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RAINFALL FIELD RECONSTRUCTION OVER ITALY THROUGH LAMPINET LIGHTNING DATA.

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INTRODUCTION

Object of this paper is to present one of the results obtained during studies developed at the Centro Nazionale di Meteorologia e Climatologia Aeronautica, Pratica di Mare, Italy, in a fellowship sponsored by Galileo Avionica, Firenze, Italy. The main intent of the fellowship programme was to study and perform a simulation of Meteosat Third Generation - Lightning Imager (MTG-LI) sensor behavior through Tropical Rainfall Measuring Mission - Lightning Imaging Sensor data (TRMM-LIS). For the next generation of earth observation geostationary satellite, major operating agencies are planning to insert an optical imaging mission, that continuously observes lightning pulses in the atmosphere; EUMETSAT has decided in recent years that on of the three candidate mission to be flown on MTG is 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, both for convection estimation, precipitation estimation and numerical cloud modeling (Ref.1).

A study carried on during the fellowship is the one presented in this paper, that establish a clear connection between lightning location and convective precipitation, as also presented in pioneering work of Uman (Ref.2), Shackford (Ref.3), Marshall and Radhakant (Ref.4), and in the works of Piepgrass and Krider (Ref.5) and Buechlet and Goodman (Ref.6), in particular trying to put in connection precipitation measured from RADAR and lightning.

THE GOAL

RADAR Network in Italy still suffers of suboptimal operational coverage, principally due to orography complexity, high cost of maintenance, radar-gauge inter-calibration (Fig.1). Moreover different governmental institutions, regional or national, have taken steps into weather radar management, but frequently there is no minimal possibility of integration in the historically present network of the Air Force. So, after the start of operations of LAMPINET, the Italian Air force Meteorological Service developed tools to integrate lightning information with other systems producing weather data, such as satellite images or satellite post-processing products, with the scope of better recognize dangerous phenomena, both for air traffic and ground users.

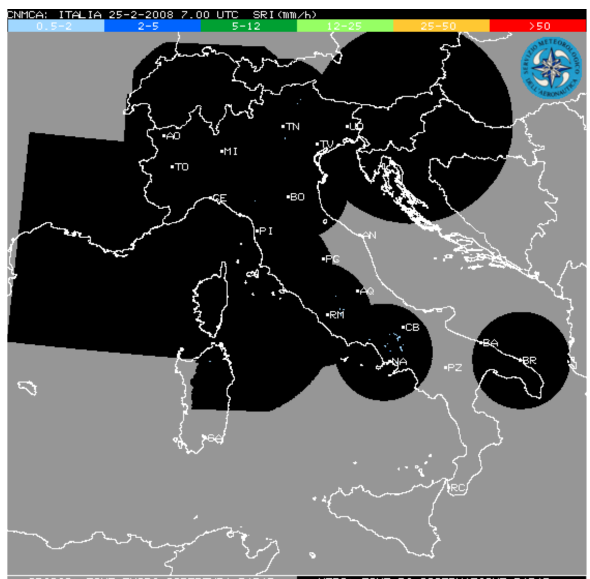

Fig.1- Italian RADAR network coverage, around 50% of national territory and sea. Some of the scans belongs to foreign RADAR participating at the OPERA programme, for the free exchange of weather radar data in Europe.

LAMPINET

The Italian lightning network, LAMPINET, is based on G.A.I.-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. LAMPINET network can reach a detection efficiency of 90% for I > 50 kA and location accuracy of 500 meters over all Italian and surrounding area. Basic requirements, fixed in the concept development phase, were highest reliability, redundancy, scalability, integrability (Fig.2).

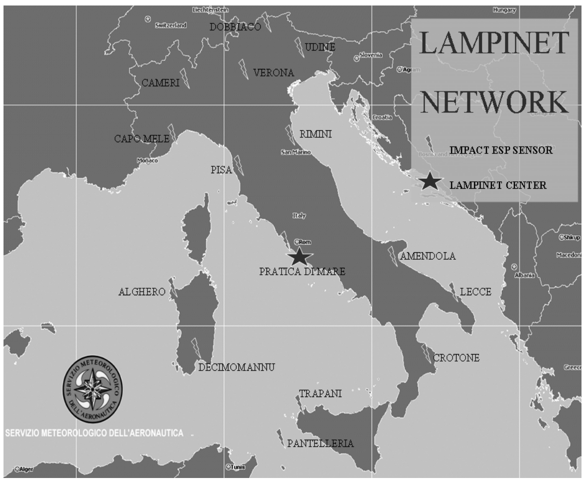

Fig.2- LAMPINET lightning location network.

