An initial meteoroid stream survey in the southern hemisphere using the Southern Argentina Agile Meteor Radar (SAAMER)

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ABSTRACT

We present in this manuscript a 4 year survey of meteor shower radiants utilizing the Southern Argentina Agile Meteor Radar (SAAMER). SAAMER, which operates at the southern most region of South America, is a new generation SKiYMET system designed with significant differences from typical meteor radars including high transmitted power and an 8-antenna transmitting array enabling large detected rates at low zenith angles. We applied the statistical methodology developed by Jones and Jones (Jones, J., Jones, W. [2006]. Month. Not. R. Astron. Soc. 367, 1050–1056) to the data collected each day and compiled the results into 1 composite representative year at 1° resolution in Solar Longitude. We then search for enhancements in the activity which last for at least 3 days and evolve temporally as is expected from a meteor shower. Using this methodology, we have identified in our data 32 shower radiants, two of which were not part of the IAU commission 22 meteor shower working list. Recently, SAAMER's capabilities were enhanced by adding two remote stations to receive meteor forward scatter signals from meteor trails and thus enable the determination of meteoroid orbital parameters. SAAMER started recording orbits in January 2012 and future surveys will focus on the search for unknown meteor streams, in particular in the southern ecliptic sky.

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1. Introduction

The collision of asteroids and disintegration of comets is the main source of dust in the Solar System. These processes give rise to a thick circumsolar disk of small debris known as the Zodiacal Dust Cloud (ZDC). Several physical effects produced by larger Solar System bodies result in the dust having relatively short lifetimes maintaining somewhat a balance in their distribution preventing this cloud from becoming dustier. For example, they can be ejected from the Solar System by Jupiter, thermally obliterated by the Sun, or physically fragmented by additional collisions amongst them. Also, a portion of the cloud is swept by the planets, and for the case of those with atmospheres will produce the more familiar phenomena of ionization and light production that is termed meteor. We now know that similar processes occur in other systems as circumstellar disks of dust have been observed, for example, around Beta Pitcoris and Formalhaut. Thus understanding the nature of ZDC can shed light to the history and development of the Solar System as well as extra solar planetary environments (Malhotra, 1995; Johansen et al., 2007; Walsh et al., 2011; Nesvorný et al., 2010; Wiegert et al., 2009).

Meteor showers, in particular, are an excellent tool for these studies because they are the direct result of cometary mass loss through their approach to the inner Solar System. Sporadic meteors, on the other hand, are characterized by orbits which have evolved significantly from their original at the moment of ejection from their parent body and thus have lost their history. This implies that, as oppose to showers, they cannot be associated with a particular parent body and/or other particles from the same parent. Thus meteor showers are an excellent tool to constraint dynamical models of cometary evolution, both orbital and physical. Surveying and studying meteor showers can shed light to cometary composition and structure, dust ejection speeds, parent body masses and some times even constrain their period in the Solar System (Sykes and Walker, 1992; Jenniskens, 2008; Wiegert and Brown, 2004; Borovička et al., 2005). Brown et al. (2008) provides a detail account of known previous shower surveys, and as discussed by the authors, meteor radars are an effective tool to perform these surveys, in particular for smaller particles. It is also shown in that work that most of the known surveys were performed in the northern hemisphere with only ~10% taking place

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at southern latitudes, the latest of which involves observations performed during a 4 year period prior to 2000 in which only six streams were found (Galligan and Baggaley, 2002a,b). A more recent survey utilizing 2 years of observations was reported by Younger et al. (2009) in which over 30 showers were identified. The continual survey of meteor showers is important because it provides information on the sometimes cyclic annual strength in the activity of showers, and thus constrain models of dust evolution in the Solar System. A good example is the Leonids meteor shower which have produced a number of noteworthy storms through out history, particularly those in 1833, 1868 and most recently in 1997–1998 period (Jenniskens, 2006) but currently its activity is very weak.

