MEDITERRANEAN TROPICAL CYCLONE REPORT

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Tropical Storm Apollo
25 October - 2 November 2021

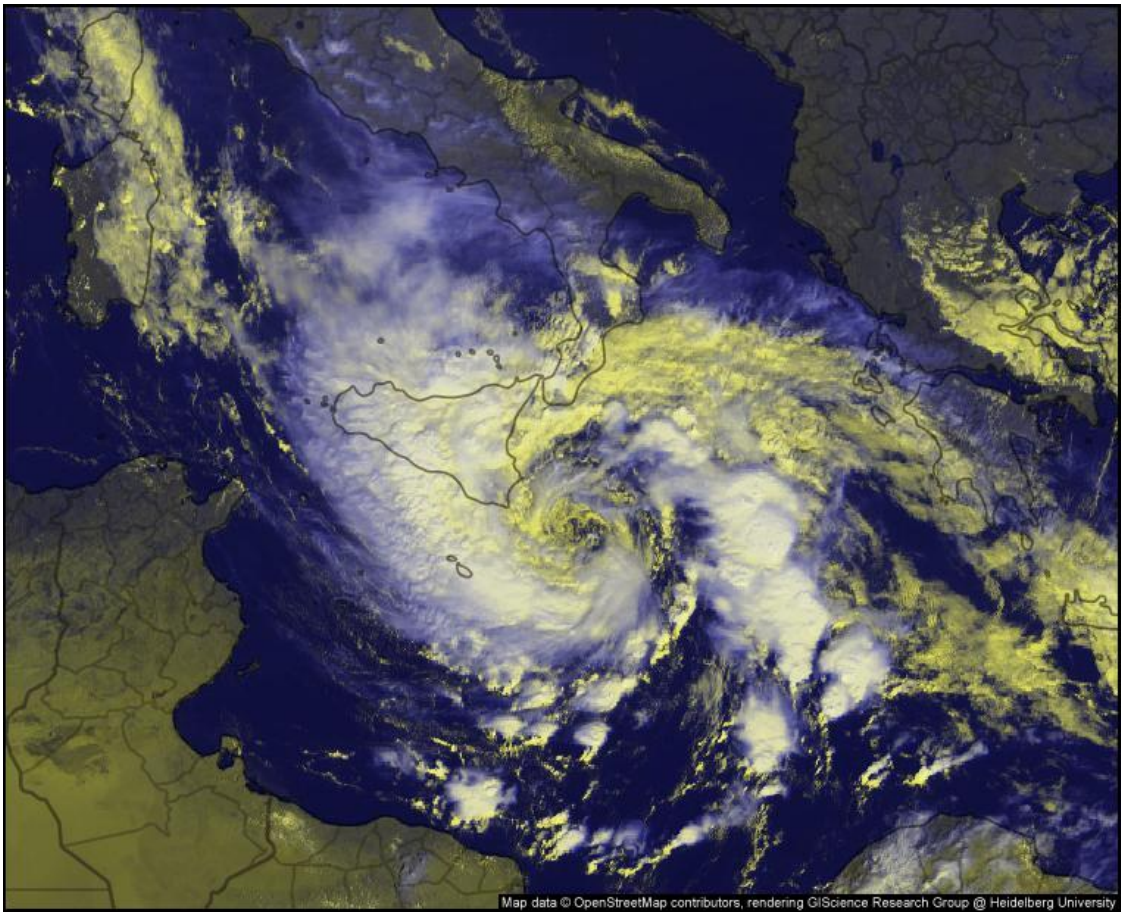

Image: EUMETSAT / Kachelmannwetter

Apollo (named by the Italian Meteorological Service) was a long-lived, complex cyclone which made (sub)tropical transition twice in its lifetime. The cyclone peaked as a strong tropical storm near Sicily on 29 October and caused heavy rains in many parts of southern Italy which led to intense floods.

Synoptic history

Around 20 October a deep cyclone system over North Europe caused strong westerly flow across the many parts of the continent while an anticyclone placed over the Mediterranean Sea. On 21 October the main, fast moving cold front of the cyclone moved through Central Europe and behind it, an anticyclone developed in this area in the next day. Along with this process a bit cooler airmass reached the western parts of the Mediterranean Sea while warm air advection started from North Africa over the central areas. These conditions led to cyclogenesis over Tunisia on 23 October. Initially a weak low-pressure area formed that moved toward northeast over Mediterranean Sea in the first half of 24 October and passed near Lampedusa Island. However, around midday a secondary low formed north of Tunisia associated with a large convective system and this feature became the dominant by the evening hours. The cyclone, which got blocked by the anticyclone, made a loop near Tunisia and Sicily and turned to southeast thereafter. This low got the name ‘Apollo’ some days later from the Italian Meteorological Service.

As the cyclone moved across the open Central Mediterranean Sea on 25 and 26 October, it occluded fast and the center area cut off from the main frontal zones, which caused heavy rains on Sicily, Malta and Tunisia. The small, but well-defined central feature mostly produces sporadic, moderate convection through these days and remained association with the upper-level low above. However, occasionally the convection became deeper with cloud top temperature around -50, -55 °C and more organized around the center, especially between the evening hours of 25 October and the early morning of 26 October, and the afternoon hours of the latter day (Fig 3). Based on this it is estimated that Apollo transitioned into a subtropical low by 1800 UTC 25 October. In the second period the structure of the cyclone was much more tropical than subtropical, but the convection was not lasted enough long time for the classification as in the evening hours the stronger vertical wind shear started to erode it. On 27 October the cyclone became almost totally convection-free, so it degenerated into a remnant low (Fig. 4). Additionally, it became embedded within an elongated convergence zone which was generated by the gap wind effect between Crete and Peloponnese (Fig. 9b).

The western side of this convergence was affected by a cut-off upper-level low over the western Mediterranean Sea and thanks to this widespread clusters of strong thunderstorms with cloud top temperature between -60, -65 °C formed in the second half of the day which gradually moved closed the low-level vortex in the evening hours. In the night the low-level center replaced northward, beneath the convective cluster and the cyclone became a subtropical storm again by 0000 UTC 28 October. In the morning hours the convection wrapped around the center very fast, led to the formation of an eye-like feature (Fig. 5), however, the cloud tops gradually warmed mainly around -45, -50 °C, only on the east-northeast side of the circulation redeveloped deeper convection later. By this time an elongated poleward outflow channel also built up on the northwestern side of the cyclone thanks to the aforementioned upper-level low. Apollo lost some convective organization in the second half of the day as it moved to northwest very slowly, but deep convection returned around its center in the night. By the next morning, a strong curved band with cloud top temperature around -55, -60 °C and well-defined upper-level outflow developed on the western half of the cyclone while an another, bit further one on the eastern side. This indicated that the cyclone finished its tropical transition (Fig. 6) around 0000 UTC 29 October. According to the measurement (see next chapter) Apollo strengthened significantly at this time and reached its peak intensity a few hours later as a strong tropical storm. However, the convection started to weaken around midday, especially on the northern and eastern side and in the cyclone's center. This was likely caused by upwelling effect since the storm moved very little for about 1 day. This theory could be justified by the further evolution of the cyclone: the deep convection almost totally dissipated near the center at night, but when Apollo started to move southeast on 30 October toward the warmer waters, it gradually returned and became even stronger than earlier. From the afternoon to next morning the cloud top temperature often reached -65 °C in a quite large area and the deepest patches sometimes approached -70 °C (Fig. 7). However, between an upper-level low to northeast and a warm front to west, the northwesterly vertical wind shear became stronger at this time, and it affected the cyclone increasingly, so the convection mostly limited to the east side of the circulation. Due to this structural effect, the cyclone could not produce significant restrengthening. In the morning of 31 October Apollo briefly made landfall on the northern coastline of Libya, but thanks to the shear only the low-level center affected the land, the strong convection remained over the water. After the cyclone emerged over the sea, the upper-level winds temporarily became a bit more favorable, and the convection wrapped over the center for some hours (see the 4th picture on Fig. 7). In the evening hours the center became exposed again as deep convection gradually moved further northeastward, and it also dissipated shortly after 0600 UTC 1 November. After 1800 UTC very deep convection with cloud tops around -70 °C returned (Fig. 8) and it persisted until around 0300 UTC

2 November, when Apollo made its final landfall in Turkey, near *Alanya*. However, satellite images suggested that the cyclone may was not fully tropical at this time since it partially interacted with an upper-level shortwave trough that approached from west. In the other hand, measurements and reanalysis data indicated that the cyclone retained its well-defined low-level circulation with warm core and concentrated vorticity at least in the lower levels, and the conclusion is that Apollo preserved enough tropical characteristics to the classification. After the landfall, the high terrain quickly disrupted the cyclone, and it dissipated by 0600 UTC.

Meteorological statistics

Apollo spent most of its lifetime over the open water, so the surface wind and pressure (Tabl. 2) data were limited from the cyclone, however, many ship reports (Tabl. 3.a and 3.b) were available. The availability of the precipitation data also was quite good, especially from Sicily (Tabl. 4.a) where many Wunderground Personal Weather Station provided reliable data, and there were additionally measurements from other areas that were affected by the cyclone (Tabl. 4.b). ASCAT (Fig. 9a and 9b) and SMAP measurements also helped the estimation of the strength and status of the cyclone.

Winds and pressure

After the cyclone formed, it produced sustained winds mainly around 50-60 km/h (30 kt) until the early morning hours of 26 October, but a SMAP measurement at 0503 UTC 26 October already indicated 65 km/h (35 kt) winds. Ships reported pressure around 1010 hPa at the beginning of the period, but the cyclone's center passed over a drifting buoy (WMO id.: 6102784) between 1200 and 1300 UTC 26 October that measured minimum pressure of 1005.4 hPa at 1300 UTC. On 27 October both ships and ASCAT measured gale-force winds, but mainly associated with the earlier mentioned gap wind area north of the cyclone's center. On 28 October the wind speeds did not change much, but the wind field became more symmetrical as the cyclone became subtropical once again. In the first half of 29 October Apollo strengthened significantly within a short period what was captured by ship reports as well as ASCAT and SMAP passes. The ship 'EUMDE34' passed through the cyclone's center in the morning hours from ESE to WNW and reported hourly wind and pressure data (Fig. 10). It measured tight pressure gradient and minimum pressure of 999.4 hPa at 0800 UTC and it reported the maximum wind of 104 km/h (56 kt) at 0700 UTC. At 1100 UTC another ship 'WHMA' also measured 104 km/h (56 kt) wind with 998.7 hPa pressure near the center. An ASCAT pass at 0819 UTC showed maximum winds around

85 km/h (45 kt) while an SMAP pass around 95 km/h (50 kt) at 0515 UTC. These data indicated that Apollo peaked as a strong tropical storm around 1200 UTC with winds around 110 km/h (60 kt).

