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Data assimilation for continuous global assessment of severe conditions over terrestrial surfaces

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This supplementary materials reports on illustrations from the evaluation of LDAS-Monde analysis (assimilation of satellite derived Surface Soil Moisture, SSM, and Leaf Area Index, LAI) and open-loop (model-only, no assimilation) against in situ measurements of (i) evapotranspiration from the FLUXNET 2015 synthesis data set (http://fluxnet.fluxdata.org/, last access June 2019), (ii) soil moisture from the International Soil Moisture Network (ISMN, https://ismn.geo.tuwien.ac.at/en/, last access June 2019) as well as river discharge from several networks across the world.

Table SI. In situ river discharge datasets used in this study. Websites last access is August 2020.

Datasets (N stations used)	**Website**
AFD (14): Anuario de aforos digital, Spain	http://ceh-flumen64.cedex.es/anuarioaforos/default.asp
ANA (23): HidroWeb, Brazil	http://hidroweb.ana.gov.br/default.as
FRENCH (37): Banque HYDRO, France	http://www.hydro.eaufrance.fr/
GRDC (360): Global Runoff Data Centre, Globe	https://www.bafg.de/GRDC/EN/02_srvcs/21_tmsrs/riverdischarge_node.html
HYBAM (11): ORE-HYBAM, Amazon Basin	http://www.ore-hybam.org/index.php/en
HYDAT (102): National Water Data Archive, Canada	https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/monitoring/survey/data-products-services/national-archive-hydat.html
USGS (435): United States Geological Survey, USA	https://www.usgs.gov/mission-areas/water-resources

