METEOROLOGICAL SATELLITE : SENSING PRINCIPLES, DATA COLLECTION AND ANALYSIS

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ICITC
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New Delhi

CERTIFICATE

This is to certified that the project report title "**Meteorological satellite : sensing principles, data collection and analysis**" is work done by Mr.YOUNKAP NINA Duplex, Air Traffic Controller - MEng Degree in Computer Science, IMD Advance Training in Meteorological Instrumentation & Information System Batch No. IX, ICITC. Under my supervision.

I recommend the project report for submission.

Place : Garoua
Date :

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INTRODUCTION

Weather monitoring and forecasting was one of the first civilian applications of satellite remote sensing, dating back to the first true weather satellite, TIROS-1 launched in 1960 by the United States. Several other weather satellites were launched over the next five years, in near-polar orbits, providing repetitive coverage of global weather patterns. In 1966, National Aeronautics and Space Administration (NASA) launched the geostationary Applications Technology Satellite (ATS-1) which provided hemispheric images of the Earth's surface and cloud cover every half hour. For the first time, the development and movement of weather systems could be routinely monitored. Today, several countries (India, China, Russia, Japan) operate weather, or meteorological satellites to monitor weather conditions around the globe. Generally speaking, these satellites use sensors which have fairly coarse spatial resolution (when compared to systems for observing land) and provide large areal coverage. Their temporal resolutions are generally quite high, providing frequent observations of the Earth's surface, atmospheric moisture, and cloud cover, which allows for near continuous monitoring of global weather conditions, and hence forecasting.

The current project report **Meteorological satellite : Sensing principles, data collection and analysis** is structured as outlined below.

The first chapter is a brief overview of processes and steps involve in satellite remote sensing.

The second chapter is a case study, we choose GOES-R series satellites, which cover East Africa countries and is used by meteorologists for weather monitoring and forecasting.

The third chapter deals about different ways to access GOES-R series data and visualise a single image band.

The fourth chapter covers satellite data analysis, we will process three hours satellite data from GLDAS and compare with data obtained from direct observation at aviation meteorolgical stations.

The fith chapter presents the results and interpretation that we can derive from our analysis.

Satellite data are large amount of data, so analysis requires computer hardware with good capabilities, softwares and programming skills.

For completion of the current work, we use the following tools:

Computer harward: HP Probook, Intel R Core i5, RAM 16 GB.

Operating systems : Ubuntu 20.04.4

Processing : GRASS GISS 7.8 with bash script for worklow automation.

Visualisation : python 3.8 and QGIS 16 LTR.

BASIC PRINCIPLES OF SATELLITE REMOTE SENSING

1.1 Definition

Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analysing, and applying that information.

In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven steps are involved. However that remote sensing also involves the sensing of emitted energy and the use of non-imaging sensors.

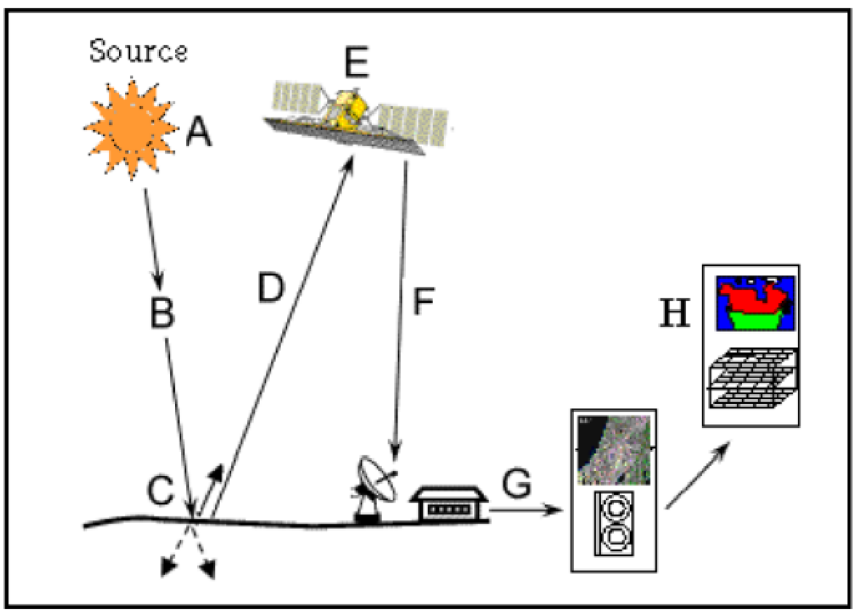


Figure 1.1: Remote sensing process

Step 1-Energy Source or Illumination (A) : the first requirement for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.

Step 2-Radiation and the Atmosphere (B) : as the energy travels from its source to the target, it will come in contact with and interact with the atmosphere it passes through. This interaction may take place a second time as the energy travels from the target to the sensor.

Step 3-Interaction with the Target (C) : once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.

Step 4-Recording of Energy by the Sensor (D) : after the energy has been scattered by, or emitted from the target, we require a sensor (remote - not in contact with the target) to collect and record the electromagnetic radiation.

Step 5-Transmission, Reception, and Processing (E) : the energy recorded by the sensor has to be transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).

Step 6-Interpretation and Analysis (F) the processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.

Step 7-Application (G) the final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

1.2 Electromagnetic Spectrum

Solar radiation can be divided into different wavelengths call Electromagnetic spectrum as depicted by the figure below.

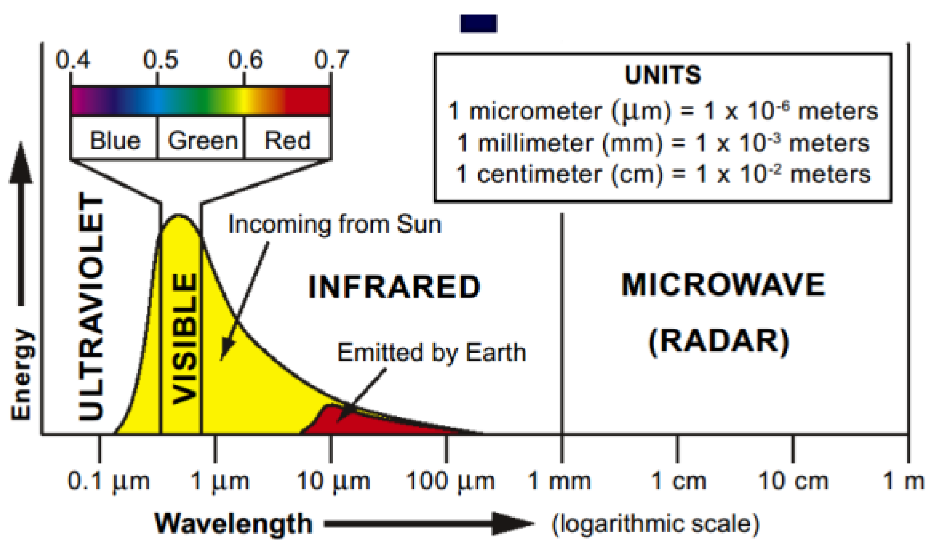


Figure 1.2: Electromagnetic spectrum

Most Multispectral satellite can acquire data in visible and infrared region (including the thermal infrared region). Nowdays there is an increasing demand for data in microwaves region, because the microwave energy can penetrate through the cloud.

1.3 Source of radiation

We have two major source of radiation: the sun and the earth.
The **sun** is the mayor source of radiation with highest energy in visible, near infrared and short-wave infrared region.
The **earth surface** can also emit energy usually in thermal Infrared and microwaves region.

1.4 Interaction in the atmosphere

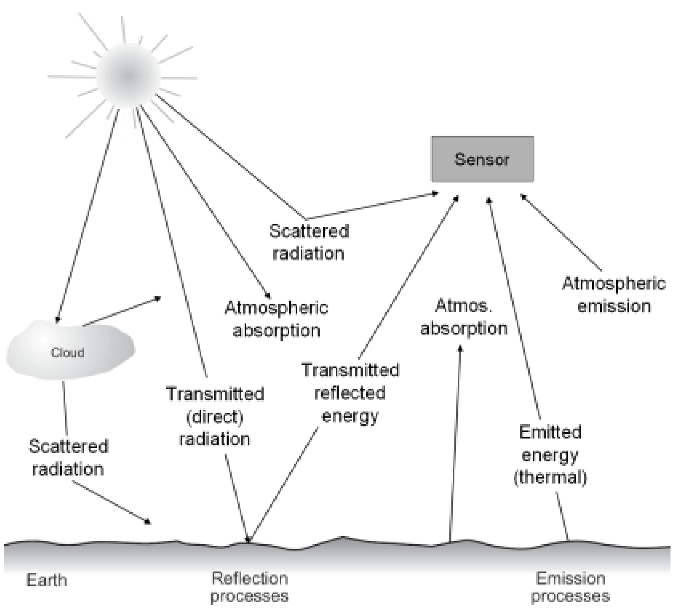


Figure 1.3: radiance at the sensor

Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere. Different processes occur due to the presence of particles and gases in the atmosphere. Some get **scattered**, some get **absorbed**, some managed to transmit through the atmosphere and get **absorbed** by the earth, and some get **reflected** . This reflected energy is captured by the sensor on board a satellite. The earth equally emits energy, the amount of energy emitted is directly proportional to the heat level of the part of the earth that emit it. This emitted energy can also be recorded by sensors on board a satellite if that sensor has capabilities to record energy in thermal infrared region. A sensor on board a satellite can record **re-mitted** or **reflected** radiation depending on the capabilities of the sensors.

Chapter 2

CASE STUDY: GOES-R Series

2.1 GOES project current status

The Geostationary Operational Environmental Satellite Program (GOES) is a joint effort of NASA and the National Oceanic and Atmospheric Administration (NOAA). The GOES system currently consists of GOES-13, operating as GOES-East, in the eastern part of the constellation at 75 degrees west longitude and GOES-15, operating as GOES-West, at 135 degrees west longitude. The GOES-R series will maintain the two-satellite system implemented by the current GOES series. However, the locations of the operational GOES-R satellites will be 75 degrees west longitude and 137 degrees west longitude. The latter is a shift in order to eliminate conflicts with other satellite systems. The GOES-R series operational lifetime extends through December 2036. These spacecraft help meteorologists observe and predict local weather events, including thunderstorms, tornadoes, fog, hurricanes, flash floods and other severe weather. In addition, GOES observations have proven helpful in monitoring dust storms, volcanic eruptions and forest fires.The benefits that directly enhance the quality of human life and protection of Earth's environment include:

- Supporting the search-and-rescue satellite aided system (SARSAT).
- Contributing to the development of worldwide environmental warning services and enhancements of basic environmental services.
- Improving the capability for forecasting and providing real-time warning of solar disturbances.
- Providing data that may be used to extend knowledge and understanding of the atmosphere and its processes.

The next series of GOES satellites includes GOES-R, S, T and U.

2.2 GOES-R Series Instruments

GOES-R Series has six instruments on board:

Earth-pointing :

- Advanced Baseline Imager (ABI) - the primary instrument for imaging Earth's weather, oceans and environment.
- Geostationary Lightning Mapper (GLM) - a single-channel, near-infrared optical transient detector that can identify momentary changes in an optical scene, indicating the presence of lightning.

Sun-pointing :

- Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) - monitors solar irradiance in the upper atmosphere using two primary sensors: the Extreme Ultraviolet Sensor (EUVS) and the X-Ray Sensor (XRS).
- Solar Ultraviolet Imager (SUVI) - a telescope that monitors the sun in the extreme ultraviolet wavelength range, detecting solar flares and solar eruptions, and compiling full disk solar images.

In-situ :

- Magnetometer (MAG) - measures the space environment magnetic field that controls charged particle dynamics in the outer region of the magnetosphere
- Space Environment In-Situ Suite (SEISS) - monitors proton, electron, and heavy ion fluxes in the magnetosphere using four sensors: the Energetic Heavy Ion Sensor (EHIS), the High and Low Magnetospheric Particle Sensors (MPS-HI and MPS-LO), and the Solar and Galactic Proton Sensor (SGPS).

Only two sensors are used for atmospheric purpose, Advanced Baseline Imager (ABI) and Geostationary Lightning Mapper (GLM).

