9.1 THE DEVELOPMENT OF THE "DAPHNE" CONCEPTUAL MODEL FOR THE POTENTIALITY OF DESIGNING A PRECIPITATION ENHANCEMENT PROJECT IN THESSALY, GREECE

Theodore Karacostas*, Ioannis Pytharoulis, Ioannis Tegoulias, Dimitrios Bampzelis, Stelios Kotsopoulos, Prodromos Zanis, Eleni Katragkou, Panagiotis Mouskos and Kostas Tympanidis
Department of Meteorology and Climatology, Aristotle University of Thessaloniki, Greece

1. INTRODUCTION

The effects of climate change and the continued increase in water needs, for both urban and agricultural use, have largely exhausted water supplies; therefore, an effort must be taken in order to find new ways to augment them. Weather modification has a rather unique status among water resource issues, dealing with cloud seeding that helps clouds more efficiently produce precipitation in the form of rain or snow, or reduce hailstone size in favor of raindrops. The most beneficial and ambitious methodology is that of the precipitation enhancement. In recent years, the development of new sophisticated atmospheric models, in conjunction with modern instruments for measuring and recording atmospheric and cloud physics data have increased the interest for weather modification, and particularly for precipitation enhancement projects (Silverman 2003).

The main objective is the development of the conceptual model DAPHNE, through the necessary scientific tools, to support the potentiality and applicability of a well designed precipitation enhancement program, to investigate its importance and assess thoroughly the impact of its implementation on the environment. Besides developing and applying state-of-the-art modeling tools, the project objectives are accomplished by performing measurement campaigns. During the experimental phase of the project, cloud seeding experiments take place on suitably chosen appropriate clouds over Thessaly area.

It is applied over the Thessaly plain, which is the most vital agricultural area in Greece, and where the water needs for urban and agricultural use have been largely exhausted. Hence, weather and climate, through the weather modification is called to play a very important role in nation's socio-economic status. Figure 1 partially depicts, in a schematic diagram, the proposed project DAPHNE.

2. DATA AND METHODOLOGY

The database of the project DAPHNE includes: a) surface observations from the available manual and automatic meteorological stations of the greater area of Thessaly, b) radiosonde data from the airport of Thessaloniki, c) weather radar images received and analyzed from the C-band (5-cm) weather radar, d) specially equipped aircraft measurements (e.g. temperature, humidity, liquid water content, height, etc.), e) meteorological data (air temperature, precipitation, humidity, atmospheric pressure and wind) from Larissa weather station for a period of 60 years (1950-2010), f) weather charts of daily analyses from ECMWF at 500 hPa at 1200 UTC, for the 10-year period 2001-2010, g) gridded analyses from the ECMWF/IFS system for the period 2001-2010, h) gridded projections of RegCM3 regional climate model (25km x 25km) carried out during ENSEMBLES project under the IPCC scenario A1B, for the period 2041-2050, i) chemical samples of soil and water from the seeded and unseeded areas, for environmental impact assessment studies.

The project DAPHNE integrates all contemporary components in order to have the most comprehensive state-of-the-science results. These components include the use of the state-of-the-art Weather Research and Forecasting (WRF) numerical model at very high resolution (1km x 1km), considering the different types of hydrometeors through sophisticated microphysical parameterizations, the adaptation and redevelopment of a 3D cloud model for performing simulations of seeding material dispersion and high-performance seeding aircraft.

