Potential of stochastic methods for improving convection-permitting ensemble forecasts of extreme events over the Western Mediterranean

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Introduction

Motivation

- The **western Mediterranean** region is frequently affected by severe weather, and especially **heavy precipitation and flash flooding**.

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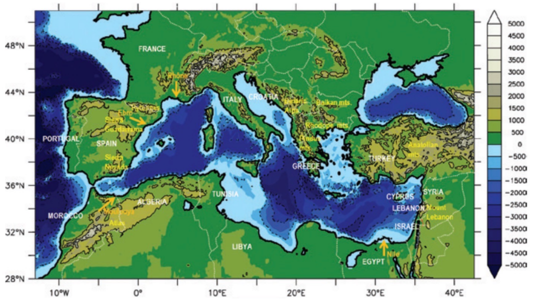
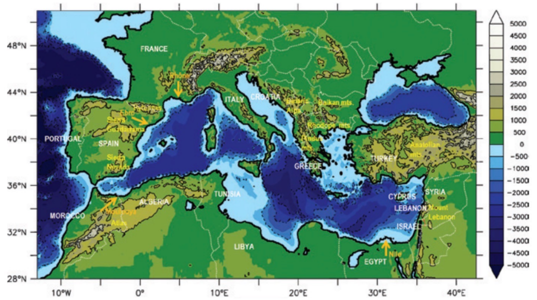


- Key **factors**: upper-level **cold disturbances**, complex **orography**, relatively **high SST**

Motivation

- The **western Mediterranean** region is frequently affected by severe weather, and especially **heavy precipitation and flash flooding**.



- Key **factors**: upper-level **cold disturbances**, complex **orography**, relatively **high SST**

- **Small**-to-medium size **catchments** (100-1000 km^2) → Short response times
- **Short predictability horizon** of socially relevant features
- All relevant uncertainties at convective-scale must be considered
- Focus on model error in this study

Case study

Impacts

The episode of **Valencia, Murcia and Almeria** of **12-13 September 2019** is a remarkable example for various reasons: precipitation amounts, duration and wide-spread and complex hydrological response.

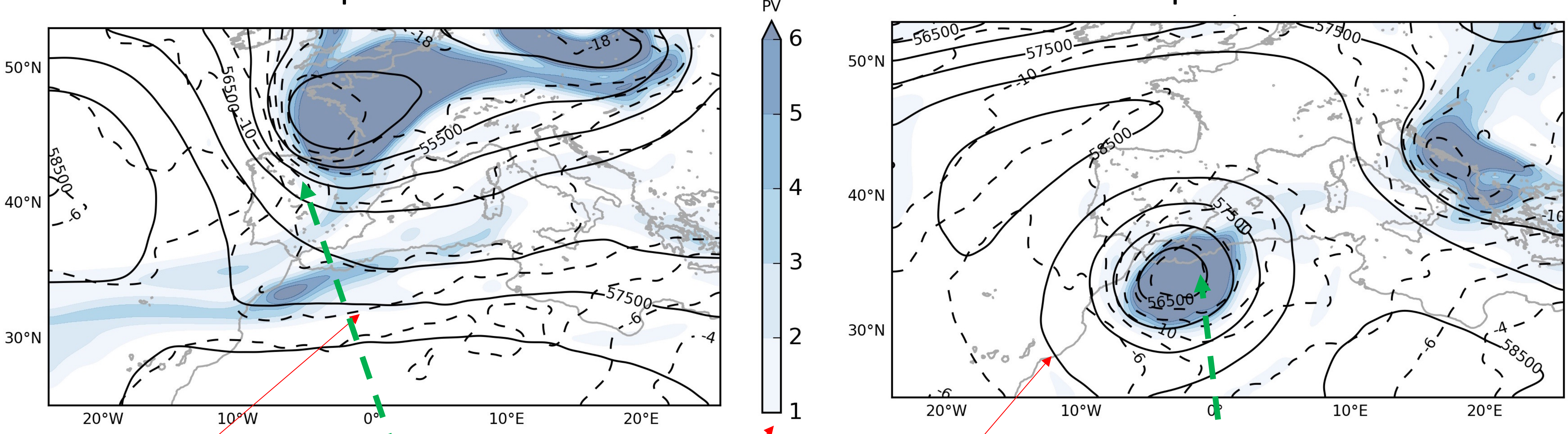
Total accumulated **precipitation near 500 mm** in 2 days

The episode produced devastating effects including **7 fatalities** and estimated **economical losses of 425 M€**.

Upper-levels synoptic situation

10 Sep 00 UTC

12 Sep 12 UTC



500 hPa Temperature

Upper-level Positively- tilted trough

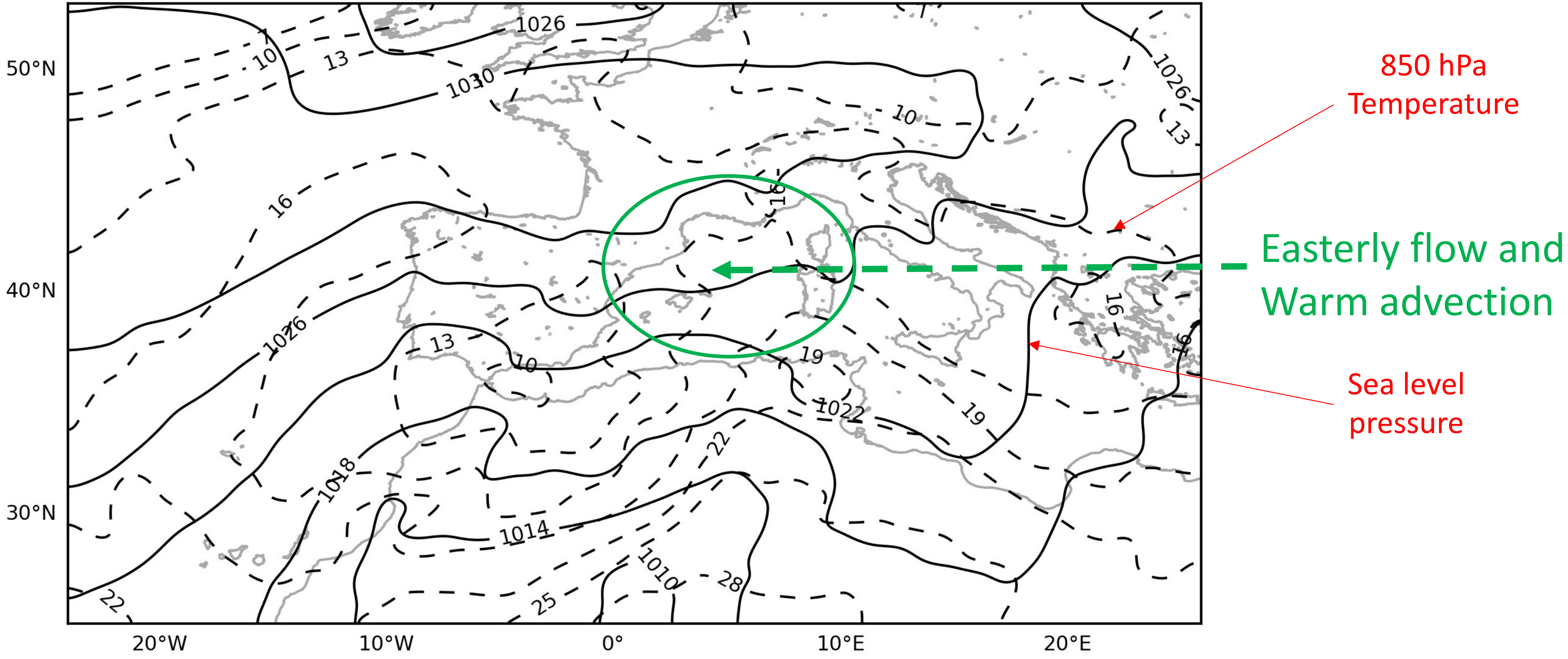
250 hPa Potential Vorticity

500 hPa Geopotential

Upper-level cold cut-off

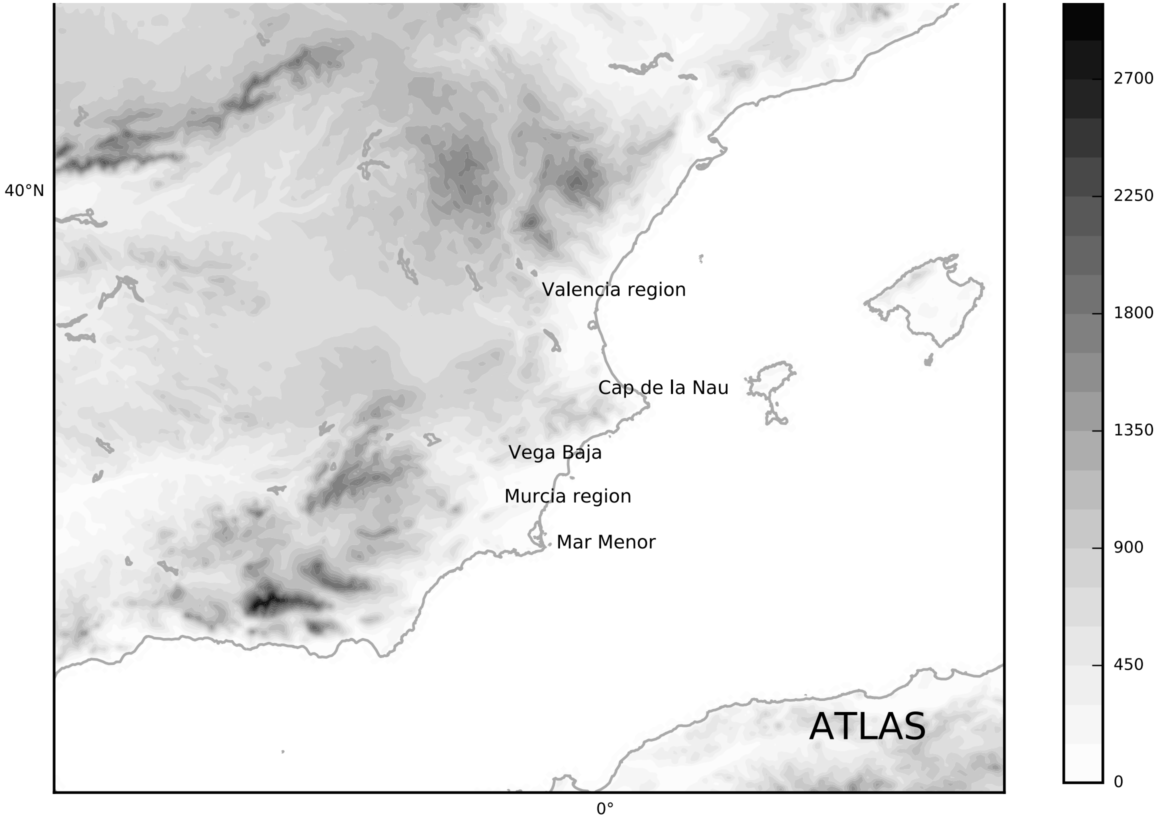
Low-levels synoptic situation

12 Sep 00 UTC



Episode phases

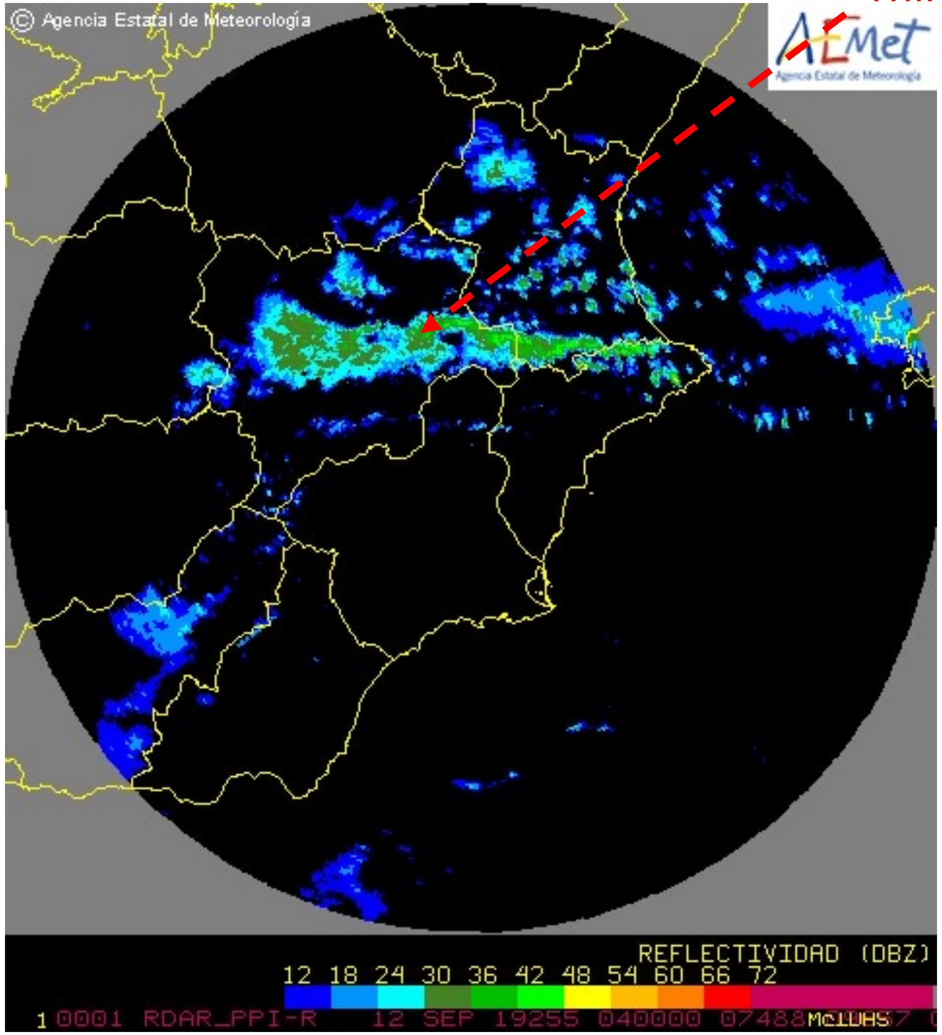
- The precipitation of the episode can be divided in **three phases**:
  - **Phase 1:** Thin line of convection around Cap de la Nau
    - 12 September 00-06 UTC
    - Hourly intensities > 65 mm
  - **Phase 2:** Linear precipitation structure at Vega Baja
    - 12 September 06-18 UTC
    - Hourly intensities ~100 mm
  - **Phase 3:** Precipitation associated to a mesoscale convective system in Murcia
    - 12 September 18 UTC-13 September 12 UTC
    - Hourly intensities > 100 mm



