Toward the operational use of GPS RO observations at NOAA: evaluation of the forward operators

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Overview

- Motivation.
- Introduction to the JCSDA/GSI.
- Evaluation of the Local Refractivity and Bending Angle Operators in the GSI.
  - Observational Operator (FM, TL, Adjoint)
  - QC checks, processing, data format, errors
- Current work and short term plan.

Motivation

- To develop the infrastructure (codes, scripts, etc.) necessary to operationally monitor and assimilate radio-occultation (RO) observations at NOAA.
- Work schedule enables complete preparation of NCEP data assimilation system in time for COSMIC launch (estimated March 2006).

GSI Analysis System

- Developed by NOAA/EMC and others JCSDA partners including NASA/GMAO.
- System still under development.
- Planned to replace the NCEP's current operational Spectral Statistical Interpolation (SSI) analysis system and regional data assimilation system prior to availability of the COSMIC data.
- Characteristics:
  - The background error covariance matrix is defined in a grid space. This allows the definition of spatially varying covariance structures.
  - T254 (nx=512,ny=256 for the linear gaussian grid) with 64 levels in the vertical (from surface to about 0.27 hPa).
  - MPP code running on IBM-SP.

Refractivity Operator (I)

- Implementation and testing of the Refractivity Forward Operator for radio occultation observations in the GSI analysis system.
  - Code
    - Linear local refractivity operator
    - Full non-linear local refractivity operator
    - Improvement of the Forward Operator (see next slides).
      - Linear local operator
      - Non-linear local operator
    - Ability to ingest refractivity profiles in the system
    - Compute the innovation vector with CHAMP data
    - Tangent Linear and Adjoint codes (implemented and tested with the improved Forward Operator)

“Old” Forward Operator

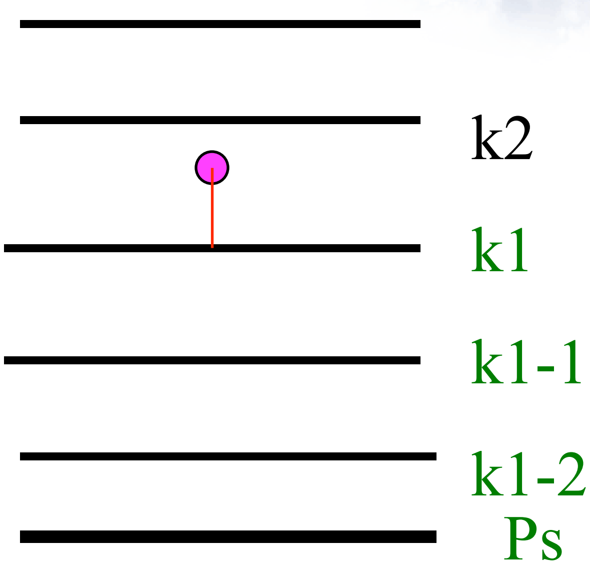
$$N = 77.6\frac{P}{T} + 3.73\times10^{-5}\frac{P_w}{T^2}$$

- (1) Geometric height of observation is converted to geopotential height.
- (2) Observation is located between two model levels.
- (3) Model variables of pressure, (virtual) temperature and specific humidity are interpolated to observation location.
- (4) Model refractivity is computed from the interpolated values.
- No pressure increments:
  - An observation of refractivity has no direct impact on surface pressure.
  - The location of an observation in a model layer is fixed in the minimization algorithm.

Improved Forward Operator

- Allow increments for pressure.
  - (1) impact on surface pressure.
  - (2) impact on (virtual) temperature of all levels below observation.
- Pressure at the observation location is computed as follows:

$$H(obs) = H(k1) + \left(\frac{R_d}{2G}\right) x[T(obs) + T(k1)] x[\ln P(k1) - \ln P(obs)]$$



$$H(k1) = H(k1-1) + \left(\frac{R_d}{2G}\right) x[T(k1) + T(k1-1)] x[\ln P(k1-1) - \ln P(k1)]$$

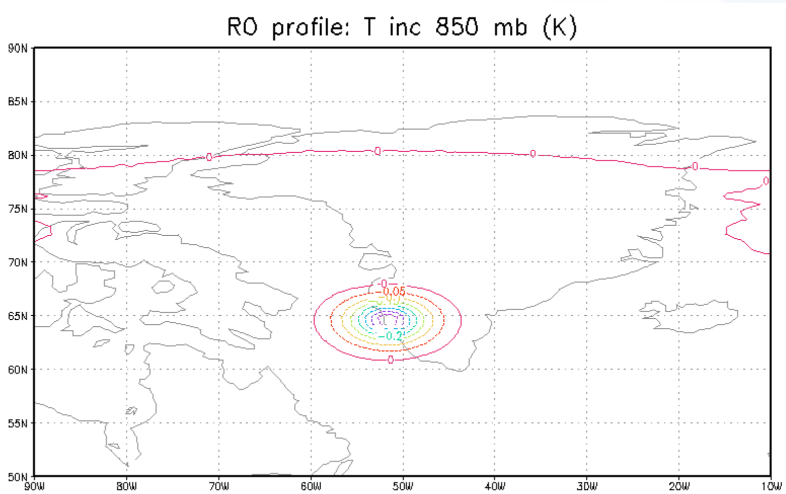
$$H(k1-1) = H(k1-2) + \left(\frac{R_d}{2G}\right) x[T(k1-1) + T(k1-2)] x[\ln P(k1-2) - \ln P(k1-1)]$$

