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

Wolfgang Pauli Institute (WPI), Vienna, 6 May 2015
Workshop on "Basic issues of extreme events in turbulence"

ROLE OF HELICAL TURBULENCE IN THE DYNAMICS OF TROPICAL CYCLONES FORMATION

or

Developing an interpretation for tropical cyclogenesis as an extreme threshold event in the helical atmospheric turbulence

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OUTLINE

Introduction.
Tropical cyclogenesis & Helicity (large-scale instabilities, atmospheric flows)

1. A vortical hot tower route to tropical cyclone (TC) genesis – self-organization of convective processes

- Discovery of the VORTICAL nature of atmospheric moist convection (2004)
- Vortical Hot Towers (VHTs) – rotating cumulus clouds

2. Helical scenario of TC genesis and intensification

- The first finding: non-zero helicity generation during TC formation
- Helicity generation on cloud scales - interaction between convection and vertical shear of horizontal wind
- VHTs are the CONNECTORS of the primary and secondary circulations in TC
- When will a nascent vortex become self-sustaining ? Energetics of a forming TC

3. Numerical diagnosis for tropical cyclogenesis

PRACTICAL OUTCOME : new criteria and numerical approach for diagnosis of tropical cyclogenesis by modern tools of meteoanalysis

TROPICAL CYCLOGENESIS

NOAA's glossary: **Tropical Cyclone (TC)**

A warm-core, non-frontal synoptic-scale cyclone, originating over tropical or subtropical waters with organized deep convection and a closed surface wind circulation about a well-defined center.

A TC in which the maximum 1-minute sustained surface wind ranges

$< 17\ m{\cdot}s^{-1}$	$17\text{–}33\ m{\cdot}s^{-1}$	$> 33\ m{\cdot}s^{-1}$
Tropical Depression (TD)	**Tropical Storm (TS)**	**Hurricane (H)**

A universally accepted definition of tropical cyclogenesis does not exist.

Ritchie and Holland (1999, *Mon. Wea. Rev*) define genesis as: " ... the series of physical processes by which a warm core, tropical-cyclone-scale vortex with maximum amplitude near the surface forms".

Montgomery et al. (2012, *BAMS*): "In this study we will define genesis as the formation of a tropical depression and we impose no formal threshold on wind speed".

Introduction to Tropical Meteorology. *2nd Edition.*
A Comprehensive Online & Print Textbook. Version 2.0, October 2011
Produced by The COMET® Program. University Corporation for Atmospheric Research :

"... tropical cyclogenesis has occurred **WHEN** the tropical storm **has become self-sustaining and can continue to intensify** ..."

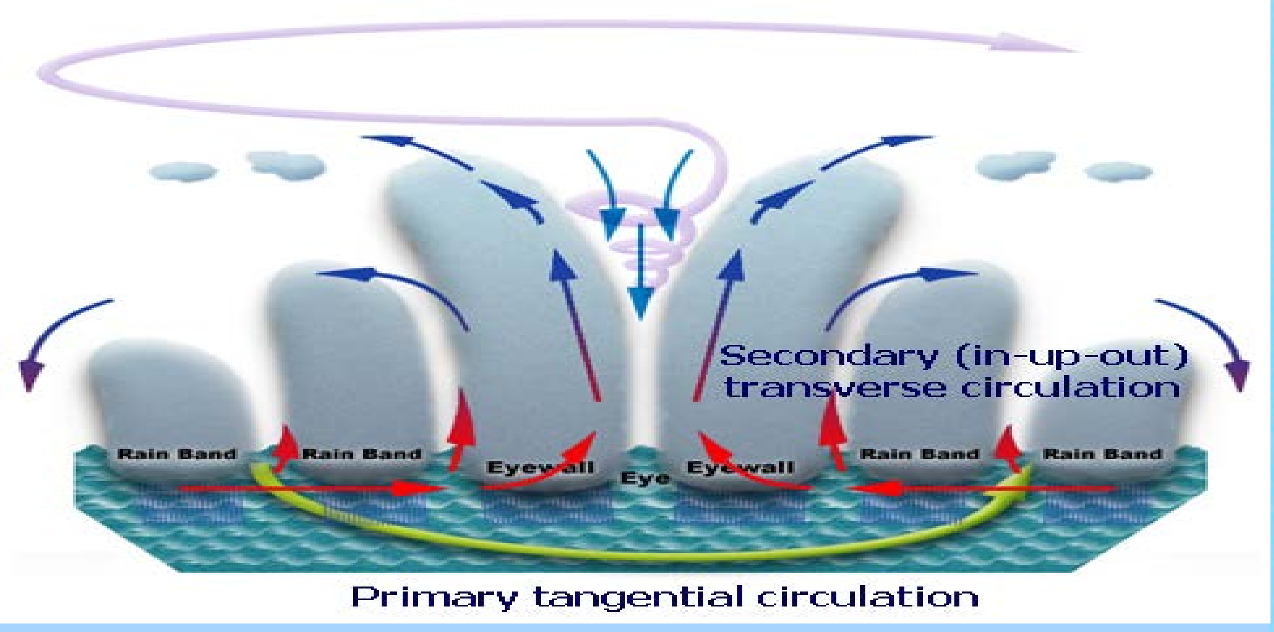
HYPOTHESIS ON THE TURBULENT VORTEX DYNAMO

Mechanism for intensification of large-scale vortex disturbances in the atmosphere –
Moiseev, Sagdeev, Tur, Khomenko, and Shukurov (1983)

In rotating non-homogeneous atmosphere moist-convective turbulence becomes helical, energy flux to dissipation scales is suppressed and large-scale vortex instability is possible

The first sign of the hypothesized large-scale instability –
generation of the linkage of primary (tangential) and secondary (transverse) circulation on the system scale and the resulting positive feedback that makes the forming vortex energy-self-sustaining

The 1st link (transverse-tangential) – is due to the Coriolis force.
How does the 2nd link (tangential-transverse) work to close the putative feedback loop?
– **This was unclear until our finding on a role of vortical moist convection**



Anatomy of a tropical cyclone in the Northern hemisphere (www.brockmann-consult.de)

HYDRODYNAMIC ALPHA-EFFECT IN A CONVECTIVE SYSTEM: MEAN-FIELD EQUATIONS

Moiseev S. S. et al. 1988, *Sov. Phys. JETP*, 67, 294–299 (Eng) ; Rutkevich P. B. 1993, *JETP*, 77, 933–938 (Eng) ;
Levina G.V., Moiseev S.S., Rutkevich P.B. – review of results 1983-1999 – in: *“Advances in Fluid Mechanics”, Nonlinear Instability, Chaos and Turbulence.* Vol. 2. P. 111–162 . WITPress, Southampton. 2000.

$$\left(Pr\frac{\partial}{\partial t}-\Delta\right)T=-\Delta_{\perp}\phi\,,$$

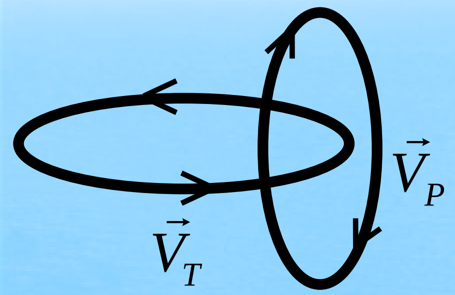
Convective

$$\left(\frac{\partial}{\partial t}-\Delta\right)\Delta\phi=Ra\,T+C\left[(\vec e\nabla)^2-\Delta_{\perp}\right]\psi-Ta^{1/2}\frac{\partial\psi}{\partial z}\,,$$

Helical

$$\left(\frac{\partial}{\partial t}-\Delta\right)\psi=-C(\vec e\nabla)^2\phi+Ta^{1/2}\frac{\partial\phi}{\partial z}\,,$$

$$Pr=\frac{\nu}{\chi},\quad Ra=\frac{g\beta A h^4}{\nu\chi},\quad \boxed{C\propto\Omega\Lambda},\quad Ta=\frac{4\Omega^2h^4}{\nu^2}$$



$$\vec V=\vec V_T+\vec V_P,\qquad \vec e=\{0,0,1\}$$

$$\vec V_T=curl\,(\vec e\,\psi),\quad \vec V_P=curl\,curl\,(\vec e\,\phi)$$

C **– characterizes the intensity of helical feedback and depends on rotation *Ω* and internal heat release intensity *Λ*, and characteristics of small-scale convective turbulence**

With the helical feedback introducing ($C \neq 0$) :

- ***C*–terms generate a new instability – ‘HELICAL’ ,**
- **there exists a threshold of instability,**
- **an increasing feedback intensity results in the threshold decrease and increase of horizontal dimensions of convective structures**

L06 : Levina G. V., and Burylov I. A. 2006, *Nonlin. Processes Geophys*., 13, 205-222.
Levina G.V. 2006, *Doklady Earth Sciences*, 411A (9), 1417–1421.

