UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A205 790

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFGL-TR-89-0068	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: Air Force Geophysics Lab; 6b. OFFICE SYMBOL (If applicable): LYP	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code): Hanscom Air Force Base, Massachusetts 01731-5000	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
62101F	6670	10	25

11. TITLE (Include Security Classification)
The Development of Numerically-based and Expert System Approaches for Airfield Nowcasting/ Very Short Range Forecasting

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Reprint	FROM ______ TO ______	8 March 1989	4

16. SUPPLEMENTARY NOTATION Reprinted from the Preprint Volume of the Third Inst. Conference on the Aviation Weather System, Jan 30-Feb 3, 1989 , Anaheim, California

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Nowcasting; Very Short Range Forecasting; Advanced Weather Systems; Numerical Weather Models; Artificial Intelligence; Expert Systems; Computer-based Processing

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Over the next several years, base weather stations in the USAF will undergo a modernization that will bring substantially increased amounts of data and processed weather information to the forecaster in support of his/her nowcasting/very short-range forecasting support to aviation and other operational weather support requirements. Among the new capabilities that most weather stations will acquire are NEXRAD Doppler weather radar, DMSP and GOES satellite imagery and soundings, conventional observations and model-generated analysis and forecast gridded fields via a system called AWDS (Automated Weather Distribution System), automated airfield observations and, in time, wind and thermodynamic vertical profiles on an hourly-updated basis. Each of these systems will comprise individual computer-based processing and display systems, none of which will be able, in their initial configuration, to effectively communicate or share data with other systems in the weather station. An R&D program at AFGL was recently undertaken to seek effective ways to process these data from diverse sources into an integrated data base. The program,

-(continued on reverse).

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: DONALD A. CHISHOLM	22b. TELEPHONE (Include Area Code): 617-377-4729; 22c. OFFICE SYMBOL: AFGL/LYP

Reprinted from the Preprint Volume of the Third Intl. Conference on the Aviation Weather System, Jan. 30-Feb. 3, 1989, Anaheim, Calif. Published by the American Meteorological Society, Boston, Mass.

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THE DEVELOPMENT OF NUMERICALLY-BASED AND EXPERT SYSTEM APPROACHES FOR AIRFIELD NOWCASTING/VERY SHORT RANGE FORECASTING

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1. INTRODUCTION

Over the next several years, air base or terminal area weather support in the USAF will undergo a modernization that will bring substantially increased amounts of data and processed weather information to the operational weather forecaster. These data will clearly provide a new era of weather support to aviation and will provide both opportunities and challenges to the operational forecaster who seeks to use these data for nowcasting and very short range forecasting purposes. Among the new capabilities that over 150 locations supporting Air Force and Army operations world-wide will acquire shortly are, NEXRAD Doppler weather radar, DMSP and GOES satellite imagery and soundings, conventional observations and model-generated analysis and forecasted gridded fields via a system called AWDS (Automated Weather Distribution System). In the second half of the next decade there's the distinct likelihood that the local observing capability will be fully automated and capable of providing a wholely new range of data availability. Finally, the prospects that ground-based sounding systems for wind and thermodynamic vertical profiling will provide substantially increased amounts of data on an hourly (or more frequent) update basis at one or more locations more frequent near an airfield has to be recognized. Each of these systems will comprise individual computer-based processing and display capabilities, none of which will be able, in their initial configuration, to effectively communicate or share data with the other new systems in the weather station.

We are faced then with a challenge, as are other agencies going through similar (but somewhat different) evolutions. The proliferation of computer and display systems are opening up "information" doors and opportunities unthought of just a few years ago that are challenging us to find ways to effectively manage the copious amounts of data into an integrated information processing system that will, in the case of Air Force weather support at the airbase or terminal area level, provide improved nowcasting and very short range weather forecasting capabilities to aviation and other customers.

