Determination of haze API from forest fire emission during the 1997 thick haze episode in Malaysia using NOAA AVHRR data

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Abstract. The results of a study conducted at the UTM Centre for Remote Sensing is reported to quantify haze from forest fire emission using NOAA AVHRR data. In this study, NOAA AVHRR LAC data dated 22 September 1997, one of the worst thick haze episode in Malaysia were used. The relationship between measured Air Pollution Index (API) of the individual haze components and satellite recorded reflectance were analysed. API measurements were carried out by Alam Sekitar Malaysia Sdn. Bhd. (ASMA) at five selected air pollution stations in Peninsular Malaysia. These relationships were shown as the best regression model. Finally, these models were used in generating maps of haze-intensity for individual haze components, namely carbon monoxide (CO), Ozone (O_3), PM10, sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) in order to predict haze API from NOAA AVHRR data. The results indicated that NOAA AVHRR data are very useful in reporting regional haze occurrence continuously.

1. Introduction

Haze can be defined as partially opaque condition of the atmosphere caused by very tiny suspended solid or liquid particles in the air (Morris 1975). Haze is related to the atmospheric aerosol released from open burning or forest fire that contains large amount of trace gases (e.g., CO, NO_2, SO_2) and particles matter (e.g., organic matter and graphitic carbon). Haze is hazardous to health, especially associated with lung and eye diseases. Long-term haze occurrence will increase the atmospheric greenhouse effects besides affecting the troposphere chemistry. Thus, haze occurrence should be identified so that necessary measures could be taken to curb such occurrence. Conventionally, haze can be determined from ground measurement instruments such as air sampler, sun photometer and optical particle counter, however these instruments could not detect an early sign of haze and is impractical if measurements are to be made over relatively large areas or for continuous monitoring.

The haze episode, which occurred during mid-May to November 1997 is considered the worst since 1980 (five similar haze episodes had occurred in April 1983, August 1990, June 1991, October 1991 and August 1994). Meteorologists had revealed that it was due to the injection of suspended ash particles from large-scale forest fires in Sumatra and Kalimantan. In addition, the occurrence of shallow localised haze in big cities (e.g., Kuala Lumpur, Klang and Johor Bahru) was mainly caused by vehicle and industrial emissions which were stimulated by the South West Monsoon seasons which acted as another contributor that made the condition worse. Such phenomenon (which is not a new experience for Malaysia) has created awareness among the people concerning the haze problem and more commitments are put to curb haze occurrence effectively.

In this study an attempt was made to quantify haze from NOAA AVHRR data and their spatial distribution based on local API. Final results were presented as maps of haze-intensity for individual haze components namely, PM10, CO, SO_2 and NO_2.

2. Materials and method

2.1 Satellite data

The NOAA-14 AVHRR satellite data dated 22 September 1997 (0831 UTC) were used in this study. The data were then subset to the area of interest, Peninsular Malaysia (Figure 1). Five air pollution stations with measurements of haze components (API) on the day of satellite data acquisition are shown in Table 1.

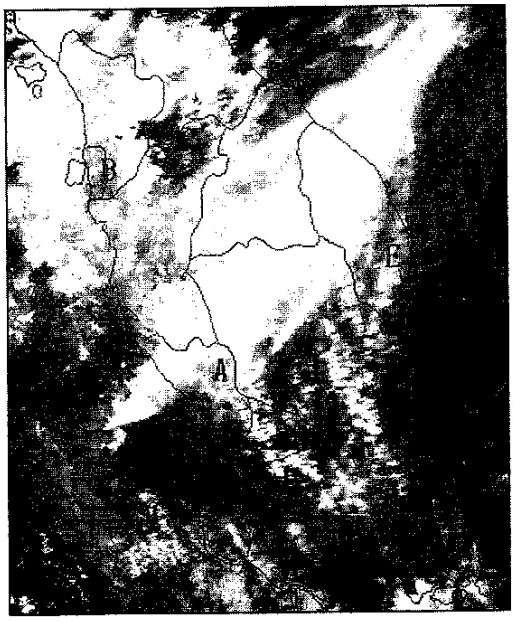


Figure 1. Combination of bands 1, 2 and 4 of NOAA AVHRR data dated 22 September 1997. Location of the selected air pollution stations are demarcated as letters A,B,C,D and E designated for Kuala Lumpur, Prai, Pasir Gudang, Bukit Rambai and Bukit Kuang respectively. Combination of bands 1, 2 and 4 are used to visually differentiate between haze (orange), low clouds (yellow) and high clouds (white) – refer cover page.

