COMMENTS BY THE TEXAS COMMISSION ON ENVIRONMENTAL QUALITY REGARDING THE CALL FOR SCIENTIFIC AND POLICY-RELEVANT INFORMATION FOR THE NATIONAL AMBIENT AIR QUALITY STANDARDS FOR OZONE

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I. Summary of Proposed Action

On June 26, 2018, the United States (U.S.) Environmental Protection Agency (EPA) published a notice in the *Federal Register* (83 FR 29785) requesting scientific and policy-relevant information related to the ozone national ambient air quality standard (NAAQS). The information will be considered in the EPA's preparation of the Integrated Review Plan (IRP) and Integrated Science Assessment (ISA) as part of the required 5-year review of the ozone NAAQS.

The IRP outlines the EPA's plan for reviewing and analyzing available scientific literature related to ozone in order to determine whether a revision of the current primary and secondary NAAQS are necessary. The IRP includes a review of decisions made in the setting of the previous ozone NAAQS, key guiding questions and issues to be evaluated in the upcoming review, and a schedule for the subsequent technical documents that will support either the retention of the existing NAAQS or the setting of a new NAAQS. The ISA is the first in a series of technical and policy assessments that provide the basis for the NAAQS. The ISA summarizes available scientific evidence and articulates the EPA's determinations for which health effects could be caused or exacerbated by ozone exposure.

II. Comments Related to Background Ozone

Definition of Background Ozone

Background ozone has been defined as the portion of ozone in ambient air that comes from sources outside the jurisdiction of an area and can include natural sources as well as transported ozone of anthropogenic origin (80 *Federal Register* 65292). The EPA has identified two specific definitions of background ozone relevant to the NAAQS: natural background and U.S. background. Natural background is defined as the ozone that would exist in the absence of any manmade precursor emissions. U.S. background is defined as ozone that would exist in the U.S. in the absence of U.S. emissions. Background ozone as defined above is a hypothetical construct that cannot be measured, and the range of background ozone concentrations must be estimated using photochemical models.

There are two common approaches to estimating background ozone: zero out and source apportionment. The zero out method estimates what background levels would be in the absence of certain sets of emissions by comparing a base model simulation and a simulation in which certain emissions were removed. The key limitation of this approach is that it is a hypothetical and unrealizable scenario under which there are zero manmade emissions. In addition, the assumption that background ozone is adequately estimated within the model simulation can be misleading in locations where ozone chemistry is non-linear. A second modeling technique attempts to circumvent these limitations by apportioning the total ozone within the model to its contributing sources. This approach has been used in regulatory settings to estimate the contribution of certain sets of emissions to ozone formation.

What the EPA has said about background

In the 2013 ISA, the EPA concluded that ozone season maximum daily 8-hour average concentrations of U.S. background ozone range from 25-50 parts per billion (ppb), with the highest estimates located across the intermountain west (USEPA 2013). Ozone season natural background concentrations were estimated to range from 15-35 ppb. Background is generally consistent across the range of ozone concentrations, meaning that high ozone days are caused by a combination of background, meteorological conditions conducive to ozone formation, and local emissions.

The U.S. background estimates from either zero out or source apportionment methods are quite similar. The spatial patterns are also consistent, with the highest fractional contributions from sources other than U.S. anthropogenic emissions occurring along U.S. borders and over the intermountain western states. Source apportionment modeling estimates that approximately 40-80 percent of the seasonal average maximum daily 8-hour average ozone concentrations at monitoring locations is due to sources other than manmade ozone precursor emissions from the U.S. The mean proportion attributable to international and natural sources over all sites is 59 percent. This is similar to the mean U.S. background estimate of 66 percent from the zero out modeling (ranging from 25-50 ppb; USEPA 2014).

From an implementation perspective, the values of background ozone on possible exceedance days is a more meaningful distinction. The modeling conducted by the EPA indicates that the mean U.S. background fractional contribution to daily maximum 8-hour average ozone concentrations between 70-75 ppb is approximately 45 percent with zero out and 35 percent with source apportionment models. For natural background, the median fraction is 35 percent for maximum daily 8-hour average concentrations between 70-75 ppb. It should be noted that there can be cases where background comprises 80-90 percent of the total ozone, such as sites in the west, including the Texas-Mexico border (Figures 2-12 and 2-13, USEPA 2014).

What the EPA has said about role of background in setting the NAAQS

The 2014 Policy Assessment described the EPA's three key issues related to background ozone: First, background ozone exists and can comprise a considerable fraction of ozone across the U.S. Air quality models can estimate the fractional contribution of background sources to total ozone in an individual area. The largest absolute values of background are modeled to occur at locations in the intermountain western U.S. and are highest in the spring and early summer seasons. Second, modeling indicates that U.S. anthropogenic emission sources are the dominant contributor to the majority of modeled ozone exceedances of the NAAQS. Higher ozone days generally have smaller fractional contributions from background. This finding indicates that the relative importance of background ozone would increase were ozone concentrations to decrease due to strategies aimed at attaining a lower ozone NAAQS. Third, while the majority of modeled ozone exceedances have local and regional emissions as their primary cause, there can be events where ozone levels approach or exceed 60-75 ppb due to the influence of background sources. These events are relatively infrequent and the EPA has policies that could allow for the exclusion of air quality monitoring data affected by these types of events from design value calculations.

