CHAPTER 24

Influence on Life Applications of a Federated Astro-Geo Database

CHRISTIAN MULLER, DR

24.1 INTRODUCTION

24.1.1 History of the Influence of Geophysical Parameters on Health

The scientific study of the influence of environmental parameters on life and human health began with Hippocrates of Kos when it was discovered that hygiene, food, and sunlight when well controlled led to an improvement in the general condition of an individual. The Hippocratic method was based on an examination of the patient including his/her geographical location, climate, age, gender, habits, and diet (Kleisiaris et al., 2014). These point already to a geographical information system (GIS), which is an element of large data that are explicit in the Hippocrates (400 BCE) treaty: "Airs, Waters, Places." Aristotle introduces classifications in biology as he did for the other sciences, introducing also an element of Big Data. Before the Pasteurian development of microbiology, it was thought that diseases were caused by miasmas, which were like the subtle fluids of the pre-Maxwellian physics. The relation between these miasmas and dirty environments and bad weather was empirically discovered and was exemplified by the construction of the Hippocrates hospital in Kos, with permanently fair weather, view on the sea, and cleanliness of the Asclepios priests, who were always dressed in white. They practiced also other aspects of medicine, including surgery and prescription of medication. See Fig. 24.1.

The revival of Hippocratic theories during the renaissance led the European physicians to have an interest in meteorology. These medical doctors unfortunately resorted also to astrology to such a point that Galileo taught astronomy in Padua essentially to medical students who used horoscopes as part of their diagnostics (Fermi and Bernardini, 2003). It is in this context, in the 18th century, that medical doctors began to consider electricity without knowing what it was and attempted the use of "animal magnetism" to perform curative actions. In the second half of the 19th century, the progresses of the scientific method brought more rationality to medicine. Especially the Pasteurian view that the prevention of most diseases went through the identification of their agents and transmission vectors has led to the cure of hundreds of pathologies in plants, animals, and humans. The 19th century brought also a form of Big Data by the health statistics related to the selection of conscripts in the European armies; also, systematic mortality and morbidity reports began to be collected and allowed comparison between diseases and behavioral or environmental elements. Beginning at the end of the 20th century, the electronic monitoring of hospital patients and emergency services statistics added new elements.

Unfortunately, the preservation of hospital electronic records is still far from being a standard or even an accepted procedure and it is almost certain that correlations between health and geophysical, astronomical, behavioral, and sociological parameters are still to be discovered.

24.2 METEOROLOGY AND CLIMATE (TEMPERATURE, HUMIDITY, ETC.) AND APPLICATION TO DISEASE PROPAGATION

The entire ecosystem is dependent on the timing of events constrained by meteorology. Pollination depends for example on insects; if blooming occurs before the insects are present in a sufficient number, the entire cycle of plant reproduction is perturbed. In the same respect, if migratory birds arrive before the insects are present, they also miss their reproductive cycle due to a lack of food. Climatological parameters thus influence local situations, and this can only be assessed by the cross-comparison of very different data sources.

The priority was the study and forecast of the presence of disease vectors as the mosquitoes responsible for the development of malaria. Their presence depends on temperature, humidity, surface water, and altitude. Malaria itself is also dependent on the human pop-

