Summary report on MEDEX studies and scientific results on Mediterranean cyclones causing high impact weather

Andrea Buzzi, Evelyne Richard, Romualdo Romero (Nov. 2005)

1. The physical mechanisms, as derived from theoretical, observational and numerical studies.

- Mediterranean cyclogenesis is often initiated as secondary cyclogenesis. This is true especially for orographic cyclogenesis (Speranza, 2001; Buzzi et al, 2003). Orographic cyclogenesis is particularly prominent in climatology (since 1950's studies, e.g. Petterssen, 1956). Orographic and especially Alpine cyclogenesis (or cyclogenesis in the Gulf of Genoa) studies initiated in the 50-60's of the last century (for example, Radinovic, 1965; Egger, 1972; Buzzi and Tibaldi, 1978) and culminated in the WMO-ALPEX programme research. It is related to many forecasting problems and high impact phenomena, as for example storm surges (Zampato et al, 2005), Mistral and Bora (Horvath et al, 2005), precipitation especially in Central-Eastern Mediterranean and Eastern Europe. Orographic cyclogenesis north of the Algerian coast, under southwesterly upper-level flow over the Atlas mountains, produces most of the times weak cyclones but that can be crucial for driving flash-flood situations in eastern Spain (Homar et al. 1999; Romero et al. 2000). A well-known area of cyclogenesis is that found in the southeast of the Atlas mountains in Algeria. It has been shown (Prezerakos, 1990; Prezerakos et al., 1990; 2005) that the so-called Saharan or Atlas depressions deriving from this cyclogenesis and migrating usually over the Mediterranean as vigorous cyclones are baroclinic disturbances developing when the polar jet stream moves much further south from its normal seasonal position and approaches the subtropical jet stream. Orographic cyclogenesis affects also the area south-east of the Pyrenees, the Adriatic Sea, the Cyprus area south of the Anatolian mountains.

- Different physical "ingredients" and "factors" have been found to be favourable for cyclogenesis (or cyclolysis): orography (usually cyclogenetic, but depending on the position of cyclones and orientation of main flow and temperature gradient), sea surface temperature, heat fluxes, latent heat release (generally cyclogenetic if coupled with positive heat fluxes), convection, degree of baroclinicity, subsynoptic structure and intensity of the upper-level precursor trough, etc. (Alpert et al, 1995; Prezerakos et al, 1997; Romero et al, 1997; Buzzi et al, 1998; Homar et al. 2002; Lionello et al, 2003; Kotroni et al, 1999; Tripoli et al. 2005; Romero et al. 2005;).

- The importance of pre-conditioning of the Mediterranean (and surrounding areas, e.g. North Africa) atmospheric state prior to cyclone formation, in terms of presence of moisture and low static stability has been documented. Preceding tropical cyclones in the Atlantic and injection of moisture from the Atlantic, the Mediterranean and even from the tropics have been found to determine the water vapour budget and the water cycle that affect the growth rate and the structure of cyclones (Reale et al., 2001; Pinto et al, 2002; Turato et al, 2004; Bertò et al, 2004; Krichak et al, 2004).

- From a theoretical point of view, stability theories have been applied for understanding cyclogenesis: baroclinic instability in the presence of orography; convective and absolute instability (in relation to mobility of disturbances in the growing stage – Fantini and Davolio, 2002); theory of vortex propagation for the cut-off mature stage; symmetric instability in relation to rainbands (Dobrochotov et al, 2002; Mantovani and Speranza, 2002: Speranza, 2005; Tartaglione and Speranza, 2005).

- Mediterranean small hurricanes ("Medicanes") affect the Mediterranean from time to time as documented mainly, but not only, in satellite images. A couple of such hurricane-like cyclones in the Mediterranean are described in the book by Rasmussen and Turner (2004, pp. 214-219) and compared with polar lows. The dynamics and physics of "Medicanes" are not yet accurately diagnosed due to data sparsity, but have been simulated in several studies (Lagouvardos et al, 1999; Reale and Atlas, 2001; Pytharoulis et al, 2000). Numerical simulations of these systems help to discriminate the role of precursor upper-level cold disturbances and air-sea interaction processes (Homar et al. 2003).

2. Synoptic and subsynoptic-mesoscale aspects and life cycle (genesis, evolution, decay)

- The evolution of fronts associated with cyclones in the Mediterranean is peculiar, especially for orographic or orographically-modified cyclogenesis, due to direct and indirect orographic forcing and dishomogeneity of surface heating and roughness. The presence of (multiple) rainband structures can produce strong orographic and convective precipitation when intersecting orography: Benzi et al., 1997; Buzzi et al, 1998; others…). The "conveyor belts" that in Mediterranean cyclones present similarities and differences from those characterizing oceanic cyclones (Ziv et al, 2005).

