Monitor Radiation and Clouds Characteristics over Arctic ocean (MoRaCCA)

2022-2023 Activity Report

Introduction

Due to several feedback mechanisms, the Surface temperature increase in the Arctic is 2–4 times larger than the global mean. This phenomenon, called the Arctic Amplifcation, has been confrmed by observations as well as model simulations. Mechanisms responsible for the Arctic Amplifcation include: Albedo feedback due to changes in sea ice extent, atmospheric and oceanic heat transports, changes in cloud cover and water vapor that alter the longwave irradiance to the surface, soot on snow and increased black carbon aerosol concentrations. Reduction in sea ice extent and thickness largely impact surface energy exchange processes. Response of the clouds to the changing surface conditions modify the planetary albedo when sea ice melts. We have a very poor knowledge of all process and interactions, being systematic measurements only made from space meanwhile ground-based observations are very low and sporadic. This limitation having an impact also on satellite measurements as a consequence of a lack of data for validation activities using observation over sea and at high-latitude.

In this context, MoRaCCA project aims to take the opportunity offer by PONANT cruices to implement a very cost-effective monitor programme for surface radiation fluxes and cloud measurements over the Arctic Ocean, with specific objectives that are both scientific and technical.

With respect to science, continuous radiation and sky observations will allow characterization of downwelling radiation at the surface (both Shortwave (SW) and Longwave (LW) components), as well as cloud coverage and radiative impact over a very wide range of latitudes along the whole summer season. To provide relevant information to researcher interested to investigate marine ecosystems, UV-A and UV-B surface flux measurements are also collected.

From a technological point of view, along the five years proposed activity, aims is to implement hopefully several new technical solutions to improve atmospheric measurements over a ship: automatici clinic systems for radiometers domes, inertial platform to increase accuracy of collected SW and LW radiation components, automatic sun-spectrometer for columnar aerosol characterization. All them in synergy with activities on-going in the frame of the Italian Antarctic Programme (PNRA).

The basic idea is to have instrumentation operating continuously with the minimum of maintenance, so that all cruises will offer opportunity to collect useful ans relevant data, and possibly transfer them in Italy in Near Real Time (NRT). Meanwhile a pre-analysis made automatically on-board will sustain use of data for outreach activities on-board on the basis of requests and needs of the PONANT Science Team.

Developing the system and installing on Commandant Charcot

We received positive result of our application around half of February 2022. Unfortunately at the same time we discover that in practice the only way to move ahead the programme as scheduled for 2022 was to prepare the system on time for installation before the starting of the Arctic Cruise season at the beginning of May 2022. In fact, after May the ship practically remains in port only long enough to change passengers. Furthermore, the transition from the Arctic to the Antarctic season takes place with a short technical stopover in North America which, not surprisingly, is the destination of the last Arctic cruise.

This put us under considerable pressure, and to abandon some other activities to devote ourselves entirely to the preparation of the system to be installed on board in the only useful period which was between 19 and 23-24 April when the ship was scheduled to prepare in a French port. Most of the problems reported later are the result of this haste and also of the impossibility of carrying out a preventive survey.

The first choice of instrument positioning was made in Bologna on the basis of the technical information passed by PONANT. They were good enough to allow us to make a choice that proved to be right at least in terms of the level at which to operate and the preparation of supports for the various instruments. In any case, when we arrived on the ship, we didn't have precise information on the internet connection or on the power supply possibilities.

When on-board in April 2022, after inspection of the ship and precise assessments relating to needs for radiation measurements and their maintenance, combined with needs for power supply and the communication, the instrumentation was positioned aft on the left side of the tenth deck (Figure 1 and 2), one of the places located higher up in the ship, but which remains easily accessible for carrying out ordinary maintenance of the instrumentation, such as cleaning it. This position offer the advantage to havwe a complete free horizon with respect the rear of the ship. However, is in any case influences by shadows generated by ship infrastructures. As a consequence, collected data need to be analysed and eventually corrected considering the absolute position of the ship, date, time and the angular position with respect to the sun (sun geometry).

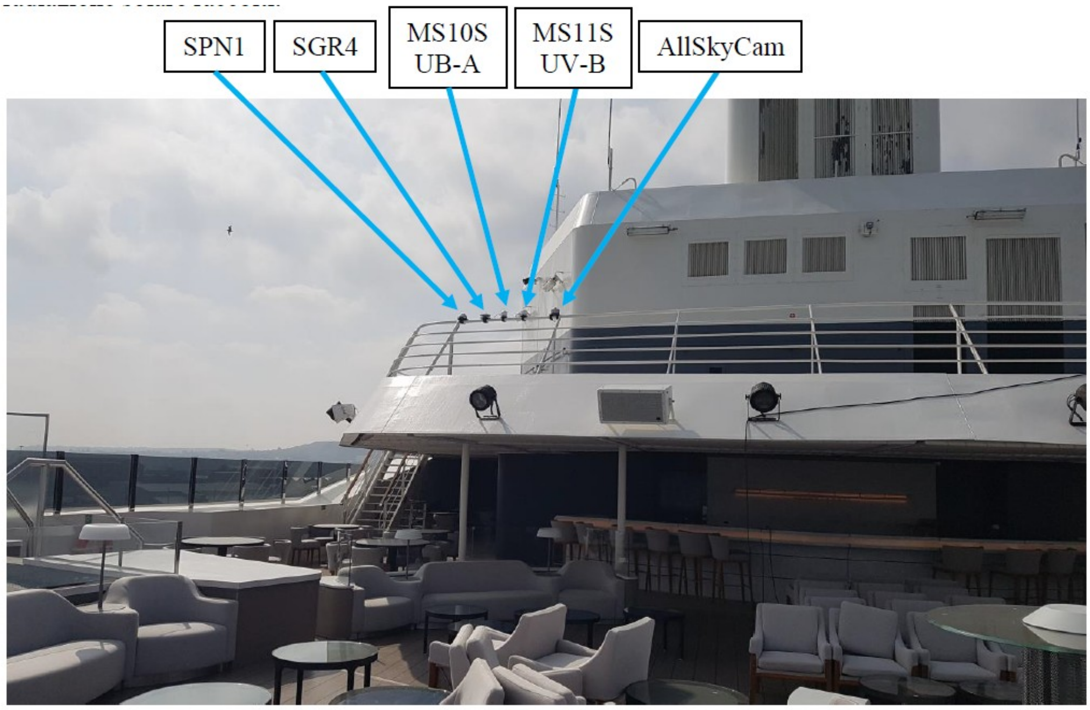


Figure 1 – Instrument location on the ship

Figure 2 – rear horizon and details of instrument mounting

All instruments have been fixed to the present railing, making use of support ad hoc designed and realized. Figure 3 shown as an example technical design of the SPN-1 mounting. All supports have been realized using a 3D printer and as material Black carbon loaded nylon (TreeD filaments)

