International Conference on Space Optics—ICSO 2022

Dubrovnik, Croatia

3–7 October 2022

Edited by Kyriaki Minoglou, Nikos Karafolas, and Bruno Cugny,

ICSO 2022

International Conference on Space Optics

3 – 7 October 2022 | Dubrovnik | Croatia

ANAtOLIA : a mobile station for site availability characterization for Optical Communications links

icso proceedings

International Conference on Space Optics — ICSO 2022, edited by Kyriaki Minoglou, Nikos Karafolas,
Bruno Cugny, Proc. of SPIE Vol. 12777, 127772M · © 2023 ESA and CNES · 0277-786X · doi: 10.1117/12.2689999

ANAtOLIA : a mobile station for site availability characterization for Optical Communications links

A. Ziad[a], C. Giordano[a], A. Aresta[b], E. Aristidi[a], C. Bailet[a], F. Berto[f], C. Bertolin[f], M. Carbillet[a], S. Cavazzani[f], D. Ceus[g], T. Charbonnel[a], J. Delanoë[e], J. Descloitres[d], Y. Fanteï-Caujolle[a], A. Gillioën[a], Y. Gonzalez-Ramos[c], A. Irbah[e], E. Jacqmart[a], A. Le Kernec[h], O. Liandrat[g], S. Poulenard[b], J. Riédi[d], N. Schmutz[g], D. Vedani[a], and S. Victori[c]

[a]Université Côte d'Azur, OCA, CNRS, Lagrange, Parc Valrose 06108 Nice Cedex 2, France
[b]Airbus Defence & Space, 31402 Toulouse Cedex 4, France
[c]Cimel Electronique, 172 rue de Charonne, 75011 Paris, France
[d]ICARE - Centre de Données et Services, CNRS, UMS 2877, 59655 Villeneuve d'Ascq Cedex, France
[e]Latmos, University of Versailles Saint-Quentin en Yvelines, CNRS, 78280 Guyancourt, France
[f]Norwegian University of Science and Technology, Faculty of Engineering, Trondheim 7491, Norway
[g]Réuniwatt, 14 rue de la Guadeloupe, 97490 Sainte Clotilde, La Réunion, France
[h]Thales Alenia Space, 26 Avenue Champolion, BP 1187, 31037 Toulouse Cedex, France

ABSTRACT

The Atmospheric moNitoring to Assess the availability of Optical LInks through the Atmosphere (ANAtOLIA) is a station developed in the framework of a project funded by the European Space Agency which aims to ground-sites selection and assess their availabilities for optical links through the atmosphere. In addition to cloud cover, space-to-ground optical communications are limited by aerosols and atmospheric turbulence. Therefore, we are developing in the framework of the ANAtOLIA project, an innovative and efficiency instrumentation and studies to specify, accurately measure, analyze, characterize, and ultimately predict critical atmospheric parameters for the purposes of the selection of the Optical Ground Station (OGS) sites and the evaluation of their availability. The main objectives of ANAtOLIA project are to design, manufacture, procure and assembly a self-standing and autonomous ground support equipment, comprising cloud, aerosol and turbulence monitoring to deliver precise measurements of the atmosphere transmission. Then, to install and commission of these atmosphere monitors at selected ground locations in ESA member states or in their vicinity and to record continuously local cloud, aerosol information and atmospheric turbulence conditions for 24 months. The last objective is to correlate these local ground measurements with data available from other sources of atmospheric conditions. The main goal of these correlations is to improve knowledge of the optical link availability for selected OGS locations and to carry out a long-term validation of the optical link availability prediction methods. ANAtOLIA is a compact 24h mobile station consisting of the Generalized Monitor of Turbulence (GMT), the Réuniwatt Sky Insight camera and the Cimel photometer CE318-T.

Keywords: Optical Communications, Site-testing, atmospheric optics, atmospheric turbulence, turbulence monitoring, cloud monitoring, aerosol characterization.

1. INTRODUCTION

The motivation for optical space communication systems stems from the expectation that substantially higher (10 times) data rates than RF-based solutions. But optical space communication through the Earth atmosphere is nearly impossible in the presence of most types of clouds. In addition to cloud cover, space-to-ground optical communications are limited by the presence of dust, aerosols and atmospheric turbulence. Therefore, it is

Further author information: (Send correspondence to A. Z.): E-mail: ziad@unice.fr, Telephone: (33) (0)4 89 15 03 92

