Marine and weather research in a cost-effective and democratic way with independently received weather satellite images

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Satellites have become an essential part of our everyday modern life. Especially weather satellites as they provide a basis for weather forecasts from a unique perspective. The objectives of this study revolve around the UN's Global Goals for sustainable development and how to introduce more accessible and democratic ways of conducting water and climate research. This study, therefore, examines if it is possible, as an individual with low-cost equipment, to independently receive and conduct a scientific study with images directly from these weather satellites. The study analyses sea surface temperature (SST) in the Baltic Sea region and its development during the fall of 2020.

Acknowledgements

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I would like to thank Justin Atkin at The Thought Emporium who were the earliest inspiration to this project. Thanks to his video, I realised to opportunities weather satellites could provide to the average person.

Contents

Acronyms

SST . . . . . . Sea Surface Temperature

POES . . . . Polar Orbiting Environmental Satellites

AVHRR . . . Advanced Very High Resolution Radiometer

NOAA . . . . National Oceanic and Atmospheric Administration

SMHI . . . . Swedish Meteorological and Hydrological Institute

APT . . . . . Automatic Picture Transmission

SML . . . . . Sea Surface Microlayer

SDR . . . . . Software Defined Radio

1 Introduction

The first satellite, Sputnik 1, was launched on October 4, 1957 from Baikonur in the former Soviet Union. Sputnik was not only the beginning of the space race but also the beginning of a new era in technology and space travel. The number of satellites and their usage has increased dramatically since the start of the space race and has revolutionized our existence in several ways. Since then, they have become an essential part in surveillance, communication, navigation and research for example.

One of the main utilization of satellites today is in meteorology. Weather and climate are some of the most difficult physical phenomena to model. Due to the number of factors that are involved, large amounts of data and advanced models are required to be able to compile weather forecasts. Despite this, many aspects of society and people's everyday lives are completely dependent on accurate and reliable weather forecasts. For example, the *Swedish Meteorological and Hydrological Institute* (SMHI) collects observations with satellites every day in order to create weather forecasts and conduct scientific studies. They collect data in many ways, including via weather satellites, which are a key tool for observing conditions and development over large areas.

What is unknown to many, however, is that certain signals from these weather satellites are possible to receive and decode for private individuals. With the help of a simple antenna and software, nearly anyone can receive the same weather images and data as the major institutions, anywhere. This has been done in previous studies where different systems and antennas have been investigated [15, 5]. It has also become a popular activity for amateur radiologists as the signal is unencrypted [12]. However, there are no studies on whether it is possible to use the received data for something practical.

To find a purpose for this existing opportunity, this work was based on the UN's Sustainable Development Goals (SDGs). The following sub-goals and targets were selected because they are relevant and interesting for how weather satellite technology and the possibility to use it yourself can be applied in practice:

9.C Increase universal access to information and communications technology.
13.3 Build knowledge and capacity to meet climate change.
14.A Increase scientific knowledge, research and technology for ocean health.

Based on the selected goals, this work thus focuses on how marine and climate surveys can be conducted with cost-effective, democratic and accessible information technology.

1.1 Scope

To investigate whether the received signals from the satellites are usable for such investigations, an applied study will be presented. The aspect of examining sea temperature in particular and its development with self-received weather satellite images will be investigated. To delimit the study, the Baltic Sea area is examined for nine weeks.

1.2 Aim

In summary, the purpose of this work is to investigate the possibilities of conducting marine and weather surveys in a cost-effective and democratic manner with self-received weather satellite images. This is done by examining the sea surface temperature (SST) development in the Baltic Sea area for nine weeks. The work also examines a simple antenna construction (horizontal V-dipole antenna) as well as the availability and cost of designing a ground station to receive and process the signal and analyze the data.

- How does the seawater temperature develop in the Baltic Sea region during the autumn of 2020?
- How does the collected data compare to official *in situ* observations?
- Is it possible to conduct marine and weather research in general with this method?
- What resources are required to build your own antenna and ground station for the study?

2 Theoretical framework

2.1 Weather satellites

2.1.1 Polar Orbiting Environmental Satellites (POES)

The National Oceanic and Atmospheric Administration (NOAA) is a U.S. government agency. The agency's mission is to study meteorological conditions and their development in the earth's oceans and atmosphere. To accomplish this, NOAA operates, among other things, civilian weather satellite systems such as the *Polar Operational Environmental Satellites* (POES) which orbit in *Low Earth Orbit* (LEO) around the Earth's poles. The purpose of the system includes conducting global meteorological surveys of weather, climate change, sea temperature, atmospheric conditions, humidity, volcanic eruptions, forest fires and vegetation [11, 12]. The system currently consists of four active satellites with an arsenal of instruments onboard. Each satellite has an orbital period of about 102 minutes and thus orbits the earth with 14 revolutions per day. The satellites are launched in a sun-synchronous orbit with an inclination of about 98 degrees. This type of orbit implies that the satellites will rotate the earth in an orbit that gives them constant and even sunlight on the earth's surface no matter where they pass [10]. This in turn means that each satellite can perform about two complete global surveys per day, one in the morning and afternoon local time [11]. For a ground receiver, a passage is about 15 minutes long, horizon to horizon. Of these, three, NOAA 15, 18 and 19, are from the fifth generation and thus equipped with the AVHRR instrument and capability for APT-transmission.

Other countries operate similar weather satellite systems. However, these systems are not as developed or accessible for individuals to use as NOAA's.

