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Some considerations on the accumulation of ice on the balloon fabric

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ABSTRACT. Data of Kachare *et al.* (1957) for up and down movements of radiosonde balloons due to collection of snow on balloon fabric were examined. It was found that accumulation of ice was related to rate of ascent of the balloon. It was also found that the rate of descent was in some way related to the rate of previous ascent. In general height descended increased with increase in rate of descent and also with the increase in the amount of snow accumulated; but there were a few exceptions to this observation. Similarly, load in balloon in general increased during successive ascents; here also there were two exceptions.

To understand the process of removal of ice amounts of melting of ice on balloon surface were calculated. It was found that in some cases amount of ice that could melt was less than the amount that was removed indicating some ice was removed without melting.

To explain all the observations a mechanism of wetting of balloon surface, accumulation of ice on and its removal from fabric have been proposed. It has been shown that the ice accumulates non-uniformly and though in general is removed by melting, sometimes ice is peeled off from the balloon surface when it descends getting warm and shrinking during the course.

1. Introduction

Kachare *et al.* (1957) studied the up and down movements of F-type radiosonde balloons due to collection of snow on their fabric. On examining their data, it was found that there was scope for further analysis. Based on their data, some new relations were found. The mechanism of accumulation of snow and its melting have been discussed.

2. Rearrangement of data

All the data given by Suryanarayan and Kachare (1951) and by Kachare *et al.* (1957) have been rearranged suitably and presented in Tables 1 and 2 for the convenience of analysis. The pressure values given in the table for the days 6 and 7 October 1950 have been taken from the data given by Suryanarayan and Kachare and for others the values were calculated from the available data on the assumption of uniform variation of pressure and temperature within the layers of ascents and descents. For calculating diameter of the balloons at various pressure levels the buoyancy of hydrogen at N.T.P. was taken to be 1·2 kgm/cubic metre. The volume of the balloon at N.T.P. was calculated first and then the volumes at other pressures and temperatures were deduced. The amount of ice accumulated has been calculated from the given total load on the balloon during ascent and descent.

On inspection, two new relations were found. Accumulation of ice on an ascending balloon may be expected to be dependent upon (*a*) the number of ice particles per unit volume of air in the region of accumulation, (*b*) the surface area of the balloon and (*c*) the rate of ascent. The condition (*a*) could not be checked. Condition (*b*) was checked but no relationship was apparent. Accumulation of ice was plotted against the rate of ascent. It is reproduced in Fig. 1. That they have some relationship will be apparent from the curves.

To check up whether there is any relationship between rates of ascents and the following descents, both of them were plotted in the graph (Fig. 2) and it was found that they vary in the same sense.

TABLE 1 (Ascents)

Date	S. No. of ascents	Max. level reached			Load on balloon		Ice accumu-lated	Rate of ascent
		Press.	Temp.	Diam. of balloon	During ascents	On the following descents		
		(mb)	(°C)	(cm)	(gm)	(gm)	(gm)	(km/hr)
28-9-55	1	592	3·5	96·3	596	1200	604	12·5
	2	604	2·9	95·6	600	1146	546	10·2
	3	576	1·1	96·9	533	1471	938	13·6
	4	605	4·0	95·7	737	1066	329	9·7
	5	592	2·1	96·1	164	1021	157	6·1
6-10-50	1	550	—0·7	166·2	768	1695	927	14·2
	2	535	—2·2	167·2	1027	1501	474	11·2
	3	510	1·2	161·0	1338	1459	121	5·0
	4	533	—2·4	167·3	970	..	..	12·6
7-10-50	1	605	2·7	161·8	877	1547	670	12·8
	2	590	2·2	163·1	1112	1513	401	9·6
	3	605	2·3	161·7	1253	1532	279	7·0
	4	550	—3·6	165·8	1008	1625	617	11·0
29-11-55	1	..	0·3	..	510	1100	590	12·8
(MDS)	2	..	2·1	..	870	1050	180	6·6
	3	..	—4·7	..	931	1023	092	5·4

TABLE 2 (Descents)

