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PD1.1 NAS WEATHER INDEX: QUANTIFYING IMPACT OF ACTUAL AND FORECAST EN-ROUTE AND SURFACE WEATHER ON AIR TRAFFIC

*Alexander Klein**

Air Traffic Analysis, Inc, Fairfax, Virginia

Thomas MacPhail

National Weather Service, Washington, DC

Sadegh Kavoussi, David Hickman, Mark Phaneuf, and Robert S. Lee

AvMet Applications International, Inc., Reston, Virginia

David Simenauer

Aviation Design Services, Inc, Reston, Virginia

1 BACKGROUND

As the Federal Aviation Administration's (FAA) Operational Evolution Plan (OEP) points out [1], "In today's NAS [National Airspace System], weather data are not well integrated into either manual procedures or automated decision support systems, are not readily available to all decision makers, and are not sufficiently accurate. Thus, improvements are needed to support the increased number of air traffic operations envisioned in the future. More importantly, unpredicted changes in weather cause significant impacts and disruptions in the NAS; the current system does not respond well to unpredicted weather. The goal is to determine the impact of weather on the NAS and use that information for better decision-making. Using integrated weather information, along with probabilistic forecasts, to determine the impact of weather on the system will minimize the effects of weather on NextGen operations."

Extensive work by organizations such as NOAA, the FAA, MIT Lincoln Lab, MITRE CAASD and others is helping to develop better methods for weather forecast accuracy verification and assess its benefits [2, 3].

The traditional scientific evaluation of the accuracy of convective forecast products compares actual and forecast weather data on a grid covering the NAS and records differences between the observations and forecasts valid for the closest time within a small (usually 5-10 min) tolerance (see, for instance, [4]). Probability of detection / false alarm is computed and overall forecast accuracy is assessed for a particular product. This approach utilizes the natural "weather-to-weather" paradigm.

For terminal/surface weather forecast evaluation, the forecast skill can be assessed by, for instance, comparing when the forecast (TAF) predicts the onset of Instrument Flight Rules (IFR) weather, primarily low ceilings, vs. actual observations of this type of weather at the same airport (METAR) [5]. In this case, forecast and actual weather data are not simply compared in their original, direct form (e.g., "ceilings predicted at 800 Ft, actual at 1300 Ft for the same time period") but in an indirect fashion, in terms of their impact on airport operations ("forecast predicted a switch to IFR at time X; actual weather did not warrant such a switch until time Y").

We take this approach a step further: we compare operational *impact* metrics generated from combining actual weather and forecast weather with scheduled air traffic. Our base metric for such comparisons is called Weather Impacted Traffic Index, or WITI [6, 7, 8]. WITI measures the "front-end" impact of inclement weather and scheduled traffic demand on an air traffic system such as the NAS, or region, or an individual airport. When computed using forecast weather data, the metric is called WITI-FA ("FA" stands for "Forecast Accuracy").

* *Corresponding author address:* Alexander Klein, Air Traffic Analysis, Inc, 3802 Ridgelea Drive, Fairfax, VA 22031

2 QUANTIFYING ACTUAL AND FORECAST WEATHER IMPACT ON THE NAS

2.1 The WITI Metric

This section provides a recap of the computation of the Weather Impacted Traffic Index (WITI) metric, also known as WITI, as a linear combination of three components. A more detailed description is provided in [8]. When this metric is applied to the entire NAS, it is also known as the NAS Weather Index (NWX).

For en-route convective impact calculation ("E-WITI") , we use "flows" – Great Circle tracks between major airports – as "ideal", shortest-path unimpeded flight trajectories; we also use actual flight frequencies on these flows scheduled for the day in question. National Convective Weather Detection (NCWD) data is used to populate a hexagonal grid covering the NAS and to calculate how convective weather impacts individual flows between major airports. Intersections of the flows with hexagonal grid cells where convective weather was reported are computed, hour by hour. Each flow's hourly flight frequency is then multiplied by the number of convective reports in all hexagonal cells the flow crosses to get the en-route WITI. Even though aircraft are affected by weather both at the airport and en route, so en-route delays are a frequent occurrence, the delays "originate" and "eventuate" at airports. According to this principle, en-route weather impact is assigned to major airports in proportion to the distance of a particular area of convective weather from the airport. This allows us to regionalize the impact of en-route convective weather.

To compute the linear portion of the terminal weather impact ("T-WITI"), we use surface weather observations, namely METARs, for major airports. Each hourly weather observation is related to the stored hierarchy of weather factors, from most severe to less severe, so that if, for instance, a thunderstorm was reported and also some rain, then rain is not a factor for the given hour. For each of these weather factors, the WITI software stores airport-specific capacity degradation percentages: user-definable parameters whose default values are obtained from FAA capacity benchmarks and from historical data. The Terminal WITI is calculated by taking the capacity degradation percentage for each airport, every hour, and multiplying it by the number of scheduled hourly operations at this airport.

For the third, non-linear WITI component ("Q-WITI") reflecting Airport Queuing Delay, the airport's capacity in a given hour is compared to scheduled demand, separately for departures and arrivals. To determine capacity, all known runway configurations for the airport, sorted from highest to lowest capacity, are checked. If, in a given hour, wind velocity exceeds operational limits for cross- and tailwind for a given runway surface condition (dry/wet), this particular configuration cannot be used and the next one down the list is checked. Several weather phenomena may affect the airport concurrently; the one with most severe impact is identified. We then find the best possible runway configuration under the circumstances. The capacity benchmarks stored for the succession of runway configurations at an airport during the day are compared to scheduled traffic demand, hour by hour, and queuing delays are computed as demand-versus-capacity balance fluctuates. In addition to terminal weather, cases when an airport is partly blocked by contiguous areas (or lines) of convective weather are also considered: this is added as another potential factor reducing airport capacity.

2.2 The Standard WITI-FA ("Forecast Accuracy") Metric

An analogous metric quantifying the perceived impact of forecast weather (and traffic demand) on the NAS can be constructed using en-route and surface weather forecast products. In order for WITI-FA to be comparable to the WITI metric, probabilistic (and partly deterministic) forecast information needs to be converted to quasi-deterministic format. En-route convective forecast needs to be converted to quasi-NCWD format and surface weather forecast needs to be converted to quasi-METAR format. This process is described in detail in [9]; a brief summary is provided below.

2.2.1 Convective Forecast: CCFP

CCFP, a set of 2-, 4- and 6-hour forecasts, consists of a number of polygons; each is characterized by forecast coverage (sparse, medium, solid) and forecast confidence (low, high). Our goal is to compare the forecast weather impact on NAS air traffic to actual impact; for that, we need to convert the forecast convective weather product (CCFP) data to quasi-actual (NCWD) format. In case of actual data, we collect hourly NCWD data in hexagonal grid cells covering the NAS. We first compute the maximum possible number of NCWD convective reports, *M,* in a single hexagonal cell in 1-hr period. Then, depending on the coverage and confidence level of a CCFP polygon that covers this hexagonal cell, we multiply *M* by the two percentages representing CCFP coverage and confidence levels (e.g., 25% for sparse coverage, 50% for high confidence, etc). This yields the quasi-NCWD score for the hexagonal cell derived from CCFP. The NCWD and quasi-NCWD scores for each hexagonal cell are used for E-WITI computation: the WITI based on actual weather and the WITI-FA based on forecast weather. Further specifics of quasi-NCWD and convective WITI-FA computation are presented in [9].

