CHARACTERIZING THE CAUSES OF LOW CEILING AND VISIBILITY AT U.S. AIRPORTS

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1. INTRODUCTION

With recent improvements to terminal area weather sensing and numerical model development, there is renewed focus on efforts to improve short–term forecasting of terminal area ceiling and visibility conditions that limit airport operational capacity. A portion of an airport's actual operating capacity is dependent upon air traffic management decisions in response to anticipated transitions from Instrument Fight Rules (IFR) to Visual Flight Rules (VFR) conditions, and vice versa. The occurrence of IFR conditions may be related to a variety of meteorological circumstances, e.g. radiation fog, advection fog, marine stratus, rain or snow occurring with or without fog, haze, etc. Understanding the predominant causes of low ceiling and visibility at key U.S. airports will help to direct the research and development efforts and approaches to allow the highest potential operational benefits. It may also act as an aid in selection of development and evaluation sites.

The study presented here examines the exposure of U.S. airports that experience considerable delay (and are responsible for significant upstream and downstream delay at other airports) to low ceiling and visibility conditions. For each occurrence of low ceiling and/ or visibility at these key airports, the primary physical forcing mechanism is identified. In addition, the frequency of occurrence of IFR conditions is quantified in terms of the number of VFR/IFR transitions, rather the the percentage of time an airport experiences IFR conditions, as is commonly reported in standard climatological summaries. The number of transitions is considered a more relevant metric for this purpose, since the expected benefit of increased airport capacity is achievable as the result of improved accuracy in the forecast of these transition times (Rhoda et al., 1995).

The analysis of low ceiling and visibility exposure is done through examination of a 5–year record of hourly surface weather observations at the key U.S. airports. Each continuous period of IFR is identified, and characteristics of each IFR episode are examined. A decision process is applied to these characteristics to categorize each event by likely primary cause. A climatological profile of causes is presented for each airport.

2. IDENTIFYING CEILING AND VISIBILITY EVENTS

A five year record (1988–92) of surface hourly weather observations was used to identify ceiling and visibility events. Analysis was done for the 23 U.S. airports that exhibit greater than 20,000 hours of annual delay (FAA, 1991), plus Memphis International Airport which is a testbed site for the Integrated Terminal Weather System (Sankey, 1995). These airports are listed in Table 1. This table also indicates the IFR approach procedure for each airport which gives an indication of restriction of airport capacity during IFR conditions.

An IFR event was defined using the nominal thresholds of 1000–foot ceiling or 3 miles visibility. The exception to this was San Francisco International Airport, where a 2500–foot ceiling threshold was used, as it better represents the true threshold for operational impact resulting from the marine stratus which commonly interferes with local area traffic management (Strauch, 1991). The beginning time of an event was the first hourly observation of IFR conditions as defined above, and the ending time was the first subsequent hourly observation of VFR conditions. At least two consecutive observations of IFR conditions were required in order to qualify an event.

For each IFR event, specific meteorological parameters were extracted in order to characterize the event. This information included start and stop times, duration, lowest ceiling height, lowest visibility, occurrence of weather (rain, snow, fog, drizzle, haze) which may impact visibility, and highest/lowest values of wind speed, temperature, and dew point depression.

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Table 1. U.S. airports with annual delay in excess of 20,000 hours (FAA, 1991).

Airport	ID	IFR Approach Procedure
Chicago O'Hare	ORD	IP
Atlanta Hartsfield	ATL	IP
Dallas–Forth Worth	DFW	IP
Los Angeles International	LAX	IP
Newark International	EWR	S
San Francisco International	SFO	S
Boston Logan	BOS	S
John F. Kennedy Int	JFK	DP
St.Louis Lambert	STL	S
Phoenix Sky Harbor	PHX	S
Miami International	MIA	IP
Philadelphia International	PHL	IC
Washington National	DCA	S
Pittsburgh International	PIT	IP
Detroit Metro Wayne	DTW	IP
Orlando McCoy	MCO	IP
Minneapolis–St.Paul	MSP	DP
Charlotte Douglas	CLT	IP
Denver Stapleton	DEN	DP
Honolulu International	HNL	IP
Houston International	IAH	IP
Seattle–Tacoma	SEA	S
New York LaGuardia	LGA	S
Memphis International	MEM	DP

IFR Approach Procedures [Arrivals/hour]:

IP	Independent Parallel Runways [52]
IC	Independent Converging Runways [52]
DP	Dependent Parallel Runways [36]
S	Single Runway [26]

Note: Generic capacities listed here (arrivals/hour) are not airport specific, and are for comparison only. Actual capacities vary with a number of factors.

