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**Stable Auroral Red Arc
Occurrences Detected by the
Pacific Northwest Laboratory
Photometer Network: A Decade
of Observations, 1978-1988**

**D. W. Slater
E. W. Kleckner**

November 1989

**Prepared for the U.S. Department of Energy
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SUMMARY

Using data obtained from a network of all-sky scanning photometers designed to operate routinely for long periods of time, a comprehensive inspection of observations covering the time period 1978-1988 has revealed features that we interpret to be Stable Auroral Red (SAR) arcs during 250 nighttime observing periods. These arcs result from high temperature within the ionospheric electron gas that is maintained by slow leakage of energy from the earth's magnetosphere. A listing of these events, the most complete available for this time interval, is presented for the purpose of complementing observations reported for earlier dates. This listing is composed of location of the observing photometer, date, time, photometric intensity, and location (as defined by the earth's magnetic coordinate system). The intent is to make these observations available to a broad range of researchers and thereby initiate further investigations of these features.

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INTRODUCTION

The existence of monochromatic 6300Å emission features now referred to as Stable Auroral Red (SAR) arcs was first reported during the International Geophysical Year period by Barbier (1958). Although displays have occasionally exceeded 3 kiloRayleighs (kR) at the 6300Å emission line of atomic oxygen, the very stability and relative weakness that typically mark these arcs prevented their recognition until that time. Since then, research has repeatedly suggested the strong relationship between the position of SAR arcs and the plasmapause density gradient (Chappell et al. 1971; Carpenter 1971; Nagy et al. 1972). Attention was directed toward the terrestrial ring current as a potential source of energy to maintain the emission when early findings of Rees and Akasofu (1963) indicated a strong correlation between the presence of SAR arcs and post-storm-time enhanced Dst magnetic indices.

Various energy transfer mechanisms have been formulated, including the thermal conduction model originally proposed by Cole (1965). Thermal conduction models have in common the preferential excitation of atomic oxygen to the (¹D) state by electrons in the high-energy tail of a Maxwellian temperature distribution. High temperatures within the ionospheric electron gas are then maintained via conduction of heat along magnetic field lines threading the plasmasphere/ring current interaction region. Cole's original model relied on transfer of energy from the ring current plasma to plasmaspheric electrons through Coulomb collisions. Later, measurements of high energy protons within the ring current population prompted Cornwall et al. (1971) to suggest the presence of ion cyclotron turbulence, which could then be absorbed by plasmaspheric electrons via Landau damping. Recent measurements of large increases of heavy ion concentrations (notably O⁺ and He⁺) in post-storm ring currents have raised questions regarding growth rates and frequencies of ion cyclotron waves to be expected in the equatorial region. Kozyra et al. (1984) have extended the theory of Cornwall et al. (1971) to these situations and find that low-frequency oxygen cyclotron wave growth may maximize just inside the plasmapause. As the phase velocity of these waves is comparable to the electron parallel thermal velocity, Landau damping of these waves by thermal electrons may proceed. Alternatively, these waves may selectively heat ambient cold ion populations that could transfer this energy through coulomb collisions with the electron gas. Direct transfer of energy from energetic ring current O⁺ to the electron gas through coulomb collisions has also been suggested (Kozyra et al. 1987). An alternative proposal by Hasegawa and Mima (1978) utilizes the existence of kinetic Alfvén waves to provide for the direct precipitation of heated electrons into the SAR arc region. Confirmation of the actual energy transfer process(es) remains to be accomplished (see, e.g., Lanzerotti et al. 1978; Lundblad and Sorass 1978), but recent measurements of highly variable ion composition within the ring current must be considered in future work. Excellent review articles have been presented by Roach and Roach (1963), Nagy et al. (1970), Hoch (1973), and Rees and Roble (1975).

Since the initial recognition that SAR arcs are distinct in nature from the more easily detected auroral emissions resulting from energetic particle precipitation, summaries of SAR arc events have been published by Cruz et al.

(1965), Marovich (1966), Hoch and Clark (1970), and Slater and Smith (1981). No similar compilation that is intended for distribution to researchers exists for solar cycle 21. As much of our present understanding derives from studies of relatively few events, the present effort is an expansion of the previous work; to update measurements of these events through 1988. Figure 1 illustrates the period covered by this report in relation to solar activity (as defined by sunspot number). This period more than any other provides the opportunity of coincident measurements among ground-based and satellite-borne instrumentation. For this report, data acquired by the Pacific Northwest Laboratory's (PNL) North American photometer network have been scrutinized in a comprehensive search for SAR arc events. Features that we interpret to be SAR arcs during the time interval 1978-1988 are reported.

FIGURE 1. Time Period Included in this Report in Relation to Recent Sunspot Cycle

OBSERVATIONS AND DISCUSSION

Beginning in 1975, an expansion of the PNL photometer network began that has permitted routine nighttime observations of auroral emissions across North America. Table 1 describes the evolution of the Mobile Automatic Scanning Photometer (MASP) network, listing both the location and time of residence at each of the sites selected for MASP placement. Observations typically consist of "all-sky" mappings of atmospheric emissions obtained during sequences of altazimuthal scans performed by the MASPs. Spectral discrimination is provided by narrow bandwidth (10Å) interference filters. For a more thorough discussion of data reduction techniques, see Slater et al. (1980) or Kleckner et al. (1981). Figure 2 depicts the regions that are viewed by the MASP units, assuming an emission altitude of 350-400 km that is typical for SAR arc emissions; the shaded area represents the composite of areas monitored by the network.

