WEATHER IN AIR CAMPAIGNS, 1990-2003 Daniel L. Haulman 24 June 2003

Forecasting increasingly determined the success of air missions in operations between 1990 and 2003. Weather affected whatever traveled through the atmosphere, including manned and unmanned aircraft, missiles, bombs, and electromagnetic signals. Commanders who knew probable atmospheric conditions for specific locations and times were better able to select systems and launch missions when and where they would most likely succeed.

As weather forecasting improved, commanders were increasingly able to incorporate it into mission planning. Reasonably accurate long-range forecasts allowed weather personnel to influence the air tasking order prepared days in advance of the mission. Because **clouds affected reconnaissance, bomb damage assessment, and the accuracy of certain air strikes**, their location, thickness, and movement was especially important. **Weather also greatly influenced aircraft deployments, aerial refueling, airlifts, parachute drops, aerial broadcasts, and leaflet drops.** Although **aircraft flew in more weather conditions than ever before**, using radar and infrared devices to compensate for lack of visibility, **airplanes remained vulnerable** to thunderstorms, icing, crosswinds, turbulence, and other weather factors. **A truly all-weather airplane had not yet been built**. Unmanned aerial vehicles, strategic reconnaissance aircraft, airborne warning and control airplanes, and helicopters were especially sensitive to certain weather conditions. Moreover, increased use of sensors magnified the importance of weather as a planning factor. For all these reasons, weather support personnel and their equipment contributed significantly to the success or failure of air campaigns.

Lessons Learned

- **Air Force weather resources should be organized to meet the needs of the combat theater customers.**
- **Military weather forecasting should be centralized.**
- **Weather forecasting must be part of the mission planning process.**
- **For any given theater, weather support personnel need as complete climate data as possible.**
- **Modern technology has altered but not decreased the need for weather forecasting**.

Table I: Adverse Effects of Weather on Air Operations[1]

Condition	**Effects**	**Most vulnerable aircraft**
Heavy clouds	Obscure targets, impeding reconnaissance, bombing accuracy, and damage assessment; restrict aerial refueling; fog increases low-level collision risk and landing danger; interferes with television and laser-guided munitions	RQ-1, MQ-1, MQ-9, HH-60, MH-53, UH-1, KC-135, KC-10
Heavy precipitation	Reduces visibility; can cause engines to fail from excessive water ingestion; can flood airfields, impeding takeoffs and landings; damages aircraft (especially hail on stealth); obscures targets (snow cover)	RQ-1, MQ-1, HH-60, MH-53, UH-1, F-117, KC-135, KC-10, MQ-9
Strong wind	Crosswinds threaten light aircraft takeoffs and landings; headwinds delay flights; blows dropped personnel, cargo, leaflets off course; affects movement of smoke and gas	RQ-1, MQ-1, MQ-9, U-2, TR-1, UH-1
Turbulence	At times causes pilots to lose control of aircraft; can make aircrews sick; can damage cargo	E-3, U-2, TR-1, F-117, F-16, KC-10, KC-135, RQ-1, MQ-1, MQ-9
Storms	Thunderstorms, tornadoes, hurricanes, and lightning threaten all aircraft	E-3, RQ-1, MQ-1, MQ-9, UH-1
Icing	Increases weight and drag, reducing control and sometimes causing crashes	RQ-1, MQ-1, E-3, U-2, TR-1, B-1, B-2, F-117, A-10
Temperature extremes	Affect engine starts of newer bombers; threaten structural integrity of light unmanned aerial vehicles; limits maintenance on airborne warning and control airplanes	B-1, B-2, RQ-1, MQ-1, E-3
High humidity	Impedes engine starts on newer bombers and cargo airplanes	B-1, B-2, C-17

TABLE II: Trends Affecting the Importance of Weather

Increasing	Decreasing
More UAVs are being used, and they are generally more sensitive to weather than manned aircraft.	More munitions are guided by the global positioning system (GPS), which is less sensitive to weather than other guidance systems.
Commanders still require visual identification of targets to minimize civilian casualties.	Manned aircraft are increasingly capable of operating in various weather conditions.
Moving vehicles are increasingly becoming targets, and GPS is less useful against them.	Commanders increasingly use cruise missiles to take out targets.
Strikes are increasingly scheduled when weather puts the enemy at a disadvantage.	Aircraft takeoffs and landings are increasingly automated.
New systems such as the airborne laser and many new sensors are vulnerable to weather.	Synthetic aperture radar can "see through" cloud cover.
Global missions and deployments require global weather information, especially important for aerial refueling and strategic airlift.	

