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Winter Anomaly – Trace Constituents Sounding Rocket Campaign

Daytime Neutral Wind Measurements in the Mesosphere and Lower Thermosphere

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Abstract. During the Winter Anomaly project 3 neutral wind profiles were obtained in the upper mesosphere and lower thermosphere, using lithium trails released from Petrel rockets. These daytime profiles, one in the first salvo (Jan. 4, 1976) and two in the second salvo (Jan. 21, 1976), extended the altitude range of neutral wind coverage during the project from 90 to 135 km. The purpose of these measurements was to examine the dynamical behaviour of the higher regions of the atmosphere and ionosphere at time of occurrence of winter anomaly, overlapping, at the lower extreme of the technique, with data obtained from the chaff cloud technique.

The experimental technique of the daytime wind experiment is described in this paper, as are the preliminary wind results of the 3 B VI experiments. Initial assessment of the 3 wind profiles obtained shows that a strong northward shear occurred in the altitude range 90–150 km, with maximum northward winds of 80–120 m s^{-1} between 100 and 104 km on each occasion. We are examining the possibilities that these features are indicative of either gravity wave or large scale circulation disturbances of the E region (lower thermosphere) associated with the D region winter anomaly condition.

Key words: Daytime mesospheric/thermospheric winds – Lithium trails – Winter anomaly.

Introduction

One of the aspects of the comprehensive studies of the atmosphere and ionosphere conducted during the Winter Anomaly campaign at Arenosillo, Spain, during January and February 1976, was the measurement of the atmospheric dynamics in the mesosphere and lower thermosphere. These studies were carried out to assess the possible role of atmospheric dynamics in generating the circum-

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stances under which the anomalous atmospheric condition develops, or else to determine the nature of any dynamical or circulation disturbances which may occur as a result of alternative causes of the Winter Anomaly condition.

One example of the possible role of atmospheric dynamics would be the advection of air towards middle latitudes from a high latitude region where its composition might have been significantly modified (i.e. Nitric Oxide enhancement) by prolonged exposure to a region of enhanced auroral electron precipitation.

Alternatively, in a local mechanism of Winter Anomaly generation, an atmospheric disturbance inducing significant thermal or density fluctuations from a normal situation would be likely to generate, by pressure gradient and Coriolis forces, a local dynamical disturbance large enough to be identified as a significant departure from the normal pattern of atmospheric winds.

During the West German Winter Anomaly project, chaff releases (Skua-rockets) and parachute sondes (Loki-darts) provided a synoptic background of atmospheric dynamical behaviour in the stratosphere and mesosphere (up to 90 or 95 km) throughout the duration of the project. To determine the dynamical conditions above 90 km with more precision, and to extend the limit of monitoring of atmospheric dynamics into the lower thermosphere (up to 130–135 km), 3 additional wind measurements were made on the 'salvo' days, one on January 4, two on January 21. These measurements, by the 'daytime lithium trail' technique, will be used, in coordination both with lower altitude synoptic wind data, and with measurements of other atmospheric parameters such as the composition, temperature and density of both ionised and neutral species, to complete the picture of atmospheric dynamics at the time of day of the salvo launches (1600–1800 Local Time), and thus to determine the role of atmospheric dynamics in Winter Anomaly production, and the extent to which any associated atmospheric disturbance propagates upwards, above the D region, where it would not be observable by conventional ground-based techniques.

Experimental Technique

The rocket-borne technique for measuring neutral winds during daytime in the mesosphere and thermosphere is based on the observation of an alkali trail release, illuminated by sunlight, from the ground or aircraft, by means of either scanning photometers or cameras respectively (Best 1970, Bedinger 1970, Rees et al. 1972, Bedinger and Mills 1977) of high spectral and spatial resolution which discriminate the resonance emission of the alkali trail against the bright daytime sky.

