

# Towards a Definitive High-Resolution Climate Dataset for Ireland – Promoting Climate Research in Ireland



**ICHEC**  
Irish Centre for High-End Computing



**epa**

Environmental Protection Agency  
*An Ghníomhaireacht um Chaomhnú Comhshaoil*



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Department of Jobs, Enterprise and Innovation



AN RÓINN  
OIDEACHAIS AGUS SCILEANNA  
DEPARTMENT OF  
EDUCATION AND SKILLS

**HEA**

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# Project Background

- Two-Year EPA-funded project
- Main Objective: utilise NWP datasets to produce long-term gridded and time-series datasets (1981-present) for priority climatological variables
- Motivated by the recent completion of ICHEC and Met Éireann reanalyses
- For each model parameter, evaluate relative skill and assign uncertainty estimates through comparison with observational data
- Results to date for precipitation, 2m temperature, 10m winds, relative humidity, sea-level pressure, global irradiance
- More to follow (e.g. upper-air winds)
- Today's focus: Why MÉRA?

# 3 Models

- MÉRA
  - HARMONIE-AROME
  - ERA-Interim 79 km -> 2.5 km resolution
  - Data assimilation
- 2 ICHEC simulations
  - WRF v3.7.1 and COSMO-CLM5
  - 2 km & 1.5 km resolutions (d03)
  - Nested domains: 18 km (d01) and 6 km (d02)



# Precipitation: Uncertainty Estimates

- Daily accumulation: ROI and NI (in brackets) gridded observations

	COSMO	WRF	MÉRA
<b>Bias (mm)</b>	0.182 (0.366)	0.238 (0.207)	0.094 (0.420)
<b>MAE (mm)</b>	4.067 (3.893)	3.241 (3.336)	2.602 (2.656)
<b>STD (mm)</b>	6.667 (6.317)	5.671 (5.664)	4.647 (4.493)

- Hourly estimates (station observations)

	COSMO	WRF	MÉRA
<b>Bias (mm)</b>	<0.01	<0.01	<0.01
<b>MAE (mm)</b>	0.177	0.176	0.155
<b>STD (mm)</b>	0.326	0.327	0.294

