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Creation and Application of 250 m Square Grid Meteorological Information for Crop Management Using a Local Weather Station Network

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Abstract

A method to estimate meteorological factors on a 250 m square grid using real-time data from a local weather station network was developed. The method had better precision than an existing one. The 250 m square grid meteorological information was created to cover Memuro City, Hokkaido. The information was used with a wheat developmental model to predict the distribution of wheat maturity days in the city, which had 6, 170 ha of wheat fields and 50 combine harvesters, to support decisions for the best management of the harvesters to avoid damage by preharvest sprouting.

Discipline: Agro-meteorology
Additional key words: maturity, mesh data, meteorological observation robot, wheat

Introduction

Hokkaido is the major granary of Japan and accounts for more than half of domestic wheat production. Wheat is harvested in late July to early August, which unfortunately, overlaps a season with frequent rainfall often resulting in preharvest sprouting, consequent poor grain quality and low selling price. Harvesting at the right time is essential to avoid this damage.

Memuro City, our study area illustrated in Fig. 1, had 6,170 ha of wheat fields (2,551 individual fields) and 50 combine harvesters in 2004. To keep the grain quality, they must dispatch the harvesters to the right field at the right time based on the distribution of the wheat maturity days, which however, is not uniform due to differences in air temperature within the city and temperature sensitivity of the wheat maturity process.

The purpose of this study is to create 250 m square grid meteorological information and use it with a wheat developmental model to predict the distribution of maturity days to support decisions for the best management of the harvesters. So far, when making this kind of decision, 1 km square grid meteorological information, estimated using the AMeDAS weather station network of Japan Meteorological Agency, is often used. The grid scale of 1 km, however, is too large to give detailed harvest time information for each farm field in the city because the

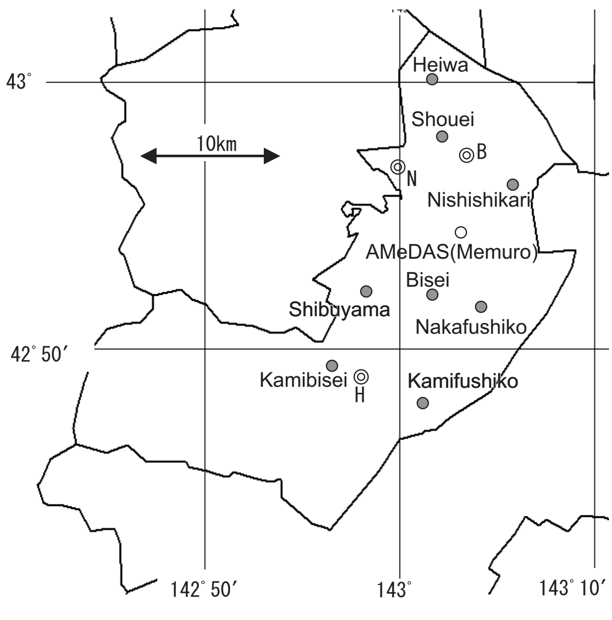

Fig. 1. Map of Memuro City study area
Supplemental portable stations (◎; H, N and B) were placed to verify the values of estimated meteorological elements on the 250 m grid.

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average field size is 160 × 160 m. Fortunately, the agricultural cooperative of the city has its own local weather station network made up of 8 stations, each of which sends hourly meteorological data to the Agricultural Cooperative Information Center. We then developed a method to create 250 m square grid meteorological information using the network to map maturity day information in the city.

Materials and methods

1. Outline of the existing method to create 1 km square grid information

We developed a method to estimate real-time meteorological data (R_d), daily meteorological values on a particular day, on a 250 m square grid by revising an existing method for 1 km scale using AMeDAS data[7], which is briefly explained as follows.

(1) A multiple regression formula is derived to calculate normal values of monthly averaged meteorological data (N_m) from the topographical factors. N_m on each 1 km square grid is then estimated by the formula[5]:

$$N_m = \sum_{i=1}^{n} A_i \times F_i + c \qquad (1)$$

where A_i is a coefficient for a topographical factor of F_i, n is the number of the factors and c is a constant. Fortunately, a ready-made data set of N_m for all the 1 km square grids covering Japan is available[2].

