SURVEYING DEAD TREES AND CO_2-INDUCED STRESSED TREES USING AVIRIS IN THE LONG VALLEY CALDERA

Steven 'M. de Jong[1]
Jet Propulsion Laboratory
California Institute of Technology, Pasadena CA 91109

1. INTRC)DUCTION

Since 1980 the Long Valley Caldera in the eastern Sierra Nevada (California) shows signs of renewed volcanic activity (Langbein et al., 1993; Hill et al., 1985). Frequent earthquakes, a re-inflation of the caldera, hydrothermal activity and gas emissions are the outer symptoms of this renewed activity. in 1990 and 1991 several areas of dying trees were found around Mammoth Mountain. The cause of the die off of the trees was first sought in the persistent drought in the preceding years. However, the trees died regardless of age and species. Farrar et al. (1995) started a soil-gas survey in 1994 in the dead-tree areas and found carbon dioxide concentrations ranging from 30 to 96% at soil depths between 30 and 60 cm. CO_2-concentrations in the atmosphere are usually around 0.03 % and in the soil profile CO_2-levels do commonly not exceed 4 to 5% (Voigt, 1962). Although not much is known about the effect of high levels of carbon dioxide in the soil profile on roots, it is most likely that the trees are dying due to oxygen deprivation: the CO_2 drives the oxygen out of the soil (Drew, 1991; Luxmoore et al,, 1986; Voigt, 1962). So far, four sites of dead trees were mapped around Mammoth Mountain.

The two largest dying trees sites are located near Horseshoe lake and near Mammoth Mountain Main Lodge covering approximately an area of 10 respectively 8 ha. Analysis of the gas composition regarding the $^3He/^4He$-ratio and the percentage biogenic carbon reveals the source of the gas: the magma body beneath the Long Valley Caldera (Farrar et al, 1995). Until recently it was not known that volcanoes release abundant carbon dioxide from their flanks and as diffuse soil emanations (Baubron et al., 1990). As a result of the magma gas emission around Mammoth Mountain there is a excellent sequence of dead trees, stressed trees, healthy trees and bare soil surfaces. This research site provides excellent opportunities to:

1. Study the capabilities of imaging spectrometry to map stressed (and dead) pines and fir species;
2. Study methods to separate the vivid vegetation, stressed vegetation and dead vegetation from the soil background of glacial deposits and crystalline rocks,

The dead tree areas are located on the flanks of Mammoth Mountain (N:37°37'45" and W:119°'02'05") at an elevation between 2600 and 3000 meters. The area is covered by an open type of Montane Forest. The dominant tree species are Lodgepole Pine (Pinus contorts), the Red Fir (Abies magnifica) and the Jeffrey Pine (Pinus jeffreyi). The soil surface near Horseshoe Lake is generally fairly bright. The surface is covered by glacial deposits (till) consisting mainly of weathered granitic rocks.

2. FIELD SPECTRAL MEASUREMENTS

in October 1995 spectral field measurements were carried out in two of the four dead tree sites using the JPL FieldSpec instrument (ASD, 1994). This instrument covers the 350-2500 nm spectral region using three individual spectrometers. It samples every 2 nm and the resolution varies between 10 and 11 nm. Together with each set of target measurements a white reference plate and the inst rument's dark current was determined. Multiple

[1] Visiting Scientist from: Department of Ph ysical Geography,
Utrecht University, 3508 TC The Netherlands (s.dejong@frw.ruu.nl)

