EMS Annual Meeting

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Understanding the role of synoptic and mesoscale models in the context of severe weather forecasts in the Basque Country

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01. INTRODUCTION

The Basque meteorology agency (Euskalmet) works with synoptic and mesoscale meteorological models for operational prediction purposes.

Weather forecast models are **essential** for predicting severe weather events such as extreme temperatures, thunderstorms, heavy rainfall, and flash floods, allowing **enhancing decision-making** processes to mitigate the effects in population and infrastructure from severe weather hazards.

Synoptic-scale models help in understanding large-scale weather patterns, while mesoscale models focus on smaller, localized weather features influenced by local characteristics. By integrating synoptic and mesoscale models, we can get a comprehensive view of weather patterns. This dual approach **improves accuracy** and **increases the detail** of forecasts, making them more reliable.

Understanding the role of synoptic and mesoscale models in weather forecasting requires **validating** these models across various scenarios. One key aspect is to assess their performance in accurately representing surface variables and particularly precipitation and temperature patterns. This process ensures reliable predictions and allows forecasters to refine and enhance their techniques.

02. METHODOLOGY

Synoptic models such as GFS (NCEP) and IFS (ECMWF), mesoscale operational models from Euskalmet (own specific configurations for WRF and MM5) and external mesoscale models such as AROME (MeteoFrance) were used.

The main objective of the analysis was to compare the model´s performance in both severe and non-severe weather events. The classification of severe events was done using the official meteorological warning system of the Basque meteorological agency.

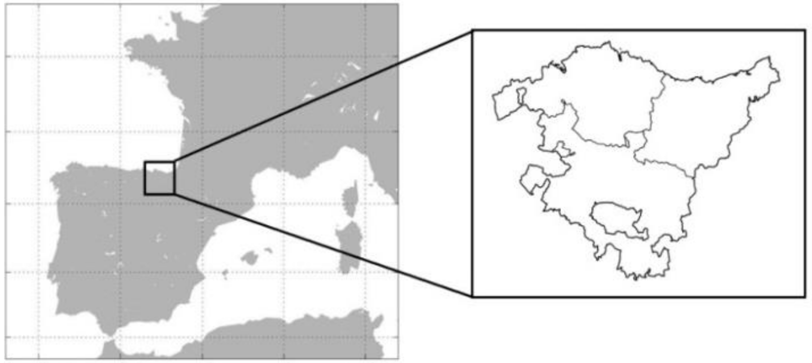
Some metrics and graphs were calculated for model comparison, including scatter plots and Taylor diagrams, to compare the quality and accuracy of weather models.

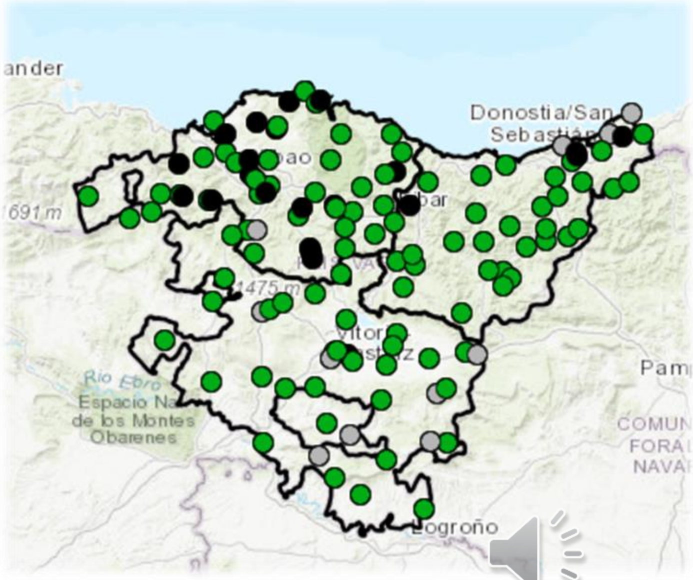
Two approaches were used to calculate validation indices: continuous (e.g., RMSE, bias, correlation), categorical (using multi-contingency tables). Various validation scores can be obtained from contingency tables, such as Proportion Correct score (PC), Probability of Detection (POD), False Alarm Rate (FAR), and Critical Success Index (CSI).

02. METHODOLOGY

The analysis is carried out in the Basque Country (N of the Iberian Peninsula, SW of Europe) using the data of Euskalmet AWS network.

- For comparing synoptic models 3-hourly data were used. Period of validation: from June 1st, 2023 to May 31st, 2024.
  - GFS 0.25º resolution
  - IFS 025º resolution
- For comparing mesoscale models hourly data were used. Period of validation: from January 1st, 2021 to December 31st, 2023.
  - WRF - 3km resolution with Initial Condition from GFS. NO DA.
  - MM5 - 3km resolution with Initial Condition from GFS. NO DA.
  - AROME – 1.3 km resolution with Initial Condition from ARPEGE-IFS. With DA.





Observational data: Euskalmet AWS network

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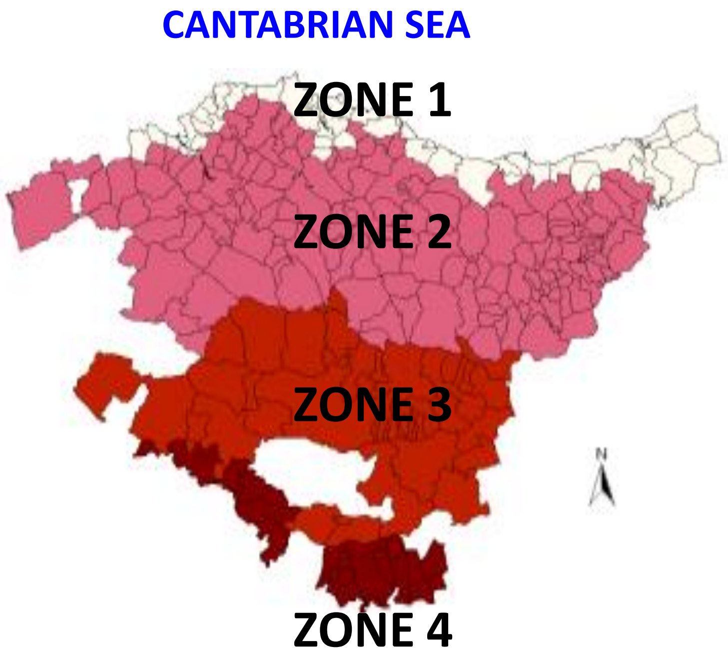
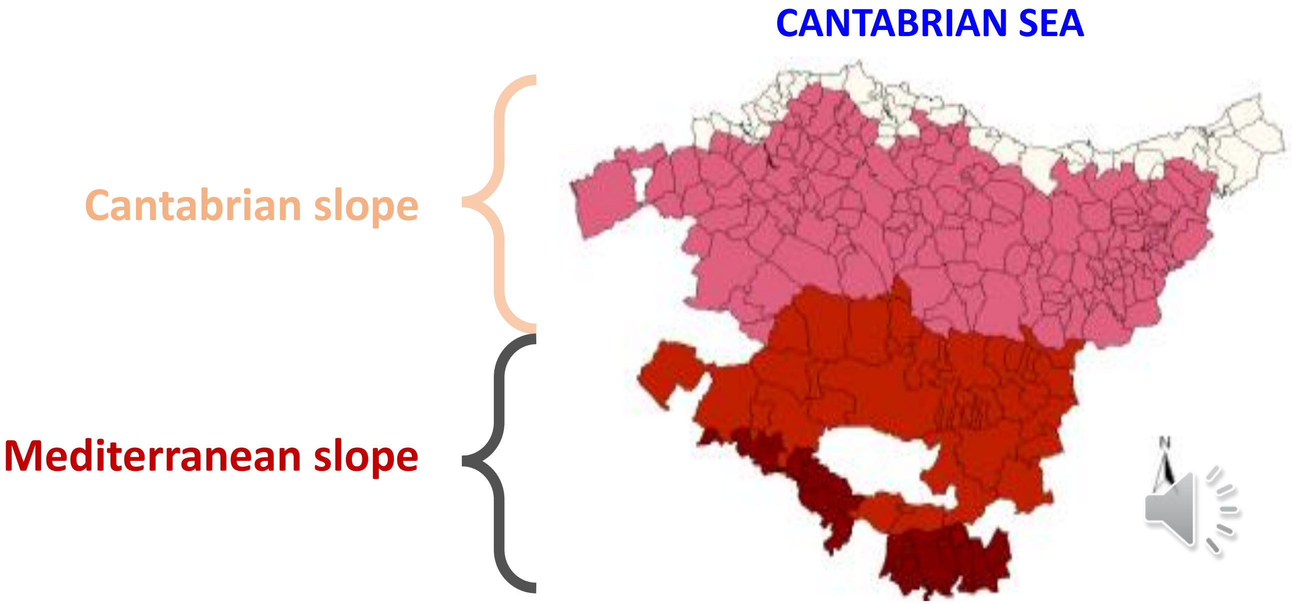
02. METHODOLOGY

