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	2021
Project Title:	NUMERICAL SIMULATION OF MOUNTAIN WAVES AND ICING CONDITIONS IN THE IBERIAN PENINSULA
Computer Project Account:	………………SPESVALE………………………….……
Principal Investigator(s):	FRANCISCO VALERO
Affiliation:	FACULTAD DE FÍSICA. UNIVERSIDAD COMPLUTENTE DE MADRID
Name of ECMWF scientist(s) collaborating to the project (if applicable)	………………………………………………….…… ………………………………………………….……
Start date of the project:	01/01/2019
Expected end date:	31/12/2021

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	300000	300000	370000
Data storage capacity	(Gbytes)	10000	10000	10000	10000

Summary of project objectives (10 lines max)

Harmonie and WRF models were implemented in the ECMWF servers in order to run simulations of several specific mountain wave and icing episodes. Besides, differences in performance between both types of simulations are analysed to eventually obtain an optimum model configuration to diagnose and forecast these events. The main project goals can be summarized as follows:

- Identify and characterize 20 mountain wave episodes in the Iberian Peninsula, using high-resolution simulations with the WRF model considering different physical schemes.
- Analyse these high-resolution simulations with both deterministic and probabilistic approaches, considering the requirement of ensembles when necessary.
- Assessment of the synoptic environment and the mesoscale factors related to mountain waves and icing conditions in the Iberian Peninsula.

Summary of problems encountered (10 lines max)

A couple of issues appeared while implementing the model configuration for both Harmonie and WRF. Initially, some meteorologically remarkable events were simulated as a test with both models, and as a result we obtained a few error messages. Particularly interesting is that we had some problems in the Harmonie suite due to the use of ecFlow in ECMWF's virtual servers. WRF model was initially found to be unreliable to produce regular simulations. Nonetheless, the Harmonie problems have been fixed by HIRLAM community and currently it runs with a satisfactory performance. The WRF issues have been solved as well. In addition to this, some extra computing resources have been required because of indirect issues linked to the COVID-19 emergency.

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

As all the mountain wave episodes initially planned have been already simulated using WRF and HARMONIE, if possible, we may extend the initial purpose by running extra episodes identified, in order to extend the available database and provide a wider climatology of simulations.

- The main variables for the development of mountain waves and icing conditions will be deeply studied considering the differences in the outputs from Harmonie and WRF.
- A system of alerts and warnings related to the potential development of mountain waves and icing conditions nearby some airports is to be developed.
- Machine learning techniques shall be applied to improve the decision tree and warning system.
- The eddy dissipation rate will be included in the study as a new key variable to be analysed.

List of publications/reports from the project with complete references

Peer review papers

Bolgiani, P., Fernández-González, S., Valero, F., Merino, A., García-Ortega, E., Sánchez, J., Martín, M. (2018). Numerical Simulation of a Heavy Precipitation Event in the Vicinity of Madrid-Barajas International Airport: Sensitivity to Initial Conditions, Domain Resolution, and Microphysics Parameterizations. *Atmosphere*, 9(9), 329. https://doi.org/10.3390/atmos9090329

Quitián-Hernández, L., S. Fernández-González, J.J. González-Alemán, F. Valero, M.L. Martín (2018). Analysis of sensitivity to different parameterization schemes for a subtropical cyclone. *Atmospheric Research*, 204, 21-36. https://doi.org/10.1016/j.atmosres.2018.01.001

Fernández-González, S., M. Sastre, F. Valero, A. Merino, E. García-Ortega, J. L. Sánchez, J. Lorenzana, M. L. Martín (2019): Characterization of Spread in a Mesoscale Ensemble Prediction System: Multiphysics versus Initial Conditions. *Meteorologische Zeitschrift*, 28(1), 59-67. https://doi.org/10.1127/metz/2018/0918

Manzano, A., M. A. Clemente, A. Morata, M. Y. Luna, S. Beguería, S. M. Vicente-Serrano, M. L. Martín (2019): Analysis of the atmospheric circulation pattern effects over SPEI drought index in Spain. *Atmospheric Research*, 230, 104630. https://doi.org/10.1016/j.atmosres.2019.104630

