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HINDCASTING EXTREME EVENTS: THE OCCURRENCE AND EXPRESSION OF DAMAGING FLOODS AND LANDSLIDES IN SOUTHERN ITALY

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ABSTRACT

Extreme rainstorm events across the Mediterranean have caused significant loss of life and damage to property and livelihoods. Italy is particularly vulnerable to natural hazards with recent events such as the 1996 floods in Versilia and the 1998 mass-movement failures at Sarno causing the deaths of 174 people. We have analysed 50 years of rainfall records to hindcast extreme rainstorms that have affected the eastern Basilicata region of southern Italy. Historical and archive data of individual floods and landslides have been compared with their antecedent rainfall conditions in order to characterize the nature of events that cause damage to society and infrastructure. Analysis of extreme-event frequency shows a decreasing annual trend related to changes in regional climate conditions in the western and central Mediterranean driven by changes in the strength of the North Atlantic Oscillation. Land-degradation problems associated with floods and landslides are decreasing due to a drier winter climate coupled with improved hazard mitigation. Copyright © 2006 John Wiley & Sons, Ltd.

KEY WORDS: climate change; extreme events; landslides; floods; hindcasting; Italy

INTRODUCTION

Extreme climatic events (intense rainfall, droughts, extremes of temperature, atmospheric disturbances such as hurricanes and tornadoes) have serious and damaging effects on human society and infrastructure as well as on ecosystems and wildlife (Meehl *et al*., 2000). Changes in the frequency and spatial distribution of extreme events are anticipated in response to future climate forcing (Easterling *et al*., 2000) through increasing global temperatures (Mann *et al*., 1998) and changes to the intensity of the hydrological cycle (Peterson *et al*., 2002; Curry and Maurtizen, 2005). The Mediterranean region, which is characterized by marked inter-annual variability in precipitation (Haylock and Goodess, 2004), is thought to be a particularly sensitive area to changes in the frequency and intensity of extreme rainfall events (droughts and intense rainstorms; Sánchez *et al*., 2004; Brunetti *et al*., 2002a, 2002b). Conte *et al*. (2002) demonstrated a decline in the number of extreme rainstorms across the western and central Mediterranean over the period 1965–1995. Whilst the number of annually occurring extreme rainstorms is small (2–5) and spatially limited across the Mediterranean region, the impacts may result in significant damage to lives, livelihoods and property (Delrieu *et al*., 2005; Luino, 2005).

In order to improve our understanding of the potential impacts on society and infrastructure of changing patterns of extreme events, we need to resolve first the relationship between climatic events such as extreme rainstorms and the land surface response or expression in the form of natural hazards. Italy is one of the most vulnerable countries

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in Europe in terms of exposure to natural hazards within the Mediterranean (Luino, 2005). Since 1980, excluding the impacts of earthquakes and volcanic activity, landslides and floods have cost the Italian government the equivalent of 42 billion Euros (Luino, 2005). In response to a number of fatal events, particularly the floods and landslides in Versilia in June 1996 which caused 14 deaths and millions of Euros of damage (D'Amato Avanzi *et al*., 2004), and the debris flows at Sarno in May 1998 which killed 160 people (Di Crescenzo and Santo, 2005; Sirangelo and Braca, 2004; Guadagno *et al*., 2005), the Italian Government commissioned a risk-based survey of all municipalities (**comuni**) within the country (Ministero dell'Ambiente, 2000) rating 45·3 per cent of the **comuni** at a high or very high risk of floods or landslides.

Here we analyse the record of extreme rainfall events, landslides and floods in part of the southern Italian region of Basilicata (Figure 1). Basilicata is one of the most vulnerable regions in Italy (Gostelow *et al*., 1997), in which 58 per cent of the 114 **comuni** are classified at high risk and a further 13 per cent at very high risk of landsliding or flooding (Ministero dell'Ambiente, 2000). Parts of Basilicata are tectonically active, with a long history of earthquakes affecting the western part of the region caused by movements on the Apennine fault systems (Del Prete *et al*., 1992). The landscape of Basilicata ranges from limestone massifs in the west, with mean annual rainfall in excess of 2000 mm and mean temperature of 10°C, to relatively low-lying basin and range topography occupying the central and eastern parts of the region with mean annual rainfall of less than 700 mm and mean annual temperatures in excess of 15°C (Cataudella, 1987). Perennial rivers (Figure 1) drain southeastwards from the limestone of the Apennines, carving through Miocene flysch and Plio-Pleistocene marine clays, sands, gravels and conglomerates of the Fossa Bradanica fill complex (Sabato and Tropeano, 1994) exposed in the hillsides of the basin and range terrain. In the east of Basilicata, hilltop settlements commonly occupy pedestal outcrops of sands and conglomerates lying up to 300 m above the valley floors (Clarke and Rendell, 2000), the high relative relief caused by differential uplift and incision (Boenzi and Guira Longo, 1994). All the hilltop towns in Basilicata are prone to periodic landsliding (Boenzi and Guira Longo, 1994) caused by rotational-translational movements with slide planes typically 20–30 m deep (Del Prete *et al*., 1992). In the eastern part of Basilicata, slide planes are often associated with contacts between unconfined aquifers in layers of sands and conglomerates and underlying impermeable clay and shales (Gostelow *et al*., 1997). Topographic slopes are steep and the formation and enlargement of fissures are often precursors to landslide activity (Guerrichio and Melidoro, 1979). Large landslides, which have caused structural damage at Pisticci, Ferrandina and Grassano (Figure 1) and the abandonment of the town of Craco, have been linked to extreme rainfall triggers (Beneo, 1967; Guerrichio and Melidoro, 1979; Del Prete and Petley, 1982; Del Prete *et al*., 1992; Gostelow *et al*., 1997).

CLIMATE AND HYDROLOGY OF EASTERN BASILICATA

The climate of the eastern part of Basilicata region is Mediterranean semiarid with more than 65 per cent of rainfall occurring during the autumn and winter months. The climate exhibits strong seasonality, with relatively wet winters contrasting with long, dry summers with maximum temperatures in excess of 40°C and humidities of less than 40 per cent. Rain gauges collecting daily totals were located at the hilltop towns of Calciano, Grassano, Tricarico, Grottole, Ferrandina, Pisticci, Bernalda and Pomarico (Figure 1) and serviced by local collectors on behalf of the Sezione Idrografico e Mareografico based at Catanzaro in the neighbouring region of Calabria. The length of available record varies between stations; most towns had rainfall stations from 1951–1977. However, by 1979 only the gauges at Pisticci, Pomarico and Bernalda were still working and by 1994 the only gauge still operational in the lower Basento and Cavone catchments was at Pisticci. Analysis of data from these gauging stations shows that the climate becomes increasingly semiarid in a southeasterly direction, with mean annual rainfall decreasing down the Basento valley from Potenza to Metaponto at a rate of -24 mm per 10 km ($r = -0{\cdot}789$, $p = 0{\cdot}01$). Flow in the Bradano, Basento, Agri and Sinni rivers is perennial whereas flow in many of their tributaries, and in the Salandrella-Cavone river, is ephemeral. Unfortunately, gauging records of river discharge are limited and all recording had ceased by 1971. Following construction of the San Giuliano Dam on the Bradano in 1957 and the Pertusillo Dam on the Agri River in 1962, the remaining perennial Basilicata rivers were impounded with the building of the Camastra Dam on the Basento in 1965 and the completion of the Monte

