# ON TROPICAL RESONANCE AND PREDICTABILITY

THESIS

By

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.... to my MAA, Preceptors
and Parents

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( R.C. RAGHAVA )

## PREFACE

There are, in general, three areas in atmospheric wave studies that still need special attention. These are (1) the sources that supply the energy to the waves, (2) mechanism of upward propagation of waves and (3) their nonlinear interaction. When nonlinearities are significant near the computational boundary, reflections will inevitably occur and ultimately contaminate the entire domain. Phenomena like ducting, reflections and coupling of the wave make the analysis very complicated. Nonlinearities in the wave system occur in many ways; the presence of a source, the effects of a strong dissipative process, wave amplitude becoming too large and the interaction between the waves are some of the examples. Energy exchange between various forced and free modes through resonance between planetary waves has been observed. It is also observed that prevailing wind produces additional meridional circulation through the nonlinear interaction with the atmospheric oscillations.

With a view to sketch comprehensively, the undulatory behaviour of the atmosphere, attention has been focussed in Chapter 1 entitled as 'General Review' on the wave mechanism, its general features, observational evidences, its genesis and static and kinematic maintenance of the atmosphere through the wave phenomenology. The applicability of the analytical approach of multiple scale techniques to the treatment of meteorologically relevant atmospheric wave phenomena have been dealt within this chapter.

In Chapter 2, entitled 'Zonal wind-wave Interaction in the Equatorial Atmosphere' the atmosphere has been assumed in hydrostatic balance and considered as homogeneous, inviscid, incompressible, barotropic and divergent. Such a system is described by the well known shallow water equations. The domain of the field variables is the infinite $\beta$-plane centered around the Earth's equator. The coriolis parameter varies linearly with the latitudinal distance from the equator over this domain. The model is of nonlinear character. Perturbations are imposed on the zonal current which varies slowly with the time. Subjecting the wave triads to the resonance conditions, coupling coefficients are computed between zonal flow and the equatorial waves. It is shown that these coupling coefficients do not involve any energy exchange between zonal current and perturbed motion, but that the zonal flow does lead to phase changes in the complex valued amplitudes of the resonant waves. A stability analysis is made to indicate how the zonal current could alter the growth of interacting waves. The imposition of zonal flow lead to the generation of some external forcing in the initially perturbed atmosphere, which, interestingly does not arise if the basic state of the atmosphere is at rest. More specifically, a slowly varying sinusoidal zonal flow and wave triads composed of

(a) mixed Rossby-gravity and (b) Kelvin waves are coupled to show that zonal flow imparts large rotation to the equatorial waves. The Kelvin waves are found to be more susceptible to the zonal wind than other equatorial waves. The stability of a wave depends on the coupling coefficients having opposite signs.

In Chapter 3 , entitled 'Wave-Triad Induced Tropical Easterly Jet' the distribution of energy in the tropical region due to nonlinear interaction among the atmospheric waves (identified as Rossby waves, mixed Rossby gravity, eastward and westward moving inertia gravity waves and Kelvin waves) is studied. Among the observed features of the general circulation are wave-like motions and theoretical investigation reveals that the tropical energy source mechanisms tend to act more efficiently upon certain wave types over preferred length scales. The essence of the theoretical investigation through CISK mechanism and observational evidence of wave-wave and wave-zonal interactions through spectral analysis have ascertained the existence of finite amplitude tropical waves which have been found to play an important role in the atmospheric dynamics. The wave numbers 1 and 3 have been identified as feeding energy significantly to the zonal flow. Further, the waves with wave numbers 2 to 4 on planetary scale form an important component of the monsoon circulation and the wave numbers 5 to 8 create the monsoon disturbances. Using the shallow water model described in the preceeding chapter, it is shown that the resonant triads composed of Rossby waves and inertia-gravity waves generate zonal flow on planetary spatial scale. It has been observed that wave-wave interactions under resonance can lead to the generation of both easterlies and westerlies wind maxima. This analysis shows that triad combination (if it exists in the tropical atmosphere) could contribute towards the generation of easterly jet.

In Chapter 4, entitled 'Quasi-Hydrostatic Equatorial Atmosphere vis-a-vis Q.B.O.' a non-hydrostatic, barotropic, divergent model is proposed to study the interaction of the waves in the equatorial stratosphere. The study gives rise to a parameter which represents the extent of the non-hydrostaticity of the equatorial atmosphere and essentially depends on the earth's rotation alone. By applying the method of multiple scales, it has been shown that the single layer barotropic model can, among all the equatorial waves in the atmosphere, support the interaction of the Kelvin waves alone. The analysis shows how the Kelvin waves transfer energy to generate westerlies on the time scale which is approximately 26 months that is known to be the period of regular alteration of zonally symmetric easterly and westerly wind regimes in the equatorial stratosphere.

Chapter 5, entitled 'The Predictability of Stationary Structure', is a numerical experiment attempted to study the structure of a certain large scale error called systematic error in numerical simulation experiments and the mechanism generating this error. This error has been found in every general circulation model existing up till now. It is shown that the presence of Rossby waves actually increases predictability through several mechanisms: direct inhibition of the nonlinear transfers in the large scales, concentration of energy in highly predictable large scale zonal structures and slow down of error propagation in the enstrophy inertial range due to the presence of anisotropy at small and intermediate scales. Some characteristics of the response to small scale initial imbalances in forced regime flows can be studied using simplified models. Initial imbalance violating the natural flow regime in the small scales can be interpreted as a systematic initial error. It will eventually contaminate large scale stationary structures for which nonlinear interactions are not hindered by dispersion and could be more easily contaminated than transient ones. In principle, it is possible to distinguish the response to initial inadequacies from the effect of climate drift by performing perfect model experiments, when artificial data with realistic distributions are produced from a long term run of the forecasting model. They are fed into the analysis-initialisation forecast process.

In this way the climatic drift is eliminated as a source systematic error. The forecast minus control difference fields reflect only the response to the initial imbalances within the dynamic and forcing fields. An experiment has been conducted along these lines to study the kinematic component of the systematic error using nonlinear quasi-geostrophic model under dissipation, Ekman-friction and the forcing on sub-grid scales, of the atmosphere ever northern hemisphere with real topography. The spectral grid point representation approach for the analysis is invoked. The evolution and structure of systematic errors for the 5-day forecasts have been graphically presented in their non-zonal modes and discussed in this chapter.

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