TABLE 1. PNL MASP Network

<u>Location</u>	<u>Latitude/Longitude (Inv. Lat.)</u>	<u>Period</u>
Washington (WASH)	46.4°/240.4° (52.7°)	Jan 1976 - Present
West Montana (W MO)	48.9°/244.9° (56.3°)	Sept 1980 - Aug 1983
West Montana (W MO)	47.1°/246.7° (54.8°)	Aug 1983 - Present
East Montana (E MO)	48.6°/252.9° (57.7°)	Jan 1976 - Sept 1981
Colorado (COLO)	40.1°/254.8° (49.3°)	Dec 1977 - Present
Michigan (MICH)	46.1°/271.9° (57.8°)	June 1977 - Present
New York (NY)	42.6°/286.0° (55.0°)	June 1978 - Oct 1980
Alberta, Canada (ALBT)	53.2°/246.7° (61.1°)	Sept 1978 - Dec 1984
Alberta, Canada (ALBT)	50.9°/245.7° (58.4°)	Oct 1985 - Oct 1987
Alberta, Canada (ALBT)	51.2°/245.8° (58.7°)	Oct 1987 - Present
N. W. Terr., Canada (NWT)	61.3°/242.4° (68.0°)	Mar 1979 - Sept 1981

Figure 3 provides an example of data acquired during an extraordinary SAR arc that existed throughout the night of March 6, 1981. This event followed the occurrence of a major geomagnetic storm during the previous day. This figure represents measurements of the 6300Å emission rates (encoded with respect to the color bar) acquired from several of the MASP sites, and subsequently combined to achieve this mapping of a SAR arc across the entire North American continent. A noteworthy feature is the nearly complete lack of emissions from the auroral zone at high latitudes; this is extremely rare during SAR arcs of this intensity.

Sensitivity of the photometric equipment is such that regions of approximately 10 Rayleighs (R) enhancement may be detected by the all-sky mapping technique. Using data reduction techniques designed specifically to enhance the detectability of arc-like structure, we have completed a thorough search of data collected during the 1978-1988 period. The major criterion used for identification of SAR arcs in this report is an enhancement of 6300Å emission rates in excess of approximately 40 R. This value has been chosen in an effort to avoid instrumental noise while

FIGURE 2. Composite of the Circular Regions Monitored by Each MASP Unit, Showing the Area Viewed by the Entire North American Network. The altitude of 6300Å emission is assumed to be 350-400 km. L-shells of the Earth's magnetic field are represented by dashed lines.

simultaneously detecting weak SAR arcs. Other factors used in assessing the presence are morphology of the enhancement and spectral purity, as indicated by measurements of 5577Å ($O(^1S)$) and 4278Å ($N_2^+(1NG)$) emissions. Simultaneous detection of SAR arc structure by adjacent MASP units also has weighed in these decisions.

Table 2 is a catalog of SAR arc occurrences, as identified by the PNL photometer network^a. This table consists of dates, time of observation (UT), location of MASP unit making identification, approximate intensity, and position (as defined by magnetic L-shell given within parentheses). For determining position, an emission altitude of 350 km is assumed.

^a It is recommended that users of this data contact the authors before use in quantitative studies. Values stated are hourly averages and may vary during any interval of interest.

SAR Arc: March 6, 1981

FIGURE 3. 6300Å Emission Rates, Encoded by the Accompanying Color Bar, During the SAR Arc that Occurred March 6, 1981. Observations from individual MASPs are depicted by circular regions. Not all sites were operational during certain periods of the night, dependent on solar depression and cloud conditions.

SAR Arc: March 6, 1981

FIGURE 3. Continued.

Inspection of Table 2 suggests that the probability of an observable SAR arc closely follows the variations of solar activity as described by the 11-year solar activity cycle, though with a possible phase delay of 2-3 years as previously reported by Slater and Smith (1981). As these features can represent a situation in which a relatively well-defined amount of heat energy is introduced into the thermosphere from the magnetosphere, they may present the opportunity for testing predictions derived from theoretical studies of thermosphere dynamics, independent of the more extreme conditions produced by active aurorae. It is the authors' hope that in making these data available to researchers, additional studies will be made possible, particularly of the class that use simultaneous *in situ* measurements of plasma properties within the arcs as well as within the equatorial plane of the magnetosphere from which the energy to sustain these emissions is believed to originate.

