

This article was downloaded by: [94.34.8.216]

On: 29 December 2011, At: 02:47

Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Grana

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/sgra20>

An improved simulation of mesoscale dispersion of airborne cedar pollen using a flowering-time map

S. Kawashima & Y. Takahashi

Available online: 05 Nov 2010

To cite this article: S. Kawashima & Y. Takahashi (1999): An improved simulation of mesoscale dispersion of airborne cedar pollen using a flowering-time map, *Grana*, 38:5, 316-324

To link to this article: <http://dx.doi.org/10.1080/001731300750044555>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.tandfonline.com/page/terms-and-conditions>

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae, and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand, or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

An improved simulation of mesoscale dispersion of airborne cedar pollen using a flowering-time map

S. KAWASHIMA and Y. TAKAHASHI

Kawashima, S. & Takahashi, Y. 1999. An improved simulation of mesoscale dispersion of airborne cedar pollen using a flowering-time map. – Grana 38: 316–324. ISSN 0017-3134.

A model that simulates emission and dispersion of pollen of Japanese cedar (*Cryptomeria japonica* D. Don) was developed and tested for the Tohoku district of Japan. To take into account the effect of altitude and local climate on flowering time, a flowering-time map was tested. The observed variation in the number of pollen grains was high in Yamagata City and relatively small in the southern cities. Sakata, facing the Sea of Japan, shows an individual pattern with two large peaks. Simulation without a flowering-time map predicted unobserved large peaks at the beginning and end of the cedar pollen season and tended to overestimate peaks in general. Simulation with a flowering-time map closely reproduced the changes in the number of airborne pollen grains with time at the beginning and end of the season and simulated the general variation in airborne pollen number well.

S. Kawashima, Laboratory of agroclimatology, National Institute of Agro-Environmental Sciences, 3-1-1 Kannondai, Tsukuba 305-8604, Japan. E-mail: sig@niaes.affrc.go.jp; Y. Takahashi, Yamagata Prefectural Institute of Public Health, 1-6-6 Tokamachi, Yamagata 990-0031, Japan. E-mail: ytak4810@eiken.yamagata.yamagata.jp.

(Manuscript accepted 15 December 1999)

Pollinosis from Japanese cedar (*Cryptomeria japonica* D. Don) occurs in early spring. In recent years, the number of patients presenting with pollinosis has increased rapidly, and the allergy is becoming a serious social problem. In response to the problem, several organizations began monitoring airborne pollen systematically, and data from these sampling stations are accumulating. The spatial distribution of vegetation in Japan has been surveyed in detail and published as vegetation maps. A dense meteorological observation network of 1300 automatic weather stations, called AMeDAS (Automated Meteorological Data Acquisition System), is used to monitor surface weather conditions continuously. The mean interval between stations of the network is about 21 km. It is important to unite these data and produce detailed pollen information. In urban areas, the synergism of pollen and air pollutants makes pollinosis worse. Even when pollen concentrations are low, information about the movement and distribution of pollen is very important.

Studies concerning the relationship between the quantity of airborne Japanese cedar pollen and weather conditions can be divided into two types. The first investigates the relationship between yearly number of airborne pollen grains and the climate of the previous year (Nemoto 1988, Saito & Usami 1980, Takahashi et al. 1989b, Kawashima 1990a). The second investigates the relationship between daily or hourly numbers of airborne pollen grains and contemporary weather conditions (Sahashi et al. 1983, Saito & Usami 1980, Takahashi et al. 1989a, Giostra et al. 1991). Results common to these studies are related to variations in air temperature. Kawashima (1991) developed a model that express the relationship between the weather conditions and the amount of pollen emitted to the atmosphere from a flowering cedar forest.

Many studies have been done of short-range dispersion

(e.g. Raynor et al. 1972, 1973; Price & Moore 1984, Di-Giovanni & Beckett 1990) and middle- and long-range transport (e.g. Markgraf 1980, Mandrioli et al. 1980, Hall 1990, Scott & van Zinderen Bakker 1985, Hjelmroos 1991) of airborne pollen.

We previously developed a method to estimate the distribution of airborne pollen of Japanese cedar by using a simulation method (Kawashima & Takahashi 1995). One of its drawbacks was related to the flowering time of Japanese cedar. The calculated pollen numbers tended to be overestimated at the beginning and end of the season, because the simulation did not take into account the variations in flowering time in the study area. The aim of our research is to develop an improved method to estimate the detailed mesoscale distribution of airborne pollen of Japanese cedar by using a simulation to synthesize weather and vegetation data. We have now revised the model to take into account the locality of flowering time and applied it to the Tohoku district of Japan, and investigated the validity of a flowering-time map with the method.

MATERIALS AND METHODS

Study area

Figure 1 shows the study location, which lies in the southern part of the Tohoku district of Japan, including the 66 AMeDAS stations and the 10 airborne pollen sampling stations it contains. The area includes Yamagata Prefecture and parts of several surrounding prefectures. It is about 205 km from north to south and 220 km from east to west.

Meteorological data

The AMeDAS data were used to determine the weather conditions requisite for pollen emission and dispersion by wind. The AMeDAS

