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PRECIPITATION AND ITS MEASUREMENT
A STATE OF THE ART

Lee W. Larson June 1971

Abstract

A comprehensive review of the literature since 1966 for studies and articles dealing with precipitation and its measurement. Topics discussed include gages, gage comparisons, gage shields, errors in measurements, precipitation data, data analysis, networks, and electronic measurements for rain and snow. A bibliography is included.

KEY WORDS: Climatic data/ equipment/ precipitation data/ statistics/ weather data/ wind/ rainfall/ rain gages/ rain/ snow/ snowfall/ snow gages/ snow surveys

NOTE: References numbered 1 through 331 in the Partially Annotated Bibliography are listed in alphabetical order. Those numbered 332 and above were obtained after the first list had been prepared for publication and form a second alphabetical listing.

TABLE OF CONTENTS

I. INTRODUCTION AND PURPOSE

The purpose of this paper is to present a brief review and compilation of available literature pertaining to precipitation and its measurement from articles and studies between 1966 and 1970.

Because the subject of precipitation and its measurement is so broad, an attempt has been made to index the bibliographical material such that an investigator interested in a specific phase of the subject will be assisted in selecting those articles of direct interest. A broad differentiation has been made between liquid and solid precipitation and, under these, subjects of more detailed interest pertaining to each. The subject areas selected are as indicated in the Table of Contents. The material so indexed is listed by a number which refers to the more complete bibliographical listings in Section IV of this report. Authors and data are included as well as an abbreviated statement about the article which should help the reader to determine his interest in a particular reference.

Section IV contains a partially annotated bibliography presented alphabetically by author, or title, in instances where the author is unknown. Each article is numbered for easy reference to the indexing in Sections II and III of this report.

No attempt has been made to draw conclusions from any of the listed references. Only a very brief summary of an article is given. This summary is not provided to give exact factual data so much as to give the reader a general feeling for the subject matter of the article in question. If a given article seems of interest to the reader, it is recommended that he obtain the article and use it rather than the summary contained herein. It is not possible nor fair to evaluate an entire study in several sentences.

Kurtyka (172), 1953, developed an annotated bibliography of 1079 references pertaining to precipitation, and discussed the methods and instruments used for measuring rain and snow from early history to 1953. Israelsen (147), 1967, extended the previous work by reviewing 164 additional references generally covering the period from 1952 to 1967. It is not the intent of this paper to duplicate any of the references or discussions given by the two aforementioned studies, but rather to concentrate mainly on reports and studies undertaken since 1966.

The reference sources searched during the preparation of this report are given in the Appendix. Omissions and errors can only be attributed to the author.

II. ARTICLES CONCERNING LIQUID PRECIPITATION

1. Gages for Measuring Liquid Precipitation

(38) Bulavko, 1968, describes a special type of rain gage designed to measure the amount of precipitation which penetrates vegetative covers.

(45) Castle, 1965, relates data on a 12-inch orifice gage which utilizes an FM repeater for telemetering precipitation data. The system is designed to operate for extended periods with no maintenance.

(60) Cox, 1968, reports on a gage developed to obtain measurements of total precipitation. The instrument consists of three parts: a hydraulic weighing platform collector, a measuring catchment, and a pressure recording system.

(62) Datar, 1967, and others explain about a rain gage designed and developed in India for collection of rainfall data from remote areas. The gage is a tipping-bucket type and it reports data by radio.

(113) Gray, 1970, describes a precipitation gage system which can be interrogated by computers. Data on precipitation levels in five major river basins in New England are given automatically.

(126) Hindley, 1968, gives a description of the configuration, capabilities, deficiencies, etc., of a telemetry-rain gage. Interrogation of the gage is by telephone.

(159) Kalma, 1969, relates a description of an accurate, inexpensive, small orifice gage for use in rainfall networks. Comparison studies indicate a good agreement with the larger standard gage.

(205) Morrissey, 1967, depicts the manual and automatic instrumentation for precipitation measurements on experimental basins.

(213) Nechaev, 1968, advises that different and new gages be developed. An outline is given of the premises on which the new gages should be developed.

(232) Peck, 1968, reports on a selective precipitation indicator which can sense the presence of dew, frost, drizzle, rain, or snow. The instrument's design, characteristics, etc., are discussed in detail.

(264) Semplak, 1966, delineates a gage which channels the precipitation through a capacitor. The rainfall rate is then sensed by the output voltage changes from an oscillator.

(284) Smoot, 1968, describes an instrument which records both cumulative rainfall and flood stages for small drainage basins.

(299) Stuart, 1966, illustrates a gage which houses a gold-plated tilting bucket. Each .01-inch of precipitation is recorded by electrical impulse. The bucket is gold-plated to reduce surface tension

Other articles of interest in this section are 18, 99, 147, 172, 209, 265, 278.

2. Rain Gage Comparisons

(98) Fuggle, 1968, gives a comparison of three types of gages (the Canadian 3-inch gage, the British Mark II gage, and the "True-Check" plastic gage). No statistical difference was found between them.

(105) Golubev, 1968, compared a rain gage with a Nipher shield, the JRPG gage, the German Democratic Republic gage, and the Tret'iakov gage. The Tret'iakov gage apparently gives the best results.

(107) Gorbunova, 1966, describes a comparison of the Tret'iakov gage, an Ukrainian gage, and a ground surface gage. It was concluded that the Urkrainian gage and the Tret'iakov gage catch the same amount of precipitation.

(130) Hoehne, 1968, in his evaluation of the Fisher-Porter Precipitation Gage, found no seasonal variation in catch for the 8-inch gage and the digital gage of the National Weather Service.

(190) McGuinness, 1969, discusses a comparison made in Ohio of a standard 8-inch gage and a digital punch gage. Yearly totals for the two gages are equal but seasonal patterns of catch are different.

(189) McGuinness, 1966, makes a comparison of lysimeter catch and rain gage catch.

(195) Melikishvili, 1966, gives the data on monthly precipitation totals for various rain and precipitation gages.

(204) Morgan, 1969, also studies the catch of lysimeter versus rain gage catch.

(217) Neff, 1966, relates a study designed to evaluate the performance of various gages. It is concluded that gages above ground catch 3-16% less rainfall than actually reaches the ground.

(279) Smirnov, 1966, presents data with which to compare precipitation gages and pluviographs.

(285) Sneyers, 1968, compares the Brussels and Uccle rain gages with the object being to define the true magnitude measured by each instrument.

Also see 172, 205, 330, 147.

3. Rain Gage Shields

(52) Chou, 1968, indicates that devices for shielding rain gages are needed and are discussed. He concludes that an Alter type shield will increase rainfall catch by 2.3%, but suggests that a turf wall or pit gage would be better.

(104) Giraytys, 1968, gives an excellent history of rain gage shielding and gives a description of various gages used by the Weather Bureau Test and Evaluation Laboratory.

(319) Vogelmann, 1968, discusses the screening of gages in order to measure cloud droplets from fog or low-lying clouds.

See also 147 and 172.

4. Errors in the Measurement of Liquid Precipitation/

(a) Wind

(30) Bratzev, 1963, points out that precipitation gages account for 64-95% of the total precipitation and that wind caused error is about 5% per 1 m/sec velocity.

(244) Robinson, 1969, made a wind tunnel study of four gages to determine airflow around the gage. He concludes that a ground level gage will give the largest catch.

(245) Rodda, 1969, states that, for all errors associated with the measurement of precipitation, the wind caused error is by far the most important. When snow is involved, this error is even larger.

(273) Shuvakhin, 1966, concludes that, for a Tret'iakov gage and a gage with a Nipher shield, the wind caused error is "considerable".

(298) Struzer, 1968, states that mean precipitation error due to wind could range from 10-20%.

(304) Taramzhenina, 1966, determined that correction factors for precipitation measurement deficits were a function of wind speed. The percent of deficit was determined by the ratio of the difference between a ground gage and a gage at 2 meters to the amount in the rain gage.

See also 108, 147, 172.

(b) Evaporation

(31) Briazgin, 1966, states that the evaporation intensity depends upon moisture deficit and that it is somewhat larger for solid precipitation than for liquid. Evaporation losses due to evaporation could range up to 13%.

(73) Dubrovin, 1968, concludes that evaporation from a gage is not constant and could be as high as 25% of total precipitation.

(193) Melikishvili, 1968, compared evaporation losses from several types of gages. Losses from a Tret'iakov gage on an average were .6 mm/day (8.6 inches/year).

(212) (214) Nechaev, 1968, determined that evaporation intensity was a function of air humidity deficit and air velocity. He also states that evaporation losses for liquid and solid precipitation are similar and amount to 3-8% of total precipitation.

See also 147, 172, 191, 231.

(c) Wetting

(31) Briazgin, 1966, states that the wetting losses in measuring precipitation during June-August are 29%.

(173) Lazareva, 1966, has developed a formula to correct for losses due to wetting. It is based upon the precipitation total, number of measurements, and a correction constant.

(182) Lutskina, 1966, concludes that the precipitation deficit due to wetting is normally 11-16%.

(194) Melikishvili, 1966, says that his studies indicate an annual precipitation deficit due to wetting of from 2-12%.

(211) Nechaev, 1966, states that the correction required for wetting is .2 mm for each measurement made.

(296) Struzer, 1968, has determined that the correction required for the wetting of vessel walls, when measured four times per day, is 5% of the total.

See also 25, 107, 108, 147, 172.

(d) Other Errors

(153) Jones, 1969, has concluded that the sloping portion of the gage housing may be a cause for reduction in catch.

(295) Struzer, 1966, gives a formula to compute the error due to the splashing of raindrops.

(297) Struzer, 1968, has evaluated the error in ground level gages due to splattering. He concludes that a splatter shield of 50 cm radius will eliminate this source of error.

See also 39, 139, 147, 172.

5. Liquid Precipitation Data

(57) Cooper, 1967, relates rainfall intensity and elevation for southwestern Idaho.

(68) Dickison, 1968, reports on the effect of relief on the distribution of precipitation.

(115) Green, 1967, gives monthly and annual data for 45 rain gages in the Santa Rita Experimental Range.

(121) Henry, 1968, presents a study of data from tropical rainstorms to include movement, precipitation amounts, distributions, means, etc.

(134) Hoover, 1965, describes the process and significance of interception in Colorado subalpine forests.

(145) Il'inova, 1968, has investigated precipitation totals, precipitation distributions, etc. for the mountainous regions of Central Asia.

(167) Kodrau, 1968, has developed precipitation data to include maximums and minimums, monthly means, etc. for the West Indies and Central America.

(186) Marx, 1967, has made a comparison study of high precipitation totals for the Upper Elbe region.

(200) Miller, 1966, has prepared maps indicating the normal number of days with precipitation equal or greater than .50, 1.00, 2.00, and 4.00 inches.

(259) Schermerhorn, 1967, reports on relations between topography and annual precipitation in Oregon and Washington.

(320) Walkotten, 1967, relates elevation effects on rainfall near Hollis, Alaska.

See also 56, 59, 74, 86, 91, 106, 147, 151, 156, 171, 172, 191, 192, 218, 229, 243, 255, 260, 309, 311.

6. Liquid Precipitation Data Analysis

(a) Statistical

(13) Babichenko, 1967, conducted a distribution study of maximum daily precipitation data. He concludes a 7-year period is inadequate to obtain stable maximum values.

(37) Buikov, 1967, has investigated correlation coefficients for precipitation totals of various time periods and for various distances between stations.

(40) Burroughs, 1967, has developed techniques whereby estimates of rain intensity statistics can be determined for any location from available climatic data.

(95) Freeney, 1969, presents the statistical treatment for calibration data from gages which are used to measure rainfall rates.

(127) Hirsch, 1967, presents a statistical study of rainfall data which enables one to develop values that characterize the climate of the region.

(165) Kisilenko, 1967, investigates by statistical analysis summer rainfall and its variation in the basin of the Rika River.

(230) Panchang, 1967, gives details of an examination of precipitation data undertaken to show the better efficiency of the method of maximum likelihood to reflect long term precipitation.

(270) Shaw, 1969, has presented a statistical analysis of rain gage densities in England.

(276) Sirotenko, 1969, relates statistical methods which are designed to increase precipitation information through the use of regression equations.

(289) Steinhausser, 1968, presents procedures which can be used to extract information on heavy precipitation from gage records.

(302) Suzuki, 1967, develops functional expressions of frequency distributions by a statistical and schematic treatment of rainfall data.

See also 39, 40, 53, 66, 94, 101, 122, 132, 137, 141, 147, 157, 163, 172, 197, 274, 278, 301, 308, 328.

(b) Corrections for Precipitation Data

(3) Aleksandrian, 1967, has developed a correction coefficient used to restore homogeneity to long term records when rain gage types have been changed.

(25) Bondarenko, 1966, presents monthly and annual corrections for the wetting of precipitation gages.

See also the references under 4(a), 4(b), and 4(c) for other error corrections.

(c) Accuracy of Precipitation Data

(63) DeByle, 1969, gives procedures to be used to verify the accuracy of readings from weighing-type precipitation gages.

(140) Huff, 1970, concludes that the variability of rainfall rates is so great within storms that accurate rate measurements are probably prohibitive in areas of 100 square miles or greater.

(158) Kagan, 1968, among other things, has developed formulae for determining the accuracy of mean precipitation totals.

(238) Rainbird, 1967, discusses the importance of precipitation in global studies and deals with the accuracy of point rainfall measurements.

See also 147 and 172.

7. Precipitation Measurements by Electronics (Radar, Radio, Microwave, etc.)

(11) Atlas, 1968, reviews the radar measurement of precipitation.

(36) Buettner, 1968, suggests that clouds complicate the interpretation of data over the ocean and that determining rainfall rates is a formidable problem.

(46) Catano, 1969, has developed radar-rainfall relationships for nine different locations throughout the world.

(76) Dutton, 1968, presents a study which considers the effect of precipitation on radio attenuation.

(90) Flanders, 1970, reports on the history and development of automatic weather radar data processing.

(109) Gorelik, 1969, describes a method of ground and radar measurements of the microstructure of precipitation.

(120) Harrold, 1967, develops a relationship between attenuation of 8.6 mm radiation and rainfall rate.

(136) Huff, 1967, presents an evaluation of using surface rain gage data to modify radar-rainfall equations for specific storms.

(154) Joss, 1968, compared the radar return of a vertical pointing radar with rain gages underneath. The daily standard deviation between the radar and spectrometer, spectrometer and gage, and gage and gage was 22%, 8%, and 6%, respectively.

(164) Kessler, 1968, describes the use of radar measurements of precipitation for hydrological purposes.

(170) Krasiuk, 1969, investigated the absorption and scattering effects produced by rain on centimeter and millimeter radio waves.

(179) Litvinov, 1967, investigated the parameters in the equation relating radar reflectivity with intensity. He concludes that unique parameters for even a single rain cannot be found.

