Search for Best Astronomical Observatory Sites in the MENA Region using Satellite Measurements

Gillali Abdelaziz, Ridha Guebsi, Nidhal Guessoum, Cyrille Flamant

Search for Best Astronomical Observatory Sites in the MENA Region using Satellite Measurements

2017 J. Phys.: Conf. Ser. 869 012070

(http://iopscience.iop.org/1742-6596/869/1/012070)

IOP Conf. Series: Journal of Physics: Conf. Series **869** (2017) 012070 doi:10.1088/1742-6596/869/1/012070

Search for Best Astronomical Observatory Sites in the MENA Region using Satellite Measurements

G Abdelaziz[1], R Guebsi[1], N Guessoum[2], C Flamant[1]

[1]Sorbonne Universités, Univ. Paris 06, CNRS & UVSQ UMR 8190 LATMOS, Paris, France
[2]American University of Sharjah, UAE
Email: nguessoum@aus.edu

Abstract. We perform a systematic search for astronomical observatory sites in the MENA (Middle-East and North Africa) region using space-based data for all the relevant factors, i.e. altitude (DEM), cloud fraction (CF), light pollution (NTL), precipitable water vapor (PWV), aerosol optical depth (AOD), relative humidity (RH), wind speed (WS), Richardson Number (RN), and diurnal temperature range (DTR). We look for the best locations overall even where altitudes are low (the threshold that we normally consider being 1,500 m) or where the combination of the afore-mentioned determining factors had previously excluded all locations in a given country.
In this aim, we use the rich data that Earth-observing satellites provide, e.g. the Terra and Aqua multi-national NASA research satellites, with their MODIS (Moderate Resolution Imaging Spectroradiometer) and AIRS (Atmospheric Infrared Sounder) instruments, the Defense Meteorological Satellite Program’s Operational Linescan System (DMSP-OLS), and other products from climate diagnostics archives (e.g. MERRA).
We present preliminary results on the best locations for the region.

1. Introduction

The Arab world currently has only one large optical astronomy telescope larger than 1 meter in diameter (the Kottamia Observatory in Egypt). And despite the existence of a decent-size astronomical community (professionals and amateurs) in the Arab world, only a few observatories have been built in recent years, and they only host telescopes of 50-60 cm size. This state of affairs has led to calls [1] for the urgent construction of international-class observatories in the region, which is blessed with hundreds of clear nights per year. Guessoum, Alsaeed, and Abdelhafez [2] performed a preliminary search for the best sites in the Middle East and North Africa, considering locations with altitudes higher than 1,500 m and using online and published meteorological data (number of clear nights per year, humidity, temperature profile, wind speeds, light pollution from nearby towns).

That work had obvious shortcomings, however (inability to do in-situ measurements, necessary interpolations and approximations for some factors at sites of interest, etc.), issues that could be remedied by the rich data that Earth-observing satellites can provide, e.g. the Terra and Aqua multi-national NASA research satellites, with their MODIS (Moderate Resolution Imaging Spectroradiometer) and AIRS (Atmospheric Infrared Sounder) instruments. We have thus undertaken a systematic search of astronomical observatory sites using real space-based data for all factors. We look for the best locations for all countries, even those that may not have any sites higher than 1,500 m or where the combination of factors (altitude, meteorological conditions, and light pollution) had previously ended up excluding all locations in some countries.

The usage of satellite data has been proposed and applied in recent site selections for potential observatory locations in Australia, Morocco and the Canary Islands, West Africa, Turkey, and Chile [3, 4, 5, 6, 7, 8, 9] using multi-criteria decision analysis coupled with geographical information systems. Vernin et al [9] stress the importance of this approach: "satellites have the advantage of providing a long-term (longer than 5 yr) database for many sites in the world by using comparable spectrographs and techniques" and "high vertical resolution and the use of appropriate channels to detect different types and levels of clouds make the satellite data a useful tool for clear/photometric time characterization for astronomical observations." The accuracy of and the uncertainty over the data produced by satellite instruments with regard to the relevant factors has been discussed by several authors [4, 8, 9].

2. Data, Method, and Results

Table 1 lists the sources and general characteristics of the data we have used (all for 2014, except for Nighttime Lights, as 2013 was the most recent available time series, all accessed in 2015 and 2016).

Table 1. Data Sources and Characteristics (from [10, 11, 12]).