Up to the present only about 15 to 20 such daytime wind profiles have been obtained by both techniques, due mainly to the high cost and complexity of the instrumentation required to observe the daytime releases compared with the simple camera systems which are adequate to observe twilight and night-time chemical releases. Lithium has generally been chosen as the alkali atom for daytime wind measurements. This is due to the large Doppler bandwidth of

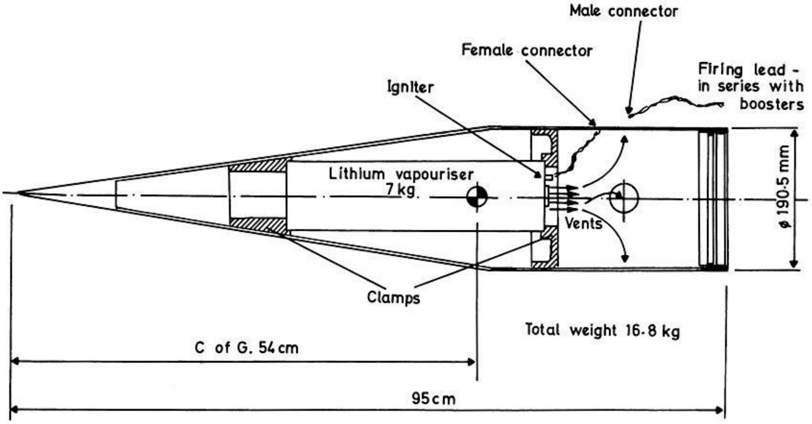

Fig. 1. Lithium vapouriser – Payload B VI (Petrel)

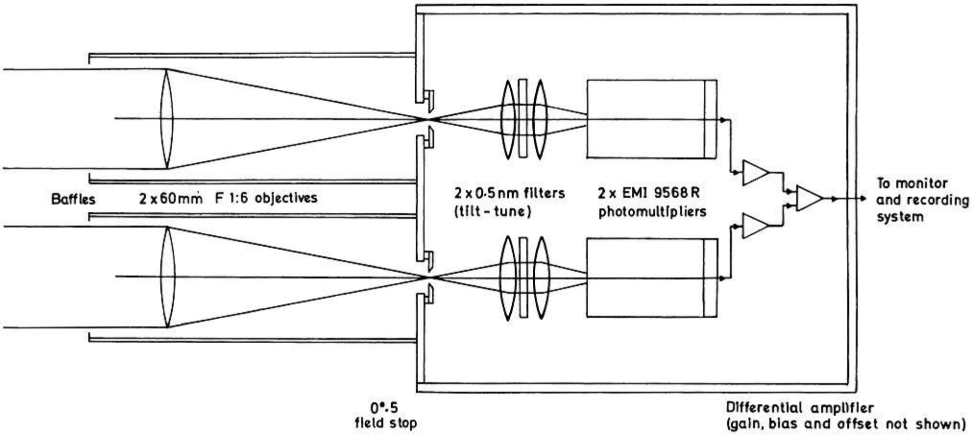

Fig. 2. Schematic diagram of dual channel differential photometer

the lithium atom (low atomic weight) and the high transitional probability of its resonance wavelength (670.8 nm) coupled with the relatively lower intensity of the daytime sky in the extreme red of the spectrum, and the absence of any significant solar or terrestrial Fraunhofer lines at the lithium wavelength which would reduce the available illumination. Other candidate alkalis, such as sodium or barium, compete at their resonance wavelengths with deep Fraunhofer lines and a greater sky brightness, although both are in fact adequately bright for observation under perfect conditions.

The lithium vapour trail is generated by a thermite burner (Fig. 1), mounted for these experiments under a fixed nose-cone on a Petrel rocket. The 7 kg thermite burner produces an optically thick trail over a period well in excess of 120 s. With a release altitude of 80–83 km as for these experiments, a bright trail is then produced over the complete upleg portions of the trajectory, and

