Recent progresses on a second world atlas of the night-sky brightness - LPTRAN/LPDART realistic models, tomography of light pollution, accurate validation methods and extended satellite data analysis

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ABSTRACT

I review recent progresses toward a second world atlas of the night-sky brightness. Almost all main steps have been or are being improved. I present up-to-date Extended Garstang Models (EGM), which provide a more general numerical solution for the radiative transfer problem applied to the propagation of light pollution in atmosphere. I present the LPTRAN software package, an application of EGM to DMSP-OLS radiance measurements and to digital elevation data, which provides an up-to-date method to predict the artificial brightness distribution of the night sky at any site in the World at any visible wavelength for a broad range of atmospheric situations and the artificial radiation density in atmosphere across the territory. I present new primary indicators, including a specific indicator for popularization purposes: the number of visible stars in a clean night. I introduce the tomography of light pollution, an analysis technique based on the capability of LPTRAN to collect radiation density and scattered flux density on a 3D grid. I also review the other main preliminary results of the efforts of the world atlas team to improve methods of validation of map predictions with Earth-based measurements, to obtain night sky brightness measurements independent from atmospheric conditions and time, to solve primary issues of photometry and radiometry of light pollution and to carry out new observational campaigns. I finally shortly review progresses in satellite data analysis toward an improved knowledge of the upward emission function and the growth of light pollution with time. I divided the presentation in four parts, each of which presents my results or reviews subprojects carried on by different grouping of team members.

1 INTRODUCTION

The first world atlas of the artificial night sky brightness was published in 2001 (Cinzano, Falchi, Elvidge 2001b). A ten year baseline for a second world atlas of the night-sky brightness has been suggested in IAU Comm. 50 WG. Authors plan was to obtain it in less years but times have been delayed because the aim is not to simply recompute the atlas with new data but to improve the methods, and this is requiring more time than planned.

The project is carried on by the Istituto di Scienza e Tecnologia dell'Inquinamento Luminoso (ISTIL, Light Pollution Science and Technology Institute), a small no-profit group created to support research about light pollution, in collaboration with the NOAA National Geophysical Data Center (Elvidge) and, for some related researches, with the Department of Astronomy of the University of Padova. I worked at the Department until 31 March 2006 and now I am working for ISTIL. Authors are the same of the first world atlas (Cinzano, Falchi, Elvidge) and the subprojects carried on by each of them are described later. Parts of the project have been supported by the Italian Space Agency (ASI) (Contract 2001 I/R/160/02, Global monitoring of light pollution and night sky brightness from satellite measurements), by the University of Padova (Young Researchers Project, Light pollution and the protection of astronomical sites), by the International Dark-Sky Association, by some observatories (NOAA/CTIO, VAT, Lowell, IAC/OTPC, etc.) and by some other organizations (CfDS, AFAM). Some national and regional agencies for environmental protection are collaborating with us by using our data but are unable to give us effective support.

The funding situation for this project is quite problematic, like figure 1 shows. Main fraction of expenses have always been payed by the author. Funding decreased after 2004 because, following the industrial-like choices of the past Italian government, ASI could not renew funds to projects carried out with not-ASI satellites, outside its primary research lines (which fully exclude environment and ecology, traditionally hated by industrial tycoons) and not resulting in products that ASI can sell. In 2004 I obtained funds at the University of Padova, but not renewable. No funds are available since 2005, even because ISTIL is a no-profit no-commercial institution and cannot sell anything, whereas

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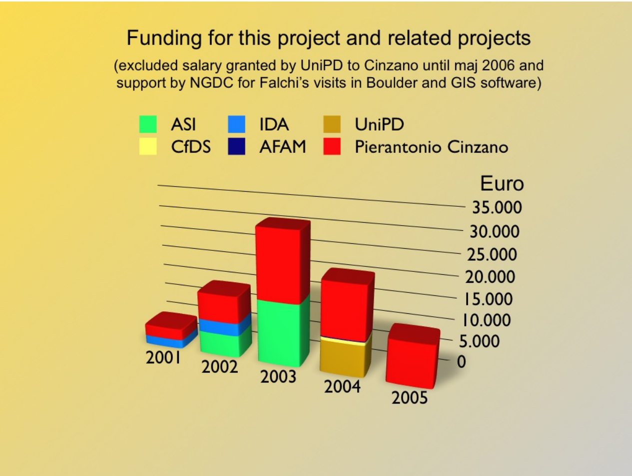


Figure 1.

Figure 2.

many environmental agencies in Italy can purchase data but cannot support the scientific research for them.

Luckily in 2003 I understood where funding situation was going and I revised our expense plans using almost all available funds to setup a precious Laboratory of Radiometry and Photometry of Light Pollution (LPLAB). Then I used the main part of 2004 funds from University of Padova for a measurement campaign and my personal funds 2004-2005 for completing the laboratory and for updating computational equipments. As a result of this strategic approach now I have all necessary instruments to continue working to the project even with zero funds. This does not mean that our project does not need funds. We still need funds desperately for many part of the work (also because I cannot continue to pay the research by myself). But, at least, the lack of funds cannot stop the project: when you have computers and instruments, no one can stop you.

The main steps of the world atlas production are the following: (i) reduction and analysis of OLS-DMSP radiance data to obtain the Geographical and spatial distribution of upward light emission; (ii) based on it and on an atmospheric model, modelling of light pollution propagation and map computation to obtain the map of night sky brightness, stellar visibility and the other indicators; (iii) validation of results based on Earth-based measurements of night sky brightness with feedback on light pollution modelling; (iv) study of the changes with time on the maps of night sky brightness and upward light emissions. The second world atlas requires time because we improved or are improving almost all these points.