2.3 Advanced Baseline Imager (ABI)

ABI is a multi-channel passive imaging radiometer that images Earth's weather, oceans and environment with 16 spectral bands (2 visible, 4 near-infrared, and 10 infrared channels).

ABI Band	Central Wavelength(µm)	Type	Nickname	Best Spatial Resolution
1	0.47	Visible	Blue	1
2	0.64	Visible	Red	0.5
3	0.86	Near-Infrared	Veggie	1
4	1.37	Near-Infrared	Cirrus	2
5	1.6	Near-Infrared	Snow/Ice	1
6	2.2	Near-Infrared	Cloud particle size	2
7	3.9	Infrared	Shortwave window	2
8	6.2	Infrared	Upper-level water vapor	2
9	6.9	Infrared	Midlevel water vapor	2
10	7.3	Infrared	Lower-level water vapor	2
11	8.4	Infrared	Cloud-top phase	2
12	9.6	Infrared	Ozone	2
13	10.3	Infrared	"Clean" longwave window	2
14	11.2	Infrared	Longwave window	2
15	12.3	Infrared	"Dirty" longwave window	2
16	13.3	Infrared	CO_2 longwave	2

Schmit, T. J., S. S. Lindstrom, J. J. Gerth, M. M. Gunshor, 2018. Applications of the 16 spectral bands on the Advanced Baseline Imager (ABI) J. Operational Meteor., 6 (4), 33-46.

Figure 2.1: ABI optical components

2.4 ABI modes of operation

ABI has four modes of operation.

Full Disk : Hemispheric Coverage of 83° local zenith angle, temporal resolution of 5-15 minutes, and spatial resolution of 0.5 to 2km.

Mesoscale : Provides coverage over a 1000x1000km box with a temporal resolution of 30 seconds, and spatial resolution of 0.5 to 2km.

Continental US/Pacific US : The CONUS and PACUS scans are performed every five minutes, providing coverage of the 5000km (east/west) and 3000km (north/south) rectangle over the continental United States (GOES-16) or the Pacific Ocean, including Hawaii (GOES-17). The spatial resolution is 0.5 to 2km.

Flex Modes : The flex modes provide a full disk scan every 10 minutes (mode 6) or every 15 minutes (mode 3), a CONUS/PACUS every five minutes, and two mesoscale domains every 60 seconds (or one sub-region every 30 seconds).

2.5 GOES-R Data Products

GOES-R Data products have three levels.

Level 0 (L0) : are observation data received directly from the 6 satellite instruments. The data is not meaningful to most users prior to processing by the ground system.

Level 1b (L1b) : are calibrated and, where applicable, geographically corrected, L0 data. This means that the data has been processed so that its values are in standard units of physical quantities. For ABI, the L1b product is Radiances. This is useful for users who require radiance units, instead of reflectance/brightness temperature (Kelvin) units. All of the instruments have L1b products available except GLM, which is only distributed as an L2+ product.

Level 2+ Products : contain environmental physical qualities, such as cloud top height or land surface temperature. Aside from the GLM Lightning Detection Product, the data source for these products is the ABI L1b data.

2.6 ABI meteorological product

The mission-critical ABI product is Cloud and Moisture Imagery (CMI), which utilizes all 16 ABI spectral bands, and is used to generate an array of products aiding forecasters in monitoring and predicting weather hazards. The following is a list ABI meteorological and space weather data products that are available to the user community.

- Aerosol detection (including smoke and dust)
- Aerosol optical depth (AOD)
- Aerosol particle size
- Clear sky masks
- Cloud layers/heights
- Cloud and moisture imagery
- Cloud optical depth
- Cloud particle size distribution

- Cloud top height
- Cloud top phase
- Cloud top pressure
- Cloud top temperature
- Derived motion winds
- Derived stability indices
- Downward shortwave radiation: surface
- Fire/hot spot characterization
- Hurricane intensity estimation
- Land surface albedo
- Land surface bidirectional reflectance factor
- Land surface temperature (skin)
- Legacy vertical moisture profile
- Legacy vertical temperature profile
- Radiances
- Rainfall rate/QPE
- Reflected shortwave radiation: TOA
- Sea and lake ice: age
- Sea and lake ice: concentration
- Sea and lake ice: motion
- Sea surface temperature (skin)
- Snow cover
- Total precipitable water
- Volcanic ash: detection and height

Chapter 3

GOES-R SERIES DATA COLLECTION AND VISUALISATION

3.1 Acces GOES-R series data files

This section describes few approaches to access, download and visualise data from GOES-R series satellites.

3.1.1 Access data files from NOAA CLASS

- The NOAA Comprehensive Large Array-data Stewardship System (CLASS) repository is the official site for accessing all available GOES-R Series Products.
- A similar but easier website to navigate is NCEI's Archive Archive Information Request System (AIRS).

3.1.2 Access data files from Amazon, Microsoft, OCC

- Amazon Web Service (AWS) - ABI L1b and L2+, GLM L2+, and SUVI L1b products are available in AWS S3 Buckets. These open datasets can be accessed by the public from AWS for free.
- Microsoft Azure - Two GOES-16 ABI Full Disk products are stored in a Azure blob container. The products currently available are L1b Radiances and L2+ MCMI, which can be accessed from Azure for free.
- Open Commons Consortium (OCC) - Stores a 100 TB rolling archive of GOES-16 data (˜8 months), the products stored are ABI L1b and ABI L2+ CMI and MCMI. OCC recommends using the AWS CLI or the python boto library, to access the data.

3.1.3 Access data files from Google Cloud

- Google Cloud - ABI L1b and L2+, GLM L2+, and SUVI L1b products are available in two different buckets for GOES-16 and GOES-17.
- Google Earth Engine (GEE) - A cloud-based platform for geospatial analysis. This service runs through Google Cloud, and pulls GOES-R datasets from the Google Cloud buckets.

3.1.4 Use Python to retrieve data from AWS

Python is the most powerful programming language using in data science and geospatial data analysis. The following sample scripts demonstrate how to retrieve GOES-R files from AWS using Python.

```python
from goespy.Downloader import ABI_Downloader
### to use ABI_Downloader, you need 7 arguments:
import datetime as dt
### Getting the current date (in UTC coordinate)
utcDateTime = dt.datetime.utcnow()
## current year
year = utcDateTime.strftime("%Y")
# current month
month = utcDateTime.strftime("%m")
## current day
day = utcDateTime.strftime("%d")
## current hour in UTC
hour = utcDateTime.strftime("%H")
##Choose a channel from your preference (can be C01-C16)
channel = ["C01"]
## In GOES satellite they have 9 products
## 3 are L1b-Rad(M,C,F)
## 3 are L2-CMIP(M,C,F)
## 3 are L2-MCMIP(M,C,F)
### In your case we will get the CMIPF, F means FullDisk (all the projection by the satellite)
product = 'L1b-L2-CMIPF'
## The Bucket is the variable contains the name of dataset server from goes on AWS
Bucket = 'noaa-goes16' ## in the future on AWS they will have goes17.
## Now we will call the function ABI_Downloader:
Abi = ABI_Downloader('noaa-goes16',year,month,day,hour,product,channel)
```

After all the dataset is downloaded, they are in your home directory with that structure:

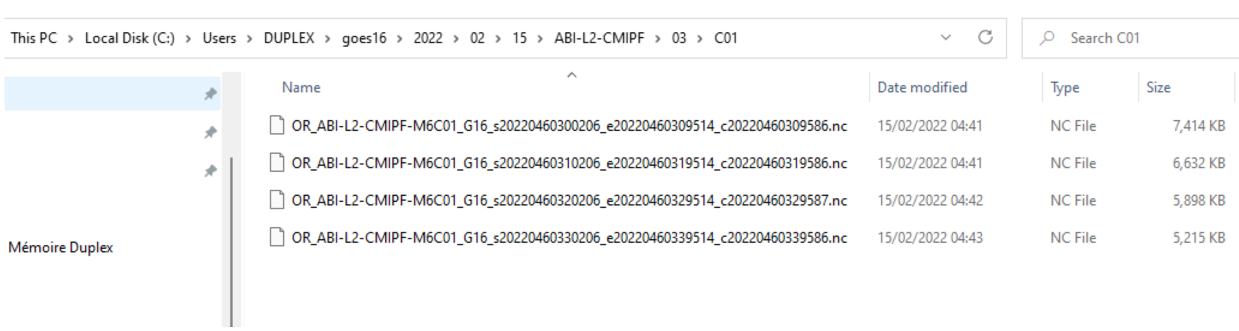


Figure 3.1: L1b-L2-CMIPF product downloaded

3.2 GOES-R Series metadata discovery

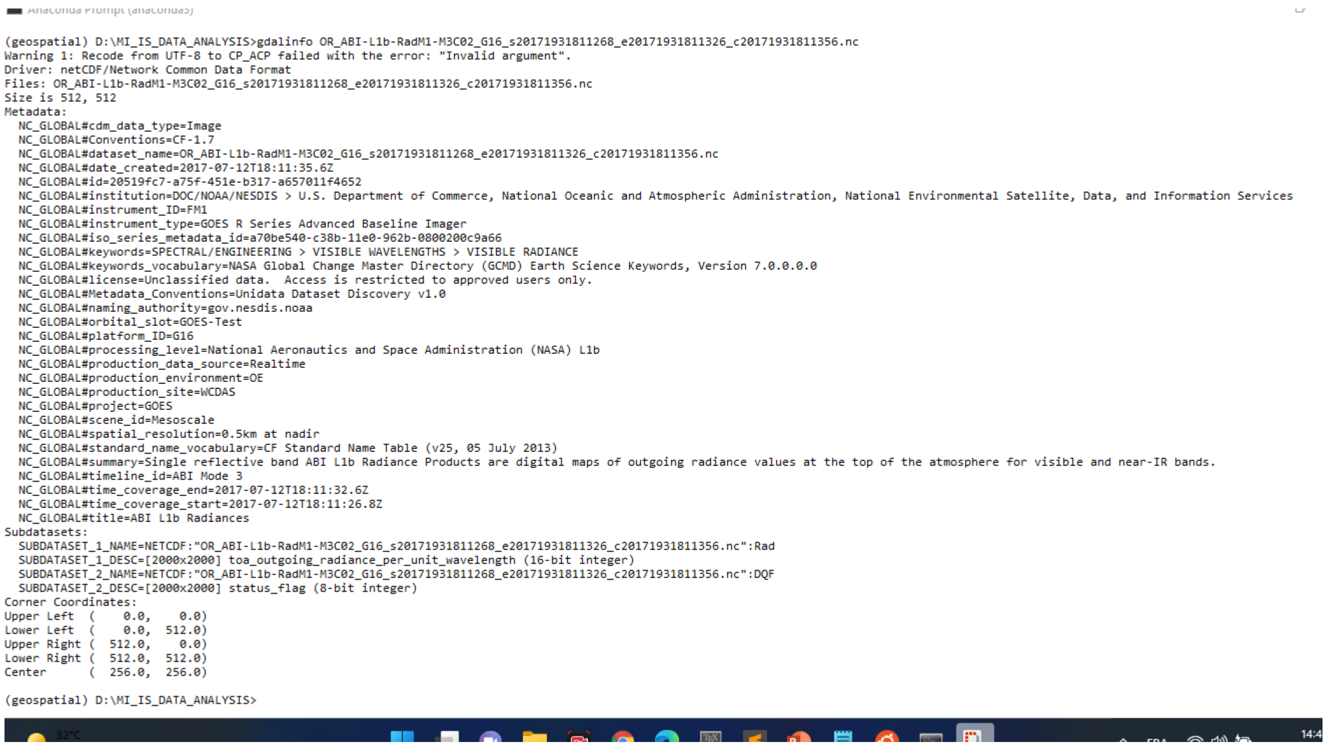
3.2.1 GOES-R Series data format

GOES-R Series product files use the netCDF-4 format. Network Common Data Form (NetCDF) is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. It is also a community standard for sharing scientific data.