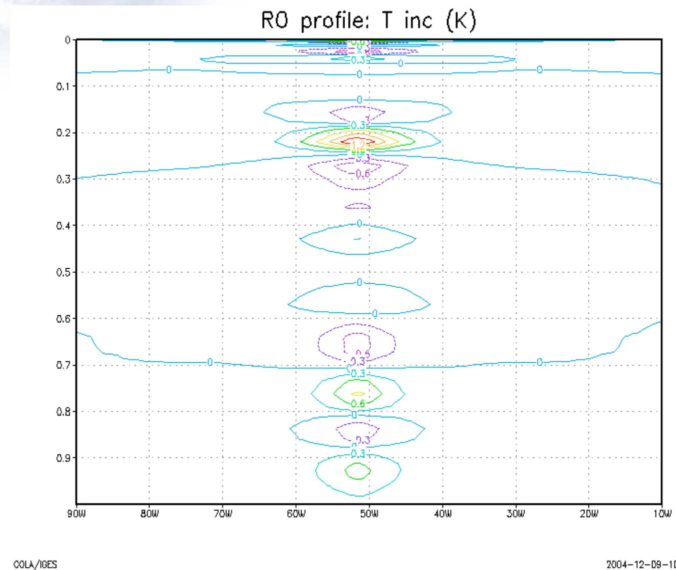
$$H(1) = H(surf) + \left(\frac{R_d}{2G}\right) x[T(1) + T(1)] x[\ln P(surf) - \ln P(1)]$$

Refractivity Operator (II)

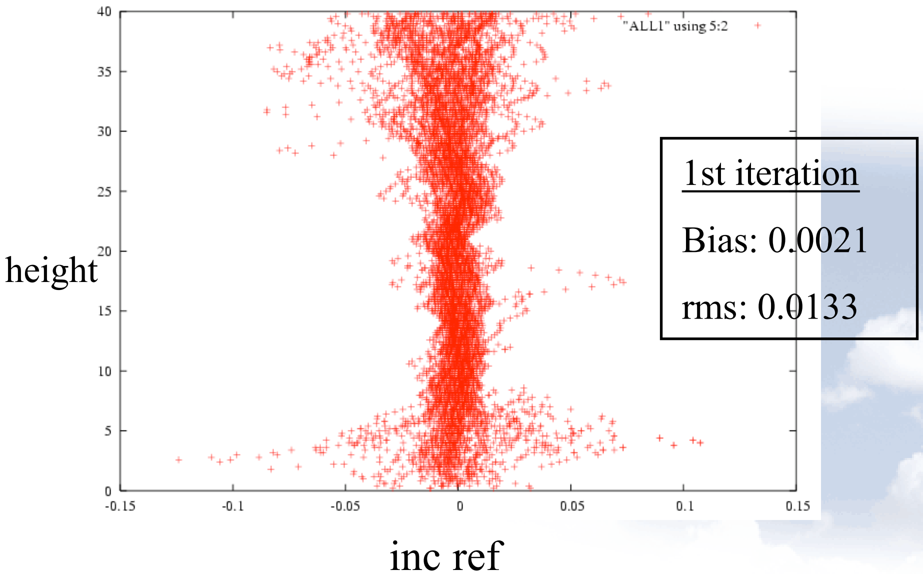
- Impact studies
  - » Assimilation of a single observation of refractivity (CHAMP)
  - » Assimilation of a single profile of refractivity (CHAMP)
  - » Assimilation of all profiles available at a given analysis time
    - Observations of refractivity alone
    - Observations of current (conventional and satellite) available observations alone
    - Both refractivity and current observations together

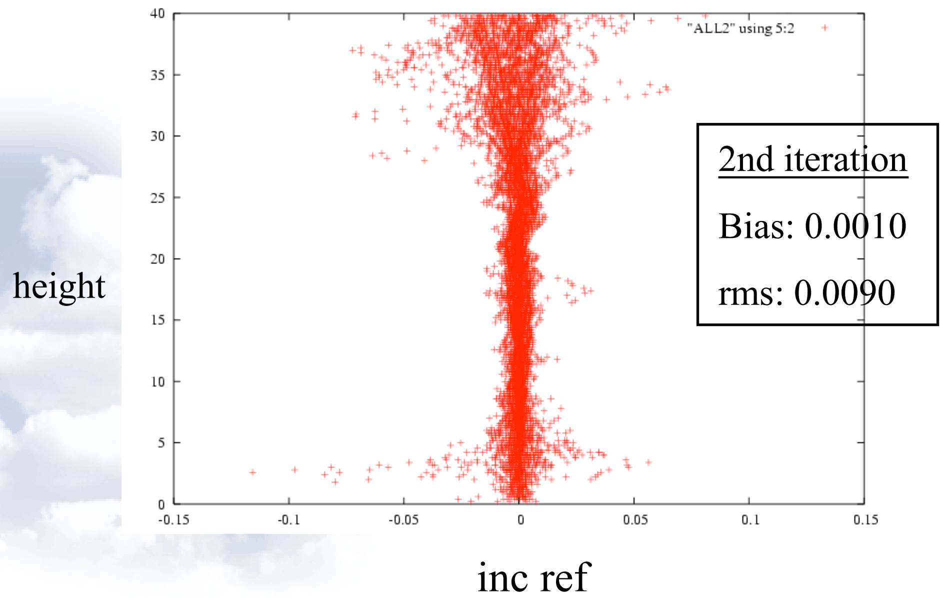
single profile (lat=65N)

