Supplement of Earth Syst. Sci. Data, 12, 2853–2880, 2020
https://doi.org/10.5194/essd-12-2853-2020-supplement

Supplement of

Development of the HadISDH.marine humidity climate monitoring dataset

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Iterative approach to calculating the Monin-Obukov length L

Step 1. Calculate the stability parameter for $f(z_x/L)$ using the estimated or provided heights z of the measurements for $x=T$, $x=q$ and $x=u$ as described above:

$$\zeta_x = \frac{z_x}{L} \qquad \text{(S1)}$$

Step 2. Calculate the dimensionless profiles for $f(z_x/L)$ for $x=T$, $x=q$ and $x=u$:

If $\zeta_x < -0.01$ (unstable):

$$\phi_u = (1 - \alpha_s \zeta_u)^{-\beta} \qquad \text{(S2a)}$$

$$\phi_t = \left((1 - \alpha_s \zeta_t)^{-\beta}\right)^2 \qquad \text{(S2b)}$$

$$\phi_q = \left((1 - \alpha_s \zeta_q)^{-\beta}\right)^2 \qquad \text{(S2c)}$$

If $\zeta_x > 0.01$ (stable):

$$\phi_u = 1 + \gamma_s \zeta_u \qquad \text{(S3a)}$$

$$\phi_t = 1 + \gamma_s \zeta_t \qquad \text{(S3b)}$$

$$\phi_q = 1 + \gamma_s \zeta_q \qquad \text{(S3c)}$$

If $-0.1 < \zeta_x < 0.01$ (neutral):

$$\phi_u = 1 \qquad \text{(S4a)}$$

$$\phi_t = 1 \qquad \text{(S4b)}$$

$$\phi_q = 1 \qquad \text{(S4c)}$$

where $\alpha_s = 16.$, $\beta = 0.25$ and $\gamma_s = 5$. Note that φ_u is called φ_m in most literature.

Step 3. Calculate the stability corrections for $f(z_x/L)$ for $x=T$, $x=q$ and $x=u$:

If $\zeta_x < -0.01$ (unstable):

$$\psi_u = 2\ln\left(\frac{1+ {\phi_u}^{-1}}{2}\right) + \ln\left(\frac{1+ {\phi_u}^{-2}}{2}\right) - 2\tan^{-1} {\phi_u}^{-1} + \frac{\pi}{2} \qquad \text{(S5a)}$$

$$\psi_t = 2\ln\left(\frac{1+\phi_t^{-1}}{2}\right) \quad \text{(S5b)}$$

$$\psi_q = 2\ln\left(\frac{1+\phi_q^{-1}}{2}\right) \quad \text{(S5c)}$$

If $\zeta_x > 0.01$ (stable):

$$\psi_u = 1 - \phi_u \quad \text{(S6a)}$$

$$\psi_t = 1 - \phi_t \quad \text{(S6b)}$$

$$\psi_q = 1 - \phi_q \quad \text{(S6c)}$$

If $-0.1 < \zeta_x < 0.01$ (neutral):

$$\psi_u = 0 \quad \text{(S7a)}$$

$$\psi_t = 0 \quad \text{(S7b)}$$

$$\psi_q = 0 \quad \text{(S7c)}$$

Note that ψ_u is called ψ_m in most literature.

Step 4. Calculate the 10 m reference height stability parameter for *f*(*10*/*L)*:

$$\zeta_{10} = \frac{10}{L} \quad \text{(S8)}$$

Step 5. Calculate the 10 m reference height dimensionless profiles for *f*(*10*/*L)* for *x*=*T*, *x*=*q* and *x*=*u*:

If $\zeta_{10} < -0.01$ (unstable):

$$\phi_{u10} = (1 - \alpha_s\zeta_{10})^{-\beta} \quad \text{(S9a)}$$

$$\phi_{t10} = \left((1 - \alpha_s\zeta_{10})^{-\beta}\right)^2 \quad \text{(S9b)}$$

$$\phi_{q10} = \left((1 - \alpha_s\zeta_{10})^{-\beta}\right)^2 \quad \text{(S9c)}$$

If $\zeta_{10} > 0.01$ (stable):

$$\phi_{u10} = 1 + \gamma_s\zeta_{10} \quad \text{(S10a)}$$

$$\phi_{t10} = 1 + \gamma_s\zeta_{10} \quad \text{(S10b)}$$

$$\phi_{q10} = 1 + \gamma_s\zeta_{10} \quad \text{(S10c)}$$

If $-0.1 < \zeta_{10} < 0.01$ (neutral):

$$\phi_{u10} = 1 \quad \text{(S11a)}$$

$$\phi_{t10} = 1 \quad \text{(S11b)}$$

$$\phi_{q10} = 1 \quad \text{(S11c)}$$

where $\alpha_s = 16.$, $\beta = 0.25$ and $\gamma_s = 5$.

Step 6. Calculate the 10 m reference height stability corrections for $f(z_x/L)$ for $x=T$, $x=q$ and $x=u$:

If $\zeta_{10} < -0.01$ (unstable):

$$\psi_{u10} = 2\ln\left(\frac{1+\phi_{u10}^{-1}}{2}\right) + \ln\left(\frac{1+\phi_{u10}^{-2}}{2}\right) - 2\tan^{-1}\phi_{u10}^{-1} + \frac{\pi}{2} \quad \text{(S12a)}$$

$$\psi_{t10} = 2\ln\left(\frac{1+\phi_{t10}^{-1}}{2}\right) \quad \text{(S12b)}$$

$$\psi_{q10} = 2\ln\left(\frac{1+\phi_{q10}^{-1}}{2}\right) \quad \text{(S12c)}$$

If $\zeta_{10} > 0.01$ (stable):

$$\psi_{u10} = 1 - \phi_{u10} \quad \text{(S13a)}$$

$$\psi_{t10} = 1 - \phi_{t10} \quad \text{(S13b)}$$

$$\psi_{q10} = 1 - \phi_{q10} \quad \text{(S13c)}$$

If $-0.1 < \zeta_{10} < 0.01$ (neutral):

$$\psi_{u10} = 0 \quad \text{(S14a)}$$

$$\psi_{t10} = 0 \quad \text{(S14b)}$$

$$\psi_{q10} = 0 \quad \text{(S14c)}$$

Step 7. Calculate the neutral drag coefficient (Smith 1980):

$$C_{Dn} = \frac{(0.61+0.063u_{10n})}{1000.} \quad \text{(S15)}$$

where u is used in lieu of u_{10n} for a first round of iteration.

Step 8. Estimate the friction velocity using the neutral drag coefficient C_{Dn} in lieu of the coefficient of drag C_D:

$$u_* = \sqrt{C_D u^2} \tag{S16}$$

Step 9. Estimate the roughness length (Smith 1988) using the estimated friction velocity:

$$z_0 = \frac{a_c u_*^2}{g} + \frac{0.11v}{u_*} \tag{S17}$$

where the Charnock parameter a_c is 0.011, acceleration due to gravity g is set at 9.81 m s^{-1} s^{-1}, and the kinematic viscosity of air v is set at 1.48×10^{-5} m^2 s^{-1}. The approximation for v assumes a temperature of 15° C and standard atmospheric pressure which is sufficient given that variations in v are very small ranging between ~1.0×10^{-5} and 1.7×10^{-5} m^2 s^{-1} between temperatures of -40 to 40° C.

Step 10. Estimate the coefficient of drag using the estimated roughness length z_0:

$$C_D = \frac{\kappa^2}{\left(\ln\left(\frac{z_u}{z_0}\right) - \psi_u\right)^2} \tag{S18}$$

Step 11. Re-estimate the friction velocity using Eq. (S17) and the estimated coefficient of drag C_D:

Step 12. Calculate neutral wind speed at 10m u_{10n} using Eq. (1) where ψ_u and ψ_{u10} are set to 0.

Step 13. Recalculate the neutral drag coefficient C_{Dn} using Eq. (S15).

Step 14. Recalculate the friction velocity u_* using Eq. (S16) using the neutral drag coefficient C_{Dn}.

Step 15. Calculate the roughness length z_0 using Eq. (S17).

Step 16. Calculate the coefficient of drag C_D using Eq. (S18).

Step 17. Recalculate the friction velocity u_* using Eq. (S16) using the coefficient of drag C_D.

Step 18. Calculate the coefficient of heat transfer:

$$C_H = \frac{\kappa^2}{\left(\left(\ln\left(\frac{z_u}{z_0}\right) - \psi_u\right)\left(\ln\left(\frac{z_t}{z_{t0}}\right) - \psi_t\right)\right)} \quad \text{(S19)}$$

where the neutral stability heat transfer coefficient z_{t0} = 0.001.

Step 19. Calculate the virtual temperature at observing height and at the surface:

$$\theta_v = \frac{T\left(\frac{1+q}{\varepsilon}\right)}{1+q} \quad \text{(S20a)}$$

$$\theta_{v0} = \frac{T_0\left(\frac{1+q_0}{\varepsilon}\right)}{1+q_0} \quad \text{(S20b)}$$

where T is in Kelvin (+273.15 in this case), q is in g g^{-1} (divided by 1000.) and ε = 0.622. Note that we have substituted q for the mixing ratio because they are very similar.

Step 20. Calculate the surface buoyancy flux:

$$B_0 = C_H u \left(\frac{g}{\theta_{v0}}\right)(\theta_{v0} - \theta_v) \quad \text{(S21)}$$

where g is the acceleration due to gravity 9.81 m s^{-1} s^{-1}.

Step 21. Calculate the Monin-Obukov length:

$$L = \frac{{u_*}^3}{\kappa B_0} \quad \text{(S22)}$$

Finally, we return to Step 1 and iterate until results converge with exceptions as stated above.

Tables

Table S1 Equations used to derive humidity variables from dry bulb temperature (T), dew point temperature (T_d) and surface pressure (Ps).