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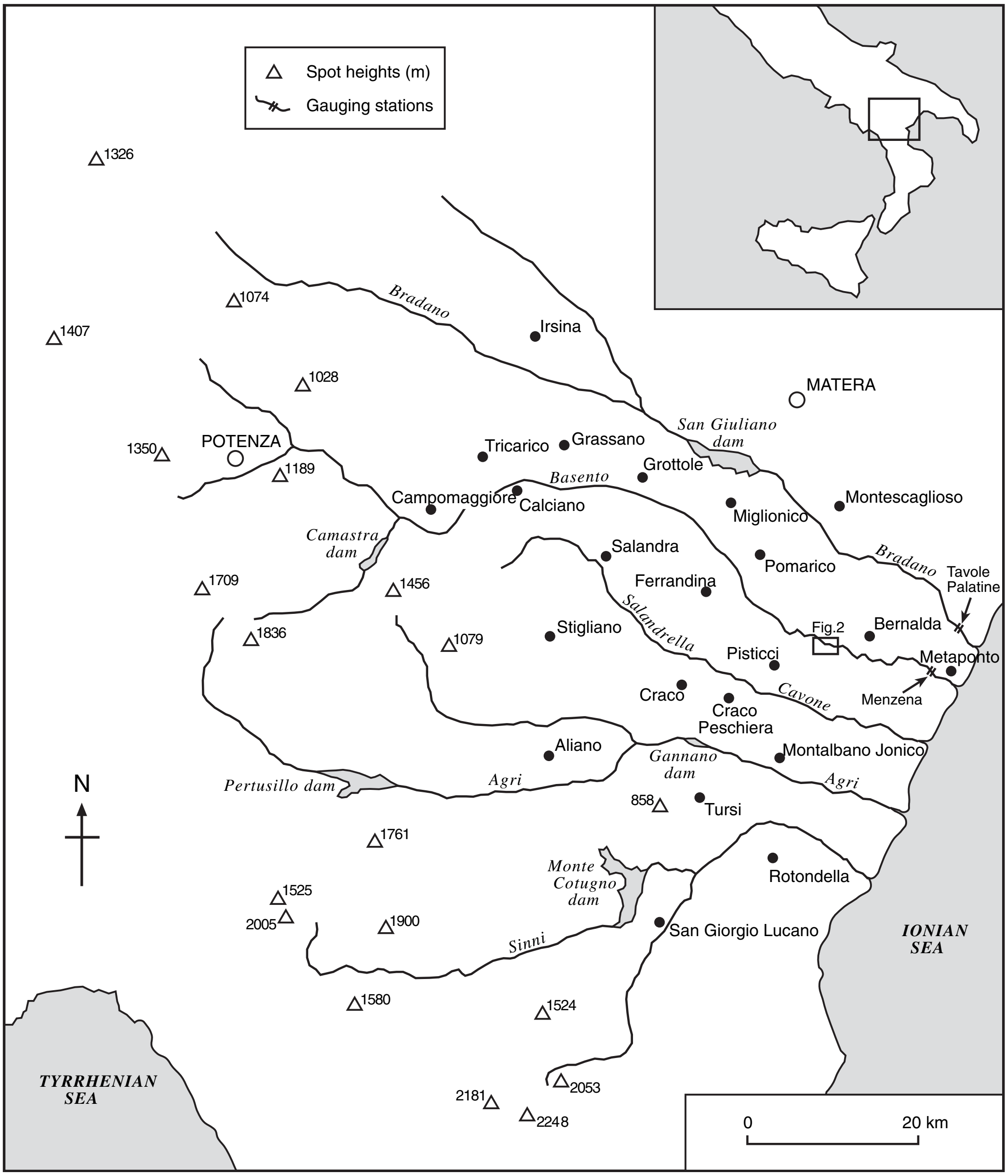

Figure 1. Map of the study area showing locations mentioned in the text.

Cotugno Dam on the Sinni River in 1982 (Figure 1). The stored water has been used to supply an extensive system of aqueducts for domestic, industrial and agricultural uses across Basilicata and the neighbouring region of Puglia (Boenzi and Giura Longo, 1994). These catchment modifications have changed the nature and impacts of flood events and have a substantial impact on the littoral zone where sediment starvation has led to coastal erosion (Cotecchia, 1986). The annual suspended sediment load of the Bradano river at Tavole Palatine decreased from 924 t km^{-2} to $\sim$0·5 t km^{-2} following the construction of the San Guiliano Dam (Fournier, 1969). Since 1960, the floodplains of the Bradano, Basento, Salandrella-Cavone, Agri and Sinni rivers have become a focus for both industrial and horticultural activity (Boenzi and Giura Longo, 1994), with significant infrastructural development on the floodplain, increasing potential vulnerability to episodic flood events.

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HISTORIC EVENTS

Basilicata has a long history of being affected by landslides and floods: more than 600 people were killed in February 1688 by a landslide affecting the hilltop town of Pisticci (Antonini, 1745; Vena, 1969); the town of Campomaggiore was abandoned after a landslide in December 1888 (Del Prete *et al*., 1992), and at least 20 people died in 1929 in a flood that affected the Bradano and Basento catchments, causing substantial infrastructural damage (Caloiero and Mercuri, 1982). We focus in the following section on the period 1951 to 2000. This period corresponds to archived daily precipitation records from a range of local stations, allowing us to analyse both antecedent rainfall conditions and spatial variability of rainstorms associated with known natural hazards. Table I provides a record of 41 landslide and 25 flood events which impacted on settlements and infrastructure in eastern Basilicata in the study period. These events were identified using published accounts, records held in the local historical archives at Matera, and the database assembled by the Consiglio Nazionale delle Ricerche, Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche (CNR-GNDCI) as part of Project Aree Vulnerate Italiane (AVI) (http://sici.irpi.cnr.it). Impacts on settlements and infrastructure tend to be well recorded (Del Prete *et al*., 1992), whereas impacts upon agricultural land have less publicity and can only be assessed by careful and immediate post-event analysis (for example, D'Amato Avanzi *et al*., 2004; Guzzetti *et al*., 2004; Malamud *et al*., 2004). The public and media perceptions of climate impacts are inevitably focused on the more spectacular events damaging lives, properties and infrastructure (Lowe *et al*., 2005), and therefore impacts not affecting towns and road and rail links tend to be rendered 'invisible' within the documentary record.