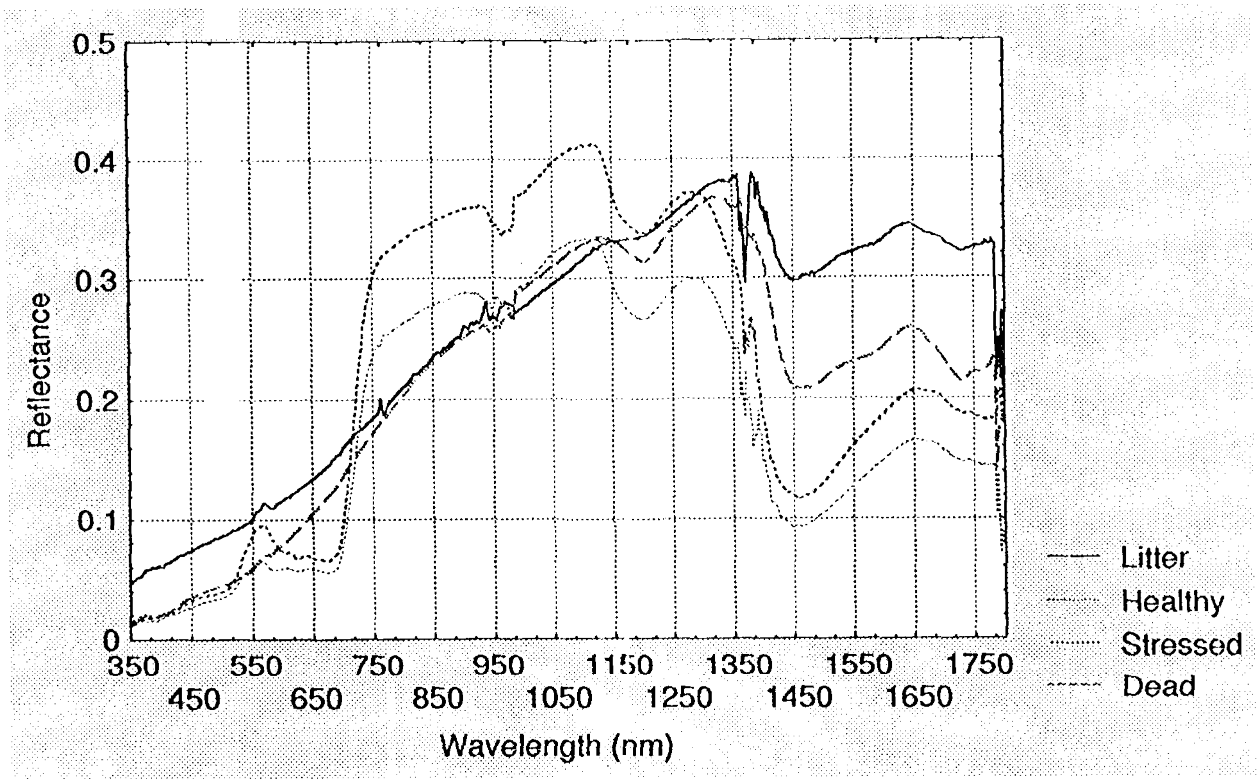

Figure 1: Examples of Field Spectra (n = 8) for litter and healthy, dead and stressed Lodgepole Pines (Pinus contorts spp. murrayana).

target measurements were averaged to increase the signal-to-noise ratio. The dark current was subtracted from tbe raw spectral measurements and the white reference measurements were used to convert the raw data to reflectance. Spectral behaviour of several surfaces was measured: healthy trees (several species), stressed and dead trees, the litter layer, dead trunks, bare soil surfaces and rock outcrops and some reference sites for radiometric image corrections. Trees were considered 'stressed' if several branches were dead or if at least some of the needles had lost color.

The field spectra were. then analyzed on their information content regarding healthy, stressed and dead trees ancl the soil background reflectance. The results yield a physical basis for the interpretation of AVIRIS imagery. Figure 1 show some examples of the collected field spectra of Lodgepole Pines. The spectra show clearly the presence respectively the absence of the chlorophyll absorption near 680 nm in the healthy and dead LodgePole Pine spectra. Anal ysis methods applied to the field spectra are 1) standard normalization procedures, 2) first derivative transform, and 3) convex hull transform and automatic absorption feature finding.

First derivative analysis (Curran, et al. 1992; Wessman et al., 1989) is a common method to enhance abrupt changes in the spectral curve of objects e.g. to enhance the red edge for vegetation. The convex hull transformation is a method to normalize spectra (De Jong, 1994a; Sedgewick, 1983). The convex-hull technique is analogous to fitting a rubber band over a spectrum to form a continuum. The difference between the hull and original spectrum is subtracted from a constant to obtain a hull-difference. Such a normalization of the spectra allows the application of quantitative absorption feature characterization.

