Ionospheric convection inferred from SuperDARN, IZMEM and DMSP observations

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Recently several studies indicated possible deterioration of the accuracy in the SuperDARN convection measurements at large distances (~3000 km) when the signal is received via the "1 & 1/2 hop" radio wave propagation path. If these signals are echoes from the ionospheric E-region, deterioration should be significant for the strong convection velocities (> 1000 m/s) since, in this case, the phase velocity of irregularities is saturated at the ion-acoustic speed. In this study, the SuperDARN convection observations are compared with direct ion drift observations made by the DMSP satellites over high latitudes to investigate the above-mentioned problem, with the focus on strong convection. Both the "merge" and "fit" radar predictions were considered. A reasonable overall agreement between the DMSP observations and both radar techniques was found though the individual points in some passes show significant differences. The effect of the velocity saturation was not found, but the data show a tendency for the SuperDARN convection vectors to be a little smaller than the DMSP ion drift velocities. The periods of "poor agreement" are to be considered in terms of the general convection patterns as predicted by the IZMEM model to explore the inconsistencies in greater detail.

1. Introduction

Information on plasma convection in the high-latitude ionosphere is currently coming from measurements of several instruments. During last decade such traditional instruments as incoherent scatter radars (ISRs) and satellite drift meters have been successfully complemented by observations of coherent SuperDARN HF radars. Advantages of SuperDARN radars are their unprecedentedly large spatial coverage, almost half of the globe, and still a reasonable time resolution of 1-2 min.

Though all methods of plasma convection measurements, as conceived, provide true convection vectors, different spatial and temporal resolutions of the systems and specifics of their operation modes can lead to different values for plasma convection in a case of simultaneous observations. In addition, the raw data post-processing might introduce more inconsistencies. A thorough and systematic inter-comparison between different systems monitoring plasma convection has not been published yet.

Plasma convection patterns can also be predicted from statistical models, such as, for example, the IZMEM model [Papitashvili et al., 1994; 1999] based on magnetometer observations and satellite ion drift measurements. Another example is the Weimer-96 model [Weimer, 1996] built on solely satellite convection data. Advantage of these models is in their capability of convection pattern prediction from known IMF and solar wind plasma parameters. Limited intercomparison between these models and SuperDARN–measured convection showed a reasonable consistency of the predictions and measurements [Kustov et al., 1997; 1998].

This paper focuses on local plasma convection measurements as given by the Saskatoon-Kapuskasing SuperDARN radar pair and ion drifts as observed by the DMSP satellites passing through this radar pair field of view. A comparison with the IZMEM model is left for the follow-on study. The ultimate goal of these comparisons is a comprehensive assessment of the consistency in the convection data supplied to the space science community.

2. Review of previous work and objectives

Besides general necessity to know how consistent are HF plasma convection vectors and the ion drifts (convection) measured on a board of the DMSP satellites, there are several additional incentives stemming from the previous work.

Villain et al. [1985] and Ruohoniemi et al. [1987] were the first who compared the HF radar Doppler velocities along a specific radar beam with plasma convection measurements performed by ISRs along the HF beam, the EISCAT and Sondrestrom radars, respectively. These studies found reasonable agreement of the HF radar estimated convection and convection measured by ISRs. There have been, however, some differences that were not focused on. For example, data presented by Ruohoniemi al. [1987] show that the Goose Bay l-o-s velocities are sometimes larger than plasma drifts (according to the Sondrestrom ISR) for strong drifts of more than 600 m/s (see their Figure 11).

Later Baker et al. [1990] compared Goose Bay velocities with DMSP satellite ion drift measurements for one pass. Data of Baker et al. (1990) show the opposite effect in some measurements; the Goose Bay l-o-s velocities are smaller than ion drifts observed by the satellite (see their Figure 3, latitudes around 69^0).

More recently Grant et al. [1995] studied SuperDARN convection maps, plasma drifts derived from ionosonde drift observations and drifts of the auroral forms in the polar cap. Individual points showed overall convection data consistency and observed minor differences did not show any preferential tendency.

