

# **An enhanced integrated water vapour dataset from more than 10,000 global ground-based GPS stations in 2020**

Peng Yuan<sup>1</sup>, Geoffrey Blewitt<sup>2</sup>, Corné Kreemer<sup>2</sup>, William C. Hammond<sup>2</sup>, Donald Argus<sup>3</sup>, Xungang Yin<sup>4</sup>, Roeland Van Malderen<sup>5</sup>, Michael Mayer<sup>1</sup>, Weiping Jiang<sup>6</sup>, Joseph Awange<sup>7</sup>, Hansjörg Kutterer<sup>1</sup>

1 Karlsruhe Institute of Technology, Geodetic Institute, Karlsruhe, BW, Germany

2 Nevada Bureau of Mines and Geology, University of Nevada, Reno, NV, USA

3 Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

4 NOAA National Centers for Environmental Information, Asheville, NC, USA

5 Royal Meteorological Institute of Belgium, Brussels, Belgium

6 Wuhan University, GNSS Research Center, Wuhan, China

7 Curtin University, School of Earth and Planetary Sciences, Perth, Australia

*Correspondence to:* Peng Yuan ([peng.yuan@kit.edu](mailto:peng.yuan@kit.edu))

## Supplementary Material

**Table S1.** Locations of the 182 GPS, radiosonde, and synoptic station clusters. The  $S_{hor}$  and  $S_{ver}$  of the radiosonde and synoptic stations indicate their distances with respect to the collocated GPS stations in horizontal and vertical, respectively.

Order	GPS stations				Radiosonde stations				Synoptic stations		
	Name	Latitude (°)	Longitude (°)	Altitude (gpm)	Name	Type	$S_{hor}$ (km)	$S_{ver}$ (gpm)	Name	$S_{hor}$ (km)	$S_{ver}$ (gpm)
1	AC24	58.68	-156.65	21.2	70326	RS41	0.9	-12.8	70326	0.2	-1.2
2	ALCE	32.95	-87.15	86.3	72230	LMS6	43.0	87.5	72230	43.0	86.0
3	AMUA	-3.09	-60.02	39.2	82332	Others	7.5	44.6	82332	7.0	42.0
4	ANMG	2.79	101.51	18.0	48650	Others	22.8	3.0	48650	23.0	3.0
5	APMA	0.05	-51.10	13.0	82099	Others	3.4	3.0	82098	2.8	4.1
6	ARGI	62.00	-6.78	53.6	06011	Others	3.0	0.5	06011	2.3	7.5
7	ARVA	39.80	-105.09	1642.1	72469	LMS6	19.1	-32.3	72565	37.2	3.9
8	ASPA	-14.33	-170.72	21.0	91765	LMS6	1.4	-15.5	91765	1.1	-17.3
9	AUCK	-36.60	174.83	97.7	93112	RS41	28.4	-67.7	93110	44.3	-90.7
10	AVLN	-41.20	174.93	26.3	93417	RS41	32.8	-20.3	93420	33.2	-19.3
11	AZFL	35.18	-111.66	2108.7	72376	RS92	16.1	67.5	72375	3.8	21.9
12	BAKE	64.32	-96.00	46.4	71926	Others	0.2	4.4	71356	0.1	4.6
13	BCOV	50.54	-126.84	51.8	71109	Graw	40.7	-34.4	71109	40.0	-30.2
14	BET1	60.79	-161.84	40.1	70219	RS41	0.3	-7.0	70219	0.8	-7.4
15	BILS	47.54	-124.25	61.1	72797	Others	49.5	-4.3	72797	49.8	-4.7
16	BLOM	40.50	-89.00	237.3	74560	LMS6	47.8	-58.2	74467	47.1	-55.4
17	BOGI	52.48	21.04	109.2	12374	Others	9.2	-14.9	12375	34.7	1.2
18	BOR3	53.29	7.02	1.9	10113	RS41	48.1	9.1	06280	34.7	3.3
19	BRAZ	-15.95	-47.88	1115.9	83378	Others	10.8	-57.5	83378	10.1	-58.1
20	BRSO	32.37	-64.70	21.4	78016	RS41	1.8	-17.4	78016	1.3	-15.9
21	BRST	48.38	-4.50	14.3	07110	M10	9.4	84.7	07100	42.4	53.7
22	BUCU	44.46	26.13	107.7	15420	RS41	6.4	-17.7	15419	47.7	52.3
23	BUTE	47.48	19.06	137.3	12843	Others	10.9	0.8	12843	10.9	1.8
24	CAG1	39.23	9.11	88.6	16546	RS41	18.0	-59.7	16546	18.4	-58.2
25	CALC	29.77	-93.34	12.6	72240	RS92	41.6	-7.8	72240	41.3	-10.6
26	CAM1	50.22	-5.33	86.2	03808	RS41	0.0	0.9	03808	0.8	1.9

