Responses to Herman Wong Memorandum of February 14, 2011

We have restated the items in the memorandum and have provided responses to each item.

A. Overview and Authority

Shell Oil Incorporated (Shell) is seeking EPA Region 10 (R10) approval under Section 3.0 in Appendix W of 40 CFR 51, to utilize an alternative technique to more accurately estimate concentration impacts in a marine environment. This technique is an over water meteorological preprocessor program that will replace the AERMET preprocessor program within the AERMOD modeling system which has been approved for regulatory application by the Agency. AERMET is approved for terrestrial applications but not for marine environment sited sources. The technique is described in Shell's "Evaluation of the COARE-AERMOD Alternative Modeling Approach Support of Simulation of Shell Exploratory Drilling Sources in the Beaufort and Chukchi Seas" (Evaluation) dated December, 2010.

Shell's request is narrower than this statement describes. Shell is not proposing an alternate technique for all marine environments, nor is it proposing an alternate model that would ultimately be part of the Guideline on Air Quality Models and used nationwide as an alternative to OCD. Rather, Shell is asking EPA to approve an alternate technique only for the Arctic drilling applications Shell is proposing. Shell is not asking EPA to approve a technique that is appropriate for all marine environments or that will be used by other regions in other marine settings.

We believe it is within the authority of the EPA Region 10 modeling lead to review and approve deviations from Guideline methods on a case-by-case basis. Shell's interpretation of the regulations is that not every deviation from the Guideline needs to be considered as having national applicability. The proposed methods are scientifically sound and appropriate for applications for drilling operations in the Beaufort and Chukchi Seas, but these methods and techniques are unique to the Arctic and to the available data and empirical relationships we have derived from these data.

B. Information/Data Request

1. *COARE Defensibility.*
    a. *Is COARE the most up-to-date science for marine boundary layer conditions? Please explain.*
    b. *Is there anything from more recent field campaigns, such as VOCALS, that would improve the science? Please explain.*

As reflected in the report provided to EPA in December, Shell believes that COARE reflects the most up-to-date science for marine boundary layer conditions. The Coupled Ocean Atmosphere Response Experiment (COARE) began with research in the late 1970s that culminated in the release of the first COARE code in 1993. It has been updated and improved several time since 1993, the current version of the code was released in 2003. It has world-

wide acceptance by organizations such as NOAA, the Institute of Atmospheric Physics, CSIRO in Australia, Woods Hole Oceanographic Institute, the French Centre d'Etude des Environments Terrestre et Planetaires and many others. In the ENVIRON report on the evaluation of the COARE-AERMOD method provided to EPA on December 16, 2010, a number of links were provided to reference papers on the topic. For example, one link leads to the following paper:

> Brunke, Michael A., Chris W. Fairall, Xubin Zeng, Laurence Eymard, and Judith A. Curry, "Which Bulk Aerodynamic Algorithms are Least Problematic in Computing Ocean Surface Turbulent Fluxes", Journal of Climate, 15 February 2003, pp. 619-635.

This study reports that the COARE algorithm is a preferred method for estimating air mixing in a marine environment. There are many other papers referenced or linked to in the December ENVIRON report that provide a sound scientific basis for the COARE algorithm. We are not stating that it is the only method that could be used, but we have clearly made the required showing that, "[t]he technique has received scientific peer review."

The VAMOS Ocean Clouds Atmospheric Land Study (VOCALS) is an ongoing research program that has not attained the level of completeness, acceptance, or peer review of COARE. The VOCALS program is work in progress and not ready to be incorporated in a methodology such as a regulatory modeling demonstration. The program may ultimately provide valuable information but it is not ready at this time.

2. *Appropriateness of COARE in Arctic conditions.*
   COARE was originally developed for tropical marine conditions. It is not entirely clear that the balance of radiation, sensible heat, and latent heat fluxes is representative of Arctic conditions. Additionally, it was developed most for light wind conditions. More recently, COARE has been modified for high wind conditions and stable boundary layers, and it has been applied outside the tropics. Region 10 needs to know if it has been applied to Arctic (or high latitude) marine conditions, and if so, how well it fared.

   a. *What evidence does Shell have that COARE is an appropriate boundary layer scheme for Arctic conditions?*
   b. *Can Shell point to examples of peer-reviewed literature in which the COARE algorithm was applied to cold, high-latitude marine environments?*

Shell's research regarding applicability of COARE for the Arctic has included conversations with industry experts as well as peer-reviewed publications.

