A convection-permitting and limited-area model hindcast driven by ERA5 data

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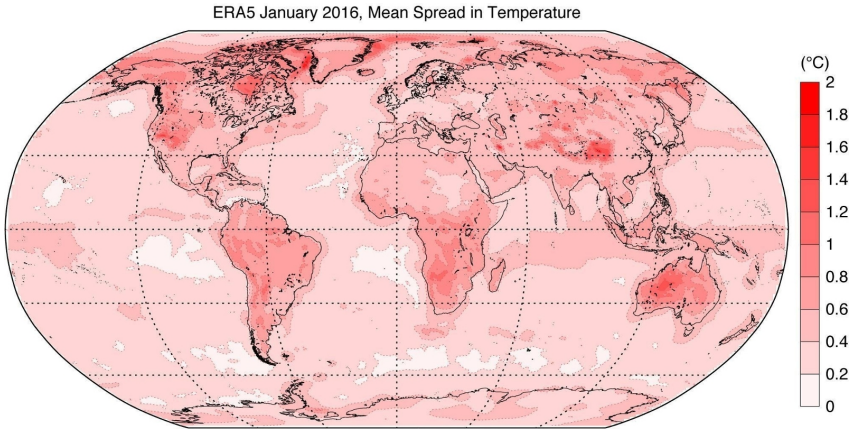
Background

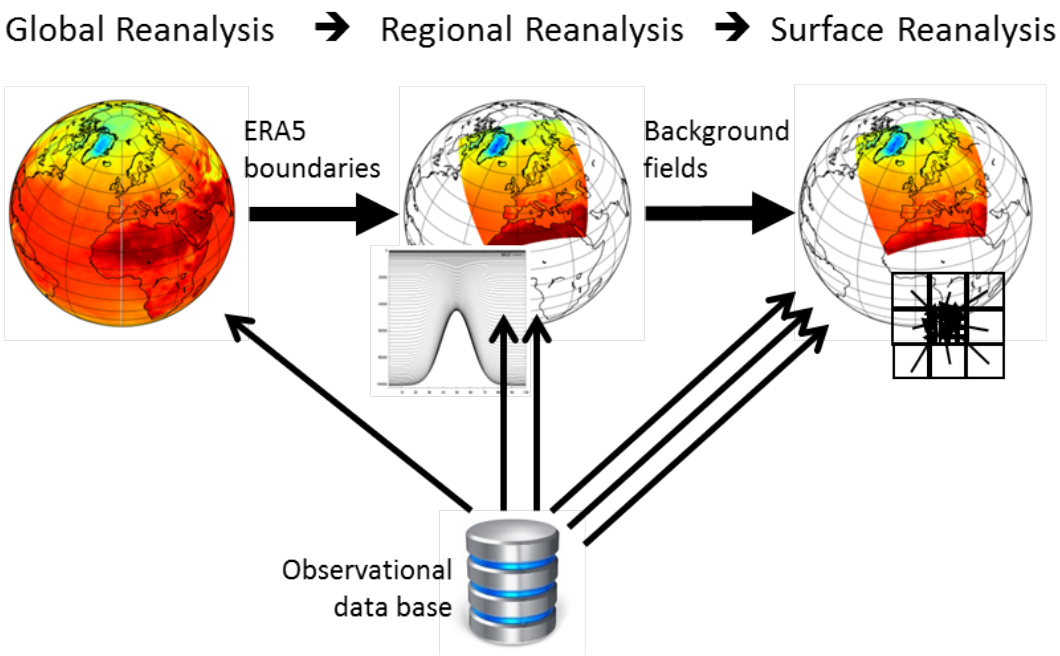
- **Nov 2017**, ERA5-International Conference on Reanalysis "*Advancing Global and Regional Reanalyses*" (Buizza et al, 2018, BAMS) ;
- **Jan 2018**, ECMWF-Special Project SPITBRAN 2018-2020 "*Evaluation of coastal climate trends [...] downscaling of ERA5 reanalysis*" ;
- **Sept 2018**, AISAM - 1° Conferenza Nazionale, *"Downscaling ERA5 for coastal applications [...]: SPITBRAN preliminary results"*



ERA5

- IFS model cycle CY41R2 (2016) | 12-hour 4DVAR |
- $\simeq$ 31 km res, 137 vertical levels (from the surface up to a height of 80km)
- hourly global estimates
- uncertainty by using 10 members (reduced resolution)
- dataset **1979-delayed real-time available**
- dataset 1950-1978 available as preliminary back extension
- Hersbach et al (2020) $\simeq$ 2300 citations (updated Jan 2022)

Regional Reanalyses — Past Projects (incomplete list)



Dataset	Domain	Period	Res (km)	Data Provider	Model
UERRA	CORDEX EUR-11	1961-2019	11 (atmo) 5.5 (surface)	Several Institutions	ALADIN (atmo) SURFEX (surface)
COSMO-REA6	CORDEX EUR-11	1995-2019	6	DWD	COSMO
HIRLAM **EURO4M**	Europe Polar regions North Africa	1979-2014	22 (atmo)	SMHI	HIRLAM (atmo) MESAN (surface)
COSMO-REA2	Central Europe	2007-2013	2	DWD	COSMO
MÉRA	Ireland and UK	1981-2015	2.5	Ireland MetSer	ALADIN HIRLAM
MERIDA	Italy	1990-2019 [1]	7	RSE	WRF
SPHERA	Italy	1995-2020	2.5	ARPAE	COSMO
VHR-REA_IT	Italy	1989-2020	2.2	CMCC	COSMO-CLM

Regional Reanalyses — Past Projects (incomplete list)

Dataset	Convection permitting	IC/BC	DA	Observations assimilated	Reference
UERRA	No	ERA-I	3DVar/Nudging	Conventional data	www.uerra.eu
COSMO-REA6	No	ERA-I	Nudging	radiosondes, aircraft and near-surface	Bollmeyer et al 2015
HIRLAM EURO4M	No	ERA-I	OI/3DVar	SYNOP measurements	Dahlgren et al 2016
COSMO-REA2	Yes	COSMO-REA6	Nudging	Conventional and radar data	Wahl et al 2017
MÉRA	Yes	ERA-I	OI/3DVar	SYNOP/BUOY/ TEMP/AMDAR/...	Whelan et al 2018
MERIDA	No	**ERA5**	OI	Surface data	Bonanno et al 2019
SPHERA	**Yes**	**ERA5**	Nudging	Surface and upper-air observations	Giordani et al 2021
VHR-REA_IT	**Yes**	**ERA5**	/	/	Raffa et al 2021

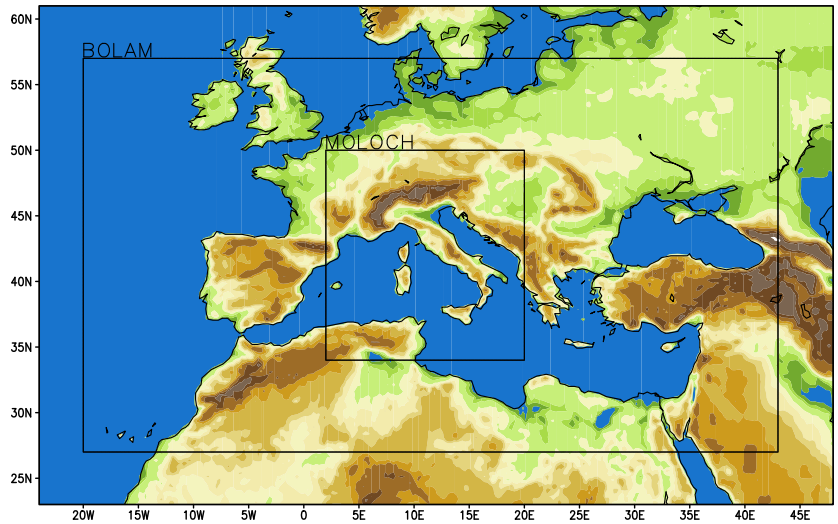
On-going project:

•**CERRA**–>European domain–>early '80s-realtime–>Res 5.5 km–>SMHI/MeteoFrance–>ERA5–>EDA to evaluate uncertainty–>Obs assimilated conventional and satellite data

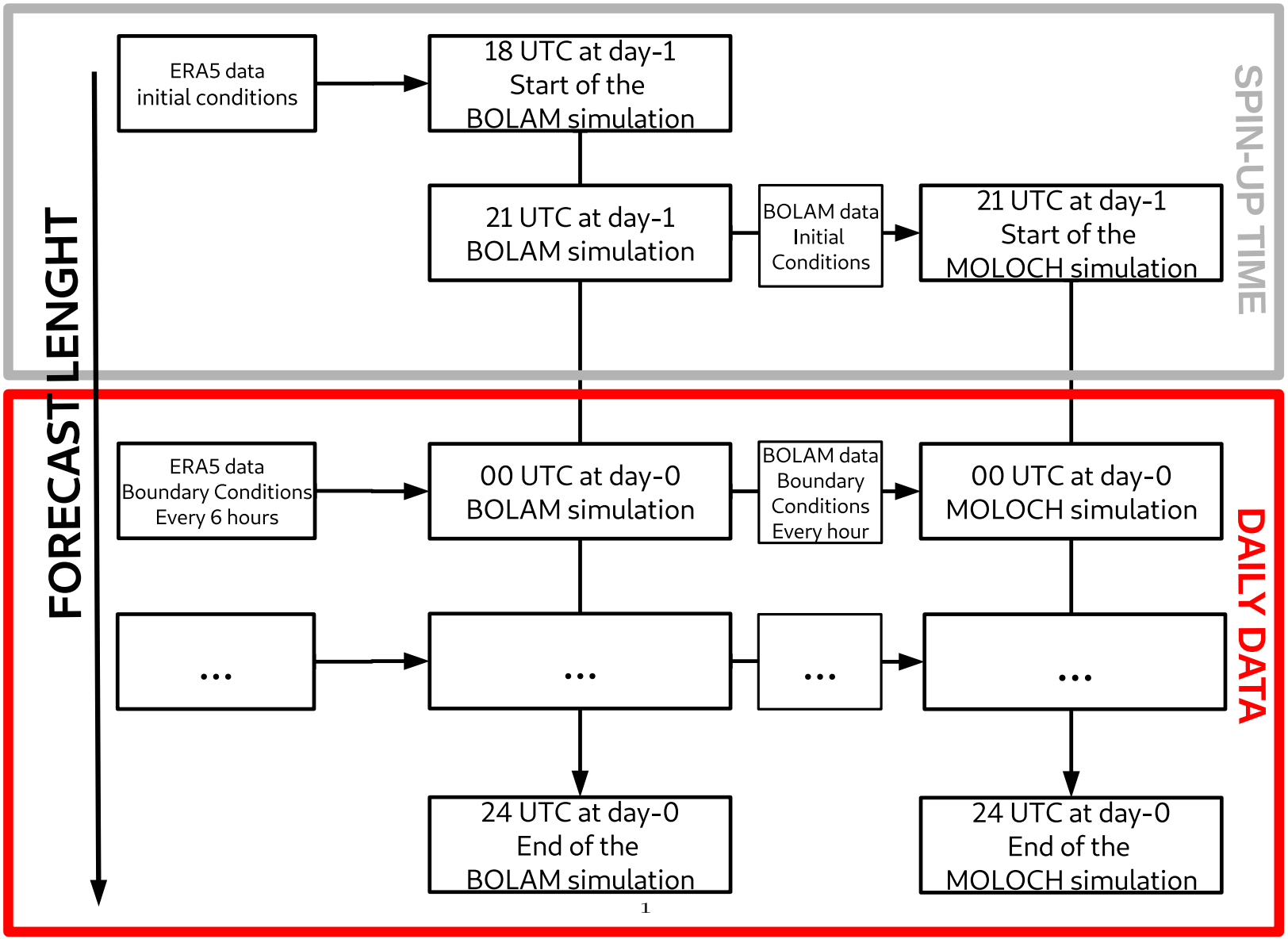
•**CONFESS**–>ISAC/ECMWF>Res 1.25 km>...

Outline

We describe a weather hindcast obtained by **dynamically downscaling** the **ERA5** data. The models used to perform the hindcast are **BOLAM** (with a grid spacing of 7 km over the Mediterranean domain) and **MOLOCH** (with a grid spacing of **2.5 km over Italy**). BOLAM is used to provide initial and boundary conditions to the inner grid of the MOLOCH model, which is set in a **convection-permitting** configuration.
The period covered is **1979-2020**.



Model setup


SPIN-UP TIME
DAILY DATA
FORECAST LENGHT
ERA5 data
initial conditions
18 UTC at day-1
Start of the
BOLAM simulation
21 UTC at day-1
BOLAM simulation
BOLAM data
Initial
Conditions
21 UTC at day-1
Start of the
MOLOCH simulation
ERA5 data
Boundary Conditions
Every 6 hours
00 UTC at day-0
BOLAM simulation
BOLAM data
Boundary
Conditions
Every hour
00 UTC at day-0
MOLOCH simulation
...
...
...
...
24 UTC at day-0
End of the
BOLAM simulation
24 UTC at day-0
End of the
MOLOCH simulation

Model setup

	BOLAM	**MOLOCH**
Grid spacing (km)	7	2.5
Number of rows and columns	482 and 890	626 and 506
Number of vertical levels	50	50
Number of soil levels	7	7
Grid points	$\simeq$21.5 million	$\simeq$15.8 million
Time step (s)	45	30
Boundary layer scheme	1.5-order E-l closure (Zampieri et al 2005)	
Radiation scheme	Ritter and Geleyn (1992) and ECMWF radiation scheme	
Microphysics scheme	Drofa and Malguzzi (2004)	
Turbulence scheme	1.5-order E-l closure (Trini Castelli et al 2020)	
Convection parameterisation	Kain (2004)	none

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Model verification

Precipitation

•Observations:**E-OBS**, 1979-2019, res $0.1° \times 0.1°$, yearly accumulated rainfall
•Method: RMSE; ME; bias; *r* Pearson correlation coefficient; Taylor diagram; performance diagram

2-m Temperature

Observations:**E-OBS**, 1979-2019, res $0.1° \times 0.1°$, min/max daily temperature
•Method: RMSE; ME; bias; *r* Pearson correlation coefficient; Taylor diagram; performance diagram