2.1.2 Advanced Very High Resolution Radiometer (AVHRR)

To perform their designated mission, POES satellites are equipped with a variety of instruments. The main visual sensor on the weather satellites is the *Advanced Very High Resolution Radiometer* (AVHRR). The instrument is s scanning radiometer which consists of lenses, a rotating mirror and six different sensors. The different sensors are chosen to sense and detect radiation at different wavelengths in the electromagnetic spectrum. Only five of the sensors are in operation at a time, sensors 3a and 3b are used alternately. The instrument works by rotating a mirror at a speed of 360 rpm. At each rotation, a narrow strip (1.3 milliradians) of the earth's surface below the satellite, perpendicular to the orbit, is read. In each rotation, the various sensors analyze the spectrum of radiation from the earth in the form of both visible and infrared light. The sensor input is then converted to a 2048 pixel long line, where each pixel has a resolution of 1.08-5 km. [12, 9]

Throughout the satellite's orbit, the instrument constructs a continuous two-dimensional image of what it reads. The transmission system also works continuously so that the images received by a possible ground station are in real-time, line by line. The image that is received and decoded by the ground station is therefore only the lines that were scanned by the instrument while the satellite passed overhead.

2.1.3 Automatic Picture Transmission (APT)

The data from the AVHRR instrument is packaged and sent to Earth in mainly two formats: *High Resolution Picture Transmission* (HRPT) and *Automatic Picture Transmission* (APT). HRPT is a digital format that transmits raw data from the AVHRR and other instruments. The transmission is sent over high frequencies and advanced modulation which makes it unsuitable for a low-cost ground station.

APT is, unlike HRPT, an analog format that is carried over a *Very High Frequency* (VHF) signal with the frequency 137-138 MHz and the bandwidth 2080 Hz amplitude modulated on a 2400 Hz carrier. Due to technical limitations, not all raw data is transmitted from the AVHRR instrument in this format. The data is pre-processed and the transmission consists mainly of two image channels (A and B) as well as some telemetry and synchronization information. However, only the data from two of the five sensors on the AVHRR instrument is included in transmission via the APT format. As a general rule, sensor 4 is used continuously while the ground control switches between sensors 1 (visible) and 3b (thermal) for day and night observations, respectively. In addition to including only two sensors, the resolution is reduced at the same time as only every third scanned line is included. Despite the reduced information, the APT format does still provide valuable data and requires less equipment to receive, which makes it interesting for cost-efficient and democratic weather research. [12]

2.1.4 Sea Surface Temperature (SST)

As previously mentioned, one of the satellites' primary purpose is to collect observations regarding temperature in bodies of water, also called *Sea Surface Temperature* (SST). For this purpose, thermal heat radiation from the sea surface can be analyzed from the APT-transmission. To calculate SST data, both channels A and B from the APT broadcast are used to create an image in false colors that represent different temperatures [7]. However, this means that the temperature itself is never measured, but only the intensity with which thermal radiation is emitted from the sea surface. This in turn leads to limitations in the method. For example, it is only the outermost surface layer of the water mass that can be analyzed and the thermal radiation can also be blocked or distorted by cloud cover and other atmospheric phenomena. [7].

2.2 Ground station

2.2.1 Antenna theory

To communicate via radio signals, two antennas are needed, one that transmits and one that receives. As a rule, the antenna that transmits and receiver should have similar characteristics to effectively communicate. The type, design and properties of the antennas largely depend on the area of use. To design an antenna for receiving signals from NOAA satellites, here are some aspects to consider:

Frequency describes the number of oscillations per unit of time. For an antenna to be able to receive signals of a certain frequency, its size needs to be adjusted accordingly.

Radiation pattern indicates how focused the antenna is. A wide radiation pattern means that the antenna can receive signals from several different angles and directions. However, antennas with a wide beam pattern usually have weaker signal strength. There are mainly two types of antennas, omnidirectional and directional. As the POES satellites pass over the ground station, this means that the direction to the signal source is continuously changing. To avoid the need to manually or mechanically direct the antenna towards the source throughout the passage, an omnidirectional design [1] is advantageously used.

Polarization is briefly described as the direction in which space the electromagnetic wave oscillates. The NOAA satellites emit a *Right Hand Circular Polarized* (RHCP) signal because it is insensitive to angular differences between the transmitter (rotating satellite in space) and the receiver [12]. To obtain the strongest possible reception, the receiving antenna should also be polarized in the same way, if a linearly polarized antenna is used, a signal loss of 3 dB is generally introduced [8, 1].

Signal strength or *signal to noise-ratio* (SNR) defines the relationship between the strength of the incoming signal and ambient interference. To receive noise-free weather satellite images from POES satellites, a relatively high signal strength of about 20 dB is required.

The design and characteristics of a basic dipole antenna can be seen in figure 1. To adjust the length to a specific frequency on a half-wave dipole antenna, the following equation [14] is used:

$$\text{Length of dipole} = \frac{143}{\text{Frequency [MHz]}} \tag{1}$$

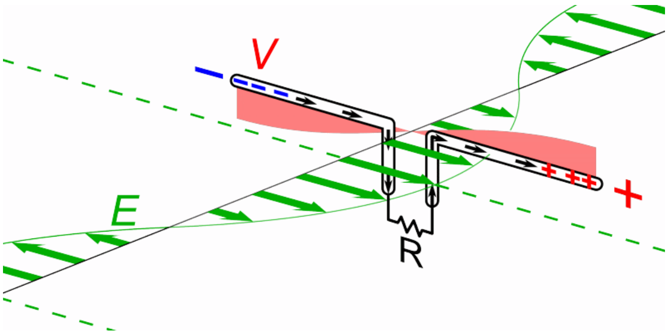


Figure 1: *Sketch of a half-wave dipole receiving a radio signal. Demonstrates the principle that a standing wave is created when the antenna is exposed to an electric field. Retrieved from [4].*

2.3 Sea temperature

The temperature of a water body is determined by several factors. One of the biggest factors is the geographical position and latitude of the sea, water overturn, depth and underwater properties. [3]

In the absolute top layer of the water surface, also known as *sea surface microlayer* (SML), the properties of water differ greatly. The temperature of this layer is affected by many external factors such as air temperature, evaporation, solar and heat radiation [6]. The temperature in the surface layer is, therefore, more sensitive, volatile and unrepresentative of the average temperature of the water mass, also called bulk temperature. Figure 2 illustrates the large differences in temperature for SML and the bulk of water between night and day. The thermal radiation measured by weather satellites comes mainly from SST_{skin} [13].

