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Updated ranking of GCM-RCM results for five Scandinavian locations

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Abstract

The ranking method from MIST-I (Landgren et al. 2014) is applied to data from 11 GCM-RCM combinations from CMIP5/Euro-CORDEX and compared with the results from CMIP3/ENSEMBLES. Annual cycle and inter-annual variability of temperature and precipitation are examined in five locations, Oslo, Bergen, Trondheim, Tromsø and Östersund. Despite the higher resolution of the regional models in CORDEX (12 km) compared to ENSEMBLES (25 km), the results indicate that the CORDEX ensemble performs slightly worse than the previous larger ENSEMBLES dataset, but without any single outlier in terms of performance. A few models still perform very well, with key improvements for two models in precipitation error and variability.

Keywords
GCM, RCM, ensemble, ranking

Disciplinary signature

Responsible signature

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1 Introduction

Several ensembles of regional downscaling data for Europe have become available during recent years; the ENSEMBLES[1] project based on global models from CMIP3 downscaled to 25 and 50 km horizontal resolution, and CORDEX[2] based on CMIP5, downscaled to 12 and 50 km. With present methods in Statkraft and other places, further impact analysis is based on a selection of data and the choice of models may be based on their qualities in reproducing the regional climate for the historical time-horizon. A part of the MIST-2 work has been to obtain a ranking of the recent Euro-CORDEX data from the performance of temperature and precipitation evaluated against several observation based reference datasets. This work follow as an update of the evaluation carried out in the MIST-I project from ENSEMBLES data.

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[1] http://ensemblesrt3.dmi.dk/

[2] Coordinated Regional Downscaling Experiment, http://cordex.org/

2 Methods

The method used is identical to the one described in Landgren et al. (2014), except for the addition of an altitude correction for temperature due to differences between model terrain height and observation site. In summary, monthly mean values of precipitation (PR) and 2-meter temperature (TAS) for the historical and RCP4.5 scenario was downloaded from Euro-CORDEX data nodes[3] and bilinearly interpolated using Climate Data Operators (cdo)[4] to five station locations, Oslo-Blindern, Bergen-Florida, Trondheim-Værnes, Tromsø-Værvarslinga and Östersund-Frösön. After interpolation, a lapse rate of -0.0065°C/m was added to the temperature values, using the altitudes from each RCM as well as the stations.

Four reference data sets were used: station observation, ERA-Interim reanalysis, E-OBS gridded observations and NORA10 hindcast. Compared to MIST-I, ERA-40 was not used since it ends in 2002.

The mean annual cycle for the years 1981-2010 was calculated as multi-year mean values for each of the 12 months and is shown in Figs. 1 and 2.

In order to assess the quality relative to reference data, the root-mean-square error values of temperature (deviation from reference, in °C) and precipitation (fraction of reference data value) were calculated, giving one value per parameter per location.

The standard deviation of the monthly mean values was used as a measure of the inter-annual variability and calculated on a per-month basis (e.g. for the period 1981-2010 there are 30 January values per model). The standard deviations are shown in Figs. 3 and 4. If SD_{mod} and SD_{ref} denote the standard deviations of a model and reference dataset for a particular month, then the following measure was used:

$$IAV = \frac{SD_{mod}}{SD_{ref}} - 1 \quad \text{if} \quad SD_{mod} > SD_{ref} \quad \text{or} \quad IAV = \frac{SD_{ref}}{SD_{mod}} - 1 \quad \text{if} \quad SD_{mod} < SD_{ref}$$

In this way the IAV measure is always positive, and a value of e.g. 0.3 means a 30% discrepancy between the model and the reference.

The root-mean-square values (of RMSE and IAV separately) over all 12 months was then calculated for each parameter, model and reference dataset combination and is shown for observations in Table 1. The RMSE and IAV columns were then ranked column-wise to give relative performance of each model per parameter and location. This was done for each reference dataset (RMSE and IAV columns in Table 1 only shows relative to observations). The ranks were then summed up row-wise, giving the total ranks in the five rightmost columns.

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[3] A list of data nodes is available at http://euro-cordex.net/060378/index.php.en

[4] https://code.zmaw.de/projects/cdo/

3 Results

3.1 Annual temperature and precipitation cycle

The mean monthly values of temperature and precipitation in the five locations are shown in Figs. 1 and 2, respectively.

