Bayesian Filtering for Incoherent Scatter Analysis

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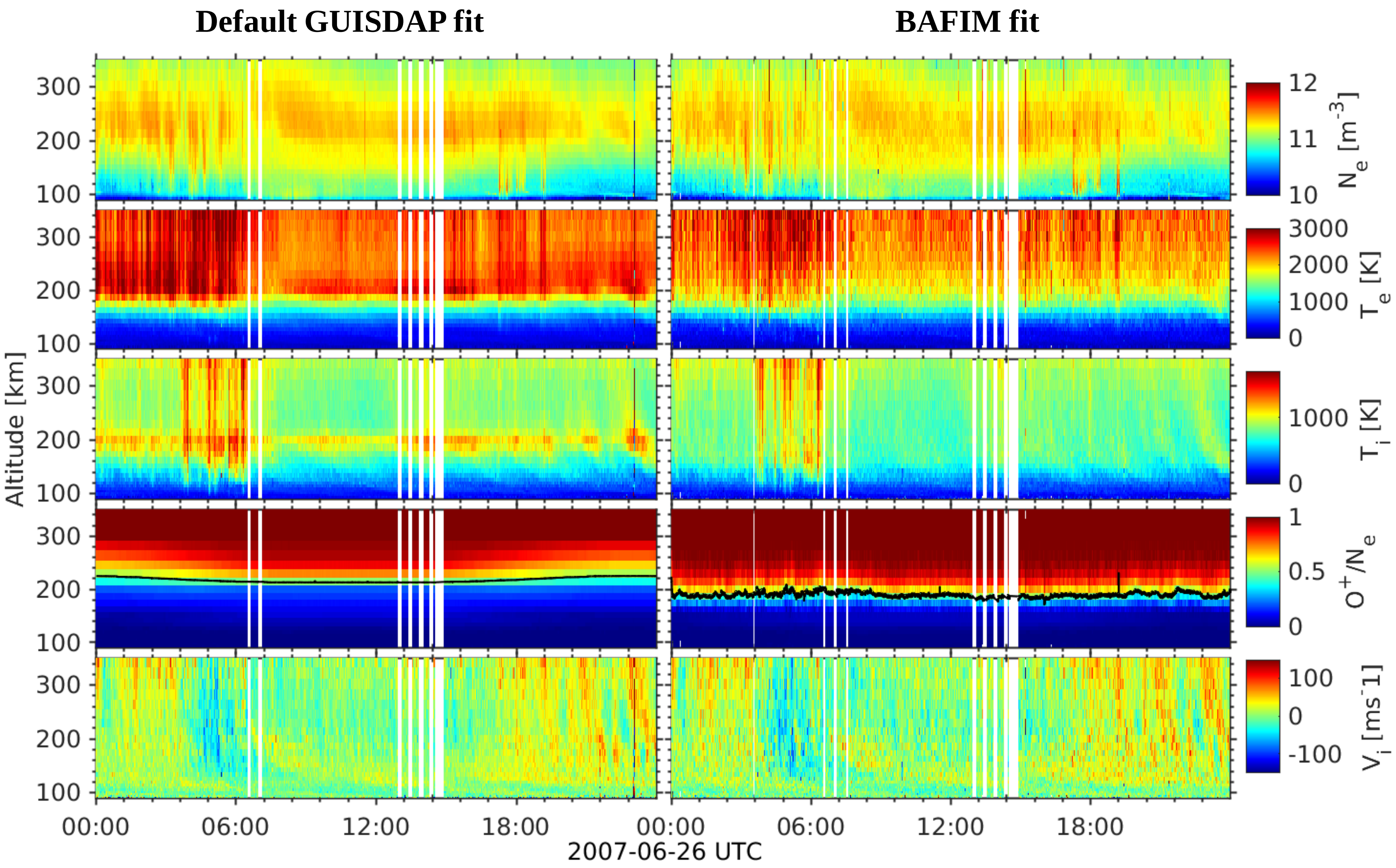
Rationale

- High time resolution (~5s) plasma parameter fits are extremely challenging for commonly used incoherent scatter analysis tools, such as the GUISDAP package of EISCAT [1].
- In addition, the electron (T_e) and ion (T_i) temperatures are calculated using ion composition $(p = [O^+]/N_e)$ profiles taken from an empirical model, for example the IRI model [2].
- High time resolved plasma parameters are necessary to investigate small scale auroral activities.
- Incorrectly modeled ion compositions may cause bias in ion and electron temperature estimates.
- In this project, we use Bayesian filtering to estimate plasma parameters, including the ion composition with high time resolution.