2.2 Air Pollution Index (API)

The measured API of major haze components namely PM10, CO, NO_2, SO_2 and O_3 used in this study were collected from Alam Sekitar Malaysia Sdn Bhd (ASMA). The corresponding API values at the five selected air pollution stations are shown in Table 1.

Table 1. API readings for 22 September 1997.

	Air Pollution Station	Location		Haze Components (API)				
		Longitude	Latitude	PM10	CO	NO_2	SO_2	O_3
1.	Kuala Lumpur	101°42.274' E	03°08.286' N	260	82	3	39	24
2.	Prai	100°24.194' E	05°23.890' N	113	26	6	32	44
3.	Pasir Gudang	103°53.637' E	01°28.225' N	56	4	4	42	46
4.	Bukit Rambai	102°10.554' E	02°15.924' N	125	5	2	73	48
5.	Bukit Kuang	103°25.826' E	03°16.260' N	82	8	1	9	45

The Malaysian Air Pollution Index (API) is based on the United States Pollutant Standard Index (PSI). The only difference is that the Malaysian cut-off point is 100 meaning 100 represents the air quality standard for Malaysia. The PSI has been developed by the Environmental Protection Agency (EPA) to provide accurate, timely and easily understandable information about daily levels of air pollution. The EPA uses the PSI to measure five major pollutants for which it has established National Ambient Air Quality Standard under the USA Clean Air Act. The pollutants are particulate matters (soot, dust, and particle), sulphur dioxide, carbon monoxide, nitrogen dioxide and ozone.

*i) **Particulate matter***

Particulate matter includes ash and soot. Ash generally refers to all types of organic and non-organic matters. Soot is very fine carbon particles which is the major component forming smoke. Particles with size less than 10 micron (10 μm) will never settle to the ground because their higher buoyancy forces exceed the gravitational pull.

*ii) **Sulphur dioxide***

One of the principal constituents of air pollutants is sulphur dioxide. The sources are the combustion of fuel, refining of crude petroleum, natural metallurgical operation, sulphuric acid plants, paper manufacturing plants and open burning of refuse and municipal incinerators. Its concentration in the atmosphere depends upon the sulphur content of the fuel used for heating and power generation.

*iii) **Carbon monoxide***

Carbon monoxide is an odourless and colourless gas with its main origin from the incomplete combustion of carbonaceous materials (e.g., combustion from vehicle exhausts, industrial operation, petroleum refining, gas manufacturing plants and coal mines). It is highly poisonous gas and generally classified as an asphyxiant.

*iv) **Oxides of nitrogen***

The oxides of nitrogen are known to be the second most abundant atmospheric contaminants, ranking next to sulphur dioxide. The highest concentration of nitrogen oxides in gas emission occurs in effluents from industries where nitric acid is produced or used in chemical reactions, the next is in automobile exhaust, power plants and those from low heat burners and furnaces. However, out of seven oxides of nitrogen (N_2O, NO, NO_2, NO_3, N_2O_3, N_2O_4, N_2O_5), only nitrogen dioxide (which is of our interest) and nitric oxide are classified as pollutants.

*v) **Ozone***

Ozone at the ground level can result in health and environmental problems but ozone is beneficial in the stratosphere (10 - 50 km above the earth) where it shields the Earth from the sun's harmful ultraviolet radiation. The API used in this study relates only to ground ozone.

2.3 Pre-processing

Raw NOAA AVHRR data are in digital numbers (DNs). To prepare for further processing, raw AVHRR data were converted from DN to reflectance in bands 1 and 2 and the brightness temperature for bands 3, 4 and 5. However, in this study, only band 1 of NOAA AVHRR was converted to reflectance in order to extract haze information. Haze information is only relevant to band 1 due to Rayleigh's scattering caused by the shorter wavelength of band 1.

i) Calibration of NOAA AVHRR data

NOAA AVHRR data calibration was done using calibration procedures described by Kidwell (1995). The calibration coefficients based on the post-calibration procedures by Rao and Chen (1996) were used for this purpose.