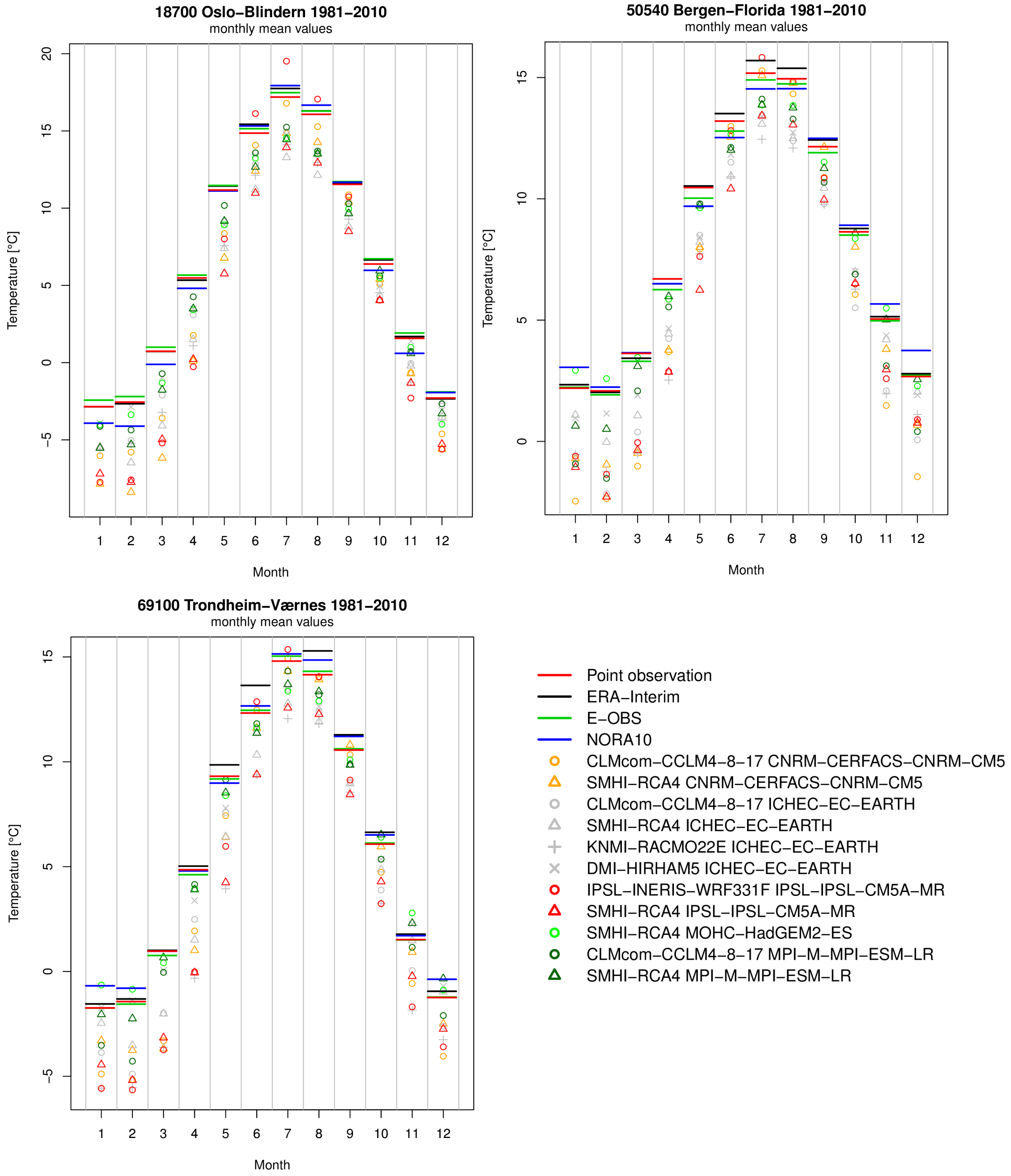

Fig. 1a: Mean annual cycle of temperature.

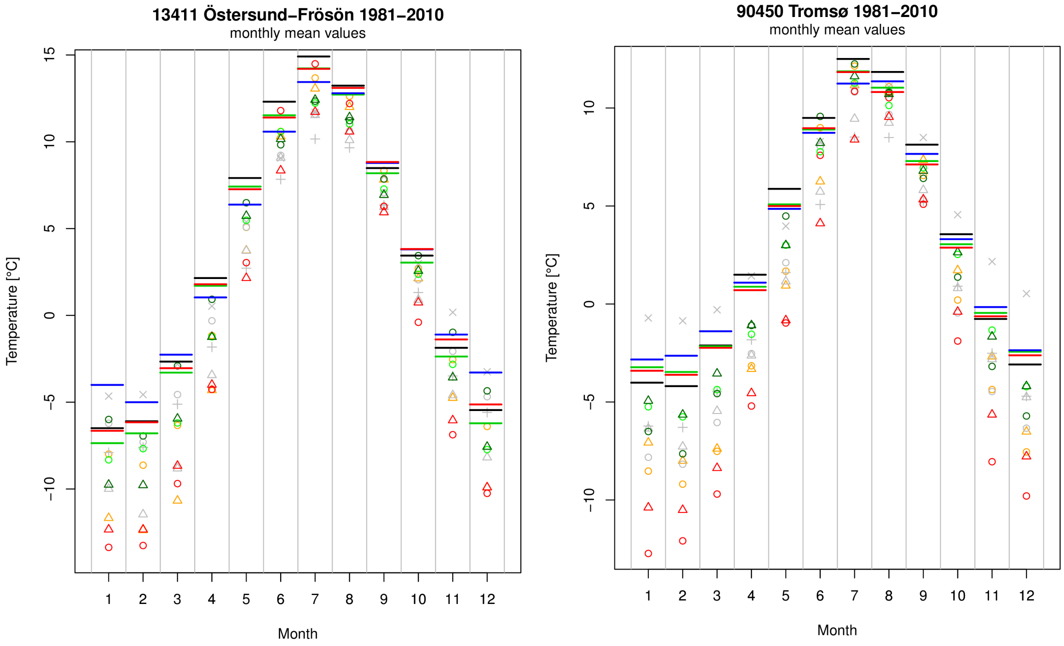

Fig. 1b: Mean annual cycle of temperature.

