21ST CENTURY WEATHER SUPPORT ARCHITECTURE

Overview

The twenty-first century battle area will be a highly lethal, cyberwar-oriented, four-dimensional regime with the dimension of time being the most critical.[1] To succeed, the warfighter must have immediate access to key information to make quick and accurate decisions faster than the enemy's OODA (observe, orient, decide, act) loop capability.[2] In a similar manner, the civilian and commercial world will be a fast-paced, computer-oriented regime where successful and profitable operations will be dependent on time sensitive decisions based on vast amounts of information.[3] One critical set of information, required by both the warfighter and the commercial/civilian world operators, is weather conditions affecting the mission to be accomplished. The weather information user, whether on the ground, at sea, or in the air, will need near instantaneous global access to worldwide weather information for a given point, a path, or an area in time and space anywhere in the world. This weather information must be accurate, universally available in a timely manner, packaged so it is easily usable by people who may or may not be weather-trained, and easily incorporated into software applications.

This paper proposes the development and operational employment of integrated weather information data bases, available to the weather information user at various on- and off-ramps of the information superhighway to meet the near instantaneous access, worldwide weather information needs of the twenty-first century.[4] Access to the weather information data bases will be obtained through interactive ports connected to the information superhighway via hardwire (fiber optic cables, coaxial cables, home and office telephone line connections), microwave or direct satellite transmission or broadcast.[5] Interactive ports will include such devices as large mainframe computer connections, small personal computers, or hand-held or vehicle-mounted (cockpit; tank; ship; ground) micro-processor receivers, capable of receiving direct satellite broadcast from the information superhighway.[6] The ultimate goal is for the weather information user to quickly obtain the information desired, anywhere in the world, through a push of a button or a flip of a switch, with or without hard-line connection or weather expertise.

Elements of the Architecture

The proposed integrated weather information data bases will consist of observational weather data, forecast products, climatological information, and weather advisories and warning information. Following are examples of possible data bases that can be made available to the weather information user via the information superhighway: [7] (1) current single station and gridded surface/upper level worldwide weather observational data; (2) global cloud imagery and cloud amount fields to include tops and bases of cloud layers; (3) area specific doppler radar and lightning strike information; (4) worldwide radiowave frequency propagation forecasts; (5) area specific environmental surface (ground, sea state) conditions; (6) single point forecasts and warnings for critical points of interest worldwide; (7) point or gridded worldwide climatology information; (8) globally gridded forecast fields of various weather parameters for specified time periods, both at the surface and specified upper levels; (9) hazard forecasts for icing, turbulence, volcanic ash, and fallout winds; and (10) gridded observed and forecaster wind fields at various levels.[8] The data bases can also consist of pre-tailored products, such as weather maps, graphic displays of data, plain language discussions, or specially processed data for use in special weather application software.

The weather information user will have several options in using the data. At the macro-scale level, forecast centers can use the information superhighway to acquire observational data from data processing centers, produce the forecast products, and then send the products back out to customers. The smaller scale user can directly order and obtain tailored products from a forecast or data processing center located at one of the information superhighway on- and off-ramps. The user can also gain access to weather information data base(s) residing at various information superhighway ramps, obtain the desired data, and generate his or her own weather products using on-site user software. For the warfighters, hand-held, vehicle or cockpit-mounted direct broadcast receiving devices could take the weather information directly from the information superhighway, insert it into microprocessors with pre-programmed decision aids, and within seconds, obtain a determination of weather impacts for a proposed mission.[9] Information provided from the microprocessor can be the actual weather data, to include direct broadcast of cloud imagery[10] and vertical sounding data, or a tailored product for direct input into a course of action decision process. The devices can also be designed to have a direct send/receive satellite transmission capability.[11] This attribute will enable the warfighter to obtain specific weather information via direct query access to the information superhighway. The warfighter will also be able to insert current weather observations, for example, back onto the superhighway via direct transmission (figure 1). Civilian and commercial applications will be similar; possible users would include truck drivers, commercial airlines, farmers, local TV, universities, and radio stations, and private car owners.

