MEDITERRANEAN TROPICAL CYCLONE REPORT

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Tropical Storm Daniel
7-10 September 2023

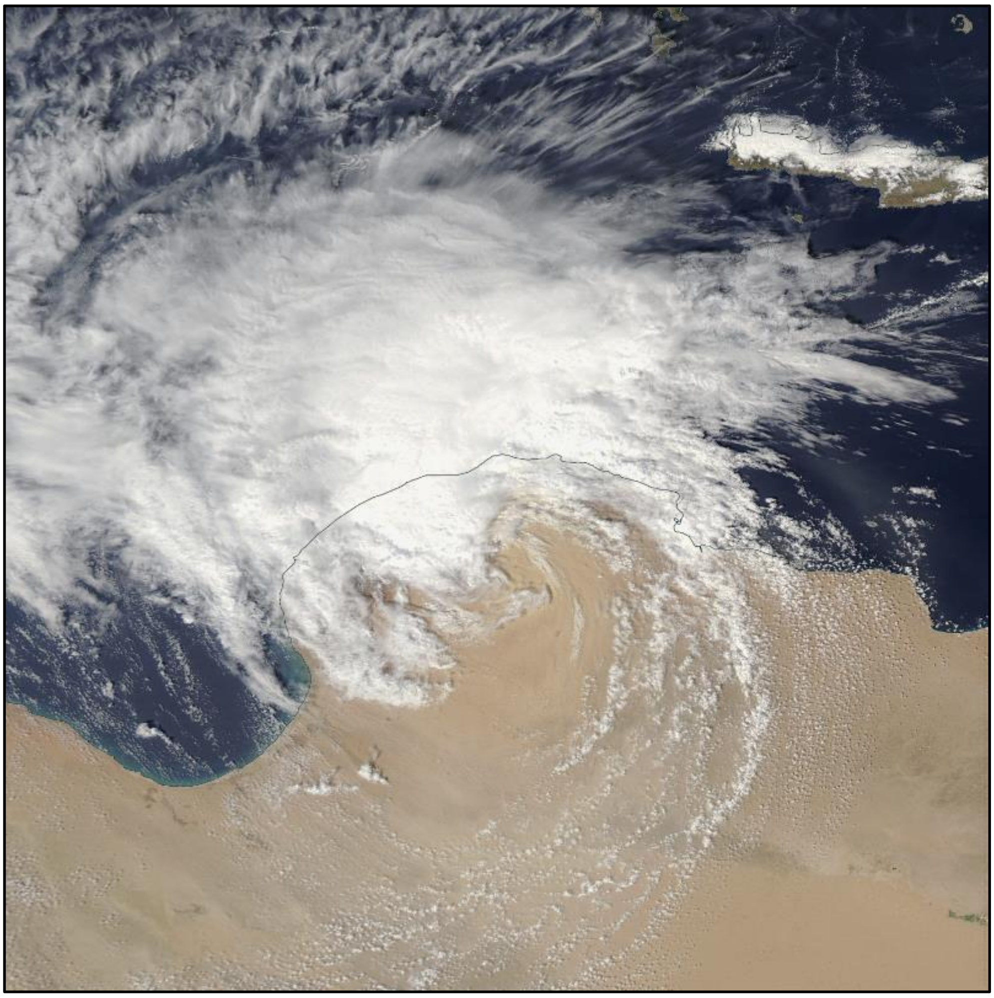

Image: NASA

Daniel (named by Hellenic National Meteorological Service) was the deadliest tropical cyclone in the Mediterranean basin in the satellite era. The cyclone formed from an upper-level cut-off low and caused extremely large amounts of rain in Greece and in Libya with severe floods and mudslides, which resulted to more than 10,000 fatalities in Libya.

Synoptic history

On 2-3 September a weak, but fast-moving cold front crossed Central Europe from north to south. Associated with the front, an upper-level trough also reached the Balkan Peninsula and generated a cut-off low near Greece on 4 September. Simultaneously, another cut-off low affected Southwest Europe while a strong anticyclone and upper-level ridge extended from the Central Mediterranean Sea toward Central Europe, lead to the formation of a classical Omega-blocking pattern. The Greek low, which was named to 'Daniel' by the Hellenic National Weather Service, did not develop well-defined fronts, but thanks to the instable atmospheric conditions, the warm water and long-lasting, strong convergence zones around it, sustained and heavy thunderstorms affected Greece, the western half of Turkey and the eastern coastline of Bulgaria on 5 and 6 September. The most persistent convective cluster formed along the Aegean coast of Thessaly on the first day (Fig. 3).

Meanwhile, the center of the low gradually moved away from Greece to south-southwest, over an area of anomalously warm sea surface temperature of 26-28 °C, and disorganized, scattered showers and thunderstorms developed around it from 5 September. In the next morning, the cyclone stalled over the Central Mediterranean Sea and started to take subtropical appearance on satellite images (Fig. 4), however, the thunderstorms weakened near the center in the afternoon hours. In the early morning of 7 September, a very strong convective band with cloud top temperature periodically around -60, -65 °C formed north-northeast of the center and it lasted until the next morning (Fig. 5). Temporarily some showers or weaker thunderstorms appeared near the center again, and based on the increasing convective organization, it estimated that Daniel became subtropical storm by 0600 UTC 7 September. At this time, the cyclone took more compact structure as the farther thunderstorms over Greece gradually dissipated. By the midday hours of 8 September, the convection weakened a bit, but stronger cells with cloud top temperature around -50, -55 °C still appeared occasionally, and the low-level center relocated to west, closer to the western part of the convective cluster. At this time, upper-level outflow increased on the north side of the storm, but cyclonic upper-level flow was still evident near the cyclone's center.

In the evening hours, the cyclone started to move slowly southeastward, followed by a temporary eastward turn in the second half of the night, and the convection tried to wrap around the center, but it weakened soon on the south side due to dry air intrusion. However, the upper-level outflow expanded on the western side of the cyclone, also appeared on the south side for a short time, indicated that Daniel transitioned into a tropical storm by 0000 UTC 9 September. In the morning hours, a stronger convective band with cloud top temperature of -50, -55 °C developed on the north side of the low, which gradually expanded toward the western side of the circulation, followed by a rapid structural change to curved band pattern in the late afternoon hours, while upper-level outflow also became more robust (Fig. 6). This process likely caused some strengthening, however, dry Saharan air wrapped into the circulation from east-southeast, so the convection quickly became disorganized and weaker in the evening hours. At this time, Daniel turned back to southeast, and its forward speed increased, so it made landfall in Libya, northeast of *Benghazi* around 0000 UTC 10 September. After the landfall, the convection continued to weaken and concentrated only to the north side of the circulation, but from the late morning hours it deepened again somewhat near the coastline. Through the daytime, the convective cluster steadily increased in size, and it stayed quite close to the low-level center and curved bands were still evident, while the upper-level outflow remained well-defined on the north side of the cyclone. These indicated that Daniel remained a tropical storm at this time, and it likely strengthened back slightly. Strong winds led to extensive dust storms around its circulation, which was visible well on the satellite images on the southern, cloud-free areas (Fig. 7). In the night hours, the low-level center gradually moved away from the decaying convection, thus the cyclone became post-tropical by 0600 UTC 11 September. The remnant vortex moved to east and cross the border of Libya and Egypt around 0730 UTC. By this time, most of the precipitation ceased near the cyclone's center as well as along the coastline of Libya. Ex-Daniel approached the delta of Rivel Nile in the night hours, but it degenerated into a trough of low-pressure area after 0000 UTC 12 September.

Meteorological statistics

Although Daniel spent most of its lifetime over the open sea, ship reports (Table 3) and various satellite-based measurements and estimates like ASCAT (Fig. 8), SMAP and AMSR were also very useful in determining the strength and the transformation of the cyclone. Some surface wind and pressure measurements also were available, mainly from Libya (Table 2). The cyclone caused very high amount of precipitation, which data were collected from Greece (Table 4.a) and from Libya (Table 4.b).

Winds and pressure

As the cut-off low formed near the western coastline in Greece, strong pressure gradient generated gale-force winds over the Ionian Sea, west of its center, indicated by ship reports and satellite measurements. On 4 and 5 September, some nearby ships and surface weather stations of *Andravida*, *Kalamata* and *Zakinthos* airports measured steadily decreasing pressure from 1005-1006 hPa to 1002-1003 hPa, while the strongest wind gusts – at least partially associated with thunderstorms – were around 60-80 km/h (35-45 kt). However, as the cyclone's center moved away from Greece, the wind lessened down slightly. Although SMAP still showed gale-fore winds occasionally, ASCAT and AMSR sensors as well as ships indicated maximum sustained winds of 50-55 km/h (25-30 kt) until the evening hours of 6 September, and the central pressure also increased by a few hPa in this period.

In the next 2 days, the cyclone gradually strengthened as it became subtropical. At 0200 UTC 7 September, the ship '3FAT9' reported sustained winds of 69 km/h (37 kt) north of Daniel's center, followed by more measurements of gale-force wind on 8 September, including the maximum of 80 km/h (43 kt) from ship 'ZCEE2' at 0500 UTC near the center and 83 km/h (45 kt) from ship 'EUMDE10' at 1000 UTC farther northeast. The latter was partially associated to the strong gap wind effects between the southern parts of the Peloponnese and Crete, which generated an east-west channel of gale-force winds toward the circulation of Daniel. This situation also caused long-lasting windy weather in *Kythira* with sustained winds around 70-80 km/h (40-45 kt) and wind gusts sometimes around 110 km/h (60 kt). At 1626 UTC 7 September, SMAP showed maximum winds of 98 km/h (53 kt), but this data appeared to be an error based on other measurements. ASCAT and AMSR data indicated that winds increased to around 85 km/h (45 kt) in the afternoon hours of 8 September, so Daniel likely reached this strength before its transitioned into a tropical storm in the night.

Unfortunately, no measurements were available in the vicinity of the cyclone in the late morning and afternoon hours of 9 September, when the quick convective development occurred, but based on the increased structural organization, Daniel likely gained some strength and reached its estimated peak intensity with winds around 95 km/h (50 kt) and central pressure around 996 hPa at 1800 UTC. However, the storm could have been slightly stronger around 1500-1600 UTC, before the convection started to weaken. Around 1920 and 2000 UTC, ASCAT-C and ASCAT-B sensors measured maximum winds around 80-85 km/h (42-45 kt), so the weakening of the cyclone began as soon as its convective structure deteriorated, and this trend lasted until 0600 UTC 10 September. At 0000 UTC, about the time of the Libyan landfall, *Benina* reported pressure of 999.3 hPa a bit southwest of the cyclone's center and it measured sustained winds of 65 km/h (35 kt) at 0900 UTC when the storm moved away to east-southeast. In the daytime, the cyclone likely strengthened back slightly despite its located over land, since an ASCAT pass measured maximum winds of about 85 km/h (45 kt) near the coastline around 1900 UTC and *Derna* reported sustained winds of 74 km/h (40 kt) at 2100 and 0000 UTC. As the cyclone moved further inland on 11 and 12 September, the winds quickly decreased under gale-force strength around its core, but the central pressure increased more steadily. Additionally, some ships over the Eastern Mediterranean Sea still measured sustained winds around 60-65 km/h (30-35 kt) occasionally.

Rainfall

Damiel and its precursor cut-off low caused very high amount of precipitation in the Central Mediterranean region, especially in Greece, in Libya and smaller parts of Bulgaria and Turkey. In Greece, the most affected region was Thessaly, where the easterly flow transport moist airmass from the Aegean Sea, which led to precipitation excess along the coastline and on the east side of the Pindus Mountains. On 4 September, rain over 100 mm had already fell in some places, while on 5 September, the earlier mentioned long-lasting, nearly stationary convergence zone caused heavy thunderstorms around *Zagora*, *Portaria* and *Volos*, where the daily precipitation amounts reached about 450-750 mm. The summary was 761.9 mm in *Portaria* and 759.6 mm in *Zagora*. The former set a new all-time daily maximum record in Greece, broke the earlier value of 664.7 mm in *Antipata* associated with Hurricane Ianos in September 2020 *(Lagouvardos et al.*[1]*)*. On the next day, long-lasting thunderstorms affected the middle parts of Thessaly with precipitation amounts between 100-400 mm and a maximum of 404.4 mm in *Karditsa*. On 7 September, another round of heavy thunderstorms occurred near *Zagora*, where it fell 197.6 mm rain, and the 4-daily amount reached 1095.6 mm. As the cyclone moved away from the country, most of the rainfalls ceased by the next day. Especially on 4 and 5 September, on the Black Sea coast of Bulgaria and Turkey also were affected by intense thunderstorms with 24-hourly precipitation values locally around 200-300 mm. In *Tsarevo* 330 mm rain fell within 20 hours.

