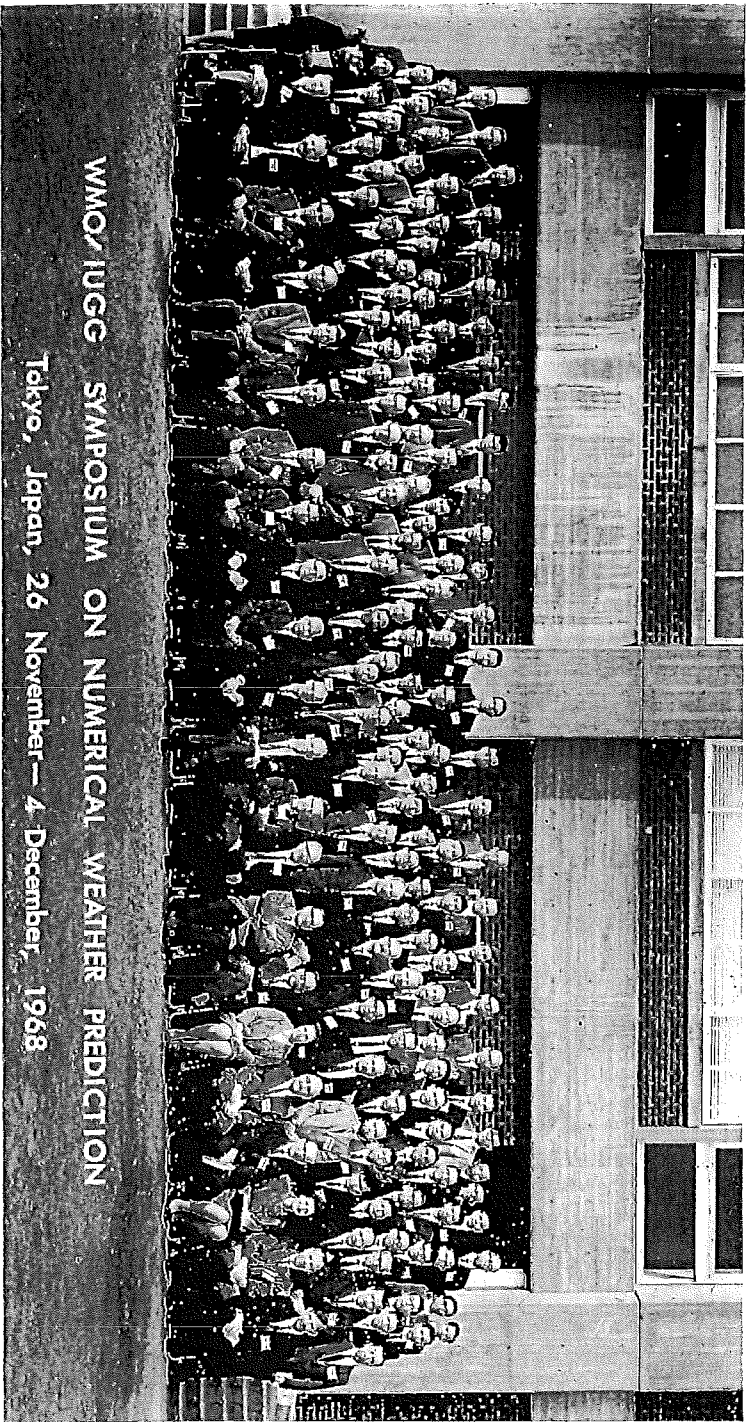


Proceedings of the WMO/IUGG Symposium  
on  
Numerical Weather Prediction in Tokyo  
November 26-December 4, 1968

*Sponsored by the  
World Meteorological Organization  
and the  
International Union of Geodesy and Geophysics*