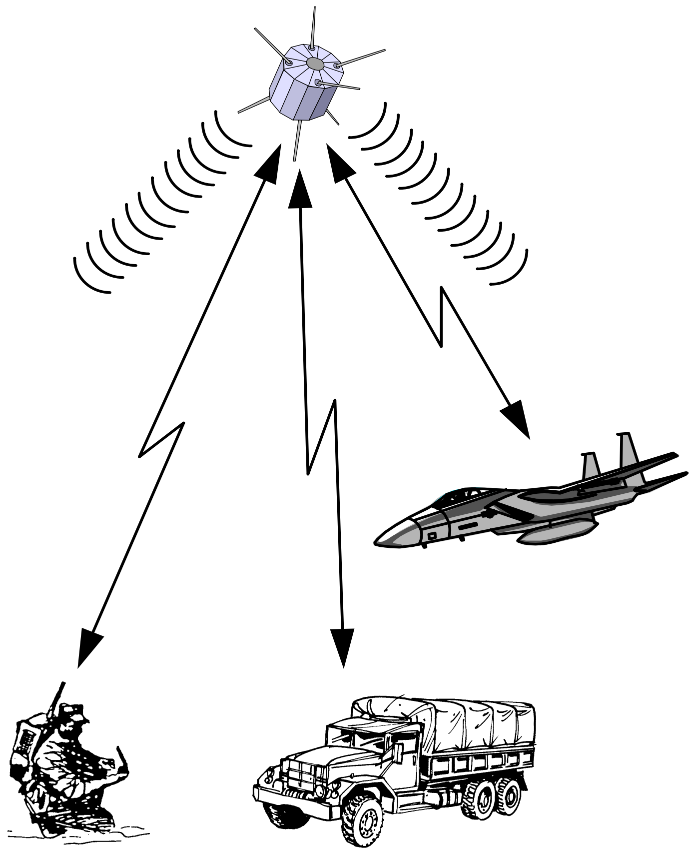

Figure 1. Near instantaneous, global access to worldwide weather data residing on the information superhighway for a given point, a path, or an area in time and space anywhere in the world. Direct access via satellite broadcast or direct send/receive satellite link.

The development of this proposed capability requires modifications and operational paradigm changes to four main aspects of the current national (Department of Defense) and civilian weather support system architecture: (1) data collection; (2) data base fusion and dissemination; (3) analysis and forecast product development; and (4) weather product and information dissemination. The extensive cost of developing new capabilities and of changing current operational weather support paradigms is expected to require a consolidated, joint-use effort among DoD, commercial, and civilian weather information producers.

Critical to the success of this proposal is the capability of our nation to continuously obtain, process, and disseminate vast amounts of worldwide, ground and satellite-based weather observations, both in war and in peacetime. Current temporal and spatial levels of observational collection will not meet the military or civilian weather information needs in the years 2020 and beyond. Every effort must be taken to expand, not decrease, our nation's weather observational capability, especially from space-based systems.[12]

The Capability and Its Relevance

Many of the pieces of the proposed capability exist in the world today or at least are on the drawing board, especially in the commercial sector, but are not woven together to produce a streamlined operational architecture providing civilian or military users near instantaneous access to worldwide weather information data bases from any location in the world in an easy, economical, or efficient manner. Development of the information superhighway and its on- and off-ramps, availability of interactive port hardware and software, computer processing capability, data availability bureaucratic barriers, budget concerns, governmental drawdowns, politics, and the actual willingness to change the weather support architecture (jobs, roles and missions, etc.) are just some of the hurdles that have to be overcome to obtain the proposed capability. Decades could pass before fruition is achieved. The SPACECAST 2020 White Paper, "Global View: An Integrated Joint Warfighters Command, Control, Communications and Intelligence Systems Architecture," (U), June 1994, addresses some of these hurdles in more detail and provides a conceptual roadmap to achieve the desired end-state of an umbrella-type, integrated information architecture to provide the communications structure to support the weather information data base concept.[13] Further discussion of the communications architecture will be left to that paper. The focus of this white paper will center on potential technologies and support architectures to be used or are believed to be needed to obtain the proposed weather support capability.

