Proceedings of ERAD 2006

Atmospheric precipitation analysis using both disdrometric and satellite data for desertification studies

Clelia Caracciolo[1,3], Franco Prodi [1,3], Marco Casazza[2, 3]

[1] Dept. of Physics, University of Ferrara, Ferrara (Italy)

[2] Nubila s.a.s, Bologna (Italy)

[3] Institute of Atmospheric Sciences and Climate (ISAC) of the Italian National Research Council (CNR), Bologna (Italy)

1 Introduction

In the study of desertification processes, an important role is obviously played by the atmospheric precipitation investigation. The Italian project RIADE (Ricerca Integrata per l'Applicazione di tecnologie e processi innovativi per la lotta alla Desertificazione), has been setup to study the atmospheric precipitation in southern Italy and islands (Sicily and Sardinia), that can be potentially affected by desertification phenomena.

A comparison with observation from different sensors having different resolution has been realized. The analysis has been conducted in a quantitative way using the new generation X-band microwave raingage-disdrometer named PLUDIX, installed in three different Italian sites. PLUDIX data have been used both for rainfall events detection and for a climatological analysis of the rain events. Moreover, through rainfall rate (R) and drop size distribution (DSD) parameters estimation, the instrument has allowed a microphysical characterization of rain at the ground and the discrimination between convective and stratiform events.

We also used satellite data from Meteosat-7, SSMI (Special Sensor Microwave Imager) and MODIS (Moderate Resolution Imaging Spectro-radiometer) for a qualitative analysis of the precipitation systems. Because of the different spatial scale of the disdrometer and satellites, satellite data was used for the temporal scale analysis and for the cloud characterization (quality, type and structure of the rain clouds) of the selected events, as well as for the comprehension of the spatial extension of each rain event (genesis and evolution). We have also linked the observed events to the corresponding conceptual models in the Mediterranean area.

Correspondence to: Clelia Caracciolo

caracciolo@fe.infn.it

2 Instruments and methodology

Pludix is a rain-gauge/disdrometer based on the analysis of an X-band (9.5 GHz) continuous wave radar signal backscattered by hydrometeors (Prodi et. al. (2000)). It provides more detailed information with respect to classical tipping-bucket rain-gages and to disdrometers, giving information about the precipitation type. The Pludix data in the three Italian sites consist of number of raindrops n_i of diameter D_i in 21 categories, ranging in size from 0.8 to 7.0 mm, with a constant step of 0.3 mm. Pludix was operated during the period October 2003 – May 2005 (20 months) at three Italian sites in southern Italy: Surigheddu - Sardinia (lat=40.5888˚, long=8.3749˚), Rotondella (Matera) - Basilicata (40.1702˚, 16.5214˚) and Licata - Sicily (37.1037˚, 13.9411˚), with a time resolution of 60 s. From the overall database, 10 significant events were selected and analyzed: moreover for these events the MODIS, Meteosat-7 and SSMI data were available at the same time.

The climatological analysis was realized analysing the time series of rainfall integral parameters, DSD moments and

DSD parameters. These analyses have allowed to discriminate between stratiform and convective rain events at the ground. For each event a detailed microphysical analysis was realized, using the exponential and gamma DSD parameters fitting the real DSD and the rainfall integral parameters (the reflectivity Z in dBZ, the rainfall rate R in mm/h, the total number of drops N_T in mm^{-3}, the equivolumetric mean diameter D_0 in mm). The N_0 [$1/mm/m^3$] and Λ [1/mm] parameters of the exponential DSD were computed using the Waldvogel (1974) method. The m, N_0 [$1/mm^{1+m}/m^3$] and Λ [1/mm] 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.

However, 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.

We also used satellite data to comprehend the spatial scale of the observed events and to analyse the genesis of the rain events. The satellite date were also used to confirm the convective/stratiform discrimination made at the ground using Pludix data and to microphysically characterise each rain event. We used data from: the geostationary satellite Meteosat-7, SSMI and MODIS mounted on polar satellites. We chose a satellite grid containing the three Pludix sites.

We extracted the cloud maps using SSMI, MODIS and Meteosat images, in particular: observing the SSMI images in three channels (19, 37 and 85 GHz), observing the Meteosat images in two channels (visible VIS and infrared IR) and applying the split window technique using MODIS data, for acquiring information about the presence of ice, water or supercooled drops (King et. al. (1992)). We also computed R from satellite data using traditional algorithms using temperature threshold (Negri Adler Weltzer technique – NAW from Meteosat IR data - Adler and Negri (1988)) and spectral information (Grody (1991) algorithm, from SSMI data). It is important to point out that the satellite techniques provide R values in an area having the satellite pixel dimension, while Pludix provides punctual rain values.

