THE INVESTIGATION OF POSSIBLE STRATOSPHERIC ORIGIN OF OZONE PRESENCE AT THE SURFACE AT NIGHT, USING HYSPLIT TRAJECTORY ANALYSIS

A Thesis by

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science, with a major in Earth, Environmental and Physical Sciences

Bill Bischoff, Committee Chair

Nathaniel Reynolds, Committee Member

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Collette Burke, Committee Member

Nikki Keene Woods, Committee Member

DEDICATION

To my wonderful and beautiful wife, my kids, my parents,

and my amazing friends

ABSTRACT

IMPORTANCE: On August 2, 2012, high tropospheric ozone levels, above the EPA limit of 75 parts per billion by mass, were forecast for Wichita, Kansas. Trajectories for ozone transport were examined using two software packages: McIDAS and HYSPLIT. The source of the rise of ozone concentration was examined, namely whether it came from the stratosphere or was a buildup from the ground level. Evidence of stratosphere ozone was lacking.

OBJECTIVE: The reason for this research is to investigate the source of high concentrations of ozone in the troposphere. One possibility is the entrance of stratospheric ozone via tropopause folding. Another possible source of high ozone concentration comes from photochemistry in the troposphere, possibly around Wichita or upstream of Wichita. However, the photochemistry details are not part of this study. Instead, the study concerns itself with transportation of ozone pollution to Wichita of either tropospheric ozone produced elsewhere or ozone precursors.

METHODS: We use the McIDAS software to analyze the data we collected from the NCAR datasets and use the information to analyze the presence of stratospheric ozone and the ozone concentration in Wichita due to the impact of tropopause folding. Also, we applied the HYSPLIT model to investigate where the polluted air was. The map area is attempting to describe the source and movement of ozone, impacting human health. Therefore, the HYSPLIT trajectory analyzes the ozone movement from August 2, 2012, and August 4, 2012, to determine the wind direction.

RESULT: During the period, the NCAR (National Center for Atmospheric Research) dataset was collected, and the ozone mixing ratio at 500 hPa and 850 hPa was run. The 500 hPa map and 850 hPa* map in figure 3 and figure 4, respectively, show the ozone values that are relatively high across the same region. The NCAR data result at 850 hPa* and 500 hPa agreed with the forecast of August 2, 2012, that the tropospheric ozone concentration was high. However, the stratosphere ozone cannot be established during this day because the HYSPLIT trajectory model suggested no wind migrating from the Rocky Mountains to Wichita, Kansas. The investigation reviewed that the data from the Cfsrr in the Cfsr (Climate Forecast System Reanalysis) was the framework for this study. It indicates the increased ozone concentration in the troposphere and shows that ozone expels from the stratosphere to the troposphere cannot be established. The 3-D grid model is used to analyze the data, and the color indicates the increase of ozone. Furthermore, the tongue-like structure suggests the presence of tropopause presence in the Rocky Mountains.

CONCLUSIONS: There was no stratospheric ozone because the wind direction was not coming from the Rocky Mountains; instead, we saw the trajectory coming from Texas and local wind-generated within Kansas, Oklahoma, Arkansas, and Missouri. However, that part of the ozone transported from Texas, Arkansas, Missouri, and Oklahoma might have escalated the ozone concentration above 75ppb (part per billion).

* The standard unit used for pressure is Pascal, with one Pascal (Pa) equal to one Newton of force per square meter. This report will measure pressure using a unit of 100 Pascals, which is one hecto-Pascal (1 hPa).

ACKNOWLEDGMENTS

We like to say thanks to Dr. Nathaniel Reynolds (thesis Advisor) of the Geology department at Wichita State University. The door of Dr. Reynolds' office was always open whenever a question arises about the research. He ensured and directed the thesis in the right direction whenever he saw there is a need.

We are grateful to the Financial aid office for their funding for this research project. We would like to personally thank: The Earth, Environmental Physical Science, for allowing the research to commence. We would thank the entire advising committee members, whose dynamism and commitment to improving the research ensure that this research meets its standard. Without their passionate participation and input, this research could not have completed.

With deepest gratitude to the family for providing their massive support, they encouraged throughout the years of study, researching, and writing. Without the Wife (Oluchi Purity), this achievement would not have been possible.

Furthermore, thanks to Dr. Edwin Akley, who gave the enthusiasm to complete the thesis. Mr. Tega Igbru, Mr. Stephen Adjarho for their massive support.

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CHAPTER 1

RESEARCH STATEMENT

1.1 INTRODUCTION

The troposphere ozone has been one of the challenges facing our environment. Ozone is not harmful in the stratosphere; in the stratosphere, it serves as a protective device by preventing the ultraviolet ray from damaging our crops and humans. However, it is difficult to distinguish the exchange of stratosphere ozone from tropospheric ozone (Fishman et al., 1978).

Nevertheless, it is harmful when ozone is in the troposphere. The tropospheric ozone is destructive to plant and human health. We are concerned about how we can prevent this lethal agent's recurrence.

There has been speculation of what would have resulted in the increased ozone concentration in the troposphere. However, summer ozone is a result of anthropogenic activities. Some are concerned with the recirculation of ozone in dense cities, in which the town of Wichita has problems.

Detailed studies emphasize that ozone production is one of the keystone products of smog, with the presence of sunlight (photochemical), volatile organic compounds (VOCs), and nitrogen oxides all reacting together in the atmosphere (air). Ozone can remain in the atmosphere for around 22 days (Wood, 2016).

This research identifies the August 2, 2012 ozone forecast's possible pathway to Wichita, Kansas. Identifying the possible ozone transportation pathways and the condition that can help build the ozone concentration helps establish the ozone environment given a forecast exceeding the EPA limit of 75 ppb (part per billion). This project gives an insight into the impact of ozone transportation into Wichita.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The troposphere (ground level) is the lowest part of the earth's atmosphere, where most of the earth's weather conditions like thunderstorms occur. The troposphere contains about 70% of the atmosphere's mass, 99% of water vapor and aerosols. The troposphere's depth varies from 20km in the tropic to 17km in the mid-latitude. The troposphere derives its name from the Greek word tropes, which means turning. The troposphere is known for a lot of turbulence (disturbance), which helps mix different compounds (Fishman et al., 1978). The day-to-day activities of the weather happen in the troposphere. The atmosphere is divided into the troposphere, stratosphere, mesosphere, and ionosphere (Meloen et al., 2003). The planet's surface and frictional force influence the airflow called the Planetary boundary layer (PBL). Therefore, boundary layers can be view as unstable if the air moving upward is less dense (buoyant) than the air moving downward during turbulent motion. However, if the air moving upward is denser than the air moving downward, it is said to be stable boundary layers (Naja et al., 2002). Therefore, Stull, R.B., defines the atmospheric boundary layer (ABL) which is the planetary boundary layer (PBL) to be "the part of the troposphere which is directly influenced by the presence of the earth's surface, and which response to surface forcing with a time scale of about an hour or less." (Stull, 1988).

Ozone (O_3) is the constituent of the troposphere, and most of the ozone is present in the upper to the medium troposphere, which is above the mixing layer (ground level). Ozone at the ground level (troposphere) constitutes a health problem. Therefore, the formation of ozone in the presence of sunlight is well understood. This reaction explains the step-by-step formation of daytime Ozone.

O_3 + light (UV) = $O + O_2$ equation (1)

$O + H_2O = 2OH$ equation (2)

$H_2O_2 + NO = OH + NO_2$ equation (3)

NO_2 + light (UV) = $NO + O$ equation (4)

$O + O_2 = O_3$ equation (5)

However, ozone formation happens when nitrogen oxides, carbon monoxide, and volatile compounds react in the atmosphere in the presence of sunlight. Therefore, nitrogen oxides, carbon monoxide, and volatile compounds are precursors of ozone. The reaction at night is different from the daytime reaction. At night, the reaction's driving force, which generates the hydroxyl radical, diminished to almost zero. Instead, a different force other than the hydroxyl radical operates during the night. Rather than the hydroxyl radical, this different force or oxidant is the nitrate radical (Stohl et al., 2000).