3.2.2 Read GOES-R Series data metadata

Metadata provides information about the distinct items, such as: means of creation, purpose of the data, time and date of creation, creator or author of data, placement on a network (electronic form) where the data was created, what standards used etc. The main purpose of metadata is to facilitate in the discovery of relevant information, more often classified as resource discovery. Metadata also helps organize electronic resources, provide digital identification, and helps support archiving and preservation of the resource. Before any manipulation of data, it is vitaly important to read metadata. Now let us see how to read the metadata of this satellite data file in command line using gdal tools.

```
## change directory to where you have downloaded the GLDAS data using the below
cd /mnt/d/MI_IS_DATA_ANALYSIS
## extatract metadata of the 'OR_ABI-L1b-RadM1-M3C02_G16_s20171931811268_e20171931811326_c20171931811356.nc'
gdalinfo OR_ABI-L1b-RadM1-M3C02_G16_s20171931811268_e20171931811326_c20171931811356.nc
## press enter
```



```
Anaconda Prompt (anaconda3)

(geospatial) D:\MI_IS_DATA_ANALYSIS>gdalinfo OR_ABI-L1b-RadM1-M3C02_G16_s20171931811268_e20171931811326_c20171931811356.nc
Warning 1: Recode from UTF-8 to CP_ACP failed with the error: "Invalid argument".
Driver: netCDF/Network Common Data Format
Files: OR_ABI-L1b-RadM1-M3C02_G16_s20171931811268_e20171931811326_c20171931811356.nc
Size is 512, 512
Metadata:
  NC_GLOBAL#cdm_data_type=Image
  NC_GLOBAL#Conventions=CF-1.7
  NC_GLOBAL#dataset_name=OR_ABI-L1b-RadM1-M3C02_G16_s20171931811268_e20171931811326_c20171931811356.nc
  NC_GLOBAL#date_created=2017-07-12T18:11:35.6Z
  NC_GLOBAL#id=20519fc7-a75f-451e-b317-a657011f4652
  NC_GLOBAL#institution=DOC/NOAA/NESDIS > U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Services
  NC_GLOBAL#instrument_ID=FM1
  NC_GLOBAL#instrument_type=GOES R Series Advanced Baseline Imager
  NC_GLOBAL#iso_series_metadata_id=a70be540-c38b-11e0-962b-0800200c9a66
  NC_GLOBAL#keywords=SPECTRAL/ENGINEERING > VISIBLE WAVELENGTHS > VISIBLE RADIANCE
  NC_GLOBAL#keywords_vocabulary=NASA Global Change Master Directory (GCMD) Earth Science Keywords, Version 7.0.0.0.0
  NC_GLOBAL#license=Unclassified data.  Access is restricted to approved users only.
  NC_GLOBAL#Metadata_Conventions=Unidata Dataset Discovery v1.0
  NC_GLOBAL#naming_authority=gov.nesdis.noaa
  NC_GLOBAL#orbital_slot=GOES-Test
  NC_GLOBAL#platform_ID=G16
  NC_GLOBAL#processing_level=National Aeronautics and Space Administration (NASA) L1b
  NC_GLOBAL#production_data_source=Realtime
  NC_GLOBAL#production_environment=OE
  NC_GLOBAL#production_site=WCDAS
  NC_GLOBAL#project=GOES
  NC_GLOBAL#scene_id=Mesoscale
  NC_GLOBAL#spatial_resolution=0.5km at nadir
  NC_GLOBAL#standard_name_vocabulary=CF Standard Name Table (v25, 05 July 2013)
  NC_GLOBAL#summary=Single reflective band ABI L1b Radiance Products are digital maps of outgoing radiance values at the top of the atmosphere for visible and near-IR bands.
  NC_GLOBAL#timeline_id=ABI Mode 3
  NC_GLOBAL#time_coverage_end=2017-07-12T18:11:32.6Z
  NC_GLOBAL#time_coverage_start=2017-07-12T18:11:26.8Z
  NC_GLOBAL#title=ABI L1b Radiances
Subdatasets:
  SUBDATASET_1_NAME=NETCDF:"OR_ABI-L1b-RadM1-M3C02_G16_s20171931811268_e20171931811326_c20171931811356.nc":Rad
  SUBDATASET_1_DESC=[2000x2000] toa_outgoing_radiance_per_unit_wavelength (16-bit integer)
  SUBDATASET_2_NAME=NETCDF:"OR_ABI-L1b-RadM1-M3C02_G16_s20171931811268_e20171931811326_c20171931811356.nc":DQF
  SUBDATASET_2_DESC=[2000x2000] status_flag (8-bit integer)
Corner Coordinates:
Upper Left  (    0.0,    0.0)
Lower Left  (    0.0,  512.0)
Upper Right (  512.0,    0.0)
Lower Right (  512.0,  512.0)
Center      (  256.0,  256.0)

(geospatial) D:\MI_IS_DATA_ANALYSIS>
```

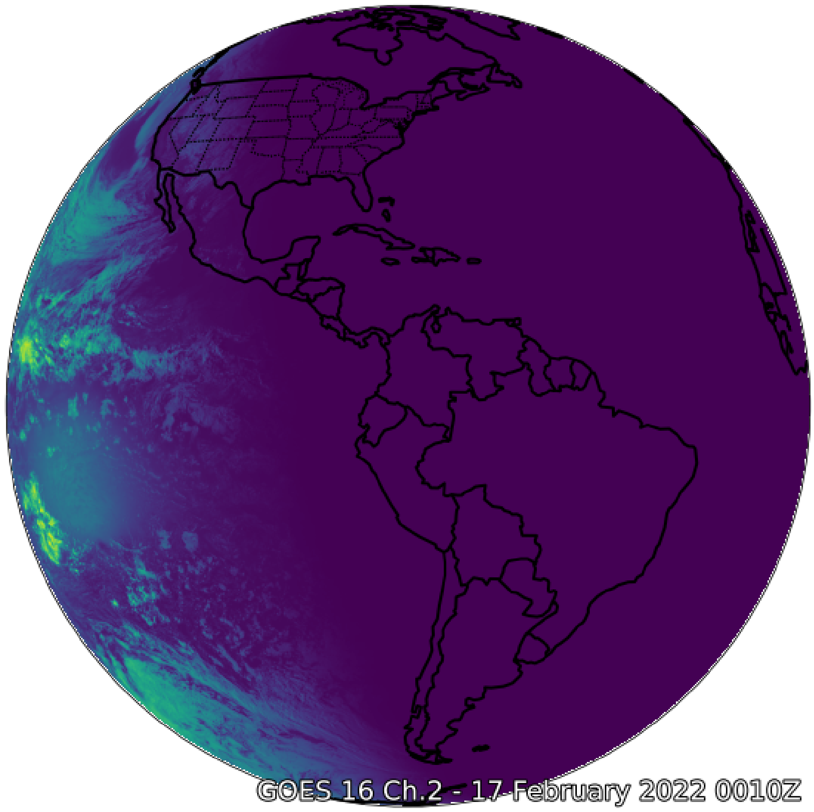
Figure 3.2: GOES-R Series metadata discovery

3.3 Visualise a single band ABI Channel image

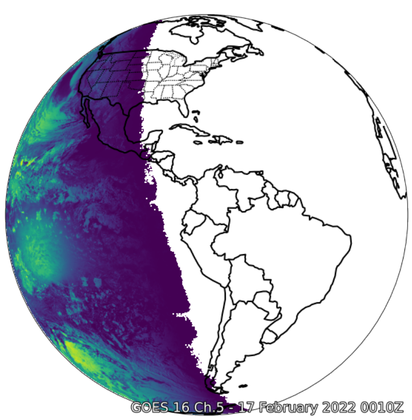
ABI imager has 16 channels, the code below show how to plot a single band ABI channel image.

```python
def open_dataset(date, channel, idx, region):
    """
    Open and return a netCDF Dataset object for a given date, channel, and image index
    of GOES-16 data from THREDDS test server.
    """
    cat = TDSCatalog('https://thredds.ucar.edu/thredds/catalog/satellite/goes/east/products/'
                     f'CloudAndMoistureImagery/{region}/Channel{channel:02d}/{date:%Y%m%d}/catalog.xml')
    ds = cat.datasets[idx]
    ds = ds.remote_access(use_xarray=True)
    return ds
def plot_GOES16_channel(date, idx, channel, region):
    """
    Get and plot a GOES 16 data band from the ABI.
    """
    ds = open_dataset(date, channel, idx, region)
    dat = ds.metpy.parse_cf('Sectorized_CMI')
    proj = dat.metpy.cartopy_crs
    x = dat['x']
```

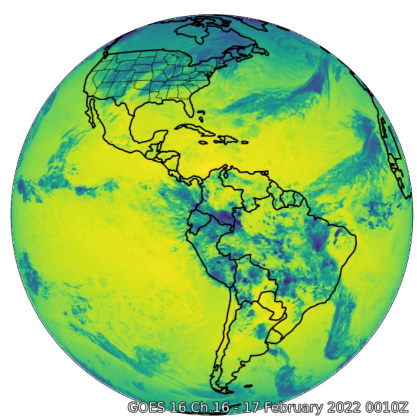
```
    y = dat['y']
    fig = plt.figure(figsize=(10, 10))
    ax = fig.add_subplot(1, 1, 1, projection=proj)
    ax.add_feature(cfeature.COASTLINE, linewidth=2)
    ax.add_feature(cfeature.STATES, linestyle=':', edgecolor='black')
    ax.add_feature(cfeature.BORDERS, linewidth=2, edgecolor='black')
    for im in ax.images:
        im.remove()
    im = ax.imshow(dat, extent=(x.min(), x.max(), y.min(), y.max()), origin='upper')
    timestamp = datetime.strptime(ds.start_date_time, '%Y%j%H%M%S')
    add_timestamp(ax, time=timestamp, high_contrast=True,
                  pretext=f'GOES 16 Ch.{channel} - ',
                  time_format='%d %B %Y %H%MZ', y=0.01,
                  fontsize=18)
    display(fig)
    plt.savefig("goes_fulldisk_C1.png")
    plt.close()
channel_list = {u'1 - Blue Band 0.47 \u03BCm': 1,
                u'2 - Red Band 0.64 \u03BCm': 2,
                u'3 - Veggie Band 0.86 \u03BCm': 3,
                u'4 - Cirrus Band 1.37 \u03BCm': 4,
                u'5 - Snow/Ice Band 1.6 \u03BCm': 5,
                u'6 - Cloud Particle Size Band 2.2 \u03BCm': 6,
                u'7 - Shortwave Window Band 3.9 \u03BCm': 7,
                u'8 - Upper-Level Tropo. WV Band 6.2 \u03BCm': 8,
                u'9 - Mid-Level Tropo. WV Band 6.9 \u03BCm': 9,
                u'10 - Low-Level WV Band 7.3 \u03BCm': 10,
                u'11 - Cloud-Top Phase Band 8.4 \u03BCm': 11,
                u'12 - Ozone Band 9.6 \u03BCm': 12,
                u'13 - Clean IR Longwave Band 10.3 \u03BCm': 13,
                u'14 - IR Longwave Band 11.2 \u03BCm': 14,
                u'15 - Dirty Longwave Band 12.3 \u03BCm': 15,
                u'16 - CO2 Longwave IR 13.3 \u03BCm': 16}
region = Select(
    options=['Mesoscale-1', 'Mesoscale-2', 'CONUS', 'PuertoRico', 'FullDisk'],
    description='Region:',)

channel = Dropdown(options=channel_list,value=16,description='Channel:',)

interact(plot_GOES16_channel, date=fixed(date), idx=fixed(-2),
         channel=channel, region=region)
```



(a) ABI channel 1 image full disk



(b) ABI channel 5 image full disk



(c) ABI channel 16 image full disk

Figure 3.3: ABI images full disk

CHAPTER 4

SATELLITE DATA ANALYSIS

The main objective of this analysis is to process satellite data and compare with data obtained from aviation meteorolgical stations. Here we will use the three hour data from GLDAS.