3. IDENTIFYING CAUSES OF LOW CEILING AND VISIBILITY

A primary objective of this study was to identifying the physical causes of low ceiling/visibility as they relate to various forecasting models and techniques (Wilson et al., 1993; Clarke et al., 1995; Porter and Seaman, 1995). These models include high spatial resolution (1–10 km) regional and mesoscale models, one–dimensional terminal area column models, models that rely on storm motion for tracking obscuration by precipitation, etc. The performance of these models will vary dependent upon the physical forcing associated with each ceiling and visibility event. For instance, a one–dimensional column model is expected to be most effective for events whose forcing is closely tied to evolution of local boundary layer conditions (i.e. those closely tied to the local radiation budget), while the regional and mesoscale models would be expected to perform better for events resulting from advection of moisture from larger scale pressure gradient or thermal forcing. In order to best isolate the physical forcing associated with low ceiling and visibility at each airport, a simple rules–based procedure was applied to classify each event into a mutually exclusive category that related to these forcing mechanisms. The 14 categories chosen, and their applicability to the various C&V models is shown in Table 2.

Table 2. Categories for characterization of low ceiling visibility causes, and relevant diagnostic/ forecasting models

Primary C&V Characterization	Model			
	C	R	S	W
Radiation Fog	X			
Advection Fog,w/Radiation Burnoff	X	X		
Advection Fog,w/Radiation Onset	X	X		
Advection Fog, no radiation impact		X		
Stratus, w/Radiation burnoff	X	X		
Stratus, no radiation impact		X		
Visibility reduced by haze only	?	?		
Low Vis, no fog, precip, or haze	?	?		
Low Visibility with rain and fog	?	X	X	
Low Visibility with snow and fog	?	X		X
Low Visibility in rain (no fog)	?	X	X	
Low Visibility in snow (no fog)	?	X		X
Low Ceiling in rain (no low visib)	?	X	X	
Low Ceiling in snow (no low visib)	?	X		X

ABBREVIATIONS:
C: Column Model
R: Regional/Mesoscale Models
S: Summer Storm Motion Models
W: Winter Storm Motion Models

For each ceiling and visibility event at each airport, the meteorological characteristics of each event were examined in order to classify the event into one of the 14 categories listed above. This decision process examined the minimum ceiling height and visibility during the event, the beginning and ending time of the event, the minimum wind speed, and the occurrence of fog, rain, snow, and haze. The logic for categorization is summarized in Figure 1. Although the decision process is somewhat simplistic, it allows for a reasonable first–order generalization of cause characterization for a large number of events. A brief summary of the key parameters that were examined and applied to the decision logic is provided as follows:

MINIMUM VALUES OF CEILING AND VISIBILITY: Events with a visibility of less than 3 miles (with

