AEMET-γSREPS

Status and Ongoing Improvements

Juan José Gómez Navarro
Alfons Callado Pallarès

5 June 2025

Outline

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γSREPS Team

Since 2002 an small core group working on Limited Area (LAM) Ensemble Prediction Systems (EPS) depending on AEMET Research and Development Department (DDA)

Alfons Callado (60%) γSREPS operational development and suite maintenance

Juan José Gómez (100%) γSREPS development

Pau Escribà (collaborator, 10%) Assimilation. AROME-ALARO NWP collaboration

David Gil (collaborator, 50%) Web page and technical developments

Not yet hired (full member 100%) 2026-2029 SRNWP-EPS (EUMENET funded)

Currently 1.6 persons actively maintaining γSREPS. We estimate we would need 4-5 people to maintain it properly and keep improving it: we are asking for more personnel... but still waiting

Collaborations With Other Institutions

Despite being a small group, We maintain a number of collaborations and memberships with other institutions

ACCORD-EPS The ACCORD-EPS is a European LAM-EPS collaboration framed within ACCORD (the scientific successor of HIRLAM)

SRNWP-EPS co-managed by us This is a program within EUMETNET. This is devoted to foster the collaboration among various European consortia in LAM-EPS approaches

Spanish universities HYDROMED (UIB), CHIONE (UB)

Other international collaborations Arome EPS (MétéoFrance), ALARO, IPMA (Portugal), JMA, CAM, etc.

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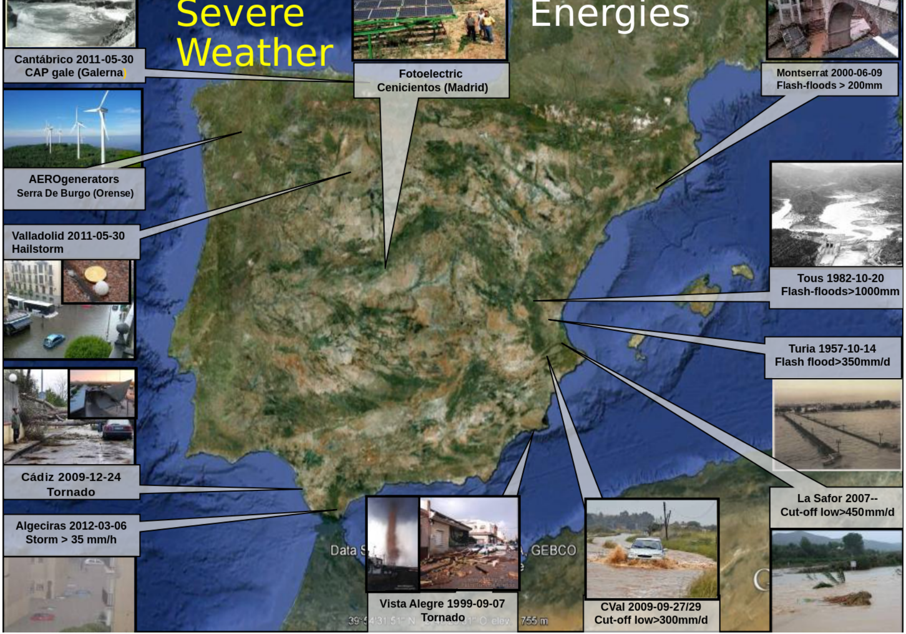
Some Reasons for a LAM-EPS in AEMET

- To improve the quality of forecasts in the short range in key locations: cities, airports
- To focus on the ability of the NWP system to represent convection (e.g. via the inclusion of WRF)
- To provide an estimation of the predictability of HIW events


Severe
Weather
Energies
Cantábrico 2011-05-30
CAP gale (Galerna)
Fotoelectric
Cenicientos (Madrid)
Montserrat 2000-06-09
Flash-floods > 200mm
AEROgenerators
Serra De Burgo (Orense)
Valladolid 2011-05-30
Hailstorm
Tous 1982-10-20
Flash-floods>1000mm
Turia 1957-10-14
Flash flood>350mm/d
Cádiz 2009-12-24
Tornado
La Safor 2007--
Cut-off low>450mm/d
Algeciras 2012-03-06
Storm > 35 mm/h
Vista Alegre 1999-09-07
Tornado
CVal 2009-09-27/29
Cut-off low>300mm/d

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Definition

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γSREPS is a...