- **Air Force weather resources should be organized to meet the needs of the combat theater customers.**

The experience of Operations DESERT SHIELD and DESERT STORM in 1990 and 1991 exposed problems with the Air Force's organization for weather. The service lacked organized units trained for contingency service. Instead, individuals from all over the country were thrown together in new units and expected to produce weather products more quickly than back home. Many had never worked together before and consumed valuable time in training and developing teamwork. Enough personnel deployed, but they were not allocated properly to match abilities with needs.[2] Personnel unfamiliar with each other or with new field meteorological systems failed to provide enough weather data to planners to influence mission success. Just after the liberation of Kuwait,

the service took the Air Weather Service from the Military Airlift Command and made it a field operating agency reporting directly to the service's headquarters.

Significant reductions in the wake of the Cold War and Operation DESERT STORM complicated the Air Force's efforts to reorganize its weather assets. Desiring to do "more with less" according to total quality management principles in vogue at the time, the Air Force inactivated six weather wings and twelve weather squadrons between 1991 and 1994.[3] By 1995, the Air Weather Service had lost more than 4,000 personnel, retaining less than 1,100. The drastic downsizing proved to be counterproductive. Manning fell too low, and further reorganization became necessary. Lt. Col Gerald D. Swoboda, Director of Resource Management for the Air Weather Service in 1995, complained that manpower reductions were seriously impeding forecasting.[4] Alleviating the problem somewhat were base closures that reduced the demand for forecasting at those locations.[5] Other functions transferred to the Air Force Reserve, such as WC-130 aircraft weather reconnaissance operations.[6]

In 1997, the Air Force began to implement a "reengineering" plan for its weather organizations to fit the strategic, operational, and tactical levels of warfare. The reengineering was largely complete by the time of Operations ENDURING FREEDOM and IRAQI FREEDOM (2001-2003). At the strategic level, the Air Weather Service became the Air Force Weather Agency and moved from Scott Air Force Base in Illinois to Offutt Air Force Base in Nebraska, taking over the facilities of Air Force Global Weather Center (formerly Air Force Global Weather Central), which inactivated.[7] Movement of the field operating agency headquarters to the site of its largest production center streamlined the organization.[8] The Air Force Combat Climatology Center at

Asheville, North Carolina (collocated with the National Climatic Data Center) and the Air Force Combat Weather Center at Hurlburt Field, Florida, both assigned to the Air Force Weather Agency, also served at the strategic level. Linked with other federal and armed service weather organizations, they provided centralized weather products and resources, utilizing advanced modeling computers whose data could be transmitted around the world.[9] By the time of Operation ENDURING FREEDOM, Air Combat Command also maintained an 8-man Air Operations Squadron Weather Flight to predict what weather the command's fighters or bombers might encounter while deploying between theaters on global missions.[10]

Table I: Operational Weather Squadrons (OWS)

Designation	Last activation date	Location
USAFE OWS	1 December 1997	Sembach Air Base, Germany
11 OWS	19 Feb 1999	Elmendorf Air Force Base, Alaska
15 OWS	15 Feb 1999	Scott Air Force Base, Illinois
17 OWS	27 Oct 2000	Hickam Air Force Base, Hawaii
20 OWS	1 Oct 2000	Yokota Air Base, Japan
25 OWS	1 Apr 1999	Davis-Monthan Air Force Base, Arizona
26 OWS	1 Oct 1999	Barksdale Air Force Base, Louisiana
28 OWS	17 Feb 1999	Shaw Air Force Base, South Carolina

At the operational level, the Air Force established eight operational weather squadrons (OWS), each a "hub" responsible for a specific geographical region. These squadrons provided forecasts specifically tailored for certain areas and accumulated and disseminated meteorological knowledge for specific theaters. The hubs served both the centers and tactical weather personnel in the field, who relied on them for reach-back support. They provided forecasts for all the bases in the region, freeing local weather personnel for base operational support. Personnel at each Air Force base or Army post could use a computer linked to the appropriate OWS to request a flight weather briefing.

