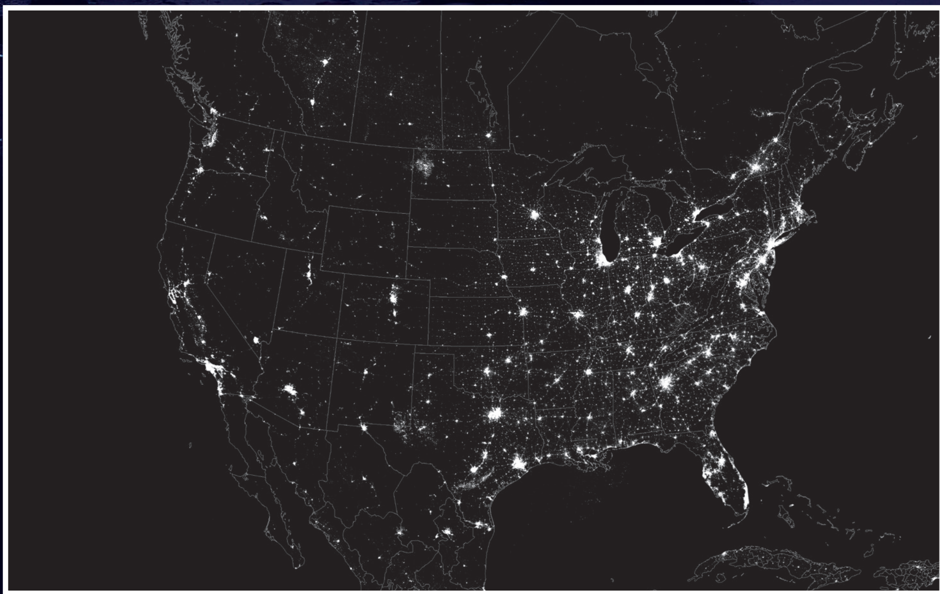


Figure 1.

Nighttime Visible Imagery of Earth from Space

by **Don Hillger** and **Garry Toth**

We start with a nighttime visible image of city lights centered over the United States (Figure 1), to foreshadow the content of this article. The image is a composite of nighttime visible imagery from polar-orbiting satellites. The individual images were selected for their cloud-free conditions, thus showing only city lights. Even without a map, the outline of the US is evident because of the dots of light on the coasts with no significant lights offshore or on the Great Lakes. Cities with enough lights to appear in the image can be located by their position in the blackness of this map despite the absence of any other geographic references.

How is it even possible to create images like this? Just over 10 years ago, the first of a new series of polar-orbiting weather satellites was sent aloft, the Suomi-National Polar-orbiting Partnership (S-NPP), launched on October 28, 2011. It was the first of three similarly instrumented polar-orbiting satellites, delivering imagery as the world turns beneath them. The two that followed S-NPP were called JPSS (Joint Polar-orbiting Satellite System)-1 and 2 until they arrived in orbit and achieved operational status. At that time, they were renamed NOAA-20 and 21, respectively. NOAA (the National Oceanic and Atmospheric Administration) has operated American environmental-observing satellites since 1960. The NOAA satellite series, which started in 1970, consists of a group of polar-orbiting satellites; each generation is equipped with improved remote-sensing capabilities, such as nighttime visible imagery. NOAA also operates a series of geostationary weather satellites that do not have the nighttime visible imaging capability.

The JPSS series was initially called the National Polar Orbiting Environmental Satellite System (NPOESS) for those interested in additional background information. NPOESS was to be a joint NOAA, NASA, and USAF satellite series. Still, due to budgetary concerns and an inability to work well with the other partners, the US Air Force, with the agreement of the US Congress, left the partnership. NOAA and NASA continued to develop the NPOESS as a follow-on to the NOAA series, which would otherwise have ended with NOAA-19. S-NPP was originally called NPP (NPOESS Preparatory Project) but was renamed for the JPSS Program as well as to honor the "father of satellite meteorology", Verner E. Soumi (1915 – 1995). The Aland Islands of Finland issued a stamp in 2021 showing the S-NPP satellite (Figure 2). The stamp also includes Suomi's name in its text. This is the only stamp known to show a JPSS-series satellite.

