ΜΕΤΕΩΡΟΛΟΓΙΑ.—**Ozone and Temperature Balloon Measurements during the Annular Solar Eclipse of 29 April 1976,** *by*
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Ἀνεκοινώθη ὑπὸ τοῦ Ἀκαδημαϊκοῦ κ. Ἠλία Μαριολοπούλου.

Abstract.

Ozone and temperature measurements were obtained from balloon soundings at Athens (37.54° N, 23.44° E) Greece, during and after the annular solar eclipse of 29 April 1976. Detailed temperature and ozone data were acquired to an altitude of 29 km. A time-height cross section of temperature data shows significant cooling (by 3^0K) above about 40 mbs, which is in agreement with independent measurements at Wallops Island on 7 March 1970. The observed (corrected) cooling in the mid-lower stratosphere exceeds computed infrared cooling at the heights in question. A brief survey on upper-air ozone soundings during eclipses is given and expected eclipse-induced changes in the upper ozonosphere are briefly discussed. As was to be expected from the photochemical theory, no significant ozone variations took place at heights near the ozone maximum during the eclipse. Evidence of Cirrus clouds after the eclipse maximum is in agreement with other observations and support the generation of relatively short duration cooling in the upper troposphere during the eclipse. Detailed radiosonde measurements at the heights where the Cirrus clouds were observed, confirmed a cooling by about 3 degrees (corrected) in the upper troposphere (320 to 340 mbs).

1. INTRODUCTION

Measurements of atmospheric parameters from ground level has been a commonly repeated experiment by eclipse observers since the 19th century (Anderson et al., 1972) and there is by now ample evidence of significant ionospheric changes during a solar eclipse (Rishbeth, 1970). However little is known concerning the response of the ozonosphere and

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the neutral upper atmosphere to a solar eclipse, since high altitude measurements are comparatively recent.

The first eclipse experiment with meteorological rockets was conducted by Ballard and colleagues on November 1966 in Argentina 22.46° S (Ballard et al., 1969). During the eclipse they observed a cooling in the vicinity of 55 km and an ozone increase at 57 km during the time of totality relative to the same measurement on the pre-eclipse day (see also Randawa, 1968). The ozone measurements, however, were available only from 39 to 60 km (Randawa, 1968) and because of other data gaps, a clear picture of the eclipse-induced changes could not be drawn. A carefully designed experiment was thus conducted at Wallops Island (37.8° N) on 6 - 8 March 1970, to study the eclipse-induced changes in the temperature and wind up to an altitude of about 65 km (Quiroz and Henry, 1973). A significant cooling was found mainly in the layer 40 - 60 km, with maximum amplitude 9^0 K, near 50 km. That cooling occurred first in a limited layer 45 - 50 km (about 30% obscuration) then spread upward and downward to about 26 km (65% obscuration). By the end of the eclipse only a shallow layer or residual cooling remained (45 - 50 km).

More recently, Randawa (1974) obtained temperature data up to about 60 km before, during and after the partial solar eclipse which occurred on December 24, 1973 at Ft Sherman (9.20° N). Randawa's observations indicate a 3^0 - 5^0C cooling, produced in the layer 50 to 52 km as the solar radiation was partially blocked. Although these observations are in agreement with those of Quiroz and Henry for the upper stratosphere, Randawa reported no effect below 45 km.

Following the above discussion it seemed to us highly desirable to investigate the mid-lower stratosphere for the evidence of the eclipse induced cooling at lower altitudes observed by Quiroz and Henry, but not by Randawa, during the annular solar eclipse of April 29, 1976 at Athens (37.54° N) Greece. Our experiment was conducted from 28 to 30 of April 1976 to measure radiosonde temperatures and ozone before, during and after the eclipse. Since meteorological rockets were not available to us, we crossed our fingers that the balloons launched reach the highest possible levels! Before presenting the results obtained, we first briefly describe previous ozone measurements and theoretically expected ozone variations during a solar eclipse.

