TREND ANALYSIS FOR ENVIRONMENTAL FACTORS: TIME EFFECTS ON NITROUS OXIDE (N_2O) LEVELS AT MACE HEAD, IRELAND

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Contents

Summary

Monitoring trends in the levels of atmospheric trace gasses such as CFC-11, CFC-12, and nitrous oxide (N_2O), is important from the viewpoint of the depletion of the ozone layer in our stratosphere. In this study we perform a trend analysis of the data on N_2O levels observed at Mace Head, Ireland, for the period January 1987-December 1991. While it has been previously noted that the N_2O levels exhibited a constant increasing trend, here we analyze the data from the perspective of identifying any prevailing time effects in the variability. Our analysis is based on the change-point methodology, which enables one to both detect and identify unknown changes in the parameters of a dynamic process. Here, we specifically choose to apply the recently developed maximum likelihood-based change-point method for identifying changes in the variability of a process. The analysis conclusively demonstrates that variability in the N_2O levels at Mace Head increased sharply at or around March 1989. The reasons for this increase in the variability should be duly probed. We only make a hazardous guess

that a pollution event reported to have occurred about the same time may have something to do with this observed change.

1. Introduction

The Department of Energy (DOE) maintains a Global Change Research Program at the Oak Ridge National Laboratory in Oak Ridge, Tennessee. As part of this program, the Carbon Dioxide Information Analysis Center (CDIAC) was created in 1982 in order to monitor carbon dioxide (CO_2) and other harmful atmospheric trace gases all around the globe. The CDIAC started publishing the *Trends* series, as a collection of quality data on atmospheric trace gases for open exchange between researchers, policy makers, educators, students, and corporate officials. The quality assurance, archiving, and distribution of data have been important long-term commitments of the CDIAC ever since its inception.

The *Trends '93* volume entitled "*A Compendium of Data on Global Change*" extensively documents data that is frequently used in the monitoring and understanding of global change. Specifically, it presents historical and modern records of atmospheric concentrations of trace gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), two chlorofluorocarbons (CFC-11 and CFC-12), a hydrochlorofluorocarbon (HCFC-22), and two halons (H-1301 and H-1211) from an expanded number of globally distributed sites. In addition, the volume contains data on records of CO_2, CH_4 and N_2O gases derived from ice cores, updates on long-term temperature and precipitation records, and several time series records for atmospheric aerosols from several sites.

An understanding of the dynamics of global change requires the examination of trace gases other than CO_2 and CH_4 in the atmosphere and an analysis of the role played by aerosols suspended in the atmosphere. Although less abundant than CO_2 or CH_4, a number of minor atmospheric trace gases are also radiatively active in that they are able to perturb the radiative energy balance of the earth's atmospheric system. Thus, they are potentially important contributors to the global climatic changes. In their introduction to the chapter on "Other trace gases and atmospheric aerosols", Boden and his associates state that "extrapolation of current trends in the atmospheric concentrations, along with estimates of their relative abilities to alter the global energy balance, suggest that the collective contribution of the minor trace gases to any future global warming may be significant." Thus, traces of nitrous oxide (N_2O), chlorofluorocarbons (CFC-11 and CFC-12), hydrochlorofluorocarbon (HCFC-22), and halons (H-1301 and H-1211) in the atmosphere need to be carefully monitored on a continuous basis. An understanding of these gases is important because they are radiative and are potential depletors of the earth's protective stratospheric ozone layer.

Among the above traces gases, the atmospheric origin of nitrous oxide (N_2O) is not yet fully understood but it may result from a combination of human influences, including ground water pollution, use of nitrogen fertilizers, combustion, and deforestation. In this study, our goal is to analyze the monthly measurements on N_2O from a specific site, namely Mace Head, Ireland. The analysis reveals a change in the trend of N_2O measurements over time that has hitherto remained unnoticed. An understanding of such changes is important for capturing the overall patterns of climatic global warming and its ramifications.

2. The Global Atmospheric Gases Experiment.

The Atmospheric Lifetime Experiment (ALE) began in July 1978 and it included measurements of CFC-11, CFC-12, and N_2O at five globally distributed sites. The experiment was designed to accurately determine the atmospheric concentrations and long-term trends of these trace gases and to calculate their global circulation rates and global atmospheric lifetimes. However, the ALE experiment was ended by mid 1986 and was succeeded by the much-enlarged Global Atmospheric Gases Experiment (GAGE) when new instruments were being used to take such measurements. Also, as part of GAGE, the station at Adrigole, Ireland was closed and was replaced by the GAGE station at nearby Mace Head, Ireland in January 1987. Thus, the five sites that became part of GAGE are: the tropical Northern Hemisphere site located at Rageed Point, Barbados; the middle-latitude Southern Hemisphere site located at Cape Grim (Tasmania), Australia; the Pacific Coast site located at Cape Mears (Oregon), USA; the middle latitude Northern Hemisphere site located at Mace Head, Ireland; and the rocky promontory Pacific Ocean site located at Cape Matatula, Samoa. Air samples were collected only four times daily under the ALE program, whereas the collection was expanded to 12 times daily under GAGE. The data measurements for GAGE were again on the trace gases CFC-11, CFC-12 and N_2O. All data were subjected to extensive review procedures to detect any errors or instrument malfunctions.