Merino, A., E. García-Ortega, S. Fernández-González, J. Díaz-Fernández, L. Quitián-Hernández, M.L. Martín, L. López, J.L. Marcos, F. Valero, J.L. Sánchez (2019): Aircraft icing: in-cloud measurements and sensitivity to physical parameterizations. *Geophysical Research Letters*, 46(20), 11559-11567. https://doi.org/10.1029/2019GL084424

Bolgiani, P., Fernández-González, S., Valero, F., Merino, A., García-Ortega, E., Sánchez, J. L., Martín, M. L. (2020): Simulation of Atmospheric Microbursts Using a Numerical Mesoscale Model at High Spatiotemporal Resolution. *Journal of Geophysical Research: Atmospheres*, 125(4), 1–23. https://doi.org/10.1029/2019JD031791

Quitián-Hernández, L., González-Alemán, J.J., Santos-Muñoz, D., Fernández-González, S., Valero, F., Martín, M. L. (2020): Subtropical cyclone formation via warm seclusion development: The importance of surface fluxes. *Journal of Geophysical Research: Atmospheres*, 125(8), e2019JD031526. https://doi.org/10.1029/2019JD031526

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

Bolgiani, P., Santos-Muñoz, D., Fernández-González, S., Sastre, M., Valero, F., Martín, M. L. (2020). Microburst Detection with the WRF Model: Effective Resolution and Forecasting Indices. *Journal of Geophysical Research: Atmospheres*, 125(14), e2020JD032883. https://doi.org/10.1029/2020JD032883

Díaz-Fernández, J., Bolgiani, P., Santos-Muñoz, D., Sastre, M., Valero, F., Sebastián-Martín, L.I., Fernández-González, S., López, L., Martín M.L. (2021). On the characterization of mountain waves and the development of a warning method for aviation safety using WRF forecast. *Atmospheric Research*, 258, 105620. https://doi.org/10.1016/j.atmosres.2021.105620

Quitián-Hernández, L., Bolgiani, P., Santos-Muñoz, D., Sastre, M., Díaz-Fernández, J., González-Alemán, J.J., Farrán, J.I., López, L., Valero, F., Martín M.L. (2021). Analysis of the October 2014 subtropical cyclone using the WRF and the HARMONIE-AROME numerical models: Assessment against observations. *Atmospheric Research*, in press. https://doi.org/10.1016/j.atmosres.2021.105697

Díaz-Fernández, J., Bolgiani, P., Santos-Muñoz, D., Quitián-Hernández, L., Sastre, M., Valero F., Farrán, J.I., González-Alemán, J.J., Martín, M.L. (2021). Comparison of the WRF and HARMONIE models ability for mountain wave warnings. *Atmospheric Research*, under review.

Conference presentations
Javier Díaz Fernández, Lara Quitián Hernández, Pedro Bolgiani, Daniel Santos-Muñoz, Mariano Sastre, Francisco Valero and María Luisa Martín.
Modelización de ondas de montaña en las proximidades del aeropuerto de Barajas.
Seminario Final de la Red Temática Winter Precipitation and Strong Winds: Observational Studies (WiPSWis).
UCM, Madrid, España.
Oral presentation.
17 June 2019

María Luisa Martín, Mariano Sastre, Sergio Fernández-González, Daniel Santos-Muñoz, Francisco Valero
Incertidumbre y predictibilidad del viento en la Península Ibérica.
Seminario Final de la Red Temática Winter Precipitation and Strong Winds: Observational Studies (WiPSWis).
UCM, Madrid, España.
Oral presentation.
17 June 2019

L. Quitián-Hernández, M. L. Martín, Javier Díaz Fernández, Pedro Bolgiani, Mariano Sastre, J.J. González-Alemán, Daniel Santos-Muñoz, S. Fernández-González
Análisis del viento en un ciclón subtropical: uso de diferentes parametrizaciones en WRF.
Seminario Final de la Red Temática Winter Precipitation and Strong Winds: Observational Studies (WiPSWis).
UCM, Madrid, España.
Oral presentation.
17 June 2019