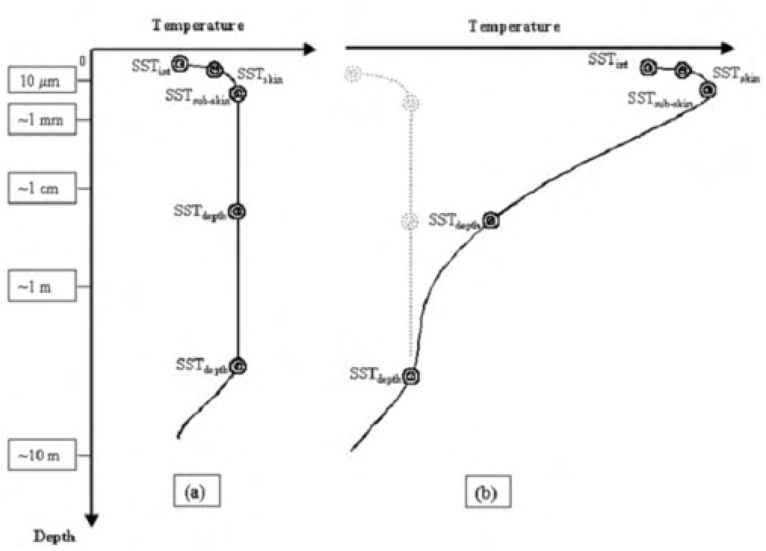


Figure 2: *Difference in sea temperature at different depths during night (a) and day (b).* SST_{int} *is the outermost transition layer between air and water.* SST_{skin} *is a layer down to 500 μm and* $SST_{subskin}$ *down to 1 mm, (not to scale). Received from [2].*

3 Methodology

In order to investigate the conditions and sea temperature development in the Baltic Sea, observations were gathered during nine weeks. The observations were done by decoding and analyzing SST-images independently received from NOAA weather satellites with a simple self-built antenna. This study focuses on quantitative temperature data collected from 28 September to 29 November 2020.

In figure 3 an overview of the method can be seen. The method consisted of three primary steps. The first step was to receive the signal from the satellites. For this, a separate antenna was built for the purpose. The second step was to convert the analog signal to digital that the computer could understand and process. For this, an SDR-receiver was utilized. The third step involved recording, demodulating, decoding, saving and processing the received signal. For this, various programs and also self-developed code were used on a computer.

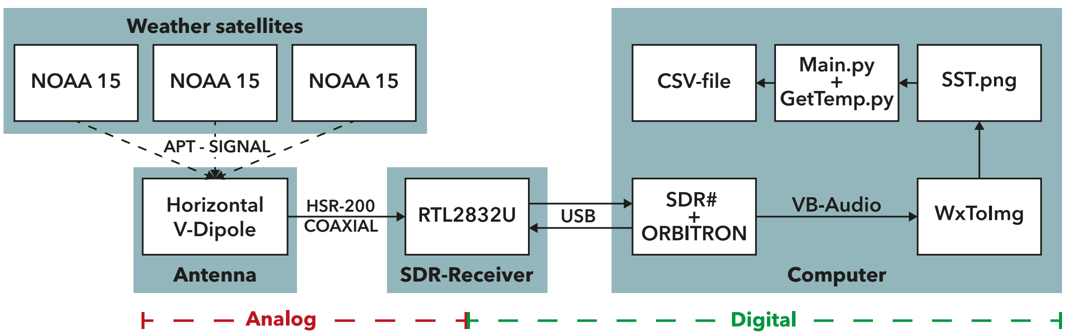


Figure 3: *Block diagram of the satellite SST-image acquisition method.*

3.1 Hardware

The antenna was the first step in the process of collecting the data to determine the sea temperature in the Baltic Sea. To receive signals from the satellites, the antenna needed to be purposefully built to match the characteristics of the signal. Popular types of antenna designs used to receive satellite signals are *Turnstile* and *Quadrifilar Helicoidal* (QFH). Both of these designs are omnidirectional and Right Hand Circular Polarized (RHCP), which matches the transmitted APT-signal's characteristics. However, it is difficult to design a perfectly circularly polarized antenna by yourself and small deviations in the design could lead to a considerable drop in signal strength. A cheaper and simpler, but still equally capable, design was instead a modified *dipole antenna*. Although the dipole antenna was neither circularly polarized nor omnidirectional, it still had the potential to be useful in satellite reception. Receiving a circularly polarized signal with a linearly polarized antenna results in about 3 dB of signal loss, however, this relatively small loss was offset by the simple design of the design. To optimize the reception of weather satellites, the standard dipole was developed into a new *horizontal V* dipole antenna. This partly means a horizontally mounting. Although the strength of the received satellite signal is independent of the orientation, a horizontal position reduces other interference from vertically polarized radio transmissions. In its traditional design, the dipole antenna also had a donut-shaped radiation pattern with weak areas in the axial directions. This is not optimal as the satellites pass in an arc above, from the horizon in the south to the north or vice versa, with different elevations. In order to increase the coverage of the radiation pattern and thus avoid the need to direct the antenna, the antenna arms were bent into a v-shape, hence the "V" in the name. See figure 4

Figure 4: *Assembled antenna construction, secured with cable ties on a balcony.*

To filter and convert the analog signal to digital, a *Software Defined Radio* (SDR) was used.

Specifically, a *RTL-SDR V3* with the A/D-converter *RTL2830U* inside. With a frequency band of 24–1700 MHz, it was optimal for receiving the satellites' signal around 137 MHz. The receiver then converted the analog signal from the antenna to a digital one with a sampling frequency of 48000 Hz and an 8-bit depth that the computer could handle via a USB interface.