As stated earlier, architecture modifications and operational paradigm changes will be necessary: (1) in the way weather data is collected; (2) in data base fusion and dissemination; (3) in the production of the analysis and forecast products; and (4) in the dissemination of the weather products and information data bases.

In the area of data collection, satellite resolution and sensing capability must be enhanced and observational frequency must be increased to obtain more accurate, gridded worldwide weather and earth-sensing information. To meet this need, the following general modifications and changes are proposed: (1) develop and employ a technologically integrated, joint-use, multispectral, articulated satellite imaging capable (i.e., sensors controlled to look at given locations with variable magnification)[14] meteorological and Earth-sensing polar orbiting satellite system,[15] consisting of four to six satellites evenly spaced in orbit by nodal time;[16] (2) continue to upgrade and maintain on orbit a high resolution, multispectral, articulated satellite imaging capable, US geostationary satellite constellation; (3) develop a quick launch capability to put LightSat weather satellites in long-dwell-over-target orbits, such as geostationary or high elliptical orbit, to support theater commanders during war or major regional contingencies; and (4) continue world cooperative efforts to maintain access to foreign geostationary satellite data as well as satellite and surface-based observations and vertical sounding data.

To continuously develop and update the integrated weather information data bases, high capacity, high speed data processing center(s) will be needed to do the data fusion and dissemination. The processing center(s) is viewed as a centralized facility that can down-link satellite data, ingest ground observations and upper air soundings, and fuse the entire realm of continuously updating data into worldwide gridded information data bases to be sent over the information superhighway. Depending on the type of data base desired, on-board processing of satellite observations can be achieved with foreseen advances in computer processing technology. Under this circumstance, the satellite down-link will receive only processed geophysical products.[17] This concept will be beneficial to a theater commander who launched a weather LightSat and needed near-realtime processed weather information for the theater. Difficulty could occur in the timely fusion of the data with other ground and satellite based observations.

Analysis and forecast product development can be accomplished at various on- and off-ramps of the information superhighway. These ramps will most likely be centralized national weather support forecast centers. These centers will receive, via the information superhighway, gridded observational data bases produced by the data processing facilities. The centers will produce tailored weather forecasts, analyses, and climatology products and gridded data bases for commercial, military, and civilian use and access via the information superhighway. By 2020, the national data processing and weather support analysis and forecast centers will probably be joint-use military and civilian centers in the continental US (CONUS). Commercial weather information producers will continue to exist, as long as there is a profitable market to exploit.

The development of the information superhighway will be one of the key factors in the product and information dissemination process. The grand vision of the information superhighway depicts it as a "massive client/server and peer-to-peer mesh capable of carrying gigabits, and eventually terabits, of data per second on its trunk lines."[18] Key to the dissemination of the integrated weather data bases onto the information superhighway will be the "back-end servers, networking technologies, client devices, and software applications"[19]at the data processing centers and at the analysis and forecast centers. At the user-end of the information superhighway, communication connectivity in the form of interactive ports and software will be the critical technology needed to obtain the weather data bases from the superhighway.

