

OCEAN-ATMOSPHERE INTERACTION
AND
THE SUMMER MONSOON OF INDIA

THESIS
BY
TUSHAR KANTI RAY

CENTRE FOR ATMOSPHERIC SCIENCES,
INDIAN INSTITUTE OF TECHNOLOGY,
DELHI

Submitted to the Indian Institute of Technology, Delhi
for the award of the degree of Doctor of Philosophy

1986

CERTIFICATE

This is to certify that the thesis entitled "OCEAN-ATMOSPHERE INTERACTION AND THE SUMMER MONSOON OF INDIA" being submitted by Tushar Kanti Ray for the award of the degree of Doctor of Philosophy, is a record of the original bonafide research work carried out by him. He has worked under our joint guidance and supervision and has fulfilled the requirements for the submission of this thesis. The results presented in this thesis have not been submitted in part or full to any other University or Institute for award of any degree/diploma.

P.K. Das

(P.K. Das)
Professor,
Centre for Atmospheric Sciences,
Indian Institute of Technology,
Delhi.

S.K. Dube

(S.K. Dube)
Senior Scientific Officer I,
Centre for Atmospheric Sciences,
Indian Institute of Technology,
Delhi.

ACKNOWLEDGEMENTS

I am indebted to Dr. P.K. Das, Professor, IIT, Delhi for many helpful discussions and assistance in clearing doubts. I also thank Dr. S.K. Dube, S.S.O., IIT, Delhi, for his encouragement and guidance, and Dr. H.S. Bedi, now a visiting scientist at the Florida State University, U.S.A., Shri D.R. Sikka, spared the time for discussions and useful suggestions, which have helped me to complete this work. Dr. S.K. Ghosh, Director, Meteorological Department of India kindly lent his support and encouragement.

I wish to record my indebtedness to Dr. R.P. Sarker, Director General of Meteorology and to Mr. S.K. Das, Ex-Director General of Meteorology for their interest and permitting me to carry out this research in addition to my official duties and for providing me with computing facilities. My colleagues at the Computer Centre of the Meteorological Department provided me with considerable support. I wish to record my thanks to them.

Appreciation is due to Shri S.D. Gaur, who neatly typed the manuscript in quick time. My genuine thanks are to Shri G.K. Chopra who drafted most of the diagrams. In addition, many of my friends and colleagues helped me to complete the work. It is my pleasure to thank them all.

Finally, I thank my wife and members of my family for their patience and understanding while I was busy with this thesis.


(TUSHAR KANTI RAY)

..... to my parents.

List of symbols

Symbol	Legend
A'	Absorption coefficient.
C	Phase velocity
d	Depth
E	Evaporation; energy of waves.
e	Vapour pressure in air.
e_p	Vapour pressure at water surface.
f	Coriolis parameter; wave frequency.
F_n	Normal component of frictional force.
F_t	Tantential component of frictional force.
F_v	Net northward flux of air.
F_{q_v}	Net northward flux of water vapour.
g	Acceleration due to gravity.
H	Height of wave.
k	Wave number
L	Wave length.
p	Pressure
q	Specific humidity
R_C	Increase in phase speed
R_H	Energy used for growth of wave.
R_v	Rate of energy, transfer by wind.
R	Tangential wind stress
S	Sheltering coefficient
T	Temperature; period
t	Time
U	Wind speed
V	Wind speed

V_a Wind speed at height (a)
 w Vertical velocity
 ρ Density
 ζ Relative vorticity (vertical component).

Fig. No.	Legend	Page
1.1	Seasonal rainfall anomaly during 1979 monsoon.	4
1.2	Monsoon rainfall for 1983.	5
1.3	Mean July winds for the lower troposphere (850 mb).	10
1.4	Mean upper tropospheric (200 mb) winds in July.	11
1.5	Low level winds prior to monsoon onset in 1979.	13
1.6	Low level winds after the onset in 1979.	14
1.7	Tracks of constant level balloons released during MONEX-1979.	15
1.8	Actual date of onset of the monsoon from 1901 to 1983.	17
1.9	Schematic representation of air-sea interaction over the Arabian Sea.	26
2.1	Energy balance at the ocean surface.	43
2.2	Sea surface temperature during pre-onset and onset.	47
2.3	(a) Mean monthly SST for 1961+64, 1965+66, 1979 and 1983.	48
	(b) Surface pressure in relation to SST.	48
2.4	SST departure during onsets of 1979 and 1983.	49
2.5	SST anomaly during active monsoon.	56
2.6	Difference of SST and air temperature during onset.	59
2.7	Surface winds during an active monsoon spell.	61
2.8	Divergence field during onset of the monsoon.	65
2.9	Vorticity field during an active monsoon.	67
2.10	(a) Evaporation rate in early onset year.	70
	(b) Evaporation rate in late onset year.	70
2.11	Evaporation rate during an active monsoon.	72
2.12	Rate of evaporation before a break monsoon.	74
2.13	Release of total heat flux during onset.	79
2.14	Net gain of heat by ocean during an active monsoon.	83

