Santa Ana Windflow in the Newhall Pass as Determined by an Analysis of Tree Deformation

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ABSTRACT

A tree deformation study was conducted in a suburban area of the Newhall Pass (located to the north of Los Angeles, California) to determine the direction and intensity of the Santa Ana windflow. Trees were used to provide the large data base necessary to study the windflow in rugged terrain in an area that is very vulnerable to the fire hazard presented by these winds.

To obtain a large data base, the study involved the use of several tree species. Comparison of the wind-direction data obtained from the trees correlates very closely with windvane data obtained in the study area. In measuring the intensity of the winds, a statistical deformation index was devised that is not affected by differing species response to the wind. This index is based upon the total number of trees per unit area that are deformed. It transforms the study of wind intensity—as reflected by the trees—from a largely qualitative judgement of the degree of tree deformation to a quantitative statistic.

With a careful consideration of non-wind effects which can deform the trees, studies of this type are very inexpensive and easy to conduct, providing an accurate climatological wind record as an adjunct to long-term meteorological data, especially in data-sparse regions.

1. Introduction

The Newhall Pass is one of the few passes in the Transverse Mountain range system that allows the flow of the Santa Ana winds to continue from the high desert into the Los Angeles basin. Unlike the other passes (Cajon, San Gorgonio and Santa Ana), the Newhall pass has not yet been studied in detail.

A 30 km^2 area on the south side of the pass was chosen as the study area. Three major canyons incise the relatively rugged terrain—Limekiln, Aliso and Bee canyons. To establish a network of wind stations in this terrain would be both difficult and costly to provide the density of wind stations required to ascertain the microtopographical wind characteristics. Trees, on the other hand, can provide a very dense data base from which the details of windflow in the area can be determined. A total of 465 trees were studied to provide a detailed reconstruction of the windflow.

The city of Los Angeles abuts against the hills in the study area. This suburban perimeter is the most sensitive to the Santa Anas that blow through the pass; the fire hazard associated with the Santa Anas is well known (Sommers, 1978; Fosberg *et al.*, 1966; Edinger *et al.*, 1964). Since fires have burned on several occasions to the edge of the suburban homes in this study area, detailed documentation of the Santa Ana intensity and direction is certainly worthwhile.

2. Determining the wind type affecting the trees

In the study of tree deformation, past studies have followed a consistent sequence of steps. The principal step is to determine what wind is deforming the trees. Only the most detrimental winds—those that have damaged the trees to an observable extent—can be measured. It is most often not the mean annual wind. Along the coast, the trees will be deformed by salt-laden winds blowing off the ocean (Davies, 1810; Edwards and Claxton, 1964; Kayane, 1969; Thomas, 1973). In regimes with winter snows, the trees will be affected by winds that blow the snow and glaze droplets (Lawrence, 1939; Yoshino, 1964, 1975) or the trees may be affected by summertime winds that damage new growth (Putnam, 1948). Yoshino (1975) emphasized these types of tree response in the following classification scheme:

I: Branches are bent drastically to the leeward of the tree by the prevailing winds during their growing period. This type consists of conifers and poplars.

II: Branches on the windward side of the tree are severed by the effects of winter winds carrying snow or frozen rain. This type consists only of conifers as far as is known.

III: Trunks and branches both deformed drastically by the prevailing wind during their growing

