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Contemporary ground-based and satellite precipitating system characterization for desertification studies in Southern Italy

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Abstract. During the research project RIADE (Ricerca Integrata per l'Applicazione di tecnologie e processi innovativi per la lotta alla DEsertificazione), devoted to the study on the potential risk of desertification in Southern Italy, a particular attention has been paid also to the analysis of precipitations from three surface stations (Licata, Sicily; Rotondella, Basilicata; Surigheddu, Sardinia) in order to improve the knowledge derived from the most modern climatological studies related to this subject. The point of view adopted is to better define the precipitation microphysical properties (in particular, the Drop Size Distribution, DSD, and its moments), which are deeply related to the cloud system that generates the precipitation events. In particular we have used a newly introduced Convective Stratiform discrimination technique, that allowed us to observe a prevalence of events, concentrated along Winter (Wi) season, of different microphysical nature. In fact the prevailing Stratiform nature is related to Licata station, while for Surigheddu and for Rotondella the nature is mainly Convective. This distinction is related to the presence of drops of bigger dimensions and more intense precipitations in the latter case, while, in the former case, a prevalence of smaller drops and a less intense precipitation is recorded. This confirms the distinctive belonging to three different climatic regions, as indicated in the study by Brunetti et al. (2006). Our findings are important in the framework of desertification studies, because the cause of desertification can be related either to fertile soils removal (in the case of Convective events) or to lack of precipitated water (in the case of Stratiform events). We have also analysed a sub-set of ten events, with contemporary presence of data from VIS/IR channels of METEOSAT-7, SSM/I data from F13 and MODIS data from Terra platform. This has been done both to confirm the findings of PLUDIX data analysis (which is, in fact, confirmed) and to show the capability of PLUDIX to detect the fast local variations related to the temporal evolution of more extended systems. The potentiality of PLUDIX as a real-time detector of precipitation events, together with the development of an adequate number of algorithms, that give a complete microphysical description of the observed events, finally, opens the way for developing a new Present Weather Sensor.

Keywords. Meteorology and atmospheric dynamics (Climatology; Precipitation; Instruments and techniques)

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1 Introduction

A comprehensive and interdisciplinary study, RIADE (Ricerca Integrata per l'Applicazione di tecnologie e processi innovativi per la lotta alla DEsertificazione), has been set up in the last years in order both to define and to study some meaningful parameters related to potential desertification risk in Italy. After the identification of the regions under the risk of desertification processes, before the starting of the project, some core processes have been identified, among which there are atmospheric precipitation events and their modifications. The reasons underlying this identification are different: the absence of precipitation events leads to a minor availability of precipitated water; the precipitation erosive power, which is related to rain drops kinetic energy, which, in turn, is related to the raindrop mass leads to removal processes of fertile soils. These are the reasons for which the study of precipitation microphysical properties, together with the traditional analysis of precipitation general characteristics (such as quantity or intensity), is of paramount importance in relation to desertification studies. The latter aspect has been already investigated in the last years through different projects, defining so the precipitation climatology not only of the areas under investigation along RIADE project, but also considering all the available data in Italy. The former

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aspect, instead, requires more detailed studies that should be performed using modern technologies such as disdrometers, through which a better precipitation parameterization is obtainable.

The most recent study on Italian precipitation climatology (Brunetti et al., 2006), starting from a homogenized database ranging from 1928 to 2003, through Principal Component Analysis, recognized the existence of different climatic regions, namely:

- North-western Italy (NW): a region covering the western Alps and the western part of the Po Plain. It extends southward to the gulf of Genoa and comprises mountain, pied-mountain and plain stations.
- South-eastern Italy (SE): a region of maritime influence, comprising Apulia and Basilicata.
- The southern part of North-eastern Italy (NES): a region surrounded northward and westward by the Alps, southward by the Apennines and eastward by the Adriatic sea. It comprises the larger northern Italy valleys: the Po valley as far as Alexandria, and the Adige valley up to Bolzano. It includes only plain stations.
- The northern part of North-eastern Italy (NEN): a region covering the central and eastern Alps. It mainly comprises mountain stations.
- Southern Italy (SO): a region covering the extreme southern part of Italy. It comprises all stations below 39° latitude.
- Central Italy (CE): a region comprising the core of the Apennines, the coastal areas of the Tyrrhenian sea and the northern part of Sardinia.

This means that the areas where we have performed our studies are the CE (Surigheddu, Sardinia), the SO (Licata, Sicily) and the SE (Rotondella, Basilicata) regions. Precipitation trends are known to be generally negative, even if the decreases are very low and rarely significant. Considering the annual precipitation amount over Italy, a decrease of 5% per century has been recorded, mainly due to the spring season (-9% per century). The region with the most evident negative trend in total precipitation is CE, with a decrease of 10% per century on a yearly basis, and 20 and 13% per century in spring and summer respectively. Among the other regions, only SE shows a significant trend, even if only in the total annual precipitation (-8% per century). Obviously the pluviometric measures are performed using traditional raingages. Guidelines produced by the World Meteorological Organization WMO (WMO, 1983) indicate the typical accuracy requirement for intensity measurements to be 62% for rates above $10\,\mathrm{mm\,h^{-1}}$ (with estimates above this threshold frequently being required as 1-min averages). At lower intensities requirements differ markedly, but a reasonable basis for design would seem to be $60.02\,\mathrm{mm\,h^{-1}}$ for 10-min rate averages below $2\,\mathrm{mm\,h^{-1}}$, and $60.2\,\mathrm{mm\,h^{-1}}$ for rates between 2 and $10\,\mathrm{mm\,h^{-1}}$. Anyway it is well known that the measures are affected by errors because of problems not only of mechanical nature, but also due to environmental factors such as presence of wind, presence of mixed-state precipitations (solid and liquid) and many other. Furthermore we must consider the possibility of a change of instrument during the lifetime of each single station. Hence it is important to underline that all those factor, when possible, have been considered in the study quoted above. Hydrological processes at the land surface – such as soil erosion, which is important in relation to desertification processes – are driven by the rainfall rate and rainfall kinetic energy flux at small spatial and temporal scales (e.g. Dunne and Leopold, 1978, chapters 6, 9, and 15; Brandt and Thornes, 1987). Past efforts in monitoring these quantities and their spatial and temporal variability have been based largely on rain gauge observations. Rain gauges provide a direct measure of rainfall; however, the rain rate may have to be inferred from tips of buckets or rainfall accumulation traces, and the kinetic energy flux has to be empirically estimated. Other ways of determining rainfall properties are the study of radar reflectivity factor Z, rainfall rate R, and rainfall kinetic energy flux E, which are depending by the variability of the raindrop size distribution. There are many raindrop spectra that can produce the same rainfall rate. Moreover raindrop size distributions can vary significantly among climatic precipitation regimes, from storm to storm, and dramatic changes may occur even within storms. This significant variation depends on the cloud system nature (Hashimoto and Harimaya, 2000). In fact there is a strong relation between precipitation Drop Size Distribution (DSD hereafter), that is the basic parameter to describe the microphysical nature of precipitation events, and two main types of cloud systems: the stratiform one and the convective one. In particular: a stratiform cloud will generate a stratiform precipitation, which is characterized by a higher percentage of smaller drops and a lower precipitation intensity (generally lower than $10\,[(\mathrm{mm/h})\mathrm{min}^{-1}]$), while a convective cloud will generate a convective precipitation, which is characterized by a higher percentage of bigger drops and a higher precipitation intensity (generally higher than $10\,[(\mathrm{mm/h})\mathrm{min}^{-1}]$). Therefore the study of cloud system nature inferred by satellite measurements together with appropriate ground measurements is very important. Furthermore, being all the parameters that describe both the microphysical nature of precipitation events and the relations with soil erosion dependent on the DSD, the ground measures are better performed using disdrometers, which allow to measure, with different methods, the DSD high temporal resolution.

Nevertheless, if not in the tropical area, studies either using disdrometers alone or considering the integrated use of satellite and disdrometric data are rarely performed. Thus in our study we wanted to improve this type of work with different purposes. The first one is to increase the informations

generally given by the most advanced climatological study such as the one reported above. The second one is to better understand desertification processes in relation to precipitation characteristics. In fact, if a prevalence of convective events is recorded, desertification processes are related to the increased kinetic energy of precipitation, on which, in turn, depends an increased precipitation erosive power. On the other hand, if a prevalence of stratiform events is recorded, any desertification process will depend on a lower amount of water of atmospheric origin. Finally we decided to verify the validity of the event discrimination using an integrated analysis between satellite and ground-based data for a sub-set of selected events.

In the following paragraphs we will describe both the instruments and methods used for collecting the precipitation data and for obtaining the results, that will be described in the third paragraph. Finally the conclusions will be drawn in the last paragraph.

