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EXPLOITATION OF LIGHTNING DATA FOR RAINFALL ESTIMATION BY MULTI-SENSOR AND CROSS-PLATFORM APPROACH

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ABSTRACT

Italian Air Force Meteorological Service set up a lightning network and put it in operation during 2004, based on Vaisala technology with 15 IMPACT ESP sensors: LAMPINET. During the first 8 years of life LAMPINET data flow has offered an incomparable capacity in detecting and monitoring atmospheric electrical activity. At Centro Nazionale di Meteorologia e Climatologia Aeronautica (CNMCA), the Operational Centre of Italian Air Force Meteorological Service, several tools have been developed to integrate lightning information with other weather data systems, such as satellite images and post-processing products, and several studies have been carried on regarding the reconstruction of weather parameters from LAMPINET data. During early 2011 a Network Performance and Evaluation Program has been done by Vaisala to bring again at best the performances of LAMPINET.

For the next generation of geostationary meteorological satellites Meteosat Third Generation (MTG) an optical Lightning Imager (LI) mission is planned. Together with the Geostationary Lightning Mapper (GLM), that will be flown on the next generation of Geostationary Operational Environmental Satellite (GOES) series, and ground-based network there will be an almost global coverage for lightning detection. This continuous flow of lightning data, both from ground and space-based assets, will be crucial and critical in many applications as in operational nowcasting, climatology and atmospheric physics research.

The presented study has as main goal the exploitation of lightning data for retrieval of rainfall by multi-sensor and cross-platform approach, it is part of a fellowship hosted by C.N.M.C.A.. Goal of the fellowship is to develop a methodology for the use of real time lightning data not only as an information per se but as a proxy for other meteorological parameters connected with convection, in particular rainfall rate for the hydrological community. A comparison with products of EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (HSAF) is also presented.

INTRODUCTION

Object of this paper is to present one of the results obtained during studies developed during a fellowship developed at the Centro Nazionale di Meteorologia e Climatologia Aeronautica, Pratica di Mare, Italy (CNMCA). This activity has the aim to fully prepare operational environments for the next generation of operational meteorological satellites, that together with state of the art lightning ground networks, as LAMPINET, will provide a unique integrated system with the capacity of detect and monitoring total lightning.
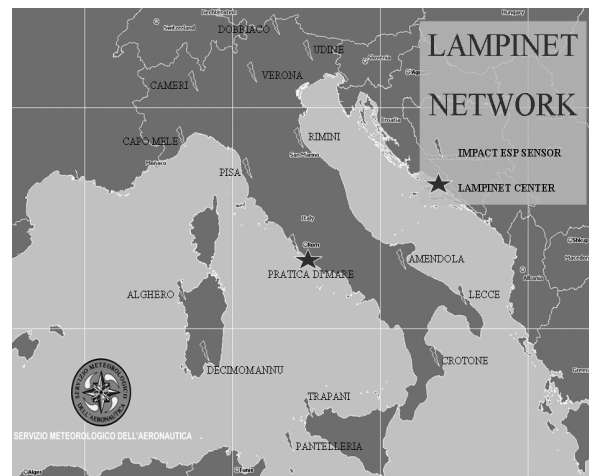

Fig.1- LAMPINET lightning location network.

On future Earth observation geostationary satellites major space operational agencies are planning to insert an optical imaging mission that will continuously monitor lightning pulses in the atmosphere; EUMETSAT, the european

organization for the exploitation of operational meteorological and environmental satellites, has planned one observing mission to be flown on Meteosat Third Generation will be LI, a Lightning Imager.

Italy, as country participating EUMETSAT, developed studies by means of its actual lightning detection capability, with the goal of define specific meteorological requirements, given from the potential use in meteorology of lightning final information for convection prediction, for estimation of a selection of weather parameters and numerical cloud modeling (Ref.1), demonstrating the need of maintain, in future, both ground and space-based assets.