(2) Normal values of daily data (N_d) are calculated from N_m by the harmonic analysis[4].

(3) R_d is estimated using N_d and real-time and normal daily data at nearby AMeDAS stations, RA_j and NA_j, respectively[6]. Usually 4 to 6 stations, within about 30 km, are used

$$R_d = \frac{\sum_{j=1}^{n} \left\{ \left(RA_j - NA_j \right) \left(\frac{1}{r_j} \right) \right\}}{\sum_{j=1}^{n} \left(\frac{1}{r_j} \right)} + N_d \qquad (2)$$

where r_j and n are the distance from a grid to a station and number of stations, respectively.

2. Setting the 250 m square grid system

Japan Industrial Standard defines the "Third Mesh Code System" made up of grids of 30" by 45" of south-north by east-west (conventionally called 1 km square grid though it is not strictly 1 km square). The 250 m square grid system proposed here was set by separating the 1 km square grid into 16 equal pieces and giving extra numbers from 00 to 15 to the end of the third mesh code.

3. Estimation of 250 m square grid meteorological information

We estimated R_d on a 250 m square grid as follows (an example for daily mean temperature is explained).

(1) Daily data at the 8 local weather stations for 7 months, from April to October, in 5 years from 1997 to 2001, was collected ($D_{i,j}$; i and j represent station and day, from 1 to 8 and from 1 to 1,071, respectively). Averaged $D_{i,j}$ over the 8 stations was calculated for the 1,071 days (L_j, j = 1 to 1,071).

(2) The range of L_j was 29.6ºC (from −3.9ºC to 25.7ºC), which was separated into 30 classes (Table 1).

(3) Each of the 1,071 days was assigned to one of the 30 classes by the value of L_j.

(4) Averaged $D_{i,j}$ in each class for each station was calculated ($C_{i,k}$, i and k represent station and class, respectively) as shown in Table 1.

(5) A regression formula for each class was derived to estimate the 5-year mean temperature of the class (N_c) using $C_{i,k}$ as a dependent variable and 4 topographical factors (mean altitude, relief, gradient, and its direction calculated using 50 m mesh elevation data[1]) as independent variables. Thirty formulas were derived to cover all the classes.

$$N_c = \sum_{i=1}^{4} A_i \times F_i + c \qquad (3)$$

(6) N_c for any day on any grid was then calculated as follows. A regression formula for the day was chosen out of these 30 by the averaged daily mean temperature over the 8 stations on the day (L_d). N_c was estimated by Eq. (3) with F_i calculated using the Digital Map 50 m Grid[1].

(7) Then, R_d was estimated using the real-time and 5-year mean temperature at the 8 local stations, RL_j and NL_j, respectively.

$$R_d = \frac{\sum_{j=1}^{8} \left\{ \left(RL_j - NL_j \right) \left(\frac{1}{r_j} \right) \right\}}{\sum_{j=1}^{8} \left(\frac{1}{r_j} \right)} + N_c \qquad (4)$$

Grid values for other meteorological elements listed in Table 2 were also calculated in our system.

4. Predicting maturity day with the grid information

In previous reports for the main island of Japan[3], the wheat maturity day, when panicle moisture reaches 40%, is predicted (calculated) starting on seeding day in the fall. In Hokkaido, however, wheat almost stops its developmental process in winter under the continuous snow cover

Table 1. Classification of daily mean air temperature and $C_{i,k}$ for the 30 classes at each station (ºC)

