NCAR

En route wake vortex dynamics; a computational study

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General information

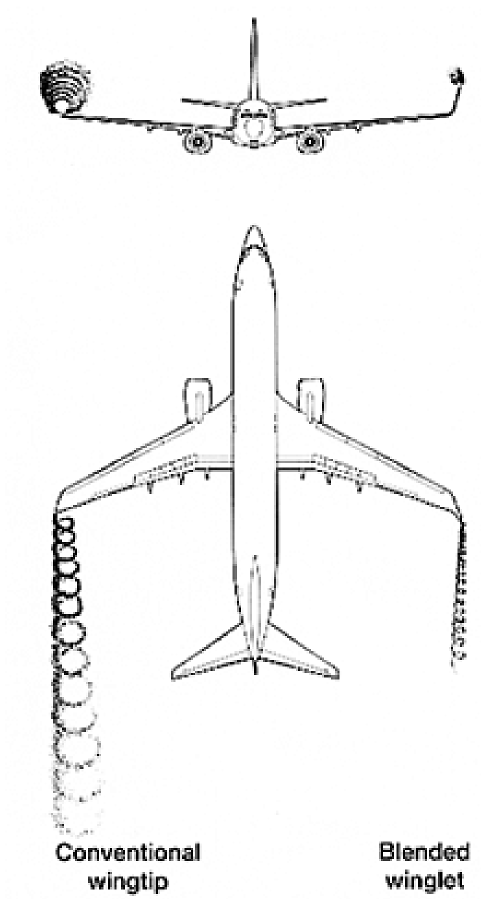
- ITT Air Traffic Management (ATM)/Federal Aviation Administration (FAA) project for evaluating the en route wake vortex hazard in the Next Generation Air Transportation System (NextGen) air traffic environment.

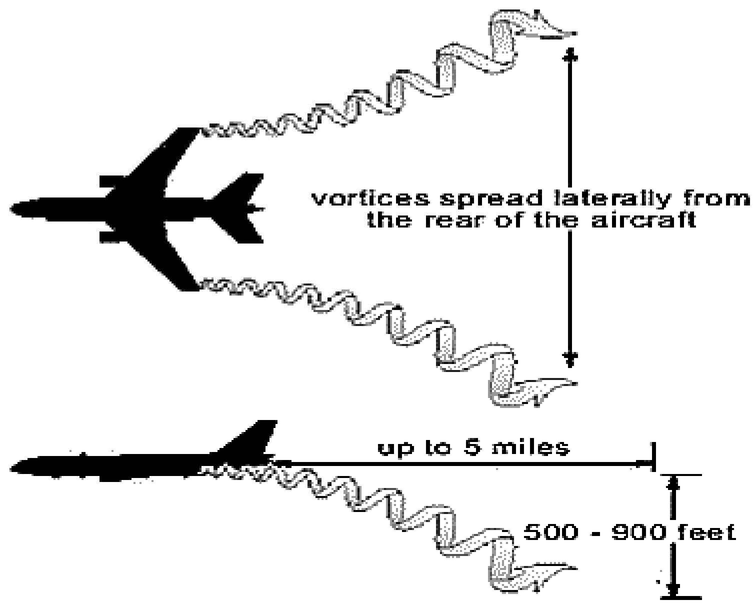
- Investigate wake vortex characteristics at the en route environment (UTLS- upper troposphere or lower stratosphere) in which commercial aircraft spend most of their time,

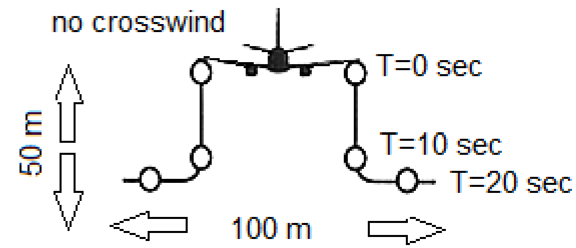
- Account for different conditions: stability, wind shear, turbulence …. factors substantially different at UTLS than in the terminal area.

Wake vortex generation and propagation

Commercial aircraft generate wake vortices that are shed from the wing tips and can persist downstream for a significant distance and time (30 sec-2 min).

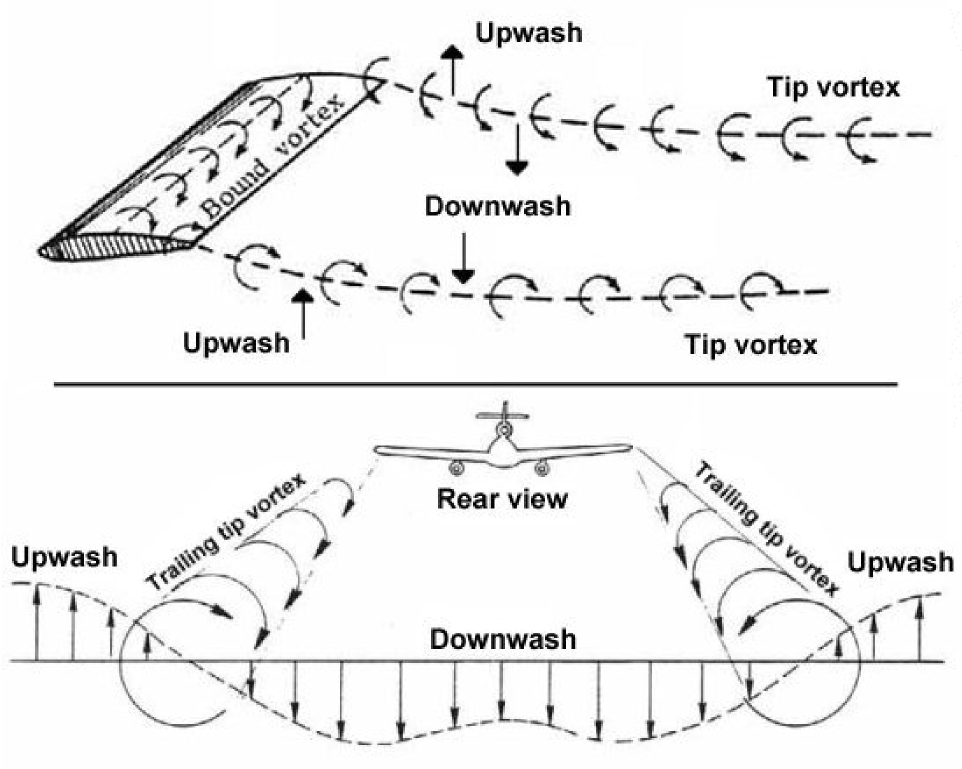


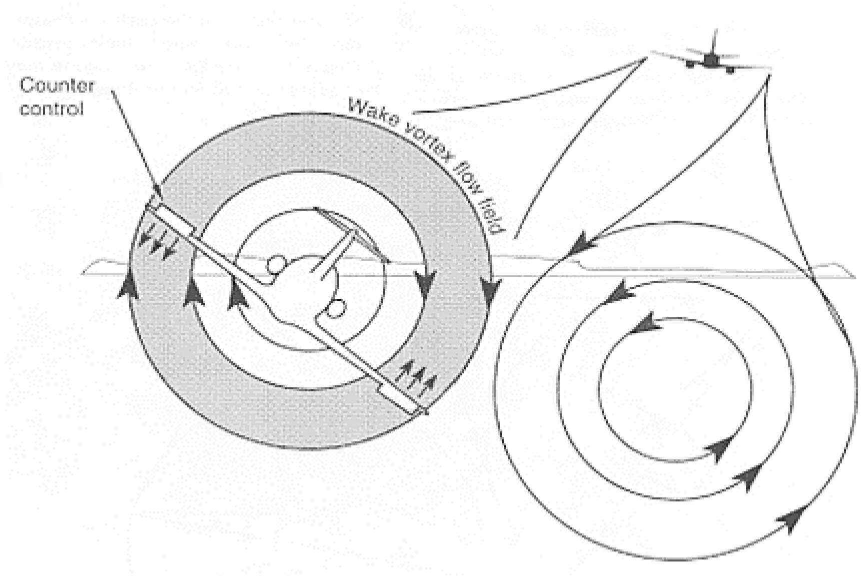




VORTEX CHARTERISTICS ARE DEPENDING ON THE TYPE, WEIGHT, CONFIGURATION, AIRSPEED OF THE AIRPLANE

Wake vortex effects





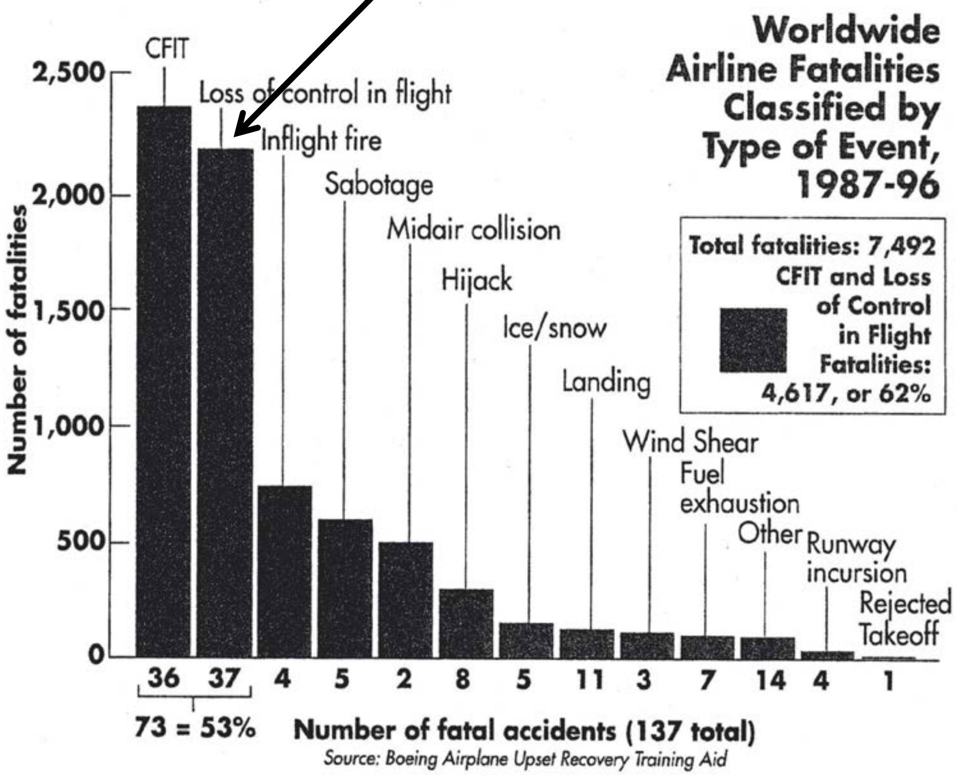
Differential pressure field above and below wing generated by the vortices causes roll up

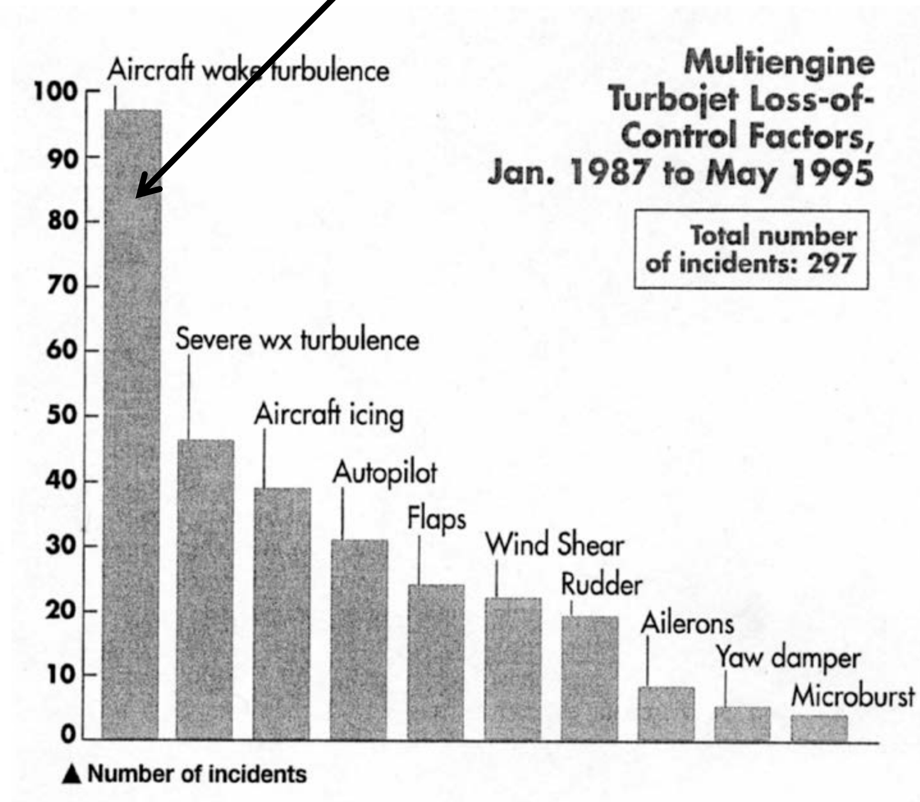
Wake vortex broader effects

Incidents and accidents in civil aviation:

all reasons

loss of control

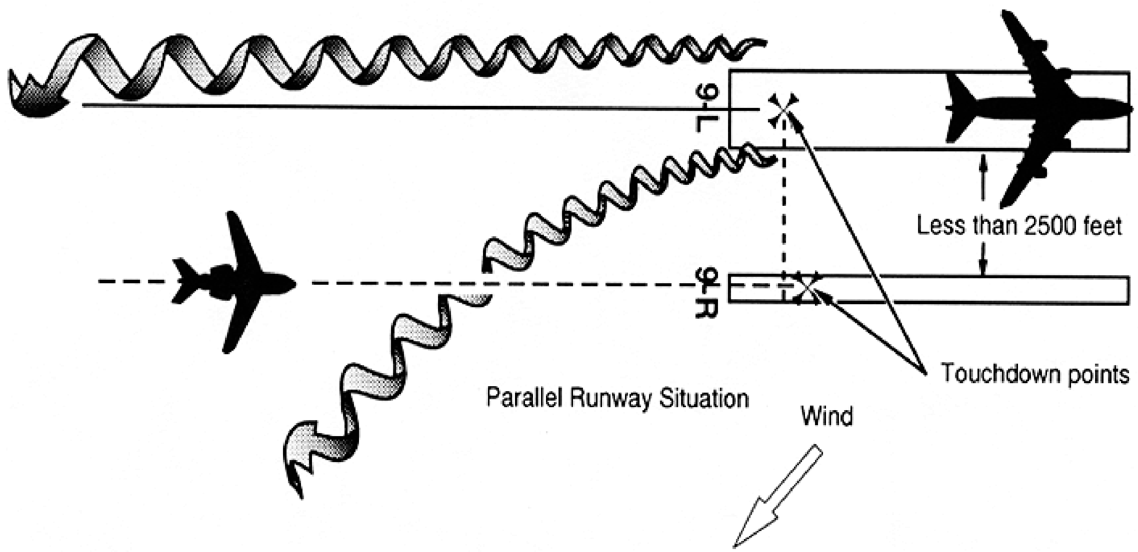




CFIT-Controlled Flight Into Terrain

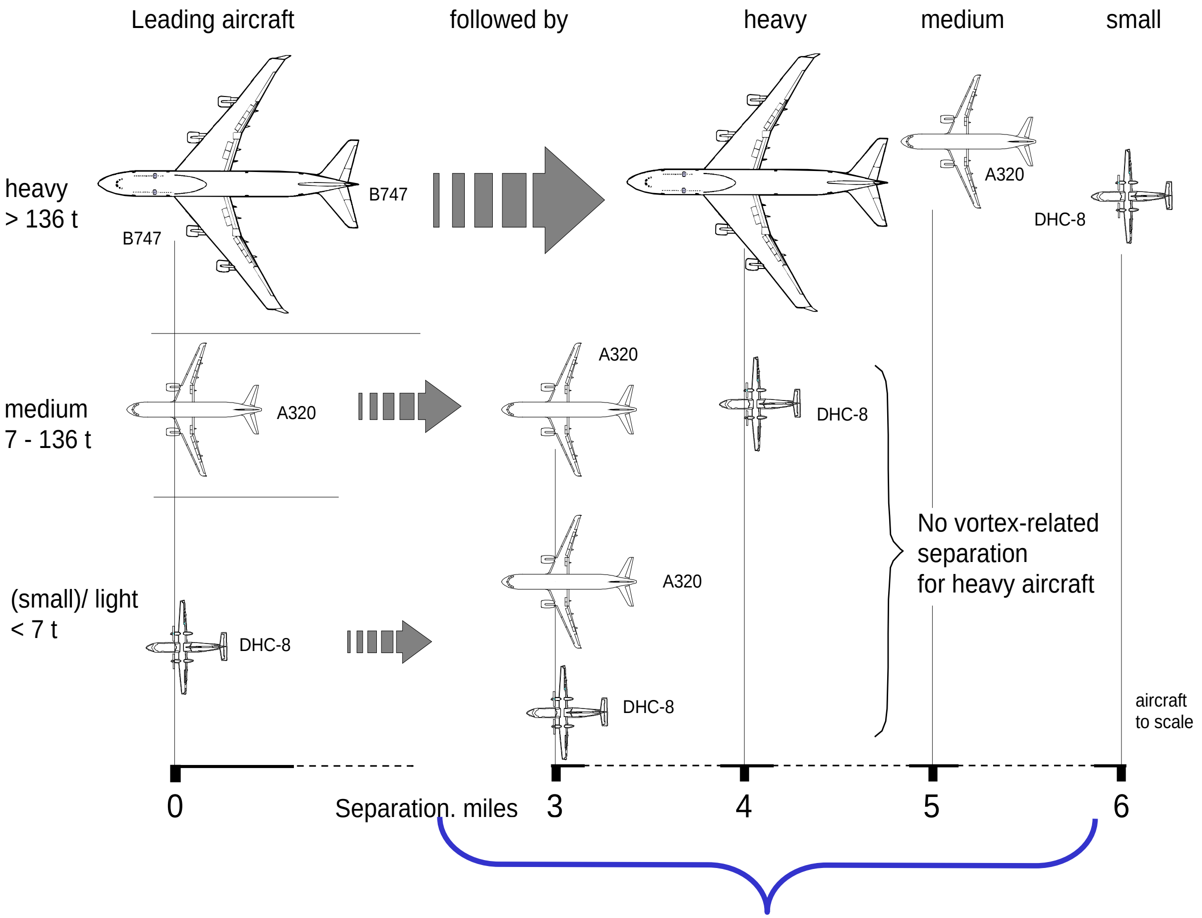
Avoidance procedures

LANDING



- **ALIGNED WITH THE VORTEX**
- **RECOMMENDED DISTANCE FROM VORTEX CENTER**
- **AUCCUNT FOR TURBULENCE WHEN ENCOUNTERED @ AN ANGLE**

ICAO wake vortex separation standards



What separations are needed at en route UTLS due to wake vortex uncertainties?

Numerical simulations

- Idealized vortex pair with 2D/3D EULAG based LES
- Initial vorticity distribution based on the Lamb-Oseen vortex

- Sensitivity of temporal evolution, decay, descent and separation to:
  - boundary and initial conditions
  - several model-grid resolutions, i.e. (3D):
    - **256x24x256 (4m)**
    - **512x48x512 (2m)**
    - **768xx72x768 (1.5m)**
    - **1024x96x1024 (1m)**
  - idealized stratified (N=0, N=0.12, N=0.2) and sheared environments
  - presence of background noise (white, naturally developed)

- Nonlinear effects:
  - vortex meandering in the sheared environment
  - onset of the Crow instability

- Vortex behavior in the UTLS for a realistic atmospheric and operational condition based on an actual wake vortex encounter

Wake vortex parameters

Table 1: Generating aircraft and initial wake specifications:

Case #	Aircraft	Weight, kg.	Vref, m/s	Span, m	Core Spacing, m	Core Radius, m	Total Circulation, m^2/s
1	DC-9-50	37422	68.0	28.48	22.36	1.42	197.03
2	B727-100	45927	70.0	32.93	25.85	1.65	227.26
3	B767-300	94575	70.0	47.59	37.37	2.38	289.84
4	DC-10-30	137100	71.0	50.43	39.59	2.52	387.66
5	B747-400	214325	74.6	64.33	50.51	3.22	431.75

NASA Technical Memorandum 110343

A Candidate Wake Vortex Strength Definition for Application to the NASA Aircraft Vortex Spacing System (AVOSS)

David A. Hinton *Langley Research Center, Hampton, Virginia*
Chris R. Tatnall *George Washington University Joint Institute for Advancement of Flight Sciences Langley Research Center, Hampton, Virginia*

Aircraft	$b_o\ (m)$	$V_o\ (m\ s^{-1})$	$\Gamma_o\ (m^2\ s^{-1})$
727	26	1.53	250
737	22	1.49	205
747	50	1.70	534
757	30	1.63	307
F28	20	1.28	161
EA 330	47	1.28	378
DC 10-30	40	1.96	493

WAKE VORTEX TRANSPORT IN PROXIMITY TO THE GROUND

David W. Hamilton[1] *and Fred Proctor*[2]
NASA Langley Research Center, Hampton, Virginia

Lamb–Oseen vortex

$$V_\theta(r) = \frac{\Gamma}{2\pi r}\left(1 - e^{-r^2/a^2}\right)$$

From a briefing by Fred Proctor:

B747: Circulation=500 m^2/s, d=50.5 m

B777: Circulation=435 m^2/s, d=47.9 m

EA-330: Circulation=370 m^2/s, d=46.7 m

EA-310: Circulation=375 m^2/s, d=34.5 m

B767: Circulation=330 m^2/s, d=37.4 m

B757: Circulation=320 m^2/s, d=29.8 m

B727: Circulation=231 m^2/s, d=25.8 m

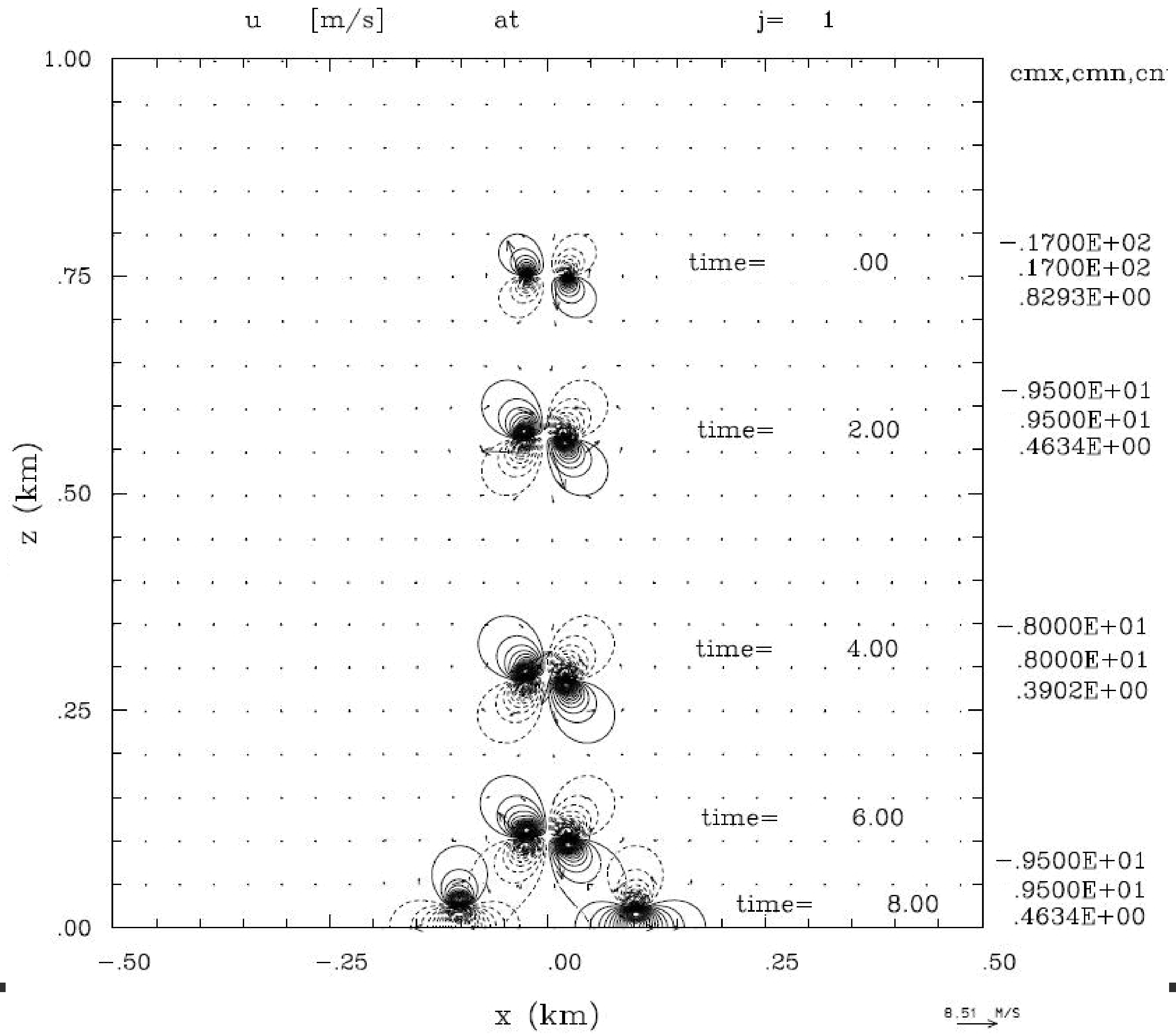
B737: Circulation=220 m^2/s, d=22.3 m

Fokker 100: Circulation=180 m^2/s, d=22.0 m

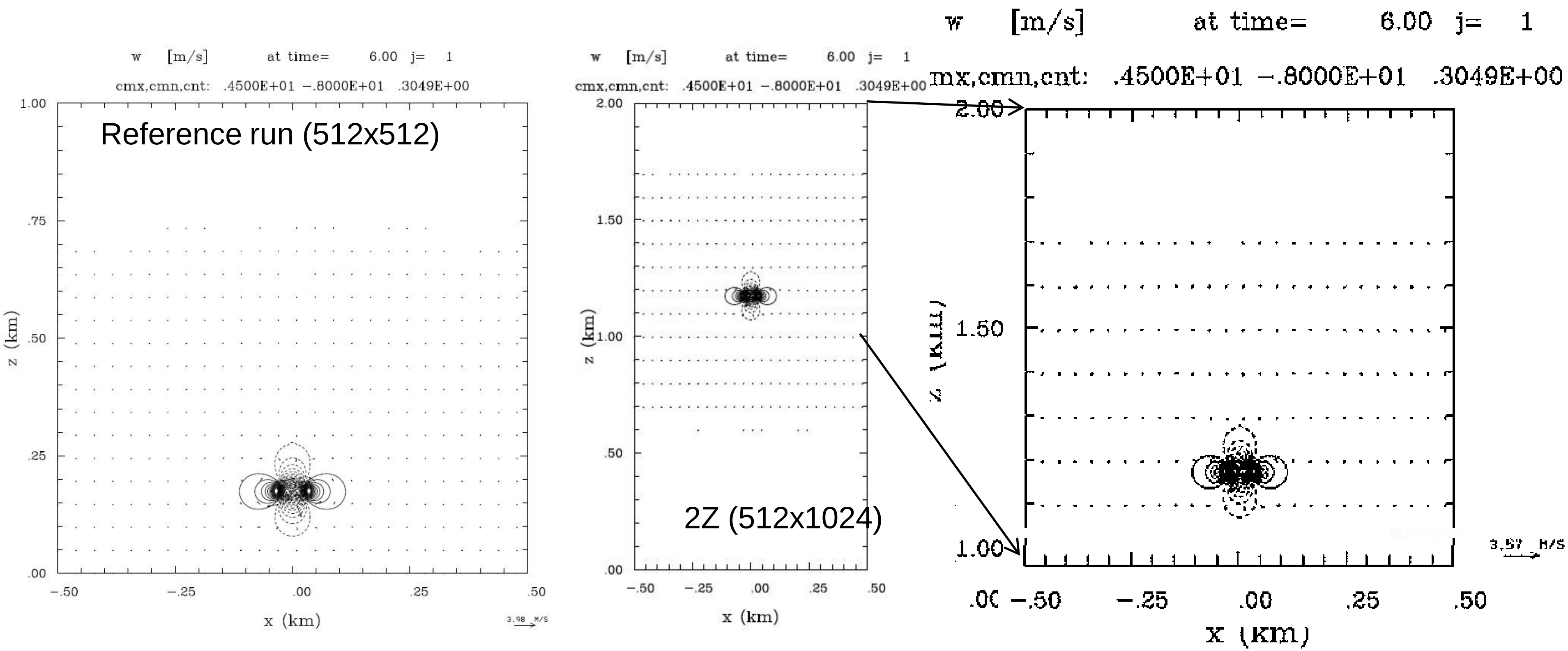
Fokker 28: Circulation=175 m^2/s, d=19.7 m