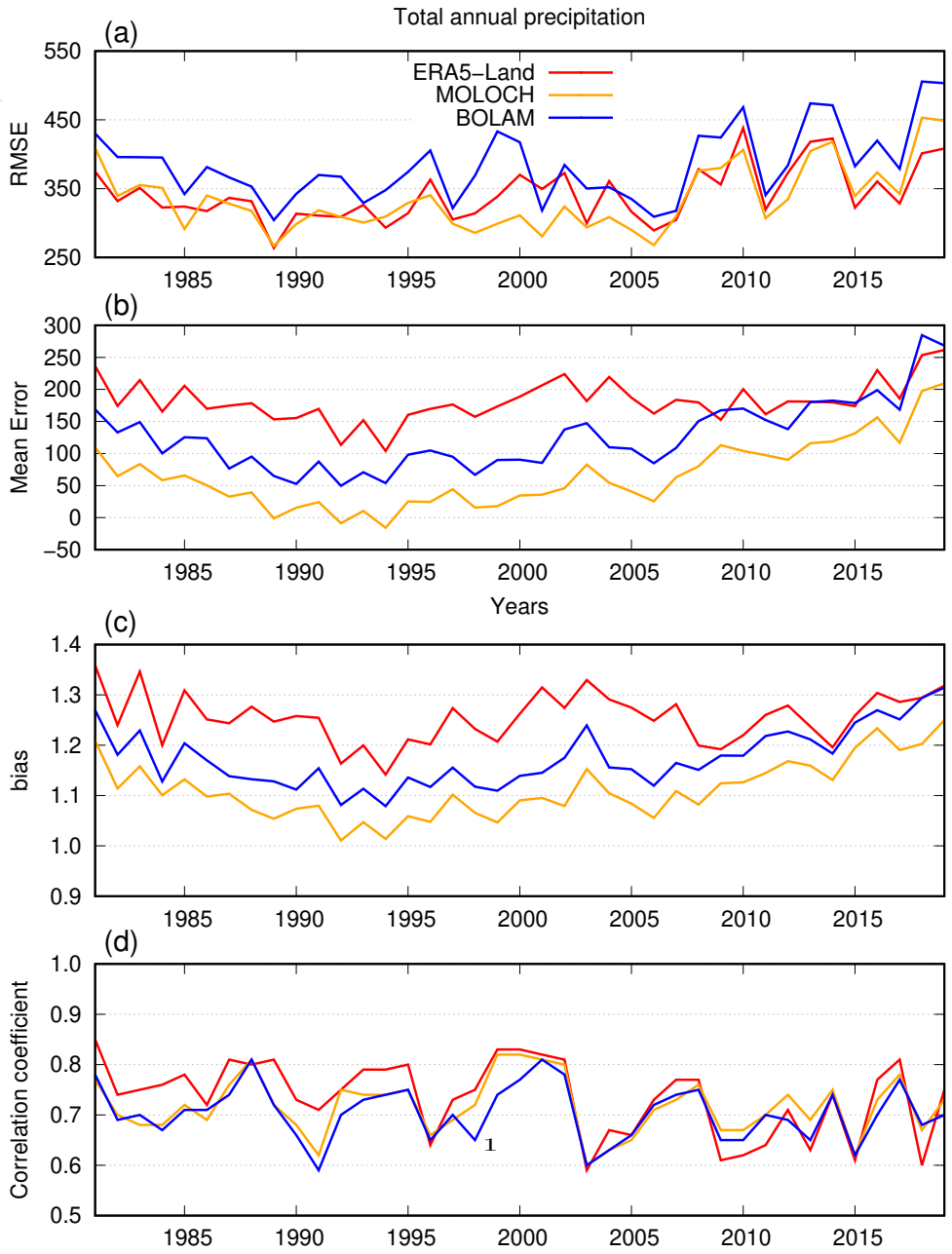
10-m Wind

Observations:**Integrated Surface Database** (ISD/NOAA), surface observations
•Method: RMSE; ME; bias; *r* Pearson correlation coefficient; Taylor diagram; performance diagram

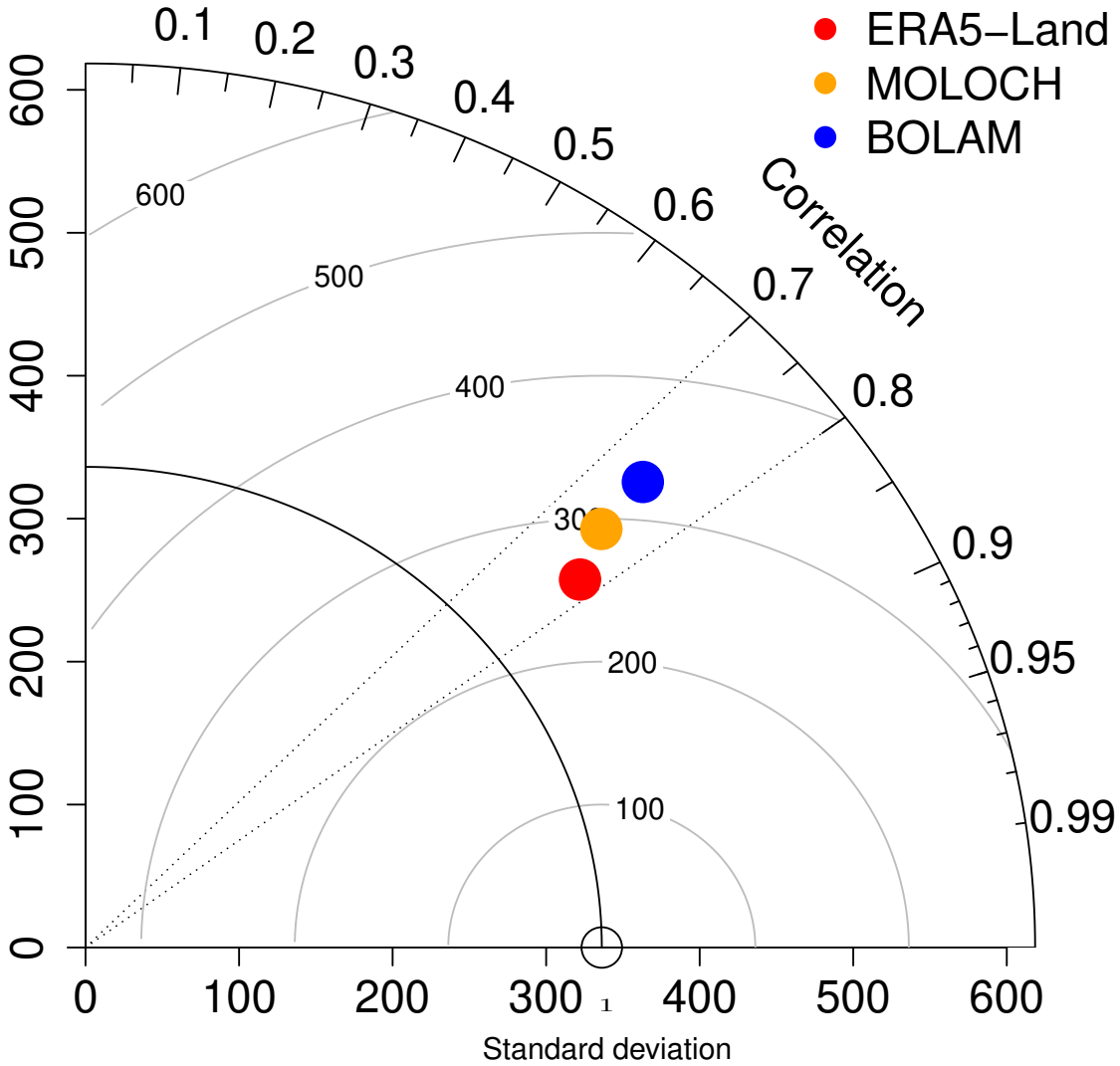
Benchmark dataset

ERA5-Land dataset, 1981-2019, res 9 km (Munoz Sabater et al., 2021)

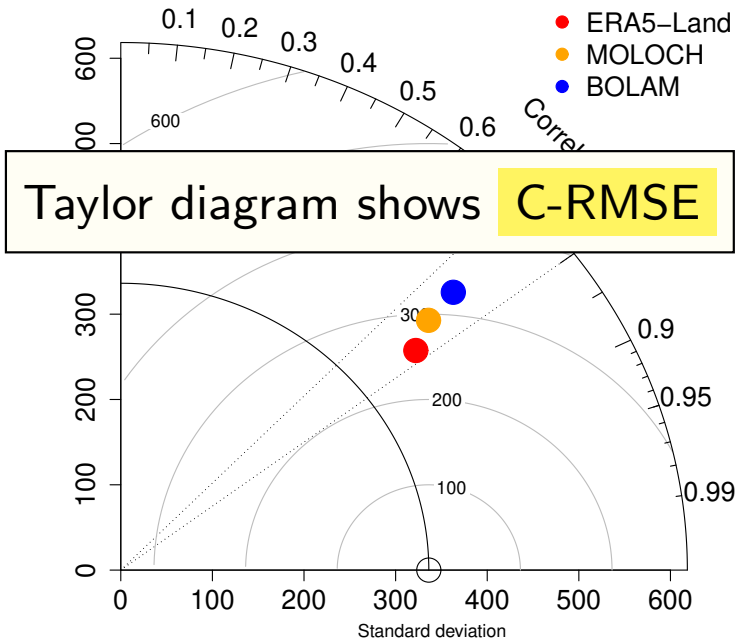
Results: Total annual preciptiation



Results: Total annual preciptiation



Results: Total annual preciptiation



$$\text{C-RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[(F_i - \overline{F}) - (O_i - \overline{O})\right]^2}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(F_i - O_i)^2}$$

$$RMSE^2 = \text{C-}RMSE^2 + \text{o-}bias^2$$

$$\text{o-}bias = \overline{F} - \overline{O}$$

Dataset	Std.dev	Corr	C-RMSE	RMSE	o-bias	m-bias
E-OBS	336	-	-	-	-	-
ERA5-Land	**413**	**0.78**	**262**	313	171	1.19
MOLOCH	447	0.75	295	**301**	**62**	**1.07**
BOLAM	489	0.74	329	351	122	1.14