During the 2008 2nd International Lightning Meteorology Conference (ILMC), held in Tucson, Arizona, same group of authors presented the exercise in reconstructing convective rainfall rate from lightning information (Ref.2) while at 2010 3rd International Lightning Meteorology Conference (ILMC), held in Orlando, Florida, it was presented an exercise in trying to connect wind field from lightning locations (Ref.3).
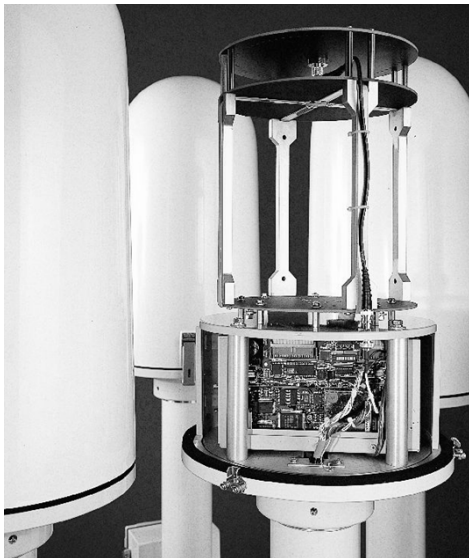
THE LAMPINET LIGHTNING NETWORK

Fig.2- Vaisala IMPACT ESP sensor.

The Italian lightning network, LAMPINET, is based on Vaisala technology, with 15 IMPACT ESP sensors uniformly distributed over the national territory, and started operations during 2004. It's based both on MDF (Magnetic Direction Finding) and TOA (Time Of Arrival) technique (Fig.2). LAMPINET network can reach a detection efficiency of 90% for I > 50 kA and location accuracy of 500 meters over all Italy and surrounding area. Basic requirements, fixed in the concept development phase, were highest reliability, redundancy, scalability, integrability (Ref.3, 4, 5).

Vaisala IMPACT ESP, detects E-B field signature of lightning discharge and frequency features of waveforms for CG-CC discrimination; radio frequencies from CG and IC discharges in a bandwidth 1-350 kHz; it measures azimuth angle of the discharge location, the time of signal arrival, the peak signal strength, the rise time and width of the discharge.
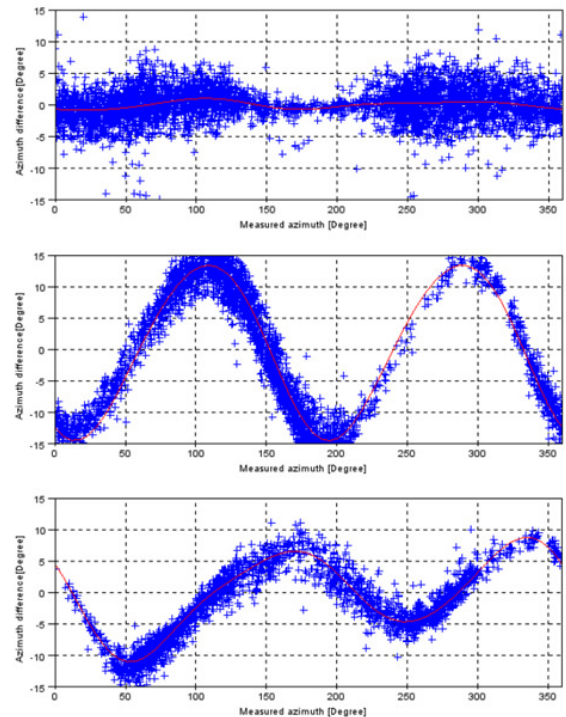

Fig.3- LAMPINET locations in a case study of one full day before (upper, 1491 strokes) and after (lower, 1899 strokes) NPEP results applied.

To ensure that LAMPINET Central Processors, LP2000, maximizes network capabilities in detecting and locating lightnings, CNMCA ordered Vaisala early 2011 a Thunderstorm Lightning Network Performance Evaluation Program (NPEP). The NPEP evidenced the need of some tuning for best network performances, especially in the physical

