Space Research Institute, Russian Academy of Sciences
Институт космических исследований Российской академии наук

XVII ВСЕРОССИЙСКАЯ ОТКРЫТАЯ КОНФЕРЕНЦИЯ «ДЗЗ-2019»
Москва, 11-15 ноября 2019

ВИХРЕВАЯ ОБЛАЧНАЯ КОНВЕКЦИЯ

Г. В. Левина
Институт космических исследований РАН, Москва, Россия
levina@iki.rssi.ru

СОДЕРЖАНИЕ ДОКЛАДА

Введение

1. **Открытие ВИХРЕВОЙ влажной конвекции в тропической атмосфере – VORTICAL Hot Towers – VHTs**
   - Горячие облачные башни – Hot Towers – **1958**
   - VHTs – Облачно-разрешающее численное моделирование – **2004**
   - VHTs – Первое наблюдательное подтверждение – **2005**
2. **Вихревые горячие башни – VHTs**
   - Основные характеристики
   - Генерация и усиление вертикальной завихренности
   - Генерация спиральности
3. **Идентификация вихревой конвекции в поле вертикальной спиральности – методические рекомендации**

ВЫВОДЫ

ВВЕДЕНИЕ: МОТИВАЦИЯ ДОКЛАДА

В серии наших предыдущих докладов на конференциях ИКИ по ДЗЗ в 2014-2018 гг. вихревая облачная конвекция обсуждалась в контексте применения теории турбулентного вихревого динамо к исследованиям тропических циклонов (ТЦ), в частности, с целью ранней диагностики зарождения ураганного вихря.

В обсуждениях последнего времени с участниками конференций, рецензентами некоторых отечественных журналов и специалистами в этой области **постоянно** возникают следующие сомнения и вопросы:

- **Доказано ли существование вихревой облачной конвекции ?**

(согласно скептикам в развитом урагане она вообще должна подавляться вращением)

- **Нужна ли такая величина как спиральность поля скорости ?**
- **Зачем в России продолжать изучение тропических циклонов ?**

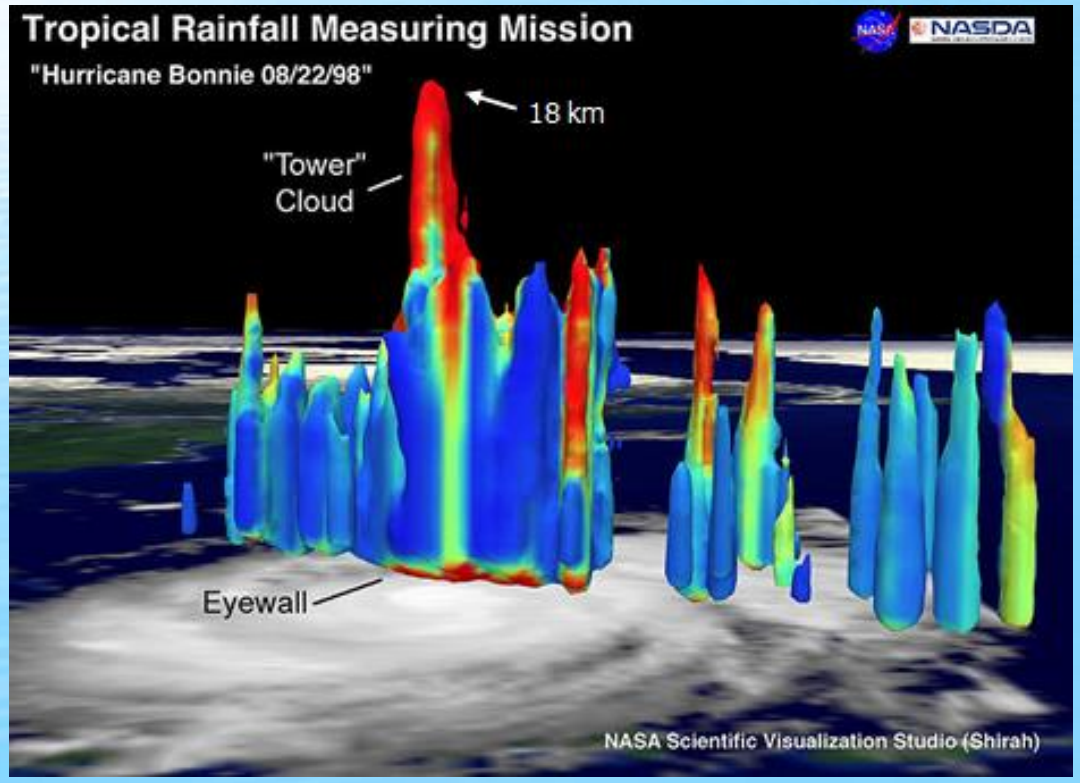
HOT TOWERS IN THE TROPICAL ATMOSPHERE

https://en.wikipedia.org/wiki/Hot_tower

Riehl and Malkus (1958) implicated the role of **HOT TOWERS**

(horizontally small but intense cumulonimbus convection cores that reach the tropopause via nearly undilute ascent) in the vertical heat transport and mass flux in the tropical atmosphere**.**

Reference: Riehl, Herbert and Malkus, Joanne.
On the heat balance in the equatorial trough zone. 1958: *Geophysica*, **6**, 503–538.



