Data Assimilation Retrieval of Electron Density Profiles from Radio Occultation Measurements

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Motivation
Assimilation method
Results and Validation
Conclusion
Two Abel retrieval methods to derive electron density profiles from RO measurements:
1. Bending angle
2. TEC along the GPS ray

Current CDAAC electron density retrieval: TEC based Abel retrieval, several assumptions are used:
1. Linear relationship between refractivity and electron density
2. Straight-line signal propagation
3. Circular satellite orbit
4. First-order estimate of electron density at the top
5. Spherical symmetry of electron density
Abel Retrieval Error

110 km

220 km

COSMIC Abel retrieval from NeQuick model

Unit: $1 \times 10^{11}/m^3$
Assimilation method and parameter choice

\[ x_t^a = x_t^b + K(y_t - Hx_t^b), \]
\[ K = P_t^b H^T (HP_t^b H^T + R)^{-1}, \]
\[ P_t^a = P_t^b - P_t^b H^T (HP_t^b H^T + R)^{-1} HP_t^b \]

\( \Box \) \( P_{ij} = r_1 x_i^b x_j^b e^{-d_{ij}/L} \quad r_1 = 0.01 \)
\( \Box \) \( R_{ij} = r_2 y^2 \delta_{ij} \quad r_2 = 0.001 \)
- **Grid division**
  - Latitude: 2.5 degree; Longitude: 5 degree; Altitude: 2.5 km
  - For one occultation event, there are ~6000 grid points that GPS rays pass through
Ionospheric Correlation Length

- **Factor** vs. **Local Time**
- **Meridional Correlation (°)** vs. **Latitude (°)**
- **Zonal Correlation (°)** vs. **Latitude (°)**
- **Vertical Correlation (km)** vs. **Altitude (km)**
Step 1: Retrieval Real Data

1: Abel Retrieval (Spherical Symmetry)
   Background Model: IRI
   Input: Real F107

2: Data Assimilation (DA) Retrieval
   Background Model: IRI
   Input: Real F107

Step 2: Simulation

1: Simulate the Occultation side slant TEC by NeQuick Model (input real F107)
2: Abel retrieval simulated sTEC
3: Data assimilation Retrieval the simulated sTEC
   and obtain the EDP along the tangent point

<table>
<thead>
<tr>
<th></th>
<th>Background</th>
<th>F107</th>
</tr>
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<tbody>
<tr>
<td>DA1</td>
<td>NeQuick</td>
<td>real</td>
</tr>
<tr>
<td>DA2</td>
<td>IRI</td>
<td>real</td>
</tr>
<tr>
<td>DA3</td>
<td>IRI</td>
<td>Real+40</td>
</tr>
</tbody>
</table>
Occultation event distribution during the selected day (2009.266). Also shown is the co-located Ionosondes and profile number (22 stations, 72 profiles in total)
Results 1:

An example of DA retrieval of simulated TEC by three different backgrounds.
Results 2:

✓ Comparison of NmF2 & hmF2 of 3 DA retrievals from simulated TEC
Comparison of all Ne and error statistical of Abel retrieval and DA2 retrieval from simulated TEC
Validation 1: Comparison of EDP retrieved by Abel and DA method between two co-located cases in the same time.

data assimilation retrieval is less influenced than Abel method by the ionospheric inhomogeneity.
Validation 2: (Simulation)

- Comparison of the latitude and altitude Ne and its retrieval error from simulation
- LT=13
- Manmade plasma cave disappears in DA retrieval.
Comparison of Ne retrieved from real data by Abel and DA

LT=13
Validation 3: (Simulation)

Comparison of Ne and its error from simulation
Cont. (real data)

✓ LT-MLat variation of Ne from real data
Validation4: (With Ionosonde)

✓ An example of retrieved EDPs in comparison with co-located Ionosonde EDP
Statistical comparison with co-located Ionosonde data (below hmF2 Ne)

a)

Abel Retrieved Ne (10^6 cm^-3)

Ionosonde Ne (10^5 cm^-3)

N = 1526

r = 0.91

RMSE = 0.58

b)

DA Retrieved Ne (10^6 cm^-3)

Ionosonde Ne (10^5 cm^-3)

N = 1526

r = 0.94

RMSE = 0.45

c)

d)

Histogram of dNe(Abel Retrieved-Ionosonde(10^5 cm^-3))

Histogram of dNe(DA Retrieved-Ionosonde(10^5 cm^-3))
Conclusion:

✓ Data assimilation Retrieval has a better performance than Abel retrieval from simulation study.

✓ DA method can improve the retrieval especially around and below F2 peak region.

✓ The climate features such as manmade plasma cave (also call 3 E layer peaks) are improved by Data assimilation retrieval.

✓ Comparison with Ionosonde data confirms the validation of DA retrieval method.