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EFFICACY OF VARIOUS ALGORITHMS IN OZONE ESTIMATION USING GOES SOUNDER RADIANCES

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Abstract

Impact of atmospheric moisture in the ozone estimation is examined with the help of different algorithms for retrieval of TOZ using GOES sounder observations. Sensitivity of ozone band with respect to temperature and humidity for ozone retrieval is calculated. Strong correlation between atmospheric temperature and ozone estimated implies that a precise knowledge of atmospheric temperature improves the ozone root mean square estimate (rsme). Percentage root mean square (rms) difference of TOZ estimates from training and testing data sets for various possible cases is approximately 0.11. Such a small value indicates the robustness of algorithms used.

Key Words: TOZ, GOES, TIROS, RTTOV.

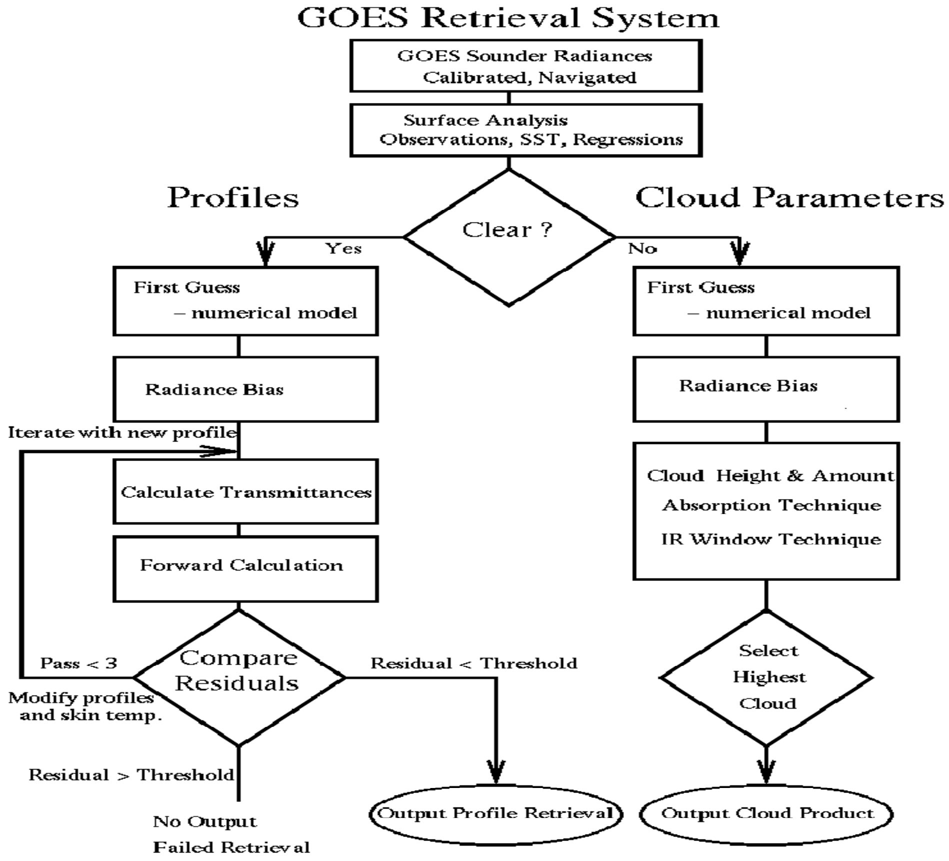
1. Introduction:

The ozone layer that resides in the earth’s stratosphere acts as a natural shield that protects living beings on earth from the harmful effects of the ultraviolet radiation of the sun. A depletion of stratospheric ozone will reduce this protection that we now have, and ozone concentrations therefore need to be monitored carefully on a global scale. The variable concentration of ozone can be detected and measured with the help of satellite observations. The earliest satellite measurements of atmospheric ozone began in 1978 with the total ozone mapping spectrometer (TOMS) sent on Nimbus-7 satellite, and they continued aboard the Russian Meteor-3 satellite until December 1994. Another TOMS instrument was launched in July 1996 on the NASA Earth Probe. The total ozone amount is computed by comparing the incoming solar energy and the backscattered UV radiation measured by TOMS at six different wavelengths. Satellite measurements of stratospheric ozone have greatly helped to generate detailed maps of the global ozone distribution and resulted in startling revelations about what has come to be known as Antarctic ozone hole. On 21 April 1995, the European Space Agency (ESA) launched the Global ozone monitoring experiment (GOME) aboard the second European Remote Sensing Satellite (ERS-2). GOME is the first European passive remote sensing instrument whose primary objective is the determination of the amounts and distribution of atmospheric trace constituents. GOME is a precursor to a more comprehensive mission known as SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric CHartographY. SCIAMACHY was launched on the ENVISAT-1 platform in 2002 (Kelkar, Satellite meteorology).

Satellite- observed infrared radiances at 9.6-µm can be used to determine the global distribution of atmospheric ozone. Previous efforts in this area of research have used Television Infrared Observational Satellite (TIROS-N) Operational Vertical Sounder (TOVS) 9.6-µm radiances to retrieve total column ozone.

The study tries to retrieve Total Column Ozone(TOZ) with the use of datasets of GOES Sounder simulated by fast Radiative Transfer for the Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (RTTOV). RTTOV is a radiative transfer model to compute very rapid calculations of top of atmosphere radiances for a range of space-borne infrared and microwave radiometer viewing the Earth’s atmosphere and surface.

The GOES window bands are located in spectral regions where the atmosphere is relatively transparent and are selected so that the atmosphere becomes progressively more opaque from one spectral band to the next. As the atmosphere becomes more opaque, the sensed signal comes from higher up in the atmosphere (Menzel, et al., 1998). The process of retrieving GOES profiles is shown in flowchart.

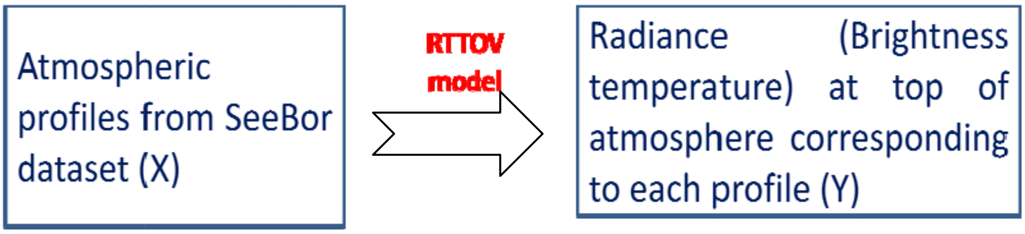


Flowchart of GOES Sounder Data Processing (Menzel, et al., 1998)

Study Area and data used

- Our area of study lies between 45 N and 45 S of Equator covering the whole tropical region.
- Data used are from SeeBor Version 5.0 data set
- This data set has a set of 15704 profiles. From them we have extracted data for tropical region (45 N and 45 S) which contains 10535 profiles.
- RTTOV model is used to get simulated data from these atmospheric profiles .
- Randomly chosen 80% of data (8400) has been used as training data and 20% of data (2135) has been used as testing data.

Flowchart for RTTOV Model



Methodology

The purpose of this study is to describe the sources of data used in this study, and the process developed to filter and manipulate this data into a useful format. The study relies on several data sources to develop final ozone profiles. For this study, a notional tropical region from 45N to 45S location is selected. The three part process begins with an initial field of forecast temperature, surface temperature and humidity values in a region surrounding the objective area. The second source of data, and the focus of this study, is a three dimensional field of satellite measured temperature values covering the same area as the forecast data. The final step in this study is to use the measured radiosonde data to validate and/or update the forecast to create a more accurate (total column ozone) TOZ profile over the selected drop zone coordinates.

Statistical retrieval technique:

- In this technique, a training data set is used to establish a relationship between input parameter (Y, observed radiance) and parameter to be retrieved (X,TOZ, temperature, humidity).
- Training data set used should be space and time collocated with satellite observations.
- Difficult and time consuming.
- Used synthetic training data set.