Communication with Ken Richmond of ENVIRON, marine boundary layer experts Dr. Andrey Grachev and Dr. Chris Fairall from NOAA provided the following insight:

> From Chris Fairall, "The original COARE version (2.5) (and the 2003 version (3.0)) was set up so that it could handle water and air temperatures from the tropics to the Arctic. Parameters such as the kinematic viscosity of air have T dependencies. I have listed below a few references to Arctic applications I dug up."
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> Mucci, A., B. Lansard, L. A. Miller, and T. N. Papakyriakou (2010), CO_2 fluxes across the air-sea interface in the southeastern Beaufort Sea: Ice-free period, *J. Geophys. Res.*,

115, C04003, doi:10.1029/2009JC005330.

Title: Characteristics and impact of a gale-force storm field over the Norwegian Sea
Author(s): Brummer B, Muller G, Klepp C, et al.
Source: TELLUS SERIES A-DYNAMIC METEOROLOGY AND OCEANOGRAPHY Volume: 62 Issue: 4 Pages: 481-496 Published: AUG 2010

Title: Mufti-event analysis of the westerly Greenland tip jet based upon 45 winters in ERA-40
Author(s): Vage K, Spengler T, Davies HC, et al.
Source: QUARTERLY JOURNAL OF THE ROYAL METEOROLOGICAL SOCIETY Volume: 135 Issue: 645 Special Issue: Part B Sp. Iss. SI Pages: 1999-2011 Part: Part B Sp. Iss. SI Published: OCT 2009
Esau, I. N. (2007), Amplification of turbulent exchange over wide Arctic leads: Large-eddy simulation study, *J. Geophys. Res.*, 112, D08109, doi:10.1029/2006JD007225.

A. Smirnov, A. Korablev, G. Alekseev and I. Esau (2010), Temporal and spatial changes in mixed layer properties and atmospheric net heat flux in the Nordic Seas, IOP Conf. Series: Earth and Environmental Science, 13 (2010), 012006, doi:10.1088/1755-1315/13/1/012006
http://iopscience.iop.org/1755-1315/13/1/012006/pdf/1755-1315_13_1_012006.pdf

Yu, L., and R.A. Weller, 2007: Objectively analyzed air-sea flux fields for the global ice-free oceans (1981-2005). Bull. Amer. Met. Soc., 88, 527-539.

3. *AERMOD-COARE incorporates surface and vertical profile data appropriately.*

    a. *Is the choice of critical Ri based solely on Gryning and Batchvarova (2003)?*
    b. *Can Shell provide more scientific basis for the choice of critical Ri? The journal they published this work in is not well-known and could potentially be of dubious quality.*

Sørensen (1998) and Vogelezang and Holtslag (1996) both suggest a value of Ri_{crit} = 0.25. However, when diagnosing high-latitude boundary layers, Gryning and Batchvarova (2003) found better agreement using Ri_{crit} = 0.03 for Rib defined by Sørensen (1998), and using Ri_{crit} = 0.05 for Rib defined by Vogelezang and Holtslag (1996). This team of S.E. Gryning and E. Batchvarova is responsible for one of the most widely used and successful bulk models of the planetary boundary layer. In many journal articles, they are so commonly cited that it is often shortened to BG91, BG94, GB96, etc.

Hong and Kim suggested the critical bulk Richardson number for the determination of the stable boundary layer top is set as a constant value of 0.25 over land, whereas it is a function of the surface Rossby number (Ro) over the oceans, following the study of Vickers and Mahrt (2003), which is given by

$$Rib_{crit} = 0.16(10^{-7}\ Ro)^{-0.18}$$

This is the form used in the popular YSU boundary layer formulation available in the numerical weather models MM5 and WRF.

Although there is some variability as to the details of the form of the bulk Richardson number and the critical value used to identify the top of the mixing layer, in practical terms for the Arctic it makes little difference. Often, the observed temperature inversion is strong enough that all forms/values of Ri/Ri_{crit} are triggered at the same level. Using the traditional definition of an inversion base (the level at which the temperature starts to increase with height as "truth"), it was impossible to pick any one of the forms/values from the others. They were statistically the same, when compared to the traditional definition.

Given that the lower the value of Ri_{crit} the lower the diagnosed mixing height, it is conservative to use the value of 0.03 when applied to AERMOD dispersion modeling. Therefore, $Ri_{crit} = 0.03$ was used to diagnose the mixing height for all non-iced hours in 2010, using the profiler data and COARE-based wind shear.

