flexibility serves behind this work. Thus, this section discusses the graphical objects being used, their properties and accessibility. This is made possible by the available graphical objects and functions provided by MATLAB. Thus, these graphical objects are being exploited for this work to provide added information for the plots produced by goGPS.

These graphical objects are organised in a hierarchical structure (Figure 23), each instance of the object being associated with a handle for its identification. There is a parent-child relationship existing between the objects, with those in the lower rank of the hierarchy being the descendants of those at the top of the hierarchy and it is essential for the existence of a parent object before a child object can be created. For instance, line objects are core graphical objects. To create a line, there is a need for an axes object to exist (because a line object is a descendant of an axes object), which also needs a figure. To create a child object, if the parent does not exist, MATLAB automatically creates the parent in order for the child to be created. Also, if parent(s) exist(s), MATLAB sets the most recent one as the parent object for the child. However, one can also specify the parent for a child object at creation time. The root object sits at the top of the hierarchy and is created at MATLAB startup by default. Thus, one does not need to create the root object. All other objects that are descendants of the root object, however, need to be instantiated before being used. For further description of these, it is recommended to read the documentation on 'Using MATLAB Graphics'. However, brief descriptions of the relevant ones for this work are reported.

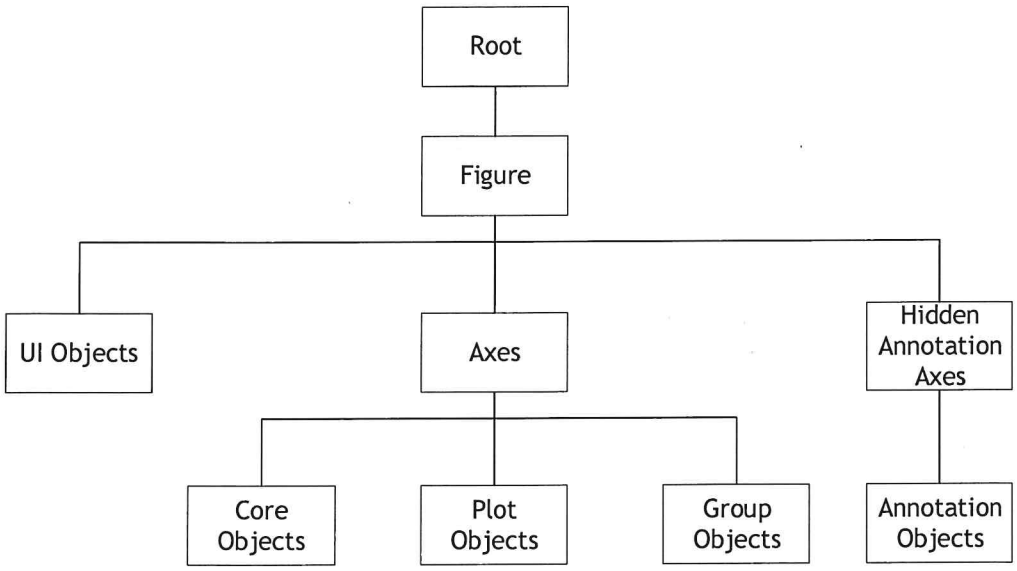


Figure 23 ***Hierarchy of graphical objects in MATLAB***

Graphical objects are displayed in a figure window containing menus, toolbars, user-interface objects, axes and its children, etc. (Figure 24).

Axes objects define the coordinate system for displaying graphs.

Core graphics objects include basic drawing primitives like line, text, patch, surface, images and light objects, which are not visible but affect the way some objects are coloured. These objects can be defined using the functions given in Table 3.

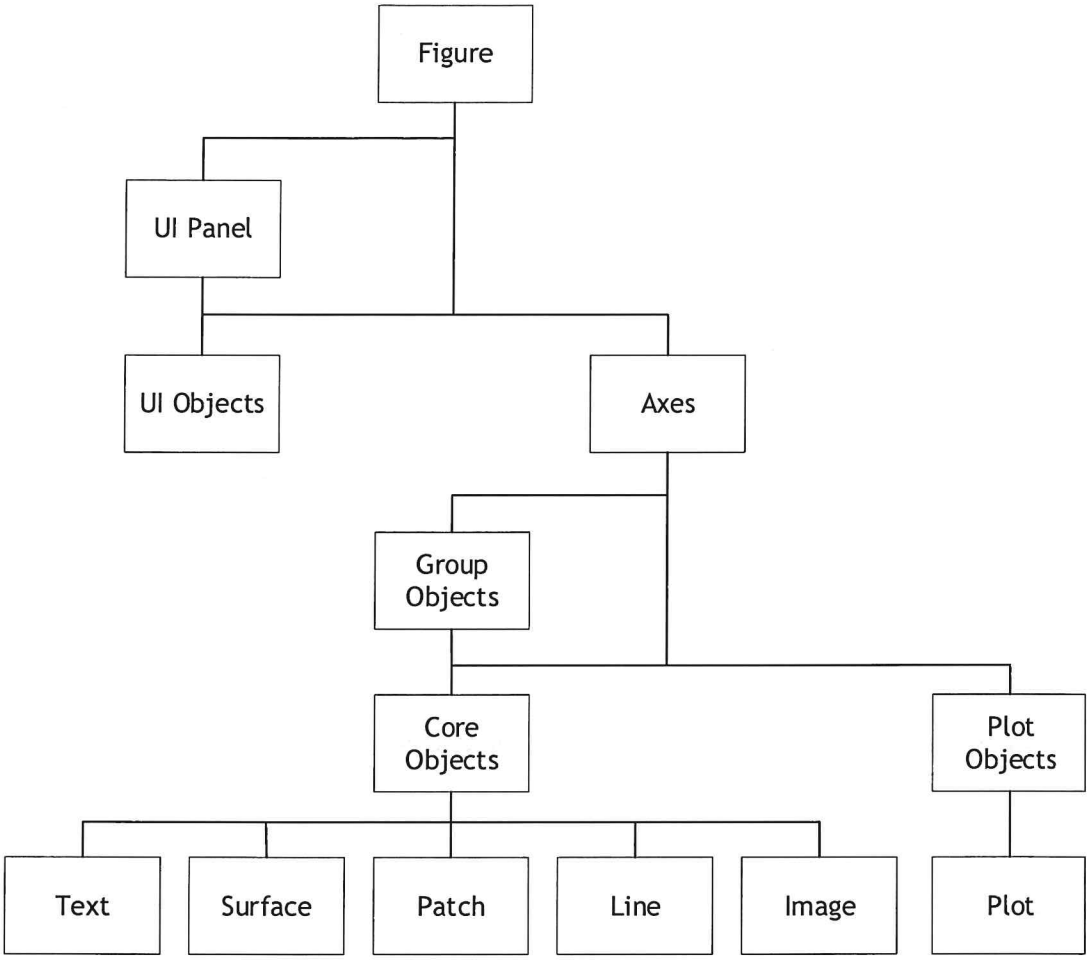


Figure 24 ***Descendants of a figure object***

Table 3 ***Graphical Object Functions***

Function	Purpose
surface	3-D grid of quadrilaterals created by plotting the value of each element in a matrix as a height above the *x*-*y* plane.

patch	Filled polygons with separate edge properties. A single patch can contain multiple faces, each coloured independently with solid or interpolated colours.
text	Character strings positioned in the axes.

4.2.2 Accessing Properties of MATLAB Graphical Objects

The properties of a graphical object control its appearance and behaviour after it has been instantiated. These properties include general information of the object such as the object's type, its parents and children (if available), whether it is visible and other relevant information peculiar to the particular object. The *'get'* function of MATLAB can be used to query the value(s) of a property of a graphical object. The basic syntax for setting the property of an object is given by:

returnedValue = get(objectHandle, *'PropertyName'*)

where objectHandle refers to the identifier for the object being queried and PropertyName refers to the property of the object whose value is needed.

In addition, the *'set'* function available in MATLAB can also be used to change the value of the property of an object. The basic syntax for using the set method is:

set(objectHandle, *'PropertyName'*, *'NewPropertyValue'*)

The objectHandle and PropertyName arguments of the *'set'* function are as defined for the *'get'* function. The *'NewPropertyValue'* however is the value being set for the property of the object. In an instance where the handle of an object has not been specified at creation time, it is possible to use the *'findobj'* method to query the particular object in the hierarchy having a particular property set to a particular value using the syntax:

findobj(*'PropertyName'*, *'PropertyValue'*)

Alternatively, the *'findall'* method can be used to find an object in case its *'HandleVisibility'* property is set to off.

Also, an object and all its descendants can be removed from a graph using the *'delete'* method available in MATLAB.

4.2.3 Dealing With Images in MATLAB

Images are represented as an array of data structure in MATLAB, thus working with images is comparable to working with any other data in MATLAB. Most images are stored as a two-dimensional array in which each element of the matrix corresponds to a single pixel in the image. On the other hand, RGB images require a three-dimensional array where in the third dimension, the first, second and third planes represent the red, green and blue pixel intensities. The image is interpreted according to the numerical class in which the data is stored: double-precision floating-point (double), 16-bit unsigned integer (uint16) and 8-bit unsigned integer (uint8). Images stored in double-precision (64-bit) floating-point numbers require a very large memory and are not always ideal for storing images. Thus, it is of recommendation to store images as 8-bit or 16-bit unsigned integers that require one-eight or one-fourth, respectively, as much memory as double precision numbers.

There are three basic data types used in MATLAB in accordance with interpretation of the data matrix of the image: indexed, intensity and RGB image. An indexed image consists of a data matrix and a colormap. The colormap is automatically loaded with the image when the *'imread'* function is used. An intensity image is a data matrix whose values represent a range of intensities of the pixel values. An RGB image on the other hand is represented as an m-by-n-by-3 data array that defines the red, green and blue colour components of each pixel. Thus, the colour of each pixel is stored as a combination of the intensities of the red, green and blue components of colour planes at each pixel's location. The *'imread'* function is used to read an image for processing an image, the *'imwrite'* function is used to write an image and the *'imfinfo'* function is used to obtain information about the image.

MATLAB supports the following graphics file formats:

- BMP (Microsoft Windows Bitmap)
- HDF (Hierarchical Data Format)
- JPEG (Joint Photographic Experts Group)
- PCX (Paintbrush)
- PNG (Portable Network Graphics)
- TIFF (Tagged Image File Format)
- XWD (X Window Dump)

The essential properties of an image in MATLAB are the CData, XData and YData. The CData property determines whether the image will be interpreted as an RGB image or as a colormap image. If the CData array is two-dimensional, the image is interpreted either as an indexed image or an intensity image and in each case, the colormap colours are used. If the CData has a dimension of m-by-n-by-3, the image is displayed as an RGB image.

CHAPTER 5

METHODOLOGY

The development of the component for goGPS software was carried out using the well-known waterfall approach for software development. This was necessitated to measure progress and keep track of the development from the start to the finish of the work. As the development proceeds, new and implicit goals emerge (Tang and Vliet, 2012) with sub goals that need to be solved to enhance the final output of the work. Changes to the output of previous stages on the waterfall line were made whenever a new requirement emerged. More so, results in each stage were communicated to GReD s.r.l. and based on the feedback, subsequent steps were taken or updates were made to the requirements.

After its completion, the visualisation tool was used to investigate an incident at Malpensa Airport in which Emirates' Boeing 777-300ER (A6-ECF) was damaged by hail storm and returned to Milan 90 minutes after taking off to John F. Kennedy (JFK) International Airport in New York City. The incident happened on July 13, 2021.

5.1 Feasibility study

At this stage in the development process, it was assessed whether the requirements for the project could be feasibly achieved. In order to achieve something comparable to what can be found on most weather prediction maps (example in Figure 25), the following questions had to be answered

- Is it possible to add an image or icon that represents different weather phenomena to a plot in MATLAB?
- Is it possible to add weather parameters such as humidity, temperature, pressure, etc. to a plot in MATLAB?
- Is it possible to display weather information for more than a day on a plot in MATLAB?
- Can the expected system be built at all?

- If it can be built, how long will it take to complete it?

Thanks to the guide provided by MATLAB on adding graphical objects to a plot, where it is explained how additional information can be added to a plot, the project was found feasible. However, there had to be a trade-off of time for its realisation.

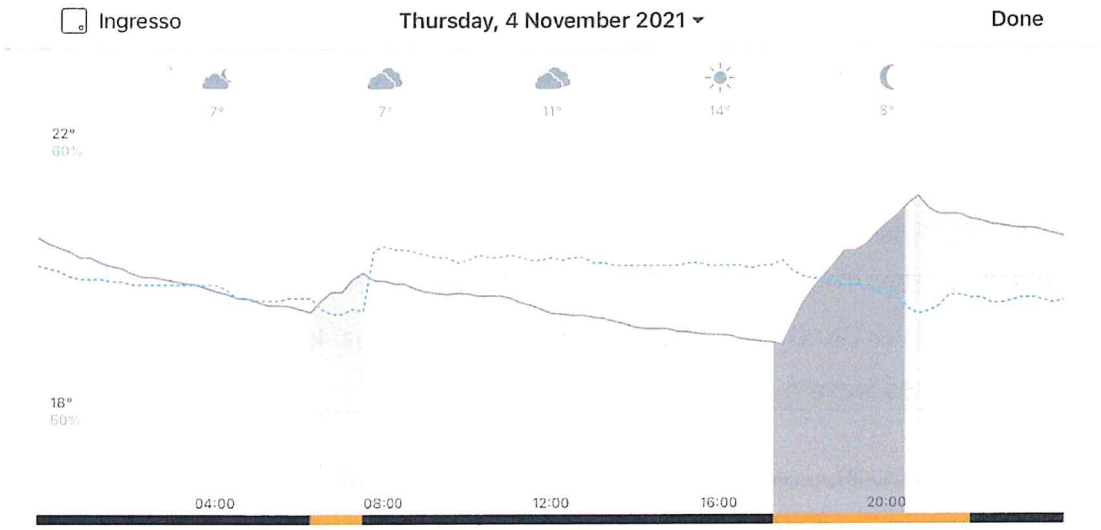


Figure 25 ***Weather prediction map interface of termostat app***

5.2 Requirements identification

During the description of the problem to be solved, that is developing an explanatory tool for goGPS, GReD s.r.l. provided initial 'MUST HAVE' requirements to be met. However, other 'SHOULD HAVE' requirements were also identified during the development stage and were agreed upon with GReD s.r.l. Below are listed the requirements the tool seeks to satisfy.

- Given any specified location in the world, it is required to obtain weather information to be shown on the plots of goGPS.
- Given any date of the past, retrieve the weather data.
- The data to be used has to be obtained from the DarkSKY API.
- It is required to show the type of weather (e.g. rainy, snowy, Sunny, etc.).
- Other parameters useful to be shown on the plots include temperature, humidity, pressure, wind speed, wind direction etc.

