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

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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.

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: Evaluation of LDAS-ERA5 analysis and open-loop surface soil moisture against in situ measurements of surface soil moisture from the International Soil Moisture Network (ISMN, https://ismn.geo.tuwien.ac.at/en/, last access June 2019). Unbiased RMSD, correlation (R) and 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).

	ubRMSD (m^3m^{-3})	**R** (-)	**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 (Lebel et al., 2009)			**FR-Aqui** (0.05-0.05cm) France, 3 sensors, Npt=1200		
Model	0.032	0.74	0.124	0.044	0.80	0.068
Analysis	0.034	0.72	0.123	0.044	0.80	0.071
	OZNET (0.00-0.05 cm) Australia, 19 sensors, Npt=1891 (Smith et al., 2012)			**HOBE** (0.00-0.05cm) Denmark, 137 sensors, Npt=795 (Bircher et al., 2011)		
Model	0.067	0.74	0.079	0.055	0.58	0.024
Analysis	0.067	0.75	0.086	0.055	0.58	0.024
	OZNET (0.00-0.08 cm) Australia, 19 sensors, Npt=949 (Smith et al., 2012)			**HYDROL-NET-PERUGIA** (0.05-0.05 cm) Italy, 1 sensors, Npt=998 (Morbidelli et al., 2014)		
Model	0.041	0.71	0.105	0.046	0.74	0.040
Analysis	0.040	0.73	0.111	0.046	0.74	0.040
	BIEBRZA-S-1 (0.05-0.05 cm) Poland, 38 sensors, Npt=617 (http://www.igik.edu.pl/en)			**MOL-RAO** (0.08-0.08 cm) Germany, 1 sensors, Npt=953 (Beyrich et al., 2007)		
Model	0.096	0.58	-0.032	0.040	0.79	0.045
Analysis	0.097	0.56	-0.042	0.040	0.80	0.047
	DAHRA (0.05-0.05 cm) Sénégal, 2 sensors, Npt=1821 (Tagesson et al., 2015)			**PBO-H20** (0.00 0.05 cm) USA, 146 sensors, Npt = 1432 (Larson et al., 2008)		
Model	0.026	0.72	0.063	0.051	0.61	0.085
Analysis	0.025	0.72	0.062	0.051	0.62	0.087
	DAHRA (0.05-0.05 cm) Sénégal, 1 sensors, Npt=1821 (Tagesson et al., 2015)			**REMEDHUS** (0.00-0.05 cm) Spain, 20 sensors, Npt=2309 (http://campus.usal.es/~hidrus/)		
Model	0.024	0.69	0.076	0.046	0.73	0.134
Analysis	0.024	0.69	0.075	0.046	0.73	0.133
	FMI (0.05-0.05 cm) Finland, 46 sensors, Npt=1108 (http://fmiarc.fmi.fi/)			**RSMN** (0.00-0.05 cm) Romania, 19 sensors, Npt=1032 (http://assimo.meteoromania.ro)		
Model	0.035	0.68	0.254	0.049	0.56	0.141
Analysis	0.036	0.67	0.248	0.049	0.56	0.143
	ARM (0.05-0.05 cm) USA, 10 sensors, Npt=932 (http://www.arm.gov/)			**SCAN** (0.05-0.05 cm) USA, 160 sensors, Npt=1841 (http://www.wcc.nrcs.usda.gov/)		
Model	0.092	0.30	-0.023	0.059	0.63	0.078
Analysis	0.091	0.29	-0.018	0.058	0.64	0.080

