Estimating 2D Neutral Wind Patterns Using Line-of-Sight Data from Multiple Scanning Doppler Imagers

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Abstract

We present a new analysis technique for estimating 2D neutral wind pattern using data from a single Scanning Doppler Imager (SDI) or a combination of SDIs, incoherent scatter radars (ISR) and Fabry-Perot interferometers (FPI) within overlapping field-of-views. Neutral wind plays an important role in ionospheric electrodynamics and Ionosphere-Thermosphere coupling, by for example affecting the Joule heating rates and plasma transport. However, reliable and extensive measurements of the neutral wind are rather difficult to obtain. Pointwise measurements can be obtained with ISRs or FPIs, but these measurements can not provide 2D latitude-longitude maps of the neutral wind pattern needed in mesospheric studies. A Scanning Doppler Imager can measure the line-of-sight (LOS) component of the neutral wind in dozens of directions simultaneously. However, further modeling is needed to convert the LOS velocities into 2D velocity maps. Unfortunately these maps are far from unique, as perpendicular velocities (e.g. rotation around the measurement site) are not visible in the LOS data. This can be mitigated by combining data from several nearby SDIs, or a combination of SDIs, FPIs and ISRs. Our analysis technique is based on fitting the LOS data with special vector basis functions called Spherical Elementary Current Systems (SECS). In this approach the wind is naturally divided into curl-free and divergence-free components, and there is no need to provide any explicit boundary conditions on the wind pattern. We present several synthetic test scenarios as well as first results using data from SDIs located in Alaska. Using the synthetic test scenarios we further estimate optimal locations for 2 or 3 SDIs that could be located around the future EISCAT_3D radar system in northern Scandinavia.

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1. Introduction

- Neutral wind plays an essential, but often ignored and poorly understood part in ionospheric electrodynamics and ionosphere-thermosphere (IT) coupling.
- A Scanning Doppler Imager (SDI) can measure the line-of-sight (LOS) component of neutral motion from the Doppler shift of auroral emissions at 630 nm (about 240 km altitude) or 558 nm (about 120 km altitude).
- SDI provides multiple simultaneous measurement directions
  → 2D map of LOS velocity, see Fig. 1
  → How to get 2D map of real velocity?
- We want to estimate the 2D neutral wind pattern using multiple SDIs, or a combination of SDIs and Fabry-Perot interferometers (FPI) with overlapping field-of-views.
- Dream: Multiple SDIs around the EISCAT_3D radar system (see Fig. 2)
  → Independent measurements of the the plasma and neutral components.

Figure 1. Simulated line-of-sight (LOS) data at Poker Flat **[PKR]**. What is the actual wind pattern?

