

15.4 SPATIAL-TEMPORAL BEHAVIOR OF RVR VISIBILITY OF ILS RUNWAYS AT SELECT MAJOR AIRPORTS

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1. INTRODUCTION

The FAA's forward scatter-based Runway Visual Range (RVR) system began service in 1994 at several key airports in the U.S. Since then, the USDOT Volpe Center has monitored data from a number of airports in order to test RVR system performance. This paper utilizes RVR data collected at Portland International Airport (PDX), Chicago/O'Hare International Airport (ORD) and Denver International Airport (DEN) in order to assess the variability of Cat I, II and III conditions during a few selected events. Previous studies (Seliga et al., 2001; Hazen et al., 2002) provided important insights into RVR variability that occurs at three airports (PDX, SEA and ORD), showing strong spatial and temporal variability over the same airport. The criticality of the events (occurrences of Cat II and III) at all three airports was found to often affect only a few of the runways at a time. This paper will demonstrate the variability than can occur within the same Instrument Landing System (ILS) runway at any time during a given event at a particular airport as well as show the variation between different ILS runways at the same airport. Events were selected based on type, duration and potential operational impacts.

The insights obtained from this and previous papers on this subject should prove valuable for air traffic planning and lead to more effective operations in the future.

1.1 Terminology

Terms used in this report are defined as follows:

RVR or Runway Visual Range is the distance of maximum visibility of runway objects as seen by a pilot approaching for a landing in visibility limiting conditions. In the US, RVR ranges from 100 - 6,500 ft. Reporting increments are: 100 ft for RVR between 100 -1,000 ft; 200 ft for RVR between 1,000 - 3,000 ft; and 500 ft from 3,000 - 6,500 ft. Internationally, RVR reports are in m: 25-60 m for RVR up to 800 m; and 100 m for RVR in the 800 - 1,500 m range (ICAO, 1995).

RVR Visibility Event is defined as any time when RVR is less than 6,500 ft (US) or 1,600 m (international). The most common causes are fog and snow. In the US, the 3 categories of RVR are: Cat I for $2,400 \leq \text{RVR} \leq 6,500$ ft; Cat II for $1,200 \leq \text{RVR} < 2,400$ ft; and Cat III for $\text{RVR} < 1,200$ ft

Since RVR products are computed and reported to controllers from extinction coefficient (σ) measurements using visibility sensors (VS) on active runways, the RVR

values used here are directly derived from σ using Kochmeider's Law for daytime using the formula

$$V = 9842.5 \sigma^{-1} \quad (1)$$

where V is the visibility in ft and σ is in km^{-1} . This corresponds to a range of about $1.5 - 4.1 \text{ km}^{-1}$ for Cat I conditions; from $4.1 - 8.2 \text{ km}^{-1}$ for Cat II; and over 8.2 km^{-1} for Cat III.

METAR Data Format is the international standard for official reporting of surface weather conditions based on either human observations or automated observing systems. All weather conditions reported in this paper are derived from METAR data recorded at the three airports. METAR visibilities are reported in statute miles (SM). Precipitation and obstruction to visibility are as follows: RN – rain; RN+ – heavy rain; SN – snow; BLSN – blowing snow; FG – fog; BCFG – patchy fog; FZFG – freezing fog; BR – mist. Events at ORD and DEN were primarily due to SN, BLSN and FG. PDX events were primarily due to FG while both FG and SN affected ORD and DEN.

2. RVR MEASUREMENTS

Tables 1-3 give the VS configurations. All runways in are ILS runways. The runway configurations applicable to the various VS's are also listed. Asterisks denote runways examined in this report.

Table 1. ORD Visibility Sensor Designations

RUNWAY	VS
4R22L*	VS01 and VS10
22R4L*	VS03 and VS11
14R32L*	VS04, VS05 and VS06
32R14L*	VS07, VS08 and VS09
27R9L	VS03 and VS09
9R27L	VS02 and VS12
18-36	VS11

Table 2. DEN Visibility Sensor Designations

RUNWAY	VS
17L35R*	VS01, VS02 and VS03
17R35L*	VS04, VS05 and VS06
16-34*	VS10, VS11 and VS12
7-25*	VS13 and VS14
8-26	VS15 and VS16
There are no VS07, VS08 or VS09 at DEN	

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Table 3. PDX Visibility Sensor Designations	
RUNWAY	VS
28R10L*	VS01, VS02 and VS03
10R28L*	VS04, VS05 and VS06

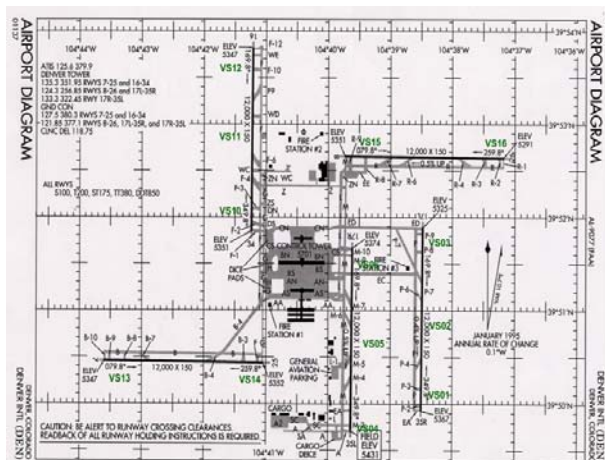


Fig. 1. Runway Map of DEN

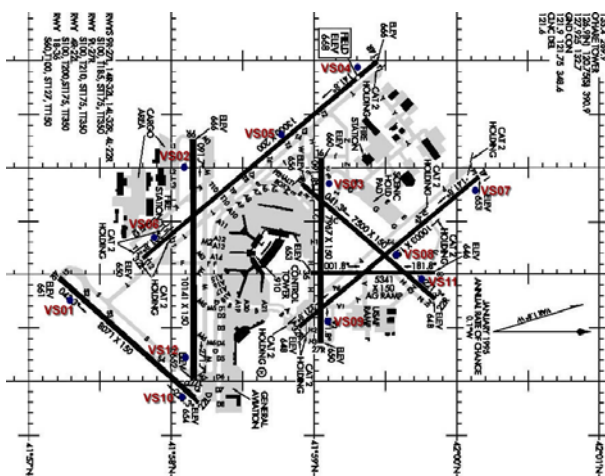


Fig. 2. Runway Map of ORD



Fig. 3. Runway Map of PDX

Of the runways listed in Tables 1-3, all parallel runways at all three airports were examined except RWs 27R/9L and 27L/9R at ORD. The following parallel runways examined had a VS at touchdown (TD), midpoint (MP) and rollout (RO): RWs 10R/28L and 10L/28R at PDX; 17R/35L and 17L/35R at DEN; and 32R/14L and 32L/14R at ORD. Runways 4R/22L and 4L/22R has VS at TD and RO. Runways 16/34 (3 VS) and 7/25 (2 VS) were also examined at DEN.

Maps of the runway areas at DEN, ORD and PDX are shown in Figs. 1-3, respectively. North is to the top in Figs. 1 and 3 and to the right in Fig. 2.

3. EVENT SELECTION

Table 4 lists all events considered at the three sites where either Cat II RVR readings were uniformly reported during some part of the event or patchy but dense FG was reported on METAR reports. In Table 4, the column 'Times' is for the periods of the events in Greenwich Mean Time (GMT), conversions to local standard time are: subtract 6 hours for ORD, 7 hours for DEN and 8 hours for PDX; 'Type' is event type; 'Max σ ' is the maximum σ and 'Min Cat II' is the time all VS reported Cat II or III simultaneously during the event.

Table 4: RVR Events Studied.					
Site	Day	Times (GMT)	Type	Max σ (km ⁻¹)	Min Cat II (ft)
DEN	1/3/98	1355-2230	FZFG; BLSN	37	255
DEN	2/1/98	0700-1145	FZFG; SN	73	71
ORD	2/25/00	0300-1730	FZFG	44	275
ORD	3/2/98	0000-1130	SN; FZFG	34	60
PDX	11/2/97	0740-1700	FG	66	0
PDX	12/31/97	0110-1500	FZFG; FG	52	339
PDX	12/31/98	0045-0500	FG	62	181

4. EVENTS

In all event history plots below, Cat I contours are colored medium blue; Cat II contours green-yellow; and Cat III contours red.