- Gerz et al. - Gamma=565, B=47.1
- **Current - Gamma=458, B=47.3**

Effect of BC
2D XZ (512x512), neutral



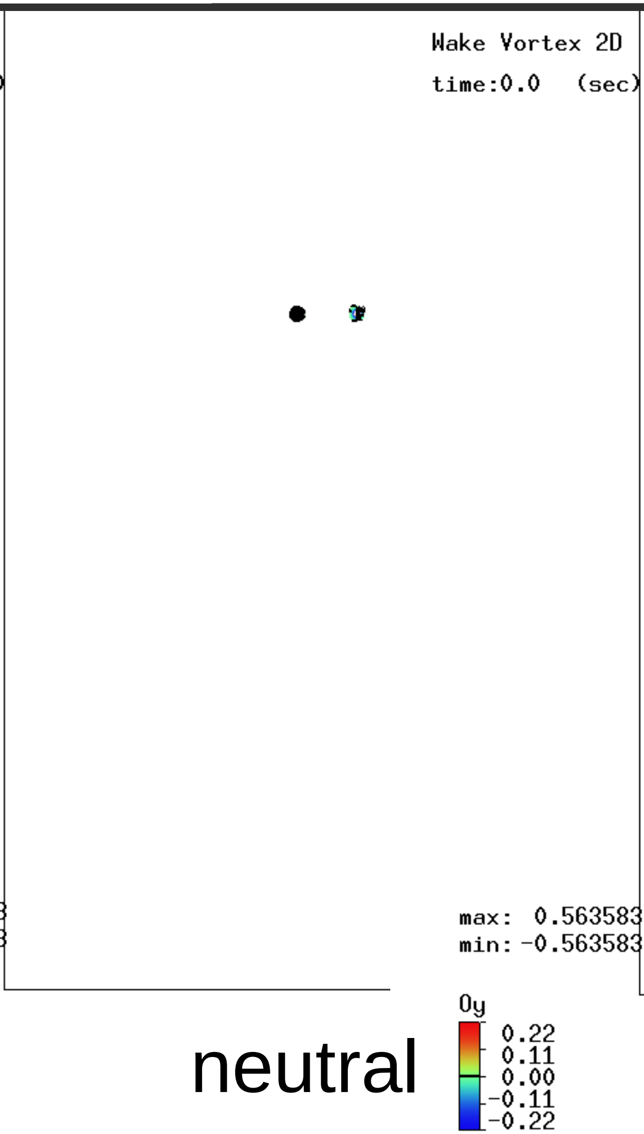
Effect of BC
2D XZ (512x512), neutral



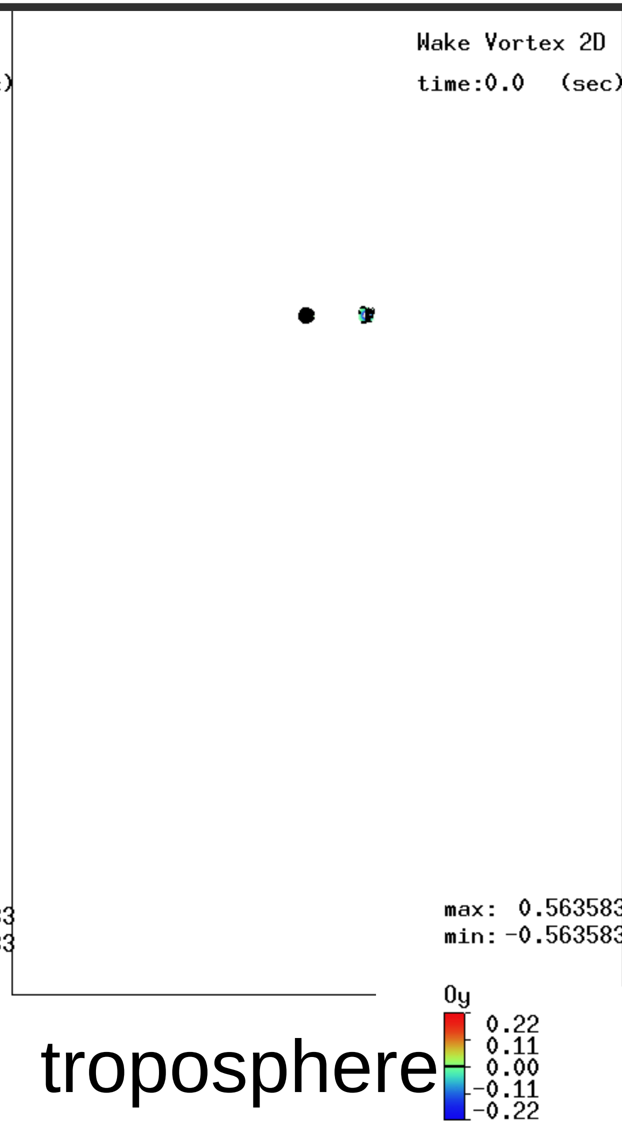
extended domain 2xZ

Cyclic BC: vortex propagation speed highly sensitive to treatment at boundary

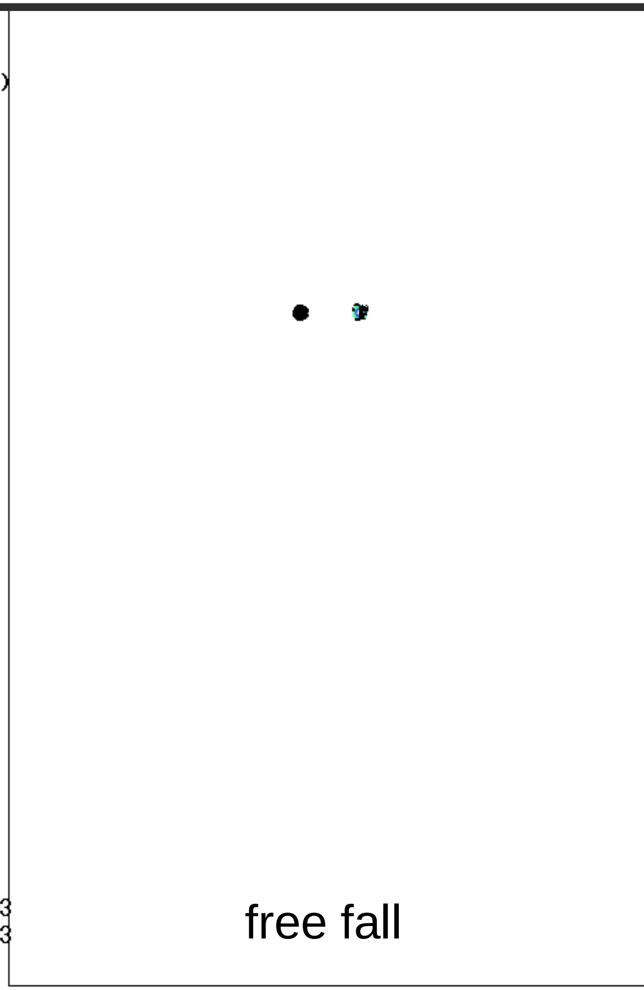
2D 1m res – sensitivity to stability, clear



neutral

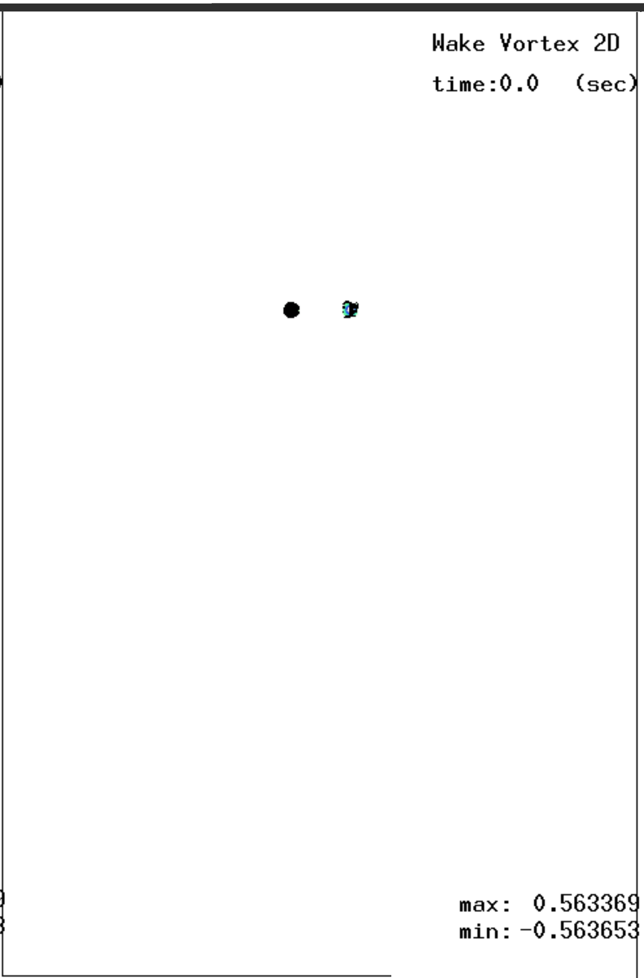


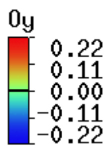
troposphere



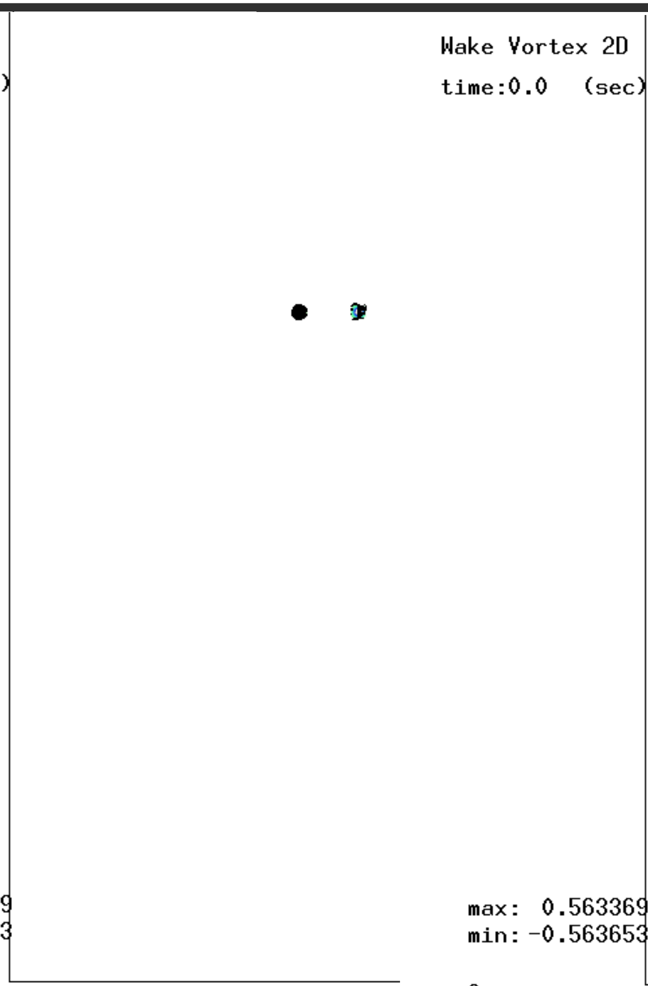
stratosphere

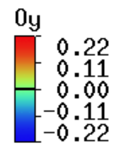
2D 1m res – sensitivity to stability, with noise