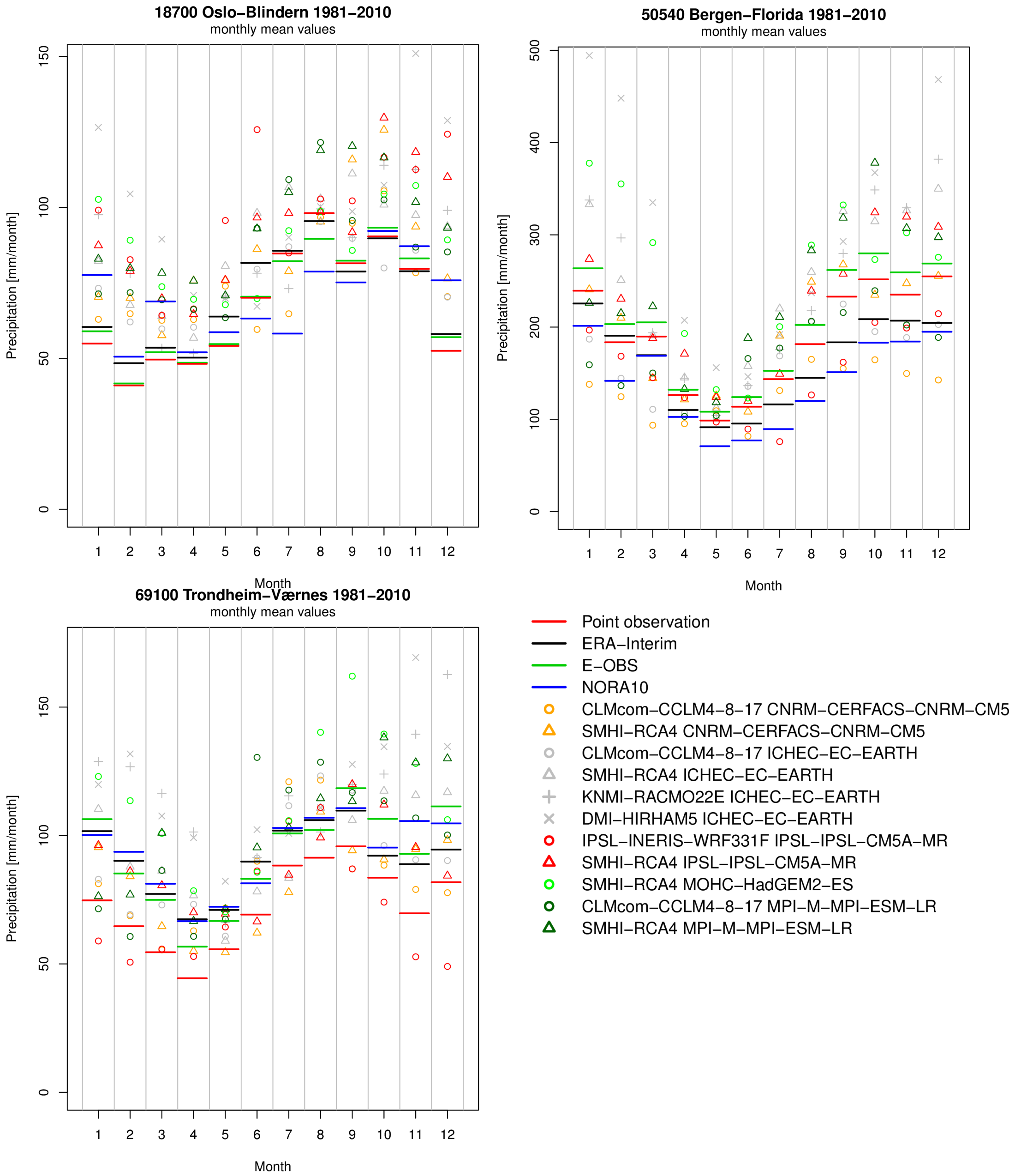

Fig. 2a: Mean annual cycle of precipitation.

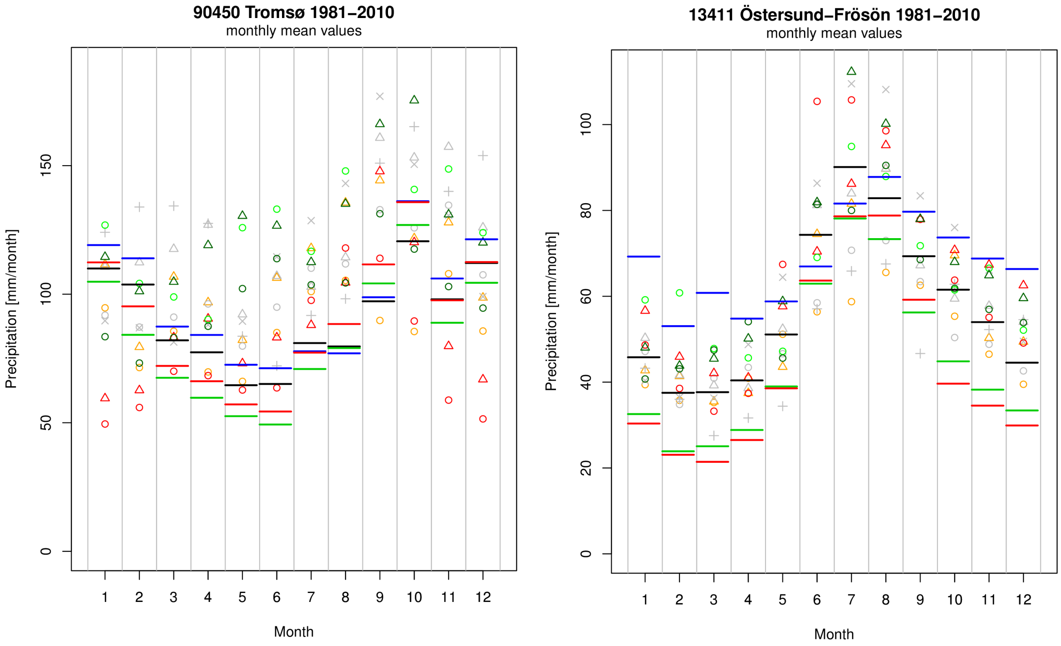

Fig. 2b: Mean annual cycle of precipitation.