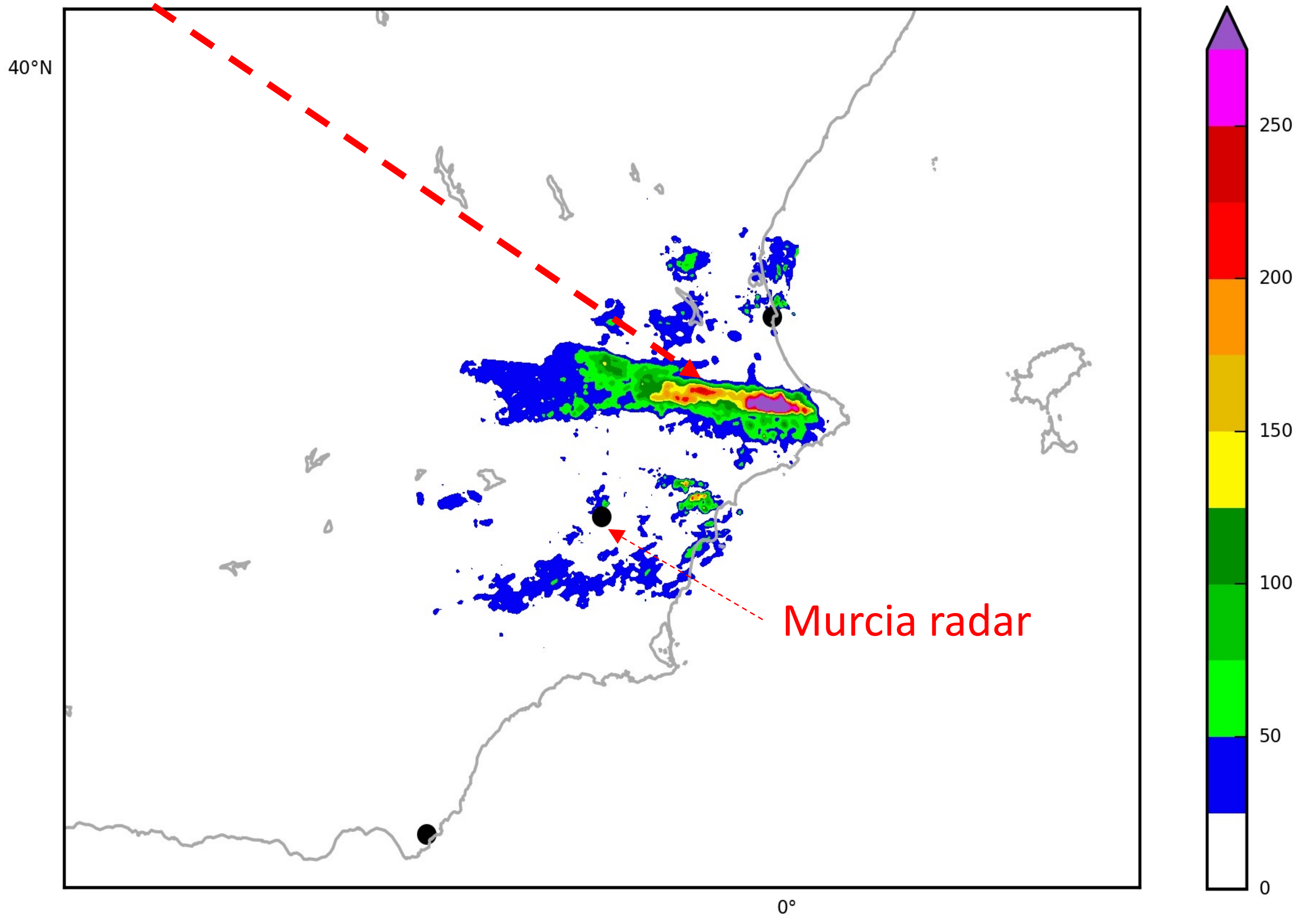
Map with geographical locations mentioned

Phase 1

Thin convective line



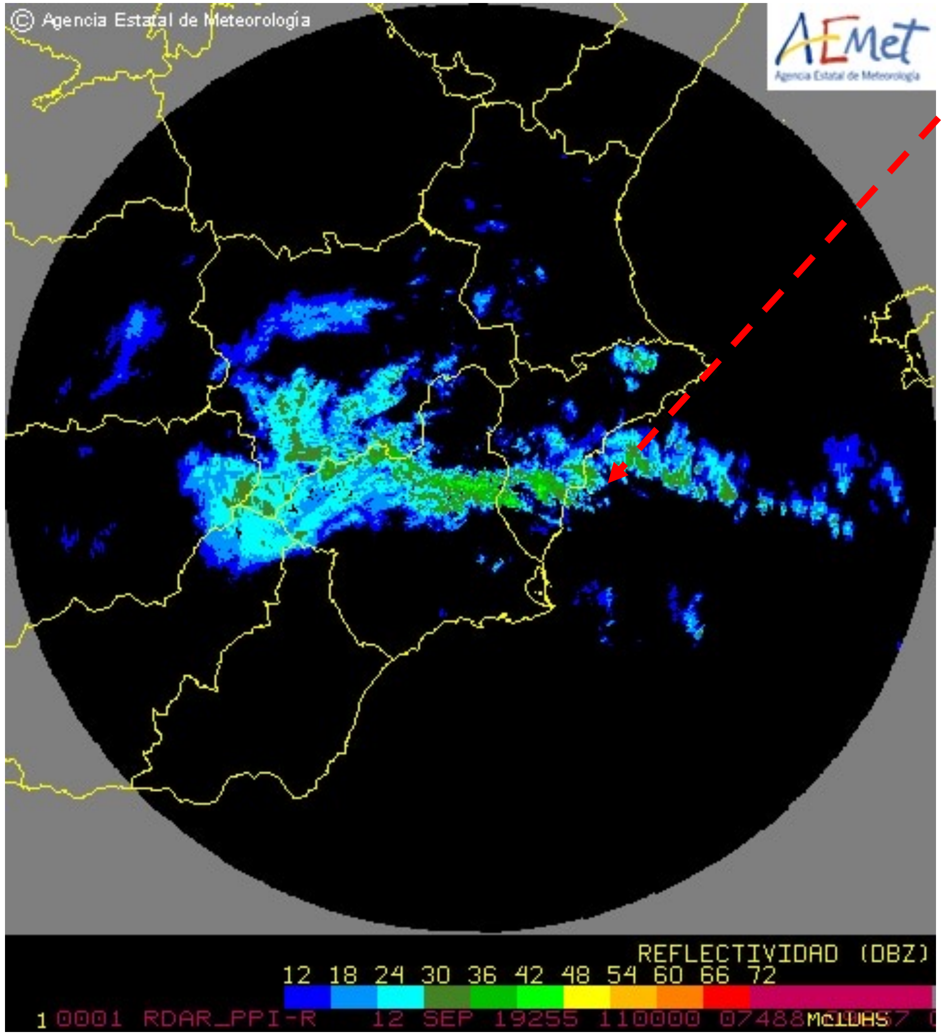
Murcia radar image
12 September 2019 04 UTC



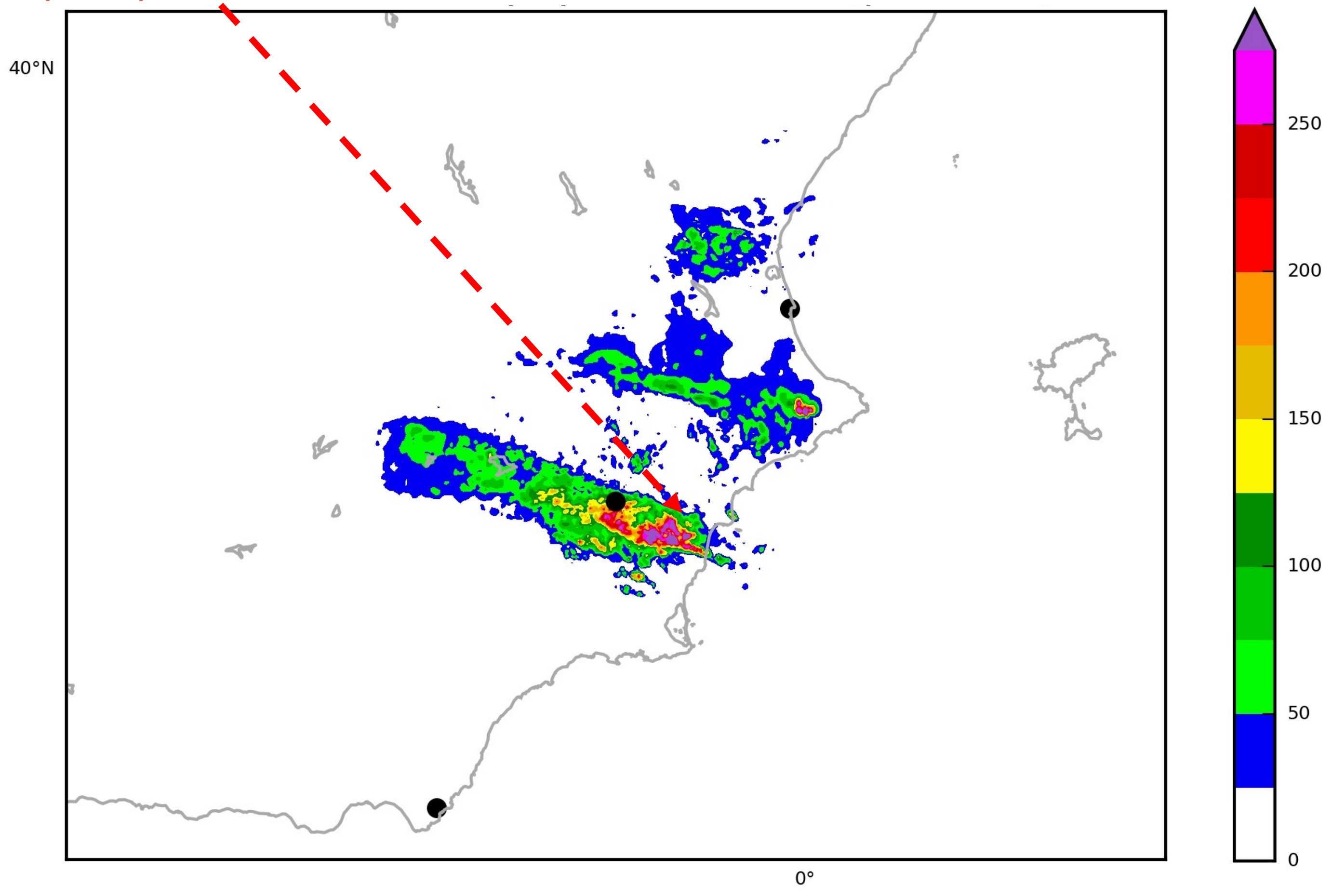
Radar estimated 12 September
00-06 UTC accumulated precipitation

