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Vince – a case study

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Abstract. Vince was an unusual hurricane that developed over the North Atlantic Ocean in an unexpected area, on October 2005. In this work, the authors analyze its background and genesis over the ocean, making use of satellite imagery and numerical models. The impacts on sea state are investigated both numerically and observationally. Landfall over the Iberian Peninsula is monitored with surface observations and a radar system at Algarve (Portugal).

1 Introduction

Hurricane Vince formed and developed northwest of the Madeira Island, north of 30° N, over ocean waters with sea surface temperature (SST) as low as 23–24°C. This fact and its trajectory towards the Iberian Peninsula gave Vince the status of a peculiar event.

Vince was thought to be the first observed tropical storm making landfall in the Iberian Peninsula. However, a recent study suggests that a similar tropical storm occurred in October 1842 (Vaquero et al., 2008).

The atmospheric and oceanic favourable conditions for the development and strengthen of a hurricane are: a pre-existing near-surface disturbance with large values of vorticity and low-level convergence, warm ocean waters of at least 26.5°C throughout a depth on the order of 50 m, relatively moist layers near the mid-troposphere (about 5 km), a potentially unstable atmosphere and vertical wind shear in the 200–850 hPa layer lower than about 10 m/s (e.g. Gray, 1968; Bosart and Bartlo, 1991; Frank and Ritchie, 2001; Zehr, 2003).

Despite the referred factors, there have been several observational evidences of systems similar to tropical storms which developed in an unexpected environment. Reale and Atlas (2001) refer two vortices formed over the Mediterranean in October 1996 that were similar to tropical cyclones. Furthermore, they stress the importance of surface heat flux and the absence of baroclinicity and vertical shear in the cyclogenetic process. Businger and Baik (1991) studied the so-called "artic hurricanes", which are polar lows that develop an eyelike feature and result from strong latent and sensible heat fluxes from sea surface into the boundary layer. On the other hand, Bosart and Bartlo (1991) studied tropical storm Diana that developed east of Florida in September 1984, in a baroclinic environment following the decaying of a frontal zone. Therefore, although tropical cyclones are included in an individual category, there is a wide variety of cyclones that challenge this categorization, as suggested by the study of Hart (2003).

2 Data and methodology

The surface atmospheric observation data (precipitation and wind) considered in this study were obtained from the Portuguese meteorological service (IM) stations network. Oceanic observation data (SST, wind and swell) were gathered from ship reports, buoys from the Portuguese hydrographic service and coastal marine stations from IM.

Over the Atlantic ocean, satellite data were used, mainly from High Resolution Visible (HRV) band of Meteosat 8 (1 km spatial resolution).

On its path to Iberia, Vince trajectory was in close range to the Loulé/Cavalos do Caldeirão (L/CC) radar system, located 25 km inland north of Faro city from which several radar products were used.

In this study, analyses from the European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric model, with an equivalent grid spacing of 0.25° were used. Additionally, forecasts from ALADIN model (Bubnová et al., 1993) have been considered. ALADIN is a spectral limited area model, which was integrated in hydrostatic mode, with 41 vertical levels and equivalent grid spacing of 24.5, 12.6 (operational at IM) and 7.3 km. The results from the three horizontal resolutions of ALADIN forecasts were generally very similar, therefore only the results from the operational resolution are presented. Its initial and lateral

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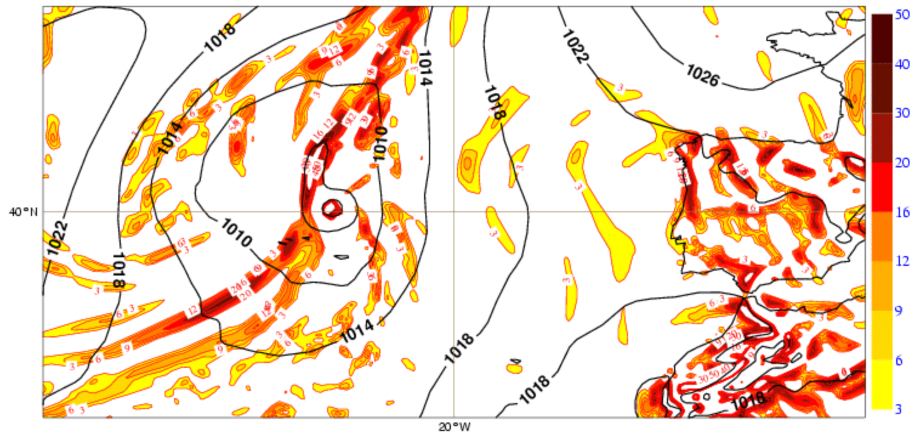