A **hot tower** is a tropical cumulonimbus cloud that reaches out of the lowest layer, of the atmosphere, the troposphere, and into the stratosphere.

In the tropics, the tropopause, typically lies at least **15 kilometers** above sea level.

These formations are called "hot" because of the large amount of latent heat released as water vapor condenses into liquid and freezes into ice – – 2 phase transitions of moisture !

CLOUD-RESOLVING NUMERICAL SIMULATION OF TROPICAL CYCLONE (TC) FORMATION

Discovery of the vortical nature of atmospheric moist convection in the tropics – Vortical Hot Towers (VHTs)

Hendricks E. A., Montgomery M. T., and Davis C. A. 2004, *J. Atmos. Sci.*, 61, 1209-1232

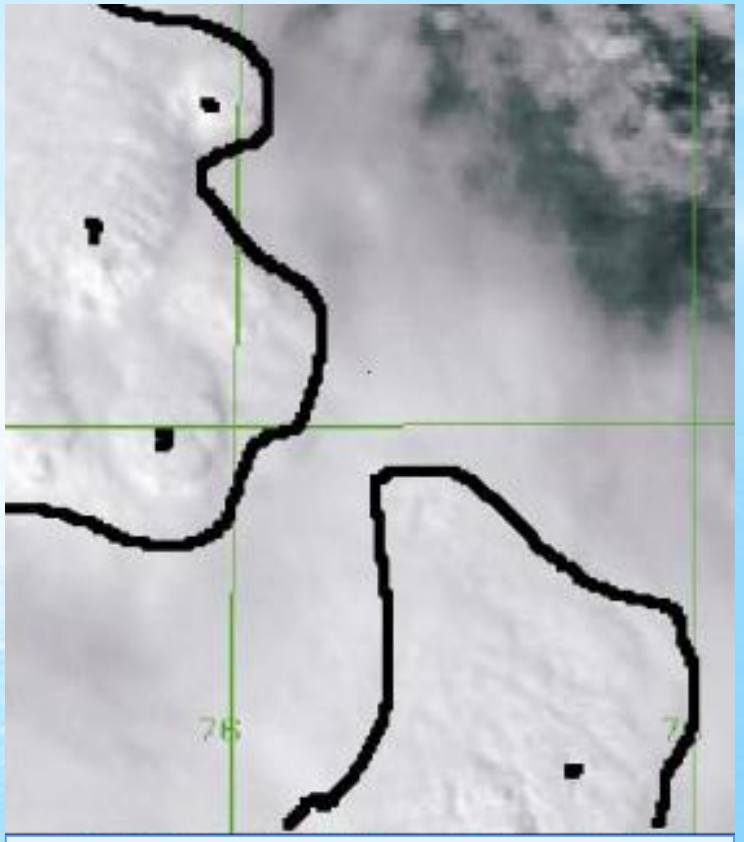
The **VORTICAL** nature of atmospheric moist convection in the tropical zone was discovered by near-cloud-resolving **numerical simulation** – **Vortical Hot Towers – VHTs**

Reasor P. D., Montgomery M. T., and Bosart L. F. 2005, *J. Atmos. Sci.*, 62, 3151-3171

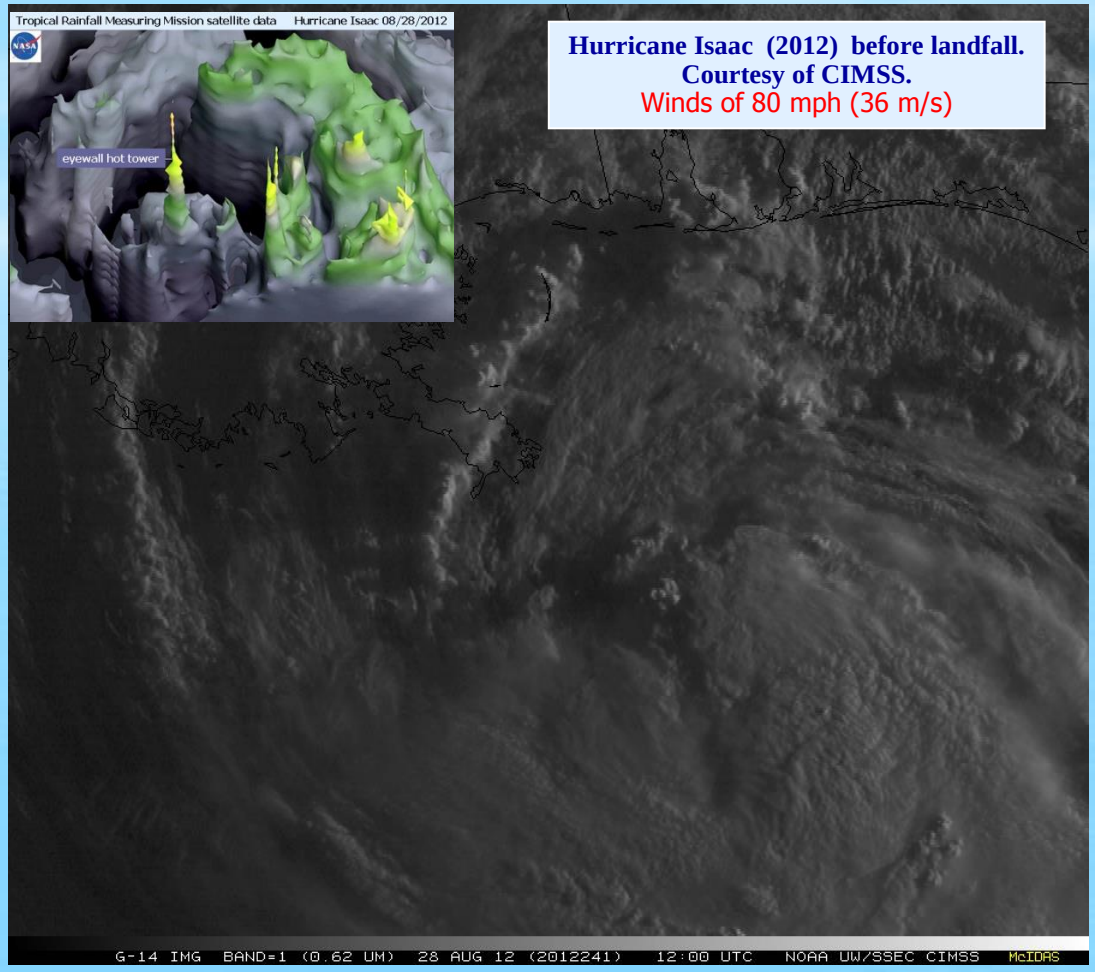
The first **observational evidence** that convective bursts have the vortical nature was obtained by aircraft measurements in the tropical atmosphere