The figures 2 and 3 and table 1 show some preliminary results. Figure 1 and 2 show the reduced chlorophyll absorption for the stressed LodgePole Pine and the absent chlorophyll absorption for the dead Pine. The red edge or blue shift (Curran et al., 1992) is visible but not very pronounced in the derivative spectra shown in figure 2. The spectral range from 1400 to 1700 displays an increasing brightness with decreasing water content (from healthy to dead pines to litter). The spectra for dead pines and litter show the absorption features for lignin around 1720 nm, described by Ustin et al. (1991), Peterson et al. (1988), Wessman et al. (1989) and Weyer (1985). Furthermore, the range from 1500 to 1750 nm shows a positive first derivative for the vegetative features while

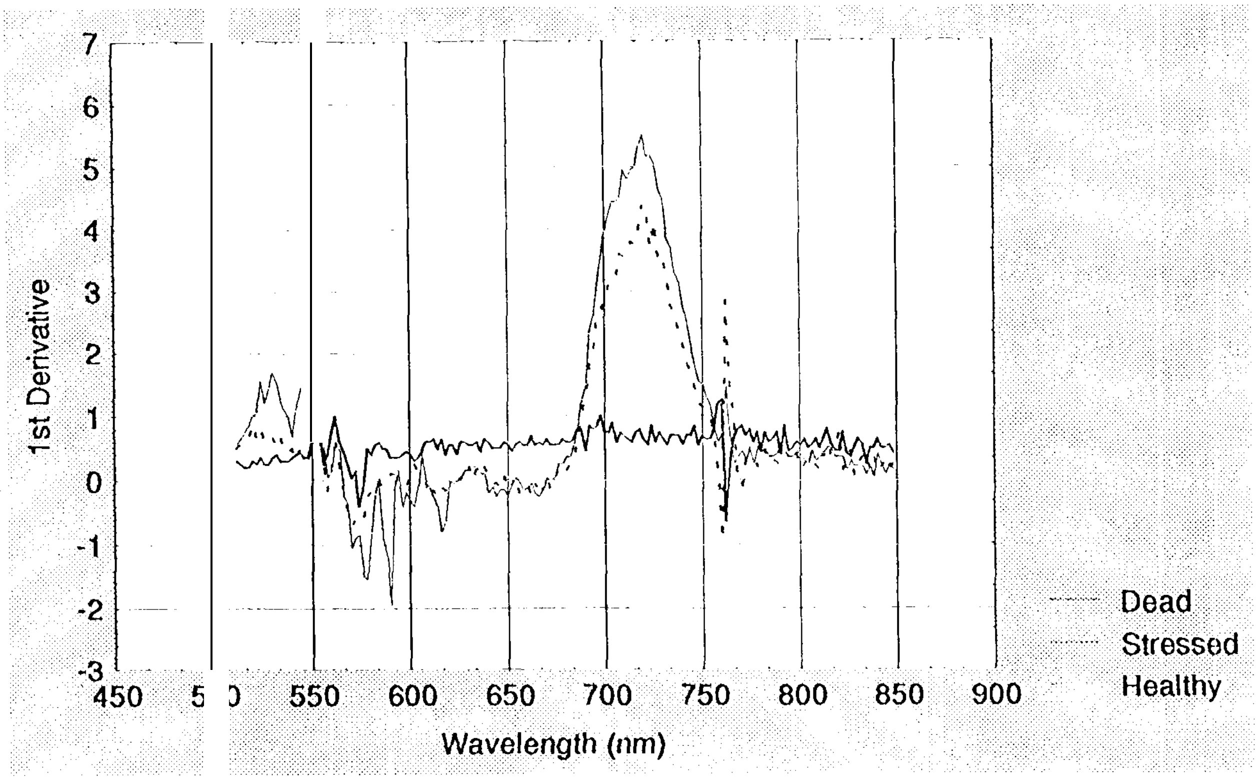

Figure 2: First Derivavtive Spectra (500 .850 nm) of Field Measurements of a Dead, Stressed and Healthy Lodgepole Pine.

non-vegetative objects are usually flat or even show the decrease of solar energy in this region. Figure 3 presents spectra derived from an AVI RIS image of August 23rd, 1994. These normalized image spectra also display the lignin absorption features and the positive slope for vegetation between 1 S00 and 1650 nm. Some first results for the convex hull transformation of the field spectra (0.4 -2.5 μm) are shown in table 1. Water is the most dominant absorption feature identified by the automatic absorption feature algorithm. The stressed Lodgepole Pine shows a decrease in chlorophyll absorption of approximately 15% compared to the healthy tree. The lignin absorption features for tbe litter spectrum and for tbe dead Lodgepole Pine spectrum arc only identified if the 'depth tolerance' of the algorithm is reduced. Absorption features are then found at 1724 nm with a depth of respectively 1.60 and 3.53.