For the study presented here we focus on the utilization of the Southern Argentina Agile Meteor Radar (SAAMER) and the application of the statistical method developed by Jones and Jones (2006) to estimate meteor shower radiants in single-station data collection mode. We report a 4 year survey of meteor shower radiants utilizing a new generation SKiYMET system designed with significant differences from typical meteor radars including high transmitted power and an 8-antenna transmitting array enabling large detected rates at low zenith angles. A full description of the new meteor radar system is provided in Section 2 while a description of our searching technique is provided in Section 3. The results are discussed in Section 4.

2. SAAMER: system description

The Southern Argentina Agile Meteor Radar (SAAMER) is a SKiY-MET system deployed at the Estacion Astronomica Rio Grande (EARG) in the city of Rio Grande (53.8°45′8″S; 67°45′5″W), province of Tierra del Fuego, Argentina. The system, which has being operational continuously since May, 2008 was enhanced, relative to standard meteor radars, in order to enable Gravity Wave (GW) momentum flux measurements in the Mesosphere and Lower Thermosphere (MLT) atmospheric region (Fritts et al., 2010b,a). These enhancements were driven by two radical changes from the typical systems: (1) significantly higher meteor counts (i.e. by at least an order of magnitude) and (2) a need for the majority of meteor detections to be at small zenith (high elevation) angles. Both needs were addressed with SAAMER, which was designed for greatly enhanced transmitter peak power (60 kW, rather than 6–20 kW used by most meteor radar systems) and uses a transmitter antenna (specially designed by Mardoc Inc.) composed of eight (instead of one) 3-element crossed yagis (rather than 2-element) arranged in a circle of diameter 27.6 m (Fig. 1). SAAMER's operating frequency and bandwidth are 32.55 and 0.3 MHz, respectively. In the normal mode of operation, as it is the