Geographical Weather-Impact Sourcing: Analytical and Data-Driven Approaches

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Abstract: The problem of weather-impact sourcing, i.e. identification and ranking of upstream National Airspace System (NAS) resources whose traffic flows are significantly impacted or modulated by a weather zone, is conceptualized. A historical case study is presented to gain insight into the geographical pattern of weather-impacted traffic. Based on these insights, we argue that highly simplified representations of air traffic and weather may be sufficient for weather-impact sourcing, and briefly introduce data- and model-driven techniques that may be promising for rapid sourcing.

I. Introduction

Weather events (including convection, winds, icing, turbulence, snow) regularly disrupt and constrain the operation of the United States National Airspace System (NAS), and as such are a primary cause of performance degradation (e.g., increased delay, risk, and/or cost). Management of the air transportation system — whether via short-term tactical decision-making, strategic shaping of flows, or long-term system planning — therefore requires understanding the impacts of weather on NAS dynamics and parameters. In studying weather impact on NAS performance, researchers have long realized that the geographical location of a weather event critically impacts the extent of its impact. To better understand how weather in different parts of the airspace can differently impact NAS performance, analysts have sought for simple techniques for measuring the impact of weather based on its location. One technique that has been gained prominence in recent years is to estimate impact based on the intersection of weather severity and traffic density (i.e., based on multiplied or overlaid weather severity and traffic). This approach highlights airspace components with both high traffic and severe weather, and has shown promise as a predictor of NAS performance measures (total delay, chance of capacity violation, etc).

While weather-traffic overlays are good indicators of total weather impact, they do not immediately indicate all NAS components whose operations are impacted by the weather, nor do they allow easy identification of resources that should be brought to bear to resolve weather impact. This is because the traffic flows constrained or modified by the weather also traverse other airspace-system components/resources (including origin and destination airports, and Sectors and Centers distal to the weather event). These other NAS components are thus also impacted by the weather constraints, i.e. the weather causes a spatio-temporal ripple in airspace flows. To effectively manage traffic bottlenecks due to weather (for real-time decision-making or planning), it is necessary to identify traffic flows and resources across the NAS that are modulated by the weather constraints. Upstream resources traversed by the affected traffic flows, including origin airports and upstream Sectors and Centers, are particularly important since management efforts require constraining or modifying flows at these resources.
In this article, we discuss our initial efforts to characterize the ripple effects of weather events using highly simplified metrics and measures. Specifically, we begin to develop geographical characterizations of the sources (upstream components and resources) of weather-impacted traffic, or in other words the upstream ripple caused by a weather event, to facilitate management of traffic flows. In particular, we seek to develop measures as well as simple model- and data-driven tools for gaining simple geographical insights into the sources of weather-impacted traffic. We also briefly discuss how these weather-impact sourcing studies can be used to assist real-time management and traffic planning, via sensitivity analyses. It is important to stress that our efforts here are very preliminary, focusing on introducing metrics and potential techniques for rapid weather-impact sourcing rather than on presenting a verified or validated approach.

II. Current Practice and Background Literature

Management and planning of traffic flows across the NAS must account for weather hazards ranging from convection to winter weather and high winds. These weather hazards reduce airspace capacities, primarily because they increase the extent of human supervision required and hence increase controller workload. They also reduce airport arrival and departure capacities because larger inter-aircraft spacing is needed for safe operations. The reduction in airspace and airport (runway) capacity due to weather hazards can incur significant delay and extraneous cost, and in fact weather events are the primary cause for delay in the NAS. Certain weather hazards (e.g., icing, turbulence) may also directly increase safety risks. Real-time management of air traffic flows across the NAS to mitigate weather impact is coordinated daily by the Air Traffic Control Strategic Command Center (ATCSCC), which interacts with the Air Route Traffic Control Centers (ARTCCs or simply Centers) and the airlines to develop and implement strategic and tactical management plans. At longer time horizons of months to years, traffic flows and management capabilities may be refined to address recurrent weather-related concerns, such as stratus-related delays for flights into San Francisco International Airport (SFO) or severe weather-related congestion in Cleveland Center (ZOB). NAS-wide management and planning of traffic to alleviate weather impact is challenging, because of the inherent uncertainty in weather propagation, and the large scale and complexity of the NAS, among other factors. As such, decision-making to resolve weather impact remains largely a manual process, which depends on the experience of traffic-control personnel and a degree of guesswork and intuition.