Table S2: Fluxnet-2015 sites used in this study

FLUXNET-ID	(latitude, longitude)	data-years used	data DOI
AR-Vir	(-33.4648, -66.4598)	2010-2012	10.18140/FLX/1440192
AT-Neu	(47.1167, 11.3175)	2010-2012	10.18140/FLX/1440121
AU-ASM	(-22.2830, 133.2490)	2010-2013	10.18140/FLX/1440194
AU-Cpr	(-34.0021, 140.5891)	2010-2014	10.18140/FLX/1440195
AU-DaP	(-14.0633, 131.3181)	2010-2013	10.18140/FLX/1440123
AU-DaS	(-14.1593, 131.3881)	2010-2014	10.18140/FLX/1440122
AU-Dry	(-15.2588, 132.3706)	2010-2014	10.18140/FLX/1440197
AU-Emr	(-23.8587, 148.4746)	2011-2013	10.18140/FLX/1440198
AU-Gin	(-31.3764, 115.7138)	2011-2014	10.18140/FLX/1440199
AU-How	(-12.4943, 131.1523)	2010-2014	10.18140/FLX/1440125
AU-Rig	(-36.6499, 145.5759)	2011-2014	10.18140/FLX/1440202
AU-Stp	(-17.1507, 133.3502)	2010-2014	10.18140/FLX/1440204
AU-TTE	(-22.2870 133.6400)	2012-2013	10.18140/FLX/1440205
AU-Tum	(-35.6566, 148.1517)	2010-2014	10.18140/FLX/1440126
AU-Whr	(-36.6732, 145.0294)	2011-2014	10.18140/FLX/1440206
AU-Wom	(-37.4222, 144.0944)	2010-2012	10.18140/FLX/1440207
BE-Bra	(51.3076, 4.5198)	2010-2014	10.18140/FLX/1440128
BE-Lon	(50.5516, 4.7461)	2010-2014	10.18140/FLX/1440129
BE-Vie	(50.3050, 5.9981)	2010-2014	10.18140/FLX/1440130
CH-Cha	(47.2102, 8.4104)	2010-2014	10.18140/FLX/1440131
CH-Dav	(46.8153, 9.8559)	2010-2014	10.18140/FLX/1440132
CH-Fru	(47.1158, 8.5378)	2010-2014	10.18140/FLX/1440133
CH-Lae	(47.4781, 8.3650)	2010-2014	10.18140/FLX/1440134
CH-Oe2	(47.2863, 7.7343)	2010-2014	10.18140/FLX/1440136
CN-Sw2	(41.7902, 111.8971)	2010-2012	10.18140/FLX/1440212
CZ-wet	(49.0247, 14.7704)	2010-2014	10.18140/FLX/1440145
DE-Akm	(53.8662, 13.6834)	2010-2014	10.18140/FLX/1440213
DE-Geb	(51.1001, 10.9143)	2010-2014	10.18140/FLX/1440146
DE-Gri	(50.9500, 13.5126)	2010-2014	10.18140/FLX/1440147
DE-Kli	(50.8931, 13.5224)	2010-2014	10.18140/FLX/1440149
DE-Lkb	(49.0996, 13.3047)	2010-2013	10.18140/FLX/1440214
DE-Obe	(50.7867, 13.7212)	2010-2014	10.18140/FLX/1440151
DE-RuR	(50.6219, 6.3041)	2011-2014	10.18140/FLX/1440215
DE-RuS	(50.8659, 6.4472)	2011-2014	10.18140/FLX/1440216
DE-SfN	(47.8064, 11.3275)	2012-2014	10.18140/FLX/1440219
DE-Spw	(51.8922, 14.0337)	2010-2014	10.18140/FLX/1440220
DE-Tha	(50.9624, 13.5652)	2010-2014	10.18140/FLX/1440152
DK-NuF	(64.1308, -51.3861)	2010-2014	10.18140/FLX/1440222
DK-Sor	(55.4859, 11.6446)	2010-2014	10.18140/FLX/1440155
DK-ZaH	(74.4733, -20.5503)	2010-2011	10.18140/FLX/1440224
FI-Hyy	(61.8474, 24.2948)	2010-2014	10.18140/FLX/1440158
FI-Sod	(67.3624, 26.6386)	2010-2014	10.18140/FLX/1440160
IT-BCi	(40.5237, 14.9574)	2010-2014	10.18140/FLX/1440166
IT-CA1	(42.3804, 12.0266)	2011-2014	10.18140/FLX/1440230
IT-CA2	(42.3772, 12.0260)	2011-2014	10.18140/FLX/1440231
IT-CA3	(42.3800, 12.0222)	2011-2014	10.18140/FLX/1440232
IT-Col	(41.8494, 13.5881)	2010-2014	10.18140/FLX/1440167
IT-Lav	(45.9562, 11.2813)	2010-2014	10.18140/FLX/1440169
IT-MBo	(46.0147, 11.0458)	2010-2013	10.18140/FLX/1440170
IT-Ren	(46.5869, 11.4337)	2010-2013	10.18140/FLX/1440173
IT-Ro2	(42.3903, 11.9209)	2010-2012	10.18140/FLX/1440175
IT-SRo	(43.7279, 10.2844)	2013-2014	10.18140/FLX/1440176
IT-Tor	(45.8444, 7.5781)	2010-2014	10.18140/FLX/1440237
NL-Loo	(52.1666, 5.7436)	2010-2013	10.18140/FLX/1440178
RU-Cok	(70.8291, 147.4943)	2010-2014	10.18140/FLX/1440182
RU-Fyo	(56.4615, 32.9221)	2010-2014	10.18140/FLX/1440183
US-AR1	(36.4267, -99.4200)	2010-2012	10.18140/FLX/1440103
US-AR2	(36.6358, -99.5975)	2010-2012	10.18140/FLX/1440104