Generation of regression coefficients:

$$RC = dX.dY^T.(dY.dY^T)^{-1}$$

$$dX = X - X_{mean} \qquad dY = Y - Y_{mean}$$

$$X_{ret} = X_{mean} + RC.(dY_{obs})^T$$

$$dY_{obs} = Y_{obs} - Y_{mean}$$

Algorithms used for TOZ retrieval (Li et al. 2001)

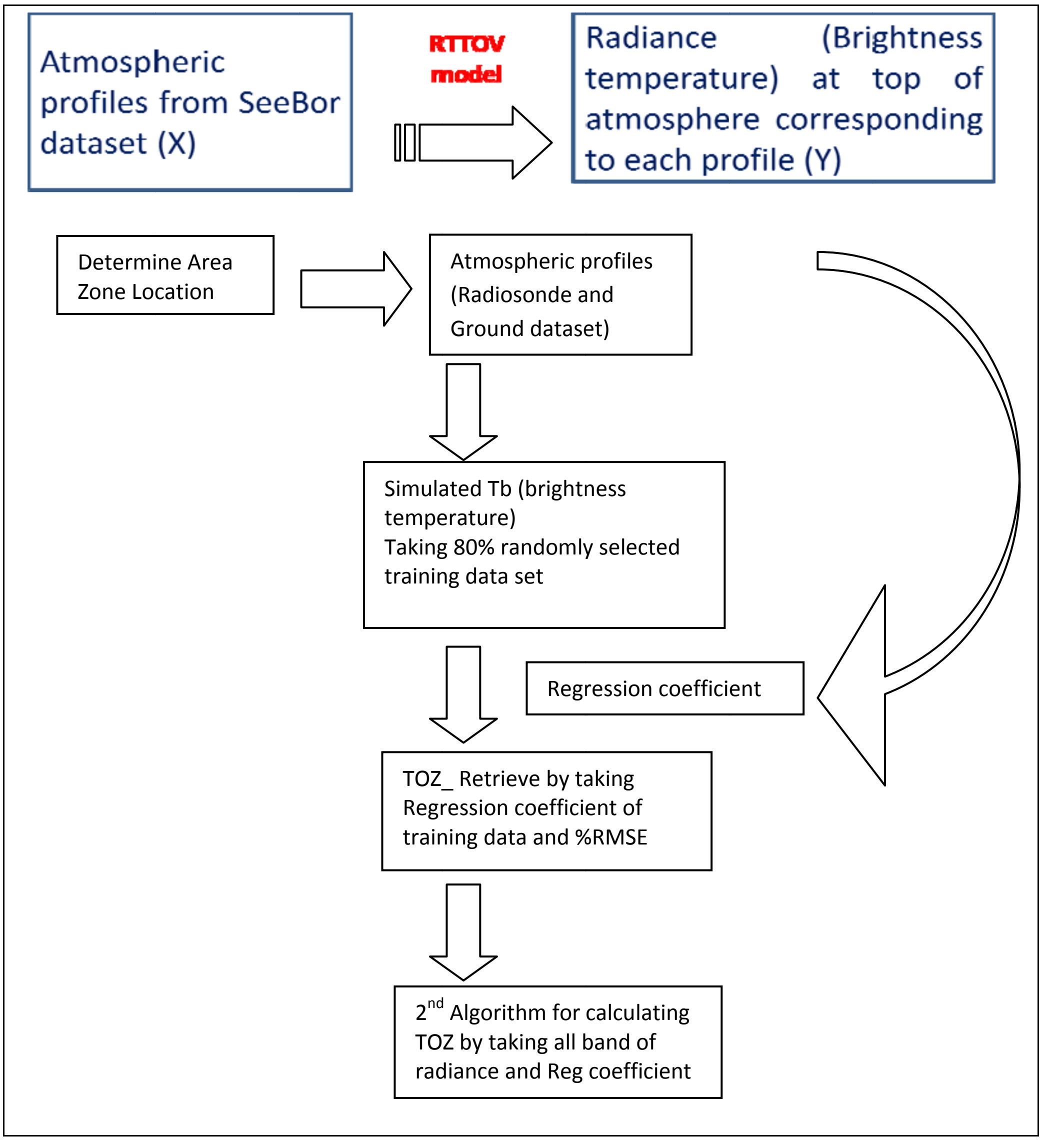
1. TOZ estimation using GOES ozone band brightness temperature along with atmospheric temperature and humidity profiles (**1st Algorithm**)