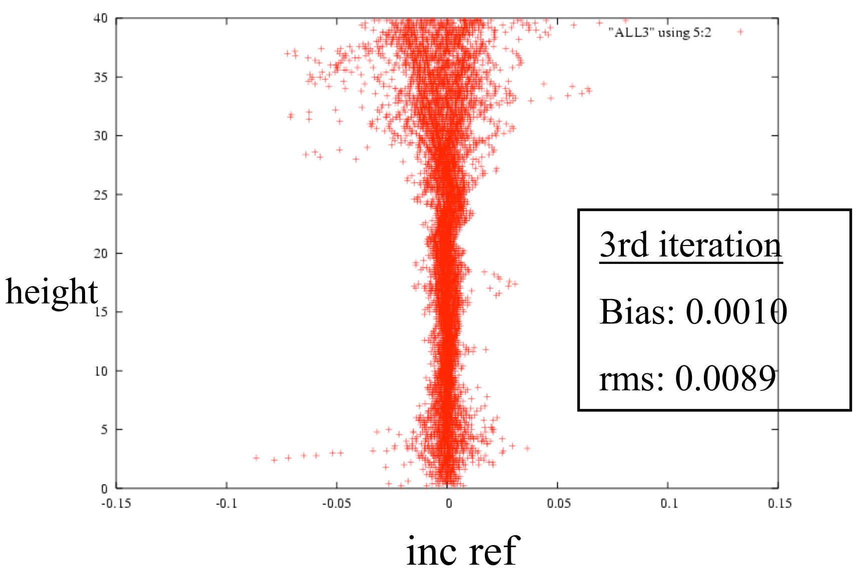




Assimilation behaves well (46 profiles)







- The analysis fits the data better after each iteration
- Some data rejected at first, get into the system in later iterations.

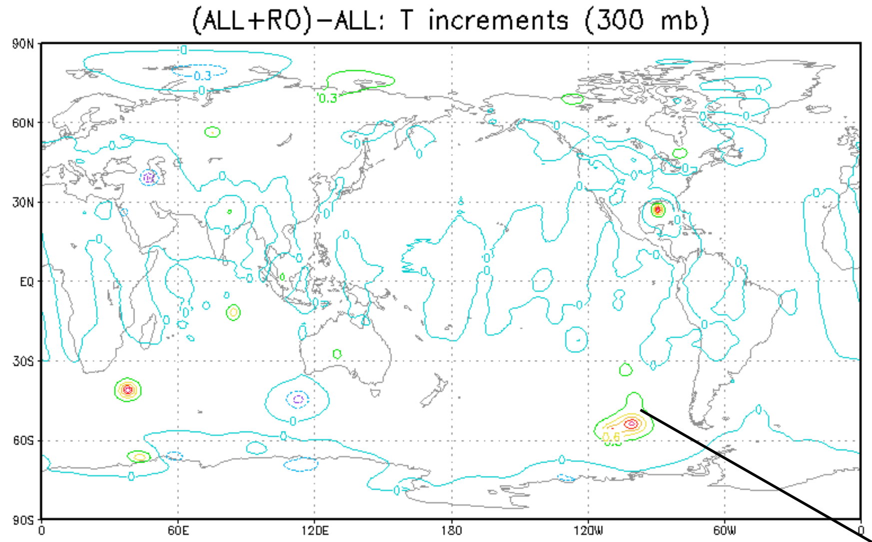
However ….

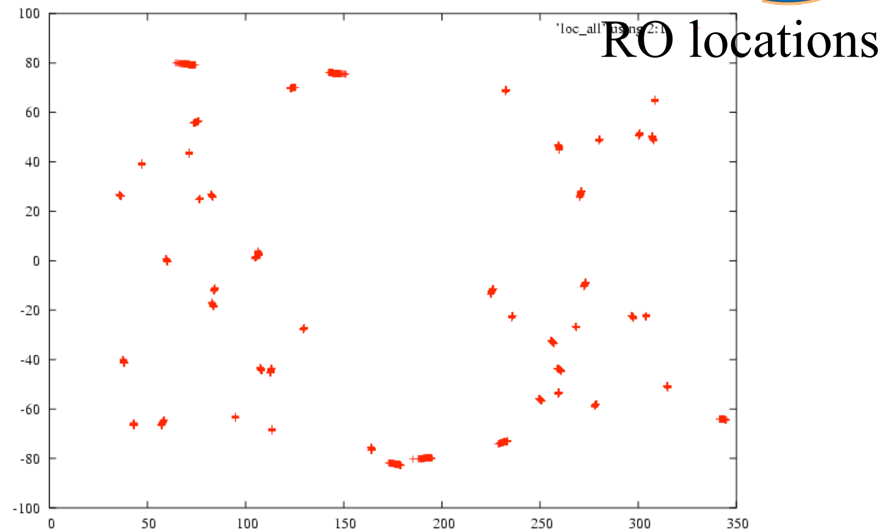
- Assimilation has less improvement above ~ 25 km
  - perturbation from the climatological guess used in the data retrieval (this should improve by assimilating local bending angle)
  - bad characterization of observational errors
  - bad QC checks in stratosphere
  - Structures not representable by the model (representativeness error)
- Some “bad” observations (i.e. do not pass the model QC checks) at the lower troposphere can get into the assimilation cycle (even if they are rejected in the first iterarion). It is very dangerous to get bad data into the system!
  - Multipath
  - tracking errors
  - superrefraction