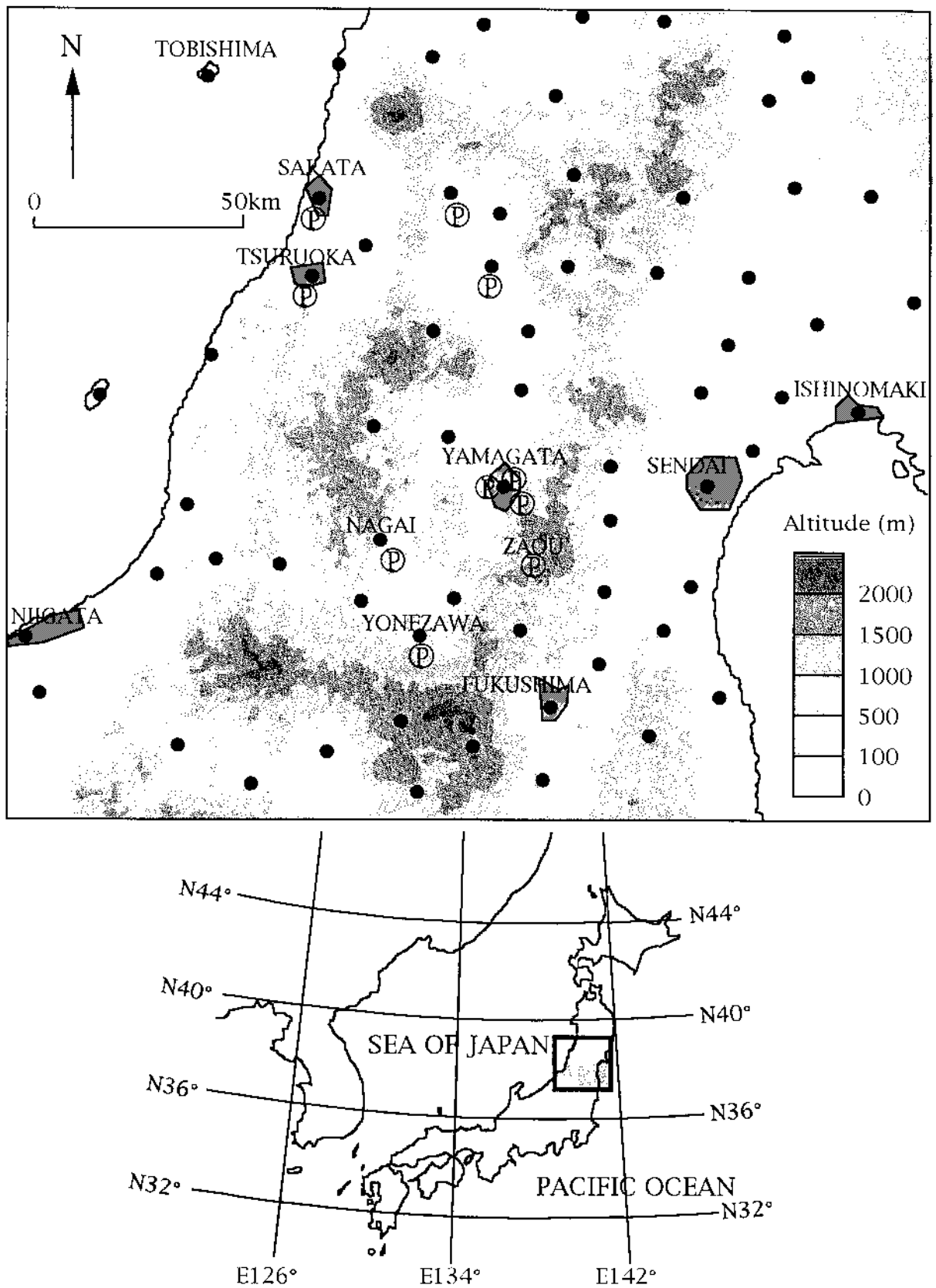


Fig. 1. Location of the study area in the southern part of the Tohoku district of Japan. The area includes Yamagata Prefecture and parts of several surrounding prefectures. It is about 205 km from north to south and 220 km from east to west. The black dots show the locations of AMeDAS stations, and the circled Ps show the locations of the airborne pollen sampling stations.

stations record air temperature, wind speed and direction, sunshine duration, and precipitation every hour. Wind speed and direction are measured at 10 m above ground level. An index file was prepared, containing the identification number, latitude, longitude, and altitude of all the AMeDAS stations. Data from February to March of several recent years were used (Kawashima 1990b).

Japanese cedar map data

Japanese bureau of nature conservation surveyed the distribution of vegetation species and published the results as vegetation maps (Bureau of Nature Conservation 1975, 1980, 1986). The percentage areas of Japanese cedar forest in every 2nd-order grid area were estimated from the vegetation maps. A 2nd-order grid area is a unit in the Japanese geographical information system (Miyazaki & Tsukahara 1987). Such a grid area corresponds to 1 frame of a 1:25000 geographical map, and has a size of about 10 by 10 km. To update the data estimated from vegetation maps, we investigated a method for detecting cedar forest using satellite images (Takahashi & Kawashima 1999a). This method could be applied to the central part of the study area. We made up a numerical map of Japanese cedar by combining the data estimated from the vegetation maps with that derived from satellite images. The map is shown in Fig. 2 with the 2nd-order grid system.

Airborne pollen data

The Yamagata Prefectural Institute of Public Health systematically and continuously monitors the quantity of airborne pollen. The 10

observation points cover a wide area from the mountains to the coast facing the Sea of Japan (Fig. 1). The Durham sampling method is used at all points for daily data (number day⁻¹ cm⁻²), and Burkard samplers are used at some points for hourly data (number per 0.5 m³). The glass slide for daily sampling is changed at 9 a.m. The Burkard sampler pollen counts in the town of Zaou were used as typical data to construct the pollen emission model.

Flowering time map of Japanese cedar

Takahashi et al. (1991) investigated the relationship between the weather conditions and flowering time at different localities. They showed that the integrated air temperature from 1 January could be used as the criterion for flowering time. Data for 1990 gave a criterion value of 210 °C. A flowering time map of Japanese cedar was made up based on this value and on the spatial distribution of the air temperature in 1990.

Pollen emission and dispersion model

A model was constructed to simulate the process of pollen emission from a forest of Japanese cedar to the atmosphere, and the process of transport and diffusion of airborne pollen by wind.

