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Supplement of

Merits of novel high-resolution estimates and existing long-term estimates of humidity and incident radiation in a complex domain

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1 Procedure to calculate the HySN data set

Era Interim daily mean 2 meter dew point temperature ($T2d_E$), 2 meter temperature ($T2_E$), surface pressure (ps_E) are taken as the arithmetic mean of the Era-Interim analysis fields, available every 6 hours. Surface incident longwave (LW_E) and shortwave (LW_E) radiation are taken from +12, +18,and +24 hours of the Era-Interim forecasts at 00 and 12 UTC, to reduce the influence spin-up effects have on the fields (see e.g. Weedon et al., 2014; Balsamo et al., 2015). The high resolution gridded observational dataset used in the compilation is the daily SeNorge v2.1 2-meter temperature ($\mathrm{T2_{SN}}$) (Lussana et al., 2018).

The Era-interim data is interpolated to the SeNorge grid in three stages, using bilinear interpolation in most areas, but nearest-neighbour interpolation for SeNorge land areas close to the Era-Interim landmask, and bilinear interpolation for SeNorge land areas outside Era-Interims landmask.

1.1 Vapour pressure [VP] and surface pressure [ps]

The method for downscaling near surface humidity follows Cosgrove (2003), where relative humidity (RH) is assumed constant with height. The assumption of constant relative humidity with elevation is explored in e.g. Feld et al. (2013), and is used in the making of NLDAS, WFD, and PGMFD. RH is given by the ratio of the ambient vapour pressure [VP] (the vapour pressure at dew point [$\mathrm{T_d}$] or frost point [$\mathrm{T_f}$] temperature) divided by the saturation vapour pressure [$\mathrm{VP_s}$] of moist air at the actual air temperature, multiplied by 100:

$$RH = \frac{VP \cdot 100}{VP_s} \tag{S1}$$

The Era-Interim 2-meter RH ($\mathrm{RH_E}$) is calculated using the Era-Interim surface pressure ($\mathrm{ps_E}$), $\mathrm{T2_E}$, and $\mathrm{T2d_E}$, and Equation ew1 in Buck (1981) [Buck81]. The resulting, vertically adjusted HySN dew point or freeze point temperature (for simplicity, denoted $\mathrm{T2d_H}$) is computed (in Celsius) directly from $\mathrm{RH_E}$ (see e.g. Feld et al. (2013)) using the Buck81 equation for water and the AERKi equation in Alduchov and Eskridge (1996) for ice:

$$T2d_H = \frac{c \cdot [ln(RH_E/100) + b(T2_{SN})/(c + T2_{SN})]}{b - ln(RH_E/100) - b(T2_{SN})/(c + T2_{SN})}. \tag{S2}$$

For water b is 17.502 and c is 240.97. For ice b is 22.587 and c is 273.86.

The vapour pressure is then calculated (still using the Buck81 for water and AERKi for ice,) with suggested pressure dependent enhancement factors ($\mathrm{f_e}$) from Alduchov and Eskridge (1996). The HySN surface pressure ($\mathrm{ps_H}$) is estimated by vertically adjusting the Era-Interim surface pressure to SeNorge orography combining the hydrostatic approximation and the ideal gas law equation (Eq. 6 in Cosgrove (2003), similar to the hypsometric equation):

$$ps_H = \frac{ps_E}{e^{(g\Delta z)/(RT2_m)}}, \tag{S3}$$

where $T2_m = \frac{T2_{SN} + T2_E}{2}$ is the estimated mean temperature (in Kelvin) in the atmospheric column between the SeNorge grid elevation and the ERA-Interim grid elevation. Δ z is the difference in elevation between the SeNorge grid and the ERA-Interim grid. Finally the adjusted vapour pressure is calculated:

$$f_e = d \cdot e^{g \cdot ps_H/100.} \tag{S4}$$

$$VP_H = f_e \cdot a \cdot e^{b \cdot T_{dH}/(c + T_{dH})} \tag{S5}$$

For water d is 1.00071 and g is 0.0000045, while for ice d is 0.99882 and g is 0.000008 (Alduchov and Eskridge, 1996). b is 17.502 and c is 240.97 for water [Buck81]. For ice b is 22.587 and c is 273.86 [AERKi]. If supersaturation occurs vapour pressure is calculated for saturation, limiting RH to 100%.