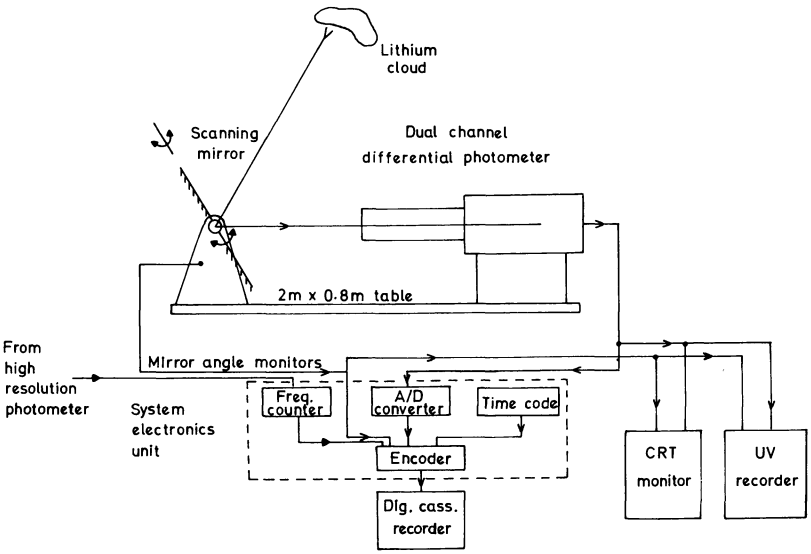

Fig. 3. Schematic diagram of electronics recording and monitoring system

continuing over apogee and downleg, to approximately 110 km altitude. In order to match as accurately as possible, the trajectories of other rockets in the Winter Anomaly project, the payload was ballasted by a heavy nose-cone structure to an all-up weight of 16.8 kg, producing apogees of the order of 130–135 km for the three B VI flights.

The design of the dual channel differential photometers used in the Winter Anomaly Campaign is shown in schematic form in Figure 2. Each channel of the optical system is carefully matched and co-aligned and the analogue outputs of the two photomultipliers are fed to a differential amplifier. One of the interference filters, of 0.3 nm bandwidth (F.W.H.H.) is tuned to the wavelength of the lithium resonance line (670.8 nm) and the second filter is tuned to about 0.5 nm on the short wavelength side of the lithium line (670.3 nm).

When the optical system is matched and the differential amplifiers are balanced to obtain a null when the instrument is looking at the clear daytime sky, observation of a sunlit lithium trail of optical thickness greater than about $\tau = 0.05$ will result in a discernible signal if the trail fills the instrument field of view ($\sim 0^\circ.5$ arc) defined by the co-aligned apertures of each channel. Alternatively, so also will a trail or cloud of dimensions less than the field of view but of proportionally greater optical thickness.

The instrument itself is rigidly mounted on a 2 m × 0.8 m table approximately 1 m high, which is aligned in the appropriate direction, with the instrument pointed horizontally, away from the expected viewing direction, looking into a 30 cm × 25 cm plane scanning mirror which performs a sequential raster scan of selected regions of the sky, approximately 40° × 40° arc in area. The two angles of the scanning mirror are continuously and synchronously scanned to provide one complete picture of the 40° × 40° area every 60 s. The azimuth scan takes two seconds, providing a resolution in elevation of about 1°.3. The resolution in 'azimuth' is limited by the aperture size (0°.5 arc) rather than by the data acquisition rate of 160 samples s^{-1} corresponding to 0°.125 arc.

A block diagram of the data processing and recording electronics is shown in Figure 3. The analogue differential output is converted to a digital signal and recorded in a 60 bit serial format along with time code and azimuth and elevation angle data on the data track of a digital cassette recorder at a rate of 160 samples s^{-1}.

Instrument Performance

The surface brightness of an optically thick lithium trail is of the order of 500 kR, compared with a mean day sky brightness near the zenith (solar elevation 30°) of the order of 10 mR integrated over the spectral transmission bandwidth of the interference filters.

A detailed discussion of instrument response is given in an accompanying paper (Rees, 1977), and only the operational response will be given here. At a fixed location in the sky, in the absence of any haze or cirrus clouds, the typical sky R.M.S. 'noise' is of the order of 20 mV with the system as used for these experiments, while the signal obtainable from the lithium cloud is about 2 Volts peak amplitude (field of view 0°.5, 1/160 s integration time).

In practice, however, there is always a difficulty caused by the greatly variable sky brightness (primarily a function of elevation and angle with respect to the sun's position). Particularly within 20° of the horizon and about 45° of the sun's position, total sky brightness variations of a factor of 2 to 5 may occur, and even greater variations may occur if any haze or thin, high level clouds are present. The limited common mode rejection of the system – primarily due to imperfect optical matching of the two channels, causes significant fluctuations of the 'background' level, generally in the form of a slow and systematic function of location within the raster system. These variations, which can clearly be seen in Figure 4, and are described in the next section, require limitation of the system gain to keep all the signals within the working range of the amplifiers and analogue to digital converter.

