Survey design of Overhead Electrical Transmission lines: A Comparative Study of Global Positioning System, Total Station, and Unmanned Aerial Vehicle.

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Abstract

Before an Overhead Electrical Transmission line is constructed, a design survey to map the transmission corridor is necessary. Overhead Electrical Transmission line projects in Malawi employ both Total Station (TS) and Global Positioning System (GPS) techniques. Unmanned Aerial Vehicles (UAV) are capable of providing meter-level accuracy in engineering surveys. However, the performance of UAV in Malawi still remains unknown against the commonly adopted approaches in line routing. Thus, this paper compares the use of Global Positioning System, the UAV and the TS in routing of electric infrastructure for Gogode 33 kV reticulation in Kasungu District. Leica GPS1200 + series receiver, Leica TS and Parrot Bepop Drone were used in fixing a 10 km transmission line. The Most Probable Value and Root Mean Square Error (RMSE) were used as accuracy measurement in Microsoft Excel and AutoCAD Civil 3D. The results indicated better performance in TS positioning than in the other approaches. Thus, it was unveiled that Bepop Drone may be used to estimate structure intervals in circumstances where the GPS and Total Station are integrated in alignment observations.

Keywords: *Angle Points, Geomatics Engineer Structure, Transmission Line, Unmanned Aerial Vehicle*

1.0 Introduction

Transmission lines form the backbone in power networks, being the installations which transmit power over long distances (Kiessling et al., 2003). The success of the electric installations partly depends on the technical know-how of a geomatics engineers and the contributions of other disciplines. For instance, Kalaga and Yenumula (2017) allude that the design of Overhead Electrical Transmission (OET) requires the involvement of structural and geotechnical engineers. However, the movement of electric energy needs supporting structures, conductors, insulators, and appropriate connecting hardware whose spatial locations depend on the expertise of geomatics engineers.

Despite that transmission lines are conduits of electric energy; their design also needs engineering survey work. Kalaga and Yenumula (2017) outline structure locations; wire sags and tensions; structure design; foundation design, and drawings as the components of basic engineering design blocks of OET lines. The survey engineer spots the 3D structure locations on site. Before the execution of the design survey for structure locations, the design engineer undertakes both office and field reconnaissance to account for routing constraints.

As Kalaga and Yenumula (2017) and Kiessling et al. (2003) broadly put, some constraining criteria to finalizing the electric route alignment include: right-of-way; soil conditions; regulatory issues; roads; railways; water; vegetation; cost; terrain; construction access, and other clearances. For example, in Kenya, Korir and Ngigi (2015) applied Geographical Information System (GIS) in high voltage transmission line routing in which topographical sheets, settlement data, geological maps, soil maps, national and country maps, transmission line data, and communication masts necessitated the routing.

From the research findings by Bailey et al. (2005), GIS simply provides a preliminary basis on which the geomatics engineer works by providing potential paths. GIS as Gui (2014) explicitly puts, merely assists in suitability analysis for an OET line. Thus, GIS plays a noteworthy role in route optimization, however, there is still a need to physically fix the electric line path on the ground.

1.1 Surveying with GNSS, TS and UAV

According to Kiessling et al. (2003), there are direct and indirect geomatics measurement techniques for interpreting an electric line on the ground. The former comprises direct observations of the terrain using Theodolites, Total Station (TS), and GPS receivers whereas the latter indirectly observes the terrain through aerial photogrammetric approach. GPS is part of Global Navigation Satellite System (GNSS) and it captures three-dimensional (3D) coordinates in World Geodetic System 1984 (WGS 84). The Unmanned Aerial Vehicles (UAV) broadly consists of a camera for capturing the scene and the GPS for identifying 3D geographical location in WGS 84. With UAV, Singh and Sujit (2016) allude that routing with UAV is only achievable with on-board GPS and inertial measurement unit (IMU). Besides, the UAV estimates distance from the commencing point (source) to the target point (goal) using range sensors (Manyam et al., 2016). The TS is an electronic transit integrated with an Electromagnetic Distance Measurement (EDM) device which measures slope distances, and 3D coordinates. The TS can be used for levelling when set to the horizontal plane. This instrument also computes angles by means of electro-optical scanning of digital bar-codes inherent in it.