By analogy with the alpha-term in the Alpha-Effect equations, *C*-terms can be interpreted as a "vortex-motive" force

$$\vec{f} = \left\{ \frac{\partial v}{\partial z}, \quad -\frac{\partial u}{\partial z}, \quad \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \right\}$$

Vertical shear of horizontal velocity — **Vertical vorticity**

- works and can pump an additional energy,
- *z*-component (vertical vorticity) is a necessary element to close the feedback loop between the horizontal and vertical circulation in a forming vortex structure

Such hypothesized "vortex-motive" force parameterizes the interaction of vertical shear and hypothetical (! before 2004) **VORTICAL** moist convection

HELICITY OF VELOCITY FIELD

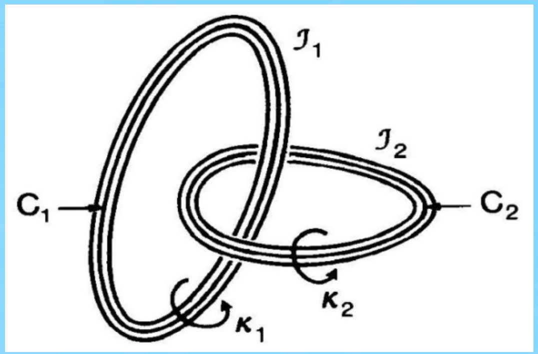
Inaugural Article, PNAS. H. Keith Moffatt (2014), v. 111, no. 10, 3663-3670

$$H = \int \vec{V} \cdot \mathrm{curl}\,\vec{V}\, d\vec{r}$$

This integral is, like energy, an invariant of the Euler equations of ideal fluid flow, although, unlike energy, it is not sign definite, and its physical interpretation is that it provides **a measure of the degree of knottedness and/or linkage of the vortex lines of the flow. It is also a measure of the lack of mirror symmetry of the flow.**

Betchov (1961) – the term ‘helicity’ ;
significance of the mean helicity $<\vec{\mathbf{V}}\cdot \mathbf{curl}\,\vec{\mathbf{V}}>$ in turbulent flow;
Moreau (1961) – the invariance of *H* in ideal fluid;
Moffatt (1969) – the most comprehensive notion of helicity in fluid dynamics and MHD

From Moffatt and Tsinober, 1992



HELICITY AND THE TURBULENT DYNAMO

H.-K. Moffatt and A. Tsinober (1992), Annu. Rev. Fluid Mech., v. 24, 281-312;
H. Keith Moffatt (2014), PNAS, v. 111, no. 10, 3663-3670

(*i*) Helicity plays a central role in MHD-dynamo theory,
i.e. the theory that is concerned with the growth of magnetic fields in electrically-conducting fluids

The discovery of the Alpha-Effect – Steenbeck, Krause, and Rädler (1966)
The seeds of this discovery – Parker (1955), Braginskii (1964).

How order (in the form of a large-scale magnetic field) **can arise out of chaos** (in the form of small-scale turbulence with zero mean).
The essential ingredient – the turbulence should lack reflectional symmetry, the simplest manifestation being a nonzero mean helicity.

(*ii*) Helicity plays a role
in depleting nonlinearity in the Navier-Stokes equations, with implications for the coherent structures and energy cascade of turbulence

Being inspired by similarity of equations for magnetic field $\vec{\mathbf{B}}$ and vorticity $\vec{\boldsymbol{\omega}} = \mathbf{curl}\,\vec{\mathbf{V}}$,

$$\partial\vec{B}/\partial t = \nabla\times(\vec{V}\times\vec{B})$$

$$\partial\vec{\omega}/\partial t = \nabla\times(\vec{V}\times\vec{\omega})$$

scientists started the search for analogs in dynamics of non-conducting fluids

ALPHA-LIKE INSTABILITIES IN NON-CONDUCTING MEDIA

there exists a threshold for large-scale instability in all cases !

Origin:

Specific properties of small-scale turbulence displaying a symmetry break

Examples:

Helical Turbulence generated by pseudovector forces –
special forcings or the Coriolis force in rotating fluid

Hydrodynamic Alpha-Effect

- *in Compressible Fluid*
  Moiseev, Sagdeev, Tur, Khomenko, and Yanovsky (1983)
- *in Incompressible Convectively Unstable Fluid*
  Moiseev, Rutkevich, Tur, and Yanovsky (1988)

Anisotropic Turbulence lacking parity-invariance – generated by a special forcing

Anisotropic Kinetic Alpha (AKA)-Effect

illustrated by full simulation in 3D **Frisch, She, and Sulem (1987)**

HELICAL CHARACTERISTICS OF ATMOSPHERIC FLOWS

ESTIMATES :	helicity density, m/s^2
ABL roll-vortices	$10^{-3} – 10^{-2}$
Rotating thermal	10^{-2}
Tropical depression (TD)	$10^{-2} – 10^{-1}$
Tropical storm (TS)	$10^{-1} – 10^{0}$
Hurricane (H)	10^{0}
Tornado	10^{1}
Dust devil	10^{1} - Earth; 10^{2} - Mars

Helicity is a pseudoscalar, its sign allows to determine a predominance of the left-handed or the right-handed spiral motions in a flow.

For example:

POSITIVE HELICITY: cyclonic updrafts & anticyclonic downdrafts,
NEGATIVE HELICITY : cyclonic downdrafts & anticyclonic updrafts

To examine atmospheric flows of different origin it is useful to introduce [1]:

the VERTICAL contribution of helicity: e.g. produced by the thermal convection,
the HORIZONTAL contribution of helicity: ––– the vertical shear of horizontal wind

1. G. V. Levina. *Helical Organization of Tropical Cyclones.* Preprint NI13001-TOD. Isaac Newton Institute for Mathematical Sciences, Preprint Series, Cambridge, UK, 2013.

A VORTICAL HOT TOWER ROUTE TO TROPICAL CYCLOGENESIS

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

M06 :

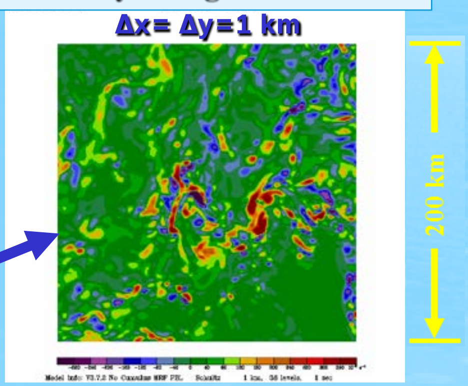
Montgomery M.T., Nicholls M.E., Cram T.A., Saunders A.B. 2006, *J. Atmos. Sci.*, 63, 355-386.

A new scenario of hurricane formation based on self-organization of convective processes:

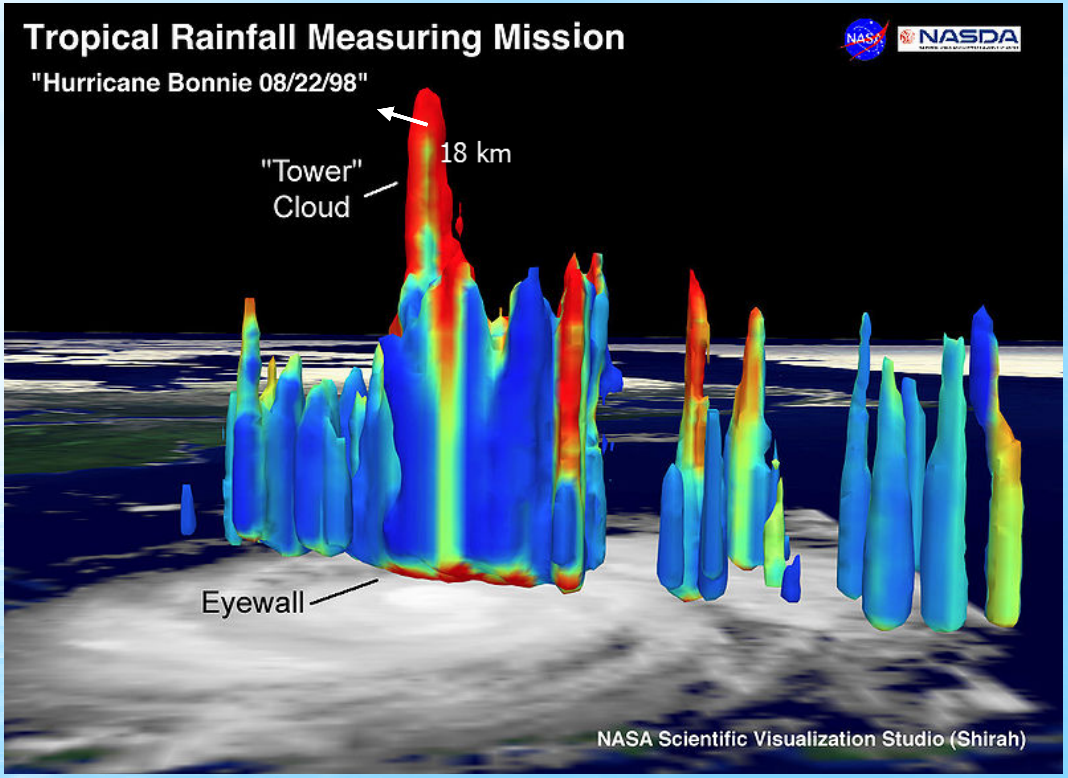
Self-organization of vortical (!) convection [M06] was observed as:

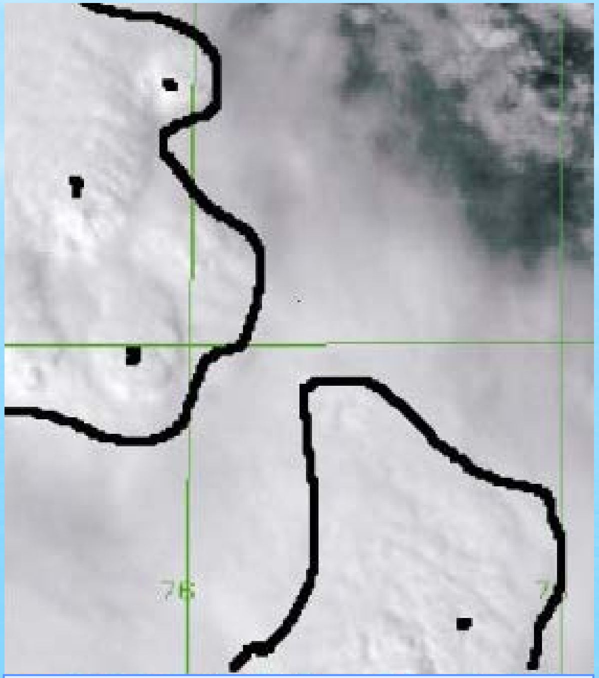
- an enlargement of vortex structures from the size of individual rotating cumulus clouds in the model;
- their induced concentration of absolute angular momentum on the system scale circulation;
- their merging with each other to yield newly forming larger vortices and intensifying circulation on the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

Vorticity−mergers at 925hPa



NEW SCENARIO FOR TROPICAL CYCLONE FORMATION: THE MAIN ACTORS – Vortical Hot Towers (VHTs)





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

VHTs – rotating convective clouds

the lifetime ~ **1 hour** , the horizontal size **10-30 km**

the most intense extend throughout the whole troposphere height **14-16 km**

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 order of magnitude exceeds the planetary rotation)

A WAY TO EXAMINE THE HELICAL NATURE OF TROPICAL CYCLOGENESIS BASED ON NEAR-CLOUD-RESOLVING NUMERICAL SIMULATION [LM10]

L06 : Levina G. V. 2006, *Doklady Earth Sciences*, 411A (9), 1417–1421.
Levina G. V., and Burylov I. A. 2006, *Nonlin. Processes Geophys*., 13, 205-222.