Variable	Equation	Source	Notes
Dewpoint Depression (DPD) in °C	$DPD = T - T_d$	---	(S23)
Specific humidity (q) in g kg^{-1}	$q = 1000\left(\frac{0.622e}{P_s - ((1-0.622)e)}\right)$	Peixoto and Oort (1996)	(S24)
Vapour pressure with respect to water © in hPa (when T_w >0°C)	$e = 6.1121 \cdot f_w \cdot EXP\left(\frac{\left(18.729 - \left(\frac{T_d}{227.3}\right)\right)T_d}{257.87 + T_d}\right)$ $f_w = 1 + 7 \times 10^{-4} + 3.46 \times 10^{-6} P_s$	Buck (1981)	(S25) substitute T for T_d to give saturated vapour pressure (e_s)
Vapour pressure with respect to ice (e_{ice}) in hPa (when T_w <0°C)	$e_{ice} = 6.1115 \cdot f_i \cdot EXP\left(\frac{\left(23.036 - \left(\frac{T_d}{333.7}\right)\right)T_d}{279.82 + T_d}\right)$ $f_i = 1 + 3 \times 10^{-4} + 4.18 \times 10^{-6} P_s$	Buck (1981)	(S26)
Wet bulb temperature (T_w) in °C	$T_w = \frac{aT + bT_d}{a + b}$ $a = 6.6 \times 10^{-5} P_s$ $b = \frac{409.8e}{(T_d + 237.3)^2}$	Jensen et al. (1990)	(S27)
Relative Humidity (RH) in %rh	$RH = 100\left(\frac{e}{e_s}\right)$	---	(S28)

Table S2 List of ship identifiers/callsigns that have been blacklisted and excluded from further processing Rayner et al., 2006, Kennedy et al, 2019.

SDRT2	VENF1	CHYV2	BLTM3	LTRM4	CHNO3	NSTP6	CBBV2	MI016	PRYC1
PTIT2	FMRF1	CRYV2	FRVM3	WNEM4	CHAO3	NPSF1	CECC1	MI019	PSBM1
PCNT2	BGCF1	DOMV2	BZBM3	RCKM4	NWPO3	NTKM3	CFPN7	MI020	PSLC1
FCGT2	MPSF1	WDSV2	MTKM3	DTLM4	SBEO3	NBLP1	CHAO3	MI100	PTAW1
FPTT2	RKXF1	SWPV2	WAXM3	NABM4	TLBO3	KWJP8	CHLV2	MI110	PTWW1
SRST2	NFBF1	CBBV2	BHBM3	PNLM4	LOPW1	KLIH1	CHYW1	MI120	QPTR1
SBPT2	VCAF1	CHLV2	IOSN2	FPTM4	ASTO3	OOUH1	CLBV2	MI130	RDYD1
PORT2	KYWF1	GDIV2	BGXN3	NPDW3	TOKW1	FGBL1	CMAN4	MI140	RI013
CAPL1	PLSF1	YKTV2	WELM1	CBRW3	WPTW1	WNDV2	CMTI2	MI145	RPLV2
MAXT2	SANF1	KPTV2	WEXM1	MNMM4	DESW1	WLON7	CPTR1	MI200	SBEO3
RCPT2	SMKF1	YKRV2	CASM1	SYWW3	LAPW1	CHTS1	CT015	MI210	SC010
RTAT2	LONF1	VMSV2	MISM1	GBLW3	TTIW1	CTGM1	DELD1	MI220	SC020
NGLT2	MLRF1	YRSV2	MDRM1	AGMW3	NEAW1	CKYF1	DUKN7	MI221	SDBC1
PTAT2	FWYF1	RPLV2	PSBM1	KWNW3	PTAW1	BHRC3	DULM5	MI230	SDHN4
PACT2	VAKF1	WAHV2	ABAN6	SGNW3	PTWW1	VAPW1	EBSW1	MI240	SLIM2
MQTT2	LKWF1	LWTV2	ALXN6	PWAW3	WPOW1	SKTA2	FL005	MI245	SMOC1
IRDT2	SPGF1	PPTM2	SUPN6	MLWW3	TCNW1	SKAW1	FL020	MI250	SPSL1
BABT2	TRDF1	BISM2	THIN6	KNSW3	EBSW1	SHNO3	FL025	MI255	SWPV2
RSJT2	GTXF1	CBIM2	OSGN6	WHRI2	SISW1	SCSN6	FL040	MI256	TCBM2
MGPT2	SAUF1	SLIM2	RPRN6	CHII2	PBFW1	PTJN6	FL050	MI257	TCNW1
CLLT2	MYPF1	COVM2	OLCN6	CMTI2	FRDW1	OFPN6	FL060	MI260	TOKW1
EPTT2	FRDF1	CAMM2	YGNN6	BHRI3	CHYW1	OH010	FL065	MI270	TX010
GTOT2	SAXG1	HPLM2	NIAN6	MCYI3	LCNA2	NY034	FL070	MI290	TX017
GPST2	SECG1	BSLM2	BUFN6	SJOM4	CDEA2	NY036	FL080	MN110	TX019
GNJT2	ARPF1	WASD2	DBLN6	SVNM4	FFIA2	NY038	FL085	MNPV2	TX020
RLOT2	PTRF1	TPLM2	CBLO1	MKGM4	PBPA2	NY041	FL087	MTKN6	TX030
MRSL1	ANCF1	FSKM2	GELO1	LDTM4	SDIA2	NY042	FL090	MTYC1	TX033
SLPL1	FHPF1	BLTM2	CNDO1	BSBM4	PRTA2	NY060	FL097	MYPF1	TX035
AMRL1	TARF1	TCBM2	OWXO1	GTBM4	EROA2	WAUO3	FL100	NBLP1	TX036
LUML1	CWBF1	CHCM2	HHLO1	GTLM4	BLTA2	ACYN4	FL110	NC040	TX037
TAML1	CAMF1	DELD1	MRHO1	TIXC1	SISA2	AK010	FOXR1	NEAW1	TX040
TRBL1	ERTF1	RDYD1	SBIO1	SDBC1	ELFA2	AK020	FRDW1	NKTA2	TX050
ILDL1	MCYF1	SJSN4	THRO1	LJAC1	CSPA2	AK030	FRVM3	NLNC3	TX060
SPLL1	OPTF1	DRSD1	THLO1	LJPC1	BLIA2	AK040	FTPC1	NMTA2	TX080
WDEL1	SAPF1	BRND1	CLSM4	OHBC1	MRKA2	AK050	FTRN6	NSTP6	WAHV2
BURL1	MTBF1	CMAN4	LSCM4	SMOC1	POTA2	AK060	GA010	NTKM3	WASD2
PSTL1	PMAF1	LWSD1	FTGM4	PTGC1	PILA2	AK070	GA020	NWPR1	WAVM6
GISL1	EGKF1	OCIM2	PSCM4	CPXC1	AMAA2	AK080	GISL1	NY015	WI010
BYGL1	ANMF1	AVAN4	HRBM4	PSLC1	FILA2	AK090	GLPV2	NY034	WI015
LABL1	BEPB6	ACMN4	SBLM4	MTYC1	OVIA2	AK100	HBYC1	NY036	WI020
LKPL1	SPAG1	ACYN4	GSLM4	ELXC1	HMRA2	AK110	HI010	NY038	WI040
NWCL1	SKMG1	JCRN4	LPNM4	MLSC1	AUGA2	AK120	HI020	NY040	WNDV2

SHBL1	TYBG1	BRBN4	APNM4	RTYC1	DRFA2	AK130	HI030	NY041	MHPA1
WYCM6	FPSN7	BDRN4	DTLM4	DMBC1	NKTA2	AL020	HI040	NY042	ALSN6
PNLM6	FPKG1	SGRN4	RCKM4	NLEC1	ANTA2	ANTA2	HI050	NY043	ATGM1
SIPM6	FRPS1	SDHN4	PILM4	AAMC1	ALIA2	ANVC1	HI060	NY046	FWIC3
ULAM6	ACXS1	BGNN4	ROAM4	FTPC1	ATKA2	APAM2	HI070	NY050	IOSN3
GDXM6	FBPS1	ROBN4	GDMM5	TIBC1	ADKA2	ASTO3	HI080	NY060	NCSC3
MBLA1	FBIS1	BATN6	SLVM5	NLEC1	NMTA2	BA010	HI090	OH010	NOSC3
DPHA1	SCIS1	KPTN6	DULM5	AAMC1	RDDA2	BATN6	HI100	OH020	MISN6

Table S3 Estimates of standard uncertainty in humidity measurements calculated in terms of equivalent psychrometer uncertainty. All uncertainties are based on a 0.15° C uncertainty in wet bulb depression. Example estimates are made for each value assuming saturation at the given temperature and comparing with a value at RH equal to 100 %rh minus the associated uncertainty in RH for that temperature band. For DPD, the 0.2° C uncertainty in dry bulb temperature is added linearly to the uncertainty in T_d as in a worst case scenario the error in T and T_w would oppose. Calculations of other humidity variables are made using equations from Table S1. (Willett et al., 2014)

T (° C)	Uncertainty in RH (%rh)	Uncertainty in q (g kg^{-1}) at saturation	Uncertainty in e (hPa) at saturation	Uncertainty in T_d (° C)	Uncertainty in DPD (° C)
-50 and below	15	0.004	0.006	1.309	1.509
-40	15	0.012	0.019	1.428	1.628
-30	15	0.035	0.057	1.553	1.753
-20	10	0.064	0.104	1.094	1.294
-10	5	0.081	0.131	0.577	0.777
0	2.75	0.105	0.169	0.338	0.538
10	1.8	0.138	0.223	0.271	0.471
20	1.35	0.199	0.318	0.219	0.419
30	1.1	0.298	0.470	0.193	0.393
40	0.95	0.459	0.707	0.179	0.379
50+	0.8	0.672	1.000	0.162	0.362

Table S4 Listings for years of data within each deck colour coded by whether there is an issue with frequency whole numbers (red) or not (black) for air temperature and dew point temperature. Years are listed as red if the proportion of whole numbers is greater than 2 times the mean of all other decimal places. Years in bold are in the ship and moored buoy selection. Those not in bold are from moored buoy platforms and therefore not in the ship-only selection.

