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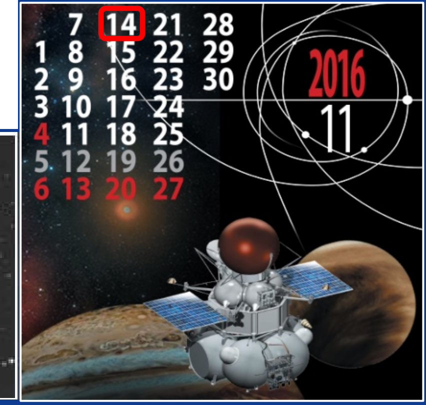

Москва, 14 ноября 2016

СПИРАЛЬНЫЙ ТРОПИЧЕСКИЙ ЦИКЛОГЕНЕЗ:
ВОЗМОЖНОСТЬ УПРАВЛЯТЬ ФОРМИРОВАНИЕМ УРАГАНОВ ?

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OUTLINE

Introduction.
Tropical Cyclogenesis, Helicity, Turbulent Vortex Dynamo

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

REFERENCES

Our publications and presentations can be found:

https://www.researchgate.net/profile/Galina_Levina

https://iki-rssi.academia.edu/GalinaLevina

TROPICAL CYCLONE

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:

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

TROPICAL CYCLOGENESIS

A universally accepted definition of tropical cyclogenesis does not exist.

Introduction to Tropical Meteorology. 2011. *2nd Edition.*
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 …"

Montgomery et al., *BAMS*, February 2012. 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."

WE PROPOSE HOW:

– THE EXACT TIMING OF GENESIS CAN BE IDENTIFIED;

– THE CHAOTIC INFLUENCE FROM MOIST CONVECTION CAN BE QUANTIFIED.

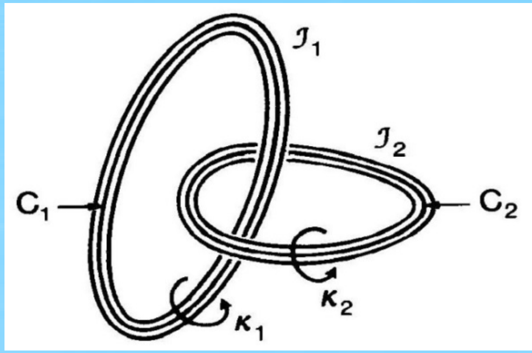
HELICITY OF VELOCITY FIELD

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 $\langle \vec{\mathbf{V}} \cdot \mathbf{curl}\, \vec{\mathbf{V}} \rangle$ 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)**

A PRE-HISTORY: THE USSR , 1983-1991

1983: THEORETICAL HYPOTHESIS ON THE TURBULENT VORTEX DYNAMO

Moiseev S.S., Sagdeev R.Z., Tur A.V., Khomenko G.A., and Yanovsky V.V.
A theory of large-scale structure origination in hydrodynamic turbulence.

Moiseev S.S., Sagdeev R.Z., Tur A.V., Khomenko G.A., and Shukurov A.M.
Physical mechanism of amplification of vortex disturbances in the atmosphere.
(Theoretical estimations for TC formation in the Earth's atmosphere were given).

The theory gives a threshold for the large-scale instability.
Threshold instabilities can be controlled!

Wide-ranging research program aimed at testing the hypothesis was initiated in several scientific centers across the USSR:

- theoretical, experimental, and numerical modeling of developed turbulent convection in rotating non-uniformly heated fluids with a focus on conditions and ways of generation of intense large-scale vortex structures;
- **search for ways of controlling the formation of such structures;**
- expeditions "Typhoon-89" and "Typhoon-90" in the tropical Pacific.

SUMMARY OF 1983-1999

Following my first visit to the USA
– The IUTAM / IUGG Symposium on Developments in Geophysical Turbulence, NCAR, Boulder, 1998 –
we got an invitation to submit a review-research article :

Levina G.V., Moiseev S.S., Rutkevich P.B.

Hydrodynamic alpha-effect in a convective system

In: “*Advances in Fluid Mechanics”, Nonlinear Instability, Chaos and Turbulence.*
Vol. 2. P. 111–162 . WITPress, Southampton. 2000.

Results of theoretical and numerical investigations, and laboratory and field experiments obtained by several Russian research teams were reviewed.

A numerical approach for diagnosis of the large-scale helical-vortex instability in a convectively unstable rotating fluid was proposed:
analysis of the energetics (kinetic energy) and topology (helicity).

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

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

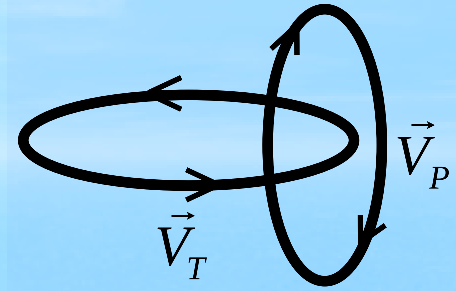
Convective

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

Helical

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

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



Large-scale helical vortex

$$\vec{V}=\vec{V}_T+\vec{V}_P,\qquad \vec{e}=\{0,0,1\}$$

$$\vec{V}_T=\mathrm{curl}\left(\vec{e}\,\psi\right),\quad \vec{V}_P=\mathrm{curl\,curl}\left(\vec{e}\,\phi\right)$$

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

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

- ***C*–terms (a 'vortex-motive' force) 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.**

$\Lambda\neq 0$ – internal volumetric heat release is a binding condition!

Constant temperature gradient is not enough to initiate the large-scale instability!

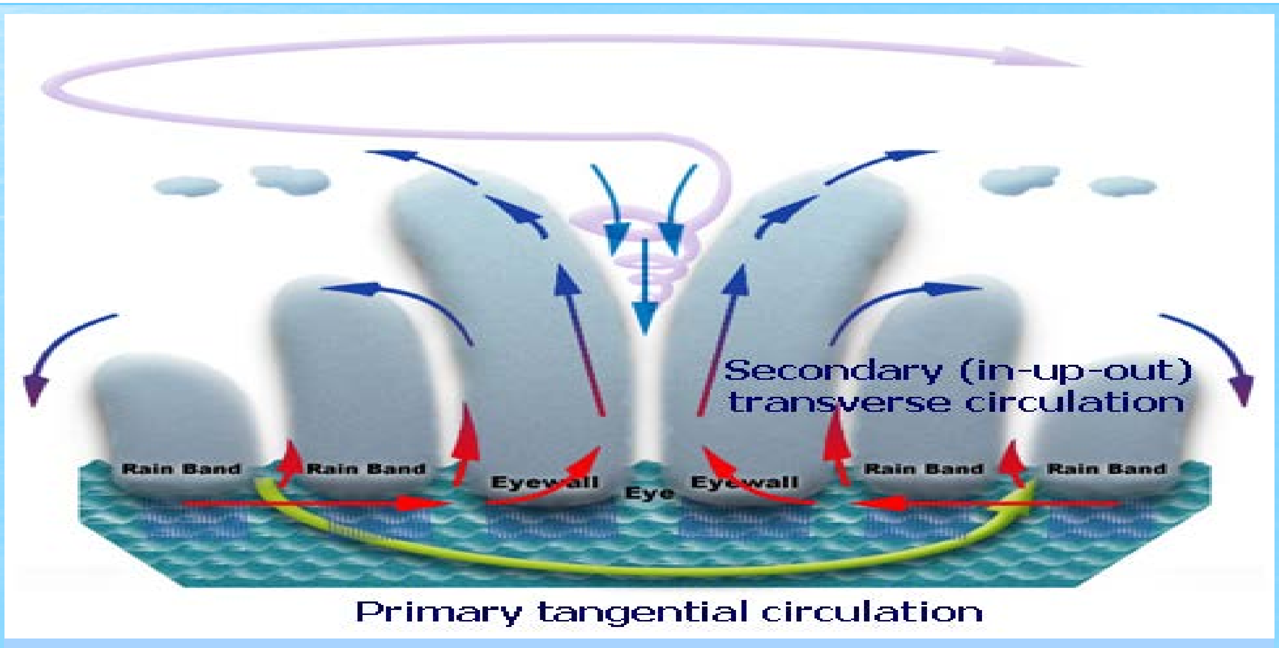
HYPOTHESIS ON THE TURBULENT VORTEX DYNAMO

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)

CLOUD-RESOLVING NUMERICAL SIMULATION OF TROPICAL CYCLONES FORMATION

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

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 :

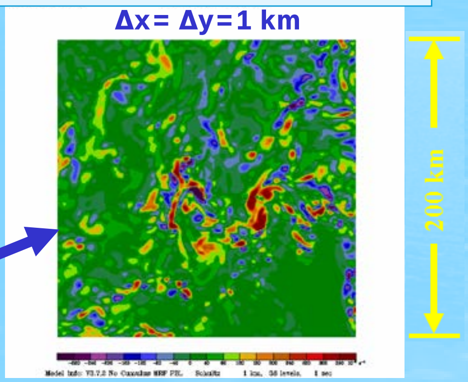
Montgomery M.T., Nicholls M.E., Cram T.A., Saunders A.B. 2006, *J. Atmos. Sci.*, 63, 355-386.

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.