- The user should be able to display the parameters using a menu item.
- The user should be able to hide or show desired parameters by accessing the menu items.
- The user should be able to hide or show all the parameters by accessing the 'show ALL' item in the Meteo-menu.
- The system has to be developed as an explanatory tool for the plots produced by goGPS software.
- The system has to be adaptable for all estimates derived from GNSS observation data.
- The system has to be used by the users of goGPS software, thus, researchers, students, Meteorologists, etc.

5.3 Design

To meet the requirements found, the components needed for the development of the explanatory tool for the plots were identified as follows:

- Meteo-Menu: This component provides a means of access to the various functions available to the user. The menu will contain the various items for displaying the necessary weather parameters on the plot. It depends on the availability of an existing figure (containing plot of goGPS).
- Figure component contains a plot on which the weather parameter needs to be shown. It is essential for the figure to contain a line plot, having a starting and ending point that define the period in which the weather parameters are needed. Also, the Figure component should contain location information (latitude and longitude) about the station being monitored or analysed. Upon this plot, the Data Manager component will either add or remove the weather parameters.
- The Data Manager component contains the essential functions that, given the starting and ending time from the Figure component, draws the graphical objects for the various weather parameters on the Figure component. It also provides a means for removing the displayed weather parameters from the plot.

- The Data Source component refers to the DarkSKY API and Open Topo Data API that provide the data used by the Data Manager component.
  The DarkSKY API has the advantage of providing data that covers the globe, is historical, gives forecast and present weather conditions. Also, it displays its data on the web making its data easier to be read using the webread function of Matlab. Alternatively, other APIs that offer weather data are the Meteoblue weather API and the Global Surface Summary of the Day (GSOD) of the National Oceanic and Atmopsheric Administration. An API key is required to be purchased before the weather dataset of Meteoblue can be accessed. GSOD requires its dataset to be first downloaded in a CSV format. Thus, the DarkSKY API was the API of choice for the purpose of this work.
  The Open Topo Data API provides the geodetic height for a given station given its geodetic coordinates. It provides a global elevation dataset (including bathymetry and ice surface elevation near poles) developed by the National Oceanic and Atmospheric Administration (NOAA). It has an estimated accuracy of about 10m, which vary spatially depending on the underlying source data. Other APIs that offer similar elevation data and could be relied upon in case of failure of Open Topo Data API are the National Geodetic Survey API, Open-Elevation API and Google Maps Elevation API. The Open Topo Data API is free and has public access without API key requirement.

The component diagram (Figure 26) shows the various components, with the arrows indicating the dependencies between them. Figure 27 also identify the properties and methods available for the various identified components

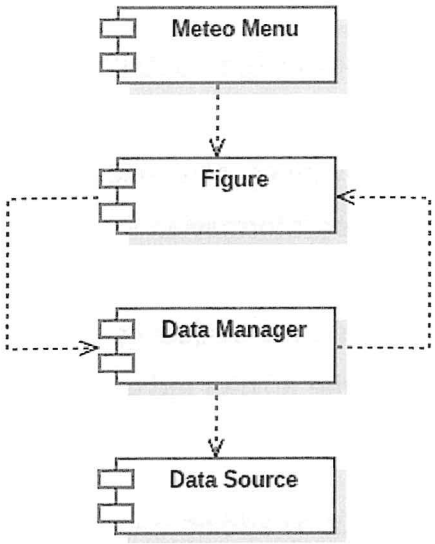


Figure 26 ***Component diagram***

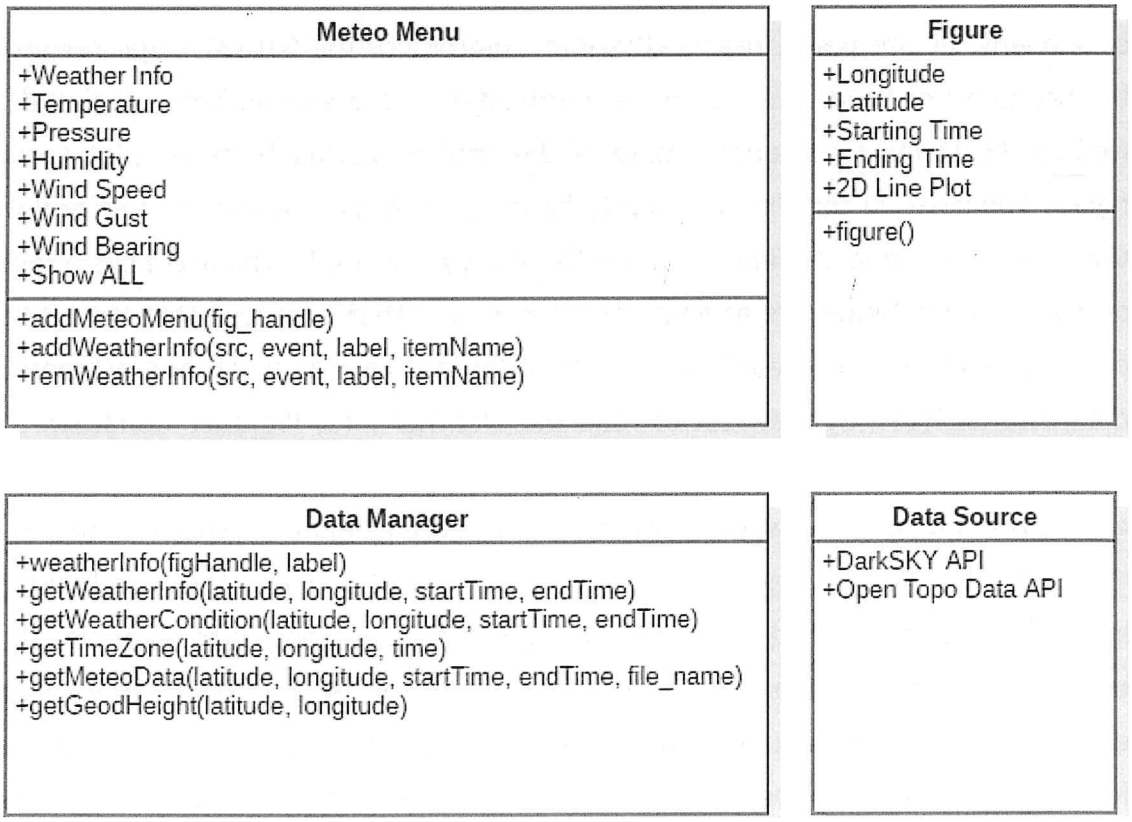


Figure 27 ***Component interfaces***

5.3.1 Sequence Diagram

To better understand the expected output and before commencing the implementation of the system, a sequence diagram (Figure 28) was created to show the interaction between the various components of the system for adding or removing the weather parameter information from the figure. The components are shown as vertical dashed lines. The horizontal direction shows the components, the vertical dimension shows with time sequence the order of message exchange between the components and the arrows indicate the message exchange between them. The rectangles indicate the period in which a component is active in a session.

The user instantiates the process by adding the Meteo Menu to the figure by calling the addMeteoMenu() method of the Meteo Menu component. The Meteo menu item contains the sub items labelled 'Weather Info', 'Temperature', 'Pressure', 'Humidity', 'Wind Speed', 'Wind Gust', 'Wind Bearing' and 'Show ALL'.

By selecting any of the items, the addWeatherInfo() method of the Meteo Menu component is activated, which gives the handle of the figure to the Data Manager component. At this point, the weatherInfo() method of the Data Manager retrieves the position (longitude and latitude) coordinates of the station being analysed as well as the starting and ending time of the analysis period from the plot on the figure. The position coordinates have to be in the WGS 84 reference system and the time values as string of numbers in the format 'yyyy-MM-dd'. The acceptable range of position coordinates are as given in Table 4. It is thus expected that the 2D line plot will be produced at least from a GNSS related data. The weatherInfo() method then uses an HTTP Get request to read the Weather Info, Weather Condition and Time Zone data from the Data Source, (DarkSKY API), using respectively the getWeatherInfo(), getWeatherCondition() and getTimeZone() methods of the Data Manager. The data is read in an HTML format. At this point, the weatherInfo() method parses the raw data by extracting the relevant ones and performs data cleaning by removing the unwanted characters. However, the time values in the extracted data are in Unix Time format, which is inconsistent with the MATLAB time format, used for the plots in goGPS. Hence, they are converted to MATLAB time format (the number of days since January 1, 0000) by calling the GPS_Time() method of goGPS. The updated time information is then used with the other data to create

the graphical objects. Depending on the label on the menu item which was selected from the Meteo Menu, the graphical object is displayed on the plot. The displayed graphical object contains information about the corresponding weather parameter. Finally, the checked property of the selected menu item is set to 'ON' status.

In addition, the getMeteoData() method of the data manager accesses the weather data retrieved from the DarkSKY API and the getGeodHeight() gets the elevation data for the station from the Open Topo Data API. These data are then used as input for methods available in the Meteo_Data object of goGPS for the generation of the rinex (i.e. Receiver INdependent Exchange (RINEX)) meteorological file.

Similarly, with the intention of removing a displayed graphical object from the plot, the user selects the corresponding checked menu item. The Figure component calls the remWeatherInfo() method of the Data Manager. The remWeatherIfno() method then gets the label of the menu item and the handle of the figure and removes the appropriate graphical object from the plot. Finally, the checked property of the respective menu item is set to 'OFF'.

Table 4 ***Acceptable Range of Position Coordinates***

Parameter	Minimum	Maximum
Latitude (Deg Decimal)	-90	90
Longitude (Deg Decimal)	-180	180

5.4 Development and testing

The implementation of the tool commenced using the bottom up approach. This was used, instead of the top-down approach, due to its flexibility for developing the units, ensuring that they produce the right results before integrating them with goGPS.

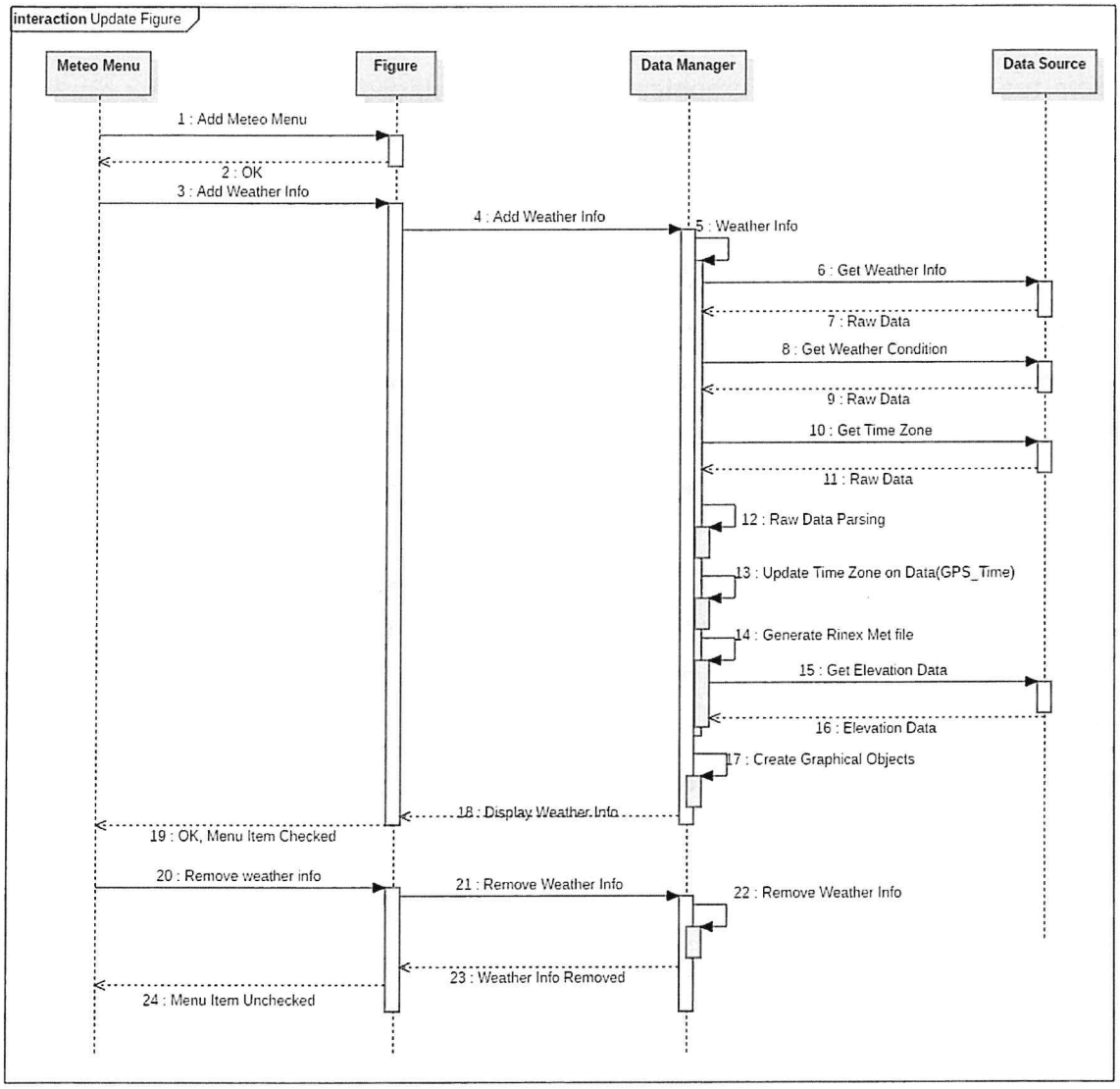


Figure 28 ***Sequence Diagram***

This section was divided into two major parts, implementation and testing of the various units and then integration and testing of the various units on the goGPS platform. The testing was carried out concurrently with the implementation phase due to the necessity of ensuring that the various units are error free and provide the right results in accordance with the specified requirements. This made it easy getting the units available and ensuring their smooth integration with the goGPS system.

5.4.1 Implementation of unit components

In this section, the components identified earlier were implemented in two steps:

i. Preparation of the data
ii. Visualisation of the data

A defensive approach was used at all stages of the implementation to handle cases where the end-user might attempt to use the program incorrectly.

Preparation of the data

At the data preparation stage, the Data Source component was developed. To start with, there was a need to create a temporary visualisation of the output of the webread() method of MATLAB to identify the necessary section where the needed data are (Figure 29). This was done using an arbitrary location and period.

Figure 29 ***Output of webread, needed data are highlighted red***

Some of the needed data were found to be in JSON format. There was a need to organise them in a structure that would be easier to use for creating the graphical objects. To create the structure out of the raw data, two major functions in MATLAB

were identified, jsondecode and cell2struct. As the name suggests, jsondecode decodes JSON-formatted text as MATLAB data type: empty double, scalar logical, scalar double, character vector, scalar structure, cell array, structure array, etc. On the other hand, cell2struct converts a cell array into a structure array. Through several trial and error, the cell2struct method was found very easy to be used for the purpose, thus, it is further discussed.