The Final Rule (pp. 65436) also communicates the EPA's view that regulatory relief from background ozone is best addressed through exceptional events demonstrations. Exceptional events result when discrete occurrences, such as specific wildfires or stratospheric intrusions, cause elevated ozone concentrations. As such, regulatory relief from exceptional events does not address routine background ozone impacts, but rather only provides relief in situations where natural sources are the clear cause of the exceedance.

In the Policy Assessment for the 2015 ozone NAAQS, the EPA indicated that an important consideration in the ozone NAAQS review is the characterization of background levels. The

Policy Assessment also indicated that substantial uncertainties in the characterization of 8-hour daily maximum background ozone concentrations remain and further research to improve the evaluation of the global and regional models that have been used to characterize estimates of background levels would improve understanding of the role of non-U.S. anthropogenic emissions on ozone levels over the U.S.

Information the EPA should consider in the next review

Estimates in background contribution

Prior to the 2015 ozone NAAQS, the EPA utilized estimates of background ozone as a threshold below which health risks were not estimated. Since then, the EPA uses air quality modeling to estimate the spatial patterns of ozone and the resulting health effects estimated when attaining various modeled levels of the NAAQS. Regardless of which method is used, the EPA should consider and provide a well-founded understanding of the fractional contribution of background sources to surface ozone in setting and implementing future ozone NAAQS. This understanding is valuable because uncertainties associated with background contributions remain in all chemical transport models and impact background ozone estimates (and ultimately risk calculations) throughout the U.S. and throughout the modeled year. Further, the EPA should include a discussion of how routine background (both natural and U.S.) informs the level and form of the ozone NAAQS, given that background ozone is a relatively large percentage of the total seasonal mean ozone concentrations in locations within the intermountain western U.S. and along the U.S. border (Section 2.4.2, USEPA 2014).

Recent published work and ongoing research also reinforce the important contribution of background ozone on 8-hour maximum daily average ozone at or near current air quality standards. Notable studies related to assessments of U.S. background ozone that ought to be considered include all of the studies associated with the Tropospheric Ozone Assessment Report, as published in the journal Elementa. These articles are open access and can be found at https://collections.elementascience.org/toar/.

Peak background

The preamble to the 2015 Ozone NAAQS Final Rule noted that the EPA could consider relative proximity to peak natural background ozone when considering alternatives within the range of reasonable values supported by the scientific evidence and judgment of the Administrator. This provides a framework for considering the contributions of international anthropogenic and natural sources within the context of considering the health evidence, when evaluating various potential alternative standards. Therefore, the EPA should explicitly evaluate this criteria in the upcoming review. For example, a specific policy-relevant question to be included in the Policy Assessment could be:

> *How does peak background ozone throughout the U.S. inform the choice between alternative standards under consideration?*

Uncertainties and trends in background estimates

In addition, Jaffe et al. (2018) details the challenges of estimating U.S. background ozone. Although the numerous studies reviewed in the article (over 100 papers that had been published since 2011) found similar spatial patterns in U.S. background ozone estimated with different techniques, the uncertainty in seasonal averages of maximum daily 8-hour average for sites across the US was ±10 ppb, with higher uncertainties for individual days. The authors noted that given the potential regulatory importance of quantifying U.S. background ozone, there should be coordinated scientific research efforts directed toward estimating U.S. background ozone more precisely.

Fleming et al. (2018) updated and expanded versions of the nationwide ozone trends figures originally published in Cooper et al. (2012) (e.g., Figure A below). Earlier assessments of background ozone trends on the U.S. west coast indicated upward trends, even at monitoring sites that were unlikely to be affected by emissions from the U.S. (e.g., Jaffe et al. 2003). Parrish et al. (2017), however, discussed at length how these upward trends have lessened and reversed in recent years (Figure B). Lin et al. (2017) examined in detail the causes and trends of high ozone in the eastern half of the U.S., and concluded, "Without emission controls, the 95th percentile summertime O_3 in the eastern U.S. would have increased by 0.2–0.4 ppb per year over 1988–2014 due to more frequent hot extremes and rising biogenic isoprene emissions."

One of the primary reasons for reversal of the upward U.S. background trend is the decrease in primary emissions of oxides of nitrogen in China since about 2010. Souri et al. (2017), Liu et al. (2017), and Van der A et al. (2017) have shown that nitrogen dioxide column densities over Chinese cities were increasing rapidly from 2005 to 2010, but have decreased since 2010 (though still have not fallen below 2005 levels as of 2014). Therefore, earlier studies, such as those by Lin et al. (2012), which showed modest influences of Asian emissions upon western U.S. ozone concentrations based on older emissions estimates from Chinese sources, may need to be reconsidered in light of the new evidence of reduction in Chinese emissions of oxides of nitrogen.

A host of modeling studies have examined U.S. background ozone levels and attempted to quantify U.S. background on high ozone days (e.g., Nopmongcol et al. 2016 and 2017, Dunker et al. 2017, Guo et al. 2018, Hogrefe et al. 2018). These studies consistently show that U.S. background ozone is higher and has a greater influence upon surface ozone concentrations on the west coast and in the intermountain west region than in the eastern half of the U.S. (i.e., east of about 100° W longitude). These conclusions are supported by the trend analyses in Cooper et al. (2012) and Fleming et al. (2018), which showed uniformly decreasing trends in the eastern U.S. at both urban and rural sites. The estimated magnitude and local percent contribution of U.S. background ozone, however, varies considerably among different modeling platforms. Fiore et al. (2014), Guo et al. (2018), Hogrefe et al. (2018), and Liu et al. (2018) show the challenges of attempting to estimate U.S. background ozone with global scale modeling. In these studies, estimates of U.S. background vary substantially, depending upon which model is being used. The EPA should consider the findings from the aforementioned peer-reviewed articles when evaluating the possible causes of observed ozone trends, the possible contributions from international emissions, and the uncertainty inherent in estimates of U.S. background ozone.