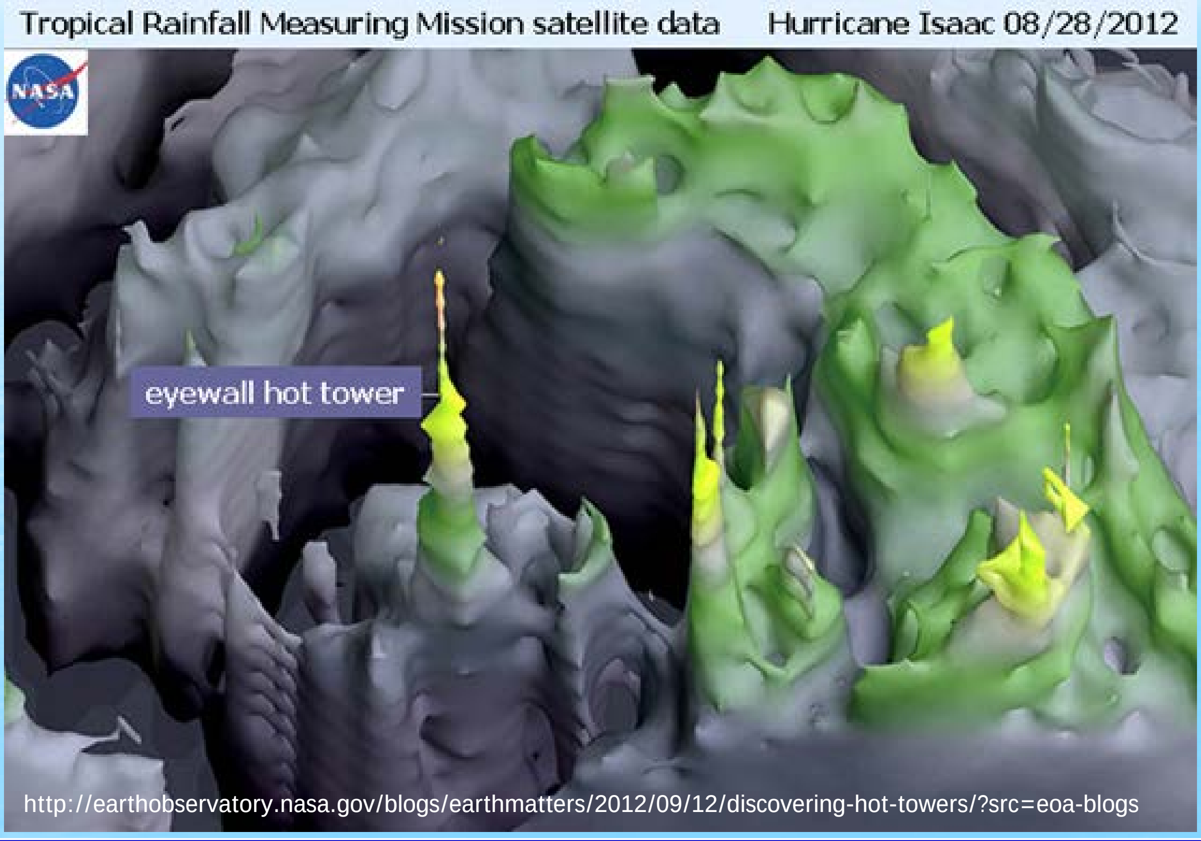
Vorticity−mergers at 925hPa



HOT TOWERS IN THE TROPICAL ATMOSPHERE

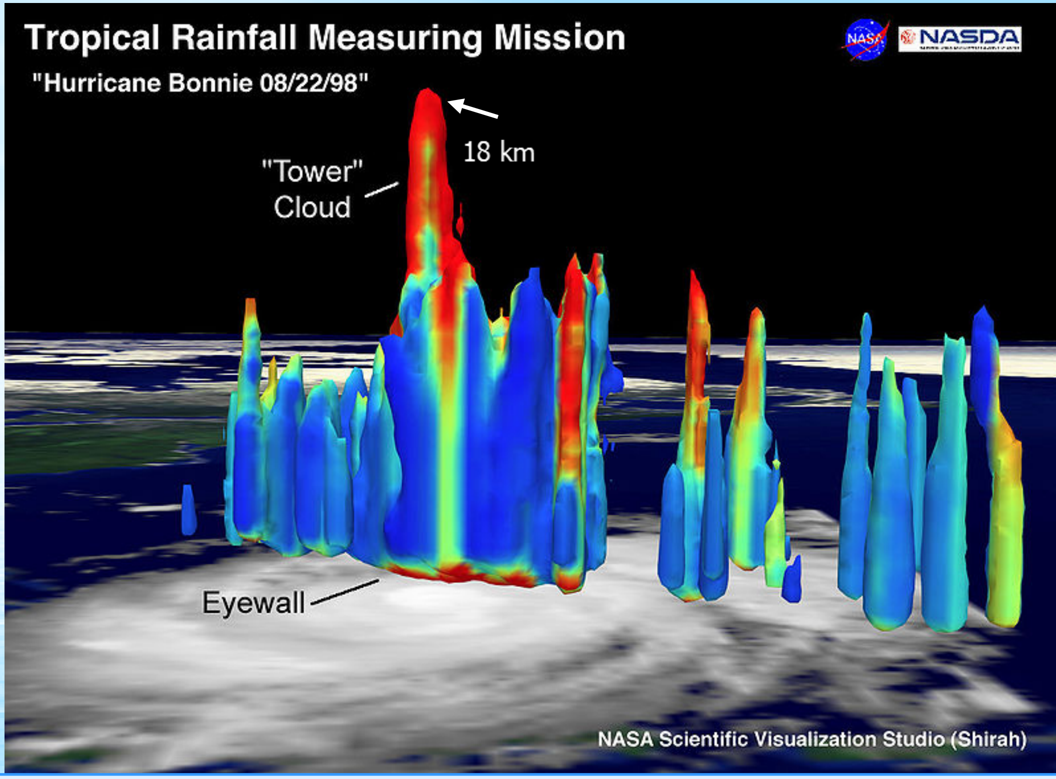
https://en.wikipedia.org/wiki/Hot_tower

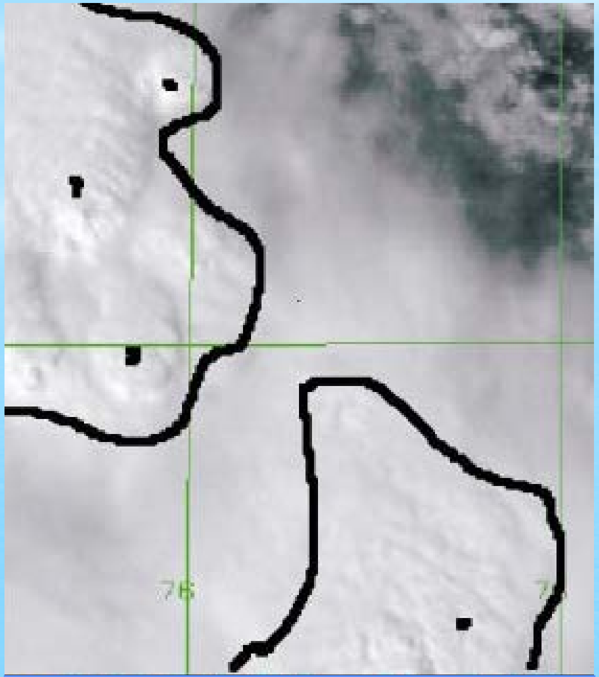
A **hot tower** is a tropical cumulonimbus cloud that penetrates the tropopause. In the tropics, the tropopause typically lies at least 15 kilometres above sea level. These towers are called "hot" because they rise high due to the large amount of latent heat released as water vapor condenses into liquid and freezes into ice.



Riehl and Malkus (1958) implicated the role of **HOT TOWERS** in the vertical heat transport and mass flux in the tropical atmosphere.

2004: DISCOVERY OF VORTICAL HOT TOWERS (VHTs)





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

VHTs – rotating convective clouds

The **'HOT'** comes not from the temperature of the air but because of the **LATENT HEAT RELEASE** due to phase transitions of moisture (vapor-water-ice) along the tower height,

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).

VORTICAL HOT TOWERS (VHTs)

"VHTs are HELICAL by definition because they contain coincident updrafts and vertical vorticity" –

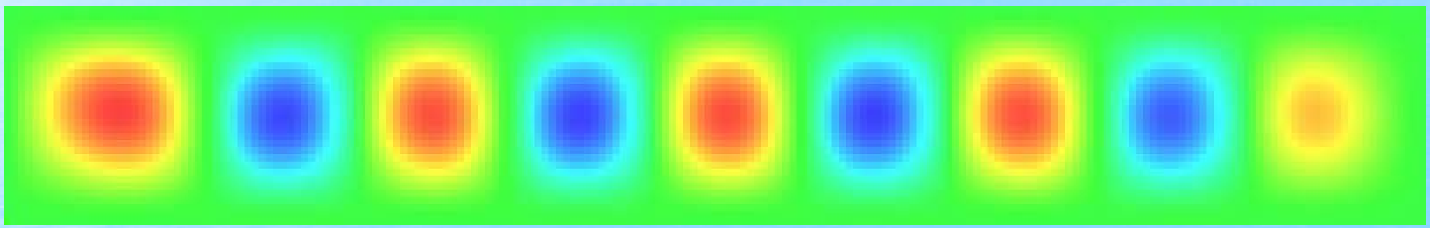
J. Molinari and D. Vollaro, 2010, *J. Atmos. Sci.*, 67, 274-284.