Mariano Sastre, Sergio Fernández-González, Francisco Valero, and María Luisa Martín
Quantification of uncertainty in wind prediction: towards a climatology for the Iberian Peninsula.
European Meteorological Society (EMS) Annual Meeting Abstracts
Copenhagen, Denmark,
Oral presentation.
09-13 September 2019

Javier Díaz-Fernández, Lara Quitián-Hernández, Daniel Santos Muñoz, Sergio Fernández-González, Francisco Valero, Andrés Merino, Eduardo García-Ortega, José Luis Sánchez, Mariano Sastre, María Luisa Martín.
Mountain wave episodes using the high-resolution HARMONIE-AROME model in Spain.
American Geophysical Union (AGU)
San Francisco, CA, USA.
Poster.
9-13 December 2019

Lara Quitián Hernández, Daniel Santos-Muñoz, Juan Jesús González Alemán, Javier Diaz-Fernandez, Sergio Fernández-González, Pedro Bolgiani, Mariano Sastre, Francisco Valero, Maria Luisa Martin (2019):
Analysis Of Several Subtropical Cyclones By Means Of The High-Resolution HARMONIE-AROME Model.
Congress of American Geophysical Union (AGU). General Assembly Conference.
San Francisco, USA.
Poster.
9-13 December 2019.

Javier Díaz Fernández, Lara Quitián Hernández, Pedro Bolgiani, Daniel Santos-Muñoz, Mariano Sastre, Juan Jesús González-Alemán, Francisco Valero, L.I. Sebastián-Martín, L. López, J.I. Farrán and María Luisa Martín
Sensitivity analysis to WRF parameterizations for mountain waves near Madrid airport (Spain)
EGU General Assembly
Vienna, Austria.
Oral presentation, Online.
19-30 April 2021

Bolgiani, P., Díaz-Fernández, J., Quitián-Hernández, L., Sastre, M., Santos-Muñoz, D., Farrán, J.I., Gonzalez-Alemán, J.J., Valero, F., Martín, M.L.
On the effective resolution of WRF simulations at microscale grid resolution.
EGU General Assembly
Vienna, Austria.
Oral presentation, Online.
19-30 April 2021

Mariano Sastre, Javier Díaz Fernández, Lara Quitián Hernández, Pedro Bolgiani, Daniel Santos-Muñoz, Juan Jesús González-Alemán, Francisco Valero, Luis Ignacio Sebastián-Martín, Laura López, José Ignacio Farrán, and María Luisa Martín
Simulation of a subtropical cyclone using the HARMONIE-AROME model
EGU General Assembly
Vienna, Austria.
Oral presentation, Online.
19-30 April 2021

Lara Quitián Hernández, Ángel García Gago, Javier Díaz Fernández, Pedro Bolgiani, Daniel Santos-Muñoz, Juan Jesús González-Alemán, Mariano Sastre, Francisco Valero, J.I. Farrán and María Luisa Martín
Analysis of the hurricane Ophelia using two high-resolution numerical weather prediction models.
34th Hurricane and Tropical Meteorology Conference; American Geophysical Union (AGU)
New Orleans, USA.
Oral presentation, Online.
9-14 May 2021

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.

The team involved in this special project is nearly coincident with the research team of the special project SPESMART. As both projects have a common part, namely one of the purposes is to implement the two models WRF and Harmonie in order to simulated different meteorological phenomena, each project can benefit from what we learn in the other project. In SPESVALE project (this project), both models are employed to simulate selected episodes of mountain waves with possibility of icing conditions.

The Harmonie model has been implemented in order to simulate mountain wave episodes and icing conditions (detailed in the original request). However, some problems were found in the suite when the model runs at a very fine resolution (1 x 1 km). Moreover, we had several technical issues to compile the WRF model, which fortunately were finally fixed.