A more comprehensive comparison of HF l-o-s velocities and corresponding plasma drifts, measured by the EISCAT ISR along the Finland CUTLASS HF radar beam #5, was reported by Davies et al. [1999]. These authors concluded that there was an overall reasonable correspondence between measurements. However, inspection of individual points show significant data spread so that velocities differ by 2 and more times. Though not mentioned, these data show a general tendency for the HF l-o-s velocities to be smaller than the EISCAT measured plasma convection (the slope of the linear regression line is 0.7, Figure 6). Clear data trend might indicate that differences could be not only due to different spatial and temporal resolution of coherent and incoherent radars.

Observations of Milan et al. [1997] give a clue to why there might be inconsistency of SuperDARN convection estimates and real convection. These authors showed that far-distant HF echoes (ranges ~2500 km) can be received through the 1&1/2 hop propagation mode so that scatter might actually occur from the E layer. It is well known that velocities of electrojet E region irregularities are “saturated” at a value of the ion-acoustic speed (400-600 m/s, depending on the electric field magnitude) for large electric fields [e.g., Greenwald et al., 1995]. For large distances, a warning fact that convection measurements are not consistent with what one would expect comes from recent observations of Kustov et al. [2000] who tried to construct a statistical convection pattern for small IMF Bz and By. It was discovered that convection in ~1800 MLT sector towards the Sun at magnetic latitude < 80^0 is not balanced out by the convection flow from the Sun at larger magnetic latitudes (>80^0).

3. Event selection for joint SuperDARN/DMSP observations

Currently two procedures of plasma convection derivation from Doppler observations of HF radars are in use. The first one is a well-established procedure of Doppler velocity “merging” at the radar beam crossings. It is assumed that the observed line-of-sight (l-o-s) velocity of individual radar is a cosine component of the total plasma drift vector so that they can be combined together to give a vector of total convection. A fact of low phase velocity of the F-region irregularities as compared to the **E×B** drift of the plasma provides a theoretical foundation for such an assumption.

The second SuperDARN procedure, put forward recently by Ruohoniemi and Baker [1998], is a variety of a beam-swinging technique with heavily involvement of corrections on a statistically known convection pattern as a function of the interplanetary magnetic field. This technique provides much better coverage than the standard “merge” approach since convection can be estimated not only at radar beam crossings but also at those spots of the ionosphere where data of only one radar are available. Because estimates in this approach are eventually made by the fitting of measured l-o-s velocities to the assumed general convection pattern, it is often referred to as a “fit” technique.

In this study, convection estimates of both techniques have been compared with the DMSP measurements. Also, since deterioration of convection estimates at large slant ranges of radar measurements was under investigation, most of the considered events had data coverage centered around 80^0 of magnetic latitude.

Figure 1 shows an example of SuperDARN convection maps as given by the merge and fit techniques (panels (a) and (b), respectively) as well as DMSP ion drifts perpendicular to the satellite path (red vectors, only this ion drift component was available for this study). We considered periods of SuperDARN radar operation in a standard mode [Greenwald et al., 1985] with radar beams being scanned through 16 azimuthal positions within common field of view. The duration of one full scan was about 2 min.

