TESTIMONY OF

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Mr. Chairmen, thank you for providing me with the opportunity to testify today on the topic of military, civilian, and commercial applications of the Landsat Program, with particular focus on scientific and global change applications. I will direct my comments to a current research project which assesses use of Landsat Thematic Mapper data to detect and monitor forest damage in eastern Europe. This change detection project is focused on upper elevation sites in the Ore Mountains, along the border between eastern Germany (the former German Democratic Republic) and the Czechoslovak Federal Republic (CSFR).

The Ore Mountains, known as the Erzgebirge in Germany and the Krusne Hory in the CSFR, are the site of some of the most heavily damaged forests to be found on this Planet. The cause of this forest damage is the heavy air pollution which characterizes this portion of the "dirty triangle" formed by eastern Germany, the CSFR, and Poland. This region of eastern Europe is an area of dense population where lignite (soft, sulfur-rich coal) is strip- mined and used to fire large power plants; an area where pollution controls are often nonexistent. The region, and the impact of air pollution on both forests and people, is the topic of the June, 1991, National Geographic cover story: "East Europe's Dark Dawn." According to published reports, the once-dense upper-elevation forests of the Ore Mountains were considered to be healthy as recently as 1978.

During 1990, I visited several heavily damaged forest sites in Poland and the CSFR. Above an elevation of approximately 1000m, entire mountain tops are devoid of living forests. Figure 1 presents a ground photograph of the type of extreme forest damage characterizing upper elevation sites in the Ore Mountains. Very little healthy vegetation occurs at these mountain sites; only a few sedges and grasses grow which are adapted to living in bogs and other areas characterized by highly acid soils. At one forest damage site in Poland, the pH of the ground water has been measured at 2.6 (both lemon juice and vinegar have pH values of approximately 3.0). The area shown in Figure 1 is near the city of Most, CSFR, and represents one of the sites where visual evidence of the collapse of this upper-elevation forest ecosystem became obvious in 1979/80.

Researchers from the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire (UNH) have focused research activities on the development of remote sensing techniques which provide Earth-bound scientists with a means of detecting, quantifying, mapping, and monitoring forest damage from orbit, a capability essential for future global change applications. As a result of previous work centered on forest decline ("acid rain") damage sites in New England and New York (Whiteface Mountain, NY, Camels Hump, VT, and Mount Moosilauke, NH), the Landsat Thematic Mapper (TM) has been identified as a very accurate tool for detecting and monitoring forest damage. Because the TM acquires reflectance data from the 1.65mu spectral region **(unique to the TM)**, a spectral region influenced in part by moisture status of the forest canopy, the use of TM data for damage assessment has been shown to be particularly sensitive to subtle (initial) and moderate levels of forest damage. No other civilian satellite, including the French SPOT and the Soviet Cosmos, acquire reflectance data in this critical spectral region.

In addition to the high degree of accuracy for detection and quantification of forest damage provided by the TM, the routine acquisition of data by both the Landsat TM and Multispectral Scanner (MSS) allows for change-over-time studies. The Landsat sensors acquire data every 16 days, while the SPOT sensors acquire data only on demand. The value of the retroactive use of multi-temporal data sets from both TM and MSS has been demonstrated in a wide range of change detection studies. Examples may be cited, such as assessment of forest decline ("acid rain") damage, tropical deforestation, and insect defoliation damage, to name a few, as well as assessing the extent of reforestation (regrowth) following damage or deforestation. A long-term archive of Landsat MSS data goes back to 1972, while TM data have been acquired since 1982.

In close collaboration with Polish and Czech scientists, a joint research effort has been developed which will use TM data to assess the current state of forest damage in Poland, the CSFR, and Germany. A second phase of this study will assess the change in forest condition over time, using multi-temporal Landsat data sets (both TM and MSS). This research effort constitutes a Pilot Study, to be conducted under the auspices of the ECE/FAO Timber Committee of the United Nations Environment Program (UNEP). This Pilot Study will contribute to a large-area operational experiment for forest damage monitoring in Europe using satellite remote sensing, to be conducted as an International Space Year (ISY) activity. The Pilot Study is sponsored in part, by NASA, the Institute of Geodesy and Cartography (IGiK), Warsaw, Poland, and the Institute for Landscape Ecology (ILE) of the Czechoslovak Academy of Sciences, Ceske Budejovice, the CSFR, and will involve researchers from UNH, IGiK, ILE, and the Smithsonian Institution.