- In the context of "PV thinking" diagnostics, the role of upper level PV anomalies and streamers has been demonstrated for Mediterranean cyclogenesis (Prezerakos et al, 1997; Homar and Stensrud, 2004; Kotroni and Lagouvardos, 2000; Lambert et al, 2003; Lambert et al, 2004; Romero, 2001; Romero et al, 2005). Low level PV anomalies and PV banners are generated by the orography and heating and can affect the cyclone life and intensity. Heavy rain events in the Mediterranean basin are often associated with an upstream upper-level trough, generally propagating eastward. For example, in the case of the Algiers flood of 10 November 2001, a deep upper-tropospheric geopotential trough was present from Scandinavia to Morocco, forcing significantly high potential vorticity values down to 700 hPa. Tripoli et al. (2005) investigated the mechanisms leading to the coupling of this upper-level PV anomaly with surface air warmed by wind induced surface heat exchanges (WHISHE). Romero et al. (2004) isolated the mutual interactions of upper-level and lower-level PV anomalies (including diabatically generated PV within the cyclone cloud system) and the background flow. Homar and Stensrud (2004), using the MM5 adjoint system, showed that the structures which influence mostly the baroclinic development were related with the surface front but also with some sub-synoptic details of the upper-level anomaly. Lambert et al. (2004), in a series of sensitivity studies to the initial conditions, examined the impact of modifying the geometry and/or the amplitude of coherent PV structures on the localisation of precipitation.

- The role of atmospheric "origin" regions and surface "source areas" of water vapour, especially in cases of heavy precipitation, have been investigated (Turato et al, 2004; Bertò et al, 2004; Krichak et al, 1998; Krichak et al, 2004; Pinto et al, 2002; Lebeaupin et al, 2005). Important origin regions are the Atlantic (at different latitudes, from sub-tropics to mid-high) but also North Africa and the Mediterranean itself.

- There are different regions of formation and subsequent prevailing paths of cyclones in both the Western and Eastern Mediterranean: Gulf of Lion, Gulf of Genoa, Alboran sea, Thyrrenian sea, Northern and Southern Adriatic; Ionian and Aegean seas; Cyprus area (Michaelides et al, 2004; Nicolaides et al, 2004; Prezerakos et al, 2005); north Africa especially in the lee of the Atlas, etc. (Prezerakos et al, 1999; Nicolaides et al, 2005). Particular attention has been devoted recently to establish relationships between cyclones and high impact weather, especially heavy precipitation, both over large basins (e.g. Jansa et al. 2001; Gil et al, 2003; Campins et al, 2005a) and for particular regions (e.g. Romero et al. 1999). Systematic intercomparison was made of intense cyclogenesis events affecting the whole of the Mediterranean basin according to the role of baroclinicity, diabatic process and orography (Fita et al, 2005). Severe weather is mainly associated with cyclones, but not necessarily with strong cyclones (Campins et al, 2005b), especially for heavy precipitation. Impact studies have concentrated on heavy rain (many authors), wind storms (for example Bora, Horvath et al, 2005), snowfalls (Pascual et. al, 2005). The impact in terms of heavy precipitation often depends on the presence of coastal mountains and of the relative position of cyclones in various areas (Ramis et al, 1994; Jansa et al, 2001).

- Among the many case studies, the Algerian-Balearic event ('superstorm') of Nov. 2001 received probably the widest attention for its exceptional intensity and disastrous consequences due to flash flood in Algiers and wind storm in the Balears. (Davolio and Buzzi, 2004; Arreola et al., 2004; Romero et al, 2004; Lambert et al, 2004; Tripoli et al, 2005; Smith et al, 2005). Regarding others strong historical events of Mediterranean cyclones, numerical reconstruction using ERA and NCEP reanalyses have been made (e.g. cyclone of Dec. 1979, Homar, 2002; Nov. 1966 event over Italy - Grossi et al, 2004; De Zolt et al, 2005).

3. **Methods and techniques used to draw the hypotheses/conclusions.**

- The most commonly applied diagnostic tools are: vorticity balance, PV dynamics, energetics (Prezerakos and Michaelides, 1989; Michaelides, 1992; Michaelides et al, 1999), Q-vectors; atmospheric trajectories with clustering to define "air mass" and water vapour paths (Bertò et al, 2004); application of the factor separation technique (Stein and Alpert, 1993; Alpert et al, 1995; Homar et al. 1999; Romero et al. 2000; Krichak and Alpert, 2002; Genoves and Jansa, 2002; Horvath et al, 2005).

- PV inversion technique: despite constant improvements of the observing and data assimilation systems, uncertainties in the initial conditions are still a major source of error for the numerical weather prediction models. When incipient analysis errors can be detected (e.g with the help of satellite imagery), alternative initial conditions (and subsequent forecast) can be obtained by editing and inverting the PV field. This method was used to investigate the sensitivity of the 2001 Algerian cyclone to sub-synoptic upper-level PV features (Lambert et al., 2004; see also Romero, 2001, and Romero et al, 2005).

- Statistical approach has been applied to relate cyclone characteristics and severe weather (e.g. heavy precipitation), using, for example, analogues and cluster analysis. Using a satellite-based climatology, Mediterranean cloud systems and troughs were automatically detected with the retrievals of the cloud top pressure and the temperature of the lower stratosphere. When focused on the south Alpine region, it is found that the most intense precipitating cases are associated with the most pronounced and elongated upper-level anomalies (Chaboureau and Claud, 2005). Martius et al (2005) obtained similar results through a climatological analysis between PV streamers and heavy precipitation events.