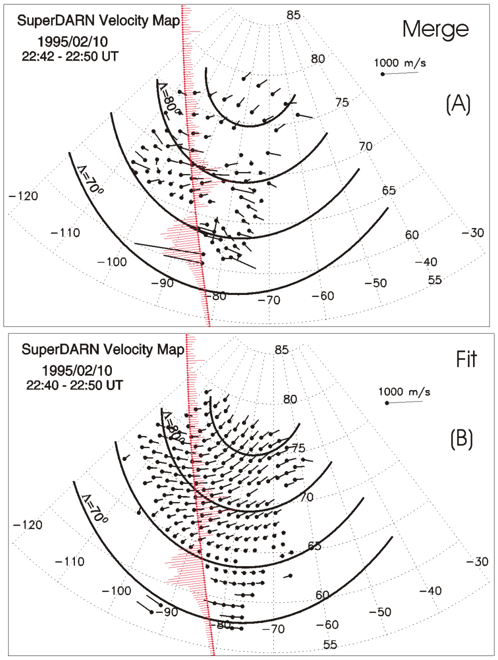

Fig. 1

Figure 2 explains the philosophy of the comparison. Here one can see individual SuperDARN velocity vectors around a DMSP track projected (from nominal altitude of 840 km) onto altitude of 300 km along the magnetic flux lines. Thin lines in Figure 2 are the ion drifts measured by the satellite. Since DMSP points of measurements are about 20 km apart, typically several DMSP points are located in the vicinity of an individual SuperDARN vector (inferred by either the “merge” or “fit” method).

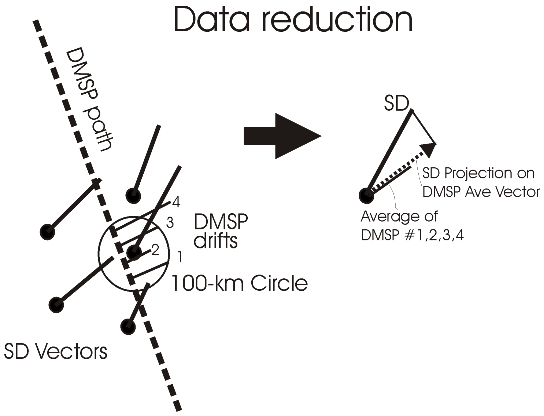

Fig.2

It was assumed in this study that only those DMSP measurements are compared with SuperDARN convection vectors whose separation from the actual SuperDARN point of measurements is not more than 50 km. Typically 3-4 DMSP points were effectively contributing to the average DMSP ion drift around one SuperDARN vector as shown in the right part of Figure 2. SuperDARN data were averaged over the time of satellite crossing the area where radar data were available. Once the average DMSP drift is found, the SuperDARN convection component along the DMSP direction is determined by simple projection. The obtained SuperDARN velocity component is then compared with the DMSP averaged drift.

4. “Merge” SuperDARN vectors and DMSP ion drifts

Overall comparison for “merge” velocities and DMSP drifts is presented in Figure 3, panel (a). 41 DMSP passes have been considered for this plot. One can clearly see overall reasonable agreement of measurements though a tendency for the SuperDARN velocities to be slightly less than the DMSP drifts is obvious for large velocities of more than 500 m/s. Figure 3, panels (b) and (c), shows similar comparison but data are now split into two latitudinal ranges, measurements below 78^0 and above 78^0. One can notice that effect of SuperDARN velocity "underestimation" is evident at large slant ranges only.