The results of the Pilot Study presented here are preliminary, and are the work of myself, Dr. James Vogelmann, and Ms. Nancy Lambert (UNH), and Dr. Martin Sima (ILE, CSFR). The work has been conducted at UNH and ILE. It is presented as an example of a global change application which utilizes the **unique environmental monitoring capabilities** of the Landsat Thematic Mapper.

Figure 2 presents a TM image of the Ore Mountains (running diagonally, from lower left to upper right) and portions of eastern Germany (upper left) and CSFR (lower right). This image was acquired by Landsat 5 on 9/30/85. The digital data have been processed to produce a damage assessment image in which reflectance values for TM band 5 (1.65um - **unique to the TM**) are used in both the green and red color planes. A ratio of TM band 5 over band 4 (in the red plane) has proven to be a highly sensitive indicator of subtle levels of forest damage. Plumes of smoke from coal-fired power plants can be seen in the lower right-hand corner of the image, and down-wind from these power plants, enormous areas of dead and dying conifer forests may be seen (portrayed in orange) in the upper-elevation regions of the Ore Mountains. Based on this satellite assessment, the area of heavy damage to conifers is estimated to be approximately 700 square kilometers. There is nothing equivalent to this in western Europe or the northeastern United States, either in terms of level of damage or extent of damage. The linear white and yellow strips between and to the right of the power plants are lignite strip mines which produce the coal burned in the power plants.

Figure 3a presents a damage assessment image for a small portion of the area depicted in Figure 2. The blue areas were non- forested in 1985, but many of these areas were forested previously, and in this image represent areas of dead, standing trees (Figure 1), or areas of clear-cuts. The dark black areas are healthy conifers, while the red and orange areas are moderate (red) to heavily damaged (orange) conifers. Figure 3b presents a damage assessment image for the same area, produced using TM data acquired on 8/3/90. Note that between 1985 and 1990, significant areas of healthy conifers (black in the 1985 image) have become damaged (red in the 1990 image), and other areas that were damaged in 1985 (red to orange) have been clear-cut (white) by 1990. In the 1990 image, many of the blue areas are characterized by dark patterns, suggesting that successful reforestation may be occurring. This particular area, near the small town of Bozi Dar in the Krusne Hory, CSFR, is the site of active reforestation plantations of Colorado blue spruce, thought to be more tolerant to pollution than the native Norway spruce. The total area covered by this image is approximately 300 square kilometers.

Figure 4 presents a change image produced by subtracting 1985 TM band 3 brightness values from 1990 TM band 3 brightness values, and adding a constant (100). The resulting image was overlaid on the 1985 image of the same area for reference. The difference data were used to identify and classify conifer regions into three classes: very severe damage (shown in red), moderate damage (yellow), and little or no damage (no color other than the true color of the image - thus black in Figure 4). The conifer stands were classified on the basis of increased brightness in TM band 3, which is considered to be related to loss of green biomass or foliage between 1985 and 1990. The conifers which are black in this image have not undergone a major reflectance change between 1985 and 1990. The background image in Figure 4 is in true color,

another unique capability of the TM. No other sensors acquire data in the blue spectral region, and thus can not produce a true color image (blue, green, and red).

The preliminary results of this study to date are as follows. Based on an evaluation of the TM data used to produce Figure 2, approximately 700 square kilometers (420 square miles) of previously forested upper-elevation sites in the Ore Mountains, were characterized by dead forests in 1985. Of the heavily damaged forests near Bozi Dar, CSFR, remaining in 1985, approximately 16 square kilometers (5.6 square miles) were clear- cut between 1985 and 1990. For the same area, an additional 46 square kilometers (17 square miles) of previously healthy conifers became moderately to severely damaged between the same time period. In summary, of the 140 square kilometers (50 square miles) of conifer forests occurring near Bozi Dar in 1985, 44% were lost, either to clear-cutting due to heavy damage, or to heavy damage directly. The actual area of forest lost to damage is much greater than these figures suggest, because much of the conifer forests damaged in 1985 remained unchanged (still heavily damaged) in 1990.

