



Full length article

Distribution of the GNSS-LEO occultation events over Egypt

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1. Introduction

The space-based GNSS RO technique is a promising tool for monitoring the Earth's atmosphere and ionosphere (Mousa et al., 2006). The current paper presents the distribution of the occultation events over Egypt using the operating LEO satellites and GNSS by its two operating systems. By the present research, Egypt could raise NWP Models efficiency by improving meteorological data quality. Twenty operating LEO missions (e.g. Argentinean SAC-C, European MetOp-A, German TerraSAR-X, Indian OceanSat-2, etc.) sent by different countries all over the world were used to derive the occultation events position through Egypt borders by receiving signal from the American global positioning system (GPS) and the Russian global navigation satellite system (GLONASS). Approximately 20,000 km Altitude satellites are transmitting enormous number of rays by the day to approximately 800 km satellites passing by the Earth atmosphere. Our mission is to derive all of these rays position (start and end) by calculating satellites position by the time, determine the rays in the occultation case and derive the atmosphere tangent point position for all occultating rays on the Earth surface (Occultation Events).

The first 8 days in the odd months (January, March, May, ...) in 2015 assumed to give an evident picture about the distribution of occultation events in 2015. All GNSS and LEO satellites positions are calculated in each of the 48 days every 10 s. The short interval allows estimating all available occultation events by the day of study all over the world. By knowing Keplerian elements for both LEO and GPS satellites orbit, satellite position and ray azimuth were estimated. Insuring the ray is in occultation is done by considering only rays with Elevation angle in the range of +5° to −5° range. From the satellite geometry, the tangent point (occultation event) position was estimated. All occultation events out of Egyptian borders were excluded and the rest of the events are drawn on the Egyptian map.

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1.1. Basics of GPS radio occultation

Atmosphere consists of neutral part and ionized one. Passing electromagnetic signal through one of the two parts makes it refracted. Refraction is made by density gradients, temperature, pressure and water vapor in the neutral part and by electrons density in the ionized one, thus relating all of these parameters to refraction makes it easy to drive it by deriving the refraction index.

Fig. 1 shows a number of series signal paths in one occultation. Each path has its tangent point in a deferent altitude some of them in the neutral medium and the other in the ionized one. The whole vertical profile is done by laying the successive tangent points in different heights so the temperature, pressure, density and water vapor pressure is derived if the tangent point laid in the neutral medium and the total electronic content in the charged one.

Unfortunately the angel of refraction of each path couldn't measured precisely, however the received signal change in the Doppler shift is done by the refraction if the transmitter and the receiver are in relative motion and then the refracted angel can be estimated.

The GNSS RO technique is an active limb sounding of the atmosphere and ionosphere (Mousa et al., 2006). GNSS transmitted signal is mainly used for navigation and the RO technique is using it to profile the atmosphere. The RO technique has many advantages such as high measurements accuracy, all-weather capability, global coverage, high vertical resolution and having long term stability.

The GNSS RO technique was demonstrated by the proof-of-concept mission GNSS/MET (Global Positioning System/Meteorology) experiment conducted by UCAR (University Corporation for Atmospheric Research) (Ware et al., 1996). GNSS/MET has successfully provided the profiles of humidity and atmospheric temperature in the troposphere and stratosphere from April 1995 to February 1997 (Rocken et al., 1997). GNSS/MET data are also used to study the electron density fluctuations in the ionosphere (e.g., Tsuda et al., 2004).

The motivations to make more GNSS/MET missions came from the success of the previous missions and to make more studies about the Earth climate, atmosphere and ionosphere. The German CHAMP, the Argentinean SAC-C and the COSMIC (six satellites) are satellites launched for RO technique. Studying the detailed behavior of the neutral atmosphere and the ionized ionosphere has a big jump by such GPS/MET experiments.

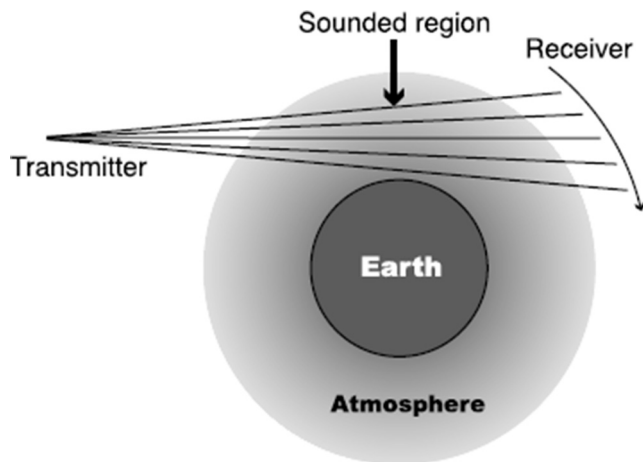


Fig. 1. Concept of refractivity profiling using the GPS radio occultation technique (after Mousa et al., 2006).