TABLE 2. SAR Arc Observations, 1978-1988

1978													
Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
Apr 12 COLO WASH							40(3.3)	120(2.8)	40(2.8)	100(2.8)	80(2.8)		
May 2 MECH WASH				40(2.7)		180(2.7)	200(2.7)	150(2.5)					
Jan 5 WASH								60(3.0)					
Jan 30 MECH						40(3.2)							
Aug 4 MECH					150(3.5)		50(3.0)						
Aug 29 WASH						50(2.9)	50(2.8)						
Sep 10 NY						40(3.5)	40(3.5)						
Sep 28 COLO NY	500(3.2)	250(3.1)					150(2.8)	70(2.7)	50(2.7)	110(2.5)	90(2.4)		
Sep 29 COLO NY				40(3.1)					100(2.3)				
Sep 30 WASH								80(3.2)					
Oct 27 WASH				40(3.1)	40(3.1)			120(2.8)					
Oct 30 WASH NY									250(3.2)	300(2.9)	280(2.9)	250(2.8)	200(2.7)
Oct 31 WASH NY		300(3.3)	250(3.2)	250(3.3)	50(3.3)	120(3.2)	100(3.3)	120(3.2)	130(3.2)	150(3.1)	170(3.1)	160(3.0)	160(3.1)
Nov 1 WASH											100(2.9)	100(3.0)	60(3.0)
Nov 2 WASH COLO												80(2.8)	80(2.7)
Nov 25 WASH											100(2.9)		
Nov 26 NY		400(3.0)	450(3.0)				350(2.5)	300(2.6)	300(2.5)	200(2.5)			
Dec 19 MECH NY	900(3.1)	700(3.1)		50(3.3)	400(3.1)		300(2.9)	400(2.9)	300(2.9)	200(2.8)			
COLO ALBT			160(3.4)	180(3.4)	200(3.4)	220(3.4)	180(3.2)	130(3.2)	100(3.1)				
Dec 21 COLO							40(3.4)						
Dec 27 MECH				50(3.7)									
1979													
Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
Jan 3 MECH ALBT			50(3.7)	40(3.6)									
Jan 4 MECH NY			100(3.2)	200(3.3)	180(3.3)	140(3.0)	80(3.0)	80(3.0)	70(2.6)	100(2.8)	80(2.8)		

TABLE 2 (Cont.)

1979 cont.

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Jan 5 WASH			200(3.1)	250(3.0)	180(2.9)	200(3.0)								
MICH	300(3.0)	350(2.9)	200(2.9)											
NY	300(2.8)	280(2.7)	220(2.7)	160(2.8)	100(2.8)	50(2.8)	40(2.8)							
Jan 6 WASH														120(3.3)
Jan 23 WASH						120(3.6)	100(3.5)	150(3.6)	100(3.5)			200(3.4)	250(3.1)	
Feb 21 COLO									400(2.7)					
Feb 22 COLO						500(3.0)	400(3.0)	350(2.9)	300(2.8)	220(2.7)	240(2.7)	120(2.6)		
Feb 24 MICH							50(3.5)	40(3.4)	50(3.3)	90(3.3)				
Feb 27 MICH		250(3.2)	200(3.2)	90(3.1)										
Mar 22 WASH												1400(3.1)		
Mar 23 WASH					150(3.1)		300(3.4)	350(3.3)	250(3.3)	200(3.4)	200(3.5)	250(3.5)		
NY			180(3.5)	220(3.3)	250(3.3)	250(3.3)	200(3.3)	160(3.3)	100(3.3)			250(3.8)		
ALBT														
Mar 34 WASH								60(3.5)						
NY								60(3.5)	60(3.3)					
Mar 26 MICH			100(3.5)	50(3.3)										
Mar 27 NY									40(3.0)					
Mar 28 NY		60(3.2)	70(3.1)	50(3.1)	40(3.1)		50(2.8)	50(2.8)						
ALBT														
Mar 29 WASH										450(2.6)	400(2.6)	250(2.6)		
Apr 3 MICH						50(3.3)	60(3.3)	150(3.2)	140(3.3)	100(3.3)				
ALBT						100(3.5)				150(3.4)	120(3.4)			
Apr 4 NY							120(2.8)	100(2.7)	80(2.6)					
COLO									300(2.5)	220(2.5)	200(2.5)			
Apr 5 WASH					100(2.9)	150(2.8)	200(2.8)		500(2.8)	400(2.8)	350(2.8)			
COLO					60(2.7)	50(2.7)								
Apr 22 B MO							70(2.9)							
MICH								60(2.6)						
COLO							100(2.8)							
Apr 23 MICH				150(3.4)										
NY				150(3.2)										
ALBT						100(3.4)								
Apr 28 WASH						50(3.1)					50(3.1)			
MICH				50(3.0)	50(2.9)									
Apr 30 WASH						50(3.0)	80(3.0)	60(3.0)	40(3.0)	40(2.9)				
Jul 27 WASH							300(3.1)	200(3.1)	100(3.0)	100(3.1)				
Aug 21 WASH							100(3.0)	90(2.9)						

TABLE 2 (Cont.)