As Daniel slowly approached Libya, showers and thunderstorms had already occurred along the northwest coastline between 7 and 9 September with daily summaries around 20-50 mm in some places, for example 48.0 mm in *Misrata* on 9 September. After the landfall, long-lasting thunderstorms affected the northeast coastline on 10 September, led to enormous

[1]*Lagouvardos K, A. Karagiannidis. S. Dafis, A. Kalimeris, and V. Kotroni (2022): Ianos – A hurricane in the Mediterranean, Bulletin of the American Meteorological Society, 103 (6): E1621–E1636. https://doi.org/10.1175/BAMS-D-20-0274.1*

precipitation amount in Jebel Akhdar mountains. The daily rain amount reached 414.1 mm in *Bayda* and rain summaries of 100-200 mm were measured in some nearby cities. The eastward-moving, weakening cyclone also caused precipitation of 5-10 mm in the extreme northeast parts of Libya as well as along northern coast of Egypt on 11 and 12 September.

The heavy thunderstorms triggered severe flash floods in the region of *Volos* and *Zagora* (Greece) *Tsarevo* (Bulgaria) and *İğneada* and *Istanbul* (Turkey) on 5 and 6 September (Fig. 9), and in *Derna* (Libya) on 10 September. Additionally, widespread, prolonged floods occurred in the middle parts of Thessaly (Fig. 10, Fig. 11). The floods led to extensive damages in the affected areas, including infrastructure, buildings and agriculture. Unfortunately, at least 28 people died in Greece, Bulgaria and Turkey, while the death toll is estimated to have exceeded 10,000 in Libya, especially in *Derna*, where two dams of Wadi Derna collapsed in the early morning hours of 11 September, and a large part of the city was completely washed away by the flash flood and mud, partially into the Mediterranean Sea (Fig. 12, Fig. 13a-b, Fig. 14a-b). The catastrophe likely destroyed the meteorological station of the city since it reported its last data at 0000 UTC 11 September. It measured total rain of 73.0 mm by that time, from which 58.0 mm fell in the preceding 6 hours.

Storm surge

Since the cyclone produced relatively steady winds of around 65-85 km/h (35-45 kt), the maximum significant wave heights were around 3.0-4.5 m (10-15 ft) in all day between 4 and 11 September according to the various satellite measurements. Large waves likely enhanced the damage in the coastal parts of *Derna*, also swept away the debris and dead people, even more than 10-20 km from the city.

Reanalysis data

Daniel was analyzed by ECMWF ERA-5 high-resolution reanalysis data. The examined parameters were 250 hPa divergence and winds (Fig. 15), 925 hPa geopotential and 850 hPa vertical speed (Fig. 16), 850 hPa equivalent potential temperature and wind (Fig. 17), 500-1000 hPa thickness and 850 hPa relative vorticity (Fig. 18), 200-1000 hPa thickness and 300 hPa potential vorticity (Fig. 19) and vertical cross-sections of potential vorticity (Fig. 20). The analysis ranged from 0000 UTC 4 September to 2100 UTC 12 September. However, only two images are listed here. The first one is at 1800 UTC 9 September, when the cyclone reached its peak intensity, and the second one is at 1800 UTC 10 September, when it located over

Northeast Libya – except the upper-level divergence and wind map, which shows the 1500 UTC data, when the poleward outflow was more remarkable. An animation of all reanalysis maps is available here:

https://www.youtube.com/watch?v=Owq8PCpllyk

The formation of Daniel followed the classical synoptic process. As the upper-level cut-off low reached the Balkan Peninsula on 4 September, the circulation of the associated jet streak on its west side generated upper-level divergence along the western coastline of Greece, where the surface low formed. The genesis was also triggered by upper-level potential vorticity advection, while the local flows enhanced the relative vorticity and – for a short time – the updrafts at 850 hPa near the cyclone's center. On 5 September, the upper-level potential vorticity wrapped over the central areas, but it quickly weakened thereafter. Simultaneously, the upper-level low became more dominant on the 250 hPa wind map, although the jet stream started to weaken, however, stronger winds of around 30 m/s expanded to the southern, then the eastern side of the low. This caused sustained upper-level divergence over Greece, which support the formation of the strong and long-lasting convective clusters on 5 and 6 September. In the first day, one of the strongest divergent areas was located over the east coastline of Thessaly, and from 2100 UTC 4 September to 1200 UTC 5 September, the strongest updrafts at 850 hPa with vertical velocity occasionally between -5 and -10 Pa/s also marked well the intense convection in that region. Another supporting effect was the advection of the moist air from the Aegean Sea, which was represented well by the 850 hPa wind and equivalent potential temperature (EPT) map. As for the central part of the cyclone, the 925 hPa geopotential decreased slightly by the morning hours of 5 September, followed by a slowly increasing thereafter, in line with the real pressure measurements around Daniel. The updrafts also weakened as it moved away from Greece, but the 850 hPa relative vorticity remained moderate and concentrated in the core. After its formation, the cyclone ingested cooler and drier air from north, so the 850 hPa EPT was quite low around its center on 4 and 5 September but it started to increase thereafter as the sea gradually warmed up and moistened the airmass.

On 7 and 8 September the 850 hPa relative vorticity and updraft became a bit more elongated, but also slightly stronger on the north-northeast side of the cyclone, where intense and long-lasting convection occurred on these days, and the EPT also increased further. Meanwhile, the upper-level low aloft lost its organization and anticyclonic, divergent flow developed on the north side of the surface low, toward Italy and western Balkans. This became a well-defined poleward outflow channel on 9 September, which was even more visible at 225 hPa (not shown here). A jet streak also remained close to Daniel to east-southeast, but the storm was in the left entrance quadrant of its circulation, which would have caused upper-level convergence and sinking air, instead, the strong divergence lasted above it until 10 September, so it likely did not have much effect. Additionally, the cyclone remained in a weak-shear environment. On 9 September, the 850 hPa EPT and relative vorticity concentrated into the cyclone's center and continued to increase slightly, while the wind field became much more symmetrical. However, the warm core did not appear very well on the thickness maps, especially between 200-1000 hPa, mainly due to the sharp contrast near the cyclone since it was located on the periphery of the colder area (lower thickness values) associated with the former upper-level low. The vertical cross-section of potential vorticity showed a PV tower in the low- and mid-levels, which was not fully contacted to the upper-level anomalies, suggested that the storm developed its weak warm core from the lower levels by convective heating, in line with the ATMS satellite data (see 'Upper-level temperature data' section). On this day, the 925 hPa geopotential did not change much and only weak upstream areas appeared around the center, which likely underrepresented the cyclone based on its satellite appearance. This was also indicated by the fact that after the landfall, in the afternoon hours of 10 September, the geopotential in the cyclone's center decreased more than 500 m^2/s^2, which seemed unrealistic. Also, much stronger updrafts appeared around the center despite the deepest convection produced similar or a bit higher cloud top temperature values compared to the previous day; however, this can be partially explained by the topography as strong northerly flow generated upslope winds over the Jedel Akhdar mountains. Additionally, the upper-level flow interacted with a small upper-level vortex west of Daniel, which increased the upper-level divergence on the north side of the storm again, and this process likely generated stronger upstreams. The 850 hPa EPT remained high in the core, but the wind strengthened on the west side of the circulation and advected dryer, cooler air from north, which wrapper around the center by the next morning. In the afternoon hours of 10 September, the 850 hPa relative vorticity also became much stronger, and the warm core appeared better in both thickness maps for some hours. The PV tower also reached the upper troposphere on the cross-sections at this time, indicating deeper warm core, and it became a bit stronger at the lower levels, which again came to an agreement with ATMS satellite measurements. On 11 September, Daniel gradually lost its organization as it became shallower and moved under the jet stream, which caused stronger wind shear.

Upper-level temperature data

CIMSS provided ATMS brightness temperature data from NOAA-20 and NOAA-21 satellites associated with Daniel. At 0104 UTC 9 September (Fig. 21a-d), shortly after the tropical transition completed, the cyclone consisted of a curved band of convection with sporadic deeper patches, but the upper-level warm core was not yet well-defined, only a shapeless warmer area was visible near the cyclone’s center. By 1219 UTC (Fig. 22a-d), a larger band of deep convection formed northwest of the center, and its cooling effect appeared well around 550 hPa (CH06 image, not shown). Around 350 and 200 hPa (CH07 and CH08 images) the warm spot became stronger in the center with positive anomaly around 1.0-1.5 K compared to its surroundings, but around 150 hPa (CH09 image) it was not yet detectable. At 0021 UTC 10 September (Fig. 23a-d), about the time of the landfall, the convection weakened significantly, but the structure of the warm core did not change much, however, slight anomaly appeared around 150 hPa (CH09) too. By 1139 UTC (Fig. 24a-d), deep convection redeveloped on the northwest side of the storm, which was visible very well again around 550 hPa (CH06, not shown) and slightly even around 350 hPa (CH07), while the strength of the warm core remained the same. The warm anomaly in the core became the strongest by the time of the last available measurement, at 0025 UTC 11 September (Fig. 25a-d)[2], when the cyclone had already started to weaken. Around 350 and 200 hPa (CH07 and CH08) the warm anomaly reached about 1.5-2.0 K, while the air was about 1.0-1.5 K warmer around 150 hPa (CH09).

[2] *Remark: at this time, the center position on the images given by CIMSS (near 31.8N, 21.5E) seems to be incorrect, since infrared satellite images and surface measurements indicated more east-southeastward position (31.4N, 23.1E) at 0000 UTC, which aligned better to the warmest areas.*

Table 1 Best track for Daniel, 4-12 September 2023

Day/Time [UTC]	Latitude [°N]	Longitude [°E]	Pressure [hPa]	Wind speed [km/h *(kt)*]	Stage
04 / 1200	38.1	20.5	1006	65 *(35)*	low
04 / 1800	37.6	20.4	1005	65 *(35)*	”
05 / 0000	37.0	20.9	1003	55 *(30)*	”
05 / 0600	37.1	19.5	1003	55 *(30)*	”
05 / 1200	36.5	18.7	1003	55 *(30)*	”
05 / 1800	35.3	18.1	1002	55 *(30)*	”
06 / 0000	34.7	18.4	1002	55 *(30)*	”
06 / 0600	34.9	18.4	1002	55 *(30)*	”
06 / 1200	34.8	18.1	1003	55 *(30)*	”
06 / 1800	34.8	17.7	1004	55 *(30)*	”
07 / 0000	33.9	17.1	1004	65 *(35)*	”
07 / 0600	33.9	18.0	1004	65 *(35)*	subtropical storm
07 / 1200	34.0	18.6	1003	65 *(35)*	”
07 / 1800	34.1	18.9	1003	65 *(35)*	”
08 / 0000	34.3	19.4	1003	75 *(40)*	”
08 / 0600	34.3	17.7	1003	75 *(40)*	”
08 / 1200	34.2	16.7	1002	85 *(45)*	”
08 / 1800	33.5	17.3	1002	85 *(45)*	”
09 / 0000	33.0	17.8	1001	85 *(45)*	tropical storm
09 / 0600	33.0	18.0	1000	85 *(45)*	”
09 / 1200	33.1	18.7	997	95 *(50)*	”
09 / 1800	33.0	19.3	996	95 *(50)*	”
10 / 0000	32.4	20.2	997	85 *(45)*	”
10 / 0600	32.1	21.1	998	75 *(40)*	”
10 / 1200	31.9	21.7	997	85 *(45)*	”
10 / 1800	31.6	22.6	997	85 *(45)*	”
11 / 0000	31.4	23.1	998	75 *(40)*	”
11 / 0600	30.5	24.3	999	55 *(30)*	post-tropical
11 / 1200	30.3	26.2	1000	45 *(25)*	”
11 / 1800	29.9	27.5	1001	35 *(20)*	”
12 / 0000	30.0	28.9	1002	35 *(20)*	”
12 / 0600					dissipated
09 / 1800			996	95 *(50)*	minimum pressure and maximum wind
10 / 0000			997	85 *(45)*	landfall near Benghazi

Table 2 Selected surface winds and pressure observation

Location	Minimum sea level pressure		Maximum surface wind speed		
	Day/Time [UTC]	Pressure [hPa]	Day/Time [UTC]	Sustained (10-min) [km/h *(kt)*]	Gust [km/h *(kt)*]
Aktion airp. (Greece)			04 / 1200	37 *(20)*	70 *(38)*
Kalamata airp. (Greece)			04 / 1200	9 *(5)*	80 *(44)*
Andravida airp. (Greece)	04 / 1500	1006.7	04 / 1500	26 *(14)*	52 *(28)*
Zakinthos (Greece)			04 / 1500	9 *(5)*	59 *(32)*
Kalamata airp. (Greece)	05 / 0300	1003.6			
Aktion airp. (Greece)			05 / 0900	46 *(25)*	65 *(35)*
Luqa (Malta)			06 / 1800	39 *(21)*	61 *(33)*
Kythira (Greece)			07 / 1200	78 *(42)*	113 *(61)*
Kythira (Greece)			08 / 0600	78 *(42)*	108 *(58)*
Sirte (Libya)			09 / 1800	48 *(26)*	
Tobruk (Libya)			09 / 2100	48 *(26)*	
Benina (Libya)	10 / 0000	999.3	10 / 0000	46 *(25)*	
Benina (Libya)	10 / 0900	1006.0	10 / 0900	65 *(35)*	
Derna (Libya)			10 / 2100	74 *(40)*	
Derna (Libya)			11 / 0000	74 *(40)*	
Tobruk (Libya)	11 / 0000	1001.5			
Sallum Plateau (Egypt)	11 / 0300	1001.0	11 / 0300	52 *(28)*	
Giarabub (Libya)	11 / 0600	1002.2			
Dabba (Egypt)	11 / 1500	1001.7			
Dabba (Egypt)	11 / 1800	1002.4			
Dabba (Egypt)	12 / 0000	1003.4			

