

**A. M. Borovikov,
A. Kh. Khragian
and Others**

CLOUD PHYSICS

TRANSLATED FROM RUSSIAN

**Published for the U.S. Department of Commerce
and the National Science Foundation, Washington D.C.
by the Israel Program for Scientific Translations**

4

A. M. BOROVIKOV, I. I. GAIVORONSKII, E. G. ZAK, V. V. KOSTAREV,
I. P. MAZIN, V. E. MINERVIN, A. Kh. KhRGIAN, S. M. SHMETER

DK 551.574
551.576

CLOUD PHYSICS

(Fizika oblakov)

A. Kh. Khrgian, editor

GIMIZ
Gidrometeorologicheskoe Izdatel'stvo
Leningrad 1961

Translated from Russian

Israel Program for Scientific Translations
Jerusalem 1963

TABLE OF CONTENTS

FOREWORD	vii
Chapter I. BASIC PROCESSES OF CLOUD FORMATION. THE	
DEVELOPMENT OF CLOUDS	1
§ 1. Fundamentals of the theory of condensation of water vapor.	2
§ 2. Condensation under natural conditions in the atmosphere	4
§ 3. Condensation nuclei	6
§ 4. Meteorological condensation nuclei	8
§ 5. Sources and nature of condensation nuclei	10
§ 6. Classical theory of condensation growth and evaporation of droplets and crystals	12
§ 7. A few corrections to the theory of condensation	16
§ 8. Temperature of cloud droplets	22
§ 9. Coalescence of droplets	25
§ 10. Formation of the solid phase. The problem of sublimation	35
§ 11. Shape and growth of ice crystals in the atmosphere	40
§ 12. Freezing of droplets	52
§ 13. Freezing nuclei	59
Chapter II. MICROSTRUCTURE OF CLOUDS 65	
§ 14. Cloud phase	65
§ 15. Sizes of elements of stratiform and frontal liquid clouds.	67
§ 16. Relation between microstructure and cloud form	70
§ 17. Are average characteristics of clouds representative?	75
§ 18. Microstructure of cumulus clouds	76
§ 19. Empirical formulas for the size distribution of cloud droplets	81
§ 20. Water content of clouds	85
§ 21. Frequencies of occurrence of different water contents	91
§ 22. Dependence of water content on height above cloud base	98
§ 23. Chemistry of clouds and precipitation	104
§ 24. Microstructure of crystal (ice) clouds	114
§ 25. Microstructure of mixed clouds	123
Chapter III. MACROPROCESSES OF CLOUD FORMATION AND	
CLASSIFICATION OF CLOUD FORMS	124
Principles of classification	124
Description of the principal cloud forms.	128

Chapter IV. CUMULUS (CONVECTIVE) CLOUDS	131
§ 26. Conditions of stability in the atmosphere and their relation to the formation of convective clouds	131
§ 27. Synoptic conditions of development of convective clouds	138
§ 28. Origin of cumulus clouds	141
§ 29. Structure of cumulus clouds	149
§ 30. Motions in cumulus clouds	159
§ 31. Turbulence in cumulus clouds	166
§ 32. L. N. Gutman's theory of convective clouds	169
§ 33. Precipitation from cumulus clouds	170
Chapter V. STRATIFORM CLOUDS	173
§ 34. Some historical remarks. Development of the concept of structure of stratiform clouds	173
§ 35. Altitude and thickness of stratiform clouds	176
§ 36. Temperature distribution	179
§ 37. Humidity distribution	183
§ 38. Microstructure of Sc-St clouds	184
§ 39. Precipitation from stratiform clouds	185
§ 40. Turbulence	186
§ 41. Lower and upper surfaces of stratiform clouds	188
§ 42. Advection of warm air	191
§ 43. Theoretical considerations on the transformation of moisture	193
§ 44. Undulating structure in stratiform clouds	195
§ 45. Cellular circulation in clouds	198
Chapter VI. ALTOSTRATUS AND ALTOCUMULUS CLOUDS	201
§ 46. Altitude, thickness and microstructure of As and Ac	201
§ 47. Forms of altostratus cloud	203
§ 48. Forms of altocumulus cloud	203
Chapter VII. FRONTAL CLOUDS	209
§ 49. Spatial structure of warm-front cloud systems	212
§ 50. Development of warm-front cloud systems	217
§ 51. Occluded-front clouds	220
§ 52. Cold-front cloud systems	222
§ 53. Distribution of meteorological elements in frontal clouds	227
§ 54. Microstructure of Ns-As clouds	230
Chapter VIII. CIRRUS CLOUDS	235
§ 55. Altitude, thickness and horizontal extent of cirrus clouds	235
§ 56. Conditions of formation of cirrus clouds	239
§ 57. Condensation trails behind aircraft	248
§ 58. Microstructure of cirrus clouds	254
§ 59. Mother-of-pearl clouds	257
§ 60. Noctilucent clouds	259

Chapter IX. AIRCRAFT ICING	262
§ 61. Physical laws of icing	262
§ 62. Coefficient of capture	264
§ 63. The freezing coefficient β	270
§ 64. Icing of high-speed aircraft.	275
§ 65. Icing in clouds of different forms	276
Chapter X. ARTIFICIAL STIMULATION OF CLOUD AND FOG	280
§ 66. Brief historical review.	280
§ 67. Some data on the nature of the influence of dry ice on supercooled cloud and fog	283
§ 68. Nature of the influence of certain iodides on supercooled cloud and fog	290
§ 69. Use of pulverized water and hygroscopic solutions as agents for stimulating cloud and fog	293
§ 70. Practical methods for stimulation of supercooled cloud and fog	295
§ 71. A few results of experiments on stimulation of cloud and fog	304
Chapter XI. METHODS OF OBSERVATION OF CLOUDS	315
§ 72. Determination of cloud altitude	315
§ 73. Balloon observation of clouds	317
§ 74. Aircraft observation of clouds	318
§ 75. Cloud photography	321
§ 76. Observation of the microstructure of clouds.	326
§ 77. Methods for determining water contents	338
§ 78. Radar methods of cloud investigation	349
§ 79. Elements of the theory of radar detection of clouds	351
§ 80. Methods of radar observation of clouds	353
§ 81. Determination of cloud water content	358
BIBLIOGRAPHY	365
LIST OF RUSSIAN ABBREVIATIONS	392