The high orbital inclination is from the characteristics distinguish the LEO satellite so it is called polar orbiting satellite due to the near poles orbit. 87° is the inclination of the CHAMP orbit and 400 km is the altitude. Also the inclination of SAC-C is 98.3° and has 705 km altitude. Also the inclination of the COSMIC is 72° and has 800 km final altitude. Since inclination angles of these satellites are high, the distribution of the GNSS occultation is mostly uniform with a bit concentration in the middle regions and gives a global coverage.

LEO satellites inclination angel varied between the most and the least value but usually not least than 72° as this number is the least number that achieve the global coverage. Egypt lies on the Middle East region but not very far from the Equator so the logic is saying that Egypt could make benefit from the other countries LEO missions and from this point was our motivation to make this research.

1.2. Concept of using radio occultation method in Egypt

Occultation means that the Earth prevents LEO satellite to see the GNSS satellite and vice versa, that achieved when the LEO satellite and the Earth and GNSS satellite are along the same line and the Earth is in between. Just before this event the signal between the LEO satellite and the GNSS satellite is connected and passes through the Earth atmosphere. Passing the signal through vacuum not distorting it by any bending or delaying; however passing through any planet atmosphere is doing that. Bending the signal is caused by refraction due to temperature and pressure in neutral medium and dispersion by electrons in the charged medium. If the bending tangent point located in Egypt that means the ability of profiling the atmosphere at this point.

Radiosonde (RS) method is the current operating method in Egypt but the low altitude data and the high cost make the method not preferable. There are six RS stations distributed over the Egyptian borders, each station has two missions per day. In other words, the Egyptian atmosphere is profiled twelve times per day for altitude mostly not exceeds 35 km. If the distribution of the RO events over Egypt found to be 12 points uniform distributed over Egypt, we could declare that the RO method is giving the same distribution given by the RS one by less effort, less cost and full vertical profile.

Meteorology and Numerical Weather Prediction (NWP) suffer from many obstacles in the Egyptian country as the NWP models is so far simple and short term. Atmosphere profiling accuracy and resolution has the direct relation with the NWP models

efficiency as that the higher the atmosphere accuracy and the resolution, the higher the NWP model efficiency. The Egyptian borders are defined approximately from (25° to 37°) in longitude and (22° to 32°) in latitude. It is very easy to see that the Egyptian country is not far away from the Equator and from the Greenwich as well. LEO satellite is mostly called polar satellite as its orbit almost passes by the North and South poles, that insures global coverage in addition to Equatorial high RO events density. Deducing occultation events position in Egypt means well knowing about neutral atmosphere medium such as temperature, pressure, water vapor pressure and humidity and about ionized medium such as total electronic content that insures accurate prediction for all parameters mentioned previously. Also GNSS users in Egypt will realize the deference as signal errors is strongly related with atmosphere parameters identifying.

2. Procedures of applying RO method for Egypt

In order to study the distribution and number of occultation events, each of the GNSS and the LEO satellites' position needs to be calculated. Fig. 2 shows the Keplerian parameters that describe the satellite orbit. The satellite is assumed to orbit under the action of the central force. The GPS almanac data (predicted Keplerian parameters) given by the USA Coast Guard navigation data center is used for calculating the position of the GPS on each day of the study days. For GLONASS, positioning data were provided by the Russian information and analysis center for positioning, navigation and timing. From the Keplerian parameters, the GPS satellites' position is calculated in an Earth-Centered Earth-Fixed frame (ECEF) (for details of these calculations, refer to any GPS text book (e.g., Xu, 2003)).

Table 1 lists the 20 LEO missions used in the Research, the owner country and the Keplerian parameters for each mission represented in its mean altitude and inclination with the Equator. The research is looking for the distribution of the LEO satellites operating as a receiver from the two GNSS systems. The LEO position is also calculated in the same way as the GPS satellites. The Keplerian parameters of each LEO satellite were provided by the European Organization for the Exploitation of Meteorological Satellites [www.romsaf.org].