The TS requires the line of sight observations in order to determine an absolute location. This calls for clearing any barriers which may block wave reception from the transmitter (TS) at the reflector. Either in relative or absolute position determination; both the GPS solution and the UAV-GPS require a good geometry of satellites. The survey design for OET with the GPS is a stop-and-go positioning which is influenced by the distance from the reference station. Just like the GPS alone positioning, the UAV-GPS positioning is also affected by the baseline distance except that the positioning is on-the-fly. Lau and Cross (2007) highlight multipath as the biggest contributor to GPS electromagnetic wave interference. OET surveying is an infrastructure survey which requires meter-accuracy. In scenarios of barriers, such as under the tree, the UAV navigates with the aid of the IMU to the desired positions. Further to that, Simultaneous Localisation and Mapping (SLAM), Modular Multi-Sensor Data Fusion, and Visual Odometry (VO) have also been used to boost UAV navigation in UAV-GPS denied environments, for instance Balamurugan, Valarmathi and Naidu (2017). It may still be manually controlled by external aids to avoid barriers in such circumstances (Singh and Sujit, 2016).

1.2 Positioning of OET lines in Malawi

UAV data of highest resolution of less than one centimetre as highlighted by Matikainen et al. (2016) and Pagnano et al. (2013) has been applied in mapping of power lines including inspection. Larrauri et al. (2013) automate the inspection of OET with UAV to pre-identify significant failure of electric lines at an early phase. Li et al. (2008) explore the strengths of satellite-based and UAV OET surveillance over ground patrols. In a similar study, Li et al. (2010) embark on automated detection of overhead electric line infrastructure by analysing the properties of the image captured by UAV. In Malawi, design surveys for OET are direct characterised by both traditional and satellite-based positioning. OET alignment in Malawi does not incorporate the indirect sighting, and neither has it experimented on UAV photogrammetry for survey designing. Survey design research on OET lines is a less common research than monitoring of electrical components from an already existing line. Following this lack of in-depth study in the potential use of the UAV in OET survey routing, thus, this paper fills the gap by undertaking a comparative study of GPS, TS, and UAV in survey design of OET lines.

2.0 Materials and Methods

The study was undertaken at Gogode in Kasungu District, Central Region of Malawi. This is one of the beneficiary districts for the Malawi Rural Electrification Programme (MAREP) Phase VII. For this experiment, a 10.003 km; 33kV reticulation was analysed using three instruments: Leica Flexline TS06+ 7 seconds R500 TS, Leica GPS1200 + Series Unit and the Parrot Bepop Drone Version 1 – UAV. The following tasks were executed in the survey design of OET line: office reconnaissance, field reconnaissance, data collection and data analysis.

1.3 Office and Field reconnaissance

Office reconnaissance involved computation of waypoint coordinates incorporating the APs, Line Stays (LS), Angle Stays (AS), Flying Stays (FS), Strata Poles (SP), and all other structures between any Aps. The coordinates were then loaded in the TS and GPS. In addition, a flight plan for the UAV was prepared that incorporated defining the waypoint, flying altitude, speed, and camera orientation. The flying altitude of 30 meters was employed in order to overcome any obstacles in the flight strip. The speed of 2m/sec was used to achieve a reasonable flight stability of the drone. The camera orientation of 70 degrees, the maximum the Bepop Drone Version 1 can attain, was used as low oblique.

Field reconnaissance involved identifying areas that needed clearing the Line-of-Sights (LOS) between Angle Points (APs) and placing witness pegs within reach of the APs. This was done to ensure maximum intervisibility between stations when using the TS, and to provide clear landing environment for the drone. The witness pegs were placed to simplify retracement of the APs.

1.4 Data collection

Datasets were collected for the 33 kV reticulation using the Leica Flexline TS06+ 7 seconds R500 TS, Leica GPS1200 + Series Unit and the Parrot Bepop Drone Version 1 – UAV. The minimum distance between APs was 1000 meters for a 10.002 km High Voltage (HV) line. Using the loaded coordinates, the positions were determined in 3D for the whole stretch.

Depending on terrain dynamics, pegs were fixed in all pre-determined structure locations in order to secure the line. In the course of surveying these stations, the horizontal and vertical profiles and all dominant objects in the right of way were captured. The GPS and TS provided 3D coordinates, using the stake-out mode, as direct measurements on the ground and all placed 3D coordinates for the pegs were recorded in internal memory of the machines. The same survey axis was retraced using the UAV. The UAV utilised had nine (9) minutes endurance. Other specifications for the UAV are depicted in Table 1.

