Atmospheric Research 132–133 (2013) 460–472

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

A global classification of snow crystals, ice crystals, and solid precipitation based on observations from middle latitudes to polar regions

Katsuhiro Kikuchi[a], Takao Kameda[b,*], Keiji Higuchi[c], Akira Yamashita[d]
Working group members for new classification of snow crystals[1]

[a] *Professor Emeritus of Hokkaido University and Akita Prefectural University, Momijidai Kita 2-5-4, Atsubetsu-ku, Sapporo, Hokkaido 004-0014, Japan*
[b] *Snow and Ice Research Laboratory, Kitami Institute of Technology, 165 Koencho, Kitami, Hokkaido 090-8507, Japan*
[c] *Professor Emeritus, Nagoya University, 1-12-4, Wagogaoka, Togocho, Aichi 470-0154, Japan*
[d] *Professor Emeritus, Osaka Kyoiku University, 1-11-1-813, Sakasegawa, Takarazuka, Hyogo 665-0035, Japan*

ARTICLE INFO

Article history:
Received 8 January 2013
Received in revised form 13 June 2013
Accepted 13 June 2013

Keywords:
Classification
Global classification
Snow crystals
Ice crystals
Solid precipitation

ABSTRACT

This paper presents an extensive revision of Magono and Lee's (1966) classification of natural snow crystals, which has been widely used in snow and ice studies to describe snow crystal shapes. The new classification catalogs snow crystals and other solid precipitation particles into 121 categories, in contrast to Magono and Lee's 80 categories. Of these, 28 categories were created to classify new types of snow crystals that have been discovered in polar regions since 1968, seven were created after reconsidering the original categories, and six categories were created to classify solid precipitation particles such as frozen cloud particles and small raindrops. Because our observational area extended from middle latitudes (Japan) to polar regions, we refer to our new classification scheme as 'global-scale classification' or 'global classification'. The global classification consists of three levels – general, intermediate, and elementary – which are composed of 8, 39, and 121 categories, respectively. This paper describes the characteristics of each type of snow crystal, ice crystal, and solid precipitation particle.

1. Introduction

Researchers have identified many types of snow crystals, which have been classified into various categories. Nakaya and Sekido (1938) classified natural snow crystals into 21 categories based on their shape, and Nakaya (1954) classified snow crystals into 42 categories. This is called 'general classification of snow crystals'. Schaefer (1951) provided a practical classification of natural solid particles using 10 categories based on their size (very small, small, medium, large, and very large) and additional characteristics (broken, rimed, flake, and wet). This classification was also described by Mason (1957, 1971). Magono and Lee (1966) classified natural snow crystals into 80 categories based on their shape; their classification scheme is widely used by scientists to describe snow crystal shapes. However, it was based mainly on observations in Japan and did not include several types of snow crystals that are observed only in Arctic and Antarctic regions.

Kikuchi proposed a 'peculiar type' category of snow crystals in 1969 (Kikuchi, 1969; 1970; 1974) based on his observations at Syowa Station, Antarctica between February 1968 and January 1969. However, this category has not been widely used. Recently, Fierz et al. (2009) proposed a classification of snow on the ground. Precipitation particles including snow

* Corresponding author. Tel.: +81 157 26 9506; fax: +81 157 25 8772.
E-mail address: kameda@mail.kitami-it.ac.jp (T. Kameda).

[1] Chair: Keiji Higuchi, Vice Chair: Katsuhiro Kikuchi and Akira Yamashita, Secretary General: Takao Kameda, Members: Hideaki Aburakawa, Takeshi Fujino, Takehiko Gonda, Naohiko Hirasawa, Masaaki Ishizaka, Masahiro Kajikawa, Kenzo Kanda, Hiroyuki Konishi, Akio Murai, Noboru Sato, Chuji Takahashi, Shuhei Takahashi, Hiroshi Uyeda, and Makoto Wada.

0169-8095/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.atmosres.2013.06.006

crystals and solid precipitation are classified into 9 categories for visual observation purpose in their Appendix A. This is basically the same as practical classification by Schaefer (1951) and Mason (1957, 1971).

On the other hand, Заморский (1955) introduced a new classification system for snow and ice crystals that he observed in Siberia in his book "Атмосферный Лед (Ice in the atmosphere)", and Клинов (1960) introduced a similar classification system for crystals that he observed in Siberia in his book "Вода в Атмосфере при Низких Температурах (Water in the atmosphere at lower temperatures)". However, neither of these authors classified crystals systematically.