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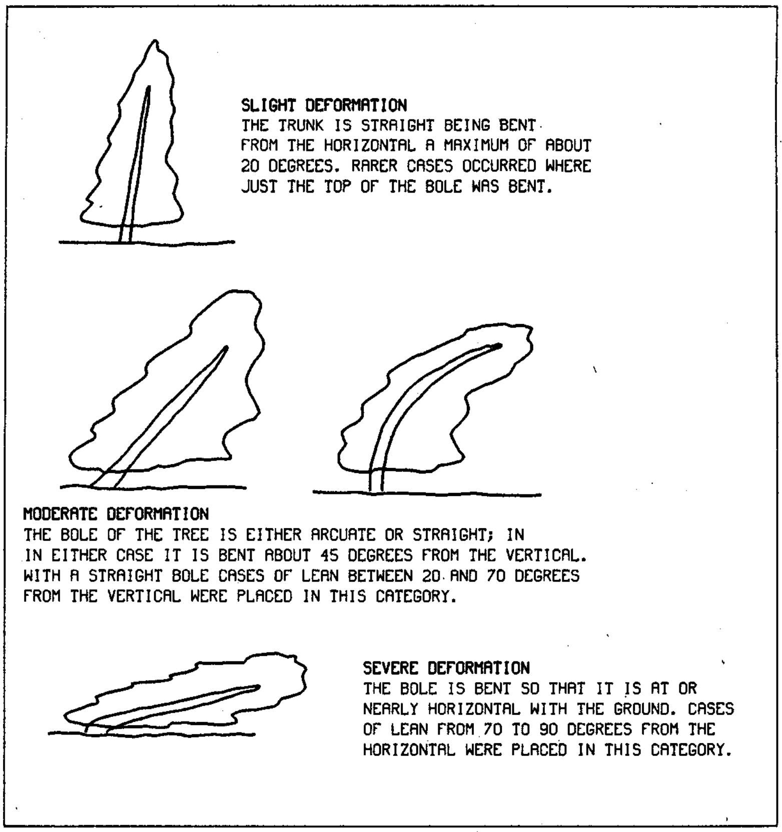


SLIGHT DEFORMATION
THE TRUNK IS STRAIGHT BEING BENT FROM THE HORIZONTAL A MAXIMUM OF ABOUT 20 DEGREES. RARER CASES OCCURRED WHERE JUST THE TOP OF THE BOLE WAS BENT.

MODERATE DEFORMATION
THE BOLE OF THE TREE IS EITHER ARCUATE OR STRAIGHT; IN IN EITHER CASE IT IS BENT ABOUT 45 DEGREES FROM THE VERTICAL. WITH A STRAIGHT BOLE CASES OF LEAN BETWEEN 20 AND 70 DEGREES FROM THE VERTICAL WERE PLACED IN THIS CATEGORY.

SEVERE DEFORMATION
THE BOLE IS BENT SO THAT IT IS AT OR NEARLY HORIZONTAL WITH THE GROUND. CASES OF LEAN FROM 70 TO 90 DEGREES FROM THE HORIZONTAL WERE PLACED IN THIS CATEGORY.

FIG. 1. Pictoral sketches and the accompanying definitions for the three levels of deformed trees comprising the deformation-intensity scale.

season. This type consists of deciduous and evergreen broadleaf trees. They are often found in coastal areas.

IV: Trunks are deformed due to occasional strong winds. The shape of the canopy is symmetrical.

This study consists of the only deformation type (according to Yoshino) that has yet to be studied—deformation type IV. The only intense winds that occur in the area are the Santa Ana winds. The Santa Anas blow almost exclusively from September to June of each year (with peak intensities in fall and spring). They exert a strong and dessicating force on the trees. During the subsequent growing season new growth sprouts unimpeded. The result is a deformed tree bole with a symmetrical and largely unaffected canopy.

There are two aspects of the winds that can be obtained from the deformed trees. The direction the tree is leaning indicates the direction the wind blew from in deforming it. Direction of lean was measured with a Lensatic compass to the nearest 5° interval. An indication of wind intensity can be gauged by establishing a scale of deformation. Fig. 1 depicts the scale devised for this study. Fig. 2 shows more complex variations of the scale which occur in the field. Photos 1–4 show actual field examples.

3. Comparisons with meteorological data

Tree data are often coupled with some meteorological data from weather stations in the study area. Such data serve as a secondary verification of the tree results. A number of locales were selected in the study area where spot windvane data were recorded during the winter of 1976–77. The idea was to have a large number of sample sites throughout the study area so that a representative wind sample would be derived. The distribution of windflow for the entire area was determined with the results compared to the distribution indicated by the trees. This provides good evidence as to whether the trees reflect the main Santa Ana flow.