Class			Stations								
No.	Min.	Max.	Average	Heiwa	Shouei	Nishi-shikari	Shibu-yama	Bisei	Naka-fushiko	Kami-bisei	Kami-fushiko
1	-4	-3	-3.9	-4.0	-3.5	-2.8	-4.1	-3.8	-3.3	-5.1	-4.4
2	-3	-2	-2.1	-2.0	-1.4	-0.7	-2.3	-2.4	-1.7	-3.8	-2.8
3	-2	-1	-1.3	-1.3	-0.9	-0.1	-1.5	-1.4	-1.1	-2.5	-1.9
4	-1	0	-0.3	-0.4	0.1	0.8	-0.5	-0.4	-0.1	-1.5	-0.8
5	0	1	0.6	0.5	1.0	1.6	0.5	0.6	0.9	-0.5	0.3
6	1	2	1.6	1.4	1.8	2.5	1.3	1.8	1.8	1.0	1.4
7	2	3	2.7	2.5	3.0	4.0	2.6	3.0	2.9	1.6	2.2
8	3	4	3.7	3.2	3.8	4.8	3.4	3.8	4.0	2.8	3.3
9	4	5	4.3	4.2	4.7	5.2	4.2	4.3	4.7	3.5	3.9
10	5	6	5.5	5.3	5.9	6.3	5.4	5.7	5.8	4.7	5.2
11	6	7	6.5	6.3	6.5	7.2	6.5	6.6	6.7	5.7	6.2
12	7	8	7.4	7.2	7.4	8.2	7.2	7.6	7.6	6.8	7.1
13	8	9	8.5	7.9	8.6	9.4	8.3	8.7	8.9	7.7	8.2
14	9	10	9.5	9.0	9.6	10.3	9.3	9.8	9.8	8.9	9.2
15	10	11	10.5	10.1	10.6	11.5	10.3	10.6	10.8	9.7	10.2
16	11	12	11.6	11.3	11.8	12.4	11.4	11.6	11.8	11.0	11.3
17	12	13	12.4	12.1	12.7	13.4	12.2	12.5	12.7	11.8	12.1
18	13	14	13.4	13.0	13.6	14.4	13.1	13.4	13.7	12.8	13.2
19	14	15	14.5	14.1	14.6	15.6	14.2	14.7	14.8	13.8	14.3
20	15	16	15.5	15.2	15.5	16.6	15.1	15.6	15.7	14.8	15.2
21	16	17	16.4	16.0	16.5	17.5	16.1	16.6	16.6	15.8	16.1
22	17	18	17.5	17.3	17.7	18.6	17.1	17.6	17.7	16.8	17.2
23	18	19	18.4	18.1	18.5	19.4	18.0	18.6	18.6	17.7	18.1
24	19	20	19.4	19.1	19.5	20.6	18.9	19.6	19.7	18.6	19.1
25	20	21	20.4	20.4	20.4	21.5	19.8	20.6	20.7	19.8	20.1
26	21	22	21.4	21.2	21.5	22.5	21.1	21.5	21.6	20.8	21.2
27	22	23	22.5	22.5	22.4	23.7	22.1	22.8	22.7	21.8	22.3
28	23	24	23.3	23.0	23.2	24.4	23.0	23.6	23.5	22.5	23.0
29	24	25	24.7	24.3	24.3	26.1	24.7	24.9	24.8	24.0	24.7
30	25	26	25.7	25.4	25.6	27.8	25.5	25.7	25.9	24.2	25.5

Table 2. Meteorological elements estimated in our system

Meteorological elements	Unit	Range of a class	Minimum	Maximum	Number of classes
Daily mean air temperature	ºC	1	-4	26	30
Daily maximum air temperature	ºC	1	-4	34	38
Daily minimum air temperature	ºC	1	-8	22	30
Daily mean relative humidity	%	10	40	100	6
Daily minimum relative humidity	%	10	20	100	8
Daily precipitation	mm	5	0.5	75	15

Minimum is the minimum value in the minimum class, and vice versa for Maximum.

and resumes it at snow melt, which is difficult to estimate and could lead to prediction error of the maturity day. A solution was to start the calculation for the prediction on heading day. We derived a developmental model for wheat variety *Hokushin*. Developmental index (*DVI*) was set to equal 0 at heading and 1.0 at maturity. Developmental rate (*DVR*), defined as daily increment of *DVI*, is related to daily mean air temperature by a linear model. Heading days on each grid was estimated by a regression model that was derived using topographical factors and measured heading days as independent and dependent variables, respectively. We used growth survey records of the agricultural cooperative (they survey heading and maturity days at more than 10 fields every year).