(188) McCallister, 1968, reports on radar requirements and direct application of radar information for operational hydrological analyses.

(203) Morgan, 1968, describes an instrument to sense rainfall rates. An oscillator relates depth changes in the gage to frequency changes. Equations then relate rainfall rate to the frequency.

(249) Ross, 1969, states that radar precipitation data during a 36-hour study were within 2% of data from ground gages and had a correlation coefficient of .91.

(264) Semplak, 1966, has developed a gage for sensing rainfall rates.

(293) Stout, 1968, concludes that relationships between radar reflectivity and rainfall amounts can be determined. These relationships show differences of up to 500% for rainfall rates at the same reflectivity.

(325) Wilson, 1970, studies the accuracy of rainfall measurements by radar.

See also 33, 43, 46, 70, 85, 114, 135, 147, 152, 160, 161, 172, 206, 210, 250, 251, 254, 275, 293, 294.

8. Precipitation Gage Networks

(4) Amorocho, 1968, applied mathematical filtering processes to data from precipitation gage networks in order to determine the effect of network densities on defining storm patterns.

(6) Andersson, 1968, studied the areal representivity of individual gages from a dense network covering 400 KM^2. It is concluded that autumn and summer rains differ in character and that estimates of areal means are more accurate in autumn.

(78) Eagleson, 1967, uses sampling theory to determine optimum density of rainfall networks.

(140) Huff, 1970, used recording gages with enlarged orifices to provide information on spatial patterns of rainfall intensity on a network. He concludes that the variability is great within and between convective storms.

(225) Ostby, 1969, describes the operation of a rain gage network near Hartford, Connecticut. The purpose is to investigate rainfall variability for that area.

(290) Stephenson, 1968, gives solutions to the problem of determining the minimum number of gages required in a network to measure rainfall depth with a given accuracy over a given area.

See also 12, 34, 54, 56, 64, 72, 95, 140, 141, 147, 172, 178, 200, 241, 288, 310.

9. Miscellaneous Measurements and Equipment

(a) Measurements

(15) Barrett, 1970, has studied inadvertent modification of weather and climate by atmospheric pollutants.

(33) Bridges, 1966, has developed two parameters with which to measure drop size distributions. These parameters are the dual-wavelength relative attenuation and the single-wavelength reflectivity.

(58) Cornford, 1968, rejects the claim that airborne impactors can be used to measure the total flow of water from a shower.

(61) Crouse, 1966, investigated the total interception loss for storms. He has determined the precipitation storage capacity of grass is proportional to the product of its height and percent ground cover.

(79) Eichenlaub, 1970, concludes that snowfall to the lee of the Great Lakes has increased in recent years.

(88) Fieg, 1968, has studied urban precipitation patterns in the St. Louis area.

(155) Julian, 1968, reviews the basis for relating tree-ring growth to climatic parameters.

(181) Lozowski, 1969, discusses the relationships between precipitation and vertical motions (up-draft).

(242) Reiter, 1968, has conducted a study of the electrical phenomena occurring in precipitation. Of special interest was the processes occurring in freely falling precipitation.

(252) Rutherford, 1967, analyzed precipitation data from 12 sites in Ontario to determine the precipitation composition (cations and anions).

(257) Shaefer, 1969, evaluates changes in precipitation regimes due to atmospheric pollution.

See also 48, 50, 133, 147, 172, 292, 322.

(b) Equipment

(29) Bradley, 1967, describes a device installed in the nose of an aircraft to collect precipitation and then to determine if radioactive particles are in it.

(75) Duncan, 1966, describes an airborne foil impactor used to measure shower rainfall.

(209) Nathan, 1968, describes a ground based spectrometer which counts all raindrops >.2 mm and classifies them into one of twelve size intervals.

See also 18, 147, 172.

III. ARTICLES CONCERNING SOLID PRECIPITATION

1. Gages for Measuring Solid Precipitation

(174) Leaf, 1962, investigated the use of snowboards to measure solid precipitation. He determined the coefficient of correlation to be .89 to .95 for a snowboard and a shielded gage.

(175) Lenda, 1968, in his study of snowpack characteristics also describes portable and stationary snow gages.

(185) Martinelli, 1965, discusses new snow measuring techniques to include pressure pillows, neutron and gamma ray devices, plate capacitors, and others.

(208) Murphy, 1966, describes a gage which can operate unattended for sixty days.

(223) Orlov, 1961, presents a description of a new Soviet snow gage which measures precipitation by the variance in intensity of a photocurrent.

(234) Peterson, 1968, reports on the development of snow sensor installations in California.

(268) Shannon, 1970, describes the development and use of electronic telemetry in order to obtain "real time" information.

(269) Shannon, 1968, gives a complete description of a snow pillow which will record the water equivalent of a snowpack for the entire winter.

(305) Tarble, 1968, presents a paper in which the advantages and limitations of various types of snow sensors are discussed.

(321) Warner, 1969, describes the measurement of falling snow by optical attenuation. The total precipitation measured from 20 storms was within 2% of that measured by a gage and Nipher shield.

See also 147, 172, 183, 324.

2. Snow Gage Comparisons

(98) Fuggle, 1968, compared three gages (Canadian 3", British Mark II, "True-Chek") and found no statistically meaningful differences.

(105) Golubev, 1968, compared the precipitation from seven gages with the snow water content of a zero transport plot. Preliminary results show that a Tret'iakov gage placed inside a low brush or fence enclosure gives the best results.

(119) Hamon, 1970, has compared gages, one shielded and one unshielded, in order to derive equations which will give "true" snowfall.

(174) Leaf, 1962, compared snowboards with shielded gages and snowboards with unshielded gages. The coefficient of correlation for the former was .89-.95 and for the latter .91.

See also 147 and 172.

3. Snow Gage Shields

(1) Adams, 1968, discusses the problem of measuring falling snow with reference to a Nipher shield and gage.

(105) Golubev, 1968, states that placing a gage inside a shield made of low brush or fence gives the most accurate determination of solid precipitation.

(236) Poggi, 1968, presents a study which shows that snow gages in a clearing are not helped by the addition of an Alter shield. In fact, when the precipitation is liquid, the Alter shield will lower the catch of the snow gage. It was found that the average difference between the storage gage in a clearing and snow pack measurements is 1.5% to 4.5%.

(240) Rechard, 1970, gives a preliminary report on the use of artificial wind barriers (snow fences) in order to provide a correct "man made" site for snow gages.

See also 147 and 172.

4. Errors in the Measurement of Solid Precipitation

(a) Wind

(8) Arkhipova, 1966, states that the error due to wind is dependent upon wind speed and increases with an increase in wind speed. The wind deficit is also dependent upon temperature and increases with a decrease in temperature.

(24) Bogdanova, 1966, presents an investigation of precipitation measurement errors due to wind. The error among other things is dependent upon precipitation structure. Wind produced error is 30-60% for winds of 2-4 m/sec (4.5-9.0 mph) and 200-300% at winds of 8-10 m/sec (17.8-22.4 mph).

(128) Hisdal, 1963, after considering the problems of measuring solid precipitation in the Antarctic concludes that the precipitation gage is satisfactory for measuring snowfall only during periods of calm weather.

(237) Popov, 1967, conducted a study on lake water balance. Data from 17 precipitation gages was corrected by 20% for wind caused error in measuring solid precipitation.

(245) Rodda, 1969, gives a study of errors and methods in measuring precipitation. He states the wind caused error is the most important. Even under the best conditions, the wind error is appreciable and, if snow is involved, the error will be even larger.

(298) Struzer, 1968, gives results which show that yearly precipitation normals should be increased from 40-80% to account for wind caused errors in measuring solid precipitation.

(304) Taramzhenina, 1966, states that a correction coefficient for wind produced errors is a function of wind speed. The percent of deficit is the ratio of the difference between a ground level gage and one at a height of 2 meters to the amount in the gage.

See also 147 and 172.

(b) Other Errors in Measuring Solid Precipitation

(31) Briazgin, 1966, has investigated the error in measuring precipitation due to evaporation and wetting. The evaporation intensity depends upon atmospheric moisture deficit and is somewhat larger for solid precipitation than for liquid precipitation.

(89) Findlay, 1969, concludes that measurements of precipitation normals for the arctic area could have an annual error of up to 6 inches (152 mm).

(100) Gedeonov, 1966, states that the correction of records at a station when measuring solid precipitation should be a function of geographical location, type of protection, and observed wind speeds.

(212) (214) Nechaev, 1968, states that evaporation losses for liquid and solid precipitation are similar and range from 3-8% of the total.

(296) Struzer, 1968, says that the error due to wetting of vessel walls when measuring solid precipitation could be as high as 19%.

See also 147 and 172.

5. Solid Precipitation Data

(93) Forcier, 1967, presents data gathered at Otis Air Force Base on rain versus snow and the collection and classification of data.

(118) Gunn, 1967, presents data on the average mass per crystal and snowfall rates. He concludes that the principal contribution to an increase in snowfall rate is the formation of new crystals rather than the growth of old ones.

(168) Konovalov, 1967, gives data on the spatial variation of the density of snow in mountain watersheds. Suggestions are given for random measurements.

(287) Summary of Snow Survey . . ., 1969, contains information on snow measurements in California and Oregon.

See also 77, 147, 172.

6. Solid Precipitation Data Analysis

(a) Statistical

(92) Fliri, 1967, has calculated the standard deviation, skewness, and monthly precipitation for the four seasons for a number of stations in the Alpine areas of Europe.

(207) Muller, 1968, deals with the application of empirical orthogonal functions to horizontal data fields. Eigenvector values were prepared for mesoscale resolution of total storm snowfalls.

(b) Corrections for Solid Precipitation Data

(65) Deleur, 1967, indicates that the water balance of snow cover during certain conditions approximately equals solid precipitation. A correction factor of 1.5 can be used for a gage in the open with no wind when measuring solid precipitation.

(89) Findlay, 1969, suggests methods for correcting precipitation gage data in the arctic area to include evapotranspiration and interception calculations, snow surveying, stream gaging, etc.

(237) Popov, 1967, made an intensive study of precipitation on Lake Ladoga. A correction factor of 1.20 was used for solid precipitation in order to account for such factors as wind.

See also 147 and 172.

7. Solid Precipitation Transfer Studies

(a) General

(9) Arsent'ev, 1967, presents a study on the factors influencing the distribution of snow in a pit. Among other things, the accumulation of snow in a pit as a result of falling solid precipitation and the volume of transported snow is discussed.

(71) Diunin, 1967, states that the magnitude of solid flux is not constant when a storm reaches its maximum intensity. Also, snow evaporation intensity is higher during storms than in the absence of snow transfer.

(199) Mikhel, 1969, gives a description of the principles involved in the computation of the transport of blowing snow.

(227) Oura, 1967, concludes that most snow particles are transported by saltation (a layer of about 10 cm (4 inches) above the ground surface).

See also 16.

(b) Snow Transfer Measurements

(2) Agafonova, 1968, presents information on snow volume transfer for the period 1936-1965. Volume is established on recurrance and duration of wind speeds greater than 6 m/sec (13.5 mph) with consideration given to snow cover and temperature.

(149) Iziumov, 1930, has concluded that 86-90% of blowing snow is in the 10 cm (4 inches) layer next to the ground surface and an additional 6% is within 20 cm (8 inches) of the surface.

(202) Molochnikov, 1939, states that snow transfer begins at 3 m/sec (6.7 mph). Maximum amounts of transported snow vary from .1 gr/sq.cm/min. to 24.4 gr/sq.cm/min. at 18 m/sec.

(271) Shiotani, 1967, has made measurements of blowing snow in layers up to 6 meters (19.7 feet).

(c) Equipment Used to Measure Snow Transfer

(110) Govorukha, 1961, describes an instrument adopted from a centrifugal dust catcher which is used to measure drifting snow. Results show drifting snow decreases logarithmically with height.

(162) Kedrolivanskii, 1953, describes instruments used in the USSR to measure blowing snow.

(196) Mellor, 1960, describes two types of snow traps. Both gages function by reducing velocity and allowing snow particles to drop out.

(226) Oura, 1967, describes several simple collectors used to estimate the amount of snow blown under high velocity conditions.

(272) Shliakhov, 1960, describes a new drifting snow gage for use in the Antarctic.

See also 51 and 169.

8. Miscellaneous Solid Precipitation Measurements and Equipment

(a) Measurements

(5) Anderson, 1967, has studied snow accumulation under varying conditions.

(20) Bilello, 1969, states that, despite areal and yearly variations, certain properties of snow and ice thickness will form definite patterns when plotted on small scale maps.

(26) Borovikova, 1968, has used precipitation totals and mean daily air temperatures to model snow cover formations in mountain basins.

(201) Miyairi, 1966, has studied the drag of bodies moving through snow at high speeds.

(280) Smith, 1967, has shown that the measurement of snow depths by aerial photogrammetry can be successful.

(300) Sulakvelidze, 1966, gives consideration to the measurement of solid precipitation by radar.

(331) Zotimov, 1968, presents an outline of the principles involved in measuring snow water equivalent based on attenuation of the natural γ radiation of the earth.

See also 198.

(b) Equipment

(20) Bilello, 1969, describes the early development of remote sensors for various snow properties and ice thickness.

(174) Leaf, 1962, describes the use of a "snowboard" to measure snow precipitation.

(175) Lenda, 1968, reviews the use of radioisotopes to measure snow pack characteristics.

See also 80 and 98.

IV. PARTIALLY ANNOTATED BIBLIOGRAPHY

1. Adams, W. P. and R. J. Rogerson. "Snowfall and Snowcover at Knob Lake, Central Labrador-Ungava", Eastern Snow Conference, 25th, Boston, Feb. 8-9, 1968, Proceedings. 1968. pp. 110-139.

   The problem of measuring falling snow with reference to a Nipher shield and gage is discussed. Other problems discussed include the validity of snow course mean values, measurement of snow on the ground, lake snow cover and others. It is concluded that the official snowfall at Knob Lake is an underestimate of true receipts.

2. Agafonova, S. M. "Perenos snega pri meteliakh v Gor'kom i Arzamase" (Snow Transfer During Snowstorms in Gorki and Arzamas), U.S.S.R. Verkhne-Volzhskoe Upravlenie Gidrometeorologicheskoi Sluzhby, Sbornik Rabot Gor'kovskoi i Volzhskoi Gidrometeorologicheskikh Observatorii, No. 5. 1968. pp. 97-100.

   The volume of snow transfer during storms is established based on recurrence and duration of wind speeds at 6 m/sec and higher with consideration given to snow cover depth and temperature. Observational data from meteorological stations from 1936-1965 are used. The winter mean maximum snow transfer values are calculated.