Results: Total annual preciptiation

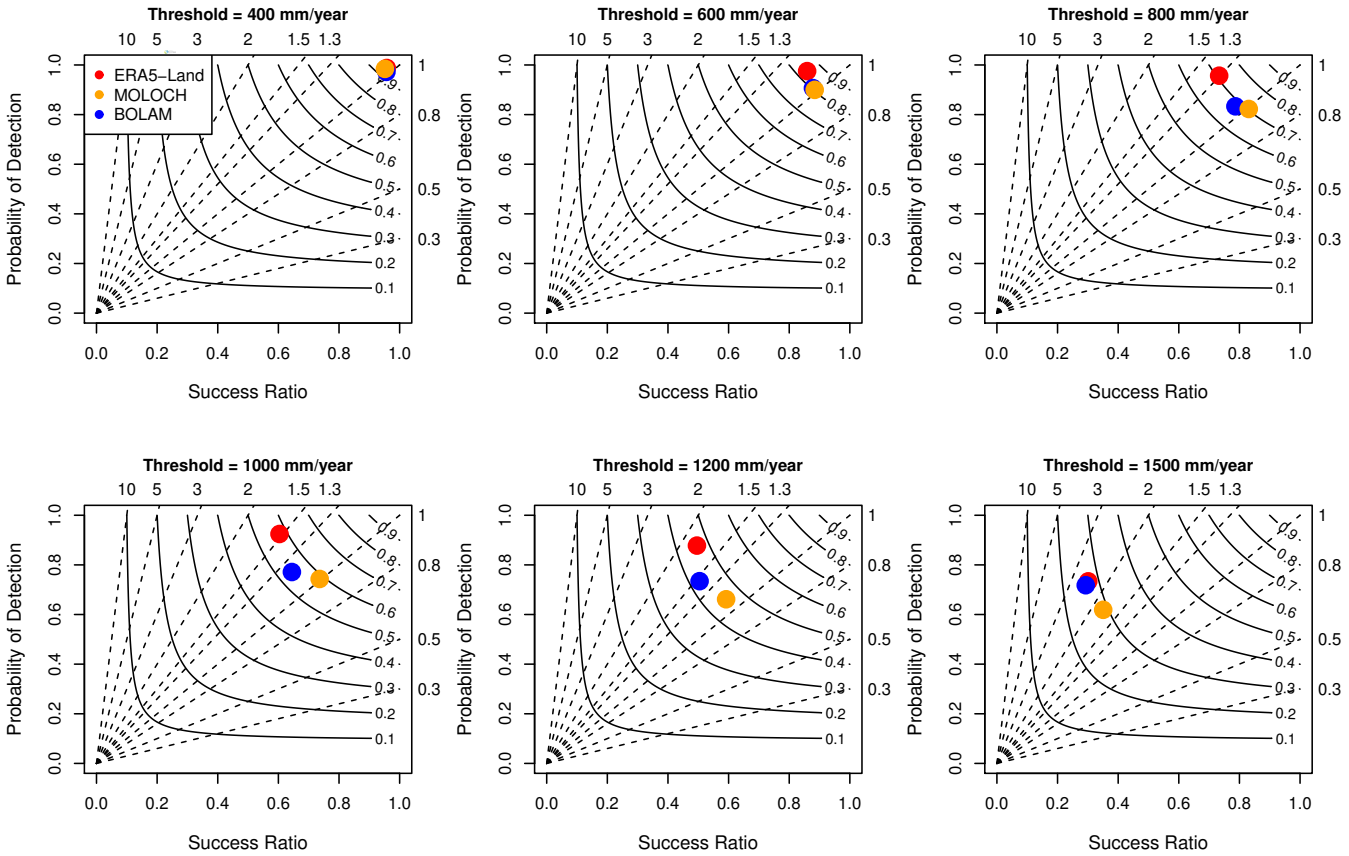
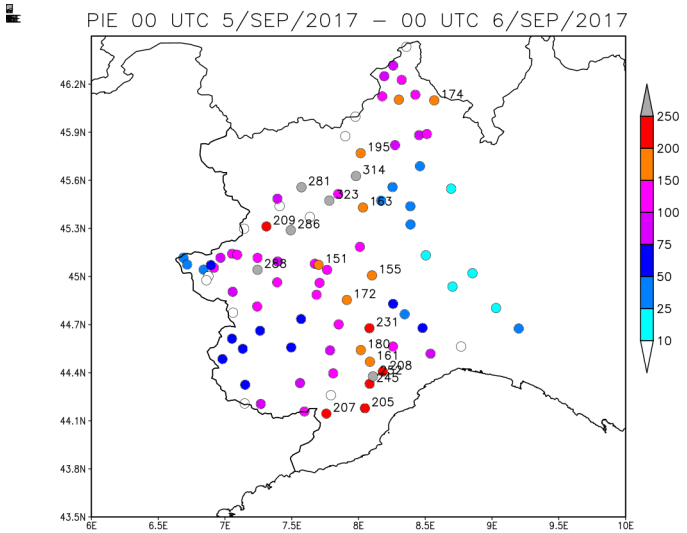


Figure: Performance diagram of the average annual precipitation of ERA5-Land (red), MOLOCH (orange), and BOLAM (blue). Skill scores are averaged over the period 1981-2019.

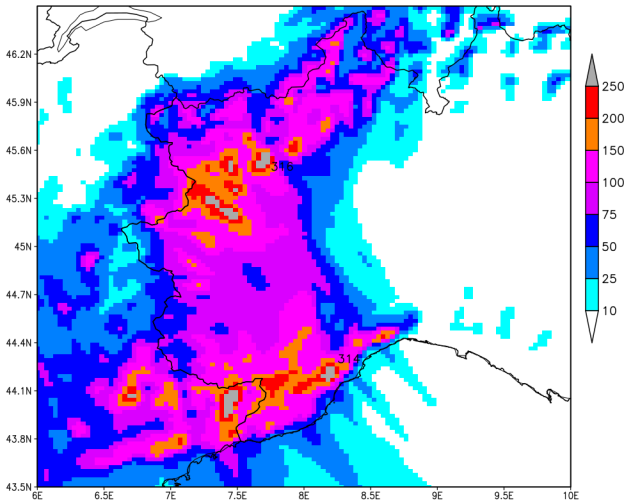
Overestimation of ERA5: Silvestri et al[1](2022) *Links between precipitation, circulation weather types and orography in central Italy*, preprint IJC.