LM10 : Levina G. V., and Montgomery M. T. 2010, *Doklady Earth Sciences*, 434, Part 1, 1285-1289.

Collaborative Studies with Montgomery Research Group

started in 2006 when the results of L06 and M06 were brought in together in seminars in Colorado State University, Fort Collins, CO, USA:

- **concept of vortical hot tower (VHT) route to tropical cyclogenesis** through an upscale vorticity growth proposed by **Montgomery et al. [M06]** represents the most appropriate basis to take into account helical features of moist convective atmospheric turbulence;

- **theoretical ground and numerical approach** developed by **Levina et al. [L06]** for diagnosis of the large-scale helical-vortex instability in tropical cyclogenesis;

- **numerical realization:**
  - non-hydrostatic version of mesoscale models – RAMS, MM5, WRF;
  - near-cloud-resolving simulation, nested grids, 1-3 km horizontal grid spacing;
  - meteorological database on TC observation and investigation.

In our work we use the velocity fields obtained in [M06] to calculate and analyze helical characteristics of the cyclogenesis and intensification process for the problem as posed by [M06].

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

MO6 : Montgomery et al., 2006, *J. Atmos. Sci.*, v. 63, pp. 355-386

The focus was on how an initial midtropospheric mesoscale convective vortex (MCV) may be transformed into a surface-concentrated tropical depression (TD)

A nonhydrostatic cloud model was used to examine the thermomechanics of tropical cyclogenesis by means of RAMS (Regional Atmospheric Modeling System) with 2-3 km horizontal grid spacing:

Nested Grids	3
Number of horiz. grid pts. for grids 1/2/3	a) 40/62/92 b) 60/90/137
Vertical levels	26
Horiz. Coordinate	Cartesian
Horiz. grid incr. for grids 1/2/3	a) 36 km/9 km/3 km b) 24 km/6 km/2 km
Vertical grid increment	400 m at the surface
Vertical grid stretch ratio	1.065
Grid top	22.6 km
Grid time step for 1/2/3	30s/10s/5s
Center latitude	15 degrees
Center longitude	-40 degrees

Cape Verde Islands → (Center latitude / Center longitude)

RAMS SIMULATIONS [M06] TO ANALYZE HELICAL SELF-ORGANIZATION OF CONVECTIVE PROCESSES

Genesis experiments (6 from 19 of M06) analyzed in our current work

Initial MCVortex characterized by max v, **Direct Numerical Simulation !**

No.	Name	Notes
A1	Control	$\Delta x = \Delta y = 2$ km, SST=29°C, max v = 6.6 m s^{-1} at 4 km
* A2	3 km	$\Delta x = \Delta y = 3$ km, SST=29°C, max v = 6.6 m s^{-1} at 4 km
B3	Cape-less (3 km)	$\Delta x = \Delta y = 3$ km, SST=29°C, max v = 6.6 m s^{-1} at 4 km, low-level moisture decreased by 2 g kg^{-1}
C1	No vortex	$\Delta x = \Delta y = 3$ km, SST=29°C
C3	Weak vortex	$\Delta x = \Delta y = 3$ km, SST=29°C, max v = 5.0 m s^{-1} at 4 km
E1	Zero Coriolis	$\Delta x = \Delta y = 3$ km, SST=29°C, max v = 6.6 m s^{-1} at 4 km

No significant differences between A1 and A2.
Experiments A1, A2, B3, and E1 resulted in TDs after ~ 24-48 h .
A1 and A2 - intensification to hurricanes during 72 h.
In B3 and C3 development notable slower than A2.
In E1 no intensification (of TD vortex) after 24 h.
C1: no intense VHTs and no surface spinup.

EXAMINATION OF THE HELICAL NATURE OF TROPICAL CYCLOGENESIS BASED ON SIMULATION RESULTS FROM [M06]

Post processing: Cartesian coordinates - x, y, z ;
i, j - 92x92 – horizontal directions, increment = 3 km;
k - 40 vertical levels, increment = 0.5 km;
Time of process evolution – 72 hours, increment = 10 min.

$$E_{i,j,k} = \frac{1}{2}\left(\vec{V}\right)^2_{i,j,k} \quad , \quad \varepsilon_{i,j,k} = \frac{1}{2}\left(curl\vec{V}\right)^2_{i,j,k} \quad , \quad H_{i,j,k} = \left(\vec{V} \bullet curl\vec{V}\right)_{i,j,k}$$

3D kinetic energy, enstrophy and helicity densities

$\langle E \rangle \; , \; \langle \varepsilon \rangle \; , \; \langle H \rangle$ - integral kinetic energy, enstrophy and helicity normalized by number of grid points

Integral kinetic energy $\langle E^P \rangle$ and $\langle E^S \rangle$ separately to identify the helical feedback

Vertical velocity, vorticity and helicity – convection/VHTs

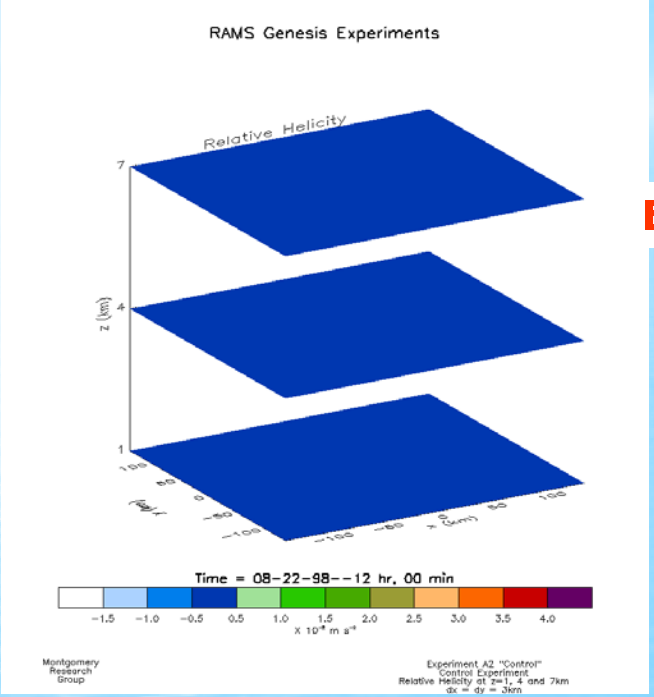
Horizontal helicity $\langle H_{xy} \rangle = \langle H_x \rangle + \langle H_y \rangle$ – vertical wind shear

Hydro- and thermodynamic fields in Cartesian and cylindrical coordinates, azimuthal averages, and a number of other characteristics

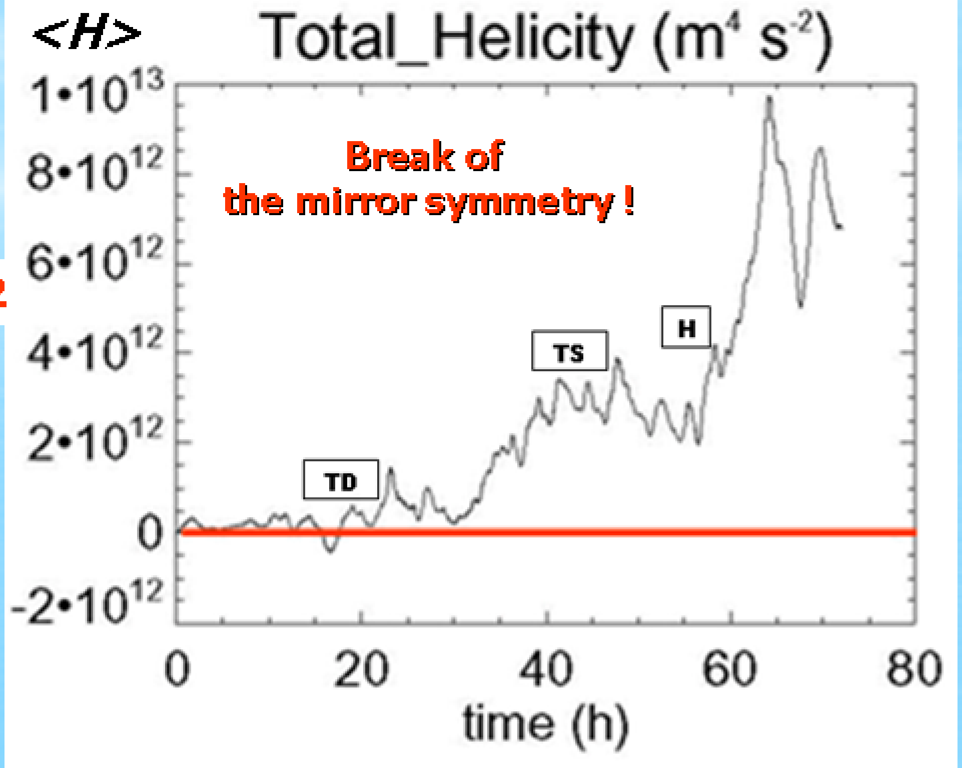
HELICITY EVOLUTION DURING 72 HOURS OF TC FORMATION

LM10 : Levina G.V., and Montgomery M.T., 2010, *Dokl. Earth Sciences.*, v. 434, part 1, pp. 1285-1289