Bayesian Filtering

- The procedure in Bayesian filtering [3] incoherent scatter analysis has two steps.
    - **Prediction step:** best prediction of plasma parameters at current time step is evaluated using estimates from the previous time step. The prediction step contains a correlation prior [4] to control smoothness of the plasma parameter profiles in range direction.
    - **Update step**: the prediction is updated using measured incoherent scatter spectra to produce our best estimates of the plasma parameters at current time step.
- We have implemented Bayesian filtering as an additional Bayesian Filtering Module (BAFIM) to the GUISDAP analysis package.

Plasma Parameter Fits



Plasma parameter Fits Cont'd

- BAFIM performance is tested with EISCAT Svalbard radar data and the analysis results are plotted in the previous slide.
- The plasma parameters in the default GUISDAP and BAFIM analysis are calculated with 60 s and 6 s time steps, respectively.
- In the default GUISDAP fit, there is enhancement in T_i around 200 km, because the IRI model assumes too much molecular ions there.
- The artefact in T_i is not present in the BAFIM results.
- The black line in the composition plot is the transition altitude where equal amount of molecular $\left(\boldsymbol{NO^+} \text{ and } \boldsymbol{O_2}^+\right)$ and atomic $(\boldsymbol{O^+})$ ions exist in the ionosphere.
- The transition altitude in the BAFIM fit is in general at lower altitude than in the IRI model, which is used in the default GUISDAP.

Energy Spectra of Precipitating Electrons

- Differential energy flux of precipitating electrons can be estimated from ISR measured electron density and temperature profiles [5, 6, 7, 8].
- In a standard analysis, the ELSPEC software [5] calculates the differential energy flux using the raw N_e, which is calculated from the backscattered power assuming T_e=T_i. The electron temperature (T_e) is fitted with the default GUISDAP with 60 s time resolution and interpolated to the resolution of the raw N_e (~5s).
- However, when there is electron heating by precipitation, the raw electron density estimation becomes biased, because $T_e > T_i$.
- With BAFIM we can fit N_e , T_e and T_i with short time steps (~5s).