4.1 Portland (PDX)

Nov 2, 1997 – Weather – BR with 2 SM visibility, clear skies, calm winds, temperature 8 °C and dew point 7 °C reported at 2357 PST. FG was recorded from 0332 to 0756 PST with BR from 0238-0213 and 0844-0847 with calm or light (3-4 kts) mostly from the west according to METAR reports. Temperature and dew point were both at 5-6 °C during FG then increased to 8 °C at 0844. Visibility-RVR event history plots along runways 10R/28L and 10L/28R are shown in Figs. 4 and 5; the event is discussed in the next two subsections.

Individual Runways – Brief Cat I conditions were recorded at MP and RO along RW 10R/28L from about 0030-0055 PST and intermittently at MP and RO from about 0000-0100 along RW 10L/28R. BR was reported along with calm winds. Along RW 10R/28L, the fog was densest at RO from about 0310-0315 and 0325-0345 with Cat III conditions recorded. MP appeared to receive the least Cat II+ activity and TD was in Cat II+ conditions somewhat longer than at MP.

Cat II+ conditions lasted longer along RW 10L/28R than along RW 10R/28L with Cat III conditions lasting the longest at RO and the most intermittent at TD. TD still had Cat II+ conditions during much of the time.

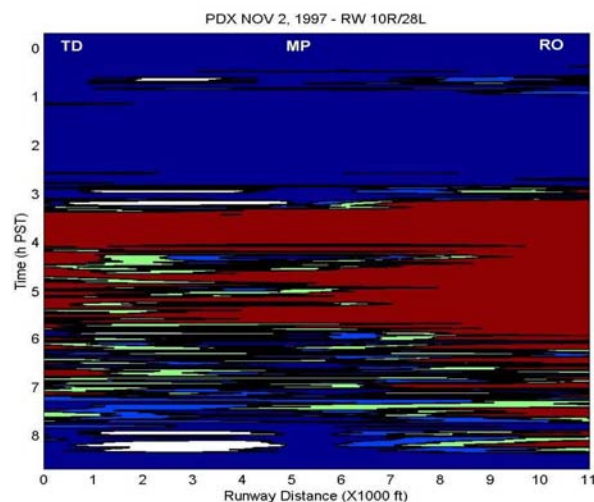


Fig. 4. Extinction Coefficient Time History Along PDX RW 10R/28L (11/02/97)

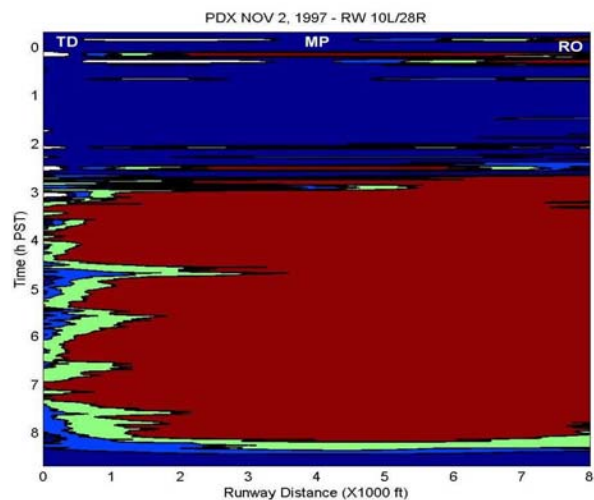


Fig. 5. Extinction Coefficient Time History along PDX RW 10L/28R (11/02/97)

The fog was often considerably variable between VS at either runway with density variations being pronounced in as little as a few minutes. Cat II+ conditions lasted somewhat longer at RW 10L/28R than at RW 10R/28L; this is consistent with the expectation that visibility

should be worst on the RW nearer to the Columbia River.

Runway Area – Cat I conditions on RW 10L/28R near VS2 at 0007 PST; Cat III there at 0010; Cat III near VS1 at 0017; Cat I near VS5 at 0029 were recorded. Similar behavior continued until about 0230 when VS1 first recorded Cat I and Cat III was recorded near VS2 by 0234. The fog expanded and contracted until the south half of the runway area was Cat III by 0315. The entire runway area was Cat III during brief time intervals such as 0332 to about 0343 when the VS03 area went to Cat II. From 0343 to 0742, Cat III conditions were largely confined to either the southern part of the area or southeastern part of the area. Sample images of a typical minute's measurements are shown in Fig. 6. The contour plot in Fig.6 shows that the fog was Cat III everywhere except the extreme northern part of the runway area at 0425. Note that σ exceeded 40 km^{-1} near VS02 in Fig. 6. There were occasions such as at 0603 where VS04 area was Cat I and the area near VS01 was Cat III. The Cat III area expanded and contracted during this time period. At 0758, only the VS02 area had Cat III conditions. At 0828, the VS06 area was Cat III. The event's decay continued at 0834 and by 0841, only the VS02 area had Cat I conditions and ended by 0845.

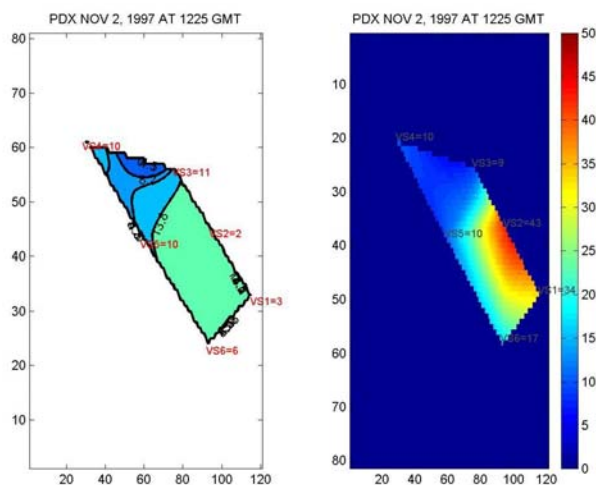


Fig. 6. Airport Contour and Extinction Coefficient (σ) Images at PDX (11/02/97). Note different scales.

Dec 31, 1997 – Weather – METAR reports indicated BR from 1728-1730 PST, FG from 1734 to 2111 and then BCFG 2122-2156 and 2231. Visibility improved to 4 SM by 2156, then decreased to 1.5 SM at 2216, 1 SM at 2220, after which it again increased to 3 SM at 2231 and then declined once more to a mile or less by 2256. BR or FG was reported during the second part of this event, which lasted from 2156 to 0556. Winds were from E-ENE at 3-6 kts at the start of the first part of the event, and then were calm or light (3-6 kts) with directions ranging from the SW to E during both parts of the event. Temperatures and dew points both ranged from 1-4 °C. The corresponding visibility-RVR event history plots along runways 10R/28L and 10L/28R are shown in Figs.

7 and 8; the event is discussed in the next two subsections.

Individual Runways - The fog quickly became dense first along RW 10L/28R, progressing from RO to TD between about 1725-1745 PST on Dec. 30, 1997. Meanwhile, the fog quickly became dense at RW 10R/28L, progressing from RO to TD between about 1735-1750. Cat III conditions encompassed both runways between about 1750-2115. The fog thinned out considerably near TD at RW 10L/28R from about 1845-1920 and near MP from about 1930-1940, but stayed in Cat III conditions.

