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Breakdown of ITCZ-like PV Patterns

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INTRODUCTION

The Inter-Tropical Convergence Zone (ITCZ) is a zonal belt of intense convection, thunderstorms, which is responsible for the genesis of over 80% of all tropical cyclones (Gray, 1978). A fundamental issue is to understand the necessary precursor events leading to the breakdown of the ITCZ and subsequent formation of tropical cyclones.

OBJECTIVES

1. Develop a numerical model to solve the non-linear shallow-water equations (SWEs) on an f-plane in MATLAB.
2. Examine the breakdown of finite and infinite PV fields representing the ITCZ.
3. Study the effects of embedded regions of higher PV and mass sinks (simulating convection) on ITCZ breakdown.

THE MODEL

All the numerical integrations described here were performed with the f-plane SWEs

$$\frac{\partial u}{\partial t} - \left(f + \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) v + \frac{\partial}{\partial x}\left[gh + \frac{1}{2}(u^2 + v^2)\right] = \kappa \nabla^2 u \quad (1)$$

$$\frac{\partial v}{\partial t} - \left(f + \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) u + \frac{\partial}{\partial y}\left[gh + \frac{1}{2}(u^2 + v^2)\right] = \kappa \nabla^2 v \quad (2)$$

$$\frac{\partial h}{\partial t} + \frac{\partial (uh)}{\partial x} + \frac{\partial (vh)}{\partial y} = S + \kappa \nabla^2 h \quad (3)$$

on a 6400 Km x 6400 Km doubly periodic domain with 512 x 512 grid points. Spectral blocking was prevented by adding ordinary diffusion with e-folding time of 53 minutes for waves with total wave number of 170.

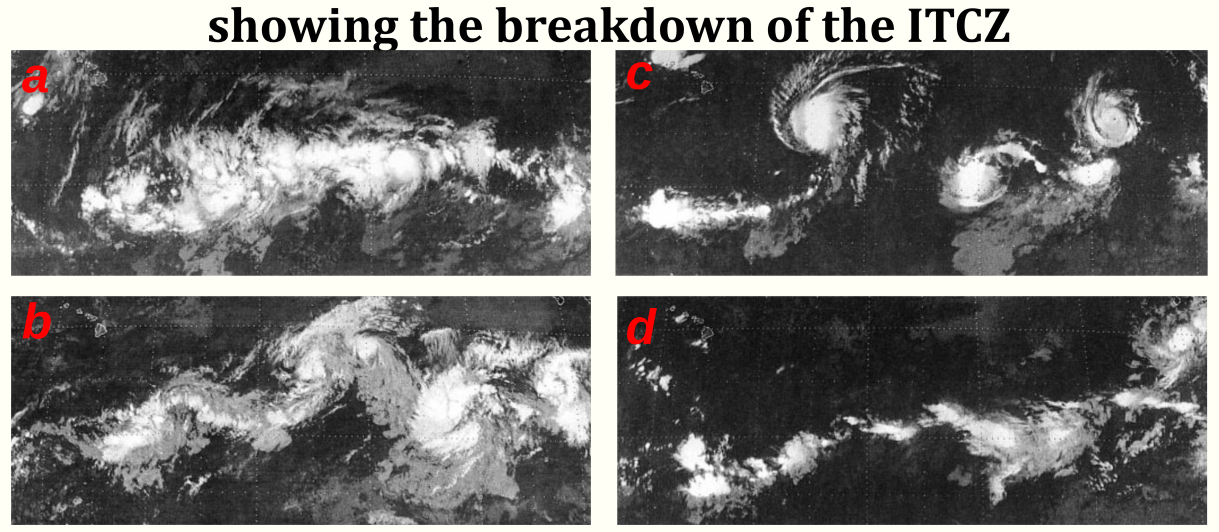
SOLUTION TECHNIQUE

A normal-mode, spectral model was develop in Mathworks MATLAB to solve Eqs. 1-3. Time integration was performed using the 4th order Adams-Bashforth-Moulton predictor-corrector method.