The cell2struct method accepts three input arguments: cellArray, fields and dim. The cellArray ~~is~~ contains the data that needs to be converted to a structure array. The field argument specifies the field names for the resulting structure array. This could be specified as a character array, a cell array of character vectors, or a string array. The dim argument on the other hand indicates which axis (row or column) of the array to be used for the structure array.

If the rows of the cell array are to be used as field names for the output structure, then the field names are to be specified such that the number of fields is equivalent to the number of rows of the cell array. In this case, dim will have a numerical double value of 1. However, if the columns of the cell array are to be used as field names for the intended structure, then the field names are specified such that the number of columns of the cell array is equivalent to the number of fields of the expected output structure. In this case, dim will have a value of 2.

Data cleaning

Here, the implementation of the Data Manager component began. Before using the cell2struct method, the raw data obtained from DarkSKY API was an HTML file with embedded JavaScript section. This implies that it contains data that are not relevant for the purpose of displaying the graphical objects on the plots. The useful information was found in the JavaScript section by visual inspection of the output of webread on the command window, as highlighted in Figure 29. This was parsed by extracting the data from the JavaScript section and then removing unwanted characters such as ' " ', ':' and '-'. The key names of the JSON formatted texts were used as field names for the expected structure. The values of the JSON formatted

texts were also supplied as values for the structure. Since in the cell array of the cleaned data the rows indicate the time sequence of observation data, a value of 2 was specified for the dim argument in order for the field names of the structure to be extracted from the columns of the cell array. The procedure was repeated in the getWeatherInfo(), getWeatherCondition() and getTimeZone() methods of the Data Manager components for retrieving the weather info, weather condition and time zone values. The outputs of the getWeatherInfo() and getWeatherCondition() methods are in a structure while that of getTimeZone() method is a numeric double data type.

The weather info refers to the values for the weather parameters such as temperature, pressure, humidity, wind speed, etc. These contain the needed information to be displayed on the plot. The weather condition refers to the condition of the weather for the epoch in which the station analysis is being made. Some of the possible values are overcast, clear, partially-clear-night, sunny etc. These are needed to select an icon for representing the weather during visualisation of the data on the plot. The time zone value represents the time zone in which the position coordinates of the station falls. This is very essential to appropriately convert the UNIX time of the cleaned data into MATLAB time in the weatherInfo() method otherwise, the position of the graphical objects will be shifted with respect to the true time-position on the plot.

At this stage, the weatherInfo() method of the Data Manager needs to be created. However, as the weatherInfo() method needs to display the graphical objects on a plot in a figure, a stub of the figure needed to be created. This was very essential as the figure on which the graphical objects are to be displayed are components of the goGPS system and only available at the integration stage. It is expected that the figure will contain a 2D line plot on which the Meteorological information is to be displayed as an explanatory tool. Thus, the stub created depicts this feature.

Once the data have been cleaned, prepared and made available in a structure, and the getWeatherInfo, getWeatherCondition and getTimeZone units are ready, the next step of the unit's implementation, i.e. visualisation of the data, begins.

Visualisation of the data

At this stage, the weatherInfo() method of the Data Manager plays a key role and its functionality is realised. It begins by obtaining the handle of the figure on which the graphical objects are to be plotted. Although the labels of the sub menu items of the Meteo menu are being used by the weatherInfo() method as input argument (as shown in the component diagram in Figure 27), a stub of the Meteo Menu component is not necessarily needed. The Meteo menu component is only needed at the integration stage.

The method retrieves the coordinates of the station being analysed from the figure. If no such information is available, the program aborts, the method returns and an error message (Figure 30) is thrown to the user in modal mode. This implies that all other operations on the figure are paused until the user attends to the message.

Figure 30 ***Support error message***

It then finds the starting and ending time information of the line plot from the axes on which the graphical objects are to be displayed. With the time and position information at hand, the getWeatherInfo(), getWeatherCondition() and getTimeZone() methods are called to retrieve the Meteorological information from the DarkSKY API. It also calls the GPS_Time method of goGPS to update the time data with the time zone in which the station falls.

Using the weather conditions, the appropriate icons need to be selected and rightly set for display, thus the next step is to choose and set the size of the icons.

Choosing the Icons

The icons used for representing the various weather conditions are similar to that published by Yangtze (2021). These contain representations of most weather phenomena. These icons were too large in size for this purpose, requiring a large amount of memory size. Images in MATLAB have a CData property that contains the actual data for the pixels of the image. According to the guidelines for using graphical objects in MATLAB, to increase the rate at which MATLAB can update the CData property of an image object you can optimise CData using the guides below

i. Use the smallest data type possible. Using a uint8 data type for an image will be faster than using a double data type.
ii. Use the smallest acceptable matrix.
iii. If the speed at which the image is displayed is of highest priority, you may need to compromise on the size and quality of the image. Again, decreasing the size will reduce the time needed to copy the matrix.

Thus, to ensure faster loading of the images and reduce the size of memory required to store them, it was essential to redesign the icons using the symbols specified by Yangtze (2021). For each icon, a dimension of 120 pixel by 120 pixel units were specified at a resolution of 100 pixels per inch. This ensured a uniform dimension of the images with an average size of 3.76 KB, which was considered very useful to store all the images and for multiple images to be loaded at the same time without delay. Additionally, a transparent background was set for all the images so that only the required symbol for the weather phenomena will be on display without background effect.

However, when analyses are being made for station data that spans two days or more, the icons appear to be crowded on display, with same images being repeated multiple times and thus too much for the plot box region of the axes. Thus, a generalisation of similar and consistent icons had to be produced, using patches with unique solid face colours to represent each icon. The patches have the same height as the icon, with the width spanning across the number of consistent and similar icons in the data. This generalisation effect was thus considered effective for

stations that have more than 30 hours of observation data. Finally, the icons are stored as 8-bit RGB images for easier handling in MATLAB.

A major setback that was faced was that, the X-axis and Y-axis properties of the axes on which the images were to be displayed have different data units, with the X-axis having units of time and the Y-axis having data unit depending on the type of data being analysed over the station. Thus, it was essential to control the aspect ratio of the images so that they will be displayed correctly, with similar height and width irrespective of the unit of data being used for the Y-axis.

Controlling Aspect Ratio and Display Size of Icons

Because the axes on which the icons are to be shown have different units, there was a need to perform transformation (Figure 31) in order to preserve the aspect ratio of the icons. This was done with respect to the constant time unit on the x-axis that is common for all other monitoring (observation) data and by exploiting the pixel units for the screen on which the figure will be shown. By this means, it will be possible to create equal width and height values for the icons, for them to be correctly displayed on the screen.

The width of the icon was determined in the original unit on the x-axis and then converted to pixel units. An equal dimension of width in pixel units was also set for the height in pixel units. Then the height was converted to the original unit on the y-axis. This helped keep the aspect ratio and sizes of the images the same on display, irrespective of the units on the y-axis.

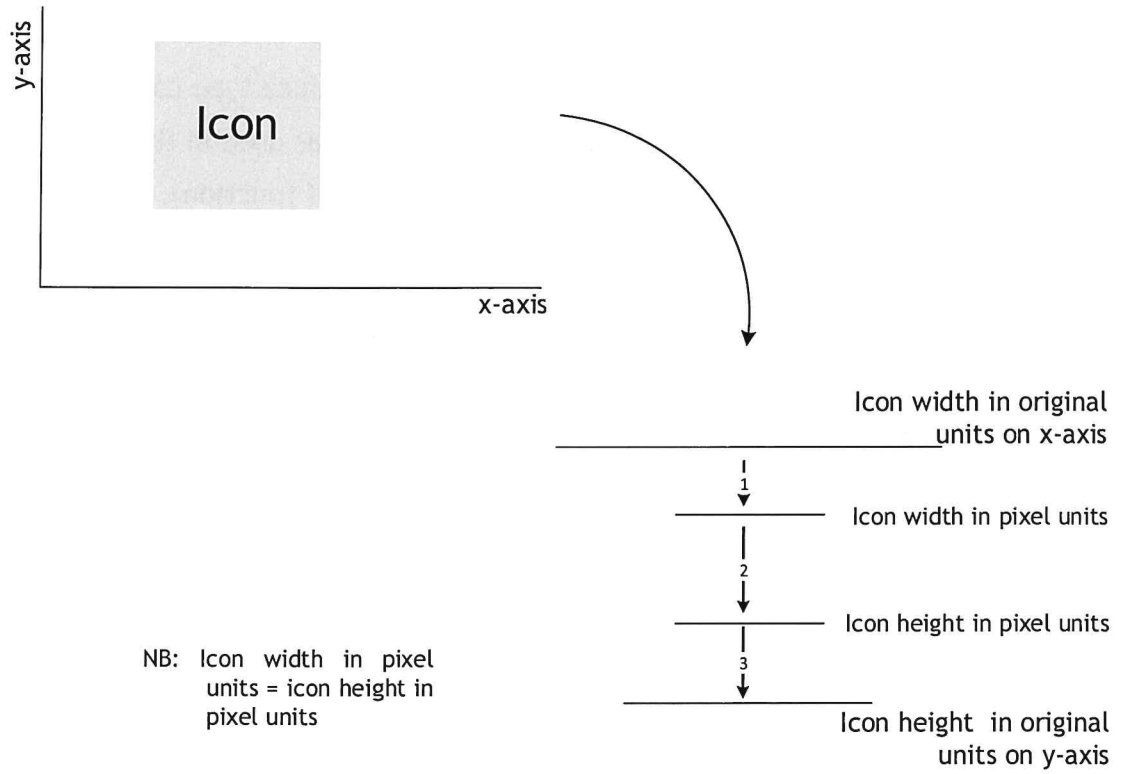


Figure 31 ***Transformation of Icon Dimensions***

Displaying the icons

The icons are then loaded into MATLAB using the syntax below where 'image name' is the name in which the image is saved.

```
imread('image name')
```

Afterwards, the image can be displayed. To properly display the images on the plots, it was essential to identify a container for them. Two graphical objects, Patch and Surface, were identified to be possible candidates to contain the images.

Patches are filled 2-D polygons that are positioned and oriented using the coordinate system of the axes object. A single patch can be coloured with multiple face colours. A patch can be created using the patch function. Surfaces are 3-D representations of matrix data created by plotting the value of each matrix element as a height

above the X-Y plane. They are composed of quadrilaterals whose vertices are specified by the matrix data. Also, the coordinate system of the axes positions and orientates the surface objects. A graphical object of the surface type can be created using the surface or surf functions. The surface function was used in this work as 3-D view was not needed for this work (required with the surf function).

Through several trial and errors, the surface object was found efficient to contain the images. Thus, the CData of the image was supplied as an input argument to the surface object and a height value of zero (0) above the XY plane. The syntax below was used to create the surface object.

```
surface(ax, [x1, x2; x1, x2], [y2, y2; y1, y1], zeros(2), ...
    'FaceColor', 'texturemap', ...
    'EdgeColor','none', ...
    'CData', im, ...
    'CDataMapping', 'direct', ...
    'AlphaData', alpha, ...
    'FaceAlpha', 'texturemap');
```

where ax is the parent axes object in which the surface is to be displayed, CData and AlphaData are the corresponding properties of the object. The other arguments are corresponding Property-Value pairs of arguments needed for creating the surface object. Of worth noting among the arguments is the FaceAlpha argument. This property sets the transparency of the surface. In MATLAB, there are four possible values that could be set for this property, which are a scalar value, flat, interp and texturemap. The scalar values could be in the 0 and 1 range, which represent fully opaque and completely transparent respectively. The flat value uses a different transparency value based on a specified AlphaData property. The 'interp' value interpolates the transparency for the face also based on a specified AlphaData property. The 'texturemap' property transforms the data in AlphaData so that it conforms to the surface. Since it was expected that the textural appearance of the

image would be maintained on display, the texturemap value was chosen as a suitable value for the FaceAlpha property of the surface object. As it was necessary to generalise the similar and consistent weather phenomenon type, the patch object was used for representing the icons, as previously discussed, using the syntax below

```
patch(ax, posX, posY, col);
```

where ax is the parent axes in which the patch object is to be displayed, posX and posY specify the position coordinates of the object, and col define the face colour to be used to represent the particular weather phenomena. Whenever a change in the icon type occurs in the observation period, the patch colour is correspondingly changed. To be able to interpret the different colours in accordance with the type of weather phenomena, a legend object was created to give interpretation to the various colours used for the patches in relation to the weather conditions available for the period of observation. A complete list of the icons and their colours are presented in Appendix I. The patches and surface objects have been created specifically for the 'Weather Info' item of the Meteo menu. The patch objects are shown for station analysis containing more than 30 hours of observation data and surface objects are shown for observation containing less than 30 hours of data.

Displaying the text objects

The other weather parameters such as temperature, pressure and humidity have values, which are of numerical data type and need to be converted to strings for display. Afterwards, these data values are displayed on the plot using the text function, parenting the text object to the axes object containing the plot. Graphical objects of the text type are character strings that are also positioned according to the coordinate system of the axes object in which it is to be placed. The text objects (containing the parameter values) are displayed with one hour spacing, with the corresponding weather parameter label (as shown in Figure 4). Thus, their positions are specified with a constant value on the Y-axis and the corresponding time values on the X-axis. The text object creation syntax is given below:

```
text(ax, posTX, posTY, parameterValue, 'Clipping', 'on');
```

where ax is the parent axes object

posX and posY are the x and y position coordinates for the object, the posY value remains fixed while the posX values are updated every hour to display the new value of the weather parameter.

parameterValue, formally labelled as the String property of the text object, is the value of the weather parameter to be displayed as a string character.

To avoid displaying the parameter values beyond the boundaries of the axes object, the 'Clipping' property of the text object has been set to the 'ON' state. By default, the horizontal alignment property of the text objects is set to the left position. However, for the text objects used for the labels of the weather parameters, they are positioned with a right horizontal alignment to avoid overlap with the starting values of the weather parameters.

It is important to note that for all the graphical objects used to add weather parameters to a plot in goGPS, a tag was specified for identifying the object according to the label of the item selected from the Meteo menu. A tag is a user-defined string that can be associated with a graphical object for identification.

The order in which the parameters are displayed on the screen

To avoid overlapping of the graphical objects, the objects are positioned for the weather parameters on a basis of first selected, first displayed. Thus, the objects are displayed depending on which item is selected first from the Meteo menu. Also, it is possible to display all the parameters using the 'Show ALL' item of the Meteo menu. A constant value depending on the units of the Y-axis has been set to separate the parameters on display, with an hour spacing on the X-axis.

Setting the axis limits

Because MATLAB automatically scales an axes to encompass a line plot, in most instances, the graphical objects will be displayed outside the bounds of the axes

object. Thus, it was necessary to update the axis limits of the plots in order to make room for the graphical objects to be visible when a menu item is selected. This was performed using the function call below:

```
xlim([xmin   xmax])

ylim([ymin   ymax])
```

where xmin and ymin are the new bottom left coordinates for the axes boundary and xmax an ymax are the top right coordinates of the axes bounds.