Variable Name	Product	Version	Source	Spatial Resolution	Units	Temporal Resolution
Digital Elevation Model	SRTM30	2	NASA - NGA	1' Global Relief Model	m	-
Cloud Fraction (Night time/ Descending)	AIRX3STD	006	AIRS	1°	-	Daily
Night time Lights (for 2013)	Stable Lights	4	DMSP-OLS	5 km x 5 km	-	Annually
Total Column Water Vapor (Night time/ Descending)	AIRX3STD	006	AIRS	1°	kg/m^2	Daily
Mean AOD (Combined Dark Target and Deep Blue) at 0.55 micron for land and ocean	MYD08_D3	006	MODIS-Aqua	1°	-	Daily
Relative Humidity at Surface (Night time/ Descending)	AIRX3STD	006	AIRS	1°	percent	Daily
Wind speed (time average) at 10 m above displacement height	MAT1NXSLV	5.2.0	MERRA Model	0.5 x 0.667°	m/s	Hourly
Surface Richardson Number	MAT1NXFLX	5.2.0	MERRA Model	0.5 x 0.667°	-	Hourly
Air temperature at surface (Daytime/ Ascending)	AIRX3STD	006	AIRS	1°	K	Daily
Air temperature at surface (Night time/ Descending)	AIRX3STD	006	AIRS	1°	K	Daily

Our goal is to determine, at least in first approximation, 'good' astronomical site locations in the MENA region, based on the general principles that a good observatory site has a high elevation (preferably above the inversion layer, i.e. above many of the aerosols that cause poor transparency), little atmospheric distortion (low and stable turbulence), and good 'seeing' (better suited for the implementation of adaptive optics), with low levels of CF, NTL, PWV, and AOD, which are sources of sky transparency degradation.

To evaluate the quality of each location over the entire region, we apply the following procedure:

- From the data sets presented in Table 1, we determine the value of each factor at every spot of the region, using a grid with 1° x 1° horizontal resolution (i.e. roughly 100 km x 100 km, which is the resolution provided by the satellite instruments) and vertical (altitude) levels of 50 m.
- For parameters with a different spatial grid resolution, we use a 'regridding' transformation, which is a process of linear interpolating (area-weighted average) from one inferior spatial grid resolution to 1° x 1° horizontal resolution.
- As a pre-processing stage, we use a Min-Max Normalization technique to compute the value of each parameter for every spot, which is then converted into a score of 1 to 10: 1 for best (lower levels of the physical parameter) and 10 for worst (higher levels of the physical parameter).
- For each location, we then calculate an overall score using a weighted average approach, considering the relative importance of the various factors. There is no wide agreement on the weighting or even the ordering of the physical parameters; experts ([13]) have suggested the following order: Cloud Fraction, Nighttime Lights, Total Column Water Vapor, AOD, Relative Humidity, Wind Speed, Richardson Number, Diurnal Temperature Range, and that is what we have adopted. Parameter weights vary between 0 and 1 and add up to 1. Tests are still being performed to determine the optimal weights, to give results that reflect the known quality of specific sites in the region. We will discuss this aspect of the calculation in a future publication.
- Finally, we rank the various locations according to their overall scores.

Below is a map showing the various areas by overall score as well as the locations of the best sites (shown with stars) obtained from the above procedure.