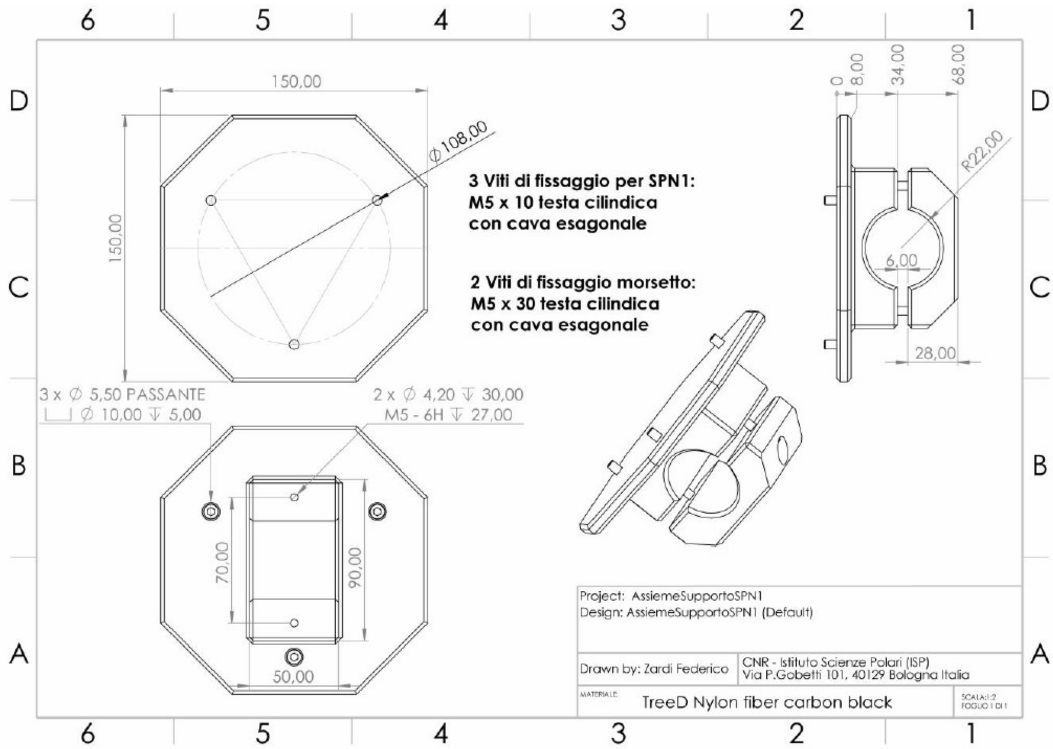


Figure 3 – the support for SPN1

The "SRU" (SolarRadiationUnit) acquisition system takes care of acquiring all the radiometers and the All Sky Camera, it is made up of a Raspberry, a USB-RS485 converter, a dedicated electronic board specially designed for the acquisition of analog and digital signals from the radiometers, a GPS and finally 2 power supplies which from the AC 230V power supply generate the following voltages useful for the previously mentioned electronic systems and sensors: DC 12V/6A, DC 5V/3A , DC 24V/1A.

All the devices mentioned are fixed on a 3D printed support in PET-G material, where there are columns with threaded holes to fix the various electronic boards and power supplies, allowing for tidy wiring. The support with the mounted devices is in turn fixed inside an insulated stainless steel box by means of 4 3D printed columns and 4 stainless steel M3 screws which from the bottom of the box hook the columns where there are O'rings that do not allow water to enter through the holes in the box for the passage of the screws. Figure 4 shows the system described above and in addition a fan useful for moving the air inside the box to make the temperature uniform between the various devices.

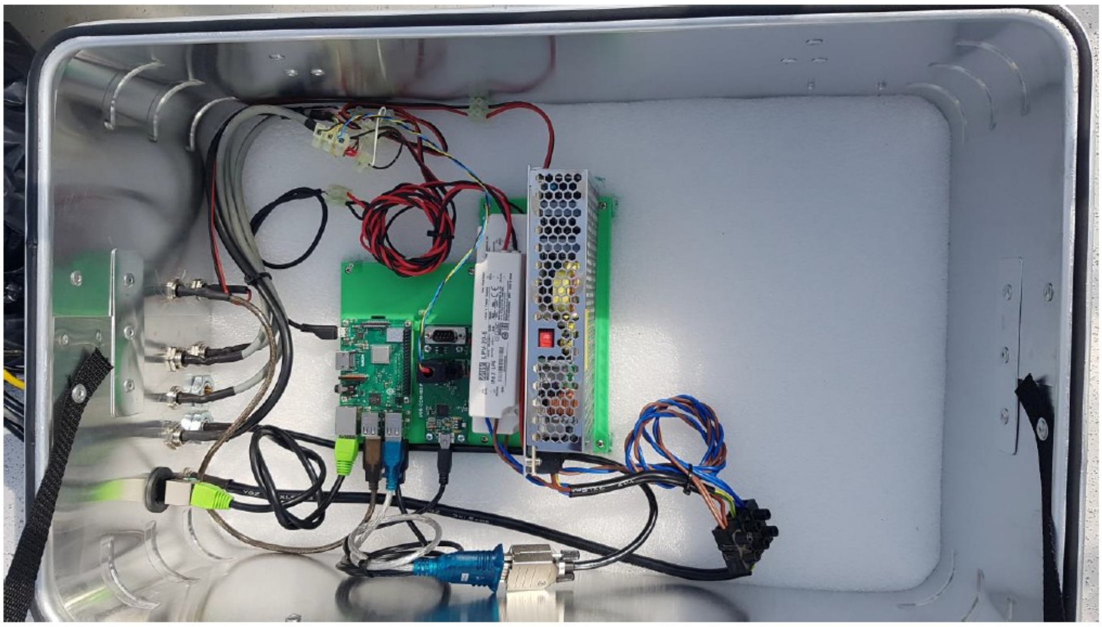


Figure 4 – Complete view of the SRU as clabed to the instruments (April 2022)