Since the publication of Magono and Lee's (1966) classification system, snow crystal observations have expanded to include polar regions (Kikuchi and Hogan, 1976, 1979; Magono, 1978; Kikuchi and Kajikawa, 1979; Kajikawa et al., 1980; Higuchi et al., 1981; Kikuchi, 1987, 1989; Kikuchi and Asuma, 1999; Walden et al., 2003), and artificial snow crystal formation experiments and analyses have been widely conducted (e.g., Yamashita, 1979; Gonda, 1980; Kikuchi and Sato, 1984; Yamashita and Ohno, 1984; Sato and Kikuchi, 1985; Takahashi et al., 1991; Fukuta and Takahashi, 1999; Bailey and Hallett, 2004, 2009; Aburakawa, 2005; Hiramatsu and Sturm, 2005; Takahashi and Mori, 2006; Murai et al., 2012). These new observations and experiments have revealed several types of new snow crystals, such as the Gohei twin, seagull-type, and skeletal-type, which have not yet been classified.

Recently, Bailey and Hallett (2004) examined the growth rates and crystal habits of ice and snow crystals that form at temperatures between −20 °C and −70 °C, and in 2009 they presented a crystal habit diagram of snow crystals (Bailey and Hallett, 2009), but they did not classify snow and ice crystals systematically. Libbrecht (2003) presented beautiful natural and artificial snow crystals, but he used the classification provided by Magono and Lee (1966).

Many other recent papers also refer to Magono and Lee (1966) for describing snow and ice crystal shapes, for example Nelson (2005), Lawson et al. (2006), and Teschl et al. (2013). Evidently, a new classification scheme is needed to include every type of snow crystal and ice crystal.

In 2012, we published a new classification of snow crystals, ice crystals, and solid precipitation particles in Japanese, which we referred to as a 'global classification' (Kikuchi et al., 2012). Our data included observations of these particles from middle latitudes to polar regions since 1968. The global classification consists of three levels: general, intermediate, and elementary. The general level has 8 categories, the intermediate level has 39 categories, and the elementary level has 121 categories.

This paper extends on our previous report and includes more detailed descriptions, in English, of each of the 121 types of snow crystals, ice crystals, and solid precipitation particles. It also includes drawings of the 121 particle types.

2. A description of snow crystals and other solid precipitation particles in the global classification

Table 1 presents the locations where the 121 types of snow crystals, ice crystals, and other solid precipitation particles were observed, and Table 2 presents each particle type's global classification. Fig. 1 presents the photographs of the 121 particle types, and Fig. 2 schematically summarizes the shape of each particle. In this chapter, we briefly describe the characteristics of each particle.

Table 1
Main observation sites of snow crystals, ice crystals, and other solid precipitation.

Number	Locations	Latitude and longitude
Observation sites in Japan		
1	Cloud Physics Observatory of Hokkaido University at Mt. Teine, Sapporo, Hokkaido	43°04′N, 141°11′E
2	Wind Wave Observation Site, Hokkaido Developing Bureau, Yokomachi, Ishikari, Hokkaido	43°15′N, 141°21′E
3	Yukomambetsu Spa, Higashikawa, Hokkaido	43°41′N, 142°47′E
4	Hachimantai Ski Slope, Kazuno, Akita	39°59′N, 140°48′E
5	Sand Dune Farming Experimental Station, Kahoku, Ishikawa	36°43′N, 136°42′E
Observation sites in polar regions in northern hemisphere		
6	Science Research Center, Inuvik, Canada	67°22′N, 133°42′W
7	Yellowknife Airport, Yellowknife, Canada	62°28′N, 114°27′W
8	Barrow, Alaska, USA	71°18′N, 156°44′W
9	Peters Lake, Alaska, USA	69°N, 145°W
10	Alta River Camping Site, Alta, Norway	69°56′N, 23°16′E
11	Kautokeino, Norway	69°01′N, 23°03′E
12	Ny-Ålesund, Svalbard, Norway	78°55′N, 11°56′E
13	Longyearbyen, Svalbard, Norway	78°13′N, 15°38′E
14	Space Physics Institute, Kiruna, Sweden	68°56′N, 21°04′E
15	Arctic Research Center, Sodankyla, Finland	67°22′N, 26°38′E
16	Arctic Station, Godhavn, Greenland	69°15′N, 53°34′W
17	Godthåb, Greenland	64°10′N, 51°45′W
Observation sites in polar regions in southern hemisphere		
18	Syowa Station, Antarctica	68°00′S, 39°35′E
19	Dome Fuji Station, Antarctica	77°19′S, 39°42′E
20	McMurdo Station, Antarctica	77°51′S, 166°40′E
21	Amundsen–Scott South Pole Station, Antarctica	90°00′S

2.1. Column crystal group (C)

'Column crystal group' includes snow crystals with characteristics similar to columns. This group is divided into four types: C1–C4.

2.1.1. Needle-type crystal (C1)

'Needle-type' refers to snow crystals shaped like needles, with tops shaped like knife-edges. This crystal type is subdivided into three categories: needle (C1a), needle bundle (C1b), and combination of needles (C1c). Crystals in C1a have a simple form, crystals in C1b have two or more needle crystals,