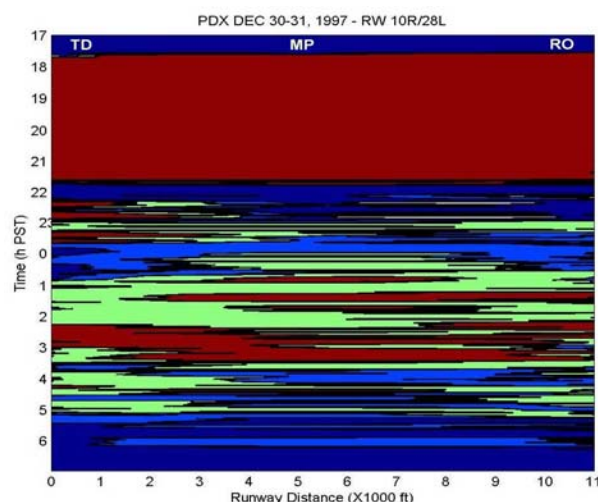


Fig. 7. Extinction Coefficient Time History Along PDX RW 10R/28L (12/31/97)

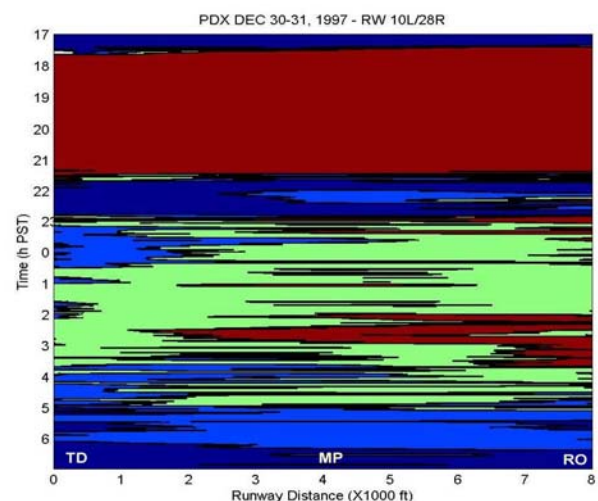


Fig. 8. Extinction Coefficient Time History Along PDX RW 10L/28R (12/31/97)

The fog first dissipated at RO along RW 10R/28L at about 2130 and progressed to MP by 2140 and TD by 2145. Intermittent and quickly varying Cat I-III conditions were experienced along different parts of RW 10R/28L from about 2145-0610. The event ended for RW 10R/28L by about 0615. Meanwhile, the fog decreased somewhat more uniformly along RW 10L/28R between 2115-2145. There were periods of Cat I or II conditions

with occasional breaks and rapid variations from about 2200-0700 along RW 10L/28R.

Runway Area – Cat I conditions were first recorded at 1716 PST near VS1 and expanded on that side by 1723. Cat III conditions were recorded by 1728 with the fog thickest near VS1 and VS6. The entire area experienced Cat III conditions by 1743 with densest fog near VS02 after 1750, near VS1 at 1828 and then near VS2 at 1830. The fog became more consistent by 1908 and was densest near VS2. The area of dense fog shifted frequently through 2126 between the VS2 area, the VS5/VS6 area (the denser fog generally prevalent in the VS2 area spread out to both VS5 and VS6 at about 1930; later spread only to VS6 at 2016 and again to VS5 and VS6 at 2025 as examples) and the VS3 and VS4 areas (by ~2103, the area of densest fog was in the combined VS3/VS4 areas) at different times. The first part of the event subsided after 2147, shortly after VS5 reported the densest fog of the runway area at 2142.

The second part of the event began at 2201 when VS2 area first experienced Cat I conditions, which then shifted to VS6 at 2209 and VS1 at 2214. VS1 and VS4 areas experienced Cat I and II conditions at 2219, while VS4 experienced Cat III conditions briefly at 2242. At 2255, the SE area was in Cat II conditions. After 2340, Cat II conditions were recorded near VS1 and VS2; this area of Cat II conditions contracted by 2356. Rapidly varying areas of Cat II conditions occurred from 0000-0030. Uniform Cat II conditions were recorded at 0100 with Cat II and occasional areas of Cat III conditions experienced at different parts of the runway area through 0330. The event began decaying, as there were varying areas of Cat I and II conditions at 0348. However, occasional areas of Cat III conditions near VS4 and VS5 reoccurred between 0414-0425 and near VS5 at 0504-0505. The event continued to decay so that, by 0522, only Cat I fog was reported in varying areas of the runway area. The event ended at 0621 after VS1 last reported Cat 1.

Dec 31, 1998 – Weather - FG from 1723-1956 PST; BR at 1711 and 2056 from METAR reports. Winds were from WNW from 1723-1756, shifting from E to SE between 1956-2111 with calm during rest of event. Temperatures and dew points gradually fell from 10 °C to 7 °C during the event. The corresponding visibility-RVR event history plots along runways 10R/28L and 10L/28R are shown in Figs. 9 and 10; the event is discussed in the next two subsections.

Individual Runways - The fog first arrived at RO along RW 10L/28R at about 1655 PST and progressed to TD by 1715 and quickly became fairly dense. Fog first arrived at RO along RW 10R/28L at about 1705 then reached TD by 1720. The fog was more uniform along RW 10R/28L, and was densest near TD along RW 28R/10L. At times, TD recorded Cat III conditions while RO recorded anything from Cat I to Cat III conditions. The fog changed considerably within a few minutes of time.

The decay of the event was more uniform than the previous two events. It took less time along RW 10R/28L than along RW 10L/28R. Decay first began at TD when conditions shifted from Cat III to Cat II at about 2020, then to Cat I at about 2035 with the event ending at TD by 2050. The Cat II phase of the decay started at about 2030 at RO and lasted to about 2045. The Cat I phase of the decay only lasted a few minutes afterwards at TD. The transition from the Cat III to Cat II phase of the decay first started near MP along RW 10L/28R at about 2030 and reached TD and RO about 10 minutes later. The Cat II to Cat I part of the decay was more continuous along TD and RO than at MP. In fact, the event ended at MP at about 2050, a few minutes after it ended at TD and RO.

VS5 and VS6 had the thickest fog off and on from 1735-1748. VS3 and VS4 had the densest fog at 1750, and then VS3 generally had the densest fog between 1750 until 1852 when the fog was densest near VS2, VS3 and VS04. The fog briefly thinned to Cat I near VS1 by 1915, then became more uniform Cat III by 1920. At 1925, the fog was thinner at VS4 and thickest near VS3. The fog was relatively uniform around 2005, and then least dense near VS3 by 2010 and near VS2 by 2023. Decay was in progress by 2028 with the VS3 area the last area to exit from Cat III conditions. The decay continued at 2044 when only Cat I and II fog were recorded. The fog completely dissipated by 2055.

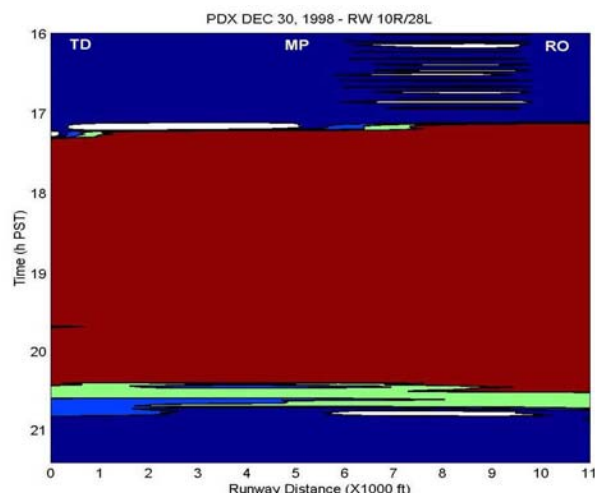


Fig. 9. Extinction Coefficient Time History Along PDX RW 10R/28L (12/31/98)

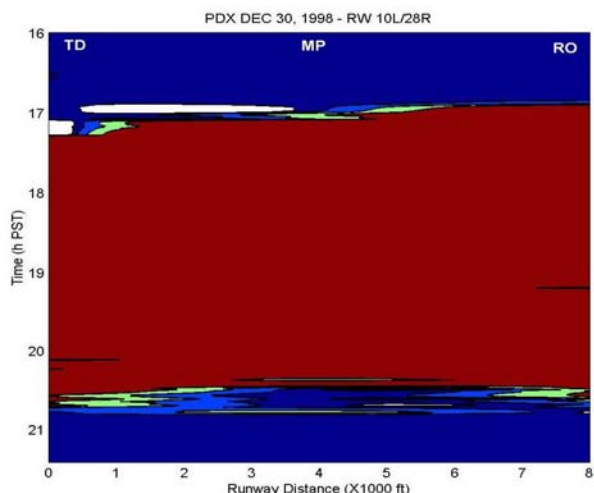


Fig. 10. Extinction Coefficient Time History Along PDX RW 10L/28R (12/31/98)