Both Harmonie and WRF models were properly compiled and a considerable amount of episodes of mountain waves and icing conditions were simulated. In particular, we are focused on the Guadarrama Mountain area because it is near the Barajas International Airport, and due to the relevance for aviation safety of the events to be simulated. In this area, we have identified several mountain wave episodes with MSG images that potentially may affect the aircrafts landing.

All the mountain wave episodes and icing conditions events in the vicinity of Barajas International Airport initially identified were simulated with the WRF model. The identification of these episodes was performed using MSG images. Next, such episodes are simulated with Harmonie.

On Figure 1 the episode on 26 January 2018 is shown. This episode was simulated using WRF and vertical motions, LWC and IWC crossections and LWC distributions are analysed. Six parameterizations are used. The domain is located in the inner of Iberian Peninsula; in particular, near the Guadarrama Mountains near the Barajas International Airport of Madrid.
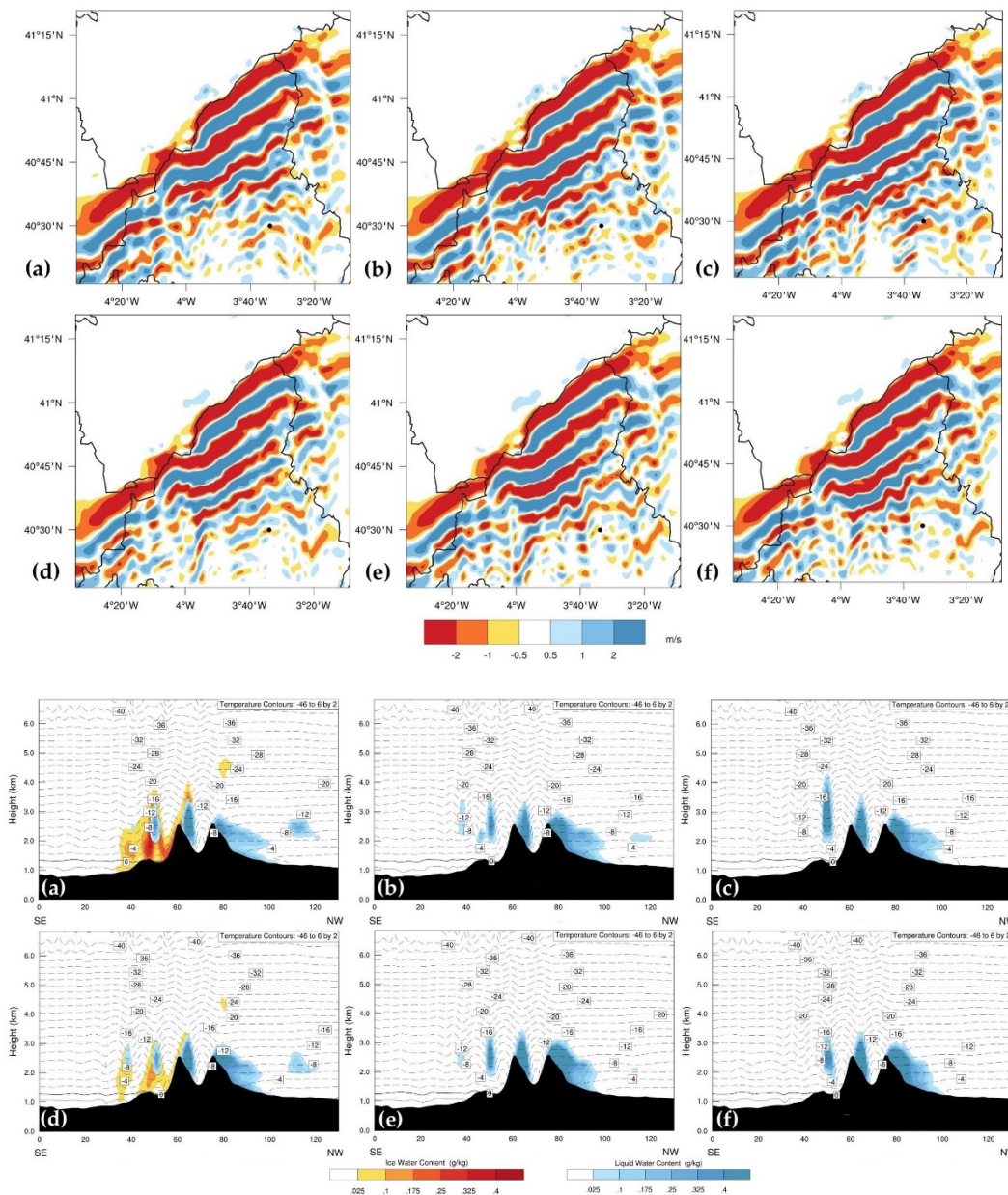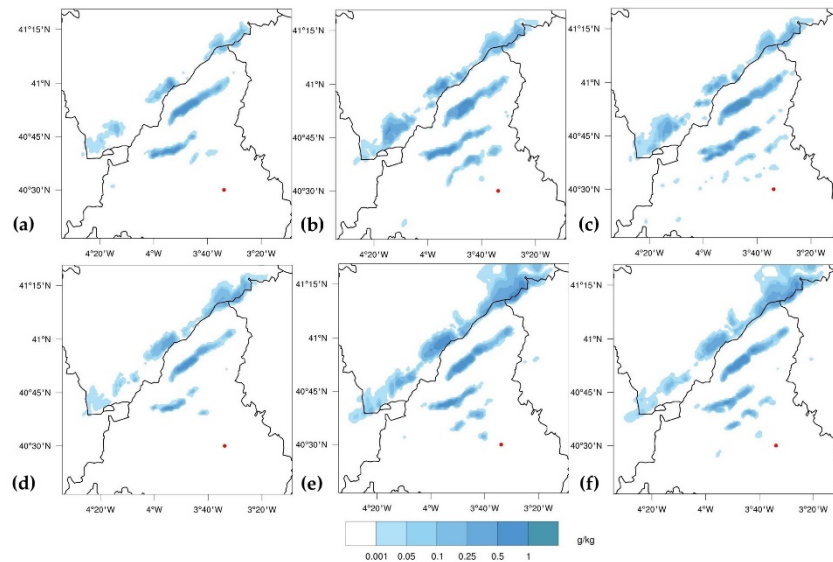
Figure 1: WRF simulations of vertical motion, LWC and IWC cross sections and LWC distributions on 26 January 2018.