Fig. 3 exhibits a number of points that have been discussed so far. The figure shows the distribution of each level of deformation and the windvane results in a cumulative graph. The following conclusions can be made from the graph:

- The graph is a normal distribution. To emphasize this, the data have been plotted on probability paper (it has the characteristic that a normal distribution will plot as a straight line). The mean direction of Santa Anas is 360° with 80% of all winds in the area blowing from between NW and NE.
- The different levels of deformation correspond very closely indicating that each is a response to the same windflow.
- The windvane and tree deformation results are almost identical; the trees are accurately reflecting the regional windflow.
- The windvane data represent a graphing of only Santa Ana winds. The close correlation of the windvane curve and the tree deformation curves shows that the trees studied are only deformed by Santa winds.

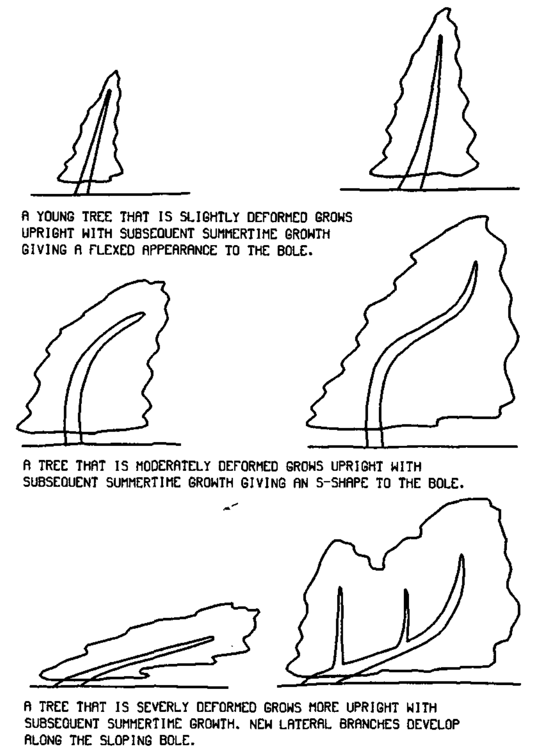
4. Non-wind effects acting on the trees

The primary source of error in a tree deformation study are non-wind effects that induce deformation of the trees. It is the most important aspect of any tree deformation study, but has received little attention in the literature. Since this is a suburban study, errors due to man-made and natural non-wind effects must be considered.

The climate is quite mild in that trees in the study area are not affected by ice, snow or glaze droplets (it never snows in the area), or salt spray (the study area is 30 km from the ocean). Nor were the rarer effects of flood, avalanche, hail, cold, lightning or fire observed. Drought is not a problem for these trees grew on homeowners' property with all trees appearing adequately watered.

Trees exhibiting any of the following characteristics were excluded from use in this study:

- Newly planted trees, that is, those with trunks that are less than 3 inches in diameter. The trunks are often tall and unable to support the canopy causing them to lean over.
- Guy-wired or staked trees (especially newly planted trees). They do not show the accurate degree of deformation of the correct azimuth of lean. Acceptable are large trees with tiny stakes that are not tied to the trees, being old remnants.
- Any tree near other trees that have since been cut down that could have influenced the growth of the tree in question. This is evidenced by the old stumps that are often not removed.
- Scars on the trunk, especially on the side opposite the direction of tree lean, indicating that the tree is leaning due to being hit by an auto or otherwise damaged.
- Wilting of a tree due to lack of water. The needles and leaves are characteristically wilted.
- Subsidence of the soil near sprinkler system pipes inducing tree lean. This is often associated with a depression of the soil adjacent to the pipe, with the tree leaning into the depression.



A YOUNG TREE THAT IS SLIGHTLY DEFORMED GROWS UPRIGHT WITH SUBSEQUENT SUMMERTIME GROWTH GIVING A FLEXED APPEARANCE TO THE BOLE.

A TREE THAT IS MODERATELY DEFORMED GROWS UPRIGHT WITH SUBSEQUENT SUMMERTIME GROWTH GIVING AN S-SHAPE TO THE BOLE.

