Dynamic statistical optimization of GNSS radio occultation bending angles: an advanced algorithm and performance analysis results

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Introduction

Outline

1. **Background and motivation**
2. **Aim and objectives**
3. **Methodology**
4. **Results**
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References:
1) Li, Y., G. Kirchengast, B. Scherllin-Pirscher, S. Wu, M. Schwaerz, J. Fritzer, S. Zhang, B.A. Carter, and K. Zhang (2013), A new dynamic approach for statistical optimization of GNSS radio occultation bending angles for optimal climate monitoring utility, *J. Geophys. Res. Atmos.*, 118, 13022–13040, doi:10.1002/2013JD020763.
2) Li, Y., G. Kirchengast, B. Scherllin-Pirscher, R. Norman., Y.B. Yuan, M. Schwaerz, J. Fritzer., and K. Zhang (2015), Dynamic statistical optimization of GNSS radio occultation bending angles: an advanced algorithm and its performance analysis, *Atmos. Meas. Tech. Discuss.*, 8, 811–855, doi:10.5194/amtd-8-811-2015.

Background and Motivation

Background

Statistical optimization is to combine a RO observed bending angle profile with a background profile to provide an optimal bending angle profile, and the weights of the two types of bending angles are determined by their error covariance matrices:

$$\alpha_{SO} = \alpha_b + \mathbf{C}_b\left(\mathbf{C}_b + \mathbf{C}_o\right)^{-1} \cdot \left(\alpha_o - \alpha_b\right)$$

- The more accurate the **error covariance matrices**, the better quality of the obtained optimized bending angles
- **Difficult to obtain accurate background and observation error covariance matrices**
- **Many current simplified estimation of background and observation error covariance matrices would degrade the accuracy of the resulting optimized bending angles**

Motivation: To propose a dynamic approach to estimate background and observation error covariance matrices accounting for their variations with latitude, longitude, altitude and time, and use the obtained matrices for the optimal estimation of bending angles.

Aim and objectives

Aim:

- To introduce a dynamic statistical optimization algorithm for optimal retrieval of RO bending angles

Objectives:

- To dynamically estimate background and observation error covariance matrices accounting for their variations with latitude, longitude, altitude and time.
- Use the dynamically estimated background and observation error covariance matrices in statistical optimization for optimal estimation of bending angles
- To confirm the long-term stability of the new approach

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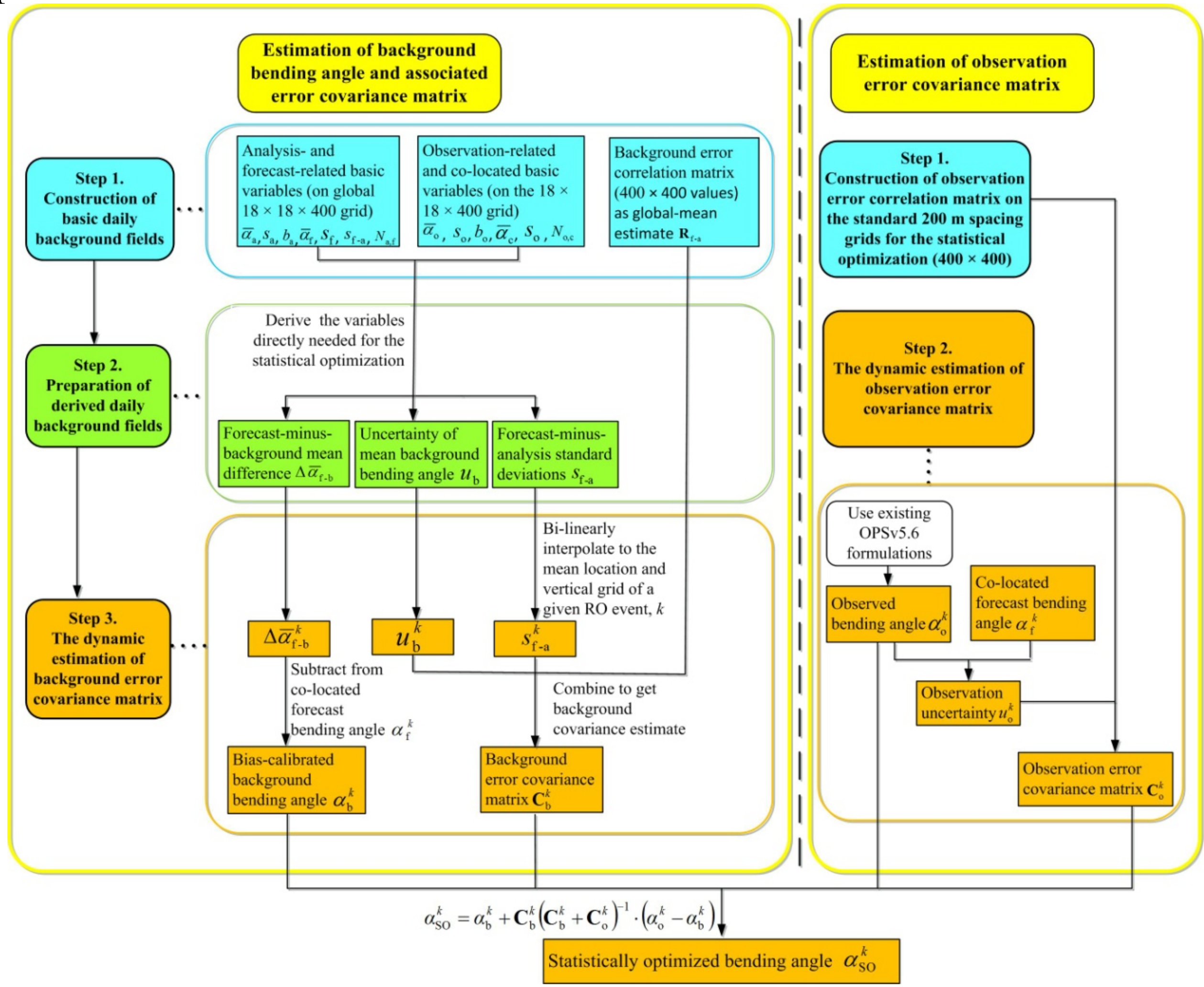
Methodology