The events listed in Table I ranged in magnitude from landslides temporarily blocking minor roads (**strade provinciale**) to those causing substantial damage to, and even forcing the abandonment of, hilltop towns. The landslide and flood events are listed in chronological order. Some events involved simultaneous landslides or floods at a number of different sites, as in November 1959 or January 1972 when all the major rivers were in flood, or in March 1973 when landslides affected 22 towns within Basilicata. With the exception of landslides at Ferrandina in May 1965 and near Aliano in September 1987, all the events listed show wet antecedent conditions with more than 50 mm of rain falling during the previous 30-day period, denoted by P_{30}. In addition, 73 per cent of the landslides and flood events had P_{30} values greater than 100 mm, while 16 per cent of the events were associated with 2-day (P_2) prior rainfalls in excess of 100 mm. The frequency of reported landslide and flood events was not constant over the 1951 to 2000 study period. Using a 10-year running mean, the number of flood events ranged from $0{\cdot}7\,yr^{-1}$ in the period 1955–1962, peaking at $1{\cdot}2\,yr^{-1}$ in the mid-1970s and then falling to less than $0{\cdot}2\,yr^{-1}$ by the mid-1990s. By contrast the frequency of landslides declined from $1{\cdot}6\,yr^{-1}$ in the period 1955–1962 to $0{\cdot}3\,yr^{-1}$ from 1990 onwards.

In terms of damage and loss of life, the largest impact events represented in the literature and newspaper coverage occurred in 1959, 1972, 1973 and 1976. The fact that no large impact events have occurred since 1976 could result from differing climatic conditions and better risk mitigation. The four largest rainfall-driven disasters are described below to illustrate the impacts of extreme rainfall events on the region. The following summary attempts to identify common causality with a view to providing a predictive model.

NOVEMBER 1959

On 25th November 1959 a violent storm hit eastern Basilicata, affecting the middle and lower courses of the Bradano, Basento, Cavone, Agri and Sinni rivers, flooding the coastal plain and causing the deaths of five people, injuring a further six and forcing the temporary evacuation of 650 people (GNDCI-CNR, 2005). A comparison of rain-gauge records suggests that an area of 8324 km^2 received more than 50 mm of rain, 638 km^2 received more than 200 mm and an area of 8 km^2 around the town of Pisticci received in excess of 300 mm precipitation (Caloiero and Mercuri, 1982). This represents the highest magnitude event occurring in the period 1951–2000, and the 24-hour total of 314·6 mm recorded at Pisticci (Figure 2a) remains the single highest rainfall amount ever recorded in Basilicata, with an estimated return period of more than 10^4 years. The estimate is based on the extrapolation of the trend of magnitude of daily rainfall events versus recurrence intervals, following the approach of Archer

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Table I. Chronological listing of landslide and flood events in southeast Basilicata 1951–2000, antecedent rainfall conditions and Alluvial Strength Index (ASI)*

Date	Comments	Source of information	P_2 (mm)	P_{30} (mm)	ASI Class
29/1–2/2/1954	Landslide at Montalbano Jonico	Progetto AVI database	62·6	105·2	1
15/3/1954	Flood on Bradano	Progetto AVI database	28·9	139·5	1
10/1/1955	Landslide at Pisticci	Progetto AVI database	21·4	126·5	1
25/1/1955	Landslides at Grassano, Grottole and Salandra	Progetto AVI database	40·0	131·5	1
10/2/1955	Landslide at Pisticci	Progetto AVI database	0·8	142·0	1
25–27/2/1956	Landslide on SS7 near Grottole. Flood Bradano	Progetto AVI database	63·6	205·1	2
2/2/1957	Landslide at Grassano	Gostelow *et al.*, 1997	0·0	142·1	—
7–10/10/1957	Landslide at Montalbano Jonico	Progetto AVI database	73·0	90·4	1
21–24/11/1957	Flood Basento, Cavone	Progetto AVI database	42·4	216·2	2
28/12/1957	Landslides Ferrandina Grassano	Gostelow *et al.*, 1997; Del Prete *et al.*, 1992	36·8	87·7	1
22/1/1958	Landslide Ferrandina	Del Prete *et al.*, 1992	0·0	110·6	—
22/4/1959	Landslide Pisticci	Progetto AVI database	51·8	120·2	1
24–25/11/1959	Flood Bradano, Basento, Cavone, Agri, Sinni. Landslides Pisticci, Ferrandina, Grassano, Salandra, Grottole	Progetto AVI database; Il Giornale d'Italia 26/11/1959, 27/11/1959; Caloiero and Mercuri, 1982; Gostelow *et al.*, 1997	375·6	570·9	6
14/1/1960	Landslide Grassano	Gostelow *et al.*, 1997	9·9	64·5	1
20/1/1960	Landslide Ferrandina	Del Prete *et al.*, 1992	0·2	78·6	1
15–17/1/1961	Landslide Pisticci (Rione Croci). Flood Basento, Cavone, Agri, Sinni	Progetto AVI database	122·2	164·1	3
29/1/1962	Landslide Montalbano Jonico	Progetto AVI database	11·2	15·4	1
6/11/1962	Landslide Montalbano Jonico	Progetto AVI database	26·0	247·5	1
9–10/10/1963	Flood Basento	*La Gazzetta del Mezzogiorno* 12/10/1963 p. 14	97·4	161·8	3
11–12/12/1963	Landslide at Craco. Localized flooding	*La Gazzetta del Mezzogiorno* 12/12/1963 p. 13, 13/12/1963 p. 11	103·2	117·5	2
26–27/12/1964	Landslide Stigliano	Progetto AVI database	62·6	105·9	1
8/5/1965	Landslide Ferrandina	Del Prete *et al.*, 1992	0·8	33·4	1**
21–25/9/1965	Flood Basento. Landslide at Craco	*La Gazzetta del Mezzogiorno* 24/9/1965 p. 1, 25/9/1965 p. 5	30·6	100·7	1
7–9/10/1966	Flood Basento. Agricultural land and roads flooded at Ferrandina, Pisticci and Bernalda	*La Gazzetta del Mezzogiorno* 9/10/1966 p. 15; 10/10/1966 p. 16	83·5	130·7	2
4/3/1968	Landslide Ferrandina	Del Prete *et al.*, 1992	3·6	60·3	1*
12–15/12/1968	Flooding of fields Pisticci, Montalbano Jonico. Landslides on access roads to Craco and Pisticci	*La Gazzetta del Mezzogiorno* 14/12/1968 p. 1	27·1	252·0	1
12/3/1969	Landslide Pisticci (Rione Croci)	Progetto AVI database	7·2	51·4	1
15–20/1/1972	Flood Bradano, Basento, Cavone, Agri, Sinni. Access road to Pisticci blocked by landslide	*La Gazzetta del Mezzogiorno* 19/1/1972 p. 1, 20/1/1972 p. 1 Caloiero and Mercuri, 1982	119·0	390·1	6