For instance, a mountain wave episode on 26 November 2018 was simulated using the Harmonie model. The HRVIS MSG image, pseudoimage satellite visible channel MSG and total cloud cover are depicted in Figure 2.
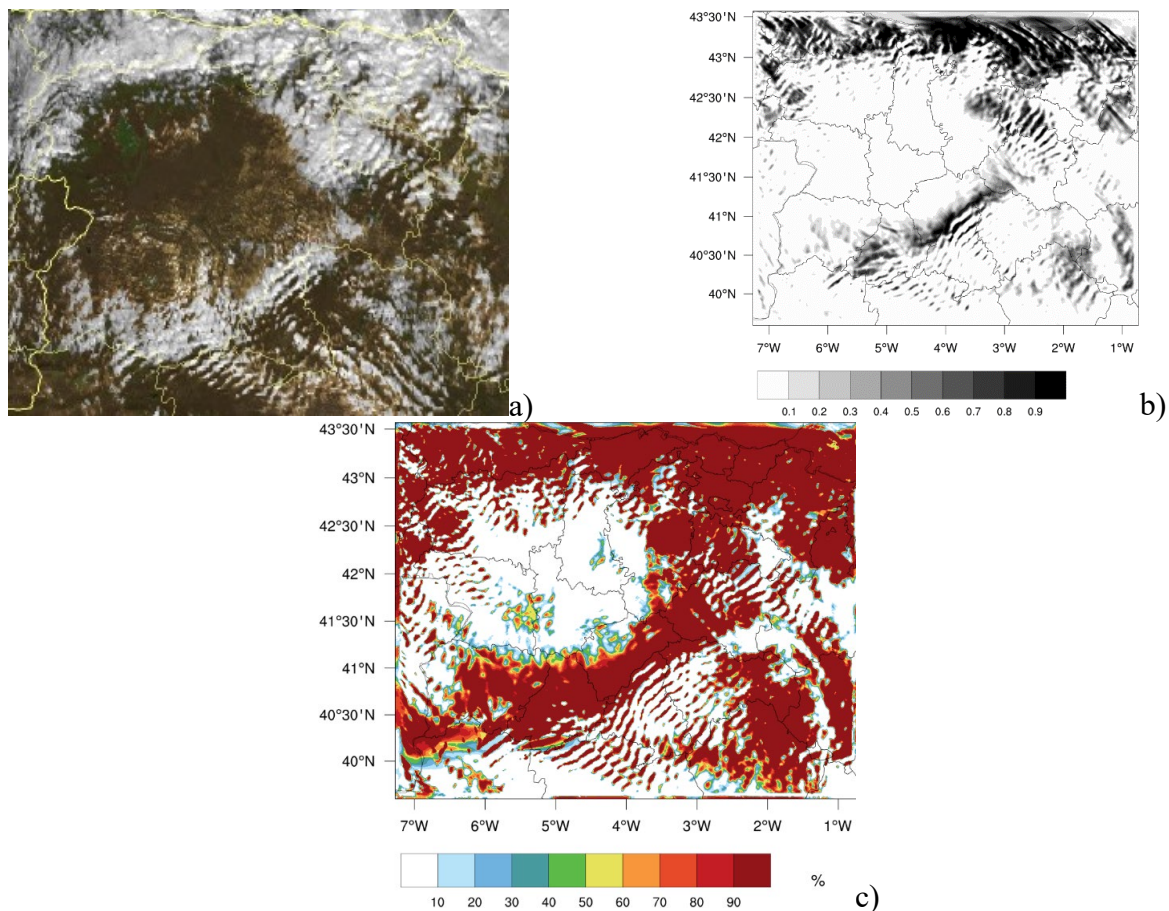