*Corresponding author address: Theodore Karacostas Dept. of Meteorology and Climatology, School of Geology, Faculty of Sciences, Aristotle Univ. of Thessaloniki, 54124 Thessaloniki, Greece;
e-mail: karac@geo.auth.gr

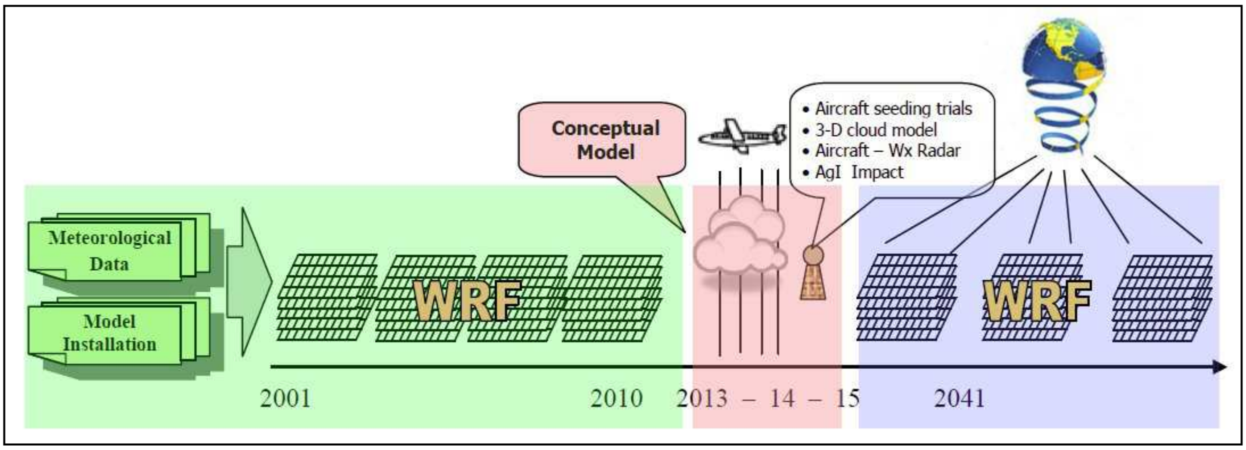

Fig. 1. The schematic diagram of the proposed project DAPHNE.

It is the first time that these state-of-the-art tools and aircraft observations are combined in order to create the fundamental principles for the development of the Conceptual Model that define the feasibility potential of a rain enhancement program in Thessaly. The conceptual model will define if, when, where and how a precipitation enhancement program would be applicable over the examined area. It sets the spatial, temporal and meteorological conditions that must be met, so as cloud seeding of appropriate cloud types will be feasible, aiming in precipitation enhancement and mitigation of drought in the area of Thessaly.

3. RESULTS

The non-hydrostatic WRF model with Advanced Research (WRF-ARW) with advanced dynamical solver (Skamarock et al. 2008, Wang et al. 2013) is utilized in the framework of project DAPHNE. The installation was performed on a parallel computing platform (cluster) and all the necessary pre and post-processing modules have been created, taking into consideration the special characteristics of the project.

The model is integrated in three domains, using 2-way telescoping nesting which cover Europe, the Mediterranean Sea and northern Africa (d01), the wider area of Greece (d02) and central Greece – Thessaly region (d03), at horizontal grid-spacings of 15km, 5km and 1km. respectively (Fig. 2), utilizing the staggered Arakawa C grid. Special care has been taken, regarding the spatial definition of the innermost domain, which focus in the area of interest (Thessaly) due to the surrounding complex topography. Fine-resolution (30''x30'' and 3''x3'') data are available for the definition of topography and land-use. ECMWF operational analyses at 6-hourly intervals (0.25°x0.25° lat.-long.) and NCEP/GFS analyses and forecasts (operationally) can be imported as initial and boundary conditions of the coarse domain.

The sea-surface temperatures (SSTs) are provided daily by NCEP (National Centers for Environmental Prediction) at a horizontal increment of 1/12°x1/12° lat.-long or ECMWF analyses. The NCEP SSTs are produced on a daily basis through the assimilation of the most recent 24-hours sea-surface observations and satellite SST measurements. In the vertical, all nests employ 39 sigma levels (up to 50 hPa) with increased resolution in the boundary layer. Microphysical processes are represented by WSM6 scheme, sub-grid scale convection by Kain-Fritsch scheme, longwave and shortwave radiation by RRTMG scheme, surface layer by Monin-Obukhov (MM5), boundary layer by Yonsei University and soil physics by NOAH Unified model.