The nitrate radical, $NO^-{}_3$, is produced at night by the reaction of NO_2 with ozone (O_3). $NO^-{}_3$ radicals further react with NO_2 to reach chemical equilibrium with N_2O_5.

$NO_2 + O_3 = NO_3 + O_2$ equation (6)

$NO_3 + NO_2 \rightleftharpoons N_2O_5$ equation (7)

However, $NO^-{}_3$ is photolysized by sunlight, and therefore $NO^-{}_3$, and its equilibrium partner N_2O_5 are both heavily suppressed during the day.

NO_3 + light = $NO_2 + O$

To this end, nighttime chemistry could not exist in isolation from daytime chemistry. Nevertheless, the reaction in equation 6 needs ozone to oxidize NO_2 to NO_3, and ozone is a product of daytime photochemistry.

According to McNider (1995), oscillatory behavior may be the cause of shear in the presence of thermal stability, which amounted to a point where there is a break down in the boundary layer. However, with the removal of shear through vertical mixing, thermal stability can be restarted by a new cooling cycle. When there is no strong disturbance or turbulence, then there is limited mixing and dispersion of pollution (pollutants) between the stable boundary layer, a cool layer of air adjacent to a cold surface of the earth, where the temperature within that layer is stably stratified. The residual layer is the middle portion of the nocturnal atmospheric boundary layer by weak, sporadic turbulence and initially uniformly mixed potential temperature and pollutants remaining from the mixed layer of the previous day (Hu et al., 2012), (Stull, 1988) and (McNider et al., 1995).

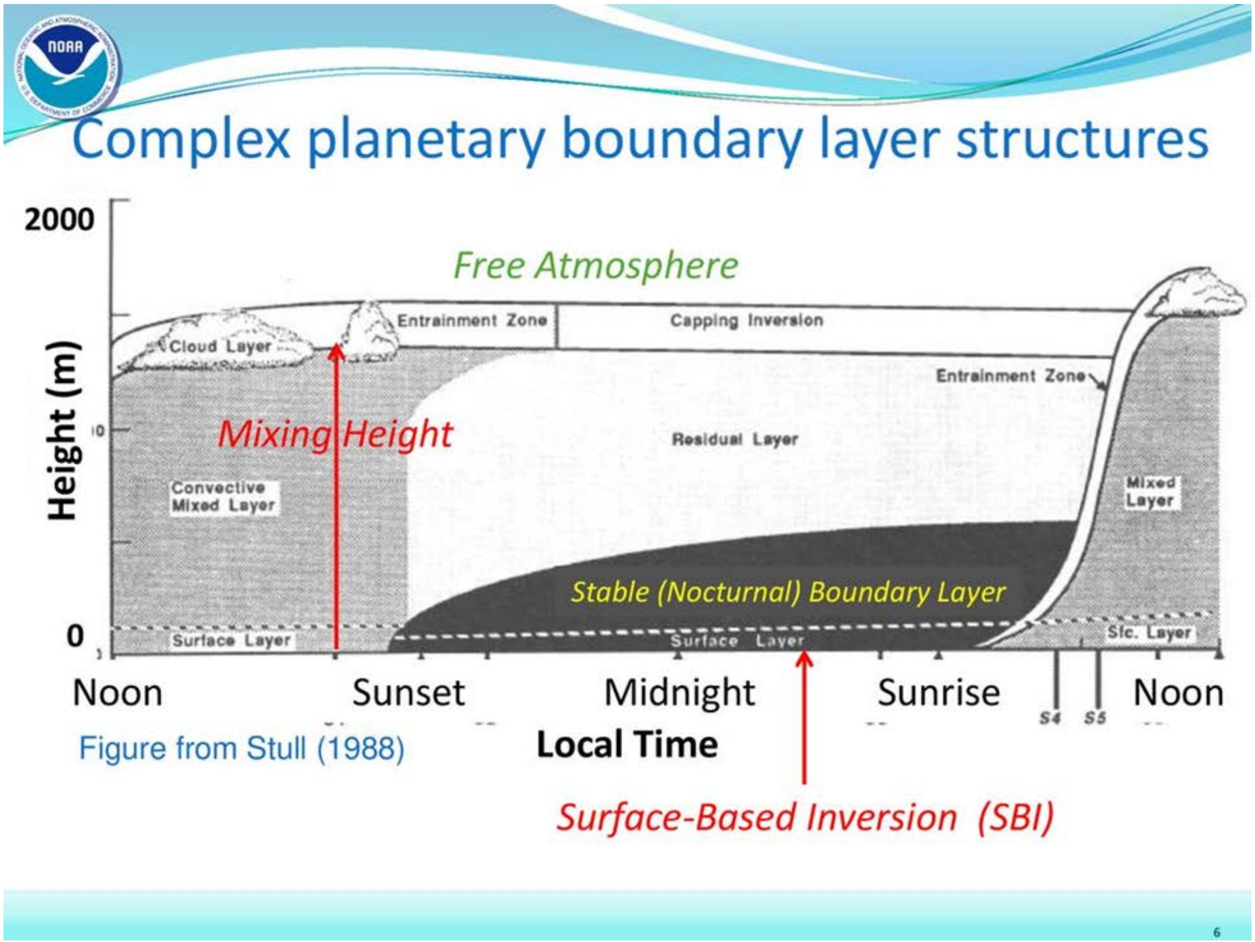

Figure 1. Boundary layer structure, after Stull (1988).

The periodic (sporadic) turbulence at night seems to be the cause that weakens the decoupling between the stable boundary layer, residual layer, and the vertical mixing at the nighttime boundary layer. Therefore, nighttime turbulence generates by mesoscale motions like the low-level jets, density current, gravity waves, and the Kelvin-Helmholtz instabilities (Hu et al., 2012).

The amplifying nighttime turbulence is associated with the vertical structure of the nighttime boundary layer and pollutants' distribution. Decoupling of the surface layer is a question used to address weather forecasting and air pollution modeling. With data limitation for a single location, it is not easy to understand the nocturnal boundary layer (Werth et al., 2011).

The focus of this thesis is on ozone transport mechanisms from the stratosphere into the troposphere. The behavior of the boundary layer can drive the chemistry of the ozone precursor to react differently. The ozone at the convective boundary layer is homogeneous because of the sunlight, which helps the mixing. However, as the nocturnal boundary layer (NBL) develops at sunset, ozone builds a positive gradient from the surface to the top of the nocturnal boundary layer due to the intrusion of surface NOx titration and insufficient downward mixing due to the nocturnal capping. But the planetary boundary layer's height varies from 100 to 3000 meters above ground level (AGL) or 100 to 2000 meters above ground level. It is the layer above the earth's surface where turbulence's vertical transports play a significant role in the transfers of heat, moisture, momentum, ozone, and other gases. The planetary boundary also varies with time, location, and weather conditions (Banta et al., 1998) (Stull, 1988).

The mechanism that dominates near the surface during nighttime needs an explanation for the Nocturnal Planetary Boundary Layer's elevated ozone. However, regional, or small-scale transport is associated with the low-level wind jet. To this end, Corsmeier stated that ozone cases correlated to an increase in the speed of wind, wind shear, and downward flux of ozone (Banta et al., 1998; Corsmeier et al., 1997), (Kuang et al., 2011), (McNider et al., 1995).

Among those mechanisms of interest are low-level jets (LLJ), which is in conjunction with the Southern Oxidants Study (SOS) (Banta et al., 1998). Hence, the pollutant plume can form during the day, when the meteorological conditions are favorable to pollutant accumulation, which is transported downwind during the nighttime, which affects the background levels on the second day.

The ozone observed close to the boundary layer is difficult to understand. The imbalance of ozone close to the boundary layer due to surface emission and deposition, interaction in the free troposphere, horizontal transport, and photochemistry (Kuang et al., 2011).