3.2 Inter-annual variability

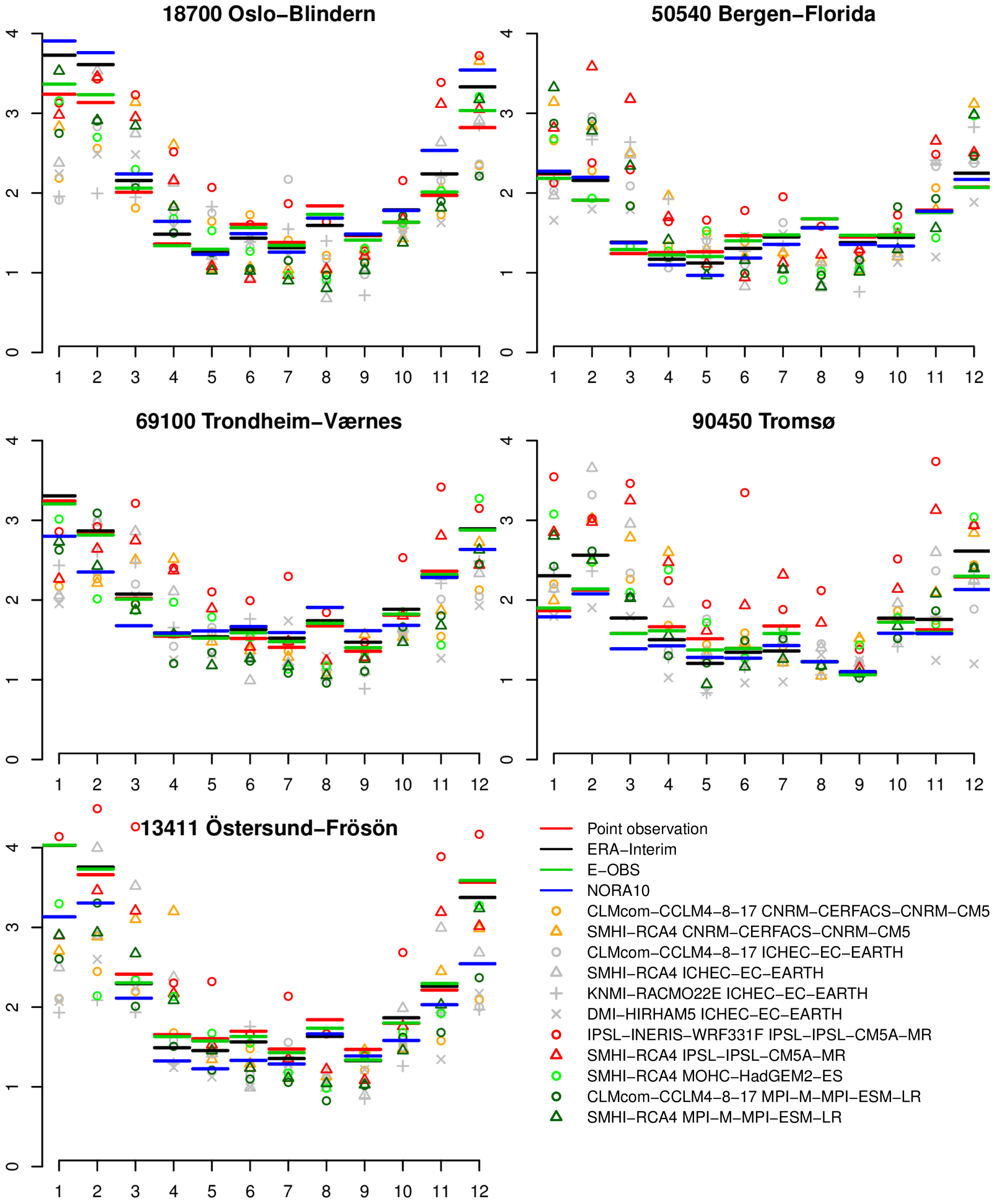

Fig. 3: Inter-annual variability of temperature in the five locations. The months are on the x-axis, and the y-axis unit is °C.

