Station Miniature et Autonome d'Observation de la Composition Atmosphérique (SMOAA)

Final report

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TABLE OF CONTENTS

PARTENARIAT SMOAA 2
LIST OF FIGURES 5
FOREWORD 7
SUMMARY 7
SYNTHESE (COURTE) 7
SYNTHESE (LONGUE) 8
1. SMOAA ORIGINAL OBJECTIVES 10
2. INTRODUCTION 11
2.1. ACRONYMS 11
3. GENERAL DESCRIPTION OF THE S-BOX SYSTEM 12
3.1. SYNOPTIC 12
3.2. ENTITIES PRESENTATION 13
4. SBOX MOUNTING ENTITY 15
4.1. INSTRUMENT BOX 16
4.2. UTILITY BOX 17
4.3. THERMAL REGULATION 17
5. ENERGY SOURCE ENTITY 21
5.1. ARCHITECTURE 21
5.2. BATTERY DESCRIPTION 22
5.3. BATTERY PROFILE 23
5.4. LI-ION BATTERIES 25
6. SAMPLING ENTITY 27
6.1. ARCHITECTURAL DIAGRAM 27
6.2. SAME CONTROL SYSTEM 28
6.2.1. INLET SYSTEM 28
6.2.2. DIFFERENTIAL PRESSURE SENSOR 29
6.2.3. ICE SENSOR 30
6.2.4. INLET HEATING 31
6.2.5. INLET EFFICIENCY 32
6.3. HUMIDITY & TEMPERATURE MONITORING 32
7. INSTRUMENTATION ENTITY 34
7.1. INSTRUMENTS MODIFICATIONS 34
7.2. DATA COLLECTING 38
8. MINI CCN (NOT IMPLEMENTED- CNRM)) 39
8.1. OVERVIEW 39
8.2. STREAMWISE THERMAL-GRADIENT CCN CHAMBER 40
8.3. DESIGN CONSTRAINTS 40
8.3.1. COLUMN RADIUS 40

8.3.2. FLOW RATE 41
8.3.3. WALL THICKNESS 41
8.4. INSTRUMENT DESIGN 42
8.4.1. CCN GROWTH COLUMN 42
8.4.2. OPTICAL PARTICLE COUNTER 42
8.5. PERFORMANCE TESTS 42

9. SYSTEM CONTROL ENTITY 44

9.1. DIAGRAM 44
9.2. FUNCTIONS 46

10. SCIENTIFIC RESULTS 50

10.1. TESTS IN THE NATURAL ATMOSPHERE 50

11. FOLLOW-UP ACTIVITIES 59

12. CONCLUSIONS 60

LIST OF FIGURES

Figure 1 Schematic description of SMOAA with the instrumented box containing all 5 instruments for gas and aerosol phases as well as the acquisition and communication systems. The second box contains batteries and standards / chemical for the instrumentation. *12*

Figure 2 Integrating test on the laboratory roof (February 2011). *13*

Figure 3 Integrating test at Laboratory roof 2 .... *13*

Figure 4 SMOAA Application diagram. *14*

Figure 5 Front panel of IBOX with and without instrumentation .3 instruments are visible from the top: Ozone analyzer, optical particle counter, condensation particle counter. *16*

Figure 6 Instruments arrangement in the SMOAA rack.. .... *16*

Figure 7 Architecture of the UBOX containing the battery box, insulated with foam, a case for the standardized CO2 gas cylinder and an insulated part for the butanol reservoir.. .... *17*

Figure 8 Principle of Heat-Pipe. *18*

Figure 9 Schematic of the SBOX Heat-Pipe system. *19*

Figure 10: Temperature comparison during integrating test at Il Forni glacier (Italia, Stelvio, July 2011). *19*

Figure 11 Architecture of the energy entity. As mentioned in the text, the energy unit is composed of a production system made with solar and Aeolian generators and an energy storage system with the batteries. *21*

Figure 12 Eolic generator used for S-BOX with left the wind propeller unit and right the theoretical charging curve as a function of wind speed. *22*

Figure 13 Battery profiles measured for different weather conditions during the integrating test at Stelvio Forni glacier (Italia, Stelvio, 02/07/2011). For two different days a) and b) *24*

Figure 14 Battery profile during all integrating test at Il Forni glacier (Italia, Stelvio, July-September 2011). *25*

Figure 15 Architecture of SAME. Pneumatic diagram. *28*

Figure 16 S-BOX inlet PM2.5 with ice probe. *29*

Figure 17 Ice probe operation schematic. *30*

Figure 18 A schematic view of the Inlet heating configuration with the ice probe also indicated. *31*

Figure 19 Inlet heating diagram. *32*

Figure 20 Sum voltage circuit (based on op-amp). *33*

Figure 21 General synoptic of the autonomous CO2 calibration. *35*

Figure 22 Synoptic of the CPC buthanol fill. *37*

Figure 23 Modifications on power supply and pump. *37*

Figure 24 Modification on OPC pneumatic. Bypass self control of OPC. *38*

Figure 25 View of the mCCN instrument......39
Figure 26 Saturation as a function of flow and T-difference......42
Figure 27 A photograph of the SYCE in its final configuration. SYCE is designed and assembled at LGGE......44
Figure 28 Diagram of the SBOX system control. It is the core of the application......45
Figure 29 Simplified SBOX software flowchart......46
Figure 30 A picture of the micro SD used to store all S-BOX data......48
Figure 31 Pressure comparison during integrating test at MTC GAW.. 51
Figure 32 Temperature comparison during integrating test at MTC GAW......51
Figure 33 CPC (left) and O3 (right) comparison during integrating test at MTC GAW 52
Figure 34 A view of the S-BOX installation at Forni Glacier during the Stelvio campaign......53
Figure 35 a,b,c,d showing: Relative humidity (upper left), Wind speed (upper right), pressure (lower left) and temperature (lower right) measured by the S-BOX at Forni glacier 54
Figure 36: CO_2 concentration measured by S-BOX during the Stelvio campaign. Concentration outliers above 400 ppm should be considered as noise in the signal. 55
Figure 37 Concentrations of particles measured by CPC during the Stelvio campaign......55
Figure 38 Concentrations of Ozone during the Stelvio campaign.. 56
Figure 39 a) energy balance of the S-BOX during the Stelvio campaign and b) thermal balance of the S-BOX......56
Figure 40 S-BOX at the Askole station Pakistan in summer 2012......57
Figure 41 (left) and b) right: concentration of particles measured by CPC and ozone during the Askole campaign 58

FOREWORD

SMOAA was organized as a collaborative work between LGGE and CNRM with 2 people Principal investigators: Paolo Laj (LGGE) and Laurent Gomes (CNRM). In January 2011, Laurent Gomes had to stop his professional activities for health reason. On February 2011, Laurent passed away.

Some of the SMOAA activities were continued under G. Roberts direction but the integration of the CCN / DMA was never integrated into the SMOAA box. This explains why SMOAA did not reach his complete list of objectives. This report and the outcome of the SMOAA project should be read with this information in mind. So far, the position of Laurent Gomes is still vacant at CNRM.

SUMMARY

SMOAA BOX is a proof of concept. We have built a totally autonomous analyzer that is suited for measuring variables such as CO2 and Ozone content, particle size and number, concentration of black carbon in addition to some meteorological variables (T, Wd, Wi, RH, P). The analyzer is powered by both solar and eaolian energy for a total consumption of less than 50 W. Energy is stored by a set of battery and the use of energy is optimized according to external conditions. The instrument is suited for external conditions ranging from -10℃ to +20℃ and for high wind-speeds and icy conditions. All instruments operate when energy conditions are satisfactory and can remain in silent mode whenever the energy available is too limited. Heat produced by instruments is stored for optimal battery usage and extra-heat is released when necessary. The instrument is connected by either satellite or radio transmitters and can be operated both ways: information pushing or data transmission. SMOAA BOX has been tested unattended at 2 locations in the high altitude (Alps and Pakistan mountains) providing scientific information that will be used as part of experimental studies documenting atmospheric composition and variability at remote locations

SYNTHESE (courte)

Le projet SMOAA-BOX est une preuve de concept. Nous avons développé un analyseur autonome permettant la mesure de composes gazeux (CO2, O3) et particulaires (Nombre et taille des particules, concentration de carbone-suie) ainsi que de variables météorologiques (T, Wd, Wi, RH, P). L'analyseur est alimenté uniquement par énergie solaire et éolienne pour une consommation totale inférieure à 50W. L'énergie est stockée par des batteries et l'utilisation des ressources est gérée en fonction des conditions extérieures. SMOAA-BOX est optimisée pour une utilisation entre -10℃ et + 20℃ et pour des conditions météorologiqu es rencontrées en haute montagne (vents forts, formation de glace). Tous les instruments fonctionnent lorsque les conditions de disponibilité électrique le permettent et passent en mode « dormant » lorsque l'énergie disponible est trop limitée.

La chaleur produite par les instruments sert à maintenir des conditions optimales dans les compartiments « instruments » et « batteries ». L'énergie peut être également évacuée si nécessaire. SMOAA-BOX est connectée par radio-modem ou satellite et la transmission peut se faire dans les 2 sens, soit par un opérateur intervenant les instruments soit par transmission directe des données. L'analyseur a été testé sur 2 sites de haute altitude (Alpes et Pakistan) permettant de recueillir des informations sur la variabilité de la composition atmosphérique dans des zones généralement très difficile d'accès pour des mesures long-terme.

SYNTHESE (Longue)

SMOAA-BOX est une preuve de concept : de nombreuses zones ne disposent pas d'observations de la composition atmosphérique compte tenu des difficultés liées à leur éloignement. C'est le cas des zones de montagne. Une analyse des données disponibles globalement montre que la communauté scientifique manque cruellement d'information sur des zones très étendues des montagnes du monde. L'objectif du projet est de développer une station de mesure autonome est adaptée aux conditions de la haute montagne et qui, reproduite en divers exemplaires, pourrait permettre de disposer d'information sur la variabilité atmosphérique à partir de zones de montagne ne disposant pas d'observations.

Nous avons identifié 6 variables essentielles, compatibles avec les limitations de poids, volume et d'énergie imposées au concept : concentration, nombre et masse des particules, concentrations en carbone-suie, nombre de noyaux de condensation (CCN), concentrations en CO_2 et O_3 ainsi qu'une série de variables météorologiques (T, P, RH, direction et force du vent). Les limitations imposées concernent principalement la portabilité de SMOAA, qui doit pouvoir être amenée en haute montagne (transport possible à dos d'homme). Les variables identifiées dans le concept sont un peu différentes de celles prévues à l'origine compte tenu de difficultés rencontrées durant la phase de développement.

SMOAA-BOX a été construite avec les fonctionnalités suivantes :

- Une alimentation par 2 panneaux solaires et une turbine éolienne fournissant l'énergie pour l'ensemble de l'instrumentation et le chargement des batteries
- Le stockage d'énergie par batterie associé à un module de gestion de l'énergie permettant de réduire la consommation énergétique et de la distribuer entre les différents compartiments de l'analyseur
- Un module de gestion de l'instrumentation permettant à chaque instant une autorégulation des fonctionnalités en fonction des conditions internes et externes : risque de gel, risque de surchauffe, énergie limitée, auto-contrôle et calibrage des instruments.
- Un système de transmission modulaire, soit par radio-modem (si existence d'un pont radio) soit par transmission satellite. SMOAA-BOX peut être également prise en main à distance par un opérateur.

- Taille, volume et consommation énergétique compatibles avec les spécificités en particulier pour le transport et l'installation en haute montagne.

Les fonctionnalités affichées ne répondent pas totalement au cahier des charges en particulier pour l'intégration du module CCN miniature. Celui-ci a été développé mais n'a pas pu être intégré compte tenu de la situation d'un des PI du projet au CNRM.

SMOAA-BOX a été testée lors de plusieurs campagnes soit dans le but d'en valider les performances, soit pour obtenir des informations à partir de sites de haute montagne. Concernant la validation des spécificités qui s'est faite soit à partir de tests en laboratoire soit à partir de test sur le terrain en parallèle à des mesures validées du réseau ACTRIS/EUSAAR, nous apportons des solutions techniques dont certaines sont très innovantes et qui permettent de faire fonctionner ce système automatique dans toutes conditions. Parmi ces solutions innovantes, nous pouvons noter l'inlet PM qui permet un dégivrage automatique et dont les performances sont validées pour des particules submicroniques (à l'exception de conditions de vent fort), le système de transfert de chaleur par « heat pipes » qui permet de réguler la température dans tous les compartiments du système, le module de régulation de l'énergie dans SMOAA permettant une mise en veille automatique dans des conditions particulières ne permettant les opérations ou les modifications apportées sur l'instrumentation commerciale. Ils nous permettent de valider le prototype SMOAA dans ces grandes configurations même si des améliorations seraient à apporter dans l'éventualité de construction d'un second prototype.

Deux campagnes ont suivi, l'une dans les Alpes, l'autre au Pakistan permettant d'engranger des informations scientifiques. Les résultats, toujours en cours d'interprétation pour certains, sont satisfaisant. Le but du projet étant la construction du prototype et non les campagnes de mesures, nous limitons dans ce rapport l'interprétation des données.

1. SMOAA original objectives

SMOAA was funded under a grant provide by ADEME PRIMEQUAL (contract #) and benefited from developments performed within a French-italian collaboration (SHARE project). The objective of SMOAA is to develop a transportable station with the following features:

- Measurements of aerosol number, size and mass, aerosol activity spectrum for varying sursaturations, concentration of black-carbon and scattering coefficient of particles
- The station will allow data transmission to a remote station possibly connected to a central institute. The information will contain information on measurements but also any information related to the functionning of the different station components.
- Weight, dimension and energy consumption of the autonomous station should be compatible with a use in the high mountain.
- Conception of the station should be suited to its use in difficult environment (meteorological conditions in particular)

Due to some technical difficulties in addition to other problems, the instrumentation inside the SMOAA box was slightly changed as respect to the original objectives. First, we realized that 250 W would be extremely problematic due to the corresponding weight of the battery system. In the proposal preparation, the information was that the newly developed Li-Ion battery would not be available for the project and that we still needed to work with the older and heavier PB-gel battery. For that reason, and to maintain the overall system to a reasonable weight (<100 kg), we decided to limit energy consumption to 50 W.

A consequence of that was a slight change with the instrumentation: scattering coefficient (which needed also an additional drying system and a pump where replaced by 2 instruments: a CO2 analyzer and an Ozone analyzer. SMOAA is now providing less information on the aerosol properties but more information on the gaseous phase. A second change as respect to the original proposal concerned the determination of BC. During the first year of SMOAA, we made several tests and finally decided to use the miniaethalometer from MAGEE scientific.

2. INTRODUCTION

Development of climate monitoring stations became of major interest in the recent years in the context of studying global warming. Those stations placed in strategic locations, covering as many areas of the globe, need to be normalized and of high quality in order to compare each other's. In parallel, strategic locations also imply to set up stations in remote locations with difficult access and those areas are still missing. To cover this gap, the development of a station easily transportable and moveable, in a concept of use as a "plug-and-play", and autonomous in energy is necessary.

The SHARE BOX project, within the SHARE project, consists to develop such station to study climate parameters in high altitude remote areas with the capacity of running for 6 months to 1 year without maintenance and fill part of the gap of climate data in such locations.

The aim of this document is to outline the conception, the different parts and the preliminary tests which make up the SHARE BOX system, also called SBOX.