1. Multimodel and Multiboundary Condition...
2. ...Convection Permitting...
3. Limited Area Model...
4. ...Ensemble Prediction System

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4. ...Ensemble Prediction System

or simply LAM-EPS for short

Where the Name Comes From?

The name γSREPS has three parts, γ-SR-EPS, and summarises some of their properties:

- γ is because it resolves the gamma scale of atmospheric phenomena (this can be discussed)

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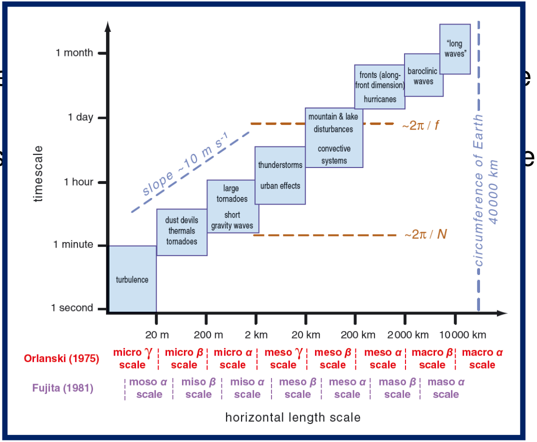

Where the Name Comes From?

The name γSREPS has three parts, γ-SR-EPS, and summarises some of their properties:

- γ is because it resolves the gamma scale of atmospheric phenomena (this can be discussed)
- **SR** is because it is aimed at short range, i.e. 2 to 3 days of lead time
- **EPS** is because, well it is an EPS

Why Ensemble Prediction System?

- Because weather is uncertain (and to some extent unpredictable)
- We are never sure about weather predictions, but we would like to quantify uncertainty
- An EPS allows to quantify uncertainty, and assess different scenarios beyond the most probable situation
- It has larger added value than single forecasts... but it requires more analysis and training
- In this regard, γSREPS is not different from any other EPS, including the one provided by ECMWF

Multimodel and Multiboundary Condition Convection Permitting Limited Area Model Ensemble Prediction System

Why Convection Permitting?

- Convection permitting means just that it has resolution *high enough* to explicitly resolve convective processes (gamma scale!)
- This improves the quality of each ensemble member (because the parametrisation of convection is very difficult)
- How do we get rid of convection parametrisation? $\Rightarrow$ high resolution
- The current resolution of γSREPS is 2.5 km
- Note that the recently implemented resolution in the ECMWF EPS is $\sim$ 9 km (not yet convection permitting)

Multimodel and Multiboundary Condition Convection Permitting Limited Area Model Ensemble Prediction System

Why Multimodel and Multiboundary?

Because it just works and outperforms other strategies, as explained in the following sections

Multimodel and Multiboundary Condition Convection Permitting Limited Area Model Ensemble Prediction System

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The 3 Sources of Uncertainty

When designing an EPS, we aim at addressing 3 sources of uncertainty

- Uncertainty/errors in the Initial Condition: we do not exactly know what's happening right now
- Uncertainty/errors in the Boundary Conditions: we are now sure if the weather systems and their timing coming through the boundaries is correct
- Uncertainty/errors in the Models: models are full of tuned parameters, simplified physical processes, and equations solved with approximated methods

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When are they most relevant?

1. Initial Condition is most important during the first few hours
2. Boundary Conditions become the dominant source of uncertainty at about 24 hours
3. Model Errors end up being the source of largest errors after about 36 hours

1. Initial Condition Uncertainty

- Models require an (unknown, but approximated) initial condition
- Data assimilation is used to constrain the model towards the observed state
- Different weather centres use different strategies
- Our approach: take the initial conditions as is from 5 different Global Models

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The 5 ICs currently implemented

1. ECMWF – IFS (European)
2. NCEP – GFS (American)
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4. CMC – GEM (Canadian)
5. JMA - GSM (Japanese)

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Room for improvement via 3DVAR assimilation within our members

2. Boundary Condition Uncertainty

- The boundaries of our LAM transport uncertain information!
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In this case there is no room for "boundary assimilation"