The steel box is oversized in its mechanical dimensions to, in the future, be able to accommodate other systems in anticipation of expanding the instrumental set used for the collection of environmental data on the ship Laura Bassi. Its external dimensions are 580x385x250h [mm] and the internal ones, considering the insulation, are 490x260x160h [mm], in Figure 5 the box fixed in the pre-established place on the ship with the residual wiring coming from the instruments installed on the left (cfr. also Figure 2). The instruments acquired by the system are connected to the box by means of waterproof connectors mounted on the short side of the box.

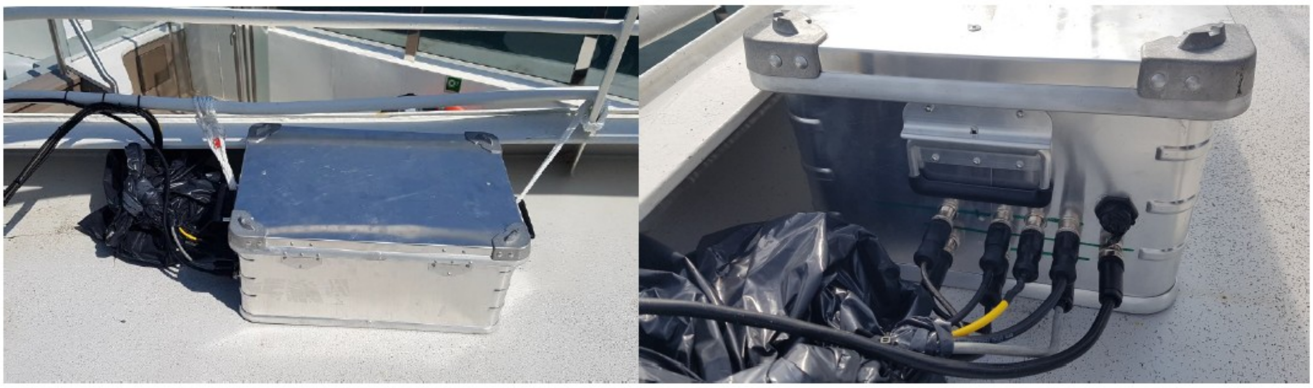


Figure 5 - The box with the SRU as mounted on the Commandat Charcot

Below is the general descriptive diagram of the connections between the systems that make up the acquisition unit and all the acquired sensors (Figure 6). As we can see, the only inputs that the system requires are the 230[V] AC power supply with a maximum required power of 70[W] and the connection of the ethernet cable to receive data or set the operating parameters.

