

STABLE ISOTOPIC COMPOSITION OF SNOW AS AN INDICATOR OF CLOUD SEEDABILITY

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ABSTRACT The stable oxygen isotopic composition has been measured in three sets of snow samples collected sequentially at a remote mountain station during winter storms. Replication techniques were used in conjunction with the sequential sampling to provide information on ice crystal habits and degree of riming in the snowfall. The results indicate stable isotope measurements combined with ice crystal replication techniques can be successfully used to estimate the weighted mean elevations of ice phase water capture by precipitating cloud particulates.

1. INTRODUCTION

It is known that the stable isotopic composition of ice is established at the time water freezes and related directly to the ambient temperature in a cloud where the ice forms. While even the ice remains frozen and is not allowed to evaporate or condense water to its surface, the original isotopic composition will be maintained.

Picciotto et al., (1960) have shown that there is an approximately linear relationship between the $^{18}\text{O}/^{16}\text{O}$ ratio in snowfall and the average temperature of the cloud volume within which the precipitation formed.

1.1 Sampling Program 1983

This isotopic composition feature has been used to obtain information on the weighted means of temperatures in the atmosphere where water has frozen prior to reaching the ground as snow in the Central Sierra Nevada. A high altitude (3000 m) mountain site was chosen for making the sample collections of precipitation. The $^{18}\text{O}/^{16}\text{O}$ ratio was determined by isotope mass spectrometry. While the sequential snow samples were being collected (every 3-30 minutes) an ice crystal replicator was also recording the characteristics of the falling ice particles. The stable isotopic composition and the snow crystal replication data have been used to estimate two temperatures of formation: (1) that related to crystal habit (T_{fc}); and (2) that related to $^{18}\text{O}/^{16}\text{O}$ ratio (T_{δ}).

The snow crystal replicas were investigated not only with respect to habit, but also to degrees of riming. The timing data yields information on the degrees to which the crystals have accreted water during their lifetime before reaching the ground.

This information was then used to estimate the weighted mean altitudes where ice phase precipitation formed. This was done by reference to altitudes and temperatures derived from local upper air soundings made during the same periods as the snow sample collections.

2. RESULTS

Three case studies are presented for the dates January 27, February 26 and February 28, 1983.

Table I: This shows results for January 27. Samples were collected from 1035 h through 1220 h (local time PST). Snowfall was relatively light (precipitation rates of 6 to 29 g min⁻¹). The surface temperature at the sampling site averaged -2.9°C.

No accretional growth was observed. Crystal habits were dendrites, stellars, sectors, columns and a few needles toward the end of the sampling period. Principal crystal dimensions were 1 to 1.5 mm.

Firstly, it can be seen that the $\delta^{18}\text{O}$ values are completely unrelated to the surface temperatures (T_a). The crystal habits indicate mean temperatures of formation from -12°C to -15°C. The $\delta^{18}\text{O}$ values indicate similar temperatures of formation from -13°C to -18°C which from the nearest rawinsonde data represents elevations of 600 to 1400 m above the sampling site elevation.

Table II: This case indicates that the principal crystal habits were originating between -9°C and -14°C (i.e., at elevations around 1000 to 1500 m higher than the sampling site, 3000 m). However the $\delta^{18}\text{O}$ values show that the bulk of the frozen water originated at much lower elevations around 2400 m. The clouds were convective on this day and moving from the southwest (250/45). It is concluded that the super-cooled liquid water was being accreted in

TABLE I: January 27, 1983

End Time Sample(PST)	Surface Temp. T _s °C	Precip. Rate g min ⁻¹	Crystal Types	T _c °C (Crystal Type)	δ O ₁₈ O/oo	T _c °C	Correspond- ing Elev. (m)
1035	-3.3	6	dendrites, stellars, sectors	-15	-18.4	-13	3600
1110	-3.3	10	dendrites, stellars aggregates	-15	-20.4	-15	3800
1115	-3.0	21	dendrites, stellars aggregates	-15	-21.9	-16	4000
1125	-2.8	24	columns, sectors, stellars, dendrites	-15	-21.5	-16	4000
1131	-2.8	29	columns, sectors, stellars, dendrites	-15	-18.5	-13	3600
1141	-2.8	21	columns, sectors, stellars, dendrites, needles	-12	-20.0	-15	3800
1220	-2.6	6	columns, sectors stellars, dendrites, needles	-12	-22.9	-18	4400