The paper in question is:

Gryning, S.E. and Batchvarova, E. (2003). Marine Atmospheric Boundary-Layer Height Estimated from NWP Model Output. Int. J. Environ. Pollut., 20, 147-153.

Sven-Erik Gryning and Ekaterina Batchvarova are well-respected international scientists in meteorology. Both scientists have many published papers in the peer-review scientific literature on boundary layer meteorology. A simple internet search on either of Sven-Erik Gryning or Ekaterina Batchvarova, brings up a plethora of scientific literature on the topic of boundary-layer meteorology. There is no reason to suspect the method they have proposed does not have an adequate scientific basis for the value of the Richardson number. The International Journal of Environment and Pollution is a refereed journal providing an international forum for the field of Environment and Pollution. One of three key journals (along with IJETM and IJGEnvI) which together offer complete coverage of key environmental issues, it addresses medium-term challenges involving scientific prediction, modeling and assessment, and social and economic policy areas. There is no evidence to imply any "dubious" quality science in the journal.

4. *The Evaluation dated December, 2010 did not include supporting documentation. Shell is requested to provide:*

    a. *A user manual.*
    b. *A model formulation document. (Account for all input data to AERMOD-COARE and all calculations that prepare the data for AERMOD-COARE [e.g., surface fluxes, convective mixing heights...etc.].)*
    c. *Any Fortran code written to support the execution of the technique.*
    d. *Copies of scientific papers referenced and/or used.*
    e. *Logic for selecting specific methods or procedures to select certain meteorological parameters.*

f. Model input and output files, and data used with the evaluations. An explanation/diagram would be helpful in understanding the steps.

Throughout this process Shell has attempted to be very clear that we are not proposing an alternative to AERMOD, nor is there a model called AERMOD-COARE. Shell is proposing to use the AERMOD model with no edits or changes. The inputs to AERMOD are exactly the same as they are in any other application of AERMOD, and hence we are not discussing AERMOD or its use in this formulation. All that is proposed by Shell in this method is to replace the AERMET meteorological pre-processor with an alternate for periods of open water only. For most of the year in the Arctic, the sea is covered with ice and the AERMET pre-processor will be used without change or modification. In ENVIRON's December report, we provided EPA with links to journal references and a User's Manual for COARE. The following excerpt was included in the December report:

Version 3.0 of the COARE algorithm with journal references and a User's Manual can be accessed at: ftp://ftp.etl.noaa.gov/users/cfairall/wcrp_wgsf/computer_programs/cor3_0/

and

http://www.coaps.fsu.edu/COARE/flux_algor/

These references provided copies of the code, descriptions of the scientific basis for the code and detailed descriptions on how to use the COARE program. However, Shell acknowledges that COARE was not designed specifically to provide an input file for AERMOD and there are certain steps that must be taken to produce the input files for AERMOD. A detailed description of those procedures was provided to EPA as Appendix B of the modeling protocol for the Kulluk air permit application (January 20, 2011).

The Shell team is in the process of providing a more mechanical description of the input variables, the source for each variable, the output variables and the spreadsheet calculations done to compute the actual meteorological parameters provided in the surface and profile data files needed by AERMOD. Any FORTRAN code written to support this effort will also be provided, but the extent of such code is very limited. The COARE algorithm code is provided from NOAA as a subroutine and a small main program was written to call the subroutine. These calculations are specific to the applications in the Beaufort and Chukchi Seas and would not be generally applicable to other settings. In particular, the procedures for determining the mixing height and vertical potential temperature gradient, parameters provided to AERMOD in the surface file, are specific to the profiler installed at Endeavor Island, and unique to the Arctic setting. Empirical relationships have been developed that allow estimation of the mixing height and vertical potential temperature gradient for locations (i.e.; the Chukchi Sea) or times (i.e.; 2009) when a profiler is not present. These empirical relationships allow estimation of these values from commonly available meteorological parameters, but are not generalized to other settings or locations. In fact specific adaptations were made to adjust the method between the Beaufort and Chukchi locations. Region 10's request for a "User's Guide," as well as statements by the Region that it intends to submit this documentation to other Regional meteorologists, suggests that EPA envisions this method to have a wider potential application

than Shell's proposed drilling applications for the Arctic. Again, Shell's proposal to use this method is unique to the setting and data that are available in the Arctic and attempts to use this method more generally in other locations are discouraged unless the same level of effort is taken to develop similarly location-specific relationships. While Shell does not object to providing EPA with complete documentation on the analysis we are proposing to perform for the Arctic, we do not believe it is Shell's responsibility to develop an alternative model for EPA to use elsewhere.