(Continues)

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Table I. (Continued)

Date	Comments	Source of information	P_2 (mm)	P_{30} (mm)	ASI Class
20–25/1/1972	Flood Basento. Landslide Montalbano Jonico	*La Gazzetta del Mezzogiorno* 24/1/1972 p. 1, 25/1/1972 p. 1	25·9	420·4	2
11–14/3/1972	Landslide Pisticci (Rione San Donato)	Progetto AVI database	29·3	166·1	1
5/9/1972	Landslide Pisticci	Progetto AVI database	7·2	51·4	1
30/12/1972–3/1/73	Flood Bradano, Basento, Agri.	*La Gazzetta del Mezzogiorno* 3/1/1973 p. 1	48·8	97·2	1
25–29/3/1973	Landslides Grassano, Craco, Pisticci, disrupting road and rail links. Flood Cavone, Basento.	*La Gazzetta del Mezzogiorno* 27/3/1973 p. 15, 31/3/1973 p. 1, 1/4/1973 p. 1, 3/4/1973 p. 1, 4/4/1973 p. 1, 5/4/1973 p. 1	47·9	145·4	1
11–13/12/1975	Flood Agri and Sinni	*La Gazzetta del Mezzogiorno* 13/12/1975 p. 1	102·9	187·4	3
5–6/11/1976	Flood Basento, Cavone, Agri. Landslide Pisticci (Rione Colombo)	*La Gazzetta del Mezzogiorno* 6/11/1976 p. 1	96·0	222·8	4
18–20/11/1976	Flood Basento, Cavone, Agri. Landslide at Pisticci (Rione Croci) 52 houses destroyed. Landslide at cemetery at Grassano	*La Gazzetta del Mezzogiorno* 22/11/1976 p. 1, 23/11/1976 p. 1, 24/11/1976 p. 11, 25/11/1976 p. 1 Gostelow *et al.*, 1997. Caloiero and Mercuri, 1982	64·6	300·3	3
18–21/2/1979	Flood Bradano, Basento, Cavone, Agri	*La Gazzetta del Mezzogiorno* 19/2/1979 p. 3	35·0	146·9	1
11–13/1/1980	Flood Basento, Cavone	*La Gazzetta del Mezzogiorno* 13/1/1980 p. 4	103·0	143·2	2
23/11/1980	Earthquake triggering landslides at Ferrandina, Stigliano, Tricarico	Progetto AVI database	0	108·4	—
3/12/1980	Landslide Ferrandina	Del Prete *et al.*, 1992	4·0	54·2	1
13–15/11/1984	Landside Bernalda. Flood Basento, Cavone	*La Gazzetta del Mezzogiorno* 15/11/1984 p. 1, 16/11/1984 p. 13	131·0	196·1	4
29–30/12/1984	Landslide Pisticci outskirts (Pozzitello), Montescaglioso. Flood Bradano, Basento	*La Gazzetta del Mezzogiorno* 30/12/1984 p. 1, 31/12/1984 p. 1 Progetto AVI database	155·9	301·0	6
15–17/1/1985	Landslide Grassano, Montescaglioso. Flood Bradano, Basento	Progetto AVI database	46·0	58·4	1
17–19/4/1985	Flood Bradano	*La Gazzetta del Mezzogiorno* 18/4/1985 p. 1	57·6	111·1	1
1/9/1987	Landslide Aliano	Progetto AVI database	0·0	0·0	—
25–27/12/1990	Flood Basento, Cavone, Agri	*La Gazzetta del Mezzogiorno* 27/12/1990 p. 1	81·9	153·6	2
28–30/1/1996	Landslide Montescaglioso. Flood Cavone, Agri	Progetto AVI database	36·3	76·7	1
4–6/10/1996	Landslide near Ferrandina	*La Gazzetta del Mezzogiorno* 9/10/1996 p. 6	54·5	130·0	1
28/10–1/11/1997	Flooding Metaponto area	*La Gazzetta del Mezzogiorno* 2/11/1997 p. 1	84·4	191·9	3
13/11/1997	Landslides Pisticci, Bernalda	Progetto AVI database	1·4	144·6	1
24/11/1997	Flood Basento	Progetto AVI database	42·2	237·7	2

*ASI: Alluvial strength index value = $P_2/2 \times P_{30}/30$.
ASI Category: index value < 150 = class 1; 150–250 = class 2; 250–350 = class 3; 350–500 = class 4; 500–700 = class 5; > 700 = class 6 (Mazzarella and Diodato, 2002).
**Landslide events related to anthropogenic trigger.

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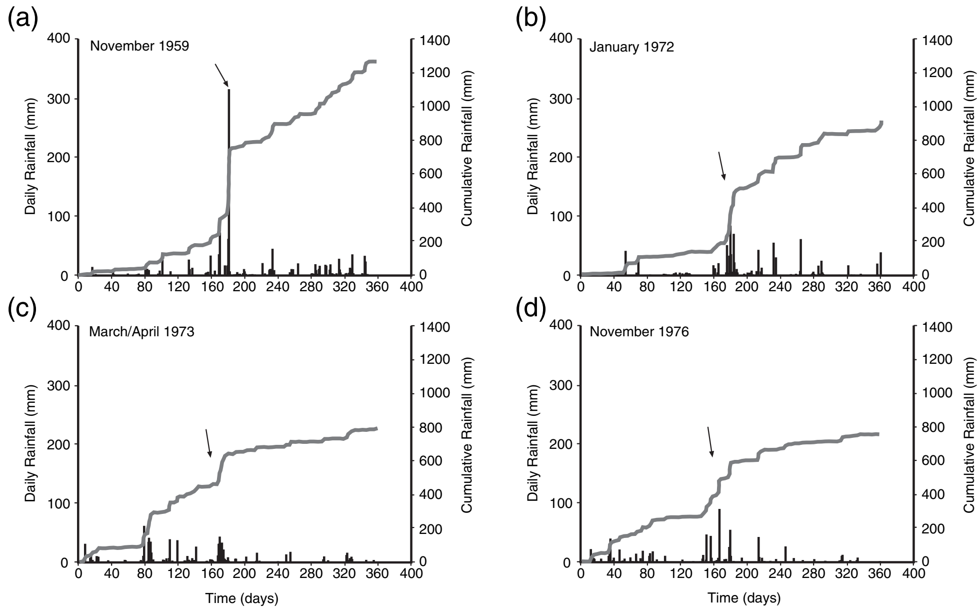

Figure 2. Rainfall patterns associated with extreme rainstorm events in (a) November 1959, (b) January 1972, (c) March–April 1973, and (d) November 1976.

(1999). Figure 2a shows the daily rainfall totals for the twelve-month period bracketing the event, which is illustrated on the graph by the position of the arrow. The grey line provides a cumulative total and illustrates antecedent conditions.