27	CANT	43.47	-3.80	48.9	08023	RS41	2.1	3.1	08023	1.2	10.1
28	CDB8	55.19	-162.71	32.5	70316	RS41	1.2	-7.2	70316	3.6	-10.5
29	CHUR	58.76	-94.09	28.9	71913	Graw	3.1	-0.3	71618	2.6	0.5
30	CJTR	34.82	-92.27	153.6	72340	LMS6	1.9	19.5	72340	11.1	-77.2
31	CLGO	64.87	-147.86	185.2	70261	RS41	6.5	-51.3	70261	7.9	-53.9
32	CRAR	-77.85	166.67	32.7	89664	RS41	0.2	-8.7	89664	4.2	-8.6
33	CTNH	41.30	-72.91	67.2	72501	RS92	48.3	-47.6	72508	48.4	70.7
34	CUT0	-32.00	115.90	56.5	94610	RS41	11.5	-36.2	94612	39.0	-11.2
35	DAV1	-68.58	77.97	27.2	89571	RS41	0.4	-9.2	89571	0.7	-4.1
36	DCDC	38.95	-77.10	88.2	72403	LMS6	33.7	0.1	72405	12.3	-84.1
37	DVPT	47.66	-118.15	746.1	72786	LMS6	39.1	-16.9	72785	46.6	-28.3
38	DWNI	-12.44	130.96	36.2	94120	RS41	7.2	-4.9	95121	41.2	-21.2
39	EUR2	79.99	-85.94	22.4	71917	Graw	0.6	-11.9	71917	0.7	-12.3
40	EXMT	-21.96	114.11	30.9	94302	RS41	31.2	-25.0	94302	30.7	-25.2
41	FALK	-51.69	-57.87	38.7	88889	RS41	41.9	35.3	88889	42.0	35.7
42	FLF1	25.62	-80.39	4.6	72202	LMS6	15.5	-0.4	72202	20.4	-3.3
43	FLKW	24.55	-81.75	11.6	72201	RS92	3.5	1.8	72201	0.4	-11.3
44	FLVR	28.25	-80.74	19.4	74794	Others	30.6	-16.4	72204	19.1	-12.7
45	FRRL	43.46	-8.34	56.8	08001	RS41	12.6	1.2	08001	12.3	10.2
46	FRUT	27.34	-82.44	15.1	72210	LMS6	41.0	-2.0	72211	13.7	-9.8
47	FS82	61.55	-149.82	52.2	70273	RS41	44.5	0.0	70272	41.9	-27.1
48	FSMC	60.03	-111.93	207.8	71934	Others	0.2	-3.4	71362	1.3	-4.5
49	G015	35.51	133.50	36.1	47741	RS41	39.3	-19.3	47741	39.3	-13.8
50	G090	31.57	131.00	96.3	47827	Others	42.7	-92.4	47827	42.5	-64.6
51	G193	33.75	135.38	42.9	47778	RS41	48.5	24.5	47778	48.1	26.2
52	G217	27.09	142.20	7.2	47971	Meisei	0.4	-4.5	47971	1.7	0.7
53	GAGN	33.25	-84.26	325.1	72215	LMS6	30.7	-80.5	72219	30.8	-84.2
54	GEOF	51.87	5.13	12.5	06260	RS41	26.2	-10.6	06356	1.8	-11.5
55	GRAF	28.45	-16.27	94.0	60018	RS41	18.8	10.9	60020	1.8	-58.0
56	GRDO	45.68	13.38	4.5	16045	RS41	41.6	45.5	16108	17.5	6.8
57	GRFL	47.06	-67.75	180.0	72712	RS92	29.4	11.0	72712	29.5	8.6
58	GUAM	13.59	144.87	146.0	91212	RS92	14.9	-70.8	91212	13.9	-68.8