The network was adopted primarily for nowcast of strong electrical activity connected with atmospheric instability, to prevent risks 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, Army and Navy, Civil Protection Agency and other governmental institutions, like National Research Council (ISAC-CNR), while some users pay for dataset, in real time or offline, for insurance dispute, film making, media information, big events in the open, amateur, etc. (Ref.7,8,9).

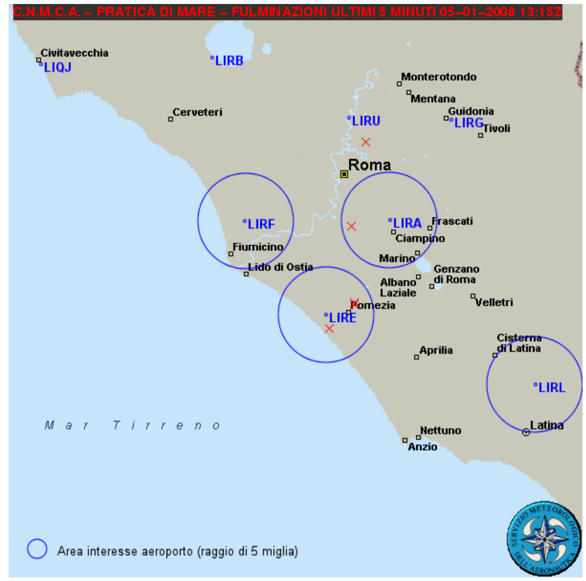

Fig.3- LAMPINET lightning location 5 minute plot, this products delivered within 1 minute is fundamental for air operations, such as maneuvering, refueling ect.

LAMPINET sensors

G.A.I.-Vaisala IMPACT ESP, (Fig.4) detect 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; measures azimuth angle of the discharge location, the time of signal arrival, the peak signal strength, the rise time and width of the discharge.

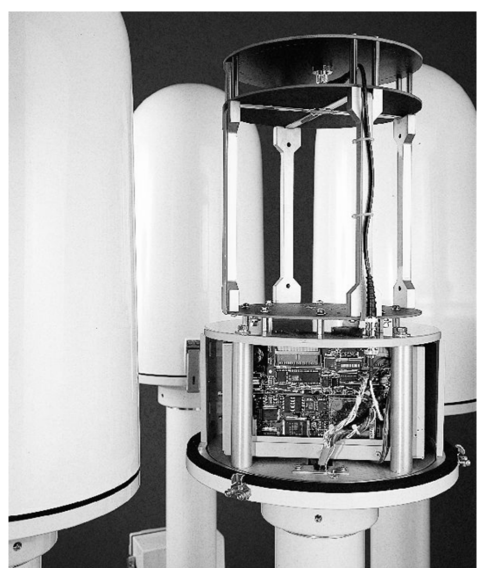

Fig.4- G.A.I.-Vaisala IMPACT ESP sensor.

THEORY

The experimental job is based on a study from Tapia and Smith (Ref.10), that put in connection lightning observation and convective rain estimate:

- Relation between Rain-Rate and Lightning-Rate (RLR);
- Rain spatial distribution respect to lightning localization;
- Rain temporal distribution respect lightning event;

Tapia and Smith derived these parameters from the analysis of 22 thunderstorm over Florida during august 1992 and 1993, with lightning locations obtained from National Lightning Detection Network (NLDN) (Ref.11) and rain rate from the Melbourne RADAR.

