5 – 7 September 2023

“Daniel” Storm:
the Unprecedented Disaster
inflicted on Thessaly, Greece

GeoEngineers Without Borders
ISSMGE

Evangelia GARINI & George GAZETAS
NTUA, Greece
Preliminary Report

5 – 7 September 2023

“Daniel” Storm: the Unprecedented Damage in Thessaly, Greece

By Evangelia GARINI & George GAZETAS

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LINK: https://osf.io/25skw/?view_only=5579a2d668524407b80ddceaf6b6c7ac6
Greece rainfall 'most extreme on record'
The flooded village of Palamas near Karditsa
after the passage of the storm
The agricultural plane of Thessaly
The Phenomenon
The path of Storm Daniel

Storm Daniel formed over Greece. It caused strong winds, heavy rains, flooding and deaths there and in Turkey and Bulgaria before crossing the Mediterranean. The storm then made landfall in Libya, causing devastating floods and thousands of deaths.
Satellite image showing the mud of flooded Pinios river, dispersed by the sea currents and moving towards Chalkidiki.

Source: Weather Analysis Greece
FACT SHEET of DANIEL STORM

97 % of the flooded area is of agricultural use

Total area affected: 700 000 acres

Human Loss: 17

Estimated Cost: $ 2.2 billion (Source: Financial Times). Our estimate: $ 4 billion

Max Precipitation: 1096 mm in 2 days

Damage Summary: Thousands houses flooded
79 bridges destroyed
> 60 landslides and rockfalls
16 points damaged in Railroad Network
Heavily damaged road network
### Summary of Effects

<table>
<thead>
<tr>
<th>Prefecture</th>
<th>Number of Inspections</th>
<th>Length (in km) of damaged ROADS</th>
<th>Damaged BRIDGES</th>
<th>Flooded SCHOOLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trikala</td>
<td>124</td>
<td>12</td>
<td>35</td>
<td>19</td>
</tr>
<tr>
<td>Karditsa</td>
<td>104</td>
<td>22</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>Magnesia</td>
<td>131</td>
<td>13</td>
<td>5</td>
<td>22</td>
</tr>
<tr>
<td>Larissa</td>
<td>84</td>
<td>11</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>Phthiotis</td>
<td>29</td>
<td>12</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>472</strong></td>
<td><strong>70</strong></td>
<td><strong>79</strong></td>
<td><strong>79</strong></td>
</tr>
</tbody>
</table>
Meteorological phenomena involved in the formation of “DANIEL”
The following satellite image (source: NASA) shows the area where high temperatures prevailed as well as the low pressure fields (Low) that were created at the edges of the Omega obstruction. The field to the east is associated with the Daniel system.

**What are the characteristics of an Omega (Ω) block?**

When an Omega (Ω) block occurs, colder air masses moving from the Atlantic to the Mediterranean are deflected northward, while warm masses from more southerly latitudes are brought into the area below the 'Ω' shaped area. This results in increased temperatures that lead, if the Omega blockage is maintained for several days, to strong and persistent heat waves that in turn worsen drought conditions and fuel forest fires.

**The case of the Daniel system**

In the case of the Daniel system, Omega blocking is mainly located in the Central and Northern European region where high temperatures prevailed (the region between the yellow arrows). At the same time, it created a stagnant field of low pressure in the Ionian Sea (shown by the formation of clouds on the following map) resulting in the flow for several days in a row of warm and moist gas masses from the northeast towards Greece (and especially towards Thessaly) resulting in the unprecedented heights of rainfall that occurred and the extreme flooding that resulted. It is also noted that the intensity of the Daniel system may also be linked to the increase in sea surface temperature in the southeastern Mediterranean (Faranda, 2023).
Omega Ω block
Explanation of storm’s formation

- High sea temperatures
- High moisture transportation from the Aegean
- COLD winds
- Slow S-SW motion of Low atmospheric pressure
- Low atmospheric pressure
Comparison of
“DANIEL” with “IANOS” storms
“IANOS” Storm

155,000 Acres flooded
"DANIEL" Storm
430 000 Acres Flooded
Precipitation Records
Ianos Storm [17-20/09/2020]  
VERSUS  
Daniel Storm [04-07/09/2023]  