I divided this presentation in four parts, each of which reviews independent subprojects carried on by different grouping of the authors:

1. New computational techniques (author: Cinzano)
2. New output products and indicators (author: Cinzano)
3. New methods for validation of results and new observational campaigns (authors: Cinzano; Falchi; Falchi & Cinzano)
4. New methods in satellite data analysis (authors: Elvidge; Cinzano; Cinzano, Falchi, & Elvidge; Falchi, Cinzano & Elvidge)

2 NEW COMPUTATIONAL TECHNIQUES

Methods to map artificial night sky brightness and stellar visibility across large territories or their distribution over the entire sky at any site, were based, so far, on the computation of the propagation of light pollution with Garstang models (Garstang 1986, 1989, 1991). They provide a simplified solution of the radiative transfer problem in atmosphere which allows a fast computation by reducing it to a ray-tracing approach. They are accurate with clear atmosphere, when a two-scattering approximation is acceptable, which is the most common situation.

Curiously the modelling technique, which now has been fully revolutionized with very interesting results, is the only part of the project that at the time was judged unnecessary to improve. In facts, as many of our papers show, Garstang models are sufficiently good in predicting night sky brightness in clear nights (the only of interest) to make unnecessary new models. However given that some delays on the availability of data for calibrating the OLS-DMSP were producing some difficulties to other parts of the project, I decided to give a fundamental improvement to them. Main aim was not much to obtain improved predictions but, honestly, to make happy many people that, for unknown reasons, think that a simple and fast Garstang model cannot be so accurate like the up-to-date ultra-detailed super-models used in atmospheric physics. So I decided to setup a computational technique for light pollution propagation in the atmosphere based on the last available models of atmospheric physics and accounting for the most larger number of details on the atmosphere, sources and soil. I also decided to write it in a modular way so that future atmospheric models from atmospheric physics or future propagation models from light pollution researchers can be used without difficulties. The result surpassed my expectations.

I present here up-to-date Extended Garstang Models (EGM), which provides a numerical solution for the radiative transfer problem applied to the propagation of light pollution in atmosphere. I also present the LPTRAN software package, an application of EGM to DMSP-OLS radiance measurements and to GTOPO30 digital elevation data, which provides an up-to-date method to predict the artificial brightness distribution of the night sky at any site in the World at any visible wavelength for a broad range of atmospheric situations and the artificial radiation density in atmosphere across the territory. (Cinzano 2006, in prep.)

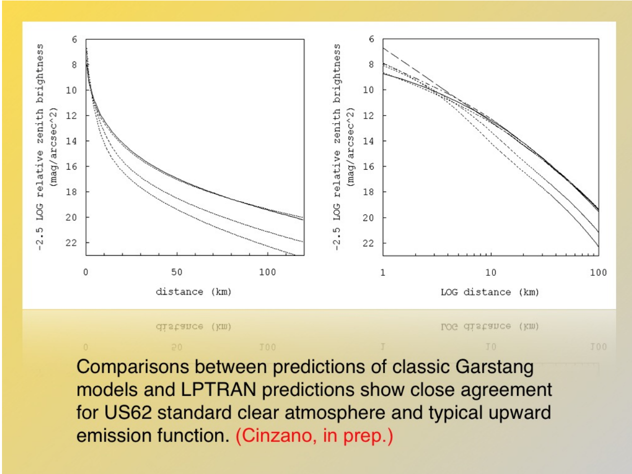
EGM account for:
1. multiple scattering
2. wavelength of the light from 250 nm to infrared
3. earth curvature and its screening effects
4. sites and sources elevation
5. many kinds of atmosphere or custom setup (e.g. thermal inversion layers)
6. mix of different boundary layer aerosols and tropospheric aerosols or custom
7. up to 5 aerosol layers in upper atmosphere including fresh and aged volcanic dust and meteoric dust
8. variations of the scattering phase function with elevation
9. continuum and line gas absorption from many species, ozone included
10. up to 5 cloud layers
11. wavelength dependant bidirectional reflectance of the ground surface from NASA/MODIS satellites, main models or custom data (snow included)
12. geographically variable upward emission function given as a three-parameter function or a Lagrange polynomial series
13. atmospheric scattering properties or libraries of light pollution propagation functions from other programs

A more general solution, which too large computational requirements at present time, also allows to account for:
1. mountain screening
2. geographical gradients of atmospheric conditions, including localized clouds
3. geographic distribution of ground surfaces
4. asymmetric sources

This will come good for the third world atlas, when there will be no problem to manage large arrays of data with computers.

My approach is resumed here. The atmosphere is divided in a 3D grid and the Earth surface in a corresponding 2D grid. The atmospheric situation and the scattering functions of each volume are computed from up-to-date models of atmospheric physics. I solve the rediative transfer problem with a Garstang-like ray-tracing approach. Based on the upward intensity function of the source I compute the irradiance on each atmospheric volume. The intensity of the light scattered in each direction by each volume is computed based on detailed scattering properties. This quantity is numerically approximated on an array. Then the irradiance on each atmospheric volume and on each surface area is calculated, due to light coming from each other volume. And, again, the total intensity of the light scattered in each direction by each volume and by each surface area is computed. Extinction is accounted along each light paths. This process is iterated some times. Each iteration improves accuracy by accounting for a further scattering. At the end, the intensity of light scattered in each direction by each volume is known, included the direction of the observer. The brightness (radiance) of the sky in a given direction is obtained from simple integration along the line-of-sight, always accounting for extinction. Other quantities like the radiation density and the irradiance at soil are also known.

The software package LPTRAN (Light Pollution radiative TRANsfer), written in Fortran-77, applies the method



Comparisons between predictions of classic Garstang models and LPTRAN predictions show close agreement for US62 standard clear atmosphere and typical upward emission function. (Cinzano, in prep.)

Figure 3.