OWS websites also provided much meteorological data tailored for the theater. Electronic links allowed pilots to access region-specific products even if they crossed from one OWS region to another.[11]

Both Operations ENDURING FREEDOM and IRAQI FREEDOM took place in the Central Command's area of responsibility. The 28th Operational Weather Squadron (OWS), collocated with the Air Force's Ninth Air Force at Shaw Air Force Base, South Carolina, assumed responsibility for that area, providing regional weather data as needed for both the U.S. Air Force and the Army.[12] The squadron furnished theater forecast data electronically to the combat weather teams that deployed, freeing them to concentrate on adapting the data to the missions at hand.[13]

The Air Force organized combat weather teams at the tactical level. Specifically trained for contingency deployment with special operations forces, the teams provided war fighters with timely weather data they obtained from the operational weather squadrons and strategic weather centers. Each team was equipped with a small satellite receiver to gain direct access to global weather data. In the pre-mission briefing process, combat weather teams linked theater commanders, pilots and soldiers with electronic meteorological data derived from satellites and computers, giving the information a human face and making it useful. The teams also set up instruments to gather local meteorological information that could be transmitted to the appropriate operational weather squadron. Approximately 350 active-duty, reserve, and Air National Guard weather forecasters deployed for Operation IRAQI FREEDOM, serving with the combat weather teams or in the weather cell at the Combined Air Operations Center.[14]

Integrated into the planning process, the new weather organizations contributed significantly to the success of operations in Afghanistan and Iraq. The Air Force's weather organizations were far more responsive in 2003 than they had been in 1991 in large measure because of the reengineering effort begun in 1997.[15]

- **Military weather forecasting should be centralized.**

During Operations DESERT SHIELD and DESERT STORM, military weather forecasting was too decentralized. Weather personnel from different military services did not exchange data or products effectively, partly because tactical weather communications systems were incompatible. Data conversions consumed too much time, and certain weather graphic products transmitted poorly.[16]

Traditionally the Air Force shared weather resources and information more easily with the Army than with the Navy. In August 1992, weather officials of the Air Force and Navy met and approved the formation of four study teams to improve inter-service cooperation and reduce duplication.[17] Sharing of information between the Air Force and the Navy became much easier as their meteorological equipment became more standardized. For example, between 1991 and 1995, the Defense Department developed satellite imagery systems that all the services could use.[18] By 2000, the Air Force's strategic weather centers and operational weather squadrons shared weather data with U.S. Navy meteorological organizations, getting information from them and delivering weather data in return.[19]

Air Force weather personnel and organizations directly supported the U.S. Army more than the U.S. Navy or Marine Corps because the latter services maintained their own weather assets.[20] After the Air Force reengineered its weather resources in the late

1990s, the Army depended on Air Force combat weather teams for weather support on the tactical level. Personnel in such teams deployed, dropped by paratroop, and rode with Army troops on the ground in Iraq during Operation IRAQI FREEDOM to provide weather information that was critical in decisions about which weapons to use and where and when to use them.[21] Air Force combat weather teams supported the Army's Integrated Meteorological System (IMETS), a tactical automated weather system mounted on Army high mobility multipurpose wheeled vehicles (HMMWV).[22]

Computer technology and the internet have increased the ability of the services to share weather information. Through the Joint Weather Impacts System (JWIS), all the services were able to access weather information directly from a variety of sources, both within and beyond the Department of Defense. The Joint Army-Air Force Weather Information Network (JAAWIN) provided electronic meteorological data not only to the Air Force and the Army but also to the other services and to allies.[23]

The Air Force Weather Agency is the Department of Defense's leading provider of cloud analyses and forecasts. In June 2002, the agency began operating Cloud Depiction and Forecasting System II, which processed on an hourly basis data from a variety of satellites using both visible and infrared sensors. The system provided the most complete picture of the atmosphere above any given theater from the ground to the ionosphere. The data was available to all the services through the internet.[24]

By 2003, Air Force weather personnel cooperated not only with weather personnel from the other services but also with civilian federal weather agencies. Space satellites served as the most accurate tools of weather forecasters both within and beyond the Air Force. The National Polar-Orbiting Operational Environmental Satellite System

(NPOESS) began to replace the Defense Meteorological Satellite System as the most important weather satellite constellation. Such satellites provide coverage of all parts of the earth as it rotates beneath them. The Department of Defense worked with the National Oceanic and Atmospheric Administration in a single federal polar orbiter effort to obtain the best possible visual and infrared imagery. The Air Force Weather Agency also supported efforts of the National Weather Service and the National Center for Atmospheric Research to develop a Weather Research and Forecasting Model to benefit not only the civilian community but also all of the armed services.[25]

- **Weather forecasting must be part of the mission planning process.**

During Operations DESERT SHIELD and DESERT STORM, weather forecasters were not involved much in the planning process, partly because they could not accurately predict the weather for a mission scheduled several days later. During Operations DESERT FOX and ALLIED FORCE in the late 1990s, weather was not factored into the planning process beyond 24 hours. Planners considered weather only at the tail end of the mission-planning cycle.[26] The normal mission-planning cycle required forecasts three to five days into the future.