Deck	***T* Whole Number Years**	**T_d Whole Number Years**
128	**1973, 1974, 1975, 1976, 1977, 1978**	**1973, 1974, 1975, 1976, 1977, 1978**
144	1990, 1991, 1992, 1993, 1994, 1995, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004	1990, 1991, 1992, 1993, 1994, 1995, 1995, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004
223	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982**	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982**
224	**1976, 1977, 1978, 1979, 1980, 1981**	**1976, 1977, 1978, 1979, 1980, 1981**
229	**1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981**	**1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981**
233	**1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994**	**1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994**
234	**1982, 1983, 1986, 1989, 1990, 1992, 1993, 1994**	**1982, 1983, 1986, 1989, 1990, 1992, 1993, 1994**
239	**1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993**	**1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993**
254	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994**	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994**
255	**1973, 1974, 1975, 1977, 1978, 1979**	**1973, 1974, 1975, 1977, 1978, 1979**
555	**1973**	**1973**
666	**1973**	**1973**
700	**2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2012**	**2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2012**
708	**2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2012**	**2001, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2012**
732	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991**	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991**
735	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000**	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000**
740	**1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 2007, 2008, 2011, 2012, 2013**	**1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 2007, 2008, 2011, 2012, 2013**
749	**1978, 1979**	**1978, 1979**
781	**1982, 1983, 1984, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993**	**1982, 1983, 1984, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993**
792	**1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018**	**1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018**
793	1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, **2013, 2014, 2015,** 2016, 2017, 2018	1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, **2013, 2014, 2015,** 2016, 2017, 2018

794	2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018	2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018
849	**1978, 1979**	**1978, 1979**
850	**1978, 1979**	**1978, 1979**
874	**1995, 1996, 1997, 2013, 2014**	**1995, 1996, 1997, 2013, 2014**
875	**2012, 2013, 2014**	**2012, 2013, 2014**
876	1973, 1974, 1975, 1976, 1977	1973, 1974, 1975, 1976, 1977
877	1973, 1974	1973, 1974
878	1974	1974
883	1983, 1984, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012	1983, 1984, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012
888	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997**	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997**
889	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995**	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995**
892	**1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997**	**1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997**
893	1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997	1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997
896	**1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990**	**1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990**
898	**1973, 1974**	**1973, 1974**
900	**1973, 1974, 1975, 1976, 1977, 1978, 1979**	**1973, 1974, 1975, 1976, 1977, 1978, 1979**
926	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014**	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014**
927	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012**	**1973, 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012**
928	**1973, 1974**	**1973, 1974**
992	**1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018**	**1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018**
993	1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, **2013, 2014, 2015, 2016, 2017, 2018**	1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, **2013, 2014, 2015, 2016, 2017, 2018**

994	1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018	1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018
995	**2015, 2016**	**2015, 2016**

Figures

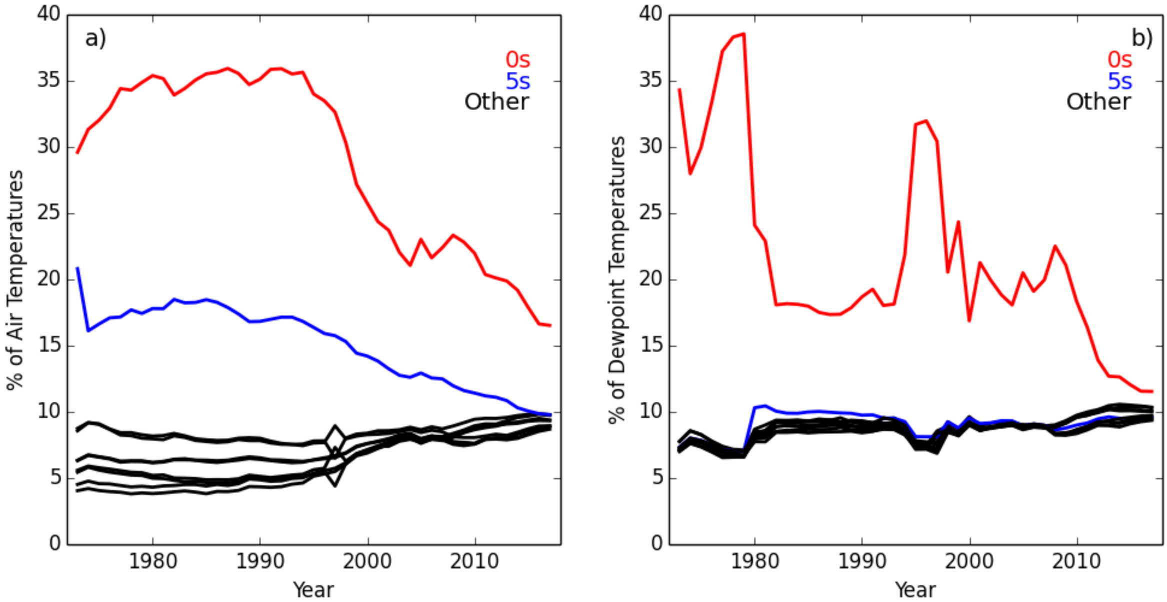


Figure S1 Changes in decimal frequency over time for all ICOADS 3.0.0/3.0.1 observations passing 3rd iteration quality control: a) Air temperature and b) dew point temperature. Note that the air temperature peak/trough in 1997 comes from a periodic decrease in 2s and 7s and simultaneous increase in 3s and 8s. This appears to be originating from deck 893 (moored buoys) and 892, with some of the increase in .8s coming from 926. This problem is noted to some extent at https://icoads.noaa.gov/e-doc/other/dupelim_1980 and https://icoads.noaa.gov/real-time.html (3. Discussion) for decks 892-896 suggesting that the conversion between formats which involved conversion from Celsius to Kelvin may have caused this.

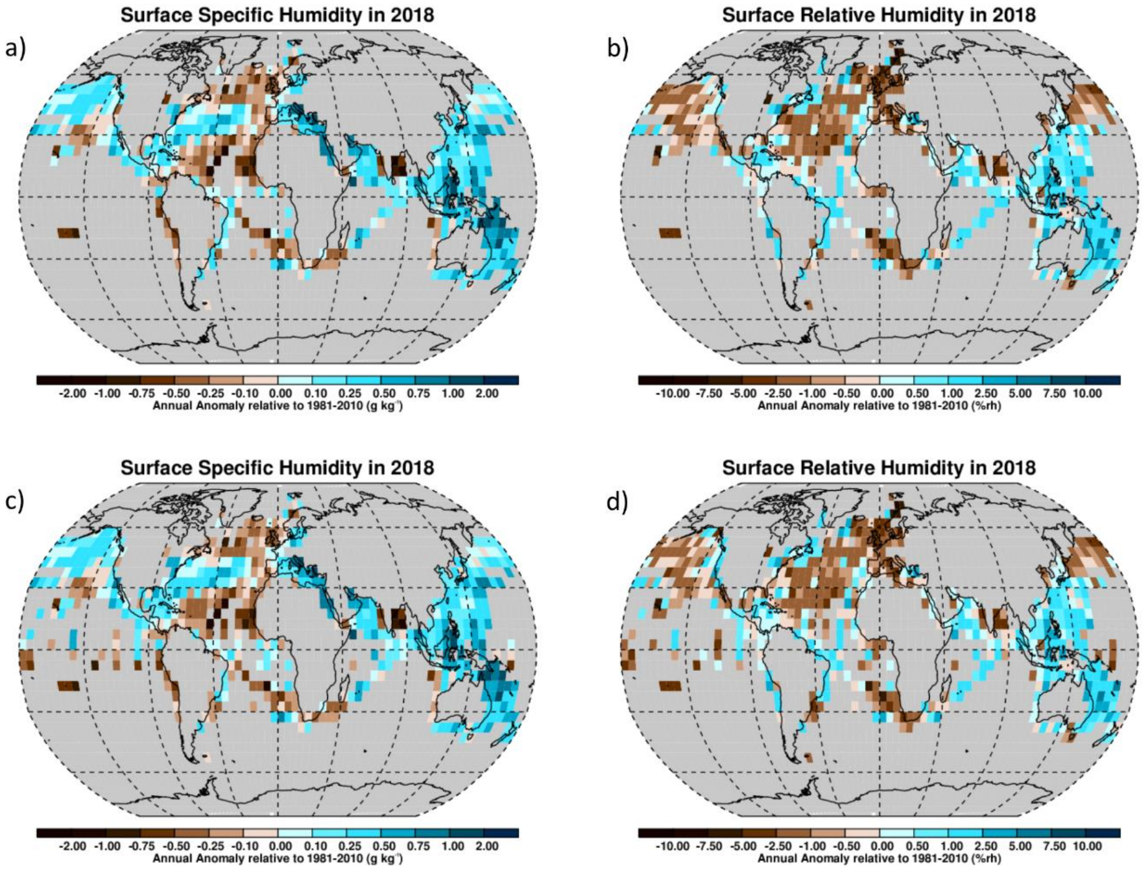


Figure S2 2018 annual averages for the 3rd iteration quality-controlled and bias-adjusted ship-only (a, b) and ship and moored buoy (c, d) for specific humidity (a, c) and relative humidity (b d) for comparison of spatial coverage.

