Track sensitivity to microphysics and radiation

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11 April 2012
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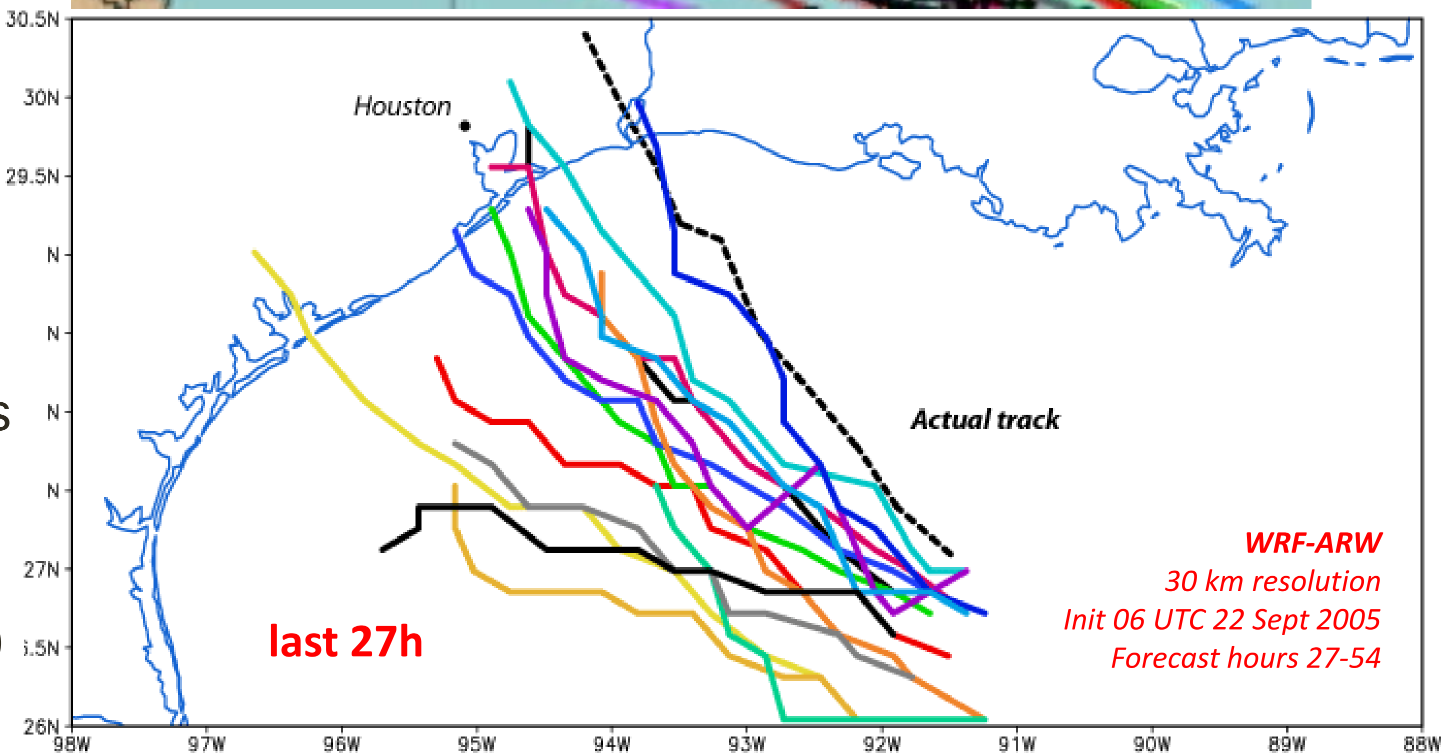
Background

- WRF-ARW, including semi-idealized version
  - Fovell and Su (2007, GRL)
  - Fovell, Corbosiero and Kuo (2009, JAS)
  - Fovell and Boucher (2009, 13th Meso. Conf.)
  - Fovell, Corbosiero, Seifert and Liou (2010, GRL)
  - Fovell, Corbosiero and Kuo (2010, 29th Hurr. Conf.)
  - Cao, Fovell and Corbosiero (2011, Terr. Atm. Ocn.)
- Some preliminary HWRF analyses **interspersed**

Rita (2005)

NHC
Multi-model
Consensus
06 UTC 22 Sept

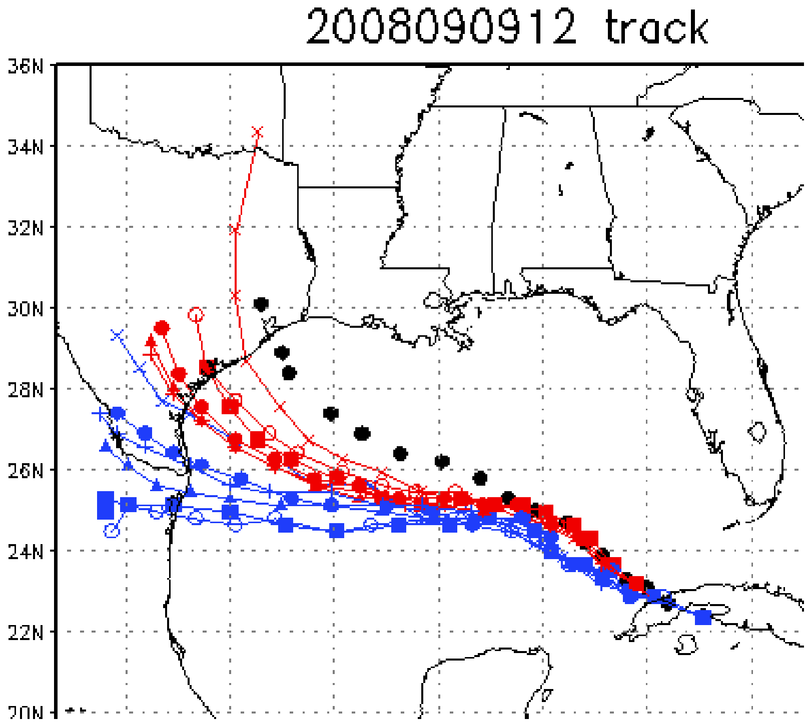
One model
One initialization
Vary model physics
(CP and MP)



Fovell and Su (2007)
[replotted]

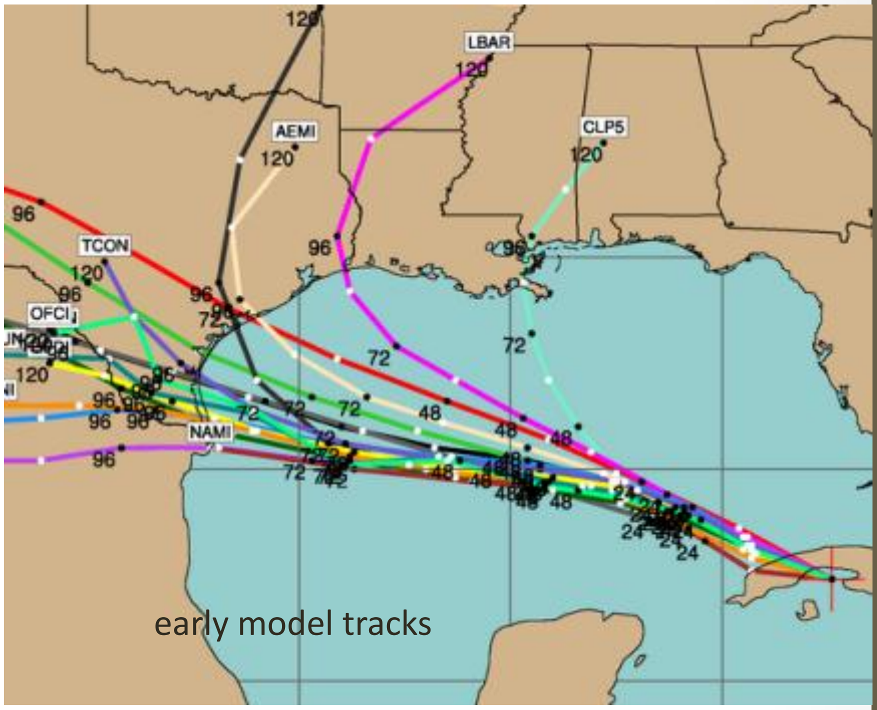
Hurricane Ike - 12 UTC 9/09/08

36 km WRF-ARW ensemble



Black dots - actual positions

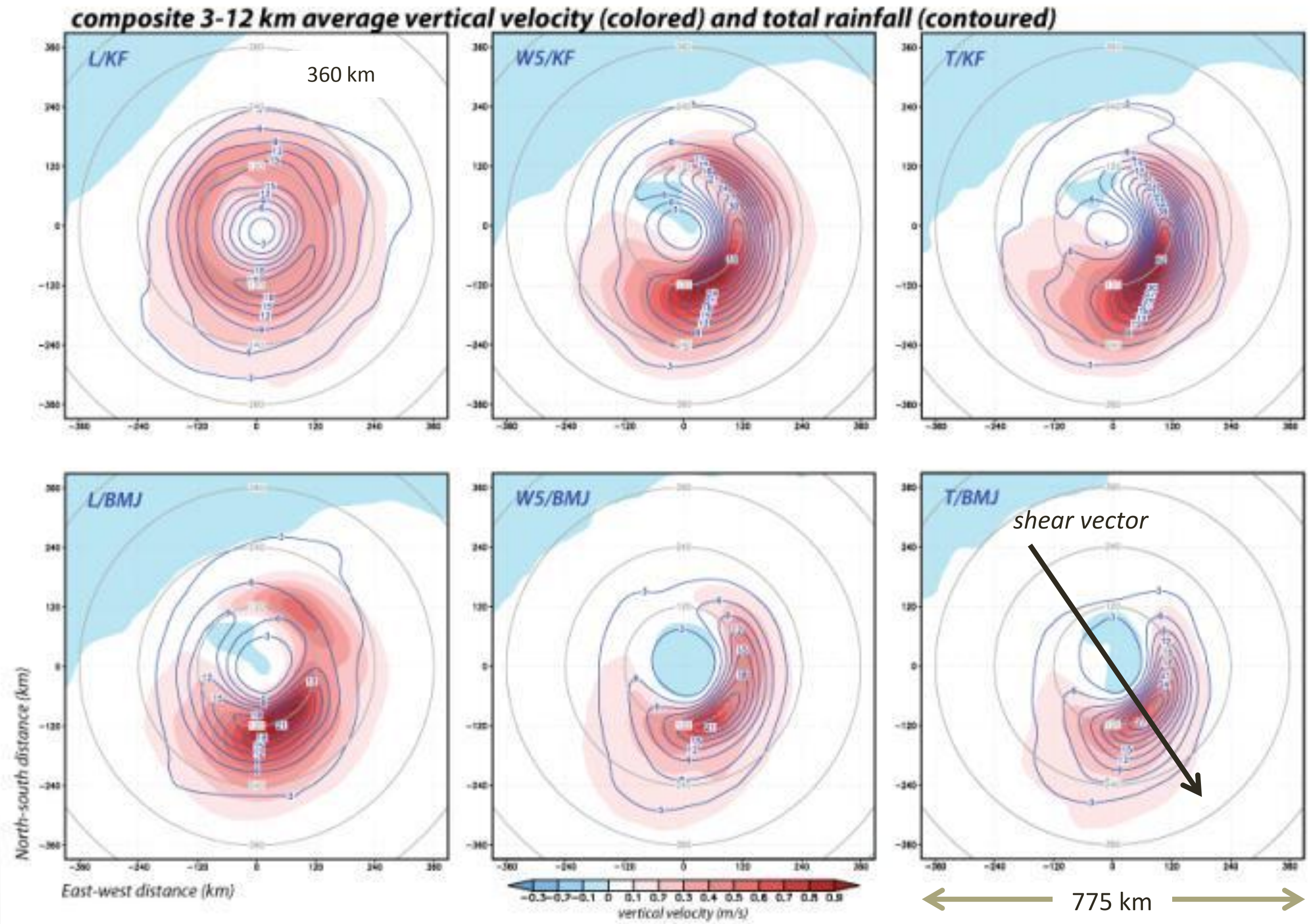
NHC multi-model ensemble



J. Vigh, NCAR

2008 Atlantic hurricane season ensemble – 36 km WRF-ARW - 12 members
6 microphysics and 2 cumulus schemes, GFS cold starts, no initial adjustments
5 landfalling storms, 68 ensemble runs, 816 simulations total
Fovell and Boucher (2009)

Ike: vertically-averaged W and surface rainfall 54-66 h



Microphysics:

L = Lin
W5 = WSM5
T = Thompson

Cumulus:

KF = Kain-Fritsch 2
BMJ = Betts-Miller-Janjic

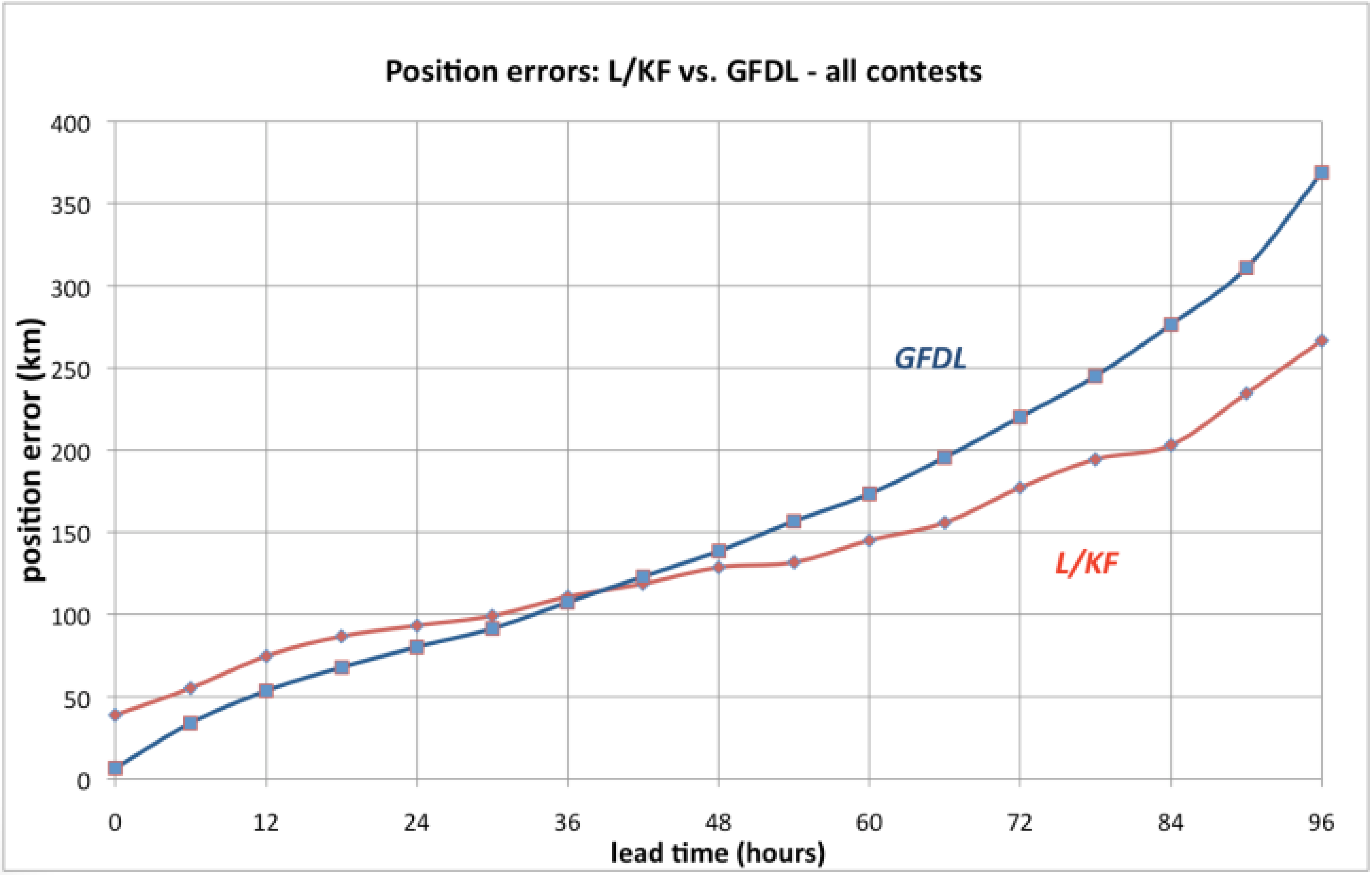
Color shaded: mean vertical velocity from 3-12 km

Contoured: total rainfall (3 mm contours)

*Composites made from **12 Ike simulations** for each member from Fovell-Boucher ensemble*

Shear according to http://rammb.cira.colostate.edu AMSU-derived products

Average position error vs. lead time over 68 ensemble runs



L/KF ensemble member vs. GFDL model forecast positions from best track database

Semi-idealized “bubble” experiments

WRF-ARW high-resolution experiments manipulating microphysics (MP) and radiation schemes

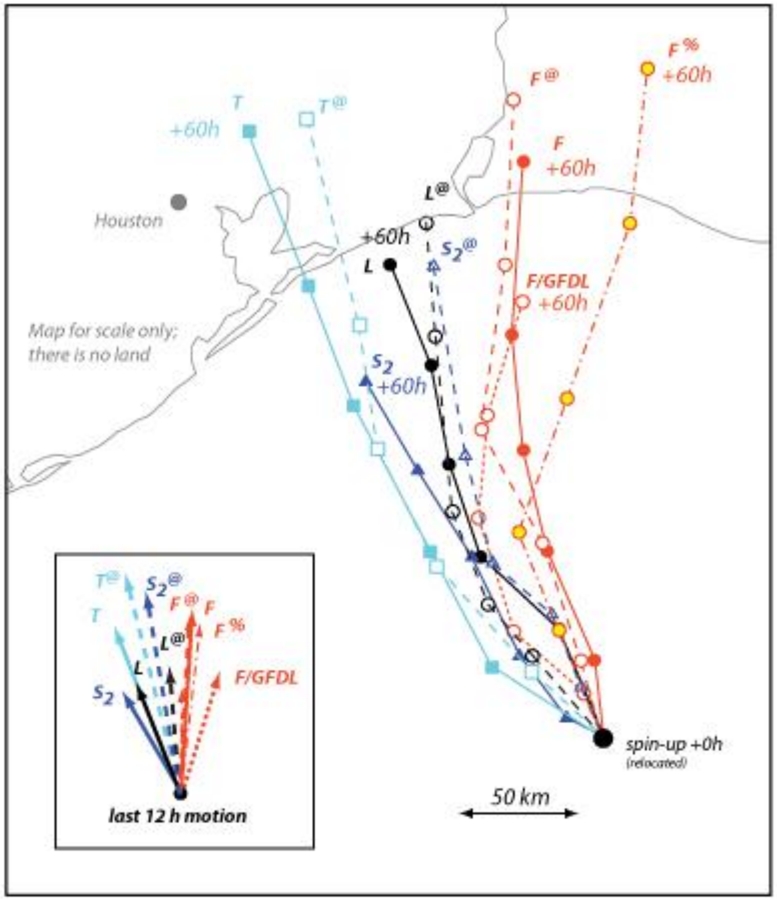
“no correct answer”

Model physics

- Modified WRF-ARW v. 3.2
- 9 km outer (fixed) and 3 km inner (moving) domains
- Modified Jordan sounding (Dunion and Marron 2008)
- NO LAND, fixed SST
- NO MEAN FLOW
- “Bubble” initialization
- Focus on 60 h after “spin-up period” (first 36 h)
  - Cumulus scheme used only during first 14 h of spin-up period
- Previous generation semi-idealized experiments published in Fovell and Su (2007), Fovell et al. (2009, 2010), Cao et al. (2011)

Tracks after spin-up period

Tracks following 36 h spin-up period

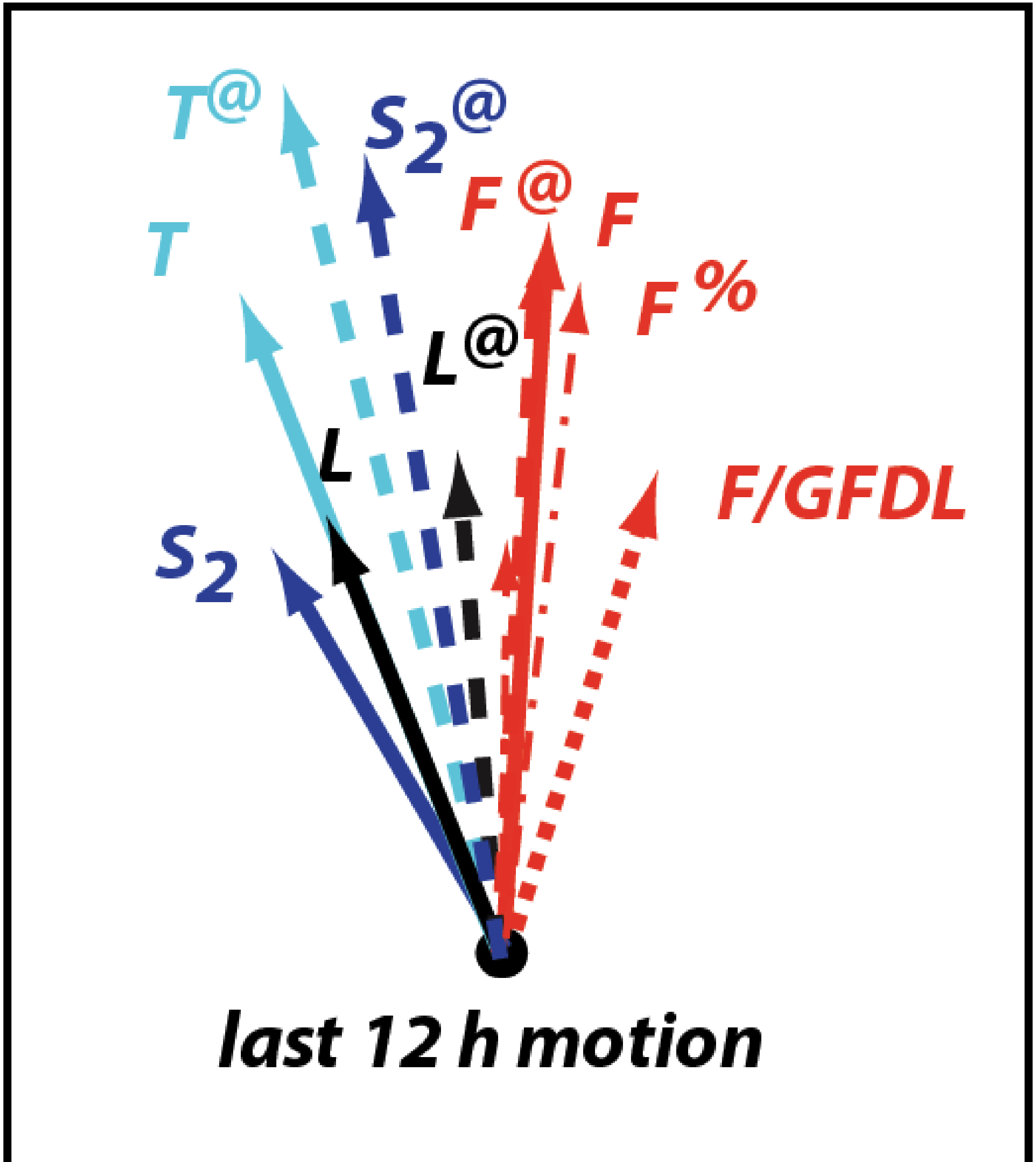


Microphysics schemes were active from model start. Storm positions relocated after 36 h spin-up period (cosmetic only)

- **NO LAND**

- Microphysical parameterizations
  - Lin (L)
  - Thompson (T)
  - Seifert-2 (S2) – two-moment scheme dominated by cloud ice
  - Ferrier (F) – AHW version, not tropical version

- Radiation schemes
  - RRTM (RRTM LW & Dudhia SW)
  - RRTMG (both LW & SW)
  - GFDL



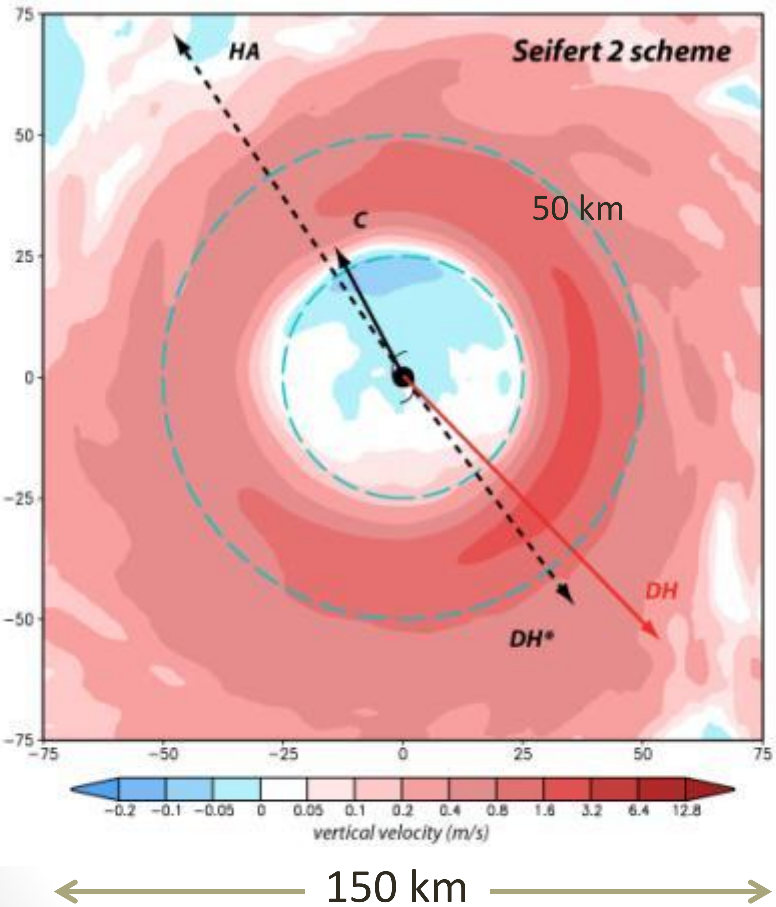
- no mean flow
- slow motion represents **beta drift** modulated by physics-dependent symmetric and asymmetric structure
- speeds range from to 1.1 to 1.7 m/s (3.9 to 6.2 km/h)
- direction variation is of interest