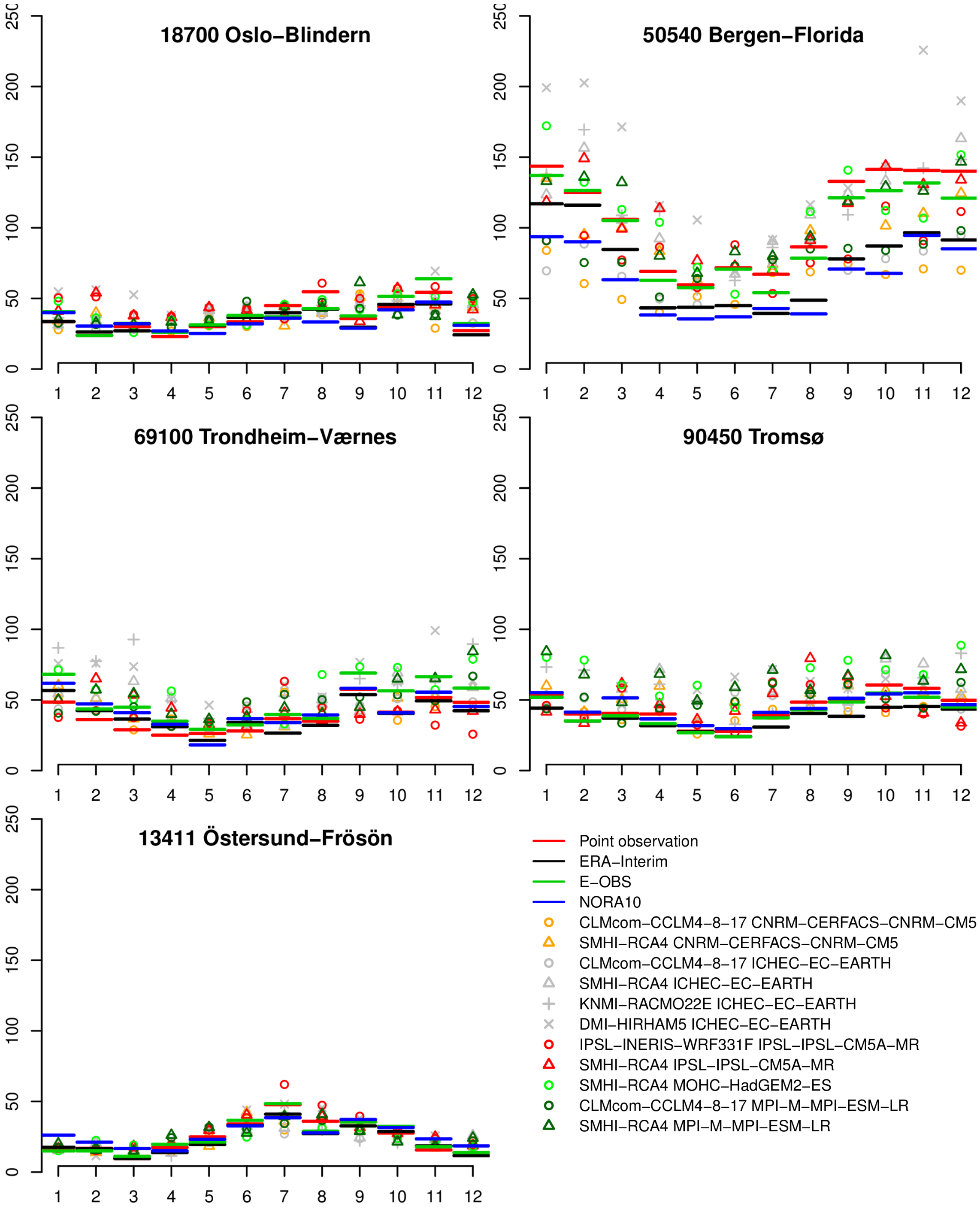

Fig. 4: Inter-annual variability of precipitation in the five locations. The months are on the x-axis and the y-axis unit is mm/month.

3.3 Integrated rank table

Similarly to MIST-I and Landgren et al. (2014), an integrated rank was calculated and is presented in Table 1.

			Oslo				Bergen				Trondheim				Tromsø				Östersund				Total rank				
			TAS		PR		TAS		PR		TAS		PR		TAS		PR		TAS		PR		Obser	ERA-I	ERA-4	E-OBS	NORA1
	RCM	**GCM**	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	*81-10*	*81-10*	*81-10*	*81-10*	*81-10*
C1	CLMcom-CCLM4-8-17	CNRM-CERFACS-CNRM-CM5	2.5	0.5	0.3	0.4	3.1	0.4	0.3	0.8	2.4	0.5	0.2	0.3	3.6	0.3	0.3	0.2	1.8	0.8	0.4	0.3	**2**	**3**	**1**	**6**	**3**
C2	SMHI-RCA4	CNRM-CERFACS-CNRM-CM5	4.0	0.6	0.4	0.4	2.2	0.7	0.2	0.2	2.1	0.5	0.2	0.2	3.2	0.6	0.4	0.3	4.2	0.7	0.5	0.3	**4**	**4**	**6**	**5**	**6**
C3	CLMcom-CCLM4-8-17	ICHEC-EC-EARTH	2.1	0.6	0.2	0.3	2.8	0.5	0.2	0.6	2.1	0.5	0.3	0.4	3.2	0.5	0.3	0.3	1.8	0.8	0.4	0.4	**3**	**2**	**2**	**3**	**2**
C4	SMHI-RCA4	ICHEC-EC-EARTH	3.4	0.6	0.4	0.4	1.9	0.6	0.3	0.2	2.1	0.5	0.4	0.6	2.8	0.7	0.5	0.5	3.8	0.8	0.5	0.5	**9**	**7**	**7**	**7**	**8**
C5	KNMI-RACMO22E	ICHEC-EC-EARTH	3.0	0.6	0.5	0.3	2.9	0.6	0.3	0.2	3.6	0.4	0.8	0.9	2.7	0.4	0.5	0.5	2.9	1.0	0.4	0.3	**7**	**9**	**10**	**8**	**10**
C6	DMI-HIRHAM5	ICHEC-EC-EARTH	1.6	0.5	0.8	0.6	1.6	0.4	0.8	0.5	1.0	0.6	0.8	0.8	1.9	0.5	0.5	0.6	1.7	0.9	0.6	0.3	**9**	**11**	**8**	**10**	**9**
C7	IPSL-INERIS-WRF331F	IPSL-IPSL-CM5A-MR	3.7	0.8	0.7	0.5	2.4	0.5	0.2	0.4	3.1	0.7	0.2	0.5	5.9	1.2	0.3	0.3	4.8	0.9	0.6	0.3	**10**	**10**	**11**	**11**	**11**
C8	SMHI-RCA4	IPSL-IPSL-CM5A-MR	4.1	0.6	0.5	0.5	3.0	0.8	0.2	0.2	3.1	0.5	0.3	0.4	5.0	0.9	0.3	0.4	4.5	0.6	0.7	0.3	**11**	**8**	**9**	**9**	**8**
C9	SMHI-RCA4	MOHC-HadGEM2-ES	1.8	0.4	0.5	0.3	0.7	0.4	0.5	0.2	0.9	0.4	0.6	0.6	1.5	0.5	0.7	0.6	2.0	0.6	0.8	0.4	**6**	**6**	**4**	**5**	**4**
C10	CLMcom-CCLM4-8-17	MPI-M-MPI-ESM-LR	1.4	0.4	0.4	0.3	2.0	0.5	0.2	0.4	1.2	0.4	0.4	0.4	2.1	0.3	0.4	0.4	1.1	0.7	0.6	0.3	**1**	**1**	**3**	**1**	**1**
C11	SMHI-RCA4	MPI-M-MPI-ESM-LR	2.1	0.5	0.5	0.4	1.0	0.7	0.4	0.1	0.8	0.4	0.5	0.5	1.3	0.4	0.7	0.6	2.3	0.5	0.7	0.4	**5**	**6**	**5**	**3**	**5**