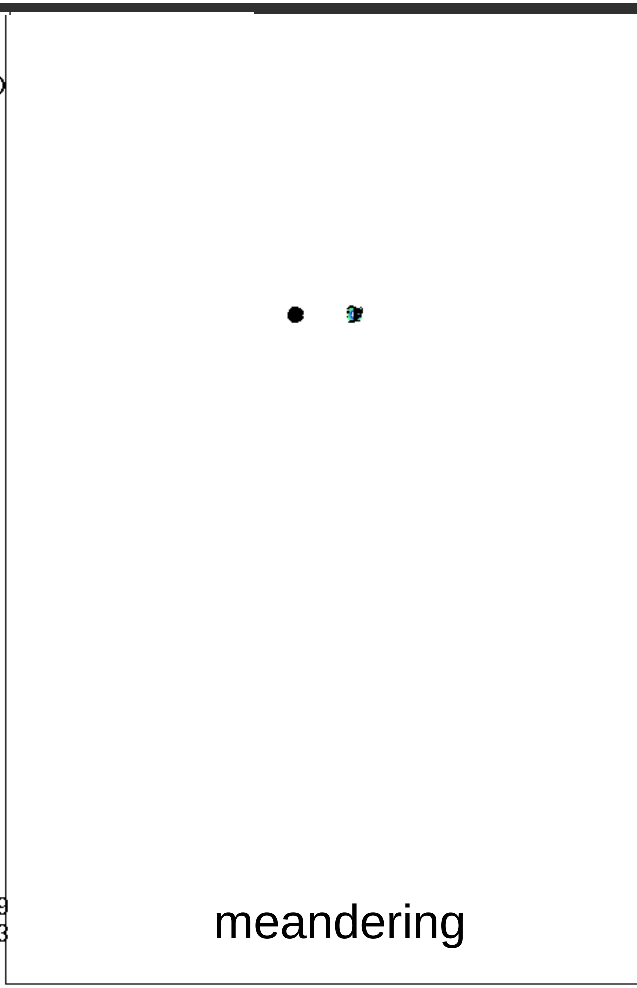


neutral



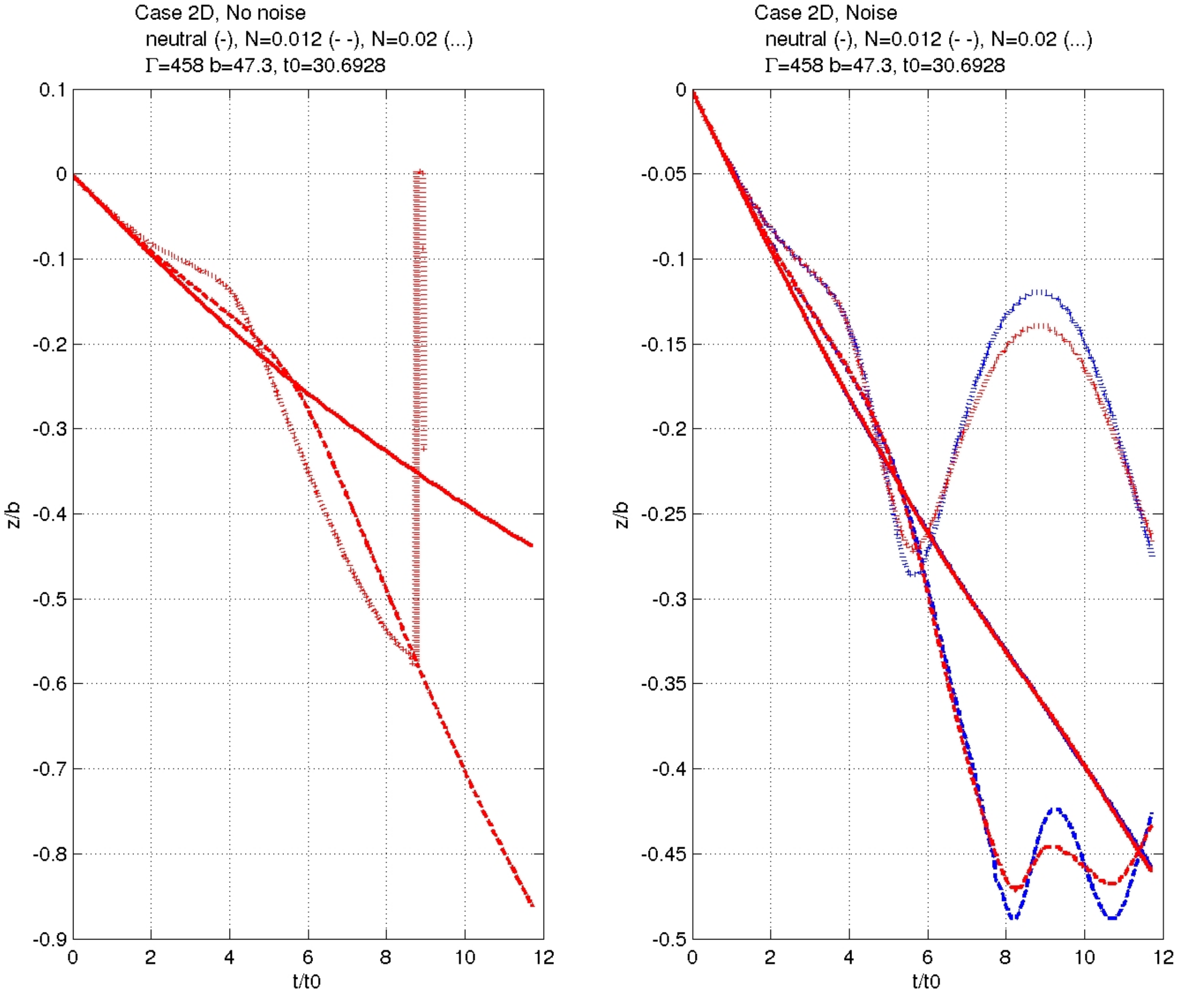


troposphere



stratosphere

Vortex descent in 2D 1.5m res



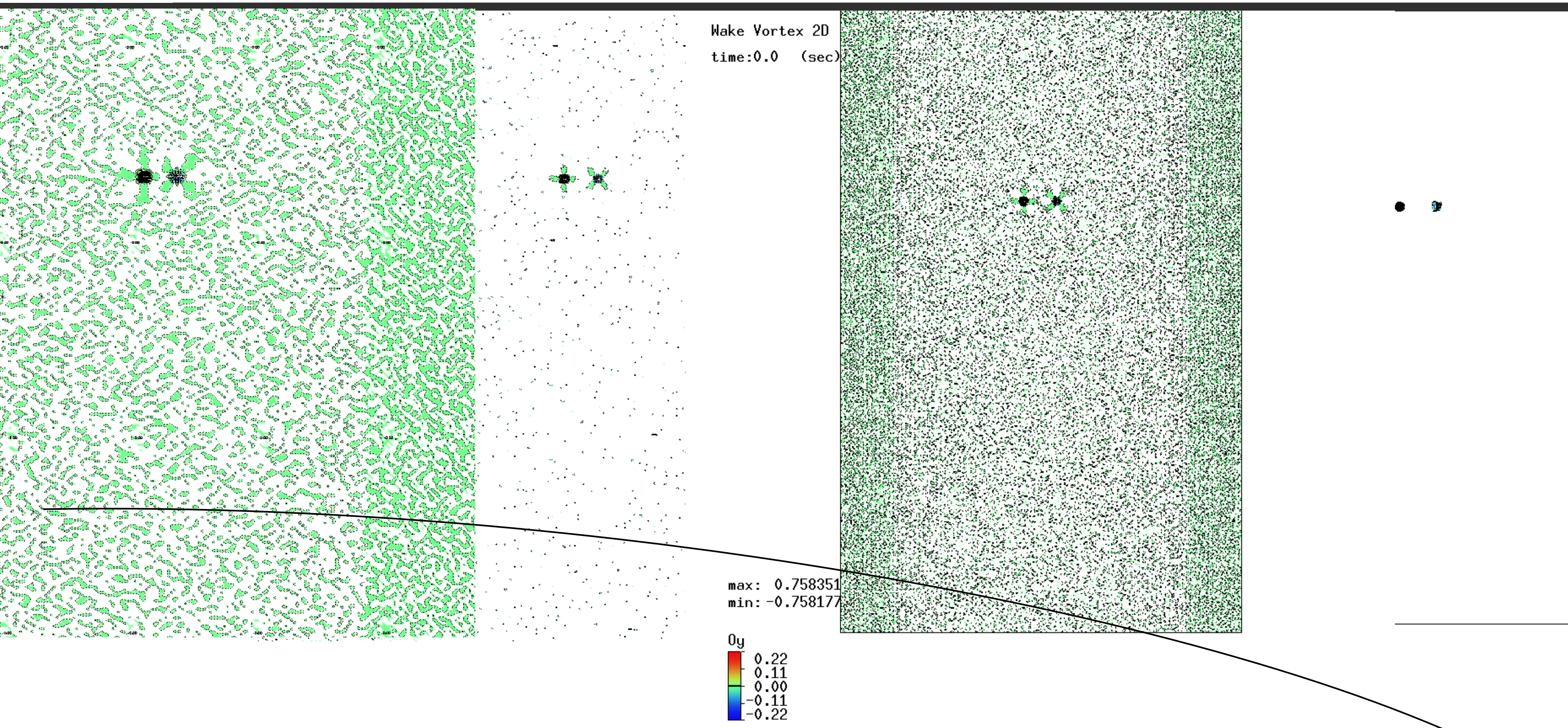
tracking of

maximum vorticity ,

blue –negative,

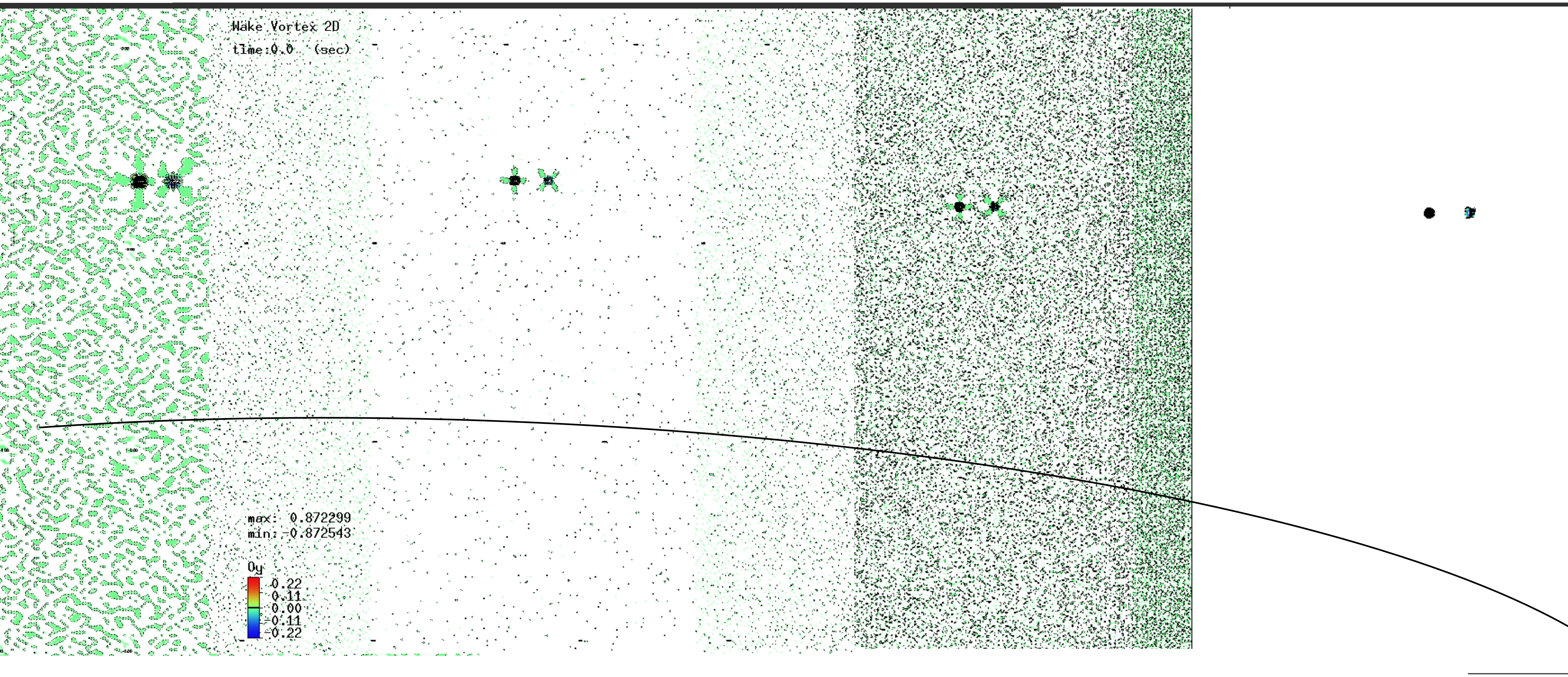
red- positive vortex

2D with noise – troposphere sensitivity to grid resolution



4m 2m 1.5m 1m

2D with noise – stratosphere sensitivity to grid resolution

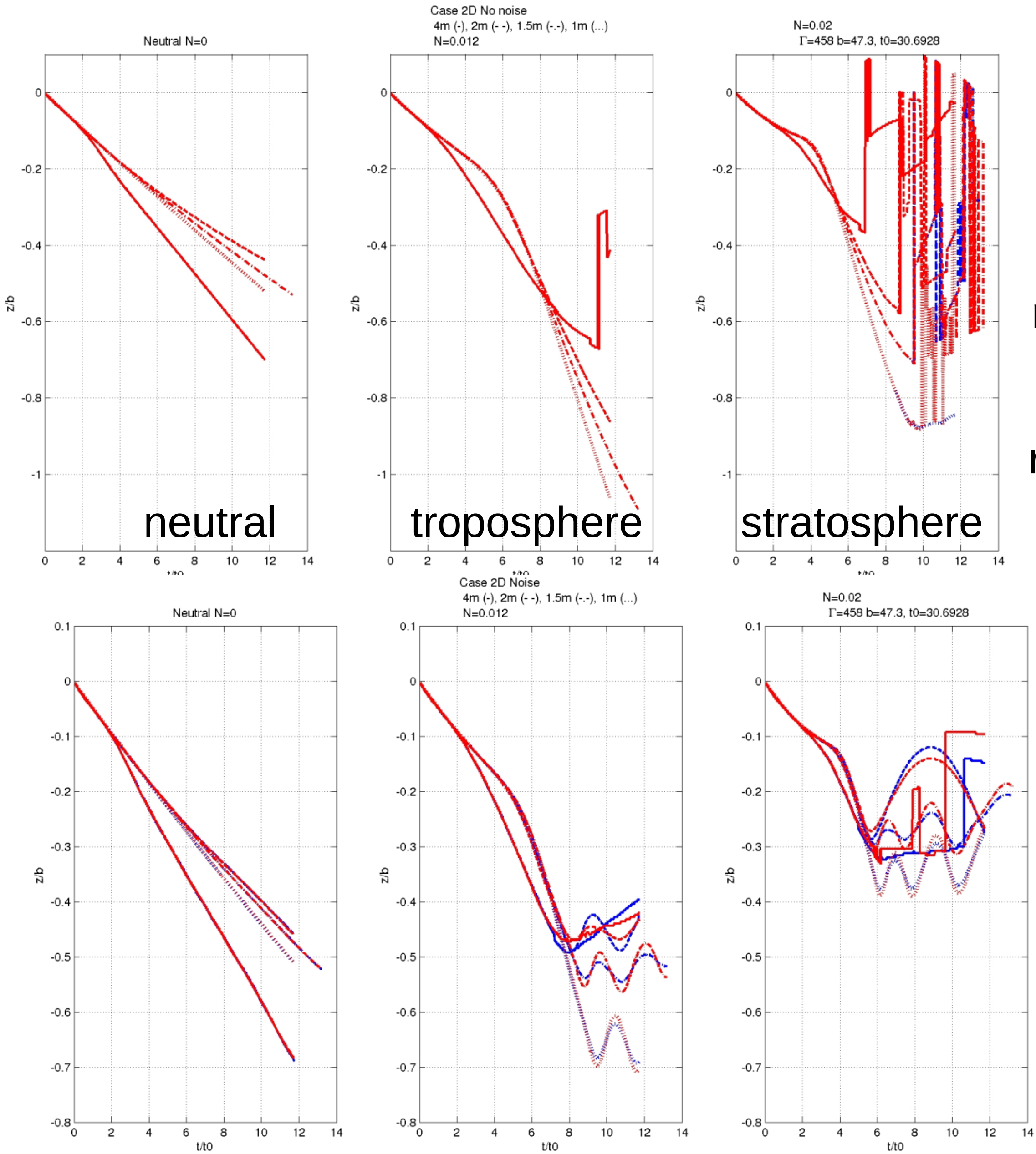


4m 2m 1.5m 1m

Vortex descent in 2D

CLEAR

WITH NOISE



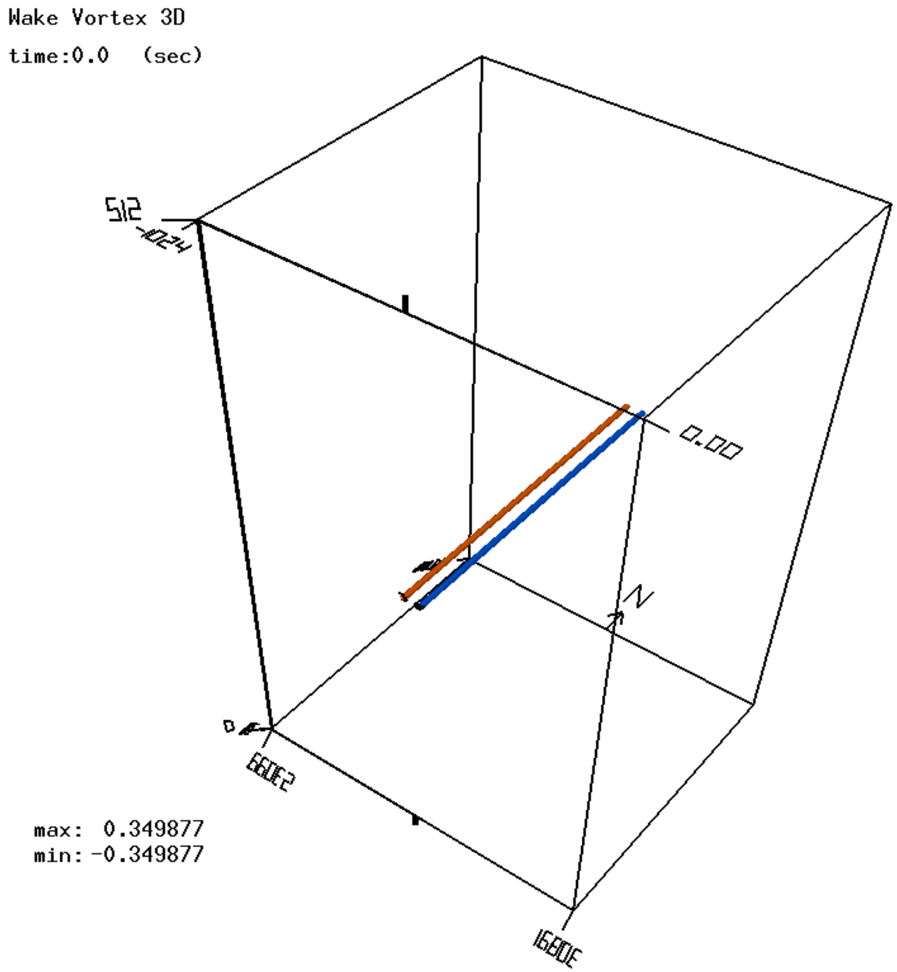
tracking of

maximum vorticity ,

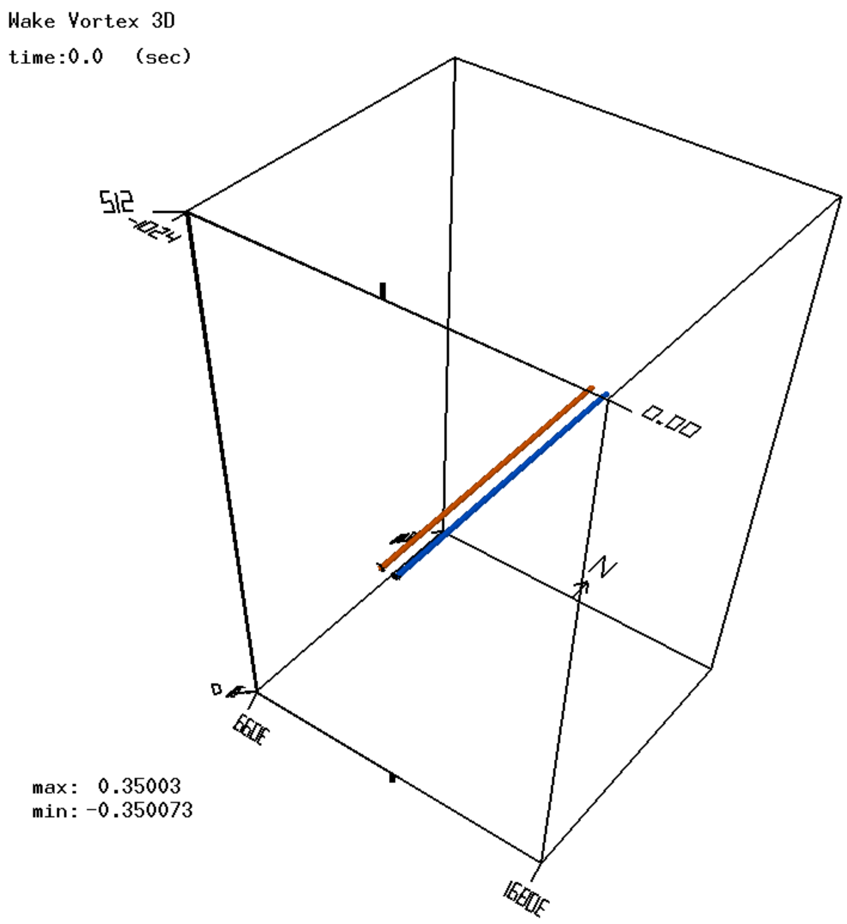
blue –negative,

red- positive vortex

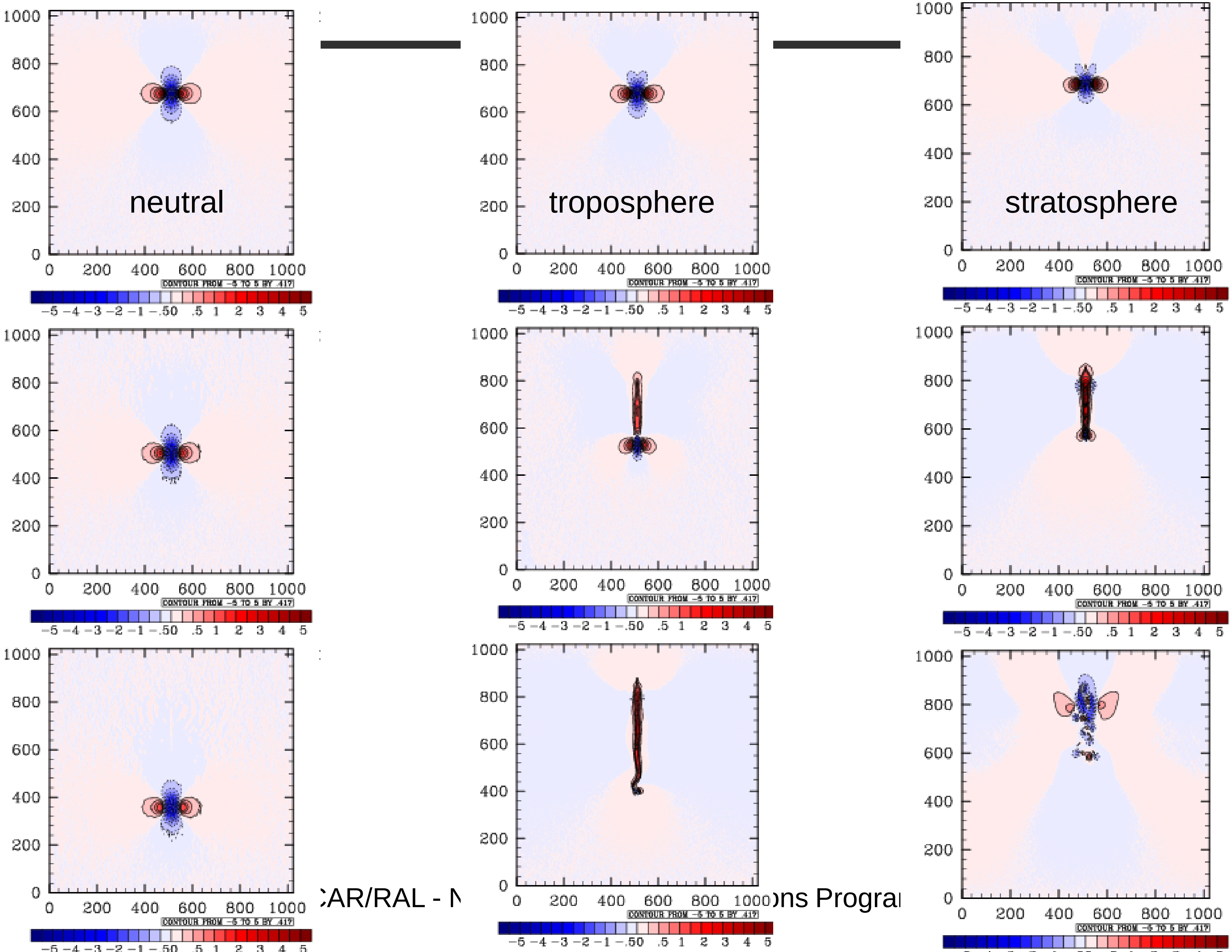
3D wake eddies, 4m res, neutral, clear



