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THE DESIGN AND IMPLEMENTATION OF THE NEW CENTER/TRACON AUTOMATION SYSTEM (CTAS) WEATHER DISTRIBUTION SYSTEM*,†

Steven D. Campbell, Richard A. Hogaboom, Richard T. Lloyd, James R. Murphy‡ and Herman F. Vandevenne

M.I.T. Lincoln Laboratory
244 Wood Street
Lexington, MA 02420-9108

ABSTRACT

The National Aeronautics and Space Administration (NASA), working with the Federal Aviation Administration (FAA), is developing a suite of decision support tools, called the Center/TRACON Automation System (CTAS). CTAS tools such as the Traffic Management Advisor (TMA) and Final Approach Spacing Tool (FAST) are designed to increase the efficiency of the air traffic flow into and through Terminal airspace. A core capability of CTAS is the Trajectory Synthesis (TS) software for accurately predicting an aircraft's trajectory. In order to compute these trajectories, TS needs an efficient access mechanism for obtaining the most up-to-date and accurate winds.

The current CTAS weather access mechanism suffers from several major drawbacks.[1] First, the mechanism can only handle a winds at a single resolution (presently 40-80 km). This prevents CTAS from taking advantage of high resolution wind from sources such as the Integrated Terminal Weather System (ITWS). Second, the present weather access mechanism is memory intensive and does not extend well to higher grid resolutions. This potentially limits CTAS in taking advantage of improvements in wind resolution from sources such as the Rapid Update Cycle (RUC). Third, the present method is processing intensive and limits the ability of CTAS to handle higher traffic loads. This potentially could impact the ability of new tools such as Direct-To and Multi-Center TMA (McTMA) to deal with increased traffic loads associated with adjacent Centers.

In response to these challenges, M.I.T. Lincoln Laboratory has developed a new CTAS weather distribution (WxDist) system. There are two key elements to the new approach. First, the single wind grid is replaced with a set of nested grids for the TRACON, Center and Adjacent Center airspaces. Each and the grids are updated independently of each other. The second key element is replacement of the present interpolation scheme with a nearest-neighbor value approach. Previous studies have shown that this nearest-neighbor method does not degrade trajectory accuracy for the grid sizes under consideration.[6,8]

The new software design replaces the current implementation, known as the Weather Data Processing Daemon (WDPD), with a new approach. The Weather Server (WxServer) sends the weather grids to a Weather Client (WxClient) residing on each CTAS workstation running TS or PGUI (Planview Graphical User Interface) processes. The present point-to-point weather file distribution is replaced in the new scheme with a reliable multi-cast mechanism. This new distribution mechanism combined with data compression techniques greatly reduces network traffic compared to the present method. Other new processes combine RUC and ITWS data in a fail-soft manner to generate the multiple grids. The nearest-neighbor access method also substantially speeds up weather access. In combination with other improvements, the winds access speed is more than doubled over the original implementation

DESIGN CONSIDERATIONS

Approach

The new weather distribution design relies on replacing the current single wind grid with a set of nested wind grids and on replacing the current interpolation method with a nearest-neighbor retrieval method. These concepts will now be discussed further.

Nested Wind Grids

The nested grid approach is presented conceptually in Figure 1. The nested grids are defined for the TRACON, ARTCC and Multi-Center airspace. The

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‡ James Murphy is now with NASA Ames Research Center, MS-210-6, Moffett Field, CA.

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nominal spatial resolution of the grids is 1 nm (~ 2 km) for the TRACON grid, 5 nm (~10 km) for the ARTCC grid and 20 nm (~40 km) for the Multi-Center grid. It should be noted that the grids are all aligned. That is, the grid points for all three grids can be thought of as being placed on a uniform 1 nm grid.

Each grid is rectangular in shape and sized in such a way to encompass the region of interest. That is, the TRACON grid is sized to be encompass the TRACON region plus a buffer region around it. Likewise, the ARTCC grid encompasses the ARTCC plus a buffer and the Multi-Center grid extends out into adjacent Centers a sufficient distance to allow boundary crossings to be scheduled.

These nested grids are used in the following way. For every wind retrieval, the position of the aircraft is checked to determine which of the nested grids should be used. As an example, imagine an aircraft approaching the ARTCC from an adjacent Center. The Multi-Center grid is sized to include the furthest aircraft in an adjacent Center for which a trajectory needs to be generated (e.g., to compute the Center boundary crossing time). The resolution of this grid is the same as the present single-resolution winds grid. As the aircraft comes closer to the ARTCC, the aircraft's position is checked for each retrieval to determine the appropriate nested grid (note: since the grids are rectangular in shape, this check is inexpensive computationally). When the aircraft crosses from the Multi-Center grid to the ARTCC grid, the wind retrievals are then made from the ARTCC grid. Similarly, when the aircraft enters the TRACON grid, the wind retrievals are then be made from that grid.

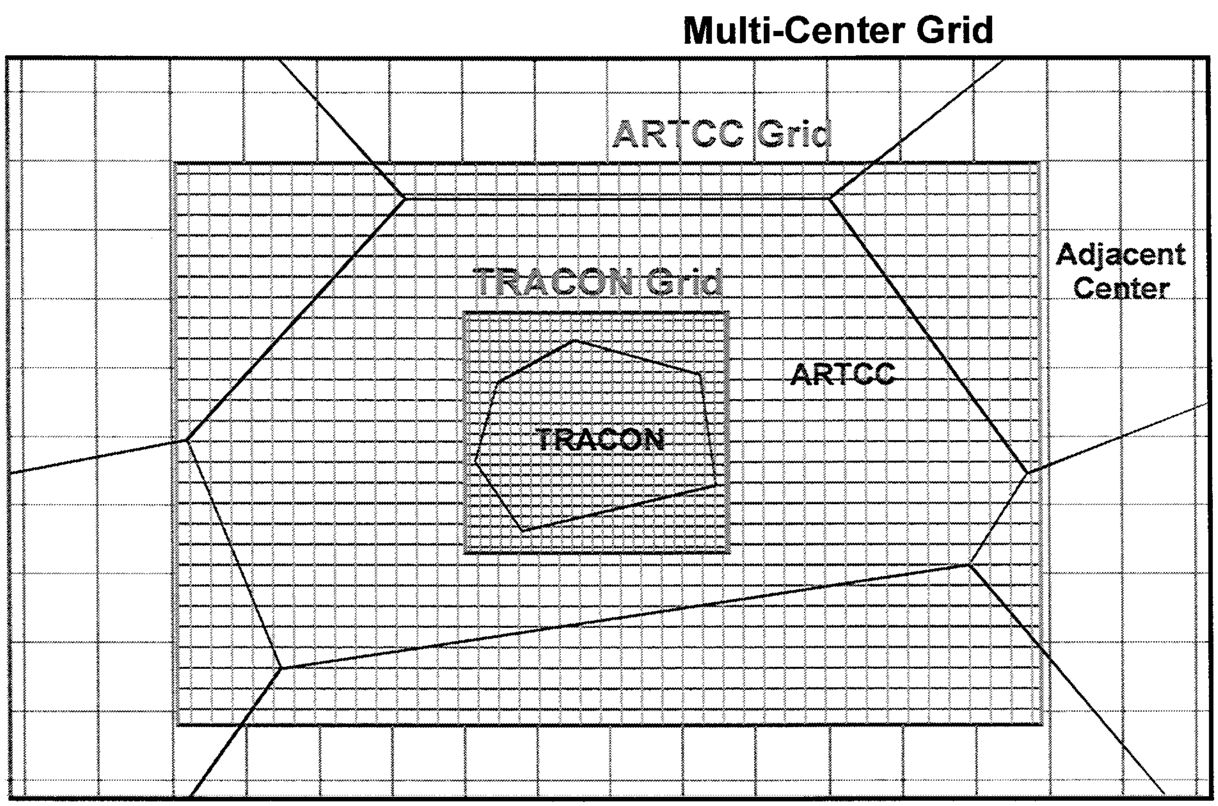

Figure 1. Nested wind grids for new weather distribution scheme.

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Figure 2 shows the data sources for the three weather grids: Rapid Update Cycle (RUC) 40 km winds and Integrated Terminal Weather System (ITWS) 10 km and 2 km winds. As shown in the figure, the Multi-Center grid is generated from RUC winds alone, the ARTCC grid is generated from RUC and ITWS 10 km winds, and the TRACON grid is generated from all three sources. Moreover, all three grids can be generated from RUC winds alone if the ITWS winds are not available. Finally, there can be alternate sources for the RUC data (not shown), including multiple RUC feeds and Eta model data.

It should be noted that the domains of the weather sources and the nested grids are independent. Likewise, the update rates of the weather sources are independent of each other. When an update for a given weather source is received, the appropriate portions of the affected nested grids are updated.

Nearest-Neighbor Retrieval Method

In the previous section, it was shown how the nested grid approach allows the use of multiple wind grids updated from various weather sources with different spatial resolutions and update rates. However, a complication arises due to the greatly increased number of grid points that need to be transmitted. In the old method, an interpolation scheme was used to allow the relatively coarse wind grids to be accessed rapidly. However, the memory requirements for the old method were very high on a per grid point basis. Previous studies determined that the memory requirements for the interpolation method made it infeasible for extension to the nested grid approach.[4,6] Accordingly a new winds retrieval method was proposed as shown in Figure 3.