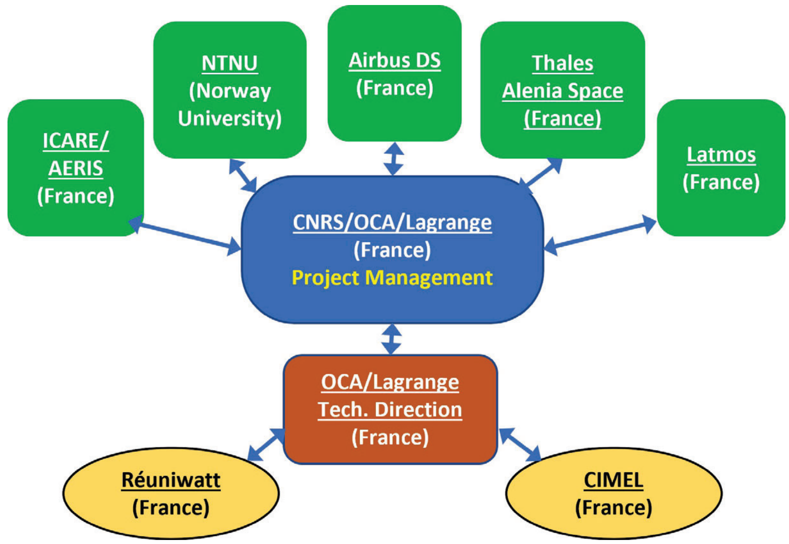

Figure 1. The structure of the ANAtOLIA consortium.

important to specify, accurately measure, analyze, characterize, and ultimately predict critical atmospheric parameters for the purposes of the selection of the OGS (optical ground station) sites and the evaluation of the OGS availability. The limited availability of OGS due to clouds and other atmospheric impacts need to be considered to give a reliable estimate of the optical link system performance. An OGS network is required for increasing the availability to acceptable figures.[1] In this case, a site diversity concept needs to be implemented in order to boost the low availability of an individual OGS to an acceptable availability of a virtual optical gateway (i.e., a network of OGS implementing handover procedure). Ultimately, the decision and frequency of the handover operation will be determined by the accuracy of the local monitoring of clouds, turbulence, and aerosols.

In this paper we present a new compact station for site-testing in terms of clouds, turbulence and aerosols. The ANAtOLIA station is under development in the framework of a european consortium (see Fig. 1) and a contract with the European Space Agency (ESA). The ANAtOLIA is a compact mobile high performance station consisting of the Generalized Monitor of Turbulence (GMT) for turbulence characterization, the Réuniwatt Sky Insight camera for the estimation of clouds parameters and the Cimel CE318-T photometer for aerosols detection and characterization. The ANAtOLIA station will be operational 24h a day, 7 days a week in any site around the world with minimal infrastructure such as power access. The ANAtOLIA is now installed at the Calern Observatory for on-sky tests and also for cross-calibration with the Calern Atmospheric Turbulence Station (CATS). The ANAtOLIA project and objectives will be presented in Sect. 2. The different instruments of the ANAtOLIA station are presented in Sect. 3. The sites to be tested in the frame of the ANAtOLIA project are the results of a specific climate study. During the campaigns of measurement on the different sites, results will be compared with other data sources (MODIS, MSG...) which are presented and discussed in Sect. 4.

2. THE ANATOLIA PROJECT

The optical communication system solution for a particular mission has to utilize optical ground stations that are geographically dispersed, such that there is a high probability of a cloud-free line of site (CFLOS) to a ground station from spacecraft at any given point in time (e.g., at the same longitude, or at a sufficient number of stations at different longitudes to allow the stored onboard data to be transmitted within the allocated time). The Optical Link Study Group (OLSG)[1] analyzed the space-Earth mission scenarios for CFLOS and expressed the results in a common metric across the scenarios-percent data transferred (PDT). The analysis indicates ground segment solutions are possible for all scenarios, but require multiple, geographically diverse ground stations in view of the spacecraft. In addition to cloud cover, space-to-ground optical communications are limited by the presence of dust, aerosols and atmospheric turbulence. Therefore, it is important to specify, accurately measure, analyze, characterize, and ultimately predict critical atmospheric parameters for the purposes of the selection of the OGS sites and the evaluation of the OGS availability.

ANAtOLIA aims to ground-sites selection and assess their availabilities for optical links through the atmosphere. Therefore, we propose an innovative and efficiency instrumentation and studies to specify, accurately measure, analyze, characterize, and ultimately predict critical atmospheric parameters for the purposes of the selection of the OGS sites and the evaluation of their availability. The main mission objectives of ANAtoLIA are to design, manufacture, procure and assembly a self-standing and autonomous ground support equipment, comprising cloud, aerosol and turbulence monitoring to deliver precise measurements of the atmosphere transmission. Secondary study goals are to install and commission of these atmosphere monitors at selected ground locations in ESA member states or in their vicinity and to record continuously local cloud, aerosol information and atmospheric turbulence conditions for a sufficiently long temporal period (24 months). The last objective is to correlate these local ground measurements from monitors with data available from other sources of cloud coverage and atmospheric conditions (e.g., MSG, MODIS, local meteorological sites). The main goal of these correlations is to improve knowledge of the optical link availability for selected optical ground station locations and to carry out a long-term validation of the optical link availability prediction methods. This study proposes to use existing instrumentation within the consortium partners and adapt them in an optimal or simplified configuration to retrieve the ESA objectives. A full high performance instrumentation is proposed allowing a fine characterization of the whole atmospheric parameters required by ESA. Based on years of knowledge and experience, the CNRS-OCA's consortium proposal consists to design and manufacture a mobile station with high performance equipment composed by (Fig. 2):