The thesis is all about the episode of August 2, 2012, Ozone that exceeded the EPA (Environmental Protective Agency) limit in Wichita-Kansas and investigated the possible pathways of this 2012 episode of ozone.

The chapter will elaborate on the transportation of ozone and its methodology. This project investigates stratospheric ozone involvement that led to an increased concentration of ground-level ozone (tropospheric or surface ozone) in the August 2, 2012 episode.

2.2 OZONE FORMATION

When ozone forms up in the stratosphere, it is beneficial to the health of human and plant growth. The formation of ozone in the troposphere has a damaging effect on humans (US Environmental Protection Agency, 2013; Lefohn et al.,1988; Langford et al., 2010). According to the EPA, research on ozone and human health relationships in 2006 and 2013 indicates that exposure to ozone, either short term or long term, has a devastating effect on human respiration and plant yield (Wood, 2016; US Environmental Protection Agency, 2013).

The tropospheric ozone problem used to be an issue that only affected urban areas, but now it is a problem of the metropolitan regions and a rural area problem. When the concentration of tropospheric ozone increases in the atmosphere, it becomes life-threatening. The rise of tropospheric ozone is terrible to human health because it causes lung disease and asthma and reduces plant growth (Meloen et al., 2003).

This thesis focuses on ozone transportation, not directly concerned with the chemistry involved in both day and nighttime precursor reactions and the effect on human health directly. Therefore, the thesis focus on the trajectory mechanisms only.

Anthropogenic activities, fossil fuel burning, biogenic activities, forest burning, lightning, and ozone intrusion from the stratosphere are the contributing factors that give rise to the concentration of ozone (Wood, 2016; Agastra, 2020; US Environmental Protection Agency, 2013). Clean skies, stagnant air, and high pressure also increase ozone concentration production during a specific period. Other researchers confirmed that previous air quality studies had their works on air quality by indicating the pattern and characteristic of ground-level ozone (Wood, 2016), (André et al., 1982).

CHAPTER 3

DATA ANALYSIS

3.1 INTRODUCTION

The NCAR dataset and the ozone data were run through the computer processor to indicate the increase of ozone concentration in Wichita, Kansas, on August 2, 2012. This thesis will address the issues of the possibility of any stratospheric ozone in Wichita.

Most of the rangeland is burned in Kansas to improve soil fertility. However, the smoke plume from Eastern Kansas burned area does migrate toward Kansas City and Wichita, which happened to degrade the air quality within this region (Liu, 2018), (Liu, 2010), and (Agastra, 2020).

3.2 STUDY AREA

Wichita is known for having a critical air problem. Therefore, it is necessary to understand while some years in Wichita, the concentration of ozone increases above 75 ppb.

According to the news report given on Thursday of August 2, 2012, the air quality in the Wichita area of Kansas past the ozone standard's EPA limit, two of the sites recorded below 75ppb, Wichita and the city of Sedgwick. However, the Peck site recorded 77ppb, which exceeded the 75ppb as of 2008 standard of 8-hours allowance by EPA. Wichita still was seen to violate the EPA standard because of the Peck record (https://www.wichita.gov/News/Pages/2012-08-03a.aspx), (US Environmental Protection Agency, 2013).

The 2015 EPA standard had reduced the ozone standard from 75ppb to 70ppb (part per billion), which put Wichita city in more threat (US Federal Register 2015). Most of the time, Kansas has a lot higher concentration of Ozone from April to October. However, ozone is a significant issue that Wichita and Kansas City face (Liu, 2018).

Table 1. Ozone Monitoring Stations

City	PPM	Date
Wichita	0.074	8/2/2012
Peck	0.077	8/2/2012
City of Sedgwick	0.071	8/2/2012

The eight-hour average in ppm records on that week at the continuous air monitors located in Sedgwick County and northern Sumner County (https://www.wichita.gov/News/Pages/2012-08-03a.aspx), (US Federal Register 2015, EPA).

Table 2. Air Quality Index

Air Quality Group	Air Quality Index	Ozone Concentration (ppm)	Ozone Concentration (ppb)	Particle Pollution Concentration (µg/m3)
Good	0-50	0-0.054	0-54	0-12
Moderate	51-100	0.055-0.070	55-70	12.1-35.4
Unhealthy for Sensitive Groups	101-150	0.071-0.085	71-85	35.5-55.4
Unhealthy	151-200	0.086-0.105	86-105	55.5-150.4
Very Unhealthy	201-300	0.106-0.200	106-200	150.5-250.4

Air Quality Guide (AQG) in Ozone and Particle Pollution. This table shows the relation between Ozone concentration (https://www.wichita.gov/News/Pages/2012-08-03a.aspx) and (US Federal Register, 2015).

Ozone can be generated locally or transported from a long-range distance downwind to its destination. Others have worked on transport medium concerning wind speed (Comrie, 1994; Schichtel and Husar, 2001; Husar and Renard, 1998). Another study established that high concentrations of ozone can be transported to the Eastern US from the Western US with wind above ground. The speed gradient or wind velocity gradient (shear wind) is the vertical gradient of the mean horizontal wind speed in the lower atmosphere (Blumenthal, 1997; Wood, 2016).

The nocturnal low-level jets can transport pollutants that have been entrained into the residual boundary layer hundreds of kilometers, contributing to the high ozone concentration overnight and in the early hours of the morning (Corsmeier et al., 1997; Langford, 2010; Wood, 2016).

3.3 NIGHTTIME WIND MECHANISM

Wind plays a role in vertical mixing (movement of gas molecules warmed up by sunlight travels upward). As was mentioned above, at night when the sun is absent, ozone formation ceases. To this end, Nighttime wind plays a role by transporting pollutants from other sources and deposit them in regions where these pollutants are not. Some of these pollutants are precursors of ozone.

Therefore, we look at the dynamic of the nighttime air to understand the activities at night. The periodic turbulence that exists at night, seen to be the cause that weakens the decoupling (separate) between the stable boundary layer, residual layer, and the vertical mixing at the nighttime boundary layer. Moreover, this is important compared to the daytime convective boundary layer, hence amplifying (enhanced) nighttime turbulence generated by mesoscale motions like the low-level jets, density current, gravity waves (Hu et al., 2012) and (McNIder et al., 1995). Wind amplifies nighttime turbulence associated with the vertical structure of the nighttime boundary layer and pollutants' distribution.

3.4 OZONE DATA

Analysis based on the NCAR climate reanalysis datasets reveals that the ozone mixing ratios were more than the EPA limit over many central Great Plains. We showed the results of the analysis of trajectories to identify air of recent stratospheric origin.

From the 2012 datasets that we collect, we plot a time-series of three different graphs to see if we can trace any possibility of tropopause folding and see if the ozone level is high at that time of the day. However, data collected from the National Center for Atmosphere Research (NCAR) from 00Z* August 2, 2012, to 00Z August 4, 2012. The height range is from 850 hPa at 00Z (54N to 135W) above the ground level to 500 hPa at 00Z.

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*Time is given in Greenwich mean time, or Universal time (UTC), and is denoted using the letter Z. The 24-hour clock (Z-time) begins at midnight, which is 00Z at this prime meridian. However, the Z-time is not influenced by the change for daylight saving time, but the local time will change. At 00Z in the Central standard time is at 6:00 p.m., but 00Z occurs at 7:00 p.m. (CDT).

CHAPTER 4

METHODOLOGY

4.1 INTRODUCTION

The thesis analysis is in two parts (a) the examination of the NCAR data, (b) the HYSPLIT backward trajectory analysis. The thesis will explain both the (a) and (b) method in this chapter.

For this study, the data are of previously collected NCAR data for tracing the possible ozone entrance from the stratosphere to the troposphere to identify the tropopause folding presence in the computer simulation. Data from Cfsrr is in Cfsr (Climate Forecast System Reanalysis) in the NCAR data source, using MclDAS to display the Ozone mixing ratio. The purpose is to address ozone intrusion from the stratosphere to the troposphere through tropopause folding.