Table 3 Selected ship reports

Day/Time [UTC]	Ship call sign	Latitude [°N]	Longitude [°E]	Wind dir [°] /speed [km/h *(kt)*]	Pressure [hPa]
04 / 1200	ZCEW2	38.4	19.8	350 / 65 *(35)*	1005.9
04 / 1800	VRBH9	36.3	20.8		1006.3
04 / 1800	9HJD9	36.4	21.6	130 / 46 *(25)*	
05 / 0000	3FZI8	38.3	20.1	060 / 48 *(26)*	
05 / 0200	EUMDE61	35.1	20.3	300 / 30 *(16)*	1004.1
05 / 0400	9HA5077	35.2	19.9	250 / 43 *(23)*	1005.5
05 / 0400	EUMDE61	35.0	21.0	300 / 22 *(12)*	1004.0
05 / 1000	9HA4766	35.3	18.4	320 / 33 *(18)*	1004.1
05 / 1800	OZDK2	35.5	17.7	050 / 50 *(27)*	1003.4
06 / 0800	OZDK2	34.4	20.8	230 / 43 *(23)*	1007.5
06 / 2000	C6FZ7	36.9	16.3		1007.0
06 / 2200	EUMDE40	36.1	15.6	020 / 43 *(23)*	1008.8
07 / 0000	C6FZ7	36.7	17.4		1005.7
07 / 0200	3FAT9	34.9	19.4	100 / 69 *(37)*	1006.3
07 / 0400	EUMDE40	35.7	17.0	020 / 25 *(14)*	1006.1
07 / 0700	3FFA5	36.8	19.5	090 / 54 *(29)*	1011.5
07 / 1000	EUMDE40	35.4	18.5	080 / 54 *(29)*	1005.6
07 / 1300	EUMDE40	35.2	19.2	080 / 43 *(23)*	1004.8
07 / 1900	EUMDE10	36.4	19.4	070 / 54 *(29)*	1008.4
08 / 0000	EUMDE10	36.0	20.3	100 / 65 *(35)*	1006.0
08 / 0200	EUMDE10	35.9	20.7	100 / 61 *(33)*	1005.7
08 / 0500	ZCEE2	36.0	16.4	360 / 80 *(43)*	1005.3
08 / 0900	ZCEE2	36.1	17.8	050 / 74 *(40)*	1009.3
08 / 1000	EUMDE10	35.3	22.2	070 / 83 *(45)*	1008.0
08 / 1200	WMPP	35.4	18.1	080 / 39 *(21)*	1004.2
08 / 2100	WTAA	35.8	16.9	030 / 54 *(29)*	1010.1
09 / 0000	WTAA	35.6	17.8	030 / 56 *(30)*	1009.2
09 / 0500	WTAA	35.3	19.4	060 / 65 *(35)*	1007.9
09 / 0900	7KNF	35.1	19.9	130 / 50 *(27)*	1008.0
10 / 0500	VRRQ5	34.3	22.7	040 / 48 *(26)*	1008.7
10 / 1800	DIXJ2	34.1	23.0	020 / 52 *(28)*	1005.3
10 / 2100	DIXJ2	34.4	22.0	030 / 56 *(30)*	1007.9
11 / 0400	9V5395	34.6	23.8	050 / 63 *(34)*	1004.0
11 / 0800	9V5395	34.2	25.0	020 / 61 *(33)*	1005.0

Table 4.a Selected surface rainfall observation (in Greece)

Location	Rain on 4 Sep. [mm]	Rain on 5 Sep. [mm]	Rain on 6 Sep. [mm]	Rain on 7 Sep. [mm]	Rain on 8 Sep. [mm]	Total rain [mm]
Zagora	**134.6**	759.6	3.8	**197.6**	0.6	1096.2
Portaria**	108.2	**761.9**	14.4	-	0.0	884.5
Anilio (mount.)	20.6	148.2	374.6	149.2	**2.6**	695.2
Karditsa	42.4	185.2	**404.4**	26.8	0.0	658.8
Volos	35.2	450.8	121.0	10.4	0.0	617.4
Kofoi	23.4	152.6	342.2	32.2	0.2	550.6
Trikala	17.6	116.6	256.8	86.4	0.0	477.4
Chalkiades	19.6	205.6	223.2	17.8	0.0	466.2
Oreoi	71.4	187.4	181.4	6.6	0.0	446.8
Skiathos Xanemos	42.4	321.8	0.8	33.6	0.0	398.6
Metsovo (mount.)	20.2	91.8	204.0	75.8	0.8	392.6
Domokos	40.4	110.0	225.2	6.4	0.0	382.0
Neradia	19.6	226.6	99.2	23.8	0.0	369.2
Kalampaka	10.8	94.2	165.8	85.2	0.2	356.2
Istiaia	41.2	192.0	111.8	10.4	0.0	355.4
Agia	11.2	218.6	15.4	90.6	0.0	335.8
Theodoriana	25.2	79.6	174.8	12.2	0.0	291.8
Pramanta	21.0	74.2	163.6	11.6	0.0	270.4
Skiathos airport*	125.0	120.0	3.0	18.2	0.0	266.2
Gonnoi	14.0	147.4	31.4	71.2	0.2	264.2
Lepiana	7.6	89.4	135.4	17.8	0.0	250.2
Lamia	24.6	22.8	167.0	10.6	0.2	225.2
Katarraktis	9.2	85.4	121.0	4.8	0.0	220.4
Vasilitsa (mount.)	17.8	55.8	73.6	62.6	2.0	211.8
Agios Georgios	10.4	96.0	50.6	25.6	0.0	182.6
Dasochori	13.8	98.6	46.4	23.0	0.0	181.8
Thermopyles	17.4	10.1	117.2	29.8	0.4	174.8
Larissa airport*	68.9	54.0	41.6	8.0	0.0	172.5
Glossa	49.0	104.4	0.4	15.0	0.2	169.0
Nesson	11.6	78.0	3.6	71.6	0.2	165.0
Elassona	26.4	72.2	19.6	40.8	0.0	159.0
Agia Triada	4.2	8.6	100.6	24.4	0.0	137.8
Athens airport*	0.0	0.4	105.4	0.0	0.0	105.8

**daily data are between 06-06 UTC, elsewhere between 00-00 UTC (daily maximums are bold blue)*

***missing data on 7 September*

Table 4.b Selected surface rainfall observation (in Libya)

Location	Rain on 7 Sep. [mm]	Rain on 8 Sep. [mm]	Rain on 9 Sep. [mm]	Rain on 10 Sep. [mm]	Rain on 11 Sep. [mm]	Total rain [mm]
Bayda				**414.1**		414.1
Marawah				240.0		240.0
Al-Marj	0.0	1.0	43.0	168.0	0.0	212.0
Labraq				170.0		170.0
Qasr Libya				158.5		158.5
Derna*	0.0	0.0	0.0	73.0	-	73.0
Misrata	2.0	2.0	**48.0**	0.0	0.0	52.0
Al Mabni				48.0		48.0
Benina	1.0	0.0	15.0	30.0	0.0	46.0
Yerfen	**21.0**	14.0	10.0	0.0	0.0	45.0
Al-Abyar				41.0		41.0
Garyan	17.0	7.0	11.0	0.0	0.0	35.0
El Khoms	4.0	**22.0**	8.0	0.0	0.0	34.0
Espiaa	7.0	7.0	9.0	0.0	0.0	23.0
Sirte	0.0	0.0	7.0	0.0	0.0	7.0
Tobruk	0.0	0.0	0.0	0.0	**4.0**	4.0
Ajdabiya				3.2		3.2
Giarabub				0.3		0.3

all daily data are between 06-06 UTC (daily maximums are bold blue)
**station did not reported data after 11 September 0000 UTC*

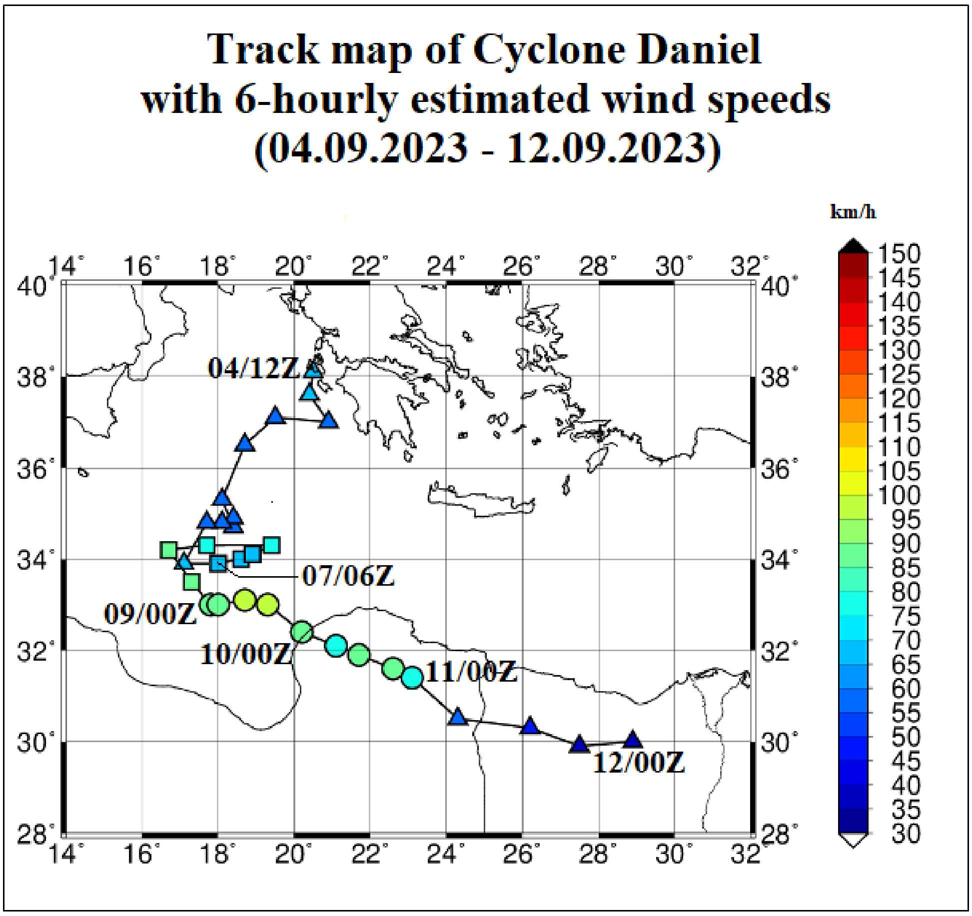

Figure 1. Best track positions for Tropical Storm Daniel, 4-12 September 2023. The triangles mean low/post-tropical, the squares subtropical and the circles tropical stage. The colors represented the estimated wind speeds (from Table 1) at the actual time. The position based on satellite images and ECMWF reanalysis.

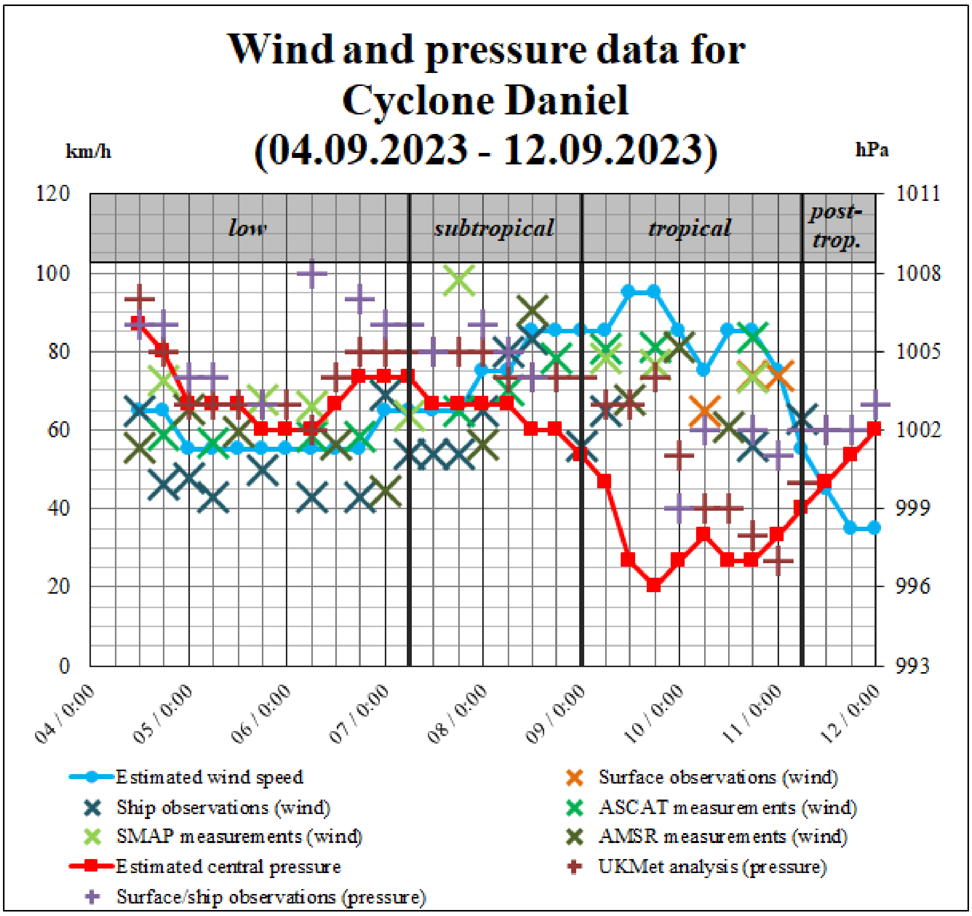

Figure 2. Selected wind and pressure observations with estimated maximum sustained wind and minimum central pressure for Tropical Storm Daniel, 4-12 September 2023. The stated 6 hourly data mean the maximum sustained wind within a 3-hour interval around the marked time in case of all measurements.