2. OZONE AND SOLAR ECLIPSES

The effect of a solar eclipse on the ozonosphere is to cause a tiny increase in the total ozone content in a vertical column of the atmosphere. There have been several reported studies on this effect, extensively summarized by Vassy (1970). Qualitatively it was shown, from a knowledge of the diurnal photochemical ozone variation and the study of the equations controlling the ozone concentration in the atmosphere, that an increase should occur above about 40 km as a result of a solar eclipse due to photochemical effects (Hunt, 1965a, b, Vassy, 1970). The theoretically expected ozone increase is however very small, about 0.6% of the total ozone amount, and the eclipse has no effect on the ozonosphere below about 45 km (Hunt, 1965a).

From the existing literature it appears that all but three of the ozone measurements during solar eclipses, were obtained from ground or at airplane heights (2.5 km) observations (Vassy, 1970) which are influenced by many factors (as for example the limb darkening of the sun, temperature of the instrument, formation of aerosols during the eclipse, synoptic variability e.t.c.) which in view of the expected minute total ozone changes may obscure any eclipse induced changes in the ozonosphere.

In order to eliminate the effects of some of the above discussed factors, Vassy and colleagues (unpublished manuscript) measured with the optical method the ozone profiles on the day before and the day after the solar eclipse which occurred as partial on 20 May 1966 in Greece. Unfortunately no information on the measurements during the eclipse day has been reported (Vassy, 1970). It is worth noting, however, that at the moment of the eclipse totality an abrupt formation of aerosols was observed in that experiment which lasted to the last contact.

The remaining two high altitude ozone measurements, both showed a doubling of ozone between about 50 and 60 km (Randawa, 1968) and an increase of the same order but at higher altitudes (80 - 90 km) in the eclipse of 15 February 1961 over the USSR (L'vova et al., 1964).

From the above discussion it appears that conducting ozonesonde measurements with the chemical method before, during and after a solar eclipse we are not expecting to find any eclipse-induced ozone changes below about 30 km (which is the average ceiling of the balloons available to us). However to the best of our knowledge, no such measurements were carried during solar eclipses and because they could provide useful information to other eclipse observers, we thought worth doing the ozonesonde measurements together with the temperature soundings discussed in the introduction.

3. MEASUREMENTS

Five Brewer-Mast ozonesondes (Type 730 - 5) in operation with U. S. Weather Bureau corresponding radiosondes were programed to be launched on the day before (one), during (three) and after (one) the solar eclipse from the radiosonde station of Hellinikon (37.54° N) in Athens, Greece. The annular solar eclipse was seen at Athens as partial (0.915) and it started in Athens at 0855 UT and ended at 1229 UT on April 29, 1976 (Amer. Eph. Naut. Almanac, 1976). Unfortunately due to technical difficulties, no measurements were obtained on the day before the eclipse. However the experiment was successful on the eclipse day and the day after, as described below.

4. RESULTS

The first balloon sounding started at 0800 UT and the instruments were at a height of approximately 9 km on first contact. The middle of the eclipse (0.915) found that balloon at about 24 km and the balloon bursted at 29 km (1126 UT). The second balloon was launched at 1154 UT and it was at a height of about 12 km at the time of the last contact. The second balloon bursted at 26 km (1306 UT). Thus, above 12 km, the second balloon provided post-eclipse stratospheric measurements separated by 2 - 3 hours from the corresponding data gathered near the middle of the eclipse. A third balloon was launched at 1644 UT (bursted at 19 km, 1802 UT) which measured only temperature aloft, and a fourth balloon was launched on April 30 at the same time as the first sonde (0755 UT). This last balloon reached 25 km and bursted at 0950 UT.

The ozonesonde results are shown in Figure 1, where the continuous line corresponds to the first sounding, crosses correspond to the second sounding and the small circles represent the measurements obtained the next day. Figure 2 shows the time-height temperature measurements obtained from all four soundings. Dots aloft give the timing (and height) of each balloon (BB is the acronym of «Balloon Burst»).