case for the data presented in this work, SAAMER transmits a 2-km long pulse with opposite phasing of every other yagi, directing the majority of radar power into eight beams at 45° azimuth increments with peak power at ~35° off zenith. This results in a majority of meteor detections at off-zenith angles between 15° and 50°. The receiving array is formed by the typical five-antenna interferometer arrangement (Hocking et al., 1997; Jones et al., 1998), all of which are also 3-element crossed yagis enabling redundant meteor position definition with errors less than 0.5°. Similarly as for the Canadian Meteor Orbits Radar (CMOR; Brown et al., 2008), SAA-MER uses the basic echo detection and analysis algorithms for the SKiYMET systems developed by Hocking et al. (2001). Together, these upgrades increase the power at the small zenith angles of interest by ~23 dB and the near-zenith (i.e. elevation angles greater than 50°) meteor counts by ~ 20 integrated over all azimuths. This is shown in Fig. 2 where daily specular underdense meteor trail detected rates are shown for the nearly 4 year long period of observations utilized in this study. During the first 16 months of operation, SAAMER transmitted a monopulse at a pulse repetition frequency (PRF) of 2140 Hz, resulting in an excess of 10,000 specular trail detections daily (top panel in Fig. 2). In September of 2009, however, we changed the transmitting scheme to a 2-bit
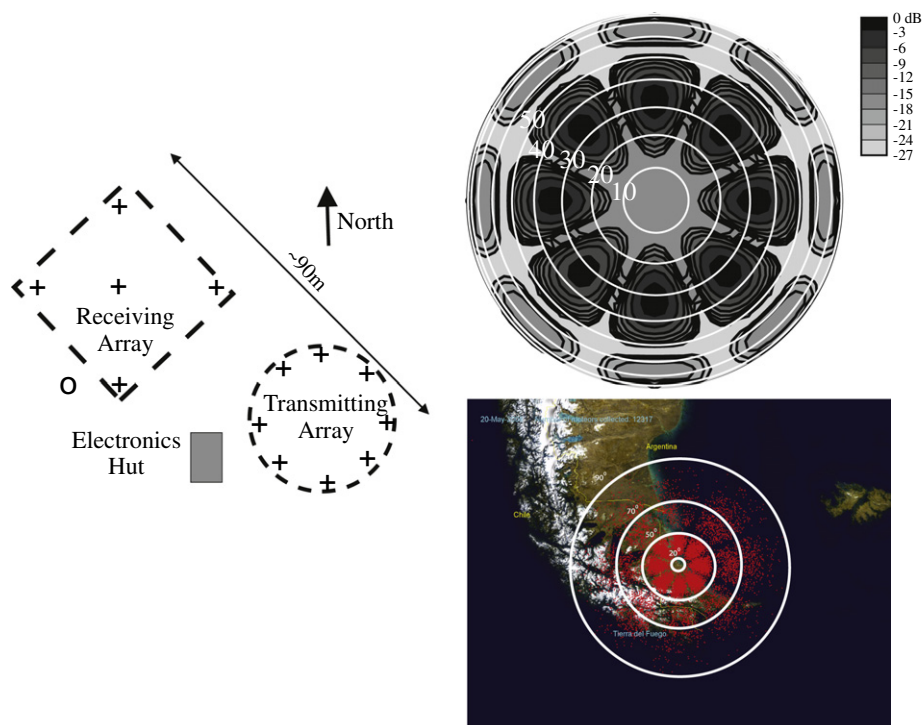
Fig. 1. (left) Antenna transmitter and receiver layout at Rio Grande, Tierra del Fuego (with individual antennas indicated with plus symbols); (top right) the anticipated beam pattern polar diagram. The resulting beams have peak sensitivity at 35 off zenith and (bottom right) SAAMER meteor detections above our acceptable detection threshold (total = 12,317) for 20 May 2008.
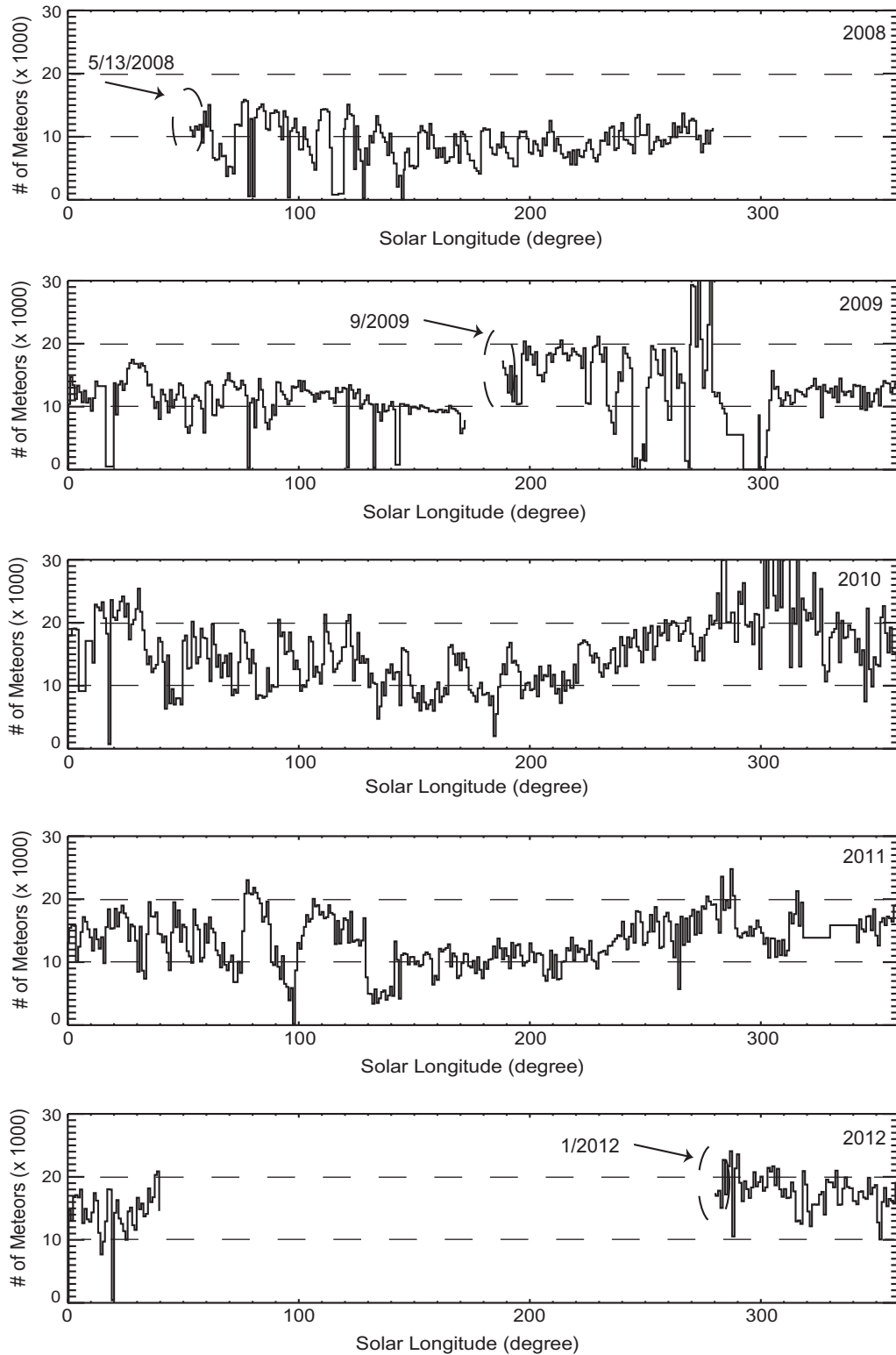
Fig. 2. Meteor rates detected by SAAMER in the normal mode of operation for the ~4 years of data utilized in this study.