2.1. Acronyms

SBOX	**SMOAA- BOX**
IBOX	**I**nstrument **BOX**
UBOX	**U**tility **BOX**
CPC	**C**ondenser **P**article **C**ounter
OPC	**O**ptical **P**article **C**ounter
BC	**B**lack **C**arbon
CPU	**C**ontrol **P**rocess **U**nit
SOME	**S**b**O**x **M**ounting **E**ntity
ENSE	**EN**ergy **S**ource **E**ntity
INSE	**INS**trumentation **E**ntity
SAME	**SAM**pling **E**ntity
SYCE	**SY**stem **C**ontrol **E**ntity
UART	**U**niversal **A**synchronous **R**eceiver **T**ransmitter
ADC	**A**nalog to **D**igital **C**onverter
NC	**N**ormally **C**losed
NO	**N**ormally **O**pened
IDE	**I**ntegrated **D**evelopment **E**nvironment
MTC	**M**on**T**e **C**imone
GAW	**G**lobal **A**tmospheric **W**atching

3. GENERAL DESCRIPTION OF THE S-BOX SYSTEM

3.1. Synoptic

SBOX system is a compact embedded station for climate monitoring. It is conceived with 2 different pieces that are easily assembled. The first piece contains all instrumentation while the second piece is used for storage of standards, chemicals and batteries. It is 50W system consumption for 30kg system weight (without utility box). This system will be installed in remote sites connected to renewable energy sources. SBOX integrates the following part (figure 1)

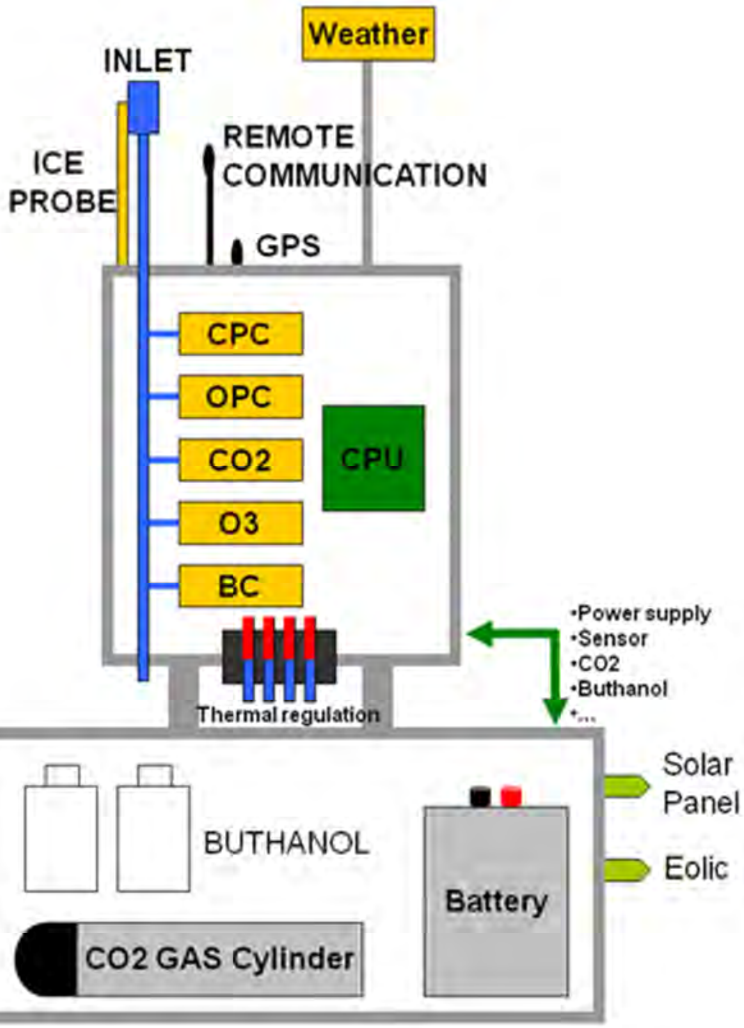

Figure 1 Schematic description of SMOAA with the instrumented box containing all 5 instruments for gas and aerosol phases as well as the acquisition and communication systems. The second box contains batteries and standards / chemical for the instrumentation.

Overall, the system can be transported separately: 1 box for solar panels that can be folded and compacted into 80 x 130 x 20 cm and 10 kg weight : 1 box for Instrumentation (external) in 38 x 50 x 65 cm and 18.5 kg approximately; and 1 box for battery housing and energy production 80 x 60 x 40 cm, and 80 kg. Figure 2 and Figure 3 are showing the entire system assembled for operational use.

Figure 2 Integrating test on the laboratory roof (February 2011).

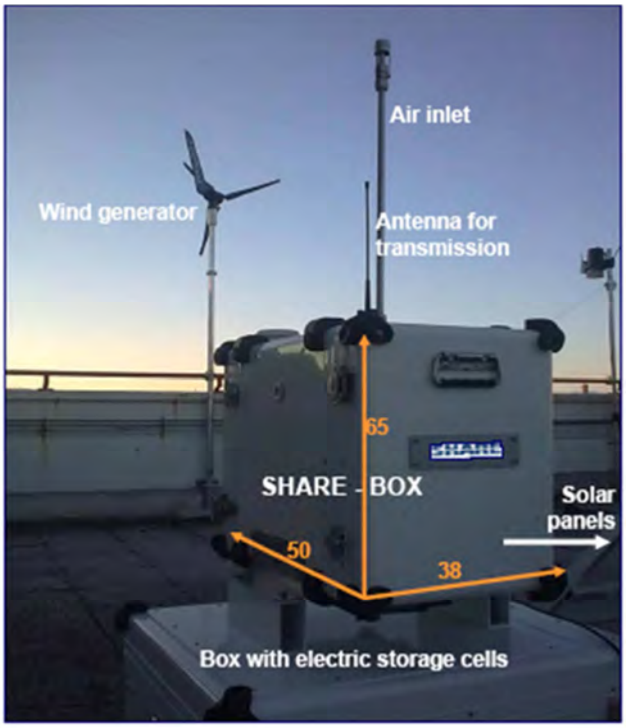

Figure 3 Integrating test at Laboratory roof 2

3.2. Entities presentation

To provide a detailed description of the system, it easier to divide it into 5 different entities:

→ SBOX mounting structure which consists of the original boxes used to host instruments and batteries. It is a fundamental piece of the system since it will be protecting the S-BOX against both varying temperatures, meteorological condition (snow, wind, precipitation, solar radiation) and at the same time should be resistant enough for transport and easy enough to handle to field operation.

→ Energy source: the energy production unit is composed of the energy production unit (solar panels and aeolian system) and of the energy storage system (batteries). It also includes the energy transmission system between the 2 S-Box structures.

- → Sampling system. The sampling system comprises the inlets suited for the sampling of aerosol and gases. The main characteristics are efficiency and resistance to adverse meteorological conditions, in particular for temperatures below freezing and high humidity (in particular the presence of clouds).
- → Instrumentation: as mentioned in the SMOAA objectives, the instrumentation is slightly changed as respect to the original proposal and is now including measurements for the aerosol phase (size, number and mass as well as absorption coefficient –that can be used to derive BC-) and for the gas phase (CO2 and Ozone levels).
- → System control: the overall station should be controlled remotely in order to work unattended for many months. The control of the instrumentation should then be reliable and should provide to the user all information related to the station operation.

The 5 different entities are presented in Figure 4. In the subsequent part of the report, each of them will be presented separately in more details.

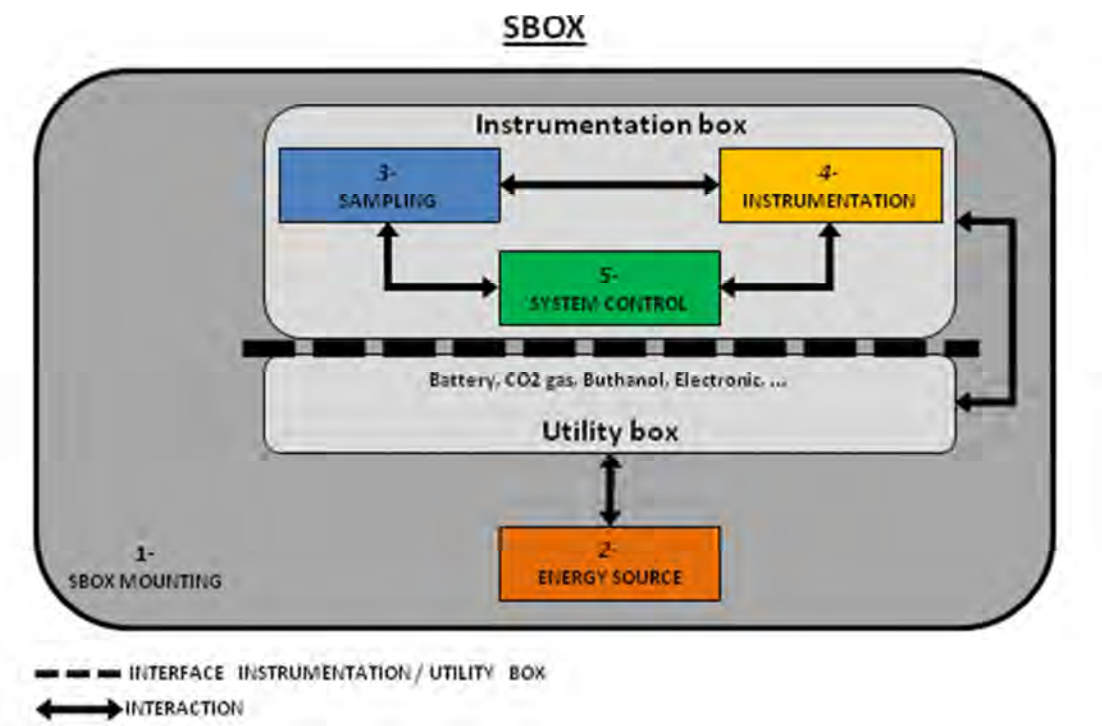

Figure 4 SMOAA Application diagram.

4. SBOX MOUNTING ENTITY

SbOx Mounting Entity (SOME) specifies two boxes: the instrument box and the utility box. The assembly of these two boxes builds the SBOX. The two S-Boxes are commercially available from the following manufacturer: BRC77 (Baie Rack Container).

The boxes have the following characteristics:

Composition	Glass fiber and polyester resin
Colour	White for better sunlight reflexion
Protection index	IP 67 and CEM treatment. Shock pads.
Insulating characteristics	Internal temperature range…………………………….+20…+25 ℃ External operating temperature………………….……..-40…+24 ℃
Dimension	Module 1 (external)… ……………………………38 x 50 x 65 cm Module 1 (instrument housing)………… ………..28 x 41 x 42 cm Module 2 (battery housing)………………… ……80 x 60 x 40 cm
Weight	Module 1 (case) ………………………………………....8.5 kg Module 1 (Instruments and rack) ………..………10.0 kg Module 2 (battery)………………………………… ……80.0 kg

Each box can be easily opened to access the instrumentation. It is equipped with systems that permit strong fixing of the box with cables.

4.1. Instrument box

The instrument box contains **INS**trumentation **E**ntity (**INSE**), **SAM**pling **E**ntity (**SAME**) and **SY**stem **C**ontrol **E**ntity (**SYCE**). All instruments are mounted in a stainless steel rack that can be easily removed from the SBOX for maintenance operations. Figure 5 shows the front panel of the instrumented box.

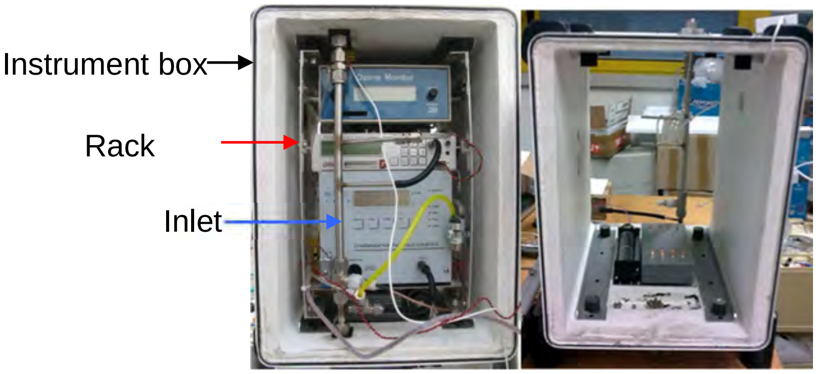

Figure 5 Front panel of IBOX with and without instrumentation .3 instruments are visible from the top: Ozone analyzer, optical particle counter, condensation particle counter.

Inside the box, the instrumentation must be placed respecting the following considerations:

- Display available when opening the front panel
- Space limitation: 5 instruments and all other devices must be placed in a reduced space
- All instruments must be accessible to a single sampling system with limited bends

Figure 6 below shows the choice for placing the instrumentation inside the S-BOX.

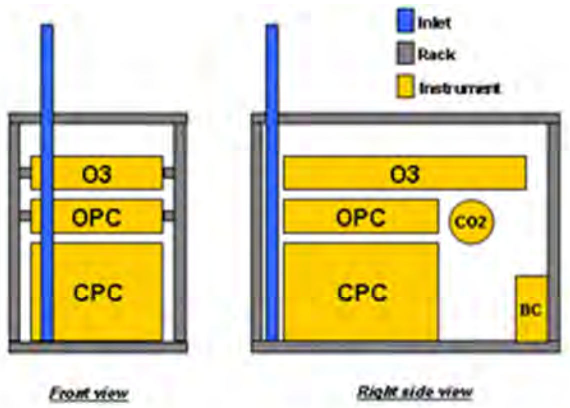

Figure 6 Instruments arrangement in the rack. The CPC (condensation Particle Counter) is the heaviest of all instruments and is placed below also for making the connexion with the butanol reservoir easier. OPC (Optical Particle counter) and Ozone (O3) monitor are placed above the CPC. The instruments for CO2 and BC are smaller in dimension and easier to include in the rack.

4.2. Utility box

The utility box (figure 7) contains the following elements:

- Battery set
- Eolic & Solar charging regulator
- Butanol reservoir & pump connected to the CPC
- CO_2 Gas standard cylinder & manometer with solenoid valve connected to the CO_2 analyzer
- Electronic sensors monitoring (Temperature, current, voltage, ...)
-

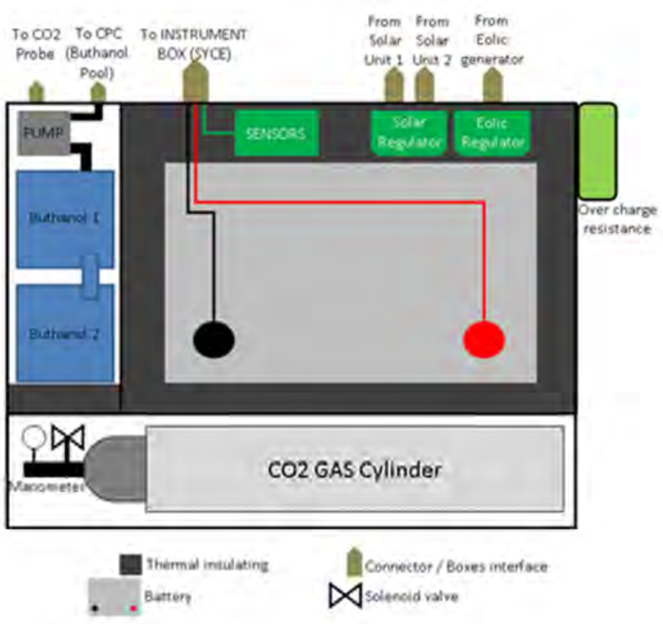

Figure 7 Architecture of the UBOX. It contains the battery box, insulated with foam, a case for the standardized CO_2 gas cylinder and an insulated part for the butanol reservoir. Clearly, the U-BOX is not meant to be trasported with all its features due to its weight (>80 kg) in full operations. However, it is all prepared for being easily reinstalled once in the field. All connnexions are simplified to facilitate operations and the space is optimized for easy packaging of the different parts. The U-BOX can be opened from different sides if necessary to access all its parts.

4.3. Thermal regulation

Thermal regulation of the 2 boxes is essential for different reasons:

- Avoid overheating of instrumentation in the S-BOX in case of intense solar radiation
- Maintain the instrumentation above freezing temperature even in the case of very low outside temperatures
- Maintain the proper conditions in the U-BOX for optimal use of the batteries

For those reasons, the S-BOXES have to be thermally regulated. Heat is mostly produced in the instrument box during normal operation of the instruments. Even if the heat production is limited, the perfect insulation of the box limits exchange with the outside. On the other side, no heat is produced in the U-BOX but the optimal use of batteries requires functioning temperatures preferably above 10℃. Naturally, the idea was to transfer heat from one box to the other.

Heat transfer between I-BOX and U-BOX is based on Heat-Pipe technology. Heat-pipe is a heat-transfer device that combines the principles of both thermal conductivity and phase transition to efficiently manage the transfer of heat between two solid interfaces. A liquid in contact with a thermally conductive solid surface turns into a vapor by absorbing heat from that surface. The vapor condenses back into a liquid at the cold interface, releasing the latent heat. The liquid then returns to the hot interface through either capillary action or gravity action where it evaporates once more and repeats the cycle (Figure 8).

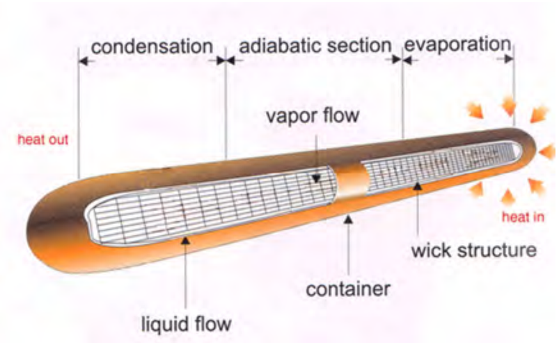

Figure 8 Principle of Heat-Pipe.

The SBOX has eight Heat-Pipes and two fans. One fan is located inside whereas the other one is outside. The fans are enabled or disabled following a temperature threshold defined in the software.