In the second half of the day Apollo weakened quite fast as deep convection almost totally dissipated near the center. But when the cyclone started to move southeast, out from its upwelled cold pool and – sheared – deep convection returned, its intensity did not change very much on 30 and 31 October. In both days some short-term re-intensifications occurred in the afternoon hours from about 75 km/h (40 kt) to 85 km/h (45 kt) which was confirmed by ASCAT and SMAP measurements. At 1200 UTC 31 October *Tobruk* reported 65 km/h (35 kt) 10-min. sustained wind with 1008.3 hPa pressure about 100 km southeast from the cyclone's center, which was the only tropical storm force wind data from the surface observations. After the negative structural changes of the cyclone's structure, it gradually weakened, and wind speeds decreased under tropical storm strength by 1200 UTC 1 November based on an ASCAT pass, which also showed that the low-level circulation remained well-defined and quite symmetrical, with some elongation to north. However, after very deep convection returned, it likely became a weak tropical storm again with winds around 65 km/h (35 kt), but there were no exact data what could confirm this. In Alanya, close to the landfall the pressure fell to 1004.3 hPa at 0300 UTC 2 November with a decreasing trend of near 5 hPa/3 h, followed by an increasing of near 8 hPa/3 h, which indicated that the cyclone's core still was quite intact.

Rainfall

The most devastating phenomenon associated with Apollo was the very extensive precipitation in Sicily. The cyclone caused heavy rainfalls in 2 separated periods, firstly on 25 and 26 October, when long-lasting clusters of thunderstorms along the dissipating frontal zones affected that area, mostly the northeast edge of Sicily. The 3-daily (24-26 October) amounts of precipitation were around 300 mm in the region of *Catania*, with maximum of 340.6 mm in *Nunziata di Mascali*. On 25 October the highest daily amount reached 268.4 mm in this city while on the next day the most, 187.5 mm rain fell in *Catania / Trapetto Nord*. Thereafter, another round of heavy rain affected the island between the second half of 28 October and the first part of 3 0October, when the cyclone approached it but slowed down significantly – the daily amounts of 30 October contain the rains from an arriving frontal zone which reached Sicily on the second half of the day. Fortunately, the most rain fell a bit more south from the most affected areas in the first period, however, the amounts and effects were similar. On 29 October the daily summary reached 323,3 mm in *Cassibile* and some nearby city also reported 100-300 mm rain. In *Avola*, *Cassibile* and *Augusta /NE/* the total 8-daily amount of precipitation exceeded 400 mm and large areas in East Sicily got 100-300 mm rain from the cyclone. It also worth to note that locally could have fallen more rain in both periods thanks to the very complex terrain of Sicily.

Apollo also caused total rain amount around 100 mm in Malta and some areas in Tunisia and Northeast Algeria as well as in Turkey. However, only a few mm rain fell in Libya despite the first landfall, thanks to the association convection was shared to the northeast side of the cyclone. The heavy rains triggered extensive flash floods, especially in East Sicily, Tunisia and Algeria. The floods caused severe damages and led to at least 7 deaths.

Storm surge

There were some satellite-based measurements of significant wave height (SWH) associated with Apollo (Fig. 11). There were no available data around the peak intensity of the storm, but on the previous day, 28 October two satellite measured maximum SWH values around 4-4.5 m (14-15 feet) near the cyclone. Some eye-witness video also showed large waves in Sicily which caused minor coastal flooding – beside the significant floods due to heavy rains.

Reanalysis data

Apollo had been analyzed by ECMWF-ERA5 high-resolution reanalysis data. The examined parameters were 300 hPa divergence and winds (Fig. 12), 925 hPa geopotential and 850 hPa vertical speed (Fig. 13), 850 hPa equivalent potential temperature and wind (Fig. 14), 500-1000 hPa thickness and 850 hPa relative vorticity (Fig. 15), 200-1000 hPa thickness and 300 hPa potential vorticity (Fig. 16) and vertical cross-sections of potential vorticity (Fig. 17). The analysis expanded from 0000 UTC 23 October to 2100 UTC 2 November. However, only two images are listed here: the first one is at 1200 UTC 29 October, when Apollo reached its peak intensity, and second one at 1200 UTC 31 October, when it was a sheared tropical storm, but it started to reorganize for a short time. An animation of all reanalysis maps is available here:

https://www.youtube.com/watch?v=zeaEAq_jcy8

The extratropical cyclone formed within favorable synoptic conditions: an approaching upper-level shortwave trough with a weak jet stream over Algeria caused generally divergent upper-level flow over Tunisia and the surrounding areas while an upper-level potential vorticity streamer also reached that area. In addition, a warm conveyor belt stretched up from West Libya in the warm sector on the 850 hPa equivalent potential temperature (EPT) maps. On 24 October a weak upper-level low formed over Tunisia which moved to east and enhanced the divergence north of the country, directly over the developing main cyclone center. On this day, the 850 hPa relative vorticity became more evident along the elongated frontal zones and definite cold advection was analyzable by the 500-1000 hPa thickness in the cold sector. The strongest vorticity and updrafts appeared around the new center north of Tunisia. On 25 October the cyclone occluded fast, the cold advection gradually diminished while the warm conveyor belt wrapped along the frontal zone, and the upper-level potential vorticity streamer also lost its organization by the end of the day. On 26 October the fronts dissipated and the 850 hPa relative vorticity maximum became more concentrated in the cyclone's center, however, the strongest updraft located over East Sicily, association with the strong showers and thunderstorms along a remained, weakening part of the fronts. On 500-1000 hPa thickness maps already appeared a warm spot occasionally, but this was not yet visible the case of the 200-1000 hPa thickness. The cyclone remained in connection with the weakening upper-level low aloft, which provides low-shear environment to it, additionally, confirmed that the low remained rather subtropical than subtropical. In the late afternoon and early evening hours the upper-level divergence increased a bit over the cyclone, which likely helped the temporary development of deep convection at this time. In the night hours westerly wind increased at 300 hPa which generated stronger vertical wind shear, and Apollo's structure gradually degraded as it became a remnant low. The 850 hPa wind field became less symmetric thereafter and the relative vorticity stretched out from west to east along the convergence zones.

Early on 28 October the upper-level wind quickly decreased over the low while a stronger jet stream reached North Libya from west, and an upper-level cut-off low placed over the Western Mediterranean Sea. The jet's circulation and the southeasterly flow in the front of the upper-level low increased the upper-level divergence significantly over the cyclone, and the latter also contributed to the development of a poleward outflow channel in the northwest quadrant. This helped the rapid structural reorganization, but since these processes gave mainly baroclinic influences and in addition, another upper-level potential vorticity streamer stretched from west to east just south of the cyclone's center which also affected it, Apollo regenerates into a subtropical storm at this time. On 29 October the storm quickly developed well-defined warm core based on both thickness map, and in addition the upper-level potential vorticity streamer moved away from the cyclone, indicated the tropical transition. The 925 hPa geopotential field also showed significant deepening with symmetrical appearance while both the 850 hPa relative vorticity and the updrafts became stronger and the latter wrapped around the center in spiral bands, mostly on the northern and western side where the strongest thunderstorms developed. The earlier upper-level low transitioned to a trough on this day over the West Mediterranean Sea as the backside jet stream became more dominant and started to move eastward, but the southeasterly flow and the well-defined poleward outflow on the west and north side of Apollo persisted until the evening hours. The jet stream approached the cyclone on 30 October causing increasement of the wind shear, and the upper-level divergence also became weaker. Since the jet was connected to a warm front, significant warm air advection appeared on its west side, and the warm core of the cyclone became much shallower – it almost dissipated on the 200-1000 hPa thickness maps. However, the 850 hPa EPT values and the relative vorticity remained relatively high and concentrated in the center. On 31 October the upper-level divergence temporarily strengthened as a shortwave trough developed north of the cyclone and generated a poleward outflow channel to north-northeast. This effect likely helped Apollo to make a little structural comeback on the second half of the day, and along with this process strong upwards appeared on the northeast and north side of the cyclone. On 1 November the upper-level trough moved away and the jet stream behind it crossed the cyclone. Additionally, some dry air wrapped into the circulation from west, but the EPT values still was unchanged directly in the center until the final landfall on the next day. These negative factors likely contributed with the dissipating of the deep convection early on 1 November. However, another shortwave trough developed west of the cyclone which again generated more divergence upper-level flow aloft the cyclone in the night hours, corresponding to the redevelopment of the very deep convection at this time. Since the 850 hPa relative vorticity remained concentrated into the center region and the upwards also strengthened a bit, it seems likely that Apollo remained tropical at this time despite the baroclinic forcing and that the warm core was only barely detectable on the thickness maps.

Table 1 Best track for Apollo, 24 October – 1 November 2021

Day/Time [UTC]	Latitude [°N]	Longitude [°E]	Pressure [hPa]	Wind speed [km/h *(kt)*]	Stage
24 / 0000	34.7	12.6	1010	55 *(30)*	low pressure area
24 / 0600	35.7	12.5	1010	55 *(30)*	”
24 / 1200	38.1	10.3	1009	55 *(30)*	”
24 / 1800	37.6	10.1	1008	55 *(30)*	”
25 / 0000	36.1	11.1	1008	55 *(30)*	”
25 / 0600	35.7	12.3	1007	55 *(30)*	”
25 / 1200	35.6	12.7	1007	55 *(30)*	
25 / 1800	35.2	14.2	1007	55 *(30)*	subtropical depression
26 / 0000	35.2	14.6	1006	55 *(30)*	”
26 / 0600	34.6	15.4	1006	55 *(30)*	”
26 / 1200	34.3	16.6	1005	55 *(30)*	”
26 / 1800	34.5	17.5	1005	65 *(35)*	subtropical storm
27 / 0000	34.5	17.9	1006	65 *(35)*	”
27 / 0600	34.1	18.0	1007	65 *(35)*	low
27 / 1200	33.8	17.7	1009	55 *(30)*	”
27 / 1800	33.6	17.6	1010	55 *(30)*	”
28 / 0000	33.5	17.3	1010	55 *(30)*	subtropical depression
28 / 0600	34.9	17.0	1010	65 *(35)*	subtropical storm
28 / 1200	35.4	16.4	1009	65 *(35)*	”
28 / 1800	35.5	16.3	1008	65 *(35)*	”
29 / 0000	36.0	16.1	1004	85 *(45)*	tropical storm
29 / 0600	36.2	16.0	997	100 *(55)*	”
29 / 1200	36.5	16.2	995	110 *(60)*	”
29 / 1800	36.4	16.3	998	85 *(45)*	”
30 / 0000	36.1	16.3	1000	75 *(40)*	”
30 / 0600	35.5	17.0	1001	75 *(40)*	”
30 / 1200	35.0	17.7	1002	75 *(40)*	”
30 / 1800	34.4	18.3	1002	85 *(45)*	”
31 / 0000	33.5	19.3	1002	85 *(45)*	”
31 / 0600	32.7	20.9	1003	75 *(40)*	”
31 / 1200	32.9	22.9	1003	75 *(40)*	”
31 / 1800	33.3	24.7	1002	85 *(45)*	”
01 / 0000	33.3	26.3	1003	75 *(40)*	”
01 / 0600	33.7	28.0	1004	65 *(35)*	”
01 / 1200	34.3	29.3	1005	55 *(30)*	tropical depression
01 / 1800	35.2	30.7	1005	55 *(30)*	”
02 / 0000	36.0	31.4	1004	65 *(35)*	tropical storm
02 / 0600	36.6	32.4			dissipated
29 / 1200			995	110 *(60)*	min. pres. / max. wind
31 / 0600			1003	75 *(40)*	landfall near El Beida (Libya)
02 / 0300			1004	65 *(35)*	landfall near Alanya (Turkey)

