SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year	2023
Project Title:	SIMULATIONS OF METEOROLOGICAL HAZARDS AFFECTING AVIATION SAFETY IN THE IBERIAN PENINSULA
Computer Project Account:	.........SPESVALE............................. ....
Principal Investigator(s):	FRANCISCO VALERO
Affiliation:	FACULTAD DE CIENCIAS FÍSICAS. UNIVERSIDAD COMPLUTENSE DE MADRID PZA. CIENCIAS, 1. 28040 MADRID. SPAIN
Name of ECMWF scientist(s) collaborating to the project (if applicable)	....
Start date of the project:	01/01/2022
Expected end date:	31/12/2024

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)			300000	1339837
Data storage capacity	(Gbytes)			10000	10000

Summary of project objectives (10 lines max)

Aviation is strongly dependent on meteorology, as flight plans and aviation safety are largely affected by several meteorological phenomena. To properly characterize aviation-related meteorological phenomena, it is desirable to use high-resolution numerical simulations. In SPESVALE, simulations of mountain waves and icing events near the Madrid Airport are carried out using the WRF-ARW and HARMONIE-AROME models. Atmospheric variables involved in the genesis of mountain waves are analysed, also focusing on the assessment of atmospheric turbulence. To this purpose, around 300 events in the period 2000-2020 have been identified, and these are the targets to be simulated with the two models. Moreover, severe convective weather phenomena related to aviation safety, such as microbursts and supercells, are also studied are using both models' simulations.

Summary of problems encountered (10 lines max)

Díaz-Fernández et al. (2020, 2021, 2022) simulated the mountain waves formation, developing several decision trees that allows us to forecast warning for mountain waves, wave clouds, icing and turbulence with at least 24 h in advance. Additionally, in Calvo-Sancho et al. (2022) differences between hail and non-hail occurrences in supercell convective environments in Spain are analyzed using the ERA5 reanalysis. During 2023, we have had several problems running the HARMONIE-AROME model which have produced running many times for testing such model and the use of more SBUs that originally planned.

Summary of plans for the continuation of the project (10 lines max)

Once the mountain waves and associated phenomena, and the differences between hail and non-hail occurrences in supercell convective environments in Spain are analysed, the project will continue with the simulation of several systems using both WRF and HARMONIE-AROME. Therefore, severe convective weather phenomena related to aviation safety, such as mountain waves, microbursts and supercells will be also studied. To do this, simulations of such systems will be run using WRF-ARW and HARMONIE-AROME. Moreover, to investigate future characteristics, intensity, and occurrence of these weather phenomena, multiple global climate models, as part of the Coupled Model Intercomparison Project (CMIP6), will be additionally used. The obtained results will be presented at congresses and published in scientific journals.

List of publications/reports from the project with complete references

Journal Publications:

J. Díaz-Fernández, P. Bolgiani, D. Santos-Muñoz, L. Quitián-Hernández, M. Sastre, F. Valero, J. I. Farrán, J.J. González-Alemán and M.L. Martín. Comparison of the WRF and HARMONIE models ability for mountain wave warnings. Atmospheric Research, 265, 1-14. 105890. doi.org/10.1016/j.atmosres.2021.105890. 2022.

Bolgiani, P., Calvo-Sancho, C., Díaz-Fernández, J., Quitián-Hernández, L., Sastre, M., Santos-Muñoz, D., Farrán, J.I., González-Alemán, J.J., Valero, F., Martín, M.L. Wind Kinetic Energy Climatology and Effective Resolution for the ERA5 Reanalysis. Cimate Dynamics. https://doi.org/10.1007/s00382-022-06154-y. 2022.

Díaz-Fernández, J., Bolgiani, P., Sastre, M., Santos-Muñoz, D., Valero, F., Farrán, J.I. & Martín, M.L. Ability of the WRF and HARMONIE-AROME models to detect turbulence related to mountain waves over central Iberia. Atmospheric Research. 274, 1-8; https://doi.org/10.1016/j.atmosres.2022.106183. 2022.

