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Fast O^+ Ion Flow Observed Around Venus At Low Altitudes

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1. Introduction

The Pioneer Venus Orbiter Neutral Mass Spectrometer (ONMS) has observed fast O^+ ions with an energy exceeding 40 eV in the spacecraft reference frame (Kasprzak et al., 1982; Kasprzak et al., 1987). From the spin modulated data the direction of the ion flow in the ecliptic plane can be determined as well as the approximate flux of ions near an energy of 45 eV.

Data obtained for the first 11 diurnal cycles (orbits 1 to 2475) have been vector averaged in solar zenith angle, latitude and altitude in order to display the general flow pattern in the ecliptic plane. The purpose of this document is to present the results of this procedure in a graphical format.

2. Data

2.1 Background

The Pioneer Venus Project, its aims and early scientific results have been described in a special issue of the Journal of Geophysical Research (1980). The instruments and spacecraft have been described in a special issue of the IEEE Transactions on Geoscience and Remote Sensing (1980). A more complete survey of results is contained in the book VENUS (Hunten et al., 1983).

The ONMS instrument is a quadrupole mass spectrometer designed primarily to determine the neutral gas composition in the thermosphere of Venus (Niemann et al., 1980). A schematic cross section of the instrument is shown in Figure 1. An electron beam, created by a hot filament, ionizes the gas coming through the entrance aperture. The ions exiting the ion source enter a quadrupole mass analyzer where specific mass-to-charge ratios are selected and subsequently detected by a secondary electron multiplier operating mainly in pulse counting mode. In the ion source, an ion repeller grid is placed between the electron beam and the entrance to the ambient atmosphere in order to reject ions with an energy of 40 eV or less relative to the spacecraft ground potential.

At high altitudes, well beyond the region where the sensible neutral atmosphere could be measured, it was discovered that instrument output signals

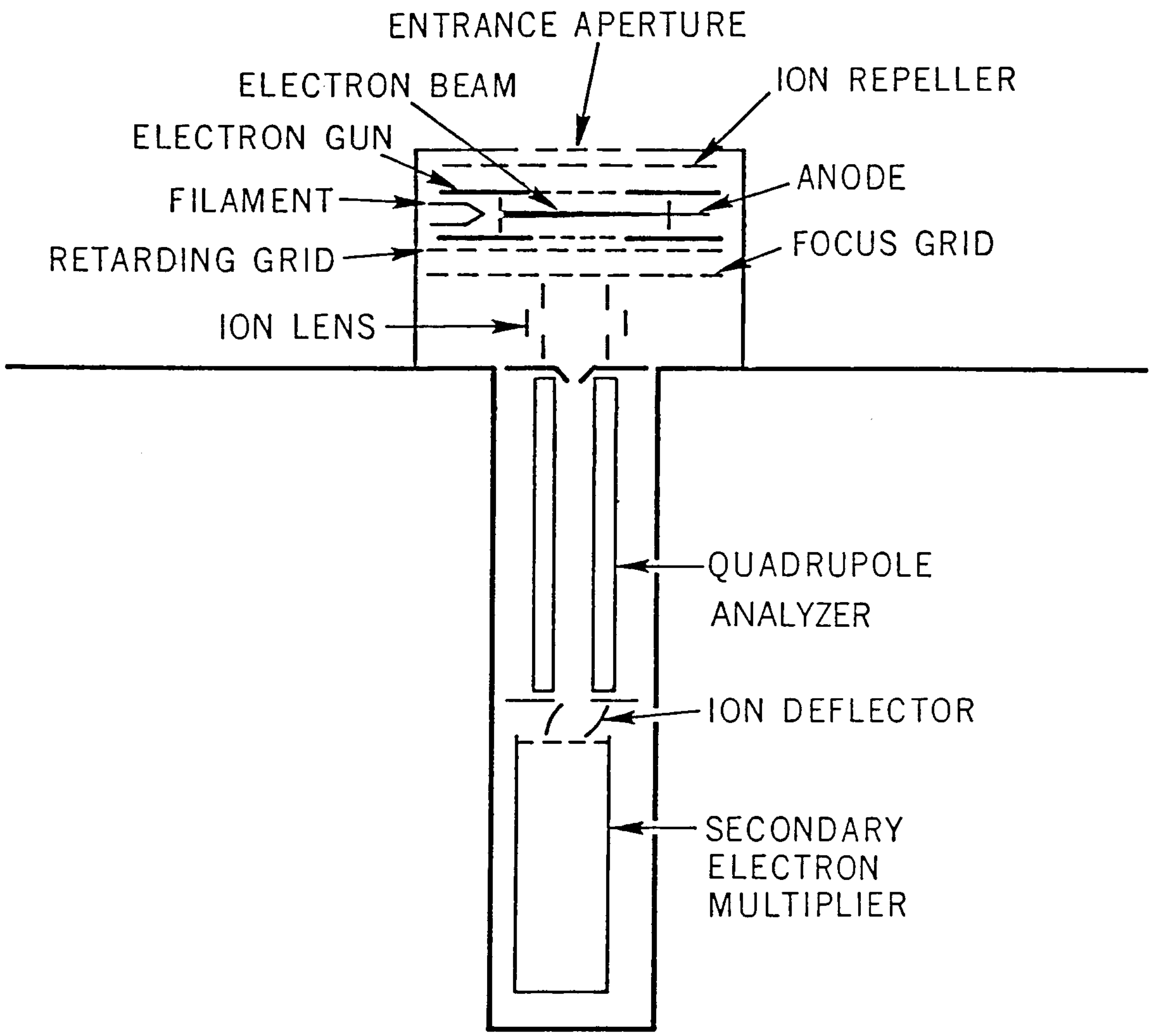

Figure 1. Schematic cross section of the Pioneer Venus Orbiter Neutral Mass Spectrometer (ONMS).

as large as those generated by the neutral atmosphere were being detected (Kasprzak et al., 1982). The source of the signals were ions whose energy was sufficient to overcome the 40 V potential placed on the ion repeller grid. Early measurements of these ions were made during the normal neutral density passes when the filament was in operation and there was a high background signal. As the orbiter periapsis altitude rose (Brace and Colin, 1984) and neutral density measurements could no longer be made, the filament was turned off in order to increase the measurement sensitivity (Kasprzak et al., 1987).

The composition of the energetic (greater than 40 eV) ions is mostly O^+ but He^+, C^+, N^+, $(CO+N_2)^+$, NO^+, O_2^+, and CO_2^+ are also observed (Kasprzak et al., 1987). Hydrogen cannot be resolved by the instrument. CO_2^+ is usually not observed because it is below the instrument's measurement threshold. The energetic ions occur at all solar zenith angles measurable from the orbit and at a variety of altitudes. The energetic ions are associated with the erratic plasma structures seen in the thermal and superthermal ions measured by the ion mass spectrometer (OIMS) and in the electron density measured by the Langmuir probe (OETP). In the dayside sector they frequently occur near the ionopause suggesting that the ions are accelerated from ionospheric plasma by the shocked solar wind through plasma wave interactions (Kasprzak et al., 1982).

The dynamic processes that transport the thermal ionosphere to the nightside can also transport the energetic ions. In addition, local nightside acceleration processes in the ion tail region are possible (Brace et al., 1987). Near 2000 km altitude in the ion tail, the energetic O^+ density observed by the ONMS is probably less than 1% of the total plasma density measured by the Langmuir probe (OETP). The relative variation of the energetic O^+ observed by the ONMS is similar to that of the superthermal oxygen ions measured by the ion mass spectrometer (OIMS) which constitute the bulk of the O^+ density at an energy near 13 eV. The implication is that the ONMS is measuring the high-energy tail of a distribution whose bulk is below 40 eV. Because of their energy these ions also have a potential for planetary escape and therefore ultimately represent a possible loss process for the neutral atmosphere.

2.2 Spin modulation and direction determination

The spacecraft orbit is approximately polar (inclination 105.6°) with periapsis near the equator. The ONMS instrument is mounted at an angle (26.5°) to the spin axis of the spacecraft which, in turn, is perpendicular to the ecliptic plane. As a result of this orientation the data accumulated by the ONMS for energetic ions is spin modulated. Data for O^+ are shown in Figure 2 where the "plusses" are the spin modulated count rate data from the ONMS instrument and the "dots" are a theoretical response curve fitted to the data (Kasprzak et al., 1987) for orbit 1878. Two different time periods are shown in Figure 2a and 2b. The vertical tick marks indicate closest approach to the sun. The ion flux (which is nearly proportional to the count rate) peaks in the solar direction in Figure 2b and, since this is a nightside orbit (periapsis is at 23 hours 48 minutes local solar time), it indicates that the corresponding ion flow is in the antisunward direction for this time period. Since the energy needed by O^+ to overcome the 40 V ion repeller potential far exceeds that due to the spacecraft motion (less than 10 km/s), the direction of the signal maximum in the ecliptic plane is very nearly that of the ion flow itself projected into that plane.

Figure 3 shows a schematic view of the geometry for the direction measurement. The spacecraft axis, Z_s, is nearly perpendicular to the ecliptic plane pointing toward the south ecliptic pole. The ONMS instrument is mounted in the spacecraft at an angle θ_n and the spacecraft rotates about the Z_s axis with a spin period of about 12 seconds. The total relative ion velocity, u, in the nonrotating spacecraft reference frame makes an angle θ_{onm} with respect to the sun in the ecliptic plane. The ONMS signal is a maximum when the angle between ONMS and u is a minimum (i.e., at minimum angle of attack). The azimuth direction of the actual ion flow in the ecliptic plane is 180° away from the measured location of the signal maximum. The component of u perpendicular to the ecliptic plane cannot be determined.

