Baseline measurements of ethene in 2002: Implications for increased ethanol use and biomass burning on air quality and ecosystems

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ABSTRACT
While it is well known that combustion of ethanol as a biofuel will lead to enhanced emissions of methane, ethene (ethylene), acetaldehyde, formaldehyde, and oxides of nitrogen (primarily NO) when compared to gasoline alone, especially during cold starts or if catalytic converters are not operating properly, the impacts of increases in atmospheric ethene levels from combustion of fuels with higher ethanol content has not received much attention. Ethene is a well known and potent plant growth hormone and exposure to agricultural crops and natural vegetation results in yield reductions especially when combined with higher levels of PAN and ozone also expected from the increased use of ethanol/gasoline blends. We report here some baseline measurements of ethene obtained in 2002 in the southwestern and south central United States. These data indicate that current ethene background levels are less than 1 ppb. Anticipated increases in fuel ethanol content of E30 or greater is expected to lead to higher atmospheric levels of ethene on regional scales due to its atmospheric lifetime of 1.5–3 days. These background measurements are discussed in light of the potential enhancement of ethene levels expected from the anticipated increases in ethanol use as a renewable biofuel.
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1. Introduction

With the realization that fossil fuels are not renewable and therefore are a limited resource, it is clear that renewable energy sources must continue to grow in importance if we are to develop a sustainable energy policy. Combustion of either fossil fuels or biofuels has impacts on the environment, particularly on air quality, which will need to be addressed in order to insure an environmentally friendly, sustainable energy economy (Gaffney and Marley, 2009). Ethanol, produced from corn and sugar cane, has developed into a renewable biofuel source that can be used as a gasoline replacement in internal combustion engines. It is usually offered as an ethanol-gasoline blend denoted as an ethanol additive at some percentage of ethanol. Thus, E10 is a mixture of 10% ethanol and 90% gasoline and E85 would be an 85% ethanol and 15% gasoline mixture. Currently E10–E15 gasoline blends are commonplace across the United States with some states moving towards the widespread use of E85.

The combustion of ethanol in internal combustion engines leads to the emission of methane, ethene (ethylene), acetaldehyde, formaldehyde, and higher oxides of nitrogen (primarily NO) compared to gasoline alone (Gaffney and Marley, 2009; Poulopoulos et al., 2001). These emissions can lead to the enhanced atmospheric production of ozone and peroxyacetyl nitrate (PAN) (Tanner et al., 1988; Jacobsen, 2007; Ginnebaugh et al., 2010; Pereira et al., 2004). For example, it is well established that the reaction of OH radicals with acetaldehyde will lead to the formation of PAN via the following reactions:

\[ \text{CH}_3\text{CHO} + \text{OH} \rightarrow \text{CH}_3\text{CO} + \text{H}_2\text{O} \]

\[ \text{CH}_3\text{CO} + \text{O}_2 \rightarrow \text{CH}_3\text{COO}_2 \]

\[ \text{CH}_3\text{COO}_2 + \text{NO}_2 \leftrightarrow \text{CH}_3\text{COO}_2\text{NO}_2 (\text{PAN}) \]

PAN initially discovered via its observed ability to damage plants in Southern California is a potent phytotoxin (Gaffney and Marley, 2005). It is also a strong lachrymator as is its precursor acetaldehyde. Currently, controls on reactive hydrocarbon emissions have led to lower PAN levels in U.S. urban centers. However, increases in
ethanol combustion are likely to lead to increased levels of acetaldehyde and nitrogen oxides (NO and NO₂) and, therefore, higher PAN levels (Jacobsen, 2007; Ginnebaugh et al., 2010).

The reactions of peroxy radicals with NO also lead to the formation of enhanced levels of ozone. Modeling studies of the anticipated use of very high ethanol fuel levels such as E85 have been shown to lead to higher ozone levels due to the higher NO emissions and photochemically active aldehyde emissions (Pereira et al., 2004; Ginnebaugh et al., 2010; Williams, 2004). Increases in both PAN and ozone levels are of concern due to their potential ability to impact plants, both natural and agricultural, leading to reduction of yields. PAN can also act to transport reactive nitrogen dioxide over larger distances thus leading to increases in regional ozone as well as the formation of peroxycetic acid (CH₃COO₂H) in remote regions, where NO levels are low, through reaction of the peroxyacetyl radical with HO₂ radicals (Gaffney et al., 1989; Gaffney and Marley, 2005).