The framework of the model is the same as that of our previous model (Kawashima & Takahashi 1995). The study area was divided into 22 blocks north to south and 20 blocks east to west to facilitate calculations. Each square corresponds to a 2nd-order grid area. All calculations have been based on this grid system. Fig. 3 shows the flow of data processing. Hourly meteorological data from AMeDAS

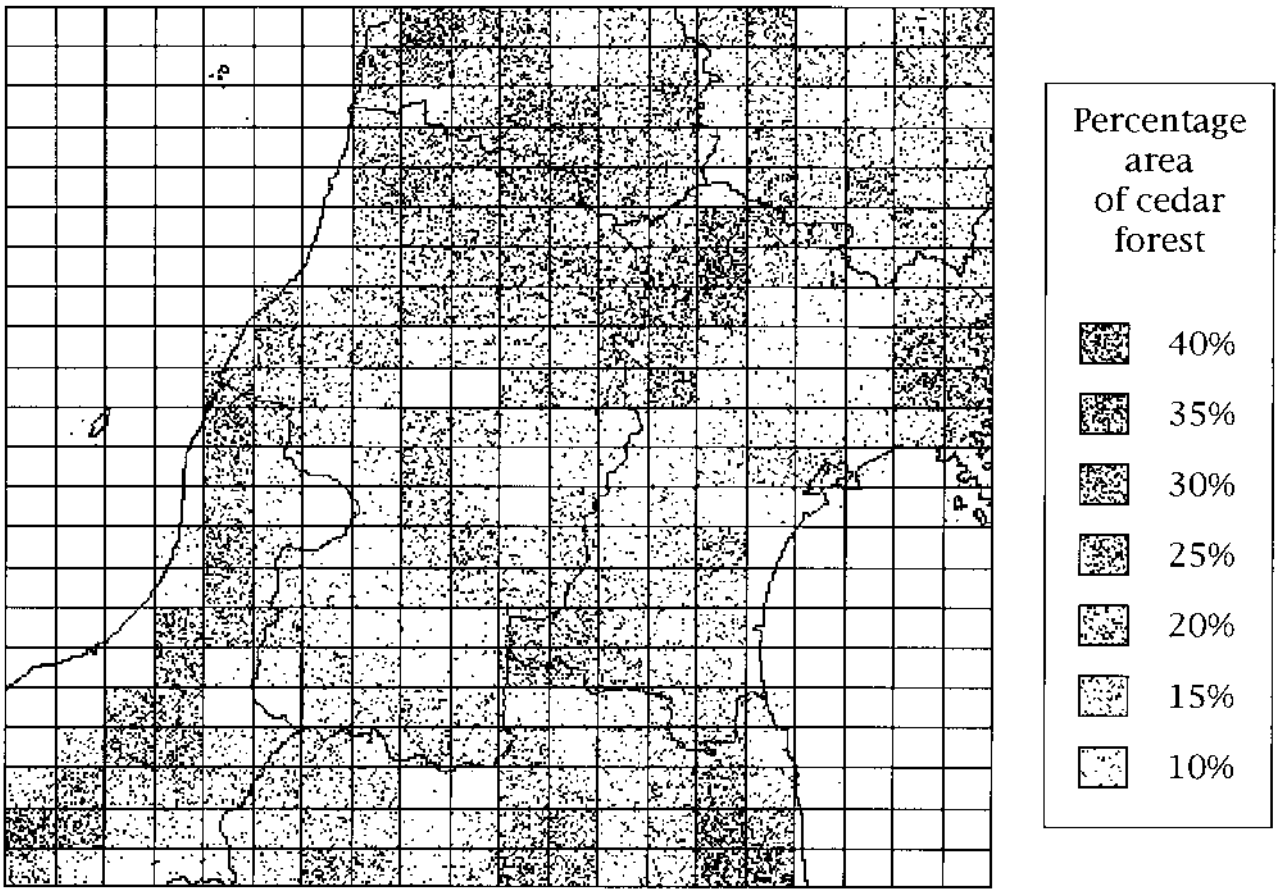


Fig. 2. Vegetation map of Japanese cedar on the 2nd-order geographical grid system. The forest density is shown by the dot density.

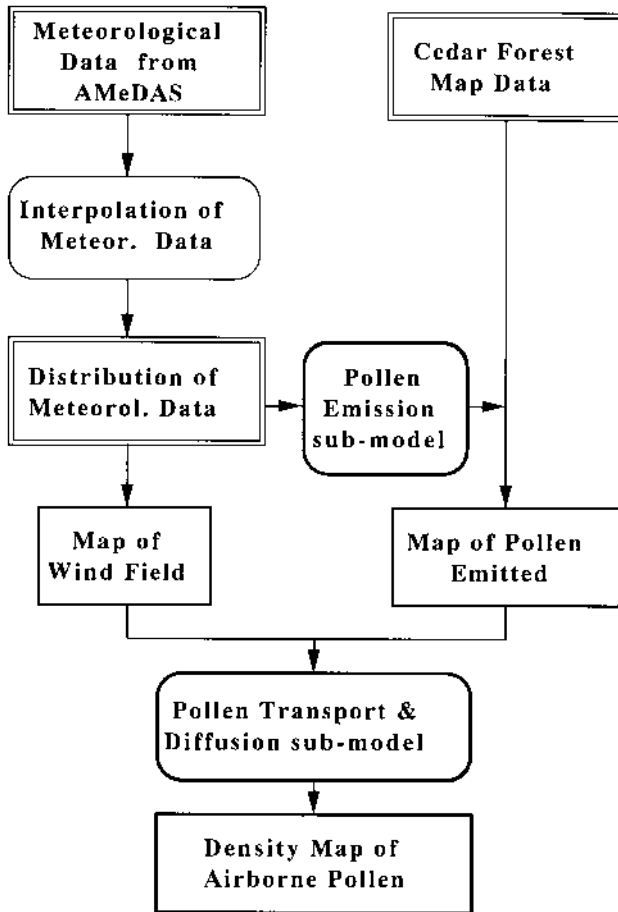


Fig. 3. Flowchart for the pollen emission and dispersion model used in this study. Hourly meteorological data from AMeDAS and the density map of Japanese cedar are the primary inputs to the model. The meteorological data for each grid square area are interpolated. The spatial distribution of meteorological data is the input to the pollen emission submodel. The interpolated wind field and the distribution of emitted pollen are the inputs to the pollen transport and diffusion submodel for calculating the distribution of total airborne pollen.

and the density map data for Japanese cedar were entered into this model.