The evolution of the Pioneer Venus orbit has been discussed by Brace and Colin (1984). Figure 4 shows typical orbits with a midnight periapsis viewed from the terminator and projected into the north-south plane. After orbit 600, when the periapsis altitude was no longer maintained in a specific altitude range, solar gravitational perturbations caused the periapsis altitude to

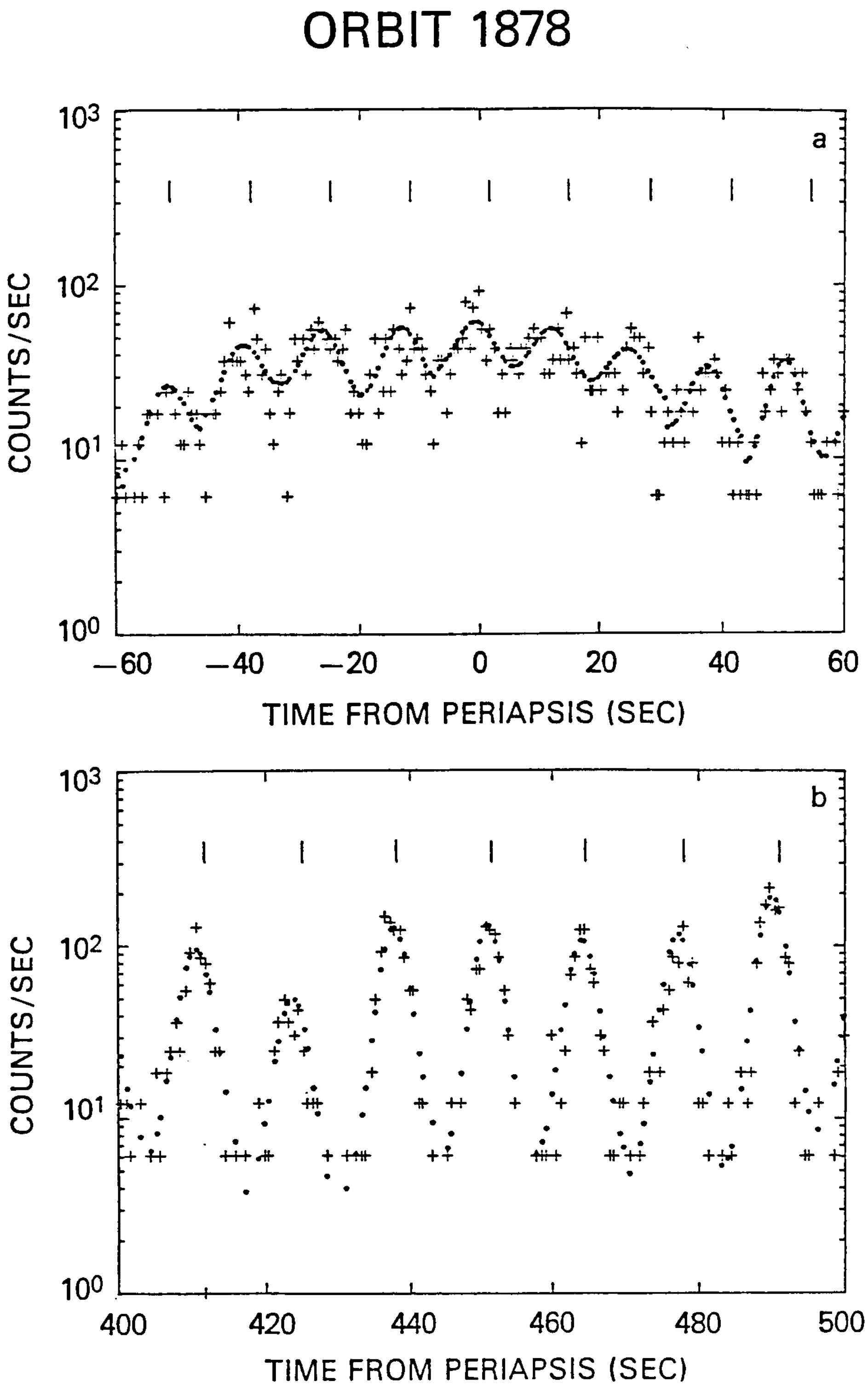

Figure 2. Example of the spin modulated energetic ion O^+ data from orbit 1878 for two periods of time.

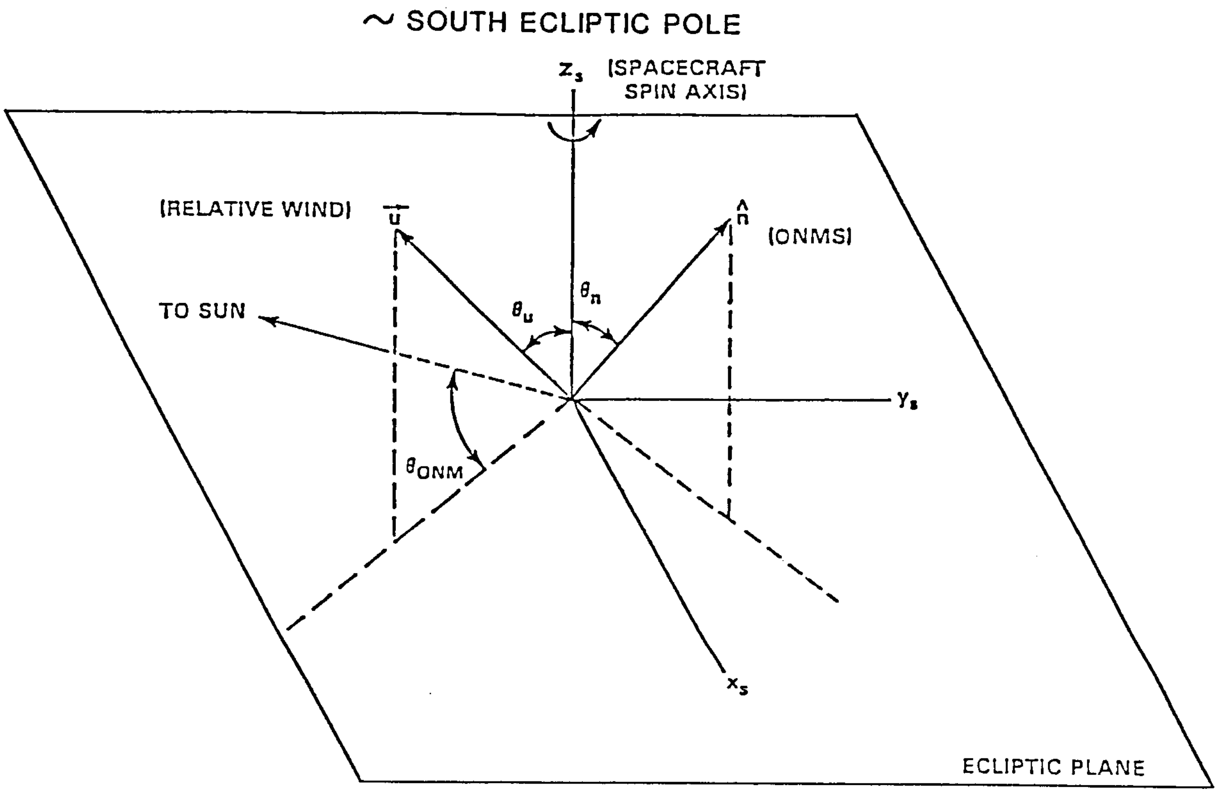

Figure 3. The geometry of the direction measurement.