3. Aleksandrian, G. A. "K voprosu ucheta neodnorodnosti riadov dozhdemernykh i osadkomernykh nabliudenii" (Taking Into Account the Heterogeneity of Series of Rain and Precipitation Measurement Data), Akademiia Nauk Armianskoi SSR, Erivan, Izvestiia. Nauki o Zemle, 20(5/6). 1967. pp. 142-150.

   The homogeneity of long term records within the Soviet Union was destroyed because rain gages with Nipher shields were replaced by Tret'iakov gages. A correction coefficient is used to restore uniformity of the series. The correction coefficient is a ratio of the monthly precipitation totals measured by a rain gage to the monthly total measured by a precipitation gage K_o.

4. Amorocho, J., A. Brandstetter and Don Morgan. "Effects of Density of Recording Rain Gauge Networks on the Description of Precipitation Patterns", International Association of Scientific Hydrology, Publication No. 78. 1968. pp. 189-202.

   Mathematical filtering processes are applied to data from dense recording precipitation gage networks in order to develop criteria for the determination of the effect of network densities on the definition of significant storm patterns. The experiment used 20 battery-driven, digital recording rain gages covering an area of 10 square miles. The spacing for adequate areal pattern definition was studied.

5. Anderson, Henry W. "Snow Accumulation as Related to Meteorological, Topographic, and Forest Variables in Central Sierra Nevada, California", International Association of Scientific Hydrology, Publication No. 78. 1967. pp. 215-224.

A study of how snow accumulates under varying conditions is made using snow measurements taken at 250 different points.

6. Andersson, Tage. "On the Representativity of Rain Measurements". Uppsala, Umversitet. Meteorologiska Institutionen, Serien Rapporter No. 7. 1968.

The areal representativity of individual rain gage figures are studied utilizing rainfall measurements of "Project Pluvius" in Uppsola, Sweden. The mean rainfall over a dense network field of 400 square KM was compared to other selected areas showing an unbroken series of observations. Results are shown by graphs which indicate the regression of the mean rainfall with the test area and by scatter diagrams which plot coefficient of variation against mean rainfall for the test area. It is concluded that the character of summer rain differs from that of autumnal and that estimates of areal mean values from point measurements are more accurate during autumn than during summer.

7. Arkhipova, V. F. "Cb uchete pogreshnosti izmereniia tverdykh osadkov osadkomerami Tret'iakova po materialan proshlykh let" (Allowing for Errors in Snow Measurements Obtained by Tret'iakov Precipitation Gages), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 175. 1965. pp. 110-116.

8. Arkhipova, V. F. "Opyt korrektirovki summ tverdykh osadkov popravkami navetrovoi nedouchet" (Correction of Total of Solid Precipitation by Corrections for Wind Deficit), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 103-112.

The error of precipitation gages in measuring solid precipitation was shown to be dependent upon wind speed. The dependence of the monthly deficit upon wind speed is presented. The wind-caused deficit in the catch of solid precipitation increases with a decrease in air temperature. A method to calculate the temperature effect is presented.

9. Arsent'ev, A. I. and V. I. Usynin. "Vliianie napravleniia razvitiia gornykh rabot na snegozanosimost' kar'era" (Effect of the Direction of Mine Development on Snow Accumulation in Pits), Nal'chik, U.S.S.R., Vysokogornyi Geofizicheskii, Trudy, No. 12. 1967. pp. 175-186.

The factors influencing the distribution of snow in a pit are presented. The snow drift is estimated by a coefficient of reduction of wind speed in the pit. Equations are given for calculating mean wind speed, amount of snow accumulating in pit as a result of falling solid precipitation by weight and volume, the volume of transported snow, the depth of snow in the pit, and the amount of snow transported by snow drifts.

10. Arsent'ev, G. I. "Zavisimost' nedoucheta tverdykh osadkov ot skorosti vetra v usloviiakh Vostochnoi Sibiri" (Relation Between Errors in Snow Measurements and Wind Velocity in East Siberia), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, Vol. 175. 1965. pp. 98-109.

11. Atlas, David. "Radar Measurement of Precipitation: A Review and Critic". 13th Radar Meteorology Conference, Aug. 1968, McGill University, Canada. 1968.

12. Austin, Pauline M. and Robert A. Houze. "Analysis of Mesoscale Precipitation Areas". Paper presented at the 14th Radar Meteorology Conference, Tucson, Arizona. 1970.

13. Babichenko, V. N. "O naibol'shikh sutochnykh kolichestvakh osadkov na Eksperimental'nom meteorologicheskom poligone" (Greatest Diurnal Amounts of Precipitation at the Experimental Meteorological Proving Ground), Kiev, Ukraine, Nauchno-Issledovatel'skii Gidrometeorologicheskii Institut, Trudy, No. 67. 1967. pp. 58-65.

A distribution of maximum daily values of precipitation over the Experimental Meteorological Proving Ground in the Ukrainian is investigated. A 7-year observation period was found to be inadequate for obtaining stable values of maximum daily precipitation. The frequency of fall of the maximum shows considerable variation for precipitation measuring stations in similar physical geographic conditions.

14. Barnes James C. and Clinton J. Bowley. "Snow Cover Distribution as Mapped from Satellite Photography", Water Resources Research, Vol. 4, No. 2. April 1968. pp. 257-272.

15. Barrett, E. W., R. F. Pueschel, H. K. Weickmann and P. M. Kuhn. "Inadvertent Modification of Weather and Climate by Atmospheric Pollutants". ESSA Tech. Report ERL 185-APCL 15, Boulder, Colorado. September 1970.

16. Bastamov, S. L. "Laboratory Study of Snowdrifting at the Geophysical Observatory at Kuchino", Trudy Nauchno-Issledovatel'skogo Upravleniia Narodnogo Komissariata Putei Soobschscheniia, Vol. 109. 1930. pp. 75-76.

A review of research conducted since 1918. Instruments suitable for measuring snow drifting intensity and snow cover mobility are described.

17. Beaumont, R. T. "Mount Hood Pressure Pillow", Jour. of Applied Meteorology, Vol. 4, No. 5. October 1965. pp. 626-631.

18. Bidwell, V. J. "Time Analysis of Rainfall on an Urban Catchment", Journal of Hydrology, Dunedin, N. Z., 6(2). 1967. pp. 74-79.

Short time-increment rainfall has been analyzed by autocorrelation at the University of Auckland. A practical method for precipitation data recording, processing, and analysis are outlined.

19. Bigler, Stuart G., R. G. McGrew and M. St. Clair. "An Experiment in Digitizing Weather Radar Data from a Four Station Network". 14th Radar Meteorology Conference, Tucson, Arizona, 1970.

20. Bilello, Michael A. "Surface Measurements of Snow and Ice for Correlation with Aircraft and Satellite Observations", U. S. Cold Regions Research and Engineering Lab., Hanover, N. H., Special Report No. 127. May 1969.

Describes early development or remote sensors to observe properties of snow and thickness of ice. Despite areal and yearly variations, definite patterns in the magnitudes of these values emerge when plotted on small scale maps. Correlation between remote sensing data and actual conditions is accomplished through the use of a network of stations in North America.

21. Billones, Louis. "Operational Problems of Storage Precipitation Gages", 31st Western Snow Conference, Yosemite National Park, California, Proceedings. April 1963. pp. 74-76.

22. Biswas, Asit K. "The Automatic Rain Gage of Sir Christopher Wren, F.R.S.". The Royal Society of London, Vol. 22, Nos. 1 & 2. September 1967.

A short history of the rain gage coupled with a thorough examination of the development of the automatic rain gage of Sir Christopher Wren.

23. Biswas, Asit K. "Development of Rain Gages", Journal of the Irrigation and Drainage Division, ASCE, Vol. 93, No. IR3, Proc. Paper 5416, September 1967. pp. 99-124.

The development of rain gages is considered for the period of 400 B.C. up to 1850 A.D. Earliest precipitation measurements were taken in India.

24. Bogdanova, E. G. "Issledovanie vetrovoi pogreshnosti izmereniia osadkov" (Investigation of Precipitation Measurement Errors Caused by Wind), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 40-62.

An investigation of precipitation measurement errors caused by wind. The wind error is determined for wind speed and rain drop dimensions. The deficit of liquid precipitation measured is usually 5-8% for a Tret'iakov gage (wind speed of 2-4 m/sec at 2 m). The wind deficit of solid precipitation depends on precipitation structure. Atmospheric temperature during precipitation fall is selected as the parameter of structure. Wind produced error is 30-60% at winds of 2-4 m/sec and 200-300% at winds at 8-10 m/sec.

25. Bondarenko, R. N. "Popravki k normam osadkov na territorii Kazakhstan, uchityvaiushchie poteri na smachivanie osadkormernykh sosudov" (Corrections to Precipitation Norms in Kazakhstan, Taking into Account Losses by Moistening of Precipitation Gage Containers), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 149-153.

Monthly and annual corrections are given for wetting of precipitation containers. The spatial annual variation of these corrections are also discussed.

26. Borovikova, L. N. "Matematicheskoe modelirovanie formirovaniia snezhnogo pokrova i raschet postupleniia vody na poverkhnost' gornogo basseina" (Mathematical Modeling in Forming a Snow Cover and Computation of the Entry of Water onto the Surface of a Mountain Basin), Sredneasiatskii Nauchno-Issledovatel'skii Gidrometeorologicheskii Institut, Tashkent, Trudy, No. 39. 1968. pp. 37-43.

Precipitation totals and mean daily air temperatures are used as the basis of a model of snow cover formation in mountain basins. A differential equation of the change in snow accumulation with time is obtained. Also considered is the problem of water discharge from melting glaciers.

27. Boston, R. C. "Radar Attenuation and Reflectivity Due to Size-Distributed Hydrometeors", Jour. of Applied Meteorology, Vol. 9, No. 1. February 1970. pp. 188-191.

28. Boston, R. C. "Scattering at Centrimetric Wavelengths", 13th Radar Meteorology Conference, August 20, 1968, Session 8: Precipitation Measurement and Z-8, McGill University, Montreal Canada. 1968.

29. Bradley, W. E. and G. E. Martin. "Airborne Precipitation Collector", Jour. of Applied Meteorology, Vol. 6, No. 4. August 1967. pp. 717-723.

A 30 cm device was installed in the nose of a twin-engine aircraft. Both air and rain enter the collector where liquid water is then separated by impaction and centrifugal force. A determination is then made to see if radioactive particles are washed from the air by precipitation.

30. Bratzev, A. P. "Influence of Wind Speed on the Quantity of Measured Precipitation", Soviet Hydrology Papers, No. 4, AGU. 1963. pp.414-417.

Results show that the precipitation gages account for 64-95% of the total precipitation. Precipitation lost on account of wind speed is about 5% per wind speed of 1 m/sec.

31. Briazgin, N. N. "Poteri sobrannykh osadkov v arkticheskikh uslov-iiakh za schet ispareniia iz osadkomernogo sosuda" (Loss of Collected Precipitation under Arctic Conditions Due to Evaporation from a Precipitation Gage Container), Leningrad, Glavnaia Grofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 163-166.

The evaporation of precipitation from a Tret'iakov gage is investigated. Investigation procedures are described and tables are given on the errors in precipitation measurement due to losses by wetting of container walls and by evaporation. Evaporation during June-August was 13% of the total precipitation and the wetting loss was 29%. The evaporation intensity depends upon the atmospheric moisture deficit and is somewhat larger for solid precipitation than for liquid precipitation.

32. Brice, H. D. "Tipping-bucket Rain-gage Attachment for a Water-Stage Recorder" in Selected Techniques in Water Resources Investigations compiled by G. N. Mesnier and K. T. Iseri, U. S. Geol. Survey Water-Supply Paper 1669-Z. November 1963. pp. 53-57.

33. Bridges, J. E. and J. R. Feldman. "Radar Attenuation - Reflectivity Technique for Remote Measurement of Drop Size Distributions of Rain", Jour. of Applied Meteorology, Vol. 5, No. 3. June 1966. pp. 349-357.

The development of two parameters of Marshall Palmer drop size distribution of rain is discussed. The parameters are dual-wavelength relative attenuation measurement and single wavelength reflectivity.

34. Brissett, Donald T. "Operation Raincheck", Weatherwise, Boston 22(2). April 1969. pp. 64-67.

A study conducted in the vicinity of Colorado Springs, Colorado, shows that precipitation rates and amounts can vary by more than two orders of magnitude over a city on a seasonal and daily basis. Also presented are maps showing distribution of rain gages around Colorado Springs.

35. Brooks, Burrow P. and John C. McWhorter. "Depth of Area Rainfall from Point Rainfall", Mississippi Water Resources Conference, Mississippi State University, State College, Mississippi, Proceedings. 1968.

36. Buettner, Konrad J. K. and William T. Kreiss. "Discussion of S. F. Singer and G. F. Williams, Jr.: Microwave Detection of Precipitation Over the Surface of the Ocean (and Reply by) Singer and Williams", Jour. of Geophysical Research, Washington, D. C., 73(22)7145. November 1968.

A suggestion that clouds play an important role and that they complicate the interpretation of data in the use of microwave detections of precipitation over the surface of the ocean. In reply to this suggestion, it is pointed out that determining liquid water content and rainfall rate along a flight path over the ocean are truly formidable problems.

37. Buikov, M. V., et al. "Korreliatsionnye funktsii summ osadkov i oshibki pri izmerensloia letnikh osadkov po dannym osadkomernoi seti Eksperimental'nogo meteorologi cheskogo poligona" (Correlation Functions of Sums of Precipitation and Errors in Measurements of the Layer of Summer Precipitation Based on Data of the Precipitation Gage Network of the Experimental Meteorological Proving Ground), Kiev, Ukraine, Nauchno-Issledvatel'skii Gidrometeorologicheskii Institut, Trudy, No. 67. 1967. pp. 18-23.

The correlation coefficients of monthly, decadal, diurnal, and semi-diurnal sums of precipitation for various distances between stations are computed. Errors of determination of mean sums of precipitation are computed by area from data at discreet points. Data are based on the precipitation gage network at Kiev, Ukraine.

38. Bulavko, A. G. "Pronikovenie atmosfernykh osadkov skvoz' pokrov sel'skokhoziaistvennykh rastenii" (Penetration of Atmospheric Precipitation Through the Covering of Agricultural Plants), Meteorologiia i Gidrologiia, Moscow, No. 12. December 1968. pp. 62-66.

A special type of rain gage is described for recording the amount of precipitation penetrating vegetative cover. The degree of penetration depends on precipitation intensity and the nature of vegetative cover.

39. Burns, Joseph I. "Small Scale Topographic Effects on Precipitation Distribution in San Dimas Experimental Forest", Transactions, American Geophysical Union, Vol. 34, No. 5. October 1953. pp. 761-767.