1979 Cont.

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Aug 30 WASH MICH NY		80(2.7)	100(2.6)	120(2.7) 80(2.5)	500(2.7) 180(2.7) 80(2.3)	400(2.6) 120(2.7) 40(2.5)	80(2.7) partially blocked	60(2.7)	60(2.7)					
Sep 18 WASH								1000(2.8)	800(2.6)					
Sep 21 WASH						100(3.5)	80(3.2)	40(3.2)						
Sep 26 MICH				50(3.7)										
Sep 27 WASH NY				80(3.2)	70(3.2)	40(3.2)					40(3.4)	50(3.4)		
Oct 8 WASH COLO ALBT				700(3.1) 200(3.0) 100(3.1)	450(3.0)		150(3.0)	80(3.0)	100(2.9)	250(2.8)				
Oct 13 B MO ALBT						50(3.9)	30(3.9)	80(3.8)	40(3.9)					
Oct 22 ALBT				100(3.7)	100(3.7)									
Nov 11 B MO MICH			50(3.6)	40(3.6)	40(3.7)	50(3.7)								
Nov 13 B MO COLO					450(3.5)	400(3.2) 350(3.1)	350(3.1) 350(3.0)	250(3.1) 300(2.9)	200(3.1) 320(2.9)	300(3.0) 480(2.8)	280(2.9) 500(2.7)	300(2.9) 700(2.6)	350(2.9)	
Nov 14 B MO MICH COLO		250(3.4)	400(3.3)	450(3.1)	500(3.1)	450(3.1)	380(3.0)	300(3.0)	200(3.0)	140(3.0)	70(3.1)	80(3.1)	70(3.1)	
			200(3.0)	400(3.0)	650(3.0)	600(3.0)	600(2.9)	400(3.0)	250(3.0)	220(3.0)	200(3.0)	180(3.1)		
Nov 25 MICH			200(3.5)	220(3.2)	180(3.1)	120(3.2)	50(3.2)							
Dec 17 MICH								100(3.6)	90(3.3)					
Dec 27 B MO									300(3.8)	100(3.8)				
Dec 28 ALBT B MO												50(4.0)	300(3.7)	100(3.3) 1000(3.2)
Dec 29 MICH					100(3.5)	80(3.3)	100(3.2)	80(3.2)		50(3.1)	60(3.0)			
1988														
Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Jan 15 WASH COLO						80(3.3) 50(3.2)	100(3.3) 60(3.3)							
Jan 17 B MO												80(3.9)		
Jan 28 WASH														60(3.1)
Feb 14 MICH											150(3.5)	150(3.4)		
Feb 16 MICH B MO				100(2.7) 700(3.0)	800(2.9)	600(2.9)					150(2.7)	120(2.6)	180(2.6)	
Feb 19 NY					100(3.4)									
Feb 27 MICH											60(3.4)			

TABLE 2 (Cont.)

1988 Cont.

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Mar 22 WASH MECH			150(3.7)	150(3.7)	40(3.5) 90(3.6)	50(3.5)	80(3.4)	70(3.4)	40(3.5)					
Mar 26 WASH					200(3.2)		180(3.4)							
Apr 7 NY								50(3.4)	100(3.4)					
Apr 12 NY COLO HMO		150(3.1)	170(3.1)	160(3.1)	100(3.0)	150(3.0)		90(2.9)	80(2.9)					
					150(3.3)	180(3.3)				50(3.2)	90(3.1)			
Apr 13 WASH HMO							40(3.1) 50(3.3)	50(3.0)	40(3.0)					
May 12 WASH							50(3.1)	40(3.0)	40(3.0)					
Jun 12 COLO						50(2.7)	50(2.7)	40(2.6)	40(2.4)					
Jul 19 WASH NY							200(3.3)	200(3.3)		160(3.4)				
					80(3.3)									
Sep 6 MECH					40(4.0)	50(4.0)	50(3.9)	40(4.0)	40(4.0)					
Oct 4 WMO							100(3.4)	80(3.4)	40(3.5)					
Oct 5 WASH WMO ALBT				220(3.3) 170(3.3) 220(3.5)	280(3.1) 200(3.2) 200(3.4)	200(3.1) 120(3.1) 180(3.4)	180(3.0) 140(3.1)	150(3.0)	130(3.0)	140(3.0)	190(2.9) 70(3.0)	100(2.9) 50(3.0)	100(2.9)	
Oct 6 WASH WMO									140(3.0) 50(3.3)	100(3.0) 50(3.1)	50(3.0) 50(3.1)			
Oct 11 WASH WMO HMO									200(2.8)	250(2.7)	150(2.7)			
			70(3.4)	60(3.3) 80(3.4)	60(3.2) 120(3.2)	50(3.1)								
Oct 19 MECH										80(3.5)				
Nov 10 HMO											90(4.3)			
Nov 12 WASH								40(3.3)						
Nov 15 WASH											80(3.0)			
Dec 1 MECH		40(3.5)		50(3.4)	50(3.4)									
Dec 16 WASH WMO													80(3.2) 70(3.5)	120(3.0) 120(3.3)
Dec 18 WASH MECH COLO								180(3.6)	100(3.5)	100(3.3) 120(3.0)	100(3.3) 90(3.2) 100(3.0)			
Dec 19 MECH											50(3.5)			

TABLE 2 (Cont.)

