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A Systems Engineering Approach to Analyzing Weather Input Sensitivities of the Joint Precision Air Drop System

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THESIS

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AFIT/GSE/ENY/07J-01

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THESIS

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Abstract

The United States Air Force is partnering with the United States Army as well as allied nations to develop a revolutionary advance in logistical support known as the Joint Precision Air Drop System (JPADS). The focus of this study is to develop a process to quantitatively analyze system sensitivities to various types of weather inputs and the corresponding effect on system accuracy. Weather balloons were used to provide representative "truth" to which forecast weather could be compared. Each data type was fed into the JPADS Mission Planner to produce navigation points which could then be compared statistically. The process was tested on a limited data set to provide a first look at the variables of forecast resolution and "lead-time." Initial results indicate best system accuracy is achieved for lowest forecast resolution (i.e., 45 km vs. 5 km data) and shortest lead-time (i.e., <12 hrs vs. >12 hrs). This result will not only allow for better accuracy of JPADS, but also reduce bandwidth and transmission time necessary to send weather forecast data to the warfighter.

Acknowledgements

Only one name goes on the front of this thesis, but it could not have been written if not for the efforts and inputs of many people. First, I wish to thank the team of Lt Col Steven Fiorino and Mr Ron Lee, my thesis advisor and sponsor respectively. They've been working this project since the beginning and shared an enormous enthusiasm that was truly infectious. I can honestly say that they made this experience fun! I also wish to express my gratitude to Dr David Jacques for bringing me and this thesis into the Systems Engineering program as a package deal, then letting me run with it.

I am also greatly indebted to one of AFIT's previous graduates, Capt Ryan Eggert of the Air Force Research Laboratory's Information Directorate, Advanced Architecture and Integration Branch. Capt Eggert's branch is working on their own piece of the JPADS pie known as WICID. His programming skills were invaluable and provided the means to greatly increase both the speed and accuracy of data preparation for this study. There was also Mr Bob Holt at Planning System Inc (PSI) and Mr Thomas Fill at Draper Labs. Both of whom fielded a whole host of questions about the inner working of the Mission Planner. Without the efforts of Ms Mary Bedrick, AFWA Det 3, there would have been nothing to study. She patiently answered (and sometimes re-answered) my weather questions. Finally, my many thanks to my AFIT instructors, like Maj Sam Wright and Lt Col Mark Abramson who helped push back the darkness with the light of understanding.

Thank God, it is done!

D. Gemas

Table of Contents

Page

Page

Page

List of Figures

Figures	Page

Figures Page

A SYSTEMS ENGINEERING APPROACH TO ANALYZING WEATHER INPUT SENSITIVITIES OF THE JOINT PRECISION AIR DROP SYSTEM

I. Introduction

Background

In the modern world of precision engagement with weapons such as the Joint Direct Attack Munition (JDAM) allowing for accuracy measured in feet, the airdrop community has had to soldier on with low precision tactics and techniques that would be recognizable to their Vietnam era counterparts. The Joint Precision Air Drop System (JPADS) is a family-of-systems developed to bring the sort of precision capability found in Global Positioning System (GPS) guided munitions to the airlift community. As such, JPADS is often touted as “the JDAM for logistics.”

The purpose of this thesis is to investigate the impact of weather data inputs on the accuracy of JPADS, specifically the JPADS Mission Planner (JPADS-MP) and the navigation outputs it creates from this weather data. Despite the conceptual similarities between JDAM and JPADS, the airdrop mission poses problems for accuracy not faced in the precision guided munition mission. A JDAM class munition falls at high velocity through the atmosphere and, while guided, still follows a relatively ballistic trajectory. As such, the precision of JDAM type munitions is not greatly affected by the weather they pass through between the launching aircraft and their target. The JPADS chute loads are quite different as they truly do fly as a paraglider. Since they are unpowered, proper energy management during their decent is critical in hitting their designated Point-of-Impact (PI). In order to achieve the desired level of precision, a Guided Parachute requires knowledge of the state of the atmosphere in which it will fly. This thesis examines the current methods used for weather data ingestion by JPADS and determines best practices for the *as-is* system. It will conclude with recommendations for further research to develop an improved *to-be* system.

Scope

Even as this thesis is being written, JPADS is evolving. At present, it is undergoing the Joint Military User Assessment stage of its Advanced Concept Technology Demonstration (ACTD) testing program at the US Army's Yuma Proving Ground (YPG). Despite the continued evolution, JPADS is already operating in the combat theatre. The fact that JPADS is already in use serves to focus the domain of this thesis. This research is the product of techniques from weather forecasting, operations research, and systems engineering. Any one of these fields can find a rich source of problems for study in the JPADS program. However, there is a pressing, operational question at hand. As the system stands today, in the field, how do we make it as accurate and precise as possible? Other organizations are already pursuing studies of the Guidance, Navigation, and Control algorithms for JPADS. That leaves the question of weather impacts.

Problem Statement

Airdrop operators require an evaluation of the sensitivity of the JPADS-MP to weather inputs. To quantify this sensitivity, it is necessary to first identify what weather products are used by JPADS-MP and what they are used for. To achieve a manageable scope, this study will focus on two weather products usable by the JPADS-MP: Air Force Weather Agency (AFWA) Forecasts and Weather Balloons. The immediate goal is to statistically compare the various types of forecasts generated by AFWA to actual weather sampled by weather balloons and thus determine the best operational practice. Of even greater value, though, is the process that will be developed to achieve this goal, as it will continue to be useful to the program as an analytical process beyond this initial research.

Research Objectives, Questions, and Hypotheses

Research Objective.

The objective of this study is to analyze the weather sensitivities of the Joint Precision Air Drop System. To do this requires the development of a standardized, statistically sound, method of comparing weather inputs to the JPADS-MP. This research will then use this process to perform an initial analysis to answer the Research Question.

Research Question.

This research will perform an initial analysis of AFWA weather forecasts to determine which, if any, provide better planning accuracy for the airdrop mission when used as input to the JPADS-MP.

Investigative Questions.

1. How does weather affect JPADS? (i.e., how does the JPADS-MP ingest and use weather data? What are the outputs?)
2. How does the JPADS-MP use weather data to generate navigation outputs?

3. How can the navigation outputs from the JPADS-MP be converted to a statistically comparable format?
4. What different types of AFWA forecasts are available?
5. How are weather balloons made available to the JPADS-MP?
6. What statistical tests and tools can be used to analyze the weather sensitivities of JPADS?

Hypotheses.

A key objective of this study is to apply statistics in order to get a quantitative understanding of how JPADS is sensitive to weather inputs. As previously mentioned, JPADS is already operating, both in test and in the field, and is doing so with certain qualitative assumptions about the best practices to use regarding weather inputs. JPADS has already made great strides in accuracy, but more is desired. To get there, qualitative assumptions must give way to quantitative results.

The statistical tests used in this study are relatively simple. In general, the Null Hypothesis (H_0) will be that the given distribution cannot be rejected; while the Alternate Hypothesis (H_a) will be that the given distribution is rejected. All statistical tests in this study will be performed at $\alpha = 0.05$.

Methodology in Brief

A standardized mission will be used in the JPADS-MP, with the different weather products being used to generate navigation outputs. These outputs will then be converted into a common Northing vs. Easting error format which is functionally like the Miss Distance charts used by the JPADS Guided Parachute systems. The data will then be subjected to statistical examination to determine Goodness-of-Fit for Bivariate Normality (a typical distribution for this type of data). Finally, the means and variances of the different data groups were compared to identify the best weather forecast type for use.

Document Structure

Chapter 2 is a literature review which will provide a more in depth discussion of the topics introduced in Chapter 1. The chapter will begin with an abbreviated history of airdrop then progress to a brief description of the JPADS system, as well as provide some insight into weather forecasting and weather products used by JPADS-MP. Chapter 3 details the means by which the research was accomplished. It includes further information on how the weather data was converted into a useful format for statistical analysis as well as the details of that analysis. Chapter 4 reports the results of the analysis and Chapter 5 provides a summary of the overall research effort as well as presents avenues for further research.

Limitations

The research documented in this thesis is limited to the analysis of historical data rather than a fully designed original experiment. As such, the analysis in this research must use data which was intended for other purposes. In this case, not all potentially available forecasts were recorded. While there are sufficient data points to extract statistical significance, care must be taken in interpreting the results so as not to over generalize beyond what the data supports.

The weather balloons that were used as a basis of comparison for the forecast data were, of course, actually launched to support the aircraft operations of the JPADS ACTD. This makes it necessary to check the data for unanticipated correlations. Additionally, it is worth noting that the primary research question, i.e. the accuracy of various forecast products, was originally raised by AFWA Det 3. It was decided to use the JPADS-MP as an analysis tool rather than analyze the various weather data products directly. This indirect method was chosen for two reasons. First, the JPADS-MP must perform an internal analysis in order to generate navigational outputs; and second by using the actual mission planning tool the operators use, the warfighter is assured of a result with immediate operational application.

Finally, all forecast data used for this thesis was collected for YPG and used the Penn State University/National Center for Atmospheric Research Mesoscale Model 5 (MM5) forecast model. This analysis will need to be reaccomplished when AFWA changes from MM5 to the Weather Research and Forecasting (WRF) model. Time limitations prevented attempting to gather data from areas other than YPG. It is therefore worthwhile to use caution in applying the results of this research to other locales before additional data can be reviewed. The methodology used in this thesis will allow for such additional analysis with ease. This is an advantage of using the JPADS-MP as an analysis tool.

II. Literature Review

Overview

The Joint Precision Air Drop System is intended to address several recognized capability gaps. It is a family of systems that includes, but is not limited to, the JPADS Fly-Away Kit and several candidate guided parachute systems. This chapter will begin with a brief discussion of the historical environment that led to JPADS. It will then progress to a description of the systems that comprise JPADS. This will be cursory as JPADS is well covered in other documents and is not the actual focus of this thesis. Attention will be given to aspects of the JPADS-MP which were of specific use in this thesis. The chapter will conclude with a review of the weather data types and formats used in this research.

Historical Background

On 16 January, 1784, an American living abroad in France penned a letter to a friend concerning a revolutionary technology he had recently observed. The technology in question was a balloon capable of lifting two men into the air. This American saw more than a mere curiosity in the balloon. In fact, he had an extraordinarily prescient vision of what would stem from the invention.

On that day he wrote:

> …where is the prince who can afford so to cover his country with troops for its defense, as that ten thousand men descending from the clouds might not in many places do an infinite deal of mischief, before a force could be brought together to repel them?

The writer of this letter was Benjamin Franklin. On 10 September, 1944, more than 160 years later, a copy of this quote was kept on the desk of another American located in England. This American was Lieutenant General Lewis H. Brereton and on that day in September, he was responsible for planning Operation MARKET – the allied airborne invasion of Holland (11:122).

Operation MARKET-GARDEN was a combined airborne and land based invasion. The First Allied Airborne Army was to drop in Holland and hold key bridges along the route to and across the Rhine. This was Operation MARKET. The British XXX Corps armored unit would drive up a narrow corridor of advance, relieving the airborne units as it went, until it crossed the Rhine. This was Operation GARDEN. If successful, it could have brought about an early end to the war. However, this was not to be.

MARKET-GARDEN would require three major airdrops of troops over three days. Once on the ground, the airborne units would require airdrop resupply. While it would be difficult to identify any one element that led to the failure of MARKET-GARDEN as being decisive, the lack of precision airdrop capability is clearly significant. History records abysmal airdrop accuracy. British airborne troops "watched in despair as thirty-five Stirling bomber-cargo planes dropped supplies everywhere but on the [drop] zones. Of eighty-seven tons of ammunition, food and supplies destined for the men of Arnhem, only twelve tons reached the troops. The remainder, widely scattered to the southwest, fell among the Germans" (11:376). This was not the first or the last time that airdrop would inadvertently supply the enemy rather than the defenders.

Figure 1. C-47's performing low altitude airdrop during Operation MARKET-GARDEN. (Source: http://www.qmfound.com/airborne2.gif)

In April of 1972, the forces of North Vietnam launched their Easter Offensive. It was an effort to overrun South Vietnam in one stroke. The key to South Vietnam was the capitol in Saigon. North Vietnamese forces planned to launch from Cambodia and drive the 90 mile distance down Highway 13 to the capitol. On this highway, approximately 26 miles from the Cambodian border, sat the city of An Loc. It was here that a major battle would ensue that would lead to a two month long siege. By 1972, the majority of American ground units have been withdrawn. The Army of the Republic of South Vietnam (ARVN) had about 6,000 troops in An Loc to defend against more than 35,000 North Vietnamese forces (19). It would fall to American air power to sustain them.

Figure 2. Route of attack on An Loc and surrounding area. (Source: http://www.vnafmamn.com/Valiant_Anloc.html)

Airdrop crews flying in support of the forces on the ground at An Loc faced a lethal curtain of fire including .51 caliber, 37mm, and 57mm Anti Aircraft Artillery (AAA) (9). On 11 May, the first SA-7 Strela, Infrared guided, Man Portable Air Defense (MANPAD) weapon was fired in the vicinity of An Loc (19). Prior to this time, the only technique that afforded an adequate level of precision was the Low Altitude Parachute Extraction System (LAPES). But such tactics proved to be suicidal in face of the anti-air environment around An Loc. The 374th Tactical Airlift Wing had an operating detachment at Tan Son Nhut Air Base and was tasked with the airlift mission for An Loc (9). They developed revolutionary techniques for high altitude airdrop called Ground Radar Aerial Delivery System (GRADS) and Adverse Weather Aerial Delivery System (AWADS). These techniques allowed for improved accuracy for airdrop from above 12,000 feet (2). The 374th also developed new parachute methodology. They devised a method for airdrop using a smaller 26 foot diameter "ring-slot" high velocity parachute than the standard 64 foot diameter G-12 parachute canopy. The ring-slot chute served not to decelerate the load, but to stabilize it at it fell. Careful packaging allowed most types of loads to survive the landing (9).

Figure 3. C-130 performing LAPES cargo drop during the siege of Khe Sahn in 1968. (Source: http://www.qmfound.com/khe_sanh1.jpg)

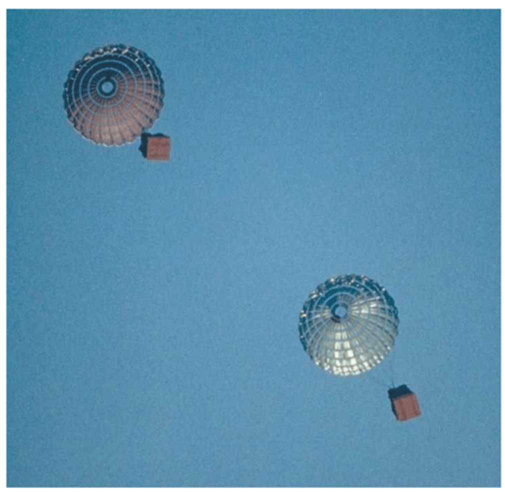


Figure 4. 26' Ring Slot High Velocity Parachutes in flight. (Source: http://www.pioneeraero.com/pop-ups/2-14-IMAGE1.htm)

These new techniques allowed the defenders of An Loc to hold out against the overwhelming odds they faced. The Easter Offensive failed and South Vietnam survived for another three years. For the airdrop forces involved, the final tally of losses were 15 aircrew casualties, numerous wounded aircrew members, 37 aircraft damaged, and the loss of 2 C-123 and 3 C-130E aircraft (19).

The techniques developed by the 374th in the support of An Loc would last far beyond that South East Asian battlefield; more than 30 years later, versions of them are still in use. Airdrop would continue to play a key in military operations all over the world. Operations JUST CAUSE, PROVIDE PROMISE, ALLIED FORCE, ENDURING FREEDOM and others would see airdrop being called on time and again. In the intervening years, the threats faced by the aircrews in Vietnam have only intensified. Reaching an adequate level of precision using conventional techniques now places aircraft and their crews at unacceptably high risk.

The airdrop mission has evolved beyond the 1970's era solution. Methods are needed to operate outside the Weapons Engagement Zone (WEZ) of MANPADS and AAA while reaching totally unprecedented levels of precision. It is additionally desirable that airdrop be able to operate at an offset from the desired PI. Such a capability will allow covert teams to be resupplied via airdrop without their position being highlighted by overflight of the drop aircraft. Fortunately, threats and requirements are not the only thing to have evolved since the 1970's.

Since the advent of the Global Positioning System (GPS) in the 1990's more and more military systems have come to rely upon the navigation technology. The Joint Direct Attack Munition (JDAM) revolutionized precision engagement and has virtually become a household word. It would not take long for the technology that made the JDAM possible to begin transiting to the airdrop world. The stage is finally set for the Joint Precision Airdrop System – JPADS.

Joint Precision Air Drop System Overview

In traditional airdrop, the aircrew must fly the aircraft to a specific point in the sky, known as the Computed Air Release Point (CARP). The CARP is calculated using variables such as payload weight, drop altitude, aircraft velocity vector, wind velocity vector, and location of the intended Point of Impact (PI). One CARP corresponds to one PI. Miss the CARP and you miss the PI. Of course, hitting the CARP does not guarantee that you will hit the PI, but it is the point of maximum likelihood given the quality of the data input into the calculations. This is where weather sensitivities become important to understand.

JPADS is intended to revolutionize how airdrop works. This is about more than bringing GPS precision to CARP calculations though. JPADS is a Family of Systems that allows for precision airdrop to one or more PI from medium to high altitude with the option of significant standoff range (i.e., without the need to fly directly over the PI as in traditional airdrop). These capabilities allow for significant operational flexibility. For example a single aircraft could, in a single airdrop pass, drop loads to different PIs. Alternately, one or more aircraft could drop loads from a broad Launch Acceptability Region (LAR) to hit a single PI from various launch points.

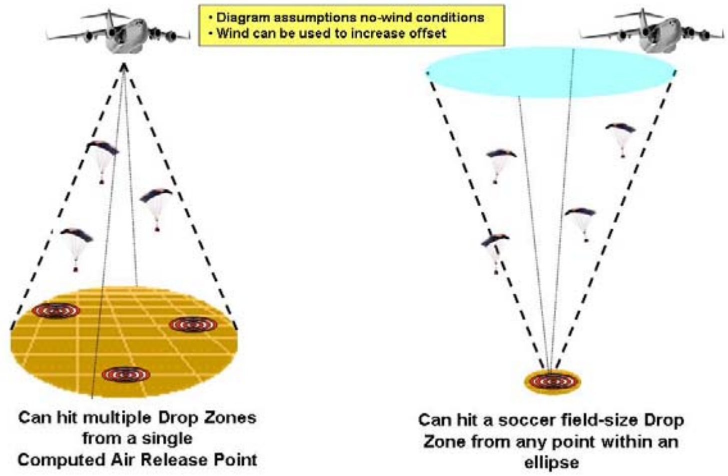


Figure 5. JPADS Guided Parachute drop capabilities (6)

These capabilities are important for tactical advantage as well as safety since JPADS allows aircrews to drop from altitudes and standoff ranges which are safe from enemy surface-to-air threats and terrain. And finally, the ability to drop on a PI without direct over-flight serves to further protect the aircraft and crew as well as to prevent highlighting the location of the PI and the airdrop recipient. Figure 6 shows the JPADS Systems Architecture Operational View (OV-1) Diagram. The OV-1 is a graphic depicting the high-level operational concept of the JPADS architecture.

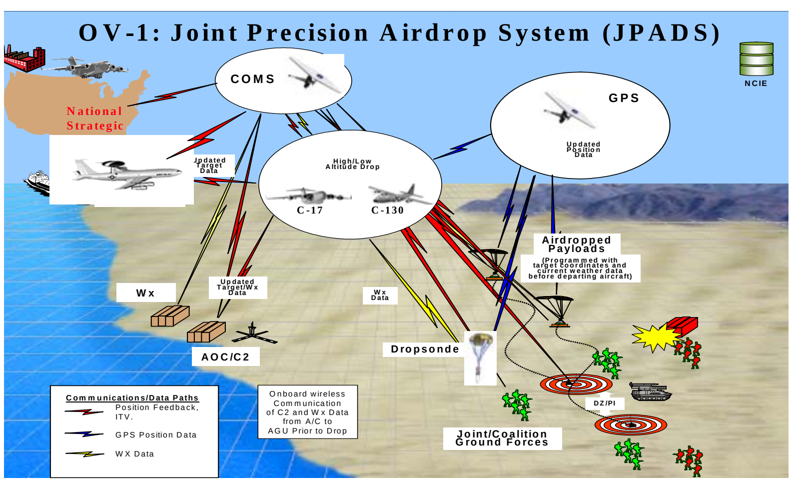


Figure 6. JPADS OV-1: Overall view of system activity. (6)

JPADS Physical Components.

JPADS consists of a roll-on/roll-off system suite for the aircraft, a mission planning element, and a variety of specialized Guided Parachute systems. The Air Force is the program lead for developing the aircraft systems which consists of the JPADS Fly-Away Kit, JPADS Mission Planner (JPADS-MP) software, and Global Positioning System (GPS) Dropsondes. The US Army has responsibility for the development of the Guided Parachute systems.

JPADS Fly-Away Kit.

The JPADS Fly-Away Kit is self-contained unit designed to give roll-on/roll-off JPADS system capability for an airlift platform such as the C-130 or C-17. The kit contains a Precision Air Drop System (PADS) software configured Panasonic CF-29 Toughbook (also known as the PADS Laptop Computer or PLC), a Global Positioning System Retransmission System (GPS – RTS), the Advanced PADS Interface Processor (APIP), and all necessary connections for the system and the aircraft. Figure 7 shows the JPADS Fly-Away Kit in its stowed and unstowed configuration. With its case, the Fly-Away Kit weighs 75 lbs. The Kit is developed by Planning Systems Inc, Draper Labs, and the Forecast Systems Lab of the NOAA (6).

Figure 7. JPADS Fly-Away Kit components. (1)

JPADS Guided Parachute Family.

Presently, several system types are under consideration. Among these are the Affordable Guided Airdrop System (AGAS), the Screamer, and the Sherpa. Each system differs in approach to the guided airdrop problem solution as well as in overall performance capabilities. This section will provide background on each system and how it fits into the JPADS architecture.

Affordable Guided Airdrop System (AGAS).

Developed in joint venture by Vertigo Inc and Capewell, AGAS is a family of systems for precision airdrop of loads from 200 to 10,000 pounds. It is intended to provide high accuracy and precision at low cost by utilizing off the shelf parachutes and rigging components and is essentially a strap-on guidance kit for the standard Container Delivery System (CDS). The AGAS system is compatible with existing inventory parachutes such as the G-12 and the 26' Ring Slot High Velocity Parachute. The heart of the system is the Autonomous Guidance Unit (AGU). The JPADS-MP generates a Wind

Profile which is used to calculate a wind corrected flight trajectory. This trajectory is passed on to the AGAS AGU. The AGU monitors the actual flight path as compared to the nominal flight path. The flight path is then adjusted by "slipping" the parachute control risers. The Figure below displays the AGAS mission profile.

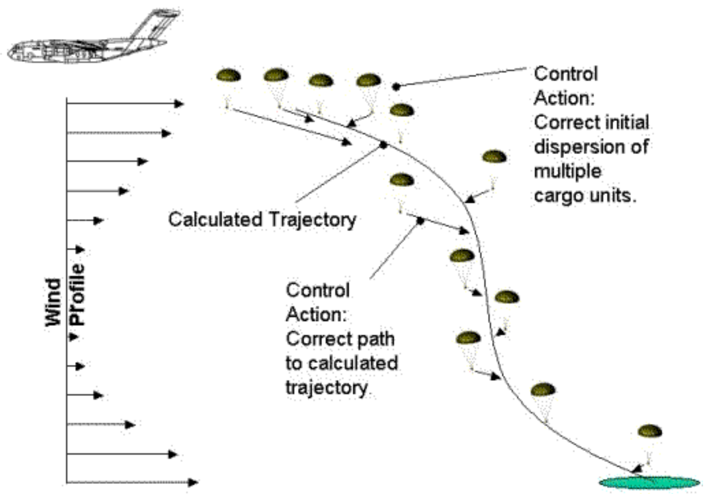


Figure 8. AGAS flight profile with Wind Profile corrections. (Source: http://www.vertigo-inc.com/agas)

In testing, AGAS has proven to be highly accurate, and typically has the smallest Circular Error Probable (CEP) of the candidate systems. However, it also has the least horizontal standoff capability among the candidates at approximately 5 km. AGAS loads typically have a 14-15 minute Total Time Aloft. The following figure shows example AGAS miss distances and their associated CEPs.

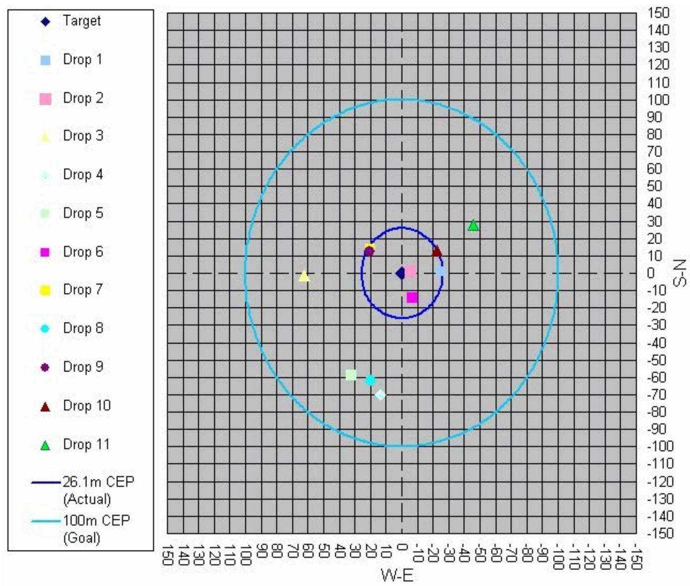


Figure 9. Sample drop score card and CEP achieved by the AGAS Guided Parachute system. (Source: http://www.vertigo-inc.com/agas/cep.jpg)

Sherpa.

The Sherpa guided parachute system is the product of Mist Mobility Integrated System Technology (MMIST). Sherpa is a family of four systems with load capacities ranging from 265 lbs to 2200 lbs. The Sherpa system uses a large Ram Air Parachute (RAP) which gives the system a significant glide range and maneuverability. The RAP affords Sherpa a horizontal standoff range of up to 20 km from a drop altitude of 25,000 feet. A unique feature of Sherpa is the option to provide terminal guidance via a hand control unit. Otherwise, the Sherpa uses an AGU to correct for windage errors with respect to the preplanned trajectory calculated by the JPADS-MP.

Figure 10. MMIST Sherpa prepares to land. (Source: http://www.mmist.ca/Sherpa.asp)

The following chart shows a series of Sherpa 2200 miss distances with associated 100, 200, and 300 m CEPs. Sherpa is a Commercial Off-The-Shelf (COTS) system already in use with US Marine Corps.

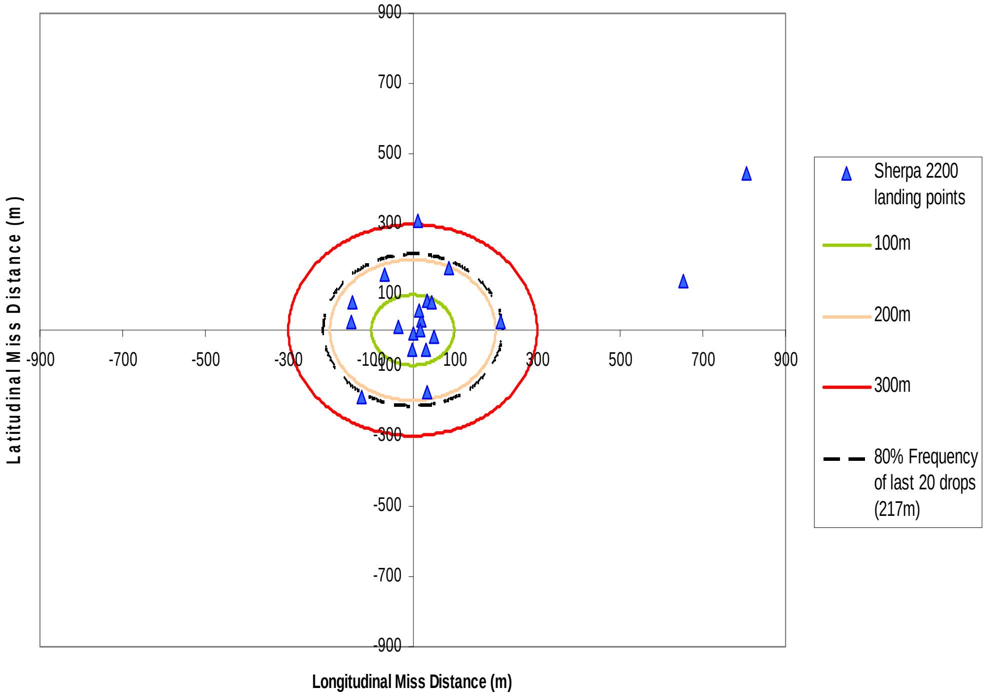


Figure 11. MMIST Sherpa sample drop score card and CEP. (Stoker, 2006)

Screamer.

Strong Enterprises with Robotek Engineering have developed the Screamer Precision Cargo Delivery System. The Screamer is unique in that it uses an undersized Ram Air Drogue (RAD) rather than a full size canopy. The RAD serves to stabilize and decelerate the payload as well provide steering capability. The use of the RAD also allows for a rapid decent from altitude and improved resistance to wind effects. However, due to its small size, the Screamer RAD is incapable of slowing the payload down for landing. This is accomplished by the deployment of one or more standard round, unguided parachutes (typically one or more G-11 parachutes) once the payload nears the surface. Once the recovery chute is deployed, the Screamer is considered to be ballistic, which is to say, at the mercy of the low-altitude winds. The figures below show the phases of Screamer flight, first under the RAD and then moments after the deployment of the Recovery Parachutes.

Figure 12. Phases of Screamer Flight. (17, 10)

As with the other systems, Screamer navigation is accomplished via an AGU which compares its real-time position with a preplanned trajectory using onboard GPS. The

Screamer has a glide ratio of 2.6:1. From a drop altitude of 25,000 feet, it has a standoff distance of about 7.2 miles and has a Total Time Aloft of approximately 8.6 minutes. The following Figure show example miss distances for the Screamer system and its associated CEPs.

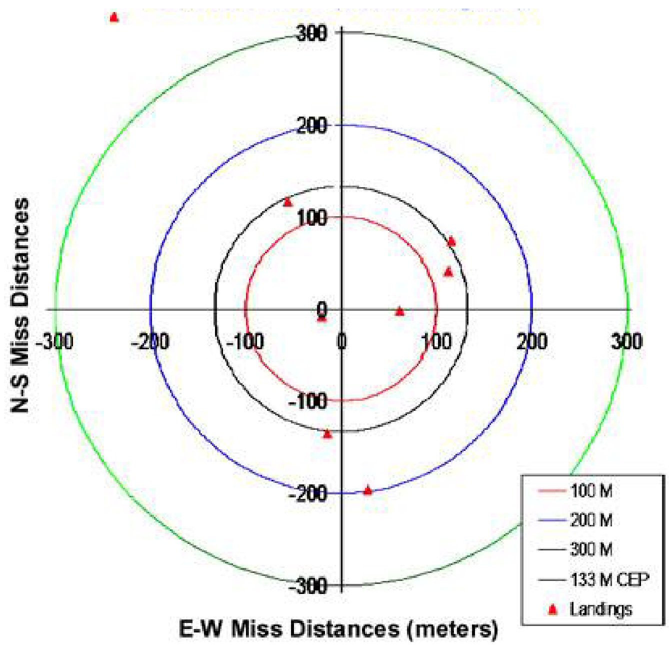


Figure 13. Scream drop score card and CEP. (10)

Joint Precision Airdrop System – Mission Planner (JPADS-MP).

The JPADS-MP is a combination of the PLC and the PADS software. Its ultimate use is to ensure that the cargo arrives at the desired PI. Figure 14 shows the functional design of JPADS as well as the data flow structure.

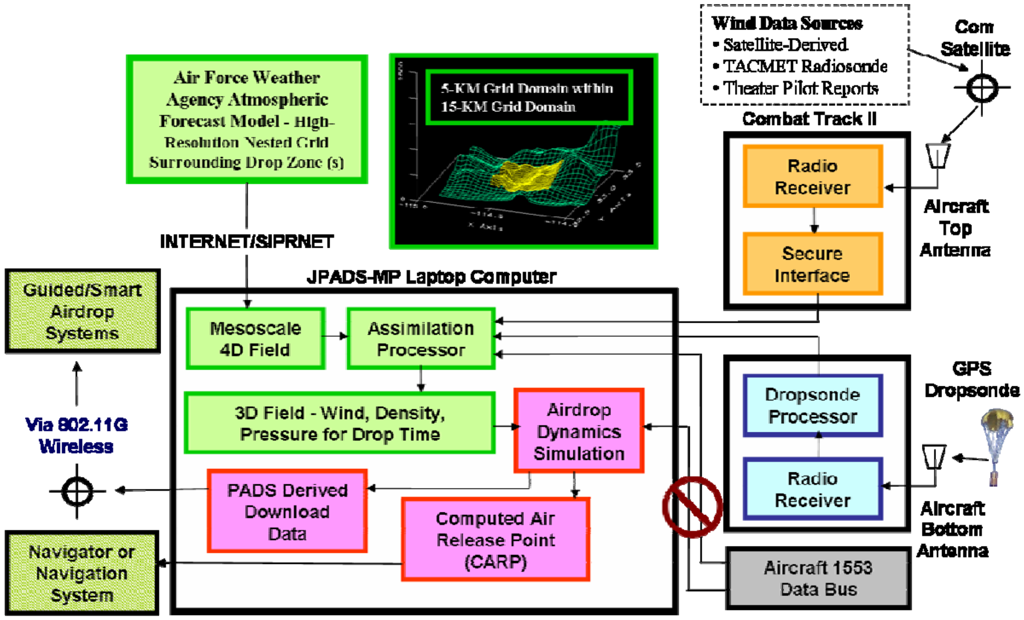


Figure 14. JPADS-MP system layout. (1)

The box at the center of the Figure shows the functions performed by the JPADS-MP. As can be seen, data flows into the JPADS-MP from the GPS dropsonde, Combat Track II messages, NIPRNET/SIPRNET, and from user input. Data flows out of the JPADS-MP to the user and to the Guided Airdrop Systems. A more comprehensive picture comes from the JPADS SV-4 System Functionality Description diagram in Figure 15.

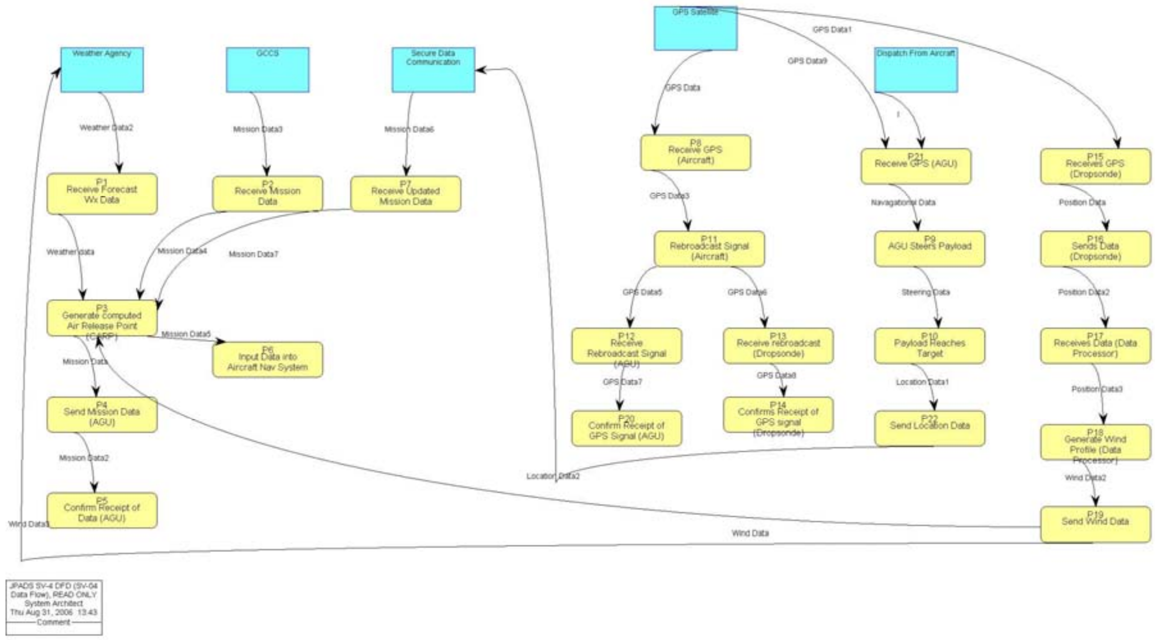


Figure 15. JPADS SV-4, Systems Functionality Description. (6)

These two diagrams (Figures 14 and 15) are important to providing the answer to the first Investigative Question: How does weather affect JPADS? (i.e., how does the JPADS-MP ingest and use weather data? What are the outputs?) The next diagram is a simplified version of the SV-4. All non-weather related items and data flows have been removed. This Systems Engineering product answers where weather enters the system and how that data flows within the system accomplish its functions.

