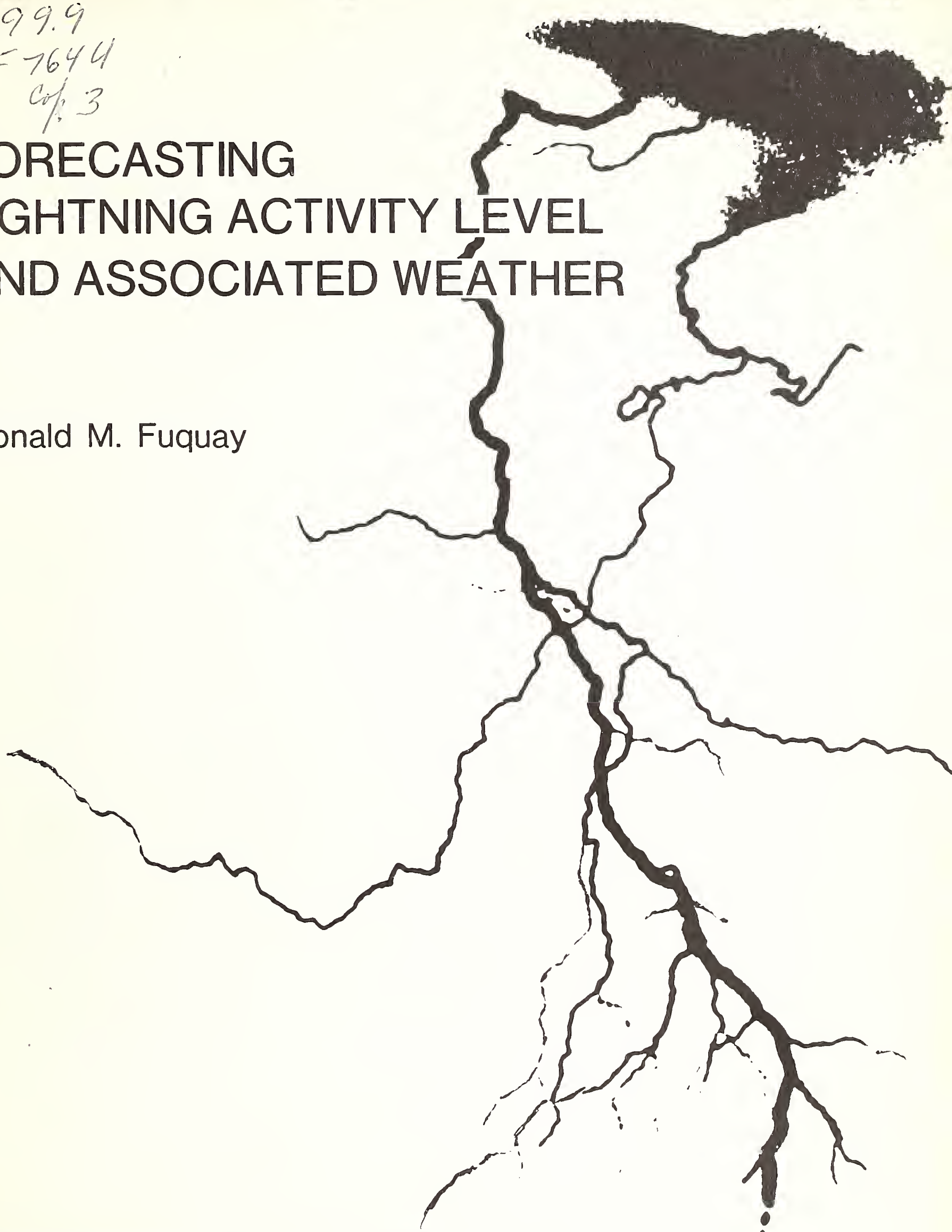
# FORECASTING LIGHTNING ACTIVITY LEVEL AND ASSOCIATED WEATHER



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# THE AUTHOR

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# RESEARCH SUMMARY

This report summarizes the concepts, development, and application of a system for forecasting Lightning Activity Level (LAL) as required for the 1978 version of the National Fire-Danger Rating System. The report is organized into two sections. The first section presents a format and guidelines for the forecasting of lightning area density. The second section guides the fire weather observer in making observations, verifying the forecast, and providing feedback to the fire weather forecaster. The appendix includes data on the occurrence and behavior of mountain thunderstorms not available from other sources.

The LAL guide, containing instructions for both fire weather forecasters and observers, was developed in three steps. First, cloud-to-ground lightning density was related to a common predictor-maximum height of radar echos for thunderstorms. Second, LAL index values were assigned to specific ranges of radar heights according to their relative frequency of occurrence to form a five-level index. Third, distributions of lightning events and associated weather were related to the LAL index based on the predictor variable, maximum radar echo height. Other variables used were maximum cloud development, intensity and coverage of radar echos, amount and coverage of precipitation, and cloud-to-ground lightning density and flash rates.

The fire weather forecaster uses primarily the expected cloud development and radar height to assign LAL index values to forecast zones. The fire weather observer uses observations of cloud development, precipitation, and cloud-to-ground lightning flash rates to verify or correct the forecasts.

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# INTRODUCTION

The National Fire-Danger Rating System (NFDRS) (Deeming and others 1972) has been updated; the revised system will be in use in 1978 (Deeming and others 1977). One of the changes in the NFDRS is treatment of lightning-caused fires. A model based on physical and stochastic processes was adapted to the NFDRS for estimating the number of new lightning-caused ignitions (Fuquay and others 1979).

The fireweather forecaster will be asked to forecast some of the inputs to the model, namely: (1) Area density of cloud-to-ground (CG) lightning, (2) storm movement, and (3) precipitation duration. This is an entirely new area of forecasting for most forecasters. Techniques and procedures will need to be developed.

This report shares our experience and data from thunderstorm and lightning field studies that might be useful to the fireweather forecaster and observer. Data on lightning and related events were gathered for other specific purposes and are not exactly suited to the topics presented here. The limited data base prevents the rigorous analyses we would like to make. In many cases, the grouping of data and the form of the output reflect the author's opinions. Nonetheless, this report should remain a useful guide and provide a basis for further investigation.

Our approach to predicting lightning related events follows the basic philosophy of the NFDRS, namely:

1. The NFDRS rates only the *potential* for fires.

2. It addresses only those aspects of fire control strategy affected by fire occurrence and behavior.

3. It uses a linear index structure wherever possible.

4. The rating is done with a *worst* case approach. Thus, weather forecasts and observations should be for the time that conditions are most severe and at midslope on southerly and westerly exposures.

The latter requirement strongly influences how the forecaster views the input to the NFDRS. The forecast should be biased towards events that will define the *upper* limit of fire ignition and behavior.

The basic assumption in developing our Lightning Activity Level (LAL) Guide was that lightning activity and accompanying meteorological conditions within a forecast area can be adequately represented by a single index value. This report describes how to use the LAL Guide, how it was developed, and guidelines for assigning and interpreting LAL index values.

# THE LIGHTNING ACTIVITY LEVEL GUIDE

The LAL Guide is a table relating several meteorological variables to CG lightning area density. The 1978 version of the NFDRS requires the forecaster to select a Lightning Activity Level (LAL) for each forecast zone. The forecast thus assigns *predetermined* values for the following: (1) Area density of CG lightning, CG's/2,500 $mi^2$ (CG's/6 500 $km^2$), (2) area intensity of radar echoes, (3) area intensity of rainfall, and (4) storm size and duration.

The LAL Guide (table 1) is structured according to the following outline:

A. Typical cloud and precipitation conditions

1. Cloud and storm development
2. Radar echoes--coverage and intensity
3. Precipitation--area and amount

B. Lightning

1. Amount per area
2. Lightning occurrence rates

The LAL Guide was developed with both forecasting and verification in mind. The forecaster can verify by using available radar data (maximum radar height of storms, precipitation coverage and duration), pilot reports, satellite data, and network meteorological data. Field personnel verify by means of cloud description, rate and amount of observed CG lightning, and area coverage of storms.

The basic data set for the LAL Guide consists of measured lightning and associated meteorological events during the summer months of 1965-1967 in western Montana (table 7, appendix). This 3-year period included seasons of high and low lightning occurrence. Basic data were supplemented by lighting measurements, radar, and other meteorological data from the Black Pine area near Philipsburg, Mont., lookout network data covering a five-State area, and data from Arizona and New Mexico. This broad data base builds confidence that the guide should be applicable over most of the Rocky Mountain area, particularly after scaling the events to local conditions.

The basic unit of area used in the guide is 2,500 $mi^2$ (a square 50 miles on a side or 6 500 $km^2$). This is almost the smallest area for which a generalized forecast can be made. Also, it is about the largest area that lightning activity can be effectively observed from a surface observation point, such as a forest fire lookout. The area within a 28-mile radius from an observer corresponds roughly to 2,500 $mi^2$ (6 500 $km^2$), or 1.5 million acres--about the size of a typical National Forest.

Although the basic area used is 2,500 $mi^2$ (6 500 $km^2$), the forecaster can adapt the descriptors to subunits or multiples of the area through proportionality factors. Of course, the forecaster must feel confident in forecasting for the area selected.

Little precedence exists for forecasting the area density of CG lightning. A coherent thunderstorm model covering both cumulus dynamics and electrification processes has not been developed. Based on observation and theory, however, we believe that the amount of electrification and lightning is associated with the characteristics of a storm, such as dynamic instability, precipitation intensity, and rate of vertical development. After correlating the amount of lightning to many different variables, we found that the maximum height of radar echoes seemed the best for linking lightning with associated weather.

Our forecasting system was developed as follows:

1. The maximum radar echo height was selected as the basis for classifying lightning activity on a given day.

2. All thunderstorm days over the 3-year period were classified according to maximum radar height and each day was assigned an LAL.

3. Distribution of related meteorological events was determined within each of the LAL's.

Table 1.--*The lightning activity level guide*

TYPICAL CLOUD AND PRECIPITATION CONDITIONS (2,500 mi² or 6 500 km² area)

| Lightning activity level | Cloud and storm development | Rel. freq. on T/S days (percent) | Fraction of area covered by radar echoes of indicated strength | | | | Percent of area receiving less than the amount of rain indicated | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | Very Light | Light | Moderate | Heavy | 0-T | <0.1" | <0.3" | <0.9" |
| 1 | No thunderstorms[1] | 0 | 0 | 0 | 0 | 0 | 100 | 100 | 100 | 100 |
| 2 | Few building cumulus only occasionally reaching cumulus congestus stage; single CB in forecast area. Visual tops: <30,000 ft (9 100 m) m.s.l. | 10 | 0.1 | <0.1 | 0 | 0 | 90 | 91 | 100 | 100 |
| 3 | Scattered cumulus to cumulus congestus; widely scattered CB's cloud-to-ground lightning averaging 1 to 2 per min max. | 35 | .2 | .1 | 0.05 | 0 | 70 | 90 | 98 | 100 |
| 4 | Growing cumulus and cumulus congestus stage over 1/10 to 3/10 of the area; scattered cloud-to-ground lightning in area averaging 2 to 3 per min max. | 35 | .2 | .1 | .05 | 0 | 65 | 80 | 95 | 100 |
| 5 | Cumulus congestus common over area, occasionally obscuring the sky; moderate to heavy rain associated with CB's; light to moderate rain preceding and following lightning activity. Lightning flashes occurring steadily at some place in or during storm period; maximum CG flash rate greater than 3 per min. | 18 | .3 | .1 | .05 | 0.02 | 50 | 75 | 85 | 100 |
| 6 | Scattered towering cumulus with a few at thunderstorm stage; very limited horizontal extent; high bases (15,000 to 17,000 ft m.s.l.). Virga in most prominent hydrometeor form. Lightning flash rate is low, averaging less than 1 to 3 per 5 min period each storm.[2] | <2 | | | | | | | | |

LIGHTNING - AMOUNT AND RATE

| Lightning activity | Maximum radar echo height, m.s.l. Feet | Meters | Cloud-to-ground lightning per 2,500 mi² (6 500 km²) | Occurrence rates, maximum CG/5 min | CG/15 min | Aver. rate/min |
|---|---|---|---|---|---|---|
| 2 | <28,000 | <8 500 | 20 | -- | -- | -- |
| 3 | 26,000 - 32,000 | 7 900 - 9 700 | 40 | 0-10 | 0-17 | 1-2 |
| 4 | 30,000 - 36,000 | 9 100 - 11 000 | 80 | 4-19 | 6-32 | 2-3 |
| 5 | >36,000 | >11 000 | 160 | 9-32 | 19-77 | >3 |
| 6 (See text for explanation) | | | | | | |

[1]In most general terms, 2 days out of 3 will not be thunderstorm days during a typical fire season in the mountainous areas of the western continental United States.