The fluid contained in the heat pipes exchanges between the inside and the outside of the instrument box by changing phase. The process is active as long as there is a temperature gradient. So the action of the fans increases this gradient. The inconvenient of this system is the process can't be stopped. Heat pipe must be sized for a given environment (Figure 9)

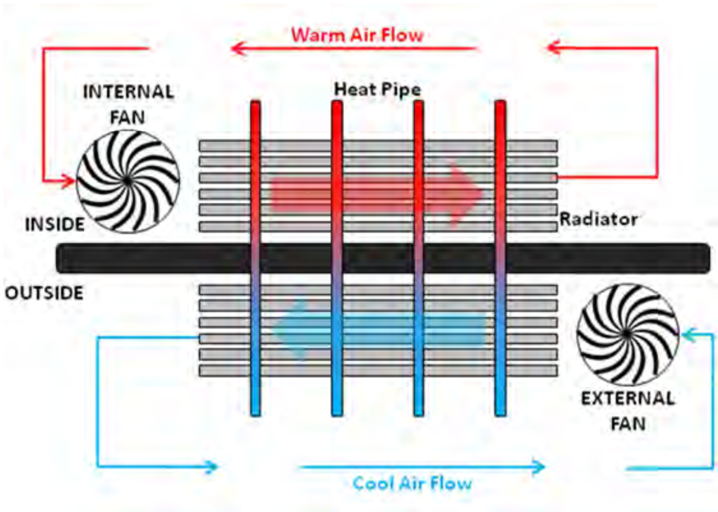

Figure 9 Schematic of the SBOX Heat-Pipe system.

To test the efficiency of heat transfer through the heat pipe, we have monitored the temperature variations inside and outside the box for varying atmospheric conditions. Figure 10 shows an example from a campaign performed in the high mountain, and hence representative of the conditions for which S-BOX is prepared.

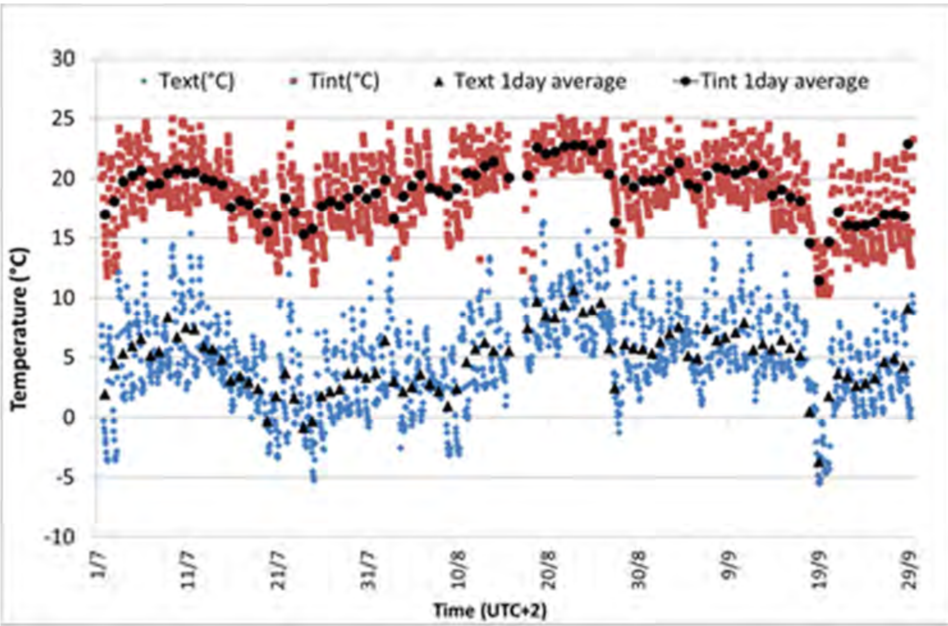

Figure 10: Temperature comparison during integrating test at Il Forni glacier (Italia, Stelvio, July 2011).

This chart represents the evolution of the temperature inside and outside the instrument box. The external temperature fluctuates from -5℃ minimum to a maximum of 15℃ whereas internal temperature varies, in the same time, from 10℃ minimum to 25℃ maximum. Fluctuations of the internal temperature are much smoother than the external temperature. There is, over the 3 months of the test campaign no occasion where the I-BOX goes outside of its proper operation range (typically <5℃ and > 30 ℃). The maximum value was measured for days with intense solar radiation directly onto the box and never exceeded 25℃. Temperature fluctuations inside the box are typically 25% lower than outside. We can estimate that the range of outside temperatures for which the box can be used is typically for a maximum of 18℃ (and intense solar radiation with clear summer sky) and -20℃, that is almost 40℃ difference. We consider that we responded properly to the requirement of adaptation of the box to the high mountain environment.

5. ENERGY SOURCE ENTITY

5.1. Architecture

One of the requirements for S-BOX was the fact that it should be adapted to the high mountain environment and therefore should produce its own energy. The ENergy Source Entity (ENSE) allows providing power supply for the working of the SBOX. It consists of solar panels and eolic generator with associated electronics necessary to charge and protect battery.

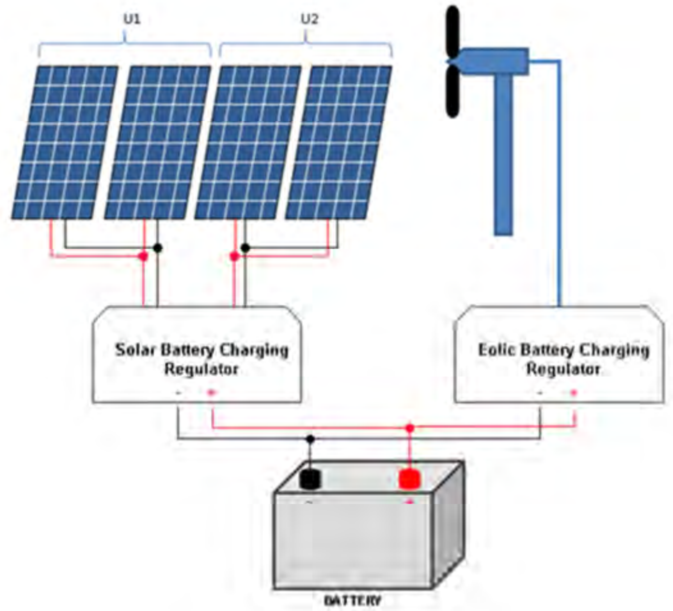

Figure 11 Architecture of the energy entity. As mentioned in the text, the energy unit is composed of a production system made with solar and Aeolian generators and an energy storage system with the batteries.

One solar panel can provide 80W in standard radiation conditions (1000 W·m^{-2}, 25℃). So with four solar panels, 320W are available. In practice, the efficiency of a solar panel is much lower and 4 panel seems a reasonable compromise between cost, weight and energy requirements for the S-BOX. For ideal conditions of radiation, the current provided by solar panels reaches about 20A.

Solar energy can only be provided during daytime. In addition, S-BOX should be prepared for operations under cloudy conditions during which solar energy production is very limited, if not zero. This is why an additional Aeolian generator was added to the system. The aeolian generator can provide a rated power of 350W for a rated speed of 12.5m·s^{-1}. The generator must be modified for adaptation to humid/below freezing conditions with extra-heating system. These are the most complex conditions for which no optimal solution is ever found. Experience at puy de Dôme or other similar mountain stations show that no heating system is totally satisfactory and moving pieces are always at risk of being blocked by contact-freezing of droplets. This will alsways be a limitation of the S-BOX.

The Aeolian system was acquired from the following manufacturer: Superwind GmBH in Germany (power@superwind.com). It is a small wind generator suited for under extreme conditions that works autonomously. The electric power generated charges batteries with the efficiency described in Figure 11)

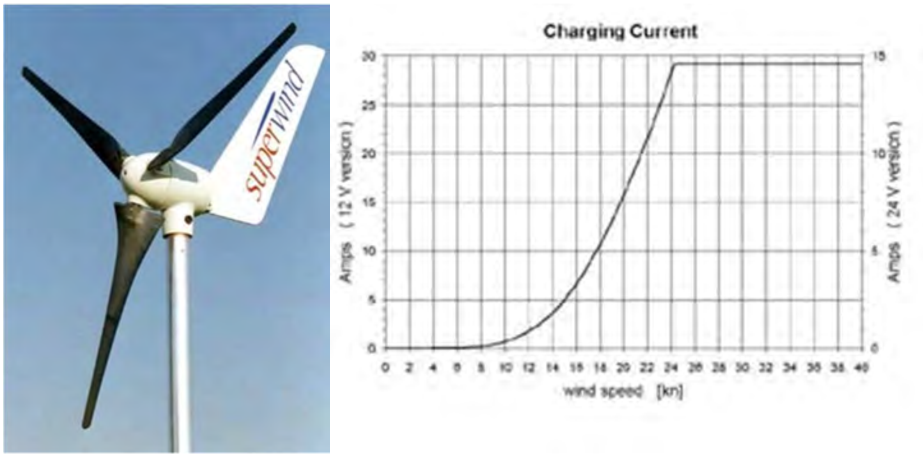

Figure 12 Eolic generator used for S-BOX with left the wind propeller unit and right the theoretical charging curve as a function of wind speed.

The charging curve shows that above 23 Kn (12 m/s) the current delivered to the battery unit corresponds to about 10% of the nominal charging capacity (240 A h). Practically, very little energy produced above these conditions will be lost. At lower wind speeds, the wind propeller will however not be adequately dimensioned to provide enough current to fully charge the battery unit.

5.2. Battery description

Energy is supplied to the instrumentation through a battery set that also serves as an energy storage system. Ideally, the battery set is dimensioned to allow two full-days of operation (48 h) in case of failure of the energy production unit or in case of external weather conditions that would limit power production by both solar panels and aeolian generator.

A first choice for the batteries was the use of the very classical Pb-gel batteries. With four Pb-Gel batteries which have a total capacity of 240Ah (60Ah each), and a nominal voltage supply of 12.5V, there is an energy of 3000Wh. The capacity of the battery set was tested in the field in S-BOX full operational conditions (continuous system consumption at 50W). It is found that ENSE can provide power supply during 60 hours (2 days and half) without charge from solar panel or aeolian generator.

Battery control is performed with the following sensors disposed for ENSE monitoring:

- Solar current monitoring the energy production by the solar panel
- Eolic current monitoring the energy production by the Aeolian generator
- Batteries voltage that monitors the state of the battery
- Temperatures inside the I-BOX, the U-BOX and outside

Batteries voltage informs about charge level. Solar and Eolic current informs about current absorbed by battery. These 3 parameters are key to decide to switch from different operation modes of the SBOX (normal, energy safety, ...). As mentioned earlier, for ideal conditions of radiation, the current provided by solar panels reaches about 20A. With the total dark night conditions (without moon and light reflection by glacier), there is no current provided, but there is a sensor's offset of 500mA. The nominal battery voltage is 12V. However, the range of battery voltage is 10V → 15V. The 10V minimum voltage corresponds to totally discharged state whereas 15V corresponds to totally charged state.

5.3. Battery profile

Pb-Gel batteries were tested during an experiment in real conditions performed in the Italian Alps (Stelvio, 3800 m) during summer 2011 (July/Sept). The S-BOX in full configuration was left unattended near the Stelvio glacier. The battery performances were tested and controlled in conditions varying from snow precipitation to clear sunny sky and from approximately -5° to +15℃ for the external temperatures. The following charts show the evolution of the battery state parameters during an integrating test for autonomous, robustness and observation working debug.

These charts represent the battery voltage and the solar panel current evolution in continuous mode. It means about 50W are continuously provided by battery.

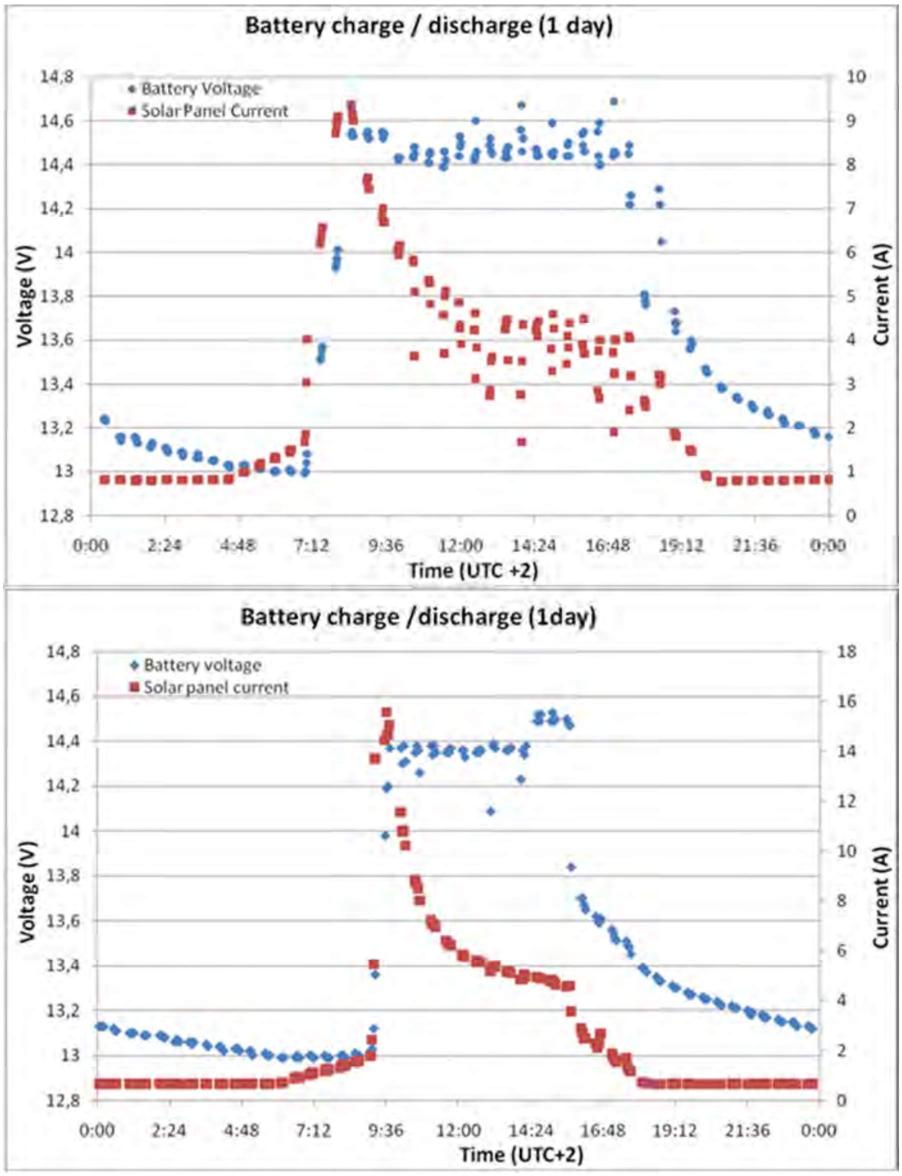

Figure 13 Battery profiles measured for different weather conditions during the integrating test at Stelvio Forni glacier (Italia, Stelvio, 02/07/2011). For two different days a) and b)

These two figures (Figure 13 a and b) represent the same evolution of battery voltage and solar panel current for two different days. In figure 13a , the solar panel current reaches 9.5A whereas the solar panel current reaches 16A on the second chart (Figure 13b). But the duration of solar panel current absorbed is longer on the first chart. For both charts, battery voltage reaches the same value but keeps constant more time on the first chart. These parameters can also be an indication about radiation conditions, as cloudly, sunny, … The weather station has not a radiation sensor.

Figure 14 is an interesting representation of battery state. On 20/09/11, current reaches only 1A, indicative of very low sunlight, and the battery voltage decreases constantly to 11.9V. The day after, there is a little bit more sunlight, and battery recharges until 12.5V. The two following days, the current curve fluctuates as the same way. The battery voltage increases more and more still allowing for the proper functioning of the whole S-BOX for several days in a row.

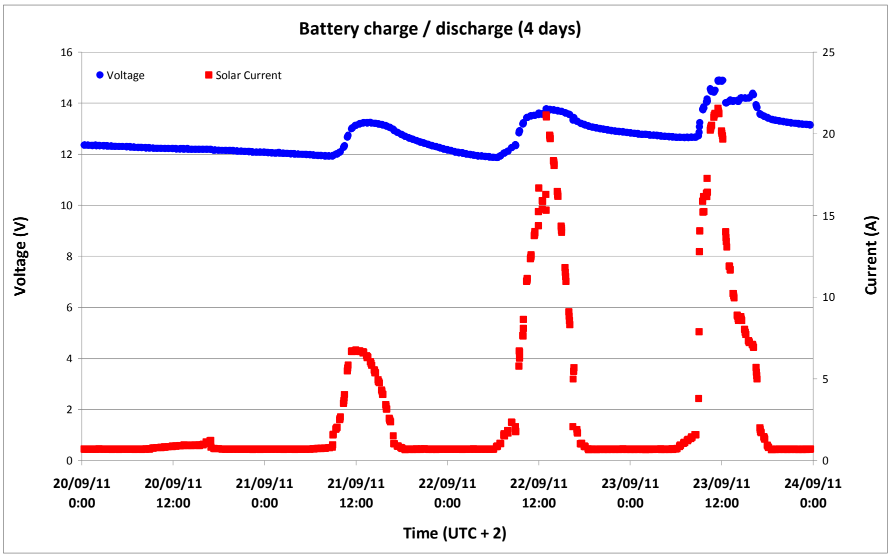

Figure 14 Battery profile during all integrating test at Il Forni glacier (Italia, Stelvio, July-September 2011).