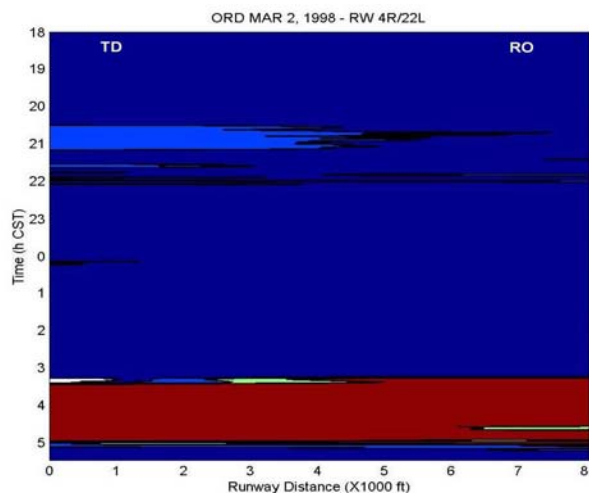


Fig. 11. Extinction Coefficient Time History Along ORD RW 4R/22L (03/02/98)

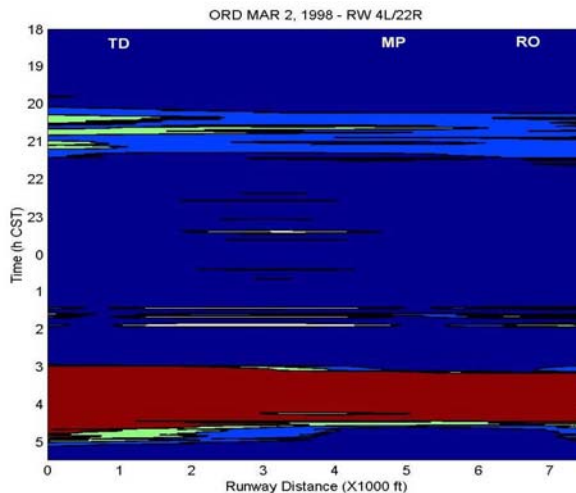


Fig. 12. Extinction Coefficient Time History Along ORD RW 4L/22R (03/02/98)

Runway Area – VS1 was the first to experience fog and Cat III conditions at 1654 PST and 1700, respectively. VS4 did not record Cat I until 1715. At that time, the fog was thickest near VS2, VS3 and VS5. The entire area was Cat III by 1725 with the fog thickest near VS03.

4.2 Chicago/O'Hare (ORD)

Mar 2, 1998- Weather - Official METAR reports recorded SN - falling until 0042 CST. The SN - was accompanied by BR until 2156. BR was reported between 0138-0207; FZFG from 0324-0456; BR from 0458-0956; SN-

resumed at 0732 and lasted until 1458. There were periods of BR during the 0732-1458 period of SN_z. Winds were calm or light, with direction generally shifting from W to NW during FZFG and BR. Temperatures were -1 to -2 °C during FZFG and BR and dew points either the same as the temperatures or a degree less. The corresponding visibility-RVR event history plots along runways 4R/22L, 4L/22R, 32R/14L and 32L/14R are shown in Figs. 11-14, respectively; the event is discussed in the next two subsections.

Individual Runways - The first period of RVR activity occurred between about 2000-2130 CST where RW 32L/14R experienced Cats I and II conditions, RWs 32R/14L and 4L/22R experienced Cat I and borderline Cat II conditions, while RW 4R/22L experienced Cat I conditions. RWs 32L/14R and 4L/22R experienced Cat I

were about 0300-0500 and 0315-0440, and along RW 4R/22L are about 0330-0505 and 0310-0510.

Figs. 13 and 14 show that decay of the event was slowest along RWs 32R/14L and 4L/22R where the lags between one end of the runway to the other exceeded 30 minutes. The decay progressed from one end to the other in RWs 32L/14R and 4R/22L in just a few minutes.

The densest fog was recorded near TD along RW 4L/22R from about 0300-0310 with extinction coefficient σ of about 40 km^{-1} . The fog was almost as dense at TD along 32R/14L at about 0315-0330 and near MP along RW 32L/14R from about 0300-0310. Note that these instances of maximum density FG late in the event were attained just minutes after onset and lasted for nearly two hours.

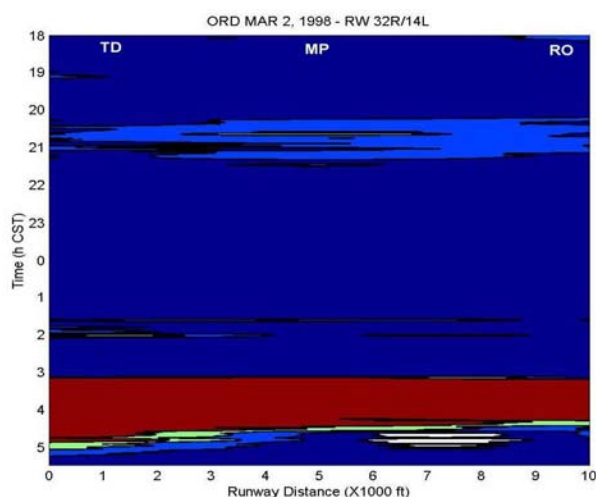


Fig. 13. Extinction Coefficient Time History Along ORD RW 32R/14L (03/02/98)

conditions longer than RWs 4R/22L and 32R/14L. The first part of the event started first and ended last at MP along RW 32L/14R; similar behavior can be seen along RW 32R/14L. The event started first at TD and ended from TD to RO along RW 4L/22R; this same conditions were experienced only at TD along parallel RW 4R/22L.

The principal part of the event first started at RO along RW 32L/14R at about 0245 and progressed to TD by about 0310 when FZFG was reported on the METAR reports. The transition to Cat II/III conditions was quick. The onset occurred first at TD along RW 32R/14L at about 0310 and then spread to RO by 0315. At RW 4L/22R, the FZFG started at TD at about 0300 and reached RO by 0315. Along RW 4R/22L, the onset at RO began at about 0310 and reached TD by 0330.

Cat II/III conditions lasted from about 0245-0450 at RO, about 0255-0455 at MP and about 0310-0500 at TD along RW 32L/14R. Meanwhile, there was a considerable variation between TD and RO at RW 32R/14L with starts and stop times at about 0310-0500 and 0320-0420, respectively. Similarly, the respective start and stop times at TD and RO along RW 4L/22R

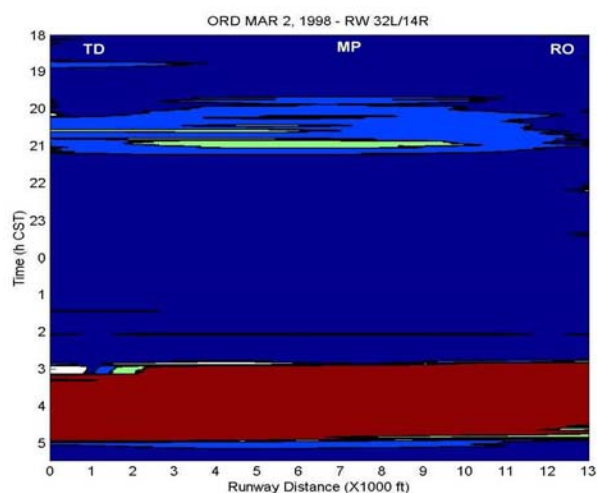


Fig. 14. Extinction Coefficient Time History Along ORD RW 32L/14R (03/02/98)