2. THE AMPS PROGRAM

Within the USAF, Air Weather Service (AWS) has the responsibility of providing operational weather support. The Air Force Geophysics Laboratory (AFGL) responds to specific R&D requirements defined by AWS by conducting basic and applied research programs. An R&D program was recently undertaken at AFGL in response to the needs for an information-processing methodology to deal with the wealth of data to be generated by these new systems in an integrated sense. The program called AMPS (for Advanced Meteorological Processing System), has the objective to develop, test and evaluate both numerically-based and expert system procedures for the assessment, analysis and short-range prediction of weather events critical to safe and efficient aviation activities on and around individual air bases. The program, though modestly funded and staffed at present, has three near-term areas of emphasis intended to provide processing modules to address specific weather forecast areas and/or new data sources. These are (1) objectively-based extrapolation procedures to nowcast/forecast NEXRAD and/or GOES imagery through the use of small but powerful image processing work stations, (2) numerically-based prediction models, suited for real-time execution in a microcomputer environment, that are designed to specifically deal with the processes of convective initiation and with non-convective cloud and precipitation systems, and (3) artificial intelligence (expert system) approaches to specific short-range aviation weather forecast problem (e.g. fog). In addition, a computer facility is under development at AFGL to support both the R&D program and to provide an environment within which to conduct experimental nowcast/very short range forecast testing of AMPS modules and alternative data integration strategies. The facility configuration is discussed in the next section. The development of numerical and expert system modules is discussed in Section 4.

3. EXPERIMENTAL FACILITY

The initial configuration of the AMPS Experimental Facility is shown in Figure 1. The portions of it that currently can provide real-time data are AIMS (AFGL Interactive Meteorological System) and the SUDBURY facility. AIMS provides conventional observations, etc. from the FAA 604 line and GOES visible/infrared/water vapor imagery and VAS sounding data via a direct down-link receiver from GOES. The SUDBURY facility provides NEXRAD-like weather radar products from it's 10-cm Doppler system which also has a polarization diversity capability. UHF Doppler wind profiler data will be routinely provides conventional observations, etc. from the FAA 604 line and GOES visible/infrared/water

AMPS EXPERIMENTAL FACILITY

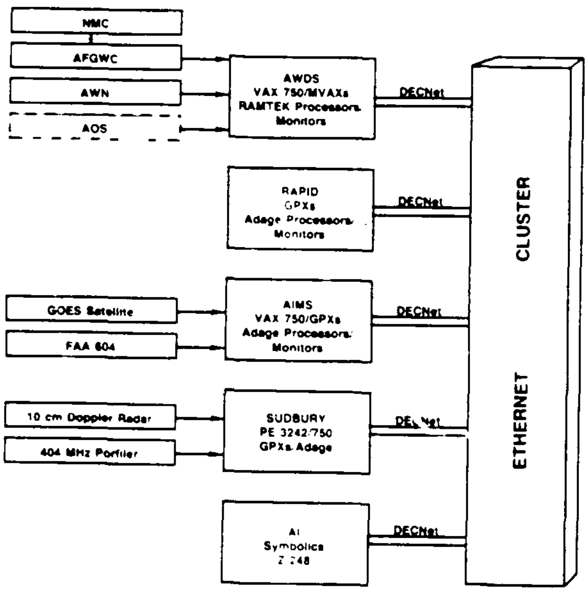

Figure 1. The AMPS Experimental Facility at AFGL.