While it is well known that ethanol combustion will lead to enhanced ethene emissions, especially during cold starts or if catalytic converters are not operating properly, the impacts of increases in atmospheric ethene levels from combustion of fuels with higher ethanol content has not received much attention. Modeling efforts have indicated that ethene levels may be significantly higher if E85 use is widespread (Jacobsen, 2007; Ginnebaugh et al., 2010). Ethene is a well known and potent plant growth hormone and was originally noted as an air pollutant of concern due to its damaging effects on crops and horticulture (Burg and Burg, 1965; Ecker, 1995; Harvey, 1928; Stahl, 1969). Indeed, yield reductions of ~50% have been found for ethene exposures to rice and wheat at levels of tens of ppb (Klassen and Bugbee, 2002).

Currently there is not a considerable amount of data available on what the regional background (baseline) ethene levels are in the U.S. This is likely due to the fact that current analytical methods used to measure volatile organic hydrocarbons have focused on the >C₂ hydrocarbons, or have looked at methane alone. As well, current measurement methods used for reactive hydrocarbons have sought to obtain rapid response analysis by using proton-transfer mass spectrometry (PTRMS). These methods, while very useful for the volatile organic compounds >C₂ do not determine ethene as it has the same mass number as molecular nitrogen and carbon monoxide. Background level ethene measurements require the use of canister sampling coupled with GC/FID analysis or absorption spectroscopic methods such as IR photoacoustic or high resolution long path FTIR spectroscopy, and these methodologies have not been routinely used. Past measurements of ethene range from the low ppt to high ppb, with levels in Los Angeles and Texas reaching the low ppm in the 1950–60s (Stahl, 1969). More recent measurements of ethene in the troposphere have been made at surface sites and from aircraft and have ranged from a few ppt to tens of ppb (e.g. Blake et al., 2003; Goldstein et al., 1996).

Measurements of tropospheric ethene have been attempted on a large scale by using infrared solar occultation with satellite measurements of the Atmospheric Chemistry Experiment FT spectrometer (ACE-FTS, Herbin et al., 2009). The satellite results yield ethene data from 6 km and above, which indicate northern high latitude wintertime maximum ethene values above 50 ppt with some values at 200 ppt levels during 2005–2006 (Herbin et al., 2009). As ethene is ground sourced from both vegetative emissions and combustion, the ACE-FTS data allow indicate that the boundary layer ethene concentrations should be significantly higher, due to its decrease by dilution and reaction before reaching 6 km and higher in the free troposphere.

We report here some baseline measurements of ethene obtained in 2002 in the southwestern and south central United States. Noting that in 2002 ethanol use was only 1% of the mobile fuel used nationwide and most of that use was in areas where ethanol addition to the gasoline was mandated as an air quality control strategy (U.S. Energy Information Energy, 2012), the canister based data presented here should serve as a reasonable regional baseline for the mid-southern U.S. for future evaluations of atmospheric ethene trends and for modeling of the impacts of increased use of ethanol as a gasoline fuel replacement. This will be of particular importance as the nation continues to move towards using mobile hydrocarbon fuels with higher ethanol content. These ethene measurements are discussed in light of the potential enhancement of ethene levels expected from the anticipated increases in ethanol use as a renewable biofuel.

2. Experimental methods

Air samples were collected at 261 sites located in New Mexico, Texas, Louisiana, Arkansas, Oklahoma, Kansas, and Mississippi (Fig. 1) from April 28 to May 3, 2002. Sample sites were chosen to be not obviously impacted by local sources of hydrocarbons. Two liter air samples were collected by hand in electropolished stainless-steel evacuated canisters at ground level and shipped to the University of California, Irvine for analysis of ethene and other non-methane hydrocarbons by using GC/FID. Details on this methodology have been described in detail previously (Barletta et al., 2005; Blake et al., 2003). All but one of the samples were taken at a significant distance from any nearby major highways to minimize local source impacts. One sample collected fairly close to a highway was found to have high ethene (3.4 ppb) as well as elevated ethyne (3.9 ppb), benzene (0.4 ppb), and toluene (1.6 ppb) indicating that a significant impact from the highway had occurred. That data point has been removed from the data analysis as it does not represent a regional value. Complete details on the data set are given in Appendix I, including location of sample (longitude and latitude), date and time sampled (CST), and concentrations for ethene, ethyne, benzene, and toluene in ppt.