Creating legend for the patch objects

The plots in goGPS are produced with a default legend based on the graphical objects displayed in the parent axes. To be able to create a legend for the patch objects, another axes object needed to be created. This is because MATLAB has the limitation of creating only one legend object per axes object. Thus, a copy of the existing axes in which the patch object has been displayed was created, hiding all its contents. To define the data content of the legend, the following steps were followed and summarised in Figure 32.

i. Create a vector containing unique icons in the icon types returned by the data of DarkSKY API.
ii. Specify the colour for each icon type in the unique icon set
iii. Create an empty vector of patch colours, patch objects, and icon names to be used for the legend. Each of these vectors has to have a length equal to the length of the set of unique icons created in step I above.
iv. At an epoch in which each parameter is to be displayed, obtain the icon to be used.
v. Find the index of the identified icon in the unique list and obtain its corresponding colour from the unique set of icon colours.
vi. Create the patch object with the icon colour as face colour.
vii. If the icon colour is not a member of the vector of patch colours, add it to the patch colours vector at the index of the icon obtained in step v.

viii. Add the handle of the patch object, whose colour has just been added to the vector of patch colours, to the vector of patch objects also at the same index as the index of the icon colour obtained in step v.

ix. Add the name of the icon to the vector of legend icons, also at the same index as the index of the icon obtained in step v above.

x. Create the legend object using the legend function of MATLAB, specifying as input arguments the vectors of patch objects and legend icons.

xi. If the number of hours in the data set is more than 30 hours, show the legend, otherwise hide it. This is necessary to ensure that the legend is displayed only when generalisation with the patches is being used to represent the weather information.

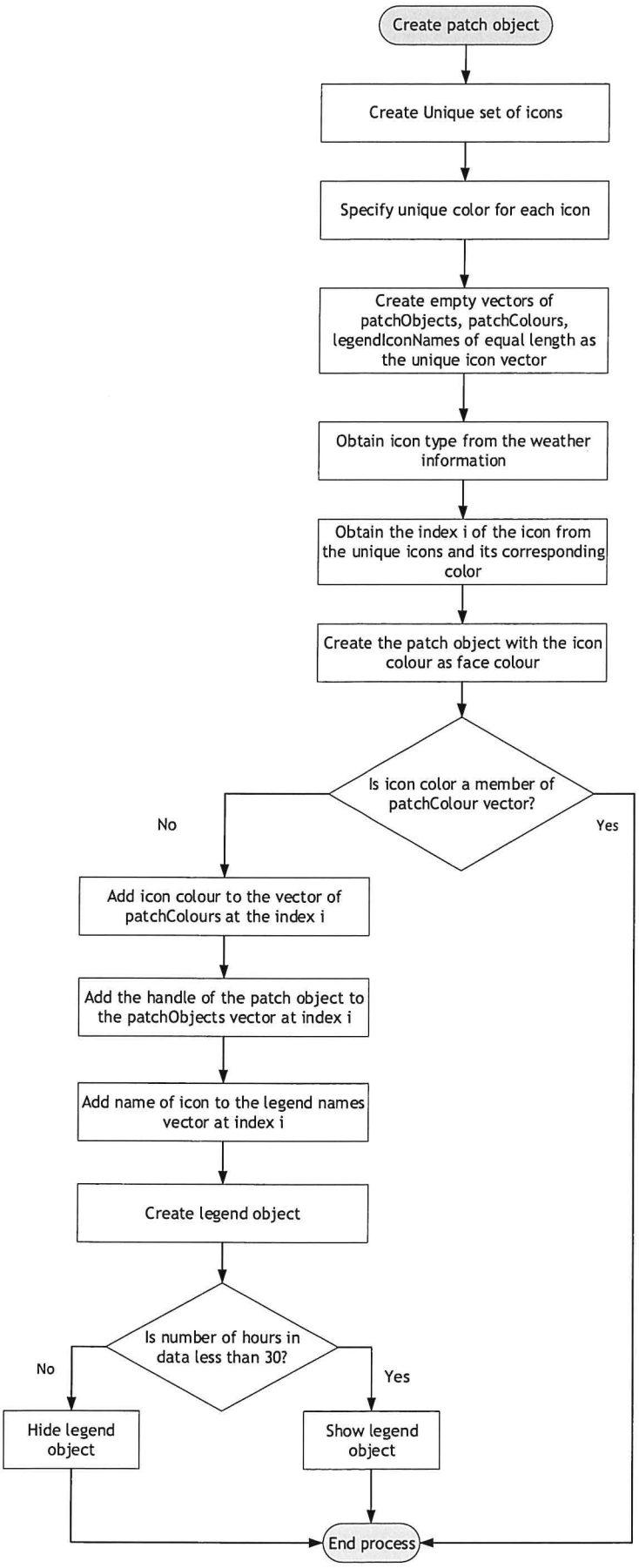


Figure 32 ***Creating legend object for the patch objects***

Removing a graphical object

By selecting an item from the Meteo menu list, its checked property is turned on and the corresponding graphical object is displayed on the plot. By selecting a checked Meteo menu item again, its checked status has to be turned off and this was implemented as follows. Using the label on the selected item, the tag on its corresponding graphical object is searched from the descendants of the parent figure. The tag identifier on the object is used as an input argument for the findobj function to find the handle of the graphical object. Then, the corresponding object is deleted passing the handle of the object as an input argument for the delete function. Then the checked status of the object is turned off.

5.4.2 Integration with the goGPS system

The developed units were integrated with the goGPS system using the bottom-up approach. This means that the components that do not depend on any other component start the integration, then successively, other components that rely on the independent or other components are integrated. The component relationship is shown as a dependency diagram in Figure 33. Here, the light blue coloured components are the newly developed components while the light green components are the components existing in the goGPS system. The methods and attributes of the newly developed components are as shown in the Component interface diagram in Figure 27. The methods and attributes of the existing goGPS components being accessed are shown in the dependency diagram in Figure 33. However, for the sake of space, only the components of goGPS that are being used in the integration are shown in Figure 33. The integration plan is executed using the following steps.

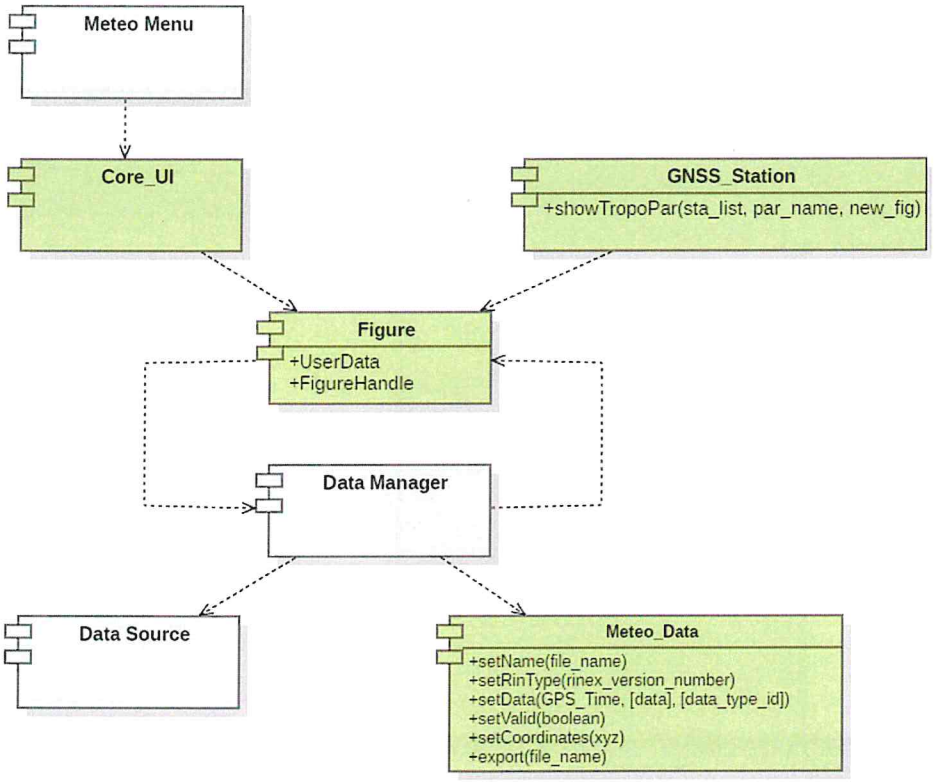


Figure 33 ***Dependency Diagram***

- Step 1

The Data Manager component is integrated with the Data source component using arbitrary latitude and longitude station coordinates and arbitrary starting and ending times (Figure 34). This is to ensure that the data structure is available for the figure later on.

Figure 34 ***Integration Step 1***

- Step 2

The figure component is made available by selecting any of the plot (Figure

35) from the goGPS after post processing

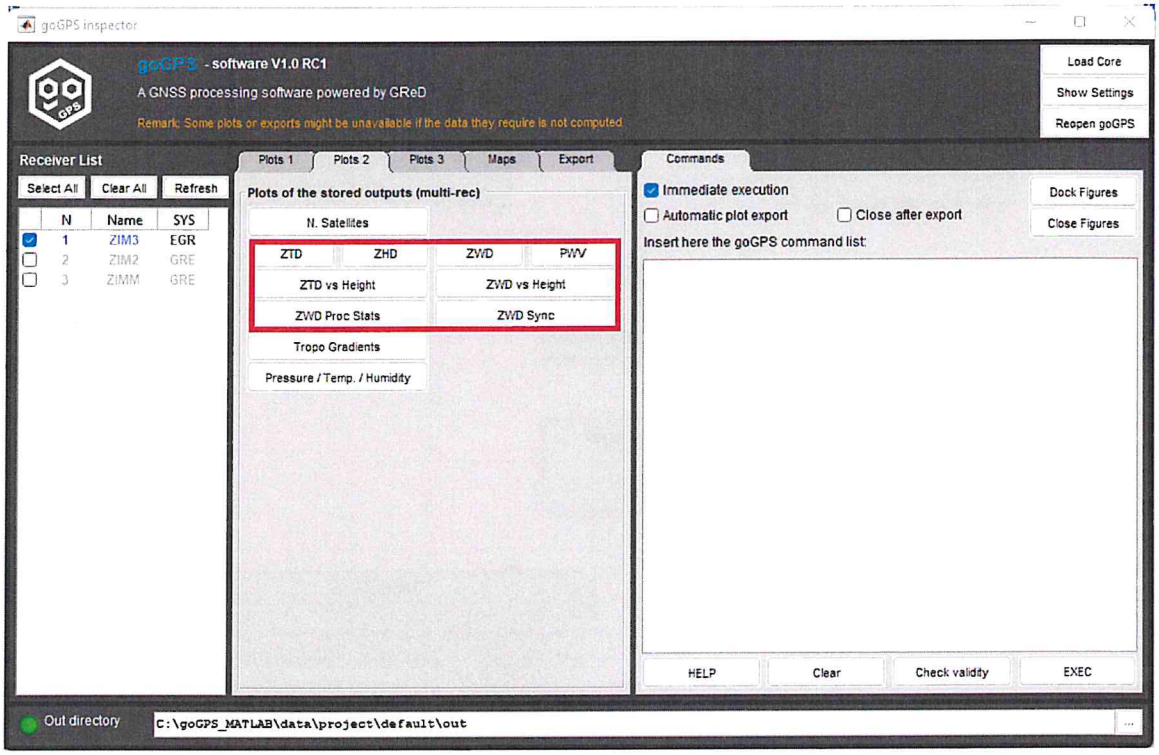


Figure 35 ***Available plots in goGPS***

- Step 3

The showTropoPar() method of the GNSS_Station component is modified using the expression below. It gets the mean of the geodetic coordinates of the station from the coordinates of the station made available after post processing. The geodetic coordinates are the longitude and latitude coordinates of the station obtained from the post-processing of the GNSS data. It then adds these coordinates to the UserData property of the Figure component using its handle (Figure 36).

```
[lat, lon] = sta_list(1).getCoo.getMedianPos.getGeodetic();

f.UserData = struct('fig_name', fig_name, 'coordinate', [lat, lon]);
```

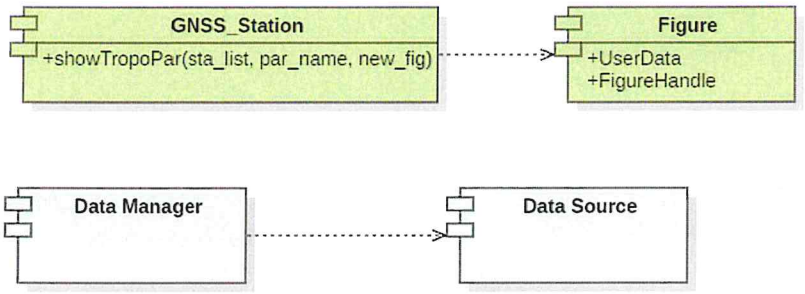


Figure 36 ***Integration Step 3***

- Step 4

At this stage, the Meteo menu component is integrated with the Core_UI component, which adds the menu item 'Meteo', and its sub-items to the figure (Figure 37).

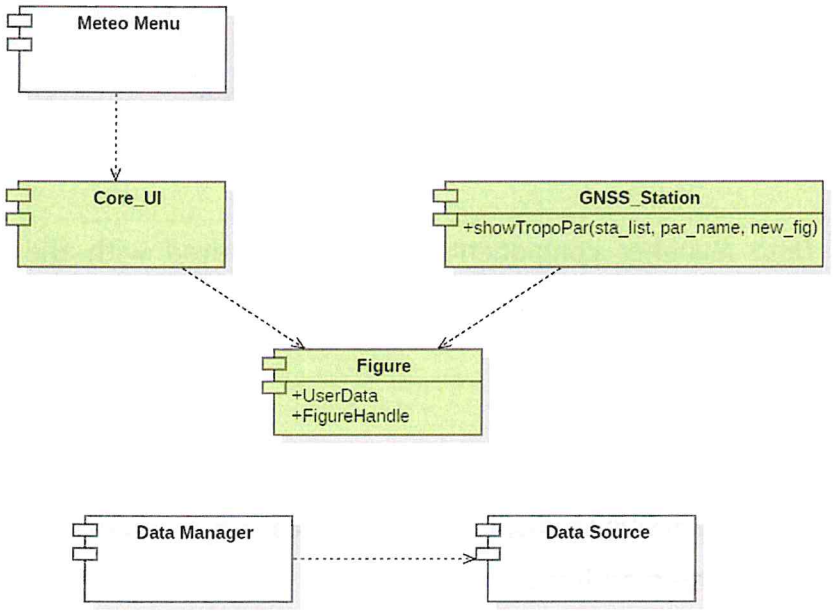


Figure 37 ***Integration Step 4***

- Step 5

At this step, by using the label(s) of the sub-items of the 'Meteo' menu item, the Figure component is integrated with the Data Manager component.