4. Numerical modelling (including analysis/assimilation) aspects.

- In order to correctly simulate and predict cyclogenesis and cyclone life cycle, it is necessary to "capture" (through assimilation and modelling) a range of scale and scale interaction processes from the quasi-planetary scale (Atlantic storm-track, mid-latitude and sub-tropical circulation) down to local scale (convection and orographic forcing). (Corazza et al, 2003; Richard et al, 2003; Accadia et al, 2005; Zampieri et al, 2005; Casaioli et al, 2005). Interaction between Atlantic tropical cyclones and mid-latitude flow may decrease the predictability of Rossby wave packets propagating towards the Mediterranean (Enamoto et al, 2005). Despite the complexity of many interacting factors, some high impact events over the Mediterranean like heavy precipitation south of the Alps may have a better predictability than average conditions through their link with large anomalies in the upper-level flow (Grazzini, 2005).

- In recent years there has been a gradual migration of models to finer scales, in scientific and especially operational models, with new approach to the implementation of operational convective-resolving models. Several case studies have been used to test models: MAP cases (e.g. IOP2b); Monserrat 2000 (Mariani et al, 2005; Zampieri and Buzzi, 2005); Aude 1999 (Ducrocq et al, 2002); Gard 2002 (Ducrocq et al, 2003; Llasat et al, 2003; Anquetin et al, 2005; Chancibault et al, 2005; Rigo and Llasat, 2005); Algiers 2001 'superstorm'; Israel heavy rain in 2001 (Krichack et al, 2004), and others (Federico et al, 2005), etc… Various problems have still to be solved, due to numerical resolution and associated numerical diffusion (Cheruy et al, 2004), to parameterization of turbulence, microphysics etc..

- Model verification, validation and intercomparison poses several issues and requires techniques that have been discussed an applied in the context of Mediterranean meteorology (Cardinali et al, 1998; Calenda et al, 2000; Kotroni and Lagouvardos, 2001; Picornell et al, 2002; Lagouvardos et al, 2003; Accadia et al, 2003; Accadia et al, 2005; Anquetin et al, 2005; Mariani et al, 2005; Anquetin et al, 2005; Yates et al, 2005), including the development of the model-to-observation approach (Caumont et al, 2005; Brenot et al, 2005).

- Models and model-related techniques have been applied to conduct sensitivity studies based on PV inversion and on the application of adjoint techniques. Identification of sensitive areas for Mediterranean cyclones has been done for a number of Mediterranean cyclones (Romero et al. 2001, Homar and Stensrud 2004, Romero et al., 2005; Homar et al, 2005). Such areas are spread both inside and outside the Mediterranean, depending on the large scale pattern, flow direction and on the time lag considered. Poorly covered areas (mid-low latitude eastern Atlantic and north Africa) are often sensitive areas. A climatological study has also confirmed that the lower troposphere of a region covering most of north Africa (up to 20 N) is potentially very sensitive for the quality of the short-term forecast over southern Europe (Marseille, 2001).

- Assimilation studies have been applied to determine the sensitivity of forecasts Mediterranean cyclones and associated severe weather to specific data assimilation, as for example assimilation of humidity (Ducroq et al, 2002); assimilation of precipitation (for the Algiers storm: Davolio and Buzzi, 2004); humidity adjustment (application in 16 cases over Eastern Mediterranean, Lagouvardos and Kotroni, 2005); assimilation of space observations (Lanciani, 2004; Mugnai, 2005, others...).

References

Accadia, C., S. Mariani, M. Casaioli, A.Lavagnini and A. Speranza. 2005: Verification of Precipitation Forecasts from Two Limited-Area Models over Italy and Comparison with ECMWF Forecasts Using a Resampling Technique. *Wea. Forecasting*, **20**, No. 3, pp. 276–300.

Accadia, C., S. Mariani, M. Casaioli, A.Lavagnini and A. Speranza. 2003: Sensitivity of Precipitation Forecast Skill Scores to Bilinear Interpolation and a Simple Nearest-Neighbor Average Method on High-Resolution Verification Grids. *Weather and Forecasting*, **18**, No. 5, pp. 918–932.

Alpert, P., U. Stein, and M. Tsidulko, 1995: Role of sea fluxes and topography in eastern Mediterranean cyclogenesis. *Global Atmos. Ocean Syst*., **3,** 55–79.

Anquetin, S., , E. Yates, V. Ducrocq, S. Samouillan, K. Chancibault, S. Davolio, C. Accadia, M. Casaioli, S. Mariani, G. Ficca, B. Gozzini, F. Pasi, M. Pasqui, A. Garcia, M. Martorell, R. Romero and P. Chessa, 2005: The 8th and 9th September 2002 fash food event in France: an intercomparison of meteorological models. *Natural Hazard Earth System Sci.*, **5**.