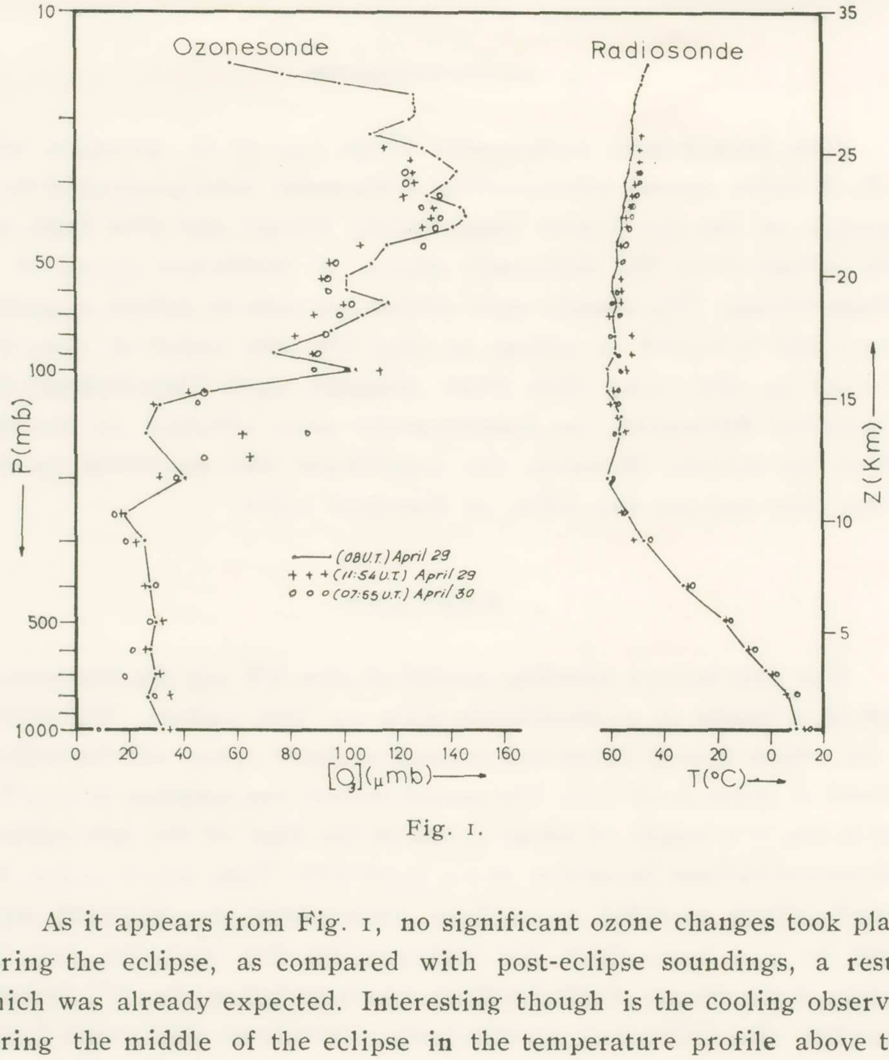

Fig. 1.

As it appears from Fig. 1, no significant ozone changes took place during the eclipse, as compared with post-eclipse soundings, a result which was already expected. Interesting though is the cooling observed during the middle of the eclipse in the temperature profile above the 40 mb level (Figs. 1 and 2). Because of the relatively slow ascent rate, the first balloon reached the 28 mbs level at the time of the middle of the eclipse (Mag 0.915). Data at that level as compared with the post-eclipse measurements with the second balloon, up to the bursting level of that balloon (23 mbs), indicate a net cooling by about 3^0 K (corrected according to McInturff and Finger, 1968). A similar cooling at these heights was also observed by Quiroz and Henry (1973) during the eclipse of 7 March in 1970. That cooling was centered at 30 km (—4 deg.) and