The receiver had two connections, an SMA male which was connected to the coaxial cable from the antenna and a USB male who was connected with a USB cable to a computer, see figure 5

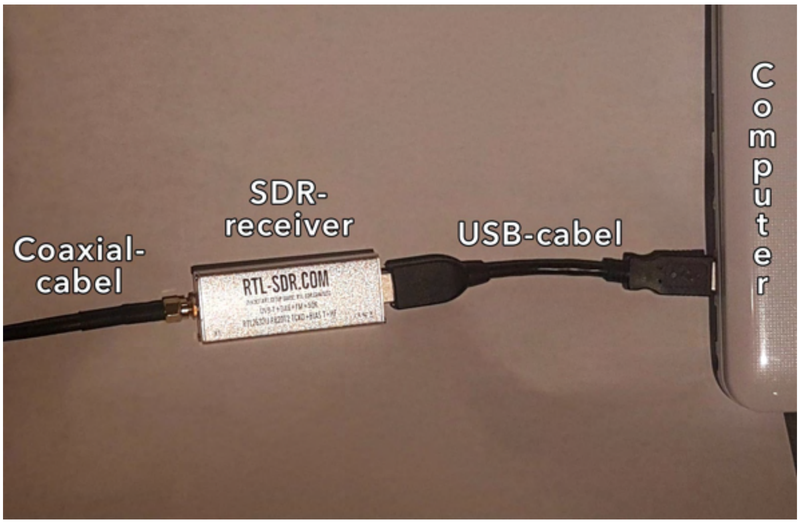


Figure 5: *Connected SDR-receiver.*

3.2 Software

In order to obtain useful information from the raw digital signal, it first had to be processed. This is done by recording, demodulating, decoding and processing the signal in different steps with various programs.

To demodulate and record the signal from the SDR receiver, the program *SDR Sharp* was used, also abbreviated *SDR#*. The SDR program worked in conjunction with the physical SDR receiver to select the exact frequency and modulation, like a fixed analog radio.

To automate the recording process, SDR# was also set up to work in conjunction with *Orbitron*. Orbitron is a satellite positioning tool that, knowing the geographical location of the ground station, provided information on when passages of the selected satellites took place and if the *Doppler effect* affected the signal. This allowed SDR# to calculate the exact time and frequency to autonomously record fly-overs.

Table 1: *The satellites and their respective APT frequencies that Orbitron was set to listen for.*

Satellite	Frequency [Mhz]
NOAA 15	137.6200
NOAA 18	137.9125
NOAA 19	137.1000

The next step was to decode the recorded signal into images. *WxToImg* is an abbreviation for

Weather To Image which was a program that received the recorded signal from SDR Sharp and decoded each transmitted line via the APT format into an image, see figure 6. The program could also interpret the decoded image and create more specific products with information about, for example, precipitation, air temperature and sea surface water temperature, see figure 7 and 8. To link SDR Sharp with WxToImg, the program *VB-CABLE Virtual Audio Device* was used.

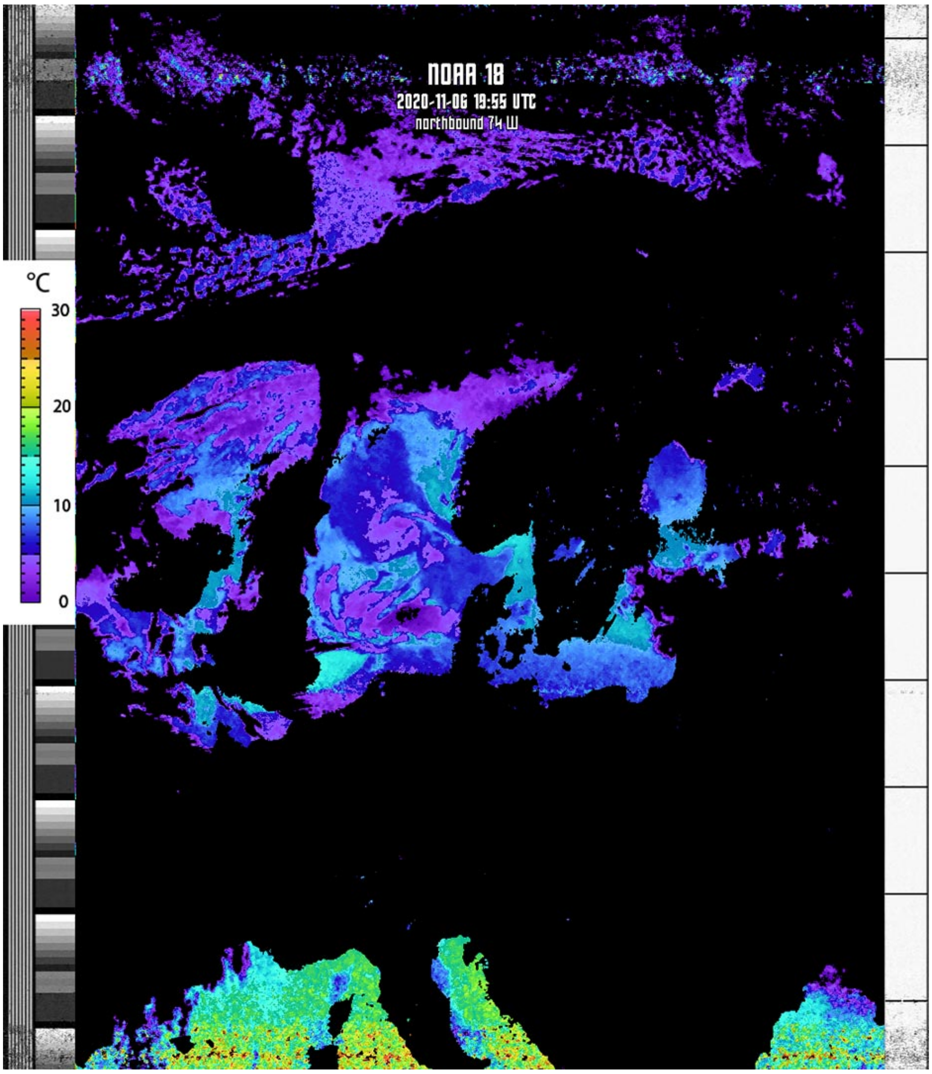


Figure 8: *SEA-enhancement. Black is landmass or cloud cover and the false-color is water of different temperatures (see the scale on the right).*

3.3 Data processing

From WxToImg, the decoded signal was exported as images in a *Portable Network Graphics* (PNG) format. To extract and analyze the temperature information from the decoded images, several scripts were developed in Python, see appendix. All images with extensive noise or insufficient coverage were removed in a manual selection process. To only read the temperature of the Baltic Sea, the images were also cropped manually with an image editing program. All collected data can be seen compiled in this project's GitHub repository, `https://github.com/Vidar-Petersson/Gymnasiearbete`.