59	HKFN	22.50	114.14	43.9	45004	RS41	18.9	-19.9	45007	30.9	-35.4
60	HOB2	-42.81	147.44	44.8	94975	RS41	6.2	-40.8	94975	6.8	-40.8
61	I003	36.20	139.81	28.4	47646	Others	32.6	-3.3	47626	38.8	3.3
62	I113	33.12	139.80	69.1	47678	Meisei	1.7	81.9	47678	1.4	83.3
63	IAMK	42.03	-90.67	216.1	74455	LMS6	47.2	14.3	74455	46.8	11.3
64	IAMY	41.55	-95.91	310.8	72558	LMS6	45.5	40.6	72552	32.5	1.1
65	IDHD	43.91	-116.20	802.0	72681	LMS6	38.0	70.8	72681	38.1	58.2
66	IFL2	48.58	-93.38	365.4	72747	Others	2.6	-8.1	72747	3.1	-12.8
67	INGR	41.83	12.52	56.1	16245	RS41	18.4	-24.1	16245	19.7	-43.6
68	INVK	68.31	-133.53	49.7	71957	Graw	1.2	53.7	71364	1.3	53.5
69	IQAL	63.76	-68.51	102.3	71909	Graw	2.1	-80.4	71321	2.1	-68.2
70	ISTA	41.10	29.02	109.9	17064	Others	25.2	-91.9	17064	25.2	-91.9
71	ITAI	-25.42	-54.59	178.0	83827	Others	10.7	1.7	83827	22.0	61.5
72	J450	33.54	130.25	45.8	47807	Others	12.7	-43.3	47807	13.3	-30.8
73	J500	24.43	123.79	15.4	47918	Meisei	39.0	-9.8	47918	41.0	12.8
74	J746	25.95	131.29	37.3	47945	Meisei	15.2	-22.0	47945	12.2	13.5
75	JA01	34.37	109.22	501.6	57131	Others	24.5	-91.0	57131	24.4	-91.0
76	KAEP	19.28	-155.12	21.9	91285	LMS6	49.1	-11.0	91285	49.3	-13.1
77	KEYW	52.88	-1.08	74.2	03354	RS41	18.2	42.9	03354	17.7	42.9
78	KNJA	43.57	22.26	246.2	13388	M10	38.7	-43.2	13388	41.2	-48.7
79	KSBK	37.55	-99.64	742.6	72451	LMS6	37.5	43.2	72451	38.2	42.4
80	LDB2	52.21	14.12	119.7	10393	RS41	0.9	-7.7	12310	36.2	-95.7
81	LERI	60.14	-1.18	82.4	03005	Others	0.1	-0.3	03005	0.6	1.7
82	LIHR	49.04	19.72	651.5	11952	Others	43.4	51.7	11934	38.1	66.8
83	LOYU	37.16	-80.43	632.3	72318	LMS6	5.0	6.6	72411	5.6	17.0
84	MAC1	-54.50	158.94	12.2	94998	RS41	0.1	-6.2	94998	0.1	-3.9
85	MAJB	7.12	171.37	4.9	91376	LMS6	9.6	-1.1	91376	11.9	-3.1
86	MALL	39.55	2.63	12.6	08302	RS41	9.2	28.4	08306	9.3	-4.6
87	MAN4	41.27	-70.08	12.9	74494	LMS6	44.3	2.2	72506	47.1	5.6
88	MARE	41.53	2.43	37.0	08190	M10	30.8	58.0	08181	39.3	-33.3
89	MC07	39.32	-108.21	1503.6	72476	LMS6	34.7	-30.8	72476	34.9	-34.4
90	MCIL	24.29	153.98	10.0	47991	Meisei	0.5	-2.9	47991	0.0	-3.3