**Note:** Similar analysis performed for 484 daily stations (MAE: 2.9, 2.6, 2.2mm)

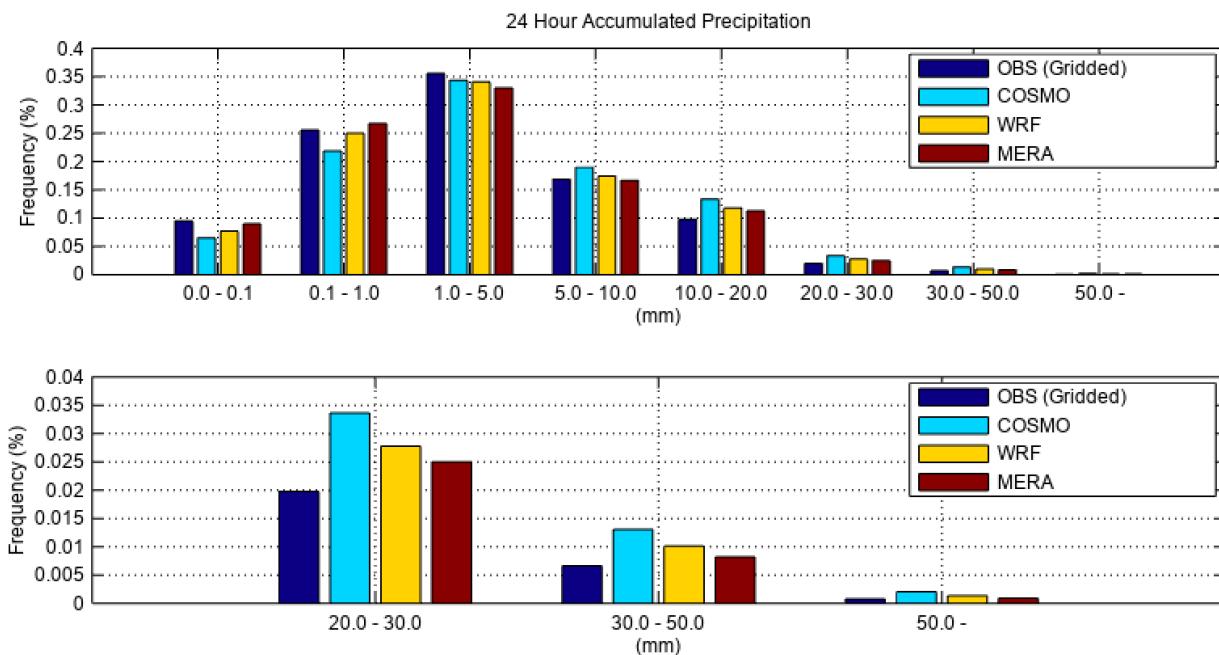
# Precipitation: Skill Scores

- Skill scores provide a measure of the value of model output
- Various measures available. Some examples
  - Fraction Skill Score (FSS) - Roberts and Lean, 2008
  - Equitable Threat Score (ETS) – Gandin and Murphy, 1992
  - Hanssen-Kuiper Skill Score (KSS) – Dahlgreen et al, 2016
- Analysis performed utilising Met Éireann's 1 km gridded datasets
- Following example from 24-hour (0900-0900 UTC) accumulated precipitation

# Precipitation: Skill Scores

- Following Dahlgren et al (2016), zeros filtered out and thresholds chosen (0.1mm, 1mm, 5mm, 10mm, 20mm, 30mm, 50mm)

- Frequency distribution: overall trend of observed rainfall is captured by the three models.

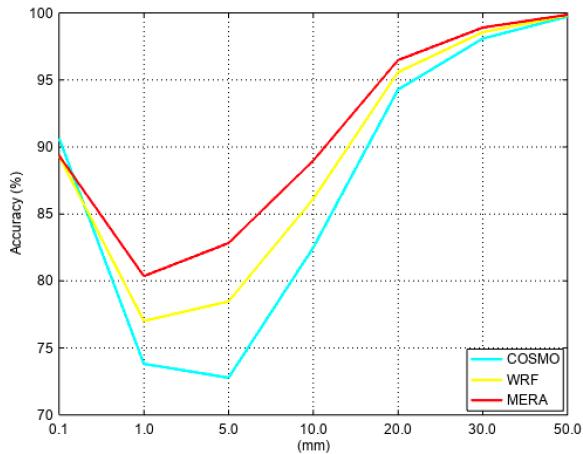


# Precipitation: Skill Scores

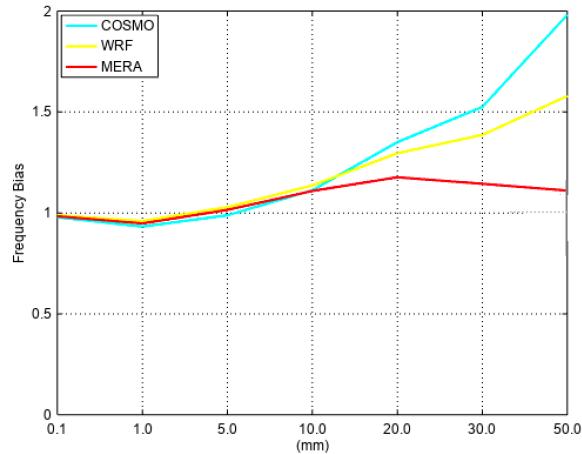
- Appropriate contingency tables (shown opposite) are calculated for each threshold.

	Observed		
Modelled	Yes	No	Total
Yes	Hits (H)	False Alarms (FA)	Modelled Yes (MY)
No	Misses (M)	Correct Negatives (CN)	Modelled No (MN)
Total	Observed Yes (OY)	Observed No (ON)	Total (T)

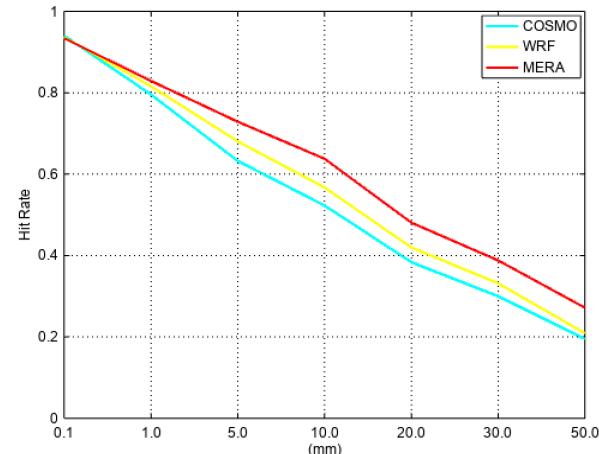
Accuracy:  $100 \times (H+CN)/T \%$



Freq Bias:  $(H + FA)/(H + M)$



Hit Rate:  $H / (H + M)$



# Precipitation: Skill Scores

- Skill Scores (Daily gridded observations, ROI and NI)