A WAY TO EXAMINE HELICAL FEATURES OF TROPICAL CYCLOGENESIS

L06 :

Levina G. V., and Burylov I. A. 2006, *Nonlin. Processes Geophys*., 13, 205-222

Helical-vortex effects were mimicked in the laminar Rayleigh-Bénard convection by a special forcing –
by the vortex-motive force



Merging of helical vortex convective cells

Levina G. V. 2006, *Doklady Earth Sciences*, 411A(9), 1417-1421

Parameterization of helical turbulence for numerical models of intense atmospheric vortices was proposed

PARAMETERIZATION OF THE INTERACTION :
VERTICAL SHEAR OF HORIZONTAL VELOCITY & VORTICAL MOIST CONVECTION

By analogy with the alpha-term − electromotive force in the Alpha-Effect equations (magnetohydrodynamics),

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**

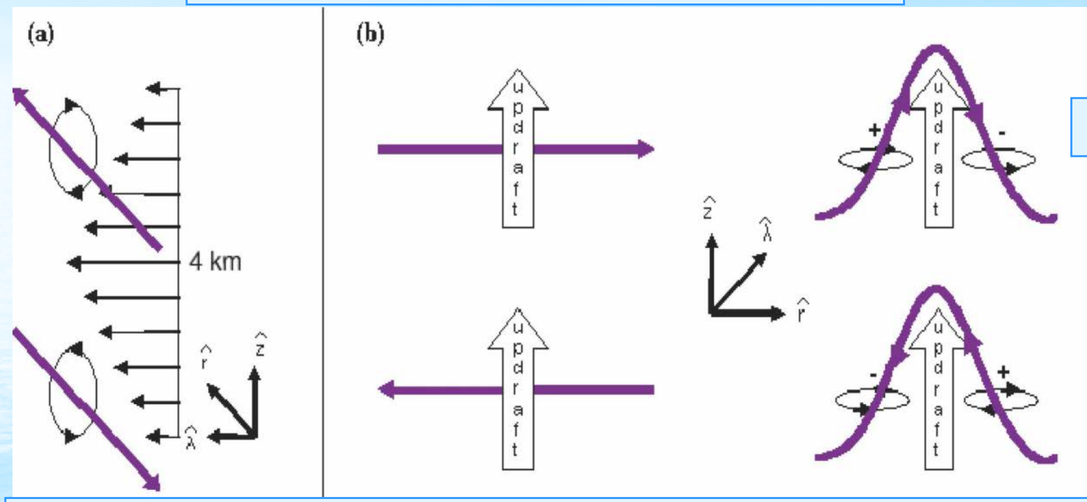
Such 'vortex-motive' force parameterizes the interaction between vertical shear and VORTICAL moist convection (hypothetical before 2004).

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]

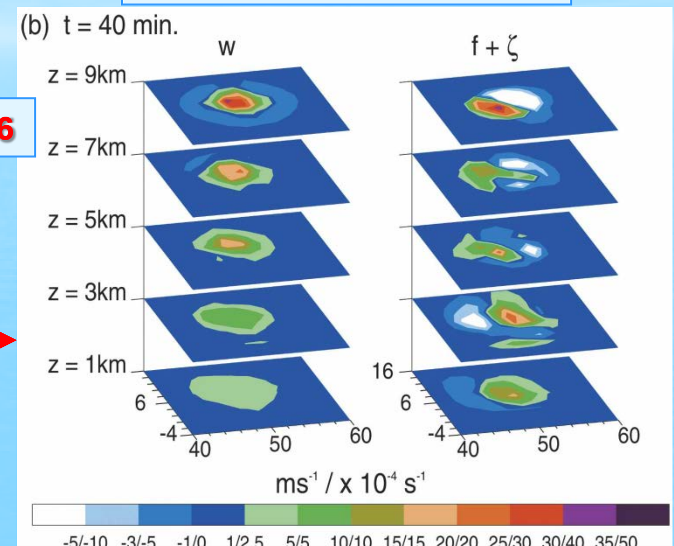
Tilting and stretching of vortex lines

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

THE VORTICAL HOT TOWERS

VHTs provide all physics described by the vortex-motive force:

Latent heat release,

Rotation,

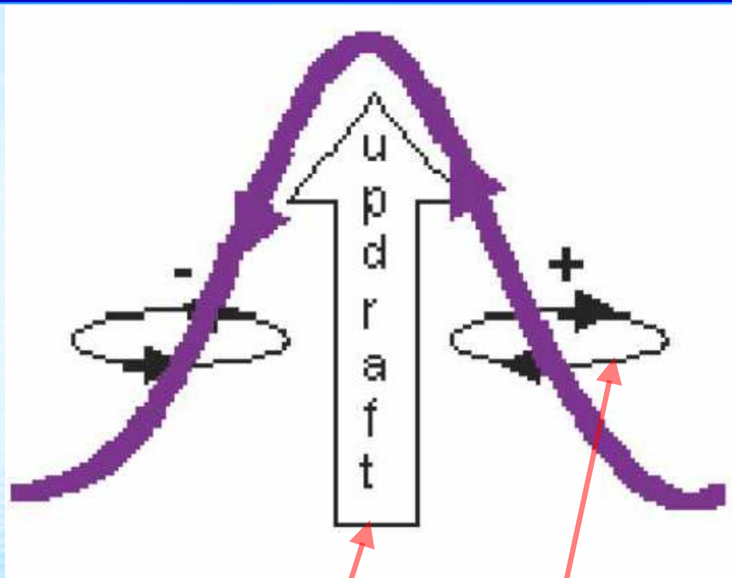
Interaction between shear and vortical convection,

Non-zero helicity on cloud 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’

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

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

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

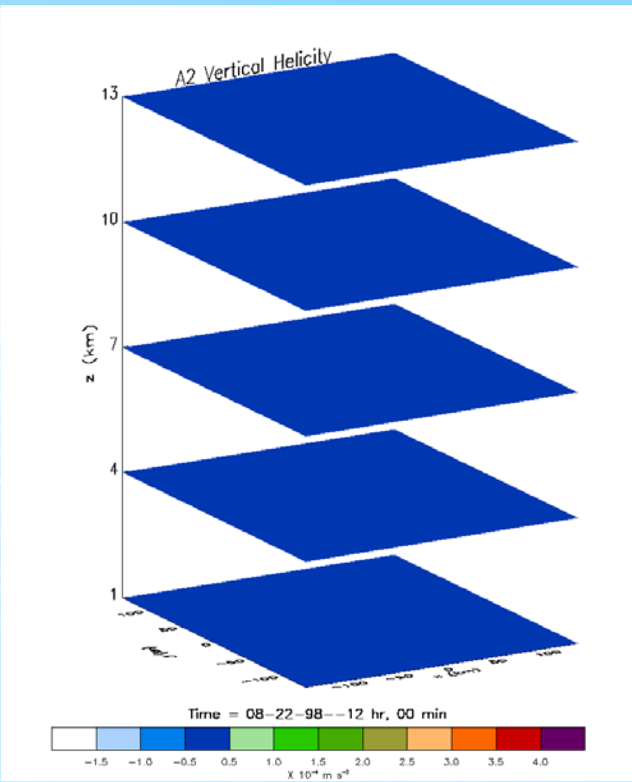
VHTs population contributes to both the horizontal and vertical motion:

- 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.