$$TOZ = D_0 + D_1 T_{b_9} + D_2 {T_{b_9}}^2 + E_o T_s + \sum_{i=1}^{i=L_s} E_i T_i + \sum_{i=1}^{i=L_s} F_i ln q_i$$

Where TOZ is the total ozone value in Dobson units (DU); Ti and qi are the atmospheric temperature and water vapour mixing ratio, Ls denotes the surface level; and D,E, and F are the regression coefficients.

2. TOZ estimation using all the 18 IR sounder bands **(2nd Algorithm)**

$$TOZ = A_0 + \sum_{j=1}^{j=18} A_j T_{b_j} + \sum_{j=1}^{j=18} A'_j T_{b_j}^2 + C_1 p_s + C_2 \cos\left(\frac{M-6}{12}\pi\right) + C_3 \cos(LAT)$$



FLOWCHART SHOWING THE PROCESS OF RETRIEVAL OF OZONE

Result and Discussion

Equation 1 quantifies the total ozone information available from the GOES ozone band radiance as well as accounting for additional atmospheric temperature, atmospheric moisture and surface skin temperature information. The quadratic term approximates the nonlinear relationship between atmospheric ozone and GOES Sounder radiance. GOES-12 ozone band radiances were simulated and 10535 global radiosonde profiles located between 45^0 N and 45^0 S. Time and space –collocated ground based ozonesonde observations or satellite based Solar Backscatter Ultraviolet measurements are incorporated into these radiosonde profiles so that they contain atmospheric temperature, moisture, and ozone profiles. A fast atmospheric transmittance model, fast Radiative Transfer for the Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (RTTOV) is used for the radiative transfer calculations. RTTOV. The GOES instrument noise of 0.2 $mWm^{-2}sr^{-1}cm^{-1}$ and 0.2 K forward model errors already added to simulated ozone band radiance. The regression coefficients were generated using 80% of the 10535 profiles(Training data). These coefficients were then applied to the remaining 20% of the profiles to get the percentage rms error of the total ozone estimates. Note that rmse is always used to indicate the error in simulation analysis since the retrieval can be evaluated against "truth,"

The simulation study is focused on the following three configurations:

- The atmospheric temperature profile, surface skin temperature, and atmospheric moisture profile are assumed unknown in the regression by setting the regression coefficients E and F to zero in equation1. Only the GOES ozone band radiance is used as predictor.
- The atmospheric temperature profile, and surface skin temperature, are assumed unknown by setting the regression coefficients E to zero in equation1, but the atmospheric moisture profile is assumed to be known. The water vapor mixing ratios are used as additional predictors in eqaution1 and it is assumed that the error for water vapor mixing ratios is constant at each pressure level. This configuration studies the impact of atmospheric moisture on the total ozone estimates by varying the moisture error from 5% to 20%. The detail of RMSE is mentioned in Table no1.
- The atmospheric temperature profile, and surface skin temperature, are assumed to be known, but the atmospheric moisture profile is assumed unknown by setting the regression coefficient F to zero in equation1. The atmospheric and surface skin temperatures are used as additional predictors in equation 1 and it is assumed that the error for temperature is also constant at each pressure level and for the surface skin. This configuration studies the impact of the atmospheric and surface skin temperatures on the total ozone estimation by varying the temperature error from 0.5 to 3.5 K.

Table No.1: The % RMSE of total ozone estimates from simulated GOES ozone band radiances with water vapor (q) error varies from 20% to 5%.