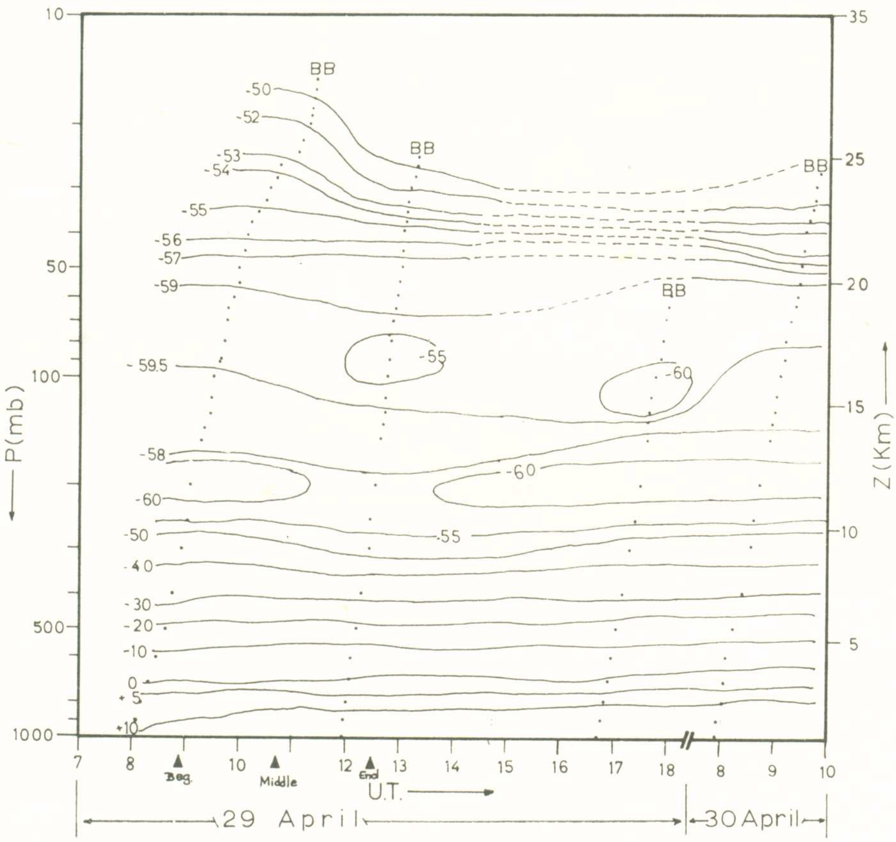

Fig. 2.

it extended upward to 35 km (—3 deg.). Unfortunately due to the lower bursting height of our second balloon we can not say if the observed cooling extended upwards as in the case of March 1970.

Our results of a cooling in the mid-lower stratosphere present a paradox, since the observed eclipse cooling far exceeds the computed infrared cooling which would amount at these heights at most to 2.0 degrees per day (Plass 1956 a, b, Kuhn and London, 1969). It should also

