

# Persistent Cloud and Plume Forecasting Using Geographic Information Systems

Marvin Matsuda  
University of Oklahoma

## **Table of Contents**

I.	Introduction.....	1
II.	Airbase Threat.....	5
III.	Airbase Defense.....	9
IV.	GIS Background.....	14
V.	ArcGIS.....	17
VI.	Cloud and Plume Forecasts: Kriging and Co-Kriging.....	20
VII.	Practicum: Concept Validation.....	25
VIII.	Network Support.....	35
IX.	Conclusion.....	38
	References.....	40

## I. Introduction

Nine-eleven ushered in new realities for the Air Force. In the process, our military strategy had to deal with a new threat that could put at considerable risk our domestic airbases for the first time. During the Cold War till the day that the twin towers collapsed, concerted air base defense was primarily an overseas issue. Two vast oceans and friendly neighbors to our north and south have provided geographical barriers, keeping conflicts primarily overseas. The triumph over the Soviet Union left no major nuclear threat. With the first attack since Pearl Harbor on American soil, it became quite clear that domestic air base defense had to be able to transition quickly to counter a logistically challenged but determined threat in international terrorists.<sup>1</sup> In addition, domestic airbases had to also be able to support the public under attack by Weapons of Massed Destruction (WMD) as directed by the President. Since, American military power relies on airpower that is also launched from the US, a limited nuclear or chemical attack on a domestic airbase would reduce our ability to project or employ airpower against any adversary anywhere in the world. A common misconception is that our domestic airbases are for garrison and training only. Not quite. For example, B-2 Spirit and B-52 Stratofortress bombers have routinely launched, struck and recovered from missions in the US during the Gulf War, war in the Balkans and most recently in Enduring Freedom or the War on Terrorism. Furthermore, our wars are not only fought with combat aircraft. Combat support in the form of military airlift such as the C-17 Globe Master II, C-5 Galaxy, etc. provide the logistical lifelines to not only deploy our forces anywhere in the world but to sustain them until the victory or the military objective is achieved.<sup>2</sup> Combat support is also responsible for getting a quick reaction force into a hotspot such as the ready brigades of the 82<sup>nd</sup> and 101<sup>st</sup> airborne divisions. In this context, the domestic airbase is of critical importance in employing and projecting power against our adversary.

The primary mission of an airbase is to launch and recover aircraft for combat and combat support missions. Consequently, the ability to accomplish the mission creates a

---

<sup>1</sup> Smith, P.J., Summer 2002, Transnational Terrorism and the Al Qaeda Model: Confronting New Realities, *Parameters*, Summer 2002, pages. 35-6.

<sup>2</sup> Bordeaux, J. & Ochmanek D., June 1993, The Lion's Share of Power Projection, *Air Force Magazine*, Vol. 76, No. 6, Feb 24, 2003, <http://www.afa.org/magazine/perspectives/0693lion.html>

natural benchmark to measure the effect an adversary has in using his weapons against us. It is a proven fact that nuclear and chemical weapons can either deny or degrade the airbase from carrying out its mission. On one hand, nuclear weapons can destroy personnel and physical assets or contaminate them as well as force surviving personnel in to shelters and protective clothing either entirely preventing or slowing aircraft launch and recovery. On the other hand, chemical weapons can kill unprotected personnel and force surviving personnel in to shelters or protective clothing, again degrading the airbase mission.<sup>3</sup>

Current toxic chemical agent and nuclear fallout information systems are inadequate for analyzing and disseminating cloud and plume and toxicity status for an airbase. Although, personnel are trained on nuclear blast/fallout, chemical agents and their respective countermeasures,<sup>4</sup> information is the needed to apply their knowledge and limited resources when and where needed. If nuclear fallout or a chemical agent plume is not near enough to be a factor, personnel need to be outside of shelters and working launching and recovering aircraft without the burden of protective clothing. Moreover, nuclear blast and fallout training involves the aftermath of a fission or fusion detonation. Logistically challenged terrorists appear to be opting for an Improvised Nuclear Device (IND), creating another scenario with a different method needed for prediction and forecast on a smaller scale.<sup>5</sup>

Geographical Information Systems (GIS) are the key to using the combined knowledge and physical resources to counter the lethal and debilitating effects of chemical agents and limited nuclear fallout degrading the airbase mission. Presently, the GIS industry leader is world renowned Environmental Systems Research Institute (ESRI), which has fielded ArcGIS as a multi-disciplinary information solution.<sup>6</sup> The ESRI graphic solution--ArcGIS--provides the fastest way of dealing with a limited long-term nuclear fallout or chemical contamination. ArcGIS has the capability to import

---

<sup>3</sup> n.d., Effects of WMD, Feb 24, 2003, [http://www.nti.org/f\\_wmd411/f1a2.html](http://www.nti.org/f_wmd411/f1a2.html).

<sup>4</sup> Gempis, V. Sep. 27, 2001, Airmen Provide Chemical, Biological Defense Training, *Air Force Print News*, Feb 24, 2003, <http://www2.hickam.af.mil/newsarchive/2001/2001238.htm>

<sup>5</sup> Kaiser, R. & Ottaway, D., Woodward, B., Dec. 4, 2001, U.S. Fears Bin Laden Made Nuclear Strides, *Washington Post Staff Writers*, Dec. 4, 2001; Page A0. February 25, 2003, <http://www.washingtonpost.com/ac2/wp-dyn?pagename=article&node=&contentId=A52369-2001Dec3&notFound=true>

<sup>6</sup> ESRI: Bringing GIS to the World, February 25, 2003, <http://www.esri.com/company/about/facts.html>

nuclear and chemical data, analyze it and produce the most effective information tool: a base map with current threat information.

The ArcGIS map can be rapidly spread through the base chain of command and information infrastructure by image as well as voice. In the former case, a map could appear on every browser of all workstation, laptop and PDA on the airbase though the wired or a wireless network. The same map information could be FAXed through a FAX server. In the latter case, map grids could be announced through the base public address and radio system. With the threat information, base personnel could take the appropriate countermeasures or more importantly delay implementation and conserve limited countermeasure resources.

The purpose of this paper will be fourfold. First, an overall description of the present airbase situation in detail will be made as it pertains to the need for a nuclear and chemical information system. Details will include general descriptions of nuclear and chemical threats to an airbase. Airbase defense will then be covered in terms of organization; physical resources used; threat information sources; and warning systems. Nuclear and chemical sensors providing critical data will be covered and analyzed in terms of what is needed versus what is available in Current-Off-The-Shelf (COTS) technology. Second, ArcGIS will be discussed in great detail as the key to an information solution. A profile of ESRI will be provided as it pertains to its revolutionary software. GEOBASE—established Air Force program using GIS—will then be presented as an existing information infrastructure asset—called the Common Installation Picture (CIP)—to be used to resolve the problem. With a CIP an argument will be made for designating safe and contaminated areas, requiring countermeasures in the former and regular operations in the latter. Other factors will be introduced into the argument in terms of facilities for shelter and monitoring roads as a source for spreading contamination. The primary solution in ArcGIS using cloud and plume analysis will then be covered, which uses graphical displays that are based on mathematical functions of Kriging for a single plume or cloud and Co-Kriging for multiple ones. A case will be made for Kriging and Co-Kriging versus the present methods of table lookups and manual plotting which are now common in software using a Gaussian distribution to determine chemical plumes. The advantages of using histograms and smoothing will be

covered as well as the limitations imposed in sampling. Third, the concepts of Kriging and Cokriging will be validated with a real world condition: air pollution. Fourth, the information infrastructure in place will be analyzed and improvements suggested to forward threat information to personnel in time to take countermeasures preventing loss of life, debilitating injury, and contamination of equipment. The present wired infrastructure in place will be covered as well as a proposed wireless solution keeping in mind inherent vulnerability to adversary intelligence gathering versus the risk of information not received and understood to prevent exposure or contamination. Fourth, present technology developments will be covered that will reduce the reliance on mathematical modeling. Technology capable of detecting low concentrations of nuclear and chemical agents and importing real time data to update a CIP will be covered both in terms of promise and development, procurement and deployment status.

From our purposeful discussion on the domestic airbase environment, problem, solution communication, and future will come a new understanding in building a quick interim then an optimal long-term information solution for chemical and nuclear attacks ushered in by the new realities of nine-eleven. This long-term solution will show how present technology will reduce the reliance on mathematical modeling and be capable of detecting low concentrations of nuclear and chemical agents, importing real time data to update a CIP.

## II. Airbase Threat

A spectrum of threats faces any airbase in the US. Although, the Cold War ended over a decade ago, a new ballistic missile threat from a rogue nation such as North Korea has emerged. Keep in mind that the National Missile Defense Initiative is still a year away. With a limited supply of nuclear warheads, chemical or biological weapons could be used on warheads. The probability of the former is higher, because it is easier to produce and store while the latter is more of a challenge to produce in a form that will survive the rigors of ballistic reentry. However, a ballistic missile launch is detectable and traceable. So any nation launching a single or small volley of missiles would expose itself to virtual nuclear annihilation by the US. In other words, the US could only muster a huge payback, not a defense. More ominously, nine-eleven just elevated the specter of nuclear and chemical weapons used by international terrorists, who are aligned by religion and ideology rather than to a host nation. Their weapons of choice would be home made or smuggled chemical weapons or explosives, an IND, or in the worst-case scenario, a smuggled or stolen biological weapon. While, nuclear weapons continue to proliferate, biological components to build weapons have not due to the sheer knowledge, economics for support and transmission previously mentioned.<sup>7</sup> Therefore, our discussion will be limited to the threats readily available to terrorists, which our technology can timely identify and track, and our knowledge and equipment can counter: Improvised Nuclear Devices (IND) and chemical weapons.

A domestic airbase could be selected as a target for several reasons by terrorists. First, it is a symbol of the government. Second, it could be directly involved in taking the war to countries allied with the terrorists. Third, the security would not be as heavily defended as an overseas base in a foreign country due to confidence in the national borders and friendly neighbors.

The nuclear threat consists of two kinds of weapons: fusion or fission weapons and IND. On one hand, a nuclear weapon would probably be either delivered by a ballistic missile from an adversary nation, delivered personally or setup near an airbase by a terrorist. On the other hand, an IND would be limited to personal delivery or nearby

---

<sup>7</sup> Dewar, H., June 27, 2002, Missile Defense Funding Increased, Washington Post, page A09, Feb. 25, 2003, <http://www.washingtonpost.com/ac2/wp-dyn?pagename=article&node=&contentId=A51529-2002Jun26&notFound=true>

setup. The good news for airbase defense is weapons grade plutonium is extremely difficult to come by. The bad news is a rather inexpensive "dirty" bomb can be built from available radioactive material or waste and assembled very cheaply.<sup>8</sup>

A fusion or fission weapon creates nuclear fallout after the explosion, which can be a ground or airburst. Obviously, a ground burst would create more fallout. Fallout is churned from the ground by the huge force of a nuclear explosion and forms into a mushroom like cloud, returning to earth radioactive. The scale of immediate destruction would be large in terms of tens of miles, which would worsen with upper level winds spreading fallout.<sup>9</sup>

An IND is an explosive device jacketed with radioactive material. Unlike a nuclear detonation, an IND relies on the limited explosive force of a conventional explosion. The scale of immediate destruction would be limited to miles and would not reach upper level winds.<sup>10</sup>

Chemical weapons can be classified into two areas of concern—persistent and non-persistent. Persistent agents are agents that remain around for a relatively long time in sufficient concentration to be lethal and to deny free use of equipment through contamination. Non-persistent agents dissipate or breakdown rapidly and do not rely on concentration. Only a small minute amount of agent would be enough to be lethal. Lethal weapons will be exclusively discussed due to the pointless cause of incapacitating agents.<sup>11</sup>

In terms of a persistent lethal agent, mustard gas is a prospective candidate. Mustard has been around since World War I and has been well studied, used and stockpiled by many countries including the US. Well-guarded US stockpiles are in Maryland, Alabama, Arkansas, Utah and Oregon, which consist of munitions and one-ton storage containers. There are three processes for making mustard gas, which produce distilled mustard gas (HD) in varied concentrations from 62 to 89 percent. All involve complexity and are very dangerous to achieve high concentrations of HD. For mustard as

---

<sup>8</sup> Ibid.