	ubRMSD (m^3m^{-3})	R (-)	Bias (Analyse or Model - insitu) (m^3m^{-3})	ubRMSD (m^3m^{-3})	R (-)	Bias (Analyse or Model - insitu) (m^3m^{-3})
	SMOSMANIA (0.05-0.05 cm) France, 23 sensors, Npt=1985 (Albergel et al., 2008)			**UMBRIA** (0.05-0.05 cm) Italy, 16 sensors, Npt=1288 (Brocca et al., 2011)		
Model	0.047	0.80	0.076	0.065	0.73	0.057
Analysis	0.047	0.80	0.077	0.064	0.73	0.057
	SNOTEL (0.05-0.05 cm) USA, 269 sensors, Npt=1160 (http://www.wcc.nrcs.usda.gov//)			**TERENO** (0.05-0.05cm) Germany, 14 sensors, Npt=1449 (Zacharias et al., 2011)		
Model	0.073	0.65	0.075	0.055	0.76	0.025
Analysis	0.073	0.65	0.075	0.054	0.76	0.024
	SOILSCAPE (0.04-0.04 cm) USA, 7 sensors, Npt=785 (Moghaddam et al., 2016)			**USCRN** (0.05 0.05 cm) USA, 114 sensors, Npt=2090 (Bell et al., 2013)		
Model	0.061	0.55	0.014	0.050	0.73	0.083
Analysis	0.060	0.56	0.018	0.050	0.73	0.085
	SOILSCAPE (0.05-0.05 cm) USA, 49 sensors, Npt=999 (Moghaddam et al., 2016)					
Model	0.054	0.88	0.064			
Analysis	0.054	0.88	0.064			