Energy Spectra Analysis

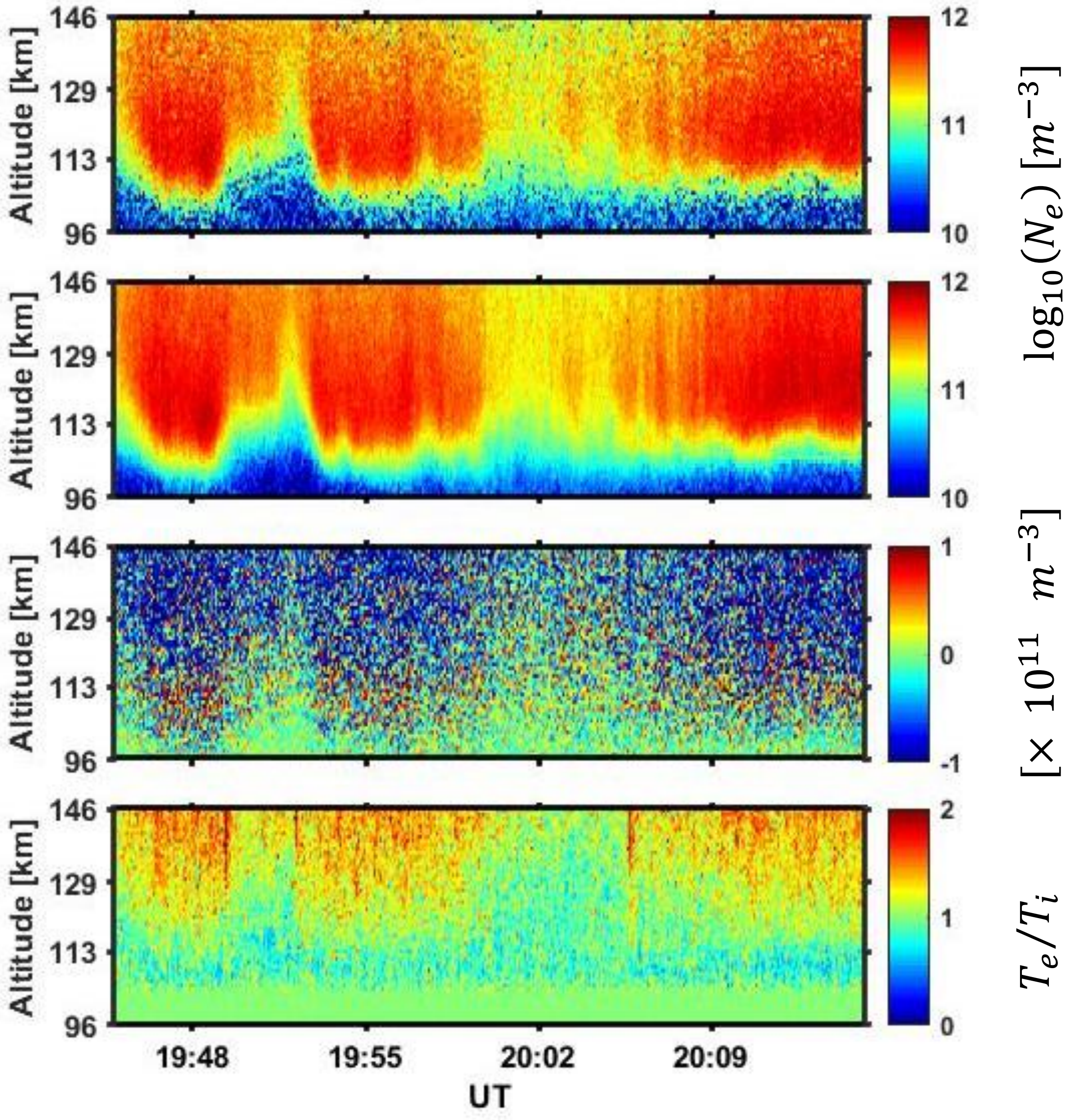
- In this work, we compared two ELSPEC fit results:

  - the first from the standard analysis using raw N_e and

  - the second from the new analysis using N_e fitted with BAFIM.