By now, observational evidence for the existence of vortical convection during TC formation has been provided for different regions of the tropical zone

VORTICAL HOT TOWERS – VHTs



VHTs in Tropical Storm Gustav (2002)
From Hendricks et al., 2004.



Hurricane Isaac (2012) before landfall.
Courtesy of CIMSS.
Winds of 80 mph (36 m/s)

VHTs – rotating convective clouds

the lifetime ~ **1 hour** , the horizontal size ~ **10-30 km ,**
the height ~ **14-18 km** of the most intense ones penetrating the entire troposphere ,
the vertical velocity from **2- 4 m·s^{-1}** up to **25-30 m·s^{-1}** ,
the relative vertical vorticity up to **10^{-3}-10^{-2} s^{-1}** (by 1-2 orders exceeds the planetary rotation).

VORTICAL HOT TOWER ROUTE TO TROPICAL CYCLOGENESIS

New scenario of hurricane formation based on self-organization of convective processes

M06 :

Montgomery M.T., Nicholls M.E., Cram T.A., Saunders A.B. 2006, *J. Atmos. Sci.*, 63, 355-386.

A nonhydrostatic cloud model was used to examine the thermomechanics of tropical cyclogenesis

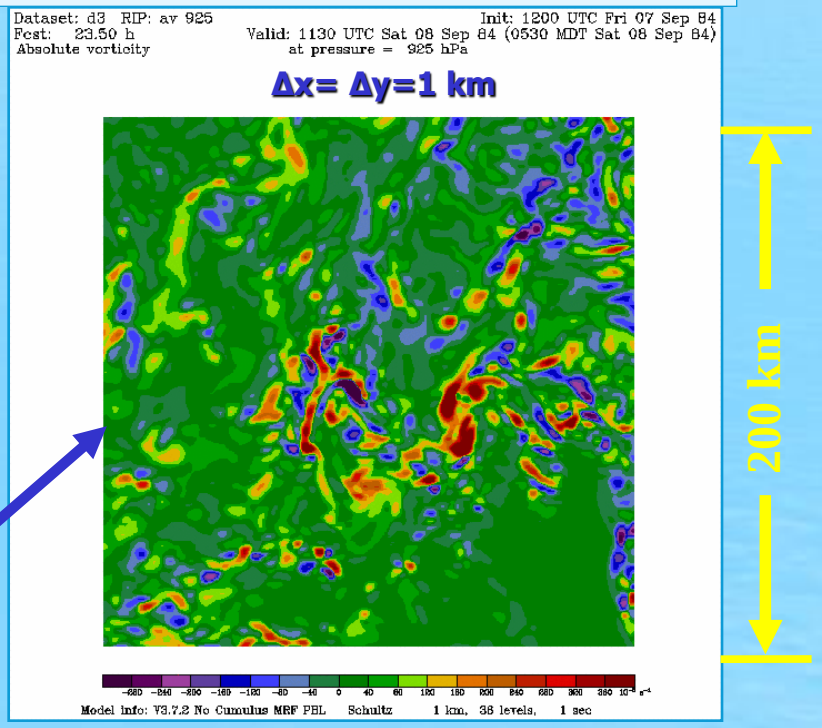
Results

A new scenario of hurricane formation has been proposed.