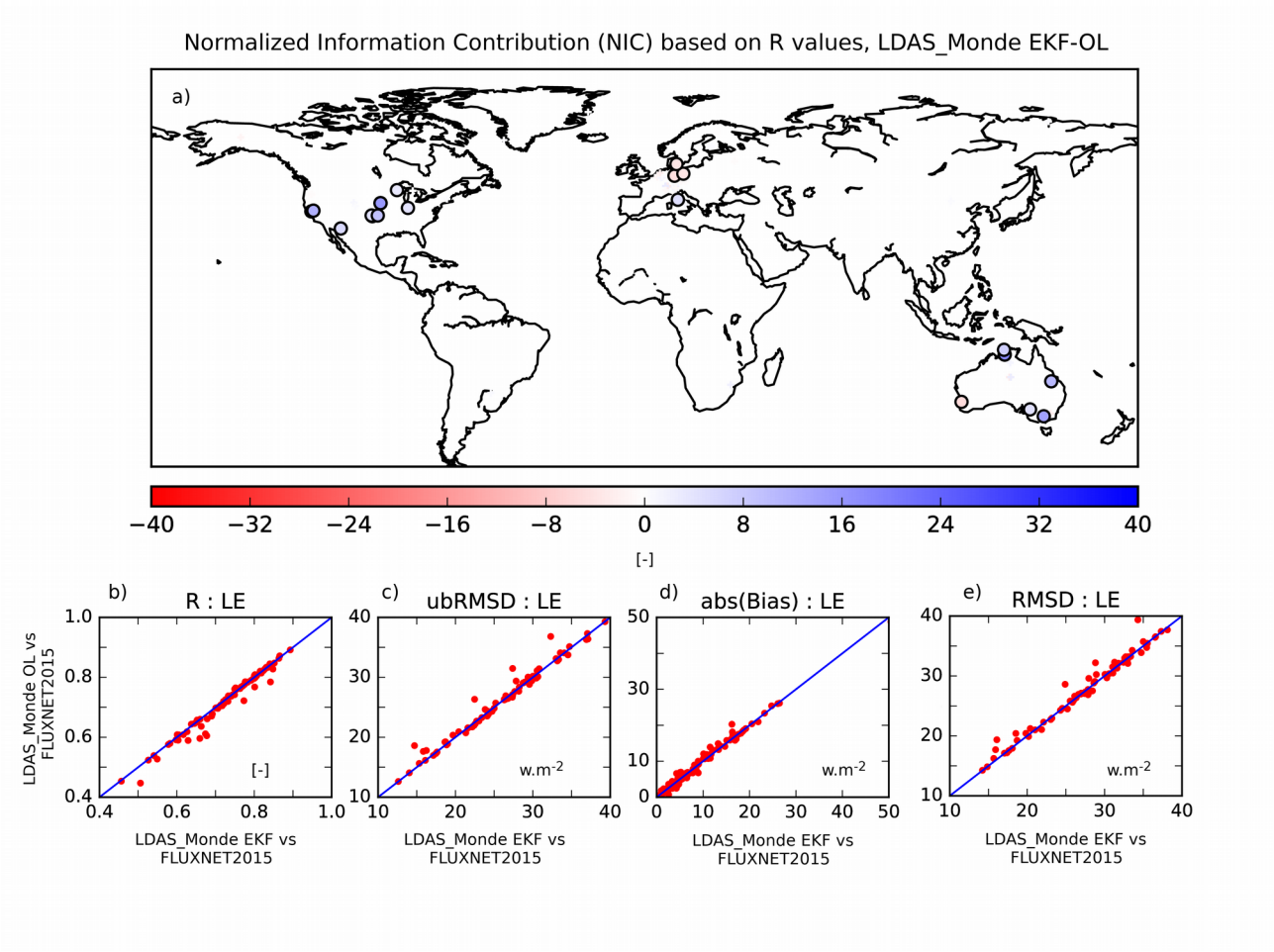

Figure S1: (a) Map of Normalized Information Contribution (NIC, Equation 1) applied on correlation values between evapotranspiration from LDAS_ERA5 analysis (open-loop) and observations from the FLUXNET 2015 synthesis data set. NIC scores are classified into 2 categories (i) negative impact from the analysis with respect to the model with values smaller than -3 % (red circles, 5 stations), (ii) positive impact from the analysis with respect to the model with values greater than +3 % (blue circles, 20 stations). For sack of clarity stations presenting a neutral impact with values between -3 % and +3 % (60 stations) are not reported. (b), (c), (d) and (e) scatter-plots of R, ubRMSD, absolute bias and RMSD between LDAS_ERA5 open-loop and the 85 stations from the FLUXNET 2015 (y-axis) and LDAS_ERA5 analysis and the same pool of stations (x-axis).

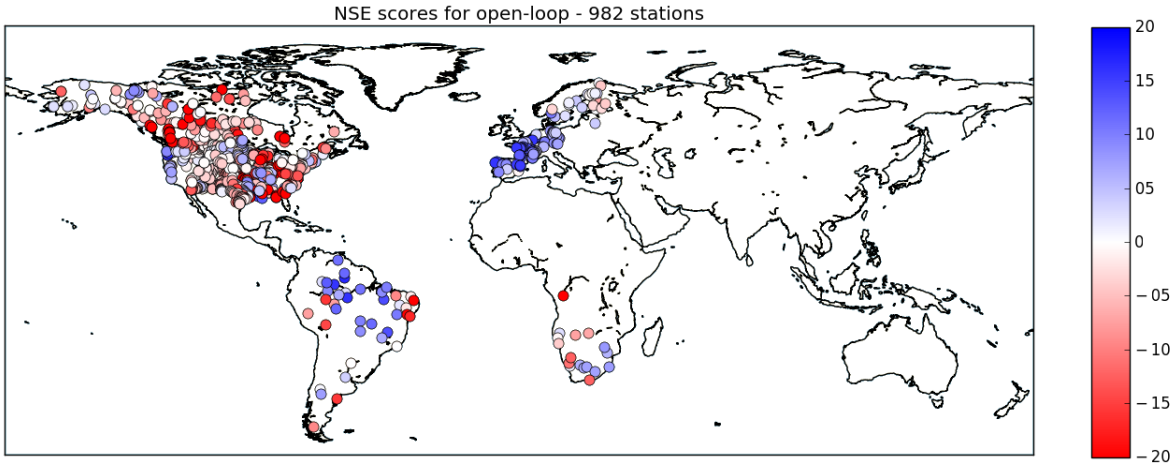

Figure S2: Global map of Nash-Sutcliff Efficiency score (NSE) between river discharge from LDAS_ERA5 open-loop and in situ measurements from the networks presented in Table S1 over 2010-2016. Only stations where more than 4-year of data are available, with a drainage area greater than 10000km^2 are considered. Stations with NSE values smaller than -2 are discarded, also, leading to a subset 982 stations available.