During hazy conditions or in the presence of thin, high level clouds, despite apparently blue skies, the system gain reduction required may be so severe that it would no longer be possible to distinguish clearly the anticipated signal levels due to lithium trails.

In practice, major constraints to the performance of the instrument, apart from the necessity for virtually cloudless skies and haze-free conditions, are set by the logistic problems of location of the photometers and their associated instrumentation. Good physical and telephone communications to the rocket range are essential for coordination of campaign preparations and count-downs. Particularly with relatively remote, coastal rocket ranges, it is usually impossible or impractical to locate the instrumentation in ideal physical sites. Ideally, the optical sites should be located approximately 50–100 km to each side of the range centre line, and approximately 50 km down-range for upleg releases (or 100 km down-range for downleg releases).

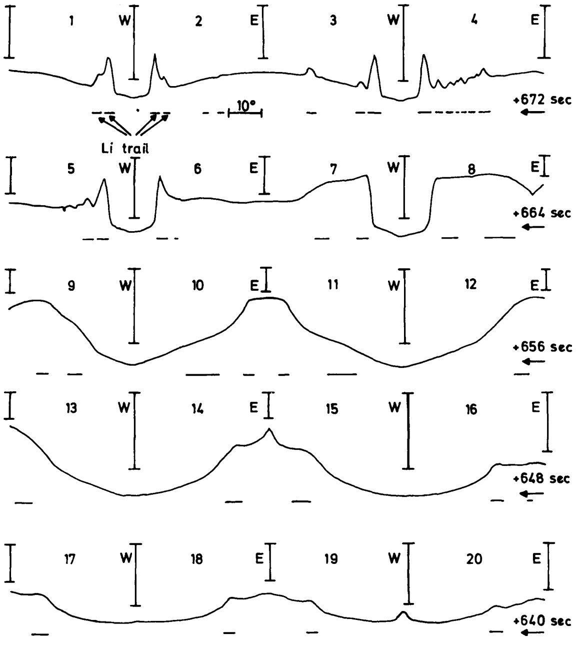

Fig. 4. Raster scan of Lithium trail at 640–680 s after launch

For the El Arenosillo experiments, the San Fernando Observatory, near Cadiz, was physically a very good location, although a little remote (three hours by road via Seville). It also suffered highly changeable local weather conditions due to its proximity to the Straits of Gibraltar and the Mediterranean. Ideally, the second site should have been to the west and south of El Arenosillo, 50 km south of the Portuguese coastline. Other considerations, however, dictated that the instrumentation should be close to El Arenosillo, and a hotel rooftop in Mazagon was eventually chosen, about 10 km NW by W of the range. The major difficulty raised by using a site so close to the rocket range is that the lithium trail on the upleg of the trajectory is released virtually along a line of sight between 80 and 120 km. It is thus often impossible to resolve the tight convolutions of the trail caused by the small scale wind variations in this height region during the first few minutes after trail release, due to overlapping of portions of the trail at different altitudes.

For this particular project, winds in the 80–110 km region were clearly of very great interest. This altitude region is at the lower limit of the lithium trail technique due to two factors. First, at altitudes below about 90 km the lithium metal (as with other metal alkali releases such as sodium, aluminium and barium) is rapidly changed into a stable chemical compound from which the atoms can no longer emit the resonance line. Below 80–83 km, no resonance emission is observed even immediately following the release. Secondly, the diameter of the trail at lower altitudes is quite narrow at release and (subject to molecular and eddy diffusion) grows rather slowly with time. Typical figures are shown in Table 1. At the time of release the apparent angular diameter