Figure 2: HRVIS MSG image (a), pseudoimage satellite visible channel MSG and total cloud cover simulated by Harmonie on 26 November 2018.

In another set of experiments, twenty different WRF configurations have been tested, showing the inability of some combinations to capture our phenomenon of interest. The two experiments with the best results are considered to simulate thirteen episodes with observed mountain waves. Then, simulated pseudosatellite images are validated using satellite observations, and an analysis is performed through several skill scores applied to brightness temperature, which is also spatially assessed (Figure 3).
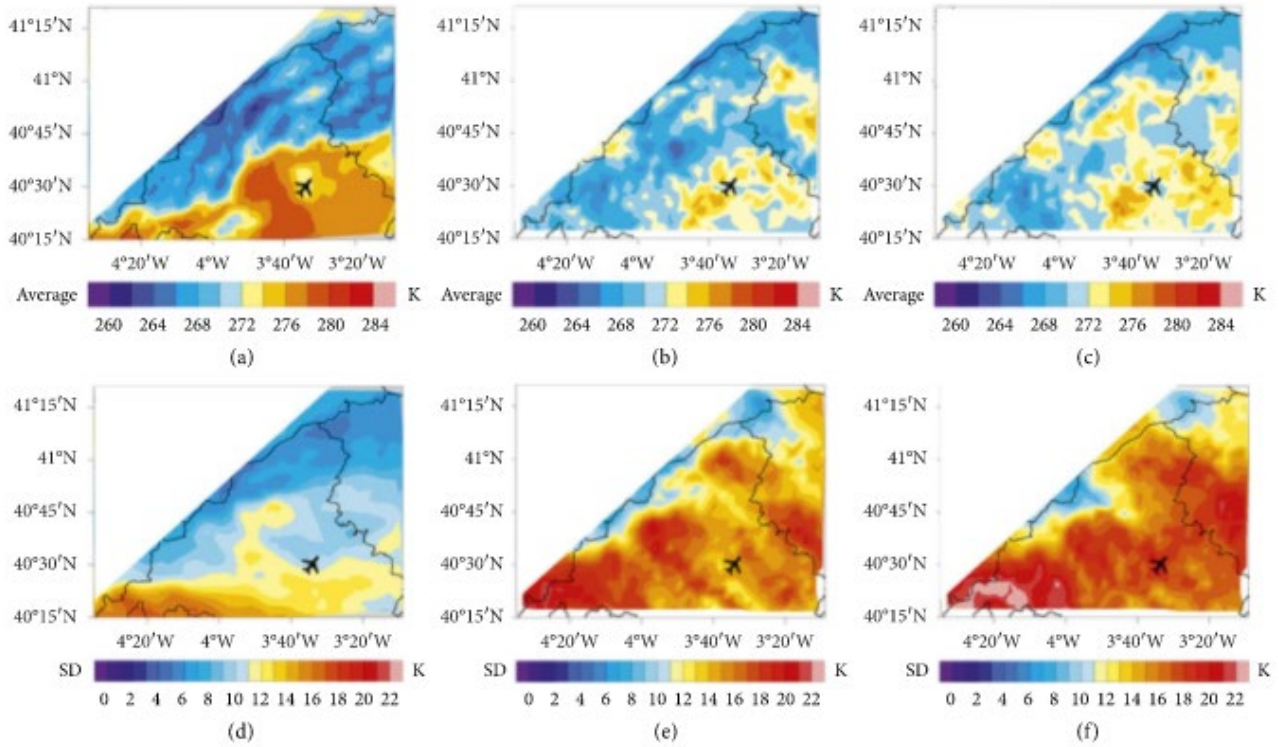