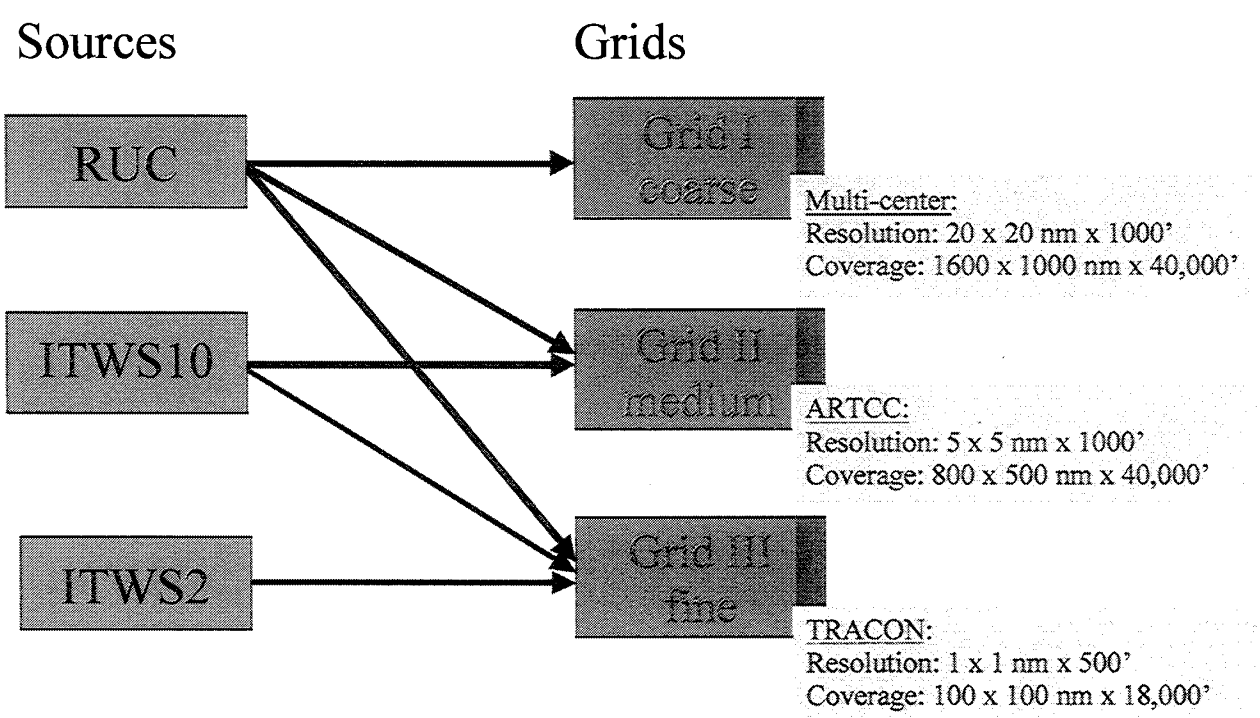

Figure 2. Data sources for weather grids.

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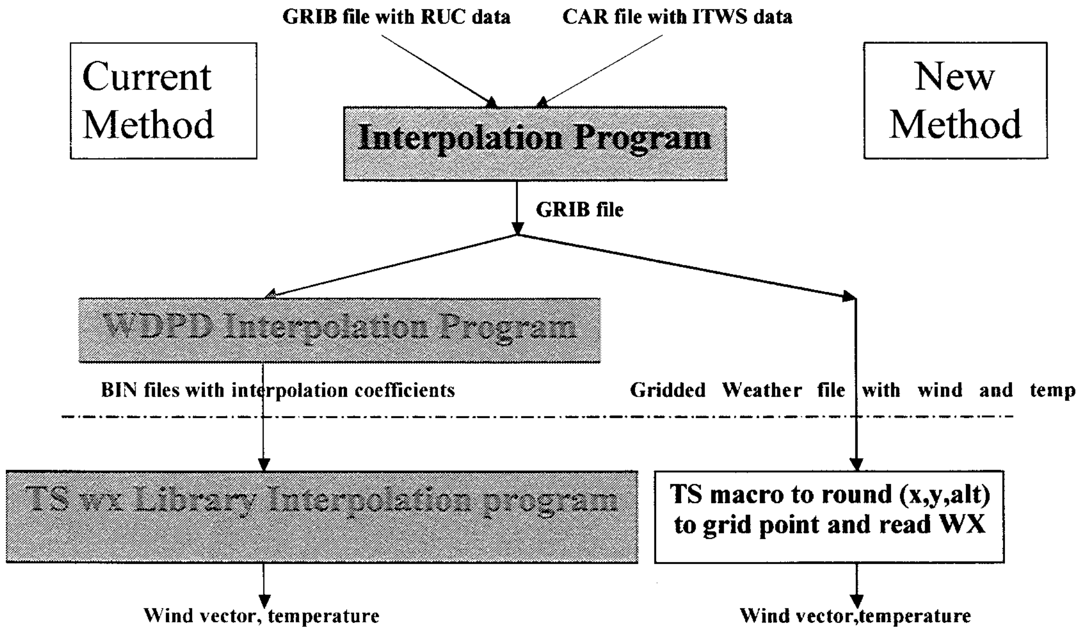

Figure 3. Illustration of replacing interpolation with nearest-neighbor retrieval method.

In the new method, the interpolation step is bypassed in favor of a nearest-neighbor retrieval scheme. The primary motivation for the nearest-neighbor approach is to make the memory requirements of the nested grids feasible, but it also has the advantage of speeding up access time and reducing processing requirements. As reported previously, the weather data access speed more than doubled with the new method (note: includes the effect of eliminating geometric altitude, which is being incorporated into the present system).[7] Figure 4 illustrates these weather data access speed improvements.

In order to employ the nearest-neighbor technique, it was necessary to verify that trajectory accuracy would not be impacted. As reported in, tests were run comparing trajectories computed using the interpolation and nearest-neighbor methods.[6] The comparison was run for two cases: a) Meter fix to threshold using ITWS 2 km winds and b) Coordination fix to meter fix using RUC interpolated to 10 km & ITWS 10 km winds.

It was found that the use of the nearest-neighbor method produced a one second RMS difference in trajectories for the first case and a four second RMS difference for the second case. These differences are negligible for the trajectories examined. An example of these results for ITWS 2 km data is shown in Figure 5. Note: the effect of using the nearest-neighbor method for the Multi-Center grid was not examined, however, the effect is assumed to be insignificant given the large distances involved and low update rate of the adjacent Center traffic data (e.g., 3 minutes via ETMS). A recent study showed the effect of using nearest-neighbor access for 40 nm winds for trajectories in the Center was a ten second RMS difference vs. interpolation.[8]

SOFTWARE DESIGN

Overview

A block diagram of the Weather Distribution (WxDist) software is shown in Figure 6. The key modules are the Weather Server (WxServer) and Weather Client (WxClient) modules. The WxServer module provides the weather data to multiple WxClient modules. There is on WxServer module for a given CTAS installation, and there is one WxClient module for each workstation employing one or more TS or PGUI processes. The external weather sources are converted into GRIB (Gridded Binary) files and divided up into minor grids as described in the previous section. The minor grids are transmitted to the WxClient processes via the reliable multi-cast protocol over the local area network (LAN). The WxClient processes provide the weather data to the application processes via a shared memory interface. The Weather Library (Wx Library) accesses the shared memory and provides the interface to the weather users.

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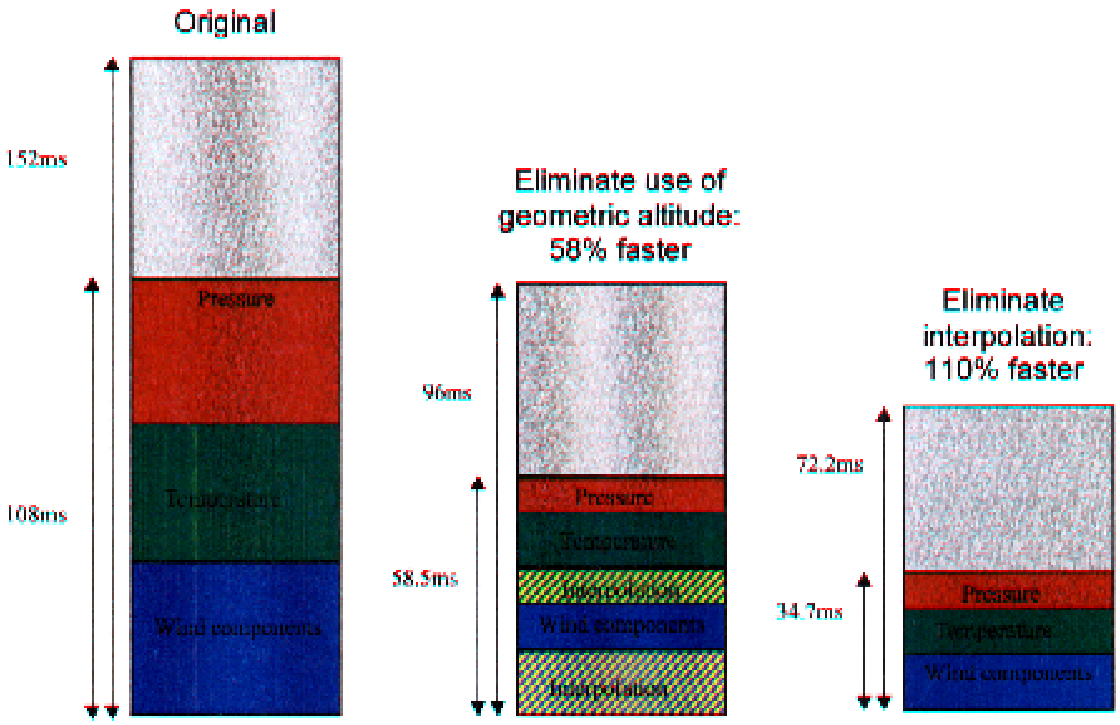

Figure 4. Weather data access speed improvement.