<sup>9</sup> Attack (Nuclear, Conventional, Chemical, and Biological), Feb. 25, 2002, <http://www.sema.state.mo.us/sh%20annex%20o.pdf>

<sup>10</sup> Keller, B., May 26, 2002, Nuclear Nightmares, Feb. 25, 2003, <http://www.physics.ohio-state.edu/~wilkins/Terror/26NUKES.html>

<sup>11</sup> Ayers, S., Summer 2000, Agents Terrorism: Chemical Weapons, Feb 25, 2003, [http://www.efilmgroup.com/Dispatch/chem\\_intro.html](http://www.efilmgroup.com/Dispatch/chem_intro.html)



well as most chemical weapons, concentration is very important. A higher concentration means higher toxicity and quicker lethality.<sup>12</sup> Higher concentration also helps with transmission. The speed at which a chemical weapons dissipates into air and becomes non-lethal is directly related to its initial concentration. If weapons-grade mustard is to be home made, it requires a high knowledge and material base in order to achieve prolonged lethal concentration. Otherwise, the mustard would have to be obtained, stolen or purchased from a country stockpiling it. The sarin attack in the Tokyo subway is a case in point. Although, Japanese doomsday cult Aum Shinrikyo—the culprit--underwent training in the former Soviet Union for synthesis, their expertise fortunately failed to produce sarin in a highly concentrated form. Even in the confines of a subway or the optimum environment, the sarin dissipated and toxicity and lethality were quickly lost. The result was fortunate: more sick than dead.<sup>13</sup>

The weapon of choice for non-persistent chemical weapons is VX, commonly known as nerve gas. VX is a relatively new agent that was made and stockpiled during the Cold War. As a highly toxic synthetic compound, it is extremely difficult to produce. Most stockpiles are either under heavy security or are in the process of being destroyed.<sup>14</sup> However, rogue nations such as Iraq—a beneficiary of the former Soviet Union—have documented programs of producing, and stockpiling this deadly chemical agent. Depending on whom you want to believe, Iraq is a source that could readily transfer the agents to terrorists bound to infiltrate the US. The use of the agent, would point to a source, since only a handful of nations have the knowledge and capacity to produce such sophisticated chemical agents. A cover story would be needed i.e. theft or corruption.

In the aftermath of nine-eleven, an investigation appears to show that the terrorist seemed to be brainstorming a scheme for massive destruction. Moreover, they appear to have limited resources, sending back funds not used before their suicide missions. Although, we were attacked in several places at one time, there were no subsequent waves of terrorist attacks on the US as feared. However, it is important to not that before terrorists expediently settled on the White House, Twin Towers and the Pentagon with

---

<sup>12</sup> Chemical Weapons, Feb. 26, 2003, <http://www.fas.org/nuke/guide/usa/cbw/cw.htm>

<sup>13</sup> WMD Terrorism in Historical Context, Feb. 25, 2003, [http://www.nti.org/f\\_wmd411/fla6\\_1.html](http://www.nti.org/f_wmd411/fla6_1.html)

<sup>14</sup> VX: What is it?, Feb 25, 2003, <http://www.foxnews.com/story/0,2933,76872.00.html>

airliners, they were observed to be looking at crop dusting.<sup>15</sup> When taken in a chemical weapon context, it would have been a means of breaching the airbase perimeter security and efficiently transmitting a chemical agent over a wide area. In comparison, an imposter in a vehicle would have run the risk of interception penetrating base security. Whereas, weapons outside the base perimeter such as rocket or mortar would need accuracy, range and have limited time before being engaged by base security or civilian law enforcement. In short, a new wave of terrorists could use a dirty bomb or chemical weapon, now that commercial airlines have been taken away as soft targets with higher security. With limited resources, one can expect them to attack a target with limited defenses and high psychological value with a weapon. Specifically, the options are a weapon produced locally in considerable quantities or if smuggled, extremely small quantities of a highly toxic agent, which would make it easier to hide or disguise.

---

<sup>15</sup> Can Moussaoui Get a Fair Trial in America?, Feb 25, 2003, <http://www.foxnews.com/story/0,2933,40985,00.html>

### III. Airbase Defense

Airbase defense against nuclear and chemical weapons calls for response and then recovery actions. A response is immediate and short term, while recovery is long-term action returning to normalcy. The airbase organization and physical resources dictate the level of both actions based on threat warning and information. Air Force personnel are well trained to respond, but what makes them effective is threat warning and information, especially when a persistent threat such as an IND or chemical weapons are encountered. Information—accurate, timely and readily available—is paramount. Therefore, airbase defense will be described in terms of organization, then equipment and finally by threat information systems and warning.

Effective nuclear and chemical defense is dealt with by the airbase organization. Moreover, the airbase command system is composed of a tiered command system, which is flexible at the lower tiers. The installation commander is in charge of all operations including flight and airbase operations. The commander and his staff are stationed in the Wing Recovery Center (WRC) also called the WCP or Wing Command Post. From there, decisions are made from information gathered locally or from higher headquarters off base. Higher headquarters also tasks an airbase through the installation commander. Under the installation commander are different organization commanders whose personnel and resources are used in airbase defense. Among the subordinate commanders, the Mission Support Group (MSG) Commander is in charge of airbase defense. The MSG Commander and his staff man the Survival Recovery Center (SRC), which manages all airbase defense operations from a command post near the Support Group headquarters. The SRC coordinates all airbase defense actions for all organizations. Each organization or unit on base has a Unit Control Center (UCC), which manages the unit mission as well as airbase defense operations. A unit commander or senior officer mans the UCC, if the commander is on the WRC or SRC staff. Subordinate to the SRC is the Damage Control Group (DCG), which can be either in a command post or on-scene. The DCG has an officer-in-charge when located at a command post or an On-Scene Commander (OSC) if the base is responding to a limited threat, requiring real time supervision at the scene. The DCG is the focal point managing initial threat response through recovery. When a response is needed a Disaster Response

Force (DRF) is marshaled and deployed. The DRF consists of two waves: first responders and second responders. First responders would be some mix depending on the threat of Security Police, medical personnel and Civil Engineers—Fire Protection, Explosive Ordnance and Disposal (EOD) or Disaster Preparedness (DP), trained in Nuclear, Biological and Chemical (NBC) warfare as needed.<sup>16</sup> The second responders would be other units needed to sustain a prolonged response or recovery operation and reinforcements. For example, the Services Unit may be needed to setup and run field kitchens at the scene or provide a temporary morgue for casualties.

In a nuclear or chemical attack, the DRF OSC depends on the type of mission. If the mission is dealing with nuclear or chemical agent with possible hostile presence nearby then the ranking Security Police person is in charge until relieved by competent authority. The scene of the nuclear or chemical attack is considered a crime scene and evidence needs to be undisturbed as much as possible. Fire Protection puts out any fires while medical personnel triage or evacuate casualties. EOD goes in to disarm and dispose of any unexploded munitions. Disaster Preparedness has two jobs. The first job is to test for any NBC agent. And, the second job is to setup and supervise nuclear and chemical decontamination, which may be needed by all first responders and if needed second responders, too. If the mission is dealing with a nuclear or chemical agent without any hostile presence nearby, then the senior Fire Protection or ranking member first on scene assumes command of the site of the attack for response operations.<sup>17</sup> The law comes into play if the attack site is off base or just off the airbase with another set of rules coming into play. Off base, the FBI is in charge of a crime scene or an attack where there may still be hostile presence in the area.<sup>18</sup> FEMA takes command if there is no hostile presence. If a state or city government off the airbase is attacked and asks for help, the military may assist and come under the command of either the senior law enforcement officer or emergency responder. However, Security Police is limited in its authority off the airbase to assist specifically in the arrest of civilian criminals under the

---

<sup>16</sup> Martin, R., Dec. 7, 2000, Units Act Quickly during Major Accident, *Hill Top Times*, Feb. 28, 2003, <http://www.hilltoptimes.com/archive/20001207/12.html>

<sup>17</sup> May1, 2002, Air Force Instruction 32-2001, Feb 28, 2003, [http://www.e-publishing.af.mil/pubfiles/afspc/32/afi32-2001\\_afspcsup1/afi32-2001\\_afspcsup1.pdf](http://www.e-publishing.af.mil/pubfiles/afspc/32/afi32-2001_afspcsup1/afi32-2001_afspcsup1.pdf)

<sup>18</sup> Concept of Operations: Command and Control, Feb 27, 2003, <http://216.239.51.100/search?q=cache:IMb2WeoSkToC:www.oes.ca.gov/oeshomep.nsf/all/TerrorPlan/%24file/TerrorPlan.pdf+Oklahoma+FEMA+%22FBI+onscene+commander%22&hl=en&ie=UTF-8>

provisions of Posse Comitatus. A Defense Nuclear Area, if a nuclear attack is involved, or Marshal Law must be declared in order to override posse comitatus.

Physical resources for nuclear and chemical resources are sheltering and protective clothing; detection devices and decontamination equipment. Sheltering can be temporary or long term. Temporary shelters can be any facility sealed for contamination with the added precaution of personnel wearing Nuclear Biological and Chemical (NBC) suits and masks inside. Long terms shelters generally have air handling and purification systems where suits aren't needed and decontamination at the entrances to keep nuclear fallout and chemical contamination outside. Protective clothing consists of NBC suits, masks, gloves and boots as mentioned earlier, which can be worn up to 30 days.<sup>19</sup> When worn properly, the suits, which are issued to all base personnel, affords complete protection from chemical agents and limited protection from fallout. The limited protection to fallout just keeps particulate matter off a person, but the radiation from the matter does penetrate the suit. Nuclear and chemical agents require different detection devices. High altitude or mushroom clouds require measurement without disruption i.e. a weather balloon. Clouds from explosions do not. Nuclear agents are detected by dosimeters that give radioactive readings. When a human comes into contact with radiation, the dose and length of time must be closely monitored to prevent radiation sickness or death. Dosage is cumulative and not reversible.<sup>20</sup> There are three types of technology in use for chemical agent detection. The first, litmus paper is the most plentiful. Any agent that comes into contact with the paper changes its color. The resulting color identifies the agent present but unfortunately not the concentration. Second, electronic handheld or vehicle-mounted detectors give out alarms and identify the chemical agent and concentration. Lastly, automated air sampling systems test for chemicals then alert, identify agent and concentration down to Parts Per Million (PPM).<sup>21</sup> The air sampling systems are very expensive and bulky and only available overseas in high threat areas. One new technology from Rae Systems involves the identification and

---

<sup>19</sup> Darlene Superville, Nov 27,2002, Chemical warfare suit: a stifling lifesaver that limits movement in combat, Feb 27, 2002,

[http://www.timesrecord.com/Military/11\\_27\\_suit.html](http://www.timesrecord.com/Military/11_27_suit.html)

<sup>20</sup> US Army Field Manual 7-7, Appendix M, Nuclear, Biological and Chemical Operations, Section I. Nuclear Weapons, page M-7, Feb 27, 2003, <http://www.adtdl.army.mil/cgi-bin/atdl.dll/fm/7-7/appm.pdf>

<sup>21</sup> *Ibid.*, pages M7-8.

reporting of chemical concentrations through a wireless network. The system used by the National Guard Civil Response Teams for Weapons of Massed Destruction (WMD) has a range of 2 miles Line-Of-Sight (LOS) and one data monitoring station can track as many as 16 unmanned detection devices.<sup>22</sup> At present, the airbase doesn't have but do need this capability. The National Guard is not assigned formally to airbase defense.

