

T.N. Krishnamurti  
Lydia Stefanova  
Vasubandhu Misra

# Tropical Meteorology

An Introduction

INPE - B1  
CPTEC

26843



379119

551.5(213)

K897t

2013

Tropical meteorology: an introduction



Springer

# Contents

<b>1 The Zonally Averaged Tropical Circulation . . . . .</b>	1
1.1 Introduction . . . . .	1
1.2 Zonally Averaged Time Mean Fields . . . . .	2
1.2.1 Zonal Velocity . . . . .	2
1.2.2 Mean Meridional Circulation . . . . .	3
1.2.3 Temperature Field . . . . .	5
1.2.4 Moisture Field . . . . .	6
1.3 Meridional Transports by the Zonally Symmetric Circulation . . . . .	6
1.4 Theory of the Hadley Cell . . . . .	9
1.4.1 Derivation of the Kuo-Eliassen Equation . . . . .	10
1.4.2 Interpretation of the Kuo-Eliassen Equation . . . . .	13
References . . . . .	15
<b>2 Zonally Asymmetric Features of the Tropics . . . . .</b>	17
2.1 Introduction . . . . .	17
2.2 Tropospheric Winds at 850 and 200 mb Levels . . . . .	17
2.3 The Motion Field in the Upper Troposphere . . . . .	20
2.4 The Temperature Field . . . . .	22
2.5 The East/West Circulations in the Tropics . . . . .	24
2.6 The Moisture Field . . . . .	25
2.7 The Sea Level Pressure Field . . . . .	27
2.8 Precipitation Field . . . . .	28
2.9 Other Parameters . . . . .	32
References . . . . .	32
<b>3 The Intertropical Convergence Zone . . . . .</b>	35
3.1 Observational Aspects of the ITCZ . . . . .	35
3.2 ITCZ Theory . . . . .	39
3.3 Regulation of the Warm Pool SST . . . . .	43
References . . . . .	46

<b>10</b>	<b>Diabatic Potential Vorticity Over the Global Tropics</b>	221
10.1	Introduction	221
10.2	Diabatic Potential Vorticity Equation	222
10.3	Application of the Diabatic Potential Vorticity Equation to the Global Tropics	223
10.3.1	Potential Vorticity	223
10.3.2	Horizontal Advection of Potential Vorticity	224
10.3.3	Vertical Advection of Potential Vorticity	224
10.3.4	Vertical Differential Heating	224
10.3.5	Horizontal Differential Heating	227
10.3.6	Frictional Contribution	228
10.4	Application of the Diabatic Potential Vorticity Equation to Hurricanes	229
	References	231
<b>11</b>	<b>Tropical Cloud Ensembles</b>	233
11.1	Introduction	233
11.2	Understanding Simple Buoyancy-Driven Dry Convection	235
11.3	Understanding Simple Buoyancy-Driven Shallow Moist Convection	237
11.3.1	A Simple Cloud Model	237
11.3.2	Initial and Boundary Conditions and Domain Definition	241
11.3.3	Numerical Model Results	242
11.4	A Cloud Ensemble Model	244
11.4.1	Kinematics and Thermodynamics	244
11.4.2	Cloud Microphysics	247
11.4.3	Conversion Processes	250
11.4.4	Modeling Results	254
	References	258
<b>12</b>	<b>Tropical Boundary Layer</b>	261
12.1	Empirical Concepts	261
12.1.1	The Mixing-Length Concept	261
12.1.2	The Wind Profile and Surface Drag	262
12.1.3	Bulk Aerodynamic Method	264
12.2	Observational Aspects of the Boundary Layer	265
12.3	A Simple Model of the Tropical Boundary Layer	270
12.4	Surface Similarity Theory	272
12.5	Scale Analysis of the Large-Scale Tropical Boundary Layer	275
12.6	Cross-Equatorial Flows and Planetary Boundary Layer Dynamics	277
	References	279