ii) Atmospheric correction

Atmospheric correction algorithm based on Jensen (1996) was used to eliminate unwanted atmospherics effects. Atmospheric transmittance was generated using LOWTRAN model (Kneizys *et al.* 1989).

iii) Geometric correction

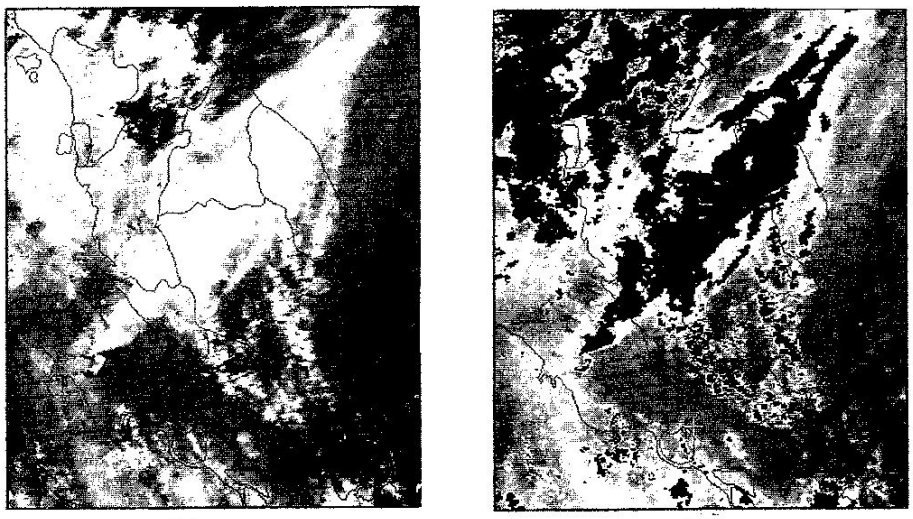
The NOAA AVHRR data were rectified using image to map approach. In this study, the coastline of the area of interest (Peninsular Malaysia) was digitised into the digital image processing system where the image was rectified. The rectified image was resampled using nearest neighbour scheme to ensure radiometric values remain unchanged for the new data. Geometric accuracy of the new rectified data was less than 0.5 pixel.

2.4 Processing

Data processing of the study involves developing computer program to discriminate clouds from haze and to produce haze-intensity maps of major individual components that formed the haze. All image processing tasks were carried out using PCI EASI/PACE digital image processing system. It is assumed that each API measurement presented in Table 1 represents a locus of 2 km-radius around each of the air pollution stations.

i) Discrimination between haze and clouds

AVHRR band 1 reflectance is used to discriminate between cloud and haze. A simple procedure described by Baum (1997) was implemented which stated that haze and cloud pixels show reflectance below 0.45 and above 0.55 respectively.



(a) (b)

Figure 2. Band 1 NOAA AVHRR in percent reflectance (a) and clouds masking (b).

ii) Generation of haze-intensity map

The relationship between ground-truth measurements of haze API and satellite recorded reflectance of band 1 AVHRR was shown as the best regression models for individual haze components, namely PM10, carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3). Finally, these models were used in generating maps of haze individual component intensity in order to predict for haze API from NOAA AVHRR data.

3. Results

Results of the best regression models for each of the haze constituents with band 1 of NOAA AVHRR data are shown in Table 2. The final haze intensity maps generated from best regressed models for each constituent are shown in Figure 3(a), 3(b), 3(c), 3(d) and 3(e). The best R^2 is exhibited by sulphur dioxide and relatively average relationship in the case of carbon monoxide and PM10. Ozone and nitrogen monoxide showed weak relationship with reflectance. Limited numbers of *in-situ* air pollution station measurements have been identified to be the main factor that hinders better result. In the on-going study, the number of air station input will be increased so that better and more meaningful relationships can be established.

Table 2. Models used in generating the haze intensity maps using band 1.

Haze components	Regression Model	R^2
PM10	$y = -1.263 + 79.518x - 1075.200$	0.3057
CO	$y = 0.0002x^{3.3774}$	0.3125
NO_2	$y = 0.157\ x^2 - 11.070x + 222.386$	0.1934
SO_2	$y = 0.0416x^2 - 2.407x + 36.739$	0.8142
O_3	$y = 0.129\ x^2 + 8.052x + 162.410$	0.2097

4. Summary

The relationship using NOAA-14 AVHRR band 1 and API of haze constituents data were examined. The best model was for SO_2 while CO, PM10, O_3 and NO_2 showed average to weak relationships. In the on-going research, the number of air pollution stations will be increased to obtain more accurate and meaningful results.

