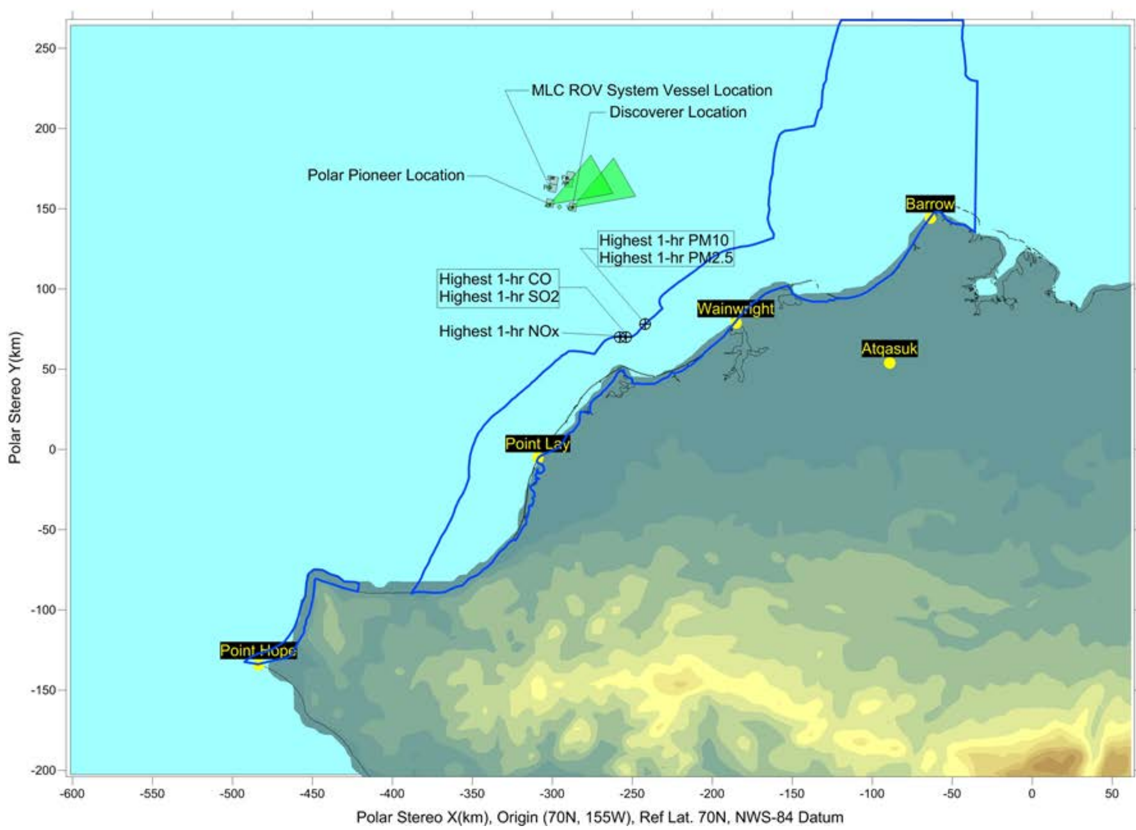

Figure 6. Locations of Receptors for Peak Model Predictions in Subsistence Area

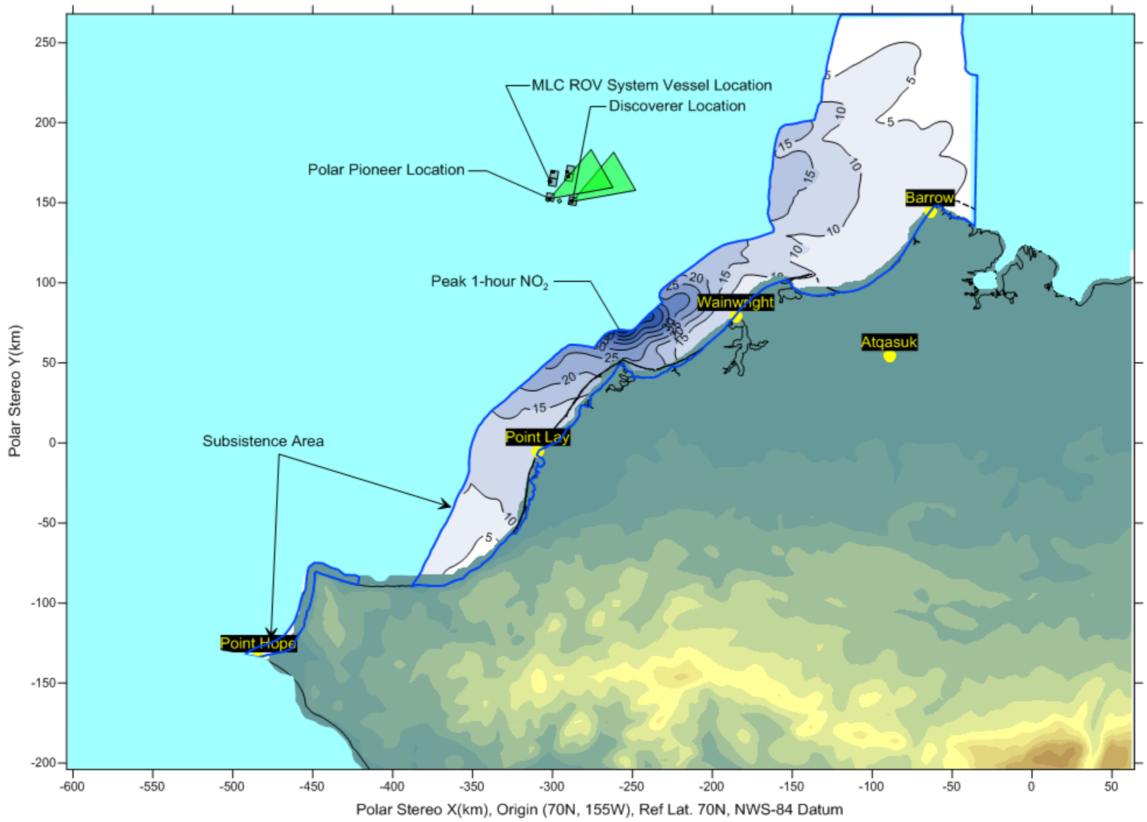

Figure 7. Isopleths of Peak 1-hour NO_2 Concentration in Subsistence Area in micrograms per cubic meter (µg/m^3)