<table>
<thead>
<tr>
<th>Location</th>
<th>Precipitation Sum [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zagora</td>
<td>1096</td>
</tr>
<tr>
<td>Portaria</td>
<td>885</td>
</tr>
<tr>
<td>Volos</td>
<td>617</td>
</tr>
<tr>
<td>Trikala</td>
<td>438</td>
</tr>
<tr>
<td>Mouzaki</td>
<td>274</td>
</tr>
<tr>
<td>Pertouli</td>
<td>317</td>
</tr>
<tr>
<td>Kalambak</td>
<td>356</td>
</tr>
<tr>
<td>Agia Village</td>
<td>455</td>
</tr>
<tr>
<td>Larisa</td>
<td>305</td>
</tr>
<tr>
<td>Tempi</td>
<td>268</td>
</tr>
</tbody>
</table>

Sum of precipitation [mm]
### Total **ANNUAL** Precipitation

<table>
<thead>
<tr>
<th>City</th>
<th>Annual Precipitation (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paris</td>
<td>641</td>
</tr>
<tr>
<td>London</td>
<td>585</td>
</tr>
<tr>
<td>Copenhagen</td>
<td>660</td>
</tr>
<tr>
<td>Milano</td>
<td>1160</td>
</tr>
<tr>
<td>San Francisco</td>
<td>500</td>
</tr>
<tr>
<td>Zurich</td>
<td>1134</td>
</tr>
<tr>
<td>Vienna</td>
<td>550</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>844</td>
</tr>
<tr>
<td>New York</td>
<td>1183</td>
</tr>
<tr>
<td>Seattle</td>
<td>940</td>
</tr>
</tbody>
</table>

Contrast with the **1096 mm** in Zagora within **2 days**!!

(Few European and US cities have total **annual** rainfall as much as Zagora in Pelion received in 24 hours)
Geomorphology of Thessaly
The main River Network of Thessaly

Pinios
Larissa
Enipeas
Karditsa
Karabalis
Kalentzis
Sofaditis
The Complete River Network of Thessaly

Bathrellos et al. 2018
Geological formations in the riverine zone of Pinios

1a: Alluvial and modern deposits
1b: Littoral sediments
2a: Terraces
2b: Old terraces
3: Alluvial fans
4: Eluvial deposits
5: Conglomerates, sandstones, clays, marls
6: Molassic formations
7: Flysch
8: Limestones
9: Cherts, schists
10: Crystalline limestones, marbles
11: Gneisses
12: Olistholites, peridotites, ophiolites, serpentinites

BEFORE and AFTER Images
Satellite image of the flooded Metamorphosis region, Karditsa prefecture

Flooding of Thessaly induced by the DANIEL storm
Satellite Images
Flooding of Thessaly induced by the DANIEL storm

Flooding Areas

Trikala
Karditsa
Larissa
Volos

Sentinel-1 • 07/09/2023 - 19:24 Τοπική
A satellite image shows flooded fields at east Palamas during floods, Greece, September 9, 2023.
Maxar Technologies/Handout via REUTERS
Destroyed/Damaged BRIDGES
More than 70 bridges collapsed in the Thessaly region from the deadly floods caused by the sweeping passage of storm Daniel. 

[https://www.protothema.gr/politics/article/1417446/kakokairia-daniel-terasties-oi-zimies-stis-upodomies-tis-thessalias-/]

Most of them are 50 years old, but a few were much younger.

We note the relatively modern Diava bridge (near Kalambaka and Meteora), a multispan bridge which was repaired after a flood-triggered pier failure in 2016. Now, during “Daniel”, another central pier tilted/settled due to scouring from Pinios river.

**IMPORTANT OBSERVATION–CONCLUSION:**

Notice in the photos (which follow) that in most bridge failures, the destruction originated either from the weakest abutment which was swept away, or from a central pier whose foundation was undermined by scouring.
List of some main bridges damaged by “Daniel”

- Diava, Kalambaka
- The suspension pedestrian bridge of Tempi
- Argyris Bridge in Mouzaki
- Vrychonas Bridge in Kato Lechonia, Volos
- Ampelias bridge in Farsala
- Kaklitzorema Bridge in Farsala
- Xirias bridge in Almyros
- Palaeopyrgos bridge of Larissa
- Kala Nera bridge in Pelion
- Stournareika bridge, Trikala
- The arch bridge of Sarakina
Destroyed bridge near Karditsa
Bridge near Bellegrino
Bridge near Kala Nera: abutment failure

Photo: Stamos Prousalis, Reuters
Pier settlement due to scouring
Palaiopyrgos bridge
Diava Bridge

(Flooding in 2016 had damaged the bridge, by scouring and 26°-tilting of one pier. It had been fully repaired, as seen in the photo.)
The entire restoration project of Diava’s bridge, together with the additional works had a total cost of 4,600,000 euros. BUT, “Daniel” came...
The Diava Bridge after “Daniel”: Scouring, tilting and settlement again
Diava: Scouring of a pier’s foundation induced settlement and tilting of the pier, with consequent depression of the deck.
The Xirias bridge at Almyros, Volos
Xirias bridge in Almyros
Fallen deck of Xirias bridge, from eroded abutment
The first part of the Xirias bridge was built in the 1950s and its extension in the 1980s.