4. AVIRIS IMAGE ANALYSIS

Three AVIRIS images of tbe Mammoth Mountain region were retrieved from the JPL archive acquired at the following dates: May 21st 1994, August 23rd, 1994 and June 22nd, 1995. The AVIRIS radiance data were converted to reflectance using the empirical line method. A linear regression function was computed between the field reflectance and tbe AVIRIS data of a dark and a bright surface (a large asphalt parking lot near Mammoth Mountain I.edge and a gravel field south of Mammoth Village). Reflectance of a number of sites throughout the three multi-temporal images were compared to verify the results of the empirical line conversion, The next steps in this research are 1) to study further the AVIRIS spectral properties of the dead trees area at Horseshoe Lake, 2) to examine the temporal changes of the dead trees areas using the AVIRIS images available for different dates, 3) to study stress indicators for tbe Pine t rees and 4) to use spectral unmixing to produce a map of stressed, dead and healthy trees.

4.1 Dead **Tree Image Transect**

in tbe August 1994 image a transect was put over the dead tree area near Horseshoe Lake. The transect covers from north-east to south-west: the Borrow pit, stressed trees, dead t rces and bare soil areas, dead and stressed trees and healthy trees. Along this transect the spectral information is analyzed regarding chlorophyll ab-

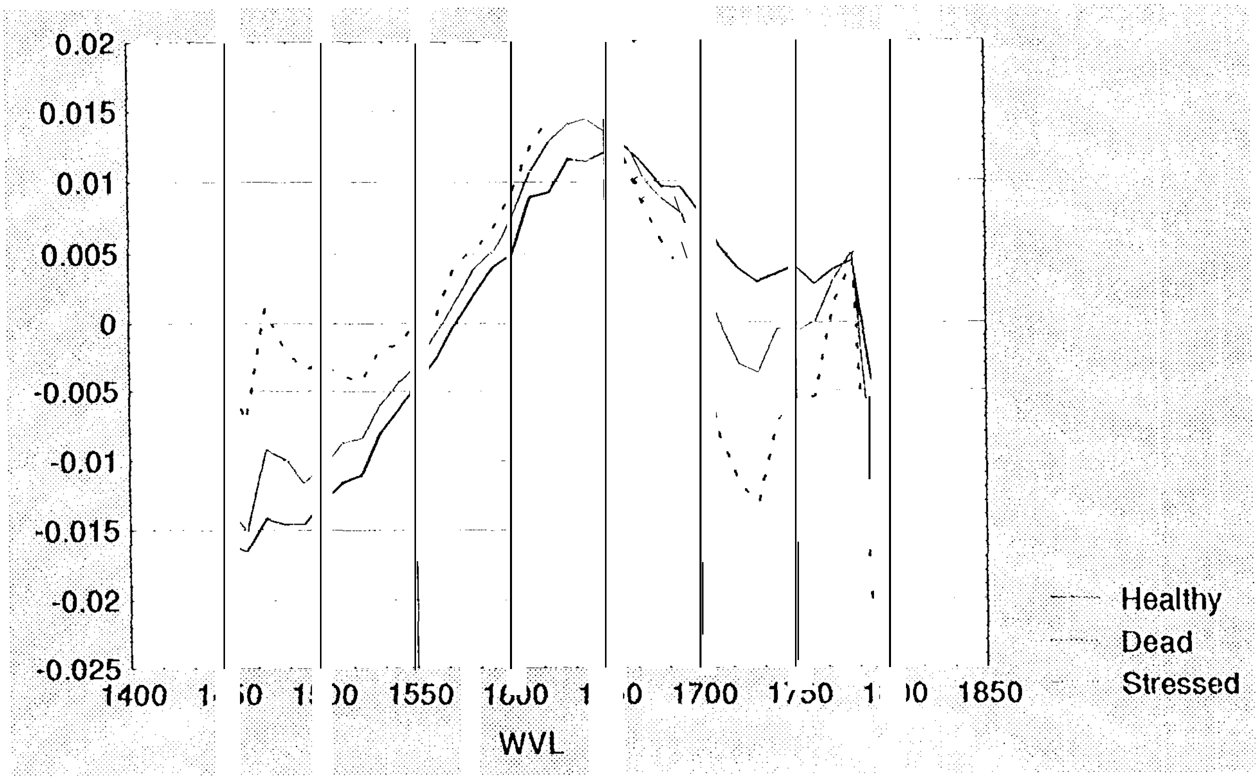

Figure 3: Normalized AVIRIS Spectra (1450 . 1800 nm) of Healthy, Stressed and Dead Pine Species near Horseshoe Lake.

sorption, lignin absorption and stress indicators. **Figure 4 shows** a 3D plot of the transect. The Y-axis show the AVIRIS spectral bands from 460 to 1250 nm, **the** X-axis assigns the distance along the transect (total distance is approximately 1200 m) and the Z-axis reflectance. Pixels 74 to 77 (X-axis) show the high reflectance throughout the spectrum of the bright surface of the Borrow pit, Pixels 62 to 74 cover an area of stressed pine trees, the typical vegetation shape of the