4.1 Aviation meteorological stations in cameroon

Table 4.1: Aviation meteorological stations

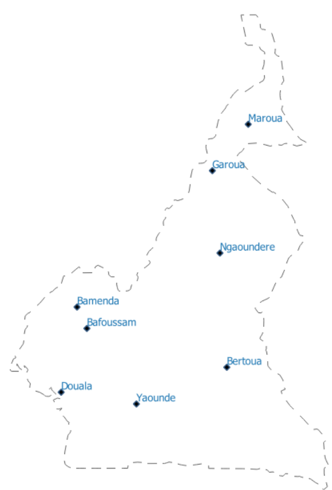


Figure 4.1: aviation meteorological stations

NAME	OMM CODE	ICAO CODE	LATITUDE	LONGITUDE
Yaounde	64950	FKYS	03°50’N	011°31E
Douala	64910	FKKD	04°00’N	009°44’E
Garoua	64860	FKKR	09°20N	013°23’E
Maroua	64851	FKKL	10°27’N	14°15’E
Bafoussam	64894	FKKU	05°32’05N	010°21’15E
Bertoua	64930	FKKO	04°36’N	013°44’E
Bamenda	64892	FKKV	06°03’N	010°07’E

4.2 GLDAS data

The goal of the Global Land Data Assimilation System (GLDAS) is to ingest satellite- and ground-based observational data products, using advanced land surface modeling and data assimilation techniques, in order to generate optimal fields of land surface states and fluxes (Rodell et al., 2004a). GLDAS data are available to download from this link. Detailed documentation about GLDAS 2.1 product is available here

4.3 Specific requirements

The requirements for the metereorological data at aviation station are:

Table 4.2: meteorological data required

PARAMETER	SYMBOLS	UNIT
Wind Speed	Ws	m/s
Air Temperature	Tair	°C
Pressure	P	hpa
Relative Humidity	Rh	%

The units at which GLDAS provide air temperature (K) and Pressure(Pa). Further GLDAS provide specific humidity. To match requirements the following conversion steps have to be performed:

Step 1 : Convert GLDAS air temperature from Kelvin to Deg C.

Step 2 : Convert the unit of GLDAS pressure from Pa to Milli bar (Mb).

Step 3 : Convert specific humidity to relative humidity following the description here.

Step 4 : Extract the Ws, Tair, P and Rh corresponding at our aviation meteorological stations at observation time : 00:00, 03:00, 06:00, 09:00, 12:00, 15:00, 18:00 and 21:00 UTC.

Step 5 : Compare the results with data collected at the stations.

4.4 Download GLDAS data

GLDAS documentation project provide python script to download data. We run the script below to download data from 01 to 31 January 2021.

```
## In the Ubuntu session.
## Type in the following command to install the python package "gldas"
pip3 install gldas
```

```
## press enter
## Below code will download the GLDAS data between the dates provided in the command.
gldas_download -s 2021-01-01 -e 2021-01-31 --product GLDAS_Noah_v21_025 --username nina.younkap --password ****** /mnt/path/to/folder
## Note that the last argument in above command is path to a folder where the downloaded files will be stored.
```

4.5 Processing single data file

4.5.1 Data file structure

Let us now see how to process a single NetCDF file (.nc4) dowloaded from GLDAS using the previous step and perform the required conversions. For example let us consider the GLDAS data representing 06:00 hours on 31 January 2021. The GLDAS file name follows a particular structure. The file name is GLDAS_NOAH025_3H.A20210131.0600.021.nc4

- **GLDAS_NOAH025_3H** represents the name, spatial resolution (025 means 0.25 degree resolution) and temporal resolution (3H means three hour data)
- **A20210131** represents the date of acquisition
- **0600** represents the time (in this case 06:00 GMT) the parameters are computed for.
- **021** represents the version of GLDAS data, in this case 2.1.
- **nc4** represents the extension and format of the data, in this case netCDF4.

4.5.2 Metadata discovery

Now let us see how to read the metadata of this file in command line using gdal tools

```
## change directory to where you have downloaded the GLDAS data using the below
cd /mnt/d/mi_is_project_data/2021/31"
## Extract metadata of the 'GLDAS_NOAH025_3H.A20210131.0600.021.nc4' in the file "metadata.txt"
gdalinfo GLDAS_NOAH025_3H.A20210131.0600.021.nc4 > metadata.txt
## press enter
## Read metadata using vim editor
vim metadata.txt
```

In the metadata, under Subdatasets: all the parameters provided as subdatasets are listed. These subdataset names are used in the further steps to process individual parameters. For example, netCDF : "GLDAS_NOAH025_3H.A20210131.0600.021.nc4" : Tair_f_inst is the name of air temperature grid at 06:00 on 31 January 2021 and we will use this name to extract/process this single grid. The codes of the parameters are listed in the GLDAS user manual (Table 3.1).

4.5.3 Single data extraction

So for our project we need the following subdatasets from a single GLDAS file:

NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":Qair_f_inst - Specific humidity (Kg/Kg)

NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":Psurf_f_inst - Surface Pressure (Pa)

NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":Tair_f_inst - Air Temperature (K)

NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":Wind_f_inst - Wind speed (m/s)

NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":SWdown_f_inst - Downward short-wave radiation flux (W m-2)

Now let us extract each of the above subdatasets and convert them into tif file. For this we will use a gdal command called gdal_translate which is a global conversion tool for all kind of raster formats. Detailed documentation on gdal_translate is given here.

```
##  Convert specific humidity to tif - below command
gdal_translate NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":Qair_f_inst
   GLDAS_NOAH025_3H_A20210131_0600_Qair.tif
## Convert Surface Pressure to tif - below command
gdal_translate NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":Psurf_f_inst
   GLDAS_NOAH025_3H_A20210131_0600_Psurf.tif
## Convert air temperature to tif - below command
gdal_translate NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":Tair_f_inst
   GLDAS_NOAH025_3H_A20210131_0600_Tair.tif
## Convert Wind speed to tif - below command
gdal_translate NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":Wind_f_inst
   GLDAS_NOAH025_3H_A20210131_0600_Wind.tif
## Convert Short wave downward radiation to tif - below command
gdal_translate NETCDF:"GLDAS_NOAH025_3H.A20210131.0600.021.nc4":SWdown_f_tavg
   GLDAS_NOAH025_3H_A20210131_0600_SWdown.tif
## Press enter
```

4.5.4 Data visualisation in QGIS

Now that we have the required parameters of 31 January 2021 in .tif format, let us open the air temperature map in QGIS and see how it looks!

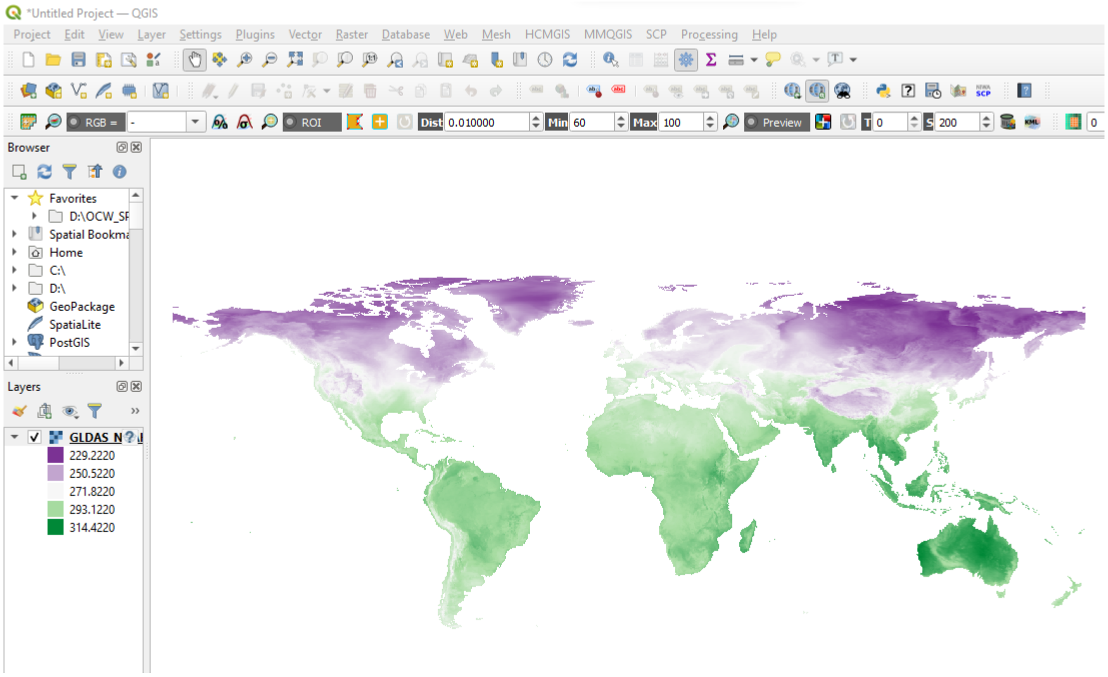


Figure 4.2: GLDAS Tair data displayed in QGIS

Let us also zoom to Cameroon boundaries and have a look at the Tair map. Remember the resolution of data is 0.25 degrees.

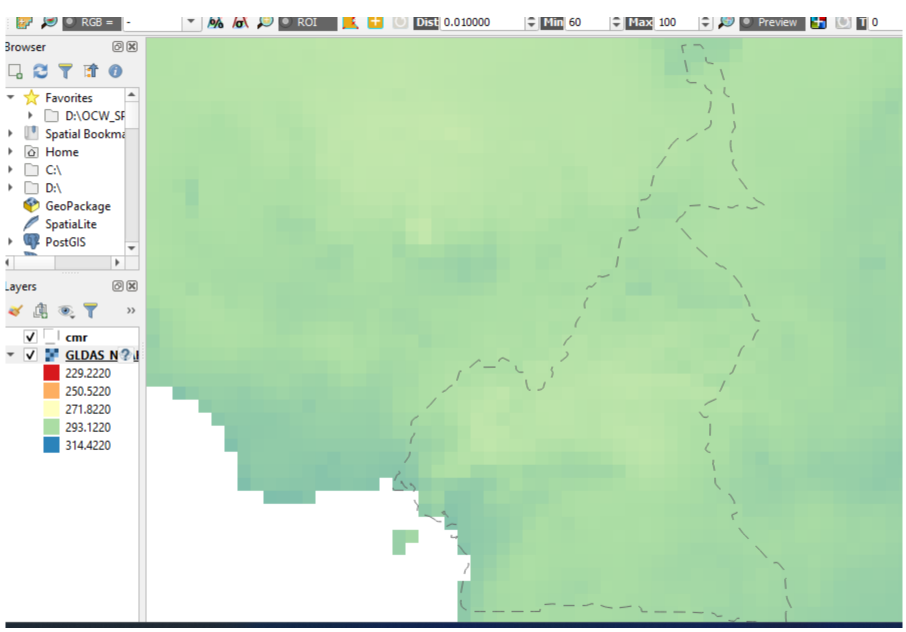


Figure 4.3: GLDAS Tair data displayed in QGIS and zoomed to Cameroon

4.5.5 Unit data conversion

Now let us see how to do unit conversion of all the four parameters required for aviation. One additional step is to clip the unit converted maps to cameroon boundaries as we are only interested in that region not global.