Date	S. No. of descents	Start of descent			End of descent			Height descen-ded	Amount of ice removed	Grad. of temp.	Rate of descent
		Height (gpm)	Temp. (°C)	Load (gm)	Height (gpm)	Temp. (°C)	Load (gm)	(gpm)	(gm)	(°C/km)	(km/hr)
28-9-55	1	4530	3·5	1200	3500	8·6	600	1030	600	4·95	10·3
	2	4350	3·9	1146	3550	8·1	533	800	613	5·25	9·1
	3	4740	1·1	1471	3540	6·3	737	1200	734	4·32	14·4
	4	4350	4·0	1066	3350	8·1	864	1000	202	4·10	7·1
	5	4530	2·1	1021	3870	..	950	660	71	..	5·6
6-10-50	1	5300	—0·7	1695	2830	10·8	1027	2470	668	4·66	9·0
	2	5540	—2·2	1501	3550	12·5	1338	1990	173	7·40	5·0
	3	4340	1·2	1459	3260	9·3	970	1080	489	7·51	3.5
7-10-50	1	4350	2·7	1547	2940	10·2	1112	1410	435	5·32	6·4
	2	4540	2·2	1513	3330	5·8	1253	1210	260	2·98	5·6
	3	4350	2·3	1532	3330	6·0	1008	1020	524	3·64	6·0
	4	5100	—3·6	1625	3070	5·1	1097	2030	528	4·29	8·0
29-11-55 (MDS)	1	4390	0·3	1100	3060	4·3	870	1330	230	3·02	5·8
	2	3990	2·1	1050	3380	3·3	931	610	119	1·92	4·0
	3	4080	—4·7	1023	3490	2·8	..	590	..	..	2·8

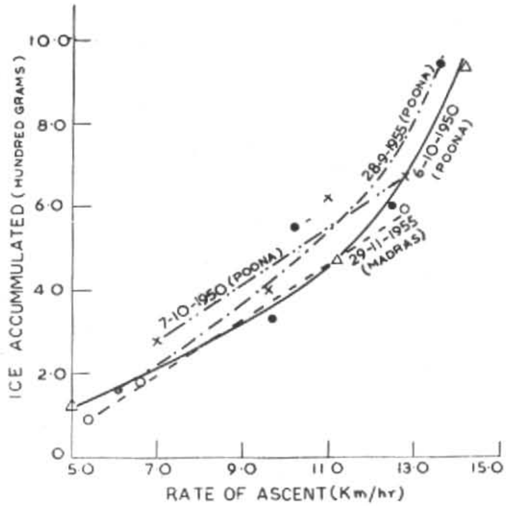

Fig. 1

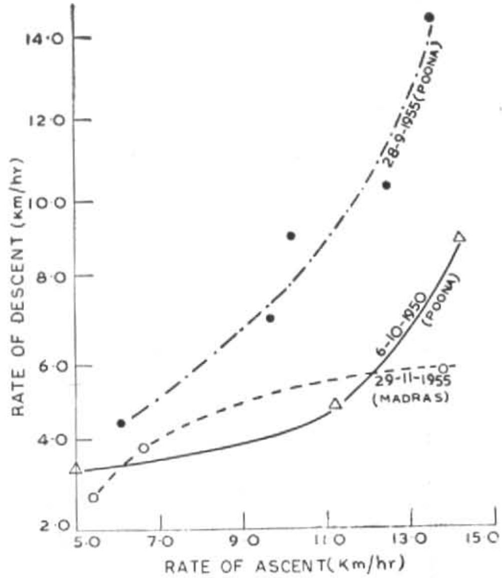

Fig. 2

3. Exceptions to general observations

Kachare *et al.* stated that lower levels were reached with increase in rate of descent or larger accumulation of ice. Scrutiny of data in Table 2 reveals that there is no relationship between rates of descents and levels reached. Similarly no relationship was found between the amount of ice accumulated as also the total load and the levels reached. Probably by the above statement the authors meant that height descended would be more with increase in rate of descent. This was generally correct except for 2nd and 4th descents on 28 September 1955 and 2nd and 3rd descents of 7 October 1950. Considering accumulation of snow, the greater the accumulation the greater was the height descended by the balloon. Here also the 2nd and 4th descents of 28 September 1955 are found to show exceptions.

Kachare *et al.* observed that, in general, the load on the balloon increased during successive ascents. Here there were two exceptions. The load on balloon decreased from 2nd to 3rd ascents on 28 September 1955 and 3rd to 4th ascent of 7 October 1950.