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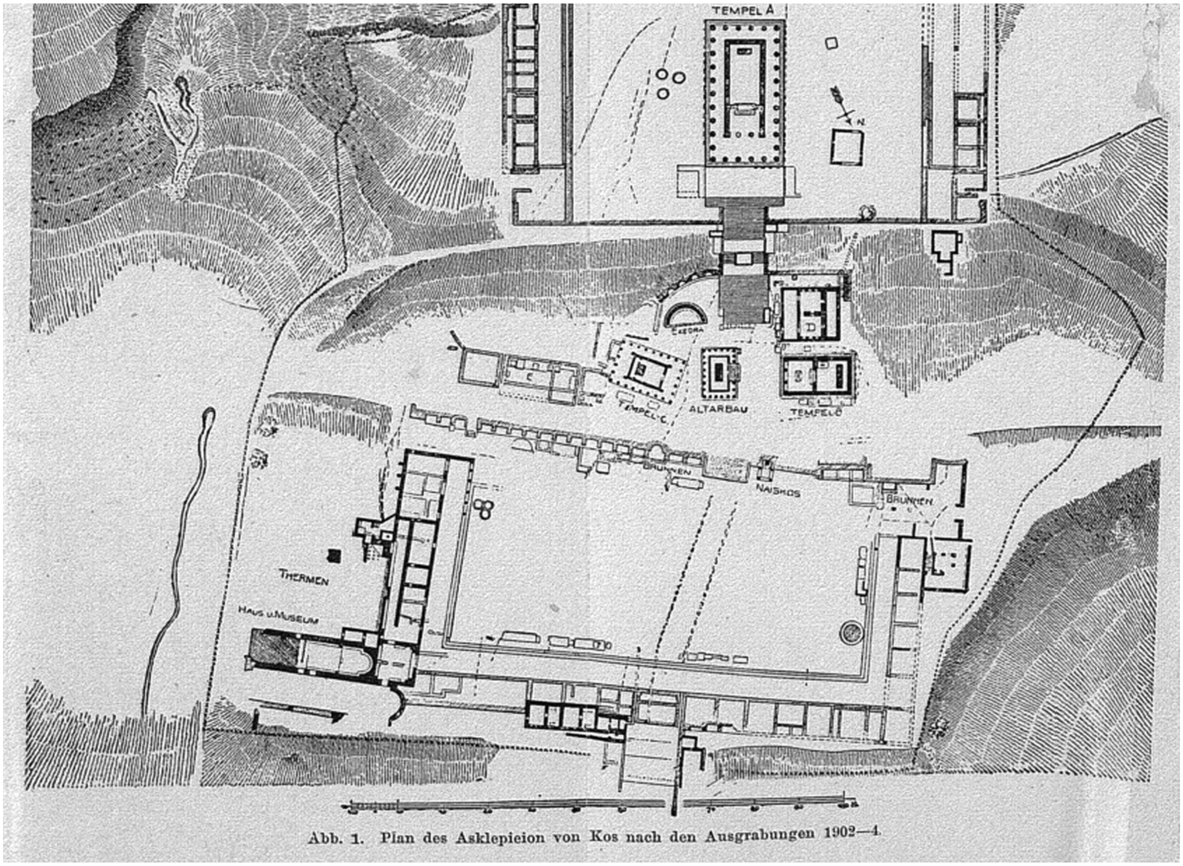

FIG. 24.1 Drawing of the Asklepion of Kos following the excavations of 1902–1904 (Herzog, 1907). Asklepions were the ancestors of modern hospitals. The cure involved purification baths and a special diet, empirically eliminating disease vectors. It involved also exercise and psychological aspects as the observation of dreams.

ulation; this requires the collection of a considerable amount of data, which became possible in the satellite era.

An early example is given by the treatment of Africa by Rogers et al. (2002), where low and medium spatial resolution sensors are used to make an elaborate modeling of the different parameters affecting malaria.

Higher spatial resolution leads to a local mapping of the propagation zones even in scarcely populated areas near the Southern border of French Guyana (Fig. 24.2, Adde et al., 2016). This kind of mapping will definitively require Big Data if extended to the entire malaria-infested part of the planet. Figs. 24.3 and 24.4 present the World Health Organization 2016 report on the status of malaria; more than 200 million new cases appear every year, around 90% of which occur in Africa. Europe and North Africa are clearly close to having eradicated the disease. The surface of the affected regions is however huge compared to the French Guyana example of Fig. 24.2, and a generalized high-resolution treatment of the whole area would mean an unprecedented dataset. The same rationale applies when a population of around 1000 persons is compared to the several billions in the countries where the disease is still endemic.