[2]Used with red-flag warnings of extreme fire activity.

4. Generalized descriptors were developed for each LAL.

5. Results were summarized as the LAL Guide.

Figure 1 illustrates the events occurring over a selected area in the course of a day. Note that in the course of a day, conditions normally become progressively more severe, going from LAL 2 in mid-morning to LAL 3 around noon and reaching a peak of severity in mid-afternoon. Because we want to predict the most severe level (worst case) representing events over *all* of the area, we might select LAL 4 for this example.

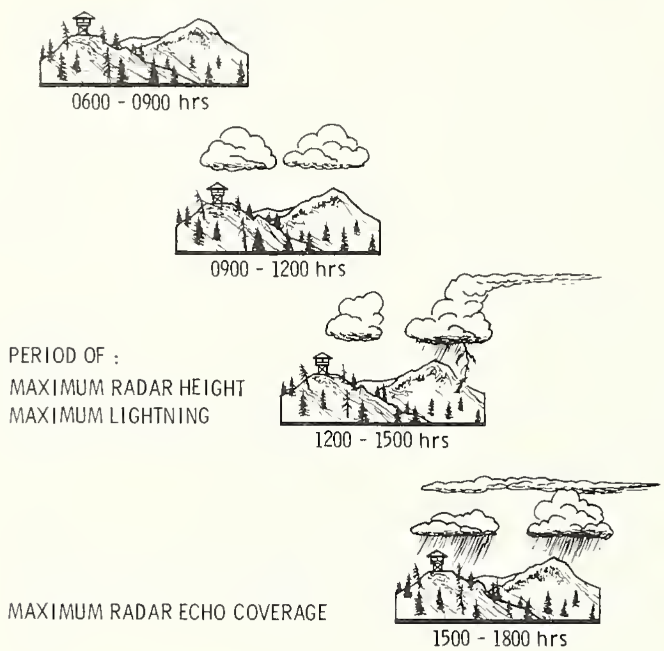



Figure 1.--Events within a forecast area for successive time periods during a thunderstorm day.

We do not look for a *single* maximum radar height in the area. In our example, LAL 4 says, rather, to expect maximum vertical development of radar echoes distributed over the area to range within the limits of 30,000 to 36,000 ft m.s.l. (9 100 to 11 000 m) with a representative maximum height for all echoes of about 33,000 ft m.s.l. (10 000 m).

# FORECASTING OR VERIFYING LAL

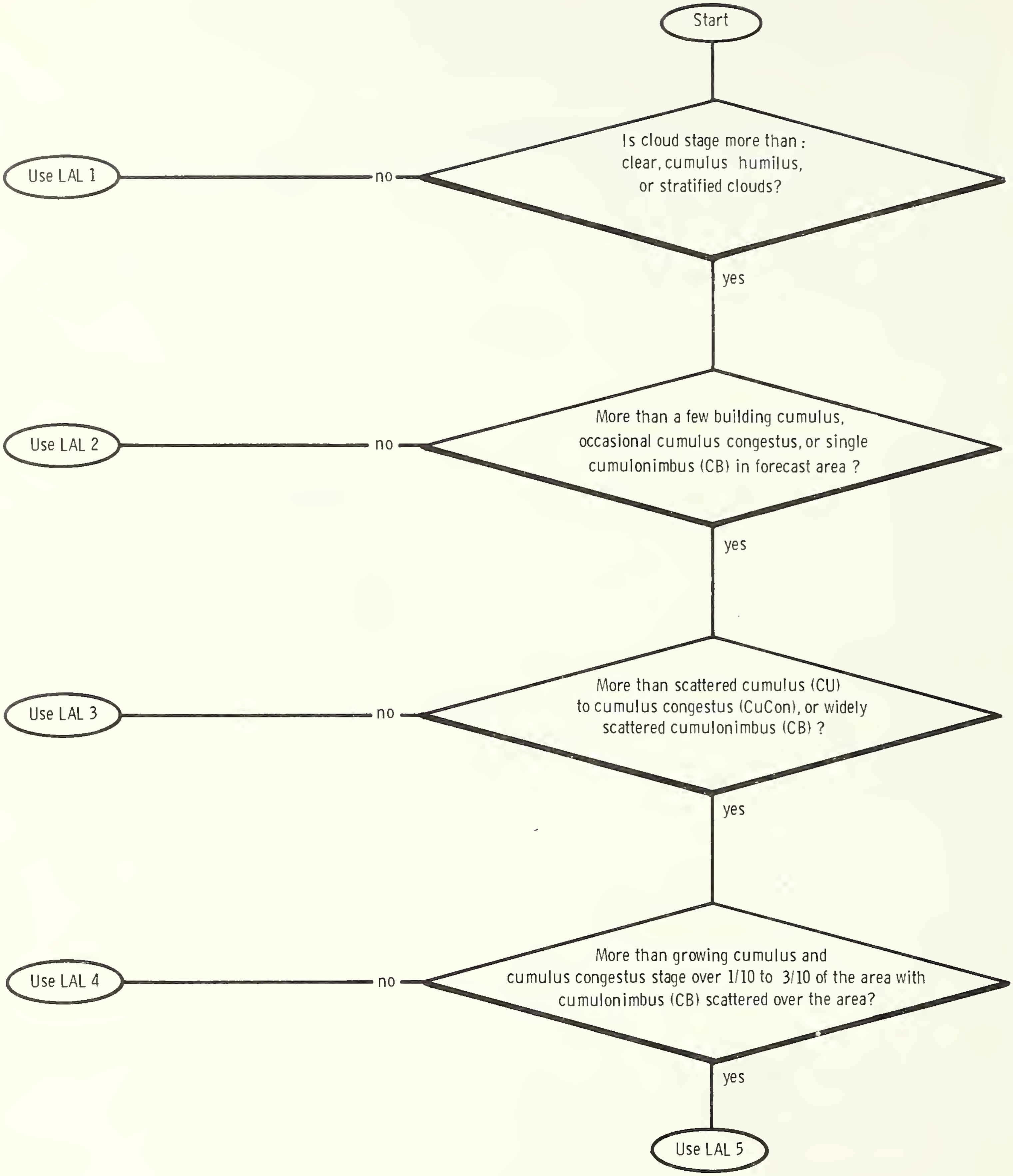
Ideally, a single value should describe lightning and associated weather in each forecast area. Although a single value can only be derived from a gross generalization of the weather, such a value is vital to determining lightning-caused fire risk in the NFDRS.

We have established an association between specific LAL and the following phenomena: maximum cloud development, maximum height of radar echoes, radar echoes--intensity and area coverage, precipitation--amount and area coverage, and CG lightning--density and flash rates.

As many of the above phenomena can be used as there are available data on which to base a decision. The final step, arriving at a composite LAL value, requires subjective judgment by the forecaster or the observer. Each user should consider the reliability and representativeness of the data available and give most weight to the better data when making an LAL decision.

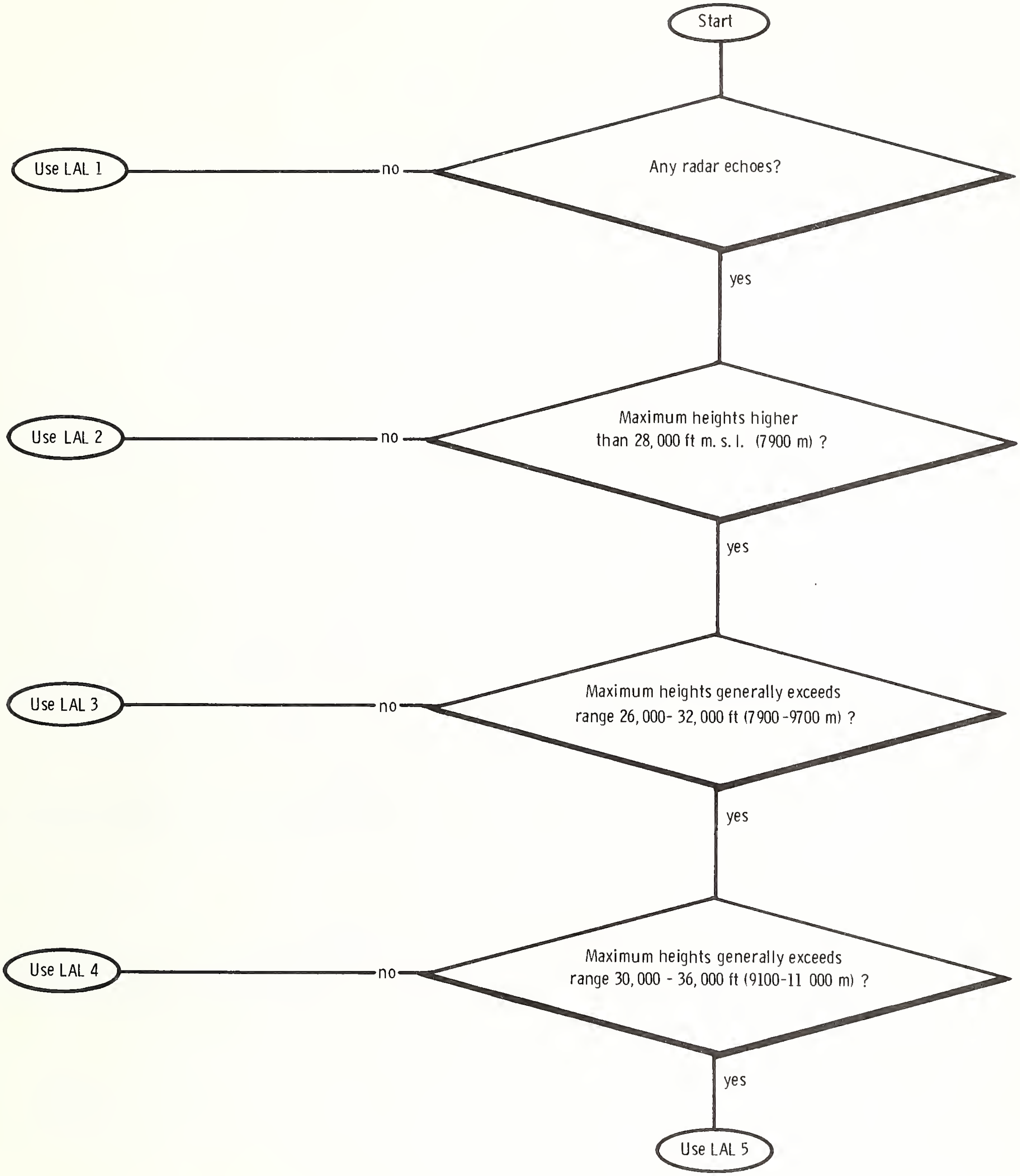
In figures 2 through 7 we relate general descriptors of each phenomena to LAL levels. The idea is to progress through each description until an upper limit is reached for the existing situation. Use the highest LAL reached as representative of that phenomena for the day.

The subjective nature of an LAL selection has already been mentioned. For that reason we can expect that skill in selecting the best LAL to improve as the user becomes better acquainted with the reliability of each predictor for a particular area. For example, a forecaster may find cloud development (fig. 2) as most useful in forecasting tomorrow's LAL and radar echoes (fig. 3) as best for verifying the forecast. A forest dispatcher may find observations of cloud development (fig. 2) most reliable when confirmed by lightning counts (fig. 6) or maximum flash rates (fig. 7) from a nearby lookout Figures 4 and 5 provide estimates of the percent of an area receiving rainfall from storms associated with each LAL level. In general, the storms become more intense with higher LAL's but do not show a corresponding increase in area covered by the storm. Even with LAL 5, over 50 percent of a forecast area will receive no measurable rain.