1981

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Jan 1 E MO					50(3.5)	40(3.5)								
Jan 11 MICH E MO					50(3.5)	80(3.5)								
Jan 31 WASH												50(3.0)	40(3.0)	
Feb 3 MICH COLO								80(3.6)	100(3.5)	150(3.2)	80(3.0)			
Feb 5 COLO										100(3.2)				
Feb 6 WASH COLO							40(3.4)	50(3.5)	40(3.5)	40(3.5)	60(3.5)		40(3.4)	
Feb 7 WASH COLO E MO			320(2.9)	200(3.0)	190(2.9)	220(2.9)	140(2.8)	100(2.8)		120(2.9)	140(2.8)			
Feb 23 E MO					250(3.0)	150(3.0)	160(3.0)	170(3.0)	120(3.0)	120(3.0)		140(2.9)	100(2.8)	
Feb 25 WASH E MO					50(4.0)							70(2.9)		
Mar 2 W MO COLO						40(3.4)	50(3.4)							
Mar 6 WASH MICH COLO ALBT E MO									50(3.2)			50(2.6)		
Mar 8 MICH E MO												50(3.3)	50(3.4)	
Mar 14 WASH MICH W MO														
Mar 15 WASH MICH W MO COLO E MO														
Mar 27 MICH W MO ALBT														
Mar 31 COLO														
Apr 1 WASH MICH														
Apr 14 WASH W MO COLO ALBT E MO														
Apr 23 COLO														
Apr 28 COLO E MO														

TABLE 2 (Cont.)

1981 Cont.

Time	8-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Apr 27 WASH							60(2.9)	50(2.8)		40(2.8)	40(2.7)			
Jun 29 WASH										50(2.7)				
Jun 30 MOCH					40(3.6)	50(3.6)	50(3.6)							
Jul 1 MOCH					40(3.7)									
Jul 13 WASH								70(2.9)						
Jul 26 WASH						60(2.3)	40(2.3)	50(2.3)	40(2.3)					
Aug 23 WASH E MO						100(3.5) 200(3.5)	40(3.4)							
Aug 24 E MO						40(3.0)								
Aug 25 WASH COLO								40(3.3)		40(3.0) 40(3.0)	40(3.0)			
Aug 26 WASH									40(3.4)	40(3.3)				
Sep 19 MOCH			700(3.6)											
Sep 27 COLO											40(3.1)			
Oct 4 WASH						50(3.3)	70(3.4)	60(3.3)	40(3.3)					
Oct 8 MOCH COLO WASH		200(3.3)	150(3.2)	100(3.1)	150(3.1)		160(3.1) 70(3.1) 150(3.1)		90(3.0)	100(2.8)				
Oct 14 WASH						1200(2.9)	1400(2.9)	2000(3.0)	1000(3.0)	600(2.9)				
Oct 19 WASH											40(3.1)			
Oct 20 WASH MOCH COLO					100(3.4) 80(3.3)					40(3.3)	80(3.1)	200(2.9)	180(2.8)	
Oct 21 WASH MOCH COLO		2000(2.9)	2000(2.8) 2200(2.9) 2000(2.6)	2200(2.7) 2000(2.8) 2100(2.6)	1800(2.7) 1300(2.7)	1700(2.7) 1100(2.7)	1600(2.7)	1650(2.7)	1600(2.6)	1500(2.6)	1300(2.5)	800(2.5)	600(2.5)	
Oct 22 WASH			40(2.6)	90(2.5)	80(2.6)	70(2.6)								
Oct 23 WASH COLO W MO		1000(2.5)	1200(2.7)	1000(2.6)	950(2.6)	750(2.6)	600(2.6)	700(2.6)	500(2.5)	800(2.5)	500(2.6)	450(2.6)	400(2.6)	
Oct 25 WASH COLO									60(3.0) 50(2.9)	50(3.0) 50(2.9)	50(2.9) 40(2.9)	50(2.8)	50(2.8)	
Nov 7 WASH MOCH W MO							180(3.1) 200(3.2)	200(3.1) 100(3.3)	100(3.1)	80(3.0) 150(3.1)	90(3.0)	100(3.0)	100(3.0)	
Nov 15 WASH			100(3.0)	120(3.0)	80(3.1)	100(3.2)		50(3.2)						
Nov 18 COLO							50(3.0)	100(3.0)	160(2.9)	120(2.7)	150(2.5)	170(2.5)	170(2.4)	

TABLE 2 (Cont.)