Results: Extreme events - Tanaro 4/Nov/1994

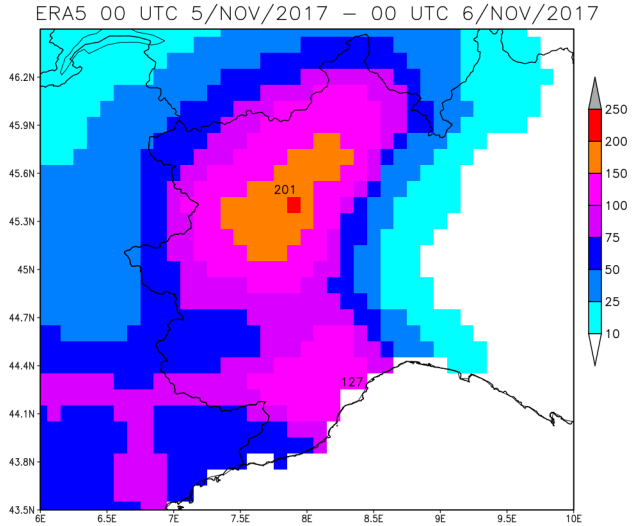
Observations



MOLOCH

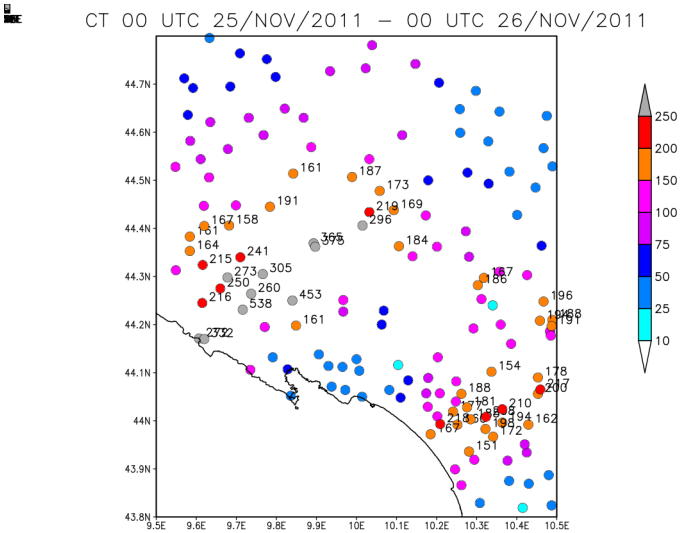


ERA5-Land

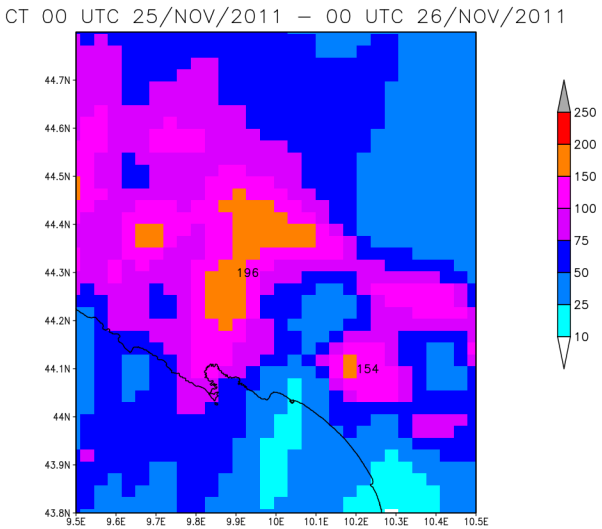


Results: Extreme events - Cinque Terre 25/Oct/2011

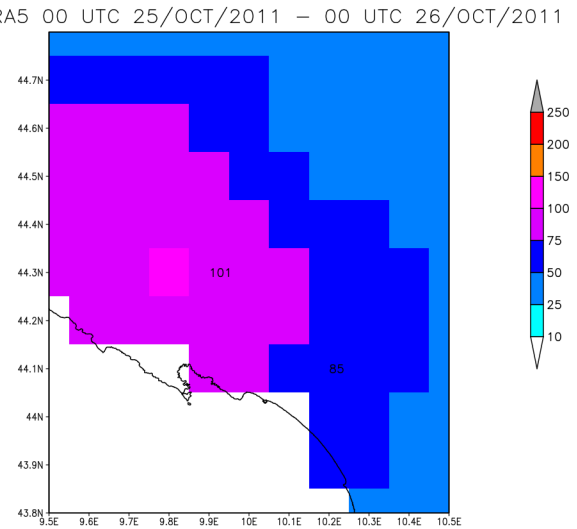
Observations



MOLOCH

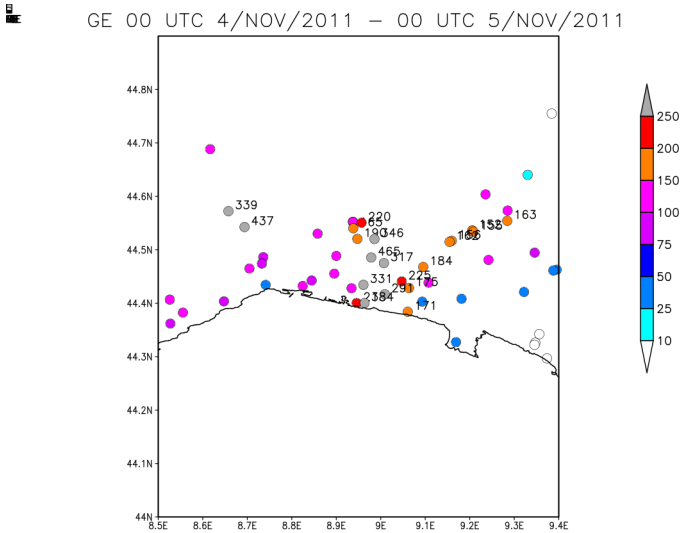


ERA5-Land

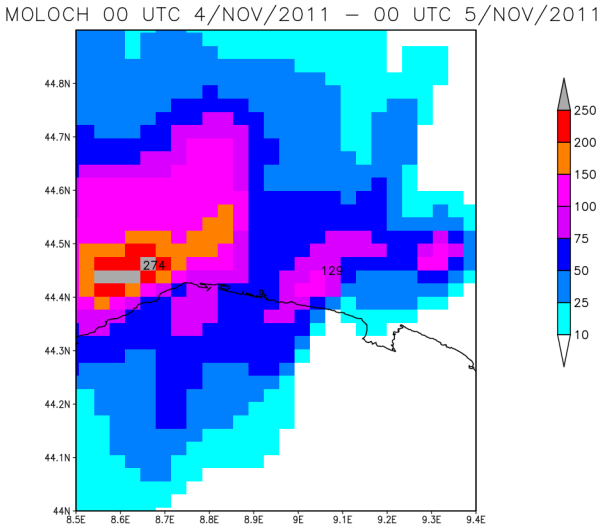


Results: Extreme events - Genova 4/Nov/2011

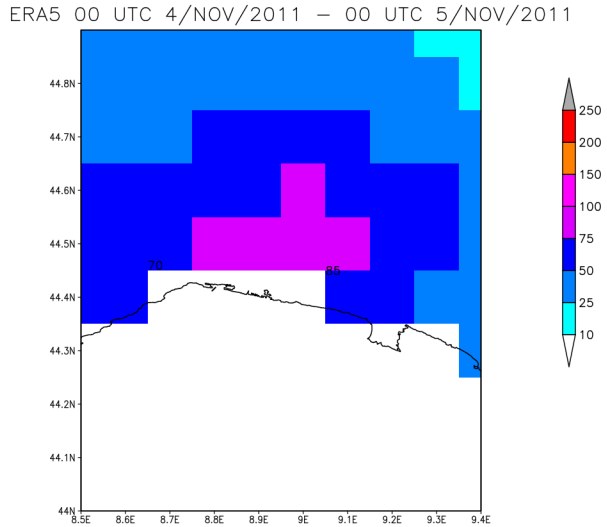
Observations



MOLOCH



ERA5-Land



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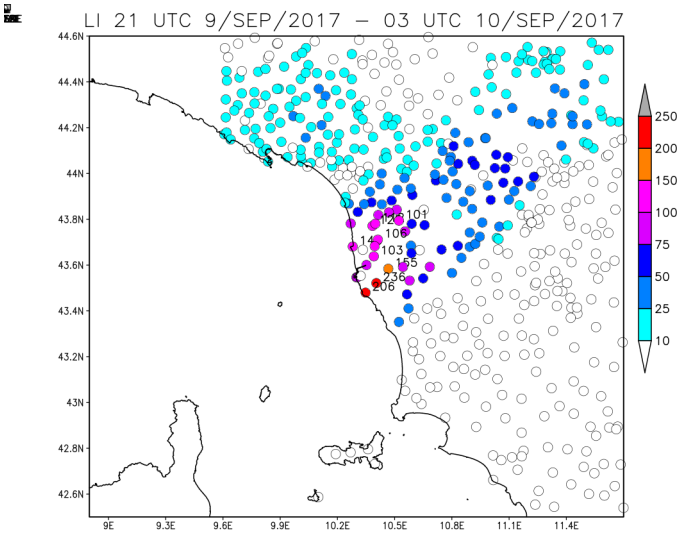
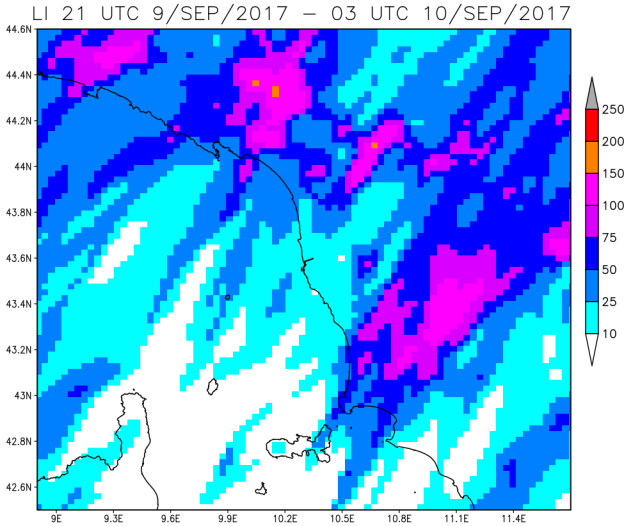
Results: Extreme events - Livorno 9-10/Sep/2017