Figure 3: Brightness temperature spatial patterns for the total selected events using the 10.8 μm MSG-SEVIRI band (a, d) and the WRF simulations with WSM6 (b, e) and Thompson (c, f) schemes. Aircraft symbol corresponds to the airport location.

The results show that north-northwest wind direction (Figure 4), as well as moderate wind speed, and neutral or slightly stable conditions are the main features for the episodes evaluated.
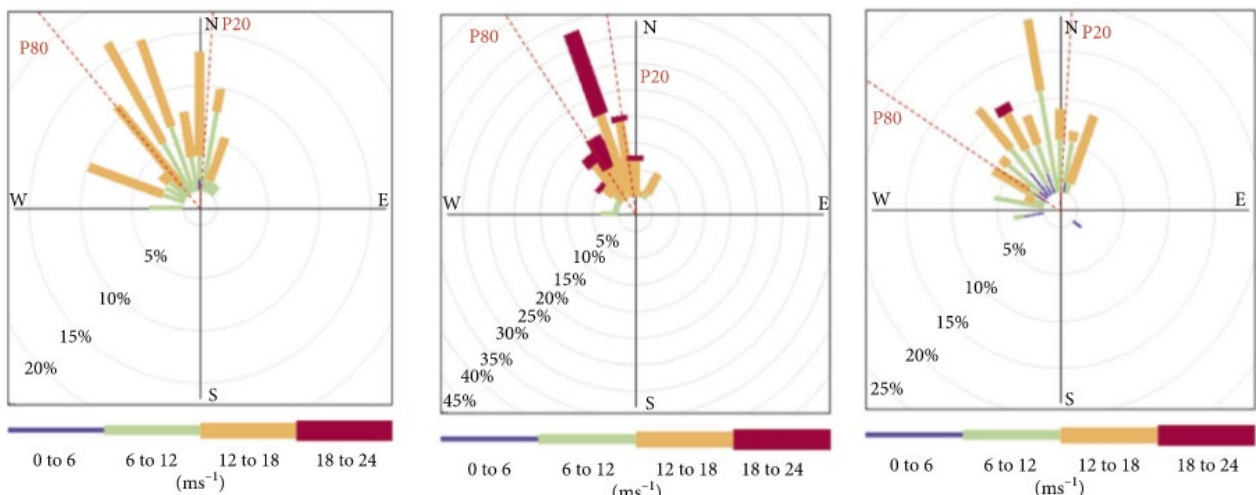

Figure 4: Wind rose for the total selected mountain wave events evaluated at 2500 masl on (a) windward side (a), Navacerrada mountains (b), and leeward side (c).