Self-organization of vortical (!) convection was observed as:

- an enlargement of vortex structures from the size of individual rotating cumulus clouds in the model;
- their induced concentration of absolute angular momentum on the system scale circulation;
- their merging with each other to yield newly forming larger vortices and intensifying circulation on the system scale.

absolute vorticity—mergers at 925hPa

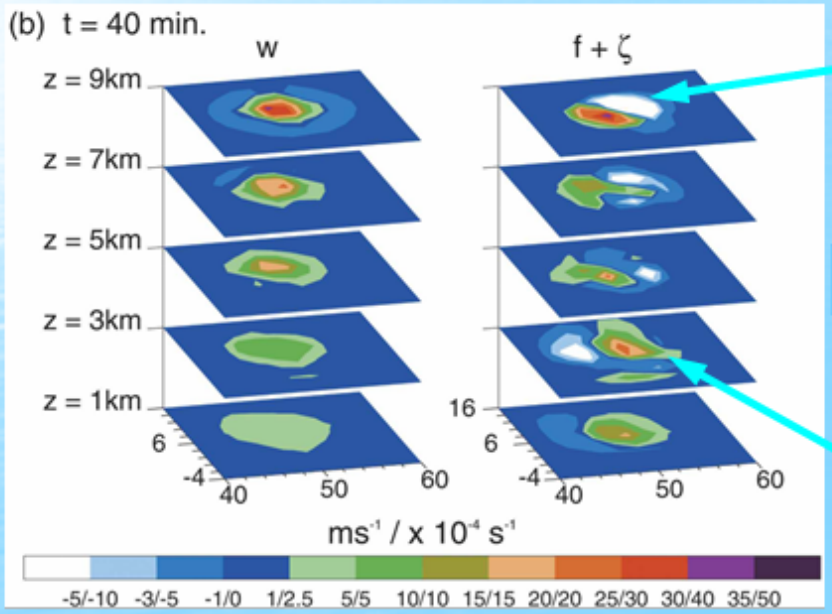


VHTs: NUMERICAL AND OBSERVATIONAL EVIDENCE

Houze R. A., Lee W. C., and Bell M. M. 2009, *Mon. Wea. Rev.*, 137, 2778–2800. – Aircraft mission measurements

The paper presents the detailed direct observational documentation of vortical convection as well as evidence that corroborates the basic notion of a VHT route to cyclogenesis by Montgomery et al.

Montgomery et al., JAS, M06: Fig. 9b.
Numerical simulation, Experiment A1, $\Delta x = \Delta y = 2$ km;
The first VHT in the simulation at t = 40 min



At z = 3–9 km: **Max cyclonic vorticity 2–5·10⁻³ s⁻¹**

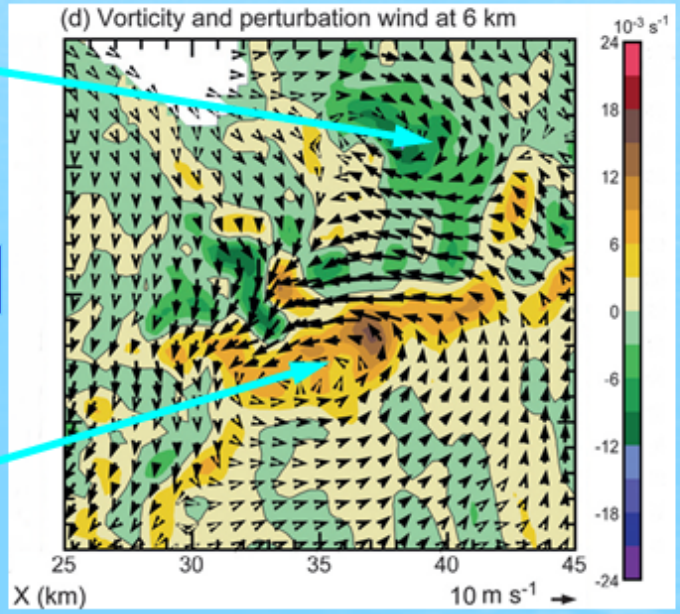
The updraft wide 10 km, height 16 km.
Max vertical velocity 33 m·s⁻¹ at z = 10 km

Anticyclonic

Vortex dipole

Cyclonic

Houze et al., MWR, 2009: Fig. 10d.
***ELDORA 3D wind field** in pre-Hurricane Ophelia (2005)
A VHT at t = 2108–2122 UTC, 6 Sep 2005



At 6 km: **Max cyclonic vorticity 12·10⁻³ s⁻¹**

The updraft wide 10 km, height 17 km.
Vertical velocity 10–25 m·s⁻¹ at upper levels