- A unique atmospheric turbulence monitor GMT capable of extracting 24h/day, the whole atmospheric turbulence parameters required by ESA (Fried parameter, seeing, Isoplanatic angle, Angle of Arrival fluctuations, Greenwood frequency, Scintillation, Refractive index structure profile $C_N^2(h)$ with high vertical resolution, Outer scale, Coherence time, Wind speed). This GMT monitor is a compact version of the completely automated CATS station installed since 7 years at the Calern Observatory.
- The Reuniwatt Sky Insight which is a wide field IR sky imager as a monitoring equipment 24h/day for a precise characterization of clouds (coverage, height, type/phase, optical thickness and attenuation). The Sky Insight imager is a confirmed and validated instrument. In addition, several weather sensors are also embedded into the Sky Insight: a solar reference cell, a thermometer, and a humidity sensor.
- The Cimel CE318-T photometer. This is a multispectral atmospheric photometer which is the reference for automatic aerosols monitoring for day and night conditions. The CE318-T performs Sun, sky and lunar light measurements, for the retrieval of aerosol transmittance, visual Range, sky radiance and cloud optical thickness.

This compact mobile station consisting of GMT monitor, Réuniwatt Sky Insight camera and Cimel CE318-T photometer will be operational 24h a day, 7 days a week in any site around the world with minimal infrastructure such as power access.

The ANAtOLIA high performance instrumentation is now installed for one year at at the Calern Observatory for cross-calibration under different turbulence conditions by means of CATS station (Fig 3).

Before starting instrumental development, a specific attention has been dedicated to the definition of the list of critical atmospheric parameters and the selection of optical ground stations. Based on numerical simulations and on the atmosphere data, impacts of atmospheric transmission on link performances has been studied to finalize the list of the pertinent parameters in terms of clouds, aerosols and turbulence. In front of this final list of critical parameters we provided a finalized list of instrumental solutions to perform the measurements with the required precision and the adequate sampling. The chosen instrumentation has been installed and now under on-sky tests on Calern Observatory and then will be moved to the selected sites for measurement operations during a period of 24 months. Then, data extraction and analysis, including correlations with data from other data sources (MODIS, MSG, etc...) will be performed. Finally, we propose to carry out long-term characterization of the selected sites by means of predictive methods and models.

Figure 2. The high performance ANAtOLIA station.

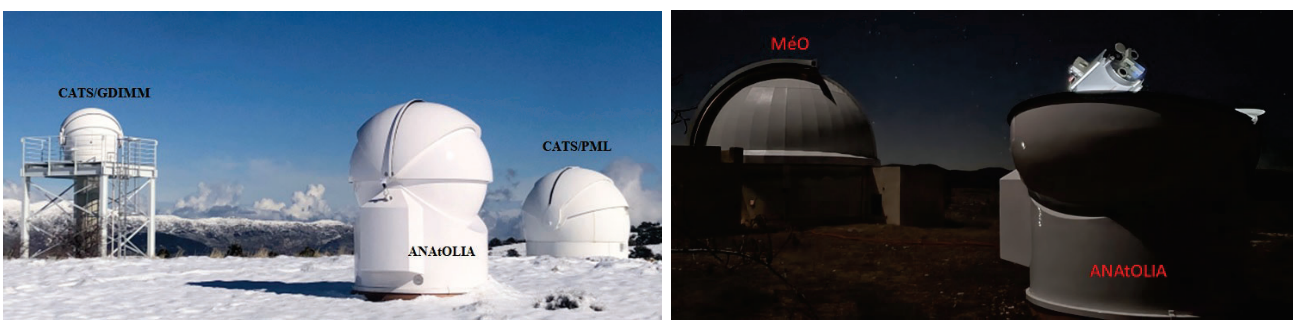

Figure 3. The GMT instrument set up at the Calern Observatory near the CATS station with its GDIMM and PML monitors (left). GMT is also installed near the MéO station (right).

3. ANATOLIA STATION

To achieve the requirements of the ANAtOLIA in terms of scientific goals and budget, we were aware in the consortium that the CATS station deserves to be compacted and completed to reduce its cost while meeting the needs of ESA in terms of turbulence, aerosols and clouds characterization with high performances. Thus, we proposed to merge GDIMM*[2] and PML†[3,4] of the CATS station ([5]) in one unique and compact monitor called GMT (Generalized Monitor of Turbulence) without impacting the list of the measured parameters. To this GMT instrument we added two instruments for clouds and aerosols detection and characterization corresponding respectively to the Reuniwatt Sky Insight camera and the Cimel CE318-T photometer in addition to a ground weather station (Fig. 2).

This compact mobile station consisting of GMT monitor, Réuniwatt Sky Insight camera and Cimel CE318-T photometer is a high performance and confirmed instrument. This station is operational 24h a day, 7 days a week in any site around the world with minimal infrastructure such power access.

*Generalized Differential Image Motion Monitor
†Profiler of Moon Limb

3.1 GMT instrument

The Generalized Monitor of Turbulence (GMT) is a unique instrument to monitor the optical turbulence in any site around the world and during daytime and nighttime conditions. The GMT is a compact and improved version of the CATS station as shown in Fig. 3 and as explained in detail here-after.