The estimate of convective rain is:

$$R(t,x) = C\sum_{i=1}^{Nt} \Phi\, f(t,T_i)\, g(x,X_i)$$

where the sum is performed over N_t flashes observed in the time frame $t \pm \Delta t/2$, and:

- $R(t,x)$ is the rain rate (mm/h) in the x location at time t;
- T_i time of observation of each individual lightning;
- Xi spatial location of each individual lightning;
- Φ is the RLR factor (Kg/flash);
- C is a conversion factor;
- $g(x, X_i)$ is the precipitation flux in x linked to a lightning occurred in X_i
- $f(t, T_i)$ is the temporal distribution at time t induced by a lightning at time T_i.

In Tapia and Smith paper RLR factor has value of 43x10^6 Kg/flash. Anyway this factor is strongly correlated with the point of observation and the particular climatology of the region of interest.

The temporal precipitation distribution is considered uniform over a period of Δt duration, centred at the timestamp of the lightning:

$$f(t, T_i) = 1 \quad \text{if} \quad |t - T_i| < \Delta t/2$$
$$f(t, T_i) = 0 \quad \text{if} \quad |t - T_i| \geq \Delta t/2$$

In our case Δt is 5 minutes, as in Tapia and Smith, while precipitation is assumed uniform around lightning:

$$g(x, X_i) = 1 \quad \text{se } |x - X_i| < 5 \text{ km}$$
$$g(x, X_i) = 0 \quad \text{se } |x - X_i| \geq 5 \text{ km}$$

In Tapia and Smith job each individual lightning produces a precipitation of 0.55 mm at ground, uniform in a circle of 10 km of diameter, centrered on the lightning location.

EXERCISE

With LAMPINET data we applay a similar theory of the one proposed by Tapia and Smith, and in a Thesis work developed in 2006 at Centro Nazionale di Meteorologia e Climatologia Aeronautica (CNMCA), Pratica di Mare, Italy, Ciolli at al. (ref.12) built simulated surface rainfall intensities. A proper RLR value was set at 15x10^6 Kg/flash, estimated after several run, while for other parameters similar values of Tapia and Smith where chosen.

In the subsequent images (Fig.5,6) there are reported the composite RADAR pattern with the instantaneous Surface Rainfall Intensity (SRI) from RADAR and the one reconstructed from LAMPINET data, with the score matrix (Tab.1). The false alarm rate (FAR) is quite high due to singular isolated lightning that frequently occurred in no-rain area, while probability of detection (POD) good enough to describe adequately rain pattern. The synoptical situation presents a squall line south east of France, coming west to east in the direction of Ligurian Sea and Corse, with clusters of precipitation (red) higher than 50 mm/h.

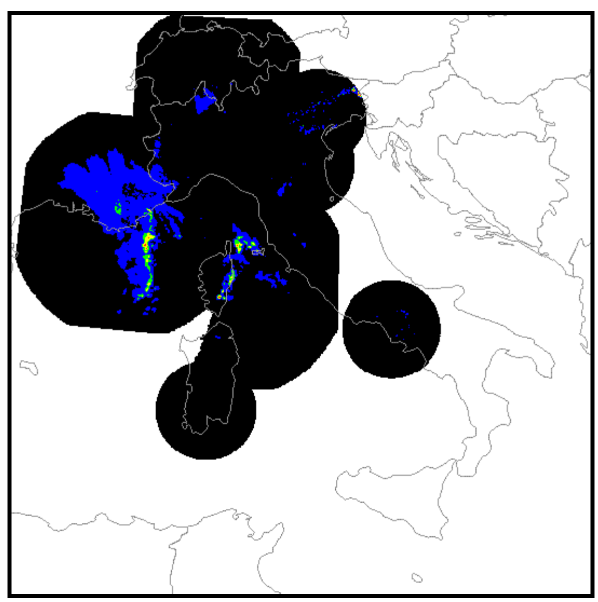

Fig.5- 07 Sept 2005 00:00 UTC.
SRI (mm/h) from RADAR scans.

Blue: 0.5 ≤ SRI < 12
Green: 12 ≤ SRI < 25,
Yellow: 25 ≤ SRI < 50,
Red: SRI > 50,
White: NO covertures,
Black: RADAR covertures.