Vortex-following composite fields for the semi-idealized storms

Averaged over 24 h, between 48-60 h after spin-up period

"no correct answer"

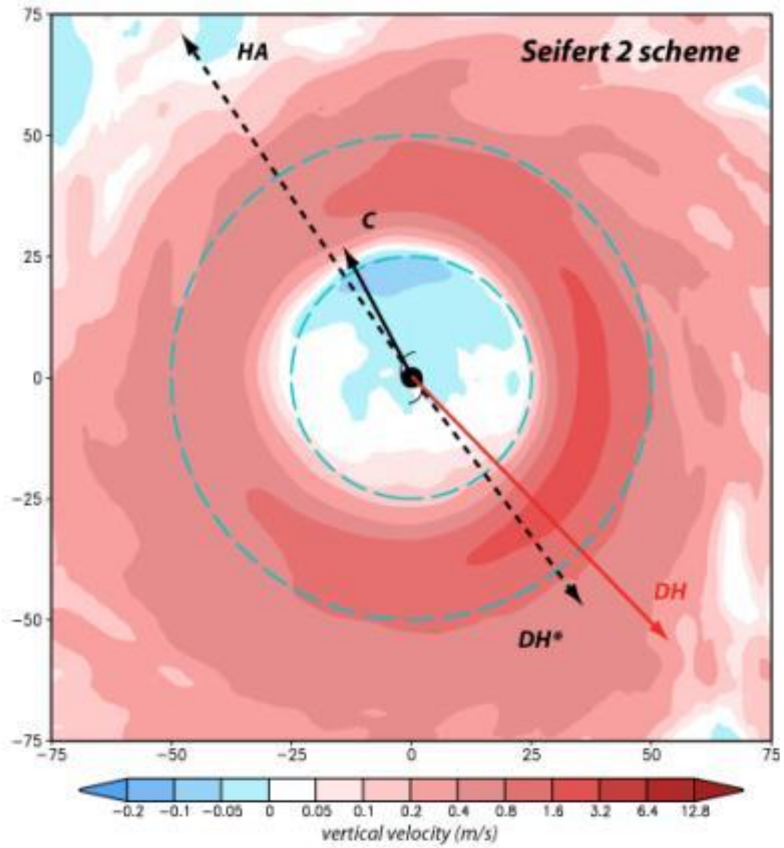
Vertically averaged W

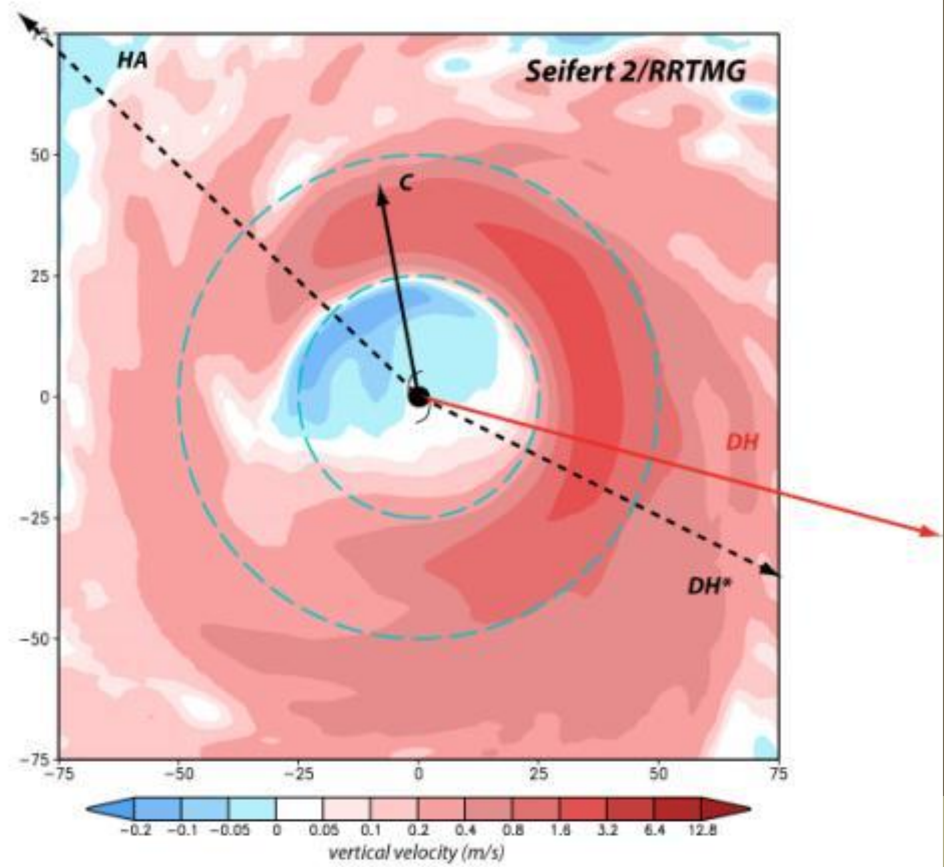


S2 with RRTM

- Color shaded: vertically averaged vertical velocity (sfc-500 mb)
- PV analysis (cf. Wu and Wang 2000):
  - **C** = storm motion
  - **HA** = horizontal advection
  - **DH** = diabatic heating term
  - **DH*** = DH + VA (vertical advection)
  - **C ~ HA+DH***