By 2001, improvements in satellite, computer, Doppler radar, and communication technology allowed Air Force forecasters to predict weather enough days in advance to accommodate the planning process. Weather data previously entered manually was updated automatically in a new Joint Weather Impacts System (JWIS). The web-based system allowed warfighters to get updated forecasts not only from operational weather squadrons responsible for the various theaters but also directly from many different sources. During Operations ENDURING FREEDOM and IRAQI FREEDOM, weather

forecasting personnel served with planners at operational headquarters, providing briefing information instantly available from the operational weather squadron responsible for the Central Command theater and from the strategic weather centers. For example, a combat weather team at an airbase at Bagram, Afghanistan, delivered five-day weather forecasts for eleven different locations throughout the country. A member of the team maintained a permanent seat in Bagram's Joint Operations Center, where ENDURING FREEDOM missions were planned. Another forecaster sat in the 82d Airborne Tactical Operations Center helping planners of ground combat missions.[27] In the first months of the war on terrorism, commanders frequently changed the types of aircraft scheduled for missions because of the advice of their weather forecasters.[28] The Afghanistan theater commander delayed insertion of a ground force into Mazar-e-Sharif in Afghanistan for two days because forecasters predicted that bad weather would deprive the force of adequate close air support. The decision probably saved many American lives.[29]

During Operation IRAQI FREEDOM, a weather cell at the Combined Air Operations Center (CAOC) in the theater advised mission planners, offering forecast information that helped them to select the best weapons, targets, and times.[30] Lt. Col. Fred Fahlbusch, who served as the staff weather officer for the air component commander of Operation IRAQI FREEDOM, noted "Most systems we have are weather-sensitive, so weather predictions must be integrated into the planning at all times." His weather cell began providing crucial weather information to operators beginning as early as five days before each mission and throughout the process of preparation. Weather personnel provided input throughout the air tasking order process. Even during mission execution, the weather cell advised the chief of combat operations for any last minute

changes. After each mission, the weather cell determined how weather contributed to its success or failure.[31]

Reorganization and training allowed weather personnel to exploit the new equipment available to them in the field. Combat weather teams helped both air and ground commanders select which weapon systems to use and when and where to use them.[32] By the time of Operation IRAQI FREEDOM, Joint Weather Impacts System (JWIS) information was available at computer terminals at the Prince Sultan Air Base Combined Air Operations Center (CAOC) in Saudi Arabia, allowing operations planners to gain access to the latest meteorological data.[33] Greater incorporation of weather forecasting in campaign planning contributed to the fact that only four percent of all Operation IRAQI FREEDOM sorties were lost or ineffective due to weather.[34]

In the future, weather intelligence will guide planners who develop courses of action (COA). Stealthy weather sensors covertly seeded throughout the combat theater will monitor changes in the atmospheric environment. Weather forecast models will predict battlefield meteorological conditions as much as a week in advance, helping planners match weapon systems with the times and places they will be most effective.[35]

- **For any given theater, weather support personnel need as complete climate data as possible.**

During DESERT SHIELD and DESERT STORM in 1990-1991, Air Force weather units lacked enough theater climate data to expect as much overcast, fog, precipitation, and wind as actually occurred during January and February 1991. Climate records for Iraq and Kuwait went back only 14 years, and they were not complete.[36] Weather records for Afghanistan in 2001 were also inadequate. At war for almost 30 years, people in Afghanistan devoted little attention to the daily recording of

meteorological data.[37] The Taliban government, isolated from the west, did not maintain the latest meteorological facilities. Not expecting to have to conduct military operations in central Asia, and having had no military forces based in Afghanistan, the United States had collected little weather data on that country. Because of the relatively cloudless Afghan skies, however, coalition forces did not face major weather problems, such as low overcasts for days on end.

Thirteen years before Operation IRAQI FREEDOM commenced, the United States began collecting detailed meteorological data on the Iraqi theater weather. U.S. military forces occupied parts of the area for a series of operations beginning in 1990, including DESERT SHIELD, DESERT STORM, PROVIDE COMFORT, NORTHERN WATCH, AND SOUTHERN WATCH. By 2003, Air Force weather personnel had become familiar with the cyclical variations of the local weather around the Persian Gulf and applied that knowledge to the campaign.