Deferent LEO orbit Keplerian parameters are depending mainly on deferring orbit inclination (i), altitude and right ascension of the ascending node (Ω) that leading to deference in distribution of RO events on the Earth surface and disparity in the number of RO events. By changing Keplerian parameters each country tried to serve a particular area by a certain number and distribution of occultation events; however, the whole globe is often served.

The orbital period of the GPS is 11 h and 58 min, and, as a result, the satellite reaches the same point 4 min earlier every day, as result, each GPS satellite takes a complete year to reach its position in the same exact day time and for GLONASS it takes 32 days to appear again in the same position and exact time. Repeating data processing every day of the year is needed for making a complete simulation but this is not practical and difficult so it is assumed that carrying a complete simulation analyses for the first 8 days every 2 months will be adequate to make the data statistically significant. January, March, May, July, September, and November of the year 2015 were chosen for the analysis. Thus, 48 days of the 2015 year will be analyzed which considered about 13.2% of the whole year and this is expected to cover approximately the GPS and GLONASS periods in the same time.

Also it is assumed that the signal path from the GNSS to the LEO satellite is a straight line to make the calculations faster and simpler but in fact it is bent due to refraction. This assuming is expected to be permissible as the maximum angle of bending

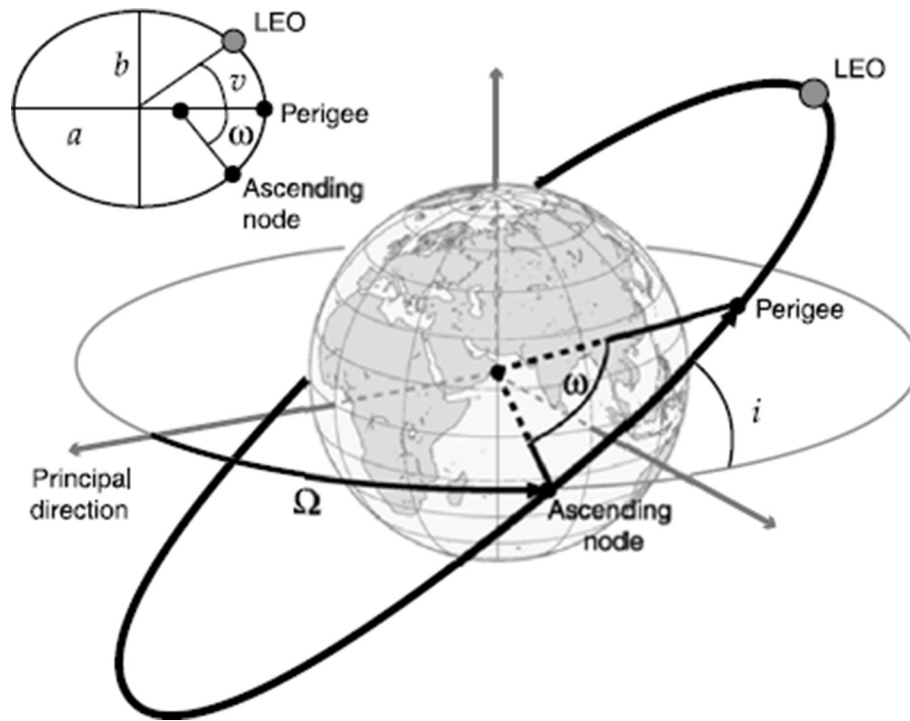


Fig. 2. Satellite orbital Keplerian parameters; inclination of the orbital plan (i), mean anomaly (v), the right ascension of the ascending node (Ω), the argument of perigee (ω), the semimajor axis (a), and semiminor axis (b). The semimajor and semiminor axes of the orbital ellipse are explained in the upper-left part of the figure (after Mousa et al., 2006).

Table 1

List of the operating LEO missions that used in the research, owner country, orbit mean altitude and inclination.

No.	Mission	Country	Altitude (km)	Inclination (°)
1	Ørsted	Denmark	655	96.5
2	SUNSAT	South Africa	600	96.5
3	CHAMP	German	454	87.3
4	SAC-C	Argentina	702	98
5	GRACE	German	485	89
6	COSMIC	Taiwan	800	72
7	MetOp	ESA	817	98.7
8	TerraSAR-X	German	514.8	97.5
9	C/NOFS	USA	464	13
10	OceanSat-2	India	720	98.2
11	MEGHA-TROPIQUES	India & France	865.6	20
12	KOMPSAT-5	Korea	550	97.6
13	EQUARS	Brazil	750	20
14	Microlab-1	USA	735	70
15	FedSat	Australia	800	98.3
16	ACE	Canada	750	90
17	CanX-2	Canada	630	97.6
18	SAC-D	Argentina	657	98
19	FY-3	China	836	98.75
20	NPP	USA	825	98.7

due to the Earth atmosphere is 1° and this is expected to be too small to affect the results.