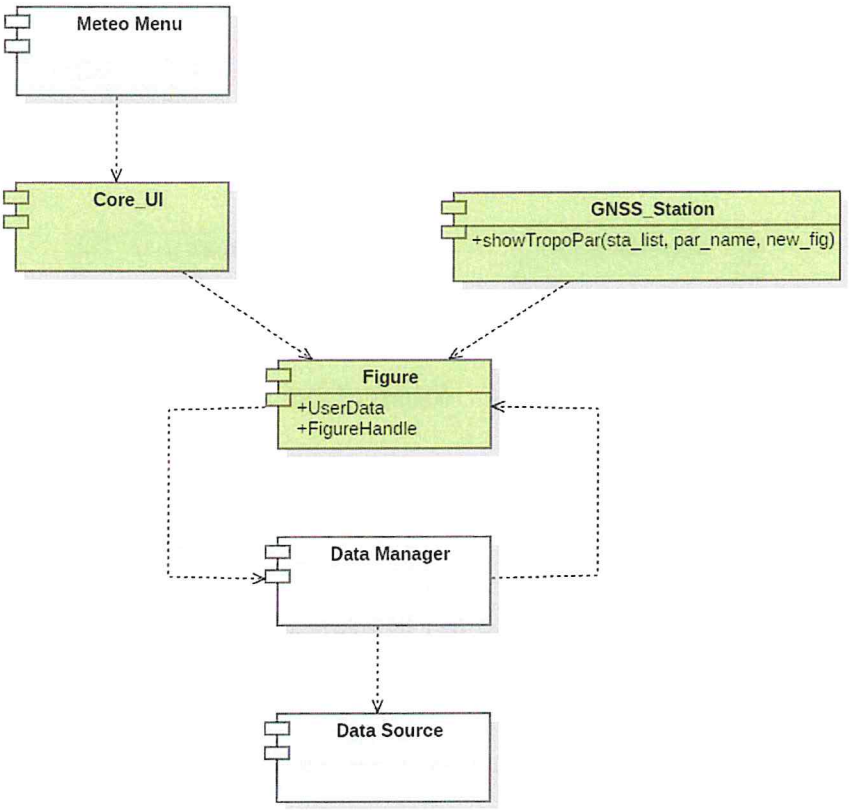


Figure 38 ***Integration Step 5***

- Step 6

Finally, the Data Manager component is then integrated with the Meteo_Data component of goGPS (Figure 35) to complete the system integration (Figure 38).

After the integration, the Meteo menu and its sub-items are available and the user can select any of the items to display the graphical objects (weather parameter) associated with the selected item.

To ensure confidence in the developed system, lots of tests were carried out and are described below.

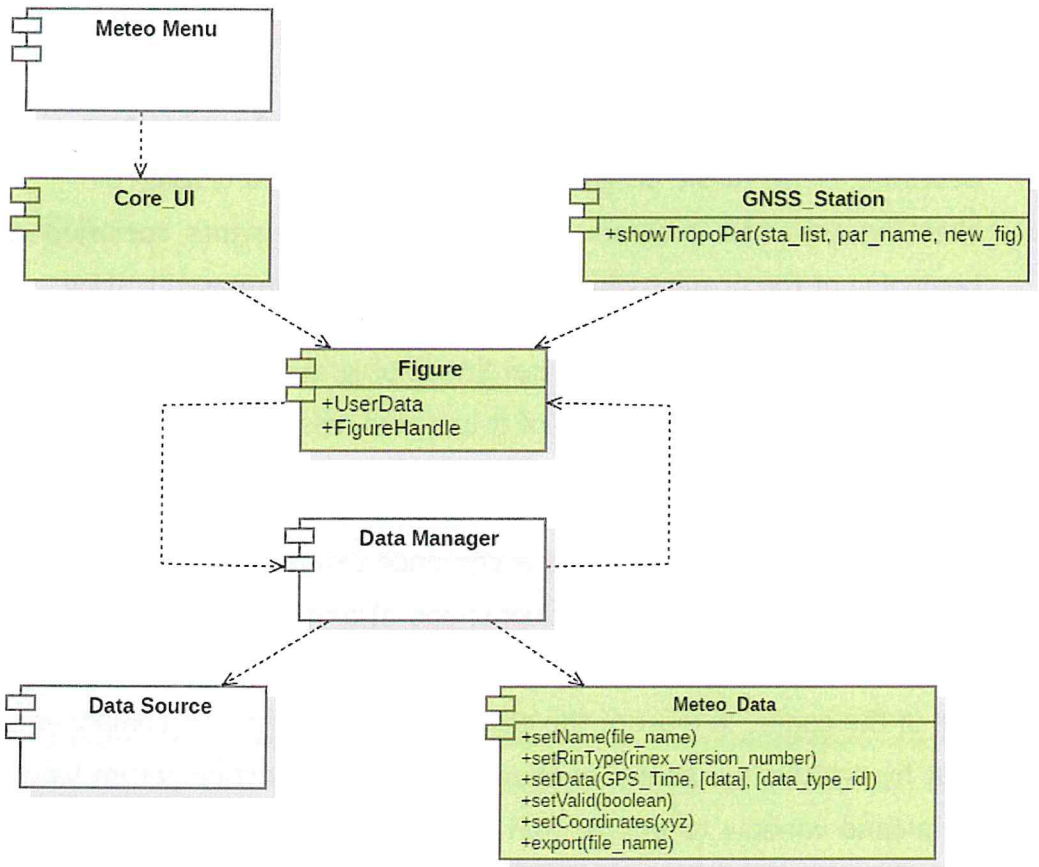


Figure 39 ***Integration Step 6***

5.4.3 Testing

Of major importance in the execution of a software project is the satisfaction and reliability of the end-product in meeting the demands, requirements and specifications of the end-user. The end-product thus needs to be tested to ensure that it is free from errors, faults and failures before being released to the end user. Testing of a software means executing the end product of a software project to see whether it produces the correct output for a given input (Vliet, 2007). This involves the use of a set of test cases which according to the IEEE standard for software development is a set of test inputs, execution conditions and expected results developed for a particular objective, such as to verify compliance with a specific requirement. The set of test cases may be derived from the specifications of the software, in which case it is known as black-box testing, or derived from the

implementation of the software, in which case it is known as white-box testing. In similar vein, the technique to be used could be based on

i. detecting faults in the program also known as Fault-based testing,
ii. detecting errors in the program known as Error-based testing or
iii. checking that the program satisfies the requirements specified at the beginning of the project which is known as Coverage-based testing.

As stated in Section 5.4, testing of the developed program was carried out along the implementation. However, the details of it are here discussed.

The bottom-up approach was adopted for the testing, in the order of unit testing, integration testing, system testing and acceptance testing. The white-box test was used for the testing of the unit components and also at the integration stage. The main objective for carrying out the test in this instance was to find as many errors as possible in the codes. In most of the cases, the test of the unit components were carried out by printing variables, computation results, function return values etc. on the command window to ensure that there are no errors in the code. In this instance, anomalous input variables were used for the attributes of the various components. Also, the data manager was tested several times to ensure that after parsing the raw data from the data source (DarkSKY), it organises the data in a structure. Finally, the integration test was performed for the purpose of finding that the interaction between the components depicted in the dependency diagram in Figure 32 works perfectly.

The black-box testing approach was used for the system and acceptance testing, ensuring that the program developed meets the requirements specified in Section 5.2. This test was performed for the purpose of enhancing confidence in the developed system in appropriately displaying the graphical objects for the various weather parameters. In the system testing, it was found that the font colour of the graphical objects of the text type does not contrast the light background colour of goGPS. This was because the text objects are created with an explicit default font colour of white, which is similar to the light background of goGPS. This was reported to GReD s.r.l. and improvements are being made on it. After the system test, the files were given to GReD s.r.l. for performing code inspection and walkthrough. At

present, the developed system works on the Windows Operating System platform. It is anticipated that it will work on other operating system platforms as well, in accordance with goGPS requirements. The test is stopped after all the requirements specified in Section 5.2 have been met and the recommendations proposed by GReD s.r.l. are satisfied after code inspection.

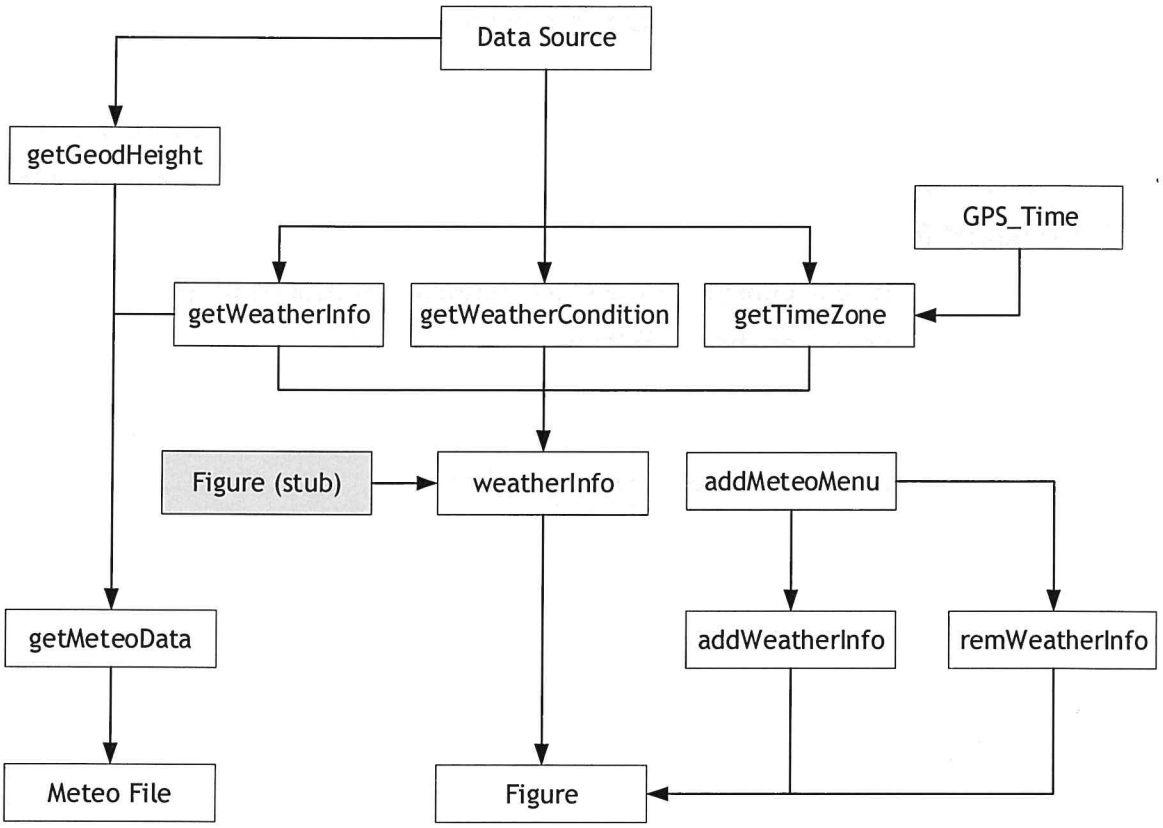


Figure 40 ***Test plan***

5.5 Deployment

The developed component will be deployed through the GitHub repository of goGPS MATLAB.

5.6 Maintenance

The initial version of the software component has been developed and deployed. The reliability and availability of the developed components depend on the Data Source component (DarkSKY API) making its data available 24/7. However, it is anticipated that through daily usage, additional requirements might evolve. Thus, in cognisance of the laws of software evolution by Lehman (1980), continuous communication with GReD s.r.l. will be ensured for maintenance to be made whenever a change in the requirement is recognised. In this case also, regression testing techniques will be employed to ensure that the software performs after the maintenance task. It will not be essential to rerun all the tests previously performed but a selection of some of the test cases will be carried out. However, to reduce the effort required for the maintenance of the software, the initial development of the program was carried out bearing in mind the following solutions proposed by Vliet (2007) for reducing maintenance problems.

i. By writing higher-quality code, better test procedures, better documentation and adherence to standards and conventions;
ii. By anticipating changes during requirements engineering and design and by taking them into account during realisation, future perfective and adaptive maintenance can be realised more easily.
iii. Fine tuning to user needs may lead to savings in perfective maintenance.
iv. By writing less code

5.7 Case Study

The purpose of this case study is to relate the ZWD derived from observations made by GNSS stations with weather paramterrs. This is to analyse the dynamics of ZWD and the weather parameters to analyse an incident that happened on July 13, 2021 at Malpensa Airport, in which Emirates' Boeing 777-300ER (A6-ECF) was damaged by hail storm on its way to John F. Kennedy (JFK) International Airport, New York City. The airline suffered serious damages with shattered windshields, nose cone, engine

cowlings and wings. The flight departed Milan Malpensa airport at 16:23 but returned at 18:04.

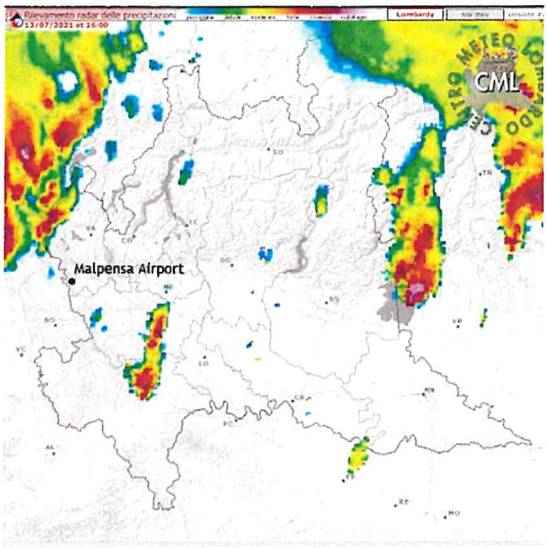
Weather radar maps have the capability of detecting areas of precipitation as well as its intensity, type and direction. On a weather radar map, different colours (Table 5) are used to represent the type of precipitation when one is detected over an area, Hebby (2022).