3. Results

The regional distribution of atmospheric ethene levels observed during this period is shown in Fig. 2 and a frequency distribution of the results is shown in Fig. 3. The time of sampling versus the ethene levels are given in Fig. 4. These samples were collected across the region under a variety of meteorological conditions from...
calm to windy. An examination of the ethene concentrations as a function of time of day indicates no significant differences between early morning, afternoon, and evening across the entire region (See Fig. 4). Hourly means, minima, and maxima values along with the number of samples taken during each hourly period are shown as a whisker plot in Fig. 4. The hourly means indicate that slightly higher values may have occurred during the early morning and early evening hours, which would be consistent with the anticipated boundary layer increases in ethene emissions from ground-based regional vegetative sources. However, the variance indicates that the ethene levels reported in this data set were not impacted by any significant local ethene sources.

The minimum ethene concentration over all 260 sample sites was observed in New Mexico at 14 parts per trillion (ppt) and the maximum ethene concentration was measured in East Texas at 2407 ppt (i.e. 2.4 ppb). The mean concentration observed over all sample sites was 204 ppt with a standard deviation of 282 ppt and a median concentration of 112 ppt. Only 5 samples were observed over 1 ppb ethene and these were collected in East Texas (2.4 and 2.2 ppb), West Texas (1.5 ppb), New Mexico (1.3 ppb), and Louisiana (1.1 ppb). Overall, the results show that the background ethene levels over the sampling region were fairly low, in the <1 ppb range.

The observed ethene concentrations are summarized by region in Table 1. The highest overall ethene concentrations were observed in East Texas (mean of 399 ppt), and Louisiana, Arkansas, and Mississippi (mean of 337 ppt). The lowest overall ethene concentrations were observed in New Mexico (mean of 95 ppt). Intermediate overall ethene concentrations were observed in

| Region          | Number of samples | Mean | Minimum | Maximum |
|-----------------|-------------------|------|---------|---------|
| East Texas      | 44                | 399  | 64      | 2243    |
| West Texas      | 46                | 126  | 17      | 1523    |
| Kansas          | 45                | 117  | 24      | 951     |
| Oklahoma        | 44                | 137  | 17      | 652     |
| LA, AR, MS      | 42                | 337  | 47      | 1060    |
| New Mexico      | 39                | 95   | 14      | 1282    |
| Total           | 260               | 204  | 14      | 2243    |

Table 1

Ethane concentrations (ppt) observed from April 28 to May 3, 2002 in 6 sampling regions in the southwestern and south central U.S.
West Texas (mean of 126 ppt), Kansas (mean of 117 ppt), and Oklahoma (mean of 137 ppt). This is consistent with ethene being associated with biological sources. Indeed, a comparison of the ethene values shown in (Fig. 2) with vegetation maps for the 260 samples collected. Linear correlation plots of ethyne and ethene have been used to determine the influence of local and regional sources due to internal combustion engines in Ireland (O’Donoughue and Broderick, 2009). Correlation of ethene versus ethyne, benzene, and toluene are presented in Fig. 5 for the 260 samples collected. Linear correlation fits for ethene versus ethyne had an \( R^2 \) of 0.33, while ethene versus benzene gave an \( R^2 \) of 0.26. Toluene showed little or no correlation with ethene. These correlations indicate that approximately 70 percent of ethene seen at these sites is due to biogenic sources. These biogenic sources would include natural vegetative emissions as well as biomass burning (natural fires and agricultural burning). The correlations observed are consistent with previous estimates of ethene sources reported in the 1980s where 21% of ethene was apportioned to anthropogenic fossil fuel sources, and 77% was estimated to be from biomass burning (Sawada and Totsuka, 1986). Strong correlations between ethene and ethyne are usually seen where there is a direct impact from combustion sources, such as mobile sourced emissions from highways, (O’Donoughue and Broderick, 2009). The lower correlations reported here for ethene versus ethyne, benzene, and toluene along with no significant trends in the ethene levels as a function of time of day as well as the observed lower levels found in the desert regions in the west compared to the more vegetated eastern sites all indicate that this data set in 2002 is representative of a biogenically sourced regional background for ethene.