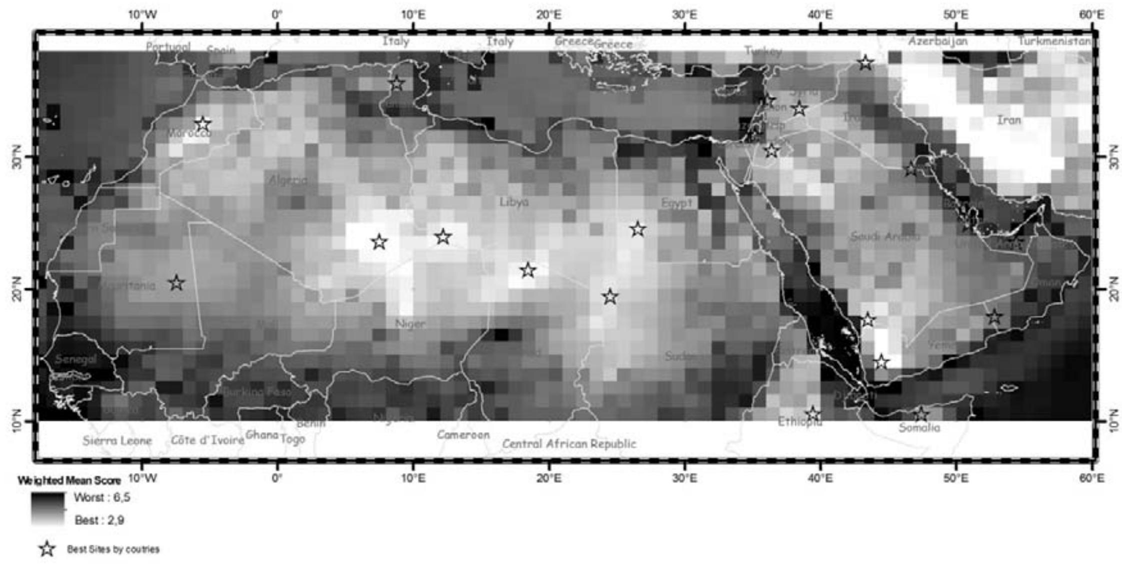

Figure 1. – Map of all locations with weighted scores: the whitest areas represent the best sites, the darkest represent the worst ones, and the stars are the very best sites.

Conclusion

We performed a systematic search for potential astronomical observatory sites in the MENA region using remotely sensed key parameters (affecting the sky transparency) as well as climate diagnostics archives and meteorological databases (parameters that affect the optical turbulence). We cover the whole region, including countries/areas where altitudes are lower than 1,500 m or where the combination of factors make locations unsuitable for observatories in principle, to help countries with limited altitudes or generally bad conditions in case educational or non-advanced observatories are to be built.

Astronomical observations depend critically on sky transparency, which we evaluate using a weighted sum of levels of cloud fraction, nighttime light pollution, precipitable water vapor, aerosol optical depth, relative humidity, wind speed, turbulence (surface Richardson number), and diurnal temperature range, all being measured from space. The score is obtained using a three-step process: a 'regridding' transformation, a normalization technique, and a weighted average.

We want to stress that this work must be regarded as a first phase in the determination of astronomical observatory locations, it must be followed up by on-site testing, with in situ measurements, using telescopes, photometers, airborne particles counters, ground meteorological stations, etc. This necessary second phase will increase the accuracy of the final list of locations and ensure that the data grid (recall the 1^o x 1^o, i.e. 100 km x 100 km cell size) of the space-based data did not smooth out any important local effect. Regional and international expert site-testing teams can greatly help in this endeavour.

We are conducting further investigations and refinements of this work. In particular, the effect of each factor (its weight in the overall score of a given site) requires more extensive simulations and tests. We aim to present a more detailed version of this work in the near future, with the exact locations of the best sites over the whole MENA region and for each Arab country. We hope this will facilitate and accelerate the construction of high-quality astronomical observatories in the Arab world.

References

[1] Guessoum N 2013 Time for an Arab astronomy renaissance *Nature* **498** pp 161–164
[2] Guessoum N, Alsaeed N and Abdelhafez N 2014 Preliminary search for astronomical observatory sites in the MENA region, *The Observatory* **134** pp 339-34
[3] Varela A M *et al* 2008 Astronomical site selection: on the use of satellite data for aerosol content monitoring *Mon. Not. R. Astron. Soc*. **391**:2 pp 507-520.
[4] Bounhir A 2009 *Qualification des sites Astronomiques: Nouvelle approche par l'utilisation des données satellitaires et météorologiques* Marrakech, Morocco: Université Cadi Ayyad
[5] Hotan C E, Tingay S J and Glazebrook K 2013 Testing Potential New Sites for Optical Telescopes in Australia *Publ. Astron. Soc. Aus.* **30** id.e002
[6] Erasmus, D A and van Rooyen, R 2006 A satellite survey of cloud cover and water vapor in northwest Africa and southern Spain Ground-based and Airborne Telescopes, edited by Larry M. Stepp, Proc. of SPIE Vol. 6267, 62671O
[7] Aksaker N *et al* 2015 Astronomical Site Selection for Turkey Using GIS Techniques *Exp. Astro.* **39**:3 pp 547-566
[8] Varela A M *et al*. 2012 On the Use of Remotely Sensed Data for Astronomical Site Characterization http://www.iac.es/proyecto/site-testing/images/stories/pdf/varela_et_al_2012.pdf
[9] Vernin, J *et al* 2011 European Extremely Large Telescope Site Characterization I: Overview *Publications of the Astronomical Society of the Pacific*, 123:909 pp 1334–1346
[10] GIOVANNI (from Goddard Earth Sciences Data Information Services Center) http://Giovanni.gsfc.nasa.gov/giovanni
[11] Global Modeling and Assimilation Office (GMAO)(2008), tavg1_2d_flx_Nx: MERRA 2D IAU Diagnostic, Surface Fluxes, Time Average 1-hourly V5.2.0, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed June 05, 2016 10.5067/4EQ54AKI405R
[12] National Geophysical Data Center https://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html
[13] Ziad, A and Conan, J-M, private communications