As the air transportation system becomes increasingly congested and stressed, decision-support automation is increasingly needed to assist the human decision-makers in traffic management and planning. In recent years, air transportation engineers have developed numerous models and analyses that allow evaluation of weather impact on traffic, and are developing software tools that inform decision-making by leveraging these models [1-3]. A comprehensive review of these efforts is outside our scope. However, we stress that models at several resolutions for weather and traffic, and their interface, have been developed.

With regard to weather modeling, several recent studies have leveraged ensemble forecasting products to generate stochastic futures of weather or weather-impact on NAS parameters [4,5]. These ensemble forecast-based approaches are appealing because they give an indication of the possible variability in weather, and hence aid in developing decision-support capabilities. The ensemble-forecast-based models have served as a starting point for meshed modeling and analysis of weather and traffic.
Air transportation engineers are pursuing research along two thrusts, toward achieving meshed analysis of weather and traffic. First, a major research thrust is concerned with developing detailed models for traffic that can be meshed with weather models, to capture traffic evolution under uncertain weather propagation. With regard to detailed modeling of traffic, many detailed simulation tools are available that track the movement of individual aircraft through the airspace (e.g., [1]), however these simulation models are often computationally intensive, unwieldy to interface with weather-propagation models, and at the wrong resolution for capturing management initiatives. Recently, several flow-based models for traffic have been proposed as alternatives to the aircraft-tracking models [3]. These flow-based models are appealing in that they can reduce the computational cost of simulating traffic and also capture demand uncertainty, while forecasting traffic with sufficient accuracy for flow management and planning. Used in tandem, the weather and traffic models can permit evaluation of weather impact on traffic flows across the NAS, including estimation of delays, congestion, and workload. While these modeling approaches are promising for evaluating weather impact, managing and planning traffic flows across the NAS remains challenging: model simulations under weather uncertainty are computationally expensive (even for the more abstract flow-based models) and formal analyses are difficult to obtain, thus making design using the models cumbersome. From the perspective of our study here, we stress that the detailed traffic models (when meshed with weather-forecasting tools) are able to capture in detail the ripple effects of many weather events, however they are often too complicated to permit NAS-wide design and also they often do not naturally identify impact locations and measure/rank the extent of impact. Because the models are computationally taxing, performance evaluation under significant weather and demand uncertainty can also be challenging. As such, these models may be better suited for refinement and evaluation of designs for particular weather futures, rather than initial NAS-wide planning of flow management capabilities across possible weather futures.

As an alternative to the traffic-simulation-based approaches, techniques for approximating weather impact based on highly abstracted measurement of weather-traffic interaction have also been proposed. A prominent approach of this sort for measuring weather-traffic interaction is based on overlaying weather and traffic on a map to compute impact. Formally, the intersection of weather severity and traffic density – or, more specifically, the product of weather severity and traffic density integrated over an airspace region – is used as a crude measure for total weather impact on traffic [6,7]. This simple impact measure, which is often termed the Weather Impacted Traffic Index (WITI), is a surprisingly accurate predictor for regional and NAS-wide traffic impacts such as total delays caused by the weather. In sharp contrast with the simulation-model-based approaches, the WITI permits low-computational-cost analysis from historical data or baseline simulations, as well as statistical analysis given weather forecasts. However, the WITI simply measures total weather impact, and abstracts away all details about the traffic flows that are impacted; as such, it does not naturally facilitate management and planning of traffic flows to mitigate weather impact.

Our studies here on weather-impact sourcing seek a middle ground. We seek to replicate the simplicity of abstract weather-traffic interaction measures like the WITI, while providing basic information on impacted flows and resources (i.e., on the ripple effect) so as to inform traffic management and planning. In the following sections, we will first discuss goals and metrics for weather-impact sourcing. We will then describe several possible data-driven and/or model-driven techniques for weather-impact sourcing, including illustrative examples for some of the techniques.
III. Goals and Metrics in Weather-Impact Sourcing

Our primary goal in weather-impact sourcing is to gain a rough understanding of upstream resources, including airports, airspace regions, and routes, that are likely to be impacted by a (forecasted or known) weather event. In particular, we seek to generate ordered lists of the 1) major airports, 2) Sectors, and 3) major flows/routes that are most significantly impacted by the weather event, as well as simplistic numerical measures of the extent of impact. We stress that we do not seek detailed characterizations of local or aircraft-specific performance measures such as delays, workload, congestion, etc, that would be provided by a detailed simulation model. Instead, we seek for simplistic methods that allow rapid, system-wide identification of significantly-impacted resources and simple characterizations of the impact.