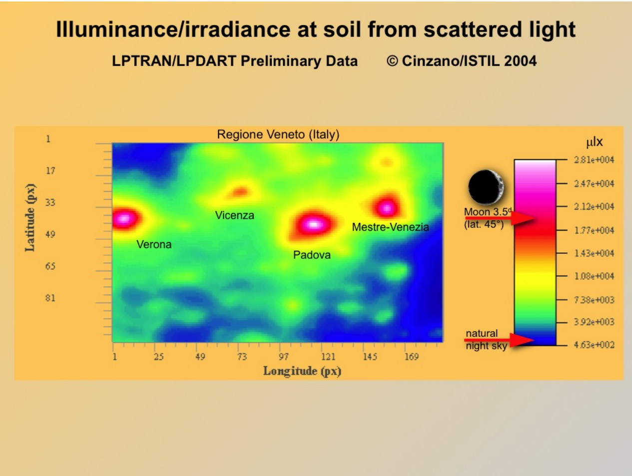
for the case of axial symmetry of sources. It is composed by a number of programs. The main program LPTRAN (the same name of the package) computes the radiative transfer and light pollution propagation based on input atmospheric and surface models for the given wavelength. LPDART evaluates light pollution and night sky brightness on the grid and writes a library of light pollution propagation functions. Lpskymap_lptran computes night sky brightness in a site based on DMSP-OLS radiance data, a Digital Elevation Map and the lptran library. The lpskymap package (Cinzano & Elvidge 2004) allows to obtain polar plots and other indicators. Lpskyalt, lpskydens and lpskyfrzh compute across a territory the artificial night sky brightness at any chosen azimuth and elevation, the radiation and scattered flux densities in atmosphere and their fractionary contribution to the zenith night sky brightness at sea level. The lpmap package (Cinzano, Falchi & Elvidge 2001) allows to obtain the maps of limiting magnitudes across the territory.

Comparisons between predictions of classic Garstang models and LPTRAN predictions show close agreement for US62 standard clear atmosphere and typical upward emission function, like figure 3 shows. So in principle there was no need of new models, but the astonishing computational possibilities allowed by LPTRAN worth the effort.

3 NEW OUTPUT PRODUCTS AND INDICATORS

Our classic products and indicators are:
1. Upward flux
2. Artificial night sky brightness at sea level
3. Total night sky brightness (accounting for elevation)
4. Stellar visibility (limiting magnitude)
5. Loss of stellar visibility (loss of limiting magnitude)
6. Statistical indicators like the fraction of population (or the fraction of territory) living under a sky of given luminosity.

They can be computed as (a) maps across the territory of the quantity in a given direction of sky (e.g. zenith) or (b) maps of the quantity across the sky in an individual site. These last can be polar maps, Cartesian maps or hypermaps where the third coordinate is the atmospheric content.



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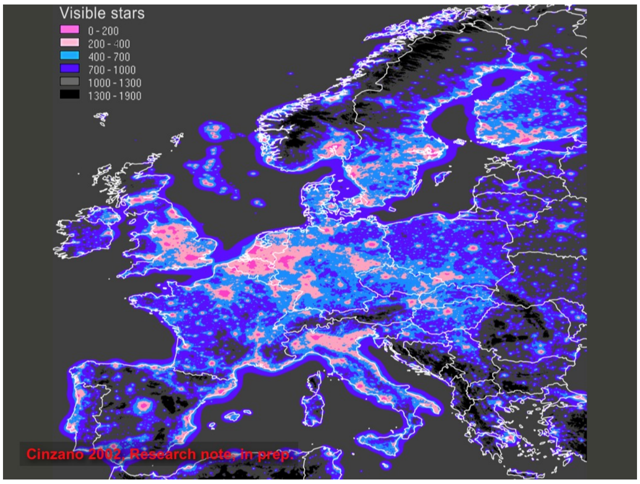

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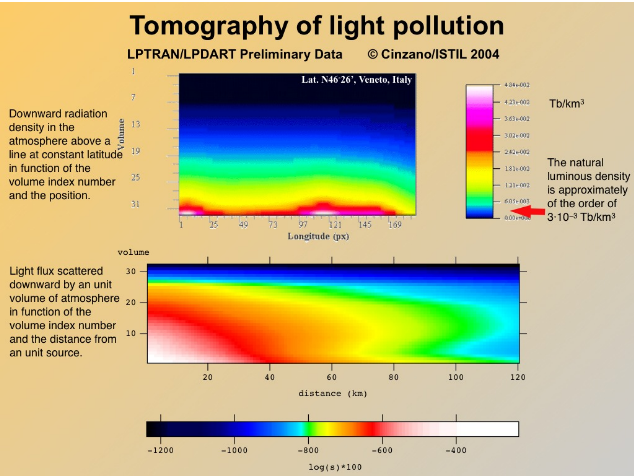

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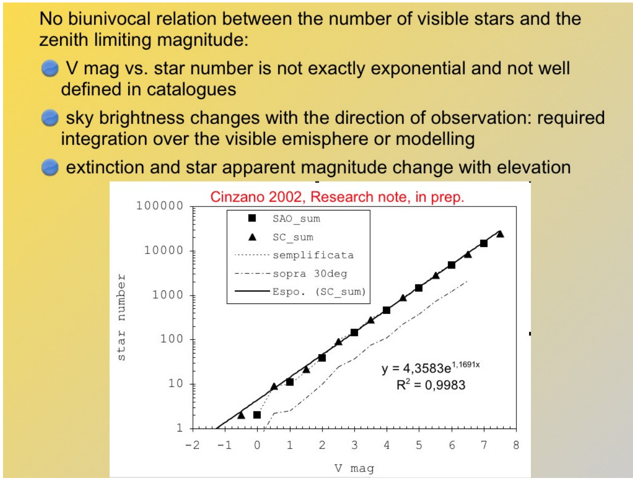


Figure 7.

Thanks to LPTRAN, I extended our primary indicators, that now are:

(i) the artificial night sky brightness (or radiance or luminance), which indicates the integral of the artificial light scattered along the line of sight of an observer and has important effect on the perceived luminosity of the sky, on the star visibility, on the perception of the universe by mankind, on the darkness and the perception of the environment, etc; Derived quantities: total night sky brightness, star visibility (limiting magnitude), number of visible stars.

(ii) the sky irradiance (or illuminance) on the earth surface, which has effects on the luminosity of the ground surface and on the luminosity of the night environment as perceived by animals, plants and mankind (where direct irradiance by nearby lighting installations is not overwhelming); See figure 5.