Chemical and nuclear threat information and warning comes from several different systems. At the onset of a chemical or nuclear attack, speed is critical. In a nuclear attack, all base personnel need to take shelter from any explosive blast. Fallout or residual radiation must be dealt with after the detonation. In a chemical attack, personnel must either take shelter or be completely suited up in their NBC suits. NBC suits due to their restrictive nature are either carried or worn according to the threat level. While suits keep out chemical and radiological contamination, they keep in body heat. When in a suit for a prolonged period of time, fatigue sets in through heat exhaustion and dehydration. If the threat level is low, a suit should be carried or nearby, because it takes minutes to don and fit properly. If the threat level is high, more pieces of the suit can be worn to allow for faster protection. In a chemical attack, the difference between life and death could be as little as 9 seconds.<sup>23</sup> The suit can be worn in combinations minus the boots, gloves or mask. These combinations are called Mission Oriented Protective Posture (MOPP). MOPP 0 is carrying your mask only with the suit nearby in a low threat. MOPP 4 is wearing the suit and mask in a high threat environment. Commanders like to keep the MOPP level is low as possible to keep personnel from fatigue and retain productivity. After all, the suits also limit vision and the manual dexterity to do work in addition creating fatigue. Taken in perspective, the threat warning and information systems, supports the lowest MOPP possible allowing sufficient time to react prior to the threat arrival. All available means of communication are used to broadcast an imminent threat.<sup>24</sup> By voice, this means the base public-address system or GIANT VOICE, siren, radio, telephone or crash net, which is a dedicated hotline between all first and second

---

<sup>22</sup> Feb 27, 2003, <http://www.raesystems.com/products.html>

<sup>23</sup> Nuclear Biological Chemical Warfare FM 3-3, 3-3-1, 3-4, 3-5, 3-7, 3-100, Feb 27, 2003, <http://knox-www.army.mil/samc/Study%20Guide/NBC.doc>

<sup>24</sup> US Army Field Manual 7-7, Appendix M, Nuclear, Biological and Chemical Operations, Section I. Nuclear Weapons, page M-15-16, Feb 27, 2003, <http://www.adtdl.army.mil/cgi-bin/atdl.dll/fm/7-7/appm.pdf>

responders.<sup>25</sup> By data, this can range from messages over the Tactical Battle Management Computer System (TBMCS),<sup>26</sup> which is a secure command and control system linking WRC, SRC, DCG and UCC; email over the unclassified airbase information network; FAX server; and base cable TV. Once an attack has occurred and affected and unaffected areas have been determined, other forms of communication can be used such as text or color-coded signs to warn personnel to don protection or to avoid transiting a contaminated area, and public address speakers on vehicles. In short, a variety of means are used to communicate a chemical or nuclear attack to the base. This threat information is for airbase personnel who have NBC suits and shelters and the base population who need to take shelter.

Thus far, the big picture of airbase defense has been presented in terms of organization to meet the decision-making demands of a nuclear or chemical attack; physical resources to prevent injury and death and warning and information systems. The stage is now set to focus on dealing with the information demands of the worst-case scenario: a persistent nuclear and chemical threat on an airbase.

---

<sup>25</sup> Giant Voice Military Audio Systems, Feb 27, 2003, [http://www.technomad.com/military/FAQ\\_mil.html](http://www.technomad.com/military/FAQ_mil.html)

<sup>26</sup> Madden, T., Dec 16, 1999, TBMCS Deployment Underway to USAF Air Bases, Feb 27, 2003, <http://www.missionsystems.lockheedmartin.com/announce/releases/TBMCS.html>

#### **IV. GIS Background**

The long-range vision of the Air Force is Joint Vision 2020, which simply put is information dominance or decision-superiority. Quite often, US forces are either outnumbered or face an adversary with equal technology. The vision isn't hubris, but a reality check given the data that can inundate information system users. In order to be successful in achieving national security objectives, the Air Force believes that it must be able to focus on pertinent information and make better, quicker decisions to be successful in any conflict.<sup>27</sup>

Air Force Civil Engineering has made 2020 a reality by adopting another private industry trend in pursuing the one map concept in geo spatial information systems i.e. ESRI GIS to streamline decision-making.<sup>28</sup> Specifically, a program for US airbases has taken the lead utilizing ESRI ArcInfo and ArcGIS software: GEOBASE.<sup>29</sup>

In 1995, the Air Force used fledgling GIS software to solve a real world problem given a short time constraint. The rape of a Japanese schoolgirl by a US marine stoked anti-American sentiment in Okinawa to an unprecedented level. A sensitive Clinton administration at that time directed a reduction of all US presence to placate the Japanese, appealing to their one great need—land. Ironically, the Air Force used GIS to radically scale down the size of Kadena Air Base by 50 percent, while keeping enough land to support a force for all missions essential for the defense of Japan, Korea and Taiwan from attack.<sup>7</sup> Base planning using Current-Off-the-Shelf (COTS) ESRI GIS software became known as GEOBASE.<sup>29</sup>

Very rarely does a “killer app” appear on the scene. Software programs can come and go like flavors of the month in the Air Force. However, ESRI GIS found a new niche in wartime or contingency planning after it proved its value in Okinawa. The Air Force is just scratching the surface of GIS. Industries such as transportation, hotel, oil, medicine etc. have discovered and are investing heavily in GIS as a new employment tool

---

<sup>27</sup>Garamone, J. Jun 2, 2000, Joint Vision 2020 Emphasizes Full-spectrum Dominance, Feb 28, 2003, [http://www.defenselink.mil/news/Jun2000/n06022000\\_20006025.html](http://www.defenselink.mil/news/Jun2000/n06022000_20006025.html)

<sup>28</sup> Nevada GIS (www.ngis.org) Sponsors GIS Day Events Celebrate Your World with GIS, Feb 28, 2003,

<sup>29</sup> March 15, 2002, Strategic Data And Image Service Feeds Mission Planners, *Engineering News Record*, Feb 28, 2003, <http://cartome.org/geo-reach.htm>



to facilitate knowledge management, which offers by its very nature the competitive advantage sought by Joint Vision 2020.

My present assignment at Elmendorf Air Force Base, Alaska involves the GEOBASE program. Two issues are at the forefront: a change from non-OOD (Object Oriented Design) to OOD software and implementing one map for all users.

Presently, ArcInfo Pro, ArcSDE and ArcIMS<sup>30</sup> are being used and heavily relied upon with gradual use of ArcGIS. ArcView 3.X (ArcInfo), et al is non-OOP while the new ArcView 8.2 (ArcGIS) and its suite are OOD.<sup>31</sup> Due to Operation Noble Eagle (domestic operations) and Enduring Freedom or the War on Terrorism, ArcInfo was still kept online as the primary system. Although, ArcView 3.1 continued to deliver as advertised, new requirements have begun to surface along with cross functionality issues. Difficulty in interfacing with DBMS connections and other command and control systems have cropped up with the new requests for accessing and displaying new data formats—streaming video, 3-D, etc. Scripting has been done to solve interface problems and other new data formats were shelved due to time and workload constraints. Suffice to say, ArcGIS was an unknown factor and an incremental changeover was put in effect. In private industry, the same holds true. Firms are relying on ArcInfo with ArcGIS running in parallel or undergoing testing and validation. In short, we've recognized the potential power and the strategic advantage gained in information management for decision-making by ArcView 8.2. Up until now, we're waiting for the learning curve to go up on ArcGIS, using it on routine projects

Like other Air Force bases, we have many geo-spatial command and control systems besides GEOBASE. Some instances are Installation Logistic Engineering (ILE), Tactical Battle Management Core<sup>32</sup> System (TBMCS), Communication Infrastructure Planning (CIP), and Air Force Common Installation Picture (AFCIP),<sup>33</sup> which over the years have collected massive volumes of data. However, the choice has been narrowed to

---

<sup>30</sup> GEOREACH Concept of Operations Version 2.2 June 14, 2001, Section I, page 16.

<sup>31</sup> ArcInfo 8: A New Architecture for GIS", Feb 28, 2003,  
<http://www.esri.com/news/arcnews/spring00/articles/esrirobust.html>

<sup>32</sup> Rubel, J., "Tactical Battle Management Core System (TBMCS) Status", Feb. 28, 2003,  
<http://216.239.51.100/search?q=cache:QKyNit0SSBsC:cno-n6.hq.navy.mil/N62/TBMCS/BRIEFS/CCG4FEB00.ppt++%22TBMCS%22&hl=en&ie=UTF-8>

<sup>33</sup> Cullis, B., "Lessons Learned in the USAF", Feb. 28, 2003,  
[http://www.foundationknowledge.com/library/organizations/Air\\_Force/AF%20GeoBase%20Vision.ppt](http://www.foundationknowledge.com/library/organizations/Air_Force/AF%20GeoBase%20Vision.ppt)

TBMCS and GEOBASE with the latter providing the airbase picture and the former web content for command and control.

GEOBASE now provides the Common Installation Picture (CIP) or one and only map for the airbase. GIS is currently used in the WRC and SRC for Minimum Operating Strip, which is the plotting of the smallest possible length of undamaged or clear runway to launch and recover aircraft. The conditions are now ripe with "one map" for using ArcGIS and its OOD and cross functionality to other applications to track nuclear and chemical attacks, which are well within its capability. Moreover, ArcGIS' capability is definitely what is needed to respond and recover the airbase in the best possible condition from a nuclear or chemical attack.

## V. ArcGIS

ArcGIS is a suite of products from Environmental Systems Research Institute (ESRI), the undisputed world-leader in Geographical Information Systems (GIS).<sup>34</sup> The most prominent application of ArcGIS is ArcView or the mapping software, which integrates the science of quantitative geography with information systems to produce a multi-dimensional problem model or map. The former will be taken up in the next section on modeling nuclear clouds and chemical agent plumes.

ArcView 8.2 can access data from databases, spreadsheets, Global Positioning Satellite (GPS) systems, flat files and other data sources and then geocode them for display on a digitized map. Moreover, ArcView can also import and use satellite imagery, which can be used either exclusively or overlaid to create a map. Its map can utilize any coordinate system or for that matter any known map projection in the world to fit user needs as well as provide accurate information well below one meter. ArcView can incorporate either points or Computer Aided Design (CAD) maps, which can replace points. Essentially, ArcView can combine all aspects of the macro and micro worlds on one digital map, which is accurate to the nth degree.<sup>35</sup>

Not all versions of ArcView are created equal. Previously, ArcView 3.x—non-OOD (Object Oriented Design)—and ArcView 8.2—OOD—were discussed. The future is obviously ArcView 8.2 due to its cross application functionality. While a great deal of functionality has been built into ArcView 8.2, Subject Query Language (SQL) and Visual Basic for Applications (VBA) scripts can still be run for custom projects or research.<sup>36</sup> As a result, the user interface of 8.2 is friendlier eliminating the command line, but allowing some command input for customization and tweaking through the interfaces.