GNSS and LEO satellite position is estimated every 10 s for each day of the case study days and this insures not losing any rays connecting GNSS with LEO satellites. The elevation angle is the parameter that determines the occultation event rays as the range $\pm 5^\circ$ of the occultation antenna bore sight direction is the range of occultation events rays. Also the tangent points more than 150 km and less than 80 km are excluded for defining a single occultation event (Mousa et al., 2006). The analyses made using the position of the start and the end points of each ray in the three dimensions. Unless otherwise mentioned, both rising and setting occultation arriving at the front and aft antennas are considered in the analysis.

3. Results and discussion

The number of occultation events and their spatial and time distribution over the Egyptian country are considered here as the criteria for showing the research results. As an additional task (not in the main research objectives) the Middle East region RO events spatial distribution was checked. Section 3.1 discusses an overall view for the number of occultation events for the year 2015 and Sections 3.2 and 3.3 show the spatial and time distribution of RO events through the maximum, average and minimum day for the same year.

As mentioned before, the signal path transmitted from the GNSS to the LEO satellite is assumed to be a straight path and has no bending. This approximation may reduce the signal delay by 1 km and also lower the tangent point by 50 km (Mousa et al.,

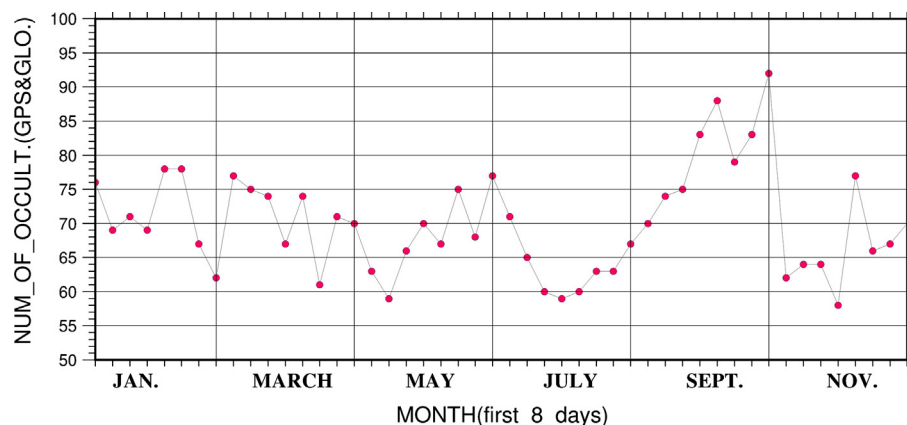
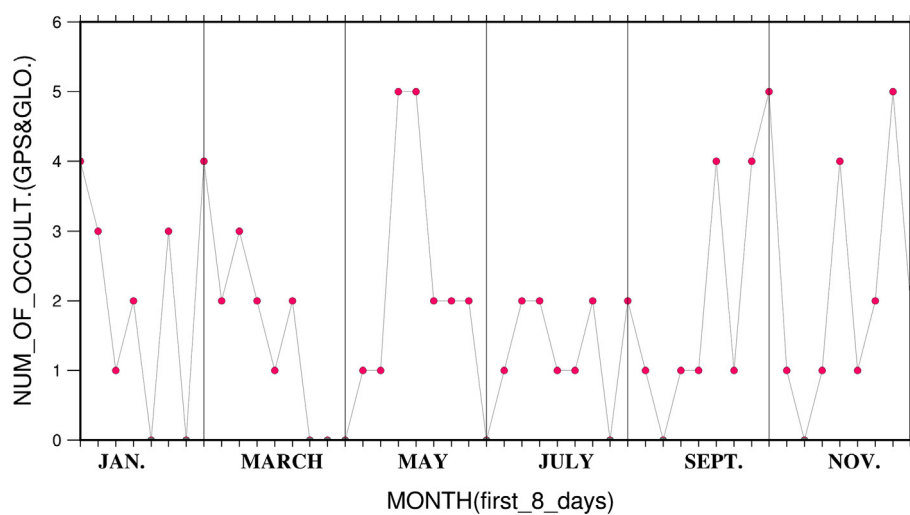
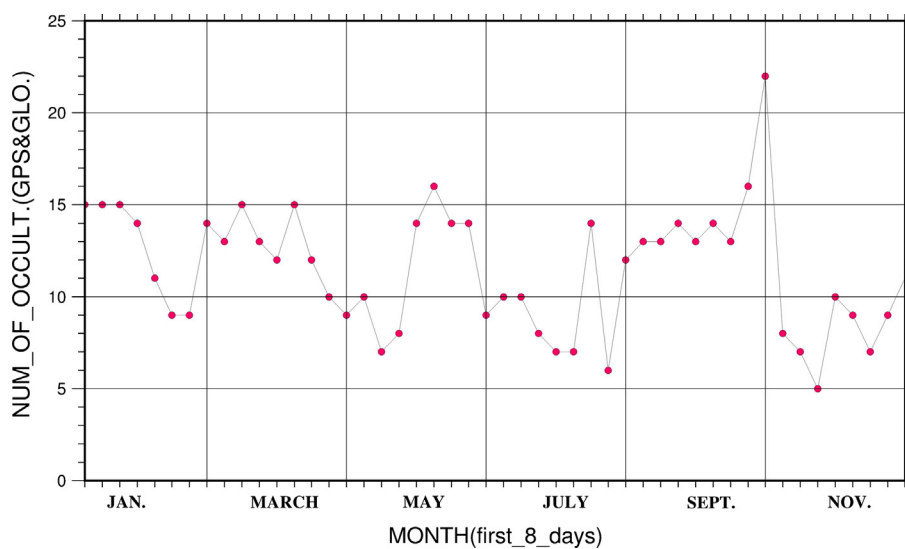