Arreola, J. L., V. Homar, R. Romero, C. Ramis, and S. Alonso, 2004: Un caso de estudio de un evento de ciclogénesis intensa en el Mediterráneo Occidental. 3rd Simpósio de Meteorologia e Geofísica da APMG / 4th Encontro Luso-Espanhol de Meteorologia, Aveiro (Portugal), 10-13 February 2003, Session M11, 197-201. *Proceedings.*

Benzi, R., M. Fantini, R. Mantovani, A. Speranza, 1997: "Orographic Cyclogenesis in a Saturated Atmosphere and Intense Precipitation: Baroclinic Modal Solutions Under the Joint Action of Localized Mountains and Humidity". *Annals of Geophysics,* **XL,** 1579-1590.

Bertò, A., A. Buzzi and D. Zardi, 2004: Back-tracking water vapour contributing to precipitation events over Trentino. *Meteorol. Z*., **13**, 189-200.

Brenot, H., V. Ducrocq, A. Walpersdorf, C. Champollion and O. Caumont, 2005: GPS Zenith Delay Sensitivity evaluated from High-Resolution NWP Simulations of the 8-9th September 2002 Flash-Flood over Southeastern France, *Journal of Geophysical Research*, submitted.

Buzzi, A., M. D'Isidoro, S. Davolio, 2003: A case study of an orographic cyclone south of the Alps during the MAP SOP. *Quart. J. Roy. Meteor. Soc.,* **129**, 1795-1818.

Buzzi, A., and S. Tibaldi, 1977: Inertial and frictional effects on rotating and stratified flow over topography. *Quart. J. Roy. Meteor. Soc.*, **103**, 135-150.

Buzzi, A., N. Tartaglione and P. Malguzzi, 1998: Numerical simulations of the 1994 Piedmont flood: Role of orography and moist processes. *Mon. Wea. Rev.*, **126**, 2369-2383.

Calenda, G., M. Casaioli, C. Cosentino, R. Mantovani, and A. Speranza, 2000: Flood forecasting in the Tiber catchment area: A methodological analysis. *Annals of Geophyics*, **43**, 869-888.

Campins J., A. Jansà and A. Genovés, 2005a: Three-dimensional structure of Western Mediterranean Cyclones. *Int. J. Climatol.* (in press).

Campins J., A. Jansà and A. Genovés, 2005b: Heavy rain and strong wind events and cyclones in the Balearics. 7th EGS Plinius Conference on Mediterranean Storms.

Cardinali, C., M. Caian, J. Pailleaux, N. Tartaglione, A. Buzzi, A. Lavagnini, 1998: An intercomparison between a global variable mesh and two limited area models on a case of rapid cyclogenesis. *Meteorol. Atmos. Phys.*, **65**, 93-111.

Casaioli, M., S. Mariani, C. Accadia, N. Tartaglione, A. Speranza, A. Lavagnini, M. Bollinger 2005: Unsatisfying hydro-meteorological forecast of a Mediterranean cyclone: a verification study employing state-of-the-art techniques, 2005: *Proceedings 7th Plinius Conference, Crete, 5-7 October 2005.*

Caumont, O., V. Ducrocq, G. Delrieu, M. Gosset, J. Parent du Chatelet, J. P. Pinty, H. Andrieu, Y. Lemaitre, and G. Scialom, 2005: A Radar Observation Operator for high-resolution Non-hydrostatic Numerical Weather Prediction. *Journal of Atmospheric and Oceanic Technology, submitted*.

Chaboureau J.-P. and C. Claud, 2005: Satellite-based climatology of Mediterranean cloud systems and their association with large-scale circulation. *J. Geophys. Res.*, (in print).

Chancibault, K., S. Anquetin, V. Ducrocq, and G. M. Saulnier, 2005: Hydrological evaluation of high resolution precipitation forecasts of the Gard flash-flood event (8-9 September 2002), *Q. J. Roy. Meteor. Soc.*, (in print).

Cheruy F., A. Speranza, A. Sutera, N. Tartaglione 2004: Surface wind in the Euro-Mediterranean area: the real resolution of numerical grids. *Annales Geophysicae* **22**, 4043-4048.

Corazza, M., A. Buzzi, D. Sacchetti, E. Trovatore, C. F. Ratto, 2003: Simulating extreme precipitation with a mesoscale forecast model. *Meteorol. Atmos. Phys.*, **83**, 131-143.

Davolio, S., and A. Buzzi, 2004: A nudging scheme for the assimilation of precipitation data into a mesoscale model. *Wea. Forecasting*, **19**, 855-871.

Delrieu, G., V. Ducrocq, E. Gaume, J. Nicol, O. Payrastre, E. Yates, P.-E. Kirstetter, H. Andrieu, P. A. Ayral, C. Bouvier, J. D. Creutin, M. Livet, A. Anquetin, M. Lang, L. Neppel, C. Obled, J. Parent-du-Chatelet, G. M. Saulnier, A. Walpersdorf, and W. Wobrock, 2005: The catastrophic flash-flood event of 8-9 September 2002 in the Gard region, France: a first case study for the Cévennes-Vivarais Mediterranean Hydro-meteorological Observatory. *Journal of Hydrometeorology*, **6,** 34-52.

De Zolt, S., P. Lionello, P. Malguzzi, A. Nuhu, A. Tomasin, 2005 : The disastrous storm of 4th November 1966 on Italy. (in submission).