For categorical validation of extreme temperature events, we calculate the average of the data for all the stations corresponding to each zone. A warning level is reached when this average value surpass the threshold. These zones (4) and their thresholds are defined within the Euskalmet warning protocol.

For categorical validation of precipitation events, 2 zones are considered (Cantabrian and Mediterranean slopes) and the threshold related to a warning level is considered to be exceeded when the **threshold is exceeded in at least one of the stations** belonging to the study area.



Warning Zones for extreme temperature events



Warning Zones for precipitation events

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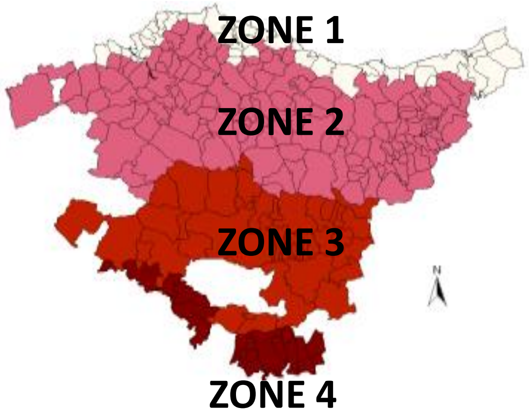
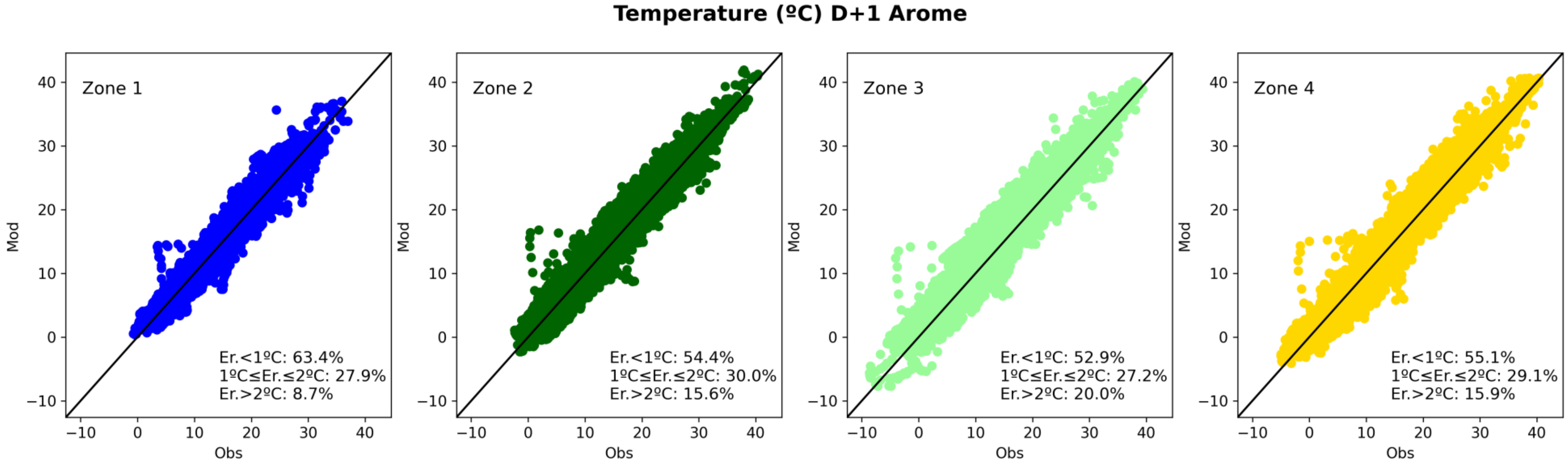
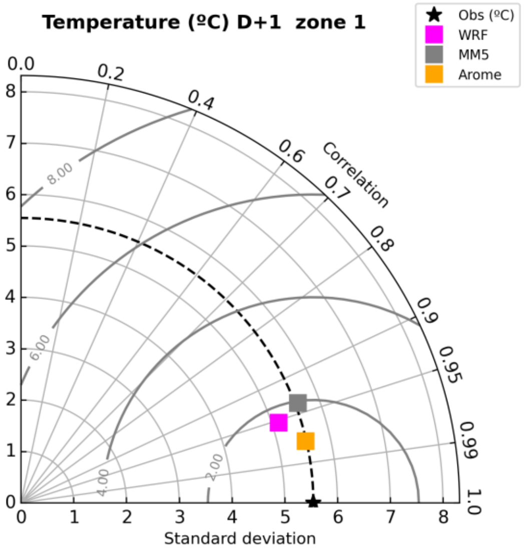
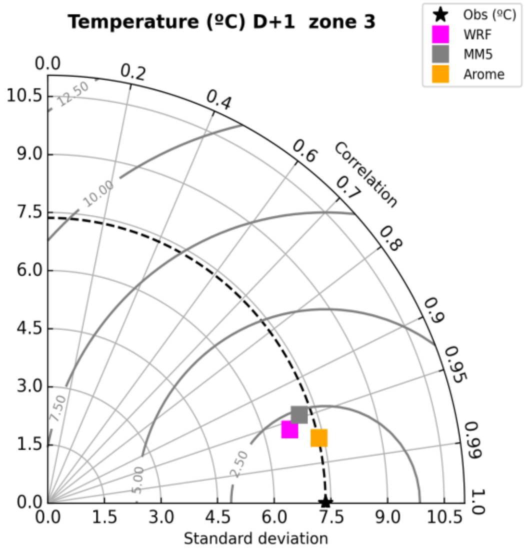
03. RESULTS. Temperature validation in mesoscale models









Compared to other mesoscale models, AROME presents better results in all zones.