Although Verner Suomi was not directly involved with the JPSS Program or the nighttime visible imagery, he did lay the foundations of satellite remote sensing for meteorological purposes. His first satellite experiment, designed with the help of Robert Parent, determined Earth's radiation (heat) budget by measuring the balance between in-

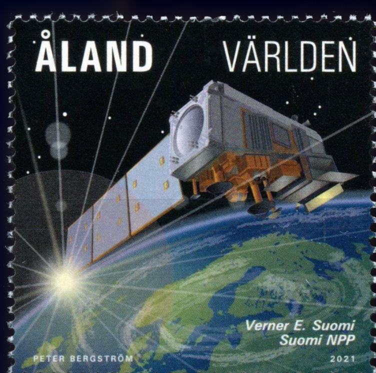


Figure 2. Aland (Islands of Finland) Scott 442 (2021) showing the "Suomi NPP" satellite, named after "Verner E. Suomi," whose last name means 'Finland' in Finnish.

coming solar energy and outgoing energy due to the sum of solar energy reflected from Earth and infrared energy emitted by Earth. That experiment flew on Explorer-7 (launched in 1959) and was a pioneering study of Earth's climate. For more details, see *https://nssdc.gsfc.nasa.gov/nmc/experiment/display.action?id=1959-009A-01*). A stamp issued by Togo in 2019 shows Suomi and the Explorer-7 satellite before launch (Figure 3).

Figure 3. Togo (2019), showing Verner E. Suomi, the "father of satellite meteorology," and Explorer-7.

As a further aside, Suomi was also responsible for the first full-disk imaging of Earth from geostationary orbit, from Applications Technology Satellite (ATS)-1 and ATS-3 (Figure 4). Those first images were not traditional photographs. Instead, they were constructed of pixels as the camera on board scanned the Earth's disk as the satellite rotated. The image was then stitched together at a ground station, using signals it received from the satellite. Suomi's colleagues at the University of Wisconsin-Madison were also responsible for one of the first computer systems used to process those satellite images of Earth. The images from ATS-1 were black and white, while those from ATS-3 were taken in three (red, green, and blue) visible components, allowing the first true-color full-disk images of Earth. (Although multi-spectral imaging from geostationary orbit continued after the ATS series, it was not until about the year 2000 that true-color imaging resumed as standard fare from geostationary-based instrumentation.)

Figure 4. Grenada Scott 494, (1973) with ATS-3.

With that bit of history, we can return to the nighttime visible imagery that is the subject of this article. The main imaging instrument on the JPSS/NOAA satellites is the Visible Infrared Imaging Radiometer Suite (VIIRS). A high spatial resolution (as fine as 375 m) imaging instrument, VIIRS takes visible/reflected-energy imagery during the daytime and infrared/emissive-energy imagery both day and night. However, VIIRS also has a special Day/Night Band (DNB) that can produce visible imagery day and night. While the Sun provides the visible energy reflected off Earth's surface and clouds during the day, the Moon provides visible energy at night. It was initially thought that this nighttime visible energy would only be bright enough for imagery when the Moon was at least a quarter full. However, the DNB instrument was sensitive enough to provide usable imagery even during new (no) Moon periods. That capability is partly due to the inherent “airglow” of the atmosphere. (See *https://en.wikipedia.org/wiki/Airglow*). The effect of airglow on nighttime visible imagery was not understood very well until DNB imagery was developed. The Earth is never totally dark because of the airglow as well as city and other manmade lights that show up as prominent features at night when there are no clouds to block them. Manmade lights are primarily what is seen in the first image in this article.

Nighttime visible imagery was originally a USAF requirement for the NPOESS system, but it remained in the program after they departed. A precursor instrument called the OLS (Operational Linescan System) has been deployed on the military DMSP (Defense Meteorological Satellite Program) satellites since 1992. However, OLS remote-sensing capabilities were far less robust than those of DNB. Although it did provide nighttime visible imagery, the OLS lacked the sensitivity to low-level light to do imaging under new Moon conditions. Thus, NOAA inherited this capability, making it a significant new contribution to its environmental-observing network and yielding many new imagery products and capabilities. Those capabilities include monitoring manmade lights and other features (such as auroras, wildfires and smoke, and volcanic hotspots and ash) at night, as well as clouds.

VIIRS Imagery and Data

NOAA polar-orbiting satellites are 833 km above the Earth’s surface. This means they see only a swath around the surface during each 90-minute orbit, unlike geostationary satellites (perched at 35,786 km) that continuously view an entire Earth hemisphere. The orbital swaths (or portions of them) from NOAA satellites are stitched together via computer to form larger images or even images of the entire Earth. Polar-orbiting data are particularly useful for high-latitude regions since all the satellite orbits converge at the poles, providing frequent images. In contrast, for lower latitudes, a particular polar-orbiting satellite will cross overhead only two times each day. Multiple polar-orbiting satellites provide additional images, each covering the entire world twice daily. Readers are encouraged to look online for animations of NOAA satellites to see how they orbit and provide worldwide data. (See, for example, *https://www.youtube.com/watch?v=TYef_ptIORY*.)