configuration of sensors. After the full implementation of NPEP results LAMPINET returned to the highest level of performance.
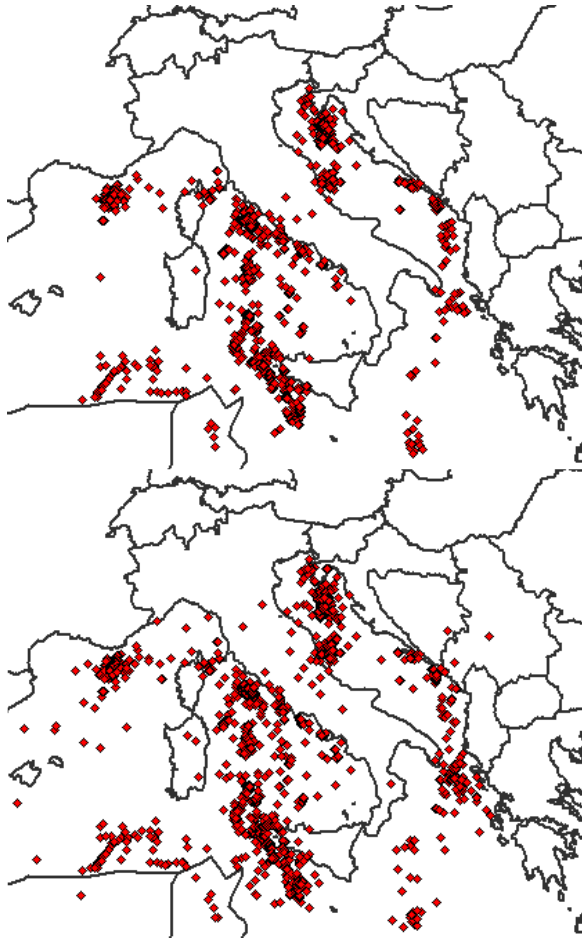

Fig.4- LAMPINET locations in a case study of one full day before (upper, 1491 strokes) and after NPEP results applied (lower, 1899 strokes).
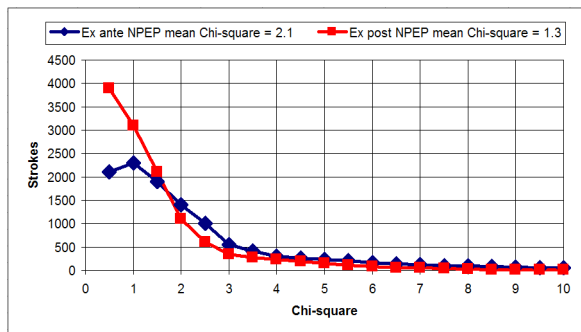

Fig.5- LAMPINET Chi-square for locations in a case study of one day before (blue) and after (red) NPEP results applied.

The network was adopted primarily for nowcast of strong electrical activity connected with atmospheric instability, to prevent risk both in air operation and ground activities, such as refueling, power plants protection, human life in the open. LAMPINET data are used by the Italian Air Force (Fig.6), Army and Navy, Civil Protection Agency and other governmental institutions, like National Research Council (CNR), together with a group of non-institutional users, both in real time or offline.
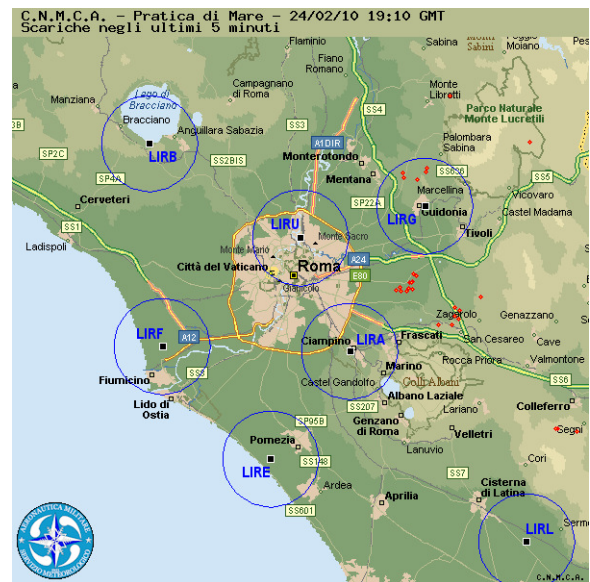

Fig.6- LAMPINET lightning location 5 minute plot; this products delivered to users on the ground within 1 minute from nominal hour is fundamental for air operations, such as maneuvering, refueling ect.

LIGHTNING AND RAINFALL

In the paper of 2008 ILMC (Ref.2) was present the general conclusion that lightning data contain useful information for rainfall estimation, in particular in describing the field shape and the location of higher intensity rain cluster, but probably this is not enough to compute convective rainfall rates.