Detailed List of BCs

BCs	How they are			What we get		
				(Every 3 hours - 00 and 12 UTC)		
	Hor Res (km)	Vert Levels #	Type of levels	Hor Res (Km)	Vert Levels	Type of levels
ECMWF	∼9	137	Hybrid	∼11 (0.1 deg)	137 [109]	Hybrid
GFS	13	127	Sigma	26 (0.25 deg)	47 [42]	Pressure
CMC	15	80	Hybrid	15 (0.15 deg)	28	Pressure
ARPÈGE	5.0 [France]	105	Hybrid	11 (0.1 deg)	28	Pressure
ARPÈGE	5.0 [France]	105	Hybrid	10	70 / 80	Hybrid
JMA	14 (0.125 deg)	128	Hybrid	26 (0.25 deg)	111 [86]	Hybrid

3. Model Errors

- Models are full of uncertainties in physical processes
- Also in the mathematical methods to solve differential equations
- There are plenty of different ways of solving the problem, each with pros and cons
- Our approach: use 4 different LAMs

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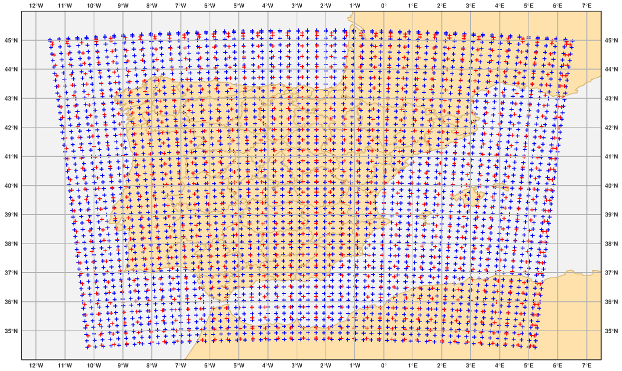
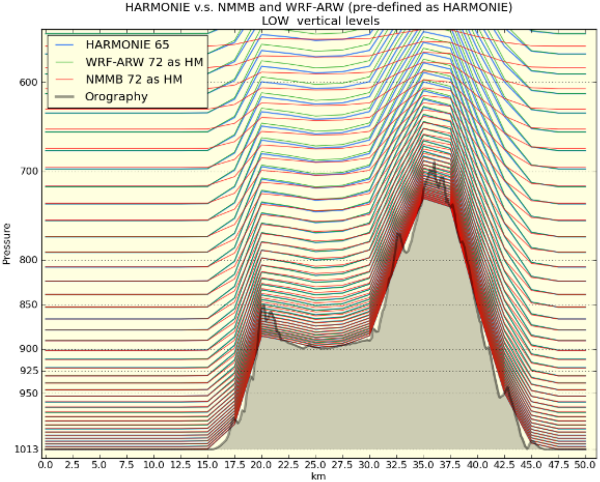
Room for improvement adding more models. GEM-LAM? ICON?

Details of Horizontal Grids



- We tried to make the grids as similar as possible
- HARMONIEs: 576 × 480, Lambert Conformal Conic
- WRF: 566 × 470, Lambert Conformal Conic
- NMMB: 568 × 472, Rotated Lat-Lon
- Common GRIB: Lambert 565 × 469, identical codification to operational HARMONIE

