Estimating 2D neutral wind pattern using line-of-sight data from multiple Scanning Doppler Imagers

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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.

Related talks & posters

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

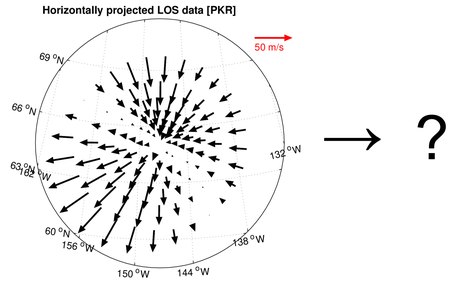


Figure 1. Simulated line-of-sight (LOS) data at Poker Flat [**PKR**]. What is the actual wind pattern?

→ ?

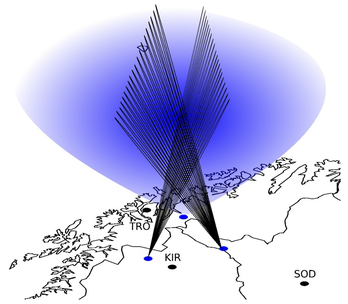


Figure 2. EISCAT_3D incoherent scatter radar system.

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.

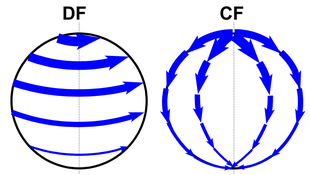


Figure 3. Divergence-free SECS & Curl-free SECS.

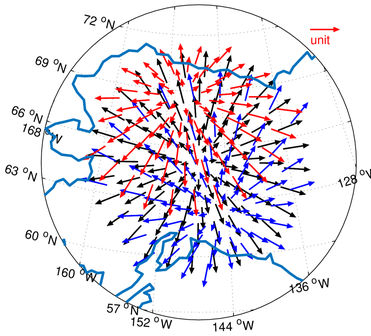


Figure 4. Horizontally projected LOS vectors from **PKR**, **TLK** and **HRP** at 240 km altitude. Only common area around PKR is shown.

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.

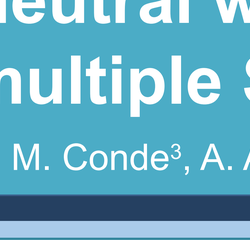
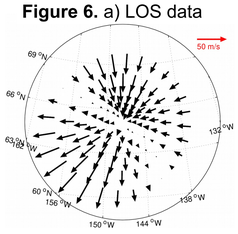
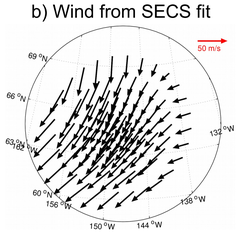


Figure 5. DF model wind.

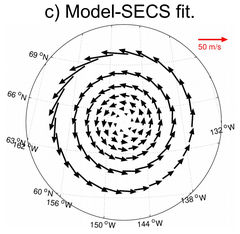
Figure 6. a) LOS data



b) Wind from SECS fit

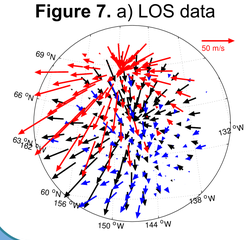


c) Model-SECS fit.

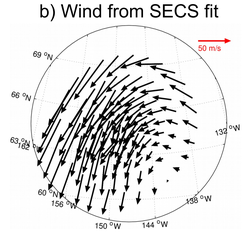


- Add LOS data from **TLK** and **HRP** → Result is almost perfect (Fig. 7 a-c).

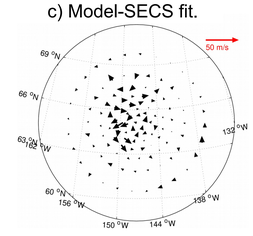
Figure 7. a) LOS data



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.

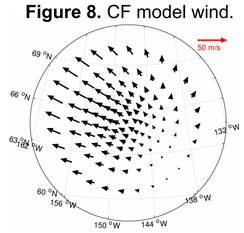
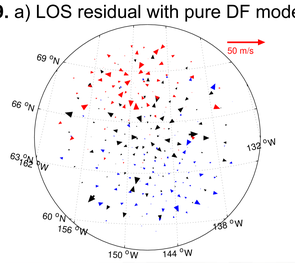


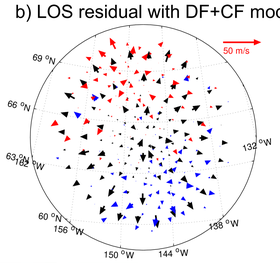
Figure 8. CF model wind.

- 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