Vertically averaged W

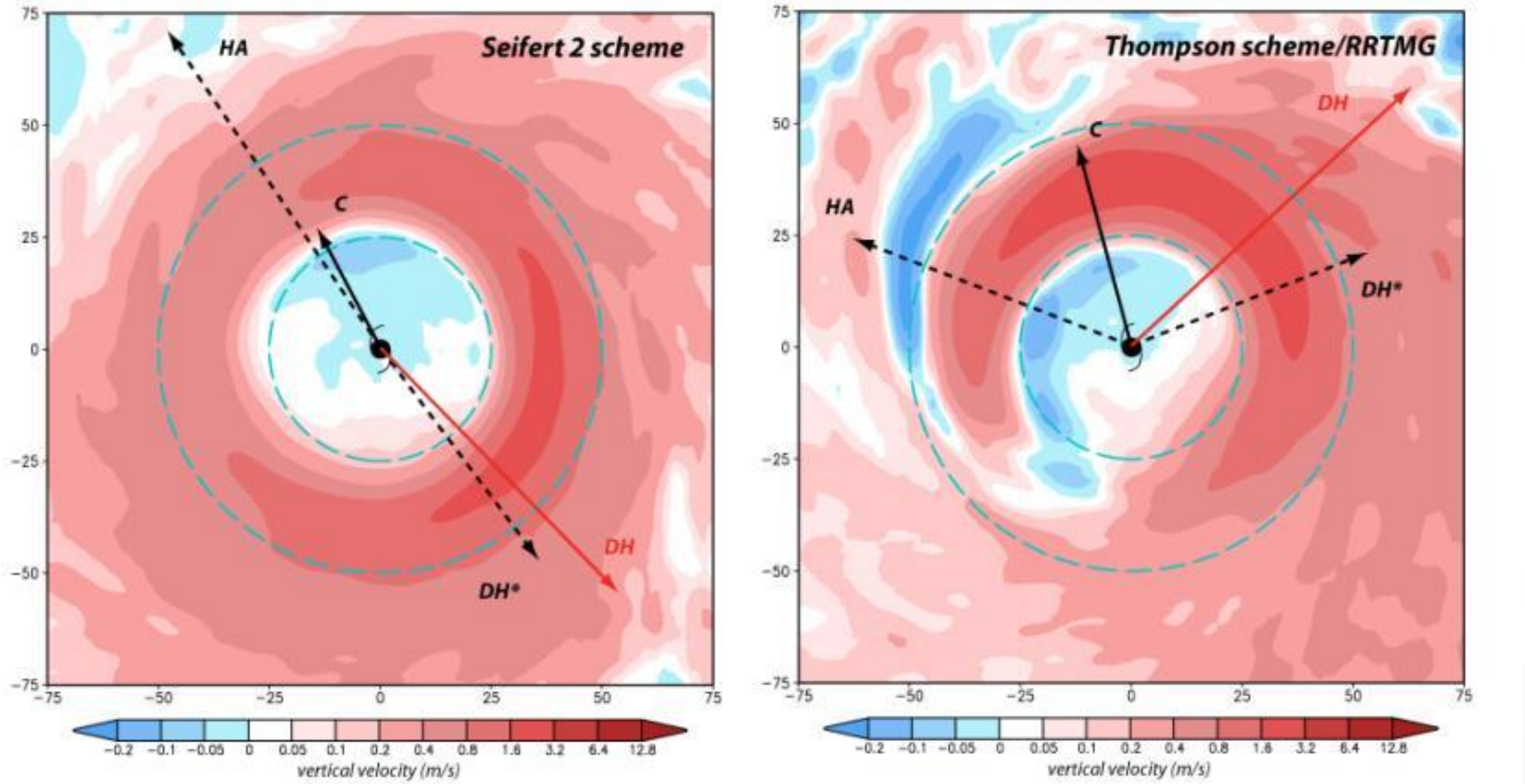




S2 with RRTM

S2 with RRTMG

Vertically averaged W



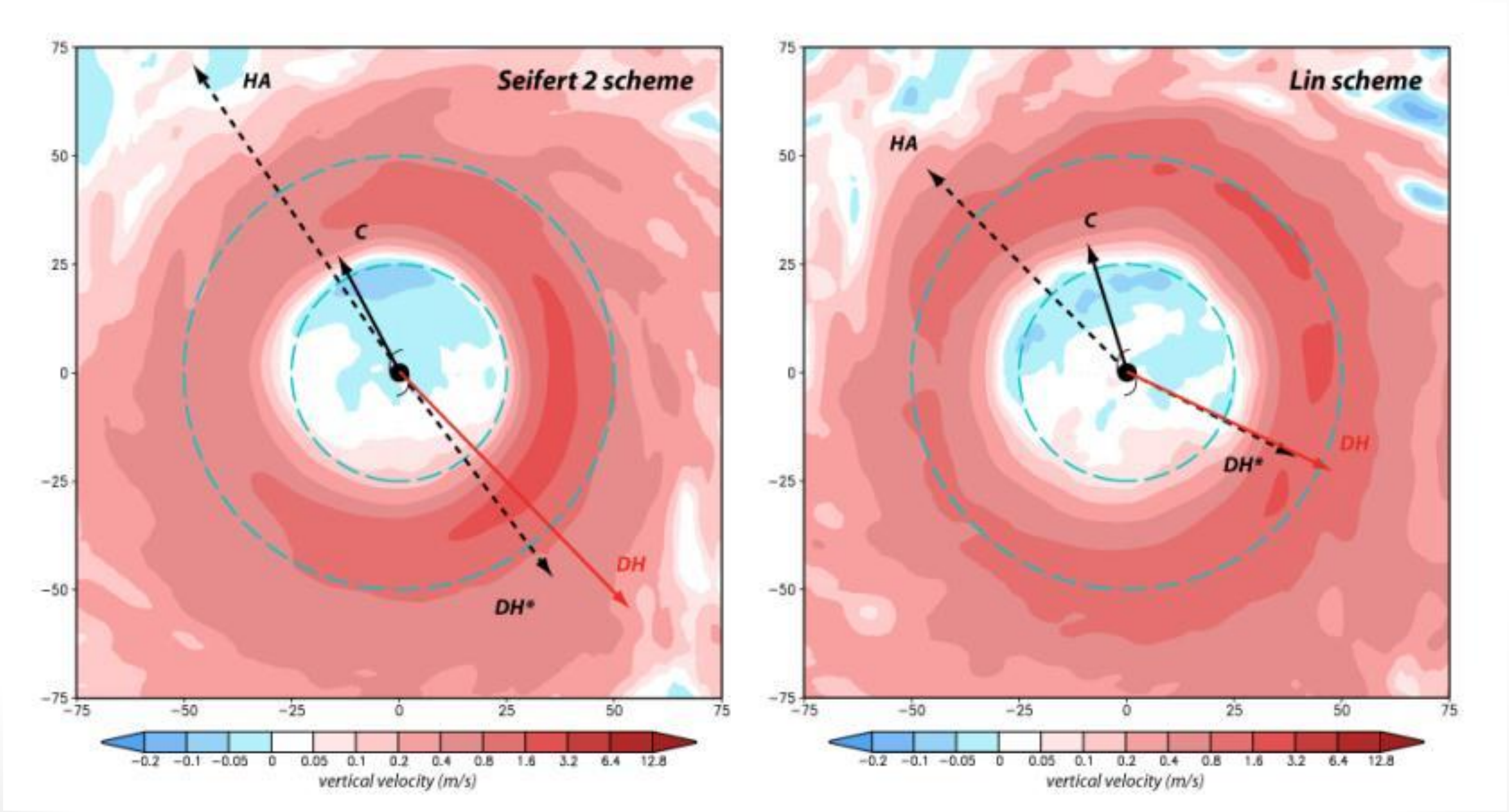
Note DH has component *against* motion

Note DH has component *towards* motion

S2 with RRTM

T with RRTMG

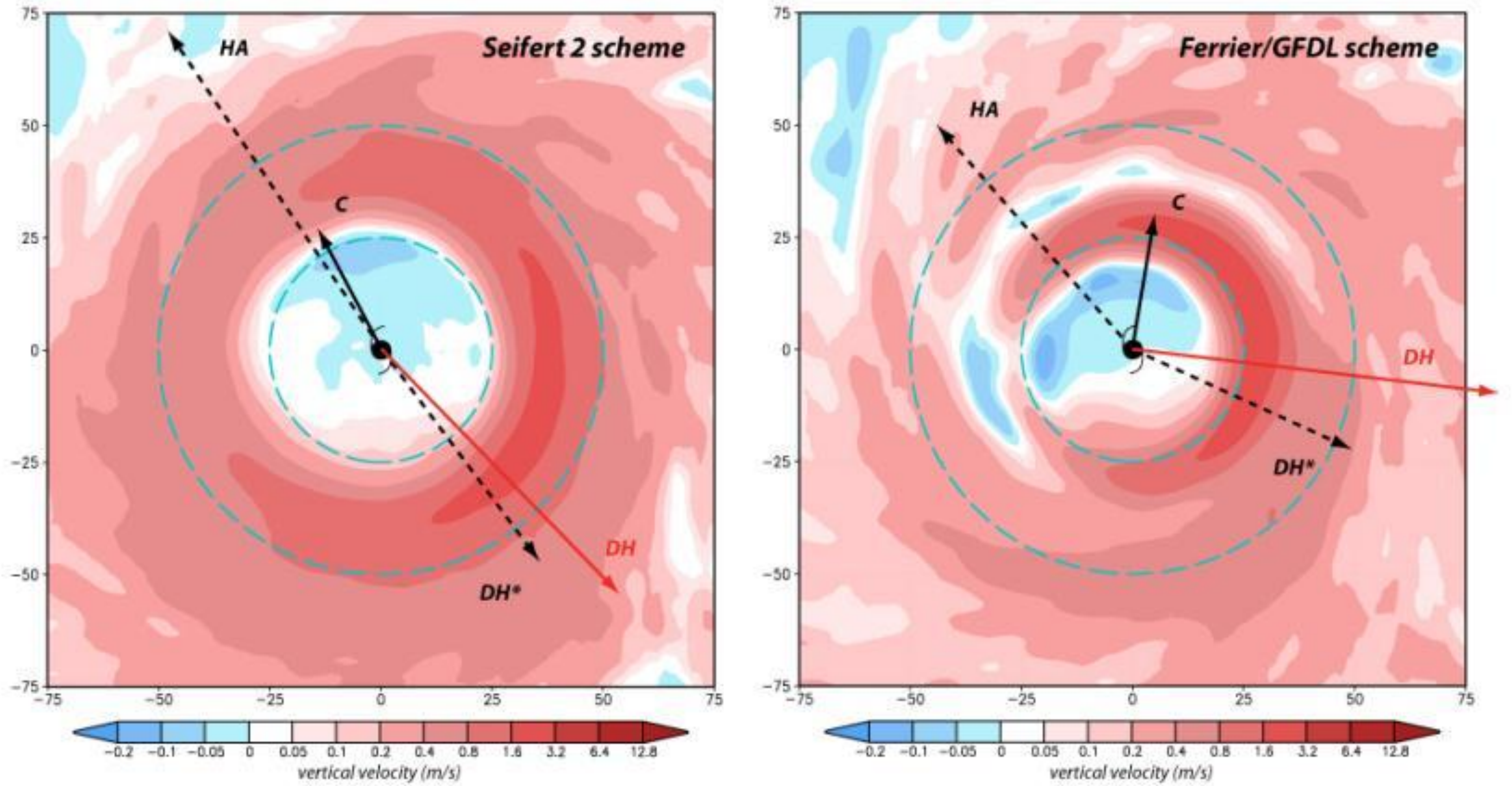
Vertically averaged W



S2 with RRTM

L with RRTM

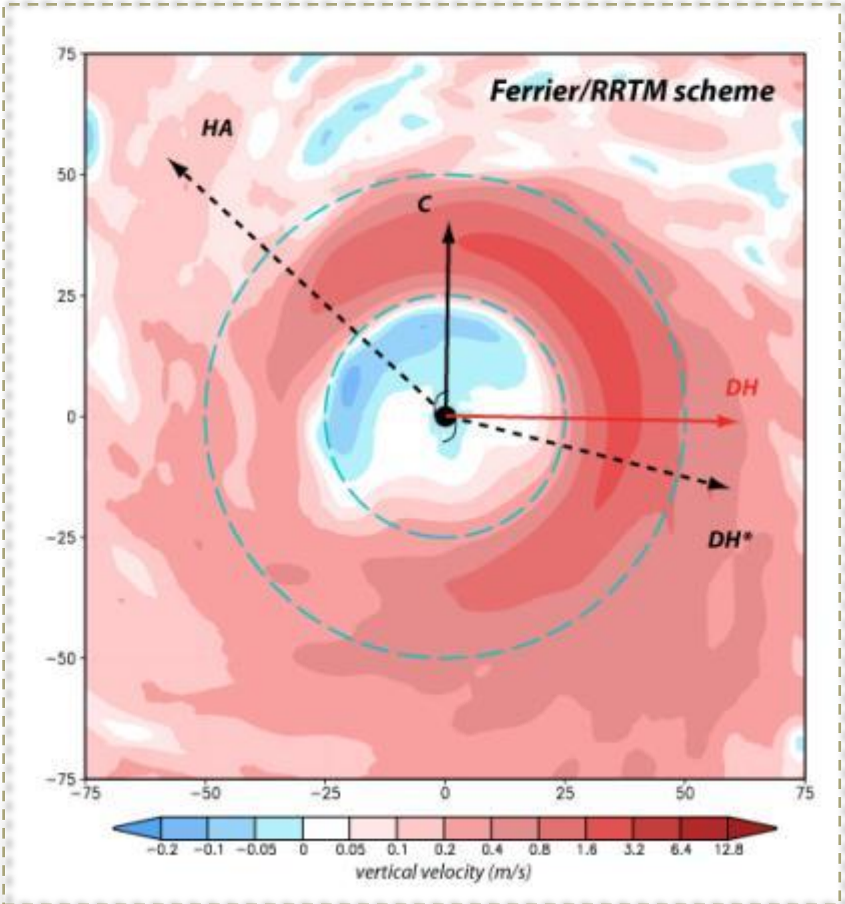
Vertically averaged W

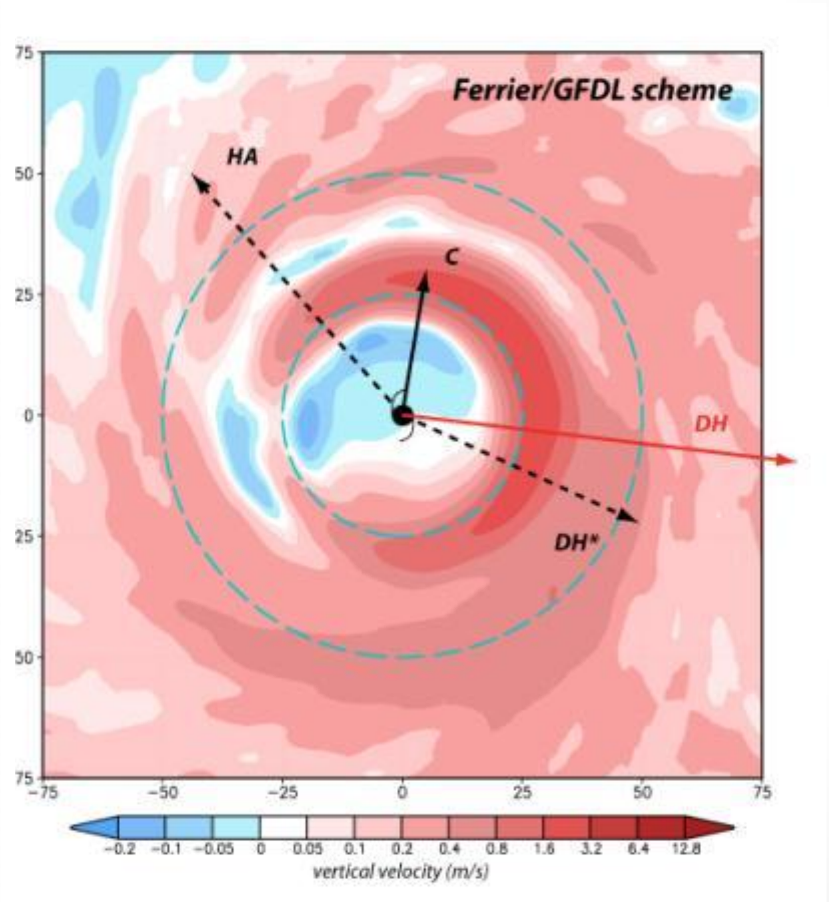


S2 with RRTM

F with GFDL

Vertically averaged W

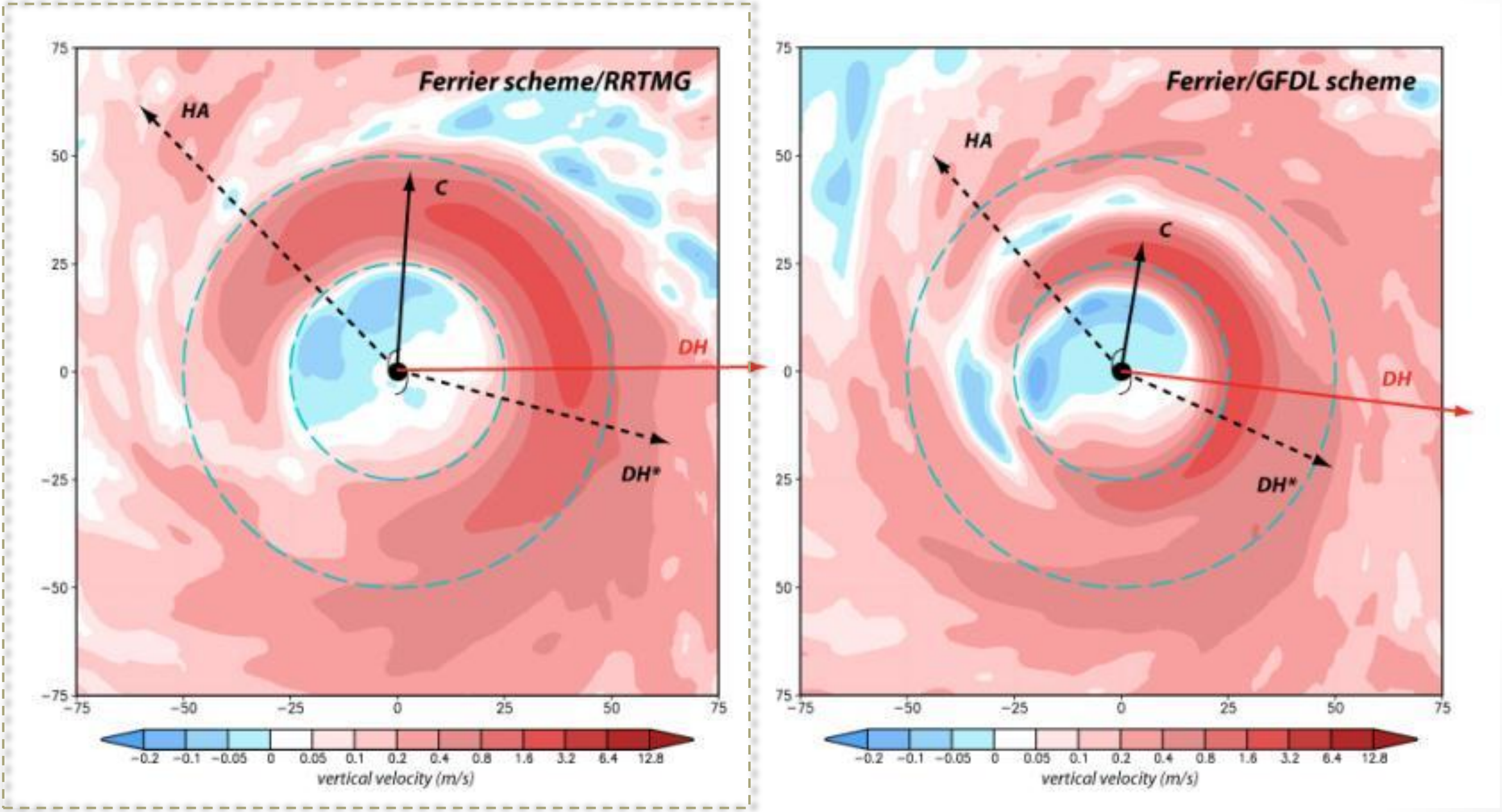




F with RRTM

F with GFDL

Vertically averaged W



F with RRTM

F with GFDL

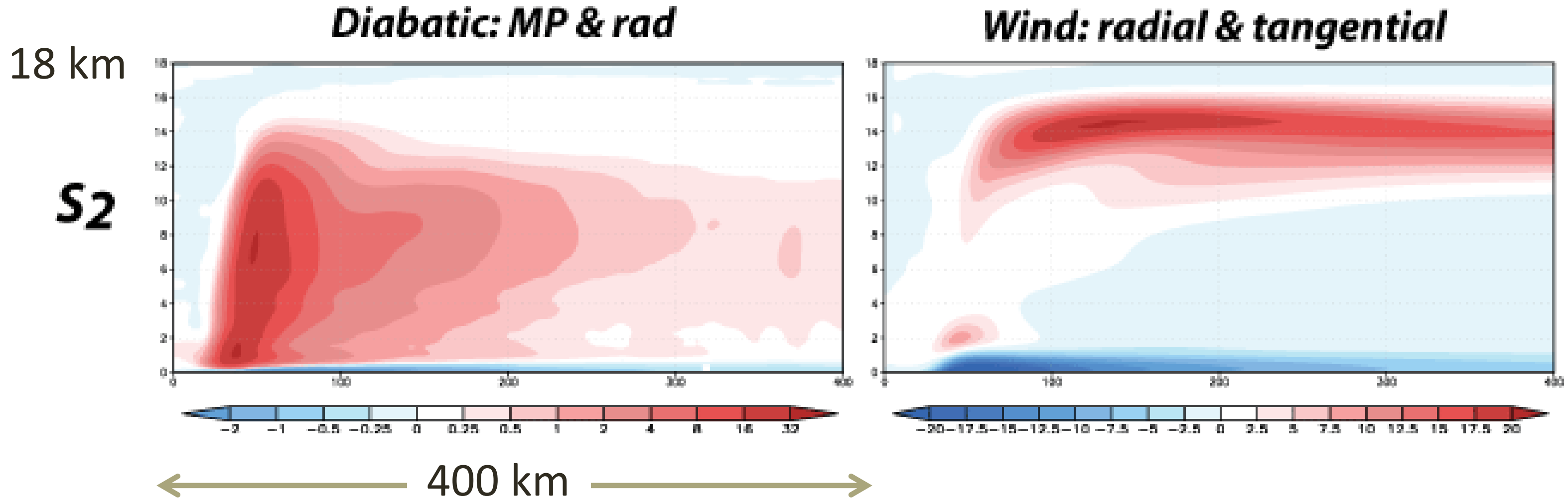
Discussion

- Most storms show asymmetric structures broadly consistent with beta shear (e.g. Bender 1997), with enhanced convection on downshear to downshear-left (Frank and Ritchie 1999; Corbosiero and Molinari 2002)
- Distinct asymmetry patterns may be related to specific microphysical assumptions and interaction with dynamics and other physics