For an enterprise level deployment, ArcIMS is used at the server level and ArcView at the client level. ArcIMS allows more users to access maps through browsers without the technical knowledge required for ArcView.<sup>37</sup>

With almost unlimited access to data and ease of use, ArcView can help many users with only cursory knowledge of geography and information systems. Users can

---

<sup>34</sup> ESRI History, Feb. 28, 2003, <http://www.esri.com/company/about/history.html>

<sup>35</sup> Minami, M., Using, Chapter 4, Creating Maps, *Using ArcMap*, page 103.

<sup>36</sup> *Ibid.*, page 495.

<sup>37</sup> *What is ArcGIS?: GIS by ESRI*, 2002, page 33.

display geography, topology and infrastructure without much difficulty. In terms of an airbase, the entire infrastructure can be displayed on one map, which can be labeled for quick reference. OOD allows information objects on the map. For example, a logistical database of supplies stored in a building are only a click away or they can be displayed on a map. Moreover, all users may not want to see the same items. OOD allows different layers with different data sets to fit the roles and needs of users in different organizations and their counterparts in other organizations. Layers can be selected and deselected to provide the best airbase picture to do work with or communicate information.<sup>38</sup> Consequently, it's easy to focus on clouds or plumes by just placing all pertinent information on a single layer for general use.

Another member of the ArcGIS suite that can help users is ArcScene. ArcScene makes an ArcView map 3-D. The 3-D technology works off elevation data from GPS or topographical sources versus linear data, giving spatial data with the third dimension. The graphical solution that results produces the options of stationary and moving 3-D, which is also known as flythrough. With CAD incorporated into a map, a flythrough would be like a bird flying through an airbase; flying to a building; and flying through a window into a room. All features of the flight would be animated like a video game including features in the room sourced by CAD.<sup>39</sup> Topography has a direct affect on persistent chemical agents. Agents such as mustard gas remain longer in low-lying areas due to their density. Furthermore, barriers such a hill or large, tall building, for example a warehouse, could contain the spread of mustard gas. ArcScene could readily show the hills and with CAD of all facilities from Civil Engineers could show the building—barrier—as well. Enough sensors with Global Positioning Satellite (GPS) at different heights could theoretically show a 3-D cloud. GPS would be providing not only position but elevation information.

ArcView has a very extensive graphical capability. Points as described earlier and shapes can be drawn without any difficulty. The ESRI concept for shapes is polygons, which are a series of lines connected by points to form a regular or irregular

---

<sup>38</sup> Minami, M., Using, Chapter 4, Creating Maps, *Using ArcMap*, page 96.

<sup>39</sup> *Ibid.*, page 103-4.

shape.<sup>40</sup> The significance of the points will be unveiled when mathematical calculations are discussed in the next section. Suffice it to say, ArcView drawing a 2-D or even 3-D polygon to represent a nuclear or chemical plume or cloud would not be a problem.<sup>41</sup> However, given the sudden nature of a nuclear or chemical attack mapping a plume or cloud at the outset would take up precious time. To workaround the problem, the OOD nature of ArcView could be used to import a graphical image object using some VBA to integrate software designed specifically for calculating initial plumes. Examples of free software available from the Environmental Protection Agency (EPA) are ALOHA and MARPLOT, which are easily loaded on a laptop.<sup>42</sup> The Air Force uses VLRS, which is more or less the same level of technology. Both have the capability of mapping clouds and plumes given an estimated initial quantity and surface wind information. Their limitations are the simple mathematical algorithms used for dispersion and estimates used for source concentration. Their databases contain toxic and corrosive industrial chemicals as well as chemical warfare agents, such as sarin, mustard, etc.<sup>43</sup> On one hand, they are adequate in initially dealing with a release of an agent on the ground and into the atmosphere to give first responders an idea of the scope and magnitude of the threat. On the other hand, the simple mathematical algorithms prohibit accuracy, which becomes more and more a factor as time goes on. For example, the algorithm accepts an average wind direction, which in reality can be the combination of several different vectors. The nice, neat symmetrically shape soon becomes irrelevant in places. Also, estimation of concentration is based on an agent container that may not be readily visible due to the deadly agent around it and the fact that most munitions go subterranean upon impact with the ground. Crater size is then the only alternative in estimating the size of the agent container, which per se has some associated error.

The problem of mapping a persistent cloud or plume of a nuclear or chemical agent still remains. ArcView, however, can readily use two software extensions—Geostatistical Analyst and Spatial Analyst—that will solve these problems, which will be covered next.

---

<sup>40</sup> Shaner, J. & Wrightsell, J., Chapter 2: Quick-Start Tutorial, *Editing ArcMap*, circa 2000, page 12.

<sup>41</sup> ESRI Corporation, circa 2002, ArcGIS Geostatistical Analyst, *What is ArcGIS?*, page 25.

<sup>42</sup> Aloha, Feb. 28, 2003, <http://response.restoration.noaa.gov/comeo/aloha.html> & Marplot, Feb. 28, 2003, <http://response.restoration.noaa.gov/comeo/marplot.html>

<sup>43</sup> Ibid.

## VI. Cloud and Plume Forecasts: Kriging and Co-Kriging

ArcView has two software extensions named Spatial Analysis and Geostatistical Analysis, which can be applied to forecasts persistent nuclear fallout clouds and chemical agent plumes after an attack.<sup>44</sup> In turn, the extensions respectively contain Kriging and Cokriging are prediction methods that process sensor data mathematically and statistically then display them graphically in polygon shape on a map or map layer. Kriging would be used for a single source, while Cokriging would be used for multiple emission sources. In order to build a polygon shape representing a cloud or plume, sampling must be done and organized 2-D and 3-D by a histogram—bar graph. Many graphic software applications use the histogram to alter color and light. Alteration is done with task settings. Then, using relationships between pixels (picture elements), a display is configured accordingly. Thereafter, smoothing, sans outliers (errors or spurious values), is used to connect sampling points in the polygon boundaries together into a regular, comprehensive shape for viewing. As the crux of this paper, Kriging and Cokriging will be discussed next in great detail for concept validation as they apply to a creation process of a polygon representing a cloud or plume. Because Kriging and Cokriging have many derivatives such as Ordinary, Universal, Simple, Indicator, Probability and Disjunctive, only the simplistic Ordinary derivative will be covered and be synonymous with the terms. Both have all the desired qualities—predictions, prediction standard errors, quantile maps and probability maps— for the task at plume and cloud modeling. Subsequently, Kriging and Cokriging will be related to sampling, histograms and smoothing to complete the process discussion.

Kriging depends on mathematical and statistical models. Kriging is defined as:

“Weighting the surrounding measured values to derive a prediction for each location. However, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement among the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified.”<sup>45</sup>

---

<sup>44</sup> ESRI Corporation, circa 2002, ArcGIS Geostatistical Analyst, *What is ArcGIS?*, page 25 & ESRI Corporation, circa 2002, ArcGIS Spatial Analyst, *What is ArcGIS?*, page 23.

<sup>45</sup> HTML Help Control Version 4.74.8702: “Kriging”, *ESRI ArcMap 8.2 (Build 700)*. 2002.

The previous definition mentions weighting, a common concept in PERT and neural network used in data mining. Given two points, the vector between them will be assigned a numeric value. The value alone has no significance but when combined with other vectors from other points that are interrelated, minimum and maximum values for example become evident. In PERT the minimum sum of all the values is the critical path. In Kriging, Inverse Distance Weighted (IDW)<sup>46</sup> is used to establish values, where all possible paths to and from points are statistically compared before point values are assigned. The closest points receive the highest value. Spatial arrangement among measured points and not only distance among the points is factored into the final point value used in the weighting process. What separates Kriging from other deterministic methods to include statistics is the use of probability, which is very useful when forecasting a point value outside the network of sampled points. However, probability does come with error. For instance, a national poll on CNN lists the percent of people in favor of war with Iraq and those opposed will not include all Americans. A sampling of perhaps twenty-five hundred would be used from many demographic groups and geographical areas to represent a cross section of America. The polls do list their statistical limitation as a plus or minus error footnote. Kriging has some built in error correction, which reduces the impact of error by having two distinct cases. The first is a measurement with an error factor and second is without factor. With a known error factor such as a sampling device's sensitivity error or several different readings from the same device, an error factor is then determined statistically as in the CNN example.

Ordinary Kriging assumes the following equation to build a model:

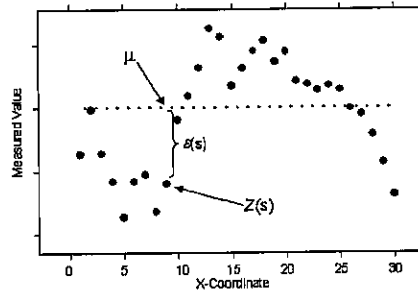
$$Z(s) = \mu + \varepsilon(s),$$

where  $\mu$  is an unknown constant,  $Z$  a function and  $\varepsilon(s)$  is still another function for error. In Ordinary Kriging, a constant mean is assumed, making it only a candidate for one source of sampling.<sup>47</sup> Yet, Kriging has remarkable flexibility as a method of prediction. The following figure is an example in one spatial dimension which subscribes to it univariate orientation.

---

<sup>46</sup> Ibid.

<sup>47</sup> Ibid.



The example is elevation values collected from a line transection through a valley and mountain. Although, it appears like the data is more variable on the left and becomes smoother on the right; it was really derived from an Ordinary Kriging model with a constant mean  $\mu$ . The actual mean is the dashed line. Consequently, Ordinary Kriging can be used for data that seems to have a trend. It isn't possible, based on the data alone, to decide whether the observed pattern is the derived from auto-correlation—close proximity—alone (among the errors  $\epsilon(s)$  with  $\mu$  constant) or trend (with  $\mu(s)$  changing with  $s$ ).<sup>48</sup>

Unlike Kriging, which is univariate, Cokriging can process data from several variables. The significance of multi-variate processing means that models can be made from several sources at once. In order to work, several similar equations for each source are used simultaneously, but with different values for functions, means and error function derived from each source. The mathematical equations are the same as Kriging but run in parallel and are relational autocorrelation or trend determination. Autocorrelation and trending help separate different data sources from one another. Data associated with a source are grouped together by autocorrelation. Trend determination can then be used to organize the data not only around a source but also in terms of the data around other sources.<sup>49</sup> Where Kriging would give the highest statistical location for concentration among three data sources, Cokriging would give the actual location of each one, surrounding concentrations and assistance to sources nearby.