(iii) the radiation density in the atmosphere, which is the energy (or the light or the number of photons) per unit volume of atmosphere in course of transit, per unit time, in the neighbourhood of the point (x, y, z). UNITS: photon density in ph m^{-3}, luminous density in Tb m^{-3}, where the Talbot (lm × sec) is the unit of luminous energy. It can be split in upward and downward radiation densities, which quantify approximately the light coming back toward the soil and going toward the outer Space. The radiation density due to direct illumination by the sources, gives the direct light travelling through a unit volume of atmosphere.

(vi) the upward and downward scattered flux densities, which are the flux density of the scattered radiation; the downward one, in particular, quantifies the strength of the unit volume of atmosphere at position (x, y, z) as secondary source of light pollution when subjected to the light polluting action. UNITS: density of flux in ph s^{-1} m^{-3}.

These integrated quantities are useful only as generic indictors of the alteration of the atmosphere. The effects of the atmosphere as a secondary source of light pollution should be evaluated based on the intensity of light in each direction at each volume and not based on integrated quantities like fluxes, which do not account for the direction of the light. Just like light pollution from lighting installations should be evaluated based on the intensity of light in each direction and not based on integrated quantities like the upward flux.

The ability of LPTRAN to collect radiation density and scattered flux densities data on a 3D grid allowed me to introduce a true tomography of light pollution, similar to a

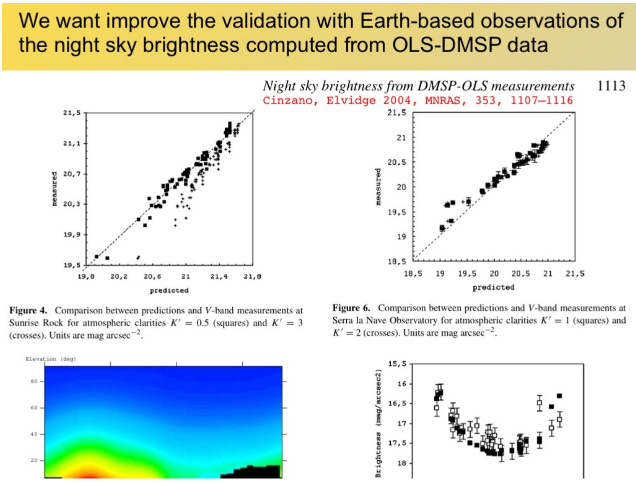


Figure 8.

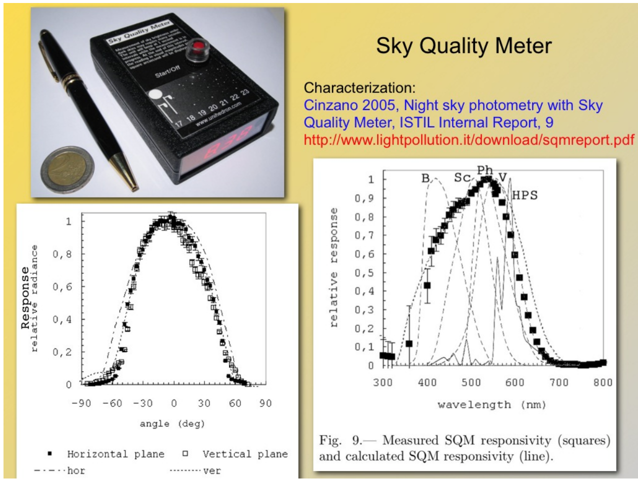


Figure 9.

sectional radiography. I can select a narrow section of atmosphere over a strip of considered territory and examine how these quantities vary with elevation or along the strip. Some examples are presented in figure 5.

For popularization purposes, I also introduced a new indicator, which is more understandable from the general public: the number of visible stars in a clean night. Its computation is less trivial than expected. In fact there is no biunivocal relation between the number of visible stars and the zenith limiting magnitude: (i) V mag vs. star number is not exactly exponential and not well defined in catalogues, (ii) sky brightness changes with the direction of observation, requiring integration over the visible hemisphere or modelling, (iii) stellar extinction and stars apparent magnitude change with elevation. Figure 6 shows a preliminary map for Europe. The number is estimated for observers of average experience and capability, aged 40 years, with the eyes adapted to the dark, observing with both eyes the upward hemisphere and counting all the stars surely seen (detection probability 98%).

4 NEW METHODS FOR VALIDATION OF RESULTS AND NEW OBSERVATIONAL CAMPAIGNS

The validation with Earth-based observations of the night sky brightness computed from OLS-DMSP data is a fundamental step. So far comparisons between earth-based measurements and map predictions showed a good agreement, in particular if we consider the measurement errors and the scatter of data points. See e.g. figures 4 and 5 of Cinzano & Elvidge (2004) shown in figure 8. They show measurements taken in individual sites and the scatter is still larger for measurements collected in different sites. If we want to be able to distinguish between different models for similar atmospheric conditions, we need to improve the measurement process in order to reduce the scattering of data.

To reach this goal Cinzano and Falchi started a number of steps.

4.1 Search for better instruments and procedures

If the goal is the situation of the light pollution in the territory, then a lot of measurements in many different sites, each clean night, are needed. Main requirements are:
1. Fast movements of the observer across the territory, possibly returning at the same site at different times in the same night, so the number of measured sites in a night should depend almost exclusively on the transfer times from one site to the following one;
2. Measurements should be taken each night resulting clean over the entire territory for long times (because these nights are not many). This is very different from usual astronomer activity based on scheduled telescope time and it strongly interacts with private life of the observer so the measurement process should be not awkward or the observer will give up.