Figure 1. Thermal frontal parameter (10^{-11} K/m^{-2}) and mean sea level pressure (contour interval is 4 hPa) at 00:00 UTC 5 October 2005 (ECMWF analysis).

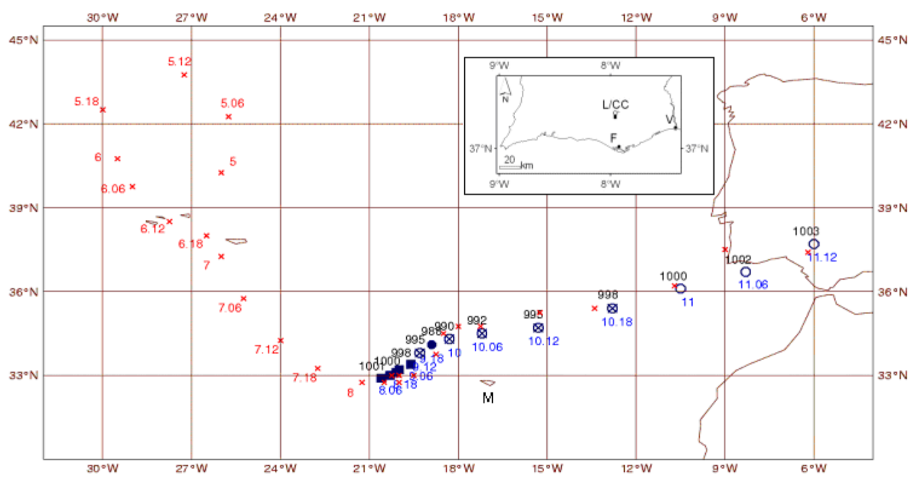

Figure 2. Vince and its precursor trajectories according to ECMWF analysis are shown in *red crosses* (from 00:00 UTC 5 October until 12:00 UTC 11 October). The day and hour (format day.hour) of the depression centre location given by ECMWF are also shown in *red*. NHC trajectory (from 06:00 UTC 8 October until 12:00 UTC 11 October) and the different stages of Vince lifecycle are shown with symbols in navy colour. Subtropical storm is represented by *solid squares*, tropical storm by *circles with a cross*, hurricane by *solid circles* and tropical depression by *open circles*. The mslp given by NHC is shown in *black* and the day.hour of Vince centre location are shown in *blue*. M represents Madeira. Faro (F), Vila Real de Santo António (V) and Loulé/Cavalos do Caldeirão radar (L/CC) locations in southern Portugal, are depicted in the zoom box.

boundary conditions are obtained from Arpège forecasts (grid spacing of approximately 21 km), with a coupling frequency of 3 h. The integration domain covers the Iberian Peninsula and the Azores and Madeira Islands. ALADIN simulations were initialized at 12:00 UTC, from 7, 8 and 9 October and integrated for 48h. Third generation wind-wave model MAR3G (Pires, 1993) forecasts were also used to evaluate Vince's impact on the sea surface. MAR3G uses a Mercator projection, with a 1° latitude per 1° longitude grid mesh over the North Atlantic. This model computes directional wave spectra using wind fields from 12:00 UTC dissemination (analysis and forecast) of ECMWF atmospheric model, generating wave parameters and spectra once a day every 6 h, up to 5 days.