Increase in load in successive ascents were explained by Kachare *et al.* by assuming that more and more surface of the balloon got wet during the successive ascents. This implies that the surface was not fully wet on previous ascents. It may be possible that during the first ascent a part of balloon was not wet. But after the balloon moves up and then downwards inside a cloud, probably in the field of rain, the whole of balloon surface should be wet. Thus the increase in load from the first to second ascent can be explained by the above assumption but new explanation is needed for understanding the behaviour of the balloons.

In the present paper probable mechanisms of wetting of balloon surface, accumulation of ice on, and its removal from fabric have been discussed and attempts have been made to explain the general observations and also their exceptions for ascents and descents. It has been assumed that the whole balloon surface was wet during the first ascent. The explanations will hold good even if some part of the fabric was not wet during the first ascent.

TABLE 3

Date	S. No. of descent	Duration	Mean values for the descent: Press.	Temp.	Radius of balloon	Density of air (ρ) $\times 10^4$	Viscosity (η) $\times 10^6$	$Re = Ud\rho/\eta$	C	Diffusivity (D)	Thermal conductivity (K_a) $\times 10^5$	Density of sat. vap. $\times 10^6$ ρ_v	Ice melted
		(min)	(mb)	(°C)	(cm)	(gm/cc)	(poise)			(cm²/sec)	(cal/cm/sec/°C)	(gm/cc)	(gm)
28 Sep 1955	1	0—1	605	4·4	95·7	7·69	173	24·4	149·8	0·383	5·87	6·53	87·1
	2	1—2	618	5·2	95·1	7·843	173	24·7	150·9	0·378	5·89	6·89	104·0
	3	2—3	631	6·1	94·6	7·980	174	24·9	151·3	0·373	5·90	7·31	122·9
	4	3—4	644	6·9	94·0	8·117	174	25·2	152·3	0·368	5·92	7·70	140·1
	5	4—5	657	7·8	93·5	8·256	175	25·3	152·5	0·362	5·93	8·16	158·9
	6	5—6	670	8·6	92·9	8·397	175	25·6	153·4	0·357	5·95	8·69	176·7

4. Melting of Ice

Kachare *et al.* stated that balloon loses ice due to melting. As a general statement, this is correct. As such we have attempted to calculate the amount of ice that could melt during descent. For this we have assumed (*a*) ice accumulated uniformly over the balloon, (*b*) rate of descent was constant, and (*c*) temperature and pressure increased uniformly throughout the descent.

Let us consider a sphere of solid ice of radius r and density ρ falling towards the ground. If the surface temperature of the solid ice is T_s and that of the environment at any instant is T_a, the basic equation for melting becomes

$$L_f \cdot m = 4\pi r C \left[k_a (T_a - T_s) + L_v D \left\{ \rho_v - \rho_v (s) \right\} \right]$$

where k_a = Thermal conductivity of air

L_f = Latent heat of fusion of ice

L_v = Latent heat of evaporation of water

D = Diffusion coefficient of water vapour in air

ρ_v = Vapour density at remote environment

$\rho_v (s)$ = Vapour density at the vicinity of ice, and

C = Ventilation coefficient (as the balloon is moving in air)

$= 1 \cdot 6 + 0 \cdot 3\, Re^{\frac{1}{2}}$ (Re = Reynold's number)

This is the same equation as was used by Mason (1957) for calculating melting of hailstones.

Using this equation the amount of ice that could melt at every minute during the descent was calculated for the first descent of 28 September 1955. Adding up the individual values the total amount of ice that could melt during the first descent was determined. The data are presented in Table 3. The amount of ice that could melt was also calculated by considering the mean pressure and temperature of the level descended and the total time the balloon took for its descent. The two values were almost same. Hence, for other descents, melting was calculated by the latter method and the values are shown in Table 4. The values of constants were taken from Mason (1957) and from Smithsonian Tables. Column 15 of Table 4 represents the amount of ice that could melt on the basis of assumptions stated above and is marked M. Column 17 represents the total load on the balloon during the descent and is marked A. Column 19 represents the mass of ice actually removed at the end of the descent and is marked R.