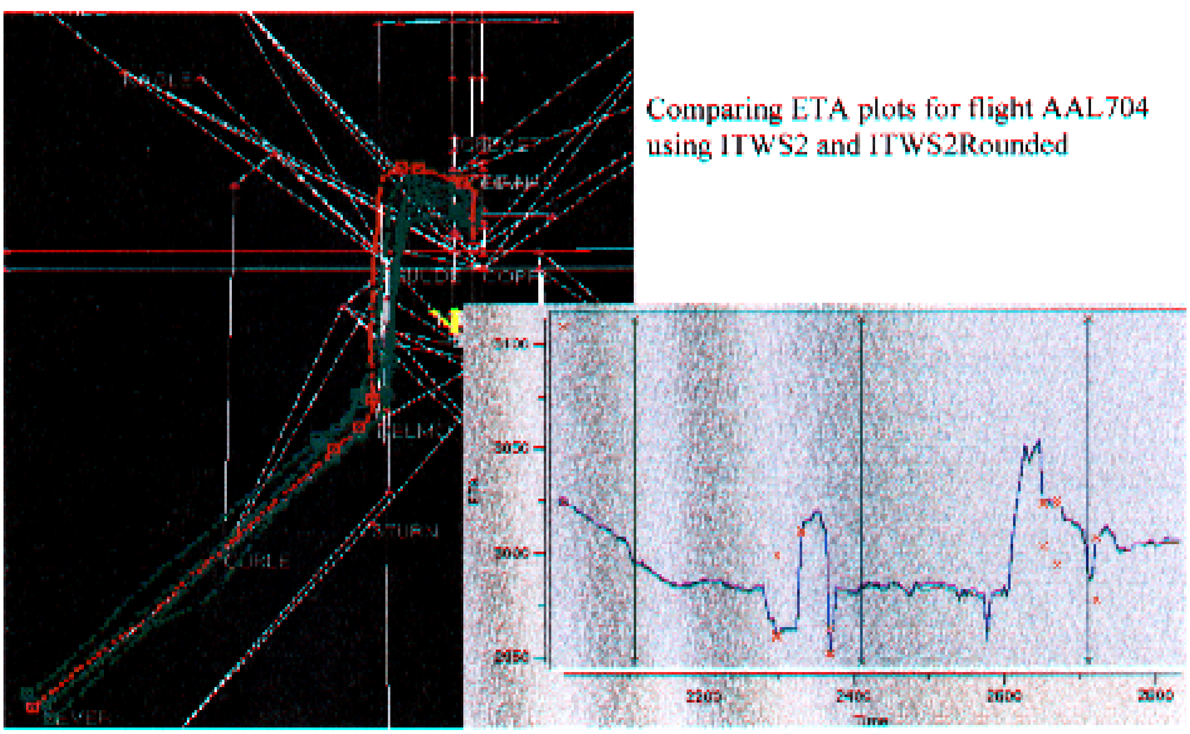

Figure 5. Comparison of trajectories for interpolated vs. nearest-neighbor methods.

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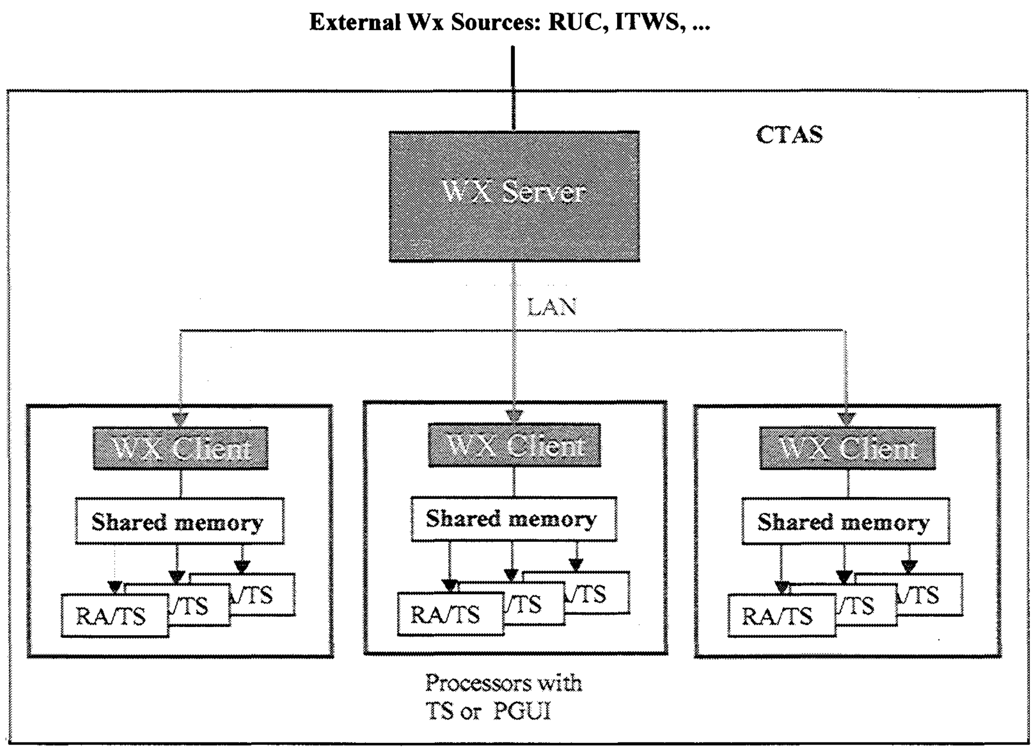

Figure 6. Weather distribution system block diagram.

Figure 7 shows a more detailed view of the CTAS weather distribution modules. As shown in the figure, the ITWS data is processed by the ITWS Connection Module into GRIB files and passed to the WxServer. The WxServer module also receives RUC files in GRIB format from the existing WDAD (Weather Data Acquisition Daemon) process. Note that the processes for acquiring the ITWS and RUC data reside outside the firewall to isolate the weather sources from the CTAS system. The CTAS Weather Communication module implements the reliable multi-cast protocol for transferring the minor grids over the LAN. Finally, the WxLibrary module provides the interface between the weather distribution system and the applications.

Table 1 lists the major modules in the new weather distribution system. The functionality of each module is summarized in the table. These modules will now be briefly described.

ITWS Communication Module

The ITWS Communication Module (itws_rtdc) obtains the Terminal Winds data feed from the ITWS testbed via stream connections and converts the data from Cartesian (CAR) format to GRIB (Gridded Binary) [3] format. It establishes socket connections to transmit the converted ITWS Terminal Winds data to multiple local and/or remote Weather Servers.

Weather Server

The Weather Server (WxServer) module sets up the site-adaptable wind grids from a WxServer configuration file. The file defines the resolution, spatial extent and data sources for each grid. It also defines the backup strategy for generating these grids from alternate sources.

The WxServer accepts Terminal Winds data from the ITWS Communications module via socket connections and RUC data from the existing Weather Data Acquisition Daemon (WDAD) process via file transfer. The WxServer automatically selects between the alternate weather sources to determine the best available data. It then translates the input data to the NAS coordinate system and compresses the data for transmission using the GRIB compression algorithm. It then transmits the data to each Weather Client using the reliable multicast protocol.

The details of the automatic source selection logic is shown in Figure 8. In this example, the ITWS 2 km winds data feed is interrupted at time T_1. After a timeout period (nominally 6 minutes), this weather source is declared unavailable. However, the last data received continues to be used until the nominal ITWS 10 km update time.

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If the ITWS 10 km update is received, the ITWS 2 km grids are now generated from the 10 km winds data. If the 10 km data is not available, then this source is declared unavailable and the most recent data continues to be used until the nominal RUC update time. When the RUC update is received, then the ITWS 2 km and 10 km grids are now generated from the RUC data. If the ITWS data later becomes available, then the system returns to using that data to generate the 2 km and 10 km wind grids.

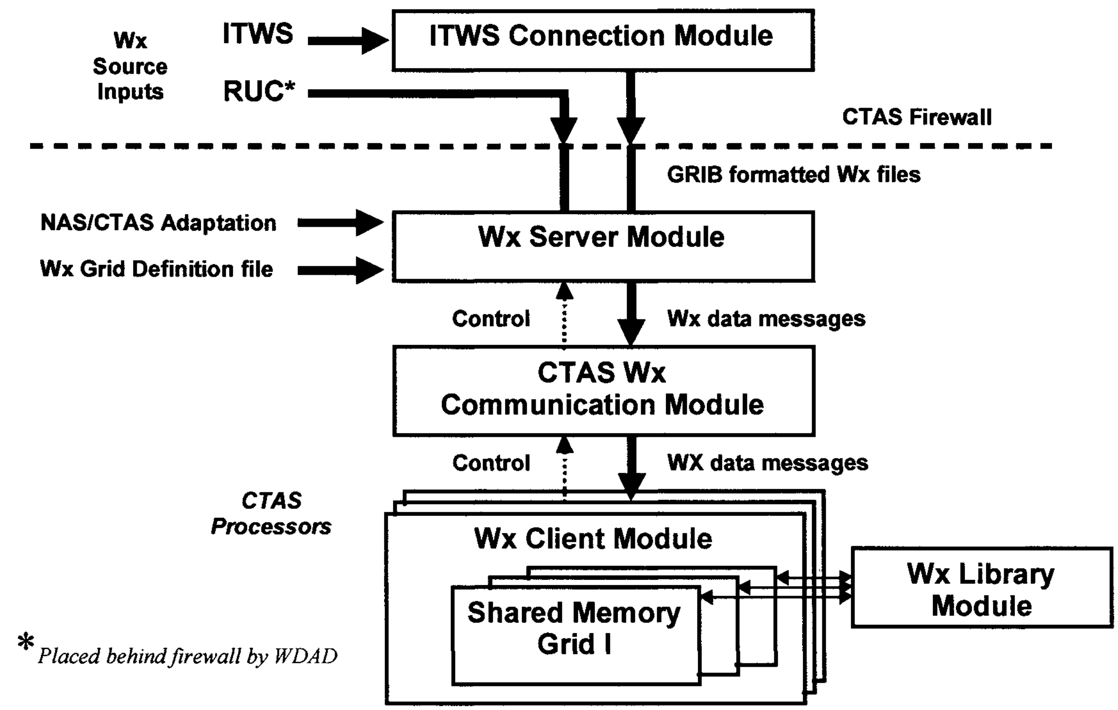

Figure 7. CTAS weather distribution modules.