1.2 Longwave incident radiation [LW]

The longwave radiation is adjusted (following Eq. 14 in Cosgrove (2003)) by scaling $\mathrm{LW_E}$ with the ratio of the estimated Stefan-Boltzmann grey body radiation in the SeNorge grid to the estimated Era-Interim Stefan-Boltzmann grey body radiation.

$$LW_H = \frac{\varepsilon_H \, \sigma_{sb}}{\varepsilon_E \, \sigma_{sb}} (\frac{T2_{SN}}{T2_E})^4 \, LW_E. \tag{S6}$$

σ_{sb} is the Stephen-Boltzmann constant, ε_{E} is the Satterlund (1979) estimate of clear sky emissivity given the Era-Interim humidity and temperature: $\varepsilon_E = 1.08(1 - e(-VP_E^{T2E/2016}))$, and ε_{H} is similarly the Satterlund (1979) estimate of clear sky emissivity given the SeNorge temperature and HySN humidity: $\varepsilon_H = 1.08(1 - e(-VP_H^{T2_{SN}/2016}))$.

1.3 Shortwave incident radiation [SW]

No consistent approach is used in other forcing datasets for adjusting SW radiation. Given that SW is very sensitive to near surface humidity, and that the Cosgrove (2003) method used above adjusts VP, we choose to scale the Era-Interim SW based on the estimated clear sky transmissivity for the two datasets; i.e. a method similar to that used to the derive the adjusted LW is used. In Thornton and Running (1999) [TR99] different empirical estimates of the total daily clear sky transmissivity of SW are found, given different input data. Method (z, e) in Table 2 in TR99 predicts the daily clear sky transmissivity based on altitude (z) and VP (denoted with e in TR99):

$$\tau cc = \tau_0^{ps(z)/ps_0} + \alpha VP$$

τ_0 is 0.72 and is an empirical expression of the instantaneous transmittance for a dry atmosphere at reference pressure, $\mathrm{ps(z)}$ is the surface air pressure at grid elevation and $\mathrm{ps_0}$ is the reference surface pressure (e.g. 101300 Pa; it is cancelled out in the calculations). α is $-1.5 \cdot 10^{-5}\mathrm{Pa}^{-1}$ and is a slope parameter relating the influence of water vapour on the transmissivity. The adjusted SW is then calculated by scaling the Era-Interim SW with the ratio of the empirical expression of clear sky SW transmissivity given the difference in grid elevation and VP in the SeNorge and the Era-Interim grid. Since the expression for SW in TR99 is a multiplicative expression of extra-terrestrial (astronomical) radiation scaled by both an all-sky and clear-sky transmissivity, the ratio of the clear-sky transmissivity is squared.

$$SW_H = (\frac{\tau_0^{ps_H(z)/ps_0} + \alpha VP_H}{\tau_0^{ps_E(z)/ps_0} + \alpha VP_E})^2 \, SW_E. \tag{S7}$$

The HySN data product is freely available from Zenodo (https://doi.org/10.5281/zenodo.1970170), and the Python code to generate the data is available on GitHub (https://doi.org/10.5281/zenodo.1435555).

2 Vertical gradients in vapour pressure

Both the observations and model estimates were analysed for dependence on geographical predictors. In order to derive the coefficients to adjust the model estimates to the station observations linear regression was used on seasonal mean values at the location of the 84 measurement stations (see Table S1 and S2). For brevity the vertical gradients of the annual mean humidity values is show in in Fig. S2. Fig S3 shows the vertical gradient when also latitude (above 57 °N) is included in the regression models, while Fig. S4 shows the vertical gradient when altitude, latitude (above 57 °N), distance to the coast, with interaction allowed between the altitude and distance to the coast. Altitude is a significant predictor of vapour pressure in the observations and models, also when additional geographical predictors are included.