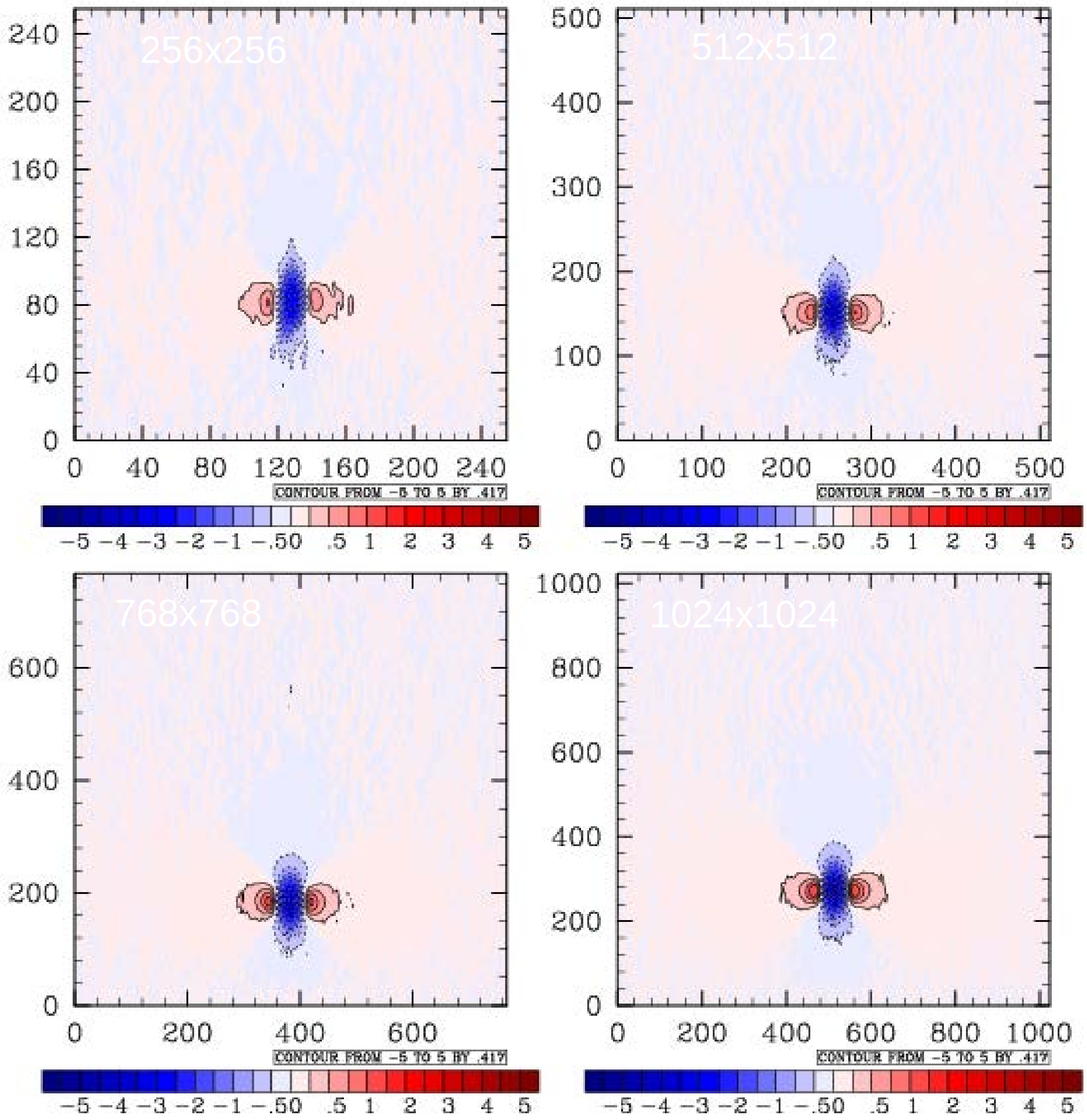
3D wake eddies, 4m, neutral, noise



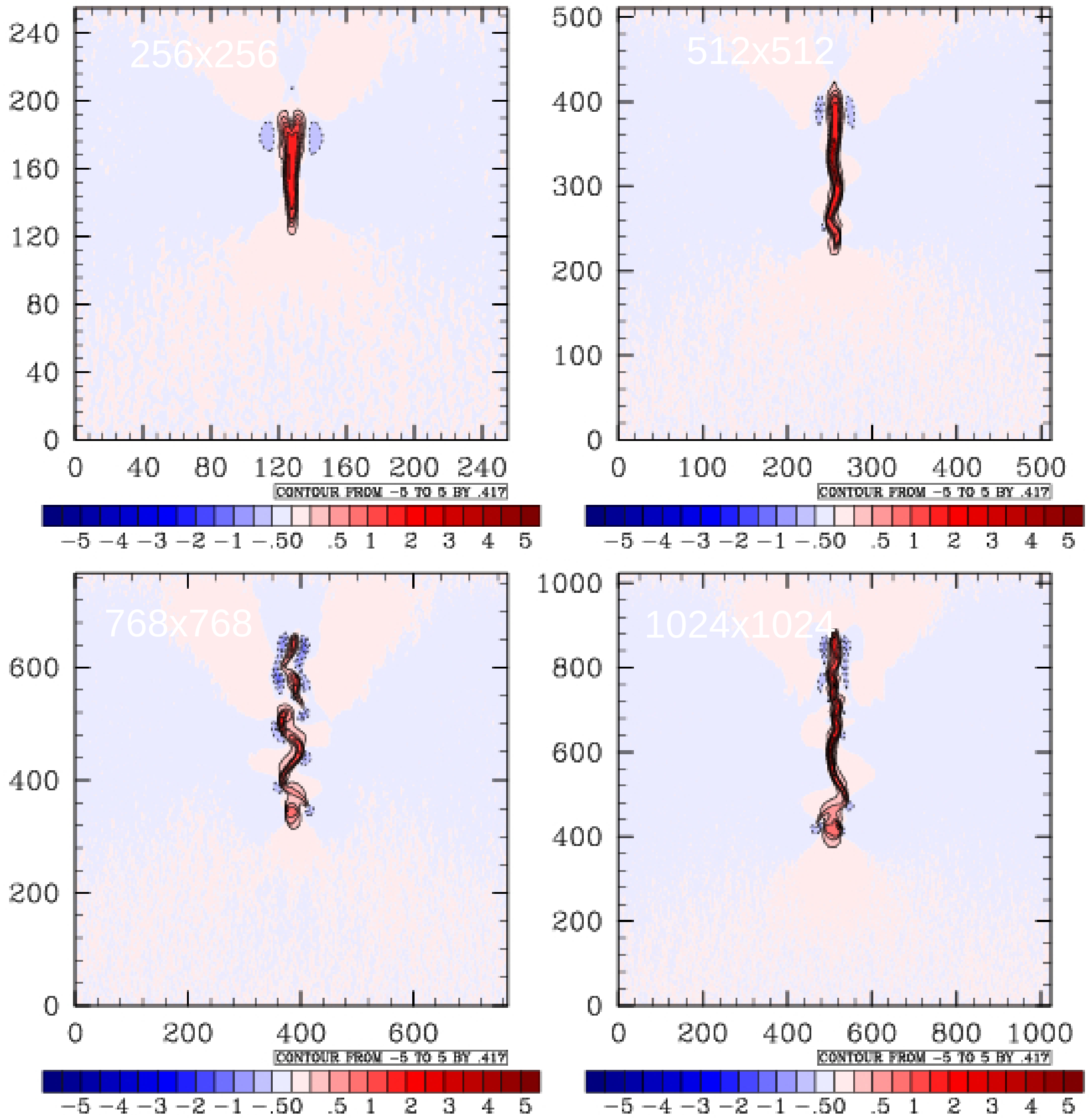
3D wake eddies, 1m, time evolution



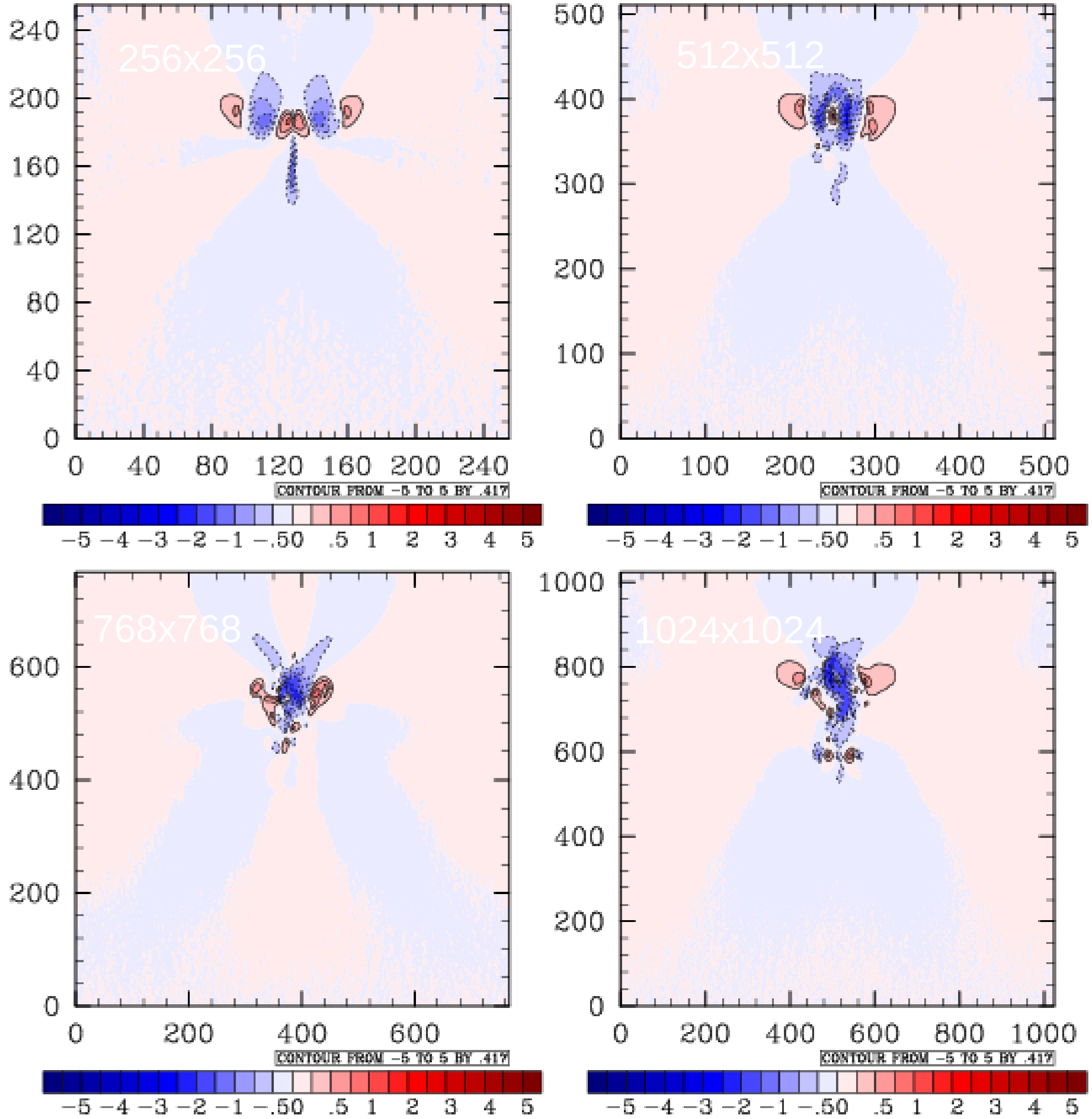
3D wake eddies, neutral, grid effect



3D wake eddies, troposphere, grid effect



3D wake eddies, stratosphere, grid effect



wake decay statistics

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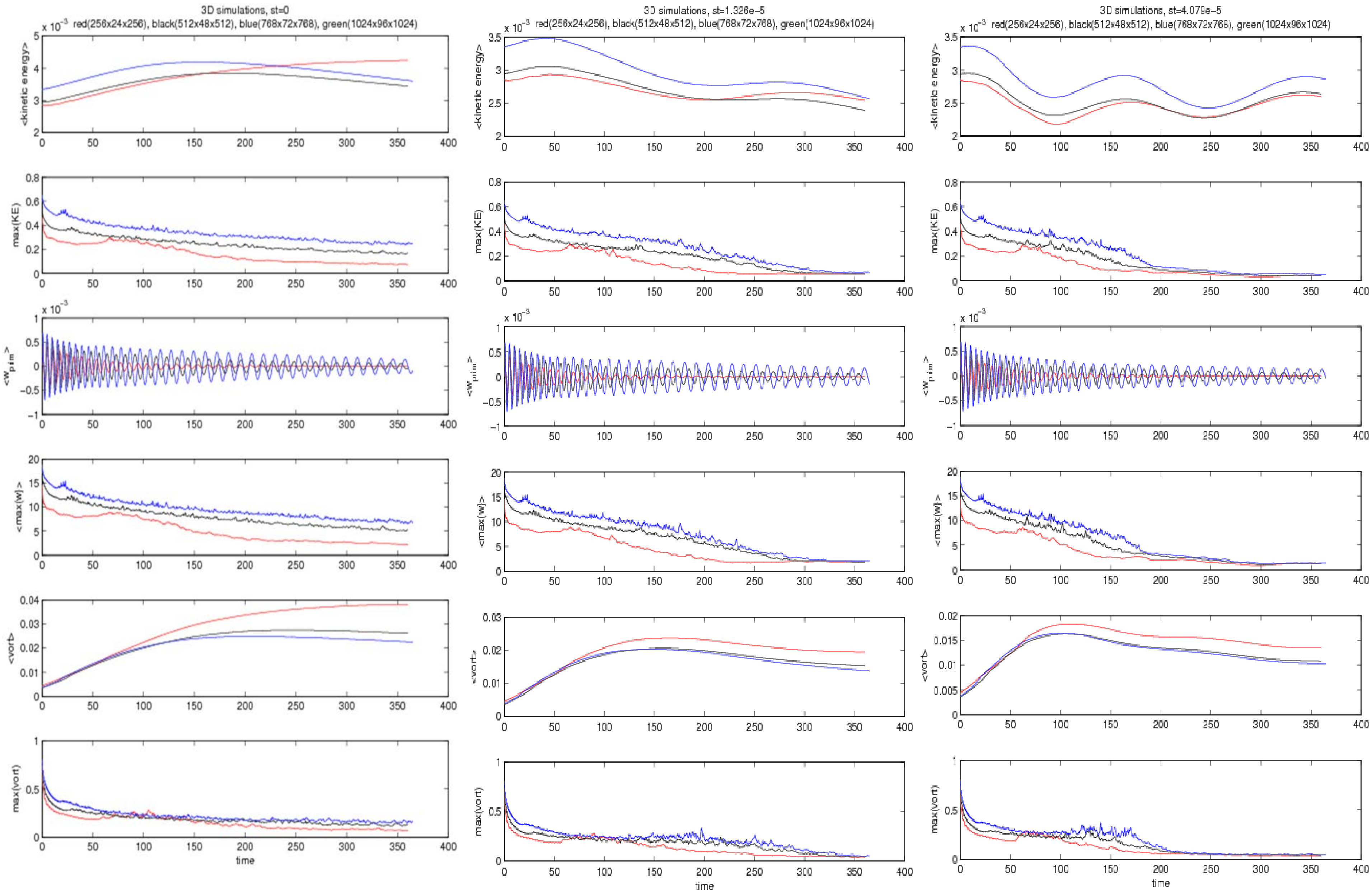
3D neutral BV=0 | 3D stable BV=0.0114 | 3D stable BV=0.02



wake decay rate and displacement statistics

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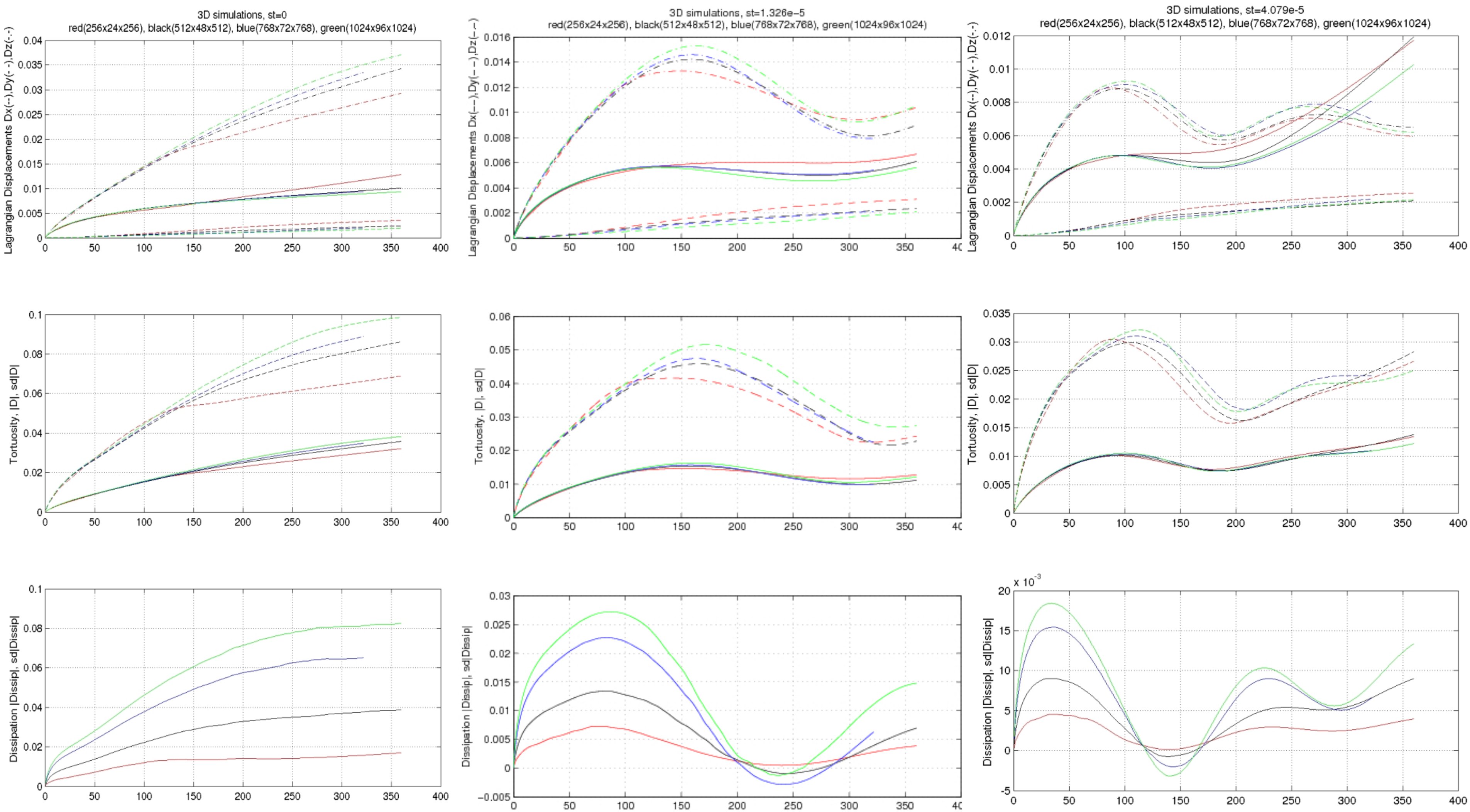
3D neutral BV=0

3D stable BV=0.0114

3D stable BV=0.02



Computational costs - CPU usage

JOB	GRID	NT	PE	Wall [H:M:S]	GAU
@ BLUEFIRE					