coded pulse at a PRF of 1765 Hz resulting in a ~40% increase in the daily counts. Overall, the detected rates are ~2–3 times larger than for example rates detected with CMOR (Brown et al., 2008). This is particularly remarkable considering that, most of the detections occur overhead, opposite to most of meteor radar designs. A comparison between SAAMER's meteor detection performance and

that of typical systems is presented in Fritts et al. (2012). In August 2010, we enhanced the capabilities of the radar by adding two remote stations to receive meteor forward scatter signals from meteor trails. The information provided by the outlying receiving stations enables the determination of meteoroid trajectories and speeds of meteoroids and thus leads to the determination of their

orbital parameters (Baggaley et al., 1994; Brown et al., 2008). Orbital information have been recorded since January 2012 and will be reported in future works.

3. Data analysis

Traditional VHF meteor radars (often called all-sky radars) primarily detect the specular reflection of meteor trails traveling perpendicular to the line of sight of the scattering trail. This implies that their velocity vector (traveling direction) must fall within the plane perpendicular to the line between the radar and the point in the sky where the echo was recorded (line-of-sight). As pointed out earlier, this information is accurately recorded using the interferometer receiving array. In other words, all possible meteor radiants will fall within a circle perpendicular to the meteor line-of-sight. If there are meteors belonging to a particular stream, the circles defined by these particular meteors will all intersect in one common point producing an enhancement above the noise. By locating these enhancements projected in equatorial coordinates (i.e. Right Ascension RA and Declination δ), meteor shower radiants can be determined. For this purpose Jones and Morton (1977) developed a statistical technique, later improved by Jones and Jones (2006), which looks at each possible radiant and count the detections in a band perpendicular to each of them. This is performed by defining acceptance bands which are convolved with the filter function given by

$$\omega(\theta) = \begin{cases} 1 - 6\left(\frac{\theta}{\delta\theta}\right)^2 + 5\left(\frac{\theta}{\delta\theta}\right)^4 & \text{for } |\theta| \leqslant \delta\theta \\ 0 & \text{for } |\theta| > \delta\theta \end{cases} \quad (1)$$