Table 5 Precipitation type according to colour on radar map

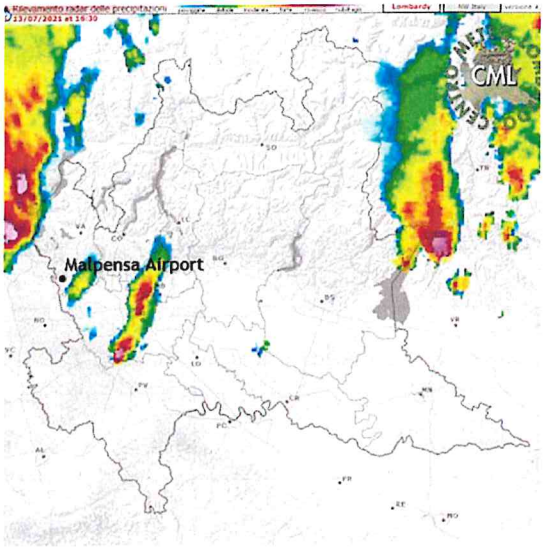
Colour on Radar Map	**Precipitation Type**
Light green	Light rain, or light rain aloft not reaching ground
Dark green	Light to moderate rain
Yellow	Moderate rain
Orange	Heavy rain
Red	Very heavy rain or rain and hail
White or blue	Snow
Pink	Freezing rain or sleet or mix of winter precipitation types

To better analyse the Malpensa airport incident using the developed visualisation tool, it ~~will be~~ would very useful to have pre-knowledge of the type of precipitation that was moving across the area using radar images (Figure 41) available on the website of Centro Meteo Lombardo. By inference of the radar images, there was a frontal system that was moving to the north-west of Milan Malpensa Airport with intense precipitation and strong winds (see Section 6.6) at the time the airline set off. Also, on the north-west part of the airport, the assumed path of the flight, there were

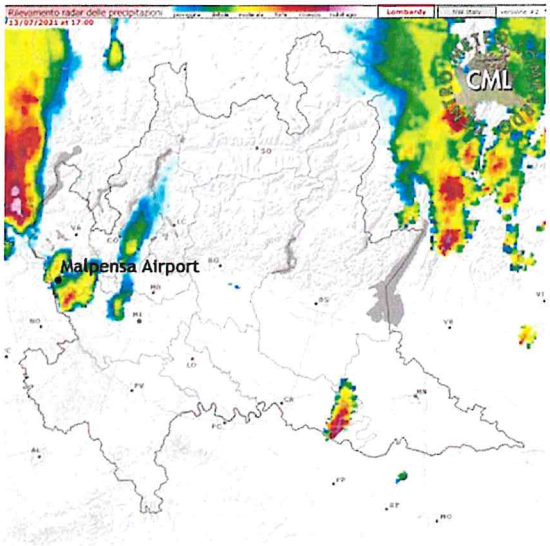
hail or rain that was also moving towards the east, in opposition to the flight trajectory.



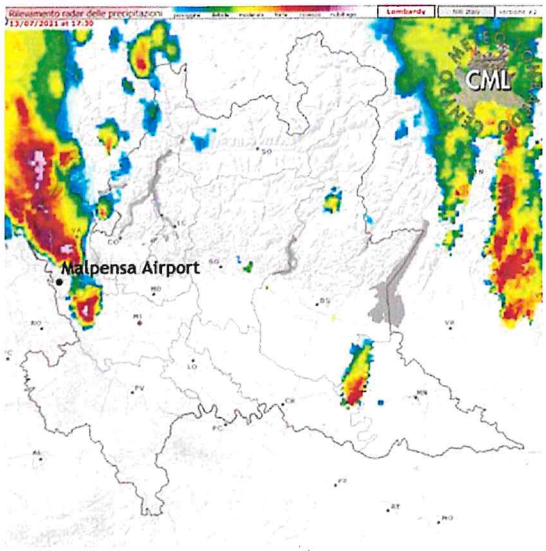
July 13, 2021-16:00



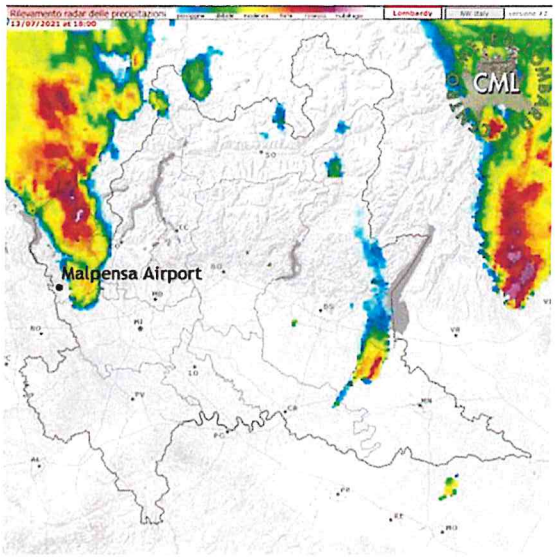
July 13, 2021-16:30



July 13, 2021-17:00



July 13, 2021-17:30



July 13, 2021-18:00

Figure 41 *Progression of the hail over the Malpensa airport*

(source: http://www.centrometeolombardo.com/radar/)

The considered GNSS stations (Figure 42), 17 in all, 12 of which belong to the SPIN network (a GNSS data infrastructure of the Piedmont, Lombardy and Valle d'Aosta Autonomous Regions of Italy), one (CATU) belonging to the NetGEO network owned by Geotop society and GRTR belonging to GReD srl. These stations make observation of GNSS signals on a daily basis, are closer to the Malpensa Airport and their data made available to the public. Thus, they were considered for this study. The data obtained from these stations were processed using the goGPS software and the ZWD derived from them to analyse the trend in the atmospheric water vapour content in the area during the incident. The ZWDs were obtained for a day preceding the event and on the day of the event. The meteorological information were then displayed on the plot of the ZWD to aid explanation of the ZWD plot. This was also to find possible correlation between the weather parameters and the ZWD plot.

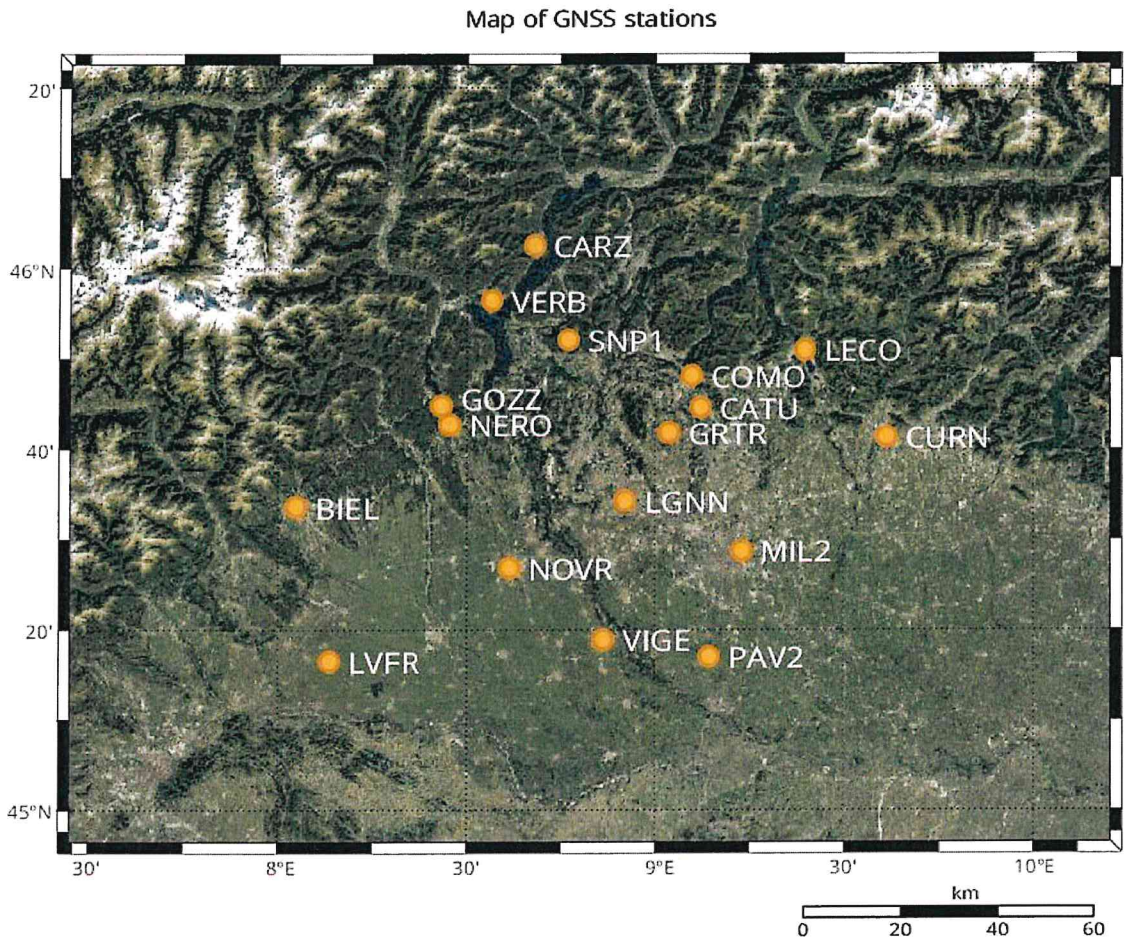


Figure 42 ***Neighbouring GNSS Stations***

CHAPTER 6

RESULTS AND DISCUSSION

Adding additional information to a plot is of great importance to better explain the data contained in the plot. This has been the objective of this work, specifically, obtaining data containing global coverage of weather information from DarkSKY API, and displaying them using graphical objects of MATLAB on a plot. The plot (2D line plot) as produced by the goGPS software could contain information about any of the following parameters derived from processing of GNSS observation data:

- Zenith Tropospheric/Total Delay (ZTD), which represents the delay of a GNSS satellite signal, projected in the zenith direction above a receiver station.
- Zenith Wet Delay (ZWD) which represents the wet component of the ZTD
- Zenith Hydrostatic Delay (ZHD) representing the hydrostatic component of the ZTD and obtained from the difference between the ZTD and the ZWD
- Position coordinates (East, North or Height) of a monitoring station

As discussed in Section 5.4.1, the display of the weather data on the 2D line plots is divided into two stages, preparation and visualisation of the data. The procedures for the various stages have been discussed in Chapter 5 and the results are explained here.

6.1 Addition of the Meteo menu to figure

After the integration of the unit components with the goGPS system, the Meteo menu item (Figure 40) was added to the figure containing the plot of the monitoring data. The Meteo menu contains all the items necessary for adding weather parameters to the plot, being displayed in a first selected, first shown basis. The label of the sub items bear the corresponding weather parameter needed to show. For instance, the 'Wind Direction' sub item displays the wind direction weather-parameter on the plot. The menu also contains the 'Show ALL' sub item that could be used to display

all the weather parameters at the same time. The sub items of the Meteo menu have appropriate call back functions that are called to update the plot when they are selected. Thus, by flagging an item, the plot is updated with the corresponding data and by unflagging, they are removed from the plot. This is made possible by tag identifiers set on the function calls for the various graphical objects for displaying the weather parameters.

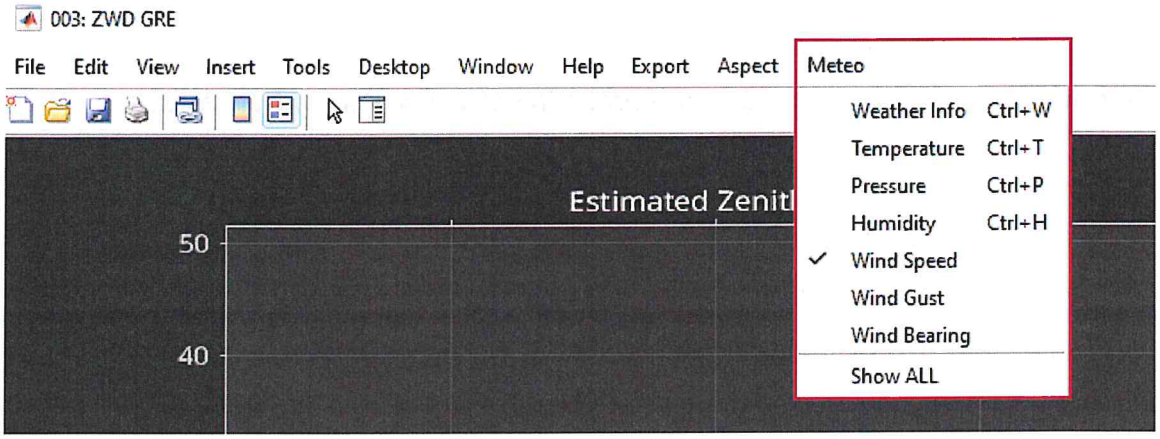


Figure 43 ***Meteo menu item and its sub-items***

6.2 Organisation of data in structure

After parsing the raw data obtained from the Data Source component, the raw data is organised in a structure to be accessed for creating the graphical objects. It is organised at an hourly rate for the number of days in which the analysis is being made. For example in Figure 41 is shown the data structure for the first hour of a 7 days observation dataset. The number of fields might vary depending on the station being observed and the time. However, through trial and error, the following fields were always found to be present: time, icon, temperature, pressure, wind gust, wind bearing, humidity, wind speed, and dew point.

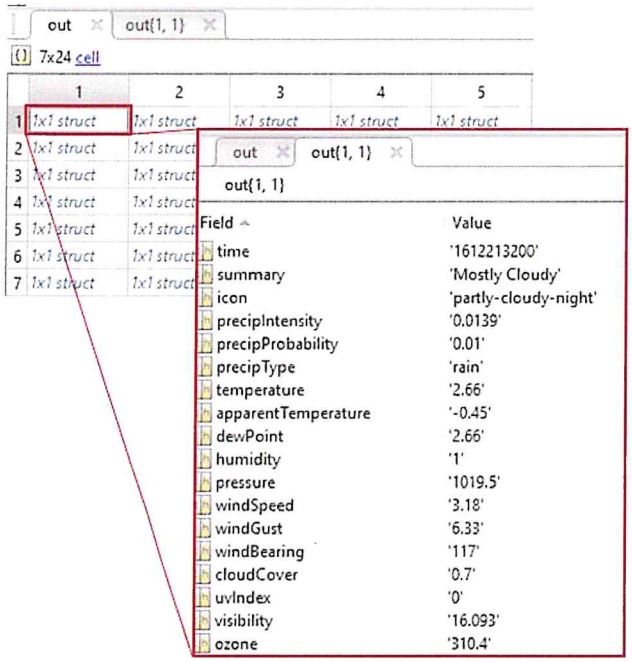


Figure 44 ***Organisation of data in structure***

6.3 Visualisation of output

By selecting an item from the Meteo menu, the values of the selected parameter are displayed over the plot for the same time period as the data on the plot. The corresponding graphical objects are shown on the plot. However, for the sake of readability, the pressure values are shown at 2-hour intervals while for the other parameters, they are spaced at an hour interval. All parameter values are horizontally aligned for easier reading. Also, for easier identification of the parameters, a label has been set in relation to each parameter on the left side of the display. Most likely weather conditions to be observed are cloudy, sunny, partial-cloudy, rainy, snowy, etc. Most common weather conditions have been listed in Appendix 1. However, additional weather conditions could be added to the list.

To remove a graphical object from the plot, select the checked item. This finds the handle of the object using its tag identifier and the object is removed from the plot.

6.3.1 Display of data for less than 30-hour period

When a user displays weather information for a plot containing less than 30 hours of data, icons representing the weather conditions are shown at hourly intervals (Figure 42 and 43). The size of the icons are set relative to the dimensions of the axes object in which the data is displayed. However, they can be created or viewed at any zoom level of the plot, especially to see greater details for a short time period of data analysis.