Texas-specific regional background ozone

In Texas, regional background ozone is a major factor on high ozone days observed in the state (Langford et al. 2009; Berlin et al. 2013). Regional background ozone can be defined as the ozone affecting a metropolitan area that was not generated by emissions from the metropolitan area in question. Regional background ozone may be formed by emissions outside the control of the metropolitan area, though they may be within control of the state or federal government. Regional background ozone includes contributions from U.S. background ozone. Langford et al. (2009) was one of the first to systematically investigate and quantify regional background ozone in the Houston metropolitan area. The researchers found that even on high ozone days that apparently had large local contributions, regional background ozone was elevated relative to low ozone days. Berlin et al. (2013) used Langford's technique and a second technique that inferred background ozone from upwind monitors to investigate more than a decade of Houston ozone data. These analyses confirmed observations in Langford et al. (2009), indicating average regional background ozone in the Houston area was approximately 30 ppbv, peak ozone values were well correlated with regional background ozone, and background ozone reached concentrations of >50 ppbv on high ozone days. However, the stagnant conditions prevailing on high ozone days left open the possibility that the estimated values of regional background ozone may have been influenced by recirculated emissions from the Houston area. Therefore, these values should be considered an upper limit to regional background ozone.

Studies of the meteorological conditions prevailing in Houston during high ozone days have shown that ozone is strongly related to the direction and strength of transport into the Houston area. Several studies have used cluster analysis of back trajectories to study relationships between flow patterns and ozone in Houston. Souri et al. (2016) confirmed the results of unpublished studies (i.e., Smith et al. 2013, Sullivan 2009) that showed low ozone concentrations when transport winds were from the south and southeast, but high concentrations when winds were from the east and northeast (Figure C). Southerly winds brought clean air from the Gulf of Mexico into Houston, but easterly winds brought polluted air from the continental U.S. into Houston. Northerly and westerly winds did not occur as often as other patterns. These studies generally could not capture the fine details of wind flow within the urban areas of Houston but captured the larger-scale transport into the area.

When the seasonal patterns of regional background ozone were compared with seasonal variations in transport, the TCEQ found that there was frequently a mid-summer lull in high ozone from about mid-June to mid-August. The transport winds during this period were strongly southerly. The underlying synoptic weather patterns driving these southerly winds were identified by Zhu and Liang (2013), who had investigated the linkages between synoptic weather patterns and air quality. They found that the location of the Bermuda High determined when and where southerly flow set up along the Texas Gulf Coast. Their findings were verified and refined by Shen et al. (2015) and Wang et al. (2016), who found that a westward extension of the Bermuda High resulted in strong southerly flow from the Gulf of Mexico into Houston, bringing a respite in high ozone concentrations in mid-summer. When the western edge of the Bermuda High retreated eastward, other weather features sometimes allowed easterly flow bring high regional background ozone into eastern Texas, or allowed a ridge to build in eastern Texas, resulting in stagnant conditions and poor air quality. These findings confirmed the similar observations of patterns in 1980s-1990s ozone data in the Houston area by Davis et al. (1998).

Other studies linking weather patterns to ozone have been published. Rappenglück et al. (2008), Lefer et al. (2010), and Ngan and Byun (2011) examined data from 2005-2006 and found that high ozone days in Houston often followed one or two days after a frontal passage in the spring and fall. Lei et al. (2018) examined a decade of ozone events and concluded that post-frontal conditions were frequently associated with high ozone in the Houston area. This finding is consistent with the findings of Wang et al. (2016), who concluded that the absence of the Bermuda High influence would allow frontal passages to occur. The subsequent high pressure to the north of Houston after frontal passage could provide stagnant and/or subsiding conditions, clear skies, dry air, and easterly flow, all of which are conducive to higher ozone in Houston, either due to local ozone formation or transport of elevated regional background ozone.

A new study by Shen and Mickley (2018) found a link between a certain type of El Niño event and poor air quality in the eastern U.S. The elevated sea surface temperatures in Niño Areas 1 and 2 appear to be teleconnected to westward extensions of the Bermuda High, which results in higher ozone for the southeast U.S., but lower ozone for the south-central U.S., including Houston, central Texas, and Dallas-Fort Worth. Shen and Mickley concluded that it may be possible to predict poor air quality several months in advance due to this teleconnection.