3 Results

Here we report the analysis for a significant rain event (11/12/2003) which occurred, with different intensities, in all the three Pludix sites. The analysis was conducted using both Pludix and satellite data, as explained in section 2.

The geostationary satellite Meteosat at 11:21 Local Time (LT) reveals a MCS (Mesoscale Convective System) between Africa and Sicily, with a characteristic V-shape (fig. 1). Observing the 30 minutes 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 in the night hours a precipitation less than 2.5 mm/h). Successively, the system grows, moving south-east, producing in 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.

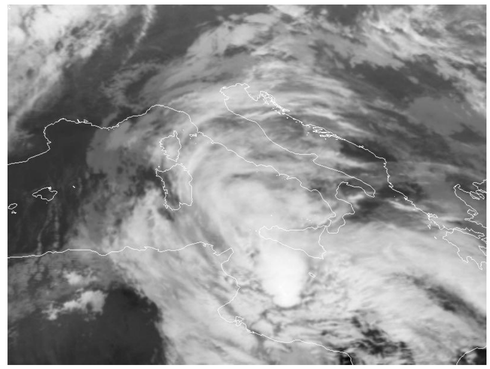

Fig. 1. Meteosat-7 IR image (11/12/2003 – 11:21 LT)

The NAW technique reveals a convective rain (8 mm/h) associated to the MCS (fig. 2).

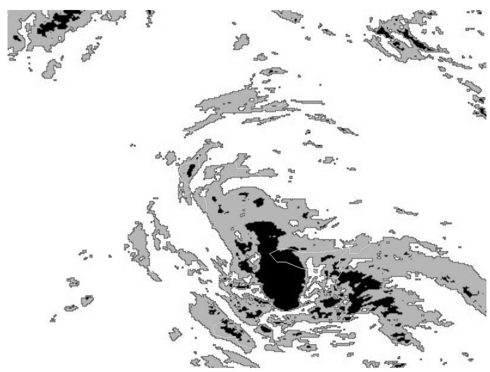

Fig. 2. NAWT rain from Meteosat-7 IR channel (11/12/2003 – 11:21 LT). Black = 8 mm/h, grey=2 mm/h, white=0 mm/h.

From the SSMI image in the 85GHz channel (F13, from 16:02 to 16:53 Solar Local Time, ascending), we found the presence of two very cold spots, characterized by brightness temperatures below 180K; they are the "convective cores" of the MCS, characterized by the presence of ice crystals in the highest part of the cloud. The brightness temperature images in the others two channels (19 and 37 GHz) confirm the presence of a MCS with remarkable vertical extension, identified at the low (19GHz), medium (37GHz) and high (85GHz) levels. The Grody algorithm provides a high rainfall rate associated to the MCS convective cores.

With the Split Window technique, using three MODIS (timetable 10:35→10:40 SLT) IR channels (channel 29, 31 and 33 at the wavelengths of 8.6, 11 and 12 μm respectively), it was possible to discriminate between water clouds, ice clouds, mixed clouds, land, sea and clear sky. If Tb31-Tb33~0 and Tb29-Tb31>>0 there is an ice cloud (very clear in fig. 3 in association with the MCS); if Tb31-Tb33>>0 and Tb29-Tb31~0 there is a water cloud; if Tb31-Tb33>>0 and Tb29-Tb31>>0 there is a mixed cloud. Finally, if Tb29-Tb31<0 there is land or clear sky. From fig. 3 it is clear the black area in the right-bottom side of the plot, associated to ice in the MCS.

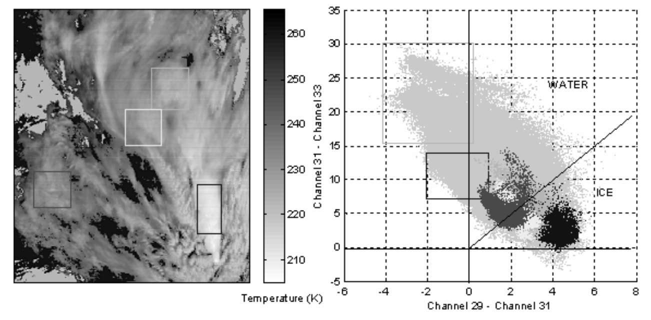

Fig. 3. Scatterplot of the infrared channels 29-31 vs. 31-33, MODIS sensor (11/12/2003, 10:35 SLT)

From the Pludix Surigheddu station for this event, it was found that the R values are always below 2.5 mm/h (fig. 4) and the Z values are always below 30 dBZ, indicating a stratiform precipitation. The Z-R relationship ($Z=269.15R^{1.09}$) is not significantly far from the Marshall and Palmer (1948) (hereinafter MP) relationship ($Z=200R^{1.6}$) for widespread mid-latitudes precipitation. From the N_T (mm^{-3}), DSD 0-order moment, temporal evolution, it was found that N_T for this event is very low (<300 mm^{-3}). Analysing this parameter in combination 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.