vapor imagery and VAS sounding data via a direct down-link receiver from GOES. The SUDBURY facility provides NEXRAD-like weather radar products from it's 10-cm Doppler system which also has a polarization diversity capability. UHF Doppler wind profiler data will be routinely available from SUDBURY in 1989 after installation of a 404,37 MHz system. The RAPID system (Remote Atmospheric Processing and Interactive Display) consists of two Micro-VAX III workstations and an Adage image processor and display system for rapid manipulation and display of radar and satellite imagery data. One workstation supports the development of nowcasting extrapolation techniques and the other hosts the convective initiation model developed under contract. The Symbolics/Z-248 computers in the AI module support the development and evaluation of expert systems. Lastly, the AWDS component comprises the prototype system developed for eventual USAF operational deployment. In its present configuration it does not have real-time access to USAF operational data sources at AF Global Weather Central (AFGWC) and the Automated Weather Network (AWN). It does consist of a VAX750 and Micro-VAX II/RAMTEK image processing work stations with CONRAC high-resolution displays. It has been incorporated into the AMPS Experimental Facility, in this form at this time, to gain necessary familiarity with its data-base structure operating system and application software which will be implemented USAF-wide over the next few years. The inclusion of automated airfield observations sensors (AOS) will await further developments in key areas.

Collectively these on-line data gathering and processing systems provide the necessary inputs and components for the AMPS R&D program and experimental test facility. The focus of the program is to develop new analysis, display, and nowcast/forecast modules that seek to capitalize on data integrated from two or more of the individual sources to provide enhanced aviation weather support.

4. DEVELOPMENT PROGRAM

4.1 Numerically-based Methods

This portion of the AMPS development program currently consists of two foci: (1) extrapolation procedures to nowcast/forecast radar and satellite imagery and (2) numerically-based prediction models to deal with (a) convective initiation and (b) non-convective cloud and precipitation systems. These efforts are described briefly below.

The general approach to the extrapolation nowcast/forecast method(s) is embodied in image processing models that can be applied to radar (NEXRAD) and satellite (GOES) imagery. They involve the following steps: data acquisition, interpolation and editing, feature representation, feature monitoring, feature forecasting and feature reconstruction and display. The details of these steps are discussed in Bohne et al (1988) and Sadoski et al (1988). Feature representation is, perhaps, the most important step in the process. The desire to run in real time dictates that the amount of data that can be monitored, tracked and forecasted between observation times (which can be on the order of 10 min with NEXRAD) must be minimized. The method used here is to represent features by their encompassing contours (e.g., the 40dBZ reflectivity level). One such method (Freeman, 1961) is the Freeman Chain Code (FCC), a set of eight straight-line unit direction vectors, representing the eight directions one can travel from any imagery pixel to a neighboring pixel on the same contour. A second feature defining method termed the Complex Chain Code (CCC), also being evaluated, maps the eight directional vectors into complex space. Figure 2 illustrates these two feature representation methodologies. The FCC approach supports what we refer to as the contour segmentation forecast method in which the individual line segments are separately monitored (from successive imagery depictions) and extrapolated, after which the procedure reconnects the individual segment endpoints to form a closed contour. The CCC, on the other hand, is used in the whole-contour forecasting method in which the Discrete Fourier Transform (DFT) method is applied to determine the spectral amplitude and phase attributes of the CCC and an inverse (IDPT) method applied to recover the CCC vectors and construct the forecast contour. The whole contour method is more straightforward and more easily automated than the segment method and as such offers the best chance for real-time application as computer technology advances. A nowcast/forecast concern with these methods is the realization that contours do not evolve in a similar fashion in time. The forecast algorithms use a simple adaptive trending method for the forecast variable, thus, if the number of elements comprising a contour increase/decrease markedly between observation times, the algorithms will extrapolate this trend into the future. Therefore, constraints to control the rate of growth (or decay) of a contour area will undoubtedly be needed in order to extend the method, where applicable, to 1-2 hours. We may need, for example, to constrain predicted radar contour variations based on observed storm parameters (height, stage of development, storm structure, etc.).