The GMT instrument is mainly dedicated to the extraction of the C_n^2 profile with high vertical resolution from lunar (or solar) limb fluctuations. The GMT instrument is based on a differential method by observation of the lunar (or solar) limb through two sub-apertures (Fig. 4). The Moon or Sun limb acts as a continuum of double stars with all possible angular separations required between two points to scan the atmosphere with a very fine resolution.[3,4]

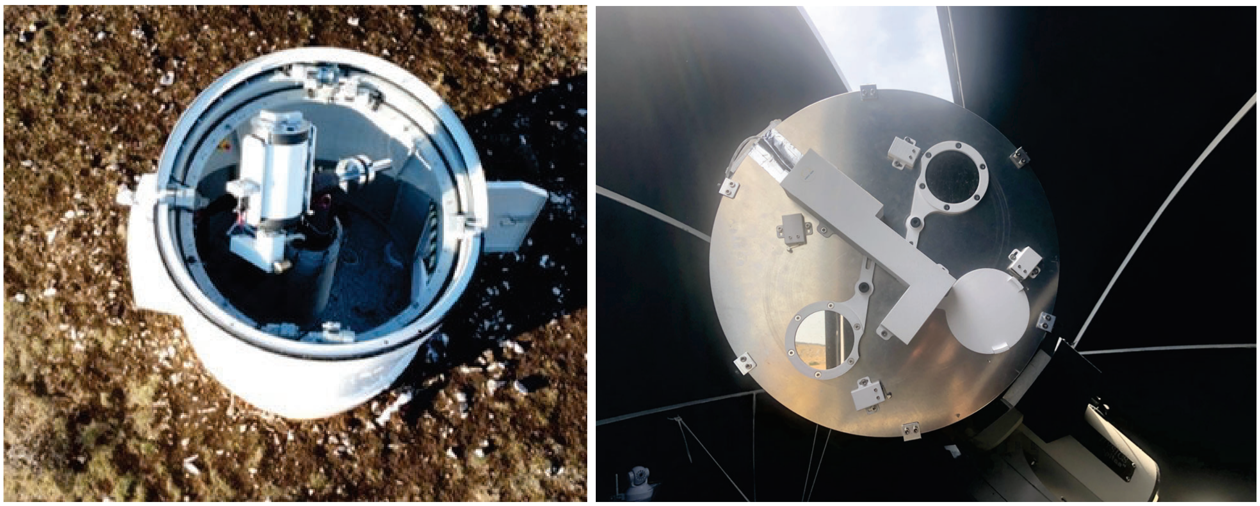

Figure 4. Left: the GMT instrument inside its 2.3m AllSky Baader dome. Right: The pupil mask and the optical device of the GMT instrument.

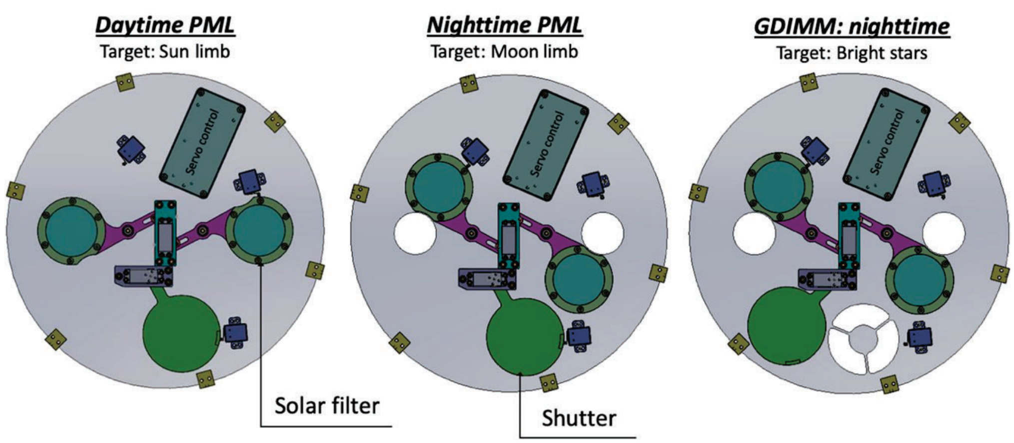

Figure 5. Different GMT's mask configurations for 24h atmospheric turbulence monitoring passing from PML to GDIMM mode.

The GMT instrument consists of a small telescope installed on an precise direct drive mount. The pupil mask, composed of two sub-apertures of diameter $D = 6$cm separated by a baseline $B = 26.7$ cm, is placed at the entrance pupil of the telescope (Fig. 4). In addition, the GMT instrument is equipped with automatic panels to cover the two subapertures with solar filters for a fast and automatic switch from night/Moon observation to day/Sun observation (Fig. 4 & Fig. 5). The GMT is also equipped with a third subaperture of 10cm with a central obstruction of 4cm which is masked with a panel during Moon/Sun observations and removed to observe bright stars in the GDIMM mode. This third subaperture is also covered by a prism to avoid overlapping with the two other spots when observing a bright star in the GDIMM mode.