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)*]
Bizerte (Tunisia)	24 / 1800	1009.8	24 / 1800	43 *(23)*	
Lampedusa (Italy)	25 / 1200	1008.2			
Luqa (Malta)			28 / 0300	35 *(19)*	65 *(35)*
Cozzo Spadaro (It. / Sicily)			28 / 1500	46 *(25)*	
Luqa (Malta)			28 / 1600	39 *(21)*	63 *(34)*
Gudja (Malta)			29 / 0600	39 *(21)*	61 *(33)*
Cozzo Spadaro (It. / Sicily)	29 / 1300	1005.9			
Siracusa (It. / Sicily)			29 / 1300	46 *(25)*	
El Khoms (Libya)			30 / 1200	52 *(28)*	
Derna (Libya)			31 / 1500	52 *(28)*	
Tobruk (Libya)	31 / 1500	1008.3	31 / 1500	65 *(35)*	
Anamur (Turkey)			02 / 0100	48 *(26)*	
Alanya (Turkey)	02 / 0300	1004.3			

Table 3.a Selected ship reports

Day/Time [UTC]	Ship call sign	Latitude [°N]	Longitude [°E]	Wind dir/speed [km/h *(kt)*]	Pressure [hPa]
24 / 0200	EUCDE43	36.3	14.1		1010.0
24 / 0500	TBWUK59	36.0	14.9	180 / 47 *(25)*	1010.4
24 / 1300	EUMDE08	37.0	12.5	080 / 54 *(29)*	1010.1
25 / 0200	EUMDE08	35.8	17.0	080 / 40 *(21)*	1013.5
25 / 0600	EUMDE08	35.5	18.3	160 / 58 *(31)*	1015.8
25 / 1800	9V5240	35.8	16.4	110 / 43 *(23)*	1012.0
25 / 2300	TBWUK74	35.8	14.9		1009.9
26 / 0500	TBWUK59	35.9	14.9	050 / 47 *(25)*	1010.3
26 / 1200	9VFV4	34.7	16.8	250 / 39 *(21)*	1010.0
26 / 1700	9VFV4	35.3	15.1	030 / 43 *(23)*	1011.3
26 / 2300	DGWD2	35.1	19.9	110 / 40 *(21)*	1013.9
27 / 0900	A8YD3	34.8	20.9	070 / 83 *(45)*	1014.3
28 / 0000	EUMDE25	34.9	20.6	090 / 40 *(21)*	1017.0
28 / 0300	EUCDE47	36.2	18.3		1014.0
28 / 0500	TBWUK59	35.9	14.9	100 / 65 *(35)*	1014.1
28 / 0900	EUMDE25	35.8	17.2	100 / 40 *(21)*	1013.3
28 / 1200	EUMDE25	36.1	16.0	030 / 65 *(35)*	1011.4
29 / 0000	WMKN	36.4	15.8	030 / 65 (35)	1007.0
29 / 0100	WMKN	36.3	16.1		1004.1
29 / 0300	WMKN	36.2	16.8	150 / 44 *(24)*	1006.3
29 / 1100	WMHA	36.1	16.1	270 / 104 *(56)*	998.7
29 / 1200	WMHA	36.2	15.8	290 / 98 *(53)*	998.7
29 / 1300	WMHA	36.2	15.5	350 / 89 *(48)*	1003.0
29 / 1600	9V2004	34.6	14.9	260 / 56 *(30)*	1011.2
29 / 1800	3EPD8	35.4	17.8	180 / 43 *(23)*	1010.8
30 / 0000	OVXO2	35.9	16.4	230 / 46 *(25)*	1003.1
30 / 0600	EUMDE03	35.8	16.9		1004.1
30 / 0600	C6CN5	35.4	19.2	130 / 43 *(23)*	1013.0
30 / 2200	VRZI3	35.0	20.0	090 / 67 *(36)*	1014.0
31 / 0000	DDVK2	35.0	20.2	130 / 50 *(27)*	1013.2
31 / 0600	DDVK2	34.5	21.9	090 / 54 *(29)*	1012.4
31 / 1200	DDVK2	34.0	24.0	090 / 40 *(21)*	1012.2
31 / 1800	EUMDE46	33.8	24.6	100 / 32 *(17)*	1008.6
31 / 1800	DDVK2	33.5	25.8	090 / 65 *(35)*	1009.1
01 / 0000	DDVK2	33.0	27.9	140 / 65 (35)	1009.3
01 / 0000	DGWE2	34.1	26.3		1008.3

Table 3.b Hourly reports from ship 'EUMDE34' on 29 October

Day/Time [UTC]	Latitude [°N]	Longitude [°E]	Wind dir/speed [km/h *(kt)*]	Pressure [hPa]
29 / 0100	35.5	18.3	170 / 36 *(19)*	1012.0
29 / 0200	35.6	17.9	170 / 40 (21)	1011.0
29 / 0300	35.6	17.6	200 / 58 *(31)*	1009.9
29 / 0400	35.7	17.3	210 / 65 *(35)*	1008.2
29 / 0500	35.8	17.0	240 / 76 *(41)*	1006.1
29 / 0600	35.9	16.7	210 / 83 (45)	1005.6
29 / 0700	35.9	16.5	250 / 104 *(56)*	999.8
29 / 0800	36.0	16.3	250 / 90 *(49)*	999.4
29 / 0900	36.0	16.0	270 / 61 *(33)*	1000.8
29 / 1000	36.1	15.8	280 / 79 *(43)*	1000.3
29 / 1100	36.2	15.5	290 / 79 *(43)*	1001.8
29 / 1200	36.2	15.3	290 / 76 (41)	1003.7
29 / 1300	36.3	15.1	300 / 68 *(37)*	1006.0
29 / 1400	36.4	14.8	340 / 76 *(41)*	1008.2
29 / 1500	36.4	14.5	350 / 65 *(35)*	1009.3
29 / 1600	36.5	14.2	330 / 47 *(25)*	1010.1
29 / 1700	36.6	13.9	350 / 50 *(27)*	1011.6
29 / 1800	36.7	13.6	360 / 47 *(25)*	1012.9

Table 4.a Selected surface rainfall observation (in Sicily and South Italy)

Location	Rain on 23 Oct. [mm]	Rain on 24 Oct. [mm]	Rain on 25 Oct. [mm]	Rain on 26 Oct. [mm]	Rain on 27 Oct. [mm]	Rain on 28 Oct. [mm]	Rain on 29 Oct. [mm]	Rain on 30 Oct. [mm]	Total rain [mm]
Avola /N/ (Sicily)	0.0	0.2	21.1	100.6	14.7	54.5	247.9	20.0	458.9
Cassibile (Sicily)	0.0	0.8	5.3	61.3	3.0	29.3	**323.3**	16.8	440.1
Augusta /NE/ (Sicily)	0.0	11.9	89.4	76.8	4.8	23.1	199.9	17.8	423.7
Santa Venerina (Sicily)	0.0	46.5	102.9	174.0	0.0	3.1	22.1	33.3	381.9
Nunziata di Mascali (Sicily)	0.0	10.6	**268.4**	61.6	0.0	4.8	4.2	22.8	372.4
Catania / Trapetto Nord (Sicily)	0.0	23.9	91.2	**187.5**	0.0	3.8	33.0	19.1	358.5
Zafferana Etnea (Sicily)	0.0	62.5	114.8	104.6	0.0	3.8	15.0	30.0	330.7
Catania (Sicilly)	0.0	23.4	96.3	145.5	0.0	2.0	33.3	25.4	325.9
San Giovanni la Punta / Tr. (Sicily)	0.0	13.2	104.7	148.8	0.0	2.5	39.1	11.9	320.2
Catania /center/ (Sicily)	0.0	12.5	94.5	159.3	0.0	2.5	37.3	10.2	316.3
Augusta /N/ (Sicily)	0.0	47.0	71.9	30.0	3.8	11.4	135.9	12.2	312.2
Calatabiano (Sicily)	0.0	30.5	160.8	53.1	0.0	0.8	8.9	51.8	305.9
Avola /S/ (Sicily)	0.0	0.2	7.1	77.0	20.3	33.8	158.0	6.1	302.5
Catania / Fontanar. (Sicily)*	0.6	36.0	122.0	85.0	1.0	26.0	18.6	9.0	298.2
Serralta Di. S. Vito (S. Italy)	0.8	67.0	147.0	2.0	0.0	0.0	48.0	2.0	266.8
Melilli (Sicily)	0.0	3.8	25.2	31.2	21.1	30.2	135.6	17.8	264.9
Santa Maria Ammalati (Sicily)	0.0	56.4	90.4	74.7	0.0	0.0	29.7	9.7	260.9
Gallodoro /SE/ (Sicily)	0.0	42.4	133.7	43.1	0.0	0.0	6.9	30.3	256.4
Aci Bonaccorsi (Sicily)	0.0	32.8	79.0	111.8	0.0	0.0	21.6	9.4	254.6
Pachino (Sicily)	0.0	5.4	0.7	20.4	18.1	29.5	137.1	34.3	245.5

Punta Cungo / Augusta (Sicily)	0.0	2.3	44.5	36.3	5.8	13.2	118.9	5.1	226.1
Catania / Canalic. (Sicily)	0.0	8.1	62.5	100.6	0.0	2.0	25.7	15.5	214.4
Lido di Noto (Sicily)	0.0	1.3	2.0	59.4	14.2	22.6	110.5	1.5	211.5
Palacanica (S. Italy)	0.0	19.6	58.7	19.3	0.0	0.0	51.3	15.5	164.4
Brancaleone (S. Italy)	0.0	17.2	23.1	23.4	0.0	0.5	41.9	40.6	146.7
Soverato /N/ (S. Italy)	0.0	30.5	66.5	16.0	0.0	0.0	16.8	9.9	139.7
Reggio Calabria (S. Italy)	0.0	80.0	11.0	9.0	0.0	0.0	5.0	14.4	119.4
Santa Margherita Marina (Sicily)	0.0	14.5	63.0	12.5	0.0	0.0	5.1	17.8	112.9
Montepaone Lido (S. Italy)	0.0	28.2	50.8	12.9	0.0	0.0	11.7	7.9	111.5
Messina (Sicily)	0.1	66.0	14.0	9.0	0.0	0.0	18.0	1.0	108.1
Pachino /SW/ (Sicily)	0.0	0.0	3.0	13.3	11.6	6.7	27.8	4.9	67.3
Mirabella Imbaccari (Sicily)	0.0	10.6	0.0	14.4	0.0	31.4	8.0	0.0	64.4

Table 4.b Selected surface rainfall observation (out of Sicily and South Italy)

Location	Rain on 23 Oct. [mm]	Rain on 24 Oct. [mm]	Rain on 25 Oct. [mm]	Rain on 26 Oct. [mm]	Rain on 27 Oct. [mm]	Rain on 28 Oct. [mm]	Rain on 29 Oct. [mm]	Rain on 30 Oct. [mm]	Rain on 31 Oct. [mm]	Rain on 1 Nov. [mm]	Total rain [mm]
Luqa (Malta)	0.0	0.0	57.8	10.6	8.6	32.2	7.8	2.6			119.6
Tabarka (Tunisia)	34.6	71.0	17.0	1.6							124.2
Beja (Tunisia)	11.4	62.0	26.0	5.6							105.0
Bizerte (Tunisia)	37.8	33.0	6.0	0.0							76.8
Tunis-Carthage (Tunisia)	41.4	10.0	20.0	1.0							74.2
Derna (Libya)					0.0	22.0	0.0	5.0	3.0		30.0
Tobruk (Libya)					0.0	2.0	0.0	0.0	2.0		4.0
Anamur (Turkey)							0.0	2.1	4.9	87.5	94.5
Alanya (Turkey)							0.0	5.6	20.0	49.6	75.2
Finike (Turkey)							0.7	14.8	20.1	16.9	52.5
Antalya (Turkey)							0.0	0.2	9.4	39.6	49.2
Silifke (Turkey)							0.0	0.0	0.6	27.0	27.6

