NOTES AND CORRESPONDENCE

**Measurement of Stratospheric Turbulence by
Balloon-Borne "Glow-Discharge" Anemometer**

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1. Introduction

In situ measurements of stratospheric turbulence are important in order to verify the theorem of gravity-wave stress in the middle atmospheric dynamics [see Yamanaka and Tanaka (1984a) and references therein]. We have already performed an observation at 24–26 km levels using sensitive propellor anemometers reeled down and up from balloon, and have reported on multiple gust layers probably associated with gravity waves just before breakdown (see Yamanaka and Tanaka, 1984c; Yamanaka *et al.*, 1985b). However, we could not detect such quick and weak fluctuations as measured so far by Barat's (1975, 1982b) *anémomètres ionique*.

Many investigators have tried to apply ionized air generated by a corona discharge for tracers in various air flows [see Yamanaka *et al.* (1985a) and references therein]. For balloon-borne use, however, none of them could observe stratospheric turbulence longer than few hours, possibly because the corona discharge is transient and unstable. Long duration observations are necessary to reveal the life cycles of layered turbulence, in particular those generated by long gravity waves which must be different from that of short waves (Yamanaka and Tanaka, 1984b). The longest period of internal gravity waves is approxi-

mately limited by the Coriolis period (about 18 hours around 40° latitude), so that an observation duration longer than one day is requested to satisfy above-mentioned objectives perfectly.

Here we report briefly on the specifications of another type of balloon-borne ionic anemometer newly developed. We utilized a kind of glow discharge studied originally by Sekiguchi *et al.* (1963) and Hirosawa *et al.* (1964) as the ion source of the new anemometer for long duration observations. Detailed descriptions on the principle and improvement of the anemometer will be given in a subsequent paper (Yamanaka *et al.*, 1985a). A quick look of original data obtained by the anemometer during the first flight carried out in September 1983 shows inhomogeneous fine structures inside a stratospheric turbulence layer.

2. Glow-discharge ionic anemometer

The glow-discharge anemometer newly developed has the form of a triode as shown in Fig. 1(a). It was so far found out by Sekiguchi *et al.* (1963) that such a triode with a fine-mesh grid in gasses of 15–30 torr (20–40 hPa) pressures behaves as a diode since a glow discharge occurs only on one side of the grid. Hirosawa *et al.* (1964) showed that the penetration rate of glow-discharge plasma toward the opposite side of the grid is strongly dependent upon the geometry of the grid. In the case of the anemometer described here,

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(a)

(b)

Fig. 1 Structure of the glow-discharge ionic anemometer (unit: mm): (a) design of a prototype; (b) appearance of a flight model. 'Macor' is a machinable ceramic material invented and produced by Corning Co.

air is ionized by a glow discharge between the anode and the grid (*i.e.*, discharge *cathode*). Then a part of the positively ionized air penetrates through the cathode toward the third electrode (cation *collector*). The cation beam is drifted by a wind perpendicular to the electric field. Hence we can measure the wind velocity by detecting how the differential electric current is generated between each segments of the participated cathode.

We consider that wind-ion beam interactions in the cathode-collector space are essen-

tially the same as those in the corona-discharge anemometers so far made (see, *e.g.*, Good *et al.* 1978; Barat, 1982b). On the other hand, from a viewpoint of the gaseous electronics, such a glow-discharge ion source as used here is superior to any corona-discharge sources especially in relation to stability and reproducibility. Up to now we have not found any corona-discharge ion source adequate to our objectives mentioned in Section 1. The glow discharge can be maintained by a relatively lower gap voltage, so that we are almost free from cares of damages on other devices due to electric leakage from the gap-voltage power supply. We also notice, however, that the corona discharge has some merits; low battery consumption and calibration in the normal pressure (see Barat, 1982a). The electrode materials described in Fig. 1(a) are selected on the basis of experimental trials aiming at high stability of the glow discharge during several tens of hours. Fig. 1(b) shows a glow-discharge anemometer for actual observa-

Fig. 2 Examples of the distributions of ion current densities. Solid lines show the current densities (ordinate, in a logarithmic scale) plotted versus the radii from the collector center (abscissa, in a squared scale), so that the Gaussian dispersions can be easily obtained from the inclinations of the fitted lines. The cathode-collector distance (l) is taken as a parameter. A dashed line in the graph shows a case of the opposite polarities of glow-discharge electrodes, when the negative ions and electrons injected into the collector (highest voltage, in this case).

tional use, which is entirely the same as the prototype shown in Fig. 1(a) except for some options to set it on the balloon gondola.