A better exploitation of lightning data for precipitation estimation could be by a multi-sensor and cross-platform approach. As in the EUMETSAT Satellite Application Facility in support to Hydrology (H-SAF), that focuses on the development of new geophysical products on precipitation, soil moisture and snow parameters

and the utilisation of these parameters in hydrological models, NWP models and water management. C.N.M.C.A. physically hosts the generation chain of precipitation products, develops activities to study algorithms, validates results, implements operational procedures to supply the continuity and to monitor the service performances (Ref.6).

For an example of possible application of lightning in a multi-sensor and cross-platform approach it is considered precipitation product H02 (instantaneous rain rate from cross-track scanning MW), aka PR-OBS-2, is based on MW instruments as AMSU-A and AMSU-B or MHS flying both on NOAA and MetOp polar satellites.
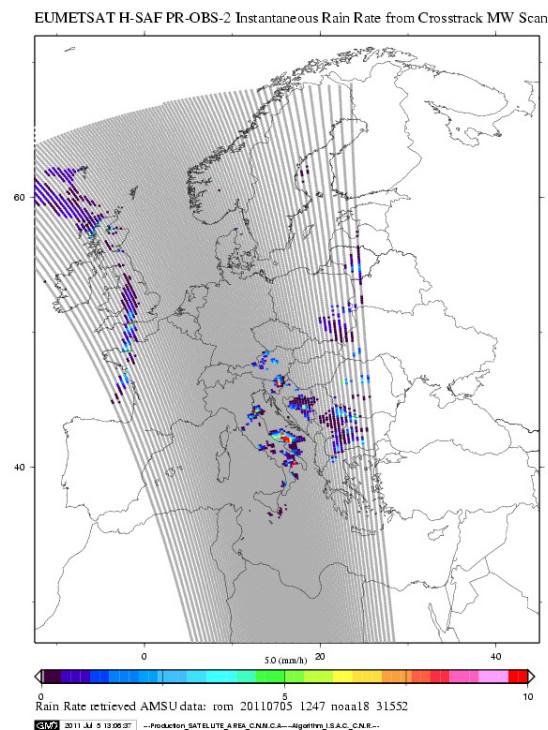

Fig.7- H02 (instantaneous rain rate from cross-track scanning MW).

These cross-track scanners provide images with constant angular sampling across track: IFOV elongates as the beam moves from nadir toward the edge of the scan. H02 is sampled accordingly AMSU-B or MHS IFOV, at nadir 16X16 Km^2, at the edge: 27X50 Km^2. Since the incidence angle changes moving cross-track, the effect of polarisation also changes, and various frequencies are observed in a single polarisation, V or H.

Algorithms are developed with the scientific support of Italian National Research Council – Institute for the Atmosphere and Climate Science (C.N.R.- I.S.A.C.)

Polar satellites alone present some problems to identify convective rain because of their low temporal resolution and narrow area of observation. It's even possible that a severe storm can start and finish between two passages of satellites. In the figures below there is a comparison between precipitation retrieval by microwave sensor on polar satellite (turquoise elliptical footprint) and radar (with colour scale). Precipitation volume estimation between satellite and radar is very similar but field shape is different, in detail MW space measurement could not distinguish inside active pixel. Far below there is the electrical activity in the same area. The position of convective precipitation is almost entirely seen by means of lightning rate and locations.
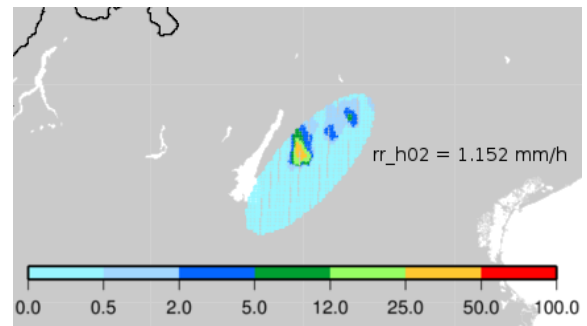

Fig.8- H02 precipitation retrieval by microwave sensor on polar satellite (turquoise elliptical footprint) and radar (with colour scale).
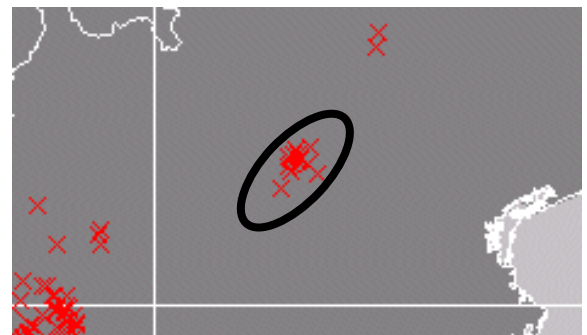

Fig.9- H02 ellipsis as above and occurred lightnings in 15 minutes centred in microwave observation timestamp.