Malaria is the most evident example of an environmentally controlled infectious disease, but the same rationale applies to other water-borne and vector-borne diseases, as reviewed by Singh et al. (2015). Climatic changes might extend the zone where the vector can be

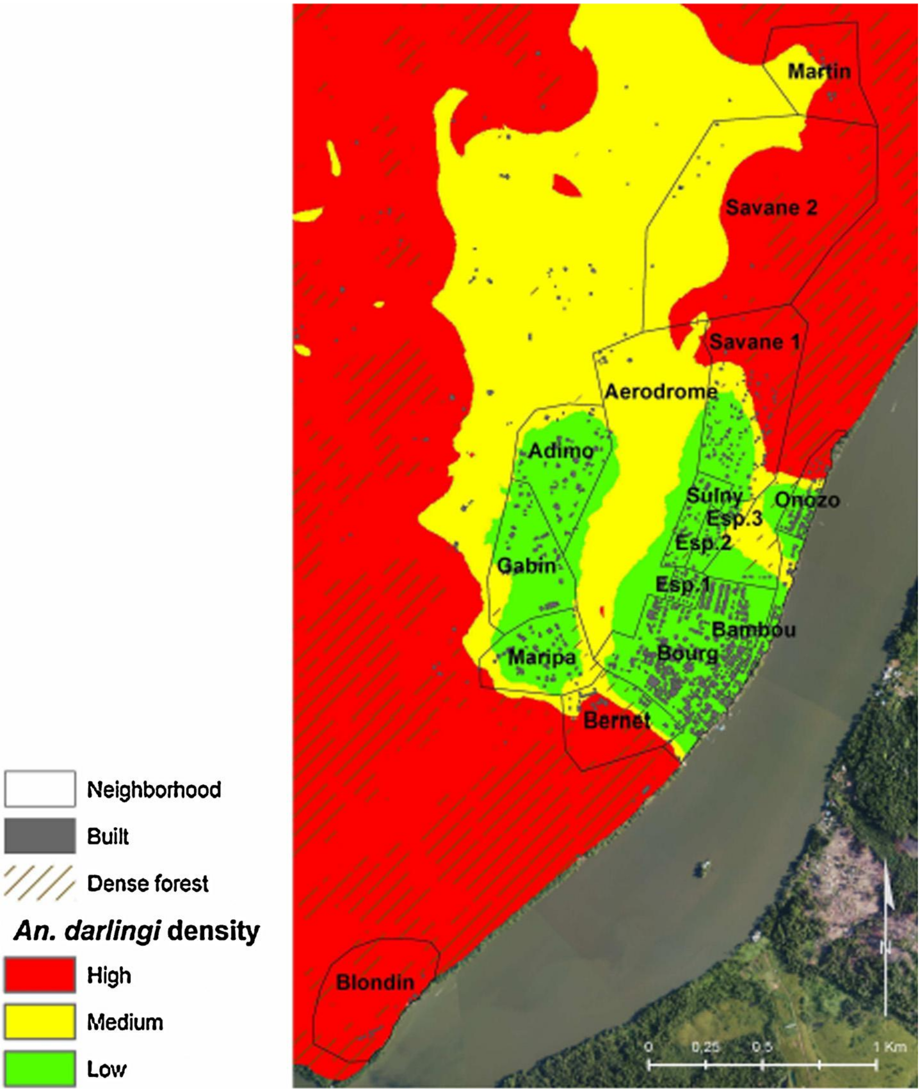

FIG. 24.2 Mosquito modeling of a French Guyana settlement along the Oyapock river using high-resolution satellite imagery. Individual housings are visible. High- and medium-density zones are defined with a resolution better than 10 m.

active as was already observed for the West Nile virus in Europe and North America. For each case, the specific conditions could be monitored from space using existing Earth observation satellites. The combination of geographical information systems (GISs), environment and climate, entomology, microbiology, veterinary medicine, and social sciences requires Big Data from various sources to produce epidemic forecasts and thus deploy protective and curative strategies.

24.3 INFLUENCE OF EXTRATERRESTRIAL SOURCES: SOLAR ACTIVITY, GALACTIC COSMIC RAYS, AND GEOMAGNETISM

The first inference of an influence of the sun on a biology-related indicator was the study of the correlation between sunspots and the price of wheat on the Windsor market by William Hershell (1801) just after the first statistics application to economics by Adam