Ordinary Cokriging assumes the models,

<sup>48</sup> *Ibid.*

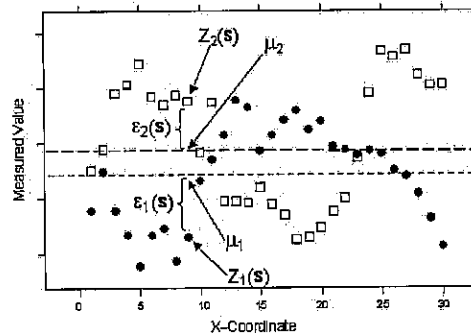
<sup>49</sup> Fotheringham, A.S., Brunston, C., & Charlton, M., *Quantitative Geography: Perspectives on Spatial Data Analysis*, 2000, page 171-183 & HTML Help Control Version 4.74.8702: "Cokriging", *ESRI ArcMap 8.2 (Build 700)*. 2002.



$$Z_1(s) = \mu_1 + \varepsilon_1(s)$$

$$Z_2(s) = \mu_2 + \varepsilon_2(s),$$

where  $\mu_1$  and  $\mu_2$  are unknowns and constants. There are two types of random errors,  $\varepsilon_1(s)$  and  $\varepsilon_2(s)$ , allowing autocorrelation and cross-correlation of trends. Ordinary Cokriging predicts  $Z_1(s_0)$  like Ordinary Kriging, but uses the covariate  $\{Z_2(s)\}$  thereby increasing the resolution. A case in point is the exact same diagram on the next page used for Kriging with a second variable added.  $Z_1$  and  $Z_2$  are auto-correlated. When  $Z_1$  is below the mean  $\mu_1$ , then  $Z_2$  is often above its mean  $\mu_2$ , and vice versa. Therefore,  $Z_1$  and  $Z_2$  aren't cross-correlated. Although, each location  $s$  had the same values in both  $Z_1(s)$  and  $Z_2(s)$ ; this is inconsequential.  $Z_1$  and  $Z_2$ , both autocorrelate and cross-correlate and are used to make better predictions.<sup>50</sup>



Cokriging can use either semi-variograms or co-variances (autocorrelation) and cross-covariance (cross-correlation) as well as do transformations and remove trends, which attest to their flexibility over Kriging. Measurement error is dealt with cross comparison and multiple ongoing error correction refine each solution based on the depth of sampling.<sup>51</sup>

Sampling data from emission sources provides the foundation for the mathematical and statistical processes in Kriging and Cokriging. Specifically, the data samples would be derived from detection devices widely spread out around emission sources such as dosimeters for radiation and Area Rae devices for measuring chemical

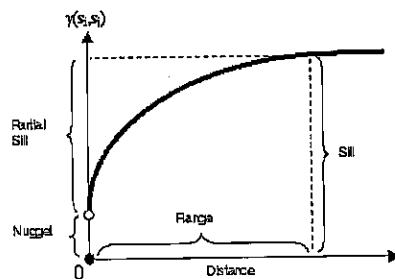
<sup>50</sup> HTML Help Control Version 4.74.8702: "Cokriging", *ESRI ArcMap 8.2 (Build 700)*. 2002.

<sup>51</sup> Ibid.

concentrations in parts per million (PPM). Distance between sampling points is important. The closer sampling points are; the more accurate they become. Conversely, the farther apart they are, accuracy becomes an issue along with detection. Null value samples help in better defining the boundaries. The point at which distance per se begins to become a factor from the emission source is called a sill. And, the distance from the source to the sill or point of diminished accuracy is called range. Mathematically, the equation for a sampling relationship known as a semi-variogram is:

$$\gamma(s_i, s_j) = \frac{1}{2} \text{var}(Z(s_i) - Z(s_j)),$$

where *var* is variance.<sup>52</sup> On one hand, if samples,  $s_i$  and  $s_j$ , are close to each other the distance of  $d(s_i, s_j)$ , then we would be equal or similar, and the difference in their values,  $Z(s_i) - Z(s_j)$ , should be equal or small. On the other hand, increasing  $s_i$  and  $s_j$  expands the values of  $Z(s_i) - Z(s_j)$ . The following diagram shows the semivariogram relationships and depicts the concepts of range and sill.



Noteworthy is the variance of the difference increases with distance pointing to the semivariogram as a dissimilarity function. Moreover, error discussed earlier is a part of the semivariogram. The nugget is the vertical distance between zero and a value above it on the y-axis. The distance is called the nugget effect. The effect is derived from measurement error, scalar variation or the variance in measurement. The nugget effect can range from zero to a positive value and helps in realigning values. In terms of numbers, logic would dictate that an increase in sampling would increase the accuracy as it draws nearer and nearer to the higher population. The nugget effect used within range

<sup>52</sup> HTML Help Control Version 4.74.8702: "SemiVariogram", *ESRI ArcMap 8.2 (Build 700)*. 2002.

constraints helps reduce the reliance on greater numbers of samples by integration with error and variation.<sup>53</sup> In short, sampling for Cokriging can be done with less sampling than standard statistical models i.e. ArcMap needs only 10 samples/neighbors per source. More samples with readings will only provide a limited increase in resolution of concentration levels around an emission source. Similarly, more samples without readings will help define the boundaries of a cloud or plume around an emission source. However, there is a way to mathematically improve concentration level determinations and boundaries by mathematically through smoothing.

Smoothing involves establishing a seemingly continuous relationship between adjacent points.<sup>54</sup> Since Kriging and Cokriging are able to routinely handle unknown sampling points between known points, smoothing is needed to increase the resolution of the boundary, where the separation of values with and without values exist. To begin, dealing with unknown values won't help computation. Therefore, a relationship is such as a line through a group of random points involving the least amount of distance between all points. The small line and close proximity of the points would be the goal. With these requirements, a weighted square difference between all points achieving minima could be derived. Repeated again and again, a regular continuous shape could be derived with a boundary. With the boundary established, the organization of concentration levels surrounding the emission source still remains.

The histogram helps organize all sampling values for graphical display surrounding an emission source. A histogram is no more than a bell-shaped curve with a peak in the center representing an emission source and various concentration levels tapering off as distance from the center increases. Subsequently, an abnormal distribution of values to one side skews the curve to one side or the other. Histograms also utilize a third dimension in Kriging and Cokriging.<sup>55</sup> Up to this time, our discussion has been linear. For example, both methods can develop relationships in three quadrants (x, y and z) much as one would consider lateral displacement, which is 2-D and

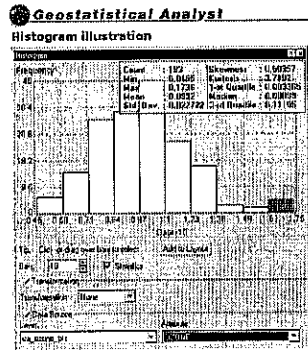
---

<sup>53</sup> HTML Help Control Version 4.74.8702: "Nugget Effect", *ESRI ArcMap 8.2 (Build 700)*. 2002.

<sup>54</sup> Fotheringham, A.S., Brunston, C., & Charlton, M., *Quantitative Geography: Perspectives on Spatial Data Analysis*, 2000, page 171-183

<sup>55</sup> HTML Help Control Version 4.74.8702: "Histogram", *ESRI ArcMap 8.2 (Build 700)*. 2002.

elevation, which makes it 3-D. In this way, winds or gusts on a plume or cloud can be simulated. An illustration of a histogram follows:



The most prominent point in the histogram represents the source while samples are the points on either side. The points represent either single values or a bin—a container of multiple values represented by a mean or mode.<sup>56</sup> In Kriging, there would be a single histogram, or values around a single source. In Cokriging, there would be multiple peaks due to multiple sources. The choice of the method would be determined by the number of sources to be monitored as well as other constraints that will be covered in the field study next.

<sup>56</sup> Ibid.

## VII. Practicum: Concept Validation

Although the condition of a limited nuclear and chemical attack can't be tested even on a small scale, a similar real world conditions can be used to closely approximate if not clearly validate our previous discussion on Kriging and Cokriging. Pollution poses as an ideal condition for modeling because it's extensively studied, sampled and highly analyzed with a wealth of data on lethal and dangerous substances. Moreover, a case can be found for gaseous elements and particulate matter closely simulating chemical agents and radioactive fallout respectively.

Air pollution in California is a large scale and complex problem, which subscribes to modeling. Moreover, sampling in statistically sufficient quantities contributes to the model, which is predicated on theoretical toxicity levels. The data for this practicum was derived from an analysis of ground level ozone distribution based on 1996 figures for the highest concentration measured during an eight-hour period.<sup>57</sup> A geostatistical approach employing Kriging was used to model ozone concentration distribution as well as prediction in turn.

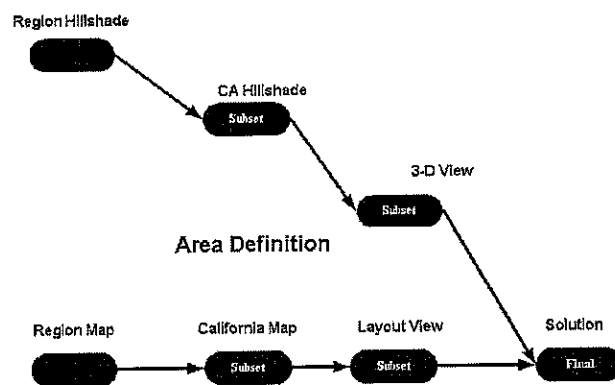
Ground level ozone is a major pollutant responsible for mucous membrane irritation, respiratory problems, lung damage and death at various levels. Furthermore, ozone is a toxic end product of the most significant, prodigious pollution source: the automobile. The automobile produces Nitrous Oxides (NOX), which are the precursors to ozone, while releasing unburned hydrocarbons and particulate matter into the air. Ozone poses not only a direct toxicity problem to humans but contributes to acid rain, which threatens both vegetation as well as animal life. In our practicum, ozone concentration levels were taken from 1996 EPA data for California. At the same time, so were NOX and PM-10 concentrations—particulate matter 10 microns or smaller is diameter. From the data, ozone modeling was done and NOX and PM-10 were subject to cursory review due to their transitory nature.

The approach went through five distinct though non-sequential phases—study area definition, primary Exploratory Spatial Data Analysis (ESDA); Kriging; integration and resolution; and secondary ESDA. In the study area definition phase, adjacent bodies and areas such and areas such as the Pacific Ocean, Oregon, Nevada and Arizona were

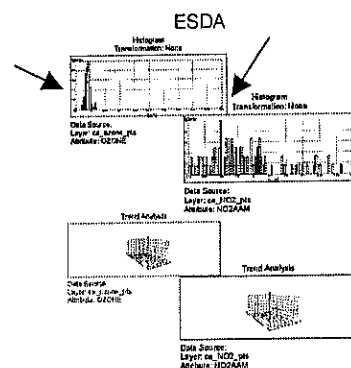
---

<sup>57</sup> AirData : Access to Air Pollution Data, Feb 28, 2003, <http://www.epa.gov/air/data/index.html>

eliminated from the map isolating California with ArcView. Two surfaces were redefined in terms of a regional map (shape file) and hillshade (raster)—graphics file types. The former was used for layout and tabular display analysis while the later contributed to a 3-D view and logically deduced deterministic argument. The argument would be that ozone concentrations appear lower on the coast than inland due to the trade winds, which introduced winds into the analysis. Furthermore, the highest probability is inland would be up against a natural barrier—mountain range, etc., which is also deterministic. For example, one can visually see the smog lingering near the base of the mountains nearing Riverside. The ArcView map clip function was used on the shape file