Extensive ground assessment activities are now required to fully understand the implications of the change detection assessment presented here. A research team from UNH will join researchers from the IGiK and ILE at this and other damage sites in July, 1991. In addition, a multi-temporal assessment of forest conditions at this site prior to 1985 will be conducted. A total of five MSS scenes for the area have been ordered, which will allow assessment of change-over-time for these upper-elevation forests, beginning in 1972.

It is important to note that assessing the areal extent of non- forest vs. forest depicted in Figure 2 could be done using a number of currently available satellite data sets, including SPOT, TM, and MSS. However, many of the subtle changes detected and presented in Figures 3a and 3b **require the extended spectral coverage (TM band 5) provided by the Thematic Mapper**. In previously published studies, conducted for forest damage sites in the northeastern United States, as well as in Poland, SPOT, MSS, and Cosmos data were not adequate for detecting even moderate levels of forest damage, while the TM band 5 data provided highly accurate damage assessment capabilities for the same sites.

In summary, due to the **extended spectral coverage** (covering the spectral region from 0.4um to 2.5um), the **routine acquisition of data** (repeat coverage every 16 days), and the **spatial resolution** (30m pixels), the TM has been shown to provide highly accurate forest damage assessment capabilities when compared with other sensors such as the Landsat MSS, SPOT, NOAA's Advanced Very High Resolution Radiometer (AVHRR), and the Soviet Cosmos. Combined with the long-term record provided by the MSS, forest damage assessment and change detection studies are possible using Landsat data that would not be possible using any other satellite data.

The present study represents only one application of Landsat TM data for the purpose of studying a global change phenomenon. Many other applications, of equal or greater importance, also rely on **remote sensing capabilities unique to the Landsat series**. Extensive studies of

tropical deforestation rely on the routine data acquisition and spatial resolution of the TM and MSS. **Desertification studies** rely on extended spectral coverage (sensitivity to moisture) and routine data acquisition. **Snow and ice mapping studies** rely on the extended spectral coverage (TM band 5 allows for separation of snow and ice from clouds - a very important capability). **Coastal bathometric studies** require the use of TM band 1 (blue band) for assessing water depth, of great importance for both military and civilian shipping, as well as for assessing future changes in sea level. **Thermal assessment studies** make extensive use of TM bands 5, 6 (a thermal band), and 7, due to the influence of heat at these wavelengths, for the study of forest fires and volcanic eruptions (fires and hot lava can be seen through the smoke).

In conclusion, I would like to state as strongly as possible, that the Landsat series, and in particular, the Landsat Thematic Mapper, provides the ecological community with **unique environmental monitoring capabilities**. Other current and future sensor systems, including the proposed Earth Observing System (EOS), can not and will not duplicate these capabilities. I view the Landsat Thematic Mapper as **mission essential** for conducting future global change studies. Maintaining the Landsat series of sensors as essential environmental monitoring tools is not simply a matter of National pride, it is a moral obligation that we have to the people of this planet. Thank you.

Figure 1. Ground photograph of heavy forest damage in the Krusne Hory of Czechoslovakia. Taken from the June issue of the National Geographic, 1991, pp. 46-7.

Figure 2. Landsat TM damage assessment image of the Ore Mountains between the former German Democratic Republic and the Czechoslovak Federal Republic. Data acquired September 30, 1985.

Figure 3a. Landsat TM damage assessment image for a small portion of the image shown in Figure 2. Data acquired September 30, 1985.

Figure 3b. Landsat TM damage assessment image for the same area shown above. Data acquired August 3, 1990.

Figure 4. Landsat TM change detection image showing change in forest damage conditions between 1985 and 1990. Red denotes total forest death or clear-cutting, while yellow indicates areas of significant increases in forest damage conditions.