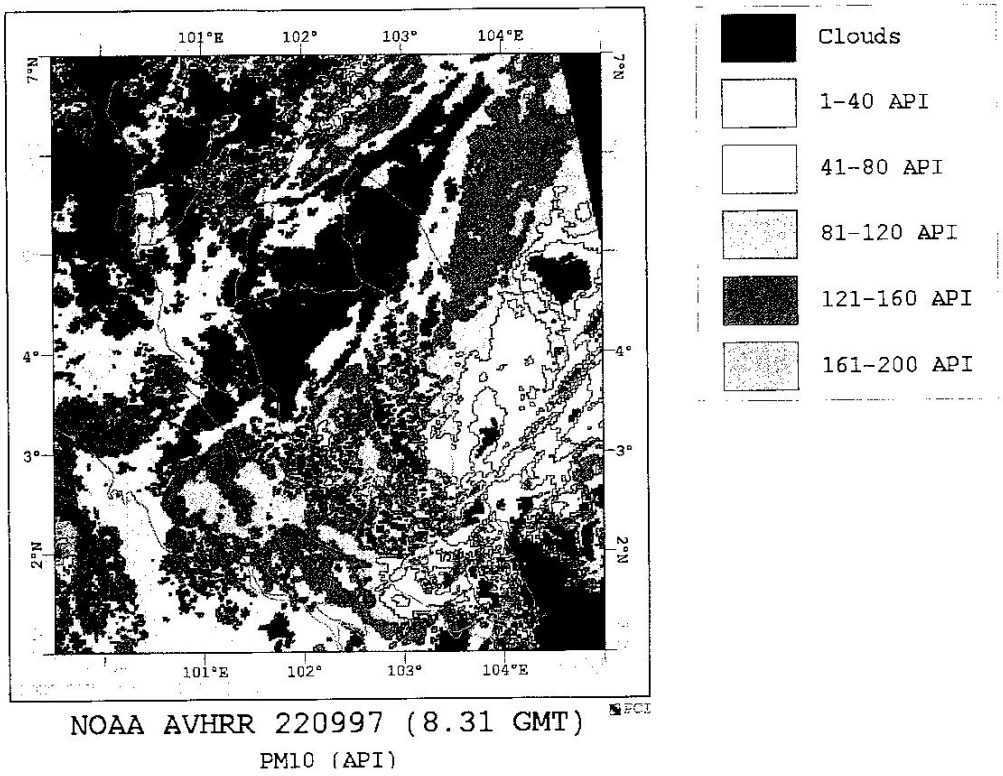


Figure 3(a). Intensity map of PM 10.