For further steps let us move to **GRASS GIS** as it is easier to do spatial and temporal analysis with GRASS library. We will create a new location and mapset for processing GLDAS data for Cameroon boundaries.

```
# Create (-c) just the location called "cmr" in epsg:4326 and exit (-e)
grass78 epsg:4326 /mnt/d/grassdata/cmr -c -e
# Create (-c) mapset called "met_data" inside the location "cmr" and open GRASS
    GIS in "cmr/met_data" mapset
grass78 /mnt/d/grassdata/cmr/met_data -c
# "-c" flag in above command is required only one time to create the mapset
   met_data
# Afterwards use below command to just start the existing mapset.
# grass78 /mnt/d/grassdata/cmr/met_data
```

Import the cameroon vector file , aviation meteorological station file , and others file required for our project into grass location.

```
## IMPORT VECTOR DATA: Boundaries of Cameroon an  Aviation meteorological
   station in cameroon
## Navigate (cd) to the folder Cmr_Base_Layers
cd /mnt/d/mi_is_project_data/Cmr_Base_Layers
# Import 'Cameroon' boundary shapefile into a vector in Grass GIS
v.import in=cmr.shp out=cmr
# Import 'Aviation meteorological staitions' points shapefile into a vector in
   Grass GIS
v.import in=aero_met_station_cmr.shp out=met_station
# Import 'FKKR TMA2' boundary shapefile into a vector in Grass GIS
v.import in=Fkkr_tma2.shp out=fkkr_tma2
# Import 'FKKN TMA' boundary shapefile into a vector in Grass GIS
v.import in=Fkkn_tma.shp out=fkkn_tma
# Import 'FKKL CONTROL ZONE' boundary shapefile into a vector in Grass GIS
v.import in=Fkkl_ctr.shp out=fkkl_ctr
# set the computational region to Cameroon Boundaries and set the computational
    resolution to 0.25 degrees
g.region vector=cmr res=0.25 -a
```

To automate workflows, the following bash script process all the four required parameters (Tair, Rh, Wind speed and Psurf), clipped on cameroon boundaries and converted to the required units from .nc4 files in a day.

```bash
#!/bin/bash
## This script process a single day GLDAS data and do all the required conversions needed for our project.
## GENERAL ##
if [ -z "$GISBASE" ] ; then
    echo "You must be in GRASS GIS to run this program." >&2
    exit 1
fi
# Set a environment to enable overwrite by default
export GRASS_OVERWRITE=1

# Navigate to the folder containing single day .nc4 files
#e.g INDAT="/mnt/d/mi_is_project_data/Cmr_Base_Layers/2021/01" for 01 January 2021
#Here we work on the  31 January 2021 data
INDAT="/mnt/d/mi_is_project_data/2021/031"
cd ${INDAT}
# set the computational region to Urmia Lake basin and set the computational resolution to 0.25 degrees
g.region vector=cmr res=0.25 -a
# set the mask to cameroon boundaries

# For loop to process all the .nc files in one go
for i in `ls GLDAS*.nc4`; do
    dt=`echo ${i}|cut -d. -f2-3`
    #  Convert specific humidity to tif - below command
    gdal_translate NETCDF:"${i}":Qair_f_inst GLDAS_NOAH025_3H_${dt}_Qair.tif
    # Convert Surface Pressure to tif - below command
    gdal_translate NETCDF:"${i}":Psurf_f_inst GLDAS_NOAH025_3H_${dt}_Psurf.tif
    # Convert air temperature to tif - below command
    gdal_translate NETCDF:"${i}":Tair_f_inst GLDAS_NOAH025_3H_${dt}_Tair.tif
    # Convert Wind speed to tif - below command
    gdal_translate NETCDF:"${i}":Wind_f_inst GLDAS_NOAH025_3H_${dt}_Wind.tif
    # Convert Short wave downward radiation to tif - below command
    gdal_translate NETCDF:"${i}":SWdown_f_tavg GLDAS_NOAH025_3H_${dt}_SWdown.tif
    # Import to GRASS
    # Import and clip specific humidity
    r.import in=GLDAS_NOAH025_3H_${dt}_Qair.tif out=GLDAS_NOAH025_3H_${dt}_Qair -o
    # Import and clip Surface Pressure
    r.import in=GLDAS_NOAH025_3H_${dt}_Psurf.tif out=GLDAS_NOAH025_3H_${dt}_Psurf -o
    # Import and clip Tair
```

```
    r.import in=GLDAS_NOAH025_3H_${dt}_Tair.tif out=GLDAS_NOAH025_3H_${dt}_Tair -o
    # Import and clip Wind speed
    r.import in=GLDAS_NOAH025_3H_${dt}_Wind.tif out=GLDAS_NOAH025_3H_${dt}_Wind -o
    # Import and clip Short wave radiation
    r.import in=GLDAS_NOAH025_3H_${dt}_SWdown.tif out=GLDAS_NOAH025_3H_${dt}_SWdown -o
    # Unit conversion
    # Air temperature from Kelvin to degree celsius
    r.mapcalc "GLDAS_NOAH025_3H_${dt}_Tair_final = GLDAS_NOAH025_3H_${dt}_Tair - 273.15"
    # Short wave radiation (no conversion required)
    r.mapcalc "GLDAS_NOAH025_3H_${dt}_SWdown_final = GLDAS_NOAH025_3H_${dt}_SWdown"
    # Wind speed (no conversion required)
    r.mapcalc "GLDAS_NOAH025_3H_${dt}_Wind_final = GLDAS_NOAH025_3H_${dt}_Wind"
    ## Specific humidity re saved
    r.mapcalc "GLDAS_NOAH025_3H_${dt}_Qair_final = GLDAS_NOAH025_3H_${dt}_Qair"
    ## Pressure convert from pa to mb
    r.mapcalc "GLDAS_NOAH025_3H_${dt}_Psurf_final = GLDAS_NOAH025_3H_${dt}_Psurf / 100"
    ## Humidity according to the url: https://earthscience.stackexchange.com/questions/2360/how-do-i-convert-specific-humidity-to-relative-humidity
    r.mapcalc "es = 6.112 * exp((17.67 * GLDAS_NOAH025_3H_${dt}_Tair_final) / (GLDAS_NOAH025_3H_${dt}_Tair_final + 243.5))"
    r.mapcalc "e = (GLDAS_NOAH025_3H_${dt}_Qair_final * GLDAS_NOAH025_3H_${dt}_Psurf_final) / (0.378 * GLDAS_NOAH025_3H_${dt}_Qair_final + 0.622)"
    r.mapcalc "GLDAS_NOAH025_3H_${dt}_Rh = (e / es) * 100"
    # Final Relative humidity in %
    r.mapcalc "GLDAS_NOAH025_3H_${dt}_Rh_final = float(if(GLDAS_NOAH025_3H_${dt}_Rh > 100, 100, if(GLDAS_NOAH025_3H_${dt}_Rh < 0, 0, GLDAS_NOAH025_3H_${dt}_Rh)))"

done
```

We save the script above in the file myscript.sh.The following code show how to run this file on Linux Operating System.

```
# Run the following command to install dos2unix
sudo apt-get install dos2unix
# Below command removes the trailing spaces from your script
dos2unix myscript.sh
# Run the following command to run the above saved script file
sh myscript.sh
# press enter
```

RESULTS

This chapter deals about the outcome of our analysis and how to share the results with the community.

5.1 Extract chart command line tools.

5.1.1 Visualise temperature chart.

The script below show how to extract temperature chart from GRASS GISS using command line. The same code work for others meteorological parameters (Wind, Surface Pressure, Relative Humidity), we just need to change few parameters in the script.

```
# Visualize data
#Set date and time on 31 January 2021 at 03:00 UTC
dt="20210131.0300"
#Set date and time on 31 January 2021 at 03:00 UTC
#dt="20210131.1500"
# Open a monitor
d.mon wx0
#set the coordinate grid
d.grid 3
# Display a raster map
d.rast GLDAS_NOAH025_3H_A${dt}_Tair_final
# Display a vector map
d.vect map=cmr type=boundary
#Add text
#d.text text="31 JAN 2021 0300Z" color=black bgcolor=white size=3
d.text text="31 JAN 2021 1500Z" color=black bgcolor=white size=3
# Add raster legend
# Add raster legend
d.legend -t -s -b raster=GLDAS_NOAH025_3H_A${dt}_Tair_final title=TEMPERATURE
    title_fontsize=20 font=sans fontsize=18
# Add North arrow
d.northarrow style=1b text_color=black
#clear the monitor
#d.erase -f
# press enter
```