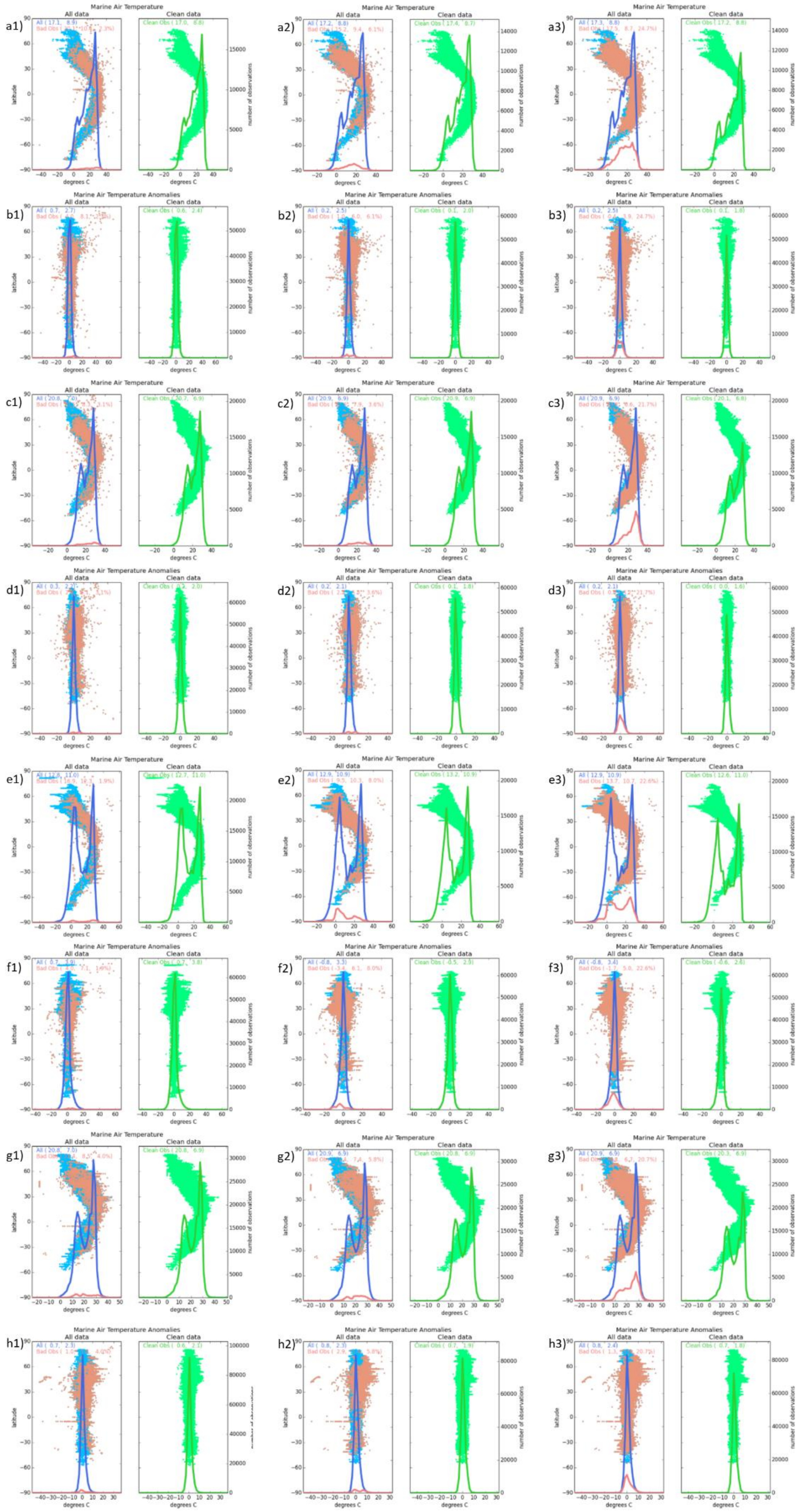

a1)
a2)
a3)
b1)
b2)
b3)
c1)
c2)
c3)
d1)
d2)
d3)
e1)
e2)
e3)
f1)
f2)
f3)
g1)
g2)
g3)
h1)
h2)
h3)
Marine Air Temperature
Marine Air Temperature Anomalies
All data
Clean data
latitude
degrees C
number of observations

Figure S3 Air temperature comparisons of actual (a, c, e, h) and anomaly (b, d, f, i) distributions for all selected data (blue – left panel), failed data (pink – left panel) and passed data (green – right panel) for each iteration of the build process (1, 2, 3, Sect. 3.6), for January (a, b) and July (c, d) in 1980, and January (e, f) and July (h, i) in 2010. The mean and standard deviation of the distribution is shown respectively in parentheses with the percentage of bad observations removed also shown. Bad observations are those where one or more of the following quality control checks has been failed: climatology check, track check, or repeated value check. For the 3rd iteration the buddy check is also included. **Note that the total number of observations, and hence the mean and standard deviation for 'All', changes between iterations because only observations with a co-located 1° by 1° pentad climatology are used. ERA-Interim (1st iteration) provides complete spatial coverage whereas observation based climatologies in subsequent iterations do not.**

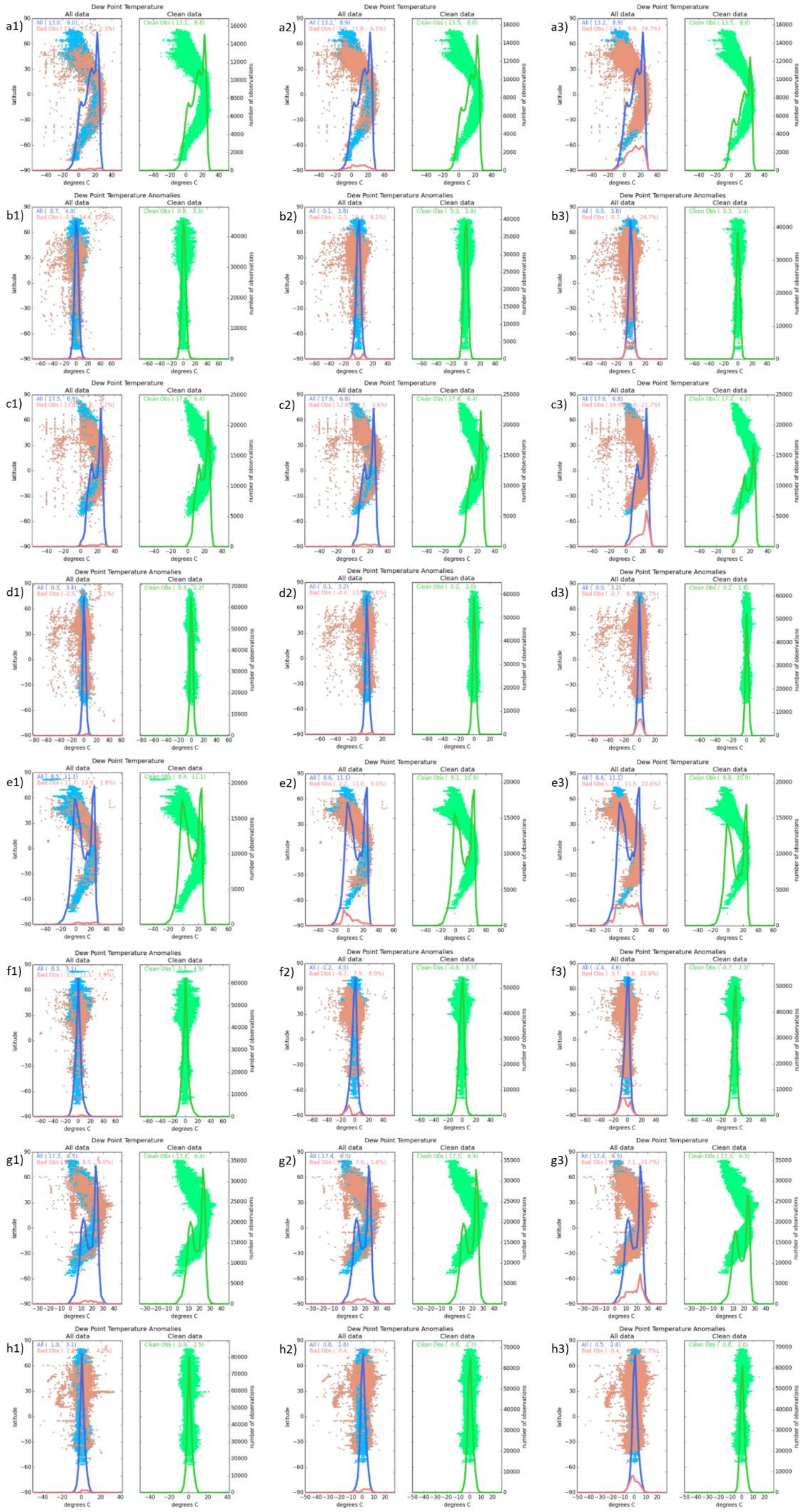

a1) a2) a3)
Dew Point Temperature
b1) b2) b3)
Dew Point Temperature Anomalies
c1) c2) c3)
Dew Point Temperature
d1) d2) d3)
Dew Point Temperature Anomalies
e1) e2) e3)
Dew Point Temperature
f1) f2) f3)
Dew Point Temperature Anomalies
g1) g2) g3)
Dew Point Temperature
h1) h2) h3)
Dew Point Temperature Anomalies
All data
Clean data
latitude
degrees C
number of observations

Figure S4 Dew point temperature comparisons of actual (a, c, e, h) and anomaly (b, d, f, i) distributions for all selected data (blue – left panel), failed data (pink – left panel) and passed data (green – right panel) for each iteration of the build process (Sect. 3.6), for January (a, b) and July (c, d) in 1980, and January (e, f) and July (h, i) in 2010. The mean and standard deviation of the distribution is shown respectively in parentheses with the percentage of bad observations removed also shown. Bad observations are those where one or more of the following quality control checks has been failed: climatology check, super saturation check, track check, repeated value check or repeated saturation check. For the 3rd iteration the buddy check is also included. **Note that the total number of observations, and hence the mean and standard deviation for 'All', changes between iterations because only observations with a co-located 1° by 1° pentad climatology are used. ERA-Interim (1st iteration) provides complete spatial coverage whereas observation based climatologies in subsequent iterations do not.**