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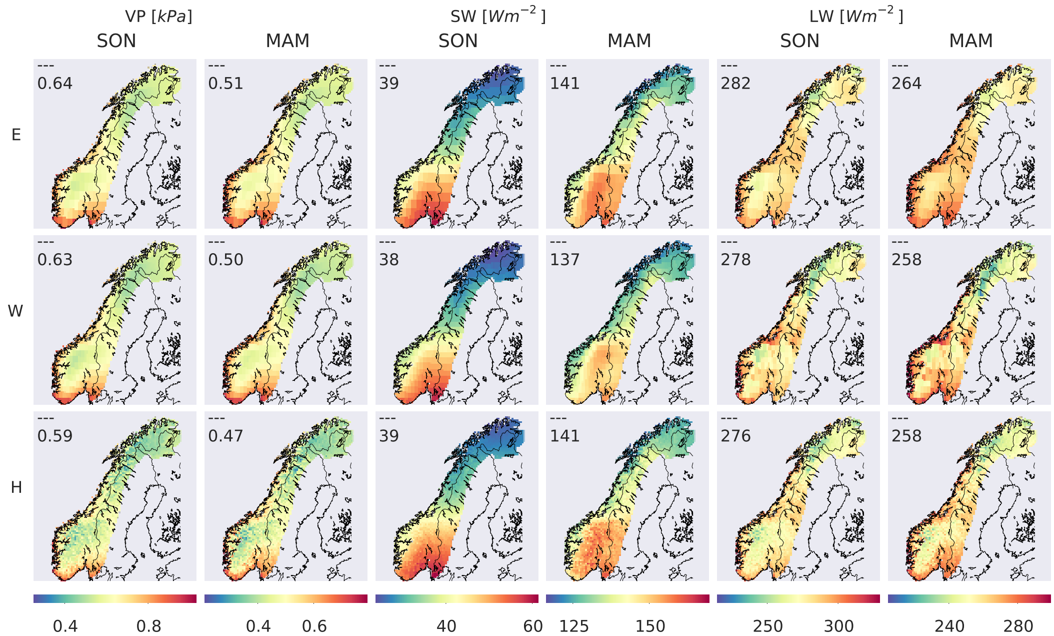

Figure S1. Mean (1982-2000) vapor pressure (VP), incident shortwave (SW ↓) and longwave (LW ↓) radiation estimates in fall (SON) and spring (MAM) of Era-Interim, WFDEI, and HySN. The mean value for the points which are land points for all models are denoted in the upper left corner of each image.