US-ARM	(36.6058, -97.4888)	2010-2012	10.18140/FLX/1440066
US-GLE	(41.3665, -106.2399)	2010-2014	10.18140/FLX/1440069
US-Ha1	(42.5378, -72.1715)	2010-2012	10.18140/FLX/1440071
US-Los	(46.0827, -89.9792)	2010-2014	10.18140/FLX/1440076
US-Me2	(44.4523, -121.557)	2010-2014	10.18140/FLX/1440079
US-Me6	(44.3233, -121.6078)	2010-2014	10.18140/FLX/1440099
US-MMS	(39.3232, -86.4131)	2010-2014	10.18140/FLX/1440083
US-Myb	(38.0499, -121.7650)	2010-2014	10.18140/FLX/1440105
US-Ne1	(41.1651, -96.4766)	2010-2013	10.18140/FLX/1440084
US-Ne2	(41.1649, -96.4701)	2010-2013	10.18140/FLX/1440085
US-Ne3	(41.1797, -96.4397)	2010-2013	10.18140/FLX/1440086
US-NR1	(40.0329, -105.5464)	2010-2014	10.18140/FLX/1440087
US-PFa	(45.9459, -90.2723)	2010-2014	10.18140/FLX/1440089
US-Prr	(65.1237, -147.4876)	2010-2013	10.18140/FLX/1440113
US-SRG	(31.7894, -110.8277)	2010-2014	10.18140/FLX/1440114
US-SRM	(31.8214, -110.8661)	2010-2014	10.18140/FLX/1440090
US-Syv	(46.2420, -89.3477)	2010-2014	10.18140/FLX/1440091
US-Ton	(38.4316, -120.9660)	2010-2014	10.18140/FLX/1440092
US-Tw1	(38.1074, -121.6469)	2012-2014	10.18140/FLX/1440108
US-Twt	(38.1087, -121.6531)	2010-2014	10.18140/FLX/1440106
US-UMB	(45.5598, -84.7138)	2010-2014	10.18140/FLX/1440093
US-UMd	(45.5625, -84.6975)	2010-2014	10.18140/FLX/1440101
US-Var	(38.4133, -120.9507)	2010-2014	10.18140/FLX/1440094
US-WCr	(45.8059, -90.0799)	2010-2014	10.18140/FLX/1440095
US-Whs	(31.7438, -110.0522)	2010-2014	10.18140/FLX/1440097
US-Wkg	(31.7365, -109.9419)	2010-2014	10.18140/FLX/1440096
ZA-Kru	(-25.0197, 31.4969)	2010-2010	10.18140/FLX/1440188

Table S3: Left column: evaluation of LDAS_ERA5 analysis and open-loop soil moisture (third layer of soil, 4 and 10 cm) against in situ measurements of soil moisture at 5cm depth from the International Soil Moisture Network (ISMN, https://ismn.geo.tuwien.ac.at/en/, last access June 2019). Unbiased RMSD, correlation on absolute values (R), anomaly values ($R_{anomaly}$) along with their 95% Confidence Interval, bias values are reported along with informations specific to each network used (acronyms, sensor depth, localisation, number of sensors used in the study as well as mean sampling for absolute values (anomaly values)), 786 stations are available. Right column: same as left for LDAS_ERA5 soil moisture (fourth layer of soil, 10 and 20 cm depth) and in situ measurements at 20 cm depth when available, 685 stations are available. Websites last access is August 2020.

	ubRMSD (m^3m^{-3})	**R, $R_{anomaly}$ [-]**	**Bias (Analysis or Model - insitu) (m^3m^{-3})**	**ubRMSD (m^3m^{-3})**	**R [-]**	**Bias (Analysis or Model - insitu) (m^3m^{-3})**
	AMMA-CATCH (0.05-0.05 cm) Benin, Niger, Mali, 9 sensors, Npt=1661(1647) (Lebel et al., 2009)			**AMMA-CATCH** (0.20-0.20 cm) Benin, Niger, Mali, 4 sensors, Npt=1355 (Lebel et al., 2009)		
Model	0.032	0.74±0.02 (0.19±0.04)	0.124	0.037	0.87±0.01	0.141
Analysis	0.034	0.72±0.02 (0.19±0.04)	0.123	0.037	0.87±0.01	0.141
	FR-Aqui (0.05-0.05cm) France, 3 sensors, Npt=1200(1200)			**FR-Aqui** (0.20-0.20cm) France, 1 sensors, Npt=1350		
Model	0.044	0.80±0.02 (0.64±0.03)	0.068	0.072	0.75±0.02	0.060
Analysis	0.044	0.80±0.02 (0.65±0.03)	0.071	0.072	0.77±0.02	0.067
	OZNET (0.00-0.05 cm) Australia, 19 sensors, Npt=1891(1878) (Smith et al., 2012)			**OZNET** (0.00-0.08 cm) Australia, 19 sensors, Npt=949(932) (Smith et al., 2012)		
Model	0.067	0.74±0.02 (0.63±0.03)	0.079	0.041	0.71±0.03 (0.65±0.03)	0.105
Analysis	0.067	0.75±0.02 (0.64±0.03)	0.086	0.040	0.73±0.03 (0.65±0.03)	0.111
	HOBE (0.00-0.05cm) Denmark, 44 sensors, Npt=1088(1083) (Bircher et al., 2011)			**HOBE** (0.20-0.25cm) Denmark, 33 sensors, Npt=1088 (Bircher et al., 2011)		
Model	0.045	0.64±0.03 (0.66±0.03)	0.041	0.039	0.66±0.03	0.037
Analysis	0.044	0.65±0.03 (0.67±0.03)	0.041	0.039	0.67±0.03	0.036
	HYDROL-NET-PERUGIA (0.05-0.05 cm) Italy, 1 sensors, Npt=998(988) (Morbidelli et al., 2014)					
Model	0.046	0.74±0.03 (0.67±0.03)	0.040			
Analysis	0.046	0.74±0.03 (0.68±0.03)	0.040			
	BIEBRZA-S-1 (0.05-0.05 cm) Poland, 38 sensors, Npt=617(690)					