2Dxz	256x256	3000	128	0:04:36	11
2Dxz	512x512	6000	128	1:13:12	176
3DLR	512x48x512	6000	384	1:50:21	950
@ FROST IBM BG/L					
3DPR	256x24x256	3000	256	0:55:00	80
3DLR	512x48x512	6000	512	5:35:00	950
3DMR	768x72x768	9000	512	19:16:00	3200
3DDR	1024x96x1024	12000	2048	16:24:00	11200

Real test case

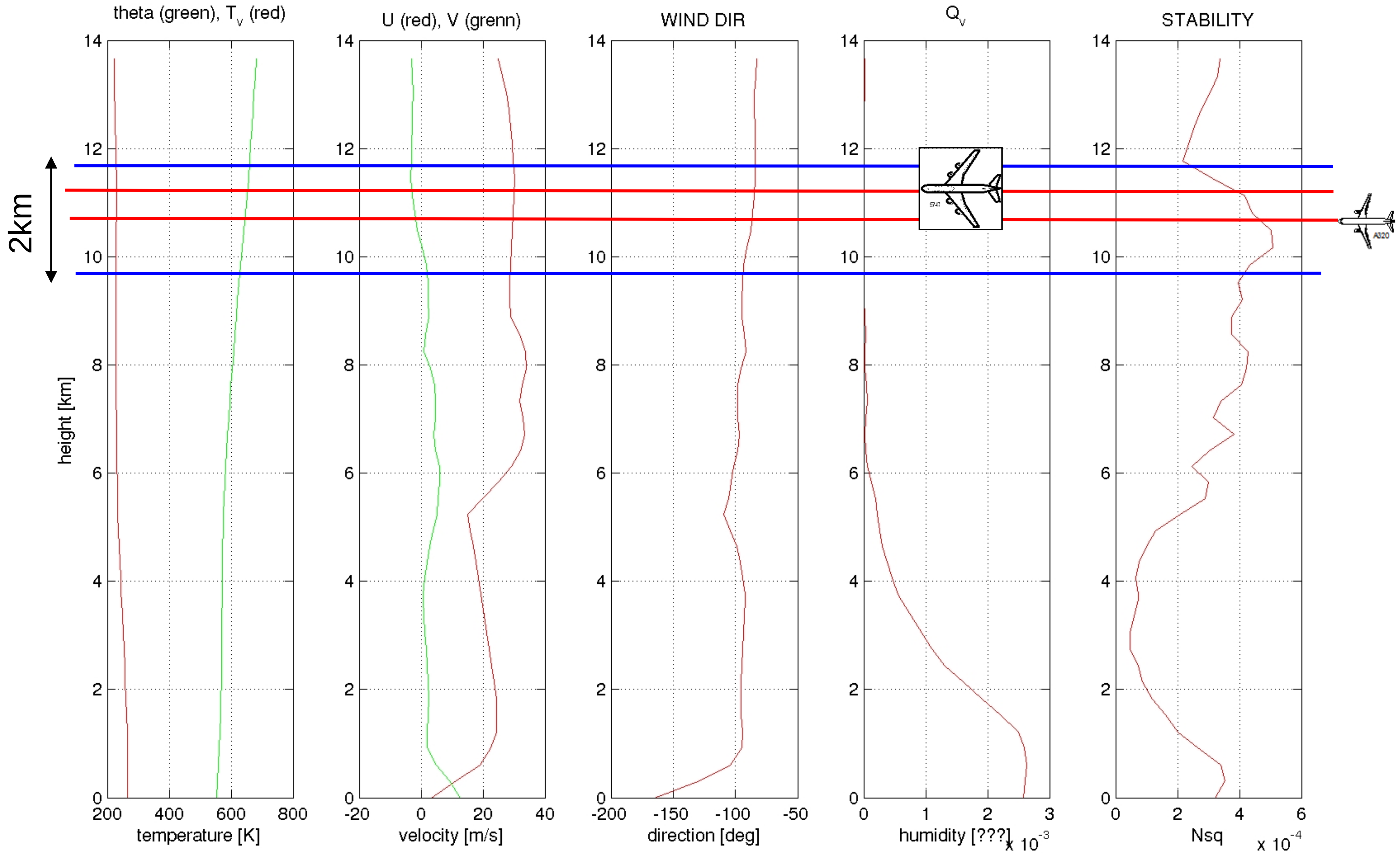
- LES of vortex behavior in the UTLS for a realistic atmospheric and operational condition based on an actual wake vortex encounter that occurred over northern Washington State on 10 Jan 2008.

- A319 aircraft was at FL350 (~10.7 km altitude) following
- B747-400 at FL370 (~11.3 km).

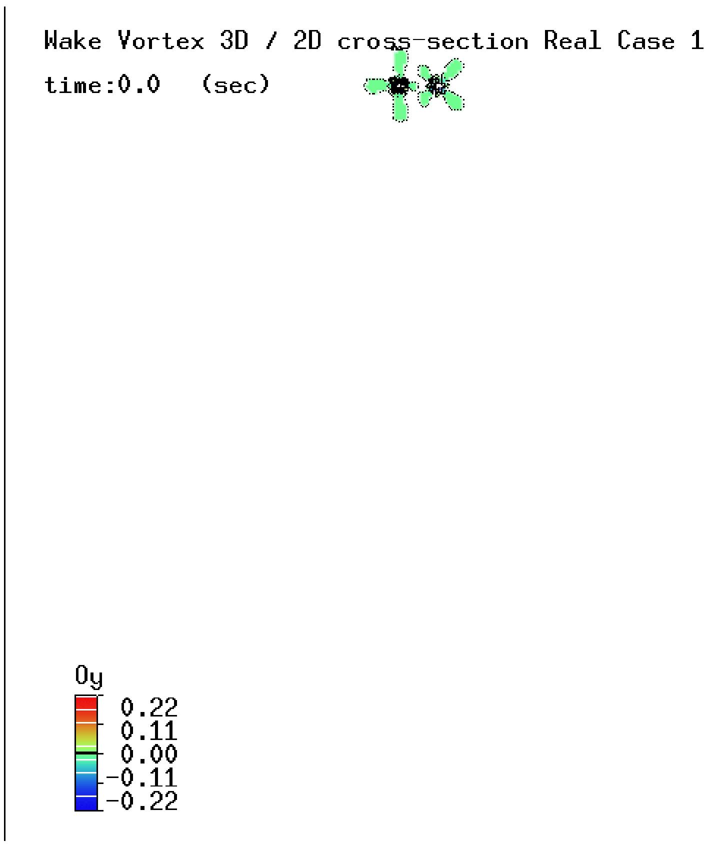
- Due to the encounter, eight passengers and crew received minor injuries and three received serious injuries, and the flight was diverted.