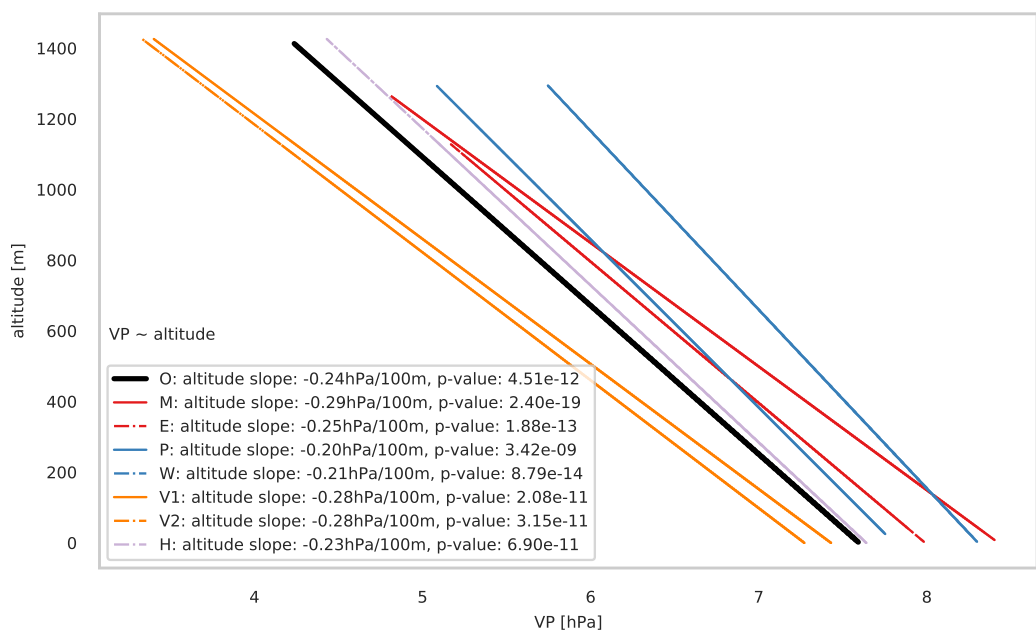

Figure S2. Vapour pressure as a function of altitude based on linear regression using only altitude, with annual means of vapour pressure at or near the location of the 84 measurement stations as predictand.

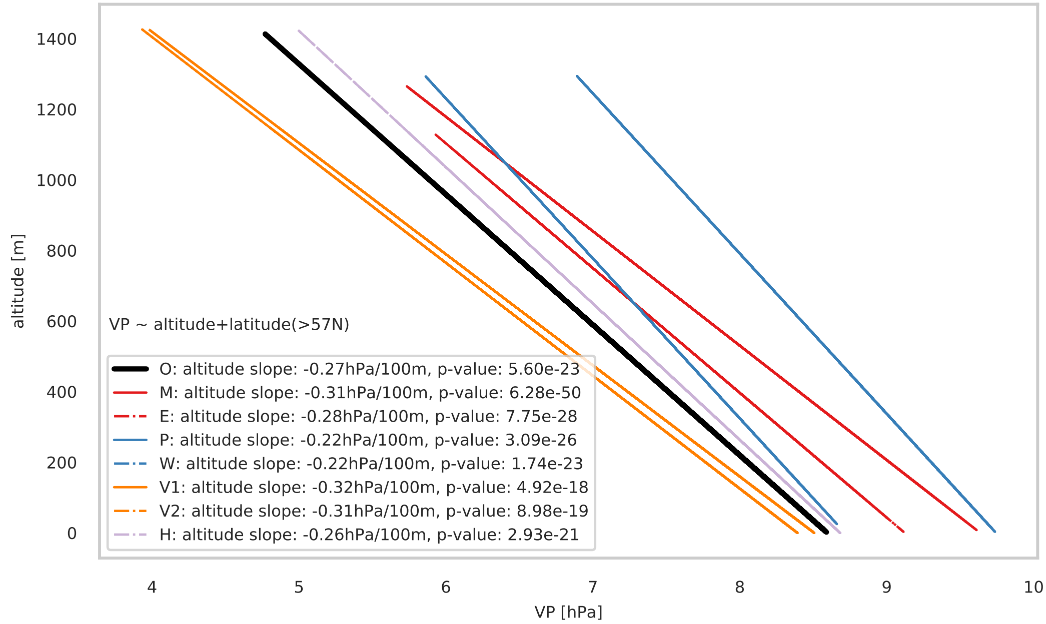

Figure S3. Vapour pressure as a function of altitude based on linear regression using only latitude (above 57 °N) and altitude, for mean annual values of vapour pressure at or near the location of the 84 measurement stations.