5. *Discuss the minimal meteorological variables needed, and what options are available to use alternative methods to derive any missing variables.*

Minimum meteorological variables needed to run the COARE algorithm are the wind speed, the sea surface temperature, the air temperature, and some form of humidity measurement (e.g. relative humidity, absolute humidity, dew point, and wet bulb-temperature). Barometric pressure, precipitation, and a typical mixed layer height are also input variables that can be provided or assigned by COARE default parameters. If options are selected for warm-layer heating and/or cool-skin effects then solar radiation and downward longwave radiation are needed. Shell is not planning to invoke these options but has tested and provided a framework for the provision of these variables using measured solar radiation, cloud cover and ceiling height. COARE also contains several options for the surface roughness length based on wave period and wave height. Shell plans to use the default option that does not need these variables. Our sensitivity tests have shown that for conditions in the Arctic, the COARE predicted surface fluxes are not sensitive to warm-layer heating, cool-skin or the optional surface roughness treatments with COARE. These sensitivity tests were provided in:

ENVIRON 2010a. *Comparison of OCD vs. COARE-AERMOD, Support for Simulation of Shell Exploratory Drilling Sources in the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Ave W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, October 24, 2010.

ENVIRON 2010b. *Evaluation of the COARE-AERMOD Alternative Modeling Approach, Support for Simulation of Shell Exploratory Drilling Sources In the Beaufort and Chukchi Seas.* ENVIRON, 19020 33rd Ave W, Suite 310, Lynnwood, WA 98036; Job No. 0322090, December 16, 2010.

There are almost no missing data for the minimum meteorological variables in the COARE input database for the Beaufort Sea. A few hours of buoy data are missing and these hours are filled in assuming persistence. For the Chukchi, our procedures were clearly outlined in "Appendix B: Preparation of AERMOD Meteorological Data Input Files" of the Kulluk modeling protocol submitted on January 20, 2010.

6. *Are standard tower and/or buoy measurements enough to drive to COARE? If not, what non standard measurements or calculations need to be performed?*

Yes, standard tower and/or buoy measurements are enough to drive the COARE algorithm assuming the tower measurements are embedded in marine layer.

7. *Please identify the location in the support documentation in which Shell has satisfied the five conditions in Subsection 3.2.2.e.*

- *The Technique has received scientific peer review*. The documentation provided in the December 16, 2010 evaluation report submitted to EPA included references to numerous scientific articles in refereed journals and publications which describe the world-wide acceptance of the COARE formulation. The formulation has been in the open literature for a decade and has received extensive peer review
- *The technique can be demonstrated to be applicable to the problem on a theoretical bases.* Section 2 of the December report provides a detailed discussion of the rationale for the COARE use with AERMOD. The scientific literature referenced in that document provide clear theoretical basis for the application of the method to this problem. See in particular the Brunke et. al. reference noted above.
- *The data bases that are necessary to perform the analysis are available and adequate.* The meteorological collection programs to support regulatory modeling for Shell Exploratory Drilling sources in the Arctic Ocean have been approved by EPA Region 10 and include a meteorological site on a low relief barrier island embedded in the marine layer, buoys, and a thermal profiler. As described in Appendix B of the modeling protocol submitted to support the Kulluk drilling application, the meteorological data needed for this analysis are specifically specified and are available.
- *Appropriate performance evaluations of the technique have shown that the model is not biased toward underestimation.* In the meetings the Shell team held with EPA throughout the fall, the focus has been on making this demonstration. Evaluations of the proposed method were conducted with 3 field experiment programs, Pismo Beach, Cameroon and Carpinteria. The December report submitted to EPA clearly demonstrated that the proposed technique is not biased toward under-prediction.
- *A protocol on methods and procedure to be followed has been established.* A protocol for developing the meteorological data using the COARE algorithm for periods of open water was provided as part of the modeling protocol submitted by Shell for the Kulluk drilling program on January 20, 2011. See Appendix B of the protocol.

8. *After R10 accepts all your responses to the information and data requests, Shell is requested to bundle all documents, comments and responses into a single package. In addition, Shell is requested to generate a DVD that includes all model input and output files, meteorological data sets, Fortran codes, spreadsheets...etc. R10 will inform Shell of the number of copies required.*

The shell Team is prepared to provide EPA with all requested documentation upon acceptance of the method.