Published by the  
Japan Meteorological Agency, Tokyo

March 1969



WMO/IGCC SYMPOSIUM ON NUMERICAL WEATHER PREDICTION

Tokyo, Japan, 26 November - 4 December, 1968

- 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000

1. R. P. Pearce (U. K.) (P)
2. A. Eliassen (Norway) (P)
3. Rose Kwizak (Canada)
4. M. Kwizak (Canada) (P)
5. F. G. Shuman (U. S. A.) (P)
6. Elena Shuman (U. S. A.)
7. S. N. Sen (ECAPF)
8. R. V. Garcia (I. P. S.)
9. E. Knighting (U. K.) (C)
10. G. W. Kronebach (W. M. O.) (C)
11. Bo R. Döds (Sweden) (C)
12. Y. Shibata (Japan) (D)
13. K. Sakamoto (Japan) (N)
14. T. Komura (Japan) (N)
15. T. Kitaoka (Japan) (N, La)
16. I. Inai (Japan) (N)
17. J. G. Charney (U. S. A.) (P)
18. Y. Ogura (Japan) (N, P)
19. K. Mohri (Japan) (N, Lb)
20. Y. Takahashi (Japan) (C)
21. F. H. Bushby (U. K.) (P)
22. E. H. Sundqvist (Sweden) (P)
23. Y. Tokoi (Japan) (L)
24. M. Takahashi (Japan) (P)
25. T. Iwashima (Japan) (P)
26. K. Takeda (Japan) (P)
27. P. S. Gburčik (Yugoslavia) (P)
28. N. Saito (Japan) (P)
29. T. Asakura (Japan) (P)
30. C. E. Leith (U. S. A.) (P)
31. A. C. Wiin-Nielsen (U. S. A.) (P)
32. G. J. Haltner (U. S. A.) (P)
33. T. N. Krishnamurti (U. S. A.) (P)
34. H. Itoo (Japan) (P)
35. M. Magata (Japan) (P)
36. P. Queney (France) (P)
37. R. Sadourny (France) (P)
38. P. R. Morel (France) (P)
39. D. O. Triefgaardt (South Africa) (P)
40. K. Gambo (Japan) (P)
41. M. A. Alaka (U. S. A.) (P)
42. F. Baer (U. S. A.) (P)
43. Y. Hayashi (Japan) (P)
44. Y. Omoto (Japan) (P)
45. M. B. Danard (Canada) (P)
46. H. L. Kuo (U. S. A.) (P)
47. Y. Sekiguchi (Japan) (P)
48. K. Mashiko (Japan) (L)
49. N. Arizumi (Japan) (O)
50. T. Tokioka (Japan) (P)
51. L. La Valle (Italy) (P)
52. S. L. Rosenthal (U. S. A.) (P)
53. H. Fortak (Germany F. R.) (P)
54. M. Watanabe (Japan) (P)
55. Y. Masuda (Japan) (P)
56. A. Kurosaki (Japan) (P)
57. Y. Okamura (Japan) (P)
58. C. J. Schuurmans (Netherlands) (P)
59. D. J. Bouman (Netherlands) (P)
60. E. A. Williamson (New Zealand) (P)
61. M. M. Elsayy (U. A. R.) (P)
62. S. A. Diab (U. A. R.) (P)
63. H. Wada (Japan) (P)
64. S. Ito (Japan) (O)
65. Y. Nabeshima (Japan) (P)
66. K. Takeuchi (Japan) (P)
67. T. Fujinori (Japan) (O)
68. M. Iwasaki (Japan) (L)
69. T. Nagao (Japan) (O)
70. T. Kawamura (Japan) (O)
71. E. Kamijo (Japan) (L)