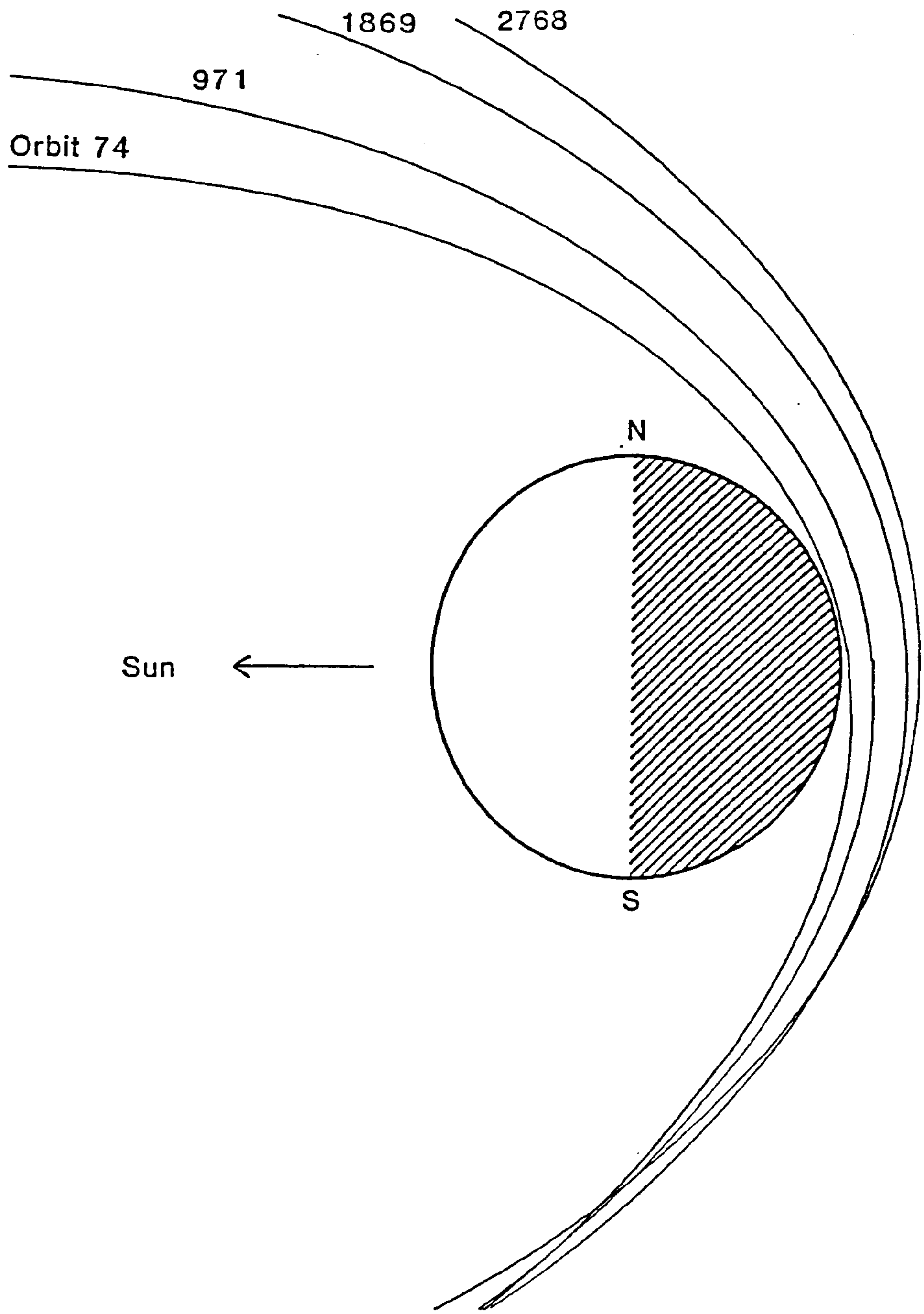

Figure 4. Midnight orbit tracks projected into the north-south plane and viewed from the terminator.

increase and the latitude of periapsis to move from 16 degrees north to the equator. The orbit period is 24 hours and it requires 225 orbits to complete one diurnal cycle of 24 hours in local solar time.

3. Direction plots of energetic atomic oxygen

3.1 Individual measurements

The direction of the fast O^+ can only be measured in the plane perpendicular to the spacecraft spin axis (approximately the ecliptic plane). Although species other than O^+ could be used, only O^+ occurs frequently enough above the measurement threshold to be of value in a global survey. The data for the polar orbit covers a wide range of latitudes and solar zenith angles. The principal planetary location variables are altitude, celestial latitude, solar zenith angle and local solar time. The determined quantities are the estimated flux at 45 eV and the direction component in the ecliptic plane measured with respect to the direction of the sun. The location of a data point (e.g., Figure 5) can be displayed on a polar plot using the solar zenith angle as the angular variable and distance from the planet as the radial variable. In order to distinguish between the dawn and dusk hemispheres the solar zenith angle is further subdivided according to local solar time with noon to evening to midnight being one hemisphere and noon to morning to midnight being the other hemisphere. An additional division according to latitude range is done to complete the location description.

Figure 5 illustrates two detailed orbits plotted in the coordinate system described. Orbit 979 is in the left morning hemisphere and orbit 951 is plotted in the right evening hemisphere. The direction data for the inferred ion flow in the ecliptic plane are determined once per spin period, if there is sufficient signal amplitude. The vectors are plotted relative to the sun (the orange circle at the top of the diagram) at a planetary position specified by the altitude and solar zenith angle of the data. Noon is at the top, midnight at the bottom, morning on the left and evening on the right. The data are further coded according to the latitude band in which they occur (-75° to -45°, -45° to -15°, -15° to 15°, 15° to 45° and 45° to 75°). The data for this orbit occur within the ionosphere and the extreme latitude points at low altitude correspond to the ionopause. At low altitudes, near

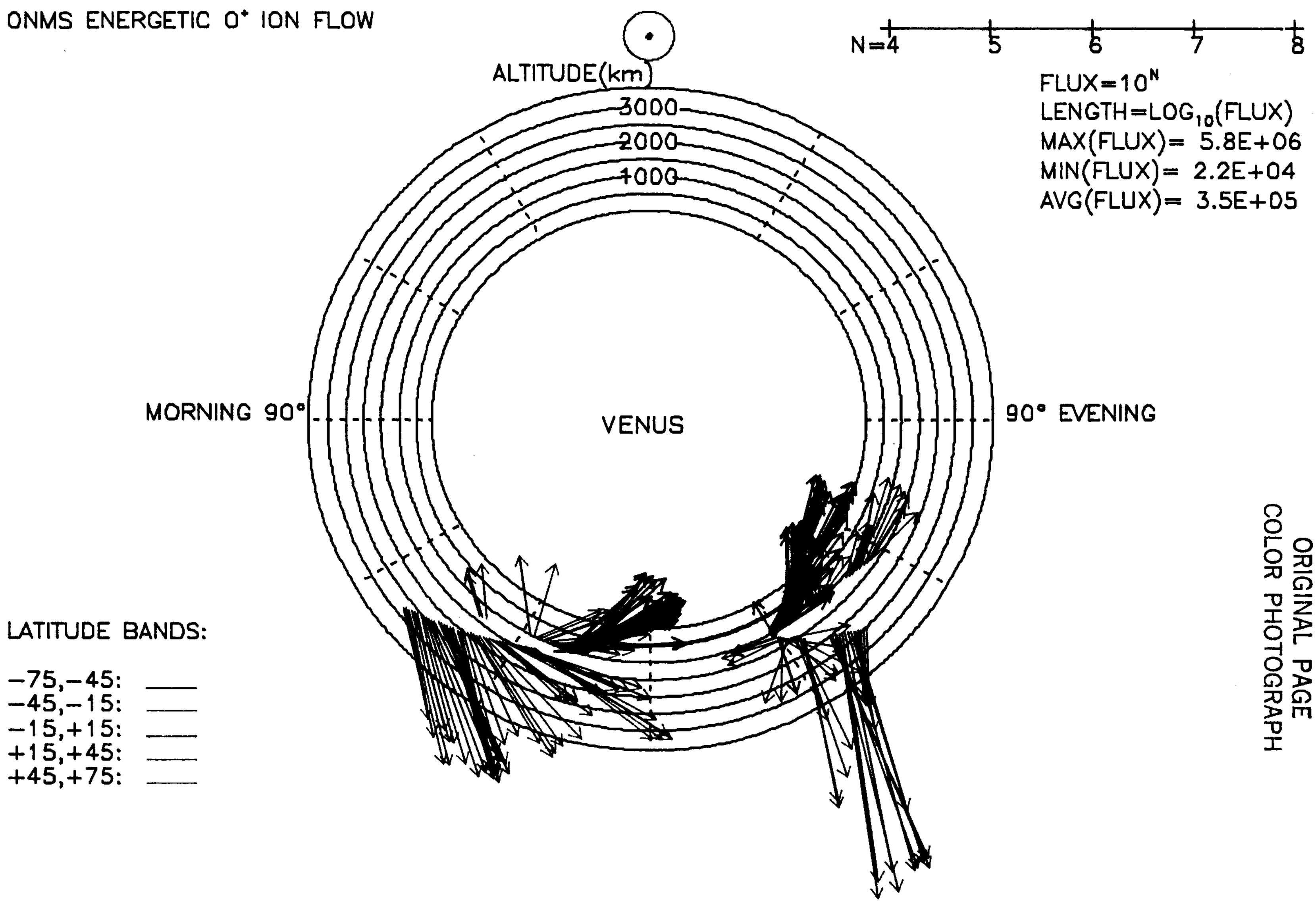

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Figure 5. Detailed direction data from orbit 951 (right) and 979 (left).

the equator, flow directions point generally from morning to evening. At higher altitudes and larger southern latitudes the directions rotate to an almost antisunward direction.

3.2 Average directions

The general features of the flow pattern can be examined by sorting the direction data into solar zenith angle (SZA), altitude (ALT), and latitude (LAT) bins and vector averaging to create one data point per bin. The bin size is 15° for solar zenith angle, 250 km for altitude and 30° for latitude. For convenience, the data have been segregated according to the diurnal cycle in which they occur and cover 225 orbits or 225 days. Figures 6a to 6i show the data for cycles 1 to 11. No data is available for cycle 4 and cycles 10 and 11 have been combined for better statistics. The long dashed lines on the plots indicate the limits placed on the altitude and solar zenith angle coverage due to the nature of the orbit, the inner line for latitudes north of the periapsis latitude and the outer one for latitudes south of the periapsis latitude. The amount of data acquired by the ONMS is limited during later cycles to the nightside ion tail region (Kasprzak et al., 1987). Energetic ions are not observed on the dayside once the periapsis altitude is well above the ionopause nor do they seem to be observed at bow shock crossings. Other limitations in data acquisition are due to spacecraft operations and instrument acquisition periods of 2 or 3 times per week.

Figures 7a to 7c are plots for combined diurnal cycles 1 to 3, 5 to 11 and 1 to 11 respectively.