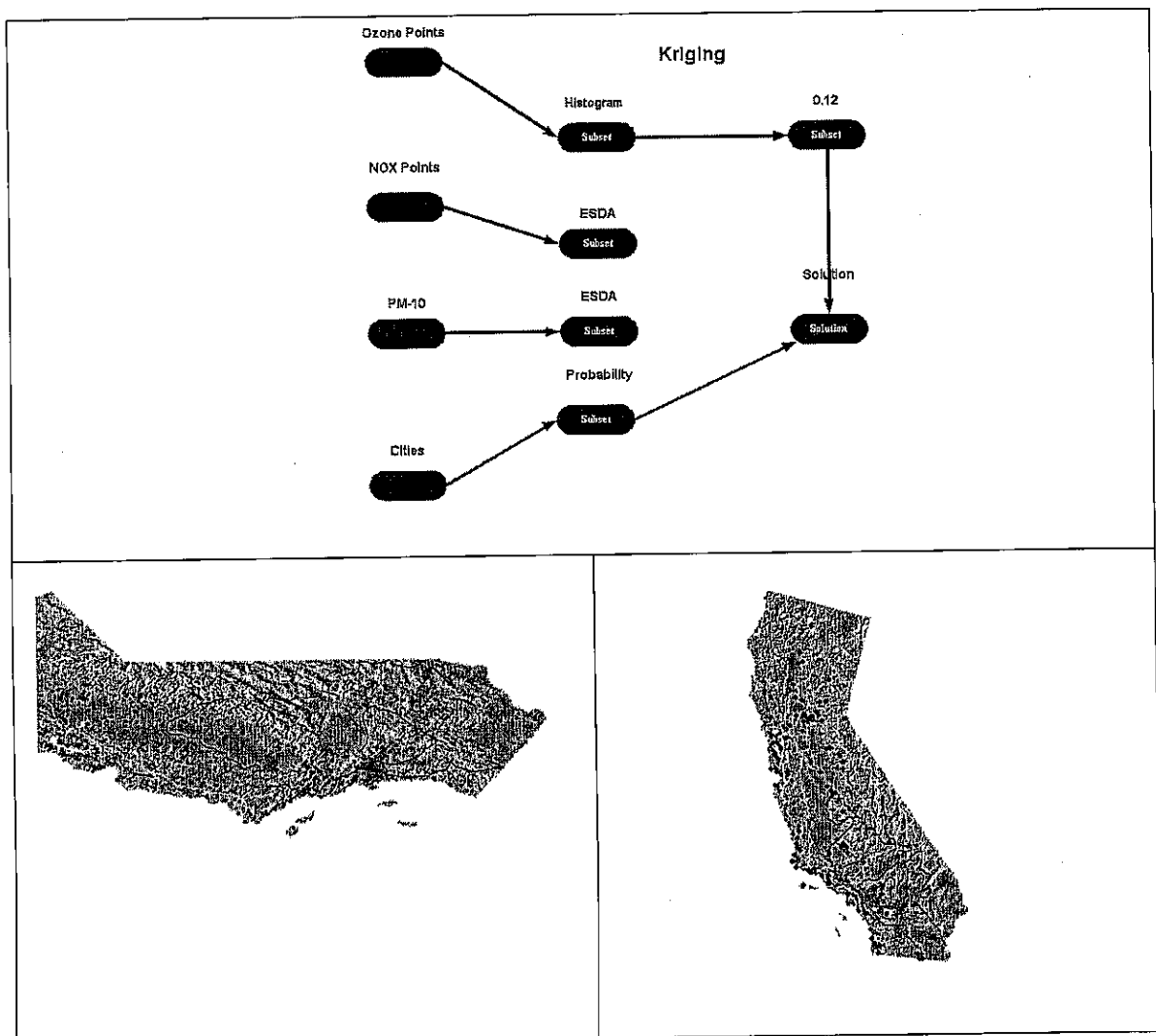


and map algebra—spatial calculations--on the raster. A workflow diagram follows: The primary ESDA phase involved a histogram and trend analysis for accumulation of ozone, while NOX and PM-10 due to their nature resisted univariate analysis and smoothing (log and arcsine) operations. No outliers or statistically insignificant samples were found for NOX or PM-10. Normal QQ Plot—another statistical feature of ArcView— and trend analysis were done nonetheless on Ozone and NOX. In any event, outliers were only identified in the ozone histogram and removed.



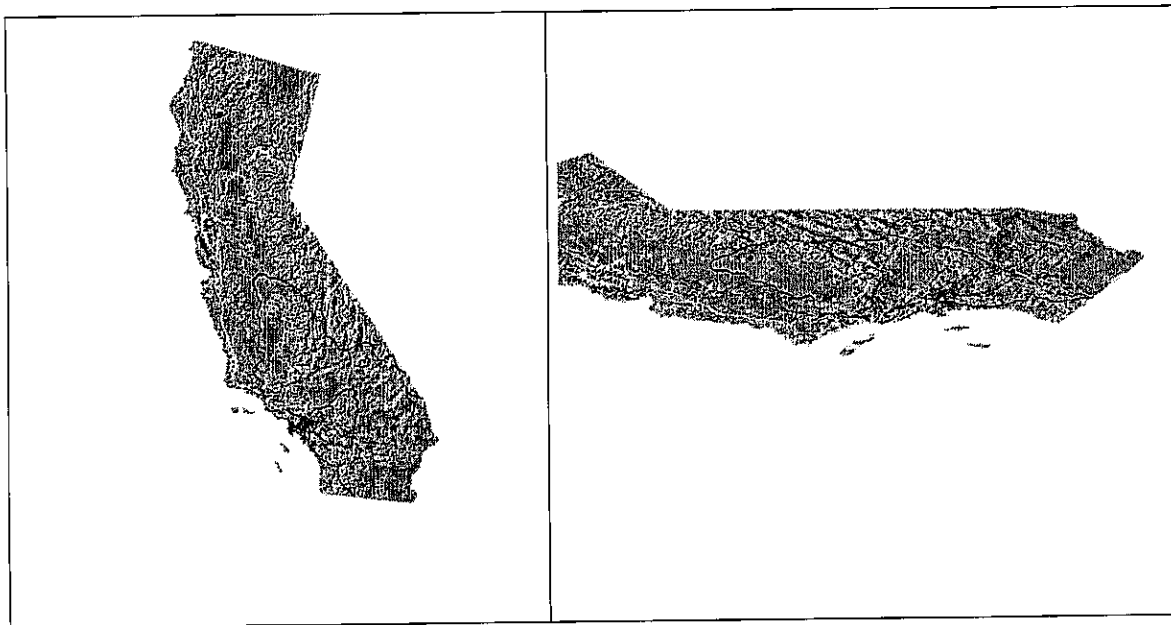
Histogram Outlier Selection and Trend Analysis

The first iteration of the Kriging phase used ordinary as a type and the prediction map option on the ozone points sans outliers. A filled contour feature was produced, which was changed to only hollow contours for display purposes. Subsequently, the layer was expanded and sized for California. The export-to-vector function and California outline were used to produce the final ozone distribution map. The workflow appears below and is followed by 3-D which shows to scale a natural barrier/corridor and layout with cities and ozone sampling points.



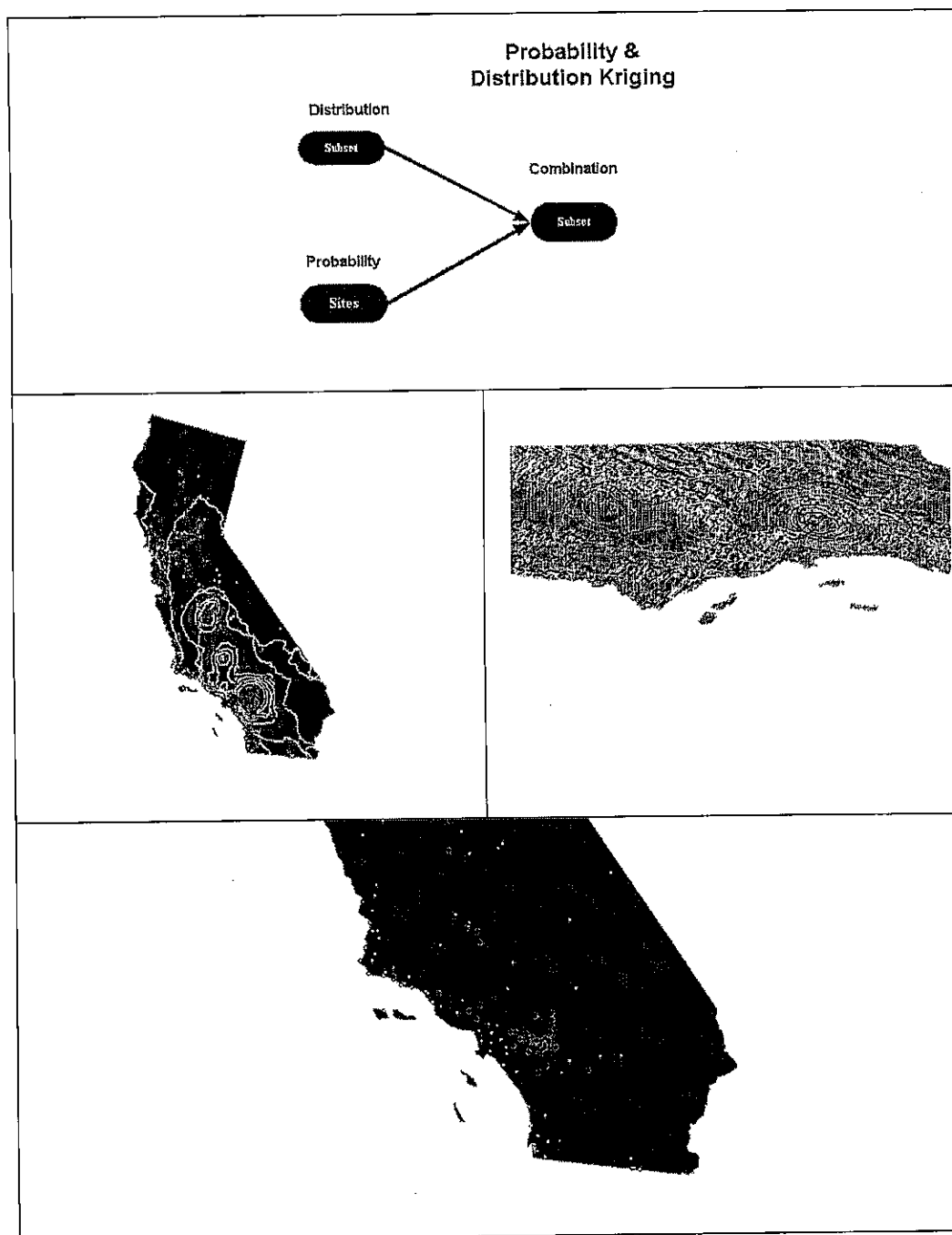
The cities are in blue with the distribution rings red for the greatest concentration to yellow for the least. The second iteration of Kriging was preceded by an interval

reduction of two consisting of greater and less than 0.12 implementing a concentration threshold of concern. See diagram/map above, which has points below 0.12 in yellow and above in brown. Ordinary Kriging was then performed on newly categorized points to produce a probability map. The same process accomplished on the previous iteration was used to apply the map to California exclusively. Below are the layout and 3-D views.



In the integration and resolution phase, both maps were merged and set against a hillshade backdrop with cities and ozone collection points—greater and less than 0.12—for 3-D bird's eye and west to east views in ArcScene—the 3-D extension of ArcView. To derive the cities with the minimum and maximum probability for having the maximum concentration, point features from different classes were spatially joined—merging separate layers of a map—and integrated with the now merged maps. Spatial join also gave the option of finding points in a polygon that was utilized to discern the maximum and minimum probabilities. Below are the layout and 3-D views for the combination and distribution and probability.