The solar panel current coupled to the battery voltage is a real indication on battery state for SBOX software and allows the management of the power supply. S-BOX can switch automatically from the normal functioning to the energy saving mode where instruments are switched one by one according to the current indicator. In full safety mode, all instruments are switched off and only I-BOX sensors are still in operation. During the experimental campaigns, we never encountered conditions that required a switch to the full safety mode.

5.4. Li-Ion batteries

Pb-gel batteries are quite cheap. However, one of important limitation of this set up is that each battery has a weight of 20kg leading to total weight is 80kg. An additional limitation is that Pb-Gel batteries are very sensitive to cold conditions with a rapid decrease of their capacity with decreasing temperatures.

To respond to these limitations, we have tested another battery type. Lithium-ion batteries (LIB) are rechargeable battery types (to be distinguished from the non-rechargeable lithium battery), common for use in small electronics given its high energy densities and slow loss of charge when not in use. Their price use to be problematic for applications requiring larger energy consumption; however their growing popularity for the electric vehicle and aerospace applications is pulling prices down. Research is yielding a stream of improvements to traditional LIB technology, focusing on energy density, durability, cost, and intrinsic safety. In the case of S-BOX, a clear competitive advantage is also weight and functioning under cold condition as respect to the original Pb-gel choice. It remains however, a much more expensive solution that will require extra protection when S-BOX will be left unattended in the field.

The table below compares weight and energy production for two battery sets. A Li-Ion battery can provide 3696Wh for a total weight of 30kg which would require almost 80 kg for the Pb-gel set. .

Pb-Gel	Li-Ion
80 kg	30 kg
3000 Wh	3696 Wh

Converted into energy densities, Li-Ion can provide 123Wh/kg whereas Pb-Gel can provide 38Wh/kg which, in the case of S-BOX transportation is a clear advantage. The S-BOX electronics is now set for Li-Ion batteries but this was only performed during the last year of the project. We therefore do not present the performances of S-BOX with these batteries but we expect now more autonomy in addition to gain in weight.

6. SAMPLING ENTITY

The sampling system of the S-BOX is far from being trivial. Mountain sites had to develop solution for efficient sampling of aerosol and gases under adverse meteorological conditions: whole air inlets, capable of sampling the aerosol phase even in cloudy conditions, counter-flow virtual impactors for sampling the activated phase only, interstitial inlets for interstitial aerosol and gas only, etc..For activities under the PM regulation, PM10 and PM2.5 are regularly used. None of the solutions mentioned above could be directly transferred to the S-BOX due to space and energy limitation. Original solutions had to be found that would permit:

- Efficient sampling of particles and gases in clear sky conditions
- Embedded de-icing device
- Limited power consumption
- Control system preventing from sampling if conditions are not suitable (clogging of inlet due to ice formation for example)

Sampling in cloudy conditions is not addressed here. Sampling of large drops (>5 µm) should be avoided first to avoid freezing of drops inside the tubing and second to prevent humidity to reach the instrumentation. It is therefore the whole SAMpling Entity (SAME) that carries the air to each measurement device that should be properly dimensioned. The SAME unit contains:

- Pumps
- Differential pressure sensors for flow measurements
- Ice sensor
- Inlet Heating system
- Humidity & Temperature sensors

All these systems operate according to a given cycle: pumps are activated when measurement starts. The flow rate of the inlet is checked. If the value is higher than a threshold defined by the differential pressure system, the corresponding flag “Inlet block control” is set and pumps are stopped. A flow limitation is indicative of inlet clogging and instruments must not work at low pressure (in particular the CPC). Otherwise, task waits to be sure the air sampling will be in devices measure chamber. It is a control performed to protect pumps and instruments. This control is also performed during the measurement.

6.1. Architectural diagram

The overall sampling flow chart is shown in Figure 15, including the different instruments installed as core instruments of the S-BOX.

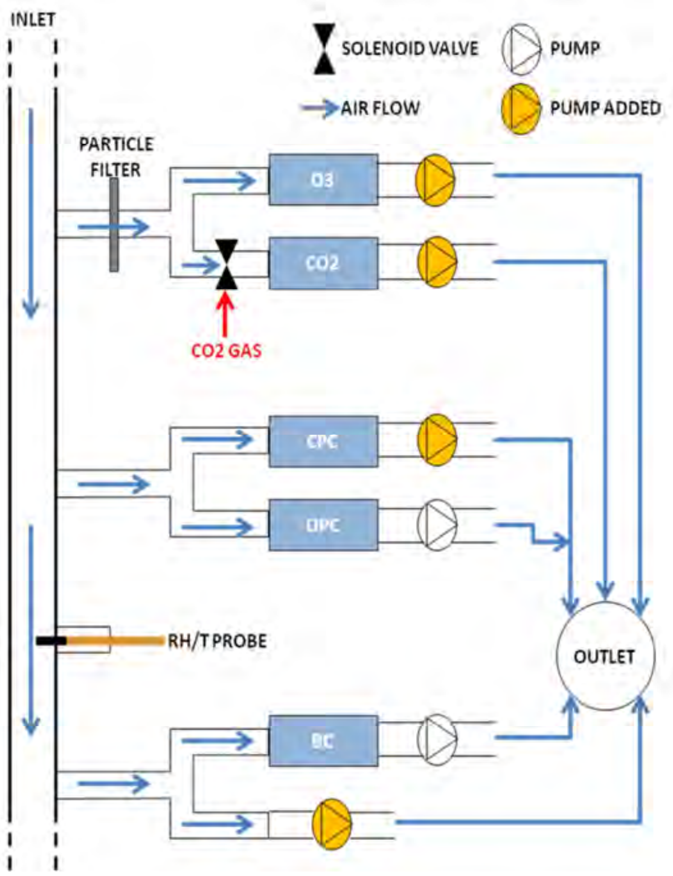

Figure 15 Architecture of SAME. Pneumatic diagram.

The overall sampling system is dimensioned with both internal pumps of the specific instruments and additional pumps to increase flow rate. We have used exclusively 12V pumps protected against short-circuit. This implied modification of some instruments (CPC in particular) to adapt to low voltage. This was done through joint collaboration with instrument manufacturers. All pumps are controlled by the SYCE. Overall the flow though the inlet varies from 1 to 10 l/min depending on the degree of energy saving mode.

6.2. SAME control system

6.2.1. Inlet system

The inlet system is fully designed for the S-BOX. The inlet is made of stainless steel material and has the following characteristics:

- Inlet flow rate 10 l/min allowing for a PM0.8 sampling
- Cover prevents snow to penetrate inside the inlet
- Ice sensor detects formation of ice (see 6.2.3

- PTRH sensor for detecting ice forming conditions
- Vibrator underneath the cover to help removing ice
- Heating system to melt snow and ice

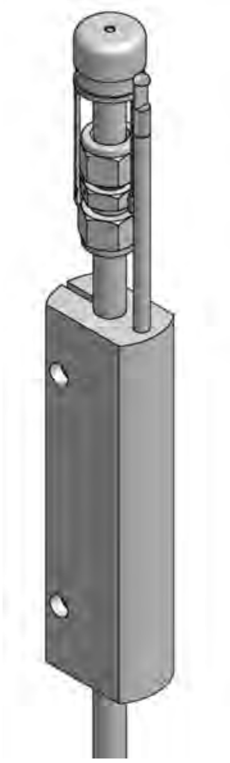

Figure 16 S-BOX inlet PM2.5 with ice probe.

6.2.2. Differential pressure sensor

To control the inlet flow rate and avoid damaging pumps (or instruments) when working at low pressure, a Differantial Pressure (DP) measure is installed. This control is called “Inlet blocked control”. To do this, the sensor used is a BSDX0010D4D of Sensor Technics firm. Its pressure range is 0 ± 10 mbar. Whenever a possible clogging is detected (DP above a certain threshold between P1 and P2, or between P1 and Pexternal), the system is stopped and the whole system performs internal check to identify the cause for the problem.

For a voltage supply of 5V, the sensor analog response is 2.5V with a null flow. Then, the ± 10mbar response will be 4.5V or 0.5V depending of the tubing connection. So the linear response of the sensor is:

$P(U) = 5 \cdot U - 12.5$

With **P** the pressure in mbar and **U** sensor output voltage in V.

The principle consists of measuring sensor output signal when all pumps are switch on. Then, by progressively blocking inlet (ice top simulation), output signal reaches a value which corresponds to critical conditions for pumps operations. This value will be the threshold for the "Inlet Block Control".

6.2.3. Ice sensor

An ice sensor is required in order to fully control whether the external conditions are suited for S-BOX operation. Formation of ice in inlet system is a problem that all operators sampling in high altitude conditions have to face. In whole air inlets, de-icing is automatically switched on as soon as certain conditions of RH and T are reached, to prevent ice formation. Usually, de-icing systems are dimensioned with several hundreds of Watts which are not a problem when energy ressources are available. It is obviously not the case for S-BOX. A different strategy has been chosen for S-BOX given the limiting energy available for de-icing. Because the de-icing energy is limited, the strategy is to prevent ice formation by early detection of ice and to switch to full safety mode whenever conditions are not suited for sampling. The ice control system is therefore chosen as an indicator for sampling conditions.

The ice control is based on an optic measure. It is a "NewAvionics Corporation" sensor called "Ice Meister Model 9732-OEM". This ice detecting probe consists of opacity and index-of-refraction of substance which is on the probe. It functions with the following synoptic (Figure 17):

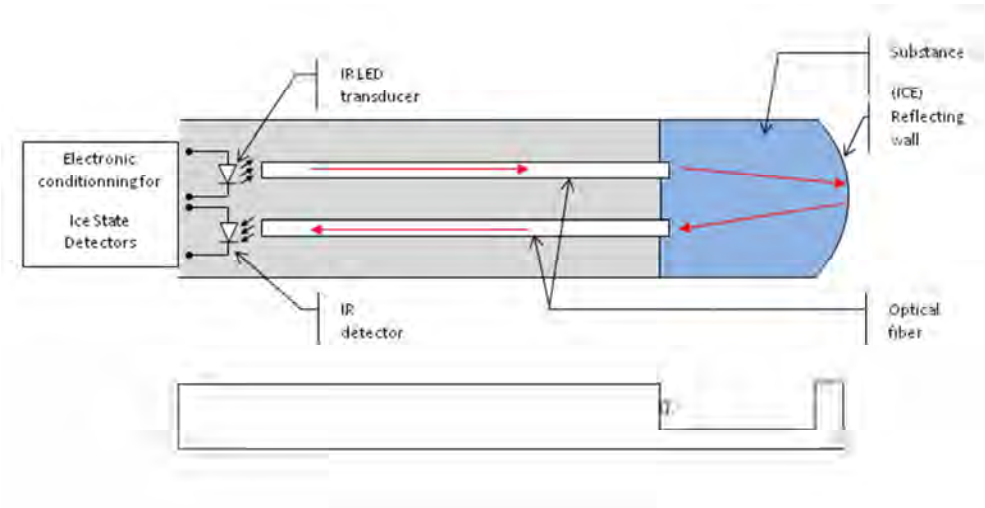

Figure 17 Ice probe operation schematic.

Both transducer and detector are coupled to optical fiber. The detector voltage signal depends of the substance optical properties. This signal is amplified by an op-amp (operational amplifier) and compared to several thresholds which allow detecting different states.

The probe can detect four states:

- No Ice

- Ice Alert and heating mode
- More Ice and heating mode
- Saturation Ice and safety mode

Each state is available on 3.3V TTL pin. If a 3.3V voltage is read, the state is true. Otherwise, the state is false. For example, if 3.3V is read on More Ice state pin, this means there is some ice on probe and inlet. The ice control system is installed as part of the inlet system.

6.2.4. Inlet heating

To prevent ice cap and avoid inlet blocking in ice alert and more ice modes, a heating system is installed on the inlet head. It consists of a heating resistance placed within a stainless steel cover. The inlet resistance value is 21Ω (corresponding to 6W).

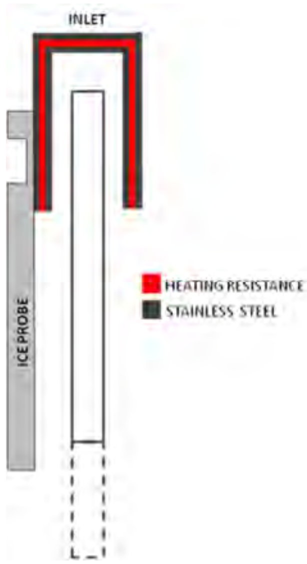

Figure 18 A schematic view of the Inlet heating configuration with the ice probe also indicated.

The heating resistance is coupled to the ice sensor. So it can be decided to activate heating system under specific ice state. It also depends of SBOX energy state.The dimension of the resistance is not suited for operation in supercooled clouds as confirmed during the test campaign performed at Monte Cimone in Italy. Another problem is linked to re-icing of the melted snow present in the inlet that produces denser ice than the original snow. The inlet is designed to ensure that melted snow/ice will not contribute to additional clogging but the perfect inlet does not exist under these conditions.

The safety mode is therefore the best solution that is found for S-BOX operations. Figure 19 explains the electronic operation controlling the heating system.

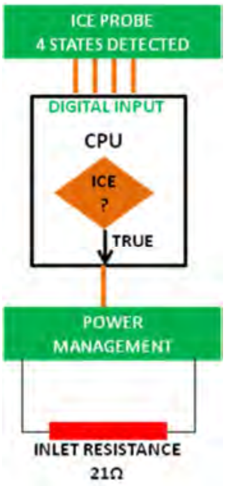

Figure 19 Inlet heating diagram.

6.2.5. Inlet efficiency

The inlet flow controls the inlet efficiency. Penetration efficiency of the inlet tube inclined at 90° under turbulent flow conditions can be estimated to 1 (100% penetration) for particles lower than 1 µm given the inlet geometry and the flows applied. The presence of a sampler cover may have an impact on the overall penetration but calculation using the sampling criteria in still air shows that this will not affect the sampling efficiency for particles < 1µm. For high wind speed (>5 m/s), sampling criteria in still air is not applicable and we can estimate the transmission efficiency in the conduct with Hangal and Willeke, Environ. Sci. Tech. 24:688-691 (1990). In that case, with a 0.1 m/s sampling velocity in the inlet (corresponding to 10 l/min sampling), the sampling efficiency for a 1µm particle and an external wind velocity of 10 m/s would be close to 20%. Under the same conditions, the sampling efficiency for a 0.6 µm particle would be close to 50%. The penetration efficiency increases with decreasing wind speed. At 3 m/s, the efficiency of a 1 µm-particle would be close to 80%.

Overall, the inlet construction is problematic. A static inlet sampling at 90° angle with respect to wind direction will have limitations given the limited flow rate in the duct. In case of high wind speeds (>10 m/s) the efficiency will drop below 20% even for fine particles. An ideal inlet would be rotating towards the wind and sampling at 0° angle (losses in bends are more limited). Unfortunately, this would imply a very complex rotating system and additional heating to operate in supercooled conditions. We believe the inlet geometry is an acceptable trade-off considering the conditions and the fact that particles >1µm are not the primary target of the prototype.

6.3. Humidity & Temperature monitoring

An important element in SAME is the Relative Humidity & Temperature (RH/T) measurement. This monitoring will be used for quality of scientific data (corrections, sample conditions, ...) but also to evaluate the proper working conditions. It is therefore important that this measurement is performed with good accuracy, trueness and precision (depends of quality and metrology device). To satisfy these constraints, the sensor used is a "Rotronic" probe referenced as "HC2-C05". This probe is shipped with calibration certificate.

Results output are numeric (UART) or analog data. Analog range is as follow:

0 → 1V = -40 → 60℃

So the result follows the equation: $\mathbf{T_{℃}(U_V) = 100 \cdot U_V - 40}$

This means 1mV is equivalent to 0.1℃. With common ADC, it is not a problem to have resolution and good accuracy of 1mV.

For old version of HC2-C05 probe, the analog range is different, and there is not the UART interface.

Analog range is:

0.4 → 1V = -40 → 100℃

And equation is $\mathbf{T_{(℃)}(U_{(V)}) = 100 \cdot U_{(V)}}$

So it may have a negative value for negative temperature. For conception reason, ADC unit is designed for 0...5V analog range.