		(http://www.igik.edu.pl/en)				
Model	0.096	0.58±0.04 (0.60±0.04)	-0.032			
Analysis	0.097	0.56±0.04 (0.60±0.04)	-0.042			
		MOL-RAO (0.08-0.08 cm) Germany, 1 sensors, Npt=953(944) (Beyrich et al., 2007)				
Model	0.040	0.79±0.02 (0.70±0.03)	0.045			
Analysis	0.040	0.80±0.02 (0.70±0.03)	0.047			

	ubRMSD (m^3m^{-3})	**$R(R_{anomaly})$ [-]**	**Bias (Analysis or Model - insitu) (m^3m^{-3})**	**ubRMSD (m^3m^{-3})**	**R [-]**	**Bias (Analysis or Model - insitu) (m^3m^{-3})**
		DAHRA (0.05-0.05 cm) Sénégal, 1 sensors, Npt=1821(1821) (Tagesson et al., 2015)				
Model	0.024	0.69±0.02 (0.23±0.04)	0.076			
Analysis	0.024	0.69±0.02 (0.23±0.04)	0.075			
		REMEDHUS (0.00-0.05 cm) Spain, 20 sensors, Npt=2309(2295) (http://campus.usal.es/~hidrus/)				
Model	0.046	0.73±0.02 (0.50±0.03)	0.134			
Analysis	0.046	0.73±0.02 (0.50±0.03)	0.133			
		FMI (0.05-0.05 cm) Finland, 10 sensors, Npt=792(790) (http://fmiarc.fmi.fi/)			**FMI** (0.20-0.20 cm) Finland, 3 sensors, Npt=786 (http://fmiarc.fmi.fi/)	
Model	0.035	0.68±0.03 (0.74±0.03)	0.254	0.037	0.48±0.04	0.284
Analysis	0.036	0.67±0.03 (0.75±0.03)	0.248	0.037	0.49±0.04	0.279
		RSMN (0.00-0.05 cm) Romania, 19 sensors, Npt=1032(1023) (http://assimo.meteoromania.ro)				
Model	0.049	0.56±0.04 (0.57±0.04)	0.141			
Analysis	0.049	0.56±0.04 (0.57±0.04)	0.143			
		ARM (0.05-0.05 cm) USA, 10 sensors, Npt=932(918) (http://www.arm.gov/)				
Model	0.092	0.30±0.05 (0.47±0.04)	-0.023			

Analysis	0.091	0.29±0.05 (0.47±0.04)	-0.018			
	SCAN (0.05-0.05 cm) USA, 160 sensors, Npt=1841(1829) (http://www.wcc.nrcs.usda.gov/)			**SCAN** (0.20-0.20 cm) USA, 158 sensors, Npt=1998 (http://www.wcc.nrcs.usda.gov/)		
Model	0.059	0.63±0.03 (0.55±0.03)	0.078	0.050	0.56±0.03	0.027
Analysis	0.058	0.64±0.03 (0.55±0.03)	0.080	0.049	0.57±0.03	0.029
	SMOSMANIA (0.05-0.05 cm) France, 23 sensors, Npt=1985(1980) (Albergel et al., 2008)			**SMOSMANIA** (0.20-0.20 cm) France, 23 sensors, Npt=1985 (Albergel et al., 2008)		
Model	0.047	0.80±0.01 (0,70±0.02)	0.076	0.042	0.78±0.03	0.093
Analysis	0.047	0.80±0.01 (0.70±0.02)	0.077	0.042	0.77±0.03	0.094
	UMBRIA (0.05-0.05 cm) Italy, 16 sensors, Npt=2184(2181) (Brocca et al., 2011)					
Model	0.065	0.73±0.02 (0.58±0.03)	0.057			
Analysis	0.064	0.73±0.02 (0.58±0.03)	0.057			