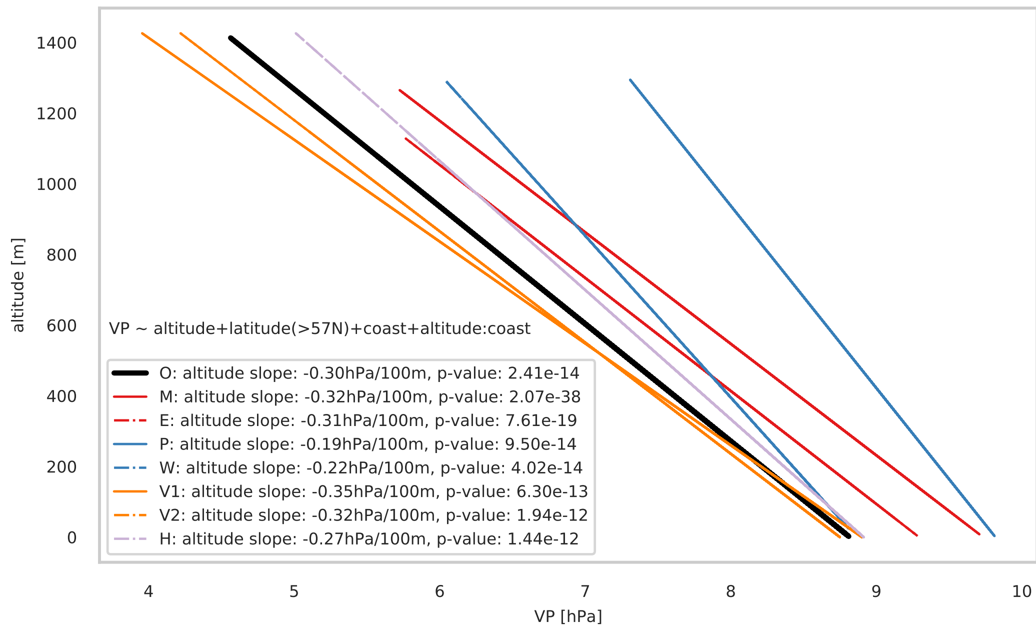

Figure S4. Vapour pressure as a function of altitude alone (excluding the interaction term between distance to the coast and altitude), when based on a linear regression model including latitude (above 57 °N), altitude, distance to the coast, with interaction allowed between the latter predictors. The regression is based on annual mean values of vapour pressure at or near the location of the 84 measurement stations.

Observation stations

Table S1. Stations observing humidity which are included in the analysis. For each station the name, latitude (lat, [°N]), longitude (lon, [°E]), altitude [m], and distance to the ocean [km] of the station are denoted, as well as the first and last month and year of the time-series included in the study.