That's why the output voltage is shifted to be in the range. The principle is to add a 2.5V reference voltage (Figure 20):

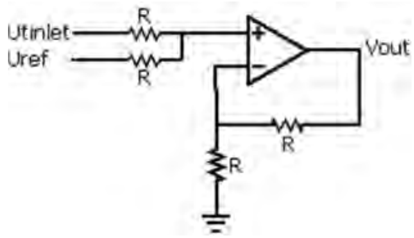

Figure 20 Sum voltage circuit (based on op-amp).

This circuit gives $V_{out} = U_{tinlet} + U_{ref}$

$V_{out} = U_{tinlet} + 2.5$

Finally, the temperature is given by $\mathbf{T_{(℃)}(U_{(V)}) = 100 \cdot (U_{(V)} - 2.5)}$

7. INSTRUMENTATION ENTITY

INStrumentation Entity (INSE) contains all *"scientific instruments"* which are used for climate monitoring. Climate variables concern ozone (O3), carbon dioxide (CO2), black carbon (BC) concentration, and finally number (CPC) and size (OPC) of particles. In parallel, there is a weather station (VXT).

7.1. Instruments modifications

As mentioned previously, S-BOX is constructed with commercial instrumentation. At present, there are 6 instruments embedded:

- **O3 Monitor "2B_TECHNOLOGIES" Model 202 Ozone Analyzer.** The Ozone Monitor is designed to enable accurate and precise (±1.5 ppb) measurements of ozone ranging from a few ppb to 100,000 ppb (0-100 ppm) based on UV absorbance at 254 nm. The Model 202 was chosen for its light weight (2.1 kg.) and its limited power consumption of only 4 watts.
- CO2 Probe "VAISALA" Vaisala CARBOCAP Probe GMP343 Carbon Dioxide Analyzer.
- BC microAethalo "MAGEE SCIENTIFIC" AE51 Miniature real-time monitor for Aerosol Black Carbon detection
- CPC "TSI" Concentration of particles between 10 nm and 1 µm
- OPC "GRIMM" Size and mass of particles between 150 nm and 10µm
- VXT "VAISALA" Weather station measuring

Information on these instruments can easily be found in the web and we will skip the theory of operation and principle of each instrument. In this report, we will only discuss the modifications that were required on this instrumentation for embedding the instrument into the S-BOX. These modifications are described for each instrument.

O3 Monitor
This instrument has a control on the cell temperature and starts a heating resistance when temperature is below a certain treshold. So for safety energy reason, this resistance is kept disconnected. We therefore only rely upon our temperature control for O3 analysis; As mentioned before, it is very unlikely that temperature in the box goes below this threshold. In addition, the instrument cover is removed to gain some weight.

CO2 Probe
This probe is, per se, small, light and low power consumption. No modification is required prior to installation. However, as for any other CO2 probe, accurate calibration is required. Obviously, the calibration procedure has to be automatically managed (Figure 21). This calibration needs:

- A certified CO2 Gas cylinder (provided by LSCE)
- A Manometer with micro valve (flowrate regulator)
- 3 solenoid valves

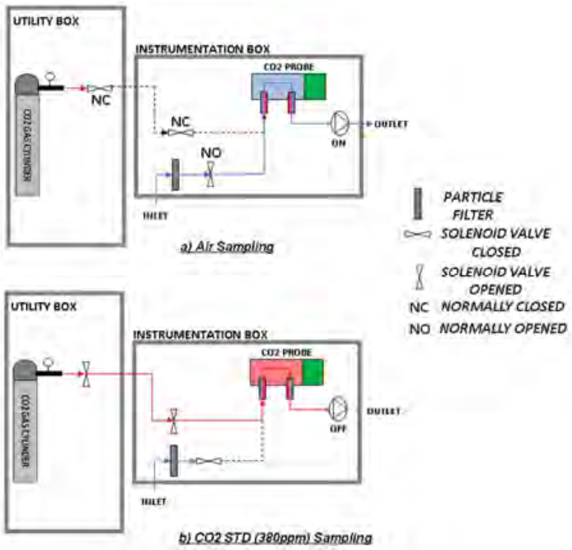

Figure 21 General synoptic of the autonomous CO2 calibration.

The solenoid valve has two states:
- Open (ON) → fluid goes through
- Close (OFF) → fluid is stopped

These two states are switched by applying a 12V or GND voltage. GND voltage state is called *Normal State*. User can choose ON or OFF for the Normal State. Then, by applying 12V, solenoid valve switches in the other state.

Calibration of the CO2 probe is performed every 12 hours.

BC Analyzer

The micro-aethalometer is based on measuring the rate of change in absorption of transmitted light due to continuous collection of aerosol deposit on filter. Measurement at 880 nm is interpreted as concentration of Black Carbon ('BC') assuming a certain mass absorption coefficient.

This "*microAeth*" is designed to work independently in continuous mode during 1 month without filter change. Under normal conditions, the filter has to be changed manually every day which does not make it a suitable instrument for an autonomous station meant to operate unattended for months. However, for very low concentration (such as those expected at high altitude remote areas), one filter may sufficient for monitoring of up to 2 months. No other technical solutions were available at the time of S-BOX construction. There are now other solutions but that could not be prepared on time for SMOAA.

One problem aroused for data storage of the microAeth that requires communication between the SMOAA electronic system and the microAeth AE51. Unfortunately, the manufacturer never agreed to provide the proper command lines to retrieve data from the device. Users of microaeth AE51 are required to use Windows®-based software provided by the manufacturer which obviously is not suited for S-BOX operations. At present, the microAeth is therefore used as an external instrument not controlled by the central S-BOX system. It is not a problem for the sampling unit considering the very limited flow use by the instrument. It is however a strong limitation when using S-BOX either for very long unattended periods or in high polluted environments. It is not a problem if personnel can regularly download data sets (and change filters). We also do not control the MicroAeth remotely.

CPC

The “Condensation Particle Counter” (CPC) is the heaviest and the “warm-up” instrument of the SBOX. We have decided to use the 3010 model from TSI given its strong reliability. The instrument is however no longer manufactured anymore by TSI and the modifications on the instrument are not applicable to the newest TSI versions of CPCs

One first limitation of the CPC concerns its energy consumption when used in its commercial version. Operation requires butanol as a condensing fluid. The buthanol consumption depends on working conditions but typically, the butanol external reservoir (capacity of 250mL) will allow for just a few days of operation. Typical Butanol consumption is indicated in the table below (for 1L of buthanol):

Running time	Duration
Continuous	1 week
15min/hour	1 month

With an intermittent running time of 15min/hour, the CPC can operate up to 4 months. This is a first consideration for the CPC working conditions inside the S-BOX.

A second consideration relates to the Peltier cooling system that permits particle condensational growth by thermal gradient but that consumes a high level of energy that prevents a continuous use in normal S-BOX operations.

For that reasons, the CPC cannot be used in continuous mode but has to switch from energy saving to operations. This switch has to be based upon the charging conditions of the batteries.
To implement these choices into S-BOX and to account for space limitation inside the I-BOX, the butanol reservoir had to be installed inside the U-BOX. This then requires an additional filling system since the CPC in normal use has its reservoir placed on its top and is filled by gravity. we have added to the system a automatic filling unit (Figure 22).

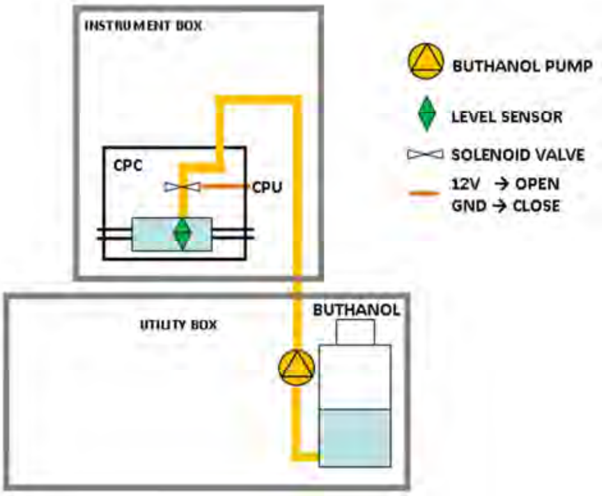

Figure 22 Synoptic of the CPC buthanol fill.

The CPC can fill automatically its butanol internal reservoir with both solenoid valve and level sensor but this requires that the external reservoir is placed above the CPC. If there is not enough space in the instrument box, filling of butanol can be made using a pump. In this case, a control on solenoid valve is necessary to avoid filling whereas solenoid valve is closed. We therefore had to add a control on the external pump to avoid activation of the pump with closed solenoid which would damage the instrument (Figure 23).

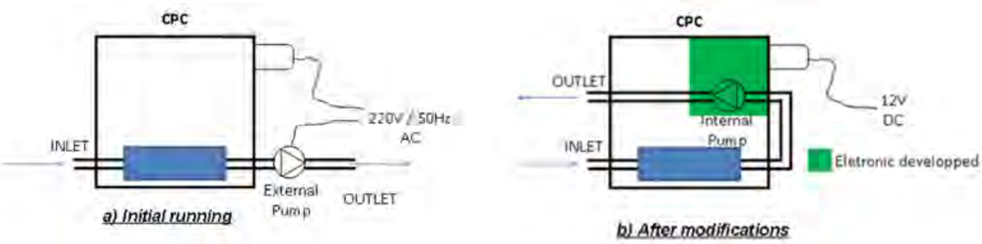

Figure 23 Modifications on power supply and pump.

CPC requires 220V alternative input power supply and an external pump. Some modifications have been necessary to adapt power supply to SBOX conditions and add an internal pump. This includes modify the power requirements to adapt 12V input power supply and removing all parts that induce pressure drop and require then a larger pump. In particular,the critical orifice that controls flow rate in a conventional configuration is removed. This requires then careful calibration of the CPC in a modified state. An important issue is that modifications performed on this CPC 3010 cannot be directly transferred to the new generation of TSI CPCs.

OPC

"Optical Particle Counter" (OPC) works independently and the interval to get data is defined by user. OPC performed a series of internal tests during its working operations. Because the flow is now controlled by the S-BOX itself, working under the S-BOX conditions would have induced an alarm on its inlet flow test. A modification had to be performed to bypass the self control of the OPC (Figure 24).

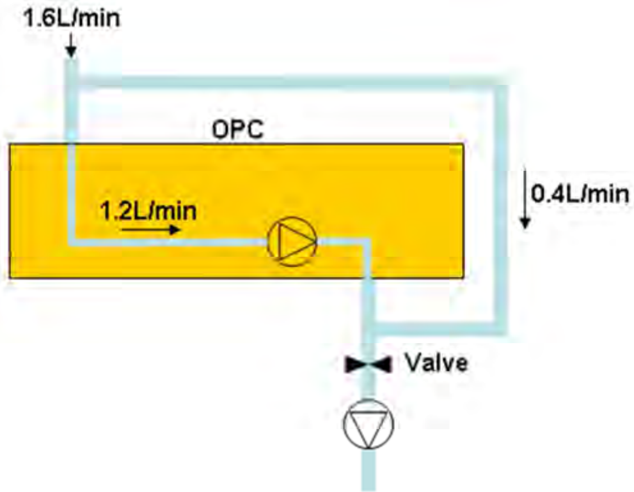

Figure 24 Modification on OPC pneumatic. Bypass self control of OPC.

VXT

Weather station is handled on the SBOX by a stainless steel tube. This station allows knowing weather conditions of the SBOX environment:

- Temperature, Humidity, Pressure
- Wind speed and direction
- Rain intensity, duration and accumulation

Apart from the information itself that are required for data interpretation, knowledge of these parameters is also important for comparing internal and external conditions. This is also important for the internal control for example to activate temperature regulation in the box. The weather station is also equipped with a heating system that allows working under rough conditions (high winds, low temperatures and high relative humidity).

7.2. Data collecting

Data from all instruments besides Mini Aethalometer for the reasons explained above, are all centralized and processed along similar streamflows. The SYCE electronic and serial interface allows collecting all instruments data by serial communication (RS232 protocol). Instruments data contains *"variable measured"* and *"instrument working parameters"* data in order to remotely control the proper functioning of all instruments and possibly identify causes for malfunctioning before manual check in the field. All data are saved on microSD as sensor data.

8. MINI CCN (NOT IMPLEMENTED- CNRM))

For reasons explained before, the Miniature streamwise thermal-gradient CCN chamber (miniCCN) was not installed in the S-BOX but developed independently by CNRM partner. Here we provide a description of MiniCCN performances.

8.1. Overview

Measurements of cloud condensation nuclei (CCN) are fundamental for providing the link between cloud microphysics and the physical and chemical properties of aerosol. Significant improvements in the measurement techniques are needed and the continuous-flow streamwise thermal-gradient technique has provided high quality CCN measurements on the ground as well as on airborne platforms. Theory and model simulations have been developed to optimize design and operating conditions of the streamwise thermal-gradient CCN chamber. These calculations ensure proper performance and enable us to reduce the overall size of the instrument – making the multi-column device easier for field deployment.

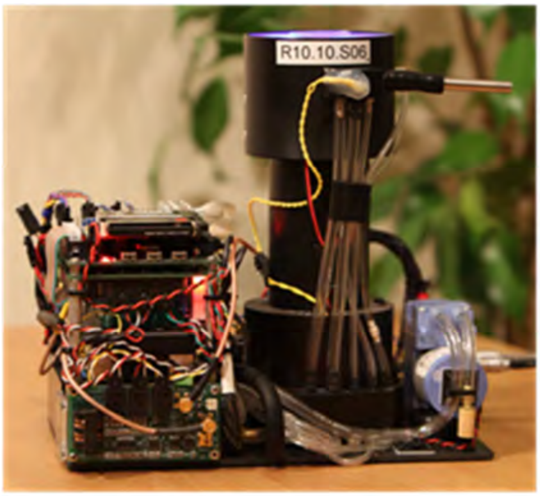

Figure 25 View of the mCCN instrument.

The miniature CCN (mCCN; Figure 25) has been built with a small column (10 cm diameter x 21.5 cm height) and electronics unit (17 cm width x 10 cm depth x 12 cm height) that weighs 2kg and operates at 25W. In addition to the development of the electronic interface, the capabilities of the mCCN instrument have also been expanded by allowing the scanning of flows and temperatures to retrieve CCN spectra. In addition, the mini CCN incorporates a pressure controller which allows the instrument to be transported to different locations (which may be at different altitudes) without the need for recalibration – this feature is important for mobile stations.

8.2. Streamwise thermal-gradient CCN chamber

The CCN instrument establishes a constant temperature gradient in the direction of flow; exploiting the differences in diffusion between water vapor and heat to maintain a quasi-uniform supersaturation at the centerline [*Roberts and Nenes*, 2005]. The main features of this instrument are:

- supersaturation is a function of flow rate, pressure and temperature, which can be easily controlled and maintained;
- continuous flow allows fast sampling (1 Hz measurements);
- supersaturation is nearly constant at the centerline, which maximizes droplet growth;
- simple cylindrical geometry reduces size and minimizes buoyancy effects.

A cylindrical column, whose surfaces are wetted and exposed to an increasing temperature gradient along the stream-wise axis, constitutes the chamber volume. An air sample is introduced at the center of the column and is surrounded by an aerosol-free humidified sheath flow. This configuration keeps the sample in a region of nearly uniform supersaturation and minimizes wall losses. The air then flows through the chamber, where CCN activate and grow into droplets. An optical particle counter at the outlet detects and sizes all particles. Those particles larger than a threshold size are considered CCN. This design maximizes the growth rate of activated droplets, thereby enhancing the performance of the instrument. The temperature gradient and the flow through the column control the supersaturation and may be modified to retrieve the CCN spectra.

To ensure proper performance and obtain miniature CCN chamber, we employed the following strategy for designing the multi-column CCN instrument:

1) establish the column radius to avoid buoyancy effects;
2) determine the appropriate range of allowable flow rates;
3) estimate the residence time (and column length) necessary for a particular supersaturation;
4) calculate wall thickness to ensure linear temperature profile;
5) incorporate previous designs and field experience to develop a small, robust and low power instrument based on parameters in 1 to 4;

8.3. Design constraints

8.3.1. Column radius

When fluids are heated down-flow, as is the case in our CCN instrument, fluid near the wall is slowed down with respect to fluid in the center of the tube. If the temperature gradient is high enough, flow in the center accelerates and flow at the wall reverses. Such flow reversal can significantly affect

CCN instrument operation; therefore, we evaluated conditions under which buoyancy effects on the flow can be neglected. Therefore, to evaluate the importance of free convection (due to buoyancy) relative to the forced convection (due to inertia), we compare two non-dimensional sets of numbers:

$$\frac{\text{Gr (Grashof number)}}{\text{Re (Reynolds number)}} = \frac{\text{Boyancy forces}}{\text{Inertial forces}}$$

When this ratio is << 1, buoyancy forces can be neglected and heat transfer is be governed by forced convection. Using this relationship, we evaluated conditions when free convection, and therefore the effect of buoyancy on the flow, can be neglected.