ROTATING CONVECTION IN SIMULATION AND OBSERVATIONS

Expt. A2. VERTICAL HELICITY: ROTATING CONVECTION

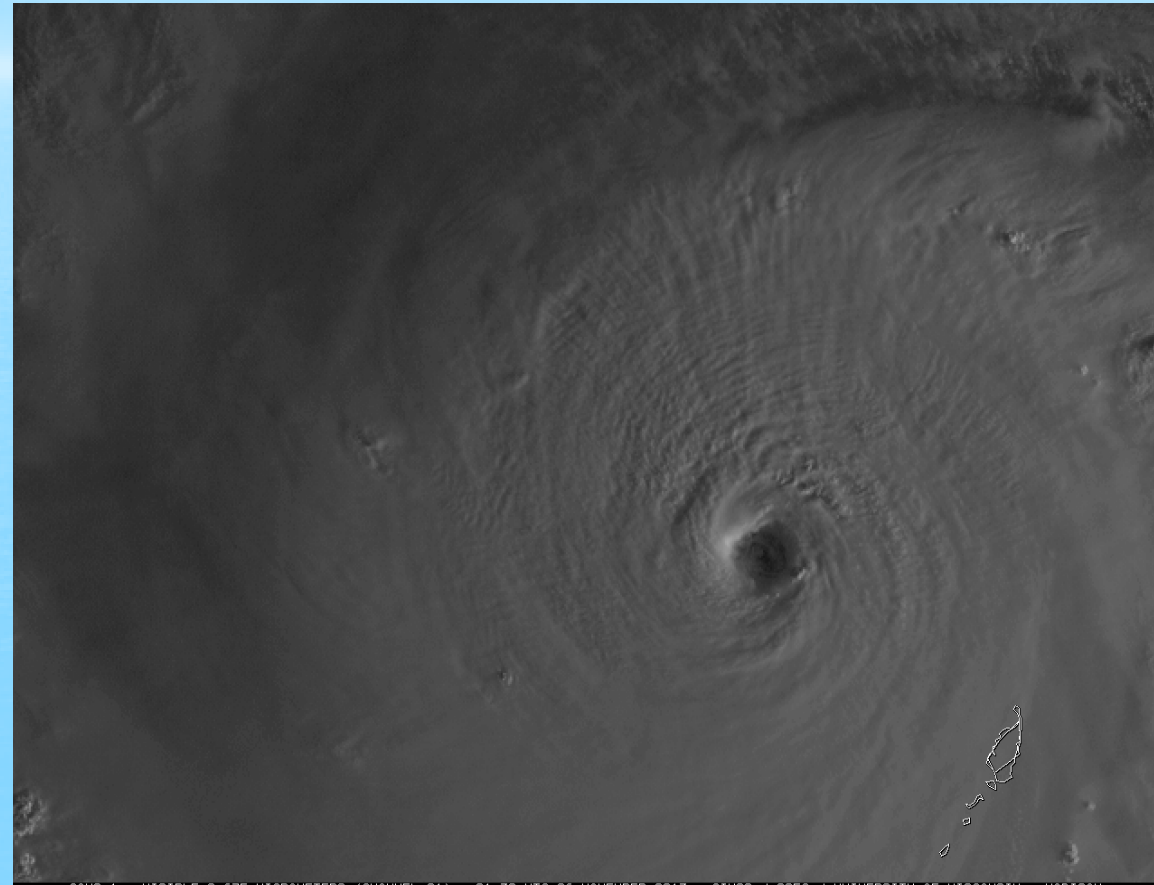
The first updraft is generated by the initial 300 s local heating at low levels



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)

Courtesy of CIMSS.



PRIOR TO LANDFALL – 5 CAT. INTENSITY

10-minute sustained wind 64-76 m/s
1-minute sustained wind 94 m/s

RUSSIAN-AMERICAN COLLABORATION

Collaborative Studies with Montgomery Research Group started in February 2006 when the results of L06 and M06 were brought together in seminars at 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 energetic and 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 →

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 $<E^P>$ and $<E^S>$ separately to identify the helical feedback

Vertical velocity, vorticity and helicity – convection/VHTs

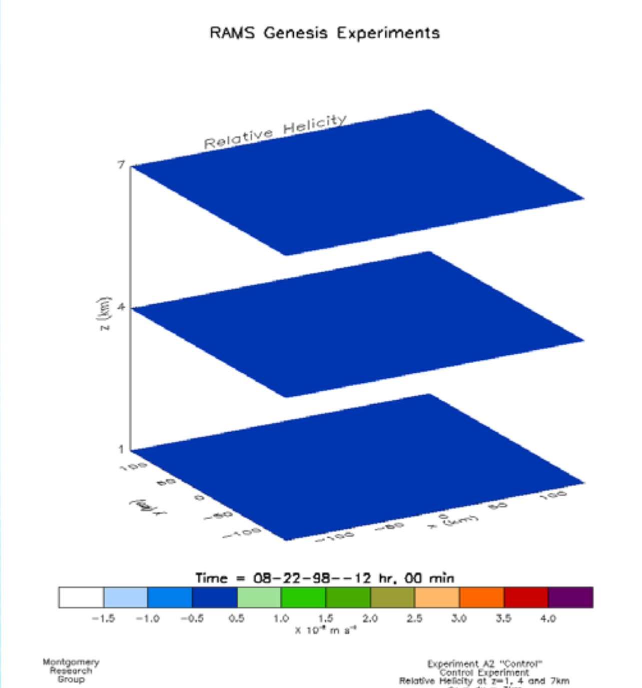
Horizontal helicity $<H_{xy}> = <H_x> + <H_y>$ – vertical wind shear

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

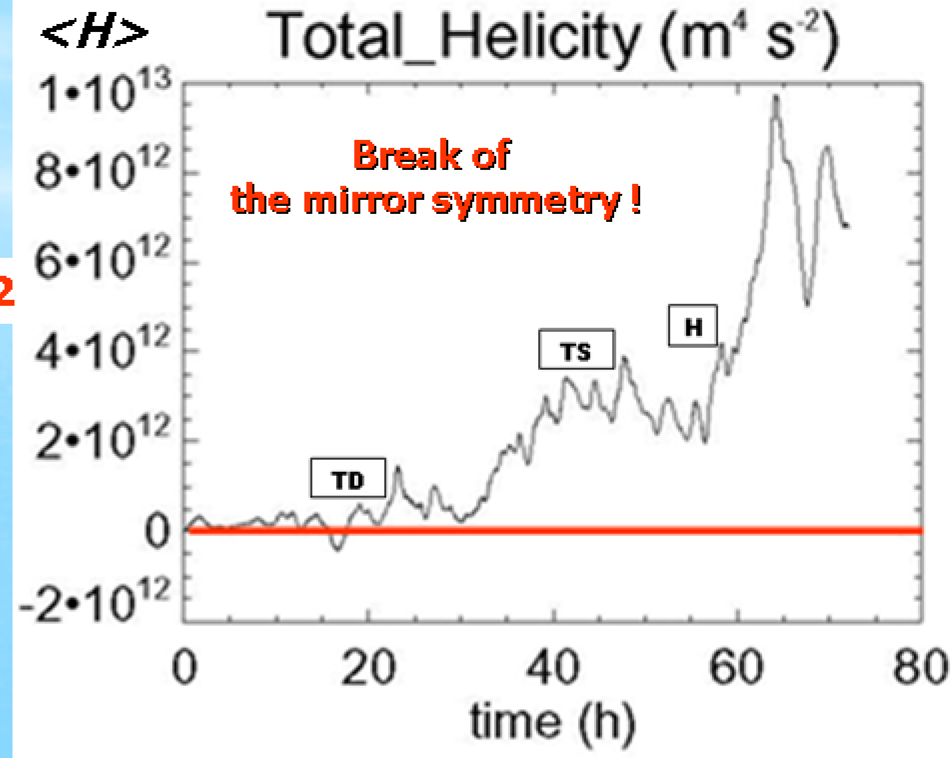
HELICITY EVOLUTION DURING 72 HOURS OF TC FORMATION

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

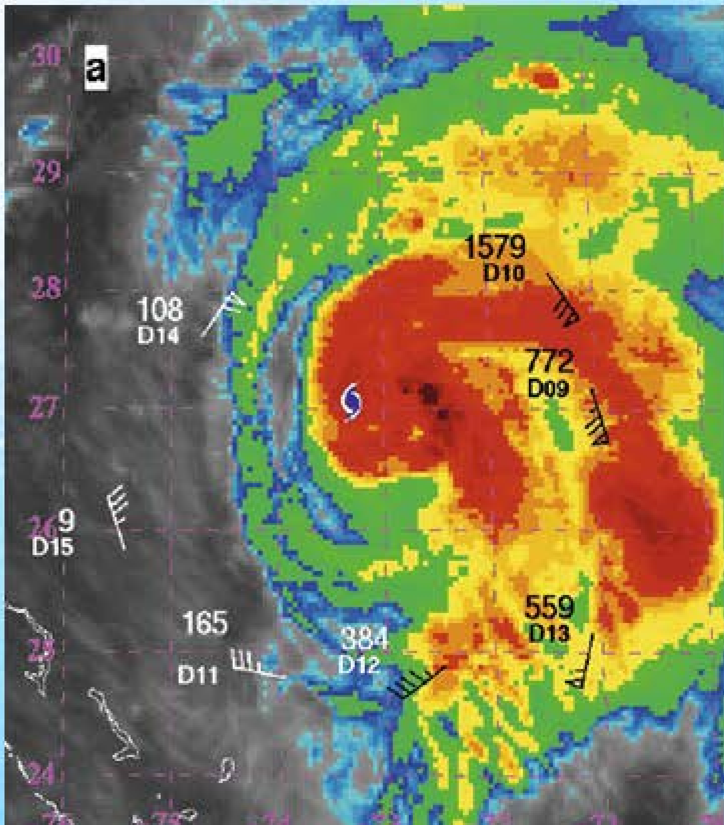
t = 16-18 h	9 m s^{-1}	**TD** formation,
t = 45 h	17.2 m s^{-1}	**TS** formation,
t = 56 h	33.4 m s^{-1}	**H** formation,
t = 60-63 h	42.5 m s^{-1}	**H** Maximal wind

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 $m \cdot s^{-1}$.

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)

HELICAL CLOUD CONVECTION

HELICITY MAY HELP QUANTIFY THE CHAOTIC INFLUENCE FROM MOIST CONVECTION

NON-ZERO HELICITY DURING TC FORMATION

A persistent break of the mirror symmetry of turbulence during TC formation was found in [LM10], namely, that helicity is non-zero.

This is the first example of such phenomenon in a real natural system – in the tropical atmosphere of the Earth.

During a long time that was only a hypothesis whether $\langle H \rangle \neq 0$ is really possible.

WE HAVE A CASE OF HELICAL TURBULENCE!