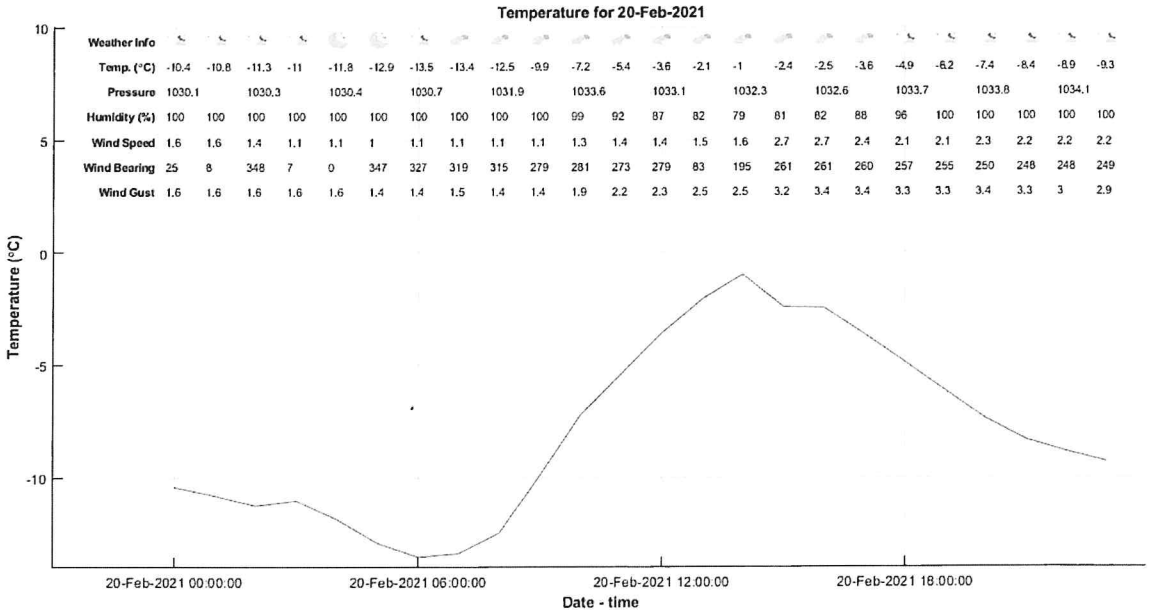


Figure 45 ***Display of data for less than 30-hour period***

6.3.2 Display of data for more than 30-hour period

When a user displays weather information for a plot containing more than 30 hours, of data, a rectangular patch is shown instead of the icons (Figure 44). This feature has been used in order to avoid clumsy or overcrowding of the weather icons and to enhance the appearance of the graph. A legend is added to the graph to explain the colours being used as face colour for the patches. The items in the legend vary depending on the number of weather conditions available for the epoch at the station being analysed. The legend is also positioned in the best location so as to avoid it overlaying or intersecting with another graphical object.

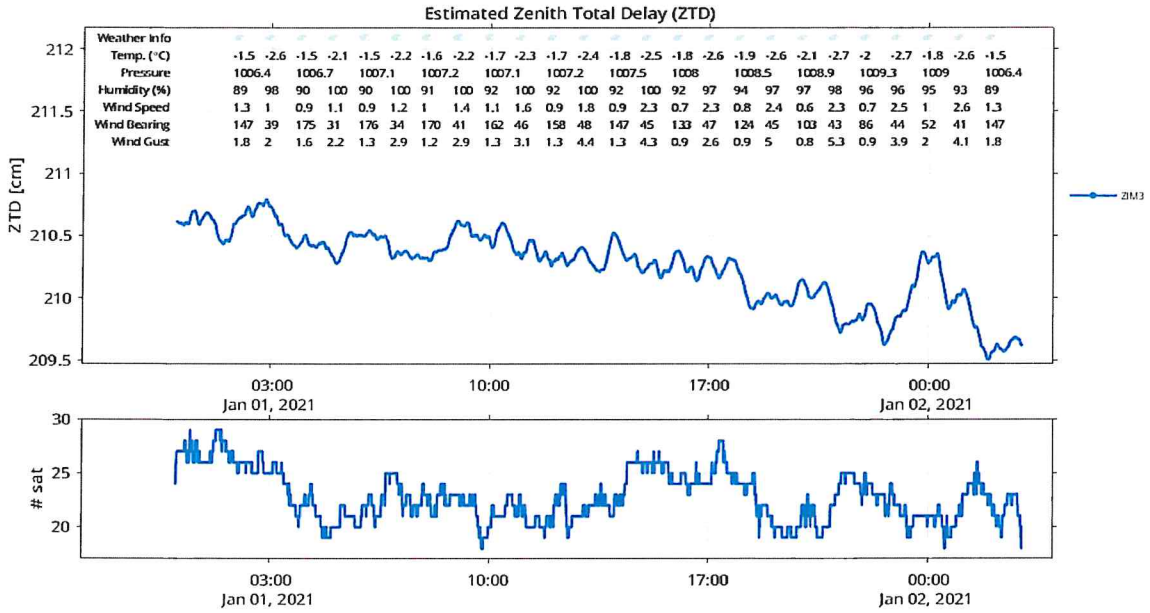


Figure 46 ***Display of data for less than 30-hour period on ZTD plot***

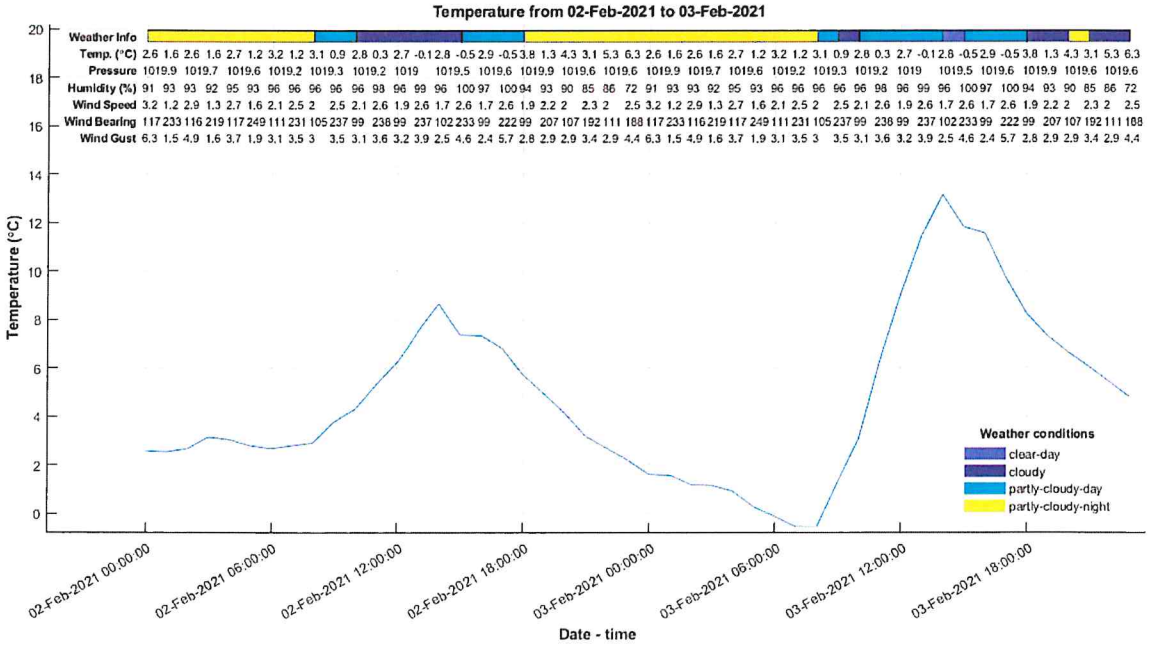


Figure 47 ***Display of data for more than 30-hour period***

6.4 Test results

The development of the program proceeded with monitoring of the command window for print of errors. Especially with the unit components building, variables and function return values were printed to the command window to ensure that they produce the correct values. Also, in the integration, it was ensured that a component calls the appropriate function or component that it interacts with for the satisfaction of specified requirements. In the performance testing, it was however realised that because a default font colour of white has been specified for the text graphical objects, they do not contrast with the light background of the plot when the object is to be displayed on the light aspect mode of goGPS. However, this has been communicated to GReD s.r.l. and efforts are being made to correct this. The display of the weather parameters runs correctly without any error being thrown to the command window, (Figure 45).

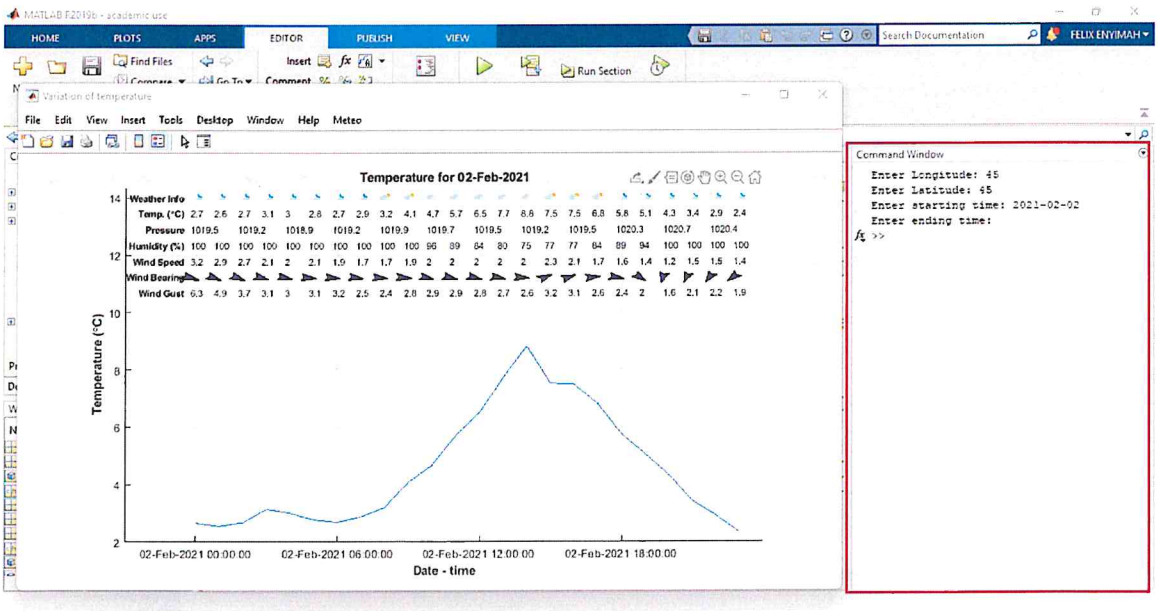


Figure 48 ***Monitoring of the command window for print of errors***

In the acceptance testing that was performed by GReD s.r.l., additional features were identified such as the need to provide a readme file for the work and to create a demo for the work. These were added to complete the project.

6.5 Meteorological Data File

The generated file contain meteorological data per hour for the station and period being analysed. The file is generated per day. Thus, data containing 3 days of observations will have 3 generated files. The file is subdivided into two main sections: the header section and the data record section. The header section contains global information for the entire file and is placed at the beginning, in accordance with the standards for rinex file generation. The data record section contain the meteorological data for a particular station. The following are the meteorological observation data types that can be found in the data record section.

- Pressure (mbar)
- Dry temperature (°C)
- Relative humidity (%)
- Wind azimuth (°) from where the wind blows
- Wind speed (m/s)
- Rain increment (1/10 mm)

Figure 48 shows a sample meteorological file contents. Each observation record is read in the following order: epoch (yyyy-MM-dd HH:mm:ss), pressure, temperature, humidity, wind azimuth, wind speed and rain increment.

ZWD_194.21m

```
     3.03           METEOROLOGICAL DATA                     RINEX VERSION / TYPE
EXPORTED MET FILE FROM METEO_DATA MATLAB CLASS              COMMENT
ZWD_                                                        MARKER_NAME
     1    PR                                               # / TYPES OF OBSERV
  4429544.5026   626321.1633  4531501.0754      372.3413 PR SENSOR POS XYZ/H
                                                            END OF HEADER
 2021 07 13 00 00 00  1009.5   19.1    0.8  334.0    2.4    0.4
 2021 07 13 01 00 00  1009.2   18.7    0.8  321.0    2.1    0.4
 2021 07 13 02 00 00  1008.8   18.3    0.8  325.0    2.0    0.3
 2021 07 13 03 00 00  1008.4   17.4    0.8  328.0    1.9    0.5
 2021 07 13 04 00 00  1007.9   17.0    0.9  355.0    1.8    1.2
 2021 07 13 05 00 00  1007.7   16.7    0.9  213.0    1.9    2.9
 2021 07 13 06 00 00  1007.9   17.0    0.9  244.0    1.8    4.5
 2021 07 13 07 00 00  1008.1   17.2    0.9  278.0    1.7    4.1
 2021 07 13 08 00 00  1007.9   17.5    0.8  267.0    1.7    2.9
 2021 07 13 09 00 00  1008.0   18.2    0.8  214.0    1.6    2.0
 2021 07 13 10 00 00  1007.7   18.6    0.8  151.0    1.4    1.6
```

Figure 49 ***Sample Meteorological Data File Content***

6.6 Case Study Analysis

From Figure 50 and considering the combined ZWD plot of all the stations, the wet path delay increased from midnight of July 12, 2021 with an approximate value of 18 cm to a higher value of about 25 cm at 21:00. The trend gradually decreased the following day to about 12 cm at a period around which the incident involving Emirates flight EK205 happened.

From the weather information displayed on the plot, the direction of the wind changed suddenly from south-east to the northern direction in the Airport, in the direction of traverse of the hail progression seen from the radar graphs in Figure 41.

The wind speed also increased abruptly from the lower value of 1.9 m/s at the mid-night of the day of the incident to a higher value of 8.7 m/s. There was also a decrease in the values of the humidity, pressure and temperature during the incident period. The trend of these parameters are in favour of the heavy frontal wind that was traversing the Airport area. Moreover, these were accompanied by a higher increase in wind gust from a lower value of 2.3 m/s at 3:00 AM of the previous day to a higher value of 8.7 m/s at the period of the incidence.