Comparing between zones: best results are obtained for zone 1, worst results for zone 3.

Minimum Temperatures. AROME best performance. WRF better than MM5. For zone 3, all three models overestimate values.

Maximum temperatures. MM5 underestimates in all zones, WRF shows less underestimation than MM5 and AROME presents better results, especially for the highest values.

Comparison between the 3 mesoscale models

Verification scores: Temperature (ºC) D+1 zone 1

	Model	BIAS	RMSE	MAE	r
1	WRF	-0.266	1.714	1.352	0.953
2	MM5	-1.136	2.27	1.759	0.938
3	Arome	0.16	1.219	0.923	0.976

Verification scores: Temperature (ºC) D+1 zone 2

	Model	BIAS	RMSE	MAE	r
1	WRF	-0.616	2.156	1.738	0.947
2	MM5	-0.629	2.317	1.824	0.941
3	Arome	-0.152	1.492	1.13	0.973

Verification scores: Temperature (ºC) D+1 zone 3

	Model	BIAS	RMSE	MAE	r
1	WRF	-0.39	2.152	1.71	0.959
2	MM5	-0.144	2.377	1.853	0.947
3	Arome	0.28	1.713	1.258	0.974

Verification scores: Temperature (ºC) D+1 zone 4

	Model	BIAS	RMSE	MAE	r
1	WRF	-0.861	2.082	1.665	0.97
2	MM5	-0.819	2.299	1.803	0.96
3	Arome	0.006	1.535	1.138	0.981

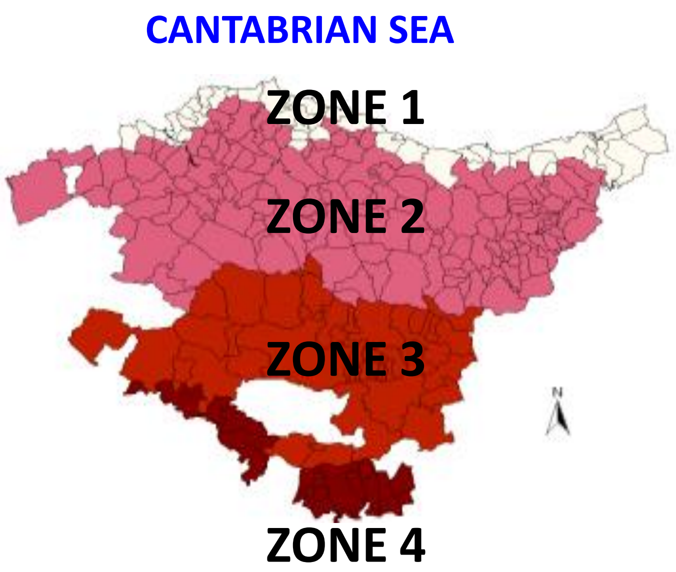
03. RESULTS. Extreme Temperatures categorical validation

To evaluate the performance of the different models in forecasting events related to exceeding thresholds, multi-category contingency tables have been generated. With these tables different scores have been calculated to measure models performance.

Extreme maximum temperatures and Extreme minimum temperatures have been analysed

The forecasts for D+1 horizon (+24h--+47h) were used.

For validation of extreme temperature events, we calculate the average of the data for all the stations corresponding to each zone. These zones (4) and their thresholds are defined within the Euskalmet warning protocol.



Warning Zones for extreme temperature events

Multicategory contingency tables for low temperatures warning thresholds. Example: zone 3

Categorical scores MM5 D+1: Low Temperatures (ºC) Zone 3

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<-10	0	0.0	0.0	0.0	0.0
2	[-10, -6]	4	0.75	0.25	1.0	0.6
3	[-6, 0]	138	0.47	0.29	0.67	0.39
4	>0	951	0.97	0.07	1.05	0.9

PC=0.91 HSS=0.54

Categorical scores WRF D+1: Low Temperatures (ºC) Zone 3

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<-10	0	0.0	0.0	0.0	0.0
2	[-10, -6]	4	0.75	0.0	0.75	0.75
3	[-6, 0]	138	0.36	0.3	0.51	0.31
4	>0	951	0.98	0.09	1.07	0.89

PC=0.9 HSS=0.44

Categorical scores Arome D+1: Low Temperatures (ºC) Zone 3

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<-10	0	0.0	0.0	0.0	0.0
2	[-10, -6]	3	1.0	0.0	1.0	1.0
3	[-6, 0]	114	0.42	0.11	0.47	0.4
4	>0	924	0.99	0.07	1.06	0.93

PC=0.93 HSS=0.56

Zone 1. *There are no relevant events in the period of study*

Zone 2*. AROME shows better performance, with a bias denoting underestimation. WRF and MM5 high FAR values.*

Zone 3*. All three models improve their performance*

Zone 4*. Models behaviour very similar to zone 3, MM5 and WRF closer to AROME. FAR score increase.*

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Multicategory contingency tables for high temperatures warning thresholds. Example: zone 3

Categorical scores MM5 D+1: High Temperatures (ºC) Zone 3

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<34	1066	1.0	0.02	1.03	0.98
2	[34, 37]	17	0.0	0.0	0.0	0.0
3	[37, 39]	9	0.0	0.0	0.0	0.0
4	>39	1	0.0	0.0	0.0	0.0

PC=0.98 HSS=-0.01

Categorical scores WRF D+1: High Temperatures (ºC) Zone 3

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<34	1066	1.0	0.02	1.02	0.98
2	[34, 37]	17	0.0	1.0	0.47	0.0
3	[37, 39]	9	0.0	0.0	0.0	0.0
4	>39	1	0.0	0.0	0.0	0.0

PC=0.98 HSS=0.21

Categorical scores Arome D+1: High Temperatures (ºC) Zone 3

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<34	1014	1.0	0.0	1.0	0.99
2	[34, 37]	17	0.82	0.22	1.06	0.67
3	[37, 39]	9	0.56	0.29	0.78	0.45
4	>39	1	1.0	0.75	4.0	0.25

PC=0.99 HSS=0.79

AROME performance is the best for the 3 warning levels in all zones. With a high FAR score for red warning level in zone 3

WRF shows some ability for the orange warning level but with a high FAR score for the zone 2