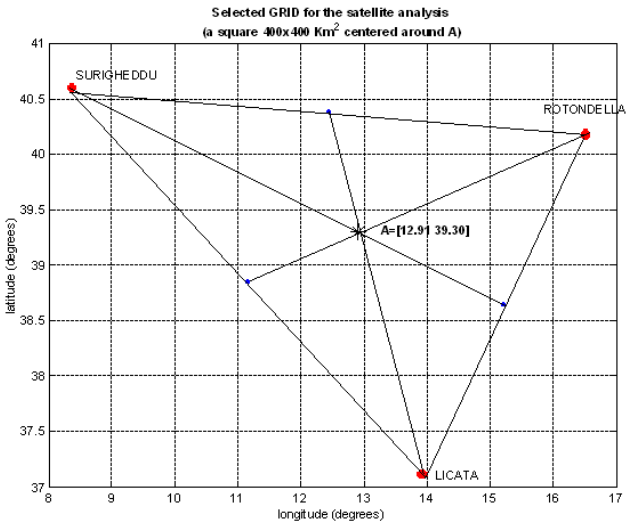

Fig. 1. Selected minimum grid for satellite data analysis.

2 Instruments and methods

Along RIADE project we performed the measures of DSD in three selected sites, from October 2003 to May 2005, for a total of 20 months: Surigheddu, Sardinia (lat: 40.5888° N; lon: 8.3749° E); Rotondella, Basilicata (lat: 40.1702° N; lon: 16.5214° E) and Licata, Sicily (lat: 37.1037° N; lon: 13.9411° E). We have selected those three stations in order to have the measuring points in three different homogeneous areas. In fact Surigheddu is inside (CE) area, Rotondella is inside (SE) area, while Licata is inside (SO) area. The three stations can be included in a square grid with area of $400\times400\,\mathrm{km}^2$ (Fig. 1). The purpose of the DSD analysis is improve the details of the general climatological analysis given by Brunetti et al. (2006). To confirm and verify the experimental ground-based results obtained through our new dataset analysis, we have selected a sub-dataset of 10 events, considering the fact of the relation between ground-based and in-cloud processes observed by satellite (as indicated by Harimaya and Hashimoto, 2000). In order both to observe through satellite sensors and classify the cloud systems associated to some of the recorded precipitation events an area of $800\times800\,\mathrm{km}^2$ has been chosen.

The main data directly obtained from ground measurements are, as indicated before, the DSD time series. The time series of rainfall integral parameters, DSD moments and DSD parameters then have been derived, mainly to discriminate between stratiform and convective events. In particular the parameterization of DSD suggested by Caracciolo et al. (2006a) has been used. As for the possible analytical parameterization of DSD, the exponential one has been the most widely used analytical parameterization for the raindrop size distribution:

$$N(D) = N_0 \exp(-\Lambda D) \tag{1}$$

where $N(D)$ [$\mathrm{mm}^{-1}\,\mathrm{m}^{-3}$] is the number of raindrops for unit volume for size interval. N_0 [$\mathrm{mm}^{-1}\,\mathrm{m}^{-3}$] and Λ [mm^{-1}] are the DSD parameters (intercept and slope of the exponential distribution in a semi-logarithmic plot, respectively). Marshall and Palmer (1948) (hereinafter referred to as MP) suggested that N_0 has a constant value equal to $8000\,\mathrm{mm}^{-1}\,\mathrm{m}^{-3}$ and Λ [mm^{-1}] varies with R as Λ=4.1 $R^{-0.21}$ (or Λ=3.67/D_0, with D_0 the median volume diameter in [mm]). Sekhon and Srivastava (1971) and Waldvogel (1974) generalized the MP formula, considering N_0 as a variable parameter. Since the mid-1970s on, many studies have indicated that, unless sufficiently averaged in space and/or time, the exponential DSD overestimates the concentrations of both very small and very large raindrops (Gunn and Marshall, 1955; Joss and Gori, 1978). To account for these effects, Ulbrich (1983) introduced the three-parameter gamma distribution:

$$N(D) = N_0 D^m \exp(-\Lambda D) \tag{2}$$

where Λ=(3.67+m)/D_0 [mm^{-1}] is a scale parameter, N_0, expressed in units of [$\mathrm{mm}^{-1}\,\mathrm{mm}^{-3}$], is a concentration parameter, and m is the shape parameter (positive or negative). The above mentioned parameterisations have been considered in this study, using both the gamma and exponential DSD parameters fitting the measured DSD distribution. In particular, the integral precipitation parameters have also been considered (in particular, the reflectivity Z expressed in [dB(Z)], R in [$\mathrm{mm\,h}^{-1}$], the total number of drops N_T and the equivolumetric mean diameter D_0 expressed in [mm]). The N_0 [$\mathrm{mm}^{-1}\,\mathrm{m}^{-3}$] and Λ [mm^{-1}] parameters of the exponential DSD were computed using the Waldvogel (1974) method, while the m, N_0 [$\mathrm{mm}^{-1}\,\mathrm{m}^{-3}$] and Λ [mm^{-1}] values of a gamma DSD were computed following the Tokay and Short (1996) method of moments. Moreover the Z-R relationships,

computed by a linear regression method, were analyzed. It is important to point out that the convective/stratiform discrimination methods based on disdrometric data, as evidenced by Caracciolo et al. (2006), are useful to discriminate between weak-stratiform ($R<2$ mm/h) and strong-convective precipitation ($R>10$ mm/h) events, but they have to be used in combination with polarimetric radar data for the discrimination in the $2<R<10$ mm/h range, in which shallow convective and heavy stratiform events (characterized at the ground by the presence of large drops generated from strong aggregation mechanisms in clouds) can occur. In this range the disdrometric analysis can however provide useful information.

All the DSD data have been derived using an innovative X-band low power (10 mW) continuous wave raingage – disdrometer operating at the frequency of 9.5 GHz, named PLUDIX. Its working principle is based on the analysis of the RADAR signal backscattered from hydrometeors (Prodi et al., 2000), providing a more comprehensive information on the evolution of the precipitation event. In particular, the Doppler shift of each individual falling particle, which is supposed to cross randomly the detection volume of the sensor, is detected. The 2048 readings of the instrument are inverted to generate, with an integration period of 1 min, a hydrometeor size distribution subdivided in 21 bands. This means that the basic output data consists of the number N_i of rain drops of equivalent diameter D_i in 21 bands ranging, in size, from 0.8 mm to 7 mm, which is the DSD. The relative error for N_i calculation is of 7%, while the relative error for the first order moment, which is the 1-min integrated rainfall intensity, R, expressed in [(mm/h)min^{-1}], has a relative error lower than 1%. The mean detection volume of the instrument is a cylinder having a diameter of 3 m and being 3 m in height. The instrument has been chosen mainly because of two reasons: the reduced need of assistance along the campaign and the previous knowledge of the results of intercomparison campaign with both a traditional JW mechanical disdrometer (Caracciolo et al., 2006a) and a 2DVD optical disdrometer (Caracciolo et al., 2006b).

Informations about the cloud system nature have been derived from satellite data analysis of the geostationary VIS and IR channels of satellite METEOSAT-7, plus SSM/I on platform F13 and MODIS sensors mounted on Terra platform.

The spectral bands of METEOSAT-7 are VIS (0.4–0.9 μm) IR (10.5–12.5 μm) and WV (5.7–7.1 μm); the scan time is 25 min with scan directions S-N and E-W; the instantaneous field of view is 0.14 mrad; the azimuth step is 0.125 mrad; the view angle is 2.618 rad (Heart) and 0.314 (satellite); the temporal resolution is 30 min; the pixel (from Italy) has an area of 7.5×5 km^2 and we have the data for the 21st and 51st minutes of each hour (for a total of 48 slots per day).

The used SSM/I channels are: 19 GHz with Vertical and Horizontal polarization; 22 GHz with Vertical polarization; 37 GHz with Vertical and Horizontal polarization; 85 GHz with Vertical and Horizontal polarization. The spatial resolution is 25 km for the first two channels and 12.5 km for the third one.

MODIS, mounted on polar satellite Terra, with free data available from web (http://ladsweb.nascom.nasa.gov/data/search.html), provides data within 36 channels from 0.4 to 14.5 μm. In particular, we have used three IR channels, that are generally used for deriving different informations about the cloud characteristics: channel 29, with spatial resolution of 1 km, wavelength of 8.550 μm, spectral radiance (at 300 K) of 9.58 W/m^2/μm/sr used for detecting the cloud general properties; channel 31, with spatial resolution of 1 Km, wavelength of 11.030 μm, spectral radiance (at 300 K) of 9.55 W/m^2/μm/sr used for detecting the surface and cloud temperature; channel 33, with spatial resolution of 1 km, wavelength of 13.335 μm, spectral radiance (at 260 K) of 4.52 W/m^2/μm/sr used for detecting the cloud top altitude.