- **Modern technology has altered but not decreased the need for weather forecasting.**

At first glance, weather forecasting seems less important today than it was in the past. The global positioning system (GPS) uses a constellation of 24 satellites to guide increasing numbers of aircraft and munitions accurately to their targets, transmitting on frequencies almost impervious to precipitation, clouds, smoke, and storms. By April 5, 2003, coalition forces in Operation IRAQI FREEDOM had dropped more than 3,000 Joint Direct Attack Munitions (JDAMS), all of which were guided by GPS signals.[38] Avionics, new materials, thrust vectoring, and de-icing equipment allow modern aircraft to cope with a greater variety of weather conditions than the airplanes of the past. The

obscurity of night once impeded air operations, but technological advances made darkness an ally rather than an enemy.[39] During Operations ENDURING FREEDOM in Afghanistan and IRAQI FREEDOM, missions often proceeded under the cover of darkness. Aircraft takeoffs, flights, and landings are increasingly automated, reducing the need for pilot visibility. Commanders increasingly use cruise missiles rather than aircraft to destroy enemy targets. Finally, synthetic aperture radar allows pilots to "see through the clouds".

More than offsetting these factors are others that increase the importance of weather forecasting. Despite the desert environment of DESERT STORM in 1991, nearly half of coalition air sorties were adversely affected by weather. During Operation ALLIED FORCE, the NATO air offensive halted for days when targets were obscured by clouds. Over Yugoslavia, there was at least 50 percent cloud cover for more than 70 percent of the time.[40] During Operation IRAQI FREEDOM, 70 percent of Iraq was cloud-free only 30 percent of the time. Just 17 of 31 days were free of significant low-level clouds or dust.[41] Massive sandstorms in late March degraded the effectiveness of certain coalition aircraft such as the tank-busting A-10 and Apache helicopter, allowing Iraqi armored columns to move south from Baghdad. However, the storms did not linger long enough to deprive coalition forces of the air support they needed to push into the Iraqi capital early in April.[42]

Unmanned aerial vehicles (UAVs) are flying greater percentages of sorties, and they are more vulnerable to adverse weather conditions than manned aircraft. Clouds, rain, and wind impede their performance.[43] In the Balkans during Operation ALLIED FORCE, icing sometimes prevented the RQ-1 Predator from performing effectively. In

September 2002, a Predator flying over southwestern Asia entered a cloud, lost communications with its controller, and crashed.[44]

No aircraft, manned or unmanned, is a completely "all weather airplane," and pilots still attempt to avoid severe weather if at all possible. Thunderstorm hazards such as severe turbulence, icing, lightning, hail, low ceilings, low visibility, tornadoes, wind shear, and microbursts can force even advanced modern military airplanes to crash.[45] Pressure fluctuations can cause altimeter errors, and heavy precipitation can result in excessive engine ingestion of water. During Operation IRAQI FREEDOM in 2003, weather sometimes delayed maintenance on E-3 AWACS airplanes because excessive heat or winds kept maintenance personnel off of the huge radar disks at the top of the aircraft.[46] As Erin Zagursky of Air Combat Command put it, "Freezing rain, gusting winds, and heavy clouds can delay or damage an aircraft just as easily as surface-to-air missiles or hostile enemy aircraft."[47]

Commanders require visual identification of targets to minimize collateral damage. This is especially important in cities, where the buildings do not move but the people do. Differential heating of buildings results in thermal clutter that confuses infrared sensors.[48] During Operation ALLIED FORCE in 1999, NATO commanders attempted to avoid attacking civilian vehicles that might be mistaken for armored columns. In March and April of 2003, Lt. Gen. T. Michael Moseley, the Joint Forces Air Component Commander for Operation IRAQI FREEDOM, ordered pilots to return with their bombs if they could not see their targets.[49]

Other factors also enhance the importance of weather forecasting in modern campaigns. Increasingly targets are not fixed, such as a terrorist leader in a speeding car

or a moving missile launcher or tank. Without the latitude and longitude coordinates of such targets, commanders cannot use GPS-guided munitions effectively, and must rely on alternative laser and television-guided munitions that often fail in heavy clouds. Operators increasingly select strike at times and places in which weather will be an ally, as when it hinders the radar of the enemy. New systems such as the airborne laser depend on certain weather conditions to operate correctly.