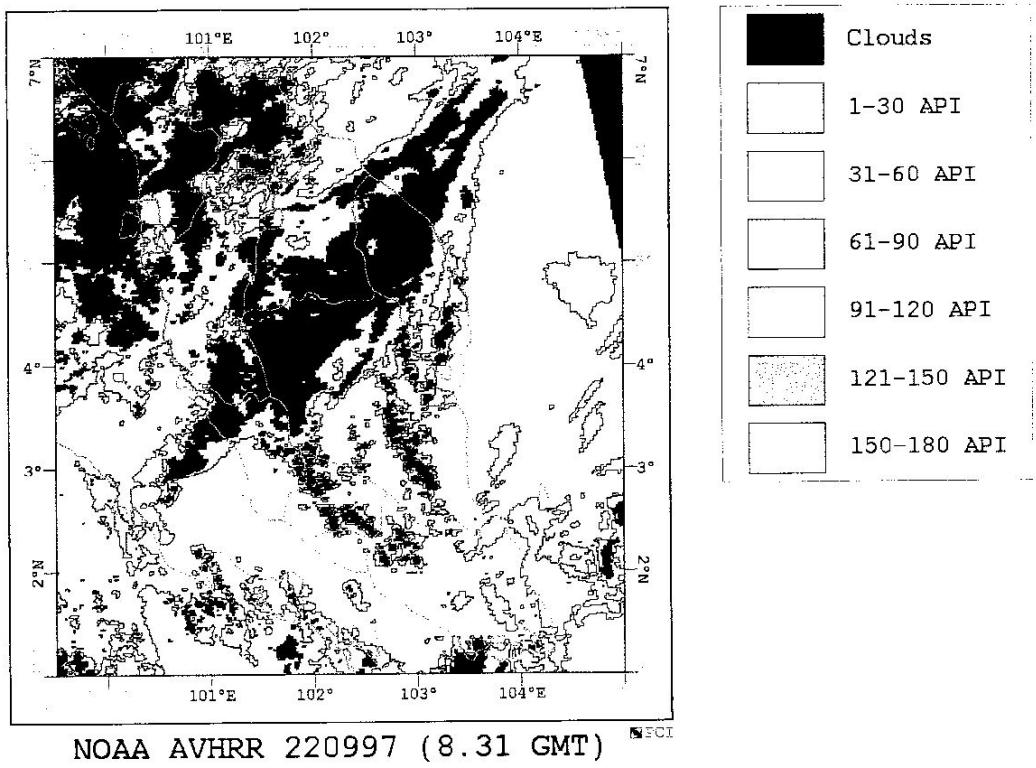


Figure 3(b). Intensity map of SO2.

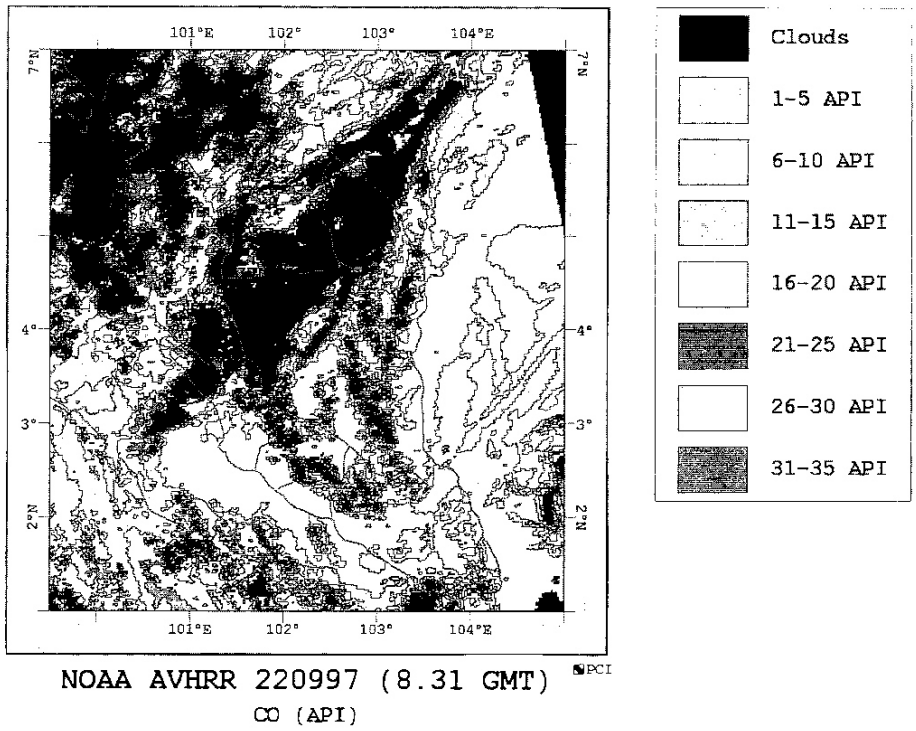


Figure 3(c). Intensity map of CO.