It will be seen that—

For all three descents of 6 October 1950 and descents Nos. 1 and 2 of 7 October 1950

$$M>A>R \qquad \text{(I)}$$

for descents Nos. 2 and 3 of 28 September 1955

$$M<A<R \qquad \text{(II)}$$

for all other descents

$$A>M>R \qquad \text{(III)}$$

As for condition (III), it appears that descent was completed before all the ice could melt and that is quite expected. Total weight removed is also found to be less than the total ice melted and this indicated that a part of liquid water formed by melting of ice might have been used for wetting the surface of the balloon.

Condition (I) indicates that during the period of descent more ice could melt than the total load on the balloon. It is probably due to the fact that at places, the ice accumulated was so thick that it took lot of time to melt. This points to the possibility of non-uniform accumulation of ice.

Condition (II) indicates that more ice was removed than it could melt during the period. This points to the fact that a part of ice might have been removed in ice phase from the balloon surface.

5. Mechanisms of accumulation and melting

To explain the above observations the following mechanisms of accumulation of ice and its melting on the balloon surface are suggested.

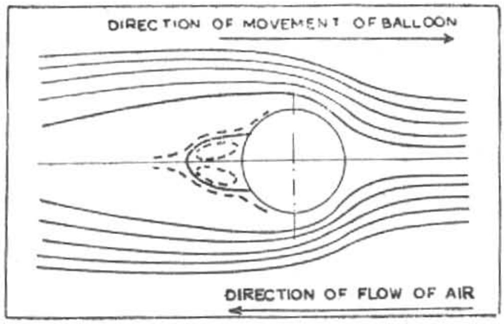

Fig. 3

When the balloon is released in rain, whole of the balloon surface becomes wet. When this balloon comes in the region where the conditions are favourable for ice accumulation, it accumulates. Since the balloon is moving up the upper portion of the surface of the balloon is likely to get more ice. Cloud particles are expected to be deflected from the path of balloon due to relative aerodynamic flow of air. Calculation by Langmuir's method (1948) indicates there will be no accumulation of cloud particles on the balloon. Considering the flow past the spherical obstacle we get two vortices (Fig. 3) in the wake. It is in this region that small cloud particles can come into contact with balloon. In the region of ice accumulation these particles are expected to freeze. Thus on the upper and lower parts of the rising balloon thicker accumulation of ice should take place compared to its sides.

When the balloon with ice on its surface moves down in the region of temperature greater than the freezing, the ice should melt and then will be removed. Hydrogen gas inside the balloon will also be heated up (though to a small extent) due to compression. Due to this, ice in contact with balloon fabric may melt. Due to this and also due to contraction of the balloon surface, some amount of ice may be peeled off.

TABLE

Date	S. No. of descents	Duration	Press.	Temp.	Radius of balloon	Rate of descent	Density of air (ρ) $\times 10^3$	Viscosity (η) $\times 10^6$	$Re = \frac{Ud\rho}{\eta}$	C
			Mean values							
		(min)	(mb)	(°C)	(cm)	(km/hr)	(gm/cc)	(poise)		
1	2	3	4	5	6	7	8	9	10	11
28-9-55	1	6	631	6·1	94·6	—	—	—	—	—
	2	$5\frac{1}{4}$	635	5·5	94·3	9·1	0·805	173	22·2	142·9
	3	5	621	3·7	94·8	14·4	0·790	173	34·63	178·3
	4	$8\frac{1}{2}$	644	6·0	94·0	7·1	0·815	173	17·45	127·0
	5	7	615	4·1	95·2	5·6	0·783	173	13·36	111·1
6-10-50	1	$16\frac{1}{2}$	635	5·4	159·6	9·0	0·786	174	35·24	179·8
	2	$23\frac{3}{4}$	609	6·3	162·0	5·0	0·760	174	19·67	134·8
	3	$18\frac{3}{4}$	645	5·3	158·8	3·5	0·808	174	14·31	114·0
7-10-50	1	$13\frac{1}{4}$	653	6·5	158·5	6·4	0·814	174	26·93	158·8
	2	13	630	4·0	160·0	5·6	0·791	174	22·70	144·5
	3	$10\frac{1}{2}$	655	4·1	158·0	6·0	0·823	174	24·97	151·6
	4	$15\frac{1}{4}$	655	2·5	157·6	8·0	0·828	174	33·3	174·7

6. Explanations

We have seen in Table 4 that in case of certain descents $M>A>R$. The calculation of melting was done on the basis of uniform thickness of ice on the balloon surface. As we have already shown the ice accumulated in a non-uniform manner due to greater thickness of ice, it took long time to melt. So that though on the assumption of uniform accumulation M comes to be greater than A, actual ice melted might have been less than the total load due to the presence of thick layers of ice and favoured places on the balloon surface.