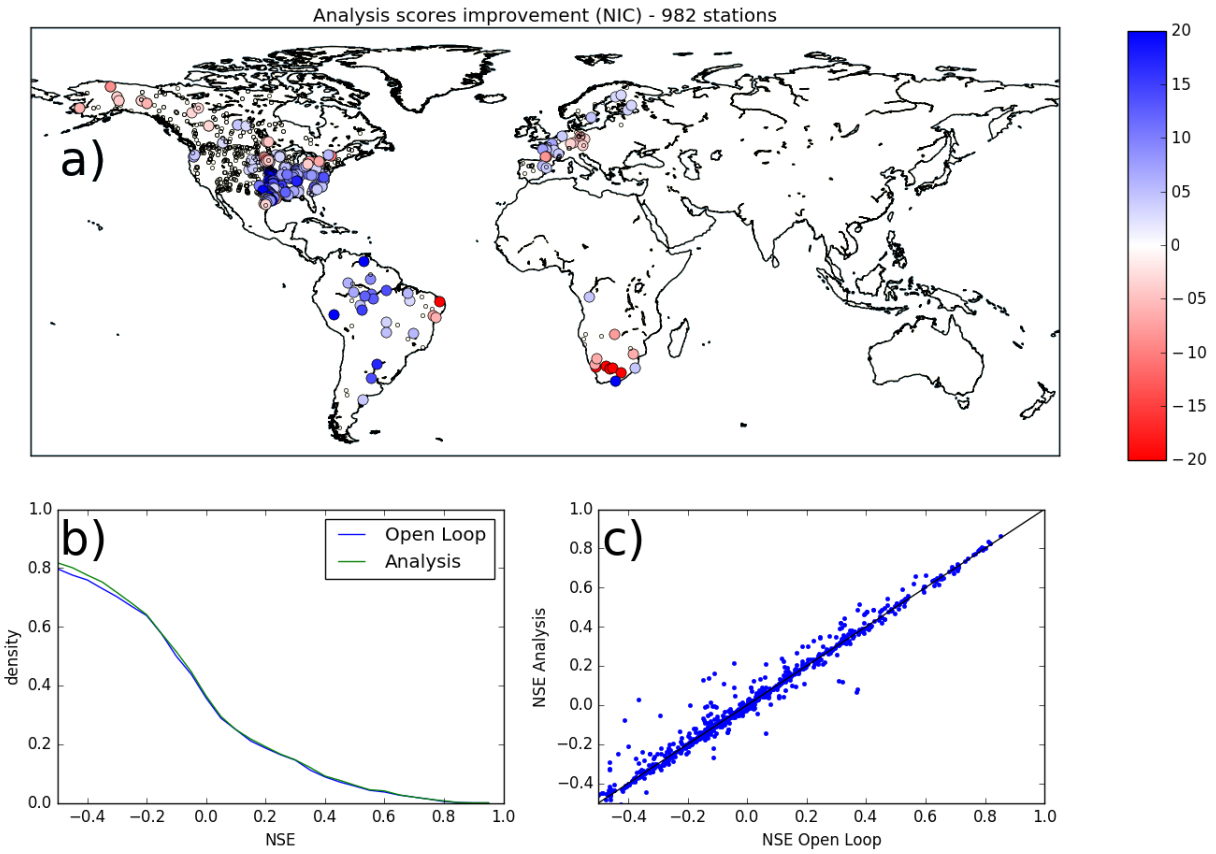

Figure S3: (a) Normalized Information Contribution scores (NIC) based on NSE scores on river discharge. Small dots represent stations for which NIC are between [-3%, +3%] (i.e. neutral impact from LDAS_ERA5 analysis), NIC values greater than +3% (blue large circles) suggest an improvement from LDAS_ERA5 analysis over LDAS_ERA5 open-loop while values smaller than -3% (large red circles) suggest a degradation. (b) density of NIC values for LDAS_ERA5 open-loop (in blue) and analysis (in red), (c) scatter-plots of NIC values for LDAS_ERA5 open-loop (x-axis) and analysis (y-axis).