Figure A. Observed trends at rural ozone monitoring sites, 2000-2014. (Source: Fleming et al. (2017))

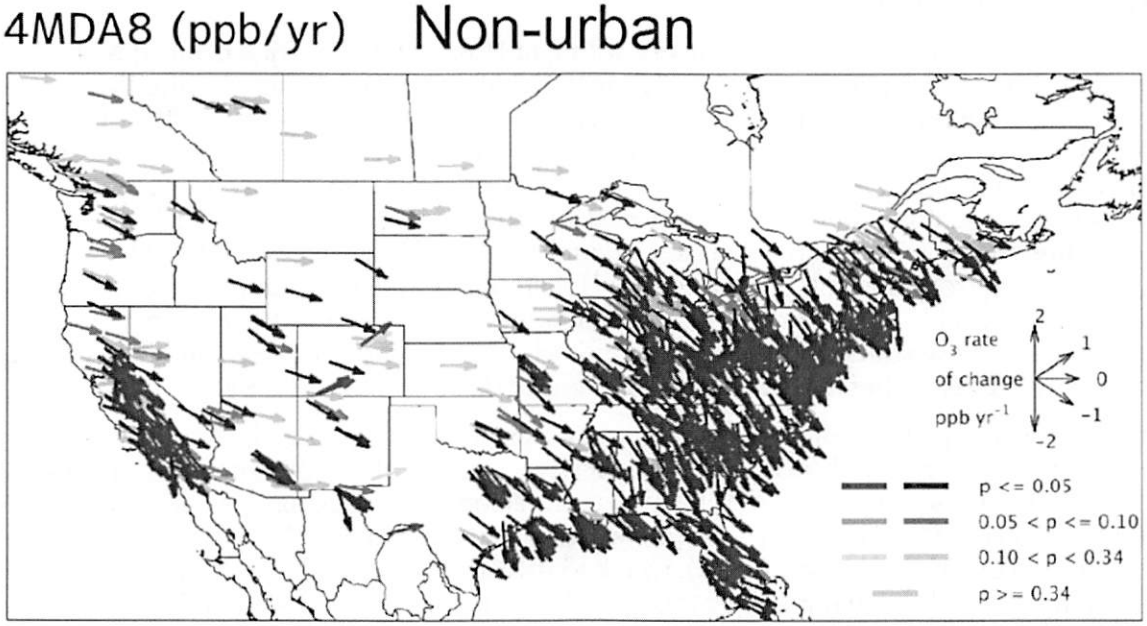


Figure B. Reversal of long-term baseline ozone trends on the U.S. west coast. (Source: Parrish et al. (2017))