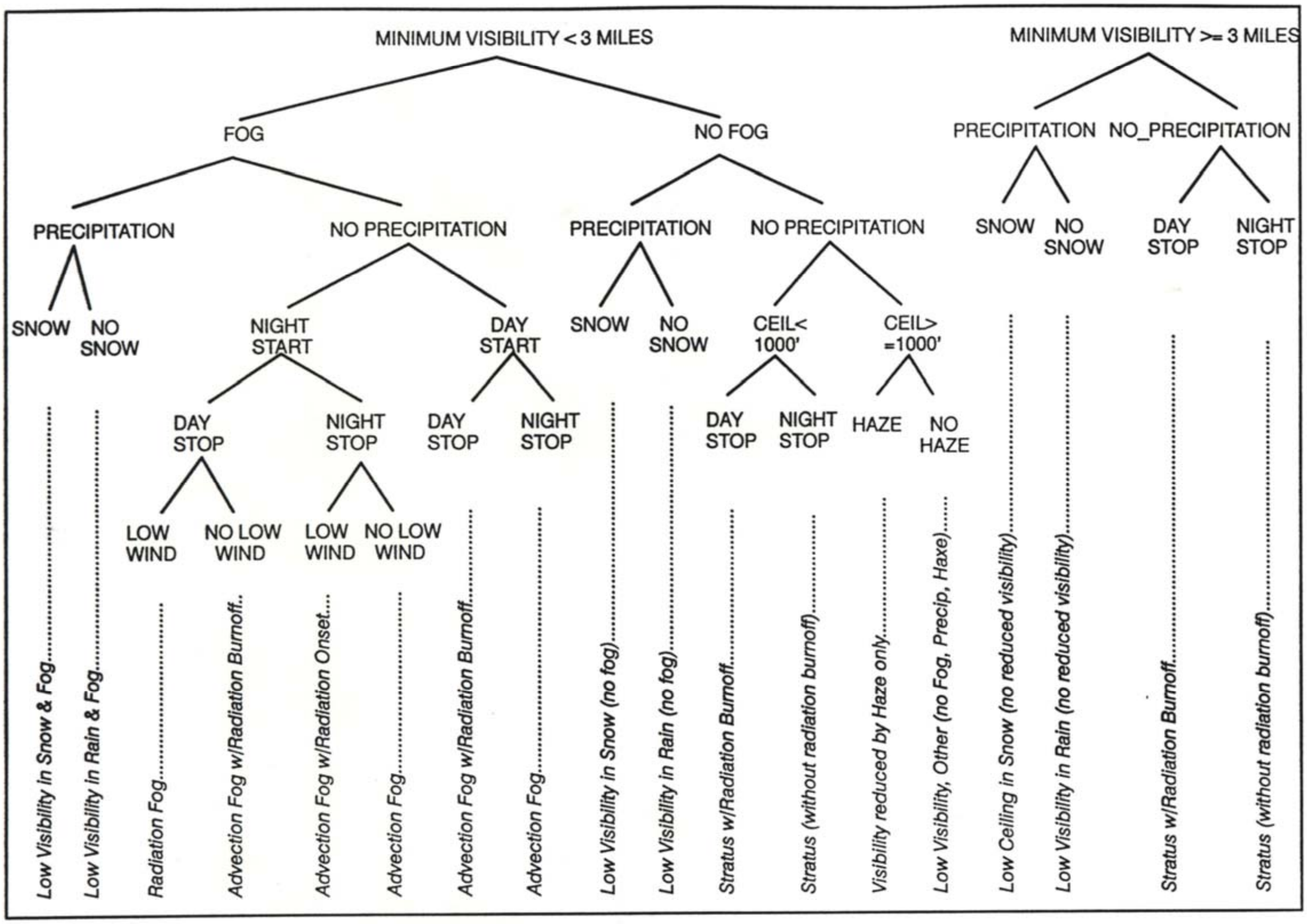

Figure 1. Decision Logic For Characterizing Causes of IFR Events

or without low ceiling) were categorized separately from those events which exhibited a low ceiling (<1000 ft) but no reduction of visibility to less than 3 miles.

FOG: Fog events were those events with minimum visibility of less than 3 miles and at least one report of fog (not necessarily simultaneously).

PRECIPITATION: Precipitation events were designated as either snow or no–snow events. Snow events had at least one report of snow or sleet (including showers), while no–snow events had at least one report of rain or freezing rain (including showers) but no snow or sleet. Reports of drizzle were not sufficient to qualify a precipitation event.

EVENT START/STOP TIME: The start and stop time of each event was examined to assess whether radiation was likely to have played a significant role in the onset or burnoff of a non–precipitation event. A necessary but not sufficient condition for radiation contributing to onset (i.e. via radiational cooling) was that the event started after sunset (defined as 6 PM Local Standard Time) and prior to sunrise (6 AM LST). A necessary condition for radiation contributing to burnoff was a stop time between sunrise and sunset.