1/ Use LAL 6 if high-level, dry thunderstorms are forecast or observed.

Figure 2.--Maximum stage of cumulus cloud development (after Fischer and Hardy 1972). Use LAL 6 if high-level dry thunderstorms are forecast or observed.




1/ For visual tops, add 2, 000 ft (about 600 meters).

Figure 3.--Maximum radar echo height. For visual tops, add 2,000 feet (about 600 meters).

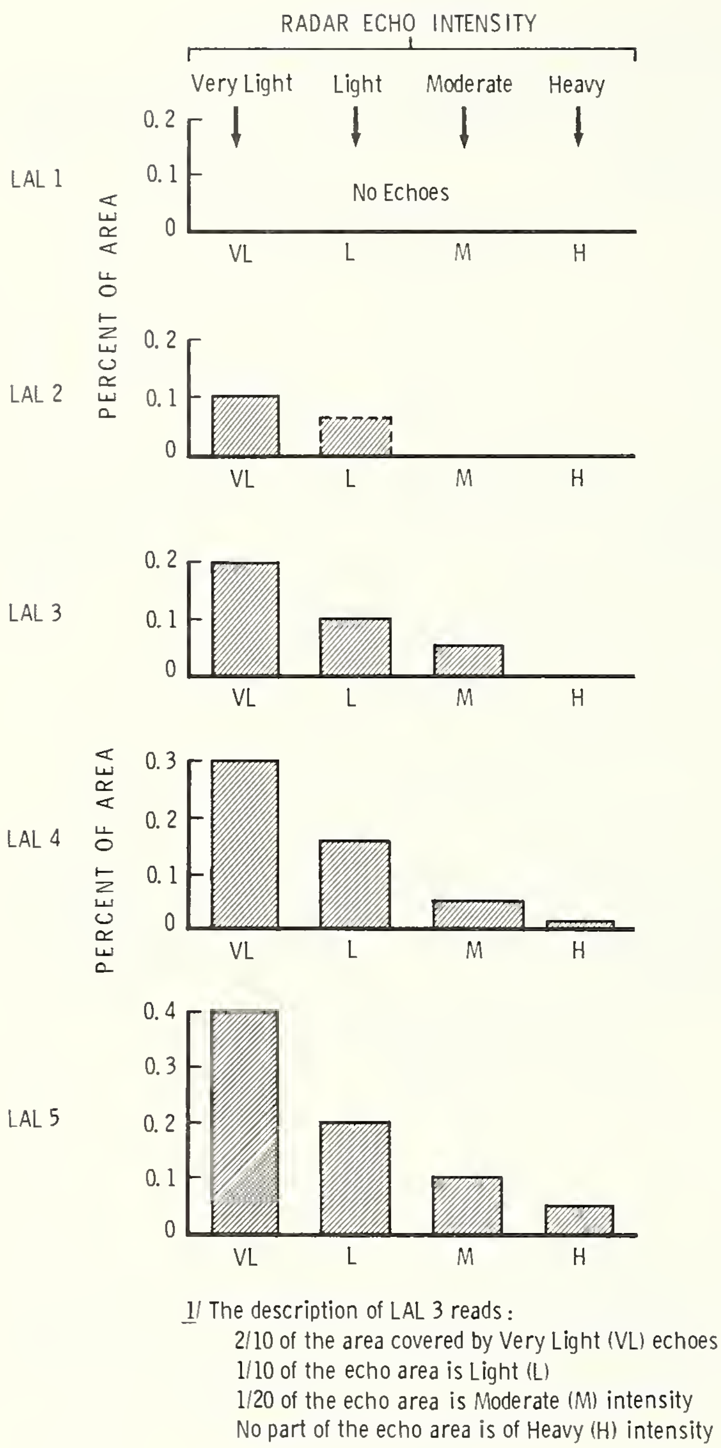



Figure 4.--Radar echoes - intensity and area coverage (midseason, nonfrontal thunderstorm). The description of LAL 3 reads: 2/10 of the area covered by Very Light (VL) echoes; 1/10 of the echo area is Light (L); 1/20 of the echo area is Moderate (M) intensity; No part of the echo area is of Heavy (H) intensity.

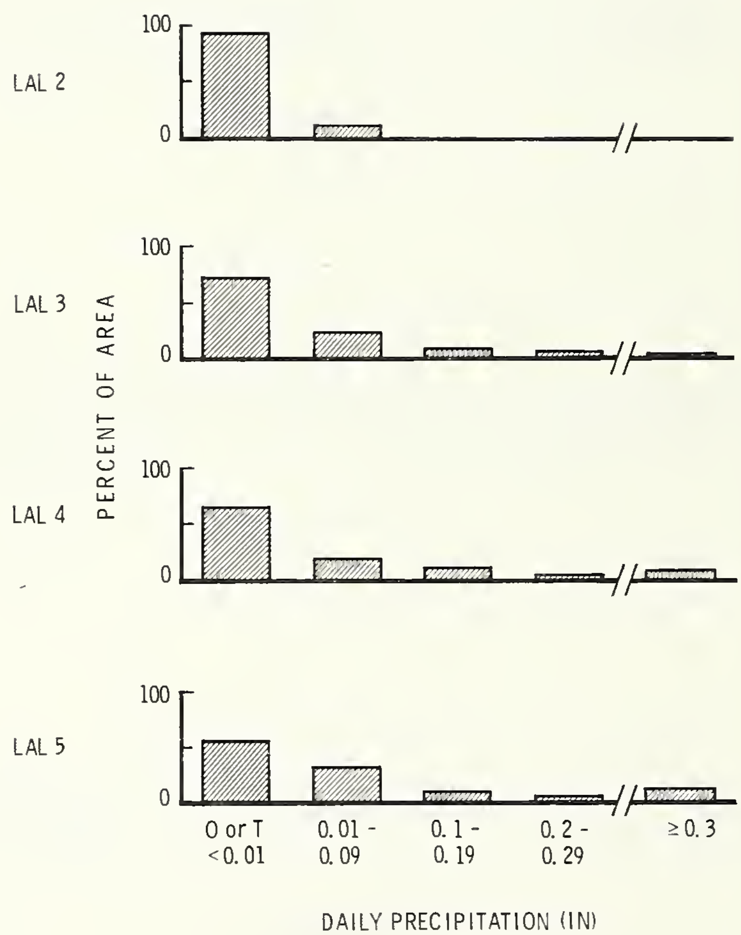



Figure 5.--Amount of daily precipitation and area coverage (midseason, nonfrontal thunderstorms).

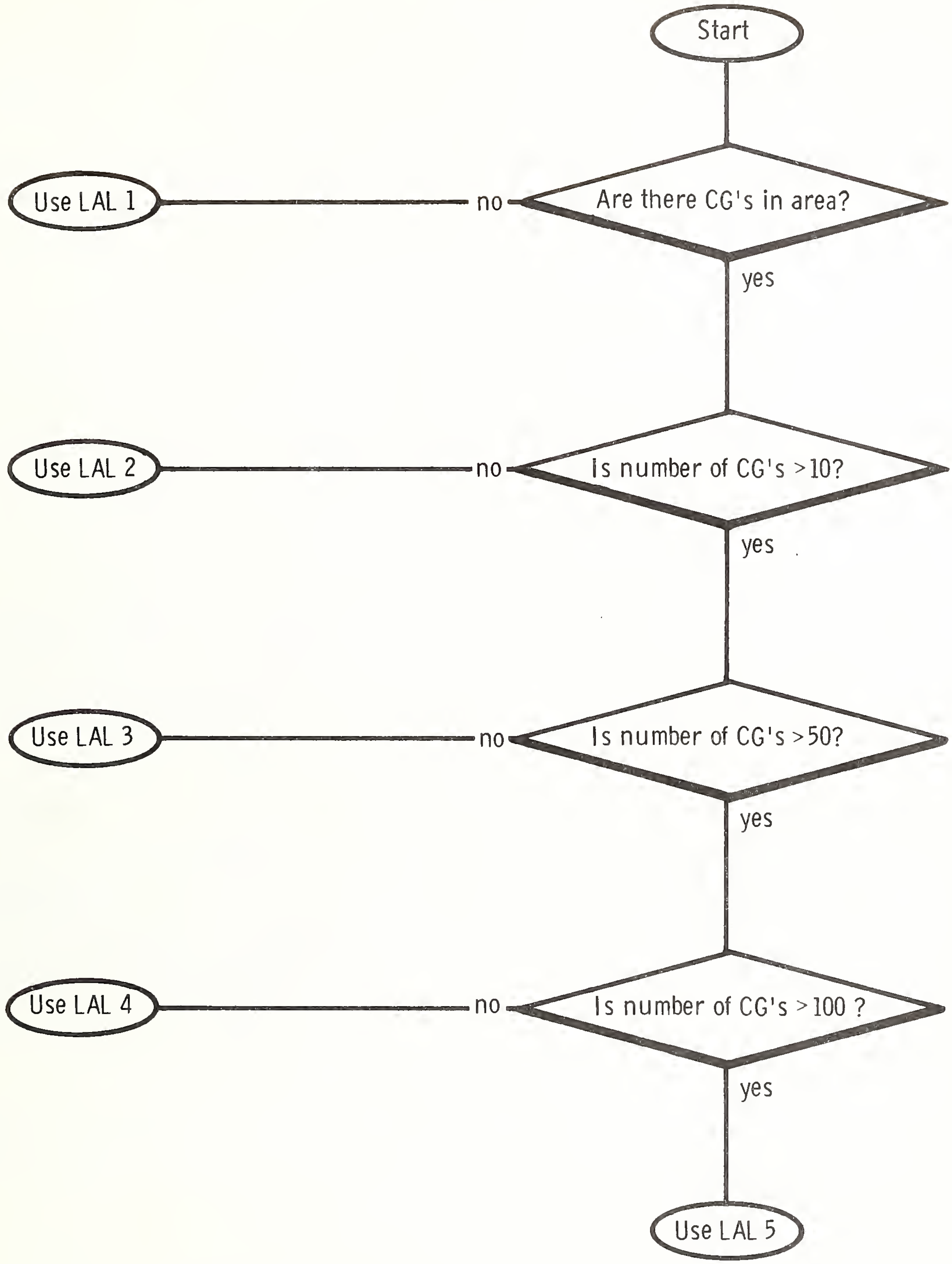
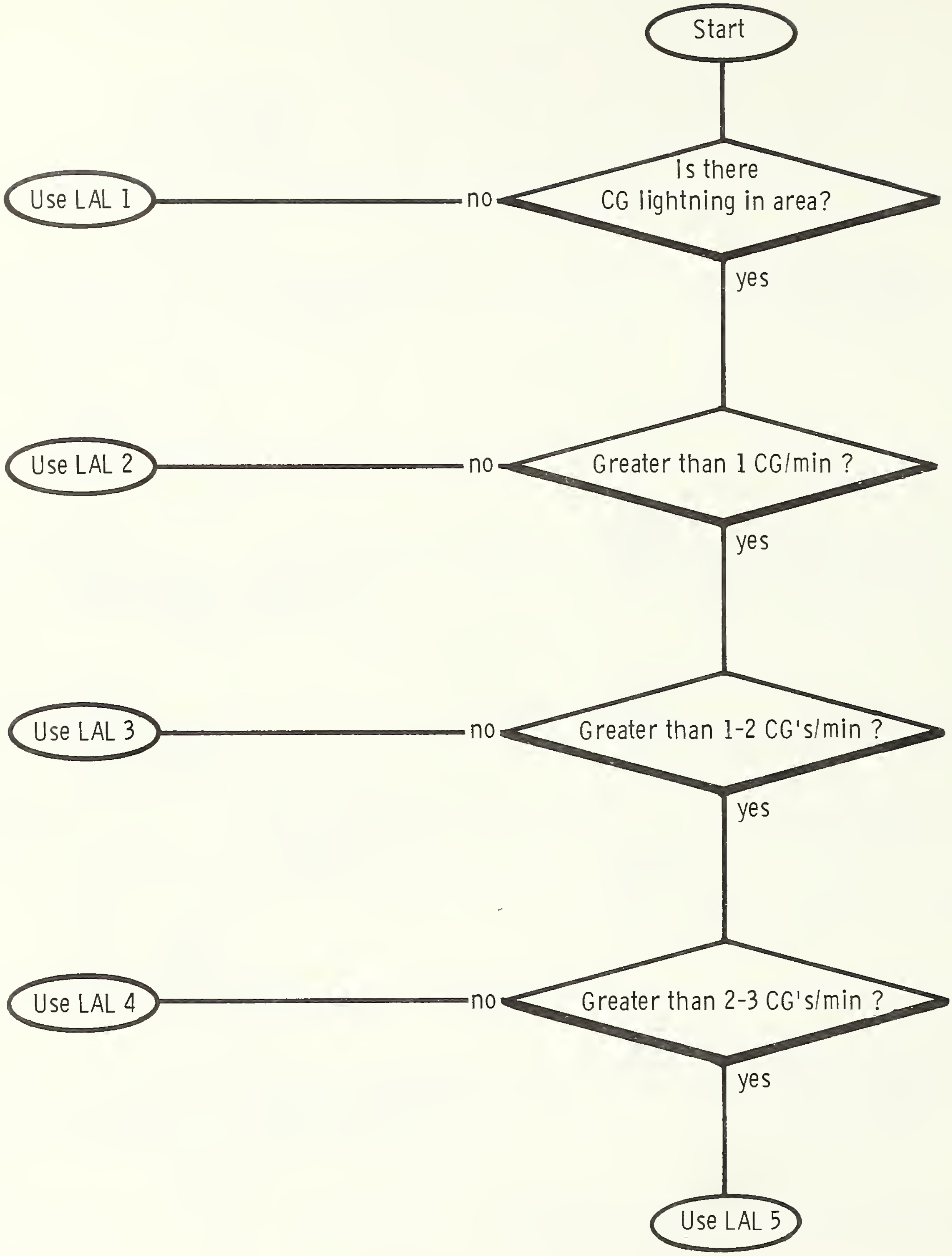