Then fast "point-and-shot" mobile instrument are needed with short setup times, easy to manage, portable, accurate, not requiring awkward data reduction. Main choices at our disposal are:
1. Automatized portable CCD imagers: accurate measurements of both brightness and aerosol content (extinction) but not so quick setup, professional data reduction required (e.g. WASBAM and WASBAM-SSH with spectrographic capabilities, Cinzano, Falchi 2003; Cinzano 2004)
2. Mobile fish-eye CCD cameras pointed at zenith: fast setup but professional data reduction required, geometric corrections, some limitations (e.g. Duriscoe et al. 2004; see also the CONCAM fisheye webcam network, Nemiroff & Schwarz 2003 and the Jan Hollans effort to obtain scientific grade data with simple digital cameras, this meeting)
3. Portable research radiometers: point-and-shoot, very accurate, continuous sampling but no measure of the atmospheric situation so external data on aerosol content are needed from lidars or sun-photometers (e.g. the LPLAB radiometer, Cinzano 2003).
4. Sky quality meters: super-quick but not best accuracy and atmospheric data needed; they require accurate characterization and that the user understand the instrument (Cinzano 2005).

We used data from all these instruments. We do not recognized a best class of instruments. The choice depends

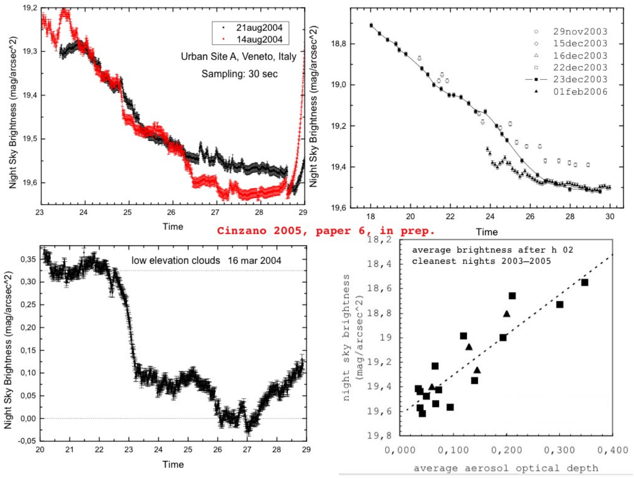


Figure 10.

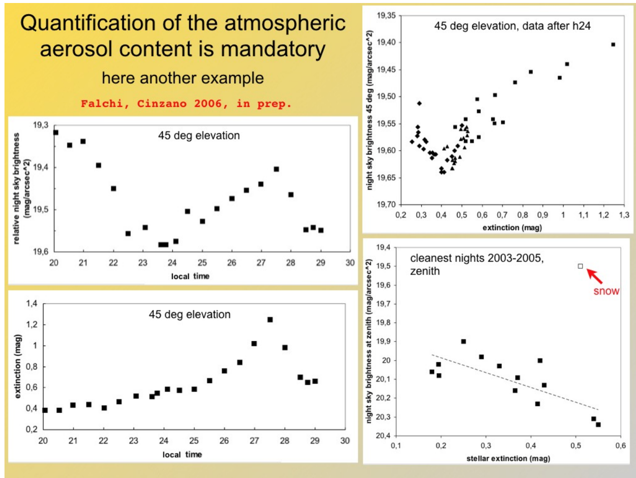


Figure 11.

on the needs of the research. We used automatized portable CCD imagers and portable research radiometers in our campaigns but I also successfully used data taken by Duriscoe with a fish-eye CCD camera in Cinzano & Elvidge 2004 and the fit to predictions was very good as figure 9 shows.

I also characterized and tested an SQM and, in the limits of its capabilities, I found it really amazing. The report is downloadable from http://www.lightpollution.it/download/sqmreport.pdf (Cinzano 2005). Figure 9 shows the large angular response of this instrument reaching 60 degrees and the large spectral response covering the V band, the photopic response, the scotopic response, and, partially, the B band.

4.2 Improvement of methods of measure

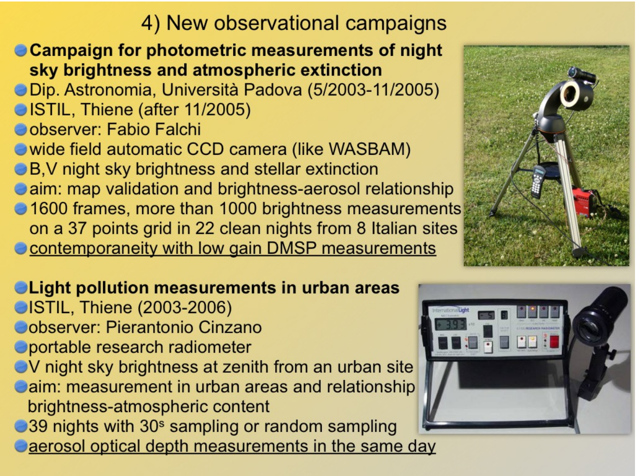
Measurements need to be:
1. accurate (high accuracy and stable instrument with accurate calibration);
2. taken in an accurately shaped passband (wide-field instruments are calibrated over a laboratory source rather than over stars so proper filters need to be accurately fitted to the detector response or passband mismatch correction is needed);
3. independent from the time of the night (they should be taken all at the same time of the night, first or second part of the night; frequent sampling allows minimizing atmospheric fluctuations by averaging data e.g. over 1 hour);
4. independent from atmospheric conditions.
In order to obtain an atmospheric independent measurement a large sample of data is required from the same site, taken in many clean nights along one or more years with contemporary measurements of atmospheric aerosol optical depth (stellar extinction or lidar measurements taken inside the polluting area).

Figure 10 (Cinzano 2006b, in prep.) shows how much large can be the variation of night sky brightness along the night in an urban site in a large densely populated area, in part due to a reduction of lighting emission along the night and in part due to atmospheric variations. Zenith brightness is well correlated with the atmospheric aerosol optical depth (lower right panel) like e.g. measurements obtained in the previous day from sun-photometers located in the area where main sources of pollution lie. The preliminary results of one of ours measurement campaign show that if a sufficiently large dataset is collected and there is an aerosol measurement site inside the polluting area, a night sky brightness value independent from the atmospheric conditions can be obtained without measuring stellar extinction, with an uncertainty of about 0.1 mag/arcsec^2.

Quantification of the atmospheric aerosol content is mandatory. Figure 11 (Falchi, Cinzano 2006, in prep.) shows other examples. Strange variations of night sky brightness during the night can be explained by monitoring continuously the aerosol content through the stellar extinction (left panels). Stellar extinction measurements can help to obtain an atmospheric and time independent measurement for a site, but the relation between brightness and stellar extinction can be different when looking to different directions (right panels).