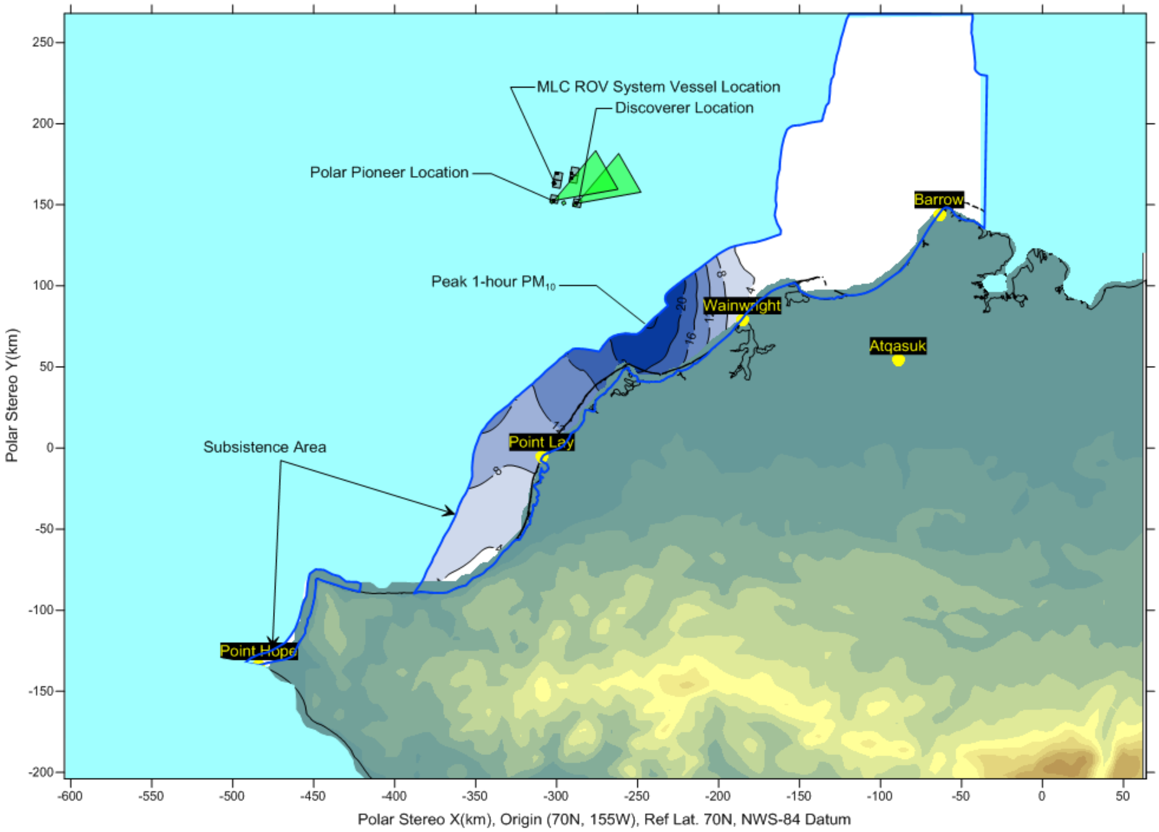

Figure 8. Isopleths of Peak 1-hour PM_{10} Concentration in Subsistence Area in micrograms per cubic meter (μg/m^3)