Figure 6.--Cloud-to-ground (CG) lightning within 2,500 $mi^2$ (6 500 $km^2$) area for rating period.




1/ CG count averaged over at least a 5-min period.

Figure 7.--Average CG flash rate (CG's per minute). CG count averaged over at least a 5-min period.

# DEVELOPMENT OF THE LAL FORECAST GUIDE

## Bases for the Lightning Activity Levels

An index should be easily related to a prescribed range of events. In this case, it should relate to the severity of situations involving lightning-caused fires even though the lightning activity is only a part of this problem. So, we start out with the postulate that the *potential* lightning-caused fire severity is directly related to the amount of CG lightning that an area experiences. It then follows that we can build our index on the basis of area density of CG lightning. Other factors influencing the number of ignitions, such as rainfall, can be related to the same index.

An index ranging from 1 to 5 was selected because it is compatible with the NFDRS and because users have said that five levels are sufficient. We use LAL 1 to denote all situations in which no lightning is forecast. The remaining four values in the index represent the following situations:

LAL 2--The marginal case where lightning-caused fires may or may not occur. The maximum expected fireload would be *light.*

LAL 3 and 4--Delineate conditions where the lightning fireload might be described as *moderate* and *heavy.*

LAL 5--The upper limits of lightning activity are characterized by large, wet storms.

The selection of a 5-level index does not prevent the forecaster from developing additional levels or sublevels within the present system if valid reasons exist. For instance, some areas might use LAL 4*a* and *b* to denote conditions over grasslands and forested areas. In fact, we have already added LAL 6 to represent the high-level, dry thunderstorm situation.

### LIGHTNING

Forecasting the number of CG lightning flashes expected in a given area is a demanding task because a formidable array of meteorological variables can be expected to influence the formation, electrification, and discharge of cumulus clouds. Numerical methods are virtually nonexistent. Further, although data on the occurrence of storms based on visual observations are available from some stations, there is a paucity of measurements of lightning frequency and rates. In this section, we bring together the data, experience, and methods that are available to help forecast lightning activity levels.

The yield of lightning from a thunderstorm varies widely in both space and time. Further, the proportion of CG's within storms on a single day and between storm days also varies. The high variance in lightning further complicates the predicting of lightning density. The problems in handling high natural variance of lightning can be reduced through the use of predictor variables or covariants.

Fuquay (1967) found a strong association between maximum radar echo height and the total amount of lightning experienced in the immediate area. This relationship for storms in western Montana in the summers of 1965-1967 is shown in figure 8. Total lightning varies considerably within each radar echo height class. In addition to natural variability, we had errors in measurement because: (1) the radar scan missed the actual echo maximum in following fixed observing procedures, (2) location of the measured lightning was incorrect, and (3) sampling errors were introduced by the relatively small area that could be observed in relation to the high variability of lightning occurrence.

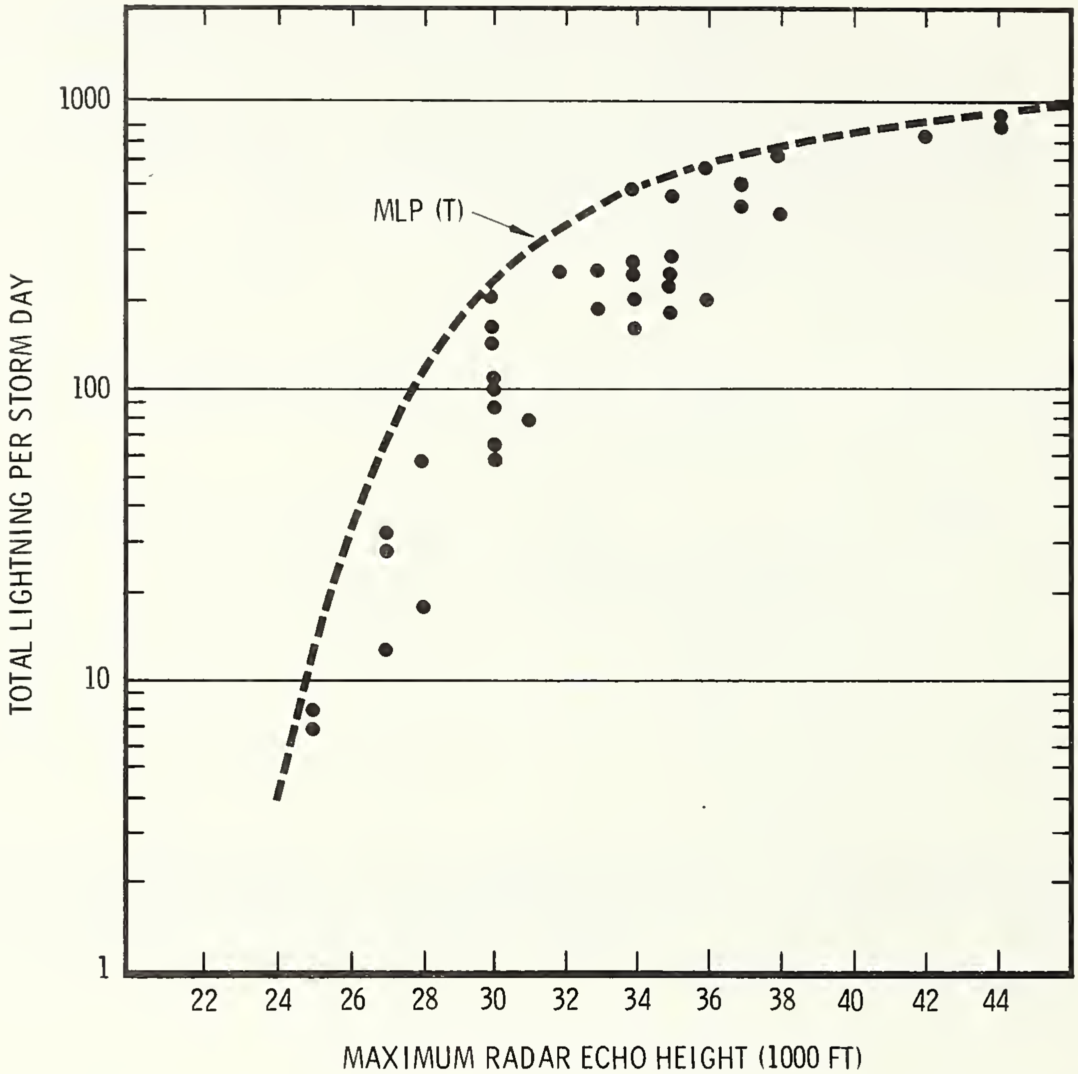



Figure 8.--Total lightning flashes per storm day versus maximum radar echo height.

We are concerned with the *maximum* density of CG lightning for predicting lightning-caused fire ignitions. We must estimate the maximum lightning density expected during the day, knowing only the maximum radar height. To do this, we define a variable called Maximum Lightning Potential (MLP) which is a covariant with the maximum area density of lightning. In figure 8, a smooth curve is drawn as an upper boundary to the data points. A least-squares fit to this curve is defined as the continuous variable MLP (T), which is a function only of maximum radar height. The lightning data for figure 8 covered about 500 $mi^2$ (1 300 $km^2$). Only about 20 percent of a 2,500 $mi^2$ (6 500 $km^2$) area will receive lightning from a nonfrontal thunderstorm on a single day. Further, on most days only one continuous period of lightning activity will occur over an area. Thus, MLP derived from figure 8 approximates maximum lightning density per 2,500 $mi^2$ (6 500 $km^2$) per day.

A least-squares fit to the upper envelope in figure 8 gave the following relationship with an $R^2$ value of 0.978:

$$\text{MLP (T)} = -1102 + 45.8 H \qquad (1)$$

where MLP (T) = maximum lightning density of total lightning per 2,500 $mi^2$ (6 500 $km^2$) per day; H = maximum measured radar echo height (1,000 ft, m.s.l.). A second-order polynomial fit to this curve only slightly improved the fit, i.e., $R^2$ = 0.980.

Counting the number of lightning events, or flashes, from an isolated storm using lightning counters or analog recordings is relatively simple; relating these counts to a specific area to obtain lightning density presents problems. However, what we really need is an estimate of the density of *CG lightning*. Two approaches are available--estimating CG lightning from total lightning counts and direct measurements of CG lightning. Each approach has merits, depending on the situation.

The distribution of the ratio of CG to total lightning for 46 storm days in 1965-1967 is shown in figure 9. We have a mean CG/T ratio from the expression:

$$\overline{CG/T} = \sum_{1}^{N} \frac{CG/T}{N} = 0.19 \qquad (2)$$

where N = number of storm days (46).