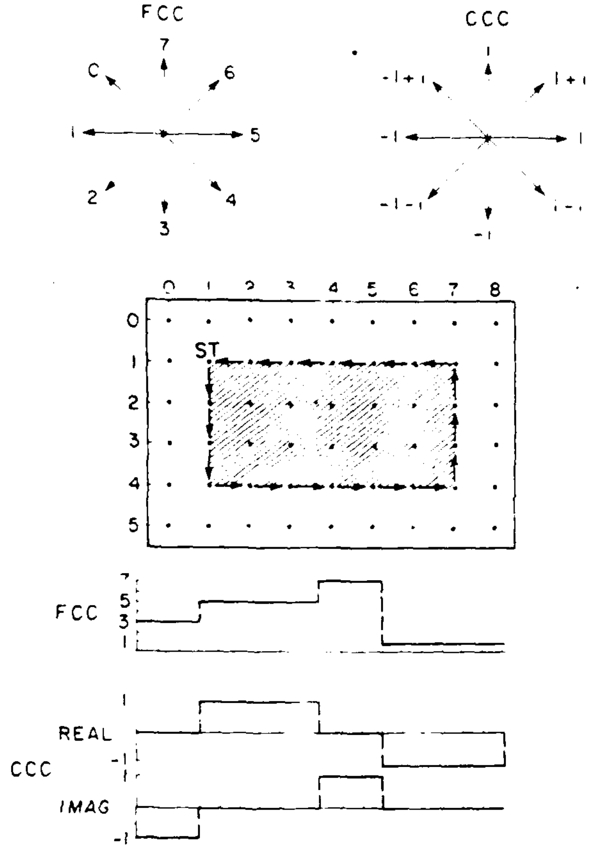

Figure 2. An example of the Freeman Chain Code (FCC) and Complex Chain Code (CCC) representations of a contour region. The resulting code lists are shown graphically at the bottom.

Numerical prediction models suitable to operate within operational time lines on microcomputers are under development. For convection initiation purposes two modeling approaches are being considered: (1) a mixed layer model which is drawn partly from Lavoie (1972) and partly from Keyser and Anthes (1977) and (2) a fully 3-D numerical weather prediction model adapted from the CSU Regional Atmospheric Modeling System (RAMS) which comprises models of Tripoli and Cotton (1982), Tremback et al (1985) and Mahrer and Pielke (1977). In addition to standard thermodynamics/wind soundings, both models are designed to be initialized and frequently updated with single-Doppler wind field data which can be used to identify and track the evolution of convergence zones in the boundary layer. The numerical model component then predicts, based on dynamic and physical processes it accounts for, the development of new regions of convective clouds. Eventually, we plan to have this model serve as a precursor to activating the NEXRAD extrapolation methods which would be applicable after convection onset.

The second model development effort is intended for application mainly in nonconvective but active weather regimes (i.e. with regions of clouds and precipitation from generally stratiform systems). The approach here is to develop a nested modeling system involving a four-layer adaptation of the Anthes and Warner (1978) model coupled with a two-layer model which is coincident in depth with the lowest layer of the four-layer model. Within the 2-layer model there is a lower layer which represents the variable-depth boundary layer. A unique feature of these models is the two-way interactive vertical nesting of the 2-layer model with the lowest layer of the 4-layer signia coordinate model. Model physics will be limited to surface radiation and unstable boundary layer parameterization schemes from Colby (1984), stable boundary layer scheme from Nieuwstadt (1980) and stratiform precipitation including only the possibility of saturation during dry convective adjustment of superadiabatic layers (i.e. no moist convective processes accounted for). Development is proceeding under contract using a Micro-VAX II architecture as well as evaluation of the potential for real-time application given different domain sizes and grid resolutions.

4.2 Expert System Applications

The expert system portion of the AMPS development program currently consists of three efforts: (1) evaluation of fog forecast rule-based systems, (2) expansion of the NEXRAD in-cloud turbulence algorithm via rule-based procedures, and (3) extension of an earlier-developed single station weather forecast module to a range of climatic and geographic regimes. The first two have the potential of general application in AMPS-like environments. The third represents an operational problem area unique to the DOD in that its purpose is to provide a basic forecast capability when all sources of outside data are denied (e.g., a wartime scenario). It is a problem area ideally suited for expert system consideration in that the problem can only be solved by a forecaster applying fundamental rules-of-thumb. It is the dependence on forecast rules and the dearth of forecasters with the expertise in these rules that makes this an ideal problem area to develop an expert system capability.