RESULTS

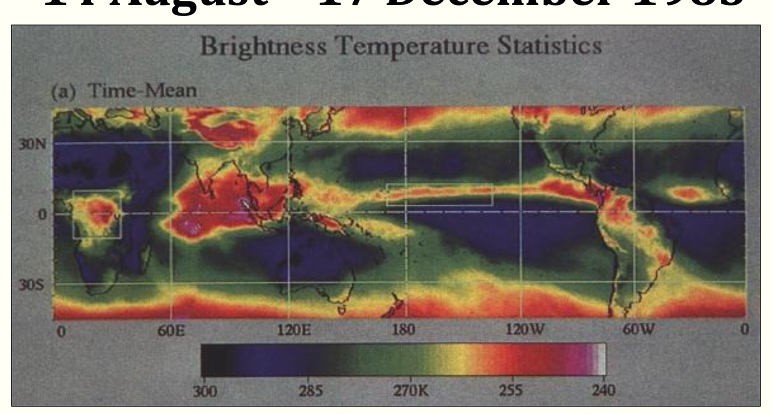
1. Broadband perturbations and mass sinks accelerate the breakdown of infinite strips.
2. Pockets of PV along the center of the strip have a negligent effect on the breakdown of infinite strips.
3. The lopsided PV shape (Case 5) is suggestive of the breakdown of the ITCZ and formation of TCs observed in the Eastern-Pacific.

Images from NASA's GOES East Full Disk Scan showing the breakdown of the ITCZ



GOES IR images at 1646 UTC on (a) 26 July, (b) 28 July, (c) 3 August and (d) 12 August -1988 showing a case of ITCZ breakdown. *Credit to Ferreira and Schubert (1997)*

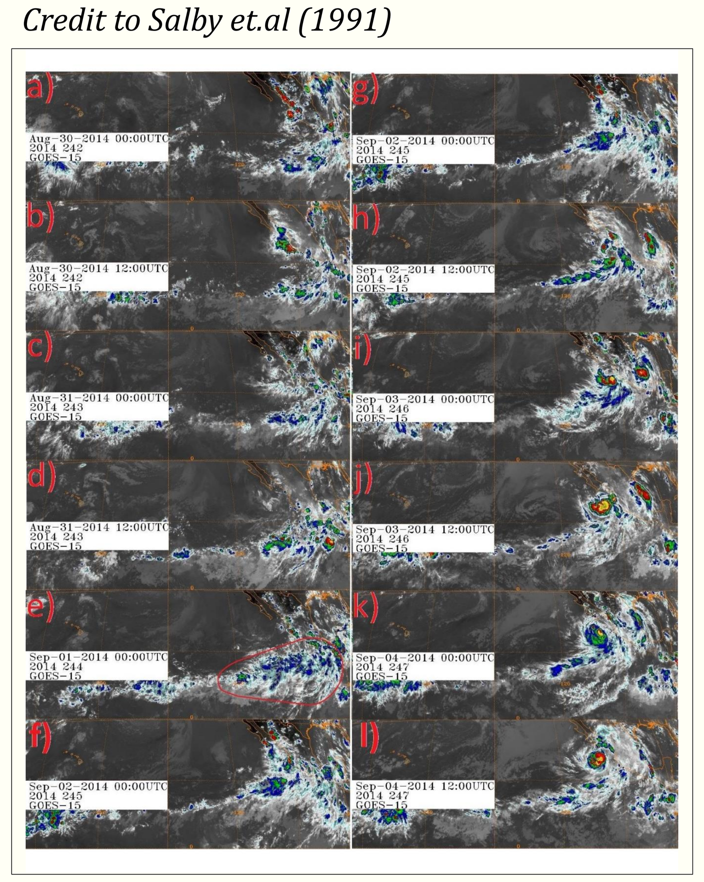
Time-mean brightness temperature from 14 August – 17 December 1983



Credit to Salby et.al (1991)

The ITCZ in the Eastern-Pacific has a unique shape. Case 5 aims at studying the reoccurring ITCZ pattern unique of the eastern Pacific region.

A Time Lapse of an ITCZ Breakdown occurring between 30 Aug - 4 Sep 2014



GOES-15 IR images at 0000 UTC and 1200 UTC between 30-August and 4-September-2014 showing a case of ITCZ breakdown in the Eastern-Pacific.