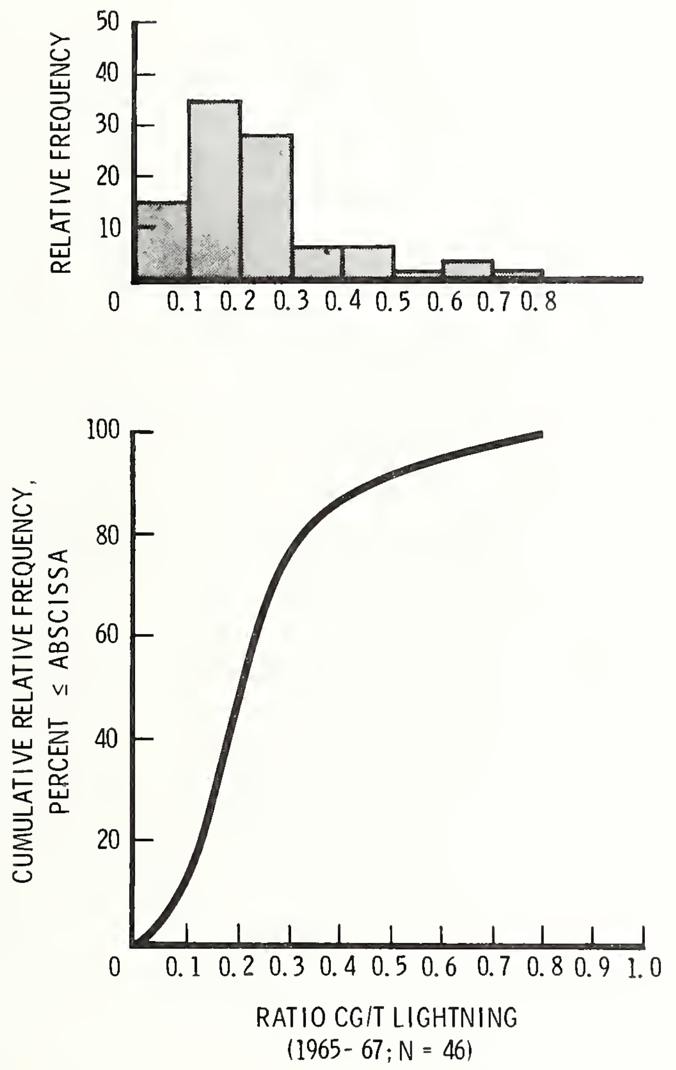



Figure 9.--Distribution of the ratio of CG and total lightning per storm day.

The proportion of CG lightning for all storm days compares favorably with that derived from a sample of 11 individual storms (i.e, single storms tracked throughout their life cycle) where $\overline{CG/T}$ = 0.23. Based on this, a reasonable long-term estimate of the ratio of CG lightning and total lightning is 1/4. However, figure 9 shows variations to expect when this rule is applied to specific storm days.

We will now examine data from direct measurement of CG lightning. We can remotely sense electrical and light signals emitted by lightning discharges. These signals form characteristic signatures for cloud, air, and ground discharges (Fuquay 1967; Fuquay and others 1972), but the attributes for each type of discharge overlap to some degree. Thus within any group of lightning signatures, some of the discharges cannot be classified as cloud, air, or ground. These indeterminate signals make up only about 3 percent of all flashes measured during the 3-year test period. For example, on 7/12/66 only 2 out of 635 flashes were indeterminate. However, in some storms, these flashes can be an appreciable proportion of the total measured lightning. For example, on 8/26/66, 126 of a total of 427 measured flashes were classed indeterminate. Thus, we cannot identify the amount of CG lightning as accurately by direct measurement as we can determine the total number of flashes that occur.

The measured CG lightning versus maximum radar height on 35 storm days in 1965-1967 is plotted in figure 10. The X's denote days on which the indeterminate class of discharges was greater than 5 percent of the total. A least-squares curve was fitted to the upper boundary of the CG data points. This is the MLP (CG) curve. The first order linear curve

$$H = -575 + 21\ H \qquad (3)$$

yielded $R^2 = 0.917$.

A second-order polynomial of the form

$$MLP\ (CG) = 700 - 56.4\ H + 1.14\ H^2 \qquad (4)$$

gave $R^2 = 0.998$.

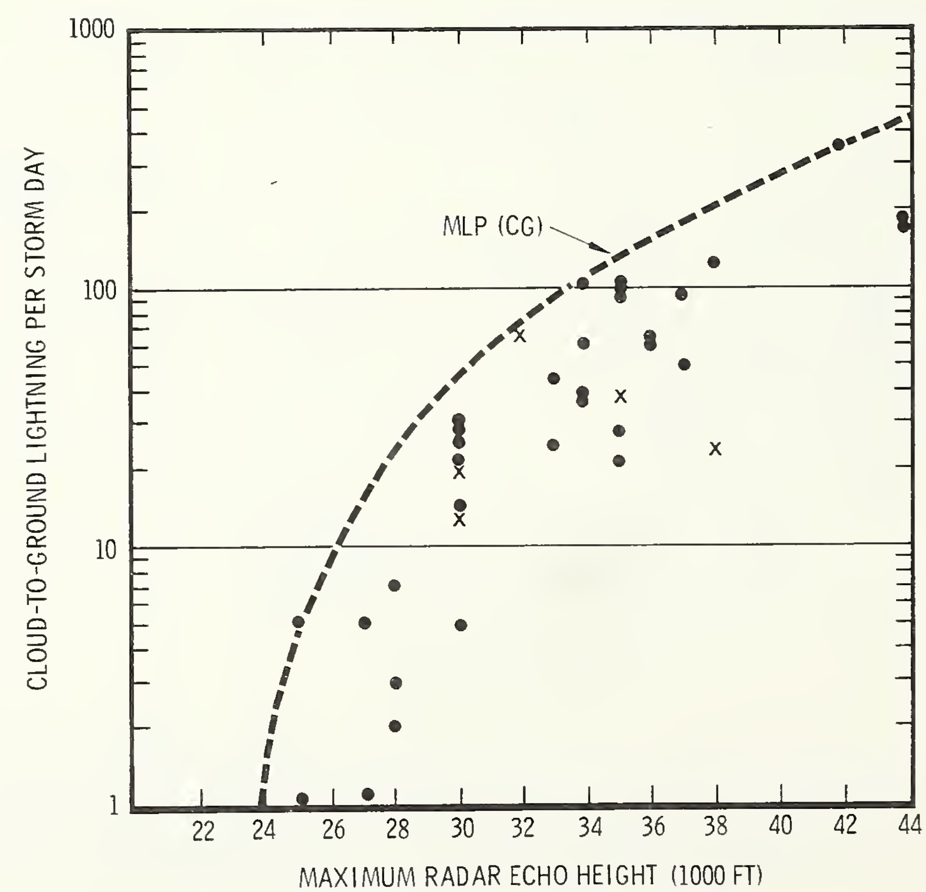



Figure 10.--Measured cloud-to-ground lightning for 35 storm days, 1965-1967.

The estimate of MLP (CG) derived from measured CG lightning and from taking 0.25 of MLP (T) for all days with measured H was compared for each day for data from 1965-1967. We found that both methods yield about the same value over the long term. However, the method of estimating lightning density should be known when using field observation of CG and total lightning to verify a forecast LAL.

Keep in mind that we are estimating only the *maximum* amount of lightning to be expected based on *maximum* radar echo height. Thus, the high $R^2$ values for equations 1 and 3 reflect only the fit to the MLP curves on figures 8 and 10. Just to illustrate the broad scatter of the data points, we have the following least-squares fit to all the data points in figures 8 and 10:

$$T = -1215 + 44.6\ H \qquad (5)$$

($R^2 = 0.82$) and

$$T = 498 - 58.1\ H \qquad (6)$$

($R^2 = 0.85$), where T = total lightning on a storm day and H = maximum radar height (1,000 ft, m.s.l.) measured during the day. Also,

$$CG = -170 + 7.1\ H \qquad (7)$$

($R^2 = 0.71$) where CG = cloud-to-ground lightning per storm day and H = maximum radar height measured during the day. Again, we see that the maximum radar height explains more of the variance in T than for CG in the corresponding equations.

The NFDRS value shown in table 2 is the lightning density (CG's/2,500 $mi^2$ or CG's per 6 500 $km^2$) assigned to each LAL for computing the number of lightning-caused fire ignitions. Note that the assigned lightning density, which is also lightning risk, increases geometrically with LAL values.

Table 2.--*Assignment of maximum radar height and lightning density to LAL*[1]

| LAL | Relative frequency (percent) | Maximum radar height, m.s.l. | | Lightning density, CG's/2,500 $mi^2$ (6 500 $km^2$) | |
|---|---|---|---|---|---|
| | | Feet | Meters | Range | NFDRS value |
| 2 | 15 | ≤28,000 | ≤8500 | 1-25 | 20 |
| 3 | 35 | 26-32,000 | 7900-9700 | 10-75 | 40 |
| 4 | 35 | 30-36,000 | 9100-11000 | 50-150 | 80 |
| 5 | 15 | >36,000 | >11000 | >150 | 160 |

[1]All tabulated values are approximate or rounded.

The cumulative frequency of maximum radar heights during 41 thunderstorm days is shown in figure 11. A corresponding distribution for nonthunderstorm days is not available. Therefore, we do not know if a forecast of maximum expected radar echo height is a useful estimator of the probability of occurrence of thunderstorms, although we strongly suspect a close association exists for summer air mass storms. Rather, *if* a thunderstorm occurs, the maximum radar echo height can be used to estimate the amount of lightning to be expected over a given area (fig. 12).

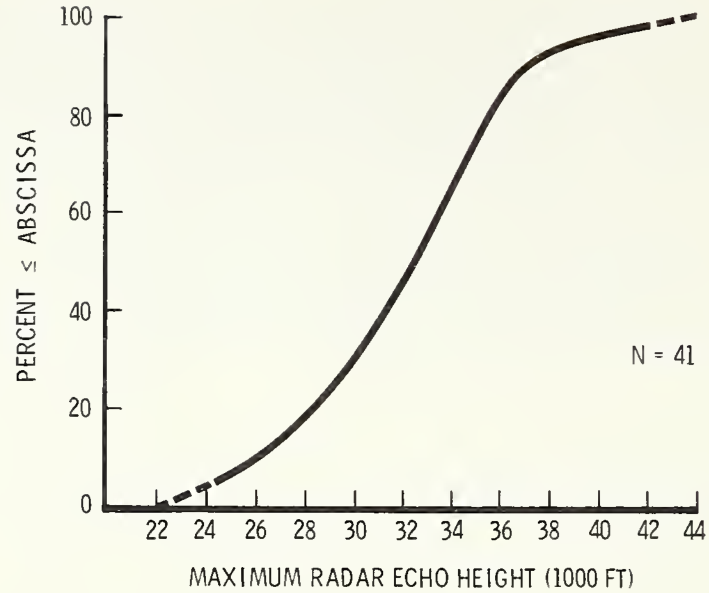



Figure 11.--Distribution of maximum radar echo heights per storm period, July-August, 1965-67.

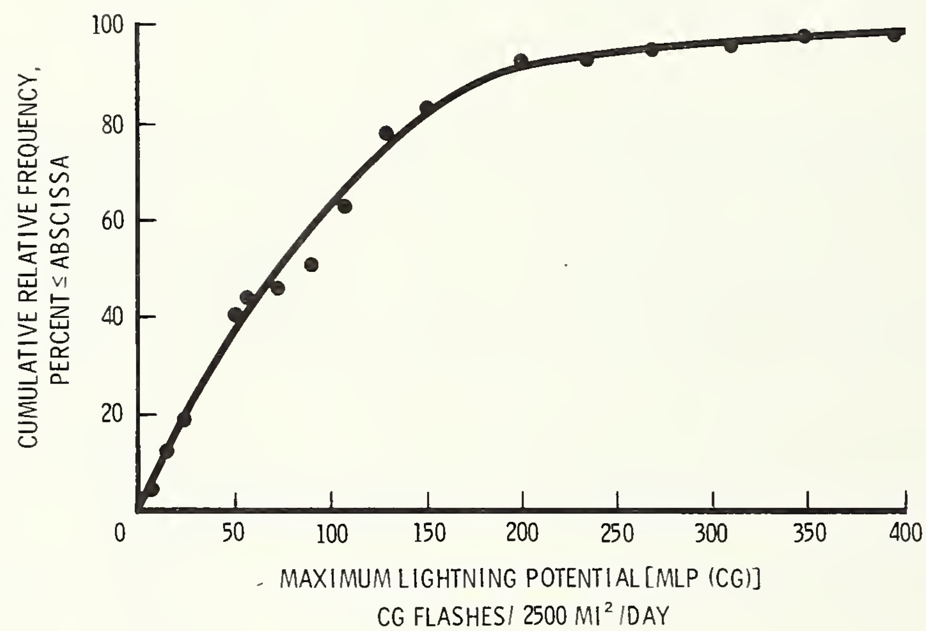



Figure 12.--Cumulative frequency of maximum lightning potential.