NON-ZERO HELICITY DURING TC FORMATION

In helical turbulence, the energy transfer to dissipation scales is suppressed and an inverse energy transfer to larger scales is possible in 3D:
the alpha-effect in magnetohydrodynamics (1966), hydrodynamic alpha-effect (1983), anisotropic kinetic alpha (AKA) effect (1987), numerical simulations at NCAR by Pouquet, Marino, Mininni et al. (2010s).

In helical atmospheric turbulence, energy released due to phase transitions of moisture within the VHTs is accumulated on cloud scales.

We need a new channel for the energy discharge – this can be a large-scale vortex instability.

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**

Genesis of Hurricane Karl (2010)
Alt. 14500 m. Flight RF19. NSF/NCAR G-V
14 Sep 2010. GL's photo

FROM <H>≠0 TO THE VORTEX DYNAMO

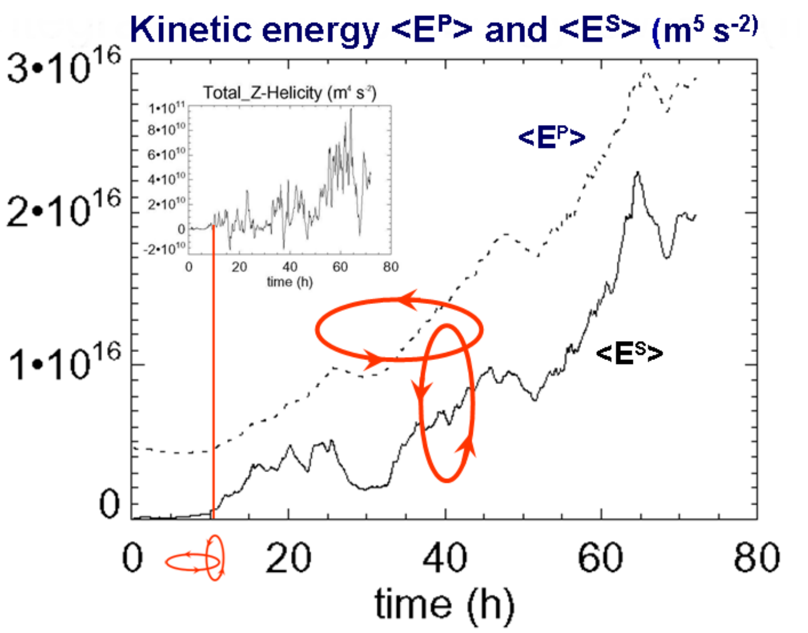
The non-zero helicity does not necessarily mean that the large-scale vortex instability is underway.

In fact, this only means that there exists a persistent departure of the mirror symmetry in turbulence during TC formation and, hence, an environment conducive to the emergence of large-scale instability.

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

t=12 h:

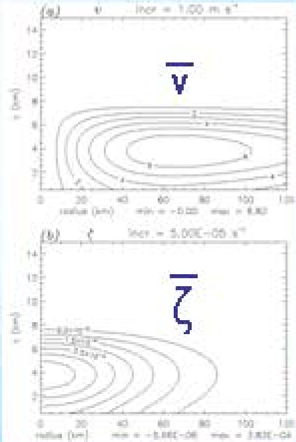
1. **Mutual intensification of the primary and secondary circulation starts**
2. **The Z-helicity increases**



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

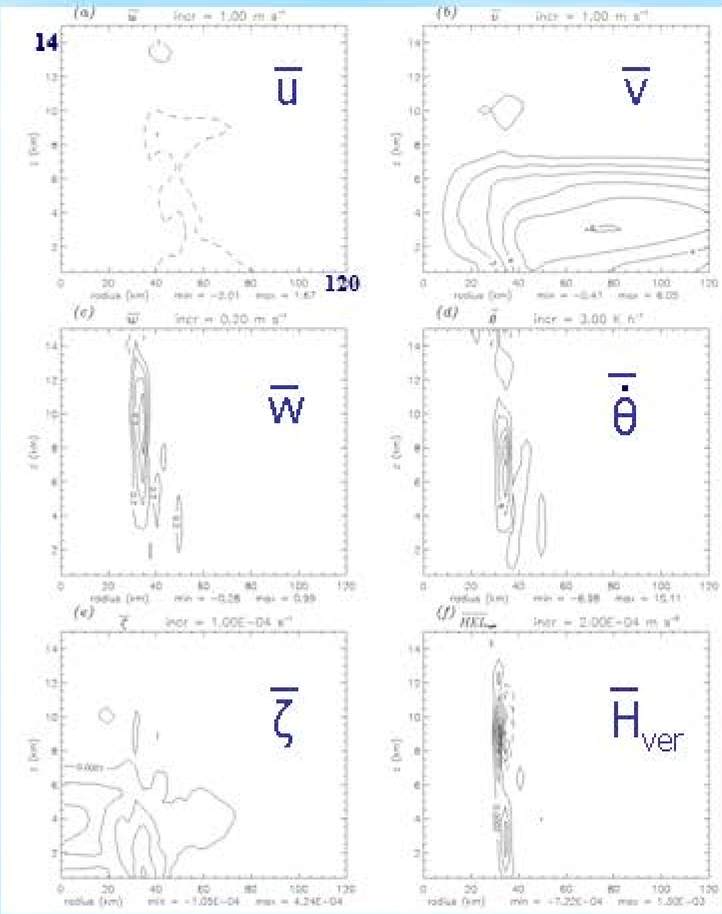
FORMATION OF THE SECONDARY OVERTURNING CIRCULATION IN (u) – UP (w) – OUT (u) FLOW during t = 10 – 12 h