Table 1: Parameters of the Parrot UAV

Date	**Sky Controller**	**Bepop Drone**
Software Version	1.2.3	2.0.57
Wi-Fi Band	2.4 GHz	2.4 GHz
Motor Software Version	-	1.21.R.4

Gui (2014) proposed point guiding measuring technique and coordinate back computation to control direction measurements. This approach is applicable in a forested area where trees interfere with the line of sight. The drone has a GPS navigation system which is enhanced by Wi-Fi hotspot connection. This permitted the UAV to follow the established plan; making it to land exactly in locations established on the flight plan (Figure 1).

While in flight, the UAV returned to the commencing point when the "Automatic Return to Home" key was pressed. Besides that, this drone recorded the coordinates of the last station of its waypoint. To determine the 2D coordinates of the commencing point, the UAV was piloted from 0+000 to an altitude of 30 m and back to 0+000. The flight plan prepared was in such a way that the drone landed at each interval. Pegs were hammered at each point the UAV landed. Then, the coordinates were extracted from the UAV last stations.

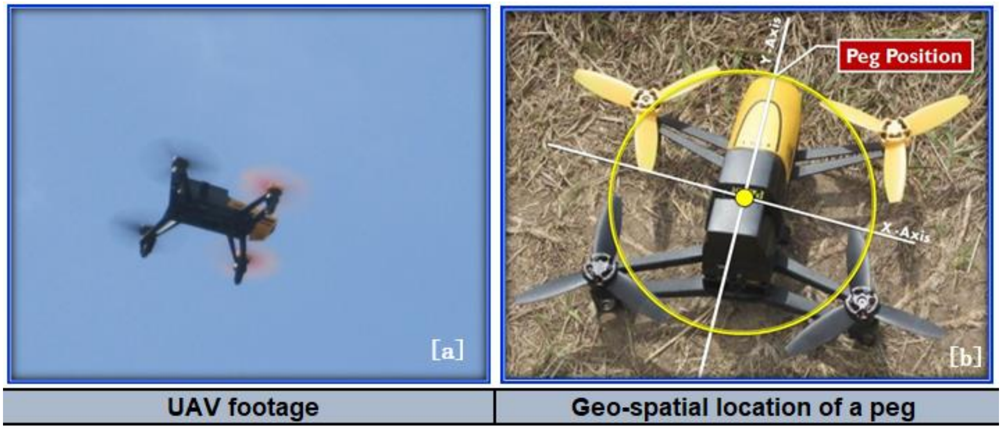

Figure 1: The UAV in flight and on position .

For the sake of consistency, a peg was fixed at the intersection of the circle and the y-axis (the centre of the lens), as shown in Figure 1 [b]. The coordinates recorded were 2D: Latitudes and Longitudes. Kalaga and Yenumula (2017) demonstrate the need of 3D coordinates as facilitation of graphical assessment. By design, the UAV employed did not have the capability of deducing the elevation of the last point of its navigation. Therefore, the coordinates captured lacked one dimension; the elevation.

To achieve 3D coordinates, the Z-coordinate for each UAV landing station (Peg position) was collected with the TS. This provided a combination of UAV extracted coordinates and the TS surveyed elevation which was then used to process longitudinal representation of the terrain. The drone implemented a stop-and-go GNSS positioning rather than using it as a camera to capture the route as a scene. Eventually, all the three instruments (GPS, TS and UAV) provided 3D coordinates for analysis.

1.5 Data analysis

The 3D datasets from the three instruments were downloaded and compared for positional accuracy in AutoCAD Civil 3D. The coordinates were then exported to Microsoft Excel in order to compute the coordinate differences, Most Probable Values (MPV) and Root Mean Square Error (RMSE). The MPV and RMSE between was calculated between the GPS and TS, GPS and UAV, and TS and UAV. The datasets from the GPS, TS and UAV were also compared in terms of route alignment in APs and total route distance. Using the 3D coordinates, the longitudinal and vertical profile were drawn.