For the purposes of our study, we define significantly-impacted resources conceptually as ones whose traffic flow patterns are modified from their nominal values by a significant amount with sufficient probability. Specifically, we note that NAS resources – including airports, airspace regions, and routes – have traffic flows associated with them (i.e., groups of aircraft traversing the resource as they transit from origins to destinations) whose rates and compositions vary with time. Weather disturbances modify these flow rates and compositions by imposing capacity constraints downstream, forcing rerouting of flows, etc. The extent to which the flows are modified is a measure of the impact of the NAS resource. As a particular measure, the integrated absolute difference between the nominal flow rate and the flow rate upon disturbance can be used as a measure of impact: resources for which this metric exceeds a threshold, or does so with sufficient probability, can be labeled as significantly-impacted resources. We notice that such flow-change-based metrics naturally capture the ripple effect of weather, since flow patterns will be changed at upstream resources (including origin airports and upstream routes/Sectors) whose flows impinge on the weather-constrained zone.

The measure defined above (or its statistics, if there is forecast uncertainty) is a natural numerical characterization of the weather impact on the resource. We also expect this numerical measure to be strongly correlated with airspace-performance-related measures, such as the total or en route delay incurred on aircraft passing through the resource, and congestion or potential workload excess caused by the weather event at the resource. The weather-impact measure is also potentially indicative of the need for and strength of management initiatives to resolve weather-based congestion. With these connections in mind, we focus on methods for approximating or estimating the impact on flows of weather constraints according to this measure.

IV. Approaches for Weather-Impact Sourcing

We have begun to explore several model- and data-driven- approaches for identifying sources for weather-impacted traffic, i.e. for identifying and ranking upstream resources traversed by key weather-impacted flows. The challenge that we face is to develop simple and computationally efficient techniques for approximating the flow-impact measures defined in the previous section. In particular, we seek for approaches that do not require detailed simulation of traffic throughout the NAS, yet give insight into the ripple effect caused by weather events.

To motivate the proposed weather-impact sourcing approaches, we find it instructive to first present a historical case study, which gives an indication of the geographical scope of weather impact. We focus on a tropically-driven convective weather even in the Southeastern United States on September 26,
2010. This example, which has been the focus of several studies on strategic traffic management, involved a long-duration nearly-stationary band of convective weather across the Atlanta Air Route Traffic Control Center’s airspace (abbreviated as ZTL). The convective weather significantly altered arrival and departure operations at Atlanta’s Hartfield Jackson International Airport (KATL), also impacting other regional airports’ operations for part of the day (e.g., Birmingham, Charlotte) and constraining en route traffic within ZTL.

![Impact Map](image)

**Figure 1:** A case study of the geographical impact of a long-duration convective weather event in ZTL on September 26, 2010 is presented. The above map shows the convective weather zone, and plots airports whose on-time departure percentages were depressed by at least 7% from their average for September 2010. The size of the circle for each airport represents the size of the anomaly in on-time departure percentage; circles for airports with greater than 10% decrease are also colored yellow, for emphasis. The map highlights that the weather event incurs significant impact outside the critical weather zone, especially in the highly congested Northeastern United States.

Here, to get an indication of the geographical scope of the weather event’s upstream ripple effect, we study anomalies in departure delays at airports across the NAS on the day of interest. Specifically, in Figure 1, we identify and locate the airports whose on-time departure rates are most significantly depressed, compared to the historical average. Specifically, we have computed the difference between the average on-time-departure percentage during September 2010, and the on-time departure percentage on the day of interest (September 26, 2010). Figure 1 locates all airports for which this on-time-departure anomaly is over 7%, with the size of the circle for the airport reflecting the size of the on-time-departure percentage anomaly. We note that airports for which the anomaly is over 10% are indicated with a filled circle, as locations with significant or major impact. The primary convective-weather zone is also indicated on the figure. Several characteristics of the ripple effect of the weather event are evident in Figure 1. First, we see that flows from terminals subject to direct weather impact
are indeed significantly impacted, leading to degradation in on-time performance. While the most significant degradation is in the weather zone, however, airports throughout a much large area have flows modulated by the weather impact: significant performance degradation results to the southeast, northwest, and northeast of the convective-weather zone. It is worth stressing that these impacted terminals are proximate to the weather zones: all are in the Eastern United States, with airports within three hundred miles of the convective weather particularly significantly impacted. The example also highlights that the geographical ripple effect is disproportionate in the Northeastern United States, which is highly congested under nominal weather conditions and highly prone to traffic disruption.