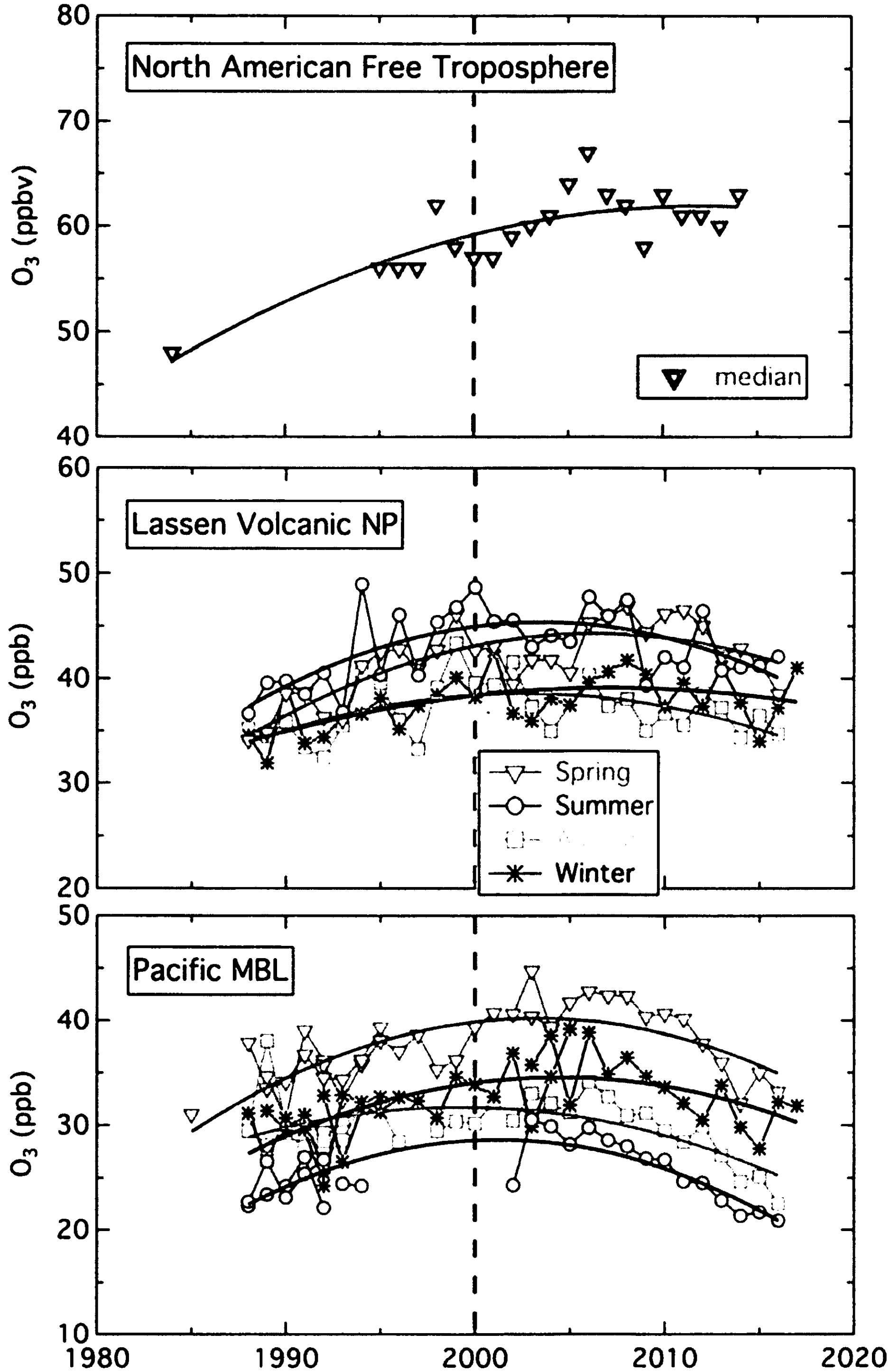
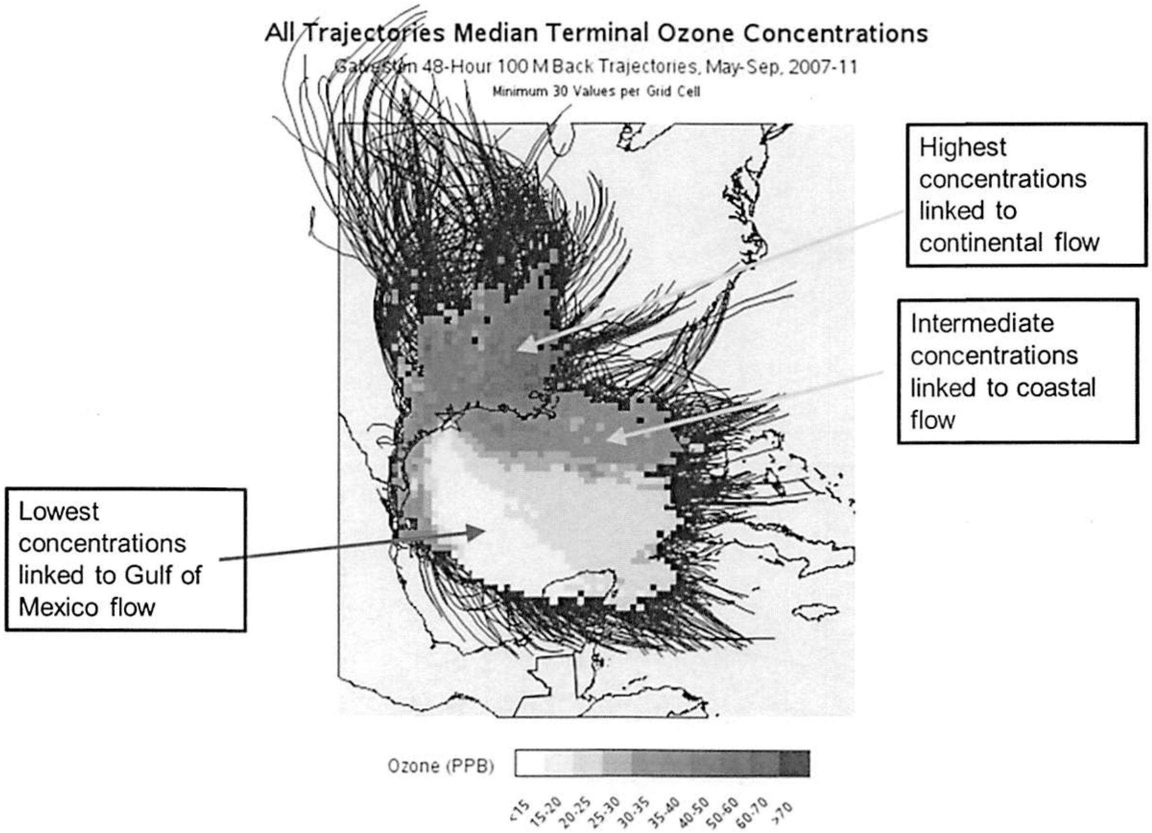


Figure C. Regional transport patterns linked to high and low ozone in the Houston area. (Source: Smith et al. (2013))



III. Other Relevant Scientific Information to be Considered

TCEQ Research

The TCEQ develops technical support and research contracts and work orders with vendors and Texas institutes of higher education[1]. These contractors are currently involved with several projects that will advance the science of air quality modeling and research. A number of these studies, particularly those listed below, are relevant to the ozone NAAQS and should be included in the upcoming review.

Emery, Christopher, Zhen Liu, Bonyoung Koo, and Greg Yarwood. Ramboll Environ US Corporation. May 2016. Final Report: Improved Halogen Chemistry for CAMx Modeling. TCEQ Work Order #582-16-61842-13. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/pm/5821661842FY1613-20160526-environ-CAMx_Halogens.pdf

Johnson, Jeremiah, and Gary Wilson, Michele Jimenez, Tejas Shah, Ross Beardsley, Kurt Richman, Greg Yarwood. Ramboll Environ. July 2017. Final Report: Fire Impact Modeling with CAMx. TCEQ Work Order #582-17-74141-26. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/pm/582177414126-20170728-re-fire_impact_modeling.pdf

[1] https://www.tceq.texas.gov/airquality/airmod/project

Kemball-Cook, Sue, Jaegun Jung, Thomas Pavlovic, Wei-Chun Hsieh, Jeremiah Johnson, and Greg Yarwood. Ramboll Environ. Final Report: Simulation of the Stratospheric Contribution to Surface Ozone. TCEQ Work Order #582-15-50417. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/pm/5821150417FY1546-20150815-environ-simulation_of_stratospheric_ozone_contribution.pdf