3.0 Results and Discussion

The most probable 3D coordinates (placing and checking with the GPS and TS) were adopted and their disparities are illustrated in Table 2. As depicted in Table 2, the mean Easting difference between GPS surveyed points and TS was 1.3 mm ± 14.2 mm; whereas the mean Northing and elevation difference between GPS and TS surveyed points were 1.0 mm ± 14 mm and 3.7 mm ± 11.4 mm, respectively. Table 2 indicates that the GPS and TS positioning was done with better precision than the other two.

The positioning of electric structures require meter-level accuracy (usually 0.020 m to 0.030 m). This is so, because the actual alignment is done during construction of the structures. Despite the better positioning in GPS and TS, the results obtained from all the method were within the acceptable range. Furthermore, there were no meaningful differences in accuracy between the TS and UAV and GPS and UAV.

Table 2: The Most probable values and Root Mean Square Error for stake-out positions

Instrument(s)	**E**	**N**	**H**	**Remarks**
GPS+TS	1.3	1.0	3.7	MPV(mm)
	14.2	14.0	11.4	RMSE(mm)
TS+UAV	3.2	2.7	4.0	MPV(mm)
	10.0	15.0	12.0	RMSE(mm)
GPS+UAV	4.0	3.0	9.0	MPV(mm)
	15.0	17.0	30.0	RMSE(mm)

The survey design for OET lines does not require centimetre-level accuracy. This qualified the drone in question to be tested. However, the drone survey was slow because it was landing at each station to determine the position. Besides, it had to be launched at each station for the whole route. Unlike the TS which required setting only in APs and the GPS only a single base station. The drone also took longer to communicate with the Sky-Controller in 67 stations (67%) of out 100 stations (this delayed the survey work).

In wooded areas, as pointed out by Gui (2014), there is short range of visibility in measurement with the TS. Surveying in the Stake-Out mode allows clearing only the positions where the coordinates are falling. This overcomes short-range visibility when the angles-to-the-right approach is used in fixing the pegs for structure positions. This is so because; cleaning the line of collimation to account for visibility is only applicable to the identified station. In cases where the line of collimation is not directly required, TS with GNSS interface (Smart Station) simplifies the task of coordinate determination.

1.6 Route alignment

The configuration of OET line obeys the concepts of engineering surveying. The transmission line consists of two separate structural systems: the structural support system and the wire system (Jerry et al., 2010). The structural supports are equivalent to traverse stations (survey stations) whereas the wire system can be taken as the line of collimation (or survey line).

The y-axis in plan view (Figure 1b), was taken to denote the line-of-sight through the eyepiece focus of the TS. This was done to assist in checking the orientation of structure positions as a result of drone landing. The alignment of pegs fixed with UAV navigation was checked with the TS. Based on the flight plan, the UAV landed in orientations that matched the direction of the OET line with minimum differences as depicted in Figure 4.

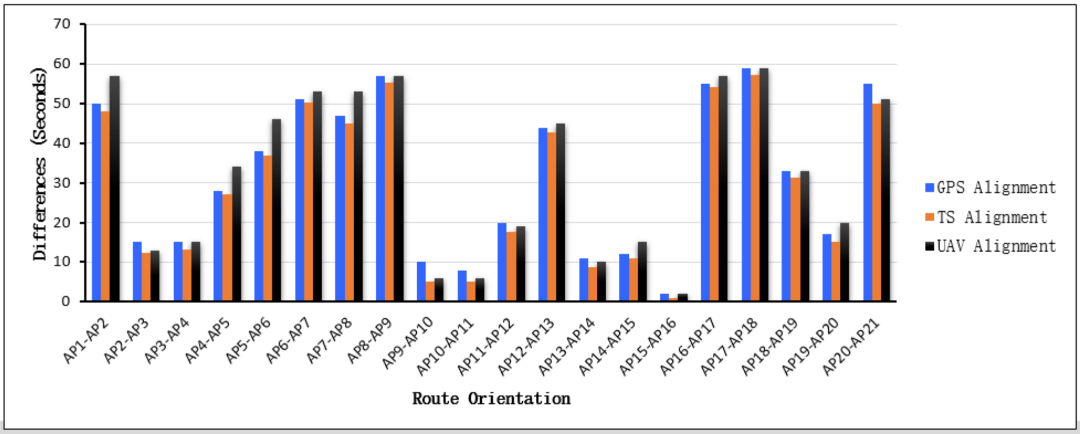

Figure 2: Differences in GPS, TS and UAV route alignment.