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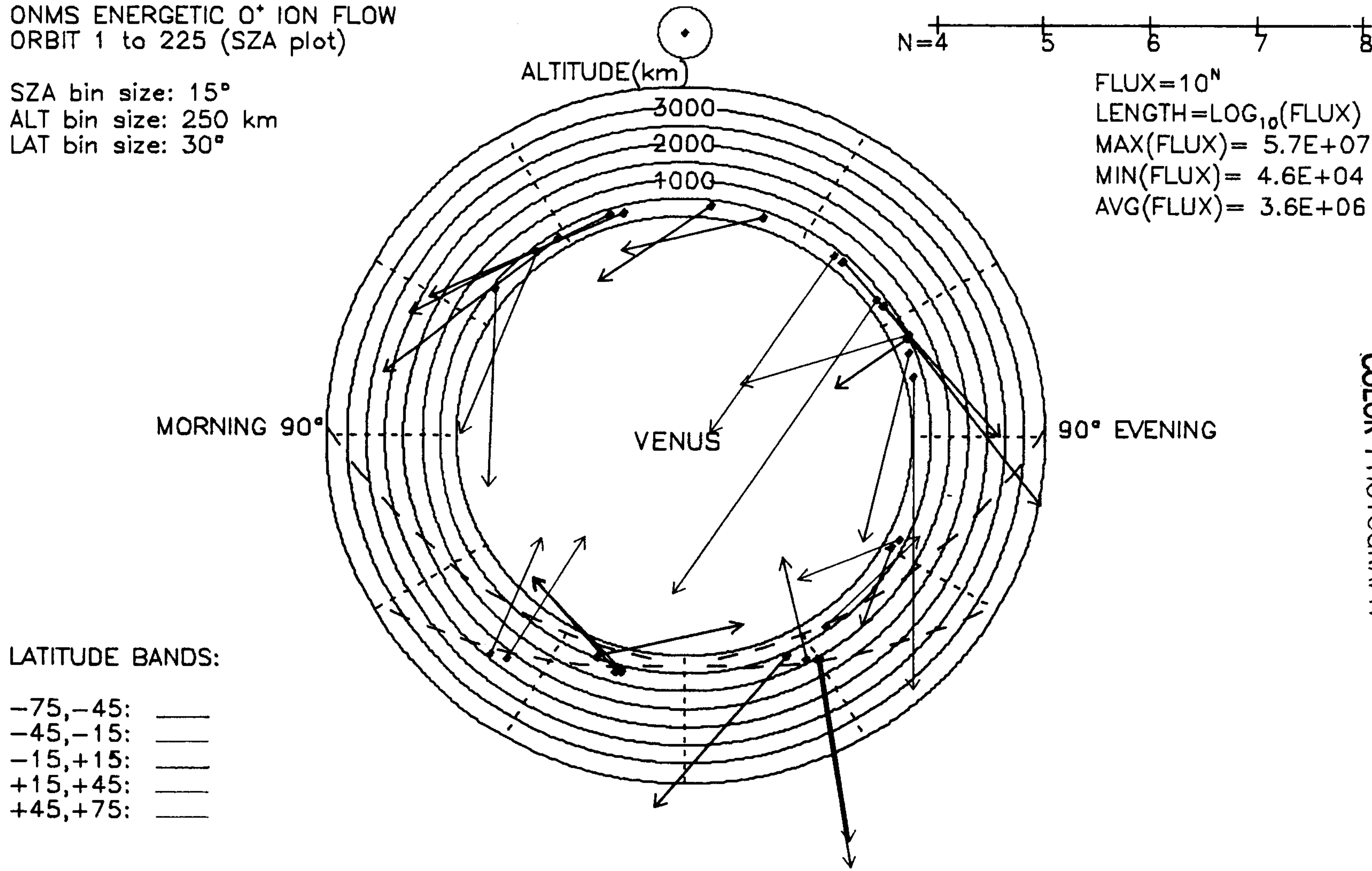

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Figure 6a. Average direction data for diurnal cycle 1, orbits 1-225.

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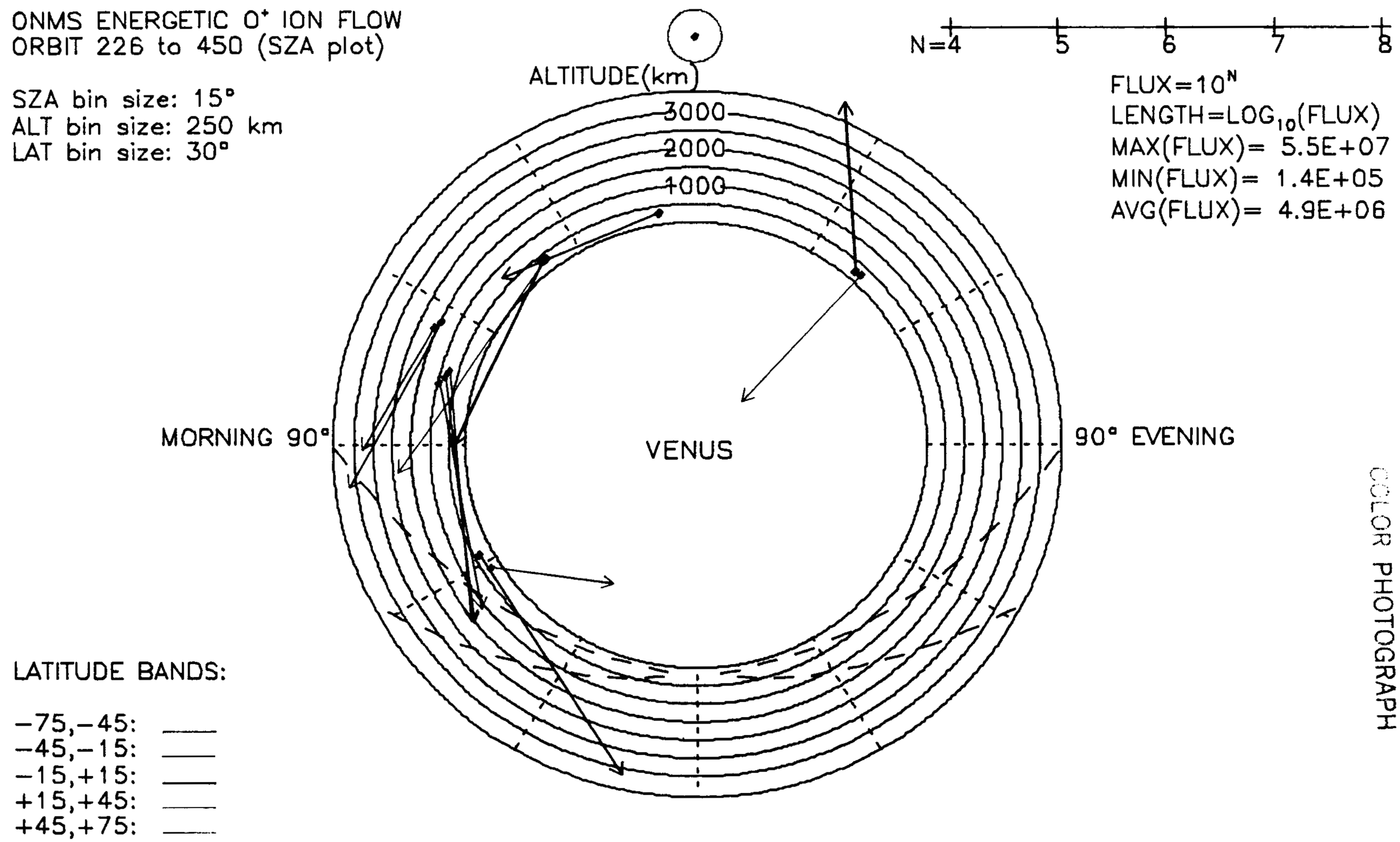

Figure 6b. Average direction data for diurnal cycle 2, orbits 226-450.

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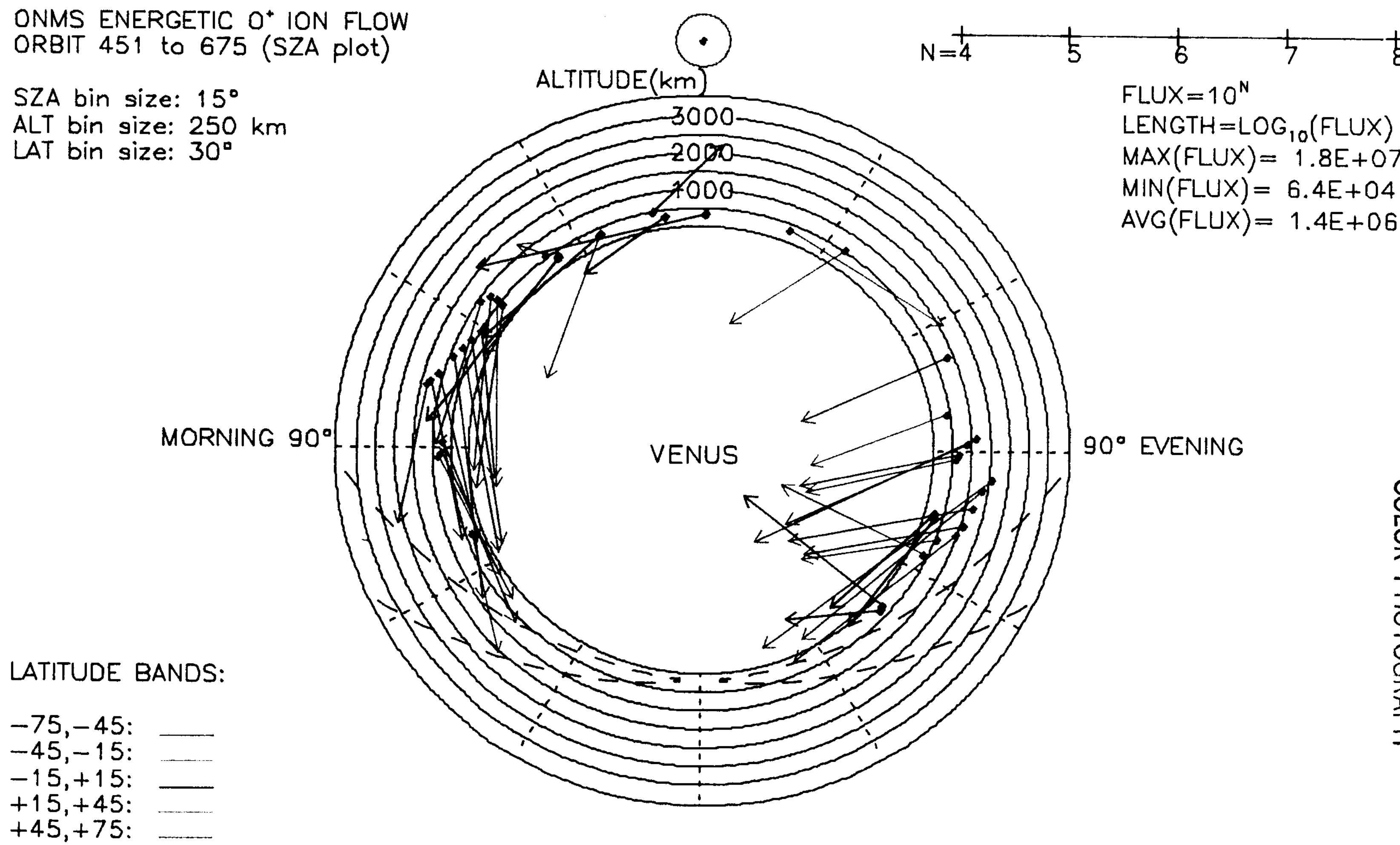

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Figure 6c. Average direction data for diurnal cycle 3, orbits 451-675.