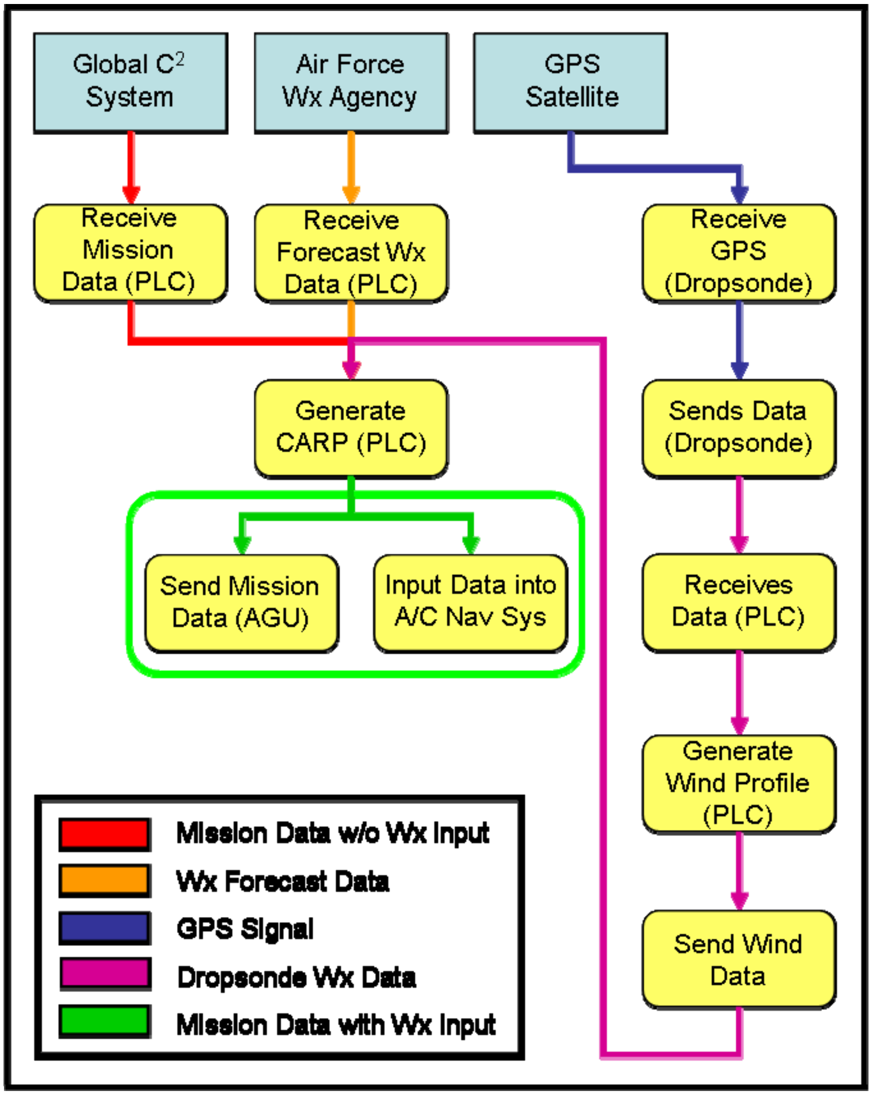


Figure 16. Weather Data Flows within JPADS.

In this color coded, streamlined version of the SV-4, the data flow is easy to follow. Looking at the functions at the bottom of the flow, we find (as one would expect) the AGU and the aircraft navigation system. What stands out as the critical function lies one step above these: Generate CARP – the Computed Air Release Point, a function of the PLC. The flows shown here are the primary ones available to operational users. There are options not shown here. These include Pilot Reports (PIREPS), Ballistic Winds, and

Climatology. However, it turns out that the critical path is the same in all cases. The PADS Laptop Computer (PLC) requires at least two inputs to calculate the CARP: mission data and at least one type of weather data. The next sections will discus these inputs as well as the CARP in more detail.

Air Force Weather Agency (AFWA) Weather Forecasts.

The JPADS-MP uses 4 Dimensional forecast models in order to generate the best CARP solutions. These forecasts are called 4 Dimensional as they include x, y, and z spatial coordinates as well as a temporal coordinate. AFWA generates forecasts for YPG in three levels of resolution: 5km, 15km, and 45km. In 4 Dimensional forecast models, resolution refers to how closely spaced the data weather data points are on the x/y grid plane. Thus, 5km spacing is high resolution, containing much more data than a resolution with 45km spacing of grid points. Obviously, higher resolution means a larger data file, and thus greater band-width for transmission and longer download times.

The 5 and 15km models are run every 12 hours and the 45km model is run every 6 hours. One model run simulates 24 hours of weather. To get a forecast for a given time, say 1200Z, several options are available. The 5 and 15km forecasts are initiated at 0600Z and 1800Z. To get a forecast valid for 1200Z, you could use the model initiated on the current day at 0600 and take the predicted weather conditions 6 hours after model start. An 0600Z start time plus 6 hours lead time equals a valid time of 1200Z. Alternately, the 1800Z start time from the previous day with an 18 hour lead time also results in the desired 1200Z valid time on the current day. If the 45km resolution is considered, five more forecasts (three from the current day and two from the previous) are available to predict the conditions at 1200Z.

A unique aspect of weather forecasting is that models are initiated “dry.” This means that data such as humidity, dew point, and pressure are fed into them, but not information on precipitation or cloud effects. It is left to the model’s weather physics to generate this information. This results in a certain amount of spin-up time being required by the model before it begins to provide realistic forecast results. It is this feature which calls into question how model lead time affects forecast accuracy.

A collection of these forecasts as well as corresponding weather balloon soundings covering the JPADS ACTD test activity from 20 June 2005 to 5 December 2006 has been provided by AFWA Detachment 3 for the purposes of this research. A list of the weather balloons specifically used for this analysis is included in Appendix H. This data is used to determine which forecasts can be used for CARP generation.

Computed Air Release Point (CARP) and Launch Acceptability Region (LAR).

Certainly, one of the keys to precise airdrop is positioning the drop aircraft in the proper position in space with respect to the PI, taking into account the variables of aircraft velocity as well as the wind velocity at each altitude from the drop level down to the ground. This point in space is traditionally known as the Computed Air Release Point (CARP). One of the chief functions of the JPADS-MP is creating a highly accurate CARP. This is accomplished by taking into account aircraft type, altitude, heading, airspeed, position, and ramp-angle, as well as parachute type, load weight, et cetera. To these variables, a final key ingredient is added: the wind profile. While the payloads are guided, they are unpowered and cannot regain kinetic energy once spent. This makes a good knowledge of the air mass they are to fly through critical to hitting the PI. This CARP is then input (by hand) into the drop aircraft navigation system. Although a precise formulation of the CARP is not as critical for Guided Parachute systems, JPADS-MP is also used to improve the accuracy of cheaper, unguided parachute systems such as the High Velocity Container Delivery System (HV-CDS). Thus, operators need the best possible weather estimate to ensure accurate airdrop.

Since the Guided Parachute systems have the energy to fly to the PI from a large area, the JPADS-MP calculates a Launch Acceptability Region (LAR) in addition to the CARP. The LAR is an elliptical region which represents the approximate area in space from which a Guided Parachute system could successfully reach the designated PI given the weather inputs to the JPADS-MP. Mathematically, it is the solution space containing all feasible CARPS for the Guided Parachute systems for a given set of PI coordinates and weather inputs. It is important to note that this region is an approximation intended to give aircrews a good idea of the system limitations. The edge of the LAR should not be considered a precision measurement for drop purposes. To deal with this and other uncontrollable variables (such as the true weather vs. forecast) a safety factor of 11% is subtracted from the LAR ellipse. The safety factor is a user definable option within the JPADS-MP.

Figure 17 shows a comparison of airdrop missions using traditional, non-JPADS planning, as well as JPADS planned guided and unguided drops. Note that for unguided drops, only one CARP is available to hit the PI; while for guided drops an elliptical area defined by an Early, Nominal, and Late CARP (the Launch Acceptability Region) is sufficient to hit the PI.

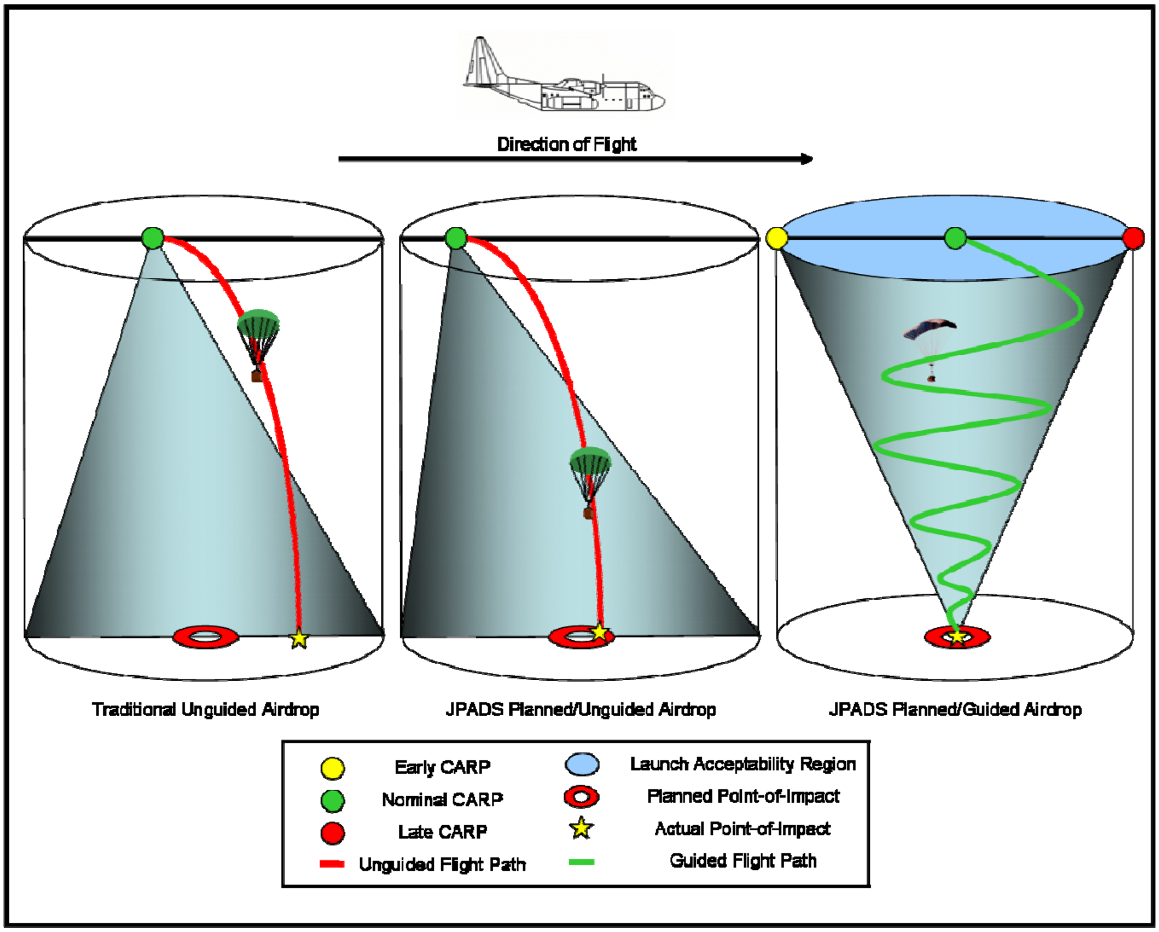


Figure 17. Comparison of Flight Profiles for traditional vs. guided airdrop options.

Screamer Recovery Chute Opening Point (OP).

In addition to the CARP/LAR, a third calculation is made by the JPADS-MP in support of the Screamer Guided Parachute system. Unlike the AGAS and Sherpa, the Screamer requires an additional AGU command beyond the CARP/LAR computation. This is for the recovery chute Opening Point (OP), also called the *pickle-point*. The correct calculation of this point is critical to hitting the PI since the Screamer payload is no longer guided from there. Figure 18 demonstrates the particular case of the Screamer system and its sensitivity to correct weather forecasting. The conic section indicates the volume of space in which the Screamer system has sufficient energy to maneuver to reach the Opening Point (OP) calculated by the JPADS-MP. Once the OP is reached, the Screamer payload is carried to the ground by the low-level winds. As Figure 18 shows, if these winds are correctly forecast, Screamer can hit the PI with high accuracy. Conversely, poor forecasting leads to missing the PI.

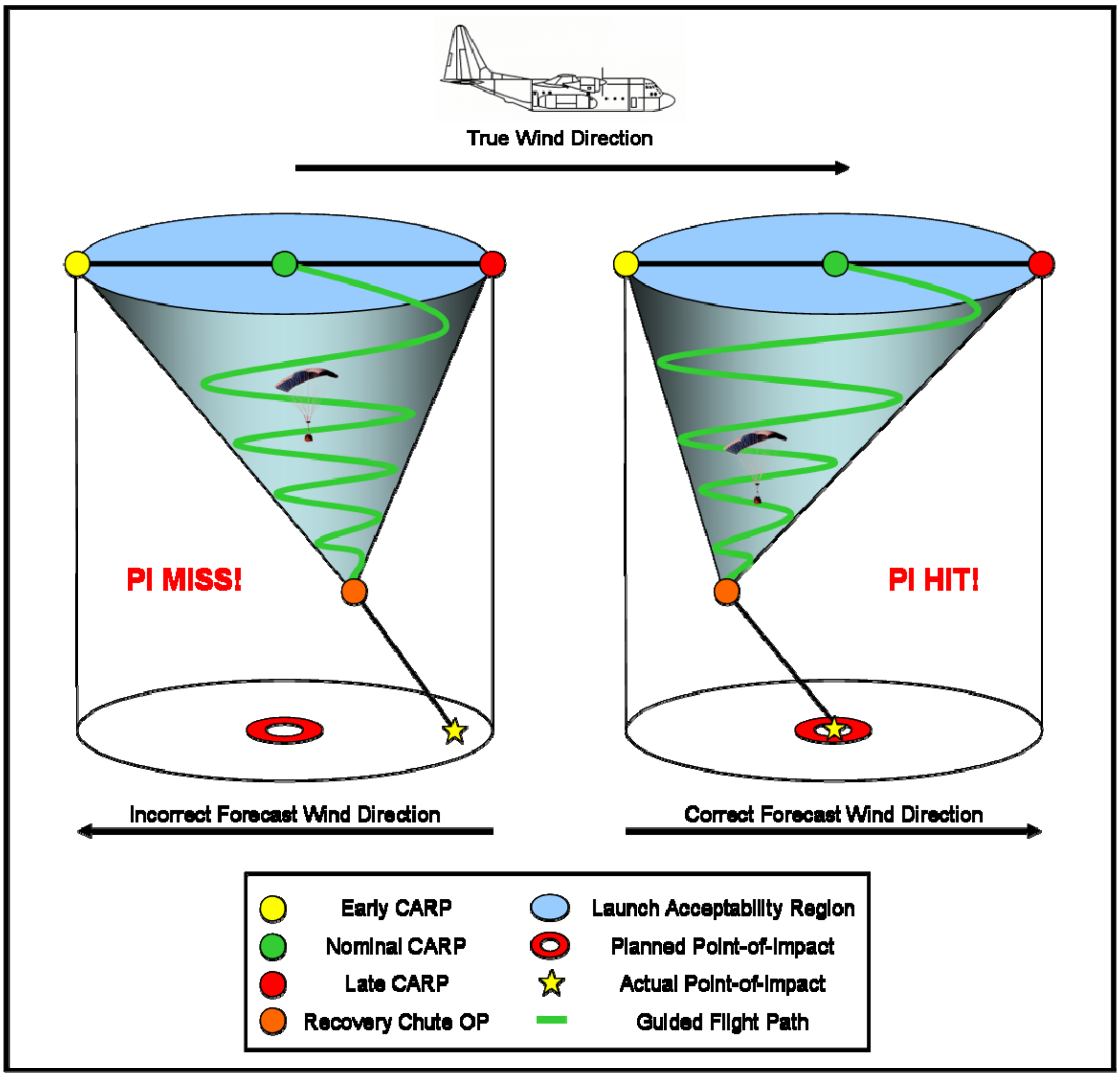


Figure 18. Screamer Flight Profile and weather sensitivities.

GPS Dropsonde.

This is a GPS instrumented unit that falls under parachute at a known velocity (typically 70 fps). The dropsonde is released from an aircraft to gather a sounding of the true weather in close geographical and temporal proximity to the planned airdrop location and time. The weather data gathered from the dropsonde can be integrated in flight with the preflight mission planning forecast to improve the preflight planned CARP/LAR and OP.

A natural assumption is that updating the CARP/LAR and OP generated from pre-mission forecasts with sampled atmospheric data should improve their estimates. There are, however, potential faults in this assumption. First, dropsondes take time – both to fall and for their data to be assimilated into the model. In order to ensure adequate time, combat tactics call for dropsondes to be employed no later than ten minutes prior to the planned airdrop. Since airdrop missions are typically flown at approximately 150 mph, this equates to a minimum difference of more than 25 miles between where the atmosphere was sampled and where the actual drop will occur. It is easily conceivable that a dropsonde could be sampling weather on one side of a mountain ridge and the airdrop take place on the other side in completely different weather conditions. Additionally, in tests, dropsonde data reception becomes unreliable at low altitude – precisely the time when accurate information is most critical.

Finally, there is the afore mentioned 11% factor of safety. This margin of safety is essentially energy in the bank for the on board guidance system to use should it encounter unexpected weather during descent. The question then becomes, is a dropsonde likely to ever dictate moving the LAR more than 11%, particularly considering the other limitations of dropsonde employment? Since dropsondes are a consumable, they add to mission cost as well as complexity.

Initial planning for this study called for an analysis of these questions. However, this was de-scoped from the thesis after consulting with Draper Labs concerning the LAR calculation performed by the JPADS-MP version used in this research. As the JPADS-MP continues to evolve, the calculation of LAR will change significantly rendering any work done valueless.

III. Methodology

Research Strategy

The first challenge with this research was in determining what was meant by weather sensitivity of the JPADS system and how to measure it. The intent was to apply statistical analysis to data, but to what data and how? The obvious answer to the first part of that question was the data recorded by AFWA Det 3 in support of the JPADS ACTD. For each test, a record was kept of the weather balloons launched in support of that day's missions as well as the associated valid weather forecasts. This data covers a period from 20 June 2005 to 5 December 2006. This was a lot of data, over 50 GB worth. The next question is how to analyze it. AFWA Det 3 has already begun looking at a direct, altitude by altitude, comparison between weather balloons and weather forecasts. This research compared the forecast wind velocity (heading and speed) against observed wind velocity for the three different forecast resolutions and various lead times. It was this initial research that prompted this thesis.

The JPADS-MP served as a means for providing an *apples-to-apples* analysis of the weather input options within the context of the Mission Planner, something which would be very useful to the user community. This is possible since the JPADS-MP can perform its navigational computations from either the forecasts alone or the weather balloons alone. This capability allows for the creation of Northing vs. Easting error comparisons, much like the Miss Distance charts for the various Guided Parachute systems shown previously in Chapter 2. To execute this, a standard mission scenario is used for evaluating all input data. The scenario is detailed as follows:

Mission Name: N (for due North Run-In heading)
Drop Aircraft: C-130
Run-In: 360° Magnetic
Weather Reference Point:
YPG Site 16 (Weather Balloon Launch Location)
Lat: N 33 19.800 Lon: W 114 19.800
Elevation: 1421 ft MSL
Drop Altitude: 17500 ft AGL Airspeed: 135 KIAS
Magnetic Variation: 12.346 W (deg)
Total Ramp Load(s): 1
Loads To Drop This Pass: 1
Exit Location: RAMP
Stick Type: Single
Aircraft Altimeter Setting: 29.92 inches Hg
Chute/System Type: Screamer
Total Rigged (All-up) Weight (lbs): 8000
Flight Station (load c.g.): 677
Stick Position: Left
Glide Safety Factor: 0.89
PI: YPG JPADS Center PI
PI Coordinates: N 33 19.612/W 114 22.226
PI Elevation: 1249 ft MSL
Ballistic Chute Type: 2 G11
Steerable Chute Type: 850 Sq-Ft (Screamer 10k System)

This *N* mission was used to generate CARP and OP navigation data from the historical weather data. These were then grouped by resolution for analysis. Analysis was performed in Excel, Matlab, and JMP 6. There are two stages to the analysis; the first compares the three resolutions, and the second compares lead time. The comparison variables are the population mean and variance. To ensure that the N mission was not introducing error, a second mission was tested on the 5 km data set. This *S* mission differed only in the Run-In heading of 180° Magnetic. The results indicated virtually no difference from the CARPs calculated in the N mission. The remainder of this chapter will detail how the N Mission was entered into the JPADS-MP and how the resulting data was captured and evaluated.

JPADS-MP Operation – N Mission

The JPADS-MP is developed by Draper Labs and Planning Systems Inc (PSI), and a complete user's manual is available from them. This discussion will be limited to the aspects of the JPADS-MP that were used in the execution of this research. Appendix G contains a sequence of figures that will provide the reader with sufficient familiarity with the JPADS-MP Graphical User Interface (GUI) to recreate the steps taken in this research. Upon starting the JPADS-MP, the user is presented with the main GUI page as shown in following figure:

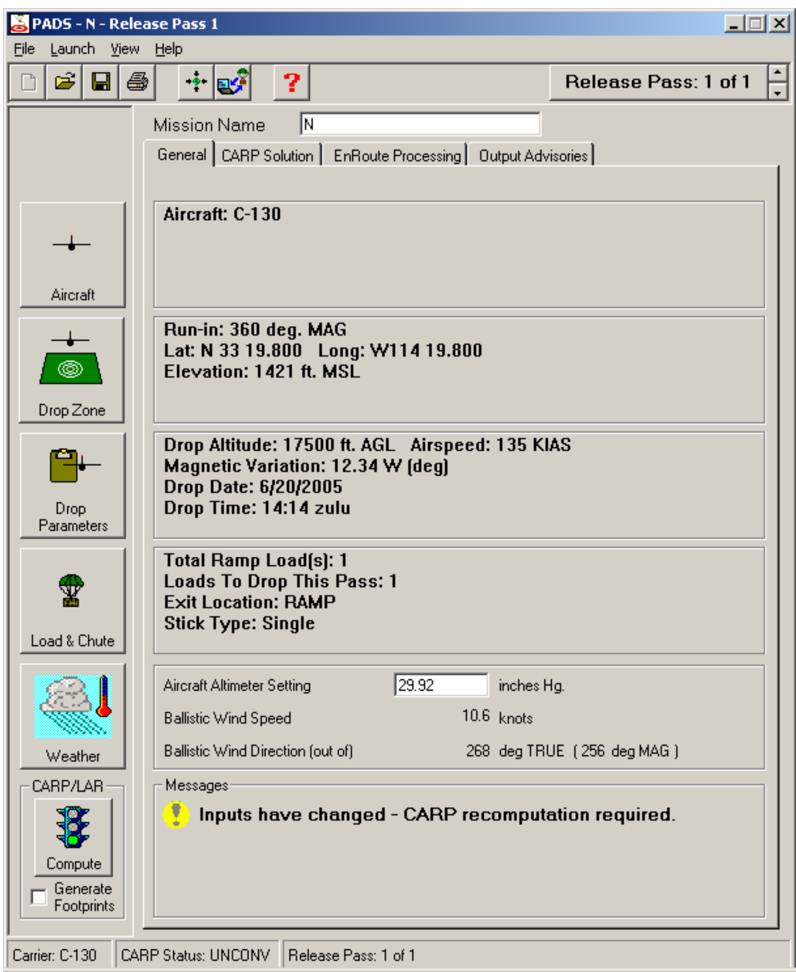


Figure 19. JPADS-MP main GUI.

For this study, the coordinates for Site 16 at YPG are used for the weather forecast reference point as this is the location from which the weather balloons were launched. This representative mission was created using an actual test point from the ACTD program, the only modification being a change in the Run-In heading to a cardinal direction. As a result, the PI is set as being the JPADS Center PI target at YPG, as used in testing. This is located 3.7 km from Site 16. It may have been better for the purposes of this analysis to have set Site 16 to be the PI. Unfortunately, this was realized too late for implementation. However, any error incurred by this is believed to be minimal when considering that the highest weather resolution was 5 km.

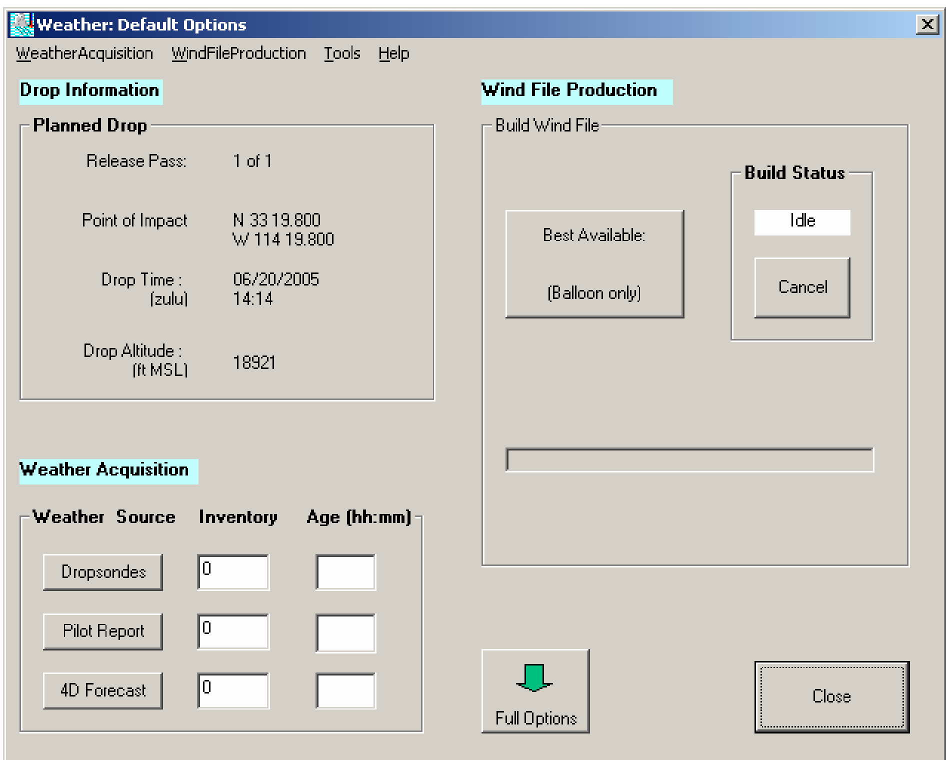


Figure 20. Weather GUI

The *Weather GUI*, shown in Figure 20, is where most of the work in this research was done. The next step is to acquire weather data. This is done by selecting one of the options under the Weather Acquisition section. The options relevant to this research are: Dropsondes, 4D Forecast, Balloon, and Climatology.

The JPADS-MP uses the 4D Forecasts generated by AFWA. These come in a format known as GRidded Information in Binary format (GRIB) files. Once these are downloaded, the *Browse* button is used to point the Weather Source GUI to the location of required GRIB files. Once the appropriate path is specified in the "GRIB Files Location" field, select the "Acquire Forecast" button. This will read the weather forecast into the JPADS-MP Environmental Data folder.

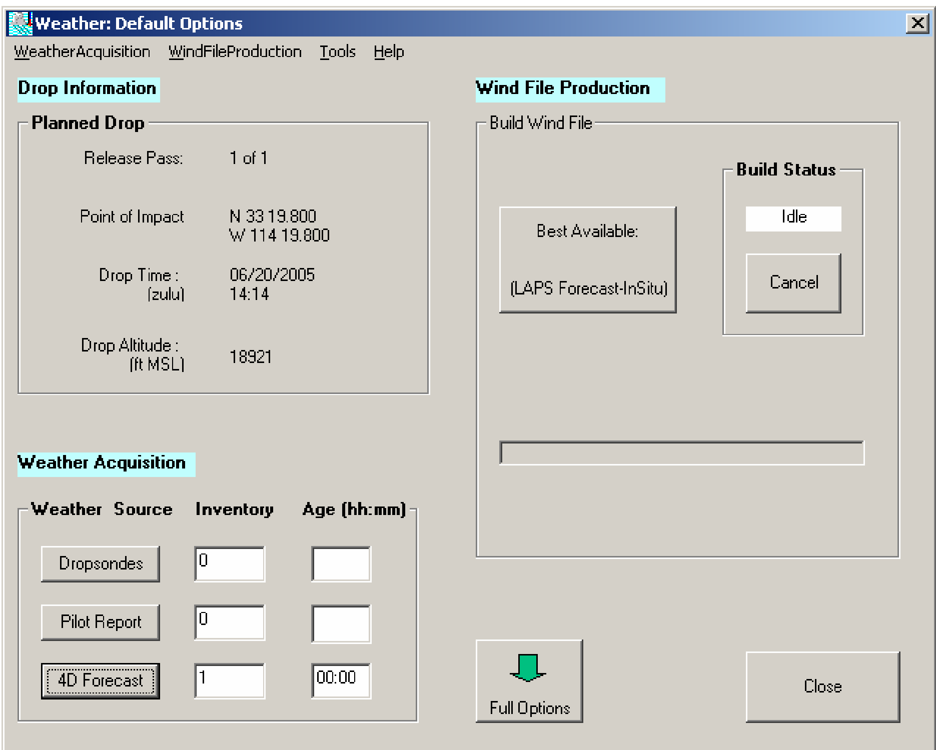


Figure 21. Weather GUI with 4D Forecast loaded.

In Figure 21, the 4D Forecast inventory now shows an increment of one and the Wind File Production section now has the options for wind file generation via LAPS Forecast. The Local Analysis and Prediction System (LAPS) is the most advanced modeling method included within the JPADS-MP. It allows complex modeling of wind interaction with terrain features such as how wind will flow over or around terrain obstacles. Select either the *Best Available* or *LAPS Forecast-only* (available under *Full Options*) to begin Wind File production.

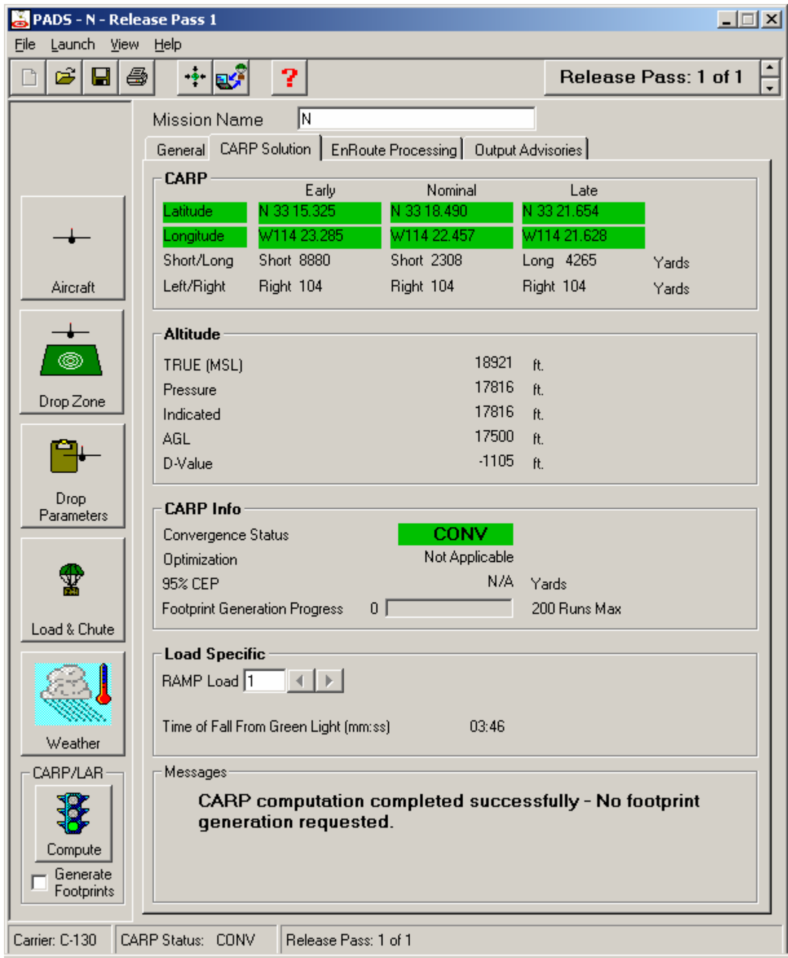


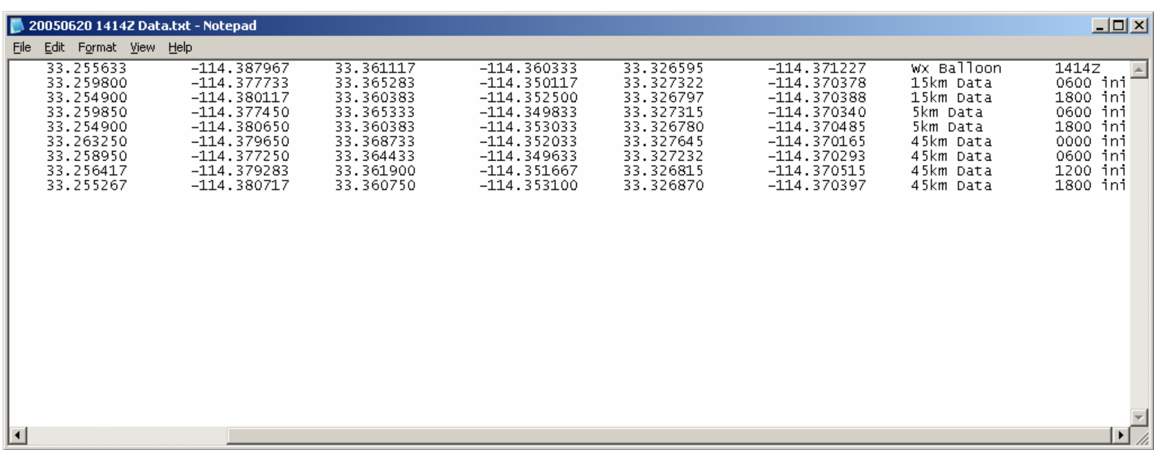
Figure 22. JPADS Main GUI CARP Solution TAB after successful CARP calculation.

Selecting *Compute* CARP will now automatically open the CARP solution tab. The CARP section shows the Latitude and Longitude of the Early, Nominal, and Late CARPs which also define the boundaries of the LAR. In order to collect this data, an Optical

Screen Reader tool was developed by Captain Ryan Eggert of the Air Force Research Laboratory Advanced Architecture and Integration Branch.

The Screen OCR tool reads the values in the Early, Nominal, and Late CARP coordinate boxes and copies them to a text file. In doing so, it also converts them from a DDD MM.mmm format to a DDD.dddddd format. The conversion to decimal degrees allows for easier mathematical operations later. Additionally, the Screen OCR copies the coordinates for the Screamer OP from its memory location and writes it to the same text file.