1981 Cont.

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Dec 18 MOCH					60(4.0)	70(3.8)		70(4.0)						
Dec 29 WASH MOCH							250(3.5)	400(3.2) 280(3.1)	500(2.9) 400(2.9)	550(2.8) 300(2.9)	350(2.7) 200(2.8)	200(2.7)		
Dec 30 MOCH									400(3.0)	500(3.0)	300(3.0)	200(3.0)		

1982

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Jan 17 WASH									40(4.0)		70(3.5)	50(3.5)		
Jan 31 WASH														50(2.8)
Feb 4 WASH MOCH		200(3.2)	100(3.1)		40(3.1)	40(2.9)	80(2.9)	100(2.9)	50(2.9)	80(2.9)		100(2.8)	80(2.7)	80(2.7)
Feb 11 MOCH		200(3.3)	250(3.2)											
Feb 12 WASH						100(3.2)								
Feb 19 COLO						80(2.9)	40(2.9)	40(2.9)						
Feb 23 WASH							100(2.8)	100(2.8)	80(2.8)	80(2.8)	40(2.7)	50(2.7)		
Feb 24 WASH							40(3.0)							
Mar 2 WASH					400(2.5)	250(2.5)	1300(2.5)	700(2.5)	800(2.5)	900(2.3)				
Mar 3 MOCH		50(3.1)	60(3.1)	60(3.1)	70(3.0)	100(3.0)								
Mar 22 WASH							100(3.0)	100(2.9)	40(2.9)	40(2.9)	40(2.9)	50(2.9)		
Apr 3 COLO				40(2.9)		80(2.8)	350(2.7)	100(2.5)						
Apr 21 MOCH				40(3.5)										
Jun 23 WASH							450(3.2)	150(2.9)	50(2.9)					
Jul 19 MOCH					50(3.5)									
Aug 17 MOCH						300(3.7)	150(3.6)							
Sep 7 WASH					50(2.4)									
Sep 19 MOCH						100(3.4)								
Sep 22 WASH COLO			60(2.9)	100(2.6)	130(2.3) 160(2.3)	100(2.3) 250(2.2)	80(2.2) 200(2.0)	140(1.7)						
Sep 27 COLO WASH W MO				300(2.5)	200(2.5)	160(2.5) 90(2.6)	160(2.5) 100(2.6)	180(2.5) 140(2.6)	190(2.5) 160(2.6)	170(2.5) 120(2.6)	130(2.4)	100(2.4) 100(2.5)		
Oct 7 COLO				80(3.0)										
Oct 14 WASH COLO W MO			40(3.0)	50(3.0) 70(3.0) 60(3.0)	60(2.9) 50(2.9)	50(2.8) 40(2.9)	40(2.8) 40(2.9)	40(2.7)						

TABLE 2 (Cont.)

1982 Cont.

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Nov 11 WASH												50(3.1)		
Nov 16 MICH							50(3.7)							
Nov 22 WASH				160(3.0)	250(2.8)	300(2.8)	350(2.8)	350(2.8)	200(2.8)	100(2.8)				
COLO				130(2.8)	280(2.7)	320(2.6)	350(2.7)	200(2.6)	150(2.6)					
WMO				200(3.0)	250(2.8)	200(2.8)	300(2.8)	300(2.8)	100(2.8)					
Nov 23 WASH							50(2.9)							
Nov 25 MICH		240(2.8)	60(2.7)											
Dec 8 WASH				140(3.5)	100(3.4)	100(3.3)	90(3.3)	100(3.2)						
MICH	220(3.5)	240(3.4)	250(3.4)	160(3.4)	160(3.3)	170(3.3)	160(3.3)							
ALBT				250(3.7)	180(3.6)									
WMO				150(3.7)	200(3.4)	160(3.4)	140(3.3)	200(3.1)						
Dec 9 MICH				60(3.3)	90(3.2)	60(3.2)	50(3.2)	40(3.2)						
Dec 10 WASH									80(2.8)	140(2.6)	220(2.5)	150(2.6)		
Dec 17 WASH										100(2.7)				
MICH	100(3.6)	110(3.5)	150(3.4)	150(3.3)	150(3.3)	140(3.2)	120(3.1)	100(3.0)						
COLO				40(3.2)	40(3.1)					140(2.5)	150(2.5)	110(2.4)	100(2.3)	
Dec 18 COLO											100(2.5)	80(2.5)		
Dec 19 WASH														60(2.9)
Dec 22 WASH					100(2.6)									

1983

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Jan 10 COLO				400(2.6)		700(2.4)	800(2.3)	600(2.2)	300(2.2)	250(2.3)				
Feb 5 COLO			300(2.7)	300(2.5)	400(2.4)	200(2.3)								
WASH					300(2.6)	150(2.4)	130(2.4)							
Feb 6 WASH				60(2.7)										
COLO			100(2.5)	50(2.5)	60(2.5)	40(2.6)	40(2.5)	50(2.4)						
Mar 3 COLO				40(3.0)	40(2.8)									
Mar 12 MICH		40(3.4)												
Mar 13 MICH		50(2.9)				40(2.9)	40(2.9)	40(2.9)						
May 23 WASH							80(3.0)							
Sep 8 MICH								80(3.9)	200(3.5)	200(3.3)				
Oct 15 MICH			80(3.7)	50(3.5)	50(3.5)									
WASH												40(3.1)	40(3.0)	
Oct 18 WASH									50(2.9)	50(2.5)				
Oct 29 MICH		300(3.8)	100(3.8)											

TABLE 2 (Cont.)

