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Case Study

Synoptic and Dynamic Drivers of Extreme Precipitation in Greece: The Case of "Daniel" and the Cold Lake- Omega Block Interaction

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A B S T R A C T

This study investigates the meteorological phenomenon known as the "Cold Lake" in conjunction with the synoptic pattern of the Omega Blocker over Southeastern Europe, with particular emphasis on the extreme weather event "Daniel" that struck the Thessaly region of Greece in September 2023. The analysis focuses on the dynamic interplay between contrasting air masses, enhanced moisture transport from the Mediterranean and orographic interactions, which collectively contributed to the intensification of persistent and catastrophic precipitation. Event Daniel is examined as a case study, linking theoretical atmospheric mechanisms with observed societal and environmental impacts. Moreover, the research explores whether such high-impact phenomena are symptomatic of anthropogenic climate change or primarily driven by localized land-use practices and mismanagement. The findings underscore the need for an integrated meteorological, hydrological and urban planning framework to anticipate and mitigate the consequences of extreme weather events in a warming climate.

Keywords: Cold lake; Omega block; Atmospheric moisture transport; Extreme precipitation; Daniel storm; Thessaly; Climate change; Land use

Introduction

In recent years, Europe has experienced an increasing frequency of extreme weather events, often linked to persistent atmospheric circulation patterns. One such configuration, the "Omega Block," is known for its role in prolonging weather systems over specific regions. When combined with upper-level cold air masses, the result can be the formation of a "Cold Lake" - a closed low-pressure system associated with instability and intense precipitation.

In September 2023, the region of Thessaly in central Greece was struck by the extreme storm system "Daniel," which resulted in record-breaking rainfall and widespread destruction. This event provided a unique opportunity to analyze the interaction between large-scale synoptic features, mesoscale moisture transport orographic effects and their cumulative role in producing high-impact hydrometeorological hazards.

This paper aims to examine the meteorological dynamics that led to the Daniel event, investigate the role of climate change in the increasing frequency of such events and discuss the extent to which local anthropogenic factors (e.g., land use changes, inadequate infrastructure) may have exacerbated the impacts.

Results and Discussion

The synoptic setup preceding storm Daniel revealed a well-defined Omega Block over Central Europe, with a closed low-pressure system detaching southward to form a Cold Lake over the central Mediterranean. The juxtaposition of this upper-level cold pool with warm, moisture-rich air from the eastern Mediterranean created an environment highly conducive to convective instability[1]. Satellite and ERA5 reanalysis data confirmed the persistence of positive precipitable water anomalies over Greece during 3-6 September 2023.

Thessaly, a largely flat and agricultural basin surrounded by mountainous terrain, became the focal point for this enhanced instability. Orographic lifting along the Pindus range played a crucial role in sustaining mesoscale convective systems (MCS), which continuously regenerated over the same area-a phenomenon known as back-building convection. Rainfall totals exceeding 750 mm in less than 48 hours were recorded in regions such as Zagora and Pelion, representing one of the most intense rainfall episodes in Greece's meteorological history[2].

Hydrological models show that the saturated soil conditions from preceding storms, in combination with poor watershed management and urban expansion in flood-prone areas, significantly amplified flood magnitudes. According to Lekkas, et al, the lack of effective zoning laws, degradation of natural floodplains and insufficient maintenance of drainage infrastructure contributed directly to the catastrophic impacts[3].

Field surveys by Lekkas and colleagues from the National and Kapodistrian University of Athens (NKUA) documented severe geomorphological alterations, river avulsions and extensive destruction of infrastructure and farmland. The flooding of the Karditsa and Larissa plains resulted in the displacement of thousands of residents and the loss of large portions of agricultural production.

Furthermore, statistical analysis of reanalysis data from the past 40 years demonstrates a marked increase in the frequency of Omega Block events associated with Cold Lakes in the Eastern Mediterranean, suggesting a link to anthropogenic climate trends[4,5]. However, the work of Lekkas, emphasizes that natural hazards evolve into disasters only when human vulnerability is high, stressing the need for integrative risk governance[3,6,7].

Conclusion

The case study of Storm Daniel highlights the complex interplay between large-scale atmospheric patterns-namely, the Cold Lake-Omega Block configuration-and localized factors such as terrain and land management. Enhanced moisture fluxes from the Mediterranean, combined with air mass contrasts and orographic lifting, led to extreme and prolonged precipitation over central Greece. The catastrophic outcomes of the event underscore both the vulnerability of the region and the need for integrated early warning systems.

While there is increasing evidence linking such persistent circulation anomalies to anthropogenic climate change, the severity of impacts in Thessaly also reflects decades of insufficient planning and environmental degradation. A multi-disciplinary approach, incorporating climate science, hydrology and urban policy, is essential for anticipating future risks and enhancing societal resilience.

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