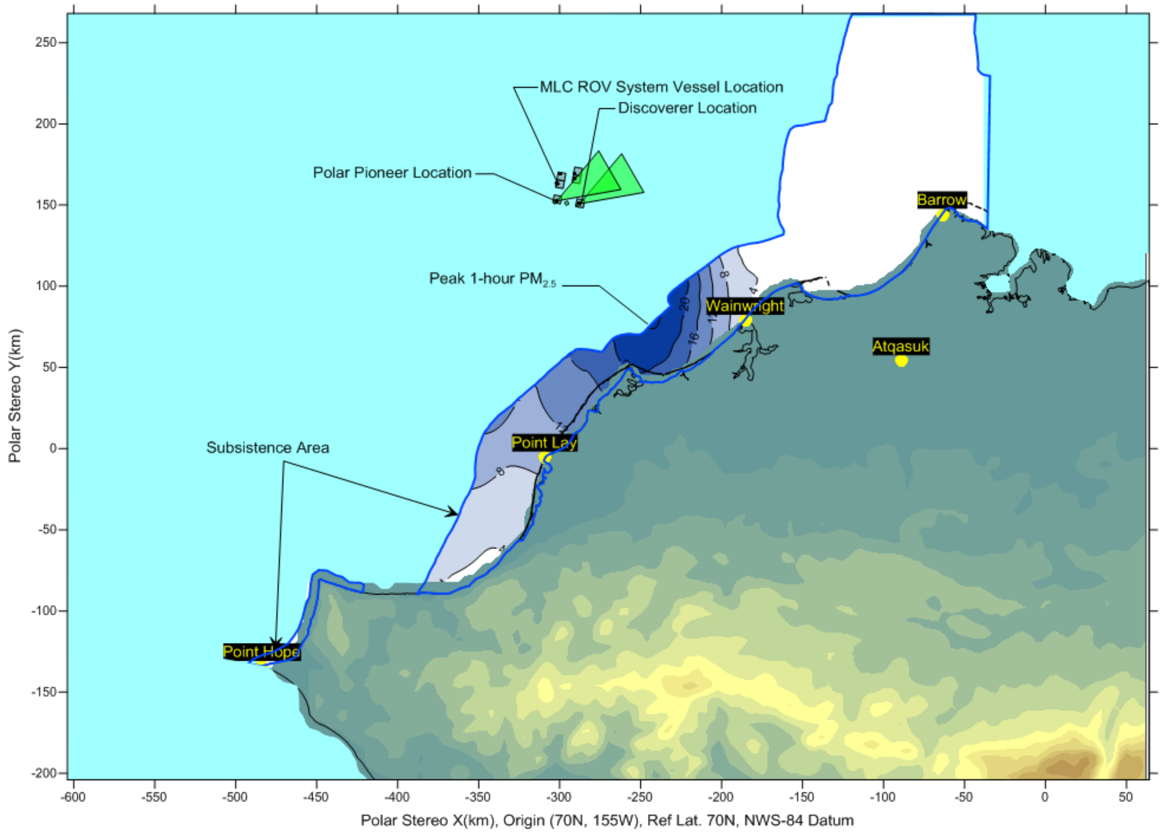

Figure 9. Isopleths of Peak 1-hour $PM_{2.5}$ Concentration in Subsistence Area in micrograms per cubic meter (μg/m^3)