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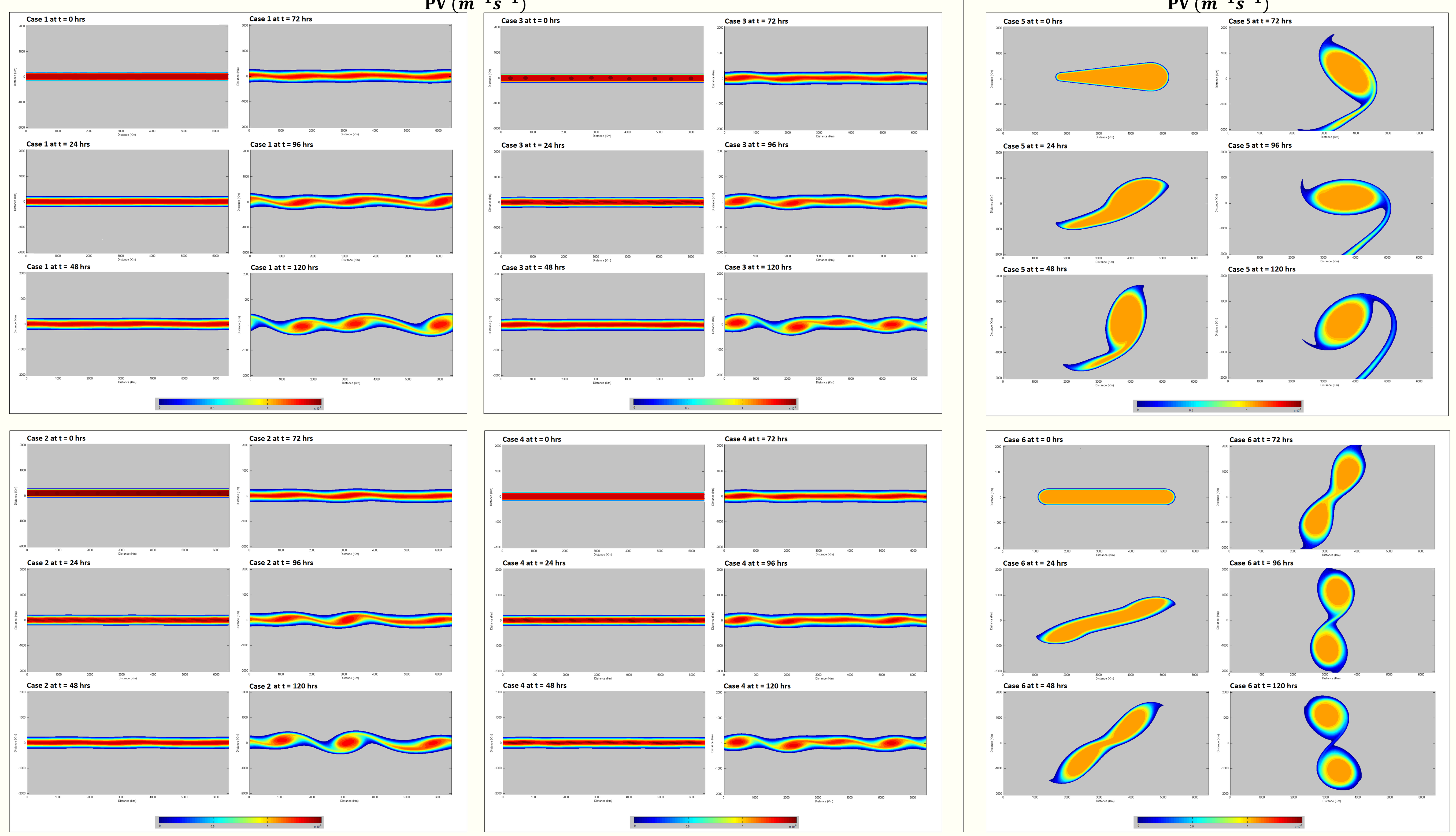
THE EVOLUTION OF PV FROM THE 6 CASES

Infinite Strips PV ($m^{-1}s^{-1}$) — **Finite Strips** PV ($m^{-1}s^{-1}$)