**Figure 2:** As a further characterization of weather impact in the case study, aircraft whose flights were anomalously constrained by TMIs are shown (using unshaded red circles), in addition to the airports with depressed on-time departure fractions (using filled yellow circles). Large airports in congested airspace that are proximate to the weather zone (e.g., LGA, DCA, and DFW) were particularly subjected to departure constraints.

To further delineate the ripple effect of the weather event, we have also located the airports whose departure flows were anomalously subjected to departure constraints to meet TMI requirements (including Airspace Flow Program rates and Ground Delay/Ground Stop program requirements). Specifically, we have computed the anomaly in the number of departure flights subject to Expect Departure Clearing Time (EDCT) constraints on the day of interest, compared to the month-long average. In Figure 2, we have overlaid a map of airports with anomalous EDCT constraints over the on-time-departure-performance anomaly map: specifically, airports with 8 or more constrained flights compared to the monthly average are indicated using red circles. We see that the airports subject to departure constraints are not the ones in the weather zone, but most are relatively close to the weather zone (and hence sources of significant traffic that would intersect with the convective weather). It is worth pointing out that large hub airports and airports in the Northeast corridor of the United States were
particularly subject to departure constraint, including New York’s Laguardia airport (21 more constrained aircraft than on average), Washington’s Reagan National Airport (14 more), and Dallas Fort Worth International Airport (13 more). Thus, we see that the ripple effect was particularly significant at large terminals, and for congested airspace.

The case study that we have presented illustrates the geographical scope of the impact of a weather disturbance, in this case a meso-scale long-duration convective-weather event. In particular, the example suggests that traffic flows (including specifically arrival and departure traffic) in a region around the weather zone are significantly modulated by the weather, with particularly long-range and anomalous effects in nearby congested airspace. The case study primarily focuses on departure flows; unfortunately, data on en route flows and Sector counts is more complex to extract from records, but we conjecture that similar relationships would be seen: flows in proximate and nearby congested airspace would be significantly modulated by the weather event. We also leave for future work a study of the temporal progression of the ripple effect; model-based studies suggest that congested airspace is particularly prone to extended impacts.

The case study suggests that simple geographical and congestion-related considerations can provide significant insight into the ripple effect of weather events. We are pursuing strategies for weather-impact sourcing that leverage these simple insights. Specifically, we are taking the approach that highly abstracted models rather than detailed traffic simulations can be used to obtain simple geographic insights into weather-impact sources. While these approaches will not permit detailed characterization of local performance, they can potentially allow rapid identification and ranking of impacted resources – which is our primary goal in weather-impact sourcing. In particular, we are exploring three abstract modeling approaches for weather-impact sourcing, including one data-driven approach and two simplified-model-based approaches. Our studies of these approaches are in their initial stages, and so we focus primarily on a conceptual description of the approaches. For the second of the three approaches (which is based on an Eulerian traffic model), we also briefly discuss initial simulation-based and analytical results. Here are the three approaches:

1) **A Data-Driven, Regression-Based Methodology**: In our simplest approach, we postulate that the flow impact measure for each NAS resource, as defined in Section III, is functionally dependent on a small set of parameters. We thus consider regression of the measure in terms of these parameters. Specifically, we consider regression of the flow-impact metric in terms of the following: 1) the mean distance of the resource of interest (airport, Sector, etc) to the weather zone; 2) the total intersection of the weather with traffic, as measured by the WITI; 3) the total traffic passing through the resource; and 4) the average congestion level of the resource. We note that these parameters can be extracted from historical data sets, and anomalies in traffic flow patterns (as measured in e.g. changes in on-time-departure rates) can be tabulated as the flow-impact measure. These data sets can then be used to construct the regression. We are just beginning the process of developing the regression, and so leave specification of the functional form to future work. Broadly, we expect an inverse dependence of impact on distance, and a positive dependence on the other three parameters (the WITI, the traffic density at the resource, and the congestion at the resource).

The simplicity of the regression methodology is appealing, and a developed regression will likely be easy to validate using test data. Also, once the regression is developed, statistical characterizations of the impact measures should be easy to find given stochastic forecasts since the regressors can be computed straightforwardly from the forecasts and nominal information on flows. However, the method cannot
provide much insight into the relationship between the network’s structure and weather impact patterns, does not give insight into the dynamics of the ripple, and cannot distinguish impact to different origin-destination traffic contributing to a flow. The method also potentially may require a significant data set that captures the rich diversity of impactful weather events.