On the heading day, the prediction of the maturity day was conducted using N_d because real-time data for the ripening period was not yet available. To provide day-by-day updated maturity day information, the prediction was updated by replacing N_d with R_d.

Results and discussion

1. Multiple regression formula to estimate N_c

Relationship of the values of $C_{i,k}$ among stations changed depending on classes (an example is shown in Fig. 2 for daily minimum air temperature (T_{min}) at four stations). This means that the dependence of R_d on the topographical factors is affected by the class which the day belongs to. There were a number of classes in a month as shown in Fig. 3 and we need the respective regression formulas, which our method can provide. On the other hand, R_d is calculated using N_d, processed from a single N_m by a single formula in a month, by the existing method (Eq. 2). In this respect, our method using N_c instead of N_d is considered to have an advantage over the existing method.

An example of the coefficient in Eq. (3) for altitude that corresponds to temperature lapse rate (ºC/m) is shown in Fig. 4. The value of the coefficient was within the range of −1.9 to 0.3ºC/100 m which is compatible with the typical lapse rate of −0.6ºC/100 m suggesting our model is consistent with the physical meteorology process. Coefficients are fitted to a cubic polynomial to cancel the scattering as shown in Fig. 4.

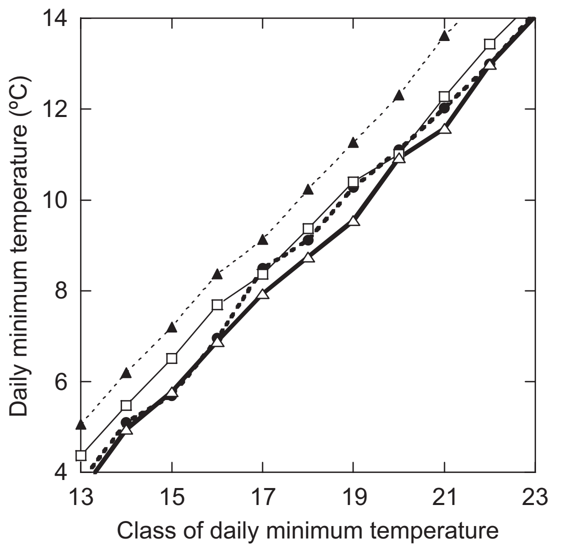

Fig. 2. Comparison of $C_{i,k}$ among stations
-●-: Heiwa, -▲-: Nishishikari,
-□-: Shibuyama, -△-: Kamibisei.

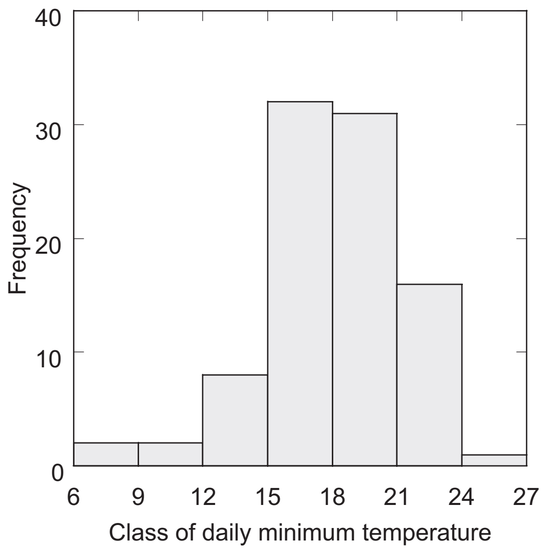

Fig. 3. Frequency distribution of daily minimum air temperature at the Memuro AMeDAS station in June for 3 years from 2000 to 2002