where θ is the angular separation to the center of the acceptance band. As suggested by Jones and Jones (2006) we implement this filter using $\delta\theta = 4°$ and searching all possible directions which lay above the local horizon with a $\sim 1.8°$ resolution in both equatorial coordinates.
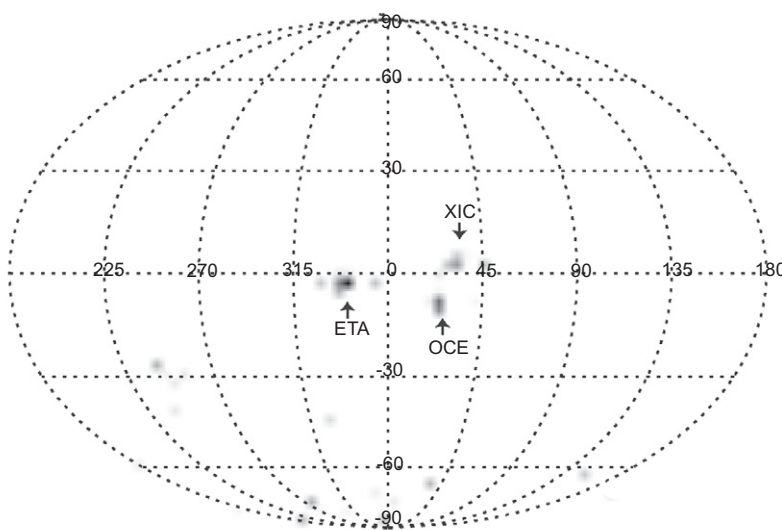

Fig. 3. A single station radiant activity map in equatorial coordinates determined from SAAMER data for $\lambda = 48°$ in which activity from three showers are evident. The nearly 4 year of data are included in this map.
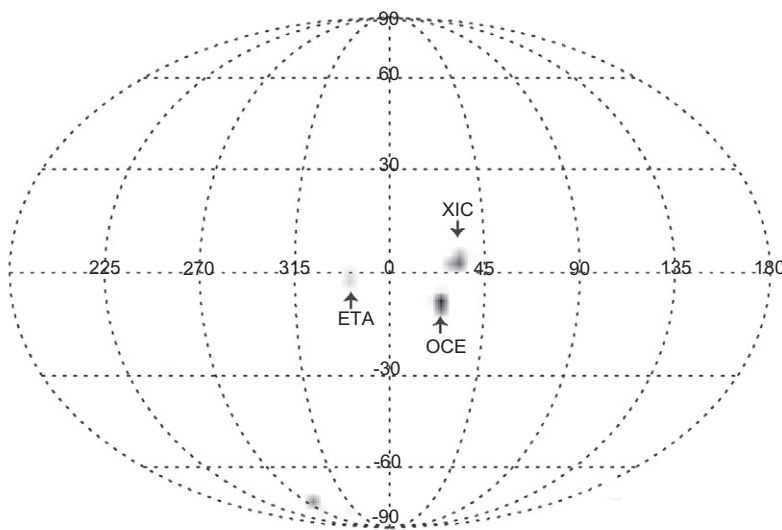

Fig. 4. 2D Gaussian fitted results to the data shown in Fig. 3

For this work and similarly to Brown et al. (2008) we focus on defining showers that are active year-to-year and thus we combined all data from all years into a single equivalent solar year, by binning the echo data by Solar Longitude and constructing radiant maps in equatorial coordinates. Fig. 3 shows an example resulting from this methodology where enhancements due to the presence of three different showers at Solar Longitude (λ) equal to 48° are evident. These are the η Aquariids (ETA), Daytime ξ Cetids (XIC) and Southern Daytime ω Cetids (OCE). Note that due to the high southern latitude location, SAAMER is prevented to see declinations much higher than ∼35°, conjugate to CMOR which efficiently detects meteors which radiant declination lies poleward ∼−35°.