Phase 2

Linear precipitation structure



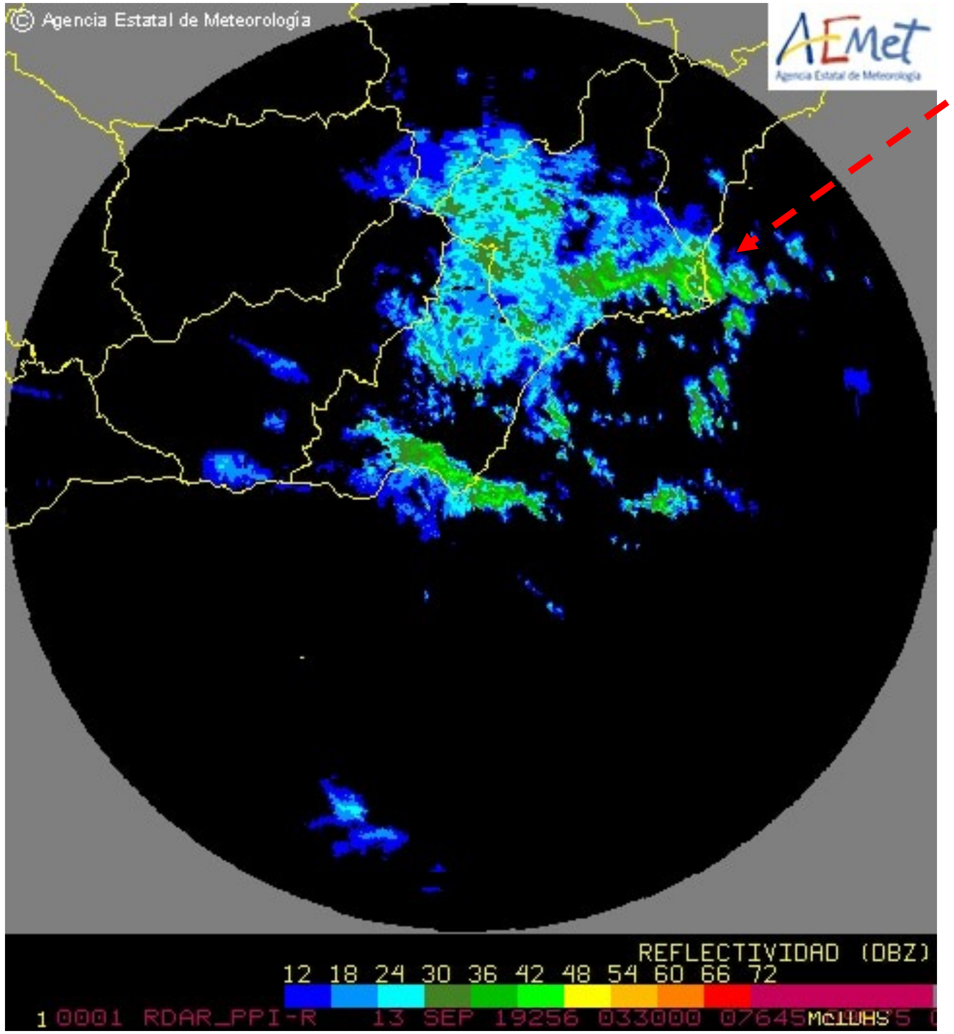
Murcia radar image
12 September 2019 11 UTC



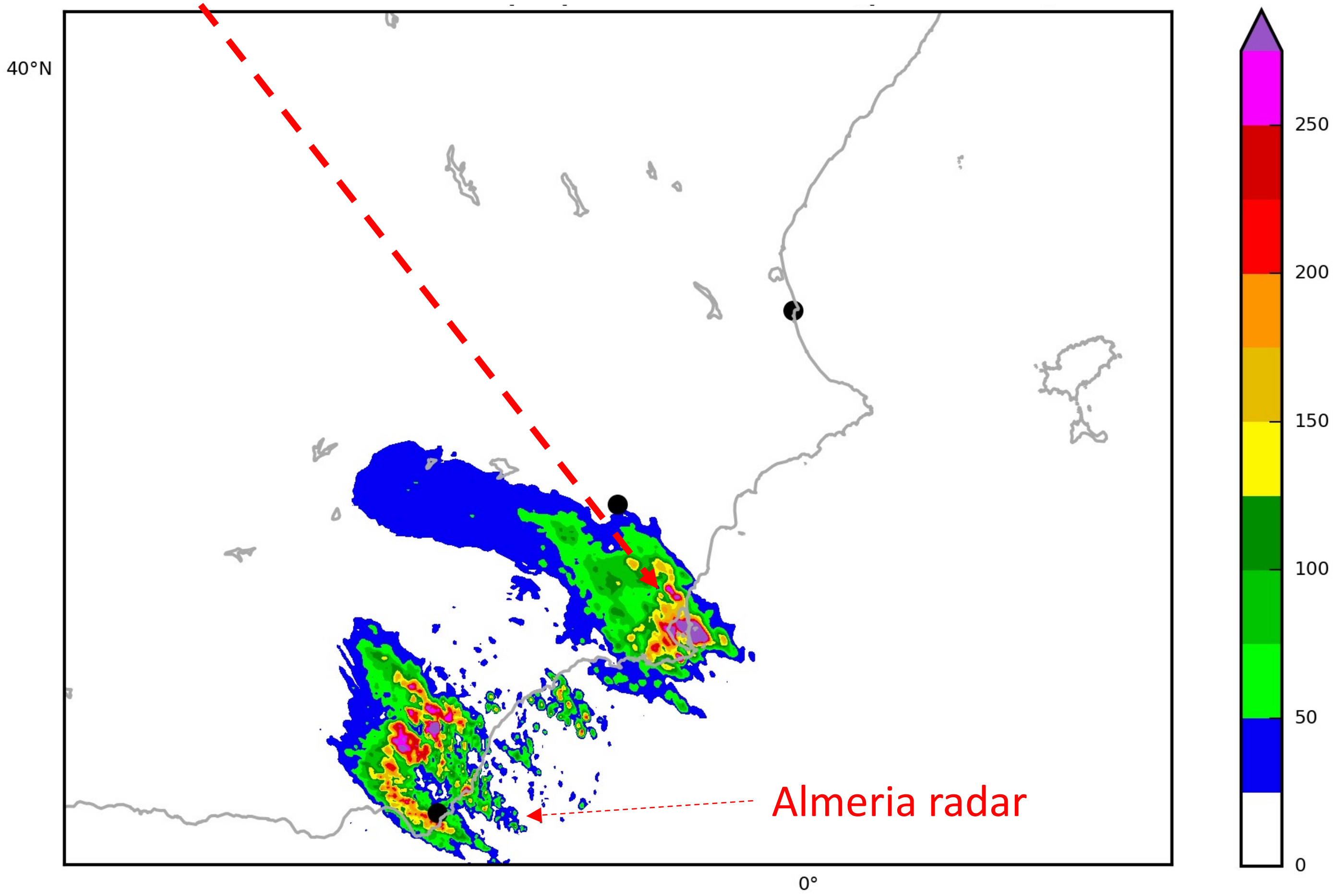
Radar estimated 12 September
06-12 UTC accumulated precipitation

Phase 3

MCS over Murcia



Almeria radar image
13 September 2019 03:30 UTC



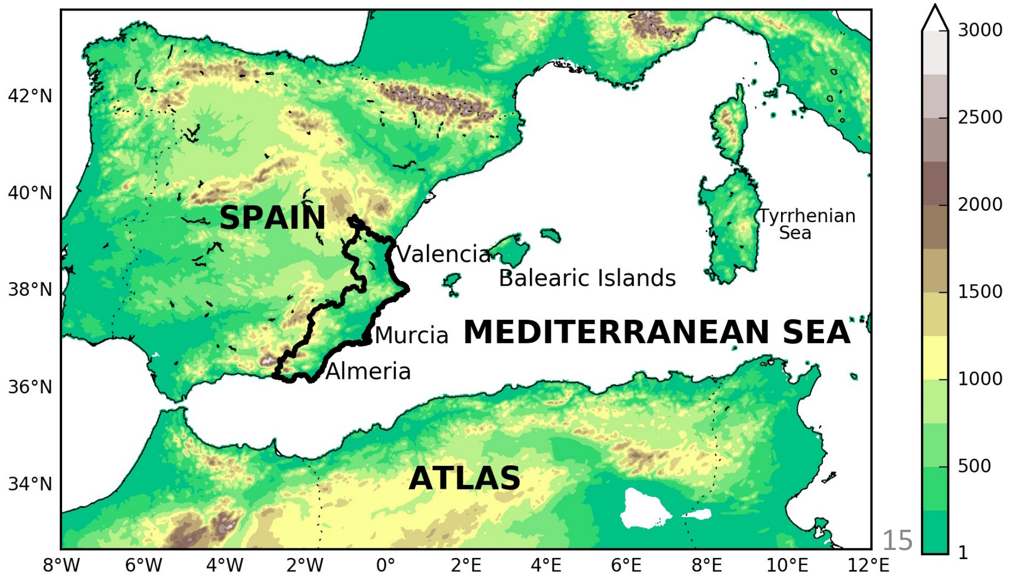
Radar estimated 13 September
00-06 UTC accumulated precipitation

Methodology

Simulation set-up

- The model used is the WRF-ARW v3.9.1
- 2.5 km horizontal resolution and 50 vertical levels
- 30 h lead time (6 h for spin-up and 24 h effective)
- Initialization times: 11 September 18 UTC and 12 September 18 UTC
- 10 different initial conditions selected with a k-means clustering algorithm from the 50-member ECMWF-EPS
- 50-members ensembles introducing model error

Simulation domain



Multiphysics (MPS)

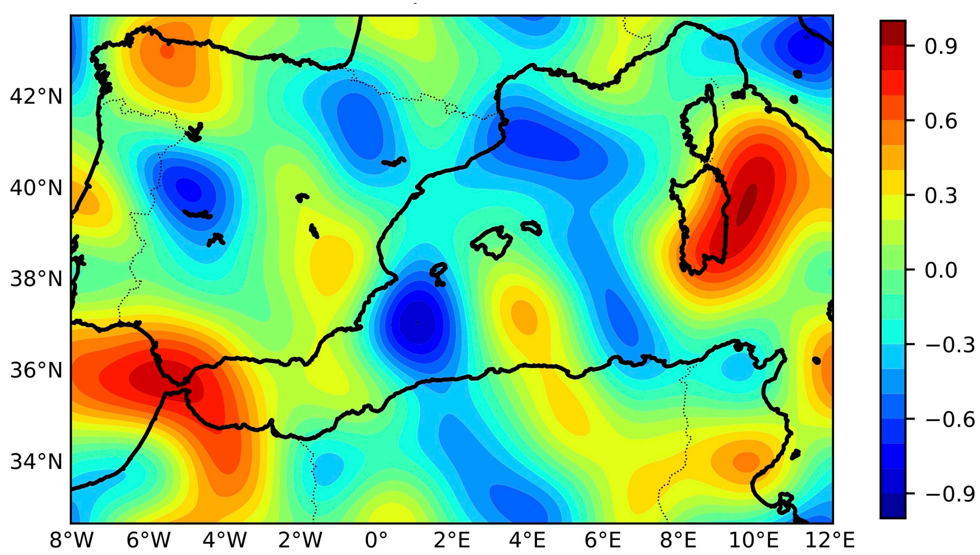
- 5 different combinations of microphysics and planetary boundary layer
- Microphysics: **NSSL 2-moment**, WSM6, Thompson
- PBL: **MYNN**, MYJ
- Same radiation (RRTMG) and land-surface (RUC)
- No parameterised convection

Microphysics	PBL
NSSL 2-mom	**MYNN**
WSM6	MYNN
Thompson	MYNN
NSSL 2-mom	MYJ
WSM6	MYJ

Baseline configuration

SPPT

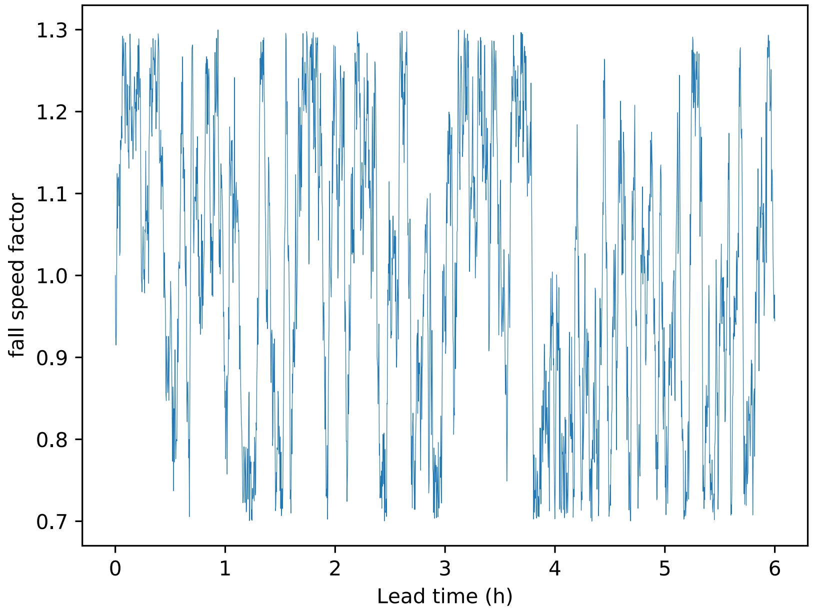
- Stochastic perturbed physics tendencies (SPPT) from Berner et al. (2015)
- Total physics tendencies are multiplied by a spatially and temporally correlated random pattern:
  - $X = X_{dyn} + X_{phys}$ $\quad X'_{phys} = (1 + r)X_{phys}$