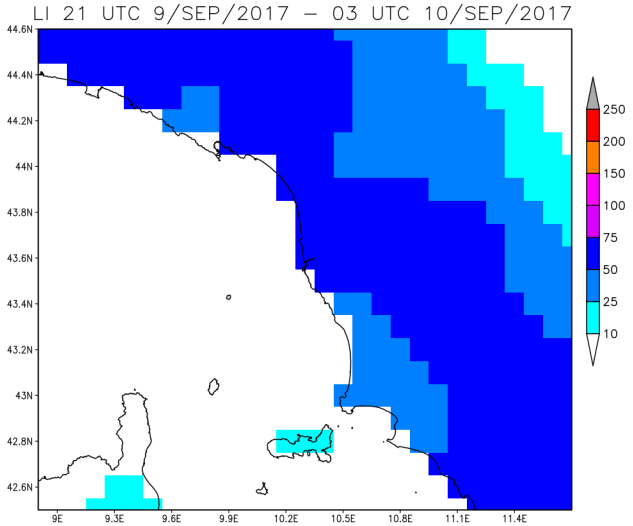
Observations



MOLOCH

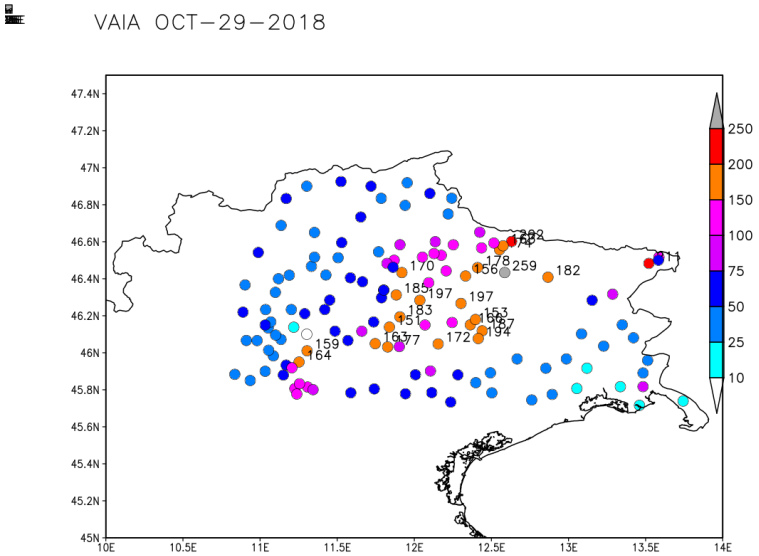


ERA5-Land

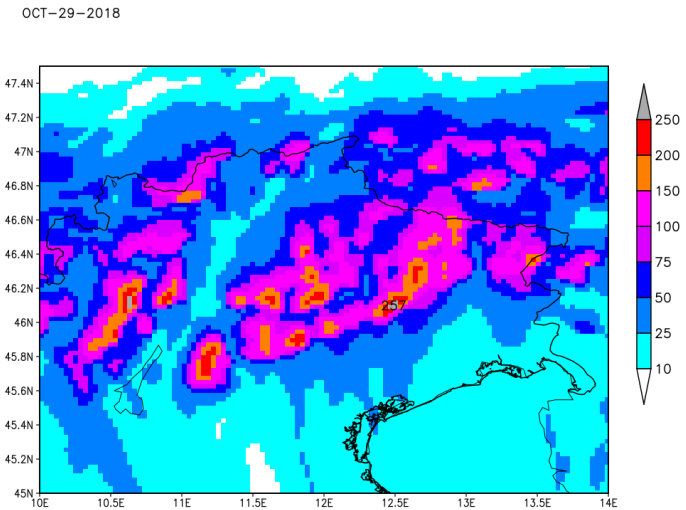


Results: Extreme events - Vaia 29/Oct/2018

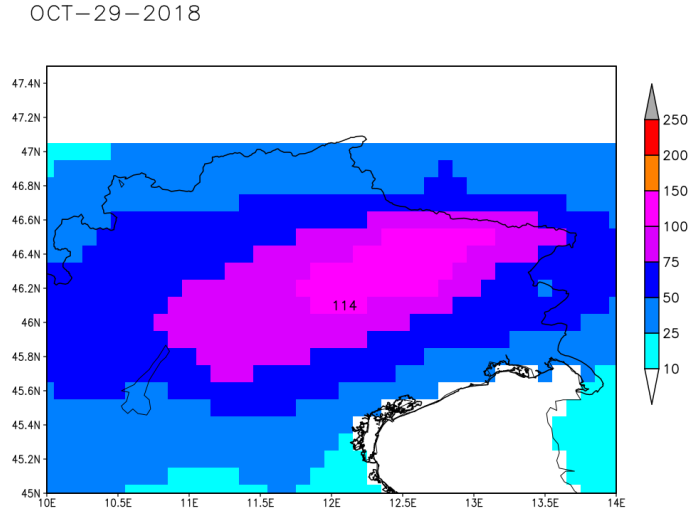
Observations



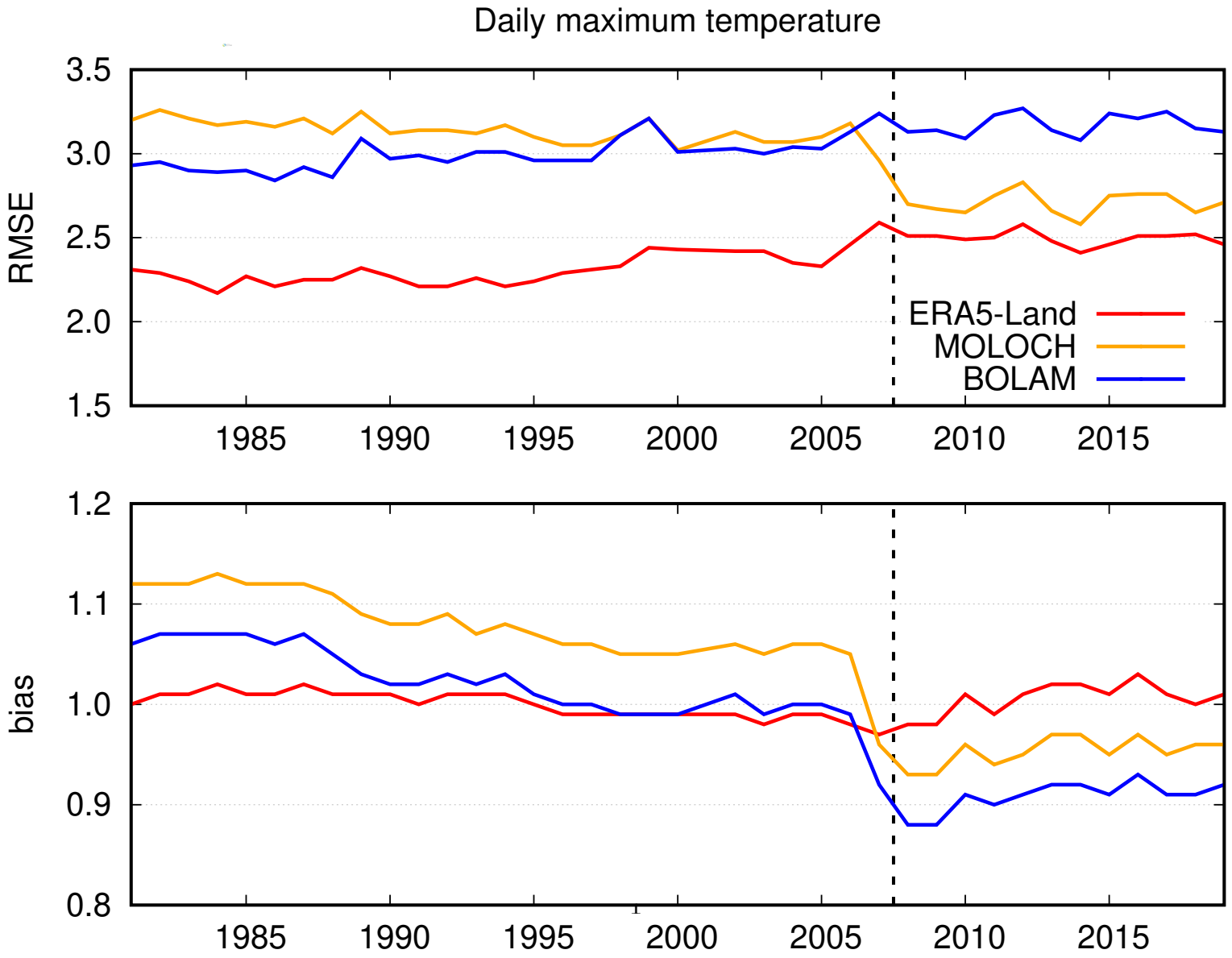
MOLOCH



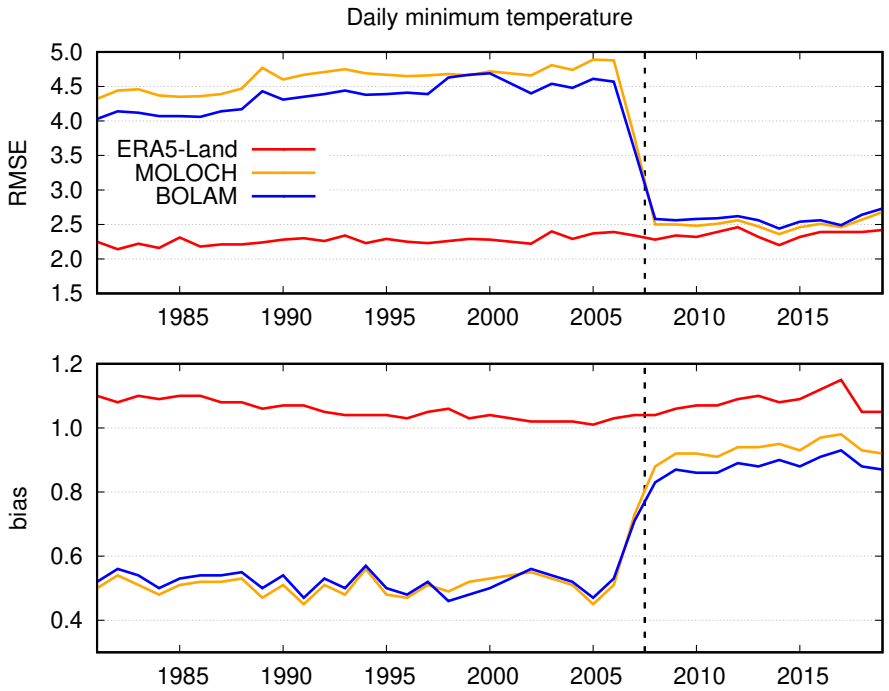
ERA5-Land



Results: 2-m temperature (daily max)



Results: 2-m temperature (daily min)



Bug nel codice di pre-processing dei dati ERA5 (versioni BOLAM/MOLOCH Dic 2017, bug-fix versioni successive)