t = 0 h

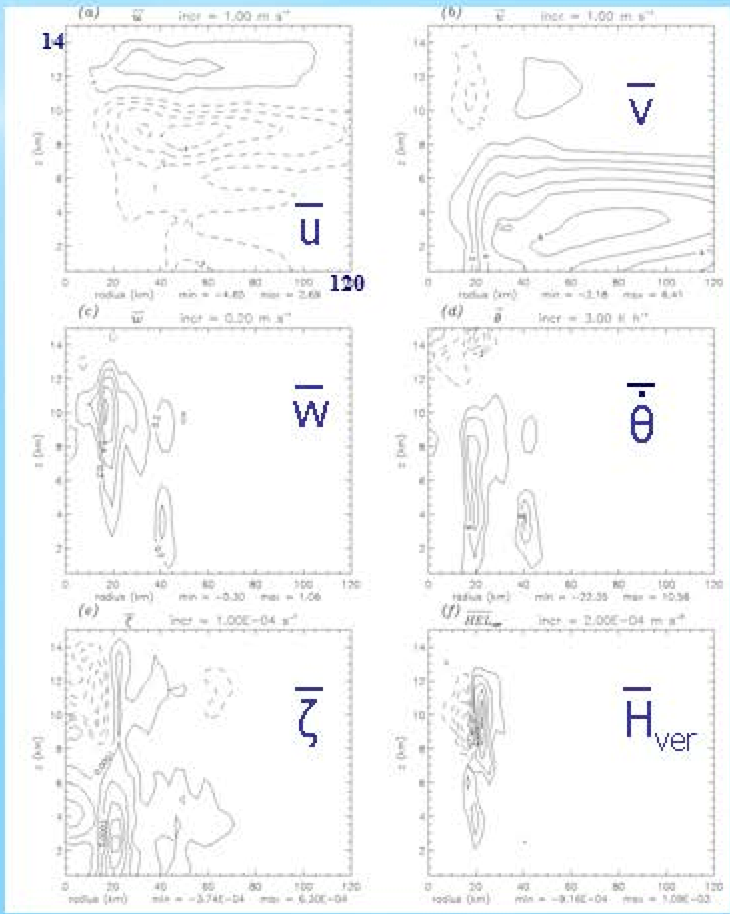


Initial MCV

t = 10 h



t = 12 h



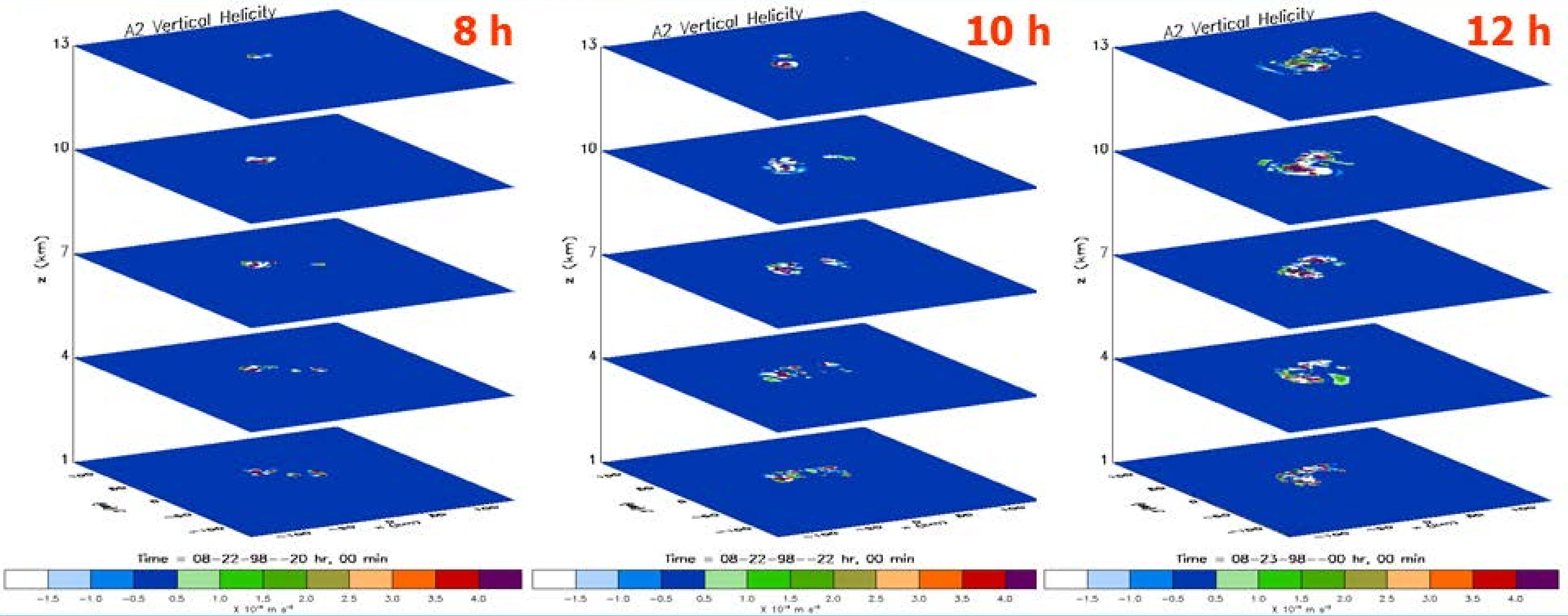
Azimuthally averaged fields: VHTs are well recognized in w, θ, and H_{ver}

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

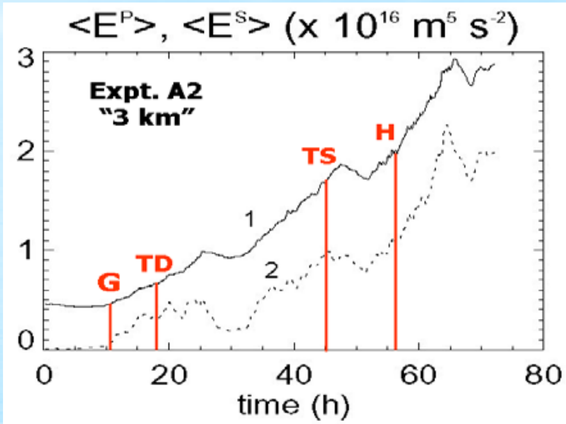
THE VERTICAL HELICITY ALLOWS TO DISCERN VERTICAL ROTATING FLOWS:

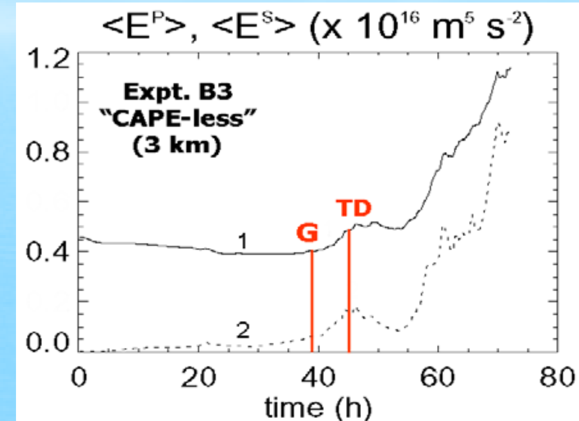
+ cyclonic updrafts or/and anticyclonic downdrafts

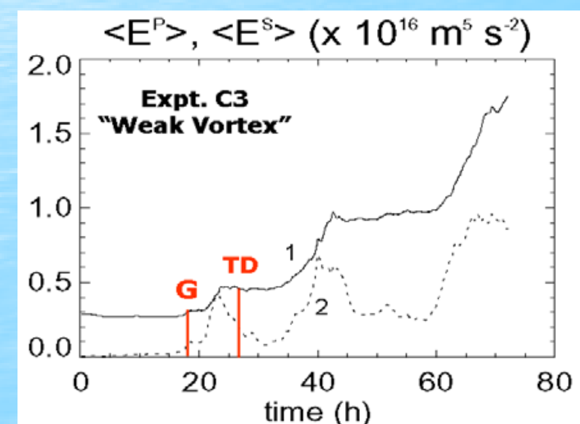
- cyclonic downdrafts or/and anticyclonic updrafts

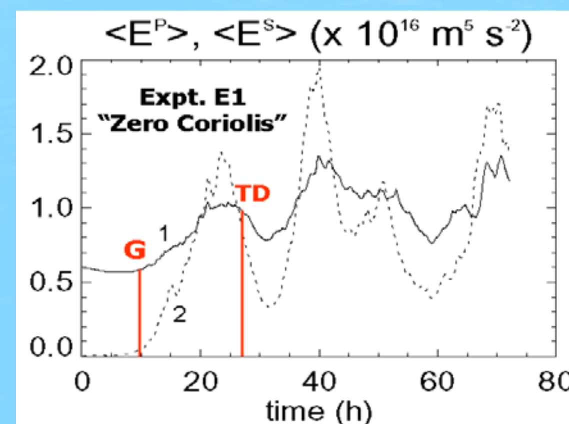
WHEN WILL A NASCENT VORTEX BECOME SELF-SUSTAINING ?
GENESIS TIME – G ?

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.

TOOLS FOR DIAGNOSIS OF TC GENESIS

For purposes of quantitative diagnosis of GENESIS we should analyze the evolution of energetics and structure (topology) of the newly forming mesoscale vortex :

– the integral kinetic energy of primary and secondary circulation (separately) is applied to diagnose WHEN their mutual intensification starts, and correspondingly – a nascent large vortex becomes self-sustaining;

– helicity of the velocity field allows to quantify the contribution of cloud convection which is responsible for **the linkage of primary and secondary circulations**,

NO LINKAGE – NO TC!

TROPICAL CYCLOGENESIS CANNOT BE DIAGNOSED WITHIN THE ONLY TRADITIONAL FRAMEWORK OF VORTICITY, THERMODYNAMICS, AND MOIST PHYSICS ANALYSIS.

DIAGNOSIS OF TC GENESIS

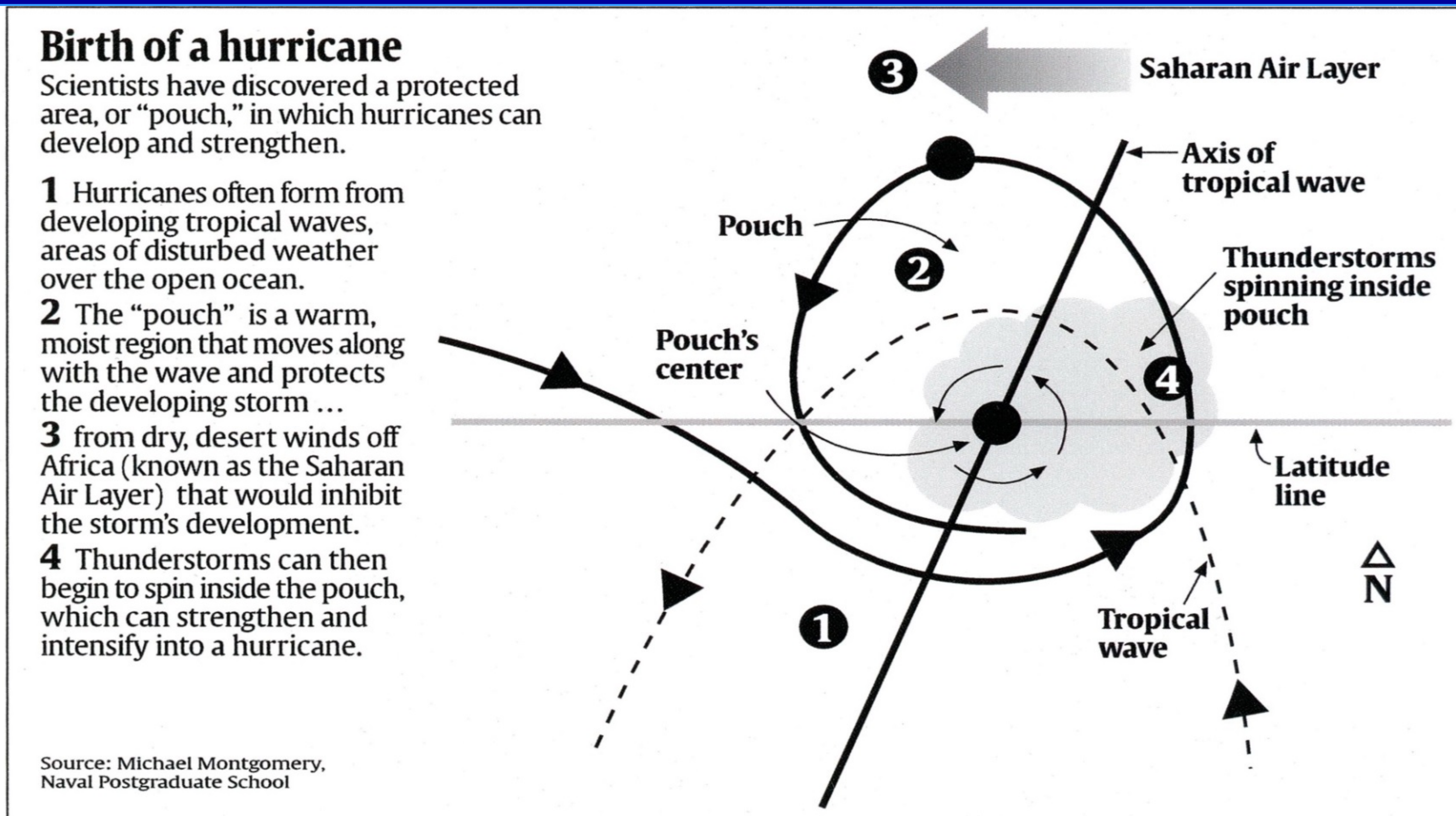
How the proposed procedure can be integrated into existing analysis tools?