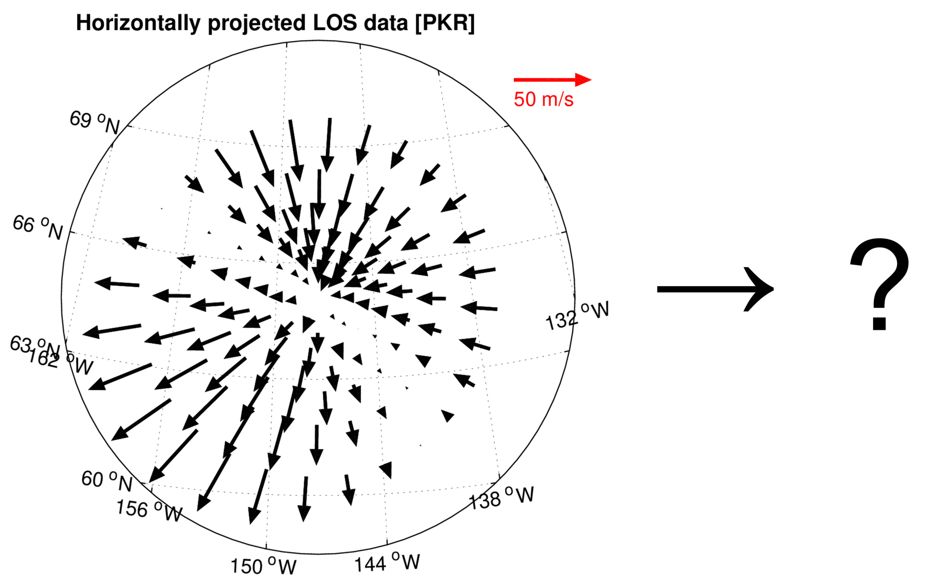
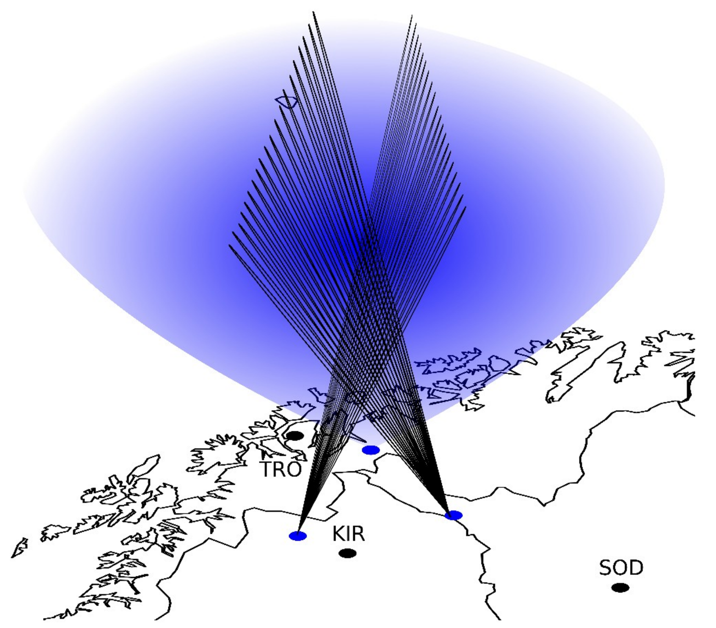


Figure 2. EISCAT_3D incoherent scatter radar system.



Related talks & posters

- Oyama et al. Poster SA43C-3521, THIS SESSION.
- Conde et al. Talk SMA41A-07, this morning 09:30.

2. Analysis method

- Develop a new analysis method for estimating the wind pattern.
  - Conde et al. have developed several methods.
    → Compare, weak & strong points, select best.
- Idea: Fit the LOS data with Spherical Elementary Current Systems (SECS).
  - SECS are vector basis functions for the curl-free (CF) and divergence-free (DF) parts of the horizontal wind, see Fig. 3.
  - No explicit boundary conditions on the wind pattern.
  - Vertical wind need to be represented in some other way.
- **Present analysis code:** Use only DF systems ↔ Assume wind is perfectly horizontal & in-compressible.
  - CF part (compressible wind) & vertical part to be added later.
- Reference point: SDIs operated in Alaska by Conde et al., Fig. 4.
  - Poker Flat **[PKR]**, Toolik **[TLK]**, and HAARP at Gakona **[HRP]**.
  - Use their measurement pattern in synthetic test cases.
  - Test analysis method using real data.
- Test the analysis method with synthetic wind models.
  → Synthetic LOS data + some noise.
  → Feed to the analysis program.
  → Compare result with the original model.