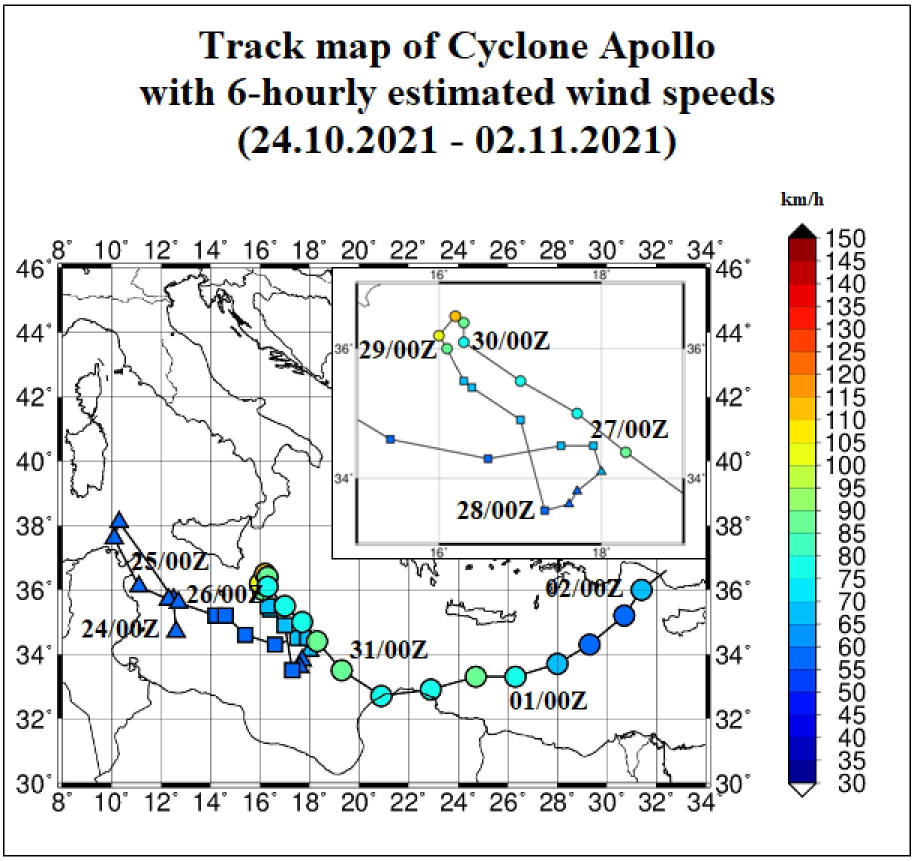

Figure 1. Best track positions for Tropical Storm Apollo, 24 October – 2 November 2021. The triangles mean extratropical, the squares subtropical and the circles tropical stage. The colors represented the estimated wind speeds (from Table 1) at the actual time. The position based on satellite images and ECMWF reanalysis.

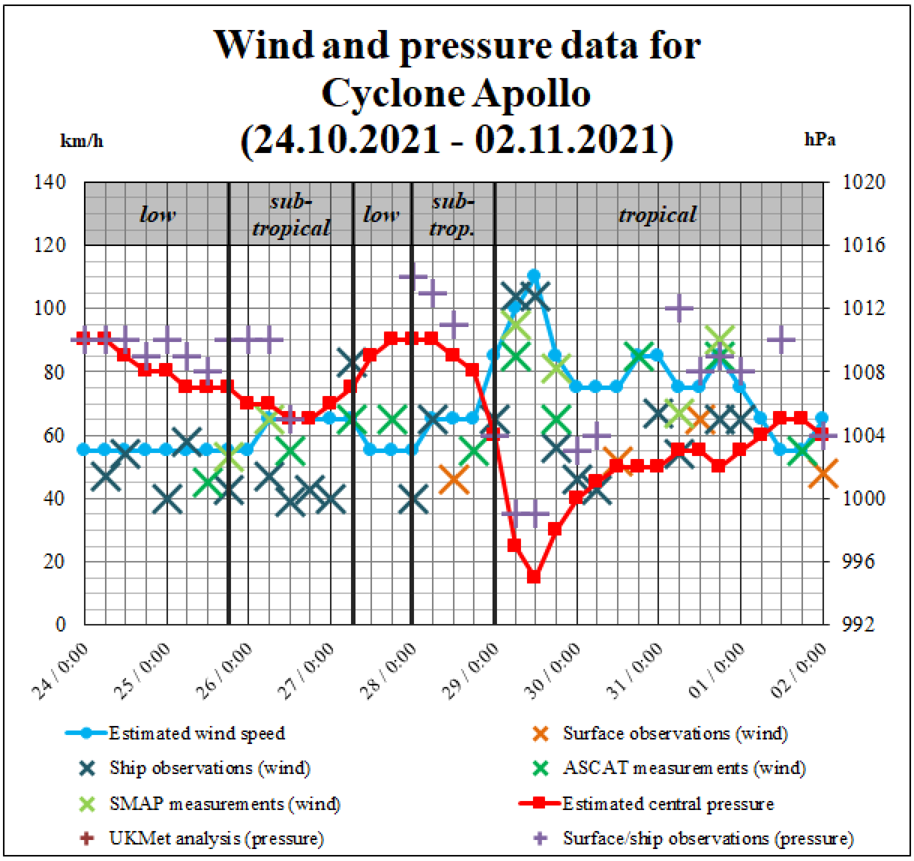

Figure 2. Selected wind and pressure observations with estimated maximum sustained wind and minimum central pressure for Tropical Storm Apollo, 24 October – 2 November 2021. The stated 6 hourly data mean the maximum sustained wind within a 3-hour interval around the marked time in case of all measurements.

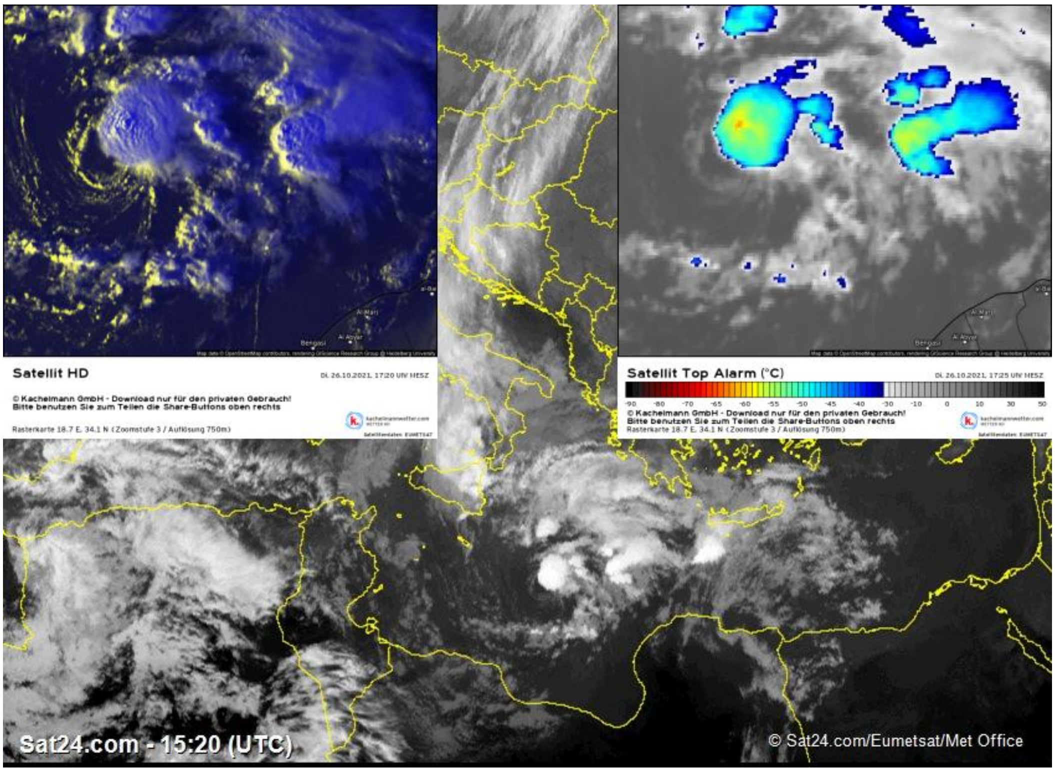

Figure 3. Infrared, visible (RGB) and cloud top temperature satellite images of Apollo at 1520 UTC 26 October. The cyclone briefly acquired tropical characteristics at this time. *Source: EUMETSAT / Sat24.com, Kachelmannwetter*

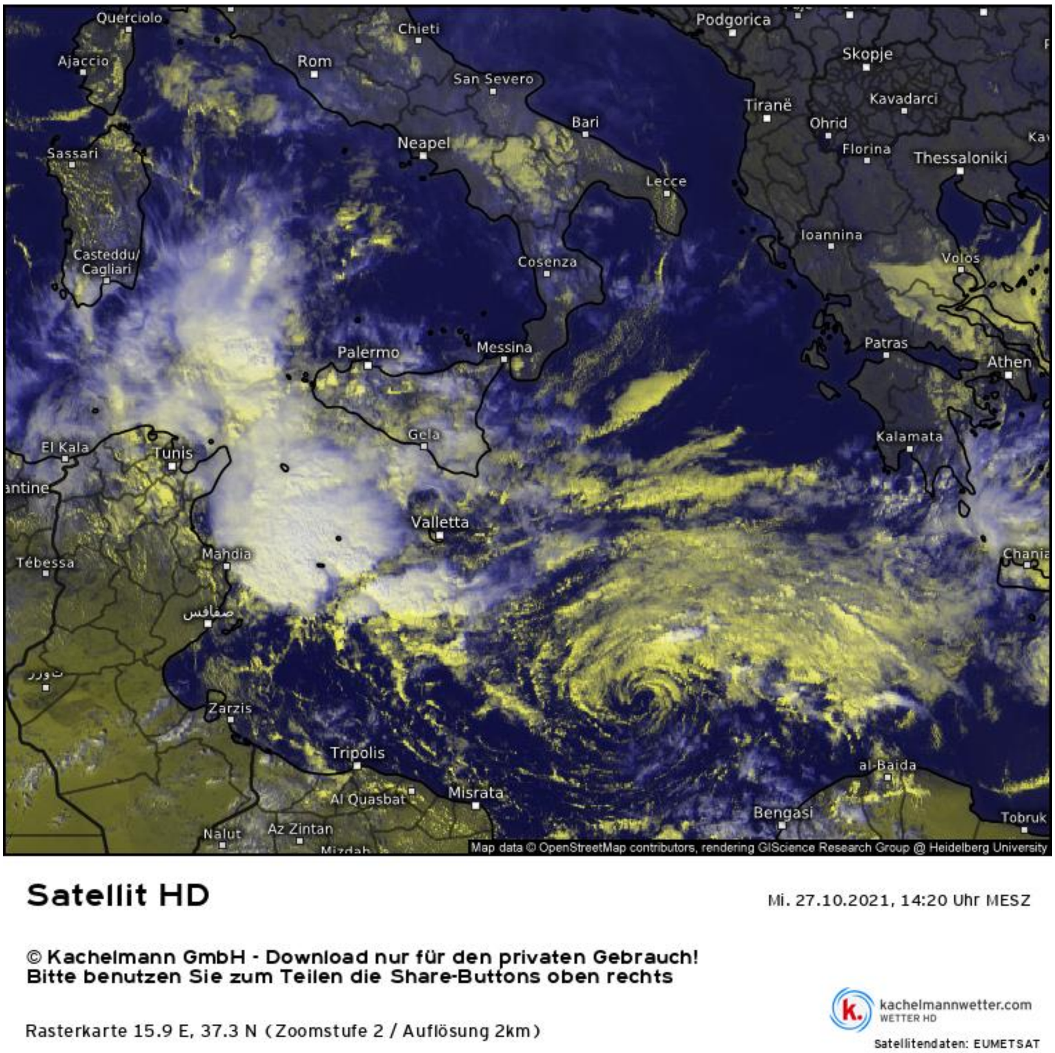

Figure 4. Visible (RGB) satellite image of Apollo at 1220 UTC 27 October. The cyclone became a convection-free low-level vortex by this time while a large cluster of thunderstorms developed to west-northwest, and later these two systems merged with each other. *Source: EUMETSAT / Kachelmannwetter*