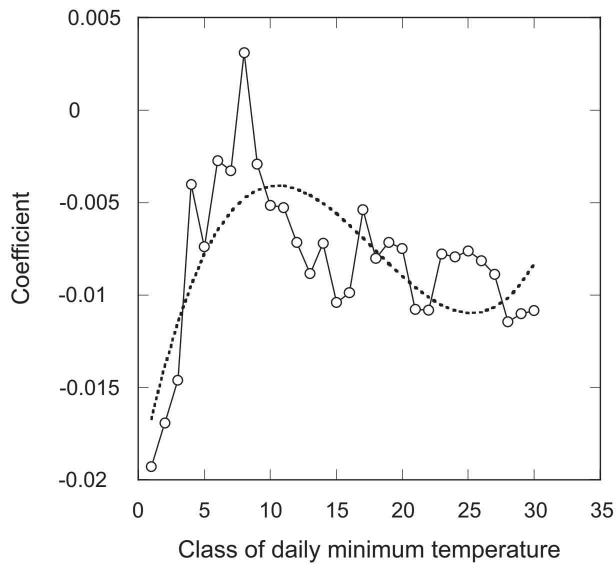

Fig. 4. Coefficient of regression formula for altitude

2. The 250 m square grid meteorological information

Our method creating 250 m square grid information gave better precision of temperature and precipitation than the method presently used[7] when compared using the root mean square errors for the two methods as shown in Table 3.

An example of a 250 m square grid map, for daily mean temperature on 23 June 2004 is shown in Fig. 5.

3. The 250 m square grid information of maturity day

A developmental model shown in Fig. 6 was obtained and used to estimate maturity days with the above 250 m square grid meteorological information. To test the accuracy of the estimation, a map was created after all the wheat reached maturity using R_d from heading to maturity (Fig. 7). Average difference and standard deviation between estimated and measured maturity days were 1.1 and 2.5 days, respectively, for 3-year data of 59 fields from 1999 to 2002.

Conclusion

The 250 m square grid information system is operating at the Agricultural Cooperative Information Center of Memuro City with its GIS system which keeps maps for all the farm fields in the city offering field-specific information of maturity days. The system is also giving other crop information, *e.g.* predicting reduction of wheat quality due to preharvest sprouting after maturity stage.

The same 250 m square grid system explained in this report can be constructed by any organization that has a local weather station network as shown in Fig. 8. Recently portable type network-ready weather stations are available, typically for less than ¥300,000, and it is becoming easier to construct weather station networks with a real-time data acquisition system.

Acknowledgments

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Table 3. Comparisons between observed and estimated values of meteorological elements

Meteorological elements		Error (observed - estimated)			
		H station	N station	B station	AMeDAS
Daily mean temperature (ºC)	MD	-0.4	-0.1	-0.3	0.2
	RMSE	0.4	0.3	0.3	0.3
Daily maximum temperature (ºC)	MD	-0.1	0.2	-0.7	0.5
	RMSE	0.3	0.5	0.7	0.8
Daily minimum temperature (ºC)	MD	-0.5	0.0	-0.3	0.1
	RMSE	0.5	0.4	0.3	0.3
Daily mean relative humidity (%)	MD	2.6	1.3	3.8	–
	RMSE	3.0	1.7	3.9	–
Daily minimum relative humidity (%)	MD	2.8	0.2	4.3	–
	RMSE	3.5	2.1	4.8	–
Daily precipitation (mm)	MD	-0.2	-1.6	-2.1	-0.9
	RMSE	1.1	2.4	2.9	1.7

June and July of 2003.
MD: Mean difference.
RMSE: Root mean square error. RMSE for daily mean, maximum and minimum temperature by the existing method are 0.8ºC, 1.0ºC and 1.5ºC respectively, and 3.1 mm for precipitation in the Tokachi region of Hokkaido[7].
The locations of H, N, B, and AMeDAS stations are shown in Fig. 1.