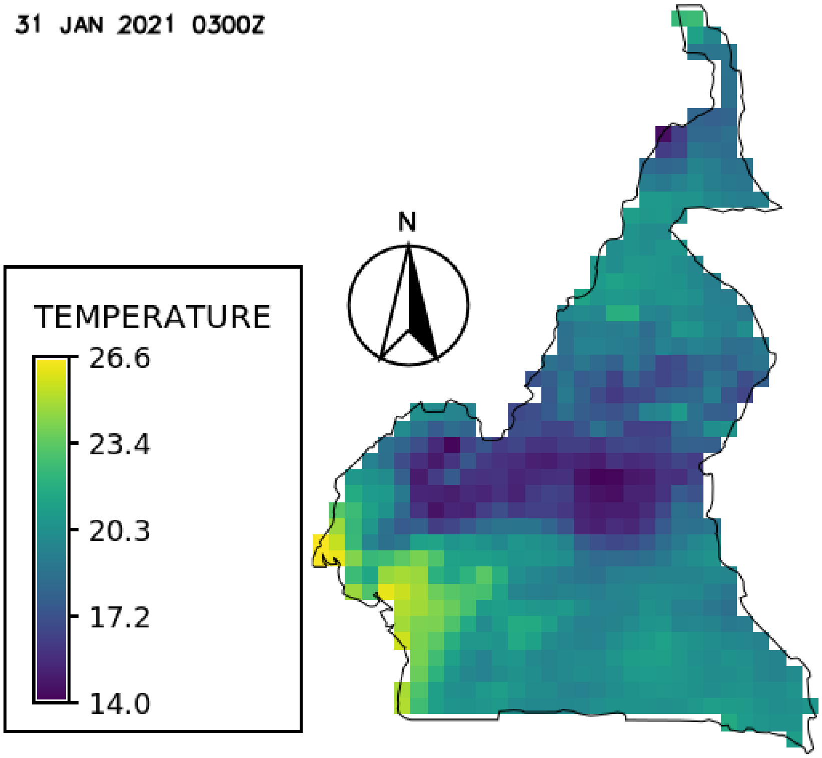


Figure 5.1: Temperature at 03:00 UTC

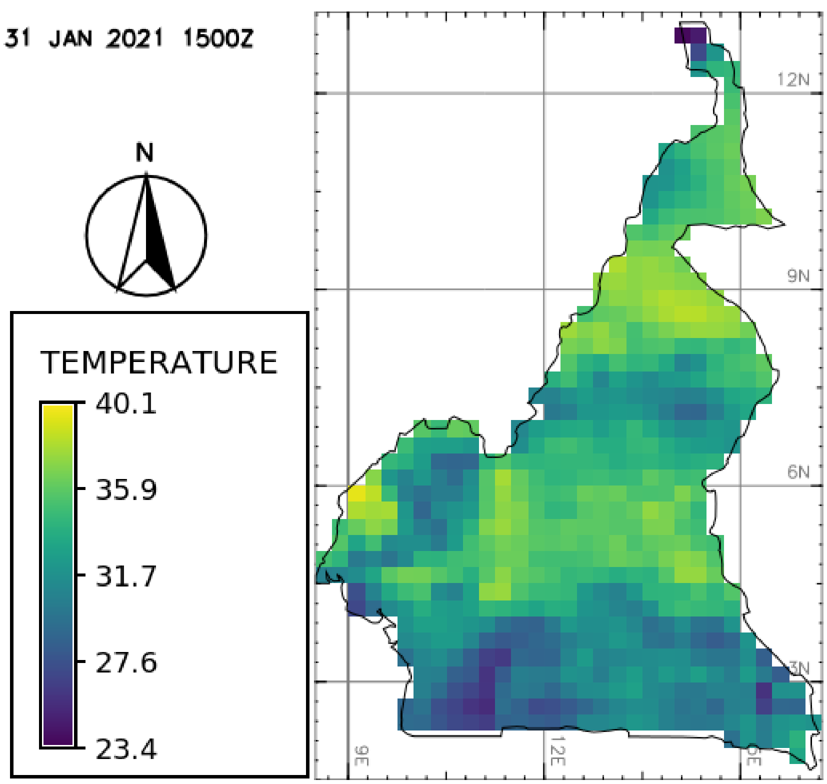


Figure 5.2: Temperature at 15:00 UTC

5.1.2 Visualise Relative Humidity Chart

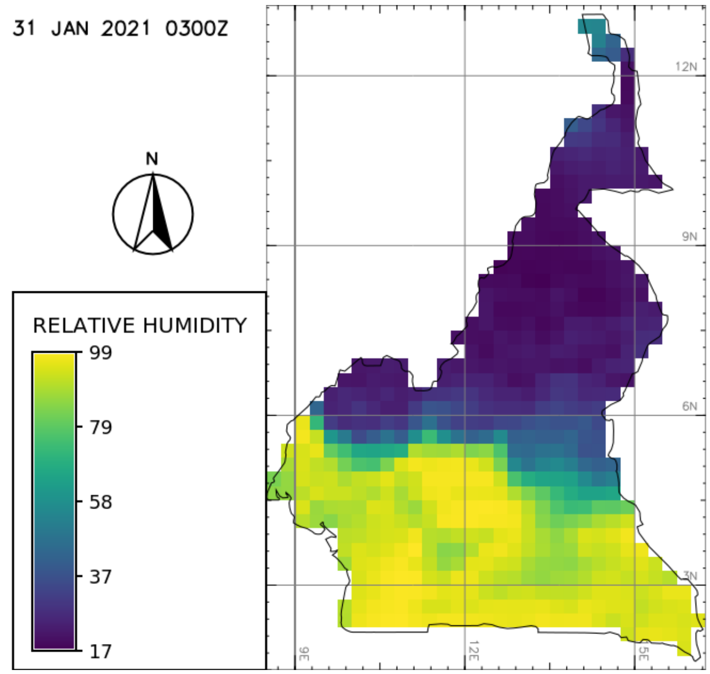


Figure 5.3: Relative Humidity at 03:00 UTC

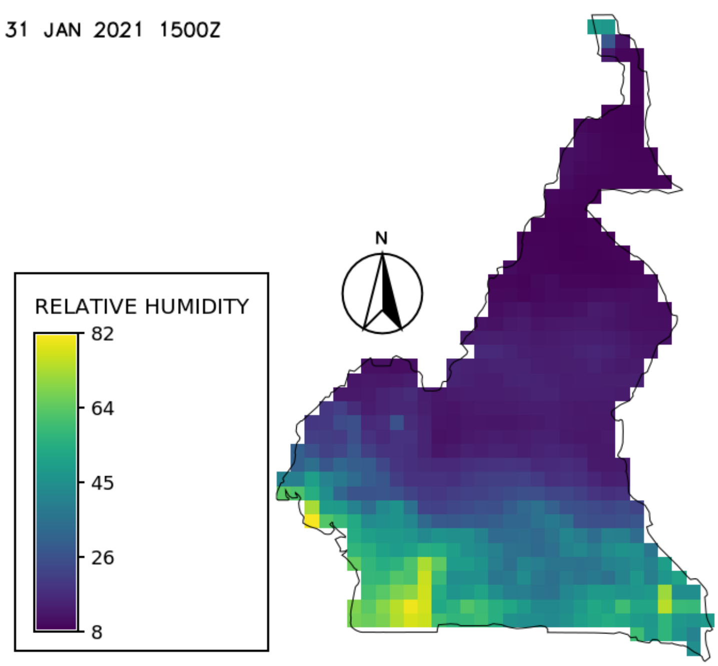


Figure 5.4: Relative Humidity at 15:00 UTC

5.1.3 Visualise Surface Pressure Chart

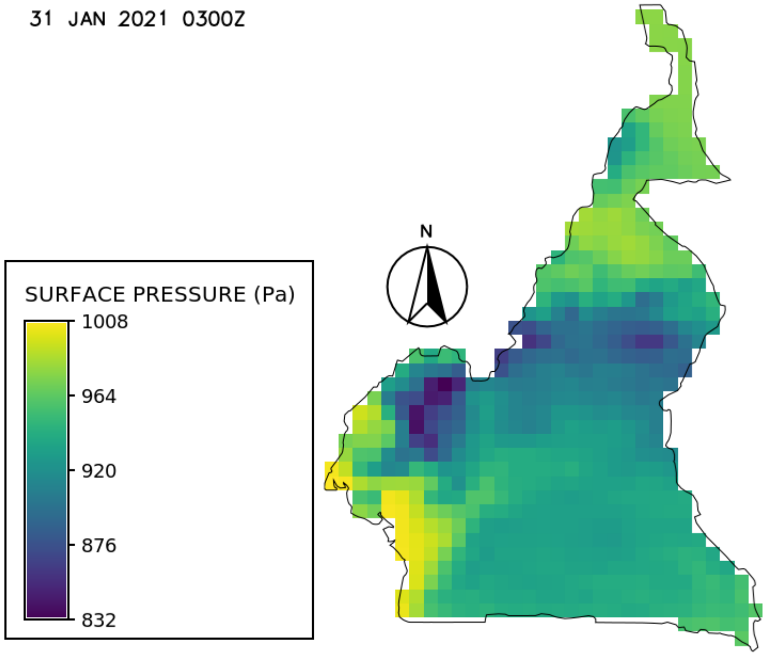


Figure 5.5: Surface Pressure at 03:00 UTC

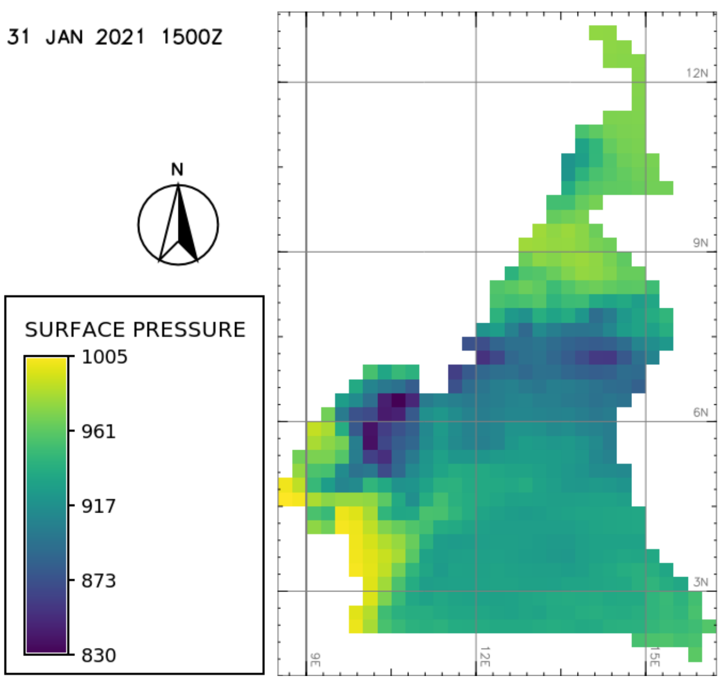


Figure 5.6: Surface Pressure at 15:00 UTC

5.1.4 Visualise Wind Speed Chart

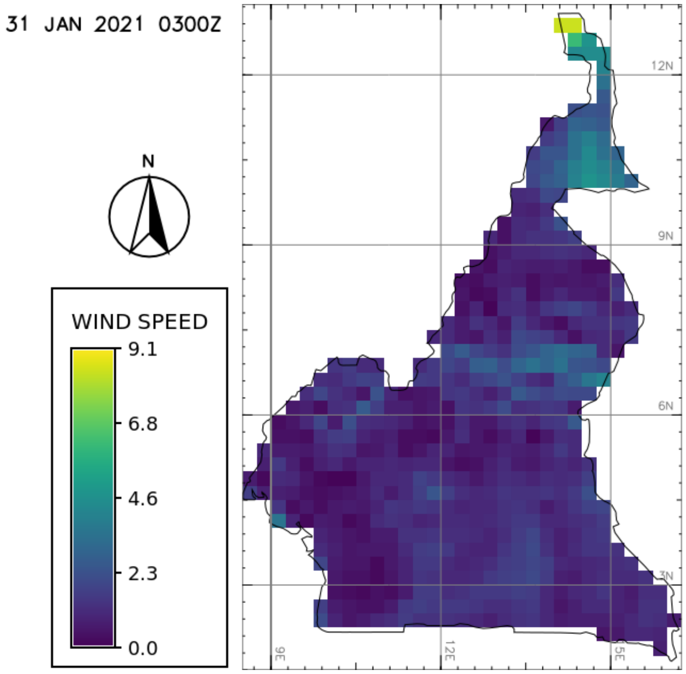


Figure 5.7: Wind Speed at 03:00 UTC

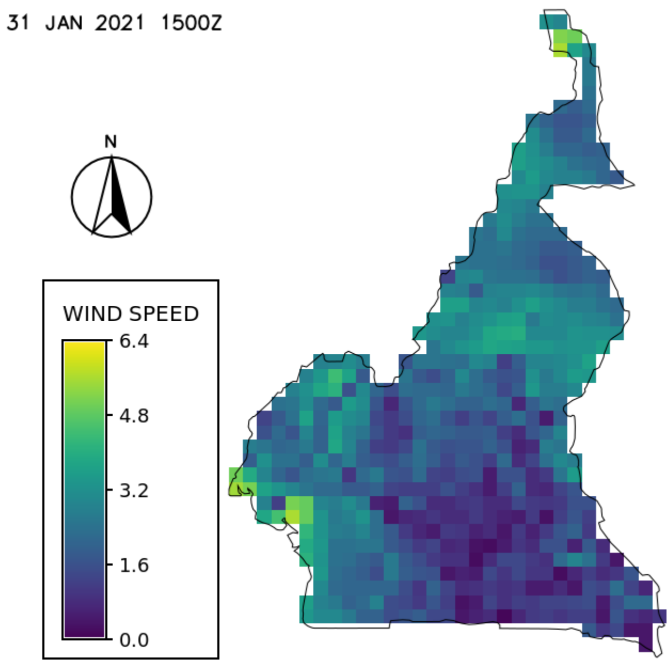


Figure 5.8: Wind Speed at 15:00 UTC

5.2 Extract data

Let us see how to extract raster values at particular observation points given as a vector layer. Here we will use aviation meteorological observation points in cameroon, to extract meterological parameters Tair, Ws, P and Rh at observation time: 00:00,03:00,06:00,09:00,12:00,15:00,18:00 and 21:00.

```bash
#!/bin/bash
## This script process a single day GLDAS data and do all the required
   conversions needed for PySEBAL
## GENERAL ##
if [ -z "$GISBASE" ] ; then
    echo "You must be in GRASS GIS to run this program." >&2
    exit 1
fi
# Set a environment to enable overwrite by default
export GRASS_OVERWRITE=1
# Navigate to the folder containing single day .nc4 files
INDAT="/mnt/d/mi_is_project_data/2021/031"
cd ${INDAT}
# set the computational region to Urmia Lake basin and set the computational
   resolution to 0.25 degrees
g.region vector=cmr res=0.25 -a
r.mask vect=cmr

# For loop to process all the .nc files in one go

for i in `ls GLDAS*.nc4`; do
    dt=`echo ${i}|cut -d. -f2-3`
    # Extract Air Temperature values 8 aviation meteorological station at time
   = dt and save the value in .csv file
    r.what -n map=GLDAS_NOAH025_3H_${dt}_Tair_final points=met_station  sep=
   comma output=a_temp_${dt}Z.csv
    # Extract Relative Humidity values 8 aviation meteorological station at
   time = dt and save the value in .csv file
    r.what -n map=GLDAS_NOAH025_3H_${dt}_Rh_final points=met_station  sep=comma
    output=a_rh_${dt}Z.csv
    # Extract Surface Pressure values 8 aviation meteorological station at time
    = dt and save the value in .csv file
    r.what -n map=GLDAS_NOAH025_3H_${dt}_Psurf_final points=met_station  sep=
   comma output=a_p_${dt}Z.csv
    # Extract Surface wind values 8 aviation meteorological station at time =
   dt and save the value in .csv file
    r.what -n map=GLDAS_NOAH025_3H_${dt}_Wind_final points=met_station  sep=
   comma output=a_ws_${dt}Z.csv
done
```

We save the script abive in the file `extraction.sh` , then run the bash script on Ubuntu using the command `sh extract.sh` .