4.2 THE GOAL OF HYSPLIT ANALYSIS

The goal is to use the HYSPLIT model to determine the wind direction trajectory. In contrast, the MclDAS model examines the presence of ozone concentration, which interprets the ozone NCAR dataset in a predictive and deterministic model to help plan the boundary layer better. Data from the NCAR dataset was applied to the HYSPLIT techniques to determine ozone's trajectory pathways. The area of concern will be on the wind pathway, which will help us understand ozone transport behavior at nighttime airflow.

4.3 McLDAS AND GRIB ANALYSIS

Using MclDAS to indicate tropopause folding, the menu item with GRIB data as an option is selected. Under the 3D grid, the 3D grid option is chosen.

Under the trace gas option, the ozone mixing ratio is selected. On the right-hand side, “displays” is clicked.

The procedure to be followed is as follows here. Times: the arrow and use set; Level: click on all levels; Region: click on the United States. Data sample: click on "use the default" and under ("x," "y," and "z") use all points.

Keep in mind that the ozone mixing ratio thresholds are 50ppb, 100ppb, and 150ppb (part per billion). Nevertheless, high values from 0.5ppm and 5ppm (part per million) are in the stratosphere.

4.4 HYSPLIT ANALYSIS

The HYSPLIT model is used to check surface ozone data collection, wind analysis, climate modeling, air circulation modeling, and wind trajectory modeling to study surface ozone transport. All these use the Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPLIT). The Air Resources Laboratory's (ARL's) model is a tool that helps explain how, when, and where potentially harmful materials are atmospherically transported from, dispersed to, and deposited in a location other than where it is generated (ARL, 2016). "The model uses a calculation which is a hybrid Eulerian and the Lagrangian. The Lagrangian approach uses a moving frame of reference for the advection and diffusion as the trajectories or air parcels move from their initial location (ARL, 2016). The Eulerian method uses a fixed three-dimensional grid as a frame of reference to compute pollutant air concentrations" (ARL, 2016, p. 1; Wood, 2016).

The HYSPLIT model can calculate air parcels' back trajectories to determine air mass (ARL, 2016).

According to Wood in 2016; The HYSPLIT model has similar applications in determining the back trajectories of other meteorological events such as dust storms or "blood" rains. To this end, the model for mapping the backward trajectories of "blood" rain events in Europe, which are rain with a reddish color. However, the model has been used to map the back trajectories of three specific "blood" rain events in Europe to dust events in Northern Africa (Wood, 2016).

The HYSPLIT model has been used to map dust storms in China; they then overlaid the back trajectories on satellite imagery to see which circuit overlapped with dust plumes (Yan et al., 2015 and Wood 2016). Apart from the HYSPLIT model, other models apply to study surface ozone transport, but it is a more conventional model for investigating pollution transport.

The HYSPLIT model is applied to analyze the backward trajectory of an air parcel from the monitoring sites at the time of an exceedance event. The HYSPLIT model is a trajectory and a dispersion model useful in modeling an air parcel dispersion; It provides visual representations of the air mass's origin at the time of the ozone exceedance. The model runs for the data with an ozone exceedance from August 2 - August 4, 2012.

The HYSPLIT model runs the meteorological conditions model from the North American Mesoscale (12km NAM) as a hybrid sigma pressure, US;03/20/10-present). The NAM meteorological model is one of the significant weather models run by the National Centers for Environmental Prediction (NCEP) for producing weather forecasts and is a high-resolution numerical model (Agastra, 2020). We selected this meteorological model as the input conditions because of its high resolution and because it was the same model used to initialize the EPA's ozone transport study (Wood, 2016) (US Environmental Protection Agency, 2015). We selected an ensemble trajectory model to establish a back trajectory and a vertical motion.

CHAPTER 5

RESULT

5.1 INTRODUCTION

The ozone mixing ratio at the 500 hPa level (5,500 m), shown in figure 3, and the 850 hPa (1,500 m) shown in figure 4 below, both indicate ozone values that are relatively high across the same region. The 500hPa map from 00Z August 2, 2012, to 00Z August 4, 2012, and the 850hPa map at 12Z August 2, 2012 indicate high concentrations of ozone in that day at both levels. This is to verify if ozone is expelled from the stratosphere via the 500 hPa level into the lower troposphere (850 hPa) region. Therefore, air flow or wind direction from the 500 hPa will be an indication of stratosphere ozone. It has been demonstrated that the Ozone concentrations was high on that day in Wichita with the data from both the 500 hPa map and 850 hPa map. But the NCAR dataset did not indicate the ozone path. To this end, we employed the HYSPLIT to determine the wind direction. The HYSPLIT trajectory showed the wind direction from Texas, Oklahoma, and Missouri on August 2, 2012, and on August 4, 2012, the wind trajectory was majorly from Texas and Oklahoma according to the trajectory path. Nevertheless, from a public health standpoint, a little increase in ozone concentration impacts people's health.