Looking ahead, several technological hurdles will need to be overcome to successfully build the architecture for the proposed capability. First, the fusion of multispectral cloud data from polar orbiters and geostationary satellites into a universal cloud data base will be needed; the geometry, temporal, and resolution differences between the satellite systems significantly complicates the fusion effort. Secondly, the fusion of special remote sensing data with surface data and vertical soundings will be needed. The key difficulty in this fusion process will be maintaining the currency of the data due to continuous update. The third hurdle is the rapid processing of vast volumes of continuously updating data from surface and satellite sensors. High speed, high capacity computer processing and satellite down link capabilities will be essential to meet the data processing need. Other potential technologies that need to be developed or upgraded include: (1) weather micro-processor receivers with built-in decision-aids designed for specific needs; (2) integrated satellite bus technology and design; (3) development of articulated satellite imaging devices; (4) enhanced high resolution geostationary satellite systems; (5) computer systems architecture that can process trillions of data bytes every hour, (6) forecast model development that will take into account the high-dimensional, non-linearity of the atmosphere,[20] and (7) development of enhanced weather simulation model capabilities for use in evaluating new, emerging systems and operational concepts as well as mission planning, tactical applications of weather information data bases, training, and design and use of satellite systems.[21] More discussions of technological hurdles and potential advances in satellite observation are contained in the SPACECAST 2020 White Paper "Surveillance and Reconnaissance In 2020" (U), June 1994.[22] Many of the technologies discussed in this paper will greatly enhance remote sensing of the atmosphere and the Earth's surface, especially those enabling magnification of a special area for closer examination and measurement (articulated satellite imaging devices).

Potential Technologies

Now that the proposed capability and its relevance, in general terms, have been discussed; a closer, more detailed look at existing weather support architecture, operational paradigms, and current and potential technologies that may be useful in achieving the integrated weather information data base end-state will be taken. The ideas presented represent a possible future architecture to support the proposed capability.

By the year 2020, with declining federal budgets and the rapidly increasing computer hardware and software technologies, the military and National Weather Service centralized weather support structures will probably consolidate--a major shift from the current operational paradigm. The resulting national weather support structure must then process, develop and disseminate weather information data and provide tailored product support to military, civilian, and commercial weather information users. A very limited number of centralized data ingest and processing centers will be needed to produce the worldwide weather information observation and cloud imagery data bases for transmission via the information superhighway. However, to produce the forecast data bases and specially tailored products, a distributed network of governmental forecast centers pulling the basic weather information off the information superhighway can be used. Commercial weather support companies, who currently obtain weather data and cloud imagery through agreements and purchase requests from the government, will continue to operate as long as they produce a profitable product.

If consolidation does occur between DoD and National Weather Service, it is envisioned that the weather support personnel, at least for CONUS locations, would be governmental civilian employees, in a paramilitary-status, supporting the military mission as a civilian during peacetime, becoming active duty military personnel during war, contingency, national emergency, or possibly exercise. This type of weather support structure already exists for many of our NATO allies (Great Britain and Germany are prime examples). Benefits from this consolidated paramilitary structure are expected to be reduced manpower, operating and facility costs, enhanced technological performance, and a more focused and rigorous technological development program. Permanently assigned active duty weather personnel, however, will probably still be needed to support forward deployed forces.

To improve observations of the atmosphere and earth, and to help build timely worldwide weather observation and information data bases, high resolution, multispectral, articulated satellite imaging capable, meteorological satellite coverage is needed. Currently, the DoD develops and operates the high resolution, Defense Meteorological Satellite Program (DMSP) which normally maintains two satellites in polar, sun-synchronous orbits at low altitude.[23] The National Oceanic and Atmospheric Administration (NOAA) develops and manages both the low orbit, sun-synchronous (POES-Polar Orbiting Environmental Satellite) and the geostationary orbit (GOES-Geostationary Orbiting Environmental Satellite) programs.[24] National Aeronautics and Space Administration (NASA) operates the polar orbiting LANDSAT remote multispectral sensing satellite. The DMSP and NOAA polar orbiters fly to support respective missions, many of which require similar data. DMSP is driven by strategic taskings while NOAA launches to support forecast model production needs. Unfortunately, DMSP and NOAA often have nodal times fairly close to each other. Thus, timing of satellite coverage around the world is uneven and often leaves gaps of several hours which lessens tactical use of the data and forecast accuracy. LANDSAT is in a different orbit and generally measures the Earth's surface at tasked locations, which usually are not aligned with the weather satellite orbits. LANDSAT, though a civilian satellite, has the capability to provide wide-area surveillance surface data to support theater commanders.[25]