2.2.2 Surface Weather Forecast: TAF

T-WITI-FA is created to quantify the forecast surface weather impact on air traffic (airport by airport, with aggregation to regional or NAS level). For actual weather, we use METARs; for the forecast weather, a natural choice is the Terminal Area Forecast (TAF). A series of TAFs issued throughout the day creates a forecast "stream" of weather events. In this process, probabilistic forecast information from TAF is converted to quasi-deterministic format identical to METAR format. We create a "rolling" forecast stream in 2-hr, 4-hr and 6-hr look-ahead variants. That is, at any given hour we want to know what the most up-to-date surface weather information for this airport / hour was available 2, 4 or 6 hours ago.

Each actual hourly weather observation (or forecast) may lead to airport capacity degradation if inclement weather was observed (forecast, respectively). The T-WITI-FA metric is then computed, analogously to T-WITI, as the forecast percent capacity degradation multiplied by the number of scheduled hourly operations at the airport. The process is described in detail in [9]. Once airport capacity estimates from TAFs are obtained, they can be used for computing the third WITI-FA component, Q-WITI-FA. This is analogous to Q-WITI and it estimates queuing delays for airport departures and arrivals based on forecast surface weather (TAF stream).

2.3 Tracking Forecast and Actual Weather Impact on the NAS vs. System Response

2.3.1 Daily Impact Charts

The WITI metric is computed on a regular basis (at the time of writing this paper, weekly; soon to be made available daily) and reported to the project sponsors, the Federal Aviation Administration and the National Weather Service. An example of a chart showing daily NAS metrics is shown in Fig. 1. One can see that the NAS operational response metric

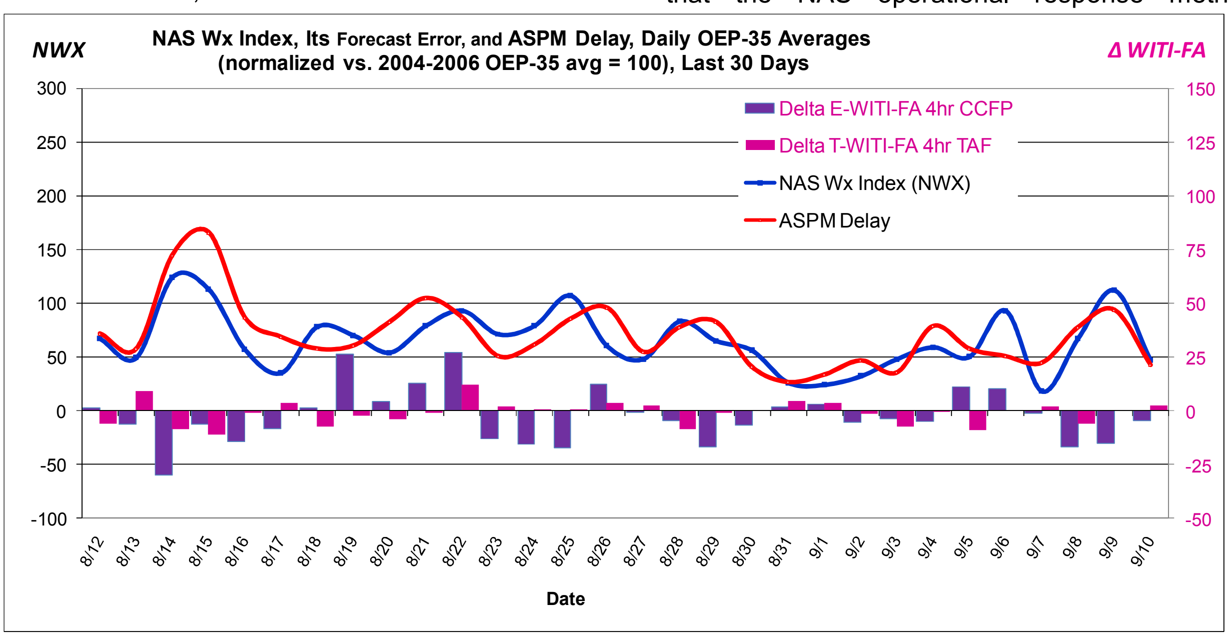


Figure 1: Normalized NAS WITI (NWX), Total Airport Delay from FAA ASPM database, as well as E-WITI minus E-WITI-FA and T-WITI minus T-WITI-FA "Deltas" for rolling 4-hour look-ahead forecasts (negative "delta": underforecast, positive "delta": overforecast) for a 30-day period in 2008

(ASPM Delay, red line) is highly correlated with NAS weather impact (WITI, blue line). Also, WITI minus WITI-FA “deltas” are generally higher when weather impact (and Delay) is greater. Note that the “delta” scale is ½ of the WITI scale, to highlight instances of over- and underforecast more clearly.

2.3.2 Airport Arrival Rate Comparison and Discussion on Avoidable Delays

In order to better understand the meaning of weather impact over- and underforecast, we use the WITI/WITI-FA output database analysis and drill-down capability provided by AvMet’s WITI-FA website [10] and identify airports with largest “deltas”. We then compute four different variants of airport arrival rates for each such airport:

- Scheduled arrival rates from FAA ASPM database
- Actual arrival rates, also from ASPM
- WITI model-generated arrival rates based on METARs (i.e., actual weather data)
- WITI model-generated rates based on TAFs (i.e., forecast weather data).

The WITI model-generated rates may or may not match actual or scheduled rates. They show idealized airport throughput given historical data on airport capacity benchmarks and actually achieved rates under various weather conditions.

As an example, consider New York LaGuardia (LGA) airport on January 11, 2008, see Figure 2. LGA was partially impacted by low ceilings and wind. The 4-hour look-ahead TAF indicated very heavy impact in early morning (with arrival rate at only half of optimal) which did not materialize. The TAF then predicted the impact in the early afternoon hours mostly correctly, and airlines cancelled many dozens of flights in anticipation of this impact (dashed blue line, actual arrivals, decline). However, by mid-afternoon the weather had improved, yet the TAF predicted more heavy impact for 2100-2200Z. Cancellations and delays extended through the evening and the airport reached its normal arrival rate only by midnight Zulu.

Analysis of the relationship between the four arrival rates can provide an indication of avoidable delay. In case of an overforecast as in Fig. 2, the difference between the smaller of scheduled and METAR-indicated rates and the larger of actual and TAF-indicated rates would be the “avoidable arrival rate deficit” related to the avoidable portion of delay. This is denoted by a blue arrow in Fig. 2. In fact, rather than talking about just delays, we should use the term “avoidable costs” which would include the cost of delays, cancellations, diversions and, in case of convective weather impact, cost of excess miles flown [11].