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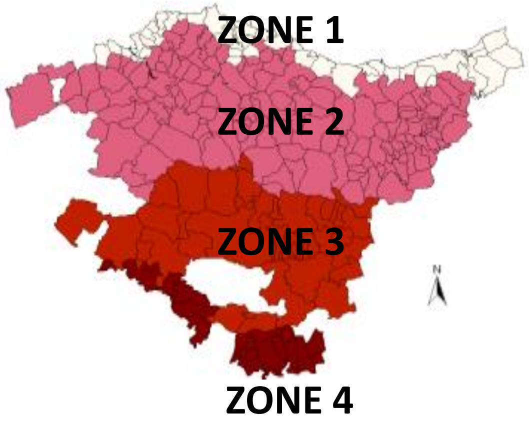
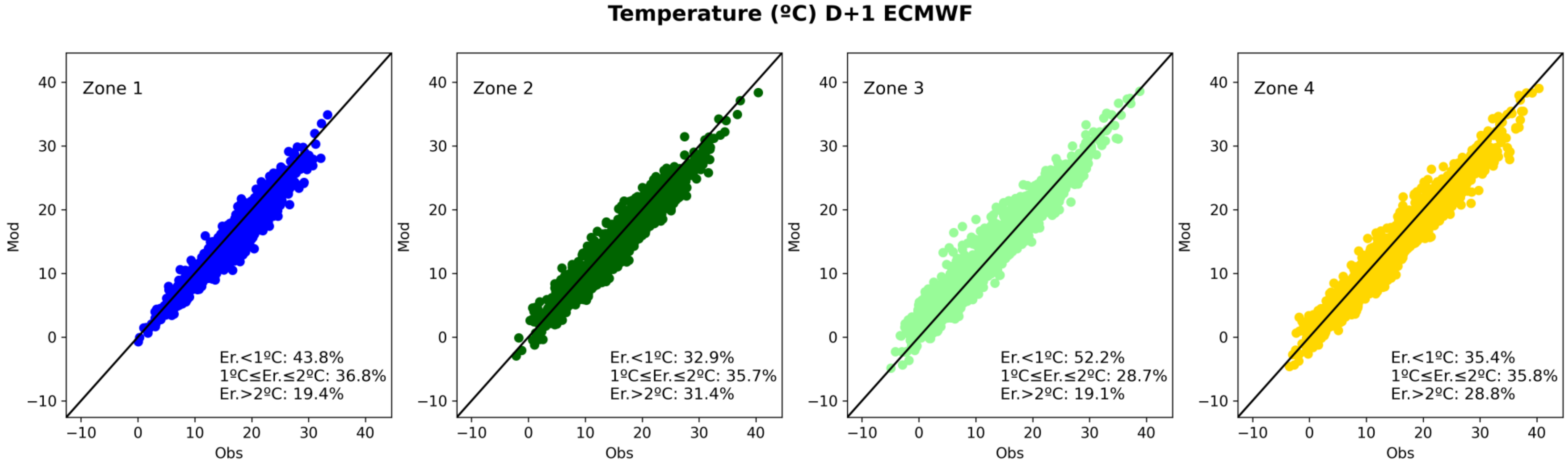
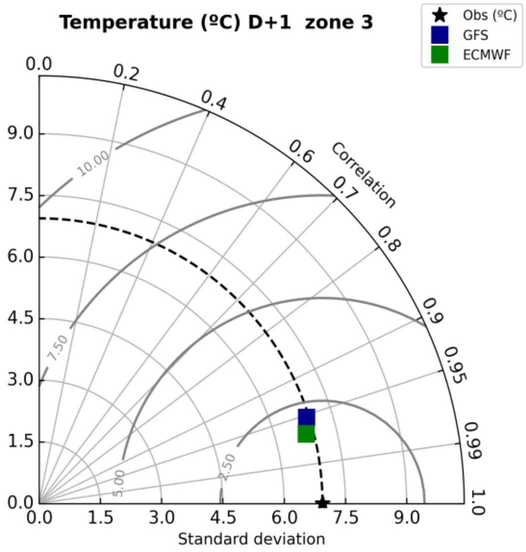
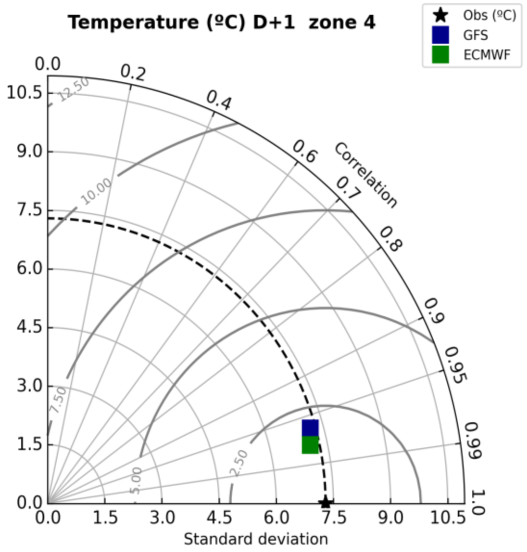
03. RESULTS. Temperature validation in synoptic models









IFS show good results in all zones, with its best result in zone 3.

For minimum temperatures IFS works better than GFS. In zone 3 both IFS and GFS overestimate minimum temperatures

IFS and GFS underestimate the maximum temperatures in all zones except zone 3, in this zone IFS works better than GFS. In the rest of zones GFS shows better results.

Comparison between the 2 synoptic models

Verification scores: Temperature (ºC) D+1 zone 1

	Model	BIAS	RMSE	MAE	r
1	GFS	-1.127	1.866	1.43	0.959
2	ECMWF	-1.086	1.647	1.317	0.972

Verification scores: Temperature (ºC) D+1 zone 2

	Model	BIAS	RMSE	MAE	r
1	GFS	-1.339	2.274	1.902	0.955
2	ECMWF	-1.144	1.867	1.572	0.97

Verification scores: Temperature (ºC) D+1 zone 3

	Model	BIAS	RMSE	MAE	r
1	GFS	-0.292	2.147	1.652	0.953
2	ECMWF	0.014	1.744	1.277	0.968

Verification scores: Temperature (ºC) D+1 zone 4

	Model	BIAS	RMSE	MAE	r
1	GFS	-0.877	2.146	1.719	0.964
2	ECMWF	-1.045	1.872	1.539	0.977

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Multicategory contingency tables for low temperatures warning thresholds. Example: zone 3

Categorical scores GFS D+1: Low Temperatures (ºC) Zone 3

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<-10	0	0.0	0.0	0.0	0.0
2	[-10, -6]	0	0.0	0.0	0.0	0.0
3	[-6, 0]	21	0.24	0.17	0.29	0.23
4	>0	334	1.0	0.05	1.04	0.95

PC=0.95 HSS=0.35

Categorical scores ECMWF D+1: Low Temperatures (ºC) Zone 3

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<-10	0	0.0	0.0	0.0	0.0
2	[-10, -6]	0	0.0	0.0	0.0	0.0
3	[-6, 0]	21	0.38	0.2	0.48	0.35
4	>0	331	0.99	0.04	1.03	0.96

PC=0.96 HSS=0.49

Categorical scores GFS D+1: Low Temperatures (ºC) Zone 4

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<-8	0	0.0	0.0	0.0	0.0
2	[-8, -5]	0	0.0	0.0	0.0	0.0
3	[-5, 0]	10	0.4	0.33	0.6	0.33
4	>0	345	0.99	0.02	1.01	0.98

PC=0.98 HSS=0.48

Categorical scores ECMWF D+1: Low Temperatures (ºC) Zone 4

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<-8	0	0.0	0.0	0.0	0.0
2	[-8, -5]	0	0.0	0.0	0.0	0.0
3	[-5, 0]	11	0.55	0.45	1.0	0.38
4	>0	341	0.99	0.01	1.0	0.97

PC=0.97 HSS=0.54

Scores for zones 1 and 2 not shown (only 1 event observed with temperature < 0 ºC).

