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MINIMUM ENERGY ROUTING THROUGH INTERACTIVE TECHNIQUES (MERIT) MODELLING

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I. INTRODUCTION

The basic premise of the MERIT program is that airlines could save fuel if they improved their route selections with the wind observations from their own fleet. Most airlines select routes using wind information and forecasts from the National Weather Service of the United States or similar weather service of a foreign country. Their routes are designed to optimize the head winds or tail winds. Errors in these wind forecasts often result in greater fuel usage.

Many flights are planned using wind forecasts that are 18 to 24 hours old (Steinberg, 1982, 1984). There are long delays between the time upper air observations are made (by weather service balloons) and when the analysis and forecast products are received by the airlines. The delays are caused by several factors; mainly the collection of the data inside the weather service and by transmission of the final product to the airlines. All of these delays add up to inaccuracies in the wind patterns used for flight planning and route selection.

The airlines are in a position to correct the wind forecasts since they have more recent observations from their own fleet. Some airlines are making these corrections using labor intensive techniques. Meteorologists plot the observations of their fleet and then correct the wind forecasts before running the flight planning models. These corrections, to our knowledge, are made by a person retyping in new values for each grid point where a major change is needed in the wind field. This tedious process prevents extensive revisions from being made to the forecast wind fields. The corrections are only made when large discrepancies are found between the weather service wind forecasts and the fleet observations.

The original proposal of the MERIT program (Dr. Steinberg of the NASA Lewis Research Center) was to attack this problem with computer systems that aid the meteorologists. Part of the wind correction process could be automated using computer analysis techniques tailored for aircraft winds. This could relieve the meteorologists of some of their labor-intensive burden. Short-range wind forecasts using simple models could be developed to reduce the number of corrections that have to be made. We have explored the proposals of Steinberg and are reporting on their feasibility.

The same wind information that is needed for improving fuel efficiency of the airlines also is needed by NASA's Advanced Transport Operating Systems (ATOPS) program (NASA Langley Research Center). The object of this program is to improve air traffic flow. ATOPS will test models for predicting the arrival of aircraft in crowded terminal areas so that the air traffic control system can be more efficient and handle a greater capacity. To predict aircraft arrival times, wind forecasts along the route of the aircraft are vitally important. Thus, the ATOPS program shares the same goals as MERIT-- improving the wind forecast for aircraft routes. For this reason the MERIT programs was funded by the ATOPS program of the NASA Langley Research Center after funding was discontinued by the NASA Lewis Research Center.

At the University of Wisconsin-Madison we tested some of these concepts proposed by Dr. Steinberg using our own wind data base. This report summarizes our opinions of the feasibility of these ideas and discusses methods by which the MERIT concept can be achieved. This report is divided into six sections. The data which we used to test the MERIT concept are described in Section 2. Section 3 describes an interactive computer technique for making manual corrections to the wind fields. Our experiments with making automatic corrections to wind fields are described in Section 4. Experiments with short range forecasting models is described in Section 5. Finally our plans for an implementation of a MERIT system in the future are described in Section 6.

II. WEATHER AND AIRCRAFT DATA

The Man-computer Interactive Data Access System (McIDAS) of the University of Wisconsin-Madison receives many data and model products from the National Weather Service (NWS). They include the upper air balloon rawinsonde wind observations made twice per day by the NWS, the Aircraft-Satellite Data Relay (ASDAR, Sparkman and Girayty, 1978) wind observations, and wind analyses and forecasts from three of the U. S. National Weather Service Models.

The rawinsonde balloon observations are made twice per day by the NWS at approximately 70 stations in North America. These data are the primary basis for upper air analysis by the NWS. The ASDAR system transmitted wind observations from the inertial navigation systems on approximately 20 wide body aircraft. Most of the observations from this fleet are over the Western United States and the Eastern Pacific Ocean.

For this study we chose numerical model products that are commonly used for a wide variety of forecast and analysis purposes. The LFM (Limited Fine Mesh) model is an old model that is run by the NWS. It uses the standard level observations from the rawinsondes. It's domain is primarily the North American continent and some of its neighboring oceans. It has a grid resolution of approximately 100 km (1° latitude and longitude).

The Global Spectral Model is a newer model that uses a spectral coordinate system. It covers the entire northern hemisphere with a grid resolution of approximately 4° of latitude and longitude.

NWS also runs a Nested Grid Model (NGM) which has a higher resolution grid for North America than the Global Spectral Model, while using the same resolution else where. The products from the nested grid model are transmitted under the heading RGL which stands for Regional Grid replacement for the LFM. These models are the primary guidance for weather forecasters inside the NWS.