Spatial correlation: 100 km
Temporal correlation: 1h
Variance: 0.25

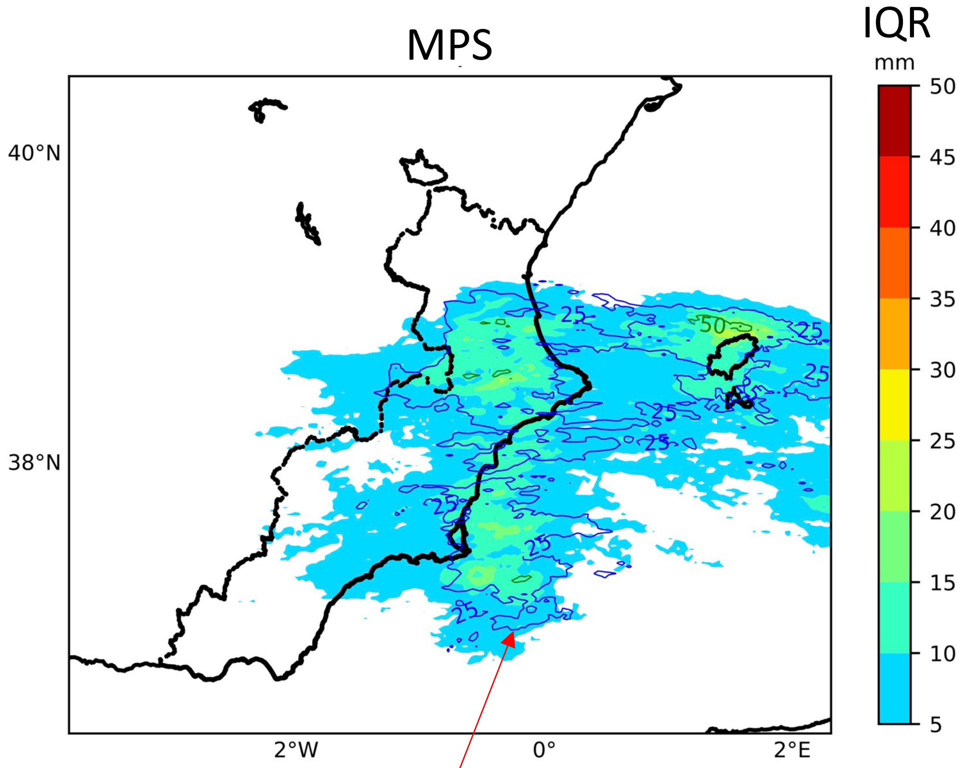
MPRP and SPPT_MPRP

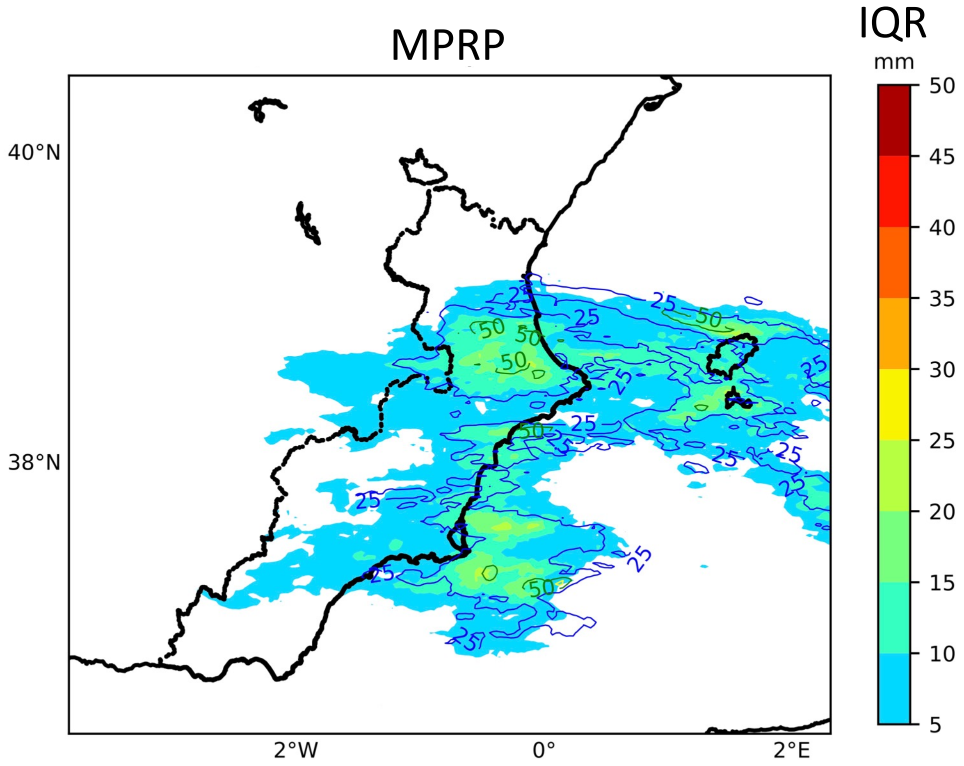
- Microphysics perturbations are not included in WRF current implementation
- The approach: perturb specific parameters within the microphysics scheme following McCabe et al. (2016)
- Parameters evolve with time stochastically. Only temporal correlation
- Parameters perturbed: CCN, graupel and hail fall factors, saturation percentage for cloud formation
- Two ensembles: MPRP (only microphysics perturbations) and SPPT_MPRP (combination of both)



Results

Spread characteristics (phase 1)

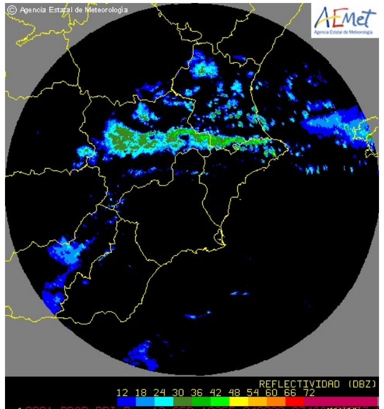




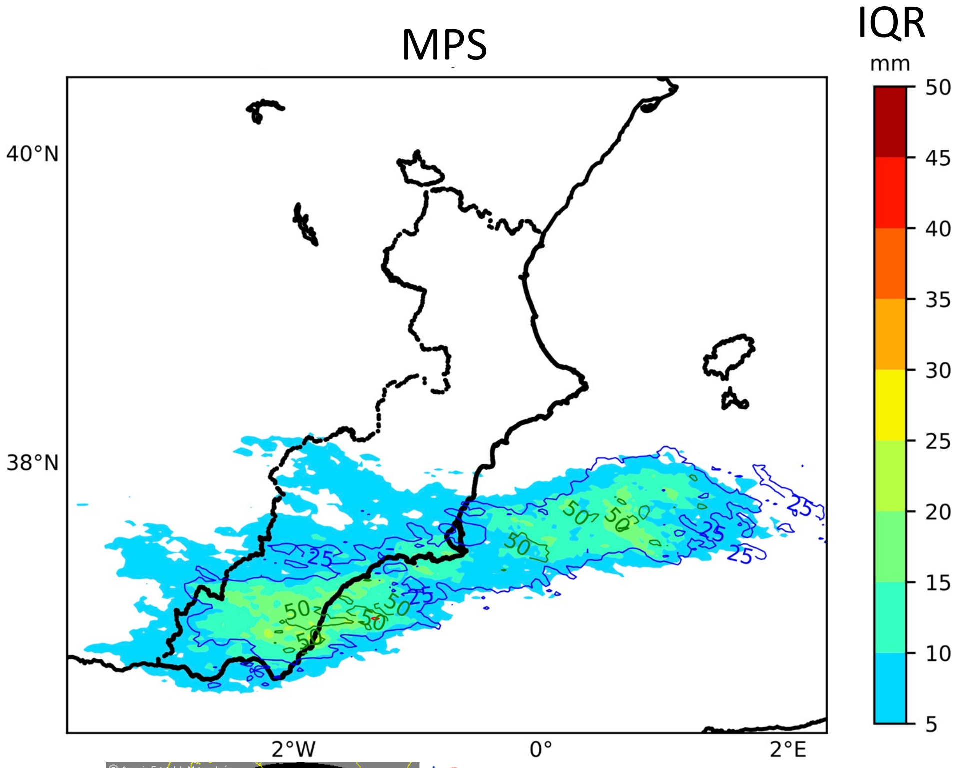
95 percentile
(solid lines)

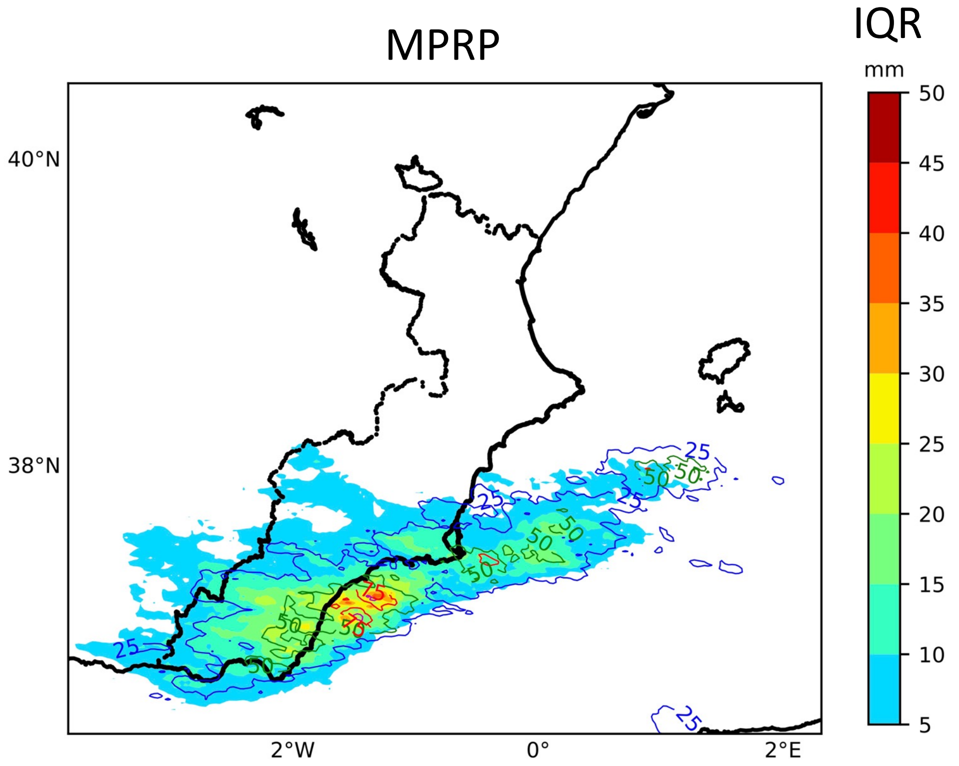
Higher precipitation accumulations and spread when microphysics is perturbed

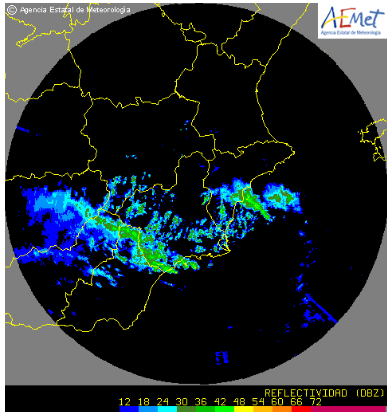
Similar results for other ensembles including microphysics perturbations



Spread characteristics (phase 2)