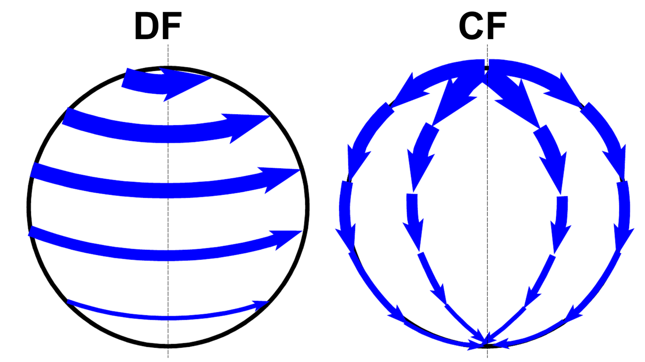
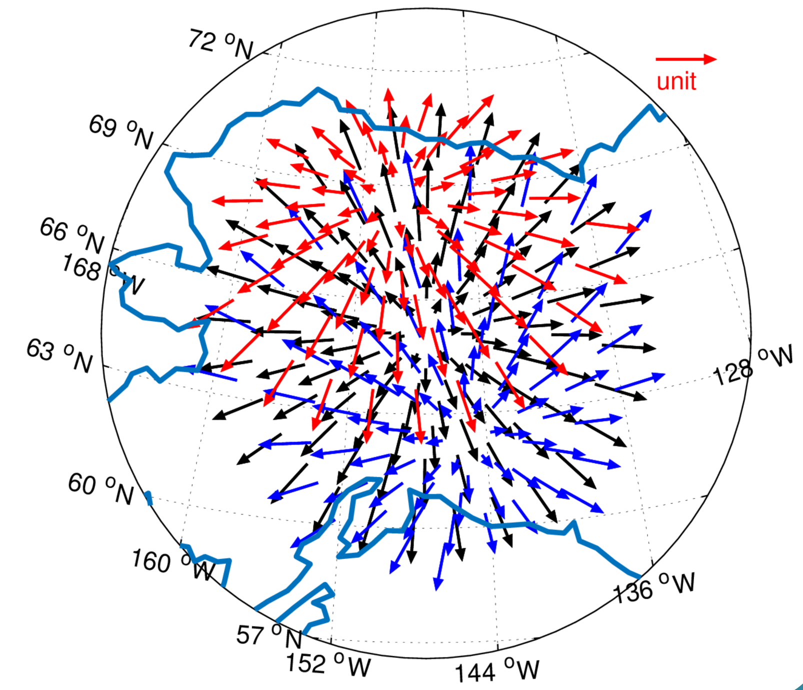


Figure 3. Divergence-free SECS & Curl-free SECS.

Figure 4. Horizontally projected LOS vectors from **PKR**, **TLK** and **HRP** at 240 km altitude. Only common area around PKR is shown.



3. One vs many SDIs

- First test analysis using 1 SDI at Poker Flat.
- Model wind (Fig. 5) is perfectly horizontal & in-compressible. Add 5 m/s gaussian noise to synthetic LOS data (Fig. 6 a).
- SECS can fit LOS data very well (not shown), but result is wrong (Fig. 6 b-c): Rotation around the SDI is invisible in LOS data.

Figure 5. DF model wind.