➢The idea of the dynamical estimation of the background and observation error covariance matrices is to develop a daily updated error fields based on pre-defined latitude, longitude and altitude (3-D) grids. The ECMWF forecast fields are used to provide background information

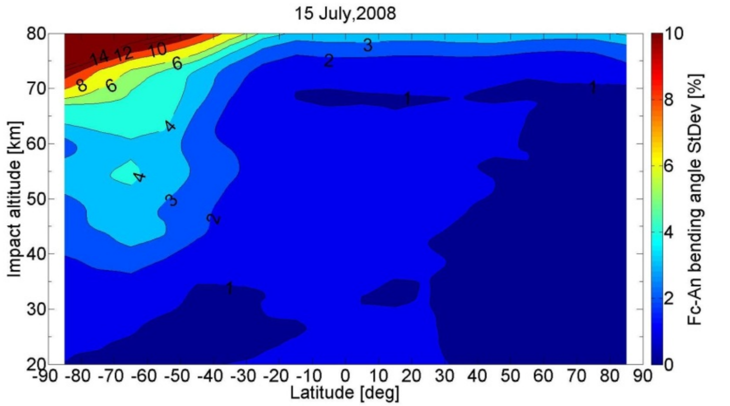
➢This daily error fields contain background uncertainties on the pre-defined 3-D grids, and a global-mean error correlation matrix for both background and observed bending angles

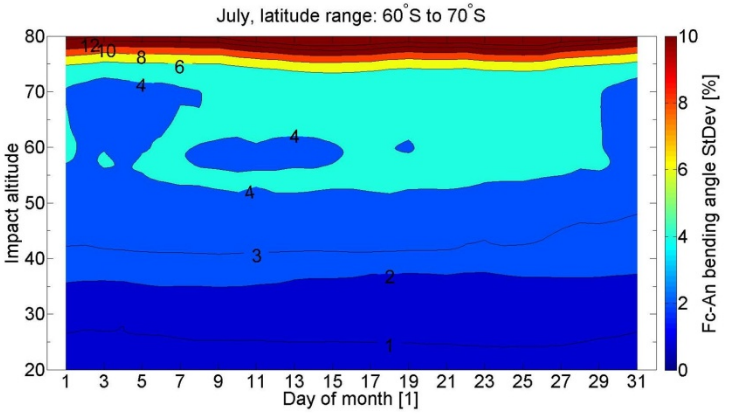
➢For any coming in RO events, we would read in the background uncertainties and the two global-mean correlation matrices from the constructed error fields and then use these variables to construct background and observation error covariance matrices. Therefore, we consider that the resulting matrices are constructed accounting for their variations with latitude, longitude, altitude and time.