Table 1. Major Software Modules

NAME	FUNCTIONALITY
ITWS Connection Module	• Connection to ITWS for winds data • Data conversion to GRIB format • Connection to multiple WxServers
WxServer Module	• Site adaptable weather grids • File connection for ITWS data • Conversion to NAS coordinates • Automatic weather source selection • Weather data compression
Communications Protocol	• Automatic connection/reconnection • Reliable multicast to transmit compressed weather data
WxClient Module	• Read multicast weather data • Update shared memory buffers • Switch buffers on command
WxLibrary Module	• When user asks for weather products: 1. Determine appropriate grid 1. Select nearest-neighbor value 1. Read weather product • Switch memory page on command • Identify current weather sources Note: grid structures transparent to users.

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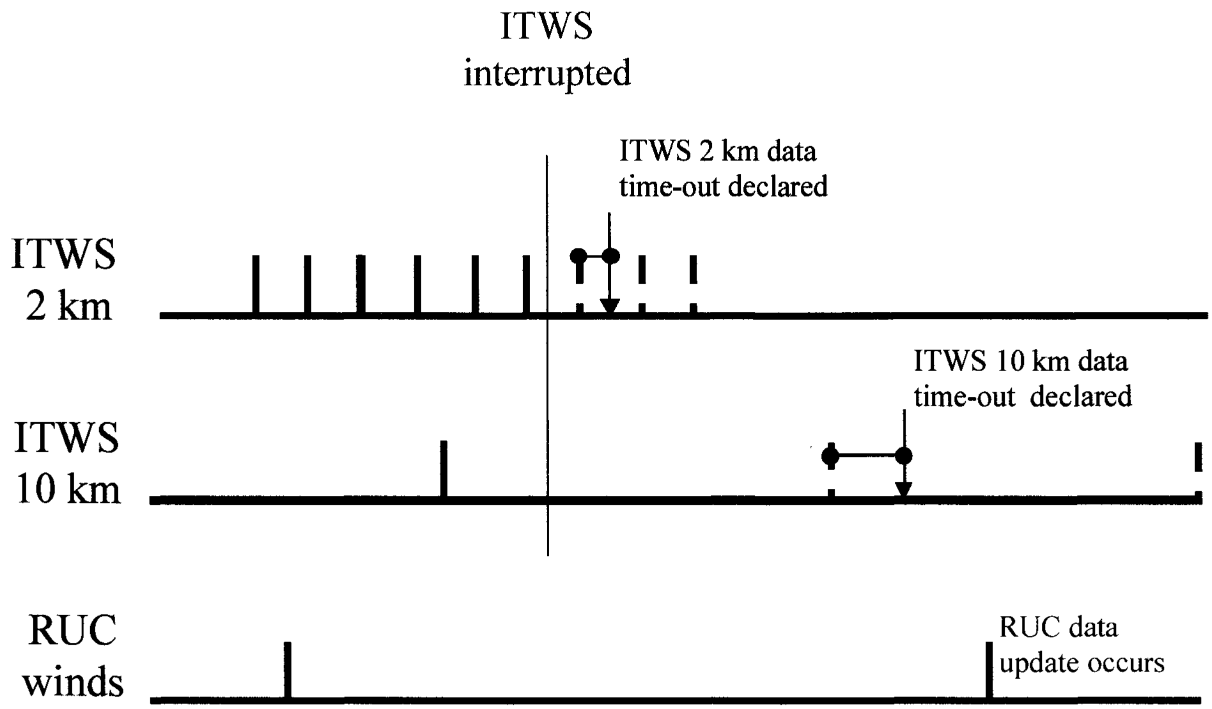

Figure 8. Timeliness check logic illustration.

WxServer/WxClient Communications Protocol

Figure 9 summarizes the WxServer/WxClient communications protocol. The WxServer process delivers the nested grid data to one or more WxClient processes using a reliable multicast protocol. This protocol makes use of a TCP/IP based socket connection between the WxServer and each WxClient as a control channel. It uses IP Multicast as the data channel from the WxServer to all WxClients.

The use of TCP/IP for the control channel provides reliability and ensures that no control message will be lost or delivered out of sequence. This guarantees the stability of the shared data view within the WxServer/WxClients group. The use of IP Multicast for the data channel allows us to transmit the data once for all WxClients regardless of how many are in use on the CTAS system. This minimizes the network load associated with weather data and allows the transmission of higher spatial and temporal resolution data sets.

WxClient

The Weather Client (WxClient) reads the weather grids via the reliable multicast protocol and updates the appropriate area of shared memory. The details of the shared memory interface with the weather users is discussed below.

Shared Memory Interface

Shared memory is used by the WxClient to make the weather data available for the Wx User. Two buffers are used for each data grid, one contains the current data and is available for reading, the other is being written to with new data. The form of each buffer is fixed with a standard header followed by a three dimensional array of product structures.

The double buffered approach used for shared memory is illustrated in Figure 10. As shown in the figure, new data is written into the write page while the users access the read page. When the update is complete, the pages are swapped. There is a signal handling scheme employed to ensure that all the users have the current information before the swap is carried out. Another implementation detail is that the contents of the new read page need to be copied back to the old read page prior to allowing further updates to occur to the new write page.

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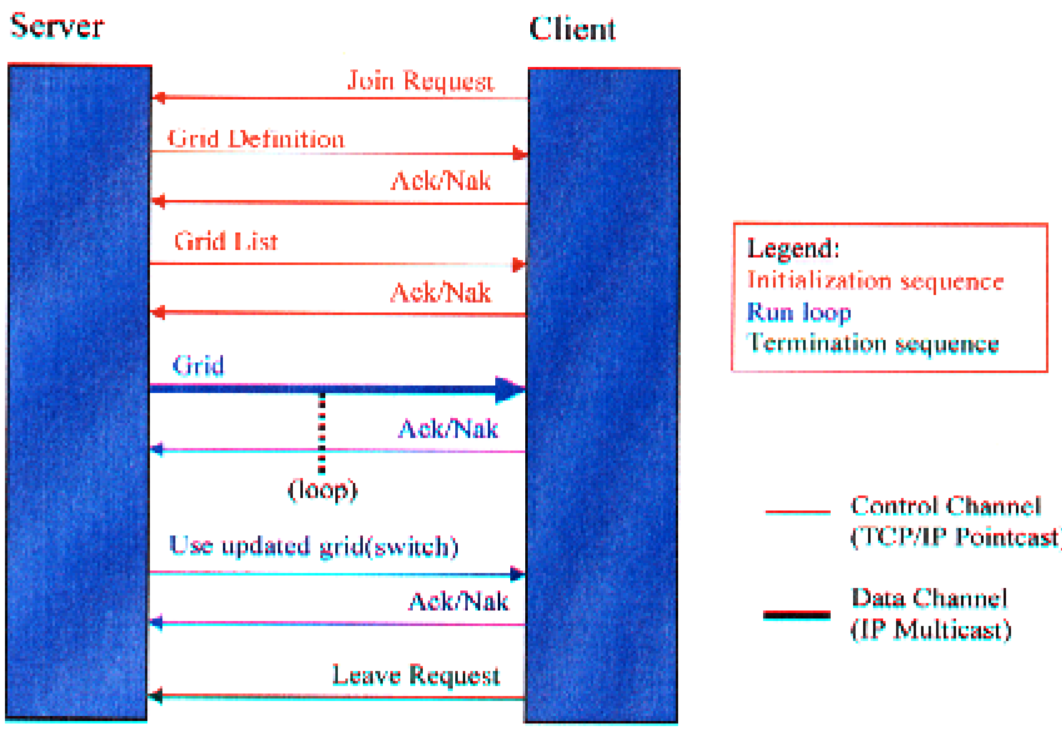

Figure 9. WxServer/WxClient Communications Protocol.

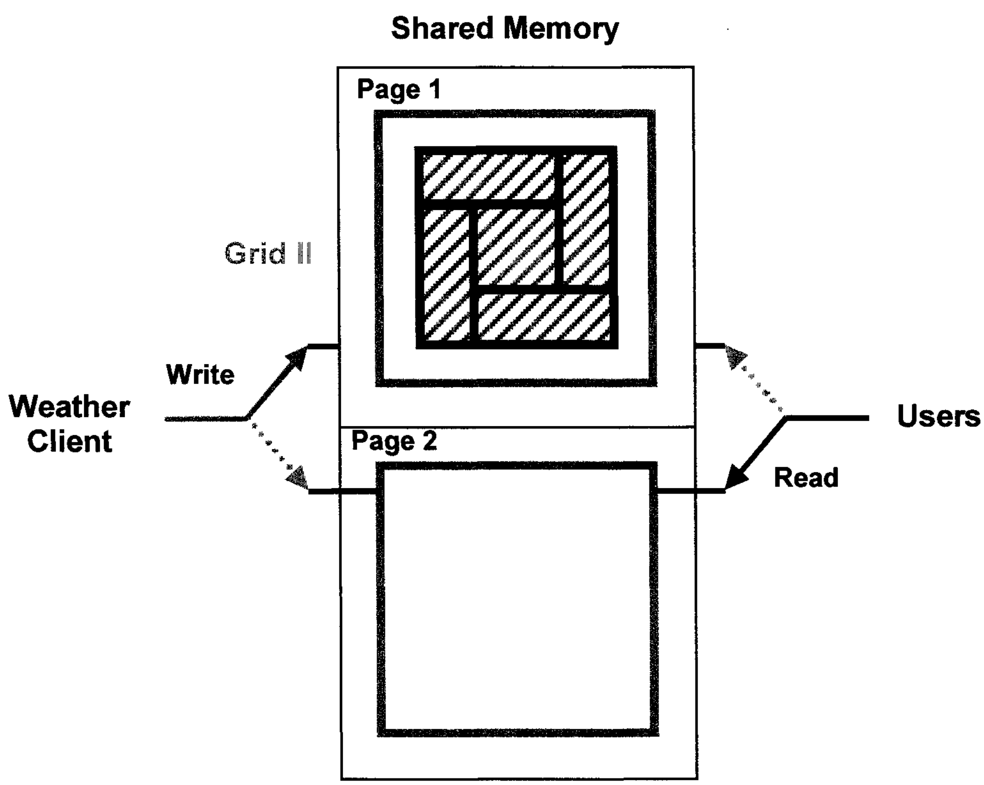

Figure 10. Shared memory double buffered scheme.