Aviation products are also produced by the NWS using the Global Spectral Model or a very similar version of it.

III. MANUALLY CORRECTING WIND FIELDS

The most common fault of wind analyses made by numerical models is that they smooth the intense winds of the jet stream core. This problem happens nearly daily with all automatically generated wind analyses. It is very obvious to meteorologists when wind observations are plotted on the numerically generated analyses. This smoothing results from the coarse spacing of the grid points in the numerical models and also the need to balance the wind field with the pressure field. Any imbalance between the wind and pressure fields will generate gravity waves inside the model which may not exist in the "real world." The forecasts produced under these conditions also will be distorted by the presence of these waves.

It is very easy for a meteorologist to draw new contours of wind speed over a plot of a numerical analysis where he finds these errors. However, to impact the flight planning operation of an airline, he must transfer his paper drawings to digital values at grid points inside the computerized data base. This is a harder task than simply spotting the locations of errors in the analysis.

The manual corrections of the wind grids have traditionally been made by the meteorologist typing new values on an alphanumeric terminal for the grid points that require changes. This is the procedure of United Airlines and Delta Airlines. It is a very tedious operation because the meteorologist has to determine the exact value of each grid point in the region where a correction is needed. Many neighboring grid points also have to be changed because the flight planning systems uses a spatial interpolation function for determining winds between grid points. Delta Airlines requires 21 grid points to be simultaneously changed at one level to have an impact on the flight planning computations because of their interpolation function. Multiple flight levels are considered by their flight planning system so the wind correction task is even more complicated. The extensive time required for this task has prevented it from being used on a daily basis. Changes to wind fields are made at Delta only when very large errors in the wind analysis are found.

The overwhelming amount of labor in this task can be drastically reduced by using interactive graphic techniques. The desire of the meteorologist is to draw new contours of wind speed and direction over the old analysis. We developed a drawing technique on McIDAS that was simple to implement (See Appendix A). It was most useful for raising the wind speeds in the jet stream. Wind direction changes also were possible with only a small additional effort. This technique could be implemented on any computer systems with a graphical display so that errors in the wind field could be corrected for the flight planning system on a regular basis.

IV. AUTOMATIC CORRECTIONS TO WIND FIELDS

Manual corrections to wind fields require the meteorologist to inspect aircraft wind reports. The volume of aircraft reports could rapidly increase in the future as more automatic transmission systems such as ASDAR are installed by the airlines. Any increase in wind data will strain the ability of the meteorologist to use these data. Thus automatic methods for ingesting aircraft observations and correcting wind analyses are desirable. The automatic system could be used as a first pass to make most of the corrections. The meteorologist still may wish to follow the automatic process with more refined corrections where they are necessary.

The method we tested for correcting wind fields is described in Appendix B. It is part of the data ingestion procedure for the Australian Mesoscale Model. This data ingestion system balances the wind and pressure height fields so that dynamic consistency is maintained and spurious gravity waves are not manufactured in the model. The system uses the wind observations to correct both the wind and pressure height fields simultaneously. This resulted in improvements to the fields. Examples of the improvements to the wind analysis are shown in Appendix B.

A statistical evaluation of the Australian Model initialization scheme was made using seven days of rawinsonde and four days of ASDAR data (see Table I). The wind analyses were compared at the locations of the observations by linear interpolation of the analyses. We ran the same comparison procedure on three NMC models as well as our version of the Australian model.

It should be noted that all the models used the rawinsonde and ASDAR data in their initialization schemes so these data were not an independent comparison. What this comparison shows is the ability of the model to fit the data given to it. There are other data that the models considered in making their analyses. We did not compare to all the rawinsonde data that were used in the model's initialization. Also, satellite soundings were available to the models in addition to the rawinsonde and ASDAR data. The models also considered the dynamic balancing as previously mentioned and the previous history of the wind field prior to the time that these comparisons were made. The models have to consider all of these factors and data in forming a wind field so it is no surprise that they cannot perfectly fit the rawinsonde and ASDAR observations.

Table I shows the mean bias error between the model wind speed and the observations followed by the root mean squared (rms) deviation for these data.