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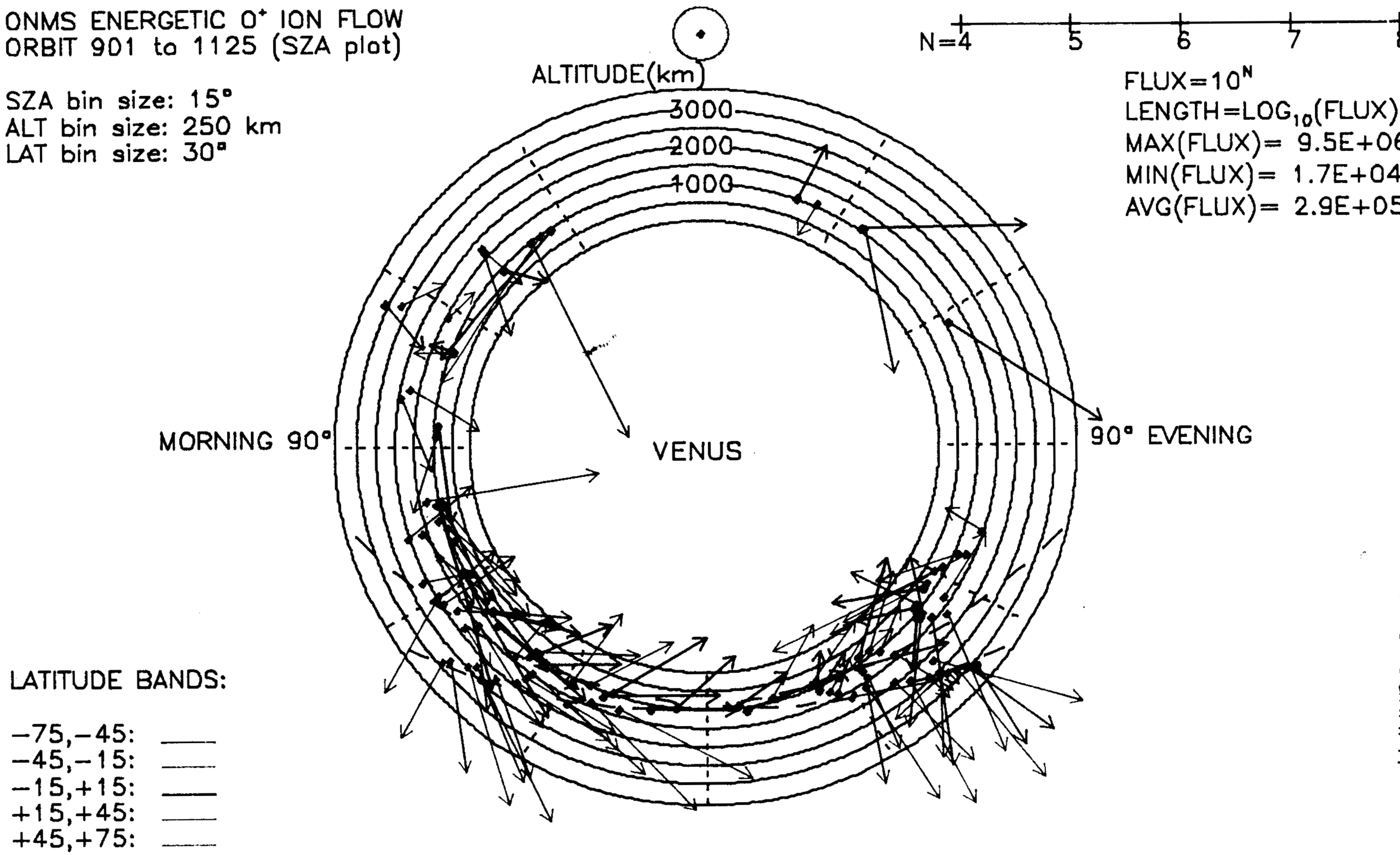

Figure 6d. Average direction data for diurnal cycle 5, orbits 901-1125.

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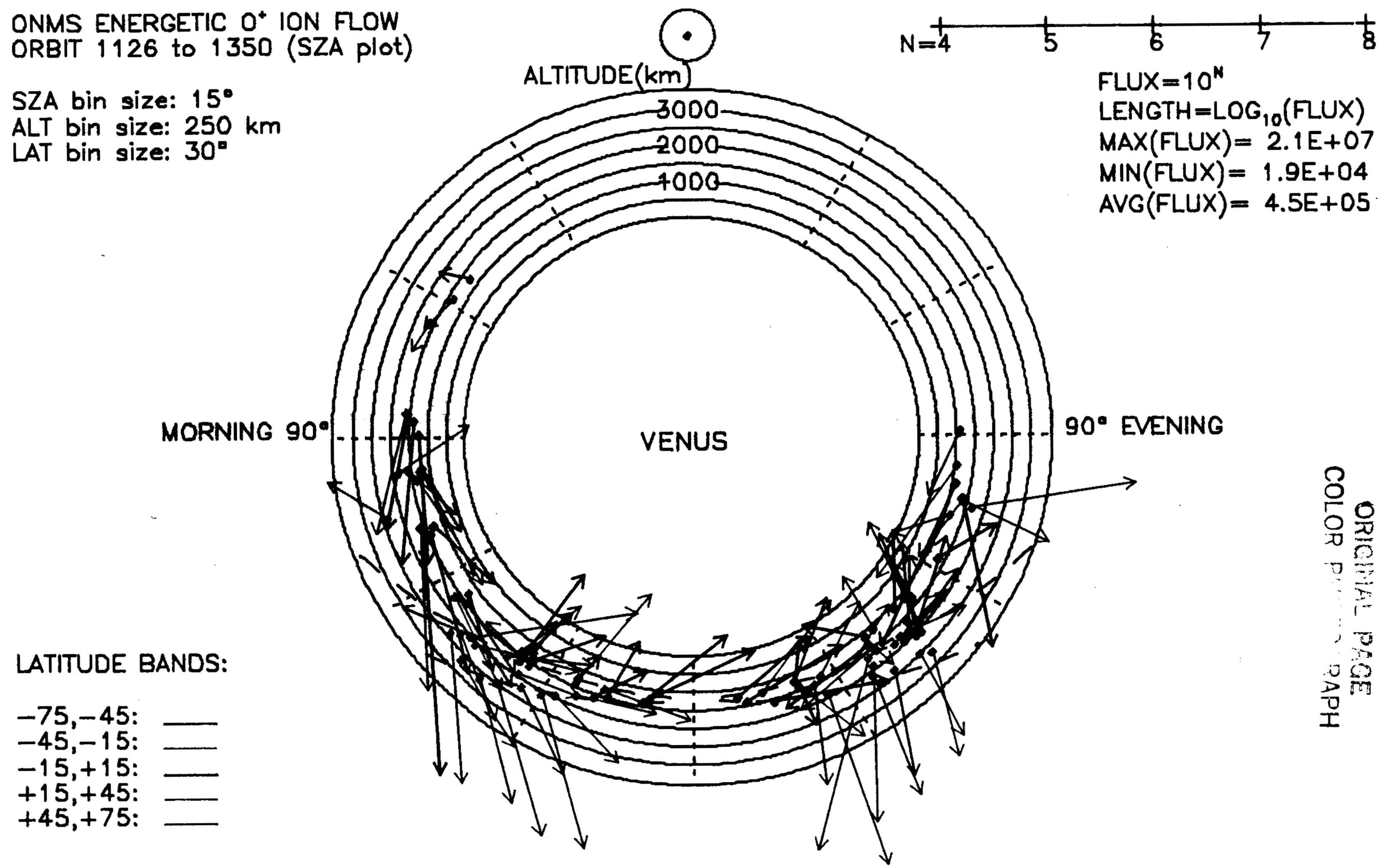

Figure 6e. Average direction data for diurnal cycle 6, orbits 1126-1350.