Name	Lat	Lon	Altitude [m]	Δ ocean [km]	From	To
MANDALII	58.0	7.4	138	2.3	January 1982	December 1999
LANDVIK	58.3	8.5	10	4.6	January 1982	December 1999
NELAUG	58.7	8.6	142	18.1	January 1982	December 1999
OBRESTADFYR	58.7	5.6	24	0.5	January 1982	December 1999
BYGLANDSFJORD-SOLBAKKEN	58.7	7.8	212	49.7	January 1982	December 1999
SOLA	58.9	5.6	7	1.3	January 1982	December 1999
SIRDAL-TJOERHOM	58.9	6.8	500	21.7	January 1982	December 1999
STAVANGER-VAALAND	59.0	5.7	72	1.0	January 1982	January 1988
PRESTEBAKKE	59.0	11.5	157	16.6	January 1982	December 1999
TVEITSUND	59.0	8.5	252	45.3	January 1982	December 1999
RENNESOEY-GALTA	59.1	5.6	19	11.3	January 1982	December 1999
SKUDENESII	59.1	5.2	2	1.2	November 1992	December 1999
MELSOM	59.2	10.3	26	1.2	January 1982	August 1994
SARPSBORG	59.3	11.1	57	10.1	December 1991	December 1999
RYGGE	59.4	10.8	40	4.9	January 1982	December 1999
GVARV	59.4	9.2	26	34.4	January 1982	July 1989
AAS	59.7	10.8	94	9.4	January 1982	December 1999
KONGSBERGIV	59.7	9.7	168	34.5	January 1982	December 1999
DRAMMEN-MARIENLYST	59.7	10.2	3	18.0	January 1982	December 1999
MOESSTRANDII	59.8	8.2	977	93.0	January 1982	December 1999
MIDTLAEGER	59.8	7.0	1079	33.8	January 1982	December 1999
ASKER	59.9	10.4	163	3.2	January 1983	December 1999
DOENSKI	59.9	10.5	59	2.3	January 1982	December 1999
LYNGDALINUMEDAL	59.9	9.5	288	27.1	January 1982	December 1999
OSLO-BLINDERN	59.9	10.7	94	3.2	January 1982	December 1999
MAGNOR	60.0	12.2	154	35.7	January 1982	December 1999
HAKADAL-BLIKSRUDHAGAN	60.1	10.9	174	21.9	December 1982	December 1999
GARDERMOEN	60.2	11.1	202	22.6	January 1982	December 1999
VINGER	60.2	12.0	175	48.7	January 1982	December 1999
FLESLAND	60.3	5.2	48	1.5	January 1982	December 1999
BERGEN-FLORIDA	60.4	5.3	12	0.96	January 1982	December 1999
KVAMSKOGEN	60.4	5.9	408	8.1	January 1982	December 1999
GEILO-GEILOSTOELEN	60.5	8.2	810	58.1	January 1982	December 1999
NESBYEN-SKOGLUND	60.6	9.1	167	60.7	January 1982	December 1999
VOSS-BOE	60.6	6.5	125	18.2	January 1982	December 1999
GOL-STAKE	60.7	8.9	542	65.3	January 1982	February 1991
KISEPAHEDMARK	60.8	10.8	129	3.1	April 1987	December 1999
MODALENII	60.8	6.0	114	14.5	January 1982	December 1999
AABJOERSBRAATEN	60.9	9.3	639	48.2	January 1982	December 1999

Table S2. Stations observing humidity which are included in the analysis. For each station the name, latitude (lat, [°N]), longitude (lon, [°E]), altitude [m], and distance to the ocean [km] of the station are denoted, as well as the first and last month and year of the time-series included in the study.

