Genesis of tropical cyclone Agni: Physical Mechanisms

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Introduction

Development of tropical disturbances

Factors interacting on various spatial and temporal scales (Gray, 1968; Cheung, 2004) and responsible for genesis

- SST
- Vertical wind shear (850 - 200 hPa)
- Conditional instability
- Cyclonic absolute vorticity in lower troposphere
- Relative Humidity (RH) in middle troposphere (500 - 700 hPa)
- Meridional wind shear; anti-cyclonic relative vorticity in upper troposphere;
- 200 hPa divergence and sensible heat

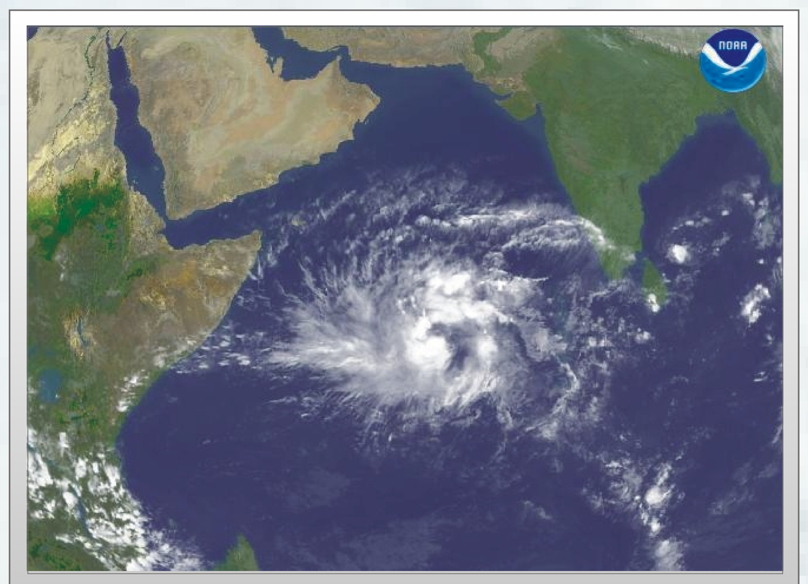
Existing Theories

- Ooyama, 1964; Charney and Eliassen, 1964: Conceptual model of cooperative intensification
- Arakawa and Schubert, 1974: Smaller observed rate of change of CAPE in the maritime tropical atmosphere
- Neelin et al., 1987: Wind-evaporation feedback mechanism
- Yano and Emanuel, 1991: Wind-induced surface heat exchange
- Bister and Emanuel, 1997; Ritchie & Holland, 1997: genesis of a surface vortex through mid-level mesoscale convective vortices
- Montgomery and Farrell, 1993; Montegomery & Enagonio, 1998 and Hendricks et al., 2004: mechanism of vortical hot towers

Downscaling of the pregenesis period of the tropical cyclone Agni (28th Nov. - 3rd Dec., 2004) using a mesoscale model Advanced Research WRF version 2.1.1 (WRF) to understand the role of mesoscale features and to identify associated physical processes in the genesis of tropical cyclone Agni.

Synoptic History

- Originated from two deep convective mesoscale disturbances over the Equatorial Indian ocean
- Genesis at about 160 Km north of equator.
- Organized itself to form Tropical Cyclone Agni: 27 November 2004 to 03 UTC 28 November 2004
- During organization, the centers of the intensification moved about half degree south of the equator without losing its counter clockwise rotation.
- Questioned the necessary condition of required large Coriolis parameter either side of equator for the genesis of tropical cyclone.
- At 06 UTC 28 November 2004 tropical disturbance strengthened to tropical storm and was located around 75 Km north of equator.
- Cyclone Agni followed northwestward track for most of its life span
- Intensified as tropical cyclone on 12 UTC 29 November, 2004.
- 06 UTC 30 November 2004: passed through the region of heavy wind shear. Dissipation on 18 UTC 3 December 2004.



