Estimation of an En Route Weather Severity Index
Using Lightning Strike and Flight Plan Data

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Ongoing and proposed studies of National Airspace System (NAS) operations hope to quantify its performance in order to gauge the impact of new equipment and procedures, and potentially to establish organizational performance goals. The ever-changing nature of the environment in which we operate, particularly variations in weather, makes comparing different periods of time problematic. Methods are needed to normalize for these effects, so that we may make more accurate assessments of system performance and more informed decisions.

A method has been developed to estimate the severity of en route weather relative to air traffic. We have created an en route weather severity index, which may be used in NAS operations analyses to normalize observed results for changes in en route weather. We have assumed that convective weather is the principal en route weather hazard, at least for airlines operating turbine aircraft. For many years a network of sensors has recorded all cloud-to-ground lightning strikes throughout the nation. This data has been archived by Vaisala-GAI Inc., and may be readily used for analysis [1]. The proposed En Route Weather Severity Index is derived from this lightning strike data and Enhanced Traffic Management System (ETMS) flight plan data. Our index is similar to one previously proposed by researchers at MITRE/CAASD [2] know as the Weather Impacted Traffic Index (WITI). The differences between the two approaches are discussed at the end of the paper. Our approach essentially scales the lightning strike data by the number of flights that had *planned* to be in the vicinity of the lightning. Flight plans are used rather than actual tracks since most aircraft will have maneuvered or been delayed in order to avoid thunderstorms. Initial flight plans, on the other hand, should reflect where users actually desire to go, given airspace constraints.

We begin by superimposing a two-dimensional "rectangular" grid over the airspace of the contiguous 48 states. For this application we have used a grid size of 0.125 degrees of longitude by 0.125 degrees of latitude. For each cell, we count the number of lightning strikes in a given period of time, typically 15 minutes, thereby generating a lightning strike density grid. Next, we estimate the number of aircraft that planned to be in each grid cell during the same period of time, using data from ETMS *FS* messages [3]. We use the filed estimated time en route (ETE) and flight plan distance to estimate an average ground speed for the flight. We then generate pseudo-track points for the flight plan route at 1 minute time increments along the proposed route of flight. These pseudo-track points are used to compute flight plan densities. Finally, we take the product of the logarithm of one plus the number of lightning strikes and the number of flight plan points in each grid cell, sum all of the cells for the 15 minute interval, and scale by a constant representing the approximate area of a cell at the equator, i.e.,

$$EWI = \frac{1}{(60 \cdot 1/8)^2} \sum_{t=1}^{96} \sum_{i=1}^{480} \sum_{j=1}^{240} f_{i,j,t} \cdot \ln\left(1 + l_{i,j,t}\right)$$

where

EWI = en route weather index

$f_{i,j,t}$ = flight plan density in cell *i,j* at time *t*

$l_{i,j,t}$ = lightning strike density in cell *i,j* at time *t*.

We use the logarithm of the lightning strike density because we have assumed that the number of recorded strikes is nonlinearly related to the severity of convection. The process is then repeated for each 15 minute interval in a day, the values are summed, and an index is obtained that reflects the severity of convective weather relative to the traffic that was planned for that day. We have used this approach to compute an index for the entire Continental United States (CONUS) airspace, but the same technique may be used to study regions, corridors, or city pairs, or for time intervals other than one day.