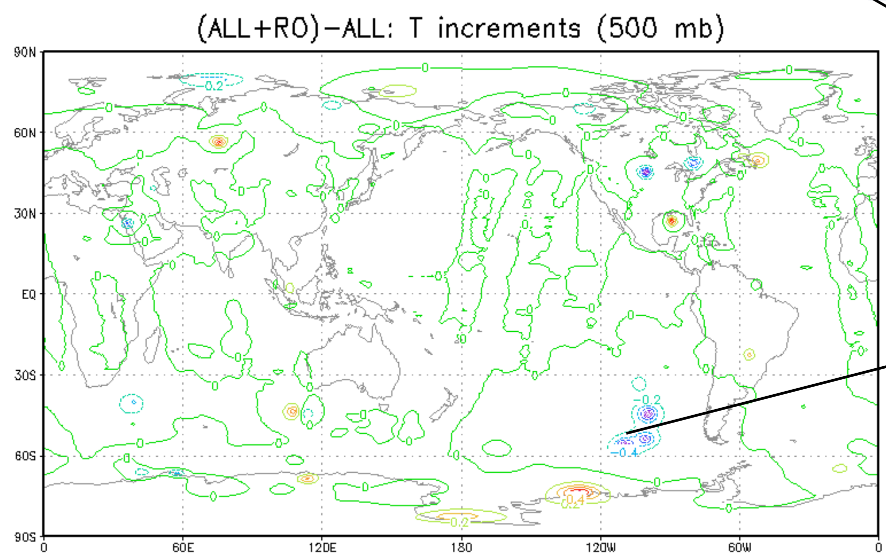
Impact of RO observations

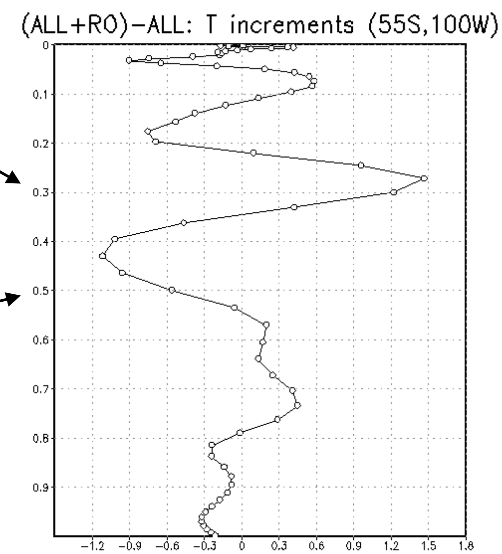
- The impact of the assimilation of the GPS RO observations must be evaluated in the context of all the other data used in real time operations.
- Hopefully, RO will provide information in some areas of the analysis in which the currently available observations are weak
  - Poor sampling
  - Large errors
  - …
- Next slide shows the impact of the RO data in the presence of all other observations (2002080812).

Assimilation of RO + other data



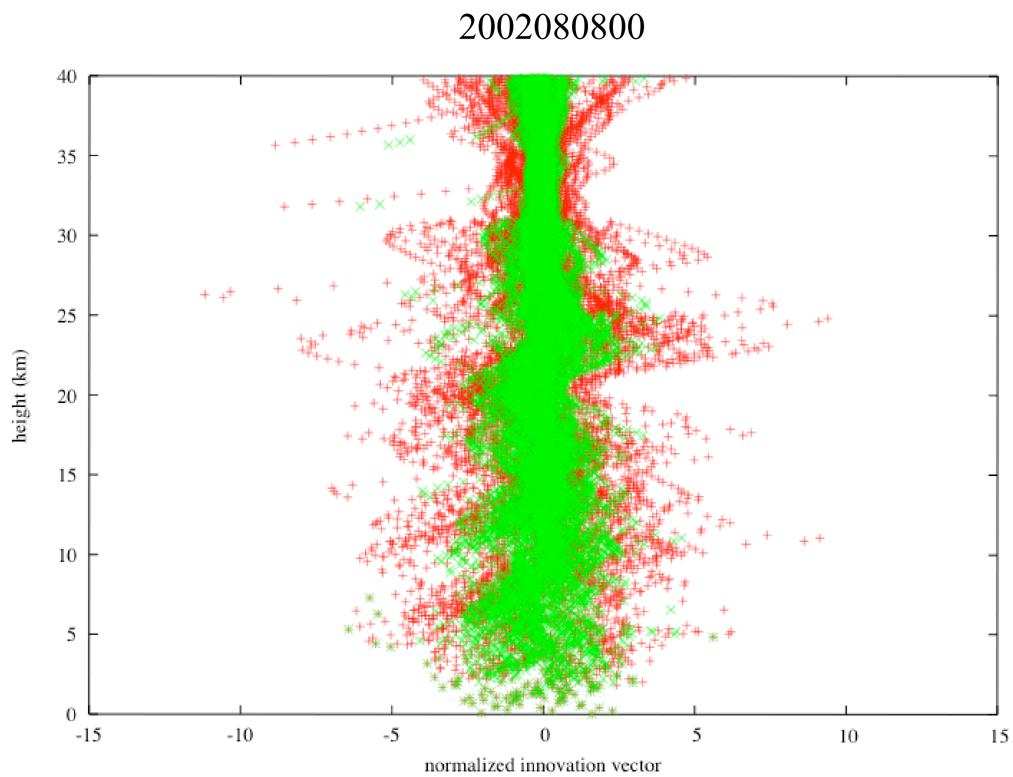






QC, processing, data format, errors (I)

– Superob vertical levels appropriate to model vertical resolution

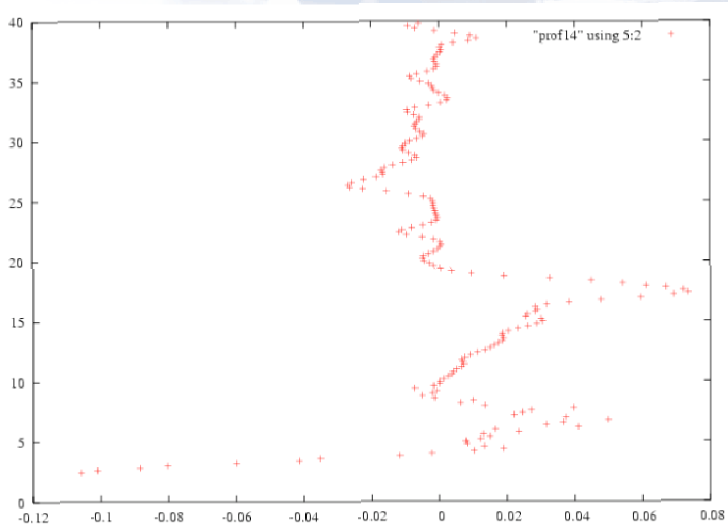


QC, processing, data format, errors (II)