		Threshold (mm) – NI values in brackets							
Skill Score	Model	0.1	1.0	5.0	10.0	20.0	30.0	50.0	
Accuracy	COSMO	0.91 (0.91)	0.74 (0.74)	0.73 (0.72)	0.82 (0.83)	0.94 (0.95)	0.98 (0.99)	0.997 (0.998)	
	WRF	0.89 (0.90)	0.77 (0.75)	0.78 (0.76)	0.86 (0.86)	0.96 (0.96)	0.99 (0.99)	0.998 (0.999)	
	MÉRA	0.89 (0.91)	0.80 (0.80)	0.83 (0.81)	0.89 (0.88)	0.96 (0.97)	0.99 (0.99)	0.998 (0.999)	
Frequency Bias	COSMO	0.98 (0.99)	0.93 (0.97)	0.99 (1.05)	1.11 (1.18)	1.35 (1.35)	1.53 (1.56)	1.98 (2.17)	
	WRF	0.99 (0.99)	0.96 (0.97)	1.03 (1.03)	1.14 (1.13)	1.30 (1.23)	1.39 (1.31)	1.58 (1.72)	
	MÉRA	0.98 (1.00)	0.95 (1.02)	1.02 (1.10)	1.11 (1.21)	1.18 (1.24)	1.14 (1.18)	1.11 (1.16)	

# Precipitation: Skill Scores

- Skill Scores (Daily gridded observations, ROI and NI)

		Threshold (mm) – NI values in brackets							
Skill Score	Model	0.1	1.0	5.0	10.0	20.0	30.0	50.0	
Hit Rate	COSMO	0.94 (0.95)	0.80 (0.81)	0.63 (0.63)	0.52 (0.50)	0.38 (0.35)	0.30 (0.36)	0.20 (0.15)	
	WRF	0.94 (0.94)	0.82 (0.81)	0.68 (0.64)	0.57 (0.51)	0.42 (0.33)	0.33 (0.24)	0.21 (0.13)	
	MÉRA	0.93 (0.95)	0.83 (0.86)	0.73 (0.74)	0.64 (0.63)	0.48 (0.46)	0.39 (0.35)	0.27 (0.15)	
False Alarm Rate	COSMO	0.82 (0.84)	0.45 (0.50)	0.21 (0.23)	0.12 (0.12)	0.04 (0.03)	0.01 (0.01)	0.002 (0.001)	
	WRF	0.73 (0.77)	0.34 (0.40)	0.17 (0.18)	0.09 (0.09)	0.03 (0.02)	0.01 (0.01)	0.001 (0.001)	
	MÉRA	0.61 (0.69)	0.25 (0.35)	0.13 (0.16)	0.07 (0.08)	0.02 (0.02)	0.01 (0.005)	0.001 (0.001)	

# Precipitation: Skill Scores

- Skill Scores (Daily gridded observations, ROI and NI)

		Threshold (mm) – NI values in brackets							
Skill Score	Model	0.1	1.0	5.0	10.0	20.0	30.0	50.0	
<b>Hanssen-Kuiper (KSS)</b>	<b>COSMO</b>	0.12 (0.11)	0.34 (0.32)	0.42 (0.40)	0.41 (0.38)	0.35 (0.32)	0.29 (0.25)	0.19 (0.14)	
	<b>WRF</b>	0.21 (0.17)	0.48 (0.41)	0.51 (0.46)	0.48 (0.41)	0.39 (0.31)	0.32 (0.24)	0.21 (0.13)	
	<b>MÉRA</b>	0.32 (0.26)	0.58 (0.52)	0.60 (0.59)	0.57 (0.55)	0.46 (0.44)	0.38 (0.34)	0.27 (0.15)	
<b>Equitable Threat (ETS)</b>	<b>COSMO</b>	0.05 (0.05)	0.19 (0.18)	0.26 (0.25)	0.24 (0.22)	0.17 (0.16)	0.13 (0.11)	0.07 (0.05)	
	<b>WRF</b>	0.11 (0.09)	0.30 (0.25)	0.34 (0.30)	0.29 (0.24)	0.21 (0.16)	0.16 (0.11)	0.09 (0.05)	
	<b>MÉRA</b>	0.17 (0.15)	0.39 (0.35)	0.43 (0.40)	0.37 (0.34)	0.27 (0.25)	0.22 (0.19)	0.15 (0.07)	

# 2m Temperature

- Daily average (gridded observations)