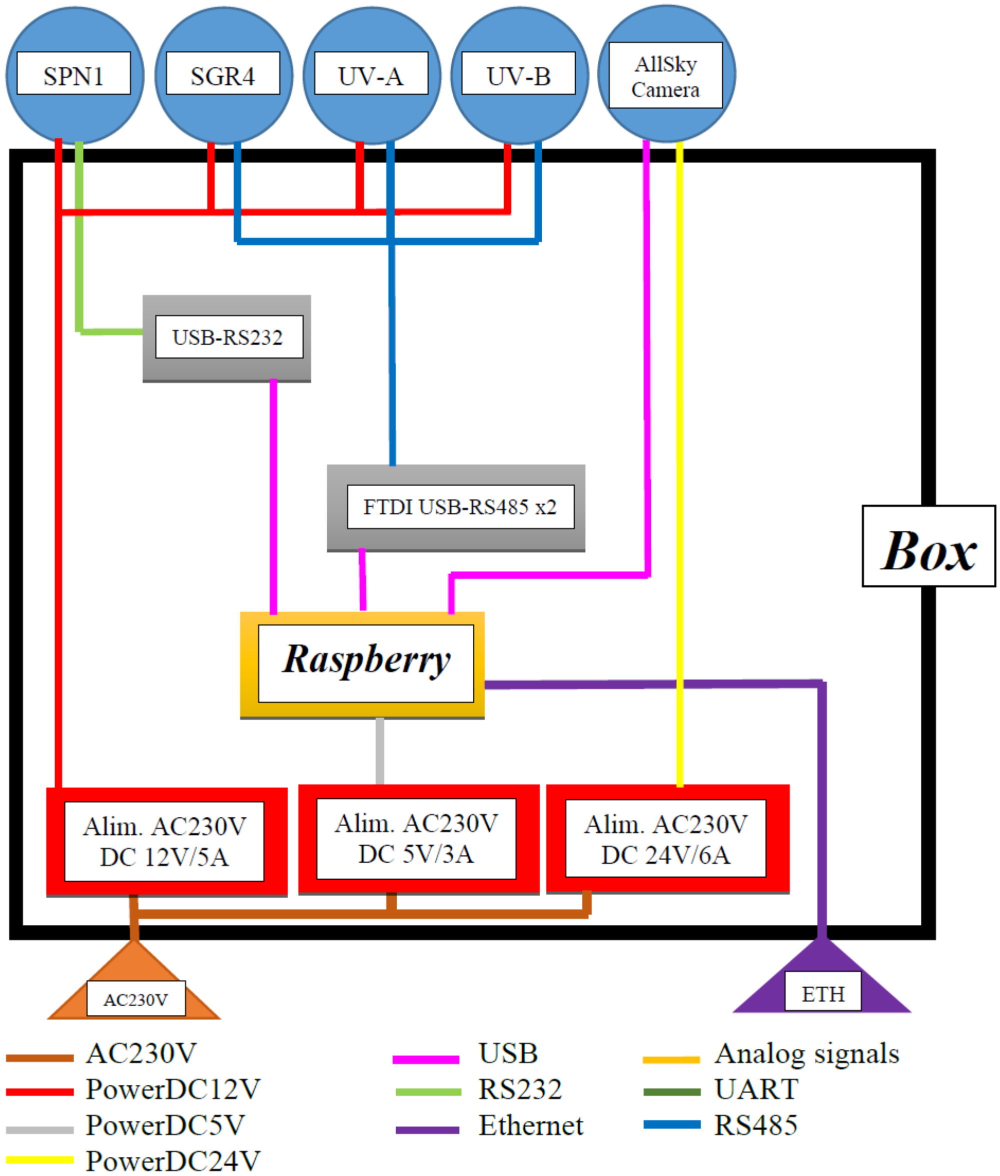


Figure 6 – The elenctronic and connection scheme

Data collection and storage

The measuring instruments that make up the set are a pyranometer, a pyrgeometer, a UV-A sensor, a UV-B sensor and an All sky camera:

- SPN1 (pyranometer) by DeltaT.
- SGR4 (pyrgeometerro) by Kipp & Zonen
- MS-10S (UV-A) by EKO
- MS-11S (UV-B) by EKO
- ALPHEA 3CW (All Sky Camera) by Alcor System

The Solar Radiation Unit acquires the GPS data, 3 radiation sensors and an AllSkyCam: SPN1, SGR4, PQS1, AllSkyCamera, through the Raspberry mini PC connected to the SRU conversion board, storing the data in text format inside its memory, and then processing them by creating the daily graphs and finally every day at midnight and 20 GMT it sends, via FTP protocol, the data to the Server/NAS present on board the ship, eliminating them from its internal memory. The acquisition of the SkyCam is managed by another program which is launched at system startup. In addition to being acquired, it is also possible to view the image captured by the camera through a web server created within the Raspberry.

At April 2022, the Ponant Comandant Charcot ship was equipped with a local wired and WiFi network used for scientific research called "Scientific" capable of going out to the internet to which we have connected the Raspberry via WiFi. So configuring the Raspberry with a static IP on the network, was possible to download the data stored in the memory via SSH internet connection, or was possible to connect to the Raspberry via remote desktop (Anydesk), having direct access to the system to monitor its status and/or make any change.

Thanks to remote access data was possible to acquire data not only locally but also in Italy FROM end of APRIL until BEGINNING of JULY 2022 (about 7 Mb of data). At beginning of July, something happen and remote access became not more possible, despite a couple of attempts to switch off and on again the system, preventing possibility for us to check autonomously the status of the system and measurtements. Due to the problems and issues descrived in the last session, we discover only after a while (September/October 2022) connection problems of the SRU with NAS of the system. And, unfortunaltely, at that time, when we were able to obtain sufficient assistence by science team on-board, a complete failure of the Raspberry occured during the communication restoration intervention. Due to this failure no data could be acquired until our return to the ship in April 2023.

The 2023 check of the system and modifications

During winter 2023, we organized the intervention on the ship to restore the SRU, check all instruments and solve the little instabilities experience in the spring and early summer 2022 system operation. We also need to adapt data transfer and communication to the changes occured on the Commandat Charcot that during last part of 2022 and wonter 2023 have installed for data acquisition and management the WARUM DSHIP software (the same used by AWI research ships).

Again considering the time necessary and different options we make the choice to operate when the ship are in the harbur preparing for the Arctic Cruise season. This because the 2022 experience was positive. In fact, despite the few time at disposal, the zero knowledge of the ship and its characteristics in terms of internet and poweer supply points, the time devoted to find the best solution/compromise for instruments location, we were able to implement the system and have it working for three months continuously.

Two people operate on the ship from 18 of April till 20 of April 2023, trying to recover the unexpected bad condition of the system in terms of cabling and connectors (never experienced on Laura Bassi), probably a consequence of much more temperature and humidity changes with respect to a typical single research cruise. Figures 7 and 8 below shown from one side the status of the system after one year and also the new cabling through which we hope the degradation can be reduced. Is important to underlying that in part the cabling has been also forced by the lack of components and the impossibility of procuring them in good time and/or recovering them from the ship (very deficient in this sense).

Since colleagues of CNR-ISP will be onboard the ship at the end of August, we are preparing material for them to improve the cabling and also thoroughly analyze its durability over time.

Unfortunately the 24V power supply for all sky camere was found broken and since was nota at disposal a spare part, it will be reinstalled only at the end of August

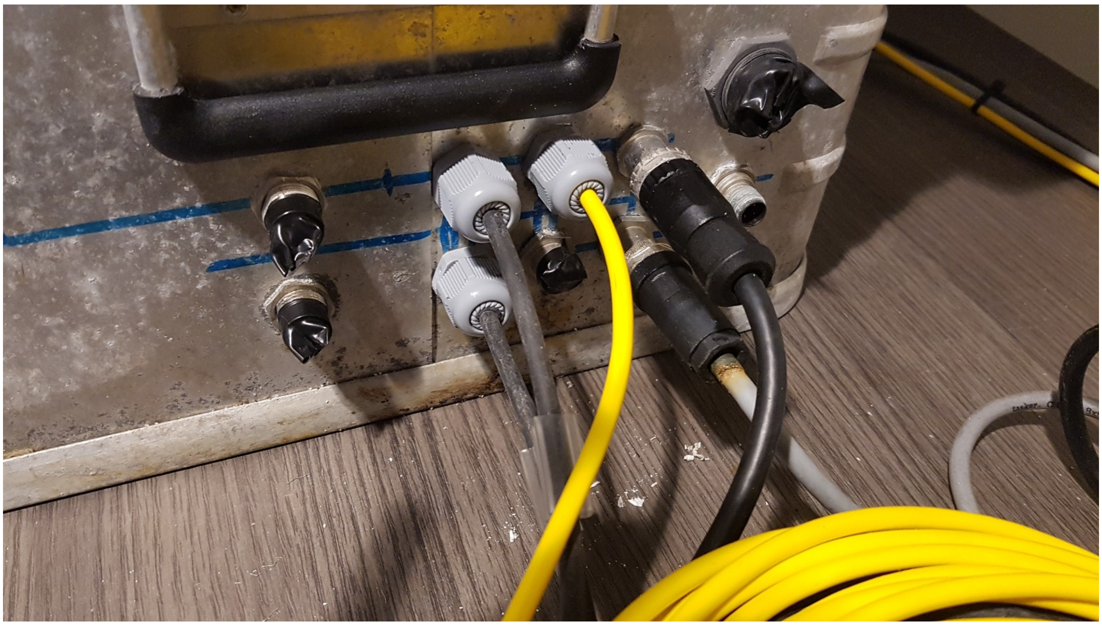


Figure 7 – The new cabling – external connectors (April 2023)