Details of Vertical resolution

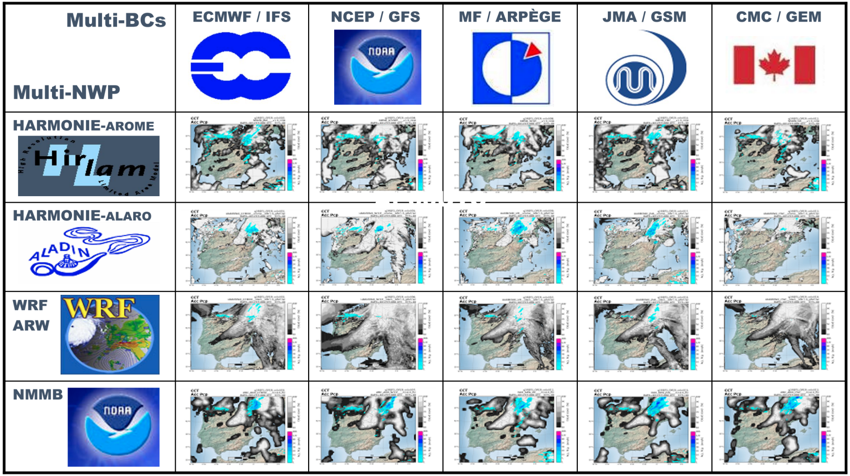


- We tried to make the vertical spacing as similar as possible
- HARMONIEs: 65 hybrid sigma-pressure vertical levels
- WRF: 66 sigma (ETA) hydrostatic-pressure levels up to 40 hPa
- NMMB: 66 hybrid sigma-pressure levels up to 40 hPa

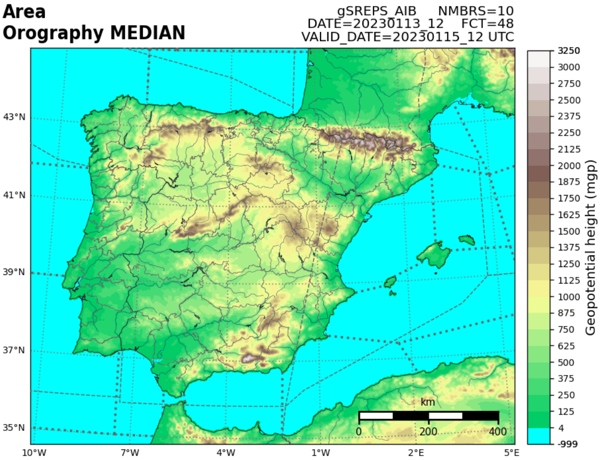
Details of Model Setup

NWP models' settings		
HARMONIEs	WRF	NMMB
AROME physics ALARO physics + 3MT	ARW dynamical core	NMM dynamical core
65 Hybrid sigma-pressure vertical levels	66 sigma (ETA) hydrostatic-pressure levels up to 40 hPa	66 Hybrid sigma-pressure up to 40 hPa
60 s time step	12 s time step	5.625 s time step
Lambert Conformal Conic projection: lon -2.5° / lat 40.0° 565 × 469 grid-points		Rotated lon-lat B-grid: lon -2.5° / lat 40.0° 568 × 472 grid-points
Calling radiation every 15 minutes		
8 LBC relaxation points around grid area		

The γSREPS Matrix: $4 \times 5 = 20$ Members

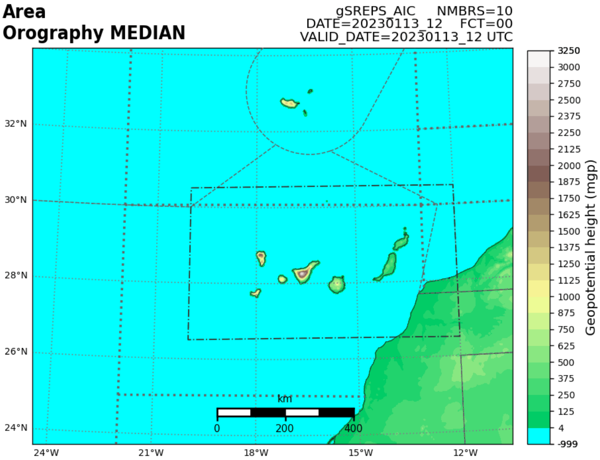


Domain 1: Iberia



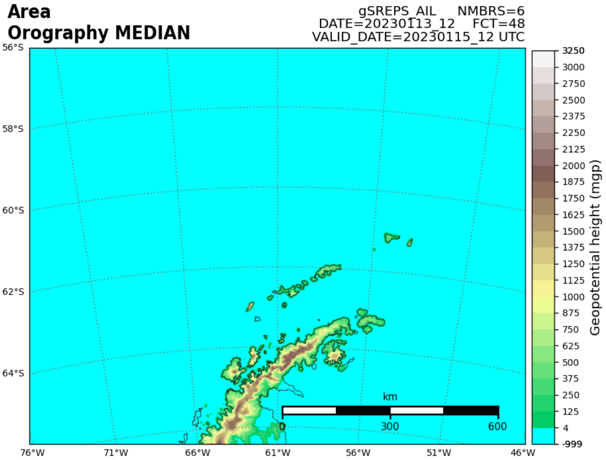
- All Iberian Peninsula at 2.5 km
- Run twice a day: 00 and 12 UTC
- Lead time 72 hours
- Various subdomains for products: *IBERIAN_2.5, NORTHWEST, SOUTH*, etc