We derived our informations in the following way. We extracted the cloud maps using SSM/I, MODIS and METEOSAT data. In particular, we observed the SSM/I images in three channels (19, 37 and 85 GHz) and the METEOSAT images in two channels (visible VIS and infrared IR). Then we computed the rainfall rate R from satellite data using traditional algorithms using temperature threshold considering the midlatitudes-adapted Negri Adler Weltzer technique (NAW hereafter) from METEOSAT IR data (Adler and Negri, 1988), which is a Convective-Stratiform Technique (CST, as indicated by Adler and Negri, 1991) that identifies the cloudy areas with a surface greater than 250 Km^2 through the brightness temperature, T_b. In particular at 10% colder part of cloud ($T_{10\%}$) is associated an intense precipitation (8 mm/h), at the next 40% ($T_{40\%}$) is attributed a moderate precipitation (3 mm/h), while for the last 50% ($T_{50\%}$) is related with the absence of precipitation. We have also used Grody (1991) algorithm, from SSM/I data, that, as indicated in the related article, is referred to dual polarized 19 GHz channel, plus Vertical polarized 22 GHz and 85 GHz channels. A specific modification adapting the CST to SSM/I has been introduced in the 85 GHz channel to discriminate thunderstorms from cirrus clouds. We have tested different T_b threshold limits (230, 235 and 240 K), that are related – as for CST – to the minimum temperatures detected from the images, for distinguishing the latter from the former. After this test, operating at midlatitudes instead of tropical areas, we have fixed the threshold on the brightness temperature at the lower level of 240 K instead of 253 K. The modal temperature has been chosen, then, not considering a fixed area of 80×80 Km^2 around the minimum, but an area obtained considering all the pixels around the minimum one, with T_b lower than 240 K. In this way the area varies for each cloud. MODIS data are analysed through a channel comparison operation called Split Window Technique. In particular, if we consider the brightness temperature (T_b) associated to a specific channel indicated with an index "xx" (T_b"xx"), if $T_b31-T_b33\sim0$ and $T_b29-T_b31\gg0$ there is an ice cloud (associated, for example, with Mesoscale Convective Systems);

Table 1. Characteristic single-event seasonal and year precipitation amounts (upper part) and precipitation intensity (1-min integrated signal) (lower part).

Season	Licata	Surigheddu	Trisaia
Winter (Wi) – [mm]	13.412	5.568	3.067
Spring (Sp) – [mm]	10.782	8.932	2.739
Summer (Su) – [mm]	2.857	4.102	1.083
Autumn (Au) – [mm]	8.502	8.502	5.759
Characteristic values – year-based – [mm]	8.888	6.776	3.162
Winter (Wi) [(mm/h) $\min^{-1}$]	6.57 E+03	6.88 E+04	6.27 E+03
Spring (Sp) [(mm/h) $\min^{-1}$]	4.53 E+03	4.27 E+03	6.26 E+03
Summer (Su) [(mm/h) $\min^{-1}$]	1.30 E+03	2.93 E+03	1.30 E+03
Autumn (Au) [(mm/h) $\min^{-1}$]	4.63 E+03	3.91 E+03	5.69 E+03
Characteristic values – year-based [(mm/h)$\min^{-1}$]	4.26 E+03	2.00 E+04	4.88 E+03

if T_b31–$T_b33 \gg 0$ and T_b29–$T_b31 \sim 0$ there is a water cloud; if T_b31–$T_b33 \gg 0$ and T_b29–$T_b31 \gg 0$ there is a mixed cloud. Finally, if T_b29–$T_b31 < 0$ there is land or clear sky. The combined use of geostationary and polar satellites derived data allow us to combine two advantages: the good spatio-temporal resolution of METEOSAT-7 and the better accuracy of polar satellites microwave sensors derived estimations. In the following paragraph we will give an analysis of the data under the particular point of view of the discrimination between Convective and Stratiform events generated by the microphysical analysis of the events (DSD and its moments). Considering a sub-set of ten events, we have shown a meaningful example of contemporary PLUDIX and satellite data analysis, considering the fact that we want both to confirm the validity of PLUDIX data analysis and to show the capability of detecting the local variations of events generated by bigger systems (such as Mesoscale Convective Systems, cold fronts and so on). We will, finally discuss the results of our study both in relation to the risk of desertification and in relation to the most recent climatological studies related to the same area.

Table 2. Z-R analysis for 20 months record in the three stations. Derived A and b terms of equation $Z=AR^b$.

Station	A	B
Surigheddu	269.15	1.50
Rotondella	205.59	0.84
Licata	257.04	1.02

Table 3. DSD gamma distribution parameters that fits a real distribution (m [adimensional]; Λ is expressed in units of [mm^{-1}], N_0 is expressed in units of [$\mathrm{mm}^{-1}\,\mathrm{m}^{-3}$]), for the event of 11 December 2003.

Station 11 Dec 2003	m [–]	Λ [1/mm]	N_0 [$1/\mathrm{mm}^{1+m}/\mathrm{m}^3$]
Surigheddu	4.51	7.48	5.16×10^5
Rotondella	5.58	7.78	3.42×10^7
Licata	3.67	6.70	1.73×10^5

3 Results

3.1 General results

Along the period starting from October 2003 and ending to May 2005, the number of rainy days recorded by PLUDIX are: 139 (Surigheddu, Sardinia); 149 (Rotondella, Basilicata); 110 (Licata, Sicily), while the total number of minutes of recorded events is 19 764. We have subdivided them into four seasons according to the same criteria of Brunetti (2006): Spring (Sp), in the period March–May; Summer (Su), in the period June–August; Autumn (Au), in the period September–November; Winter (Wi), in the period December–February. We have calculated the mean characteristic daily values both for the amount of precipitated water, expressed in [mm] and for the 1-min integrated mean characteristic daily value of precipitation intensity, expressed in [(mm/h) $\min^{-1}$]. The characteristic values are calculated respect to a reference period of integration of both a season and the whole dataset. Those values are reported in Table 1. The maximum value of characteristic precipitation amount is related to (Wi) period in Licata, while the maximum characteristic rainfall intensity is related to (Wi) season in Surigheddu. The common features among the stations are the following. The minima are, for all three stations, related to (Su) period.

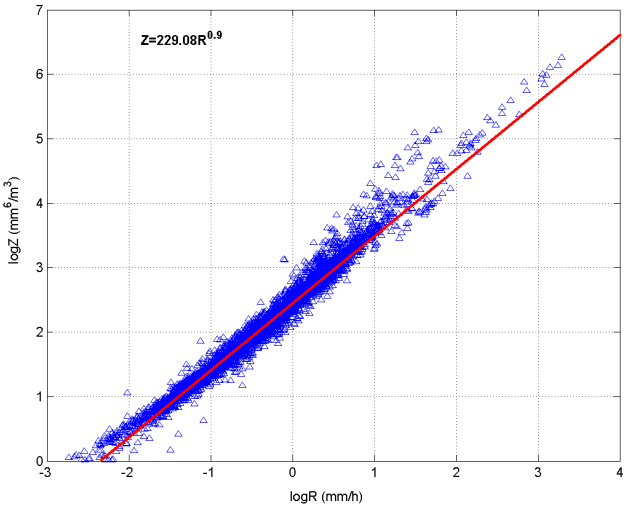

Fig. 2. Overall Z-R relation for the three stations in log-log plot (93 events, Surigheddu; 107 events, Licata; 69 events, Rotondella). Z (ordinate): [mm^6/m^3]; R (abscissa): [mm/h]. Fit line red, with equation Z=259.08 $R^{0.9}$.

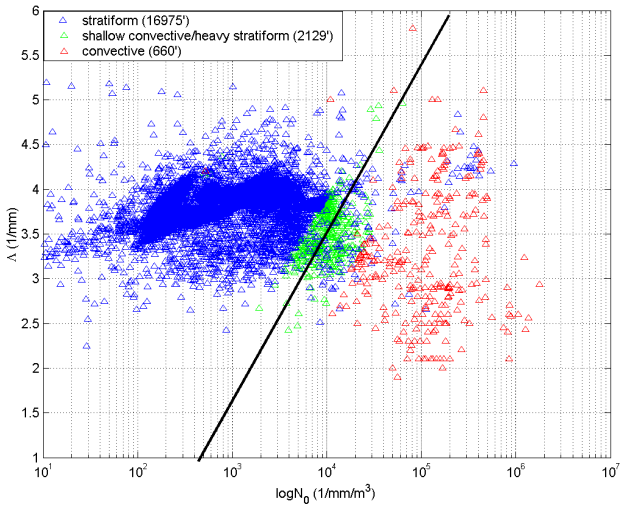

Fig. 3. Exponential distribution parameters for the three stations. Λ+4.17=1.92logN_0 is the separation line between convective and stratiform events. Blue triangles: stratiform events; green triangles: shallow-convective and/or heavy stratiform events; red triangles: stratiform events.