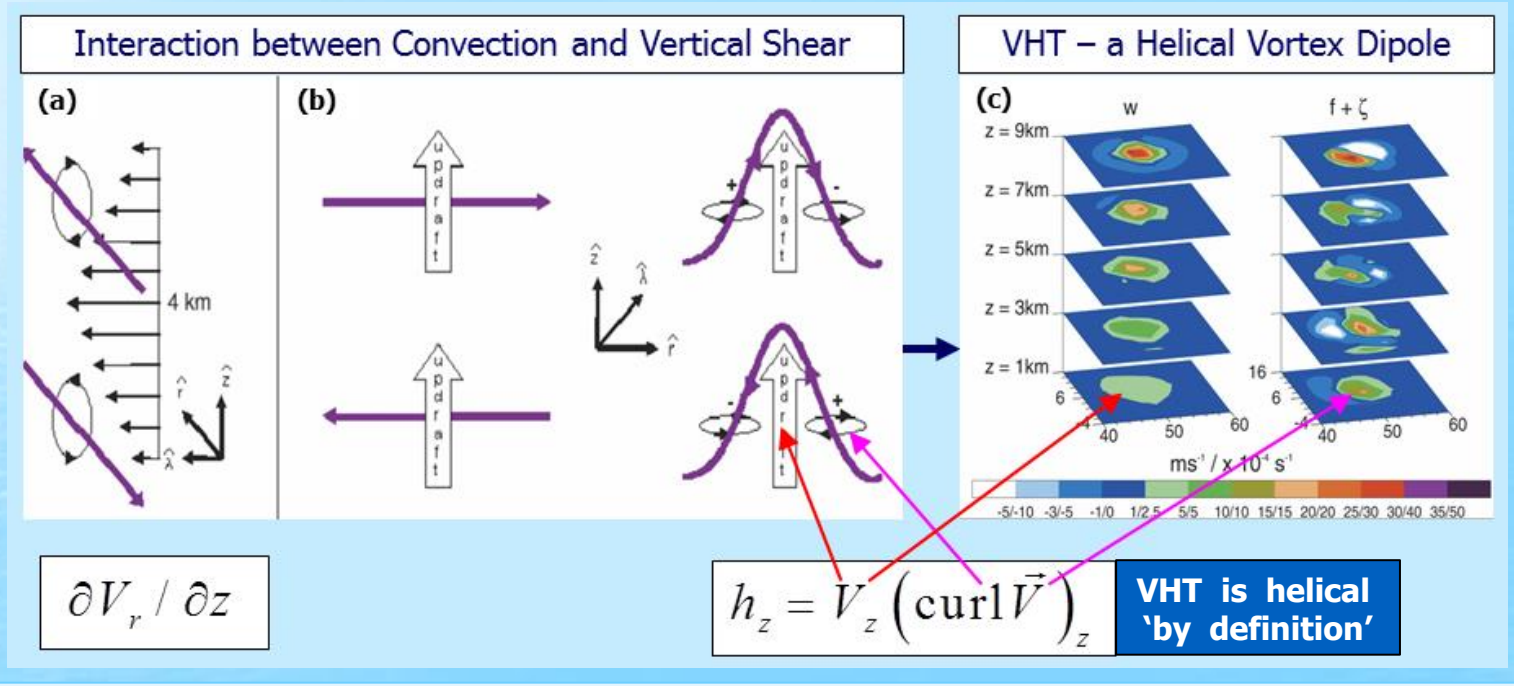
*) **ELDORA** – the especially high-resolution Electra Doppler Radar

FORMATION OF A VORTICAL HOT TOWER

GENERATION OF VERTICAL VORTICITY AND LINKAGE OF VORTEX LINES ⟶ HELICITY

Montgomery M.T., Nicholls M.E., Cram T.A., Saunders A.B. 2006, *J. Atmos. Sci.*, 63, 355-386 – [M06]

Levina G. 2018, *Open Journal of Fluid Dynamics*, 8, 86-114 – helicity generation emphasized.



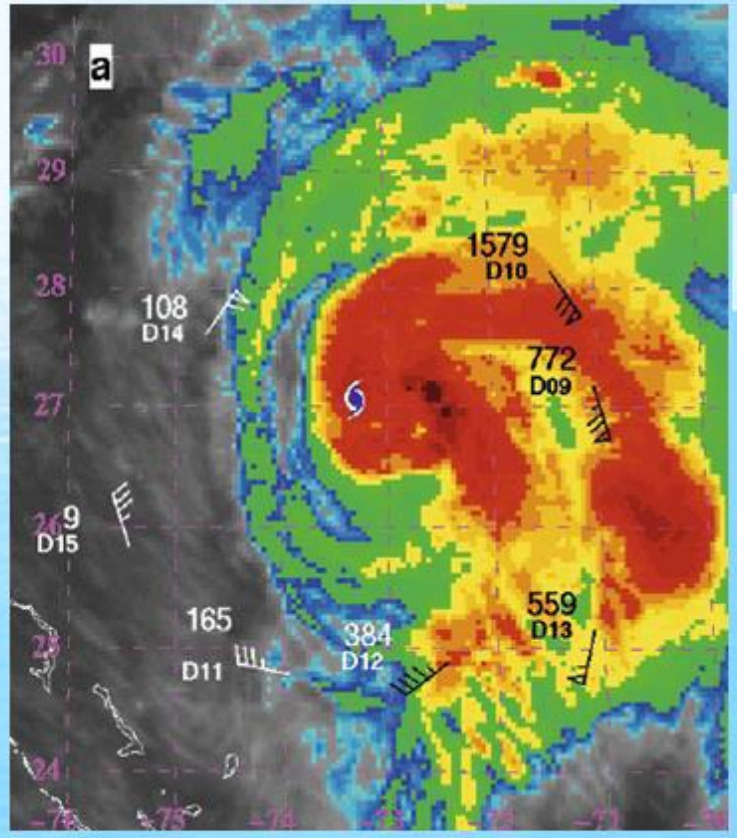
Generation of vertical vorticity and helicity within a mesoscale convective vortex (MCV). *Combination of figures: Montgomery et al., 2006 and Levina, 2018. Purple lines represent vortex filaments.* ***(a)*** *Radial vorticity generated by vertical shear profile of initial MCV.* ***(b)*** *Updraft tilts radial vortex filament upward, generating a vertical vorticity dipole with positive and negative relative vorticity.* ***(c)*** *Vertical velocity (m/s) and absolute vertical vorticity ($\times 10^{-4}$ 1/s) signatures associated with deep cumulus convection.*