- These can influence motion, as suggested by the PV analysis
- Thompson scheme develops a sharply defined asymmetric structure, while Lin scheme structure is more symmetric (as also occurred in real-data simulations of Ike)
- F/GFDL develops the smallest eye and most sharply defined asymmetry in the vertical velocity field
- Differences likely emerge most distinctly in cases with little steering and shear

Vertical cross-sections for the semi-idealized storms

Symmetric components in radius-height space, averaged between 48-60 h

"no correct answer"

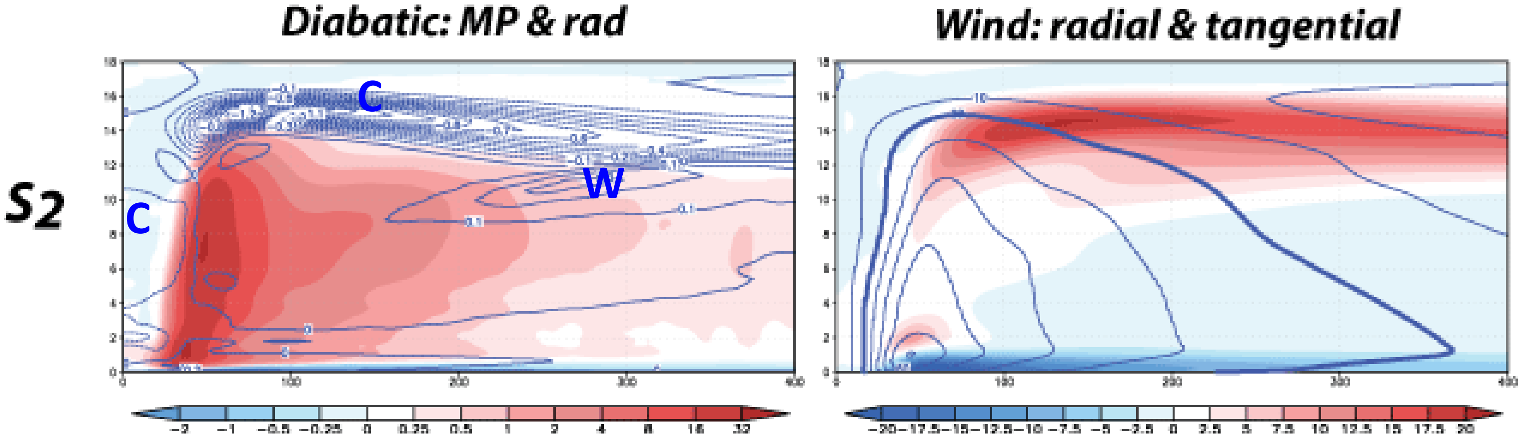


Symmetric components of

Diabatic heating from microphysics (color shaded; K/h)

Radial velocity (color shaded; K/h)

Note the microphysics heating color shading interval is log_2 scaled



Symmetric components of

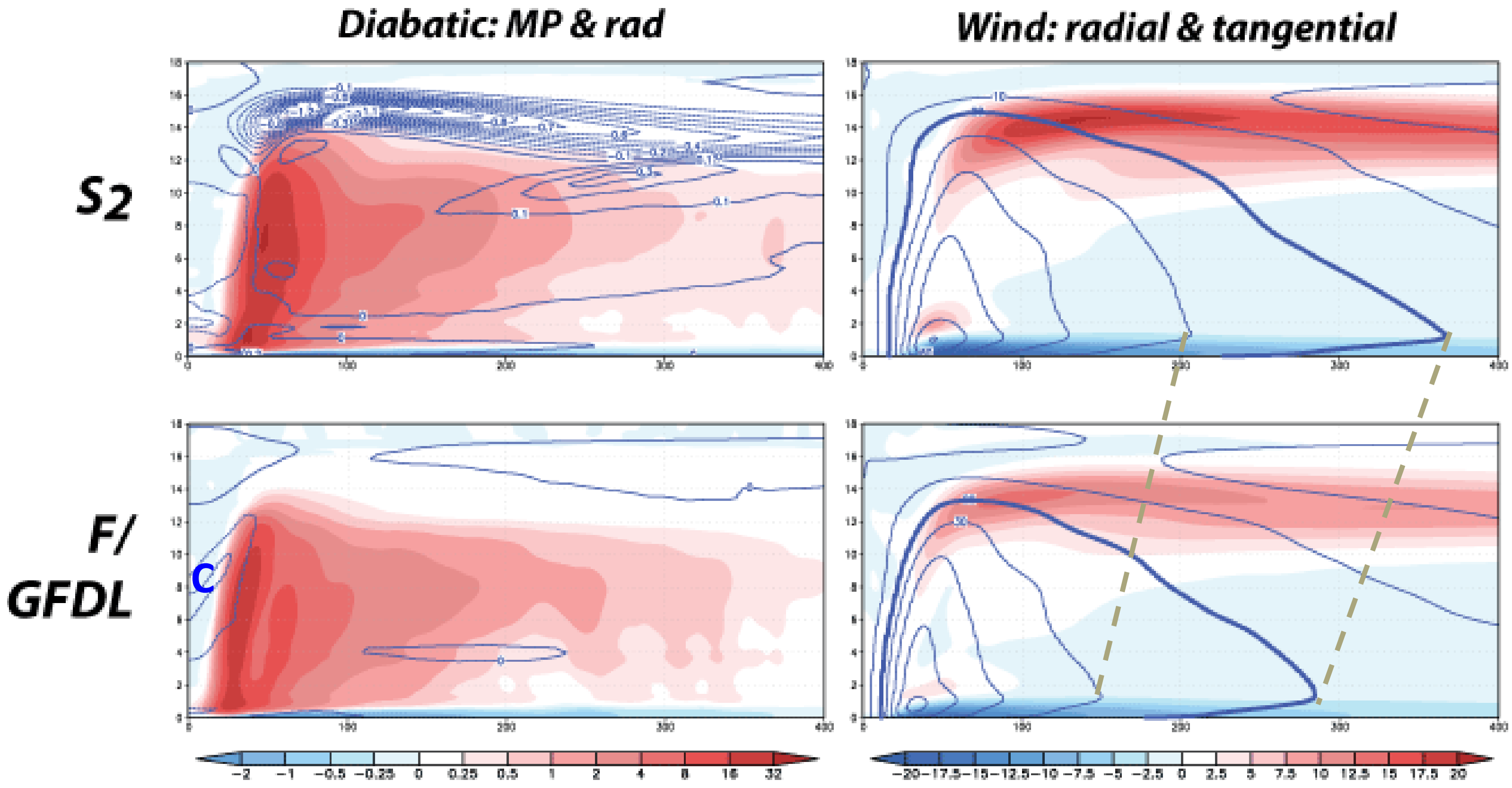
Diabatic heating from microphysics (color shaded; K/h)

Diabatic heating from radiation (0.1 K/h contours)

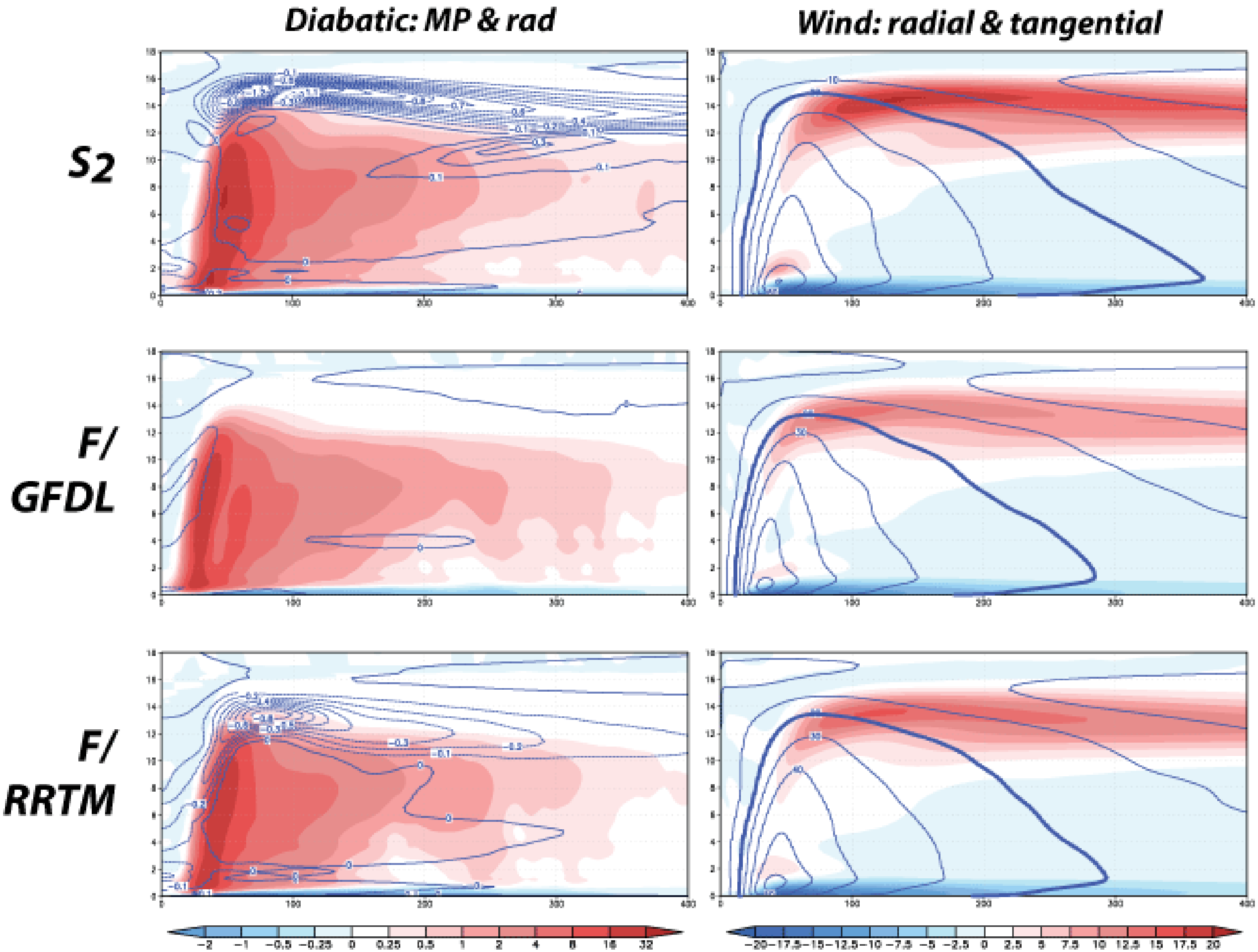
Radial velocity (color shaded; K/h)