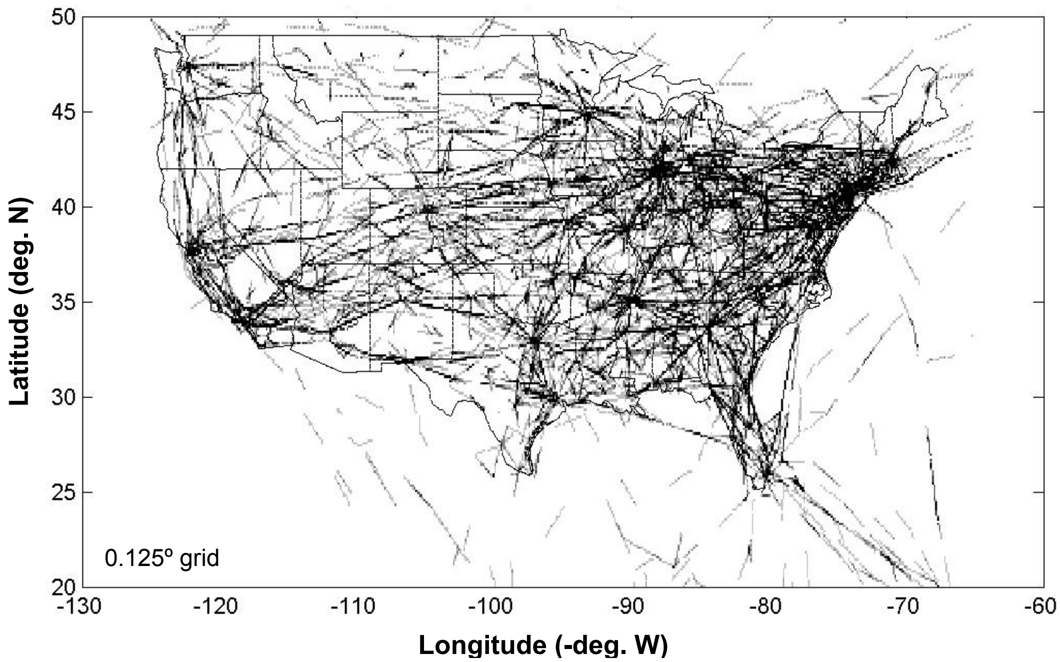


Figure 1. Sample Flight Plan Density, 21 JUN 2001 16:00-16:15 UTC

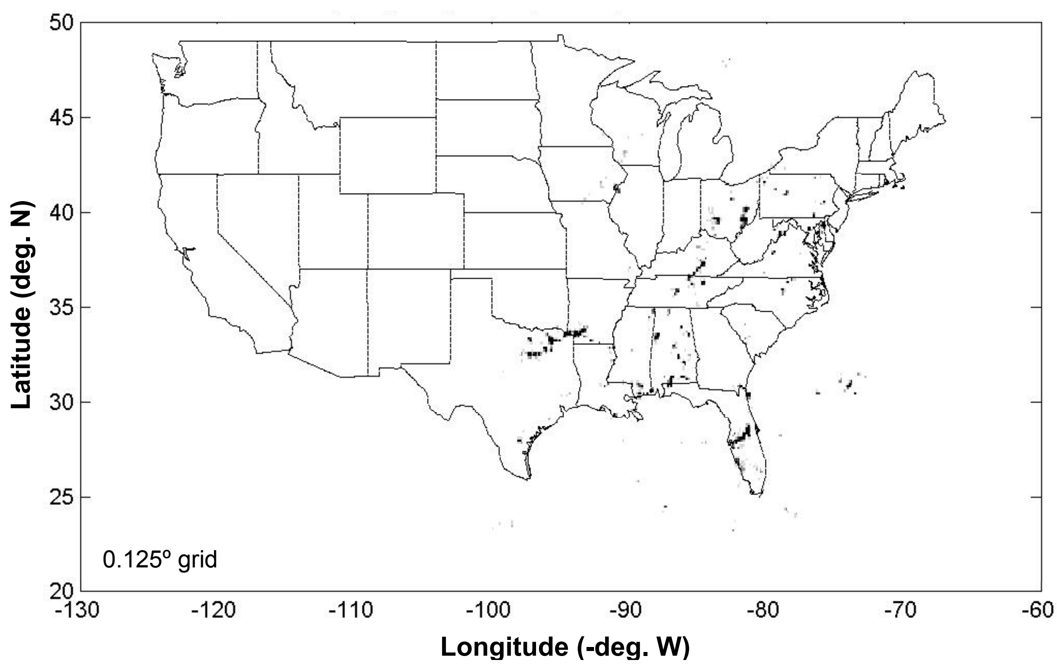


Figure 2. Sample Lightning Strike Density, 21 JUN 2001 16:00-16:15 UTC

We have calculated this en route weather index for 20 days from the summer of 2001, and compared it to several popular measures of NAS-wide delay. We would expect there to be a strong relationship between the weather index and en route delays. Figure 3 plots the Aviation System Performance Metrics (ASPM) NAS-wide average arrival delay (relative to flight plans)[1] against the en route weather severity index. As can be seen, there is good correlation between this delay metric and the weather index. An ordinary least-squares regression of the weather index on ASPM average arrival delay yields a coefficient of determination (i.e., R^2) of approximately 0.76. Figure 4 plots the ASPM on-time arrival rate for the same days against the en route weather index. Again, the correlation is good, with an R^2 value of 0.72.

While both our approach and the MITRE WITI place a grid over the CONUS airspace and multiply convective activity by some measure of traffic intensity in each cell of the grid, there are two major differences between the two approaches. First, the WITI uses NCWF severe weather polygons as the source for convective activity. Lightning strike data is a more precise measure of convective activity. Second, the WITI uses actual flight tracks from a "good weather day" as the data source for traffic. Our approach, on the other hand, uses flight plan traffic for the particular day being analyzed. Our approach has the advantage of being more dynamic, in that day-to-day (and consequently weekly, monthly, and seasonal) changes in traffic are accounted for.