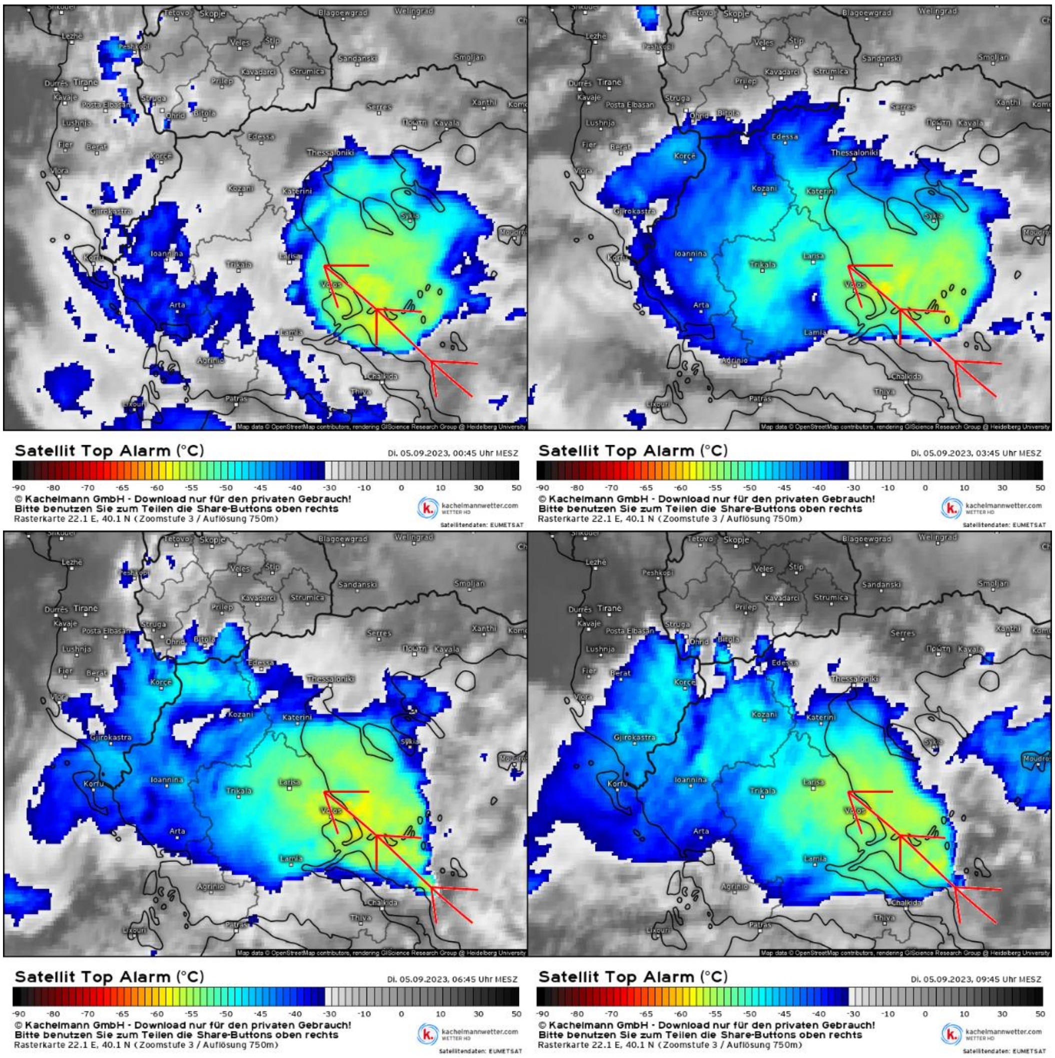

Figure 3. Cloud top temperature satellite images of Daniel at 2245 UTC 4 September and 0145 UTC, 0445 UTC and 0745 UTC 5 September. A stationary convergence zone along the coastline of the Aegean Sea generated sustained deep convection for hours, and heavy thunderstorms caused very high amount of precipitation as well as severe flash floods in that area. *Source: EUMETSAT / Kachelmannwetter*

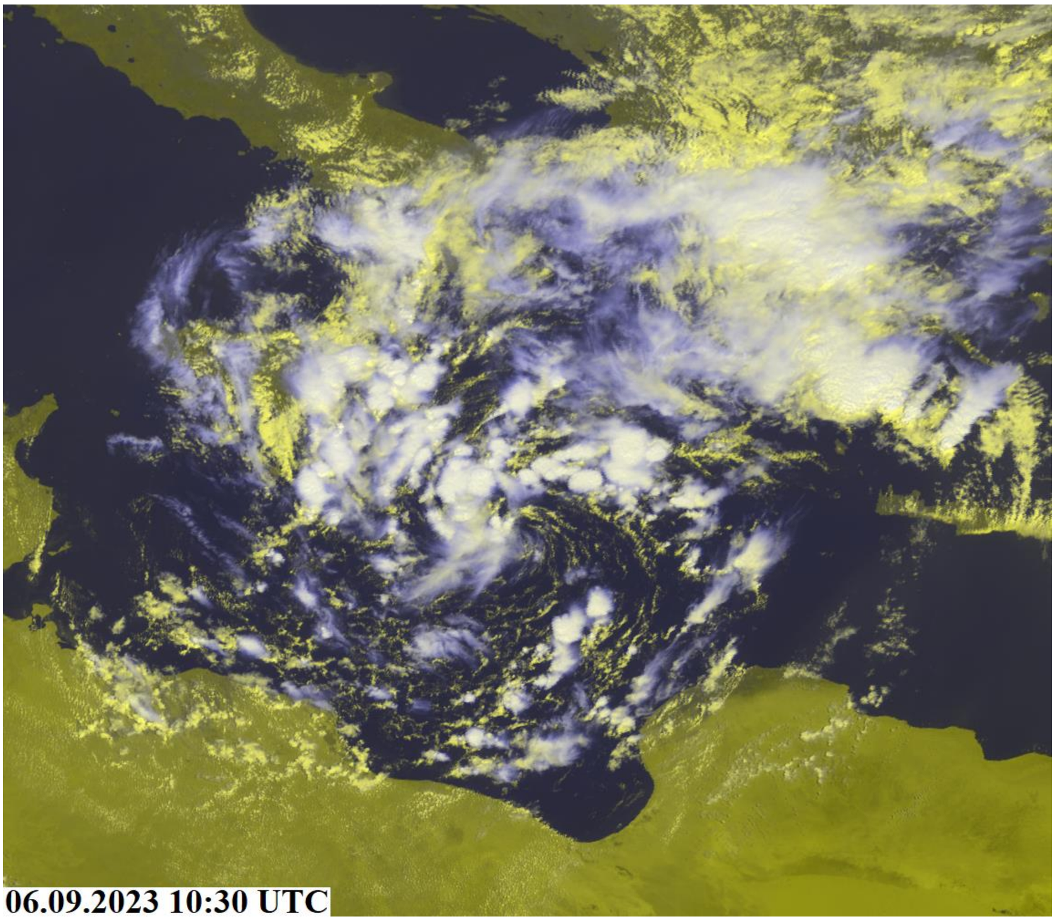

Figure 4. Visible (RGB) satellite image of Daniel at 1030 UTC 6 September. At this time, the cyclone started to take subtropical appearance as showers and thunderstorms developed closer to the center and farther convective bands weakened, however, its structure became more disorganized after that. *Source: EUMETSAT*

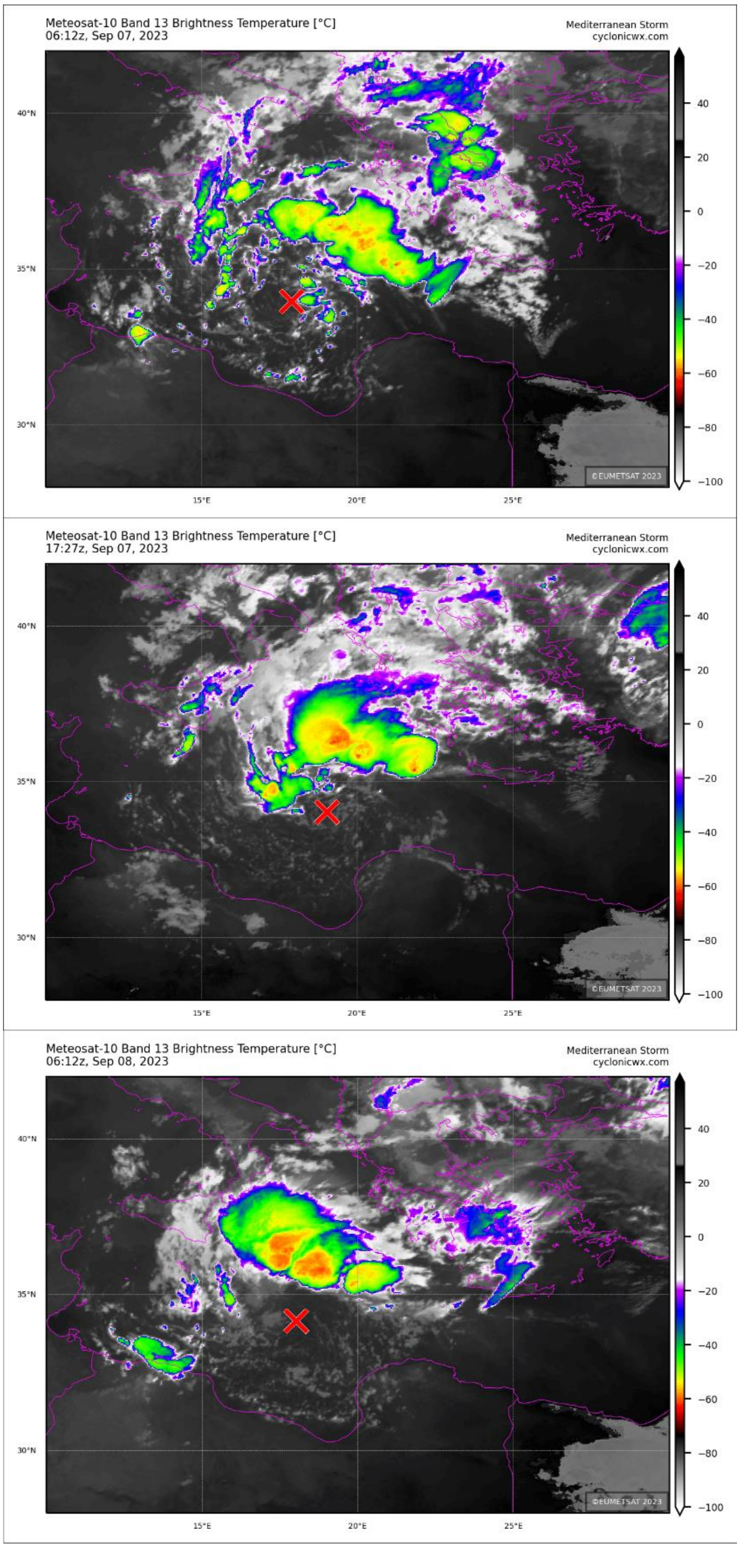

Figure 5. Cloud top temperature satellite images of Daniel at 0612 UTC and 1727 UTC 7 September and 0612 UTC 8 September. The cyclone produced sustained deep convection on the north and northeast side, but its structure remained disorganized in this period. The red X marks the estimated center positions. *Source: EUMETSAT / cyclonicwx.com*