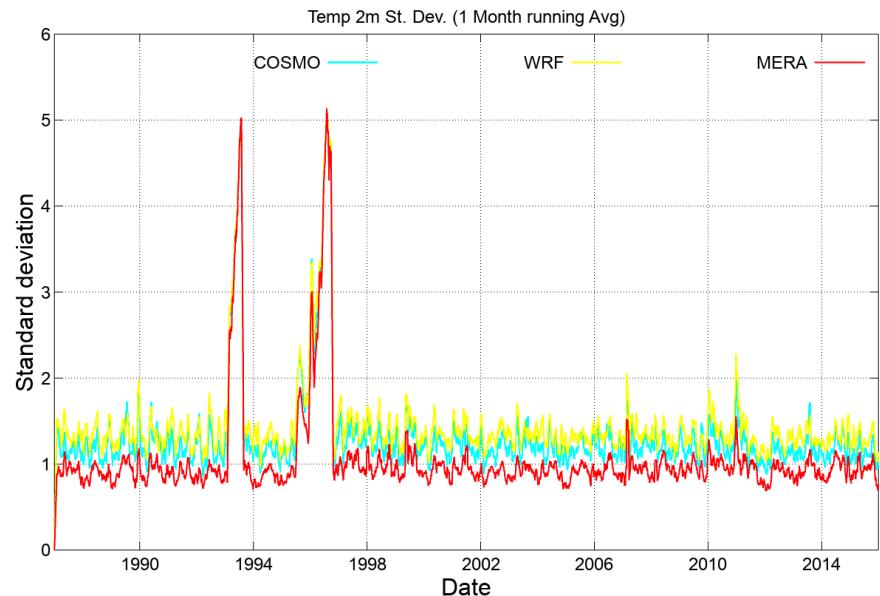
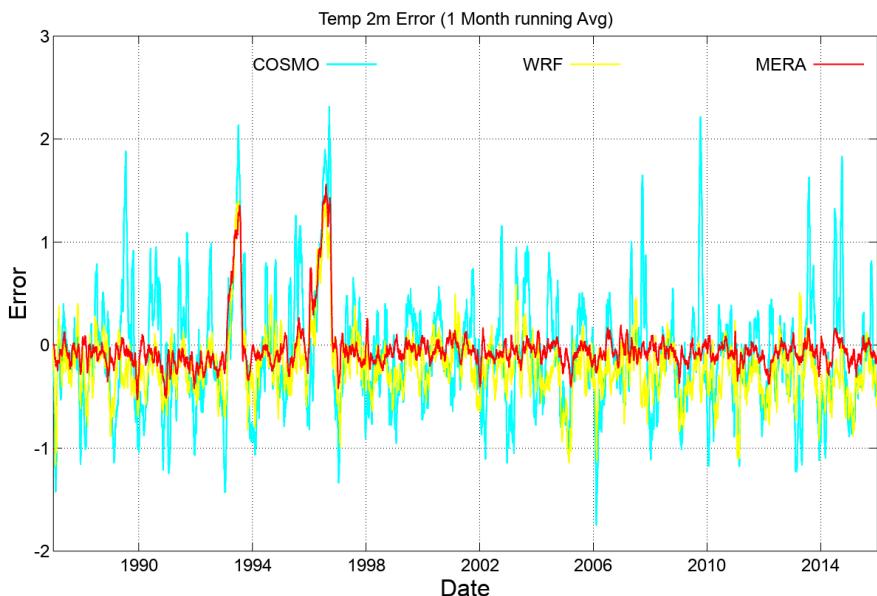
	COSMO	WRF	MÉRA
Bias (°C)	-0.36	-0.63	-0.38
MAE (°C)	1.19	1.18	0.89
St. Dev. (°C)	1.49	1.33	1.04

- Hourly estimates (station observations)

	COSMO	WRF	MÉRA
Bias (°C)	-0.18	-0.30	-0.11
MAE (°C)	1.33	1.30	0.81
St. Dev. (°C)	1.19	1.33	0.91

# 2m Temperature

- Caveat



	COSMO	WRF	MÉRA
<b>MAE (°C)</b>	1.37	1.34	0.85
<b>*MAE (°C)</b>	1.33	1.30	0.81

	COSMO	WRF	MÉRA
<b>St. Dev. (°C)</b>	1.93	1.85	1.31
<b>*St. Dev. (°C)</b>	1.19	1.33	0.91