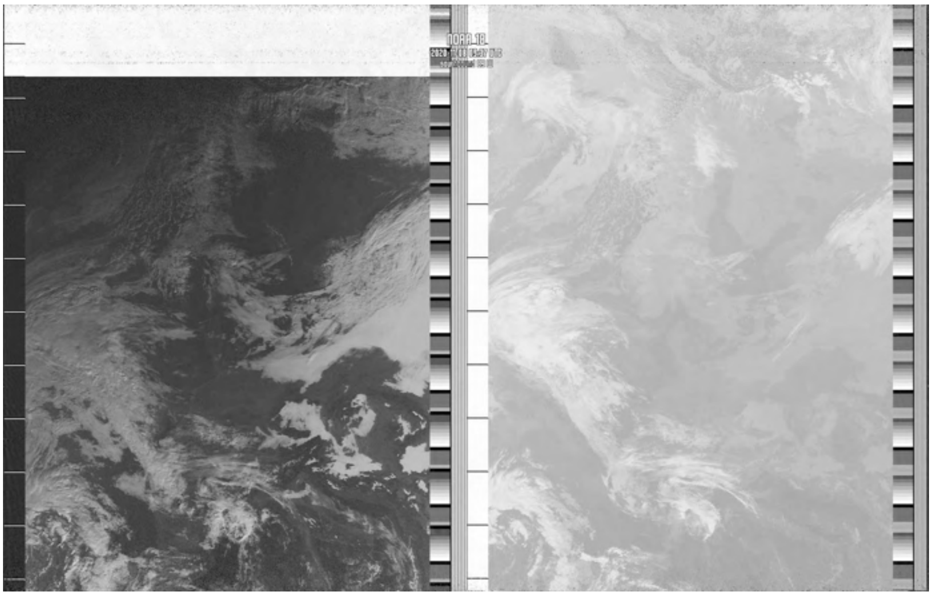


Figure 6: *Normal-enhancement. On the right is Channel A (visible light) and on the left is Channel B (thermal).*

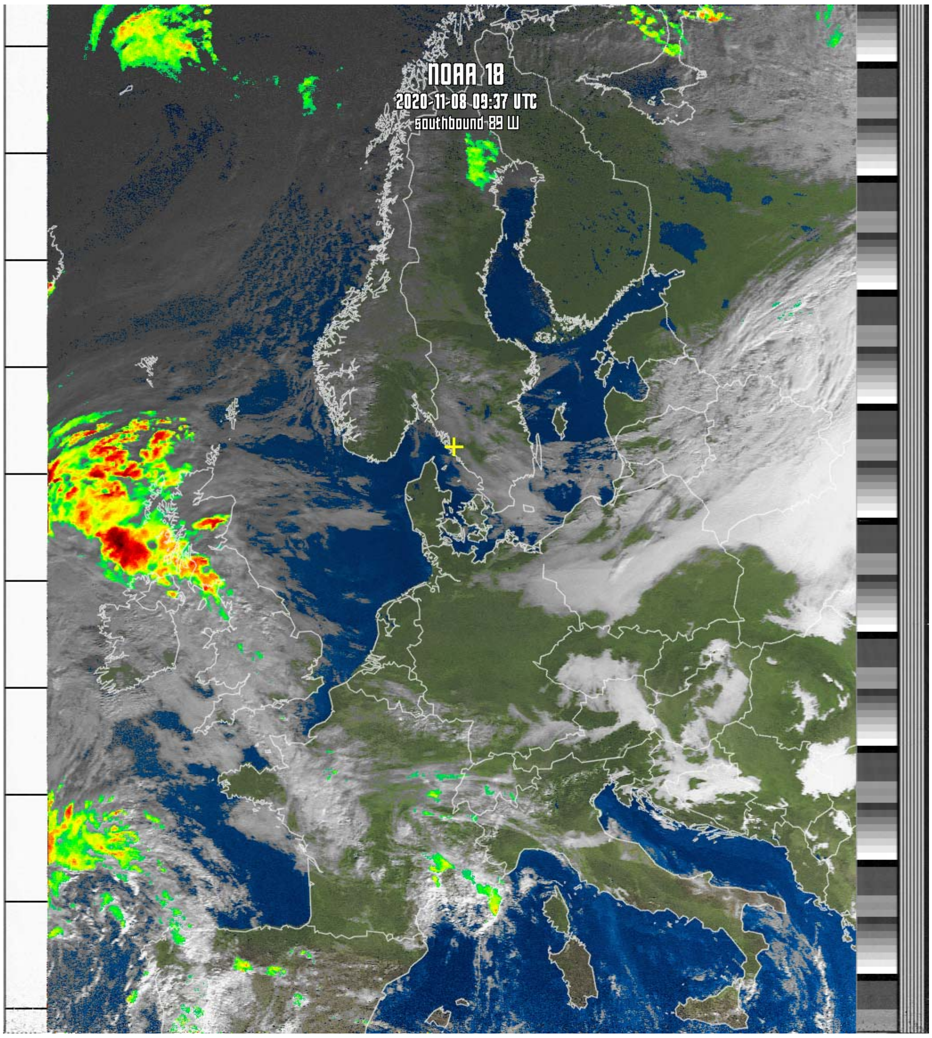


Figure 7: *Multispectral Analysis-enchancement. Clouds are colored white, landmass green and water blue. Borders and precipitation in false-color.*

The image analysis was conducted in two parts. To extract the temperature data from the images, one of the scripts read all the individual pixel values in the image and matched them against the included temperature scale. The resolution was set to 0.1 °C. Thereafter, the script returned the average temperature value of the image and the number of pixels read based on the included pixels. The second part of the image analysis involved extracting related metadata. The date, satellite number and maximum angle of elevation were saved together with the information in the previous step.