Domain 2: Canary Islands



- Canary Islands at 2.5 km
- Run twice a day: 00 and 12 UTC
- Lead time 72 hours
- Various subdomains for products: *CANARIAS_2.5*, *WEST*, etc

Domain 3: Antarctica



- Antarctic Peninsula at 2.5 km
- Run twice a day: 00 and 12 UTC
- Only during the antarctic campaign: 13 December to 31 March
- Lead time 72 hours
- Various subdomains for products: *Shetlands, Livingston*, etc

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The Performance of Each Member IS Important

- For an EPS to be useful each member, evaluated independently, must be *good enough*
- We are *quite confident* that each member performs as state-of-art models at similar resolution
- We inspect all members performance after major modification
- Still, we are not systematically evaluating the performance of each member
- We want to setup an automatic verification protocol (HARP) as part of our suites $\Rightarrow$ future work

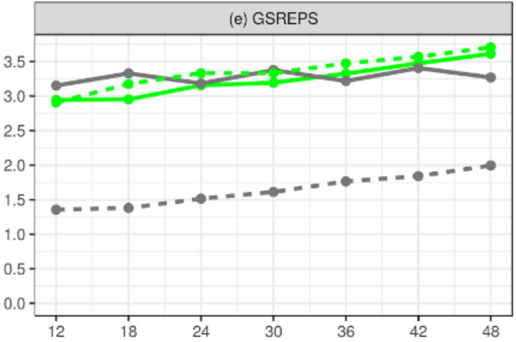
A Good EPS is a Consistent EPS

What does it mean for an EPS to be *useful*? There are many metrics, but one of the most important for EPS verification is consistency.

- How far is reality from models? $\Rightarrow$ error
- How big is the spread among models? $\Rightarrow$ uncertainty

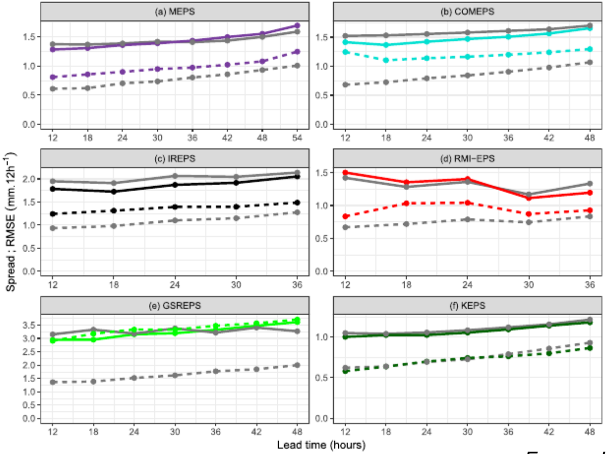
An EPS is consistent if the uncertainty indicated by the model spread matches the errors between models and reality. This is, if model spread is a good estimation for model error

Consistency Diagram



- We represent error (solid line) versus spread (dashed line) for a given variable. In this case precipitation
- In the horizontal, the evolution for various lead times
- In green, a consistent ensemble
- In grey, an inconsistent one (the spread is lower than the error)

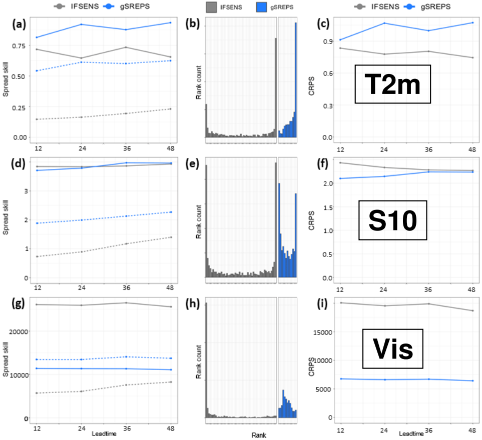
Consistency Diagram for γSREPS



- Frogner et al. 2019 evaluated various LAM-EPS running in Europe against ECMWF
- ECMWF is underdispersive (for this variable and time lead time), a problem that is ameliorated by the LAM-EPSs
- Overall, γSREPS is the most consistent
- Note: γSREPS is the only multimodel and multi boundary condition EPS

Frogner I.L. et al, 2019 https://doi.org/10.1175/WAF-D-19-0030.1.