4.3 Solution of primary issues

I solved some primary issues of photometry and radiometry of light pollution at LPLAB (Cinzano, series of papers in prep.). Here a short list:
1. Procedures for characterization and testing of instruments
2. Procedures for calibration of instruments (all handy or wide field instruments needs laboratory calibration)
3. Calibration of a TTL luminance-meter over the Moon (useful for periodical check of the calibration standards of the laboratory and to make longer the interval between re-calibrations).
4. Laboratory calibration of large-field radiometers in V band (this is fundamental because you cannot calibrate on stars a hand-on radiometer with 5°field of view and the method is not obvious because V band magnitudes are defined based on calibration stars, so the work required synthetic spectrophotometry et cetera)
5. Conversion between CIE photopic and astronomical V band (a main problem,for result comparison given that they are the two primary bands)
6. Effects and correction of passband mismatch (they are much more important in light pollution studies than in usual



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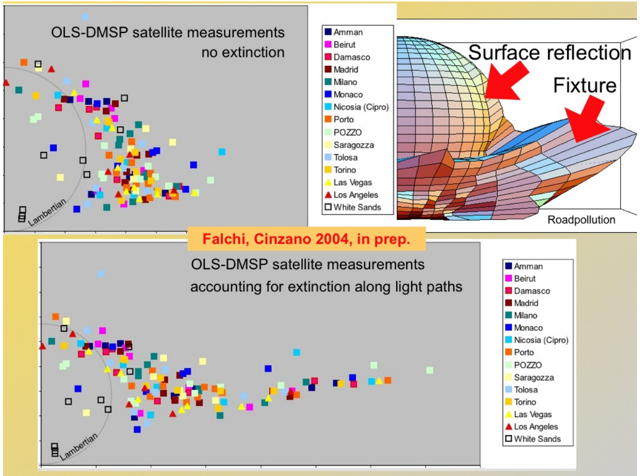


Figure 13.

astronomy because measurements of stars are calibrated over standard stars with similar spectra whereas measurements of the sky, which spectrum changes with pollution sources and level, are made with an instrument calibrated in laboratory, usually using an Illuminant-A with a completely different spectrum.)
7. Procedures for photometrical and spectral data reduction
8. Development of software for instruments management (based on LABVIEW).
I have a number of papers at the final stages of preparation.

4.4 New observational campaigns

Two new observational campaigns have been undertaken.

A Campaign for photometric measurements of night sky brightness and atmospheric extinction was carried on from Dipartimento di Astronomia, Universitá di Padova (5/2003-11/2005) and continued from ISTIL after 11/2005. The observer Fabio Falchi used a wide field automatic CCD camera (like WASBAM) to measure B,V night sky brightness and stellar extinction for map validation and to study the brightness-aerosol content relationship. He obtained 1600 frames, more than 1000 brightness measurements on a 37 points grid in 22 clean nights from 8 Italian sites. For some of them there are contemporaneous low gain DMSP measurements. (Falchi 2006; Falchi, Cinzano 2006, in prep.).

A campaign for Light pollution measurements in urban areas was carried on from ISTIL, Thiene (2003-2006). The observer Pierantonio Cinzano used a portable research radiometer to measure V night sky brightness at zenith from an urban site with the aim to better understand the problems related to accurate measurement of night sky brightness in urban areas and the relationship brightness-atmospheric content. He take measurements in 39 nights with 30 sec sampling or random sampling. Measurements of aerosol optical depth in the same day are available (Cinzano 2006b, in prep.).

Other campaigns are likely to be useful to this project, like e.g. those carried on with fish-eye cameras by Duriscoe or with SQM by others. CONCAM fish-eye cameras network apparently do not uses filters with standard responses like B band, V band, SI scotopic or SI photopic. However they carry interesting sodium and mercury filters so they could add useful informations.

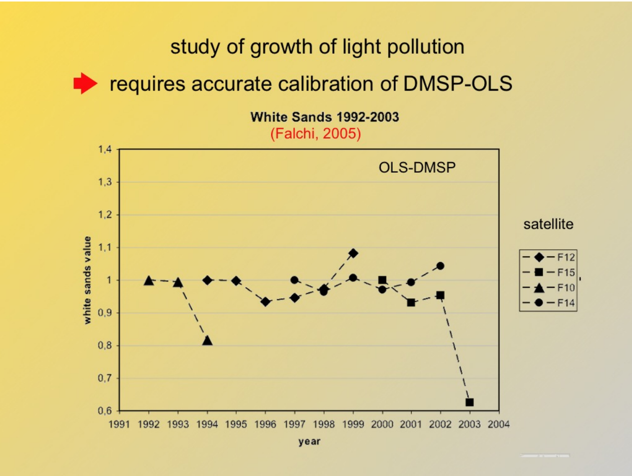
5 NEW METHODS IN SATELLITE DATA ANALYSIS

A main improvement planned for the next world atlas computation is to account for different distributions of the light intensity of source areas with the elevation angle (upward emission functions) in the considered territory. In fact in some countries the battle against light pollution has grown consistently in the last years and then the hypothesis of uniform lighting habits adopted for the first world atlas is becoming less viable.

As a consequence the group (Cinzano, Falchi, Elvidge) managed to use new extended satellite data sets. New datasets are composed by:
1. visible band geolocated images in 30 arc second grids with both low gain and high gain, extended to large view angles (about 80 from nadir)
2. scan angles from the OLS toward the Earth
3. times of observation of each scan line
4. thermal band images
5. thermal band brightness temperature difference from NCEP surface
6. temperature model
7. flags (data quality labels, clouds, snow, etc.)
8. lunar illuminance.
Elvidge also improved data reduction process. Some data have been reduced and analyzed by Falchi during his visits at NGDC, Boulder.