Melting of ice calculated on the basis of uniform thickness of accumulated ice is the maximum amount that could melt on the balloon during the descent. But in two descents we have got $M<R<A$ or in other words some ice was removed before it actually melted. This can be explained by the mechanism of removal of ice proposed earlier where it has been stated that under some favourable conditions some ice may be peeled off from the balloon surface.

On all other cases $A>M>R$ or in other words ice that could melt on the basis of uniform accumulation of ice on the surface of the balloon was less than the total load on the balloon but more than the ice actually removed. Since ice was not uniformly accumulated on the balloon, ice actually melted may be less than M and may even be equal to R. Generally speaking, all the ice accumulated need not melt during a descent. When a part only melts and is removed, balloon may start ascending.

4

for the descent			Amount of ice that could be melted		Total load on the balloon		Amount of ice actually removed R
Diffusivity (D) (cm²/sec)	Thermal conductivity $Ka \times 10^5$ (cal/sec/cm/°K)	Density of sat. vap. $\rho_v \times 10^6$	Total mass M (gm)	Equivalent thickness on balloon surface $\times 10^4$ (cm)	Total mass A (gm)	Equivalent thickness on balloon surface $\times 10^4$ (cm)	(gm)
12	13	14	15	16	17	18	19
—	—	—	790	77·0	1200	116·6	600
0·366	5·89	7·03	536	47·8	1146	102·4	613
0·375	5·89	6·23	408	39·5	1471	142·2	734
0·362	5·89	7·26	840	82·6	1066	104·8	202
0·380	5·98	6·40	668	64·2	1021	98·2	71
0·405	5·91	7·12	2510	86·2	1695	58·2	668
0·386	5·90	7·41	3977	131·9	1501	49·8	173
0·394	5·88	6·93	1787	61·9	1459	50·2	489
0·392	5·90	7·50	1950	67·4	1547	53·6	435
0·400	5·87	6·36	1693	57·4	1513	51·4	260
0·385	5·87	6·40	1520	49·5	1532	53·4	524
0·352	5·84	5·75	779	27·3	1625	57·0	528

During the first ascent in rain the balloon was not having any ice accumulated on it and there was only thin layer of liquid water wetting the whole of the balloon surface as assumed earlier. When ice accumulated, the balloon descended. At the end of first descent all the ice in solid phase might not have melted. So during second ascent the balloon was having some unmelted ice and liquid water film over the entire surface including those portion where ice was still present. Hence load on balloon during second ascent would be more than that during first ascent. By similar arguments it can be shown that during third ascent load would be more than during the second and so on. Thus load on balloon would increase in successive ascents.

There may, however, be occasions when ice would be peeled off from the surface of the balloon. Subsequent load on the balloon on those cases may be less than that on its previous ascent. Even all the ice might be peeled off exposing either bare or thinly wet surface of the balloon. Fresh wetting of the surface may lead to the formation of a thinner water film than it was in the first ascent. This explains how on the third ascent the load on balloon was less than that during the first ascent of 28 September 1955. Incidentally, it may be mentioned that possibility of removal of ice by being peeled off from the surface during the second descent of the day, *i.e.*, just before the commencement of the third ascent has been already indicated.

As regards the relation between the load on the balloon and the height descended, except for two cases, the greater the load the greater was the extent of descent. If the process of removal of ice from balloon fabric is a gradual one, this is what can be expected. If, however, the removal of ice is sudden as in case of peeling off the accumulated ice from the balloon fabric there may not be any relationship between the load and the height descended as we cannot fix up the point at which such sudden removal would take place. Under such conditions the height descended may be less with greater load on it. This explains why during second descent (where peeling-off of the ice was possible) the balloon descended 800 metres with a load of 1146 gms whereas the same balloon from same height descended 1000 metres with a load 1066 gms during the fourth descent. For second and third descents of 7 October 1950 the balloon descended a greater height with less load during the former. On this date though we are not able to ascertain any peeling off of ice from the balloon, yet its possibility during the third descent cannot be ruled out especially when the load on the fourth ascent was less than the third one.

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