Fig. 3. Daily number of RO events for the first 8 days every two months for the year 2015 (48 days) due to GPS and GLONASS systems.



(a) Delta Region



(b) Along Nile

Fig. 4. Daily number of RO events for the first 8 days every two months for the year 2015 (48 days) for Delta and Nile regions due to GPS and GLONASS systems. Part (a), (b) shows the numerical distribution through the Delta and Nile regions, respectively.

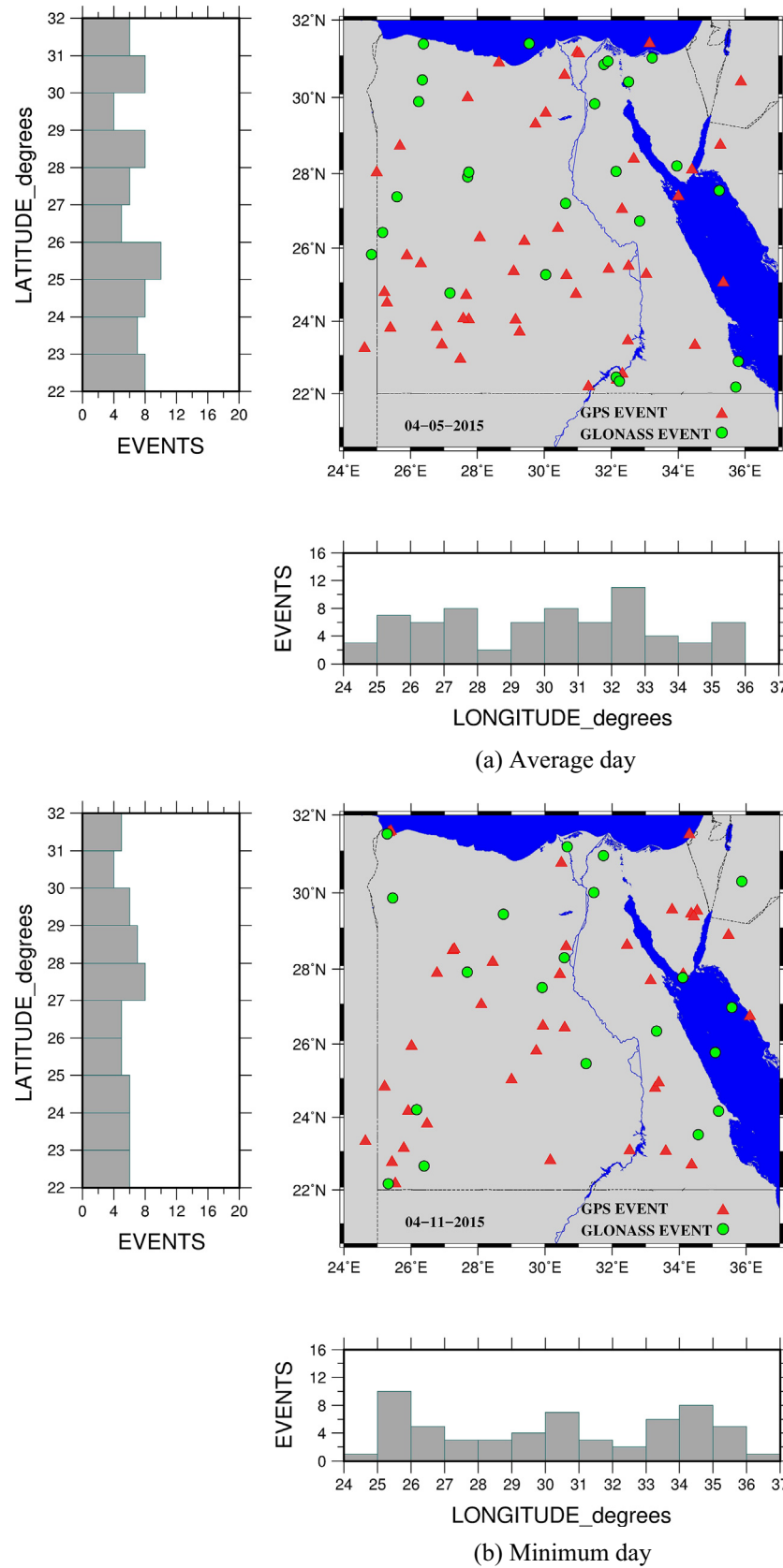


Fig. 5. Spatial distribution of RO events through the Egyptian country map due to GPS and GLONASS systems with two histograms clarify the number of occultation events