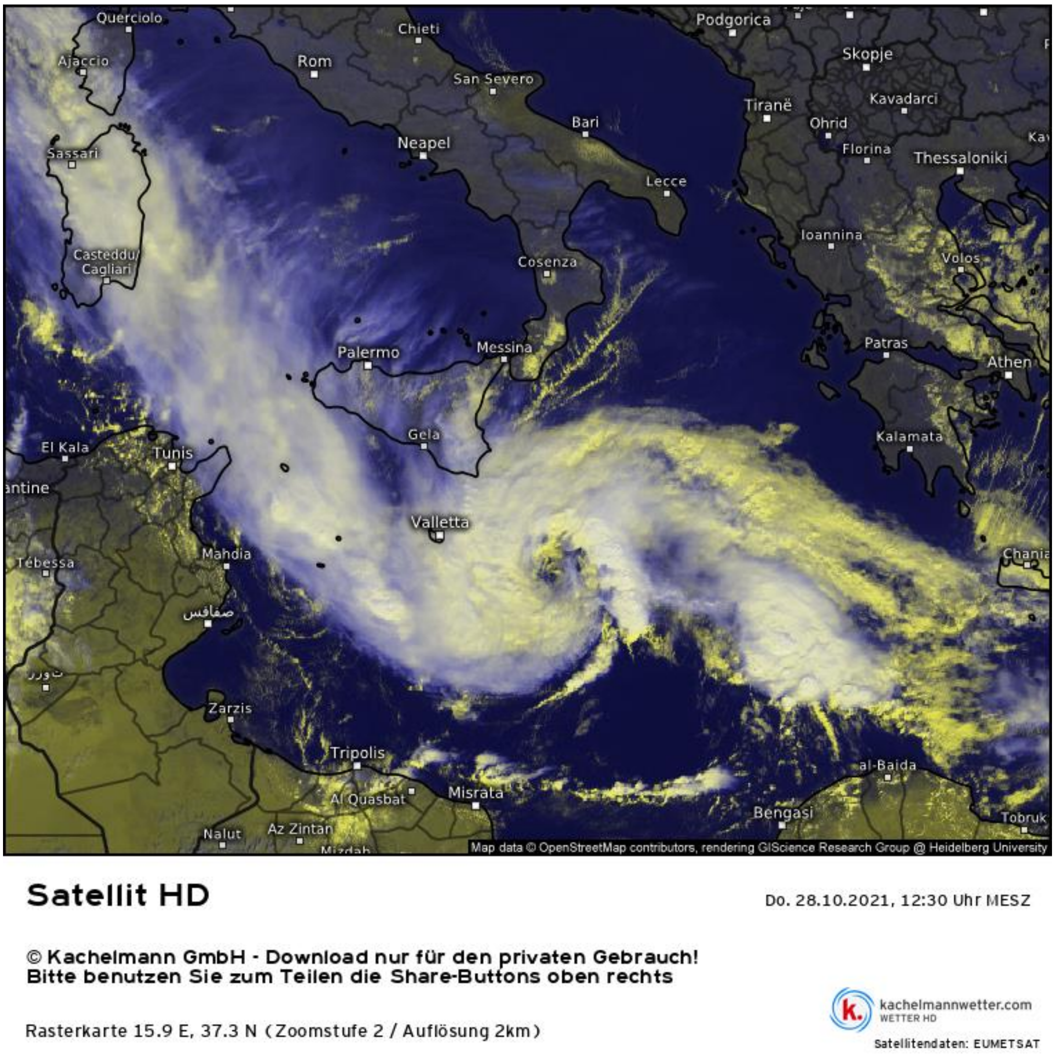

Figure 5. Visible (RGB) satellite image of Apollo at 1030 UTC 28 October. The cyclone rapidly acquired a well-defined structure with quite deep convection surrounding the eye-like feature and thanks to an upper level low over the Western Mediterranean Sea an elongated poleward outflow channel also developed in its northwest quadrant. *Source: EUMETSAT / Kachelmannwetter*

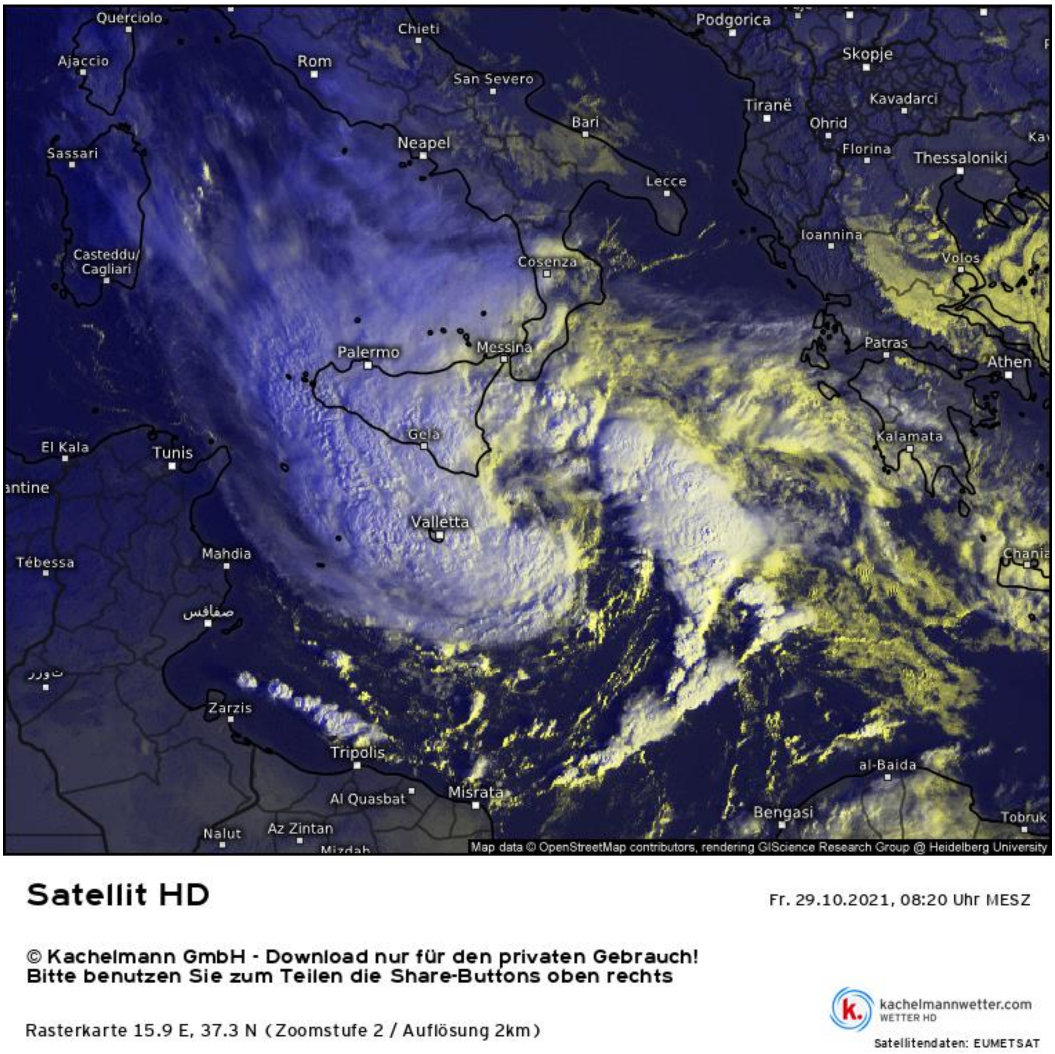

Figure 6. Visible (RGB) satellite image of Apollo at 0620 UTC 29 October. The cyclone had the best structure around this time and reached its peak intensity a few hours later. *Source: EUMETSAT / Kachelmannwetter*

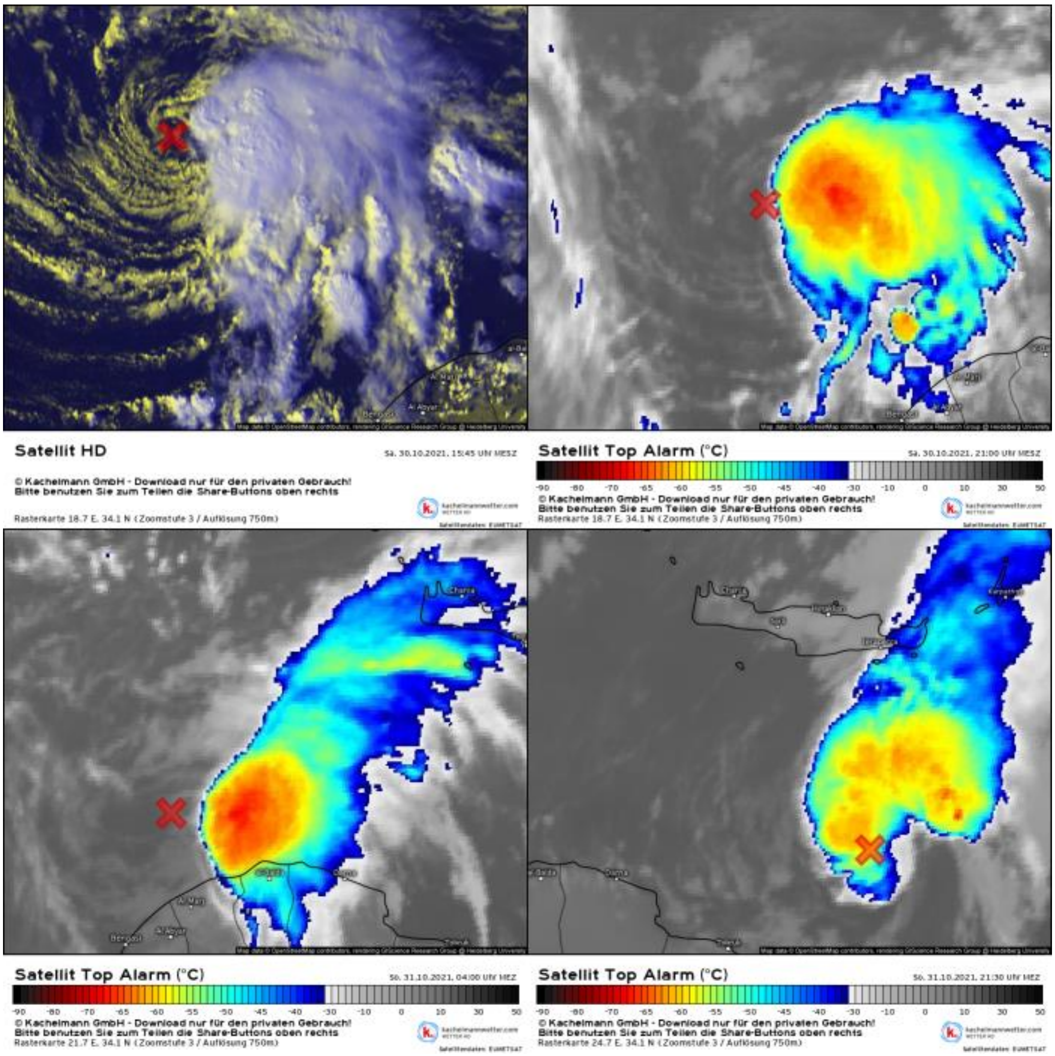

Figure 7. Visible (RGB) and cloud top temperature satellite images of Apollo at 1345 UTC, 1900 UTC 30 October and 0300 UTC, 2030 UTC 31 October. Despite the stronger shear, the cyclone produced quite deep convection periodically before and after its landfall in Libya, mainly east of the center. However, due to the short-time, favorable change in the upper-level winds, the center temporarily moved under the thunderstorm cluster by the evening hours of 31 October. The red X marks the estimated center positions. *Source: EUMETSAT / Kachelmannwetter*