8.3.2. Flow rate

A small flow rate is favorable because it increases the residence time of particles inside CCN growth chamber and reduces the overall length of the column. As CCN activation and growth is diffusion limited, there is a minimum time particles require to activate and grow to sizes detectable by optical particle counter (OPC). In addition, reducing the flow shortens the hydrodynamic entry length, allowing more of the column becomes available for droplet growth. However, there is also a restraint on how small the flow rate can be – the main constraints include counting statistics associated with counting low number concentration of particles and maintaining flow greater than activated droplets' terminal settling velocities. To satisfy the low concentration environments, we define a lower concentration limit based on clean maritime CCN concentrations and calculate a minimum counts per second to maintain adequate counting statistics. Our model simulations and laboratory experiments show that a residence time of 10 sec allows for a broad range of supersaturations (0.07% < SS <2%).

8.3.3. Wall thickness

Once the column length has been determined, the appropriate wall thickness must be calculated to ensure a linear temperature profile along the column's axis, *z*. We approximate the temperature profile for a steady-state system, neglecting heat transfer from the column to the insulation and sample flow, as well as latent heat loss from evaporation at the wetted surface. When the CCN instrument operates with walls that are too thin, a transition to large temperature gradients may initiate adverse buoyancy effects and reduce its performance. A longer column, in order to achieve lower supersaturations, require a thicker wall than shorter columns.

8.4. Instrument design

8.4.1. CCN growth column

The CCN columns measure 10 mm radius and between 50 and 300 mm long. The wall thickness must be between 4 mm and 8 mm depending on the length. Based on the simulations, we conclude that flow reversal is avoided; yet, sufficient residence time also exists to accurately measure CCN concentrations at low supersaturations of 0.07%. The inside of the column is 'gun-barreled' to ensure uniform wetting and lined with porous ceramic as the wetting material. The ceramic exhibits better heat transfer compared to wetted filter paper. Temperature sensors and thermal electric coolers (TECs) regulate the temperature on each end of the column. The temperature sensors are placed as far as possible into the column for the most accurate measurement.

8.4.2. Optical particle counter

The OPC assembly comprises a collection cone, OPC, and water trap. The collection cone directs the aerosol and sheath flows into the OPC. Since the Stokes numbers are low, we use a curved cone to reduce the axial length making the overall instrument shorter. The sample passes through a capillary into the scatter volume where the particles are counted and sized. A ribbon heater and temperature sensor regulate the OPC temperature to ca. 1 degree C above the lower column temperature to prevent condensation in the optical cavity.

8.5. Performance tests

The physical and intrinsic limits of the CCN chambers were studied to determine the minimum and maximum supersaturations (0.07 to 2.5% Figure 26). Certain limits, such as flow rates and maximum temperature gradients, are inherent to the hardware components used in constructing the CCN instruments. To avoid complications originating from unexpected instrument performance (i.e., buoyancy effects and non-linear temperature profiles), we have identified the operational limits of the streamwise CCN instrument. The aerosol capillary, sheath frit and differential pressure sensors determine the range of flow rates; for

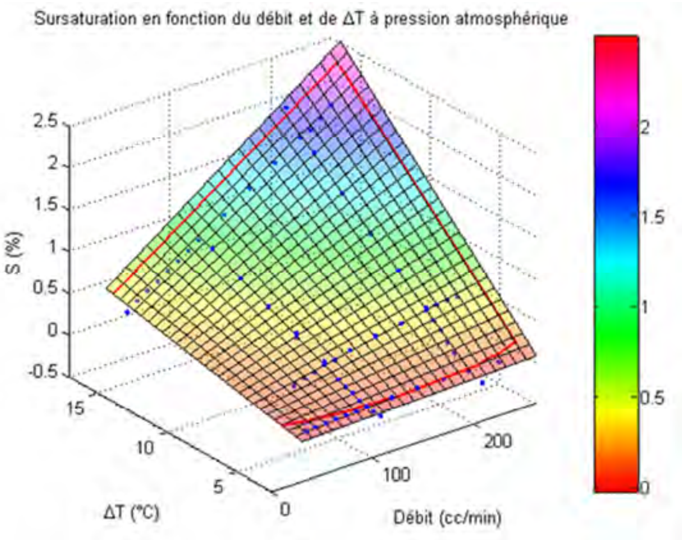

Figure 26 Saturation as a function of flow and T-difference

the current configuration we are limited to a total flow of ca. 250 /cc. The maximum temperature gradient is limited by the power of the thermal electrical coolers; which we determined to be 15 degrees C. Hence, a maximum supersaturation of 2.5% Sc is attained by operating the CCN instrument at the maximum flow and temperature gradient. Determining of the minimum supersaturation, however, requires coupling observation with simulations of particle growth based on residence time in the column. By studying the instrument calibrations at low supersaturations, coupled with a model of droplet growth inside the chamber, we determined the minimum time necessary to achieve droplet activation. The minimum flow rate and temperature gradient dictate the conditions to achieve the minimum supersaturation; which we found to be 0.07% for the short-column miniature CCN instruments. Furthermore, we developed a method to fully map the CCN instrument at a given pressure using four points of calibration (see Figure above). The method exploits the linear response of the supersaturation with respect to flow and temperature gradient. This method facilitates field calibrations and its deployment.

Clearly, the miniCCN would be a valuable addition to S-BOX in its final configuration but due to delays, this implementation was not feasible in the context of this project. SMOAA project has ended and CNRM is engaged into another project were this development is being used. The investment made in SMOAA should therefore be considered a levee for obtaining additional funding towards operating sampling instruments on mobile plate-forms.

9. SYSTEM CONTROL ENTITY

A large effort was devoted to developing the SYstem Control Entity (SYCE) that contains all electronics components and sensors necessary to SBOX operation. Several versions of the SYCE were developed before the final version that not only allows control of all electronic parts but also can be upgraded in case additional sensors or instruments are installed in the S-BOX. The design of SYCE requires both hardware and software development. SYCE works around a microcontroller (µC) ATMEL ATMEGA1280. It is AVR 8bit core architecture. It manages the SBOX and drives all subsystems (Figure 27).

Figure 27 A photograph of the SYCE in its final configuration. SYCE is designed and assembled at LGGE.

9.1. Diagram

A schematic description of the SYCE environment is provided below. As shown in Figure 28, it is the central core of the S-BOX that controls instruments, sensors, data acquisition and transmission and regulation of all operations. It is therefore essential that SYCE is built with a high degree of quality and be reliable for unmanned operations in the field.

The software is written in C with the ATMEL IDE *“AVR Studio 4”* and the toolchain *“WinAVR”* which are both free tools to design C/C++ application for AVR microcontroller.

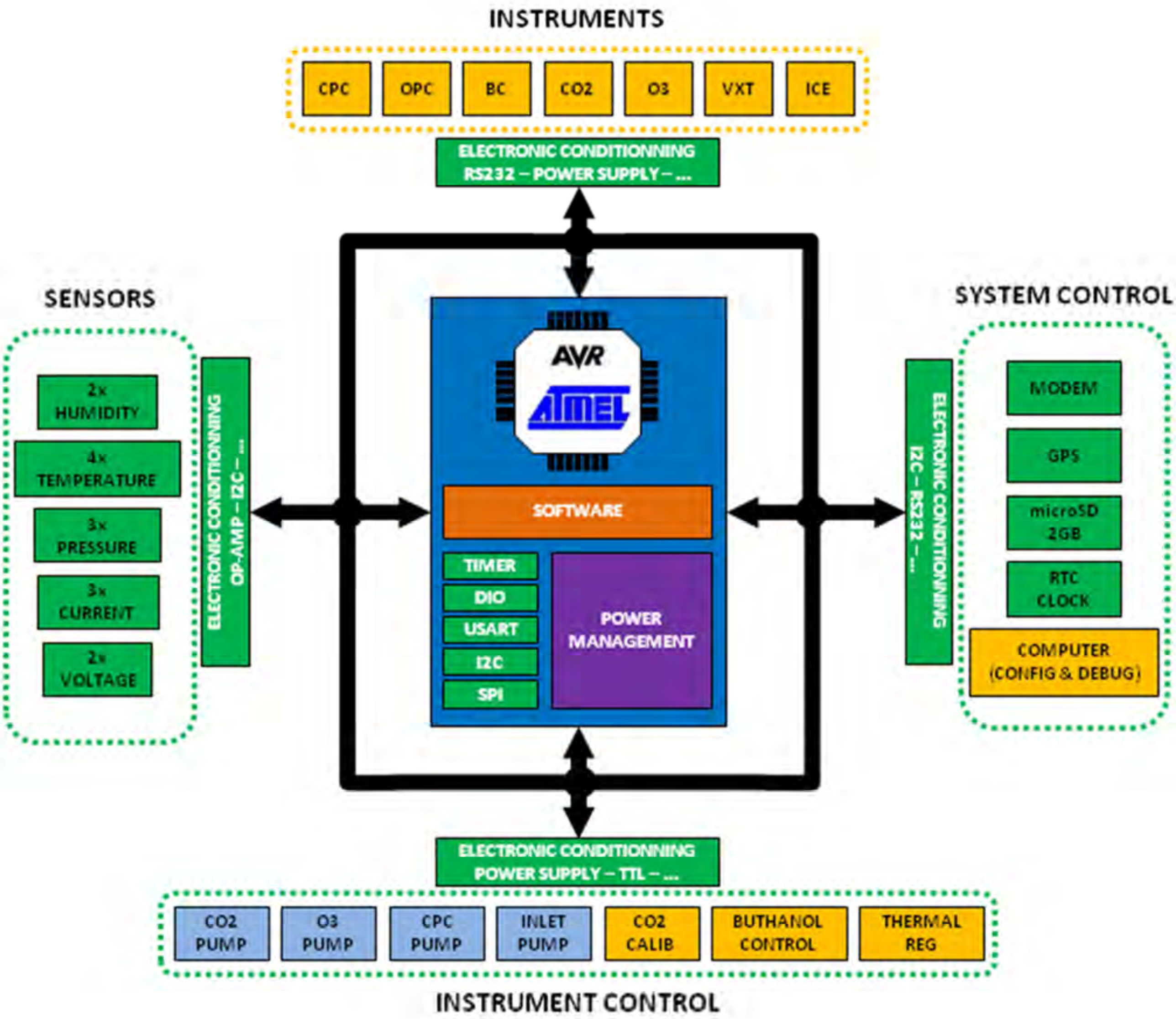

Figure 28 Diagram of the SBOX system control. It is the core of the application.

9.2. Functions

SYCE ensures the following functions:

- Scientific instrument operations
- Scientific instrument data collection
- Sensors data collection
- Data saving
- Data remote communication (out)
- Power management
- Real time CO2 calibration
- Instrument protection
- Station working report

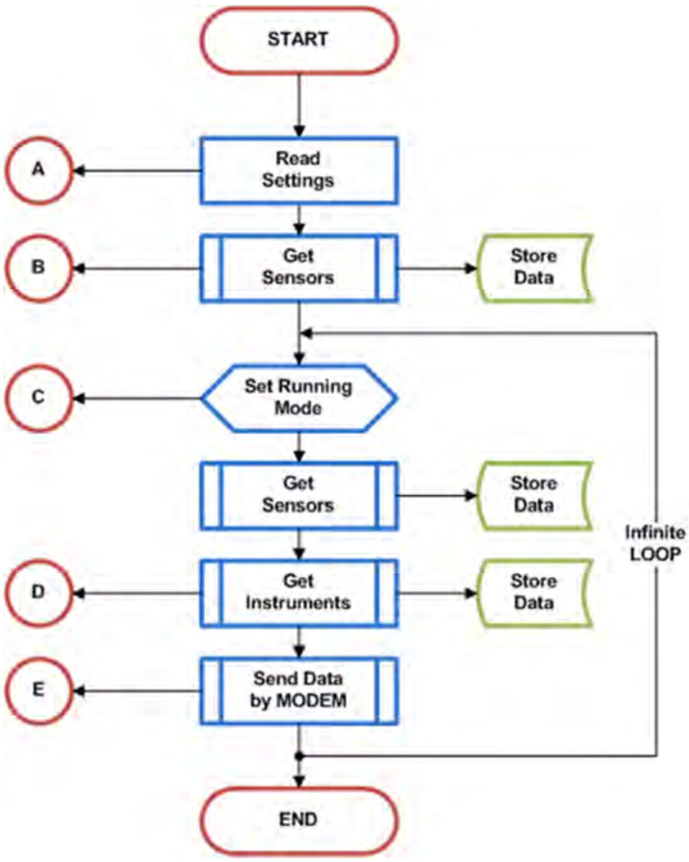

Figure 29 Simplified SBOX software flowchart.

Instruments

All instruments have a serial RS232 protocol communication. The uC can manage 4 RS232 lines in parallel. In the SBOX system, there are 8 RS232 lines which are the following:

- CPC
- OPC
- CO2
- O3
- VXT
- GPS
- MODEM
- Sensor's uC
- PC

The CPC, OPC, CO2, O3 and VXT are multiplexed on the first RS232 line (0) of the uC. The MODEM and the PC are alone on one line (respectively 1 and 2) and finally the GPS and the sensor's uC are multiplexed on the last RS232 line (3).

The uC has numeric signal level. That means the low level is 0V and the high level is 5V. It's also called TTL level. GPS and sensor's uC have TTL level. All other peripheral have EIA-RS232 level (or now TIA-RS232). That's the original hardware and software norm of the RS232 protocol. Particularly, the low level is from +3V to +25V and the high level is from -3V to -25V. +12V and -12V are commonly used. So some hardware interfaces are used to drive TTL level to EIA level. These interfaces are placed between instruments and multiplexer. For the PC and because there is no serial port on new notebook, the interface is RS232 TTL – USB interface called FT232RL. It allows creating a virtual serial port on a USB port.

So when the uC wants to get instruments data (D in flowchart), the software drives the multiplexer, enable the RS232 driver and collects data. This sequence is realized for each instrument.

Concerning power supply, each instrument is controlled by a mosfet which allows switching ON/OFF. The mosfets used are INFINEON profet ITS716G. It is 4 channel smart power switch for industrial application. It allows for example to detect a fault condition created by a short cut or open load condition. So the uC is able to understand if the instrument works or not and if there is a fault condition on the device. The instruments power supply is controlled mainly by battery level (energy safe) and internal temperature (instrument protection)

Finally, all pumps are driven independently. The power switch is controlled by the profet mentioned above. And after, there is a power stage allowing the adjustment of the pump's voltage. By doing a calibration in the laboratory, the pump's voltage is set to have the proper flow rate at the altitude of the remote site of the installation of the station. On this power stage, there is also a manual adjustment, performed by a potentiometer, allowing to set the flow rate in-situ.

Sensors
There are 14 sensors to monitor. To reduce the work of the main uC, a smaller uC of the same family (ATMEGA644P) was added. This stage performed an average value of each sensor each minute. The uC send all values by receiving a request from the main uC.

The acquisition of the sensors is performed by a very low power consumption and very stable Analog/Digital Converter (ADC) ADS1100 from Texas Instruments. It can convert analog signal from 0V to 5V with a 16 bits resolution at 8 samples per second. So there is a quantum of 76µV/bit.

Some analog signals have to be conditioned to fit the 0-5V range. This ADC has one channel. So a 16 channel multiplexer is used to collect all data.

The main loop runs by driving the multiplexer on a channel, performed a conversion with the ADC by I2C communication, store the value. This sequence is realized continuously and scans all multiplexer channels (sensors). Each minute, all values stored for each channel are averaged (34 elements). The 14 averaged values string is updated to reply to the main uC request.

Data saving
All data are saved in a micro SD card with a capacity of 2GB. The microC stores data in the card by a SPI communication. This communication protocol can reach a data rate of 100MHz. The fat file system supported is the FAT16. The card is organized with a setting file text and 2 folders on the root. One folder is used for device's files and the other for sensor's files. The microC writes one file per day for instruments and sensors data.

With a large estimation, one day of data has a size of 100kbytes (instruments + sensors). So with 2GB, the system is autonomous during 20000 days. The micro SD is very low power consumption, very small package and easily readable on all new computer (figure 30).

Figure 30 A picture of the micro SD used to store all S-BOX data.

Data remote communication
The SBOX can send wireless data by 2 ways:
- Radio Modem
- Satellite Modem

The radio modem (SATEL, model SATELLINE-3AS) can send data around 10km. The wireless communication and RF protocol is fully supported by the modem, and the uC communicates with a serial RS232 protocol. All the data can easily send. It is used if there is a radio modem network, or a station with internet connection around 10km.

The satellite modem is an Iridium modem. It is a very small package and very low power consumption. It supports Short Burst Data (SBD) messages. This modem is used if the station is in real remote area without anything around 10km. The SBOX send small data message with the state of the station.