Dobrochotov, S.Y., E.S.Semenov, A.Speranza, B.Tirozzi, 2002: A Hamiltonian model for the trajectory of the typhoon center". *Russian Journal of Mathematical Physics*, in print, Copyright 2005 by MAIK "Nauka/Interperiodica" (Russia).

Ducrocq, V., D. Ricard, J. Lafore, J., and F. Orain, 2002: Storm-scale numerical rainfall prediction for five precipitating events over France: On the importance of the initial humidity field, *Wea. Forecasting*, **17**, 1236.1256.

Ducrocq, V., G. Aullo et P. Santurette, 2003a : Les précipitations intenses et les inondations des 12 et 13 novembre 1999 sur le sud de la France, *La Météorologie 8ème série*, **42**, 18-27.

Ducrocq, V.,K . Chancibault, F. Habets, S. Anquetin, 2003b : Mesoscale modelling of a flooding storm. Application to the extreme flood of Gard, *5th EGS Plinius Conference*, Ajaccio, Corsica, France.

Ducrocq, V., C. Lebeaupin, T. Thouvenin, H. Giordani, K. Chancbault, S. Anquetin, G.M. Saulnier, 2004: L'évènement des 8-9 septembre 2002 : situation météorologique et simulation à mésoéchelle, *La Houille Blanche*, **6,** 86-92.

Egger, J., 1972: Numerical experiments on the cyclogenesis in the Gulf of Genoa. *Beitr. Phys. Atmos.*, **45**, 320-346.

Enamoto, T., H. Nakamura and M. A. Shapiro, 2005: Remote effects of tropical storm Cristobal upon a cut-off cyclone over Europe in August 2002. *Submitted to Meteorology and Atmospheric Physics*.

Fantini, M. and S. Davolio , 2001: Instability of Neutral Eady Waves and orography . *J. Atmos. Sci*., **58**, 1146-1154.

Federico, S., E. Avolio, C. Bellecci and M. Colacino, 2005: The 11-12 December 2003 storm in Southern Italy. 7th Plinius Conference.

Fita, L., R. Romero, and C. Ramis, 2005: Intercomparison of intense cyclogenesis events over the Mediterranean basin based on baroclinic, diabatic and topographical influences. Plinius Conference on Mediterranean Storms VII, European Geosciences Union, Rethymnon, Crete (Greece), 5-7 October. *Proceedings.*

Genovés, A. and A. Jansa, 2002: Diabatic processes contribution to the November 2001 Storm. 4th Plinius Conference.

Gil V., A. Genovés, M.A. Picornell, A. Jansà and B. Navascués, 2003: HIRLAM_INM and ECMWF analyses: Comparison of their behaviour in cyclones detection. 5th Plinius Conference on Mediterranean Storms

Grossi G., B. Bacchi, R. Ranzi, R. Buizza, S. Uppala, E. Klinker, A. Buzzi and P. Malguzzi, 2003: Hydrological verification of ECMWF and limited area model simulations for the November 1966 catastrophic floods in Italy (Florence and Eastern Alps). *Proceedings* of the International Conference on Alpine Meteorology and MAP-Meeting 2003 (Brig, May 2003). Publications of MeteoSwiss, **66**, 376-378.

Grazzini F., 2005: Predictive skill of a large-scale flow conducive to extreme precipitation over the Alps. *Submitted to Meteorology and Atmospheric Physics*.

Homar, V., C. Ramis, and S. Alonso, 2002: A deep cyclone of African origin over the Western Mediterranean: Diagnosis and numerical simulation. *Ann. Geophys*., **20**, 93-106.

Homar, V., A. Jansà, J. Campins and C. Ramis, 2005: Numerical sensitivities of Mediterranean severe weather. 7th Plinius Conference.

Homar, V., C. Ramis, R. Romero and S. Alonso, J. A. García-Moya, and M. Alarcón,1999: A case of convection development over the western Mediterranean Sea: A study through numerical simulations. *Meteorol. Atmos. Phys*., **71**, 169-188.

Homar, V., R. Romero, C. Ramis, and S. Alonso, 2002: Numerical study of the October 2000 torrential precipitation event over eastern Spain: Analysis of the synoptic-scale stationarity. *Annales Geophysicae,* **20**, 2047-2066.

Homar, V. and D. J. Stensrud, 2004: Sensitivities of an intense Mediterranean cyclone: Analysis and validation. *Q. J. R. Meteorol. Soc.*, **130** 2519-2540. *Hydrology Earth System Sciences (HESS)*, **7(6)**, 799-811.

Horvath, K., L. Fita, R. Romero, B. Ivančan-Picek, I. Stiperski, 2005: Sensitivity of the November 2004 Mediterranean cyclone and induced Bura flow in the Adriatic Sea to macroscale dynamical factors. 7th Plinius Conference.

Illari L., P. Malguzzi and A. Speranza, 1981*:* "On breakdowns of the Westerlies". *Geophys. Astrophys. Fluid Dynamics*, **17**, 27-49.