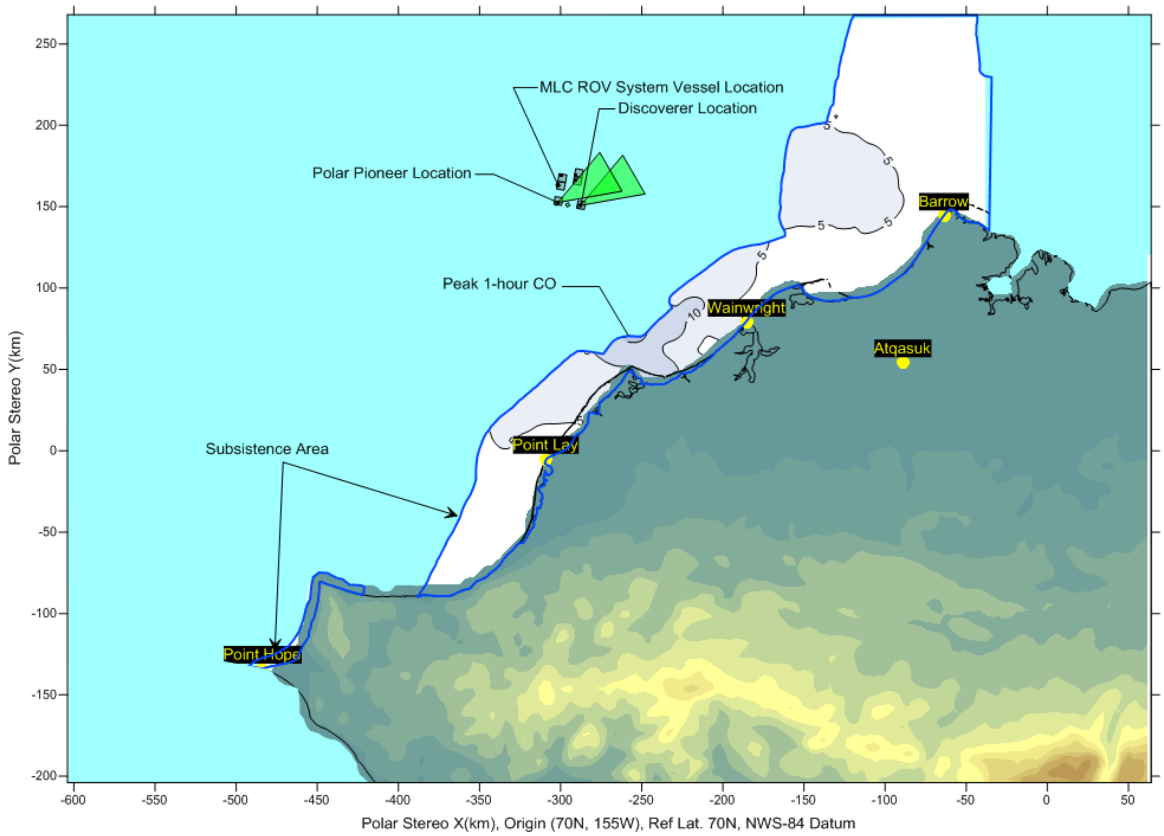

Figure 10. Isopleths of Peak 1-hour CO Concentration in Subsistence Area in micrograms per cubic meter (µg/m^3)