spectrum is still visible but chlorophyll absorption is reduced, Pixels 46 to 60 covers an area of exclusively dead trees and of bright soil surfaces of weathered granite and glacial till (many trees have been cut and removed from this former campground). Pixels 20 to 45 show a transition zone of stressed and healthy pine trees. The beginning of the transect is an area of vivid deciduous trees and pine species with a strong chlorophyll absorption and a significant infrared reflectance.

4.2 Multi-temporal Analysis

A multi-temporal analysis of the three available airborne images was carried out to assess the temporal changes of forest cover between the first available AVIRIS scene (940521) and the last acquired image (950622). The three images were geometrically matched to one another using ground control points and a first degree polynomial warping algorithm. Next a Normalized Difference Vegetation Index (NDVI) was computed for each image. Large NDVI values indicate pixels with high proportions of green biomass, low values indicate pixels of bare soil, water bodies or built up areas and intermediate values give an indication for differences in coverage with green vegetation (De Jong, 1994b; Tucker, 1979). The three multi-temporal NDVI images were displayed as a red, green and blue combination and visually interpreted. Different combinations of red, green and blue mark a change of NDVI values, which is an indication for an increase or decrease of vegetative cover. Results show that the Horseshoe Lake dead trees area is fairly constant over the 13 months studied. Only the western edge of this region shows some minor enlargement. The second dead tree area further uphill of Horseshoe Lake shows a significant decrease of NDVI values over time and hence, an important enlargement of the dead tree area since May 1994. At the western flank of Mammoth Mountain uphill of Satcher Lake another area of diminishing NDVI values was found. It was first identified as a fifth, so far unknown **dead** tree area. However, image and topographic