Jansa, A., A. Genovés, M. A. Picornell, J. Campins, R. Riosalido, and O. Carretero, 2001: Western Mediterranean Cyclones and Heavy Rain. Part 2: Statistical Approach. *Meteorol. Appl.*, **8**, 43-56.

Kotroni V., K. Lagouvardos, G. Kallos, and D. Ziakopoulos, 1999: Severe flooding over central and southern Greece associated with pre-cold frontal orographic lifting. *Quart. J. Roy. Meteorol. Soc.*, **125**, 967-991.

Kotroni V. and K. Lagouvardos, 2001: Precipitation forecast skill of different convective parameterization and microphysical schemes: application for the cold season over Greece. *Geophys. Res. Letters,* Vol. **108**, No 10, 1977-1980.

Krichak, S. O., and P. Alpert, 1998: Role of large-scale moist dynamics in the November 1–5, 1994, hazardous Mediterranean weather. *J. Geophys. Res.*, 103 (D16), 19 453–19 468.

Krichak, S.O., and P. Alpert. 2002: A Fractional Approach to the Factor Separation Method. *J. Atmos. Sci.*, **59**, 2243–2252.

Krichak, S.O., P. Alpert and M. Dayan, 2004:The role of atmospheric processes associated with hurricane Olga in the December 2001 floods in Israel. *J. Hydromet.*, 5, 1260-1270.

Lagouvardos K., V. Kotroni, S. Nickovic, D. Jovic, and G. Kallos, 1999: "Observations and model simulations of a winter sub-synoptic vortex over the Central Mediterranean". *Meteorological Applications,* **6**, 371-383.

Lagouvardos K., and Kotroni V., 2000: Use of METEOSAT Water-Vapour images for the diagnosis of a vigorous stratospheric intrusion over Central Mediterranean. *Meteorological Applications*, **7**, 205-210.

Lagouvardos, K., V. Kotroni, A. Koussis, C. Feidas, A. Buzzi, P. Malguzzi, 2003: The meteorological model BOLAM at the National Observatory of Athens: Assessment of two-year operational use. *J. Appl. Meteor.,* **42**, 1667-1678.

Lagouvardos K. and V. Kotroni, 2005: Improvement of high-resolution weather forecasts through humidity adjustment, based on satellite data. *Quart. J. Roy. Meteorol. Soc.* (in print).

Lambert, D., P. Arbogast, J.-P. Chaboureau, F. Crépin, M. Farge and E. Richard, 2004: Mediterranean rainstorm study using potential vorticity inversion method. 1st EGU General Assembly, 25-30 Avril, Nice.

Lambert, D., P. Arbogast, J.-P. Chaboureau, P. Mascart and E. Richard, 2003: Study of a Mediterranean rainstorm episode using potential vorticity inversion method. 5rd EGS Plinius Conference on Mediterranean storms, 1-3 October, Ajaccio, France, EGS Ed., pp. 155-158.

Lanciani A., 2004: *Assimilating vertical velocity in a large scale atmospheric model: A sensitivity study*. Doctorate in Physics University Roma Tre, Thesis, Rome.

Lebeaupin, C., V. Ducrocq and H. Giordani, 2005 : Sensitivity of Mediterranean torrential rain events to the Sea Surface Temperature based on high-resolution numerical forecasts, *Journal of Geophysical Research*, submitted.

Lionello, P., G. Martucci, and M. Zampieri, 2003: Implementation of a coupled atmosphere-wave-ocean model in the Mediterranean sea: Sensitivity of the short time scale evolution to the air-sae coupling mechanism. *Global Atmosphere Ocean System*., **1-2**, 65-95.

Llasat, M.C., T. Rigo and M. Barriendos, 2003: The 'Montserrat-2000' flash-flood event: a comparison with the floods in the Northeastern Iberian Peninsula since the 14th century. *International Journal of Climatology,* **23**, 453-469.

Mantovani R., A. Speranza, 2002: Baroclinic instability of a symmetric, rotating, stratified flow: a study of the nonlinear stabilisation mechanisms in the presence of viscosity. *Nonlinear Processes in Geophysics*, **9**, 487–496.

Mariani, S., M. Casaioli, C. Accadia, M. C. Llasat, F. Pasi, S. Davolio, M. Elementi, G. Ficca, and R. Romero, 2005: A limited area model intercomparison on the "Montserrat-2000" flash-flood event using statistical and deterministic methods. *Natural Hazard Earth System Sci*., **5**.

Marseille G. J. and F. Bouttier, 2001 : Climatologies of sensitive areas for short-term forecast errors over Europe. ECMWF Techincal Memorandum n.334. Available at http://www.ecmwf.int/publications/

Martius O., E. Zenklusen , C. Schwierz and H. C. Davis, 2005: Episodes of Alpine heavy precipitation with an overlying elongated stratospheric intrusion: A Climatology. Submitted to Int. J. Climatol.

Michaelides, S.C., 1992: A spatial and temporal energetics analysis of a baroclinic disturbance in the Mediterranean. *Mon. Wea. Rev.*, **120**, 1224-1243.