- Comparisons to onboard flight recorder data taken during the encounter are used to evaluate the realism of the simulation.

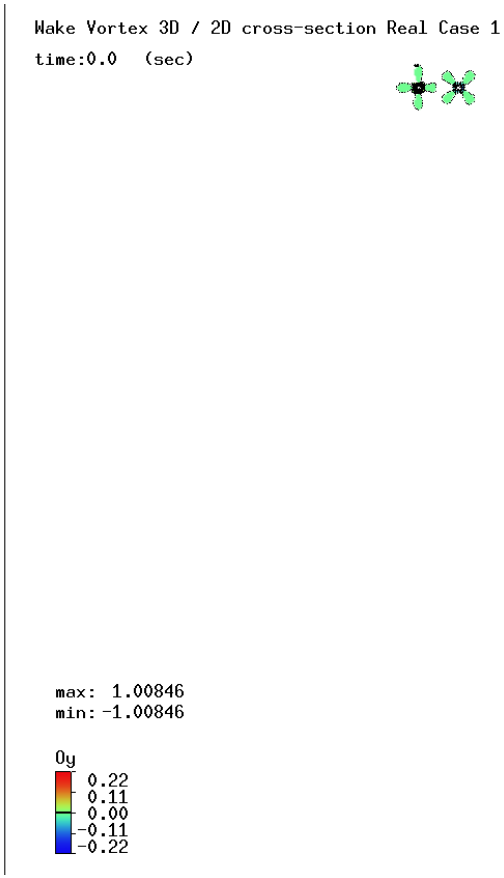
Real test case



Real test case, clear

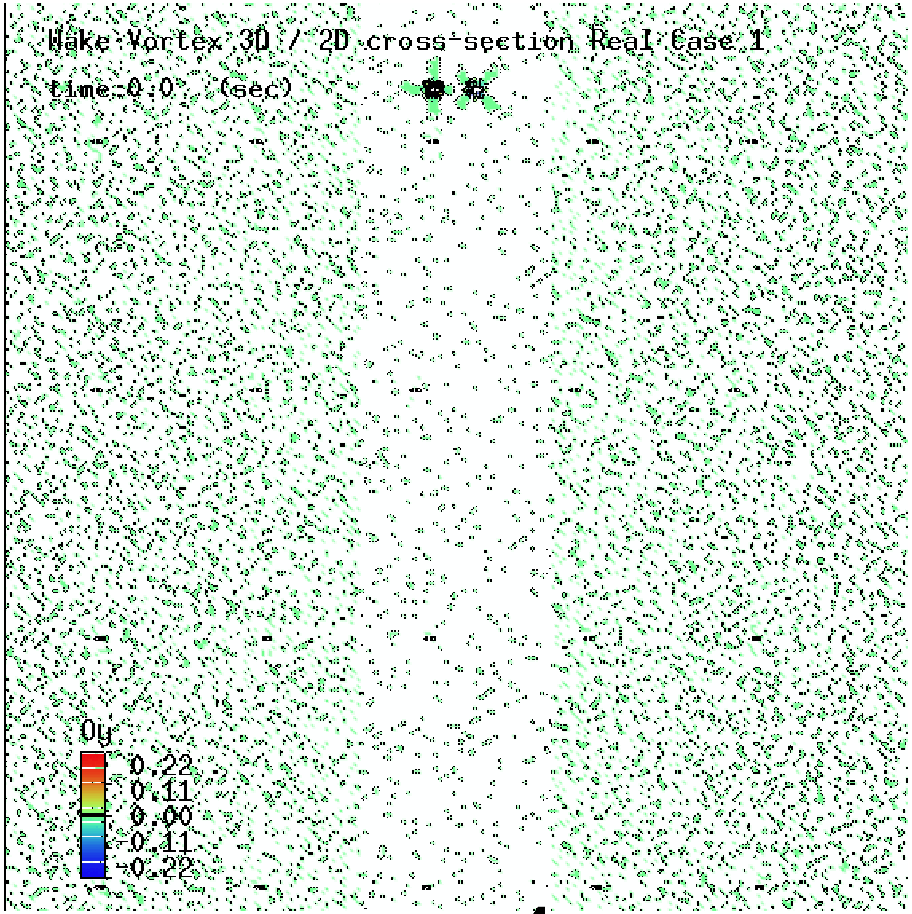


4m

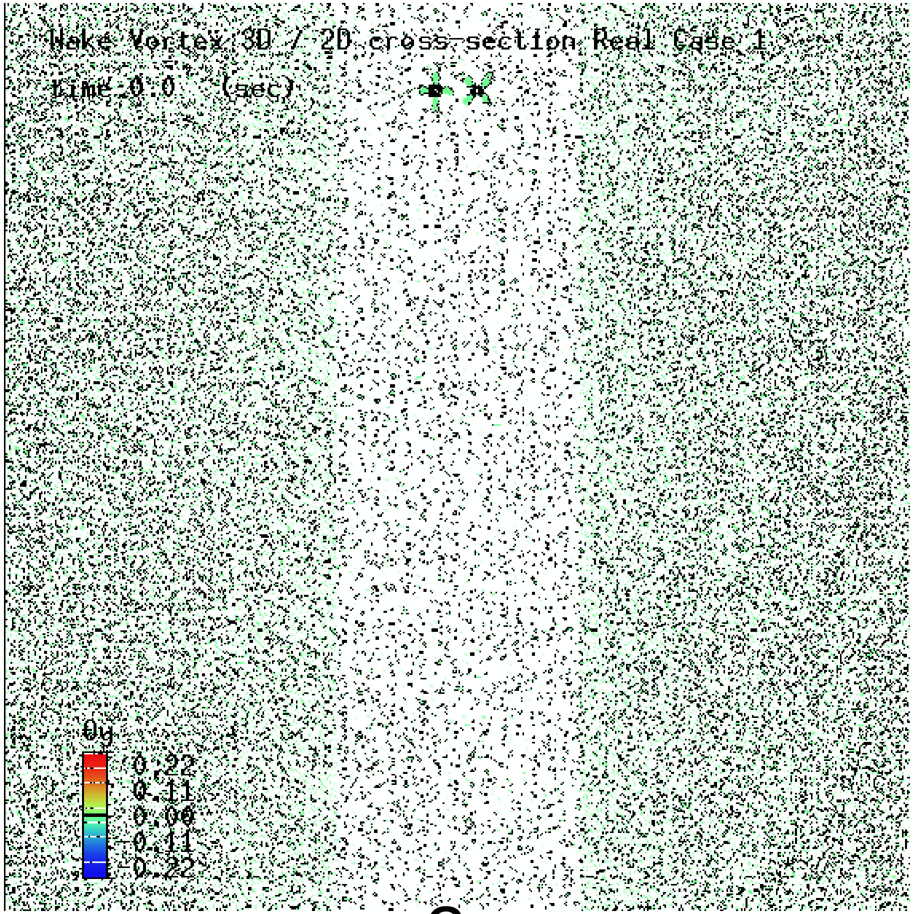


2m

Real test case, noise

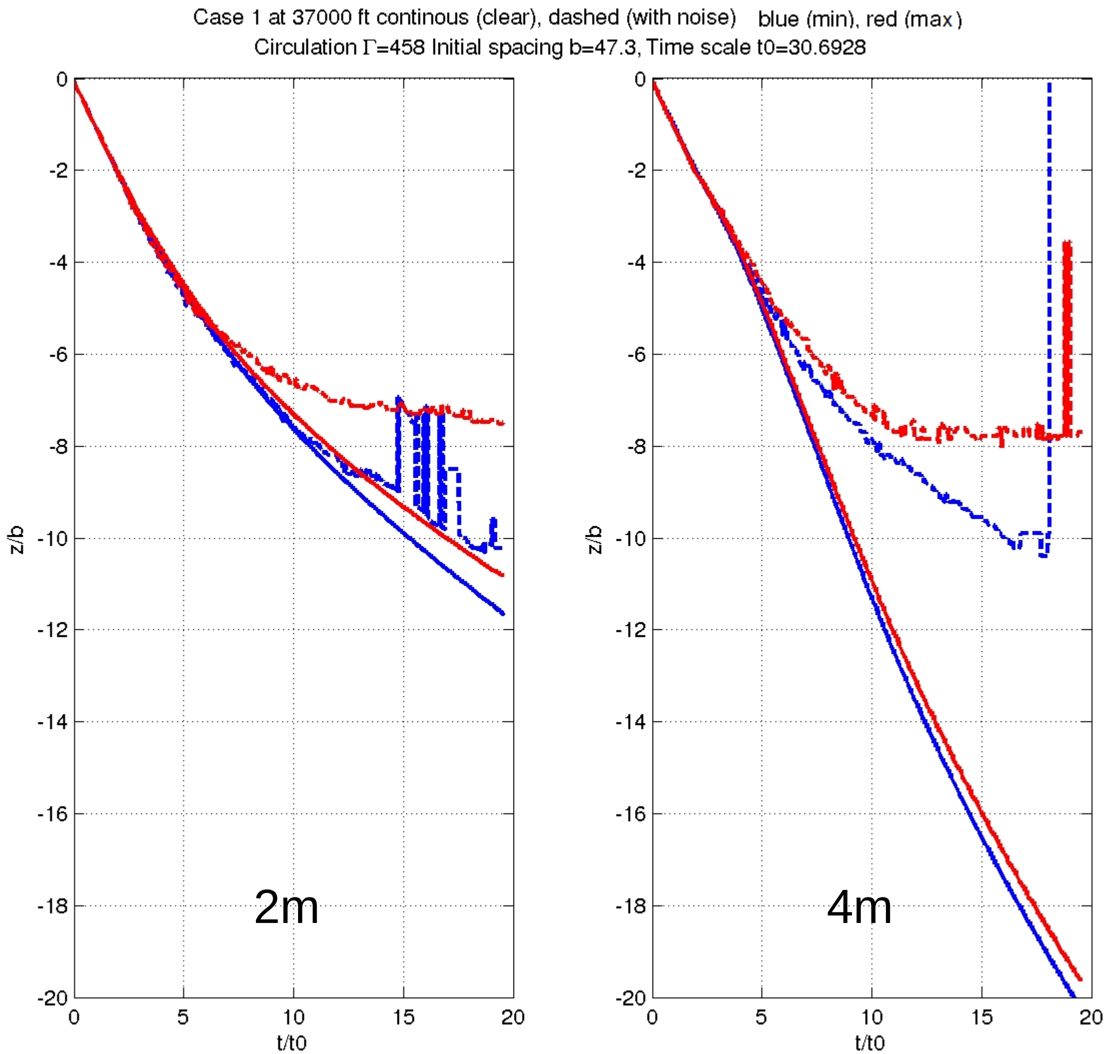


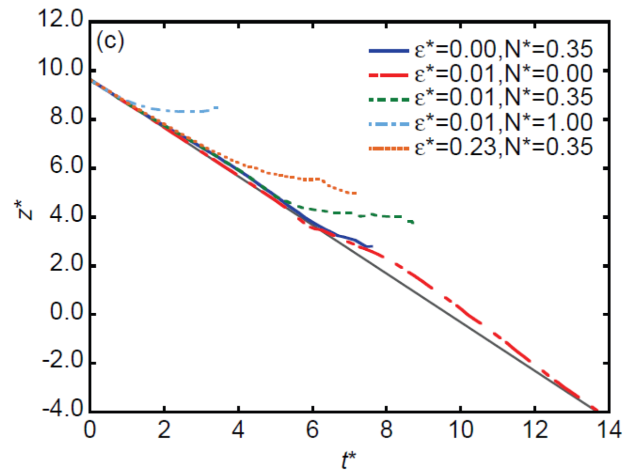
4m



2m

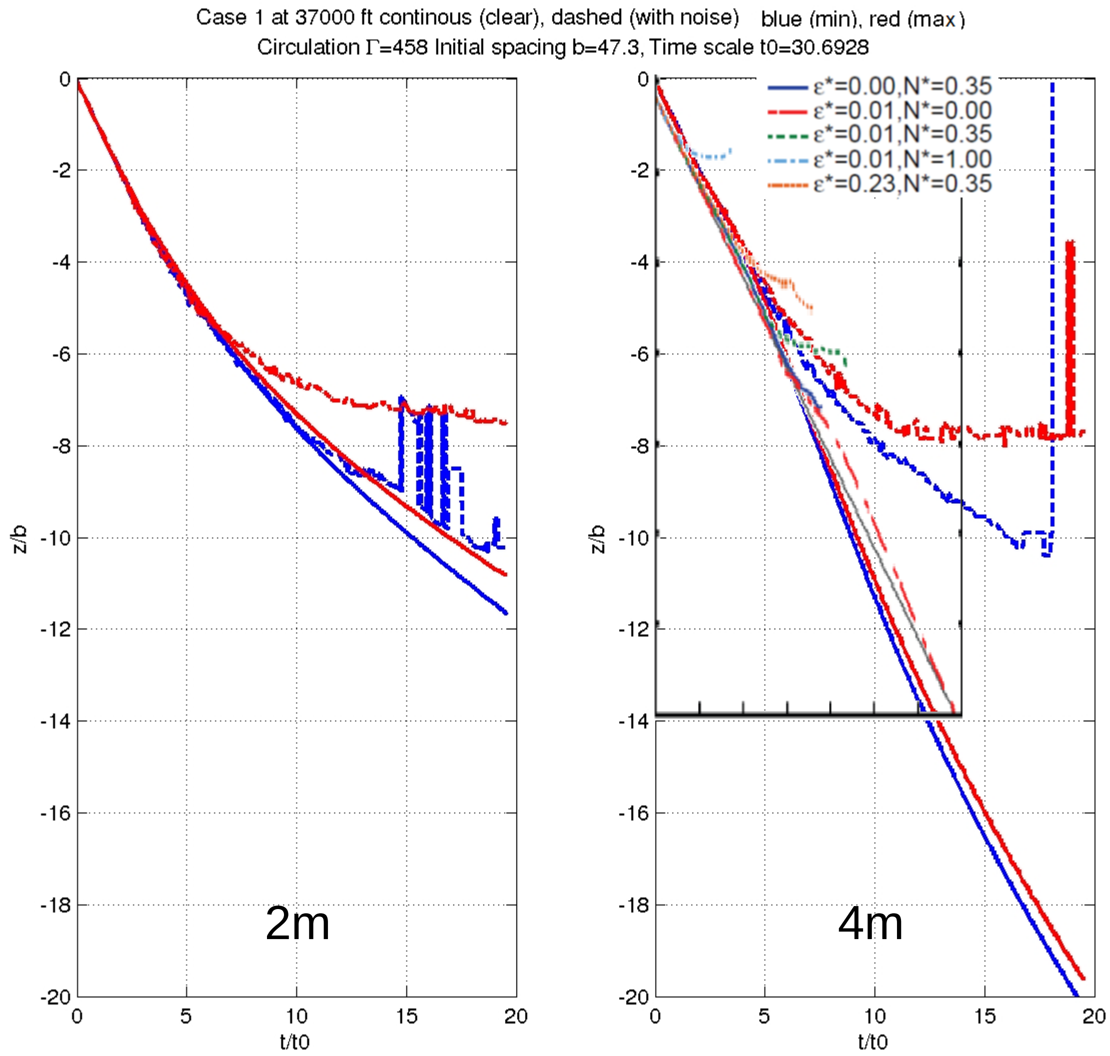
Vortex descent





DLR results

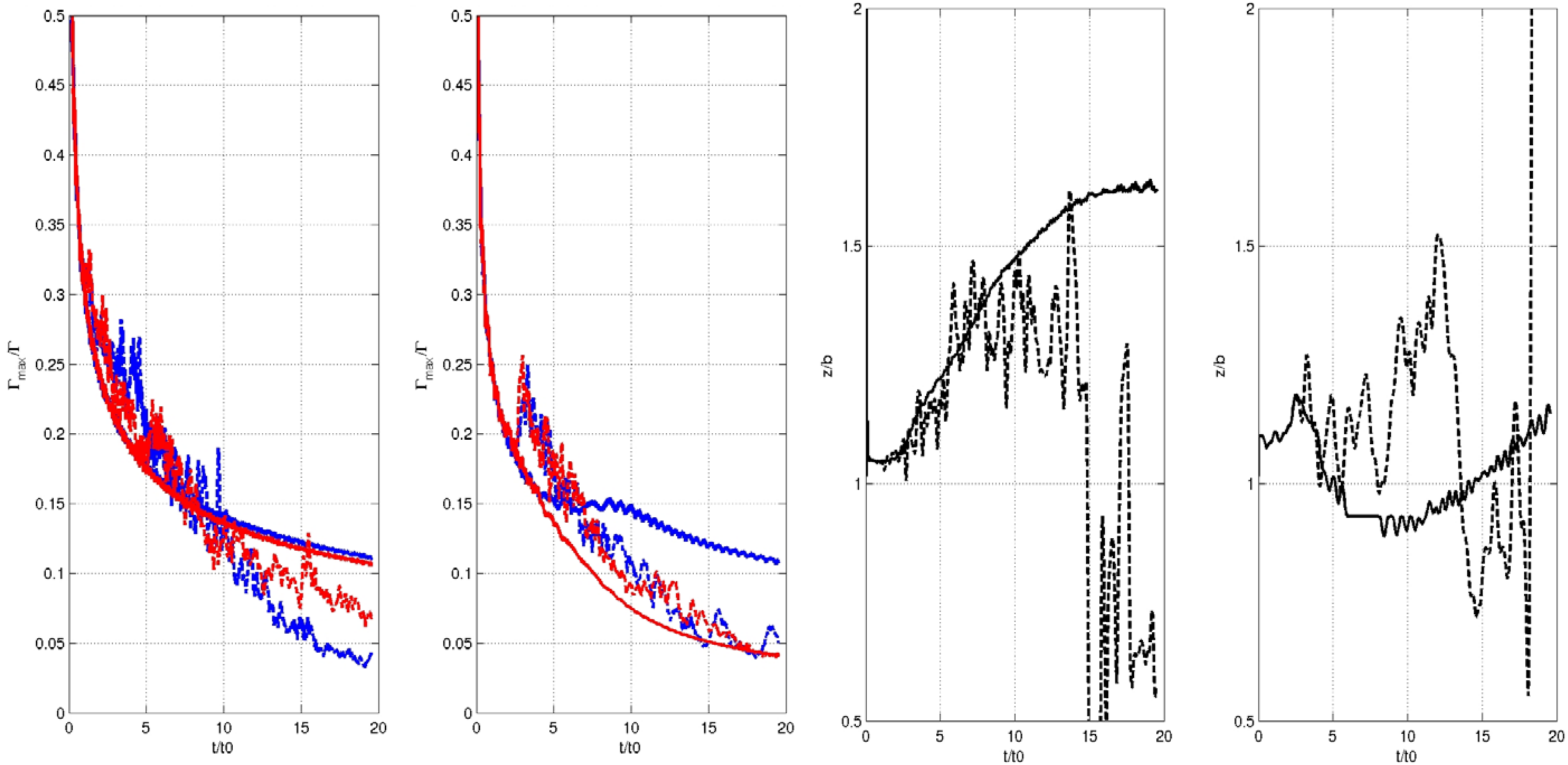
Vortex descent



Vortex decay and spacing

Case 1 at 37000 ft continous (clear), dashed (with noise) blue (min), red (max)

Circulation Γ=458 Initial spacing b=47.3, Time scale t0=30.6928



2m 4m 2m 4m

Vortex instability: crow

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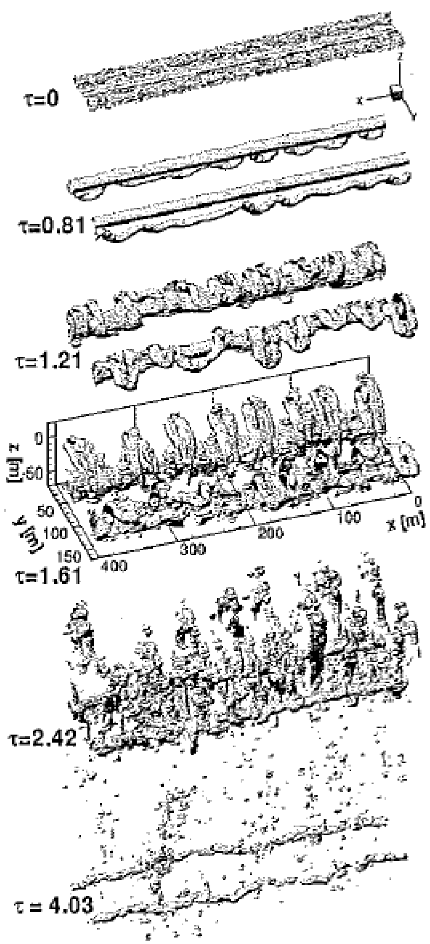
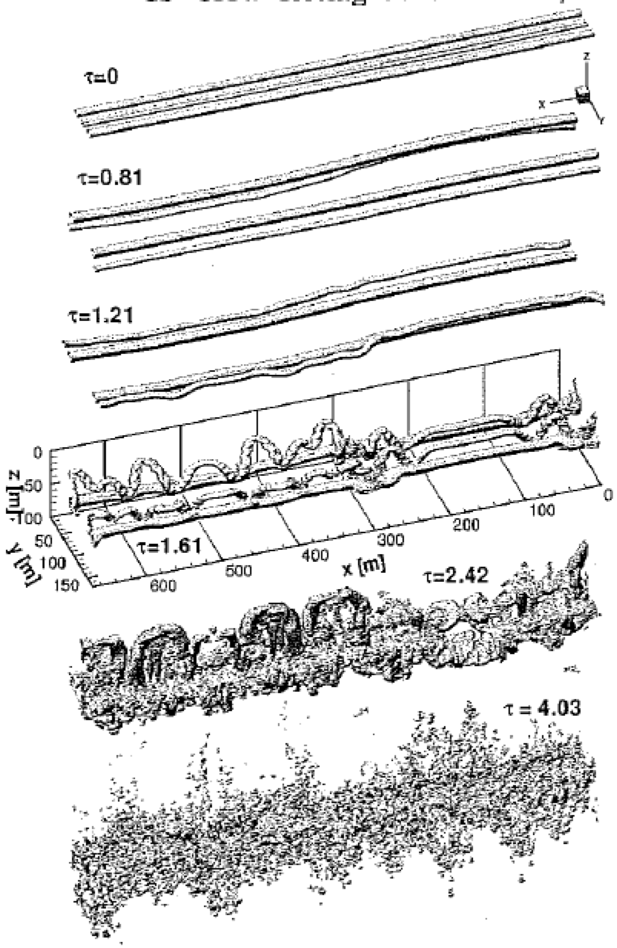
Abstract for the EUROMECH Colloquium No 443 *Dynamics of Trailing Vortices* at RWTH Aachen, D, 21.-22. 3. 2002

Robert Baumann and Thomas Gerz : **Large-eddy simulations of two disturbed counter-rotating vortex pairs**

'high turbulence' case HT with $V_{RMS} = 2$ m/s.



'long-wave disturbed' case CF
CF Crow forcing no turbulence,