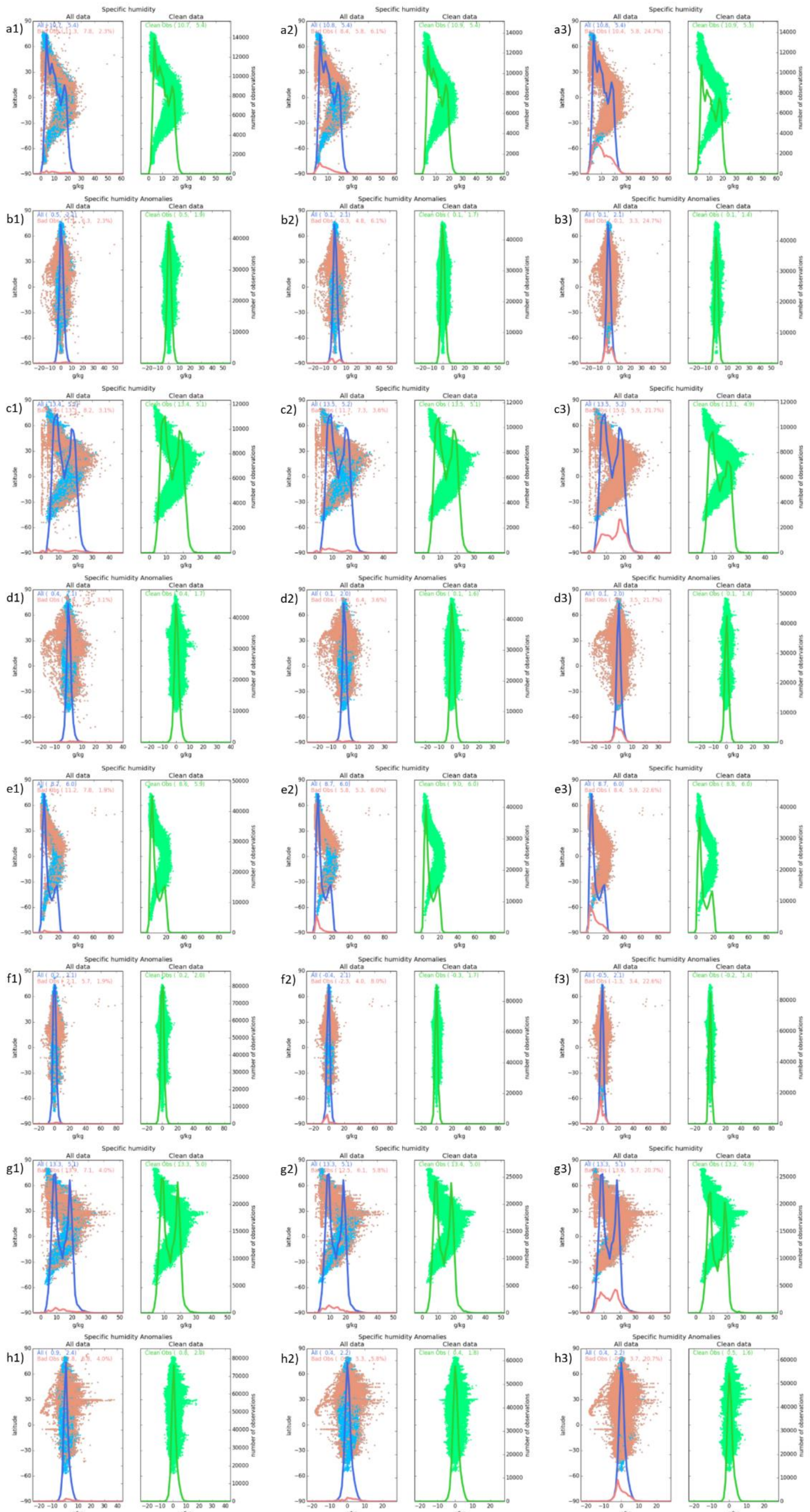
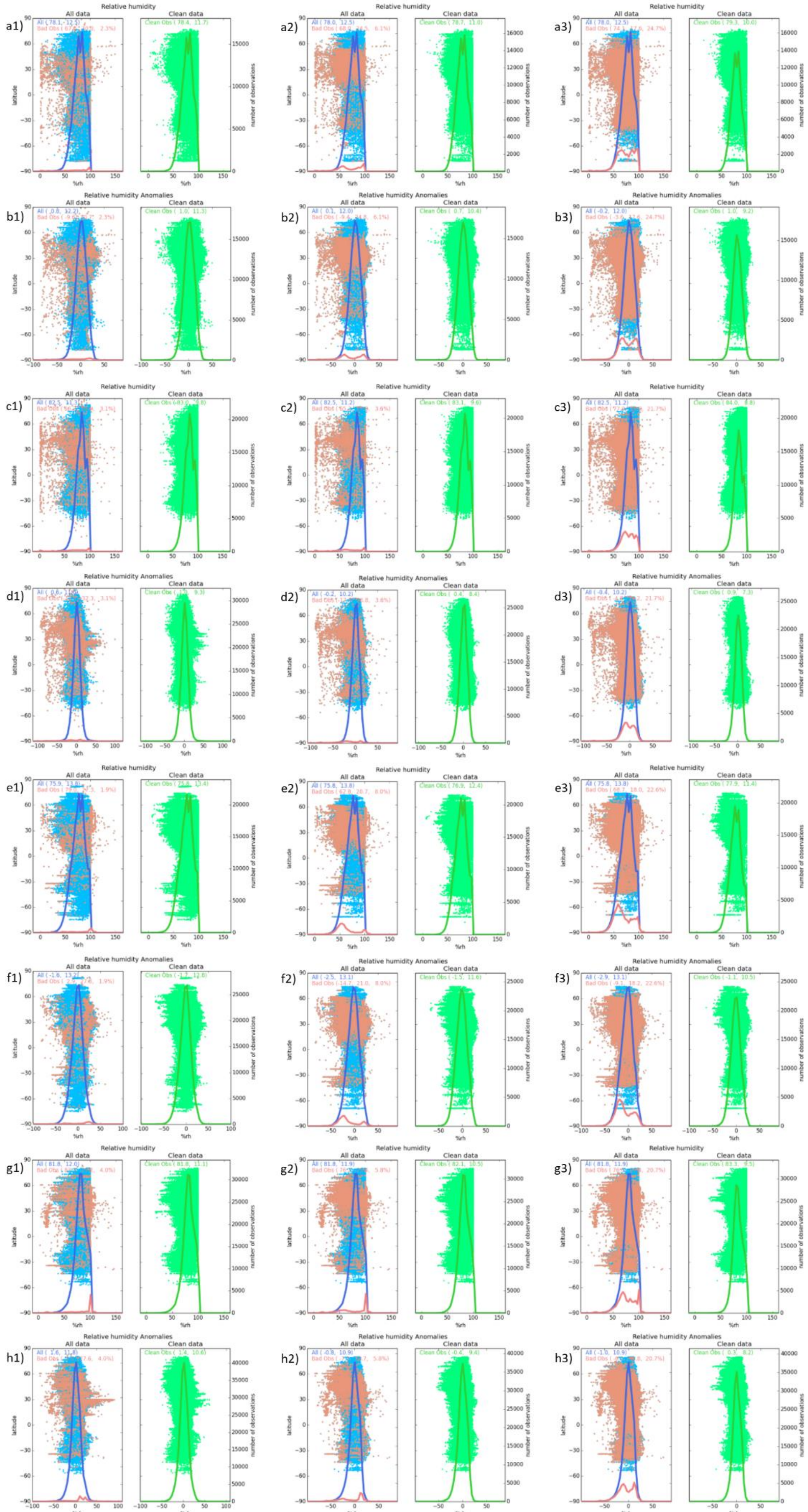

a1)
a2)
a3)
b1)
b2)
b3)
c1)
c2)
c3)
d1)
d2)
d3)
e1)
e2)
e3)
f1)
f2)
f3)
g1)
g2)
g3)
h1)
h2)
h3)
Specific humidity
Specific humidity Anomalies
All data
Clean data
latitude
number of observations
g/kg

Figure S5 Specific humidity comparisons of actual (a, c, e, h) and anomaly (b, d, f, i) distributions for all selected data (blue – left panel), failed data (pink – left panel) and passed data (green – right panel) for each iteration of the build process (Sect. 3.6), for January (a, b) and July (c, d) in 1980, and January (e, f) and July (h, i) in 2010. The mean and standard deviation of the distribution is shown respectively in parentheses with the percentage of bad observations removed also shown. Bad observations are those where one or more of the following quality control checks has been failed: climatology check, super saturation check, track check, repeated value check or repeated saturation check. For the 3rd iteration the buddy check is also included. **Note that the total number of observations, and hence the mean and standard deviation for 'All', changes between iterations because only observations with a co-located 1° by 1° pentad climatology are used. ERA-Interim (1st iteration) provides complete spatial coverage whereas observation based climatologies in subsequent iterations do not.**



a1)
a2)
a3)
b1)
b2)
b3)
c1)
c2)
c3)
d1)
d2)
d3)
e1)
e2)
e3)
f1)
f2)
f3)
g1)
g2)
g3)
h1)
h2)
h3)
Relative humidity
Relative humidity Anomalies
All data
Clean data
latitude
number of observations
%rh

Figure S6 Relative humidity comparisons of actual (a, c, e, h) and anomaly (b, d, f, i) distributions for all selected data (blue – left panel), failed data (pink – left panel) and passed data (green – right panel) for each iteration of the build process (Sect. 3.6), for January (a, b) and July (c, d) in 1980, and January (e, f) and July (h, i) in 2010. The mean and standard deviation of the distribution is shown respectively in parentheses with the percentage of bad observations removed also shown. Bad observations are those where one or more of the following quality control checks has been failed: climatology check, super saturation check, track check, repeated value check or repeated saturation check. For the 3rd iteration the buddy check is also included. **Note that the total number of observations, and hence the mean and standard deviation for 'All', changes between iterations because only observations with a co-located 1° by 1° pentad climatology are used. ERA-Interim (1st iteration) provides complete spatial coverage whereas observation based climatologies in subsequent iterations do not.**