A study based on eleven years of record from 96 gages in San Dimas Experimental Forest. A multiple graphical correlation is developed to show correlation of elevation, slope, rise, aspect and zone with annual precipitation.

40. Burroughs, H. H. "Rain Intensity-time Distributions", U. S. Naval Ordnance Lab., Corona, California, NOLC Report No. 729. June 1967.

Techniques have been developed whereby estimates of rain intensity statistics for any location can be obtained from available climate data. Graphical representations of such estimates are shown.

41. Bussinger, J. "Eddy Diffusion and Settling Speed in Blown Snow", Jour. Geophys. Res., No. 70. 1965. pp. 3307-3313.

42. Butson, Keith D. "Snow Cover Observation Review, U. S. Weather Bureau", Western Snow Conference, 21st, Boise, Idaho, 1953, Proceedings. 1953. pp. 5-6.

43. Carlson, Paul E. "Measurement of Snowfall by Radar", 13th Radar Meteorology Conference, McGill University, Canada, August 1968.

44. Castle, G. H. "Operational Experience with Snow Pillows in California", American Society of Civil Engineering, Proc. 95, IR1 No. 6444. 1969. pp. 105-116.

45. Castle, G. H. "Telemetering Precipitation Gages for Remote Areas", Western Snow Conference, 33rd, Colorado Springs, Colorado, 1965, Proceedings. 1965. pp. 36-41.

Describes operating experience obtained in tests of a 12" orifice gage using a battery operated fully transistorized FM repeater. System was designed to operate for extended periods of time without adjustment.

46. Catano, Robert. "Method for Estimating Rainfall Rate-Radar Reflectivity Relationships", Journal of Applied Meteorology, Boston 8(5). October 1969. pp. 815-819.

Rainfall rate - radar reflectivity relationships for nine different locations throughout the world are obtained. Regression equations based on mean annual percent of thunderstorm days and the mean annual relative humidity are determined. This permits an estimate of the relationship for any area once the parameters are obtained.

47. Chadwick, Duane G. and Gregory L. Pearson. "An Economical Total Precipitation Telemetering System", Western Snow Conference, 32nd, Nelson, British Columbia, Canada, 1964, Proceedings. 1964. pp. 1-7.

48. Changnon, J. P., Jr. "A Climatological Evaluation of Precipitation Patterns", SED Tech. Report A62-5, Symposium, Air Over Cities, Cincinnati, Ohio, November 1969. pp. 37-67.

49. Changnon, S. A., Jr. "Precipitation in a 550-Square Mile Area of Southern Illinois", Illinois State Academy of Science Transactions, Vol. 56, No. 4. December 1963. pp. 165-187.

50. Changnon, Stanley A., Jr. "The La Porte Weather Anomaly - Fact or Fiction?", Bull. of American Meteorological Society, Vol. 49, No. 1. January 1968.

51. Cherepanov, N. V. "Measurement of Amount of Snow Drifted by Snowstorms", Vestnik Edinoi Gidrometeorologicheskoi Sluzhby, Vol. 3, No. 7. 1933. pp. 15-16.

An instrument for measuring blowing snow at various heights is described.

52. Chou, Ken Chuan. "Research and Discussion on Definite Precipitation Measurements", Tai-Pei, Formosa, National Taiwan University, Dept. of Geography and Meteorology, Science Report No. 5. June 1968. pp. 48-65.

A rain gage is an obstruction to the free flow of wind. Rising currents exist on the windward side and descending currents on the lee side with complicated eddies occurring about the gage. Devices for shielding the gage are needed and are discussed. An Alter-type shield results in additional rainfall catch of 2.3%. The author suggests this is insignificant and indicates that a turf wall or pit gage would be better.

53. Coffin, James C. "A Method of Estimating Precipitation Normals for Short Record Stations", American Geophysical Union, Transactions, Vol. 35, No. 3. June 1954. pp. 405-412.

Regression formulae are developed from which estimates of the monthly normal precipitation at a station having a short record can be obtained.

54. Collinge, V. K. and D. G. Jamieson. "The Spatial Distribution of Storm Rainfall", Journal of Hydrology, Vol. 6. 1968. pp. 45-57.

55. Collis, R. T. H. "The Feasibility of Measuring Rainfall by Reference to Radar Attenuation". Stanford Research Institute, Menlo Park, California. May 1960.

56. Colorado State University. "Comments on the Northeast Brazil Project by the 1969 Class in 'The Atmosphere and the Water Cycle'", Department of Atmospheric Science, Weather Disturbances over Tropical Continents and the Effects on Ground Conditions Report No. 3. March 1969.

An observing program in northeastern Brazil designed to study and predict the low precipitation of the area. The analysis of the network precipitation is discussed with respect to processes leading to the observed mean climatic state, prognoses for operational purposes, prediction of rainfall fluctuations, and potential for cloud modification.

57. Cooper, Charles F. "Rainfall Intensity and Elevation in Southwestern Idaho", Water Resources Research, Vol. 3, No. 1. 1967. pp. 131-137.

58. Cornford, S. G. "Measurement of Shower Rainfall Using an Airborne Foil Impactor", Journal of Applied Meteorology, Boston, 7(5). October 1968. pp. 956-957.

59. Court, Arnold. "Wind Direction During Snowfall at Central Sierra Snow Laboratory", Western Snow Conference, 25th, Santa Barbara, Calif., Proceedings. April 1957. pp.39-43.

A study of predominate wind patterns (speed and direction) during precipitation at Donner Pass is discussed.

60. Cox, Lloyd M. and Russel W. Hamon. "A Universal Surface Precipitation Gage", Western Snow Conference, 36th, South Shore Lake Tahoe, Nevada, Proceedings. April 1968. pp. 6-8.

The great need for a recording system to obtain measurements of total precipitation has fostered the development of this universal precipitation gage. The instrument consists of 3 major parts - an hydraulic weighing platform collector, a measuring catchment, a pressure recording system. Complete description and drawings are shown.

61. Crouse, R. P., E. S. Corbett and D. W. Seegrist. "Methods of Measuring and Analyzing Rainfall Interception by Grass", International Association of Scientific Hydrology, Bulletin VII, No. 2. June 1966. pp. 110-120.

A study near Glendora, California, which showed that water storage capacity of grass was proportional to product of average height and percent ground cover. Total interception loss for a storm was a function of storage capacity and number of showers per storm.

62. Datar, S. V., P. Mohammed and A. Mani. "Automatic Radio Reporting Rain Gage System", Irrigation and Power (India), Vol. 24, No. 2. April 1967. pp. 145-150.

A rain gage data transmission system designed and developed in India for collection of rainfall data from remote and inaccessible areas is described. A tipping bucket gage measures rainfall and stores information in data register. A programmer clock switches on coding and programming units and radio transmitter at predetermined times. Coded messages are then sent by UHF transmitter up to 100 KM away.

63. DeByle, Norbert V. and Harold F. Haupt. "Verifying Recording Precipitation Gauge Records", Journal of Soil and Water Conservation, Vol. 24, No. 5. 1969.

A procedure is presented to verify the final readings from charts of weighing-type precipitation gages in order to insure accurate records.

64. Delaine, R. J. "Measuring Rainfall on Forest Catchments", Journal of Hydrology, Vol. 9, No. 1. September 1969. pp. 103-112.

65. Deleur, M. S. I "K voprosu o tochnosti ucheta tverdykh osadkov" (Accuracy of Measuring Solid Precipitation), Kiev, Ukraine, Nauchna-Issledovatel'skii Gidrometeorologicheskii Institut, Trudy, No. 68. 1967. pp. 66-73.

A study which shows that the water balance of snow cover (for a period of no thaws, no drifting and little evaporation) approximately equals solid precipitation. Observations from certain "indicator areas", when compared to twelve Tret'iakov gages indicate that a correction factor of 1-5 can be used for a gage in the open with an absence of wind when measuring solid precipitation.

66. Denisov, V. M. "Raschet naibol'shei srednei intensivnosti osadkov za razlichnye intervaly.vremeni i maksimal'noi intensivnosti dozhdia zadannoi veroiatnosti prevy-sheniia pri otsutsvii ili nedostatochnosti nabliudenii po poliuviografam" (Computation of Maximum Mean Intensity of Precipitation During Various Time Intervals and Maximum Intensity of Rain of a Specified Exceedance Probability in the Case of Deficient or Insufficient Recording Rain Gage Observations), Sredneaziatskii Nauchno-Issledovatel'skii Gidrometeorologicheskii Institut, Tashkent, Trudy, No. 39(54). 1968. pp. 50-57.

The determination of rainfall intensities of a specified probability are hampered by a lack of recording rain gages. It is proposed to extropolate the desired parameters (rainfall intensities, greater average intensity, precipitation amounts for various time intervals) from appropriate USSR reference books and examples are given of verification of this possibility with data of various authors and with actual rain gage records.

67. Denit, R. M., et al. "Determination of Water Equivalent of Snow Cover by Method of Aerial Gamma Survey", Soviet Hydrology Paper No. 2, AGU. 1965. pp. 183-187.

68. Dickison, R. B. B. "The Effect of Minor Relief on the Distribution of Precipitation", TEC-700, Toronto, Ontario, Canada. November 1968.

69. "Digital Flood Warning System, Aquadat", Electronics and Power, Vol. 4. November 1968. pp. 447.

70. Dimaksyan, A. M. and N. V. Zotimov. "Results of Radar Measurements of Liquid Precipitation", Soviet Hydrology Paper No. 6, AGU. 1965. pp. 530-537.

This is a study which shows that definite correlations exist between strength of radar echo return signals and the rate of storm precipitation.

71. Diunin, A. K. "Fundamentals of the Mechanics of Snow Storms", International Conference on Low Temperature, Sapporo, Japan, August 14-19, 1966, Proceedings, Vol. 1, Physics of Snow and Ice, Pt. 2. 1967. pp. 1065-1073.

A snow storm is a 2-phase turbulent stream with hard particles, and the magnitude of the solid flux is not constant when the storm reaches maximum intensity. Also, snow evaporation takes place at a higher intensity during storms than in the absence of snow transfer. This may be partly explained by the exposure of all surfaces of flakes in the snow stream during the storm.

72. Drissel, J. C. and H. B. Osbourn. "Variability in Rainfall Producing Runoff from a Semiarid Rangeland Watershed, Alamogordo Creek, New Mexico", Journal of Hydrology, Vol. 6. 1968. pp. 194-201.

73. Dubrovin, L. V. "Eksperimental'noe opredelenie ispareniia iz osadkomernykh i dozhdemernykh veder" (Experimental Determination of Evaporation from Precipitation and Rain Gage Buckets), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 215. 1968. pp. 88-96.

In dry areas, evaporation from a rain gage can cause up to 25% error in collected precipitation. The evaporation rate from a precipitation gage is not constant but varies from .027-.127 mm/hr. Data were obtained from 2 standard precipitation gages on the site of Kuibyshev Hydromet.

74. Duff, H. W., et al. "Rain-Gauging Program to Provide Guide to Storm Sewer Design", Water and Sewage Works, Vol. 116. November 1969. pp. 420-424.

75. Duncan, A. D. "The Measurement of Shower Rainfall Using an Airborne Foil Impactor", Jour. of Applied Meteorology, Vol. 5. 1966. pp. 198-204.

76. Dutton, E. J. "Radio Climatology for Precipitation and Clouds in Central Europe", U. S. Wave Propagation Lab., Boulder, Colorado, Tech. Report ERL 68-WPL 3. April 1968.

A study which considers the effect of precipitation on radio attenuation. The type of cloud and precipitation drop size distribution is determined from general data based on seasonal vertical occurrence of particular cloud types.

77. Dyer, R. M. "Persistence in Snowfall Intensities Measured at the Ground", Jour. of Applied Meteorology, Vol. 9. 1970. pp. 29-34.

78. Eagleson, P. S. "Optimum Density of Rainfall Networks", Water Resources Research, Vol. 3, No. 4. 1967. pp. 1021-1033.

79. Eichenlaub, Val L. "Lake Effect Snowfall to the Lee of the Great Lakes: Its Role in Michigan", Bull. of American Meteorological Society, Vol. 51, No. 5. May 1970. pp. 403-411.

80. "Electronic Snow Pillow Achieves Effective Snow Survey", Electronics World, Vol. 172. December 1, 1969. pp. 49.

81. Environmental Sciences Services Administration. "A Grid Method for Estimating Precipitation Amounts Using the WSR-57 Radar". Weather Bureau Tech. Memo, WBTM WR-19, Salt Lake City, Utah. December 1966.

82. Environmental Science Services Administration. "Probable Maximum Precipitation, Mekong River Basin". Hydrometeorological Report No. 46. May 1970.

83. Environmental Science Services Administration. "A Study of the Effect of Sea Surface Temperature on the Areal Distribution of Radar Detected Precipitation Over the South Carolina Coastal Waters". Weather Bureau Tech. Memo, WBTM ER-23, 9p, Garden City, New York. June 1967.

84. Environmental Science Services Administration. "A Theory for the Determination of Wind and Precipitation Velocities with Doppler Radars". Institute for Environmental Research Tech. Memo, IERTM NSSL-35, 20p, Norman, Oklahoma. August 1967.

85. Esterbrook, B. M. and D. Turner. "Prediction of Attenuation by Rainfall in the 10.7-11.7 ghz Communication Band", Institute for Electrical Engineering Proceedings, Vol. 114. May 1967. pp. 557-565.

86. Fedorov, S. F. and A. S. Burov. "Vliianie lesa na osadki" (Effect of Forest on Precipitation), Leningrad, Gosudarstvennyi Gidrologicheskii Institut, Trudy, No. 142. 1967. pp. 8-19.

A comprehensive investigation of precipitation measurements in forests and open fields. Results show that over a period of years, forests increase precipitation 10 to 15 percent on the average.

87. Fedorova, E. A. "Uchet stepeni zashchishchennosti stantsii pri vychislenii skorosti vetra na urovne ustanovki osadkomera" (Calculation of Wind Velocity at the Level of the Precipitation Gage Considering the Degree of Screening from Stations), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 63-69.

An objective method is presented for the consideration of "screening" when calculating wind velocity at the precipitation gage level from a known wind velocity at anemometer height. Height conversion factors can be obtained for each station for the wind speed and each of the eight wind directions. Accuracy is sufficient for correcting precipitation normals.

88. Fieg, A. M. "An Evaluation of the Precipitation Patterns Over the Metropolitan St. Louis Area", 1st National Conference on Weather Modification, Albany, New York, 1968, Proceedings. 1968. pp. 210-219.

89. Findlay, B. F. "Precipitation in Northern Quebec and Labrador: An Evaluation of Measurement Techniques", Arctic 22(2). June 1969. pp. 140-150.

A study which suggests that precipitation normals for the continental arctic area could have an annual error of 6 inches. Methods and indirect techniques available for the adjustment of precipitation gage data include snow surveying, stream gaging, interception and evapotranspiration calculations, and watershed rain gage networks.