S.No	**Atmospheric prior information**	%RMSE of Training data	%RMSE of Testing data
1	T Unknown ; q unknown	9.47	9.35
2	T Unknown ; q known with 20% error	9.19	9.11
3	T Unknown ; q known with 15% error	9.18	9.08
4	T Unknown ; q known with 10% error	9.15	9.00
5	T Unknown ; q known with 05% error	9.09	8.96

Table No.2 The % RMSE of total ozone estimates from simulated GOES ozone band radiances with Temperature (T) error varies from 3.5K to 0.5K.

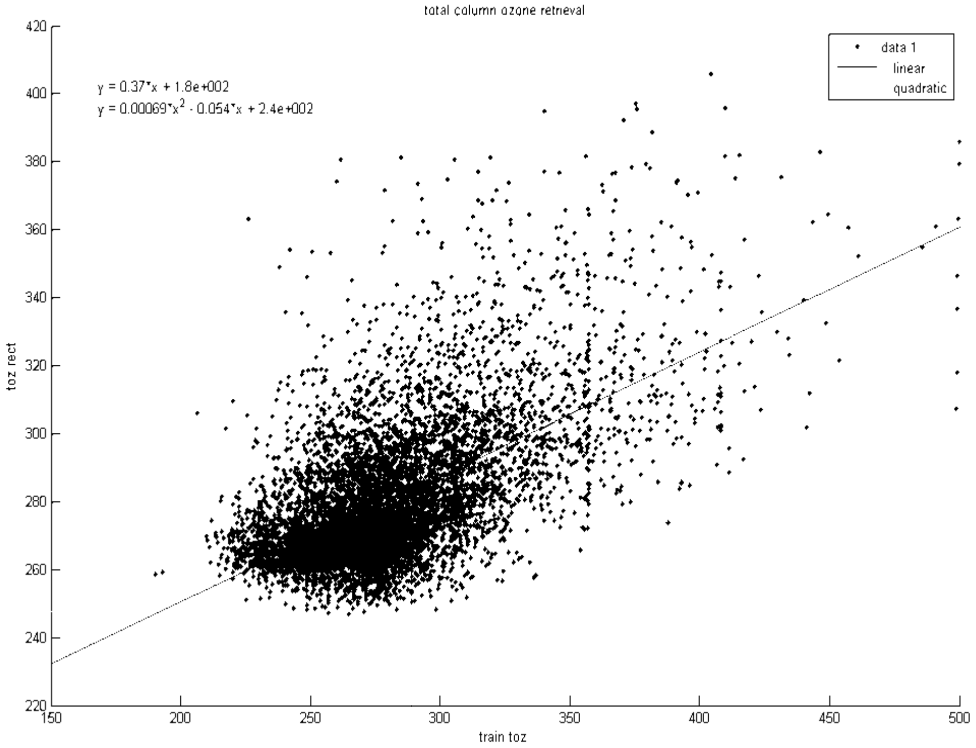
S.No	**Atmospheric prior information**	%RMSE of Training data	%RMSE of Testing data
1	T Unknown ; q unknown	9.47	9.35
2	T known with 3.5 K error ; q Unknown	5.77	5.79
3	T known with 2.5 K error ; q Unknown	5.69	5.73
4	T known with 2.0 K error ; q Unknown	5.68	5.70
5	T known with 1.5 K error ; q Unknown	5.64	5.65
6	T known with 1.0 K error ; q Unknown	5.60	5.61
7	T known with 0.5 K error ; q Unknown	5.5875	5.5873

Table no.1 lists the % rmse of total ozone estimates from configuration 1,2. There is little impact of atmospheric moisture in the ozone estimation. The % rmse shows little change as water vapor error is reduced from 20% to 5%. The % rmse of ozone estimates when water vapor information is available is very close to that when both water vapor and temperature are unknown. This indicates that only a general a priori moisture profile is needed for GOES ozone estimates.

Table no.2 gives the % rmse of total ozone from configuration 3 and those from configuration 1. There are large sensitivities to temperature in the ozone estimation. The %rmse decrease when temperature is known is prominent while it is not so when moisture is known. Table no indicates that the %rmse of configuration 1 estimates can be large as 9% while the % rmse of configuration 3 estimates is 5%. This strong correlation between atmospheric temperature and ozone estimates implies that a precise knowledge of atmospheric temperature improves the ozone rmse. This conclusion is also consistent with previous IR zone retrieval studies summarized by Neuendorffer (1996), Li (2000) etc.