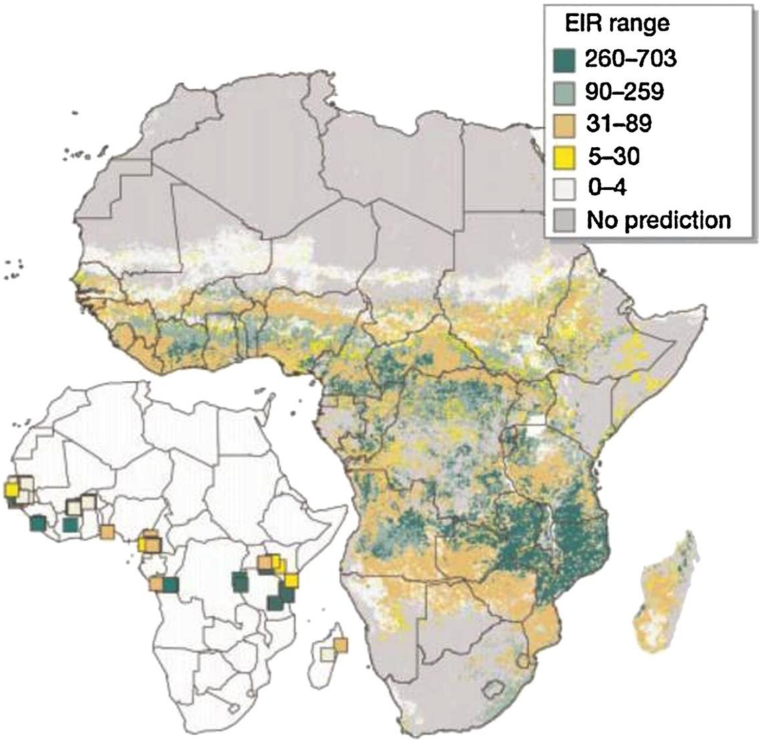

FIG. 24.3 Satellite-derived predictions of entomological malaria inoculation rate (EIR) in Africa. EIR data were grouped into five approximately equal-sized classes of mean levels of malaria challenge. Insufficient training data were available to define EIR in those parts of the continent marked gray (Rogers et al., 2002). Training is the ground truth or validation process that permits to control the quality of data deduced from satellite observations.

Smith: "The result of this review of the foregoing five periods is, that, from the price of wheat, it seems probable that some temporary scarcity or defect of vegetation has generally taken place, when the sun has been without those appearances which we surmise to be symptoms of copious emission of light and heat." Hershell did not discover the 11 year cycle in this analysis as his series still included the Maunder minimum of the 17th century which dominated the 11 year cycle. Schwabe (1844) was the first to put it in evidence after three textbook solar cycles. The Hershell anti-correlation was met with criticism since its first publication and revisited in an appendix of the Carrington (1863) analysis of sunspots. Besides being a superior solar observer, Richard Carrington was also a brewer and had his income tied to the cereals price. He concluded that in the 19th century, wheat prices, and especially the import duties, were dependent on tax laws passed by the British parliament. These taxes were amounting to import subsidies in order to have British farmworkers leave their job to participate in the new industrial expansion in the cities and be sufficiently fed with minimal wages. However, the work of Hershell after more than 200 years is still open for discussion both in the study of the influence of geophysical parameters on economy and in the use of statistics to determine causality (see, for example, Love, 2013). These points are at the basis of the reflection concerning the use of Big Data in current forecasts.

The relations between solar activity, magnetism, and galactic cosmic rays were discovered later in the 19th and 20th century. Large scale biological effects are still under discussion; the 1859 large solar flare event known as the Carrington effect led to significant perturbations of the telegraphic network, but any influence on biological parameters does not show up in the morbidity and mortality record with the exception of an increase in the birth rate in the Paris region nine months after the event, which was at the time attributed to the weather conditions (Muller, 2014). See Fig. 24.5.