NOAA satellite picture of cyclone Agni of 30th Nov., 2004

Simulated Features

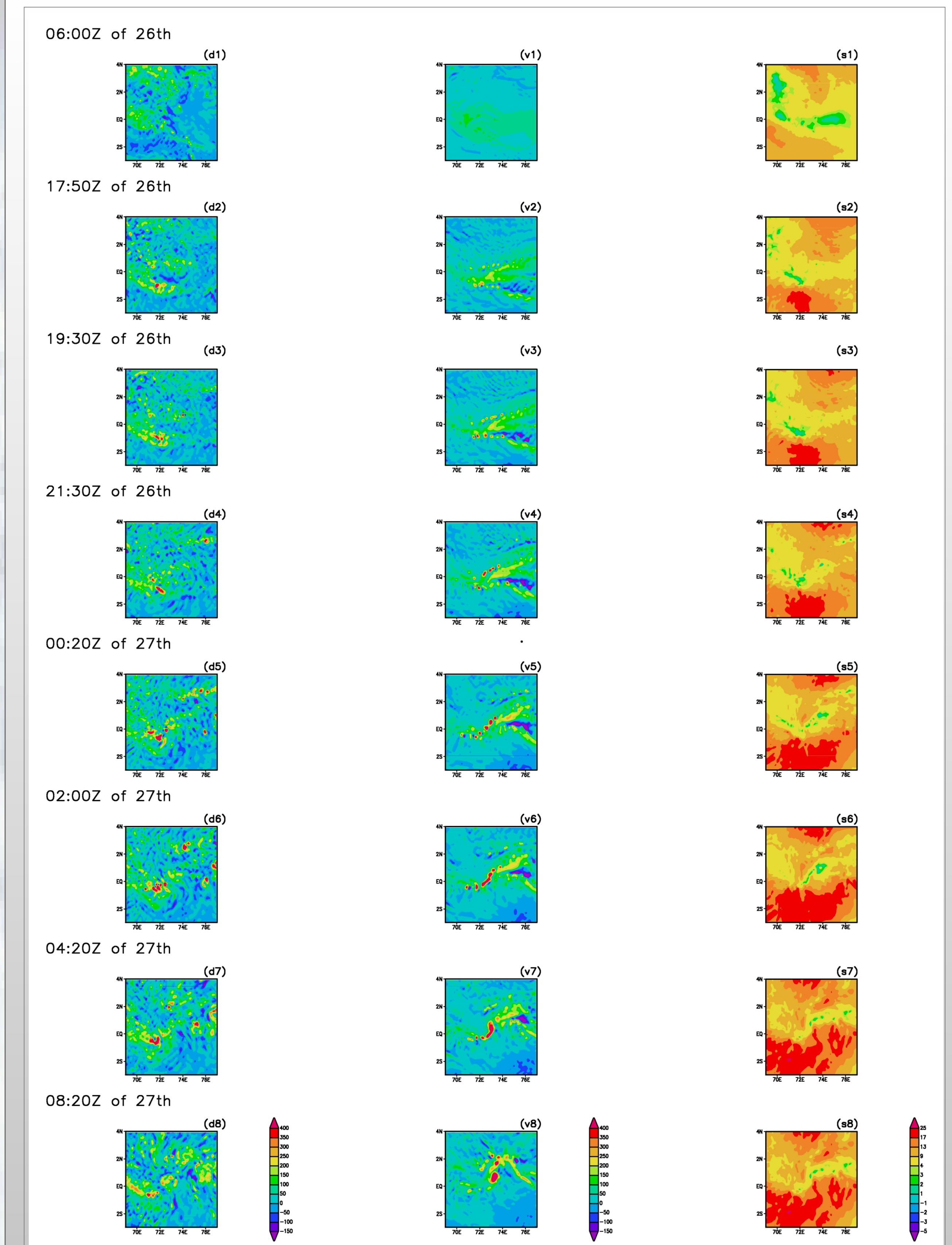


Fig.1: Upper tropospheric divergence (d1 – d8), relative vorticity (v1 – v8) and vertical wind shear (s1 – s8) during the pre-genesis period of Agni for the selected periods

Circulation and Thermodynamic Features

- The simulated surface heat flux 10 – 80 W m^{-2} on either side of the equator
- Presence of equatorial trough over the Arabian sea with
- Embedded low level circulations
- Maximum surrounding wind speed of around 15 m s^{-1}
- South – north migration of low level cyclonic
- circulation across the equator

SST: ranging between $28.6^0 – 29.4^0$ C

Heat input by isothermal expansion

- Mid-tropospheric Relative Humidity: > 80% Responsible for sustainable convective development by avoiding downdraught

Vortical Hot towers

- 0600Z of 26th (Fig. 1, v1): relative vorticity between 100-150 X $10^{-5} s^{-1}$
- 1750Z of 26th (Fig. 1, v2): relative vorticity between 200-250 X $10^{-5} s^{-1}$ and 2130Z of 26th (Fig. 1, v3): relative vorticity between 350 - 450 X $10^{-5} s^{-1}$

Further intensification:

- meso-regions with relative vorticity > 400 X $10^{-5} s^{-1}$ (formation of vortical hot towers),
- rearrangement (Fig. 1 v4-v5) around the common centre of rotation and
- subsequently the merging of meso vortices (Fig. 1 v6-v8).

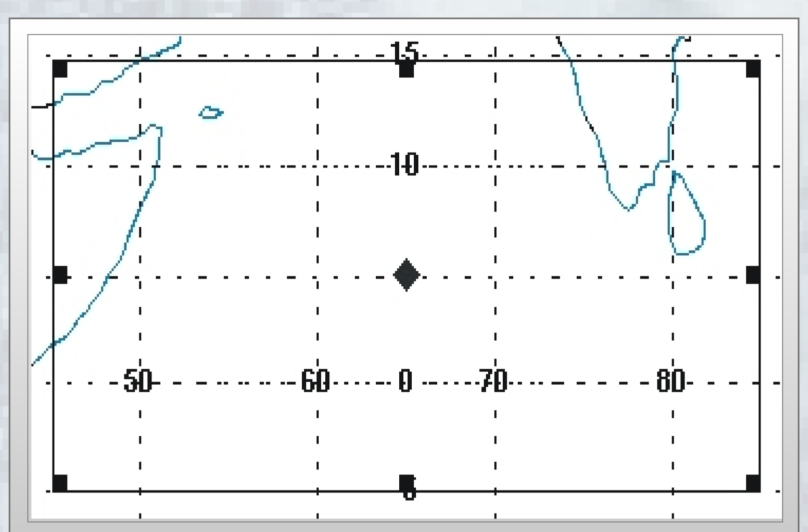
Upper Tropospheric Divergence

- Fig 1. d1- d8: higher values of UTD on south-west side of the vortical hot towers

