

considered to be generally biologically active vary within the UV-B radiation spectrum. These different action spectra have different sensitivities to changes in total column O₃, which are formalized as numerical radiation amplification factors (RAF).⁵¹ In general, a 1 percent change in total column O₃ will produce greater than a 1 percent change (e.g., 1.1 to 1.8 percent) in effective radiation dose for particular effects.

Nevertheless, as noted above, typical summertime ground-level O₃ pollution in the eastern U.S. is less than 1 percent of total column O₃. Even considering the relative effectiveness of ground-level O₃ in reducing UV-B radiation and the amplification of effective dose, such pollution could add a few percent at most to naturally occurring biologically effective UV-B radiation shielding.⁵² Viewed from one perspective and holding all other factors constant, the assumed typical O₃ pollution level is providing some "improvement" or incremental UV-B radiation shielding above the natural conditions that would otherwise exist in the mixing layer. It should also be noted that, if typical summertime O₃ levels were assumed to approximate the estimated continental background of about 40 ppb for daylight hours (U.S. EPA, 1996b, p.p. 20–21), this too would represent an "improvement" over the natural conditions that would exist in the mixing layer without the influence of international transport of O₃.⁵³

The extent to which changes in ground-level O₃ concentrations would translate into changes in UV-B radiation-related health effects in various locations cannot, however, be adequately viewed by reference to uniform assumptions applicable for specific sun angle, latitude, time of day, cloud cover, and the presence of other pollutants.⁵⁴ In the real world, all of

these factors vary with location, season, meteorology, and time of day. Moreover, the complex causal relationships noted above among all of these factors mean that neither static calculations holding other factors constant (e.g., Cupitt, 1994) nor simple empirical associations between measured ground-level O₃ and UV-B radiation (e.g., Frederick *et al.*, 1993) provide an adequate basis for assessing the "net" shielding associated with control strategy driven changes in ground-level pollution in various locations over an extended time period. Moreover, as for the direct effects of O₃, the extent of resultant UV-B radiation-related health effects is also heavily dependent on the variation of these physical changes superimposed on the activity patterns and other factors that determine population exposures and sensitivities to UV-B radiation, and on the extent to which significant biological responses can be attributed in part to episodic peak exposures as well as to long-term cumulative exposures.

Assessing the effective O₃ layer shielding is considerably more difficult for ground-level O₃ than for stratospheric O₃ because of its far greater spatial and temporal variability and the much smaller contribution to the total O₃ column made by ground-level O₃. Some insights into the relative variability of these two layers are provided in Fishman *et al.* (1990), which compares satellite measurements of stratospheric O₃ with "residual" tropospheric O₃, a measure that actually excludes the lowest portion of the ground-layer O₃ in the mixing layer. For the summer months, the long-term spatial variability in the amount of O₃ in the stratosphere across the lower 48 U.S. States is about 7 percent (Figure 8c), while the variability in the tropospheric "residual" is nearly 4 times greater, at about 25 percent (Figure 9c). By comparison, the spatial variability in ground-level O₃ measurements across regions and cities in the U.S. is far greater (U.S. EPA, 1996a, Chapter 4) reaching 200 percent and higher for comparable long-term measurements. Within an area as small as the Los Angeles basin alone, for example, the median ground-level 8-hour O₃ values in different locations varied by more than a factor of 2 (Table 28; Johnson *et al.*, 1996c). The satellite information also shows a marked contrast in the seasonal variations in O₃ for these two layers. The variation in the summer/winter stratospheric O₃ column over the U.S. is only about 2 to 4 percent, while the variation in seasonal

"residual" tropospheric O₃ is about 50 to 80 percent (Figures 8a,c;9a,c; Fishman *et al.*, 1990). Again, the variability is even greater for ground-level measurements (e.g., U.S. EPA, 1996a, Figure 4–23; Frederick *et al.*, 1993).

Although Fishman *et al.* (1990) do not compare daily variations in stratospheric O₃ above the U.S., it is reasonable to conclude that the spatial and annual/seasonal temporal stability evidenced by this large stratospheric reservoir would result in far more stable day-to-day and diurnal patterns as compared to ground-level O₃. The high variability of daytime O₃ concentrations for these temporal scales is amply documented in the Criteria Document (U.S. EPA, 1996a, Figure 4–23).

The spatial and temporal stability of the expansive and deep stratospheric O₃ reservoir means that assessments of the effects of long-term declines or restoration can reasonably assume that short-term and local-scale variations in important factors such as cloud cover, other pollutants, temperature, population demographics and activity patterns beneath this layer will tend to "even out" over time, permitting more confidence in the magnitude and direction of such assessments. In contrast to the stability of the stratospheric O₃ layer, the large spatial and day-to-day variability outlined above for ground-level O₃ means that geographical or temporal variations in other factors such as weather, other pollutants, sensitive population subgroups and human activity patterns may not "even out" in particular areas under assessment. Moreover, it is reasonable to assume that the variations in ground-level O₃ are not independent of the variations in many of these other factors. Such variability may have a substantial impact on the outcome of any assessment of the relative effects of a change in ground-level O₃ strategies or standards. This, combined with the many local- and regional-scale interactions among all of these factors, would complicate any such ground-level O₃ assessment.

A few commenters expressed the view that since EPA, and other agencies such as UNEP, have developed quantitative estimates of the public health impacts of relatively large increases in incident UV-B radiation associated with projected changes in the global reservoir of stratospheric O₃, it is necessarily the case that EPA can now develop credible estimates of the public health impacts associated with the relatively very small increases in incident UV-B radiation that could result from changes in ground-level O₃ likely to occur as a

⁵¹ The RAF is defined as the percent increase in effective dose divided by the percent decrease in total column O₃ (Madronich, 1992).

⁵² For reasons discussed below, any such shielding would vary widely from day-to-day, even in the summer O₃ season.

⁵³ This estimated continental background is due in part to natural sources of emissions in North America and in part to the long-range transport of emissions from both anthropogenic and natural sources outside of North America.

⁵⁴ Adding to the complexity of understanding this relationship are the results of high-dose animal toxicology studies that suggest more research is needed into the direct effects of ground-level O₃ on the skin. Tests by Thiele *et al.* (1997) suggest that long-term exposure to O₃ can deplete vitamin E in the skin, and this could make the skin more susceptible to the effects of UV-B radiation (U.S. EPA, 1997). Therefore, reducing long-term ground-level O₃ exposure might serve to reduce skin problems. Even a relatively small O₃ effect here could partially or completely offset any small

UV-B radiation mediated effect estimated based on O₃–UV-B interactions alone.