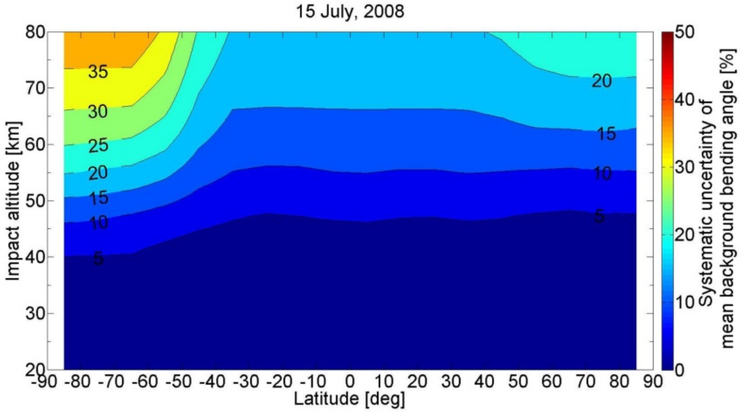


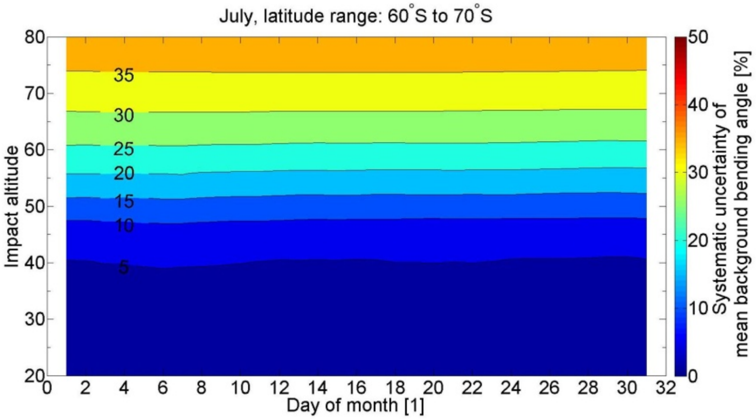
Flowchart of the new dynamic statistical optimization algorithm

Key variables in the estimation of background uncertainties



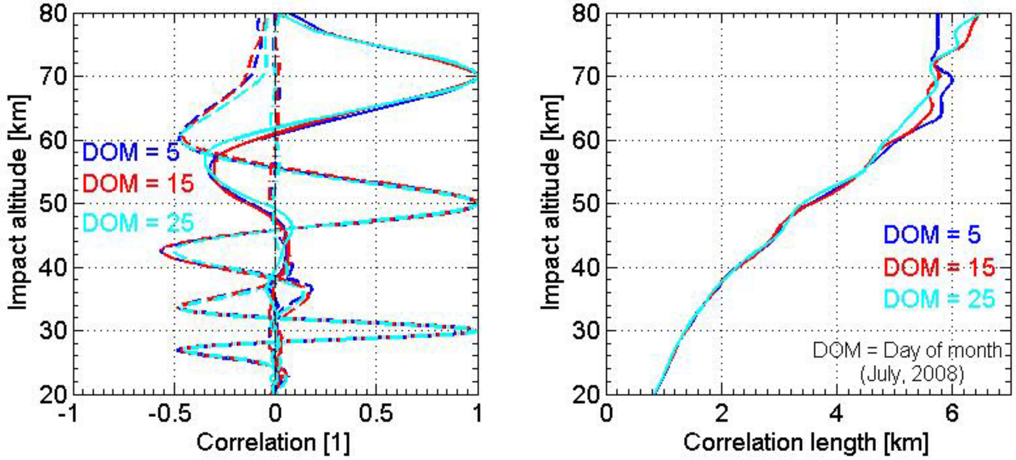




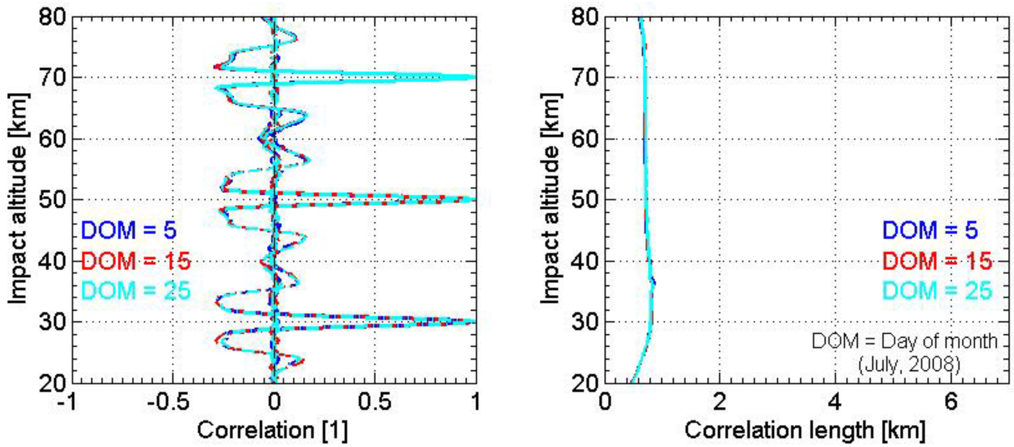


The upper two panels show the ECMWF forecast-minus-analysis standard deviations and the bottom panels show the modeled systematic biases of ECMWF analysis bending angles. For both upper and bottom panels, the left panels show the variation of variables with latitude and altitude, and the right panels show the variations of variables with day of month and altitude in the latitude range of 60ºS to 70ºS .