In September 2020, "Ianos" inflicted serious damages. It was restored and strengthened.

March 2023: "The upgrading of the bridge of Xirias is completed [...] The work of arranging the riverbed and the strengthening of the piers of the bridge have been completed."

However, part of the "upgraded" bridge collapsed during the Daniel storm.
The collapsed Xirias bridge at Almyros, Volos
The waters reached 18 meters in Tempi Valley!
The destroyed pedestrian suspension bridge at Tempi

For sixty-three years, the bridge of Agia Paraskevi in Pinios stood in the narrow valley of Tempi
Top view of the suspension bridge of Agia Paraskevi
The collapsed deck of Ampelias bridge near Farsala

The overflowing of the Enipeas river, induced the fall of the deck at the bridge which connects Karditsa and Farsala with Volos, located at the 15th kilometer of the national road Farsala-Volos.
Road bridge connecting the village of Kalo Nero with Larissa
Stournareika Bridge, Trikala
Stournareika Bridge, Trikala
On Wednesday, September 20, the installation of a military Bailey-type metal bridge with a span of 120 feet and a bearing capacity of wheeled vehicles up to 10 tons, in Stournareika, Trikala, was completed.
Stournareika Bridge, Trikala

Installed military Bailey metal bridge
The Central steel-arch Bridge of Trikala is a jewel of 19th century architecture, a symbol of the city. Constructed in 1886.
No visible damage!
Sarakina Arch Bridge
Sarakina Arch Bridge

The bridge was built in the 16th century, in 1520 by Bissarion II. In its original form, the bridge had six arches, with the third longer than the left (eastern) bank, under which passes Pinios river.

From the old bridge, four semicircular arches are preserved today, which have the following characteristics starting from the left bank:

1. The small arch, which has been built in parts, has a span of 7.50 m, a height of 3.70 m and a thickness of 0.50 m.
2. The second largest arch has a span of 16.70 m, a height of 9.70 m and thickness of 0.60 m.
3. The third arch, which is also the largest, has a span of 19.70 m, a height of 9.70 m and a thickness of 0.80 m.
4. The fourth arch on the right bank has a span of 8.50 m, a height of 3.50 m and a thickness of 0.50 m.

In 1970 the wooden structure was replaced with a concrete carrier and the deck was widened by 2 m to add sidewalks and also for the passage of wheeled vehicles. The width of the carrier and deck, in the old bridge, is 3.20 m, while with the widening it reaches 5.20 m. The total length of the bridge is 120 m.
The largest third arch with a span of 20 m collapsed from “Daniel”
Vrychonas Bridge in Kato Lechonia
The Vrychonas Bridge in Kato Lechonia:

Installed military Bailey metal bridge
Argyri’s Bridge
The collapsed deck of a small road bridge in Karditsa prefecture
Landslides & Rockfalls
Blocked road from mudslide
Rockfalls in the highway at Sxistos
A landslide in the mountainous region of Pelion
A landslide in the mountainous region of Pelion
Rockfalls in Zagora, Pelion
Rockfalls in Zagora, Pelion
A small slide and road failure in Zagora, Pelion

Photo by Eirini Saravanou
Hellenic Survey of Geology & Mineral Exploration (EAGME)
Zagora, Pelion

Hellenic Survey of Geology & Mineral Exploration (EAGME)
Zagora, Pelion

Hellenic Survey of Geology & Mineral Exploration (EAGME)
Promyri village
Pelion

Intense rock falls in the road connecting Zagora to Karavoma village
Road Damage
A car is stuck on a caved in road in Volos

(Photo: Sevina Dariotou/Eurokinissi via Reuters)
A view shows a destroyed main road connecting the tourist villages of Portaria and Makrynitsa