On the other hand geostationary satellites offer a

better spatial e temporal resolution but sensors onboard (in the visible and infrared) are not the best to retrieve precipitation. Therefore lightning detection, and the correlation between number of lightning and rainfall, can be very useful to improve satellite retrieval of precipitation both from polar and geostationary satellite.

For this purpose a software named RELASE (Rainfall Estimation from Lightning And SEviri data) has been developed at CNMCA.

RELEASE SUITE

The presented study has as main goal the exploitation of lightning data for retrieval of rainfall by multi-sensor and cross-platform approach. The authors developed RELASE (Rainfall Estimation from Lightning And SEviri data). To determine a quantitative relationship for rainfall estimation using lightning and SEVIRI data a bivariate linear regression for clusters rain volume has been employed:

$$RR=(b_0+b_1 \cdot S/N+b_2 \cdot T)N$$

where RR is the radar measured cluster rain volume in on hour (mm h^{-1} km^2), S is the LAMPINET number of strokes in the cluster, T (°K) is the minimum SEVIRI 10.8µm brightness temperature in the cluster and N is the number of pixels in the cluster. The coefficients b_0, b_1, and b_2 are calculated by means of least squares regression. To disaggregate cluster rain volume to its individual pixel, it was built the histogram counting all pixels associated with lightning that exist in the dataset for a given temperature. The probability $P(T) = P$(that raining pixel temperature > T) is retrieved from the histogram features. The disaggregating procedure uses these probabilities to compute weights for each individual pixel of a convective cluster. A pixel weight is defined as the ratio of the pixel's probability to the sum of probabilities of all pixels located within the same convective cluster.
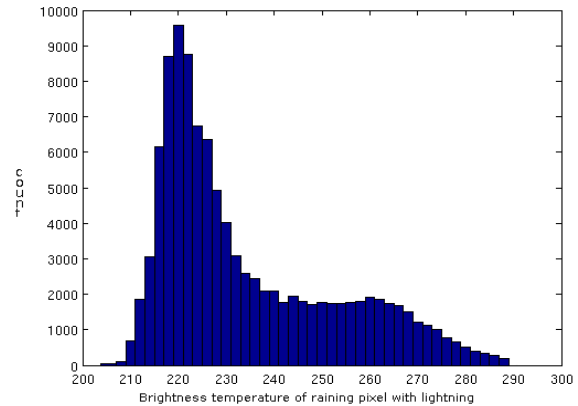

Fig.10- Histogram counting all pixels associated with lightning that exist in the dataset for a given temperature.

The proposed algorithm combining brightness temperature and lightning for the estimation of convective rainfall can be summarized as follows:

1. loading HRIT SEVIRI IR data and compute 10.8µm brightness temperature;
2. compute lightnings number within a 15 minutes window, centred around IR sampling time;
3. individuate lightnings clusters;
4. estimate rain volume of each cluster with the equation above;
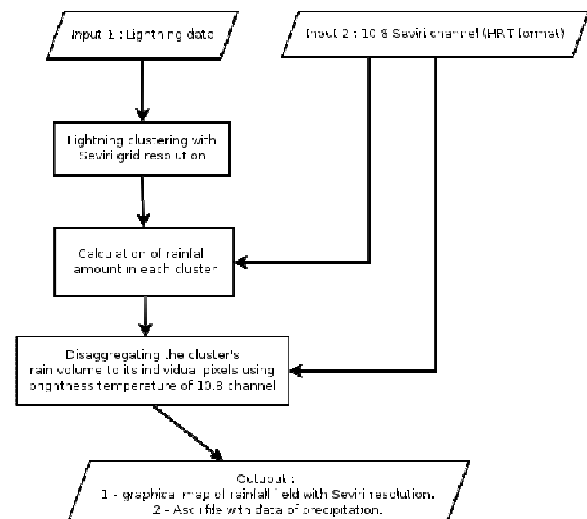5. allocate the rain volume of each cluster to pixels based on probability as above.