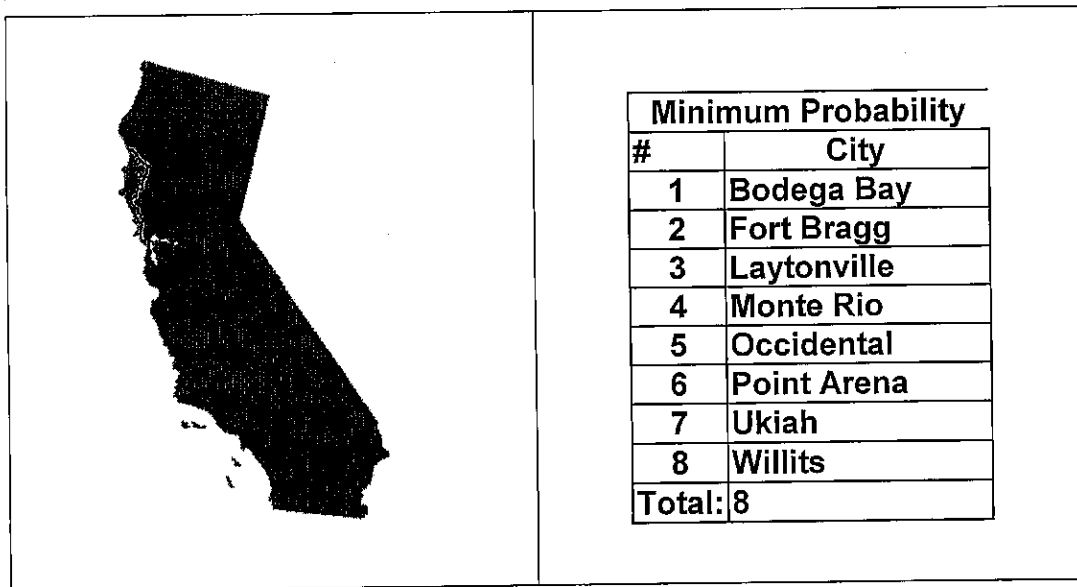




The map above displays the area with the highest probability for receiving the maximum concentration, which points toward the I-40 corridor traveling toward Los Angeles. Yellow marks are values less than 0.12 PPM and red are greater. Tabular data showing affected cities along with total in the red circle come from the spatially joined database in the ArcView map appear below:

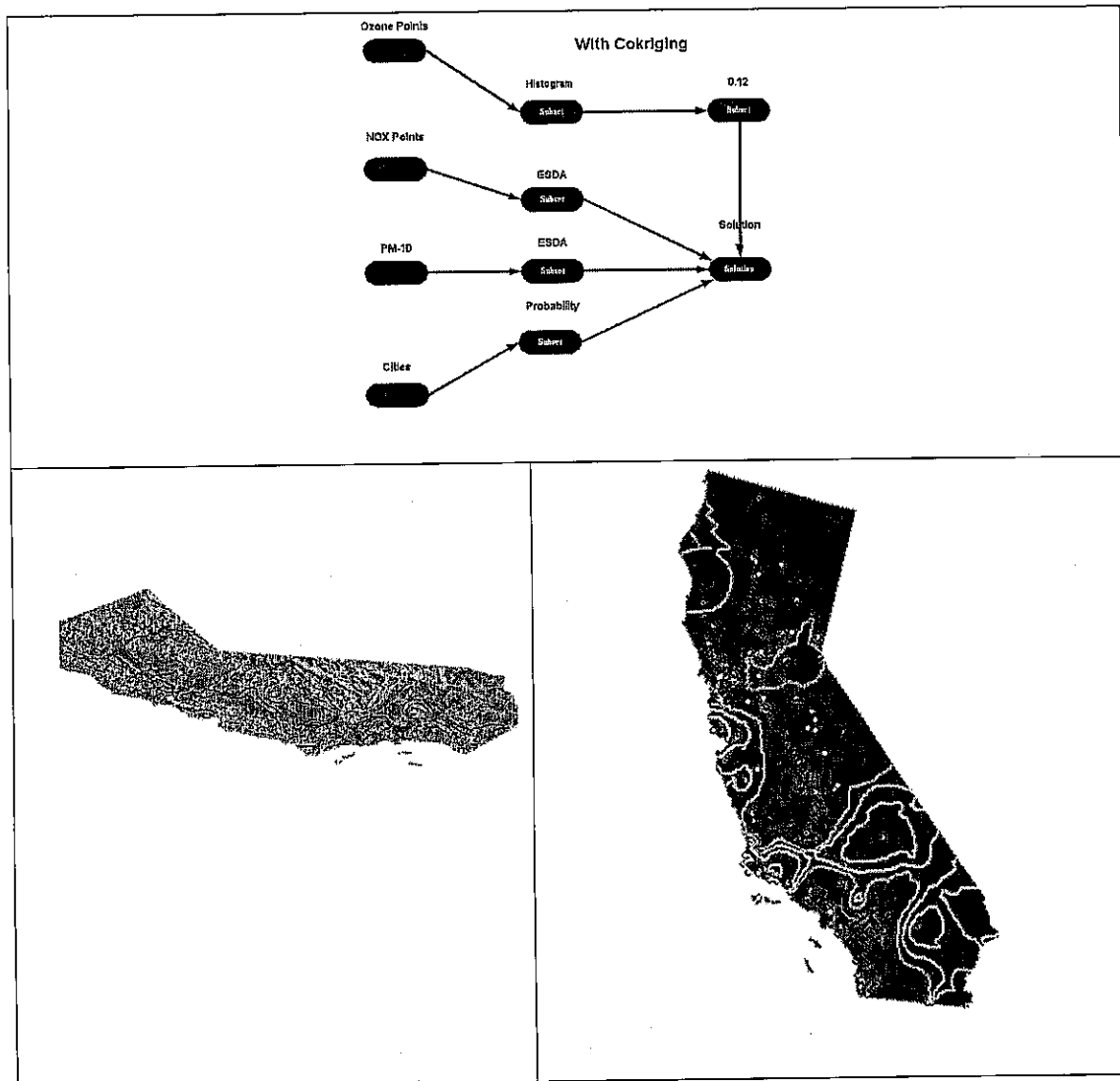
<b>Maximum Probability</b>			
<b>#</b>	<b>City</b>	<b>#</b>	<b>City</b>
1	Bloomington	11	Ontario
2	Colton	12	Pedley
3	Crestline	13	Rancho Cucamonga
4	Fontana	14	Rialto
5	Glen Avon	15	Rubidoux
6	Grand Terrace	16	San Antonio Heights
7	Highgrove	17	San Bernardino
8	Loma Linda	18	Sunnyslope
9	Mira Loma	19	Upland
10	Muscoy	<b>Total: 19</b>	

The map below displays the area with the lowest probability, which is on the coast assisted by trade winds. The map is followed by tabular list of the cities:



The secondary ESDA phase was done to apply Cokriging on a limited basis to resolve any issues and to approach the analysis from a deterministic perspective. Obviously, the I-40 corridor isn't the only polluted area in California! The same histograms were used, but this time two prominent sample humps (potential variables or hotspots) were treated separately. The features were highlighted and exported from the map, then exposed to Cokriging. Cokriging better revealed high distributions around major cities such as Los Angeles, San Francisco, Fresno and San Diego, where one would expect to find high

concentrations of air pollution. ArcView needed just 10 samples or bins (like values in close proximity) in each of the two humps experimented with to provide the results. The significance of the operations is quite evident. Only 10 samples are needed for each concentration even in a multi-emission environment. Below are the workflow diagrams and results of Cokriging.



Kriging provided a valid albeit limited solution for distribution and prediction models for our practicum. But, Kriging was quickly done and was especially relevant in dealing with one variable. The information for the lowest and highest probability for maximum concentration isolated to two points proves this fact. They would be the most dangerous and safest place on a base hit by a limited nuclear or chemical attack. However, departing from a normal distribution case and univariate instance, Kriging was

of little use in determining actual sources or hotspots much less adding additional variables such as NOX and PM-10 to the analysis. Subsequently, Cokriging delivered in dealing with a multi-variable instance on sources with concentric rings of concentration levels for pollution in gaseous form and particulate matter down to 10 microns.

To summarize, the practicum shows in a larger scale that Kriging and Cokriging work on forecasting and calculating concentration levels for toxic chemicals and particulate matter. The case does hold true when applied to chemical agents and nuclear fallout. Rather than going from smaller to larger, the process is reversed lending more credence from the State of California down to an airbase, which is about the size of a small city in the practicum.

## VIII. Network Support

ArcView renders an excellent map depicting a polygon shape for a nuclear cloud or chemical plume. However, the renderings need to get quickly out to all base personnel so that mission impact can be minimized. With everyone at maximum MOPP—suited up for maximum protection—those unaffected personnel need to know as soon as possible to avoid fatigue and continuing their work unencumbered. Information can do this in various forms: maps being the quickest most intuitive form of communication. Moreover, the maps or renderings need to be sent in a continuous flow to adjust for changing conditions such as wind, rain and dissipation or radioactive half-life. Therefore, the present airbase information infrastructure will be applied along with recommendations for improvement.

The US airbase information infrastructure has several options for relaying threat information from an ArcView map. The telecommunications and radio systems can be used to broadcast information using a common map with a grid system with affected areas identified by ArcView. Doing so, communicates the information quickly, but leaves large unaffected areas with many personnel in the designated grids, or something we are trying to avoid or reduce further. ArcView workstations can send maps to all users enabling them to see maps with a map viewer. ArcView can divert all renderings to a FAX server quickly spreading transportable maps. ArcView can use an ArcIMS server to publish all maps for use with any browser on the Internet or airbase intranet.<sup>58</sup> An ArcIMS server can also host users connected to a wireless network—laptops would be compatible but the image would have to be simplified for Personal Digital Assistant (PDA) due to browser limitations.

While other options could join those already presented, the price tag for ArcView software is prohibitively expensive: \$1,500 per seat without extensions such as Geostatistical Analyst and Spatial Analyst needed for Kriging and Cokriging, which cost more.<sup>59</sup> Most businesses operate ArcView in a tier system with only a few workstations with a wider audience of users viewing information either through browsers or map viewers.

---

<sup>58</sup> <sup>41</sup> ESRI Corporation, circa 2002, *What is ArcIMS?*, *What is ArcGIS?*, page 33.

<sup>59</sup> ArcView 8.x, Feb. 28, 2003, <http://www.esri.com/software/arcgis/arcview/index.html>

Resuming our discussion, ArcView workstations can send maps to all users enabling them to see maps with a map viewer. The map viewer can be ESRI software, which is a free download from their corporate website, or a normal browser. In the latter case, an ArcView map can be saved as a JPEG complete with legend and sent via email to mass address lists.

ArcView maps can be switched from a map rendering to a layout—printer friendly—form and easily printed. What can be printed can also be FAXed. All that's required is to setup an ArcView workstation with a FAX server with all FAX and FAX enabled copy machines on the airbase. The end result would be a portable map to distribute to personnel to carry to increase threat awareness and delay going to maximum MOPP until the appropriate time comes.

If ArcView is the per seat utilization, ArcIMS is the per server ESRI solution to deploying maps throughout an organization. server to publish all maps for use with any browser on the Internet or airbase intranet. An ArcIMS server can also host users connected to a wireless network—laptops would be compatible but the image would have to be simplified for Personal Digital Assistant (PDA) due to browser limitations.

Most US airbases are essentially Wide Area Networks (WAN), composed of several LAN, which can be for classified or unclassified use. Presently, Asynchronous Transfer Mode (ATM), an old telecommunication technology, is being replaced by the newer FDDI cable to increase bandwidth and security—fiber optic being extremely difficult to tap with out alerting intrusion detection as well as having more working bandwidth. An ArcIMS server would be sending out maps on the network described above. ArcIMS servers would be used on the unclassified side of the network to maximize user awareness to threat information. Another ArcIMS server outside the DMZ<sup>60</sup> around classified computers would be used to connect to the Tactical Battle Management Computer System (TBMCS) with much more detailed information. TBMCS is basically a command and control system tying together servers with incoming information and transmitting command directives within the airbase intranet. It uses the airbase intranet, which outside users can't access, then tunnels to consoles cleared for classified information. TBMCS consoles would be located at the WRC, SRC, DCG and

---

<sup>60</sup> Tyson, J. How Firewalls Work, Feb. 28, 2003, <http://www.howstuffworks.com/firewall4.htm>

all UCCs. TBMCS has had problems with bandwidth usage, which is being addressed. ArcView used primarily by the Civil Engineer would be located at the SRC, where it is used for managing the airbase infrastructure as well as the facilities, which make extensive use of Computer Aided Design (CAD). Again, ArcView could be used in a classified or unclassified way.