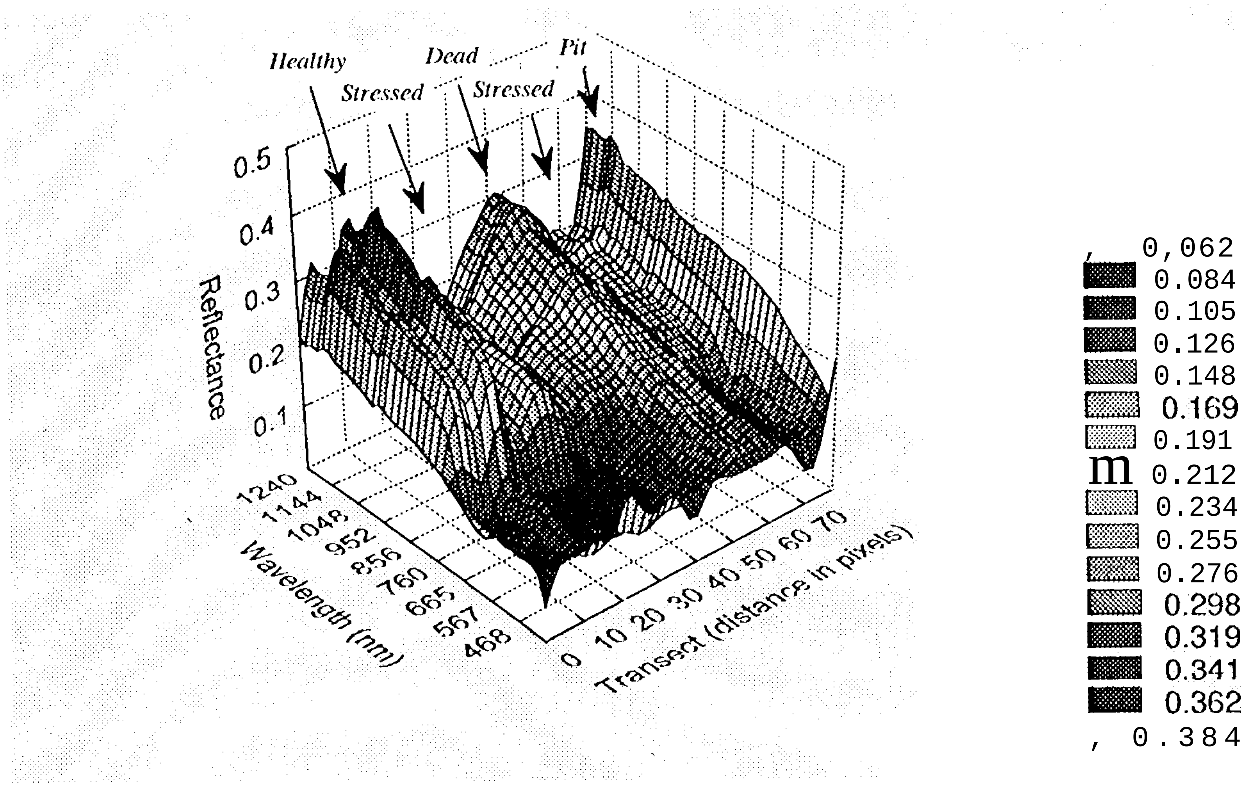

Figure 4: 3-Dimensional Plot of the AVIRIS image Transect near Horseshoe Lake. The Transect Crosses a Gravel Pit and Healthy, Stressed and Dead Pine Trees. The X ,Y,Z Axes Represent Respectively the Distance along the Transect, the AVIRIS Spectral Range from 460 to 1250 nm and the Reflectance.

interpretation revealed that it is most probably an avalanche area where some trees vanished. Fieldwork must reveal the definite cause of the NDVI drop as differences in snow cover hampers multi-temporal image interpretation. The dead tree areas near Reel Lake and the Mammoth main lodge are unfortunately outside the Coverage of this multi-temporal data set.

4.3 Stress Indicators

The first sign that vegetation is exposed to stress (senescence, water deficiency, or herbicide) is usually a decrease of the absorption by chlorophyll (Carter, 1994; Carter & Miller, 1994; Hoque & Hutzler, 1992; Ruth et al., 199 1). These subtle changes of light absorption are at first detectable at the edges of the chlorophyll absorption feature i.e. around 605 nm and 695 nm. The plant stress indicators proposed by Carter (1994) were applied to the field and image spectra to determine its suitability to map the stressed' pines near Mammoth. Reflectance ratios as stress indicator suggested by Carter (1994) use the following bands: 606 and 760 nm, 695 and 420 nm or 695 and 760 nm. If the Mammoth field data (e.g. figure 2) arc compared to Carter's dataset, a small shift of the chlorophyll absorption band towards longer wavelengths seems to occur. This shift might be duc to different vegetation species or to a shift in sensor sensitivity.

Carter's first stress indicator (R606/R760) applied to tbe spectra of figure 1 yields values for healthy, stressed and dead pines of 0.22, 0.2S and 0.45 respectively. Carter (1994) reports values determined in the laboratory ranging from 0.13 to 0.47. The image transect of figure 4 yields values ranging from 0.24 to 0.S for the tree covered areas. The values for the bare surface areas were not considered. A prerequisite for deriving valuable early stress indications for trees using AVIRIS, requires first a separation of vegetated areas from bare areas. The latter is onc of the topics for future planned work.