Fig.11- Flux diagram of RELASE software.

EXERCISE

Dataset is composed by 27 days of gathered data (radar rainfall rate maps, 10.8 µm SEVIRI images, LAMPINET lightning data) from 3rd March 2011 to 30th June 2011. In each of these days there were multiple storms over Italy and surrounding. Dataset contains 4703 lightning's clusters. This dataset has been used for the calibration of software (i.e. least squares regression to determinate the coefficients b_0, b_1, and b_2). The mean parameters value calculated by this calibration are $b_0 = 0.51$, $b_1 = 0.24$ and $b_2 = -0.0014$.

From 1st July 2011 RELASE is in operative chain at CNMCA and works H24. In the first period of evaluation, to characterize statistically the agreement between radar rainfall rate (considered as "reference" value) and lightning observations three performance scores has been used:

POD, the probability of detection;
FAR, the false alarm rate;
CSI, the critical success index;

$$POD = n_{success} / n_{success} + n_{failure}$$
$$FAR = n_{falsealarm} / n_{success} + n_{falsealarm}$$
$$CSI = n_{success} / n_{success} + n_{falsealarm} + n_{failure}$$

A comparison yields a success when there is lightning and a radar rainfall rate greater than 10 mm/h, a false alarm when there is lightning without rain, and a failure when there is rainfall greater than 10 mm/h with no lightning indications.

The software has been tested on 873 lightning's clusters and the results are:
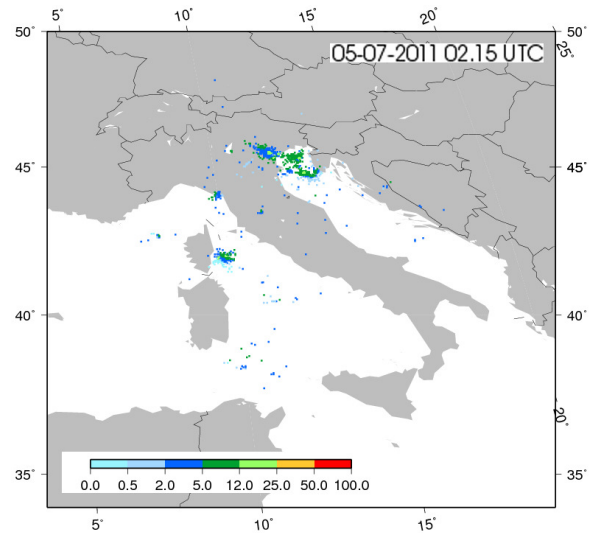
POD = 0.48
FAR = 0.34
CSI = 0.30

Fig.12

Fig.13, 12- visual comparison in a case study (5th July 2011 02:15 UTC) between RELASE output above a and radar rainfall rate (mm/h) below.

CONCLUSIONS

Italian Air Force Meteorological Service set up a lightning network and put it in operation during 2004: LAMPINET, based on VAISALA technology with 15 IMPACT ESP sensors. During the first 8 years of life LAMPINET data flow has offered an incomparable capacity in detecting and monitoring atmospheric electrical activity. At Centro Nazionale di Meteorologia e Climatologia Aeronautica (C.N.M.C.A.), the operational Centre of Italian Air Force Meteorological Service, several tools have been developed to integrate lightning information with other weather data systems, such as satellite images and post-processing products, and several studies have been carried on regarding the reconstruction of weather parameters from LAMPINET data.

It has been presented a study for the exploitation of lightning data to retrieve rainfall by multi-sensor and cross-platform approach, part of a fellowship hosted by C.N.M.C.A. with the scope in developing a methodology for the use of real time lightning data not only as an information per se but as a proxy for other meteorological parameters connected with convection for the hydrological community. A comparison with products of EUMETSAT Satellite Application Facility on Support to Operational Hydrology and Water Management (HSAF) has been presented.

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(6) For more information regarding HSAF initiative visit http://hsaf.meteoam.it/