The Goddard scheme, the Betts-Miller-Janjic scheme, the RRTMG, the Monin-Obukhov (Eta), the Mellor-Yamada-Janjic and the NOAH Unified model are employed in all nests to represent microphysics, sub-grid scale convection, longwave/shortwave radiation, surface layer, boundary layer and soil physics, respectively. The Goddard microphysical scheme (Tao and Simpson 1993, Tao et al. 2003) contains separate variables for the calculation of cloud water, rain water, ice, snow and graupel (or hail).

The WRF model is used to produce very high spatiotemporal resolution simulations of the atmospheric conditions in the area of interest and provide the forcing fields to the 3D Cloud model.

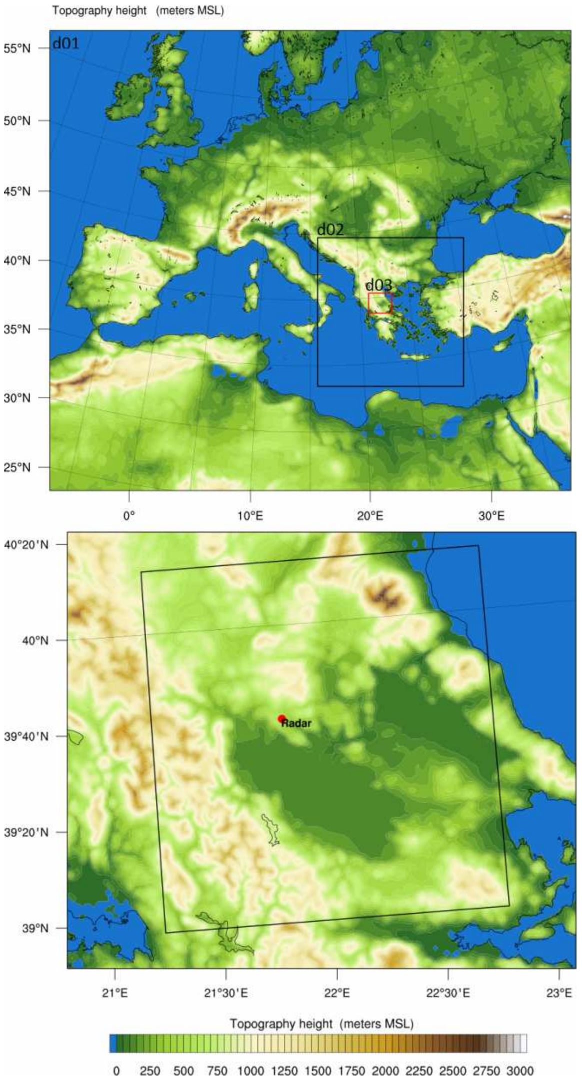

Fig. 2. The topography of (a) the first – d01 and (b) the third – d03 nest used by WRF-ARW. On panel (a), d02 (black frame) and d03 (red frame) are illustrated. On panel (b), Radar denotes the location of the weather radar while the black frame over Thessaly encompasses the region with radar data.

The 3D cloud model, initially developed by Telenta and Aleksic (1988) and modified by Spiridonov and Curic (2003), is applied to representative cases of past/present-weather and future projected conditions, using the actual radiosonde data of the nearest upper air station (Thessaloniki synoptic station) and the output of the WRF simulations. The cloud model sensitivity to the different sources of input data (radiosonde, WRF) is assessed for the present-weather cases.

Storm characteristics are obtained and identified from weather radar reflectivity images received and analyzed from the C-band (5-cm) weather radar, being located at Liopraso area, within the area of interest. Figure 3 depicts the antenna of the C-band radar.

Fig. 3. The antenna of the C-Band radar.