90. Flanders, Allen and Stuart G. Bigler. "History and Development of Automatic Weather Radar Data Processing". Paper presented at World Meteorological Organization Tech. Conf. of Hydrological and Meteorological Services, Geneva, Switzerland, 1970.

91. Fletcher, Robert D. "A Relation Between Maximum Observed Point and Areal Values", Transactions, American Geophysical Union, Vol. 31, No. 3. June 1950. pp. 344-348.

The envelope of world record point rainfall values for durations ranging from a few minutes to six months is closely approximated by the relationship that maximum depth is proportional to the square root of duration.

92. Fliri, F. "Beitraege zur Kenntnis der zeitlichen und racumlichen Verteilung des Niederschlages in den Alpen in der Periode 1931-1960" (Space and Time Distribution of Precipitation in the Alps During the Period 1931-1960), International Congress on Alpine Meteorology, 9th, Brig, Switzerland, September 14-17, 1966, Wissenschaftliche Abhandlungen, Zurich. 1967. pp. 72-79.

The relative standard direction, skewness, and monthly sums of precipitation in the four seasons for a number of stations in the alpine area of Europe are calculated. A discussion is given concerning the relation of the results with respect to the problem of the reduction of precipitation data and with the general climatology of the Alps.

93. Forcier, Henry Emile. "Study of Rain Versus Snow at Otis Air Force Base During the Winter Season of 1966-1967". Otis AFB, Mass., 12th Weather Squadron Publication. April 26, 1967.

A study of rain versus snow and the collection and classification of data at Otis Air Force Base.

94. Foster, Walter D. "A Comparison of Nine Indices of Rainfall Intensity", Transactions, American Geophysical Union, Vol. 31, No. 6. December 1950. pp. 894-900.

In order to supplement the four frequently used simple indices of rainfall intensity (5 min. intensity, 15 min. intensity, 30 min. intensity, and average intensity (p/t)),five compounded measures are suggested by the author. The nine measures are compared by appropriate statistical methods for their relative merit in characterizing rainfall intensity.

95. Freeney, A. E. "Statistical Treatment of Rain Gage Calibration Data", Bell System Tech. Jour., Vol. 48, No. 6. 1969. pp. 1757-1766.

The statistical treatment of calibration data of capacitance gages used for measuring rainfall rates in a rain gage network set up in a 160 square KM area in New Jersey is described.

96. Freeney, A. E. and R. A. Semplak. "Measuring Rainfall", Bell Lab. Rec. No. 47. November 1969. pp. 314-319.

97. Frind, E. O. "Rainfall-Runoff Relationships Expressed by Distribution Parameters", Journal of Hydrology, Vol. 9, No. 4. 1969. pp. 405-426.

98. Fuggle, R. F. "Note to Compare the Records from Three Rain Gauges Similarly Exposed at Mont St. Hilaire, Quebec", McGill University, Montreal, Department of Geography, Climatological Bulletin No. 4. July 1968. pp. 49-51.

A comparison of three types of gages revealed no statistically meaningful differences between them. The gages compared were the Canadian 3-inch gage, the British Mark II gage, and the True-Chek" plastic gage.

99. Gamble, E. E. "An Inexpensive Raingage", Agronomy Journal 59(2). 1967. pp. 206-207.

100. Gedeonov, A. D., et al. "Opyt vychisleniia srednego mnogoletnego Kolichestva osadkov pri nabliudeniiakh po dvum priboram, dozhdemeru i osadkomeru" (An Attempt at Calculating the Mean Long-Period Amount of Precipitation from Observations with Two Instruments, a Rain Gage and a Precipitation Gage), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 88-102.

A discussion of the problems arising in the computation of precipitation from rain gages with Nipher shields and the Tret'iakov precipitation gages and the need for obtaining uniform precipitation records. A recalculation for solid precipitation falling at a station is determined as a function of physical geographical location, type of protection and the observed wind speed.

101. Gerasimov, Strakhil. "Reduktsionni krivi na duzhdovete v baseinite na rekite Maritsa, Arda i Tundzha" (Reduction Curves of the Rainfalls in the Basins of the Maritsa, Arda and Tundzha Rivers), Bulgaria, Institut po Khidrologiia i Meteorologiia, Isvestiia 11. 1967. pp. 77-109.

The use of curves for the calculation of maximum water runoff quantities originating from various rainfalls in certain river basins, is presented. The nature of the curves and the method of obtaining them are described.

102. Gerdel, R. W. "The Simulation of a Blowing Snow Environment in a Wind Tunnel", 29th Western Snow Conference, Spokane, Washington, April 1961, Proceedings. 1961. pp. 106-111.

103. Gerdel, R. W., B. L. Hansen and W. C. Cassidy. "The Use of Radio-isotopes for the Measurement of the Water Equivalent of a Snow Pack", American Geophysical Union, Vol. 31, No. 3. June 1950. pp. 449-453.

104. Giraytys, James and Albert Heck "Some Relevant Early Events and the United States Participation in an International Precipitation Gage Comparison Program", Weatherwise, Boston 21(5). October 1968. pp. 198-202.

A paper which reviews the history of rain gage shielding and describes the various gages used at the Weather Bureau Test. and Evaluation Lab, Sterling, Virginia, and at the Urbana, Illinois airport.

105. Golubev, V. S. and R. E. Rogotskaia. "Predvaritel'nye rezul'taty issledovanii ulavlivaemosti tverdykh atmosfernykh osadkov osadkomernymi priborami" (Preliminary Results of Investigations of the Effectiveness of Precipitation Meters in Sampling Solid Atmospheric Precipitation), Leningrad, Gosudarstvennyi Gidrologicheskii Institut, Trudy, No. 152. 1968. pp. 4-17.

The measured precipitation from seven gages is compared with the snow water content on a zero transport plot. The gages compared are the rain gage with a Nipher shield, the JRPG gage, the German Democratic Republic gage, and the Tret'iakov gage. Preliminary results show that, for measuring solid precipitation, the best results were obtained with the Tret'iakov gage placed inside a low brush or double fence enclosure.

106. Goodyear, Hugo V. "Frequency and Areal Distributions of Tropical Storm Rainfall in the United States Coastal Region on the Gulf of Mexico", Weather Bureau Tech. Report WB7, Silver Springs, Maryland. July 1968.

107. Gorbunova, I. G. "Rezul'taty ispytanii dozhdemera konstruktsii UkrNIGMI" (Results of Tests of a Rain Gage Constructed at the Ukrainian Hydrometeorological Institute), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 190-195.

A comparison of the Tret'iakov precipitation gage, a rain gage of the Ukrainian Hydromet, and a ground surface rain gage. Data are given on the variability of corrections for wetting and the dependence of a wind caused precipitation deficit upon wind speed is examined.

108. Gorbunova, I. G., V. G. Bozhenko and N. P. Pavlova. "O sistematicheskikh pagreshnostiakh standartnogo pliuviografa" (Systematic Errors of the Standard Pluviograph), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 215. 1968. pp. 125-134.

Evaluations are made of the losses of precipitation collected by a pluviograph due to wetting and splattering and the effect of wind and distortions in the mean rain intensity. It is concluded that splattering losses could be from 1 to 8% of the total precipitation, depending on droplet diameter. The pluviograph was compared to a ground level gage and was found to give readings which were 6-38% low. The range of errors for monthly averages was large and still larger for individual rainfalls.

109. Gorelik, A. G., et al. "Nekotorye rezul'taty sovmestnykh radiolokatsionnykh i nazemnykh izmerenii mikrostruktury osadkov (Some Results of Combined Radar and Ground Measurements of the Precipitation Microstructure), Vsesoiuznoe Soveshchanie po Radiolokatsionnoi Meteorologii, 3rd, Dolgo-Prodnaya, USSR, April 1966, Trudy. 1969. pp. 26-31.

A method of ground and radar measurements of the microstructure of precipitation is described. The deviation of the radar equations for determining precipitation intensity and the concentration of particles in a volume are derived.

110. Govorukha, L. S. and E. F. Kirpichev. "First Results of Drifting Snow Observations with the Drifting Snow Meter 'Cyclone'", Inform. Biul. Sov. Antarkticheskoi Eksped, No. 26. 1961. pp. 22-25.

An instrument which is adopted from a centrifugal dust catcher is employed to measure drifting snow. Results show that the density of drifting snow decreases logarithmically with height.

111. Grant, L. O. and J. D. Marwitz. "Application of Radar to Snow Surveying", Western Snow Conference, 33rd, Colorado Springs, Colorado, Proceedings. April 1965. pp. 42-48.

112. Grant, Lewis O. and Richard A. Schleusener. "Snowfall and Snowfall Accumulation Near Climax, Colorado", Western Snow Conference, 29th, Spokane, Washington, Proceedings. April 1961. pp. 53-64.

113. Gray, Carlton H. "The Automatic Hydrological Radio Reporting Network, New England Division, Corps of Engineers", Western Snow Conference, 38th, Victoria, B.C., Proceedings. April 1970. pp. 102-107.

A system is described which can be interrogated by computer and among other things gives precipitation levels in five major New England river basins automatically.

114. Grayman, Walter M. and Peter S. Eagleson. "A Review of the Accuracy of Radar and Raingages for Precipitation Measurement". Massachusetts Institute of Technology, Hydrodynamics Lab. Report No. 119. February 1970.

The various methos of measuring precipitation are summarized and the characteristics that affect their accuracy are described. Raingage errors are normally ± 5% to ± 10%. The conjunctive use of radar and raingages is found to be potentially beneficial in improving precipitation measurements.

115. Green, Christine R. and S. Clark Martin. "Evaluation of Precipitation, Vegetation and Related Factors on the Santa Rita Experimental Range". Arizona University, Institute of Atmospheric Physics, Technical Reports on Meteorology and Climatology of Arid Regions No. 17. April 1967.

Monthly and annual data for 45 rain gages in the Santa Rita Experimental range are presented. A statistical analysis for 22 of the gages over a 26-year period is presented.

116. Green, M. J. "Effects of Exposure on the Catch of Rain Gauges". Water Research Association TP No. 67, Medmenham, Morlow, Buchinghamshire, England. July 1969.

An extensive study on the catch of rain gages with respect to gage height, wind speed, rain inclination, and exposure. Conclusions are that the gage should be pit mounted, orifice at ground level, in a clearing of 100 m radius, and with a surrounding splash guard.

117. Grunow, Johannes. "Assessment of Winter Precipitation in the Mountains", Meteorologie, 4th, Ser. No. 45-46. June 1957. pp. 117-126.

118. Gunn, K. L. S. "Number Flux of Snow Crystals at the Ground", Monthly Weather Review, Washington, D. C. 95(12). December 1967. pp. 921-924.

Measurements of the snowfall rate and the average mass per crystal have provided values for the number of snow crystals reaching a unit area of surface per unit time. Thus, the principal contribution to an increase in snowfall rate is the formation of new crystals rather than the growth of existing ones.

119. Hamon, W. R. "Evaluation of Precipitation Gage Performance, Annual Report for 1969". Northwest Watershed Research Center, Agricultural Res. Serv., USDA, Boise, Idaho. 1970.

120. Harrold, T. W. "Attenuation of 8.6 mm - Wavelength Radiation in Rain", Institute of Electrical Engineers, Proceedings, Vol. 114, No. 2. February 1967. pp. 201-203.

A relationship between attenuation of 8.6 mm radiation and the rate of rainfall was developed using 8 recording rain gages as an estimate of rate of rainfall.

121. Henry, Walter K., et al. "Research on Tropical Rainfall Patterns and Associated Mesoscale Systems", U. S. Army Electronics Command, Ft. Monmouth, New Jersey, Tech. Report ECOM-02312-SF. December 1968.

A study of tropical rainstorms to include the use of mass distribution curves to predict average daily maximum rainfall amounts, and the mean of given rainstorms in different parts of South East Asia. Also a study of frequency of wet and dry days, rainfall analysis for long periods, and the movement of mesoscale systems.

122. Hershfield, D. M. "Method for Estimating Probable Maximum Rainfall", American Water Works Association Journal, Vol. 57. August 1965. pp. 965-972.

123. Hershfield, D. M. "Precipitation", American Geophys. Union, Trans., Vol. 44, No. 2. June 1963. pp. 530-555.

124. Hershfield, D. M. and R. A. Schleusener. "Precipitation", Association of Scientific Hydrology, IUGG, Quad. Report. pp. 707-711.

125. Hershfield, David M. "Rainfall Input for Hydrologic Models", General Assembly of Bern, Sept.-Oct. 1967, Symposium on Geochem,, Precip., Evap., Soil Moisture, Hydrom., Int. Ass. Sci. Hydrol. Pub. No. 78. 1968. pp.177-188.

126. Hindley, D. R. "Meteorological Office Telemetry Rain Gage", Inst. of Water Engineers Journal, Vol. 22. May 1968. pp. 201-204.

A description of the configurations, capabilities, installation, deficiencies, and future development of a 2-unit telemetry-rain gage. Interrogation of the rain gage is by telephone.

127. Hirsch, Francois. "Application de l'analyse statistique a l'etude de la pluviometrie: le Bassin de la Bruche" (Application of Statistical Analysis to the Study of Rainfall in the Bruche Basin), La Meteorologic, Ser. 4, Paris, No. 81. 1967. pp. 25-46.

A statistical study of the rainfall measurements of the basin of the Bruche make it possible to calculate the values that characterize the climate of the region. The analysis determined the probable maximum and minimum for certain periods of recurrence: 10, 20, 50 and 100 years.

128. Hisdal, V. "Visibility, Cloudiness, Humidity, and Precipitation", Oslo University, Norweigian-British-Swedish Antarctic Expedition, 1949-1952, Scientific Results, Vol. I. 1963.

The problems and results of snow measurements in the Antarctic are discussed. It is generally concluded that the precipitation gage is a satisfactory device for measuring snowfall only during periods of calm weather.

129. Hiser, H. W., et al. "Investigation of Rainfall Measurements by Radar", University of Miami 1956-1959, Weather Bureau Contracts cwb 8614 and cwb 9283.

130. Hoehne, Walter E. "Final Report - Test and Evaluation of the Fisher and Porter Precipitation Gage", Weather Bureau Tech. Memo. T & EL 7, Office of Systems Development, Sterling, Virginia. 1968.

131. Hogg, D. C. "Statistics of Attenuation on Microwaves by Interval Rain", Bell System Tech. Journal, Vol. 48. November 1969. pp. 2949-2962.

132. Holland, D. J. "Cardington Rainfall Experiment", Meteorological Magazine, London 96(1140). July 1967. pp. 193-202.

Sixteen Dines tilting syphon rain gages were utilized in research aimed at providing improved data and methods for the design of urban storm water drainage systems. The work attempts to specify the return period of heavy point rainfall in time periods varying from a few minutes to two hours. Correlations between pairs of gage catches were calculated.