Power management

As mentioned above, the SBOX is supplied by solar panel and eolic generator which charge batteries. The energy balance is estimated with some variables measured:

- Solar panel current provided
- Eolic current provided
- System current consumed
- Battery voltage level

With these values, even if it is difficult, it is possible to evaluate the battery state. Consequently, by setting some threshold, the uC cut off some elements of the system.

Software

The main firmware of the system contains 2 softwares:

- CPU software with the main uC ATMEGA1280:
  - → Application size: 35971 bytes (27% of total size available)
  - → Source code size: 50 files, 6915 lines, 214 functions

- Sensor software with the second uC ATMEGA644P → 11495 bytes / xxxx lines
  - → Application size: 11495 bytes (17.5% of total size available)
  - → Source code size: 13 files, 1001 lines, 40 functions

Both cpu and sensor software are written in C language and developed with the WinAVR toolchain. The informations about source code of each application have been collected with SourceMonitor.

10. SCIENTIFIC RESULTS

10.1. Tests in the natural atmosphere

A number of tests were performed to check performances of the S-BOX under varying conditions. Apart from laboratory tests, 2 main campaigns have been performed in the natural atmosphere. First during a winter campaign at Monte Cimone to test performances of the scientific instruments by comparison with ACTRIS/EUSAAR standardized measurements routinely performed. Second, by performing a long term campaign with S-BOX running in full operation installed at a high altitude site in the Alps.

- MTC campaign: February – March 2011. S-BOX tested in winter time conditions at the MTC station (2200 m, Italian Appenins)
- Stelvio campaign: June-August 2011. S-BOX tested in full operation on the Stelvio Glacier, Italian Alps, 3600 m.

The objective of the MTC campaign was to test proper functioning of instrumentation by comparison with measurements performed from a Global GAW station for which quality is controlled. The campaign was therefore not performed with S-BOX in automatic mode but connected to electrical power. Tests were mainly performed to check sampling efficiency, calibration procedures and resistance to cold. Given the very rough conditions encountered during the period, we also tested the capacity of the inlet to run in supercooled cloud conditions.

External conditions encountered during the campaign are shown in Figures 31 and 32 showing the evolution of the pressure and the ambient temperature measured by the SBOX and the MTC GAW, respectively. Both pressure and temperature are measured with the Vaisala weather station WXT500 for the SBOX and another model of Vaisala weather station for MTC GAW. Concerning the pressure, there is an offset (around 5hPa) but there is clearly the same fluctuation. Regarding the temperature, both curves still present a similar trend, but cause to the different location of the two sensors, a 2℃ difference is observed. This is rather a micrometeorological effect then a calibration issue.

During the campaign, temperature varied from +1℃ to -14℃. During the colder conditions, RH reached high levels and clouds were forming at the station. It is therefore considered very problematic conditions for sampling aerosol and gases. The use of whole air inlet in these conditions is highly recommended due to limited sampling of droplets in conventional inlets. Whole air inlets have inbuilt devices that evaporate cloud droplets so that CCNs and interstitial aerosol are sampled altogether without cloud artifact. The S-BOX inlet is obviously not dimensioned for sampling whole air. This can only be performed using larger tube giving the stopping distance of cloud droplets in high wind conditions. We therefore do not expect at first a 100% agreement between the 2 CPCs behind different inlets.

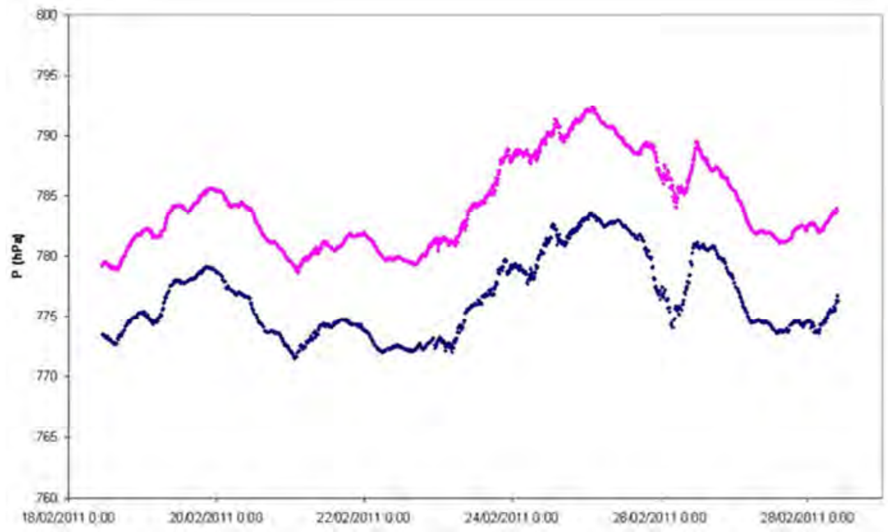

Figure 31 Pressure comparison during integrating test at MTC GAW (Italia, Monte Cimone, January 2011). Blue dots : S-BOX, Pink dots: MTC.

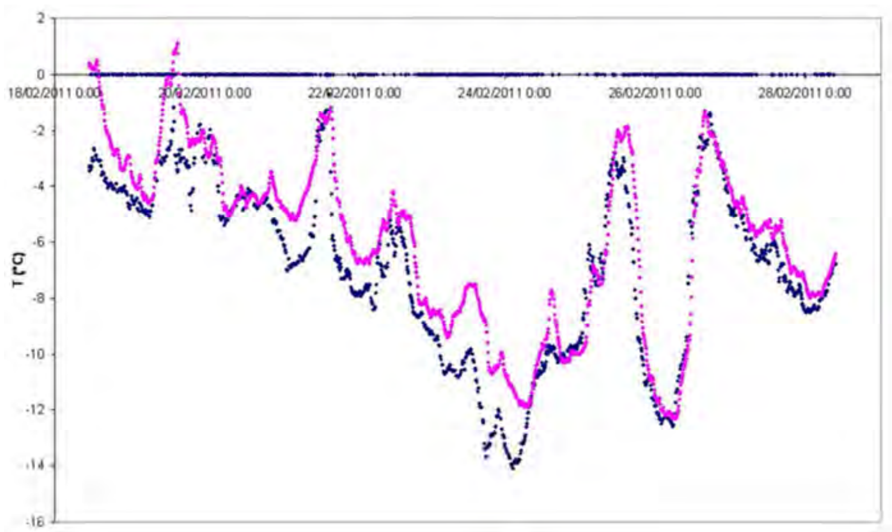

Figure 32 Temperature comparison during integrating test at MTC GAW (Italia, Monte Cimone, January 2011). Blue dots : S-BOX, Pink dots: MTC

A first comparison concerned CPC measurements that are performed at MTC behind whole air inlet calibrated in the framework of EUSAAR and designed by IFT. We can therefore consider that losses are minimal even in cloudy conditions and for wind speed below 20 m/s. Direct comparisons between S-BOX and MTC CPCs are shown in Figure 33 for 10 days of measurements. Concentrations range from a few hundred to a few thousands particles/cc. This is typical of very low background sampled at night on one end and of advection of boundary layer air from the Po Valley for the largest observed concentrations.

As shown in Figure 33a, the S-BOX concentrations are generally lower than the MTC concentrations for total particle number. The difference lies between 0 and -50%. Time with high discrepancy between MTC and S-BOX is often associated to high wind speed and presence of clouds as in the case of 24 and 25 february. Clearly, as mentioned previously, the S-BOX inlet suffers from low flow rate and limited inlet diameter that clearly is not efficient when sampling in these conditions. For lower wind speeds, the general agreement is good with a difference that does not exceed 20%. Given the typical size distribution at Monte Cimone, the number median diameter is lower than 100 nm and the 80 percentile is close to 800 nm (for most conditions besides Saharan dust events). A 20% discrepancy between S-BOX and MTC measurements can be explained by different sampling efficiency between MTC whole air inlet and S-BOX inlet. For still or low wind speed air conditions, S-BOX inlet is therefore close to a PM0.8. For conditions of higher wind speed (>10 m/s), the inlet efficiency drops to less than a PM0.5. For sampling in cloudy conditions, the S-BOX inlet cannot be used and data should be discarded.

This problem cannot be solved with the present S-BOX configuration. The inlet will always have limited efficiency when operating at high wind speeds. Applying a correction factor is tricky as it will have to be size-dependent in addition to wind dependent.

We have compared the O3 record at MTC and S-BOX during the same period (Figure 33b). Please note that the version of the SBOX O3 Monitor is an embedded version contrary to the MTC GAW O3 Monitor which is a laboratory version. We therefore do expect higher reliability and accuracy of the former instrument. However, we still observe similar fluctuations in both records. Average values of MTC and S-BOX over the testing period are in agreement within 15%. Clearly, with a good noise processing, correlation may be satisfying. The inlet is this time performing well showing that the limitation previously evidenced for particles are indeed linked to non-efficient sampling due to particle stopping distance larger than inlet diameter.

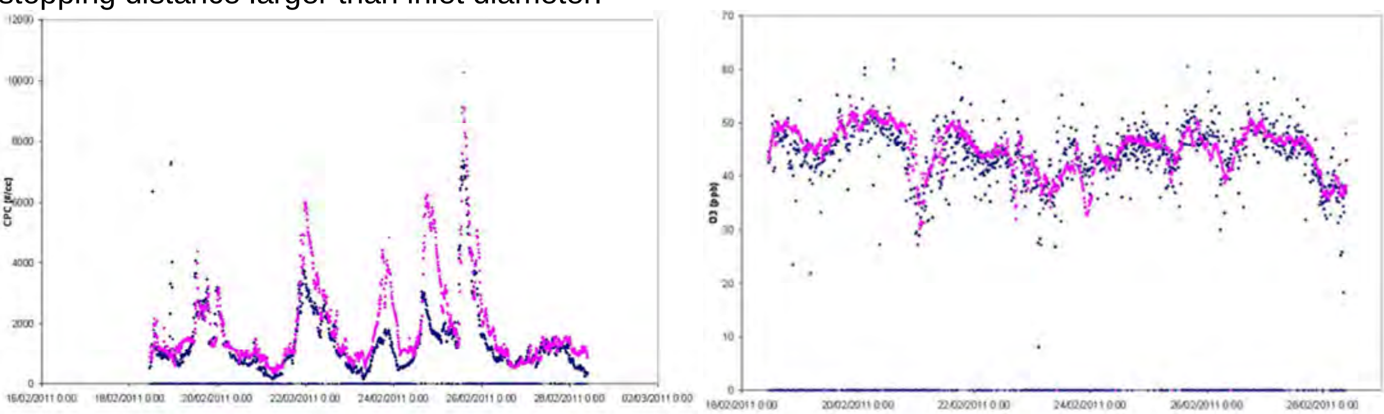

Figure 33 CPC (left) and O3 (right) comparison during integrating test at MTC GAW (Italia, Monte Cimone, January 2011).Blue dots : S-BOX, Pink dots: MTC

Towards the end of the campaign, very cloudy conditions were encountered at below zero conditions and high wind speeds (>30 m/s). Under these conditions, the box rapidly became covered by rime clogging the inlet with ice. The limited heating capacity was not sufficient to melt rime forming at the inlet. The S-Box switched to safety mode. The MTC campaign was then very satisfactory showing both acceptable performances, proper behavior of the box and its limitation in some very harsh conditions. To conclude about SBOX & MTC GAW instruments comparison in integrating test, the most important is to assure there is a global identical variation of variables measured between the SBOX and the MTC GAW reference station. Absolute value may be adjusted by performing adapted calibrations which have to be developed.

The second test campaign took place at the Stelvio mountain during the summer of 2011. Rifugio Guasti (3285 m asl) lies at a high elevation in the Ortler Alps (German: Ortler-Alpen; Italian: Ortles-Cevedale), near the wide glacial saddle of the Cevedale Pass, in the heart of this mountain group between vast icy expanses and impressive summits. The Forni glacier is the most extensive valley glacier in Italy, with an area of about 12 km2, and it is located in the Ortles-Cevedale Group, Stelvio National Park, Lombardy Alps. The glacier has a North exposition and it spans between 2600 m and 3670 m of altitude (Figure 34).

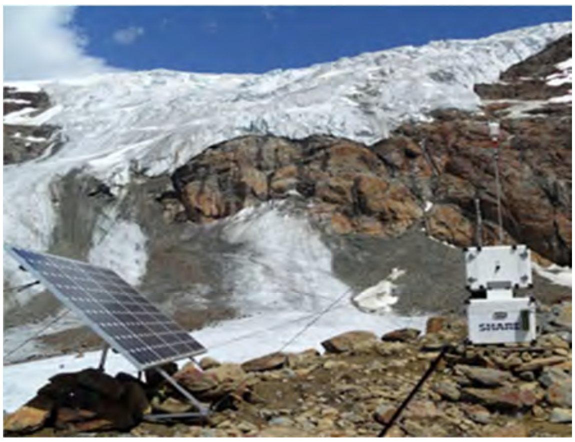

Figure 34 A view of the S-BOX installation at Forni Glacier during the Stelvio campaign.

The S-BOX was installed on a morainic terrain on the merge of the Forni glacier at 2800 m altitude in June 2011. It was brought up to the site by helicopter flights and assembled by LGGE and Italian colleagues on site. It is installed in full operation with solar panels and eolian generator and with the Pb battery set. Measurements include UV-absorption ozone analyser, Optical Particle Counter, Condensation particle counter, Black carbon analyser, NDIR CO_2 sonde and the Integrated weather station. The station is left unattended for the whole period besides regular visits from the refuge personnel. The campaign was stopped on 18 august 2011 after the S-BOX was turned upside-down by both movements of the morain and a strong wind storm. Also, the wind generator was stolen around mi-August.

The meteorological conditions during the Stelvio campaign have been registered by the Vaisala probe. They are shown in Figure 35a, b, c,d below. Most of the campaign took place in fairly good summer weather: temperature varied from -3℃ to 12° C, as expected at this location. Variation of RH showed the absence of cloud forming conditions with values never exceeding 95℃. This will obviously facilitate sampling with the S-BOX. The wind conditions were also very good for the S-BOX sampling prospective as it never exceeded 12 m/s apart in one exception on 26/07 where wind speed higher than 20 m/s on a min basis was measured.

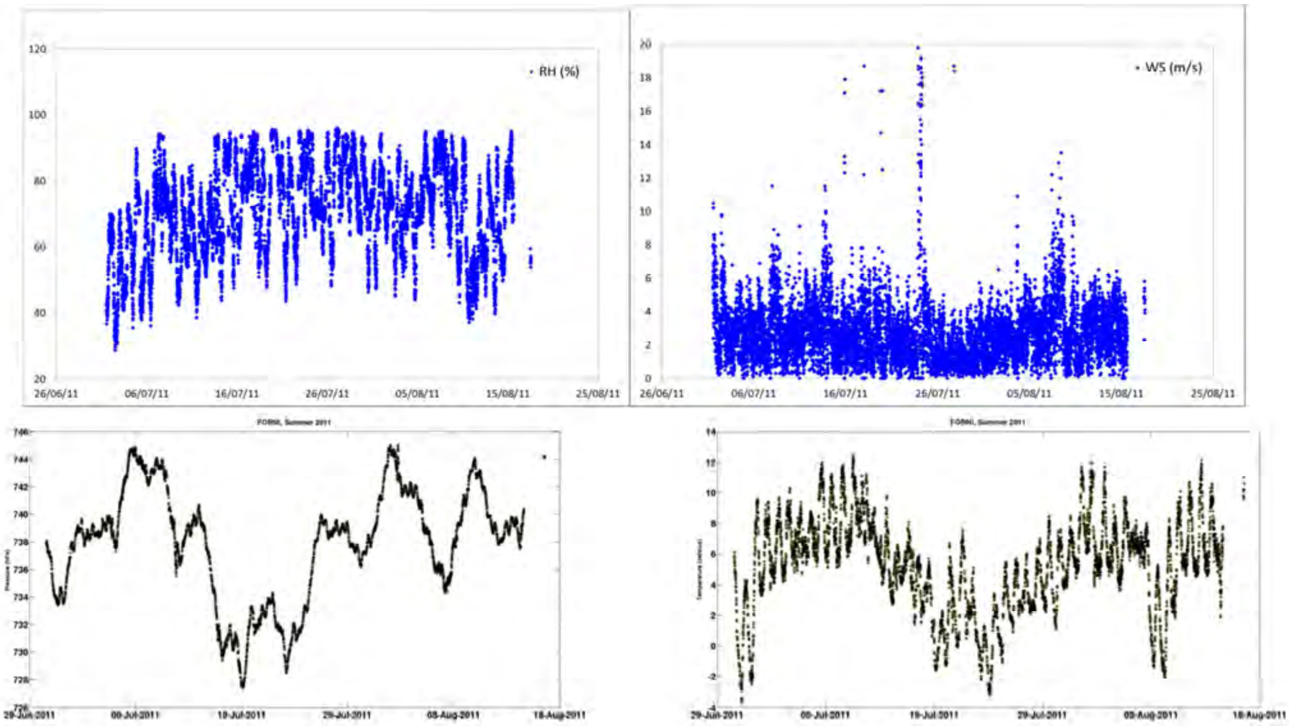

Figure 35 a,b,c,d showing: Relative humidity (upper left), Wind speed (upper right), pressure (lower left) and temperature (lower right) measured by the S-BOX at Forni glacier during the 2011 campaign.