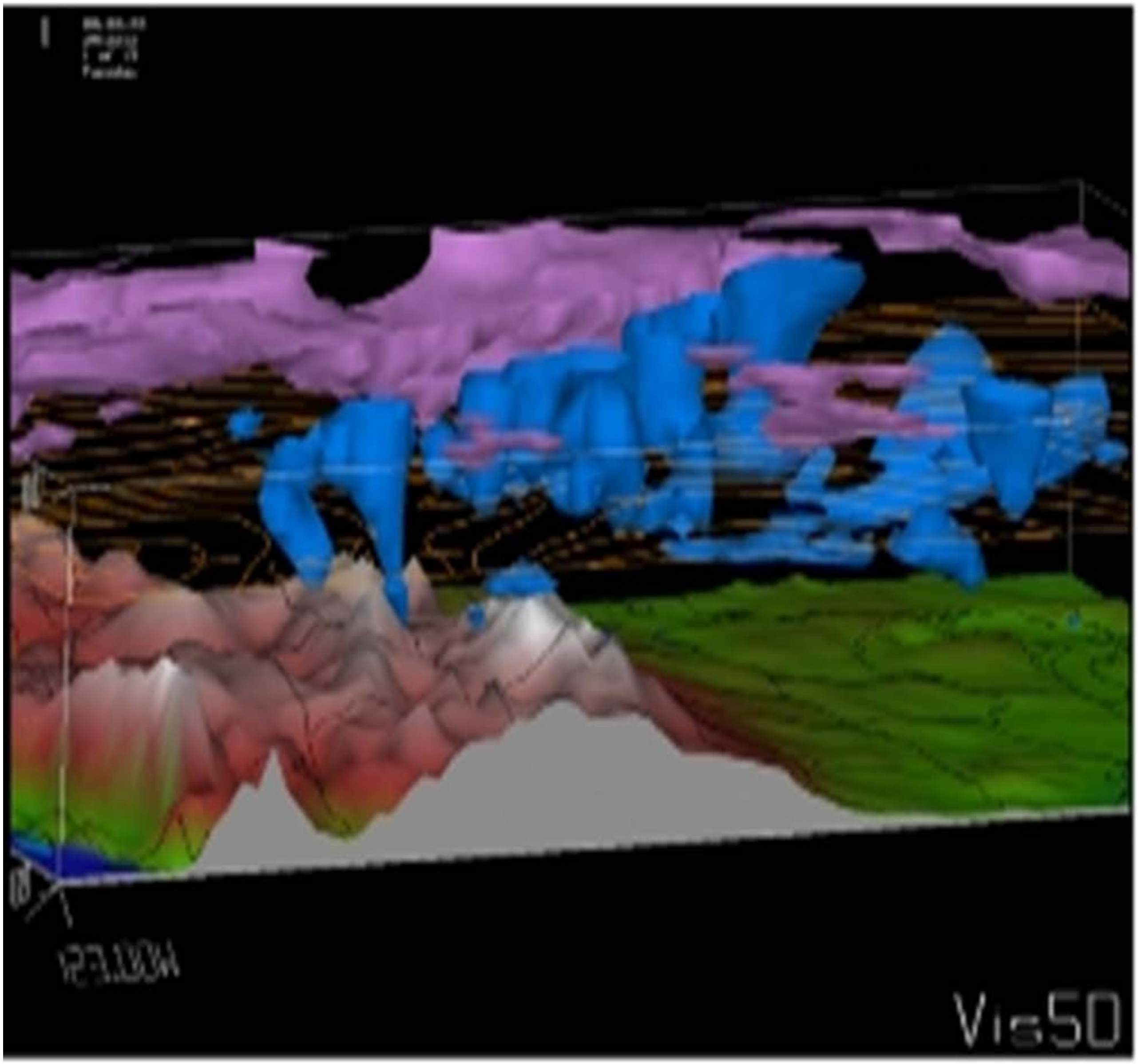

Figure 2. A 3-D representation of the atmosphere over the western and central US, from the surface to 300 hPa level, cloud mixing ratio > .15 grams H2O to Kg (kilogram) of air are shown in blue, the threshold of ozone mixing ration > 140 parts per billion by mass shown in purple which exceeds the EPA limit which is 75 parts per billion. The topography show state boundaries are shown in green and lavender color. The lower left portion of the domain is latitude 34 North and longitude 123.00 West.

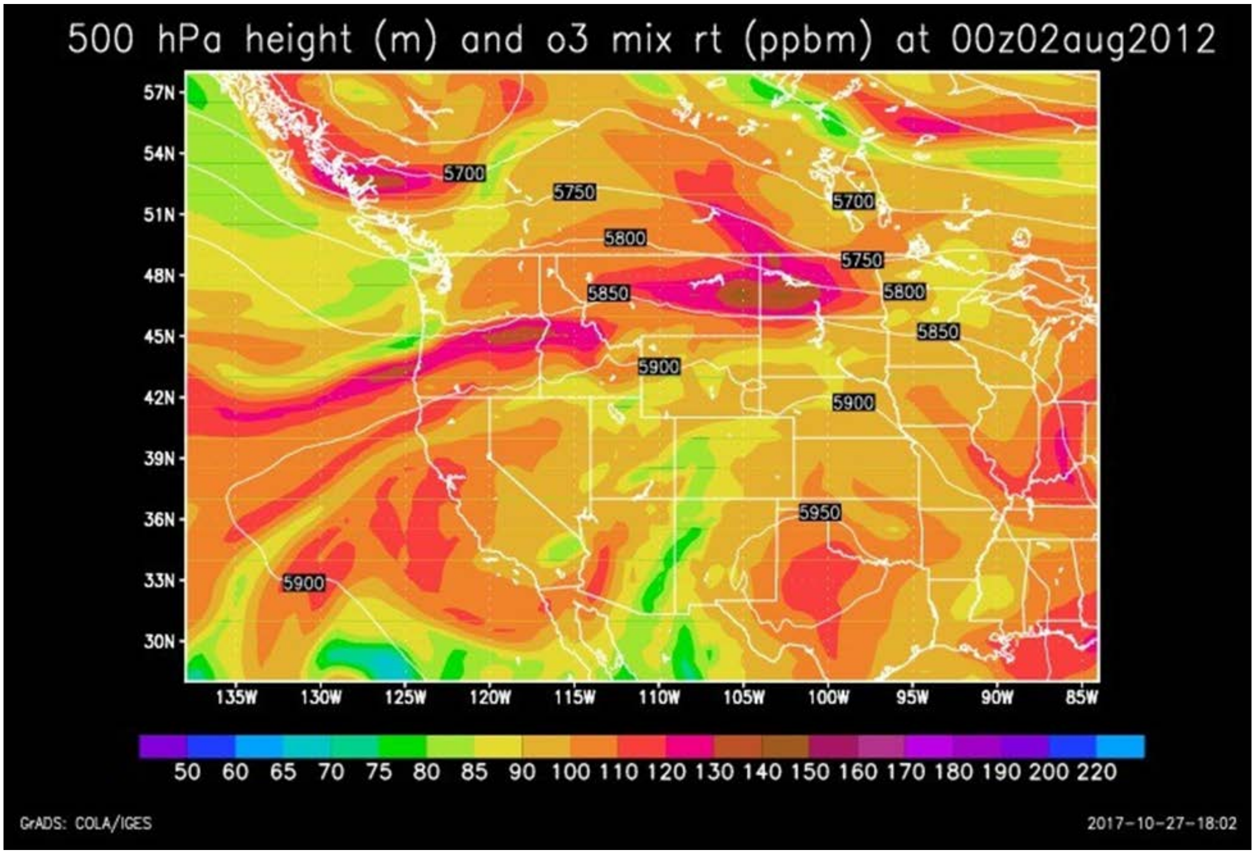

Figure 3. Ozone mixing ratio at 500 hPa. The 500 hPa map shows the ozone values that are relatively high across the same region. The shape of the maximal region of 500hPa ozone seems to be like, which might result from the tropopause folding.

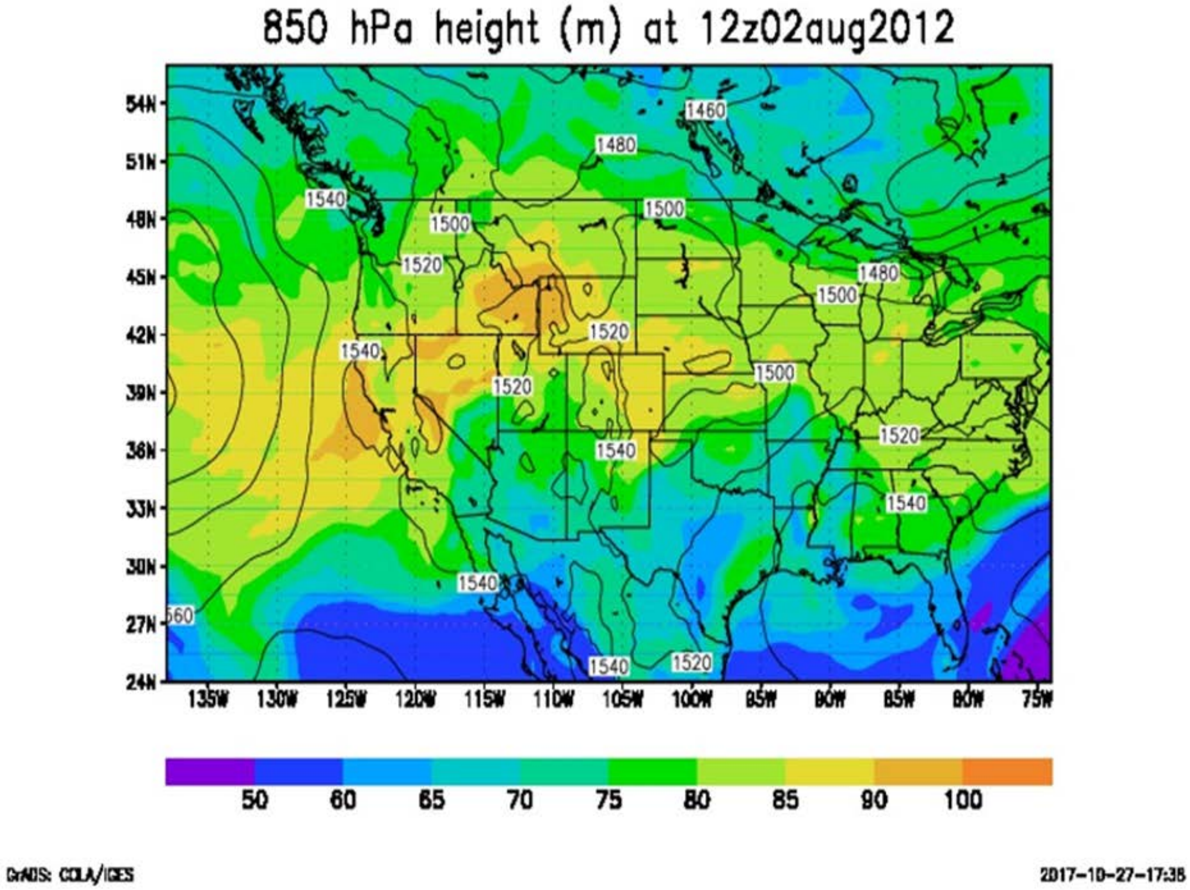

Figure 4. Ozone mixing ratio at 850 hPa, in parts per billion by mass (ppbm). 850 hPa is approximately 1500m above sea level.