As a first step in the search and identification of radiant enhancements, we use the ETA and Southern June Aquiliids (SZC), two of the strongest annual showers, in these radiant maps to define the minimum relative strength with respect to the background noise that an enhancement needs to have in order to be consider a potential candidate. This threshold is determined by the relative strength of these showers during the first and last days during which they are visible with respect to the sporadic background. Each map for each degree of Solar Longitude was examined by fitting a 2D Gaussian curve of ∼4° × 4° on all enhancements where the maxima was equal or greater than this threshold. Fig. 4 shows the fitted results for the data corresponding to Fig. 3 where it can be observed that not only the three showers were successfully identified, but also most of the noise is removed. A list of potential radiants was compiled for each Solar Longitude. Following this step, we search in the resulting list of potential radiants and select those which were present for a minimum of 3° in Solar Longitude and within 2° in RA and δ between continuous bins. We then recorded all these points together as a possible

linked radiant constituting a shower. The final step on the search is to visually examine these linked radiants and those showing consistent positive drifts in RA, and consistent drifts throughout their activity period in δ were singled out for identification. Fig. 5 shows the time evolutions of RA and δ for OCE as well as a line fit used to calculate the drift.

4. Results and discussions

Utilizing the methodology described in Section 3, we identified over 60 radiant candidates. In order to unequivocally identify a meteor stream, however, it is crucial to determine geocentric velocity and orbital information which are not accessible for the data presented in this survey. Due to this limitation, we only focus on reporting those radiants for which identification was possible, which was carried out initially by comparing our results with the Meteor Working List (MWL) reported by the International Astronomical Union (IAU) Meteor Data Center (Jopek and Jenniskens, 2011). For this, we search for values in λ, RA and δ reported in the MWL, which represent those at maximum activity, that are within the initial and final values derived from SAAMER's observations. As it will be discussed in this section, due to either inconsistencies with the MWL or because the particular candidate was not present in the list, for a few particular streams we have also compared our results with the surveys reported by Younger et al. (2009) and, when possible due to their conjugate locations, Brown et al. (2010).

Table 1 presents the radiants for which identification was confirmed. The first two columns on this table provide the MWL shower name and IAU three letter code. The following 6 columns present the initial and final observed λ, RA and δ. These are determined from the first and last days during which the relative strength of the shower is above the noise threshold (see Section 3). The last two columns in Table 1 present the measured temporal drifts obtained by fitting a line to the observed RA and δ as a function of λ (see Fig. 5). Overall we have identified the presence of 32 shower radiants in the observations presented in this study, similar to the number of showers found in southern hemisphere survey reported by Younger et al. (2009). Brown et al. (2008), using CMOR also in single station mode identified 45 showers.

From the results shown in Table 1, it can be observed that for over 60% of the radiants found, the MWL values fall within the observed initial and final values for at least two of the three coordinates, giving us confidence that SAAMER's observations do indeed correspond to those showers. For three of the observed showers (APS, CAP and SDA), the MWL values are very close to those observed ones but some differences are evident. For the case of APS, the radiant was observed during 6° in λ, a much shorter interval than the one observed by CMOR (Brown et al., 2010), and the final observed Solar Longitude is 13° lower than the MWL value. Similarly for the case of SDA for which the expected maximum activity Solar Longitude value is 5° lower than the initial value observed by SAAMER. The Aquariid complex, however, does get quite crowded with a number of different constituent streams around the same time that SDA peaks. It may be the active radiants classified as SDA includes other components.