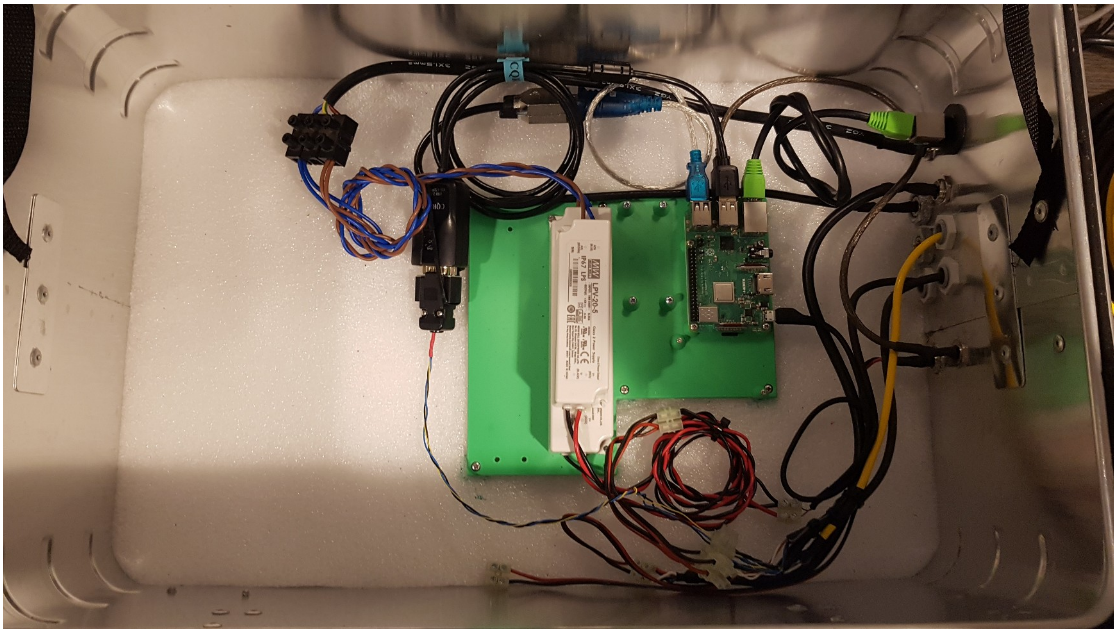


Figure 8 - The new cabling – connections to SRU (April 2023)

We need unfortunately to report that a completely unexpected difficulty resulted in the limited ability to access the system. Since the ship is powered by gas, on deck 10 you need to operate very precisely. Unfortunately compared to 2022, this time access was only allowed accompanied by a crew officer. This has led to much slower operations and not being able to use all the available time. Please refer to the final section for an overall discussion on learned lessons.

Planned future activities

- restore completely the system and consolidate the cabling; improve the system including a PAR sensor
- restore the remote access and capability to control autonmously the system operation

- thanks to the new DSHIP software collect necessary ancillary data ans start data analysis
- continue to discuss with PONANT way to improve our contribution to outreach activities and add radiation fluxes to information routinedly provided onboard
- in Italy continue the technolgical development related in particular to “automatic dome cleaning system”, inertial platform, spectrometer for columnar aerosol and atmospheric gases.

Outreach and dissemination

Being not ob-board during cruises, we have no possibility to put in we have no possibility of operating directly in this area, communicating with cruise passengers, answering their questions/curiosity, holding seminars or other classic dissemination and outreach activities. Due PONANT Science team actual organization, also training the personnel assisting in the research activities for this purpose was not directly possible, despite having offered the willingness to host someone in Bologna for 2-3 days for this purpose.

We have tried to overcome these intuitive difficulties:

(a) for cruise passengers by preparing rich and informative fact sheets which on the one hand explain the reasons and usefulness of the measurements carried out and on the other hand provide details on how the various parameters are measured

(b) on the science team training side, we have prepared and supplied an information package with some general articles and other material.

Offer for remote webinars during cruises when communication can allow that, have not been used up to now but we will continue to work on this point in the future.

Fact sheets are attached to this report together with a list of the material provided in the info package.

The fact sheets prepared, from what is known, have been reproduced and laminated for distribution. Unfortunately we have no feedback on to what extent and how this happens.

We also no feedback on whether the information material was used and found to be really helpful.

A weakness in this area is the significant turnover of people and skills that involved the Science Team in the period 2022-2023.

Difficultiers and lesson learned after 18 months of activity

Activity we have proposed is a long-term continuous observation programme. This is quite different from the more standard projects that develop their activity during a specific cruise and with personnel onboard.

Weaknesses and challenging arising from our side are connected to

(i) not long experience of operation on the ships and an instrumental setup in development (that means need for more assistance in these first phases)

(ii) under-evaluation of the problems and over-estimation of the support we can receive from PONANT Science Team. Both leading to the “wrong” decision up to now to operate when the ship is in an harbour and not take part to a cruise.

Decision is “wrong” not not in absolute terms, but considering the current development and structure of the PONANT science team and science programme, and some unforeseen difficulties in interfacing with the operating methods of accessing the identified space. If we consider that our instruments can be easily accessed with a short staircase that starts from the bar and recreation area which is found at the stern of the ship. And that our typical maintenance operations do not contemplate any truly risky behavior, it is quite clear that the latter arise mainly from miscommunication.