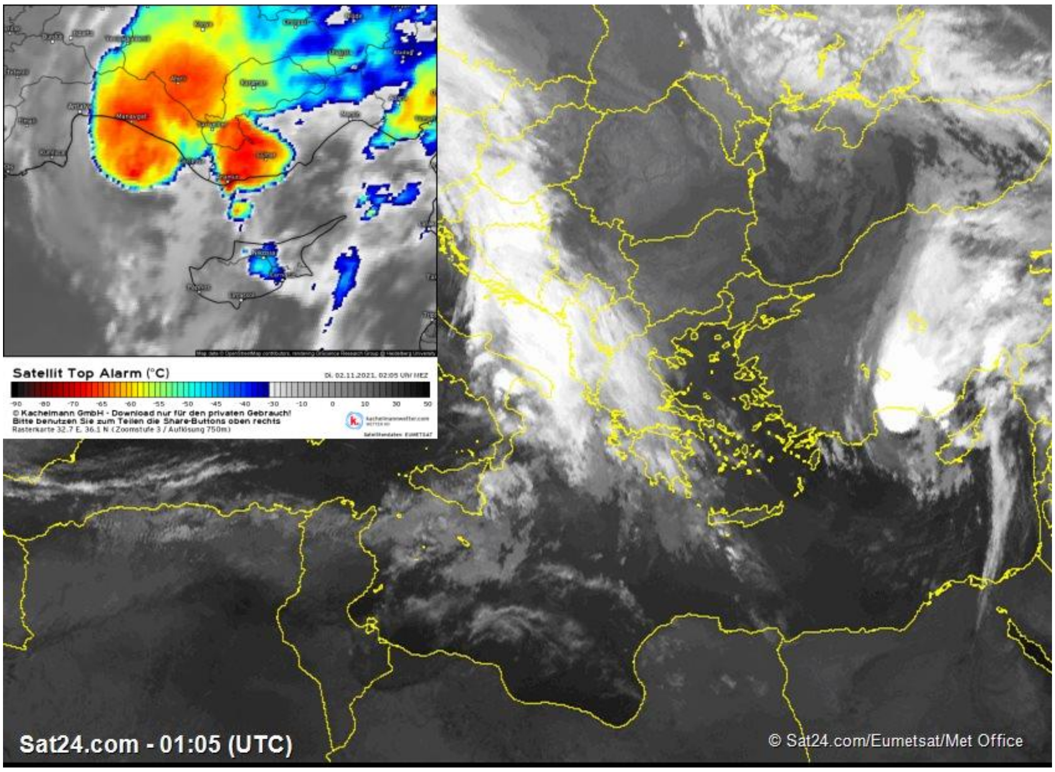

Figure 8. Infrared and cloud top temperature satellite images of Apollo at 0105 UTC 2 November. Shortly before its final landfall in Turkey, the cyclone produced a large and very deep convective burst. *Source: EUMETSAT / Sat24.com, Kachelmannwetter*

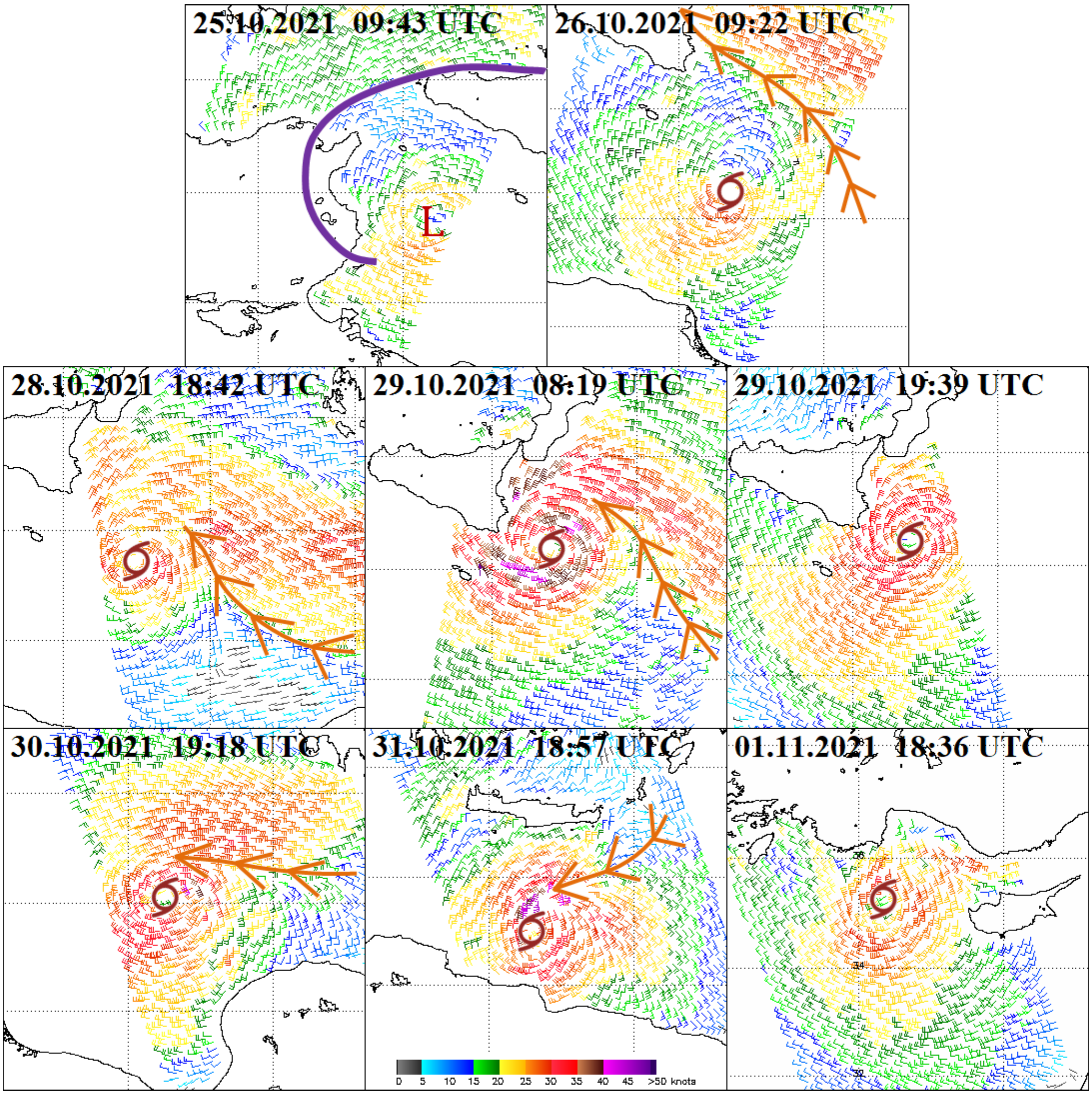

Figure 9a. Satellite-based wind data of Apollo between 25 October and 1 November measured by ASCAT-A and ASCAT-B sensors. The images show the evolution of the cyclone in its first (upper line) and second (middle and bottom line) tropical phase. *Source: NOAA NESDIS*

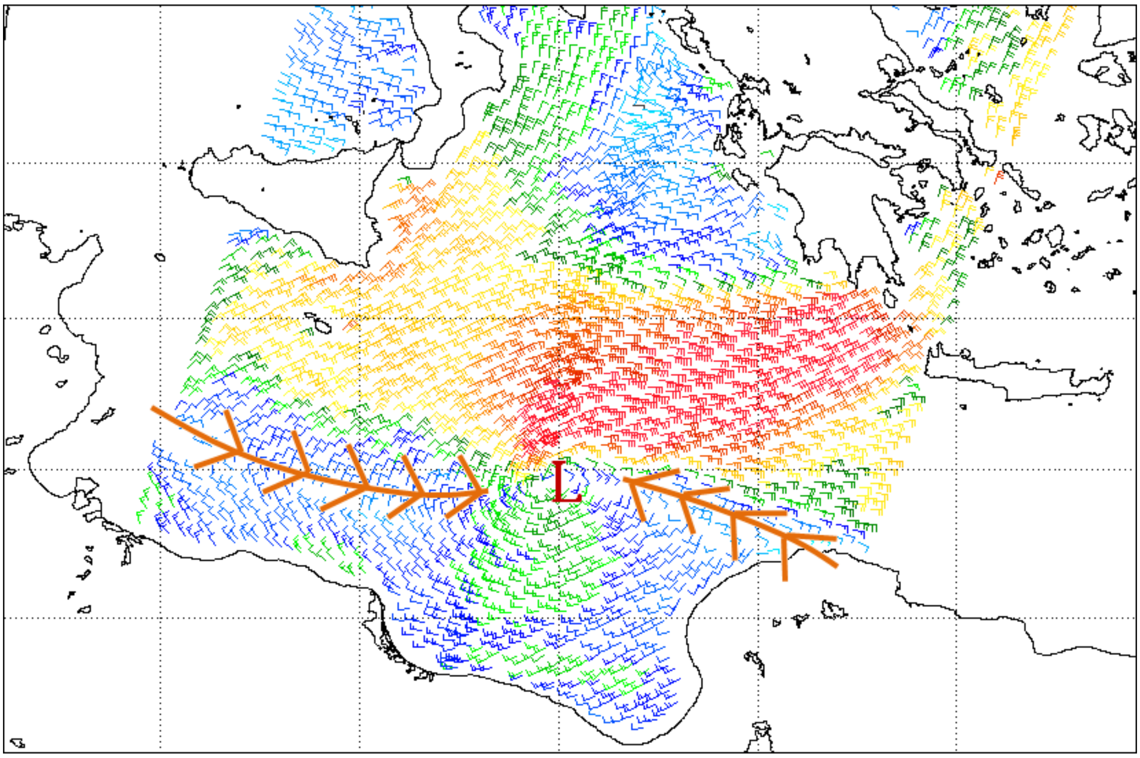

Figure 9b. Satellite-based wind data of Ex-Apollo and its environment on 27 October measured by ASCAT-A and ASCAT-B sensors. The image is a combination of the 0744 UTC (left side) and the 0901 UTC (right side) overpasses. The cyclone merged into an elongated convergence zone by this time which was generated by the gap wind effect between the Peloponnese and Crete. *Source: NOAA NESDIS*