Consolidation of the polar orbiters will reduce costs, enhance technological performance and capability, and provide more frequent measurement of the atmosphere and the Earth's surface. Integrating the polar orbiter missions onto one satellite bus and maintaining four-to-six satellites in uniformly spaced orbits (i.e. nodal times six hours apart or four hours apart, respectively) will provide significant benefit to forecast accuracy and weather support to both civilian and military users.[26] Currently, the atmosphere is vertically sounded from the surface twice a day. Remote sensing from DMSP and NOAA POES satellite systems generally can occur twice a day over a particular region, if tasked. Integrated capability of four-to-six satellites can provide an average of four soundings for a given location a day, if needed. Increased frequency of vertical soundings will provide a more accurate picture of the atmosphere's structure for use in forecast models. Forecast accuracy should significantly improve since data used in the models will be only four to six hours old instead of the current twelve hours.

The development and launch of higher resolution, enhanced multispectral, articulated satellite imaging capable, geostationary satellites coupled with the incorporation of the 30 minute geostationary satellite images into the polar orbiter data base will greatly enhance the weather support architecture. Tracks of polar-orbiting satellites overlap in mid-latitudes and above so that more frequent coverage is provided for a location at these latitudes. In the equatorial regions, this is not the case; equatorial cloud data will be a few hours older than the higher latitude cloud data. Updating the cloud data bases with geostationary data will improve the accuracy of equatorial cloud depiction which should, in turn, improve forecast accuracy in the equatorial regions.

Currently, the US and other major countries maintain geostationary environmental satellites on orbit. These satellites provide timely cloud cover images (every 30 minutes) that have proven highly beneficial to near-term forecasting applications, both military and civilian. Disadvantages of these satellite images are the decrease in imagery resolution as one progresses away from the subpoint of the satellite, the overall lower resolution of the image, the earth limb distortion of the imagery,[27] and the difficulty in fusing the data into data bases containing polar-orbiter weather data. In the twenty-first century, geostationary satellites must be designed to take higher resolution imagery, provide an expanded multispectral sensing capability, and configured to produce a data flow that is easily fused into a gridded data field for use on the information superhighway.

In addition to the primary geostationary weather satellite system just discussed, LightSat weather satellites, placed in long-dwell-over-target orbits, such as geostationary or high elliptical orbits, must be a commonly available asset for theater military commanders to quick-launch in support of a war or major regional contingency. Even during peacetime, availability of foreign geostationary weather satellite data for a region may not exist. Currently, India refuses to allow any nation real-time access to their geostationary INSAT weather satellite data.[28] This data would have greatly benefited war time weather support during Operations DESERT SHIELD and DESERT STORM. The European Space Agency moved one of their METEOSAT weather satellites further eastward to provide better coverage of the Southwest Asia area to support the Gulf War effort.[29] This move significantly helped the weather support effort, but the imagery still contained significant distortion over the Southwest Asian region due to the satellite's angular viewing access (i.e., limb of the hemispheric view). Three DMSP satellites covered the theater area providing high resolution satellite updates about every six hours. This satellite support combination met the theater need; however, a CINC-directed, quick-launch geostationary weather satellite would have greatly benefited the nowcasting capability of the forecasters in the Kuwaiti Theater of Operations.[30]

Significant capability enhancement, or possibly new technological design, of satellite down-link capability as well as data ingestion, fusion, and processing capability are necessary. High speed, high capacity computers are required to process the trillions of data bytes coming through the funnel every hour. Process must convert the data into synthesized gridded fields containing several variables to be sent through the pipeline into the information superhighway for further use.