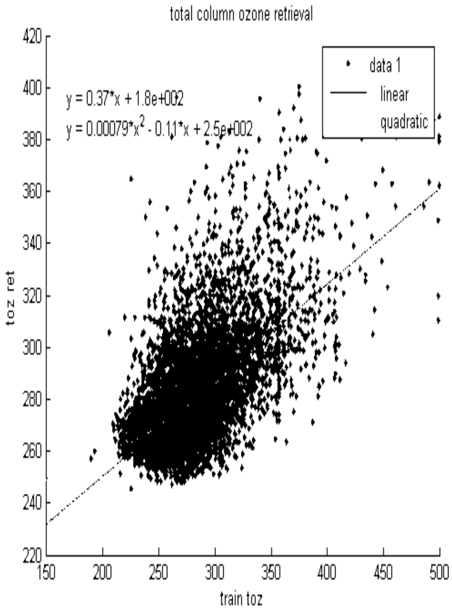
The simulation study focused on the above three configuration was applied to the remaining 20% of the profiles (testing data). This also shows nearly the same pattern as was with training data. The %rmse is less when temperature is known (configuration 3) is more in comparison to when moisture is known (configuration 1) but temperature is unknown.

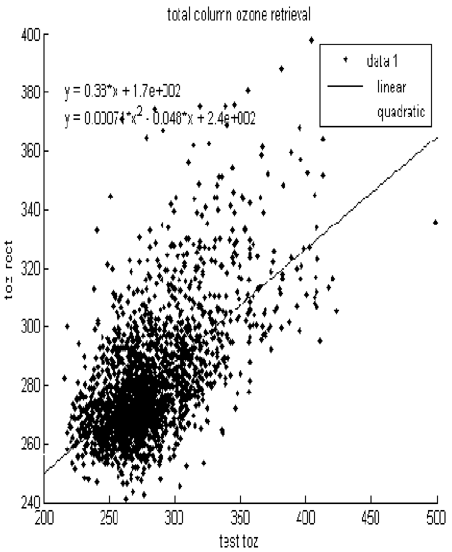
Plot for Actual TOZVsRet._TOZ with T,q Unknown



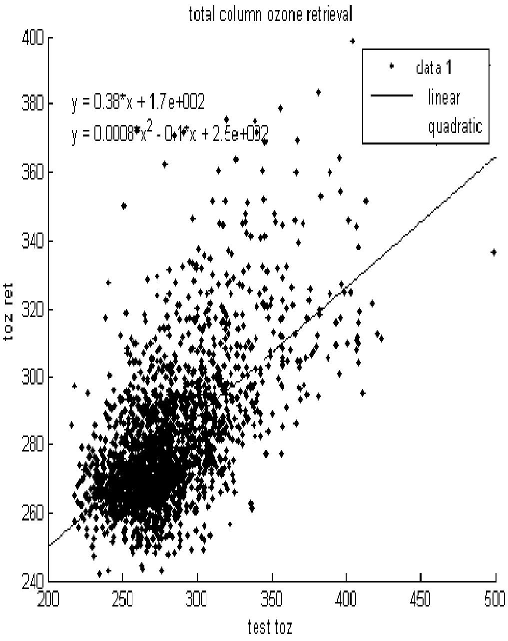
Scatter plot with temperature unknown and humidity known with error