## **IX. Conclusion**

While, nine-eleven ushered in new realities for the Air Force the knowledge and technology to deal with Weapons of Massed Destruction (WMD) on a US airbase with ArcGIS is not only available but with some imagination within reach. Al Qaeda has taken care of the common misconception that our domestic airbases are for garrison and training only. American military power continues to use air power that is also launched from the US. A nuclear or chemical attack on a domestic airbase would reduce our ability to project or employ air power against any adversary in the world.

The primary mission of an airbase is to launch and recover aircraft for combat and combat support missions. And, the ability to accomplish the mission creates a natural benchmark to measure the effect an adversary has in using his weapons against us. It is a proven fact that nuclear and chemical weapons can either deny or degrade the base from carrying out its mission. While we can't stop attacks, we can lessen their effects with ArcGIS. Armed with information, an airbase can continue to operate and take the war to our adversary.

It has been shown that current toxic chemical agent and nuclear fallout information systems are inadequate for analyzing and disseminating plume and toxicity status for an airbase. Although, personnel are trained on nuclear blast/fallout, chemical agents and their respective countermeasures, information is the needed to apply their knowledge and limited resources when and where needed. If nuclear fallout or a chemical agent plume is not near enough to be a factor, personnel need to be outside of shelters and working launching and recovering aircraft without the burden of protective clothing.

Geographical Information Systems (GIS) are the key to using the combined knowledge and physical resources to counter the lethal and debilitating effects of chemical agents and nuclear fallout degrading the airbase mission. Presently, the GIS industry leader is world renowned Environmental Systems Research Institute (ESRI), which has fielded ArcGIS as a multi-disciplinary information solution. The ESRI graphic solution--ArcGIS--provides the fastest way of dealing with a long-term nuclear fallout or chemical contamination. ArcGIS has the capability to import nuclear and



chemical data, analyze it and produce the most effective information tool: a base map with threat information.

The ArcGIS map has the ability to spread the information rapidly through the base chain of command and information infrastructure by image as well as voice. In the former case, a map could appear on every browser of all workstation, laptop and PDA on base though the wired or a wireless network. The same map information could be FAXed through a FAX server and announced through the base public address and radio system. With the threat information, base personnel could take the appropriate countermeasures or more importantly delay implementation and conserve limited resources.

With this paper four salient points have been covered. First, an overall description of the present airbase situation provides dividends in productivity and savings in personnel death and injury. Second, ArcGIS was covered in great detail and tested to fit a cloud or plume attack scenario. Third, the information infrastructure appears adequate and could be augmented by wireless to increase information workflow. Fourth, present technology developments have been covered that will enhance the mathematical modeling used.

From our purposeful discussion on the domestic airbase environment, problem, solution communication, and future come s a new understanding in building a quick interim information solution to the nuclear and chemical attack problem. The long-term solution would be to add more sensor technology for sampling and mobile computing to the infrastructure.

## References

### **Books:**

- ESRI Corporation. (2002). *What is ArcGIS?*. Redlands: ESRI Corporation.
- Fotheringham, A.S., Brunston, C., & Charlton, M. (2000). *Quantitative Geography: Perspectives on Spatial Data Analysis*. Thousand Oaks: Sage Publishing.
- Minami, M.. (2000). *Using ArcMap*. Redlands: ESRI Corporation.
- Pacific Air Forces. (2001). *GEOREACH Concept of Operations* (Version 2.2). Honolulu: US Government Printing Office.
- Shaner, J. & Wrightsell, J. (2000). *Editing ArcMap*. Redlands: ESRI Corporation.

### **Web Documents:**

- AirData : Access to Air Pollution Data, Retrieved Feb 28, 2003, <http://www.epa.gov/air/data/index.html>
- Air Force Instruction 32-2001, May1, 2002, Retrieved Feb 28, 2003, [http://www.e-publishing.af.mil/pubfiles/afspc/32/afi32-2001\\_afspcsup1/afi32-2001\\_afspcsup1.pdf](http://www.e-publishing.af.mil/pubfiles/afspc/32/afi32-2001_afspcsup1/afi32-2001_afspcsup1.pdf)
- Aloha, Retrieved Feb. 28, 2003, <http://response.restoration.noaa.gov/comeo/aloha.html>
- ArcInfo 8: A New Architecture for GIS, Retrieved Feb 28, 2003, <http://www.esri.com/news/arcnews/spring00articles/esrirobust.html>
- ArcView 8.x, Feb. 28, 2003, <http://www.esri.com/software/arcgis/arcview/index.html>
- Attack (Nuclear, Conventional, Chemical, and Biological), Retrieved Feb. 25, 2002, <http://www.sema.state.mo.us/sh%20annex%20o.pdf>
- Ayers, S. (2000). Agents Terrorism: Chemical Weapons, Retrieved Feb 25, 2003, [http://www.efilmgroup.com/Dispatch/chem\\_intro.html](http://www.efilmgroup.com/Dispatch/chem_intro.html)
- Bordeaux, J. & Ochmanek D. (1993). The Lion's Share of Power Projection, *Air Force Magazine*, Vol. 76, No. 6, Retrieved Feb 24, 2003, <http://www.afa.org/magazine/perspectives/0693lion.html>
- Can Moussaoui Get a Fair Trial in America?, Retrieved Feb 25, 2003, <http://www.foxnews.com/story/0,2933,40985,00.html>
- Chemical Weapons, Retrieved Feb. 26, 2003, <http://www.fas.org/nuke/guide/usa/cbw/cw.htm>

Concept of Operations: Command and Control, Retrieved Feb 27, 2003,  
<http://216.239.51.100/search?q=cache:IMb2WeoSkToC:www.oes.ca.gov/oeshomep.nsf/a1l/TerrorPlan/%24file/TerrorPlan.pdf+Oklahoma+FEMA+%22FBI+onscene+commander%22&hl=en&ie=UTF-8>

Cullis, B. Lessons Learned in the USAF, Retrieved Feb. 28, 2003,  
[http://www.foundationknowledge.com/library/organizations/Air\\_Force/AF%20GeoBase%20Vision.ppt](http://www.foundationknowledge.com/library/organizations/Air_Force/AF%20GeoBase%20Vision.ppt)

Dewar, H. (2002). Missile Defense Funding Increased, *Washington Post*. Retrieved Feb. 25, 2003, <http://www.washingtonpost.com/ac2/wp-dyn?pagename=article&node=&contentId=A51529-2002Jun26&notFound=true>

Effects of WMD, Retrieved Feb 24, 2003, [http://www.nti.org/f\\_wmd411/fla2.html](http://www.nti.org/f_wmd411/fla2.html).

ESRI: Bringing GIS to the World, Retrieved February 25, 2003,  
<http://www.esri.com/company/about/facts.html>

ESRI History, Retrieved Feb. 28, 2003, <http://www.esri.com/company/about/history.html>

Garamone, J. Jun 2, 2000, Joint Vision 2020 Emphasizes Full-spectrum Dominance, Retrieved Feb 28, 2003,  
[http://www.defenselink.mil/news/Jun2000/n06022000\\_20006025.html](http://www.defenselink.mil/news/Jun2000/n06022000_20006025.html)

Gempis, V. (2001). Airmen Provide Chemical, Biological Defense Training, *Air Force Print News*, Retrieved Feb 24, 2003,  
<http://www2.hickam.af.mil/newsarchive/2001/2001238.htm>

Giant Voice Military Audio Systems, Retrieved Feb 27, 2003,  
[http://www.technomad.com/military/FAQ\\_mil.html](http://www.technomad.com/military/FAQ_mil.html)

HTML Help Control Version 4.74.8702: "Cokriging", *ESRI ArcMap 8.2 (Build 700)*. 2002.

HTML Help Control Version 4.74.8702: "Histogram", *ESRI ArcMap 8.2 (Build 700)*. 2002.

HTML Help Control Version 4.74.8702: "Kriging", *ESRI ArcMap 8.2 (Build 700)*. 2002.

HTML Help Control Version 4.74.8702: "SemiVariogram", *ESRI ArcMap 8.2 (Build 700)*. 2002.

HTML Help Control Version 4.74.8702: "Nugget Effect", *ESRI ArcMap 8.2 (Build 700)*. 2002.

Kaiser, R. & Ottaway, D., Woodward, B., Dec. 4, 2001, U.S. Fears Bin Laden Made Nuclear Strides, *Washington Post Staff Writers*, Dec. 4, 2001; Page A0. February 25, 2003, <http://www.washingtonpost.com/ac2/wp-dyn?pagename=article&node=&contentId=A52369-2001Dec3&notFound=true>

Keller, B. (2002). Nuclear Nightmares, Retrieved Feb. 25, 2003, <http://www.physics.ohio-state.edu/~wilkins/Terror/26NUKES.html>

Madden, T. (1999). TBMCS Deployment Underway to USAF Air Bases, Retrieved Feb 27, 2003, <http://www.missionsystems.lockheedmartin.com/announce/releases/TBMCS.html>

Marplot, Retrieved Feb. 28, 2003, <http://response.restoration.noaa.gov/cameo/marplot.html>

Martin, R. (2000) Units Act Quickly during Major Accident, *Hill Top Times*, Feb. 28, 2003, <http://www.hilltoptimes.com/archive/20001207/12.html>

Nevada GIS (www.ngis.org) Sponsors GIS Day Events Celebrate Your World with GIS, Retrieved Feb 28, 2003, <http://spatialnews.geocomm.com/dailynews/2002/oct/28/news2.html>

Nuclear Biological Chemical Warfare FM 3-3, 3-3-1, 3-4, 3-5, 3-7, 3-100, Retrieved Feb 27, 2003, <http://knox-www.army.mil/samc/Study%20Guide/NBC.doc>

Rae Systems, Retrieved Feb 27, 2003, <http://www.raesystems.com/products.html>

Rubel, J., "Tactical Battle Management Core System (TBMCS) Status", Retrieved Feb. 28, 2003, <http://216.239.51.100/search?q=cache:QKyNit0SSBsC:cno-n6.hq.navy.mil/N62/TBMCS/BRIEFS/CCG4FEB00.ppt++%22TBMCS%22&hl=en&ie=UTF-8>

Sawyer, T. (2002). Strategic Data And Image Service Feeds Mission Planners, *Engineering News Record*, Retrieved Feb 28, 2003, <http://www.enr.construction.com/features/technologyconst/archives/020225c.asp>

Smith, P.J. (2002). Transnational Terrorism and the Al Qaeda Model: Confronting New Realities, *Parameters*, 35-6, Retrieved March 1, 2003. <http://carlisle-www.army.mil/usawc/Parameters/02summer/smith.htm>

Superville, D. (2002). Chemical warfare suit: a stifling lifesaver that limits movement in combat, Retrieved Feb 27, 2002, [http://www.timesrecord.com/Military/11\\_27\\_suit.html](http://www.timesrecord.com/Military/11_27_suit.html)

Tyson, J. How Firewalls Work, Retrieved Feb. 28, 2003, <http://www.howstuffworks.com/firewall4.htm>

US Army Field Manual 7-7, Appendix M, Nuclear, Biological and Chemical Operations, Section I. Nuclear Weapons. Retrieved Feb 27, 2003, <http://www.adtdl.army.mil/cgi-bin/atdl.dll/fm/7-7/appm.pdf>

VX: What is it?, Retrieved Feb 25, 2003, <http://www.foxnews.com/story/0,2933,76872,00.html>

WMD Terrorism in Historical Context, Retrieved Feb. 25, 2003, [http://www.nti.org/f\\_wmd411/fla6\\_1.html](http://www.nti.org/f_wmd411/fla6_1.html)