The cell tracker TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) (Dixon and Wiener, 1993) has been used to retrieve convective storm tracks and characteristics from radar reflectivity measurements that roughly have 750x750m spatial and 3.5min temporal resolution. The storm characteristics include: initiation time (UTC hour), duration (minutes), direction (^{o}), speed (km/hr), volume (km^3), area and precipitation area (km^2), rain rate (mm/hr), maximum reflectivity (dBz), cloud top (km) and many more parameters.

The prevailing synoptic conditions in the greater area of central Greece, during the 10-year period 2001-2010, have been classified, one by one day, according to the general circulation pattern of the middle troposphere. This information was retrieved by daily analyses of ECMWF at 500 hPa at 1200 UTC. The classification is based on the methodology introduced by Karacostas et al. (1992), and verified by WMO (2003). Following the same methodology and procedure, the mid-tropospheric synoptic circulation patterns, projected by RegCM3 regional climate model under the IPCC scenario A1B, during the period 2041-2050, will also be classified. The resulting daily synoptic circulation patterns will be statistically analyzed and compared, in order to investigate the prevailing near-present and future synoptic conditions. To meet the project objectives, representative cases of the near-present and future synoptic conditions will be selected for the model simulations.

The core experimental work of the project DAPHNE takes place from the 1st of March to the 31st of October 2014, with emphasis on the first 45 days and the last 31, due to the luck of existed previous data information. During these measurement campaigns, the following procedures will be scheduled to take place, according to our own operational meteorological forecasts. Appropriate surface and upper air meteorological measurements. Weather radar images will be received and analyzed from the C-band (5-cm) weather radar being located at Liopraso area, within the area of interest. Aircraft flights will be conducted, by specially instrumented and equipped aircrafts, with specialized on the subject pilots, in order to perform in-situ measurements. At the same time, and after meeting pre-specified criteria, cloud seeding experiments will carry out on selected clouds. Chemical samplings of soil and water from the seeded area will be conducted, in order to perform the impacts study analysis. Sampling from background areas will also take place for comparison purposes.

It is believed that the aforementioned field experiments and measurement campaigns, coupled with numerical model simulations and proper seeding technologies and procedures, could very well support the objective of the project DAPHNE and of this research.

4. CONCLUSIONS

The implementation scope of the project DAPHNE is to tackle the problem of drought in Thessaly by the scientific means of weather modification. The Thessaly plain is known to be a vital agricultural area in Greece, and thus the weather and climate play a very important role in its socio-economic status. Anthropogenic climate change is expected to further deteriorate the problem of drought and water shortage, posing a serious threat in human and agricultural activities. It appears, thus, a necessity to investigate the potential impact of present weather and climate change on drought, in order to suggest effective ways of tackling the already existed -and for sure- future problem.

Taking into consideration the aforementioned, the main objective of DAPHNE is to integrate all the presented contemporary scientific components, in order to have the most comprehensive state-of-the-science results, in the form of a Conceptual Model, emerging through out the analyzed and studied data information. Some of these components are: the use of the state-of-the-art WRF numerical model with sophisticated microphysical parameter-rizations, the adaptation of the 3D cloud model for performing simulations of cloud seeding experiments, the radar information from the C-band (5-cm) weather radar through the TITAN algorithm, the conduction of instrumented aircraft flights for in-situ measurements and to carry out actual cloud seeding experiments.

It is strongly believed, that it is for the first time that all these state-of-the-art tools and aircraft observations are combined, in order to create the necessary fundamental principles for the development of the Conceptual Model that will define the feasibility potential and applicability of a rain enhancement program in Thessaly. The conceptual model will define ***-if, when, where and how-*** a precipitation enhancement program would be applicable over the examined area. It sets the spatial, temporal and meteorological conditions that must be met, so that cloud seeding of appropriate cloud types will be feasible, aiming in precipitation enhancement and mitigation of drought in the area of Thessaly.