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Support for Multiple Weather Users

Each WxClient is capable of supporting multiple weather users. Recall that there is one WxClient for each workstation that supports all the weather users residing on that physical piece of hardware. As described in the previous section, a double buffer scheme is used to allow the weather users to read the current weather data from one buffer while the other buffer is being filled with the next weather data to be used. An important consideration is to ensure that all weather users switch from one buffer to the other buffer in concert. This synchronization is carried out using a semaphore mechanism.

WxLibrary

The Weather Library API provides the necessary interface to the weather server for all weather using applications. The intent is to allow the weather using application to request one or more weather products at one or more locations in a single request. Units used for both the locations and the weather products are felt to be those most suitable to the using application.

ALGORITHMIC ISSUES

There are three issues which have been identified as potentially requiring changes to TS in order to accommodate the new weather distribution system. These issues include:

- gradient computation,
- temperature interpolation and
- capture condition completion.

These issues will now be discussed.

Gradient Computation

The first TS weather use issue is the calculation of the vertical wind gradient. This gradient was originally calculated by accessing wind data at two slightly different altitudes h and h+Δh, taking the difference and dividing by Δh to obtain a discrete approximation of the vertical wind gradient.

In the original system, a value of 50' was used for Δh, which works properly when interpolation is used. However, when nearest-neighbor retrieval is used with this small value, the coordinates h and h+Δh usually round off to the same grid point and produce the same wind values. The resulting gradient is then zero.

In an exceptional case, the second value would round to the next altitude level and the resulting gradient would be very large. The TS software copes with large gradients by limiting the vertical wind gradient to 10 knots. The zero gradient simply means that the effect of wind is ignored. In neither case does TS fail in its trajectory calculations.

One specific instance where the vertical gradient is used is in the en route portion of the trajectory: specifically the Constant CAS and Constant Mach segments. As part of the TS algorithm, a system of differential equations is solved using a discrete step method called Runge-Kutta. This applies in particular calculations of True Airspeed, vertical speed and ground speed.

The principal equation in TS in solving for V_t is (Eq 1):

$$\frac{dV_t}{dt} = \frac{T-D}{m} - \frac{w}{m}\gamma_a + \frac{d}{dt}(V_w \cos\theta_{rw}) \quad (1)$$

where γ_a is the aerodynamic flight path angle, T is thrust, D is drag force, m is aircraft mass and w its weight, V_w is the wind speed and θ_{rw} is the relative wind angle.

For constant Mach or constant CAS, the above differential equation reduces to an algebraic expression. This is apparent if one considers the fundamental relationship (Eq. 2):

$$V_t = a(h)M(V_{CAS}, h) \quad (2)$$

where $a(h)$ is the speed of sound (as a function of altitude) and $M(.,.)$ is the Mach number (as a function of V_{cas} and altitude). It is clear that when Mach or CAS is constant, that the true airspeed is a simple function of altitude.

One can then write (Eq. 3):

$$\frac{dV_t}{dt} = \frac{dh}{dt} \cdot \frac{dV_t}{dh} \quad (3)$$

where (Eq. 4)

$$\frac{dh}{dt} = V_t \cdot \gamma_a \quad (4)$$

Making the approximation that the wind velocity over short x or y distances is constant (i.e. only dependent on h) then (Eq. 5):

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$$\frac{d}{dt}(V_w \cos\theta_{rw}) = V_t.\gamma_a.\frac{d}{dh}(V_w.\cos\theta_{rw}) \qquad (5)$$

This then leads to the expression for the aerodynamic glide slope (Eq. 6):

$$\gamma_a = \frac{(T - D).g}{w[V_t(\frac{dV_t}{dh} - \frac{d}{dh}\{V_w.\cos\theta_{rw}\})]} \qquad (6)$$

Note that the wind gradient shows up in the denominator. Thus, the reason for limiting the gradient value to a maximum value is to avoid a singularity condition for the aerodynamic glide slope and eventually a sign reversal. This would certainly make TS fail, since in a descent phase it then could not satisfy the required boundary conditions. It can also be seen that if the wind gradient comes out to be zero, the only effect is that the glide slope used in the trajectory prediction is a slightly small.

But the same formula uses weather in other ways: the altitude derivative of the True Airspeed uses temperature readings at two different altitudes. This would lead to problems also if the chosen altitude difference is a small value.

The solution for both the wind gradient and the True Airspeed gradient is to force the altitude increment to be equal to the weather grid vertical spacing. In the case of nested weather grids that increment could be different for the different nested grids. This introduces some complications in the event that the gradient computation crosses the nested grid boundaries. For this reason, it would be preferable to introduce an explicit call for the gradient at a particular point. This would allow these complications to be isolated from the weather user.

Temperature Interpolation

The second TS weather use issue involves temperature interpolation. One important TS function is to meet capture conditions, such as matching cruise and descent segments to identify the top of descent (TOD). In certain cases involving iteration to meet capture conditions, the TS was found to fail when nearest-neighbor retrieval was used. This is because TS uses small changes in temperature with altitude to drive the solution in the correct direction. When the nearest-neighbor value is used, the TS could possibly to converge because the same temperature value is always retrieved.

This problem was observed for the ARTCC grid when a grid spacing in altitude of 2000' was used. However, it was found when the altitude grid spacing was reduced to 1000', no TS failures were observed. As previously noted, the grid spacing in altitude can be traded against the horizontal grid spacing without increasing the memory required if even greater vertical resolution is needed (e.g., the vertical grid spacing could be decreased from 1000' to 250' if the horizontal spacing was increased from 10 nm to 20 nm).

Another considered was a fix to always linearly interpolate the temperature values between the nearest-neighbor values above and below the current altitude. This approach incurs a minor performance penalty due to the need to retrieve two temperature values (instead of one) and to perform a simple interpolation. However, this approach has the virtue of keeping the API unchanged. It also improves the accuracy of the temperature values, which feature a strong dependence on altitude. However, in practice it has been found that the decrease in vertical grid spacing proved sufficient and this fix was not implemented.

Capture Condition Completion

A problem was found in the way that TS completes the capture condition iteration. When TS iterates to point where the altitude is within the capture limits, it stops and returns the capture altitude. For example, the desired capture altitude might be 25,000' and the actual capture altitude might be 25,010'. Originally, TS did not recompute the derived variables (CAS, ground speed, etc) for the desired capture altitude but returned the derived variables for the actual capture altitude instead.

This behavior caused problems in the TS computations due to the nearest-neighbor retrieval for temperature. Fore example, if the gridded winds layers had 2000' vertical spacing, then the temperature might be 433 ^{o}R at 24,000' and 426 ^{o}R at 26,000'. The nearest-neighbor temperature value would therefore be 433 ^{o}R at 25,000' and 426 ^{o}R at 25,010'. This would create a discontinuity in the temperature values between flight segments that might cause TS to fail.

A fix was implemented is to force TS to recompute the derived values at the end of the iteration for the desired (instead of actual) capture altitude. This fix has been accepted for incorporation into the CTAS baseline software. It should be noted that the proposed temperature interpolation fix would also address this particular problem.

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TESTING PROCEDURES

Tests were carried out on the prototype implementation to validated functionality and measure performance. Note: the results presented here should be considered preliminary in nature and subject to further refinement.

Functionality Testing

The functionality tests were carried out in several steps. The first step was to perform a regression test using RUC data only. The second step was to add ITWS winds and validate correct insertion into the wind grids. The third step was to validate that the wind grids continue to be properly generated when the ITWS winds are transiently added and removed. The fourth step was to verify proper TS operation in the presence of wind field discontinuities. The fifth step was to quantify the difference in ETA (Estimated Time of Arrival) values with the addition of ITWS winds.

For testing purposes, a version of the new system was created which returns the linearly interpolated weather value instead of the nearest-neighbor value. This version (WxDist Interpolated) is not intended for operational use (since it runs more slowly than the nearest-neighbor version) but allows direct comparison between the weather values returned by the new vs. old systems from the **getWeatherValue** function.

The CTAS software was also instrumented to generate ETA logs, ETA log summaries, track logs and getWeatherValue logs. The standard output is to produce the ETA log, ETA log summary and track log (if radar track data is used). If verbose output is selected, then the getWeatherValue log is also produced (generally limited to short runs due to the large volume of output generated).

A capability to generate synthetic RUC data sets was also implemented to assist in regression testing. A utility program was written which allows synthetic RUC data to be generated for various test conditions. For example, one file was created with uniform wind values and temperature values that increased linearly with pressure level, and a second file was created with uniform temperature at all levels and U &V values that increased linearly with RUC X & Y coordinates, respectively. These files were used to validate the RUC-to-CTAS coordinate transformation in the vertical and horizontal dimensions, respectively.

Additional utility programs & Unix scripts were written for examining the input RUC data and processing the output test data. Unix scripts were also written to simplify making test runs and to automatically save the output logs. Processing and examination of the test data was primarily done using IDL and Excel.

Regression Testing

Regression testing was carried out to ensure that the new weather distribution system preserves the CTAS functionality. In particular, it is necessary to ensure that trajectories are correctly generated with the new vs. old systems. In order to do this, it is necessary to use RUC data only, since the old system cannot ingest ITWS winds data.

RUC winds ingestion

The first regression test was to verify that the RUC data is properly ingested into the new system. In order to do this, actual and synthetic RUC files were input to the WDPD, WxDist Gridded (nearest-neighbor) and WxDist Interpolated versions of CTAS. The outputs of the three versions were then compared and any inconsistencies diagnosed. In the process of carrying out the regression testing, several problems were found in the WDPD processing which were diagnosed and fixed. These changes are being evaluated for incorporation into the current CTAS baseline software but will not be further discussed here.