Calvo-Sancho, C., González-Aleman, J.J., Bolgiani, P., Santos-Muñoz, D., Farrán, J.I., Martín, M.L. An Environmental Synoptic Analysis of Tropical Transitions in the Central and Eastern North

Atlantic. Atmospheric Research. 278, 10635, 1-16. https://doi.org/10.1016/j.atmosres.2022.1063532022. 2022.

Carlos Calvo-Sancho, Javier Díaz-Fernández, Yago Martín, Pedro Bolgiani, Mariano Sastre, Juan Jesús González Alemán, Daniel Santos-Muñoz, José Ignacio Farrán, María Luisa Martín, Supercell Convective Environments in Spain based on ERA5: Hail and Non-Hail Differences. Weather and Climate Dynamics. 3, 1021–1036. https://doi.org/10.5194/wcd-3-1021-20222022. 2022.

C. Calvo-Sancho, L. Quitián-Hernández, P. Bolgiani, J. J. González-Alemán, D. Santos-Muñoz, M. L. Martín. Assessment of HARMONIE-AROME in the simulation of the convective activity associated to a subtropical transition using satellite data. Atmospheric Research, 290, 106794; https://doi.org/10.1016/j.atmosres.2023.106794. 2023.

Calvo-Sancho, C., Quitián-Hernández, L., González-Aleman, J.J., Bolgiani, P., Santos-Muñoz, D., Martín, M.L. Assessing the performance of the HARMONIE-AROME and WRF-ARW numerical models in North Atlantic Tropical Transitions. Atmospheric Research, 291, 106801; https://doi.org/10.1016/j.atmosres.2023.106801. 2023.

Meetings:

Díaz-Fernández, J., L. Quitián-Hernández, P. Bolgiani, D. Santos-Muñoz, Á. García-Gago, S. Fernández-González, F. Valero, A. Merino, E. García-Ortega, J.L. Sánchez, M. Sastre, M.L. Martín (2020). Mountain waves analysis in the vicinity of the Madrid-Barajas airport using the WRF model. Advances in Meteorology, Article ID 8871546, 17 pp. https://doi.org/10.1155/2020/8871546.

Calvo-Sancho, C., González-Alemán, J. J., Bolgiani, P., Santos-Muñoz, D., Farrán, J. I., Sastre, M., and Martín, M. L.: A Climatology of Tropical Transitions in the North Atlantic Ocean, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-2395, https://doi.org/10.5194/egusphere-egu22-2395, 2022.

Díaz Fernández, J., Bolgiani, P., Santos Muñoz, D., Sastre, M., Valero, F., Farrán, J. I., González Alemán, J. J., and Martín Pérez, M. L.: Characterization and warnings for mountain waves using HARMONIE-AROME, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-2471, https://doi.org/10.5194/egusphere-egu22-2471, 2022.

Calvo-Sancho, González-Alemán, J.J., Díaz-Fernández, J., Quitián-Hernández, L., Bolgiani, P., Santos-Muñoz, D., Farrán, J.I., Sastre, M., Calvo, J., and Martín, M.L.: Ianos in the HARMONIE-AROME model, I MedCyclones Workshop and Training School, MedCyclones Cost Action, Athens, Greece, 27 June - 2 July 2022.

Díaz-Fernández, J., Calvo-Sancho, C., González-Alemán, J.J., Bolgiani, P., Santos-Muñoz, D., Farrán, J. I., Sastre, M., Quitián-Hernández, L., and Martín, M. L.: WRF vs HARMONIE-AROME: A Comparison in a Supercell Event, Online Mini-European Conference on Severe Storms (mini ECSS), European Severe Storms Laboratory, Online, 27-28 September 2022.

Calvo-Sancho, C., Díaz-Fernández, J., Bolgiani, P., González-Fernández, S., González-Alemán, J.J., Santos-Muñoz, D., Farrán, J. I., Sastre, M., Quitián-Hernández, L., and Martín, M. L.: Microburst and Supercell Analysis - A study of 1 July 2018 Severe Weather Event over Zaragoza's Airport, Online Mini-European Conference on Severe Storms (mini ECSS), European Severe Storms Laboratory, Online, 27-28 September 2022.