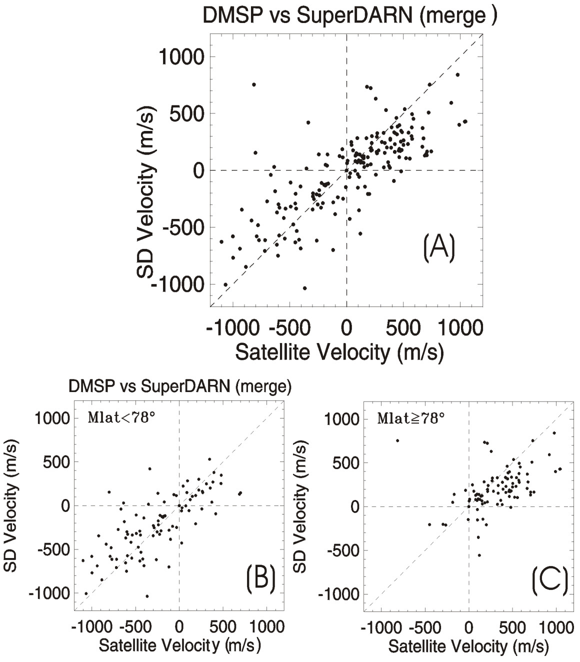

Fig. 3

5. "Fit" SuperDARN vectors and DMSP ion drifts

Figure 4, panel (a), shows overall comparison for "fit" velocities and DMSP drifts. All fit data were obtained by keeping 8-order approximation for the potential expansion [Ruohoniemi and Baker, 1999]. This would ensure retaining of the convection pattern details normally smoothed out in the standard 4-order polynomial approximation. Certainly, the number of "fit" points here is much larger than in a case of "merge" comparison and the data are clustered better. Again, overall reasonable agreement of measurements is obvious. However, the tendency for SuperDARN velocities to be slightly less than the DMSP drifts for large velocities is more obvious in this diagram, both for positive and negative directions (eastward and westward, respectively). Figure 4, panels (b) and (c), shows similar comparison but data again split into two latitudinal ranges, measurements below 78^0 and above 78^0. For these data, SuperDARN velocity "underestimation" is evident in both latitudinal ranges.

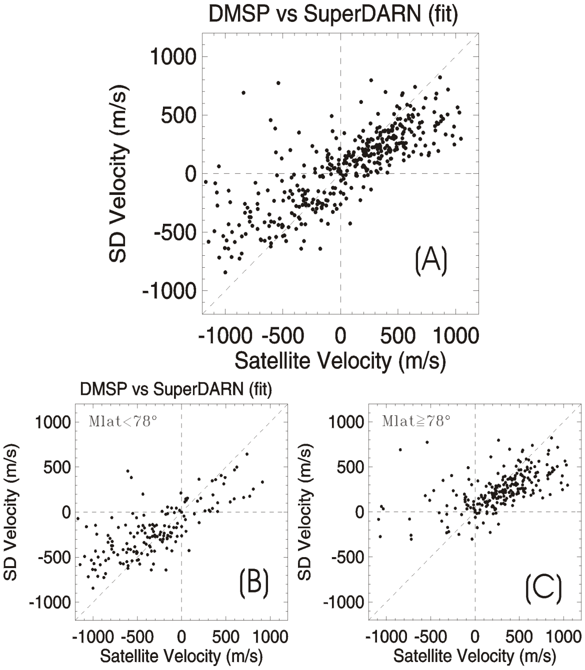

Fig. 4

6. Discussion

The SuperDARN/DMSP velocity comparison presented in this study, first of all, confirms clearly that in spite of physically different methods of convection measurements and the difference in spatial and temporal resolutions of the instruments, the obtained convection data are fairly consistent in a broad sense.

During the data selection process, the only restriction for considering a specific event was the availability of at least several "merge" vectors at latitudes around 80^0. Because overall echo occurrence for the Saskatoon-Kapuskasing radar pair is enhanced in the noon sector [Huber, 1999], the majority of the data belongs to the dayside though some evening events were included as well. Several events for which DMSP measurements were not reliable due to low ion densities were not considered as well as several other events were rejected due to very irregular SuperDARN patterns indicating the hardware problems.

Our comparison has shown that both radar techniques of raw l-o-s velocity reprocessing and converting them into the convection vectors give very similar results. This result is, of course, highly anticipated by the "fit" technique developers, and here, for the first time, we confirm independently that both radar methods are equivalent in a broad sense and give convection close to the one measured by the DMSP satellites. This means that the fit technique provides reliable velocity estimates in the areas where merged vectors cannot be derived due to echo absence for one of the radars. No attempt has been made in this study to check how consistent are fit convection estimates and DMSP ion drifts beyond the areas of radar measurements.