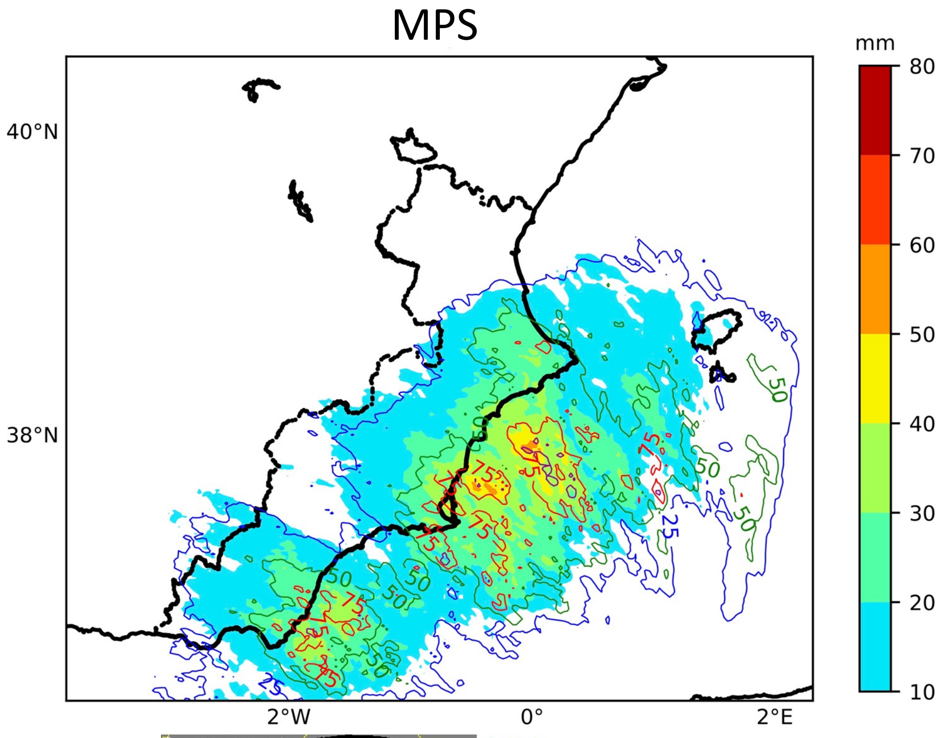


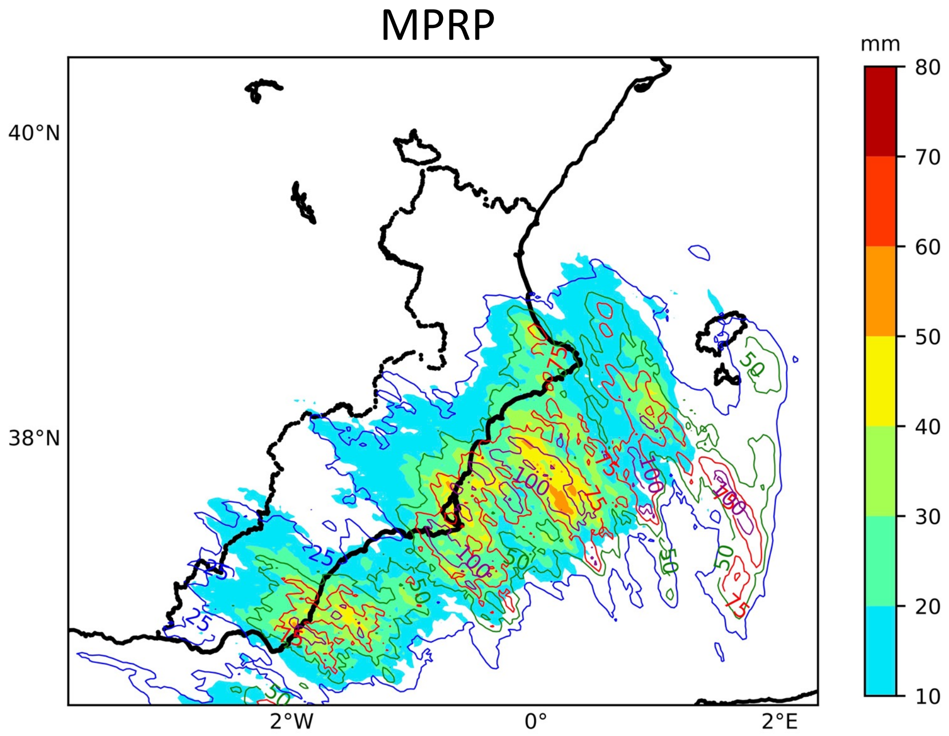


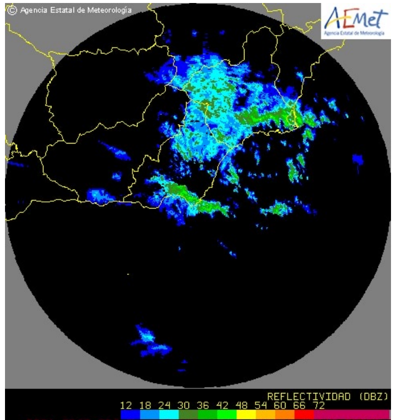
Higher precipitation accumulations and spread when microphysics is perturbed

Ensemble spread for stochastic methods centred over the region of convective development

Spread characteristics (phase 3)





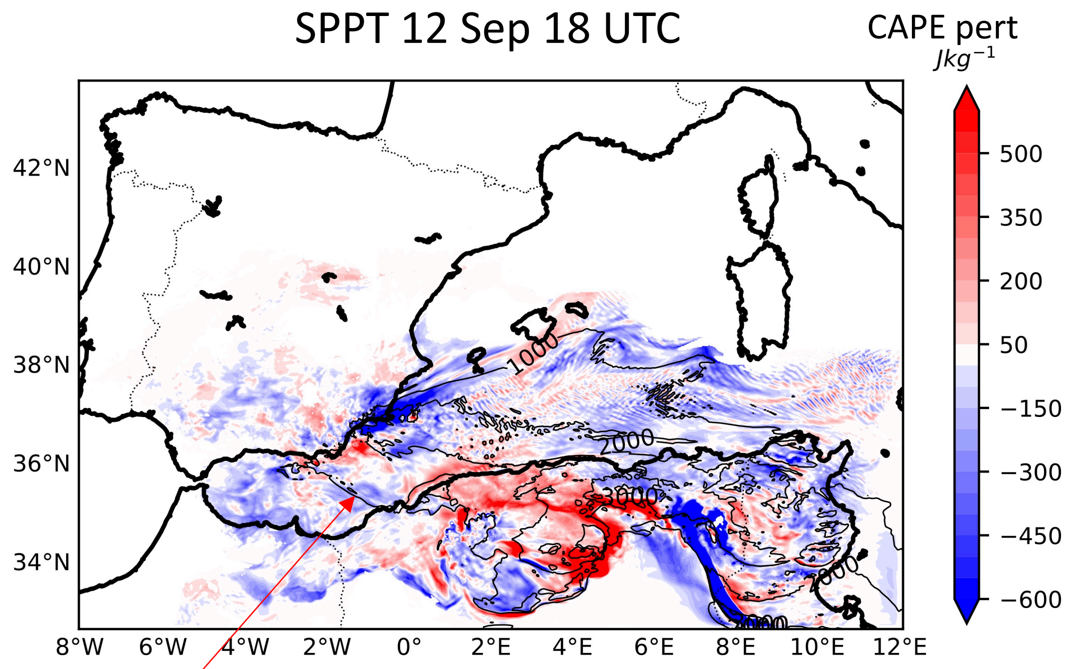


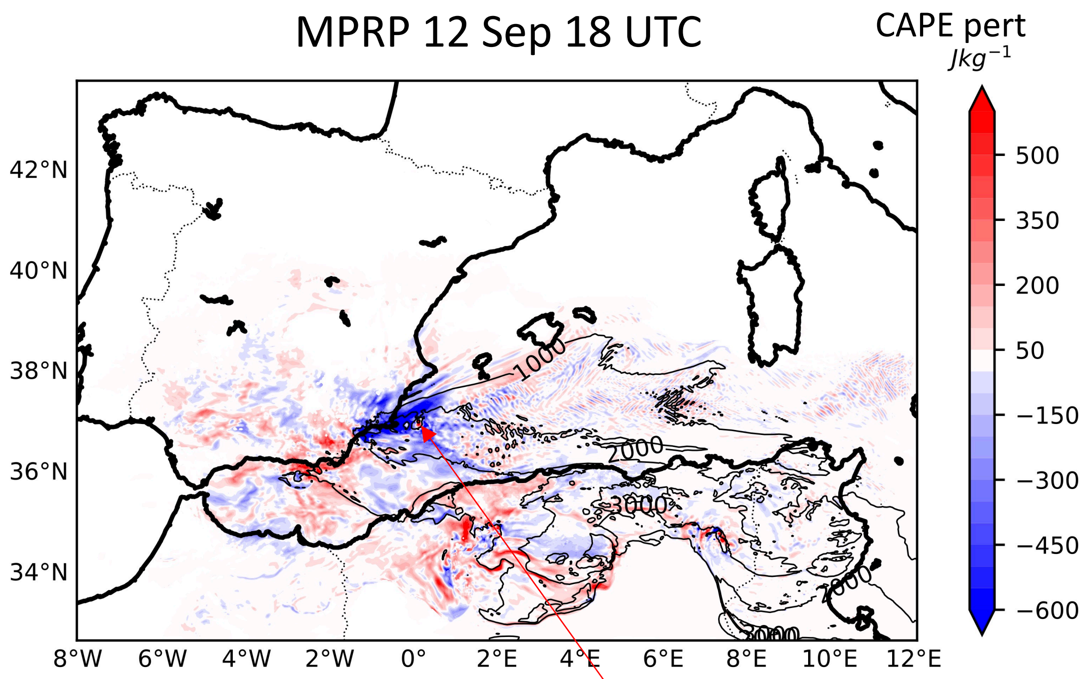
Higher precipitation accumulations and spread for stochastic strategies

Larger diversity of stochastic methods over land

Perturbation characteristics

Single member comparison





Unperturbed CAPE field (solid black lines)

Small-scale perturbations for MPRP

Perturbation growth over areas of high convective instability

Larger scale initial perturbation for SPPT linked to parameter specification

CAPE differences from unperturbed member (shaded)

Precipitation verification

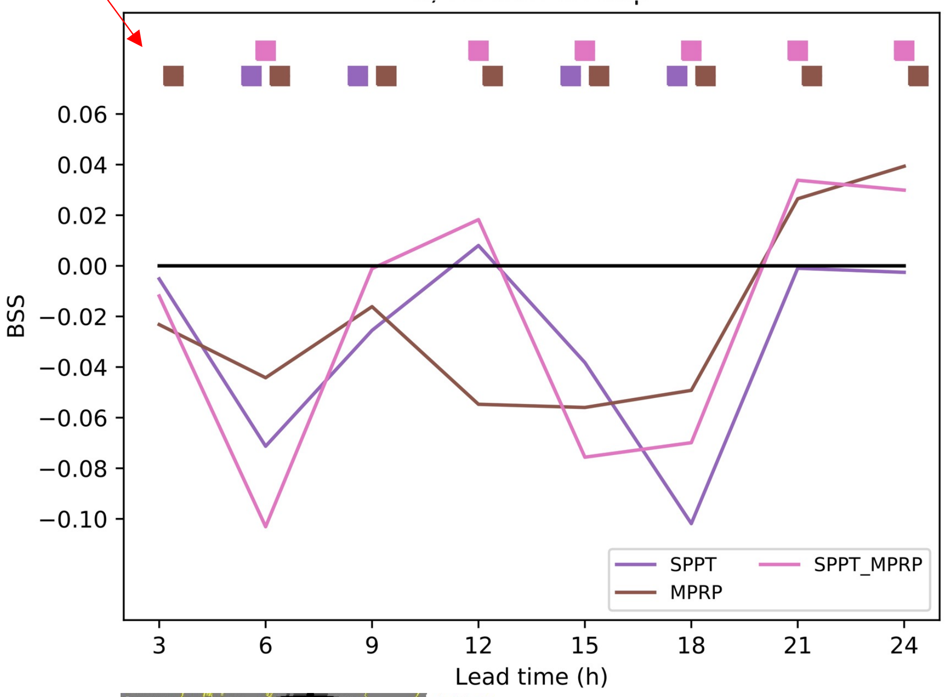
- 3-h accumulated precipitation
- Radar reflectivity data from València, Murcia and Almería radars
- Data coming from 10-min reflectivity volume scans at 1 km resolution spanning and 12 elevations.
- Corrected radar errors: partial beam occlusion and signal attenuation
- Radar precipitation calibrated with rain-gauge data (369 automatic rain gauges)
- Brier skill score computed using MPS as reference

Brier skill score 12 September

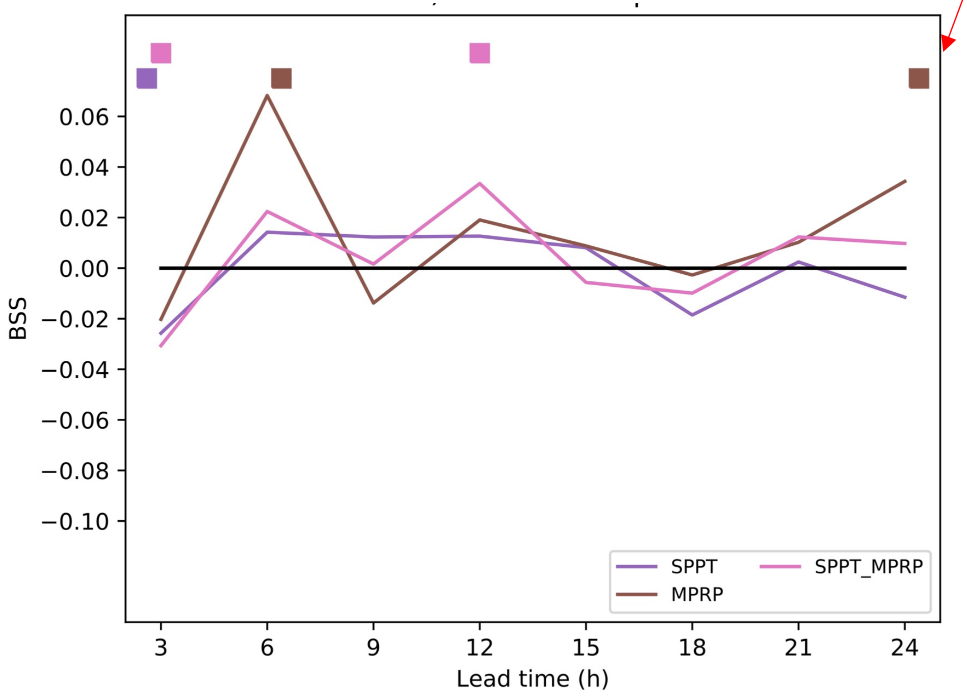
Significant differences
With respect to MPS