Currently, effort is underway to identify all meaningful combinations of the different relationships between these four arrival rate variants for both over- and underforecast cases and to develop a method to translate the arrival rate deficit (for overforecast) or excess (for underforecast) into avoidable-delay and -cost estimates. Clearly, weather impact underforecast is more difficult to deal with; but it can be argued that a relationship can be established between arrival rate excess (cases of underutilized airport capacity or sudden onset of underforecast weather causing unplanned traffic management actions) and associated delays and costs.

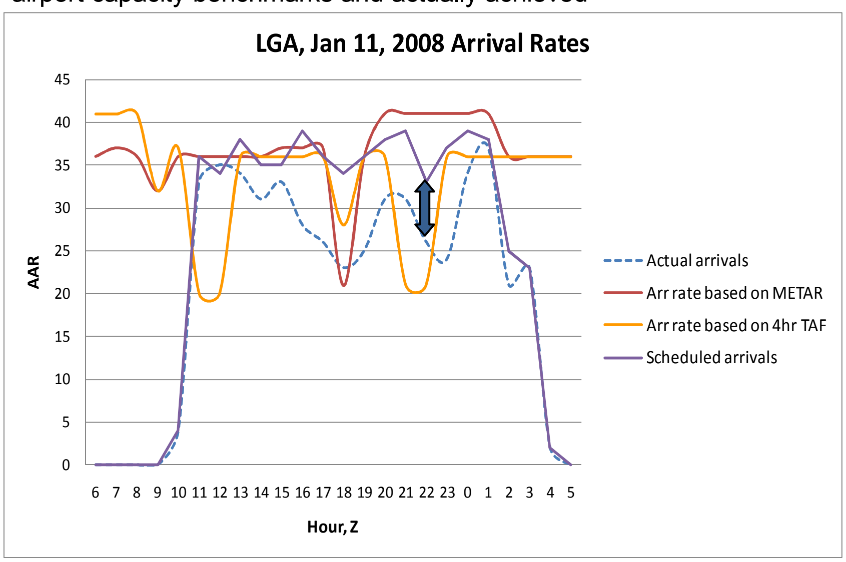


Figure 2: Scheduled, actual and WITI model-computed arrival rates at LGA airport, January 11, 2008 (significant impact forecast due to low visibility and wind). Overforecast in the afternoon and evening hours is evident. The arrow indicates avoidable delay.

3 COMPARING DIFFERENT EN-ROUTE CONVECTIVE FORECAST PRODUCTS

3.1 Key Assumptions

As discussed briefly in the Section 2.2.1, the key to translating the probabilistic convective forecast information into quasi-deterministic format is the notion of maximum hourly NCWD score for a hexagonal grid cell. This maximum hourly score, *M,* is computed as

$$M = N * 12$$

where *N* is the number of 4x4 Km NCWD reporting points in a hexagonal grid cell and 12 is the number of 5-minute NCWD reports in an hour. This would correspond to each 4x4 Km NCWD reporting point inside a hexagonal cell "firing" every 5 minutes, indicating continuous convective activity of VIP Level 3 or higher. Of course, actual NCWD scores on a day with convective weather are usually lower (often, much lower) than the maximum *M.*

If the same hexagonal grid is used for quantifying impact of convective forecast products on air traffic, we can translate convective forecast data into quasi-NCWD format by multiplying *M* by convective probability valid for the area that covers the hexagon. If a gridded forecast product is used, the probabilities are computed for grid points inside each hexagon and averaged for the hexagon / hour. If it is the convective weather intensity that is forecast, not the probability of convection, gridded forecast reports are gathered in the same hourly/hexagonal-grid-cell "bins". Corridor Integrated Weather System (CIWS) is one such product. In case of CCFP, there are not one but two parameters, coverage and confidence percentages, that are used as multipliers. Thus, hexagons covered by a CCFP area of, say, sparse coverage and high confidence will get quasi-NCWD scores of 0.125 * *M* because sparse coverage multiplier is 25% and high confidence multiplier is 50% [9].

Various convective forecast products have different time granularity: CCFP, for instance, is issued every two hours while CIWS forecasts are issued every 5 minutes. In the first case, forecast data in hexagonal grid cells would be interpolated "down" to 1-hr granularity while in the second case, it would be aggregated "up" to fit 1-hr time bins.

To restate, converting both actual and forecast weather data into the same "currency" – proportion of maximum hourly NCWD score *M* on the same hexagonal grid – provides the basis for comparing very different products in terms of how they forecast convective impact on en-route traffic.

3.2 Two Methods of Quantifying Convective Weather Impact

3.2.1 E-WITI-FA

We compute E-WITI for actual weather and E-WITI-FA for forecast weather using the convective forecast data translation model into quasi-NCWD format, as described above. We compute total NCWD and convective forecast's quasi-NCWD score along each Great Circle "flow" between major city pairs and aggregate these scores for the NAS. We then multiply these scores by the hourly frequency of traffic on the flow which yields E-WITI / E-WITI-FA.Two metrics are then used: the correlation between daily (or hourly) averages of E-WITI and E-WITI-FA for the evaluation period, typically a range of summer days, and the difference between mean values of E-WITI / E-WITI-FA. This reflects both the accuracy of the forecast impact and the over- / under-forecast trend. The E-WITI-FA method thus uses "weather weighted by traffic" paradigm.

3.2.2 Scanning Method (Directional Airspace Availability Estimation)

The second method we employ is based on the scanning algorithm first presented in [12]. We estimate the airspace availability of a Center (or sector) by scanning it in a series of directions, e.g., every 20^{O}, using scan lines with spacing commensurate with the granularity of our airspace availability estimation (Figure 3).

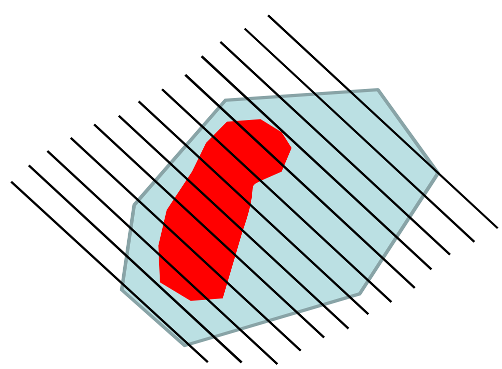


Figure 3: Scanning algorithm illustration

In the example above, a Center is scanned in the 320^O direction (and the reciprocal 140^O direction). Each scan line may or may not encounter convective weather significant enough to block traffic flow along this line. During the scanning, we are looking for the maximum intensity of convective weather along the scan line (rather than total score along a scan line or flow, as was the case with E-WITI-FA based method). This maximum will determine whether this area of weather is permeable by the given scan line. We introduce the notion of a convective weather area being "half permeable" in addition to "permeable" and "not permeable".

To determine permeability, we relate the maximum convective score found in the hexagonal grid cells that are crossed by a scan line (and are inside the Center being evaluated) to the maximum possible NCWD score *M*. This ratio, ranging from 0 to 100%, is then compared to the pre-determined "Permeability Thresholds" that indicate at what probability or actual intensity of convective weather will most aircraft be likely to deviate (or plan the flight around the weather in the first place). These permeability thresholds were introduced in [12] and discussed in detail in [13].