3 Synoptic background and lifecycle

3.1 Background

Vince formed in the North Atlantic on 9 October 2005. Its genesis was related to a low pressure system located northwest of Cape Verde Islands, on 30 September. This low moved slowly north-westward until 2 October and then

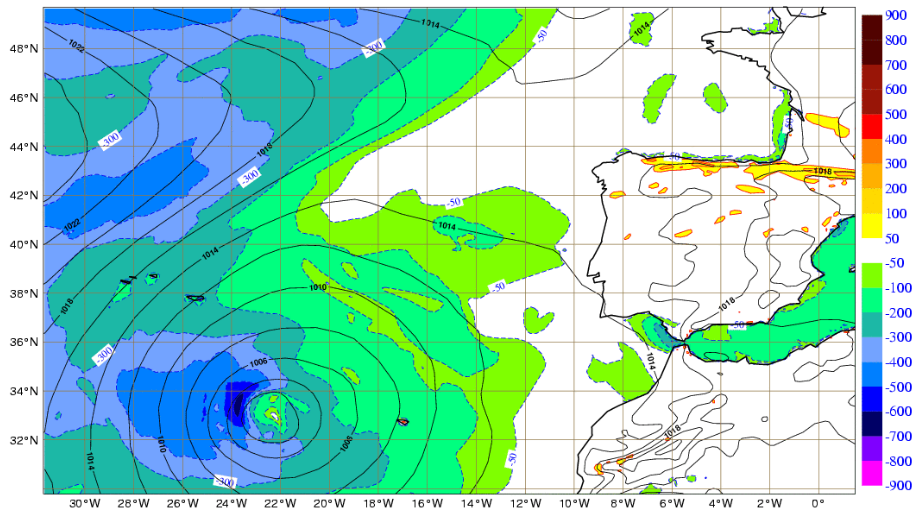

Figure 3. Surface latent and sensible heat fluxes (W/m^2) and mean sea level pressure (contour interval is 2 hPa) valid at 00:00 UTC 8 October 2005 (12 h forecast by ALADIN).

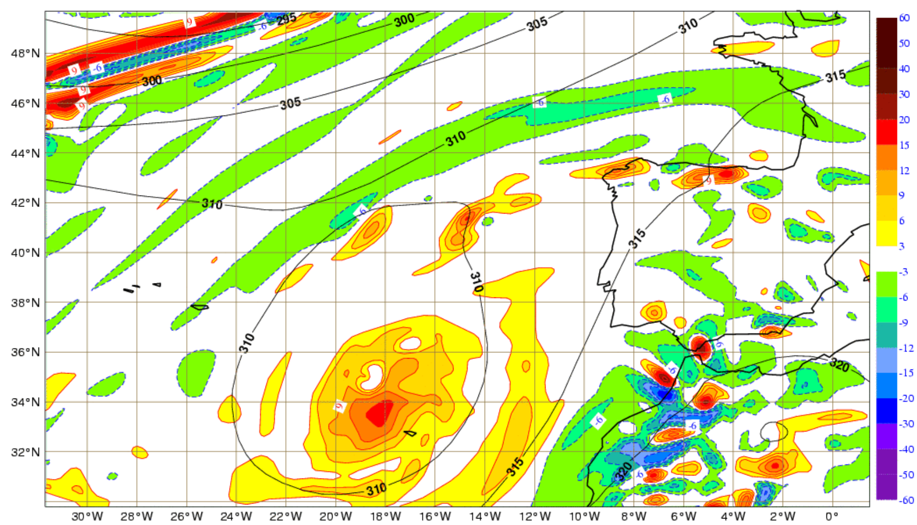

Figure 4. Relative vorticity (10^{-5} s^{-1}) and geopotential height at 700 hPa (contour interval is 50 gpm), valid at 15:00 UTC 9 October 2005 (27 h forecast by ALADIN).

veered towards the Azores Islands, where it arrived on 4 October. During the first hours of this day, ECMWF analysis show minimum sea level pressure between 1005 and 1010 hPa. Afterwards, the low started to deepen as it moved northward and interacted with a cold front coming from northwest of the Azores Islands. This cold front is depicted using the thermal frontal parameter (Lynch et al., 2001) and the surface low is identified using mean sea level pressure (mslp) at 00:00 UTC 5 October (Fig. 1). In the next 18 h pressure falls 7 hPa over Azores area. Afterwards, a single low remained over the area until 12:00 UTC 6 October, with minimum pressure values between 993 and 999 hPa according to ECMWF analysis. Then, this system started to move to the southeast, towards the west of Madeira Island, as it can be seen in Fig. 2.