A TREE THAT IS SEVERLY DEFORMED GROWS MORE UPRIGHT WITH SUBSEQUENT SUMMERTIME GROWTH. NEW LATERAL BRANCHES DEVELOP ALONG THE SLOPING BOLE.

FIG. 2. Examples of more complex variations of the deformation-intensity scale that occur in the field are depicted.

- Trees with undermined or exposed roots. The roots are exposed due to erosion or windthrow (trees uprooted partially and leaning due to a single, intense windstorm).
- Trees planted in non-compacted earth fill, especially trees planted in soil filled behind brick embankments.
- Soil creep and landsliding. These trees are on noticeable slopes with the trees leaning downhill.
- Groves of trees, since they could be deformed by winds altered by the grove itself.
- Trees sheltered from winds blowing from any direction. This includes sheltering by other trees and by the local terrain. Sheltering by houses is by far the most common—probably why far less trees exhibit deformation in the area than would be expected in a natural forest setting.
- Pruning, inducing irregular trunk growth and artificial bole curvature. Trees arching over with evidence of old branch or prior tree shoot stubs at the point of curvature.
- Reaching for sunlight by growing out from houses or other trees.

PHOTO 1. A eucalyptus tree exhibiting slight deformation. Though this tree shows a tendency for more foliage to occur to the lee, this is not found with the three trees in the immediate background. Foliage assymetry is not as consistent a characteristic of tree deformation intensity (for this area) as is the curvature of the tree bole.

- Trenches, streetwork or other digging that could have damaged the roots or softened the soil so that the tree collapsed into the area of soft soil.
- Trees that bend along the bole length in more than one direction. This is often a result of several prior times of tree guy-wiring and/or pruning.
- This study selected for trees with straight boles for at least one foot from ground-level then leaning over. This minimizes the possibility of recording one-time windthrow events rather than long-term wind deformation effects. Trees with straight boles from the ground up were scrutinized for evidence of windthrow. The dislodging of the roots produces a mounding of the soil upwind with the near-surface roots becoming exposed in subsequent years.

Fig. 4 shows a frequently observed pattern of man-induced deformation. Several effects on the trees that are difficult or impossible to determine are changes in soil fertility, differences in soil type, retarded root growth, disease or insect pests, effects of tree age, summertime heat stress, air pollution and injurious chemicals.

One final error source needs to be considered. Most studies have used only one species of tree to use as a wind indicator. The logic involves the concept of a ''species effect''. The concept is that since different species have different degrees of resistance to the wind, the use of a scale of tree deformation must be a unispecies study. This recently was reemphasized by Wade and Hewson (1979).

This study is a multispecies study. About 51% of the trees studied were pines, 23% were eucalyptus and 12% evergreen pear (*Pyrus kawakami*). The remainder consists of lesser percentages of other tree types. In a suburban setting the tree type will not be homogenous. To have a large data base a multispecies study is necessary. The primary ques-

PHOTO 2. Two large eucalyptus trees exhibiting moderate deformation. Note the arcuate bole of the tree on the right. The tree on the left has the same arcuate trunk, but this is partially obscured by more recent growth directed more upright.

PHOTO 3. A pine with a straight trunk classified as moderate deformation.

PHOTO 4. A pine exhibiting severe deformation. The bole extends straight up for about 1 ft, then bends at an angle of 80° from the vertical. This emphasizes the violent nature and power of the worst Santa Ana windstorms.

tion considered here is the following: Are the other errors so great that the species effect need even be considered? Is the species effect a minor error?

With regards to the direction of tree lean, a species effect is not evidenced. Fig. 5 is a cumulative graph of two groups and one species of tree: pines, euca-