The method of building text files for analysis is to segregate the data by weather balloons. The Screen OCR allows for a new file to be opened and then to append subsequent data to this file. First, the CARP/LAR/OP is calculated for a weather balloon. This data is saved to a new file bearing the date and time of the balloon launch as the file name. Next, the CARP/LAR/OP is calculated for each weather forecast that was valid for the time of that weather balloon launch. Each new data set is appended to the text file resulting in a file similar to the one shown below:


20050620 1414Z Data.txt - Notepad

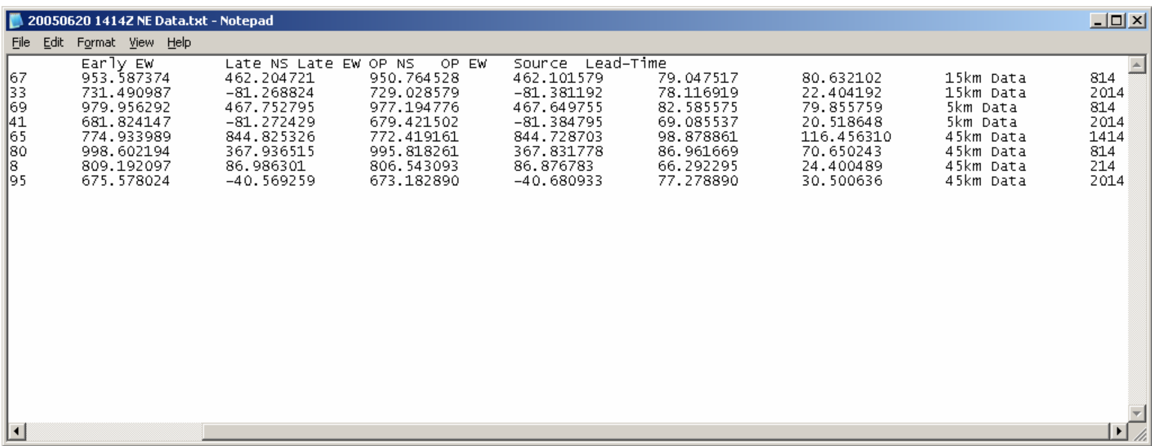
File Edit Format View Help

33.255633	-114.387967	33.361117	-114.360333	33.326595	-114.371227	Wx Balloon	1414Z
33.259800	-114.377733	33.365283	-114.350117	33.327322	-114.370378	15km Data	0600 ini
33.254900	-114.380117	33.360383	-114.352500	33.326797	-114.370388	15km Data	1800 ini
33.259850	-114.377450	33.365333	-114.349833	33.327315	-114.370340	5km Data	0600 ini
33.254900	-114.380650	33.360383	-114.353033	33.326780	-114.370485	5km Data	1800 ini
33.263250	-114.379650	33.368733	-114.352033	33.327645	-114.370165	45km Data	0000 ini
33.258950	-114.377250	33.364433	-114.349633	33.327232	-114.370293	45km Data	0600 ini
33.256417	-114.379283	33.361900	-114.351667	33.326815	-114.370515	45km Data	1200 ini
33.255267	-114.380717	33.360750	-114.353100	33.326870	-114.370397	45km Data	1800 ini

Figure 23. Sample text file record of CARP and OP calculations from the JPADS-MP captured by the Screen OCR program.

As can be seen, each line represents a different weather input: weather balloon on the first line, followed by weather forecasts of varying resolution and initialization time. The coordinates of the CARPs and OP are to the left of the metadata. Capt Eggert also developed a CARP Analysis tool to generate Northing and Easting data from the raw coordinates captured by the Screen OCR.

The CARP analysis tool functions by comparing each weather forecast to the weather balloon data in line one of the text file. This results in a file similar to the one shown in Figure 24, below:



```
20050620 1414Z NE Data.txt - Notepad
File  Edit  Format  View  Help
          Early EW          Late NS Late EW OP NS    OP EW    Source   Lead-Time
67        953.587374        462.204721        950.764528        462.101579        79.047517        80.632102        15km Data        814
33        731.490987        -81.268824        729.028579        -81.381192        78.116919        22.404192        15km Data        2014
69        979.956292        467.752795        977.194776        467.649755        82.585575        79.855759        5km Data         814
41        681.824147        -81.272429        679.421502        -81.384795        69.085537        20.518648        5km Data         2014
65        774.933989        844.825326        772.419161        844.728703        98.878861        116.456310       45km Data        1414
80        998.602194        367.936515        995.818261        367.831778        86.961669        70.650243        45km Data        814
8         809.192097        86.986301         806.543093        86.876783         66.292295        24.400489        45km Data        214
95        675.578024        -40.569259        673.182890        -40.680933        77.278890        30.500636        45km Data        2014
```

Figure 24. Sample text file containing output from the CARP Analysis Tool.

In this file, the data represents error in the forecasting. A value in the Nominal NS column of -40.578024 means that particular forecast generated a Nominal CARP coordinate that was 40.578024 m South of the correct Nominal CARP coordinate as defined by the Nominal CARP calculated from the weather balloon (an actual sampling of the atmosphere). Also note that, while the resolution data is unchanged, the initialization time has been replaced by the Lead-Time. This is accomplished by simply taking the difference between the weather balloon launch time and the forecast initialization time. The data from each weather balloon (and its corresponding forecasts) is saved in a folder named for the day the balloons were launched on.

Once all the data has been run through the JPADS-MP and the final Northing/Easting data has been saved, the whole lot is read into Microsoft Excel. Excel is used to organize the data into continuous columns by resolution and then order them according to Lead-Time. The first order of business was to determine if a separate analysis would need to be performed on the Early, Nominal, and Late CARPS. However, comparing scatter diagrams for each type of CARP indicated this was unnecessary and that the Nominal CARP would suffice for all.

Each resolution is then entered into Matlab to test for Bivariate Normality. This test is taken from Walsh and Lynch's discussion on the Multivariate Normal Distribution (16:2). It was possible to code the test they describe into Matlab to produce a Goodness-of-Fit test for scaled distances to a Chi-Squared Distribution with n degrees of freedom. These are then fit to a regression model. The R^2adjusted for the fit then give an indication of the GoF, where linearity correlates to normality. The Matlab input script and function are included in Appendix E and F, respectively.

Having passed this test, the data sets are then entered into JMP 6 for detailed analysis. JMP 6 was used to perform Analysis of Variance (ANOVA) as well as Multivariate Analysis. This was first performed for the full data set of each resolution in order to characterize each and determine if one was more favorable than the others in terms of mean (error) and variance. Then, each set was subdivided in order to examine the effect of Lead-Time on sample mean and variance. For 5 and 15 km data, there was insufficient data for anything other than a morning vs. afternoon comparison. The 45 km data, however, was sufficient to group Lead-Times into seven bins of three hours each.

The Lead-Times for 45 km resolution range from approximately 2 to 23 hours.

IV. Results and Analysis

First Look

Before commencing the statistical analysis, the first objective was to verify that earlier assumptions made in setting up the test were valid. The following diagram is a scatter plot showing CARP data generated from the comparison of 5km weather data to their corresponding weather balloon derived CARP. The points on the graph show the error in the forecast based CARP with respect to the "true" weather balloon based CARP. The first check was to ensure that it would not be necessary to test the Early, Nominal, and Late CARPs individually, but rather, that one category would suffice for all. This chart shows that the errors for each type of CARP are perfectly correlated and validates the concept of analyzing only the Nominal CARP as a representative for the whole.

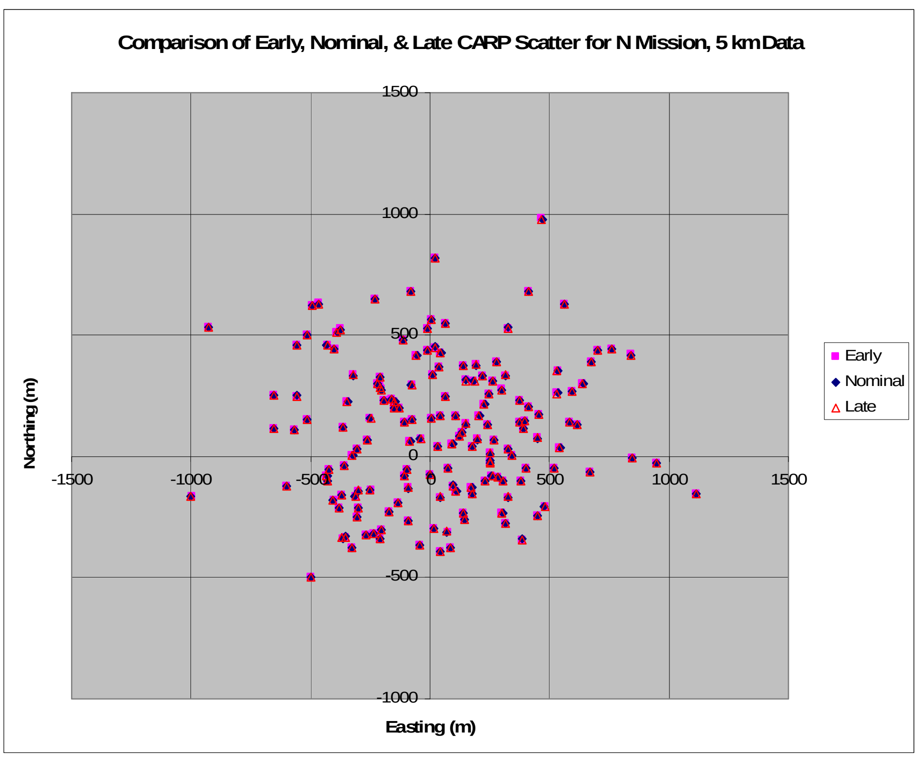


Figure 25. Scatter Plot of Northing and Easting Errors for Early, Nominal, and Late CARPs.

The next chart compares the N Mission used in this study with a notional S Mission. The only difference being a Run-In heading of 180° magnetic as opposed to 360° magnetic. The purpose of this test is to determine if the aircraft velocity vector played a significant role in the observed CARP errors. As can be seen below, there is excellent correlation between the N and S Missions, discounting any such concerns.

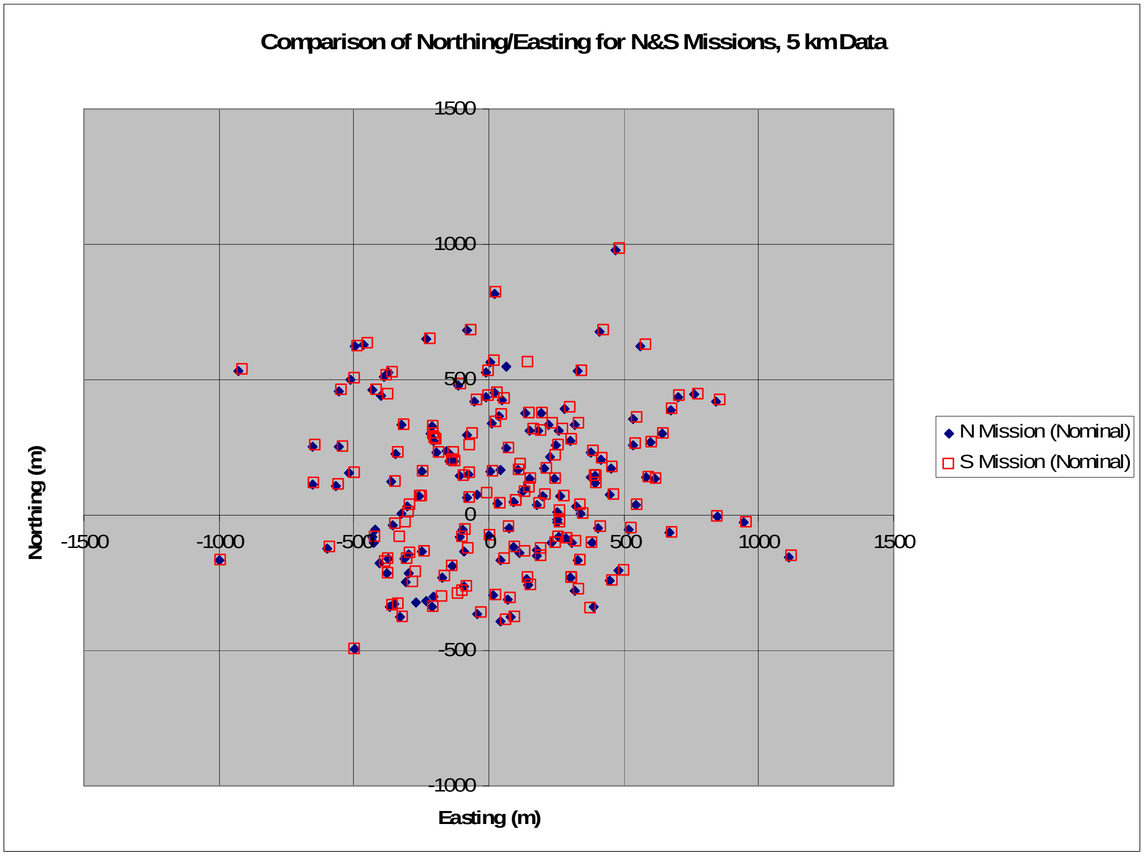


Figure 26. Scatter Plot of Northing and Easting errors of Nominal CARP comparing results from N and S Missions.

Figure 27 shows the results of the full data set. The upper chart shows the CARP errors in Northing and Easting between weather balloon and weather forecast inputs; the lower chart displays the same errors for the Screamer OPs.

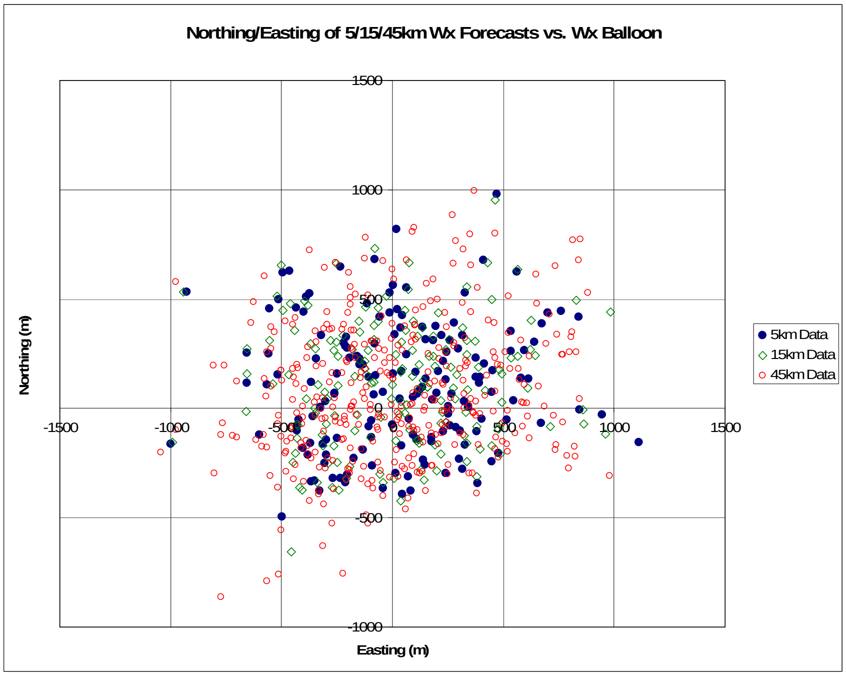


Figure 27. Scatter Plot of Northing and Easting errors of Nominal CARPs at 5, 15, and 45km Resolution

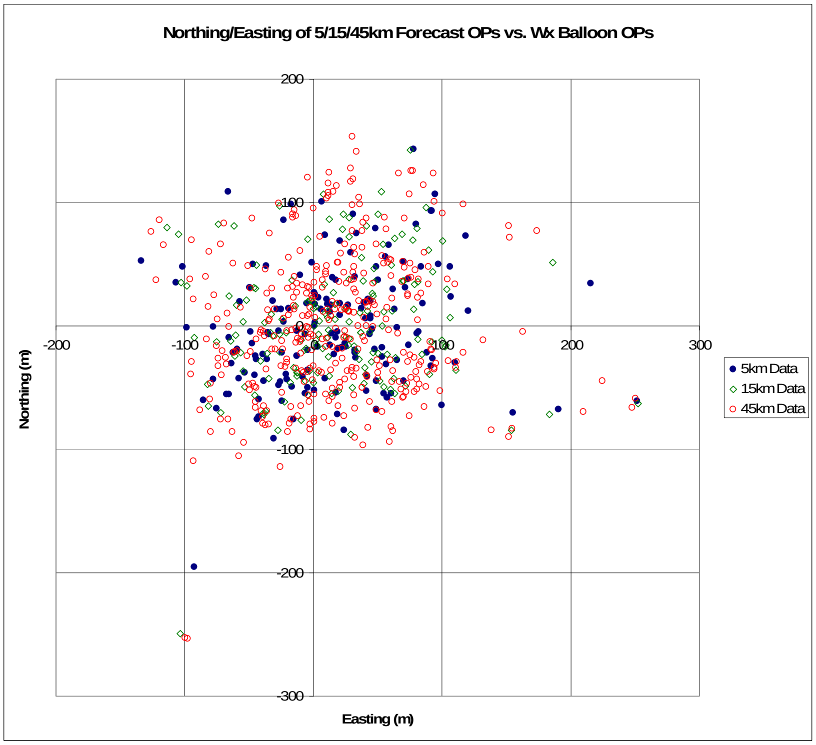


Figure 28. Scatter Plot of Northing and Easting errors of OPs at 5, 15, and 45km Resolutions

Goodness of Fit (GoF) Testing for Bivariate Normality

The next assumption to check is that of Bivariate Normal distribution of the data. As mentioned in Chapter 3, this is accomplished by fitting a line to a comparison of scaled distances to a Chi-Square distribution. As can be seen in the figure below, The CARP error data is a good fit to Bivariate Normal. However, the OP data is strongly influenced by outliers which, when included in the line-fit calculation, cause the OP data to fail the GoF test. Exclusion of these outliers allows for fits (shown in green on the charts) with R2 adjusted in the range of 0.98 – 0.99; clearly an excellent fit. Unfortunately, using historical data, there is no way to account for the cause of these outliers. Therefore, for the purposes of this study, they will not be removed.

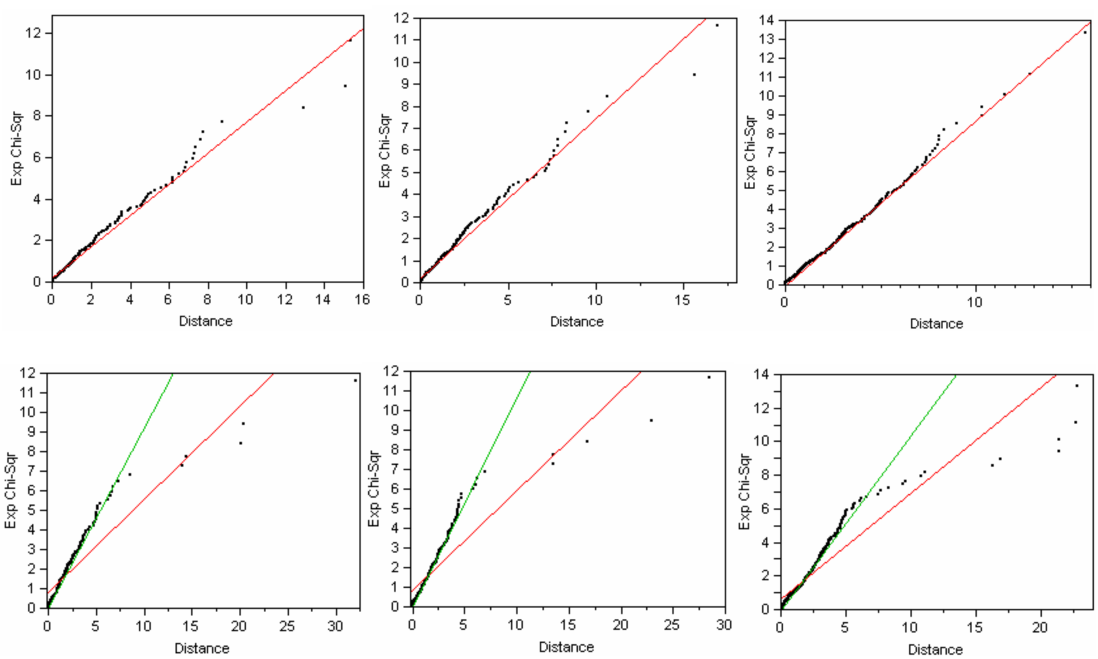


Figure 29. Bivariate Normal Goodness-of-Fit test applied to CARP data (top row) and OP data (bottom row) at 5, 15, and 45km Resolution (columns 1,2, and 3 respectively).

Since this establishes Bivariate Normal as a good distribution to describe the data, we now move on to analyzing the data in that light. The next series of figures will display statistical data necessary to answer whether there is an ideal weather forecast resolution for calculating the CARP.

Figure 30 shows the CARP error scatter for the 5, 15, and 45km resolution data. The green lines indicate the mean value for Northing and Easting. The solid red line is the Least Squares regression fit and the broken red lines indicate the 95% confidence interval around the fit. The fit is indicative of the correlation between Northing and Easting. The aqua line and shaded region is the 95% density ellipse for the data set. It is worth noting that in both the 5 and 15km resolutions, H_0 (there is no correlation between Northing and Easting) cannot be rejected at $\alpha = 0.05$. However, for the 45km resolution, H_0 is rejected at $\alpha = 0.05$. This can been seen in Figure 30, as the 95% confidence interval for the 45km data does not include a line of zero slope.

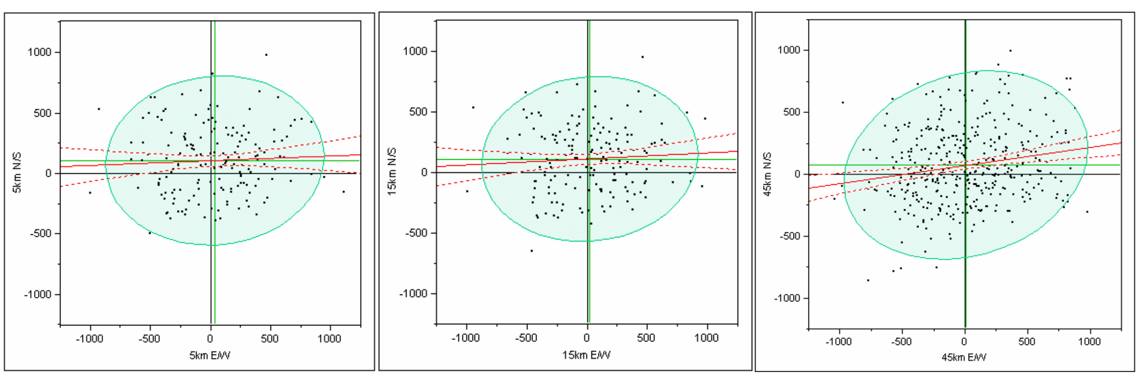


Figure 30. Scatter Plot of Northing and Easting errors with mean errors (green lines), correlation (solid red line), 95% confidence interval on correlation (dotted red line), and 95% density ellipse displayed for 5, 15, and 45km Resolutions.

This positive correlation was unexpected. As with the question of outlier data in the OP analysis, there is no clear cut answer to the source of this correlation. It does call into question the N Mission setup as a possible explanation. Weather data (both balloon and forecast) records wind direction using true headings. However, aircrews typically plan using magnetic headings. Since the N Mission borrowed its details from an actual mission, aircraft Run-In headings were entered using magnetic headings. The magnetic variance at YPG is approximately 13°. It is unknown if this plays a role in the observed correlation or not as there was insufficient time for testing after the discovery of the anomaly.

What is clear from these figures is the effect of resolution on both the means and variance of CARP errors. General improvement in mean error is seen as resolution decreases from 5km to 45km. However, the finer resolutions (i.e., 5 and 15km) have lower variance than does the 45km resolution. Additionally, all three resolutions exhibit a marked Northing error. The following tables provide summary statistics for Figure 30. The sample means and standard deviations are contained in the Correlation Table. Complete output from JMP 6 is included for all data in Appendix B, C, and D.

Linear Fit

5km N/S = 104.20727 + 0.0403265 5km E/W
15km N/S = 111.32849 + 0.0493597 15km E/W
45km N/S = 72.951882 + 0.1476738 45km E/W

Summary of Fit

RSquare	0.002742
RSquare Adj	-0.00349
RSquare	0.004211
RSquare Adj	-0.00197
RSquare	0.035599
RSquare Adj	0.033014

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	36162	36162.2	0.4400
Error	160	13149793	82186.2	Prob > F
C. Total	161	13185955		0.5081
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	53276	53275.6	0.6808
Error	161	12599340	78256.8	Prob > F
C. Total	162	12652615		0.4105
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1295163	1295163	13.7687
Error	373	35086535	94066	Prob > F
C. Total	374	36381698		0.0002

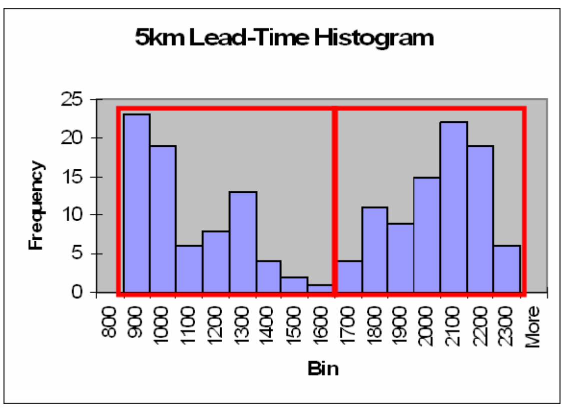
Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
5km E/W	36.49546	371.6411	0.052369	0.5081	162
5km N/S	105.679	286.1824			
Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
15km E/W	22.48796	367.396	0.064889	0.4105	163
15km N/S	112.4385	279.4684			
Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W	7.961625	398.495	0.188678	0.0002	375
45km N/S	74.12761	311.893			

Figure 31. JMP 6 Statistical Output for 5, 15, and 45km Resolution CARP data.

The answer to the question of resolution appears to be that that 45km data provides the lowest mean error, but the greatest variance. The next question is that of the effect of Lead-Time on CARP error. Figures 32 and 33 show the frequency of Lead-Times for each data set. Recall that Lead-Time is the delta between forecast initialization and the planned drop time. Since the historical data used was never intended for this type of study, it presents certain difficulties which will now be addressed.

Testing at YPG typically occurs in two temporal groups: before noon and after noon local time. Since the 5 and 15km forecasts are only generated twice per day (at 0600Z and 1800Z), there are significantly less data points available for the Lead-Time study at these resolutions than for the 45km data (which is generated every 6 hours). Ideally, there would be at least thirty data points for each hour of Lead-Team to allow for a complete comparison; unfortunately that is not the case. In order to ensure enough data for statistical significance, Lead-Times must be grouped together in "bins." Due to the general paucity of data at the 5 and 15km resolution, these were lumped into two bins at the natural break point in the histogram. This compares Short Lead-Times (8 to 17 hours) to Long Lead-Times (17-24 hours).



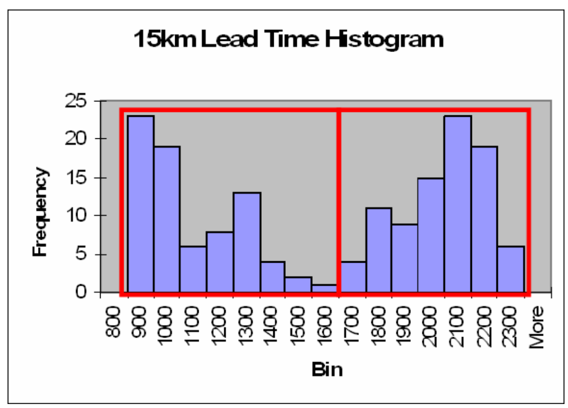


Figure 32. Lead-Time Histogram for 5 and 15km Resolution data.

The 45km data is more extensive, but still requires grouping for best results. In this case there are seven bins containing three hours of data each with a range from 2 hours of Lead-Time out to 23 hours – a much more complete set of observations.

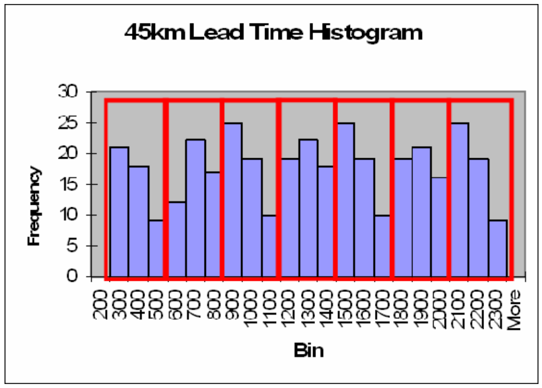
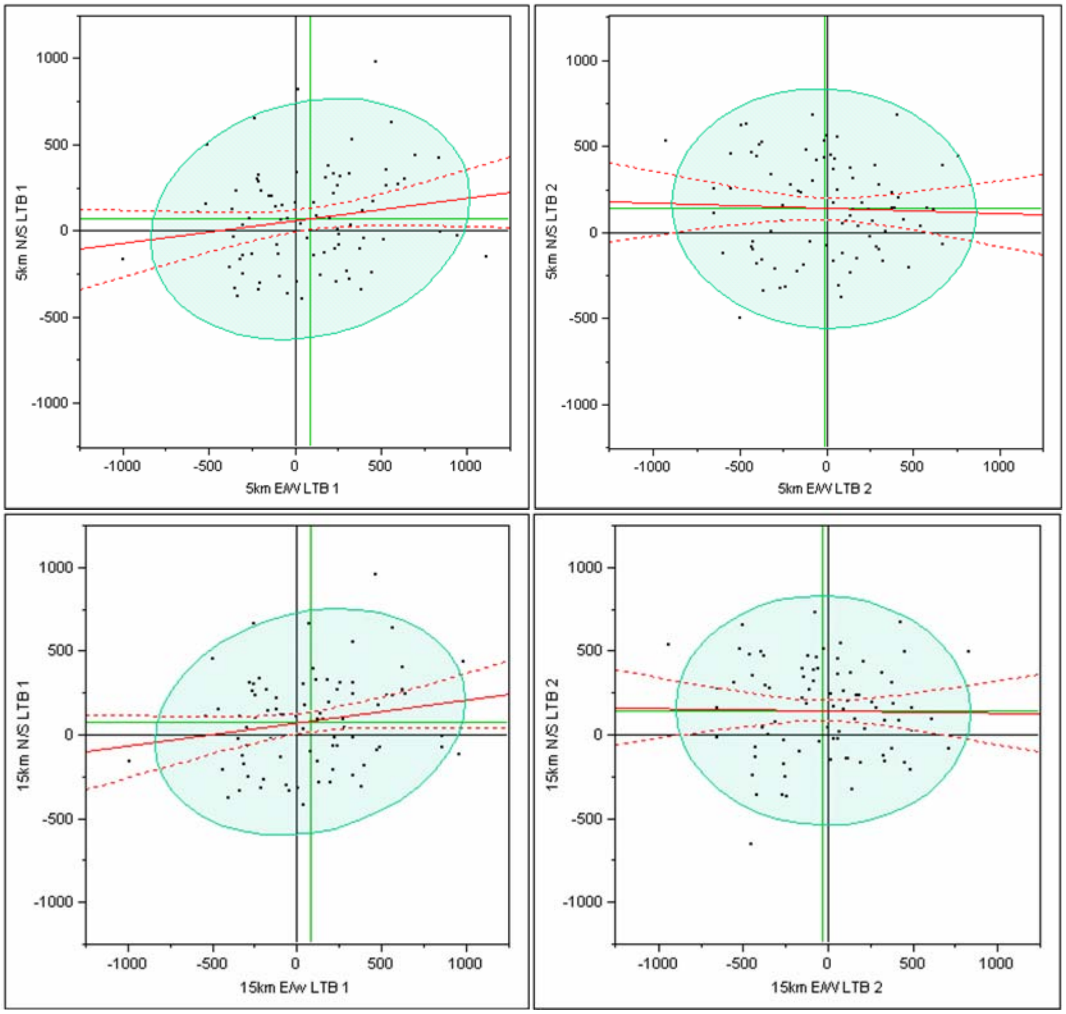


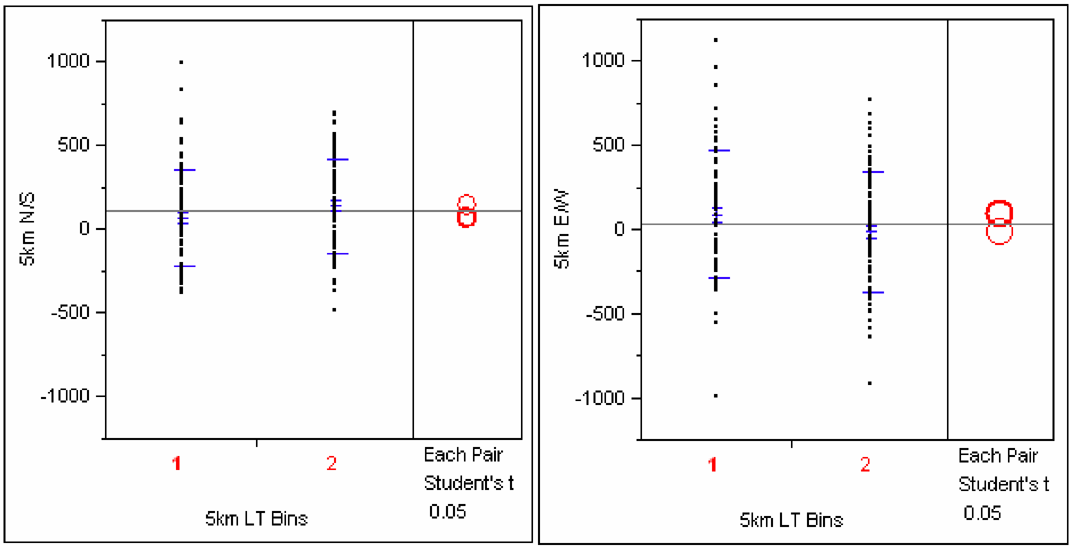
Figure 33. Lead-Time Histogram for 45km Resolution Data.

The analysis begins as before; this time with Northing and Easting error plots differentiated by Lead-Time as well as Resolution. We then move on to a One-Way Layout to further investigate the behavior of the means and variances as Lead-Time is adjusted.



Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
5km E/W LTB 1	89.39787	378.7505	0.174259	0.1221	80
5km N/S LTB 1	70.10861	285.9311			
Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
5km E/W LTB 2	-15.1166	359.3861	-0.03591	0.7488	82
5km N/S LTB 2	140.3818	283.8712			
Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
15km E/w LTB 1	77.10047	374.5915	0.186249	0.0981	80
15km N/S LTB 1	78.08283	276.2784			
Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
15km E/W LTB 2	-30.1506	354.6377	-0.01824	0.8700	83
15km N/S LTB 2	145.5524	280.1813			

Figure 34. Scatter Plot of Northing and Easting errors for 5 and 15km Resolution sorted by Lead-Time bins as well as the associated statistical data.