3.4 Reference data

One of the main objectives was to validate and compare the collected data to *in situ* observations. To produce relevant reference data that would result in a fair comparison, official observations from SMHI's website were used. SMHI uses, among other things, wave and sea buoys to measure various meteorological conditions at sea. Three of these buoys in different places in the Baltic Sea were selected, see appendix.

Table 2: *SMHI sea buoys utilized to create the reference data.*

SMHI ID	Name	Latitude [°N]	Longitude [°E]
33008	Knolls Grund Buoy	57.5167	17.6167
33002	Huvudskär Ost Buoy	58.9333	19.1667
33003	Finngrundet WR Buoy	60.9	18.6167

3.5 Equipment

Table 3: *Material och cost, including taxes. The market price is based on purchases made during the autumn of 2020 in Sweden*

Equipment	Market price [SEK]
Antenna	
2x Aluminum rundstång Ø4 mm (1 m)	107,8
Choc block terminals 2,5-10 mm^2	39,9
HSR-200 coaxialcable 50 Ω (10 m)	299
Receiver	
RTL-SDR V3	329
Generic Laptop	-
Software	
SDR-Sharp	0
Orbitron	0
VB-Audio cable	0
WxToImg	0
Total cost	**775,7**

4 Results

The survey resulted in a total of 283 observations over a nine-week measurement period, from 28 September to 29 November 2020. All data collected can be seen in the appendix. The collected data is compiled and key observations are reported in this chapter through statistics in the form of figures and tables.

The mean number of observations per day was 4.88 and the standard deviation 2.44. Please note that days, when no observations were made, are not included. On five different days (10, 12 and 21 October and 11 and 12 November) no observations were made due to technical errors.

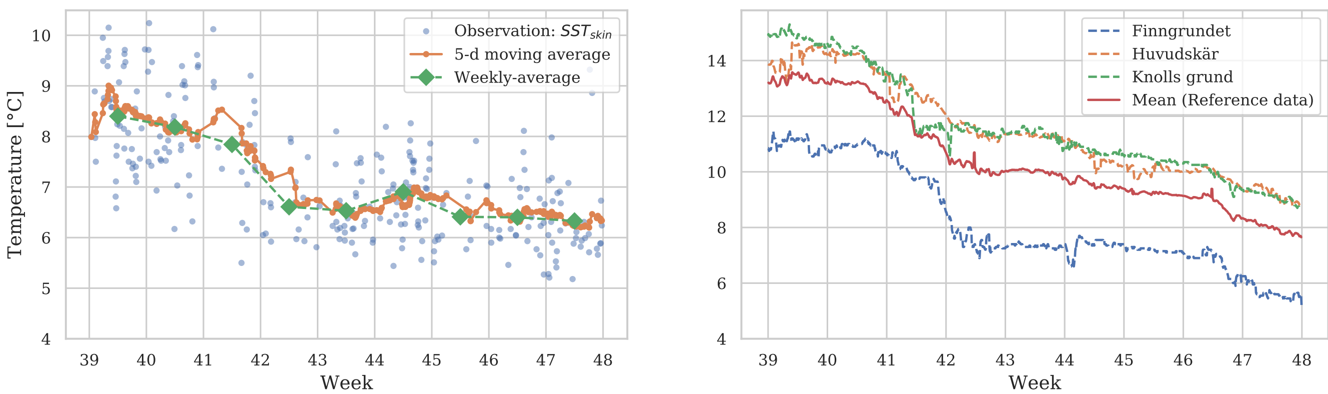
In table 4 a more detailed analysis of the temperature observations can be seen. It is important to note that the values are temperatures from the entire measurement period and do not represent or take into account any development or change over time.

Table 4: *Statistical key values for all temperature observations throughout the time series. All values except N is in °C.*

N	Mean	Std	Min	25 %	50 %	75 %	Max
283	7.16	1.15	5.18	6.23	6.96	7.85	10.24

4.1 Temperature development

The development of the temperature during the measurement period can be seen in figure 9a. Note that the week numbers represent the Monday of each new week. The average temperature between the first and last week decreased by 2.07 °C. In eight of nine examined weeks, there was a decrease in temperature and the average value of the temperature change each week was −0.26 °C. The average value of the temperature change per day was thus −0.035 °C.



(a) *Histogram över antalet observationer per dag.*

(b) *Reference data: Temperature development at a depth of 0.5 meters for the various SMHI buoys.*

Figure 9: *SST development over time. Week numbers marks the Monday in each week.*

A dispersion of the observations can be seen in both figures. In figure 9a all individual values can be seen, the mean value for the standard deviation every day was 0.61 °C.

4.2 Validation of data

The collected data via the self-built ground station were compared with official reference data from SMHI. This is to examine the discrepancy between the collected data and *in situ*. The sea temperature measuring instruments collected temperature observations every hour at a depth of 0.5 meters. In figure 9b the temperature development of the reference data can be seen, also the individual buoys on which the reference data is based.

The mean standard deviation of the temperature each day was 0.07 °C. The weekly average temperature decreased by a total of 5.32 °C from the first to the last week. The mean value for the difference between the mean values each day in the comparison of the observations and the reference data was about 3.35 °C, see figure 10.