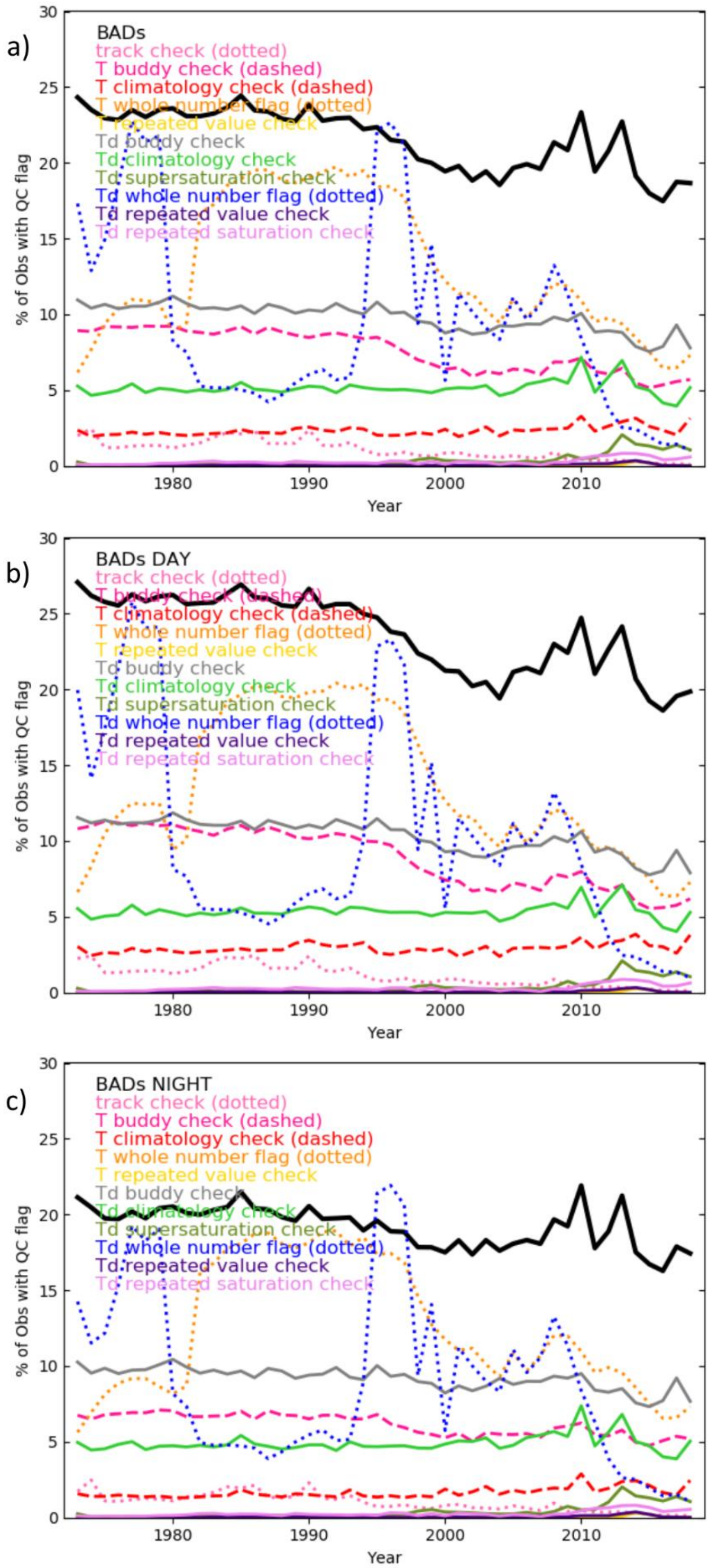


Figure S7 3rd iteration quality control removals over time. Annual quality control flagging rates as a percentage of all selected observations for all (a), daytime only (b) and night time only (c). The total number of QC failing observations (black) is comprised of any observation failing at least one of the tests listed with the exception of T and T_d whole number flags.

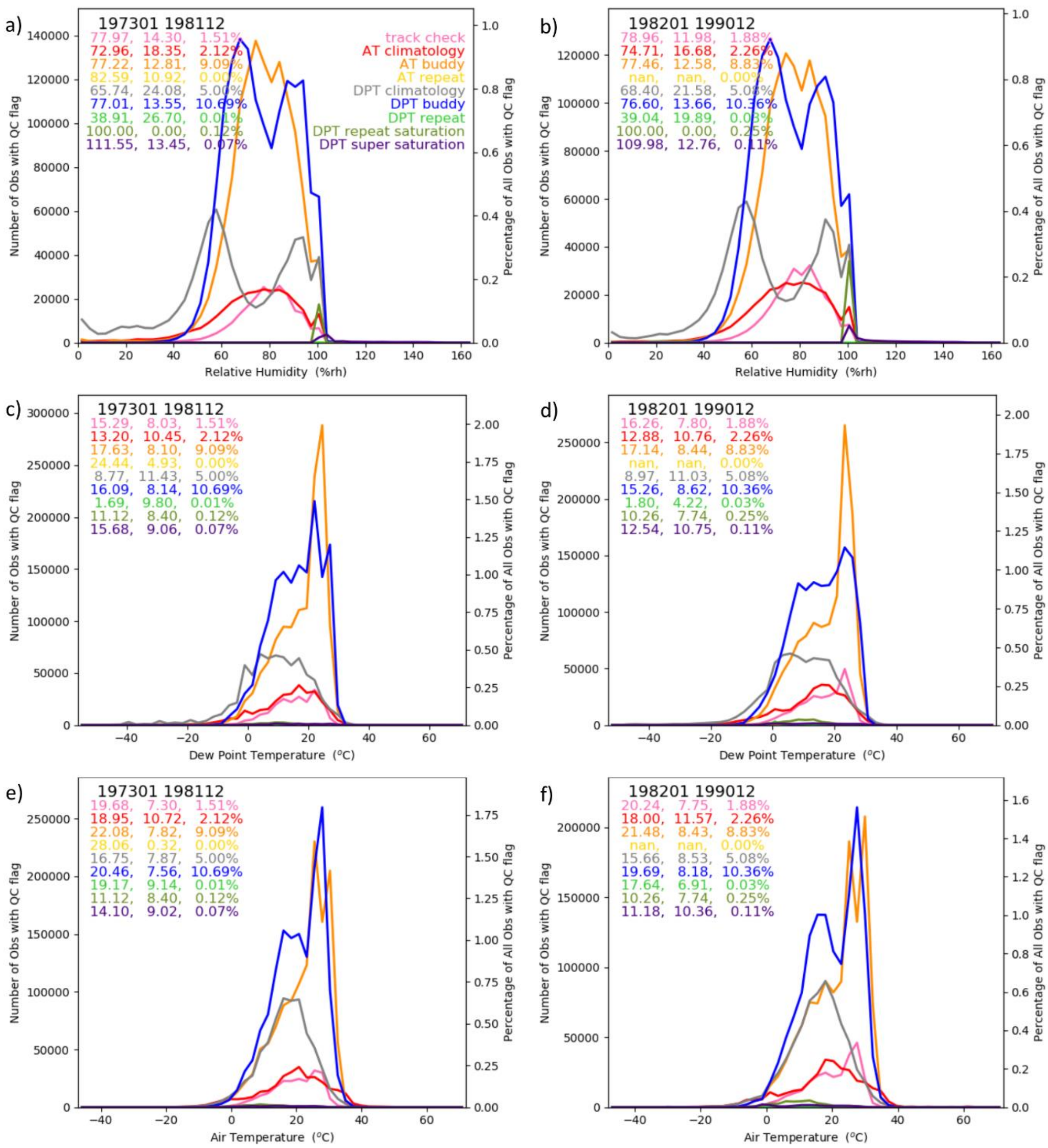


Figure S8 3rd iteration quality control removals as distributions for each variable. Distributions in terms of relative humidity (a, b), dew point temperature (c, d) and air temperature (e, f) of the data removed by each test are shown for two periods for all times: 1973-1981 (a, c, e) and 1982-1990 (b, d, f). The mean, standard deviation and percentage removed are shown for each test.

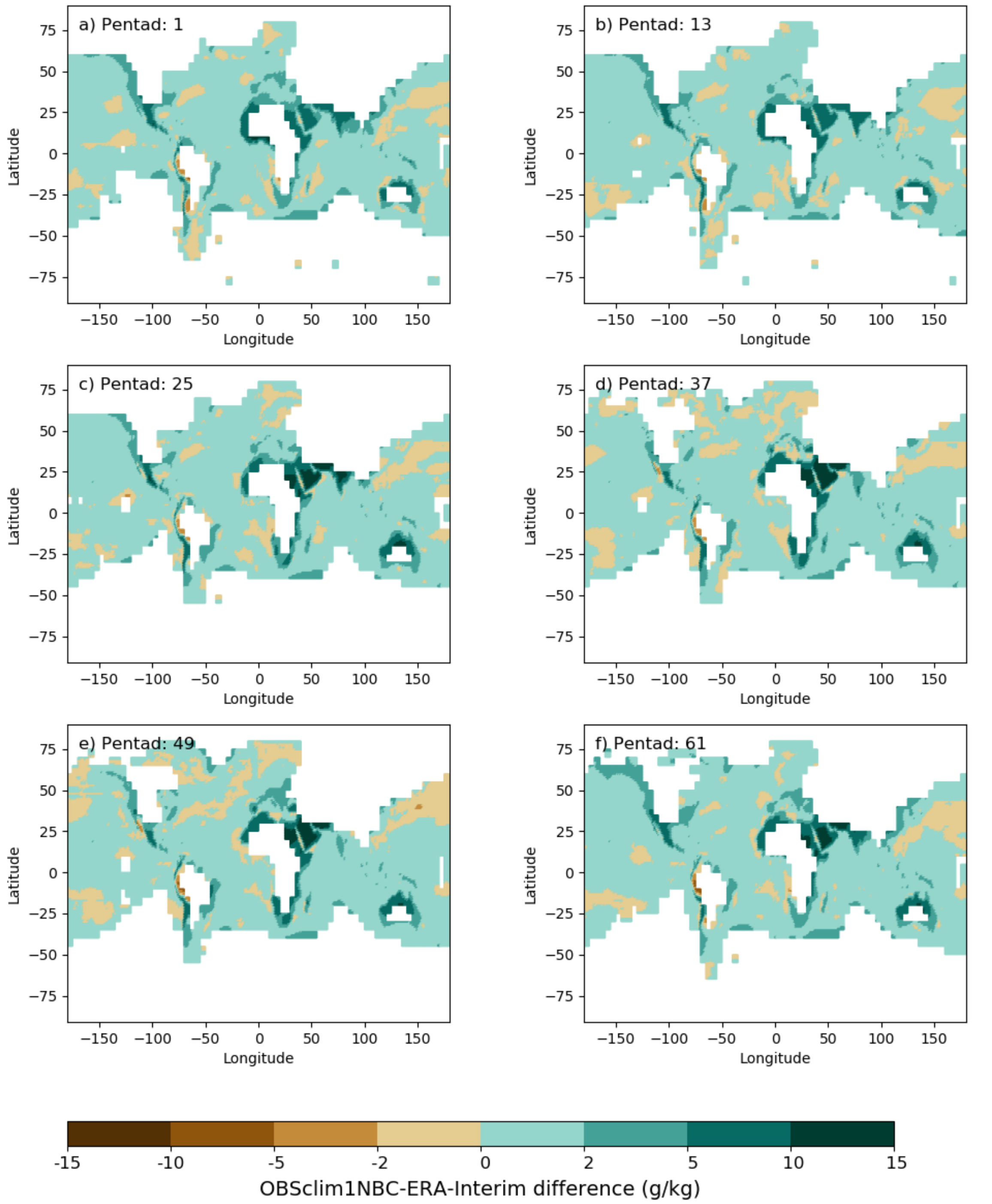


Figure S9 Differences in the 1981-2010 pentad 1° by 1° mean specific humidity climatology between the 2nd Iteration infilled gridded observation climatology, used to create the 3rd iteration and bias corrected products, and ERA-Interim, for a range of pentads. Note that the 1° by 1° grids are interpolated from 5° by 5° grids.