J. Díaz-Fernández, M.Y. Luna, P. Bolgiani, D. Santos-Muñoz, M. Sastre, F. Valero, J.I. Farrán, JJ. González-Alemán, L Quitián-Hernández, M.L. Martín (2022). Climatología de ondas de montaña en la sierra de Guadarrama: caracterización con el modelo meteorológico de alta resolución WRF. XII

Congreso Internacional de la Asociación Española de Climatología (AEC): Retos del Cambio Climático: impactos, mitigación y adaptación. Santiago de Compostela (Spain), October 2022.

C. Calvo-Sancho, J.J. González-Alemán, M.Y. Luna, P. Bolgiani, D. Santos-Muñoz, L. Quitián-Hernández, M.Sastre, F.Valero, J.I. Farrán, J.Díaz-Fernández, L. López, M.L. Martín. Identificación y Distribución Temporal de Transiciones Tropicales en el Océano Atlántico Norte. XII Congreso Internacional de la Asociación Española de Climatología (AEC): Retos del Cambio Climático: impactos, mitigación y adaptación. Santiago de Compostela (Spain), October 2022.

Díaz-Fernández, J., Calvo-Sancho, C., Quitián-Hernández, L., Bolgiani, P., Santos Muñoz, D., Luna, M.Y., González Alemán, J. J., Sastre, M., Valero, F., Farrán, J. I. & Martín, M. L. (2022). Análisis del evento supercelular del 31 de julio de 2015 en España con el modelo WRF-ARW. 10ª Asamblea Hispano Portuguesa de Geodesia y Geofísica. Toledo (Spain). 2022

Quitián-Hernández, L., J., Calvo-Sancho, C., Díaz-Fernández, Bolgiani, P., Santos Muñoz, D., Luna, M.Y., González Alemán, J. J., Sastre, M., Valero, F., Farrán, J. I. & Martín, M. L. Análisis de un ciclón subtropical en el Océano Atlántico Norte mediante el modelo numérico HARMONIE-AROME. 10ª Asamblea Hispano Portuguesa de Geodesia y Geofísica. Toledo (Spain). 2022

Calvo-Sancho, C., Díaz-Fernández, J., González Alemán, J. J., Martín, Y., Quitián-Hernández, L., Bolgiani, P., Santos Muñoz, D., Farrán, J. I. Sastre, M., & Martín, M. L. Numerical Analysis of a Spanish Supercell Outbreak. European Geosciences Union (EGU) 2023. Vienna (Austria). 2023

Calvo-Sancho, C., González Alemán, J. J., Martín, Y., Calvo, J., Martín, M. L., Martín Pérez, D. & Viana Jiménez, S. (2023). Testing very high-resolution simulations in a high-impact static convective system in Spain using HARMONIE-AROME model. European Conference on Severe Storms (ECSS) 2023. Bucarest (Rumanía). 2023

Calvo-Sancho, C., Díaz-Fernández, J., González Alemán, J. J., Martín, Y., Quitián-Hernández, L., Bolgiani, P., Santos Muñoz, D., Farrán, J. I. Sastre, M., & Martín, M. L. (2023). Supercell synoptic configurations and pre-convective environments in Spain. European Meteorology Society (ECSS) Annual Meeting 2023. Bratislava (Eslovaquia). 2023

Summary of results

If submitted **during the first project year**, please summarise the results achieved during the period from the project start to June of the current year. A few paragraphs might be sufficient. If submitted **during the second project year**, this summary should be more detailed and cover the period from the project start. The length, at most 8 pages, should reflect the complexity of the project. Alternatively, it could be replaced by a short summary plus an existing scientific report on the project attached to this document. If submitted **during the third project year**, please summarise the results achieved during the period from July of the previous year to June of the current year. A few paragraphs might be sufficient.

During the first year of the project, a characterization of turbulence associated to mountain lee waves in the vicinity of the Adolfo Suarez-Madrid Barajas International Airport was carried out using WRF-ARW and HARMONIE-AROME models. The vertical wind speed and the eddy dissipation rate (EDR; shown in the previous report) have been successfully evaluated to know the turbulence intensity associated to these events. Also, the results show the ability of the models to detect clear air turbulence when lenticular clouds are not present. Moreover, based on probability density functions of the maximum EDR, the highest values of EDR were obtained when lenticular cloud bands associated to mountain lee waves are diagnosed in the leeward of the mountain range. Differences in results from WRF-ARW and HARMONIE-AROME are discussed in Díaz-Fernández et al. (2022).