3D HELICITY DENSITY



Expt. A2



Local helicity values

Time (hrs)	H_{local} (m s^{-2})
0 ÷ 10-12	0.002 – 0.004
12 ÷ 25-30	0.008 – 0.4
30 ÷ 72	0.5 – 1.0

Intensity of the forming TC

Max az-mean surface tangential wind

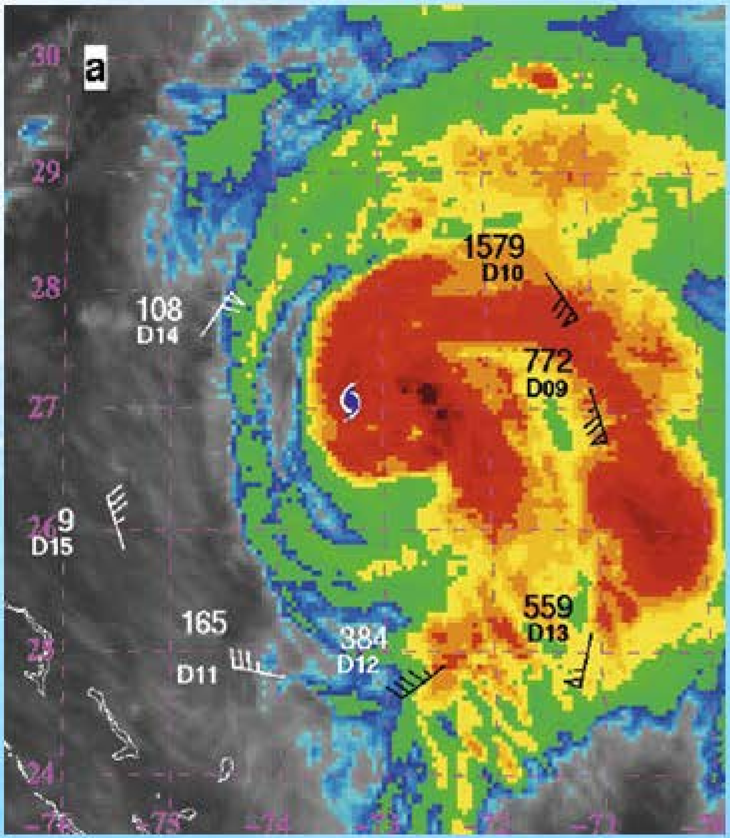
t = 16-18 h	9 m s^{-1}	**TD** formation,
t = 45 h	17.2 m s^{-1}	**TS** formation,
t = 56 h	33.4 m s^{-1}	**H** formation,
t = 60-63 h	42.5 m s^{-1}	**H** Maximal wind

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·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·s^{-1}.

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

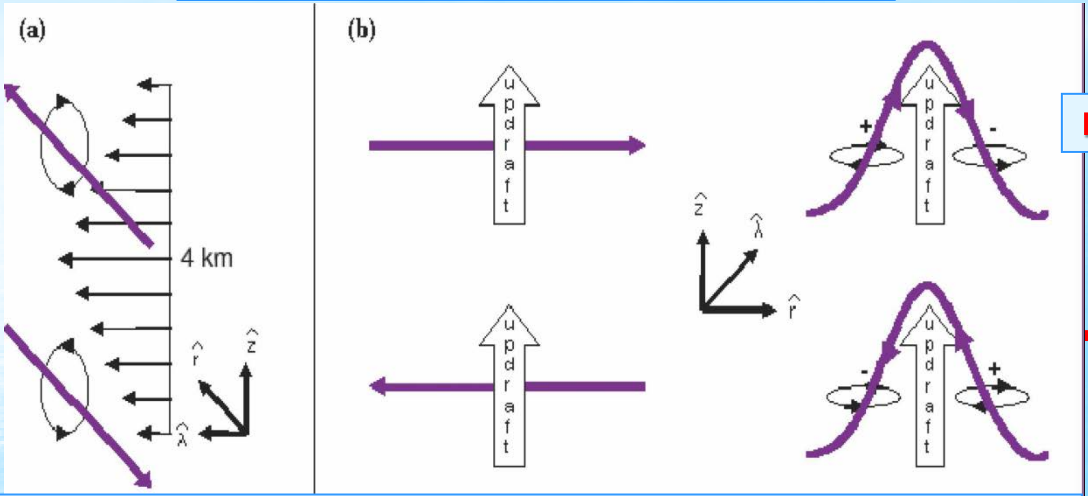
MV 2010, *J. Atmos. Sci.*, 67, 274–284. The study of helicity was extended to 8 tropical cyclones sampled by NASA during CAMEX (1998/2001)

VERTICAL VORTICITY GENERATION and AMPLIFICATION by VHTs
THE LINKAGE OF VORTEX LINES – HELICITY

1. In the presence of the initial Mesoscale Convective Vortex (MCV) – Expt. A1 [M06]

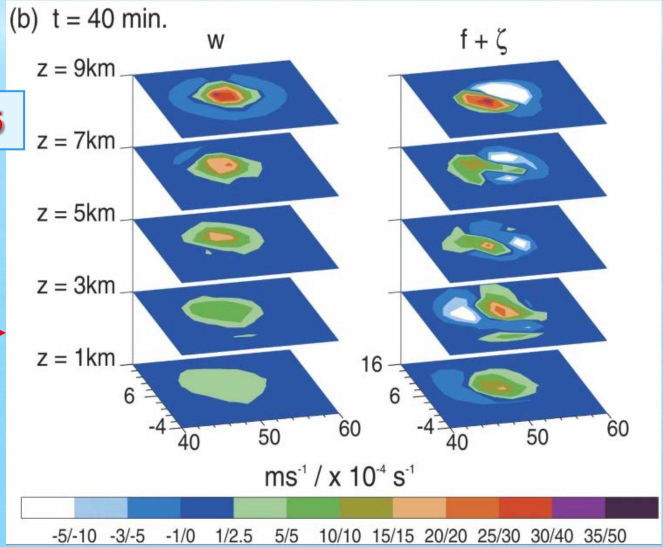
Tilting and stretching of vortex lines

VHT – a vortex dipole



(a) Radial vorticity generated by vertical shear profile of the MCV, V_{max} at z = 4 km

M06



2. NO initial MCVortex – Expt. C1 [M06]

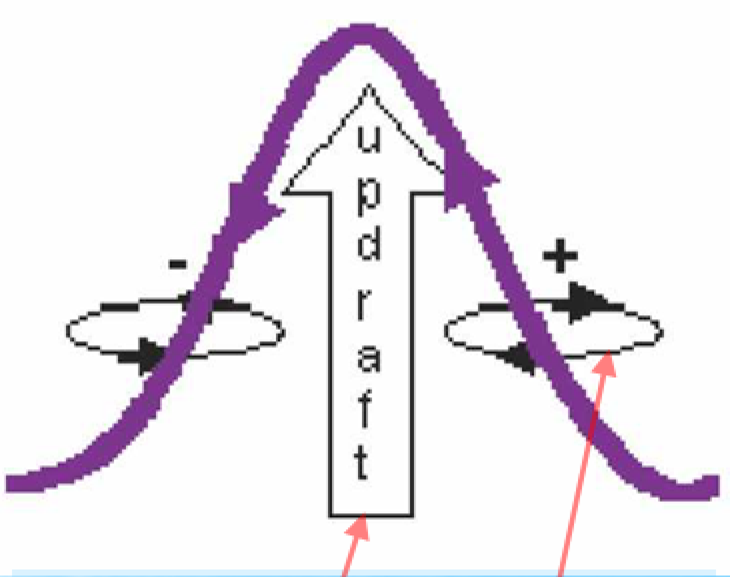
A warm convective updraft creates a horizontal temperature inhomogeneity that results in a local overturning circulation. The circulation is also characterized by vertical shear profile, and **the vertical component of vorticity can be generated very similarly.**

In both cases, this is an effective way for helicity generation on cloud convection scales

VHTs – THE CONNECTORS OF CIRCULATIONS

Levina G.V. Helical Organization of Tropical Cyclones. Preprint NI13001-TOD. 2013. Isaac Newton Institute, Cambridge, UK.

VORTICAL HOT TOWERS WORK AS 'DYNAMICAL STAPLES'



VHT is helical 'by definition'

$$H_z = V_z \left(curl\,\vec{V} \right)_z$$

Each individual VHT:

- contributes to both the horizontal and vertical motion,
- generates a local linkage of vortex lines HELICITY

The vertical contribution of helicity, H_z is the indicator of the rotating vertical flows

In our work, we consider the broad spectrum of such structures rather than emphasizing the most intense updrafts

VHTs population contributes to both the horizontal and vertical motion:

- transforms the horizontal vorticity generated by vertical shear profile of the primary tangential circulation into the vertical vorticity and amplifies it by stretching;
- contributes to both the formation and intensification of the secondary overturning circulation, and intensification of the tangential circulation;
- tightly links the primary and secondary circulations on the TC vortex mesoscales.

HELICAL NATURE OF TROPICAL CYCLOGENESIS : WHEN WILL A NASCENT VORTEX BECOME SELF-SUSTAINING ?

LM10 : **Levina G.V., and Montgomery M.T., 2010, *Dokl. Earth Sciences*., v. 434, part 1, pp. 1285-1289**

LM14 : **Levina G.V., and Montgomery M.T., 2014, *Dokl. Earth Sciences*., v. 458, part 1, pp. 1143-1148**

FROM <H>≠0 TO THE VORTEX DYNAMO

- **The non-zero integral helicity found in our works of 2009-2010 was the first example of such phenomenon in a real natural system – the tropical atmosphere of the Earth ;**

  during a long time it was only a hypothesis whether <H>≠0 is possible.