Tai, Ed, Ou Nopmongcol, Jaegun Jung, Jim King, Yesica Alvarez, and Greg Yarwood. Environ International Corporation. Foreign Contributions to Texas' Ozone. TCEQ Work Order #582-11-10365-FY13-14. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/pm/5821110365FY1314-20130831-environ-foreignContributionsTexasOzone.pdf

Osterman, Gregory, Christopher Boxe. NASA Jet Propulsion Laboratory. April 6, 2011. Improving the Characterization of Pollution Transported into Texas Using OMI and TES Satellite and In Situ data and HYSPLIT Back Trajectory Analysis. TCEQ PGA #582-056-4594-FY10-13. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/pm/5821110365FY1314-20130831-environ-foreignContributionsTexasOzone.pdf

Flynn, James. University of Houston. June 30, 2018. An Investigation of Background Ozone and Particulate Matter Levels in the Houston/Galveston/Brazoria Metropolitan Area. TCEQ PGA #582-15-52601-FY15-06. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/da/5821552601FY1506-20180720-uh-BackgroundOzonePM25LevelsInHouston.pdf

McVey, Amy, Richard Pernak, Jennifer Hegarty, and Matthew Alvarado. Atmospheric and Environmental Research, Inc. June 29, 2018. Final Report: El Paso Ozone and PM2.5 Background and Totals Trend Analysis. TCEQ Work Order #582-18-81763-07. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/da/582188176307-20180629-aer-ElPasoOzonePMBackgroundTotalsTrends.pdf

Alvarado, Matthew, Christopher Brodowski, and Chantelle Lonsdale. Atmospheric and Environmental Research, Inc. June 30, 2016. Final Report: An Analysis of Biomass Burning Impacts on Texas. TCEQ Work Order #582-16-62311-03. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/da/582166231103-20160630-aer-BiomassBurningImpactsOnTexas.pdf

Alvarado, Matthew, Chantelle Lonsdale, Marikate Mountain, and Jennifer Hegarty. Atmospheric and Environmental Research, Inc. August 31, 2015. Final Report: Investigating the Impact of Meteorology on O3 and PM2.5 Trends, Background Levels, and NAAQS Exceedances. TCEQ Work Order #582-15-54118-01. https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/da/5821554118FY1501-20150831-aer-MeteorologyAndO3PMTrends.pdf

Texas Air Quality Research Program

The State of Texas Air Quality Research Program (AQRP) is administered by The University of Texas at Austin and is funded by the Texas Commission on Environmental Quality (TCEQ), through the Texas Emission Reduction Program (TERP), which funds emission reduction projects in communities throughout Texas[2]. In order to ensure that these emission reductions are as effective as possible in improving air quality, a fraction of the TERP funding is used to improve our scientific understanding of how emissions impact air quality in Texas. The specific goal of the Texas AQRP is to support scientific research related to Texas air quality in the areas of emissions inventory development, atmospheric chemistry, meteorology and air quality modeling. The following studies from this program are relevant to the ozone NAAQS and should be included in the upcoming review.

Wang, Yuxuan. University of Houston. Texas AQRP Project 16-008. October 2017. High Background Ozone Events in the Houston-Galveston-Brazoria Area: Causes, Effects, and Case Studies of Central American Fires. http://aqrp.ceer.utexas.edu/projectinfoFY16_17/16-008/16-008%20Final%20Report.pdf

Wang, Yuxuan. Texas A&M University-Galveston. Texas AQRP Project 14-010. September 2015. Impact of Large-scale circulation patterns on surface ozone concentrations in Houston-Galveston-Brazoria (HGB). http://aqrp.ceer.utexas.edu/projectinfoFY14_15/14-010/14-010%20Final%20Report.pdf

Emery, Chris, Ed Tai, Greg Yarwood, Meiyun Lin. Environ International. Texas AQRP Project 12-011. November 2013. Investigation of Global Modeling and Lightning NOx Emissions as Sources of Regional Background Ozone in Texas. http://aqrp.ceer.utexas.edu/projectinfoFY12_13/12-011/12-011%20Final%20Report.pdf

Considerations for Interpretation of Ozone Toxicology and Epidemiology Studies

In the past year scientists at the TCEQ have published several studies that provide insight into how ozone toxicology and epidemiology studies can be interpreted in a regulatory context, particularly in the context of the NAAQS. McCant et al. (2017) reveals a pervasive misconception that rats receive a 3-5 times lower lung tissue dose than humans who are exposed to the same concentration of ozone. The source of this misconception is the findings of Hatch et al. (1994), which demonstrate similar ozone tissue doses in rats exposed to 2 ppm ozone compared to humans exposed to 0.4 ppm ozone. However, as was later clarified in Hatch et al. (2013), the humans were exercising during exposure, and this exercise increased their ventilation rate by approximately 5-fold, which explained the discrepancy in lung tissue dose. McCant et al. (2017) found that >60 percent of articles that cite Hatch et al. (1994) about tissue dose improperly attribute this difference in lung tissue dose to interspecies differences, instead of appropriately considering exercise. It is important to correct this misconception to ensure that information from animal toxicology studies is appropriately applied to humans in ozone regulatory risk assessment processes.