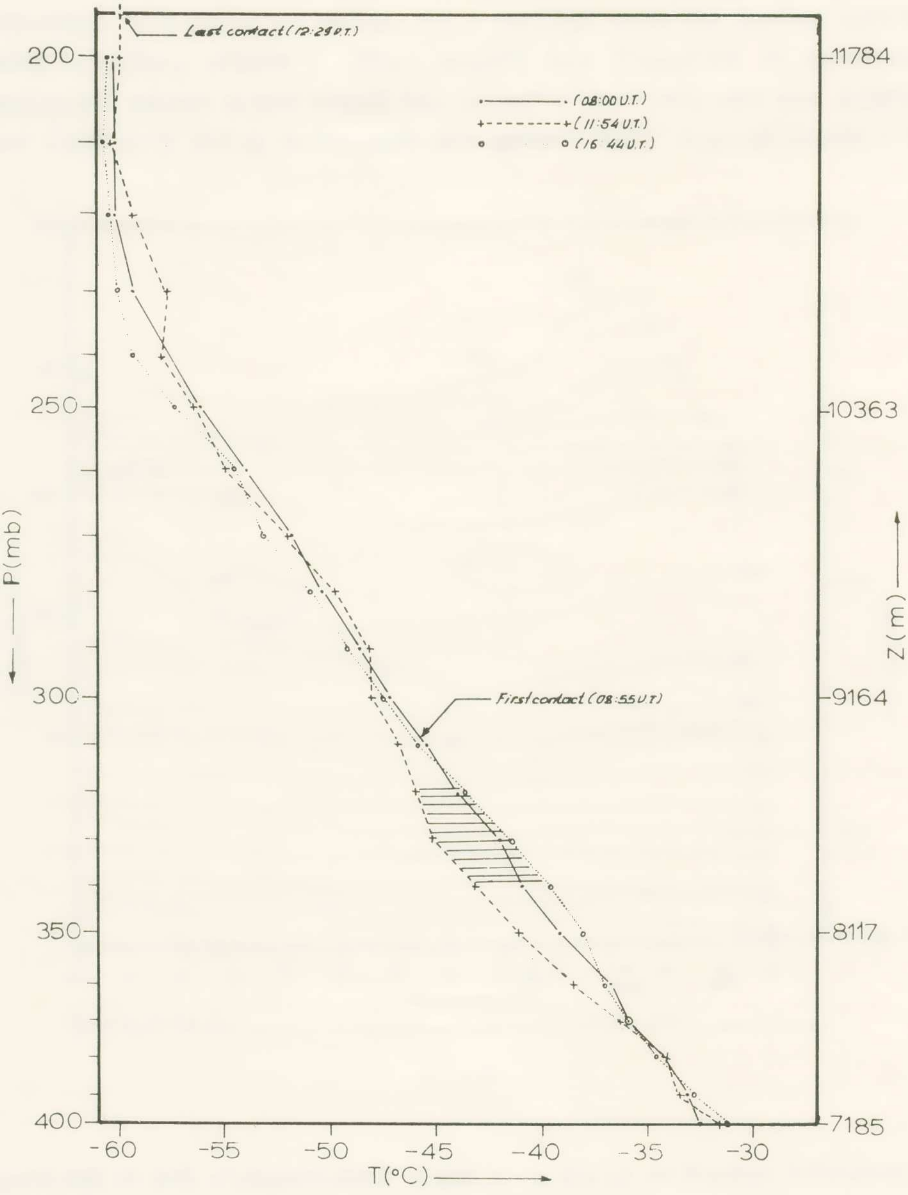

Fig. 3.

be noted that the observed diurnal temperature amplitudes at 25 - 30 km lie between 1 and 1.5 degrees (Finger et al., 1965).

Evidence of Cirrus clouds after the eclipse maximum is in agreement with other observations (Mariolopoulos, 1937) and support the occurrence of cooling with relatively short duration in the upper troposphere. A careful examination of the radiosonde measurements at the heights of these clouds confirms a cooling by about 3 degrees in the upper troposphere (320 - 340 mbs) as shown in detail in Figure 3.

Other details of the radiosonde soundings we believe are of minor importance, as far as the eclipse effects are concerned, the warming which is observed in Fig. 2 immediately after the eclipse (between 100 and 80 mbs) being probably produced by subsidence.

5. CONCLUSIONS

Our measurements indicate no ozone changes at the level of the ozone maximum during the eclipse of April 29, 1976. During the middle of the eclipse a cooling by about 3° K occurred above the 40 mb level. That amount of cooling significantly exceeds the observational uncertainty as well as the computed infrared cooling rates at the levels in question. A same amount of cooling was observed in the middle stratosphere at Wallops Island during the eclipse of 7 March, 1970. Cirrus clouds were observed during the eclipse maximum (faint Cirrus were present from the early morning on the eclipse day but they dissapeared at 10 UT). The later Cirrus clouds dissapeared a little after last contact. A detailed analysis of the radiosonde data in the layer 400 mb to 200 mb, showed the occurrence of a cooling in the upper troposphere (340 - 320 mbs). That cooling amounted to about 3° K near 330 mbs (Fig. 3) and it obviously exceeds (see last paragraph) computed infrared cooling rates, observational uncertainty and day-night differences in temperature known for the upper troposphere.

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ΠΕΡΙΛΗΨΙΣ

Εἰς τὴν παροῦσαν μελέτην περιλαμβάνονται μετρήσεις τῶν καθ' ὕψος μεταβολῶν τῆς θερμοκρασίας τοῦ ἀέρος καὶ τῆς συγκεντρώσεως τοῦ ὄζοντος τόσον κατὰ τὴν διάρκειαν ὅσον καὶ μετὰ τὸ πέρας τῆς δακτυλιοειδοῦς ἐκλείψεως, ἥτις ἔλαβε χώραν τὴν 29ην Ἀπριλίου ἐ. ἔ. Αἱ μετρήσεις ἐγένοντο δι' ἀεροστάτων τῶν 1200 γρ., εἰς τὰ ὁποῖα εἶχον καταλλήλως προσαρμοσθῆ ραδιοβολίδες καὶ ὀζοντοβολίδες. Ὅλαι αἱ παρατηρήσεις ἐγένοντο ἐκ τοῦ Σταθμοῦ ἀνωτέρας ἀτμοσφαίρας εἰς τὸ Ἑλληνικόν (37.54° Β). Λεπτομερειακαὶ μετρήσεις τῆς θερμοκρασίας καὶ τοῦ ὄζοντος ἐπετεύχθησαν μέχρι τοῦ ὕψους τῶν 29 περίπου χιλιομέτρων, τὰ δὲ ἀποτελέσματα τῶν παρατηρήσεων τούτων δύνανται νὰ συνοψισθοῦν ὡς ἀκολούθως:

Κατὰ τὴν διάρκειαν τῆς ἡλιακῆς ἐκλείψεως ἔλαβε χώραν σημαντικὴ ψῦξις εἰς τὴν μέσην στρατοσφαῖραν καὶ δὴ εἰς ὕψη ἄνω τῶν 23 περίπου χιλιομέτρων, ἀνερχομένη εἰς 3° Κ ἐντὸς δύο ὡρῶν. Πρέπει νὰ σημειωθῇ ὅτι ἡ ψῦξις αὕτη ὑπερβαίνει κατὰ πολὺ τὴν ἐξ ὑπολογισμῶν ἀναμενομένην ψῦξιν λόγῳ ἀκτινοβολίας εἰς τὸ ὑπέρυθρον τοῦ διοξειδίου τοῦ ἄνθρακος καὶ τοῦ ὄζοντος εἰς τὰ ἐν λόγῳ ὕψη. Ἐπίσης ὑπερβαίνει τὰ πειραματικὰ σφάλματα καὶ τὴν εἰς τὰ ὕψη ταῦτα παρατηρουμένην ἡμερησίαν πορείαν τῆς θερμοκρασίας, τὸ εὖρος τῆς ὁποίας δὲν ὑπερβαίνει τὸν 1.5° Κ. Τὸ αὐτὸ φαινόμενον παρετηρήθη καὶ κατὰ τὴν ἔκλειψιν τοῦ ἡλίου εἰς τὸ Wallops Island τὸν Μάρτιον τοῦ 1970, ὡς διεπιστώθη διὰ συγχρόνων παρατηρήσεων ἀεροστάτων καὶ πυραύλων.

Ἐκτὸς τῆς ἐν τῇ στρατοσφαίρᾳ παρατηρηθείσης ψύξεως, ἔλαβε χώραν καὶ ἑτέρα ἀνάλογος ψῦξις εἰς τὴν ἀνωτέραν τροποσφαῖραν, ἡ ὁποία εἶχε πιθανῶς ὡς ἀποτέλεσμα τὴν δημιουργίαν νεφῶν Cirrus, CiCu τὰ ὁποῖα ἐνεφανίσθησαν κατὰ τὴν διάρκειαν τοῦ μεγίστου τῆς ἐκλείψεως, διελύθησαν δὲ πρὸ τοῦ τέλους ταύτης, ὡς ἄλλως τε παρετηρήθη ὑφ' ἡμῶν καὶ κατὰ τὴν ὁλικὴν ἔκλειψιν τοῦ ἡλίου ἐν Σουνίῳ κατὰ τὸν Ἰούνιον 1936.

Ἐκ τῶν καθ' ὕψος μετρήσεων τῆς συγκεντρώσεως τοῦ ὄζοντος, οὐδεμία σημαντικὴ μεταβολὴ παρετηρήθη ὑφ' ἡμῶν κατὰ τὴν διάρκειαν τῆς ἐκλείψεως, ἀποτέλεσμα τὸ ὁποῖον εὑρίσκεται ἐν συμφωνίᾳ μετὰ τῆς φωτοχημικῆς θεωρίας περὶ τοῦ ἐν τῇ στρατοσφαίρᾳ ὄζοντος, συμφώνως πρὸς τὴν ὁποίαν οἱαδήποτε μεταβολὴ τοῦ ἀερίου τούτου ὀφειλομένη εἰς σημαντικὴν ἐλάττωσιν τῆς ἡλιακῆς ἀκτινοβολίας (ἐν προκειμένῳ λόγῳ τῆς ἐκλείψεως) θὰ ἐλάμβανε χώραν εἰς ὕψη μεγαλύτερα τῶν 40 χιλιομέτρων, δηλαδὴ ἀρκετὰ ὑψηλότερα τῶν ἡμετέρων παρατηρήσεων.

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