In zones 3 and 4 the behavior is similar for the two models, showing better results for zone 4. Better results in ECMWF for very low temperatures, although with a slightly greater FAR.

Multicategory contingency tables for high temperatures warning thresholds. Example: zone 3

Categorical scores GFS D+1: High Temperatures (ºC) Zone 2

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<33	349	1.0	0.0	1.0	1.0
2	[33, 38]	5	0.8	0.0	0.8	0.8
3	[38, 40]	0	0.0	0.0	0.0	0.0
4	>40	1	1.0	0.0	1.0	1.0

PC=1.0 HSS=0.9

Categorical scores ECMWF D+1: High Temperatures (ºC) Zone 2

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<33	346	1.0	0.01	1.01	0.99
2	[33, 38]	5	0.4	0.0	0.4	0.4
3	[38, 40]	0	0.0	1.0	0.0	0.0
4	>40	1	0.0	0.0	0.0	0.0

PC=0.99 HSS=0.57

Categorical scores GFS D+1: High Temperatures (ºC) Zone 4

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<35	345	1.0	0.0	1.0	1.0
2	[35, 38]	8	0.75	0.0	0.75	0.75
3	[38, 40]	1	1.0	0.5	2.0	0.5
4	>40	1	1.0	0.5	2.0	0.5

PC=0.99 HSS=0.89

Categorical scores ECMWF D+1: High Temperatures (ºC) Zone 4

	Interval (ºC)	nº obs	POD	FAR	BIAS	CSI
1	<35	342	1.0	0.01	1.01	0.99
2	[35, 38]	8	0.38	0.0	0.38	0.38
3	[38, 40]	1	1.0	0.5	2.0	0.5
4	>40	1	0.0	0.0	0.0	0.0

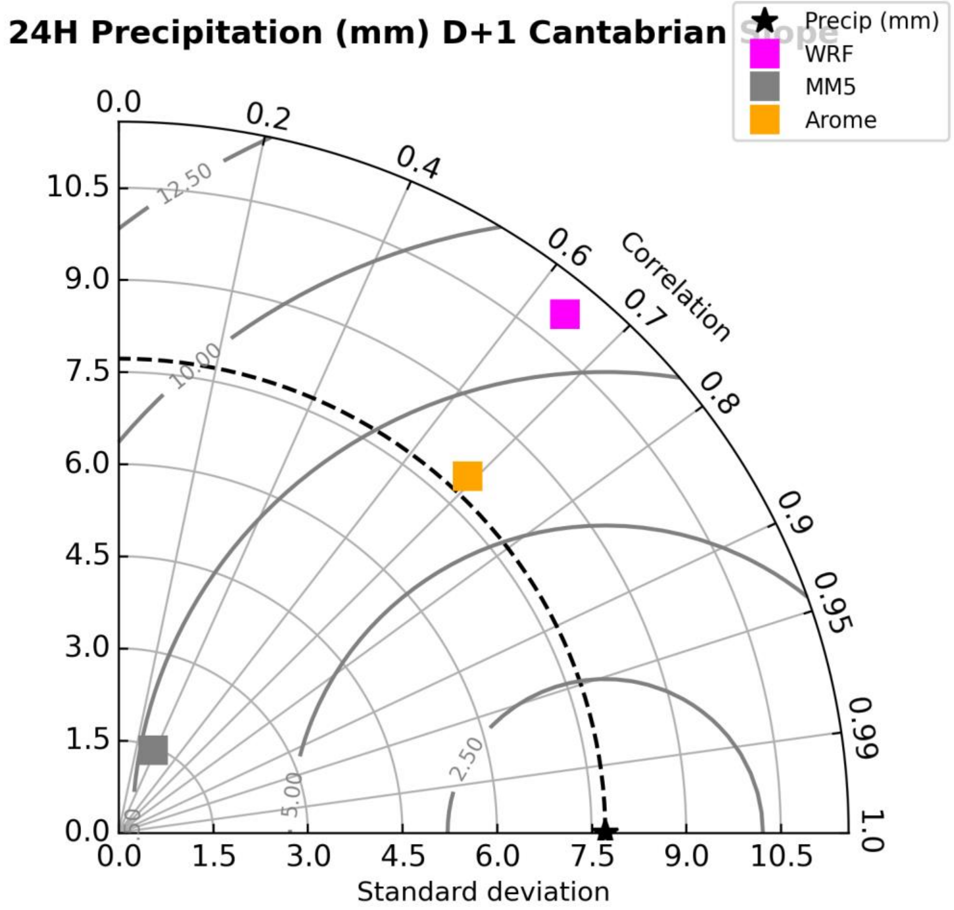
PC=0.98 HSS=0.6

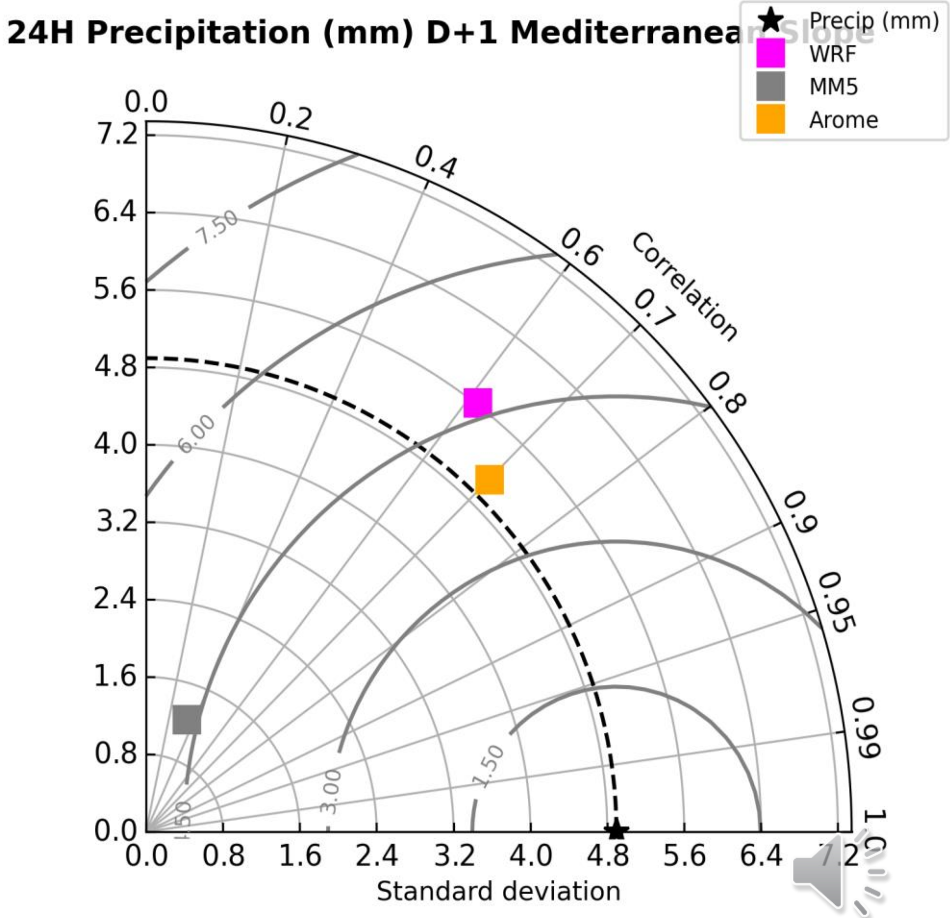
For extreme high temperatures, in zone 1, none of the models show good performance in the forecast of observed yellow warning level events.