per each degree of latitude and longitude. Part (a), (b) shows the spatial distribution for the average and minimum days, respectively.

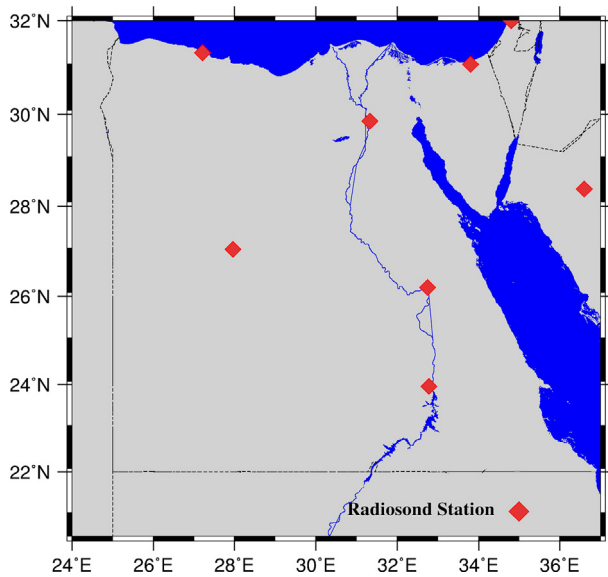


Fig. 6. Spatial distribution of RS stations through the Egyptian country.

2006). As only the number and distribution of occultation per each day of 2015 is considered here, the results are expected to not change due to this approximation.

3.1. Daily distribution of RO events in 2015

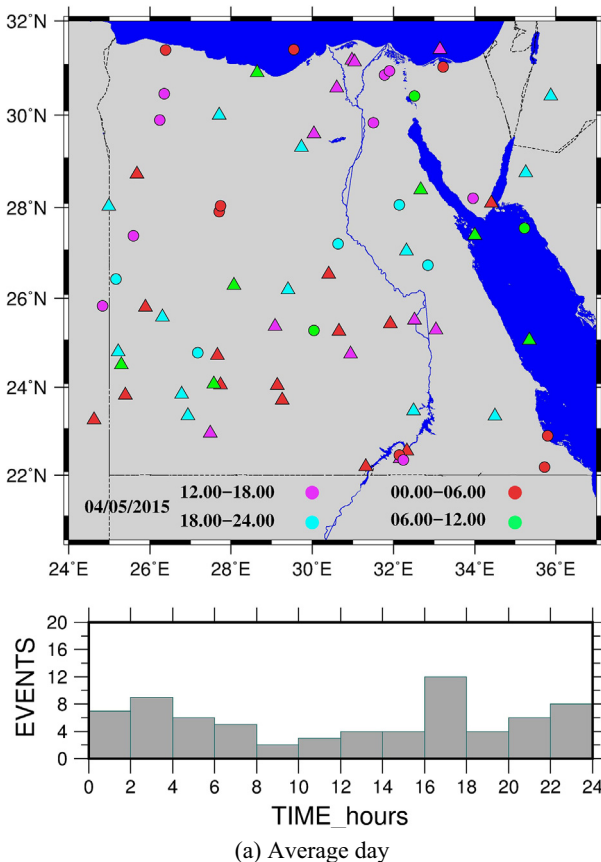
As illustrated recently, the first 8 days every two months is assumed to draw the clear picture for RO events distribution