Global-mean correlation functions and correlation lengths of background and observation errors



Global mean correlation functions and correlation lengths of background errors



Global mean correlation functions and correlation lengths of observation errors

- Both background and observation correlation functions show a near-Gaussian shape at the main peak, followed by two negative side peaks, and then generally two small positive peaks.
- The correlation length of the background errors is ~0.8 km at 20 km and then linearly increases to about 6 km at 80 km.
- The correlation length of the observation errors stays around 0.7–0.8 km in the full height range from 20 km to 80 km
- Both background and observation correlation functions and correlation lengths vary little with day of month

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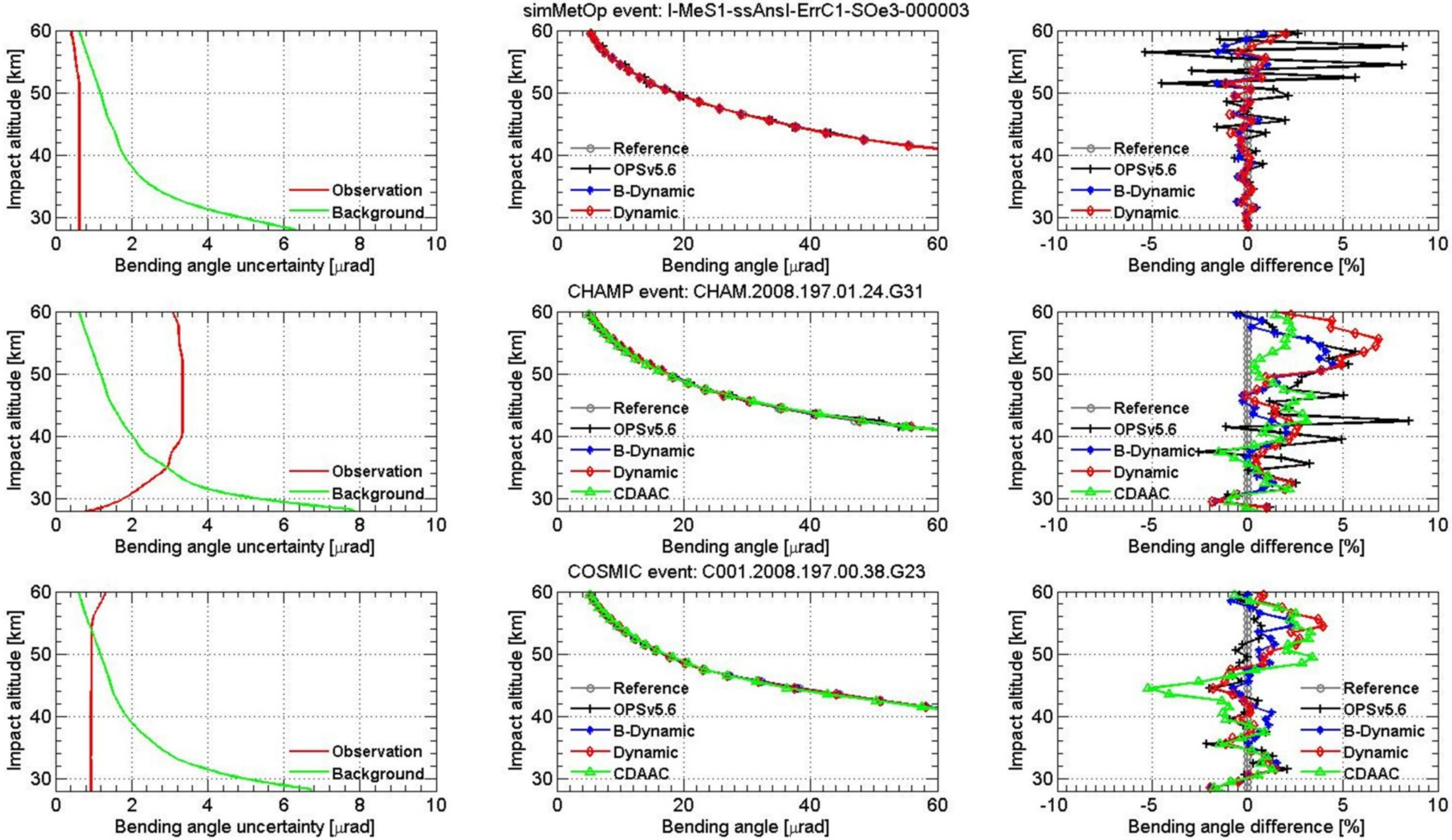
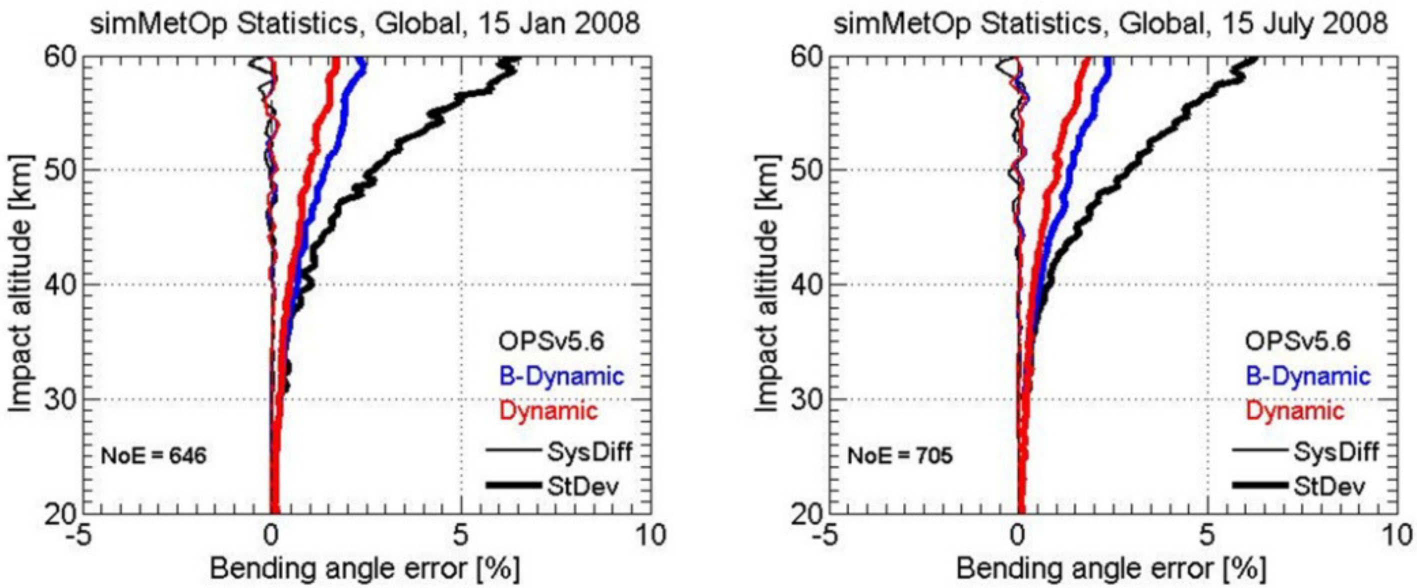
Individual bending angle results