72. M. Kaneko (Japan) (L)
73. T. Sato (Japan) (Le)
74. K. Masuda (Japan)
75. G. Arnason (U. S. A.) (P)
76. H. Kato (Japan) (L)
77. Y. Tsuchida (Japan) (O)
78. S. Yagi (Japan) (P)
79. T. Kitade (Japan) (P)
80. P. Schanz (Germany F. R.) (P)
81. H. Reiser (Germany F. R.) (P)
82. V. P. Sadoikov (W. M. O.) (P)
83. M. M. Osman (U. A. R.) (P)
84. W. E. Langlois (U. S. A.) (P)
85. Y. Sato (Japan) (P)
86. H. Tsu (Japan) (P)
87. G. Fischer (Germany F. R.) (P)
88. R. Kimura (Japan) (P)
89. T. Oobayashi (Japan) (O)
90. T. Ozawa (Japan) (O)
91. J. Sanpei (Japan) (P)
92. J. Aden (U. S. A.) (P)
93. G. Dady (France) (P)
94. M. Trochu (France) (P)
95. A. Kasahara (U. S. A.) (P)
96. J. Sakagami (Japan) (P)
97. J. Nemoto (Japan) (O)
98. T. Nitta (Japan) (P)
99. H. Washizaki (Japan) (L)
100. N. Miyakawa (Japan) (L)
101. S. Tohyama (Japan) (L)
102. Y. Watanabe (Japan) (L)
103. M. Watanabe (Japan) (L)
104. S. Matsumoto (Japan) (P)
105. Y. Sasaki (U. S. A.) (P)
106. E. C. Kung (U. S. A.) (P)
107. K. Miyakoda (U. S. A.) (P)
108. S. Fujiwhara (Japan) (P)
109. A. Arakawa (U. S. A.) (P)
110. T. Asai (Japan) (P)
111. M. Kanamitsu (Japan) (P)
112. S. Kato (Japan) (O)
113. S. Miyazawa (Japan) (O)
114. E. Machida (Japan) (L)
115. M. Alhara (Japan) (P)
116. T. Yoshida (Japan) (P)
117. M. J. D. Janssen (Australia) (P)
118. B. Tanaka (Japan) (O)
119. S. Narita (Japan) (P)
120. N. Shishido (Japan) (L)
121. T. Izawa (Japan) (L)
122. S. Ooi (Japan) (O)
123. T. Tachi (Japan) (L)
124. H. Sakai (Japan) (L)
125. Y. Sasaki (Japan) (Le)
126. M. Yoshino (Japan) (O)
127. T. Suni (Japan) (L)
128. E. Teranuchi (Japan) (L)
129. Y. Isono (Japan) (P)
130. Z. Nakazawa (Japan) (O)
131. M. Takeuchi (Japan) (O)
132. M. Yamasaki (Japan) (P)
133. T. Maruyama (Japan) (P)
134. E. Inoue (Japan) (P)
135. H. Uemura (Japan) (P)
136. K. Yamashita (Japan) (O)
137. Y. Okochi (Japan) (L)
138. T. Nitta (Japan) (P)
139. I. Hirota (Japan) (P)
140. J. Yamamoto (Japan) (L)
141. T. Kitamura (Japan) (L)
142. A. Huss (Israel) (P)
143. L. Berkofsky (U. S. A.) (P)
144. A. Karayama (Japan) (P)
145. K. Ooyama (U. S. A.) (P)
146. S. Kubota (Japan) (Ld)
147. I. Shimizu (Japan) (L)
148. K. Shirasaki (Japan) (L)
149. I. Kubota (Japan) (L)
150. M. Sasuchi (Japan) (L)
151. S. Kaneda (Japan) (L)
152. M. Tanaka (Japan) (L)