WIND SPEED: For radiation fog events, or advection fog events with radiation contributing to onset or burnoff, at least one observation of wind speed less than or equal to 5 knots was required.

HAZE: Low visibility events exclusively attributable to haze required at least one observation of haze with no other reports of fog, precipitation, or low ceiling at any time during the event.

4. RESULTS

Figure 2 presents a graphic representation of the causes of IFR events at the 24 airports considered. The figure indicates the breakdown of cause by 8 mutually

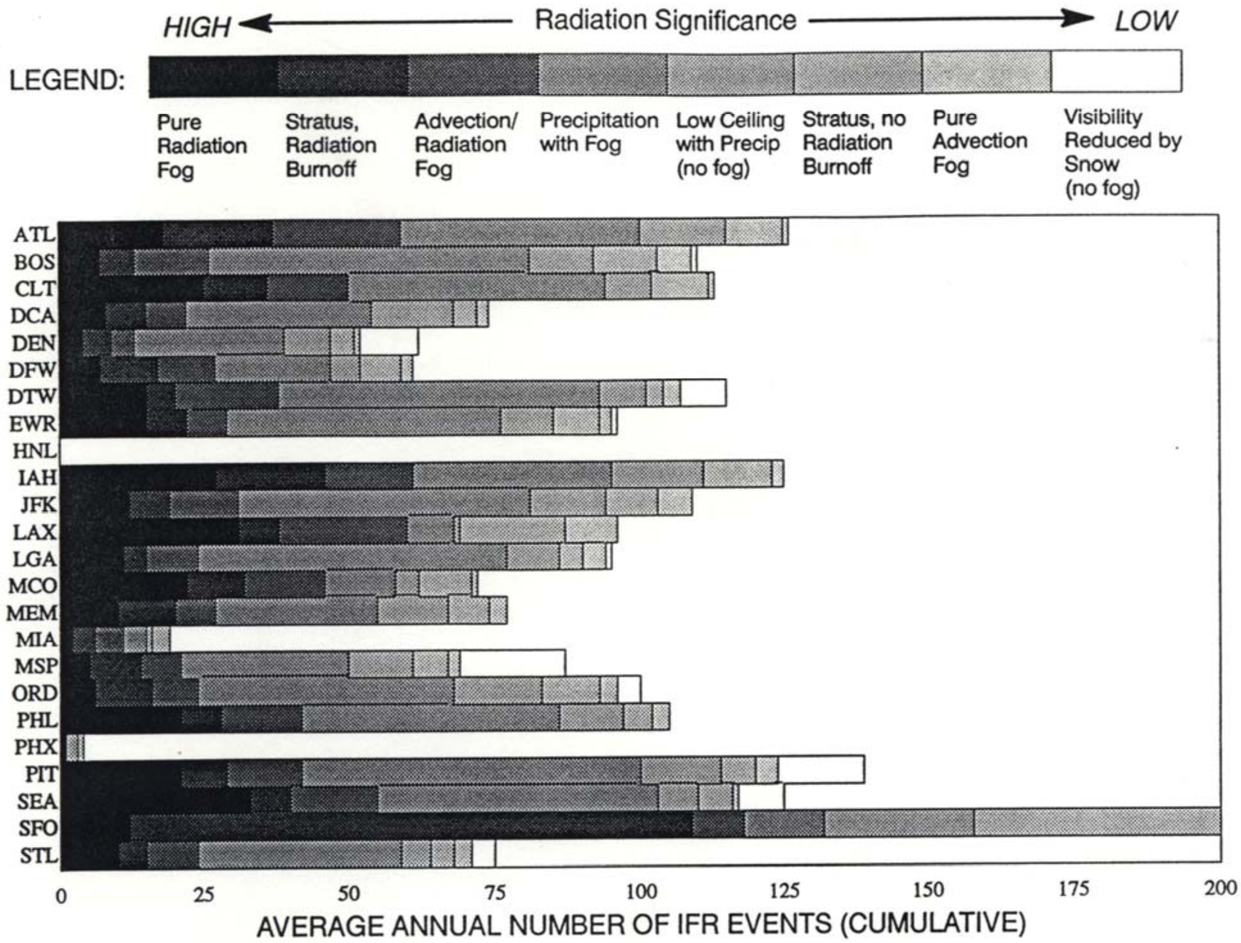

Figure 2. Average annual number of IFR events at U.S. airports, indicating distribution by primary cause.