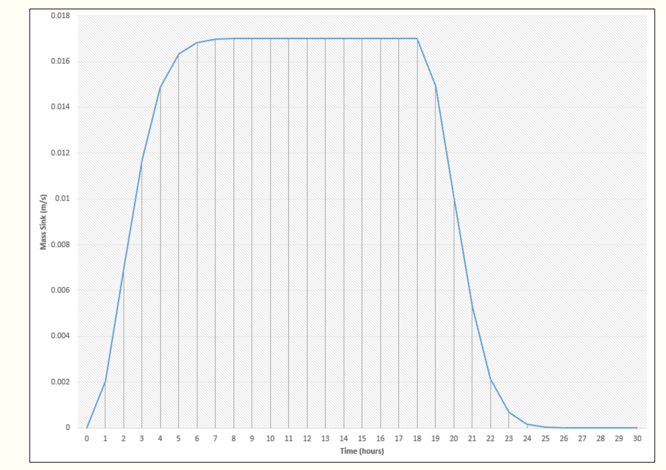
	Type	Width	Pockets of Higher PV	Mass Sink
Case 1	Infinite strip	400 Km	No	No
Case 2	Infinite strip	400 Km	Yes	No
Case 3	Infinite strip	400 Km	Yes	No
Case 4	Infinite strip	400 Km	No	Yes
Case 5	Finite Strip	Variable	No	No
Case 6	Finite Strip	700 Km	No	No

See manuscript for a detailed explanation.

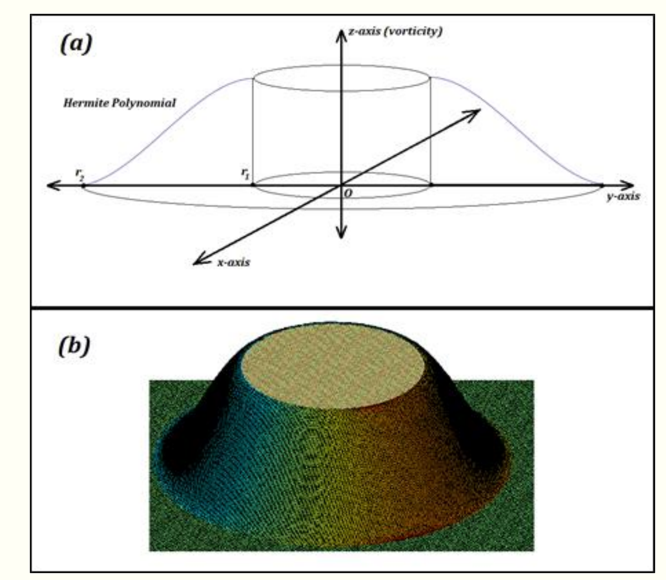
To simulate regions of enhanced convection, 10 uniform (Case 2) and randomly (case 3) spaced regions of higher vorticity was added to the initial condition. In case 4, Ten uniform linearly-spaced mass sinks were added. In the real atmosphere, convection results in diabatic heating. In the shallow water framework this is analogous to shallower fluid depth.

Ertel's PV $PV = \frac{1}{\rho}(\zeta + f)\frac{\partial \theta}{\partial z}$ **Shallow water PV** $PV = \frac{(\zeta + f)}{h}$

where ρ is the density of the fluid, θ is the potential temperature and z is the distance between the θ surfaces.



In case 4, convection was simulated by using a mass sinks that was gradually turned on, kept at a constant rate and later turned off. At its peak value, fluid was drained at the rate of 0.017 ms-1 to simulate heating of 10˚K per day.



Visualizing a pocket of vorticity in Case 2 and 3 of this section. (a) A sketch of the vortex pocket. Two concentric cylinders of radii r_1 and r_2 and, the Hermite Polynomial smoothly reducing the value of vorticity over a radial distance from r_1 to r_2. (b) A 3D plot of the packet of vorticity.

RESEARCH POTENTIAL, COMMENTS AND FUTURE WORK

The SWEs can help us better understand the fundamental dynamics of processes such as the breakdown of the ITCZ and hurricane eye wall evolution. One of the objectives of this project was to develop a numerical model in a new generation user-friendly programing language that can be used for both education and research. The Fast Fourier Transform and matrix manipulation methods in Mathwork's MATLAB made it an ideal choice for this research project and future research work. Please contact the author if you are interested in obtaining a copy of the MATLAB scripts used for this project.

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