In order to improve our knowledge of the upward emission function of cities we are following three methods, in progress:

(i) Satellite measurements. I already wrote the data analysis software, which is under testing. The main problem is that we need to know the OLS angular response. This mean that we need standard sources on the Earth surface, stable and with known photometry. They are not easily available. Actually we are measuring special standard sites known to be Lambertian, lighted by the Moon, which is a



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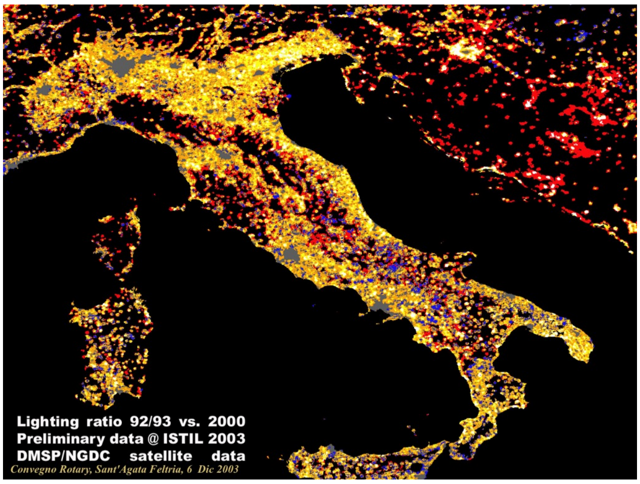

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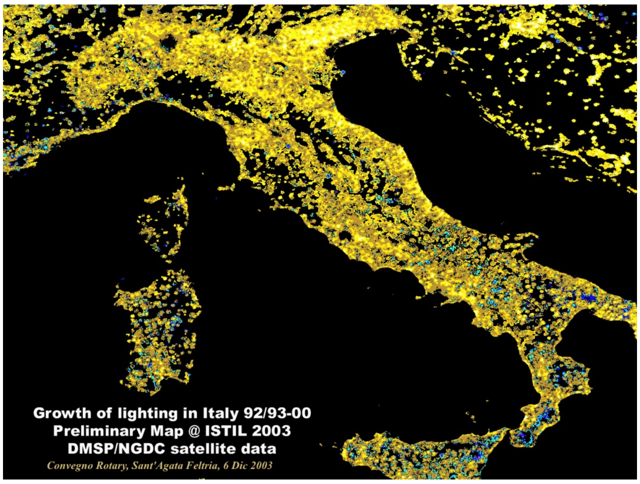

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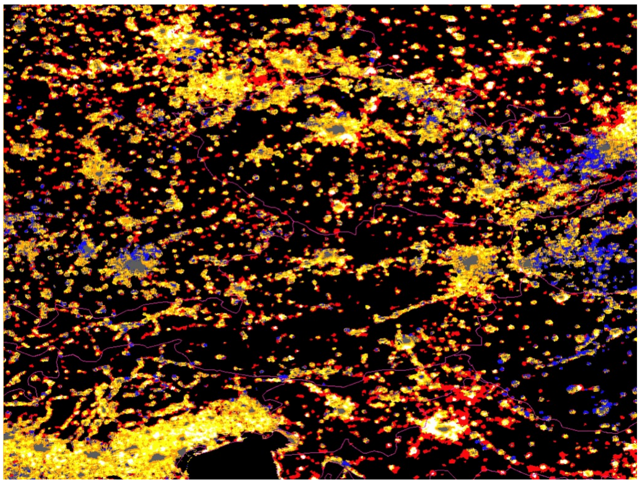

Figure 17.

good standard source. I already wrote sufficiently accurate software for the computation of Moon illuminance. The remaining problem is the lack of contemporary measurement of stellar extinction at the site (Cinzano, Falchi, Elvidge, in prep.).

(ii) Earth-based measurements with inversion of models. Given the observed brightness and the atmospheric situation, they search for the upward emission function which explain it. I already wrote the software and started a test application but I plan some improvements (Cinzano, in prep.).

(iii) Modelling of cities by summing the upward emission function of a sample of lighting installations randomly oriented. This uses an extension of Roadpollution, free software for the evaluation of the environmental impact of lighting installations that I made available at the web address www.lightpollution.it/roadpollution/ (Cinzano 2005b). The main problem is that this approach requires an accurate modelling of the city lighting providing the number of installations of each kind and surrounding (Cinzano, in prep.).

Figure 13 shows, in polar coordinates, the intensity of upward light emission of some cities obtained with the OLS and measured by Falchi. The upper left panel does not take into account of the extinction of light along its path, which is accounted in the panel at bottom left. Emission at high elevations and near zenith is usually due mainly to nearly-Lambertian light reflection by surfaces and low angle emission is usually due to fixtures upward light, as shown in the upper right panel, computed with Roadpollution. Available comparison data do not allow us to be sure on what correction must be applied to satellite data. However, in both cases these preliminary results show that in general the emission of cities is not Lambertian (the line shows the intensity of a Lambertian source and open squares show measurements a White Sand, a site expected to be Lambertian).

Finally, the study of growth of light pollution requires an accurate relative calibration of the OLS of DMSP satellites. Even excluding the abrupt decrease of OLS sensitivity at the end of their life, measurements of a standard site shows some fluctuations, smaller for satellite F14, which has a simple internal calibration system. We tried the rough rescaling between satellites shown in figure 14, based on Falchi's analysis of DMSP data. Excluding data from the last year of life of each OLS, fluctuations are under 10% (Cinzano, Falchi, Elvidge, in prep.).

A very preliminary map in figure 15 shows the growth of lighting in Italy from 1992/1993 to 2000. Shown are the

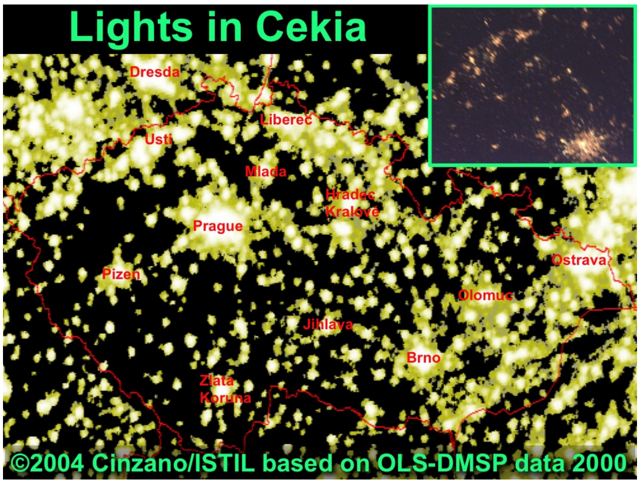

Figure 18.