91	MDCF	37.98	-75.86	12.4	72402	LMS6	33.2	-0.2	72402	34.7	-2.7
92	MEEL	43.59	-70.23	32.8	74389	RS92	33.3	91.7	72606	8.1	-19.3
93	MERI	20.98	-89.62	21.4	76644	RS41	4.5	-10.4	76644	6.2	-9.8
94	MIGD	45.03	-84.65	403.3	72634	RS92	14.5	44.3	72540	3.6	2.5
95	MIRO	42.82	-83.00	240.2	72632	RS92	40.9	89.9	72537	45.6	-50.5
96	MNBP	44.62	-93.75	263.1	72649	LMS6	28.9	27.1	72657	31.8	12.6
97	MOBS	-37.83	144.98	36.0	94866	RS41	22.1	96.2	94866	20.9	96.2
98	MOMF	37.35	-92.95	444.7	72440	RS92	41.8	-53.9	72440	40.6	-60.3
99	MORI	53.80	-113.64	707.9	71119	Others	41.4	58.9	71121	18.6	-19.5
100	MRY2	30.02	-89.91	3.2	72233	RS92	35.9	6.7	72233	36.8	4.3
101	MSJK	32.33	-90.18	114.5	72235	LMS6	9.6	-23.9	72235	3.9	-13.0
102	MTGW	48.37	-106.79	688.8	72768	LMS6	22.0	4.3	72768	21.5	9.0
103	MTP2	43.64	3.86	79.0	07645	M10	49.9	-19.1	07645	50.0	-17.1
104	NAVI	-33.95	-71.83	124.4	85586	RS41	38.4	-51.5	85586	38.7	-49.5
105	NCAO	35.72	-79.77	242.3	72317	LMS6	45.4	33.9	72317	45.3	32.4
106	NCAS	54.98	-1.62	75.9	03238	RS41	17.5	66.2	03238	16.5	70.2
107	NCNR	35.09	-77.03	9.6	72305	RS92	37.6	1.4	72309	2.6	-6.4
108	NENP	41.14	-100.77	857.7	72562	LMS6	5.5	-9.3	72562	8.2	-16.2
109	NMAB	35.02	-106.60	1573.8	72365	LMS6	3.2	43.3	72365	3.1	42.7
110	NRIL	69.36	88.36	62.1	23078	Others	4.1	-2.0	23078	5.4	2.0
111	NTUS	1.35	103.68	67.8	48698	RS41	33.8	-62.8	48698	34.9	-61.1
112	NVLV	36.08	-115.19	681.9	72388	LMS6	3.7	14.6	72386	2.3	-19.7
113	NVSK	54.84	83.24	159.8	29634	Others	23.0	-16.7	29638	19.4	-26.7
114	NWEL	65.30	-126.71	187.1	71043	Graw	2.2	-93.3	71480	2.4	-92.9
115	OHDT	39.77	-84.18	229.2	72426	LMS6	49.0	93.3	72429	16.0	73.3
116	OKCS	35.05	-97.94	339.5	72357	LMS6	47.8	5.0	72353	48.4	50.0
117	ORMF	42.38	-122.88	403.3	72597	RS92	0.4	-5.2	72597	0.8	-3.1
118	ORMO	45.15	-122.60	103.0	72694	Others	42.0	-40.6	72688	42.0	-54.8
119	OSN4	37.08	127.03	40.9	47122	Others	0.1	-29.1	47119	21.0	-5.9
120	OTZ1	66.89	-162.61	7.0	70133	RS41	0.1	-1.9	70133	0.2	-3.6
121	P049	47.35	-110.91	1198.9	72776	RS92	38.1	-66.9	72776	37.6	-68.4
122	P139	39.91	-119.72	1545.0	72489	LMS6	38.3	-28.2	72083	29.9	-6.0