	ubRMSD (m^3m^{-3})	**R($R_{anomaly}$) [-]**	**Bias (Analysis or Model - insitu) (m^3m^{-3})**	**ubRMSD (m^3m^{-3})**	**R [-]**	**Bias (Analysis or Model - insitu) (m^3m^{-3})**
	SNOTEL (0.05-0.05 cm) USA, 269 sensors, Npt=1160 (1150) (http://www.wcc.nrcs.usda.gov//)			**SNOTEL** (0.20-0.20 cm) USA, 310 sensors, Npt=1187 (http://www.wcc.nrcs.usda.gov//)		
Model	0.073	0.65±0.03 (0.44±0.04)	0.075	0.066	0.64±0.03	0.055
Analysis	0.073	0.65±0.03 (0.44±0.04)	0.075	0.065	0.65±0.03	0.056
	TERENO (0.05-0.05cm) Germany, 14 sensors, Npt=1449(1447) (Zacharias et al., 2011)			**TERENO** (0.20-0.20cm) Germany, 14 sensors, Npt=1489 (Zacharias et al., 2011)		
Model	0.055	0.76±0.02 (0.65±0.03)	0.025	0.045	0.69±0.03	0.029
Analysis	0.054	0.76±0.02 (0.65±0.03)	0.024	0.045	0.69±0.03	0.028
	USCRN (0.05 0.05 cm) USA, 114 sensors, Npt=2090(2082) (Bell et al., 2013)			**USCRN** (0.20 0.20 cm) USA, 91 sensors, Npt=2107 (Bell et al., 2013)		
Model	0.050	0.73±0.02	0.083	0.048	0.64±0.02	0.045

		(0.64±0.04)				
Analysis	0.050	0.73±0.02 (0.65±0.04)	0.085	0.047	0.63±0.02	0.048
	SOILSCAPE (0.04-0.04 cm) USA, 7 sensors, Npt=785(784) (Moghaddam et al., 2016)			**SOILSCAPE** (0.20-0.20 cm) USA, 49 sensors, Npt=988 (Moghaddam et al., 2016)		
Model	0.061	0.55±0.05 (0.44±0.05)	0.014	0.051	0.82±0.02	0.058
Analysis	0.060	0.56±0.05 (0.44±0.05)	0.018	0.051	0.82±0.02	0.059
	SOILSCAPE (0.05-0.05 cm) USA, 49 sensors, Npt=999(999) (Moghaddam et al., 2016)					
Model	0.054	0.88±0.01 (0.60±0.04)	0.064			
Analysis	0.054	0.88±0.01 (0.58±0.04)	0.064			