Simultaneously with stressing the reasonable consistency in DMSP/SuperDARN convection measurements by either method, we note that significant differences at some points (including opposite direction of the convection) were seen. These differences are not difficult to explain keeping in mind so different way of the convection estimates, in terms of raw data first of all. Typically, it takes 5-8 min for the DMSP satellite to cross the radar field of view. Over this time interval, radars would make at least 2 full scans. Since the SuperDARN data were averaged over the intervals of DMSP crossings, the time difference between satellite and radar measurements at some points could be more than 2-4 min, the duration of one-two SuperDARN scans. One also has to always keep in mind that even though SuperDARN produces a 2-min convection map, every map is not an instantaneous picture but an integrated pattern made of measurements at different parts of the ionosphere at slightly different time, up to almost 2 minutes for the most eastward and most westward vectors. So, one of the sources of differences is a quite different time resolution of the instruments.

There were also differences in spatial resolution, especially at large latitudes where the SuperDARN radar beam covers ionospheric area of several hundreds of kilometers in azimuthal direction (the radar beam width is more than 5^0). Contrary to radar echo signals, coming from a very large scattering volume, the DMSP measurements have been carried out in very localized regions along the satellite path. In addition to coverage differences, the altitudes of DMSP measurements were about 400-500 km above the radar scatter heights so that some inconsistencies might be originated from an error in the DMSP position tracing down to the ionosphere along the magnetic field-line. One also should keep in mind that the heights of radar scatter are not well known as well.

All sorts of uncertainties in the course of the comparison makes it easy to understand the observed differences between the DMSP and radar convection measurements. In this view, the surprising result is a tendency for the radar velocities to be slightly smaller than the DMSP velocities at large values of plasma convection. Similar result was obtained by Xu et al. [1999] when SuperDARN derived convection was compared with Sondrestrom plasma drifts. In addition, once again, data published by Davies et al. [1999] also give a hint on such a trend. It is not clear, however, whether this tendency is an absolute fact; data statistics is still not large enough to make such a conclusion with confidence. More data comparison is required.

Xu et al. [1999] discussed several potential factors that might contribute to this tendency, but none of them can clearly be identified as a sole source. What we found new in this study is that the DMSP/SuperDARN differences are stronger at higher latitudes, at least for merge SuperDARN velocities. This would explain, at least partially, inconsistencies in the convection magnitude at low and high latitudes for the statistical convection pattern at small IMF Bz and By reported by Kustov et al. [2000]. This fact also suggests that the cause of the problem can be an error in the positioning of the radar echoes in a case of SuperDARN (these must be larger for higher latitudes) and/or errors in ion drift measurements at large electric fields (that could be matched with the ion density depletions) in a case of DMSP measurements. In this sense it would be interesting to compare simultaneous DMSP and SuperDARN plasma convection vectors with predictions of the IZMEM statistical convection model. This task is interesting on its own in view that the IZMEM model is also utilized for space physics research. The IZMEM model is of special interest since it is capable of convection pattern prediction on a global scale by using information on the IMF conditions only. This has a direct application for the space weather short term forecasting. Preliminary testing by Kustov et al. [1997] has been done for latitudes below 80^0. Since WIND IMF and solar wind velocity measurements are available for most of the events considered in this study, it is a routine work to make such comparison and it is in our plans for the second stage of this project.

6. Conclusions

In this paper we show that for more than 40 DMSP passes over SuperDARN Saskatoon-Kapuskasing radar pair field of view

- both “merge” and “fit” procedures of plasma convection derivation give convection vectors that agree reasonably well with the convection component measured by the DMSP satellites
- “merge” procedure gives slightly higher spread of the data points
- both “merge-” and “fit-” derived convection have a tendency to be slightly less than the DMSP-measured convection component for large values of the DMSP velocities of more than 500 m/s
- Both techniques show this effect at high latitudes of more than 78^0
- SuperDARN “merge” data do not clearly show this tendency at latitudes of less than 78^0.

Extension of this work is a comparison of simultaneous DMSP/SuperDARN measurements with the IZMEM convection model with a primary goal to asses local differences in convection patterns and with a second objective to gain more information on possible sources for some differences between SuperDARN and DMSP convection measurements.

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