Another study (Lange 2018) compared ozone concentration summary metrics used in key epidemiology studies to the ozone concentration metrics that comprise the ozone NAAQS (the

[2] http://aqrp.ceer.utexas.edu/

annual 4th highest daily 8-hour maximum average ozone concentration, averaged over three years, with compliance based on the monitor with the highest concentrations). Lange (2018) found that epidemiology studies often used metrics that were different from the NAAQS ozone metrics, such as 1-hour or 24-hour ozone concentrations, multiple-day averages, averaging of concentrations from all monitors across an area, and averaging concentrations over different months of the year. Using ozone concentration data from 12 study cities in the U.S., Lange (2018) demonstrated that using different summary metrics can generate numbers that are very different from the NAAQS regulatory value, even when starting with identical raw concentration data. In addition, these metrics may not vary in similar way as the NAAQS - for example, annual average ozone concentrations often did not correlate with the NAAQS regulatory value. This work demonstrates that the choice of ozone metrics is important and often results in ozone concentrations that cannot be directly compared to the ozone NAAQS.

A third study, Lange et al. (2018), discusses alternative net benefits from reducing the ozone standard to 65 ppb. This paper presents a combined toxicological and economic assessment of the EPA's 2014 and 2015 Ozone Regulatory Impact Analyses that quantified the costs and benefits of the 2015 ozone NAAQS. For the benefits assessment, Lange et al. (2018) assessed the quality of the underlying epidemiology studies based on considerations of bias, confounding, chance, evidence integration, and future risk, and then used this quality assessment to generate two alternative benefits estimates. For the cost assessment, Lange et al. (2018) reviewed the cost analyses completed by EPA and others, and then outlined an alternative method for calculating costs of a 65 ppb ozone standard. Altogether this work demonstrated that making reasonable changes in cost and benefit analysis assumptions can result in very different net benefits estimates, which may impact how policy makers view the potential societal outcomes of a rule.

References

Berlin, S.R., A.O. Langford, M. Estes, M. Dong, D.D. Parrish (2013), Magnitude, decadal changes, and impact of regional background ozone transported into the greater Houston, Texas area, *Environ. Sci. Technol.*, 47(24): 13985-13992, doi: 10.1021/es4037644.

Cooper, O. R., R.-S. Gao, D. Tarasick, T. Leblanc, and C. Sweeney (2012), Long-term ozone trends at rural ozone monitoring sites across the United States, 1990–2010, J. Geophys. Res., 117, D22307, doi: 10.1029/2012JD018261.

Davis, J.M., B.K. Eder, D. Nychka, Q. Yang (1998), Modeling the effects of meteorology on ozone in Houston using cluster analysis and generalized additive models, Atmos. Environ., 32 (14/15): 2505-2520.

Dunker, A.M. et al. (2017), Contributions of foreign, domestic, and natural emissions to US ozone estimated using the path-integral method in CAMx nested within GEOS-Chem, Atmos. Chem. Phys., doi: 10.5194/acp-17-12553-2017.

Fiore, A.M. et al. (2014), Estimating North American background ozone in U.S. surface air with two independent global models: Variability, uncertainties, and recommendations, Atmos. Environ. 96: 284-300, doi: 10.1016/j.atmosenv.2014.07.045.

Fleming, ZL, et al. (2018), Tropospheric Ozone Assessment Report: Present-day ozone distribution and trends relevant to human health. Elem Sci Anth, 6: 12. doi: 10.1525/elementa.273.

Guo, J.J. et al. (2018), Average versus high surface ozone levels over the continental USA: Model bias, background influences, and interannual variability, Atmos. Chem. Phys. Discuss., doi: 10.5194/acp-2018-115.

Hogrefe, C. et al. (2018), Impacts of different characterizations of large-scale background on simulated regional-scale ozone over the continental United States, Atmos. Chem. Phys., doi: 10.5194/acp-18-3839-2018.

Jaffe et al. (2003). Increasing background ozone in the spring on the west coast of North America. Geophys. Res. Lett. 30 (12): 1613, doi:10.1029/2003GL017024.

Jaffe et al. (2018). Scientific assessment of background ozone over the U.S.: Implications for air quality management, Elem Sci Anth, 6: 56, DOI: https://doi.org/10.1525/elementa.309

Lange, S. Comparing apples to oranges: Interpreting ozone concentrations from observational studies in the context of the United States ozone regulatory standard. 2018. Sci Total Environ. 644, pp. 1547-1556.

Lange, S., Mulholland, S.E., and M.E. Honeycutt. What are the net benefits of reducing the ozone standard to 65 ppb? An alternative analysis. 2018. Int J Env Res Pub Health. 2018, 15 (8), p. 1586.

Langford, A. O., C. J. Senff, R. M. Banta, R. M. Hardesty, R. J. Alvarez II, S. P. Sandberg, and L. S. Darby (2009), Regional and local background ozone in Houston during Texas Air Quality Study 2006, J. Geophys. Res., 114, D00F15, doi: 10.1029/2008JD011687.

Lefer, B., Rappenglück, B., Flynn, J., Haman, C. (2010), Photochemical and meteorological relationships during the Texas-II Radical and Aerosol Measurement Project (TRAMP), Atmospheric Environment, doi: 10.1016/j.atmosenv.2010.03.011.