123	P262	38.03	-122.10	23.2	72493	Others	33.2	-20.7	72482	41.0	8.5
124	P472	32.89	-117.11	172.0	72293	Others	6.3	-38.7	72290	36.3	-13.3
125	P514	35.01	-120.41	175.8	72393	Others	32.3	-54.9	72393	35.7	-63.4
126	P802	46.56	-100.62	593.8	72764	LMS6	26.0	-87.6	72764	27.0	-90.6
127	PAAP	40.45	-79.96	346.9	72520	LMS6	23.9	13.5	72520	22.0	-6.0
128	PAC2	-29.71	-57.09	83.1	83928	Others	9.2	-9.2	87289	6.9	-13.1
129	PAVI	45.20	9.14	102.1	16080	RS41	30.9	1.9	16080	29.1	5.5
130	PICL	51.48	-90.16	353.1	71845	Others	4.2	33.2	71845	4.2	33.2
131	PLBB	-33.99	25.61	75.2	68842	Others	0.0	-12.2	68842	0.6	-6.3
132	POLI	-23.56	-46.73	732.5	83779	Others	11.7	-11.9	83780	11.0	67.8
133	PRFJ	18.33	-65.65	21.0	78526	RS92	37.8	-17.0	78526	39.8	-18.0
134	PRGO	53.91	-122.78	614.5	71908	Graw	0.7	-13.6	71302	8.1	65.9
135	QUB1	54.59	-5.94	30.2	03918	RS41	27.1	-12.2	03915	45.4	34.9
136	REDZ	54.47	17.12	76.6	12120	Others	41.2	-74.8	12115	20.3	-65.6
137	RJNI	-22.91	-43.13	28.2	83746	Others	15.5	-22.2	83746	15.6	-19.7
138	SAL7	37.84	-0.78	17.0	08430	M10	39.1	43.9	08430	38.7	44.9
139	SALU	-2.59	-44.21	44.2	82281	Others	2.4	8.7	82281	2.6	10.0
140	SAS0	24.74	46.64	641.0	40437	RS41	23.3	-28.1	40437	25.4	-17.7
141	SCFJ	32.75	-79.90	12.9	72208	LMS6	20.0	0.4	72208	21.1	-1.1
142	SCOR	70.49	-21.95	71.7	04339	RS41	0.1	-1.5	04341	39.1	-61.6
143	SDAB	45.46	-98.41	405.1	72659	LMS6	0.3	-6.7	72659	1.6	-9.5
144	SDRC	44.08	-103.23	997.9	72662	LMS6	1.7	30.8	72662	14.3	-34.4
145	SEPT	50.21	-66.39	14.9	71811	Graw	9.8	38.2	71279	9.8	38.1
146	SHAO	31.10	121.20	11.2	58362	Others	42.5	-2.3	58362	41.9	-7.3
147	SHRV	32.43	-93.71	63.6	72248	Others	13.1	21.4	72248	11.4	5.9
148	SMAR	-29.72	-53.72	103.4	83937	Others	1.6	-18.6	83936	2.6	-8.6
149	STBN	-35.25	138.90	91.1	94672	RS41	47.9	-85.0	94672	47.8	-85.0
150	STJ3	47.60	-52.68	144.8	71802	Graw	11.8	-32.4	71801	6.1	-4.3
151	SUN6	62.23	17.66	7.8	02365	RS41	35.2	-3.9	02366	34.7	-2.9
152	TALH	30.40	-84.36	21.7	72214	LMS6	7.7	31.0	72214	0.5	-4.6
153	TEHN	35.70	51.33	1189.4	40754	Others	2.2	13.3	40754	2.1	16.9
154	TIXG	71.63	128.87	54.0	21824	Others	6.0	-48.0	21824	7.2	-44.9