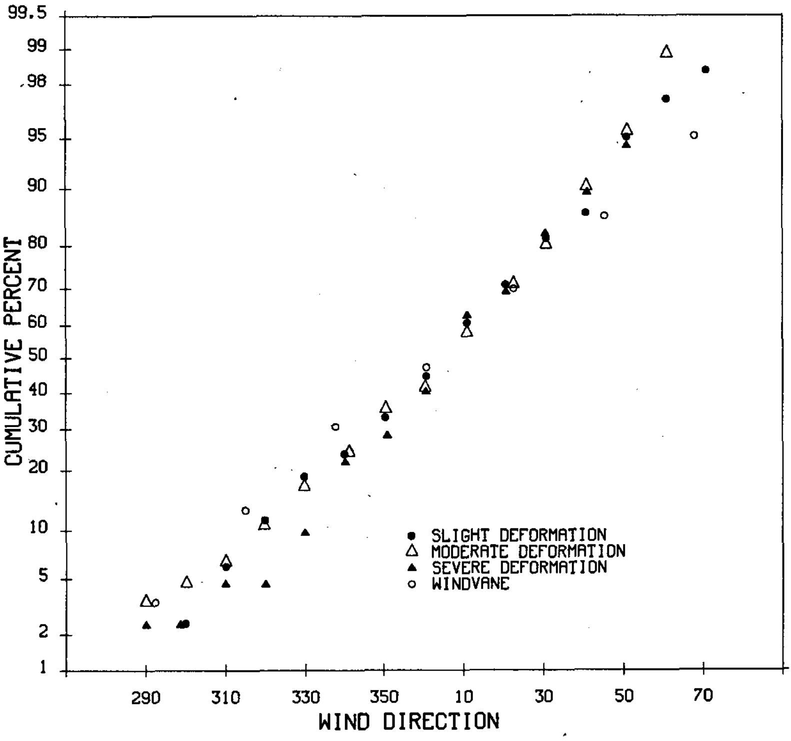


FIG. 3. A comparison of the levels of slight, moderate and severe deformation as compared to the windvane results. The close relationship between the tree and windvane results is emphasized by plotting the data on probability paper (which has the effect that a normal distribution plots as a straight line).

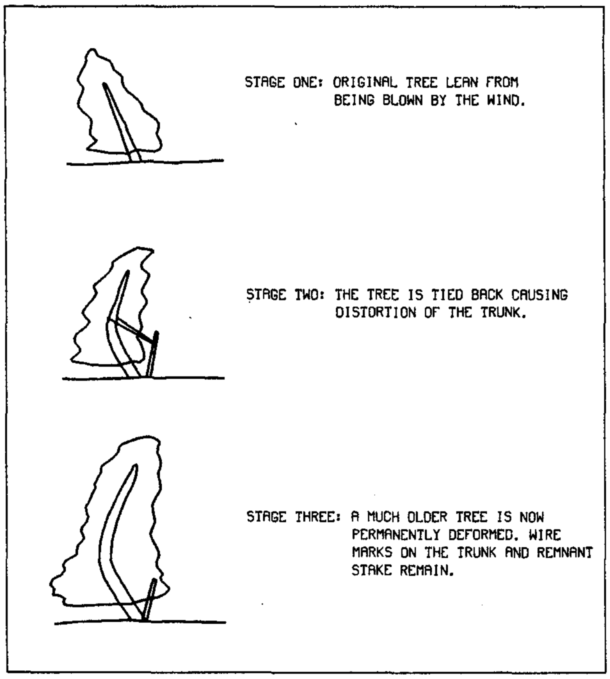


FIG. 4. Man-induced effects considerably alter the appearance of the trees. Shown here is a common sequence of events that produces an unnatural curvature of the tree. As these suburban trees become more deformed by the wind they are concurrently more apt to be altered by man in some way.

lyptus and the tree *Pyrus kawakami*. The distribution of each is graphed along with the windvane results. These groups compare closely to each other and the windvane distribution. The distributions are identical to those of Fig. 3 (where all types of trees were included together). This shows quite clearly that more than one species of tree can be used in studying wind direction.

5. Pattern of windflow in the study area

Testing the magnitude of tree deformation for evidence of a species effect is much harder though two lines of evidence cast doubt on any strong species effect in the study area. If a species effect was pronounced, it would be expected that when mapped, the boundaries separating the magnitudes of deformation would correspond to different tree types. Regions of severe deformation would exist only where pines are found, for example. The occurrence of pine and eucalyptus trees are distributed throughout the study area with no evidence of such an effect observed.