Abbreviations: . . .

- D : Director of Symposium  
 C : Co-Director  
 P : Participant  
 O : Observer
- N : Member of National Organizing Committee  
 L : Member of Local Secretariat  
 a; Chief, b; Deputy, c; Administration  
 d; Conference, e; Events

## THE RECORDS OF THE SYMPOSIUM

*Place:* Auditorium of JMA headquarters' building  
Ote-machi, Chiyoda-ku, Tokyo

*Period:* November 26-December 4, 1968

### OPENING CEREMONY

#### First Day (November 26, Tuesday)

10.00-11.00

An opening address by Y. Shibata (Director of the Symposium and Director-General of the Japan Meteorological Agency)

An address by B. R. Döös (Chairman of the Planning Committee of the Symposium)

An address by E. Knighting (representing International Union of Geodesy and Geophysics)

An address by G. W. Kronebach (representing World Meteorological Organization)

### SESSION I

(Physical basis for numerical weather prediction)

#### Morning Session

11.00-12.30 *Chairman:* J. G. Charney (Massachusetts Institute of Technology, U. S. A.)

K. Gambo (Japan Meteorological Agency, Japan)

Treatment of the interaction between the large-scale and convective motions in relation with the cloud amount and the stability factor

T. Asai (Kyoto University, Japan)

Controlling influence of large-scale atmospheric condition on cumulus convection

#### Afternoon Session

2.00-5.00 *Chairman:* K. Gambo (Japan Meteorological Agency, Japan)

G. Arnason, P. S. Brown and R. T. Chu (Travelers Research Center, Inc. U. S. A.)

Numerical simulation of the macrophysical and microphysical processes of moist convection

R. P. Pearce (Imperial College, U. K.) and H. Riehl (Colorado State University, U. S. A.)

Parametrisation of convective heat and momentum transfer suggested by analysis of Caribbean data

H. L. Kuo (University of Chicago, U. S. A.)

On the boundary layer of a maintained vortex

M. B. Danard (University of Waterloo, Canada)

Computing long-wave radiation from clouds and water vapor in a numerical prediction model

C. E. Leith (National Center for Atmospheric Research, U. S. A.)

Two dimensional eddy viscosity coefficients

H. L. Kuo (University of Chicago, U. S. A.)

On a simplified radiative-convective heat transfer equation

6.00-7.30

Beer party at Geihin-kan

**Second Day (November 27, Wednesday)**

**Morning Session**

9.30-12.30 *Chairman:* F. H. Bushby (Meteorological Office, Bracknell, U. K.)

E. C. Kung (University of Missouri, U. S. A.)

On kinetic energy dissipation in the atmosphere

F. Baer (Colorado State University, U. S. A.)

The influence of cyclone scale waves on the planetary scale

I. Hirota (Tokyo University, Japan)

Some dynamical aspects of ultra-long waves in a baroclinic zonal current

A. Eliassen (University of Oslo, Norway)

On meso-scale mountain waves of small amplitude

**SESSION II**

(Mathematical models of the atmosphere for short range and medium range forecasting and models for special phenomena)

**Afternoon Session**

1.30-5.00 *Chairman:* A. Eliassen (University of Oslo, Norway)

F. G. Shuman and J. Stackpole (National Meteorological Center, U. S. A.)

The currently operational NMC model, and results of a recent simple numerical experiment

H. Reiser (Deutscher Wetterdienst, Germany F. R.)

On short-range forecasting with a baroclinic unfiltered model

F. H. Bushby (Meteorological Office, Bracknell, U. K.)

Further developments of a model for forecasting rain and weather

M. Kwizak and D. Davies (Meteorological Service of Canada, Canada)

Numerical forecasts of 24-hour precipitation

**Third Day (November 28, Thursday)**

**Morning Session**

9.30-12.30 *Chairman:* E. Knighting (Meteorological Office, Bracknell, U. K.)

G. Fischer (University of Hamburg, Germany F. R.)

On the generation of quasi-geostrophic waves by mountains, numerical experiment with a barotropic model

M. Magata (Meteorological Research Institute, Japan)

On the study of the airflow over mountains by the numerical experiment

P. Queney (Université de Paris, France)

Models for the generation of stratospheric vortices in a steady atmospheric flow over a ground corrugation

- L. Berkofsky (Air Force Cambridge Research Laboratories, U. S. A.)  
A numerical model for investigation of upper atmosphere effects
- V. A. Bugaev, E. Dobrischman, C. M. Olevskaya and A. A. Unukova (Hydrometeorological Centre, U. S. S. R.)  
Analysis of the biennial oscillation of zonal wind in the equatorial zone stratosphere

### SESSION III

(Mathematical models for forecasting in the tropics; typhoon and hurricane formation)