Runway Area - The first Cat I conditions were experienced near VS07 on the SE side at 1805 CST and dissipated about 10 minutes later. There was more brief Cat I activity near VS01 around 1838. A lull in the event occurred throughout the entire runway area from about 1840-1930. Then, the VS04 area initiated activity at ~1940. VS05 showed Cat I activity from about 1948-1953 and again at 1957. Cat II was first observed near VS03 and VS05 around 2025 with most runways in Cat I conditions. The area near VS02 was in Cat II conditions by 2030. The west interior part of the airport experienced Cat II conditions occasionally through 2110. The VS06 area experienced Cat II conditions at 2120 and intermittently thereafter up to 2130. Little or no activity was reported from about 2135-0010. Then, the VS01 area experienced intermittent activity; similar behavior occurred at the VS02 area from 0038-0041, the VS09 area briefly around 0047; the VS02 area at about 0102; the VS02 and VS05 areas at 0117; and the VS02 area at 0121. There was light activity at both north and south areas of the airport runway areas at 0128. VS11 area recorded Cat I and II conditions at 0140, followed by Cat I near VS09 at 0149. VS09 and VS11 areas

recorded Cat II conditions at 0154; the VS09 area had Cat II conditions at 0200 and the VS02 area had Cat I conditions at 0208. Little or no activity was observed from about 0235-0245. At 0248, Cat I conditions were recorded near VS04, followed by Cat III conditions at 0252; these conditions then spread east, being intense near VS04 by 0300 but light near VS10.

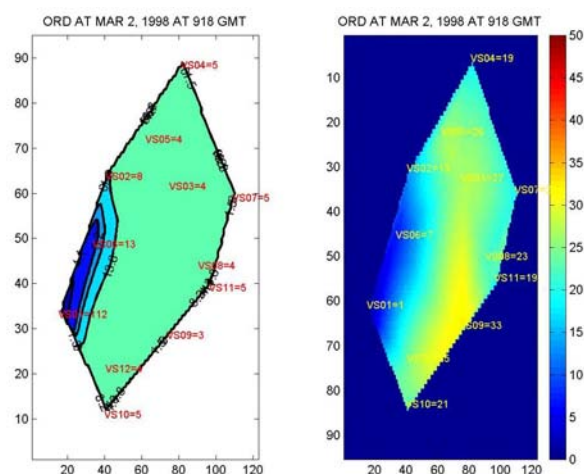


Fig. 15. Airport Contour and Extinction Coefficient (σ) Images at ORD (03/02/98). Note different scales.

Almost the entire ORD runway area had Cat III conditions by 0315 which up to 0405. Fig 15 shows contour and σ plots of the runway area at 0318. The contour plot shows Cat III conditions throughout except near VS01 on the SW. VS09 and VS11 areas had the lowest visibility with σ at times ranging between ~ 20 - 25 km^{-1} from 0320 to 0343. By 0354, activity began to decay near VS07 and, by 0359, there was less intense activity on the northern part of the runway area; later on this region again experienced uniform Cat III conditions at 0400. The VS11 area recorded lighter activity at 0405, followed by the VS07 area at 0416. The VS07 area recorded Cats I and II conditions by 0430, but the remaining area was Cat III. The last of the Cat III conditions was recorded at 0502, last of Cat II at 0506 and Cat I at 0513 with light activity continuing through 0530.

Feb 25, 2000 – Weather - METAR reported BR from 2056-0226, 0403-0613 and 1046 through the end of the event, FG from 0256-0356 and 0628-1038. Winds shifted from E to SSE during the course of the event with speeds from 5-9 kts, attaining highest values late in the event. The temperatures and dew points increased from 5°C at the start of the event to 12°C by the end of the event. The corresponding visibility-RVR event history plots along runways 4R/22L, 4L/22R, 32R/14L and 32L/14R are shown in Figs. 16-19, respectively; the event is discussed in the next two subsections.

Individual Runways - The event was intermittent from about 2130-0100. There were a few minutes of Cat II conditions experienced near MP along RW 32L/14R at about 2145 with Cat I conditions occurring for about 15 minutes before and 20 minutes after. The other runways

did not experience Cat II/III conditions until about 2230 at RO along RW 32L/14R and at RO along RW 4R/22L. Cat II/III conditions were experienced only on part of each runway at any given time during this period. There was a relative lull along RW 4R/22L from about 2305-0015.

The mist (BR) became more uniform after about 0120 along RW 4L/22R and after 0140 along RW 4R/22L with more intermittent activity from about 0000-0120 along RW 4L/22R and from 0020-0140 along RW 4R/22L. The onset was somewhat better defined along RW 4R/22L than at 4L/22R. The denser fog started at RO a few minutes before TD along RW 4R/22L. Onsets were more gradual along RWs 32L/14R and 32R/14L with RO experiencing Cat II/III conditions about 15 minutes prior to TD with more intermittent activity at RO and MP along both runways a couple hours prior. RO had its onset at about 0100 on RW 32R/14L and at about 0120 along RW 32L/14R.

Cat III conditions were uniform along RW 32L/14R from about 0145-0300; along RW 32R/14L from about 0125-0240; along RW 4R/22L from about 0130-0305; and along RW 4L/22R from about 0110-0255. Cat III conditions persisted somewhat longer at TD than along MP or RO along RW 4L/22R. The fog thinned from Cat III to Cat I gradually along RW 32L/14R from 0310-0350; along RW 32R/14L about 0250-0340; along 4L/22R about 0230-0400 and along RW 4R/22L from about 0300-0400.

The lull in the event between about 0300-0500 was only partial observed along RW 4R/22L with at least Cat I conditions persisting at TD and MP. RO stopped experiencing Cat I conditions from about 0340-0510 along RW 4R/22L. The lull lasted to about 0420 at RW 4L/22R. Cat I conditions resumed first along TD at about 0420. The lull was more intermittent at TD along RW 32L/14R through about 0435.

Cat I conditions resumed at RO there at about 0440 and to TD and MP by 0510. Cat I conditions resumed at TD along RW 32R/14L at about 0440 and spread to RO and MP there by 0515.

The last and most uniform part of this event was less dense than the previous part. Cat II conditions resumed at about 0525 along RO of RW 32L/14R and about 0535 at TD and about 0545 at MP. Cat II conditions resumed at TD and MP along RW 32R/14L at about 0520 and about 10 or 15 min later at RO. Cat II and III conditions were somewhat more uniform at RW 32R/14L than it was at RW 32L/14R. The fog and mist lasted until about 1100. It should be noted that there was almost no fog observed near MP along RW 32L/14R for a brief period at about 0700. The fog thinned to Cat I near TD from about 0710-0745 and approached RO at times along RW 4R/22L. Cat III was uniformly recorded almost continuously along RW 4R/22L from about 0550-0710 and again from about 0800-0915; along RW 4L/22R from about 0540-0900; along RW 32L/14R from about 0555-0655, 0710-0715 and 0800-0935; and along RW 32R/14L from about 0550-0750 and 0805-0925.

Decay was almost simultaneous across RWs 32R14L and 32L14R. The decay was more gradual along RWs 4L22R and 4R22L with decay at MP along 4L22R at about 1045 and about 10-15 minutes lasted at TD and RO. The decay started at RO along RW 4R/22L at about 0940 and reached TD about 15-20 minutes later.