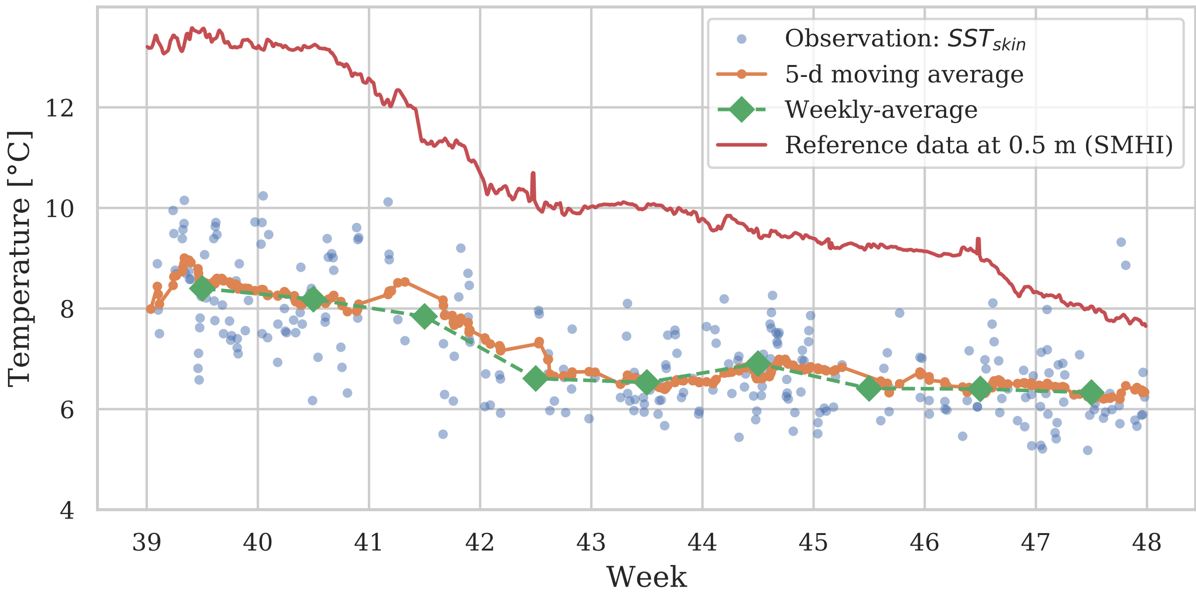


Figure 10: *Comparison of the independent observations and the reference data from SMHI.*

5 Discussion

How did the sea temperature in the Baltic Sea develop during the measurement period? The largest temperature change occurred between weeks 41 and 42, where the temperature dropped by as much as 1.23 °C. This may be due to a cold front drawing in over the area and cooling the surface water relatively quickly. In contrast, however, there is a relatively small temperature change during the period week 42 to 47, with a fairly stable average temperature around 6.5 °C. This may be due to the temperature stabilizing or the method reaching some type of lower limit value.

The relatively large spread of observations makes it inappropriate to study only individual observations and draw conclusions about them. Instead, several observations over time should be used to examine trends in the area. This was also why a five-day rolling average was chosen in figure 9a to more accurately display the development. It is also important to mention that the temperature observed by the satellites is only the absolute surface layer (SST_{skin}) of the ocean that emits infrared radiation. Therefore, the observed sea temperature is not necessarily representative of the bulk temperature.

5.1 Validation of observations

To validate how exactly the observed temperature corresponded to *in situ*, one of the objectives was to compare the observations with official reference data. However, one must be careful not to draw too concrete conclusions about the comparison. The data were collected in two completely different ways and the comparison is not necessarily fair, see the *limitations* section.

In the figure 9b the observations from the three measuring stations used to compile the reference data can be seen. Finngrundet stands out because it has a systematically lower temperature than the other buoys. This is most likely due to Finngrundet's geographical location in the Bothnian Sea. The Bothnian Sea is further north than the other buoys and at the far end of the Baltic Sea, which means less water turnover in the area. This discrepancy between the individual buoys' measured values thus indicates that there is a relatively large natural variation for the sea temperature in the Baltic Sea area.

One of the most noticeable differences between the observed temperature and the reference data is the systematically lower temperature. This is most likely caused by limitations in the method and how the AVHRR instrument analyzes the thermal SST radiation. This is probably due to a bias in the decoding program (WxToImg). During the work, it was noted several times how the program failed to distinguish between visible thin cloud cover and cold water. Another possible explanation is that the AVHRR instrument itself has a lack of calibration, which introduces a bias.

One discovery was the difference in the dispersion of the data. The mean value for the standard deviation over a day was 0.61 °C, in contrast to the reference data's 0.07 °C. There are many probable explanations for this which probably accumulate. One explanation is due to the fact that the satellites only examine the outermost layer (SML) on the water [7]. The temperature in this layer tends to vary [13] considerably due to ambient factors. An additional contributing factor may have been that different areas of the Baltic Sea were observed due to varying cloud cover in each observation. Since the analysis only produces an average value from the SST-image, it did not take into account whether the observed area was in the north or south, which locally have different temperatures. Due to the nature of SST surveys, the time of day may also have played a role in the temperature. The satellite passes, and thus the observations, usually took place in the morning and late afternoon (local time). Observations that took place in the afternoon can be assumed to be warmer because the sun during the day had warmed up the outer SST_{skin} layer. An overly generous selection process of the images may also have contributed to the spread. By analyzing images with a small visible sea surface, local variations may have had a greater impact. However, it should only have caused a few deviating values.

The development otherwise follows much the same character. A relatively sharp decline can be seen around weeks 41 to 42 and then a plateau. Both measurement methods thus follow the same development and are affected by the same trends in temperature. This validates the correctness of the observations even though there is a certain discrepancy.

5.2 Accessibility and applicability

To evaluate whether it is practically feasible and efficient to conduct marine and weather surveys with self-received weather satellite images, two of this project's objectives were: What equipment and resources are required to construct the ground station and how broad are the possible applications to conduct other types of surveys.