133. Holzman, B. G. and H. C. S. Thom. "The La Porte Precipitation Anomaly", Correspondence, Bull. Amer. Meteorological Society, Vol. 51, No. 4. April 1970.

134. Hoover, Marvin D. and Charles F. Leaf. "Process and Significance of Interception in Colorado Subalpine Forest", International Symposium on Forest Hydrology, 1965, Penn State University. 1965. pp. 213-224.

135. Hudlow, Michael D. and Robert A. Clark. "The Feasibility of Using Radar Measurements in the Synthesis of Flood Hydrographs", 13th Radar Meteorology Conference, Aug. 20-23, 1968, Session 9: Operational Applications, McGill University, Montreal, Canada. 1968.

136. Huff, F. A. "Adjustment of Radar Estimates of Storm Mean Rainfall with Rain Gage Data", Journal of Applied Meteorology, Vol. 6, No. 1. February 1967. pp. 52-56.

An evaluation of the feasibility of using surface rain gage data to modify radar-rainfall equation for specific storm conditions. Data were used from 19 storms and study was restricted to warm season and 10 cm radar. A normal climatic network was found inadequate for modification.

137. Huff, F. A. "Climatological Assessment of Natural Precipitation Characteristics for Use in Weather Modification", Jour. of Applied Meteorology, Boston 8(3). June 1969. pp. 401-410.

A study of the climatological characteristics of storm precipitation on a point and areal basis. Two sets of data are used. One set is from a dense rain gage network and the other set is from U. S. Weather Bureau climatic stations. The data were used to investigate precipitation type, intensity, duration, wet and dry periods, frequency distributions, and other factors.

138. Huff, F. A. "Precipitation Detection by Fixed Sampling Densities", Jour. of Applied Meteorology, Vol. 8. October 1969. pp. 834-837.

139. Huff, F. A. "Sampling Errors in Measurement of Mean Precipitation", Jour. of Applied Meteorology, Vol. 9. February 1970. pp. 35-44.

140. Huff, F. A. "Spatial Distribution of Rainfall Rates", Water Resources Research, Vol. 6, No. 1. February 1970. pp. 254-260.

Recording gages with enlarged orifices and 6-hour charts were used to provide information on spatial patterns of rainfall intensity on a network. It was concluded that the variability of rainfall rates is so great within and between connective storms that accurate rate measurements may be prohibitive for most users in sampling areas of 100 square miles or greater.

141. Huff, F. A. and W. L. Shipp. "Mesoscale Spatial Variability in Midwestern Precipitation", Jour. of Applied Meteorology, Vol. 7, No. October 1968. pp. 886-891.

142. Huff, Floyd A. "Spatial Distribution of Heavy Storm Rainfalls in Illinois", Water Resources Research, Vol. 4, No. 1. February 1968. pp. 47-54.

143. Huff, Floyd A. and W. L. Shipp. "Spatial Correlations of Storm, Monthly and Seasonal Precipitation", Jour. of Applied Meteorology, Vol. 8, No. 4. August 1969. pp. 542-550.

144. Hutchinson, Peter. "Estimation of Rainfall in Sparsely Gauged Areas", International Association of Scientific Hydrology, Bulletin No. 14(1). March 1969. pp. 101-119.

The paper shows that topography affects rainfall distribution and that areal variability is also dependent upon relief. The conclusions reached are used for three purposes. First, a method is developed to ascribe objectively areas to a particular rain gage, taking into account the nature of the terrain. Secondly, a procedure is established for estimating rainfall at an ungaged point by using data from a selected nearby gage and the topographic situation of the point in question. A third purpose is to provide a means whereby a correction factor for a rain gage reading may be used in order that the reading may more accurately represent the area ascribed to it.

145. Il'inova, E. S., O. A. Semenova and E. M. Kozik. "O nekotorykh osebennostiakh raspredeleniia osadkov v gornykh raionakh Srednei Azii (Some Peculiarities of Precipitation Distribution in Mountain Areas of Central Asia), Sredneaziatskii Nauchino-Issledovatel'skii Gidrometeorologicheskii Institut, Tashkent, Trudy, 33(48). 1968. pp. 49-63.

An investigation of the distribution of precipitation in the course of a year in the mountain regions of Central Asia. Paper contents include maximum daily precipitation totals, relationships between precipitation during warm and cold periods of the year, annual march of precipitation, and general distribution of annual and monthly precipitation.

146. Inove, R. and R. Sanbongi. "On the Catching Characteristics of Snow Gages", Jour. of Meteorological Research, Vol. 7. December 1955. pp. 734-739.

147. Israelsen, C. Earl. "Reliability of Can-type Precipitation Gage Measurements - a State-of-the-Science Study", Utah Water Research Lab. Report No. 2, Utah State University, College of Engineering, Logan, Utah. July 1967.

148. Itagaki, K. "An Improved Radio Snow Gage for Practical Use", American Geophysical Union, Vol. 64, No. 3. March 1959. pp. 375-383.

149. Iziumov, N. N. "Instruments for Measuring the Amount of Drifted Snow", Trudy Nauchno-Issledovatel' skogo Upravleniia Nardodnogo Komissariata Putei Soobshcheniia, Vol. 109. 1930. pp. 86-91.

Data obtained from a Kuznetsov meter indicates that 86-90% of drifting snow is in the 10 cm air layer next to the surface. 5-6% is in the 10-20 cm layer, and 4-9% is in the 20-200 cm air layer. These experiments aided in the design of new instruments.

150. Jackson, I. J. "Tropical Rainfall Variations Over a Small Area", Journal of Hydrology, Vol. 8, No. 1. 1969. pp. 99-110.

151. Jacobs, Woodrow C. "Seasonal Apportionment of Precipitation Over the Ocean, Eclectic Climatology, Selected Essays Written in Memory of David I. Blumenstock (Arnold Court (Ed.), Oregon State University, Corvallis, Oregon. 1968. pp. 63-78.

A discussion of the importance of determining precipitation amounts on the ocean surface, the existing procedures for constructing annual precipitation charts over the ocean, and the computation of seasonal precipitation involving the use of a given equation.

152. Jones, Douglas. "Raindrop Distributions Near Flagstaff, Arizona". Contract DA-ARO-D-31-124-G-937, Final Report of Illinois State Water Survey. January 1969.

153. Jones, Douglas M. A. "Effect of Housing Shape on the Catch of Recording Gages", Monthly Weather Review, Vol. 97, No. 8. August 1969. pp. 604-606.

154. Joss, J., J. C. Thams, and A. Waldvogel. "Accuracy of Daily Rainfall Measurements by Radar", Conference on Radar Meteorology, 13th, McGill University, Montreal, Canada, August 20-23, 1968, Proceedings. 1968. pp. 448-451.

The radar return of a vertical pointing radar was compared with the rain intensity as measured by rain gages. The distribution of raindrops with size was measured. The rain intensity measured by radar, rain gage, and raindrop spectrometer was integrated to get the amount of rain. The standard deviations of the daily amounts of rainfall as measured by the radar, the raindrop spectrometer, and the raingages was determined.

155. Julian, P. R. "On the Possibility of Quantitatively Extending Precipitation Records by Means of Dendroclimatological Analysis", International Association of Scientific Hydrology, No. 78. 1968. pp. 243-251.

A review of the plant-physiological basis for relating annual tree-ring growth in certain environments to certain climatic parameters.

Emphasis is also placed upon the statistical techniques designed to relate tree-ring growth to observed climatic parameters. Four major problem areas are specified and new techniques are described. The statistical relationships indicate that the optimum sites specified by the characteristics of the sampled tree-ring series are best related to a weighted combination of precipitation proceding the growing season.

156. Junghans, Horst. "Die Verteilung des Niederschlags auf die Windrichtungen" (Distribution of Precipitation as Related to Wind Directions), Zietschrift füir Meteorologie, Berlin, 20(7/8). 1968. pp. 248-251.

The precipitation pattern associated with wind directions is established for a station near Dresden. An "intensity per wind direction" is established as a quotient of the amount of precipitation and the frequency of wind directions.

157. Junghans, Horst. "Statistische Bearbeitung von Niederschlagsdaten mit logarithmischen Merkmalsteilungen" (Statistical Treatment of Precipitation Data Using Logarithmic Graduations), Zietschrift füir Meteorologie, Berlin, 20(11/12). 1968. pp. 351-354.

A discussion of logarithmic gradations as compared to theoretical gradations in the treatment of precipitation data.

158. Kagan, R. L. "Interpretatsiia osadkomernykh dannykh i otsenka gustoty seti stantsii" (Interpretation of Rain Gage Data and Evaluation of the Density of Station Networks), Idojaras, Budapest, 72(4). July/August 1968. pp. 197-203.

The solution of many problems requires the use of mean precipitation values of areas rather than precipitation values of individual points. In this article the author presents formulae for establishing the representativeness of the precipitation at a point for the mean precipitation in the surrounding areas, for estimating the accuracy of the mean precipitation totals over a region as a function of the size of the region and the density of the precipitation network.

159. Kalma, J. D., et al. "Accurate Small Orifice Rain Gage", Water Resources Research, Vol. 5, No. 1. February 1969. pp. 300-305.

An accurate, inexpensive, small orifice (29.2 mm) rain gage has been developed for use in rainfall networks and hydrological studies. Comparisons with standard rain gages showed good agreement under various conditions of exposure and use. It has a large capacity, is easily installed, and easily read.

160. Kawecki, Arnold. "O zasiegu radiolokatora w przypadku obiektow meteorologicznykh" (Radar Detection in Case of Meteorological Targets), Poland, Panstwowy Instytut Hydrologiczno-Meteorologiczny, No. 92. 1967. pp. 43-50.

The radar equation for a meteorological target determines only the potential possibilities of the radar to detect the target in the space depending on the radar target parameters. It is noted, in this paper, that the range of precipitation detection is dependent on the probability of the precipitation existence in the analyzed area.

161. Kawecki, Arnold. "Statystyczna ocena parametrow rozkladow natezenia opadu w poziomym przekroju kolumn opadow przelotnych" (Statistical Evaluation of Intensity Distribution Parameters in Horizontal Cross Sections of Showers Measured by Radar), Poland, Panstwowy Instytut Llydrologiezno-Meteorologiczny, Wiadomosci Sluzby Hydrologicznej i Meteorologicznej, 2(4). 1966. pp. 39-51.

An analysis of the statistical descriptions of the distributions of radar measurements of intensity distributions in horizontal cross sections of precipitation columns.

162. Kedrolivanskii, V. N. and M. S. Sternzat. "Blowing-Snow Meters", Meteorologicheskie pribory, Gidrometeorologicheskoe Izdatel'stvo, Leningrad. 1953. pp. 165-167.

163. Kelway, P. S. and S. I. Herbert. "Short-term Rainfall Analysis", Weather, London, 24(9). September 1969. pp. 342-354.

A parameter called the "Intensity Factor" (I.F.) is developed in order that suitable figures for short-term rainfall values can be obtained. It is based on the rainfall occurring in a given short time interval expressed as a percentage of the total rainfall for the storm under investigation. I.F. values can be interpolated more reliably than the rainfall amounts themselves since they are to a considerable degree, independent of local topographic and other effects.

164. Kessler, Edwin and K. E. Wilk. "The Radar Measurement of Precipitation for Hydrological Purposes". Report No. 5, Reports on WMO/IHD Secretariat of the World Meteorological Organization, Geneva, Switzerland. 1968.

165. Kisilenko, A. A. "Issledovanie zakonomernostei formirovaniia i raspredeleniia letnikh osadkov v Ukrainshikh Karpatakh (na primere gustoi osadkomernoi seti v basseine na Riki)" (Investigation of Regularities of the Formation and Distribution of Summer Precipitation in the Ukrainian Carpathians, Based on the Example of a Dense Network of Rain Gages in the Rika River Basin), Kiev, Ukraine, Nauchno-Issledovatel'skii Gidrometeorologicheskii Institut, Trudy, No. 67. 1967. pp. 82-96.

The synoptic-statistical analysis of summer rainfall and its variation in the basin of the Rika River is investigated on the basis of data of a dense precipitation gaging network.

166. Knapp, J. W., J. C. Schaake, Jr. and Warren Viessman, Jr. "Measuring Rainfall and Runoff at Storm-Water Inlets", American Society of Civil Engineers, Proc. Paper 3644, Hydraulics Div. Jour., Vol. 89, No. HY5. September 1963. pp. 99-115.

167. Kodrau, O. D. "Prostranstvenno-vremennaia izmenchivost' osadkov v Tsentral'noi Amerike i Vest-Indii" (Spatial and Temporal Variability of Precipitation in Central America and the West Indies), Lengingrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 232. 1968. pp. 28-38.

The variability of the monthly mean precipitation, maximum and minimum precipitation, number of days of precipitation, and the diurnal precipitation maximum in the West Indies and Central America is investigated.

168. Konovalov, V. G. "Problemy ratsionalizatsii metodov izmereniia zapasov sezonnogo snega v gorakh Srednei Azii" (Greater Efficiency of Methods for Measuring Seasonal Snow Accumulation in the Mountains of Central Asia), Sredneaziatskii Nauchno-Issledovatel'skii Gidrometeorologicheskii Institut, Tashkent, Trudy, 30(45). 1967. pp. 58-78.

The characterstics of the spatial variation of the density of snow cover in a mountain watershed in Central Asia is investigated. Suggestions for methods of random measurement of snow density in the mountains with reference to helicopter use is given.

169. Kooznetsov, V. "On Measurements of the Amount of Snow Carried Horizontally by the Wind". 1900. Transl. by I. I. Schell, Blue Hill Observatory. 1946.

An instrument is described and illustrated for measuring the horizontal snow transport during a given time interval.

170. Krasiuk, N. P., V. I. Rosenberg and D. A. Chistiakov. "Oslablenie i rasseianie elektromagnitnykh voln dozhdiami razlichnoi prirody" (Attenuation and Scattering of Electromagnetic Waves by Rains of Different Origin), U.S.S.R. Ministerstvo Vysshego Obrazovaniia, Izvestiia Vysshikh Uchebnykh Zavedenii, Radiofizika, I2(1). 1969. pp. 54-59.

An investigation on the absorption and scattering effects produced by rains of different origin in propagating centimeter and millimeter radio waves.

171. Kravchenko, I. V. "Osobye gidroseteorologicheskie iavleniia v fevrale-mae 1968 goda" (Hydrometeorological Phenomena in February-May 1968), Meteorologiia i gidrologiia, 8. August 1968. pp. 109-111

172. Kurtyka, J. C. "Precipitation Measurements Study", Illinois Water Survey Report of Invest. No. 20, State Water Survey Division, Urbana, Illinois, 1953.