Table 1: Results for the 11 Euro-CORDEX models at the 5 stations. The red and light blue columns show RMSE and IAV values relative to station observations. Lower numbers are better. Each parameter and station is ranked separately (by columns) and summed up (by rows) for each model, giving the total rank in the purple column. Total ranks relative to the other reference datasets are shown in the four rightmost columns (underlying data not shown).

3.4 Comparison with MIST-I

A comparison of both ENSEMBLES and Euro-CORDEX data is shown in Table 2. Since altitude data for the ENSEMBLES models was not readily available, the MIST-I analysis was made without altitude correction. The analysis here is therefore made without altitude correction for the Euro-CORDEX data as well, which is why the data is not identical to the data shown in Table 1.

			Oslo				Bergen				Trondheim				Tromsø				Östersund					Separated by parameter									
			TAS		PR		TAS		PR		TAS		PR		TAS		PR		TAS		PR		Total	TAS		PR		Separated by Location					
	RCM	GCM	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	RMS	IAV	rank	RMS	IAV	RMS	IAV	Oslo	Bergen	Trondh	Troms	Östersu	
C1	CLMcom-CCLM4-8-17	CNRM-CERFACS-CM5	3.1	0.5	0.3	0.4	3.7	0.4	0.3	0.8	3.4	0.5	0.2	0.3	4.5	0.3	0.3	0.2	1.4	0.8	0.4	0.3	11	20	17	***2***	***5***	***9***	30	13	***8***	***3***	C1
C2	SMHI-RCA4	CNRM-CERFACS-CM5	4.5	0.6	0.4	0.4	3.0	0.7	0.2	0.2	3.0	0.5	0.2	0.2	3.7	0.6	0.4	0.3	3.9	0.7	0.5	0.3	14	26	33	***6***	***1***	29	14	***8***	18	***10***	C2
C3	CLMcom-CCLM4-8-17	ICHEC-EC-EARTH	2.8	0.6	0.2	0.3	3.4	0.5	0.2	0.6	3.2	0.5	0.3	0.4	4.2	0.5	0.3	0.3	1.4	0.8	0.4	0.4	13	19	24	***6***	***8***	***7***	29	16	17	12	C3
C4	SMHI-RCA4	ICHEC-EC-EARTH	4.0	0.6	0.4	0.4	2.9	0.6	0.3	0.2	3.0	0.5	0.4	0.6	3.3	0.7	0.5	0.5	3.4	0.8	0.5	0.5	31	22	34	26	24	28	23	28	34	28	C4
C5	KNMI-RACMO22E	ICHEC-EC-EARTH	3.6	0.6	0.5	0.3	4.0	0.6	0.3	0.2	4.6	0.4	0.8	0.9	3.2	0.4	0.5	0.5	2.6	1.0	0.4	0.3	27	28	27	27	13	23	32	34	19	17	C5
C6	DMI-HIRHAM5	ICHEC-EC-EARTH	2.2	0.5	0.8	0.6	2.5	0.4	0.8	0.5	1.9	0.6	0.8	0.8	1.6	0.5	0.5	0.6	1.7	0.9	0.6	0.3	29	14	24	33	31	32	27	32	21	24	C6
C7	IPSL-INERIS-WRF331F	IPSL-IPSL-CM5A-MR	4.2	0.8	0.7	0.5	3.3	0.5	0.2	0.4	4.0	0.7	0.2	0.5	6.4	1.2	0.3	0.3	4.5	0.9	0.6	0.3	33	32	36	17	17	35	19	26	30	26	C7
C8	SMHI-RCA4	IPSL-IPSL-CM5A-MR	4.7	0.6	0.5	0.5	4.0	0.8	0.2	0.2	4.2	0.5	0.3	0.4	5.5	0.9	0.3	0.4	4.2	0.6	0.7	0.3	31	33	31	23	***10***	34	28	22	27	24	C8
C9	SMHI-RCA4	MOHC-HadGEM2-ES	2.4	0.4	0.5	0.3	1.5	0.4	0.5	0.2	1.6	0.4	0.6	0.6	2.0	0.5	0.7	0.6	1.7	0.6	0.8	0.4	17	***9***	12	34	22	13	***8***	21	31	20	C9
C10	CLMcom-CCLM4-8-17	MPI-M-MPI-ESM-LR	2.1	0.4	0.4	0.3	2.6	0.5	0.2	0.4	2.2	0.4	0.4	0.4	3.0	0.3	0.4	0.4	0.9	0.7	0.6	0.3	***10***	16	13	20	***7***	***4***	21	13	14	***4***	C10
C11	SMHI-RCA4	MPI-M-MPI-ESM-LR	2.7	0.5	0.5	0.4	1.9	0.7	0.4	0.1	1.6	0.4	0.5	0.5	1.8	0.4	0.7	0.6	2.0	0.5	0.7	0.4	21	16	20	31	21	27	17	16	24	15	C11
E1	C4I-RCA3	HadCM3Q16_25km	1.2	0.5	0.3	0.3	2.1	0.4	0.3	0.8	1.9	0.4	0.2	0.5	0.8	0.4	0.3	0.3	0.8	0.8	0.8	0.5	9	6	21	13	23	2	19	7	9	27	E1
E2	CNRM-RM5.1	ARPEGE_25km	2.1	0.7	0.5	0.4	2.9	0.4	0.2	0.6	4.3	0.5	0.6	0.5	2.2	0.8	0.3	0.3	1.4	0.9	0.6	0.4	24	18	32	19	26	30	16	29	13	26	E2