3.2 Genesis and evolution

Although SST values above 26.5°C are considered to be a necessary condition for hurricane formation, Vince developed over ocean waters with SST around 23–24°C. Ship reports, surface observations from coastal marine stations and data buoys also confirmed there were no significant variations of SST during this stage.

The development of hurricanes strongly depends on latent and sensible ocean heat fluxes. The largest surface total heat flux (latent and sensible) forecasted by ALADIN on

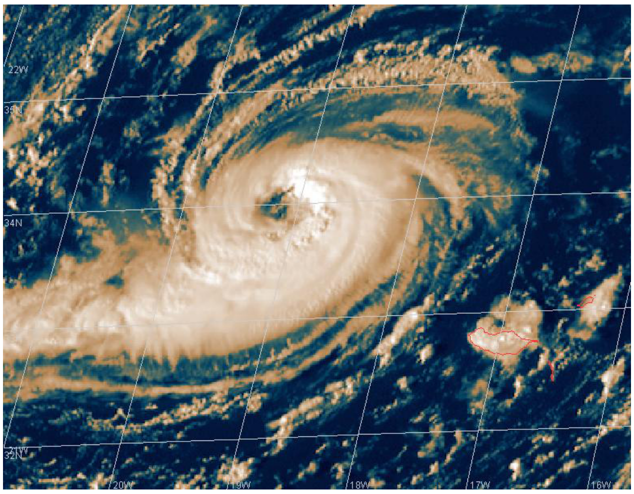

Figure 5. Meteosat 8 HRV image at 15:45 UTC 9 October 2005.

the western flank of the storm occurs between 16:00 UTC 7 October and 05:00 UTC 8 October. Maximum values around 600–700 W/m^2 in this area are illustrated in Fig. 3, at 00:00 UTC 8 October 2005. These values are below the expected 1000 W/m^2 in tropical storms (Reale and Atlas, 2001). However, according to ALADIN simulations, the latent heat flux is much stronger than the sensible heat flux (maximum values of 50–100 W/m^2), as expected in tropical storms, while in extratropical cyclones the magnitude of these fluxes is similar (Reale and Atlas, 2001).

ALADIN 700 hPa relative vorticity at 15:00 UTC 9 October, from both 3 h and 27 h forecasts, locate the storm around 34° N 19° W (27 h forecast is depicted in Fig. 4). This location is confirmed by Meteosat 8 HRV image at 15:45 UTC of the same day (Fig. 5), in which a typical eye feature is clearly visible. In fact, this was the instant when National Hurricane Centre (NHC) in Miami, first classified Vince as a tropical storm in advisory bulletins. This classification was based on the Dvorak technique (Velden et al., 2006), which classifies tropical cyclones according to satellite and numerical model estimates. The trajectory given by NHC report (Franklin, 2006) and its life cycle are shown in Fig. 2. Vince was classified as a tropical storm at 12:00 UTC 9 October and as a hurricane at 18:00 UTC the same day, with a mslp of 988 hPa and maximum sustained surface winds of 65 kt. It is important to refer that both ECMWF analysis and ALADIN forecasts underestimate the deepening of the system, during the whole day. This underestimation is maximum during the hurricane stage, being 16 hPa for ECMWF analysis and 17–18 hPa for ALADIN forecasts. The results from the three resolutions of ALADIN forecasts and ECMWF analysis were very similar regarding pressure deepening. This fact suggests that a low resolution in which convection is not explicitly resolved can be the main responsible for such behaviour. Furthermore, between 8 and 10 October, the maximum wind speed forecasted by ALADIN was 25–30 kt, while according to NHC the values of wind speed vary between 35 and 65 kt. This wind speed underestimation suggests that surface heat fluxes could also be underestimated. Vince was considered to decay to tropical storm strength at 00:00 UTC 10 October, by NHC (Fig. 2), when it started to lose the eye feature in satellite imagery and to move eastward.

Vince trajectory given by ALADIN simulations is compared with the one from NHC in Fig. 6. ALADIN simulations closely agree with NHC track until 10 October. Afterwards, the forecasted trajectories deviate significantly from the observed one, placing landfall around Lisbon area rather than Andaluzia (Spain).