VIIRS Imagery is sent to Earth through two ground stations, one on the island of Svalbard, Norway, and the other at McMurdo Base in Antarctica. The data goes via undersea cables from these near-polar locations to the main destination, the NOAA Satellite Operations Facility (NSOF) in Suitland, Maryland. The imagery is then distributed via the Internet to research facilities and to operational users such as the National Weather Service.

VIIRS and DNB imagery was initially available only to the teams of scientists and engineers who had created the capability. The checkout period for S-NPP, the first of the JPSS series, was about a year. This is usually the case with a new generation of spacecraft and ground system hardware and software that capture the imagery and create the image products derived from that imagery. The first nighttime images were made public in October 2012 after a year of intensive calibration and validation of the imagery from this new and complex instrument.

Examples of DNB Imagery on Postal Items

At the time of writing, the authors are aware of 18 countries that have produced postage stamps that include DNB images. The first such stamps depicting city lights appeared in 2015. Some have only a small or poor depiction of the lights on Earth at night; others have excellent depictions. Only some of the better examples are presented here. Readers can refer to the website at the end of this article to see all items with nighttime lights known to the authors.

The first example, issued by Gambia in 2015, is one of the earliest depictions of nighttime visible imagery on stamps (Figure 5). A block of four stamps from a sheet is shown. Interestingly, the theme of these stamps is the UNESCO "International Year of Light," with the sub-theme of "Dark Skies Awareness," which appears in the border (not shown here) of the sheet that contains these stamps. The four stamps include the text "Map of Earth's city lights" and show parts of Asia, North America, South America, and Europe/Africa, respectively. The image backgrounds are colored, unlike raw nighttime visible imagery, which is monochrome. Therefore, these are composite images with the nighttime city lights overlaid on otherwise true-color imagery, with over-emphasis on green compared to what humans would see if they were looking down from space. The image of eastern North America (at the upper right) has multiple city lights; the reader can compare it to the image of the USA at the beginning of this article. The images in these stamps were chosen to be primarily cloud-free. However, some clouds remain, such as the clockwise swirl off the east coast of South America, which marks a low-pressure center in the southern hemisphere. Europe has many city lights, unlike northern Africa, with no lights across the vast Sahara Desert.

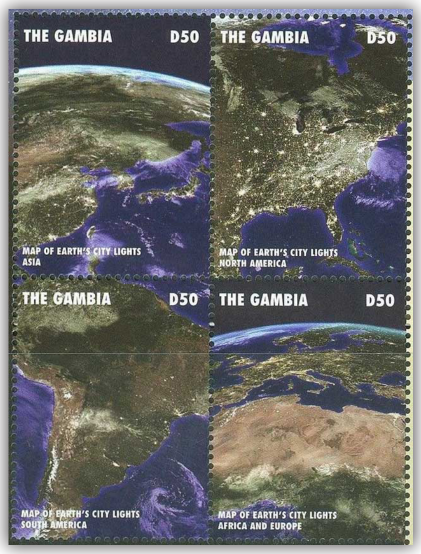


Figure 5. Gambia Scott 3652a-d, block of 4 from a sheet (2015).

Another example from Gambia is a stamp from a souvenir sheet of one stamp (Figure 6), issued at the same time as the block of four stamps already presented. The image in this nearly full-disk view transitions from daytime on the left to nighttime on the right. The day-night terminator can be seen extending from Scandinavia down across the western edge of Africa. To the left of the terminator is a daytime view of clouds and land features. To its right is a nighttime view of myriad city lights in Europe, Africa, and part of Asia. For example, the Nile River is prominently illuminated (in the lower-right of the image). This string of lights is caused by the high density of illuminated fishing boats on the river. The text on the stamp, "Map of Earth's city lights," is consistent with the "Dark Skies Awareness" and "International Year of Light" themes found in the border of this sheet (not shown here), as was the case with the block of four stamps already presented.

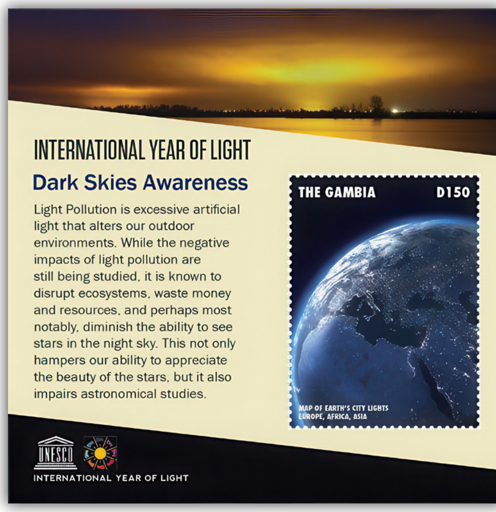


Figure 6. Gambia Scott 3653, a souvenir sheet of one stamp (2015).

