Application of Uncertainty of COSMIC RO Signals to Derivation of Dynamic RO Errors for Data Assimilation in the Low Troposphere

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Physical uncertainty in RO bending angle and refractivity related to water vapor in the tropical troposphere varies substantially (from low to very high).

Statistical and empirical RO error variances for data assimilation usually do not consider the uncertainty of individual RO and only vary in latitudes and height.

This may result in over-weighting of bad RO and under-weighting of good RO in assimilation.

COSMIC recently developed a few physical parameters which measure the uncertainty of RO in the tropical lower troposphere.

We use these parameters to develop uncertainty-based RO error variances and quality controls to improve RO assimilation.
Outline

• Uncertainty of COSMIC ROs in the Tropical Low Troposphere and the Definition of Local Spectral Width (LSW)
• Large Bending Angle and Refractivity Errors of COSMIC ROs in the Presence of Large LSWs
• Development of LSW-based Dynamic Error variances for RO Bending Angle and Refractivity Assimilation
• Incorporating the Dynamic Error variances into RO Refractivity Data Assimilation and Subsequent Forecasts
A measure of the N fluctuations from the structure of RO signal
(from Sergey Sokolovskiy)

The structure of RO signal transformed to impact parameter representation has the information of N fluctuations. Increase of the Local spectral width of spectrogram (LSW, Gorbunov et al., 2006) is caused by N fluctuations.

• A larger LSW indicates a higher uncertainty in determining the dominating bending angle
• A large LSW does not necessarily lead to a large error for an individual RO

Local Spectral Width (LSW) = BA₂ - BA₁

Spectrograms of RO signals

low latitudes (strong N fluctuations, high BA uncertainty below a certain height)
Scatter Plot of the Uncertainty estimate by LSW for COSMIC ROs during April 21-25, 2012 in the Tropics

- LSW varies greatly from one RO to another in the tropical low troposphere
- Many ROs have high LSW values (e.g., > 20%) below 6 km
Spatial Distribution of LSWs of COSMIC ROs during April 21-25, 2012 in the Tropics

- ROs with LSW >35% occurred over oceans
- ROs with LSW <20% occurred over both oceans and land
Errors of bending angle and refractivity increase approximately linearly with respect to LSW.

(RO data were not assimilated in ECMWF analysis below impact height of 5 km)
• RO error variances are estimated using Hollingsworth method (Wee, 2016)
• The RO error variances and LSW/2 have similar structure in the low troposphere
The statistical errors increase approximately linearly with respect to LSW/2.

Relationship of LSW to RO BA/N Errors within 1-1.5km

Bending Angle

Refractivity

Correlation = 0.95

Correlation = 0.96
Dynamic BA/N Error Variances as a Linear Function of LSW

Obtained by a linear regression using LSW/2 as a predictor

\[ \sigma_{\alpha,LSW}^2 = a_{1,\alpha} \frac{LSW}{2} + a_{2,\alpha} \]

\[ \sigma_{N,LSW}^2 = a_{1,N} \frac{LSW}{2} + a_{2,N} \]

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<th>coef2</th>
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<table>
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<th>Impact height (km)</th>
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<tr>
<td>7</td>
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The non-zero constant coefficients of coef2 and coef4 indicate contributions of other error sources.
Global Distribution of LSW-derived BA/N Errors Variances

(June-August, 2008, 0-1.5km)

The dynamic error variances show substantial zonal variations.
Impacts of LSW-derived Refractivity Error Variance on Refractivity Assimilation and Forecasts

- Super-typhoon Sinlaku (2008) case (September 9-12, 2008)
- GSI/WRF hybrid EnVar
- Assimilate refractivity over western Pacific at 16-km resolution

- Two experiments:
  - **CTLE** run: use GSI default static refractivity error
  - **LSWE** run: use LSW-derived refractivity error
Comparison of the Magnitudes between Dynamic and GSI Static Refractivity Error Variances

- Green dots: LSWE < CTRL by 20%
- Red dots: LSWE > CTRL by 20%
- Black dots: LSWE = CTRL

CTRL: GSI static refractivity error variance
LSWE: LSW-derived dynamic error variance

12Z September 9-12, 2008, at 3.5 km
This COSMIC RO is located at (24.7N, 131.4E), 0547Z September 12, 2008.

- This RO profile has low LSW and good quality
- LSWE analysis fits closer to the RO observations than CTRL analysis
Analysis Fits to a RO Profile with high LSW

This COSMIC RO is located at (26.8N, 133.3E), 0428Z September 12, 2008.

- This RO profile has high LSW below 4.5 km and low quality
- LSWE analysis fits less closer to the RO observations than CTRL analysis
Mean Errors of Refractivity Analysis at 700 hPa
Compared with NCEP Analysis (September 9-12, 2008)

LSWE analysis has smaller bias than the CTRL.
Comparison of Water Vapor Analysis with Radiosondes

(averaged for all radiosondes in 110E-170E, 0-55N at 12 Z September 9-12, 2008)

The LSWE analysis has smaller biases and RMS errors at radiosonde locations than those of CTRL.
Means of Three-day Track Forecasts of Typhoon Sinlaku (2008)

(September 9-12, 2008, a total of 13 forecast cases)

• Red line: CTRL mean track
• Green line: LSWE mean track
• Black line: Observed track
Mean Errors of 200 hPa Wind for 3-day Forecasts Compared with NCEP Analysis (September 9-12, 2008)

The LSWE forecasts have smaller southward wind biases over Eastern China Sea than those of CTRL.
Summary and Conclusions

• Demonstrated that the errors of COSMIC RO BA/N are substantially higher over the tropical low troposphere where LSW are large

• Proposes new LSW-derived dynamic error variances for RO BA/N, assimilation

• Preliminary results of the COSMIC RO refractivity assimilation experiments demonstrated that an incorporation of the dynamic error variances into the GSI system bought positive impacts on the analysis and forecasts in the tropical low troposphere as well as tropical cyclone forecast