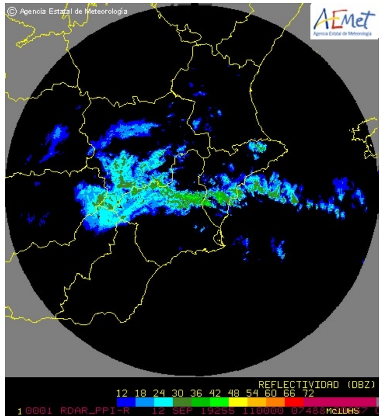
Significant differences between
stochastic experiments

20 mm 12 Sep



50 mm 12 Sep





Multiphysics outperforms stochastic schemes during phases 1 and 2 (0-18 h) for low thresholds

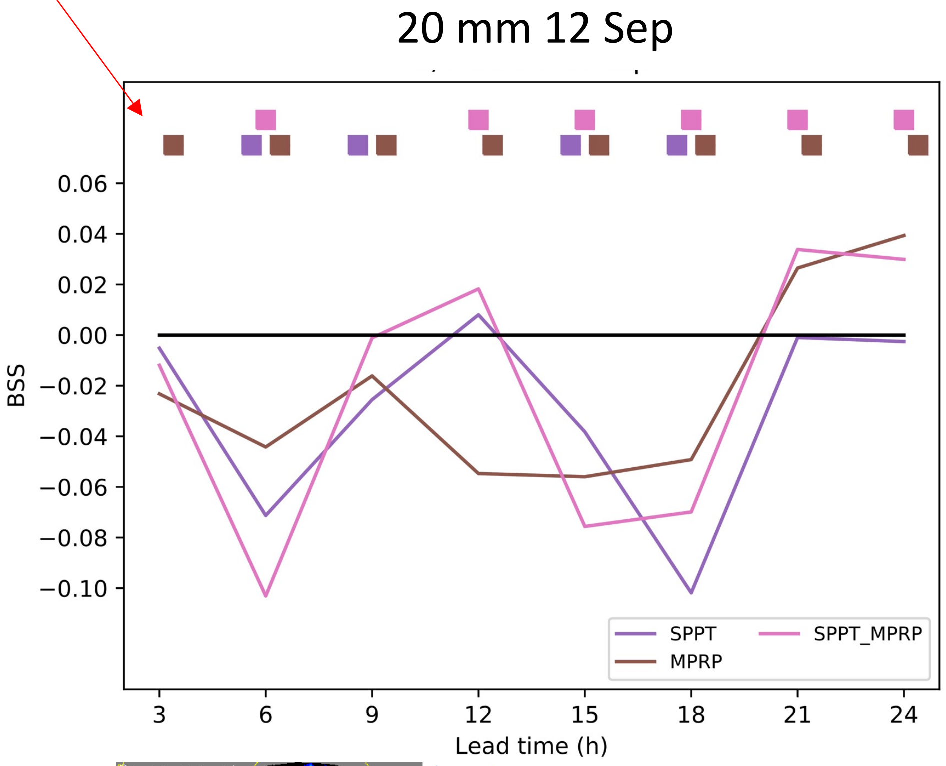
Improvement of stochastic techniques for higher thresholds (not significant)

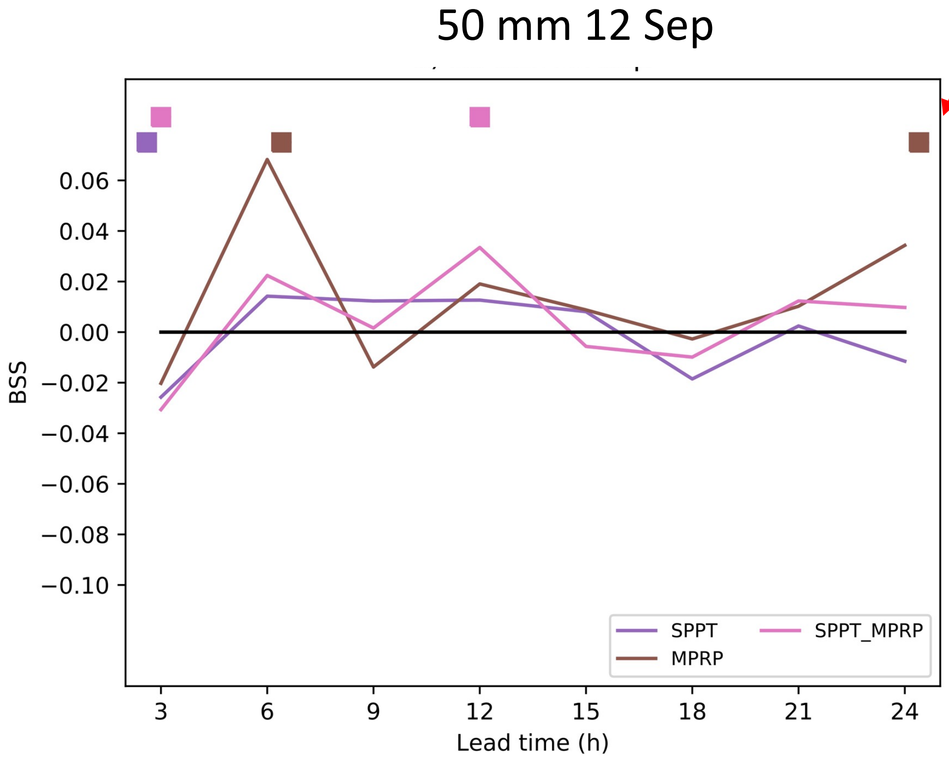
Significant differences between MPS and MPRP methods at the beginning of phase 3 (18-24 h)

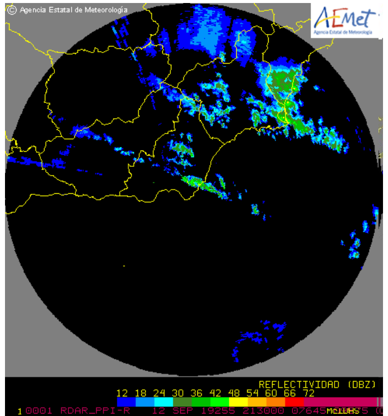
Brier skill score 12 September

Significant differences
With respect to MPS

Significant differences between
stochastic experiments







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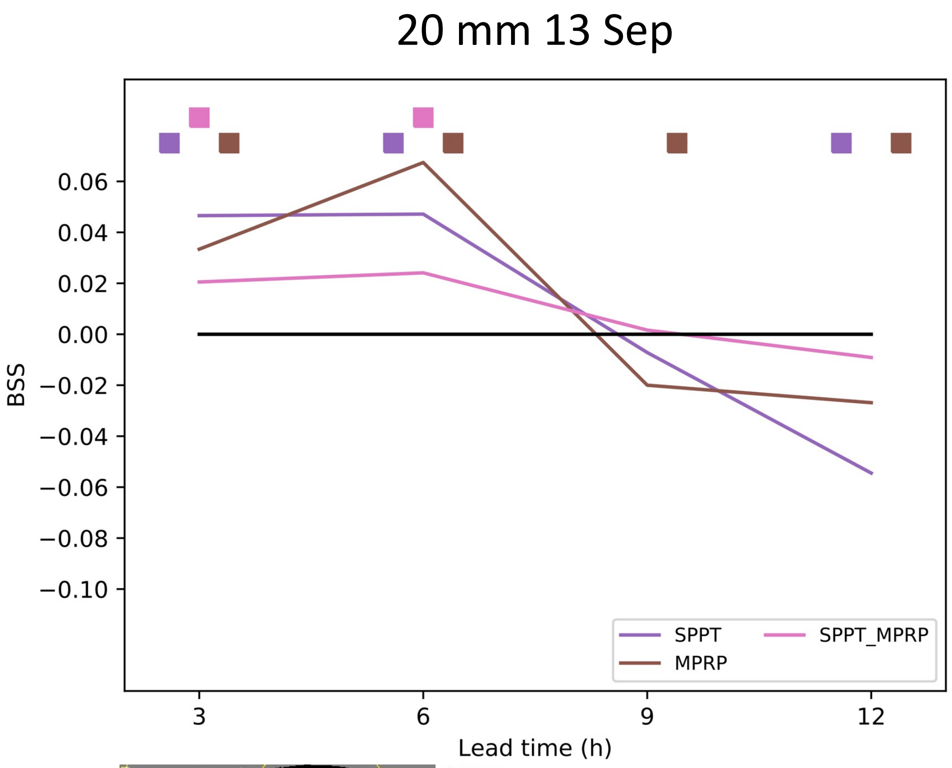
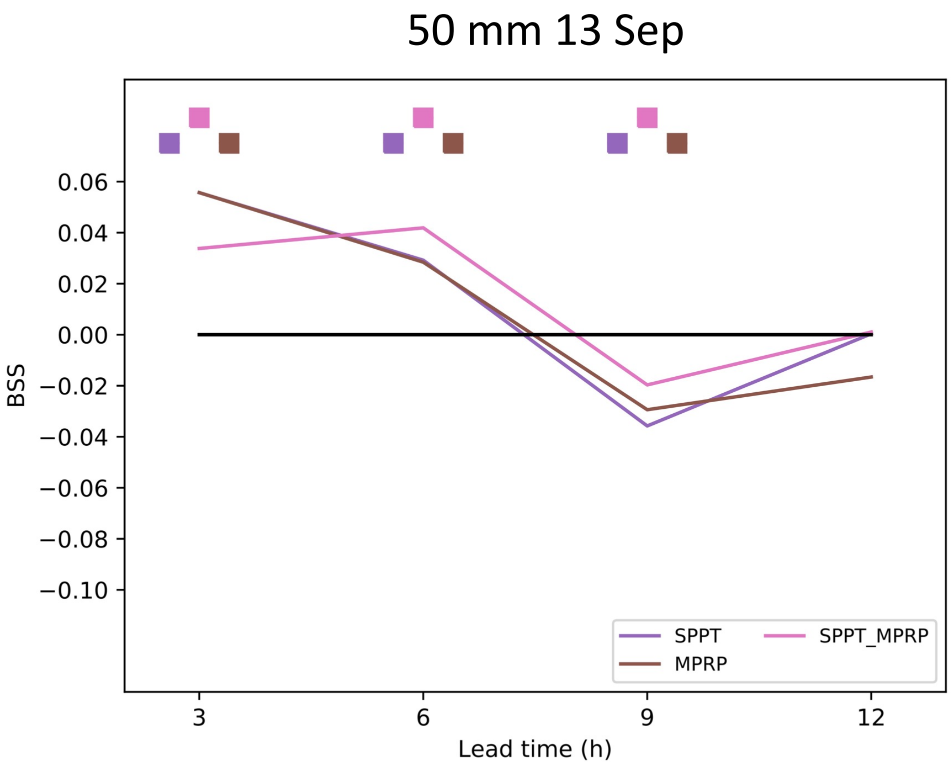
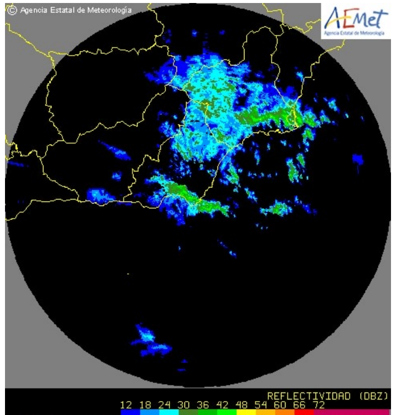