Other methods for determining angles and directions exist. As mentioned by Anderson and Mikhail (1998), apart from the TS, Direction Theodolites, a Magnetic Compasses, and Tapes are used alternative geomatics instruments for observing angles and directions. In this paper, each angle between the line and the prolongation of the preceding line was checked with the TS. Ghilani and Wolf (2012) record this angle as *angle to the right* or *angle to the left* depending on whether the line is observed clockwise or counter-clockwise of the fore-line.

Differences in route alignment between the three instruments adopted are illustrated in Figure 4. The mean angles in alignment were 31", 28", and 33" for the GPS, TS and UAV, respectively. As can be seen in the Figure 4, the TS alignment was the best of the three. The larger mean angles in the GPS and UAV could be as a caused by multipath bias as a result of differences in receiver environment along the route. In addition, the total linear distance calculated from the UAV coordinates equalled that of the GPS and TS (1000 meters).

1.7 Longitudinal and Vertical Profile

The profiles drawn from different datasets (GPS, TS, and UAV) had no meaningful differences when compared to those generated from averaged coordinates. Figure 2 depicts the horizontal profile for the first 1.2 km showing the tapping point other features across the profile drawn from the averaged coordinates. The circles denote the spatial locations of the structures as surveyed by the TS, GPS and UAV.

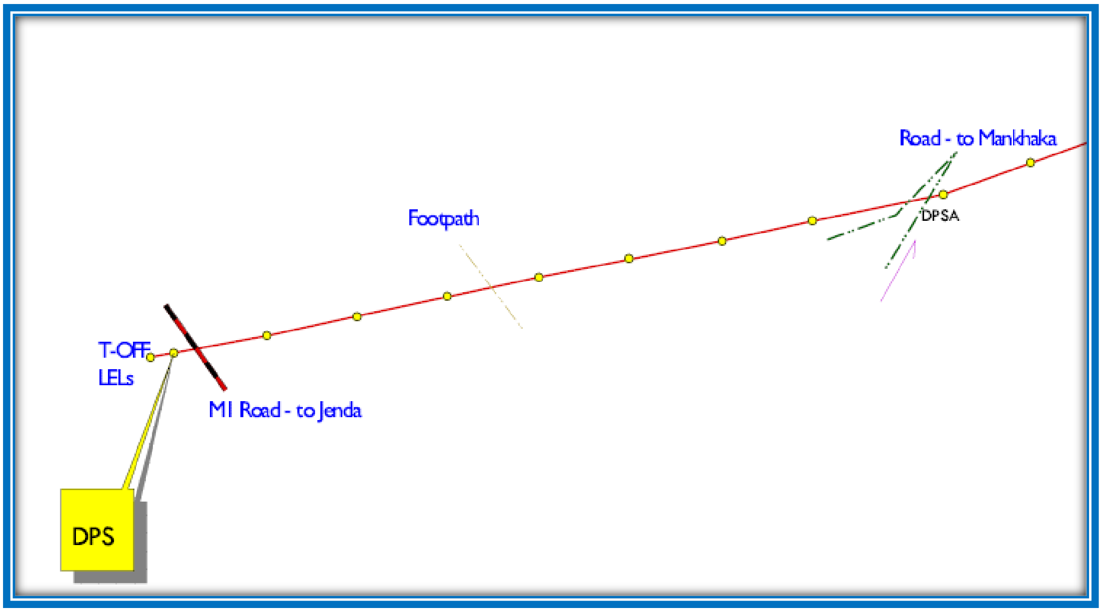

Figure 3: Horizontal profile for 1200 meters.

Figure 3 is vertical profile illustrating ten structures for the first 900 meters generated in AutoCAD Civil 3D 2016. As can be seen, Figure 3 demonstrates the following structures: Tee-Off (T-OFF); intermediate (INT); the H-Pole section (DPS); and the H-Pole Section Angle (DPSA).