Michaelides, S.C., N.G. Prezerakos and H.A. Flocas, 1999: Quasi-Lagrangian energetics of an intense Mediterranean cyclone. *Quart. J. Roy. Meteorol. Soc*.,**125**,139-168.

Michaelides, S.C., K. Nicolaides and T. Karacostas, 1999: Statistical characteristics of the cold season depressions over the area of Cyprus. *Meteorologický časopis*, **7**, 61-66.

Mugnai, A., C. Adamo, F. Baordo, B. Bizzarri, S. Dietrich, J. Hoch, V. Levizzani, C.M. Medaglia, A. Metha, S. Pinori, F. Porcù, F. Prodi, E.A. Smith, F. Torricella and G.J. Tripoli, 2005: Unified framework for precipitation retrieval and analysis by means of multisensor satellite observations and cloud model simulations: Application to severe storm events within the Mediterranean basin. 7th Plinius Conference.

Nicolaides, K,A, S. C. Michaelides and T. Karacostas, 2004: Spatial distribution of some dynamic parameters during the evolution of selected depressions over the area of Cyprus. *Intern. J. Climatol.*, **24**, 1829-1844.

Nicolaides, K,A, S. C. Michaelides and T. Karacostas, 2005: Synoptic and dynamic characteristics of selected deep depressions that affected the area of Cyprus. 7th Plinius Conference.

Pascual, R., A. Callado, M. Berenguer, 2005: Analysis of a strong snowstorm in Catalonia on December 2001. (?)

Picornell, M.A., N. A. Carrassi and A. Jansà, 2002: A study on the forecast's quality of the Mediterranean cyclones. 4th EGS Plinius Conference on Mediterranean Storms.

Pinto,J.G., M. Klawa, U. Ulbrich, R. .Rudari, P. Speth, 2002: Extreme precipitation events over northwest Italy and their relationship with tropical-extratropical interactions over the Atlantic. Mediterranean Storms (Proceedings of the 3rd EGS Plinius Conference held at Baja Sardinia, Italy, October 2001).

Prezerakos, N. G., 1990: Synoptic flow patterns leading to the generation of the northwest African depressions. *Int. J. of Climatology*, **10**, 33-47.

Prezerakos,N.G., and S.C. Mechaelides, 1989: A composite diagnosis in sigma coordinates of the atmospheric energy balance during intense cyclonic activity. *Quart. J. Roy. Meteor. Soc*., **115**, 463-486.

Prezerakos, N. G., S. C. Mechaelides and A. S. Vlassi, 1990: Atmospheric synoptic conditions associated with the initiation of northwest African depressions. *Int. J. of Climatology*, **10,** 711-729.

Prezerakos, N. G., S. C. Mechaelides and H. A. Flocas, 1997. The role of a developing upper diffluent trough in surface cyclogenesis over central Mediteranean. *Meteorol. Zeitschrift*, **6**, 108-119.

Prezerakos, N.G., H.A. Flocas, S.C. Michaelides, 1999: Upper tropospheric downstream development over northwest Europe leading to surface cyclogenesis in the central Mediterranean. *Meteorol. Appl,* **4**, 313–322.

Prezerakos, N.G., H.A. Flocas and D. Brikas, 2005:The role of the interaction between polar and subtropical jet in a case of depression rejuvenation over the Eastern Mediterranean. *Meteorol. Atmos. Phys*. (*online*).

Pytharoulis, I., G.C. Craig and S. P. Ballard, 2000: The hurricane-like Mediterranean cyclone of January 1995. *Meteorol. Appl.,* **7**, 261–279.

Radinovic. D., 1965: On forecasting of cyclogenesis in the West Mediterranean and other areas bounded by mountain range by baroclinic model. *Archiv. Met. Geoph. Bioklim*., A, **14**, 279-299.

Ramis, C., M.C. Llasat, A. Genovés and A. Jansà, 1994: The October-1987 floods in Catalonia: synoptic and mesoscale mechanisms. *Met. Apps*., 1, 337-350.

Rasmussen, E. A., and Turner J., 2003: Polar Lows, *Cambridge press*.

Reale, O., and R. Atlas. 2001: Tropical Cyclone–Like Vortices in the Extratropics: Observational Evidence and Synoptic Analysis. *Weather and Forecasting,* **16**, No. 1, pp. 7–34.

Reale, O., L. Feudale, and B. Turato, 2001: Evaporative moisture sources during a sequence of floods in the Mediterranean region. *Geophys. Res. Lett.,* **28,** 2085–2088.

Richard., E., S. Cosma, R. Benoit, P. Binder, A. Buzzi and P. Kaufmann, 2003: Intercomparison of mesoscale meteorological models for precipitation forecasting. *Hydrology Earth System Sciences (HESS)*, **7(6)**, 799-811.

Rigo, T. and M.C. Llasat, 2005. Radar analysis of the life cycle of Mesoscale Convective Systems during the 10 June event. *Natural Hazards and Earth System Science*, **5**, 1-12.

Romero, R., G. Sumner, C. Ramis, and A. Genovés, 1999: A classification of the atmospheric circulation patterns producing significant daily rainfall in the Spanish Mediterranean area. *Int. J. Climatol*., **19**, 765-785.