HELICITY CALCULATION BASED ON DIRECT MEASUREMENTS IN TROPICAL CYCLONES – a TEST for NUMERICAL RESULTS

Molinari J., and Vollaro D. 2008, *Mon. Wea. Rev.*, 136, 4355–4372. – [MV08]

Extreme Helicity and Intense Convective Towers in Hurricane Bonnie

Helicity was calculated in Hurricane Bonnie (1998) using tropospheric-deep dropsonde soundings from the NASA Convection and Moisture Experiment (CAMEX). The most extreme values of helicity, among the largest ever reported in the literature, occurred in the vicinity of deep convective cells. These cells reached as high as 17.5 km.



Infrared satellite image at 0100 UTC 25 Aug.
Helicity values (cell motion ≠ 0) and mean winds over 0–6 km.
Sondes D9–D15 were released 2330 UTC 24 Aug – 0153 UTC 25 Aug

Helicity values (cell motion = 0) over 0–6 km were also calculated [MV08].
They can be compared with our results of numerical simulation [LM].

The highest helicity value [**MV08**] was found for D10 on Aug 24 when the maximum surface wind was about 55 $m \cdot s^{-1}$.

In simulations [**LM**] the total 0-6 km helicity reaches its highest value near the simulation time 60 hours when the maximum wind is 42.5 $m \cdot s^{-1}$.

	MV08	LM
Max Helicity 0-6 km	2578 $m^2 \cdot s^{-2}$	2700 $m^2 \cdot s^{-2}$
Max surface wind	55 $m \cdot s^{-1}$	42.5 $m \cdot s^{-1}$

MV 2010, *J. Atmos. Sci.*, 67, 274–284. The study of helicity was extended to 8 tropical cyclones sampled by NASA during CAMEX (1998/2001)

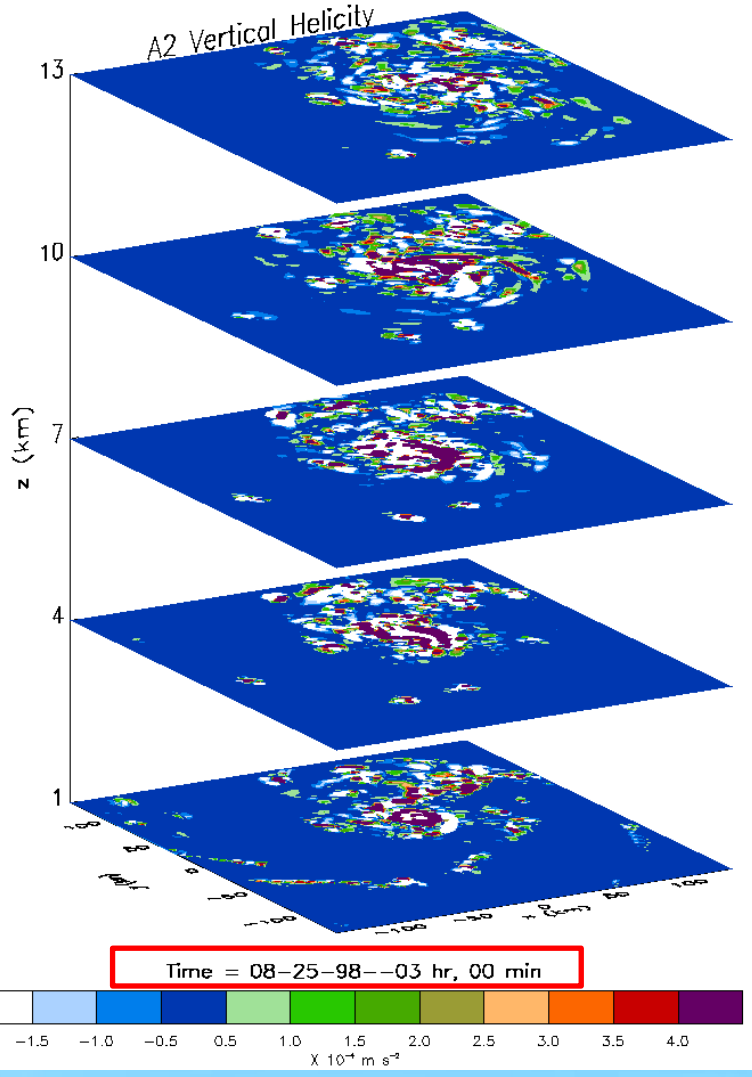
VORTICAL CLOUD CONVECTION

Vertical helicity density:

$$h_z = V_z \left(\text{curl} \vec{V} \right)_z$$

POSITIVE HELICITY:
cyclonic updrafts &
anticyclonic downdrafts,

NEGATIVE HELICITY:
cyclonic downdrafts &
anticyclonic updrafts



08-23-98 00 hr V ≈ 6 m/s
08-23-98 06 hr V ≈ 9 m/s
08-24-98 09 hr V ≈ 17 m/s
08-24-98 20 hr V ≈ 34 m/s
08-25-98 03 hr Max Wind 43 m/s