Lei, R.; Talbot, R.; Wang, Y.; Wang, S.-C.; Estes, M. (2018), Influence of Cold Fronts on Variability of Daily Surface O3 over the Houston-Galveston-Brazoria Area in Texas USA during 2003–2016. Atmosphere 9: 159, doi:10.3390/atmos9050159.

Lin, Meiyun, et al. (2012), Transport of Asian ozone pollution into surface air over the western United States in spring, J. Geophys. Res., 117, D00V07, doi: 10.1029/2011JD016961

Lin, Meiyun et al. (2017), US surface ozone trends and extremes from 1980 to 2014: quantifying the roles of rising Asian emissions, domestic controls, wildfires, and climate, Atmos. Chem. Phys., doi: 10.5194/acp-17-2943-2017.

Liu, Fei et al. (2017), NOx emission trends over Chinese cities estimated from OMI observations during 2005 to 2015, Atmos. Chem. Phys., doi: 10.5194/acp-17-9261-2017.

Liu, Peng et al. (2018), Multi-model comparison in the impact of lateral boundary conditions on simulated surface ozone across the United States using chemically inert tracers, Atmos. Chem. Phys. Discuss., doi: 10.5194/acp-2018-106.

McCant, D., Lange, S., Haney, J., and M. Honeycutt. The perpetuation of the misconception that rats receive a 3-5 times lower lung tissue dose than humans at the same ozone concentration. 2017. Inhal Toxicol. 12, pp. 1-10.

Ngan, F. and D. Byun (2011), Classification of weather patterns and associated trajectories of high-ozone episodes in the Houston-Galveston-Brazoria area during the 2005/06 TexAQS-II, J. Appl. Met. Clim., 50: 485-499, DOI: 10.1175/2010JAMC2483.1

Nopmongcol, U., Jung, J., Kumar, N., Yarwood, G., (2016), Changes in US background ozone due to global anthropogenic emissions from 1970 to 2020, Atmospheric Environment, doi: 10.1016/j.atmosenv.2016.06.026.

Nopmongcol, Uarporn et al. (2017), Source contributions to United States ozone and particulate matter over five decades from 1970 to 2020, Atmos. Environ., doi: 10.1016/j.atmosenv.2017.08.009.

Parrish, D. D. (2017), Reversal of long-term trend in baseline ozone concentrations at the North American West Coast. Geophysical Research Letters, 44, doi: 10.1002/2017GL074960.

Rappenglück B., R. Perna, S. Zhong, G. A. Morris (2008), An analysis of the vertical structure of the atmosphere and the upper-level meteorology and their impact on surface ozone levels in Houston, Texas, J. Geophys. Res., 113, D17315, doi: 10.1029/2007JD009745.

Shen, L., L.J. Mickley, and A.P.K. Tai (2015), Influence of synoptic patterns on surface ozone variability over the Eastern United States from 1980 to 2012, ACPD 15:13073-13108, doi:10.5194/acpd-15-13073-2015.

Shen, L., & Mickley, L. J. (2017). Effects of El Niño on summertime ozone air quality in the eastern United States. Geophysical Research Letters, 44, 12,543–12,550, doi: 10.1002/2017GL076150.

Smith, James, Fernando Mercado, and Mark Estes, (2013), Characterization of Gulf of Mexico background ozone concentrations, 12th Annual CMAS Conference, Chapel Hill, North Carolina, October 28-30, 2013.

Souri, Amir Hossein, Yunsoo Choi, Xiangshang Li, Alexander Kotsakis, Xun Jiang (2016), A 15-year climatology of wind pattern impacts on surface ozone in Houston, Texas, Atmospheric Research, 174-175: 124-134, doi: 10.1016/j.atmosres.2016.02.007.

Souri, A. H. et al., (2017), Remote sensing evidence of decadal changes in major tropospheric ozone precursors over East Asia, J. Geophys. Res. Atmos., 122, 2474–2492, doi: 10.1002/2016JD025663.

Sullivan, 2009. Effects of Meteorology on Pollutant Trends, Final Report to TCEQ, Grant 582-5-86245-FY08-01, March 16, 2009, 163 pgs., https://www.tceq.texas.gov/assets/public/implementation/air/am/contracts/reports/da/5820586245FY0801-20090316-ut-met_effects_on_pollutant_trends.pdf

United States Environmental Protection Agency (USEPA). 2013. Integrated Science Assessment for Ozone and Related Photochemical Oxidants, Final Report. Vol. EPA 600/R-10/076F. ORD.

USEPA. 2014. Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards. EPA-452/R-14-006. OAR.

Van der A, R.J., et al. (2017), Cleaning up the air: effectiveness of air quality policy for SO2 and NOx emissions in China, Atmos. Chem. Phys., doi: 10.5194/acp-17-1775-2017.

Wang, Yuxuan, Beixi Jia, Sing-Chun Wang, Mark Estes, Lu Shen, Yuanyu Xie (2016), Influence of the Bermuda High on interannual variability of summertime ozone in the Houston-Galveston-Brazoria region, Atmos. Chem. Phys., 16: 15265-15276, doi: 10.5194/acp-16-15265-2016.

Zhu, J. and X-Z. Liang (2013), Impacts of the Bermuda High on regional climate and ozone over the United States, J. Climate, 26: 1018 – 1032, doi: 10.1175/JCLI-D-12-00168.1.