E3	DMI-HIRHAM5	BCM_A1B_25km	5.8	0.5	0.5	0.3	4.4	0.4	0.4	0.6	5.6	0.3	0.3	0.5	6.1	1.1	0.4	0.3	5.6	0.5	0.6	0.4	25	35	9	23	10	21	33	16	30	18	E3
E4	DMI-HIRHAM5	ECHAM5_25km	2.3	0.6	1.5	1.0	1.8	0.3	0.3	0.6	2.0	0.3	0.2	0.5	0.7	0.3	0.5	0.6	1.6	0.7	1.5	0.8	22	11	8	29	34	33	11	4	15	34	E4
E5	DMI-HIRHAM5	ARPEGE_25km	1.7	0.4	0.7	0.5	2.2	0.4	0.3	0.3	2.3	0.4	0.8	0.6	2.4	0.7	0.6	0.5	1.5	0.5	1.0	0.7	23	14	8	32	33	22	7	23	28	29	E5
E6	ETHZ-CLM	HadCM3Q0_25km	3.4	0.6	0.4	0.3	2.7	0.4	0.3	0.3	3.2	0.6	0.7	0.8	*NA*	*NA*	*NA*	*NA*	3.1	0.7	0.9	0.6	28	26	29	31	28	19	10	35	36	34	E6
E7	GKSS-CLM3	IPSL_25km	4.5	0.5	0.4	0.3	3.8	0.4	0.3	0.3	4.5	0.4	0.8	0.7	3.4	0.4	0.2	0.3	3.9	0.4	0.8	0.4	20	30	5	24	16	15	16	32	12	24	E7
E8	METO-HC_HadRM3Q0	HadCM3Q0_25km	3.2	0.3	0.5	0.3	2.9	0.6	0.2	0.4	3.6	0.4	0.3	0.5	4.7	0.6	0.2	0.4	2.9	0.4	0.4	0.3	12	24	15	7	13	11	26	20	16	1	E8
E9	METO-HC_HadRM3Q16	HadCM3Q16_25km	1.8	0.5	0.6	0.4	1.9	0.5	0.2	0.4	2.2	0.4	0.3	0.3	2.7	0.4	0.2	0.3	1.0	0.6	0.6	0.6	8	10	12	17	19	21	13	6	7	9	E9
E10	METO-HC_HadRM3Q3	HadCM3Q3_25km	2.5	0.7	0.3	0.3	3.0	0.5	0.2	0.3	3.2	0.5	0.3	0.5	4.7	0.7	0.4	0.5	2.1	0.5	0.4	0.4	20	23	26	8	16	17	12	24	32	6	E10
E11	ICTP-REGCM3	ECHAM5_r3_25km	2.0	0.5	0.7	0.5	2.4	0.5	0.4	0.3	2.1	0.4	0.7	0.7	0.7	0.4	0.1	0.2	1.6	0.6	1.1	0.6	16	12	17	28	27	26	20	25	2	30	E11
E12	KNMI-RACMO2	ECHAM5-r1_50km	1.2	0.4	0.4	0.4	1.7	0.5	0.1	0.3	2.0	0.3	0.3	0.3	0.7	0.3	0.3	0.3	0.9	0.6	0.7	0.3	1	5	1	14	4	8	5	3	3	2	E12
E13	KNMI-RACMO2	ECHAM5-r2_50km	1.1	0.4	0.4	0.4	1.6	0.5	0.1	0.3	1.9	0.4	0.4	0.5	0.7	0.4	0.3	0.4	0.9	0.4	0.7	0.6	5	4	4	15	25	6	2	11	12	8	E13
E14	KNMI-RACMO2	ECHAM5-r3_50km	1.1	0.4	0.4	0.5	1.6	0.4	0.2	0.2	1.9	0.3	0.3	0.5	0.6	0.3	0.2	0.2	1.1	0.6	0.7	0.5	4	2	6	11	14	11	1	9	1	20	E14
E15	KNMI-RACMO2	MIROC3.2-hires_50km	0.8	0.5	0.2	0.3	0.9	0.4	0.2	0.5	1.4	0.5	0.3	0.3	0.8	0.3	0.3	0.2	0.9	0.8	0.6	0.4	3	1	15	10	6	1	6	5	6	15	E15
E16	KNMI-RACMO2	ECHAM5-r3_25km	1.2	0.4	0.5	0.5	1.5	0.4	0.3	0.2	1.2	0.4	0.3	0.4	0.7	0.3	0.4	0.4	1.4	0.7	0.6	0.5	6	3	3	25	18	14	3	3	10	17	E16
E17	METNO-HIRHAM	HadCM3Q0_25km	2.6	0.5	0.5	0.3	2.3	0.4	0.2	0.3	2.8	0.5	0.3	0.5	3.0	0.3	0.2	0.3	1.2	0.7	0.8	0.3	7	17	10	12	2	13	4	19	5	15	E17
E18	METNO-HIRHAM	BCM_25km	5.7	0.4	0.4	0.3	4.4	0.3	0.3	0.5	5.4	0.2	0.2	0.4	6.8	1.3	0.3	0.4	4.4	0.4	0.5	0.3	15	34	2	9	13	18	26	10	27	5	E18
E19	MPI-M-REMO	ECHAM5_25km	1.7	0.6	0.6	0.5	1.6	0.5	0.5	0.4	1.4	0.7	1.3	1.4	2.4	0.3	0.6	0.6	1.7	0.9	1.3	0.6	34	8	28	35	35	31	23	33	20	36	E19
E20	OURANOS-MRCC4.2.1	CGCM3_25km	7.7	0.5	0.2	0.4	5.0	0.5	0.2	0.5	8.1	0.4	0.3	0.2	9.2	1.2	0.3	0.6	7.3	0.5	0.4	0.6	26	36	22	1	30	25	34	17	35	21	E20
E21	SMHI-RCA	BCM_25km	2.2	0.6	0.3	0.4	2.2	0.5	0.4	1.1	4.4	0.5	0.3	0.7	4.3	1.3	0.3	0.4	4.0	0.6	0.8	0.5	29	22	26	21	33	16	31	27	27	31	E21
E22	SMHI-RCA	ECHAM5-r3_25km	1.4	0.6	0.3	0.3	1.4	0.5	0.2	0.5	2.0	0.4	0.2	0.2	1.2	0.4	0.1	0.2	1.4	0.6	0.7	0.4	2	7	18	3	3	3	9	1	4	11	E22
E23	SMHI-RCA	HadCM3Q3_25km	3.7	0.3	0.1	0.4	3.8	0.5	0.4	0.9	4.8	0.7	0.1	0.2	3.6	0.8	0.3	0.5	4.2	0.5	0.5	0.3	18	31	20	6	20	6	36	19	22	7	E23
E24	UCLM-PROMES	HadCM3Q0_25km_MM	3.7	0.6	0.4	0.3	3.4	0.5	0.2	0.4	3.5	0.5	0.4	0.6	3.8	0.7	0.3	0.5	2.9	0.8	0.7	0.6	32	27	35	18	29	24	26	30	23	32	E24
E25	VMGO-RRCM	HadCM3Q0_25km	4.7	0.7	1.3	1.0	2.8	0.5	1.1	1.1	4.0	0.8	1.5	1.9	3.2	0.4	0.7	0.8	4.8	0.7	1.0	0.5	36	29	30	36	36	36	36	36	34	35	E25