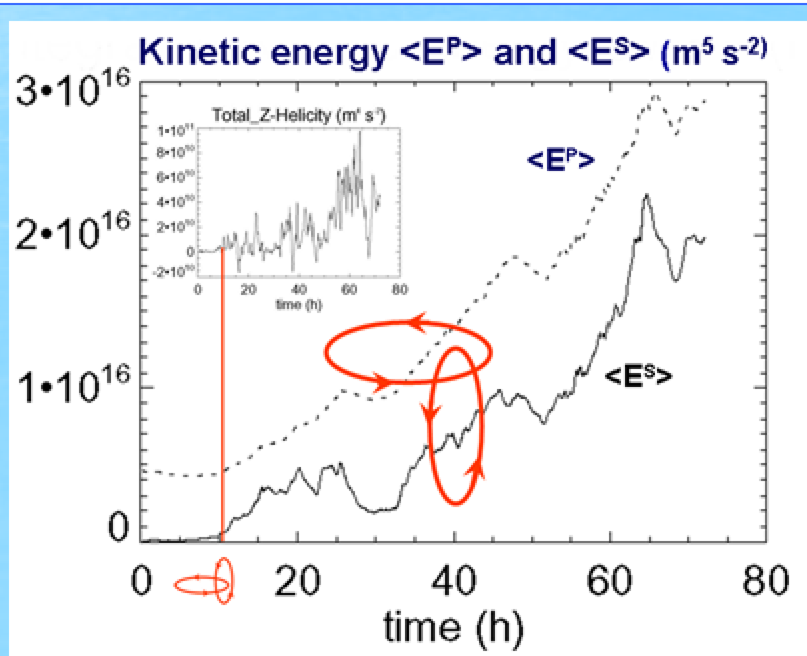
  However, this does not necessarily mean that the large-scale vortex instability is underway.

  In fact, this only means that there exists a persistent departure of the mirror symmetry in turbulence during TC formation. We have a case of the helical turbulence. The theory of turbulence gives a few examples of large-scale instabilities in helical turbulence, between them – the turbulent vortex dynamo.

- **Diagnosis of the large-scale vortex instability: analysis of the energetics**

t=12 h:

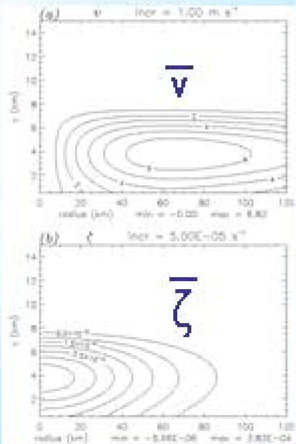
1. **Mutual intensification of the primary and secondary circulation starts**
2. **The Z-helicity increases**



What is flow evolution behind these changes at t=12 h ?

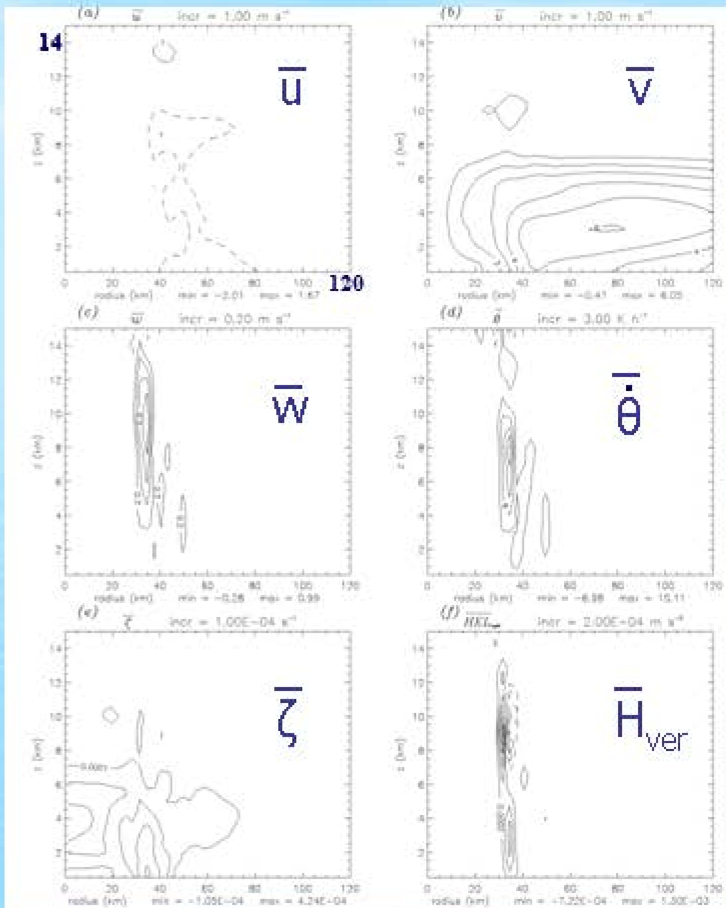
FORMATION OF THE SECONDARY OVERTURNING CIRCULATION IN (u) – UP (w) – OUT (u) FLOW during t = 10 – 12 h

t = 0 h

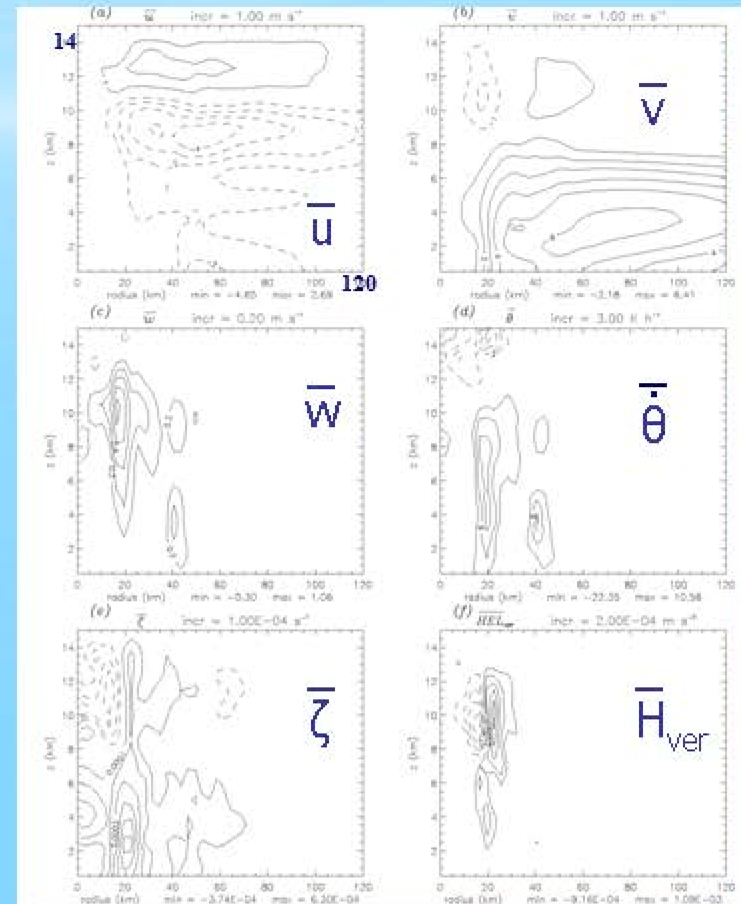


Initial MCV

t = 10 h



t = 12 h



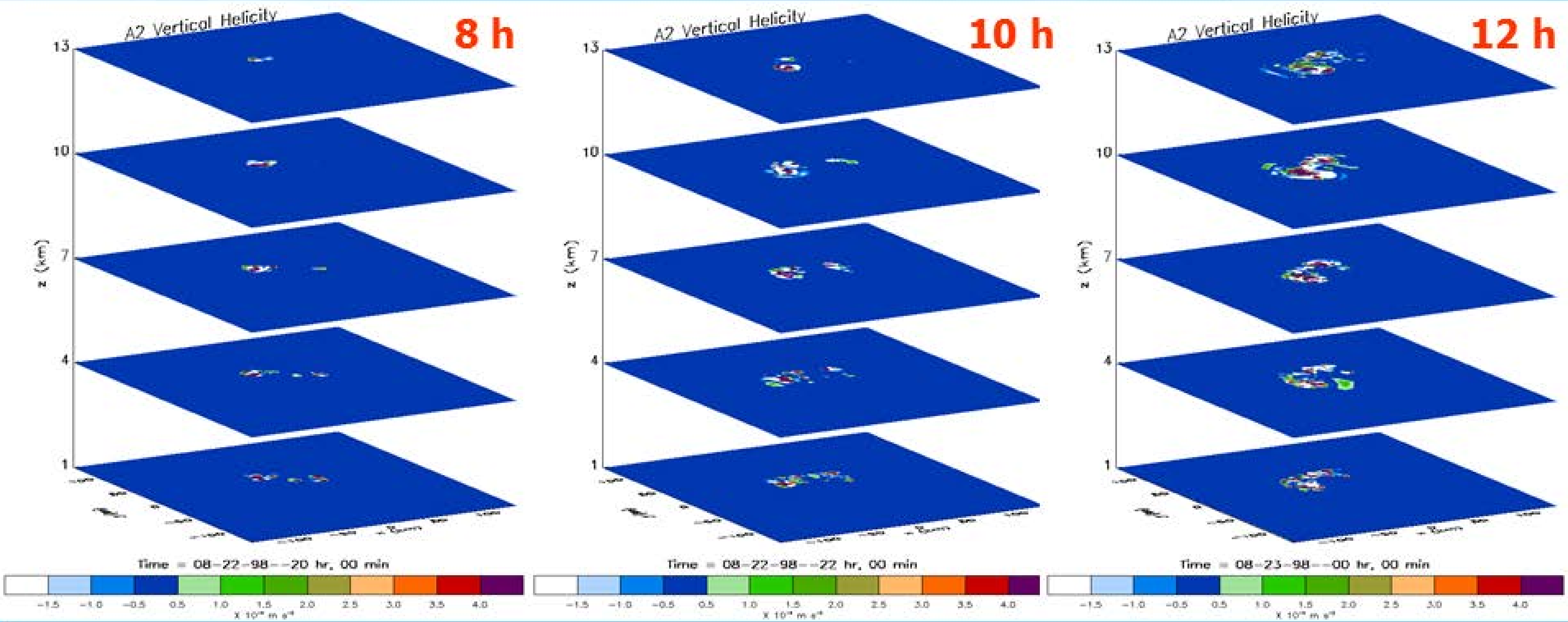
Azimuthally averaged fields: VHTs are well recognized in w, θ, and H_{ver}

u – the radial velocity, v – the tangential velocity, w – the vertical velocity,

θ – the diabatic heating rate, ζ – the relative vorticity, H_{ver} – the vertical contribution of helicity.