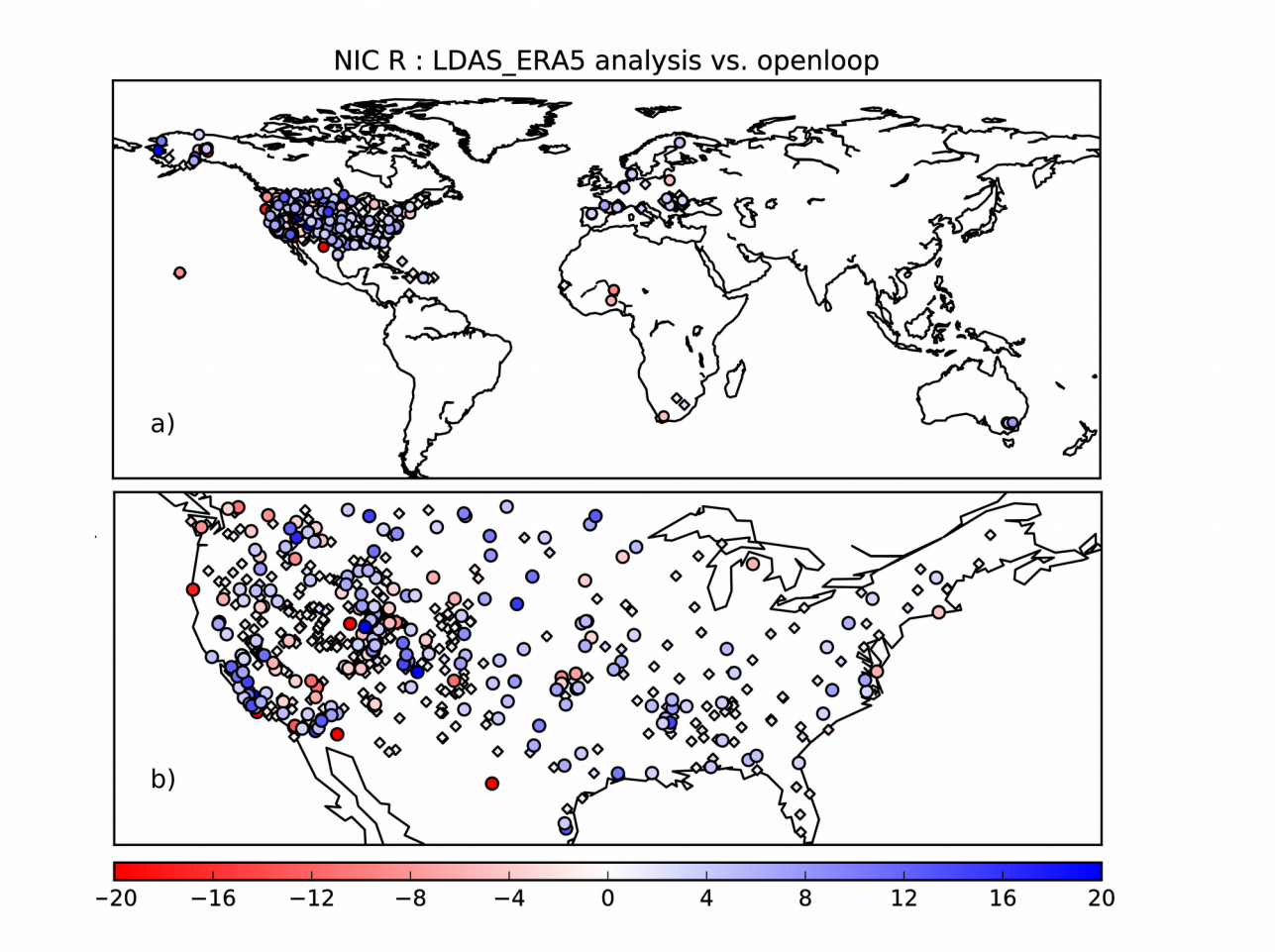

Figure S4: (a) Normalized Information Contribution scores (NIC) based on correlations (R) scores between in situ surface soil moisture and surface soil moisture from LDAS_ERA5 (analysis or open-loop). Small dots represent stations for which NIC are between [-3%, +3%] (i.e. neutral impact from LDAS_ERA5 analysis), NIC values greater than +3% (blue large circles) suggest an improvement from LDAS_ERA5 analysis over LDAS_ERA5 open-loop while values smaller than -3% (large red circles) suggest a degradation. (b) Same as (a) zooming on the continental USA.

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