Rank Histograms for Antarctica

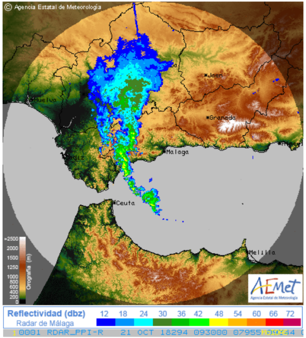


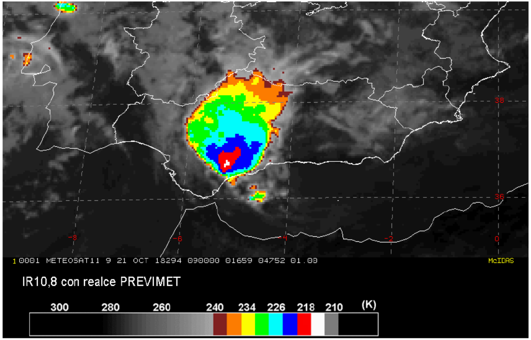
- Rank histogram is other form of evaluation of model performance
- γSREPS was evaluated against ECMWF in Antarctica in three key variables: T2m, 10m wind and visibility
- Similar errors, but larger spread $\Rightarrow$ better consistency
- Flatter histograms
- Overall: an important added value for predictors in difficult conditions

S. Gonzalez et al. 2020, https://doi.org/10.5194/asr-17-209-2020

AEMET Maximum Record of 289 mm / 6 hours

This was an event occurred in Alpandeire (Málaga): a convective Mesoscale System associated to a DANA, a blocking ride and low level wet jet
This event was very difficult to predict, with high spatial/temporal uncertainty





C. M. Jiménez Cavero, 2019, "RÉCORD NACIONAL DE PRECIPITACIÓN EN 6 HORAS...", internal AEMET publication

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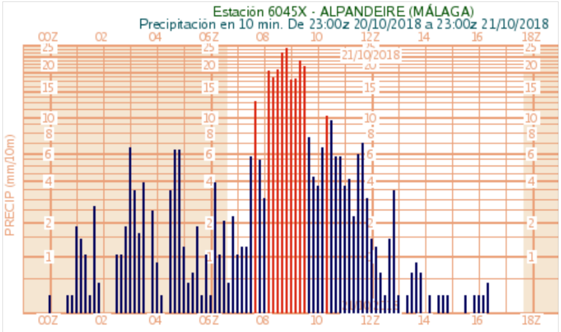

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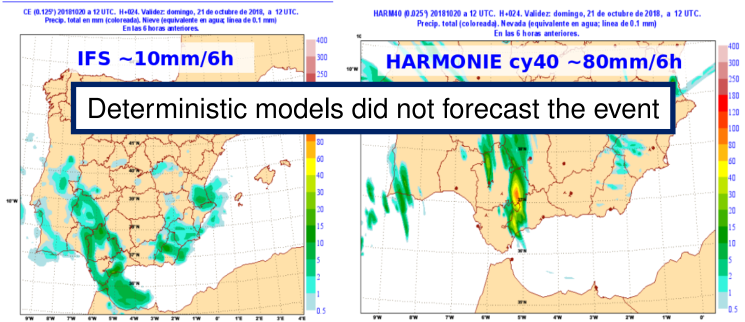

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aemet
Agencia Estatal de Meteorología