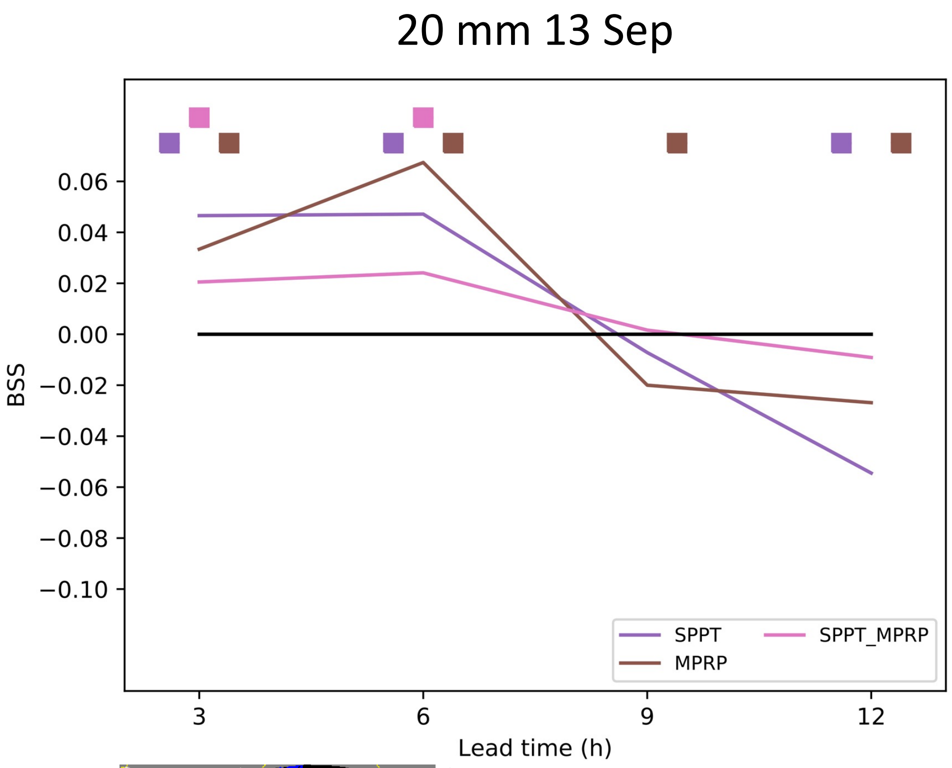


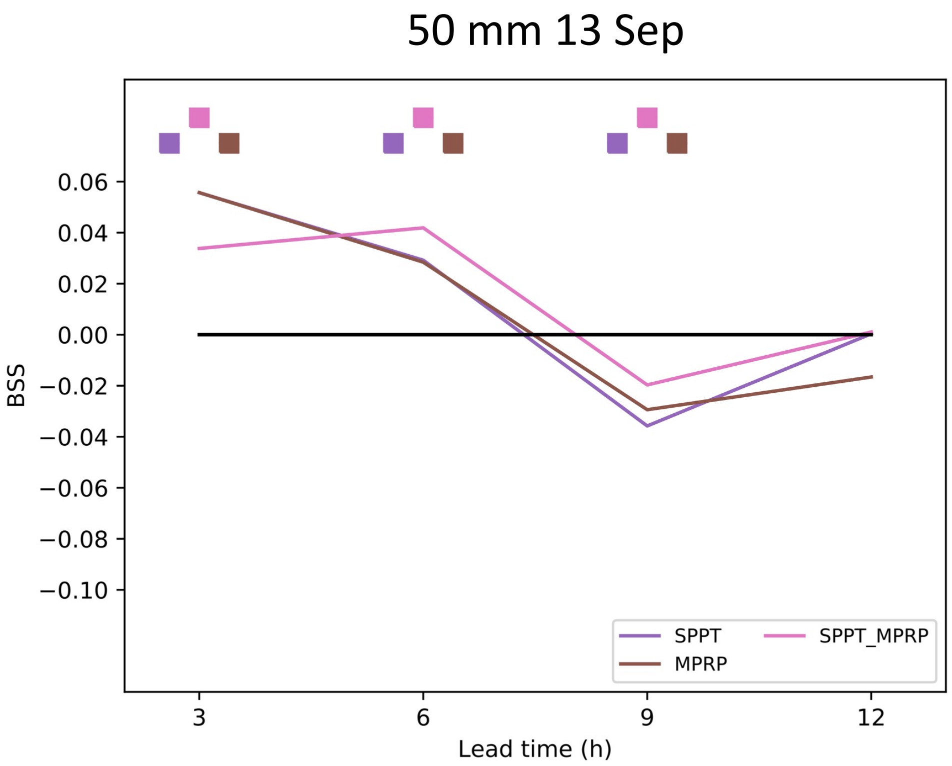


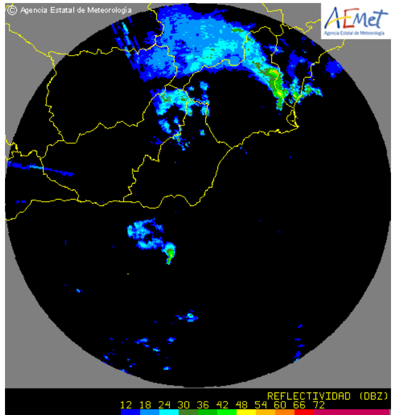
Significant better performance of stochastic during the first hours

Slight deterioration during the last part of the episode

Brier skill score 13 September







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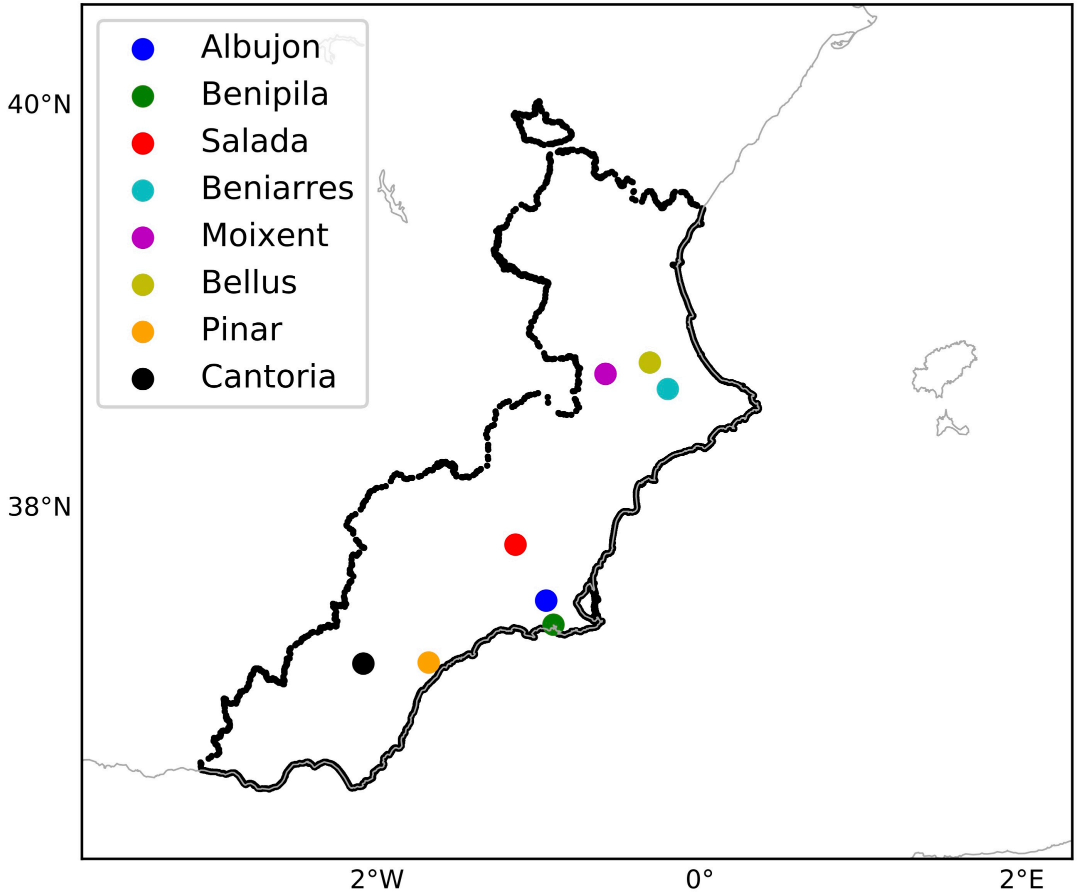
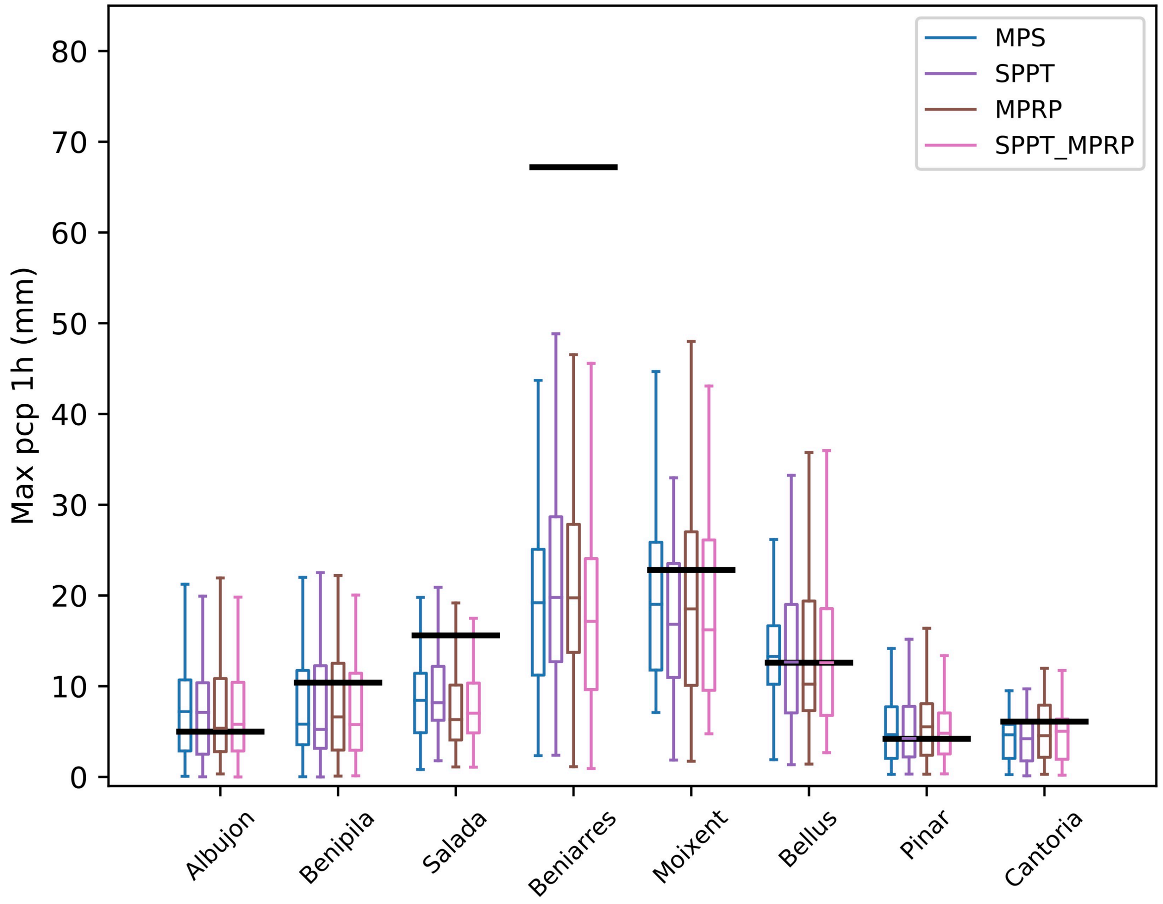
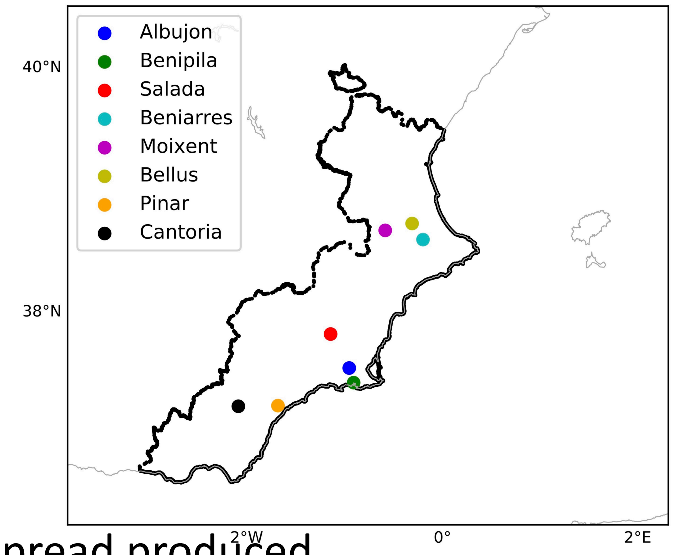
Ensemble features at catchment scale

- Analysis of maximum 1-h precipitation intensity in 6-h intervals over eight catchments compared against rain gauge values



Ensemble features at catchment scale (phase 1)