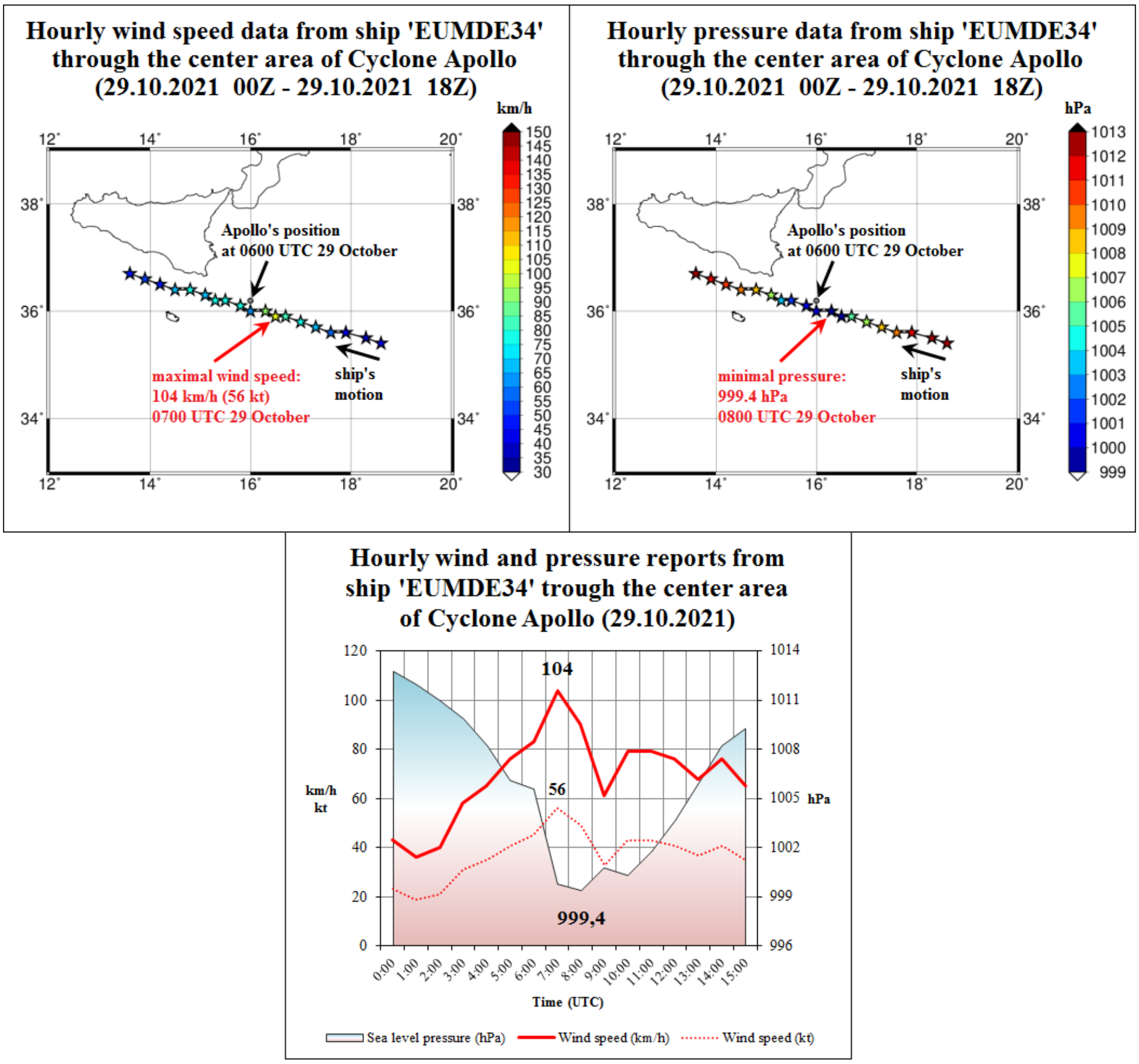

Figure 10. Hourly wind speed and pressure data from ship 'EUMDE34' as it crossed Apollo's center region on 29 October. *Data source: Ogimet*

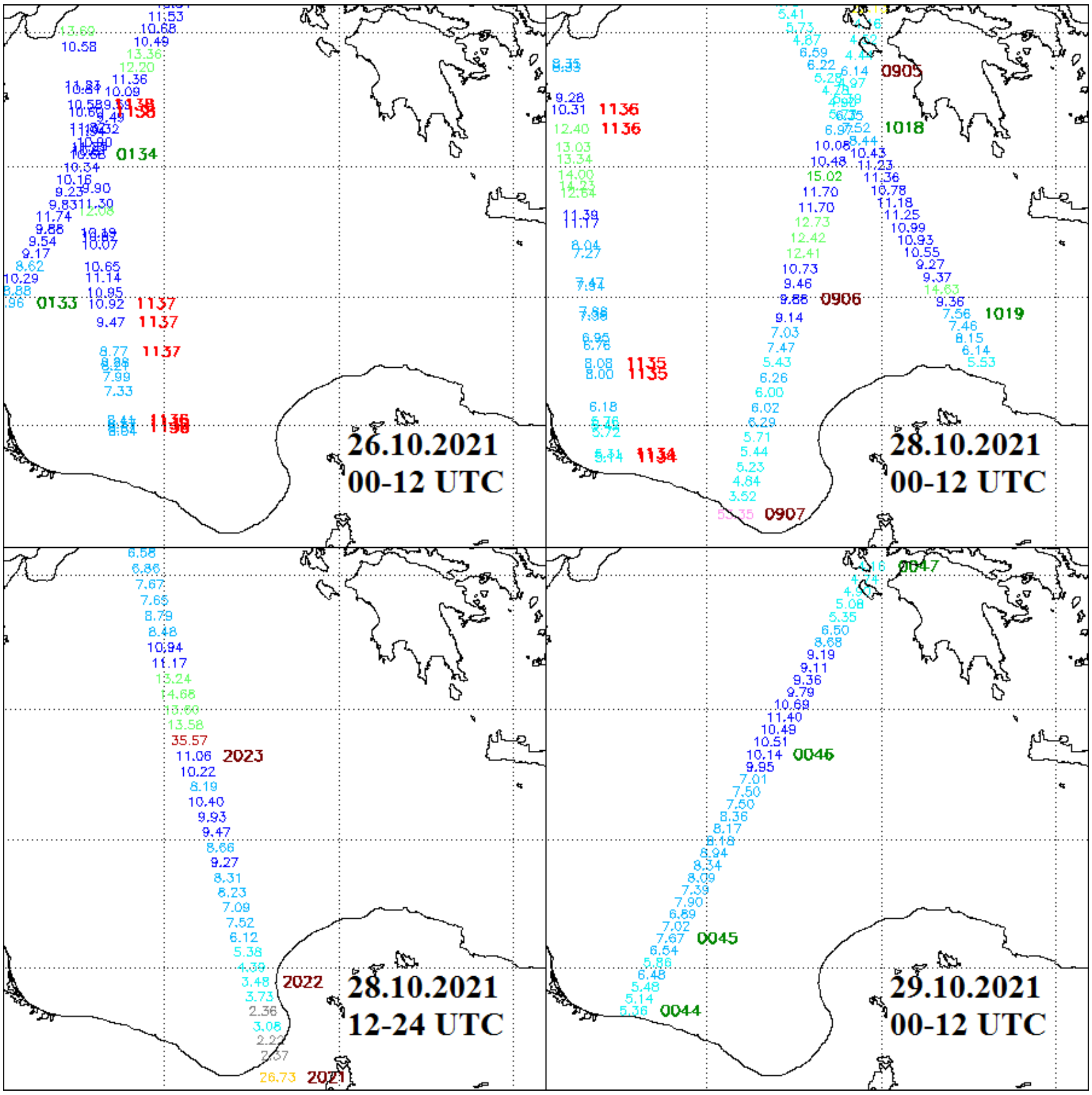

Figure 11. Satellite-based significant wave height data (smaller numbers in line, in feet) related to Apollo on 26-29 October. The larger numbers show the time of the measurements (in UTC). *Data source: NOAA NESDIS*

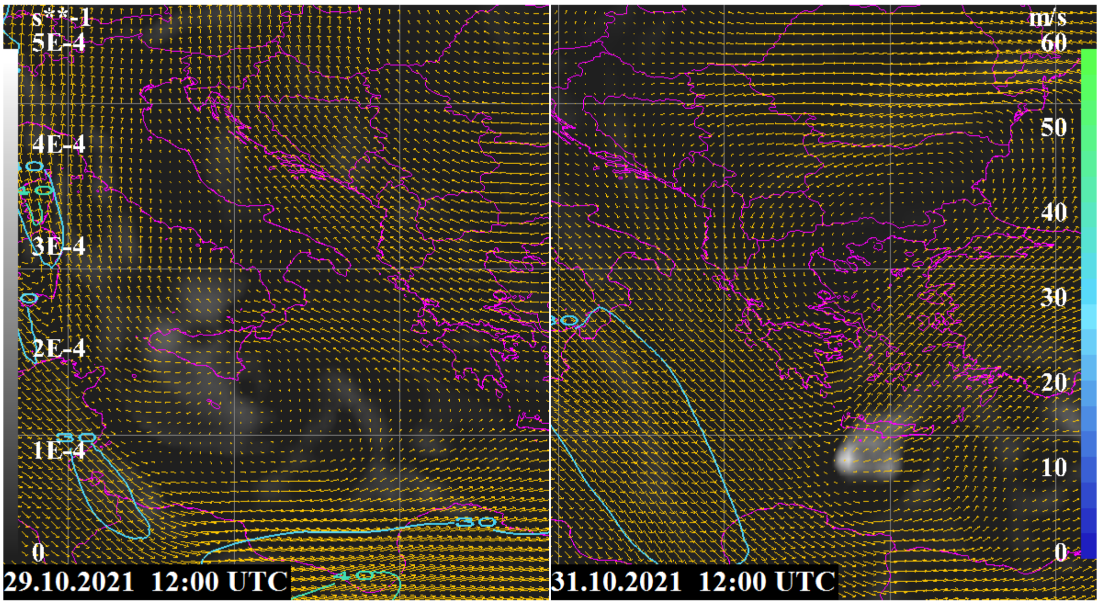

Figure 12. 300 hPa divergence (shaded) and winds (vectors and contours per 10 m/s from 30) over the Central Mediterranean Sea at 1200 UTC 29 October and 1200 UTC 31 October. *Data source: ECMWF/Copernicus*