Global deployments require longer flights and more aerial refueling than what was typical in the past, increasing dependence on weather information.[50] Air mobility pilots depend on visual conditions more than the pilots of many other kinds of military aircraft, in part because tankers and the aircraft they refuel must be able to see each other.[51] In the first sixteen days of Operation IRAQI FREEDOM, transports and tankers carried out more than half of all the U.S. Air Force's wartime sorties. Air Force C-17 air crews depended on visibility between aircraft and ground to drop nearly a thousand Army paratroopers over Northern Iraq in 2003, the largest airborne operation since Operation JUST CAUSE in Panama in 1989.

What seems like good weather on the surface can be bad weather for high-flying reconnaissance aircraft or satellites because very high clouds between them and the ground can prevent infrared and light radiation from reaching their sensors with enough intensity for high-resolution imagery.[52] Stratospheric turbulence affects the performance of the U-2 and the Global Hawk because of the extremely high altitudes at which they fly.[53]

"Space weather" has grown in importance, primarily because modern air campaigns rely so heavily on satellites and communications with them. GPS electronic

transmissions are virtually immune from the effects of atmospheric conditions in the troposphere (such as precipitation, clouds, and wind) but they can fade and even disappear because of changing conditions in the ionosphere and stratosphere through which they must travel.[54] Large solar flares called mass coronal ejections emit electromagnetic radiation that can interrupt high-frequency radio communication and satellite links, including GPS signals. Space weather forecasting allows more accurate guidance for aircraft, missiles, and munitions. During Operation ENDURING FREEDOM, pre-mission weather briefings included both terrestrial and space weather information.[55] A recent Department of Defense study concluded that a 10 percent improvement in forecasting accuracy might lead to a 15 percent improvement in the accuracy of precision-guided munitions.[56] In recent years, the space forecast function transferred from Air Force Space Command in Colorado to the Air Force Weather Agency headquarters at Offutt Air Force Base, Nebraska. Six solar observatories now report directly to the Air Force Weather Agency.[57] The Air Force constructed a global network of twelve ground-based sensors and a computer system to allow GPS users to select satellites whose signals are less distorted because of ionospheric fluctuations. In 2003, the Air Force will launch a "scintillation forecasting" satellite to monitor such fluctuations. More such sensors are needed.[58]

Conclusion

Since the Air Force **reengineered its weather organization** in the late 1990s, it can provide meteorological services to war fighters more easily than in the past. The new structure provides **centralized weather** data facilities at the strategic level, a set of

operational weather squadrons as "hubs" at the operational level, and **combat weather teams** at the tactical level. During Operations ENDURING FREEDOM and IRAQI FREEDOM (2001-2003) they proved to be more useful than Air Force weather organizations in earlier operations.

The various military services share weather information more easily than in the past, partly because of **centralized meteorological data production and communication** using satellites, computers, and the internet. The Air Force and Navy continue to maintain their own weather resources but trade data more freely than in the past. The line between the Army and the Air Force is perhaps faintest of all in the area of weather because of the meteorological services each provides the other.

Technological and administrative improvements since the early 1990s have allowed weather forecasters to be **included in the mission planning process**. Forecasts have become more accurate for enough days in advance, and key meteorological information that is readily available provides war fighters with the capability to choose the most appropriate weapon systems and the times and places to use them most effectively. Field commanders now work side-by-side with weather personnel to develop and execute mission plans.

For any given theater**, a sizable climate history** should be available. Not enough meteorological data was available for Iraq and Kuwait in 1991 or for Afghanistan in 2001, resulting in some weather surprises. Forecasters could predict more accurately what the weather was going to be over Iraq in 2003 because of an abundance of meteorological data collected over the course of a decade of theater operations.

Technological changes have increased the importance of weather forecasting even as they have made that forecasting more accurate. Certain new weapon systems, including unmanned aerial vehicles and the airborne laser**,** are **more sensitive to weather** than previous systems. Cloud locations and movements are still important to commanders hoping to strike mobile targets and to limit civilian casualties by visually identifying targets. Although the global positioning system (GPS) has allowed more accurate strikes on fixed targets regardless of weather, even GPS satellites are subject to fluctuations of solar radiation and the ionosphere, making **"space weather" more significant** than in the past**.** As missions become more instant and long-range, **global forecasting** becomes increasingly important for deployments, aerial refueling, and intercontinental airlift.

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NOTES

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