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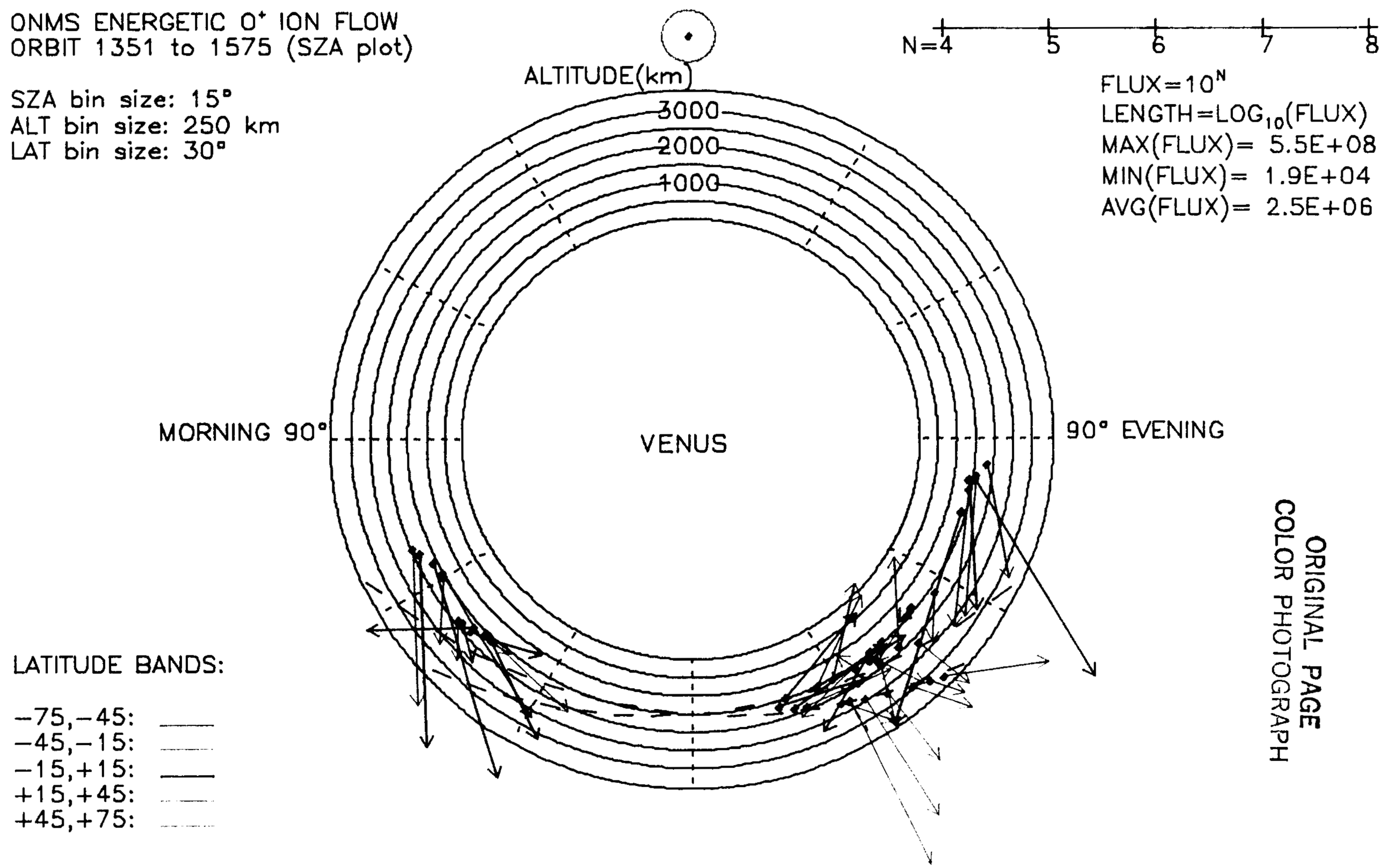

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Figure 6f. Average direction data for diurnal cycle 7, orbits 1351-1575.

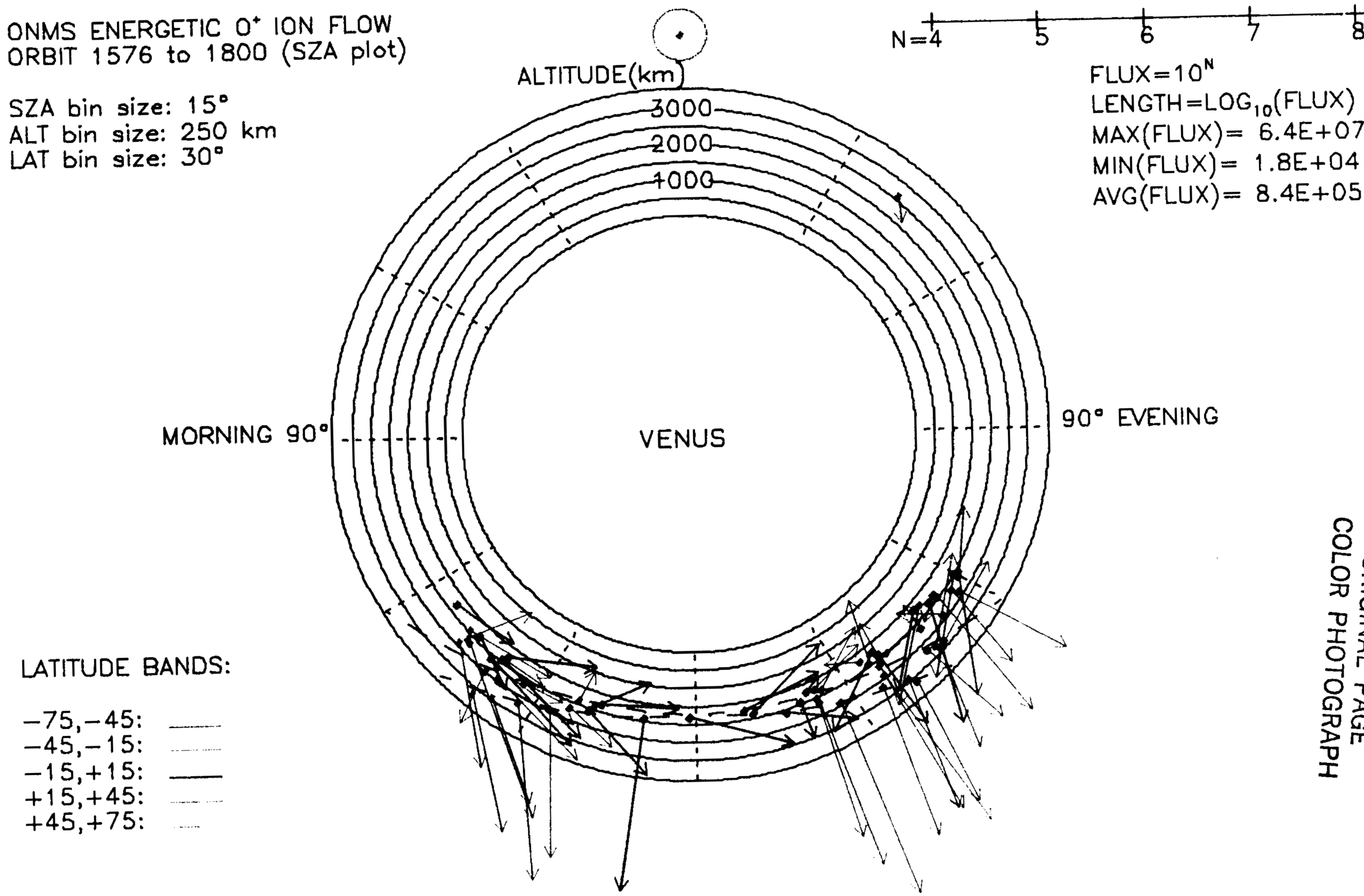

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Figure 6g. Average direction data for diurnal cycle 8, orbits 1576-1800.

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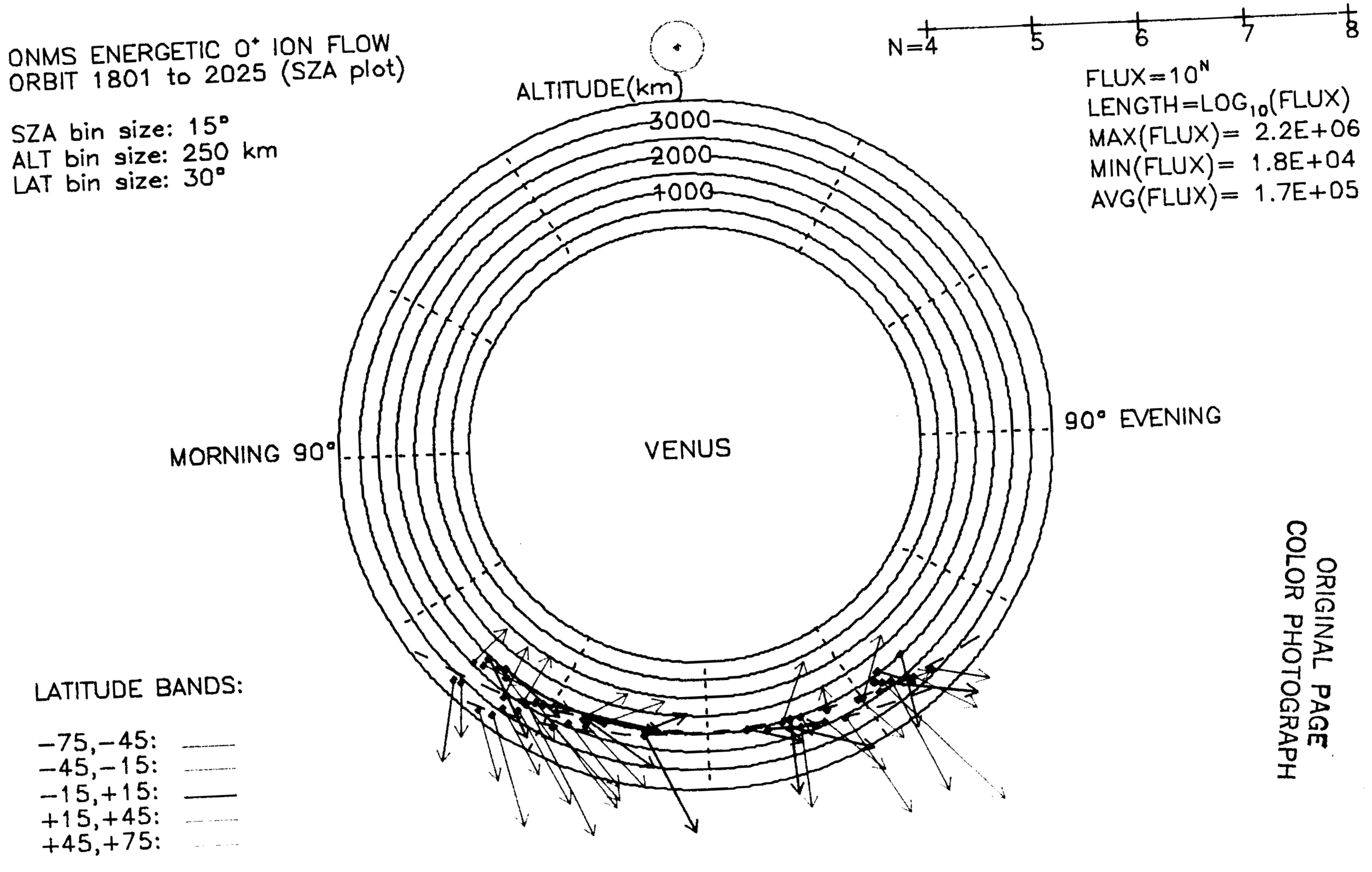