The top, middle and bottom panels show individual bending angle results for simulated MetOp, CHAMP and COSMIC events respectively. The left panels show the estimated background and observation uncertainties for corresponding RO events, the middle panels show bending angles profiles obtained from different approaches, and the right panels show the differences of bending angle relative to reference bending angles. Reference represents ECMWF co-located data, OPSv5.6 represents the algorithm used in OPSv5.6 software, b-dynamic represents results obtained from using newly estimated background error covariance matrices only, and dynamic represents the new approach, CDAAC represents data downloaded from CDAAC.

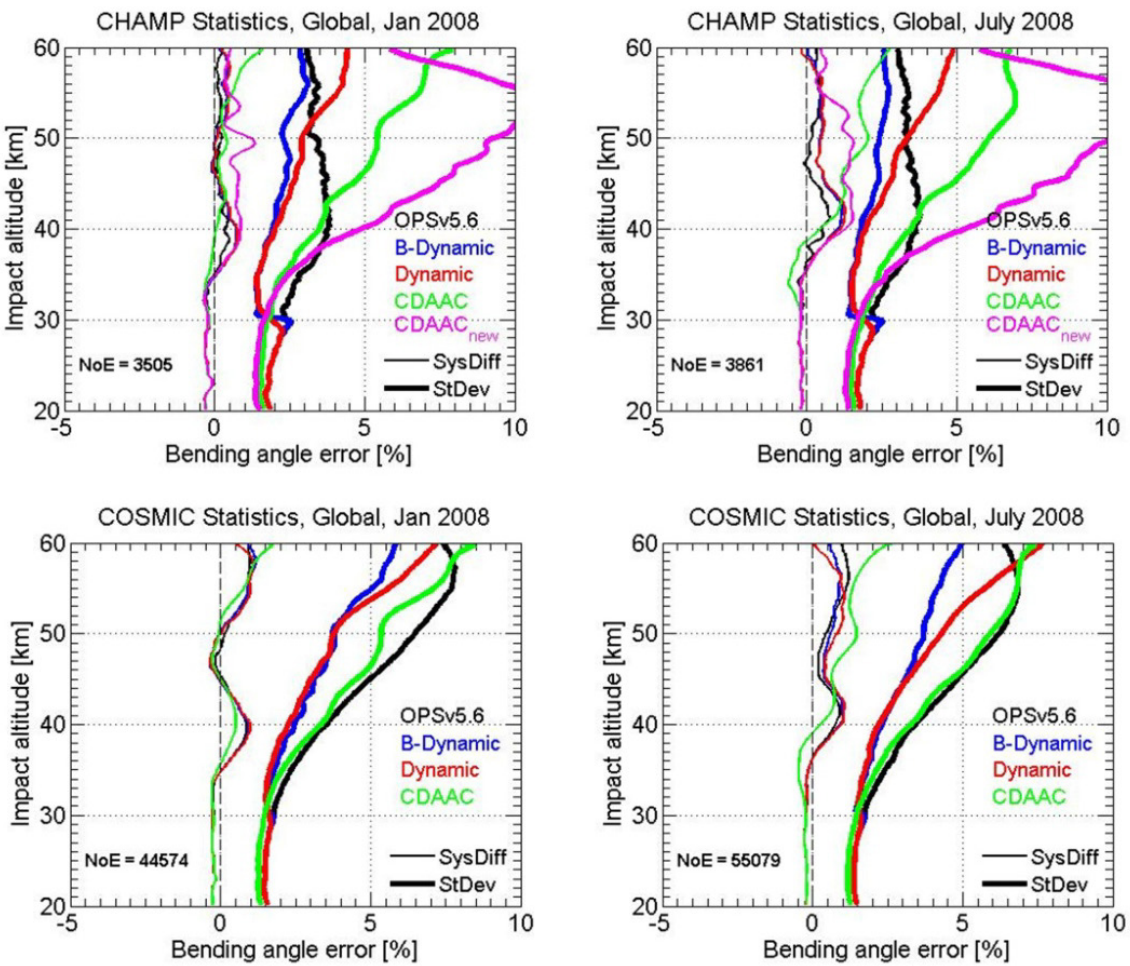
Statistical bending angle errors of simulated MetOp data