Table 2: Combined ranking of the 11 Euro-CORDEX model runs (C1-C11) and the 25 ENSEMBLES runs (E1-E25). For the Euro-CORDEX models, ranks in the top 10 are marked in bold.

4 Discussion and conclusion

The annual cycles in Figs. 1 and 2 show that there is in general a positive precipitation bias, both in winter and summer, and a negative temperature bias which is largest in winter. As shown in Figs. 3 and 4, most models seem to capture the main features in the variability, although the spread is still large. Table 1 shows that different regional models can give very different results when using the same GCM.
Comparing with the results from MIST-I, the combined results Table 2 shows that for this method, the 11-member Euro-CORDEX ensemble performs overall worse than the 25-member ENSEMBLES ensemble. This may be due to several factors.

Firstly, the selection of GCMs and RCMs and the number of ensemble members are different. For instance, RACMO+ECHAM5, the best performing model combination from ENSEMBLES, is not present in the CORDEX ensemble. Since the 12 km resolution is more computationally expensive, institutes participating in Euro-CORDEX have not been able to produce as many runs as in the ENSEMBLES project. Secondly, there may be specific model biases in the new model selection. An evaluation by Kotlarski et al. (2014) showed that, for Scandinavia, biases of the 12 km ensemble are larger than in the ENSEMBLES data. While ENSEMBLES has a positive temperature bias in the winter, Euro-CORDEX has negative. Most models also seem to have a positive precipitation bias in Scandinavia, which is confirmed in our results.

Casanueva et al. (2015) analysed precipitation in 50 and 12 km resolution Euro-CORDEX runs and found only limited evidence of added value of higher resolution for precipitation intensity and frequency. The high resolution runs did however improve the spatial patterns. The paper also discussed some of the improvements and challenges in applying bias-correction, where the correction of some features usually lead to deterioration of other.

Most evaluations, including Kotlarski et al. (2014), are comparing RCM performance when driven by reanalyses. This has the benefits of preserving day-to-day variations as well as keeping consistent driving data between all models. Our method has instead focused on historical scenarios from the GCMs since we argued that the model performance then should be more similar to expected future performance when driven by GCMs and future scenarios. There may therefore be contributions, although small, from differences in the historical scenario between CMIP3 and CMIP5.

There are however some hints of improvement. C1-C3 all perform well for precipitation, with C2 beating all other models on precipitation variability and C1 having the second lowest precipitation error. Unlike in the ENSEMBLES dataset, there are no single model runs performing so badly as to warrant immediate exclusion.

Despite the seemingly disappointing results, there may still be benefits in other sub-regions not analysed in this study. Further work could for instance include stations in central Norway which have particular hydrological relevance. There are also additional Euro-CORDEX model runs on 50 km resolution that could be included. In the meantime, a selection of regional model results should be based on models from both ENSEMBLES and CORDEX.

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