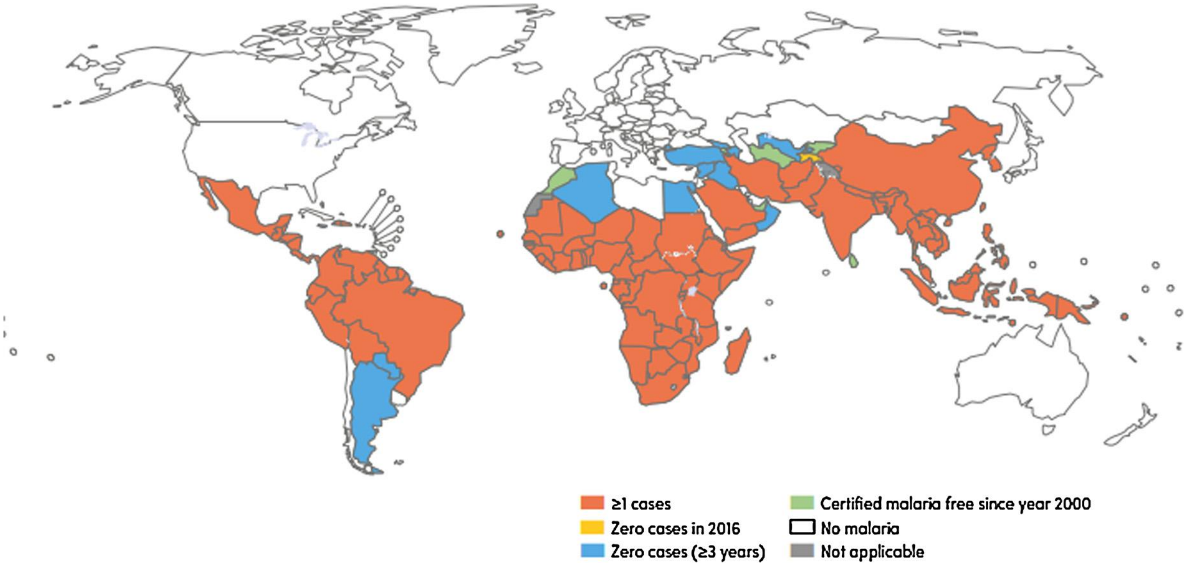

FIG. 24.4 Countries and territories with indigenous cases in 2000 and their status by 2016. Countries with zero indigenous cases over at least the past three consecutive years are eligible to request certification of malaria-free status from the WHO. All countries in the WHO European Region reported zero indigenous cases in 2016. Kyrgyzstan and Sri Lanka were certified malaria-free in 2016. Source: WHO database (latest full report: WHO, 2015).

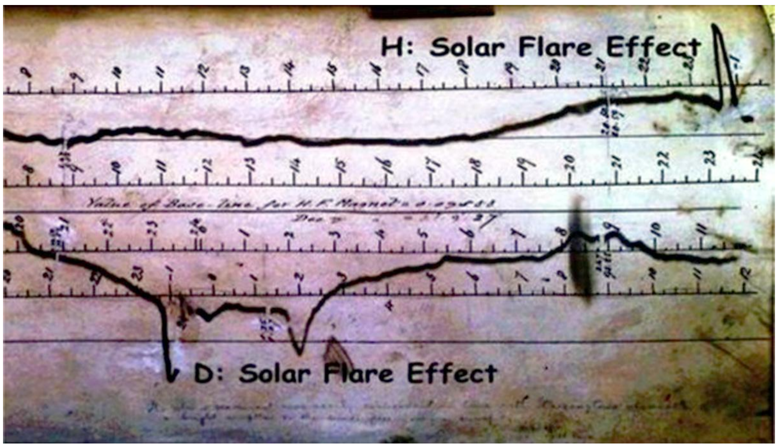

FIG. 24.5 Trace of the horizontal component of the Earth's magnetic field from Kew Observatory for 1–2 September 1859, showing the magnetic crochet at 11:15 UTC on 1 September and the great geomagnetic storm that followed 17.6 h later and drove the record off-scale (Cliver and Svalgaard, 2004). The geomagnetic storm generated auroral displays that were observed as close to the equator as the Caribbean islands.

In the 20th century, several less important solar storm events occurred and had consequences on electric transport lines as well as on communication networks, but again, the relation with public health records has not been universally studied. However, studies related to flight and space medicine have shown, especially in the Russian hearth morbidity statistics, a relation between space weather and hearth-related emergencies (Breus et al., 1995). The verification of these correlations would necessitate a worldwide study of hospital electronic patient records at the time of a solar event.

