within a cell. We have used a localization sequence contained in *bcd* RNA to target *osk* RNA to a novel location. A similar approach will be useful to identify les cr to germ-cell determination.

Received 15 May; accepted 22 June 1992.

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ACKNOWLEDGEMENTS. We thank J. Moore for technical assistance, W. Driever, D. T and A. Williamson for gifts of antibodies, L. Dickinson, L. Gavis and C. Wang for sharing the unpublished results, the members of the Lehmann laboratory for discussions, S. Burden, L. Gavis and C. Wang for comments on the manuscript and A. Kron for help with its preparation. A.E. would is a Howard Hughes Medical Institute investigator.

LETTERS TO NATURE

Seasonal cycle of surface ozone over the western North Atlantic

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THE possible impact of pollution from North America and Europe on tropospheric ozone throughout the Northern Hemisphere is a major environmental concern[1-4]. We report here continuous measurements of ozone from Bermuda (32° N, 65° W) and Barbados (13° N, 60° W), which suggest that despite their proximity to the eastern US seaboard, natural processes rather than pollution control surface ozone in these regions. Although springtime daily average ozone concentrations at Bermuda are greater than 70 parts per billion (10^9) by volume (p.p.b.v.) and hourly values in 1989 sometimes exceeded the Canadian Air Quality limit of 80 p.p.b.v., trajectory analyses indicate that these high levels of ozone are transported from the unpolluted upper troposphere >5 km above the northern United States and Canada[5]. During the summer, when surface ozone concentrations over the eastern United States can exceed 70 p.p.b.v. owing to pollution[6], typical values at Bermuda are between 15 and 25 p.p.b.v. At Barbados, both the seasonal and diurnal variations in surface ozone are nearly identical to those at Samoa in the tropical South Pacific, where the isolation from anthropogenic sources[7] and low levels of NO_x (ref. 8) ensure that natural processes control surface ozone[9-11].

Tropospheric ozone, which controls the chemical cycling of atmospheric trace gases[12] and has a considerable impact on climate[13], is supplied naturally by downward transport from the stratosphere[11] and is also produced photochemically (depending on the local level of nitrogen oxides (NO_x))[12]. Over polluted regions of the continental Northern Hemisphere, tropospheric ozone concentrations frequently rise above the natural background[1,6], and levels in Europe may have increased by more than a factor of two in the last 100 years[14]. Furthermore, in the summer, ozone-rich air transported from Europe has been observed episodically at Mace Head, Ireland[15] and Izania, Canary Islands[16] in the eastern North Atlantic; and we report here some instances of ozone pollution transported from North A to Bermuda in the western North Atlantic. But the bulk of our observations from the western North Atlantic, when combined with earlier ozone data from the Bahamas[17] and shipboard data from the eastern North Atlantic[18,19], suggest that for most of the year it is transport from the stratosphere and natural photochemical destruction, rather than pollution-driven photochemical production, that controls surface ozone levels over much of the North Atlantic.

As part of the Atmosphere/Ocean Chemistry Experiment (AEROCE), we began ozone measurements from 20-m towers at two sites: Bermuda in October 1988 and Barbados in April 1989. The ultraviolet absorption instruments used to measure ozone[20] have been intercompared with a network standard instrument maintained by the NOAA Climate Monitoring and Diagnostics Laboratory in Boulder, Colorado. This instrument, in turn, is compared to the US National Institute for Standards and Technology reference ozone photometer maintained at Gaithersburg, Maryland. Data from American Samoa are tied to the same standard. Measurements are made at 20-s intervals and averaged into hourly values.

The monthly average ozone concentrations at Bermuda (Fig. 1) show a marked seasonal cycle, with median values reaching 50 p.p.b.v. in April and dropping to below 20 p.p.b.v. in August. The large monthly variabilities result from frequent multi-day transport events (see insets *a* and *b* in Fig. 1) and from year-to-year differences. Throughout the winter and spring there are a number of multi-day events when hourly concentrations exceed 70 p.p.b.v., whereas in the summer, peak hourly values seldom reach 50 p.p.b.v. and the daily average dips below 1 This deep summer minimum is in marked contrast to surface observations over the eastern United States, where as a result of regional pollution, the monthly means range from 35 50 p.p.b.v. and afternoon hourly averages frequently exceed 70 p.p.b.v. (ref. 6). The seasonal cycle observed at I qualitatively similar to earlier observations from the Bahamas[17] (also in the western North Atlantic at 21.5° N, 70° W) and to ship cruise data from the eastern North Atlantic at 30–40° N (ref. 18).