Let see how these file look in the directory

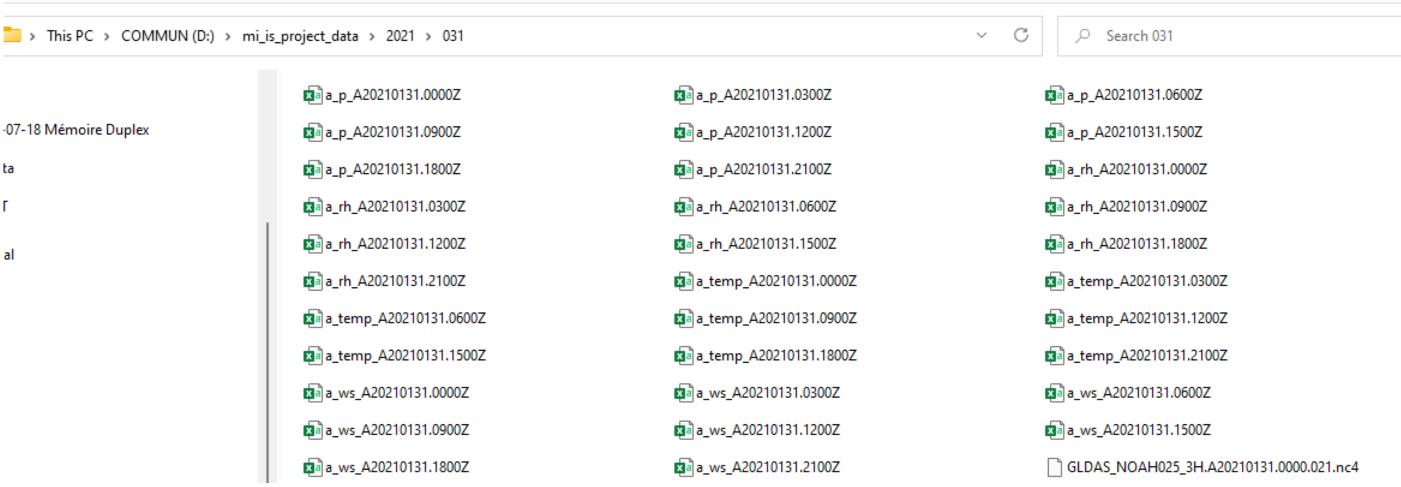


Figure 5.9: File in directory

Table 5.1: Station Temperature extracted

Time	Temperature							
	Yaounde	Douala	Garoua	Maroua	Ngaoundere	Bafoussam	Bertoua	Bamenda
00:00	20.53	NA	22.69	21.88	17.82	16.16	19.95	16.23
03:00	20.89	NA	20.52	20.06	17.20	15.30	18.65	15.74
06:00	20.56	NA	20.26	19.83	17.15	15.12	18.81	15.93
09:00	28.19	NA	29.55	27.78	28.93	28.41	28.84	29.24
12:00	32.79	NA	35.92	32.96	32.38	31.97	37.50	33.15
15:00	28.80	NA	37.19	34.56	31.21	31.29	34.05	32.20
18:00	24.12	NA	29.08	25.97	22.35	21.54	25.18	20.65
21:00	22.51	NA	25.92	24.92	18.47	18.26	21.30	17.94

Table 5.2: Station Relative Humidity extracted

Time	Relative Humidity							
	Yaounde	Douala	Garoua	Maroua	Ngaoundere	Bafoussam	Bertoua	Bamenda
00:00	94.54	NA	16.14	20.95	21.98	54.31	58.72	32.07
03:00	90.14	NA	18.46	23.37	20.91	40.82	72.48	29.25
06:00	90.39	NA	19.23	23.40	23.16	33.04	91.95	26.58
09:00	54.54	NA	11.91	13.46	13.44	14.43	50.12	13.34
12:00	33.52	NA	8.54	9.56	12.56	14.23	21.82	12.27
15:00	45.02	NA	8.18	9.07	13.46	15.93	23.29	13.37
18:00	60.96	NA	12.36	14.20	20.06	32.72	38.15	28.70
21:00	79.47	NA	14.99	14.70	25.07	54.81	54.48	34.51

Table 5.3: Station Surface Pressure extracted

Time	Surface pressure							
	Yaounde	Douala	Garoua	Maroua	Ngaoundere	Bafoussam	Bertoua	Bamenda
00:00	930.2783	NA	979.7773	962.4352	889.6512	871.1833	933.2983	873.8692
03:00	929.7397	NA	979.4847	961.8867	888.5327	870.0627	932.4217	872.4927
06:00	930.5676	NA	981.7227	963.8837	890.0356	871.6027	933.8506	873.8066
09:00	931.4058	NA	982.3198	964.6767	890.5017	872.1998	934.3908	874.4767
12:00	928.5176	NA	979.0986	962.0646	888.1417	869.7606	931.1577	871.7536
15:00	925.8957	NA	975.8347	959.1037	886.0237	867.2417	928.1847	869.2897
18:00	929.0854	NA	978.3014	961.4464	888.9214	870.0524	930.8405	872.8555
21:00	930.7338	NA	979.9328	962.7498	890.4208	871.8887	932.9238	874.6868

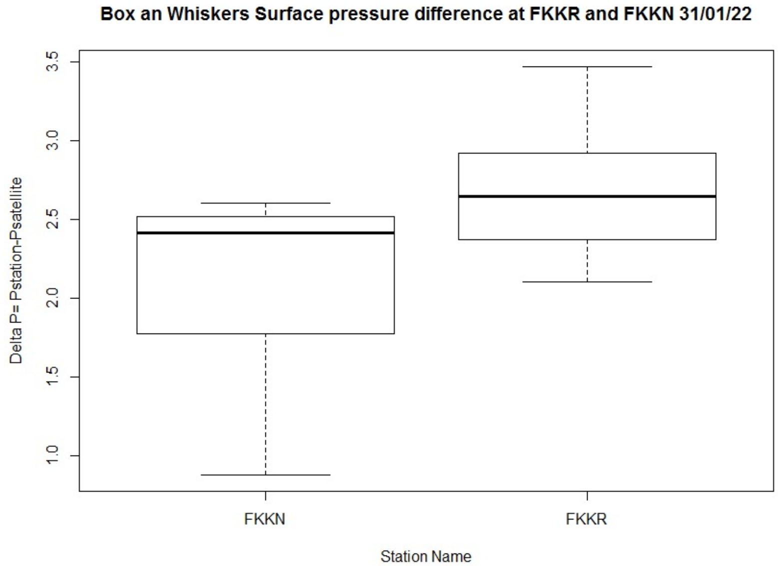
5.3 Comparison between values extracted from satellite and those obseved at met station

Table 5.4: Values extracted from satellite and observed at Garoua station

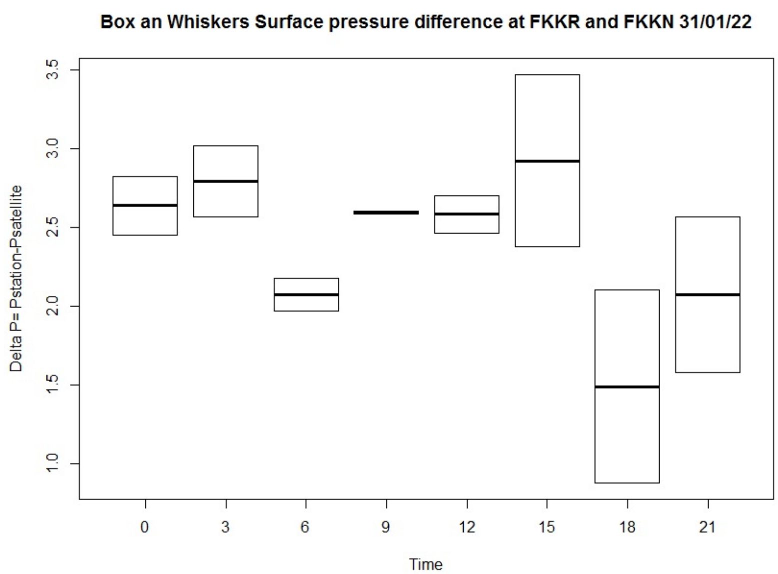
Time	Garoua meteorological station					
	Tair_satellite	Tair_station	Rh_satellite	Rh_station	P_satellite	P_station
00:00	22.69231567	24	16.14377	31	979.7773	982.6
03:00	20.52959595	20.2	18.45571	39	979.4847	982.5
06:00	20.26201782	19.5	19.2371	43	981.7227	983.9
09:00	29.55059204	29	11.90664	25	982.3198	984.9
12:00	35.92055664	34	8.537706	15	979.0986	981.8
15:00	37.19307861	36	8.181383	17	975.8347	979.3
18:00	29.08526001	30.5	12.35657	27	978.3014	980.4
21:00	25.92067871	25.9	14.98635	31	979.9328	982.5

Table 5.5: Values extracted from satellite and observed at Ngaoundere station

Time	Ngaoundere meteorological station					
	Tair_satellite	Tair_station	Rh_satellite	Rh_station	P_satellite	P_station
00:00	17.82232056	13.8	21.97756	31	889.6512	892.1
03:00	17.19960938	12.7	20.90649	30	888.5327	891.1
06:00	17.15200195	11.5	23.15677	38	890.0356	892.0
09:00	28.93059692	22.4	13.43818	19	890.5017	893.1
12:00	32.38057861	26.4	12.56398	13	888.1417	890.6
15:00	31.21306763	28.6	13.45516	12	886.0237	888.4
18:00	22.35527954	20.8	20.06234	24	888.9214	889.8
21:00	18.47069702	16.5	5.06882	27	890.4208	892.0



On the whole the satelitte over estimates the temperature, but at Garoua the difference is less than 1°C compared to Ngaoundere where we can have up to -6°C, that might be explained by the uneven landshape over Ngaoundere.



Regardless to the time, the temperature is over estimated by the satellite, nevertheless the difference is high from 6 to 12 AM, when the sun radiation is highest.

Table 5.6: Temperature summary at FKKR

Min.	1st Qu.	Median	Mean	3rd Qu.	3rd Qu.
-1.9206	-0.8698	-0.4401	-0.2568	0.3114	1.4147

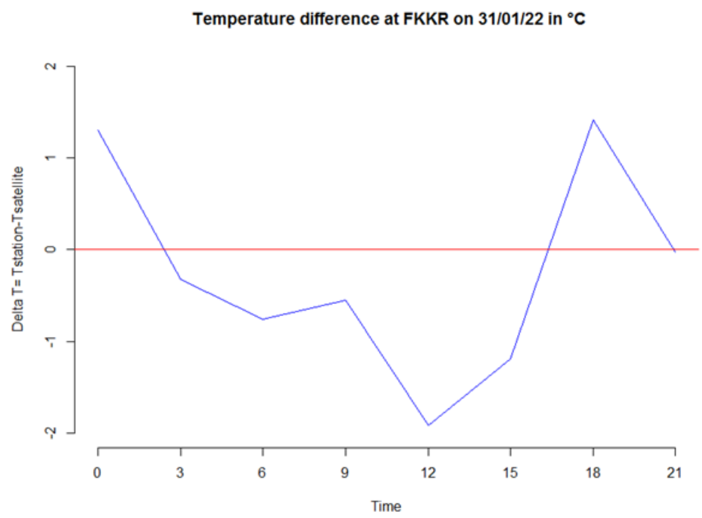
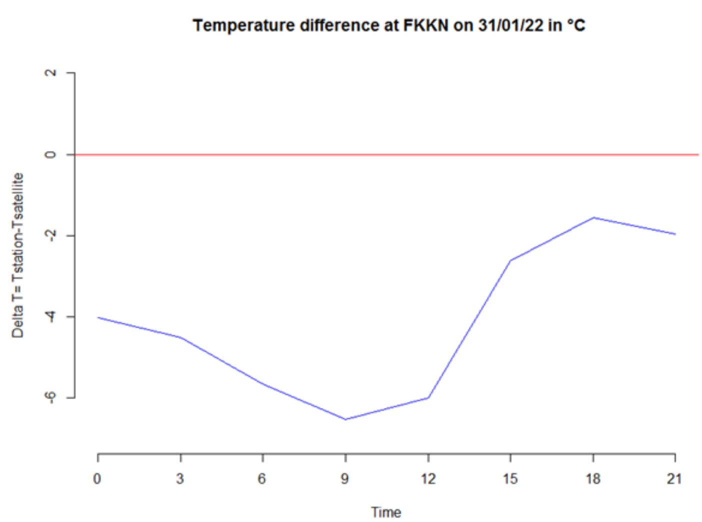
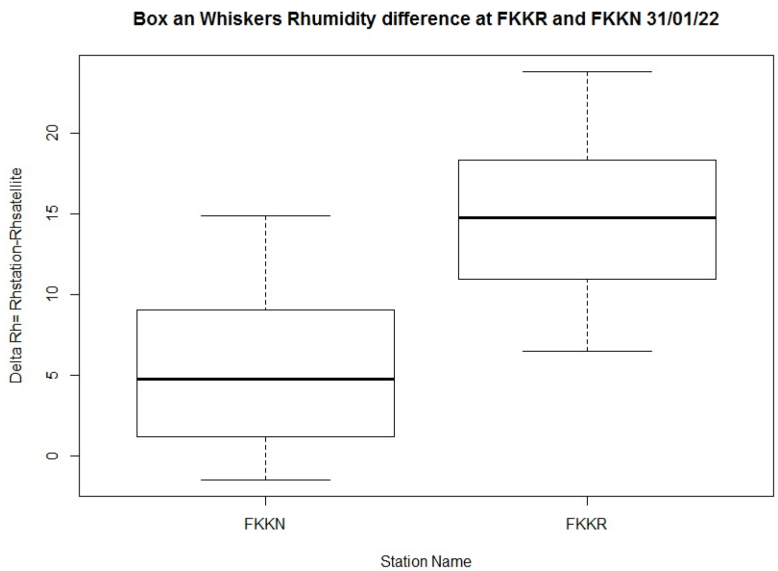