Name	lat	lon	altitude [m]	Δ ocean [km]	start	end
FAGERNES	61.0	9.2	358	53.8	July 1982	December 1999
LOEKENIVOLBU	61.1	9.1	521	68.8	January 1982	December 1999
RENA-HAUGEDALEN	61.2	11.4	240	42.5	January 1982	December 1999
EVENSTAD-OEVERENGET	61.4	11.1	255	49.8	January 1982	December 1999
FJAERLAND-SKARESTAD	61.4	6.8	10	2.3	February 1982	December 1999
SKAABU-STORSLAAEN	61.5	9.4	890	71.1	January 1982	December 1999
SOGNEFJELLHYTTA	61.6	8.0	1413	23.2	January 1982	December 1999
VENABU	61.7	10.1	930	61.6	January 1982	December 1999
BJOERKEHAUGIJOSTEDAL	61.7	7.3	305	24.7	January 1982	December 1999
SANDANE	61.8	6.2	51	1.9	January 1982	December 1999
DREVSJOE	61.9	12.0	672	7.7	January 1982	December 1999
KJOEREMSGRENDE	62.1	9.0	626	69.1	January 1982	December 1999
FISKAABYGD	62.1	5.6	41	1.0	January 1982	December 1999
FOKSTUGU	62.1	9.3	973	72.9	January 1982	December 1999
TAFJORD	62.2	7.4	11	0.1	January 1982	December 1999
LESJASKOG	62.2	8.4	621	48.9	January 1982	December 1999
VIGRA	62.6	6.1	22	7.8	January 1982	December 1999
ROEROS	62.6	11.4	628	31.6	January 1982	December 1999
SUNNDALSOERAIII	62.7	8.6	10	1.5	February 1983	December 1999
TINGVOLL-HANEM	62.8	8.3	69	2.2	January 1982	December 1999
ORKDAL-OEYUM	63.2	9.8	22	12.1	January 1982	December 1999
SELBU-STUBBE	63.2	11.1	242	28.0	January 1982	December 1999
VAERNES	63.5	10.9	12	1.8	January 1982	December 1999
OERLANDIII	63.7	9.6	10	2.4	January 1982	December 1999
NAMDALSEID	64.3	11.2	86	6.9	August 1982	November 1999
LEKA	65.1	11.7	47	8.7	January 1982	December 1999
SVENNINGDAL	65.4	13.4	121	24.3	January 1982	June 1987
GLOMFJORD	66.8	14.0	39	1.4	January 1982	December 1999
BODOEVI	67.3	14.4	11	1.0	January 1982	December 1999
FINNOEYIHAMAROEY	68.0	15.6	53	5.0	January 1982	December 1999
NARVIKIII	68.5	17.5	17	1.0	January 1982	December 1999
BOEIVESTERAALENII	68.6	14.5	12	3.0	January 1982	December 1999
SORTLAND-KLEIVA	68.6	15.3	14	2.5	January 1982	August 1991
TENNEVOLL	68.7	17.8	22	1.8	January 1982	December 1999
SIHCCAJAVRI	68.8	23.5	382	122.3	April 1982	December 1999
BORKENES	68.8	16.2	36	3.1	September 1983	December 1999
DIVIDALEN	68.8	19.7	228	48.9	January 1982	December 1999
BARDUFOSS	69.1	18.5	76	15.0	January 1982	December 1999
ANDOEYA	69.3	16.1	10	1.9	June 1982	December 1999
CUOVDDATMOHKKI	69.4	24.4	286	77.5	January 1982	December 1999
KARASJOK	69.5	25.5	155	67.5	January 1982	December 1999
SUOLOVUOPMI	69.6	23.5	377	41.2	March 1982	December 1999
TROMSOE	69.7	18.9	100	3.3	January 1982	December 1999
TROMSOE-LANGNES	69.7	18.9	8	2.0	January 1982	December 1999
KIRKENESLUFTHAVN	69.7	29.9	89	0.9	January 1982	December 1999

Table S3. The stations observing SW $\downarrow$ and LW $\downarrow$ included in the analysis are listed. For each station the name, latitude (lat, [$^\circ$N]), longitude (lon, [$^\circ$E]), altitude [m], and distance to the ocean [km] of the station are denoted, as well as the first and last month and year of the time-series included in the study. The stations with a +-sign are agricultural stations drifted by Bioforsk. The LW observation stations are marked with an asterisk. The percentage of discarded data within the time-series and the total number of days used in the validation are given, for LW data this is given in parenthesis. % flagged data includes missing data within the time-series.

Name	lat.	lon.	altitude	Δ ocean	start	end	% flagged	# Days
+Saerheim	58.8	5.7	90	27.6	April 1987	December 1999	27	3365
+Aas	59.7	10.8	94	9.4	August 1991	December 1999	13	2655
*Bergen-GFI	60.4	5.3	40	3.5	January 1982	December 1999	3(*4)	6357(*6460)
+Apelsvoll	60.7	10.9	262	88.2	March 1987	December 1999	25	3494
+Kise	60.8	10.8	129	96.1	April 1987	December 1999	4	4455
Loeken	61.1	9.1	527	73.4	January 1991	December 1999	15	2778
Gjengedal	61.7	6.0	355	24.6	July 1989	June 1996	18	2062
+*Trondheim	63.4	10.5	127	4.1	September 1996	December 1999	(23)	(675)
+Bodoe	67.3	14.5	26	6.5	April 1987	December 1999	15	4002
Maze	69.5	23.7	277	59.0	August 1982	January 1990	13	2408
+Tromsoe	69.7	18.9	12	3.5	June 1987	December 1999	29	3468