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Atmospheric Measurement Techniques Discussions

Interactive comment on "Novel specular meteor radar systems using coherent MIMO techniques to study the mesosphere and lower thermosphere" *by* Jorge Luis Chau et al.

Anonymous Referee #1

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This paper describes the application of multiple-input multiple-output (MIMO) techniques for specular meteor radars.

The paper illustrates that MIMO techniques can be used to increase underdense meteor count rates. This potentially allows the application of a number of post-processing techniques whose application is limited due by count rates obtained using current conventional (i.e. non-MIMO) meteor radars.

The paper is of relevance to researchers developing new meteor radars architectures and is a welcome addition to the literature

I have five significant concerns with the paper that I recommend the authors consider

in the revised version of the paper.

1) The authors show that MIMO increases the number of meteor detections, but there is no explanation as to *why* this increase is achieved.

2) The paper does not adequately describe the signal processing requirements of a MIMO meteor. Reference is made to a companion paper describing the processing (which as far as I can tell has not been made available to the reviewers – even a draft paper would have been useful), but in my opinion a paper should stand on its own merits rather than require a reader (or reviewer) to seek out previous or companion papers. I urge the authors to incorporate more information on the processing used – this does not have to be exhaustive, just more than is currently supplied in the paper.

3) There is no explanation of why the successive processing variations (i.e. MISO-CW, then MIMO-CW MISO-like) increase the count rate. Again, this may be present in previous papers, but it needs to be stated in the current paper. In this regard most researchers investigating application of MIMO techniques in radar declare that they are pursuing MIMO as it provides an ability to "steer the transmit beam" on reception, therefore providing the ability to maximise the transmit power incident on each target (or in this case, meteor trail) present in the field of view. There are no statements of this kind in this paper which may leave the reader unfamiliar with MIMO techniques scratching their heads and wondering what kind of "black magic" the authors apply to get the results they do!

4) The authors appear to have selected a difficult means of applying MIMO. In one regard they deserve credit for making it work, but from my perspective it could have been simpler and not require use of sparsity and/or compressed sensing. The last two lines on page 4 make the point that transmit diversity can be achieved "in time, polarization or code," and the authors have elected to use diversity in waveform (i.e. code). As far as I can tell, the easiest approach would have been to use diversity in time - i.e. by using the same waveform for each transmit antenna but delayed by a different

time (time staggered). I would appreciate some discussion on why the authors chose diversity in code rather than the (in my opinion) simpler diversity in time. Further, I question whether diversity in polarization would actually work in this context given that the two orthogonal polarisations (O and E mode) will suffer different amounts of group rerardation such that the meteor echoes will appear at (slightly) different ranges for the two polarisations.

5) The count rate increase between the Juliusruh SMR (i.e. SIMO Figure 2) and the MISO-CW system (Figure 4) is not relevant because the systems are completely different. There are differences in the effective radiated power, bi-static count rate gain, differences in antenna efficiency (if the systems use different antennas, which isn't clear from the manuscript) and polarization, and differences in analysis procedures (if any). In this regard, a simple calculation suggests the effective radiated power of the MISO-CW system (400 W) is less than that of the SMR (660 W = 15 kW @ 4.4% duty cycle). The bottom line is that the results do not imply that a MISO-CW will produce a higher count rate than an equivalent SIMO (or SIMO-CW system). The MIMO-CW MISO-like Vs MIMO-CW SIMO-like is a more appropriate comparison of the gains provided by MIMO (albeit not the full potential gains).

A frustrating aspect of the paper is the authors use of the terminology "transmitting AOAs" (e.g. page 5, line 2). This is an oxymoron. AOA is an acronym for "angle of arrival", with "arrival" indicating that the signal is "arriving" at the antenna. Clearly this is not the case for a transmitted signal, so the correct terminology is "angle of departure", and the corresponding acronym is "AOD".

I also suggest the authors include a map of the sites used including coordinates (lat/lon) and site separations.

Some further concerns are listed below. Note that I have also included an annotated version of the manuscript with some suggested grammatical corrections. I have also included a scanned copy of a suggested table that the authors include to better sum-

marise the MIMO/MISO/SIMO results (see comment below).

Page 3, line 17: Since the van Cittert and Zernike theorem is little known outside of the radio astronomy field, it would be worth a few extra sentences explaining the theorem and why it is relevant to the current work.