3.3 Sea state

Air-sea interaction process during the development stage of the tropical storm Vince, originated a cyclonic circulation, creating a wind sea (waves growing under the influence of wind) with a significant wave height (Hs) above 3.5 m on 9 October (12:00 UTC) offshore Madeira. Wind waves moved outward from this system (decreasing their significant wave height and increasing their wavelength) generating swell. In fact, the buoy located off the south coast of Portugal (Faro) showed an increase of Hs from the first hours on 10 October. On 11 October, observations near Faro identified a Hs peak of 4.6 m and a maximum wave height (Hmax) of 9.6 m, above the normal sea conditions in this region, as Vince was approaching land (Fig. 7). Due to the sparse temporal resolution of MAR3G outputs it was not possible to evaluate the performance of the model to predict this peak. Despite this, there was a good agreement between MAR3G and the observations up to 12 October. Afterwards the model overestimated Hmax.

3.4 Landfall

The C band Doppler radar observed Vince between 00:00 UTC and 13:00 UTC on 11 October, in a dissipating stage. It has been described that tropical cyclones usually exhibit a stationary band complex (SBC), including a main rainfall band that limits the internal vortex, secondary rainfall bands (outside the eyewall) and connecting bands (Atlas, 1990). Part of the SBC structure was visible during that period, just up to landfall, since the main band and two secondary bands were observed, but connecting bands were not visible (Fig. 8).

Barnes et al. (1983) have noticed that an external eyewall structure (around 90 km from the storm centre) is sometimes visible, being related to the interruption of the convective feeding, thus associated with the storm weakening. In this event a convective line was detected over the Cadiz gulf, about 1 h before landfall. A detailed analysis of its vertical reflectivity structure revealed that the line was not closely linked to the eyewall.

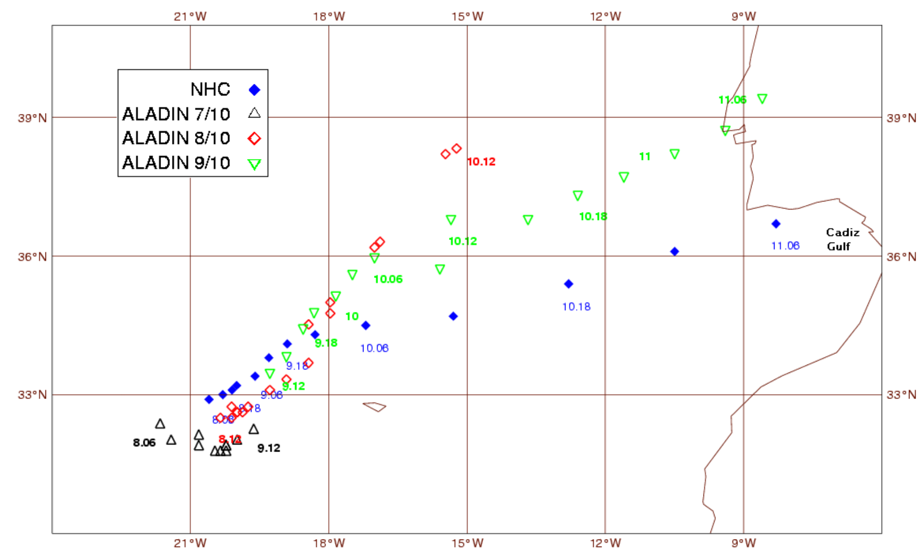

Figure 6. NHC trajectory from 06:00 UTC 8 October until 12:00 UTC 11 October, with a 6 h interval, is shown in blue. Vince trajectory forecasted by ALADIN from 06:00 UTC 8 October until 12:00 UTC 9 October, starting at 12:00 UTC 7 October, is shown in black. The 48 h integration starting at 12:00 UTC 8 October and at 12:00 UTC 9 October are shown, respectively, in red and green. The trajectories forecasted by ALADIN are shown with a 3 h interval.