exclusive categories. For clarity, three of the original 14 categories are not shown (Haze Only, Visibility Reduced by rain (no fog), and Other), as they represented a very small portion of events at nearly every airport. (The only exception to this was Los Angeles International, which averaged eight Haze Only events per year.) Also, 6 of the original 14 categories were combined into pairs, and are represented here as 3 mutually exlusive categories. Since one of the key distinctions amongst the proposed C&V forecasting models is dependence upon monitoring of the local radiation budget (and evolution of the local boundary layer), this figure presents the distribution of causes at each airport in such a way as to emphasize the relative significance of radiation onset/burnoff to each physical forcing mechanism.

A couple of additional notes are warranted regarding events involving fog and precipitation, which represent a significant portion of IFR events at many airports. First, it should be pointed out that only a single observation of precipitation during the continuous IFR period was required to qualify a precipitation event. As such, it is quite possible that the physical forcing that was primarily responsible for the onset or burnoff of IFR conditions was not directly related to the precipitation portion of the event itself. For example, either radiative or advective forcing (unrelated to a synoptic scale precipitation forcing) may lead to the onset of fog well prior to the start of precipitation, or burnoff well after precipitation has ended. This is particularly noteworthy since it is the accurate forecasting of the IFR/VFR transition times that represent the greatest potential benefit with regarding to improving effective airport capacity. As a cursory check, examination of a small sample of data indicates that radiation may have played a role in onset or burnoff in approximately 15–25% of the events categorized as precipitation with fog. Even for events clearly dominated by precipitation, it is very typical for advection to be the primary mechanism for supplying moisture that ultimately leads to low cloud and fog, with radiation contributing significantly to cloud and fog burnoff. Since fog associated with precipitation is one of the most common causes of IFR at many airports, this category is worthy of further investigation. For now it is assumed that advection plays a major role for this category of events, with radiation playing at least a small to moderate role.

Tables 3A through 3H provide rank–order summaries of the IFR characterizations by cause. Table 3A shows a ranking by airport of annual frequency of IFR events for all causes combined. Tables 3B through 3F show annual frequency of IFR events involving fog; 3B includes all fog events, while 2C and 2D show a breakdown of fog events with and without precipitation respectively. Table 3E shows the average annual frequency of fog events that were categorized as purely radiative. Table 3F indicates frequency of advective fog events; these include advection fog events during which radiation may have played a contribution during onset or burnoff, but were primarily advective in nature. They do not include fog events which were accompanied by precipitation. Table 3G shows annual frequency of "stratus" events, which are defined here as IFR conditions caused solely by low ceiling conditions, with no reduction of visibility (to below 3 miles), and no precipitation. Table 3H shows events during which there was at least one observation of snow or sleet.

Table 3. Rank order lists of airports by annual average frequency of occurrence of IFR events, for various categories of event characteristics.

(A) **ALL IFR EVENTS**	
San Francisco*	215
Pittsburgh	139
Seattle	133
Atlanta	129
Houston	122
Charlotte	116
Detroit	116
Boston	111
NY–Kennedy	109
Philadelphia	105
Los Angeles	104
Chicago	101
Newark	101
NY–LaGuardia	99
Minneapolis	88
Memphis	79
Orlando	76
St. Louis	76
Washington–National	74
Dallas	64
Denver	62
Miami	23
Phoenix	5
Honolulu	2

(B) **ALL FOG EVENTS**	
Pittsburgh	96
Detroit	90
Charlotte	85
Seattle	85
Atlanta	82
Philadelphia	81
Boston	80
NY–Kennedy	79
NY–LaGuardia	77
Houston	74