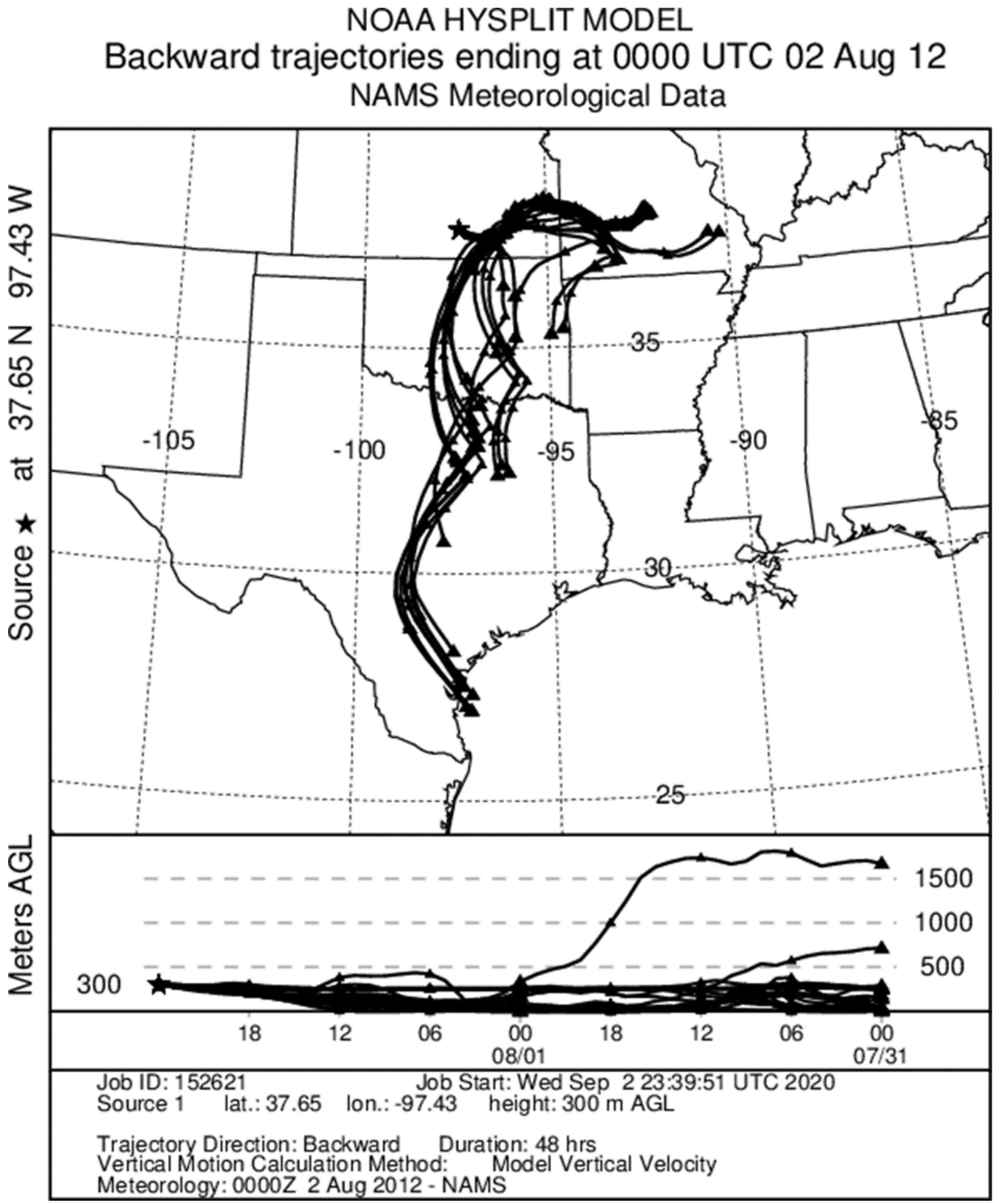

Figure 5. The backward trajectory is ending at 00 UTC August 2, 2012, at 300m AGL for Wichita, Kansas. These were showing the pathway of wind direction to Wichita.

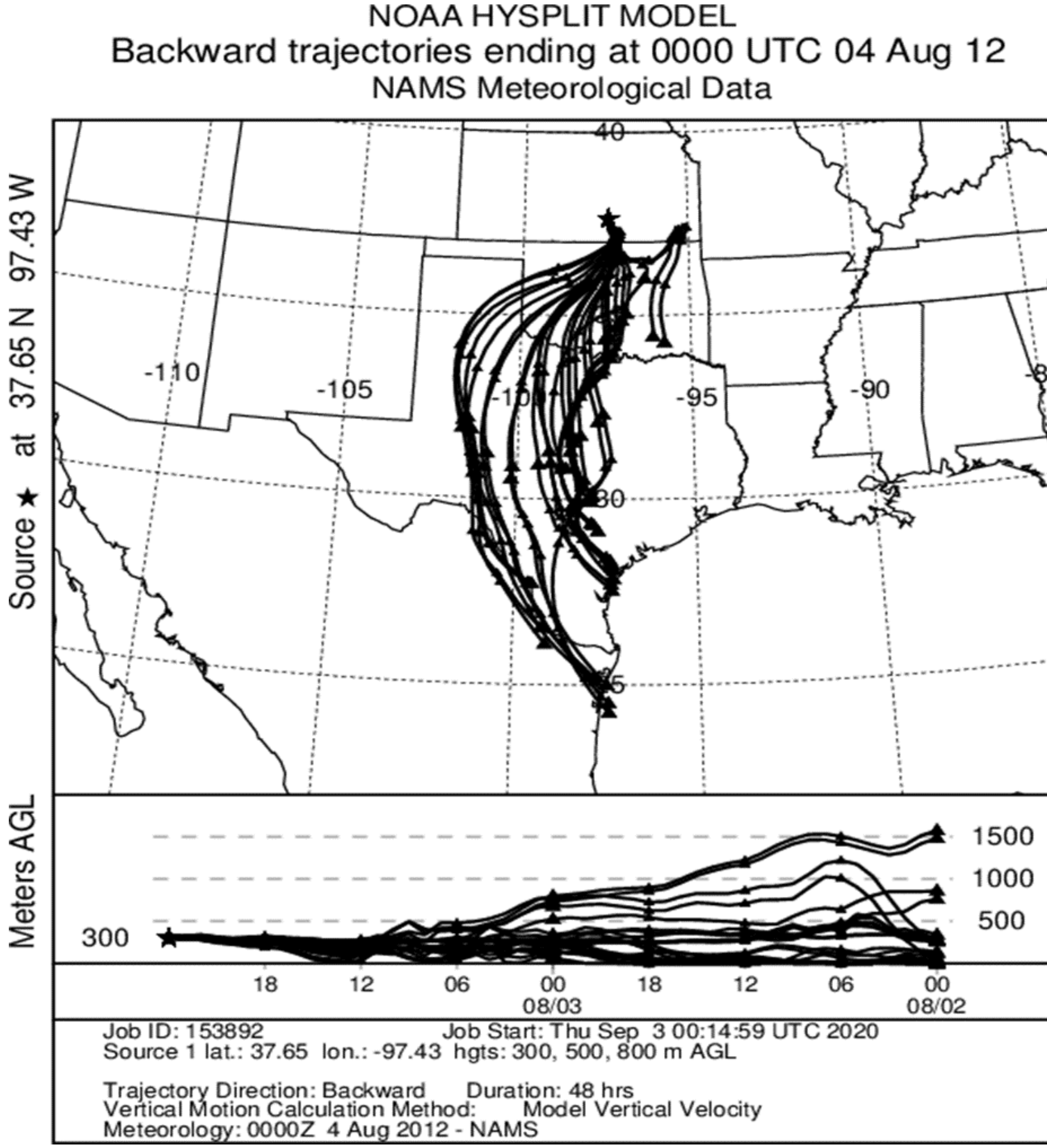

Figure 6. The backward trajectory is ending at 00 UTC August 4, 2012, at 300m, 500m, 800m AGL for Wichita, Kansas.