Si assume la presenza di un solo soil-type (invece che 7) per date antecedenti al 2007/06/06

$\longrightarrow$ errore nel contenuto idrico del suolo $\longrightarrow$ errore nella stima di 2-m temperature

Results: 10-m wind (preliminary results)

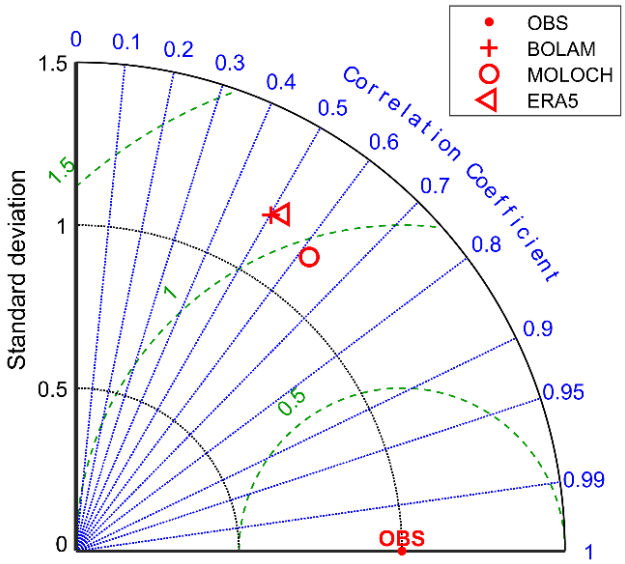


Figure: Capalbio

Vannucchi V, et al (2021) *"Dynamical Downscaling of ERA5 Data on the North-Western Mediterranean Sea: From Atmosphere to High-Resolution Coastal Wave Climate"*, Journal of Marine Science and Engineering

Results: 10-m wind (preliminary results)