3. Nitrous Oxide Levels at Mace Head.

	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
1987	305.8	305.5	305.2	305.6	305.5	305.4	305.2	305.2	305.8	305.9	306.0	306.2
1988	306.1	305.8	305.4	305.9	306.2	306.4	306.0	306.6	306.7	306.9	306.4	306.4
1989	306.5	306.4	306.4	308.1	308.7	308.2	308.4	308.6	308.5	307.3	308.2	308.7
1990	307.9	308.0	308.1	308.5	308.8	308.4	308.2	307.9	308.2	308.3	308.8	308.9
1991	309.1	310.1	309.4	309.6	309.2	308.9	308.8	308.5	307.4	308.0	308.1	309.6

From Prinn, R.G., Weiss, R.F., Alyea, F.N., Cunnold, D.M., Fraser, P.J., Simmonds, P.G., Crawford, A.J., Rasmussen, R.A., and Rosen, R.D. (1994). Atmospheric CFC-11, CFC-12, and N_2O from the ALE/GAGE network. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (Eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee, pp. 396-420.

Table 1. Monthly nitrous oxide (N_2O) levels in ppb at Mace Head, Ireland, January 1987-December 1991

In 1994, Prinn and his associates reported data on monthly averages for the trace gases CFC-11, CFC-12 and N_2O measured at Mace Head, Ireland for the period January 1987-December 1991. The reported monthly averages were based on averaging the 12-times daily measurements for the month. However, measurements for certain months that were decided to be reflecting “pollution” events were omitted from the recording. The pollution events were decided on the basis of air contamination masses that contained higher than background levels of the halocarbons being measured. The monthly average N_2O measurements (measured in parts per billion) reported at Mace Head, Ireland for the period January 1987-December 1991 consisted of one missing observation for the month of May 1989. This data as reported by Prinn and presented below in Table 1 and also in Figure 1 is the primary focus of our attention and analysis.

In presenting the data, one may notice that we replaced the missing data point for May 1989 with 308.7. The rationale for doing so is that our time series-based analysis requires that there are no missing observations in the data. The value of 308.7 has been decided after much contemplation. While there is any number of ways of replacing the missing observation, noting that the particular month was declared as a pollution event, we decided to replace it with the maximum of the reported measurements during that year. It was felt that this was a prudent thing to do under the prevailing circumstances.

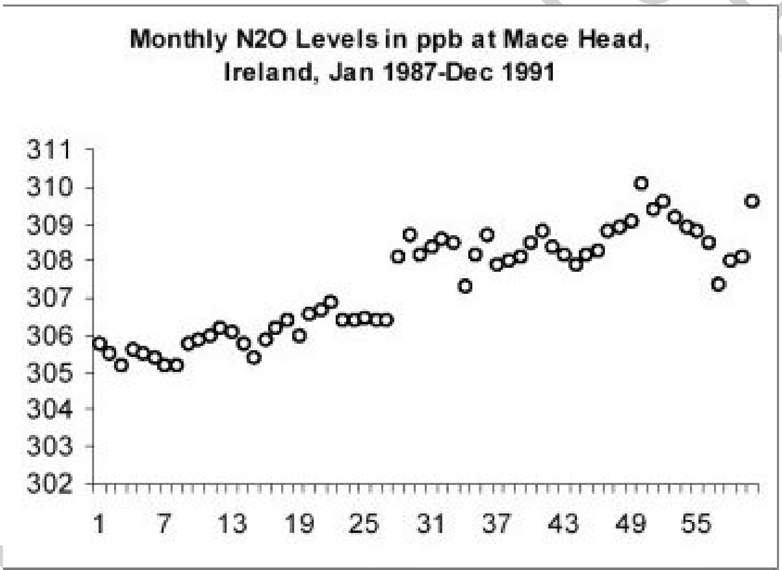

Figure 1. Monthly nitrous oxide (N_2O) levels in ppb at Mace Head, Ireland, January 1987-December 1991

4. Identifying Trends.

Our goal in pursuing an analysis of this data is to identify the existence of any time effects and/or trends in the N_2O measurements at Mace Head. To this effect, Prinn and his associates reported that the monthly N_2O at Mace Head increased from 305.8 parts per billion (ppb) in January 1987 to 309.6 ppb in December 1991 and that the values showed a highly significant trend (P-value<0.0001) during this period, with an average rate of increase of 0.857 ppb/year. They also reported that there was no evidence of periodicity in the data. While these preliminary observations are valuable, they are inadequate from the viewpoint of a thorough statistical analysis of the N_2O measurements at Mace Head. The question is whether there is more to be said about the time effects and/or trends in the N_2O measurements. Our pursuit here is to perform a statistical analysis for identifying as well as estimating other prevailing trend effects in the data.

Figure 1 clearly shows a constant increasing trend in the data measurements. Here we wish to statistically examine whether the variability in the observations remains constant around the trend line. Any evidence of departures in the constancy of the variability provides important information for a thorough understanding of time trends in the nitrous oxide levels at Mace Head.

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Biographical Sketches

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