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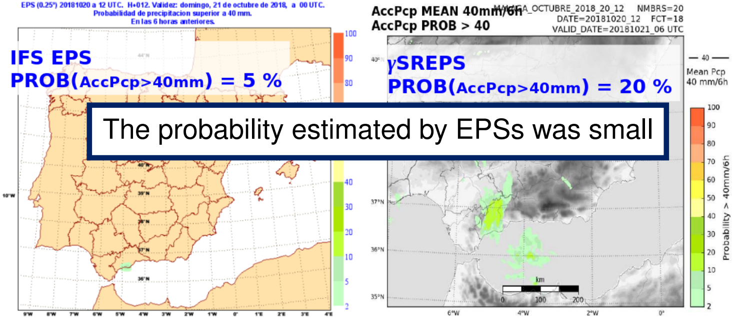

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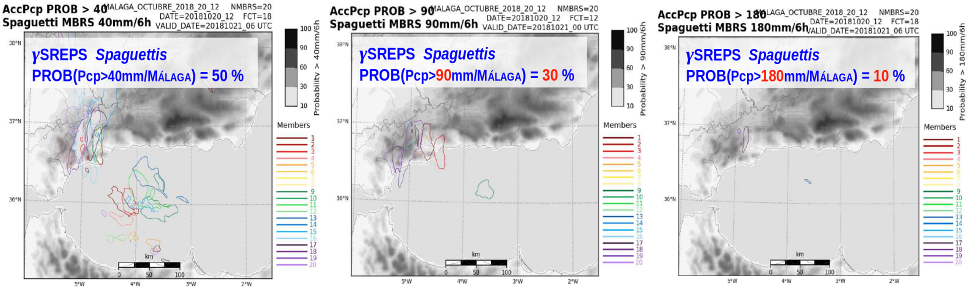
AEMET Maximum Record of 289 mm / 6 hours

The event was very difficult to forecast due to high spatial uncertainty. Eventually, only 1 member in γSREPS reproduced precipitation in about 300 mm/6h. The aggregation of members sometimes masks valuable information.



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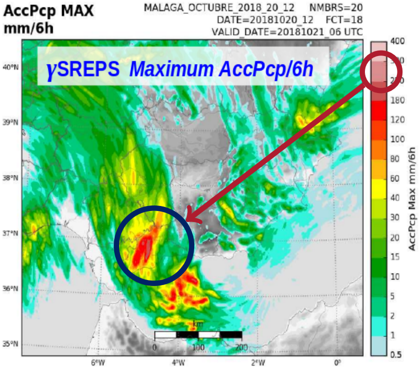


- The extreme was actually captured by the tail of the distribution (1 member)
- When in doubt, do not look just at aggregated products, go to individual members, maxima, etc

C. M. Jiménez Cavero, 2019, "RÉCORD NACIONAL DE PRECIPITACIÓN EN 6 HORAS...", internal AEMET publication

DANA in Valencia, 2024

Forecast maximum of 300-432 mm/24h close to Turís, while observed of 771.8 ll/24h. 7 out of 15 members with regions of precipitation above 180 mm/24h, with relatively small spatial uncertainty

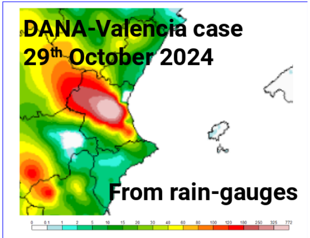
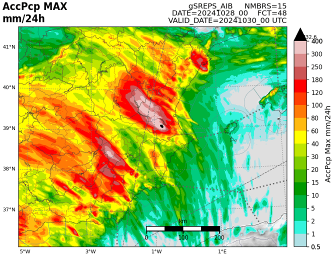
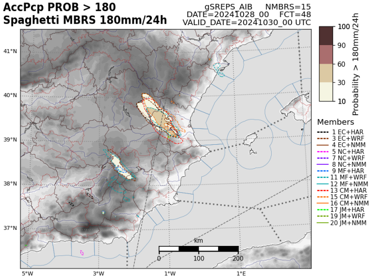


Figura 6. Precipitación acumulada el día 29 de octubre de 2024
(fuente: AEMET y Confederaciones Hidrográficas)





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Current Status

- γSREPS is a mature system that is customarily used in forecasters in AEMET since 2016, although not officially operational
- We like talking with predictors, and listening to their requests for new products, which has been the key to the success of the system
- We keep maintaining/monitoring the system ourselves, fixing bugs and coping with problems when the HPC does not work as expected
- We are always looking for ways to improve the system and making it more useful, e. g. tomorrow we hold a meeting with the GPV