In Fig. 6 the distribution of the direction and intensity of tree deformation in the study area has been mapped. The pattern corresponds not to one of species differences, but rather, strictly topographical effects are noted. In the west and central parts of the study area the pattern is the simplest. The area of Horse ravine, in the direct lee of the Santa Susana mountains which rise to 3000 ft to the immediate north is an area of slight deformation except for the western portion which is affected by winds coming down Limekiln Canyon. The area titled Porter Ranch golf course is affected almost solely by NNE winds with Limekiln Canyon winds having a minimal effect.

The boundary of moderate deformation (called the moderate deformation line) follows the 1100 ft contour up to the southern edge of Bull Canyon. This is the elevation at which the canyons and rugged terrain give way to the flatlands of the San Fernando Valley. The trees indicate a merging of the canyon winds with the NNE winds—the NNE winds dominating. Since these canyon winds do not extend into the flatlands where the NNE winds dominate, the canyon winds are not regarded as being as strong. It would be hard for Aliso and Limekiln canyons to direct much of the Santa Ana winds considering that their origins are downslope and to the lee of the Santa Susana mountain ridge so are laregly sheltered from the main Santa Ana flow. The moderate deformation line is believed to be a result of more intense winds occurring in the hills of the western and northern part of the study area. Note the dominance of the NNE winds with little canyon flow discernible there.

North and South Knollwood ravines contain the Knollwood golf course, being the sites of severe deformation in the eastern part of the study area. On the western edges of these two ravines, low north-south oriented ridges occur that block the

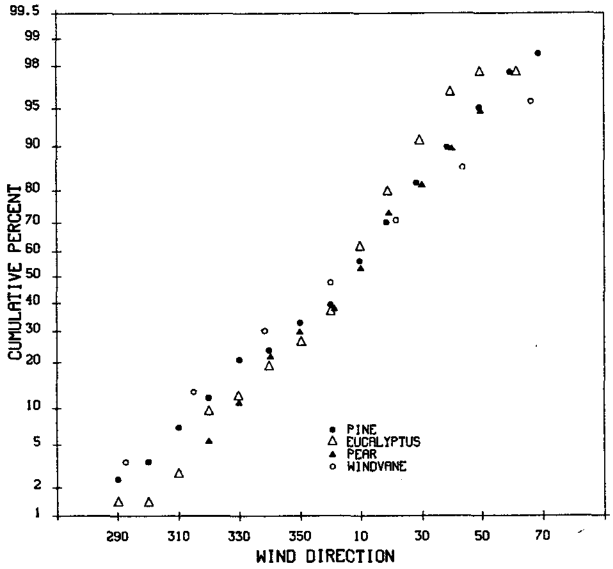


FIG. 5. A comparison of three tree types and the windvane results. The close relationship between the tree types and the windvane results is emphasized by plotting the data on probability paper (which has the effect that a normal distribution plots as a straight line).