During the event, peak discharges of 1420 $m^3 s^{-1}$ and 1930 $m^3 s^{-1}$ were recorded on 25th November 1959 for the Basento at Menzena and the Bradano at Tavole Palatine, respectively, compared with mean discharges of 12·4 $m^3 s^{-1}$ and 6·3 $m^3 s^{-1}$ (Fournier, 1969; Caloiero and Mercuri, 1982). More than 400 km^2 of land were flooded in the Metaponto area, and 69 individual records of flood damage are listed on the Progetto AVI database (GNDCI-CNR, 2005). Road and rail bridges over the Basento, Cavone and Sinni rivers were damaged, and contemporary newspaper accounts (*La Gazzetta del Mezzogiorno*, 27/11/1959) noted that only the construction of the San Giuliano Dam on the Bradano River prevented the disaster from having greater consequences. The flooding associated with this storm changed the planform geometry of the Basento (Figure 3), increasing the sinuosity of the channel from 2·23 in 1955 to 2·74 in 1965. These changes are attributed to the substantial influx of fine sediments into the channel from the adjacent slopes during the 1959 event. In terms of mass movements, the main road links in eastern Basilicata were affected by at least 12 landslides (Caloiero and Mercuri, 1982), and landslides were also reported from the towns of Pisticci, Ferrandina, Salandra and Grassano (Table I) and Craco (Gostelow *et al*., 1997). The antecedent rainfall conditions at Pisticci prior to this storm event were exceptional, with a 2-day (P_2) total of 375·6 mm and a 30-day (P_{30}) total of 570·9 mm.

JANUARY 1972

During the 18th and 19th of January, 1972, more than 300 mm of rain fell in the middle Basento and Agri valleys and the upper catchment of the Salandrella-Cavone, ending a relatively dry autumn spell (see Figure 2b). The areas receiving in excess of 100 mm, 200 mm and 300 mm were estimated to extend over 1775 km^2, 241 km^2 and 63 km^2, respectively (Caloiero and Mercuri, 1982). No gauging records are available for this event, but flooding in the lower courses of the Bradano and Basento rivers damaged several square kilometers of land in the Metaponto plain, and a similar-sized area was flooded near the agricultural settlement of San Teodoro, to the southeast of

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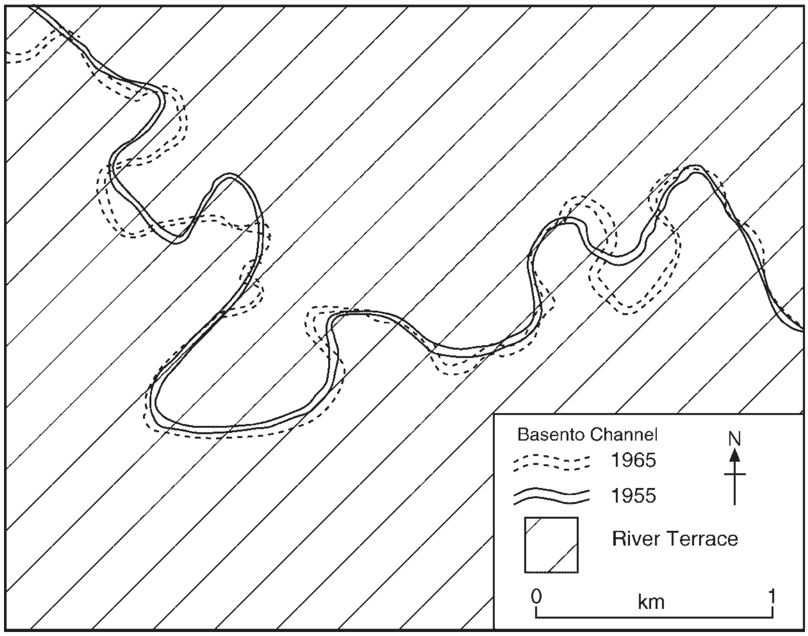

Figure 3. Planform changes in Basento River reach north of Pisticci 1955–1965 attributed to sediment inputs associated with the November 1959 rainfall events.

Pisticci. As the rainfall continued another 134·4 mm fell at Pisticci between January 20th and 25th (Figure 2b). Further flooding was reported in the Basento and Agri valleys and landslides occurred at Pisticci, Craco, Montalbano Jonico, Stigliano and Tursi (*La Gazzetta del Mezzogiorno*, 25/1/1972). Although there were no fatalities or injuries, 400 people were evacuated from the towns of Montalbano Jonico and Tursi as a result of landslide fears (GNDCI-CNR, 2005).

MARCH–APRIL 1973

A wet winter culminated in a period at the end of March 1973 that was characterized by persistent rain (see Figure 2c), totalling between 100 mm and 200 mm, measured at Salandra, Bernalda, Pisticci and Montescaglioso. By the 5th April newspapers were reporting damage to 100 **comuni** in Basilicata with 22 towns affected by landslides, including Pisticci, Grassano and Craco (*La Gazzetta del Mezzogiorno*, 5/4/1973), forcing the temporary evacuation of 100 people (GNDCI-CNR, 2005). Motorway and rail links between Potenza and Grassano Scalo were severed by large landslides (*La Gazzetta del Mezzogiorno*, 3/4/1973), and a rockfall failure involving 350 000 m^3 of material occurred at Massa Abate, near Grottole (Clarke and Rendell, 2006). The newspaper headlines seem dramatic: ‘Basilicata: An entire region destroyed’ (*La Gazzetta del Mezzogiorno*, 31/3/1973, p. 1); but they focus on the impact of renewed landsliding at Craco, which prompted the Regional Government to force the permanent evacuation of 1800 inhabitants (Gostelow *et al.*, 1997) to a purpose-built new town, Craco Peschiera, in the Salandrella-Cavone valley (see Figure 1).

NOVEMBER 1976

November 1976 was characterized by persistent low pressure in the central Mediterranean and fronts moving over Basilicata and the neighbouring regions of Calabria and Sicily (Caloiero and Mercuri, 1982). Heavy rainfall during the 5th and 6th of November (see Figure 2d) was concentrated in the Sinni valley, with in excess of 300 mm at

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San Giorgio Lucano. An area of 1374 km^2 in the Agri and Salandrella-Cavone valleys received more than 100 mm. Floods were recorded in the Agri, Sinni and Basento valleys. Ten days later, a second period of rainfall began with 111·4 mm falling at Grassano and 89·8 mm at Pisticci over the 4–5 days between the 17th and 21st November. During the night of the 20th–21st November a large landslide occurred in the Rione Croci area of Pisticci, destroying 52 houses and forcing the abandonment of 15 others (*La Gazzetta del Mezzogiorno*, 22/11/1976). Fortunately there were no fatalities or injuries associated with the mass failure, but it is estimated that 1000 people had to be evacuated (GNDCI-CNR, 2005). The head scarp of the landslide was 25 m high, extending about 300 m along the slope on the southern side of the town (Figure 4). Further up the Basento Valley at Grassano, a landslide cut through the town's cemetery on 21st November, 1976, dividing it in two and breaking open many of the tombs (Caloiero and Mercuri, 1982). The slide scarp was 400 m long with landslide material moving down into the Fosso della Fontana, a tributary of the Basento river. Again there were no fatalities, but this event caused substantial distress as well as presenting a health risk for the local authorities. During this period landslides were also reported from Aliano, Montalbano Jonico, Rotondella and Pomarico.