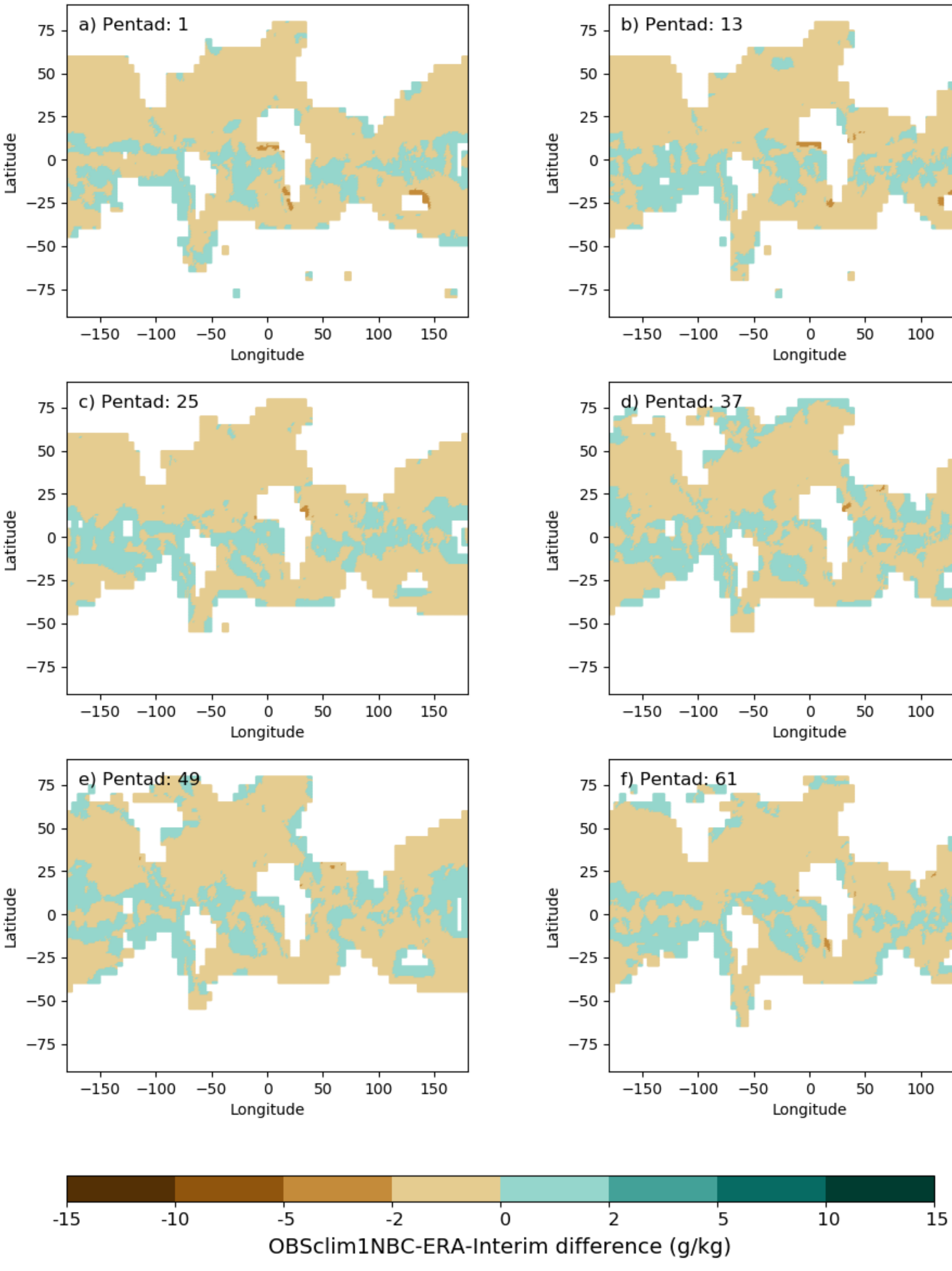


Figure S10 Differences in the 1981-2010 pentad 1° by 1° mean specific humidity climatological standard deviation between the 2nd Iteration infilled gridded observation climatology, used to create the 3rd iteration and bias corrected products, and ERA-Interim, for a range of pentads. Note that the 1° by 1° grids are interpolated from 5° by 5° grids.

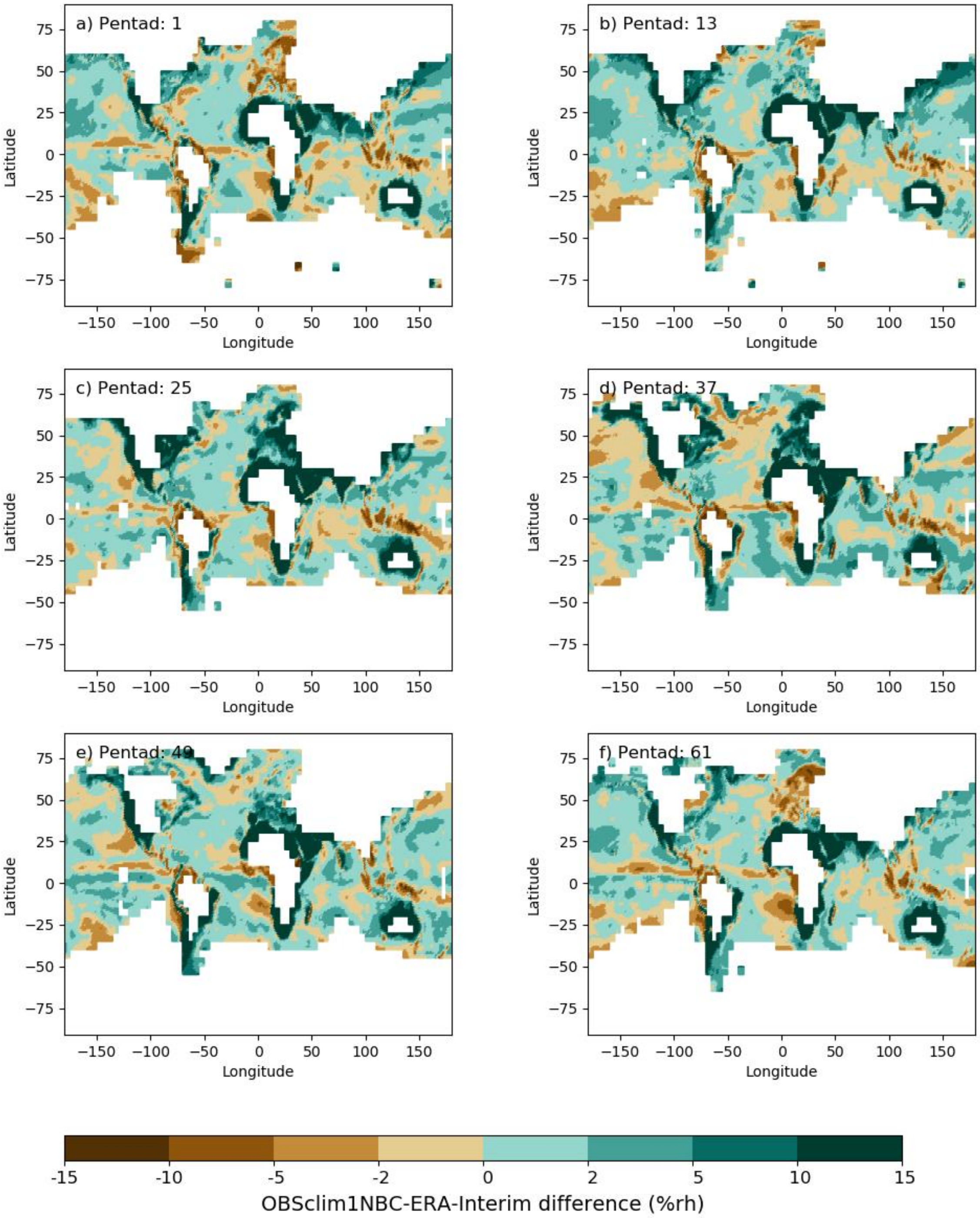


Figure S11 Differences in the 1981-2010 pentad 1° by 1° mean relative humidity climatology between the 2nd Iteration infilled gridded observation climatology, used to create the 3rd iteration and bias corrected products, and ERA-Interim, for a range of pentads. Note that the 1° by 1° grids are interpolated from 5° by 5° grids.