As the AMeDAS stations are not located at regular intervals with respect to the grid, the meteorological data for each grid square area were interpolated by the inverse distance method, following a comparison of the merits of several interpolation methods (Tronci et al. 1986, Kawashima & Takahashi 1990c). The spatial distribution of each interpolated datum was entered into the pollen emission submodel and the pollen transport and diffusion submodel.

Pollen emission submodel

This is based on a formulation of the relationship between the weather conditions and the quantity of pollen emitted from Japanese cedar forest to the atmosphere. On the basis of our previous results (Kawashima & Takahashi 1995), equations (1), (2), and (3) express the relationship between the weather conditions and the amount of pollen emitted to the atmosphere from a uniformly flowering cedar forest. This model simultaneously takes

account of the effects of daily and hourly changes in weather conditions.

$$\Delta T_i = T_i - \left(\sum_{j=1}^{24N} T_{i-j} \right) / 24N \quad (1)$$

$$\Delta W_i = W_i - \left(\sum_{j=1}^{24N} W_{i-j} \right) / 24N \quad (2)$$

$$P = a\Delta T_i + b\Delta W_i + c \quad (3)$$

T_i is hourly air temperature ($^{\circ}\text{C}$), W_i is hourly wind speed (m/s), N is the period of averaging (day), and P represents the quantity of pollen emitted to the atmosphere from the cedar forest per unit time. In the model, it is assumed that P is an average concentration of emitted pollen in the transport air layer.

The general level of the parameters a , b , and c are related to the quantity of male flowers at the year. It was known that the quantity of male flowers was related to the climate of the previous year (Takahashi et al. 1989b, Kanazashi et al. 1990). We developed a new method for predicting the quantity of male flowers of Japanese cedar based on variation in annual summertime temperature (Takahashi & Kawashima 1999b). The quantity of male flower is closely related with the difference between the temperature of the last summer and that of the summer before last. The general level of the parameters a , b , and c could be predicted using this method.

Equation (3) was selected because its multiple correlation coefficient was highest when we compared various combinations of meteorological variables and their derivations, such as T_i , ΔT_i , W_i , and ΔW_i . The optimum values of the weighting parameters were calculated as $a=1.3$, $b=1.2$, and $c=0.63$ using ΔT_i , ΔW_i , $N=19$, and the number of airborne pollen grains recorded in the source area.

The output of the submodel is the potential quantity of pollen emitted from a uniform forest per unit time and unit area. The quantity of emitted pollen for each grid square area is estimated by multiplying the potential quantity of emitted pollen by the percentage area of cedar forest for that square. The interpolated wind vectors for all grid areas and the distribution of emitted pollen are then entered into the pollen transport and diffusion submodel.

Pollen transport and diffusion submodel

The public health agency of Kawasaki City measured concentration profiles by helicopter on several occasions in 1988. The helicopter flew at 300, 600, and 900 m above the ground and sampled airborne pollen grains with Vaseline-coated glass slide that was mounted away from the helicopter body. When many pollen grains were observed, more than half were observed at 300 m. This result suggests that most of the cedar pollen is transported in the lower part of the convective boundary layer. The distribution of pollen concentration with respect to the height and depth of the transport layer might change with atmospheric instability. However, only very little information about the vertical profile of cedar pollen distribution has been obtained. Further measurements of the vertical distribution of airborne pollen are needed for modeling the multi-layer diffusion of cedar pollen.

The main objective of this paper was to determine how we can estimate, as a first step, the horizontal transportation and spatial distribution of airborne cedar pollen. We used the Eulerian-type diffusion model with 1 layer specified for the transport of cedar pollen. The change in concentration of any material that is transported in the atmosphere is, in general, described by the following equation:

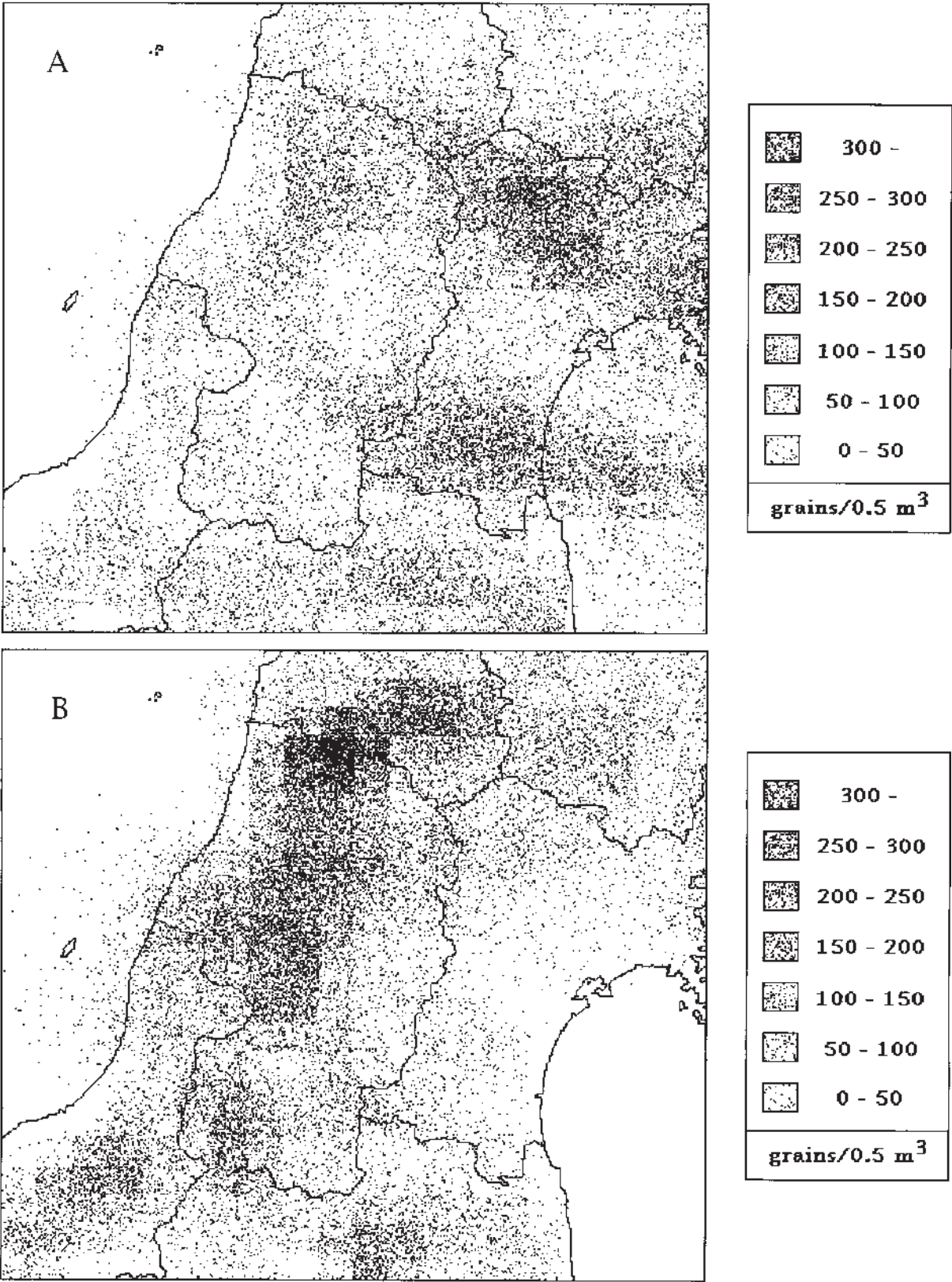


Fig. 4. Spatial distribution of airborne pollen obtained from the simulation. The sections with more dots represent areas where the concentration of pollen is higher. (A) The airborne pollen grains emitted from the cedar forest areas were transported to the Pacific Ocean side of the district, as the wind blew from a high-pressure area over the Sea of Japan (4 p.m., 10 April 1990). (B) The pollen grains were transported to the Sea of Japan side of the district, as the wind blew from a high-pressure area over the Pacific Ocean (5 p.m., 11 April 1990).

$$\frac{\partial M}{\partial t} = \nabla \cdot (\mathbf{V}M) - \nabla \cdot (\mathbf{K} \nabla M) + S_0 - S_1 \quad (4)$$

where $\nabla = \partial/\partial x + \partial/\partial y$; M is the concentration of the material in the air; $\mathbf{V}$ is the wind vector; $\mathbf{K}$ is the diffusion coefficient; S_0 is a source term; S_1 is a sink term; x , y , and z indicate an orthogonal coordinate system; and t represents time.

This equation shows that the change in concentration of airborne material at an arbitrary point in the atmosphere depends on the effects of transportation, diffusion, source, and sink. We applied this equation to the dispersion of airborne pollen of Japanese cedar using a discrete grid system. In this study, M is the number of pollen grains in a unit volume of air. The wind speed of the transport layer is extrapolated from the surface wind speed by using the logarithmic law of wind profile. The wind direction in the lower part of the convective boundary layer is not very different from the AMeDAS observation. So the surface wind direction, which is interpolated from AMeDAS data, is used as the wind direction of the transport layer. The transport term is calculated from the wind vector corresponding to each grid square area and the spatial distribution of airborne pollen in the previous time step. The diffusion term is estimated as diffusion to the surroundings for each air mass after movement by transportation. This term is calculated, in the actual calculation program, by using a Gaussian distribution with a standard width of diffusion that depends on wind speed. The diffusion width σ and the wind speed $|\mathbf{V}|$ are related by the following equation:

$$\sigma = d_1 + d_2 |\mathbf{V}| \quad (5)$$

where d_1 and d_2 are constant variables. The source term S_0 is calculated by multiplying the output of the pollen emission submodel (P) by the percentage area of cedar forest. The sink term S_1 consists of dry deposition and wet deposition such that

$$S_1 = D_d M + D_w M \quad (6)$$

where D_d is the dry deposition rate and D_w is the wet deposition rate. The parameters d_1 , d_2 , and D_d are difficult to predict, because of the lack of observations. We estimated them after several trial simulations and comparisons between simulated and observed pollen data. D_w is estimated from the changes in airborne pollen concentration obtained from Burkard sampler records before and after precipitation.

Simulation

The weather data were for 1990, when the most abundant pollen was observed in the Tohoku district. The parameters of the pollen emission submodel were $a=1.3$, $b=1.2$, $c=0.63$, and $N=19$ days. In this paper, we assume that the same model can be used to represent the relationship between the amount of pollen emitted and the weather conditions for the same species of Japanese cedar in the study area. Several parameters of the pollen transport and diffusion submodel were set after we repeated the trial and error calculations and compared the results with the time sequence and spatial distribution of observed airborne pollen data. The optimum parameters for calculating the diffusion and sink terms were $d_1=10$ km, $d_2=500$ sec, $D_d=0.02$, and $D_w=0.99$.

The daily airborne pollen densities were calculated for the fixed sampling sites by summing the hourly simulated pollen concentration considering the exchange time of the glass slide, and the simulated results were compared with the observed pollen data. To clarify the applicability and the effect of the flowering-time map, simulations were run with and without the flowering-time map.

RESULTS AND DISCUSSION

Figure 4 shows examples of spatial distribution of airborne pollen obtained from the simulation. The sections with more dots represent areas where the concentration of pollen is higher. In Fig. 4A (4 p.m., 10 April 1990), the pollen grains emitted from the cedar forest areas were transported to the Pacific Ocean side of the district, as the wind blew from a high-pressure area over the Sea of Japan. In Fig. 4B (5 p.m., 11 April 1990), the pollen grains were transported to the Sea of Japan side of the district, as the wind blew from a high-pressure area over the Pacific Ocean.