Table 1. Trail diameters due to molecular and turbulent diffusion

Altitude (km)	80	85	90	95	100	105	110
'Initial' radius (m)	20	30	50	80	100	150	200
Molecular diffusion coefficient ($m^2 s^{-1}$)	2	5	12	30	80	150	400
Radius after:							
10 s	22	35	52	85	120	170	230
100 s	35	55	85	140	200	270	440
1000 s	65	105	170	250	420	560	920
Angular diam. (mrad) after:							
10 s	0.03	0.04	0.06	0.10	0.12	0.16	0.22
100 s	0.04	0.06	0.10	0.16	0.22	0.30	0.44
1000 s	0.08	0.12	0.22	0.30	0.44	0.58	0.88
With maximum turbulence ($m^2 s^{-1}$)		100		200		500	
Angular diam. (mrad) after:							
10 s		0.12		0.24		0.60	
100 s		0.22		0.44		1.00	
1000 s		0.44		0.88		2.20	
Depletion time	~5	~50	~200	$\gtrsim 10$		?	
constant exponent		(s)		(min)		(~h)	

of the trail is considerably smaller than the 0°.5 field of view set by the aperture stop of the instrument, reducing the signal level considerably. Although this angular diameter grows with time, the lower altitudes suffer severe depletion of the lithium content and, below about 85 km, the trail is probably always unobservable in daytime with the standard differential photometers.

A special photometer of novel design was built and used in the Winter Anomaly project to try to overcome the difficulties with wind measurements in the 80–100 km region. Its design and some experimental results are described in an accompanying paper (Rees, 1977).

Calibration

To obtain a successful triangulation of trail and cloud features with a standard deviation of the order of 300–500 m, the scanned field of view of the photometer at both observation sites must be known to within about ±0°.1 or 0°.2. It is generally impractical to set up the instruments this precisely and, following installation to a precision of ±1° or 2°, the angular residuals are calibrated by means of transits of the sun, moon or bright stars across the scanned field of view of the photometers. For the El Arenosillo experiment, the moon was most useful, covering, particularly at Mazagon, virtually the entire field of view over a period of a few days near first quarter. For these experiments the angular residuals were of the order of 0°.15 at Mazagon and 0°.25 at San Fernando, where the moon only entered the edge of the field of view.

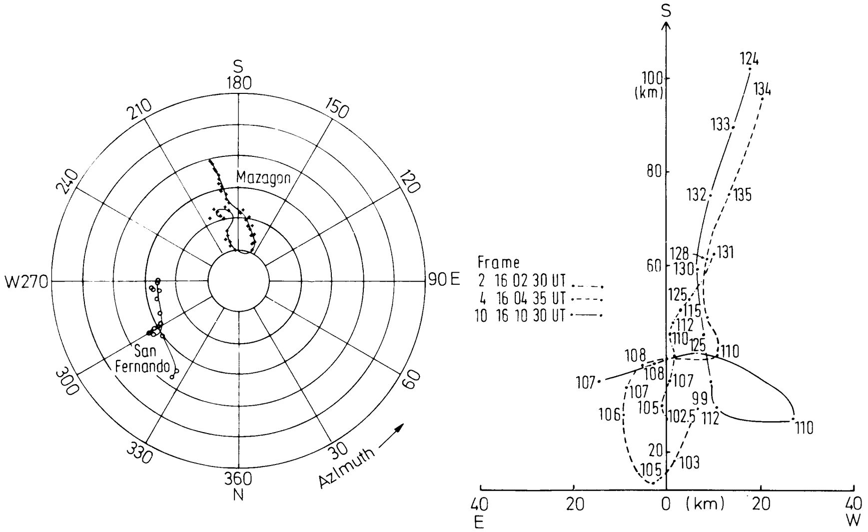

Fig. 5. (**a**) Raster scans at 160435 from Mazagon and San Fernando (275 s). (**b**) Ground track of B VI/1 launch, Jan 4, 1976, 1600 UT

Normally, a further improvement in precision can be made using the radar tracking of the rocket to provide precise initial angular coordinates of the trail release position. Thus far, however, it has not been possible to obtain a fully consistent match of optical and radar data on any of the B VI experiments (R.M.S. discrepancies between radar and optical trajectories are about 5 to 10 km).