Galactic cosmic rays anticorrelate with solar activity; when the sun is low in activity, the heliosphere is weaker and thus the extrasolar flux is more important. The health risks are rarely considered, except for astronauts and flight crews, for whom several studies exist, and even a European Union directive imposes to inform crews of the radiation doses occurring during flights. Up to now, no direct causality relation between high-altitude flight and disease has been established (Lim, 2002). However, further studies might lead to regulations limiting the number of flight hours for specific categories such as pregnant women or imposing a lowering of flight altitude. In the case of astronauts, the small number of the cohort, a little more than 500, cannot lead to a definitive conclusion. A recent review (Hodkinson et al., 2017) lists the radiation risks encountered by the current astronauts. However, in the case of flight to Mars and beyond, the situation becomes more complex as for this long duration, statistical data are not a sufficient element to characterize the risk and both shielding procedures and pharmaceutical protection are under study.

24.4 SOLAR UV AND LIFE

Until the middle of the 20th century, medicine followed the Hippocrates hypothesis that exposition to solar radiation was beneficial. However, these effects could only be quantified when physicists developed both lamps and UV sensors and used them in a hospital environment (Latarjet, 1937). Subsequent studies showed damages comparable to the effects of ionizing radiation on plants and test animals and ended up establishing a relation between UV and the genesis of human skin cancer (Latarjet and Wahl, 1945; Latarjet, 1959). The progress of UV sensors led not only to this new development on the biological effects of solar radiation but also to studies of what was called at the time "the UV limit of the solar spectrum." These were precursors of the determination of the UV effects on atmospheric chemistry and its climate effects.

From a biological point of view, UV radiation is divided between UV-A (400–315 nm), UV-B (315–280 nm), and UV-C (280–100 nm). It is well known that UV-A is necessary in moderate doses to initiate metabolic processes as for example the production of vitamin D in the human skin.

Stratospheric ozone entirely filters UV-C and the largest part of UV-B. Ozone is not the only effective UV filter; carbon dioxide filters all UV below 220 nm, but a reduction in ozone would expose the biosphere to UV-B with consequences on both plants and animals.

The decrease of the ozone layer observed since the 1970s and especially since the Antarctic spring "ozone hole" has led to the 1987 Montréal protocol on ozone depleting species. Solar variations play a role in the equilibrium of the ozone layer, but this effect is buffered by the fact that atomic oxygen produced by the dissociation of molecular oxygen more than compensates for the destruction of ozone by UV radiation of longer wavelengths. Thus, the solar climate has very little effect on the UV radiation received at the Earth's surface; however, again, scientific research should never overlook the effects of perturbations and never consider a part of the Earth's system as definitively autostabilizing.

The Montréal protocol, while reversing the trend in ozone depletion, had very little effect on skin cancer incidence, which keeps increasing (for example, https://melanoma.canceraustralia.gov.au/statistics, 2018). Again, this shows the difficulties in treating causality when diverse effects intervene in the final result.

24.5 APPLICATIONS TO AGRICULTURE

The study of agriculture parameters from space began as early as the first military reconnaissance satellite as the worldwide status of crops gave important information on the food market in the near future. Early studies were made on both the US and the Soviet side but proved inconclusive until the concept of validation was introduced; validation consists in the comparison between ground truth and forecasts on a few carefully chosen test sites. A lot of these early attempts have been lost until the NASA civilian LANDSAT program began in 1972, evolving from an experimental digital multispectral mapping program to a fully operational Earth resource monitoring system. It is now managed by the United States Geological Survey, it has launched its eighth satellite, and other agencies have built similar programs with elements of compatibility with LANDSAT. The agriculture applications have been recently reviewed by Leslie et al. (2017) and range from academic research to operation products directly applied to actual farm operations. It is for example at the basis of the CropScape data portal of the US Department of Agriculture, as illustrated in Fig. 24.6.

CropScape can be accessed at https://nassgeodata.gmu.edu/CropScape/ (Han et al., 2012) and gives access to a complete mapping of several crops, which could be zoomed in on with a 200 m spatial resolution. These data can thus be exploited both locally and globally.