Additionally, some resources have been used to simulate microbursts generated near airports in the Iberian Peninsula (as an example, Figure 1). This last research line force us to continue using SBUs to better simulate this kind of phenomena, like supercells, so destructive and dangerous for aeronautics.

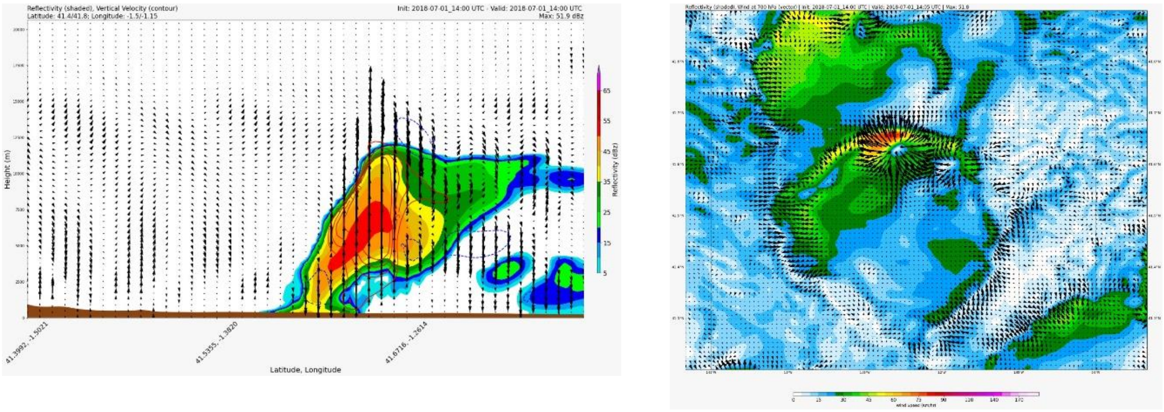

Figure 1: Simulations with WRF for the microburst on 1st July 2018 in vicinity of Zaragoza Airport: (left) reflectivity (shadow) and vertical velocity (contours); (right) wind speed (shadow) and wind vectors at 700 hPa.

During the second project year, several supercell events have been simulated and analyzed using WRF-ARW and HARMONIE-AROME; in particular, some supercells occurred on July 31, 2015, in a complex topography area of the eastern Iberia. At least six confirmed supercell events were reported (Figure 2), producing large hail and significant damage. WRF-ARW and HARMONIE-AROME numerical weather prediction models of IR 10.8 μm pseudo-brightness temperatures (BTs) are assessed against satellite data from MSG-SEVIRI using several skill scores, BT probability density functions and the SAL verification method. Furthermore, radiosounding data is chosen to extract several convective variables and instability indices to compare with those simulated by the models. The results reveal different results according to the verification method selected. WRF-ARW simulates with a higher level of accuracy the convective clouds associated with supercells, while HARMONIE-AROME better simulates the structure of the deep convective clouds. Finally, convective variables and instability indices suggest that the environment in the study area is favourable for the development of deep convection.

Figure 2: Orography of the study area with the WRF-ARW and HARMONIE-AROME domain configuration (rectangles) of several supercells analyzed with supercell ellipse tracks from the Spanish Supercell Database. The red star indicates the Murcia radiosounding station.

The WRF-ARW (version 4.0.3) is used with four one-way nested domains with a horizontal resolution of 27 km (195x177 grid points), 9 km (277x253 grid points), 3 km (559x487 grid points) and 1 km (712x757 grid points). The WRF-ARW physics parameterizations include the New Goddard (Chou and Suarez, 1999; Chou et al., 2001) short and longwave schemes, the revised MM5 (Jimenez et al., 2012) as the surface layer scheme, the 5-Layer (Dudhia, 1996) as land surface, the BouLac (Bougeault and Lacarrere, 1989) as the planetary boundary layer, the Aerosol–aware Thompson (Thompson and Eidhammer, 2014) as the microphysics scheme and the Tiedke scheme (Zhang et al., 2011) for cumulus physics in the outer domain.