The maxima related to the daily precipitation amount, expressed in [mm], are found to be (Wi) season for Licata; (Sp) and (Au) for Surigheddu and (Au) for Trisaia, while the rainfall intensity R has a maximum, for all the stations, in the (Wi) period. Finally the minimum (due to the low amount of both rainy days and precipitated water) is related to (Su) season. Finally the maxima, related to the number of rainy days, is related to (Wi) season. The microphysical nature of the recorded events has been investigated. The overall Z-R analysis, referring to equation $Z=AR^b$ reported in the previous paragraph (for the 20 months, for all three stations, Table 2), gives A=259.08 and b=0.9 values (Fig. 2), which are not significantly far from the A=200 and b=1.6 relative to MP for widespread midlatitudes precipitation. The nature of the events has been investigated using the method proposed by Caracciolo et al. (2006a). Considering the total amount of recorded minutes of precipitation, which is 19 764, we have found that 16 975 min are related to stratiform events (Fig. 3, blue triangles on the top-left of the graph), 660 min are related to convective events (Fig. 3, red triangles on the bottom – right of the graph), while 2129 min are related to a sort of transition subset that we can define as shallow convective and/or heavy stratiform events (Fig. 3, green triangles in the middle of the graph). The $N_0-\Lambda$ graph of Fig. 3 shows clearly the differences between weak-stratiform and strong-convection, but those results should be supported by polarimetric radar measurements (not available during our research project), in order to better discriminate the shallow-convective and heavy-stratiform region. The first general consideration that we can derive is that all the precipitation events are mainly concentrated along (Wi) season, while the minima are mainly concentrated along (Su) season. This is a typical feature of all the areas influenced by the Mediterranean sea. A confirmation of the influence of the Mediterranean sea comes from the Z-R values, which do not differ significantly from the typical values found in mid-latitudes Mediterranean area (e.g. Caracciolo et. al., 2006a). A different feature, due to the fact that Licata station is directly facing toward the Mediterranean Sea is visible in Table 1, where we see that the mean daily precipitation amount, having as one year as reference period, is greater there in comparison to the other two stations. This confirms the study of Brunetti (2006), where a decrease of precipitation amount of SE and CE has been found. Another reason for the difference between Licata and both Surigheddu and Rotondella is the fact that the first station is directly facing toward the Mediterranean Sea. Comparing, inside Table 1, the data of precipitation amount and intensity together with the general data derived by Fig. 3, we can derive some more informations. Licata records show a major amount of precipitated water together with a minor intensity of the events. This means that the stratiform feature prevails. This means also that desertification processes in this area will be mainly related to lack of availability of precipitable water. Surigheddu and Trisaia show a prevailing nature of convective events, that are, in nature, more intense. Being the intensity of events related to a major number of bigger rain drops, this means, because of the considerations done in the previous paragraph, a major erosive power, that is related to fertile soil particles removal. Thus, in Surigheddu and Trisaia the reason of desertification in relation to precipitation processes has to be put in relation to precipitation intensity. We can give a confirmation of the regionalization indicated by Brunetti et al., considering the

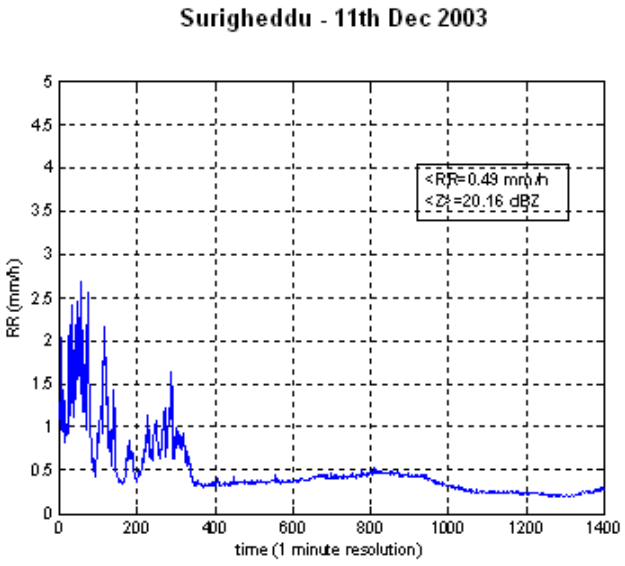

Fig. 4. Time evolution of precipitation Rainfall Rate [(mm/h)] (1-min derived data) for 11 December 2003 event in Surigheddu, Sardinia.

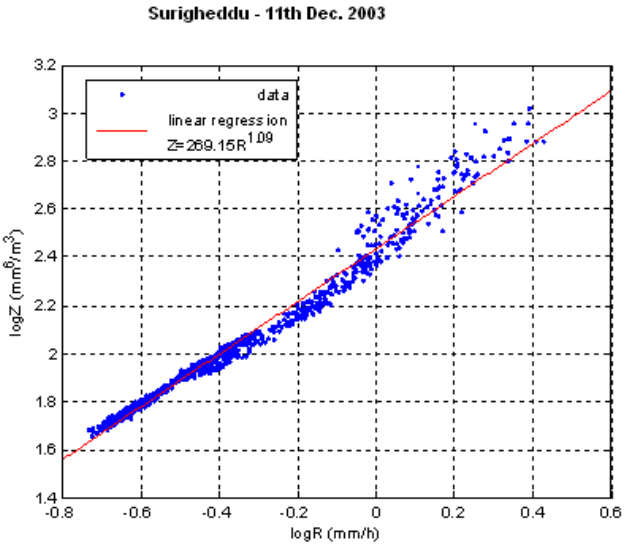

Fig. 5. Z-R relation for Surigheddu station (11 December 2003) in log-log plot. Z (ordinate) is expressed in units of [mm^6/mm^3]. R (abscissa) is expressed in units of [mm/h] respect to 1-min integrated signal. Linear regression (red line) is here reported. Experimental data: blue points.

fact that the maxima for the characteristic daily precipitation amount is different for the three sites respect to the different seasons.

3.2 Sub-set data analysis and case study

In order to test the good capability of PLUDIX in detecting the variation of nature of the different events, confirming so the ground-based observations and analysis, we have selected, as indicated before, a subset of ten events with contemporary availability of METEOSAT-7 and SSM/I data for all the three stations. We have, then, performed a detailed analysis of the time evolution of the events considering both the ground-based and the satellite-derived data. We will now show an example of this analysis, relative to the day 11 December 2003. The same analysis performed for all the other nine days hasn't been reported here because no additional information would have been added either about the methods or about the obtained results and/or about some additional features of the observed phenomena analysis not considered before. On 11 December 2003 a Mesoscale Convective System (MCS), formed over the Mediterranean Sea between Sicily and Africa, has been detected by METEOSAT images. This system, under formation when it was first detected in Surigheddu (Sardinia), moved toward SE, producing a convective precipitation over Rotondella (Basilicata). The MCS didn't reach Licata, while it reached other parts of the region. In fact the recorded precipitation over Licata has been moderate, but not intense.

We will analyse the separate station data. Surigheddu R values are always below 2.5 [mm/h] (Fig. 4) and the Z values are always below 30 [dB(Z)], indicating a stratiform precipitation. The Z-R relationship (Fig. 5, generally writable as $Z=AR^b$, and, in this case, $Z=269.15\,R^{1.09}$) is not remarkably far from the Marshall and Palmer (1948) (hereinafter MP) relationship ($Z=200\,R^{1.6}$) for widespread midlatitudes precipitation. The analysis of the 0th order moment, which is the total drop number N_T, expressed in units of [mm^{-3}], shows that N_T for this event is very low ($<300\,\mathrm{mm}^{-3}$). By analysing this parameter associated with the equivolumetric mean diameter D_0 (mm), it was found that the event is characterised by a reduced number of small drops ($D_0<1.25$ mm), indicating a stratiform precipitation. The DSD gives more information than N_T. It provides the number of drops per unit drop volume and per unit drop diameter; it therefore indicates if large drops dominate over small ones or vice-versa. We performed three different DSD analyses. Figure 6 shows the time-averaged DSD for the considered event, in a semi-logarithmic scale. The MP-DSD for the mean rainfall-rate of the event and the two-dimensional exponential fitted DSD (Waldvogel, 1974), are superimposed to the plot as a dashed and a dotted line respectively, showing that the exponential DSD is a better parameterization than a gamma DSD (Ulbrich, 1983). In fact, as shown in Caracciolo (2006a) the gamma DSD gives a better precipitation parameterization in the case of insufficiently averaged series, when the exponential DSD overestimates the concentrations of both very small and very large raindrops. Moreover, the MP-DSD generally fails to fit the observed DSD. It underestimates the high tail of the distribution, while, with sufficient averaging, it seems to fit better the light-moderate rain categories. For this event, the MP distribution underestimates