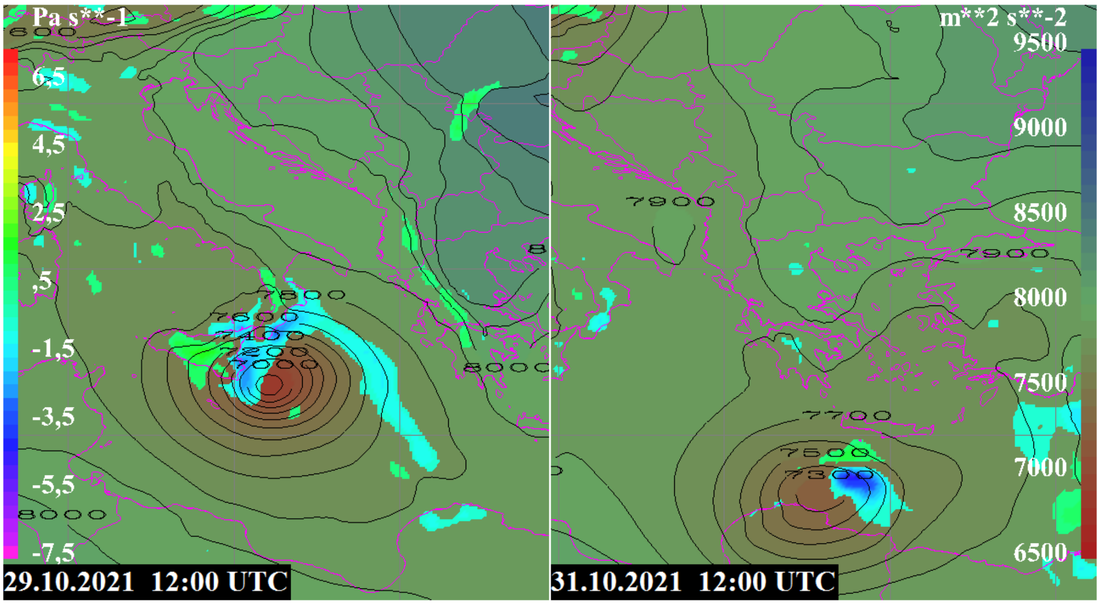

Figure 13. 925 hPa geopotential (shaded with black contours) and 850 hPa vertical speed (shaded patches, without the -0,5 to 0,5 Pa/s range) over the Central Mediterranean Sea at 1200 UTC 29 October and 1200 UTC 31 October. *Data source: ECMWF/Copernicus*

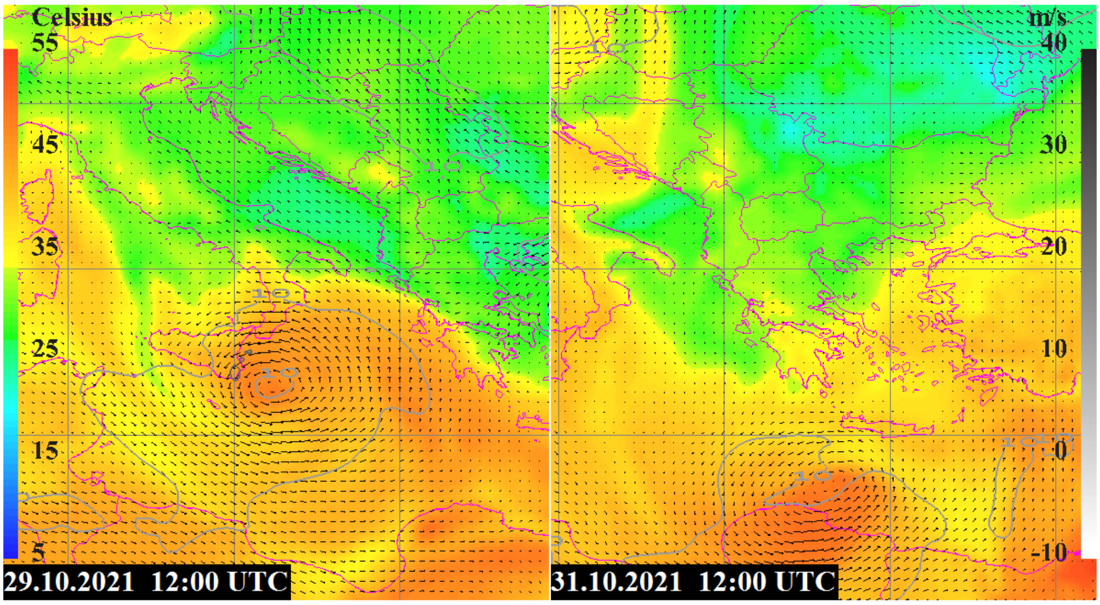

Figure 14. 850 hPa equivalent potential temperature (shaded) and winds (vectors and contours per 10 m/s) over the Central Mediterranean Sea at 1200 UTC 29 October and 1200 UTC 31 October. *Data source: ECMWF/Copernicus*

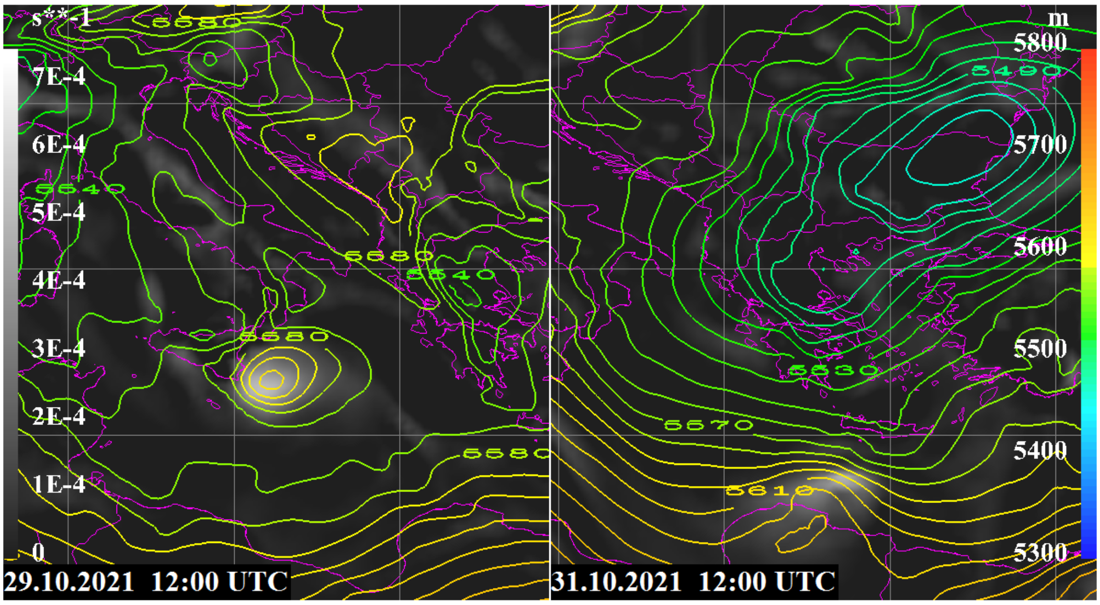

Figure 15. 500-1000 hPa thickness (contours per 10 m) and 850 hPa relative vorticity (shaded) over the Central Mediterranean Sea at 1200 UTC 29 October and 1200 UTC 31 October. *Data source: ECMWF/Copercus*

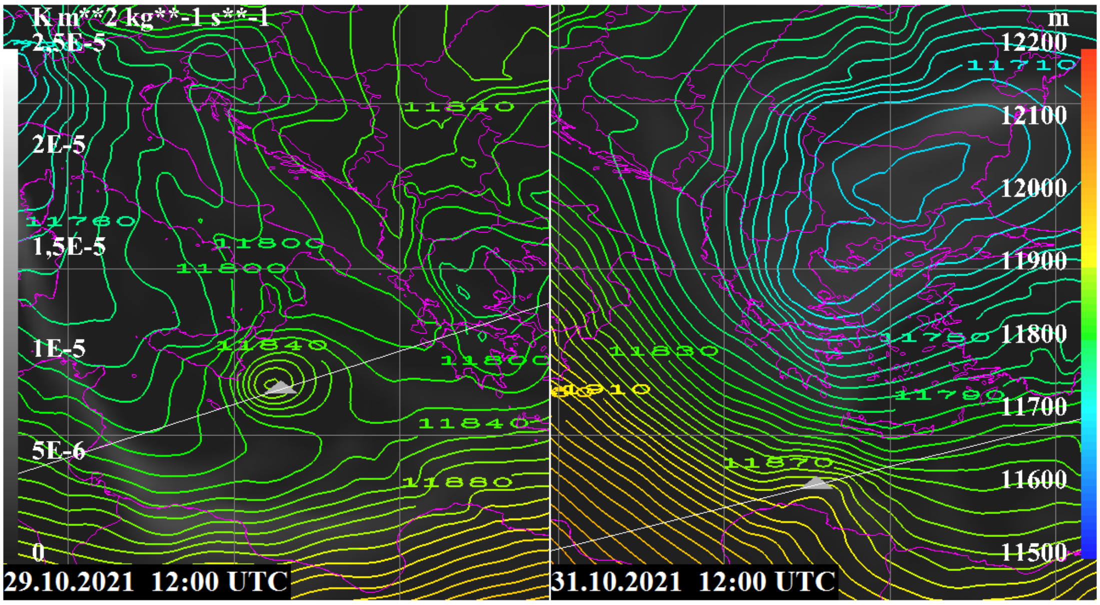

Figure 16. 200-1000 hPa thickness (contours per 10 m) and 300 hPa potential vorticity (shaded) over the Central Mediterranean Sea at 1200 UTC 29 October and 1200 UTC 31 October. *Data source: ECMWF/Copernicus*

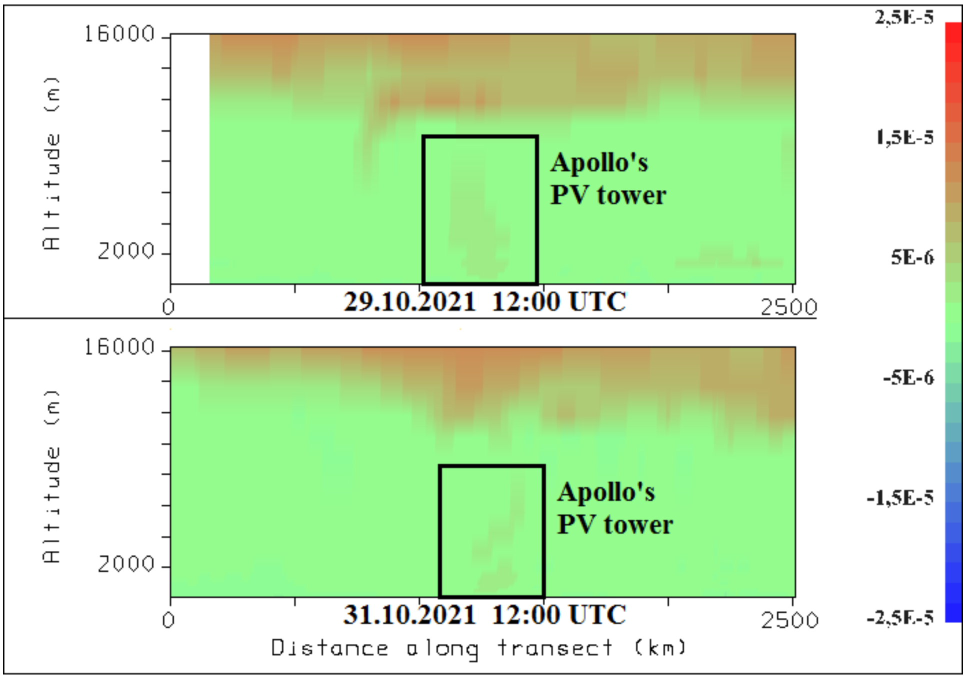

Figure 17. Potential vorticity vertical crosses through the center of Apollo and its environment at 1200 UTC 29 October and 1200 UTC 31 October. The cross-sections marked with thin white lines on Figure 16. *Data source: ECMWF/Copernicus*