(C) **FOG EVENTS, NO PRECIP**	
Los Angeles	61
Houston	44
Seattle	44
Atlanta	41
Charlotte	41
Pittsburgh	38
Orlando	38
Philadelphia	37
Detroit	35
NY–Kennedy	30

(D) **PRECIPITATION WITH FOG**	
Pittsburgh	58
Detroit	55
Boston	54
NY–LaGuardia	53
NY–Kennedy	49
Newark	47
Philadelphia	44
Charlotte	44
Chicago	43
Seattle	42

(E) **RADIATION FOG**	
Los Angeles	31
Houston	27
Charlotte	25
Orlando	22
Seattle	22
Philadelphia	21
Pittsburgh	21
Atlanta	18
Newark	15
Detroit	15

(F) **ADVECTION FOG**	
Los Angeles	31
Atlanta	23
Seattle	22
Detroit	21
Boston	19
NY–Kennedy	18
Philadelphia	17
Houston	17
Pittsburgh	17
Charlotte	15
Orlando	15

(G) **STRATUS**	
San Francisco*	149
Houston	30
Atlanta	29
Seattle	27
Los Angeles	24
Charlotte	21
Chicago	19
Orlando	19
Boston	17
Dallas	17
Memphis	17

(H) **EVENTS WITH SNOW**	
Minneapolis	38
Pittsburgh	38
Denver	37
Detroit	27
Chicago	25
Boston	17
St. Louis	13
Newark	10
NY–Kennedy	10
NY–LaGuardia	10

* Note: A 2500' ceiling threshold (rather than 1000') was used for SFO.

5. DISCUSSION

In addition to annual exposure to IFR conditions, two other factors must be considered in assessing the potential reduction in air traffic system delay that would result from improvement to forecasts of IFR/VFR transition times. First is the restriction to capacity imposed by runway configuration and approach procedures during IFR conditions (see Table 1). Many airports are able to maintain independent parallel approaches during IFR conditions and, as such, the adverse effects are less dramatic. Others require dependent approaches on closely spaced parallel runways, while some airports are reduced to a single runway for arrivals. Airports that experience a significant loss of capacity during IFR conditions include Boston, St.Louis, San Francisco, Seattle, and the three New York City area airports (JFK, LGA, and EWR). The capacity problem at the three New York airports is compounded by the limitation of airspace in that area. Of the seven airports with large IFR capacity restrictions, all but St.Louis are seen to exhibit a moderate to high exposure to IFR conditions. Of particular significance is the extremely high exposure to low ceiling conditions at San Francisco due to the regular intrusion of marine stratus during the spring and summer months.

The other factor for consideration is the daily operational demand, including the distribution of arrival demand throughout the day. In addition to high peak arrival rates, some airports maintain such a continuously high demand that there is little opportunity to absorb delay once it is incurred. In these instances, a small disruption can have significant follow–on effects, both locally and at downstream airports. Consequently, a small improvement to capacity can lead to significant savings in overall system delay. Examples of this are Chicago, Atlanta, and Dallas. Since these are all hub airports that involve frequent flight connections, the impact of flight delay at the local terminal is likely to translate to significant downstream delay. Once again, a small improvement in capacity at these airports will translate to a more substantial benefit to the air traffic system as a whole.

6. SUMMARY

The meteorological parameters associated with a large number of IFR events were examined in order to make a first–order estimate of the primary cause of low ceiling and visibility conditions at U.S. airports that experience significant annual delay. These causes were defined in mutually exclusive categories that are relevant to various models that have been proposed to provide improved forecasts of low ceiling and visibility conditions at U.S. airports. A distribution of event frequency by primary cause was presented for key airports.

In addition to annual exposure to IFR conditions, other factors were considered that are relevant to potential benefits associated with improved ceiling and visibility forecasts. These include the restriction to capacity imposed by IFR conditions at the various airports, as well as the overall demand at each airport, and the distribution of demand throughout the day.

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