For the case of MIC and ECR, although the observed Solar Longitudes as well as RA agree with the MWL values, the observed declinations are 5–7° higher than the expected values. In particular, the ECR observed declination agrees with the values observed by Younger et al. (2009) utilizing meteor radars in Australia and Antarctica. This shower is located at a very high southern latitude and thus recent data are scarce. We hope that our future orbital determination will shed lights as to the origin of these differences. Similarly with the STA, although differences between the observed and
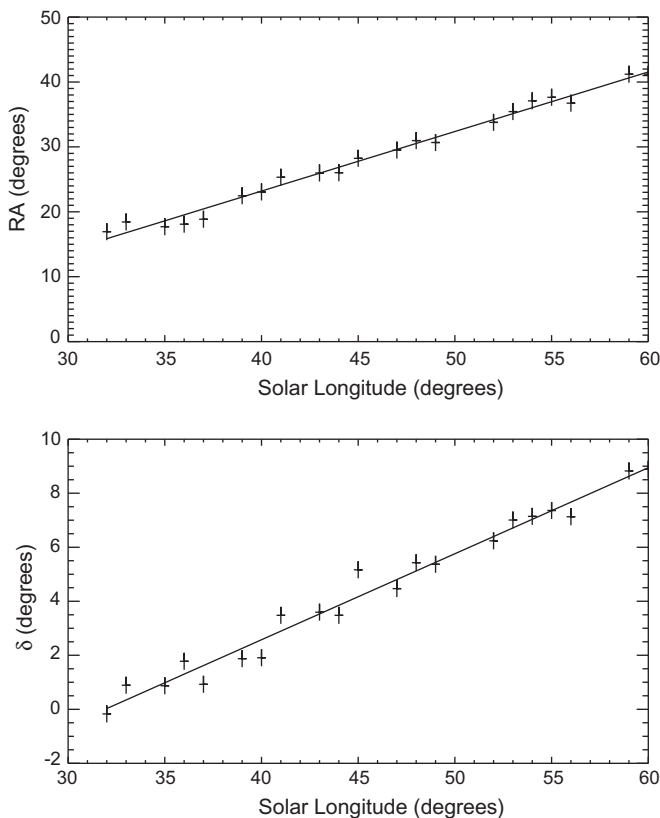
Fig. 5. Activity plots for the OCE meteor shower.

Table 1
List of meteor shower radiants observed with SAAMER.

Name	IAU Code	λ_i	λ_f	RA_i	RA_f	δ_i	δ_f	ΔRA	$\Delta\delta$
Daytime April Piscids	APS	21	27	359	3.1	0.9	4.4	0.7	0.4
Daytime ξ Cetids	XIC	32	60	16.9	41.2	−0.2	8.9	0.9	0.3
η Aquarids	ETA	35	59	329.6	346.5	−4.5	3.6	0.7	0.3
Southern Daytime ω Cetids	OCE	40	57	16.5	32.1	−9.1	−1.9	0.9	0.4
α Scorpiids	ASC	58	61	249.7	250.2	−28.4	−29.8	−0.1	−0.2
Southern μ Sagitariids	SSG	67	94	255.2	278.5	−30.2	−33.9	0.9	−0.1
Daytime Arietids	ARI	71	85	39.52	48.36	21.6	25.8	0.63	0.3
Southern June Aquiliids	SZC	74	113	304.4	327.7	−37.4	−28	0.6	0.3
Northern June Aquiliids	NZC	85	95	297.9	303.3	−9.2	−6.6	0.6	0.3
Southern σ Sagitariids	SSS	84	100	286.6	298	−28.4	−23.5	0.6	0.3
α Capricornids	CAP	96	113	305.3	318.8	−7.1	−2.5	0.9	0.2
July Phoenicids	PHE	100	123	20.6	43	−55.2	−40.1	0.8	0.7
Microscopiids	MIC	108	125	311.8	327	−23.1	−21	0.9	0.08
σ Capricornids	SCA	110	128	297.3	304.9	−15.1	−11.2	0.5	0.2
Piscis Austrinids	PAU	114	127	332.8	350.7	−21.4	−24	1.5	−0.4
99 Aquariids	NNA	124	134	353.8	357.2	−26.9	−21.4	0.5	0.5
August β Piscids	BPI	126	167	325	359.9	−10.8	1.9	0.9	0.3
Southern δ Aquarids	SDA	130	141	342.8	352.7	−17.4	−14.3	0.8	0.3
Northern δ Aquarids	NDA	126	138	342.1	345.7	−3.5	0.9	0.2	0.3
ω Piscids	OPC	162	172	0.4	5.9	1.5	3.6	0.5	0.2
Southern Taurids	STA	178	212	17.6	43	−0.06	7.2	0.8	0.2
Daytime Sextantids	DSX	179	194	148.8	159.4	0.07	−6.2	0.7	−0.5
Orionids	ORI	205	212	92.2	97.7	15.1	16	0.8	0.03
November ω Orionids	NOO	241	246	86.5	90.4	14.4	14.4	0.8	0.002
Geminids	GEM	259	262	110.1	113.6	30.3	30.5	1.1	0.03
η Carinids	ECR	280	291	159.4	169.3	−51.5	−53.3	0.9	−0.2
ζ Puppids	ZPU	234	240	124.6	127	−45.4	−43.9	0.3	0.09
γ Puppids	PUP	247	264	131.7	142.1	−48.1	−55.4	0.8	−0.5
b Puppids	PVE	274	276	139	140.6	−49.5	−51.2		
January α Pixids	APY	299	301	129.9	133.2	−33.7	−37.1	1.6	−1.7
Daytime ξ Sagitariids	XSA	288	293	281.3	285.7	−19.5	−19.5	0.7	0.04
Daytime Chi Capricornids	DXC	291	300	299.8	302.8	−33.9	−32	0.4	0.2