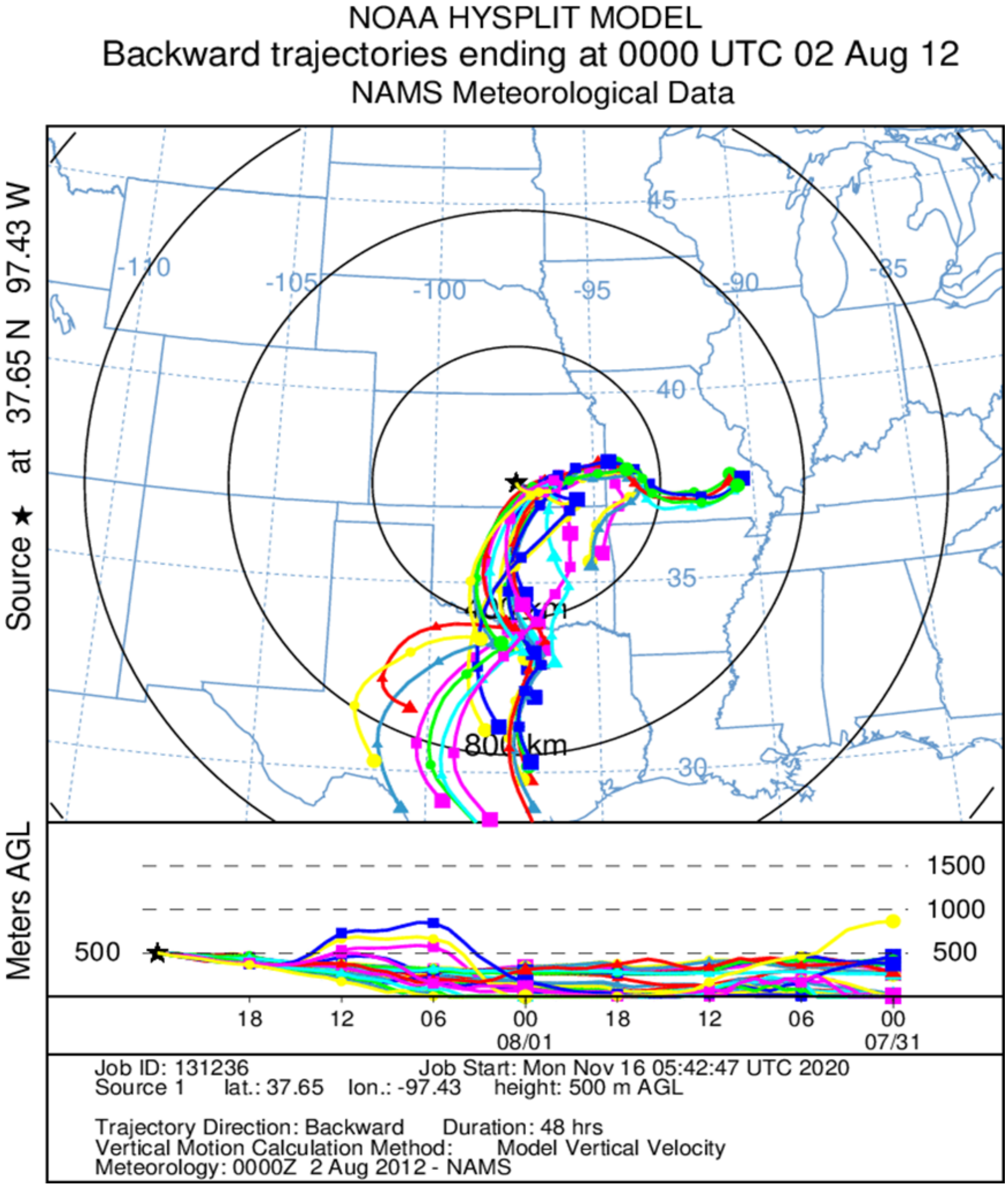

Figure 7. The backward trajectory is ending at 00 UTC August 2, 2012, at 500m AGL for Wichita, Kansas.

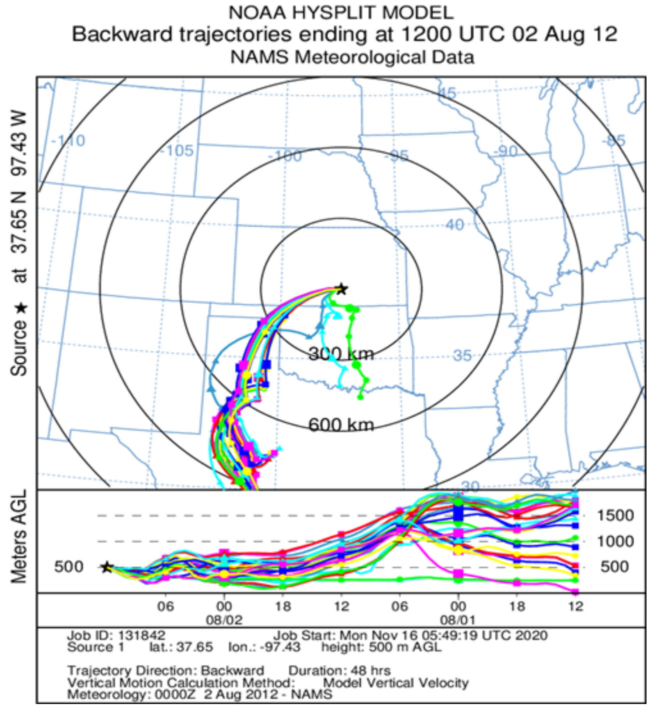

Figure 8. The backward trajectory is ending at 1200 UTC August 2, 2012, at 500m AGL for Wichita, Kansas.

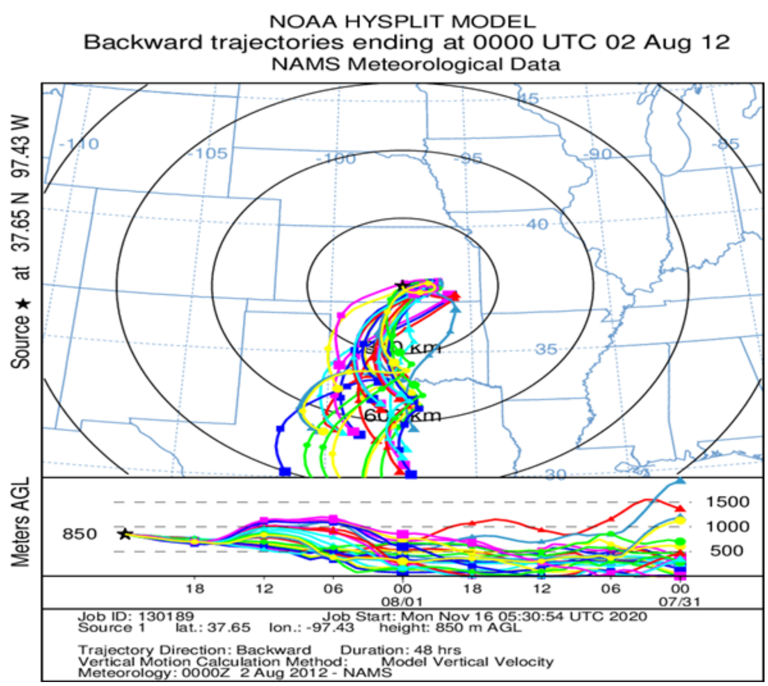

Figure 9. The backward trajectory is ending at 00 UTC August 2, 2012, at 850m AGL for Wichita, Kansas.