We would like to use observed lightning flash rates to estimate an LAL value for the day. In general, local lightning storms are coherent groups of cells covering less than 500 $mi^2$ (1 300 $km^2$). Two or more of the localized storms may occur within a forecast area during a thunderstorm day. Usually, the maximum flash rate will occur during the middle one-third of the storm period.

CG lightning flash rates from localized storms were related to LAL values in the following manner. First, individual storm periods were identified on lightning recordings taken during the summers of 1965-1967. Second, each storm was assigned an LAL value using the criteria for storm heights shown in table 2. Third, flash rates were analyzed and summarized (table 3). The analysis indicated only a casual association between lightning rates and LAL. Therefore, observed flash rates should not be given strong weight in setting the LAL. Rather, they should be used to support other evidence of a specific LAL.

Table 3.--*Maximum flash rates versus LAL*

| LAL | Maximum flash rates CG's/5 min | CG's/15 min | Average CG's/min |
|---|---|---|---|
| 2 | -- | -- | <1 |
| 3 | 0-10 | 0-17 | 1-2 |
| 4 | 4-19 | 6-32 | 2-3 |
| 5 | 9-32 | 19-77 | >3 |

## RADAR ECHOES

The 1972 NFDRS used the percentage of forecast area covered by radar echoes over a 24-hour period as a significant factor in assigning an LAL value. The 1978 NFDRS uses both echo intensity and area coverage during only the period of lightning activity as significant indicators of LAL.

There have been few previous attempts to relate lightning to precipitation and radar echoes. Kuettner (1950), from a mountaintop location, observed that the most active lightning occurs in the region of heaviest precipitation. Workman and Holzer (1942) reported that the most severe lightning activity was associated with clouds of greatest vertical extent. Since the highest clouds produce the heaviest rainfall, we would expect a correlation between lightning and precipitation (Battan 1965).

Kinzer (1972) made several observations relating radar echoes to lightning activity. After analyzing a limited sample of Oklahoma storms, he suggested that areas of greater reflectivity are apt to be areas of higher rates of CG lightning and that, on the average, the lightning activity increases rapidly with an increase in the radial depth of reflectivity. He answered the question, "Is there a radar reflectivity threshold for the occurrence of CG lightning?" with a qualified, "Yes,"--the threshold being about 555 $mm^6/m^3$ when larger reflectivities exist in the nearby storms. Of particular interest is his observation that with squall-line storms, maybe 9 out 10 CG's occur within areas of radar reflectivity. On airmass storms, however, only about 6 out of 10 flashes occur within areas of reflectivity.

In the revision of the NFDRS, we demonstrated that both radar echo intensity and area coverage can be useful in determining LAL and produced guidelines for their application. We also compared LAL values arrived at using the 1972 and the 1978 criteria . The following data were used in that comparison:

1. Lightning records for all storm days on which lightning was recorded in the period June-September, 1965-1967, near the Northern Forest Fire Laboratory, west of Missoula, Mont. The description of this data base and how it was obtained is covered by Fuquay and Baughman (1969) and other published reports available from the Northern Forest Fire Laboratory (NFFL) (table 8, appendix).

2. Maximum radar echo height data for each storm day obtained by WSR-57 and SO-12 radar at Missoula (table 9, appendix).

3. Hourly radar overlays from the WSR-57 radar at Missoula that show the boundaries of radar echoes with intensity classes: Very Light, Light, Moderate, and Heavy (U.S. Department of Commerce 1962). (*Note*: operational designation of intensity classes has been changed since 1967).

A day was accepted for analysis as a thunderstorm day if: (a) there was a complete record of lightning occurring within a 20 mi (32 km) radius of NFFL, and (b) a maximum radar height value for the same area could be estimated from available radar records. In all, 41 thunderstorm days in June-September 1965-1967 fit the criteria and were used in the analysis.

These steps were followed in analyzing the data:

1. The hourly overlays from the WSR-57 radar were integrated over time to give a radar echo-intensity map for the total period of lightning activity.

2. A simulated forecast area grid was randomly fit over the composite radar echo map. The percentage of the forecast area covered by echoes having standard intensity levels--Very Light (VL), Light (L), Moderate (M), and Heavy (H)--was estimated for each position of the grid. A representative area coverage for each intensity level was then estimated.

The representative echo intensity and coverage values for 41 days are shown in table 4. Each of the 41 days was assigned a "new" index value using the following maximum radar echo height (HMAX) criteria:

| HMAX, m.s.l. | | Index value |
|---|---|---|
| *Feet* | *Meters* | |
| <27,000 | <8 200 | 2 |
| 27-33,000 | 8 200-10 000 | 3 |
| 33-36,000 | 10 000-11 000 | 4 |
| >36,000 | >11 000 | 5 |

The arbitary LAL value vs. Hmax assignment differs slightly from the final versions shown in table 1 and 2. This difference does not significantly change the conclusions drawn from this earlier study.

For comparative purposes, an "old" LAL value for each thunderstorm day was guessed by judging the radar echo overlays using the criteria for radar echo coverage from Deeming and others (1972). Note the differences in values in table 4. Under the "old" criteria, over half of the storm days were assigned the highest value (LAL 5), while the "new" criteria assigned only a fifth of the days as LAL 5.

We need a method for recognizing seasonality in comparing storms, particularly where radar echoes and precipitation amounts are concerned. We have subjectively noted the sharp transition from spring to summer thunderstorm regimes. A similar transition occurs in the fall and marks the end of the summer storms. An objective method for noting these transitions is not available. In this analysis, the author's experiences and judgment were the only bases for classifying storms as pre-, mid, or postsummer season.

We next classified the data by storm type (Finklin 1971)[1]:

Type A: "pure" airmass. No defined frontal influence. No indication of upper-level disturbance or divergence factors.

Type AU: Upper-level disturbance or divergence factor superimposed upon airmass situation.

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[1]Unpublished report titled "Classification and meteorological characteristics of lightning storms in western Montana," on file at the Northern Forest Fire Laboratory, Missoula, Mont.

Table 4.--*Radar echo intensity and coverage, lightning frequency, and maximum radar height, 1965-1967*

| Index values | | Maximum radar ht. x 1000 ft | Storm | Lightning | | Radar echo intensity and fraction of area covered | | | | Storm |
|---|---|---|---|---|---|---|---|---|---|---|
| Old | New | (ht x 305 m) | date | CG | Total | Very light | Light | Mod. | Heavy | type |
| 3 | 2 | 25 | 8-20-67 | 5 | 7 | 0.1 | <0.1 | | | AU |
| 2 | 2 | 25 | 7-28-65 | 1 | 8 | .1 | <.1 | | | AU |
| 5 | 3 | 27 | 6-12-65 | 1 | 13 | >.7 | .7 | | | F |
| 4 | 3 | 27 | 6-23-65 | 1 | 29 | >.1 | .1 | | | AU |
| 3 | 3 | 27 | 6-24-65 | 5 | 32 | .1 | <.1 | | | F |
| 3 | 3 | 28 | 7-14-67 | 2 | 10 | <.1 | <.1 | | | F |
| - | 3 | 28 | 7-19-67 | 3 | 18 | .2 | .1 | | | AU |
| 3 | 3 | 28 | 7-18-67b | 7 | 57 | <.1 | | | | msg. |
| - | 3 | 30 | 8-11-65 | 14 | 60 | >.3 | .3 | dot | | AU |
| 4 | 3 | 30 | 9-05-67 | *13 | 64 | .1 | <.1 | | | AU |
| - | 3 | 30 | 8-04-67 | 22 | 90 | msg. | msg. | msg. | msg. | AU |
| 4 | 3 | 30 | 6-18-67 | *0 | 104 | .1 | <.1 | dot | | F |
| 3 | 3 | 30 | 7-15-66 | 27 | 107 | .1 | <.1 | dot | | AU |
| 5 | 3 | 30 | 9-07-66 | *20 | 152 | .1 | <<.1 | | | F |
| 5 | 3 | 30 | 8-19-65 | 30 | 158 | >.2 | .2 | | | U |
| - | 3 | 30 | 7-26-67 | 5 | 163 | msg. | msg. | msg. | msg. | AU |
| 5 | 3 | 30 | 9-08-67 | 47 | 217 | .5 | .1 | <0.1 | | AU |
| 4 | 3 | 31 | 7-06-66 | 29 | 79 | msg. | .1 | <.1 | | AU |
| 4 | 3 | 32 | 8-29-66 | *65 | 259 | .1 | <.1 | | | F |
| 4 | 3 | 33 | 8-04-66 | 24 | 196 | .1 | .1 | <<.1 | | AU |
| 5 | 4 | 33 | 7-08-65b | 45 | 256 | >.2 | .2 | .1 | | F |
| 5 | 4 | 34 | 7-07-66 | 104 | 161 | msg. | .2 | <.1 | | F |
| 5 | 4 | 34 | 7-29-65 | 36 | 204 | msg. | .1 | <.1 | <0.1 | AU |
| 5 | 4 | 34 | 7-08-65a | 39 | 350 | >.1 | .1 | <.1 | | F |
| 5 | 4 | 34 | 5-29-65 | 61 | 264 | >.7 | .7 | <.1 | | F |
| - | 4 | 34 | 9-14-66 | 107 | 500 | .2 | .1 | <.1 | | U |
| - | 4 | 35 | 8-25-65 | 21 | 111 | msg. | msg. | msg. | msg. | U |
| 5 | 4 | 35 | 8-21-65 | 95 | 189 | msg. | .1 | <.1 | | U |
| 5 | 4 | 35 | 9-06-66 | 90 | 232 | msg. | .1 | <.1 | | F |
| 5 | 4 | 35 | 8-02-65 | 100 | 251 | >.2 | .2 | .1 | | AU |
| 5 | 4 | 35 | 7-07-65 | *38 | 289 | .4 | .3 | | | AU |
| 5 | 4 | 35 | 8-27-65 | 28 | 493 | <.1 | <.1 | <.1 | dot | F |
| 5 | 5 | 36 | 7-14-66[1] | 67 | 205 | .2 | .1 | <.1 | | F |
| - | 5 | 36 | 7-02-65 | 62 | 543 | msg. | msg. | msg. | msg. | AU |
| - | 5 | 37 | 7-04-65 | 95 | 439 | msg. | .2 | .1 | <.1 | U |
| 5 | 5 | 37 | 7-18-67a | 50 | 506 | .3 | .1 | <.1 | | F |
| 5 | 5 | 38 | 6-21-67 | *23 | 404 | .4 | .2 | <.1 | | F |
| 5 | 5 | 38 | 7-12-66 | 123 | 635 | msg. | .7 | .2 | | F |
| 5 | 5 | 42 | 9-12-66 | 356 | 714 | msg. | msg. | msg. | msg. | F |
| 5 | 5 | 44 | 7-27-65 | 178 | 831 | msg. | msg. | msg. | msg. | AU |
| 5 | 5 | 44 | 7-03-67 | 192 | 864 | .4 | .1 | <.1 | | AU |

*Indeterminate class exceeds 5 percent of total.

[1]Beginning of storm that moved out of area to NE 75 nmi and became intense (max. height 55,000 ft).

Type F: Frontal. This category includes cold (or occluded) fronts, quasi-stationary fronts with or without wave and deep low development, and the combination of a cold front moving into a frontal wave system.

Type U: Upper level. A storm situation where the dominant feature is an upper-level trough or closed low (500 mbar or 300 mbar) located overhead or somewhat upwind; a surface front is not a contributing factor. It is distinguished from the AU type in that troughs are more entrenched and large scale, rather then briefly denting a prevailing warm ridge.

In our study, no storm days in 1965-1967 were Type A. Out of 41 days, 18 were Type AU; 17 were Type F; and 5 were Type U.

Within any of the LAL's, storm Type F shows the greatest range of area coverage, that is, the greatest variation between storms within the type (table 7, appendix). For example, the fractional area coverage by radar echo intensity VL (Very Light), L (Light), M (Moderate), H (Heavy) in LAL 3 varied from VL>0.7, L = 0.7 on 6/11/65, to VL<0.1, L<0.1 on 7/14/67. In LAL 4, the differences between F and AU storms are still strong (note storm on 5/29/65).