Tangential velocity (10 m/s contours; 20 m/s highlighted)

Diabatic heating from radiation combines LW and SW



F/GFDL has almost no cloud-radiative interaction



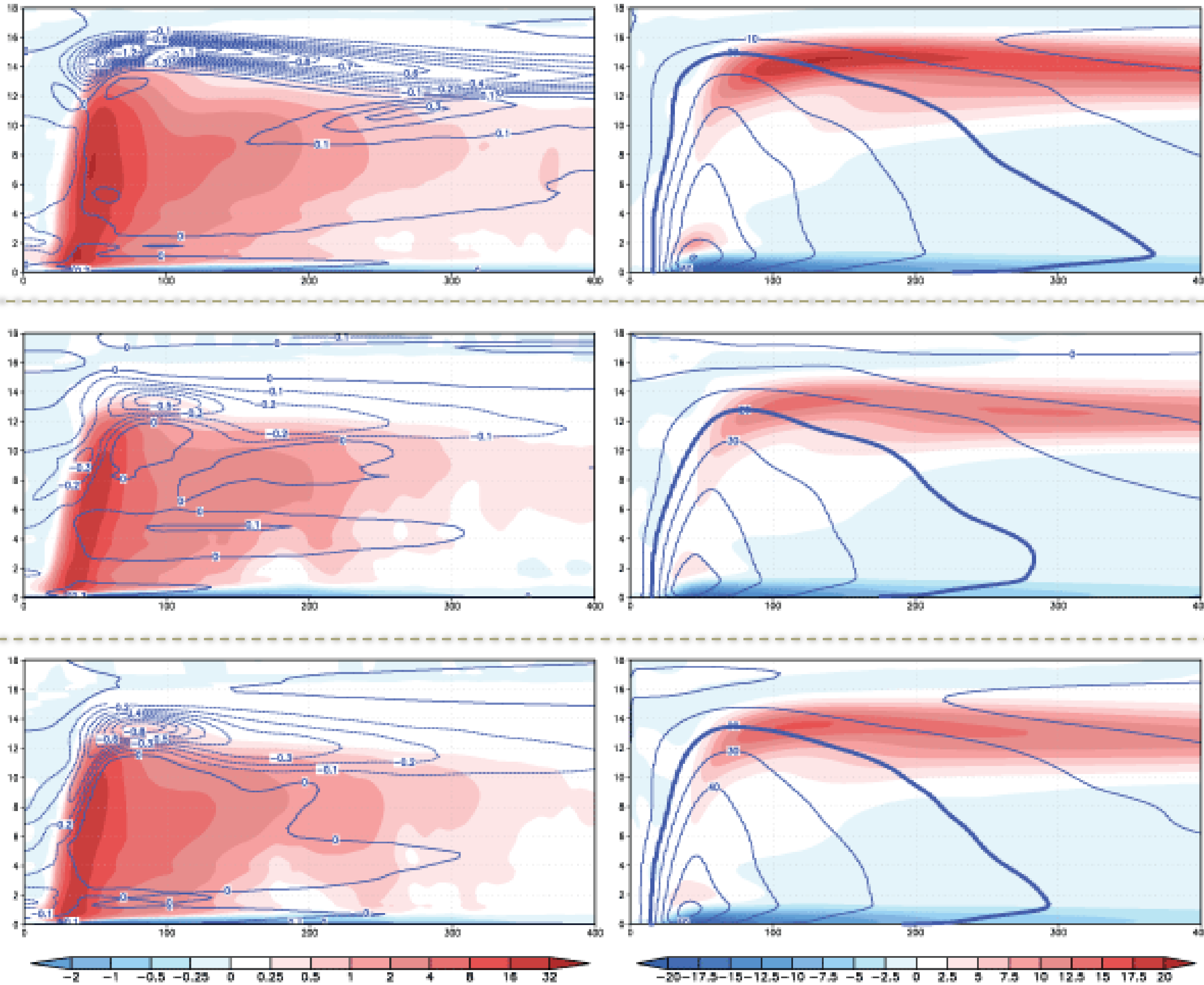
Diabatic: MP & rad
Wind: radial & tangential
S2
F/
GFDL
F/
RRTM

Diabatic: MP & rad | **Wind: radial & tangential**

S2

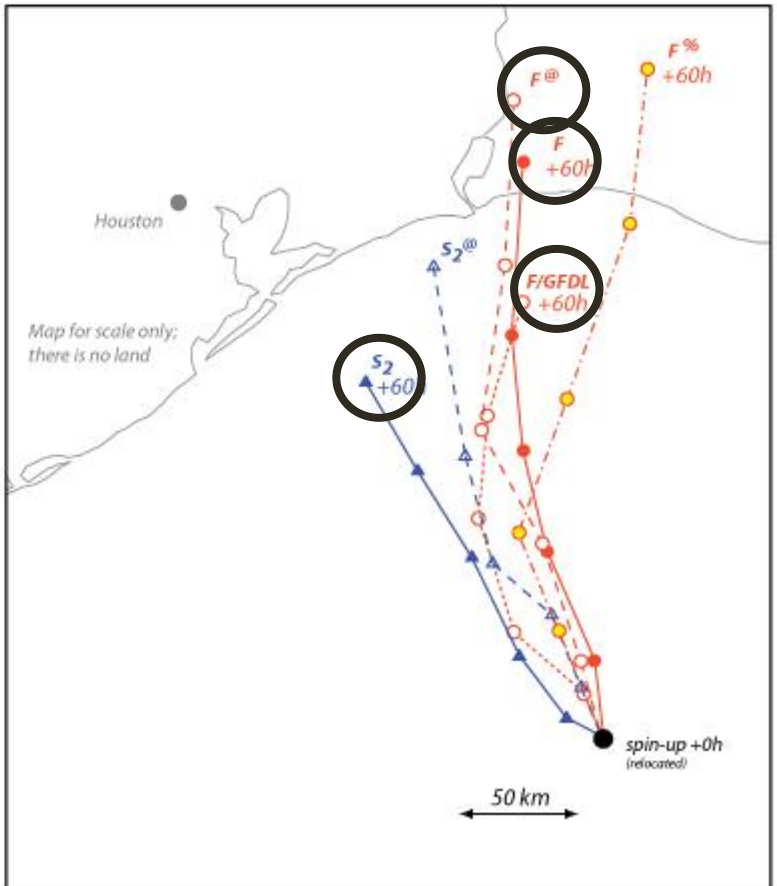
F/ RRTM (G)

F/ RRTM



Tracks after spin-up period

Tracks following 36 h spin-up period



- Focus mainly on simulations based on S2 and F

S2: RRTM
S2@: RRTMG

F: RRTM
F@: RRTMG
F%: RRTM w/ snow seen as cloud ice

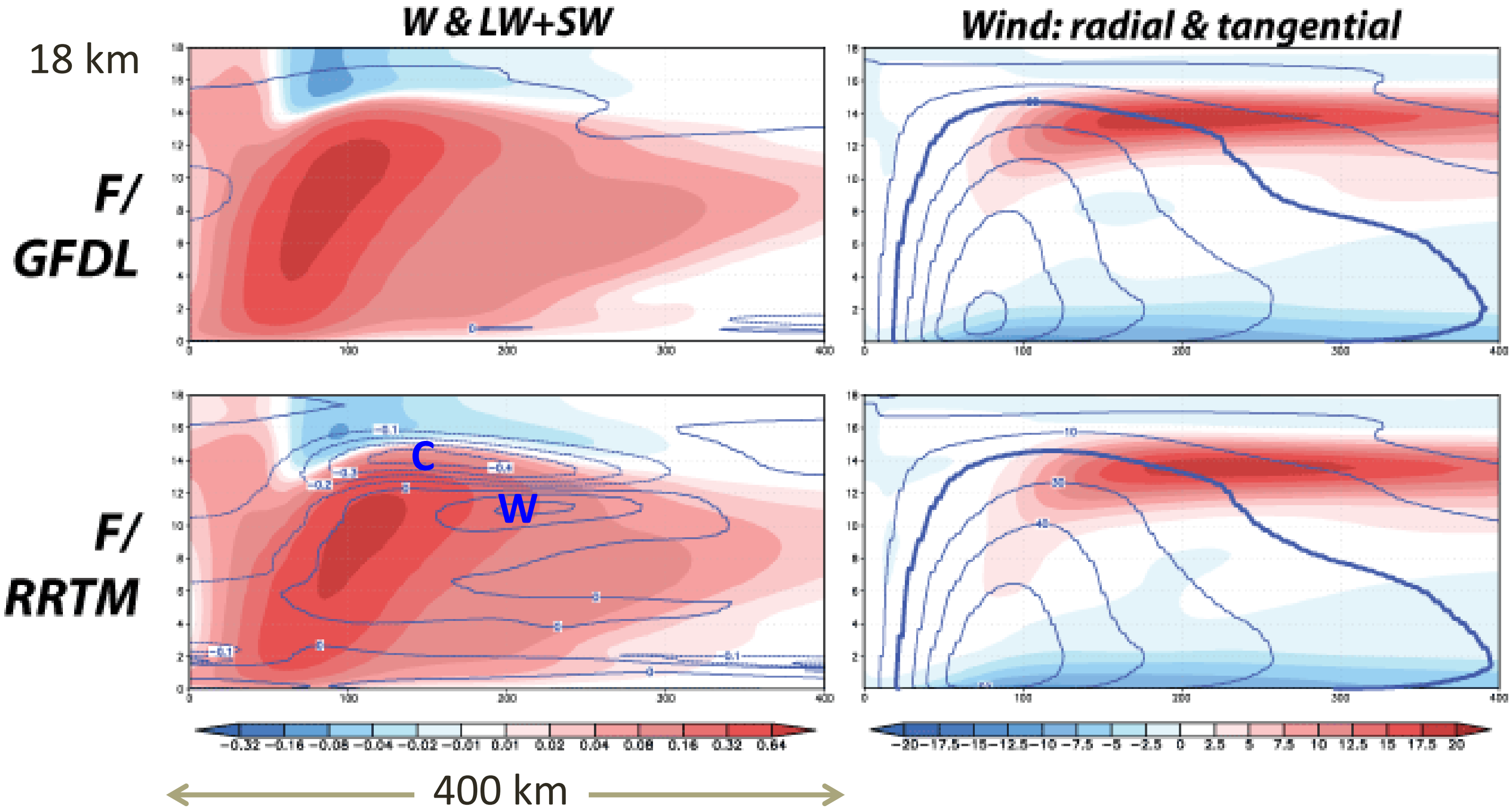
F/GFDL

Microphysics schemes were active from model start. Storm positions relocated after 36 h spin-up period (cosmetic only)