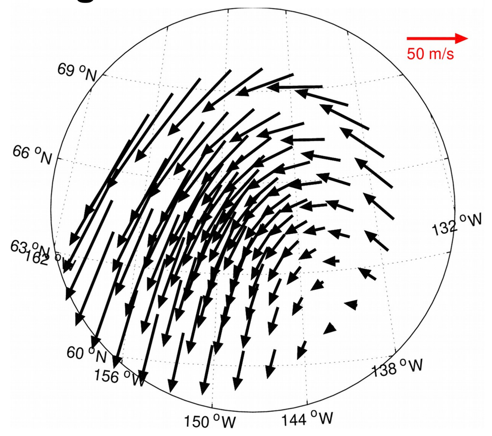
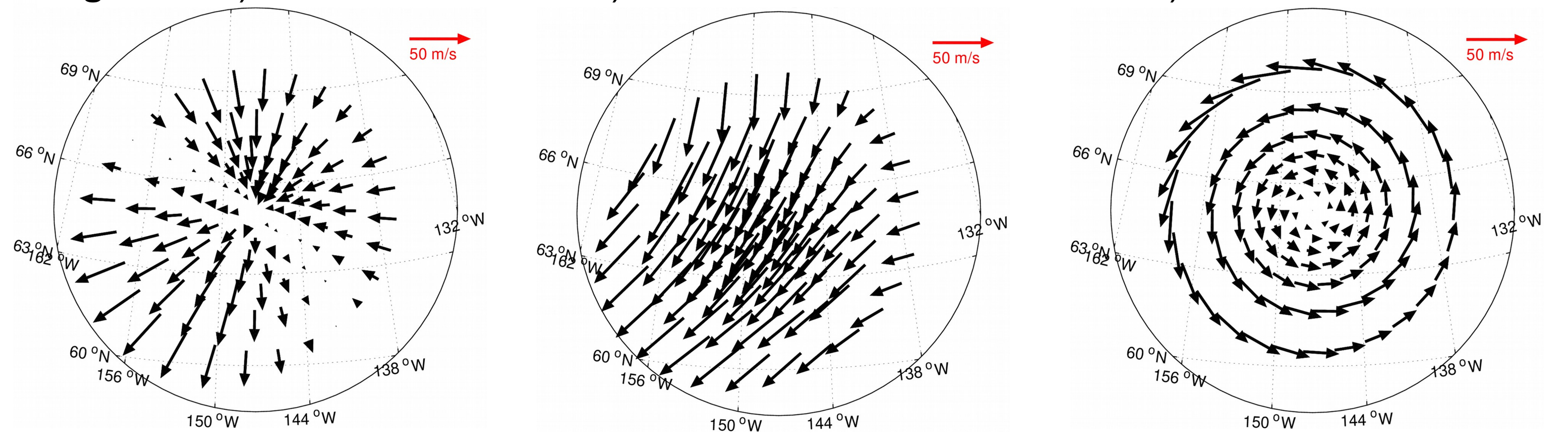
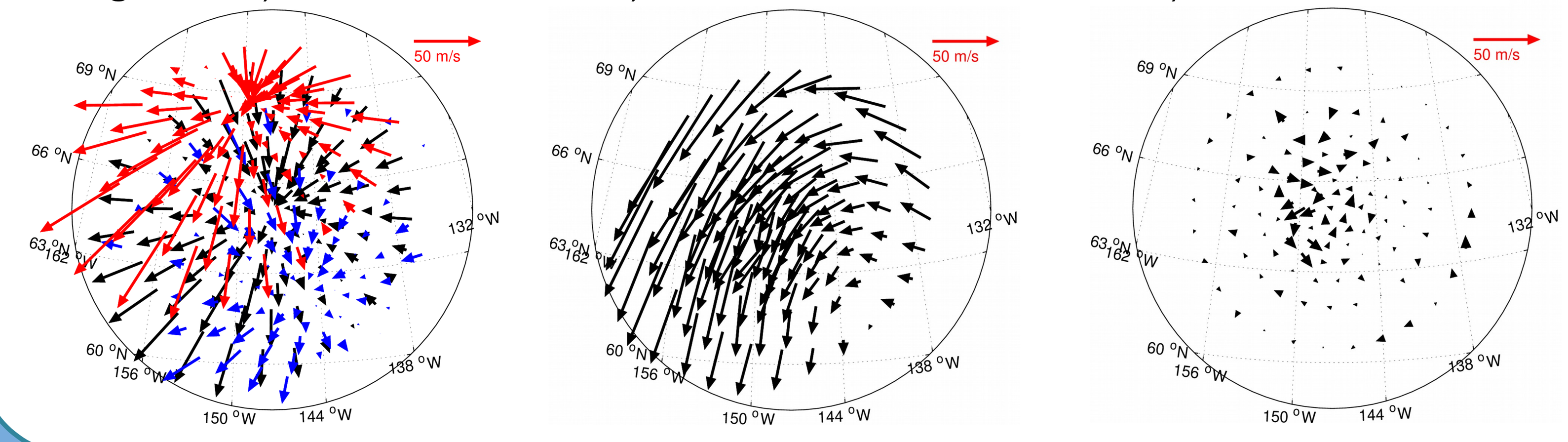


Figure 6. a) LOS data b) Wind from SECS fit c) Model-SECS fit.



- Add LOS data from **TLK** and **HRP** → Result is almost perfect (Fig. 7 a-c).

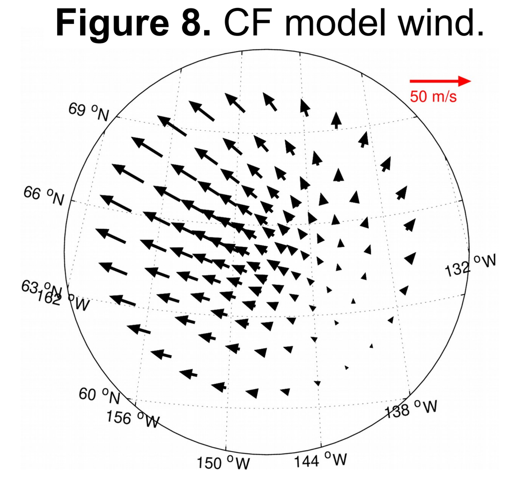
Figure 7. a) LOS data b) Wind from SECS fit c) Model-SECS fit.