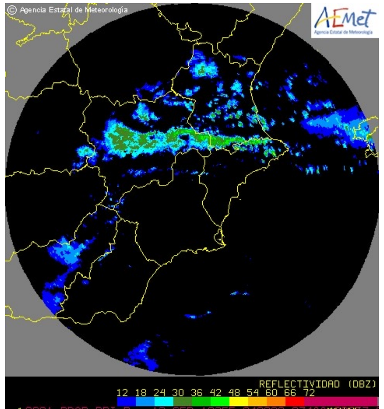




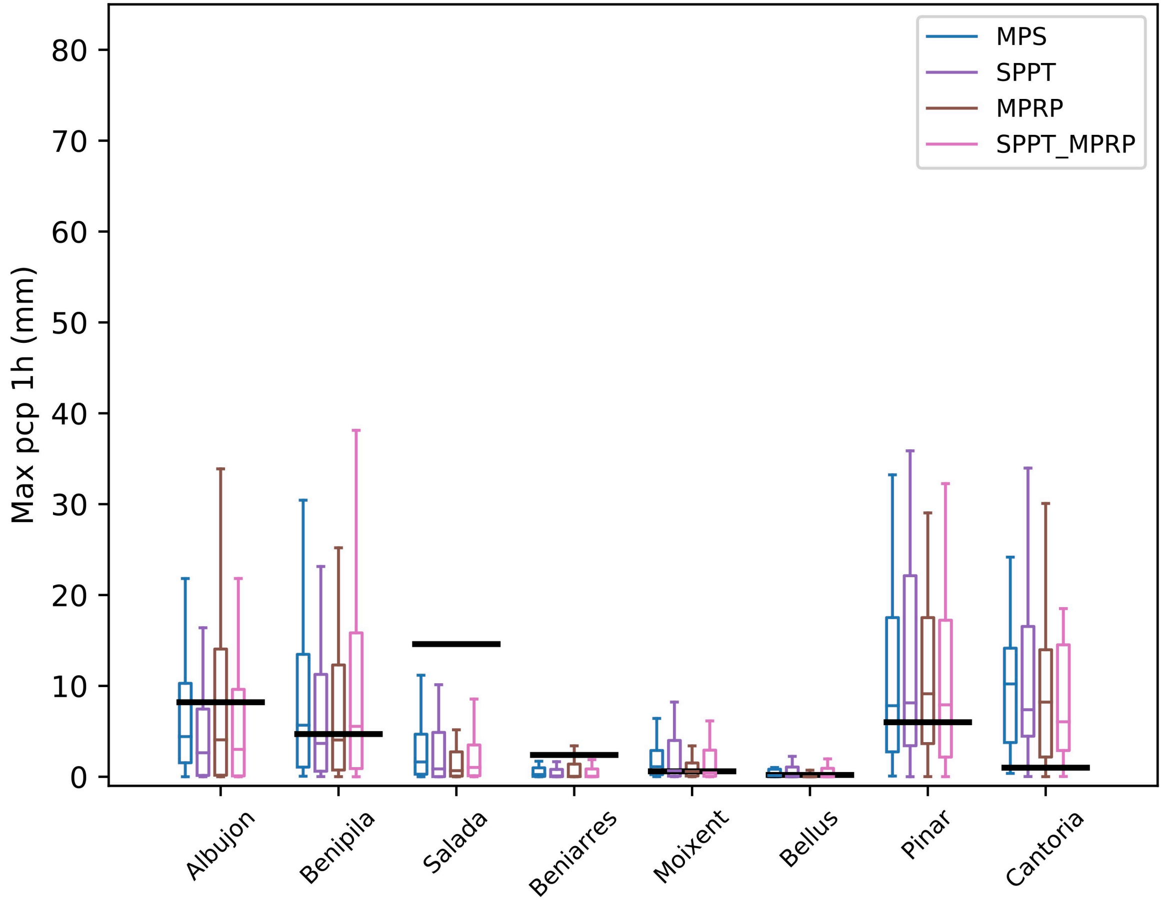
Observed maximum hourly intensities reproduced by all ensembles except Beniarrés

Increase of ensemble spread produced by microphysics perturbations in Moixent

Larger ensemble spread for stochastic experiments in Bellús

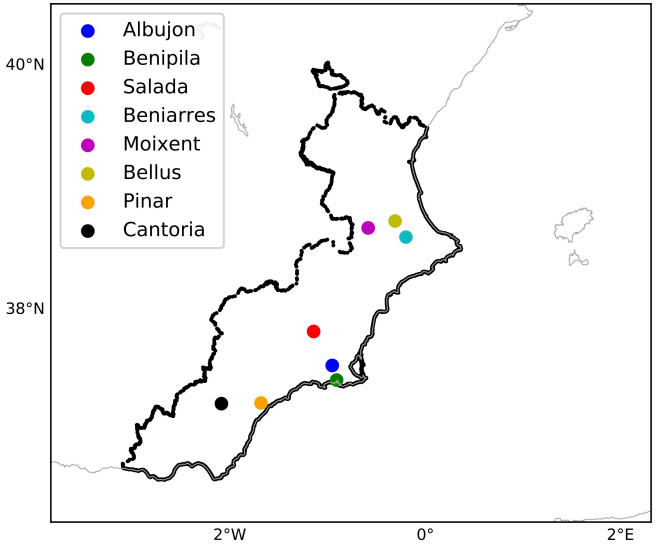


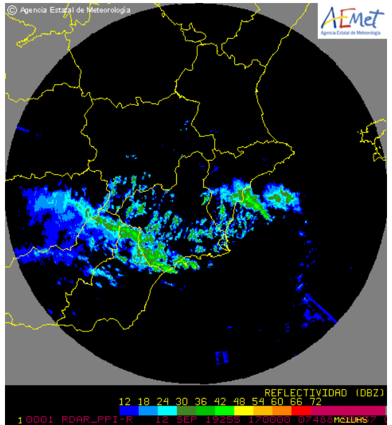
Ensemble features at catchment scale (phase 2)



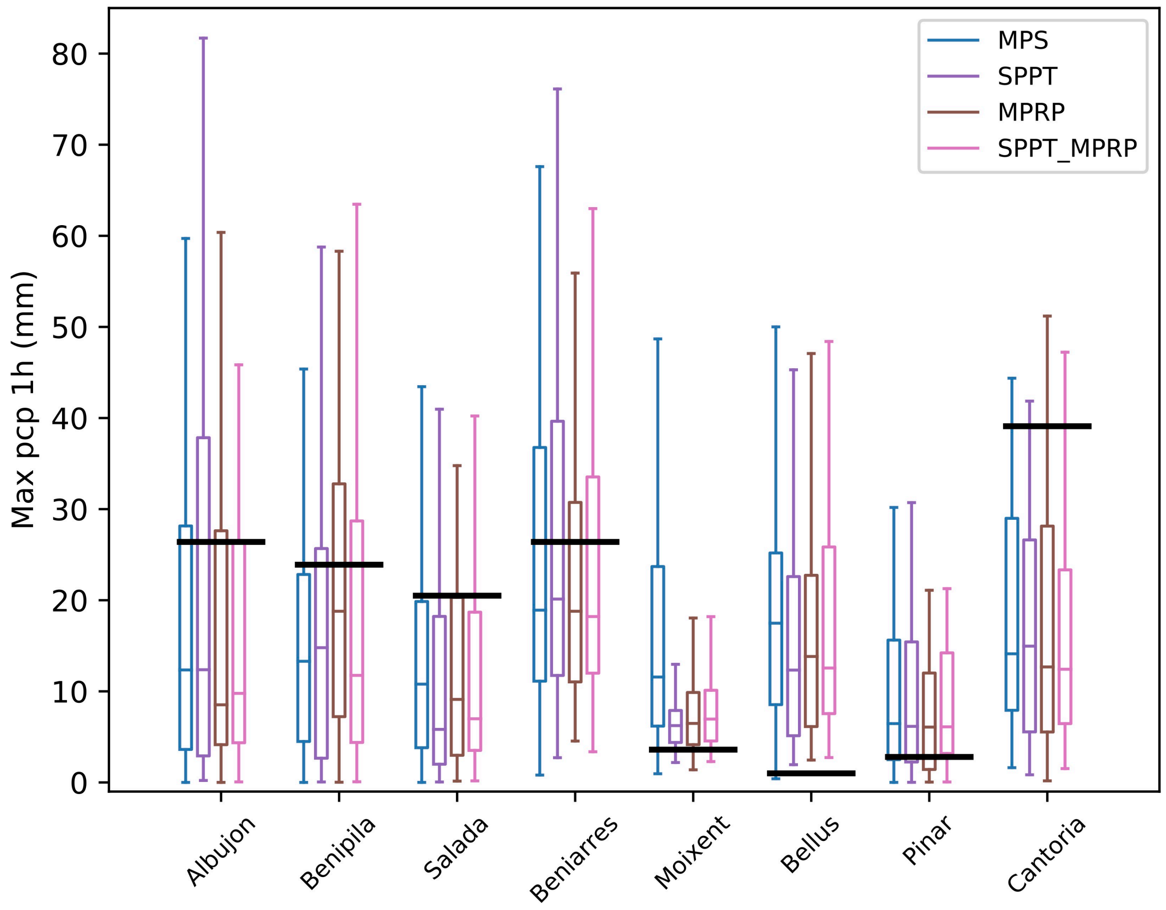
Higher spread over central and southern basins, where larger precipitation amounts were registered

All ensemble strategies fail at reproducing the observed precipitation intensity in Salada





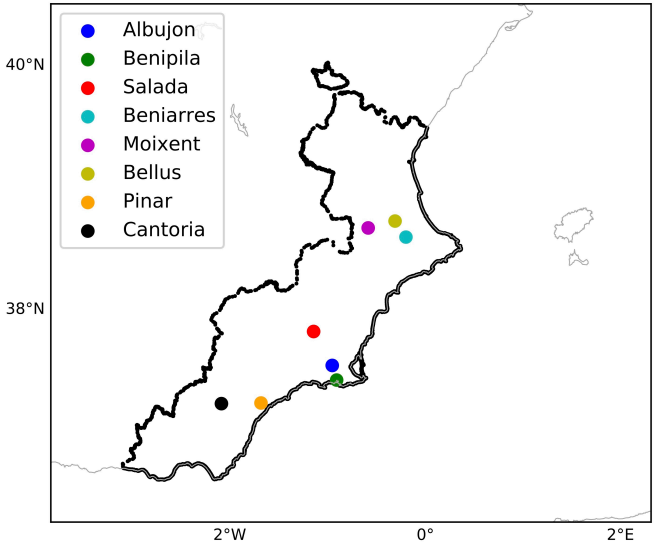
Ensemble features at catchment scale (phase 3)

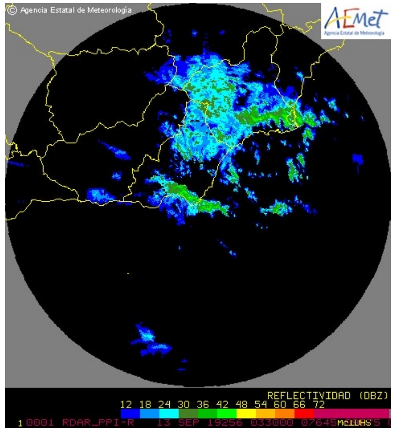


Extreme values produced by some SPPT members

Combination of multiple stochastic schemes (SPPT_MPRP) result in a reduction of these extremes

Some false alarms are produced over the northern catchments





Conclusions

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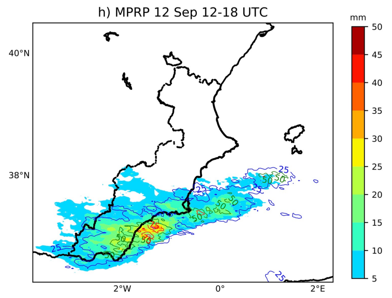

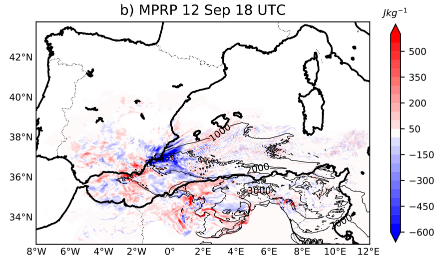

- An examination of multiple methods to account for model uncertainties in a heavy precipitation episode has been performed
- **Microphysics** perturbations:
    - **Substantial influence** on the development of the episode
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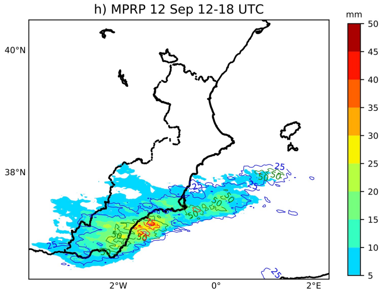

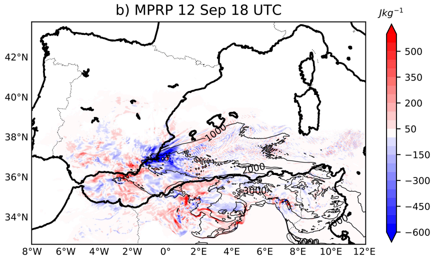

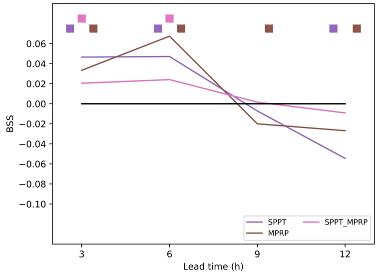

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  - **Lower initial** spatial **correlation**, but intensified in areas of high convective instability
- During the **last phase**, **stochastic** perturbations produce **more skilful** forecasts
- The **increase in ensemble spread** of stochastic techniques is also noted at **catchment scale**