Real-data simulations with HWRF

2011 Code and **Earl (2010)** test case from DTC,

vortex-following composites made between 24-42 h



Symmetric components of

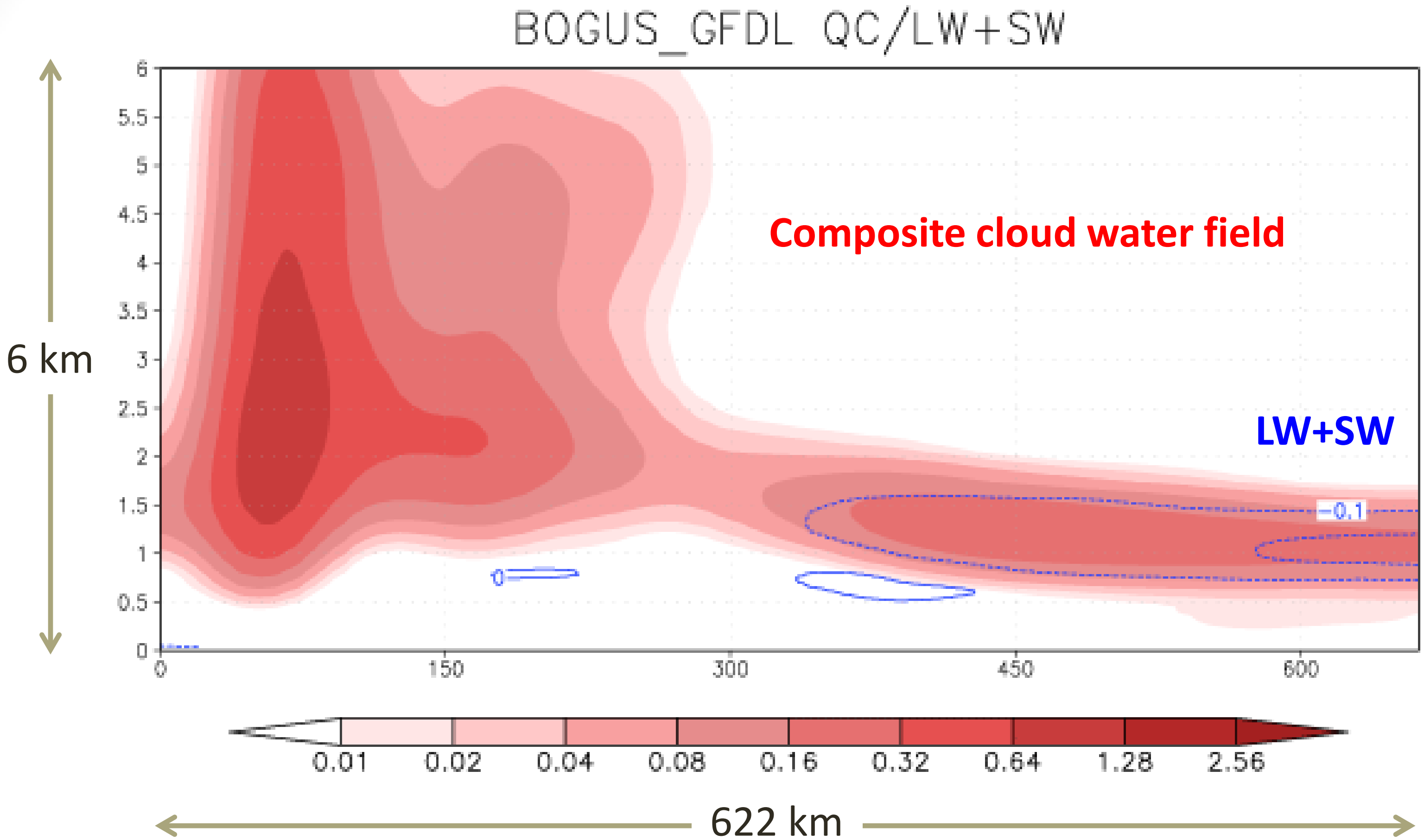
Vertical velocity (color shaded; m/s)

Radial velocity (color shaded; K/h)

Diabatic heating from radiation (0.1 K/h contours)

Tangential velocity (10 m/s contours; 20 m/s highlighted)

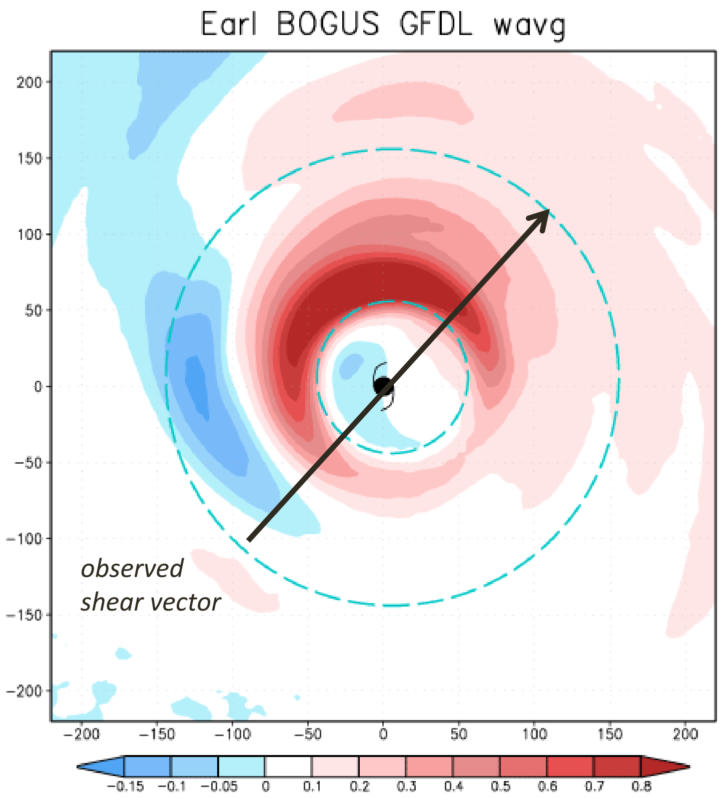
<u>F/GFDL also has almost no cloud-radiative interaction in the 2011 version of HWRF</u>



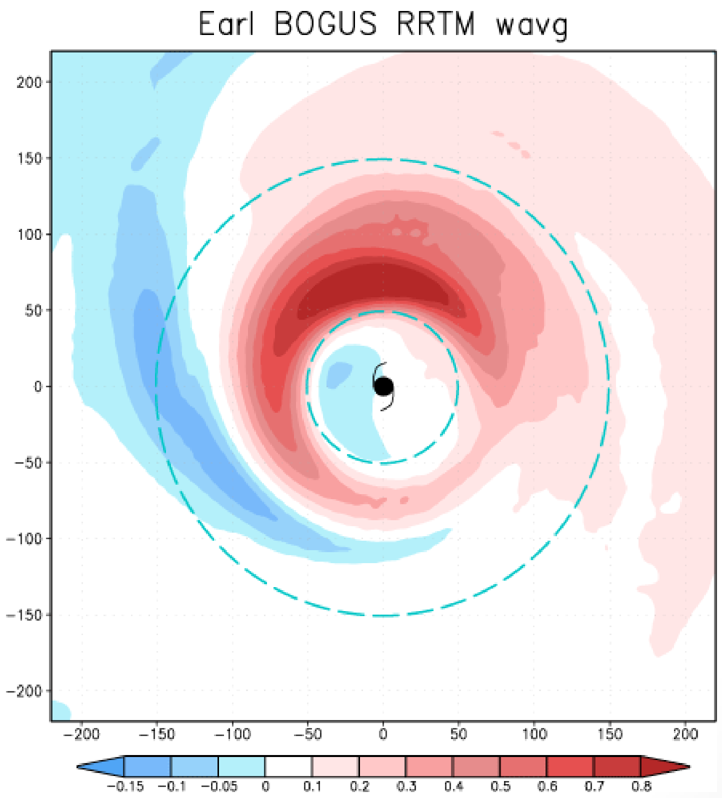
GFDL radiation scheme **does "see" shallow clouds** but not deep ones.
The SW scheme does respond to thin ice clouds (not shown)
but not the LW scheme.

Vertically averaged W, hours 24-42

F/GFDL



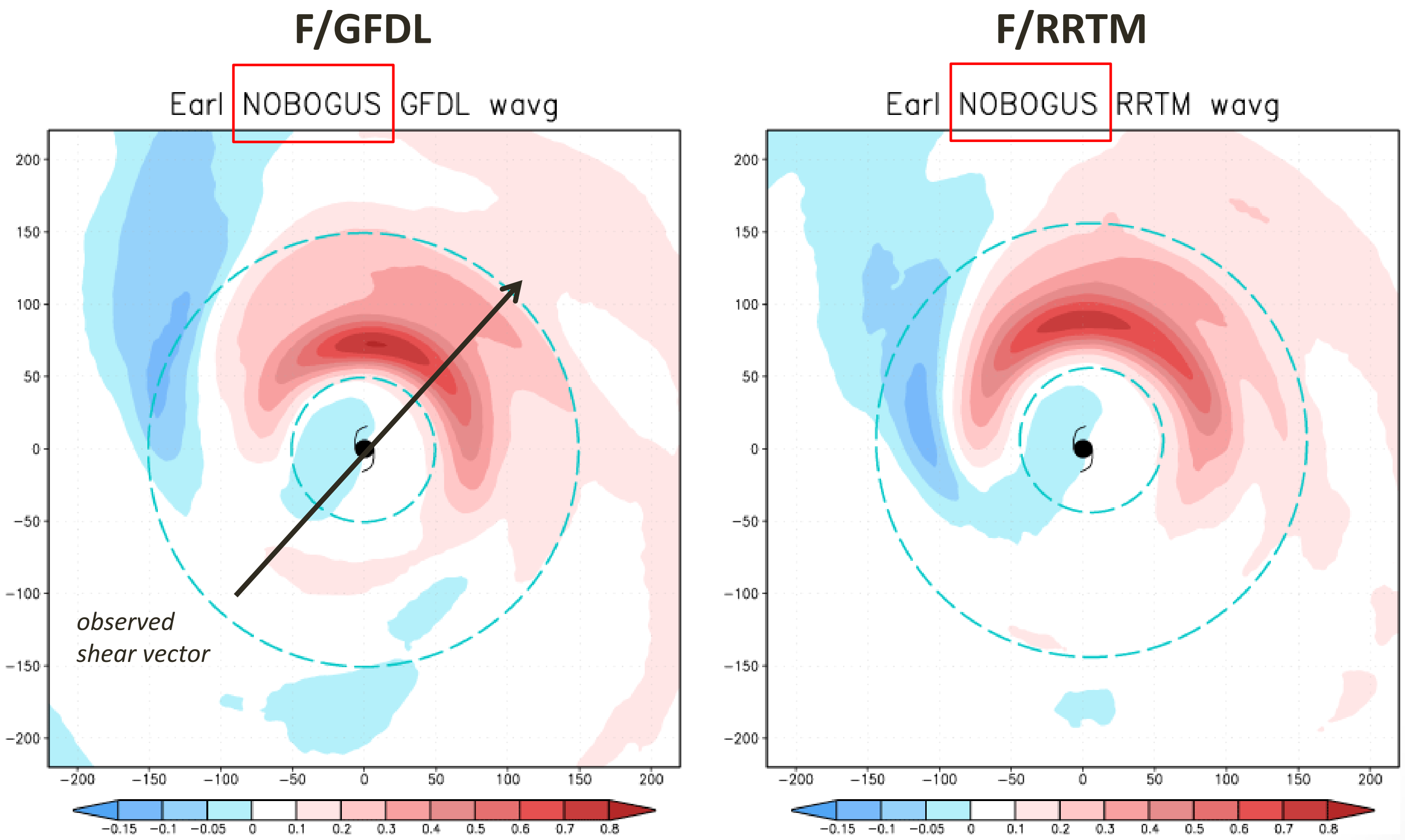
F/RRTM



Little influence of radiation scheme on structure or motion in the Earl test case.

Shear according to
http://rammb.cira.colostate.edu
AMSU-derived products

Vertically averaged W, hours 24-42



Even the bogus initial vortex had relatively little impact on the Earl test case (motion, structure, asymmetry).

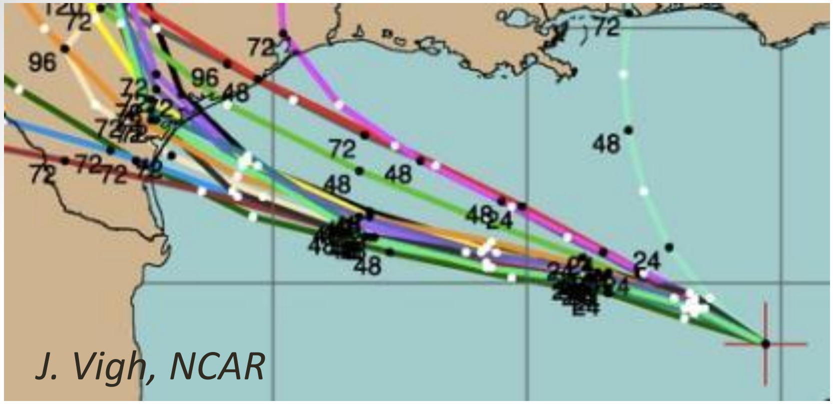
Shear according to
http://rammb.cira.colostate.edu
AMSU-derived products

Real-data simulations with WRF-ARW

Ike (2008) 9 September 12Z,
9 km fixed and 3 km moving nests
cold start from GFS with no initial condition modification
vortex-following composites made between 30-48 h