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Figure 6h. Average direction data for diurnal cycle 9, orbits 1801-2025.

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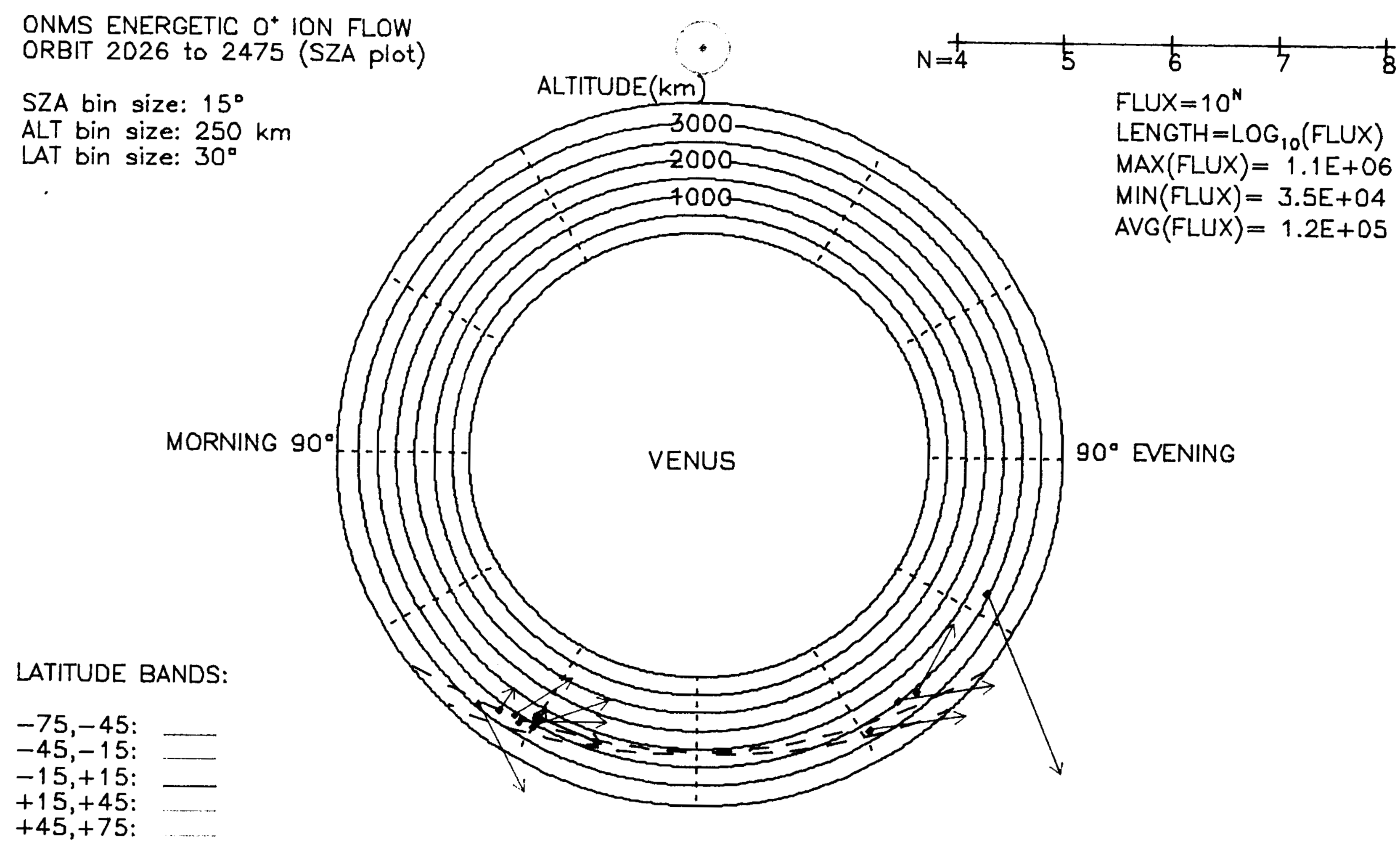

Figure 6i. Average direction data for diurnal cycles 10-11, orbits 2026-2475.

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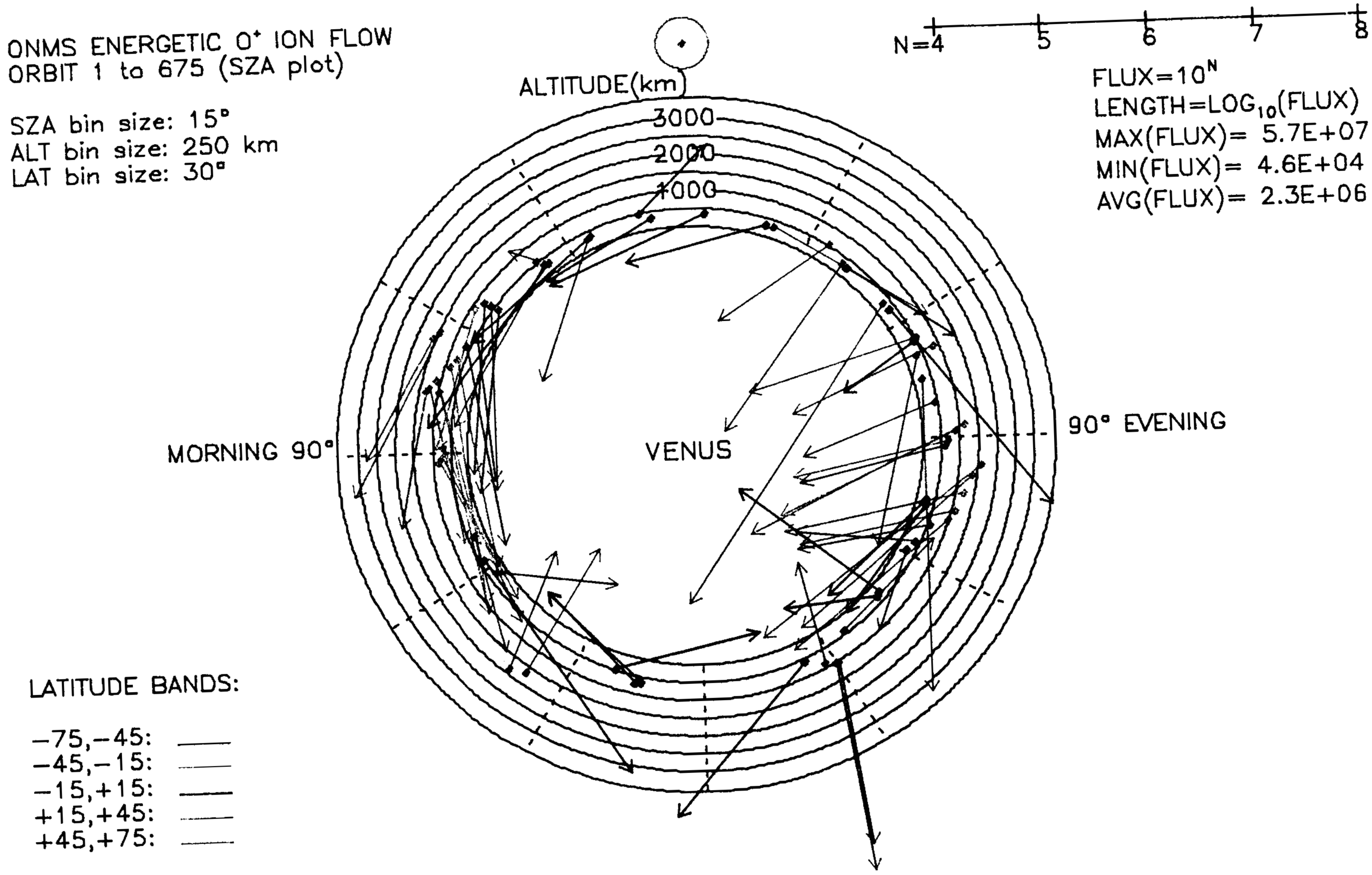

Figure 7a. Average direction data for diurnal cycles 1-3, orbits 1-675.