173. Lazareva, M. D. "Korrektirovka godovykh norm osadov Uzbekistane popravkami na smachivanie osadkomernykh sosudov" (Correction of Annual Precipitation Normals in Uzbekistan by Adjustment for Moistening of Precipitation Gage Containers), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 143-148.

A study on the corrections required for losses of precipitation by wetting of containers of precipitation gages. The corrections are made by the following formula:

$$\Delta q = \frac{.2M}{Q} \quad (100\%)$$

where Δq = Correction for wetting for the annual total
M = Number of measurements
Q = Precipitation total
.2 = Constant correction for each measurement

This correction is only applicable for stations located in Uzbekistan.

174. Leaf, Charles F. "Snow Measurement in Mountainous Regions". Master's Thesis, Colorado State University, Fort Collins, Colorado. February 1962.

A study of snow precipitation obtained from Fremont Pass, Colorado, using snowboards. It was found that the coefficients of correlation for the snowboard and a shielded gage were .89 to .95 and for a snowboard and an unshielded gage, it was .91.

175. Lenda, Andrzej. "Zastosowanie aparatury izotopowej do okreslania parametrow hydrologicznych pokrywy snieznej" (Use of Radioisotopes for Determination of Hydrologic Characteristics of Snow Cover), Przeglad Goefizyczny, Waraaw, 13(3). 1968. pp. 307-315.

A review of recent methods used for the determination of snowpack characteristics by means of radioisotopes. A description of portable and stationary snow gages is also given.

176. Leonov, M. P. "Preliminary Results of a Study of Steady Precipitation Based on Data of a Dense Rain-gage Network", American Meteorological Society, Translation T-R-553. January 1968.

The methods of investigation and the properties of precipitation fields are studied. The results find application in the computation of the precipitation amount over an arbitrary, specified area and in other areas of study.

177. Lhermitte, R. M. "Indirect Probing of Cloud and Precipitation by Microwave Radiometer", International Association of Scientific Hydrology, Transactions, Vol. 7, No. 2. 1968. pp. 138-142.

178. Linsley, Ray K. and Max A. Kohler. "Variations in Storm Rainfall Over Small Areas", Transactions, American Geophysical Union, Vol. 32, No. 2. April 1951. pp. 245-250.

A precipitation gage network near Wilmington, Ohio includes 55 rain gages located at approximately 2-mile intervals. Data from this network were analyzed for variations in average precipitation for storms computed from networks of differing densities.

179. Litvinov, I. V. "Ustoichivost' vo vremeni velichiny radiolokatsionnoi otrazhaemosti zhidkikh osadkov" (Stability of the Radar Reflectivity Value of Liquid Precipitation), Akademiia Nauk SSSR Institut Prikladnoi Geofiziki, Trudy, No. 9. 1967. pp. 70-76.

An investigation of the parameters in the equation which associates radar reflectivity of precipitation and their intensity. It is shown that unique parameters for describing even a single rain cannot be obtained.

180. Llamas, Jose and M. M. Siddiqui. "Runs of Precipitation Series", Colorado State University Hydrology Paper No. 33. May 1969.

181. Lozowski, E. P. and R. List. "Updraft Divergence Associated with Hydrometeor Drag: A Numerical Computation", Conference on Severe Local Storms, 6th, Chicago, April 8-10, 1969, Preprints of Papers Presented at the Conference, Boston, American Meteorological Society. 1969. pp. 55-58.

182. Lutskina, Sh. G. "Popravki k godovym summam osadkov na Territorii Ural'skogo UGMS" (Corrections to Annual Precipitation Totals in the Territory of the Ural Hydrometeorological Service), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 154-157.

The author classifies the territory of the Ural Hydromet into regions for the purpose of determining the magnitude of the wetting adjustment necessary for correction of annual totals. The precipitation deficit in precipitation normals due to wetting is normally 11 to 16% of the measured precipitation amounts.

183. Madigan, C. T. "Snowfall and Snowdrift", Australasian Antarctic Expedition, 1911-1914, Science Reports, Ser. B, Vol. 4. June 1929. pp. 49-51.

An improved snow gage made from stove piping is described. Also described is a drift gage consisting of a wooden box, 3 x 2.5 x 3 ft., equipped with a tin cone at one end and baffles at the other. The snow is removed periodically and weighed.

184. Mansurova, E. P. and I. S. Sosedov. "opyt otsenki velichiny atmosfernkh osadkov v gorakh Zailiiskogo Alatau" (Estimating the Amount of Precipitation in the Trans-Ili Ala Tau Mountains), Akademiia Nauk Kozakhskoi SSR. Institut Gidrogeologii i Gidrofiziki, Trudy, 2. 1969. pp. 3-18.

The Hydrogeological Observatory gives recommendations which result in more accurate precipitation values for mountainous terrain. The methods are based on the use of empirical relationships that compensate for altitude of the locality.

185. Martinelli, M., Jr. "New Snow Measuring Instruments", International Symposium on Forest Hydrology, Proceedings, August 29-September 10, 1965, Penn State University, Pennsylvania. 1965.

A discussion of new instruments for measuring various snow properties to include pressure pillows, neutron and gamma ray devices, plate capacitors, aerial snow markers, snow resistographs, glide shoes, and photoelectric drift snow gages.

186. Marx, Siegfried. "Die Tagessummen des Nicderschlages am 7. Juli 1906 im oberen Elbegebiet" (Daily Precipitation Totals on July 7, 1906 in the Upper Elbe Region), Zietscheift fiir Meteorologie, Berlin, 19(5/6). 1967. pp. 165-167.

Very high precipitation totals in the Upper Elbe region in 1906 are compared with high totals in 1937 and 1954. The prevailing synoptic situations are described.

187. Matalas, N. C. "Autocorrelation of Rainfall and Streamflow Minimums". U. S. Geological Survey Prof. Paper 434-B. March 1963. pp. B1-B10.

188. McCallister, John P. and Jack L. Teague. "Radar Requirements for Operational Hydrologic Analyses", Radar Meteorology Conference, 13th, August 20-23, 1968, Section 9: Operational Applications, McGill University, Montreal, Canada. 1968.

189. McGuinness, J. L. "A Comparison of Lysimeter Catch and Rain Gage Catch". U. S. Department of Agriculture, ARS 41, No. 124, Beltsville, Maryland. October 1966.

190. McGuinness, J. L. and Grant W. Vaughan. "Seasonal Variation in Rain Gage Catch", Water Resources Research, Vol. 5, No. 5. October 1969. pp. 1142-1146.

In Northern Ohio, 8-inch standard rain gages consistently caught more precipitation in summer and less in winter than adjacent digital punch gages although average annual totals were almost identical. A similar seasonal pattern was found for weighing lysimeters and recording gages in Ohio and in standard and recording rain gages in Nebraska.

191. Meade, P. J. "Rainfall and Evaporation - Distribution in Space and Time", Institn. Water Engrs, Journal, Vol. 21, No. 3. May 1967. pp. 210-215.

A study of rainfall distribution and evaporation for Great Britain.

192. Meiman, J. R. "Snow Accumulation Related to Elevation, Aspect and Forest Canopy", Snow Hydrology, Proc. of Workshop Seminar at New Brunswick University Federation, February 28-29, 1969. pp. 35-47.

193. Melikishvili, O. E. "Isparenie iz dozhdemernykh priborov razlichnykh konstruktsii" (Evaporation from Various Types of Rain Gages), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 215. 1968. pp. 97-106.

An investigation into the evaporation of liquid precipitation from rain gages that the average intensity of evaporation from a Tret'iokov precipitation gage was 0.024 mm/hour and 0.66 mm/day. The losses for a rain gage with a Nipher shield were smaller by a factor of 3, for a Hydromet gage smaller by a factor of 4, and for a bottle gage smaller by a factor of 5.

194. Melikishvili, O. E. "Raionirovanie territorii Gruzii dlia korroktirovki mesiachnykh summ i norm osadkov popravkami na smachivanie osadkomernykh sosudov" (Regional Classification of Georgia for Correction of Monthly Precipitation Totals and Normals by Adjustment for Moistening of Precipitation Gage Containers), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 138-142.

A study of the corrections necessary for losses due to wetting for monthly normals of precipitation in different regions of Georgia. The annual reduction in measured precipitation due to wetting is generally 2-12%.

195. Melikishvili, O. E. "Nekotorye rezul'tary,issledovanii pogreshnostei iamereniia osadkov na eksperimental'noi baze v Poti" (Some Results of Investigations of Precipitation Measurement Errors at an Experimental Base in Poti), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 171-182.

Preliminary results of investigations of monthly precipitation measurements of liquid precipitation by different rain gages and precipitation gages. The various gages are listed along with monthly precipitation totals, seasonal totals, evaporation totals, and a diagram of gage disposition in the area.

196. Mellor, M. "Gauging Antarctic Drift Snow", Antarctic Meteorology, Proceedings, Symposium held in Melbourne, New York, February 1959. 1960. pp. 347-358.

Two types of snow traps are described. One is rocket shaped and the other is airfoil shaped. Both orient themselves into the wind and can be set at any height. The rocket type trap was found to collect drifting snow with complete efficiency. Both gages function by expanding the stream's cross section, thus reducing velocity by 50%, allowing the snow to drop out.

197. Micheller, I and Amalia Szakacs. "Die Kontrolle der Niederschlagsangaben mit Rechenautomaten" (Verification of Precipitation Data by Electronic Computers), Adija'ras, Budapest, 72(2). 1968. pp. 85-90.

A description of the procedure used to verify daily precipitation data and to construct daily precipitation maps by means of an electronic computer.

198. "Microwave Radiometers Aids in Snow Pack Runoff Survey", Electronics World, Vol. 172. August 1969. pp. 62.

199. Mikhel, V. M. and A. V. Rudheva. "Regionalization of the U.S.S.R. According to the Transport of Snow", Soviet Hydrology: Selected Papers, No. 5. 1969. pp. 441-450.

A description of the main principles used in the computation of the transport of blowing snow and the method of mapping the largest volume of snow transported in winter.

200. Miller, John F. and R. H. Frederick. "Normal Monthly Number of Days with Precipitation of 0.5, 1.0, 2.0, and 4.0 Inches or More in the Counterminous United States", Weather Bureau Tech. Report No. 57. 1966.

201. Miyairi, M., J. Ohkushi and S. Ozawa. "Drag of Bodies Moving Through Snow with High Speeds", Seppyo (Snow and Ice), Tokyo, 28(1). January 1966, pp. 23-29.

A study of the drag of bodies moving through snow with high speeds.

202. Molochnikov, A. V. "Measurements of Blowing Snow at Yukspor", Meteorologiia i Gidrologiia, Vol. 5, No. 6. June 1939. pp. 137-138.

203. Morgan, Brian E. "Rainfall Rate Sensor". U. S. National Severe Storms Lab., Tech. Memo ERLTM-NSSL-42. November 1968.

A description of an instrument designed to measure rainfall rates. The water depth in a collecting reservoir is related to the rainfall rate and determines the capacitance between two electrodes. An oscillator then relates depth changes into frequency variations. Equations are then developed which relate rainfall rate to frequency.

204. Morgan, D. L. and E. J. Laurence. "Comparison Between Rain Gage and Lysimeter Measurements", Water Resources Research, Vol. 5, No. 3, June 1969. pp. 724-728.

205. Morrissey, W. B. "Precipitation Measurement in New Zealand Representative and Experimental Basins", Journal of Hydrology, New Zealand, Vol. 6, No. 1. 1967. pp. 20-32.

Manual and automatic instrumentation of precipitation measurement on experimental basins is described. Performance of available recording precipitation gages are compared and resolutions of time and rainfall for various purposes and situations are discussed.

206. Moszkowicz, Stanislaw. "Uwagi o qyznaczaniu zaleznosci miedzy radiolokacyjna zdolnoscia odbicia a natezeniem opadu" (Comments on the Methods of Determination of the Relation Between Radar Reflectivity and Rain Intensity), Poland, Panstwowy Instytut Hydrologiczno-Meteorologiczny, Wiadomosci Stuzby Hydrologicznej i Meteorologicznej, 2(4). 1966. pp. 29-38.

A study which takes into consideration the random behavior of both Z and R values which are utilized in determining the relations between radar reflectivity and rain intensity. It shows that the generally used method of determining the Z-R relationship omits their random behavior.

207. Muller, F. B. and J. Clodman. "Application of Empirical Orthogonal Functions to the Analysis of Mesoscale Variations of Precipitation in Storms". National Conference on Statistical Meteorology, 1st, Hartford, Connecticut, May 27-29, 1968, Proceedings, American Meteorological Society, Boston. 1968. pp. 116-123.

Deals with the application of empirical orthogonal functions to quasi-horizontal data fields in which the error-variance is not small in relation to the overall variance of the data. Eigenvector values were prepared for mesoscale resolution of total storm snowfalls in the vicinity of Toronto, Ontario.

208. Murphy, T. D. and S. Schamach. "Mountain Versus Sea Level Rainfall Measurements During Storms at Juneau, Alaska", Journal of Hydrology, Vol. 4, No. 1. April 1966. pp. 12-20.

A new type of gage was used in this study which can operate unattended for sixty days. The study presents comparisons of concurrent rainfall measurements at sea level and a nearby mountain station.

209. Nathan, Alan M. "Ground Based Raindrop Spectrometer II", U. S. Army Electronics Command, Ft. Monmouth, New Jersey, Tech. Report ECOM-00157-F, March 1968.

A ground based spectrometer is described which counts all raindrops >.2 mm and classifies them into 12 size intervals. The drops are counted on a 25 cm^2 sampling square and the total number will be printed on punch tape for any interval from 5 seconds to 3 minutes.

210. Naumov, A. P. and V. S. Stankevich. "Ob oslablenii millimetrovykh i submillimetrovykh radiovoln v dozhdiakh" (Millimeter and Submillimeter Radio Waves Attenuation in Rains), U.S.S.R. Ministerstvo Vasshego i Srednego Spetsial'nogo Obrazovaniia, Izvestiia Vysshikh Uchebnykh Zaledenii, Radiofizika, 12(2). 1969. pp. 181-184.

The statistical characteristics of beam transverse shifts in turbulent atmosphere are calculated in order to determine the attenuation of radio waves by rain.

211. Nechaev, I. N. "Korrektirovka mesiachnykh i godovykh norm osadkov popravkami na smachivanie osadkomernykh sosudov" (Correction of Monthly and Annual Precipitation Normals by Adjustments for Moistening of Precipitation Gage Containers), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 5-39.

The results of 992 control measurements of precipitation losses as a result of wetting of the container of a standard precipitation gage, indicates that the correction is .22 mm for each measurement for both liquid and solid precipitation. The correction for precipitation losses by wetting for a month or year is $\Delta q = .2$ M mm, where M = number of measurements for a given period of time.