4. Effect of CF and/or vertical wind

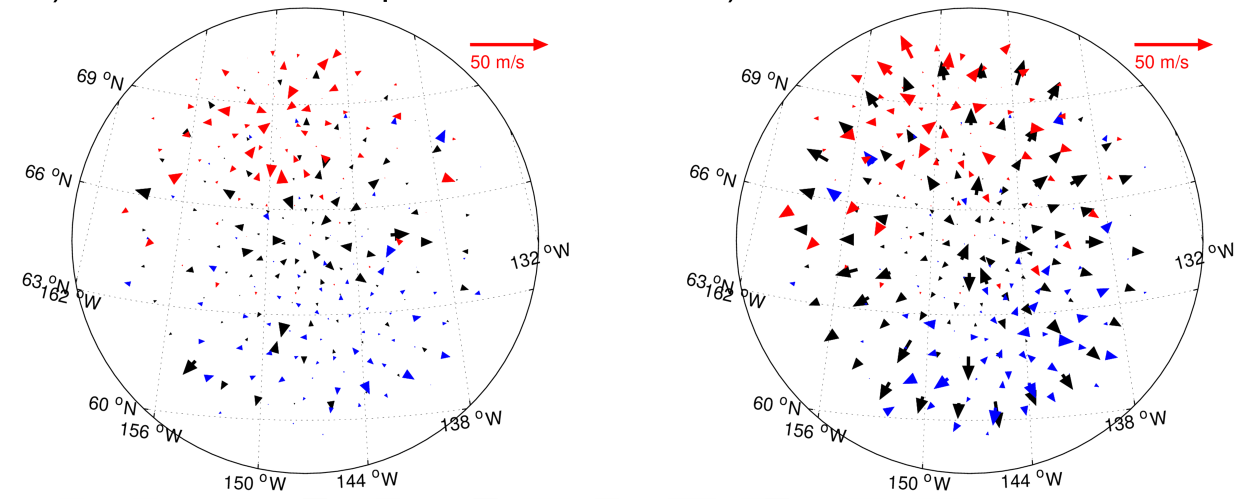
- At the moment we use only DF SECS in the fit.
  ↔ Assume wind is in-compressible and horizontal.
- What happens if the wind has compressible (CF) and/or vertical component?
- Add CF wind from Fig. 8 to DF wind shown in Fig. 5.

Figure 8. CF model wind.



- Result is still reasonable (not shown), but we can detect that something is missing: Residual in LOS fit is not noise.
- Compare LOS residual when fitting the pure DF model (Fig. 9 a) and residual when fitting the DF+CF model (Fig. 9 b)
  → There is weak but clear expanding/contracting ring patter, especially in **PKR** data (black arrows in Fig. 9 b).

Figure 9. a) LOS residual with pure DF model b) LOS residual with DF+CF model.



- Vertical wind leaves very similar ring pattern.
  → Can not distinguish vertical and CF wind, but can see that pure DF fit is insufficient.
- In the future, include CF SECS and vertical wind to the analysis.

5. Discussion & Things to be done

- The SECS-based analysis tool seems to work well with data from multiple SDIs.
  - Work in progress: First results are promising, more testing & development is needed.
- Do we really need several SDIs?
  - Maybe not: tests indicate that even 2-4 extra data points improve the result in Fig. 6c
    → 1 SDI (2D data) + 1 FPI (2-4 points) might work.
  - However, this depends on the noise level (and maybe on the test model).
- Need to include CF SECS and vertical wind to the analysis.
  - CF SECS in principle straightforward.
  - Vertical wind can not be parameterized with SECS → Maybe Spherical Cap Harmonics?
  - Maybe still best to fit DF SECS first and check the LOS residual?
- Need more realistic test models.
  - Typical length scales, vertical vs. horizontal speed, noise in measurement, ...
- Need to compare results with real data to other analysis methods (Conde et al.).
- Need to estimate optimal locations for 1-3 SDIs to be placed around the EISCAT_3D.
  - As a first result, below is the RMS error in Model-SECS wind as a function of distance between 2 SDIs (calculated for 630 nm observations, and 3 noise levels).

Figure 10. 2 SDIs, 240 km altitude