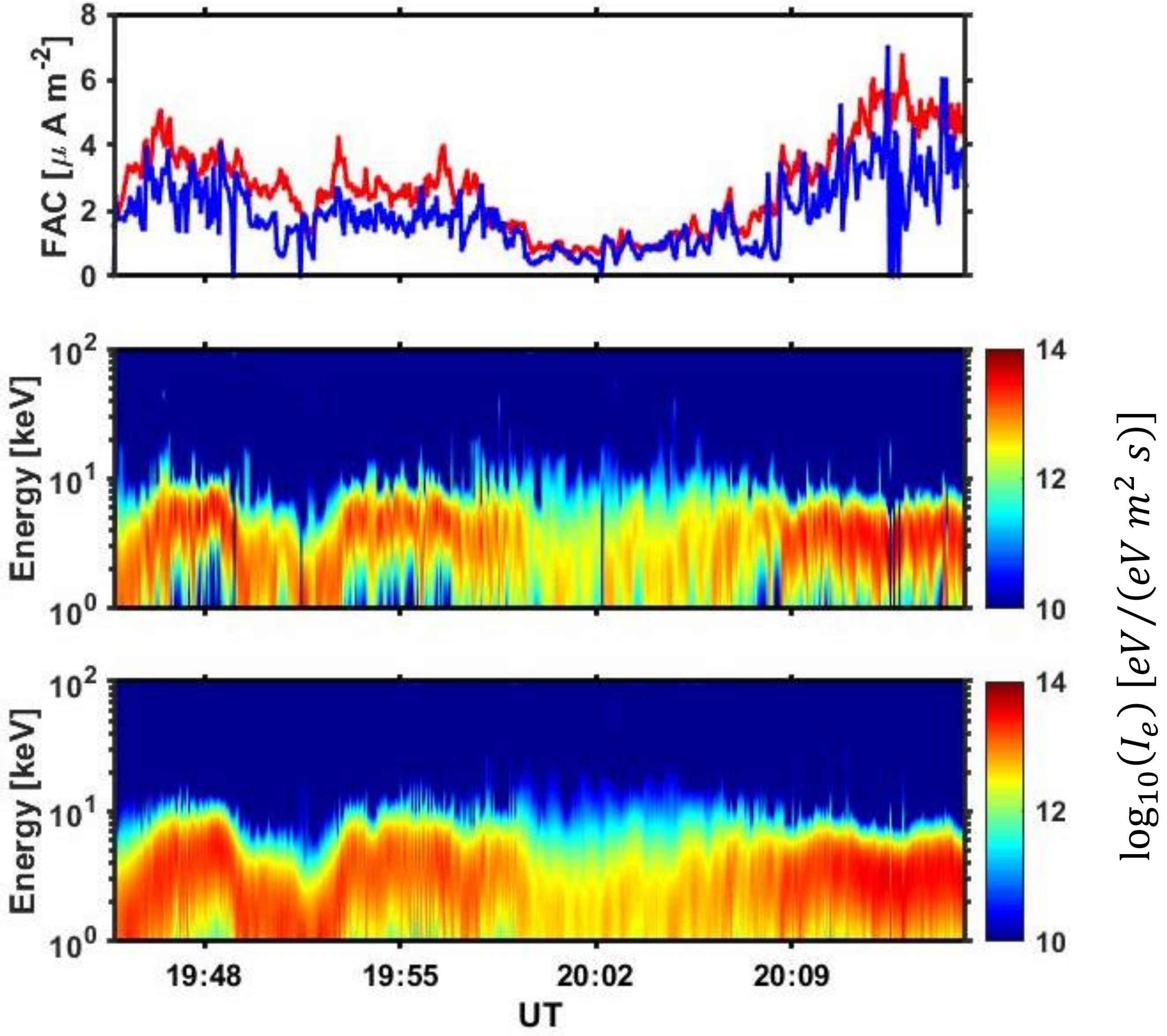
- We investigated the 2016/03/09 auroral event using data from EISCAT UHF radar observation in Tromsø, Norway.

Energy Spectra Analysis, Raw vs BAFIM N_e



- Top: raw electron density, evaluated under the assumption of T_e=T_i.
- 2nd : BAFIM electron density.
- 3rd : difference in N_e , (BAFIM fit subtracted from raw fit).
- Bottom: temperature ratio fitted with BAFIM.
- BAFIM fitted N_e is larger than raw N_e when the electron gas is heated by precipitation ($T_e > T_i$).

Energy Spectra Analysis, Raw vs BAFIM N_e Cont'd



- Top: the upward field-aligned current (FAC) carried by precipitating electrons.
  - ELSPEC with raw N_e (blue).
  - ELSPEC with BAFIM fitted N_e (red).
- Middle: energy spectra calculated using raw electron density.
- Bottom: energy spectra calculated using electron density fitted with BAFIM.

Energy Spectra Analysis, Raw vs BAFIM N_e Cont'd

- Considerable differences can be observed both in the FAC and energy spectra.

- ELSPEC with BAFIM fitted N_e produces wider energy spectral shapes than ELSPEC with raw N_e.

- More soft (less energetic) electrons are observed with BAFIM fitted N_e than with raw N_e, because the raw N_e underestimates the electron density in the upper part of E region.

- Current densities become higher for BAFIM fitted N_e than with raw N_e.

Summary

- We used the Bayesian filtering method (BAFIM) to fit the plasma parameters, including the ion composition with short time steps (6 s).
- The BAFIM fit produces an estimate of the ion composition profile and as a result clear artefacts from the ion temperature profiles are removed.
- Differential energy spectra and FAC calculated with ELSPEC using raw N_e and BAFIM fitted N_e as inputs may be considerably different, especially if T_e is elevated.
- ELSPEC with BAFIM fitted N_e gives larger fluxes of low-energy electrons than ELSPEC with raw N_e, because the raw N_e are underestimates in the upper part of E region during electron heating.

References

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