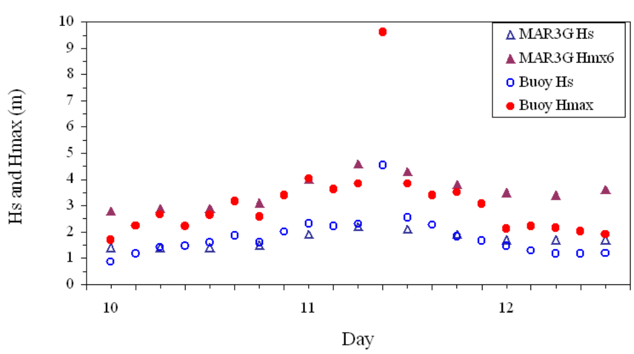

Figure 7. Faro wave height between 00:00 UTC 10 October and 12:00 UTC 12 October. Observed Hs and Hmax (maximum wave height occurring in a record) with a 3 h interval and forecasted Hs and Hmx6 (maximum wave height in a period of 6 h) with a 6 h interval.

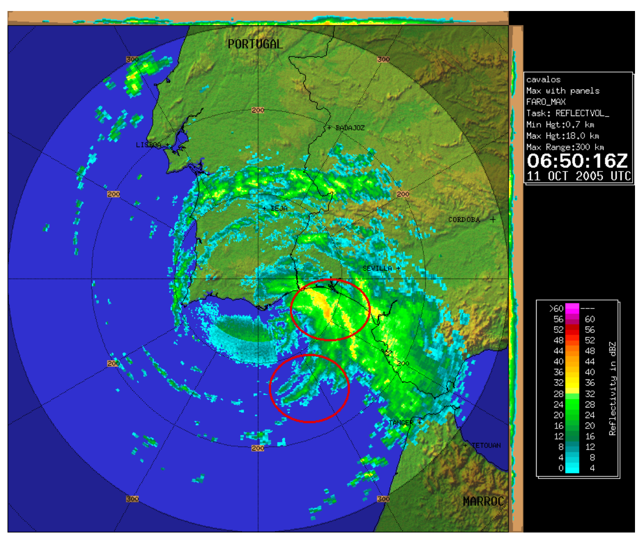

Figure 8. MAXZ (L/CC radar) at 06:50 UTC on 11 October 2005. Main rainfall band (northern circle) and two secondary rainfall bands (southern circle) are visible in the SBC a few hours before landfall.

The IM stations network did not reveal significant precipitation amounts and wind gust values during the period previous to landfall. The observations obtained between 00:00 and 12:00 UTC on 11 October in the coastal area, showed that the highest hourly precipitation values were observed in Faro (7.0 mm between 05:00 and 06:00 UTC) and Vila Real de Santo António (6.0 mm between 07:00 and 08:00 UTC). Regarding wind gust, the highest values were also observed in Faro and Vila Real de Santo António (68 km/h, 04:00–05:00 UTC and 06:00–07:00 UTC, respectively). According to the Spanish meteorological service, the most significant precipitation amount occurred in Córdoba (84 mm between 12:00 and 16:00 UTC on 11 October, with an hourly maximum of 54.2 mm).

As a landfall occurs, storms of this kind usually weaken dynamically (centre pressure increases and maximum sustained winds decreases) and its rain bands intensity increases, mainly due to topographic and roughness effects (Jorgensen and Willis, 1982). The comparison between Portuguese and

Spanish observations seems to indicate this last phenomenon occurred. Both rainfall intensity and rainfall accumulation fields obtained from radar observation could determine that the rainfall field captured soon after landfall built up significantly, thus confirming surface observations. The area with values over 20 mm in one hour increased dramatically inland, on the order of 4, if compared with the corresponding area before landfall. Stronger convective activity after landfall was also confirmed using both echo top and vertically integrated reflectivity measurements.

A landfall estimation is frequently very difficult to achieve especially if the storm is already in a dissipating stage. The accuracy of the path diagnose of such phenomena is strongly dependent on its centre identification (Atlas, 1990). An analysis using both reflectivity and wind fields obtained from radar observation, allowed the estimation of a probable radar centre location between 03:00 UTC and 13:00 UTC on 11 October. Accordingly, the storm landfall was estimated to occur in the Andaluzia coast (Spain), between 09:00 UTC and 09:40 UTC, of the same day.