SUMMARY

The landslide and flood events listed in Table I were not distributed equally throughout the year. Instead, the majority (54 per cent) occurred in winter (December–February), with 34 per cent in autumn (September–November) and the remaining 12 per cent in spring (March–May). This seasonal bias in the distribution of events suggests that antecedent rainfall conditions played an important rôle in determining their timing, and this is illustrated in the cumulative rainfall curves of Figure 2. In the next section we examine whether extreme events identified independently within the precipitation record can be cross referenced with the event-driven impacts listed in Table I, in order to characterize the climatic triggers that force landslide and flooding expression.

HINDCASTING ANALYSIS OF EXTREME EVENTS IN THE PRECIPITATION RECORD

Within the Mediterranean region extreme events are commonly defined in terms of climatic triggers (such as the nature of a precipitation event and its likely return period; Frei *et al.*, 1998; Brunetti *et al.*, 2002a; Conte *et al.*, 2002; Sánchez *et al.*, 2004), rather than the nature of the impact or land-surface expression of that event (flood, landslides, loss of life or damage to property; Luino, 2005). Conte *et al.* (2002) have described how extreme events in the Mediterranean are often linked to 'meteorological bombs', comprising rapidly deepening, extra-tropical low-pressure systems. These systems appear to be associated with cyclogenesis in the lee of the Alps or with the interaction between a mid-latitude depression penetrating the Mediterranean and a depression of North African origin. In this way, specific climatic conditions are required to generate extreme event occurrence (Conte *et al.*, 2002). Heavy rainfall events, irrespective of synoptic forcing, can be defined statistically from rain-gauge records by specifying either exceedence of a percentile value (Brunetti *et al.*, 2002a; Luino, 2005; Sánchez *et al.*, 2004) or a specific daily rainfall amount (Frei *et al.*, 1998). However, empirically derived frequencies of critical rainfalls for predicting landslide reactivation should be used with caution, because each movement potentially alters topography and ground conditions therefore changing the likely trigger event (Gostelow *et al.*, 1997).

Due to the discontinuous nature of many of the rainfall records for eastern Basilicata, we have used the continuous daily record from Pisticci from 1951–2000 as a basis for event definition. As a test of the spatial coherence of this record, the available records for adjacent stations were correlated with annual and monthly records. In addition, once events were defined in the Pisticci record, all available daily rainfall data for the other stations were used to evaluate the spatial concentration of the event. We identified 46 extreme rainfall events within the daily rainfall series for Pisticci, using the criterion of 10 per cent of the mean annual rainfall of the region falling over a consecutive 5- day period (Brunetti *et al.*, 2002a), with the 10 per cent threshold (84·2 mm) based on the mean annual rainfall value for Basilicata 1951–2000 of 842 mm (Piccaretta *et al.*, 2004). The distribution of these extreme events is strongly seasonal, with 91 per cent occurring in autumn (September–November) and winter (December–February) and the remainder in spring (March–May). Nine of these

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a)

b)

Figure 4. Photographs of (a) the 1976 landslide at Pisticci, and (b) the same view in 1983 to illustrate subsequent mitigation measures in the form of concrete revetment works.

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meteorologically defined events had threshold surpluses (Brunetti *et al.*, 2002a) exceeding 50 mm (that is, 5-day rainfall totals $> 134{\cdot}2$ mm), and the event in November 1959 had a threshold surplus of 313·9 mm (5-day rainfall total of 398·1 mm).

If the 46 extreme rainfall events are cross-referenced against the event-driven impacts (or natural hazards) in Table I, 59 per cent of the rainfall events were associated with the occurrence of landslides or floods or both, whereas 41 per cent of the extreme rainfall events identified using the 84·2 mm threshold were not associated with specific events in the documentary record. In addition, 18 landslide records and four flood records listed in Table I were not associated with any of the extreme rainfall events identified here. There are two reasons for this lack of correlation. Either the events were low magnitude, with correspondingly smaller triggers in terms of rainfall amounts, or the triggers were not exclusively associated with antecedent rainfall and may instead reflect tectonic or anthropogenic factors. In terms of magnitude of event-driven impacts, the list of landslides (see Table I) ranges from small landslides blocking local roads to large failures involving substantial damage to property and infrastructure and requiring months, if not years, of remedial work. Similarly, some floods are identified on the basis of a single record relating to one river, suggesting an association with spatially limited storms affecting single catchments, while others have in excess of 50 records in the CNR-GNDCI database with all the major rivers in flood. Some of the landslides listed in Table I also had tectonic or anthropogenic triggers. The earthquake of 23rd November 1980 caused at least 17 landslides in the western part of the region, affecting the towns of Grassano, Ferrandina, Tricarico and Stigliano in the Province of Matera, and Atella, Albano di Lucania, Avigliano, Balvano, Bella, Muro Lucano, Pescopagano, San Fele, Lauria, Vaglio and Vietri di Potenza in the Province of Potenza. In contrast some of the landslides at Ferrandina, notably those in May 1965 and March 1968, were triggered by water leaking from broken water or sewerage pipes (Del Prete *et al.*, 1992).

In order to differentiate between events of different magnitudes we have used the Alluvial Strength Index (ASI), developed by Mazzarella and Diodato (2002), which is defined as the product of the rainfall occurring two days before a particular event (P_2) (normalized to mm day^{-1}) and that occurring during the 30 days before the event (P_{30}) (normalized to mm day^{-1}). The ASI scale ranges from 1 (very weak) to 6 (catastrophic), with each interval representing an increase by a factor of 2 in magnitude (Mazzarella and Diodato, 2002). If all the landslide and flood events in Table I are categorized in terms of the ASI index, then the events of 24th–25th November 1959 and 15th–20th January 1972 were category 6, while those of 20th–21st November 1976 were category 4 (strong). The 18 landslide events that were not associated with extreme rainfall events were all category 1 (very weak) on the ASI scale. The distribution of the antecedent rainfall values (P_{30}) for all the landslide and flood events and their ASI classifications are shown in Figures 5a and 5b. Only 20 per cent of all events fall into ASI categories 4–6 (strong–catastrophic).