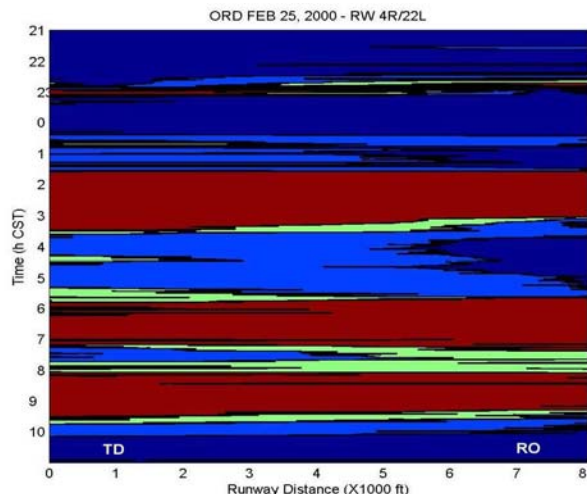


Fig. 16. Extinction Coefficient Time History Along ORD RW 4R/22L (02/25/00)

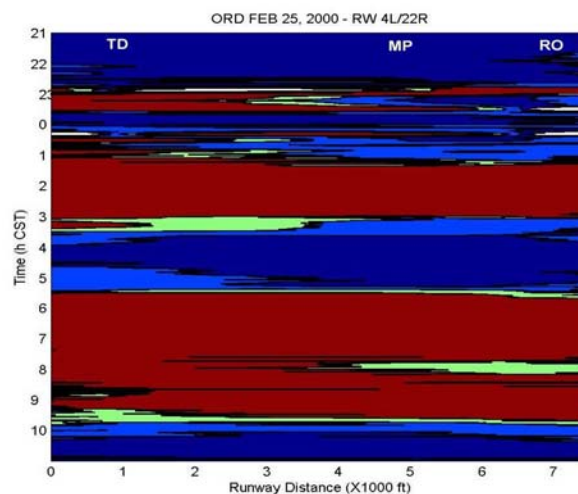


Fig. 17. Extinction Coefficient Time History Along ORD RW 4L/22R (02/25/00)

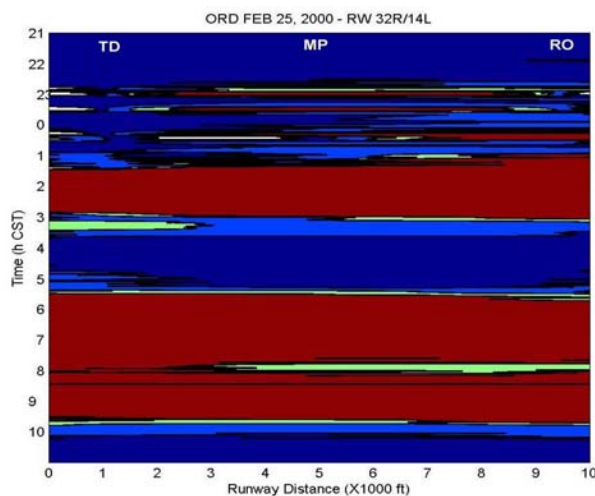


Fig. 18. Extinction Coefficient Time History Along ORD RW 32R/14L (02/25/00)

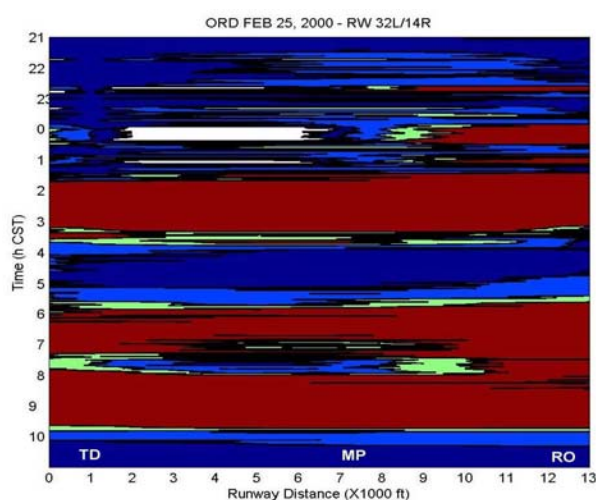


Fig. 19. Extinction Coefficient Time History Along ORD RW 32L/14R (00/25/00)

Runway Area - VS01 recorded first activity at about 2100 CST with the south side of the runway area recording activity a few minutes later; most of the area was affected by 2125. The first Cat I conditions occurred at VS05 at about 2130, followed rapidly by Cat II a few minutes later. Later on, VS05 and VS07 experienced Cat I conditions at 2153, followed by VS04 at 2200. At 2205, Cat I conditions were observed in different areas in the eastern and western interior portions of the runway area, up to about 2215 and then reoccurring again at 2220. Cat III conditions were first recorded near VS12 at 2232.

By 2237, the eastern and western parts of the runway area experienced Cat III conditions, followed by the southwestern and northeastern parts at 2245. By 2254, CAT III remained only at the northeastern part. Cat III conditions were recorded near VS03 by 2300 and expanded and contracted through 2331, then moved to

the northwest. The fog lessened to Cat I by 2345 in the western part with Cat II recorded in the extreme west by 2355. Cat III was recorded first in the extreme west at about 0000 and expanded and contracted through 0029. The Cat III area shifted to near VS07 at 0030, and then thinned to Cat I by 0040. Cat II and III conditions returned to the western part by 0050, shifted to the west center part by 0054, west at 0058 and north at 0100 and back west at 0103. Cat III conditions expanded and shifted south towards VS03 by 0120. Most of the runway area was in Cat III conditions by 0135 with the south side having the densest fog. The entire area

experienced Cat III conditions by 0145 with the south side experiencing the densest fog.

VS09 was the first sensor to go from Cat III to Cat II by 0255 with the event's decay progressing westward until only the VS05 area was recording Cat III by 0342; it was also the last one recording Cat II at ~ 0349. The event continued later on with VS01 indicating Cat I with intermittent Cat II around 0425.

The fog returned as most of the area experienced Cat I conditions by 0425, Cat II by 0525 and Cat III by 0531. The entire runway area was in Cat III conditions by 0555 for a brief time period and stayed all Cat III except for occasional Cat II on the south end through 0613. The latter were near VS05 at 0650 and 0705 and near VS02 at 0702. During this period, VS01 observed the least amount of fog at 0717 with Cat I or II conditions. At 0755, VS05 experienced Cat I conditions while the rest of the area had Cat II or III conditions. Cat III conditions covered most of the area by 1405, and the entire area at 0818. VS03 experienced Cat II conditions with Cat III elsewhere at 0840 with the entire airport being under Cat III at 0845 with greatest visibility being near VS03.

Final decay of this event began ~ 0920 with VS03 retreating into Cat I conditions and the VS10 area also improving. The entire runway area experienced mostly Cat II conditions by 0940 and Cat I by 0948. VS04 recorded the last Cat I condition at 1018.

shown in Figs. 20-23, respectively; the event is discussed in the next two subsections.

Individual Runways - The event first began at about 0705 MST at TD along RW 17R/35L and a few minutes later at TD at RW 17L/35R. The onset reached MP at about 0710 on both RW 17L/35R and 17L/35R; it then progressed to RO by 0720 as shown in Figs. 20-21. The event started by 0710 at MP along RW 16/34 and at RO on RW 7/25 by 0720 as shown in Figs. 22-23. Both runways were entirely in Cat II and III conditions by 0750.

At RW 16/34, all three VS experienced Cat III conditions from about 0810-1115 except for occasional very brief breaks at TD and RO exhibiting Cat III between 0735-0810 and 1115-1145. MP was the first to experience Cat III conditions at about 0730, then TD a few minutes later. RO did not first experience Cat III conditions until about 0750. RW 7/25 experienced uniform Cat III conditions from about 0805-1155; RW 17L/35R had Cat III from about 0735-1310; and RW 17R/35L had Cat III from about 0740-1240. RO had the longest Cat III conditions, lasting from about 0715-1410.