[Photo: REUTERS/Louisa Gouliamaki]
Cars are stuck on a bridge surrounded by flood waters in the village of Flamouli, near Trikala.
Photo: REUTERS/Stergios Spiropoulos
A flooded road, village of Nea Lefki near Larissa

Photo: Konstantinos Tsakalidis/Bloomberg
Aerial view of partially destroyed road, Volos

(PHOTO / AFP)
Aegean Motorway
Aegean Motorway
Ano Meria, near Volos

Photo: Louisa Gouliamaki, AFP
Cut roads in Pelion
Another cut road due to flooding
Damage in Railway Infrastructure
Flood-effected rail, Karditsa prefecture
The foundation disappeared ➞ the rail is on the air!
For this length the rails are on the air

Water path
The rails are unsupported.
SCOURING-induced Damage (mainly) to Buildings
In Mouzaki (near Karditsa) a 2-story RC building, that functioned as a gym, collapsed next to the river.
building displaced as a rigid body
undermined 2-story house in the village Chorto, Pelion.

[Photo: EPA/YANNIS KOLESIDIS]
The house had **rotated towards the river**, as the soil at its foundation was scoured by the storming river water.

The wooden pedestrian bridge experienced differential settlement on its left end.
A 3-story RC residential building tilted and balanced on a bus, Pelion
A wing of the Volos Nursing Home collapsed due to the rushing waters of the river.
Photos of the flooded villages and towns in Thessaly after the Daniel storm
A flooded area is seen in the aftermath of Storm Daniel, in Megala Kalyvia, Greece, September 9, 2023. [Photo: REUTERS/Giannis Floulis]
A flooded area is seen in the aftermath of Storm Daniel, in Megala Kalyvia, Greece, September 9, 2023. REUTERS/Giannis Floulis
Flood waters cover an area of the suburbs of the city of Larissa, as the levels of Pinios River have risen overnight, in Larissa, Greece, September 9, 2023.
REUTERS/Stamos Prousalis
Locals flee a flooded area on a rubber boat, as the levels of Pinios River have risen overnight, in the aftermath of Storm Daniel, in Larissa, Greece, September 9, 2023. REUTERS/Louisa Gouliamaki
A drone photograph shows a car driving on a flooded road during storm ‘Daniel’, in Piniada, near Trikala
Photo: EPA-EFE/ACHILLEAS CHIRAS
Flooded factory after storm ‘Daniel’ hit the area of Volos, Magnesia, Greece, 7 September 2023.
Photo: EPA-EFE/HATZIPOULITIS NICOLAOS
A drone photograph shows a flooded area in Piniada, near Trikala

Photo: EPA-EFE/ACHILLEAS CHIRAS
VOLOS

(Photograph: Sevina Dariotou / Eurokinissi via Reuters)
A local resident walks on a muddy road in the village of Milina
[Photo: Alexandros Avramidis, Reuters]
Floodwaters cover houses and farms in the village of Kastro, near Larissa
The village of Agiá

[Photo: STAMOS PROUSALIS VIA REUTERS]
Agiá [Photo: STAMOS PROUSALIS VIA REUTERS]
The case of Lake Carla
Lake Carla is a lake that was drained in 1962, because at that time it caused flooding in the surrounding agricultural crops.

The **draining of Lake Carla** began at the end of **August 1962** with the inauguration of the **10 km** long tunnel and was one of the most important projects for the development of Greek agriculture.

After the Daniel storm, Lake Carla regained its initial area (and more) as can be seen from the satellite images of the next slides.
Satellite image at 31st August

After the Daniel storm, Lake Carla regained its old size

31/08/2023

Satellite image at 16th September

the small remnant of Lake Carla

16/09/2023

190,000 acres

After the Daniel storm, Lake Carla regained its old size
A photo of 1962, after draining Lake Carla
Area of water surface

DANIEL Storm: The Carla Lake
Structural Damage
Until 25th September, the Civil Protection, the Greek Army, the Technical Chamber of Greece have carried out a total of 17 453 structural autopsies.

From the inspections, so far:

- **439 houses** and other buildings have been identified as **dangerous to use** ["red"],

- **376 houses** and other buildings that are characterized as **temporarily unfit to use – before repair** [“yellow”]

- **782 houses** and other buildings characterized as **suitable to use in need of minor repairs** ["green"]

Source: Kathimerini
A residential building in Pelion
Totally collapsed stone building
stone building subjected to differential settlement
partial collapse of a 2-story stone building
REFERENCES


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