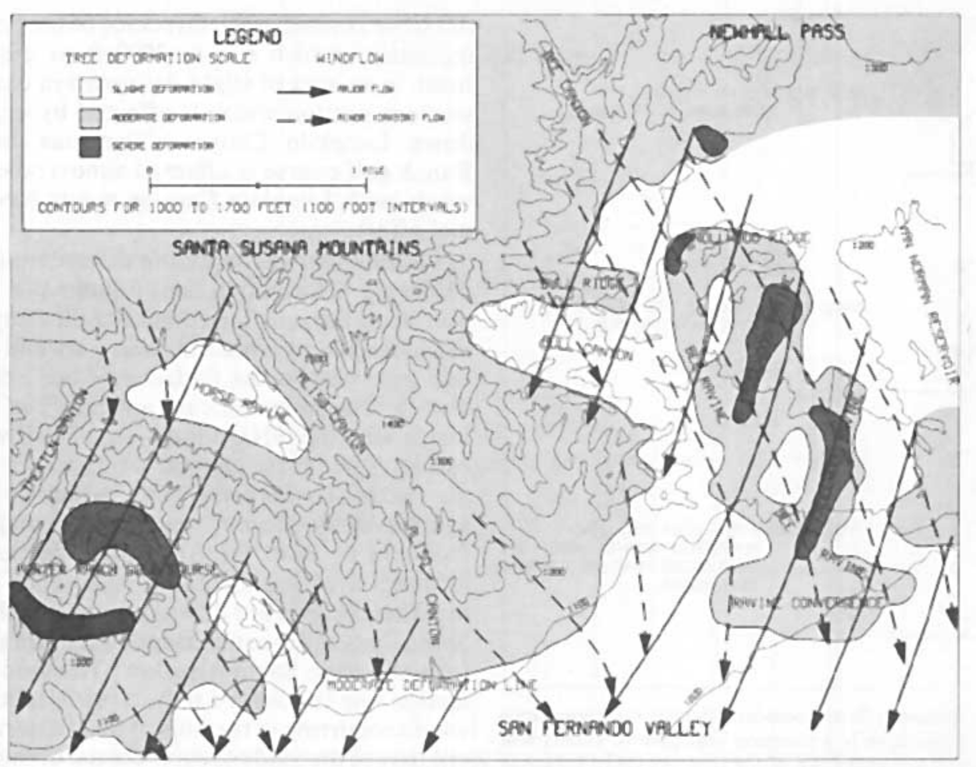


FIG. 6. Relative wind intensity and direction of windflow derived from the deformation intensity index and the direction of tree lean. This map is based on the interpretation of 465 trees for this area.

NNE flow. As a result, areas of slight deformation occur in their lee.

Bee Canyon is different than Aliso and Limekiln canyons. Bee Canyon is situated in the western part of the Newhall Pass (in the northeastern part of the study area). It is the most prominent canyon in the pass. As expected, a strong flow coming down the canyon (and its southern extension called Bee Ravine) is indicated by both the pattern of tree deformation and the direction of tree lean. This flow

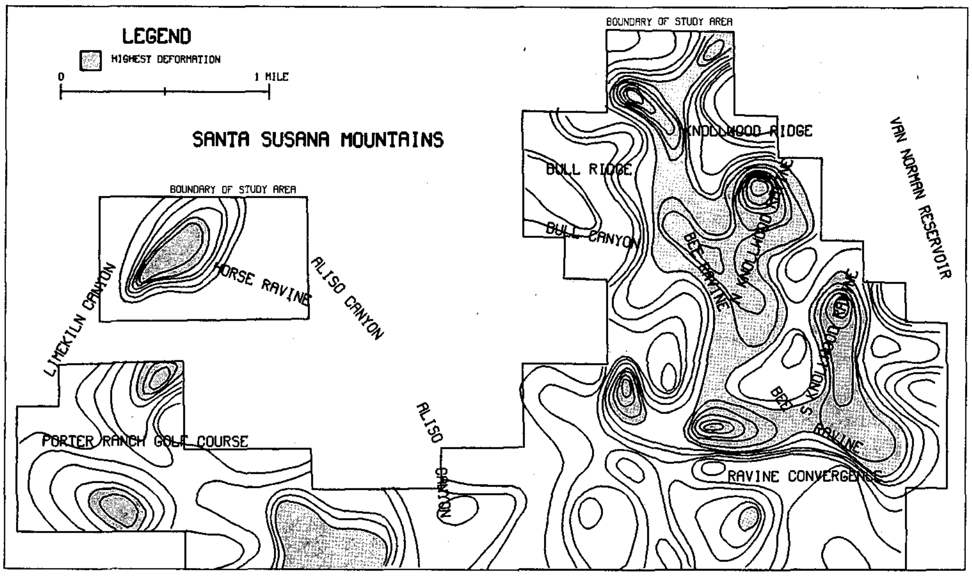


FIG. 7. Contour map of relative wind intensity derived from the statistical deformation index. Though its basis is different than the deformation–intensity index, the results are quite similar (see Fig. 6).

hits Bull and Knollwood ridges causing greater deformation there than adjacent areas. Little wind occurs in the lee of Bull Ridge or the ravine to the south and east of the mouth of Bee Canyon. This NW (canyon) flow extends no further than the ravine convergence area where the main Santa Ana flow dominates.