Simulations without the flowering-time map

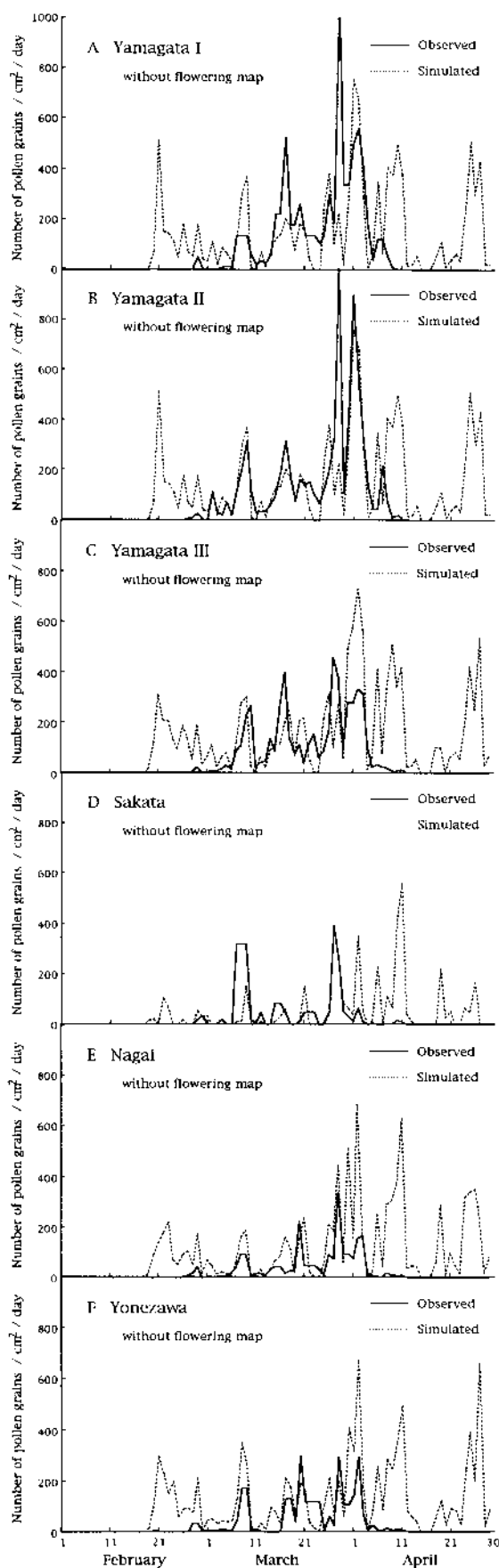
Simulation was done under the hypothetical condition that the cedar was flowering uniformly across the area after 20 February. This condition corresponds to a case of no information available about the regional differences in flowering time. Fig. 5 shows the observed and calculated changes in the number of airborne pollen grains with time. Volumetric data were converted to gravitational data by using the relationship between the Burkard sampler data and the Durham sampler data at the same observation point.

Yamagata I is located at the Yamagata Prefectural Institute of Public Health in the central area of Yamagata City. Most of the surrounding ground surface is covered by buildings and asphalt road. Yamagata II is located at the Yamagata meteorological observatory in the northeast part of the city. The surrounding ground surface condition there is the same as that at Yamagata I. Yamagata III is located in the southeastern suburbs, surrounded by housing and agricultural fields. Sakata is located in the northern region, facing the Sea of Japan, and is apt to be affected by seasonal winds. Nagai is located in a wide basin in the southern region of Yamagata Prefecture. Yonezawa is located in a basin surrounded by mountains.

At Yamagata I, unobserved large peaks were calculated at the beginning and end of the season, and the observed large peak at the end of March was not reproduced by the simulation. Although the problems in simulation at Yamagata II were almost the same, the agreement between the observed and calculated values during the main pollen season was better at Yamagata II than at Yamagata I. This means that Yamagata II is more representative than Yamagata I in Yamagata City. At Yamagata III, unobserved large peaks were also calculated at the beginning and end of the season, and the observed peak at the beginning of April was overestimated by the simulation.

In Sakata, unobserved large peaks were calculated at the end of the pollen season, and the observed large peak at the beginning of March was underestimated by the simulation. However, the large peak at the end of March was reproduced very well by the simulation.

The problems in Nagai and Yonezawa were similar to those at Yamagata. Unobserved large peaks and overestimated peaks were calculated at the beginning and end of the pollen season. In general, the observed variation in the number of pollen grains was high in Yamagata City and



relatively small in the southern two cities. Sakata, facing the Sea of Japan, shows an individual pattern with two large peaks.

Simulations with the flowering-time map

Simulation was done using the flowering-time map from a former study (Takahashi et al. 1991). Spatial variability in flowering time in the study area is large, because of the widely ranging altitude and complex topography. Taira et al. (1991) surveyed the cedar forest in Toyama Prefecture and showed that the duration of pollen emission for an individual cedar tree varies from 7 to 27 days, and that the main emission period when abundant pollen could be released lasts about 9 days. Takahashi et al. (1993) surveyed the flowering period at 11 points along the way from Yamagata City to Mt. Zaou, and found a mean duration of flowering of 10 days. The flowering duration in this simulation was set to 10 days. Figure 6 shows the observed and calculated changes in the number of airborne pollen grains with time.