To differentiate between anthropogenic and natural control of ozone concentrations, we use isentropic back-trajectory analysis to identify the sources of both the high and the low ozone mixing ratios. These trajectories, which trace back in time the

three-dimensional path that an adiabatic air parcel would have taken to reach the measurement site[21,22], are calculated at 12-hour intervals from the National Meteorological Center's global analysis of meteorological data[23]. They follow the flow of the large-scale winds in the stably stratified atmosphere and must remain above the non-adiabatic mixed layer (above 950–850 hPa). In this analysis, it is assumed that any parcel descending to the top of the mixed layer over the measurement site will be transported down to the tower at 20 m by boundary-layer turbulence. Although such trajectories are a simplification of the complex meteorology, they can be used to identify the general direction of transport, to differentiate between air that has remained in the lower troposphere and air that has descended from the mid- and upper troposphere, and to estimate the speed at which the tracer has travelled to the measurement site.

All of the high springtime ozone events (>50 p.p.b.) are associated with back-trajectories that start 5 to 10 days earlier north and west of Bermuda, at least a few kilometres above the surface. Back-trajectories associated with the highest ozone mixing ratios originate north of 50° N at 500 mbar (5.5 km) or higher, where in the spring 'tropopause fold' events have been directly observed to carry ozone-rich air down from the lower stratosphere[24] and the monthly average mixing ratio exceeds 60 p.p.b.v.[1,5]. This picture is consistent with ozone measurements from a ship cruise in the eastern North Atlantic. Smit *et al.*[19] found high springtime surface values between 25° and 40° N that seemed to have come from the upper troposphere. During the summer, atmospheric transport to Bermuda is dominated by a large anticyclone (the Bermuda high) and air parcels travel slowly in the lower troposphere over the subtropical and tropical Atlantic. As a result, the ozone levels decline throughout the summer and often dip below 15 p.p.b.v. (see inset *b* in Fig. 1). There are occasional influxes of aged pollution, which have travelled slowly from the eastern United States (see the four peaks between 35 and 45 p.p.b.v. in inset *b*).

A particularly striking transport event occurred during the passage of a cold front on 19 May 1990 (see inset *a* in Fig. 1). Ahead of the front on 18 May, the near-surface wind was from the southwest, the relative humidity was >95% and the ozone concentration was <15 p.p.b.v. The 10-day isentropic back-trajectories associated with these very low ozone levels represent clean air that has travelled slowly over the ocean south of Bermuda (Fig. 2*b*) and has remained in the lower troposphere below 800 hPa (1.6 km) (Fig. 2*a*). After the passage of the front on 20 May, the wind blew from the northwest, the relative humidity dropped sharply to ~50% and ozone concentration increased rapidly to 70 p.p.b.v. Accompanying the increase in ozone concentration is an equally rapid shift in the isentropic back-trajectories (see Fig. 2*c*, *d*). They now represent clean air that started in the upper troposphere over western Canada and descended rapidly behind the front as it travelled across the eastern United States and out to Bermuda.

The seasonal pattern at Barbados, which has surface winds blowing almost continuously from the east, differs somewhat from that at Bermuda (Fig. 3). Although both locations have August minima, the Barbados maximum comes in January instead of April, and as can be seen from the boxes and whiskers in Fig. 3, there is much less day-to-day, seasonal and year-to-year variability. The periods of relatively high ozone levels, which are most frequent during the winter and more persistent than