6. An alternate deformation intensity index

It could logically be expected that areas of higher wind speeds would exhibit not only trees of greater deformation intensity but also that more trees per unit area would be affected. No previous study has used this index primarily because of the small number of trees that have generally been sampled. This type of statistical deformation index has several advantages over the use of a deformation-intensity type of index especially with regards to suburban studies:

- Half of all the trees studied occurred in parking strips and yet virtually none of the severely deformed trees were found there. While the size distribution of slight and moderately deformed trees are quite similar with 59% of slight and 51% of moderately deformed trees being 3–10 inches in diameter, only 24% of severely deformed trees are in this size range. Apparently, small and severely deformed trees are greatly pruned or removed. This induces a bias toward areas where the trees are less likely to be removed such as parks, golf courses and the front yards of homes. The statistical deformation index, including all levels of deformation, will eliminate this effect since trees of slight and moderate deformation are frequently found in parking strips.
- A deformation scale does not have to be devised. A major component of deformation-intensity type indices is the climatic effects acting upon the trees. Since each study area has different climatic effects dominating, previously devised deformation scales cannot be applied to new study areas without careful research and consideration. The statistical deformation index does not greatly depend upon the interpretation of single trees (reflecting climatic effects). A minimization of climatic influence should make tree deformation results between different study areas more readily comparable.
- The index minimizes the influence from any species effect. Any tree deformed above a low threshold (reflected as slight deformation) will be included in the index. This also provides portability of the index to other areas with different tree types.
- In allowing more than one species to be studied, a much larger data base is available to study the windflow.
- Problems of where to draw the boundaries of the various levels of deformation do not arise. The researcher does not have to rely on his judgement as where to exactly draw boundaries in areas with little data.
- It takes the study of tree deformation from a largely qualitative deformation scale to a quantitative statistic. A contour map can be drawn from the statistical deformation index results.
- Finer resolution of deformation intensity is available. Far more contour levels are available compared to the three grades of deformation.
- The new index minimizes the influence of single trees, especially in areas with few trees. This will concurrently minimize the influence of erroneously identified trees.

A map of the study area was marked off into grid cells with the total number of deformed trees being counted for each. From this, the contours were drawn. Fig. 7 shows deformation in the study area using this index. Despite the different nature of this index from the deformation-intensity index, the patterns of deformation are quite similar. Note especially the lack of any indication of strong canyon flow out of Aliso Canyon. Also, the ravine convergence area is more clearly delineated by the index. As a result of the similarity of these two indices, it appears that the species effect is not a significant source of error operating here.

7. Conclusions

A total of 465 trees were studied in a 30 km^2 area of the south side of the Newhall Pass to study the direction and intensity of the Santa Ana windflow as it leaves the brushland to the north and abuts against the suburban area of the city of Los Angeles. This large sampling was taken to see if the trees could provide a detailed reconstruction of these winds as they blow down the ravines and over the ridges in rugged terrain.

Rather than duplicate the methodology of past studies which have generally compared single station wind data to a surrounding region (often with mixed results) it was decided to use a portable windvane to sample the winds at a number of locales in the study area. Comparison of the windvane data to the wind direction indicated by lean of the trees showed a very close correlation—the trees accurately indicate the direction of the Santa Ana windflow in the area.

To study wind intensity in the study area, two indices were devised. First, a deformation scale was established similar to previous studies which have been conducted. Additionally, a new deformation-intensity index was developed based on the total number of trees per unit area that were deformed. This new index is superior to that it does not rely upon a qualitative judgement of the extent of deformation for a tree.

The study placed considerable emphasis on discerning wind from non-wind effects. An analysis of non-wind effects is one of the most important aspects of any tree study. As a suburban study, both natural and man-made effects were considered.

For small-scale studies involving Santa Ana winds, trees can provide a large data base at very low cost. They are climatological indicators of very long-term wind effects. Tree deformation data act as a useful adjunct to standard meteorological data in providing a more detailed analysis of the winds being studied.

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