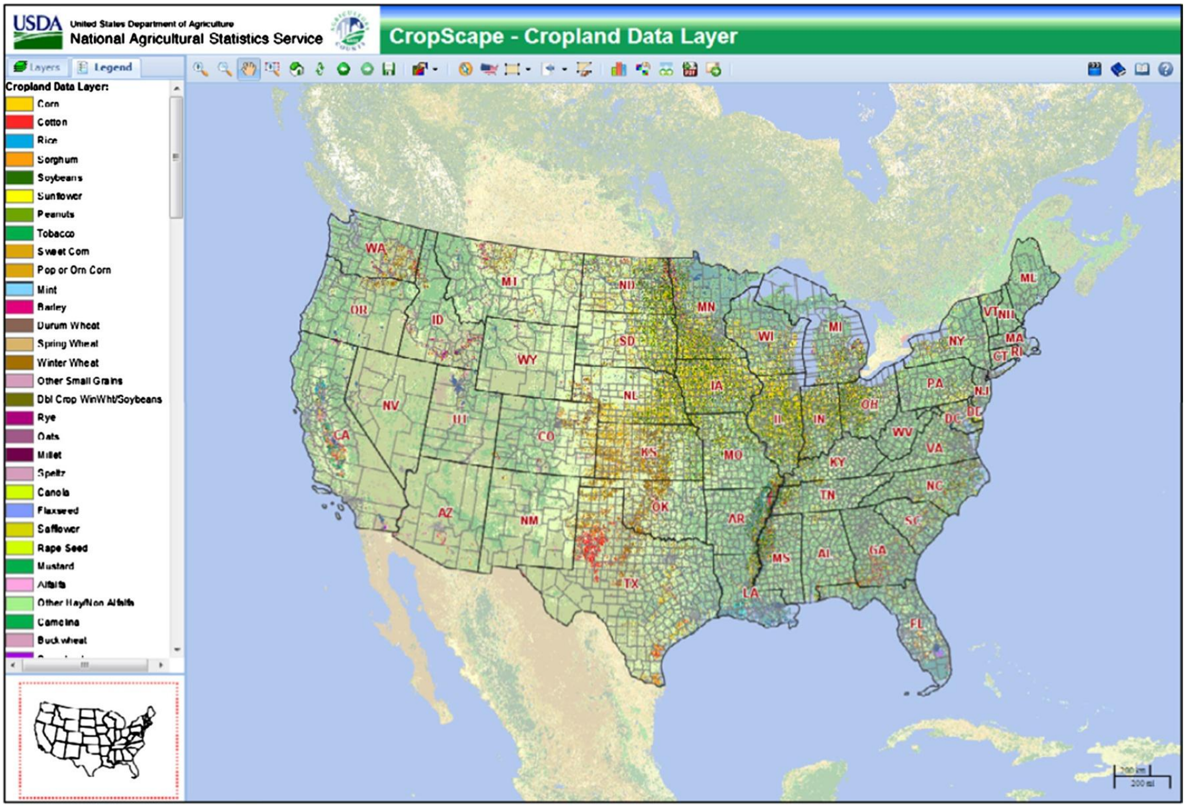

FIG. 24.6 The CropScape data portal, which allows for the display of the Cropland Data Layer by year from 1997 to the present; derived products such as the Cultivated and Crop Frequency Layers; and supporting layers like boundaries, water, and roads (USDA National Agricultural Statistics Service, 2017).

A color code identifies the number of years in which crops have been exploited and is thus a precious tool for forecasts. Zone maps can also be used to assess the efficiency of agricultural practices as fertilizer application and irrigation.

The US federal agricultural services have an international branch called the Foreign Agricultural Service (FAS). Originally, this service searched potential markets for US agriculture; now it has involved in a collaboration agency with other space faring nations in the frame of the Global Agricultural Monitoring System (GAMS). It also provides data to the United Nations Food and Agricultural Organization (FAO).

Parallel efforts are accomplished by other space agencies. ESA uses its Earth observation satellites for agricultural applications. As an example, the ESA Soil Moisture and Ocean Salinity (SMOS) mission monitoring satellite is used in combination with NASA green vegetation data from the MODIS instrument to make forecasts of the conditions leading to the reproduction of locusts. See Fig. 24.7.

Early forecasts and detection of locust swarms ensure the deployment of countermeasures to preserve crops essential for human alimentation. The current forecasts made by CIRAD use a lower spatial resolution than the maximum available from the sensors. Big Data techniques taking full advantage of high resolution might in the future enable to destroy locusts at the constitution of groups.