FORMATION OF THE SECONDARY OVERTURNING CIRCULATION
VHTs in the VERTICAL HELICITY FIELD : t = 8; 10; 12 hours

Expt. A2: XY – 276 x 276 km, Z – 13 km shown



8 h: one intense rotating updraft reaches 13 km in height ; **10-12 h:** a population of VHTs is forming

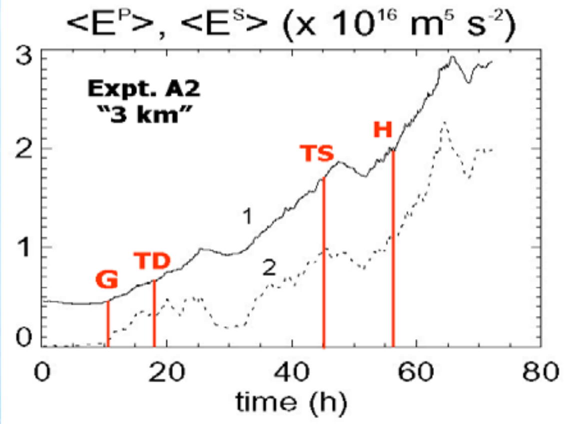
THE VERTICAL HELICITY ALLOWS TO DISCERN VERTICAL ROTATING FLOWS:

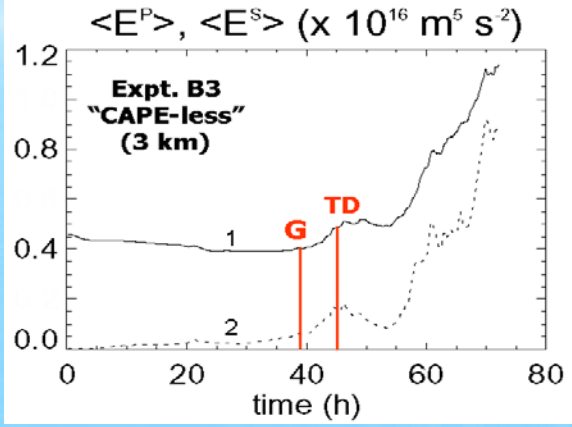
+ cyclonic updrafts or/and anticyclonic downdrafts

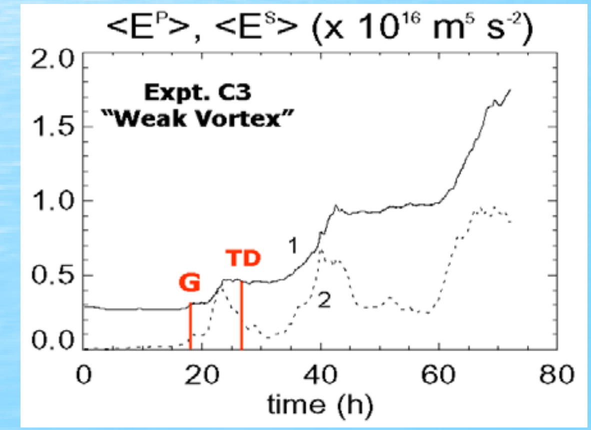
- cyclonic downdrafts or/and anticyclonic updrafts

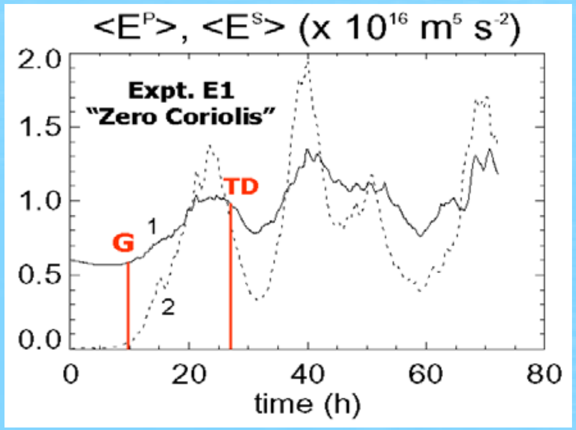
WHEN WILL A NASCENT VORTEX BECOME SELF-SUSTAINING ?
GENESIS TIME – G ?

The forming TC becomes self-sustaining when the primary (1) and secondary (2) circulations become linked by rotating convective cores – Vortical Hot Towers. The mutual intensification of (1) and (2) starts – G.









A FEW HOURS LATER (!)
the evolving instability results in a surface-concentrated tropical depression (TD) vortex.

IS TC GENESIS A THRESHOLD PHENOMENON ?

Experiment		Total Helicity $< H >$
H	A2	$3.3 \times 10^{11}\ m^4\ s^{-2}$
TD	B3	$2.0 \times 10^{11}\ m^4\ s^{-2}$
None	C1	$2.0 \times 10^{10}\ m^4\ s^{-2}$
TD	C3	$2.5 \times 10^{11}\ m^4\ s^{-2}$
TD	E1	$3.5 \times 10^{11}\ m^4\ s^{-2}$

Helical Organization of Tropical Cyclones. NI13001-TOD.

Table 2. The highest values of Total Helicity attained due to the initial break of mirror symmetry generated by the initial conditions.

Does there exist a threshold for the large-scale helical-vortex instability in the atmosphere (as it does in the Dynamo theory and vortical RB convection simulation)?

CONTROLLING OF TROPICAL CYCLOGENESIS ?

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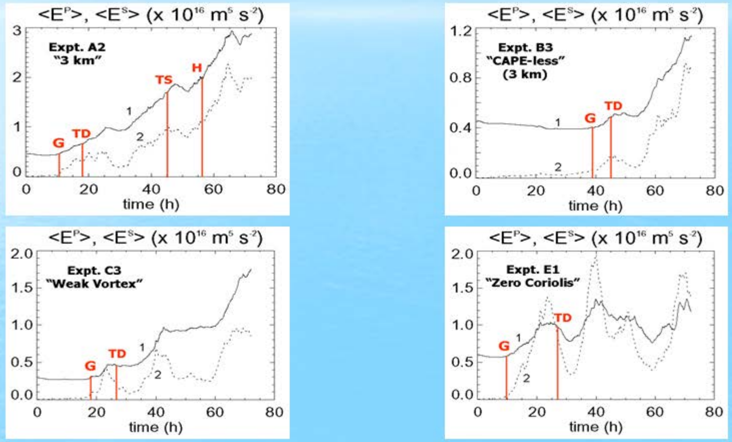

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Does there exist a threshold for the large-scale helical-vortex instability in the atmosphere (as it does in the Dynamo theory and vortical RB convection simulation)?

The above questions are also about a possibility to try controlling tropical cyclogenesis

1. Though Expt. C1 [M06] did not bring any vortex organization it showed how helicity is generated by a single VHT initiated by a local heating at low levels – the 'warm bubble method'

2. **The idea of controlling by helicity generation:**
to affect the linkage of the primary and secondary circulation near the time moment **G**

TESTING ON REAL ATMOSPHERIC DATA
AND
PRACTICAL PERSPECTIVE

Genesis of Hurricane Karl (2010)

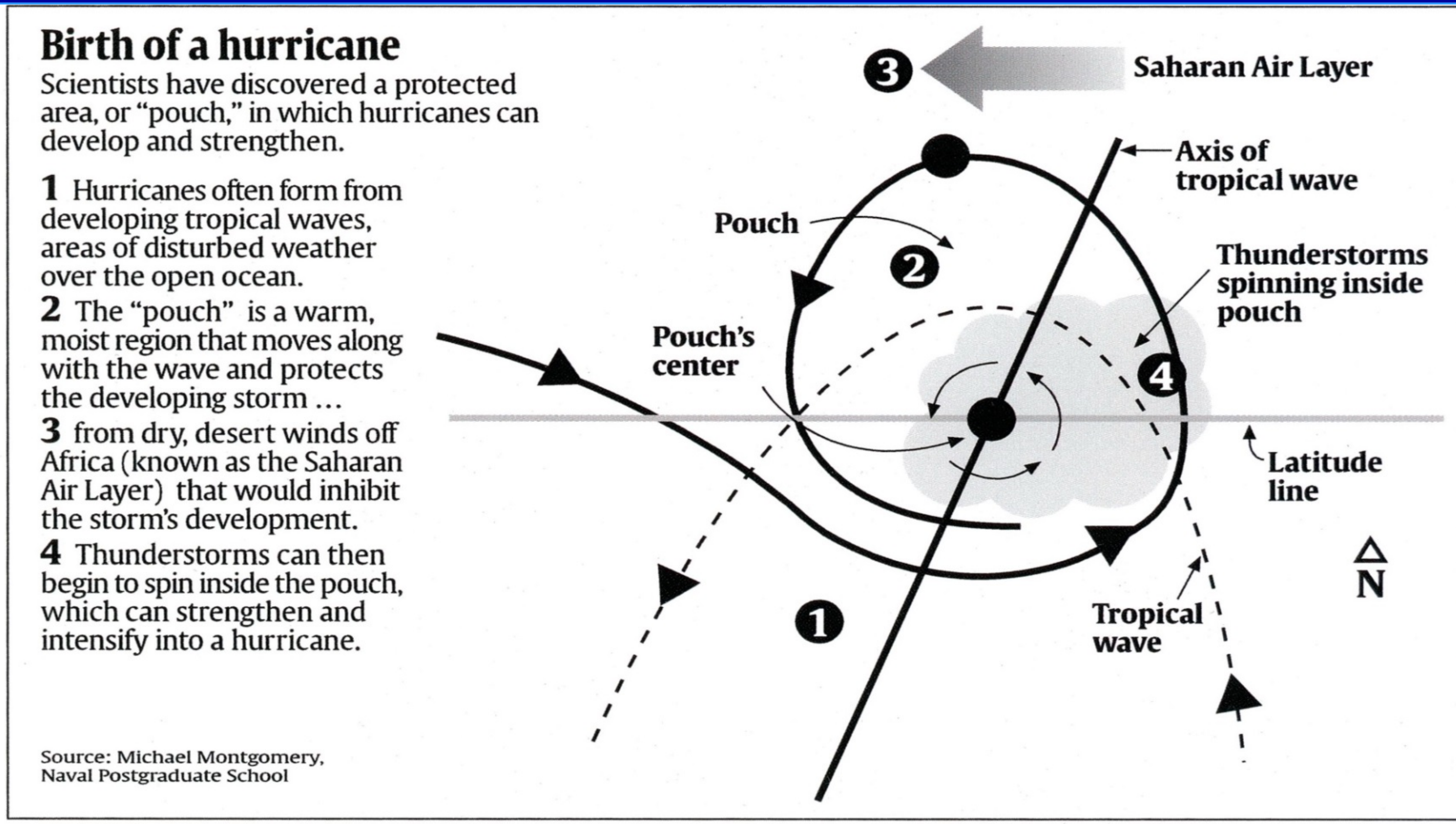
Alt. 14500 m. Flight RF19. NSF/NCAR G-V
14 Sep 2010. GL's photos