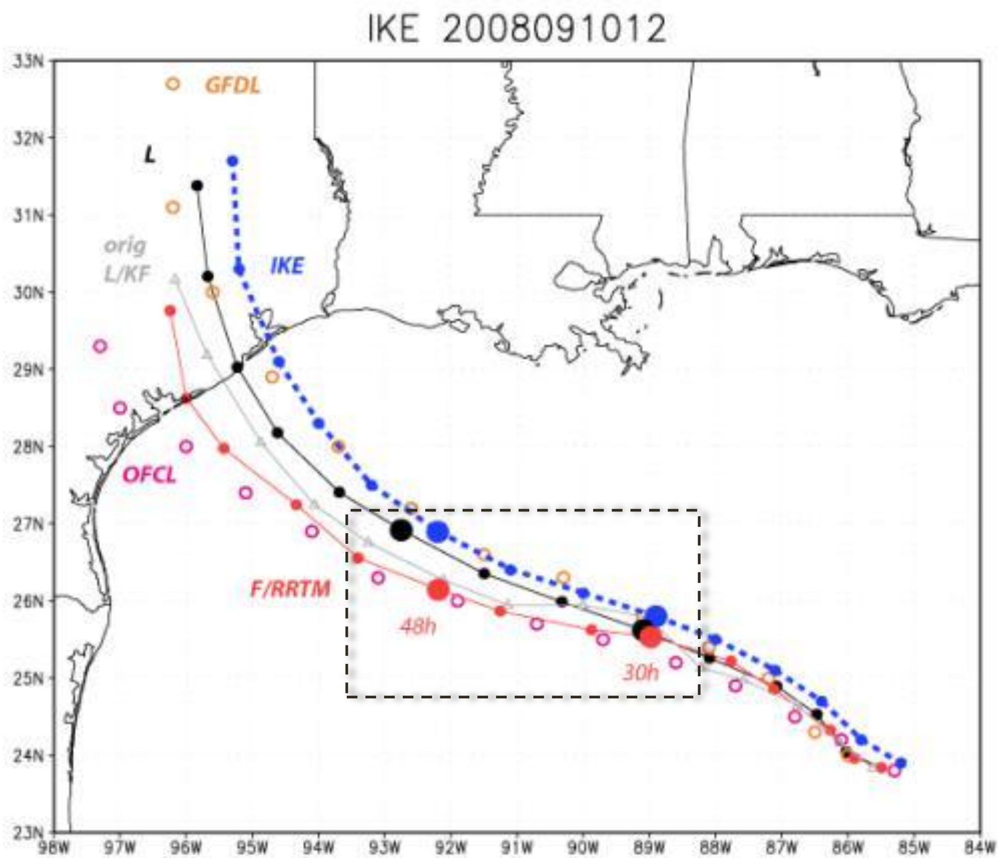
Legend for next slide

- **9 & 3 km** WRF-ARW forecasts:
  - L/RRTM
  - F/RRTM
- 36 km WRF-ARW forecasts:
  - L/KF
- Other tracks
  - GFDL
  - OFCL
  - **Ike best track**



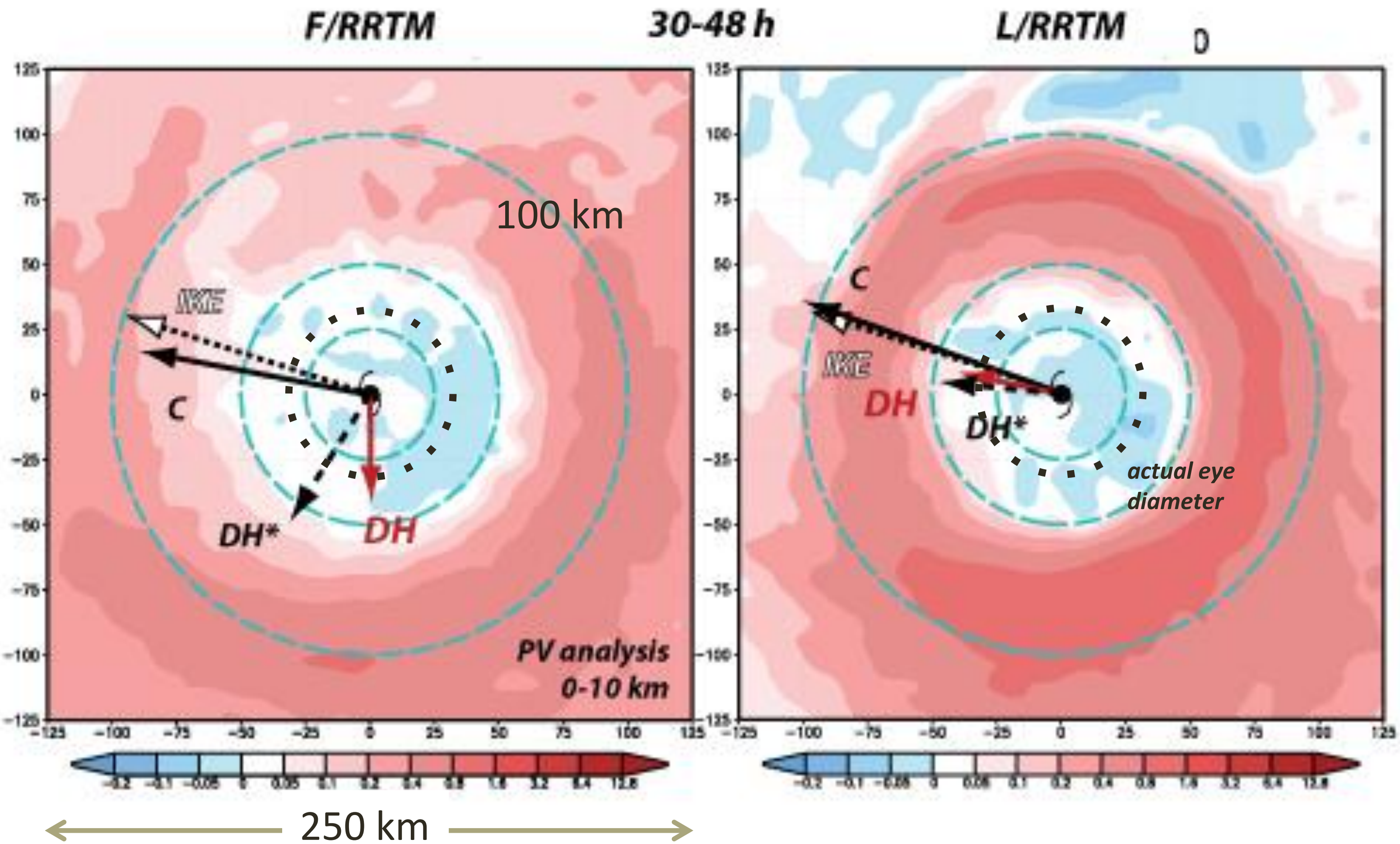
NHC multi-model ensemble

(revisit slide #4)



- **Critical period appears to be between 30-48 h**
- During that time, F/RRTM moves *too slowly*, *too far west*, as does OFCL forecast
- GFDL track is good but motion is too fast
- Many of the NHC consensus models evinced similar (or worse) position errors
- Original 36 km L/KF track is competitive (!)

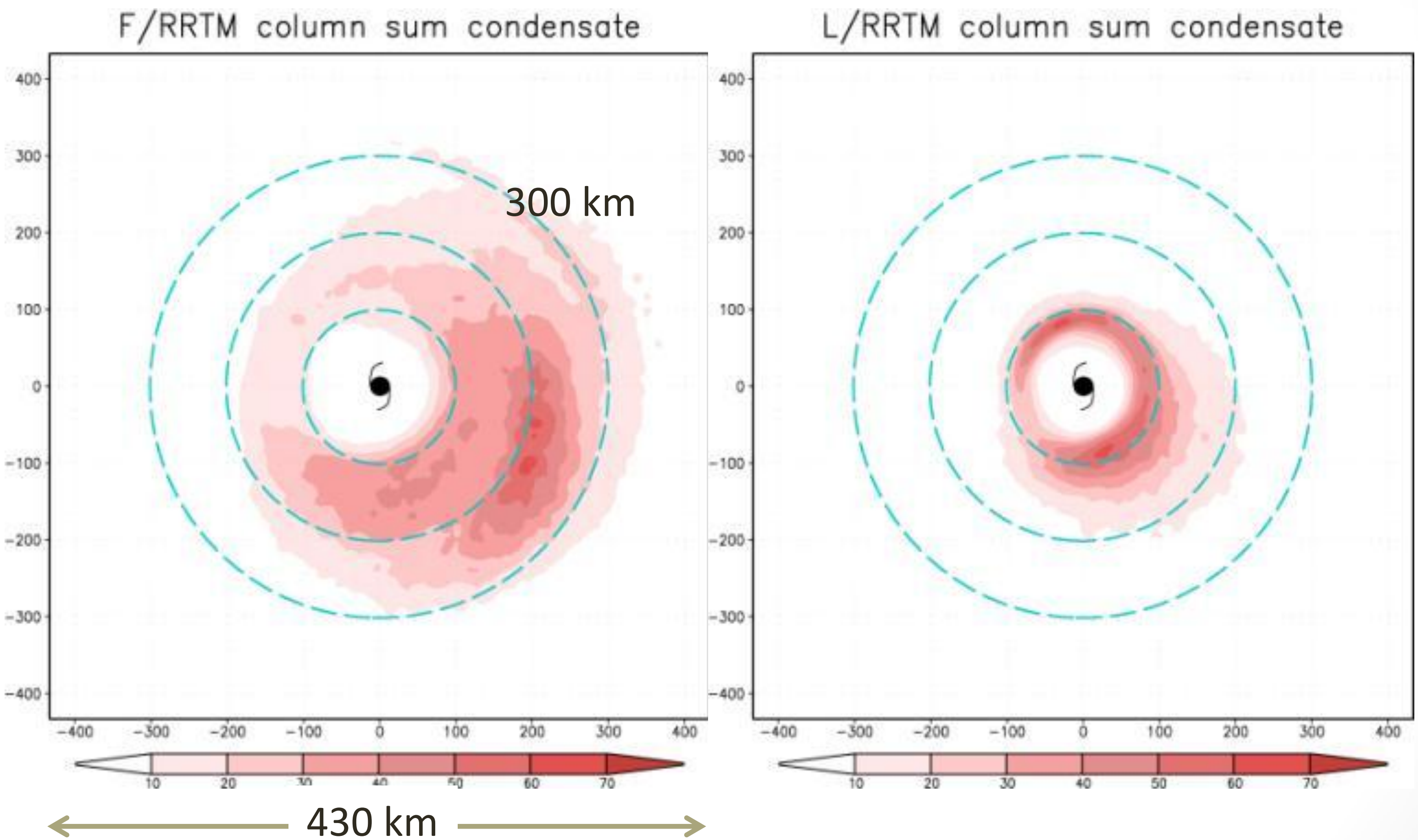
W and PV analysis (sfc-10 km)



F/RRTM is weaker and shallower. DH* appears to encourage more westerly motion.
L/RRTM is deeper and somewhat more symmetric. DH* acts in direction of motion.

Total column condensate

30-48h



F/RRTM produces a much wider (and more realistic) condensation field than graupel-dominated L/RRTM.

Discussion/summary

- GFDL radiation scheme appears to ignore deep clouds
  - In WRF-ARW and apparently in HWRF (2011) as well
- It is not clear (to us) what the magnitudes of radiative heating and cooling forced by clouds should be
- Different model physics appears to encourage distinct symmetric and asymmetric structures that can influence storm motion and may provide means of validating, modifying model physics
- Working towards examining other cases, and alternate model physics (as available)

Wu and Wang (2000, JAS)
PV analysis

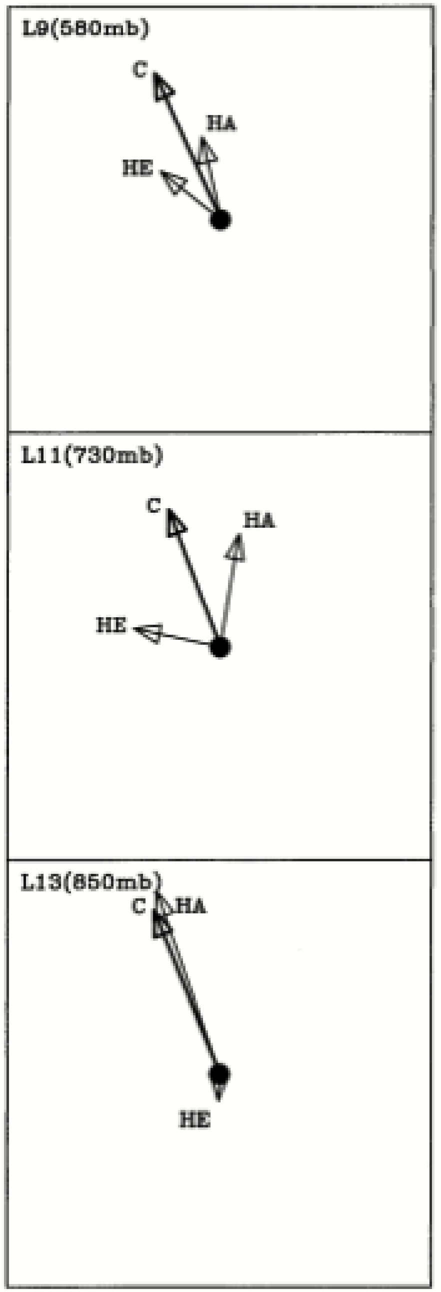


FIG. 11. Variations of the contributions (the maximum is 2.9 m s^{-1}) of horizontal advection (HA), vertical advection (VA), and diabatic heating (HE) at 36 h in the diabatic experiment on a beta plane with a resting environment (E4).

$$\frac{\partial PV}{\partial t} = \Lambda_1 [HA + VA + DH + R]$$
$$= \Lambda_1 [HA + DH*]$$

HA = horizontal advection
VA = vertical advection
DH = diabatic heating term
Λ_1 extracts wavenumber 1 component