Examples of this comparison are shown in Figures 11 and 12. For these examples, the getWeatherValue calls were logged using the verbose option for a single aircraft trajectory. Figure 11 shows the retrieved temperature vs. altitude and Figure 12 shows the retrieved U wind vs. altitude. As seen in the figures, the WxDist gridded (nearest-neighbor) retrievals exhibit the expected staircase behavior whereas the WDPD and WxDist interpolated values vary smoothly. (Note: there is a small anomaly in the WDPD results below 5000' which is currently being investigated.)

ETA comparison

The second regression test was to compare trajectories generated using the WDPD and WxDist Gridded weather distribution schemes. For this test, 489 flight plan trajectories were compared for 158 aircraft using DFWF RUC weather data from November 22, 2000 at 1400Z. Figure 13 plots the ETA difference between the new and old systems for meter fix to threshold trajectories. The worst case differences range from -7 s to + 15 s. The mean ETA difference was 0.9 s (0.12%) and the RMS ETA difference was 3.3 s (0.44%). Also shown is the comparison for the WxDist Interpolated version which produced identical results to the WxDist Gridded version.

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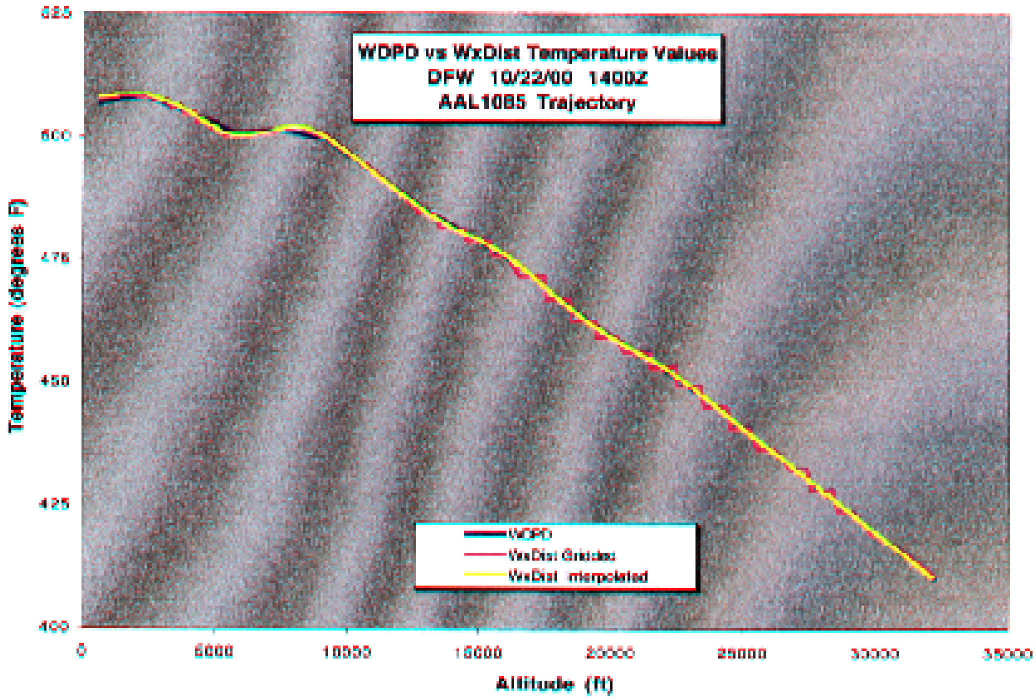

Figure 11. Comparison of retrieved temperature values for new (WxDist) vs. old (WDPD) systems

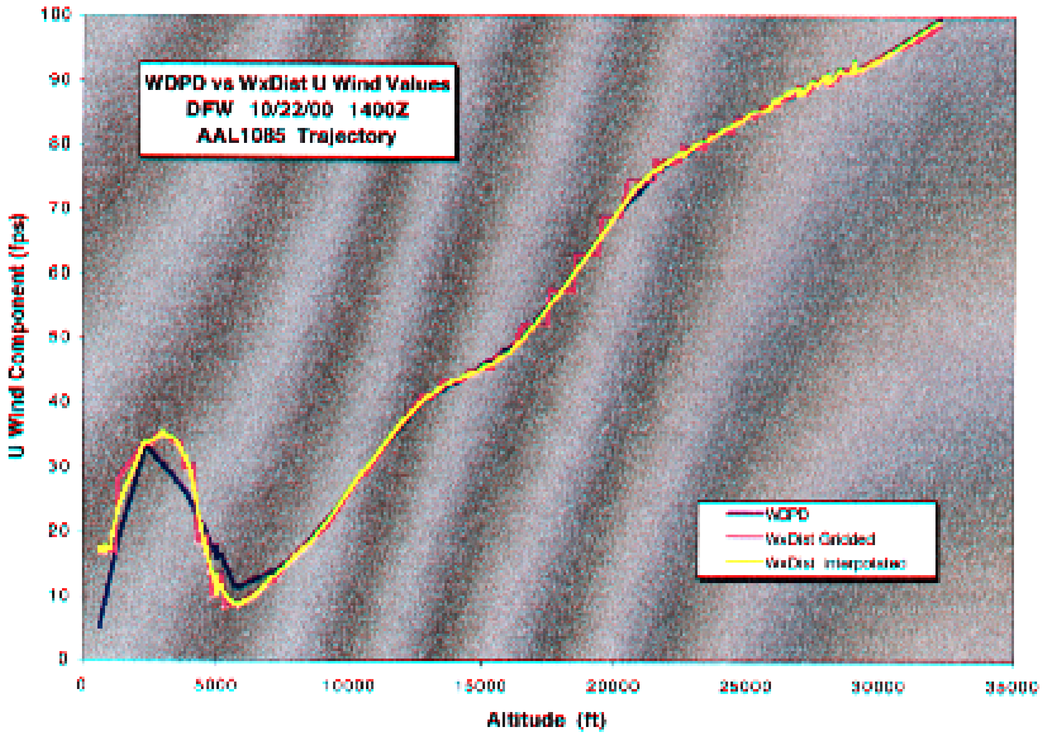

Figure 12. Comparison of retrieved U wind values for new (WxDist) vs. old (WDPD) systems.

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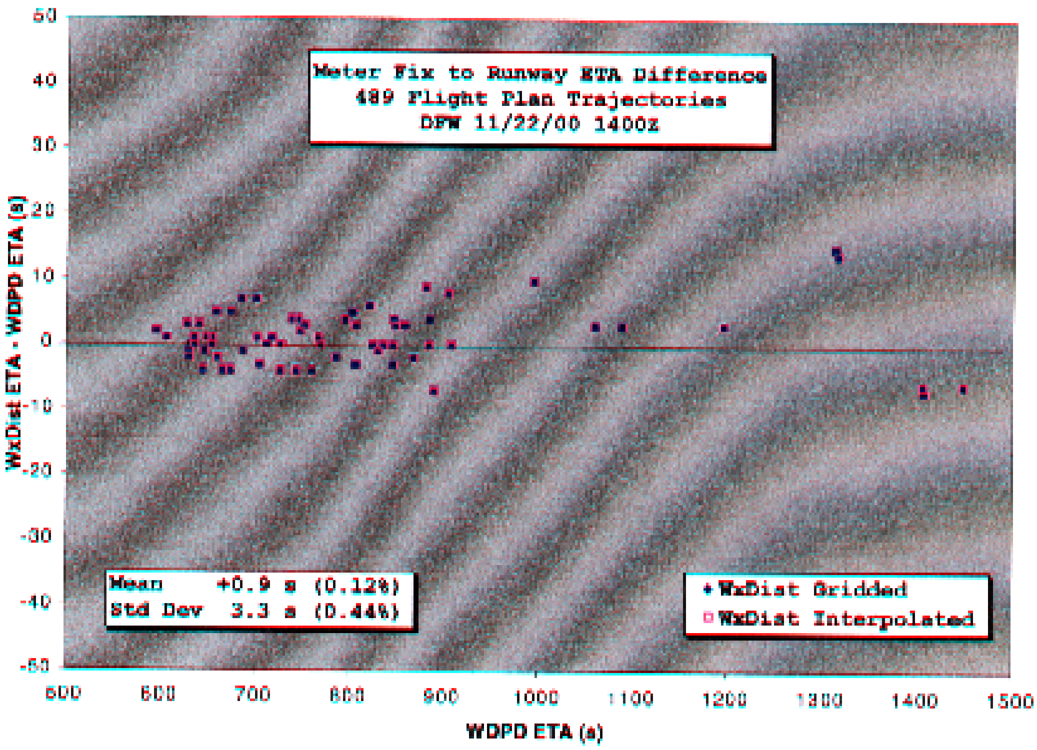

Figure 13. Flight Plan ETA difference between WDPD and WxDist for meter fix to threshold trajectories.

Figure 14 shows the ETA difference for the same set of aircraft for trajectories from the coordination fix to the meter fix. The worst-case ETA differences range from -45 s to +31 s. The mean ETA difference was -1.0 s (0.06%) and the RMS difference was 5.6 s (0.33%). Generally, the values matched very closely with the exception of a few large differences which are currently under investigation. Also shown is the comparison for the WxDist Interpolated version which were essentially the same as the WxDist Gridded results except that there was one fewer large excursion.

These error differences are slightly larger than predicted by reference (6). That study predicted ETA differences of 1 s RMS for the meter fix to threshold case and 4 s RMS for the coordination fix to meter fix case based on the use of nearest-neighbor vs. interpolated weather value retrieval. However, the ETA differences between the WxDist Gridded and WxDist Interpolated versions are in fact much smaller that predicted by the study. The observed variation is therefore likely to be due to as yet undiagnosed differences between WDPD and WxDist. However, the test results show that these differences have been reduced to very small values.