2) A Linear Eulerian Model-based Approach: Several linear Eulerian models for air traffic, i.e. aggregate linear models that track aircraft densities in airspace regions and at other NAS resources, have been developed [8]. These Eulerian models, whose dynamics are similar to simple linear circuit models, are too simplistic to provide detailed forecasts of local traffic-flow characteristics. However, the Eulerian models have been shown to be abstractions of more detailed queueing-type models of the air traffic system [9]. We believe that they are sufficiently detailed to achieve the identification goals of weather-impact sourcing. At the same time, because of their linear and networked structure, the models easily permit statistically analysis of ripple effects due to local topology modifications (corresponding to weather impact), as well as geographical characterization of these ripples. Eulerian models at several different abstraction levels potentially could be used for weather-impact sourcing; in each case, an analysis of flow changes due to weather-dependent topological modifications would be used to identify impacted. Here, we discuss one approach, which is based on multi-layered network in which each layer captures all flows to a particular destination.

The model that we consider here captures abstracted flows at the resolution of Sectors (specifically, between Sector boundaries and, if desired, an abstract waypoint in the middle of each Sector). Each layer of the network captures traffic flows from all possible origin airports to a single destination. These traffic flows are modeled as traversing the defined links along a directed network to the destination; at waypoints where flow splitting is possible, a fraction of the incoming traffic to the waypoint follows each available link. Formally, the model represents the (possibly time-varying) origin and destination flow rates, the traffic flows on each link, and the total incoming and outgoing flow at each waypoint or Sector boundary. At each waypoint and Sector boundary, flow conservation is assumed. We refer the reader to the literature (e.g., [8,10]) for formal mathematical descriptions of Eulerian models of this sort. Of relevance to our development here, these Eulerian models for traffic flow can be equivalenced or approximated with linear circuit models. In particular, aggregate or steady-state operations may be represented using resistive circuit models with the following components: 1) current sources representing origin airports, with the current injection representing the flow rate; 2) a single current drain representing the destination airport, with the drawn current capturing the total arrival rate at the airport; 3) resistors representing the abstract traffic-flow links between Sector waypoints and boundaries, with the resistances set to properly capture the flow fractions at splitting waypoints. We note that the current flows on the resistors in the circuit indicate traffic flow rates in the Eulerian traffic model, while the voltages (or voltage differences) give an indication of flow constraint or latencies incurred on links or on flows from origin airports. If transient analyses are required, time-varying current sources and drains, along with capacitive models to approximate traffic dynamics at waypoints, can be used.

The circuit equivalence to the Eulerian model is appealing because it can permit rapid simulation and, possibly, formal graph-theoretic analysis of stochastic weather impacts. Specifically, weather events can be modeled as modifying a nominal circuit model. Most weather events will be represented as (deterministically or probabilistically) increasing resistances in a local subnetwork, reflecting the additional constraints on traffic flow in the weather zone. The circuit model then permits characterization of weather impact on traffic flows, by allowing calculation of flow modifications relative
to the nominal model throughout the airspace system. Specifically, the model permits approximation of aggregate or transient weather impact on a variety of NAS resources, including: 1) flow changes on a single link, corresponding to traffic to a single destination or summed over all destinations; 2) total flow modifications within a Sector; and 3) total impact on flows destined to (or originating from) each airport, as measured by the disruption in these flows from their nominal values throughout the airspace system; among many other measures. The impact of both deterministic (known) weather events and stochastic scenarios on each resource can be characterized easily, either via a formal analysis or via rapid simulation. Thus, the model naturally permits characterization of the ripple-effect of weather disturbances and, specifically, weather-impact sourcing. We also stress that, since only rough identification/estimation of impact is sought, the Eulerian network model and its circuit equivalent can be constructed a priori from historical traffic data.

We are just beginning to explore weather-impact sourcing using the Eulerian model and circuit equivalence. Here, we include a simple constructed example, to illustrate how the Eulerian model can be used to characterize weather impact on traffic flows, and to demonstrate that the model yields plausible predictions. We focus here on an aggregate or steady-state analysis rather than a dynamical one. The example comprises a network with 100 flow splitting/merging waypoints (see Figure 3), with links between nearby waypoints illustrated with blue lines in the figure. We consider one layer of the Eulerian network model, capturing flows to a single destination airport, indicated by a black diamond in Figure 3 (see the top right part of the figure). We assume that traffic to the destination may originate from 30 airports, indicated by green squares in the figure; the traffic flow rate from each origin airport to the destination is selected according to a uniform random variable. For the sake of illustration, we consider a highly localized and deterministic weather event that closes one link, indicated in black on Figure 3.