MARSUPIAL PARADIGM . MARSUPIAL POUCH TRACKING

"...the marsupial ideas are the only ones that specifically connect wave dynamics, convection, moistening, and genesis... "

John Molinari, University at Albany, SUNY, Albany, NY;
January 2015 (private correspondence))

From a paper «Storm alert: 'Pouches' protect embryonic hurricanes». By Doyle Rice, USA TODAY, August 18, 2008.



Dunkerton, T. J., M. T. Montgomery, and Z. Wang. 2009, *Atmos. Chem. Phys.*, 9, 5587-5646.

Wang, Z., M. T. Montgomery, and T. J. Dunkerton. 2009, *Geophys. Res. Lett.*, 36, L03801.

EXPERIMENTS – PREDICT, GRIP, IFEX

August 15 – September 30, 2010

Three Field Campaigns in the Tropical Atlantic : Hurricane Season 2010

National Science Foundation
PREDICT
Pre-Depression Investigation of Cloud-systems in the Tropics

National Aeronautics and Space Administration
GRIP
Genesis and Rapid Intensification Processes

National Oceanic and Atmospheric Administration
IFEX
Intensity Forecasting EXperiment

Coordination of research flights of PREDICT, GRIP and IFEX into the 'pouches' with taking into account research facilities of each group allowed collecting a versatile amount of data.

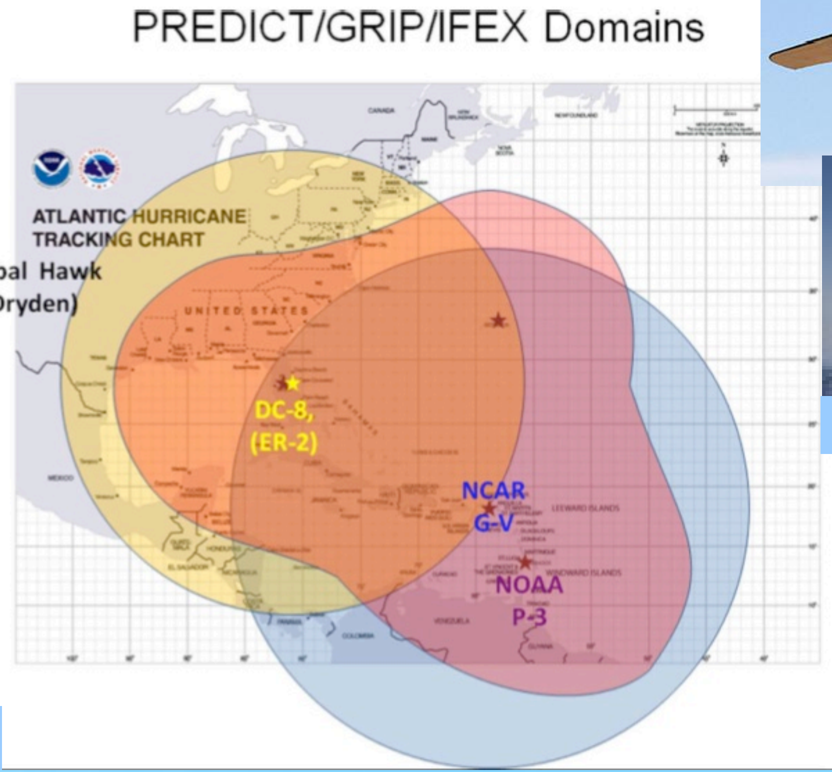
EXPERIMENTS – PREDICT, GRIP, IFEX
August 15 – September 30, 2010

7 Aircraft-participants

Unmanned

Global Hawk (h≈20 km)

PREDICT/GRIP/IFEX Domains



WB-57 (h≈21.5 km)

Gulfstream-V (h≈15.5 km)

Gulfstream-IV (h≈12.5 km)

DC-8 (h≈12.5 km)

NOAA's "Hurricane Hunter" Aircraft
Lockheed WP-3D Orion (h≈8.3 km)

FIELD EXPERIMENT NSF-PREDICT 2010

Saint Croix, U.S. Virgin Islands, August 15 – September 30, 2010

Pre-Depression Investigation of Cloud-systems in the Tropics

With participation of the Earth Observing Laboratory, NCAR
Lead Principal Investigator & Science Director – Dr. M.T. Montgomery

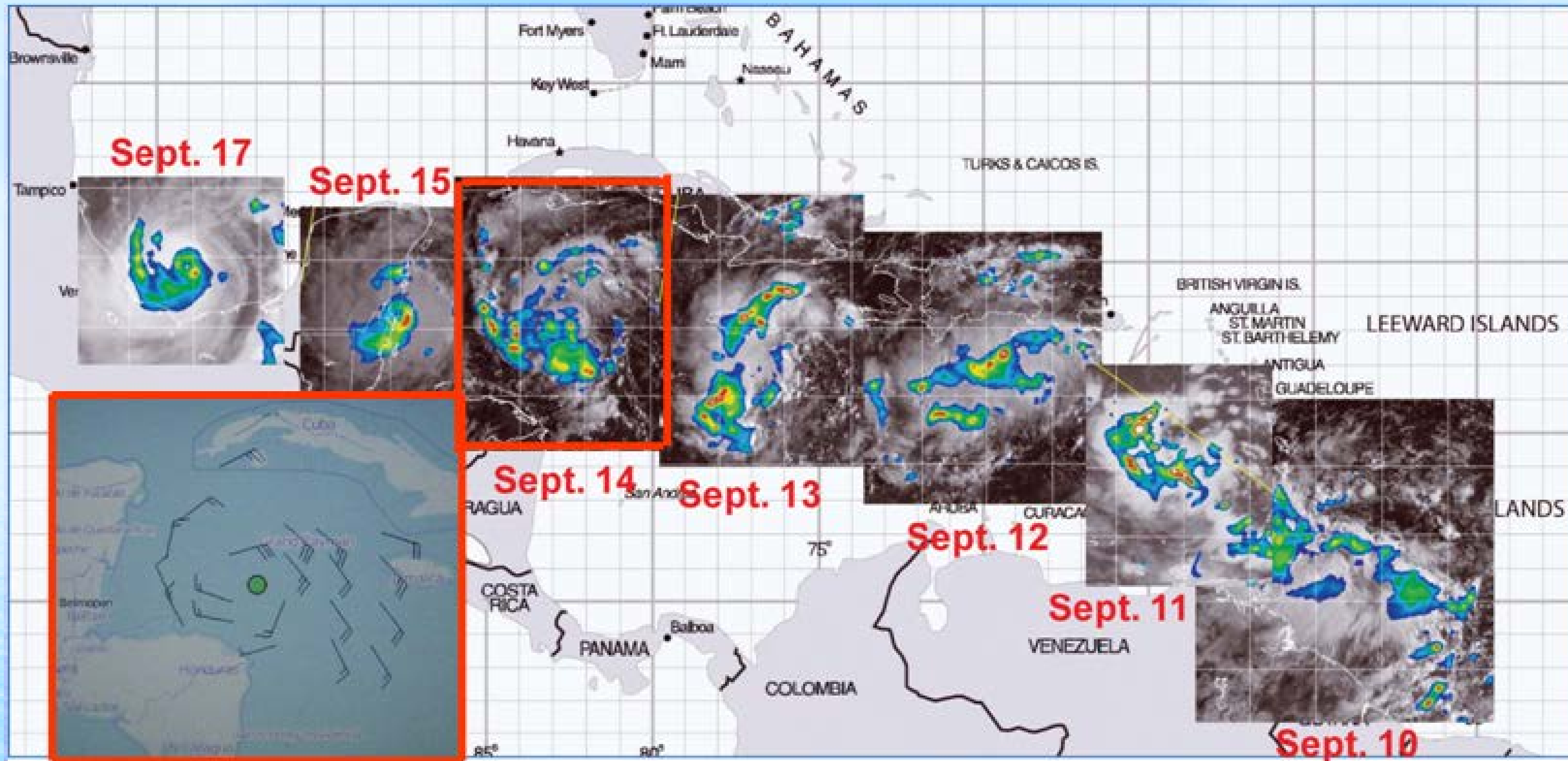
65 participants

GOALS of the EXPERIMENT :

- **Investigations of deep convection – VHTs**
- **Testing the "Marsupial Paradigm"**-
  a series of hypotheses on tropical cyclogenesis in a critical layer of tropical easterly waves
  (Dunkerton, Montgomery, Wang, 2009, Atmos. Chem. Phys.)
- **Testing the "Marsupial Pouch Tracking"**
  high accuracy predicting of genesis location – up to 3 days with an error < 200 km
  (Wang, Montgomery, Dunkerton, 2009, Geophys. Res. Lett.)