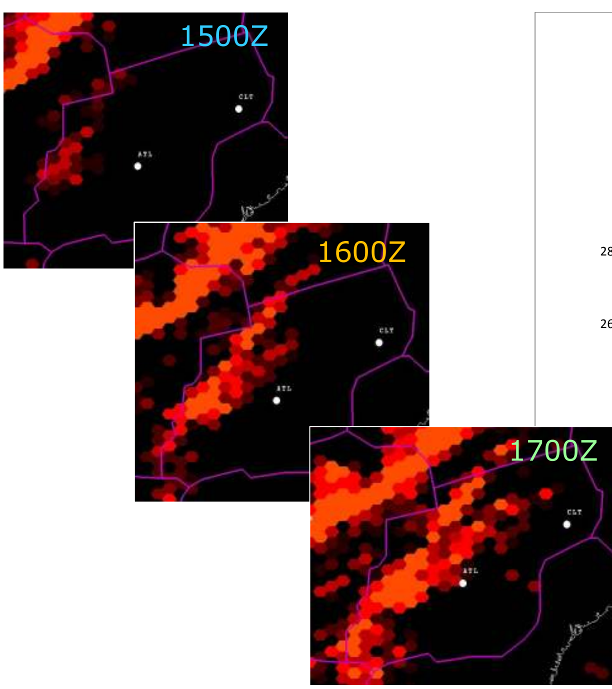
Then, Directional Airspace Availability (DAA) percentage (vs. airspace volume clear of any weather) along direction (heading) *i* is

$$DAA\_Perc_i = \sum_{k=1}^{N} P_k / N$$

where P_k is the permeability score (which can be 0, 0.5 or 1) for a scan line *k* that crosses the Center and possibly encounters some significant weather area(s), and *N* is the total number of scan lines that cross the Center.

Having computed permeability scores and directional airspace availability for a Center, we can construct a "wind rose" chart such as shown in Figure 4. Here, Atlanta Center (ZTL) is impacted by a convective weather front. At 1500Z, most of ZTL airspace is permeable, and the "wind rose" chart – blue polygon – almost fills the entire 100% circle. At 1600Z (brown polygon), 2/3 of ZTL airspace is blocked in roughly northwest-southeast direction but in perpendicular direction, a substantial portion of ZTL airspace is still permeable. This permeable portion shrinks further at 1700Z (green polygon) as the weather moves east-southeast.

Similar computations can be performed using convective forecast rather than actual weather products. Since the scanning algorithm relies on the same NCWD (or quasi-NCWD) scores in hexagonal grid cells, the airspace availability as indicated by actual or forecast weather can be compared. "Wind rose" charts for different weather products can be computed and compared visually; and each hour / direction on a "wind rose" chart is a data point for numerical comparison. We typically use only 1100Z – 2300Z hours, which yields 13 * 18 = 234 data points per day. Examples of these



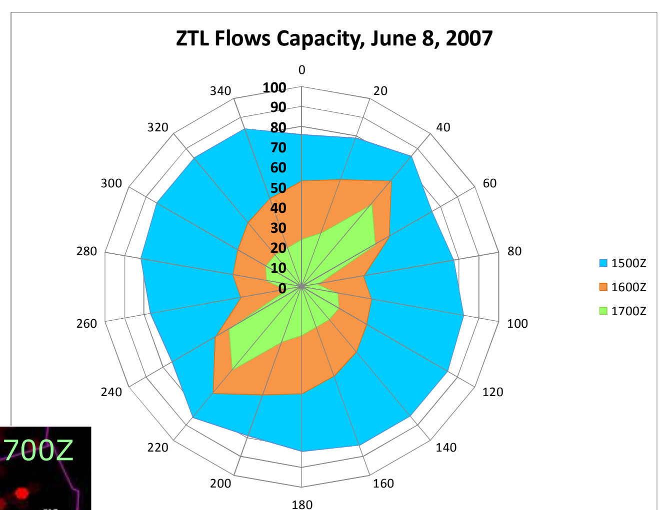


Figure 4: Convective weather (NCWD) situation and directional airspace availability "wind rose" chart for ZTL Center on June 8, 2007

comparisons are given in the next Section.

Unlike the E-WITI-FA based method, the scanning method does not weigh weather by air traffic demand. We therefore have two different but complementary methods for convective forecast product comparisons that both rely on our forecast weather translation method (NCWD and quasi-NCWD score computation).

To underscore an important point, these convective forecast product comparison methods are different from standard verification techniques used by the weather research community: here, we estimate and compare the impact of actual and forecast weather on air traffic. Among other things, this means that "not all weather is equal" [9].

3.3 Examples of Convective Forecast Product Comparisons

3.3.1 NCWF-6

National Convective Weather Forecast with a 6-hr look-ahead span (NCWF-6) is a model-based forecast product developed by the National Center for Atmospheric Research (NCAR) [14]. It computes probabilities of convective activity of VIP Level 3 or higher on a rectangular grid identical to that for NCWD. In order to compare NCWF-6 to CCFP, we process the 2-hr, 4-hr and 6-hr "rolling" look-ahead NCWF-6 data streams. That is, for any hour Z, we check NCWF-6 forecasts issued, respectively, two, four and six hours prior and compare those forecasts to actual convective weather at hour Z. Having collected probabilistic data at NCWF-6 reporting points inside a WITI hexagonal cell, we compute the average probability for this cell over a 1-hr time period. The quasi-NCWD score for NCWF-6 is then obtained by multiplying the maximum NCWD score *M* by this averaged probability.

Figure 5 shows actual and 4-hr look-ahead NCWF-6-forecast convective situation at a specific hour on a day with heavy convective impact: 2200Z, July 19, 2007. Brighter red indicates heavier weather / higher convective probabilities (i.e., in the end, higher NCWD / quasi-NCWD scores in hexagonal grid cells). Blue outlines are the 4-hr look-ahead CCFP polygons for the same time period.

Next, Figure 6 shows the E-WITI and E-WITI-FA daily averages computed for 32 days in summer 2007. At 2-hr look-ahead, NCWF-6 has higher correlation with NCWD than CCFP but also tends to over-forecast convection; the situation evens out for the 4-hr look-ahead and reverses for the 6-hr look-ahead: now, NCWF-6 has about the same correlation with NCWD as CCFP and it tends to under-forecast convection.

This impression is reinforced by analyzing results from the application of the second method of comparison: the scanning algorithm.