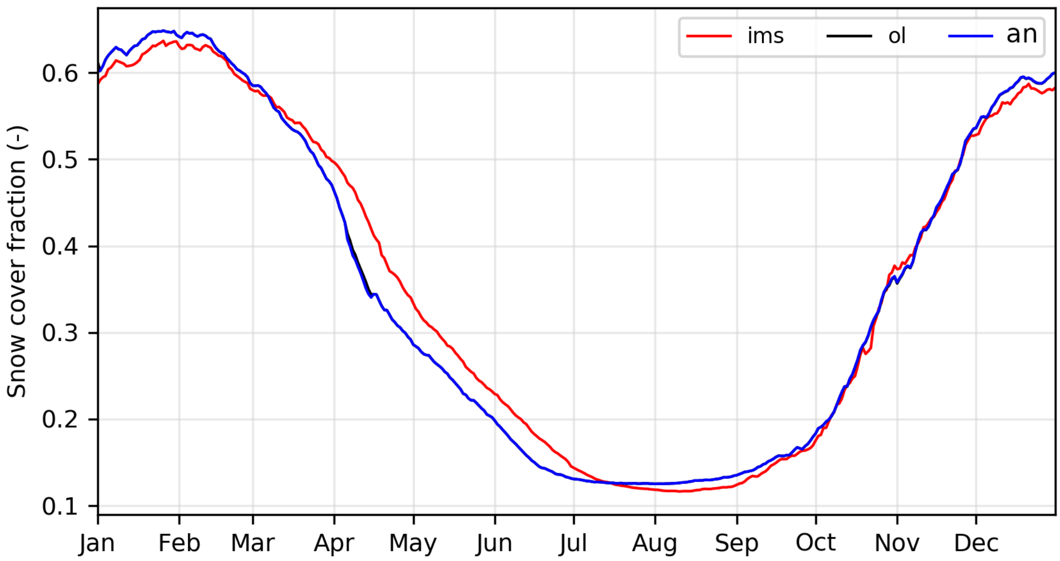

Figure S1: Mean northern hemisphere snow cover fraction over 2010-2018 for the Interactive Multi-sensor Snow and Ice Mapping System data (ims, in red), LDAS-Monde open-loop (ol, in black) and analysis (an, in blue) forced by ERA-5 atmospheric reanalysis.