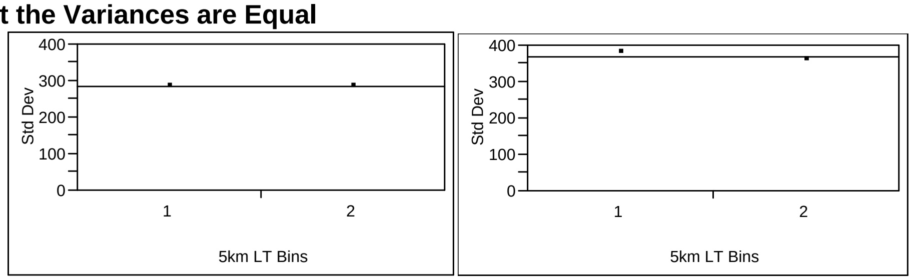


Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	80	70.109	285.931	31.968	6.478	133.74
2	82	140.382	283.871	31.348	78.008	202.76

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	80	89.398	378.751	42.346	5.11	173.68
2	82	-15.117	359.386	39.688	-94.08	63.85

Tests that the Variances are Equal



Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0048	1	160	0.9448
Brown-Forsythe	0.0712	1	160	0.7899
Levene	0.0706	1	160	0.7908
Bartlett	0.0042	1	.	0.9486
F Test 2-sided	1.0146	79	81	0.9479

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.2339	1	160	0.6293
Brown-Forsythe	0.1441	1	160	0.7047
Levene	0.1079	1	160	0.7430
Bartlett	0.2189	1	.	0.6399
F Test 2-sided	1.1107	79	81	0.6392

Means Comparisons for each pair using Student's t

t	Alpha
1.97490	0.05

Abs(Dif)-LSD	2	1
2	-87.868	-18.142
1	-18.142	-88.960

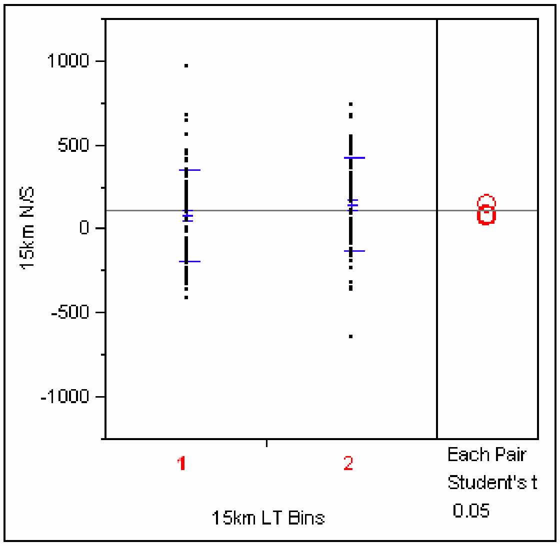
t	Alpha
1.97490	0.05

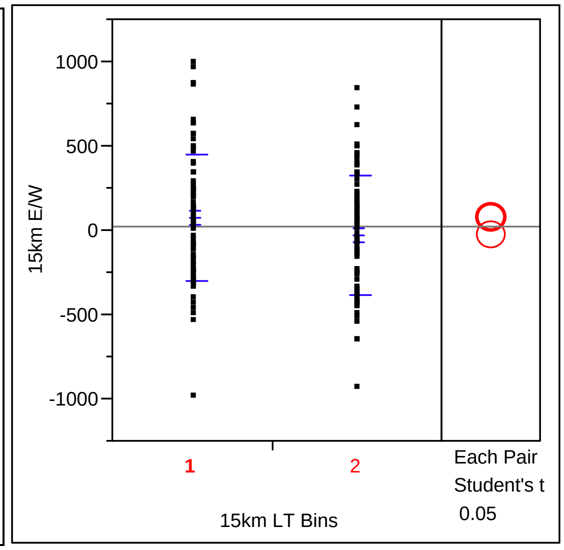
Abs(Dif)-LSD	1	2
1	-115.25	-10.03
2	-10.03	-113.83

Positive values show pairs of means that are significantly different.

Figure 35. Results of JMP 6 Oneway Layout Analysis for 5km Resolution data. Northing data is on the left side of the figure and Easting is on the right for ease of comparison.

Figure 35 is a combination of the JMP 6 output for the 5km resolution forecast data. It allows for a side-by-side comparison of the means and variances of both the Northing and Easting data. The first two graphs show the distance errors with their associated bin number. The inner set of blue dashes indicates the mean of that set and its confidence interval. The outer set of blue dashes indicates 1 Standard Deviation. The red rings to the right of the chart are a visualization tool for comparing means. When this data is displayed in JMP 6, selecting one ring will cause it to be highlighted with a thick red ring (as opposed to a standard thin, black ring). Subsequently, all groups whose means are not significantly different change from black rings to red rings. Groups with significantly different means become gray. This test indicates that there is no significant difference in the means of Lead-Time bins 1 and 2 in either the Northing or the Easting data. The lower portion of the table is a test to verify that the variance between the bins is not significant. JMP 6 applies five different methods to this evaluation. In each case, the high p-Value indicates failure to reject H_0: the variances between bins are equal. Figure 36 presents the same analysis for the 15km resolution data with comparable results.

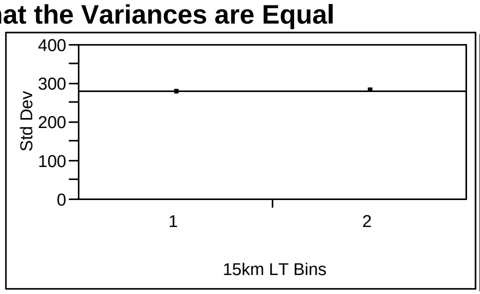


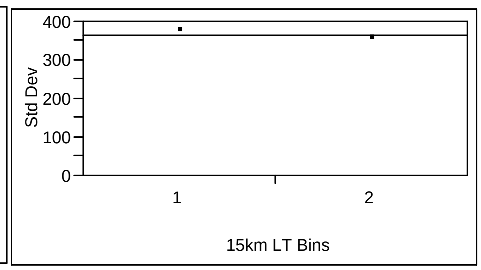


Means and Std Deviations

Level	Number	Northing Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	80	78.083	276.278	30.889	16.600	139.57
2	83	145.552	280.181	30.754	84.373	206.73
Level	Number	Easting Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	80	77.100	374.591	41.881	-6.3	160.46
2	83	-30.151	354.638	38.927	-107.6	47.29

Tests that the Variances are Equal





Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0168	1	161	0.8970
Brown-Forsythe	0.1502	1	161	0.6989
Levene	0.1432	1	161	0.7056
Bartlett	0.0157	1	.	0.9002
F Test 2-sided	1.0285	82	79	0.9013

Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.2584	1	161	0.6119
Brown-Forsythe	0.1041	1	161	0.7473
Levene	0.1018	1	161	0.7501
Bartlett	0.2397	1	.	0.6244
F Test 2-sided	1.1157	79	82	0.6235

Means Comparisons for each pair using Student's t

t	Alpha
1.97481	0.05

Abs(Dif)-LSD	2	1
2	-85.305	-18.631
1	-18.631	-86.889

t	Alpha
1.97481	0.05

Abs(Dif)-LSD	1	2
1	-113.83	-5.55
2	-5.55	-111.76

Positive values show pairs of means that are significantly different.

Figure 36. Results of JMP 6 Oneway Layout Analysis for 15km Resolution data. Northing data is on the left side of the figure and Easting is on the right for ease of comparison.

Again, means and variances do not appear to vary significantly between Lead-Times at 15km resolution. We move on now to the 45km resolution data. Figures 37 and 38 display the CARP error data for each of the seven Lead-Time bins of the 45km data. In this sequence of charts, the Easting mean remains relatively close to zero with the greatest deviation occurring in Lead-Time bin 5, which represents data Lead-Time of 15 to 17 hours. Of more interest are the results of the Northing mean. For the first two bins (2 – 8 hours Lead-Time), the Northing mean is very close to zero. The precise values of the means are highlighted in Figure 39. The trend of the Northing error mean is generally worse beyond 8 hours of Lead-Time.

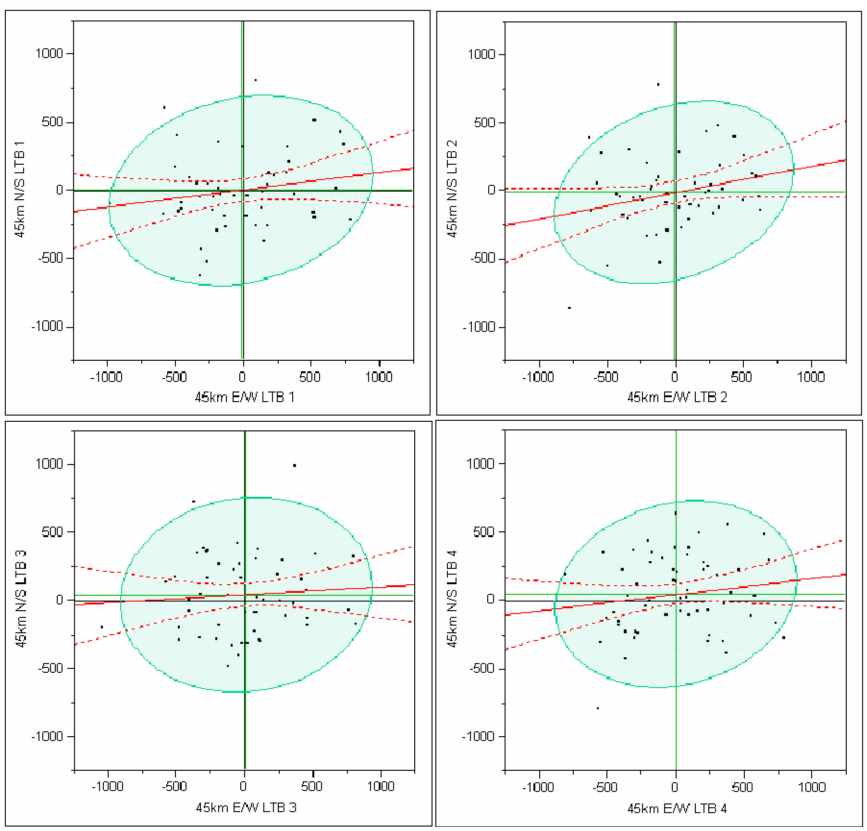


Figure 37. Scatter Plot of 45km Resolution Northing and Easting error sorted by bin, Bins 1 – 4.

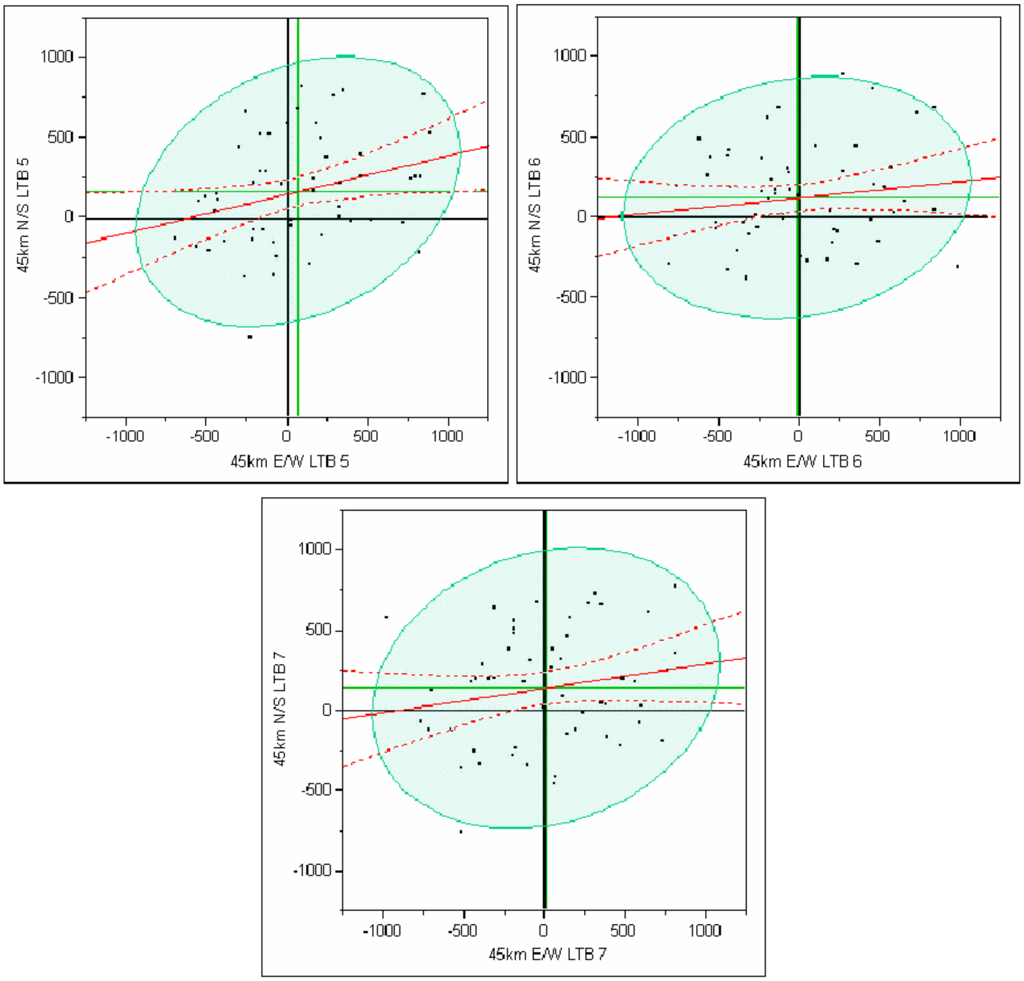
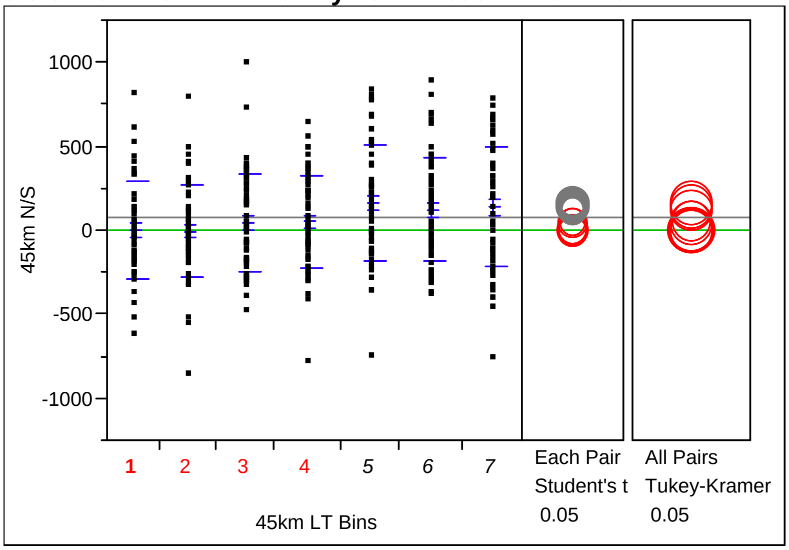


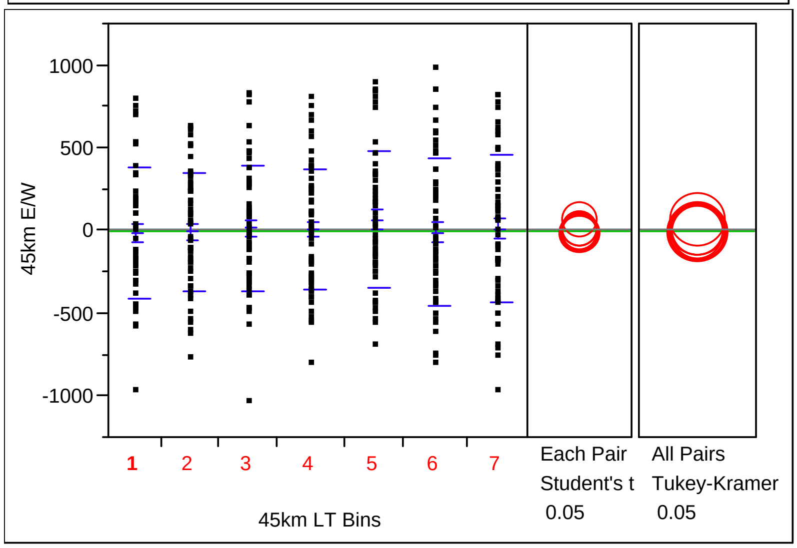
Figure 38. Scatter Plot of 45km Resolution Northing and Easting error sorted by bin, Bins 5 – 7.

Bin 5 is again the location of largest mean error, this time for the Northing error. Additionally, Bin 5 shows the greatest level of potential correlation between Northing and Easting error.

The next series of tables presents the Oneway Layout for the 45km resolution forecast data. There are some differences in the data presented here due to the addition levels (i.e., bins) available for comparison. First is the Tukey-Kramer HSD (Honestly Significant Difference) Test in addition to the pair-wise Student's t Test.

Oneway Analysis of 45km CARP Error By 45km Lead-Time Bins



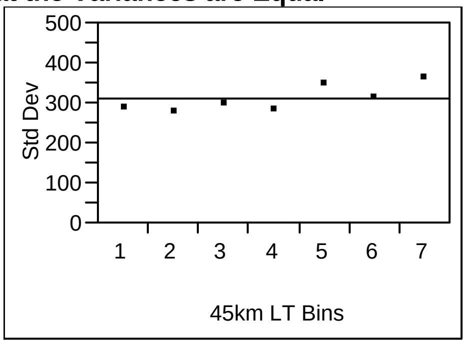


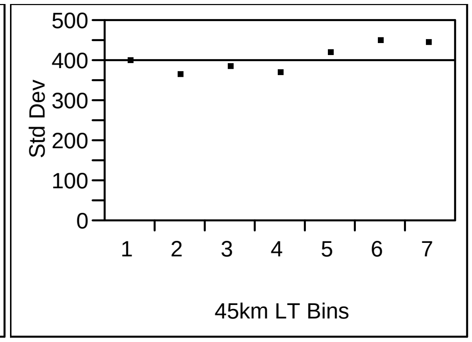
Means and Std Deviations

Level	Number	Northing Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	48	0.10	286.139	41.301	-82.98	83.19
2	51	-6.76	274.515	38.440	-83.97	70.45
3	53	44.09	294.586	40.464	-37.10	125.29
4	60	49.32	278.429	35.945	-22.60	121.25
5	53	162.64	345.121	47.406	67.51	257.77
6	57	120.32	308.757	40.896	38.39	202.24
7	53	138.93	359.118	49.329	39.94	237.91
Level	Number	Easting Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	48	-15.632	397.339	57.351	-131.0	99.74
2	51	-10.805	359.155	50.292	-111.8	90.21
3	53	11.717	378.416	51.979	-92.6	116.02
4	60	5.949	363.862	46.974	-88.0	99.94
5	53	65.746	413.535	56.803	-48.2	179.73
6	57	-12.650	442.575	58.620	-130.1	104.78
7	53	10.295	441.901	60.700	-111.5	132.10

Figure 39. JMP 6 Oneway Layout Analysis of 45km Resolution data, Part 1.

Tests that the Variances are Equal





Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.2329	6	368	0.2885
Brown-Forsythe	1.9188	6	368	0.0768
Levene	1.9868	6	368	0.0667
Bartlett	1.1944	6	.	0.3057

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.0776	6	368	0.3753
Brown-Forsythe	0.8953	6	368	0.4983
Levene	1.0443	6	368	0.3961
Bartlett	0.7998	6	.	0.5699

Welch Anova testing Means Equal,
allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.4046	6	162.36	0.0297

F Ratio	DFNum	DFDen	Prob > F
0.2408	6	162.4	0.9624

Northing Means Comparisons for each pair using Student's t

Level	- Level	Difference	Lower CL	Upper CL	p-Value	Difference
5	2	169.3968	50.542	288.2513	0.0053	
5	1	162.5347	41.802	283.2672	0.0085	
7	2	145.6865	26.832	264.5410	0.0164	
7	1	138.8244	18.092	259.5569	0.0243	
6	2	127.0771	10.286	243.8686	0.0330	
6	1	120.2150	1.513	238.9171	0.0472	
5	3	118.5439	0.838	236.2500	0.0484	
5	4	113.3135	-0.908	227.5349	0.0518	
7	3	94.8336	-22.872	212.5398	0.1140	
7	4	89.6032	-24.618	203.8247	0.1238	
6	3	76.2242	-39.398	191.8468	0.1957	
6	4	70.9938	-41.079	183.0670	0.2137	
4	2	56.0833	-59.321	171.4878	0.3399	
3	2	50.8529	-68.002	169.7074	0.4007	
4	1	49.2212	-68.117	166.5589	0.4100	
3	1	43.9908	-76.742	164.7233	0.4741	
5	6	42.3197	-73.303	157.9424	0.4721	
5	7	23.7103	-93.996	141.4164	0.6923	
7	6	18.6095	-97.013	134.2321	0.7518	
1	2	6.8621	-114.990	128.7144	0.9119	
4	3	5.2304	-108.991	119.4518	0.9283	

Figure 40. JMP 6 Oneway Layout Analysis of 45km Resolution data, Part 2

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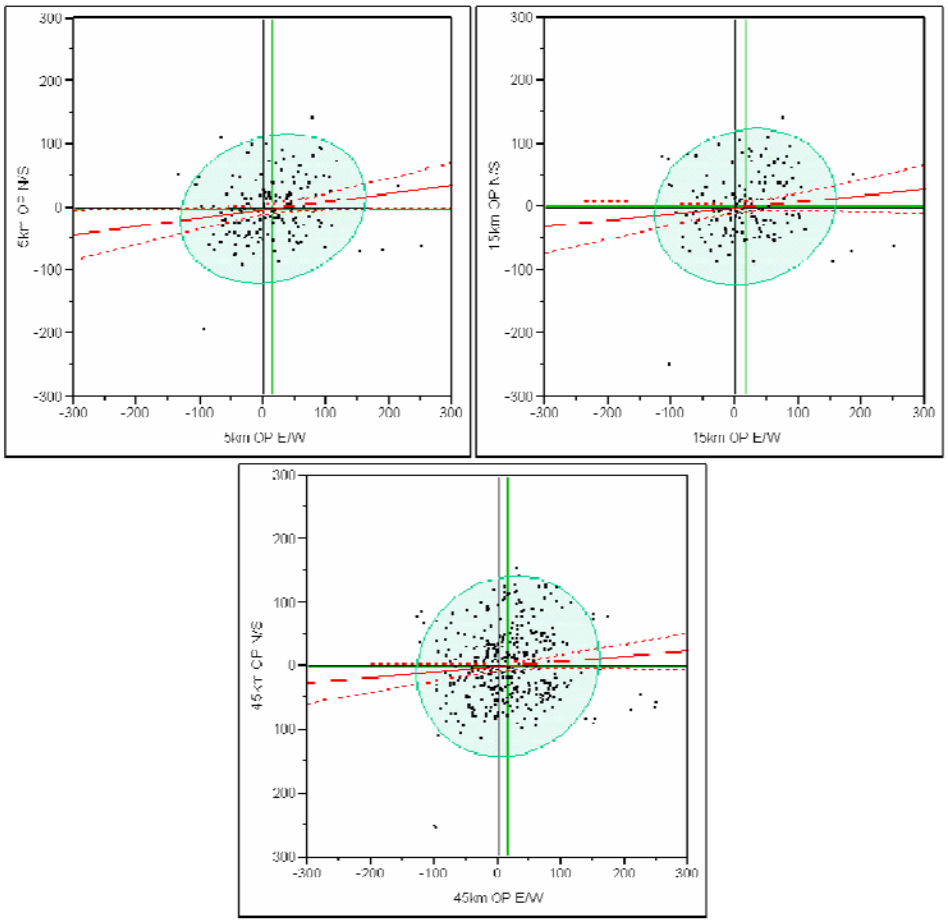
As previously mentioned, the rings to the right of the data plots are a visual tool for comparing the means of each group Based on the Student's t Test, we see two groups of similar means: 1,2,3, and 4 in the first group and 5,6, and 7 in the second. A green line has been added to the plot to indicate zero mean error. The black line on the plot displays the overall mean error. As can be seen, the first grouping of means fall below the black line while the second grouping lies above it. This corresponds (as expected) with the scatter plot data indicating generally greater error as Lead-Time increases, with the greatest error located in bin 5. Note the data table for the Student's t comparisons. Cells highlighted in red indicate a p-Value less than $\alpha = 0.05$ and thus a rejection of H_0: no significant difference in means between bins.

The Tukey-Kramer HSD Test is used here in addition to the Student's t because the number of observations in each bin is unequal. In such conditions, Tukey-Kramer is intended to provide a conservative test for difference in the means. In this case, the Tukey-Kramer result differs from the Student's t, indicating that that H_0 cannot be rejected under that test. For the Easting error data, both Student's t and Tukey-Kramer fail to reject H_0, which is wholly expected from a visual inspection of the plot.

In both cases, bins with shorter Lead-Times display smaller Standard Deviations, and hence, smaller variance. However, the testing suite for equal variance fails to reject H_0: no significant difference in variances between bins. The complete JMP 6 report is available in Appendices B, C, and D.

Next we will briefly examine the Screamer Opening Point (OP) error scatter plots. The improvement in overall error as compared to the CARP calculations is immediately apparent. These diagrams are on a 300x300m plot as opposed to the 1250x1250m plots for CARP errors. The radius for 95% density ellipse radius is about 150m at all resolutions. Additionally, it is not possible to reject H_0 (no correlation between Northing and Easting) for the OPs at any resolution. The mean Northing and Easting errors remain virtually constant across all three resolutions, as can be seen in Figure 41. It is worth recalling that this data includes anomalous outliers. These were left in the data set as there is no method available for determining their cause (and thus justify their removal) from the historical data.



Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
5km OP E/W	15.65148	60.22144	0.165302	0.0355	162
5km OP N/S	-1.77951	48.40718			
Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
15km OP E/W	16.04198	58.63512	0.113049	0.1508	163
15km OP N/S	0.552814	50.58542			
Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km OP E/W	16.2265	58.74914	0.084928	0.1006	375
45km OP N/S	-0.13898	58.04491			

Figure 41. Scatter Plot of Northing and Easting errors for 5, 15, and 45km Resolution OP data as well as the associated statistical data.

This chapter concludes with a quick look at Yuma Proving Ground Site 16, the location where this weather data was collected. Figure 42 shows the locations of YPG Site 16 as well as the JPADS Center PI drop zone.

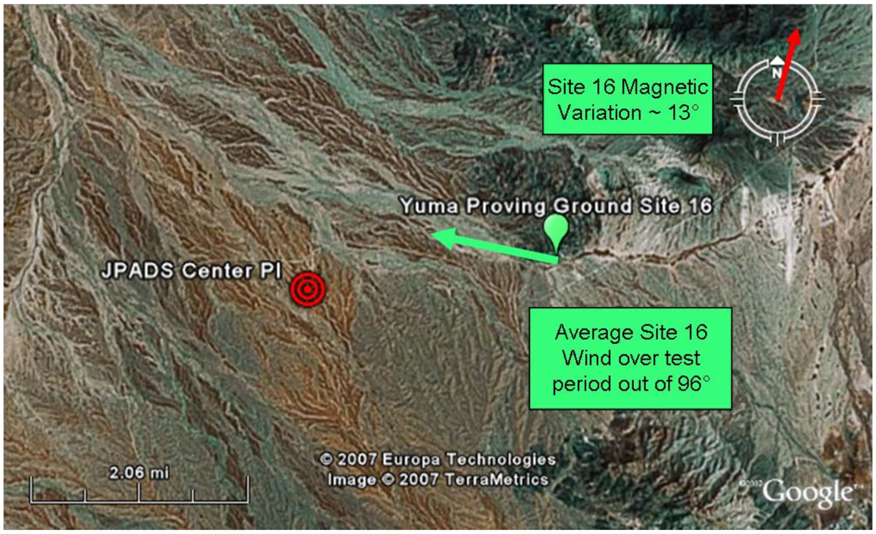


Figure 42. Satellite view of Yuma Proving Ground Site 16 and JPADS Center PI. (Source: Google Earth)

As can be seen in the figure, the average wind at Site 16 follows the local terrain. Wind in this area can generally be expected to flow up the valley during daylight heating and down the valley during night-time cooling. The effect is shown in the diagram below:

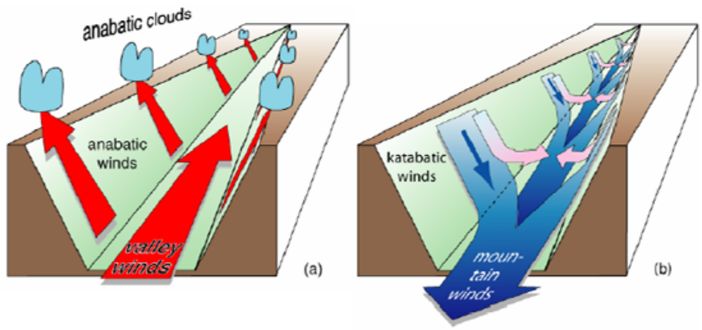


Figure 43. Wind flow effects due to terrain and diurnal heating effects. (15:406)

It is reasonable to believe that this local weather effect may be responsible for the greater variability observed in CARP Easting errors. However, certainty would require testing at other locations. Finally, Figure 44 is a composite image showing a Bivarite Normal distribution generated in Matlab from the 45km data with an overlay of the Eigen vectors of the distribution. The Eigen vectors are collinear with the axes of the ellipse. The angle between the Eigen vectors and the y-axis is approximately 18.7°. While this value is greater than the magnetic variance for the area, it is not by much. Also, it is aligned very closely to the direction of True North, as can been in Figure 44 below:

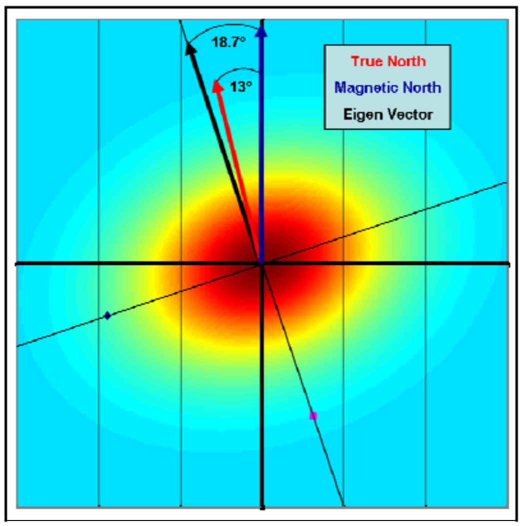


Figure 44. Overlay of Eigen Vectors on 45km Resolution derived Bivariate Normal distribution along with the approximate relationship to True and Magnetic North.

This argues in favor of the idea that inputting magnetic heading rather than true may be the cause of the apparent correlation.

V. Summary and Conclusions

The Bottom Line

This study set out to determine how JPADS-MP outputs were sensitive to weather inputs. The main question being: are there ideal weather inputs to obtain the most accurate outputs? To answer this question required gaining a detailed understanding of how these three entities (input-system-output) interact. Not surprisingly, some questions remain. However there are clear, useful results from this research:

- 45km resolution weather forecast data has lower mean CARP calculation error than does 5 or 15km resolution weather forecast data. (*More accurate*)
- 45km resolution weather forecast data has higher variance in CARP calculation error than does 5 or 15km resolution forecast data. (*Less precise*)
- 2 to 8 hours of Lead-Time offers lowest mean CARP calculation error with least variance.
- Screamer Opening Point CARP calculation errors do not appear to depend upon weather forecast resolution.
- For the JPADS-MP, there appears to be no advantage to using higher resolution weather forecast data. High resolution weather forecasts have larger file sizes requiring greater bandwidth utilization and more time to acquire. Further, they are only run twice daily as opposed to the four times daily run of the 45km resolution data. It is clear that within the context of the JPADS-MP *as-is*, the lower resolution 45km weather forecast data is of greatest value to the user.

Future Research

This study actually had two goals: the first, to attempt to answer the stated research question; the second, to determine if further research on this particular topic was needed. The answer to the second question is clearly: yes! Now that there is a better understanding of the system, the best way to achieve definitive results is to conduct a Designed Experiment rather than attempting to make do with historical data. While this is a time intensive process, this study has produced sufficiently interesting results to warrant the effort. Goals for a follow-on study should include the following:

- Gather weather balloon and weather forecast data from several, geographically diverse locations.
- Gather a sufficient number of weather forecasts at each resolution to allow full coverage of potential Lead-Times as well as to avoid the need of grouping Lead-Times into bins (as well as an equal number of observations at each level).
- Determine if entering navigation data using magnetic heading versus true heading is a source of error.
- Attempt to determine cause of the excessive Northing errors.

The final recommendation for future research is to address deficiencies in the method for acquiring climatology data for JPADS. JPADS-MP uses climatology data as filler whenever data necessary for calculations is not available from the current weather input data. Additionally, climatology may be used as a last resort for mission planning should no other source of weather input be available. At present, climatology is acquired by sending a request to the Air Force Combat Climatology Center and waiting for them to provide the data. This can take as long as two weeks. AFIT's Engineering Physics department has developed an excellent software alternative known as the Laser Environmental Effects Definition and Reference (LEEDR), which could allow the JPADS-MP user to have the ability to generate accurate climatology data on the same PADS Laptop Computer that they use for the JPADS-MP. This would require only minor modifications to allow the two programs to talk to each other (certainly a Systems Engineering area of expertise!) and would provide immediate and tangible improvement in the system for the warfighter.