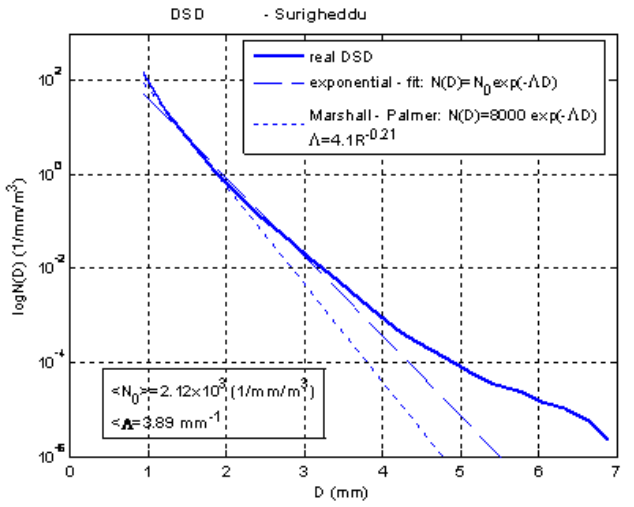

Fig. 6. Mean DSD [1/mm/mm^3] (continuous line) for 11 December 2003, Surigheddu station. Exponential fit (dashed line) and Marshall-Palmer (dotted line) are reported.

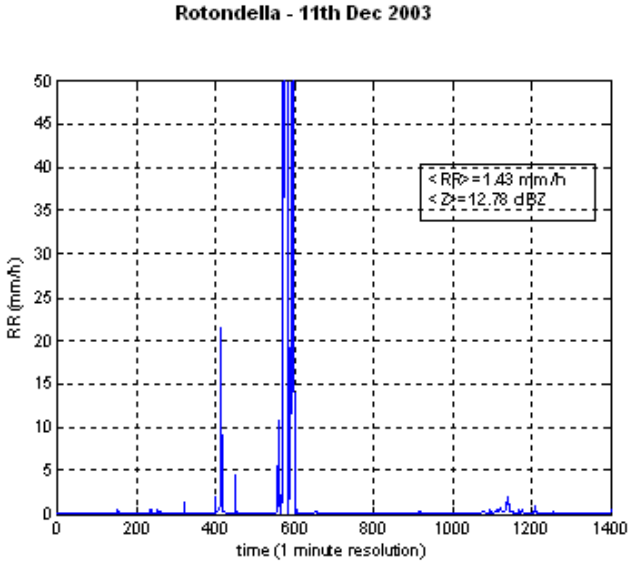

Fig. 7. Time evolution of precipitation Rainfall Rate [(mm/h)] (1-min derived data) for 11 December 2003 event in Rotondella, Basilicata.

the measured DSD, especially in the 3–5 mm diameter range. We successively analysed the 1-min time evolution of the two parameters of an exponential DSD fitting the observed DSD, whose time averaged values are shown in Fig. 3. It was found that the N_0 values are always lower than 10 000 mm^{-1} m^{-3}, while the Λ ([mm^{-1}]) values do not change significantly and their values are around 4 mm^{-1}. We also analyzed the 1-min DSD evolution, which confirms the marked presence of a low number of small drops for all the time duration of the event.

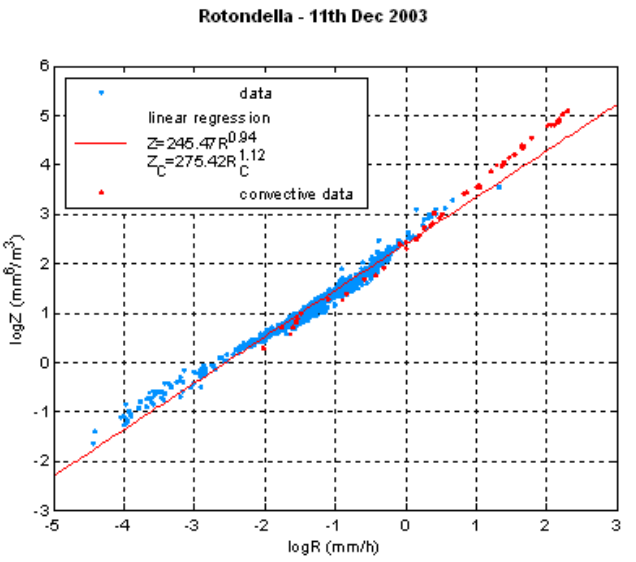

Fig. 8. Z-R relation for Rotondella station (11 December 2003) in log-log plot. Z (ordinate) is expressed in units of [mm^6/mm^3]. R (abscissa) is expressed in units of [mm/h] respect to 1-min integrated signal. Linear regression (red line) is here reported. Experimental data: blue points. Linear regression for convective events distinguished (Z_C–R_C relation). Experimental convective data: red points.

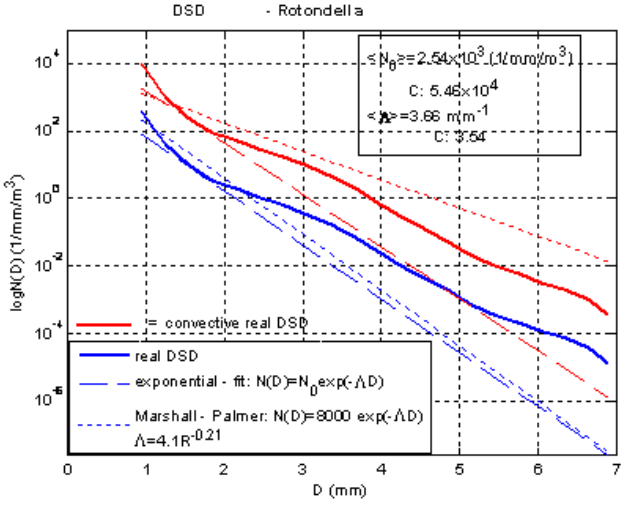

Fig. 9. Mean DSD [1/mm/mm^3] (continuous line) for 11 December 2003, Rotondella station (continuous blue line). DSD of the convective part of the event (continuous red line). Exponential (dashed line) and Marshall Palmer (dotted line) fits for the whole event (blue colour) and for the convective part of the event (red line).

The Rotondella station detects two convective showers (Fig. 7) having R values greater than >20 [mm/h] and Z values greater than 35 [dB(Z)]. The Z-R relationship gives high A and b values, indicating the presence of drops with large

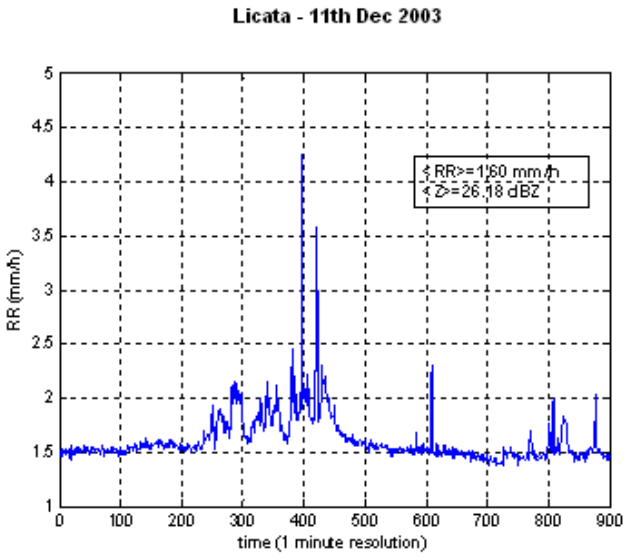

Fig. 10. Time evolution of precipitation Rainfall Rate [mm/h] (1-min derived data) for 11 December 2003 event in Licata, Sicily.