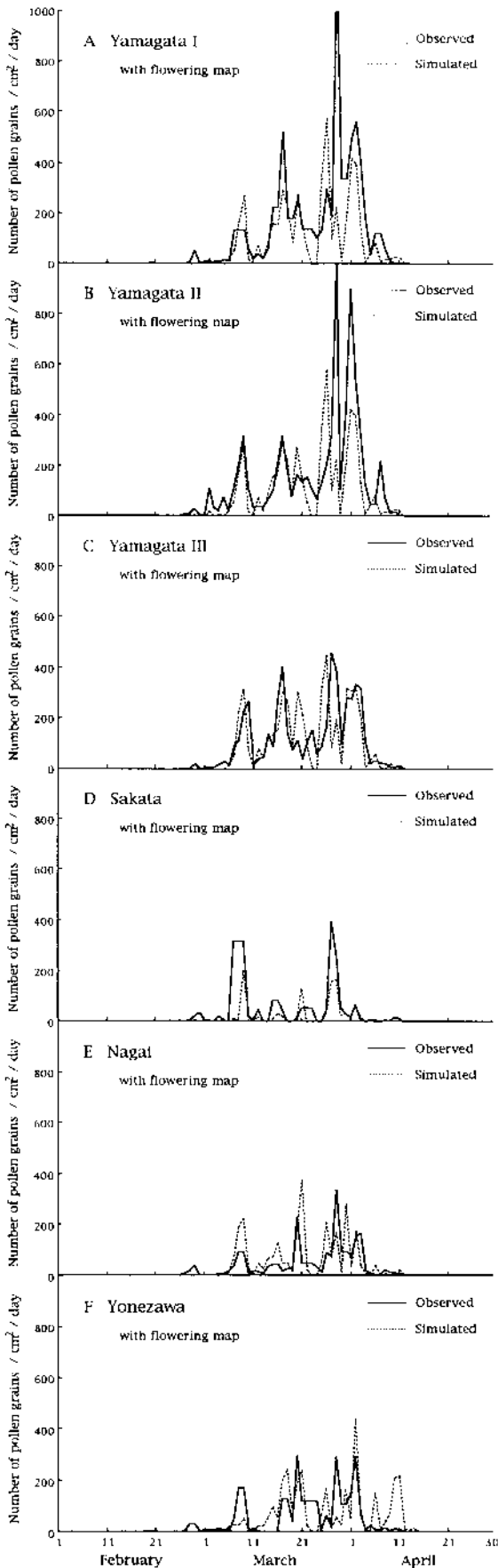
At Yamagata I, the unobserved peaks were absent at the beginning and end of the pollen season. The simulation reproduced very well the changes in the number of airborne pollen grains with time during the beginning and end of the season. Although the simulation reproduced the general variation during the season, the maximum peak at the end of March was underestimated. We believe this to be because the simulation does not take into account the re-emission of the dropped pollen grains in the urban area. Re-emission of pollen grains dropped on concrete or asphalt needs further examination.

At Yamagata II, the simulation reproduced the observed changes in the number of airborne pollen grains very well. The agreement between the observed and calculated values is better than at Yamagata I. Thus Yamagata II is a more representative location for monitoring airborne cedar pollen grains in Yamagata City area. However, the maximum peak at the end of March was still underestimated. This problem and the overestimation 2 days before the maximum peak remain to be solved by further analysis.

At Yamagata III, the simulation reproduced the general variation in airborne cedar pollen very well, and also simulated the variation in the broad peak at the beginning of April. The error for the maximum peak at the end of March is smaller than at Yamagata I and II, because the observed peak is smaller.

In Sakata, although the simulation reproduced all observed peaks, the simulated values are generally smaller than the observed values. This problem is most notable in the broad peak at the beginning of March. In Nagai, the agreement between the observed and simulated variations improved very well. The simulated values show a tendency to be larger than the observed values at the beginning and middle of the pollen season. In Yonezawa, although the

Fig. 5. Observed and calculated changes in the number of airborne pollen grains with time, simulated without the flowering map. The calculated pollen numbers tended to be overestimated at the beginning and end of the season.



agreement between the observed and simulated variation improved well, the simulated dispersion period is later than the observed period. The simulated values are lower than the observed values at the beginning of March and higher at the beginning of April. This problem suggests an error in the flowering-time map of the high-altitude area around Yonezawa. The algorithm and the accuracy for estimating the flowering time need to be improved, especially for high-altitude regions.

CONCLUSIONS

The use of a flowering-time map allowed the simulation of cedar pollen dispersion to reproduce very well the increase in the number of airborne cedar pollen grains at the beginning of the season and the decrease at the end of the season. The variation in the number of airborne cedar pollen grains during the season could be simulated well in general. The merits of the methodology described in this paper are as follows.

1. Our method takes into account various physical processes, such as the fact that cedar pollen is emitted from a cedar forest, and that the pollen is transported and diffused by wind.
2. We also take into account the spatial variation of flowering time using a flowering-time map.
3. It is possible to estimate the concentration of airborne pollen for every 10 km × 10 km square. Thus a more detailed spatial distribution of airborne pollen can be made.
4. Using this methodology and data of numerical weather forecasts such as GPV (Grid Point Value), the distribution of airborne pollen on the following day can be predicted.
5. The location of the main source area of cedar pollen that reaches a specific city, and the aerial routes taken by the pollen can be investigated.
6. The information obtained from this methodology cannot only be used as pollen information for the pollenosis patients, but can also be utilized for the management of cedar forests.

There are 3 remaining problems:

1. The simulation could not reproduce the large peak in the urban area. Re-emission from paved ground surfaces should be examined.
2. The estimated flowering times for the high-altitude region tend to be late.
3. Although the general variation in the number of airborne pollen grains could be simulated, the estimation errors for each day must be decreased further.

These problems will be reduced to make the model match more closely to actual results and to improve the algorithm

Fig. 6. Results of simulation with the flowering map. The calculated changes in the number of airborne pollen grains were greatly improved. Although several peaks were not estimated precisely, the improved model could simulate most of the daily variation and spatial distribution of airborne pollen during the pollen season.

and the accuracy of the simulation. The structure and parameters of the model could be improved by analyzing data from other years and occasions.

ACKNOWLEDGEMENTS

The authors would like to thank Dr. Gamal El-Ghazaly of the Swedish Museum of Natural History for helpful guidance and Dr. Tetsuhisa Miwa of the National Institute of Agro-Environmental Sciences for guidance in statistical analyses.