Comparison of airspace availability estimates obtained from both convective forecast products show rather good correlation, NCWF's being higher. For 4-hr and 6-hr look-ahead forecasts, however, the situation changes. This is illustrated in Figure 7 which shows overall correlations across all 32 days from summer 2007 period. While NCWF-6 at 2-hr look-ahead has better correlation with NCWD results, the NCWF-6 accuracy decreases rapidly as the look-ahead time extends to 4 and 6

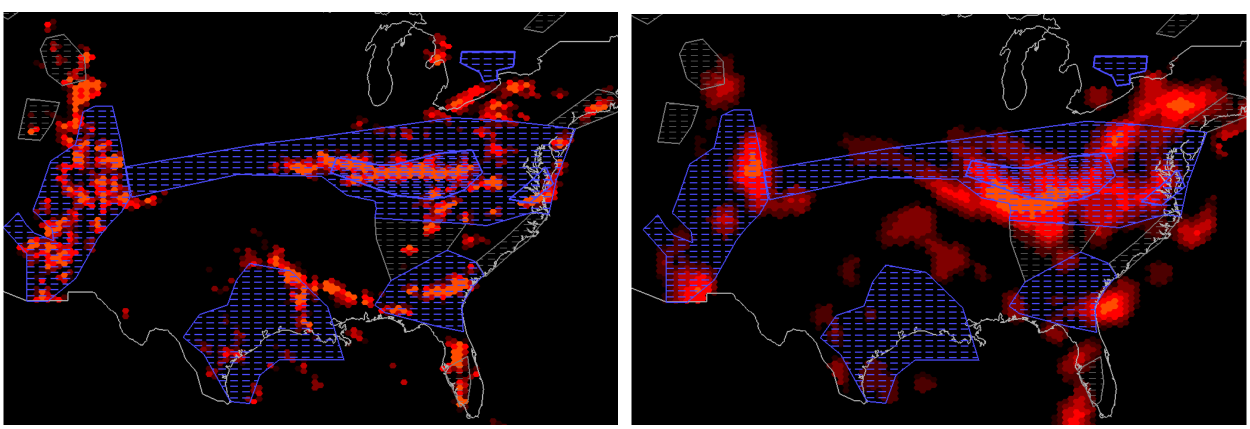


Figure 5: NCWD/CFFP (Left) and NCWF-6/CCFP (Right), 2200Z, July 19, 2007

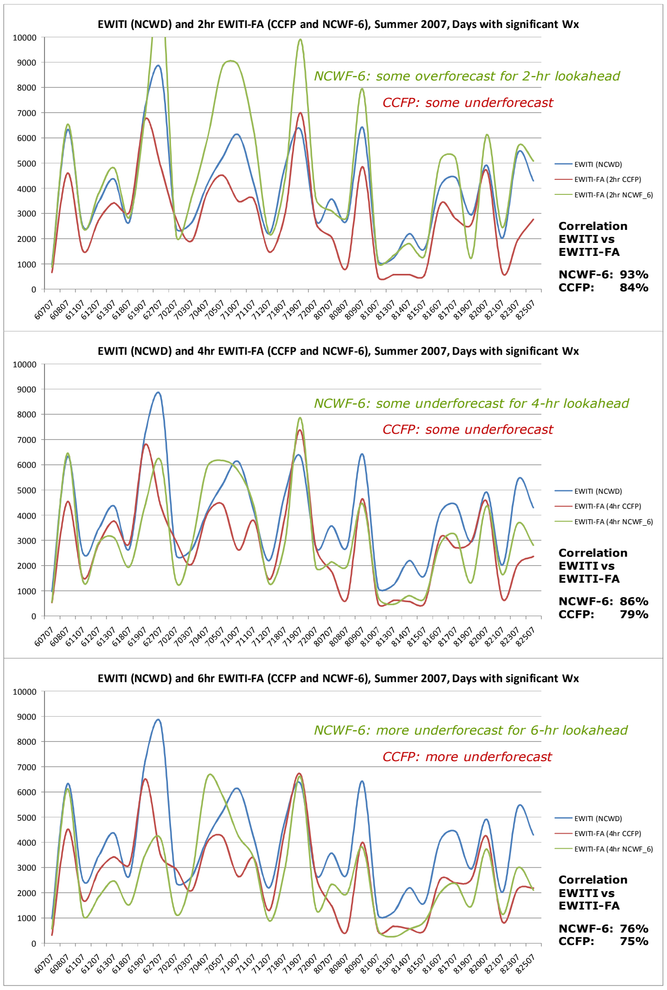


Figure 6: E-WITI and E-WITI-FA for CCFP and NCWF-6; 2-, 4- and 6-hr look-ahead (top to bottom)

hours. This is not unusual for the current generation of model-based forecast products.

Figure 8 shows the detailed estimates of directional airspace availability for one Center, in this case Indianapolis (ZID). Each data point is one direction (20-degree steps from 0 to 360 degrees), one hour between 11Z and 23Z.

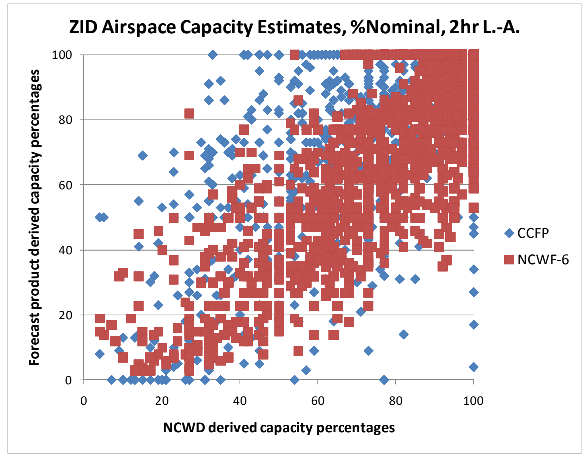


Figure 8: ZID Directional Airspace Capacity estimates by CCFP and NCWF-6, 2-hr look-ahead forecasts, vs. those obtained from NCWD

Another way of presenting the overload / under-load trends is to compute the average airspace availabilities for each Center, every hour and to sort them from worst weather impact to least. Such a chart is shown in Figure 9. The blue line represents NCWD (actual weather) based airspace availability estimates for ZID; all hours for 2007 summer days are sorted from highest NCWD impact to lowest (which is no impact at all, at right). Red chart (jagged) shows CCFP based airspace availability estimates for ZID for the same hours and a red polynomial trend line is added. Green chart (jagged) shows

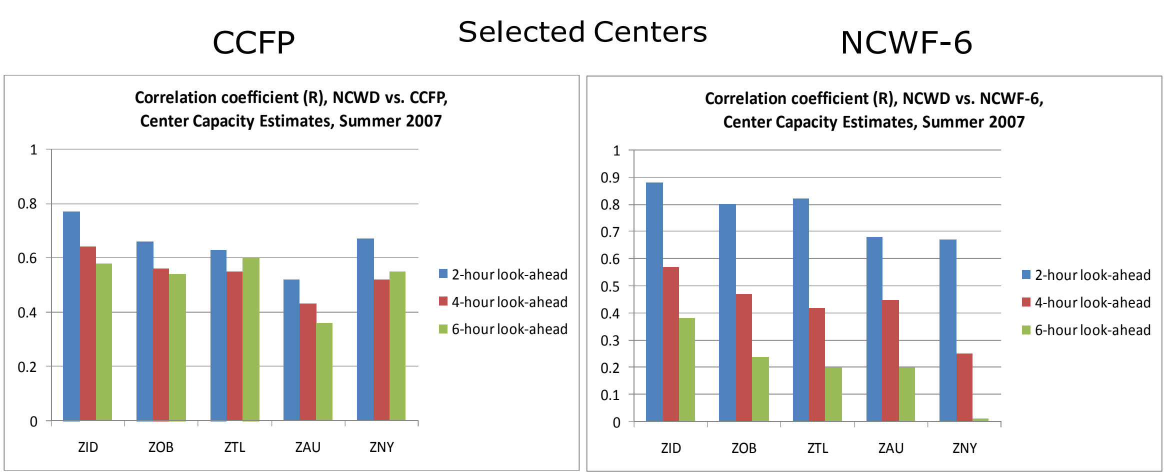


Figure 7: Correlation between directional airspace availability estimates computed from actual (NCWD) and convective forecast (CCFP, left, and NCWF-6, right) products.