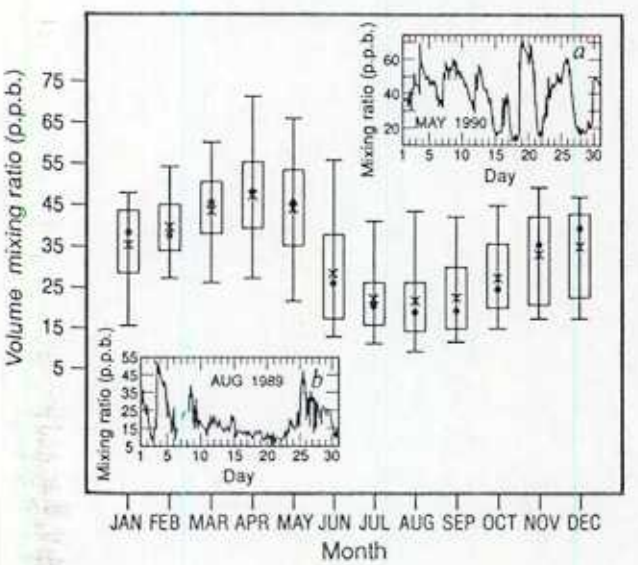

FIG. 1 Average monthly near-surface ozone mixing ratios at Bermuda during the period October 1988 to September 1991. The filled circle is the median, the cross is the mean, the box represents the middle fiftieth percentile and the whiskers the fifth and ninety-fifth percentiles. Inset *a* shows the hourly mixing ratios from May 1990, and inset *b* shows the mixing ratios from August 1989; note the difference in the ordinate scale.

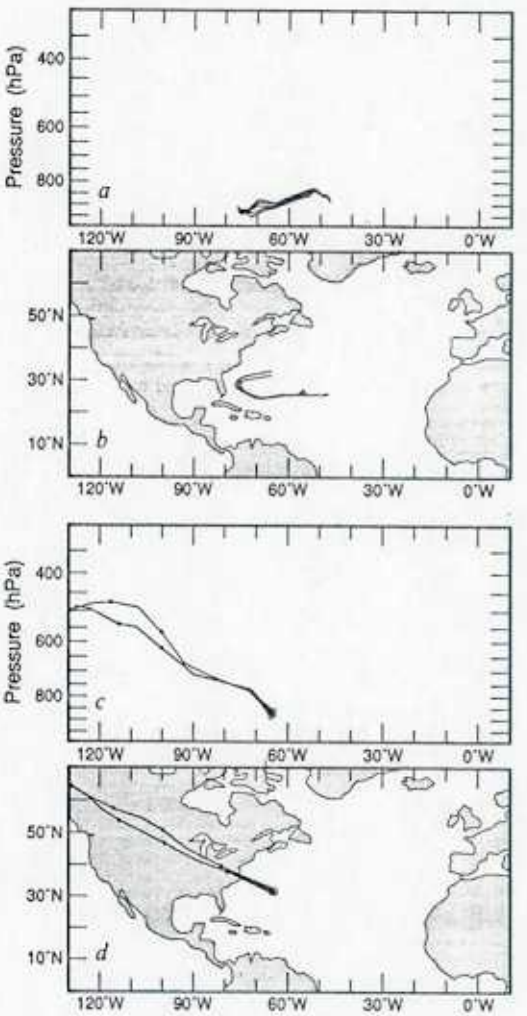

FIG. 2 Ten-day isentropic back-trajectories to Bermuda on 18 May 1990 at 00:00 UT (300 K isentropic surface) are shown in panels *a* and *b*, and those to Bermuda on May 20 1990 at 00:00 UT (298 K isentropic surface) are shown in panels *c* and *d*. Panels *a* and *c* plot the longitude and the altitude of the 10-day isentropic back-trajectories and panels *b* and *d* show the longitude and latitude for the same trajectories. Four trajectories are plotted on each surface, where the appropriate surface is the one just at the top of the atmospheric boundary layer over Bermuda. Details of the trajectory calculation are given in Merrill *et al.*[23]. Note that the trajectories for 18 May proceed west of Bermuda to 75° W and then curve cyclonically back to 65° W.

at Bermuda, are associated with atmospheric transport from higher latitudes and altitudes. In the summer and autumn months the ozone levels remain uniformly low, even during the frequent periods of enhanced transport from Africa (D. Savoie, personal communication). Imposed on the relatively low day-to-day variability is a marked diurnal cycle which is easily seen in the hourly time series for March 1990 shown in the inset *b*. This diurnal cycle persists throughout the 3-year record and has an amplitude of ~2.5 p.p.b. with a maximum at ~08:00 local time (LT) and a minimum at ~17:00 LT (see inset *b*).