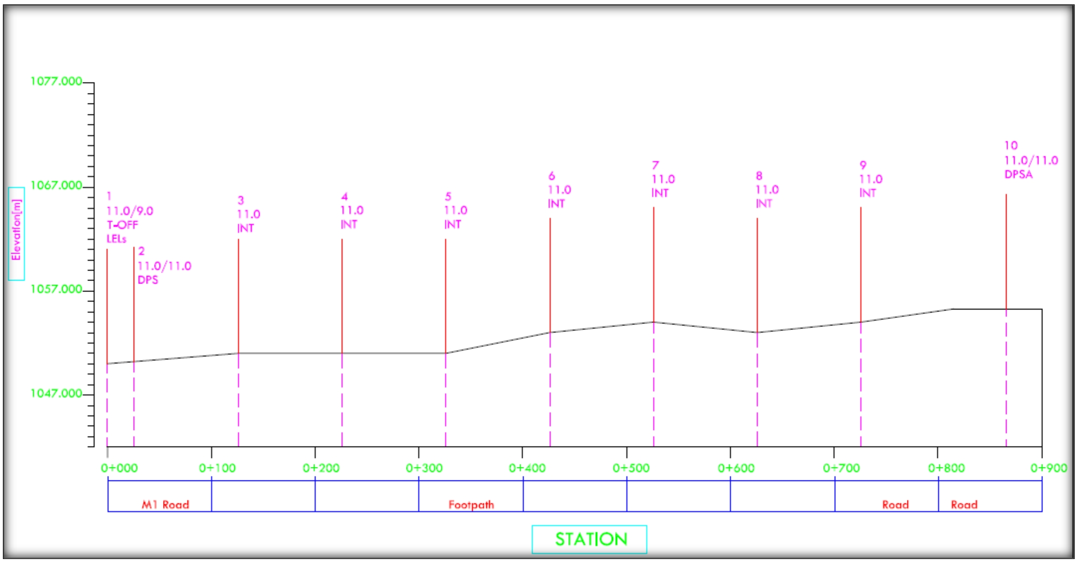

Figure 4: Vertical profile of the HV line.

4.0 Conclusion and recommendations

This paper has established that fixing of Stays with UAV is time-consuming than fixing with the TS and GPS. However, the GPS-alone signals and UAV-GPS signals experience disturbances on their way through the ionosphere. The disturbances are group delay and phase delay and they alter the measured GPS ranges. Among others, GPS signals are also affected by multipath; whereas the TS surveying has visibility problems in built-up or forested areas. The UAV also experiences intermittent communication with the Sky-controller.

Kiessling et al., (2003) singles out that direct surveying techniques are superior to the indirect ones in case of existing OET lines. With pre-computed coordinates for OET line structure position, this paper gathers that positioning by Leica GPS1200 + series unit enables quicker recording in the open terrain than the TS and UAV-GPS. The results of the GPS 1200 and the TS are 3D; whereas those of the GPS receiver of the UAV are 2D. However, the paper has also gathered that the Smart Station (SS) may be used in situations where direct line of sight is not required instead of TS-only. The SS integrates the GPS and the TS which may be used a base-station or free-station. The GPS requires long occupations in forested areas which are usual routes for OET lines.

Thus, the GPS included in the UAV may be used in spotting positions for electric structures in open terrain with fewer tree canopies. However, it renders a challenge to the structure construction team because during structure position-picking, there is no cleaning of the line of sight as opposed to the TS surveys. In areas with poor satellite constellation, the UAV-GPS makes use of IMU thereby redeeming the long occupations experienced by the GPS- only solution. It can therefore be discerned that the TS and UAV can be used in GPS denied environments.

Additionally, the UAV may be used for verifying the positions of fixed pegs if the pegs are taken as Ground Control Points (GCP) during UAV photography by geo-referencing in absence of strong winds. Colomina and Molina (2014) gathered centimetre-level resolution and accuracy from UAV photogrammetry and remote sensing. The drone airplane utilized in this exercise requires geo-referencing in order to survey the structure positions on the photograph. This is different from other drones, for example the Copter UAV, DJI Phantom 4 Pro, which generates ready geo-referenced 2D and 3D models when picking the scene. Whether the UAV generates automatically geo-referenced images on not, either case is fundamental in spotting visible pegs which may as well be used for producing profile design drawings.

Further experiment

A similar experiment may be done over an already constructed OET line with a low cost drone by defining the structures as landmarks. This can be used for generating as-built drawings for the reticulation, but requires uncommissioned line for safety purposes.

Acknowledgements

The author acknowledges the reviewers comments which refined the coherence and presentation of this paper.

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