New forecast models and specially tailored products, for both military and civilian use, must be devised to ingest the gridded data and produce a usable product. With increased frequency and coverage of data, the accuracy of forecast models should increase. Expansion of current spectral forecast model capability will be possible due to the availability of more data and faster computers. New modeling techniques and product production are also anticipated, especially those involving high-dimensional nonlinear iterative methods, designed to handle the non-linearity of the atmosphere.[31]

A worldwide ground-based observation and atmospheric sounding network is already in place and overseen by the United Nations' World Meteorological Organization (WMO), but requires upgrade in technical quality and made less manpower intensive. The Air Force maintains the Automated Weather Network (AWN) which is a global, high speed data network used to collect worldwide weather data and disseminate weather information out to DoD and civilian users. A capability upgrade or potentially redesign of the AWN into the information superhighway architecture will be needed to meet the fast-paced weather data requirements of the twenty-first century.

During war time, access to portions of the world weather data may be denied. Surface and upper air observations are critical to military operations, thus, a capability to obtain data from denied areas is needed. One suggestion is to insert, by air, missile, or hand, micro-miniaturized surface weather sensors to measure surface conditions continuously and transmit data back to a communications relay satellite for collection and dissemination by direct broadcast back to the users or the information superhighway. Also, these sensors will provide ground truth for satellite vertical soundings in the area. A polar orbiting weather satellite or possibly a LightSat geostationary weather satellite, can receive the ground sensor transmission and then generate a vertical atmospheric profile. The sounding could be directly broadcasted to the theater or input to the weather data collection network residing on the information superhighway (figure 2).[32]

In addition, worldwide access to special observation systems, such as the doppler radar and lightning detection systems, must be obtained and expanded. Information gathered will greatly benefit weather information users who must quickly make decisions in situations where severe storms and lightning occurrences endanger