Both the diurnal and seasonal patterns at Barbados bear a striking resemblance to those seen at Samoa[9]. The seasonal maxima are roughly twice their respective seasonal minima, and the diurnal amplitudes are 1.8–2.8 p.p.b.v. per day. Oltmans[9] has already suggested that the diurnal pattern at Samoa, which follows the diurnal change in solar flux, is driven by the net chemical destruction of ozone. Detailed chemical calculations for the tropical South Pacific by Liu *et al.*[10], using the low NO_x levels observed for that region[8], yield daily ozone net destruction rates of 1.0–2.4 p.p.b.v. per day. This range, which depends on the ozone concentration, agrees with diurnal amplitudes observed at both tropical locations. We infer that Barbados also has extremely low levels of NO_x and a resulting net photochemical destruction of ozone. Although Bermuda's higher synoptic variability (particularly during the large winter and spring transport events) greatly increases the statistical variance, a similar diurnal cycle of ~2 p.p.b.v. per day in the hourly means is observed. This, together with the seasonal cycle, suggests that the ozone chemistry at Bermuda is also dominated by photochemical destruction.

Although the diurnal and seasonal patterns are very similar, note that the monthly means at Barbados are 8–10 p.p.b.v. higher than those at Samoa. Two explanations have been offered for this interhemispheric difference, which is also observed over the eastern Atlantic[18,19] and the Pacific[5]: either there is more effective downward transport of stratospheric ozone in the Northern Hemisphere[11,25], or there is chemical production of tropospheric ozone there, due to a higher background level of NO_x (ref. 26). Although our observations support the dominant role of transport, they may not be representative of the tropospheric column. For example, satellite measurements of tropospheric ozone[27] show a summertime maximum over Bermuda, whereas we find a minimum in the atmospheric boundary layer. Indeed, differences in both tropospheric ozone transport[11,17] and chemistry[1,28] may cause the seasonal cycle in ozone to vary with altitude. *In situ* systematic measurements of NO_x and ozone vertical profiles to determine the relative contributions of transport and chemistry over the North Atlantic are needed to resolve this question. □

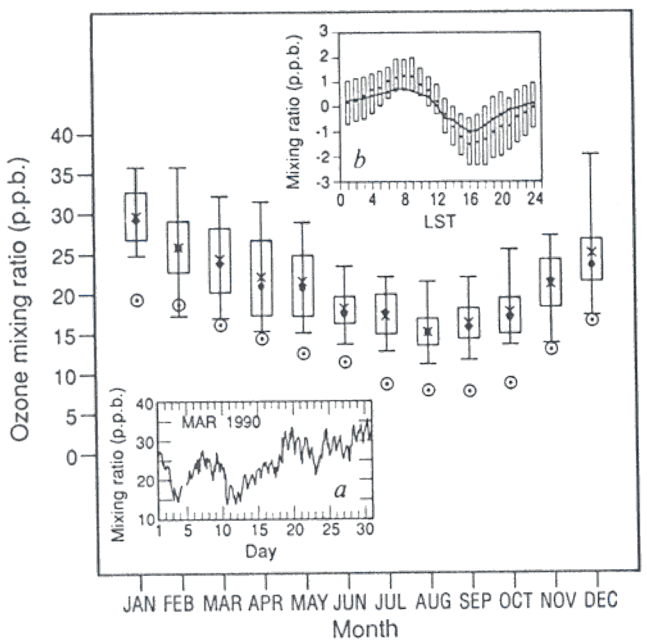

FIG. 3 Average monthly near-surface ozone mixing ratios at Barbados during the period April 1989–September 1991. Symbols are as in Fig. 1. The open circles are monthly median mixing ratios at American Samoa (1973–1991) offset by 6 months. Inset *a* shows the hourly mixing ratios at Barbados for March 1990. Inset *b* shows the average hourly deviations from the daily mean ozone mixing ratio at Barbados (1989–1991). The symbols are as in Fig. 1. The plus signs (+), which are connected by a solid line, are the hourly deviations at Samoa.

Received 6 January; accepted 5 June 1992.

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ACKNOWLEDGEMENTS. We thank S. Manabe for helpful comments. The trajectory calculations were performed by J. Merrill and the ozone observations by A. Glasspool and C. Shea.

Cirrus-cloud thermostat for tropical sea surface temperatures tested using satellite data

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RAMANATHAN and Collins[1] have suggested cirrus clouds associated with tropical convection might act as a 'thermostat' to limit tropical sea surface temperatures (SSTs) to less than 305 K by shielding the ocean from sunlight. Here we use satellite radiance data to test this hypothesis. We find that changes in the properties of cirrus clouds do not seem to be related to changes in SSTs. During the 1987 El Niño event, large-scale perturbations to the radiative effects of cirrus clouds were controlled by changes in large-scale atmospheric circulation rather than directly by SSTs. If they are averaged over the entire tropical Pacific, increases in surface evaporative cooling are stronger than decreases in solar