Discussion of:
Project Jet Stream
Research Flight No. 30, April 1957

By
E.R. Reiter

(Read 17 January 1962. Presented by J.K. Bannon. See Q.J., 187, p. 332)

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Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado

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Mr. A. H. Gordon: Can the area of dynamic instability shown to be present on the anticyclonic side of the jet be associated with any other parametric pattern, for example, divergence or development of the underlying surface system?

Dr. R. C. Sutcliffe: The paper seems to be in satisfactory confirmation of similar studies made in this country. May I ask whether any attempt was made to link the ageostrophic winds quantitatively with the accelerations other than those due to anticyclonic curvative. The fine structure of the wind is of particular interest and importance. Could I be told where this aspect of the problem is discussed? The data seems to be available.

Dr. G. B. Tucker: At a recent Monday-afternoon Discussion Meeting held at the Meteorological Office, Dr. J. K. Angell presented some investigations of upper-air flow using constant-level balloons. One of his results was that when in a jet stream the balloons tend to move with a speed appreciably greater than geostrophic. Dr. Angell could not explain this but suggested it might be due to some mechanism keeping a constant-level balloon in the core of the jet. Dr. Reiter has clearly shown in his paper that, at least on this occasion, the ageostrophic component shows a maximum in the jet core, the winds being super-geostrophic. Does this study also suggest any way in which constant-level particles can be kept in the jet core?

Mr. J. K. Bannon: Further to Dr. Tucker's comments, qualitative evidence from the travel of radioactive particles suggests that air in the core of the jet stream tends to remain in the strongest flow.

Dr. E. R. Reiter (in reply): Dr. Tucker's quest for a mechanism, which would keep balloons or other particles--as Mr. Bannon suggests--in the jet core, is rather intriguing, because it also seems to apply to 'dish-pan' experiments. There it was found that aluminum powder floating on the water surface tends to concentrate in the 'jet stream' which forms at the surface of the rotating annulus. Unfortunately at this moment I cannot offer more than a mere hypothesis. There has been no provision in this particular flight programme--and in others analysed by me (Reiter 1962)--to study the four-dimensional behaviour of the flow pattern. Hence no quantitative conclusions can be drawn as to the energetics of the flow. I have recently conducted a multi-aircraft survey of the jet stream off the U.S. East Coast, which was flown by the U.S. Weather Bureau and the U.S. Navy and which, it is hoped, might shed some light on this problem. Meanwhile, let me make the following conjecture: the air in the entrance region of a jet maximum is accelerating strongly, and at the same time undergoing a stream-line convergence. Accepting the existence of jet maxima as an effect of inertia oscillations superimposed upon a quasi-geostrophic current that changes with time (Newton 1959), it is readily understood why, on the average, the flow in the jet maximum itself will be super-geostrophic--which goes well with Dr. Angell's findings.

I have explained in detail in my textbook (Reiter 1961, cf. also Q.J., 87, 1962) the existence of strong sinking motions in the jet core, as evident from the dryness and the large ozone content of the air body underneath the jet maximum (Murgatroyd 1959, Reiter 1961). This sinking motion, together with the isobaric stream-line convergence observed on high-level constant pressure charts would indicate genuine horizontal convergence, in spite of the acceleration of flow that takes place in the entrance region of the jet maximum.

A transosonde, of course, is not a true tracer of air motions, since, in approximation, it travels isobarically, while the latter occur along isentropic surfaces. A floating balloon at, say, 30,000 ft will be onstantly subject to the horizontal convergence present in the rear of the jet maximum, thus staying near the core of strongest winds. It will be ejected from the wind maximum on its leading edge (delta region) but soon will be entrained into the next maximum downstream. This might explain why some transosondes near 30,000 ft travel at record speeds, seemingly staying near the core of jet streams. The results might be different, however, if the balloons were made to float at a level appreciably above or below the jet core, where the convergence to the rear of a wind maximum is not as pronounced any more--or even reversed in sign.

As to Mr. Bannon's remark on the concentration of atomic debris near the jet core, this seems to follow a different effect: the aforementioned isentropic sinking motions near the jet core -- which, incidentally, cannot be followed by a constant-pressure balloon -- import air from stratospheric levels down into the middle troposphere, in extreme cases may be as far as the 700-mb level. (This may be substantiated from potential temperature and potential vorticity patterns near a frontal zone). The sinking occurs in a rather confined atmospheric slab which extends along the jet axis in the entrance region of a well-pronounced wind maximum. Thus, air particles originally located in the stratosphere, travel into the jet maximum, and at the same time sink down to middle-tropospheric levels. In doing so, the air mass acquires thermal stability and, from the theorem of conservation of potential vorticity, the trajectory assumes an anticyclonic curvature (Danielsen 1961). Thus, the air body will finally end up in the anticyclone to the south of the jet maximum. It will take a few days of diabatic cooling (approximately 1° C/day) until this air will reach the earth's surface.

Following the assumption, that the stratosphere is rather widely contaminated by suspended radioactive debris, these originally stratospheric air bodies reaching the ground will bring about an increase in the level of fair-weather radioactivity. (The washing-out effect of precipitation, naturally, may modify this pattern occasionally). In my opinion, this point brought up on Mr. Bannon's suggestion has not nearly received as much attention as it deserves. The peculiarities of the general circulation provide certain regions of preferred occurrence of these sinking motions in jet streams, and of the establishment of high-pressure cells containing originally stratospheric air. Such areas might be for instance, the southeastern United States near the climatological position of the upper-trough -- and a corresponding region to the east of the Himalayas. Thus, it appears, these regions would suffer from an above-average rate of stratospheric fall-out. For further details, again, reference is made to my textbook.

Mr. Gordon's comment has been well taken. Yes, the surface cyclone shown in Fig. 2 of my paper did deepen appreciably. By 9 April 12,000 GCT it was located 100 naut. mi. east of Nantucket Island with a centre pressure less than 985 mb. This seems to agree well with the divergence pattern shown in Fig. 12, and with what could be derived about the magnitude of $\partial u/\partial x$ in the proximity of this research flight. To decide how this might tie in with the observed dynamic instability would require more research on the subject, and for that matter more accurate measurements near the jet stream.

Last, not least, to answer Dr. Sutcliffe's question. To my knowledge no attempts have been made as yet to correlate quantitatively the ageostrophic components of flow with any accelerations of air particles, probably because the latter are difficult to obtain: we do not have any sensors, measuring the flow along isentropic surfaces, and our rawin data, unfortunately, are not dense and accurate enough, to produce more than statistical evidence. (Some of these aspects are discussed in Reiter (1961)). The aforementioned research flights, conducted during February and March of this year off the east coast of the U.S., might yield some results along these lines, because the D-values (equivalent to the pressure-field), which have been measured directly on several of these missions, may b e compared quantitatively -- so it is hoped -- with the field of flow, and with the accelerations it contains. The data are still in the process of reduction and evaluation, and it will be some time until results can be made known. In my opinion, such flight measurements over the ocean, with D-values readily available, are at the present our only means of tackling this problem. I might conclude with the statement that Dr. Sutcliffe has really pointed out a sore spot of jet-stream research: as long as we do not know the complete quantitative relationships between ageostrophic components and accelerations in a scale range much more detailed than our present sounding network permits, our 'conclusions' as to the energetics of atmospheric circulation systems will remain sophisticated, yet approximate, guess work.

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