On the side of PONANT, the weaknesses and difficulties encountered are:

(i) an objective difficulty of accessing the ship. In practice, if you don't go on a cruise, the times available to operate are minimal, fraught with difficulties and limited to once or twice a year (only once if only Europe is considered)

(ii) a lack of clarity on how the science program operates and what the lines of communication are with ship management. This ends up making it almost mandatory to go on a cruise and try to build the necessary trust with the captain, officers and crew

(iii) apparently a difficulty of the science team personnel on board to interact regularly with external solicitations. Let's imagine this linked to an overload of work, having to divide themselves from the necessary outreach action towards cruise passengers and assistance to the various projects and researchers on board

(iv) the cost of a system which we thought was already completed when we prepared the proposal and imagined the activity and which is now slowly being completed, above all in terms of data acquisition and centralisation. Unexpectedly then some things possible in the beginning have become much more difficult apparently now. On all remote access to our system (due to a security policy that did not take due account of all needs).

From the experience gained we have basically learned that:

A - we will necessarily have to identify some cruise in which to have personnel on board and work to definitively fix our setup and above all the communication issues both towards the central acquisition system (finally activated) and remotely. This second is crucial at this point since the science team can never give us all the regular attention we need to avoid large data gaps.

B - work with more attention and commitment to build the relationship of trust that is necessary both with the science team and its management and with the captain and crew. We are well aware that help and support for businesses like ours can come from many people with a minimum of training effort. The strengthening of this relationship of trust and collaboration could also have the effect of greater satisfaction and involvement in dissemination and awareness actions on our research topics and measures.

C - work to forge a better bond with the researchers present on the ship from time to time. Many of them certainly need our data and measurements and therefore can be the first to help us maintain their continuity, quality and accuracy.

Unfortunately, the coordination of the scientific program is going through a moment of change which will take place during the summer. it is our intention to organize a meeting with the new coordinator to try to discuss all the problems listed above together and find suitable solutions in the light of the lessons learned and the lines and resolutions A, B, C mentioned.

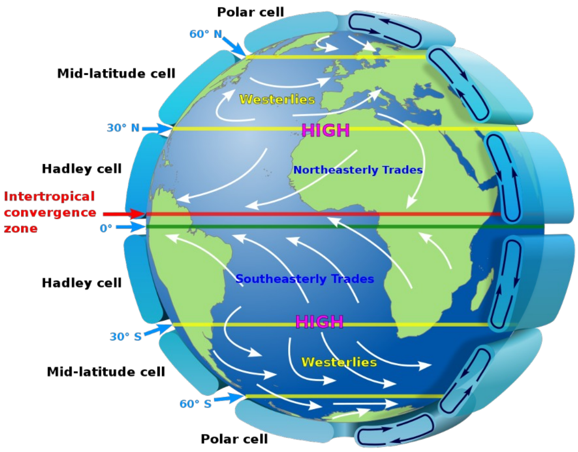
ANNEX

A1. - fact sheets prepared for outreach activities

A2. - List of material provided in the info package to PONANT Science Team

CLIMATE MACHINE

At the heart of the climate system, the atmosphere and oceans, through their winds and currents, distribute excess solar energy reaching the equator from low latitudes towards the poles, which are in deficit. It is in this sense that physicists speak of a “machine” looking to thermodynamic: temperature differences are converted into motion, whose kinetic energy is, of course, dissipated into heat.



This analogy can be used also in a more popular and less physical way. If we consider the climate as for example a car, the obvious questions are basically 4:

1 - who supplies the petrol? 2 - on what principle is the engine of this machine based?

3 - who finally turns the key and turns it on?

4 - can this machine ever stop?

And the answers to these questions provide the basic of the climate system functioning:

1 - the sun is our gas station, more generous with the equator and less with the poles;

2 - the engine of the car is the combination of the universal rule for which nature tries to bring everything to the same temperature ALWAYS and the luckiness have two willing helpers like the air and water to make the job;

3 - the sun that heats the equator more than the poles ends up starting the engine;

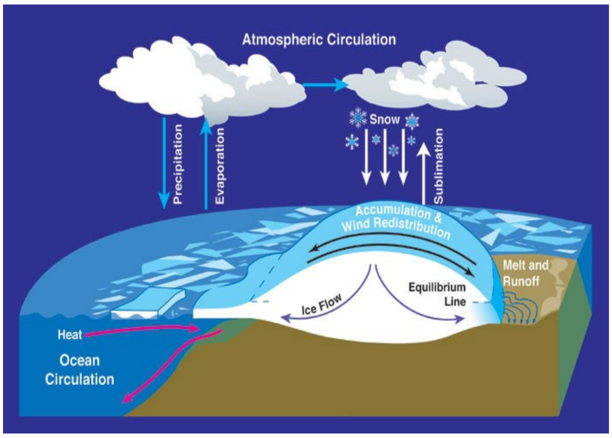
4 - as long as the sun gives us the energy and the hottest equator of the poles the machine will remain in motion (how however can be affected a lot by climate change)

INCOMING RADIATION AT EARTH SURFACE

The foregoing highlights the extent to which the weather and the climatic machine are driven and regulated by the differences (of radiation, temperature, pressure, altitude, land and water distribution, etc.) both in space and in time.

This consideration makes clear the importance of monitoring the radiation that manages to reach the surface of the Earth. On the sea, this measure is clearly much more difficult than elsewhere. And satellites can only partially help us because they look from very far away and their vision is obstructed by the atmosphere (think when the sky is cloudy).

The importance can also be deduced by thinking about the water cycle and the fact that it is triggered by the radiation that heats the oceans and evaporates its waters. Without this process we could not have clouds and rain.