#### Afternoon Session

- 1.45-5.00 *Chairman:* M. Yanai (Tokyo University, Japan)
- J. G. Charney (Massachusetts Institute of Technology, U. S. A.)  
The intertropical convergence zone and the Hadley circulation of the atmosphere
- T. Nitta and M. Yanai (Tokyo University, Japan)  
Barotropic instability of the equatorial easterly current
- T. N. Krishnamurti (Florida State University, U. S. A.)  
Experiments in numerical prediction in low latitudes
- T. Maruyama (Tokyo Gakugei University, Japan)  
Upward transport of energy and westerly momentum due to large-scale disturbances in the equatorial lower stratosphere
- L. Berkofsky (Air Force Cambridge Research Laboratories, U. S. A.)  
Some numerical results from a model for hurricane prediction

#### Fourth Day (November 29, Friday)

##### Morning Session

- 9.30-12.30 *Chairman:* H. L. Kuo (University of Chicago, U. S. A.)
- K. Ooyama (New York University, U. S. A.)  
Numerical simulation of tropical cyclones with an axi-symmetric model
- S. L. Rosenthal (National Hurricane Research Laboratory, U. S. A.)  
Preliminary results from numerical experiments with a primitive equation model designed to simulate the development of tropical cyclones
- E. H. Sundqvist (University of Stockholm, Sweden)  
A ten-level model for simulation of the development of a tropical cyclone
- M. Yamasaki (Meteorological Research Institute, Japan)  
Numerical simulation of tropical cyclone development

### SESSION IV

(Mathematical models for long range forecasting and numerical simulation of the general circulation)

#### Afternoon Session

- 2.00-5.00 *Chairman:* M. A. Alaka (Weather Bureau, U. S. A.)

- K. Miyakoda and Staff Members (Geophysical Fluid Dynamics Laboratory, U. S. A.)  
 Extended prediction with a nine-level global model on the Kurihara-grid
- A. Arakawa, A. Katayama and Y. Mintz (University of California, U. S. A.)  
 Numerical simulation of the general circulation of the atmosphere
- J. Adem (Weather Bureau, U. S. A.)  
 Long-range numerical prediction with a time-averaged thermodynamic model
- J. S. A. Green (Imperial College, U. K.)  
 Transfer of heat and momentum by cyclone scale eddies in the general circulation  
 (presented by R. P. Pearce)
- A. Huss and E. Doron (Hebrew University, Israel)  
 Planetary circulations obtained by means of two-level quasi-geostrophic models  
 with various formulations of diabatic heating

**Fifth Day (November 30, Saturday)**

**Morning Session**

- 9.30-12.30 *Chairman:* A. Kasahara (National Center for Atmospheric Research, U. S. A.)  
 A. Kasahara and W. M. Washington (National Center for Atmospheric Research,  
 U. S. A.)  
 Thermal and dynamical effects of orography on the general circulation of the  
 atmosphere
- S. Mashkovich (Hydrometeorological Centre, U. S. S. R.)  
 On controlling influence of cloud systems on large-scale atmospheric processes
- A. C. Wiin-Nielsen (University of Michigan, U. S. A.)  
 On atmospheric response to large-scale seasonal forcing
- J. Shukla (Institute of Tropical Meteorology, India)  
 A numerical experiment on disturbance in the tropical easterlies

2.00-4.00

Tour around Japan Meteorological Agency

**Sixth Day (December 1, Sunday)**

1.00-5.00

Sightseeing in Tokyo

**SESSION V**

(Numerical experiments to determine the requirements on a global  
 observing system and the predictability of the atmosphere)

**Seventh Day (December 2, Monday)**

**Morning Session**

- 9.30-12.30 *Chairman:* B. R. Bolin (University of Stockholm, Sweden)  
 E. Lorenz (Massachusetts Institute of Technology, U. S. A.)  
 Estimate of the range of atmospheric predictability (presented by J. G. Charney)
- J. Smagorinsky and K. Miyakoda (Geophysical Fluid Dynamics Laboratory, U. S. A.)  
 The relative importance of variables in initial conditions for numerical predictions