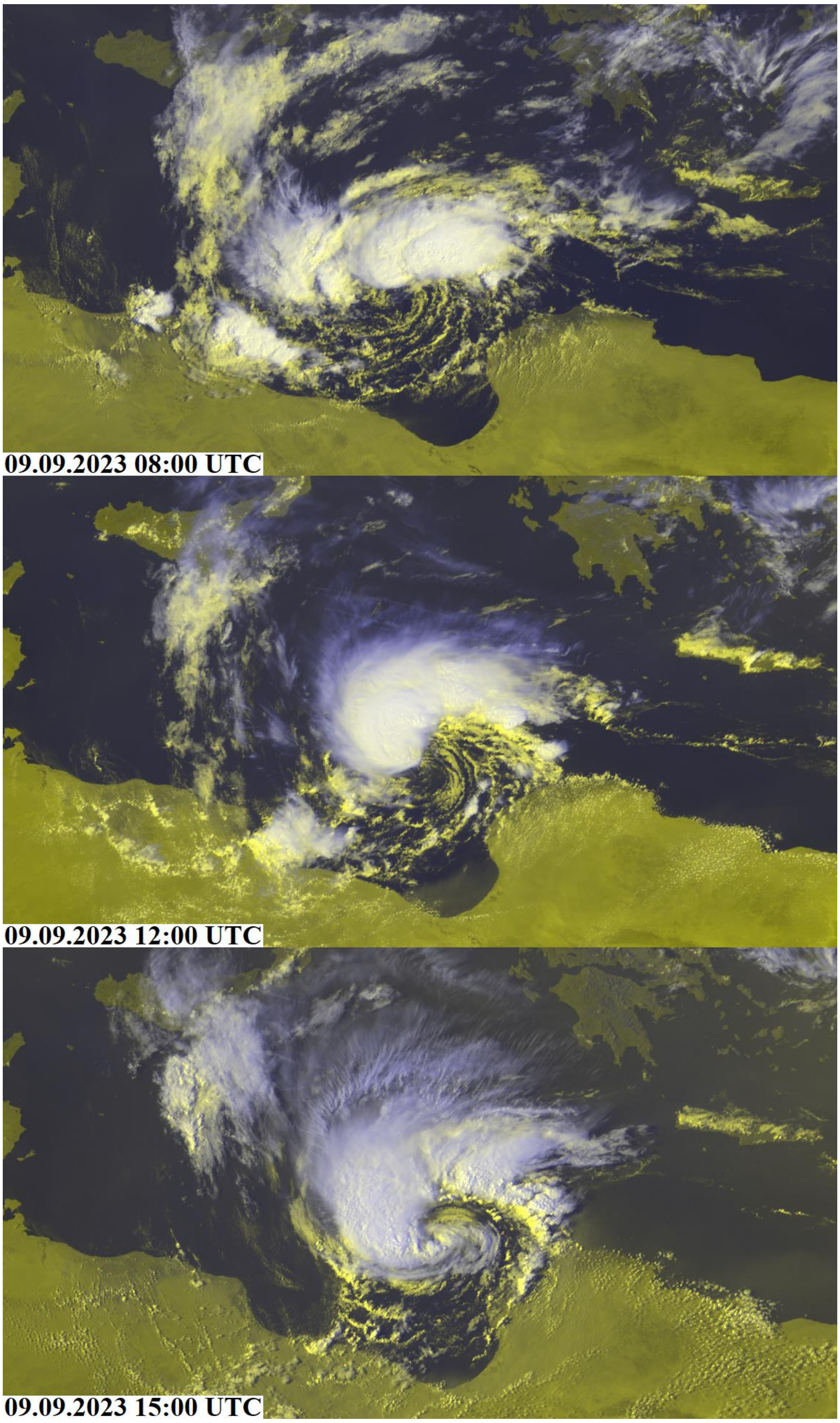

Figure 6. Visible (RGB) satellite images of Daniel on 9 September. The images show well the structural evolution of the cyclone as it changed into curved band pattern. The upper-level outflow also became more distinct at this time. *Source: EUMETSAT*

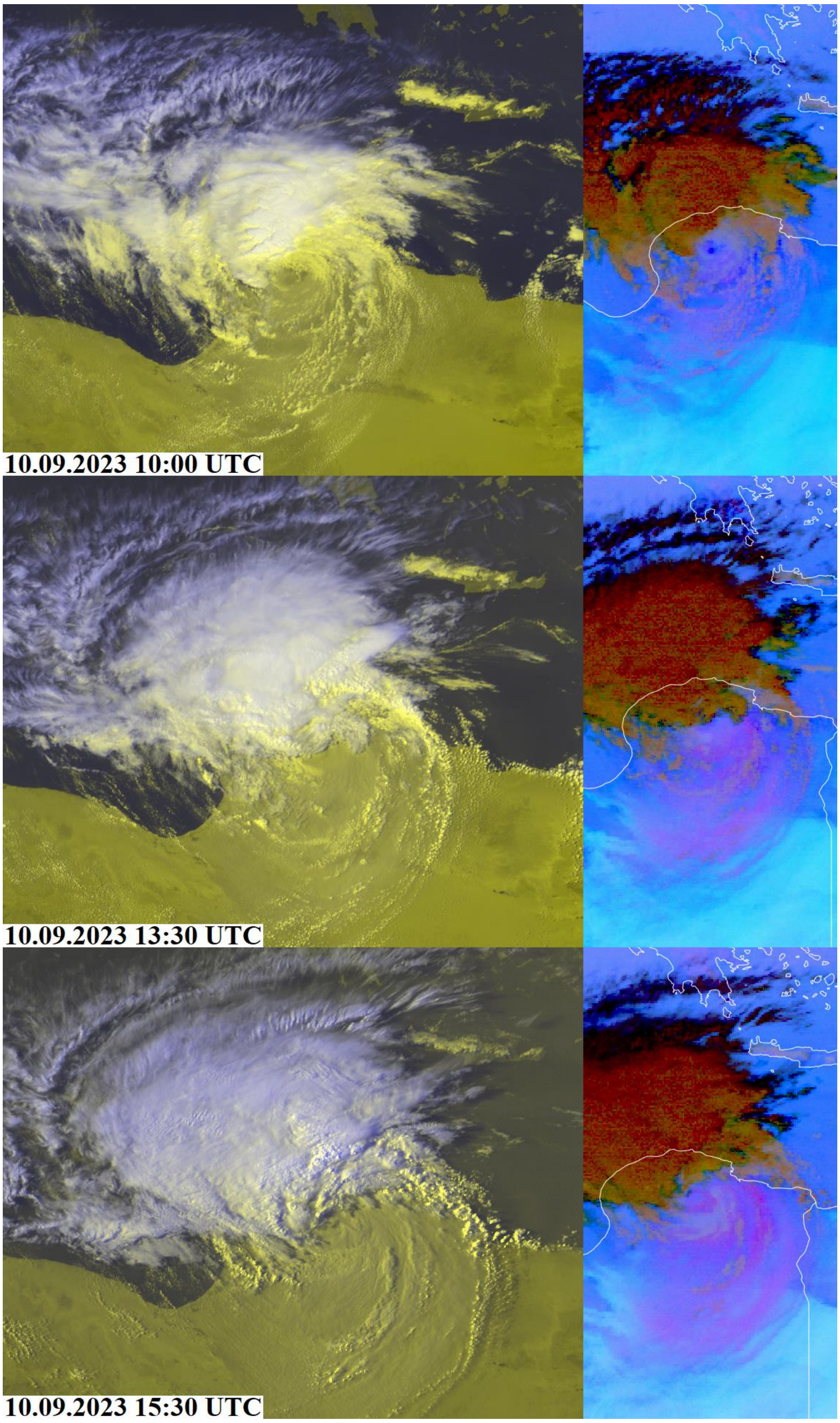

Figure 7. Visible (RGB) and dust composite (RGB) satellite images of Daniel on 10 September. After the slight weakening in the night hours, the convection became stronger again north of the center with well-defined banding features and upper-level outflow, while widespread dust storms (purple/magenta areas on dust images) occurred on its south side. *Source: EUMETSAT*

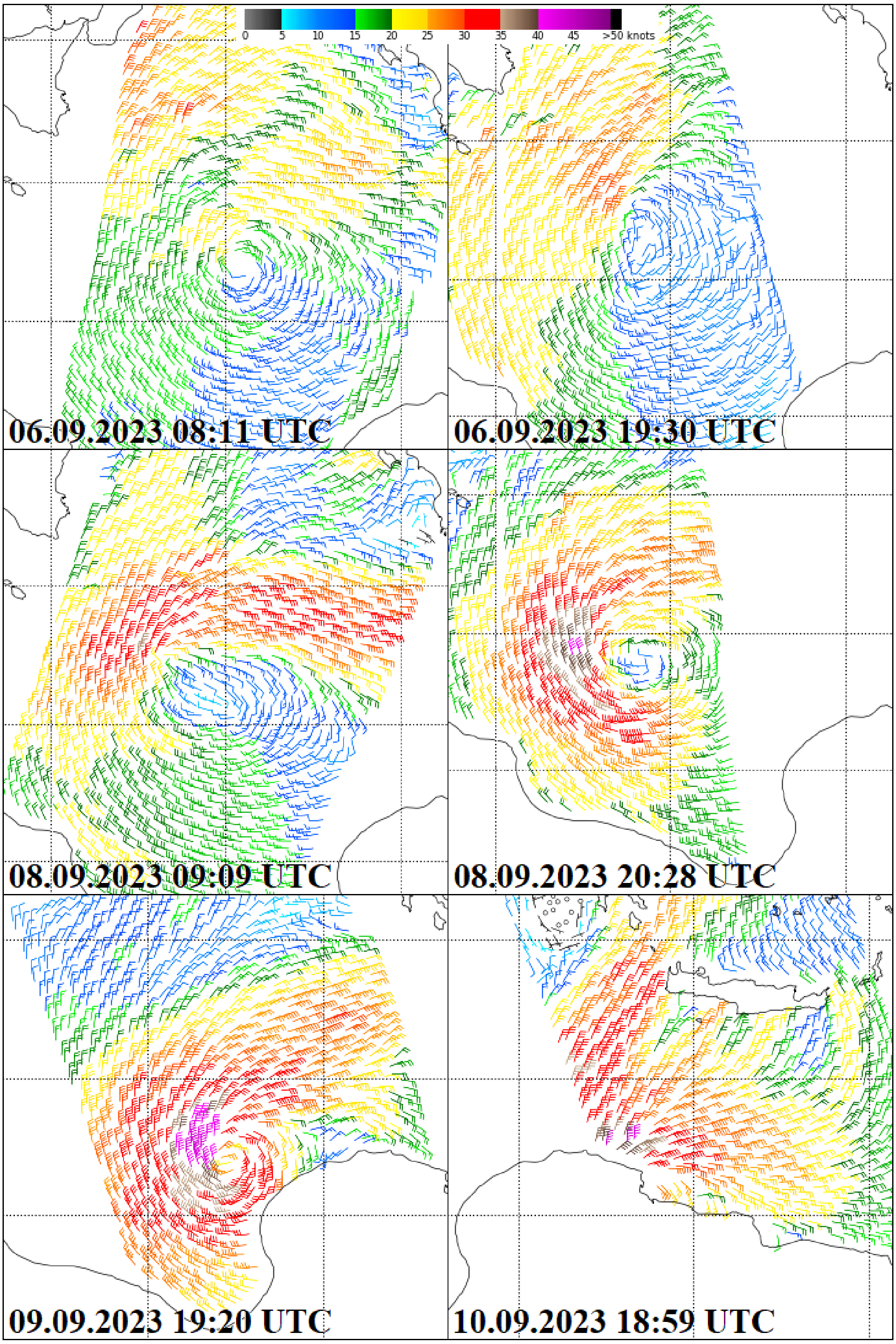

Figure 8. Satellite-based wind data of Daniel between 6-10 September measured by ASCAT-B and ASCAT-C sensors. The measurements showed well the tropical transition of the cyclone. *Source: NOAA OSPO*

Figure 9. Severe flash flood in Volos on 5 September. *Source: George Kidonas / InTime News via AP*

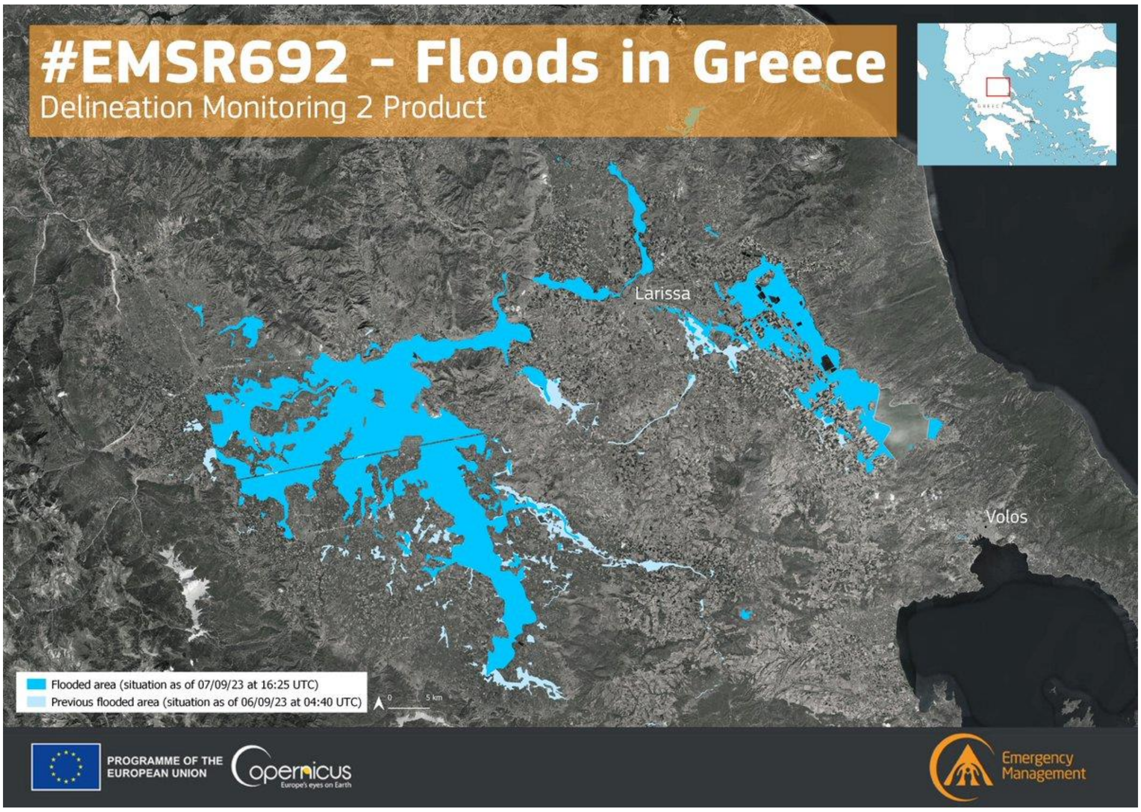

Figure 10. Flooded areas in Thessaly on 7 September (blue) and on the previous day (light blue). *Source: European Union / Copernicus Emergency Management Service* (*[link]*)