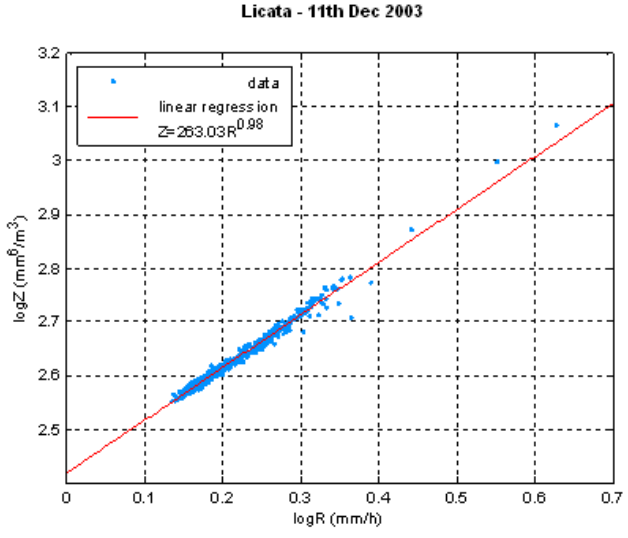

Fig. 11. Z-R relation for Licata station (11 December 2003) in log-log plot. Z (ordinate) is expressed in units of [mm^6/mm^3]. R (abscissa) is expressed in units of [mm/h] respect to 1-min integrated signal. Linear regression (red line) is here reported. Experimental data: blue points.

values of D_0, which varies in a broad interval (Fig. 8). In particular, we have applied a distinction between the general feature of the event, calculating a Z-R relationship, which is Z=245.47 $R^{0.94}$, and the convective parts of the event, from which a Z_C-R_C relation (where C stands for Convective), which is Z_C=275.42 $R_C^{1.12}$ (as reported in Fig. 8). From the N_T ([mm^{-3}]) analysis it was found that the total number of drops is very high (about 104 [mm^{-3}]). Combining

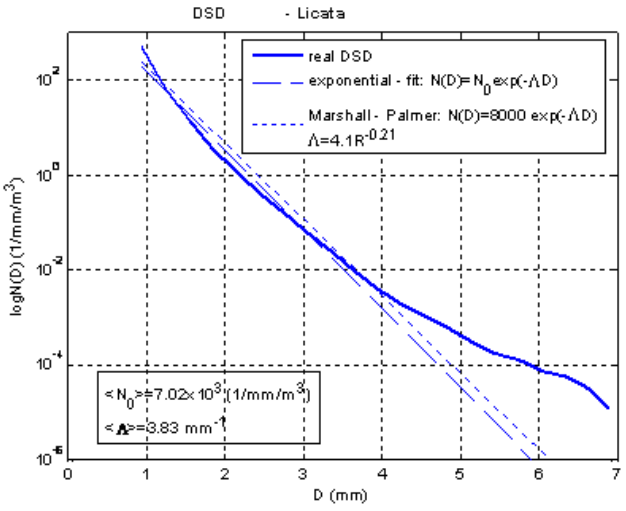

Fig. 12. Mean DSD [1/mm/mm^3] (continuous line) for 11 December 2003, Licata station. Exponential fit (dashed line) and Marshall-Palmer (dotted line) are reported.

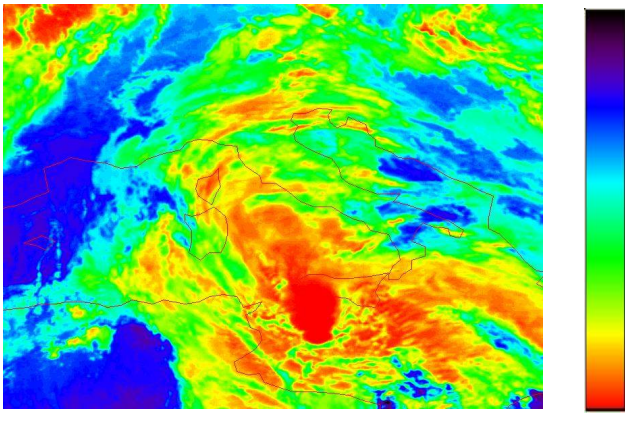

Fig. 13. METEOSAT at 11:21 Local Time (LT) of 11 December 2003 reveals a Mesoscale Convective System (MCS) between Africa and Sicily, with a characteristic V-shape. The colour scale is referred to the threshold limit of precipitation intensity ([mm/h]), which decreases from red (which is referred to the higher threshold) to blue and violet (no precipitation).

this analysis with the 1-min DSD time evolution for the considered event, it was found that the convective episodes are characterized by a high number of large drops, but also by small drops (even if in smaller concentration), probably due to drop break-up, which is related to the drop deformation and scission due to drag forces. From Fig. 9 it can be noticed that the mean DSD for the convective episodes moves toward high values, indicating that both the concentrations of small and large drops grow. For the convective episodes, the N_0 values grow (by a factor of 10), while the Λ parameter does not show large variations (it tends to decrease, indicating an increase of large drops). This behaviour was also confirmed

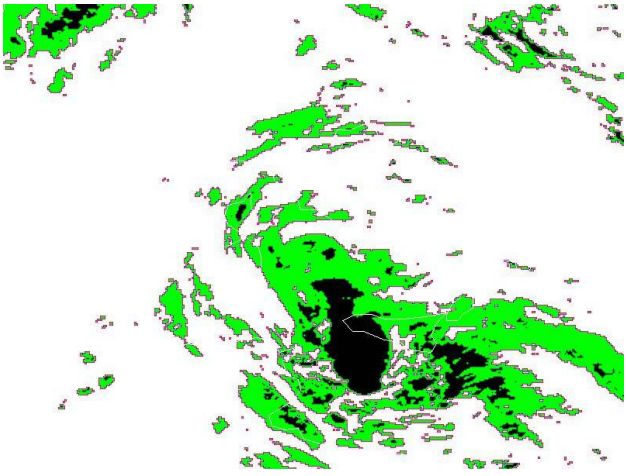

Fig. 14. Elaboration of image through NAW technique derived from IR data of METEOSAT 7 IR channel (11 December 2003, 11:21 LT). Convective rain associated to the MCS visible through METEOSAT (see Fig. 10). Precipitation thresholds expressed through colour image: black: 8 mm/h; green: 2 mm/h; white: 0 mm/h.

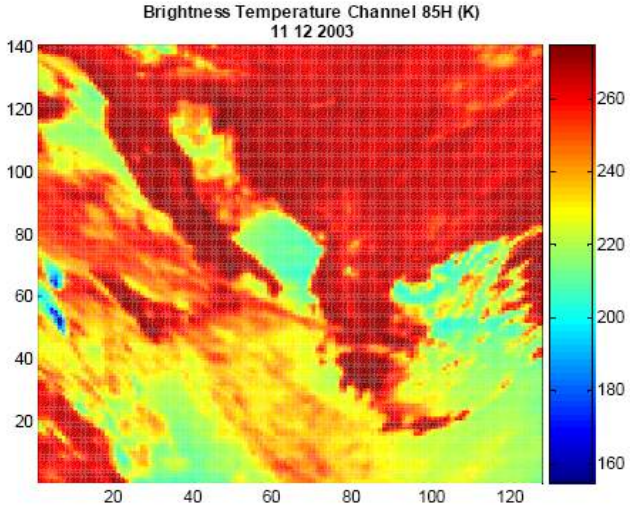

Fig. 15. SSM/I – NASA SMFC F13, ascending – derived brightness temperature, T_b, expressed in [K] – channel 85 GHz (Horizontal polarization). On the right of the figure the brightness temperature scale is shown. 11 December 2003 event. Continental background, dark red: $T_b \approx 280$ K. Newly formed Mesoscale Convective System, red: $T_b \approx 240$ K. Green background correspondent to sea areas: $T_b \approx 210$ K. Convective spots, blue color: $T_b \approx 170$ K.

by the 1-min time evolution of N_0 and Λ, indicating that the N_0 values are of the order of 105 ([$\mathrm{mm}^{-1}\,\mathrm{m}^{-3}$]) while the Λ ([mm^{-1}]) values do not vary significantly, and their values are around 4 [mm^{-1}].

The Licata station detects a stratiform rain event (Fig. 10) having R values always less than 4.5 [mm/h] and Z values always less than 31 [dB(Z)]. The Z-R relationship (Fig. 11, Z=263.03 $R^{0.98}$) is not far from the MP one for widespread midlatitudes precipitation. The low and nearly equal to 1 b value indicates nearly constant D_0 values (the mean D_0 value is low, 0.96 mm). Moreover, from the N_T (mm^{-3}) temporal evolution, it was found that the total number of drops for this event is very low ($<400\,\mathrm{mm}^{-3}$). Analysing this parameter in combination with the 1-min DSD time evolution, it was found that the event is characterised by a reduced number of small drops, indicating a stratiform precipitation. From the time-averaged DSD analysis (Fig. 12), it was found that with sufficient averaging, both the MP and the exponential DSD seem to fit with good accuracy the observed DSD in the 1–4 mm diameter range. The temporal evolution of the two exponential DSD parameters shows that the N_0 values are always lower than 10 000 ($\mathrm{mm}^{-1}\,\mathrm{m}^{-3}$), while the Λ (mm^{-1}) values do not change significantly and their values are around 3 mm^{-1}, indicating a stratiform precipitation.