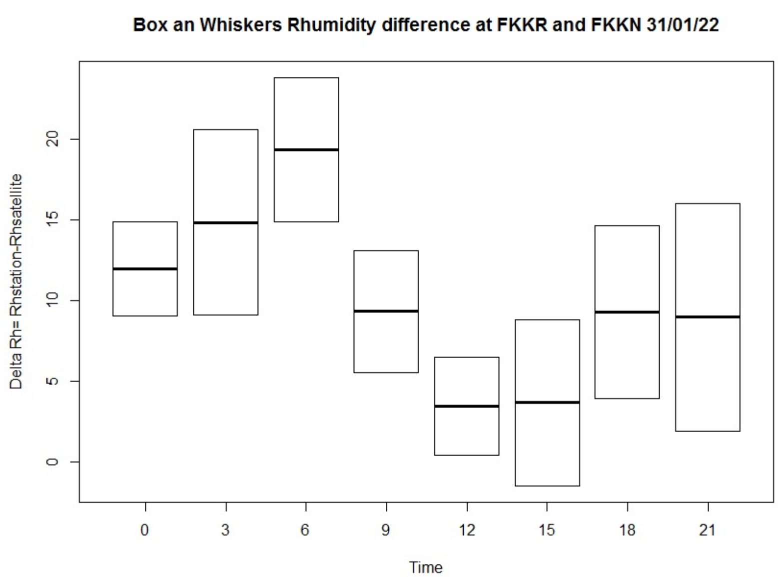
Table 5.7: Temperature summary at FKKN

Min.	1st Qu.	Median	Mean	3rd Qu.	3rd Qu.
-6.531	-5.734	-4.261	-4.103	-2.452	-1.555





On the whole the Relative humidity is under estimated by the satellite



The difference of Relative humidity is more than 10% from 0 to 6 AM and less than 10% from 09:00 to 21:00 UTC

Table 5.8: Relative humidity summary at FKKR

Min.	1st Qu.	Median	Mean	3rd Qu.	3rd Qu.
6.462	12.025	14.750	14.774	17.146	23.763

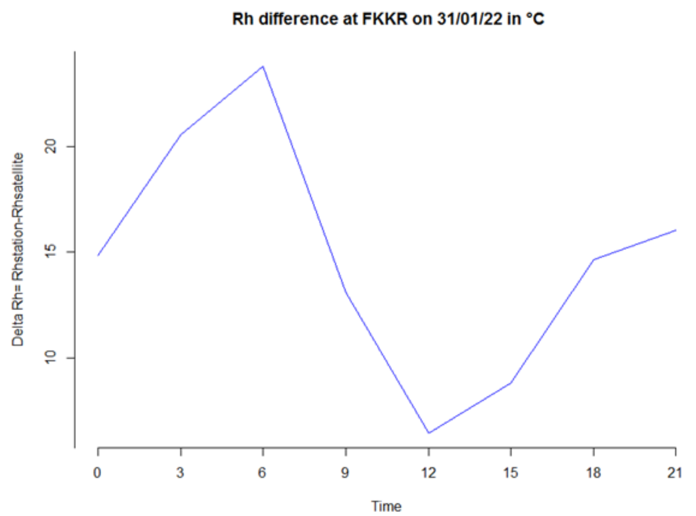
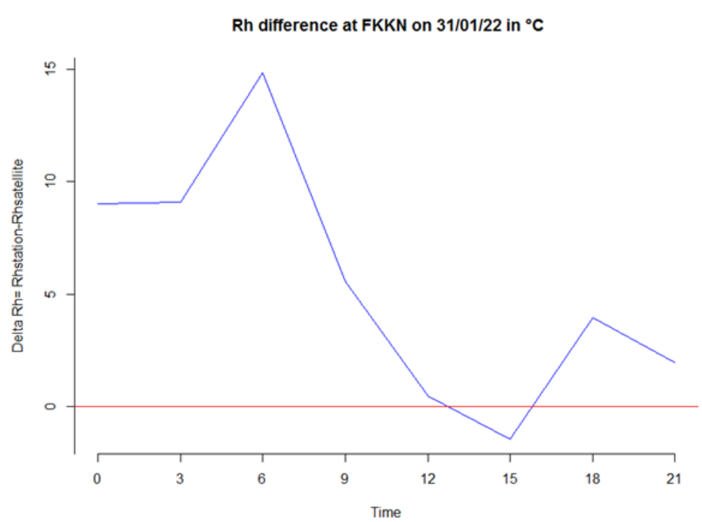
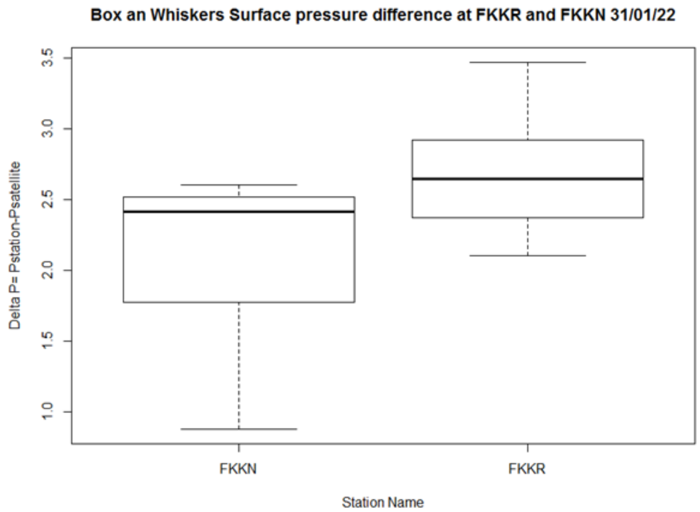


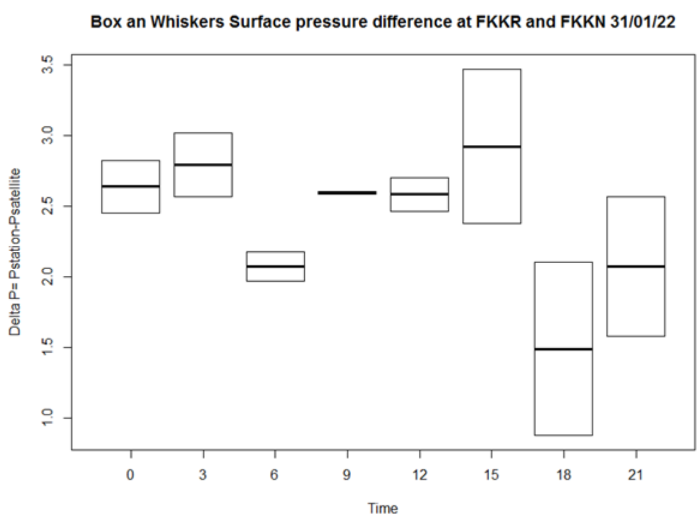
Table 5.9: Relative humidity summary at FKKN

Min.	1st Qu.	Median	Mean	3rd Qu.	Qu.
-1.455	1.557	4.750	5.421	9.040	14.843





On the whole the surface pressure is under estimated by the satellite, however the gap is greater in Garoua than in Ngaoundere



The pressure is under estimated, the difference of pressure has two minimum (at 6 and 18 AM) and two maximum (at 3 and 15 AM) , this refers to the daily cycle of the pressure

Table 5.10: Surface pressure humidity summary at FKKR

Min.	1st Qu.	Median	Mean	3rd Qu.	3rd Qu.
2.099	2.470	2.641	2.679	2.871	3.465

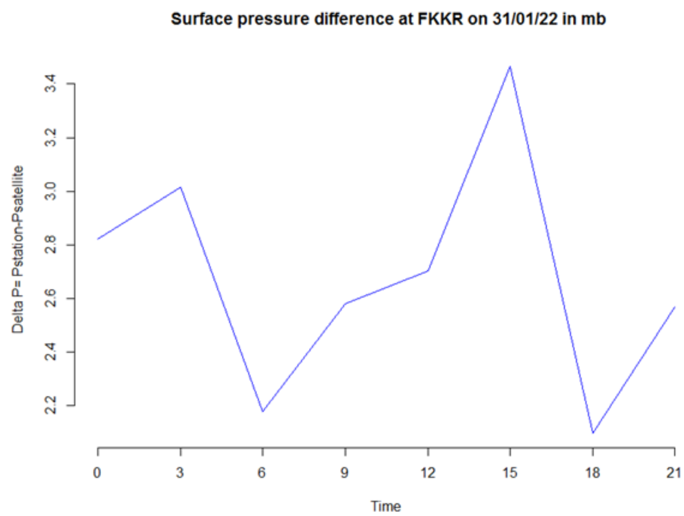
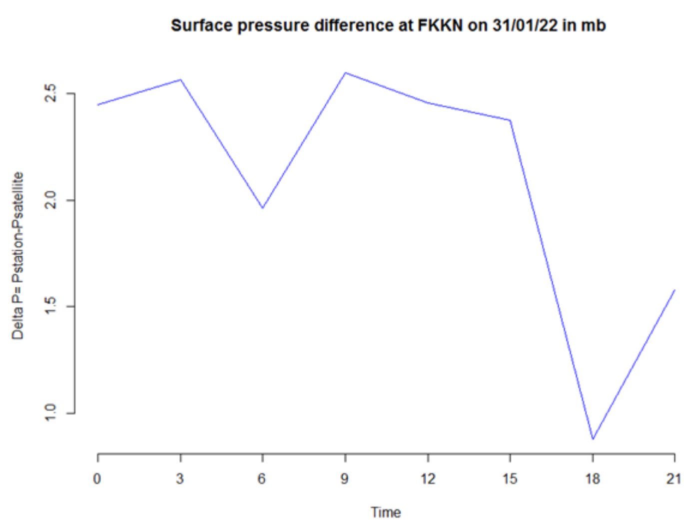


Table 5.11: Surface pressure summary at FKKN

Min.	1st Qu.	Median	Mean	3rd Qu.	3rd Qu.
0.87865	1.8681	2.4125	2.1089	2.4855	2.5983



CONCLUSION AND FUTURE ENHANCEMENT

This project enable us to succesfully perform spatio-temporal analysis of satellite data through the following operations:

- Extraction of single meteorological parameters (temperature, relative humidity, surface pressure and wind) required for avaition safety and efficiency;
- Conversion of temperature from Kelvin to Deg C and surface pressure from Pa to hpa;
- Conversion from specific humidity to relative humidity ;
- Computation and visualisation on thematic chart of meteorological parameters to the extent of Cameroon boundaries ;
- Extraction of meteorological parameters corresponding to our ground observation points;
- Comparison between data extracted from satellite remote sensing and those directly obtained in situ at ground observation points.

We found that on the whole the satellite **over estimates** temperature and **under estimates** pressure and relative humidity.
But due to the time allow for this project the comparison between satellite data and in situ data was limited to two stations (Ngaoundere and Garoua) and on a single day (31 January 2021). These space and time limitations can not enable us to draws a global picture representative for the whole cameroon boundaries. So, as enhancement for this work, we are planing to:

- Extend our study space on the 19 meteorological stations (8 aviation and 11 agro) that compose the cameroon meteorolgical network ;
- Extend our study time on the last 5, 10 and 30 years ;
- Extend our study to others meteorological parameters required for agriculture (AETI, Net radiation, precipittation, NDVI , transpiration, PET, etc.).

Given the fact that the installation, operation and maintenance of a conventional or automatic weather station is expensive and unaffordable for many farmers. We aim to provide farmers with **free** weather data derived from publicly available satellites (Goes-R, Landsat, EumetSat, Modis etc.) to fufill their meteorological needs and support their business operations.

REFERENCES

Bhattacharyya Debnath, Ranjan Rahul, A. Farkhod, Alisherov, and Choi Minkyu. Biometric authentication: A review. *International*, page 16, sep 2009.