through the Egyptian country and Fig. 3 shows the number of occultation events for the 48 days. Not only the daily number of RO events responsible to draw the clear picture of RO events distribution in Egypt, but also the spatial and the hourly distribution do that. The first fact we must light from Fig. 3 is that, Egypt includes adequate daily number of RO events to use this advanced method using operating LEO and GNSS satellites. As well the minimum daily number of RO events is 58 occ./day through the Egyptian country, that reassures us about using this method. The average number is 70 occ./day and the maximum number is 92 occ./day on 8 September 2015. From the clear remarks, that generally September days has the maximum number of RO events (see Fig. 4).

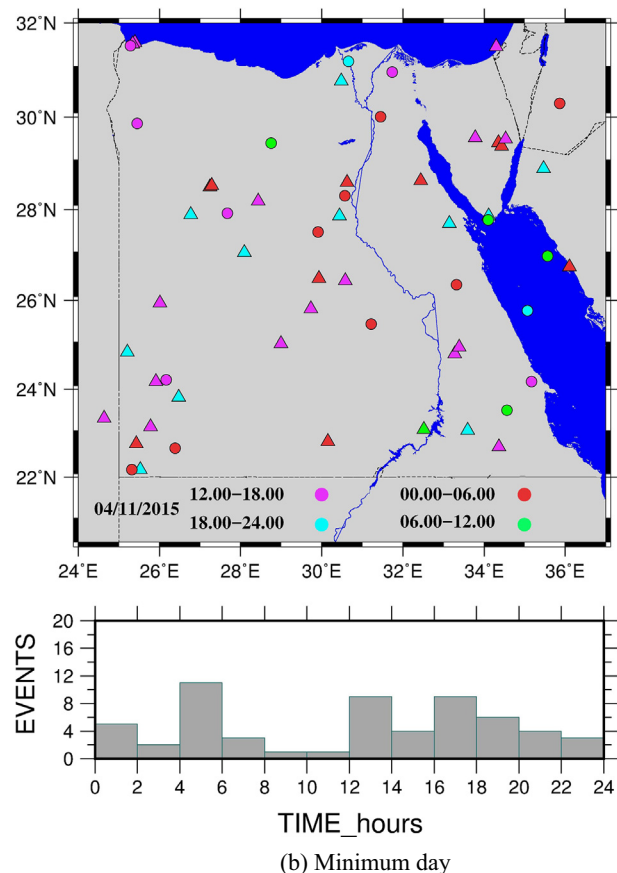
There is a quite increasing in the number of occultation events in September days, analyzing the number of occultation events for GPS and GLONASS indicates that this increasing depends on increasing the number of occultation events in GLONASS only. In addition, the average number of occultation per day for GPS only is 42 occ./day and for GLONASS is 33 occ./day, this means that if there is any obstacles to receive the signal from one system, the other one is adequate (numerically) to cover the Egyptian country.

3.2. Spatial distribution of RO occultation events

Not only the numerical distribution is adequate to insure the capability of applying RO method in Egypt, but also the spatial distribution is playing an important role to do that. The average day (the day that has the average number of RO events) is the one we could construct all of our recommendations on it however, the minimum day is used to ensure that at the worst case, the number of RO events will not be less than the minimum to cover



(a) Average day



(b) Minimum day

Fig. 7. Time distribution of RO events through the Egyptian country map due to GPS and GLONASS systems with two histograms clarify the number of occultation events per each day hour. Part (a), (b) shows the time distribution for the average and minimum days with its two histograms, respectively.

the country. Fig. 5 shows the distribution of occultation events through the average and minimum days, the red triangle is related to GPS occultation events and the green circle is related to the GLO-NASS ones. The figure shows that, for the average day, the occultation events are so far uniformly distributed on the Egyptian country, the maximum distance between two successive RO events not exceeds 2° from latitude or longitude (approximately 240 km) that less than the average distance of weather parameters change. 70 RO events distributed on the country area, Nile region also has more than 10 RO events on the average day, Delta region has 6 RO events 2 in between the two Nile branches and 4 out of them.

The minimum day also has 58 RO events which considered so fare uniformly distribute on the country area, The Nile region have 8 RO events and the Delta has 4 events that is considered adequate. The max distance is 3° in latitude or longitude (approximately 360 km), as the minimum day is as a critical case, all of these indicators mean that applying the method on Egypt will be useful.