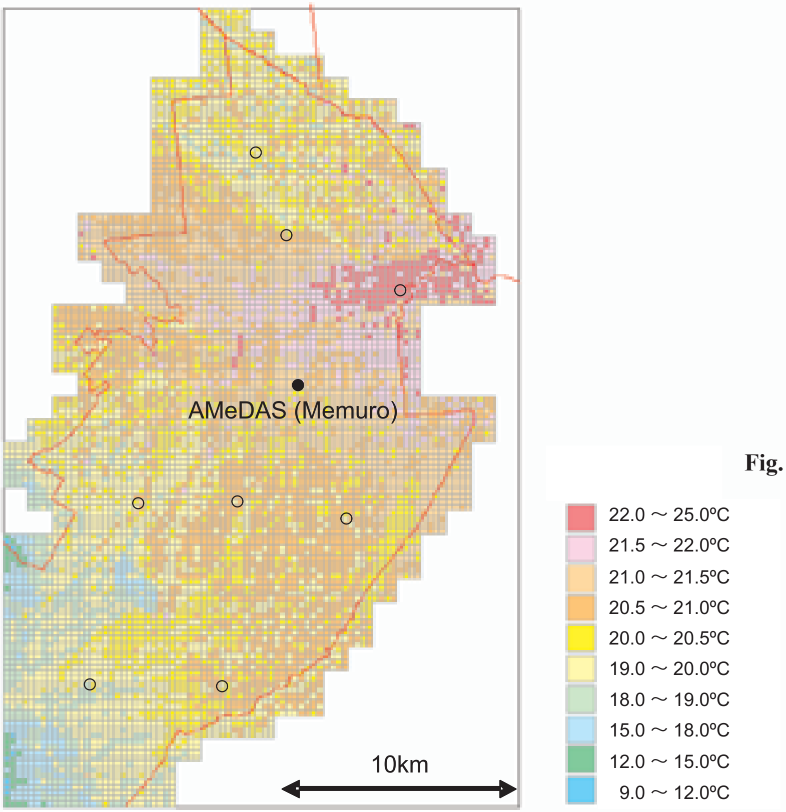

Fig. 5. The 250 m square grid map of estimated daily mean air temperature (June 23, 2004)