Page 4, line 32: Regarding the comment "For the specular meteor echo, the most suitable diversity is coding," the authors should state why they believe this is the case. It is also worth noting it is possible to incorporate more than one form of diversity. For instance, time and code diversity could be combined by transmitting time staggered versions of the same code provided the code has a low cross correlation value at non-zero lags.

Page 5, lines 5-16. These two paragraphs would be a lot clearer (and less repetitive) if the authors first described the MIMO system, then describe the MISO system as being a subset of this.

Page 5, line 23. "So far none of these experiments could be implemented by existing commercially available SMR systems." I'm not sure of the current state of the art of commercially available SMR systems, but earlier the authors mention that some SMR systems use multiple antennas, in which case MIMO would be possible using time diversity by time staggering the pulses used on each antenna.

Page 5, line 30. I recommend the authors also include the operating frequency of the Juliusruh system.

Page 6, line 12 "The decoding process was done...solving a sparsity-constrained least squares problem." The decoding approach is traditionally performed using a matched filter. The authors should explain why they have instead adopted a compressed sensing approach.

Page 6, line 24: An identification process....was applied on the detected events". It is not clear to me how the authors are processing this data. I *assume* detection is applied to the 5 virtual antenna "incoherently integrated" data? I *assume* AOA (or more appropriately, AOD) is calculated using the 5 virtual antennas, and that the rest of the processing (e.g. decay time, radial velocity, etc) is calculated using the "coherently integrated" data (i.e. incorporating phase corrections implied by the AOD)? I can only *assume* as this isn't explicitly stated, so I encourage the authors to do so.

Page 7, line 3: "different Bragg wavelengths excited". The authors should explain why this is the case. Is it because the Juliusruh SMR operates at a different operating frequency to the MISO/MIMO system (noting that the Juliusruh operating frequency is not mentioned in the paper) or is it because the angle of incidence (and reflection) from the trail is differs for the SMR and MISO/MIMO system - or both of these?

Page 7, line 7: What is L1LRS? MLE?

Page 7, lines 9-21. Again, based on the description provided, it is not clear to me how the authors are processing this data. My interpretation is that they are analysing the data in the same way as the MISO example *except* using 25 "virtual" receivers rather than 5 for detection. I *assume* they are then using the same procedure described in the comment above (i.e. Page 6, line 24) for the remainder of the processing? It might help to include a table (based on the attachment that makes the analysis and resulting count rates a bit clearer.

Page 8, line 23: Again (and note comment below) I don't think major upgrades to commercial SMR are needed if time diversity is used.

Page 12, lines 12-13: "MIMO ideas could be applied to pulsed systems ....use of relatively long codes with suitable diversity (orthogonality)." Again, I don't think CW pseudo-random coding is necessary to allow MIMO. Couldn't typical SMR pulse coding (i.e. Barker, Complementary) be used with time diversity: i.e. time-staggered pulses? This would provide a simpler upgrade path than upgrading transmitters to allow pseudo-random coding.

Figure 8: There are no labels (e.g. a), b), c)) on the plot, but I would assume the left plot is a), etc. In which case the caption is mixed up: a) describes c), and vice versa.

Please also note the supplement to this comment:
https://www.atmos-meas-tech-discuss.net/amt-2018-287/amt-2018-287-RC1-supplement.pdf

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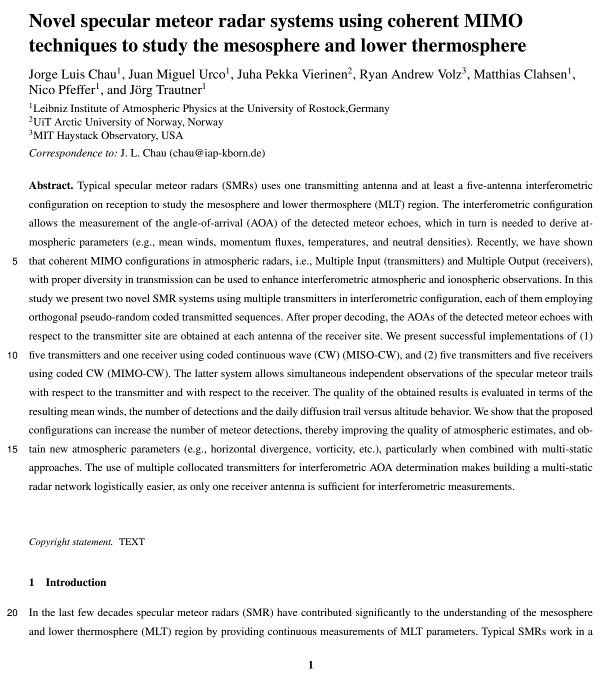