Systematic differences and its standard deviations of statistically optimized bending angle relative to simulated "true" bending angles of the global ensemble of simulated MetOp events on 15th January and 15th July 2008. Statistics of the OPSv5.6 (black), b-dynamic (blue) and dynamic (red) statistical optimization algorithms are shown.

- The systematic differences and its standard deviations of bending angles from the dynamic algorithm are smallest.
- These results for the simulated events are very encouraging and confirm the fundamental capabilities of the dynamic algorithm

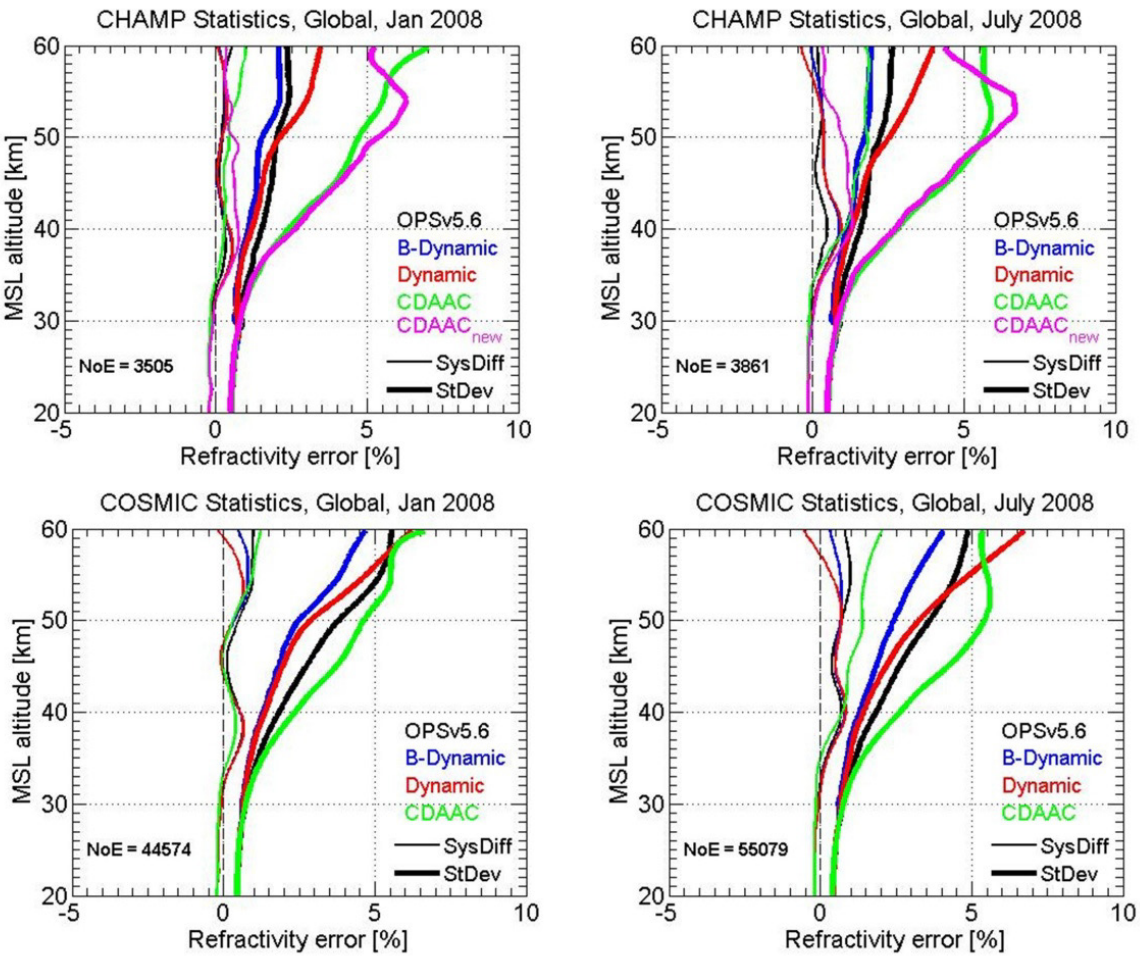
Statistical bending angle errors of CHAMP and COSMIC