Table 1: Results Automatic Absorption Feature Search.

Wavelength	Depth	Area	Asymmetry
Healthy Lodgepole Pine (Pines contorta):			
1.8040	25.2592	3.6183	0.0314
1.4540	22.2009	4.79s4	0.4094
0.6860	18.44S5	2.2596	2.6633
1.9860	13.6994	0.3587	0.1768
1.9700	13.6013	0.1553	1.9560
Stressed Lodgepole Pine (Pines contorta):			
1.8040	18.5023	2.6410	0.0441
1.4460	17.5540	3.S220	0.3128
0.6880	14.2796	1.925s	3.1891
1.9640	12.0939	0.2501	0.3853
1.7940	11.8013	0.1222	4,3238
Dead Lodgepole Pine (Pines contorta):			
1.8040	2S. 1266	3.5749	0.0278
1.9640	14.9782	0.1669	0,5096
1.9560	14.148s	0.0831	0.5139
1.4540	13.5969	2.3908	0.3469
2.1060	11.1379	0.2055	1.5145
1.7880	10.8838	0.1313	0.5303
Litter:			
1.8040	31.5548	4.6171	0.0400
1.9560	11.5030	0.0454	1.0037
1.9600	11.3799	0.1287	0.2122
1.7880	9.1239	0.0661	0.8646
1.4460	8.0103	1.1761	0.3211
Healthy Red Fir (Abies magnifica):			
1.4460	25.3815	4.6679	0.0950
1.4280	2s.2224	1.0844	20.5118
1.8040	24.0184	3.435'7	0.0349
0.6880	23.6689	2.9338	2.9247
1.9640	16.S759	0.2219	1.3108

4.4 Spectral Unmixing

In the next phase of this study spectral unmixing (Roberts et al., 1993; Adams et al., 1993) will be used to assess the spatial distribution of the stressed and dead trees. A group of spectral end members is currently prepared. Results will be presented at the workshop.

5. DISCUSSION ANI) RESULTS

Field and image spectra are used in this study to determine the practical use of AVIRIS images to survey CO, induced stress and dead pine trees. First results show either field and image spectra contain information on the chlorophyll absorption and a decline of chlorophyll absorption in ease of stressed trees. In the dead tree areas the chlorophyll absorption is absent but the presence of dead vegetative material can be revealed from absorption features in the 1500 to 1750 nm range. The use of multi-temporal AVIRIS images appeared useful to detect changes of the surface area of dead and/or stressed trees although the time period of 13 months is rather short and some problems were experienced with differences in snow cover and sun angle. Some preliminary results using AVIRIS images to derive stress indicators for pine trees are encouraging but need further study.

Acknowledgments

The research described in this paper was financially supported by the Netherlands Organization for Scientific Research (N WO Talent program). Mr. D.A. Roberts (UCSB) is acknowledged for providing the Prism software and for the fruitful discussions.

REFERENCES

Adams J.B., M.O. Smith, A.R. Gillespie, 1993, Imaging Spectroscopy: Interpretation Based on Spectral Mixture Analysis. In: Pitters C.M. & P.A.J. Englert (Eds.), Remote Geochemical Analysis: Elemental and Mineralogical Composition. Cambridge Universit y Press, New York. pp. 145-166.

ASD, 1994, FieldSpec FR User's Guide. Analytical Spectral Devices inc., Boulder CO.

Baubron J .C., P. Allard & J.P. Toutain, 1990, Diffuse Volcanic Emissions of Carbon Dioxide front Volcano island, Italy. *Nature Vol.344, pp.51-53.*

Carter G. A., 1994, Ratios of Leaf Reflectances in Narrow Wavebands as Indicators of Plant Stress. *International Journal of Remote Sensing vol. 15, pp. 697-70-?.*

Carter G .A. & R.L. Miller, 1994, Early Detection of Plant Stress by Digital Imaging within Narrow Stress-Sensitive Wavebands. *Remote Seining of Environment vol.50, pp.295-302.*

Curran P. J., J.L. Dungan, B.A. Macler, S.E. Plummer & D.L. Peterson, 1992, Reflectance Spectroscopy of Fresh Whole Leaves for the Estimation of Chemical Concentration, *Remote Sensing of Environment 39, pp. 153-166.*