Table I. Model Initial Conditions

Average Wind Speed Error (m/sec)

Speed (Model) Minus Speed (Observation) (25 - 50N)

(70 - 125W)

Part 1. 250 mb RAOBS

DAY	SSEC		LFM		GBL		RGL	
5 Jan 87	-0.1	±5.0 mb	-3.2	±8.5 mb	-1.2	±6.2 mb	-3.7	±6.0 mb
6 Jan 87	-0.4	±5.0	-1.7	±7.8	-0.9	±5.7	-2.2	±5.0
7 Jan 87	-0.7	±4.5	-1.9	±5.7	-0.4	±3.9	-2.0	±3.7
8 Jan 87	-0.4	±5.2	-0.6	±4.7	-1.5	±4.4	-1.7	±3.9
29 Dec 86	+0.2	±5.2	-0.7	±6.0	-0.8	±4.7	-5.9	±11.1
12 Dec 86	+4.1	±5.9	-0.5	±6.6	-1.5	±5.5	-2.0	±6.5
11 Dec 86	+0.6	±5.9	-1.7	±6.9	-1.9	±5.9	-2.2	±5.5
	+0.5(m/s)		-1.5(m/s)		-1.1(m/s)		-2.8(m/s)	

Part 3. 200 - 300 mb RAOBS

5 Jan 87	-3.9	±7.5	-6.8	±9.2	-4.8	±7.2	-7.2	±7.0
6 Jan 87	-4.3	±11.8	-5.6	±12.8	-4.9	±10.1	-6.2	±10.0
7 Jan 87	-4.4	±6.6	-4.8	±7.1	-3.3	±4.8	-5.1	±5.1
8 Jan 87	-2.2	±8.8	-2.1	±8.5	-3.0	±8.0	-3.1	±7.9
29 Dec 86	-3.7(m/s)		-4.8(m/s)		-4.0(m/s)		-5.4(m/s)	

Part 2. 200 - 300 mb ASDAR

5 Jan 87	-1.5	±8.2	-2.5	±10.3	-0.8	±7.8	-4.6	±7.9
6 Jan 87	-1.5	±8.8	-0.4	±11.4	-3.4	±9.7	-3.3	±10.3
7 Jan 87	-1.1	±5.3	-0.3	±6.9	-1.4	±6.8	-2.1	±6.6
8 Jan 87	-1.9	±6.2	-2.6	±6.0	-4.7	±6.2	-3.5	±5.7
	-1.5(m/s)		-1.4(m/s)		-2.5(m/s)		-3.3(m/s)	

A negative bias indicates the model wind speeds were lower than the observations on the average.

The comparisons were made at the 250 mb (34,000) level for the rawinsondes since both the observations and model had data for this level (Part 1 of Table I). The ASDAR wind reports were at variable altitudes. For this comparison we had used only ASDAR observations from 30,000' to 38,000' (200-300 mb). They were compared to the layer mean winds in the models from 200-300 mb (Part 2 of Table I). For consistency, the rawinsonde winds were averaged from 300-300 mb and compared to the corresponding model layer mean (Part 3 of Table I).

All of the model wind fields were biased low. The largest biases were found in the RGL analyses. While the Australian model (SSEC) we ran had the smallest biases, this was expected since the models tend to smooth the high winds of the jet stream core. Examples of this smoothing are shown in Appendix B.

The biases appear to be weather pattern dependent. There was a large variance between the days examined for each model. Each model also had their best and worst skill on different days indicating that the models analyzed the days differently.

V. SHORT-RANGE PREDICTION MODELS

We experimented with a barotropic prediction model as a candidate for making short-range wind forecast from 12 to 18 hours. Our purpose for using this model is to project the wind corrections identified from past aircraft flights into the time period of flights currently preparing for launch. Features of the wind patterns observed by one flight may not exist by the time a second flight crosses the same area. Flight plans are made two hours before launch in most cases. The data available for these plans may be two additional hours old. Thus flight plans are being made for a time period of about one-quarter of a day after the most recent observations. The current system uses wind forecasts from data that are one-half to three-quarters of a day old as discussed by Steinberg (1982, 1984).

The purpose of the short-range model is to improve the wind forecasts inside the period between major model runs made by the NWS. The major models are run every 12 hours. The airlines, however, don't receive these model forecasts until at least 5 hours after the rawinsonde observations because of the time needed for data collection, computer time to run the models, and transmission of the forecasts to the airlines. When all of these delays are added together, the airlines are using 12 to 18 hour forecasts generating flight plans.

The barotropic model is the first numerical model used by meteorologist. It uses the concept of the atmosphere advecting its momentum. That is, the changes in the wind field are caused by a redistribution of the mass of the atmosphere carried by the winds. Thermodynamic effects from heating or the distribution of heat are not considered by the model. The model uses the equation of conservation of vorticity. Details of it's formulation can be found in Haltiner (1980) and Haltiner and Martin (1957).