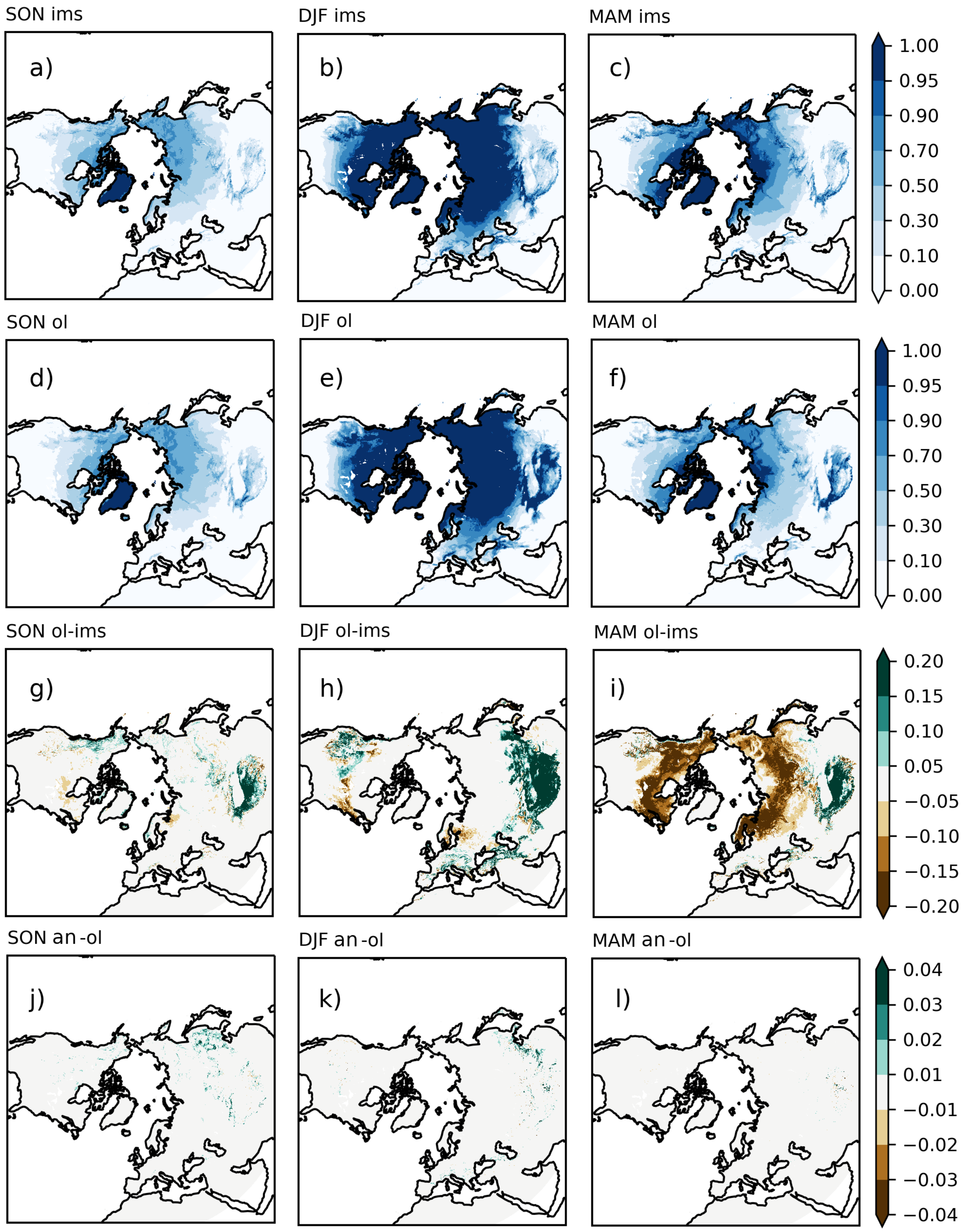

Figure S2: a), b) and c) Maps of snow cover fraction from the Interactive Multi-sensor Snow and Ice Mapping System data (ims) for September-October-November (SON), December-January-February (DJF) and March-April-May (MAM), respectively for the period 2010-2018. d), e) and f) same as a), b) and c) for LDAS-Monde open-loop (ol) forced by ERA-5. g), h) and i) maps of snow cover differences, ims-ol for SON, DJF and MAM, respectively, for the 2010-2018 period. j), k) and l), same as g), h) and I) between LDAS-Monde analysis and open-loop (an-ol).

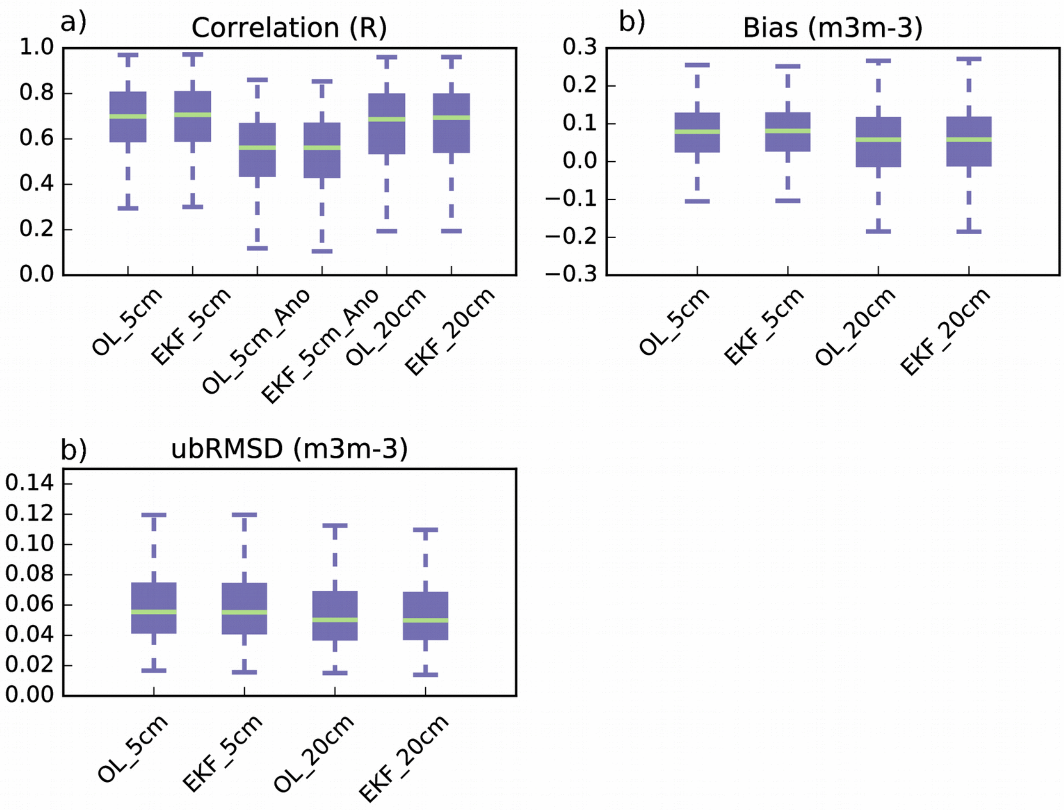

Figure S3: a) Boxplots representing the distribution of the correlation values on absolute time-series and anomaly time-series ("Ano") between the stations with in situ measurements of soil moisture either 5cm depth or 20 cm depth and soil moisture from LDAS_ERA5 openloop and analysis over 2010-2018 (third and forth layer of soil, respectively). Correlation values rae presented for surface soil moisture (5 cm depth measurements against third layer of soil), only. Distribution are centred on the median values. b) Distribution of the Bias values between the stations with in situ measurements of soil moisture either 5cm depth or 20 cm depth and soil moisture from LDAS_ERA5 openloop and analysis over 2010-2018 (third and forth layer of soil, respectively).c) Same as b) for ubRMSD.

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