Thus, the ethene concentrations observed below 1 ppb across this region are likely to be a good estimate of the regional background ethene levels that vegetation and agricultural ecosystems are currently being exposed to in the absence of significantly higher ethanol use and biomass burning, which are anticipated to be significant sources of ethene. Indeed, recent biomass burning emission estimates for a wide range of natural biomass materials (e.g. grassland to forest fires) indicate emissions of ethene at approximately one gram per kg of material burned (Akagi et al., 2011; Andreae and Merlet, 2001).

### Fig. 5
Linear least squares correlations of atmospheric ethene (x-axis) vs benzene, toluene, and ethyne concentrations (ppt) observed in 260 samples collected from April 28 to May 3, 2002 in the southwestern and south central U.S.

### Discussion

Note that the lifetime of ethene is determined by atmospheric oxidation as it does not undergo photolysis in the troposphere. Ethene is oxidized in the troposphere primarily by OH radical at room temperature with a rate constant of \( 8.5 \times 10^{-12} \) cm\(^3\) molecule\(^{-1}\) s\(^{-1}\) at 298 K and to a lesser extent by ozone with a rate of \( 1.75 \times 10^{-16} \) cm\(^3\) molecule\(^{-1}\) s\(^{-1}\) at 298 K (Finlayson-Pitts and Pitts, 2000). Both OH and ozone reactions with ethene lead to the formation of formaldehyde and radical species, which can increase the formation of tropospheric ozone through the conversion of NO to NO\(_2\) by peroxyradicals such as HO\(_2\) formed from formaldehyde oxidation and photolysis. In continental air, ethene lifetimes are anticipated to be approximately 1.5–3 days, assuming that OH concentrations are in the range of 0.5 to 1.0 \( \times 10^6 \) molecules cm\(^{-3}\). Thus, the production of ethene from combustion including wildfires, agricultural burning, and the use of increased levels of ethanol/gasoline fuel blends will have impacts on regional scales, due to the half-life of about 2 days.

Background measurements of ethene along with few other light alkenes were determined over a season at the Harvard Forest. That
data set was found to have a weak correlation with acetylene measurements suggesting that there was some transport of anthropogenic combustion sourced ethene emissions impacting the site (Goldstein et al., 1996). Measurements of ethylene/acetylene were found to be better correlated in January than in July consistent with a biogenic source of ethene in the spring. The data from that work are consistent with those reported here, i.e. that background levels of ethene are at levels of <1 ppb when the correlation with acetylene was taken into account indicating some anthropogenic contributions impacting the Harvard Forest site. Background levels of ethene as well as measurements made during a forest fire plume event were obtained in Australia by using high resolution FTIR techniques (Rinsland et al., 2005). Again, background ethene levels were found to be less than 1 ppb consistent with the results reported here, while ethene production from the fires led to observations of 37 ppb in the fire plume.

Measurements of ethene in a megacity environment (Mexico City) were found to be at much higher levels than observed in this study. Atmospheric concentrations of ethene were reported in the range of 10–60 ppb in Mexico City with higher levels in the commercial sectors and lower values in residential areas (Altuzar et al., 2001, 2005; Velasco et al., 2007). High levels of biomass combustion have been reported in Mexico City (Marley et al., 2007, 2009). It is anticipated that the high ethene levels observed in this megacity might be similar to levels that could be reached with the anticipated use of higher ethanol/gasoline fuel blends such as E85 during early morning hours when boundary layer heights are at a minimum and maximum emissions are expected (Jacobson, 2007; Ginnebaugh et al., 2010). The anticipated enhanced ethene emissions from the use of increased ethanol fuel usage could lead to a significant enhancement in ethene exposure to both natural and agricultural vegetation. Studies of wheat and rice production in enclosed structures conducted as preparation for possible lunar food production, found reductions in crop yields of 50% or greater with ethene exposures of 50 ppb (Klassen and Bugbee, 2002).