The extreme rainfall event analysis captures all the larger impact landslides and 84 per cent of the floods. However, there remain 41 per cent of the extreme rainfall events, including one in ASI category 4 (strong) and three in category 3 (moderate) for which no documentary evidence of impacts has been found. Assuming that the documentary record is complete, this suggests that in 41 per cent of cases, extreme rainfall on its own did not provide a sufficient condition for the natural hazard expression; additional factors such as mitigation measures may have been important. We can, however, conclude that on the basis of the analysis of the 50-year record, when a 5-day rainfall event exceeded 10 per cent of the regional mean annual rainfall there was a 59 per cent chance that such an event would have an impact on property or infrastructure.

EXTREME EVENT FREQUENCY AND REGIONAL CLIMATE FORCING

The frequency of extreme rainfall events in this area declined by more than 50 per cent in the 1990s compared to the 1950s (Figure 6). This trend is strikingly similar to the decrease in frequency of 'meteorological bombs' for the western and central Mediterranean demonstrated by Conte *et al.* (2002). Not only did extreme rainfall event frequency decrease in eastern Basilicata but impact frequency also decreased, with landslide-event frequency changing from 1·6 yr^{-1} in the period 1955–1962 to 0·3 yr^{-1} from 1985 to 2005, while flood frequency peaked at 1·0 yr^{-1} in the late 1970s before declining to less than 0·2 yr^{-1} from 1990 (Figure 6). Unlike the changes in the

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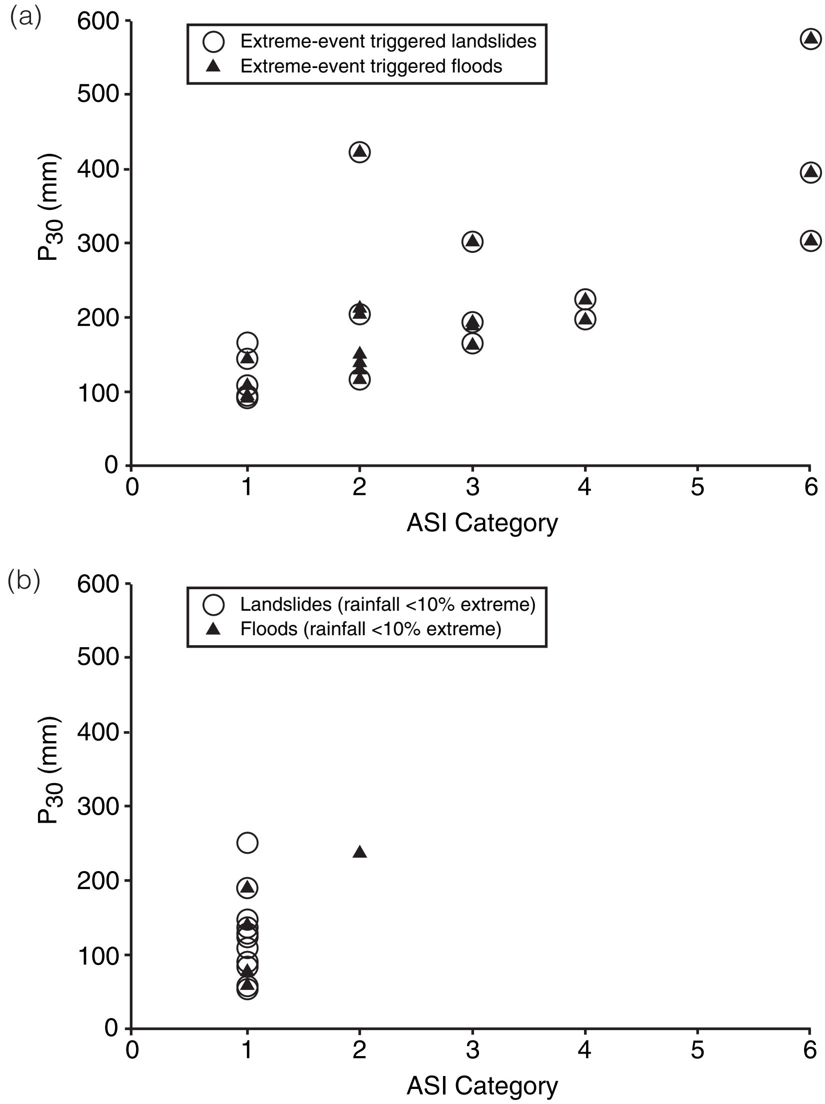

Figure 5. Alluvial Strength Index (ASI) magnitudes for (a) extreme rainfall event triggered landslides and floods, and (b) landslides and floods triggered by other rainfall events.

frequency of extreme rainfall events, changes in the expression of the hazard may reflect decreasing vulnerability to floods and landslides and particularly the effectiveness of mitigation measures, including the management of the dams on the major rivers, and drainage and retaining walls in the case of landslides affecting settlements and infrastructure. Flood frequency may have been under reported in the 1950s and 1960s until industrial and agricultural activity was fully established in the Bradano, Basento and Agri river floodplains. However, the reductions in extreme events, whether defined in terms of extreme rainfall or expressions of the hazard (Easterling *et al.*, 2000), appear to coincide with changes in the pattern of atmospheric circulation and winter precipitation in the Mediterranean.

Reductions in winter precipitation since 1980 relate to increased winter air pressure over the western and central Mediterranean (Brunetti *et al.*, 2001, 2002b). Patterns of atmospheric circulation in the western and central Mediterranean are strongly influenced by the inter-annual variability of sea-level pressure over the North Atlantic,

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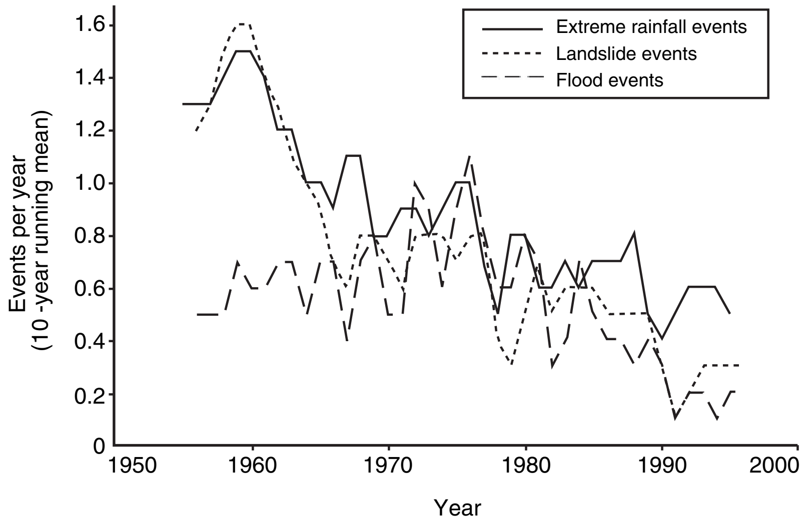

Figure 6. Changes in frequency of extreme rainfall events, landslide and floods using a 10-year running mean for the period 1951–2000.