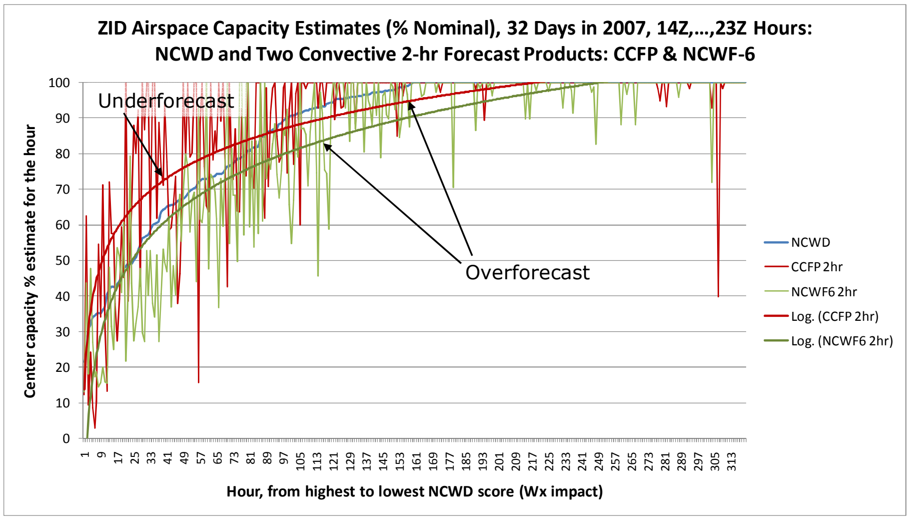


Figure 9: CCFP and NCWF-6 trend lines vs. NCWD, airspace capacity estimation, ZID, 2-hr look-ahead, 1400Z – 2300Z, 32 days in summer 2007

NCWF-6 based airspace availability estimates for ZID for the same hours and its green polynomial trend line is added also. The comparison of the NCWD chart and the two forecast trend lines is quite informative. When a forecast product trend line is above NCWD's, this indicates an under-forecast (more optimistic estimate of available airspace than derived from actual weather. A trend line being below NCWD's indicates an overforecast (less optimistic prediction of airspace availability than what has actually materialized). The position of the trend lines helps one to see the relative scale of under- / overforecast, as well as the forecast tendency when overall weather impact is high, medium or low.

3.3.2 RCPF

Rapid Update Cycle (RUC) Convective Probability Forecast (RCPF) is another model-based forecast product. Its data is provided on a 20-Km coordinate grid, as convective probabilities with 1-hr update frequency. In order to convert this data into quasi-NCWD scores, we compute the averages of these probabilities at 20-Km grid points that fall within each WITI hexagonal grid cell.

Figure 10 shows the convective situation at 2200Z on July 19, 2007 as derived from NCWD and RCPF, with CCFP overlay – compare this to Figure 5 (NCWD vs. NCWF-6).

The first impression is that RCPF probabilities tend to be higher than those obtained from NCWF-6 or CCFP. This is confirmed by E-WITI-FA based analysis. Figure 11 shows an example for 4-hr look-ahead forecast. While RCPF-based E-WITI-FA correlation with E-WITI is higher than that of CCFP-based E-WITI-FA's, the magnitude of RCPF-based E-WITI-FA is much higher.

Directional airspace estimate trend charts for selected ATC Centers, such as ZID (Fig. 12), echo this overforecast trend. Compare this to Fig. 9.

The WITI toolset and metric can be used in "what-if" capacity; one such application was prompted by this RCPF analysis. Several alternatives were proposed for tuning RCPF convective probabilities: for example, the original

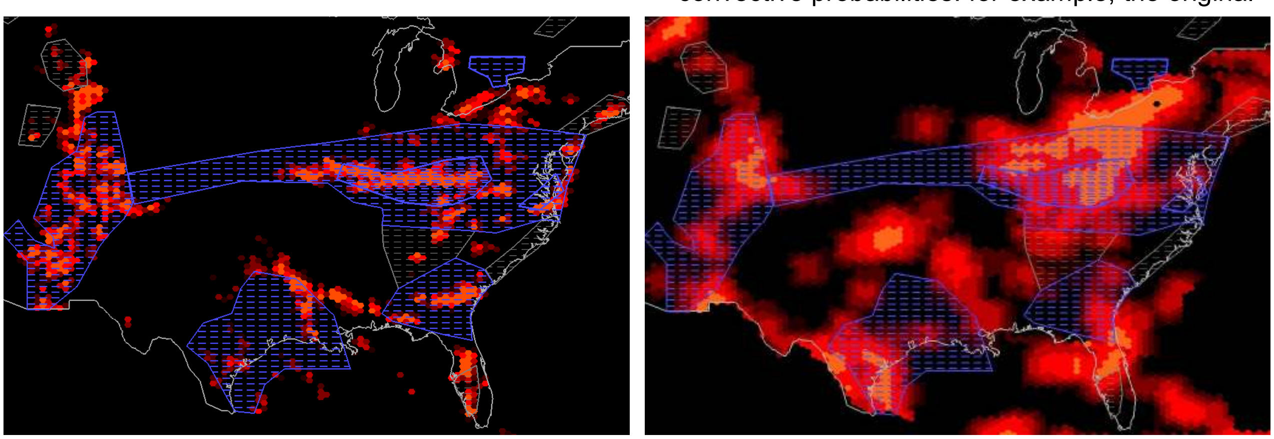


Figure 10: NCWD/CFFP (Left) and RCPF/CCFP (Right), 2200Z, July 19, 2007

probabilities could be reduced by a certain percentage, or shrunk in a certain proportion; or probabilities below a certain percentage could be ignored.

Figure 13 shows a sample result of this “what-if” analysis and tuning. After the original RCPF probabilities have been reduced by 30%, RCPF forecast trend is much closer to the NCWD line.

4 FROM ANALYSIS TO OPERATIONAL DECISION SUPPORT

4.1 WITI Use in Operational Environment

In potential future applications proposed in this section, WITI would be used as an indicator of predicted weather and traffic demand impact on a portion of the NAS. This builds upon the analytical applications of this toolset and metric presented earlier in this paper. WITI acts as a proxy for delays and, more broadly, proxy for excess operational costs. A decision support tool that ranks options from lowest to highest WITI score could be a reasonable – and fast – way to estimate possible delays and other excess operational costs and to select a course of action that minimizes them.