We studied the nature of the ion beam by replacing the collector by a copper disk partitioned into five concentric ring-like segments of a collector. The results indicate that the ion beam density has an axially-symmetric Gaussian distribution (Fig. 2), which is consistent to the diffusion theory for a continuous point source with a uniform advection voltage. The dimensions and distance of electrodes of the anemometer were determined mainly on the basis of such an ion beam density distribution.

We carried out two sophisticated experiments for calibrations. First, we set the anemometer on a pendulum which produces a damped oscillation in a low-pressure chamber. Then the minimum sensitivity, 0.5 cm/s, of the anemometer can be determined as the minimum oscillatory output distinguished from noises due to the glow discharge, the anemometer supports and so on (see Fig. 3). Next, the anemometer was set on the center of a turn-table placed in a constant flow inside a low-pressure wind-tunnel. Then the two-component differential currents of the anemometer became sine or cosine curves with amplitude modulations dependent on the pressure as shown in Fig. 4(a). Comparing them with calculated component velocity of the wind, we

Fig. 3 A result of the pendulum experiments (see text). Calculated oscillation velocities are also indicated.

obtained the linearity of the glow-discharge anemometer from those data [see Fig. 4(b)].

Concerning the pressure dependence of the linearity, wind-tunnel experiments led approximately to a simple relation as follows (see Fig. 5):

$$\frac{\Delta I}{\Sigma I} = \alpha \cdot u, \quad (1)$$

(a)

(b)

Fig. 4 Examples of the turn-table experiments: (a) the rotation angles (left), the anemometer outputs (centered two) and the pressure (right); (b) the calibration curve of the glow-discharge anemometer for the component wind velocity, u .

Fig. 5 The differential and total currents (top and middle) and the current ratios (bottom) in a constant wind velocity (3.8 m/s) for various pressures and corresponding standard altitudes.

where u is the wind velocity, and ΔI and ΣI are the differential and total currents, respectively, of the currents injected into two electrically insulated halves of the collector. It is interesting that the factor, α , is almost constant for pressures between 15–35 torr (20–40 hPa) in spite of pressure dependence of the mobility and diffusion constant of ions. In order to measure two-component winds, the collector was divided into four segments [see

Fig. 1(a)] as designed by Good *et al.* (1978).

It should be noted that noisy fluctuations and scattered data in Figs. 4(a) and (b), respectively, are due to wind-tunnel turbulence, because the noises due to the discharge or the anemometer supports are negligibly small as clarified from the pendulum experiments. Results of the pendulum experiments also suggest that the response over the minimum sensitivity is independent from the horizontal wind azimuth. Furthermore the dimension of cathode-collector space may be stable for any winds smaller than 10 m/s; the Reynolds number is lesser than the order of 10^2 .

The specifications and characteristics of the glow-discharge anemometer is summarized in Table 1. We can decide that this anemometer is sufficient to measure the stratospheric turbulence. Some details beyond the scope of this brief note are described in Yamanaka *et al.* (1985a).

3. Balloon observation and quick-look results

The first flight of the glow-discharge ionic anemometer was carried out at Sanriku Balloon Center of ISAS (39°N, 142°E) in 0732–2224 JST, 26 September 1983. The glow-discharge anemometers were mounted on two gondolas as shown in Fig. 6. The lower gondola can scan the vertical through 1 km by a winch (Matsuzaka *et al.*, 1984). The others are the same as those used in the balloon observation in 1982 (*viz.*, Yamanaka and Tanaka, 1984c; Yamanaka *et al.*, 1985b). The achieved observation duration in the middle stratosphere is about 14 hours; note that this does not mean the life time of the anemometer but a limit of the balloon-tracking range. In this section

Table 1 Specifications of the glow-discharge ionic anemometer.