155	TN32	36.40	-86.41	203.1	72327	LMS6	21.8	-23.1	72327	40.6	-24.3
156	TP01	50.13	14.45	323.8	11520	RS41	13.7	-21.7	11567	5.9	-38.2
157	TRAP	38.01	12.54	18.0	16429	RS41	11.8	-10.7	16429	12.2	-10.7
158	TSKT	43.87	-65.96	21.1	71603	Graw	11.0	-12.2	71603	11.1	21.9
159	TTSF	10.28	-61.47	40.0	78970	Graw	39.9	-28.1	78970	36.3	-27.9
160	TUBO	49.21	16.59	279.6	11747	RS41	47.9	-64.8	11747	47.6	-63.6
161	TUCS	32.21	-110.94	749.2	72274	RS92	1.9	1.2	72274	9.2	27.4
162	TXCD	35.10	-101.36	1036.8	72363	LMS6	34.7	57.0	72363	34.8	61.3
163	TXDR	29.36	-100.90	303.5	72261	Others	2.1	10.0	72261	3.1	1.7
164	TXFO	32.70	-97.37	215.5	72249	LMS6	16.7	-20.5	72259	39.1	-50.0
165	TXHG	26.19	-97.68	17.2	72250	RS92	40.2	-10.1	72250	40.1	-11.5
166	TXKG	27.52	-97.86	22.6	72251	RS92	45.6	-7.8	72251	44.7	-10.1
167	TXM5	31.95	-102.14	869.2	72265	LMS6	4.6	4.5	72264	23.4	38.9
168	UFPR	-25.45	-49.23	920.3	83840	Others	10.0	-14.0	83840	10.4	-11.3
169	USAL	40.34	18.11	29.0	16320	RS41	38.5	-14.5	16320	38.5	-14.7
170	UTWV	40.71	-111.98	1301.5	72572	LMS6	7.2	-13.3	72572	6.9	-13.9
171	VILL	40.44	-3.95	595.1	08221	RS41	31.6	35.6	08221	33.0	14.2
172	WEID	49.67	12.19	441.3	10771	RS41	33.4	-24.2	11406	46.8	48.8
173	WEIW	51.10	0.01	70.3	03882	RS41	31.2	-18.3	03781	23.0	99.7
174	WELL	43.00	-79.27	183.7	72528	LMS6	45.3	34.6	72528	43.9	32.4
175	WILI	-16.29	149.97	13.7	94299	RS41	0.5	-4.7	94299	0.1	-4.7
176	WIPI	44.69	-88.24	252.2	72645	LMS6	23.4	-42.9	72645	24.6	-43.6
177	WROC	51.11	17.06	140.6	12425	Others	12.6	-21.0	12424	12.3	-17.5
178	YAKT	62.03	129.68	109.0	24959	Others	2.5	-10.6	24959	2.5	-7.9
179	YSSK	47.03	142.72	66.1	32150	Others	8.9	-44.1	32150	15.6	-48.1
180	YYR1	53.31	-60.42	47.5	71816	Graw	3.6	-11.8	71816	0.9	1.3
181	ZADA	44.11	15.23	21.0	14430	RS41	9.2	56.9	14431	9.6	67.0
182	ZJX1	30.70	-81.91	31.8	72206	RS92	31.1	-21.7	72206	30.6	-24.6