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

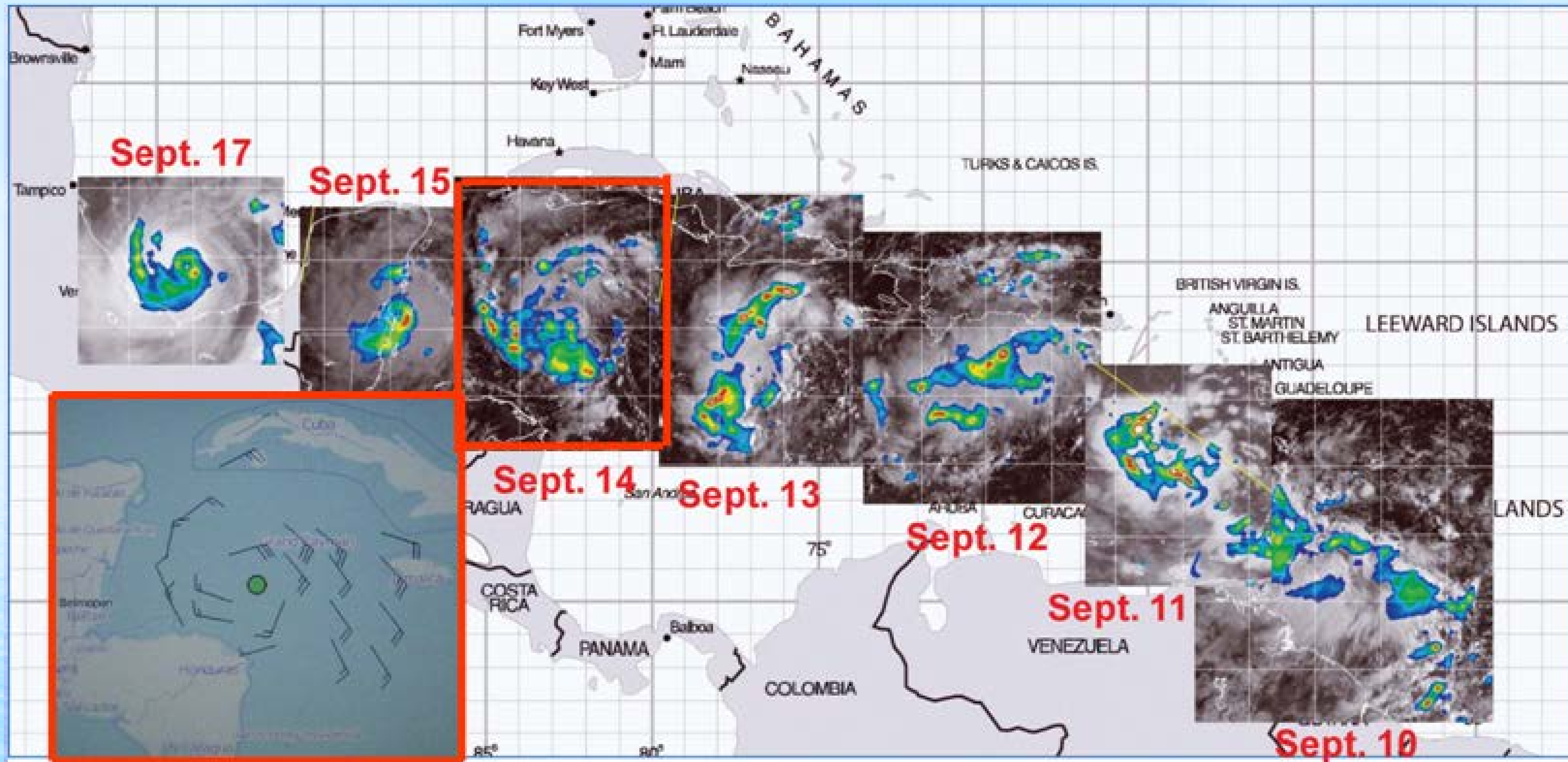
National Oceanic and Atmospheric Administration

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.

HURRICANE KARL (2010) – GENESIS, Sept. 14

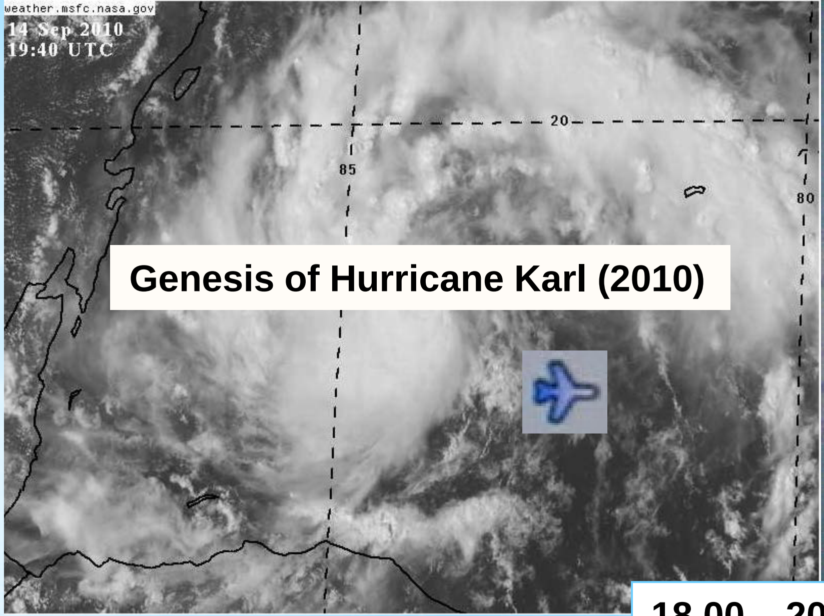


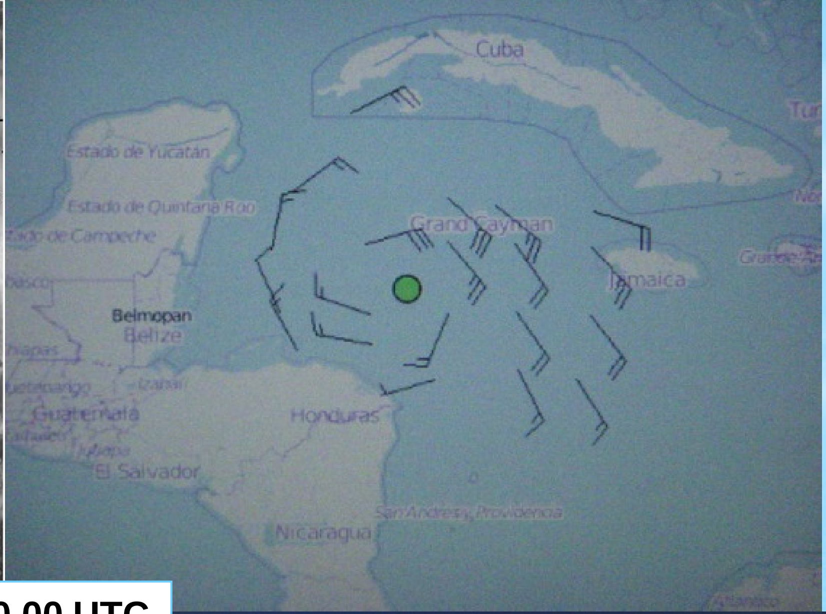
A protected area of potential cyclogenesis (‘Marsupial Pouch’) has been monitored by aircraft of NASA, NOAA, NSF-NCAR, and USAF since Sept. 10. RF19 was the 6th NSF-NCAR flight and detected the genesis :

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

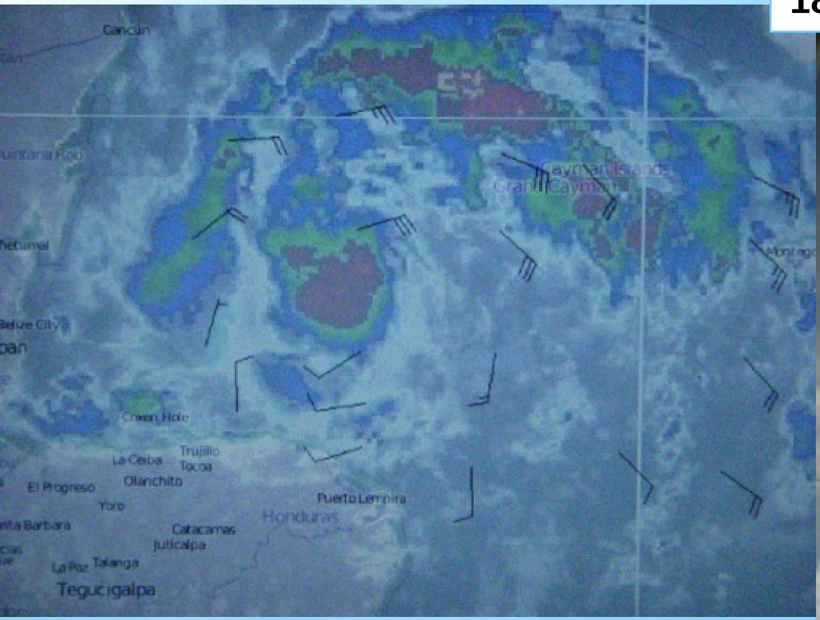
Pictures are borrowed from the reports of PREDICT Science Director M.T. Montgomery and RF19 Mission Scientist C. López-Carillo, and Montgomery et al. (2012, *BAMS*) .