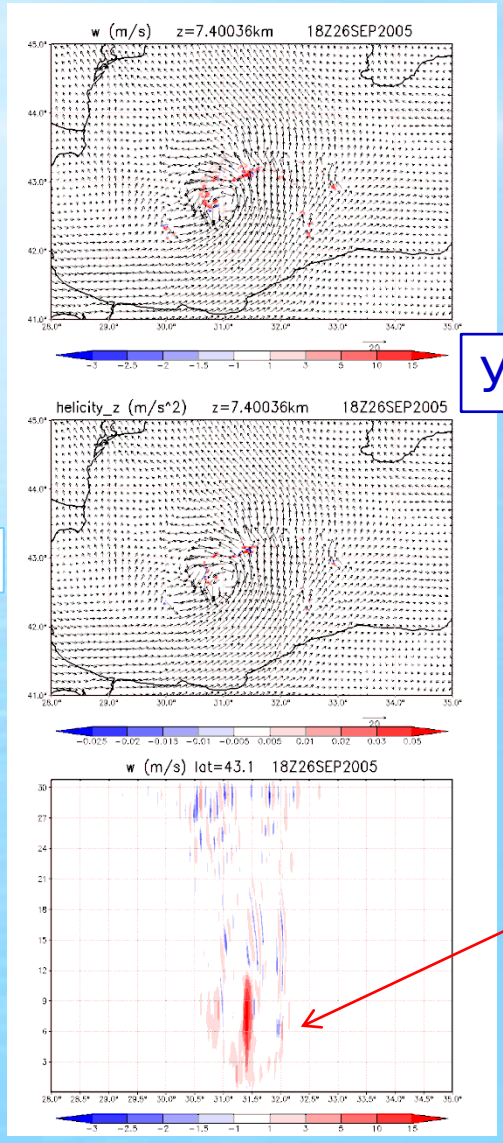
The first updraft is generated by the intial 300 s local heating at low levels

Expt. A2 [M06]. VERTICAL HELICITY: VORTICAL CONVECTION

Черноморский квази-ТЦ (2005):
Вращающаяся конвекция

Моделирование – Д.А. Яровая
МГИ РАН, Севастополь

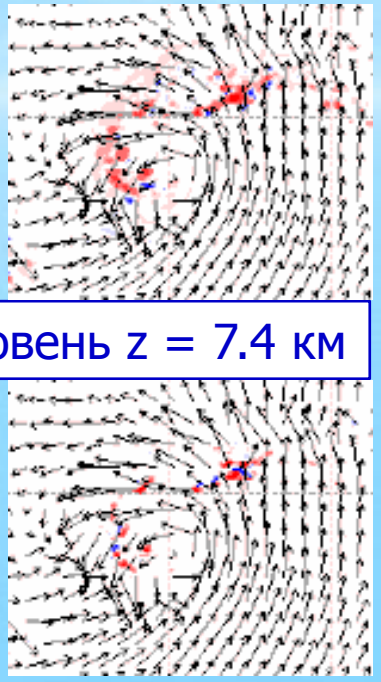
18.00 UTC 26.09.2005



W ≈ 15 m/s

h_z ≈ 0,05 m/s²

H ≈ 10 km
L ≈ 10 km



Цветом показаны:

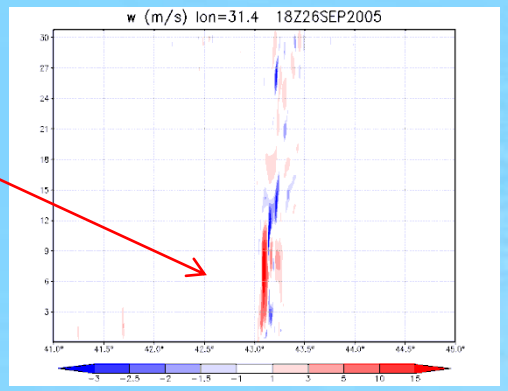
вертикальная скорость

Уровень z = 7.4 км

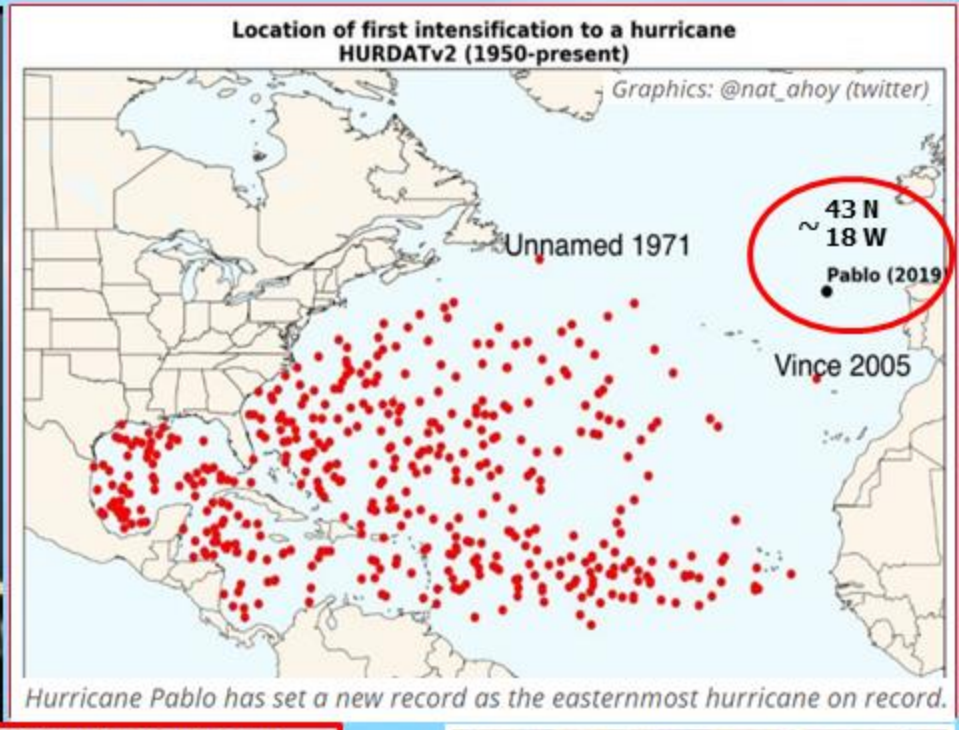
вертикальная спиральность позволяет локализовать вращающиеся конвективные структуры

Вращающаяся конвективная башня

$\omega \approx 3 \cdot 10^{-3}\ s^{-1}$



ОБСУЖДЕНИЕ НА ФОРУМЕ TSTORMS.ORG



Hurricane Pablo has set a new record as the easternmost hurricane on record.

Тема **Re[2]: [Tropical-storms] Some questions concerning our new 35-45N Main Development Region**

От Kerry Emanuel

Кому levina@iki.rssi.ru, mlander@triton.uog.edu, tropical-storms@tstorms.org

Дата 31.10.2019 15:33

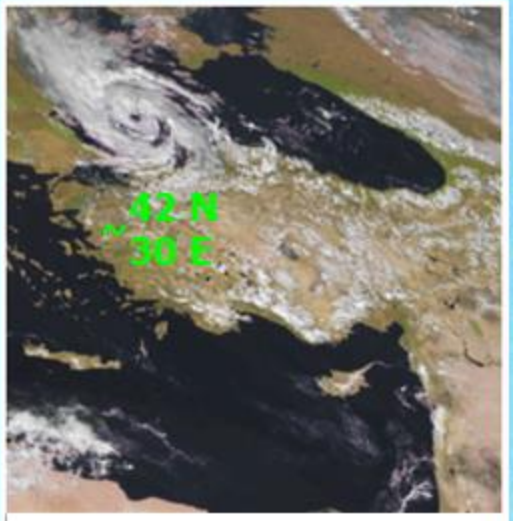
Hi Galina: We are projecting a modest increase in Black Sea TC-like storms over this century; see

Romero, R., and K. Emanuel, 2017: Climate change and hurricane-like extratropical cyclones: Projections for North Atlantic polar lows and medicanes based on CMIP5 models. *J. Clim*, **30**, 279-299.

Yours, Kerry

Kerry A. Emanuel
Rm 54-1814, MIT
77 Mass. Ave.
Cambridge, MA 02139
Web: https://emanuel.mit.edu

Professor of Atmospheric Science
Phone: (617) 253-2462
Fax: (617) 324-2055
Email: emanuel@mit.edu



Quasi-TC over the Black Sea (2005)

ИТОГИ

- **ВИХРЕВАЯ ОБЛАЧНАЯ КОНВЕКЦИЯ СУЩЕСТВУЕТ !**
- **ВИХРЕВАЯ КОНВЕКЦИЯ НАГЛЯДНО ПРОСЛЕЖИВАЕТСЯ В ПОЛЕ ВЕРТИКАЛЬНОЙ СПИРАЛЬНОСТИ** (ПЛОТНОСТЬ СПИРАЛЬНОСТИ – НЕ ИНТЕГРАЛ!)
- **ВИХРЕВАЯ КОНВЕКЦИЯ НЕ ПОДАВЛЯЕТСЯ ВРАЩЕНИЕМ ТЦ**
- **СПИРАЛЬНОСТЬ – ПОЛЕЗНАЯ ДИАГНОСТИЧЕСКАЯ ВЕЛИЧИНА И АКТИВНО ПРИМЕНЯЕТСЯ В МЕТЕОРОЛОГИИ**
- **ПРОДОЛЖАТЬ ЛИ ИЗУЧЕНИЕ ТЦ В РОССИИ ?**

СПАСИБО ЗА ВНИМАНИЕ !