In operational environment, an evolution of WITI toolset would be used in a “rolling look-ahead” fashion or for on-request decision support computations looking *N* hours ahead. WITI would use a combination of actual weather data and a range of forecast products, e.g. CIWS (<2 hours ahead), CCFP (2-4-6 hours), NCWF-6 (6 hours) and/or others. It could possibly look at several different model sets to show

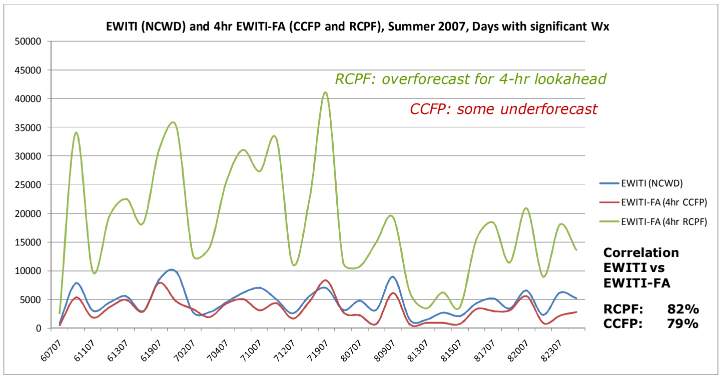


Figure 11: E-WITI and E-WITI-FA for 4-hr look-ahead CCFP and RCPF vs. NCWD, 32 days in summer 2007

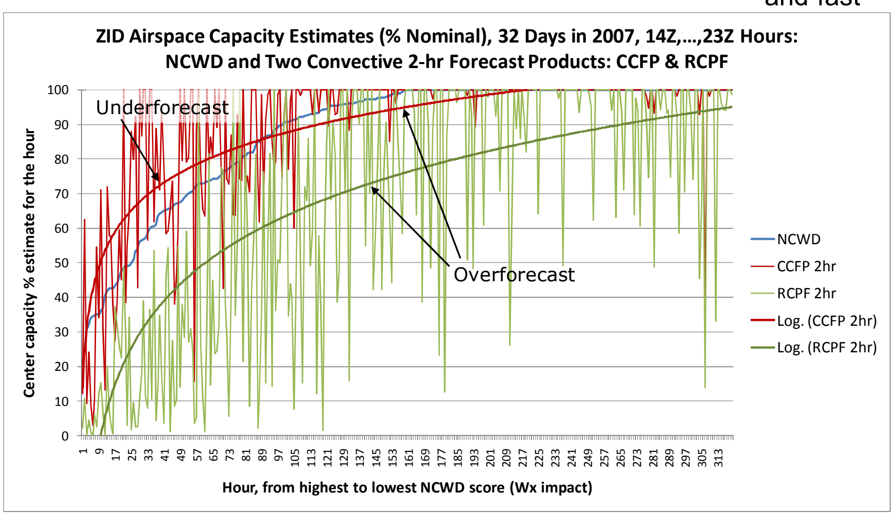


Figure 12: CCFP and RCPF trend lines vs. NCWD, airspace capacity estimation, ZID, 2-hr look-ahead, 1400Z – 2300Z, 32 days in summer 2007

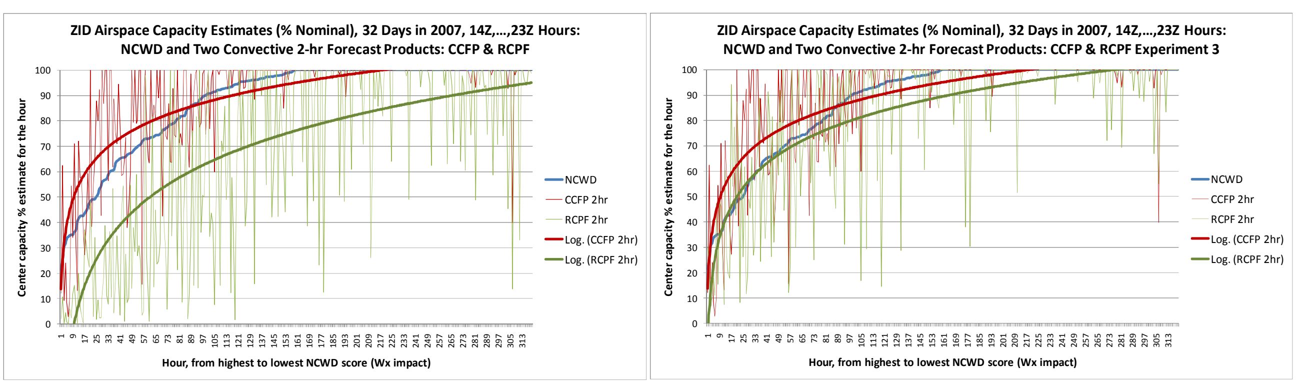


Figure 13: RCPF trend charts for airspace availability estimation vs. NCWD and CCFP: original RCPF probabilities (left) and RCPF probabilities reduced by 30 percentage points (right), ZID Center

the spread of results and perhaps a “centroid”. It would also account for increasing uncertainty of weather and traffic demand forecast as look-ahead time increases. Turbulence forecast could also be added to the WITI score computation.

4.2 Decision Support at the ATCSCC

One of the most important uses of WITI-FA could be at the strategic level of the NAS – at the Air Traffic Control System Command center (ATCSCC). WITI-FA could be used to quantify/characterize a given time period's weather impact and the severity of that impact based on the corresponding forecasts: CCFP and latest TAFs. A “0 to 5” scale for characterizing a given period's weather impact could be developed as follows: 5 - "Severely Weather Impacted" , 4 - "Moderately Weather Impacted", 3 - "Normally Weather Impacted", 2 - "Somewhat Weather Impacted" , 1 - "Minimally Weather Impacted" or 0 - "No Weather Impact". Of course, there is still much research to do to define appropriate WITI-FA ranges for each category. A ‘verification’ WITI / NAS Weather Index would be running in a continuous update mode, allowing the ATCSCC staff to both verify earlier forecasts and assess current impact of weather and traffic demand on the NAS.

4.3 *“Forecast Route WITI”: a Tool for Airline Dispatchers and Its Extensions to ATM Applications*

In this role, Forecast Route WITI (FR-WITI) tool would look at forecast weather impact along a proposed individual flight plan (4D) and compute a WITI score for each flight plan alternative. It would then create a list of flight plan options ranked from no weather impact to minor impact on passengers (e.g. light turbulence at most) to options that could impact safety. Fuel cost would obviously be a major consideration also.

The FR-WITI software would compute the NCWD or quasi-NCWD score along each flight plan alternative using a combination of forecast products with different look-ahead times. It would also take into account the deterioration in forecast accuracy as the look-ahead time increases. Figure 14 shows a notional example of a four-hour flight plan with three different route options and their respective forecast weather impact scores. The sample scale of WITI scores and respective impacts is shown at the top of Fig. 14.

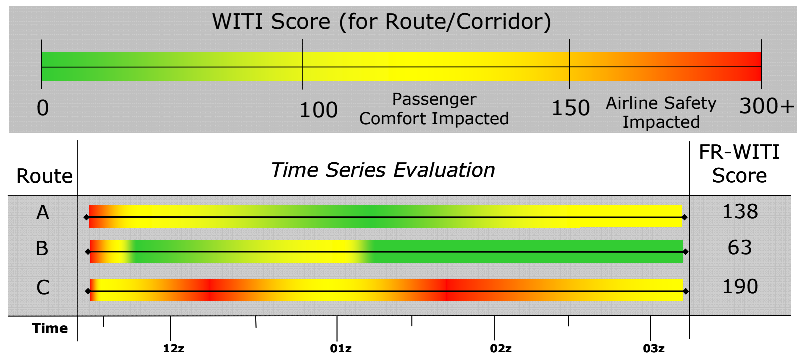


Figure 14. Notional illustration of Forecast Route WITI scoring and a list of three transcontinental route options.