A set of six stamps depicting various satellites was issued by Indonesia in 2016, with three of the 6 stamps showing city lights. The two stamps featured here (Figure 7) are the best of the set for showing a large area of city lights in the background; those stamps also depict the Indonesian Telkom-1 and -2 communications satellites. The city lights stretch from the Persian Gulf States on the left, through India, into Southeast Asia, and finally to South Korea and Japan on the right. There can be significant contrasts between light and dark areas over land, ignoring the differences between land and water. For example, the bright lights of South Korea versus the darkness of North Korea make the former country look almost like an island.

Similarly, most of India is very bright compared to the darkness of the Himalayas and Tibet to the north. Dense manmade lighting illuminates the geography in many locations. Man can indeed have a great impact in lighting up the night!

Figure 7. Indonesia Scott 2451c and d (2016).

The next example of nighttime lights is a stamp issued by Bosnia and Herzegovina (Croat Administration) in 2016 (Figure 8). The theme of this sheet of two stamps is Think

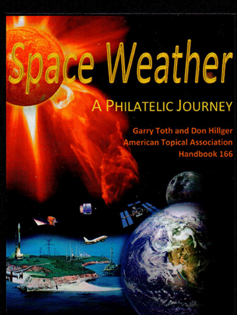
Figure 8. Bosnia and Herzegovina (Croat Admin.) Scott 330a (2016).

Green. The stamps illustrate that theme, while the left and center margins present another example of the nighttime visible imagery. The larger cities of Europe can be picked out by their city lights, and some of the thoroughfares connecting the cities are also visible. In contrast, the right side of the image is daytime visible imagery, in which the reflected energy from the Sun overwhelms the city lights so that they are no longer bright enough to stand out. The dividing line is the day-night terminator. To be usable both day and night, the DNB instrument was designed to detect light over a wide range of values, over eight orders of magnitude from the lowest light to fully reflected sunlight. In this way, a single instrument lives up to its Day-Night name.

Also, in 2016, the Netherlands issued a personalized sheet of three stamps (Figure 9) with a visible nighttime image centered on Europe in the margin. The sheet commemorates the 60^{th} anniversary of Europa stamps, a yearly theme that started in 1956. The city lights of Europe is an appropriate Europa theme. The coastal lights of Spain, the

Figure 9. Netherlands Scott 1474 personalized postage (2016).

SPACE WEATHER
A PHILATELIC JOURNEY



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Solar storms that cause bright auroras can also affect people and technology in space and on Earth. The development of the scientific understanding of that Sun-Earth relationship is examined in *Space Weather—A Philatelic Journey*, ATA Handbook #166 published in Digital Edition, PDF format by the American Topical Association.

WWW.AMERICANTOPICAL.ORG/STORE

Figure 10. Djibouti souvenir sheet (2023).

boot of Italy and some other parts of the Mediterranean in the lower margin of the sheet are particularly clear.

The last two postal item examples of nighttime visible imagery have similar themes. Both items commemorate the 65th anniversary of early satellite launches. The first one is a souvenir sheet of one stamp issued by Djibouti in 2023 for the launch of Explorer-1 (Figure 10). This was the first US artificial satellite successfully launched (in 1958) after the Soviet Union had already successfully launched both Sputnik-1 and Sputnik-2. The lower margin of the sheet contains a nighttime visible image of the familiar city lights of Western Europe. In particular, Spain in this image shows lights similar to those seen in the Netherlands item above.

Figure 11. Sierra Leone souvenir sheet (2023).

One final example of a nighttime visible imagery postal item has a nighttime visible image centered over southeastern Europe. This souvenir sheet of one stamp was issued by Sierra Leone (Figure 11) in 2023 for the 65th anniversary of the launch of the Vanguard-1 satellite in 1958. Although Vanguard-1 was also one of the first artificial satellites to be launched, it is still in orbit, as noted on this item, due to lower atmospheric drag at its high orbital altitude. This contrasts with the Explorer-1 satellite's lower orbit and, therefore, increased atmospheric drag, which eventually caused it to fall back to Earth and burn up (in 1970). In this item, the city lights of Italy are particularly prominent, with the Po Valley in northern Italy like a bowl that is lit up. The area of Rome, farther south, is also very bright. Italy is emphasized in this image, but parts of Europe to its north and east are also visible.