Figure 4 demonstrates the form of a tentative schematic diagram of such Conceptual Model. It should be noted that the estimated-calculated characteristic values, which indicate the corresponding area, volume and equivalent precipitation rates, have been resulted from cells having reflectivity greater than 35 dBz.

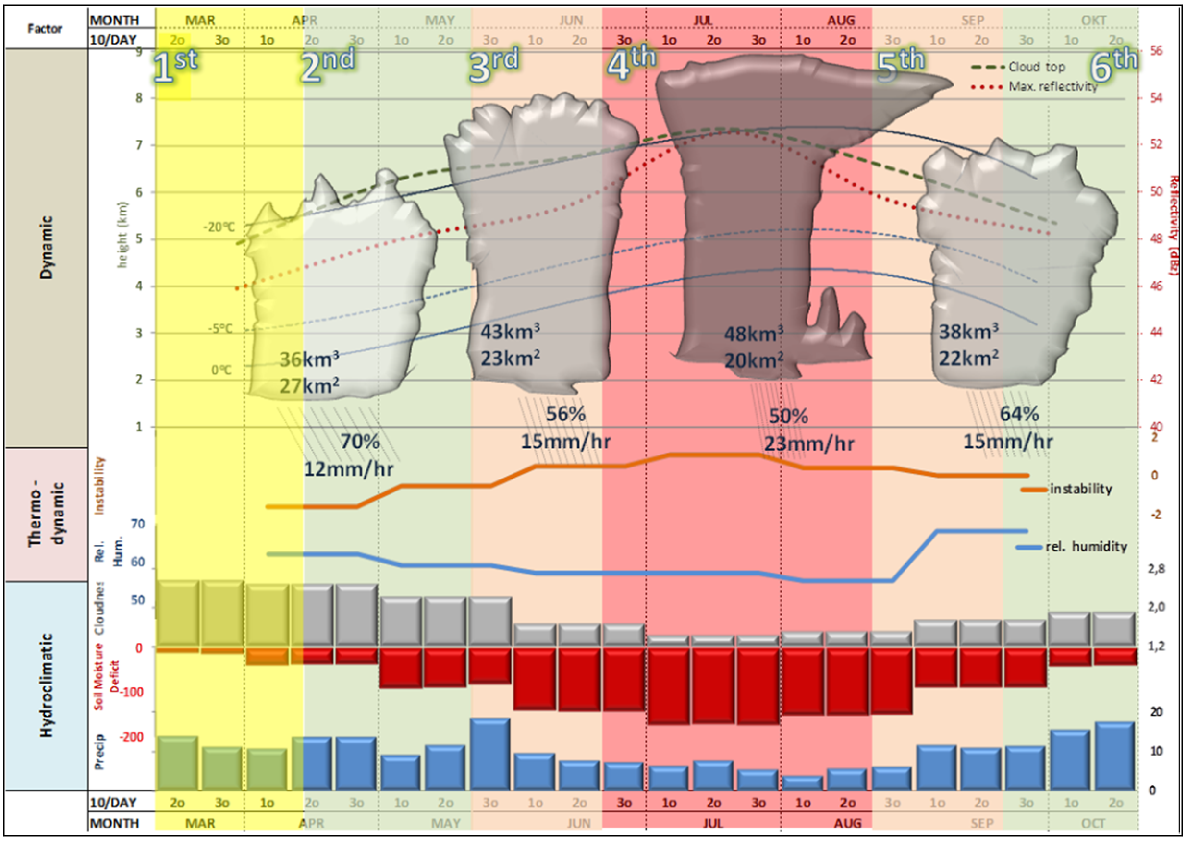

Fig. 4. A schematic diagram of the Conceptual Model of the rain enhancement program in Thessaly.

Six consecutive time periods appear to consist the yearly operational period, demonstrating thus the necessity for similar, different, or at least modified seeding hypothesis, according to the storm characteristics. It is intuitively true that all the aforementioned are expected to be fully developed and finalized through the analyses of the data by the end of the project DAPHNE.

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