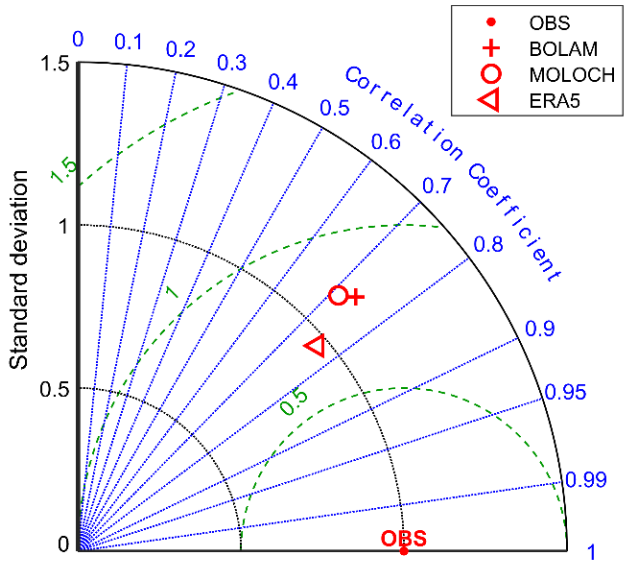
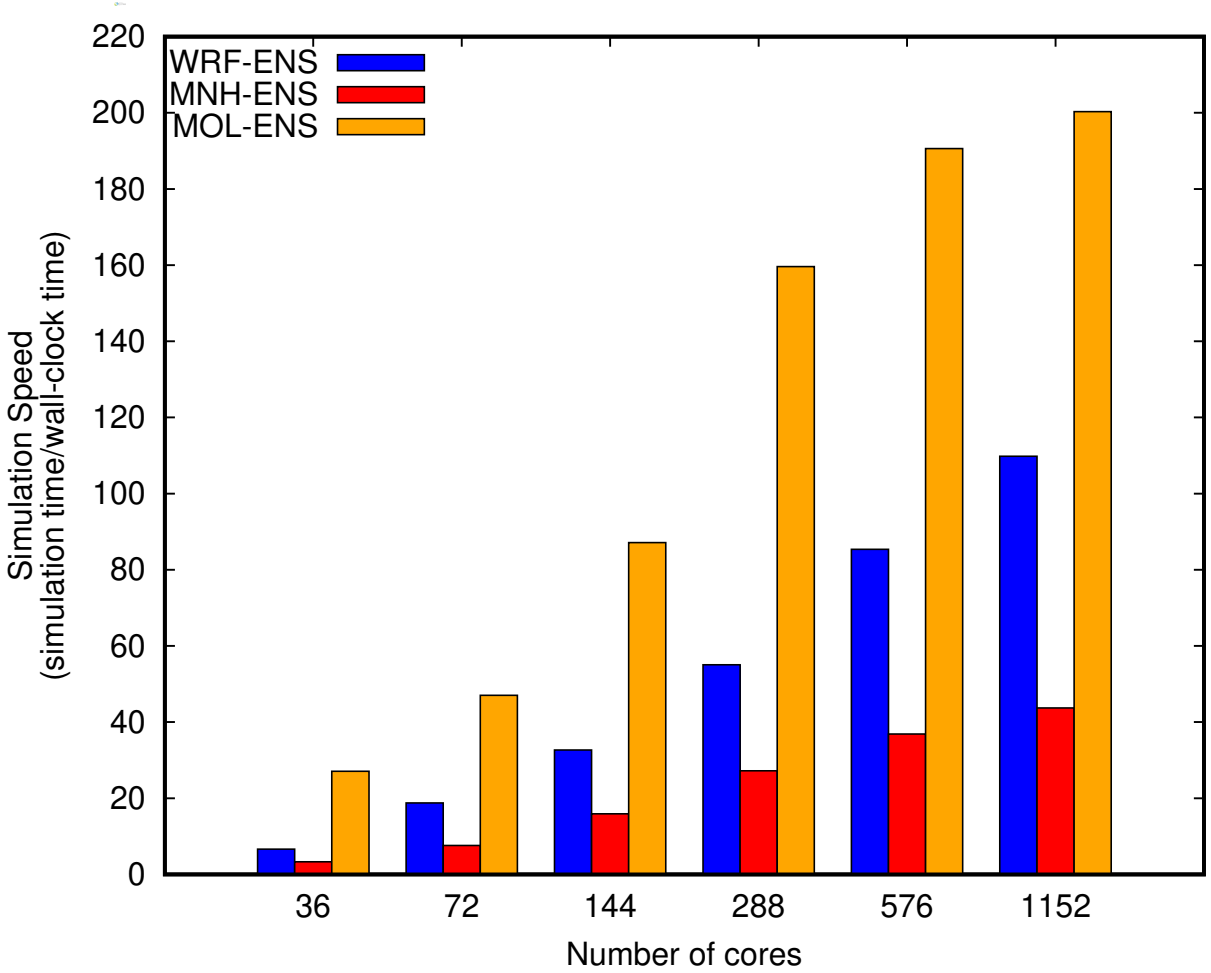


Figure: Livorno Offshore Terminal

Vannucchi V, et al (2021) *"Dynamical Downscaling of ERA5 Data on the North-Western Mediterranean Sea: From Atmosphere to High-Resolution Coastal Wave Climate"*, Journal of Marine Science and Engineering

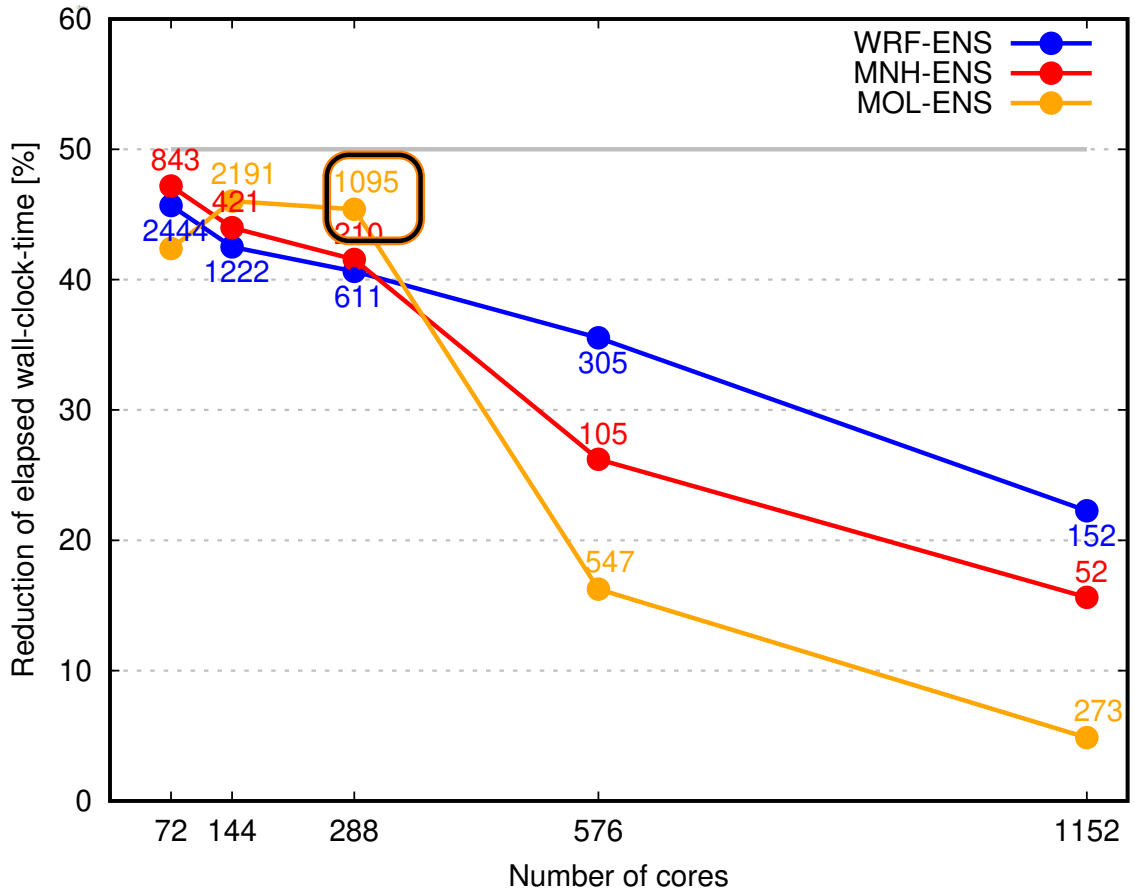
Computational cost - Simulation speed

Running a 24-hour simulation takes $\simeq$ 50 mins (144 cores Cray/ECMWF)



MOLOCH is $\begin{cases} \simeq 2.3 \text{ faster than WRF} \\ \simeq 5.1 \text{ faster than Meso-NH} \end{cases}$[1]

Computational cost - Scalability



MOLOCH is highly scalable up to $\simeq$ 1095 computing point/core[1]

[1] Capecchi, V (2021) *Reforecasting Two Heavy-Precipitation Events with Three Convection-Permitting Ensembles*, Weather and Forecasting, 36, 769-790

Conclusions

BOLAM/MOLOCH hindcast 1979-2020

- Precipitation: **improvements** *wrt* ERA5-Land for both average annual precipitation and extreme precipitations
- 2-m Temperature: **cold bias** 1979-2007 (bug fixed); ERA5-Land performs slightly better 2008-2020
- 10-m Wind: **good agreement** with observations in orography complex domains

Assessment and Developments

BOLAM/MOLOCH suite: **reliable, efficient, scalable** $\longrightarrow$ **suitable for the dynamical downscaling of reanalyses and climate projections**

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Virtual stations