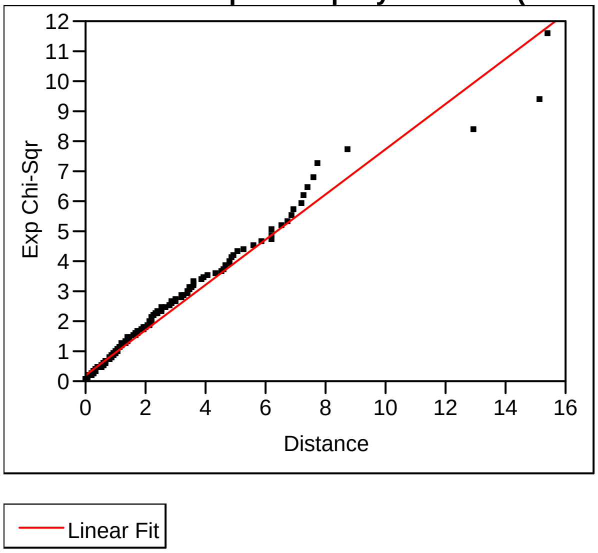
Appendix A: List of Acronyms

AAA	Anti-Aircraft Artillery
AGU	Airborne Guidance Unit
ACTD	Advanced Concept Technology Demonstration
AFIT	Air Force Institute of Tecnology
AFRL	Air Force Research Laboratory
AFWA	Air Force Weather Agency
AGAS	Affordable Guided Parachute System
AGL	Above Ground Level
ANOVA	Analysis of Variance
APIP	Advanced PADS Interface Processor
AWADS	Adverse Weather Aerial Delivery System
CARP	Computed Air Release Point
CDS	Container Delivery System
CEP	Circular Error Probable
DoD	Department of Defense
GoF	Goodness of Fit
GPS	Global Positioning System
GRP-RTS	GPS Re-Transmit Kit
GRADS	Ground Radar Air Drop System
GRIB	Gridded Information in Binary Format
GUI	Graphical User Interface
HVCDS	High Velocity Container Delivery System

JPADS	Joint Precision Air Drop System
JPADS-MP	JPADS-Mission Planner
JDAM	Joint Direct Attack Munition
LAPES	Low Altitude Parachute Extraction System
LAPS	Local Analysis and Prediction System
LAR	Launch Acceptability Region
LEEDR	Laser Environmental Effects Definition and Reference
MM5	Mesoscale Model 5
MMIST	Mist Mobility Integrated Systems Technology
NOAA	National Oceanic and Atmospheric Administration
OP	Opening Point
PADS	Precision Air Drop System
PI	Point of Impact
PIREP	Pilot Report
PLC	PADS Laptop Computer
PSI	Planning System, Inc.
RAD	Ram Air Drogue
WEZ	Weapons Engagement Zone
WRF	Weather Research and Forecasting
YPG	Yuma Proving Ground

Appendix B: 5km JMP 6 Analysis Output

Bivariate Fit of Exp Chi-Sqr By Distance (Nominal CARP)



Linear Fit

Exp Chi-Sqr = 0.2131093 + 0.7523327 Distance

Summary of Fit

RSquare	0.97758
RSquare Adj	0.97744
Root Mean Square Error	0.29726
Mean of Response	1.995723
Observations (or Sum Wgts)	162

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	158	14.137851	0.089480	655.7718
Pure Error	2	0.000273	0.000136	Prob > F
Total Error	160	14.138123		0.0015
				Max RSq
				1.0000

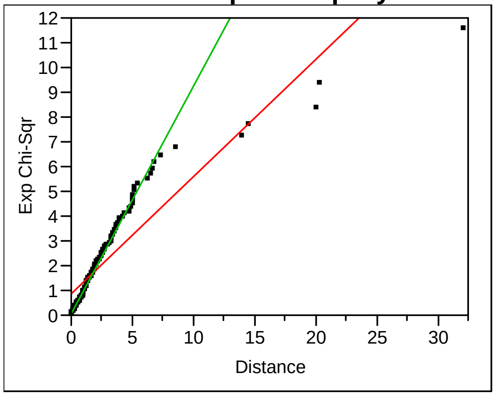
Analysis of Variance

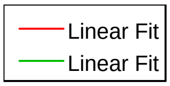
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	616.46791	616.468	6976.517
Error	160	14.13812	0.088	Prob > F
C. Total	161	630.60603		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2131093	0.031638	6.74	<.0001
Distance	0.7523327	0.009007	83.53	<.0001

Bivariate Fit of Exp Chi-Sqr By Distance (Nominal OP)





Linear Fit
Exp Chi-Sqr = 0.8372231 + 0.4746891 Distance

Summary of Fit

RSquare	0.820416
RSquare Adj	0.819294
Root Mean Square Error	0.841303
Mean of Response	1.995723
Observations (or Sum Wgts)	162

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	517.35942	517.359	730.9491
Error	160	113.24661	0.708	Prob > F
C. Total	161	630.60603		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8372231	0.078773	10.63	<.0001
Distance	0.4746891	0.017558	27.04	<.0001

Linear Fit
Exp Chi-Sqr = 0.060006 + 0.9201943 Distance

Summary of Fit

RSquare	0.995629
RSquare Adj	0.995601
Root Mean Square Error	0.10011
Mean of Response	1.746387
Observations (or Sum Wgts)	156

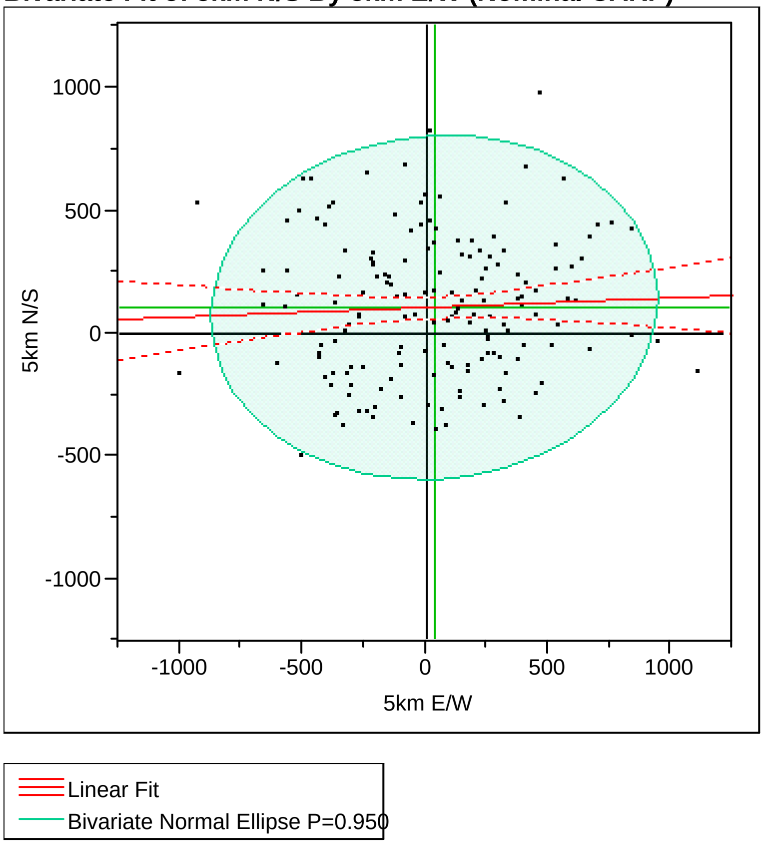
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	351.59272	351.593	35082.19
Error	154	1.54338	0.010	Prob > F
C. Total	155	353.13610		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.060006	0.012054	4.98	<.0001
Distance	0.9201943	0.004913	187.30	<.0001

Bivariate Fit of 5km N/S By 5km E/W (Nominal CARP)



Linear Fit

5km N/S = 104.20727 + 0.0403265 5km E/W

Summary of Fit

RSquare	0.002742
RSquare Adj	-0.00349
Root Mean Square Error	286.6814
Mean of Response	105.679
Observations (or Sum Wgts)	162

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	36162	36162.2	0.4400
Error	160	13149793	82186.2	Prob > F
C. Total	161	13185955		0.5081

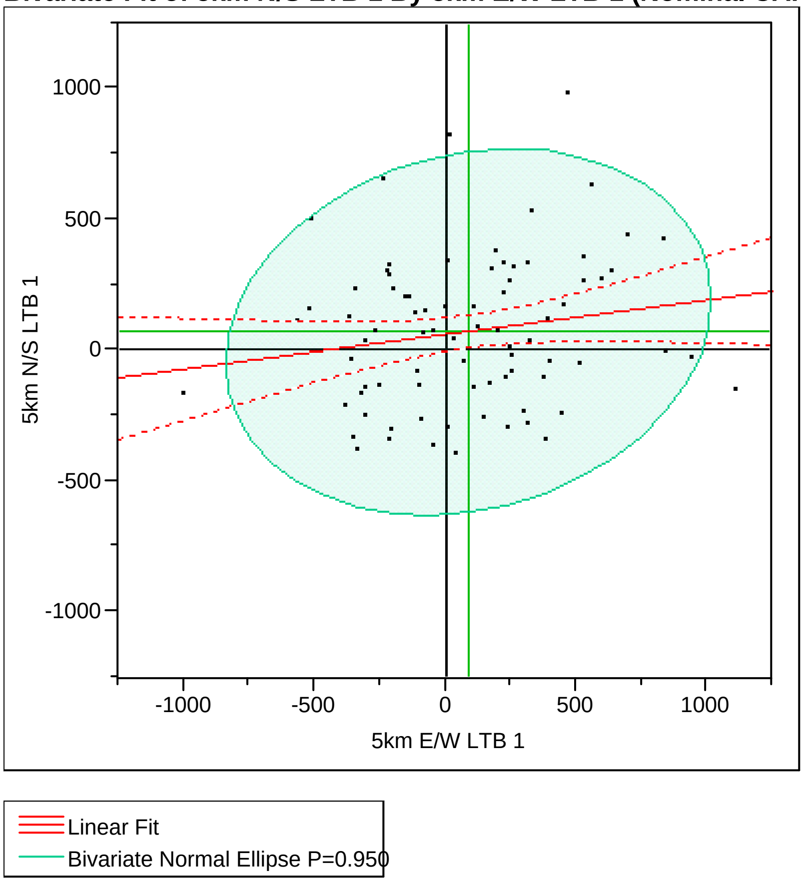
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	104.20727	22.63283	4.60	<.0001
5km E/W	0.0403265	0.060794	0.66	0.5081

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
5km E/W	36.49546	371.6411	0.052369	0.5081	162
5km N/S	105.679	286.1824			

Bivariate Fit of 5km N/S LTB 1 By 5km E/W LTB 1 (Nominal CARP)



Linear Fit

5km N/S LTB 1 = 58.347947 + 0.1315542 5km E/W LTB 1

Summary of Fit

RSquare	0.030366
RSquare Adj	0.017935
Root Mean Square Error	283.3554
Mean of Response	70.10861
Observations (or Sum Wgts)	80

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	196129.5	196129	2.4428
Error	78	6262642.5	80290	Prob > F
C. Total	79	6458772.0		0.1221

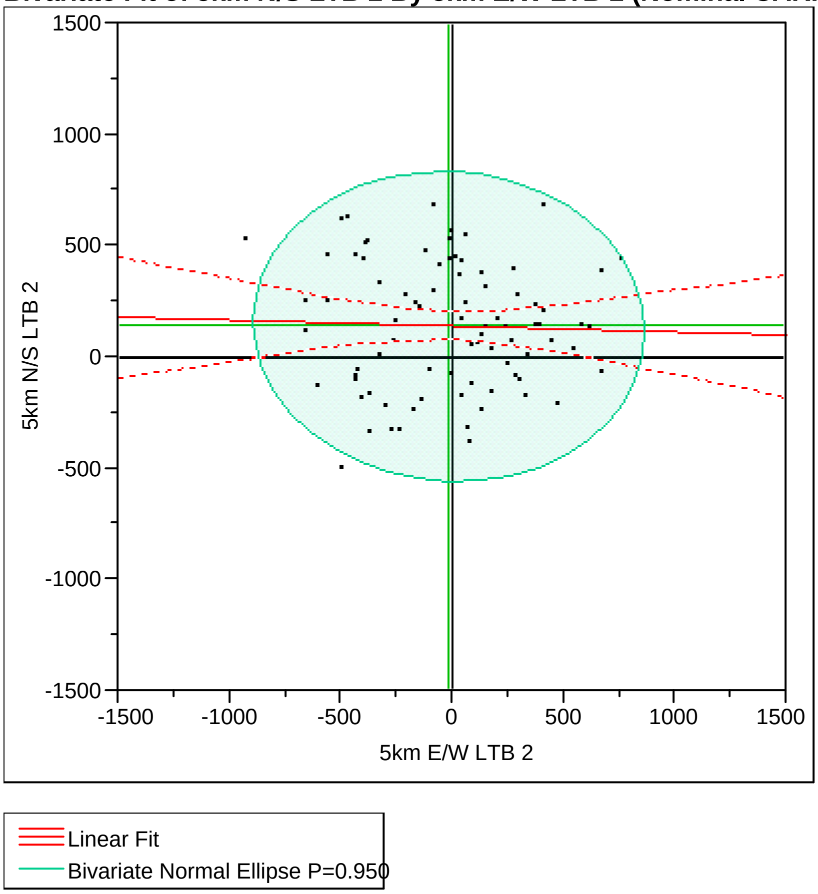
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	58.347947	32.56149	1.79	0.0770
5km E/W LTB 1	0.1315542	0.084171	1.56	0.1221

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
5km E/W LTB 1	89.39787	378.7505	0.174259	0.1221	80
5km N/S LTB 1	70.10861	285.9311			

Bivariate Fit of 5km N/S LTB 2 By 5km E/W LTB 2 (Nominal CARP)



Linear Fit

5km N/S LTB 2 = 139.95308 - 0.0283622 5km E/W LTB 2

Summary of Fit

RSquare	0.001289
RSquare Adj	-0.01119
Root Mean Square Error	285.4557
Mean of Response	140.3818
Observations (or Sum Wgts)	82

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	8415.6	8415.6	0.1033
Error	80	6518795.5	81484.9	Prob > F
C. Total	81	6527211.2		0.7488

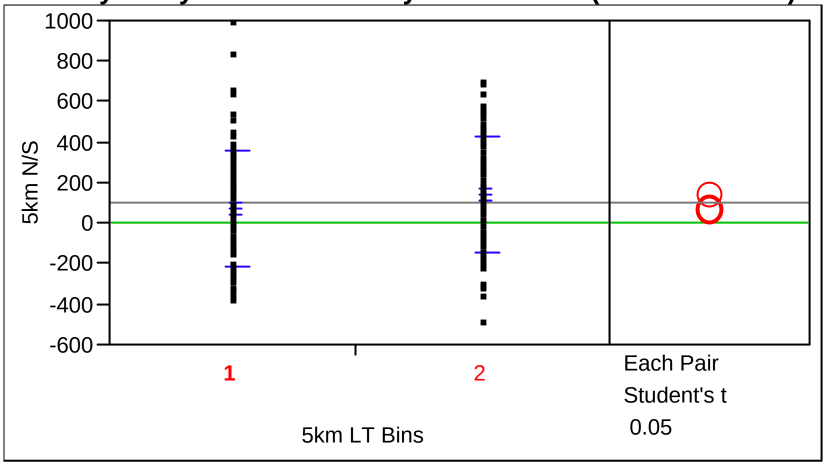
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	139.95308	31.55152	4.44	<.0001
5km E/W LTB 2	-0.028362	0.088254	-0.32	0.7488

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
5km E/W LTB 2	-15.1166	359.3861	-0.03591	0.7488	82
5km N/S LTB 2	140.3818	283.8712			

Oneway Analysis of 5km N/S By 5km LT Bins (Nominal CARP)



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	80	70.109	285.931	31.968	6.478	133.74
2	82	140.382	283.871	31.348	78.008	202.76

Means Comparisons

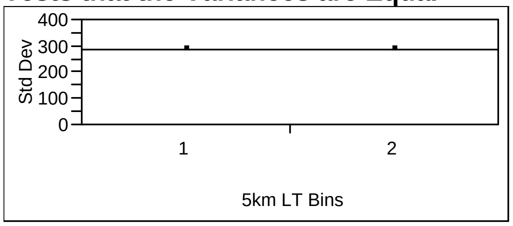
Comparisons for each pair using Student's t

t	Alpha
1.97490	0.05

Abs(Dif)-LSD	2	1
2	-87.868	-18.142
1	-18.142	-88.960

Positive values show pairs of means that are significantly different.

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1	80	285.9311	229.3837	229.3326
2	82	283.8712	236.1517	236.1347

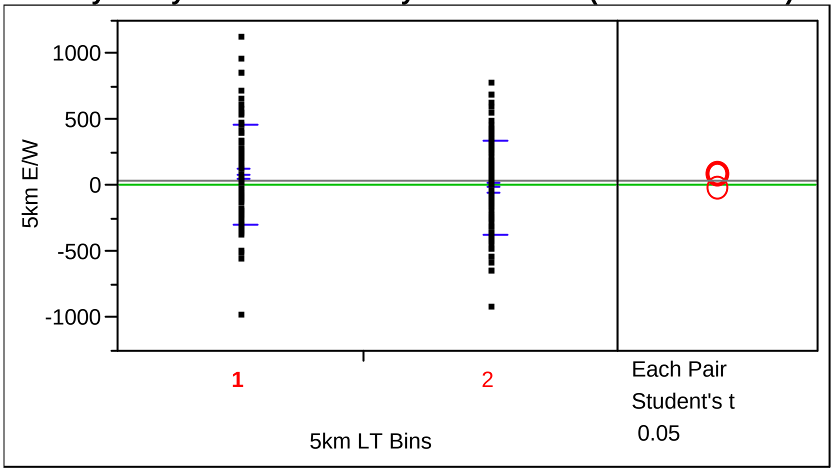
Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0048	1	160	0.9448
Brown-Forsythe	0.0712	1	160	0.7899
Levene	0.0706	1	160	0.7908
Bartlett	0.0042	1	.	0.9486
F Test 2-sided	1.0146	79	81	0.9479

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.4634	1	159.84	0.1185

t Test
1.5695

Oneway Analysis of 5km E/W By 5km LT Bins (Nominal CARP)



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	80	89.398	378.751	42.346	5.11	173.68
2	82	-15.117	359.386	39.688	-94.08	63.85

Means Comparisons

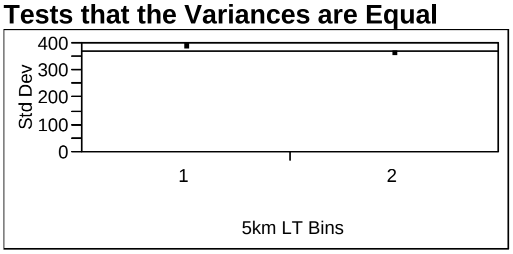
Comparisons for each pair using Student's t

t	Alpha
1.97490	0.05

Abs(Dif)-LSD	1	2
1	-115.25	-10.03
2	-10.03	-113.83

Positive values show pairs of means that are significantly different.

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1	80	378.7505	305.3941	305.3941
2	82	359.3861	294.4267	292.4927

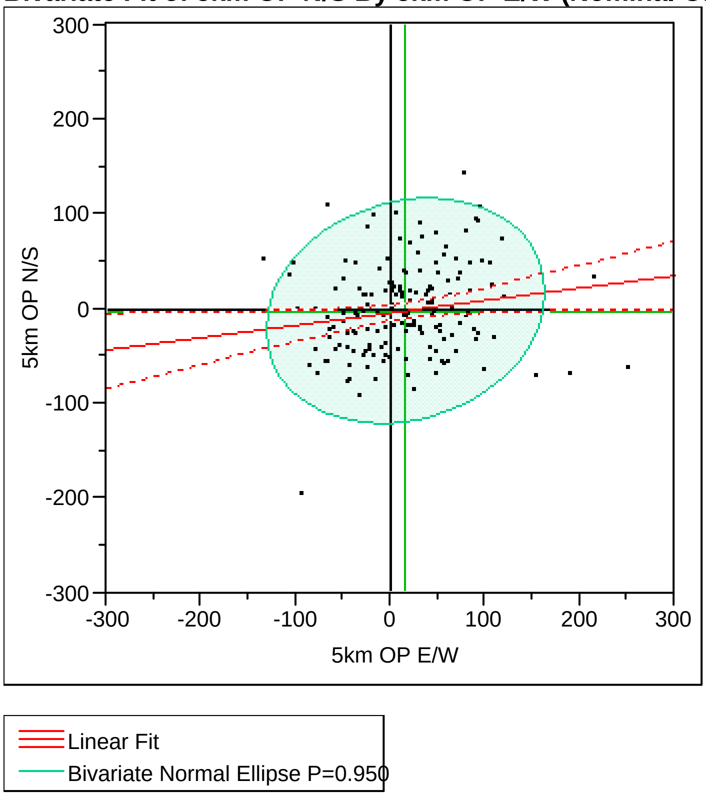
Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.2339	1	160	0.6293
Brown-Forsythe	0.1441	1	160	0.7047
Levene	0.1079	1	160	0.7430
Bartlett	0.2189	1	.	0.6399
F Test 2-sided	1.1107	79	81	0.6392

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.2430	1	159.05	0.0736

t Test
1.8008

Bivariate Fit of 5km OP N/S By 5km OP E/W (Nominal OP)



Linear Fit

5km OP N/S = -3.859172 + 0.1328734 5km OP E/W

Summary of Fit

RSquare	0.027325
RSquare Adj	0.021246
Root Mean Square Error	47.8902
Mean of Response	-1.77951
Observations (or Sum Wgts)	162

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	10308.70	10308.7	4.4948
Error	160	366955.36	2293.5	Prob > F
C. Total	161	377264.06		0.0355

Parameter Estimates

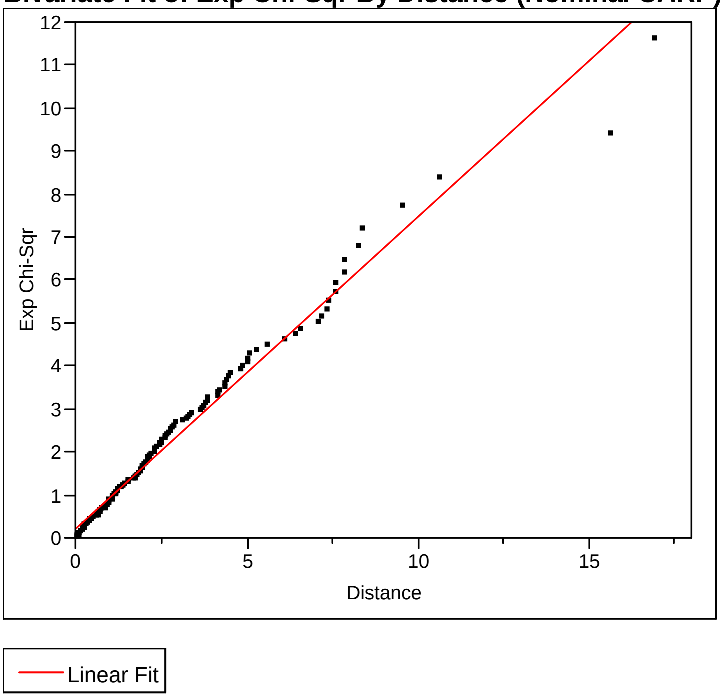
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-3.859172	3.888374	-0.99	0.3225
5km OP E/W	0.1328734	0.062673	2.12	0.0355

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
5km OP E/W	15.65148	60.22144	0.165302	0.0355	162
5km OP N/S	-1.77951	48.40718			

Appendix C: 15km JMP 6 Analysis Output

Bivariate Fit of Exp Chi-Sqr By Distance (Nominal CARP)



Linear Fit
Exp Chi-Sqr = 0.2023848 + 0.7264998 Distance

Summary of Fit

RSquare	0.98215
RSquare Adj	0.98204
Root Mean Square Error	0.265244
Mean of Response	1.995749
Observations (or Sum Wgts)	163

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	160	11.327014	0.070794	891.8347
Pure Error	1	0.000079	0.000079	Prob > F
Total Error	161	11.327093		0.0267
				Max RSq
				1.0000

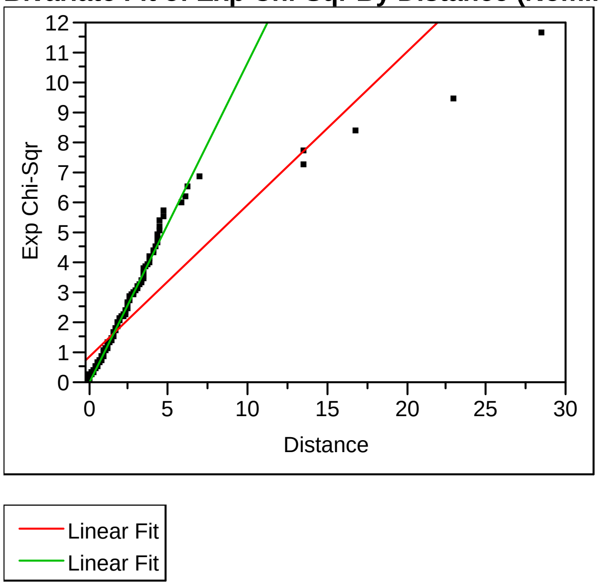
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	623.26073	623.261	8858.846
Error	161	11.32709	0.070	Prob > F
C. Total	162	634.58782		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.2023848	0.02819	7.18	<.0001
Distance	0.7264998	0.007719	94.12	<.0001

Bivariate Fit of Exp Chi-Sqr By Distance (Nominal OP)



Linear Fit

Exp Chi-Sqr = 0.8487173 + 0.5074542 Distance

Summary of Fit

RSquare	0.793745
RSquare Adj	0.792464
Root Mean Square Error	0.901644
Mean of Response	1.995749
Observations (or Sum Wgts)	163

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	160	130.88671	0.818042	5728.384
Pure Error	1	0.00014	0.000143	Prob > F
Total Error	161	130.88685		0.0105
				Max RSq
				1.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	503.70097	503.701	619.5875
Error	161	130.88685	0.813	Prob > F
C. Total	162	634.58782		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8487173	0.084327	10.06	<.0001
Distance	0.5074542	0.020387	24.89	<.0001

Linear Fit

Exp Chi-Sqr = -0.067938 + 1.0699483 Distance

Summary of Fit

RSquare	0.993236
RSquare Adj	0.993193
Root Mean Square Error	0.12467
Mean of Response	1.747532
Observations (or Sum Wgts)	157

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	154	2.4089644	0.015643	109.5384
Pure Error	1	0.0001428	0.000143	Prob > F
Total Error	155	2.4091072		0.0760
				Max RSq
				1.0000

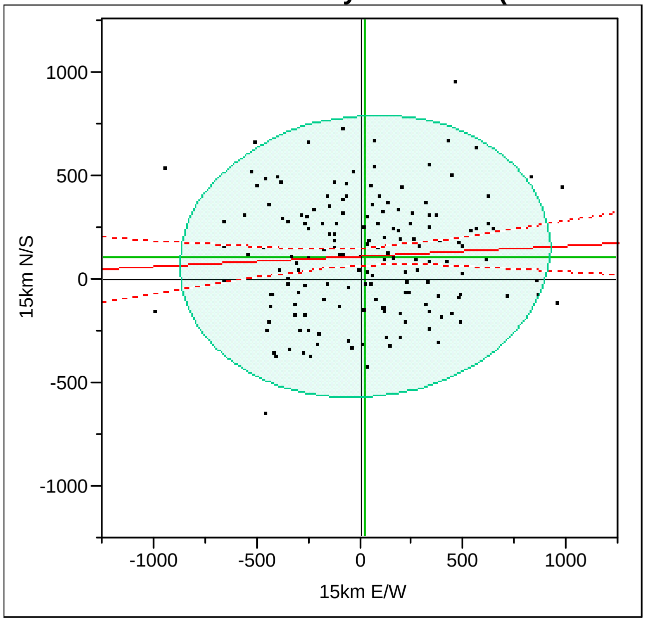
Analysis of Variance

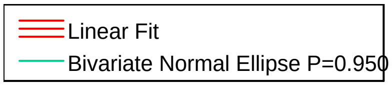
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	353.77827	353.778	22761.81
Error	155	2.40911	0.016	Prob > F
C. Total	156	356.18737		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.067938	0.015614	-4.35	<.0001
Distance	1.0699483	0.007092	150.87	<.0001

Bivariate Fit of 15km N/S By 15km E/W (Nominal CARP)





Linear Fit

15km N/S = 111.32849 + 0.0493597 15km E/W

Summary of Fit

RSquare	0.004211
RSquare Adj	-0.00197
Root Mean Square Error	279.7441
Mean of Response	112.4385
Observations (or Sum Wgts)	163

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	160	12599340	78745.9	.
Pure Error	1	0	0.0	Prob > F
Total Error	161	12599340		.
				Max RSq
				1.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	53276	53275.6	0.6808
Error	161	12599340	78256.8	Prob > F
C. Total	162	12652615		0.4105

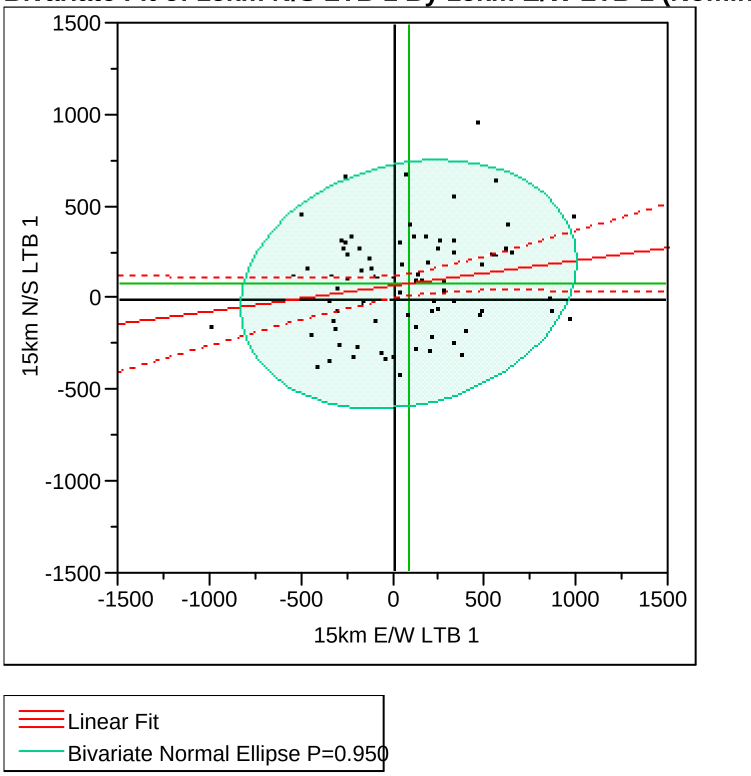
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	111.32849	21.95251	5.07	<.0001
15km E/W	0.0493597	0.059823	0.83	0.4105

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
15km E/W	22.48796	367.396	0.064889	0.4105	163
15km N/S	112.4385	279.4684			

Bivariate Fit of 15km N/S LTB 1 By 15km E/W LTB 1 (Nominal CARP)



Linear Fit

15km N/S LTB 1 = 67.491734 + 0.1373675 15km E/W LTB 1

Summary of Fit

RSquare	0.034689
RSquare Adj	0.022313
Root Mean Square Error	273.1787
Mean of Response	78.08283
Observations (or Sum Wgts)	80

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	209175.4	209175	2.8030
Error	78	5820874.9	74627	Prob > F
C. Total	79	6030050.3		0.0981

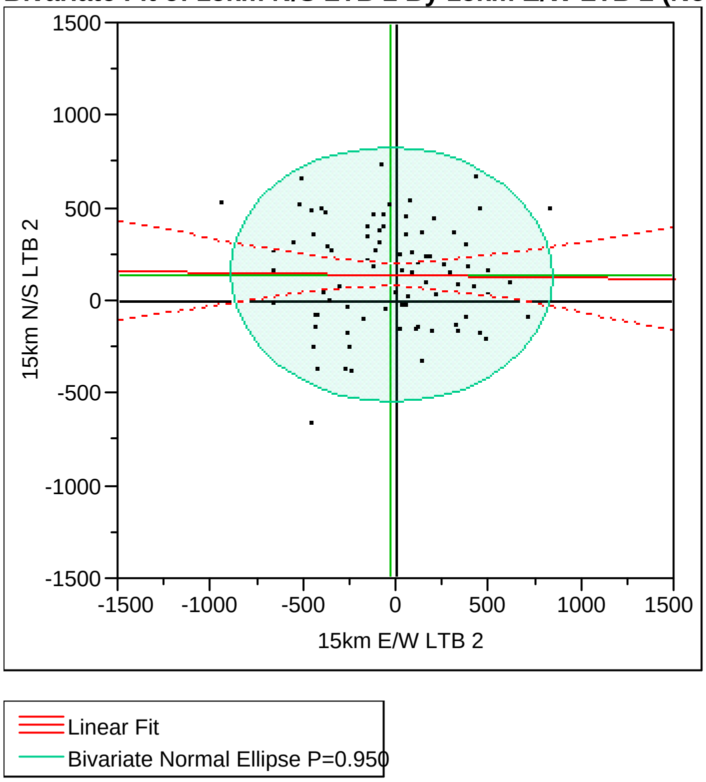
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	67.491734	31.19057	2.16	0.0335
15km E/W LTB 1	0.1373675	0.082049	1.67	0.0981

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
15km E/W LTB 1	77.10047	374.5915	0.186249	0.0981	80
15km N/S LTB 1	78.08283	276.2784			

Bivariate Fit of 15km N/S LTB 2 By 15km E/W LTB 2 (Nominal CARP)



Linear Fit

15km N/S LTB 2 = 145.11784 - 0.0144124 15km E/W LTB 2

Summary of Fit

RSquare	0.000333
RSquare Adj	-0.01201
Root Mean Square Error	281.8586
Mean of Response	145.5524
Observations (or Sum Wgts)	83

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2142.2	2142.2	0.0270
Error	81	6434986.0	79444.3	Prob > F
C. Total	82	6437128.2		0.8700

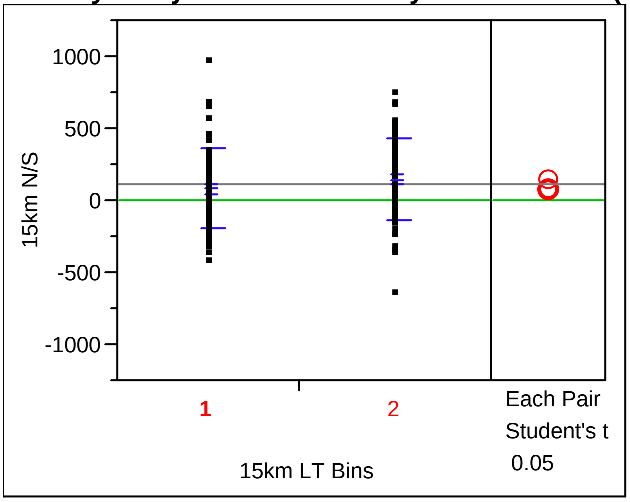
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	145.11784	31.05097	4.67	<.0001
15km E/W LTB 2	-0.014412	0.087769	-0.16	0.8700

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
15km E/W LTB 2	-30.1506	354.6377	-0.01824	0.8700	83
15km N/S LTB 2	145.5524	280.1813			

Oneway Analysis of 15km N/S By 15km LT Bins (Nominal CARP)



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	80	78.083	276.278	30.889	16.600	139.57
2	83	145.552	280.181	30.754	84.373	206.73

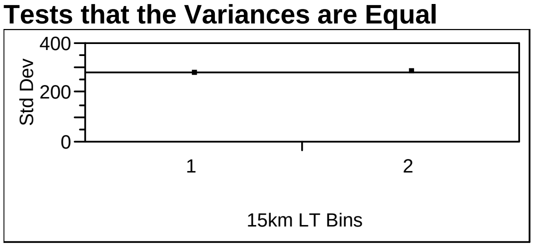
Means Comparisons
Comparisons for each pair using Student's t

t	Alpha
1.97481	0.05

Abs(Dif)-LSD	2	1
2	-85.305	-18.631
1	-18.631	-86.889

Positive values show pairs of means that are significantly different.

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1	80	276.2784	222.6416	221.5912
2	83	280.1813	232.0265	231.3428

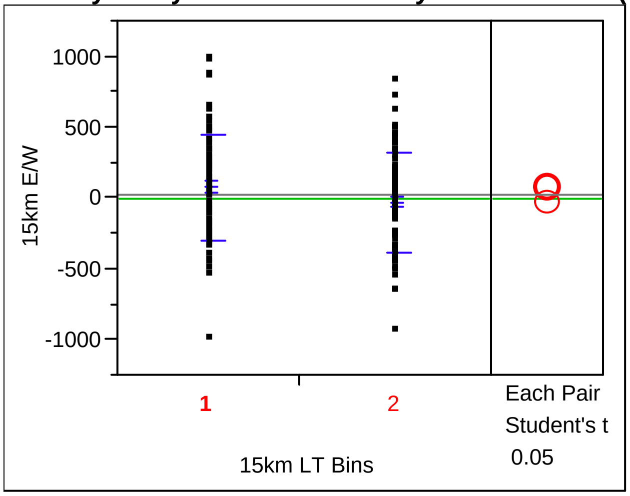
Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.0168	1	161	0.8970
Brown-Forsythe	0.1502	1	161	0.6989
Levene	0.1432	1	161	0.7056
Bartlett	0.0157	1	.	0.9002
F Test 2-sided	1.0285	82	79	0.9013

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.3960	1	160.91	0.1236

t Test
1.5479

Oneway Analysis of 15km E/W By 15km LT Bins (Nominal CARP)



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	80	77.100	374.591	41.881	-6.3	160.46
2	83	-30.151	354.638	38.927	-107.6	47.29

Means Comparisons

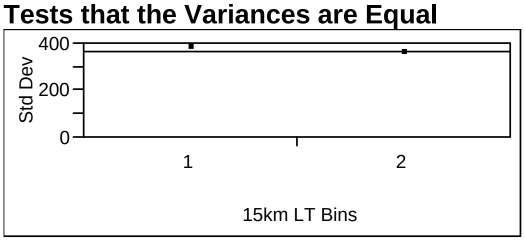
Comparisons for each pair using Student's t

t	Alpha
1.97481	0.05

Abs(Dif)-LSD	1	2
1	-113.83	-5.55
2	-5.55	-111.76

Positive values show pairs of means that are significantly different.