- Develop the model capability to read BUFR files for radio occultation observations (WMO BUFR to NCEP BUFR).
- Provide feed-back to CDAAC on the comparison of observations and model simulations of profiles of refractivity in order to improve their QC flags in CDAAC/roam. This applies to all vertical levels, not just lower troposphere or middle-higher stratosphere.

Lat=27N, Lon=90W

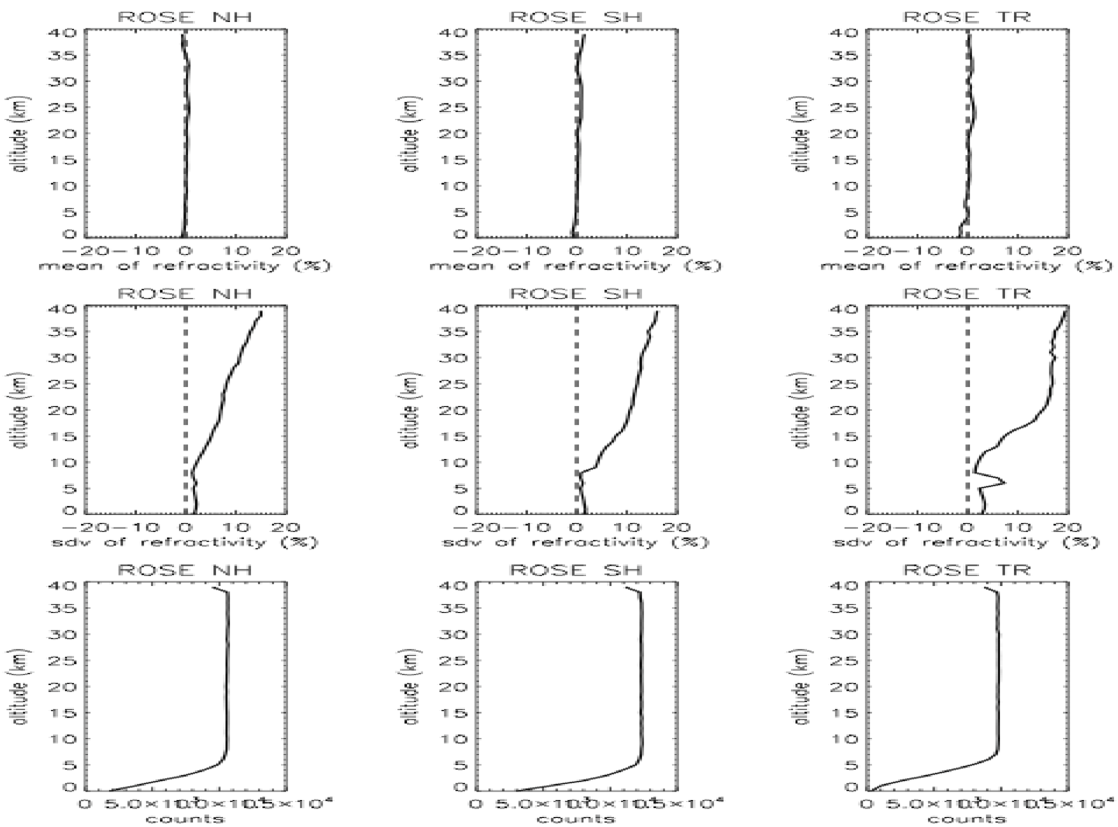
Height (km)



Incremental refractivity

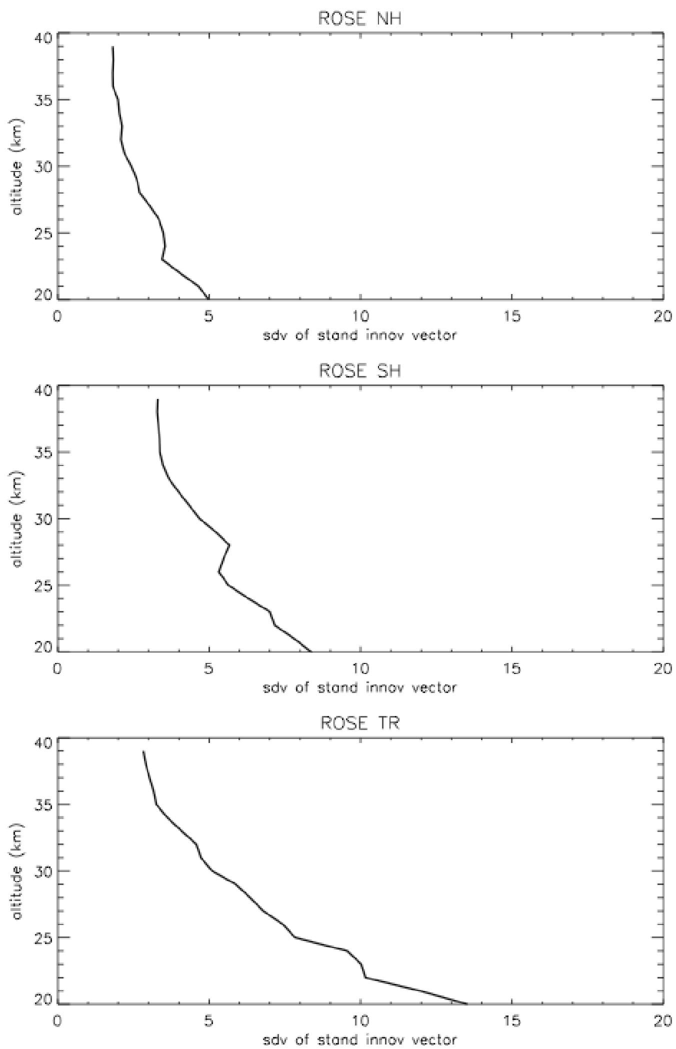
QC, processing, data format, errors (III)