Convincing confirmation, Montgomery et al. (February 2012, *Bull. Amer. Meteor. Soc.*)
P. 169: " ... an enhanced ability to anticipate the path along which genesis may occur, even though **the exact timing of genesis remains uncertain** due to the chaotic influence resulting from moist convection"

HURRICANE KARL (2010) – GENESIS, Sept. 14



A protected area of potential cyclogenesis ('Marsupial Pouch') has been monitored by aircraft of NASA, NOAA, NSF-NCAR, and USAF since Sept. 10. RF19 was the 6th NSF-NCAR flight and detected the genesis :

- the closed surface wind circulation was found,
- Tropical Storm Karl was born with max wind ~ 20 $m \cdot s^{-1}$

Pictures are borrowed from the reports of PREDICT Science Director M.T. Montgomery and RF19 Mission Scientist C. López-Carillo, and Montgomery et al. (2012, *BAMS*) .

PRACTICAL & FUNDAMENTAL PERSPECTIVE

- **The study contributes to the development of a universally accepted definition of tropical cyclogenesis**

- **Similar analysis for NSF-PREDICT 2010 data**

  The Marsupial Paradigm answers the question 'WHERE ?' about TC genesis and indicates that 'SWEET SPOT', within which a high-resolution numerical analysis of helical self-organization should be applied to answer 'WHEN ?'

- **Examination of turbulent statistics – energy and helicity transfer between flows of different scales**

  As our discussion via **TStorms.org** professional world forum in May-June 2014 showed, there were not attempts of such analysis for TC Genesis.

Recently, we joined efforts with Greg King (*Institute of Marine Sciences (ICM-CSIC), Passeig Marítim Barceloneta 37-49, 08003 Barcelona, Spain*) and our contribution

A TURBULENCE STATISTICAL ANALYSIS OF SIMULATIONS OF TROPICAL CYCLOGENESIS

by Gregory P. King[1], G. V. Levina[2] & M. T. Montgomery[3] has been accepted for **oral presentation at ETC15.**

CONTROLLING OF TROPICAL CYCLOGENESIS ?

We are looking for collaboration to investigate:

- **how helicity is generated on cloud scales;**
- **how this process can be controlled,** e.g. by the 'warm bubble method'

1. Numerical simulation with very high horizontal and vertical resolution of 100 m or so;

[M06] space resolution 2-3 km (horizontal) and ≥ 0.4 km (vertical) was not enough.

2. Laboratory experiment

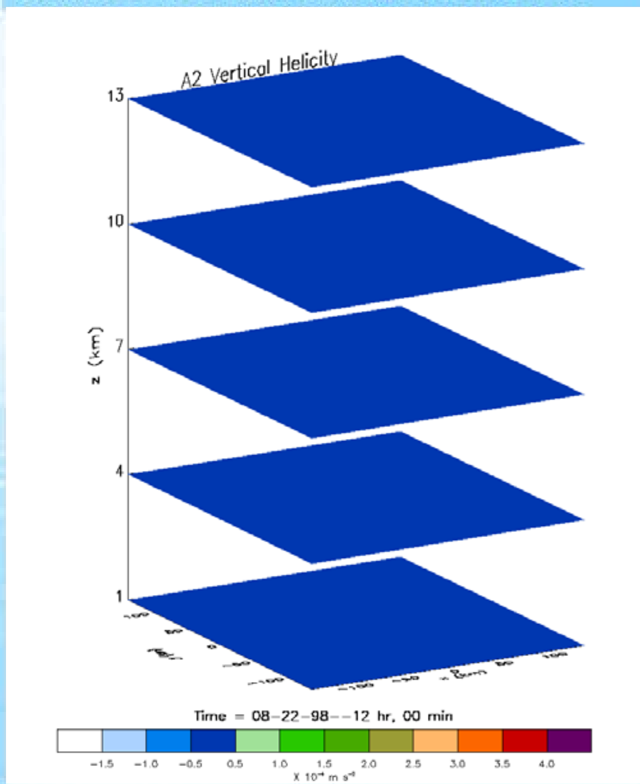
The 'warm bubble method' (as in [M06])

P. 361: "… a local heating was applied for 300 s in order to create a warm bubble (temperature surplus 2 K) at low levels ($z = 2$ km), 50 km to the east of the MCV center. The bubble method serves to stimulate cumulus convection in the local environment of the MCV. …"

THANK YOU FOR YOUR ATTENTION !

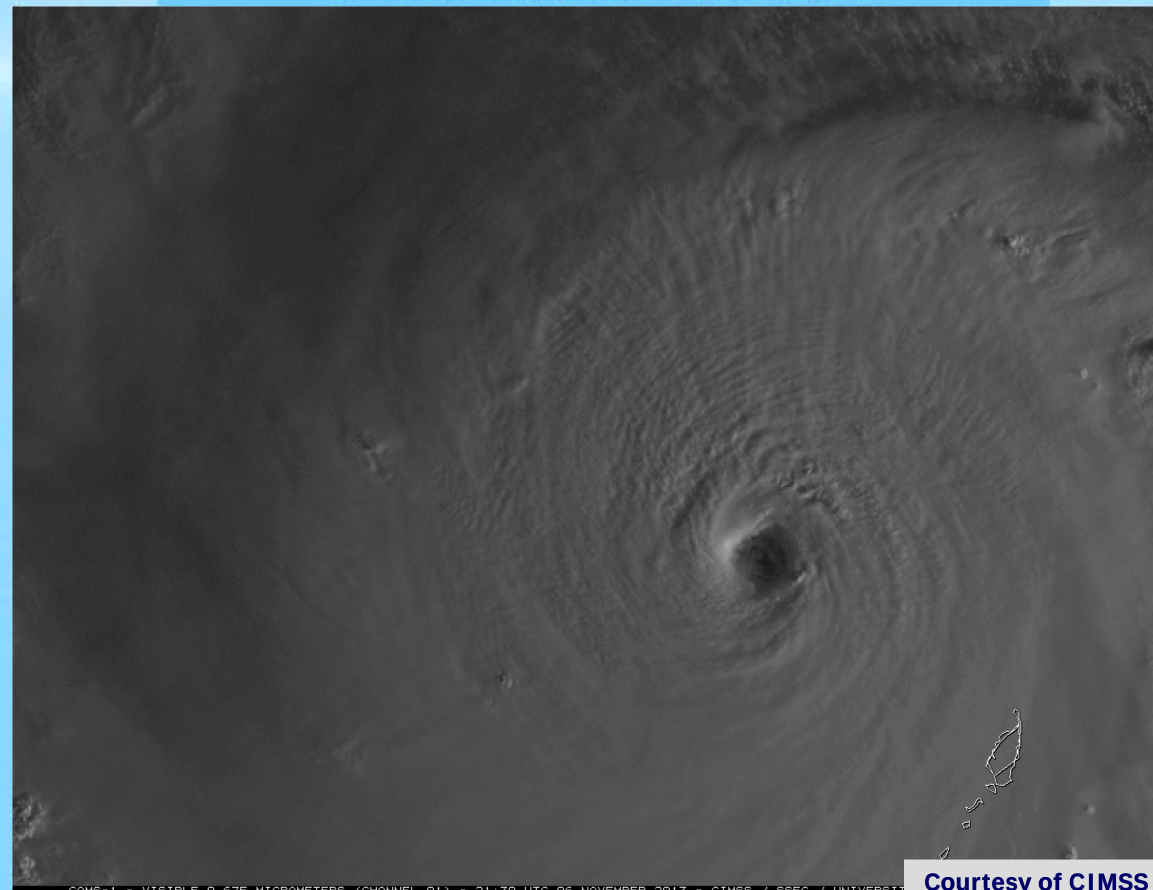
Expt. A2. VERTICAL HELICITY: ROTATING CONVECTION

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



08-23-98	00 hr	G		6 m/s
08-23-98	06 hr	TD		9 m/s
08-24-98	09 hr	TS	>	17 m/s
08-24-98	20 hr	H	>	33 m/s
08-25-98	03 hr	Max Wind		43 m/s

SUPER TYPHOON HAIYAN (2013) : ROTATING CONVECTION



Courtesy of CIMSS

PRIOR TO LANDFALL – 5 CAT. INTENSITY

10-minute sustained wind 64-76 m/s

1-minute sustained wind 94 m/s

Computer facilities used for RAMS simulation and post-processing in Montgomery Research Group, NPS, Monterey, CA, USA

Dual processor Linux workstation has
- two AMD Opteron CPUs At 2.00GHz each
- 4 GB of RAM
- 1 TB of hard drive space

It runs CentOS 4.7 Linux

Saffir–Simpson hurricane wind scale

Category	Wind speeds
Five	≥70 m/s, ≥137 knots ≥157 mph, ≥252 km/h
Four	58–70 m/s, 113–136 knots 130–156 mph, 209–251 km/h
Three	50–58 m/s, 96–112 knots 111–129 mph, 178–208 km/h
Two	43–49 m/s, 83–95 knots 96–110 mph, 154–177 km/h
One	33–42 m/s, 64–82 knots 74–95 mph, 119–153 km/h

Related classifications

Tropical storm	18–32 m/s, 34–63 knots 39–73 mph, 63–118 km/h
Tropical depression	≤17 m/s, ≤33 knots ≤38 mph, ≤62 km/h