In the rest of the zones, GFS shows an overall better behavior in the forecast of surpassing warning level thresholds.

The calculated scores are better for the case of extreme maximum temperatures than for extreme minimum temperatures.

03. RESULTS. Precipitation validation in mesoscale models
Daily precipitation





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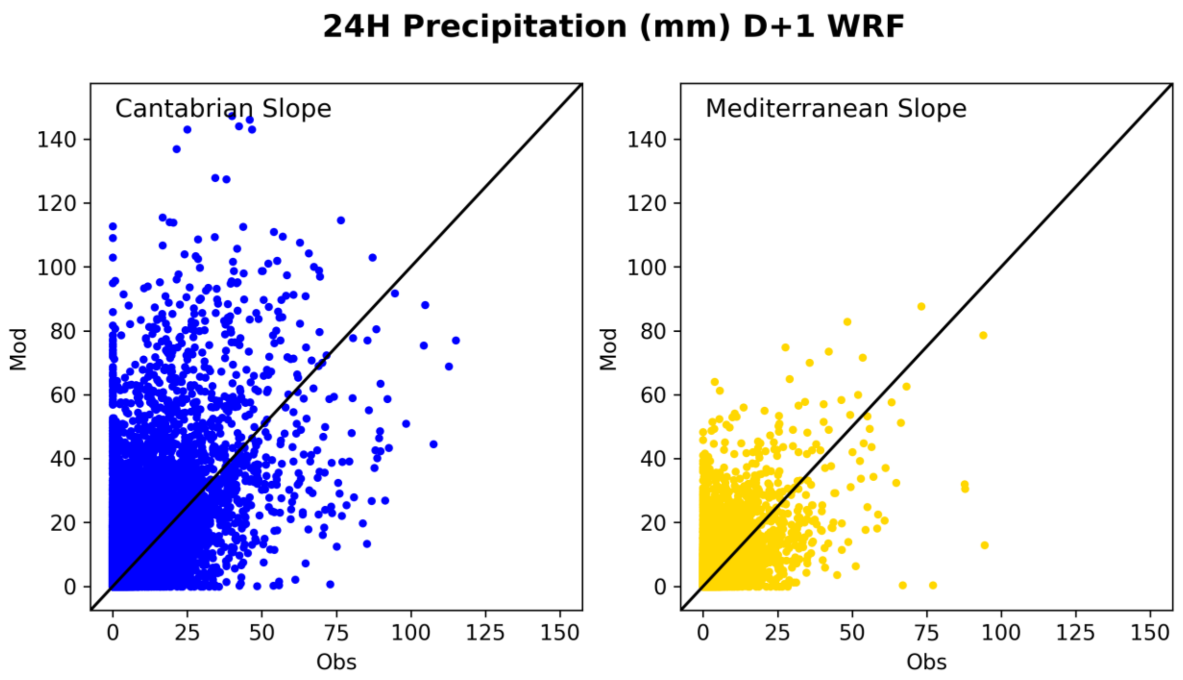
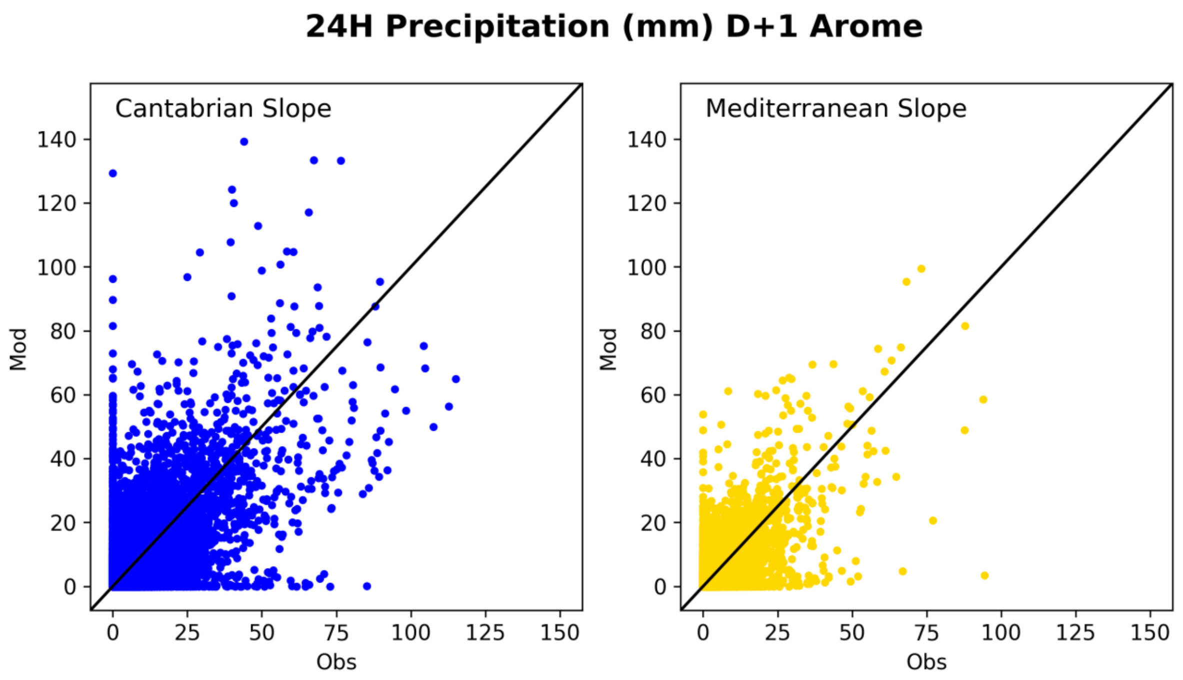
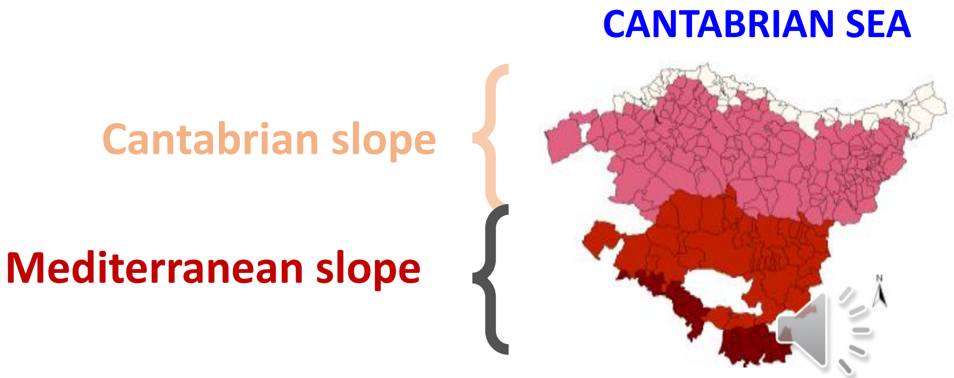