A comparison between the new and old systems was also made for aircraft trajectories from radar tracks. Figure 15 shows the Time To Fly (TTF) from 426 radar track trajectories for an aircraft landing on runway 17L. For this case, it should be noted that the WxDist ETA values were identical for the gridded and interpolated versions. The worst-case differences in TTF (ETA-current time) were -7 s to +5 seconds. The mean difference was 1.1 s (0.23%) and the RMS difference was 1.5 s (0.35%). Additional regression testing is in progress, but these results suggest that the new and old systems are working nearly identically for radar tracks.

ITWS Winds Validation

The next testing step was to validate that ITWS 10 km and 2 km winds are inserted correctly into the wind grids. For this test, the wind grids were defined as shown in Figure 16. For these tests, separate major grids were used for the ITWS 10 km and 2 km data. These major grids were set to correspond to the maximum extent of the ITWS wind fields.

In order to readily verify proper insertion of the ITWS winds, a synthetic GRIB data tool was used to generate dummy ITWS wind files. Two files were created, one for ITWS 10 km with uniform winds due East and the other for ITWS 2 km with uniform winds due North. These ITWS wind files were then processed by the Weather Server with the RUC wind file for 25 August 2000 at 1800Z for 5200' (850 mb) to produce the multiple wind grids.

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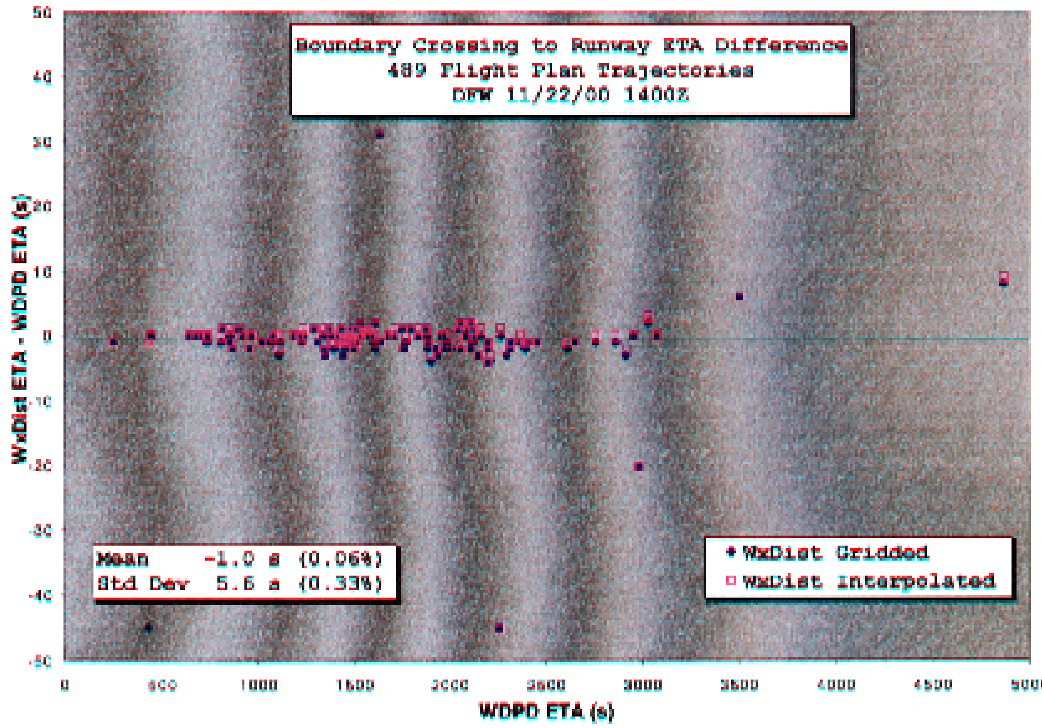

Figure 14. Flight Plan ETA difference between WDPD and WxDist for coordination fix to meter fix trajectories.

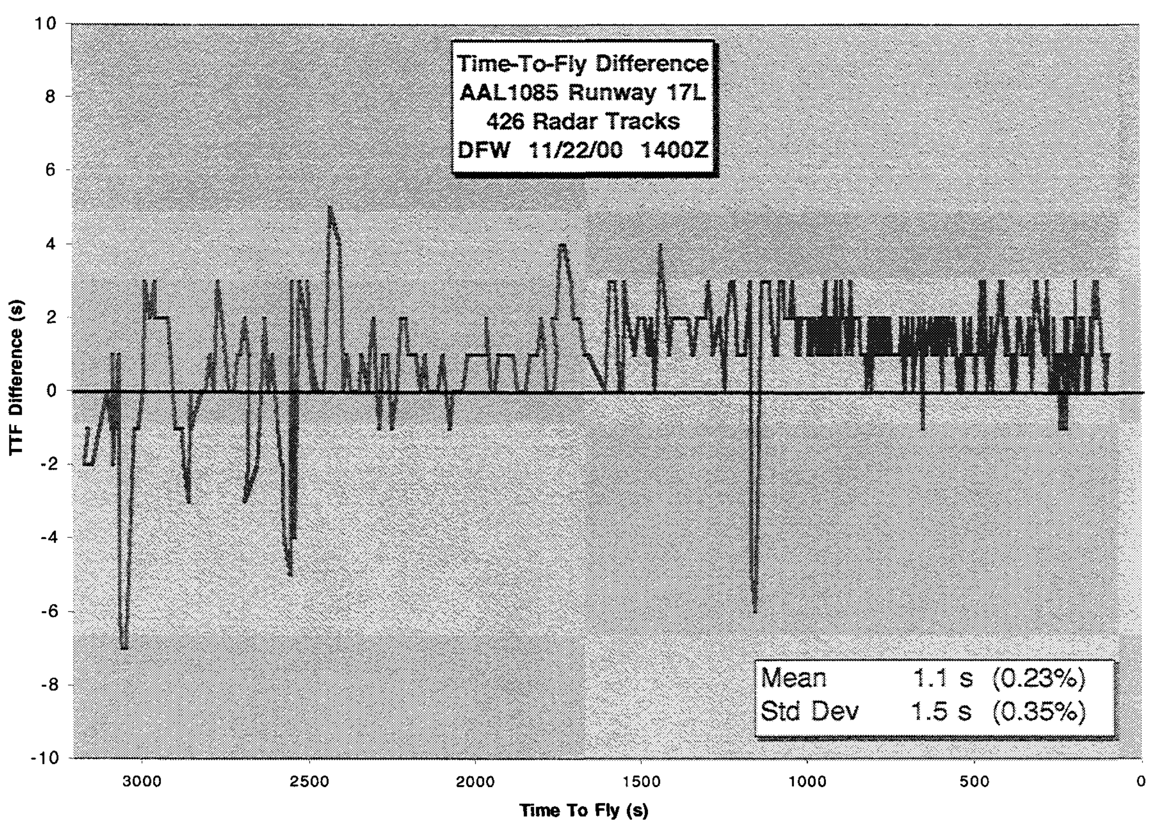

Figure 15. Time To Fly (TTF) difference for aircraft trajectories from radar tracks.

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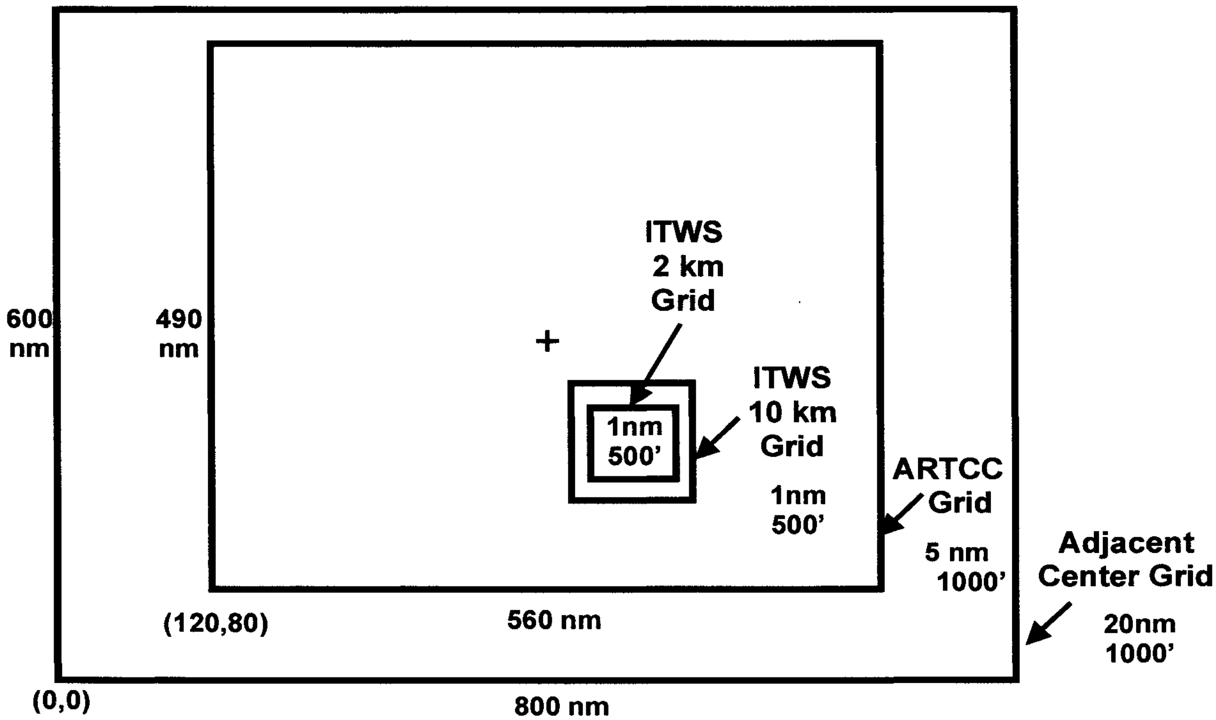

Figure 16. Major grid definitions for ITWS winds integration test.

The wind field values were retrieved on a grid approximating the 40 km RUC grid. These results are as shown in Figure 17. As seen in the figure, the insertion of the dummy ITWS wind data is clearly demonstrated.

Transient ITWS Winds Availability Testing

The third functionality test was to verify proper operation with transient ITWS winds availability. This test was carried out by interrupting the ITWS winds availability during a normal run and verifying that all the major grids continued to be generated from the RUC winds only.