Results from the measurements period are shown in Figure 36, 37, 38 for Ozone, Particles and CO_2. The records are corrected for STP. Overall, results are similar to those expected at high altitude in the Alpine regions fur this altitude. Particle number concentration background is approximately 500 #/cm3 and peaks are observed in correspondence with up-slope thermal winds developing in the afternoon. Ozone levels are also expected for summer conditions with a multi-day variability around average values of 50 ppbv. Of course, CO2 values show less variability and average levels close to 390 ppm. Results from the Stelvio campaign are still being analyzed and along with other measurements performed during that period and not linked to SMOAA, will serve as a basis for publications together with Italian colleagues.

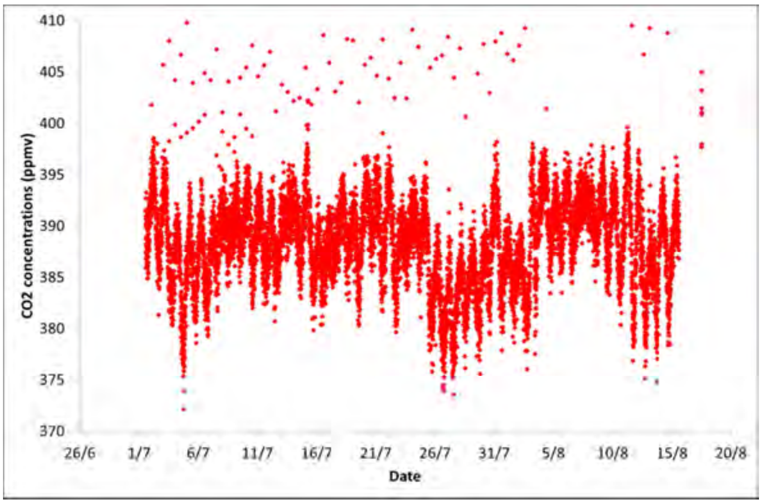

Figure 36: CO_2 concentration measured by S-BOX during the Stelvio campaign. Concentration outliers above 400 ppm should be considered as noise in the signal. The signal shows the expected diurnal variability and longer term features corresponding to changes in air masses. The S-BOX signal for CO2 seems in that case very coherent with expected results. Note that all data are corrected to STP.

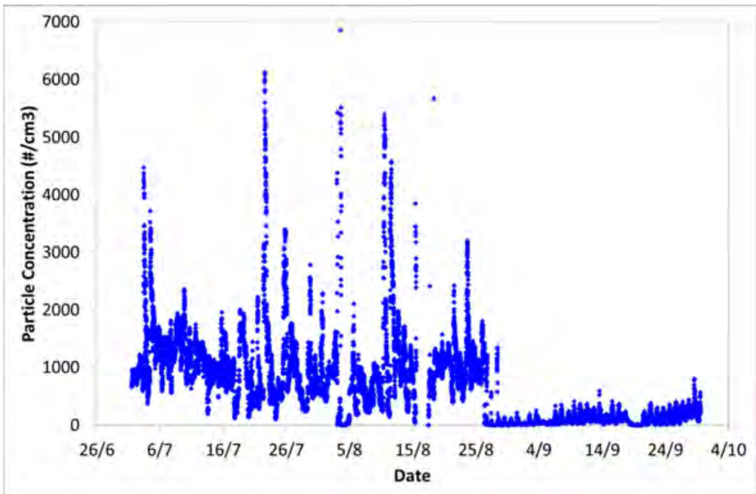

Figure 37 Concentrations of particles measured by CPC during the Stelvio campaign. Variations are showing typical diurnal variations linked to establishment of thermal up-slope/down-slope wind circulation. Measurments lies between a few hundreds cm-3 and 7000 cm-3 with average values at 1061 ± 819 cm-3. These are typical values measured in similar high mountain environments impacted by human activities (i.e. JFJ). Note the behavior of the signal after 25/8. In that case, the S-BOX was not in the upright position and the inlet was no longer sampling efficiently.

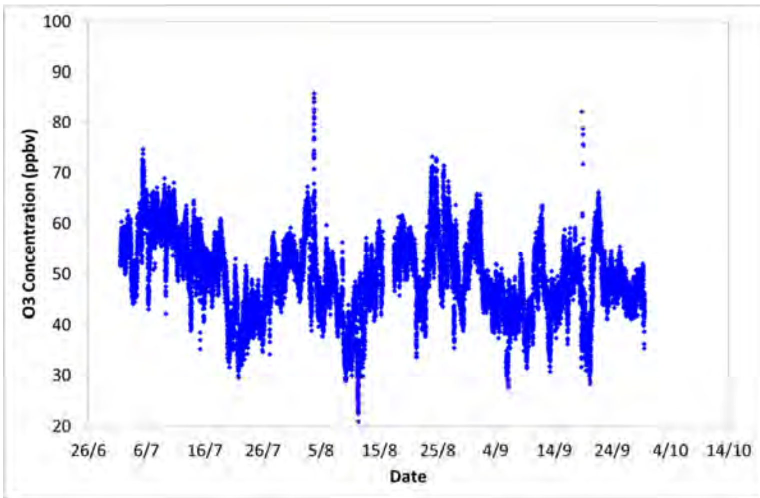

Figure 38 Concentrations of Ozone during the Stelvio campaign. diurnal variations are observed, coherent with what is expected at mountain site. The surface ozone concentration was 48.5 ± 7 ppbv with a variability that is very coherent with what is expected in summertime in the Alpine regions.

Apart from the scientific outcome from the 3-month campaign at Stelvio, that are not discussed in the context of the present report, we can consider that the S-BOX measurements are very coherent both quantitatively and in their variability with what is expected at this altitude and season in the Alps. We are confident that measurements are therefore of high quality and can be used for scientific purposes. During the campaign, all information from the box was also monitored to check for S-BOX performances. One important issue was clearly linked to energy production/consumption. Performance indicators for energy and thermal behavior are shown in Figure 39 a and b.

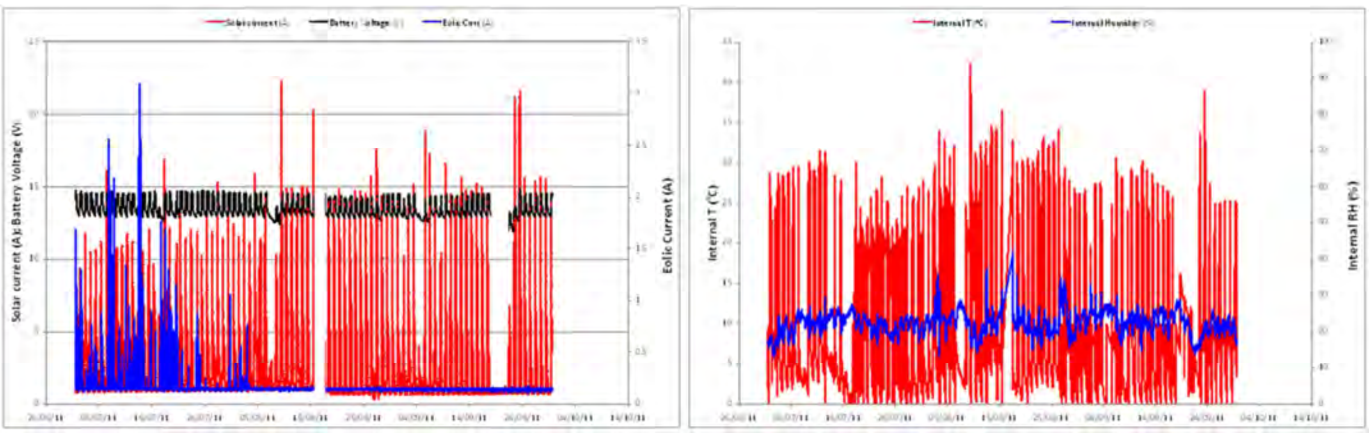

Figure 39 a) energy balance of the S-BOX during the Stelvio campaign and b) thermal balance of the S-BOX during the Stelvio campaign

When considering energy production, we can see on the graph (Figure 38a) that the battery charging is always optimal besides a few days around August 6th with a slight decrease after several cloudy days. But the small decrease was not sufficient to justify automatic switch of S-BOX to any alert mode. Energy availability is varying during the day as a response to solar power production. One important issue is linked to the eaolian power generation. As mentioned earlier, the aeolian generator was stolen during the campaign, precisely on August 4th. This however did not significantly change the battery charging behavior. Clearly, the additional power brought by aeolian energy is not stored by the battery unit which always works at almost 100% of its capacity. Bringing additional energy is in this case not necessary. This may not be true in conditions other than summertime where cloudy conditions are often not stable for periods longer than a few days. Overall we can consider that autonomy of the S-BOX in full operation is larger than 48h and that would have possibly reached autonomy of more than 64h under these conditions.

Another important issue which could have been more problematic in summer time is overheating of the instrument compartment due to intense radiation and limited diffusion of heat internally. There, results are not optimal, as seen in Figure 38b since the variability of T° in the box was extremely sensitive to diurnal changes. Thermal variability is often of almost 20℃ in the box from night to day. Relative humidity remained instead at very acceptable levels. Even though the variability was a little bit higher than expected, we should consider that internal temperature never reached the threshold for instrument switched down neither for elevated temperatures nor for low temperatures. Clearly, another version of S-BOX should permit heat transfer outside the box more efficiently than our current solution but the box remains adapted to the objectives for which it was conceived.

The S-BOX is now deployed in Pakistan, at 4000 m on the side of the Baltoro glacier (Figure 40. The installation was performed by a private company as the French government does not allow its personnel to travel to this country. The region is extremely remote and it is a typical situation where use of an automatic station is required. Data are transferred by radio modem to a nearby base and redirected through internet.

Figure 40 S-BOX at the Askole station Pakistan in summer 2012

Results haven't been analyzed so far. We just can state that the box is responding very well to temperature fluctuations (-5℃ to + 35℃) with an i nternal T° variability ranging from 18℃ to 30℃. Modification of the energy management module after the Stelvio campaign is therefore performing very well. Concentrations of particles at the site are ranging from 1000 and 2000 cm^{-3} and day time characterized by very high peaks up to 25000 $/cm^3$. These peaks are observed once or twice a day at the very same time of day: 6AM and 8 AM local time. After peaking, particle number concentrations rapidly go back to background values. No links with wind direction is detected. They are possibly indicative of nucleation events, similar to those observed at Nepal Pyramid site or contamination from biomass burning activities at a nearby village (see Figure 41). The background concentrations are one order of magnitude larger than those observed for similar altitudes in other regions of the World and Nepal in particular. Results are currently being analyzed for assessing this issue.

The ozone concentration at the site is quite low, varying from 20 to 50 ppbv but without clear diurnal variations. These values are similar to those found at other altitude sites such as at the Bolivian station of Chacaltaya. A very strange behavior is the fact that high O3 concentration values are also found in conjunction with peaking CPC values, in the morning and at night. For now, we have now explanation for such phenomena which was never observed anywhere else. CO_2 variations are also as expected with observed daily variations. The OPC instead is not responding properly and the BC was not installed for that campaign.

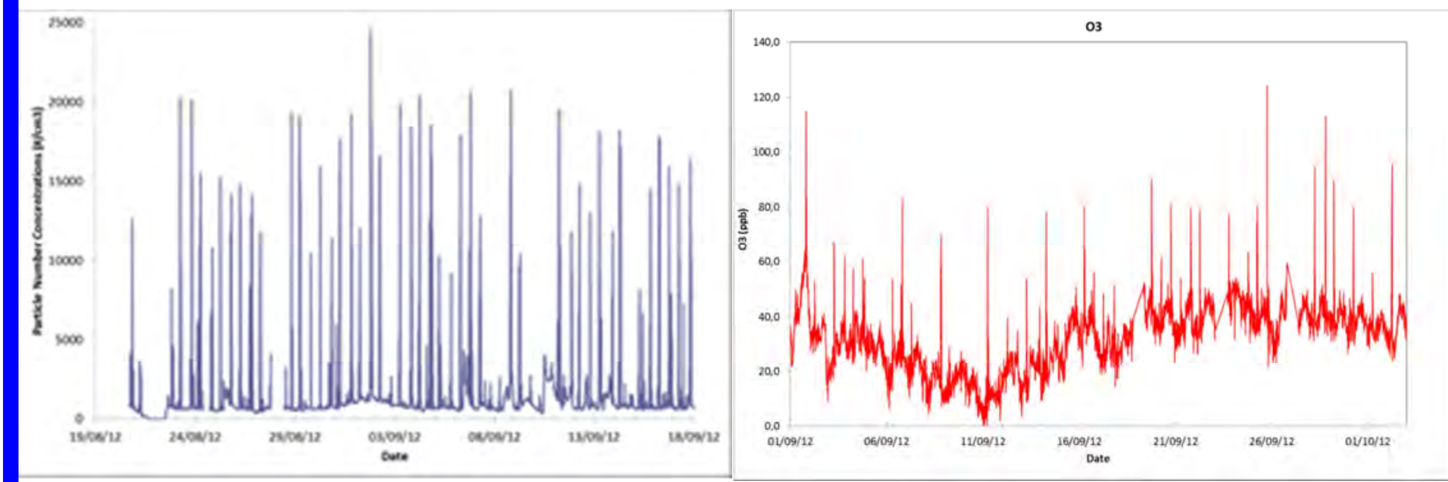

Figure 41 (left) and b) right: concentration of particles measured by CPC and ozone during the Askole campaign

11. FOLLOW-UP ACTIVITIES

Results from Stelvio and Pakistan campaigns are still in process. In Pakistan, results are extremely unexpected and we are now trying to obtain some additional information regarding practices in nearby villages. Stelvio campaign is part of a larger study and scientific publications are expected to be submitted late 2013.

The construction of the prototype is stopped since late 2012. The integration of CCN chamber will not be done as part of SMOAA. Another project funded by ANR but involving only one partner (CNRM) continues using developments initiated in SMOAA to equip drones with miniaturized sensors. From the LGGE side, the construction of a second prototype was stopped after both engineers involved in SMOAA quit the institute for more interesting job appointment. Paolo Villani is now heading a start-up company funded partly by EVK2CNR as part of a large infrastructure project to develop observing stations in Southern Italy and Antonin Broquet is now field engineer at the European Synchrotron Research facility in Grenoble, as a permanent staff. Both actually were selected based on expertise developed as part of SMOAA. Paolo Villani had more than 6-year experience as Research Engineer while Antonin Broquet spent 2.5 year as a research engineer. Their respective positions are financially more attractive than at CNRS, but in any case, CNRS institute can no longer accept non-permanent for longer than 3-year. It is a pity that research laboratories in France cannot maintain an expertise that is extremely long to develop.

12. CONCLUSIONS

The present report provides all the technical information concerning the development of the automatic station for aerosol and gas measurements. It should be said that this development was proven much more challenging than originally expected. Technical challenges were extremely complex to solve and required overall much more highly skilled personal than expected.

The project was satisfactory with respect to the following objectives:

1- Conception of the insulated box with the expected response to external temperature variations. The system including the energy transfer between instrument box and battery box was proven very efficient both in cold and hot weather conditions.
2- Adaptation of instruments and sensors to adverse meteorological conditions was successful. Clearly there are some limits to that as observed during suoercooled condition at Monte Cimone but the box and its sensors are well adapted to harsh mountain conditions.
3- Adaptation of instruments to working at low voltage. All instruments are performing quite well with the modifications that we performed.
4- Energy production and storage unit is very efficient and can maintain its autonomy for duration of several days. The Aeolian generator was never totally required but it is clearly to be maintained as a complement to solar generation
5- Integrating some instruments that were not in the original plan: namely CO2 and O3 monitors which perfomed very well during all test campaigns
6- The S-BOX can be easily deployed in ½ day by non-experts in the field.
7- Field tests at Stelvio and now Pakistan are quite successful bringing data from remote zones that are difficult to sample

Instead, we failed the following objectives:

8- Integrating all instruments as respect to original plans: we clearly failed to integrated all requested instruments in particular CCN and nephelometer. The CCN system was adapted but not integrated. For nephelometer, we never found the right set-up for starting implementation of a system inside the box. It does not says it is not feasible.
9- Performance of the BC and Optical Particle counter monitors. The two instruments are in theory very well suited to S-BOX application but their use has always been very problematic in the field. They are subject to flaw and their reliability is problematic. We recommend finding other solutions for the size distribution and mass, perhaps simply using optical counters from another company

The SMOAA project was therefore a first step towards establishing monitoring stations at high elevation and clearly permitted to develop skills that can be applied in other atmospheric applications.