Tests that the Variances are Equal



Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1	80	374.5915	299.8042	299.8042
2	83	354.6377	289.1837	289.0077

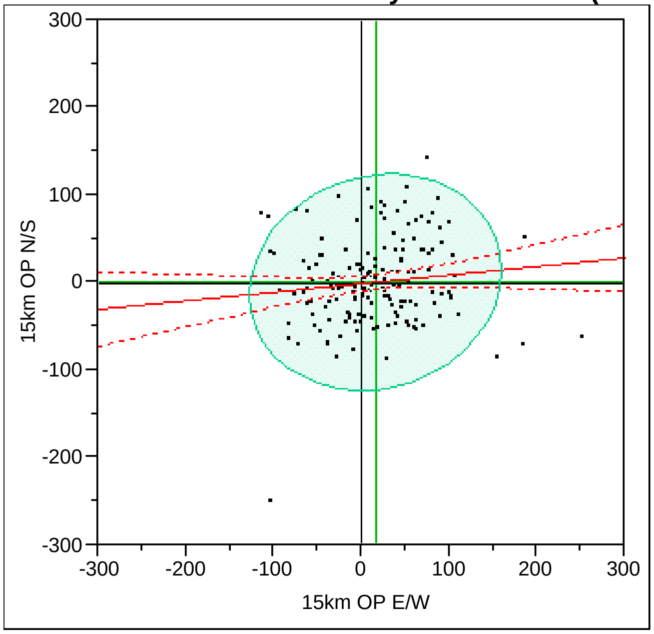
Test	F Ratio	DFNum	DFDen	p-Value
O'Brien[.5]	0.2584	1	161	0.6119
Brown-Forsythe	0.1041	1	161	0.7473
Levene	0.1018	1	161	0.7501
Bartlett	0.2397	1	.	0.6244
F Test 2-sided	1.1157	79	82	0.6235

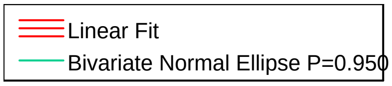
Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
3.5185	1	159.66	0.0625

t Test
1.8758

Bivariate Fit of 15km OP N/S By 15km OP E/W (Nominal OP)





Linear Fit

15km OP N/S = -1.011746 + 0.0975291 15km OP E/W

Summary of Fit

RSquare	0.01278
Rsquare Adj	0.006648
Root Mean Square Error	50.41698
Mean of Response	0.552814
Observations (or Sum Wgts)	163

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	160	409241.40	2557.76	.
Pure Error	1	0.00	0.00	Prob > F
Total Error	161	409241.40		.
				Max RSq
				1.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	5297.85	5297.85	2.0842
Error	161	409241.40	2541.87	Prob > F
C. Total	162	414539.25		0.1508

Parameter Estimates

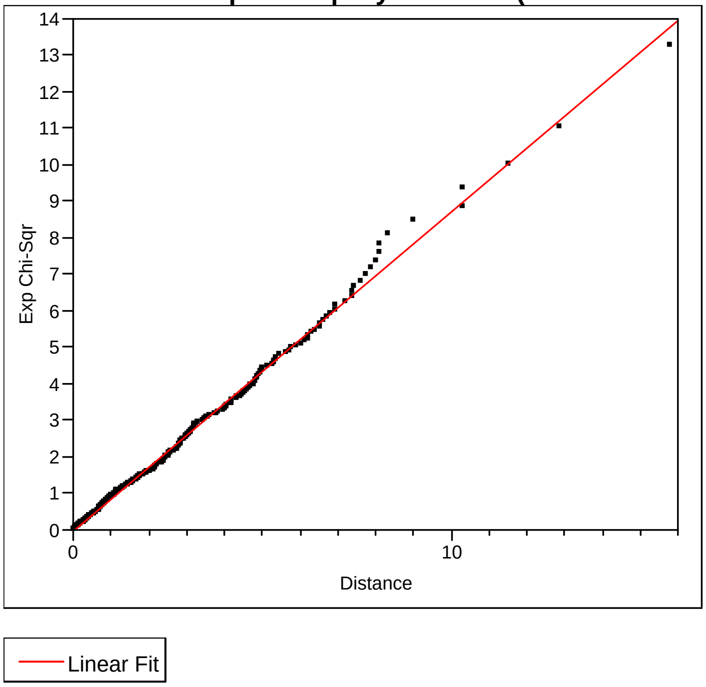
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.011746	4.094969	-0.25	0.8052
15km OP E/W	0.0975291	0.067556	1.44	0.1508

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
15km OP E/W	16.04198	58.63512	0.113049	0.1508	163
15km OP N/S	0.552814	50.58542			

Appendix D: 45km JMP 6 Analysis Output

Bivariate Fit of Exp Chi-Sqr By Distance (Nominal CARP)



Linear Fit

Exp Chi-Sqr = -0.043957 + 0.8737868 Distance

Summary of Fit

RSquare	0.996655
RSquare Adj	0.996646
Root Mean Square Error	0.115216
Mean of Response	1.998153
Observations (or Sum Wgts)	375

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	371	4.9511034	0.013345	64.8420
Pure Error	2	0.0004116	0.000206	Prob > F
Total Error	373	4.9515150		0.0153
				Max RSq
				1.0000

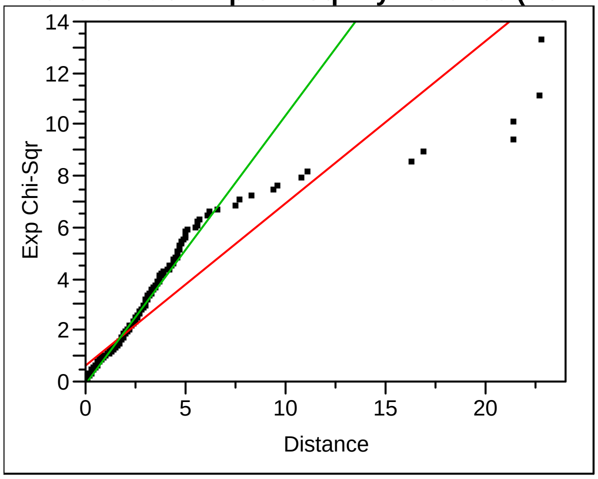
Analysis of Variance

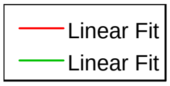
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1475.3287	1475.33	111137.2
Error	373	4.9515	0.013275	Prob > F
C. Total	374	1480.2802		0.0000

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.043957	0.008539	-5.15	<.0001
Distance	0.8737868	0.002621	333.37	0.0000

Bivariate Fit of Exp Chi-Sqr By Distance (Nominal OP)





Linear Fit

Exp Chi-Sqr = 0.6325086 + 0.6302233 Distance

Summary of Fit

RSquare	0.851123
RSquare Adj	0.850724
Root Mean Square Error	0.768656
Mean of Response	1.998153
Observations (or Sum Wgts)	375

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	369	220.37995	0.597236	16924.85
Pure Error	4	0.00014	0.000035	Prob > F
Total Error	373	220.38009		<.0001
				Max RSq
				1.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1259.9001	1259.90	2132.419
Error	373	220.3801	0.59	Prob > F
C. Total	374	1480.2802		<.0001

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.6325086	0.049499	12.78	<.0001
Distance	0.6302233	0.013648	46.18	<.0001

Linear Fit

Exp Chi-Sqr = -0.056533 + 1.0449162 Distance

Summary of Fit

RSquare	0.988978
RSquare Adj	0.988947
Root Mean Square Error	0.145563
Mean of Response	1.65801
Observations (or Sum Wgts)	354

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	348	7.4582215	0.021432	607.3446
Pure Error	4	0.0001412	0.000035	Prob > F
Total Error	352	7.4583626		<.0001
				Max RSq
				1.0000

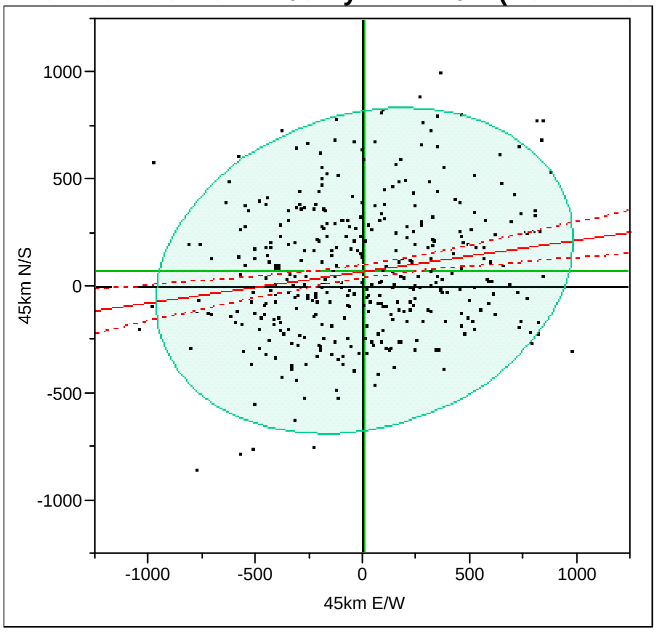
Analysis of Variance

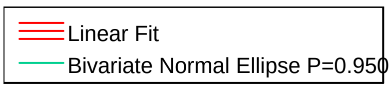
Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	669.21491	669.215	31583.83
Error	352	7.45836	0.021	Prob > F
C. Total	353	676.67327		0.0000

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.056533	0.012366	-4.57	<.0001
Distance	1.0449162	0.00588	177.72	0.0000

Bivariate Fit of 45km N/S By 45km E/W (Nominal CARP)





Linear Fit

45km N/S = 72.951882 + 0.1476738 45km E/W

Summary of Fit

RSquare	0.035599
RSquare Adj	0.033014
Root Mean Square Error	306.7014
Mean of Response	74.12761
Observations (or Sum Wgts)	375

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	371	35086535	94572.9	.
Pure Error	2	0	0.0	Prob > F
Total Error	373	35086535		.
				Max RSq
				1.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	1295163	1295163	13.7687
Error	373	35086535	94066	Prob > F
C. Total	374	36381698		0.0002

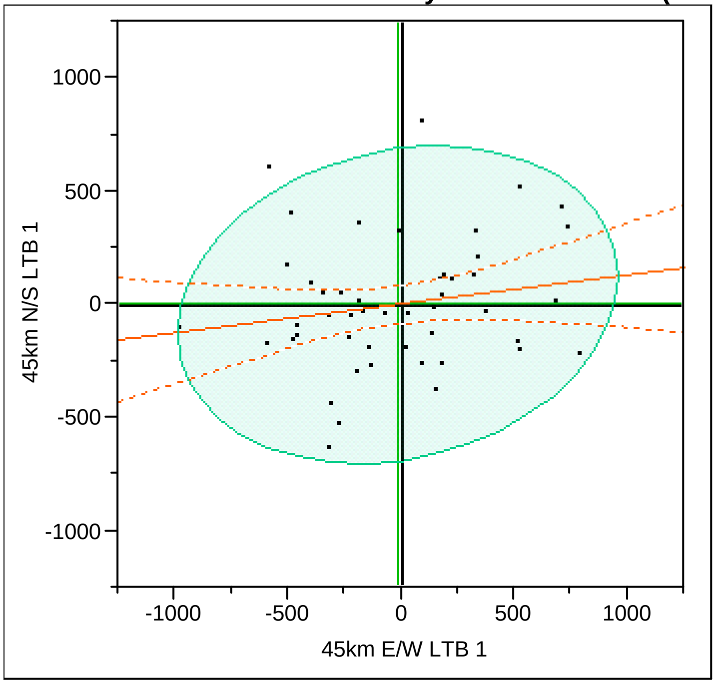
Parameter Estimates

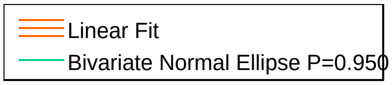
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	72.951882	15.84116	4.61	<.0001
45km E/W	0.1476738	0.039798	3.71	0.0002

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W	7.961625	398.495	0.188678	0.0002	375
45km N/S	74.12761	311.893			

Bivariate Fit of 45km N/S LTB 1 By 45km E/W LTB 1 (Nominal CARP)





Linear Fit

45km N/S LTB 1 = 2.0917632 + 0.1272016 45km E/W LTB 1

Summary of Fit

RSquare	0.0312
RSquare Adj	0.010139
Root Mean Square Error	284.6842
Mean of Response	0.103331
Observations (or Sum Wgts)	48

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	120061.9	120062	1.4814
Error	46	3728074.7	81045	Prob > F
C. Total	47	3848136.7		0.2298

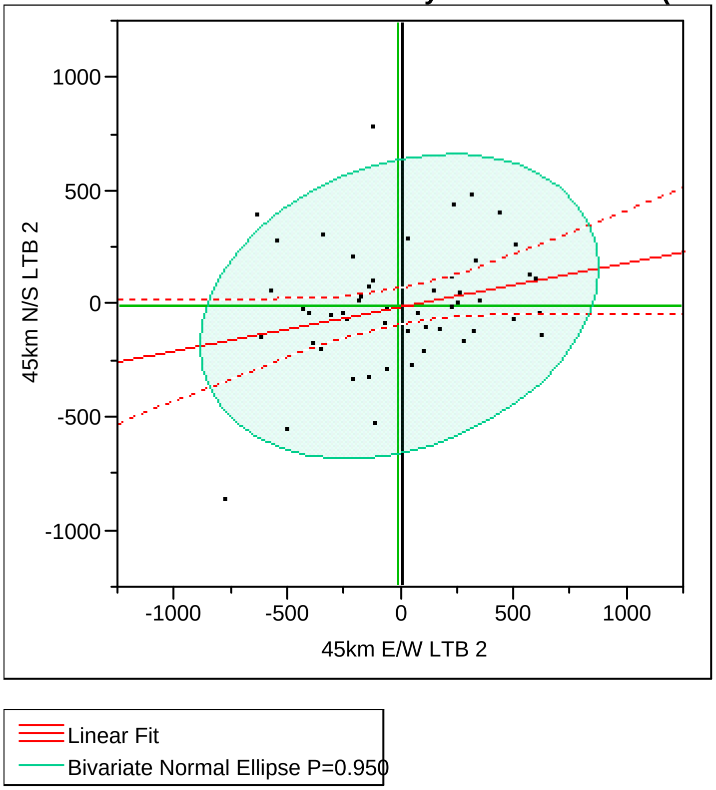
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2.0917632	41.12309	0.05	0.9597
45km E/W LTB 1	0.1272016	0.104509	1.22	0.2298

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W LTB 1	-15.6321	397.339	0.176635	0.2298	48
45km N/S LTB 1	0.103331	286.1385			

Bivariate Fit of 45km N/S LTB 2 By 45km E/W LTB 2 (Nominal CARP)



Linear Fit

45km N/S LTB 2 = -4.657001 + 0.1945243 45km E/W LTB 2

Summary of Fit

RSquare	0.064771
RSquare Adj	0.045685
Root Mean Square Error	268.1706
Mean of Response	-6.75877
Observations (or Sum Wgts)	51

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	244051.7	244052	3.3936
Error	49	3523859.1	71915	Prob > F
C. Total	50	3767910.9		0.0715

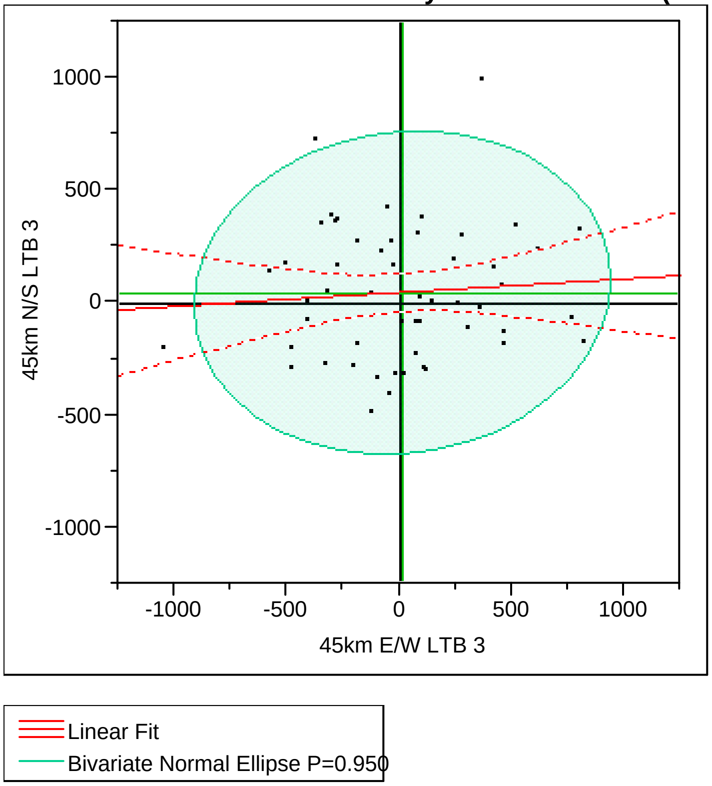
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-4.657001	37.56873	-0.12	0.9019
45km E/W LTB 2	0.1945243	0.105595	1.84	0.0715

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W LTB 2	-10.8047	359.1552	0.254502	0.0715	51
45km N/S LTB 2	-6.75877	274.5145			

Bivariate Fit of 45km N/S LTB 3 By 45km E/W LTB 3 (Nominal CARP)



Linear Fit

45km N/S LTB 3 = 43.369608 + 0.0618356 45km E/W LTB 3

Summary of Fit

RSquare	0.006309
RSquare Adj	-0.01317
Root Mean Square Error	296.5201
Mean of Response	44.09412
Observations (or Sum Wgts)	53

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	28472.0	28472.0	0.3238
Error	51	4484132.2	87924.2	Prob > F
C. Total	52	4512604.3		0.5718

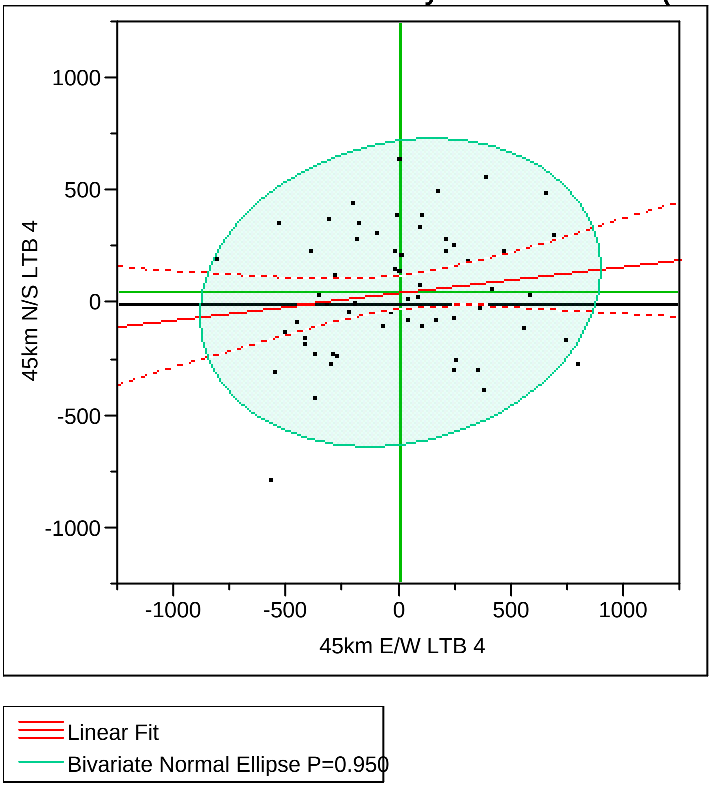
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	43.369608	40.75006	1.06	0.2922
45km E/W LTB 3	0.0618356	0.108663	0.57	0.5718

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W LTB 3	11.71682	378.4157	0.079432	0.5718	53
45km N/S LTB 3	44.09412	294.5859			

Bivariate Fit of 45km N/S LTB 4 By 45km E/W LTB 4 (Nominal CARP)



Linear Fit

45km N/S LTB 4 = 48.626014 + 0.1174245 45km E/W LTB 4

Summary of Fit

RSquare	0.023548
RSquare Adj	0.006713
Root Mean Square Error	277.4933
Mean of Response	49.32453
Observations (or Sum Wgts)	60

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	107706.7	107707	1.3987
Error	58	4466146.2	77003	Prob > F
C. Total	59	4573852.8		0.2418

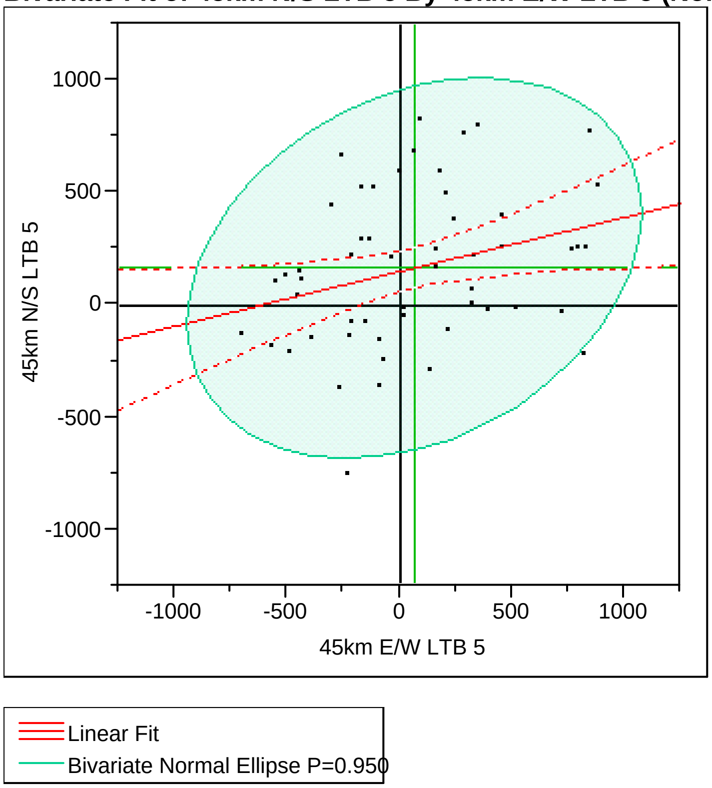
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	48.626014	35.8291	1.36	0.1800
45km E/W LTB 4	0.1174245	0.099286	1.18	0.2418

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W LTB 4	5.948603	363.862	0.153455	0.2418	60
45km N/S LTB 4	49.32453	278.4294			

Bivariate Fit of 45km N/S LTB 5 By 45km E/W LTB 5 (Nominal CARP)



Linear Fit

45km N/S LTB 5 = 146.66501 + 0.242952 45km E/W LTB 5

Summary of Fit

RSquare	0.084747
RSquare Adj	0.066801
Root Mean Square Error	333.3951
Mean of Response	162.638
Observations (or Sum Wgts)	53

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	524891.8	524892	4.7223
Error	51	5668765.7	111152	Prob > F
C. Total	52	6193657.4		0.0344

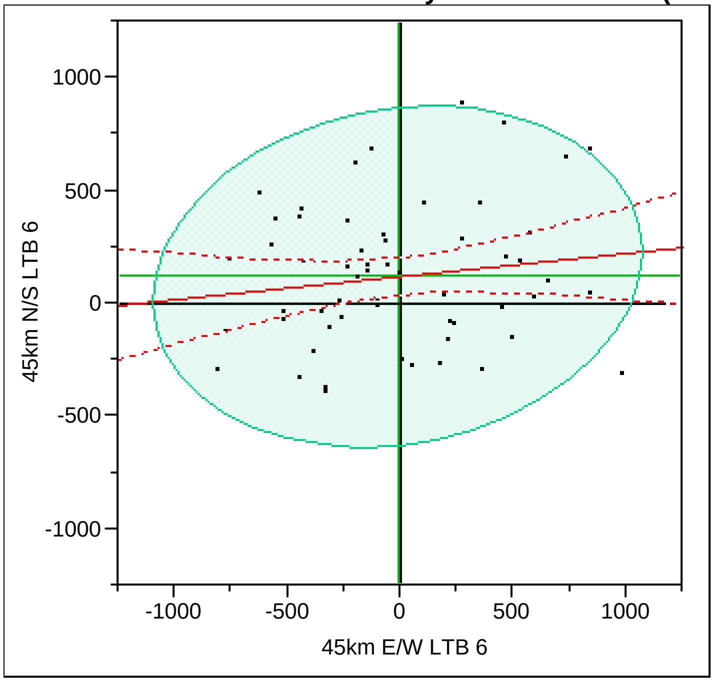
Parameter Estimates

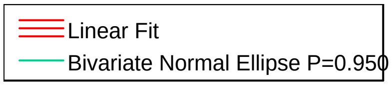
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	146.66501	46.38147	3.16	0.0026
45km E/W LTB 5	0.242952	0.111801	2.17	0.0344

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W LTB 5	65.74553	413.5354	0.291113	0.0344	53
45km N/S LTB 5	162.638	345.1214			

Bivariate Fit of 45km N/S LTB 6 By 45km E/W LTB 6 (Nominal CARP)





Linear Fit

45km N/S LTB 6 = 121.5945 + 0.1008843 45km E/W LTB 6

Summary of Fit

RSquare	0.020912
RSquare Adj	0.00311
Root Mean Square Error	308.2769
Mean of Response	120.3183
Observations (or Sum Wgts)	57

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	111637.0	111637	1.1747
Error	55	5226906.7	95035	Prob > F
C. Total	56	5338543.7		0.2832

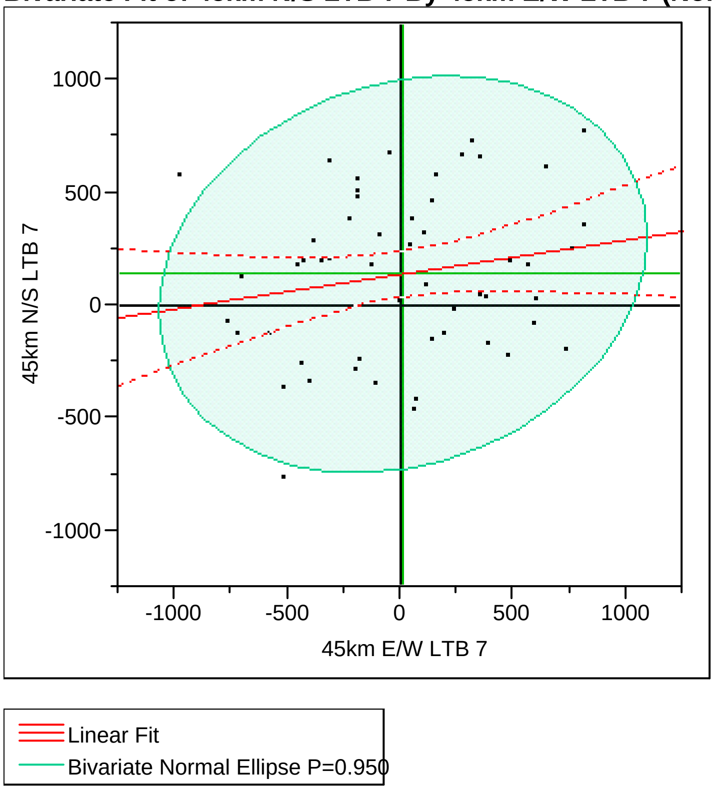
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	121.5945	40.84925	2.98	0.0043
45km E/W LTB 6	0.1008843	0.093081	1.08	0.2832

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W LTB 6	-12.6501	442.5745	0.144608	0.2832	57
45km N/S LTB 6	120.3183	308.7574			

Bivariate Fit of 45km N/S LTB 7 By 45km E/W LTB 7 (Nominal CARP)



Linear Fit

45km N/S LTB 7 = 137.36229 + 0.1520644 45km E/W LTB 7

Summary of Fit

RSquare	0.035013
RSquare Adj	0.016092
Root Mean Square Error	356.2166
Mean of Response	138.9278
Observations (or Sum Wgts)	53

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	234806.0	234806	1.8505
Error	51	6471403.7	126890	Prob > F
C. Total	52	6706209.7		0.1797

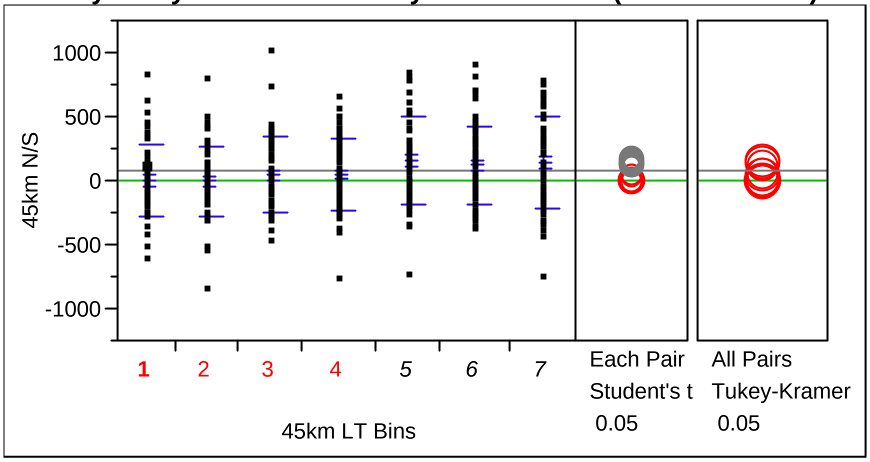
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	137.36229	48.94365	2.81	0.0071
45km E/W LTB 7	0.1520644	0.111786	1.36	0.1797

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km E/W LTB 7	10.2948	441.9014	0.187118	0.1797	53
45km N/S LTB 7	138.9278	359.1178			

Oneway Analysis of 45km N/S By 45km LT Bins (Nominal CARP)



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	48	0.10	286.139	41.301	-82.98	83.19
2	51	-6.76	274.515	38.440	-83.97	70.45
3	53	44.09	294.586	40.464	-37.10	125.29
4	60	49.32	278.429	35.945	-22.60	121.25
5	53	162.64	345.121	47.406	67.51	257.77
6	57	120.32	308.757	40.896	38.39	202.24
7	53	138.93	359.118	49.329	39.94	237.91

Means Comparisons
Comparisons for each pair using Student's t

t	Alpha
1.96643	0.05

Abs(Dif)-LSD	5	7	6	4	3	1	2
5	-117.71	-94.00	-73.30	-0.91	0.84	41.80	50.54
7	-94.00	-117.71	-97.01	-24.62	-22.87	18.09	26.83
6	-73.30	-97.01	-113.50	-41.08	-39.40	1.51	10.29
4	-0.91	-24.62	-41.08	-110.63	-108.99	-68.12	-59.32
3	0.84	-22.87	-39.40	-108.99	-117.71	-76.74	-68.00
1	41.80	18.09	1.51	-68.12	-76.74	-123.68	-114.99
2	50.54	26.83	10.29	-59.32	-68.00	-114.99	-119.99

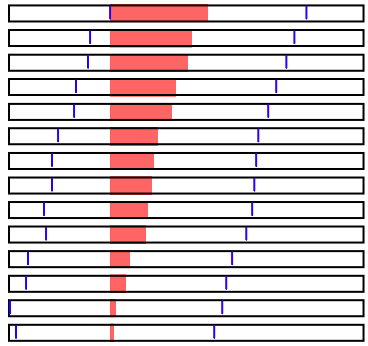
Positive values show pairs of means that are significantly different.

Level				Mean
5	A			162.6380
7	A	B		138.9278
6	A	B		120.3183
4	A	B	C	49.3245
3		B	C	44.0941
1			C	0.1033
2			C	-6.7588

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value	Difference
5	2	169.3968	50.542	288.2513	0.0053	
5	1	162.5347	41.802	283.2672	0.0085	
7	2	145.6865	26.832	264.5410	0.0164	
7	1	138.8244	18.092	259.5569	0.0243	
6	2	127.0771	10.286	243.8686	0.0330	
6	1	120.2150	1.513	238.9171	0.0472	
5	3	118.5439	0.838	236.2500	0.0484	

Level	- Level	Difference	Lower CL	Upper CL	p-Value	Difference
5	4	113.3135	-0.908	227.5349	0.0518	
7	3	94.8336	-22.872	212.5398	0.1140	
7	4	89.6032	-24.618	203.8247	0.1238	
6	3	76.2242	-39.398	191.8468	0.1957	
6	4	70.9938	-41.079	183.0670	0.2137	
4	2	56.0833	-59.321	171.4878	0.3399	
3	2	50.8529	-68.002	169.7074	0.4007	
4	1	49.2212	-68.117	166.5589	0.4100	
3	1	43.9908	-76.742	164.7233	0.4741	
5	6	42.3197	-73.303	157.9424	0.4721	
5	7	23.7103	-93.996	141.4164	0.6923	
7	6	18.6095	-97.013	134.2321	0.7518	
1	2	6.8621	-114.990	128.7144	0.9119	
4	3	5.2304	-108.991	119.4518	0.9283	



Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.96474	0.05

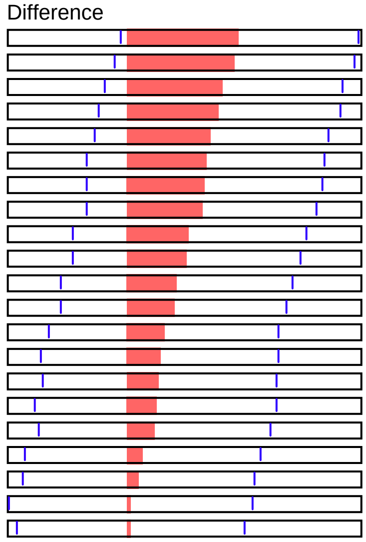
Abs(Dif)-LSD	5	7	6	4	3	1	2
5	-177.46	-153.75	-132.00	-58.90	-58.92	-19.49	-9.80
7	-153.75	-177.46	-155.71	-82.61	-82.63	-43.20	-33.51
6	-132.00	-155.71	-171.12	-97.98	-98.10	-58.75	-49.01
4	-58.90	-82.61	-97.98	-166.79	-166.98	-127.69	-117.91
3	-58.92	-82.63	-98.10	-166.98	-177.46	-138.03	-128.34
1	-19.49	-43.20	-58.75	-127.69	-138.03	-186.48	-176.85
2	-9.80	-33.51	-49.01	-117.91	-128.34	-176.85	-180.91

Positive values show pairs of means that are significantly different.

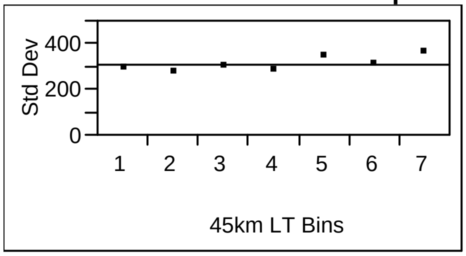
Level		Mean
5	A	162.6380
7	A	138.9278
6	A	120.3183
4	A	49.3245
3	A	44.0941
1	A	0.1033
2	A	-6.7588

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	Difference
5	2	169.3968	-9.797	348.5905	
5	1	162.5347	-19.490	344.5598	
7	2	145.6865	-33.507	324.8802	
7	1	138.8244	-43.201	320.8495	
6	2	127.0771	-49.006	303.1605	
6	1	120.2150	-58.749	299.1790	
5	3	118.5439	-58.918	296.0062	
5	4	113.3135	-58.895	285.5221	
7	3	94.8336	-82.629	272.2960	
7	4	89.6032	-82.605	261.8118	
6	3	76.2242	-98.097	250.5453	
6	4	70.9938	-97.976	239.9635	
4	2	56.0833	-117.909	230.0755	
3	2	50.8529	-128.341	230.0466	
4	1	49.2212	-127.686	226.1281	
3	1	43.9908	-138.034	226.0159	
5	6	42.3197	-132.001	216.6409	
5	7	23.7103	-153.752	201.1726	
7	6	18.6095	-155.712	192.9306	
1	2	6.8621	-176.851	190.5756	
4	3	5.2304	-166.978	177.4390	



Tests that the Variances are Equal



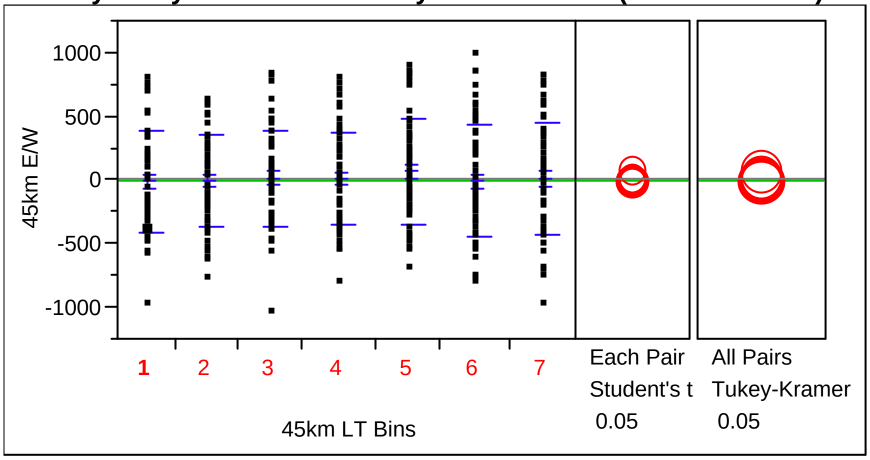
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1	48	286.1385	216.4796	213.5568
2	51	274.5145	192.9826	192.0040
3	53	294.5859	238.2328	236.6768
4	60	278.4294	228.2225	226.7965
5	53	345.1214	279.0342	278.9815
6	57	308.7574	247.6645	247.8394
7	53	359.1178	297.0261	294.7004

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.2329	6	368	0.2885
Brown-Forsythe	1.9188	6	368	0.0768
Levene	1.9868	6	368	0.0667
Bartlett	1.1944	6	.	0.3057

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
2.4046	6	162.36	0.0297

Oneway Analysis of 45km E/W By 45km LT Bins (Nominal CARP)



Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean	Lower 95%	Upper 95%
1	48	-15.632	397.339	57.351	-131.0	99.74
2	51	-10.805	359.155	50.292	-111.8	90.21
3	53	11.717	378.416	51.979	-92.6	116.02
4	60	5.949	363.862	46.974	-88.0	99.94
5	53	65.746	413.535	56.803	-48.2	179.73
6	57	-12.650	442.575	58.620	-130.1	104.78
7	53	10.295	441.901	60.700	-111.5	132.10

Means Comparisons
Comparisons for each pair using Student's t

t	Alpha
1.96643	0.05

Abs(Dif)-LSD	5	3	7	4	2	6	1
5	-153.14	-99.11	-97.69	-88.81	-78.08	-72.03	-75.70
3	-99.11	-153.14	-151.72	-142.84	-132.11	-126.06	-129.73
7	-97.69	-151.72	-153.14	-144.26	-133.53	-127.48	-131.15
4	-88.81	-142.84	-144.26	-143.93	-133.39	-127.21	-131.08
2	-78.08	-132.11	-133.53	-133.39	-156.11	-150.10	-153.71
6	-72.03	-126.06	-127.48	-127.21	-150.10	-147.67	-151.45
1	-75.70	-129.73	-131.15	-131.08	-153.71	-151.45	-160.92

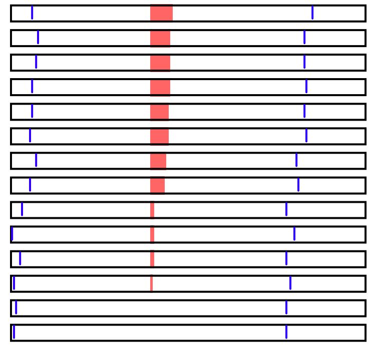
Positive values show pairs of means that are significantly different.