Soon, precision agriculture will use satellite data to the level of the individual plant (European Parliamentary Research Service, 2016). This will represent a new upscaling of the Big Data in agriculture, including real-time operations in terms of irrigation, phytopharmacy, and even harvest. This new paradigm will mean a very large extension of what has been outlined here.

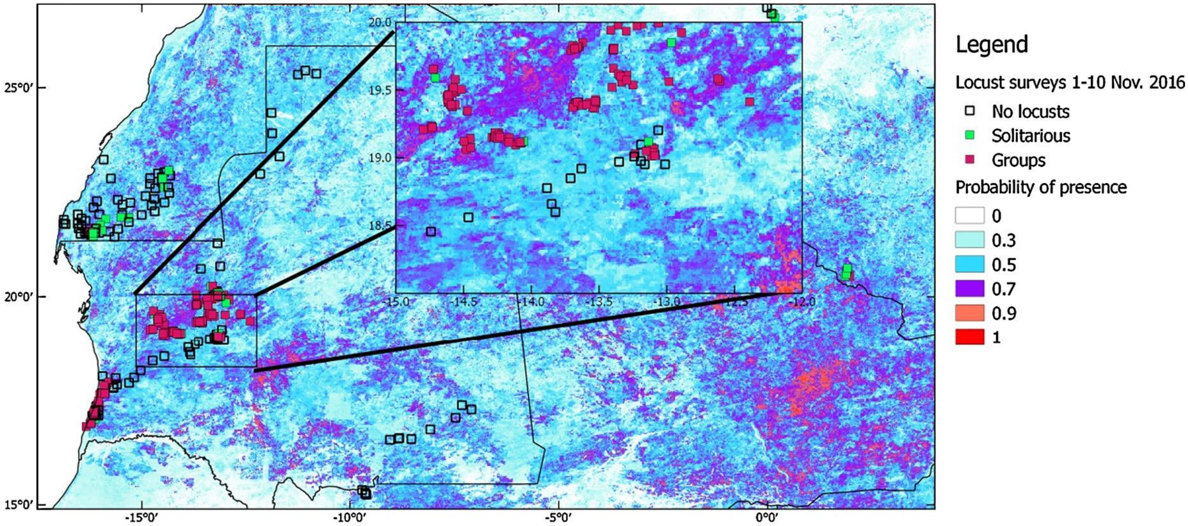

FIG. 24.7 Soil moisture data from the SMOS satellite and the MODIS instrument were used by the French CIRAD institute to create this map showing areas with favorable locust swarming conditions in red (FAO document, http://www.fao.org/news/story/en/item/895920/icode/).

24.6 CONCLUSIONS: FUTURE OF SPACE OBSERVATIONS, BIODIVERSITY, AND ASTROBIOLOGY

The different examples in agriculture and disease forecasts are going to expand rapidly in the coming years with the increase in sensor spatial resolution and repeat rates. Climatic change will modify the temperature and humidity conditions rapidly, as observed in the 20 last years. The adaptation of finely tuned ecological systems involving plants, insects, birds, and other animals is not evident and space data will be ideally positioned to observe the evolution and see if biodiversity is threatened. The threat comes from both a loss of synchronization between the different biological processes and new conditions favoring invasive species; only a large-scale inventory involving high-spatial resolution data will allow to quantify the changes in biodiversity defining new specific indices. Currently, several biodiversity indices have been proposed, and all depend on the statistics of the different populations in an ecological system. The issue is defining an inventory, the proportion of each of its elements, and applying a statistical formula to the results. The international definition of these indicators is linked to the United Nations Convention on Biodiversity, which is active since 1993 (https://www.cbd.int/convention/). A list of indicators is published on the convention's site (https://www.cbd.int/doc/strategic-plan/strategic-plan-indicators-en.pdf); each of them involves a different methodology and a few of them have not yet been identified. This field will necessarily need the techniques developed in the Big Data field for its development.

Finally, in a more tentative perspective, the discoveries of exoplanets keep increasing and their astronomical biomarkers analysis and inventories will come soon when spectroscopy of these distant worlds will become possible. Due to the very large number of planets, compared to the numbers of stars, this analysis will require techniques developed for Big Data, including artificial intelligence.

In these two cases, the techniques proposed in this book will prove fundamental to the study of life-related questions for both the Earth and the universe.

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