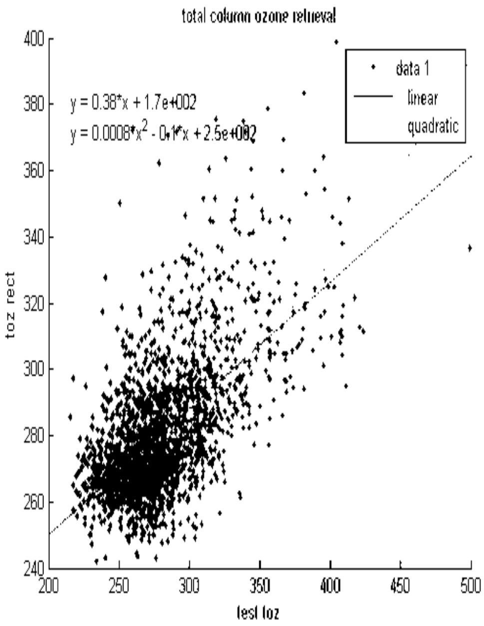
Error is increased by 20%





Error is increased by 5%



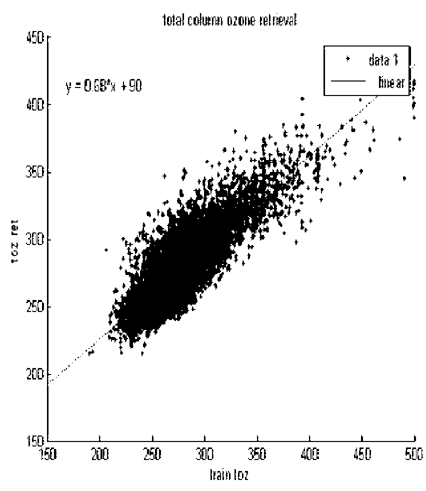


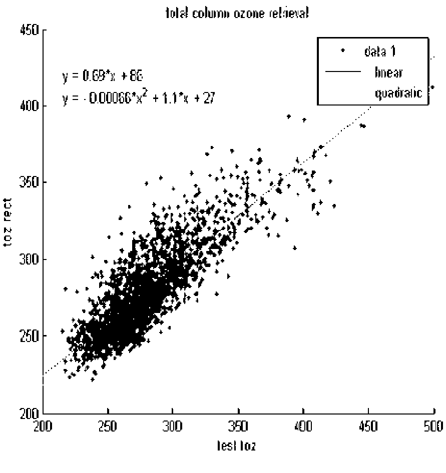
Above Table gives the % rmse of total ozone from configuration 3 and those from configuration 1.

- There are large sensitivities to temperature in the ozone estimation.
- The %rmse of configuration 1 estimates can be large as 9.5% while the % rmse of configuration 3 estimates is 5.5%.
- This strong correlation between atmospheric temperature and ozone estimates implies that a precise knowledge of atmospheric temperature improves the ozone rmse.

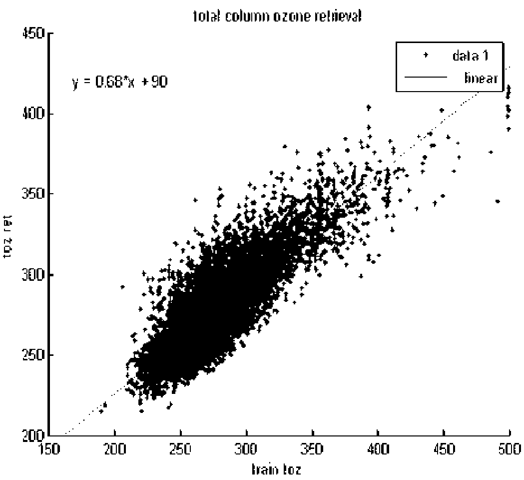
Scatter plot with humidity unknown and temperature known with error