An optical device is installed in the focal plan of the telescope. It consists of a collimated beam by using a first lens L1 placed at its focal length from the telescope focus (Fig. 6). Then, two parallel beams are formed at the output of L1 corresponding to each sub-aperture. A Dove prism is inserted on one of the two beams to reverse one of two images of the lunar (solar) edge in order to avoid an overlapping of the two images of the Moon/Sun (Fig. 6). This Dove prism is also used to avoid spots overlapping by shifting one spot when observing a bright star in the GDIMM mode. A second lens L2 is used to form the two images of the Moon limb (or Sun edge) on the CCD camera. To compensate for variations in the telescope's focus because of the temperature variations, we installed the CCD camera on an automatic micro-control plate controlled by the acquisition software (Fig. 6). Images at the focal plane are recorded using a CCD camera with 640 × 480 pixel matrix. In order to freeze atmospheric effects on the motion of the Moon's (or Sun) limb image and to have enough flux, the exposure time is set to 5ms.

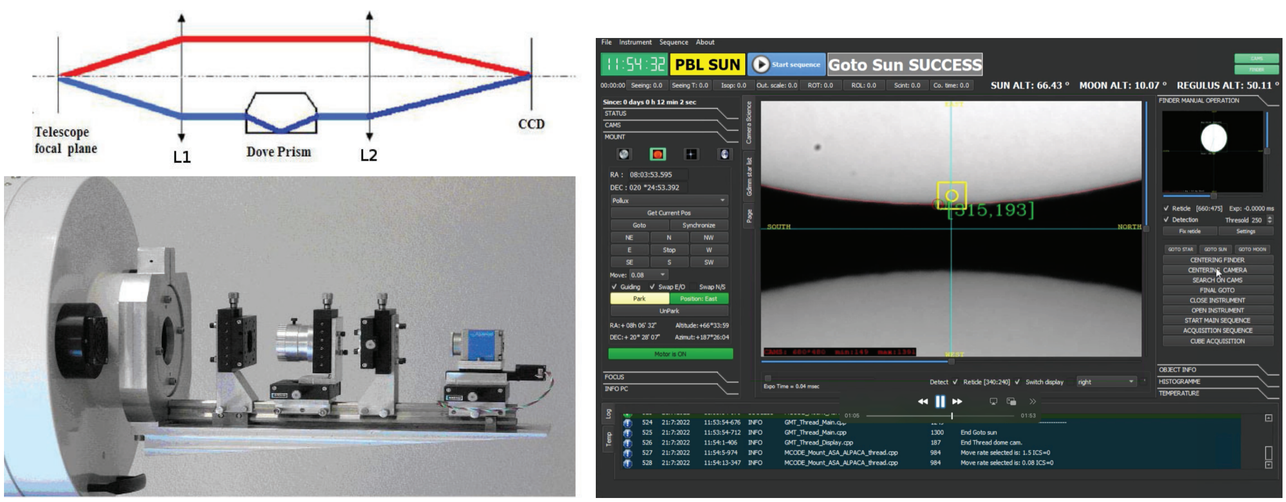

Figure 6. Left: GMT optical device. Right: the graphical user interface of the GMT instrument showing the two Sun limb images.

The principle of the GMT instrument is based in the same way than the PML monitor[3,4] on the measurement of the angular correlation of the fluctuation differences in the wavefront AA deduced from the motion of the Moon's (or Sun) limb image. The AA fluctuations are measured perpendicularly to the lunar (or solar) limb leading to transverse correlations for different angular separations along the Moon (or Sun). The observed Moon or Sun limb is parallel to the sub-apertures baseline. In this case, the transverse covariance of the difference of the AA fluctuations (motion of the Moon or Sun limb) α between the two images of the lunar (or solar) limb (Fig. 6) are deduced and then used to extract the $C_N^2(h)$ profile with high resolution by solving an inverse problem,[3,4]

The GMT acquisition software provides a real time computation of the C_n^2 profile with a high resolution vertical every 3 minutes. Other parameters of turbulence are also accessible from this instrument such as the profile of outer scale, the seeing, and the isoplanatic angle.

The GMT is also used as a GDIMM[2] when the Moon is not observable during the nighttime. Indeed, in the GDIMM mode a bright star is observed with the three subapertures as shown in Fig. 4 & Fig. 5. The GMT in GDIMM mode provides the whole integrated turbulence parameters,[2] the seeing or Fried parameter from DIMM method using the two 6cm subapertures, the isoplanatic angle is deduced from scintillation measurement with the third 10cm subaperture, the coherence time is obtained from the 3 subapertures by means of the temporal structure function and finally the outer scale is obtained from normalized Angle-of-Arrival variances. The GDIMM instrument provides results of turbulence parameters in real time each minute.

3.2 Sky Insight IR camera

The Réuniwatt[‡] Sky Insight is a patented infrared sky imager for the continuous tracking and forecasting of the cloud cover. The use of the infrared vision technology enables an unprecedented accuracy for day & night cloud detection, while catching additional information on the cloud ceiling. The Sky Insight imager is a confirmed and validated instrument allowing a precise and a complete characterization of clouds (cloud coverage, base height, type, optical thickness and attenuation). In addition, several weather sensors are also embedded into Sky Insight: a solar reference cell, a thermometer, and a humidity sensor.