The examples of nighttime imagery on postage stamps presented in this article are the best ones known to the authors. As already mentioned, others are available on the authors' website.

However, it is not just the presence of city lights that is important. Those city lights may be missing when cities are darkened due to power outages. Such was the case with Puerto Rico when it was thrown into darkness due to two hurricanes that devastated the island in 2017. The power outage was monitored from space by the unusual darkness compared to the extent of pre-hurricane lights. The lights gradually came back on over a period of months as power was restored. This is only one example of a practical application of the nighttime visible imagery.

Nighttime visible imagery is a valuable tool for monitoring almost anything that creates or reflects visible light at night, especially when there is contrast between the feature in question and darker surroundings. The following graphic explains many of the features on Earth that can be seen in nighttime visible imagery. In it, the JPSS satellite is depicted above Earth, along with many of the features that light up the night sky besides city lights, including aurora, fires and smoke, lightning, fishing boats, gas flares, and volcanoes (both hot spots and volcanic ash). When the skies are clear, city lights are the most commonly seen nighttime feature, as depicted in the postal items already presented. However, airglow allows some features to be visible even under new Moon conditions, even if they do not emit their own light (such as clouds, sea ice, and snow cover).

Stamps that depict nighttime imagery with city lights illustrate the remote sensing capabilities of the DNB system for the philatelist. High-resolution and high-sensitivity nighttime visible imagery has been available now for just over 10 years. It is a significant complement to the daytime visible imagery and day/night infrared imagery available from meteorological satellites for over 60 years.

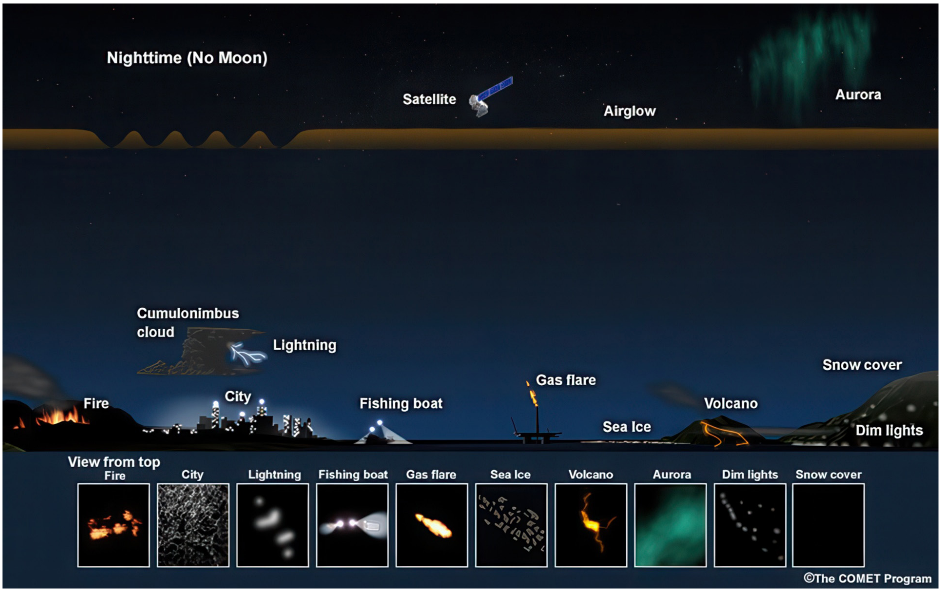

Figure 12. A slide from a training module for meteorologists listing many of the features that can be seen in nighttime visible imagery. Specific uses are named in this graphic. Graphic courtesy of Steven Miller, CIRA/Colorado State University.

Summary

This article contains a selection of examples from our collection of postal items related to nighttime visible imagery on postal items. Our online and ever-growing list of such postal items is available at *http://rammb.cira.colostate.edu/dev/hillger/satellite-images.htm#nighttime*. If readers find any additional philatelic items related to nighttime visible imagery that we have missed, please contact us at the email addresses below.

Biographical notes

The authors have researched and written extensively on the subjects of weather, climate, and unmanned spacecraft on stamps and covers and some other topics. Email correspondence is welcome using the addresses below.

Don Hillger, PhD, now retired, was a research meteorologist with the National Oceanic and Atmospheric Administration (NOAA) and is still associated with Colorado State University. Send correspondence to *don.hillger@colostate.edu* (This author was the NOAA Imagery Team Lead for the first 10 years of VIIRS Imagery, which included Day/Night Band (DNB) imagery that is the basis for the nighttime images on the postal items in this article.)

Garry Toth, MSc, has retired and worked many years at the Meteorological Service of Canada. Send correspondence to *gmt.varia@gmail.com*.