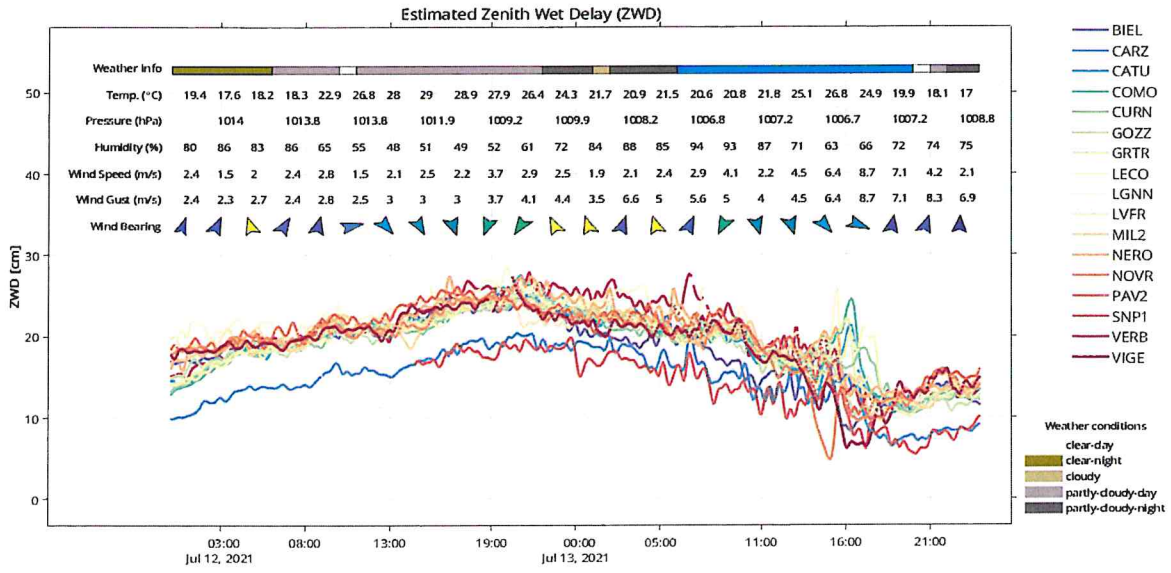


Figure 50 ***Display of Weather Information on goGPS ZWD Plot***

CHAPTER 7

CONCLUSION AND RECOMMENDATION

7.1 Conclusion

The use of GNSS for the remote sensing of atmospheric water vapour has found applications in the field of meteorology. The satellite signals of the GNSS space vehicle traverses the various layers of the atmosphere, having many encounters with the components of the atmosphere, mainly the electrically charged ionosphere and the electrically neutral troposphere. Subsequently, the signal experiences a delay before reaching the receiver. By modelling and estimating this delay, it is possible to estimate the amount of precipitable water vapour in the atmosphere which could be useful for meteorological purposes.

goGPS is one of the software that could be used to process the GNSS observation data to derive an estimate of the amount of water vapour in the atmosphere. It has the capability to produce time series plots of station coordinates, ZWD, ZHD, ZTD etc. While analysing the plots produced by the software, it will be very useful to have an additional information of the meteorological conditions of the atmosphere or events at the observation station that will serve as an explanatory tool for the plots produced.

Matlab, the programming language used for the development of goGPS provides the capability to use graphical objects to add extra information to a plot to achieve this purpose. This provision has been exploited using the meteorological data from DarkSKY API. The information can be displayed for a day or multiple-days observation dataset, with the option for a user to display variable parameters such as temperature, pressure, humidity, and wind information. It is hoped that the extra information that can be added will provide an answer to the needs of a user in interpreting the behaviour of the estimated GNSS water vapour parameter and position coordinates of a monitoring station.

7.2 Recommendation

It is recommended that

- The component will be revised to update the ylim of the graph when a graphical object is deleted.
- The components will be revised to make it possible to deselect or delete a particular weather parameter when all of them are shown using the 'Show ALL' menu item.
- The spacing between the objects will be updated when an object is deleted.
- The only limitation is that attempting to display weather information for more than 3 days makes the appearance clumsy. For better visualisation or if one wants to make plot graphs for presentation purposes, it is recommended to display for multiple days to detect when a change in environmental variable occurs and produce the graph for the particular day in which the phenomenon occurred for a more detailed analysis and nicer appearance of the displayed graphical objects.
- It is also recommended that a Microsoft HTML Help Workshop window accessible from the goGPS GUI menu bar be developed to guide a goGPS user.

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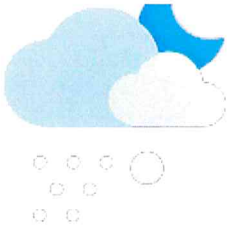
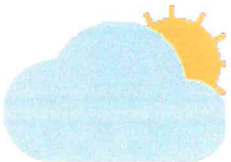
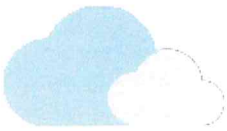
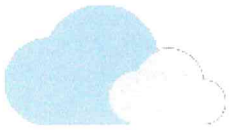
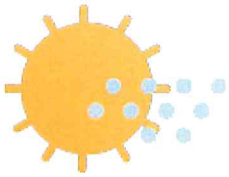
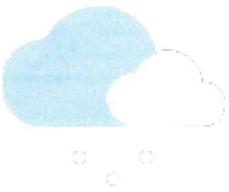
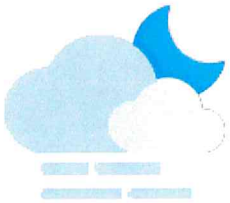
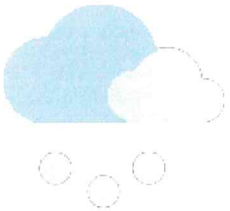
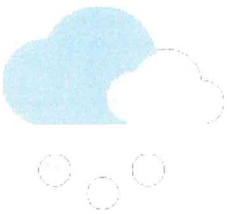
APPENDIX I

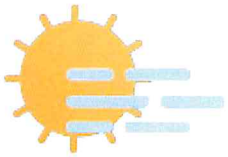
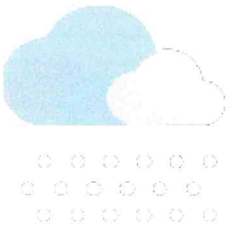
ICONS AND COLOURS

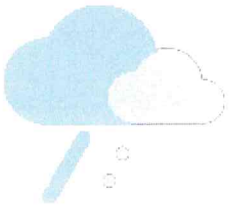
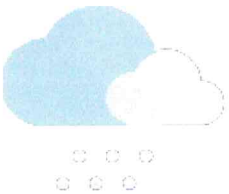
NAME	ICON	COLOUR CODE
Blizzard		#b1fb32
Blizzard-night		#466e02
Breezy		#a1b57e
Breezy-snow		#3ba19b
Clear-day		#fdfae8

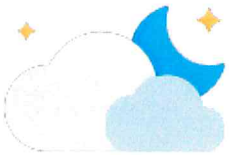
Clear-night		#816f03
Cloudy		#a9a16e
Cloudy-day		#d6d2b7
Cloudy-night		#67634c
Drizzle		#4c6762
Drizzle-day		#5a8e85

Drizzle-night		#10574a
Dust		#9ba1a1
Earthquake		#ec9558
Fire		#f4752a
Flood		#70edab
Flurries		#707271

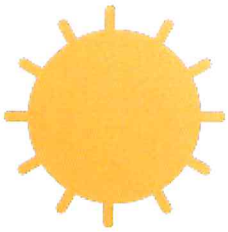
Fog		#dce6e1
Fog-day		#adb1d2
Fog-night		#535355
Hail		#b0a0b5
Hail-day		#87728e
Hail-night		#40184d

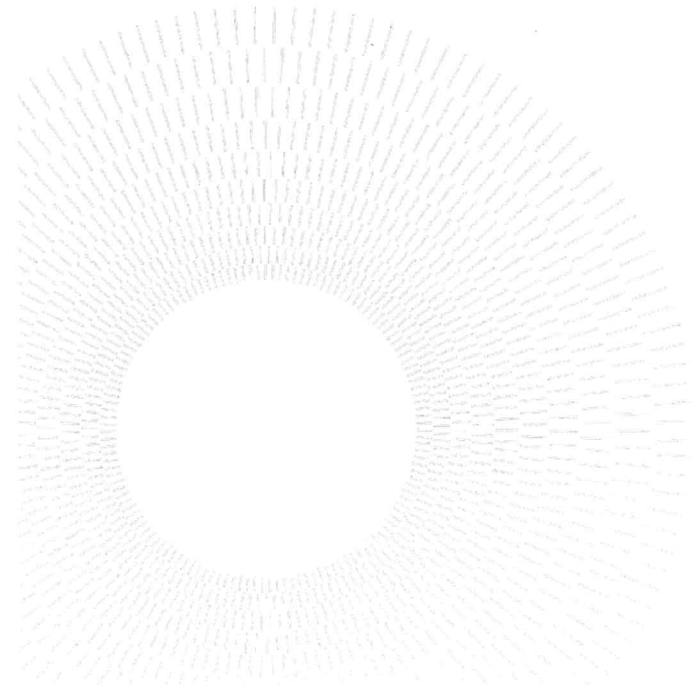
Haze		#a445e1
Heavy-rain		#1f9c9b
Heavy-rain-night		#156f6e
Heavy-sleet		#66b960
Heavy-snow		#018788
Light-rain		#8384c4

Light-rain-night		#30328d
Light-sleet		#f3bddd
Light-snow		#acf7f3
Overcast		#587270
Partly-cloudy		#d9bfda
Partly-cloudy-day		#958895

Partly-cloudy-night		#515051
Rain		#0290fd
Rain-day		#88c9fa
Rain-night		#01335a
Showers		#d1dee7
Showers-day		#829cb0

Sleet		#da6c93
Sleet-day		#afa2a7
Sleet-night		#665e61
Smoke		#c1bb8f
Snow		#2e3790
Snow-night		#232748

Sunny		#fbec02
Tornado		#975051
Wind		#57dd96



APPENDIX II

IMPLEMENTED FUNCTIONS

1.0 Function to get the time zone of a given location

```
function [outActual] = getTimeZone(latitude, longitude, time)
    baseUrl = 'https://DarkSKY.net/details/';
    httpsUrl = strcat(baseUrl,latitude,',',longitude,'/',time, '/si12/en/');
    webHTML = webread(httpsUrl);
    neededInfo = extractAfter(extractBefore(webHTML, 'units = '), 'tz_offset = ');
    outActual = replace(neededInfo, ',', '');
    outActual = str2double(outActual);
end
```

2.0 Function to get the conditions of the weather at the specified location and time

This output results vary depending on the location, time and the conditions of the atmosphere at the specified time.

```
function [structArray] = getWeatherConditions(latitude, longitude, time)
    baseUrl = 'https://DarkSKY.net/details/';
    httpsUrl = strcat(baseUrl,latitude,',',longitude,'/',time, '/si12/en/');
    webHTML = webread(httpsUrl);
    neededInfo = extractAfter(extractBefore(webHTML,'cityName'), 'conditions = ');
    out = extractBetween(neededInfo, '{', '}');
    outActual = replace(out, ':', ',');
    outActual = replace(outActual, "", '');
```

```
        outActual = replace(outActual, '-', '_');
        structArray = struct([]);
        for i = 1:length(outActual)
            tmp = strsplit(outActual{i}, ',');
            fieldValue = tmp(2:2:end);
            fields = tmp(1:2:end);
            structArray{i} = cell2struct(fieldValue, fields, 2);
        end
    end
```

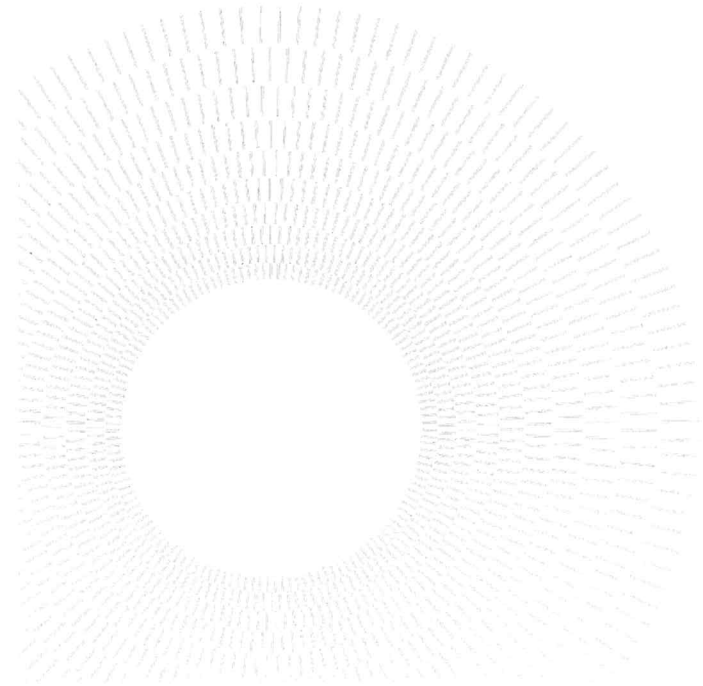
3.0 Function to get the weather data needed for making the plots

```
    function [structArray] = getWeatherInfo(latitude, longitude, startTime, endTime)
        baseUrl = 'https://DarkSKY.net/details/';
        structArray = struct([]);
        dayNum = 0;
        if isempty(endTime)
            endTime = startTime;
        end
        startTime = datetime(startTime);
        endTime = datetime(endTime);
        for i = startTime:endTime
            dayNum = dayNum+1;
```

```
            time = datestr(i);
            httpsUrl = strcat(baseUrl,latitude,',',longitude,'/',time, '/si12/en/');
            webHTML = webread(httpsUrl);
            neededInfo = extractAfter(extractBefore(webHTML,'startHour'), 'var hours =
');
            out = extractBetween(neededInfo, '{', '}');
            outActual = replace(out, ':', ',');
            outActual = replace(outActual, "", '');
            outActual = replace(outActual, '{azimuth', 'azimuth');
            outActual = replace(outActual, 'solar,', '');
            for i = 1:length(outActual)
               tmp = strsplit(outActual{i}, ',');
               fieldValue = tmp(2:2:end);
               fields = tmp(1:2:end);
               structArray{dayNum, i} = cell2struct(fieldValue, fields, 2);
            end
         end
      end
```

4.0 Function to make the plot

TB



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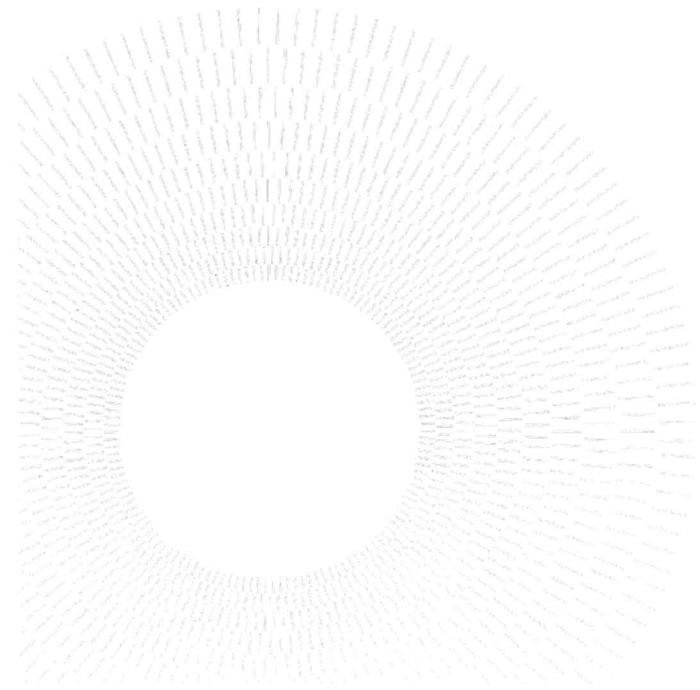

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