- M. A. Alaka and F. Lewis (Techniques Development Laboratory, U. S. A.)  
 Numerical experiments pertinent to the design of optimum aerological networks
- P. Morel and C. Cornen (Laboratoire de Météorologie Dynamique, France)  
 Perturbation effect of an equatorial wall on the Mintz-Arakawa global circulation model
- T. Nitta (Japan Meteorological Agency, Tokyo)  
 Initialization and analysis for the primitive equation model

#### SESSION VI

(Definition of the initial state in numerical weather prediction)

#### Afternoon Session

- 2.00-5.00 *Chairman:* E. Dobrichman (Hydrometeorological Centre, U. S. S. R.)
- E. Dobrichman (Hydrometeorological Centre, U. S. S. R.)  
 On a numerical scheme of wind field prediction
- Y. Sasaki (University of Oklahoma, U. S. A.)  
 Numerical variational method of analysis and prediction
- K. Ninomiya and S. Matsumoto (Meteorological Research Institute, Japan)  
 On the objective analysis with special regards to the cloud distribution and convective transfer
- S. Fujiwhara (Japan Meteorological Agency, Japan)  
 On the treatment of wind data in the height analysis
- L. S. Gandin and K. M. Lugina (Main Geophysical Observatory, U. S. A.)  
 Comparison of the accuracy of objective analysis produced in various countries  
 (presented by M. Yudin)
- 5.30-7.00  
 Cocktail Party at the Fairmont Hotel

#### SESSION VII

(Mathematical and numerical procedures)

#### Eighth Day (December 3, Tuesday)

##### Morning Session

- 9.30-12.00 *Chairman:* F. G. Shuman (National Meteorological Center, U. S. A.)
- Y. Okamura (Japan Meteorological Agency, Japan)  
 A finite-difference scheme for the primitive equation model with special emphasis on the suppress of the two-grid interval noise
- P. D. Thompson (National Center for Atmospheric Research, U. S. A.)  
 A Lagrangian variable-resolution method of short-range numerical weather prediction
- Y. Masuda (Japan Meteorological Agency, Japan)  
 A finite difference scheme by making use of hexagonal mesh-points
- R. Sadourny (Laboratoire de Météorologie Dynamique, France)



Numerical integration of the primitive equations on a spherical grid with hexagonal cells

M. I. Yudin and G. D. Kudashkin (Main Geophysical Observatory, U. S. S. R.)  
Consideration of group errors of numerical forecasts as a means of improving their accuracy

#### Afternoon Session

1. 30-2. 20 *Chairman:* M. Kwizak (Meteorological Service of Canada, Canada)

P. Schanz (Deutscher Wetterdienst, Germany F. R.)

On automatic input/output-processing in the German Meteorological Service

D. Jenssen (University of Melbourne, Australia)

The accuracy of finite difference analogues of simple differential operations

#### PANEL ON OPERATIONAL ASPECTS

2. 45-5. 00 *Chairman:* F. G. Shuman (National Meteorological Center, U. S. A.)

*Panellers:* H. Reiser (Deutscher Wetterdienst, Germany F. R.)

E. Dobrichsman (Hydrometeorological Centre, U. S. S. R.)

M. Kwizak (Meteorological Service of Canada, Canada)

F. H. Bushby (Meteorological Office, Bracknell, U. K.)

S. Kubota (Japan Meteorological Agency, Japan)

This informal meeting consisted of short presentations on three major topics, i. e.,

(1) the man-machine mix

(2) deficiencies in operational models

(3) cooperation between NWP centres

Each topic was followed by lively informative discussion. Forty-five scientists participated.

#### PANEL ON GARP

##### Ninth Day (December 4, Wednesday)

9. 30-12. 00 *Introducer:* R. V. Garcia (Joint Planning Staff for GARP)

*Chairman:* B. R. Döös (University of Stockholm, Sweden)

*Panellers:* J. G. Charney (Massachusetts Institute of Technology, U. S. A.)