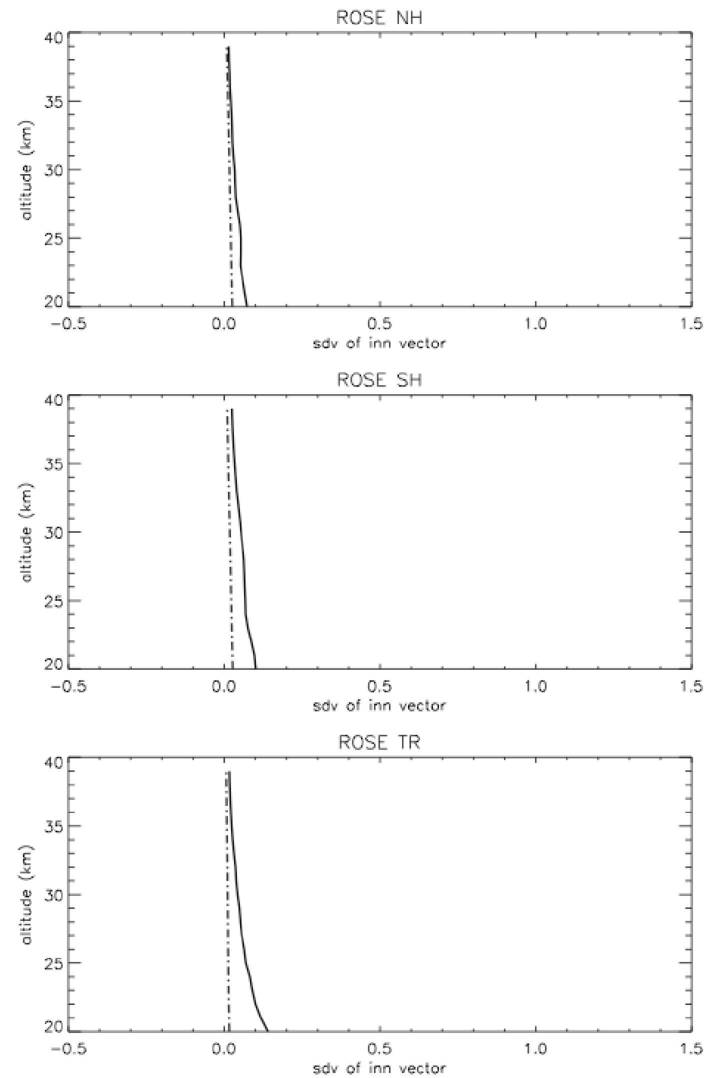
– Implementation of QC checks <u>in the code</u> (i.e. after CDAAC QC) based on a month (ROSE) comparison of observations of refractivity and model simulations



obs with pcc > 0%
(17% rejection)

QC, processing, data format, errors (IV)





Bending Angle Operator (I)

- Motivation
  - Avoid climatological effects existent in profiles of refractivity
  - Check if the structure of the errors found in refractivity still remain
- Implementation of the (Local) Bending Angle Forward Operator for radio occultation observations in the GSI analysis system.
  - Ray tracing accounts for horizontal gradients of density, but is too expensive
  - Local Bending Angle Forward Operator neglects horizontal gradients of density in the atmosphere, but it is much cheaper.
    - Forward Operator in GSI is already implemented
    - Implementation of the TL and Adjoint codes is pending.

Bending Angle Operator (II)

$$\alpha(a) = -2a\int_a^{\infty} \frac{d\ln n / dx}{(x^2 - a^2)^{1/2}} dx$$

$$(x = nr)$$

- Make-up of the integral:
  - Change of variable to avoid the singularity on a

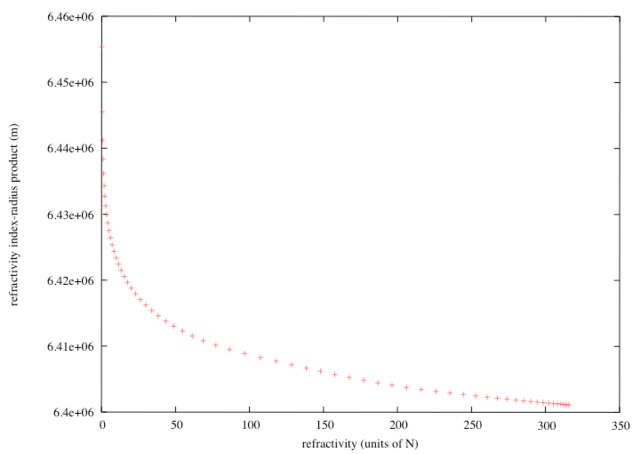
$$x = \sqrt{a^2 + s^2}$$

  - Choose an equally spaced grid to evaluate the integral by applying the trapezoid rule
  - Accurate integral

Bending Angle Operator (III)

$$\alpha(a) = -2a\int_0^{\infty} \frac{d\ln n / dx}{x}\, ds$$

- Approximations:
  - » ln(n) ~ 10^(-6)*N
  - » Refractivity N(x) varies exponentially between model levels