- ➢Compared to the OPSv5.6 algorithm, the dynamic algorithm can obviously reduce the random errors of optimized bending angles in the stratosphere
- ➢The systematic errors (biases) in the bending angles are less than or about equal to that from the OPSv5.6 algorithm

Systematic differences and its standard deviations of statistically optimized bending angle relative to co-located ECMWF analysis bending angle of the global ensemble of CHAMP and COSMIC events on January and July 2008. Statistics of the OPSv5.6 (black), b-dynamic (blue) and dynamic (red), CDAAC (version 2009.2650 for CHAMP and version 2010.2640 for COSMIC, green), and $CDAAC_{new}$ (version 2014.0140 for CHAMP, magenta)

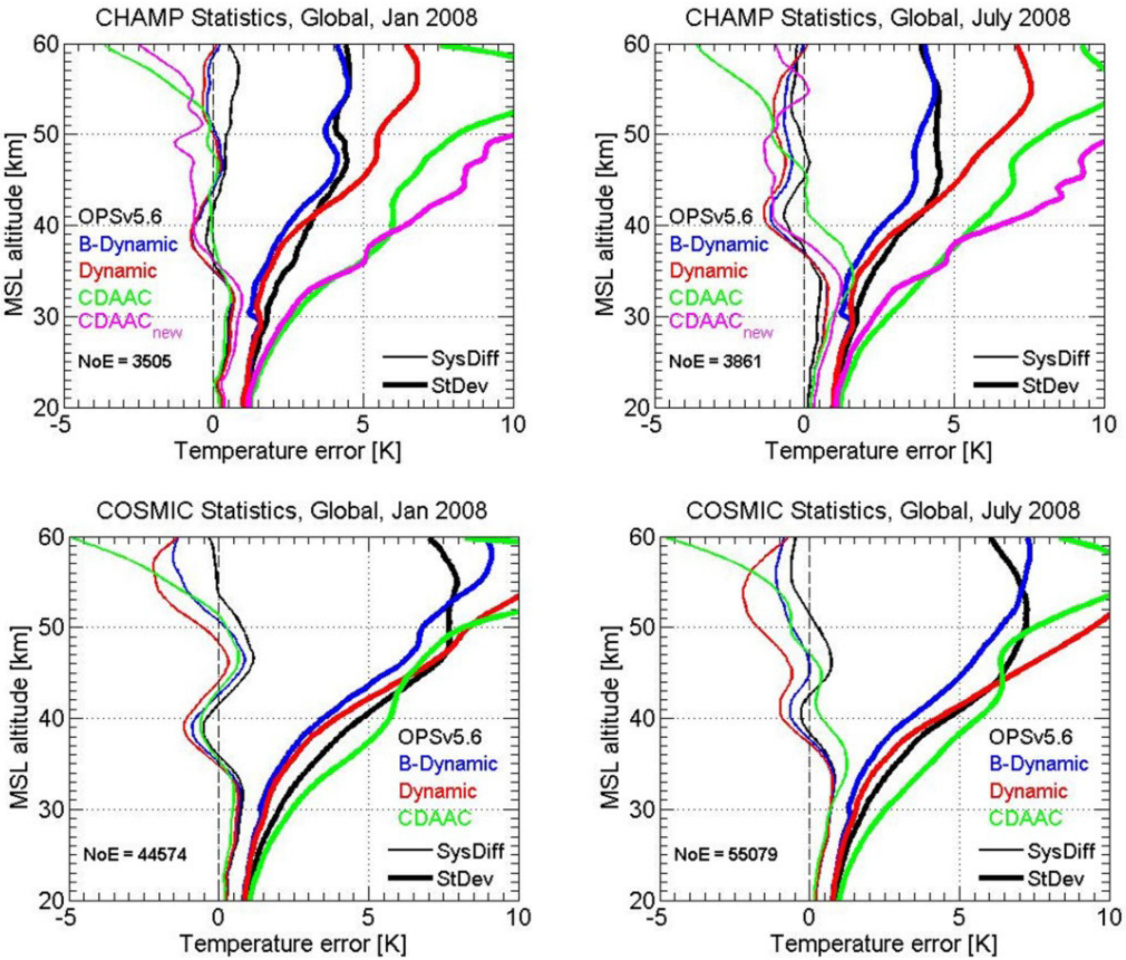
Statistical refractivity errors of CHAMP and COSMIC