Novel specular meteor radar systems using coherent MIMO techniques to study the mesosphere and lower thermosphere

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Abstract. Typical specular meteor radars (SMRs) uses one transmitting antenna and at least a five-antenna interferometric configuration on reception to study the mesosphere and lower thermosphere (MLT) region. The interferometric configuration allows the measurement of the angle-of-arrival (AOA) of the detected meteor echoes, which in turn is needed to derive atmospheric parameters (e.g., mean winds, momentum fluxes, temperatures, and neutral densities). Recently, we have shown that coherent MIMO configurations in atmospheric radars, i.e., Multiple Input (transmitters) and Multiple Output (receivers), with proper diversity in transmission can be used to enhance interferometric atmospheric and ionospheric observations. In this study we present two novel SMR systems using multiple transmitters in interferometric configuration, each of them employing orthogonal pseudo-random coded transmitted sequences. After proper decoding, the AOAs of the detected meteor echoes with respect to the transmitter site are obtained at each antenna of the receiver site. We present successful implementations of (1) five transmitters and one receiver using coded continuous wave (CW) (MISO-CW), and (2) five transmitters and five receivers using coded CW (MIMO-CW). The latter system allows simultaneous independent observations of the specular meteor trails with respect to the transmitter and with respect to the receiver. The quality of the obtained results is evaluated in terms of the resulting mean winds, the number of detections and the daily diffusion trail versus altitude behavior. We show that the proposed configurations can increase the number of meteor detections, thereby improving the quality of atmospheric estimates, and obtain new atmospheric parameters (e.g., horizontal divergence, vorticity, etc.), particularly when combined with multi-static approaches. The use of multiple collocated transmitters for interferometric AOA determination makes building a multi-static radar network logistically easier, as only one receiver antenna is sufficient for interferometric measurements.

1 Introduction

In the last few decades specular meteor radars (SMR) have contributed significantly to the understanding of the mesosphere and lower thermosphere (MLT) region by providing continuous measurements of MLT parameters. Typical SMRs work in a

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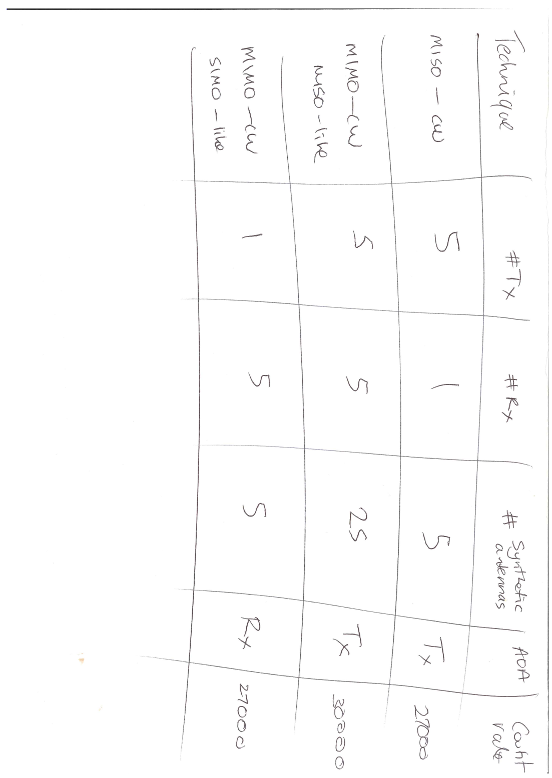
Fig. 1.



Technique	#Tx	#Rx	# Synthetic antennas	AOA	Count rate
MISO – CW	5	1	5	Tx	2700
MIMO – CW MISO – like	5	5	25	Tx	3000
MIMO – CW SIMO – like	1	5	5	Rx	2700

Fig. 2.