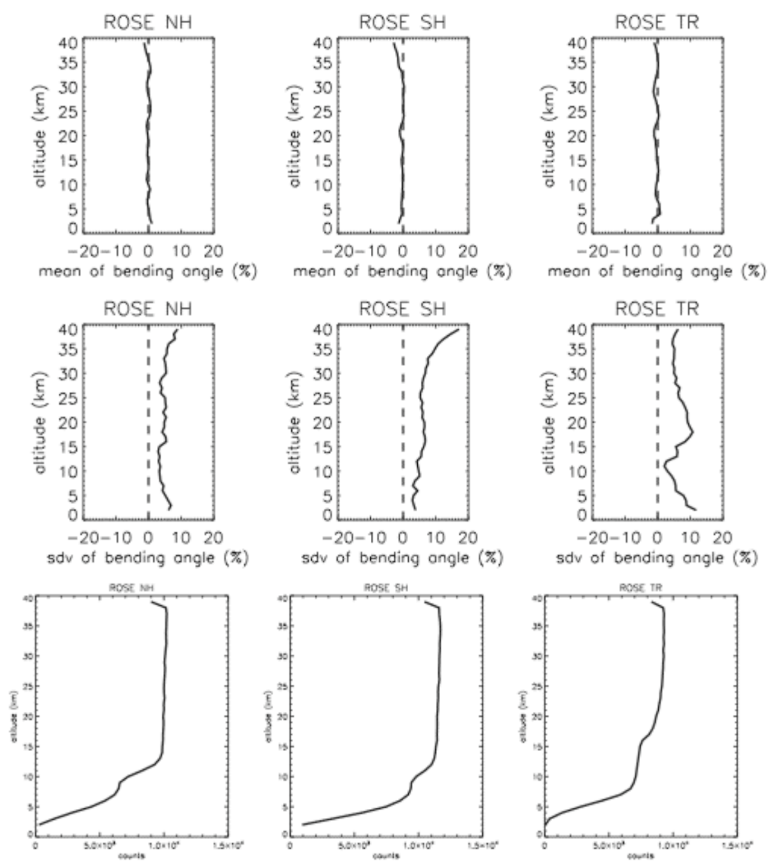


Bending Angle Operator (IV)

- Compute model geopotential heights and refractivities at the lowest tangent point of the profile
- Convert geopotential heights to geometric heights
- Add radius of curvature to the geometric heights to get the radius: r
- Convert refractivity to index of refraction: n
- Get refractional radius (x=nr) and dln(n)/dx at model levels and evaluate them in the new grid.
- Evaluate the integral in the new grid.

Paper on preparation with details on this procedure and a follow up extension of this operator.

QC, processing, data format, errors (I)



obs with pcc > 0%
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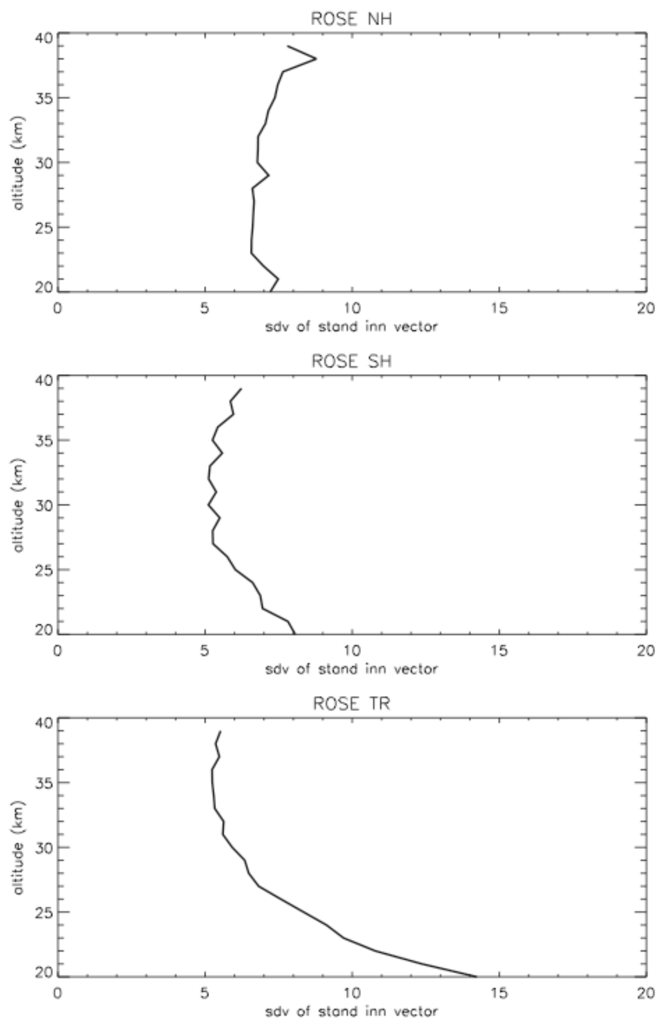
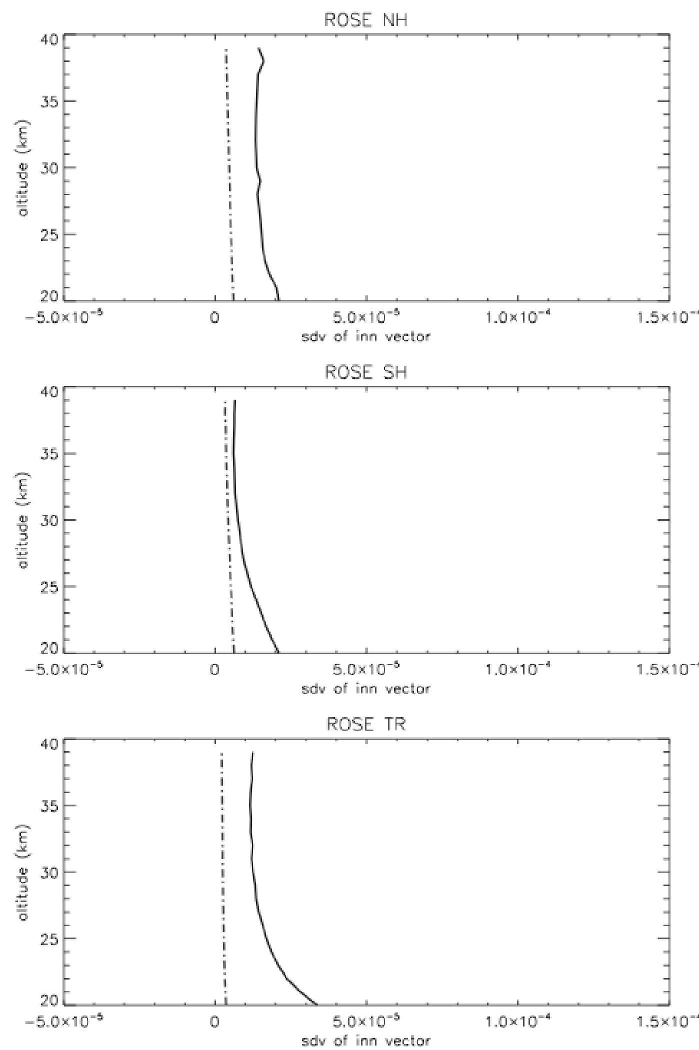
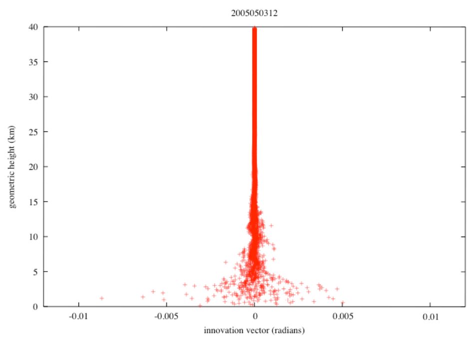
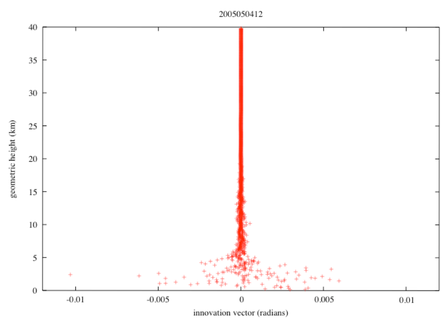
QC, processing, data format, errors (II)