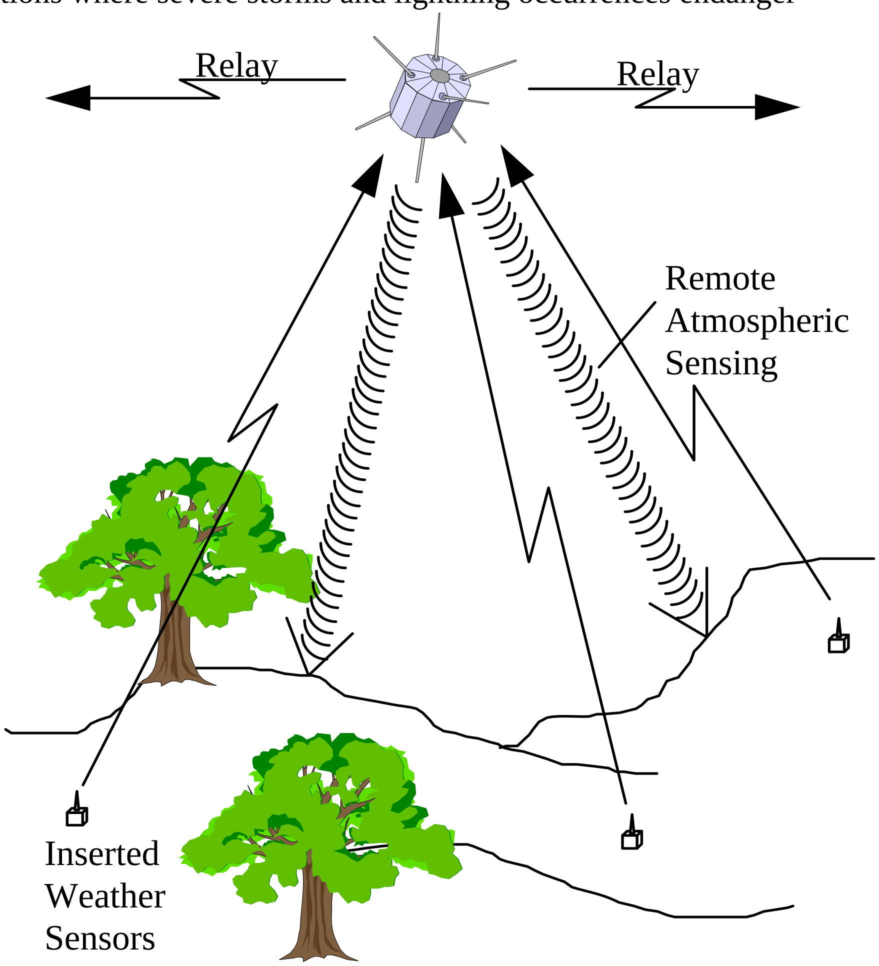

Figure 2. Obtaining surface and upper air weather information from data-denied areas.

operations. Airplane pilots, munitions and fuel supply areas, and community safety concerns are just some potential users who will benefit from access to this information residing on the information superhighway.

Near Term Technologies and Operational Exploitation Opportunities

Currently, three data distribution systems exist that are forerunners of a portion of the future capability envisioned in this paper. These systems are the Air Force's Automated Weather Distribution System (AWDS), the Navy's Naval Oceanographic Data Distribution System (NODDS), and the Air Force Global Weather Center's (AFGWC) Dial-In System (AFDIS). The AWDS is a new generation computer/communications system with a dedicated communications and switching network directly connecting AFGWC with Air Force Base Weather Stations around the world. AFGWC can flow distributed gridded data bases of current and forecast weather information to the Base Weather Stations for in-house analysis and display over a computer terminal. The NODDS and AFDIS systems uses telephone line connections between a user's small computer and the mainframes of the military centralized facilities the Fleet Numerical Oceanographic Center (FNOC) and AFGWC. Processed gridded data fields, tailored graphic displays of weather information, and satellite cloud imagery from the Satellite Global Data Base (developed by AFGWC and shared with FNOC) can be sent from the centralized facilities to the requester. This capability can greatly enhance weather support during operations where access to worldwide weather data is limited to nonexistent. NODDS proved itself during Operations DESERT SHIELD and DESERT STORM. AFDIS is currently undergoing initial employment in the field. AWDS, NODDS, and AFDIS products can be suitable as integrated weather information data bases on the information superhighway, especially if they can be obtained through direct satellite broadcast anywhere in the world using small microprocessors and receivers.

Great strides are underway by NASA, NOAA, US Geological Service, European Space Agency, Japan, and other nations to develop satellite means to observe Earth as an integrated system. The fundamental processes to be observed and which govern and integrate the earth system are the hydrologic cycle, the biogeochemical cycles, and climate processes. The current meteorological satellites and LANDSAT are forerunners of the proposed Earth Observing System (EOS).[33] The EOS program is an evolutionary program with a projected orbital observing capability of 15 years. The mission lifespan will be achieved via instrument and platform redundancy, and orbital replacement and servicing. NASA will launch two polar orbiting satellites, one in 1996, the other in 1998. European Space Agency will launch a third satellite in 1997 and Japan will follow with a fourth satellite in 1998. Satellite payloads will include sensors for remote sensing of the atmosphere, the earth, and the space environment. Cloud imagery will be possible, but it will not be the primary product. EOS will provide scientists and researchers access to integrated global data bases for the study of the Earth system science.[34] Although the system is not designed for daily operational weather sensing or to provide LANDSAT-type pictures for operational use, the concept is very close to the concept already presented of integrating and consolidating DMSP, NOAA, and LANDSAT satellites into one operational system.

Access to the information superhighway may negate the need for a hands-on local meteorologist to provide forecast support. Nothing, however, will ever replace the human intuition in forecasting or the public, personalized service. As we move into the twenty-first century, interactive graphic and data access to the information superhighway coupled with one's own decision-aid micro-processor, weather support will become more direct, timely, automatic, and user-friendly. For the warfighter, near instantaneous access to global weather information from anywhere in the world will be a critical factor in making and executing battle area decisions faster than the enemy's OODA-loop capability. Fused global weather information must be a part of every warfighter's kit.

Notes

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