212. Nechaev, I. N. "Poteri na isparenie iz osadkomernykh priborov v raznykh klimaticheskikh zoniakh" (Loss Due to Evaporation from Precipitation Gages in Various Zones), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 215. 1968. pp. 107-115.

Relationships developed previously by the author (Ref. 211) are used to calculate monthly losses of precipitation due to evaporation for seven stations in the USSR. Also, calculations show that evaporation losses when measuring solid precipitation are close to those for liquid precipitation and amount to 3-8% of total solid precipitation measured.

213. Nechaev, I. N. "Vybor elementov konstruktsii novoi modeli dozhdemera" (Selecting Elements for the Construction of a New Model Pluviometer), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 230. 1968. pp. 117-127.

The advisability of developing different precipitation gages is indicated. An outline is given of the premises on which the development of the new gage is based. Wind error is eliminated by making the gage similar aerodynamically to the Tret'iakov gage.

214. Nechaev, I. N. "Issledovanie pogreshnosti izmereniia atmosfernykh osadkov, vyzvannoi ispareniem ikh iz pribora" (Studying Precipitation Measurement Errors Due to Evaporation from the Container), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 215. 1968. pp. 73-87.

An experiment conducted to determine evaporation losses from a Tret - iakov gage and a rain gage with a Nipher shield. It was found that the evaporation intensity of liquid precipitation was a function of air humidity deficit and air velocity. The evaporation intensity varied from small values up to .20 mm/hr.

215. Neff, E. L. and G. L. Bloomsburg. "Precipitation Characteristics in the Palouse Area of Idaho and Washington", USDA, Agricultural Research Service, ARS. October 1962. pp. 41-66.

216. Neff, E. L. "Principles of Precipitation Network Design for Intensive Hydrologic Investigations", International Association of Scientific Hydrologists, Symposium on Design of Hydrometeorological Networks, No. 67. 1965. pp. 49-55.

217. Neff, Earl Lock. "Raingage Performance". University of Idaho. October 1966.

A study designed to evaluate the performance of various raingages. It is concluded that gages installed with orifices above the ground will catch 3-16% less rainfall than actually reaches the ground.

218. Netherlands Meteorologisch Instituut. "Detailanalyse van pluviogrammen, A, Frequentieverdelingen van de hoeveelheden neerslag in tijdvakken van 5 tot 660 minuten De Bilt, 1928, 1933, 1951-1960" (Detailed Analysis of Records of Pluviographs, Pt. A, Frequency Distributions of the Amounts of Precipitation in Periods of 5 to 600 Minutes, De Bilt, 1928, 1933, 1951-1960). 1966

A presentation of precipitation frequency tables. These tables are the result of a detailed analysis of records of pluviographs. The records were made with a balance gage and a float type gage. Positioning and operation of the gages and the interpretation of the data is described.

219. Neumann, J. "Distribution of 24-hr Rainfall Amounts as Function of Gage Reading Time", Jour. of Applied Meteorology, Vol. 8, No. 3. 1969. pp. 452-453.

220. Nicks, Arlin D. "Field Evaluation of Rain Gage Network Design Principles", International Association of Scientific Hydrology, No. 67, Symposium, Design of Hydrological Networks. 1965. pp. 82-93.

A network of 175 recording rain gages has been established in Oklahoma. Preliminary analysis indicates that the network might be reduced to 5 or 10 uniformly distributed gages if a daily areal rainfall estimate alone is required.

221. Odar, Fuat. "Simulation of Drifting Snow", Cold Regions Research and Engineering Laboratory, U. S. Army Materials Command, Research Report No. 174. October 1965.

222. Ord, M. J. "Some Comparisons from Use of Radio Reporting Isotope Snow Gages and the Snow Pressure Pillows", Western Snow Conference, Proc. April 16-18, 1968.

223. Orlov, N. I. "New Method of Measuring Blowing Snow", Akademiia Nauk SSSR, Institut Geografii, Rol'snezhnogo pokrova v prirodynkh protsessakh, Moscow. 1961. pp. 258-264.

A new Soviet snow gage is described. The gage consists of a photocell, a light source, anemometer, galvannometer, and a battery. The snow particles cause shading which varies the intensity of a photo-current. It is concluded that this instrument increases the accuracy of recording blowing snow.

224. Osborn, H. B. and Renard, K. G. "Analysis of Two Major Runoff-Producing Southwest Thunderstorms", Journal of Hydrology, Vol. 8, No. 3. 1969. Page 282

225. Ostby, Frederick P., A. Atwater and Frank Perry. "A Small-scale Precipitation Network Over Central Connecticut", Weatherwise, Boston, 22(2). April 1959. pp. 60-63, 87.

The operation of a rain gage network near Hartford, Connecticut is described. The network was established to investigate the nature of the rainfall variability in Central Connecticut.

226. Oura, Hirobumi, et al. "Studies on Blowing Snow", Parts I and II, International Conference on Low Temperature, Sapporo, Japan, August 14-19, 1966, Proceedings, Vol. 1, Physics of Snow and Ice, Part 2, Sapporo, Japan, Hokkaido University, Institute of Low Temperature Science. 1967. pp. 1085-1117.

Several simple collectors are used to estimate the amount of snow blown under high velocity wind conditions. Vertical distribution of the horizontal mass flux of the blowing snow on sea ice and at a point up a hill was obtained. The relation between temperature and the threshold wind speed necessary for the occurrence of blowing snow was obtained.

227. Oura, Hirobumi, et al. "Characters of the Wind Speed Profile During Drifting Snow-I" and "Motion of Snow Particles on Low Drifting Snow-II", Low Temperature Sciences, Ser. A, Physical Sciences, Sapporo, Japan, No. 25. 1967. pp. 73-97.

The roughness parameter Z_o is defined as the height where the extrapolation of the wind speed is zero. This is assuming that the wind speed profile is logarithmic. It appears that Z_o becomes larger during drifting snow. Such a tendency was not seen during a snowfall. The strength of drifting was measured by the amount of snow caught by cyclone type collectors and metyelemeters (Russian collectors). The motion of snow particles in low drifting snow consists of "saltation" and "creep". It is concluded that most of the snow particles are transported by "saltation" within a layer of about 10 cm along the surface.

228. Pagan, A. R. and R. Rothenberg. "County Rain-gage Network Useful in Design", Civil Engineering, Vol. 35. April 1965. pp. 68-69.

229. Panama Direccion de Estadistica y Censo. "Panama en cifras (Compendio estadistico: anos 1963 a 1967) (Panama in Figures (Statistical Compendium: 1963-1967). November 3, 1968.

Results from 34 meteorological stations in Central American from 1963 to 1967.

230. Panchang, G. M. "Long Term Peak Rainfall Expectations from Observed Data", Symposium on Hydrometeorology of India with Special Reference to Flood Forecasting and Warning, Proceedings, Delhi, India Meteorological Department. April 1966. pp. 183-190.

An examination of long term recorded data from 12 rain gages is undertaken in order to demonstrate the better efficiency of the method of maximum likelihood to reflect long term behavior patterns more precisely than other methods. For all 12 rain gages examined, the maximum likelihood yielded smaller margins of variations than either the moments or the mode and mean deviations.

231. Pashinskii, A. Z. "Ob isparenii iz osadkomernykh i dozhdemerny sosudov" (Evaporation from Precipitation Gage and Rain Gage Containers), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, No. 195. 1966. pp. 158-162.

Experimental data are presented on evaporation from rain gage and precipitation gage containers. Data are given for mean evaporating water for 12 hours, the maximum 12 hour values, mean values for July, and values for varying temperature and wind speeds.

232. Peck, Richard C. "A Sèlective Precipitation Indicator", U. S. Equipment Development Lab, Silver Spring, Maryland, Technical Memorandum WBTM-EDL 4, July 1968.

A Selective Precipitation Indicator is described which will sense the presence of dew, frost, drizzle, rain, or snow and will note incidence, duration, and type. The instrument is described and its design, characteristics, and use are discussed in detail.

233. Penton, W. E. and A. C. Robertson. "Experience with the Pressure Pillow as a Snow Measuring Device", Water Resources Research, Vol. 3, No. 2, 2nd Quarter. 1967. pp. 405-408.

234. Peterson, Ned R. "Snow Sensors in California: A Progress Report", Western Snow Conference, 36th, Lake Tahoe, Nevada, April 16-18, 1968, Proceedings. 1969. pp. 99

A report on the development of snow sensor installations, and a description of the existing network in California is described.

235. Pikush, N. V. "Csadkozer i sasopisets osadkov s zhidkostnoi zashchitoi" (Precipitation Gage Equipped with Automatic Pen and Protected Against Loss of Precipitate), Leningrad, Glavnaia Geofizicheskaia Observatoriia, Trudy, 175. 1965. pp. 164-166.

236. Poggi, Andre. "La mesure des precipitations neigeuses" (Measurement of Snowy Precipitation), International Association of Scientific Hydrology, No. 78. 1968. pp. 237-242.

A comparative study which shows that snow gages in a clearing are not helped by the addition of an Alter shield and, in fact, the Alter shield will lower the catch of the snow gage when it rains. The average difference between falls measured with a storage gage in a clearing and a snow pack measured with snow samples is 1.5 to 4.5%.

237. Popov, E. A. "Atmosferne osadki na Ladozhskom ozere" (Atmospheric Precipitation on Lake Ladoga), Leningrad, Universitet, Laboratoriia Ozerodedeniia, Trudy, 20. 1966. pp. 104-118.

An intensive study of precipitation on Lake Ladoga. Data from 17 precipitation stations were used to refine the precipitation component for the lakes water balance. The data was corrected by 15% for liquid precipitation and by 20% for solid precipitation in order to take into account such influencing factors as the effect of wind velocity on precipitation catch.

238. Rainbird, A. F. "Methods of Estimating Areal Average Precipitation",, International Hydrological Decade, Reports on WMO/IHD Projects, No. 3. 1967.

A discussion of the importance of precipitation as one of the parameters in global water balance studies and methods of estimating areal average precipitation. It deals with the accuracy of point measurements, adjustment of long term records, and estimating data at ungaged locations.

239. Rain Showers Dampen Solar Centimetric Radio Waves", Physics Today, Vol. 21. May 1968. pp. 74

240. Rechard, Paul A. and Lee W. Larson. "The Use of Snow Fences for Shielding Precipitation Gages". Paper presented at the National Fall Meeting, American Geophysical Union, San Francisco, California, December 9, 1970.

A preliminary report on the use of artificial wind barriers (snow fences) for the protection of precipitation gages. This report indicates that the possibilities are good that a correct "man made" site can be established for all gages by using artificial wind barriers.

241. Reich, Edward G. "A Rain Study of a Small Drainage Basin in Central Pennsylvania". MS Thesis, Penn State University, Department of Meteorology, University Park, Pennsylvania. December 1966.

242. Reiter, Reinhold. "Beitrag zu einer atmospharisch-elektrischen Phanomenologie der Wolken und Niederschlage mit Hilfe luftelektrisch-aerologischer Registrierungen zwischen 740 und 1780 m NN" (Toward a Classification of Atmospheric-Electrical Phenomena in Clouds and Precipitation: Results Contributed by Soundings Between 740 and 1780 m.a.s.l.), Fraunhofer-Gesellschaft zur Forderung der Angewandten Forschung E.V. Physikalisch-Bioklimatische Forschungsstelle, Garmisch-Partenkirchen, W-M No. 4. 1968.

A study of electrical phenomena occurring in precipitation and in clouds. Sensors were attached to a cable car; data was sensed during a run, radioed to a base station and recorded. Among the aspects of hydrometeor electricity included in the study was the processes occurring in melting and freely falling precipitation.

243. Riedel, John T. "Probable Maximum Precipitation for the Lower Rio Grande", Water Resources Bulletin, Vol. 6, No. 3. June 1970. pp. 439-451.

244. Robinson, A. C. "Rain, Wind and the Aerodynamic Characteristics of Rain-Gauges", Meteorological Magazine, London, 98(1161). April 1969. pp. 113-120.

The airflow around four types of rain gages was studied in a series of wind tunnel experiments. A subsequent field study showed that the largest catch was made with a ground level gage.

245. Rodda, John C. "Assessment of Precipitation", Water, Earth and Man, London, Methuen & Co. 1969. pp. 130-134.

A study of the errors and methods involved in measuring precipitation. Five different types of gages are discussed. It is concluded that, of all the errors involved, wind is the most important. It is concluded that even with the best of instruments, network design, and computation of rainfall means the error will be appreciable. Where snow is involved, this error will be even larger.

246. Rodda, John C. "Rainfall Measurement Problem", International Association of Scientific Hydrology, No. 78. 1968. pp. 215-231.

The quantity of rain reaching the ground is always greater than that measured by any gage. This systematic error will affect appreciably any hydrological estimates made using these measurements. A ground level gage in this study caught 6.7% more precipitation over a 5-year period than a gage at 1-foot elevation only 16 feet away. A study of wind speed, angle of rainfall trajectory, splash, and rainfall distribution across the site failed to satisfactorily explain the difference in catch. It is recommended that ground level gages be used where possible.

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The design and operation of dense rain gage systems for obtaining statistical data on heavy rainfall is given. The rain gage used is a continuous flow type with a response time of 1 second. A system which is used for recording the data onto magnetic tape is described.

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The upper limit of drifting snow was found to be 1-5 m for wind speeds at 6-10 m/sec, 12-16 m for 15-18 m/sec, and 25-28 m for 19-22 m/sec. A new drifting snow gage was designed for use in the Antarctic where standard gages are inadequate. The gage is sheet aluminum 50 cm in diameter, 350 cm long, and with a receiving slot .5 cm wide the entire length of the cylinder. A vane keeps it facing into the wind.

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The character and magnitude of errors made during the measurement of atmospheric precipitation are investigated. The data are from a Tret'iakov gage and a rain gage with a Nipher shield. The wind caused deficit for liquid precipitation in both gages is considerable. The evaporation of precipitation is of considerable importance in most cases, both during the fall and after collection in the gage. Atmospheric moisture deficit and wind speed are the principal factors involved in the evaporation of precipitation from gages.

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Comparative observations on liquid precipitation measurements made with pluviographs and precipitation gages over a limited area are presented. The correlation coefficients between different gages approach unity over the area and depend to a very slight extent upon the distance between measurement points. The mean square deviation of the precipitation amount from the areal mean of all gages is associated with the precipitation intensity and depends least upon wind speed.

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The results of experimental determinations of wind-produced errors in precipitation and rain gages are presented. The percent of precipitation deficit was determined by the ratio of the difference between a ground rain gage and one at a height of 2 meters to the amount of precipitation in the rain gage. The value of the correction coefficient is a function of wind speed.

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APPENDIX

The following references were used in preparing the previous bibliography.

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