Minimum sensitivity	0.5 cm/s (at 15–35 torr)
Linearity	0.014 ($\mu\text{A}/\mu\text{A}$)/(m/s) (at 15–35 torr)
Maximum measureble wind	10 m/s (at 20 torr)
Output channels	$\left\{ \begin{array}{l} \text{Total current: 1} \\ \text{Differential currents: 2} \\ \text{Partial currents: 4} \end{array} \right.$
High Voltage Power Supply	616 V, 8 mA
Battery	DC 15 V, 10 W
Weight	3 kg (without batteries)

we present some interesting features concerning stratospheric turbulence, based on the original data records of the glow-discharge

anemometer mounted on the lower gondola during the first continuous vertical survey.

We can distinguish “turbulence layers” from “laminar flows” in the data records in the same way as done so far by Barat (1975, 1982b).

Vertical distribution of the turbulence layers seems to be concentrated in locally strong shear zones (see Fig. 7); three groups of turbulence layers may be related three negative

(relative) shear zones. A concentrated zone has an “outer vertical scale”, called by Barat, of some hundreds of meters. This scale is consistent to turbulence layer thicknesses derived from the gravity-wave breaking theory (Tanaka, 1983; Yamanaka and Tanaka, 1984a, b).

Frequent existence of turbulence may be closely connected to induction of weak zonal winds in the middle stratosphere (Tanaka and Yamanaka, 1985). Note that the wind data might include some horizontal and temporal wind variations because the gondola moved simultaneously in the horizontal direction with the balloon flight (*cf.* Yamanaka *et al.*, 1985b).

We shall inspect a part of the wind records (indicated as “T” in Fig. 7), which shows a typical example of the stratospheric turbulence layers (see Fig. 8). Note that fluctuations have no correlations with the gondola rotations detected by a geomagnetic attitude (GA) sensor. “Turbulent Flow-I” has clearcut boundaries at the top of “a” and the bottom of “b”, and “Turbulent Flow-II” begins at “c” and continues below. It is very interesting that noticeably strong fluctuations are detected in surveying the levels marked by “a”, “b”, “c”, “d” and “e”. The maximum amplitude of such fluctuations reaches almost 1 m/s, and the vertical scales do not exceed 3 m. The fluctuation “a” is somewhat wavy and less turbulent, and we can find that similar but weaker features continue just below “a”. The fluctuation “b” is also clear but thinner and weaker than “a”. In “Turbulent Flow-I” two weak turbulent parts are also found between “a” and “b”. The maximum amplitudes and clearities of three thicker fluctuations (“c”, “d” and “e”) in “Turbulent flow-II” becomes lesser in alphabetical order, *i.e.*, as the amplitude decreases.

For an extended speculation, we assume

Fig. 6 Balloon instrumentation used in the 26 September 1983 observation.

Fig. 7 Distribution of turbulence layers (dotted regions) observed in a 1 km vertical survey. “T” denotes the part shown in Fig. 8. Relative wind speeds are averaged in each minutes.

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For an extended speculation, we assume

Fig. 8 Vertical microstructures of turbulence layers. The attitude of the x -component anemometer (left two), the anemometer outputs (centered two) and a speculation on the data record (rightmost illustration) are shown. See text, including the levels indicated by "a"–"e".

here that these systematical fluctuations correspond to the stages of Kelvin-Helmholtz (KH) billow life cycle (see the illustration in Fig. 8) at the front edges of upward propagating gravity waves (*cf.* Yamanaka and Tanaka, 1984a). Referring to a numerical study on the KH billows by Tanaka (1975), a KH billow with 2 m thickness has about 10 m horizontal scale and characteristic time scale of about 100 sec when the wind gap is assumed to be 1 m/s. Thus we can vividly imagine that KH billows of the growing and matured stage appeared typically at "a" and "c" in Fig. 8, where the glow-discharge anemometer encountered the front edges of gravity waves proceeding upward. There might be KH

billows of the breakdown stage at "e", for example, where the front edge had passed before the anemometer reached there. However, in order to clarify the reason why the KH instabilities are generated so often, data accumulation must be continued.