CONTENTS

	Page
Certificate	ii
Acknowledgements	iii
List of Symbols	v
List of Diagrams	vii
List of Tables	xi
Abstract	xii
Chapter I : Introduction	
1.1 Objectives of the study ...	1
1.2 The summer or southwest monsoon circulation.	7
1.3 Earlier work on air-sea interaction.	20
Chapter II : Surface features and energy transfer	
2.1 Introduction ...	33
2.2 Budget and transfer processes ...	35
2.3 Data and analysis ...	45
2.4 Interpretation of results ...	46
2.4.1 Sea Surface Temperature (SST) ...	46
2.4.2 Difference between SST and air temperature	57
2.4.3 Surface winds ...	60
2.4.4 Patterns of surface divergence and vorticity	63
2.4.5 Specific humidity ...	68
2.4.6 Evaporation ...	69
2.4.7 Heat fluxes ...	77
2.4.8 Bowen's Ratio ...	81

Chapter III : Ocean waves

3.1	Introduction	...	86
3.2	Data and analysis	...	92
3.3	SST and Swell height	...	93
3.4	SST and period of swells	...	97
3.5	Direction of swell and wind	...	103
3.6	Swell amplitude and southwest monsoon		107
3.7	Period of swells and monsoon features		109
3.8	Wind and waves - a linear relationship		110
3.9	Computation of swell heights	...	113
3.10	Forecasting storm generated winds and waves		116

Chapter IV : Structure of the atmosphere during the summer monsoon.

4.1	Origin of the summer monsoon	...	125
4.2	Data and analysis	...	126
4.3	Synoptic situations	...	131
4.4	Discussion of results	...	131
4.4.1	Upper winds	...	131
4.4.2	Temperature distribution	...	139
4.4.3	Kinetic energy	...	142
4.4.4	Specific humidity and precipitable water		144
4.4.5	Water vapour transport	...	147
4.4.6	Static energy (dry and moist)	...	150
4.4.7	Moisture flux inside polygons	...	152
4.4.8	Air and water vapour flux across the equator		155
4.4.9	Relative vorticity	...	159
4.4.10	Divergence	...	164
4.4.11	Vertical velocity	...	167
4.4.12	Summary	...	171

Chapter V : Vertical structure of the
north Indian Ocean.

5.1	Introduction	...	176	
5.2	Data and analysis	...	178	
5.3	Temperature profile of the central Arabian Sea and the central Bay of Bengal.		183	
5.4	Meridional variation of temperature profile		184	
5.5	Heat content	...	193	
5.6	Salinity variations	...	200	
5.7	Vertical current profile	...	202	
5.8	Vertical velocity	...	208	
Chapter VI : Summary and conclusions			...	212
References			...	219

ABSTRACT

The oceans and the atmosphere form a closely inter-related system. The interface between these two components did not receive much attention until the 1940s. Recent studies on air-sea interaction have enabled us to understand how the oceans and the atmosphere respond to forcing on different scales of space and time.

The Asian summer monsoon, known as the southwest monsoon in India, is an interesting seasonal phenomenon that occurs with regularity every year. From the latter part of the seventeenth century scientists have tried to explain the genesis and the behaviour of the southwest monsoon. From that time onwards research has helped us to understand the dynamics of the monsoon. But, a study of other aspects based on more recent data has not been made so far. The present thesis attempts to study these aspects of the Summer Monsoon. The work is based on measurements of atmospheric and oceanic variables during recent international scientific expeditions.

The expeditions with which we are concerned are : ISMEX-73, MONSCON-77 and MONEX-79. They have provided valuable data over the Indian Ocean, the Arabian Sea and the Bay of Bengal.