The geostationary satellite METEOSAT at 11:21 Local Time (LT) reveals a Mesoscale Convective System (MCS) between Africa and Sicily, with a characteristic V-shape (Fig. 13). Observing the 30 min time evolution of the METEOSAT-7 satellite images for all the event, together with the PLUDIX images in the three stations, it was found that the system is in the formation phase when it moves toward Sardinia (the Surigheddu station reveals during night hours a precipitation less than 2.5 mm/h). Successively, the system grows, moving south-east, producing at the Rotondella station, between 09:20 and 10:20 LT, a very intense convective rain with hail. The Licata station reveals a moderate rain between 11:00 and 12:00 LT. The NAW technique elaborated image, as shown in Fig. 14, reveals a convective rain (8 mm/h), black colour, associated to the MCS (see Fig. 13). In the SSM/I image in the 85 GHz channel (Fig. 15) (F13, from 16:02 to 16:53 Solar Local Time (SLT), ascending) we found the presence of two very cold spots, characterized by brightness temperatures below 180 K; they are the "convective cores" of the MCS, characterized by the presence of ice crystals in the highest part of the cloud. In particular, from the Red Green Blue (RGB) figure (Fig. 15) it is possible to identify a dark red continental background ($T_b \approx 280$ K), the red colour newly formed Mesoscale Convective System ($T_b \approx 240$ K), while the green background corresponds to sea areas ($T_b \approx 210$ K). Convective spots, blue color: $T_b \approx 170$ K. The brightness temperature images in the other two channels (19 and 37 GHz) confirm the presence of a MCS with remarkable vertical extension, identified at the low (19 GHz), medium (37 GHz) and high (85 GHz) levels. In particular, from the RGB figure (Fig. 16) it is possible to identify the dark red continental background ($T_b \approx 280$ K); the blue background correspondent to sea areas ($T_b < 160$ K), the green-yellow areas for clouds ($T_b \approx 200$–220 K); the red area visible at 37 GHz (right figure) related to clouds ($T_b \approx 230$ K). The Grody algorithm provides a high

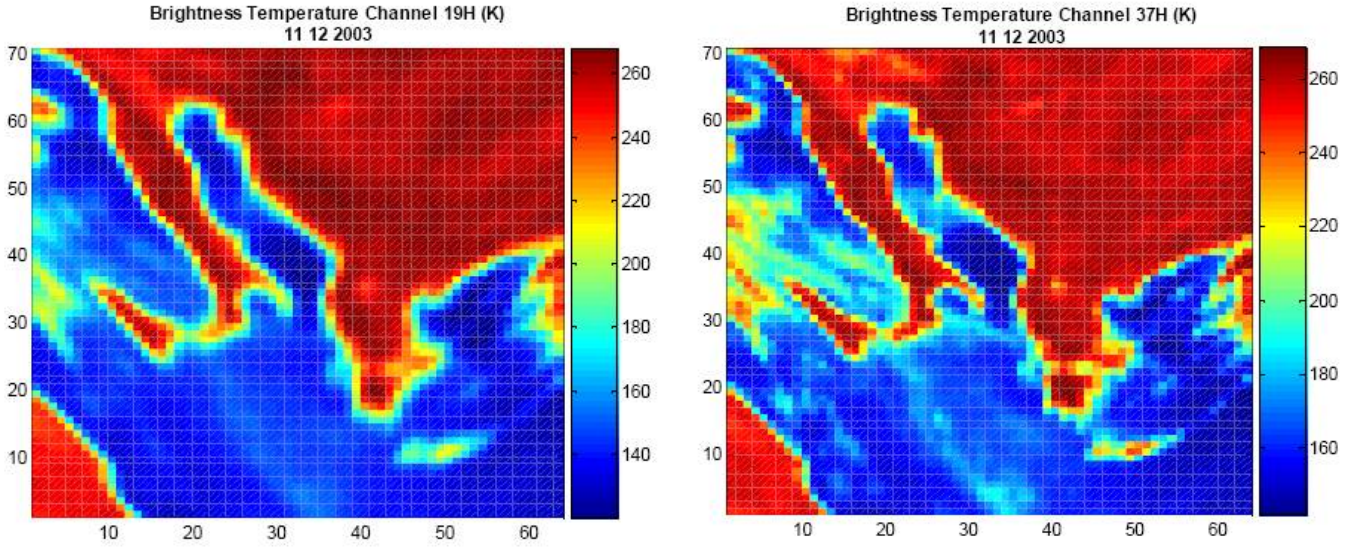

Fig. 16. SSM/I – NASA SMFC F13, ascending - derived brightness temperature, T_b, expressed in [K] – channel 19 GHz (left) and channel 37 GHz (right) (Horizontal polarization). On the right hand side of both the figures the brightness temperature scale is shown. 11 December 2003 event. Continental background, dark red: $T_b \approx 280$ K. Blue background correspondent to sea areas: $T_b < 160$ K. Green-yellow for clouds: $T_b \approx 200$–220 K. Red area at 37 GHz (right figure), clouds: $T_b \approx 230$ K.

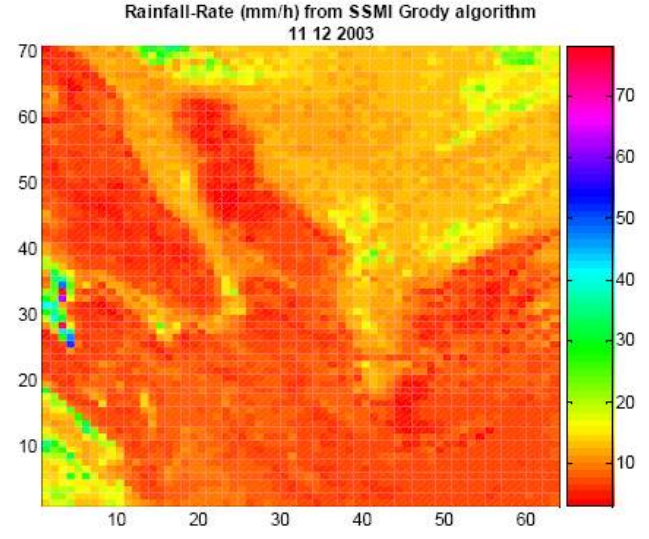

Fig. 17. Grody algorithm analysis applied to SSM/I – NASA SMFC F13, ascending – 11 December 2003 event. Precipitation rate [mm/h] expressed in RGB scale, visible on the right of the figure. Blue spots are correspondent to convective cores of the precipitating system.

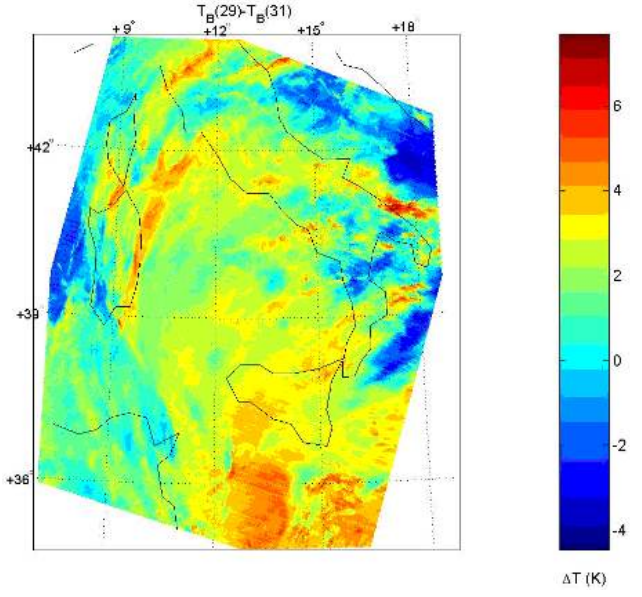

Fig. 18. Brightness temperature (T_b) difference, expressed in [K], between 29 and 31 channels of MODIS sensor mounted on Terra platform. The Lon and Lat are reported, respectively in the abscissa and ordinate axis, while the T_b difference is reported through a colour scale. The data are relative to 11 December 2003.

rainfall rate associated to the MCS convective cores (Fig. 17). The use of the Split Window technique referred to the three MODIS (timetable 10:35–10:40 SLT) IR channels 29, 31 and 33 allowed discriminating between water clouds, ice clouds, mixed clouds, land, sea and clear sky. In particular we have used the Split Window technique, that allows the comparison between T_b difference between channels 29 and 31 (Fig. 18) respect to T_b difference between channels 31 and 33 (Fig. 19). The result is shown in Fig. 20, where the blue area in the right-bottom side of the plot, associated to ice