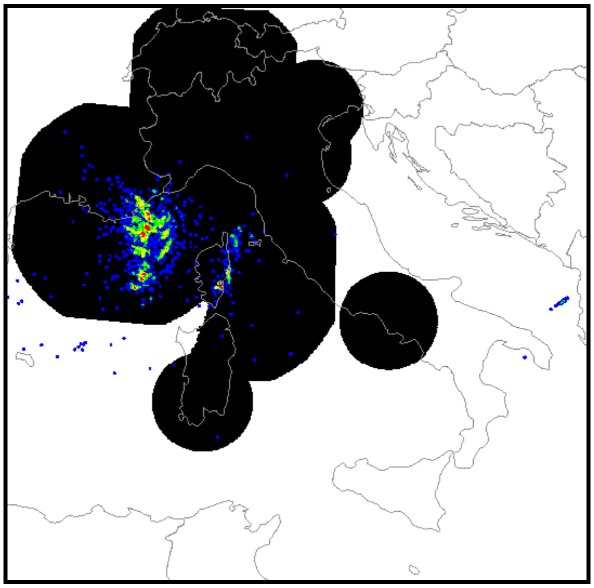

Fig.6- 07 Sept 2005 00:00 UTC.
SRI (mm/h) reconstructed from LAMPINET data.

POD	FAR	CSI
59%	45%	37%
CROSS-CORRELATION =0.40		

Tab.1- 07 Sept 2005 00:00 UTC.
Score matrix considering all grid points in the area of RADAR coverage, comparing reconstructed rain rate classes between the direct backscattered signal precipitation intensity and the one computed from LAMPINET data.

In a detail (Tab.2, Fig.7,8) of the same case-study, were the scores are better because of less isolated lightning in no-rain location.

POD	FAR	CSI
75%	32%	45%
CROSS-CORRELATION =0.64		

Tab.2- 07 Sept 2005 02:30 UTC.
Score matrix considering all grid points in the area of Aleria RADAR coverage Corse, France, comparing reconstructed rain rate classes between the direct backscattered signal precipitation intensity and the one computed from LAMPINET data.

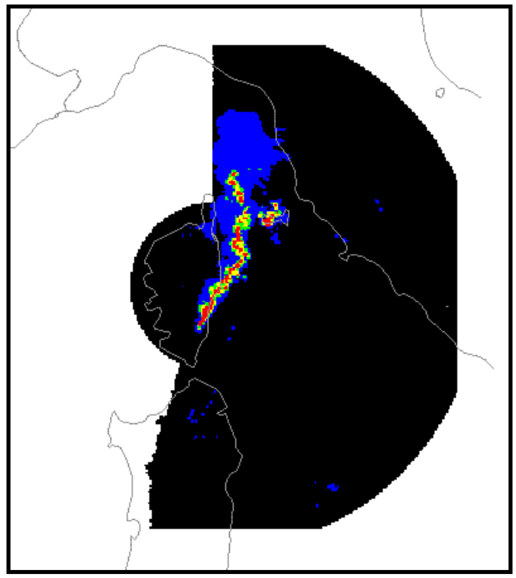

Fig.7- 07 Sept 2005 02:30 UTC.
SRI (mm/h) from Aleria RADAR scan (France).
Same lookup as Fig.5,6.

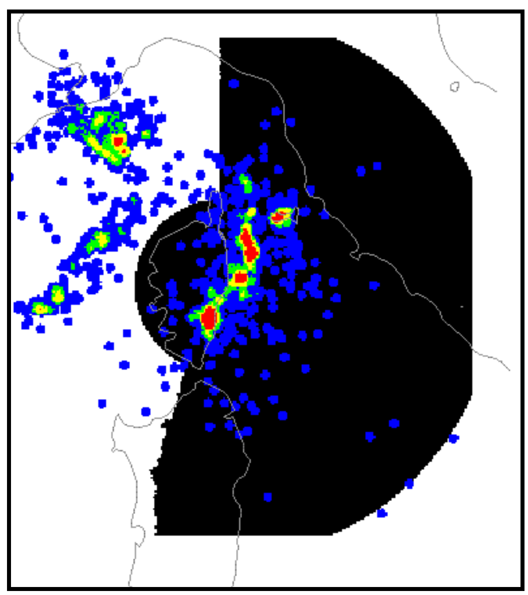

Fig.8- 07 Sept 2005 02:30 UTC.
SRI (mm/h) from LAMPINET data.