4.4 *“Forecast TRACON WITI”: a Tool for Center/TRACON/Airport Managers*

As convective weather develops in the vicinity of an airport, the degree of its impact is dependent upon both the distance from the airport as well as its position relative to the arrival fixes, departure fixes, and active runway(s).

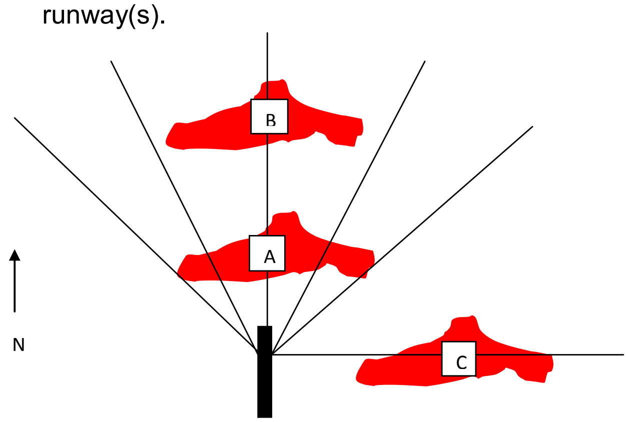


Figure 15: Notional convective weather in airport vicinity and radial scan (“sweep”) lines

Figure 15 illustrates the following methodology. Assuming traffic is landing to the south on the north/south runway, it is evident that cell A will have more impact than cell B. Both cells lie within the same quadrant but cell A occupies a greater portion of the horizon. This can be determined by scanning the airspace with radial lines emanating from the center of the airport; the total slope for each departure or arrival fix might be, say, 45 or 60 degrees and might include, say, 10 scan lines. In Fig. 15, more radial lines intersect cell A than cell B. While cell C is the same distance from the airport as cell A, its impact is less due to its position relative to the active runway. In this case the radial lines that are in the same quadrant as cell C are given less weight than the radial lines in the quadrant to the north of the runway.

TRACON WITI can be computed as a sum of “departure and arrival fix WITIs”. Each is determined as

$$W = \text{Traf\_perc} * N_{\text{permeate\_Wx}} / N_{\text{total}}$$

where Traf_perc is the proportion of traffic handled by this fix during a given time interval; and $N_{\text{permeate\_Wx}}$ / N_{total} is the ratio of the number of scan lines that can permeate the convective weather vs. the number of radial scan lines inside the overall slope emanating from the airport and allotted to a particular fix.

To provide a forecast of expected degradation in airport capacity, it will be necessary to adapt WITI to ingest weather forecasts on a near-real time (operational) basis. Various forecasts will be used depending upon how far into the future the TR-WITI is being computed. Short term forecast times will be handled with deterministic forecast input while longer time periods will be handled with probabilistic forecast input.

4.5 WITI for Principal Fixes (“Fix-WITI”): a Tool for ATC Centers

There are periods during the day when en-route fixes become heavily impacted by traffic. As these fixes are identified, traffic flows over the fixes must be examined to determine which portions of the airspace surrounding the fix are impacted the most, and at what periods of time. Figure 16 gives an example of an actual en-route fix (MAYOS) in the Washington Center where large volumes of traffic converge several times a day as they are sequenced into a single stream for arrival to the Charlotte airport. Most of the traffic originates at the northeastern airports. When the airspace containing Mayos becomes obstructed, traffic management initiatives (TMIs) can cause delays as far north as Boston Center. Traffic flows in the vicinity of such fixes must be analyzed and weights given to the radials emanating from the fixes (see Fig. 16). This is analogous to TRACON-WITI where traffic volumes over departure and arrival fixes will be determined.

Fix-WITI could therefore be created as an extension of TRACON-WITI, which is also designed as a decision support tool for air traffic planners. Its function will provide a forecast of the degradation in capacity of airspace surrounding fixes in the NAS that are typically impacted during known periods of the day.

When heavily used fixes are blocked by weather, alternative routes are typically employed. Along with these alternate routes are their associated fixes which then become impacted with traffic. As Fix-WITI is expanded throughout the NAS, it will be able to provide a forecast for the degradation in capacity for each of these fixes and from that provide a ranking of weather impact. This will assist the traffic planner in performing an objective evaluation of traffic rerouting alternatives.

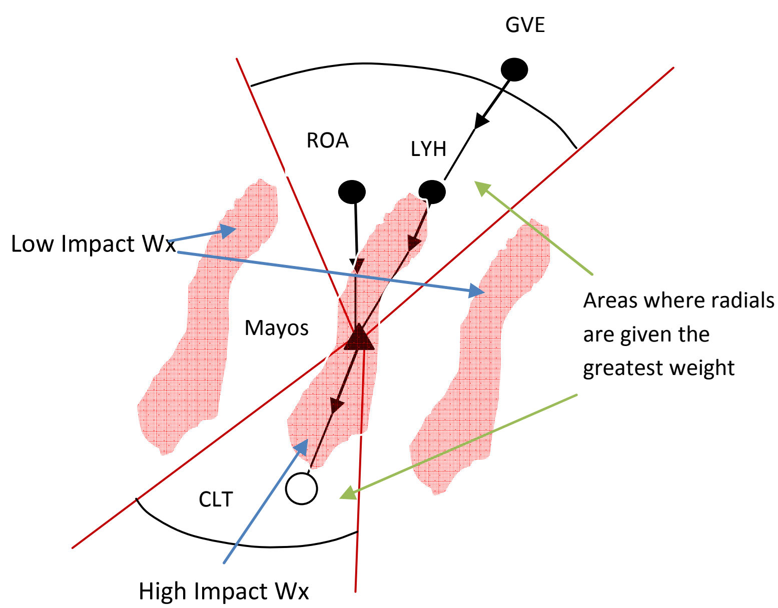


Figure 16: Traffic flows and notional weather around the Mayos fix

5 CONCLUSIONS

The well-established WITI metric has been extended to utilize forecast rather than actual weather as WITI-FA ("Forecast Accuracy") counterpart of WITI. In addition to its use as an indicator of forecast weather impact on the NAS, WITI/WITI-FA and its supporting elements, such as the scanning algorithm, have been applied to operational-impact evaluation of various convective forecast products. As we move from less-frequent (e.g., weekly or ad-hoc) post-operational evaluation to more frequent, e.g., daily, WITI/WITI-FA processing, this takes us a step closer to near-real-time operational use. A number of WITI method extensions have been proposed; it is hoped that advanced prototypes can be built and tested, and that a decision support toolset based on WITI/WITI-FA will ultimately be of use to traffic flow managers and planners in their daily operations as well as in post-operational assessments.

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