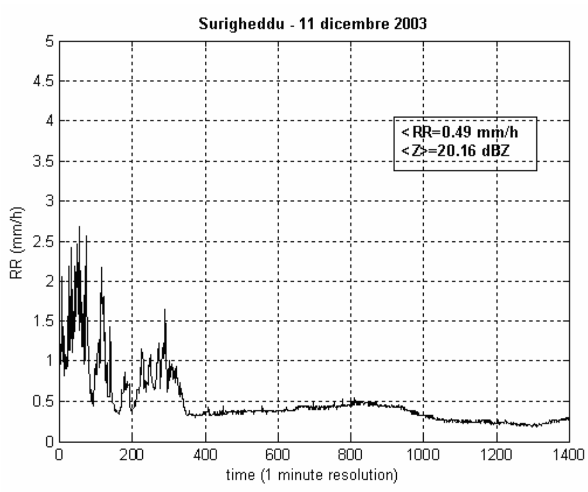

Fig. 4. Pludix R (mm/h) - Surigheddu station (11/12/2003)

The DSD gives information greater than N_T. It provides the number of drops per unit drop volume and per unit drop diameter; it therefore indicates the domination of large drops over the small ones and vice-versa. We realized three different DSD analyses. Fig. 5 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 on the plot as a dashed and a dotted line respectively, showing that the exponential DSD is a good parameterization. Generally, it was found that a gamma DSD (Ulbrich (1983)) is not a good parameterization. Moreover, the MP-DSD generally fails fitting 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 the real DSD, especially in the 3-5 mm diameter range. We successively analyzed the 1-minute time evolution of the two parameters of an exponential DSD fitting the observed DSD, which time-averaged values are shown in fig. 5. It was found that the N_0 values are always lower than 10000 ($mm^{-1}m^{-3}$), while the Λ (mm^{-1}) values do not change significantly and their values are around 4 mm^{-1}. We also analyzed the 1-minute DSD evolution, which confirms the marked presence of a low number of small drops for all the time duration of the event.

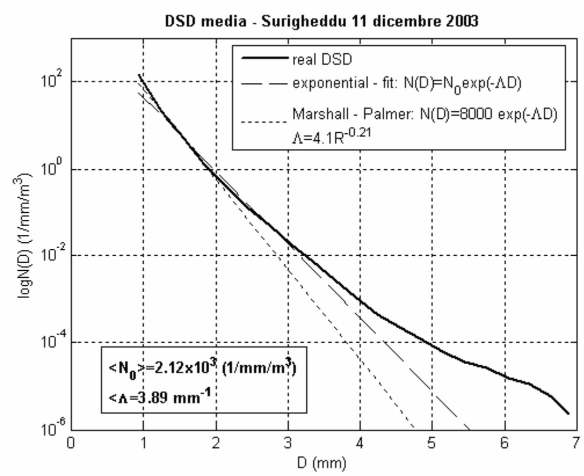

Fig. 5. Pludix DSD ($mm^{-1}mm^{-3}$) -Surigheddu station (11/12/2003)

The Rotondella station detects two convective showers having R values greater than >20 mm/h and Z values greater than 35 dBZ. The Z-R relationship gives high A and b values, indicating the presence of drops with large values of D_0, which has a large variation. From the N_T (mm^{-3}) analysis it was found that the total number of drops is very high (about 10^4 mm^{-3}). Combining this analysis with the 1-minute DSD time evolution for the considered event, it was found that the convective episodes are characterized by an high number of large drops, but also by small drops (even if in less concentration), probably due to break-up.

From fig. 6 it can be noted that the mean DSD for the convective episodes moves toward high values, indicating that both the concentration 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 by the 1-minute time evolution of N_0 and Λ, indicating that the N_0 values are of the order of 10^5 ($mm^{-1}m^{-3}$) while the Λ (mm^{-1}) values do not vary significantly, and their values are around 4 mm^{-1}.