Additionally, enhanced atmospheric levels of ozone and PAN from higher level ethanol/gasoline blends will be an added stress to ecosystems as these oxidants are also known to be potent plant toxins. The combination of ethene increases with enhanced ozone and PAN as well as increased emissions of NO and aldehydes due to use of higher than current E10 gasoline blends, (i.e. >E30) would likely lead to potential impacts on both natural and agricultural ecosystems that could also have effects on the uptake of carbon dioxide as these pollutants are known to cause senescence and reduce photosynthetic abilities of plants.

Other sources of ethene including biogenic emissions and biomass burning as well as in-situ biochar production (Sawada and Totsuka, 1986; Spokas et al., 2010) are also not well characterized. In addition to ethene increases from combustion of ethanol/gasoline blends, emissions from biomass burning and natural vegetation are also anticipated to increase in the future with increasing climate change. This is due to the projected increases in tropospheric carbon dioxide that act to “fertilize” plant growth. This enhanced plant growth in a warmer climate will likely lead to enhanced emissions of biogenic hydrocarbons including ethene. It will also lead to increases in brush and forest fires as the growth is enhanced by earlier springs and longer growing seasons. As ethene has been determined to be a very potent plant growth hormone and potential carcinogen (Burg and Burg, 1965; Ecker, 1995; Harvey, 1928; Stahl, 1969), it is important that we begin to determine the current baseline levels of ethene in the atmosphere as well as the effects of elevated ethene exposures to both natural and agricultural vegetation in order to assure that this agent does not cause significant impacts on the biosphere as we develop ethanol as a biofuel.

5. Conclusion and recommendations

Background ethene levels in vegetated and agricultural regions in the U.S. are likely to be at the levels measured in this 2002 study, of 0.5 ppb or less, in the absence of significant amounts of biomass burning or enhanced ethanol combustion. Current vegetation and agricultural ecosystems have been acclimated to these levels, noting that ethene is a potent plant growth hormone. Anticipated increases in fuel ethanol content of E30 or greater may lead to higher atmospheric levels of ethene on regional scales. As noted by previous workers (Jacobsen, 2007; Ginnebaugh et al., 2010; Tanner et al., 1988; Gaffney and Marley, 2009), the combustion of ethanol has the potential to increase regional ozone and PAN levels due to the increased emissions of acetaldehyde, ethene, and nitrogen oxides that are tied to the photochemical production of ozone and PAN. Methane releases from ethanol combustion are also likely, noting that it is produced along with ethene and is more resistant to catalytic removal in vehicular exhaust. Emission estimates for the scenario of increasing gasoline blends from E5 to E85 indicate that ethene vehicular emissions will increase by factor of 2–10 times (See: Supplementary Material Table 11 in Ginnebaugh et al., 2010). The emission of ethene is estimated to be strongly dependent on temperature with higher emissions during colder periods (i.e. winter months). The current use of motor vehicle ethanol (E10) in 2010 has risen by a factor of 6.2 since 2002 (United States Energy Information Agency, 2012), and would be expected to increase further if the country moves towards E85 use. Thus, ethanol fuel use is anticipated to increase and with it the emissions of ethene are likely to increase by a factor of 2–10. The emission of ethene will strongly depend upon the exhaust gas catalyst condition and operating conditions with “cold start” emissions being the major issue.

It is clear that there is a need for background determinations of ethene if we are to determine the impacts of potential increases in this key pollutant as we move towards the increased use of biofuels including ethanol/gasoline blends. We would note here that ethene produced from corn-derived ethanol could be distinguished from other sources of ethene by carbon isotopic measurements. Corn, as a C-4 plant, produces ethene with a stable carbon isotopic ratio ($^{13}C/^{12}C$) of approximately 13–14 parts per thousand enriched in $^{13}C$ than that produced from C-3 plants (Gaffney et al., 1978, 1979). In addition, ethene produced from fossil fuel combustion can be distinguished from that produced by combustion of modern biomass by determination of radiocarbon content. Therefore, by determining the isotopic signature for both stable and radiocarbon, the relative sources of ethene from ethanol use, natural vegetation, biomass burning, and fossil fuel combustion contribution could be evaluated (Marley et al., 2009).