<b>13 Radiative Forcing . . . . .</b>	281
13.1 Radiative Processes in the Tropics . . . . .	281
13.2 Shallow Stratocumulus Clouds and Radiative Transfer . . . . .	282
13.3 Surface Energy Balance . . . . .	283
13.3.1 Ground Temperature T <sub>g</sub> . . . . .	285
13.3.2 Evaluating Moisture Fluxes for Hydrological Budgets and Water Cycle Studies . . . . .	285
13.3.3 The Surface Sensible and Latent Heat Fluxes . . . . .	286
13.3.4 Net Solar (Shortwave) Radiation at the Earth Surface . . . . .	286
13.3.5 Net Thermal (Longwave) Radiation at the Earth Surface . . . . .	286
13.3.6 Surface Sensible Heat Flux . . . . .	288
13.3.7 Surface Latent Heat flux . . . . .	290
13.4 Top of the Atmosphere Net Radiation Fluxes . . . . .	291
13.4.1 The Net Solar Radiation at the Top of the Atmosphere . . . . .	291
13.4.2 The Net Thermal Radiation at the Top of the Atmosphere . . . . .	293
13.5 Radiative Forcing for the Hadley and East–West Circulation . . . . .	293
13.6 Life Cycle of the Monsoon . . . . .	295
References . . . . .	297
<b>14 Dry and Moist Static Stability . . . . .</b>	299
14.1 Introduction . . . . .	299
14.2 Some Useful Definitions . . . . .	300
14.3 Dry and Moist Static Energy . . . . .	300
14.3.1 Dry Static Energy . . . . .	300
14.3.2 Moist Static Energy . . . . .	302
14.4 Dry and Moist Static Stability . . . . .	302
14.4.1 The Dry Static Stability Equation . . . . .	303
14.4.2 The Moist Static Stability Equation . . . . .	306
14.5 Observational Aspects of the Trade Wind Inversion . . . . .	308
Reference . . . . .	315
<b>15 Hurricane Observations . . . . .</b>	317
15.1 Introduction . . . . .	317
15.2 Conventional Observations . . . . .	322
15.2.1 Observations of the Inner Core . . . . .	323
15.3 Tropical Cyclones Over the Indian Ocean Basin . . . . .	325
References . . . . .	330
<b>16 Genesis, Tracks, and Intensification of Hurricanes . . . . .</b>	331
16.1 Introduction . . . . .	331
16.2 Genesis . . . . .	332

16.2.1	Horizontal Shear Flow Instability . . . . .	332
16.2.2	Conservation of Potential Vorticity (PV) . . . . .	333
16.2.3	Diabatic Effects . . . . .	334
16.2.4	Order of Magnitudes for the Terms of the PV Equation in a Hurricane . . . . .	335
16.3	Tracks . . . . .	336
16.3.1	The $\beta$ Effect . . . . .	336
16.3.2	The Fujiwhara Effect . . . . .	337
16.3.3	The Extratropical Transition of Tropical Cyclones . . . . .	337
16.4	Intensity . . . . .	342
16.4.1	The Angular Momentum Principle . . . . .	342
16.4.2	Local Cylindrical Coordinates . . . . .	343
16.4.3	The Torques . . . . .	345
16.4.4	What Does the Angular Momentum Field in a Hurricane Look Like? . . . . .	345
16.4.5	Cloud Torques . . . . .	347
16.4.6	Surface Frictional Torques . . . . .	348
16.4.7	What Is a Constant Angular Momentum Profile . . . . .	349
16.4.8	Pressure Torques . . . . .	350
16.4.9	Inner Versus Outer Forcing . . . . .	352
16.4.10	Vortical Hot Towers . . . . .	355
16.4.11	Vortex Rossby Waves . . . . .	356
	Appendix 1: Transformation of shear to Curvature Vorticity . . . . .	357
	References . . . . .	358
<b>17</b>	<b>Modeling and Forecasting of Hurricanes . . . . .</b>	<b>361</b>
17.1	Introduction . . . . .	361
17.2	The Axisymmetric Hurricane Model . . . . .	362
17.3	Current Suite of Operational Models . . . . .	366
17.4	Multimodel Superensemble for Atlantic Hurricanes . . . . .	368
17.5	Multimodel Superensemble for Pacific Typhoons . . . . .	371
17.6	Ensemble Forecasts from a Suite of Mesoscale Models and Combination of Mesoscale and Large Scale Models for Atlantic Hurricanes . . . . .	373
	References . . . . .	375
<b>18</b>	<b>Sea Breeze and Diurnal Change Over the Tropics . . . . .</b>	<b>377</b>
18.1	Introduction . . . . .	377
18.2	Sea Breeze Models . . . . .	378
18.3	Some Observational Aspects of Diurnal Changes . . . . .	383
18.4	Diurnal Variation in the Monsoon Belt . . . . .	386
18.4.1	Diurnal Variation in Rainfall Over India . . . . .	390
18.4.2	Diurnal Change Transitions Between the Himalayan Foothills and the Eastern Tibetan Plateau . . . . .	391

18.4.3	The Arritt Nomogram .....	392
18.4.4	Monsoonal Scale Diurnal Oscillation of the Monsoon .....	395
References .....		397
<b>19</b>	<b>Tropical Squall Lines and Mesoscale Convective Systems .....</b>	<b>399</b>
19.1	Introduction .....	399
19.2	West African Disturbance Lines .....	400
19.2.1	Squall Lines “An Integral Part of the African Wave” .....	401
19.2.2	Squall Lines Are Located Between Two Easterly Jet Streams .....	402
19.2.3	Other Squall Line Models .....	402
19.2.4	Squall and Non-squall Systems .....	405
19.3	Mesoscale Convective Systems .....	407
19.4	Organization of Convection .....	409
References .....		413
<b>Index .....</b>		<b>415</b>