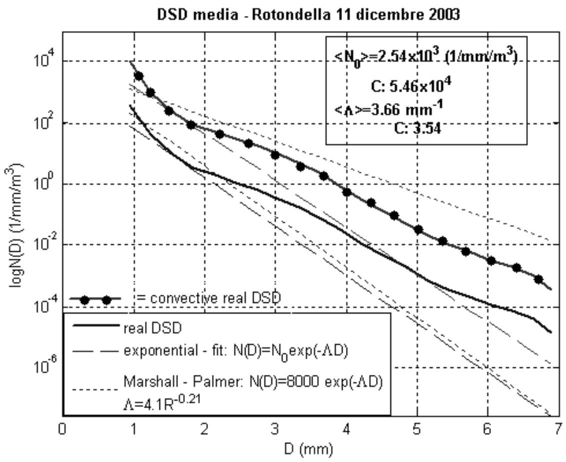

Fig. 6. Pludix DSD ($mm^{-1}mm^{-3}$) - Rotondella station (11/12/2003).

The Licata station detects a stratiform rain event having R values always less than 4.5 mm/h and Z values always less than 31 dBZ. The Z-R relationship ($Z=263.03R^{0.98}$) is not significantly far from the MP one for widespread mid-latitudes precipitation. The low and nearly equal to 1 b value indicates D_0 values nearly constant (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 mm^{-3}). Analysing this parameter in combination with the 1-minute 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, 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 10000 ($mm^{-1}m^{-3}$), while the Λ (mm^{-1}) values do not change significantly and their values are around 3 mm^{-1}, indicating a stratiform precipitation.

The overall Z-R analysis (for the 20 months, for all the three stations) gives A=259.08 and b=0.9, values not significantly far from the A=200 and b=1.6 MP ones for widespread mid-latitudes precipitation. With respect to MP, the Z-R relationship found here gives a slightly higher A value and a slightly lower b value, indicating the presence of convective events. Moreover, these values are not significantly far from typical values found in mid-latitudes Mediterranean area (e.g. Caracciolo et. al. (2006)). It was also found that, for all the three stations, there is a marked presence of stratiform events, with less presence of convective events, especially characterizing the spring months.

4 Conclusions

The raingage-disdrometer Pludix data in three Italian sites in southern Italy (20 months analysis), have been used both for the detection of rainfall events and for a climatological analysis of the rain events (microphysical characterization of rain at the ground and discrimination between convective and stratiform events). The satellite (Meteosat-7, SSMI, MODIS) data were used for a qualitative analysis of the precipitation systems (temporal scale analysis and cloud characterization in terms of quality, type and structure of the rain clouds), for the comprehension of the spatial extension, and for the microphysical characterization of each rain event (genesis and evolution). The satellite data were also used to confirm the convective/stratiform discrimination made at the ground with Pludix.

We have linked the observed events to the corresponding conceptual models in the Mediterranean area. From the combined analysis (Pludix-satellite data) it was found that southern Italy is characterized by stratiform events, relatively long in duration and slightly fluctuating, characterized by low-moderate rain intensity at the ground. Especially during the spring months (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 summer months were characterized by a nearly total absence of rain events, for all the three stations. This trend is typical of the southern Italy areas in this period of the year.

References

Adler,R.F. and A.J.Negri, 1988: A Satellite Infrared Technique to Estimates Tropical Convective and Stratiform Rainfall. *Jour. of Appl. Met*., **27**, 30-51.

Caracciolo C., F. Prodi, A. Battaglia, F. Porcu’, 2006: Analysis of the moments and parameters of a gamma DSD to infer precipitation properties: a convective stratiform discrimination algorithm. *Atm. Res.*, **80 (2-3),** 165-186.

Grody, N. C., 1991: Classification of snow cover and precipitation using the Special Sensor Microwave/Imager (SSM/I), *J. Geophys. Res.*, **96**, 7423-7435.

King M.D., Y.J. Kaufman, W.P. Menzel and D. Tanre, 1992: Remote sensing of cloud, aerosol and water vapour properties from the Moderate Resolution Imaging Spectrometer (MODIS). *IEEE Trans. Geosci. Remote Sens.*, **30**, 2-27.

Marshall J.S. and W. M. Palmer, 1948: The distribution of raindrops with size. *J. Meteor.*, **5**, 165-166.

Prodi, F., Tagliavini A., Pasqualucci F., 2000: Pludix: an X–band sensor for measuring hydrometeors size distributions and fall rate, *Proc. 13th ICCP*, 338-339.

Tokay A. and D. Short, 1996: Evidence from tropical raindrop spectra of the origin of rain from stratiform versus convective. *J. Appl. Meteor.*, **35**, 355-371.

Ulbrich C., 1983: Natural Variations in the analytical form of the raindrop size distribution. *J. Clim and Appl. Met*., **22,** 1764-1775.

Waldvogel A., 1974: The N_0 jump of raindrop spectra. *J. Atmos. Sci.*, **31**, 1067-1078.