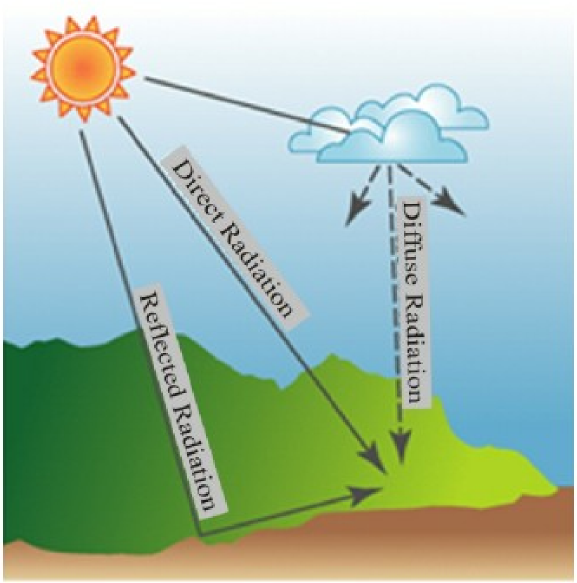


Measurements made on ships and platforms are very valuable, certainly simpler and more accurate than those that can be made on buoys. In seas that see the non-constant presence of ice they become even more important, both for the data they give and for the possibility of validating the information obtainable from the satellites.

SURFACE RADIATION COMPONENTS

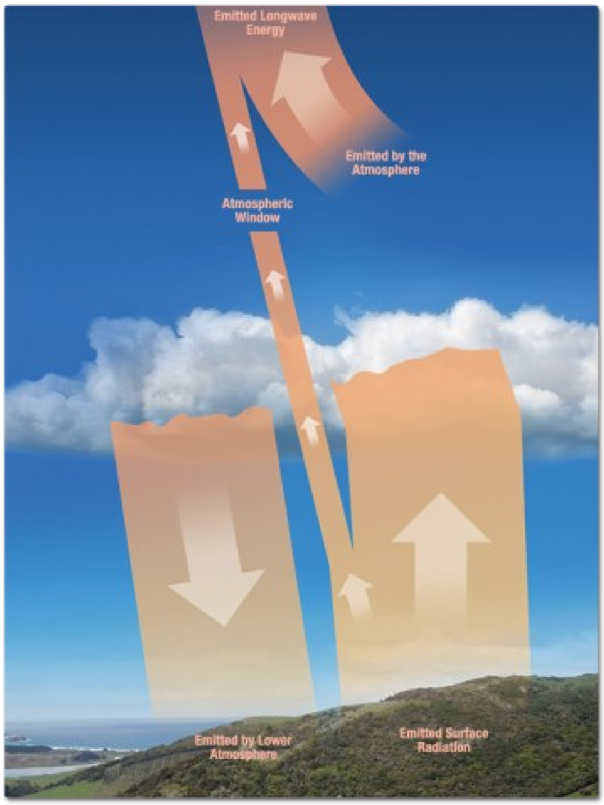
Only about 50% of the solar radiation reaches the surface directly, but as we all know this quantity varies greatly with the season and above all the cloud conditions.

The solar radiation that remains trapped in the atmosphere is at the origin of the blue sky that we are able to appreciate, as well as the beautiful fiery red sunsets or the soft pink colors in the polar areas. Some of this scattered radiation manages to reach the surface.



Solar radiation is not the only radiation reaching the surface. The atmosphere, especially the lower part of the troposphere, is a "hot" place when compared with the temperature of space which is about -270 ° C, close to absolute zero. And this thanks to the surface that, when heated by the sun, ends up also heating the atmosphere.

A hot body emits radiation according to another universal thermodynamic law (this is what the Sun also does). As a consequence, surface also receive radiation emitted from the atmosphere.



For how it arises, thermal radiation emitted by the atmospheric is a parameter directly linked to the average temperature of our planet and one of those that first change (more sensitive) due to climate change.

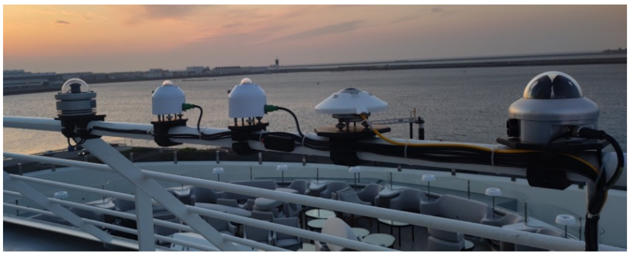
Since the Sun has a temperature close to 6000 ° C and the atmosphere on average 20 ° C, it is not at all strange that the two radiations are very different: the solar radiation cover a shorter wavelength range (SHORTWAVE), while atmospheric radiation a longer one. (LONGWAVE or also INFRARED being its wavelength range just greater than that of the red end of the visible light spectrum but less than that of microwaves).

IMAGE CREDITS

1 Wikipedia - https://en.wikipedia.org/wiki/Atmospheric_circulation
2 Science Kids - https://www.sciencekids.co.nz/pictures/earth/atmosphericcirculation.html
3 Christos Chalkias et al. - Open Journal of Applied Sciences, 2013, 3, 224-231 (doi:10.4236/ojapps.2013.32030)
4 NASA - https://science.nasa.gov/ems/13_radiationbudget

WHAT ARE WE MEASURING AND HOW

Ideally, a radiation measurement should be able to rely on a stable horizon completely free of obstructions to be able to capture the signal of the entire half-space. Compared to these ideal conditions, a ship (even a research ship) presents significant challenges. If the importance of the result justifies the deviation from ideal situations, this does not mean that we should not do everything to reduce errors, both through a judicious installation and then the development of ad hoc data analysis procedures. Until a few years ago on a ship it was possible to measure only the sum of direct and diffuse radiation (global radiation). But the developments of the instrumentation now allow the overcoming of this limit, allowing to collect information capable of enriching the subsequent analysis and the results (see next section).



The choice of sensors and parameters to be measured was made considering the following objectives: 1) to be able to monitor the radiation balance at the surface and its components; 2) use measurements to obtain information on clouds; 3) obtain information on components of radiation such as UV and photosynthetic radiation (PAR) important for ecosystems. In relation to objective 2, the addition of an all-sky camera also offers us the possibility of continuing the development of analysis techniques which are for measurements of this type at a preliminary stage.