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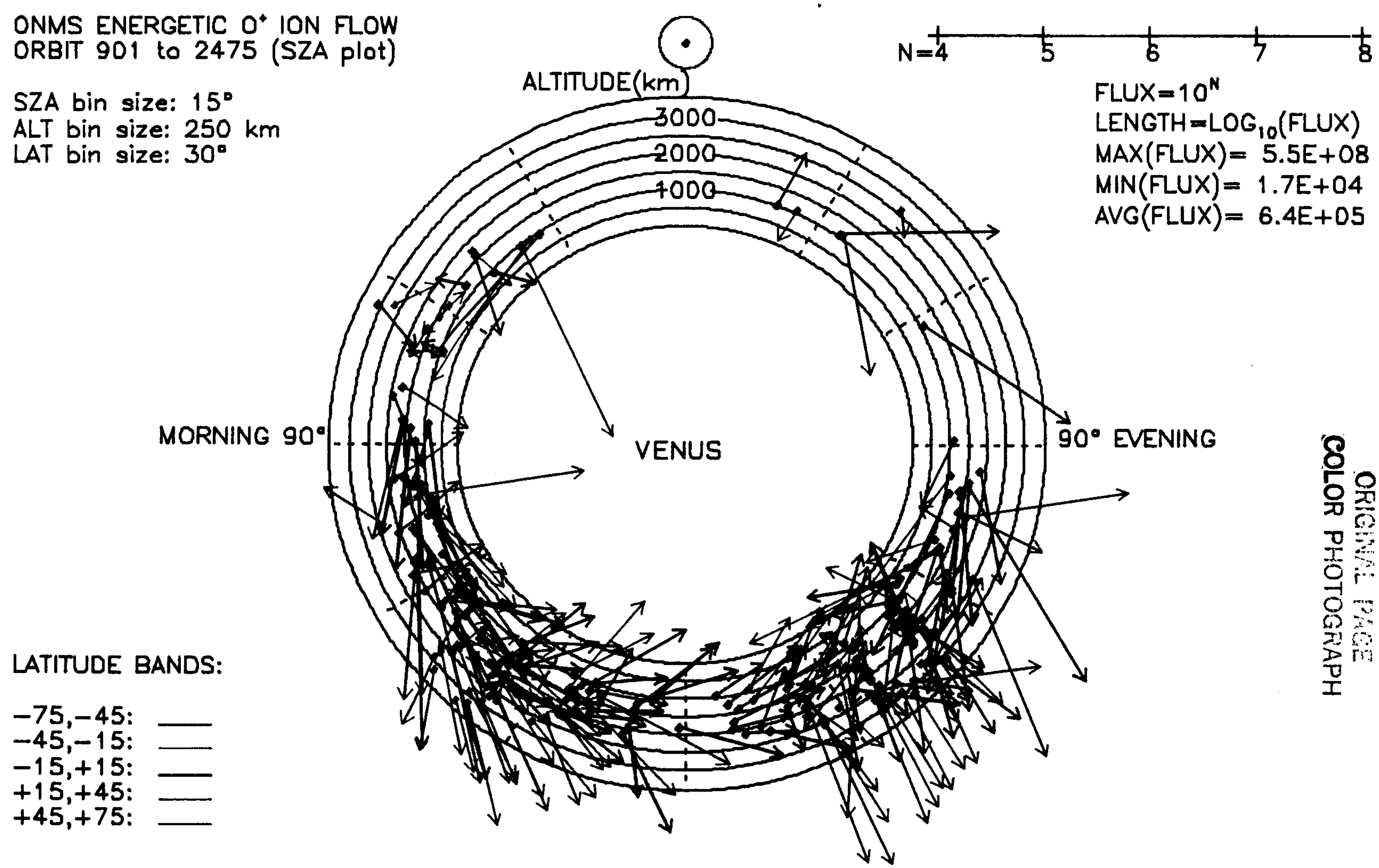

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Figure 7b. Average direction data for diurnal cycles 5-11, orbits 901-2475.

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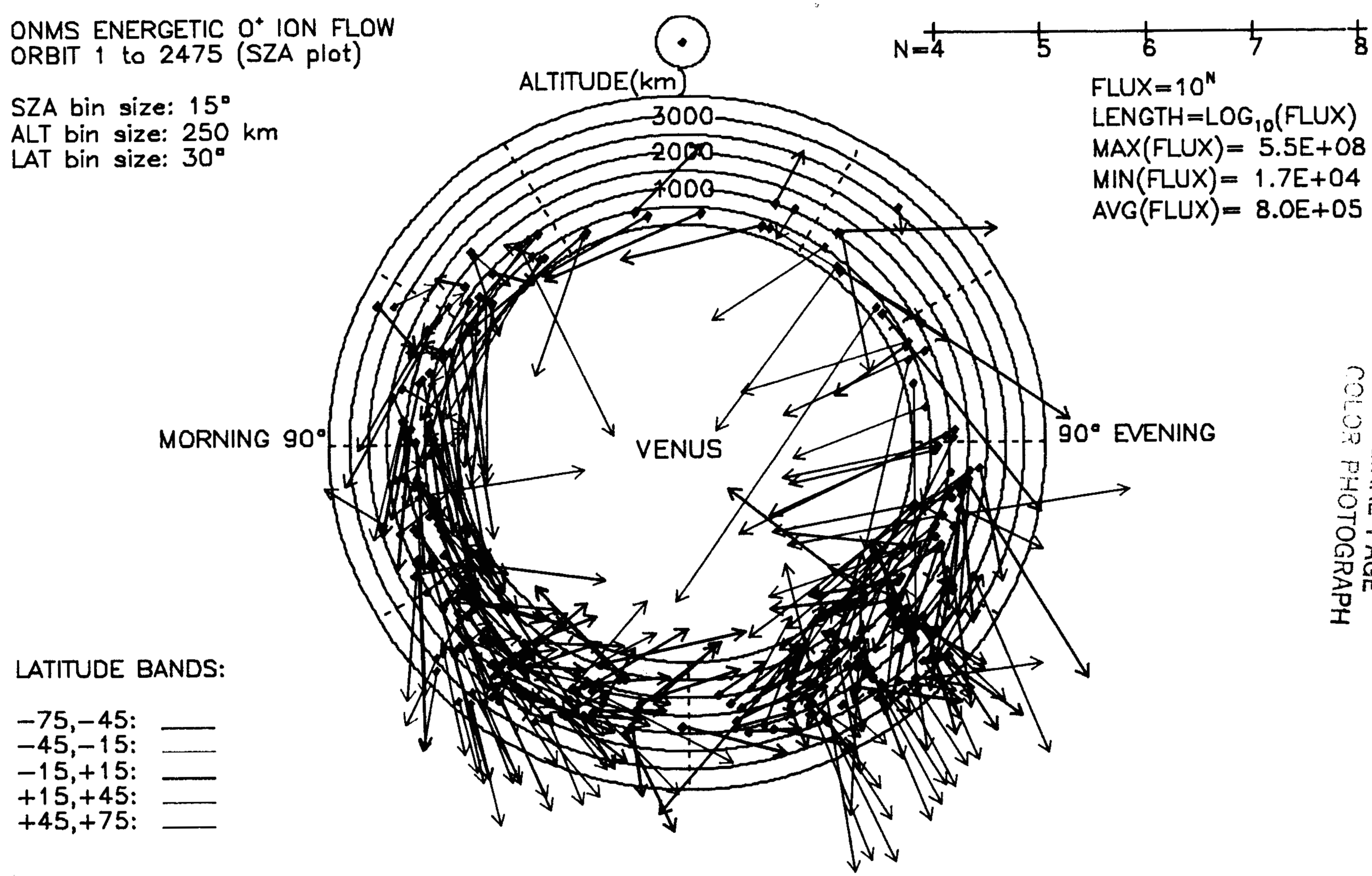

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Figure 7c. Average direction data for diurnal cycles 1-11, orbits 1-2475.

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4. Conclusion

The first 11 diurnal cycles (orbits 1 to 2475) of fast, greater than 40 eV, O^+ data have been vector averaged in order display the general flow pattern in the ecliptic plane. On the dayside and near the terminators, where energetic O^+ ions are observed near the ionopause, the directions are more or less parallel to the planet's surface with evidence of an asymmetry about the Sun-Venus line. On the nightside below 2000 km and near the equator there is a preferred dawn-to-dusk direction while at higher altitudes (lower solar zenith angles and higher southern latitudes) the flow direction is more antisunward. The average flux of O^+ ions exceeding 40 eV for this time period is 8×10^5 cm^{-2} s^{-1} with a maximum of 5×10^8 cm^{-2} s^{-1}.

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16. Abstract

The Pioneer Venus Orbiter Neutral Mass Spectrometer (ONMS) has observed fast O^+ ions with an energy exceeding 40 eV in the spacecraft reference frame. The orbit of the spacecraft is nearly polar with periapsis near the equator. The ONMS is mounted at an angle to the spin axis which, in turn, is perpendicular to the ecliptic plane. From the spin modulated data the direction of the ion flow in that plane can be determined. Data from the first 11 diurnal cycles (orbits 1 to 2475) are vector averaged in order to display the general flow pattern. Plots of the averaged data are presented. On the dayside and near the terminators, where fast O^+ is observed near the ionopause, the directions are more or less parallel to the planet's surface with evidence of an asymmetry about the sun-Venus line. On the nightside below 2000 km and near the equator there is a preferred down to dusk direction while at higher altitudes (lower solar zenith angles and higher latitudes) the flow direction is more antisunward. The averaged flux for this time period is $8x10^5/cm^2/s$ with a maximum of $5x10^8$.

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