The barotropic model is run at only one level in the atmosphere. The level is suppose to be in the middle of the troposphere where there is no convergence or divergence. This allows a simplification of the vorticity equation to where changes of vorticity are predicted only by the advection of the vorticity by the winds.

The barotropic model is usually run on the 500 mb level, 18,000 ft ASL, since this is one-half of the depth of the atmosphere. However, the actual level where the atmosphere is in balance between divergence and convergence has been found to be below this level.

For aviation applications, the model has to be run at levels where aircraft data are taken and its predictions are needed. We ran the model at 300 mb, 30,000 ft ASL. Corrections were made to the equation to compensate for divergent and convergent motions. These corrections influenced the performance of the model.

We found the barotropic model did not provide useable wind forecasts for two reasons. The first problem was the correction to the equation of wind field divergence. This addition to the equation affected the speed of movement of the wind pattern. The amount of compensation for divergence cannot be theoretically determined so it is a subjective adjustment. The adjustment could be tuned to produce the correct pattern movement in local regions for individual cases. But the wind direction pattern would have errors in other geographical area for the same case. This model introduced more errors in the wind direction patterns than it solved.

The second problem with the barotropic model was the conversion of wind information into a form that the model equation needed for its calculations. The model is formulated using the velocity potential field not the wind components themselves. The potential field is the transverse derivative of the wind field. It is very similar to the streamlines of the flow. To run the model, we first had to differentiate the wind field to a potential field. Then run the model on the potential field and then integrate back to the velocity field. This differentiation and integration process was done on a grid with points spaced at 1° of latitude and longitude. The differentiation and integration smoothed the wind field. This introduced errors because these processes are sensitive to the spacing increments of the grid and the values at the boundaries. Both of these factors destroyed some of the information in the wind field.

These two problems commonly introduced 20 kt errors into the wind fields. These errors were larger than the errors in NWS model forecasts that we were trying to correct.

VI. CONCLUSIONS AND RECOMMENDATIONS

Improvements in the wind information are possible if a system is developed for analyzing wind observations and correcting the forecasts made by the major models. It is easy for a meteorologist to spot areas where wind forecasts are in error when he has the forecast displayed with the observations. The recent observations from aircraft also help define the wind forecast errors. The problem has been getting this information to the meteorologist and giving him the tools to make digital corrections to the wind field.

Our experience has been that both the displaying of wind information and making corrections to the digital data base are possible with today's equipment. No new hardware needs to be developed for a MERIT program. It can be done with common computer display systems that are commercially available.

We have shown that one data handling system, McIDAS, can easily collect and display wind observations and model forecasts. Software for quickly correcting the digital forecast also has been developed. Refinements to this initial experiment have to be made for the operational meteorologist, of course. But, a wind correction system could be built for any computer display system.

Changing the wind forecasts beyond the time of the most recent observations is a harder problem. The meteorologist could use his own intuition and change the forecasts using the same techniques that he/she used to change the analyses fields. This will increase the work load of the meteorologists and relays on his ability to out-guess the forecasts made by the major models.

Short-range models were proposed by Steinberg (1982, 1984) for carrying the wind field corrections forward into the time period of immediate flights. We tried the barotropic model without success. It created more problems than it solved. A more sophisticated model is needed.

We tested our Australian Mesoscale Model. We found that it could make a better analysis of the wind field than the larger models run by NMC. This improvement was expected because it used techniques specifically designed for wind data. Its short-range forecasts were never thoroughly scrutinized for quality during the course of this program. However, we feel that if it was started correctly, it could forecast as well as the major models since it has a similar formulation of the fluid mechanism equations as the larger models.

The Australian Model also indicated that automation for incorporating very recent aircraft wind observations into the wind forecasts is possible. This model is designed for assimilating data from irregularly-spaced intervals in time and space. This would reduce the number of changes that need to be made by the meteorologist.

The MERIT concept could be used by any airline with a meteorology staff or inside the NWS. A national central system for collecting aircraft data and improving wind forecasts was recommended by the Aviation Weather Forecasting

Task Force (NCAR, 1984). We also endorse this recommendation. The ability to correct the wind forecasts is directly dependent on the quantity of wind data available. There are aircraft observations being take by airlines that are not transmitted to the NWS that could be used. These observations could be pooled inside the industry by cooperative airlines or sent to a central location for analysis.

Changes to wind analyses and short-range model forecasts also could be made using personal computers. These techniques have modest memory requirements and processing speeds which are within the capability of many of today's personal computers.

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