**Figure 3:** An Eulerian model for air traffic flows to a single destination airport (black diamond in the top-right part of the figure), originating from 30 airports. We illustrate using the model for weather-impact sourcing, for a weather-disturbance that closes one link (shown in black).
Weather-impact sourcing for the example network is illustrated in Figure 4. We have used the circuit equivalent of the Eulerian model to estimate flow changes on each link compared to the nominal, as well as changes in latency/constraint on aircraft departing from each source (as reflected in a changed voltage in the circuit equivalent). Links and origin airports that display significant weather impact (i.e., absolute flow changes above a threshold) are shown in red in Figure 4. The analysis shows that links near the weather-constrained one are significantly impacted, including especially the sparse links to the South of the weather constraint that have high traffic densities. Similarly, origin airports near the weather zone – particularly, airports whose flows need to cross the weather zone to reach the destination – are significantly impacted. We note that the geographical distribution of resource impacts predicted by the model appears to match the impacts observed in historical data, and hence we believe that the Eulerian modeling approach is promising. However, we caution that we have only pursued a preliminary simplistic analysis of an illustrative example, and much more exploration is needed on the proposed approach.

![Sourcing: Significant Impacts](image)

**Figure 4:** Weather-impact sourcing using the Eulerian flow model. Links whose flows are significantly changed, as well as airports whose departure flows are subject to modification or added latency, can be found easily. These significantly-impacted traffic flows are indicated in red on the figure. We note that links that are close to the weather-impact zone, and nearby origin airports that are separated from the destination airport by the weather zone, are significantly impacted.

3) **A Route-Based or Multi-hop Modeling Approach:** One limitation of the Eulerian modeling approaches is that route structures are not maintained. We are beginning to study extensions of basic Eulerian
models that maintain routing patterns, which are similar to multi-hop-type models for communication systems. We believe that these route-based models, which can also be viewed as abstractions of queueing models with defined origin-destination pairs, can permit improved weather-impact solution without incurring too much extra computational cost. We leave a careful study of route-based models to future work.

V. Future Work: Applying Weather Impact Sourcing

In this article, we have conceptualized a new functionality in air traffic network analysis, which we term weather-impact sourcing. Specifically, we have motivated the problem of identifying NAS resources upstream to a weather zone whose flows are significantly modulated by the weather event. We have also described promising techniques for rapid weather-impact sourcing using highly simplified analytical or data-driven models, which may be able to overcome the computational challenges associated with sophisticated air-traffic-system simulation. We have thus far largely developed these techniques at a conceptual level (with a few illustrative examples included), and a great deal of work remains to develop and evaluate the techniques in full (as we have pointed out at various points in this document). Equally important, however, is to make concrete the potential uses of weather-impact sourcing in real-time flow management as well as traffic planning. Here, let us briefly overview some potential applications of weather-impact sourcing in both traffic management and planning:

1. We envision using weather-impact sourcing to identify areas of interest for strategic traffic management, that indicate geographic regions wherein traffic flows may be modulated by weather and management capabilities may be needed. Such areas of interest could be directly used by traffic managers at the ATCSCC to help scope strategic management needs early on the day of operation or on the previous day. Identifying areas of interest can also aid in developing multi-resolution flow models, which can permit reduced-computation simulation of NAS-wide traffic for strategic traffic management (see e.g. [3]).

2. Weather-impact sourcing can be used generate lists of NAS resources that may be significantly impacted by a forecast weather event, perhaps along with impact statistics. These lists could be used by ATCSCC personnel to facilitate strategic management, and also could be distributed to the Air Route Traffic Control Centers to provide forewarning of potential weather-related impacts.

3. Weather-impact sourcing using the Eulerian model, in particular, potentially can be extended to allow selection or pruning of TMIs for strategic traffic management. Specifically, we envision modeling potential TMIs as additional, designable constraints in the air traffic system. TMIs that are most efficient at modulating weather impact can then be determined, using a sensitivity analysis: effective TMIs are ones that change flow profiles at significantly-impacted resources.

4. We also envision using weather-impact sourcing to identify common congestion points (or “choke” points) for long-range (months-to-years) planning of NAS traffic, and in turn to evaluate possible resolutions to congestion concerns. Weather-impact sourcing is appealing for this purpose because fast evaluation of impacted resources over a large family of weather events is possible, and hence commonly-impacted resources can be identified.
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References