Wind shear

- Fig 1 s1-s8: meso-vortices are seen aligned along low shear regions and merged in the same region.
- South-westward tilting of these meso vortices attributed to the vertical wind shear north-south- north migration of low level circulation across the equator under the influences of strong vertical wind shear induced by tread winds.

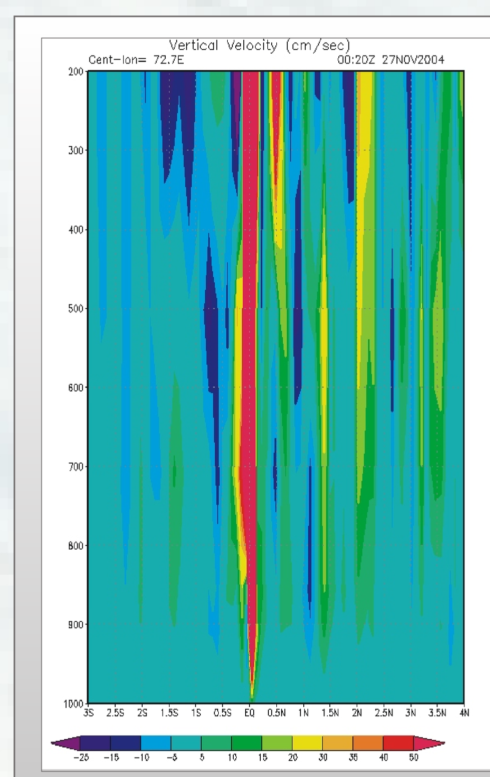
Model Configuration



Domain selected for the simulation

- WRF: version 2.1.1
- Period of Simulation: 26 November - 4 December 2004
- Domain: 45^0 E to 85^0 E; 5^0 S to 15^0 N
- Domain Size: 444 X 222 X 31
- Resolution: 10 Km
- Time Step: 60 Sec
- Initialization: FNL, NCEP-NCAR Data
- Micro-physics Lin et al., 1983
- Cumulus Parametrization: KF-Eta; Kain, 2004
- PBL Parametrization: YSU PBL (Hong and Dudhia, 2003, Hong et al., 2006)
- Long Wave Radiation Parametrization: RRTM, Mlawer et al., 1997
- Short wave radiation parametrization: Dudhia, 1989

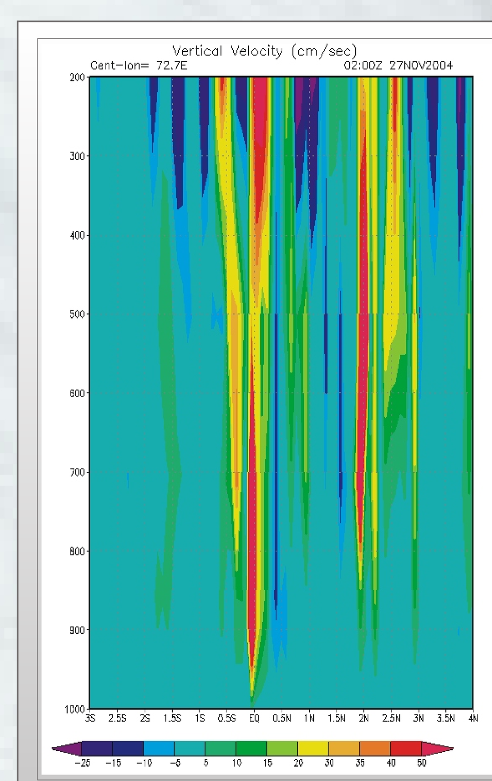
Meridonial cross section of Vertical velocity at central longitude



A

Strong vertical velocity ranging between 40 -50 cm s^{-1} over equator

Vertical cross section of merging of different vortical hot towers characterized by slight reduction in vertical velocity around center of vortex in mid-tropospheric region



B

Conclusions

- Wind induced surface heat exchange between ocean and atmosphere responsible for building the thermodynamic
- capacity necessary for development of small eddies over equatorial region of less wind shear
- "Heat input due to isothermal expansion" mechanism caused the development of deep convection due to wet mid-tropospheric region
- Reorganization, clustering and merging of meso-regions with more relative vorticity
- Migration to south and north of the equator under the influence of Low level convergence and Heavy atmospheric
- wind shear.
- However, further analysis is required to understand the forces involved in development and merging of meso-regions.

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