The non-hydrostatic spectral, semi-implicit and semi-Lagrangian HARMONIE-AROME model (cycle 43h2.1) is developed by the collaboration between ALADIN and the HIRLAM consortium (Bengtsson et al, 2017). Furthermore, it is used for operational short-term weather forecasts in over 12 European countries at a horizontal resolution of 2.5 km. Herein, this model is run with a single domain with a horizontal resolution of 1 km (1000 x1000 grid points), covering the inner WRF-ARW domain area. The default physical parameterization defined by Bengtsson et al. (2017) has been selected: Morcrette shortwave radiation scheme (Seity et al., 2011; Bengtsson et al., 2017) and the majority of the ICE-3 microphysics package (Pinty and Jabouille, 1998; Lascaux et al., 2006); the SURFEX surface parameterization scheme (Masson, et al., 2013); EDMFm as shallow convection (de Rooy and Siebesma, 2010; de Rooy et al., 2013; Bengtsson et al., 2017) and HARATU (Bengtsson et al., 2017) is used for turbulence parameterization.

The initial and boundary conditions for WRF-ARW and HARMONIE-AROME are retrieved from the ERA5 reanalysis (Hersbach et al., 2020) from the European Centre for Medium-Range Weather Forecasts (ECMWF) with 0.25º horizontal grid spacing and 1-hour temporal resolution for both models. In the current study, the whole day (July 31, 2015) is simulated, and the domains are defined using a Lambert-Conformal map projection and 30-seconds GMTED2010 terrain data (Danielson and Gesch, 2011). The simulations for each model were run for a period of 24 h (00 UTC as initialization time) with a temporal resolution of 1 h and 1 km of horizontal resolution. Finally, 65 hybrid-sigma pressure levels were defined for both models.

The observed and WRF-ARW and HARMONIE-AROME simulated vertical profiles of the supercell events at Murcia station in domain C are depicted in Figure 3. HARMONIE-AROME shows a narrower thermal inversion layer in comparison with the observed radiosounding and the WRF-ARW. A general underestimation of all convective simulated variables is noted. MUCAPE, MUCIN, MLLCL, MLLFC and WS06 obtained from WRF-ARW are closer to the observed ones than those obtained from HARMONIE-AROME. On the other hand, the SRH03 simulated by HARMONIE-AROME (291 m^2/s^2) is closer to the observed (334 m^2/s^2) than WRF (125 m^2/s^2). It is noteworthy that the HARMONIE-AROME model simulates the wind within the first 3 km better than WRF-ARW, since the HARMONIE-AROME WS03 is also closer to the observations.

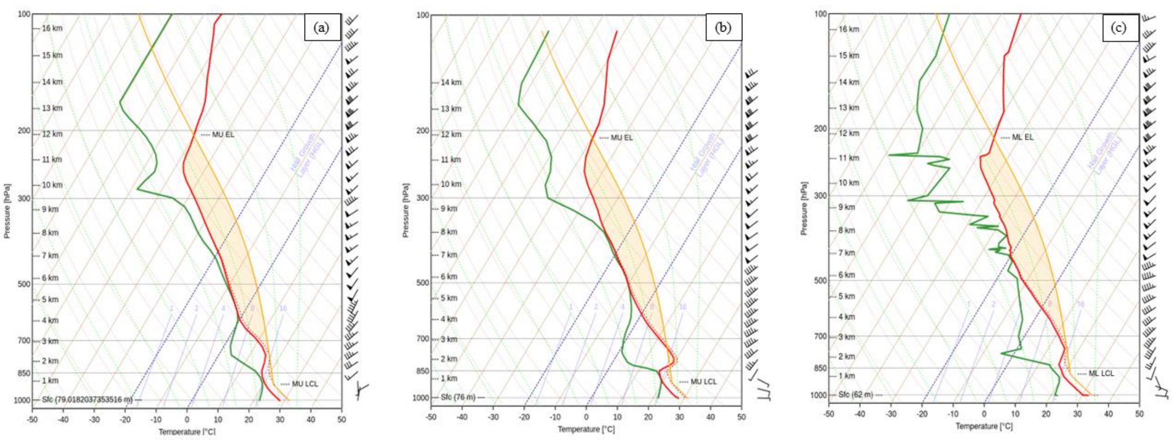

Figure 3: Skew-T diagrams of July 31, 2015, at 1200 UTC corresponding to a) Murcia radiosounding station; (b) HARMONIE-AROME; (c) WRF-ARW.