MEASURE INCOMING SOLAR RADIATION

Drived by needs of renewable solar energy, around the end of 90s a new concept was developed with the aim to be able to measure all components with only one sensor and no moving parts. **The Delta-T sunshine pyranometer SPN1** provides outputs for global and diffuse radiation. This is possible thanks to a design where shading pattern and 7 thermopiles are arranged so that at least one thermopile is always fully exposed to the solar beam, and at least one is fully shaded from it, regardless of the position of the sun in the sky. All seven thermopiles receive an equal amount of diffuse light. SPN1 computes direct radiation by subtracting the diffuse from the global (total) radiation. SPN1 needs no routine adjustment or polar alignment and works at any latitude.

MEASURE INCOMING THERMAL RADIATION

The Infrared thermal radiation (IR) emitted by the atmosphere can be measured with a **pyrgeometer**. It provides a voltage that is proportional to the radiation exchange between the instrument and the sky (or ground) in its field of view. The detector signal output can be positive or negative. For example, if the sky is colder than the pyrgeometer, the instrument radiates energy to the sky and the output is negative.
So, in order to calculate the incoming IR it is necessary to know the temperature of the instrument housing close to the detector and the data must be recorded simultaneously with the detector signal.

The typical wavelenght range cover the relevant part of radiation emitted by Earth atmosphere: 4.0 µm till about 50 µm. The dome is made in silicon to cover this spectral range, and its shape is usually realized in such a way to reduce solar influence if the instrument dome is not shaded. We use a SGR4 Kipp&Zonen pyrgeometer one of the best performing tools on the market.

MEASURE UV-A AND UV-B RADIATION

Interest in the effects of ultraviolet (UV) radiation on the marine environment surged after the Antarctic ozone hole was discovered in the mid 1980s. Much of the ensuing research has focused on quantifying the potential influence of stratospheric ozone depletion on primary productivity, the survival of marine organisms, food web processes and biogeochemical cycling. Ultraviolet radiation is now recognized as a potent environmental factor that significantly influences marine chemistry, water clarity, primary productivity, and probably pelagic food web structure. Exposures of aquatic organisms to UV are a function of location and time, modulated by clouds, vertical mixing of plankton and depth of benthic organisms and other factors. Owing to the complexity of the interactions and their demonstrated importance, the effects of UV must be understood to describe the workings of the ocean. Measure the fluxes of UV spectral components is for sure the first fundamental step for that, and our measurements can support research of marine scientists on this topic. An UV radiometer in short is basically a pyranometer (instrument used to measure global solar radiation) to which is added an element limiting the measured spectral region (band pass filter). For our measurements we have selected two radiometers produced by the company EKO always on the basis of their high performance.

OBSERVE CLOUDINESS CONDITIONS

All sky camera can carry out Full Sky (180°) images of the night or day sky, and in a continuous fashion. High sensitivity systems can record a very good image quality of the night sky. Atmospheric studies are one of the many application fields of these equipments. The most popular being astronomical observations.
For our scopes, the ALCOR camera (ALPHEA model) will collect any 15 minutes ands image of the sky, giving us the possibility to derive quantitative (cloud coverage) and qualitative (clouds type) information thanks post-processing analysis of the images. The camera has been optimized for diurnal observations.

WHERE ARE STORED AND HOW ARE USED DATA

Data are acquired locally on the ship data sharing system and at the end of the day also transferred to Italy. Our plan is to develop analysis procedures that are as automatic as possible, the only way to be able to sustain the rhythm of a daily data flow. The procedures will also include data quality controls, defined thanks to our experience in the international Baseline Surface Radiation Network (BSRN). The objective is to obtain, on a 15-minute basis, values of the incoming components of the radiation balance at the surface (global SHORTWAVE, direct, diffuse, LONGWAVE, UVA and UVB) and for cloud cover the percentage of sky covered by clouds (cloud coverage), and developing new procedures, information on the type of clouds. Once consolidated, these results will be included in the Italian databases for Antarctica (NADC) and Arctic (IADC)) and through them shared with the international community according to the principles and good practices about access to data (FAIR principles https://ogsl.ca/en/fair-principles/)

INFORMATION PACKAGE

(list of thje content)

NOTE - The information package need to be informative but also oriented to not experts, this need driven in the selection of 2-3 peer review papers included.

1 - LIST OF THE INSTRUMENTS MOUNTED ON BOARD. The list include link to web page with datasheet and information by manufacturer

2 - USEFUL LINKS TO DEEPEN TOPICS. Several links introduce to resources that offer much more topics and information. So you can easily extend your research of information and knowledge to the desidered level.

3 - HOW TO MEASURE SOLAR RADIATION. A note (8 pp.) prepared by Huseflux manufacturer that will set off the reader on the right track to get data flowing. Follow these step by step instructions to get accurate and reliable solar radiation data from a pyranometer. Even if dedicated only to global radiation, many information elements are useful also for IR measurements.

4 - BASELINE SURFACE RADIATION NETWORK (BSRN): STRUCTURE AND DATA DESCRIPTION (1992–2017). A publication describing the state of art of the most important global radiation network. Useful for motivation and also learn about best practices for good observations.

5 - A BRIEF TOUR OF THE CLIMATE MACHINE: 1 THE CLIMATE MACHINE, A TWO FLUIDS THERMAL ENGINE. Useful to deepen topics of fact sheet 1. This paper is the first part of the french paper "Visite dans les Rouages du Climat", Reflets de la Physique 49 (mai-juin 2016)

6 - VISITE DANS LES ROUAGES DU CLIMAT. The complete French paper. Abstract (translated): the climatic machine is a thermal machine which receives its heat from the Sun, and which redistributes it to the surface of the terrestrial globe by the coupled circulation of the two fluids, atmosphere and ocean, in interaction with the environment. The water cycle, present on Earth in its three physical forms: solid, liquid and gaseous, plays a key role. External forcings induce climate changes that are strongly modulated by environmental feedbacks. To elucidate the functioning of such a system and study its possible future, a whole panoply of models had to be implemented.

7 - SOLAR RADIATION MEASUREMENTS. A seminar illustrating the main aspect of solar measurements. Quite simple but informative (49 slides)