Radiosonde weather profiling method is the operating method used now in Egypt. There are six stations distributed on the Egyptian country and three complementary stations in the neighbor countries according to Fig. 6 and each station make two missions daily. In other words, RS method gives 18 measurements per day in Egypt. In comparison to the distribution of Radiosonde (RS) stations in Egypt, the RO events number is equal to more than three times of RS missions per day according to each of average and minimum day.

3.3. Time distribution of RO occultation events

In Egypt, RS missions is done twice a day hence, the Egyptian weather is profiled at each point twice per day with time separation of 12 h, this leads to nonuniform distribution of RS measurements on the day hours. Fig. 7 shows the time distribution of occultation events for each six hours per average and minimum days. The red, green, pink and cyan colors are related to the first, second, third and fourth six hours from the day, respectively.

For the average day, 10 RO events are the least number of RO events from the four periods and it is related to the second period (from 06.00 to 12.00 o'clock) and these events are so far uniform on the Egyptian country. As well, for the minimum day, 6 RO events are the least number of RO events from the four periods and it is related to the second period (from 06.00 to 12.00 o'clock) and five events from the six ones are so far uniform on the Egyptian country. Checking the minimum six hours in the minimum day from the whole 48 days represent the 2015 year is insuring the capability of applying RO method in Egypt and guarantee the obvious development in meteorology in Egypt.

Time histogram beneath each time distribution on map shows the number of occultation events per two hours per each day of average and minimum days. Two RO events per two hours is the minimum number for the average day and one for the minimum

day, this insures the high uniformity in time distribution through day hours. Comparing between the time distribution of RO and RS missions through one day, for RS, 9 measurements are done each twelve hours however, the RO number of events is 23 events per twelve hours on the minimum day that insure the ability of replacing RS method by the RO method in Egypt weather profiling or operate as a complementary method with the current operating method.

4. Conclusion

A new weather layers profiling method called "Radio Occultation" method could be applied now on Egypt. Twenty LEO satellites sent by different countries all over the world could be used as signal receivers from the two GNSS operating systems GPS and GLO-NASS to create points on the Earth surface called "Occultation Events" where we could conclude all weather parameters whether it is related to the neutral layer or ionized one. The location of RO events through the Egyptian country for the first 8 days every two months in 2015, is believed to be able to judge if the RO method could be applied on the Egyptian country or not and if we have to send any LEO satellites or not.

The obtained results indicated that the Occultation Events resulted from the existing LEO satellites are so far uniform in most of the days under study on the whole country as well as in all the Middle East Region and give us the courage to use it instead of expensive and low altitude methods or to complement it. Reassuring uniformity of the spatial and time distribution for the minimum hours through the day has the minimum number of occultation events, insuring the ability of using the method through the Egyptian country. Comparing results to the Radiosonde missions done daily in Egypt and insuring that the RO method gives better spatial and time distribution also insure the ability of using such method through the Egyptian country. As well, Egypt is not in need for sending any LEO satellites.

References

- Mousa, A., Aoyama, Y., Tsuda, T., 2006. A simulation analysis to optimize orbits for a tropical GPS radio occultation mission. *Earth Planets Space* 58, 919–925.
- Rocken, C., Anthes, R., Exner, M., Hunt, D., Sokolovskiy, S., Ware, R., Gorbunov, M., Schreiner, W., Feng, D., Herman, B., Kuo, Y.-H., Zou, X., 1997. Analysis and validation of GPS/MET data in the neutral atmosphere. *J. Geophys. Res.* 102, 29849–29866.
- Tsuda, T., Hocke, K., Takahashi, H., 2004. Utility of occultations for atmospheric wave activity studies: results of GPS/MET data analysis and future plan. In: Kirchengast, G., Foelsche, U., Steiner, A.K. (Eds.), *Occultations for Probing Atmosphere and Climate*. Springer, Germany, pp. 345–352.
- Ware, R., Exner, M., Feng, D., Gorbunov, M., Hardy, K., Herman, B., Kuo, Y., Meehan, T., Melbourne, W., Rocken, C., Schreiner, W., Sokolovskiy, S., Solheim, F., Zou, X., Anthes, R., Businger, S., Trenberth, K., 1996. GPS sounding of the atmosphere from Low Earth Orbit: preliminary results. *Bull. Am. Meteor. Soc.* 77, 19–40.
- Xu, G., 2003. *GPS Theory. Algorithms and Applications*. Springer, Germany. 315 pp.