The observed and simulated high MUCAPE values (> 2500 J/Kg) are significantly related to vertical accelerations (Markowski and Richardson, 2011). As a result, when the MUCAPE rises, the severity of thunderstorms increases, as does the presence of larger hail (Xie et al., 2010; Taszarek et al., 2017). The null MUCIN values observed and simulated by the WRF-ARW highlight a lack of energy to inhibit the development of deep convection and consequently the formation of thunderstorms. However, the moderate HARMONIE-AROME MUCIN (-70 J/Kg) would increase the resistance to the development of deep convection (Markowski and Richardson, 2011; Westermayer et al., 2017).

The derived instability indices indicate that the environment at Murcia station and the simulated by both NWP models are favourable for deep convection development, being HARMONIE-AROME values closer to the observation ones. Observed and simulated LI values are indicative of a very unstable environment. The K (> 30) and TT (between 50 to 55) values indicate that severe thunderstorms with heavy rain are more likely.

The BT images in the 10.8 μm band for MSG-SEVIRI, HARMONIE-AROME and WRF-ARW are depicted in Figure 4 at different times in each evaluated domain. The pseudo-satellite images show similar cloudiness pattern associated with supercells. However, this cloudiness can be seen more clearly in the domains A and B (Figures 3 a-c and g-i), with the observed BT cloud top (BT < 213K) matching the simulated BT.