A. Eliassen (University of Oslo, Norway)

M. Yanai (Tokyo University, Japan)

M. A. Alaka (Weather Bureau, U. S. A.)

F. G. Shuman (National Meteorological Center, U. S. A.)

B. R. Bolin (University of Stockholm, Sweden)

At the first, scientists were informed of the latest developments in the planning for GARP by R. V. Garcia, and this was followed by short presentation of six session chairmen. Each chairman summarized the substance of this session in the light of GARP. Each talk was followed by discussion which reflected a lively interest in GARP and its sub-programmes.

A NUMERICAL EXPERIMENT ON DISTURBANCE  
IN THE TROPICAL EASTERLIES

J. Shukla\*  
Institute of Tropical Meteorology, India

ABSTRACT

A numerical experiment has been performed on a tropical disturbance embedded in easterlies to test the dependency of the vertical coupling on the value of Richardson number in tropics. By a 2-layer Primitive Equation model, integrations have been performed for a period of 24 hours with two different sets of initial conditions in which the three dimensional structure of the initial easterly pattern is specified through pre-specified wind shear and different values of the Richardson number. The order of magnitude of vertical velocities, the time rate of change of kinetic energy and the phase speed of the disturbances is discussed for both the cases.

The preliminary results indicate that, even the tropical motions have appreciable degree of vertical coupling and baroclinic nature in the cases of low Richardson number. The results seem to be of special interest in context to the fact that even the mean monthly values of static stability are found to be negative in the middle and lower troposphere in the tropics.

\* The work has been done at the Electronic Computation Centre, Japn Met. Agency, Tokyo while the author was there under a WMO Fellowship.

## Discussion on J. Shukla paper

Speaker: J. Shukla (ref. page III-109).

A. Kasahara: I noticed in your presentation that you assumed the Coriolis parameter  $f$  to be constant and ignored the variation of  $f$  with respect to latitude. Since you are dealing with numerical solutions, I would think that the constant  $f$  assumption is not needed. As a matter of fact, your assumption excludes a very important mode of large-scale waves in tropics which has been discussed by Matsuno, Rosenthal and many others.

A: I agree that  $f$  was taken constant and it was done intentionally because basically this study is a model experiment. The primary aim is to see the relative behaviour of the disturbance in the two cases characterized solely by different values of static stability.

J.G. Charney: 1. I think there has been a misunderstanding:

I did not value the geostrophic assumption in my 1963 note in J.A.S.

2. I also pointed out that when condensation takes place there is vertical coupling. The main purpose was to show that when it does not take place there is little vertical coupling. Evidence for this was presented by Dr. Yanai, whose time series spectral analyses stand two maxima of disturbance K.E., one at the ground and one at the tropopause with limited vertical coherence for each: the lower extending to 600 mb or so and, there upper from 50 mb to perhaps 300 mb.

3. What is the average value of Richardson number in the tropics?

4. Since the spectrum does not give the value, I will, it is about 100, i.e., enough to guarantee decoupling.

A: 1. I agree there was a misunderstanding. However, the aim of the present work mainly is to see the effect of the value of Richardson number even in the case when Rossby number is not small.

2. The present work also confirms the idea that when the Richardson number is small, as in the condensation regions, the vertical coupling is appreciable.

3. I will not be able to give a definite figure about the average value of Richardson number for the tropics because due to the extremely inhomogeneous character of tropics, it will depend upon the type, area and time of averaging. For example, in the monsoon season over India even the mean monthly values of Richardson number may be quite small. However, at the Institute, we are now computing the stability parameters for many stations covering the entire tropical belt and after that perhaps I will be able to give a definite figure.

4. I very much agree that if value of  $Ri$  is 100, it guarantees decoupling. However, the main point which I want to bring forth is that, as also earlier stated by Dr. Charney, there are cases when  $Ri$  is quite small and such systems have vertical coupling. Thus this experiment further confirms the idea put forward by Dr. Charney on the basis of scale analysis.