Decay occurred first at TD along RW 17R/35L with the Cat I conditions last experienced after 1420, although TD was in and out of Cat I conditions between about 1345-1510. MP was out of Cat I conditions around 1420

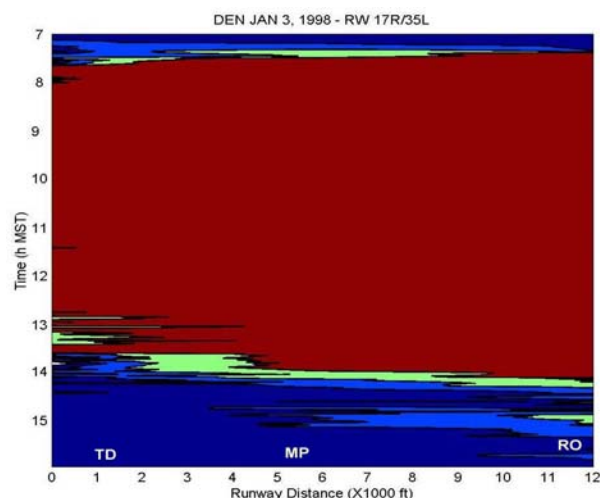


Fig. 20. Extinction Coefficient Time History Along DEN RW 17R/35L (01/03/98)

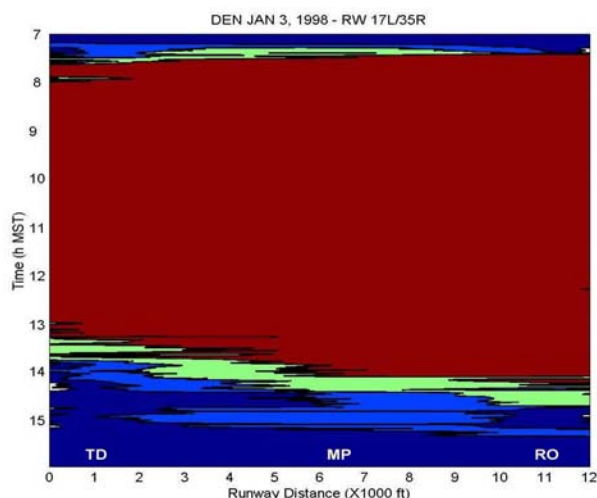


Fig. 21. Extinction Coefficient Time History Along DEN RW 17L/35R (01/03/98)

4.3 Denver (DEN)

Jan 3, 1998 – Weather – METAR reported FZFG from 0738-1426 MST. Winds peaked at 19 kts from the east at 0753 and diminished to 7 kts from ENE by 1426. Temperature and dew point varied from -2 to -3 °C. SN and BR were reported from 1447-1457 with calm winds at 1453. BR was reported at 1501-1625 with calm winds at 1601 and 4 kts from the W at 1725. Temperatures ranged from -3 to -5 °C with dew point depressions of 0-1 °C. The corresponding visibility-RVR event history along runways 17R/35L, 17L/35R, 7/25 and 16/34 are

at RW 17R/35L but re-entered Cat I conditions at about 1440 and was in and out of Cat I from 1440-1510. RO was in and out of Cat I conditions from 1420-1555 along RW 17R/35L. Meanwhile, the decay occurred first at TD on RW 17L/35R, gradually progressed to MP, then fairly quickly to RO. Cat II+ conditions ended at 1340 at TD, 1420 at MP and about 1445 at RO. The event decayed at TD roughly an hour before RO at RW 7/25. Decay first occurred at RO on RW 16/34, and then progressed to MP while fog thickened somewhat at RO between 1145-1300. After 1300, the fog dissipation largely

spread out from MP to both ends of the runway resulting in the end of the event by 1500.

Runway Area – Cat 1 conditions were first experienced near VS06 (east center interior and next to the terminal) at about 0710 MST and expanded considerably by 0716. Cat II conditions were first experienced east of the terminal at about 0720 and Cat III conditions followed a few minutes later. The area of Cat III conditions migrated to the south portion at 0725 and, by 0738, the northern and the southeastern parts were experiencing Cat III conditions. The whole area, except the southwestern corner, experienced Cat III conditions by 0743 and continued with fairly rapid variations until the whole area was in Cat III conditions at about 0806. The entire area remained in Cat III conditions until about 1045. During this time, the fog was generally denser on the eastern and northern parts of the area with minor variations on top of occasional periods of relatively uniform fog.

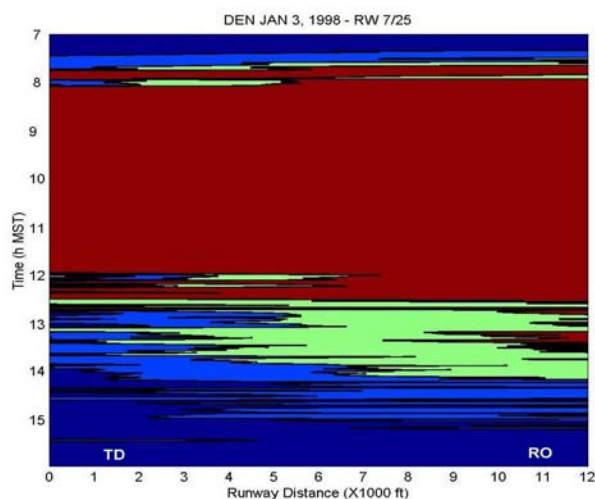


Fig. 22. Extinction Coefficient Time History Along DEN RW 7/25 (01/03/98)

At about 1048, the northeastern corner was experiencing Cat II conditions with the remaining area in Cat III. The whole area was re-experiencing Cat III conditions at 1056 until the fog thinned to Cat II towards the northwest at times by 1120. The entire area experienced Cat III conditions again at 1125, and then thinned to Cat II in the northeast by 1135. A contour plot at 1124 MST is shown in Fig. 24 with most of the runway area in Cat III conditions (light blue and green areas). The northwestern part was in and out of Cat II and III conditions between 1137-1155.

The fog then decayed with Cat I returning to the northwest corner by 1157. The VS13 area (southwest corner) was in Cat I or thinner fog with the southeast corner still in Cat III by 1201. Cat III conditions shifted to the southeast by 1212 with the northwest and middle in Cat II or I. Cat III conditions were confined to the southeast corner by 1355. By 1454, conditions were Cat I or better until 1454 when the VS04 area (southeast corner) re-experienced borderline Cat I/II conditions. The event ended in the northern part by 1510 with the

VS01 and VS04 areas in Cat I. VS04 was in Cat I until at least 1545.

Feb 1, 1998 – Weather – METAR reports indicated FZFG from 0101-0225 and 0253 MST with BR from 2153-0053, 0238 and 0306-0353. SN- was also reported from 2105-2349. Winds blew from the west at 3-6 kts during the SN- and early BR, then went to calm from 2353-0002, shifting thereafter from WSW to S then to SW by the end of the event. The temperatures decreased from 0 °C to -1 °C during the SN-, then went to -2 to -4 °C during the rest of the event. The dew point ranged from -2 to -4 °C during the event. The corresponding visibility-RVR event history plots along runways 17R/35L and 17L/35R are shown in Figs. 25 and 26.

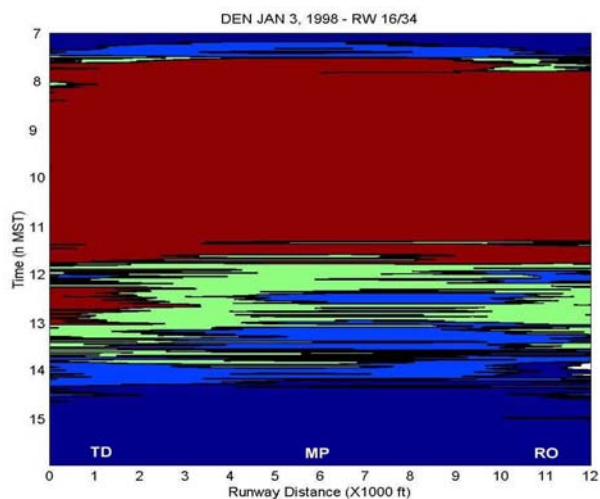


Fig. 23. Extinction Coefficient Time History Along DEN RW 16/34 (01/03/98)

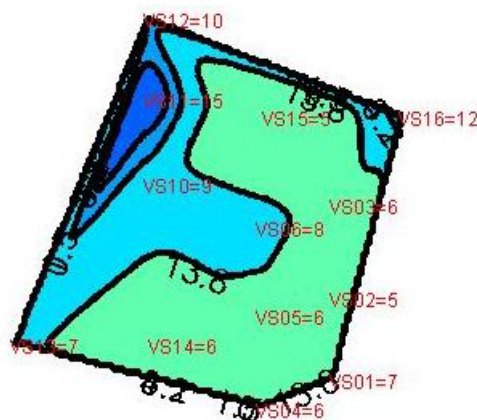


Fig. 24. Contour Image of RVR/Extinction Coefficient Over the Runway Area at DEN at 1124 MST (01/03/98)

Individual Runways - This event had a fairly gradual onset along RW 7/25 (not shown) with TD experiencing Cat I conditions first at 2330 on Jan 31 and attaining Cat III by 0040. RO experienced Cat I conditions by 2355 and Cat III by 0045. TD had the first elevated σ readings about a half hour before true onset at 2330. The onset was less gradual and more consistent along RW 16/34 (also not shown) with Cat I first experienced at TD at about 2330, then encompassing the entire runway by 0005. Cat III was first experienced at TD at about 0015 and covered the whole runway by 0030. Cat I conditions were first experienced at RO along RW 17L/35R at about 2350 with the entire runway in Cat I by 0020. Cat II and III conditions were first experienced at MP at about 0040, then RO at about 0055 and TD at about 0100. MP showed some fog dissipation at about 0100-0105. The entire runway was in Cat III conditions from about 0105-0210. Onset was quicker along RW 17R/35L with Cat I first occurring at RO at about 0020 and Cat III by 0045. The entire runway was in Cat III from about 0055-0240.