Figure 11. Widespread floods in Thessaly. *Source: Dimtiris Papamitsos / AP*

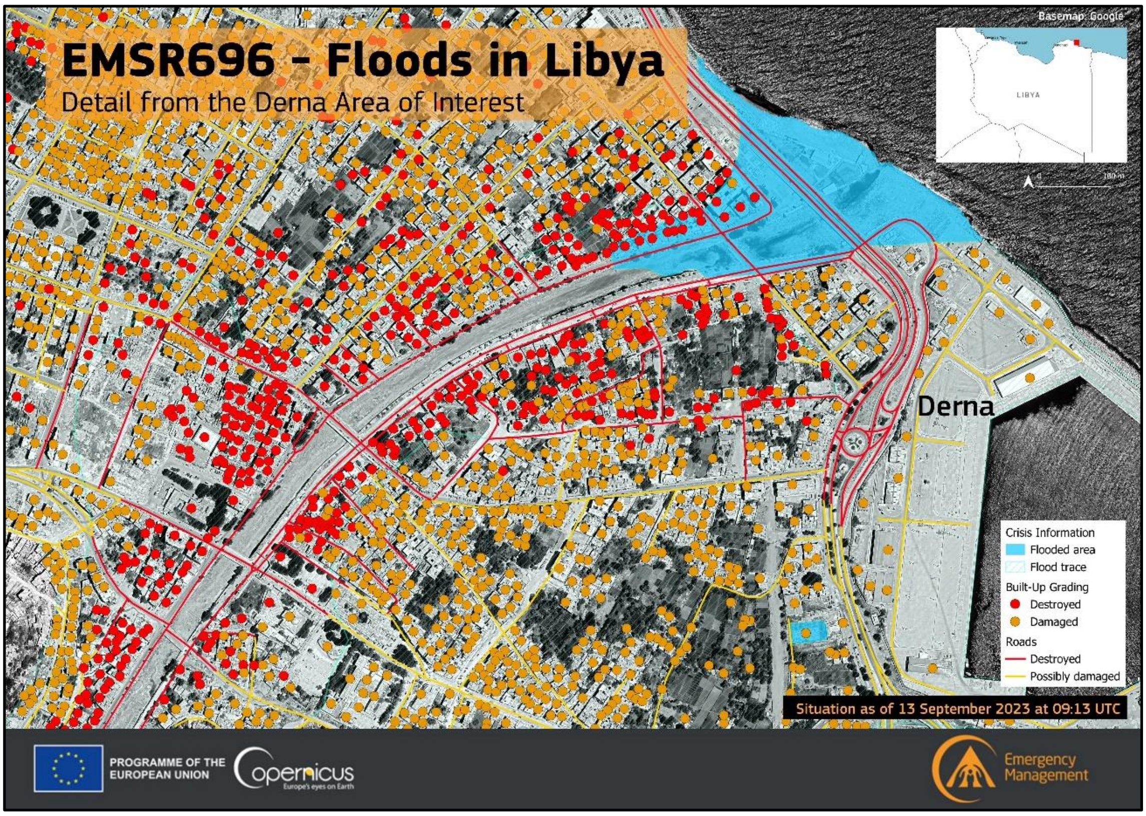

Figure 12. Satellite-based damage survey in Derna after the dam collapse. *Source: European Union / Copernicus Emergency Management Service* (*[link]*)

Figure 13a-b. High-resolution satellite images of Derna before (2 September) and after (12 September) of the destruction. *Source: Planet Labs PBC*

Figure 14a-b. Drone photos of the severe destruction in Derna. *Source:* ليبيا الأحرار / *Nahel Belgherze (Twitter/X)*

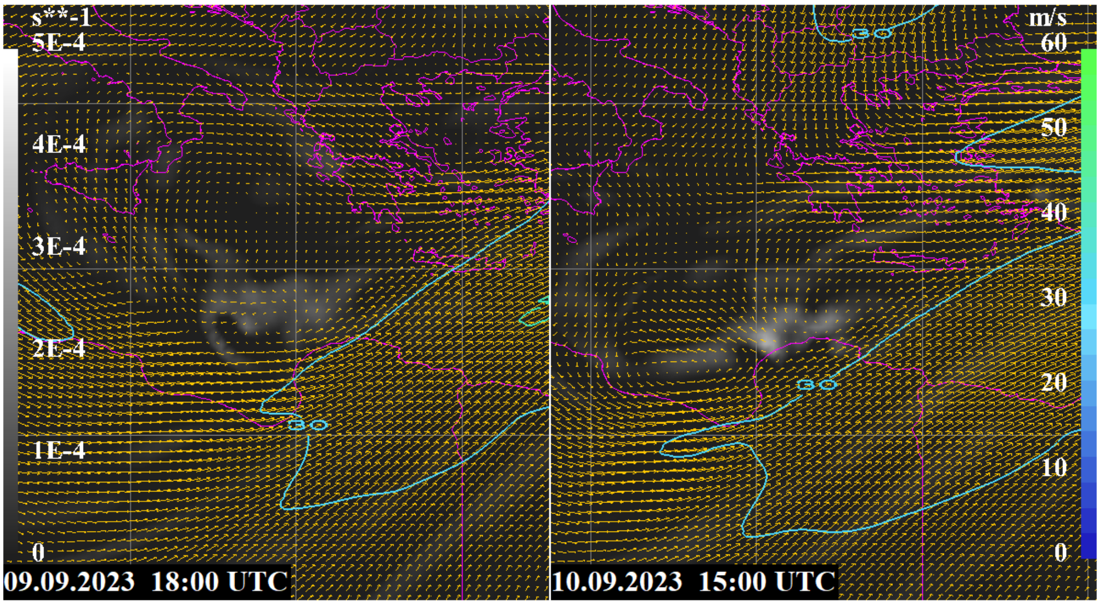

Figure 15. 250 hPa divergence (shaded) and winds (vectors and contours per 10 m/s from 30) over the Central Mediterranean Sea at 1800 UTC 9 September and 1500 UTC 10 September. *Data source: ECMWF/Copernicus*

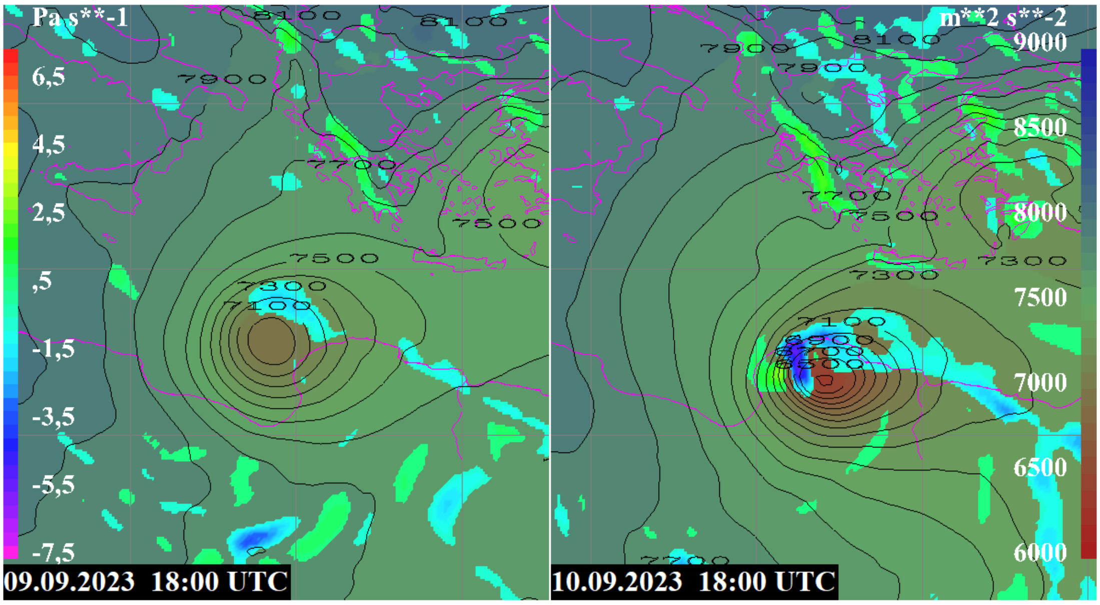

Figure 16. 925 hPa geopotential (shaded with black contours) and 850 hPa vertical speed (shaded patches, without the -0,5 to 0,5 Pa/s range) over the Central Mediterranean Sea at 1800 UTC 9 September and 1800 UTC 10 September. *Data source: ECMWF/Copernicus*

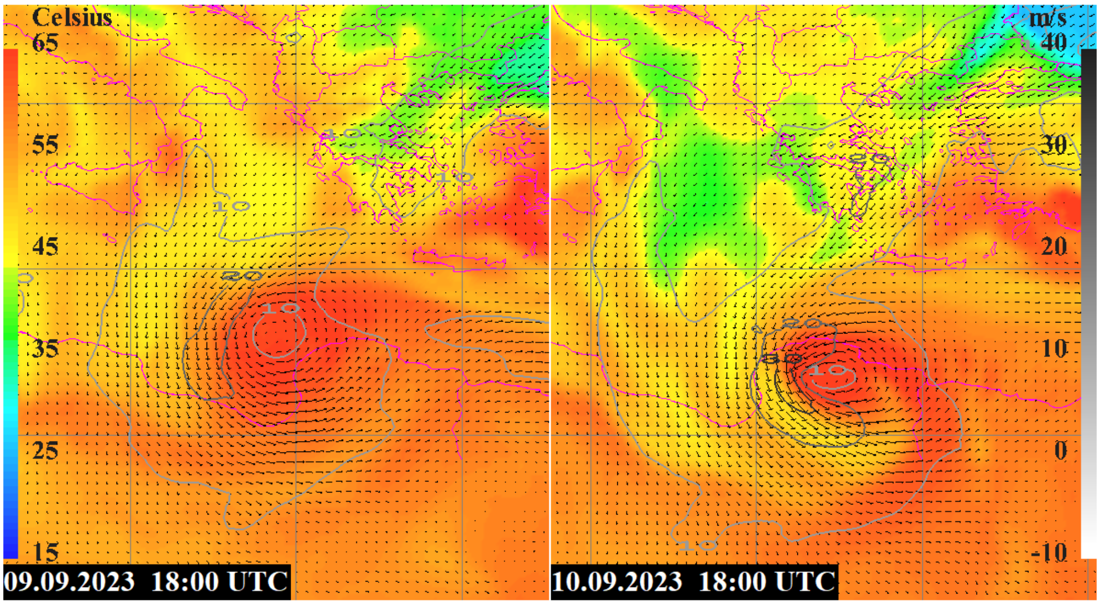

Figure 17. 850 hPa equivalent potential temperature (shaded) and winds (vectors and contours per 10 m/s) over the Central Mediterranean Sea at 1800 UTC 9 September and 1800 UTC 10 September. *Data source: ECMWF/Copernicus*

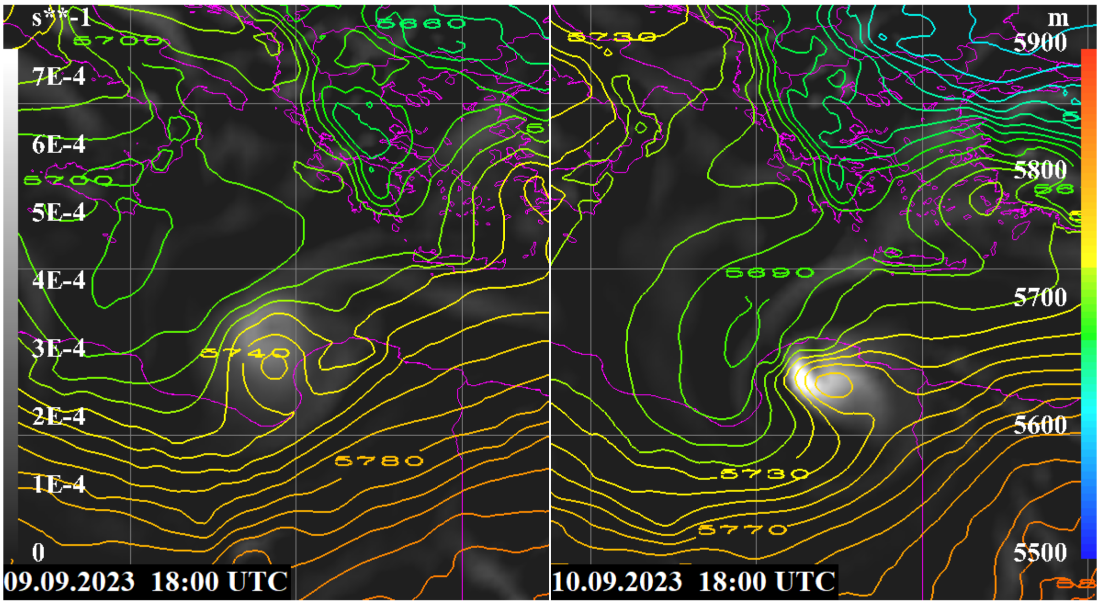

Figure 18. 500-1000 hPa thickness (contours per 10 m) and 850 hPa relative vorticity (shaded) over the Central Mediterranean Sea at 1800 UTC 9 September and 1800 UTC 10 September. *Data source: ECMWF/Copernicus*