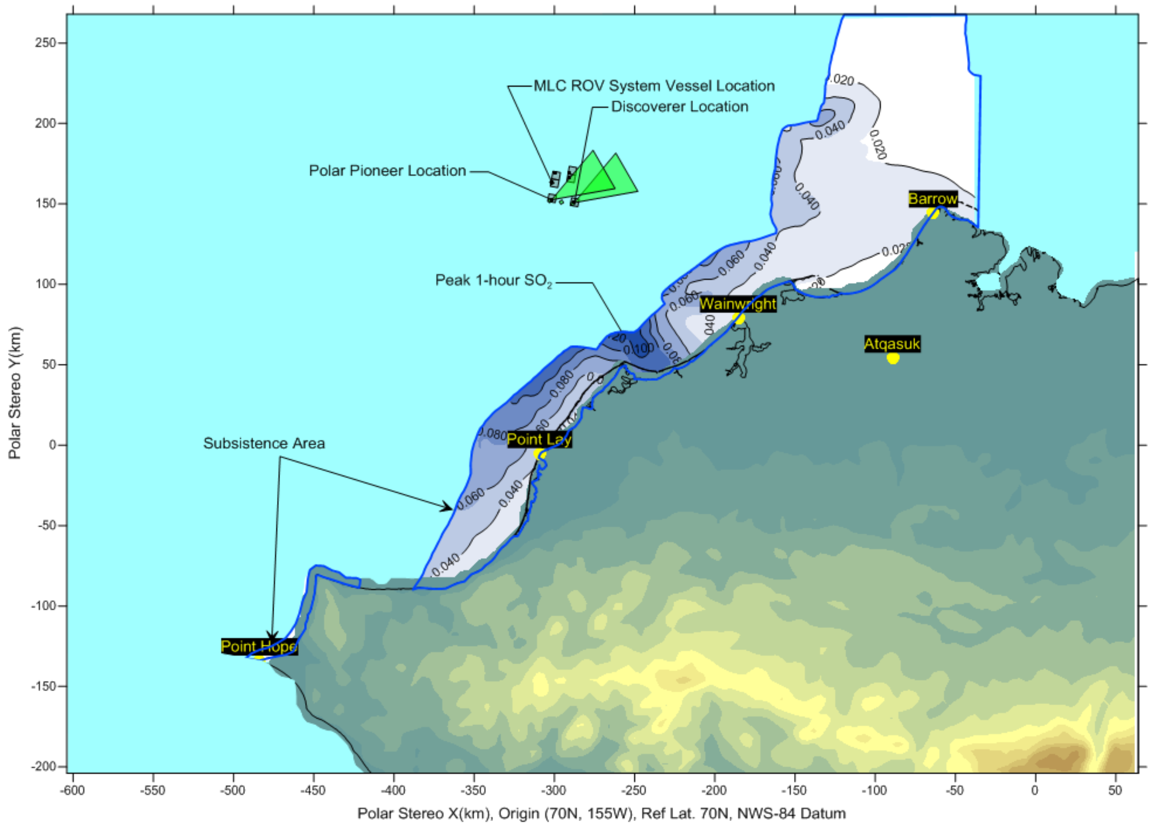

Figure 11. Isopleths of Peak 1-hour SO_2 Concentration in Subsistence Area in micrograms per cubic meter (µg/m^3)

6 References

US Environmental Protection Agency (EPA)

2004. *AERMOD User's Guide*. EPA-454/B-03-001. September 2004

CALPUFF User’s Guide