Runway Area – Cat I conditions were first recorded near VS13 (southwest corner) by 2303 and was intermittent through 2335. At 2335, Cat I conditions spread from the SW corner towards the NE. Much of the west side was in Cat I conditions by 0000. Cat II conditions first appeared by 0015, followed in a few minutes with Cat III conditions in the northwest interior. Cat II and III conditions were experienced in the southeast and northwest corners by 0029. The fog was much denser towards the northwest by 0035 and switched to the south and southeast corner by 0045. Only the northeast corner avoided Cat III conditions at about 0054. The entire area experienced Cat III conditions by 0105 with the densest fog generally in the west center interior, sometimes extending into the southeast or northwest. The Cat III fog became densest around west and south edges by 0122 and remained that way through 0140 with considerable minute-by-minute variability. The southwest corner went out of Cat III conditions by 0201. Cat III conditions were re-experienced in the entire runway area by 0211. The fog was densest in the northwest corner

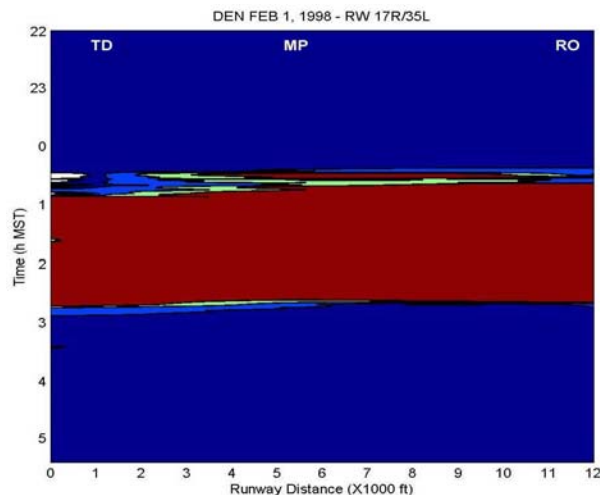


Fig. 25. Extinction Coefficient Time History Along DEN RW 17R/35L (02/01/98)

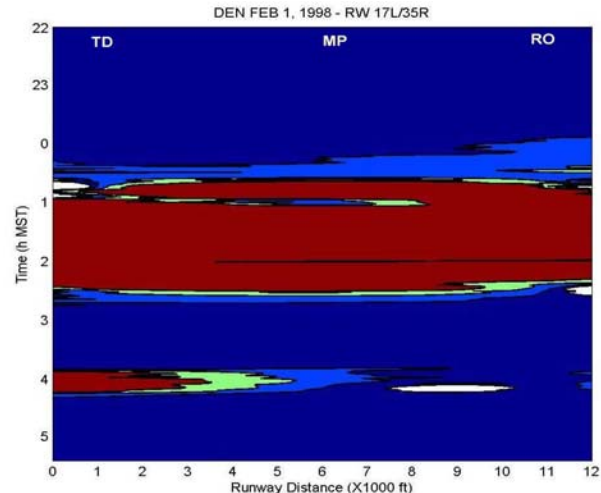


Fig. 26. Extinction Coefficient Time History Along DEN RW 17L/35R (02/01/98)

Decay was rapid along RW 17R/35L with the Cat III conditions ending within a few minutes after 0240 at MP and a few minutes after 0245 at RO and within 10 minutes of end of Cat III at TD at 0245. The event decayed less quickly at RW 17L/35R starting first at RO at 0210 and ending by 0245 at TD. TD and MP experienced some more fog between about 0345-0415. The decay was more gradual along RW 7/25 with Cat III ending about 0220 and Cat I ending by 0235 at TD and by 0245 at RO. Cat I resumed briefly at TD about 0300 and denser fog resumed at 0350 at RO and at 0400 at TD and ended at 0410 at RO and at 0435 at TD. The Cat I phase of the decay was somewhat longer at RW 16/34 starting first at TD by 0240 and at RO at 0305. The fog ended briefly by 0345 but resumed by 0400 at TD and by 0410 at RO and ended by 0445.

and thinnest near the southwest corner by 0220. By 0225, the fog was thinning out in the southwest and east edges and spreading inward. The south half of the area was out of Cat III by 0242. There was Cat II and III fog only towards the northern sections by 0258. Cat III conditions left the area from the northeast by 0306. Cat II conditions were absent briefly at 0310 then reappeared in north center part by 0313 and ended at 0325. Cat II and III conditions resumed in the northwest corner by 0331 for a few minutes with the remaining area in and out of Cat I conditions. There were intermittent Cat I conditions near VS14 about 0344. Cat III conditions resumed by 0355 in the south center and east center areas. At 0410, Cat III fog moved to the west side towards the south and center. The event finally receded northwards at 0445 and ended by 0450.

4.4 Auto-Correlations

Auto-correlations were calculated for each VS from 58 different samples during the events discussed in this paper. Each sample consisted of 15 one-minute records with a maximum lag time of 15 minutes. As a result, 580 auto-correlations were computed. Of these, about 41.5% had auto-correlation times of 2 minutes or less and more than half had 3 minutes or less autocorrelation times. The plot is shown in Fig. 27. This result indicates that visibility during intense RVR events can vary quite rapidly at a single location. This result is consistent with the considerable spatial and temporal variations observed in the previous history images of RVR along runways and over airports.

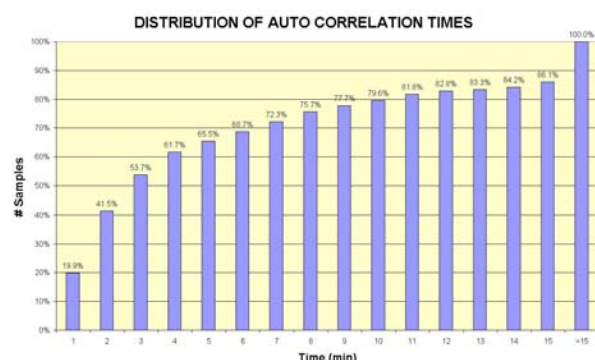


Fig. 27. Cumulative Auto-Correlation Distribution

5. CONCLUSIONS

This paper examined a few selected RVR events at PDX ORD and DEN, looking both along selected ILS runways and over the entire airport. The results provide important insights into behavior of RVR events. The spatial and temporal variations were often significant over the length of runways and over time scales of the order of minutes, respectively. Interpolations of sensor data from arrays of runways were found useful for assessing visibility over the most critical part of the airport. However, they also suggest that a more complete picture of changing visibility would be possible if additional sensors were placed strategically along or just outside the perimeter of airports. Although not discussed in detail here, it appears that local geography and airport layout can influence RVR; for example, the possible influence of the Columbia River on PDX visibility. More extensive study is clearly required in order to place the behavior of visibility events within the context of forcing mesoscale conditions. Data should be gathered and analyzed over many years at many airports in order to fully understand the climatology of visibility and relate these to forcing conditions. Relating these to actual and projected airport operational scenarios is also needed to enhance safety and efficiency of airport operations.

6. REFERENCES

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