A concern with rule-based expert systems is the extent to which they can be easily adapted at a number of locations. To examine this problem, we sponsored the development of prototype expert systems to predict runway visibility variation due to fog at three airfields in the Southeast U.S. (Stunder et al., 1987). The systems, developed for application on PCs, are comprised of over 200 rules; 30 of which are hour/day/month related, 75 relate to the general synoptic situation vis-a-vis fog potential, 30 deal with radiation fog factors and the remaining 70 or so deal with advective fog aspects. Regarding the concern about adapting the system to other airbases, it's the last 70 or so rules that may require some modification. For testing purposes, a system developed for Seymour-Johnson AFB, NC was adapted for use at Shaw AFB, SC without interviewing operational forecasters at Shaw. This test has convinced us that, for fog prediction purposes anyway, an expert system can be largely expressed in generic rules dependent on basic physical principles, and then augmented by local rules of thumb and climatology to account for differences in location. This calls for constructing new (or adapting existing) knowledge bases through a knowledge acquisition process that probes to

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find the underlying principles upon which each system component rests and to express the initial rule base in terms of those principles. The rule-building process then proceeds until a rule can only be established by resorting to location-specific parameters. These rules are then written in a "template" form where local forecasters can assign specific values in a rule for local application. We expect that expert systems (for any specific aviation forecast component) can be generated in this way for fairly widespread distribution geographically.

The objective of the single-station expert system was to provide short-range (0-6 hr) forecasts of terminal (aviation) weather conditions using only surface and upper-air observations for the desired location. It can be viewed as a classical test of inferencing from incomplete or sparse data, a problem-solving difficulty the human mind is often able to overcome much more easily than traditional digital computer processing. Working closely with one of the few experts active today in single-station forecasting, an expert system was developed with two modules: a diagnostic model that creates a "mental model" of the current synoptic situation and a forecast model from which the hour-to-hour forecasts are inferred from the observation set and the synoptic model (see Jasperson and Venne, 1987). Upon receipt of new data (e.g. the next hour), the diagnostic model of the synoptic situation is adjusted, the forecaster (user) has the option of manually interjecting changes to it, and the forecast model is executed. The initial proof-of-concept model was configured for a midcontinent temperate zone locale in flat terrain. Current emphasis is on examining the system's sensitivity to geographic and climatological variation (analogous to the aforementioned fog forecast system study).

The remaining area of expert system focus deals with the problem of the identification of significant features in radar or satellite imagery data. The specific problem being considered is in-cloud turbulence in convective cloud systems observed by NEXRAD Doppler radar. An expert system approach to determining hazards to aircraft from turbulence proceeds by invoking specific NEXRAD data fields (e.g. turbulence, wind shear, reflectivity factor) which are automatically interpreted via knowledge-based rules. Current development is focussing on an interactive approach with an ultimate goal of a fully-automated procedure that would "met-watch" NEXRAD products and advise forecasters of potential hazards.

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-/-called AMPS (for Advanced Meteorological Processing System), has the objective to develop, test and evaluate both numerically-based and expert system procedures for the assessment, analysis and prediction of weather events critical to safe and efficient aviation activities on and around air bases. Current emphasis is on (1) the development of procedures to nowcast NEXRAD reflectivity and doppler wind fields via statisticallybased extrapolation methods and to (at a later date) link these methods with a limited area numerical forecast model designed to account for convective initiation and development and (2) expert system approaches to terminal area fog prediction. Research progress in these areas and plans regarding the establishment of an AMPS Test Facility involving prototype versions of the system capabilities cited above are discussed. Reprints