References

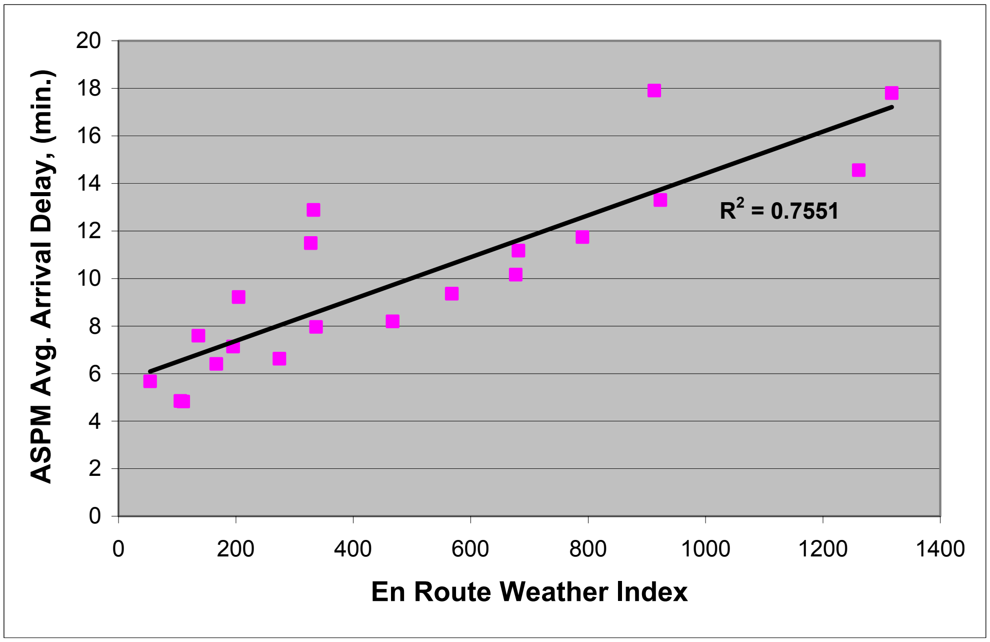
[1] Cummins, Kenneth L., E. Phillip Krider, and Mark D. Malone, Nov. 1998, "The U.S. National Lightning Detection Network and Applications of Cloud-to-Ground Lightning Data by Electric Power Utilities," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 40 No. 4, pp. 465-480.

[2] Callaham, Michael B., *et al.*, 2001, "Assessing NAS Performance: Normalizing for the Effects of Weather," *4th USA/Europe Air Traffic Management R&D Symposium*, Santa Fe, NM.

[3] Volpe National Transportation Systems Center, June 2002, "Enhanced Traffic Management System (ETMS) Functional Description," Version 7.4, VNTSC-DTS56-TMS-002, Cambridge, MA.

[4] FAA Office of Aviation Policy and Plans, May 2002, "Documentation for the Aviation System Performance Metrics (ASPM) Actual versus Scheduled Metrics," Washington, DC.

[1] ASPM arrival delay relative to flight plan is the difference between actual gate-in time and "flight plan" gate-in time, where the latter is the sum of the flight plan gate-out time and the scheduled block time from the Official Airline Guide [4].



Arrival delay computed using flight plan departure times

Figure 3. ASPM Average Arrival Delay vs. En Route Weather Severity Index

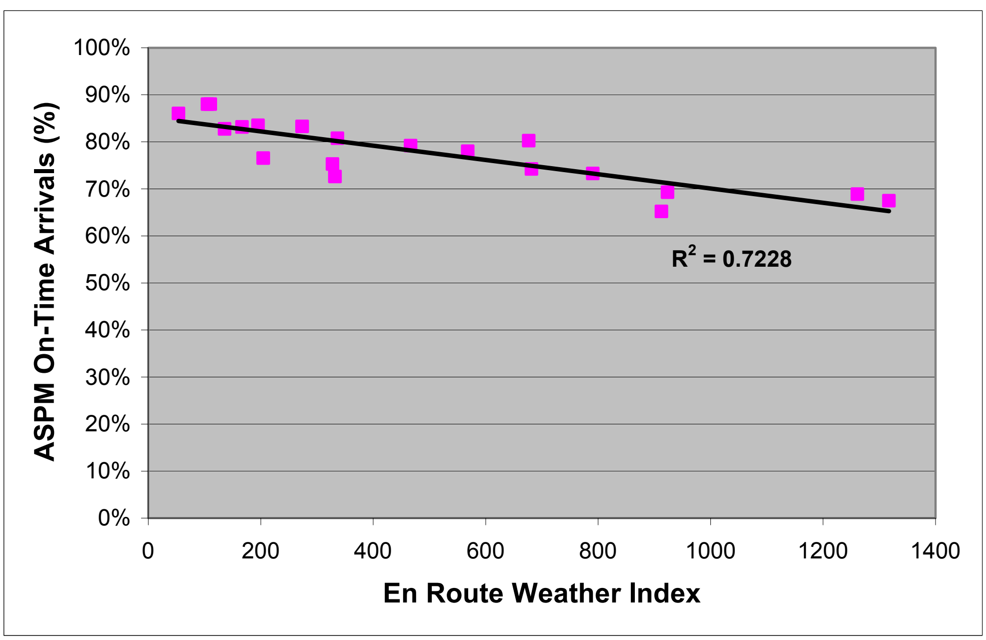


Figure 4. ASPM On-Time Arrival Rate vs. En Route Weather Severity Index