1983 Cont.

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Oct 30 MOCH		50(3.8)	60(3.5)	60(3.5)	40(3.4)	40(3.3)								
Nov 8 WASH												70(2.8)	40(2.8)	
Nov 12 WASH WMO							70(3.0)	40(2.9)		50(2.3)	40(2.3)	40(2.3)		
Dec 8 MOCH			40(3.6)											
Dec 30 MOCH									100(3.2)					

1984

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Feb 4 WASH							40(3.0)							
Mar 6 WASH									60(3.2)					
Apr 10 MOCH					120(3.7)	100(3.3)								
Sep 4 WMO									160(3.1)					
Sep 5 COLO							50(2.5)	40(2.4)	40(2.5)					
Sep 19 WMO												350(2.8)		
Sep 20 MOCH				100(3.5)	50(3.4)									
Oct 3 WMO					100(3.5)		80(3.2)							
Oct 19 WASH				50(3.3)										
Nov 16 COLO WMO			50(2.7) 50(2.7)	80(2.6) 60(2.6)		40(2.4)								
Nov 30 WASH COLO						400(3.0)	400(3.1) 250(3.0)	300(3.1)						

1985

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Jan 21 MOCH						140(4.0)	50(3.8)							
Feb 28 WASH				200(3.1)	80(3.0)	80(3.0)	160(2.8)	60(2.8)	40(2.9)					
Apr 22 WMO							50(3.8)	50(4.0)	60(3.8)	80(3.5)	60(3.3)			
Nov 14 ALBT				50(4.2)	60(4.2)	60(4.2)	50(4.2)						50(4.0)	
Dec 10 WASH													100(3.8)	100(3.5)
Dec 13 WASH													50(2.9)	50(2.7)
Dec 14 MOCH				40(3.8)	40(4.0)									
Dec 18 WASH MOCH										150(3.7)	60(3.6)	50(3.6)		50(3.6)

TABLE 2 (Cont.)

1985 Cont.

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Dec 19 MICH							80(3.5)	60(3.3)	40(3.0)	40(2.6)				

1986

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Feb 7 WMO											350(3.4)	200(2.9)	120(2.7)	
Feb 8 WASH WMO			400(2.6)	400(2.5)	300(2.9)	50(2.9)	80(2.7)	100(2.5)						
Feb 9 WASH				60(2.5)	80(2.5)	50(2.5)	50(2.6)			50(2.5)				
Sep 12 WMO						1300(2.3)	200(2.3)	50(2.3)	50(2.3)					
Sep 23 WMO							200(3.1)	50(3.2)						
Oct 14 WASH							150(3.2)	50(3.3)	40(3.3)					
Nov 4 WMO						800(2.9)	200(3.1)	50(3.4)	50(3.3)	60(3.2)				
Nov 11 MICH					300(3.7)	400(3.3)	200(3.2)							
Nov 25 MICH WMO	80(3.5)	150(3.3)	100(3.2)	90(3.1)	80(3.0)	50(3.0)	80(3.3)	50(3.2)	40(3.2)					

1987

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Feb 20 WMO											160(3.3)			
Feb 27 MICH										80(4.1)				
Feb 28 WASH MICH											140(3.6)	220(3.5)		
Sep 26 MICH		50(3.8)	50(3.7)											
Sep 30 WMO					50(3.2)									
Oct 25 WMO						150(3.0)	60(3.1)	40(3.1)		50(2.9)	40(2.7)			
Oct 28 WMO						40(3.2)								
Nov 23 WASH									120(3.1)	90(2.8)	90(2.7)		50(2.6)	
Dec 11 MICH			100(3.8)											
Dec 16 ALST WMO					120(3.5)	100(3.1)	100(3.0)							
					100(3.5)	100(3.1)	80(2.8)							

1988

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Jan 7 MICH			120(3.7)											
Jan 27 MICH							120(3.6)	40(3.5)						

TABLE 2 (Cont.)

1988 Cont.

Time	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14
Feb 18 MICH											30(3.5)			
Mar 27 WASH					80(3.0)				40(3.0)		70(3.0)	60(3.0)		
Apr 12 MICH			30(4.4)											
May 18 W MO									50(3.1)					
Jul 21 WASH										320(2.9)				
Sep 11 WASH									640(2.9)	300(2.9)				
Sep 12 WASH W MO						40(3.0)	50(3.0) 50(3.1)	60(3.0) 70(3.1)	50(3.0) 60(3.0)	40(3.0) 30(3.0)	30(3.0)			
Oct 10 WASH W MO							150(3.1)	400(2.8) 250(2.7)	500(2.8) 300(2.7)	500(2.8) 300(2.7)				
Oct 11 WASH W MO				180(3.1) 250(3.2)	160(3.0) 250(3.1)	240(3.1) 280(3.1)	250(3.1) 250(3.1)	220(3.1) 250(3.1)	270(3.1) 280(3.1)	300(3.0) 300(3.0)	380(2.9) 350(2.9)	300(2.8) 350(2.8)	200(2.8)	
Oct 18 W MO											150(3.2)	150(2.9)		
Nov 2 W MO											100(3.0)			
Nov 3 WASH								80(3.0)	40(3.0)	200(3.0)				100(2.9)
Nov 30 WASH										200(2.7)	600(2.7)	400(2.6)	200(2.6)	
Dec 2 W MO						60(3.1)	40(3.2)		40(3.3)					
Dec 3 MICH							40(3.6)							
Dec 4 MICH					50(3.6)									
Dec 5 W MO						30(3.3)								
Dec 15 MICH						50(3.8)		100(3.7)	60(3.7)					
Dec 16 W MO														40(3.5)
Dec 17 W MO									300(3.2)	400(2.9)	400(2.8)	300(2.7)	200(2.7)	
Dec 18 W MO											40(3.3)	100(3.2)	100(3.0)	
Dec 26 WASH W MO											350(3.0) 200(3.2)			
Dec 29 MICH			50(3.7)	40(3.7)										