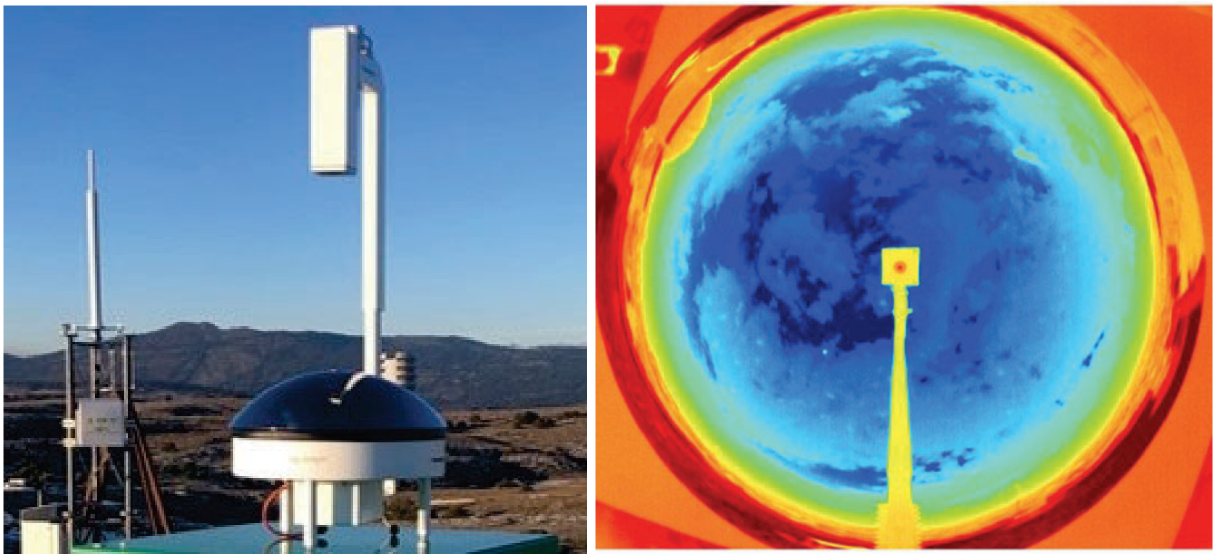

Figure 7. The Réuniwat Sky Insight IR camera installed on the roof of the MéO station at Calern Observatory (left). Right panel: example of sky image acquired by the Réuniwat Sky Insight IR camera.

Sky InSight (Fig. 7) is composed of a thermal long-wave infrared (LWIR) camera core with a 640x480 pixel spatial resolution. The radiation coming from the sky is reflected on a hemispherical mirror that provides a 360/180° view of the sky. Its chrome-coated surface ensures an optimal reflection of LWIR radiations. This mirror has been chosen for cost-reduction purposes as well as for a better calibration due to a lower curvature of the dome than that of a small germanium upward-looking fish-eye camera. Humidity and temperature sensors, installed in a ventilated casing located near the camera, provide in situ meteorological information improving the estimation of clear atmosphere radiance. An embedded computer is used to acquire and upload the data on a server for measurement processing. The LWIR atmospheric window from 8μm to 13μm is well suited for cloud observation. Cloud emission is high to present a strong contrast with a clear sky radiometric signature. A thermal infrared imager has the advantage of directly detecting cloud emission rather than relying on reflected and scattered sunlight in the case of visible or near-infrared observation systems. Thus, cloud detection performance does not depend on the illumination of the cloud cover by the Sun, enabling continuous night and day observation. Benefits of using a thermal camera are particularly obvious when you look in the Sun's direction. The pixels of visible cameras tend to be saturated, which distorts any relevant information regarding cloud presence. In contrast, Sky InSight shows a very limited saturated region. The accompanying software, provides a cloud image every 30 seconds (a higher rate is also possible) as well as the result of the automatic and real-time cloud fraction calculation in okta. Other parameters such as cloud optical depth and altitude of clouds are also provided in real time.

3.3 Aerosol photometer

Although the effect of aerosol concentration is not a primary attenuation parameter (fade is typically less than 1 dB) for optical communications, it is still important to characterize aerosols at ground station (GS) and account

[‡]https://reuniwatt.com/

for aerosols in the system's link budget. Composed of particles and droplets suspended in the atmosphere, the aerosol loading in the atmosphere can vary significantly according to location and time of year. For example, an optical ground station located on Tenerife would experience large transmission losses due to the Calima (Saharan dust) events that occur periodically in the spring and summer months.

Figure 8. The Cimel CE318-T photometer installed near the Réuniwatt caméra on the roof of the MéO station at Calern Observatory.