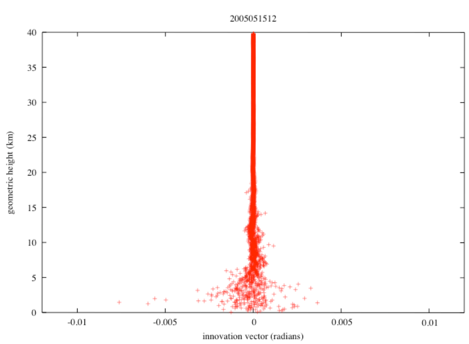


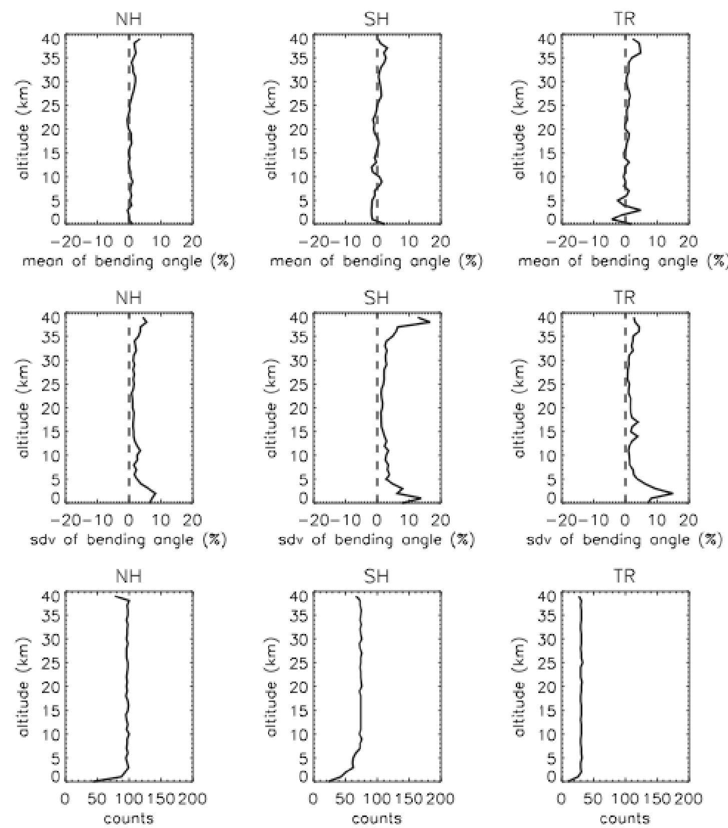


OL Data Comparison









Work in progress & short term plan

- TL and Adjoint for the Local Bending Angle Forward Operator
- Tune representativeness errors for Local Refractivity and Bending Angle Forward Operators
- Impact studies (parallel runs) with both local operators
- Selection of the Forward Operator for COSMIC
- Evaluation of non-local Operators