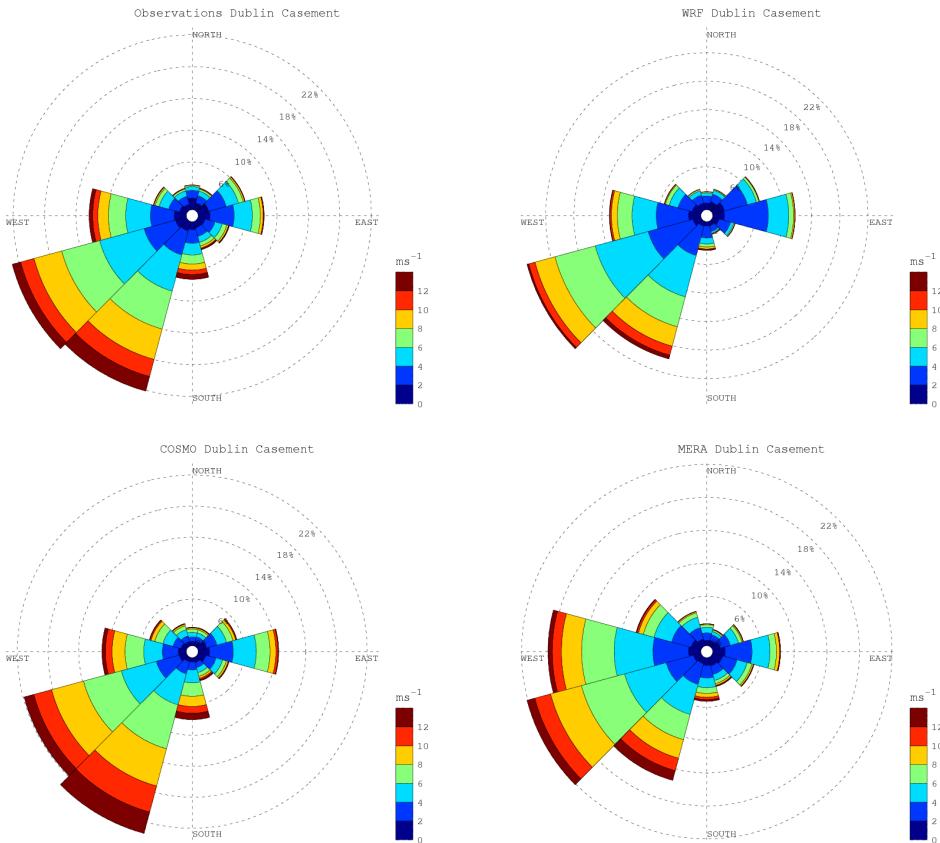
# 2m Temperature

- Skill Scores (Daily gridded observations)

			Threshold (°C)					
Skill Score (with formula)		Model	-5	0	5	10	15	20
Accuracy: $\frac{a+d}{T}$	<b>COSMO</b>	0.999	0.982	0.922	0.927	0.940	0.994	
		WRF	0.999	0.986	0.918	0.923	0.943	0.997
		MÉRA	1	0.991	0.946	0.937	0.953	0.998
Frequency Bias: $\frac{a+b}{a+c}$	<b>COSMO</b>	1	0.985	0.946	0.963	1.006	2.655	
		WRF	1	0.990	0.938	0.924	0.786	0.836
		MÉRA	1	0.994	0.977	0.950	0.767	1.082
Hit Rate (HR): $\frac{a}{a+c}$	<b>COSMO</b>	1	0.984	0.926	0.904	0.762	0.736	
		WRF	1	0.988	0.920	0.880	0.662	0.483
		MÉRA	1	0.993	0.956	0.908	0.692	0.659
False Alarm Rate (FAR): $\frac{b}{b+d}$	<b>COSMO</b>	0.682	0.149	0.099	0.053	0.034	0.006	
		WRF	0.716	0.188	0.092	0.039	0.018	0.001
		MÉRA	0.417	0.150	0.107	0.037	0.011	0.001
Hanssen-Kuiper (KSS): HR - FAR	<b>COSMO</b>	0.318	0.835	0.827	0.851	0.727	0.731	
		WRF	0.284	0.799	0.828	0.840	0.644	0.482
		MÉRA	0.583	0.843	0.849	0.870	0.681	0.658
Equitable Threat (ETS): $(a - a^*) / (a + b + c - a^*)$ , where $a^* = (a + c)(a + b) / T$	<b>COSMO</b>	0.156	0.350	0.592	0.743	0.569	0.250	
		WRF	0.161	0.391	0.582	0.730	0.550	0.356
		MÉRA	0.375	0.519	0.681	0.774	0.609	0.462

# 10m Wind Speeds

- Wind Roses generated at each station location
- Example: Dublin, Casement (01/01/1987 – 31/12/2015)