The Cimel[§] CE318 photometer is a reference for automatic multispectral atmospheric photometry. Developed for the NASA in 1992, it was constantly improved to meet the growing requirements of AERONET (AErosol RObotic NETwork), the worldwide federation of networks dedicated to the measurement of atmospheric aerosols and federated by the NASA. Other independent networks such as SKYNET, CARSNET, and SONET also operate CE318 photometers. The latest version, the CE318-T, takes advantage of cutting-edge technologies to improve metrological performance and facilitate operations. AERONET decided in 2015, after full validation, to accept only the CE318-T for new photometers entering the network. The CE318-T performs Sun, sky and lunar light measurements, for the retrieval of essential physico-optical parameters: Aerosol Optical Depth (AOD), Volume Size Distribution (VSD), complex refractive index (n), shape factor and water vapor content. The high sensitivity tracking, detection chain and internal data processing result in enhanced measurements. Flexible communication and solar autonomy allow easy operation both on fixed sites and temporary locations.

The new Sun-sky-lunar Cimel CE318-T photometer has been developed by the Cimel company improving the tracking precision in order to perform both daytime (Sun) and nighttime (Moon) measurements and providing additional and enhanced operational functionalities. The CE318-T is based on a new control unit and a new four-quadrant system in the sensor head. The CE318-T presents higher signal-to-noise ratios (better than 60 dB) to capture not only the daytime radiation from the Sun but also the limited energy during nighttime reflected by the Moon, and therefore it is able to provide valuable information of aerosols and water vapor 24h a day. The new CE318-T performs measurements at an approximate field of view of 1.29° at ten nominal wavelengths of 1020, 937, 870, 675, 500, 440, 380 and 340 nm, using a silicon photodiode detector, as well as additional measurements at 1020 and 1640 nm using an InGaAs detector. An adjustment has been done to provide measurements at optical communication wavelengths (1064nm and 1550nm). This new instrument performs three different measurement types: spectral direct Sun and direct Moon irradiance measurements to obtain aerosol and water vapor content, and spectral sky radiances to infer aerosol properties from inversion during daytime period. This is the reason for applying the term "triple" to this new Cimel photometer. As in the standard AERONET version, the CE318-T takes a sequence of three measurements (triplet) every 30s at each wavelength. The triplet value is defined as the maximum minus minimum divided by the mean value of these three consecutive measurements. It means that each triplet represents the normalized range of these three consecutive measurements. At this moment, the

[§]https://www.cimel.fr

triplet information is used to detect and remove clouds as well as to check the instrument's stability until a new operative cloud screening is applied.

4. COMPARISONS WITH OTHER DATA SOURCES AND LONG-TERM SITES CHARACTERIZATION

The last objective of the ANAtOLIA project is to correlate the local ground measurements from ANAtOLIA station instruments with data available from other sources of atmospheric conditions. And to carry out a long-term characterization of the selected sites by means of predictive methods and models.

Available sources have to be identified as much as possible for each critical atmospheric parameter to be monitored to perform correlation analysis for the remaining aerosol, atmospheric turbulence and meteorological parameters. The "a priori" data accuracy claimed by all these existing cloud and atmospheric conditions data sets, as well as the given spatial and temporal resolutions, have been critically assessed.

Satellite/ Sensor	Satellite Orbit	Dataset	Available parameters	Horizontal resolution	Temporal resolution	Period available
Terra/MODIS Aqua/MODIS	LEO	NASA MOD06/ MYD06	Cloud Fraction COT	5 km	24 hours each satellite	From 2000-02
MSG/SEVIRI	GEO	Meteo France SAFNWC	Cloud Mask Cloud Type Cloud Top height Temperature	3 km	15 minutes	From 2007-10
GOES Imager	GEO			4 km	30 minutes	2014-2018
GOES/ABI	GEO			2 km	10 minutes	From 2017-12
MTSAT Imager	GEO			4 km	30 minutes	2009-2014 2009-2016
Himawari/AHI	GEO			2 km	20 minutes	From 2017-07
CloudSAT/CPR CALIPSO/CALIOP	LEO	DARDAR	Vertical Cloud Mask Cloud base height Cloud top height	1.4 x 1.7 km	16 days	From 2006-06 To 2019

Figure 9. Satellite cloud databases.

Obtaining a spatially and temporally detailed representation of cloud cover is of interest in evaluating OGS sites and network availability. Although one might ideally want to obtain cloud blockage information at high temporal (1 min) and spatial (few hundred meters) resolution, this is practically not achievable if one seeks at the same time global coverage so that availability of any arbitrary location on Earth can be evaluated. It is also important that cloud information be provided with a quality as homogeneous as possible globally so that no systematic bias is introduced between candidate OGS sites. Finally, the database shall be covering an extended period so that any annual local anomaly in cloudiness can be smoothed out over the entire simulation period. Candidate sources of observation are therefore naturally satellite observations out of which quantitative information on cloud fraction and cloud properties can be obtained routinely.

There are two main criteria for selecting most databases. The first is that the duration of the dataset used to study the available parameters is greater than five years. The second is the provision of datasets by giving priority to AERIS/ICARE, a full partner of ANAtOLIA, which aims to facilitate and improve the use of atmospheric data whether they come from satellites, on the ground, airplanes or balloons. ICARE is hosting of the project database, setup collocation tools for validation and distribution of all data from the project to the different partners. Table in Fig. 9 summarizes the satellite cloud databases that will be used in the framework of the ANAtOLIA project.