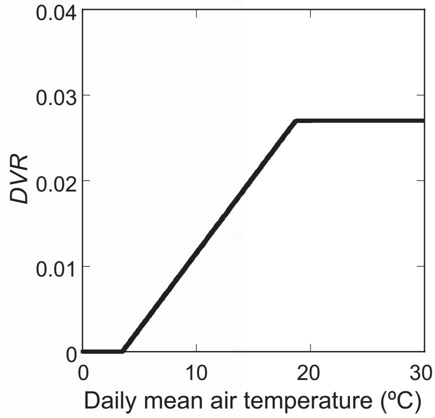

Fig. 6. Developmental model for wheat cv. *Hokushin*

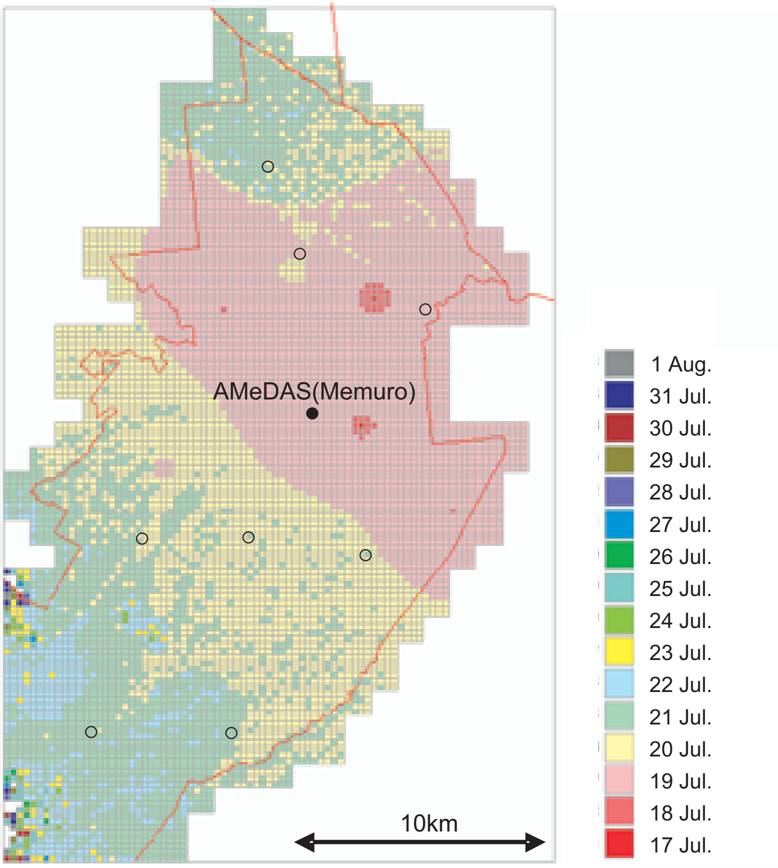

Fig. 7. The 250 m square grid map of estimated maturity days, 2004

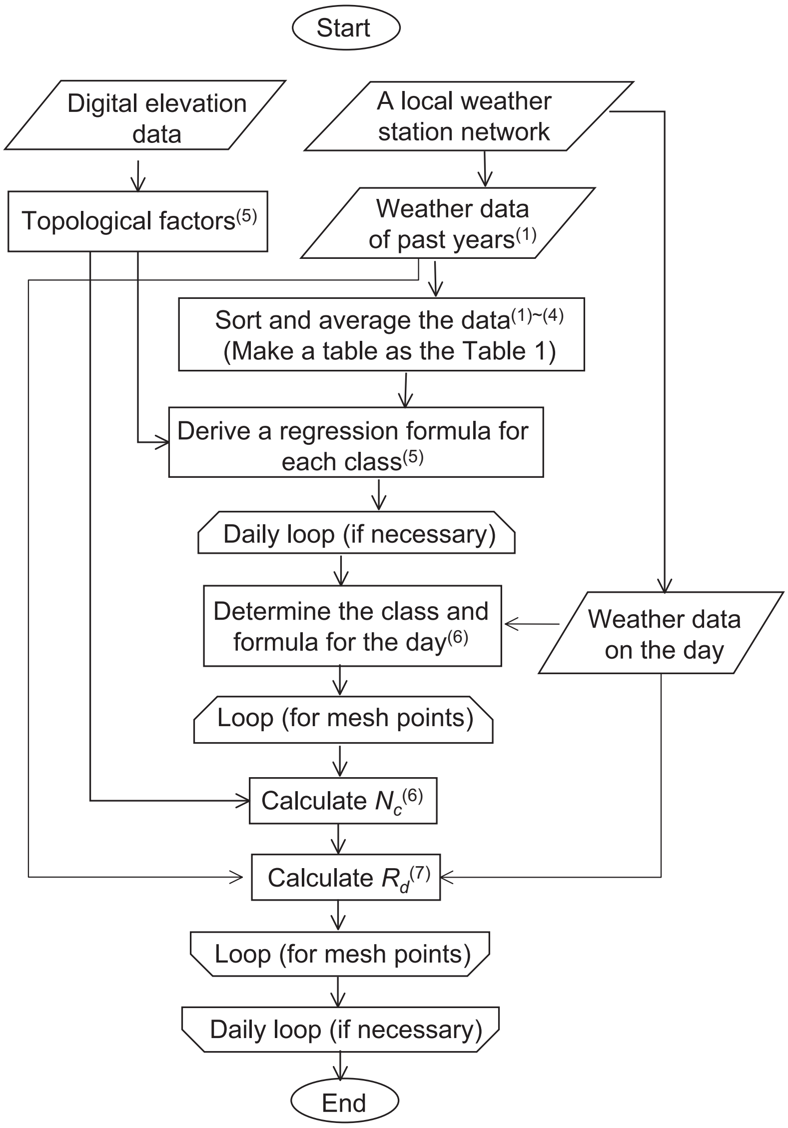

Fig. 8. A flow chart to calculate 250 m square grid meteorological information in a local area
Numbers in the superscripts indicate the procedures explained in "3. Estimation of 250 m square grid meteorological information" of materials and methods.

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