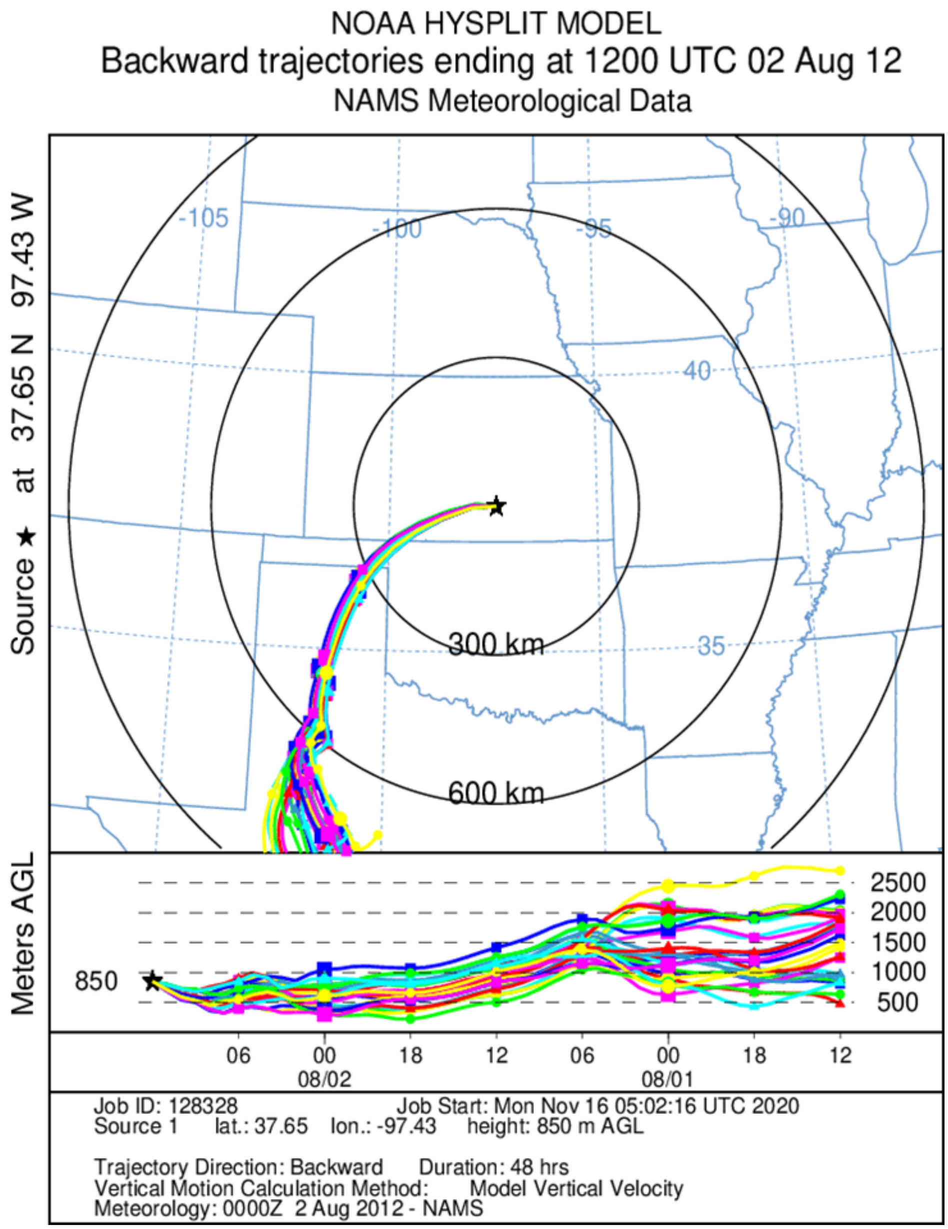

Figure 10. The backward trajectory is ending at 00 UTC August 2, 2012, at 850m AGL for Wichita, Kansas.

CHAPTER 6

EVIDENCE OF OZONE

6.1 DISCUSSION

The color bar in figures 3,4 indicates the range of ozone in ppb (part per billion). From the investigation of the result, it was a shred of evidence that the ozone ranges from the color bar are over the EPA (Environmental Protection Agent) 75ppb limit. Ozone concentration exceeded 75ppb in Texas, closer to the Gulf of Mexico, Oklahoma, Arkansas, Missouri is where the direction of trajectories finds its way to Wichita.

Furthermore, we suspect the troposphere's ozone was not stratospheric ozone, but ozone moved into Wichita from Texas. The trajectory did not indicate wind coming from the Rocky Mountains into Wichita to suggest any stratosphere transport.

However, the tongue-like structure (tongue-like structure represents the tropopause) is in the Rocky Mountains area. So, any wind from that locality could have suggested stratosphere ozone transported into Wichita. Instead, the direction of the wind trajectory was coming from Missouri and Texas.

6.2 CONCLUSION AND SUMMARY

Wind can result in atmospheric motion that carries around various chemicals like ozone. Just as the trajectory indicated in the HYSPLIT, when this chemical moves around; they obey the gas law equation whereby they bump into each other to create other compounds in the atmosphere, which result in the chemistry of ozone and other substance; through a complicated reaction from sunlight and the friction from the boundary layer. The wind can transport ozone from a source to another region. If the wind lacks the energy to remove this chemical, ozone can be trapped in the source area, which becomes detrimental to human health when found in high concentration (Naja et al., (2002)). According to Van de Weil (2002b), at night, stabilizing radiative cooling of the surface is competing with wind shear to generate turbulence in the mixing ratio of ozone. The relative magnitude of the wind will determine the presence or absence of turbulence in the atmosphere. Therefore, turbulence is externally driven by the incoming longwave radiation at the top of the boundary layer (contribution or absence of low-level clouds) and by the synoptic pressure gradient (Van de Wiel et al. 2002b; Svensson et al. 2011), (Stohl et al., 1999). However, a stable boundary layer typically operates at night when the turbulence is weak or virtually absent. When the boundary layer is stable, the ozone's precursors are trapped at the lower boundary region (Naja et al., 2002). The behavior of the boundary layer can drive the chemistry of the ozone precursor to react differently.

6.3 STRENGTH, LIMITATION AND FUTURE RESEARCH WORK

HYSPLIT is a software package that establishes high air pollution levels at a given location and the cause of the transport of air contaminants from its origin of production. HYSPLIT's back trajectories combine with satellite images (NASA's MODIS satellites) that give insight into the origin of high air pollution levels caused by local air pollution sources or whether an air pollution problem was transported by the wind. The HYSPLIT is analyzing backward trajectories over some time. HYSPLIT shows the geographic origin of pathways associated with concentrations of polluted air pathways. However, the HYSPLIT model cannot account for secondary chemical reactions. Therefore, HYSPLIT relies on the input meteorological data's resolution, which can have a rough temporal and spatial resolution. Users should evaluate results carefully in areas with complex terrain.

Here are some brief comments concerning how to obtain the software for use. Use the display system (READY) web site to install HYSPLIT on Windows, Mac, or Linux operating system applications, graphical user interface, or automated through scripts ('PySPLIT' package in Python, 'open-air' and 'split-r' packages in R). HYSPLIT developers offer annual training on the installation, configuration, and use of the modeling system and its applications (https://www.ready.noaa.gov/index.php).

The HYSPLIT model is run interactively on Real-Time Environmental Applications. Therefore, it is necessary to monitor the level of ozone, especially how much of the stratospheric ozone finds its way into the troposphere, and Wichita is known for this terrible air period. It essential for future work to trace the stratospheric ozone in Wichita's troposphere, on the trajectory of ozone migration into Wichita, and the area of ozone production concerning human health (Stohl et al., 2003).

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