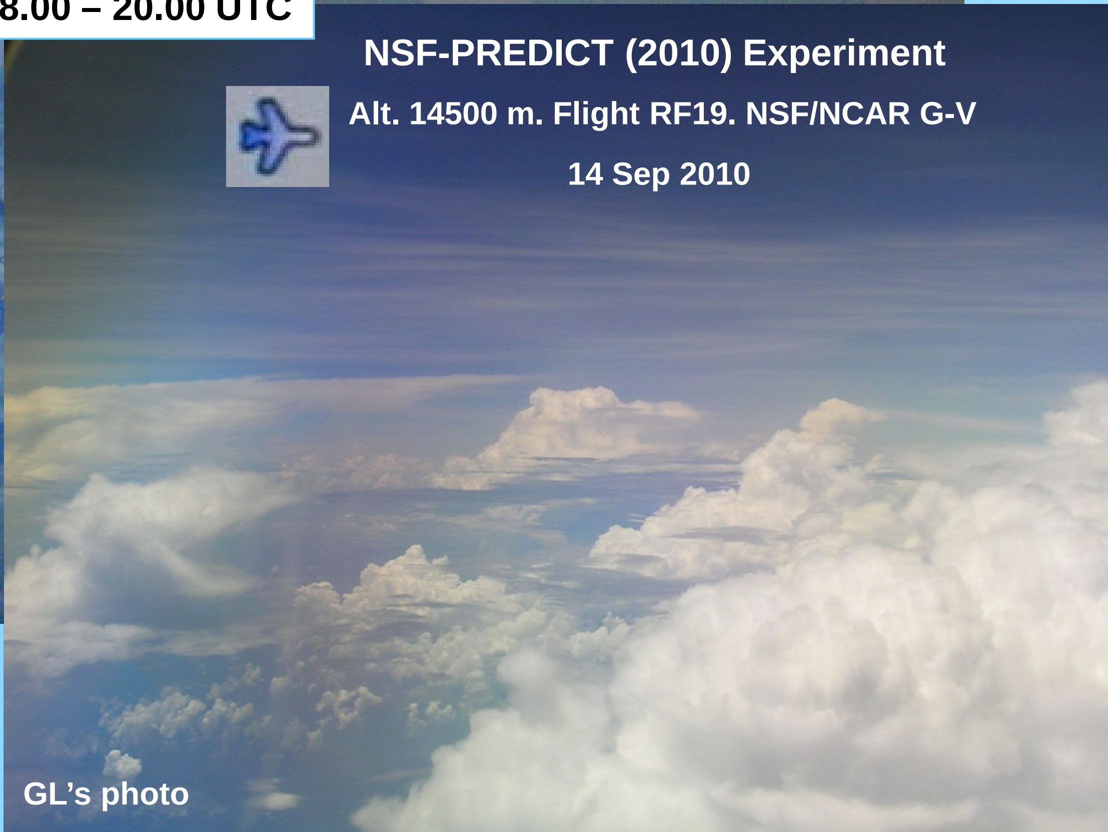
Genesis of Hurricane Karl (2010)





18.00 – 20.00 UTC





NSF-PREDICT (2010) Experiment

Alt. 14500 m. Flight RF19. NSF/NCAR G-V

14 Sep 2010

GL's photo

3 pictures are borrowed from the reports of PREDICT Science Director M.T. Montgomery and RF19 Mission Scientist C. López-Carillo.

DIAGNOSIS OF TC GENESIS

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 ?'

The above diagnosis must be supported by analysis of turbulent statistics – energy and helicity transfer across the 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.

IS TC GENESIS A THRESHOLD PHENOMENON ?

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

Though Expt. C1 (no MCV) 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’

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)?

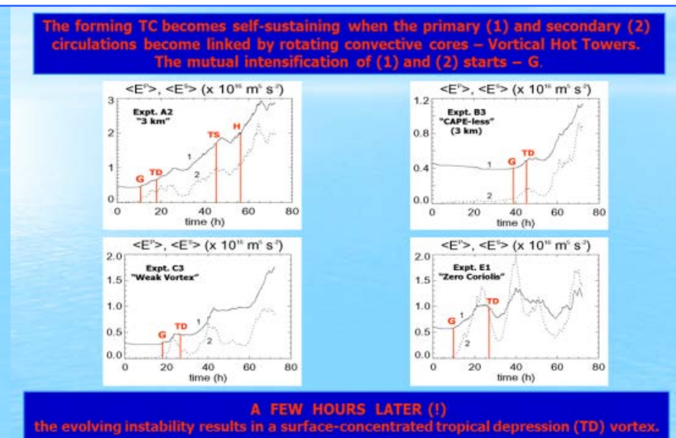
CONTROLLING OF TROPICAL CYCLOGENESIS ?

This idea was discussed still in the 1980s, and a few ways were proposed for investigation in laboratory experiments (USSR/Russia).

One of them was based on the introduction of small-scale helicity.

Now, this method may get new life because we know :

- the natural carriers of small-scale helicity – VHTs,
- how an intense VHT can be generated – by local heating [M06],
- what should be affected – the linkage of circulations,
- where it should be affected – within the Marsupial Pouch,
- when it should be affected – near the Genesis time (G).



The way of controlling by helicity generation:

to affect the linkage of the primary and secondary circulations near the time moment **G**

PERSPECTIVE

- **Development of approach for analysis of turbulent statistics – energy and helicity transfer across the scales – in order to apply it to all future investigations**

- **Diagnosis of TC genesis based on recent idealized high-resolution numerical simulations and NSF-PREDICT 2010 data:**
  - including a task of search for the threshold of large-scale instability

- **Development of a ‘Genesis Nature Run’ – GNR –**
  (similar to the ‘Hurricane Nature Run’ by Nolan et al., 2013)
  for the Caribbean summer 2010 when GRIP, IFEX, and PREDICT Experiments were underway and collected great amounts of data:
  - to validate the procedure for diagnosis of TC Genesis time,
  - to investigate ways to affect TC Genesis

- **Laboratory experiment?**

GNR may give all appropriate basis for implementation of above purposes!

The work is supported by the Russian Foundation for Basic Research, Grant 16-05-00551-a.

THINK BIG !

In April 2016, the hurricane community paid tribute

to the outstanding scientist W. Gray (1929-2016) and shared

memories about him on TStorms.org ;

W. Gray said to his younger colleagues: “Think Big!”

The co-author of the turbulent vortex dynamo and coordinator of

the corresponding Soviet research program

S. Moiseev (1929-2002) said the same: “Think Big!”

THINKING BIG

On 12 April 2016, the Breakthrough Starshot project was announced in New York City

– The interstellar journey to the Alpha Centauri star system, near 4 light-years away –

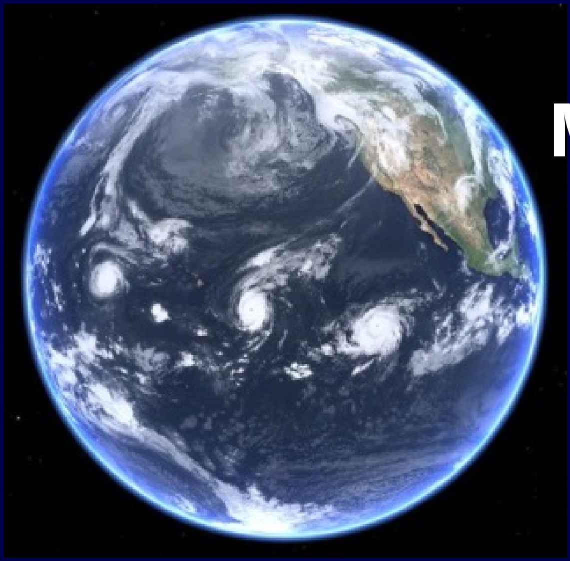
By Stephen Hawking (UK) –

Yuri Milner (Russia) –

Mark Zuckerberg (USA)

BIG Example of international cooperation !

THINKING BIG



May we look not only in deep space,

but also our home planet Earth?

And think about

TAMING HURRICANES

This may help millions of people

around the globe !

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