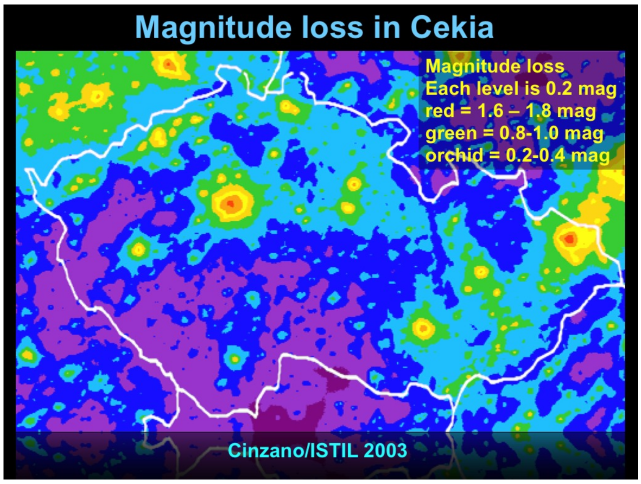

Figure 20.

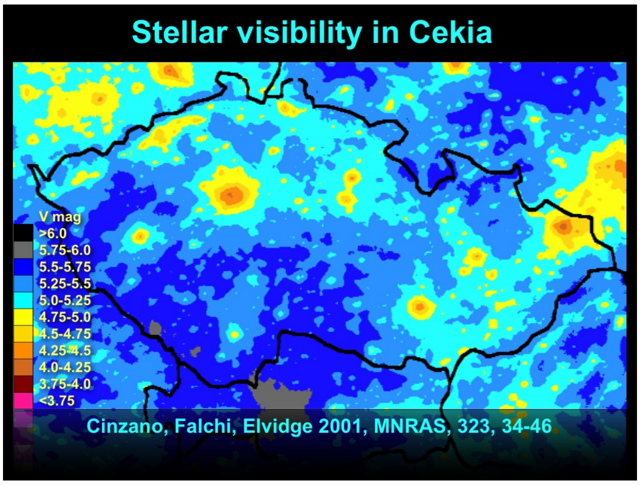

Figure 19.

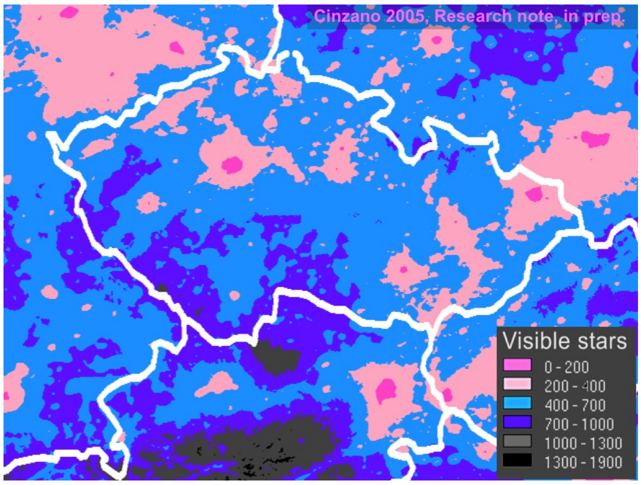

Figure 21.

new lights, installed after 1992/1993. Other very preliminary maps in figures 16 and 17 show the lighting ratio 2000 vs. 1992/1993. In red are shown the new-lighted areas, i.e. those areas that result not lighted in 1992/1993. A good way to check these preliminary results is to validate them over information on lighting growth in the observed cities and countries. Changes are expected to be due mainly to new installed flux, lamp replacement and flux reduction at curfew. These are long works still at their first steps.

6 CONCLUSIONS

I reviewed the situation of the project for an improved world atlas of the night-sky brightness. Authors aim is not to simply recompute the atlas with new data but to improve the methods, and this is requiring more time than planned. Almost all main steps have been or are being improved: The OLS-DMSP radiance data sets, their reduction and analysis, the atmospheric modelling, the computation of light pollution propagation, which have been fully revolutioned and renewed, the map computation, the primary indicators, the techniques for an accurate validation of predictions with Earth-based measurements of night sky brightness, the instrumentation, the evaluation of the upward emission function, the OLS calibration for the study of changes with time.

As a result, there are a lot of works to be completed. My planned deadline is one year to complete the many draft papers and another year to compute the new world atlas. However this plan is too much optimistic and the many works that need to be previously completed could push the world atlas computation quite later. There is no way for me to have an accurate time planning.

7 APPENDIX

Figure 18 (Lights in Cekia) shows the distribution of main sources on the Czech territory from OLS-DMSP data taken in year 2000. The upper left square shows an higher resolution colour image of Praha taken from NASA Space Shuttle.

Figure 19 (Stellar visibility in Cekia) shows the capability of the population to see the stars (naked eye limiting magnitude) on the Czech territory from Cinzano, Falchi, Elvidge (2001a). The map is computed at zenith and accounts for the extinction of the starlight in the atmosphere and the eye capability to detect point sources over a light background. Limiting magnitudes are computed for observers of average experience and capability, aged 40 years, with the eyes adapted to the dark, observing with both eyes the fainter star surely seen (detection probability 98%). The magnitude loss is shown in figure 20.

Figure 21 (Number of visible stars in Cekia) shows how many stars are visible in Czech territory in a clean sky night (preliminary data). The number is estimated for observers of average experience and capability, aged 40 years, with the eyes adapted to the dark, observing with both eyes the upward hemisphere and counting all the stars surely seen (detection probability 98%).

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