4 Final remarks and perspectives

Vince developed north of 30° N, over ocean waters with observed SST as low as 23–24°C, being one of the rare tropical storms which made landfall in the Iberian Peninsula. The weather radar allowed the identification of a main rainfall band and two secondary rainfall bands in the SBC, a few hours before landfall. Furthermore, there was a significant rainfall field intensification as it made landfall, a common feature of typical hurricanes.

Vince trajectory represented by ECMWF analyses reasonably agreed with the NHC one. However, as Vince reached the hurricane stage with a mslp of 988 hPa, both ECMWF analysis and ALADIN forecasts strongly overestimated mslp (16–18 hPa).

The trajectories forecasted by ALADIN are consistent with NHC up to the Madeira area. However, in its path from Madeira to the Iberian Peninsula, the forecasted trajectories significantly deviate from NHC, foreseeing landfall around Lisbon area rather than Andaluzia.

There was a close agreement between MAR3G and the observations up to 12 October. Afterwards, as Vince was approaching land the model performance degraded.

In a near future it will be interesting to continue investigating the sensitivity of NWP models performance to horizontal and vertical resolution. In particular, higher resolution is expected to improve the wind forecast, which could also have an impact on sea wave model. Surface heat fluxes modelled should be compared with observations.

The underestimation of deep convection as a factor to explain the insufficient deepening in this kind of storms, in model simulations, should also be investigated.

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References

Atlas, D: Radar in Meteorology, American Meteorological Society, 1990.

Barnes, G. M., Jorgensen, D. P., Marks Jr., F. D., and Zipser, E. J.: Mesoscale and convective structure of a hurricane rainband, J. Atmos. Sci., 40, 2125–2137, 1983.

Bosart, L. F. and Bartlo, J. A.: Tropical Storm Formation in a Baroclinic Environment, Mon. Weather Rev., 119, 1979–2013, 1991.

Bubnová, R., Horànyi, A., and Malardel, S.: International Project ARPEGE/ALADIN, EWGLAM Newsletter, Institut Royal Meteorologique de Belgique, 22, 117–130, 1993.

Businger, S. and Baik, J.-J.: An Artic Hurricane Over the Bearing Sea, Mon. Weather Rev., 119, 2293–2322, 1991.

Frank, W. M. and Ritchie, E. A.: Effects of vertical wind shear on the intensity and structure of numerically simulated hurricanes, Mon. Weather Rev., 129, 2249–2269, 2001.

Franklin, J.: Tropical Cyclone Report, Hurricane Vince, 8–11 October 2005, National Hurricane Centre, 2006.

Gray, W. M.: A Global View of the Origin of Tropical Disturbances and Storms, Mon. Weather Rev., 96, 669–700, 1968.

Hart, R. E.: A cyclone phase space derived from thermal wind and thermal asymmetry, Mon. Weather Rev., 131, 585–616, 2003.

Jorgensen, D. P. and Willis, P. T.: A Z-R relationship for hurricanes, J. Appl. Meteorol., 21, 356–366, 1982.

Lynch, A. H., Slater, A. G., and Serreze, M.: The Alaskan Arctic Frontal Zone: Forcing by Orography, Coastal Contrast, and the Boreal Forest, J. Climate, 14, 4351–4362, 2001.

Pires, H. O.: Modelação Numérica das Ondas Geradas pelo Vento, 1993.

Reale, O. and Atlas, R.: Tropical Cyclone-Like Vortices in the Extratropics: Observational Evidence and Synoptic Analysis, Weather Forecast., 16, 7–34, 2001.

Vaquero, J. M., Garcia-Herrera, R., Wheeler, D., Chenoweth, M., and Mock, C. J.: A historical analog of 2005 hurricane Vince, BAMS, 191–201, 2008.

Velden, C., Harper, B., Wells, F., Beven II, J.L., Zehr, R., Olander, T., Mayfield, M., Guard, C., Lander, M., Edson, R., Avila, L., Burton, A., Turk, M., Kikuchi, A., Christian, A., Caroff, P., and McCrone, P.: The Dvorak tropical cyclone intensity estimation technique – A satellite-based method that has endured for over 30 years, BAMS, 1195–1210, 2006.

Zehr, R.: Environmental vertical wind shear with hurricane Bertha (1996), Weather Forecast., 18, 345–356, 2003.