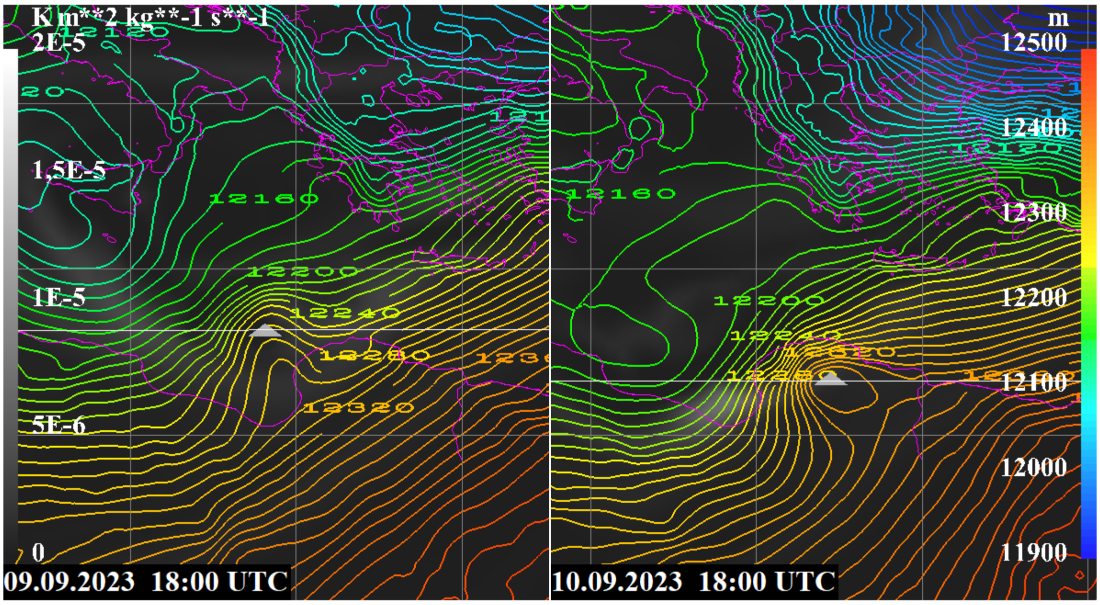

Figure 19. 200-1000 hPa thickness (contours per 10 m) and 300 hPa potential vorticity (shaded) over the Central Mediterranean Sea at 1800 UTC 9 September and 1800 UTC 10 September. *Data source: ECMWF/Copernicus*

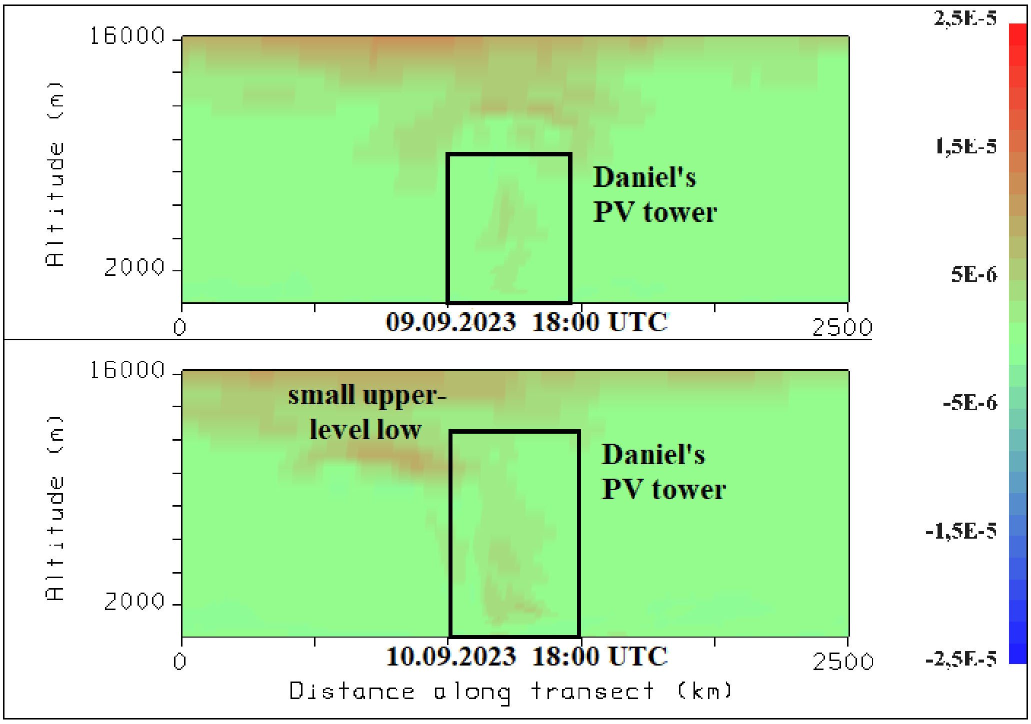

Figure 20. Potential vorticity vertical crosses through the center of Daniel and its environment at 1800 UTC 9 September and 1800 UTC 10 September. The positions of cross-sections mark with thin white lines on Figure 19. *Data source: ECMWF/Copernicus*

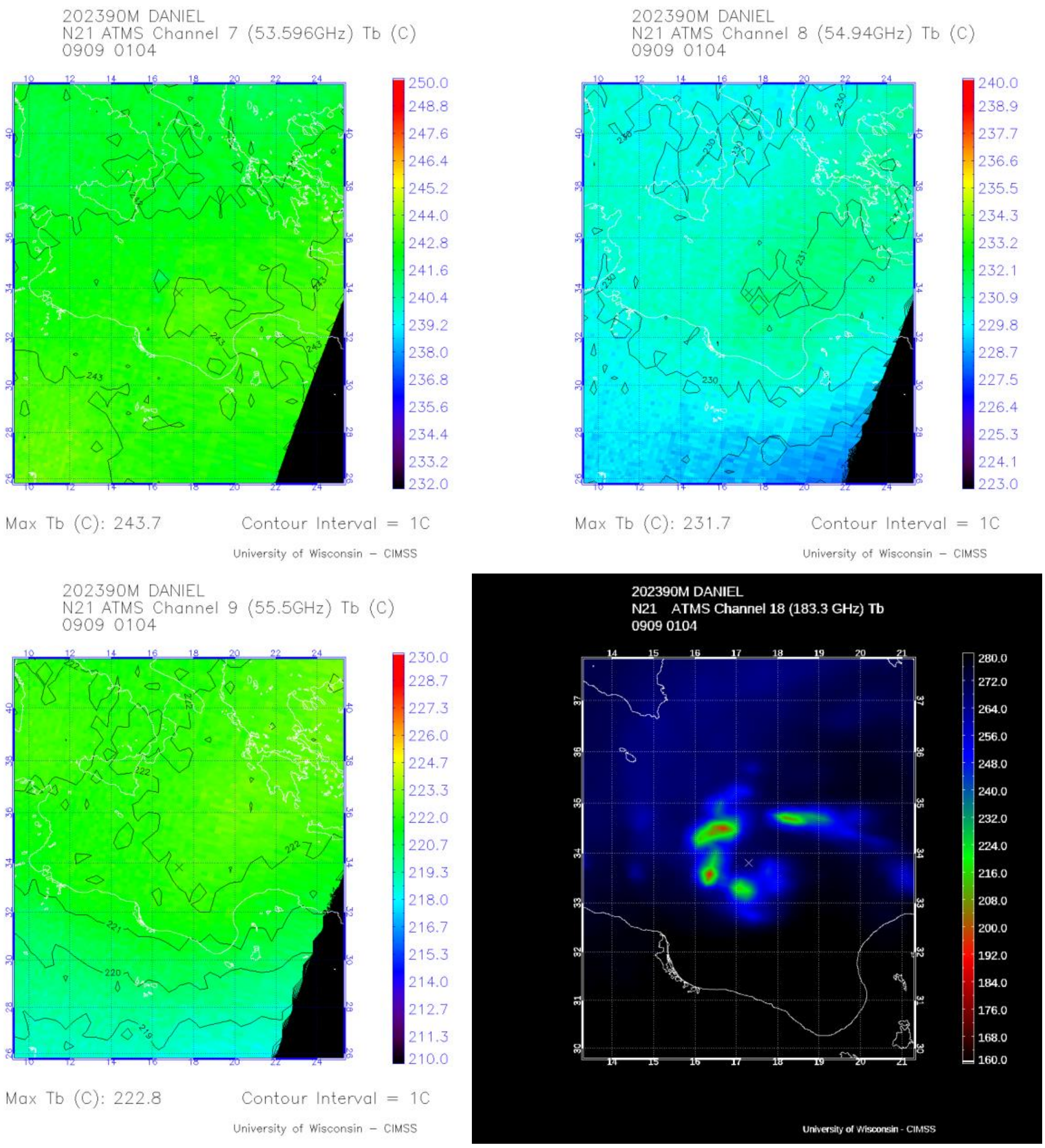

Figure 21a-d. CH07 (~350 hPa), CH08 (~200 hPa) CH09 (~150 hPa) and CH18 (183 GHz) satellite images of Tropical Storm Daniel at 0104 UTC 9 September. *Data source: CIMSS ATMS*

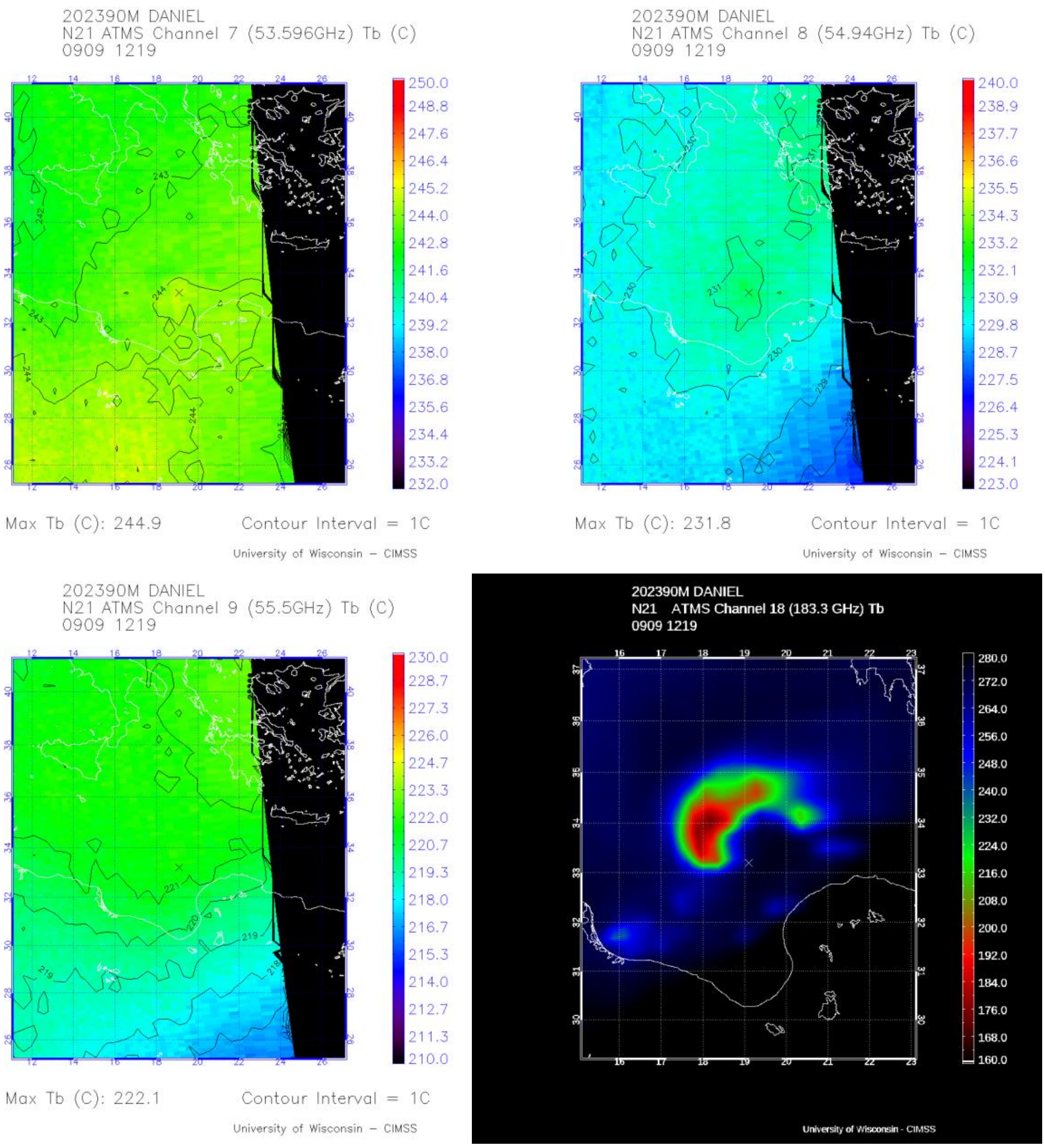

Figure 22a-d. CH07 (~350 hPa), CH08 (~200 hPa) CH09 (~150 hPa) and CH18 (183 GHz) satellite images of Tropical Storm Daniel at 1219 UTC 9 September. *Data source: CIMSS ATMS*