Experimental Results

The launch conditions of the three B VI lithium wind experiments of the Winter Anomaly project are shown in Table 2. All three rockets and their payloads performed perfectly and each was successfully observed over the full altitude range from 85 km to apogee (130–135 km) from the observation sites at Mazagon (37° 08′N, 6° 49′W) and the San Fernando Observatory (36° 28′N, 6° 44′W). Selections of raw experimental results from B VI/1 are shown in Figure 4, for various altitudes and times from release. The variation of the background level with location within the raster is due to the imperfect optical matching and limited common mode rejection of the photometer/electronics system (the

Table 2. Launch conditions for B VI payloads

Launch	Date	Local time	Solar elevation
B VI/1	4 Jan. 1976	1700	15°
B VI/2	21 Jan. 1976	1655	15°
B VI/3	21 Jan. 1976	1913	−6°

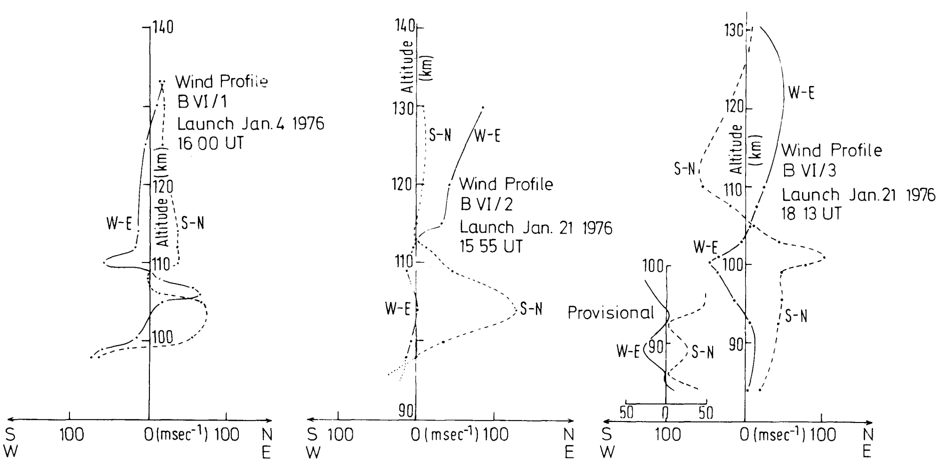

Fig. 6. Wind profiles of B VI/1, B VI/2 and B VI/3

effective common mode rejection being of the order of 60 dB for the transmission bandwidths of the interface filters, or 120 dB in 'white light').

The processed results are reconstituted by computer to obtain complete raster 'pictures' of the trails from both observation sites, as shown in Figure 5a, at a time of 275 s after launch of B VI/1. A 'manual' triangulation of these data sets is then carried out, using a Texas Instruments SR 52/PC 100 calculator/printer. This rough analysis removes spurious data points and checks the general validity of the experimental data and angular calibration of the photometers, and provides an approximate trajectory ($\pm$1–2 km), and a crude wind profile ($\pm$10 m s^{-1}, $\pm$1–2 km altitude).

A sophisticated computer analysis then utilizes this 'first-order' hand analysis as initial data and iteratively attempts to make a best fit of all the experimental data from both sites, and a radar trajectory (if available) of the initial trail location. Normally this iterative analysis will reduce the wind errors to less than 5 m s^{-1} and the height assignations to $\pm$500 m s^{-1} or better.

The first order wind analysis for each of the rocket flights is obtained from the ground tracks of the lithium trails which are shown in Figure 5b. The resulting wind profiles are shown in Figure 6.

Discussion

It is not the intention of this paper to examine in detail the aeronomic implications of the wind results described in the last section, or to compare the data from the lithium trails with that of any other wind measuring technique used in the project, or with data on other aeronomic parameters.

Despite considerable apprehension during project planning that it would prove extremely difficult, if not impossible, to obtain interesting scientific conditions for the project (i.e. presence of severe winter anomaly) while also obtaining favourable weather conditions at Mazagon and San Fernando for the lithium experiment, in practice no such difficulties occurred although, clearly, the ease of obtaining simultaneously all the correct launch conditions was fortuitous. Complete wind profiles have been obtained above 95 km for the two 'daytime' trails and above 85 km for the twilight trail. It will prove possible to extend the 'daytime' profiles down to 85 km if a good radar trajectory can eventually be obtained, thus providing an accurate location of the initial trail release so that the first few minutes of data obtained on the trails below 95 km altitude can be utilized.

Each of the wind profiles showed a strong northward feature in the altitude range 90–105 km, and an indication of complex small-scale wind structure below about 95 km, shown in detail for B VI/3 in Figure 6. We are presently examining the possibilities that some of these features are correlated with the widespread atmospheric disturbance associated with the winter anomaly conditions present during the period of the rocket experiments.

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