Crow forcing $b_i(x) = b_{i,0} + \delta_\Delta c_i b_1 \sin(2\pi x / L_x)$

outer pair $c_1 = 1$ $c_2 = -\Gamma_1/\Gamma_2$

circulation $\Gamma_1 = 565\ m^2 s^{-1}$

spacing $b_1 = 47.1$ m.
$b_2 = 0.151\ b_1$.

inner vortex pair $\Gamma_2 = -0.4\ \Gamma_1$

Case	CF	CT	LT	HT
Meshes x,y,z	128*256*360			64*256*540
Mesh size	5.25*1*1 m			6.375*1*1 m
Domain / b_1	14.26*5.44*7.64			8.66*5.44*11.5
δ_Δ	0.01	0.01	0	0
V_{RMS} (ms^{-1})	0	2	0.01	2

- **vortices amplify small sinusoidal distortions which grow exponentially, through interaction and self induction**

- **vortex amplitudes reach a critical value and forming a chain of vortex rings.**

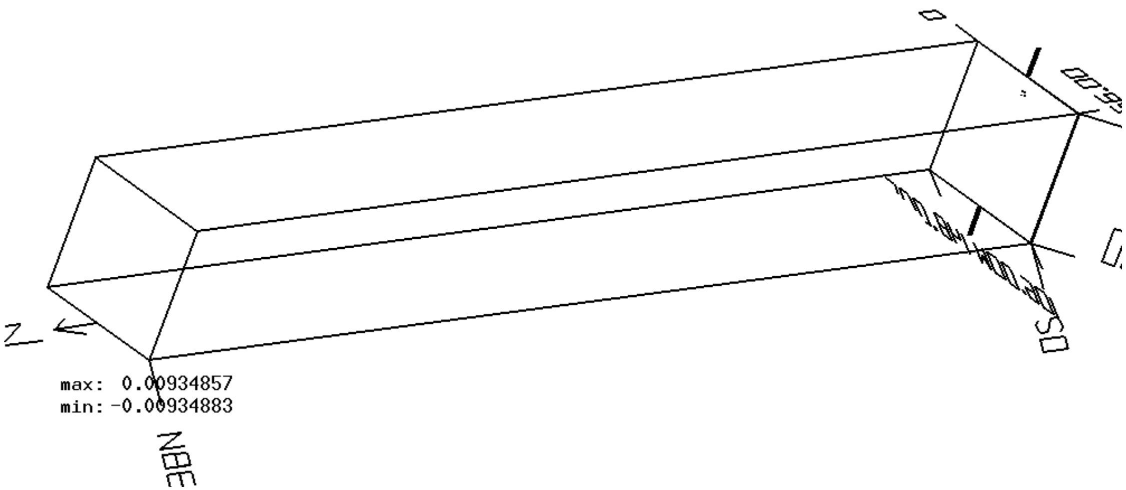
Vortex instability: crow

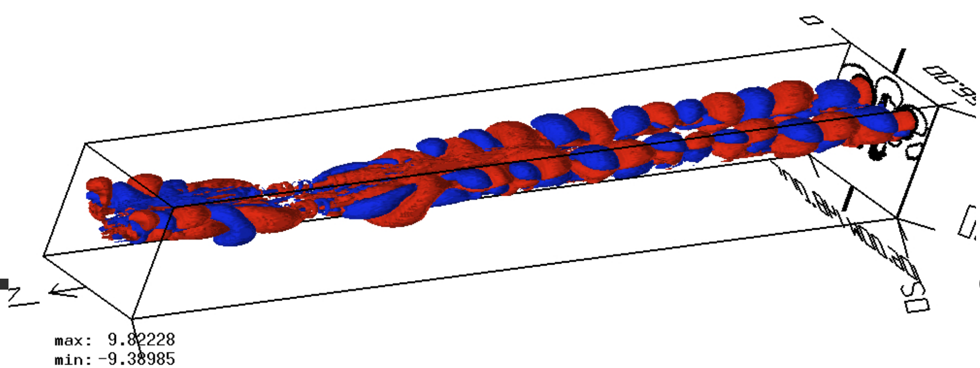
Wake Vortex 3D Crow Instability
time:0.0 (sec)

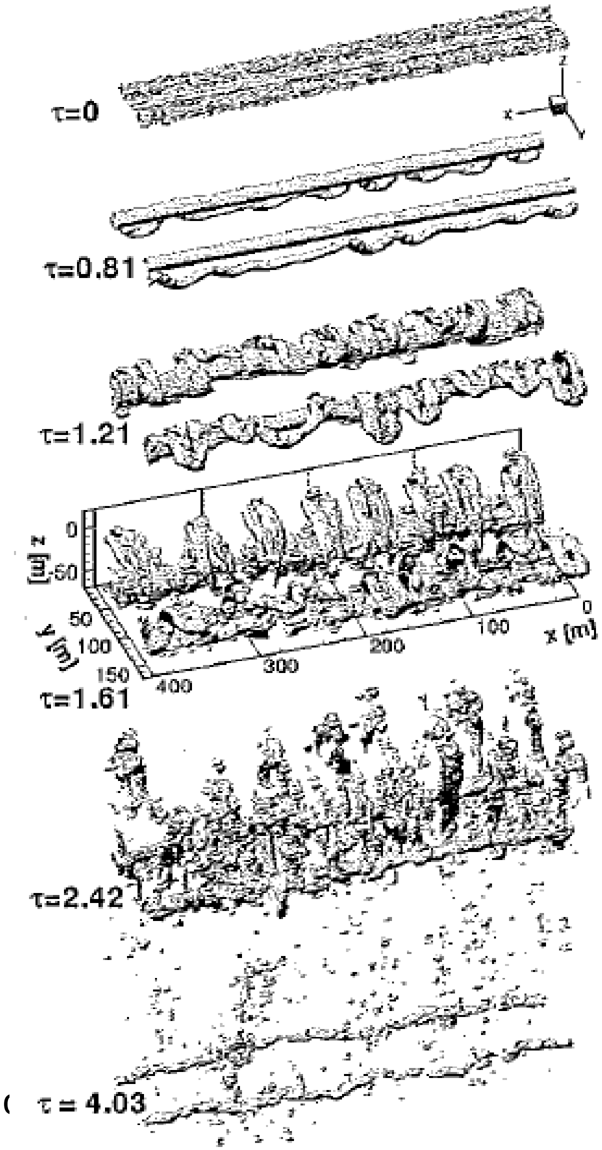
512x320x512 (1m x 2m x1 m)

Vrms=0.01

Ly=0.01







catic

Summary as of March 2012

Quantitative sensitivity results from variable key parameters:

- grid resolution
- background noise
- stratification
- wind shear

Open questions related to key parameters:

- background vorticity release and meandering effects
- instability types and their initiation
- real test case validation