	WRF	COSMO	MÉRA
<b>Bias (m/s)</b>	-0.772	0.930	0.033
<b>MAE (m/s)</b>	1.649	1.911	1.055
<b>RMSE (m/s)</b>	2.256	2.516	1.408
<b>Std. Dev. (m/s)</b>	2.119	2.337	1.407
<b>Correlation</b>	0.775	0.757	0.908

# 10m Wind Speeds (m/s)

- MÉRA outperforms WRF/COSMO at 17/23 locations

Station	MAE W	MAE C	MAE M
CW, OP	1.299	1.773	0.987
CN, BH	1.351	2.279	1.822
CE, SA	2.198	2.133	1.169
C, CA	1.427	1.720	1.039
C, MP	1.208	2.078	1.658
C, RP	2.103	2.010	1.302
C, SI	2.153	1.971	1.380
DL, Fr	1.668	1.805	1.151
DL, MH	2.592	2.168	1.716
D, Ct	1.649	1.911	1.055
D, DA	1.755	1.641	1.073
G, Ay	1.277	1.783	1.609

Station	MAE W	MAE C	MAE M
G, MH	1.830	1.941	1.294
KY, Va	1.588	2.036	1.105
MO, Bt	2.036	1.903	1.289
MO, Cs	1.278	1.328	1.260
MO, KA	1.262	1.574	0.966
MO, Nt	1.813	1.793	1.447
MH, Dy	1.178	1.956	1.254
RN, MD	1.181	2.042	0.893
T, Gn	1.148	1.520	1.060
WH, Mr	1.333	1.986	1.524
WX, Jn	1.548	2.488	2.030

Station	STDE W	STDE C	STDE M
CW, OP	1.710	1.947	1.199
CN, BH	1.375	1.789	1.403
CE, SA	2.375	2.266	1.395
C, CA	1.828	2.042	1.358
C, MP	1.456	1.918	1.451
C, RP	2.504	2.589	1.703
C, SI	2.280	2.417	1.533
DL, Fr	2.041	2.273	1.466
DL, MH	2.691	2.737	1.831
D, Ct	2.119	2.337	1.407
D, DA	2.091	2.126	1.295
G, Ay	1.529	1.759	1.469

Station	STDE W	STDE C	STDE M
G, MH	2.391	2.606	1.704
KY, Va	2.006	2.224	1.419
MO, Bt	2.402	2.430	1.545
MO, Cs	1.693	1.760	1.392
MO, KA	1.672	1.916	1.172
MO, Nt	2.298	2.339	1.880
MH, Dy	1.476	1.813	1.197
RN, MD	1.457	1.853	1.098
T, Gn	1.516	1.737	1.148
WH, Mr	1.514	1.774	1.262
WX, Jn	1.681	2.062	1.565

# 10m Wind Directions (degs)

- MÉRA outperforms WRF/COSMO at 17/23 locations

Station	MAE W	MAE C	MAE M
CW, OP	46.3	47.9	47.5
CN, BH	38.4	40.9	37.4
CE, SA	47.6	47.6	51.3
C, CA	35.7	40.0	38.4
C, MP	47.0	46.9	44.2
C, RP	42.0	43.8	42.0
C, SI	36.1	39.3	32.9
DL, Fr	36.7	37.6	21.0
DL, MH	38.3	41.0	30.9
D, Ct	39.2	39.4	33.4
D, DA	38.7	40.4	33.0
G, Ay	36.8	39.2	36.7

Station	MAE W	MAE C	MAE M
G, MH	34.4	38.8	39.0
KY, Va	45.9	46.9	42.4
MO, Bt	39.0	42.5	34.8
MO, Cs	40.9	43.2	38.6
MO, KA	35.4	39.3	35.9
MO, Nt	55.3	57.7	56.5
MH, Dy	36.8	40.2	35.0
RN, MD	44.4	46.8	43.8
T, Gn	37.6	39.3	33.3
WH, Mr	39.9	41.2	38.0
WX, Jn	38.5	43.0	33.9

Station	STDE W	STDE C	STDE M
CW, OP	84.8	87.2	90.5
CN, BH	73.3	75.9	72.5
CE, SA	87.0	86.4	90.3
C, CA	74.1	79.9	80.6
C, MP	80.2	80.5	72.8
C, RP	82.9	85.1	83.8
C, SI	73.7	77.3	65.6
DL, Fr	67.8	69.0	61.6
DL, MH	77.3	79.0	70.3
D, Ct	73.0	72.8	62.3
D, DA	74.9	77.0	66.2
G, Ay	72.0	74.3	71.4