expected declination exist, the observed ones agree well with those reported by Brown et al. (2010). The disagreement between multiple independent observations and the catalogue values may reflect limitations of the IAU MWL.

There were three observed well defined enhancements that occur within the temporal and spatial range of the Puppids complex. Without orbital or velocity information the definite correlation of which enhancement corresponds to which element of the complex cannot be done. We nevertheless report them separately to emphasize the fact that were spatially and temporally resolved. In addition, two radiants that agree with those reported by Younger et al. (2009) as Alpha Piscis Australids and Southern Piscids but are not listed in the MWL as such. The first radiant corresponds to the, previously unlisted, 99 Aquariids (NNA) shower (J. Jopek, Personal Communication, 2012) while the second one corresponds to the listed ω Piscids (OPC) shower (see Table 7, p. 726 in Jenniskens (2006), and shower 217 in IAU MWL). The names presented here follow the official nomenclature and should be refer as such in future reports (P. Jenniskens and T. Jopek, Personal Communication, 2012). Finally, Younger et al. (2009) reported nine previously undocumented showers, none of which were evident on the SAAMER's observations performed for this study. We will perform further search for these and other showers in the orbital data enabled by SAAMER's upgrades in the near future.

5. Conclusions

We presented in this manuscript an initial survey of meteor shower radiants in the southern hemisphere by applying the statistical methodology developed by Jones and Jones (2006) to the data collected during the first 4 years of SAAMER's operation as a single station radar. As described in Section 2, SAAMER is a new generation SKiYMET system designed with significant differ-

ences from typical meteor radars including high transmitted power and an 8-antenna transmitting array enabling large detected rates at low zenith angles. We applied the statistical methodology developed by Jones and Jones (2006) to the data collected each day and compiled the results into 1 composite representative year at 1° resolution in Solar Longitude. We then searched for enhancements in the activity which lasted for at least three consecutive Solar Longitudes and showed consistent positive drifts in RA and consistent drifts throughout their activity period in δ, which were then single out for identification. Using this methodology, we have identified in our data 32 shower radiants, two of which were not part of the IAU commission 22 meteor shower working list. Preliminary analysis of SAAMER data had suggested that, due to the rapid changes in SAAMER's transmitted radiation pattern, which has nulls every 45°, with respect to all-sky meteor radar systems, meteor showers radiants would not be located properly using the Jones and Jones (2006) methodology. The resulting radiant could be shifted up to 20° from their known location (M. Campbell-Brown and W. Cook, Personal Communication, 2010). In addition, because it transmits higher power in a relatively smaller volume, SAAMER has the potential to be more sensitive to lower mass meteoroids and in principle, less effective at detecting meteor showers, similar AMOR (Galligan and Baggaley, 2002b; Brown et al., 2008). The results presented here show, not only that this is not the case, but also that SAAMER is at least as effective as previous studies using traditional lower-power all-sky systems (Brown et al., 2008; Younger et al., 2009). It is also important to note from Table 1 the range of ecliptic latitudes that SAAMER enables to survey. It can effectively observe radiants from the ecliptic south pole to ~30°N (e.g. Geminids), and thus once the orbital elements are accessible in future surveys will enable the detailed study of showers at high southern latitudes (e.g July Phoenicids or Puppids complex), which are unobservable from the CMOR's location.

Acknowledgments

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