The current trend towards the use of ethanol/gasoline fuel blends with increasing ethanol content requires that the potential impacts of cold start emissions of hydrocarbons such as ethene and methane as well as the enhanced emissions of aldehydes and nitrogen oxides associated with combustion of these fuels be recognized and better evaluated. These primary emissions and their secondary products, ozone and PAN, may cause stress to agricultural and terrestrial ecosystems. Mitigation of these emissions should be considered along with long term baseline monitoring to assure that significant ecosystem damage as well as agricultural and human health impacts are avoided as we seek to develop an environmentally sound sustainable energy practice for biofuels (e.g. ethanol). Ethene measurements should be implemented in regional areas as we continue to increase ethanol use in order to determine the potential exposure levels. While it is well known that ethene is a potent plant growth hormone that is particularly effective on flowering plants (Woltering, 1987), little
quantitative data are available on the chronic effects of low ppb or sub-ppb ethene exposure for most plants and crops. As indicated in this data set, both biomass burning (agriculture and controlled burns as well as wildfires) along with increased use of ethanol fuels anticipated in the future, will likely increase current and future levels of ethene from the estimated past background of 0.1–0.3 ppb to higher levels. This will require continued measurements, modeling efforts, and biological dose/response data to be obtained that is beyond the scope of this current work. Of concern will be both chronic effects on biota due to higher levels, as well as acute impacts from high ethene level plumes from both cities (with enhanced ethane use) and from natural and agricultural burning plumes that are known to contain tens of ppb levels of ethene.

The emissions of ethene and acetaldehyde anticipated from increased use of ethanol as a motor vehicle fuel will also increase PAN and ozone levels regionally. PAN and ozone are potent plant toxins and are also of concern for human health impacts. They were originally recognized due to their causing chlorosis and leaf damage to numerous plant species including crops (Middleton and Darley, 1961). PAN is known to cause visible damage to a number of plants at 10 ppb, while ozone can stress or damage plants at levels above 40 ppb (Bell and Treshow, 2002). Indeed, there has been some recognition that higher levels of both carbon dioxide and ozone levels will affect crops and crop-yields to the extent that the need for bioengineering crops to withstand these changes may be necessary (Ainsworth et al., 2008). Noting that ethene, PAN, and also ozone increases are likely with the use of ethanol gasoline blends, especially if we move to E85, it is strongly recommended that we look to reduce the ethene, aldehyde, and NOx emissions from the combustion of these fuels. Since much of the organic emissions will primarily occur during cold-start situations or when oxidative catalyst systems are not maintained, the use of ethanol fuels anticipated in the future, will likely increase current and future levels of ethene from the estimated past background of 0.1–0.3 ppb to higher levels. This will require continued measurements, modeling efforts, and biological dose/response data to be obtained that is beyond the scope of this current work. Of concern will be both chronic effects on biota due to higher levels, as well as acute impacts from high ethene level plumes from both cities (with enhanced ethane use) and from natural and agricultural burning plumes that are known to contain tens of ppb levels of ethene.

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The authors wish to acknowledge the past support of the U.S. DOE NIECE program to Dr. Blake and Dr. F. Sherwood Rowland where data was originally gathered in 2002. Dr. Rowland was a valued colleague, mentor, and supported of our work in atmospheric science, and this paper is dedicated to his memory.

Appendix I. Data.

The authors wish to acknowledge the past support of the U.S. DOE NIECE program to Dr. Blake and Dr. F. Sherwood Rowland where data was originally gathered in 2002. Dr. Rowland was a valued colleague, mentor, and supported of our work in atmospheric science, and this paper is dedicated to his memory.
| Date       | Time  | Latitude | Longitude | Temperature | Pressure | Humidity | Dew Point | Visibility | Precipitation | Wind Speed | Wind Direction |
|------------|-------|----------|-----------|-------------|----------|----------|-----------|------------|---------------|------------|----------------|
| 4/28/02    | 11:00 | 34.23267 | 90.46623  | 288         | 143      | 76       | 32        | 10         | 7.8            | 7.8        | 15             |
| 4/29/02    | 12:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 13:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 14:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 15:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 16:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 17:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 18:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 19:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 20:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 21:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/29/02    | 22:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 01:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 02:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 03:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 04:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 05:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 06:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 07:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 08:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 09:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 10:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 11:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 12:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 13:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 14:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 15:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 16:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 17:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 18:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 19:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 20:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 21:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |
| 4/30/02    | 22:00 | 34.39078 | 90.13337  | 263         | 163      | 80       | 40        | 20         | 9.2            | 9.2        | 15             |

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