Level		Mean
5	A	65.74553
3	A	11.71682
7	A	10.29480
4	A	5.94860
2	A	-10.80468
6	A	-12.65008
1	A	-15.63213

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	p-Value	Difference
5	1	81.37766	-75.698	238.4538	0.3090	
5	6	78.39561	-72.032	228.8237	0.3061	
5	2	76.55021	-78.083	231.1830	0.3310	
5	4	59.79693	-88.808	208.4020	0.4293	
5	7	55.45073	-97.688	208.5895	0.4769	
5	3	54.02871	-99.110	207.1675	0.4883	
3	1	27.34895	-129.727	184.4251	0.7323	

Level	- Level	Difference	Lower CL	Upper CL	p-Value	Difference
7	1	25.92693	-131.149	183.0030	0.7457	
3	6	24.36690	-126.061	174.7950	0.7503	
7	6	22.94488	-127.483	173.3730	0.7644	
3	2	22.52150	-132.111	177.1543	0.7747	
4	1	21.58074	-131.079	174.2402	0.7812	
7	2	21.09948	-133.533	175.7323	0.7886	
4	6	18.59869	-127.212	164.4089	0.8021	
4	2	16.75328	-133.391	166.8976	0.8264	
3	4	5.76822	-142.837	154.3733	0.9392	
2	1	4.82746	-153.706	163.3605	0.9523	
7	4	4.34620	-144.259	152.9513	0.9542	
6	1	2.98205	-151.453	157.4167	0.9697	
2	6	1.84541	-150.103	153.7942	0.9810	
3	7	1.42202	-151.717	154.5608	0.9854	



Comparisons for all pairs using Tukey-Kramer HSD

q*	Alpha
2.96474	0.05

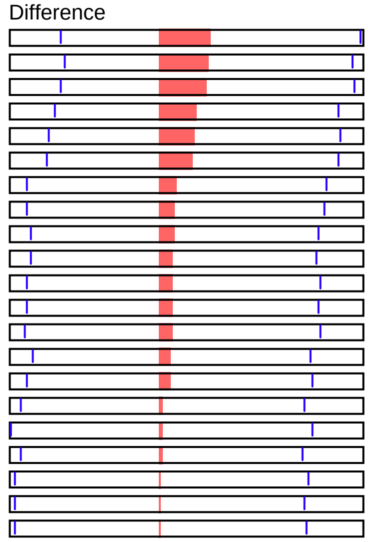
Abs(Dif)-LSD	5	3	7	4	2	6	1
5	-230.88	-176.85	-175.43	-164.25	-156.59	-148.40	-155.44
3	-176.85	-230.88	-229.46	-218.28	-210.61	-202.43	-209.47
7	-175.43	-229.46	-230.88	-219.70	-212.04	-203.85	-210.89
4	-164.25	-218.28	-219.70	-217.00	-209.62	-201.24	-208.58
2	-156.59	-210.61	-212.04	-209.62	-235.37	-227.24	-234.19
6	-148.40	-202.43	-203.85	-201.24	-227.24	-222.63	-229.85
1	-155.44	-209.47	-210.89	-208.58	-234.19	-229.85	-242.61

Positive values show pairs of means that are significantly different.

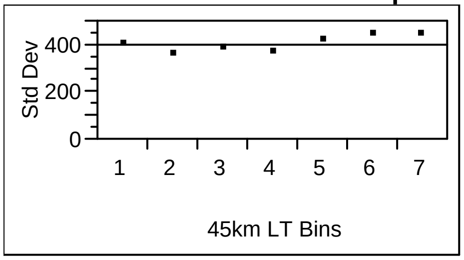
Level		Mean
5	A	65.74553
3	A	11.71682
7	A	10.29480
4	A	5.94860
2	A	-10.80468
6	A	-12.65008
1	A	-15.63213

Levels not connected by same letter are significantly different.

Level	- Level	Difference	Lower CL	Upper CL	Difference
5	1	81.37766	-155.442	318.1971	
5	6	78.39561	-148.401	305.1920	
5	2	76.55021	-156.585	309.6859	
5	4	59.79693	-164.251	283.8448	
5	7	55.45073	-175.432	286.3339	
5	3	54.02871	-176.854	284.9118	
3	1	27.34895	-209.470	264.1683	
7	1	25.92693	-210.892	262.7463	
3	6	24.36690	-202.429	251.1633	
7	6	22.94488	-203.851	249.7413	
3	2	22.52150	-210.614	255.6572	
4	1	21.58074	-208.580	251.7412	
7	2	21.09948	-212.036	254.2352	
4	6	18.59869	-201.235	238.4328	
4	2	16.75328	-209.615	243.1217	
3	4	5.76822	-218.280	229.8161	
2	1	4.82746	-234.189	243.8435	
7	4	4.34620	-219.702	228.3941	
6	1	2.98205	-229.855	235.8189	
2	6	1.84541	-227.244	230.9345	
3	7	1.42202	-229.461	232.3051	



Tests that the Variances are Equal



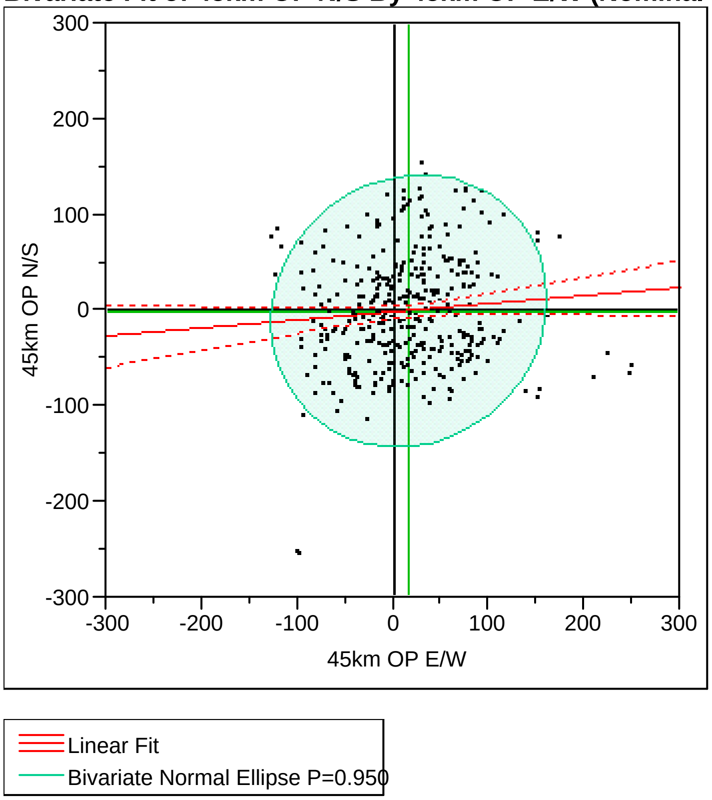
Level	Count	Std Dev	MeanAbsDif to Mean	MeanAbsDif to Median
1	48	397.3390	326.6421	326.6421
2	51	359.1552	299.1003	298.4077
3	53	378.4157	295.0329	294.6817
4	60	363.8620	294.2648	294.1885
5	53	413.5354	338.0630	335.4860
6	57	442.5745	366.6649	360.2060
7	53	441.9014	362.9761	362.5760

Test	F Ratio	DFNum	DFDen	Prob > F
O'Brien[.5]	1.0776	6	368	0.3753
Brown-Forsythe	0.8953	6	368	0.4983
Levene	1.0443	6	368	0.3961
Bartlett	0.7998	6	.	0.5699

Welch Anova testing Means Equal, allowing Std Devs Not Equal

F Ratio	DFNum	DFDen	Prob > F
0.2408	6	162.4	0.9624

Bivariate Fit of 45km OP N/S By 45km OP E/W (Nominal OP)



Linear Fit

45km OP N/S = -1.500542 + 0.0839099 45km OP E/W

Summary of Fit

RSquare	0.007213
RSquare Adj	0.004551
Root Mean Square Error	57.91268
Mean of Response	-0.13898
Observations (or Sum Wgts)	375

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	371	1250996.5	3371.96	.
Pure Error	2	0.0	0.00	Prob > F
Total Error	373	1250996.5		.
				Max RSq
				1.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	9088.7	9088.70	2.7099
Error	373	1250996.5	3353.88	Prob > F
C. Total	374	1260085.2		0.1006

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.500542	3.102866	-0.48	0.6290
45km OP E/W	0.0839099	0.050973	1.65	0.1006

Correlation

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number

Variable	Mean	Std Dev	Correlation	Signif. Prob	Number
45km OP E/W	16.2265	58.74914	0.084928	0.1006	375
45km OP N/S	-0.13898	58.04491			

Appendix E: Bivariate Normal MATLAB Code

```
function [M] = BivarStats(Z)

D = [];
k = length(Z);
x = Z(:,2);
y = Z(:,1);
Zbar = [mean(x) mean(y)]';
Sigma = cov([x,y])
v = [];

for i = 1:k
    xt = (i - .5)/k;
    Zi = Z(i,:)';
    di2 = (Zi - Zbar)'*(Sigma^-1)*(Zi - Zbar);
    Xsq = chi2inv(xt,2);
    D = [D;di2,Xsq];
end

M = sort(D);

plot(M(:,1),M(:,2),'*')


mu = [mean(x) mean(y)]
x1 = -1250:10:1250;
x2 = -1250:10:1250;
[X1,X2] = meshgrid(x1,x2);
F = mvnpdf([X1(:) X2(:)],mu,Sigma);
F = reshape(F,length(x2),length(x1));
h = surf(x1,x2,F);
caxis([min(F(:))-.5*range(F(:)),max(F(:))]);
axis([-1250 1250 -1250 1250 0 2.0e-6])
xlabel('x1'); ylabel('x2'); zlabel('Probability Density');

[V,D] = eigs(Sigma)
```

Note: This script is optimized to view CARP data. In order to view OP data, variables *x1*, *x2,* and *axis* must be changed to smaller scales to ensure correct plotting of data.

Appendix F: Bivariate Normal MATLAB Input Script

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                  %
%   Bivariate Normal Test Script    %
%                                  %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

r = menu('Choose resolution to be evaluated','5km','15km','45km','5km
OP','15km OP','45km OP');

format compact

if r == 1

    Z = [150.437523 -75.750732
        -131.954659 -92.498073
        -29.42237   946.396638
        159.860508  5.546833
        979.366917  469.531369
        32.588577   325.299697
        -46.562242  403.046916
        32.588205   -303.228644
        -46.558575  73.977157
        -263.907812 -90.609921
        -259.151387 146.072017
        -164.545424 -999.964325
        285.463218  -210.725415
        -37.245641  -358.683511
        -392.646767 44.372029
        -136.484016 -249.547516
        -364.766941 -42.471685
        -214.158804 -378.866974
        142.817998  -107.249294
        173.769628  452.84694
        -339.868473 -210.723391
        108.586868  -565.640328
        166.076721  107.251901
        648.585893  -232.890433
        -79.142105  258.753925
        -378.584711 -328.952473
        -130.384523 175.57118
        -104.021534 380.865298
        325.91052   -208.949223
        69.833144   199.638626
        -153.625722 1112.763332
        -51.213623  517.617579
        436.088357  700.628178
        121.055473  -364.117126
        62.00744    -81.407993
        -249.822042 -304.999875
        333.765964  317.98451
        68.341809   -260.63892
        375.553112  194.099854
```

229.691587	-192.204881
-296.493919	14.755564
73.008638	-40.592793
339.818724	11.096987
153.662914	-515.7301
-231.196065	303.120295
-231.196065	303.120295
-341.325626	386.306502
260.718193	534.257617
259.144239	245.780246
310.303691	183.007095
-142.764426	-299.455867
215.643433	229.25381
333.656969	221.82576
-141.274091	110.910966
302.64853	641.508008
83.812547	123.775894
-277.804449	317.982626
353.822272	534.149857
-302.586035	-203.293986
-162.938233	-314.318438
-330.558394	-351.246922
116.366124	391.958386
-243.590615	449.188988
299.552512	-218.155673
311.940967	260.643756
-82.219532	-105.364325
43.4882	33.273105
266.866183	597.032814
-6.146016	844.690329
200.209338	-147.841063
198.683175	-131.204918
-103.958339	231.027973
819.384442	20.331135
-18.624713	253.207526
530.763107	328.973875
228.128984	-343.818945
625.533231	562.000646
10.802642	251.321943
419.04352	839.26493
499.732322	-512.058407
-321.227325	-268.064812
169.167677	40.705575
-206.357891	478.80067
74.500297	449.185559
550.821917	64.787228
-159.888899	-369.661988
69.830193	-260.638981
296.392731	-79.407124
509.042745	-388.171497
443.903561	759.743693
563.420716	3.676363
-152.067713	177.457235
245.296661	64.663595
133.525494	149.729633

276.213843	-205.179526
-55.866525	-96.0481
-100.85067	305.003077
-496.570319	-497.197876
-319.646532	-234.680845
139.68508	582.27833
-52.789655	-423.344789
144.324797	395.506704
254.570803	-654.367091
-85.296202	284.706548
133.439541	615.551626
228.141097	-146.065926
628.60283	-463.9162
622.379744	-495.304997
170.701857	207.070349
-229.661101	-171.90861
-180.082911	-404.820562
457.85284	-554.540096
479.608254	-114.66905
239.005926	-158.931519
-100.8314	-428.889908
38.725473	179.342452
-169.201363	40.59455
-119.469029	94.274332
6.237754	341.936633
681.414155	-79.498541
374.031016	136.759471
68.354335	266.184125
437.59987	-11.081169
389.485016	672.899756
-167.612399	329.071647
-82.229343	-430.663267
333.630493	-321.633801
426.693836	46.25899
532.2713	-926.085193
6.238602	-323.525046
-122.523509	-600.800893
141.169977	377.09516
-336.694439	-365.997915
313.465104	149.734112
-74.49009	1.774849
460.975672	-432.538056
131.910026	240.344032
451.494029	22.192612
159.875421	-249.546644
114.901424	-654.369744
97.788801	134.977785
-66.769215	671.005521
232.779182	377.097403
417.426942	-55.446123
-310.357214	72.096539
204.856675	414.140448
35.666135	545.344413
251.427883	-556.432674
-26.4407	253.208408

```
        -214.159621 -297.680654
        678.328171  410.390456
        529.216524  -12.851172
        274.701132  299.461054
        367.758551  37.051021
        -375.64323  83.18982
        442.351826  -399.265895
        392.503062  279.169439
        524.588187  -373.308803
        49.722655   94.273773
        49.722655   94.273773
        -189.294085 -133.09044
        -235.866458 138.640492];

    disp('5km Resolution')

elseif r == 2

    Z = [153.603343 -118.340326
        -130.371625 -96.158125
        -4.655455   857.668393
        96.268581   158.934998
        952.920921  462.097767
        41.899782   282.821114
        -17.041904  332.729886
        44.971688   -295.797607
        -97.772951  79.523043
        -299.572521 -57.335875
        -282.431785 127.550683
        -155.233142 -990.758945
        302.59606   -253.203541
        -21.788671  -345.707068
        -423.652789 38.827821
        -122.519939 -317.979425
        -283.994818 199.642461
        -336.829662 -40.698133
        -206.338611 -438.093185
        119.542256  -81.40749
        176.935344  480.574498
        -319.662536 -208.949514
        113.24295   -539.798258
        180.041702  46.251358
        660.968649  -251.300742
        -17.038888  225.480539
        -373.93228  -408.475292
        -66.682078  218.159926
        -94.708016  476.913246
        335.222758  -223.699951
        88.456023   122.001625
        -116.384939 961.259364
        -74.49277   488.004722
        402.008993  624.875153
        110.160146  -334.615175
        145.802611  -170.135359
        -251.404531 -288.363305
```

311.973734	336.394839
104.002275	-244.002064
397.254163	94.281662
263.863261	-262.410237
-318.191049	9.210747
114.914741	-94.272833
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109.029759	-66.101911
20.110984	44.69687
-21.600932	-62.553378
37.242597	17.191167
47.949641	48.911561
-43.295103	-77.858922
-37.987791	-53.569595
-16.573023	3.549143
-6.238093	13.9747
-55.119935	-67.544203
34.915531	-106.917447
12.103746	120.337684
51.952955	70.428183
13.779812	63.218873
13.500566	-25.176625
-6.796856	-34.825823
-54.747081	54.900743
-31.377077	56.786116
-23.276919	16.082018
-71.320352	18.522279
30.818579	71.758997
39.849989	32.385883
-24.021732	-12.976473

```
        -21.414419  88.284619
        -6.424337   44.031387
        -54.468219  -6.543553
        93.571512   91.279627
        -14.152291  -47.802325
        6.051884    44.807761
        -22.811277  -39.151305
        -27.466798  65.215278
        6.23809 40.48226
        49.999105   -46.804006
        -9.683136   -65.658884
        48.229147   106.252177
        -67.782402  190.654977]

    disp('5km Resolution OP')

elseif r == 5

    Z = [95.899074  87.952342
        13.593605   25.509376
        35.84618    81.075483
        -5.213939   36.600398
        79.047517   80.632102
        -39.10504   40.815063
        -84.541623  -27.727203
        106.886608  7.875219
        -70.017544  -71.869603
        -76.627615  -9.316161
        -56.143669  -4.65807
        79.88727    -113.793608
        33.51843    8.651061
        -20.855995  -26.507537
        -4.65531    -6.100065
        66.384613   54.124454
        -56.050679  -45.805786
        -71.506317  -38.263786
        -11.172826  2.107302
        5.67948 -24.622084
        -52.419142  19.298532
        -70.017003  -38.263794
        -21.973346  -35.713087
        29.607676   103.701175
        90.871561   23.069768
        12.103891   61.222486
        -18.24898   7.320096
        -49.160639  54.900713
        -48.881237  71.869985
        -42.550326  -34.936644
        -22.066442  50.131471
        -39.104866  90.05923
        36.405035   69.873542
        44.225765   92.610188
        -21.042192  33.273109
        -10.055529  27.838488
        -15.26955   26.951212
```

-88.173013	29.391623
86.309948	12.200516
-28.397669	-41.147676
4.28289	4.658233
-5.213974	-33.051265
-16.852446	102.370197
15.362606	2.218218
6.5175	11.09103
-21.600939	-56.453311
69.457627	77.304719
-63.126617	252.210153
19.831798	-4.436391
11.824559	10.869216
-54.468002	14.085758
-10.707359	81.075417
31.004675	-46.249542
97.111265	-26.06343
-54.653791	62.886285
3.258755	27.94939
-15.828247	103.368389
72.158018	28.06057
3.072501	-54.346047
87.985689	27.506152
9.776251	-32.60762
81.00236	41.5917
10.05565	8.872827
24.114596	-65.658869
37.429045	-16.525561
-36.404955	-54.345973
27.187422	15.638387
-35.846266	111.021254
36.311763	70.317187
-44.691461	51.906115
70.481742	-4.103425
51.207416	185.885828
142.73328	75.42004
-84.262623	154.16563
49.160568	-44.142171
74.113393	68.764656
-6.610645	3.881862
20.949185	-2.661824
-11.172825	99.819261
-9.776303	-92.277353
14.0591	0.00001
36.032247	48.024223
-42.363571	62.331675
-46.274451	-17.856445
17.690366	16.858379
74.020453	-104.920852
32.214781	-98.377391
-40.315437	-12.97642
-49.347028	-53.347721
13.314294	78.191759
-64.989488	-81.297015
-29.328609	45.362353

-37.522429	-12.200058
81.004263	-61.554863
12.103942	42.145915
-8.19334	23.956627
-12.941824	92.388278
-249.341902	-103.697919
19.924811	-0.443621
-23.09062	57.451552
0	0.887282
16.759474	-59.891534
20.949194	-51.68417
-40.874325	12.422037
-27.094107	35.713151
-37.89465	-12.643699
-18.435389	-5.878227
-33.79782	39.927762
-16.479931	31.942177
49.345996	60.557153
26.069776	46.027808
0.279317	53.569674
-44.691605	-6.432693
16.200659	-13.863772
-6.982951	-26.285738
68.898274	100.595888
24.300845	46.582353
46.832965	47.136982
-5.213939	36.600398
78.116919	22.404192
-36.59131	-3.105419
-61.450926	-22.403683
108.934453	52.793912
2.979443	-38.042223
-46.088252	0.33284
-7.262367	-60.667921
82.68019	-73.75498
5.400157	16.969276
-24.207937	-60.889717
38.17362	28.06038
55.118876	37.487838
-47.391866	-82.406224
-33.984041	-15.08374
-15.641955	2.77277
-3.444918	11.645582
-38.17386	3.549204
-68.899703	-37.154699
35.381057	-103.035586
6.517376	106.030249
71.225877	63.330046
11.452151	55.122419
-5.400194	-20.962042
-11.266055	-9.649187
-51.302085	60.002597
-25.97685	63.662538
-24.673545	11.978341
-46.832977	39.373263

```
        33.61178    78.413623
        36.311881   39.040486
        -19.55256   -6.654597
        -21.41451   46.693257
        -4.84153    43.587744
        -50.09195   30.278634
        90.778714   50.464609
        -12.476383  -64.32796
        -9.683048   11.091034
        -8.3796 -31.609429
        -23.276901  84.624566
        10.893446   36.378583
        30.446377   -45.140433
        -12.755752  -75.418985
        61.543476   89.615708
        -71.413653  183.778566]

    disp('15km Resolution OP')

elseif r == 6

    Z = [123.365245 93.387257
        15.176372   57.562453
        26.349263   83.7373
        8.286477    -8.096448
        66.292295   24.400489
        -55.864393  31.942322
        120.573459  -4.324753
        -86.125222  -62.663922
        -79.234433  14.751391
        -65.7338    -17.190872
        59.868695   -80.964314
        31.749483   -16.08194
        -29.79426   -20.407448
        -18.621377  -23.845695
        63.777749   38.042442
        -32.494428  -25.176581
        -13.500519  -13.087405
        12.662508   -18.18928
        -75.230457  0.776663
        -75.603304  -17.41262
        -6.517464   -8.872821
        59.774092   86.621127
        106.605927  74.643222
        -3.258723   58.671542
        -21.9733    -9.64917
        -52.884692  98.488476
        -57.819535  69.319098
        -61.358192  -45.029378
        -38.080906  50.242431
        -49.439734  87.951982
        45.250205   79.079132
        39.384276   75.751803
        -7.914053   0.110914
        53.81606    59.115327
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-19.086922	34.936759
95.155205	0.333197
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13.500514	-14.751059
-0.931064	-5.212784
-11.452179	132.205056
-35.008352	94.051977
24.207745	1.220043
8.193426	13.863788
-17.224854	14.972903
-3.444953	-40.482254
56.422823	53.237101
-65.54733	86.0666
-66.385396	247.773763
31.656266	-4.21454
27.280255	33.051305
37.428849	29.50221
50.463626	75.197311
-51.394894	68.209964
-31.935857	82.739118
5.213953	56.786069
89.476321	-13.197911
87.241198	-47.247393
76.626706	-125.882896
-73.089263	24.067806
-36.311759	4.76921
-4.562206	163.038113
-40.129004	41.03689
63.778352	31.942372
15.362632	-81.408147
107.910669	11.42436
-4.469122	-38.70769
109.120713	15.528055
19.55264	15.194727
30.725108	-48.800485
-114.057168	-25.508694
37.428954	7.209241
-25.604543	-67.766152
40.036679	-83.29353
-2.141468	-7.98554
-33.518587	110.688514
-0.55864	46.249588
11.172899	27.616666
-32.587404	0.332786
-25.604364	78.524517
-252.600555	-99.483244
30.166634	-31.831207
-37.429029	88.950118
15.269434	25.731201
-109.216277	-93.164014
16.014435	-15.083786
75.323523	-34.270988
-96.552531	38.486346
-30.352905	17.745693
76.811218	173.907681

-36.684241	-8.872754
-72.902979	74.864712
-41.153302	31.94225
-42.549799	50.131544
103.161597	10.315206
11.638339	7.763728
25.790376	73.533563
125.508431	77.305277
15.828139	42.478654
9.776162	-2.994573
-83.42465	154.498354
113.868539	85.62342
13.593607	24.400273
24.021615	73.311727
35.84609	20.185739
86.961669	70.650243
-41.2465	42.145995
-72.903065	-11.867127
124.297523	12.311838
-85.939156	-79.633194
-79.607006	-2.66152
-56.329878	-3.770786
37.336623	-122.001224
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76.99883	38.042538
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-68.713117	-40.482012
-6.796768	-1.774562
34.263238	-12.643713
45.622464	-37.15484
-57.540044	14.640329
-80.072627	-37.154614
-19.180117	-32.163964
48.135818	89.837461
105.48934	11.978886
9.776232	49.576903
-9.589983	-3.549124
-68.433887	48.800764
-53.536591	72.202741
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-27.466669	49.909665
-46.832815	72.97908
36.125716	68.986258
33.797807	89.282837
12.569418	22.292977
53.536729	60.66807
-11.079732	29.169412
-90.593788	32.164402
115.638581	11.424449
-20.856009	-48.911416
26.163038	-4.990928
-8.379606	-37.709494
-28.39776	105.032071

-37.056766	80.1882
43.94633	9.538385
8.193426	13.863788
-12.755736	-10.425558
-20.018141	-70.64983
66.385299	48.800752
-61.450781	61.000849
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-32.587614	-73.977107
22.345592	-0.665436
27.09417	-12.976466
58.657201	21.184043
-49.905601	38.264174
47.018712	70.982702
-45.342993	61.000764
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-79.886411	-34.381858
48.695052	-50.796791
-9.310659	25.842101
87.80041	-15.970684
66.10609	-71.647824
85.657989	-119.782754
-69.550971	53.791737
-37.708358	6.765601
-68.992607	-35.823777
-32.587522	51.684246
-11.917782	39.927706
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-29.328786	111.243051
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58.191925	32.164157
9.869312	-66.546175
113.31078	18.079039
4.376013	-34.93674
103.813437	35.27003
4.469152	12.643772
24.673265	-77.304449
-64.896288	-38.485649
43.294829	-24.954718
-21.042264	-60.778815
-46.554262	-79.855283
18.155978	18.632944
-21.600854	116.788546
20.018072	35.3804
22.438828	61.222501
-16.75922	9.5383
-21.321471	69.984414
-253.531586	-97.819565
30.445917	-19.852895
-33.704729	94.051978
13.686648	10.869219
-105.677768	-57.672768
-7.914079	-29.945774
90.685996	-15.748838
-93.94532	59.115633

0	41.369538
81.001106	151.725649
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83.888383	38.597149
30.911463	-3.105439
17.224665	47.691443
-55.491982	9.982084
125.415342	75.863442
-1.862134	-13.531055
6.331207	-22.95843
-89.942221	152.280206
100.554307	93.941546
13.593618	16.636553
38.173852	81.630044
48.13612	31.942284
98.878861	116.45631
-45.622641	20.74033
-79.327695	-39.040095
153.625864	30.501546
-75.604052	-72.091382
-74.113571	8.651285
-49.905688	-44.363985
38.174497	-95.493668
51.487979	18.854886
-5.493298	-41.036805
26.163068	-35.934899
72.157552	5.102142
-59.495865	-80.187952
-75.417037	-66.324059
11.824543	27.39485
33.052838	-8.540037
50.55727	-62.331451
-55.119346	0.554708
-73.927535	-39.261958
-24.021748	-51.462342
37.521675	104.255754
97.761337	30.611736
-18.621453	18.743856
-27.094225	-20.185634
-36.311941	26.729445
-53.350342	78.524626
-9.031352	38.485872
-33.518714	30.278564
-41.89813	76.306366
19.180202	41.591371
40.687838	60.668009
29.514827	31.942209
52.23318	69.319065
-4.376007	24.400264
-82.679543	42.811718
127.369798	29.170243
-4.376001	-20.296583

31.283878	7.098309
-21.69404	-61.555185
-19.087045	91.722814
-12.662599	91.057345
41.711769	9.982016
-1.396609	-3.88186
11.917721	27.727578
-29.328977	-94.717337
34.263461	25.842156
-47.019054	82.406453
-44.691538	224.593389
-10.521154	-83.182709
14.71085	-2.329105
37.521994	31.720416
78.209316	56.564566
-49.905601	38.264174
34.449441	46.360563
-61.636783	44.14249
-27.746086	60.224318
-50.557227	14.97302
39.663509	-14.640078
0	34.604009
99.252751	-27.061601
69.83054	-94.273496
65.267641	-116.455603
-66.757907	32.386032
-45.250094	-7.098153
-46.833092	-46.914937
-5.95882	65.7698
-18.156028	22.514802
-60.519713	12.42214
4.469138	81.186321
-49.905314	20.962173
51.208963	19.187614
5.400164	-74.198988
116.755596	28.837379
12.569469	-35.380374
87.892087	55.788279
-10.707426	-9.760098
21.600781	-93.386448
-54.188788	-24.62193
48.787972	10.647511
-26.070096	-73.755306
-49.626666	-45.251265
8.845206	-18.854743
-19.831869	92.166459
6.424367	39.262242
19.645653	41.480465
-19.273124	-0.998173
-36.497919	62.109828
22.718044	-15.416504
-29.049442	73.422649
8.379547	-4.103677
-94.504754	-54.123754
-0.65175	-65.215247

93.758511	-14.861527
-84.913884	61.777397
71.690628	152.612859
-37.615309	-7.652737
-78.955163	-18.521696
-43.480981	24.622181
87.333278	41.037206
13.221204	-30.05668
19.552325	46.360524
-37.242996	-4.43634
123.832644	66.214227
6.703674	1.109105
5.213941	-34.04946
-84.355866	138.638193
91.429874	100.374254
-2.234555	17.745646
38.732524	73.866326
42.829011	39.151428
77.27889	30.500636
-35.473957	13.531119
-61.450803	-2.994383
141.335746	33.828668
-34.449914	-13.309172
-64.709641	19.409515
-47.484916	-49.7986
82.866367	-69.096747
45.156802	2.772862
-20.483635	-59.226072
15.176474	-56.453326
60.705546	-10.203557
-68.434265	-87.840702
-66.199253	-44.918441
-9.962428	10.536483
35.38047	0.554616
55.21239	-19.076413
-64.988754	-9.205336
-85.845153	-19.963471
-30.81865	-67.544313
33.704314	109.912166
98.692341	36.157261
-10.893563	7.098264
-12.383276	-24.067524
-33.332667	-22.071087
-57.726421	70.539111
-43.667466	-0.554453
-26.070132	22.514821
-44.970701	67.322646
23.27685	80.964529
51.208962	58.228033
20.669664	43.809588
50.557324	54.900719
-9.310653	24.067537
-51.488299	80.520999
118.710864	31.055608
-16.293801	-74.864431

```
        24.02157    -1.219983
        -10.800447  -44.031378
        -30.259937  95.604703
        -28.863301  83.51548
        43.015169   30.833158
        -9.962542   -11.867394
        10.707323   31.609437
        -39.477737  -95.382763
        42.922444   23.623985
        -43.480994  80.742783
        -69.365094  210.175198]

    disp('45km Resolution OP')
end

[M] = BivarStats_f(Z);
```

Appendix G: JPADS-MP Help

JPADS-MP Operation – N Mission

The JPADS-MP is developed by Draper Labs and Planning Systems Inc (PSI), and a complete user's manual is available from them. The following sequence of figures will provide the reader with sufficient familiarity with the JPADS-MP Graphical User Interface (GUI) to recreate the steps taken in this research. Upon starting the JPADS-MP, the user is presented with the main GUI page as shown in following figure:

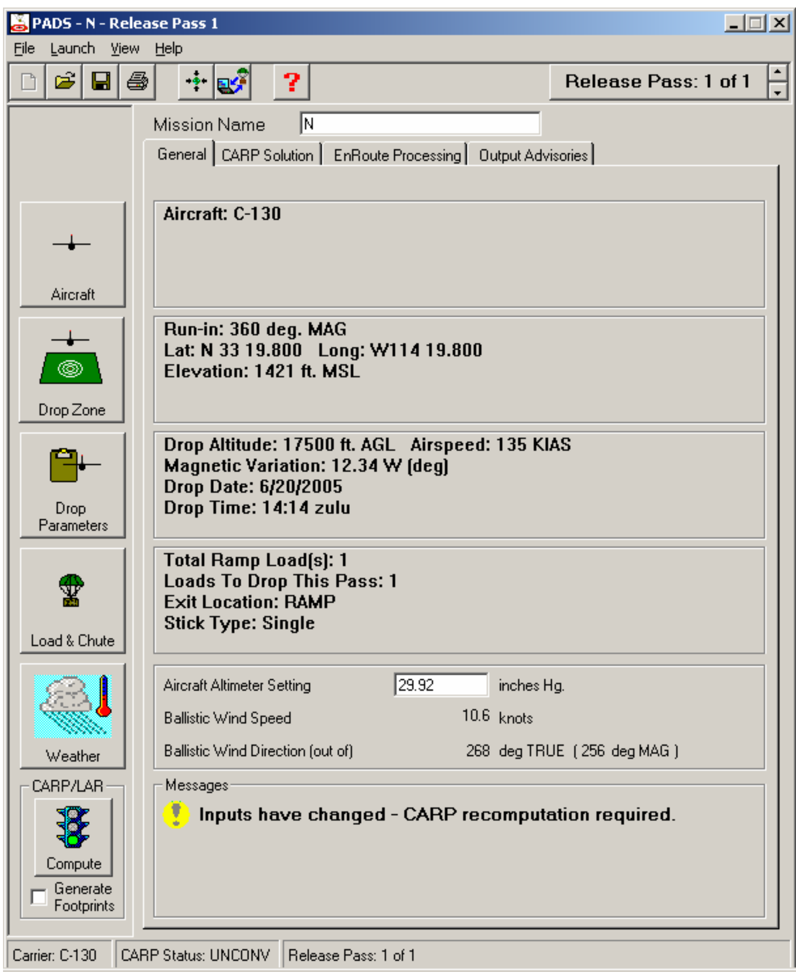


Figure 45. JPADS-MP main GUI.

In these examples, the *N* mission data already been entered. To begin anew, the user would need to enter a mission name and save the file. Clicking on the *Aircraft* tab allows the user to selects either the C-130 (the default) or the C-17. The next figure shows the *Drop Zone* tab:

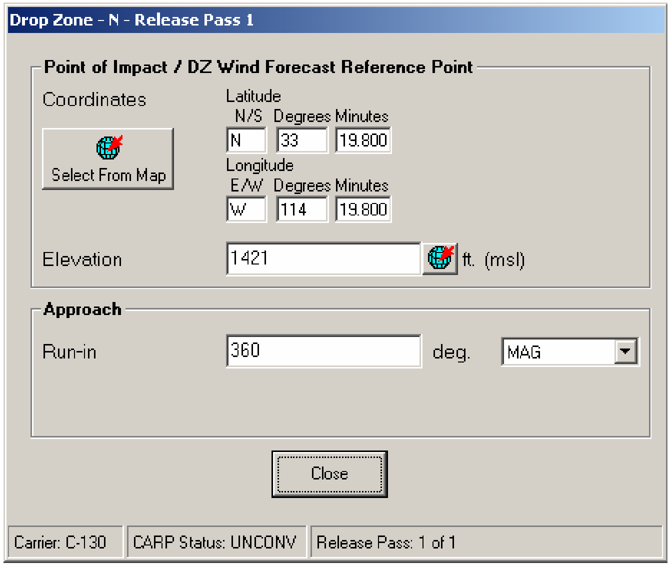


Figure 46. Drop Zone GUI

The *Drop Zone* tab allows the user to select the desired PI Wind Forecast Reference Point in terms of Latitude, Longitude, and Elevation. This is the point that the wind file will be centered on. For this study, the coordinates for Site 16 at YPG are used as this is the point from which the weather balloons were launched. This window is also where the aircraft approach data is defined. It is worth noting that the window is titled *Release Pass 1*. A key feature of JPADS is the ability to drop on multiple PIs or make multiple release passes. For this research, only a single Release Pass is used.