In less abundant accumulated precipitation (<50 mm) WRF overestimate precipitation in both slopes (Cantabrian and Mediterranean).

For daily accumulations greater than 50 mm, both models in both basins tend to underestimate these accumulations; from 75 mm onwards, all events are underestimated to a greater or lesser extent.

The errors are greater in the forecast for the Cantabrian slope than for the Mediterranean slope.



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03. RESULTS. Heavy and abundat precipitation categorical validation

To evaluate the performance of the different models in forecasting events related to exceeding thresholds, multi-category contingency tables have been generated. With these tables different scores have been calculated to measure models performance.

Heavy and abundat precipitation for mesocale models have been analysed, and abundant precipitation for synoptic models.

The forecasts made by the model for D+1 (+24h--+47h) were used.

For categorical validation of precipitation events, 2 zones are considered (Cantabrian and Mediterranean slopes) and the threshold related to the different warning levels is considered to be exceeded when the threshold is exceeded in at least one of the stations belonging to the study area.

Warning Zones for precipitation events

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Multicategory contingency tables for heavy rainfall (1h) warning thresholds

Categorical scores WRF D+1: Heavy rainfall (1h) Cantabrian Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<15	1054	0.99	0.03	1.02	0.96
2	[15, 30]	39	0.18	0.61	0.46	0.14
3	[30, 60]	1	0.0	0.0	0.0	0.0
4	>60	0	0.0	0.0	0.0	0.0

PC=0.96 HSS=0.23

Categorical scores Arome D+1: Heavy rainfall (1h) Cantabrian Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<15	1004	0.98	0.02	1.01	0.96
2	[15, 30]	38	0.34	0.58	0.82	0.23
3	[30, 60]	1	0.0	1.0	1.0	0.0
4	>60	0	0.0	0.0	0.0	0.0

PC=0.96 HSS=0.38

Categorical scores WRF D+1: Heavy rainfall (1h) Mediterranean Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<15	1072	1.0	0.02	1.01	0.98
2	[15, 30]	19	0.16	0.57	0.37	0.13
3	[30, 60]	2	0.0	0.0	0.0	0.0
4	>60	1	0.0	0.0	0.0	0.0

PC=0.98 HSS=0.2

Categorical scores Arome D+1: Heavy rainfall (1h) Mediterranean Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<15	1021	0.99	0.01	1.01	0.98
2	[15, 30]	19	0.26	0.62	0.68	0.19
3	[30, 60]	2	0.0	0.0	0.0	0.0
4	>60	1	0.0	0.0	0.0	0.0

PC=0.98 HSS=0.34

MM5 does not show any forecasting ability for heavy rainfall (not shown)

WRF and AROME have POD scores, around 0.2 for yellow warnings, which is not very high, with high FAR scores.

Scores are better for AROME than for WRF.

Multicategory contingency tables for abundat rainfall (24 h) warning thresholds

Categorical scores WRF D+1: Abundant rainfall (24h) Cantabrian Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<60	1075	0.96	0.0	0.97	0.96
2	[60, 80]	12	0.25	0.88	2.08	0.09
3	[80, 120]	7	0.29	0.92	3.43	0.07
4	>120	0	0.0	1.0	0.0	0.0

PC=0.95 HSS=0.26

Categorical scores Arome D+1: Abundant rainfall (24h) Cantabrian Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<60	1025	0.99	0.01	1.0	0.99
2	[60, 80]	11	0.45	0.64	1.27	0.25
3	[80, 120]	7	0.29	0.0	0.29	0.29
4	>120	0	0.0	1.0	0.0	0.0

PC=0.98 HSS=0.49

Categorical scores WRF D+1: Abundant rainfall (24h) Mediterranean Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<60	1087	0.99	0.0	1.0	0.99
2	[60, 80]	4	0.0	1.0	1.75	0.0
3	[80, 120]	3	0.33	0.5	0.67	0.25
4	>120	0	0.0	0.0	0.0	0.0

PC=0.99 HSS=0.24

Categorical scores Arome D+1: Abundant rainfall (24h) Mediterranean Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<60	1036	1.0	0.0	1.0	0.99
2	[60, 80]	4	0.0	1.0	0.25	0.0
3	[80, 120]	3	0.33	0.5	0.67	0.25
4	>120	0	0.0	0.0	0.0	0.0

PC=0.99 HSS=0.27

WRF overestimates the daily accumulated precipitation, particularly in the Cantabrian Slope.

Abundant precipitation in the Mediterranean Slope not well represented in both.

AROME for the Cantabrian slope shows the best results.

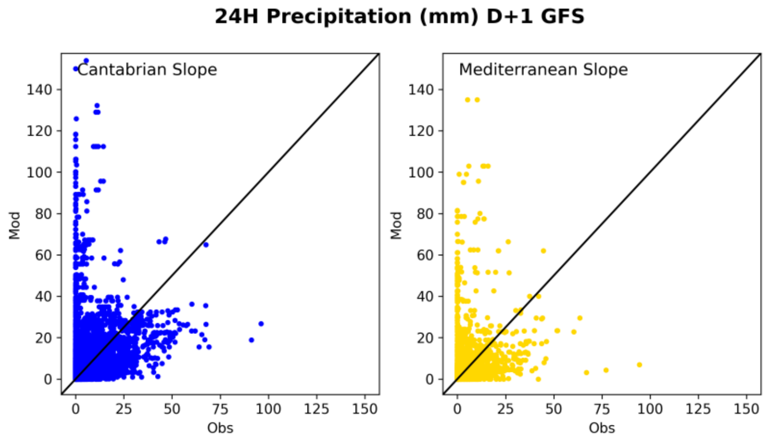
03. RESULTS. Precipitation validation in synoptic models
Daily precipitation