Storms occurring in June and September have the highest percentage of the area covered by the storm. For this study, storms in June and early July were coded preseason, and September frontal storms were coded postseason. Preseason storms associated with the spring storm regime can extend well into July. Also, postseason storms can start soon after mid-August or, as in 1967 and 1970 in the Northern Rocky Mountain region, not until late in September. In these years, the midseason storm description was applicable into September until the arrival of more extensive, wet storms (characterized by a heavy influx of cool, moist air) signaled the postseason regime.

Next, we stratified the data by LAL, season, and storm type. Representative values for radar echo intensity and coverage for each stratification were then determined. The results are summarized in table 5.

Table 5.--*Radar echo intensity and fraction of area covered*

| LAL index | Storm season | Frontal (F) | | | | Nonfrontal (AU,U) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | VL | L | M | H | VL | L | M | H |
| 2 | Preseason | 0.7 | 0.5 | - | - | - | - | - | - |
| | Midseason | .1 | .1 | - | - | 0.1 | 0.1 | - | - |
| | Postseason | - | - | - | - | - | - | - | - |
| 3 | Preseason | .7 | .5 | - | - | .2 | .1 | - | - |
| | Midseason | .3 | .1 | 0.05 | - | .2 | .1 | 0.05 | - |
| | Postseason | .5 | .1 | .05 | - | .5 | .1 | .05 | - |
| 4 | Preseason | .7 | .5 | .1 | - | - | - | - | - |
| | Midseason | .4 | .2 | .1 | - | .2 | .1 | .05 | - |
| | Postseason | .5 | .2 | .1 | - | .5 | .1 | .05 | - |
| 5 | Preseason | .7 | .5 | .1 | - | - | - | - | - |
| | Midseason | .4 | .2 | .1 | 0.05 | .3 | .1 | .05 | 0.02 |
| | Postseason | .5 | .2 | .1 | .05 | .4 | .2 | .1 | .05 |

The midseason nonfrontal storm characteristics shown in table 5 have a unique feature--an apparent gradation of both radar echo coverage and echo intensity over the LAL range. The gradient is greatest going from LAL 2, the marginal lightning occurrence level, to LAL 3 and 4, where we would expect the most severe potential lightning-caused fire conditions to prevail. The transition to LAL 5 is marked by an increase in the intensity of echoes with little increase in area coverage.

## PRECIPITATION

Because the intensity and coverage of radar echoes could be associated with the LAL, a similar relationship should exist with precipitation. Again, there are very little available data associating precipitation with lightning. Battan (1965) compared visual counts of CG lightning with rainfall on a network covering 1 000 $km^2$. About 0.03 mm of rainfall was measured for each CG lightning flash observed. This amounted to $3X10^{10}$ grams of rainfall per CG flash, on the average, for Arizona storms.

Two aspects of precipitation distribution and amounts were of particular interest in developing the criteria for assigning LAL:

1. The percentage of the total forecast area receiving precipitation.

2. The area-depth relationship for precipitation.

We estimated these two factors from precipitation data from 22 gages located in the area covered by our lightning measurements. A total of 28 storm days for July, August, and September 1965-1967 were analyzed as follows:

1. Precipitation maps were prepared showing both storm and daily total rainfall for those of the 22 stations that reported.

2. An LAL value was assigned for each day based on the number of CG lightning flashes recorded over the area.

3. The fraction F of the area covered by increments of precipitation (0, T, 0.01 to 0.99..., 0.9 to 0.99) was determined from

$$F = \frac{n_i}{N}$$

where n is the number of stations reporting precipitation in amount increment i, and N is the total number of stations reporting on that day.

The available data for LAL's 2-5 are shown in table 10, appendix. The area coverage and amount of precipitation associated with each LAL are summarized in table 6. As an example of how to apply the information in table 6, the following percentages of the forecast area will have zero or only a trace of precipitation for each LAL:

| LAL | Percent of area |
|---|---|
| 2 | 91 |
| 3 | 72 |
| 4 | 64 |
| 5 | 48 |

Table 6.--*Percentage of stations reporting less than the given amount of precipitation on storm days classed by LAL index*

| Precipitation | Lightning activity level index | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| *Inch* | | | *Percent* | | |
| 0.8-0.89 | | | | | 100 |
| .7- .79 | | | | 100 | 99 |
| .6- .69 | | | | 99 | 98 |
| .5- .59 | | | | 99 | 98 |
| .4- .49 | | | 100 | 99 | 94 |
| .3- .39 | | | 99 | 97 | 88 |
| .2- .29 | | | 99 | 96 | 85 |
| .1- .19 | | | 98 | 93 | 80 |
| .01-.09 | | 100 | 93 | 83 | 75 |
| Trace | | 91 | 72 | 64 | 48 |
| 0 | | 79 | 58 | 54 | 34 |
| Number of storms | - | 5 | 10 | 6 | 7 |
| No. of station reports | | 105 | 185 | 98 | 127 |

## The High-Level Thunderstorm (LAL 6)

The high-level dry thunderstorm (LAL 6) is a special situation not fully covered by this report. We know that this type of storm, although relatively rare, can present a severe fire problem. At the present time, a forecast for such a storm is always accompanied by a red flag warning issued by the forecaster. The determination of appropriate values for calculating the fire risk associated with such a storm will require additional study and development. In the interim, the amount of lightning associated with LAL 3 (40 CG's) will be used in the NFDRS for internal calculation of fire risk.

The term "high-level dry thunderstorm" should be reserved for the situation where sufficient moisture and instability for thunderstorm initiation are found in the upper levels only. Cloudbases in the Northern Rockies will be in the 15,000- to 17,000-ft (4 600-5 200-m) levels. Thunderstorm activity is generally triggered by the advection of cold air aloft, an upper cold front passage, or widespread vertical motion. This situation is often preceded by *altocumulus castellanus* clouds in the early- to mid-morning hours. The actual speed of storm movement varies considerably, from near stagnant conditions to rapidly moving systems. The local cells may show considerable precipitation in the form of virga, but virtually no precipitation reaches the ground from the high bases. Strong downdrafts may develop as the rain evaporates below cloud base. Downdrafts reaching the ground can cause strong erratic surface winds.

In situations with relatively high moisture content at all levels, storms may be triggered by the same mechanisms. However, bases will be generally lower and considerably more moisture will reach the ground. This situation would be better described by LAL 2 or 3.

# FURTHER APPLICATION

In this report we have shared our experience and available data to aid in the development of forecasting techniques for lightning and weather associated with forest fire ignition. The concepts described in this paper will be applied in a real-time sense in conjunction with the new lightning-locating system being installed by the Bureau of Land Management in the western United States and Alaska. The objective is to estimate the expected number of new lightning-caused fire starts based on forecast and measured parameters. We look forward to the development of a system which uses these parameters to improve our ability to predict, locate, and manage the lightning-caused forest fire.

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# APPENDIX

## Storm Data 1965-1967

Table 7.--*Storm day data, 1965-1967*

| Date | Time of recording (m.s.t.) | Maximum radar height[1] (feet, m.s.l.) | Cloud base[2] Ht x 1000 ft | Cloud base[2] Temp. °C | Cloud thickness x 1000 ft | Stability index | Precipitable water[3] | Storm type[3] |
|---|---|---|---|---|---|---|---|---|
| 1965 | | | | | | | | |
| 5-29 | 1627-1743 | 34,000 | 8 | msg. | 26 | | | F |
| 6-12 | 0045-0215 | 27,000 | 8.5 | msg. | 18.5 | | | F |
| 6-23 | 1524-1641 | 27,000 | 10 | +08 | 17 | | | AU |
| 6-24 | 1554-1737 | 27,000 | 9 | +07 | 18 | | | F |
| 7-2 | 1632-1920 | 36,000 | 10 | +06 | 26 | -1.0 | | AU |
| 7-4 | 1238-1658 | 37,000 | 8 | +09 | 29 | - .5 | .65 | U |
| 7-7 | 1042-1736 | 35,000 | 10 | +08 | 25 | 0 | -- | AU |
| 7-8a | 1718-1902 | 34,000 | 10 | +06 | 24 | 0 | -- | F |
| 7-8b | 2209-0037 | 33,000 | 10 | +06 | 23 | -- | .60 | F |
| 7-20 | 1242-1726 | no data | 10 | +05 | -- | 0 | .70 | F |
| 7-21 | 1252-1634 | no data | 10 | +05 | -- | .5 | .60 | F |
| 7-26 | 1454-1853 | no data | 10 | +05 | -- | -2.0 | .70 | AU |
| 7-27 | 1600-1813 | 44,000 | 11 | +08 | 31 | -2.5 | .73 | AU |
| 7-28 | 1805-1913 | 25,000 | 13.5 | +03 | 11.5 | -1.5 | .65 | AU |
| 7-29 | 1305-1930 | 34,000 | 12 | +04 | 22 | -1.0 | .65 | AU |
| 8-2 | 1531-1951 | 35,000 | 12 | +04 | 23 | - .5 | .83 | AU |
| 8-3 | 1245-1719 | no data | 8 | +11 | -- | .5 | .78 | U |
| 8-11 | 2237-0026 | 30,000 | 12 | +04 | 18 | - .5 | .92 | AU |
| 8-19 | 1627-1931 | 30,000 | 11.5 | +03 | 18.5 | 1.5 | .87 | U |
| 8-21 | 1650-1930 | 35,000 | 12 | +08 | 23 | 2 | .65 | U |
| 8-25 | 1304-1429 | 35,000 | 8.5 | +06 | 26.5 | 2 | .60 | U |
| 8-27 | 1738-2005 | 35,000 | 10 | +03 | 25 | 2 | -- | F |
| 1966 | | | | | | | | |
| 7-6 | 1716-2018 | 31,000 | 12 | +05 | 19 | - .5 | | AU |
| 7-7 | 2030-2249 | 34,000 | 12 | +05 | 22 | 0 | .54 | F |
| 7-12 | 1018-1810 | 38,000 | 12 | +02 | 26 | -1.5 | -- | F |
| 7-14 | 1340-1915 | 36,000 | 13 | +02 | 23 | -2 | .63 | F |
| 7-15 | 1423-1908 | 30,000 | 13 | +03 | 17 | -2.5 | .5 | AU |
| 8-4 | 1350-1809 | 33,000 | 13 | +0 | 20 | -1.5 | | AU |
| 8-13 | 2118-2208 | -- | 9.5 | +05 | -- | 1.0 | .68 | U |
| 8-19 | 1225-1833 | -- | 10 | -01 | -- | 2.5 | -- | U |
| 8-26a | 0656-0706 | -- | 13 | +01 | -- | | .70 | F |
| 8-26b | 1319-1537 | -- | 10 | +05 | -- | | .70 | F |
| 8-28 | 2239-0138 | -- | 10 | +05 | -- | 2.5 | .52 | F |
| 8-29 | 1300-1842 | 32,000 | 10 | +06 | 22 | 1.5 | .55 | F |

(continued)

| Date | Time of recording (m.s.t.) | Maximum radar height[1] (feet, m.s.l.) | Cloud base[2] Ht x 1000 ft | Cloud base[2] Temp. °C | Cloud thickness x 1000 ft | Stability index | Precipitable water[3] | Storm type[3] |
|---|---|---|---|---|---|---|---|---|
| 9-6 | 1617-2103 | 35,000 | 15 | -04 | 20 | | | F |
| 9-7 | 1705-1821 | 30,000 | 12 | +03 | 18 | | | F |
| 9-12 | 1907-2243 | 42,000 | -- | -- | -- | | | F |
| 9-14 | 1222-1656 | 34,000 | 9 | +02 | 25 | | | U |
| 1967 | | | | | | | | |
| 6-18 | 1511-1652 | 30,000 | 10 | +05 | 20 | | | F |
| 6-21 | 1948-2131 | 38,000 | 7 | +02 | 31 | | | F |
| 7-3 | 1647-2126 | 44,000 | 10 | +11 | 34 | -2.5 | .75 | AU |
| 7-14 | 0820-0947 | 28,000 | 11 | +06 | 17 | 0 | .70 | F |
| 7-18a | 0930-1731 | 37,000 | 11 | +05 | 26 | 1.5 | .51 | F |
| 7-18b | 2125-2254 | 28,000 | 11 | +05 | 17 | 0 | .63 | AU |
| 7-19 | 1049-1155 | 28,000 | 13 | -02 | 15 | 1.0 | -- | F |
| 7-26 | 1730-1921 | 30,000 | 13 | +0 | 17 | 1.0 | .52 | AU |
| 8-4 | 1446-1520 | 30,000 | 13 | +02 | 17 | - .5 | .57 | AU |
| 8-20 | 2046-2123 | 25,000 | 12 | +07 | 13 | 1.0 | .54 | AU |
| 9-5 | 1741-1900 | 30,000 | 12 | +06 | 18 | | | AU |
| 9-8 | 1650-1930 | 30,000 | 12 | +03 | 18 | | | AU |
| 9-10 | 1450-1757 | -- | 11 | +01 | -- | | | AU |

[1]From analysis of SO-12 and WSR-57 radar data (see text).
[2]Measured or estimated for beginning of storm period.
[3]From Classification and Meteorological Characteristics of Lightning Storms in Western Montana, by Arnold Finklin.