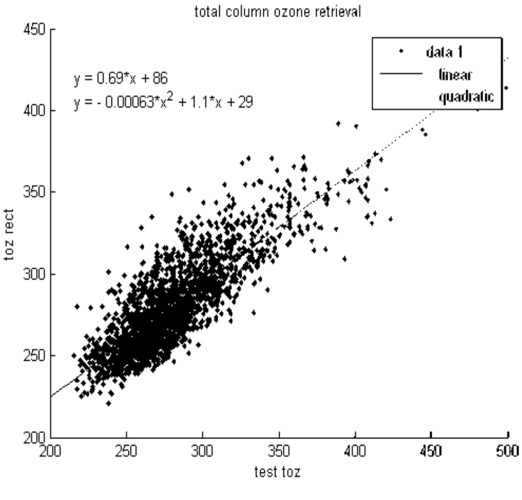
Error is increased by 3.5K



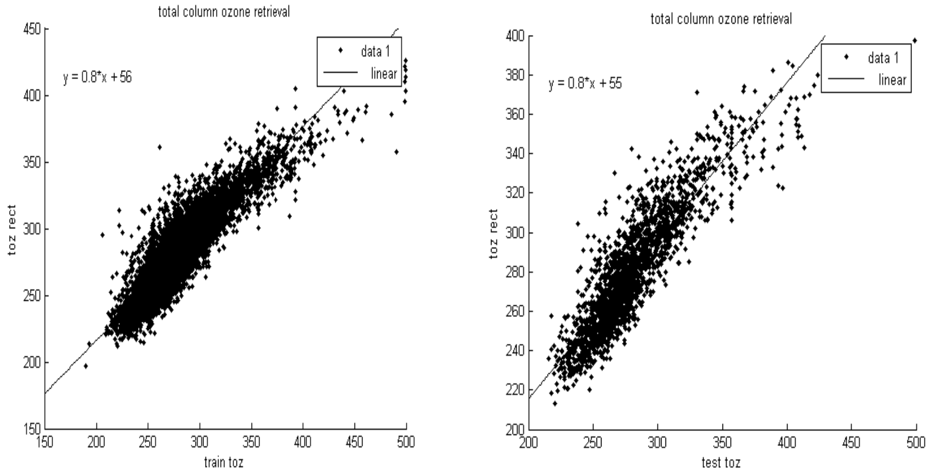


Error is increased by 0.5K



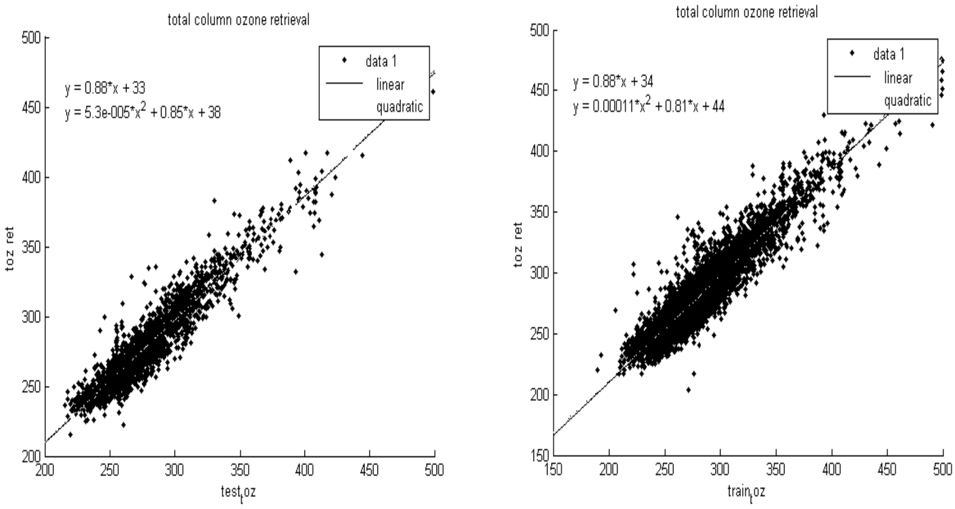


TOZ estimates using algorithm 1 when T,q known



%rmse using training data is 5.30 **%rmse using testing data is 5.34**

TOZ estimates using algorithm 2 when T,q known



%rmse using training data is 4.14 **%rmse using testing data is 4.08**

Conclusion

- There is little impact of atmospheric moisture in the ozone estimation. This indicates that only a general a priori moisture profile is needed for GOES ozone estimation.

- There are large sensitivities to temperature in the ozone estimation. This strong correlation between atmospheric temperature and ozone estimates implies that a precise knowledge of atmospheric temperature improves the ozone rmse.
- % rmse difference of TOZ estimates from training and testing data sets for various possible cases is approximately 0.11. Such a small value indicates the robustness of algorithms used.
- Algorithm 2 is better than algorithm 1 in TOZ retrieval.

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