REFERENCES

- Barbier, D. 1958. "The Auroral Activity at Low Latitudes." Ann. Geophys. 14:334.
- Carpenter, D. L. 1971. "OGO 2 and 4 VLF Observations of the Asymmetric Plasmapause Near the Time of SAR Arc Events." J. Geophys. Res. 76:3644.
- Chappell, C. R., K. K. Harris, and G. W. Sharp. 1971. "OGO 5 Measurements of the Plasmapause During Observations of Stable Auroral Red Arcs." J. Geophys. Res. 76:2357.
- Cole, K. D. 1965. "Stable Auroral Red Arcs, Sinks for Energy of Dst Main Phase." J. Geophys. Res. 70:1989.
- Cornwall, J. M., F. V. Coroniti, and R. M. Thorne. 1971. "Unified Theory of SAR Arc Formation at the Plasmapause." J. Geophys. Res. 76:4428.
- Cruz, J. E., R. Davies, L. K. Droppleman, E. Marovich, L. R. Megill, M. H. Rees, L. Relsbach, and F. E. Roach. 1965. Data Reduction for Stable Auroral Red Arcs Observed at Rapid City, South Dakota. National Bureau of Standards Tech. Note 308, Boulder, Colorado.
- Hasegawa, A., and K. Mima. 1978. "Anomalous Transport Produced by Kinetic Alfvén Wave Turbulence." J. Geophys. Res. 83:1117.
- Hoch, R. J., and K. C. Clark. 1970. "Recent Occurrences of Stable Auroral Red Arcs." J. Geophys. Res. 75:2511.
- Hoch, R. J. 1973. "Stable Auroral Red Arcs." Rev. Geophys. Space Phys. 11:935.
- Kleckner, E. W., J. J. Michalsky, L. L. Smith, J. R. Schmelzer, R. H. Severtsen, and J. L. Berndt. 1981. A Multipurpose Computer-Controlled Scanning Photometer. Pacific Northwest Laboratory, Richland, Washington. PNL-4081.
- Kozyra, J. U., T. E. Cravens, A. F. Nagy, E. G. Fontheim, and R. S. B. Ong. 1984. "Effects of Energetic Heavy Ions on Electromagnetic Ion Cyclotron Wave Generation in the Plasmapause Region." J. Geophys. Res. 89:2217.
- Kozyra, J. U., E. G. Shelley, R. H. Comfort, L. H. Brace, T. E. Cravens, and A. F. Nagy. 1987. "The Role of Ring Current O^+ in the Formation of Stable Auroral Red Arcs." J. Geophys. Res. 92:7487.
- Lanzerotti, L. J., A. Hasegawa, and C. G. MacLennan. 1978. "Hydromagnetic Waves as a Cause of an SAR Arc Event." Planet. Space Sci. 26:777.
- Lundblad, J. Å., and F. Sorass. 1978. "Proton Observations Supporting the Ion Cyclotron Wave Heating Theory of SAR Arc Formation." Planet. Space Sci. 26:245.
- Marovich, E. 1966. Fritz Peak Observations of Stable Auroral Red Arcs, Summary 1955-1965. ESSA Tech. Rep. IER 16-ITSA 16, Environmental Science Services Administration, Boulder, Colorado.
- Nagy, A. F., R. G. Roble, and P. B. Hays. 1970. "Stable Mid-Latitude Red Arcs: Observations and Theory." Space Sci. Rev. 11:709.
- Nagy, A. F., W. B. Hanson, R. J. Hoch, and T. L. Aggson. 1972. "Satellite and Ground Observations of a Red Arc." J. Geophys. Res. 77:3613.

Rees, M. H., and S. Akasofu. 1963. "On the Association Between Subvisual Red Arcs and the Dst (H) Decrease." Planet. Space Sci. 11:105.

Rees, M. H., and R. G. Roble. 1975. "Observations and Theory of the Formation of Stable Auroral Red Arcs." Rev. Geophys. Space Phys. 13:201.

Roach, F. E., and J. R. Roach. 1963. "Stable 6300Å Auroral Arcs in Mid-Latitudes." Planet. Space Sci. 11:523.

Slater, D. W., L. L. Smith, and E. W. Kleckner. 1980. "Correlated Observations of the Equatorward Diffuse Auroral Boundary." J. Geophys. Res. 85:531.

Slater, D. W., and L. L. Smith. 1981. "Modulation of Stable Auroral Red (SAR) Arc Occurrence Rates." J. Geophys. Res. 86:3669.

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