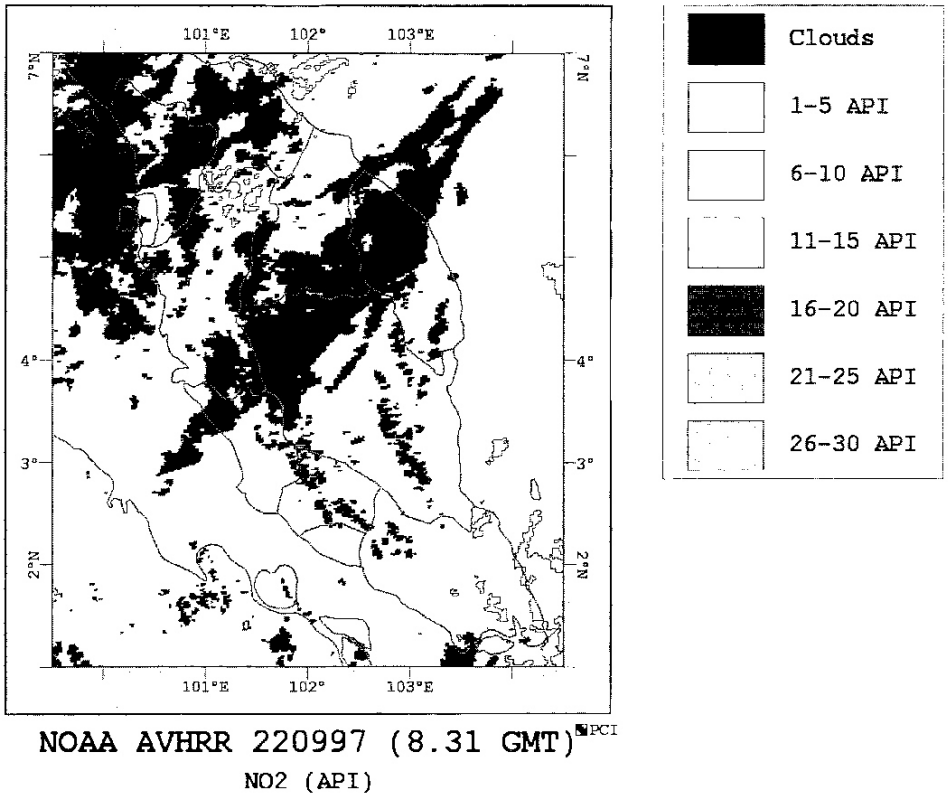


Figure 3(d). Intensity map of NO_2.

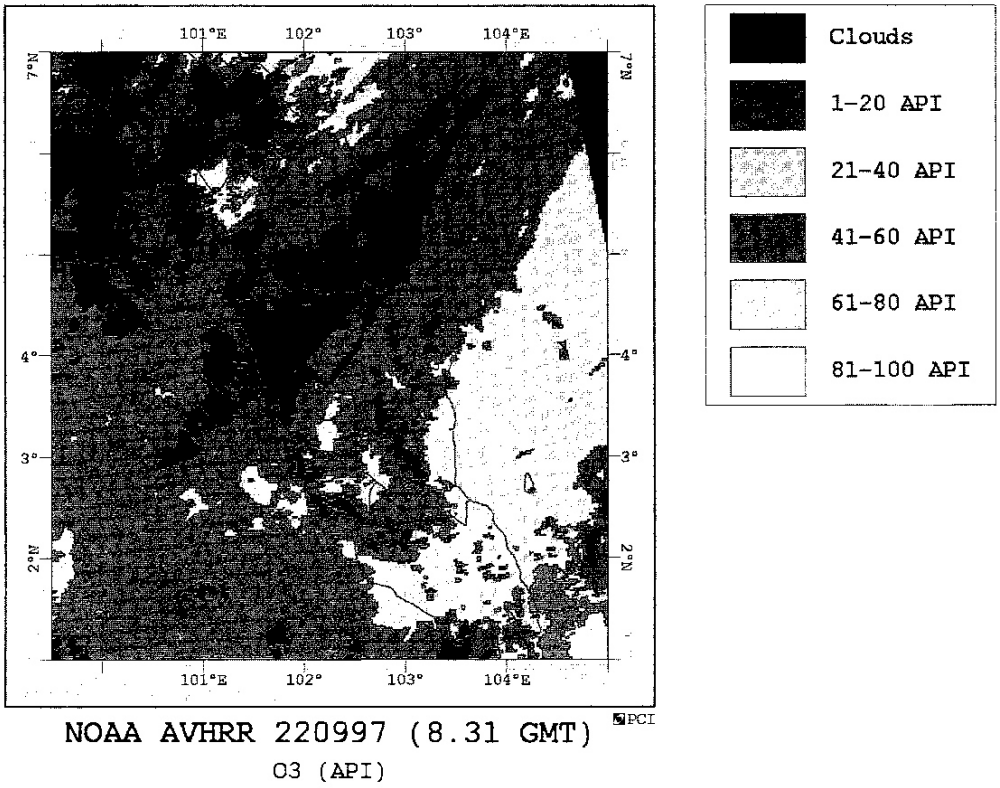


Figure 3(e). Intensity map of O_3.

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