In addition to this, the case study corresponding to Figure 2 has been deeply analysed, showing that a proper WRF configuration can detect turbulence and icing associated with mountain waves, even when no visual evidence is available.

On the other hand, almost 300 mountain wave episodes have been identified via MSG images from 2000 to 2020. From these, 68 winter events in the period 2001-2010 in the leeward side of the Guadarrama mountain range in the Iberian Peninsula have been simulated with WRF to evaluate wind speed and direction on the windward side, atmospheric stability over the Guadarrama mountain range, and maximum liquid water content and minimum temperature on the leeward side. With this analysis, relevant thresholds involved in the mountain waves formation have been derived. Moreover, a decision tree has been sketched (Figure 5) and evaluated in order to create a warning method to detect these potentially harmful events.

This decision tree allows us to forecast a warning for mountain waves, wave clouds and icing with at least 24 h in advance. After validating the results against satellite images, good skill scores are found. Additionally, when the decision tree is applied in this area to a particular case study, the warnings yielded are in accordance with the reported observations. Therefore, we consider that it might be useful to implement an advanced version of this warning method as an operational short-term forecasting tool, improving aircraft safety in the vicinity of airports, where the mountain waves and icing conditions may have critical relevance.
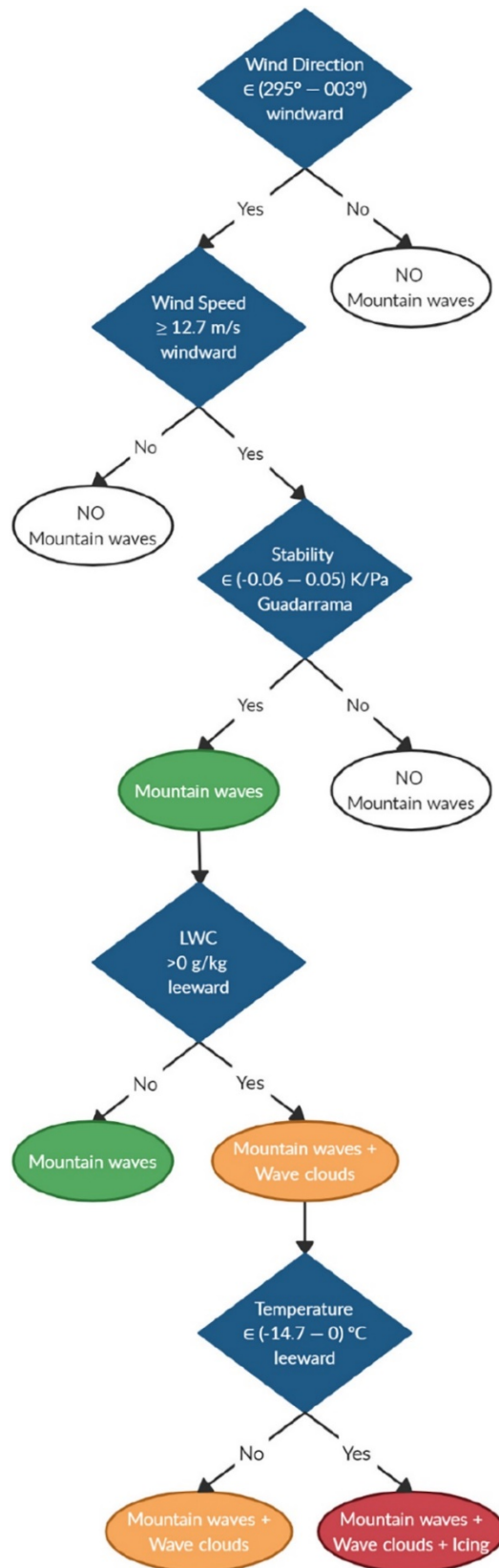
Figure 5: Decision tree for mountain waves, wave clouds and icing risk warning