Issues and On-going Work

- Since November 2022 we are running γSREPS in the new supercomputer of ECMWF in Bologna: 5/20 members are not running (Harmonie-Alaro)
- Update LAMs (WRF 3.6 $\rightarrow$ 4.6 and both Harmonies (Cycle 41 $\rightarrow$ 46)
- We are not a "Time Critical Application", so we exploit and monitor this system ourselves 24/7: currently actively working on it
- We keep adding/improving products. This year we have released a number of new products:
  - EFI/SOT calculation for many surface variables
  - Probabilistic vertical profiles with ATAP (thanks to Álvaro Subías)
  - New levels, thresholds, locations, etc
- Enlarge the domain in the Iberian Peninsula to have better organised convection and increase spread

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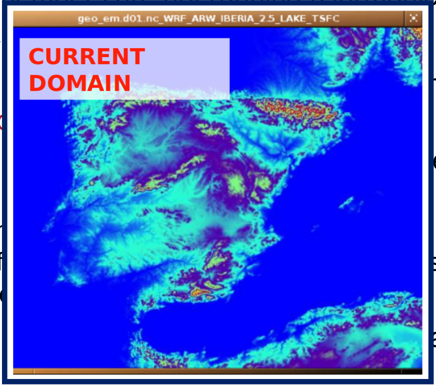

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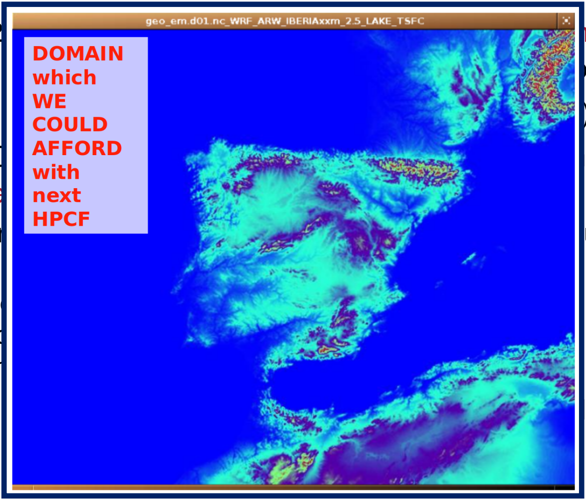

Things We Would Like to Implement

- Members are cold-started, with no data assimilation whatsoever
- Implement an auto-verification tool (HARP) to conduct periodic (monthly) verification tests to the system
- Implement a dynamic visualization tool (ADAGUC) that allows the users to visualize the products using layers and zoom in desired regions (GIS-like experience)

Long-term: A Larger γSREPS?

With the current supercomputer in Bologna (and in AEMET) we have more computational resources that allow us to run more ambitious forecasts:

- Cross the boundary towards hectometic resolution (< 1 km): still under heavy scientific development at international level?
- We are not very sure of the added value of higher resolution a the cost it implies: it is more worth to invest in more members
- Include a sixth boundary condition: ICON (German model)
- Add two more LAMs: GEM-LAM (Canadian model) ICON-LAM (German model)

Our biggest constrain isn't computational resources, but human resources to develop and maintain an ever-growing complex system, while we keep developing new products

Towards Harmonie-AROME EPS

- γSREPS has been a great success, and it has lived longer than originally planned
- The previous slide were our plans, but given the limitation in human resources, we are now about to freeze of the current system and migrate to HARMONIE-AROME EPS
- This is part of the integration within the Unified Weather Centers (as UWC-South), after the decay of HIRLAM
- This system consists of a single model, developed within the ACCORD-EPS consortium, and similarly as the European ENS-IFS, spread is obtained by perturbing the initial conditions and parametrisation (SPP)
- Setting this system up and getting valuable spread remains a challenge
- Another whole issues in IA-based NWP, which is really uncertain right now, but we must keep an eye on it

What Can We Provide to Hydromed?

- Know-how?
- Run case studies?
- Other Ideas?

Questions?

Thank you for your attention!

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