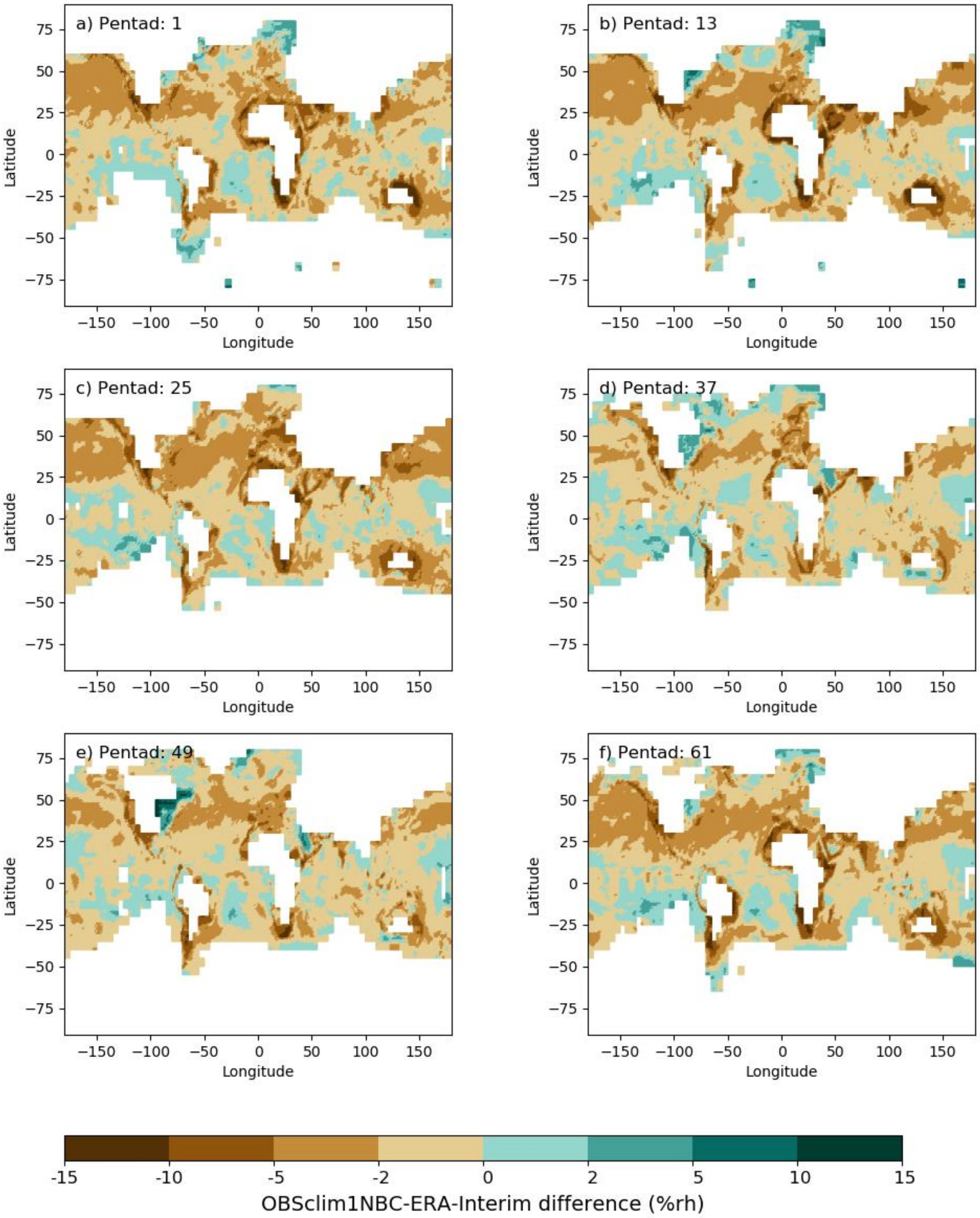


Figure S12 Differences in the 1981-2010 pentad 1° by 1° mean relative humidity climatological standard deviation between the 2nd Iteration infilled gridded observation climatology, used to create the 3rd iteration and bias corrected products, and ERA-Interim, for a range of pentads. Note that the 1° by 1° grids are interpolated from 5° by 5° grids.

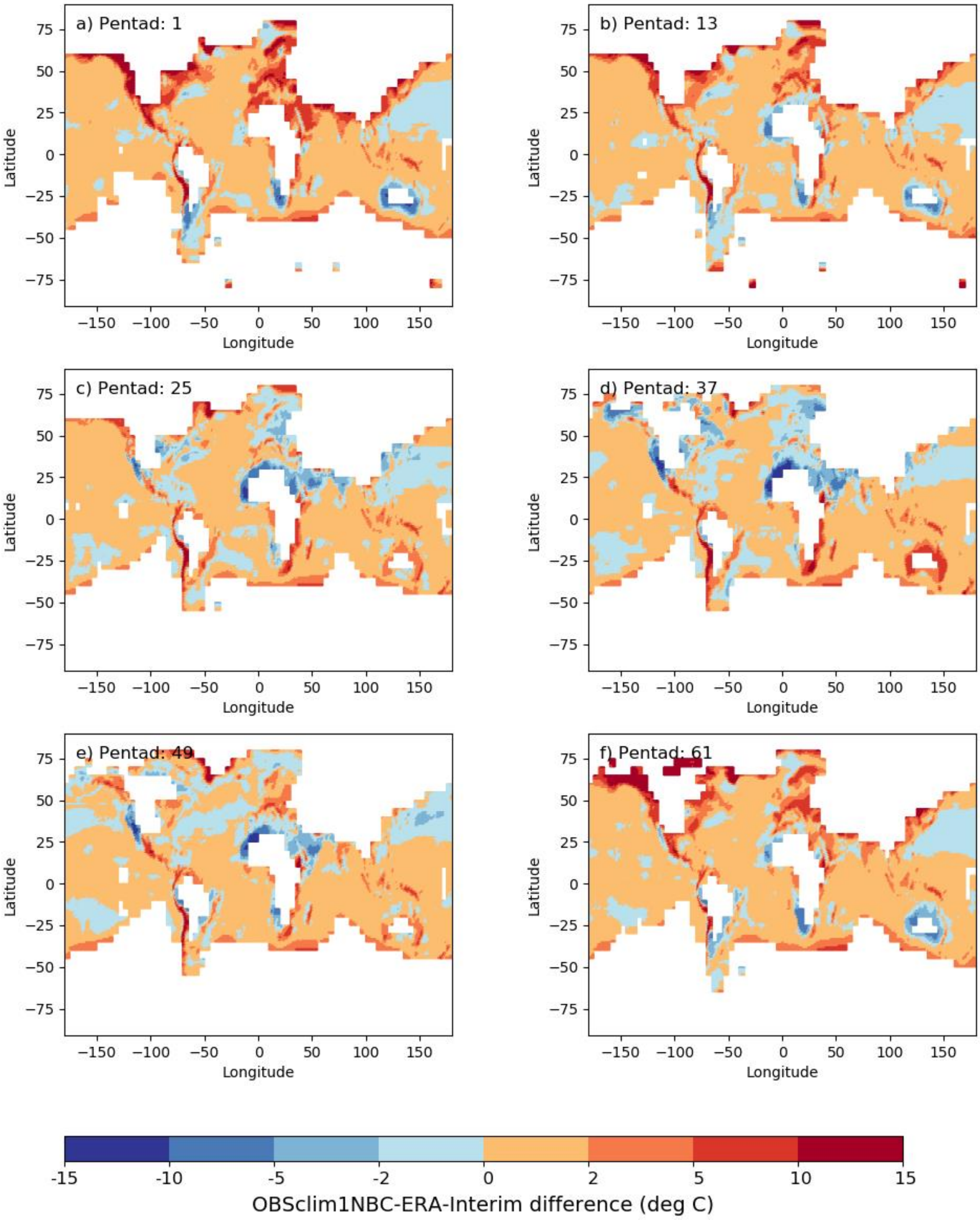


Figure S13 Differences in the 1981-2010 pentad 1° by 1° mean air temperature climatology between the 2nd Iteration infilled gridded observation climatology, used to create the 3rd iteration and bias corrected products, and ERA-Interim, for a range of pentads. Note that the 1° by 1° grids are interpolated from 5° by 5° grids.

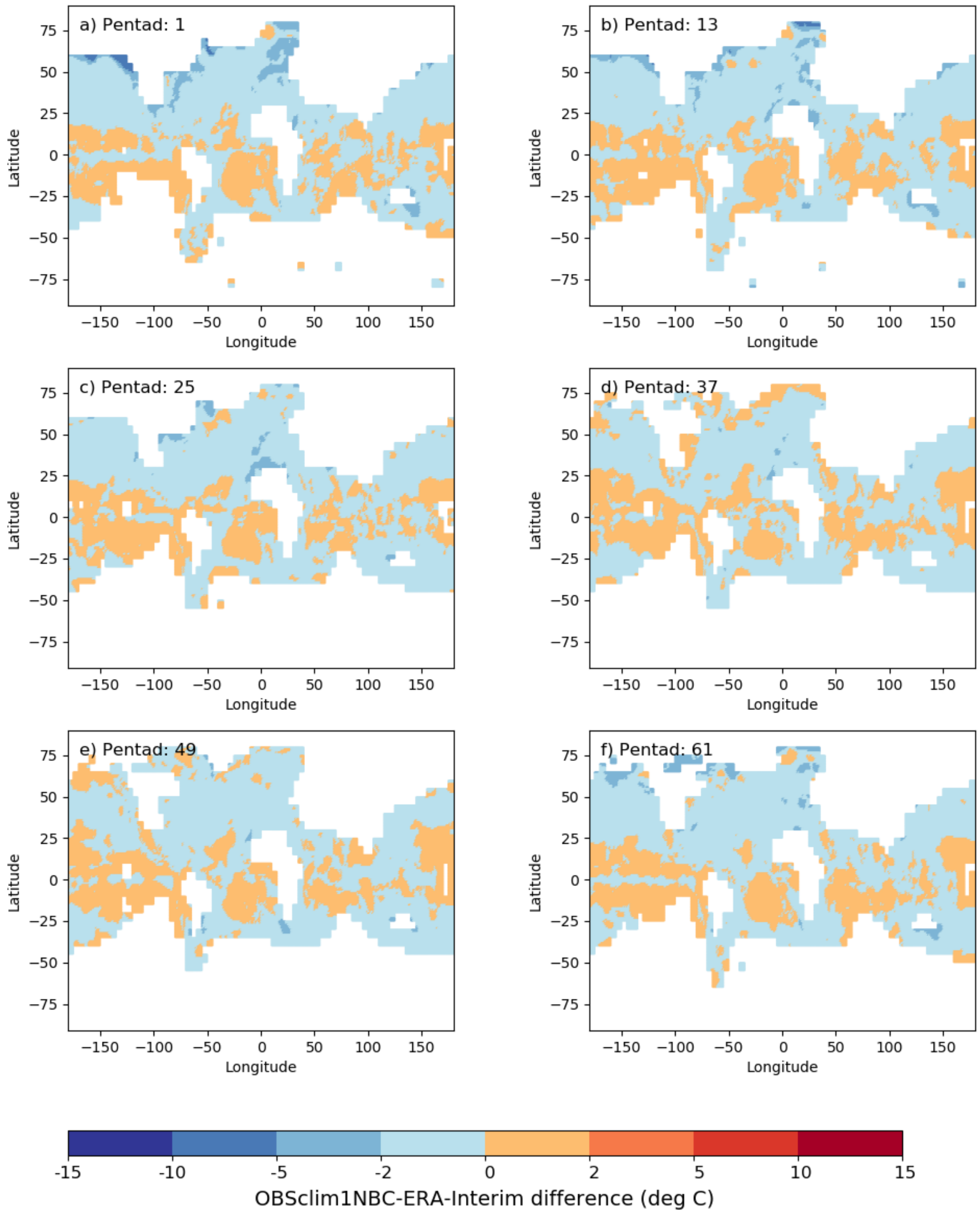


Figure S14 Differences in the 1981-2010 pentad 1° by 1° mean air temperature climatological standard deviation between the 2nd Iteration infilled gridded observation climatology, used to create the 3rd iteration and bias corrected products, and ERA-Interim, for a range of pentads. Note that the 1° by 1° grids are interpolated from 5° by 5° grids.

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