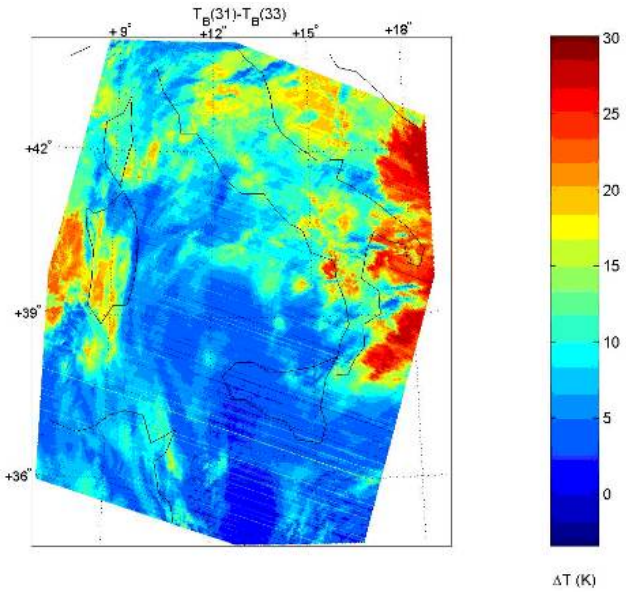

Fig. 19. Brightness temperature (T_b) difference, expressed in [K], between 31 and 33 channels of MODIS sensor mounted on Terra platform. The Lon and Lat are reported, respectively in the abscissa and ordinate axis, while the T_b difference is reported through a colour scale. The data are relative to 11 December 2003.

in the MCS, the red area is associated to water associated to clouds, while green is related to land detection and/or no rain.

The analysis of the complete sub-set of events, performed in the same way as before, has shown a majority of stratiform events, relatively long in duration and slightly fluctuating, characterized by low-moderate R at the ground. Especially during (Wi) and (Sp) 2004 (from February to June 2004) we observed the marked presence of convective episodes, relatively short in duration and highly fluctuating, characterized by high rainfall-rate values, typical of this period of the year. These events were generated by deep convection in the Mediterranean area, often associated to MCS, squall-lines or isolated convective cells. The (Su) months were characterized by a nearly total absence of rain events, for all the three stations. This trend is typical of Southern Italy areas in this period of the year. The other result that we have obtained here – which is not developed within this paper, even if confirmed by the other nine cases analysed – has been also to show the capability of PLUDIX of detecting the local variations of bigger systems, such as MCS, detectable with a lower time resolution through satellite data analysis. These results are important starting points, together with the ones of Caracciolo et al. (2006a, b) for developing a new Present Weather Sensor.

4 Conclusions

Along the RIADE project we have measured and characterised the precipitation occurring in three different stations (Surigheddu, Sardinia; Licata, Sicily; Rotondella, Basilicata) of three different regions in Southern Italy. The purpose of this study has been to better describe the precipitation processes in an area under risk of desertification. A record of 19 764 min of rain has been collected, with a number of events, which follows here: 139 (Surigheddu, Sardinia); 149 (Rotondella, Basilicata); 110 (Licata, Sicily). The general features of precipitation events, distinguishing also their nature into two main categories (Convective – Stratiform), has been performed. We have found that, considering the MP distribution (which describes the nature of precipitation respect to its intensity R versus its reflectivity Z), the characteristics of the events are typical of the Mediterranean region. Furthermore, using the new technique introduced by Caracciolo et al. (2006a), we have found that the majority of events, mainly concentrated during (Wi) season, fails under the Stratiform category, which is characterised by a lower amount of total precipitable water, smaller drops dimension and a longer duration. We have also detected some different regional features respect for the three stations. Licata record analysis shows that the typical daily precipitation amount, both respect to (Wi) season and to the year, is greater respect to the other two records, because of it faces directly toward the open Mediterranean sea. More intense events are recorded in the other stations. This characteristic is typical of Convective events, characterised by a greater amount of precipitated water in less time, together with drops of greater dimensions. Those facts are described thanks to the DSD and its moments analysis. Even if we have clearly detected the presence of strong Stratiform and weak Convective events, it hasn't been possible to determine their real nature because no polarimetric radars are located in the area of study. Analyzing the possible causes of potential desertification processes development related to precipitation effects, Licata record shows a lack of precipitated water, while, for the other two stations, the desertification process is related to the so-called "storm erosivity", which is the power of rain of detaching and remove particles of fertile soils from their original position. Our study confirms also the fact that the three stations belong to three different regions in relation to the precipitation events nature, as indicated by Brunetti et al. (2006). The combined analysis of PLUDIX and satellite-derived data, for a sub-set of ten events confirmed the general PLUDIX data analysis. Furthermore we have found a good capability of PLUDIX in detecting the local variation of events determined by larger area systems (such as MCS, cold fronts and so on). This is a valuable result, together with the ones previously obtained by Caracciolo et al. (2006a, b) along different disdrometers intercomparison campaign. In fact using PLUDIX we can obtain a high-temporal resolution microphysical detection and description of the event comparable with different

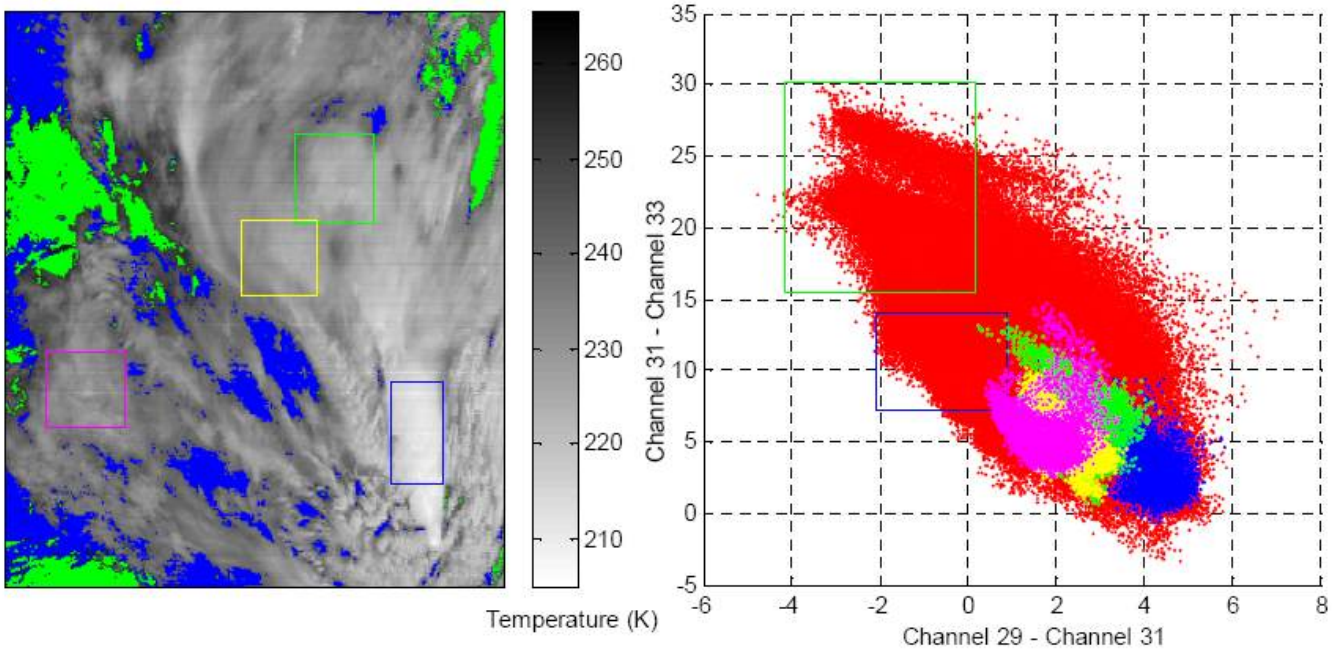

Fig. 20. 29–31 vs. 31–33 IR channels scatterplot of MODIS (11 December 2003). The blue area (right graph, right – bottom) is associated to ice in the MCS.

reference instruments. Furthermore some newly developed algorithms can be applied to its data to define the microphysical nature of the event. Thus the way for developing a Present Weather Sensor, giving real-time informations about the precipitation events and their microphysical nature, is now clearly opened.

If the trends shown in Brunetti et al. (2006) will be confirmed, it will be of paramount importance to continue to develop the dataset of DSD data that we have started, since a desertification process might be under development in the defined areas, both being related to precipitations, which are of paramount importance for biosphere preservation in those areas.

Synthetically this work can constitute a new starting point for observing both the future modifications of precipitation climatology, for creating a new type of ground-based precipitation characterization database and a way for having new hints in interpreting potential future desertification processes in Southern Italy caused by climate change. A further specific interest is, finally, given, by the use both of a new technology, the pluvio-disdrometer PLUDIX, and of a new convective-stratiform discrimination algorithm proposed by Caracciolo et al. (2006a).

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