Wind Field Discontinuity Testing

The fourth functionality test was to verify proper TS operation in the face of wind field discontinuities between the RUC and ITWS data. In order to rule out this possibility, CTAS was run with the dummy ITWS files shown in Figure 17. The results were examined and showed no evidence of TS failures in the face of worst-case discontinuities.

Effect on ETAs of Including ITWS Winds

The fifth functionality test was to quantify the effect on ETAs of including ITWS winds, as shown in Figure 18. To carry out this test, CTAS was run with RUC-only winds vs. RUC plus ITWS winds. Earlier studies showed considerable variation in meter fix to threshold ETAs as a function of time should be observed with the inclusion of ITWS 2 km winds updated every five minutes.[5,7]

Figure 18 summarizes the result of computing 489 pFAST (Passive Final Approach Spacing Tool) trajectories from 158 arrival flight plans under two conditions: 1) RUC winds only with interpolated winds (old system) and 2) RUC + ITWS winds with gridded winds (new system). These results were computed for DFW on 11/22/00 from 1500Z to 1700Z with RUC winds updated hourly, ITWS 10 km winds updated every 30 minutes and ITWS 2 km updated every 5 minutes.

As seen in the figure, the ETA values for the RUC only winds increase by 3 seconds over the two hour period. By contrast, the ETAs for the RUC + ITWS winds change by 16 seconds over this time period. These results are consistent with the earlier studies.

Performance Testing

Performance testing was carried out to assess the processing speed and memory requirements for the new vs. old systems. Table 2 shows examples of preliminary results for various grid sizes.

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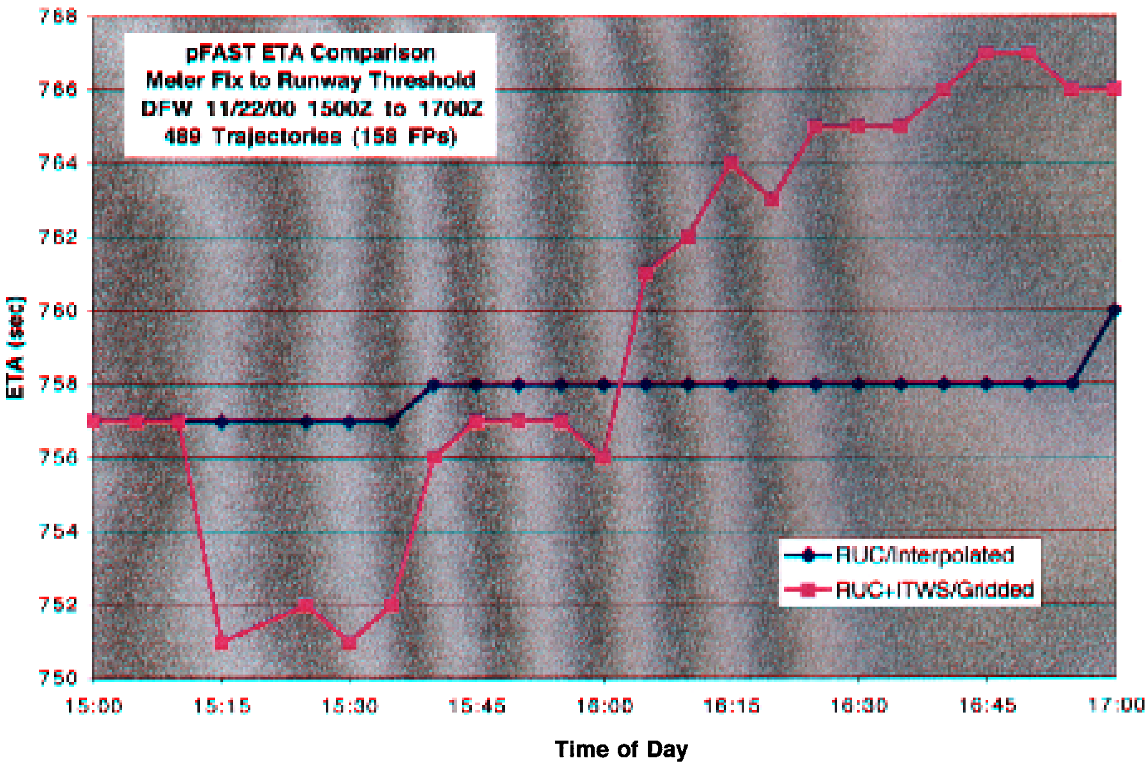

Figure 17. Example of ingesting dummy ITWS 10 km and 2 km wind field.

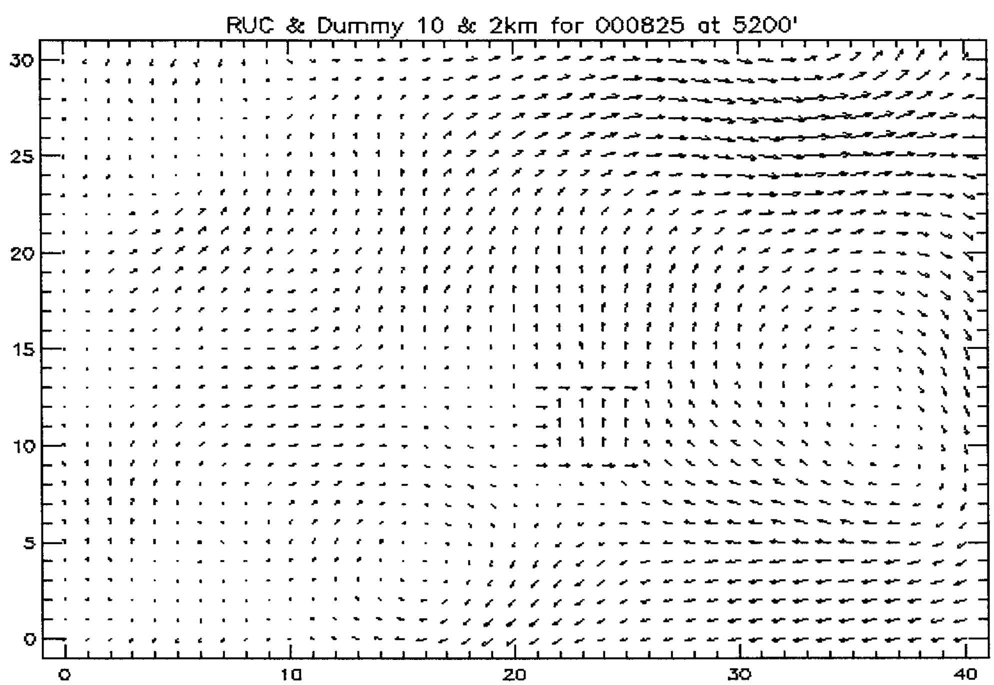

Figure 18. pFAST ETA comparison summary for RUC/Interpolated vs. RUC+ITWS/Gridded winds.

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Table 2. Example performance measurement results (preliminary).

Process	Total Data Points, XxYxZ	CPU Use, seconds	Memory Use, Mbyte	Network Load, Mbyte		
				At the Hour	At the Half Hour	At 5 Minutes
WDPD*	30 x 16 x 55	11.73	24	30**		
	15 x 8 x 55	4.86	18	7**		
	9 x 5 x 55	3.37	18	2**		
WxServer*	30 x 30 x 50	10.98***	84***	0.7***	0.5***	0.2***
	24 x 24 x 50					
	70 x 70 x 70					
WxClient****		8.85***	34***			

*270 MHz Ultra 5 – 128 MB RAM
** Assumes 5 TS, 1 PFS, 2 PGUIs == Eight Using Applications
*** Total for all grids
****60 MHz SparcStation 20 – 64 MB RAM

SUMMARY

This paper described the design and implementation of the new CTAS weather distribution system. The approach relies on two key concepts. The first concept is the use of multiple nested wind grids for the TRACON, ARTCC and Adjacent Center airspaces to replace the single low-resolution weather grid currently used. This new method allows the use of higher spatial and temporal resolution products such as IWS Terminal Winds and improved RUC winds. The spatial resolution and update rate for each grid is tailored to the weather sources and user requirements.

The second concept is the use of nearest-neighbor data retrieval to replace the interpolation method currently used. Previous analysis showed that the memory requirements of the present method prevent its extension to higher resolution weather grids. The nearest-neighbor method was introduced in order to reduce the memory requirements to feasible levels. As an added bonus, the nearest-neighbor method also yields a substantial improvement in weather data access speed. Previous work showing that use of the nearest-neighbor method should not substantially degrade trajectory accuracy for the grid resolutions under consideration was confirmed in the present study.

The software design employs the concept of a single Weather Server process that provides weather data to multiple Weather Client processes. There is one Weather Server for a given CTAS site installation and one Weather Client for each workstation running one or more TS or PGUI processes. A reliable multi-cast protocol is used for transmitting the weather data from the Weather Server to the Weather Clients. The weather grids are divided up into subunits (called minor grids) and compressed for transmission using the GRIB format data compression technique. Each minor grid has a primary weather data source and optional secondary weather data sources. In the event that the primary weather data source is not available, the minor grid can continue to be generated using the secondary weather data sources.

The software is divided into ITWS Connection, Weather Server, Communications Protocol, Weather Client, Weather Library and Weather User modules. The ITWS Connection module inputs ITWS Terminal Winds and converts it to GRIB format. The Weather Server merges the RUC data (from the existing WDAD process) and the ITWS data to generate the nested grids information. The Communications Protocol module performs the reliable multi-cast of the nested grid data to the Weather Client processes. The Weather Client module receives the nested grid data and makes it

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available to user processes via shared memory. The Weather Library provides the application program interface (API) for the user processes which selects the appropriate nested grid for data retrieval in a transparent manner. The Weather User module represents changes to the application processes where needed to accommodate the new method.

The testing procedures were also described. Results were provided including regression testing, performance measurement and software metrics. Finally, future work was described.

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