The Cross-correlation value is computed in this way:

$$P_{xy} = \frac{\sum_{K=0}^{N} \left(X_K - \overline{X}\right)\left(Y_K - \overline{Y}\right)}{\sqrt{\left[\sum_{K=0}^{N} \left(X_K - \overline{X}\right)^2\right]\left[\sum_{K=0}^{N} \left(Y_K - \overline{Y}\right)^2\right]}}$$

An a value nearly 1 means perfect superposition of images.

VALIDATION

To demonstrate the validity of the preceding exercise we chose some real data acquired from Data Collecting Platform station, present in the national observing network of the Italian Air Force Weather Service (Fig.9). In particular we pretend that the precipitation rain rate reconstructed from LAMPINET data may match the real measured. We chose only a small subset of the national synoptical observing network, 14 station, but covering different situation, and with good reliability.

Fig.9- 14 DCP station utilized for validating the tecnique.

Name	OMM	Lati.	Long.	Altit.
Tarvisio	16041	46.5	13.583	778
Udine Rivolto	16046	45.967	13.033	53
Giovi	16126	44.55	8.933	488
Sarzana Luni	16127	44.083	9.983	9
Ferrara	16133	44.833	11.617	10
M. Ravenna	16145	44.467	12.283	6
Frontone	16178	43.517	12.717	574
Tor. Chiaruccia	16215	42.033	11.833	4
Viterbo	16218	42.433	12.05	310
Latina	16247	41.55	12.9	26
Latronico	16317	40.083	16.017	896
Pantelleria	16471	36.817	11.967	185
C. S. Lorenzo	16543	39.5	9.617	3
Perdas	16545	39.667	9.45	608

Tab.3- DCP stations utilized for validating the tecnique.

As clear in Tab.3, the station are of different kind and position: over island (Pantelleria), along coast (Luni, Ravenna, Torre Chiaruccia, C.S.Lorenzo), over appenninian region (Udine, Giovi, Frontone, Viterbo, Perdas), mountains (Tarvisio, Latronico), flat areas (Ferrara, Latina). Dataset is base on LAMPINET stroke reports, more than 1 million), and DCP 15 minutes interval records, for the two month period September-October 2007. For the comparison are utilized the same precipitation classes of the RADAR comparison, but larger time interval, ±25 minutes, and larger spatial dimension, 25 km.
The score are presented in Tab.4

POD	FAR	CSI
55%	25%	33%

Tab.4- Score for the comparison of DCP real precipitation records and the one computed from LAMPINET data.

The results are substantially good, but we have to stress that the period of validation is limited, and the number of station small, and we reserve to perform new deeper comparison for spring-summer period. In conclusions the technique of reconstructing real time precipitation from lightning data appears robust and easy to achieve.

CONCLUSIONS

Italian Air force Meteorological Service set up a lightning network and put it in operation during 2004: LAMPINET. The network is based on Vaisala technology with 15 IMPACT ESP sensors distributed on the peninsula and islands. Performances of the network can reach a detection efficiency of 90% and location accuracy of 0,5 km all over Italian area.

Italy still suffers of suboptimal weather radar coverage, principally due to orography complexity, high cost of maintenance, radar-gauge inter-calibration. After the start of operation of LAMPINET the Italian Air force Meteorological Service developed tools to integrate lightning information with other weather data systems.

We have presented the activity developed at the Centro Nazionale di Meteorologia e Climatologia Aeronautica, Pratica di Mare, Italy, during a fellowship sponsored by Galileo Avionica, Firenze, Italy. The tool reconstructs from LAMPINET data the rainfall field, producing in near real time a radar-like SRI (Surface Rainfall Intensity), in a robust way, filling the gaps of weather radar coverage over Italy.

The generated product is used operatively for the nowcasting of intense precipitating phenomena.

FUTURE ASPECTS

Two major studies will follow: 1) the important role of the reconstructed rain field in storm development and dynamics, describing latent heat release in deep convective clouds, to better initialize mesoscale numerical models over the sea, or in presence of a lack of observation, or in the region of storm central depression; 2) the use of lightning observation to construct climatological records for precipitation in regions there is no synoptical observation

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