characterized by the strength and sign of the North Atlantic Oscillation (NAO) (Hurrell and Dickson, 2004). The NAO index (NAOi) is controlled by surface-pressure gradients between the subtropical Azores high-pressure system and the high latitude Aleutian and Iceland low-pressure centres (Hurrell and van Loon, 1997; Walter and Graf, 2004). Instrumental records from Portugal and Iceland provide index values that cover the period from 1864 to the present day (Hurrell and Dickson, 2004). During boreal winters in a positive NAO phase (NAO+), higher than normal surface pressures south of 55°N combine with a broad region of low pressure throughout the arctic and subarctic, creating a strengthening of subpolar westerlies (Thompson *et al.*, 2000), bringing dry weather to the Iberian Peninsula and western Mediterranean (Dickson *et al.*, 2000), whereas south of the Azores high-pressure centre, enhanced easterly trade winds carry Saharan dust to the Caribbean (Moulin *et al.*, 1997). During the negative phase (NAO−), both the Icelandic low- and the Azores high-pressure centres are weaker than normal, with the result that both the mid-latitude westerlies and subtropical tradewinds are also weak (Hurrell and Dickson, 2004). European winter temperatures are frequently lower than normal, dominated by cold air from the north and east (van Loon and Williams, 1976; Moses *et al.*, 1987). During the NAO− phase a weakening of the Azores anticyclone allows the westerlies to bring rain across the Iberian Peninsula and into the Mediterranean (Rogers, 1997; Qian and Saunders, 2003; Hurrell and van Loon, 1997; Hurrell *et al.*, 2003).

Within the Mediterranean, several empirical studies support the link between Atlantic sea-level pressure anomalies and precipitation patterns (Delitalia *et al.*, 2000; Quadrelli *et al.*, 2001; Brunetti *et al.*, 2002b). Comparisons of monthly average Italian rainfall data with the NAOi and two additional indices, the Western European Zonal Circulation Index (WEZCI; Slonosky *et al.*, 2001) and the Mediterranean Circulation Index (MCI; Brunetti *et al.*, 2002b), show that both the WEZCI and MCI explain more of the variance in the Italian seasonal rainfall record than the NAOi, with the WEZCI performing better in the south of Italy than the MCI (Brunetti *et al.*, 2002b). We compared the winter (December–February) WEZCI with the rainfall series at Pisticci ($r = -0{\cdot}455$, $p = 0{\cdot}01$) and neighbouring stations of Pomarico ($r = -0{\cdot}436$, $p = 0{\cdot}01$) and Bernalda ($r = -0{\cdot}393$, $p = 0{\cdot}05$). These winter rainfall series for southeast Basilicata are negatively correlated with the winter WEZCI for the period 1951–1995 at the 99 per cent or 95 per cent significance level. The winter WEZCI and the winter NAOi are strongly positively correlated ($r = 0{\cdot}830$, $p = 0{\cdot}01$) over the same time period. Therefore, increased winter rainfall in southeast Basilicata is correlated with periods in which both the WEZCI and the NAO are in negative phase allowing weaker westerlies and low-pressure systems to penetrate into the Mediterranean from the Atlantic.

The relationship between the composite Basilicata rainfall series and the strength and sign of the NAO (Figure 7) demonstrates that the increasingly dry winters experienced since 1980 have been the product of a

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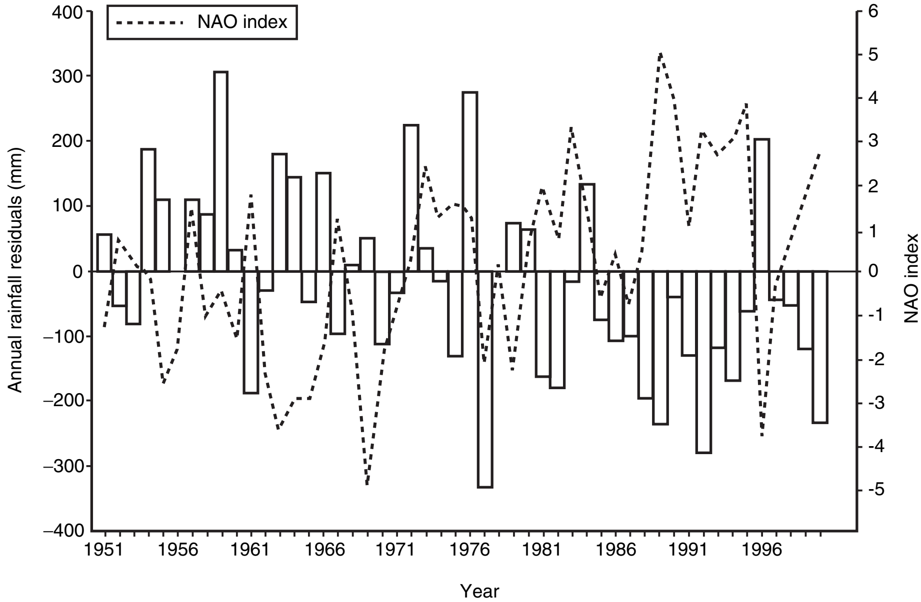

Figure 7. Comparison of winter North Atlantic Oscillation (NAO) and residuals for the Basilicata annual rainfall series 1951–2000.

positive NAO phase deflecting wet weather storm tracks towards northwest Europe (Hurrell and Dickson, 2004). Analysis of the period 1950–1995 for the Mediterranean as a whole by Conte *et al.* (2002) demonstrated that ‘meteorological bombs’ were more frequent during the late autumn and winter (November–February) and that their occurrence was negatively correlated ($r = -0{\cdot}7$) with the height of the 500 hPa level. There has been a statistically significant reduction in the number of ‘bombs’ from 1982 onwards. If these climate-driven changes continue, then the landscape of southern Italy and the west-central Mediterranean will become increasingly stable.

CONCLUSIONS

A trend of decreasing extreme event frequency has implications for future land-surface stability in Mediterranean environments, driven by decreases in winter precipitation. Modelling studies suggest that a strengthening NAO may be linked to greenhouse-gas forcing (Paeth *et al.*, 1999; Ulbrich and Christoph, 1999). With greenhouse gases at unprecedented atmospheric concentrations driving an intensification of the hydrological cycle with increased CO_2 (IPCC, 2001), future land degradation by mass movements and flooding will most likely become a decreasing annual problem. In addition, the results of modelling future changes in extreme rainfall events predict a decrease in the number of events with amounts above the 90th percentile in both summer and winter across most of the Mediterranean, including southeast Italy (Sánchez *et al.*, 2004). If reductions in the frequencies of flooding and landslides, and associated weather regimes, are a likely result of natural and anthropogenic climate change over the next century then increased land-surface stability will be the result. The focus on problems of land degradation is therefore likely to shift to issues such as salinization, with increasing use of irrigation and dwindling aquifer recharge as a result of drier winters (Conacher and Sala, 1998).

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