Remote Sensing in Ozone Estimation: A Case Study

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Abstract

Ozone a naturally occurring gas though present in very small quantity in the atmosphere plays a vital role by shielding humans and other life from harmful ultraviolet light from the Sun. It is perhaps the single most critical stratospheric constituent because its vertical distribution directly affects the deposition of energy in the stratosphere, while its total amount determines the ultraviolet radiation reaching the biosphere. Its variation over the earth surface and atmosphere is of major concern and calls for its continuous monitoring on a global scale. Precisely for this reason the present study has been undertaken using Geostationary Operational Environmental Satellite (GOES) Sounder radiance measurements to monitor total atmospheric ozone. The study validates that Satellite based sensor observation has proved to be useful by which ozone concentration can be retrieved from satellite data.

Key Words: GOES, Remote Sensing Techniques, Ozone estimation, Sounder radiance measurements, Sounder radiance observations, Ozone retrieval

Introduction

Ozone is a gas that occurs naturally in our atmosphere. Most of it is concentrated in the ozone layer, a region located in the stratosphere several miles above the surface of the Earth. About 10 percent of the atmosphere's ozone is in the lowest-lying atmospheric region, the troposphere. Although ozone represents only a small fraction of the gas present in the atmosphere, it plays a vital role by shielding humans and other life from harmful ultraviolet light from the Sun. In the process of absorbing in the UV, it generates electronically excited oxygen atoms that react to form OH, a ubiquitous atmospheric oxidant (Pitts & Pitts, 2000).

Ozone is perhaps the single most critical stratospheric constituent because its vertical distribution directly affects the deposition of energy in the stratosphere, while its total amount determines the ultraviolet radiation reaching the biosphere. Within the past decade, under the probability of increasing pollutant concentrations due to commercial stratospheric aviation and vertical transport of chloroflurocarbons as well as of oxides of nitrogen the stability of the stratospheric ozone layer has been cause of concern as reflected upon in scientific journals as well as in the press (Wofsy et al., 1975).

Increasing ozone concentration on earth surface (tropospheric ozone) and seasonal decline of mid atmospheric ozone (stratospheric ozone) worried the scientific community and policy makers. Because of this, considerable attention is currently being given to the problem of reliable and continuous monitoring of atmospheric ozone on a global scale (WMO, 1988). For better international cooperation and regional control measures large numbers of data sets are required. Ground based monitoring station can give only partial picture of grim situation. Satellite based sensor observation is one technological advancement which has proved to be useful in fulfilling of much needed requirement (Rawcliffe et al., 1966; Mateer et al., 1971; Health et al., 1978; Herman et al., 1991; Rusch et al., 1994). Atmospheric radiance is another method by which ozone concentration can be retrieved from satellite data (Neuendorffer, 1996; Engelen and Stephens, 1997; Menzel et al., 1998).

This study attempts to retrieve Total Column Ozone (TOZ) with the use of datasets of Geostationary Operational Environmental Satellites (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.

Data Sets & Methodology:

- 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.

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:

- The Statistical retrieval method uses a statistical relationship between the satellite observations and the ozone parameters. Such relations can be found from historical data, e.g. radiosoundings and corresponding satellite observations of brightness temperature which can be simulated with a radiative transfer model. Such a basic dataset, which is used to find the relationships between the various parameters, is usually referred to as the "training dataset". In the present study , 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).
- To analyse the influence of atmospheric temperature and moisture on the ozone estimation from the GOES ozone band, a simple regression relationship is generated for total ozone estimation.

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)**

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

Result and discussion

The GOES sounder channels were selected to permit atmospheric temperature and moisture profile retrieval with high spatial (10 km at nadir) and temporal (hourly) resolution (Ma, et al., 1999). In order to motivate the physical basis for ozone estimation from GOES Sounder measurements, the ozone information content of the GOES ozone band is examined through simulations. The quadratic term approximates the nonlinear relationship between atmospheric ozone and GOES Sounder radiance. About 10535 global radiosonde profiles located between 45^0 N and 45^0 S for GOES-12 ozone band radiances were simulated. Ground based ozonesonde observations for the study area bearing similar spatio-temporal conditions were incorporated into these radiosonde profiles so that they contain atmospheric temperature, moisture, and ozone profiles. 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. The ozone estimates were arrived at based on sensitivity of ozone band with respect to temperature and humidity.

Table 1 lists the % RMSE of total ozone estimates from simulated GOES ozone band radiances when water vapor (q) error varies from 20% to 5%. 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. 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 estimates.

Table 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

Similarly, the % rmse of total ozone estimates from simulated GOES ozone band radiances with Temperature (T) error variation from 3.5K to 0.5K were studied, as mentioned in Table 2. There are large sensitivities to temperature in the ozone estimation.

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

The % rmse decrease when temperature is known is prominent while it is not so when moisture is known. This strong correlation between atmospheric temperature and ozone estimates implies that a precise knowledge of atmospheric temperature improves the ozone rmse, is consistent with previous IR zone retrieval studies summarized by Neuendorffer (1996), Li (2001) etc.

Conclusion

- There are large sensitivities to temperature in the ozone estimation.
- Precise knowledge of atmospheric temperature improves the ozone rmse.
- 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.
- Satellite based sensor observation has proved to be useful by which ozone concentration can be retrieved from satellite data.

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