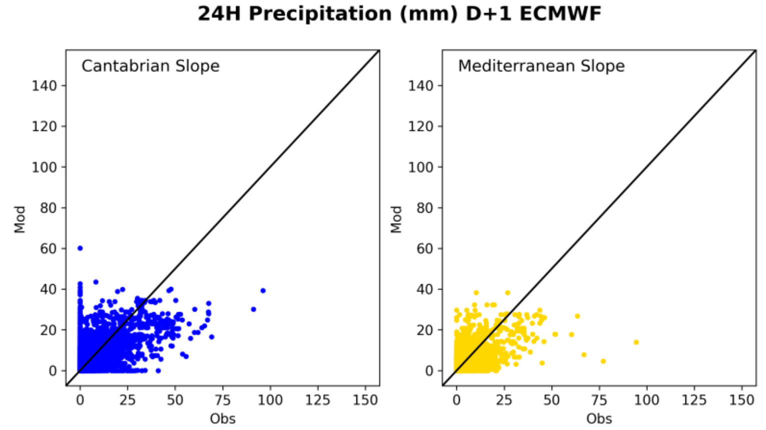
Verification scores: 24H Precipitation (mm) D+1 Cantabrian Slope

	Model	BIAS	RMSE	MAE	r
1	GFS	2.397	11.765	4.726	0.312
2	ECMWF	0.379	5.472	2.659	0.655

Verification scores: 24H Precipitation (mm) D+1 Mediterranean Slope

	Model	BIAS	RMSE	MAE	r
1	GFS	1.689	9.621	3.557	0.248
2	ECMWF	0.53	4.352	2.001	0.618

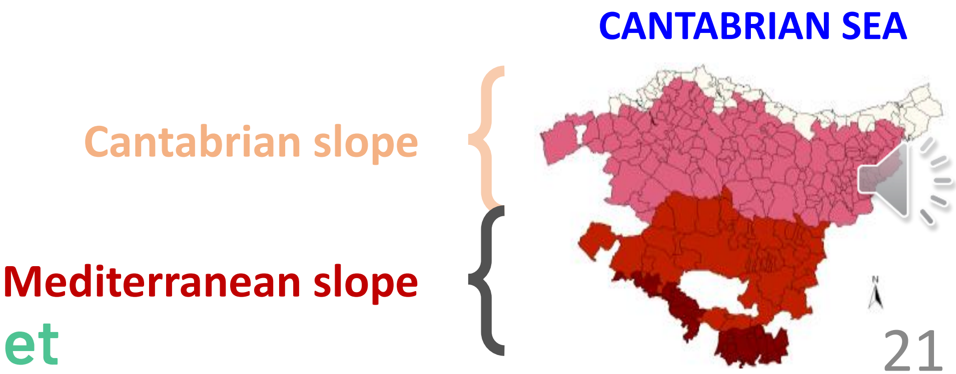




GFS and IFS underestimate remarkably, for the two slopes; the accumulated precipitation above 40-50 mm.

GFS shows great overestimation in some days with little or no precipitation.

On the Mediterranean slope in the range of 25-50 mm, IFS reduces overestimation compared with GFS.



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Multicategory contingency tables for abundat rainfall (24 h) warning thresholds

Categorical scores GFS D+1: Abundant rainfall (24h) Cantabrian Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<60	350	0.97	0.01	0.98	0.96
2	[60, 80]	4	0.0	1.0	1.25	0.0
3	[80, 120]	1	0.0	1.0	4.0	0.0
4	>120	0	0.0	1.0	0.0	0.0

PC=0.96 HSS=0.05

Categorical scores ECMWF D+1: Abundant rainfall (24h) Cantabrian Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<60	347	1.0	0.01	1.01	0.99
2	[60, 80]	4	0.0	0.0	0.0	0.0
3	[80, 120]	1	0.0	0.0	0.0	0.0
4	>120	0	0.0	0.0	0.0	0.0

PC=0.99 HSS=0.01

Categorical scores GFS D+1: Abundant rainfall (24h) Mediterranean Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<60	352	0.98	0.01	0.99	0.97
2	[60, 80]	2	0.0	1.0	2.0	0.0
3	[80, 120]	1	0.0	1.0	2.0	0.0
4	>120	0	0.0	1.0	0.0	0.0

PC=0.97 HSS=-0.0

Categorical scores ECMWF D+1: Abundant rainfall (24h) Mediterranean Slope

	Interval (mm)	nº obs	POD	FAR	BIAS	CSI
1	<60	349	1.0	0.01	1.01	0.99
2	[60, 80]	2	0.0	0.0	0.0	0.0
3	[80, 120]	1	0.0	0.0	0.0	0.0
4	>120	0	0.0	0.0	0.0	0.0

PC=0.99 HSS=-0.06

Neither of the two synoptic models shows skill in predicting the observed events surpassing the yellow and orange warning thresholds for abundant precipitations (daily accumulated).

GFS predicts some other events surpassing the thresholds, but not coinciding with the observed days.

04. DISCUSSION

AROME provides the best forecasts for maximum temperatures, particularly for high extremes.

We are aware that it is not the most appropriate to make punctual validation for synoptic models, we have done it to intercomparison purpose between IFS and GFS.

Among synoptic models, IFS performs best for minimum and maximum values in zone 3, while GFS solve better maximum temperatures in the rest of zones. All models tend to overestimate minimum and underestimate maximum temperatures.

Mesoscale models are better at predicting orange warning levels compared to yellow ones. AROME is the most reliable for extreme high temperatures across all areas and warning levels.

Synoptic models deliver acceptable results for temperature warning level forecasts, with GFS showing performance similar to mesoscale models for extreme maximum temperatures.

AROME and WRF tend to overestimate precipitation on the Cantabrian slope, and errors are more pronounced than on the Mediterranean slope.

Precipitation forecasts for warning levels are poor, with low probability of detection (POD) and high false alarm rates (FAR). Synoptic models show no ability in forecasting warning levels for both slopes.

05. CONCLUSIONS AND FUTURE WORK

Among the mesoscale models, AROME has the best scores. However, it shows some deficiencies in forecasting severe precipitation events, particularly in the Cantabrian slope. In any case, we must take into account that Arome has 1.3 km resolution with DA compared with WRF and MM5 with 3-km resolution and without DA.

IFS (ECMWF) generally predicts temperature better compared to GFS. However, for extreme high temperatures and warning leveles, GFS performs better. For extreme low temperatures, ECMWF is better, although there is still significant room for improvement.

For the precipitation forecast severe events, the synoptic models do not show skill in accurately representing it (possibly because they do not resolve convection, which plays a role in these types of events); in such cases, it is necessary to use mesoscale models.

The ability of the different systems for forecasting another surface variables such as extreme wind needs to be validated (further work).

Finally, we have implemented a new WRF configuration with 1-km resolution (not shown). In this new configuration we use a newer version of the model, more updated parameterizations (PBL, surface-layer, microphysics) and more precise land-use data, among other improvements. This new version is running with promising results that improve the AROME performance in temperature forecasting and soon will be available for operational use. However, we need a longer period of historical data to be able to carry out the validation (further work).

06. ACKNOWLEDGEMENTS

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