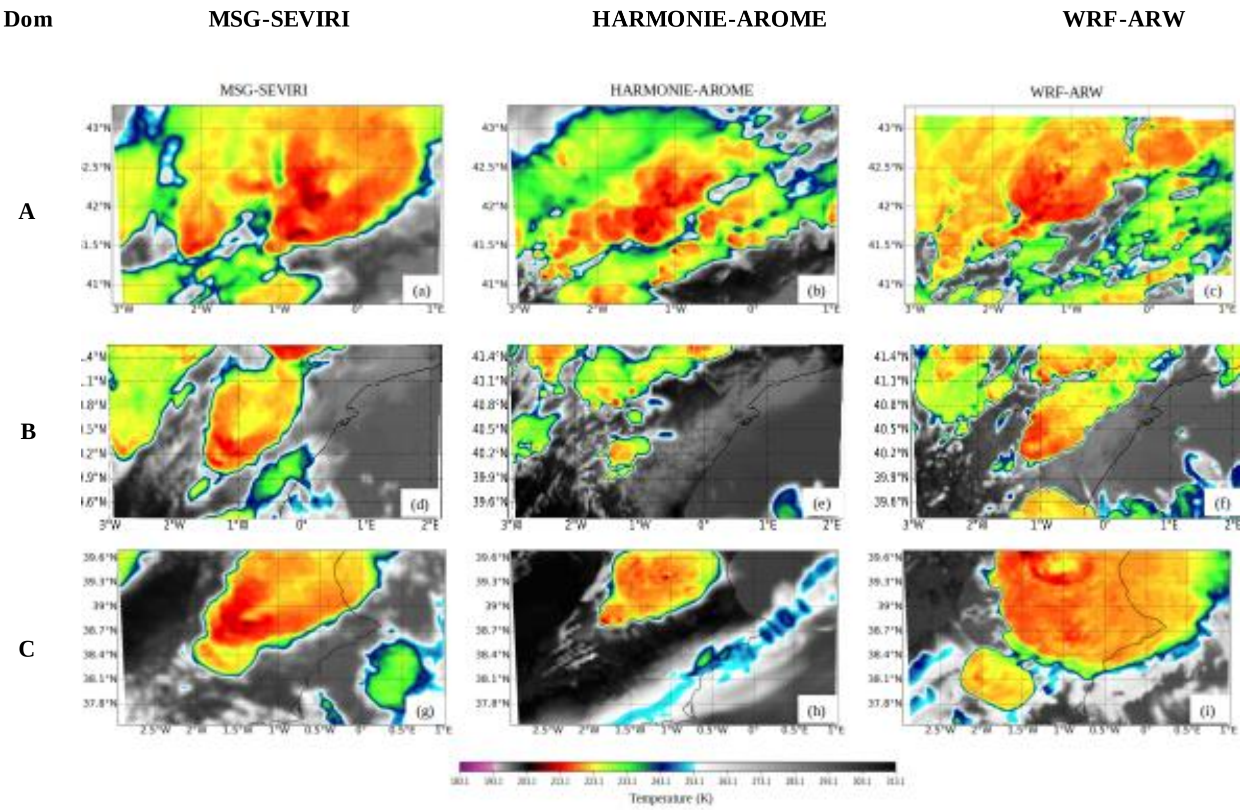

Figure 4: BT images on July 31, 2015 for (a) MSG-SEVIRI at 1300 UTC; (b) HARMONIE-AROME at 1400 UTC; (c) WRF-ARW at 1500 UTC, in domain A. (d) MSG-SEVIRI at 1300 UTC; (e) HARMONIE-AROME at 1400 UTC; (f) WRF-ARW at 1500 UTC, in domain B. (g) MSG-SEVIRI at 1300 UTC; (h) HARMONIE-AROME at 1400 UTC; (i) WRF-ARW at 1500 UTC, in domain C.

The results of the SAL verification method for the cloudiness associated with supercells for both NWP models for the selected domains are shown in Figure 5 with different behavior (near the perfect score) in the median components for both models in the three domain.

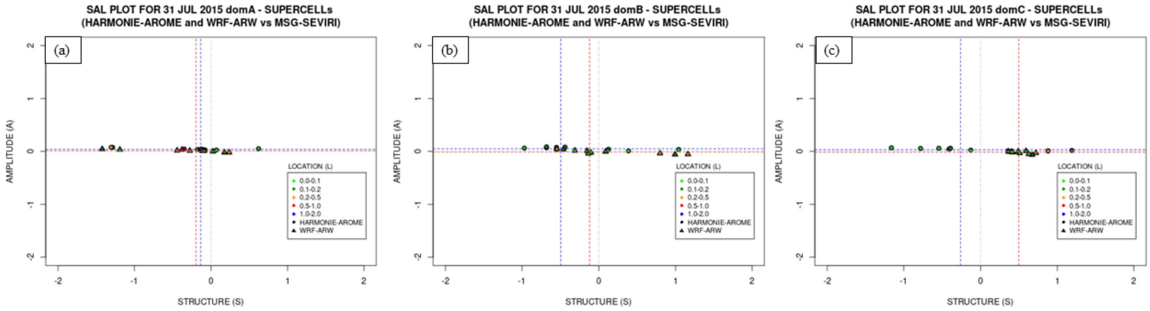

Figure 5: SAL diagrams representing Amplitude (y-axis), Structure (x-axis) and the coloured points (HARMONIE-AROME) and triangles (WRF-ARW) indicate the Location values for the supercell events on July 31, 2015 for the (a) domain A (b) domain B and (c) domain C. Dashed lines on the plot represent median values for Structure and Amplitude for HARMONIE-AROME (blue) and WRF-ARW (red).

Both NWP models are able to reproduce the cloudiness associated with supercells in an area with complex orography and a warmer Mediterranean Sea. It would be also interesting to study the dynamic processes connected with supercell development. We hope that throughout the remainder of the year, the WRF-ARW and HARMONIE-AROME models will be used to simulate more microbursts and supercells in the Iberian Peninsula. As soon as the runs are finished, we will be able to analyse the simulations to study differences and similitudes between key simulated variables.

It is worth noting that the very high resolution used to simulate the different severe convective systems require previous needed tasks which means additional SBUs. We are sorry but finally the system setup has utilized more resources than we originally expected. The high-resolution simulation of supercells and microburst can use 800 kSBUs each one; thus, we would need additional SBUs to continue simulating these events at very high-resolution, because these experiments require additional resources that in the original request we did not expect to need. We suppose that 3000000 of units of High Performance Computing Facility for the next year would be enough SBUs for running the high-resolution simulations.

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