Station	STDE W	STDE C	STDE M
G, MH	70.9	76.1	77.7
KY, Va	97.2	88.1	79.1
MO, Bt	79.8	82.8	74.1
MO, Cs	80.8	82.9	80.9
MO, KA	73.9	78.5	79.4
MO, Nt	102	104	108
MH, Dy	72.9	77.2	70.1
RN, MD	86.2	88.6	82.8
T, Gn	73.8	75.9	64.2
WH, Mr	80.2	81.8	78.5
WX, Jn	79.5	85.0	76.4

# 10m Wind Speed (overall)

- Overall values, i.e. values found when all viable records from all stations are treated as one single dataset:

Wind Speed	WRF	COSMO	MÉRA
Bias	0.07	0.85	0.29
MAE	1.67	1.89	1.27
Std	2.24	2.30	1.65
Correlation	0.73	0.74	0.86

# 10m Wind Direction (overall)

- Overall values, i.e. values found when all viable records from all stations are treated as one single dataset:

Wind Dir	WRF	COSMO	MÉRA
Bias	-0.41	2.70	-4.59
MAE	40.61	42.82	38.53
Std	79.62	81.79	77.59
Correlation	0.59	0.56	0.62

# 10m Wind Speeds (m/s)

- After simple bias removal, MÉRA outperforms WRF/COSMO at 21/23 locations

Station	MAE W	MAE C	MAE M
CW, OP	1.302	1.489	0.920
CN, BH	1.052	1.393	1.093
CE, SA	1.839	1.727	1.066
C, CA	1.389	1.543	1.035
C, MP	1.111	1.496	1.141
C, RP	1.907	1.967	1.301
C, SI	1.724	1.840	1.177
DL, Fr	1.554	1.731	1.123
DL, MH	2.061	2.083	1.417
D, Ct	1.576	1.751	1.054
D, DA	1.599	1.613	0.989
G, Ay	1.159	1.356	1.136

Station	MAE W	MAE C	MAE M
G, MH	1.775	1.941	1.239
KY, Va	1.515	1.679	1.090
MO, Bt	1.834	1.848	1.196
MO, Cs	1.275	1.328	1.069
MO, KA	1.253	1.446	0.888
MO, Nt	1.758	1.785	1.423
MH, Dy	1.125	1.385	0.923
RN, MD	1.109	1.425	0.847
T, Gn	1.148	1.314	0.882
WH, Mr	1.156	1.352	0.972
WX, Jn	1.287	1.593	1.226

Station	STDE W	STDE C	STDE M
CW, OP	1.710	1.947	1.199
CN, BH	1.375	1.789	1.403
CE, SA	2.375	2.266	1.395
C, CA	1.828	2.042	1.358
C, MP	1.456	1.918	1.451
C, RP	2.504	2.589	1.703
C, SI	2.280	2.417	1.533
DL, Fr	2.041	2.273	1.466
RN, MD	1.457	1.853	1.097
T, Gn	1.516	1.737	1.148
WH, Mr	1.514	1.774	1.262
WX, Jn	1.681	2.062	1.565
G, Ay	1.529	1.759	1.469

Station	STDE W	STDE C	STDE M
G, MH	2.391	2.606	1.704
KY, Va	2.006	2.224	1.419
MO, Bt	2.402	2.430	1.545
MO, Cs	1.693	1.760	1.391
MO, KA	1.672	1.916	1.172
MO, Nt	2.298	2.339	1.880
MH, Dy	1.476	1.813	1.197
RN, MD	1.457	1.853	1.097
T, Gn	1.516	1.737	1.148
WH, Mr	1.514	1.774	1.262
WX, Jn	1.681	2.062	1.565

Wind Speed	WRF	COSMO	MÉRA
MAE	1.67	1.89	1.27
Std	2.24	2.30	1.65



Wind Speed	WRF	COSMO	MÉRA
MAE	1.52	1.63	1.09
Std	2.03	2.17	1.44

# Relative Humidity (%)

- Hourly time series from 25 synoptic stations
- Caveat: Sherkin Island data
- Overall values, i.e. values found when all viable records from all stations are treated as one single dataset:

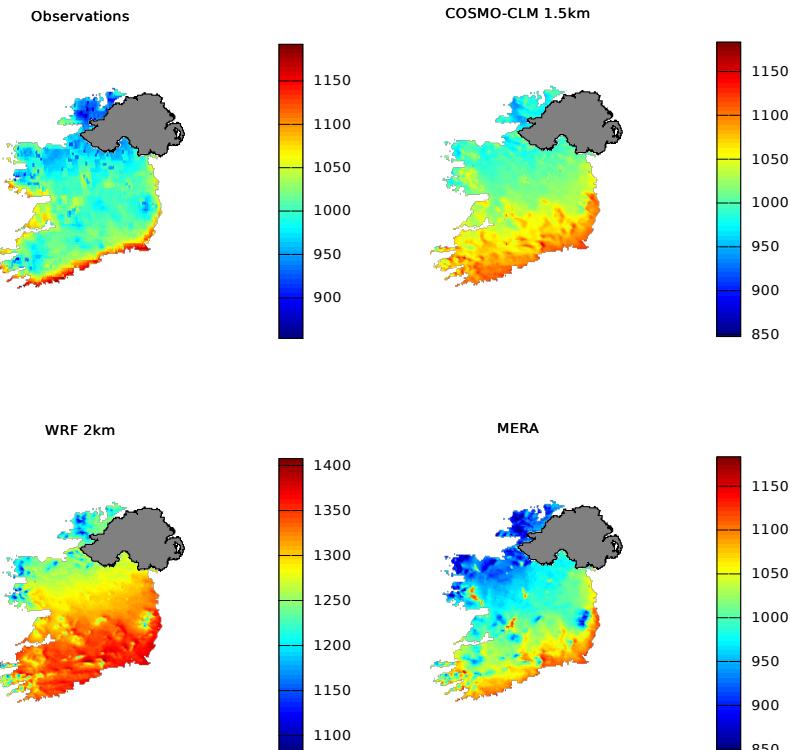
Statistic	COSMO	WRF	MÉRA
Error (St. Dev.)	-2.863 (5.850)	0.945 (6.605)	-0.423 (3.594)
MAE (St. Dev.)	7.577 (3.526)	7.672 (3.934)	5.467 (2.193)
% Error (St. Dev.)	-2.746 (7.635)	2.156 (8.916)	-0.036 (4.721)
Abs % Error (St. Dev.)	9.390 (4.944)	9.830 (6.083)	6.885 (3.325)
Correlation	0.661	0.567	0.799

# Sea Level Pressure (hPa)

- Hourly time series from 24 synoptic stations
- Overall values, i.e. values found when all viable records from all stations are treated as one single dataset:

Statistic	COSMO	WRF	MÉRA
Error (St. Dev.)	-0.873 (2.562)	-0.203 (2.387)	0.029 (0.514)
MAE (St. Dev.)	1.957 (1.870)	1.688 (1.701)	0.367 (0.361)
% Error (St. Dev.)	-0.087 (0.254)	-0.020 (0.237)	0.003 (0.051)
Abs % Error (St. Dev.)	0.194 (0.186)	0.167 (0.170)	0.036 (0.036)
Correlation	0.981	0.982	0.999

# Global Irradiance



- Average Annual 1998 – 2011
- Satellite observations from PVGIS

	COSMO	WRF	MÉRA
<b>Bias (%)</b>	2.83	29.17	-0.81
<b>MAE (%)</b>	3.58	29.17	3.48
<b>Std. Dev. (%)</b>	3.47	4.76	4.46

- Hourly: 10/2010 – 12/2015
- Satellite observations from EUMETSAT

	COSMO	WRF	MÉRA
<b>Bias (kWhr/m<sup>2</sup>)</b>	0.008	0.079	-0.003
<b>MAE (kWhr/m<sup>2</sup>)</b>	0.103	0.127	0.086
<b>Std. Dev. (kWhr/m<sup>2</sup>)</b>	0.094	0.113	0.088

# Global radiation ( $\text{MJ m}^{-2}$ )

- Daily time series from 18 stations
- Varying lengths
- Overall values, i.e. values found when all viable records from all stations are treated as one single dataset:

	Bias	Std	MAE	Correlation
MÉRA	0.122	0.855	0.589	0.921
COSMO	0.167	1.189	0.809	0.838

# Summary

- EPA-funded project aimed at the production of long-term high-resolution gridded datasets
- Motivated by ICHEC's recent simulations at 1.5 km and 2 km resolution (COSMO-CLM5 and WRF v3.7.1) and Met Éireann's MÉRA
- Task: comparison of each model output with observations
- Finding: despite lower resolution, MÉRA (2.5km) typically shows lower bias, MAE and Standard deviation as well as higher skill scores and correlations for precipitation, 2m temperature, 10m winds, relative humidity, sea-level pressure and global radiation