De Jong S. M., 1994a, Applications of Reflective Remote Sensing for Land Degradation Studies in a Mediterranean Environment. *Netherlands Geographical Studies 177, KNAG Utrecht, 240pp.*

De Jong S. M., 1994b, Derivation of Vegetative Variables from a Landsat TM Image for Erosion Modelling. *Earth Surface Processes and Landforms, Vol. 19, pp. 165-178.*

Drew M .C., 1991, Oxygen Deficiency in the Root Environment and Plant Mineral Nutrition, In: M.B. Jackson, Plant Life under Oxygen Deprivation. SPB Academic Pub. The Hague. pp.303-326.

Farrar C. D., M.L. Sorey, W.C. Evans, J.F. Howle, B. D. Kerr, B.M. Kennedy, C.Y. King & J.R. Southon, 1995, Forest-Killing Diffuse CO_2 Emission at Mammoth Mountain as a Sign of magmatic Unrest. *Nature Vol.376, pp.675-678.*

H*ill* D. P., R.A. Bailey & A .S. Ryan, 1985, Active Tectonic and Magmatic Processes Beneath long Valley Caldera, Eastern California: An Overview. *Journal of Geophysical Research, Vol.90, pp. 11111-11120.*

Hoque E. & P.J. S. Hutzler, 1992, Spectral Blue-Shift of Red Edge Monitors Damage Class of Beech Trees. *Remote Sensing of Environment* 39, **pp.** 81-84.

Luxmoore R. J., J.J. Landsberg & M. R. Kaufmann, 1986, Coupling of Carbon, Water and Nutrient interactions In Woody Plant Soil Systems. Heron **Pub.**, Victoria. 467 pp.

Peterson D. L., J.D. Aber, P.A. Matson, D.H. Card, N. Swanberg, C. Wessman & **M.** Spanner, 1988, Remote Sensing of Forest Canopy and Leaf Biochemical Contents. *Remote Sensing of Environment* 24, *pp.85-105.*

Roberts D. A., M.O. Smith & J .B. Adams, 1993, Green Ve.gctation, Non-Photosynthetic Vegetation, and Soils in AV1 RIS Data. Remote Sensing of Environment 44, pp.255-269.

Ruth B., E. Hoque, B. Weisel & P.J .S. Hutzler, 1991, Reflectance and Fluorescence Parameters of Needles of Norway Spruce Affected by Forest Decline. *Remote Sensing of Environment 38, pp. 35-44.*

Sedgewick R., 1983, Algorithms. Addison-Wesley, Reading Massachusetts.

Tucker, C.J. 1979. 'Red and Photographic Infrared linear Combinations for Monitoring Vegetation'. *Remote Sensing of Environment 8, pp. 127-150.*

Ustin S.L., C.A. Wessman, B. Curtiss, E. Kasischke, J. Way & V.C. Vanderbilt, 1991, Opportunities for Using the EOS Imaging Spectrometers and Synthetic Aperture Radar in Ecological Models. Ecology *Vol.* 72, pp. 1934-1945.

Voigt G .K., 1962, The Role of Carbon Dioxide in Soil. *In:* 7.7. *Kozlowski (Ed.), Tree Growth.* ***Ronald Press Company, New York. pp. 205-220.***

Wessman C. A., J.D. Aber & D.L. Peterson, 1989, An Evaluation of Imaging Spectrometry for estimating Forest Canopy Chemistry. *International Journal of Remote Sensing, Vol. 10, pp. 1293-1316.*

Weyer L. G., 1985, Near Infrared Spectroscopy of Organic Substances. ***Applied Spectroscopy reviews 21, pp. 1-43.***

de Ja

To: Ms . G. Peralta
Jet. Propulsion Lab.
Mail Stop 180-201
4800 Oak Grove Drive
Pasadena CA 91106

Date: December 21, 1995

Dear Ms. Peralta,

I would like to submit. the enclosed paper for publication in the proceedings of the 6th Airborne Earth Science Workshop, March 4-8, 1996.

Sincerely yours,,

Steven M. de Jong
Visiting Scientist at JPL
AVIRIS group
Tel : 4-4372
Bldg : 1 69-422