Table 8.--*Lightning records, 1965-1967*

| Date | Time of recording (m.s.t.) | Duration of recording (minutes) | Lightning | | |
|---|---|---|---|---|---|
| | | | CG | IC | Total |
| 1965 | | | | | |
| 5-29 | 1627-1743 | 73 | 61 | 196 | 264 |
| 6-12 | 0045-0215 | 90 | 1 | 12 | 13 |
| 6-23 | 1524-1641 | 77 | 1 | 28 | 29 |
| 6-24 | 1554-1737 | 103 | 5 | 27 | 32 |
| 7-2 | 1632-1920 | 168 | 62 | 481 | 543 |
| 7-4 | 1238-1658 | 260 | 95 | 335 | 439 |
| 7-7 | 1042-1736 | 418 | *38 | 189 | 289 |
| 7-8a[1] | 1718-1902 | 104 | 45 | 210 | 256 |
| 7-8b | 2209-0037 | 148 | 39 | 207 | 250 |
| 7-20 | 1242-1726 | 284 | 91 | 444 | 535 |
| 7-21 | 1252-1634 | 222 | 4 | 16 | 21 |
| 7-26 | 1454-1853 | 239 | 65 | 211 | 279 |
| 7-27 | 1600-1813 | 133 | 178 | 651 | 831 |
| 7-28 | 1805-1913 | 86 | 1 | 7 | 8 |
| 7-29 | 1305-1930 | 385[2] | 36 | 167 | 204 |
| 8-2 | 1531-1915 | 224 | 100 | 151 | 251 |
| 8-3 | 1245-1719 | 274 | 87 | 127 | 214 |
| 8-11 | 2237-0026 | 109 | 14 | 44 | 60 |
| 8-19 | 1627-1931 | 184 | 30 | 123 | 158 |
| 8-21 | 1650-1930 | 160 | 95 | 93 | 189 |
| 8-25 | 1304-1429 | 85 | 21 | 87 | 111 |
| 8-27 | 1738-2005 | 147 | 28 | 444 | 493 |
| 1966 | | | | | |
| 7-6 | 1716-2018 | 182 | 29 | 49 | 79 |
| 7-7 | 2030-2249 | 139 | 104 | 55 | 161 |
| 7-12 | 1018-1810 | 472 | 123 | 510 | 635 |
| 7-14 | 1340-1915 | 335 | 67 | 138 | 205 |
| 7-15 | 1423-1908 | 285 | 27 | 80 | 107 |
| 8-4 | 1350-1809 | 259 | 24 | 170 | 196 |
| 8-13 | 2118-2208 | 50 | 6 | 4 | 10 |
| 8-19 | 1225-1833 | 368 | 0 | 3 | 3 |
| 8-26a | 0656-0706 | 10 | *0 | 2 | 3 |
| 8-26b | 1319-1537 | 138 | *49 | 252 | 427 |
| 8-28 | 2239-0138 | 179 | 39 | 388 | 427 |
| 8-29 | 1300-1842 | 342 | *65 | 175 | 259 |
| 9-6 | 1617-2103 | 286 | 90 | 141 | 232 |
| 9-7 | 1705-1821 | 76 | *20 | 119 | 152 |
| 9-12 | 1907-2243 | 216 | 256 | 358 | 714 |
| 9-14 | 1222-1656 | 274 | 107 | 386 | 500 |
| 1967 | | | | | |
| 6-18 | 1511-1652 | 101 | *0 | 60 | 104 |
| 6-21 | 1948-2131 | 103 | *23 | 293 | 404 |
| 7-3 | 1647-2126 | 279 | 192 | 665 | 864 |
| 7-14 | 0820-0947 | 87 | 2 | 8 | 10 |
| 7-18a | 0930-1731 | 481 | 50 | 456 | 506 |
| 7-18b | 2125-2254 | 89 | 7 | 50 | 57 |
| 7-19 | 1049-1155 | 66 | 3 | 14 | 18 |
| 7-26 | 1730-1921 | 111 | 5 | 158 | 163 |
| 8-4 | 1446-1520 | 34 | 22 | 67 | 90 |
| 8-20 | 2046-2123 | 37 | 5 | 2 | 7 |
| 9-5 | 1741-1900 | 79 | *13 | 47 | 64 |
| 9-8 | 1650-1930 | 160 | 47 | 169 | 217 |
| 9-10 | 1450-1757 | 187 | *25 | 315 | 472 |

[1]Subdivided into afternoon and other storms.
[2]Weak lightning except for one active period, about 1430-1530.

* Note high number in indeterminate class; asterisk denotes indeterminate class >5 percent of total.

Table 9.--*Storm periods ranked by maximum radar height (M.S.L.), 1965-1967*

| Max. radar height x 1000 ft ht. x 305 m) | Storm date | Lightning CG | Lightning Total |
|---|---|---|---|
| 25 | 8-20-67 | 5 | 7 |
| | 7-28-65 | 1 | 8 |
| 27 | 6-12-65 | 1 | 13 |
| | 6-23-65 | 1 | 29 |
| | 6-24-65 | 5 | 32 |
| 28 | 7-14-67 | 2 | 10 |
| | 7-19-67 | 3 | 18 |
| | 7-18-67b | 7 | 57 |
| 30 | 8-11-65 | 14 | 60 |
| | 9-05-67 | *13 | 64 |
| | 8-04-67 | 22 | 90 |
| | 6-18-67 | *0 | 104 |
| | 7-15-66 | 27 | 107 |
| | 9-07-66 | *20 | 152 |
| | 8-19-65 | 30 | 158 |
| | 7-26-67 | 5 | 163 |
| | 9-08-67 | 47 | 217 |
| 31 | 7-06-66 | 29 | 79 |
| 32 | 8-29-66 | *65 | 259 |
| 33 | 8-04-66 | 24 | 196 |
| | 7-08-65b | 45 | 256 |
| 34 | 7-07-66 | 104 | 161 |
| | 7-29-65 | 36 | 204 |
| | 7-08-65a | 39 | 250 |
| | 5-29-65 | 61 | 264 |
| | 9-14-66 | 107 | 500 |
| 35 | 8-25-65 | 21 | 111 |
| | 8-21-65 | 95 | 189 |
| | 9-06-66 | 90 | 232 |
| | 8-02-65 | 100 | 251 |
| | 7-07-65 | *38 | 289 |
| | 8-27-65 | 28 | 493 |
| 36 | 7-14-66 | 67 | 205 |
| | 7-02-65 | 62 | 543 |
| 37 | 7-04-65 | 95 | 439 |
| | 7-18-67a | 50 | 506 |
| 38 | 6-21-67 | *23 | 404 |
| | 7-12-66 | 123 | 635 |
| 42 | 9-12-66 | 356 | 714 |
| 44 | 7-27-65 | 178 | 831 |
| | 7-03-67 | 192 | 864 |

*Indeterminate class exceeds 5 percent of total lightning.

Table 10.--*Number of precipitation stations reporting by precipitation amounts on 28 storm days, 1965-1967, grouped into LAL classes*

| Storm date | Precipitation amount | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | T | 0.01-0.09 | 0.1-0.19 | 0.2-0.29 | 0.3-0.39 | 0.4-0.49 | 0.5-0.59 | 0.6-0.69 | 0.7-0.79 | 0.8-0.89 |
| | *Inches* | | | | | | | | | | |
| LAL 2 (0-10 CG's) | | | | | | | | | | | |
| 7-28-65 | 20 | | 1 | | | | | | | | |
| 7-14-67 | 16 | 2 | 3 | | | | | | | | |
| 7-19-67 | 10 | 5 | 5 | | | | | | | | |
| 8-20-67 | 17 | 5 | | | | | | | | | |
| 7-26-67 | 20 | 1 | 1 | | | | | | | | |
| LAL 3 (11-50 CG's) | | | | | | | | | | | |
| 9-05-67 | 12 | 2 | 4 | | | | | | | | |
| 9-07-66 | 5 | 3 | | | | | | | | | |
| 8-04-67 | 18 | 2 | 1 | | | | | | | | |
| 8-04-66 | 13 | 3 | 2 | 4 | | | | | | | |
| 7-15-66 | 18 | 3 | 2 | | | | | | | | |
| 7-06-66 | 17 | 3 | 2 | | | | | | | | |
| 7-29-65 | 12 | 4 | 4 | 1 | | | | | | | |
| 7-07-65 | 1 | 1 | 11 | 4 | | | | | | | |
| 9-08-67 | 6 | 4 | | | 2 | | 1 | | | | |
| 7-18-67 | 5 | 2 | 12 | 1 | | | | | | | |
| LAL 4 (51-100 CG's) | | | | | | | | | | | |
| 7-02-65 | 10 | 2 | 2 | | | | | | | | |
| 8-29-65 | 3 | | 6 | 3 | | | | | | | |
| 7-14-66 | 18 | 3 | 2 | | | | | | | | |
| 9-06-66 | 10 | 3 | 2 | | | | | | | | |
| 7-04-65 | 3 | 1 | 1 | 3 | 2 | 1 | 2 | | | | |
| 8-02-65 | 9 | 1 | 5 | 4 | 1 | | | | | | |
| LAL 5 (>100 CG's) | | | | | | | | | | | |
| 7-08-65 | 1 | 1 | 3 | | 3 | 2 | 6 | 3 | | | |
| 7-07-66 | 17 | 1 | 3 | | | | | | | | |
| 9-14-66 | 7 | 4 | 3 | | | | | | | | |
| 7-12-66 | 2 | 5 | 8 | 2 | 2 | 2 | | | | | |
| 7-27-65 | 9 | 2 | 9 | 2 | | | | 1 | | | |
| 7-03-67 | 6 | 4 | 3 | 1 | 1 | | | 1 | | | 1 |
| 9-12-66 | 1 | 1 | 5 | 2 | 1 | | 1 | 1 | | | 1 |



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Fuquay, Donald M.
1980. Forecasting lightning activity level and associated weather. USDA For. Serv. Res. Pap. INT-244, 30 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Describes concepts, development, and application guidelines for forecasting Lightning Activity Level (LAL) for the National Fire-Danger Rating System (Deeming and others 1977). The LAL is a five-level index designating the expected area-density of cloud-to-ground lightning within selected forecast zones. Additional index numbers denote special cases: LAL 6 is the high-level, dry thunderstorm situation in the northern Rocky Mountains. The LAL guide is a two-part table relating generalized weather variables to the index. Part 1, for the fire weather forecaster, relates maximum radar echo heights, cloud development, and precipitation to LAL values. Part 2, for the fire weather observer to use in verifying or correcting forecasts, relates cloud development, precipitation amount and coverage, and lightning amount and flash rates to LAL values. Data and distributions of lightning and associated weather variables are included as an appendix.

KEYWORDS: Fire danger rating, lightning-caused fires, lightning, fire weather.

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The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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