REFERENCES

- Bureau of Nature Conservation. 1975. The 1st survey on the natural environment—actual vegetation map (1/200,000). – Environment Agency, Japan.
- Bureau of Nature Conservation. 1980. The 2nd national survey on the natural environment (Vegetation)—actual vegetation map (1/50,000). – Environment Agency, Japan.
- Bureau of Nature Conservation. 1986. The 3rd national survey on the natural environment (Vegetation)—actual vegetation map (1/50,000). – Environment Agency, Japan.
- Di-Giovanni, F. & Beckett, PM. 1990. On the mathematical modeling of pollen dispersal and deposition. – J. Appl. Meteor. 29: 1352–1357.
- Giostra, U., Mandrioli, P., Tampieri, F. & Trombetti, F. 1991. Model for pollen immission and transport in the evolving convective boundary layer. – Grana 30: 210–214.
- Hall, SA. 1990. Pollen deposition and vegetation in the southern Rocky Mountains and southwest plains, USA. – Grana 29: 47–61.
- Hjelmroos, M. 1991. Evidence of long-distance transport of *Betula* pollen. – Grana 30: 215–228.
- Kanazashi, T., Yokoyama, T. & Kanegawa, T. 1990. Amounts of male flowers produced in artificial forests of sugi, *Cryptomeria japonica* D. Don. – Jpn. J. Palynol. 36: 49–58.
- Kawashima, S. 1990a. A new method for forecasting the total counts of airborne Japanese cedar pollen. – KISYO 34: 8–11.
- Kawashima, S. 1990b. Elementary processing of AMeDAS data and its dynamical display. – Misc. Publ. Natl. Inst. Agro-Environ. Sci. 8.
- Kawashima, S. 1990c. A comparison of interpolation methods for hourly air temperature using AMeDAS data. – Reports of Research Project “Information Processing” Vol. 1, Natl. Agr. Res. Center: 322–333.
- Kawashima, S. 1991. Modelling of outbreak and dispersion process of airborne pollen of *Cryptomeria japonica*. – Jpn. J. Palynol. 37: 11–21.
- Kawashima, S. & Takahashi, Y. 1995. Modelling and simulation of mesoscale dispersion processes for airborne cedar pollen. – Grana 34: 142–150.
- Mandrioli, P., Negrini, MG., Scarani, C., Tampieri, F. & Trombetti, F. 1980. Mesoscale transport of *Corylus* pollen grains in winter atmosphere. – Grana 19: 227–233.
- Markgraf, V. 1980. Pollen dispersal in a mountain area. – Grana 19: 127–146.
- Miyazaki, Y. & Tsukahara, K. 1987. Digital map information in Japan. – Bull. Geogr. Survey Inst. 32: 23–29.
- Nemoto, O. 1988. Cedar pollen and weather factor. – TENKI 35: 171–178.
- Price, MDR. & Moore, PD. 1984. Pollen dispersion in the hills of Wales: a pollen shed hypothesis. – Pollen et Spores 26: 127–136.
- Raynor, GS., Ogden, EC. & Hayes, JV. 1972. Dispersion and deposition of timothy pollen from experimental sources. – Agricul. Meteorol. 9: 347–366.
- Raynor, GS., Ogden, EC. & Hayes, JV. 1973. Dispersion of pollen from low-level, crosswind line sources. – Agricul. Meteorol. 11: 177–195.
- Sahashi, N., Ikuse, M., Saito, Y., Takeda, H., Shimizu, T., Furuuchi, I., Baba, K., Oh, S., Sugaya, A., Yasuda, K., Usami, A., Baba, S. & Yokota, A. 1983. Fluctuations in 1983 of pollen grains of *Cryptomeria japonica* in central Honshu. – Jpn. J. Palyn. 29: 19–28.
- Saito, Y. & Usami, A. 1980. Pollen allergy by *Cryptomeria japonica* and meteorology. – KISYO 24: 6–9.
- Scott, L. & van Zinderen Bakker, EM. Sr. 1985. Exotic pollen and long-distance wind dispersal at a sub-Antarctic island. – Grana 24: 45–54.
- Taira, H., Tetanishi, T., Kenda, S. et al. 1991. Relationships between pollen production in sugi (*Cryptomeria japonica* D. Don.) forests and the patterns of atmospheric scattering pollens in Toyama Prefecture. – Jpn. J. Allergol. 40: 1200–1209.
- Takahashi, Y., Tohkairin, K., Katagiri, S. & Hikichi, I. 1989a. Hourly variations in the dispersion of Japanese cedar (*Cryptomeria japonica*) pollens in the Yamagata basin and the effect of cold and warm fronts on pollen counts. – Jpn. J. Allergol. 38: 407–412.
- Takahashi, Y., Yamaguchi, K., Abe, E., Tohkairin, K. & Katagiri, S. 1989b. A trial of forecasting airborne Japanese cedar pollen counts based on the estimation of the rate of male flower formation. – JJIAO 7: 98–99.
- Takahashi, Y., Kawashima, S., Oe, E. & Katagiri, S. 1991. Studies on the forecast of flowering time of *Cryptomeria japonica* by the mesh meteorological intelligence. – Jpn. J. Palynol. 37: 35–40.
- Takahashi, Y., Ono, S., Ono, S., Ishimori, H., Aoki, S., Kawashima, S., Kimura, K. & Aikawa, S. 1993. Locality of flowering time of *Cryptomeria japonica* and its estimation method from altitude or 1 km² grid temperature. – Jpn. J. Palynol. 39: 113–120.
- Takahashi, Y. & Kawashima, S. 1999a. Preparation of *Cryptomeria japonica* forest map using data from satellite. – Jpn. J. Palynol. 45: 49–54.
- Takahashi, Y. & Kawashima, S. 1999b. A new prediction method for the total pollen counts of *Cryptomeria japonica* based on variation in annual summertime temperature. – Jpn. J. Allergol. 48: 1217–1221.
- Tronci, N., Molteni, F. & Bozzini, M. 1986. A comparison of local approximation methods for the analysis of meteorological data. – Arch. Met. Geoph. Biocl. Ser. B 36: 189–211.