The resources required to construct the ground station were minimal. The total cost amounted to just under 800 SEK, which is a negligible expense compared to the costs to launch and operate the satellite system. The availability of the equipment was also great. The only component that needed to be ordered specifically was the SDR-receiver. The rest of the materials such as the antenna construction were all accessible as consumer products that could even be extracted from old electronic waste. The only material that was not included in the cost calculation was the generic laptop that was used to record and save the data from the signal.

Although this paper focuses explicitly on SST and how to analyze its development over time, there is much more information that can be extracted from the received images. The WxToImg decoding program offers various treatments for satellite images, including thermographic mapping, cloud mapping and precipitation. Because different wavelengths are included in the APT-transmission, a multispectral analysis can be conducted, see figure 7. The analyzes provide information about, among other things, cloud cover and precipitation that covers most of Europe. The possibility of being able to receive these more situational images has major uses. By seeing precipitation from above, everything from farmers to fishermen in remote areas without an internet connection can adapt their activities. By comparing several images, the development of precipitation and its direction, a simple forecast can even be compiled.

5.3 Limitations

This in turn leads to limitations in the method. For example, it is only the outermost surface layer of the water mass that can be analyzed and the thermal radiation can also be blocked or distorted by cloud cover and other atmospheric phenomena.

The reference data from SMHI was not necessarily fair to compare the observed data with. The data itself was accurate and validated by SMHI. However, it is problematic to compare the results from the two different measurement methods directly. The two different methods measure the same water temperature but in different ways under completely different circumstances, which makes some discrepancies inevitable. The buoys only measure the temperature in their immediate vicinity, in contrast to this paper's method which tries to measure the entire Baltic Sea area and compile an average value. To try to compensate for the local and geographical temperature deviations, three different buoys were therefore chosen in different parts of the Baltic Sea. The data also came from different water layers, the AVHRR instrument only examined the top layer of the ocean, SST_{skin} while the buoys measure the temperature at a depth of 0.5 meters. As the properties of the temperature differ drastically between these different depths, it is an important aspect to take into account before conclusions are drawn from the comparison of the observations and the reference data.

6 Conclusion

The underlying purpose of this project was to investigate the possibilities of using available satellite technology to achieve the global sub-goals 9.C, 13.3 and 14.A. Previous studies had confirmed the possibility of receiving signals from weather satellites. This work thus aimed to build on their work and develop a simpler antenna design, a novel way of analyzing SST-images and to introduce a practical application of the received data. This was done by building an antenna from scratch with low-cost equipment, configure an autonomous ground station and examine the sea surface temperature and its development in the Baltic Sea for nine weeks. The work resulted in a total of 283 successful observations.

The conclusion regarding the development of temperature derived from the observations was that it dropped as a result of the northern hemisphere leaning away from the sun during the winter months. To then measure how the observed temperature resembled *in situ*, it was compared with official observations from three of SMHI's buoys in the Baltic Sea. In the comparison, three distinct differences were identified. The observations made via satellite had a systematically lower temperature, less temperature change and a larger standard deviation than the reference data taken from the buoys. To explain the difference, the question of what sea temperature is also needed to be answered. As the satellites and buoys measured the temperature by different methods, it became apparent that temperature conditions and properties varied depending on whether surface water temperature from the satellites or the temperature at a depth of 0.5 meters from the buoys were measured. None of them were thus representative of the bulk temperature. The difference in measuring depth, together with certain limitations in the method, was found to be the main factor for the differences.

The conclusion that the surface water temperature in the Baltic Sea area drops during the autumn is not in itself groundbreaking. However, it instead serves as a proof-of-concept that it is indeed possible to conduct research on SST-development over time. However, further studies and more data are needed to determine how well-suited the method is to be able to be used generally in practical and commercial applications. The results of the work show that there is potential for the method to be able to perform scientific investigations, but there are still sources of error and discrepancy in the results that need to be investigated further. With its simple construction, low cost and available materials, however, the ground station presents good potential for possible opportunities to conduct general weather surveys and that it is possible to take advantage of the opportunities weather satellites offer ordinary people.

Potential users of the ground station include farmers, researchers and military operating in developing countries or other remote areas. Because all people share the same sky, everyone can, regardless of where on earth they are, gain access to the same opportunities that this method and weather satellites offer. As the information from the weather satellites is usually available via weather institutions, this method of self-reception is best suited for people without an internet connection or other opportunities to access the information. Being able to get an overview and aerial picture of weather conditions aids them in their planning and resilience to extreme weather. Being able to judge for yourself if a rainy season is on the way could save both harvests and, in the long run, life.

Another important aspect is the democratization of information. By increasing the availability of information and communication equipment in the form of satellite systems, more people can take advantage of the opportunities that weather satellites offer and engage in citizen science. With the method examined in this paper, anyone, students, climate activists and curious minds can themselves be part of the research and receive data from the same instruments used by researchers to study weather and climate change. Increasing the interest and awareness of what causes weather and climate change, as well as its affects, is a global interest for all mankind. Therefore, the democratization of weather and climate surveys is in itself an important step in the work to deal with the challenges of the future.

6.1 Further research

Since this was only a high school project with limited time and resources, there are of course opportunities to further develop this work and build on its results. Several of this paper's results and conclusions that arose in the process have aspects that may be interesting to examine from other perspectives or on a larger scale.

To perform a more representative and fair validation of the observations. Instead of using data collected from buoys, use the official product from the actual satellite system as reference data. This would provide a more honest comparison of the collection method since the official data would then be collected under the same conditions from the same instrument.

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7 Appendix

All related code and data associated with this paper can be accessed at https://github.com/Vidar-Petersson/Gymnasiearbete

All reference data was gathered from: https://www.smhi.se/data/oceanografi/ladda-ner-oceanogra param=seatemperature,stations=period,selectedDate=2020-11-29.