- ➢Due to the smoothing function of the Abelian equation, the differences in refractivity from the various algorithms become smaller and the results are similar below about 40 km.
- ➢Compared to the OPSv5.6 algorithm, the dynamic algorithm still reveal its advantage in reducing random errors below about 50 km.

Systematic differences and its standard deviations of refractivity relative to co-located refractivity profiles from ECMWF analysis fields of the global ensemble of CHAMP and COSMIC events on January and July 2008. Statistics of the OPSv5.6 (black), b-dynamic (blue) and dynamic (red), CDAAC (version 2009.2650 for CHAMP and version 2010.2640 for COSMIC, green), and $CDAAC_{new}$ (version 2014.0140 for CHAMP, magenta)

Statistical temperature errors of CHAMP and COSMIC



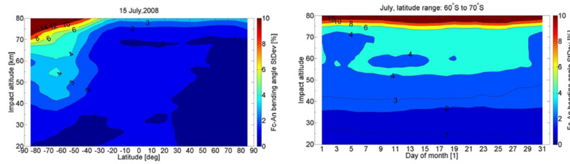
- Compared to the OPSv5.6 algorithm, the dynamic algorithm still reveal its advantage in reducing random errors below about 40 km, however, the degree of reduction are smaller than those for bending angles due to the further filtering from the hydrostatic equation.

- The temperature systematic differences of COSMIC data from the Dynamic algorithm are visibly smaller than that from the OPSv5.6 algorithm in the height range from 30 km to 40 km

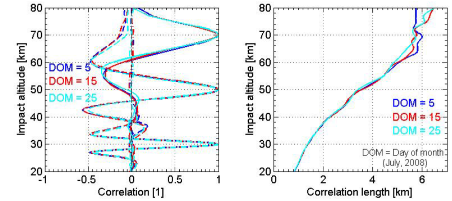
Systematic differences and its standard deviations of temperature relative to co-located temperature profiles from ECMWF analysis fields of the global ensemble of CHAMP and COSMIC events on January and July 2008. Statistics of the OPSv5.6 (black), b-dynamic (blue) and dynamic (red), CDAAC (version 2009.2650 for CHAMP and version 2010.2640 for COSMIC, green), and $CDAAC_{new}$ (version 2014.0140 for CHAMP, magenta)

Summary

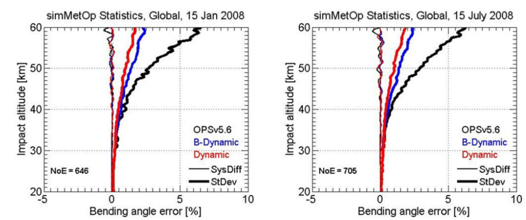
1) Developed a daily updated 3-D error fields to dynamically estimate the background and observation error covariance matrices accounting for their variations with latitude, longitude, altitude, and time.



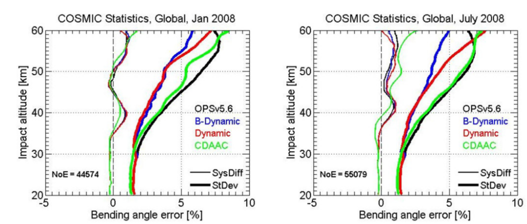
2) The newly estimated background uncertainties reveal clear variations with latitude and altitude; the estimated correlations of background and observation errors reveal near-Gaussian shape at the main peak, following by two negative side peaks; the correlation lengths of background errors vary from ~0.8 km at 20 km of altitude to ~6 km at 80 km altitude, the correlation lengths of observation errors stay around 0.7–0.8 km in the complete height range of interest.



3) Evaluation of the new dynamic approach using simulated MetOp data show that the new dynamic approach can significantly reduce the random errors of optimized bending angles compared to the OPSv5.6 algorithm, and promises to reduce systematic errors



4) Evaluation of the new dynamic approach using observed CHAMP and COSMIC data show that the new approach can also significantly reduce the random errors of bending angles, leaves less or about equal systematic differences; and the quality of the subsequently retrieved refractivity and temperature profiles is also improved



Thanks for your attention!

Comments are welcome