TABLE II: February 26, 1983

End Time Sample(PST)	Surface Temp. T _s °C	Precip. Rate g min ⁻¹	Crystal Types	T _c °C (Crystal Type)	δ O ₁₈ O/oo	T _c °C	Correspond- ing Elev. (m)
1245	-4.2	33	graupel, columns, dendrites	-13	-7.5	-2	2500
1250	-4.7	35	graupel, columns, dendrites	-13	-7.7	-2	2500
1255	-5.0	59	graupel, columns, sectors, stellars	-11	-7.1	-2	2500
1300	-4.3	64	rimed columns, sectors, needles	-9	-7.6	-2	2500
1305	-3.0	33	rimed columns, sectors, needles	-9	-7.9	-3	2700
1335	-3.9	25	graupel, columns, dendrites, needles	-11	-7.0	-2	2500
1344	-4.7	10	graupel, columns, dendrites, needles	-11	-6.8	-1.5	2400
1350	-4.9	17	graupel, columns, dendrites, needles, sectors	-11	-6.9	-1.5	2400
1415	-5.6	9	graupel, columns, dendrites, needles, stellars	-11	-5.6	0	2200
1425	-5.3	33	graupel, columns, dendrites, needles	-11	-6.9	-1	2400
1435	-4.8	11	stellars graupel, columns, dendrites, needles	-11	-6.6	-1	2300
1450	-4.3	12	stellars graupel, columns, dendrites, needles	-12	-6.5	-1	2300
1453	-5.6	55	stellars graupel, columns, dendrites, needles	-12	-6.4	-1	2300
1510	-5.6	7	stellars rimed fragments, graupel dendrites	-14	-7.1	-2	2500

the lower cloud layers on the windward slopes and then were later lifted and transported to the higher elevation sampling site. Precipitation rates were 9 to 64 g min⁻¹ and crystal sizes ranged from 0.5 mm to 2.5 mm.

Table III: This shows results for February 28. Precipitation rates ranged from 27 to 200 g min⁻¹ and crystal dimensions were from 1 mm to 5 mm. The conclusion drawn from the February 28 case is that the majority of the crystals, based on crystal habit data, originated at elevations between 4600 m and 5000 m. The δ O₁₈ values on the other hand indicate that the bulk of the water was captured by accretion at elevations between 3500 m and 4500 m.

3. CONCLUSIONS

Stable isotope measurements and ice crystal replication can be successfully used to estimate the weighted mean elevations of ice phase water captured by precipitating cloud particulates. This

TABLE III: February 28, 1983

End Time Sample(PST)	Surface Temp. T _s °C	Precip. Rate g min ⁻¹	Crystal Types	T _c °C (Crystal Type)	δ O ₁₈ O/oo	T _c °C	Correspond- ing Elev. (m)
1700	-2.2	58	99% heavily rimed dendrites	-15	-14.7	-9	4000
1710	-2.2	77	"	-15	-16.3	-11	4300
1713	-2.2	80	"	-15	-16.0	-11	4300
1719	-2.2	109	" plus graupel	-15	-11.6	-6	3500
1722	-2.2	43	" plus columns, plus needles	-13	-12.3	-7	3700
1725	-2.2	27	"	-15	-12.0	-7	3700
1728	-2.2	45	" no columns, plus graupel plus needles	-15	-13.9	-8	3900
1740	-2.4	34	"	-13	-15.6	-10	4150
1746	-2.5	49	"	-13	-15.9	-11	4300
1749	-2.5	116	"	-13	-16.3	-11	4300
1752	-2.6	200	"	-13	-14.9	-9	4000
1755	-3.2	146	"	-13	-15.6	-10	4150
1801	-3.3	50	"	-13	-16.8	-12	4500
1807	-3.3	48	"	-13	-15.7	-10	4150
1813	-3.3	56	"	-13	-15.6	-10	4150
1816	-3.3	108	"	-13	-14.8	-9	4000
1819	-3.3	45	"	-13	-16.8	-12	4500
1822	-3.3	49	"	-13	-15.6	-10	4150
1825	-3.3	88	"	-13	-15.4	-10	4150

information, when related to relevant mesoscale conditions, can be useful in developing cloud seeding strategies in the Sierra Nevada.

4. ACKNOWLEDGMENTS

This research was supported by the National Oceanic and Atmospheric Administration under Contract No. NA83-RA00026. This support is greatly appreciated.

5. REFERENCES

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