Romero, R., C. A. Doswell III, and C. Ramis, 2000: Mesoscale numerical study of two cases of long-lived quasistationary convective systems over eastern Spain. *Mon. Wea. Rev.*, **128**, 3731-3751.

Romero, R., 2001: Sensitivity of a heavy rain producing Western Mediterranean cyclone to embedded potential vorticity anomalies. *Quart. J. Roy. Meteorol. Soc.,* **127**, 2559-2597.

Romero, R., A. Martin, V., Homar, S., Alonso and C., Ramis, 2005: Predictability of prototype flash flood events in the western Mediterranean under uncertainties of the precursor upperlevel disturbance: The HYDROPTIMET case studies, *Nat. Haz. and Earth. Syst. Sci.*, **5**.

Romero, R., C., Ramis, and S., Alonso, 1997: Numerical simulation of an extreme rainfall event in Catalonia: Role of orography and evaporation from the sea, *Quart. J. Roy. Meteorol. Soc*., **123**, 537-559.

Romero, R., C. Ramis, and S. Alonso, 2004: Impacts and interactions of dry and moist potential-vorticity anomalies during the life cycle of an intense mediterranean cyclone. Plinius Conference on Mediterranean Storms V, European Geophysical Society, Ajaccio (France), 1-3 October 2003. *Proceedings.*

Smith, E. A. Metha, A. Mugnai, B.J. Sohn and G.J. Tripoli, 2005: Comparing and contrasting precipitation efficiencies and water vapour bubgets of two types of warm-core cyclones: Late summer west Pacific typhoon and late-year Mediterranean storm. 7th Plinius meeting.

Speranza A., 2001: "The Physical Mechanisms of Secondary Cyclogenesis". Recent Research Developments in Atmospheric Science, Vol. 1 (2001), *Research Signpost*, Kerala, India.

Speranza, A. 2005: "The mobility of atmospheric eddies: an asymptotic approach to studying the initial growth of local atmospheric disturbances". *Russian Journal of Mathematical Physics*, in print, Copyright 2005 by MAIK *Nauka/Interperiodica* (Russia).

Speranza, A., and N. Tartaglione, 2005: Extreme events in the Mediterranean area: a mixed deterministic-statistical approach. Submitted to *Nuovo Cimento C.*

Speranza, A., C. Accadia, M. Casaioli, S. Mariani, G. Monacelli, R. Inghilesi, N. Tartaglione, P.M. Ruti, A. Carillo, A. Bargagli, G. Pisacane, F. Valentinotti and A. Lavagnini 2004: POSEIDON: An integrated system for analysis and forecast of hydrological, meteorological and surface marine fields in the Mediterranean area. *Nuovo Cimento*, **27C**, 329-345.

Speranza, A., C. Accadia, S. Mariani, M. Casaioli, N. Tartaglione, G. Monacelli, and P. M. Ruti, 2005: SIMM: an integrated forecasting approach for the Mediterranean Area. Submitted to *Bull. Amer. Meteorol. Soc.*

Stein, U. and Alpert, P., 1993: Factor separation in numerical simulations. *J. Atmos. Sci.*, **50**, 2107-2115.

Tartaglione, N. and A. Speranza, 2005: Mobility of Atlantic cyclones and meteorological risk in a Mediterranean area. Submitted to *NHESS*.

Tartaglione, N., A. Speranza, 2003: Weather Systems on Europe during the summer of 2002. *Proceedings 5th European Geophysical Soc. Plinius Conference on "Mediterranean Storm". Ajaccio 1-4 October 2003.*

Tartaglione, N., S. Mariani, C. Accadia, A. Speranza and M. Casaioli, 2005a: Comparison of rain gauge observations with modelled precipitation over Cyprus using Contiguous Rain Area Analysis. *Atmos. Chem. Phys.,* **8**, 2147-2154.

Tripoli, G. J., C. M. Medaglia, S. Dietrich, A. Mugnai, G. Panegrossi, S. Pinori, and E. A. Smith, 2005: The 9–10 November 2001 Algerian flood: a numerical study. *Bull. Am. Meteor. Soc.*, 1229-1235.

Turato, B., O. Reale, and F. Siccardi, 2004: Water vapor sources of the October 2000 Piedmont flood. *J. Hydrometeor.*, **5**, 693–712.

Yates, E., S. Anquetin, V. Ducrocq, J. D. Creutin, D. Ricard, and K. Chancibault, 2005: Point and areal validation of forecasted precipitation fields. *Meteorological Applications* (in print).

Zampato, L., G. Umgiesser and S. Zecchetto, 2005: Storm surge in the Adriatic Sea: observation and forecast of an extreme event. 7th Plinius Conference.

Zampieri, M., P. Malguzzi and Buzzi, 2005: Sensitivity of quantitative precipitation forecasts to boundary layer parameterization: a flash flood case study in theWestern Mediterranean. *Natural Hazard Earth System Sci.*, **5**, 603-612.

Ziv, B., H. Saaroni, A. Baharad and M. Bar-Romem, 2005: The role of conveyor belts in weathern patterns associated with Mediterranean cyclones. 7th Plinius Conference.