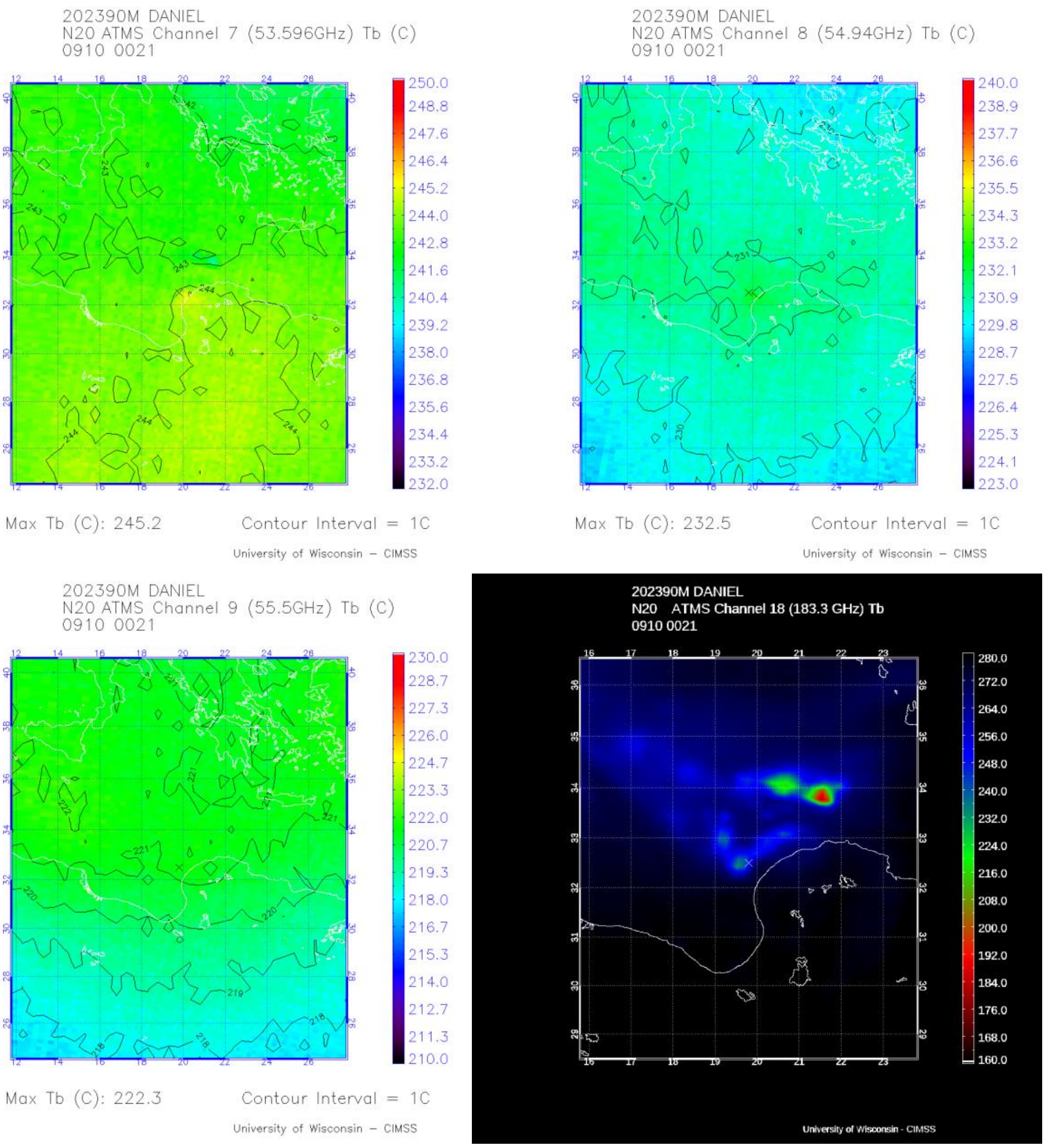

Figure 23a-d. CH07 (~350 hPa), CH08 (~200 hPa) CH09 (~150 hPa) and CH18 (183 GHz) satellite images of Tropical Storm Daniel at 0021UTC 10 September. *Data source: CIMSS ATMS*

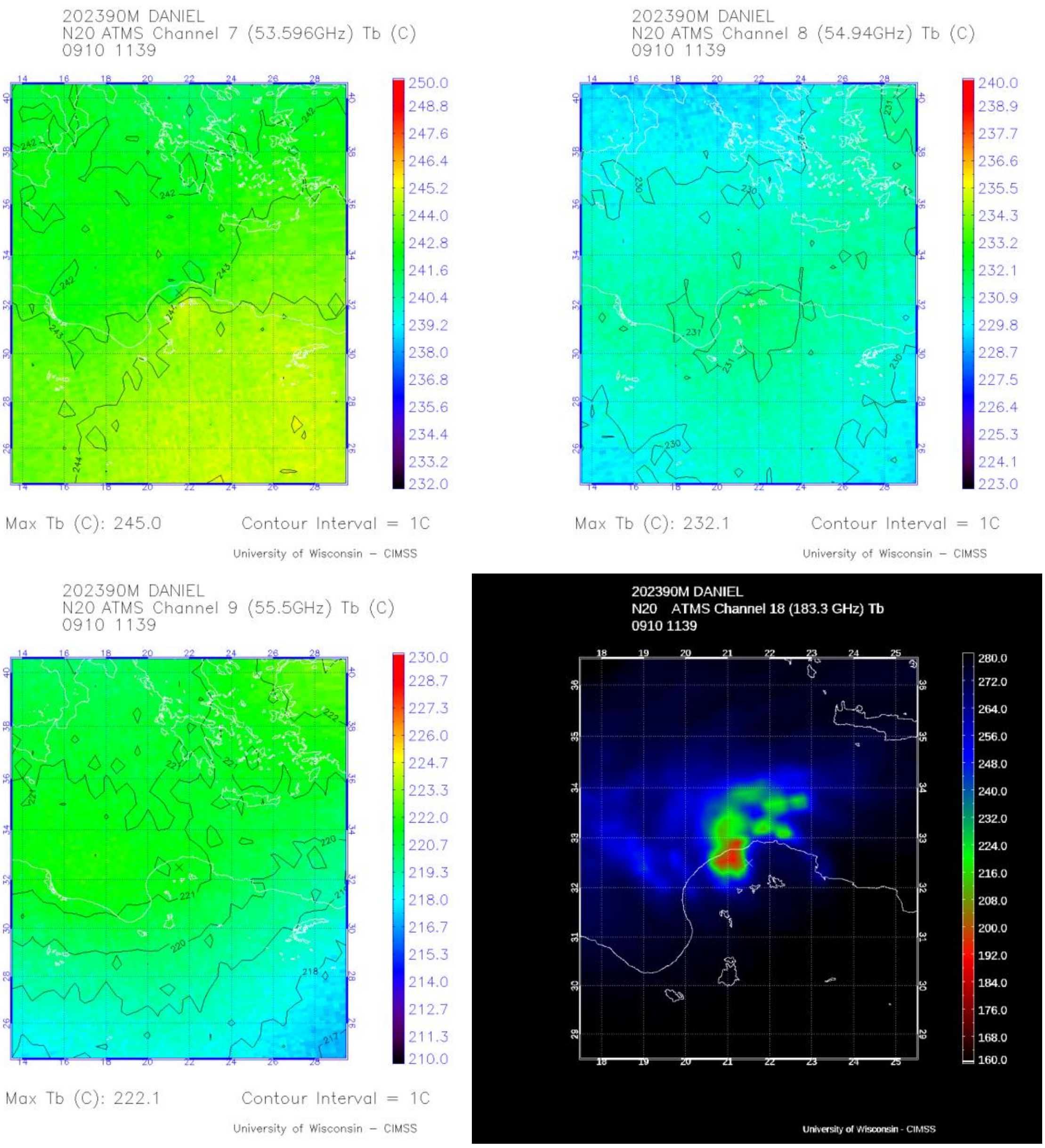

Figure 24a-d. CH07 (~350 hPa), CH08 (~200 hPa) CH09 (~150 hPa) and CH18 (183 GHz) satellite images of Tropical Storm Daniel at 1139 UTC 10 September. *Data source: CIMSS ATMS*

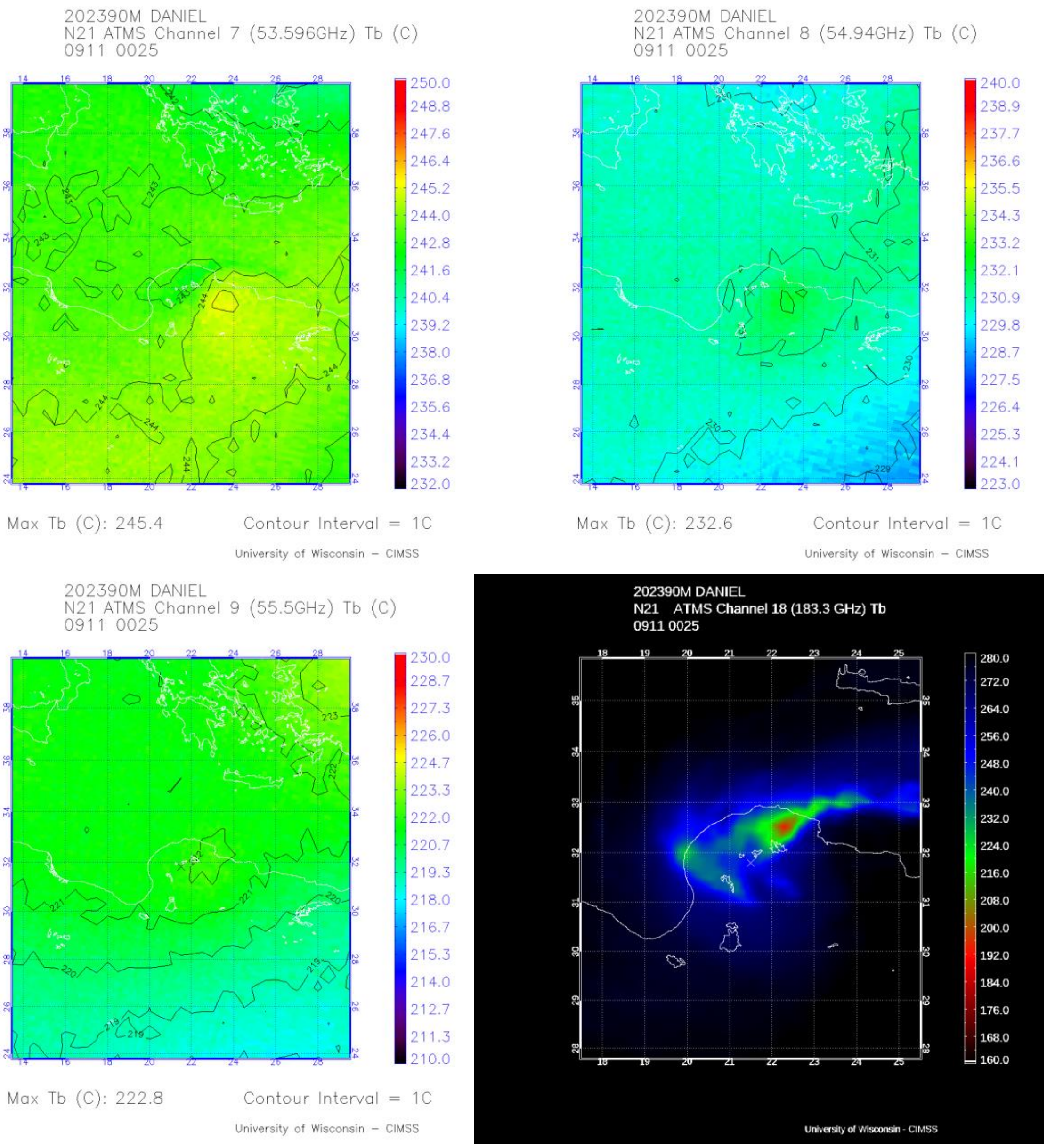

Figure 25a-d. CH07 (~350 hPa), CH08 (~200 hPa) CH09 (~150 hPa) and CH18 (183 GHz) satellite images of Tropical Storm Daniel at 0025 UTC 11 September. *Data source: CIMSS ATMS*