4. Remarks

This note is described to report quickly on a new tool for stratospheric turbulence studies. We confirmed that the glow-discharge ionic anemometer worked stably to measure turbulent wind fluctuations in the stratosphere over 14 hours. The fine structures of turbulence layers are also reported based on an intuitive inspection of wind records, which demonstrate

rather systematic structures of stratospheric turbulence. Detailed data analyses are now in progress to reveal the relation between turbulence and gravity waves, and the results will be discussed in subsequent papers.

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References

- Barat, J., 1975: Étude expérimentale de la structure du champ de turbulence dans la moyenne stratosphère. *Compt. Rend. Acad. Sci. Paris*, **B280**, 691-693.
- , 1982a: A high-resolution ionic anemometer for boundary layer measurements. *J. Appl. Meteor.*, **21**, 1480-1488.
- , 1982b: Initial results from the use of ionic anemometers under stratospheric balloon: Application to the high-resolution analysis of stratospheric motions. *J. Appl. Meteor.*, **21**, 1489-1496.
- Good, R. E., J. H. Brown and G. Harpell, 1978: Development of a corona anemometer for measurement of stratospheric turbulence. *AFGL-TR-78-0070*, 44 pp.
- Hirosawa, H., K. Kudo, T. Sekiguchi, H. Kobayashi and M. Kobayagawa, 1964: Plasma negative resistance device: I. Static characteristics. *Summaries of Papers of the International Conference on Microwaves, Circuit Theory and Information Theory, Tokyo*, Part I, 407.
- Matsuzaka, Y., T. Yamagami, J. Nishimura and M. D. Yamanaka, 1984: Reel up and down system for balloon-borne instruments. *Proc. ISTS*, **14**, 1223-1227.
- Sekiguchi, T., H. Hirosawa, H. Kobayashi and M. Kobayagawa, 1963: A plasma negative-resistance diode. *Proc. IEEE*, **51**, 919.
- Tanaka, H., 1975: Quasi-linear and non-linear interactions of finite amplitude perturbations in stably stratified fluid with hyperbolic tangent shear. *J. Meteor. Soc. Japan*, **53**, 1-32.
- , 1983: Turbulence layer thickness in the lower stratosphere under the presence of viscosity and Newtonian cooling. *J. Meteor. Soc. Japan*, **61**, 805-811.
- and M. D. Yamanaka, 1985: Atmospheric circulation in the lower stratosphere induced by the mesoscale mountain wave breakdown. *J. Meteor. Soc. Japan*, **63**, in press.
- Yamanaka, M. D., H. Hirosawa, Y. Matsuzaka and H. Tanaka, 1985a: "Glow-discharge" ionic anemometer. *Rev. Sci. Instrum.*, **56**, 617-622.
- , Y. Matsuzaka, J. Nishimura, T. Yamagami and H. Tanaka, 1985b: Stratospheric balloon-borne "adapted Gill-type" propeller anemometer. *J. Atmos. Ocean. Tech.*, **2**, in press.
- and H. Tanaka, 1984a: Multiple "gust layers" observed in the middle stratosphere. *Dynamics of the Middle Atmosphere*, J. R. Holton and T. Matsuno (ed.), TERRAPUB/D. Reidel, 117-140.
- and ———, 1984b: Propagation and breakdown of internal inertia-gravity waves near critical levels in the middle atmosphere. *Meteor. Soc. Japan*, **62**, 1-17.
- and ———, 1984c: Meso- and microscale structures of stratospheric winds: A quick look of balloon observation. *J. Meteor. Soc. Japan*, **62**, 177-182.

大気球塔載グロー放電型電離式風速計による成層圏乱流の観測

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