The next tab is *Drop Parameters*.

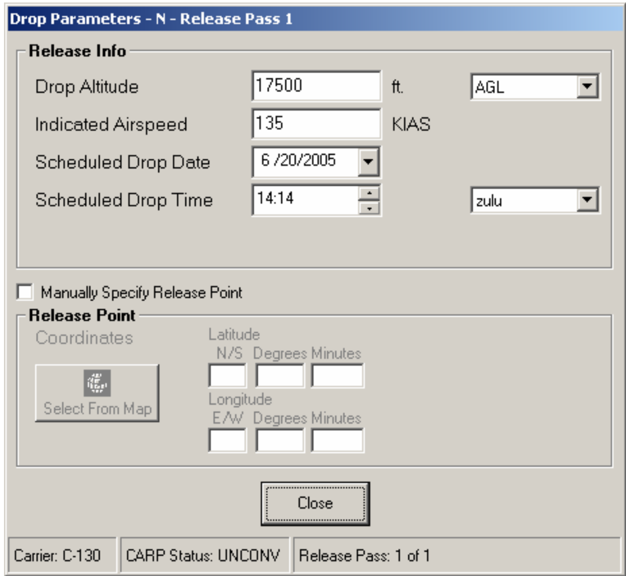


Figure 47. Drop Parameters GUI

This window allows the user to define details of airdrop in terms of Altitude, Airspeed, Date, and Time. The user has the option to manually specify a release point, but that option defeats the purpose of this research and is not used. It is critical for the data and time set here be in agreement with the date and time of the weather data the user intends to use for mission planning, otherwise the results will be invalid. The user must next fill out the *Load & Chute* tab. For full details of options for this page, please refer to the most current PSI published JPADS-MP user's manual.

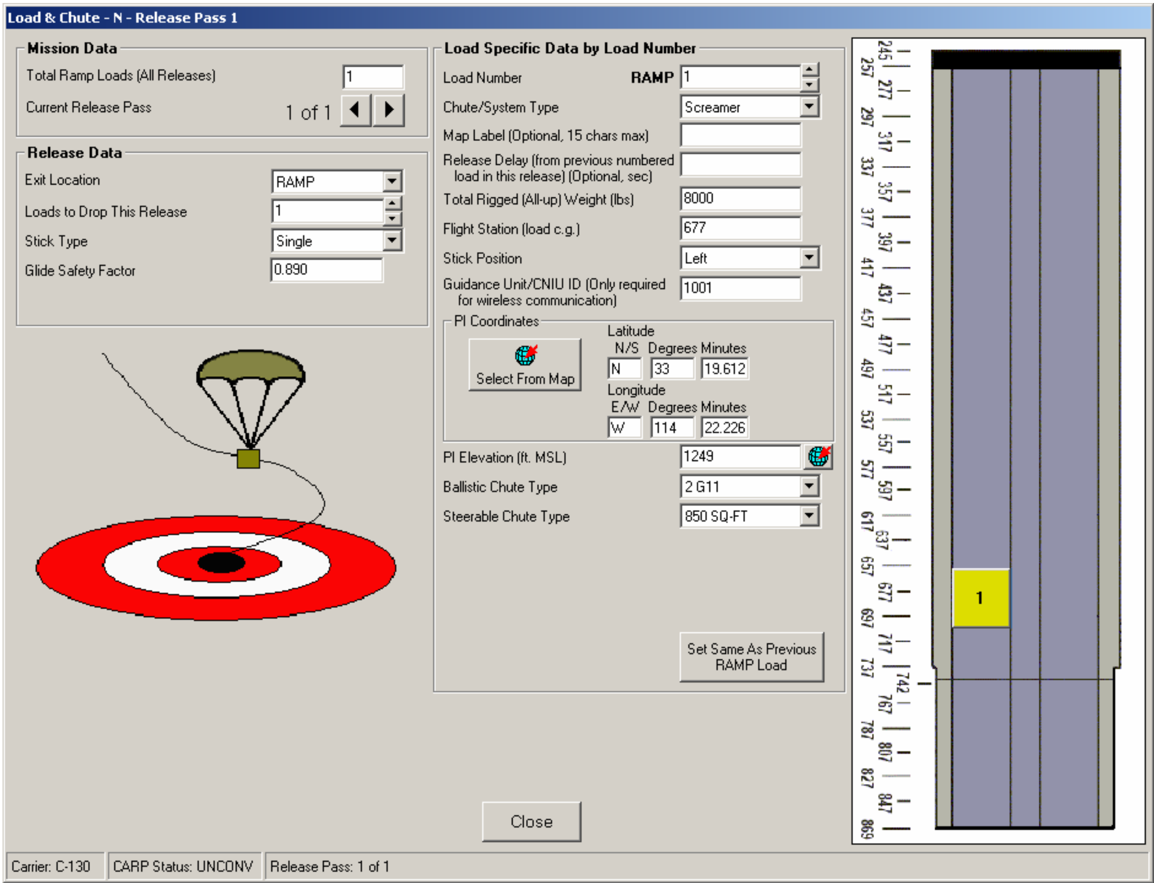


Figure 48. Load & Chute GUI

For this research, the settings in *Load & Chute* tab are held constant. The guided parachute system is the Screamer with 850 ft^2 parachute. The Ballistic Chute Type is set to two G11 parachutes. The PI coordinates and elevation are set here. This representative mission was created using an actual test point from the ACTD program, only the Run-In heading was changed to a cardinal direction. As a result, the PI is set as being the JPADS Center PI target as used in testing. This is located 3.7 km from Site 16. It may have been better for the purposes of this analysis to have set Site 16 to be the PI. Unfortunately, this was realized too late for implementation. However, any error incurred by this is believed to be minimal when considering that the minimum tested weather resolution was 5 km. Total Rigged Weight is 8000 lbs at Flight Station 677 on the left side of the fuselage. CNUI ID is set as 1001, but is not needed. The Glide Safety Factor is left at the default setting of 0.89. Finally the user is ready to gather weather data with the *Weather* tab.

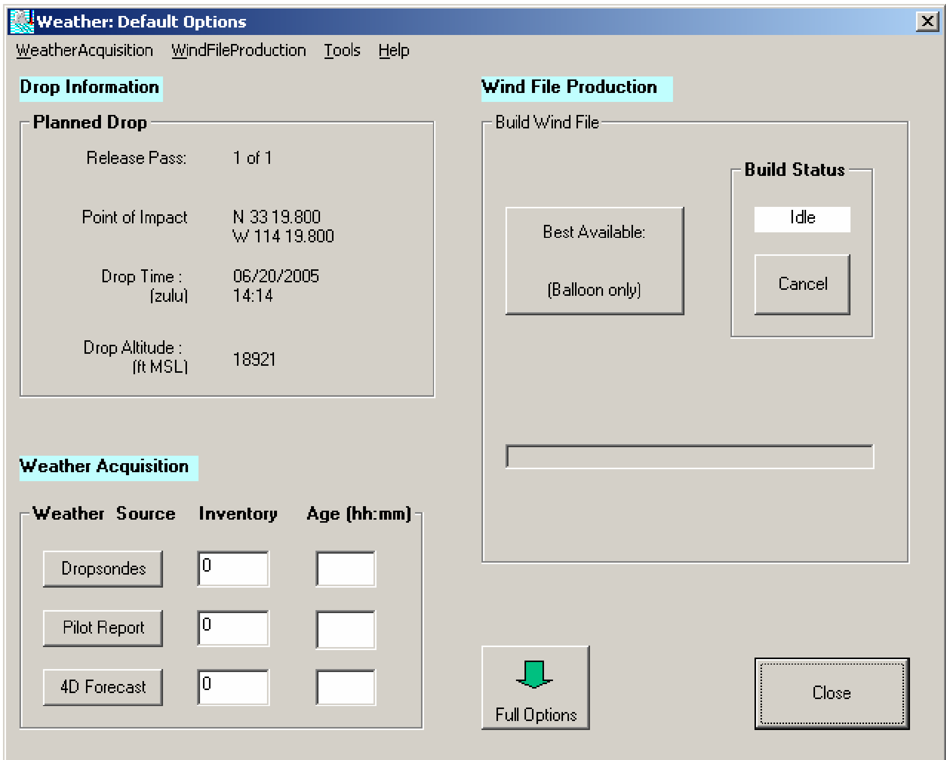


Figure 49. Weather GUI

The *Weather* tab is where most of the work in this research was done. The Drop Information shows data copied from the previous tabs. The next step is to acquire weather data. This is done by selecting one of the options under the Weather Acquisition section. The options relevant to this research are: Dropsondes, 4D Forecast, Balloon, and Climatology. In the interest of space, only the 4D Forecast method will be shown here. Other methods work similarly; where there are differences, they are detailed in the manual. Selecting an option under Weather Acquisition brings up the Weather Source – Acquire 4D Forecast GUI.

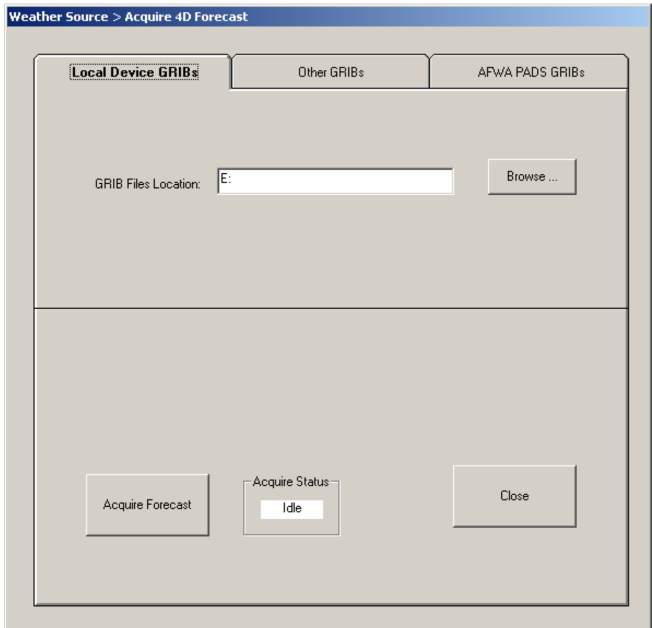


Figure 50. Weather Source GUI.

The JPADS-MP uses the 4D Forecasts generated by AFWA. These come in a format known as GRidded Information in Binary format (GRIB) files. Once these are downloaded, the *Browse* button is used to point the Weather Source GUI to the location of required GRIB files. Once the appropriate path is specified in the “GRIB Files Location” field, select the “Acquire Forecast” button. This will read the weather forecast into the JPADS-MP Environmental Data folder. Once this is complete, a *windgui* window opens showing the duration of valid times for the forecast as well as the forecast coverage area.

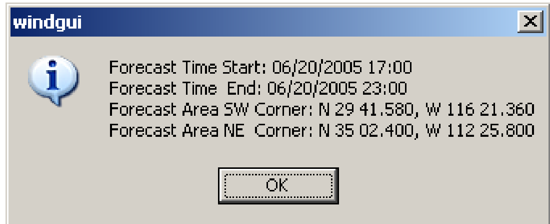


Figure 51. "windgui" Information Window

The user can then close this window as well as the Weather Source window and return to the *Weather* tab.

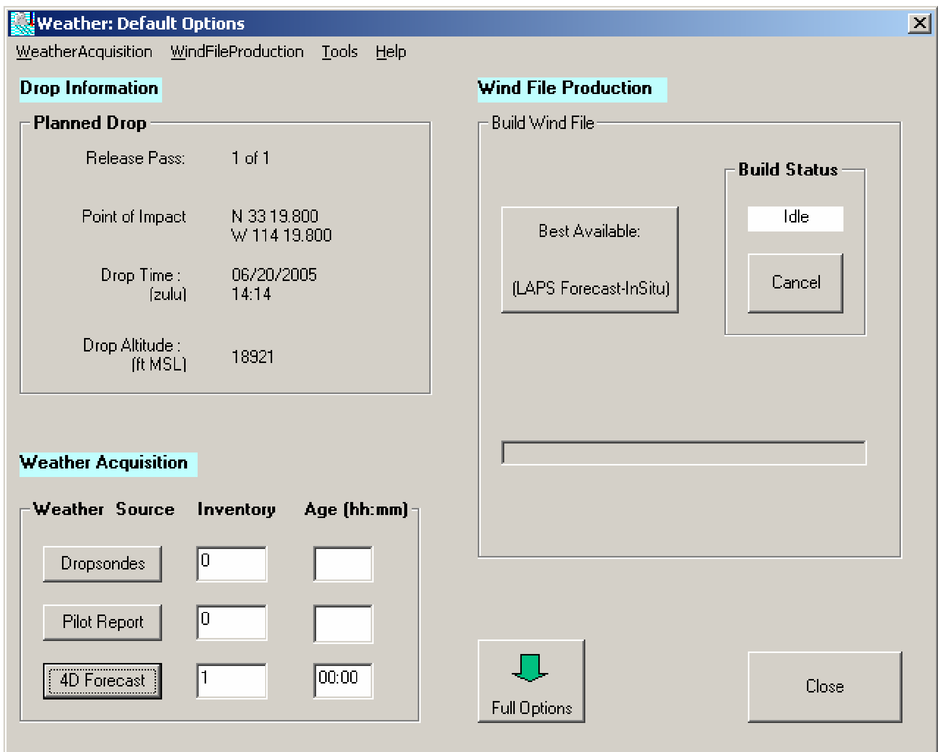


Figure 52. Weather GUI with 4D Forecast loaded.

Here, the 4D Forecast inventory now shows an increment of one and the Wind File Production section now has the options for wind file generation via LAPS Forecast-only, Forecast Only, and Climatology only. These are listed in order of best to worst methods for calculating an accurate wind file. The Local Analysis and Prediction System (LAPS) is the most advanced modeling method included within the JPADS-MP. It allows complex modeling of wind interaction with terrain features such as how wind will flow over or around terrain obstacles. Select either the *Best Available* or LAPS Forecast-only buttons to begin Wind File production.

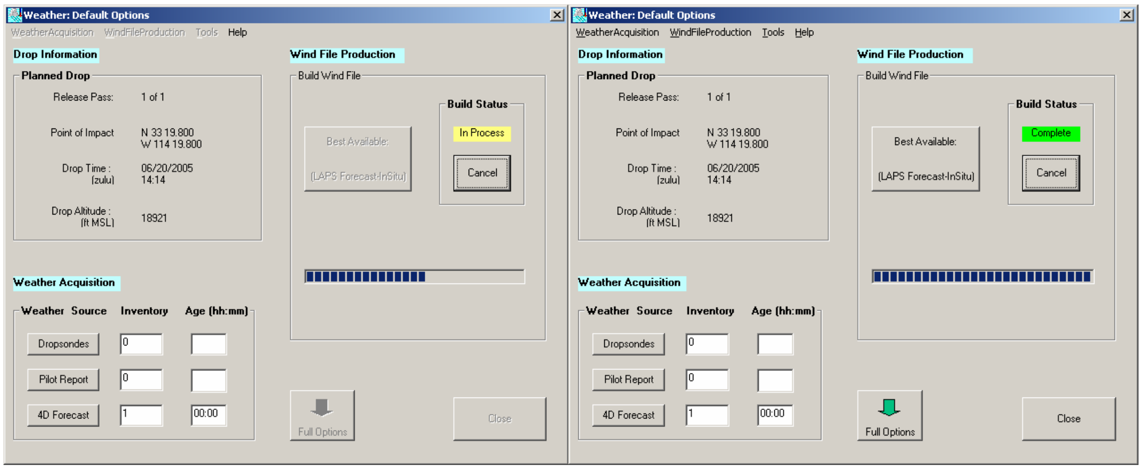


Figure 53. Weather GUI during Wind File production and production complete.

The LAPS Wind File production takes a few minutes to run. During this time, the Build Status indicator will be yellow and display "In Progress". This will change to "Complete" and the status bar will be full once the LAPS Wind File has been generated. The "Weather" tab can now be closed to return to main JPADS-MP GUI page. Once here, the user selects the *Calculate* button under the CARP/LAR section. Unless FalconView is installed, do not select generate footprints as it will result in a crash of the JPADS-MP (this option was not used in this research).

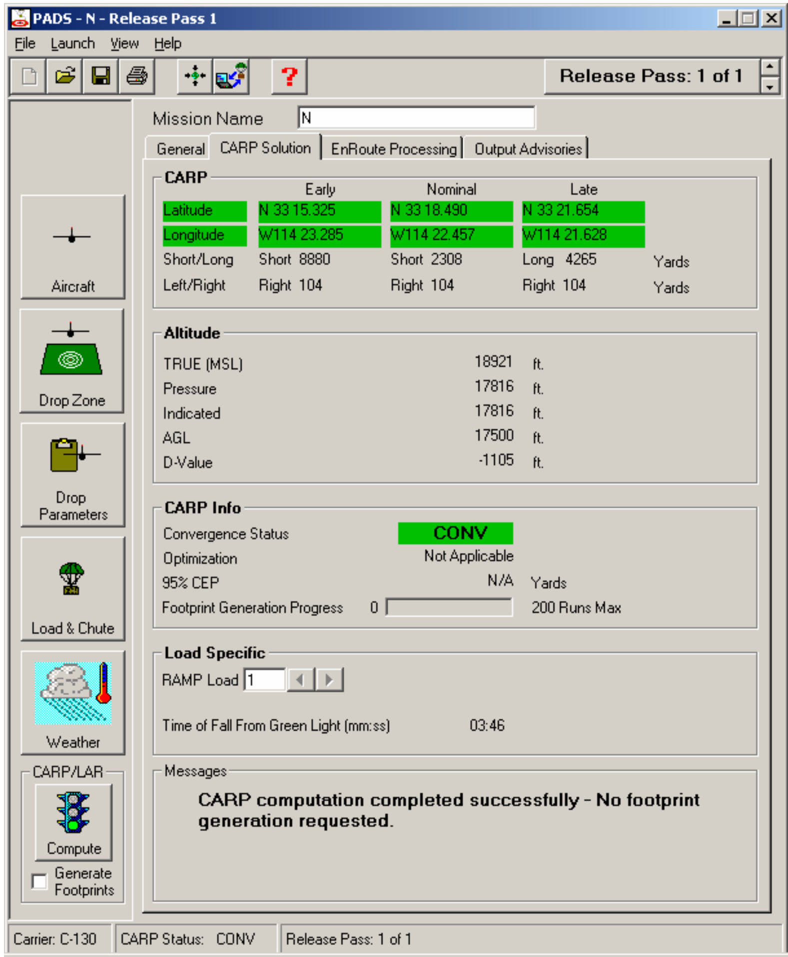


Figure 54. JPADS Main GUI CARP Solution TAB after successful CARP calculation.

Selecting *Compute* CARP will automatically open the CARP solution tab. The CARP section shows the Latitude and Longitude of the Early, Nominal, and Late CARPs which also define the boundaries of the LAR. In order to collect this data, an Optical Screen Reader tool was developed by Captain Ryan Eggert of the Air Force Research Laboratory Advanced Architecture and Integration Branch.

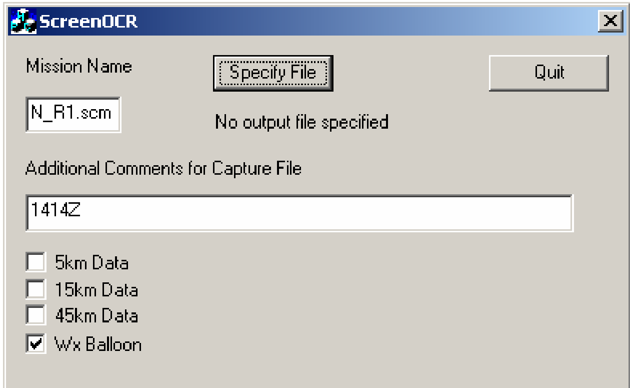


Figure 55. Screen OCR Main GUI

The Screen OCR tool reads the values in the Early, Nominal, and Late CARP coordinate boxes and copies them to a text file. In doing so, it also converts them from a DDD MM.mmm format to a DDD.dddddd format. The conversion to decimal degrees allows for easier mathematical operations later. Additionally, the Screen OCR copies the coordinates for the Screamer OP from its memory location and writes it to the same text file. To use the Screen OCR, ensure that the Mission Name is correct. This must match name of the Screamer mission data in memory. It will be mission followed by "_R1.scm". Check the type of data from which the wind profile is being generated and type in the launch time for a weather balloon (i.e., 1414Z) or the initialization time for a weather forecast (i.e., 0600 ini). Select "Specify File."

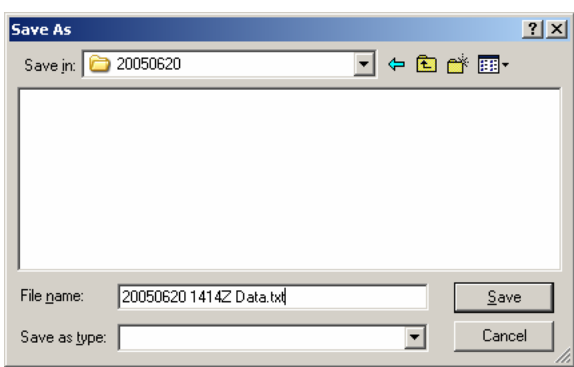
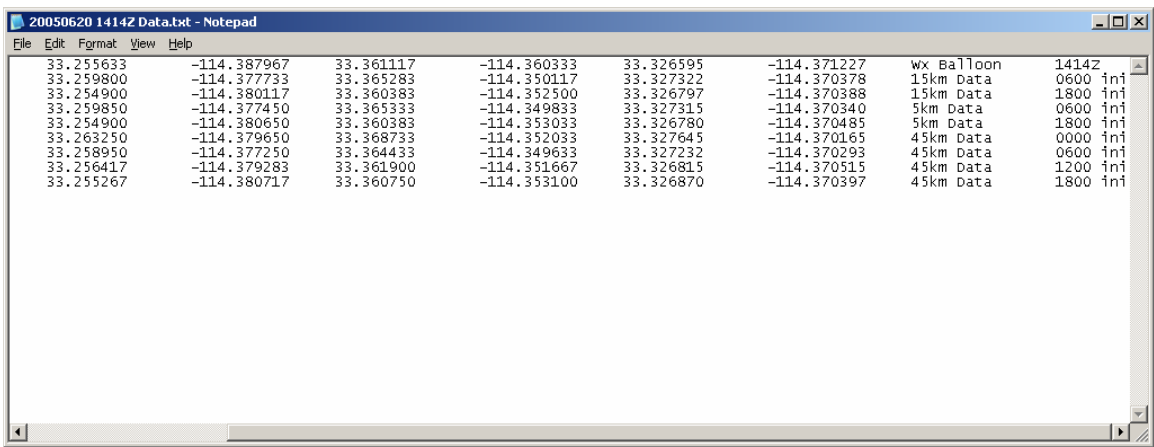


Figure 56. Screen OCR File Save As GUI

If starting a new file (for a weather balloon), enter the file name "YYYYMMDD TTTTZ Data.txt". Otherwise, click the appropriate existing file and select *Save*.

The method of building text files for analysis is to segregate the data by weather balloons. The Screen OCR allows for a new file to be opened and then to append subsequent data to this file. First, the CARP/LAR/OP is calculated for a weather balloon. This data is saved to a new file bearing the date and time of the balloon launch as the file name. Next the CARP/LAR/OP is calculated for each weather forecast that was valid for the time of that weather balloon launch. Each new data set is appended to the text file resulting in a file similar to the one shown below:


20050620 1414Z Data.txt - Notepad

File Edit Format View Help

33.255633	-114.387967	33.361117	-114.360333	33.326595	-114.371227	Wx Balloon	1414Z
33.259800	-114.377733	33.365283	-114.350117	33.327322	-114.370378	15km Data	0600 ini
33.254900	-114.380117	33.360383	-114.352500	33.326797	-114.370388	15km Data	1800 ini
33.259850	-114.377450	33.365333	-114.349833	33.327315	-114.370340	5km Data	0600 ini
33.254900	-114.380650	33.360383	-114.353033	33.326780	-114.370485	5km Data	1800 ini
33.263250	-114.379650	33.368733	-114.352033	33.327645	-114.370165	45km Data	0000 ini
33.258950	-114.377250	33.364433	-114.349633	33.327232	-114.370293	45km Data	0600 ini
33.256417	-114.379283	33.361900	-114.351667	33.326815	-114.370515	45km Data	1200 ini
33.255267	-114.380717	33.360750	-114.353100	33.326870	-114.370397	45km Data	1800 ini

Figure 57. Sample text file record of CARP and OP calculations from the JPADS-MP captured by the Screen OCR program.

As can be seen, each line represents a different weather input: weather balloon on the first line, followed by weather forecasts of varying resolution and initialization time. The coordinates of the CARPs and OP are to the left of the metadata. Capt Eggert also developed a CARP Analysis tool to generate Northing and Easting data from the raw coordinates captured by the Screen OCR. Note that in the Screen OCR created text file the column contain information in the following order:

Early Lat/Early Lon – Nom Lat/Nom Lon – Late Lat/Late Lon – OP Lat/OP Lon – Metadata

However, the CARP Analysis tool changes this order to:

Nom NS/Nom EW – Early NS/Early EW – Late NS/Late EW – OP NS/OP EW - Metadata

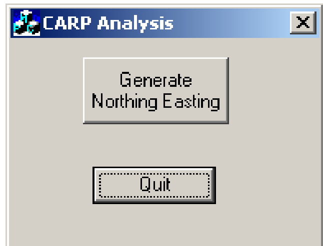


Figure 58. CARP Analysis Tool Initialization GUI.

Selecting the CARP Analysis tool opens the GUI above. Selecting *Generate Northing Easting* brings up the *Open* window for file selection.

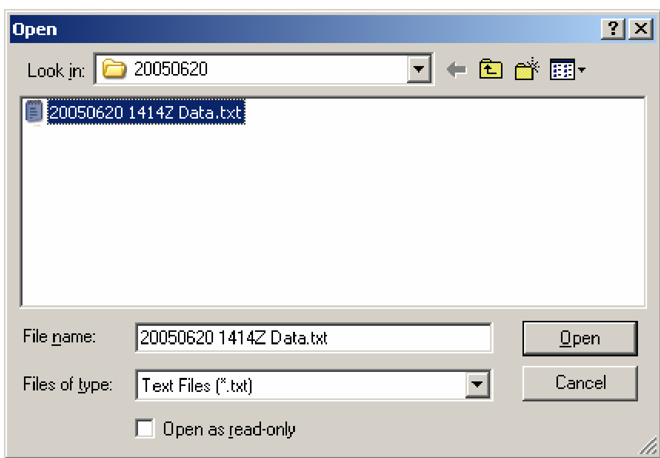


Figure 59. File selection GUI for CARP Analysis Tool.

After finding the correct file to analyze, select *Open*. This opens the *Save* window.

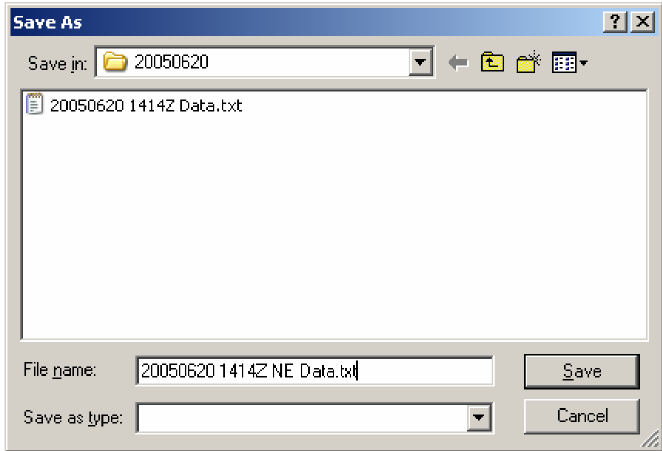
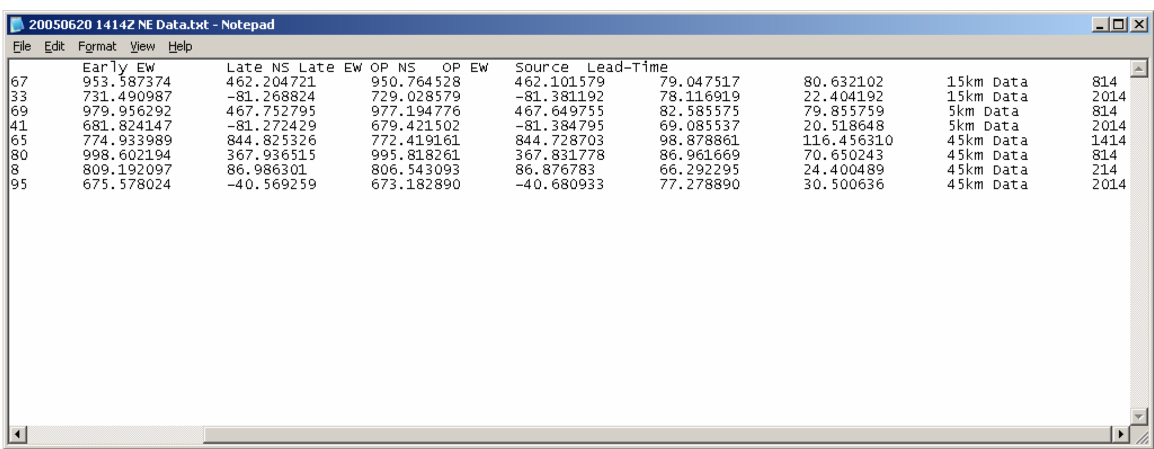


Figure 60. File *Save As* GUI for CARP Analysis Tool.

Be extremely careful to change the file name here, otherwise you will destroy you data as well a getting no results! Northing/Easting data in this study is noted by an “NE” in the file name to distinguish it from the raw data text file. The CARP analysis tool functions by comparing each weather forecast to the weather balloon data in line one of the text file. This results in a file similar to this:




```
        Early EW          Late NS Late EW OP NS    OP EW     Source   Lead-Time
67      953.587374        462.204721       950.764528        462.101579        79.047517         80.632102         15km Data         814
33      731.490987        -81.268824       729.028579        -81.381192        78.116919         22.404192         15km Data         2014
69      979.956292        467.752795       977.194776        467.649755        82.585575         79.855759         5km Data          814
41      681.824147        -81.272429       679.421502        -81.384795        69.085537         20.518648         5km Data          2014
65      774.933989        844.825326       772.419161        844.728703        98.878861         116.456310        45km Data         1414
80      998.602194        367.936515       995.818261        367.831778        86.961669         70.650243         45km Data         814
8       809.192097        86.986301        806.543093        86.876783         66.292295         24.400489         45km Data         214
95      675.578024        -40.569259       673.182890        -40.680933        77.278890         30.500636         45km Data         2014
```

Figure 61. Sample text file containing output from the CARP Analysis Tool.

In this file, the data represents error in the forecasting. A value in the Nominal NS column of -40.578024 means that particular forecast generated a Nominal CARP coordinate that was 40.578024 m South of the correct Nominal CARP coordinate as defined by the Nominal CARP calculated from the weather balloon (an actual sampling of the atmosphere). Also note that, while the resolution data is unchanged, the initialization time has been replaced by the Lead-Time. This is accomplished by simply taking the difference between the weather balloon launch time and the forecast initialization time. The data from each weather balloon (and its corresponding forecasts) is saved in a folder named for the day the balloons were launched on.

Appendix H: Weather Balloon Data Listing

Drop Date	# WxBs	WxB File	WxB Launch Time
20050620	2	08L	1414Z
		11L	1729Z
20050621	2	07L	1316Z
		10L	1557Z
20050624	3	07Z	1336Z
		08L	1458Z
		10L	1632Z
20050815	3	04L	1126Z
		08L	1403Z
		10L	1615Z
20050816	4	04L	1100Z
		05L	1148Z
		07L	1350Z
		10L	1709Z
20050817	4	04L	1037Z
		05L	1127Z
		08L	1418Z
		11L	1757Z
20050818	3	03L	1008Z
		05L	1159Z
		09L	1549Z
20050819	3	04L	1053Z
		05L	1151Z
		08L	1441Z
20050912	4	04L	1114Z
		05L	1205Z
		06L	1255Z
		07L	1409Z
20050913	1	09L	1558Z
20050915	2	05L	1145Z
		07L	1332Z
20051019	2	04L	1130Z
		07L	1355Z
20051020	4	04L	1111Z
		06L	1303Z
		07L	1356Z
		11L	1813Z
20051021	2	04L	1104Z
		06L	1257Z
20060125	1	06L	1234Z
20060126	2	10L	1654Z

		12L	1846Z
20060227	2	09L	1541Z
		12L	1911Z
20060228	2	08L	1529Z
		11L	1804Z
20060301	3	10L	1705Z
		12L	1836Z
		14L	2046Z
20060303	2	06L	1259Z
		09L	1532Z
20060327	3	08L	1431Z
		12L	1842Z
		13L	2002Z
20060328	3	09L	1540Z
		11L	1739Z
		12L	1854Z
20060329	1	11L	1731Z
20060330	3	06L	1254Z
		09L	1544Z
		11L	1817Z
20060508	2	09L	1539Z
		11L	1825Z
20060509	2	08L	1440Z
		10L	1638Z
20060510	2	06L	1306Z
		08L	1518Z
20060511	2	08L	1434Z
		12L	1836Z
20060613	2	07L	1339Z
		08L	1450Z
20060614	2	07L	1348Z
		12L	1830Z
20060615	2	07L	1342Z
		08L	1437Z
20060616	1	08L	1438Z
20060725	1	09L	1533Z
20060726	2	06L	1241Z
		08L	1432Z
20060727	2	06L	1304Z
		07L	1426Z
20060728	1	08L	1457Z
20060911	1	08L	1444Z
20060912	1	06L	1256Z

20060914	2	06L	1314Z
		07L	1427Z
20060915	2	06L	1252Z
		09L	1602Z
20061016	3	07L	1417Z
		09L	1533Z
		10L	1714Z
20061017	3	07L	1337Z
		08L	1517Z
		10L	1651Z
20061018	2	07L	1340Z
		08L	1509Z
20061019	3	07L	1412Z
		09L	1541Z
		12L	1913Z
20061020	2	08L	1433Z
		09L	1557Z
20061127	4	05L	1132Z
		11L	1812Z
		13L	1950Z
		15L	2141Z
20061128	2	07L	1409Z
		09L	1534Z
20061129	1	12L	1923Z
20061130	3	07L	1406Z
		08L	1505Z
		11L	1817Z
20061201	3	08L	1444Z
		09L	1608Z
		10L	1707Z
20061204	1	05L	1133Z
20061205	3	07L	1420Z
		09L	1549Z
		11L	1816Z

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14. ABSTRACT
The United States Air Force is partnering with the United States Army as well as allied nations to develop a revolutionary advance in logistical support known as the Joint Precision Air Drop System (JPADS). The focus of this study is to develop a process to quantitatively analyze system sensitivities to various types of weather inputs and the corresponding effect on system accuracy. Weather balloons were used to provide representative "truth" to which forecast weather could be compared. Each data type was fed into the JPADS Mission Planner to produce navigation points which could then be compared statistically. The process was tested on a limited data set to provide a first look at the variables of forecast resolution and "lead-time." Initial results indicate best system accuracy is achieved for lowest forecast resolution (i.e., 45 km vs. 5 km data) and shortest lead-time (i.e., <12 hrs vs. >12 hrs). This result will not only allow for better accuracy of JPADS, but also reduce bandwidth and transmission time necessary to send weather forecast data to the warfighter.

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