For turbulence case, there is no database available. Therefore, we propose to study the possibility to use forecasting of turbulence parameter instead of the measurements database. For the forecasting, we use the WRF model[6,7] which is a mesoscale non-hydrostatic numerical model allowing to forecast and/or simulate temporal evolution of meteorological conditions within a tridimensional domain. The main advantages of this model are its availability, its adaptability and its configurability. These points are really important because the divergence of specificities from one site to another makes impossible to have a universal configuration. We have selected meteorological databases useful for both turbulence forecasting and ground meteorological correlations with the ANAtOLIA station. We currently use the GFS data provided by the National Center for Environmental Prediction (NCEP). These data have a spatial resolution of 0.25x0.25 degree and a temporal resolution of 3 to 12h and are freely available. Another database we could use with WRF model is the ERA5 provided by the ECMWF (European Center for Medium Range Weather Forecast). This database has the same resolution than the GFS one, but it could be interesting to use both of them in order to analyze, compare and select the most appropriate database as input for each covered site. In addition, the ICARE centre is able to provide us with this database. However, our expertise is about the use of the GFS data and we cannot guarantee the possibility to use also the ECMWF data in this ANAtOLIA project. Table in Fig. 10 summarizes the databases that could be possibly used in this project and their characteristics.

Dataset	Horizontal resolution	Temporal resolution	Period available	Usable by WRF
NCEP GDAS final analysis GFS (*)	0.25x0.25 deg	6 h	From 2015-07-08	Yes
	0.25x0.25 deg	3 h -> 12 h (forecast/reanalysis)	From 2015-01-15	
ECMWF Operational	1x1 deg	6 h	From 2006-01-01	
ECMWF ERA5 (**)	0.25x0.25 deg	3 h	From 2000-01-01	

Figure 10. List of databases for meteorological parameter useful for WRF model predictions.

5. DISCUSSION

The ANAtOLIA station developed and now installed on the Calern Observatory for on-sky tests and cross-calibration with the CATS station. A second copy of the ANAtOLIA station is under development and will be also tested on Calern Observatory. In the beginning of 2023, these two ANAtOLIA stations will be then transported and installed on the three of the four selected sites for the project for one or two year campaigns (Fig. 11). A dedicated study has been performed during the first year of the project to select sites to be tested with the ANAtOLIA station. The site-selection is based on a preliminary list of sites provided by the partners of the consortium and ESA, a critical analysis has been performed to identify the best suited locations for the deployment of instrumentation, considering the diversity of sampled atmospheric conditions in terms of clear fraction (or availability), frequency of occurrence of thin cirrus and broken cloud cover, expected turbulence diversity (altitude, location, etc) as well as geographical distribution to maximize weather de-correlation among selected sites. Other practical considerations have been made also to keep travel/transport budget related to site installation and maintenance within the project allocated funding and guarantee site accessibility despite the worldwide Covid-19 crisis. Finally, the four sites selected to be tested with the ANAtOLIA station are, Catania, Cebreros (Madrid) and Lisbon in addition to the Calern Observatory equipped with the upgraded CATS station. The campaigns will start on spring 2023.

ACKNOWLEDGMENTS

Authors would thank the European Space Agency (ESA), the Centre National d'Etudes Spatiales (CNES) and the Norwegian Space Agency for funding the ANAtOLIA project.

Figure 11. Selected sites to be studied with the ANAtOLIA stations.

REFERENCES

[1] O., L., S. G., [*Optical Link Study Group Final Report*], Interagency Operations Advisory Group (2012).

[2] Aristidi, E., Ziad, A., Chabé, J., Fanteï-Caujolle, Y., Renaud, C., and Giordano, C., "The generalised differential image motion monitor," *MNRAS* **486**, 915 (2019).

[3] Ziad, A., Blary, F., Borgnino, J., Fanteï-Caujolle, Y., Aristidi, E., Martin, F., Lanteri, H., Douet, R., Bondoux, E., and Merkarnia, D., "First results of the pml monitor of atmospheric turbulence profile with high vertical resolution," *A&A* **559**, L6 (2013).

[4] Chabé, J., Aristidi, E., Ziad, A., Lantéri, H., Fanteï-Caujolle, Y., Giordano, C., Borgnino, J., Marjani, M., and Renaud, C., "Pml: a generalized monitor of atmospheric turbulence profile with high vertical resolution," *Applied Optics* **59**, 7574 (2020).

[5] Ziad, A., Chabé, J., Fanteï-Caujolle, Y., Aristidi, E., Renaud, C., and Ben Rahhal, M., "Cats: an autonomous station for atmospheric turbulence characterization," *Astronomical Telescopes+ Instrumentation, Proc. SPIE 10703, 107036L* (2018).

[6] Giordano, C., Rafalimanana, A., Ziad, A., and Aristidi, E., "Contribution of statistical site learning to improve optical turbulence forecasting," *MNRAS* **504**, 1927 (2021).

[7] Rafalimanana, A., Giordano, C., Ziad, A., and Aristidi, E., "Optimal prediction of atmospheric turbulence by means of wrf model," *PASP* **134**, 23 (2022).