Airborne and Ground-based Wake Vortex Measurements with Pulsed Lidar

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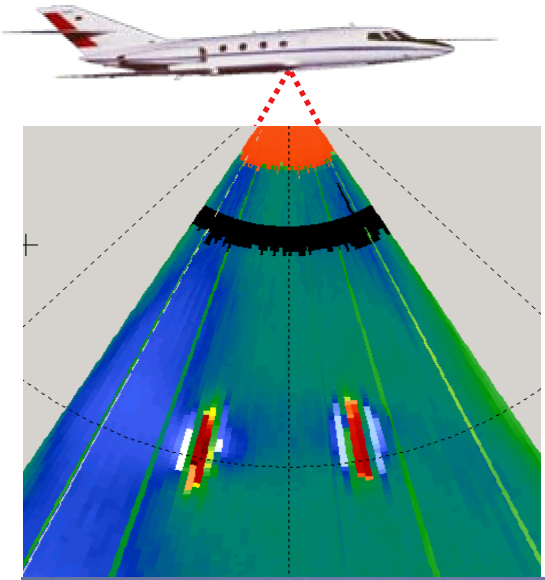
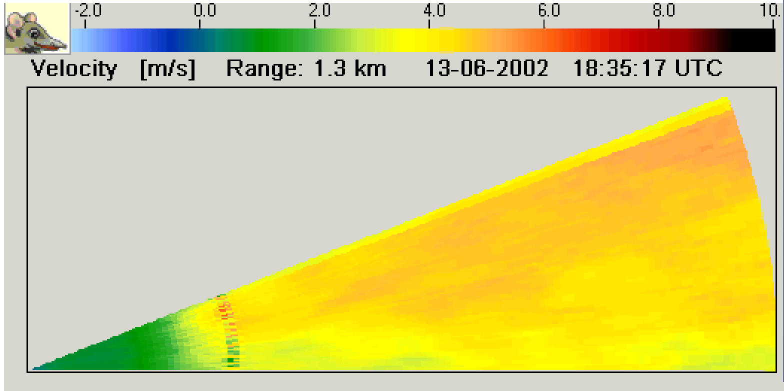


Honours to:

Friedrich Köpp, Stephan Rahm,

Rudolph Simmet, Igor Smalikho,

Andreas Wiegele



Outline

- Technical details of DLR's 2µm pulsed Lidar
- Evaluation steps for wake characterisation:
  position, spacing, orientation, circulation
- Results from ground-based measurements
- Results from airborne measurements on board of *Falcon*

Campaigns with DLR's Lidar

Wake vortex detection along flight path (safety)

- MFLAME - scanning the flight corridor during final approach
- I-Wake - first attempt to detect vortices from a/c along flight path
- GreenWake - airborne detection of atmospheric disturbances
- DELICAT - airborne detection of clear-air turbulence

Wake vortex characterisation (physics)

- WakeOP (Wirbelschleppe, 2001), WakeTarbes (C-Wake, 2002)
- Ground (F/T-1) and airborne (ATTAS try-out, F/T-2) meas.(AWIATOR, 03,05,06)
- WakeFRA, WakeIstres (Airbus, 2004)
- Ground and airborne back-to-back meas. A380 / A340 / B747 (Airbus, 2006)
- Departing a/c at Frankfurt (CREDOS, 2006-07)

Flight corridor monitoring (wake vortex forecast check)

- Test of WV advisory system WSVBS at Frankfurt (Wirbelschleppe, 2006-07)
- Test of WSVBS for single runway in München (Wetter & Fliegen, summer 2010)

Technical details of DLR's Lidar

pulsed Doppler, heterodyne
light backscattered by aerosols

Transceiver MAG-1 (prototype CTI -> LM):

Tm:LuAG laser	
wavelength	2.022 µm
repetition rate	500 Hz
pulse energy	2 mJ
pulse length	0.5 µs

Off-axis telescope:

aperture	10 cm

Scanner (2 prisms):

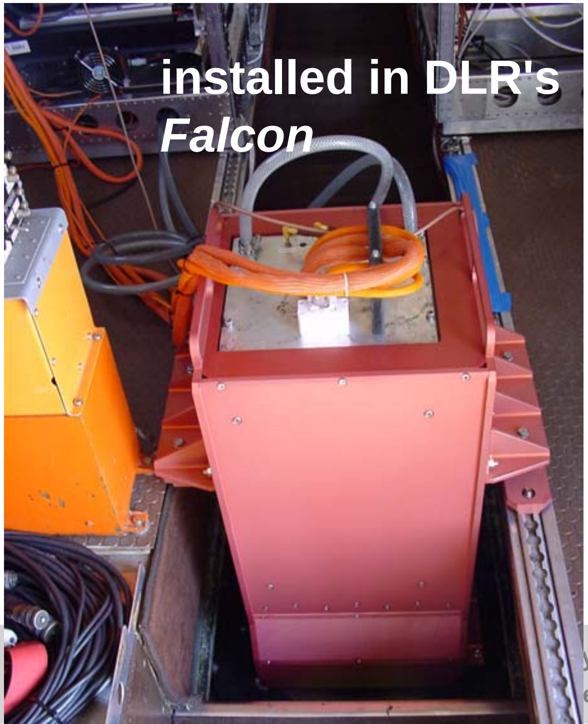
elevation sector	0 - 30°
scan speed	2 °/s

Data acquisition:

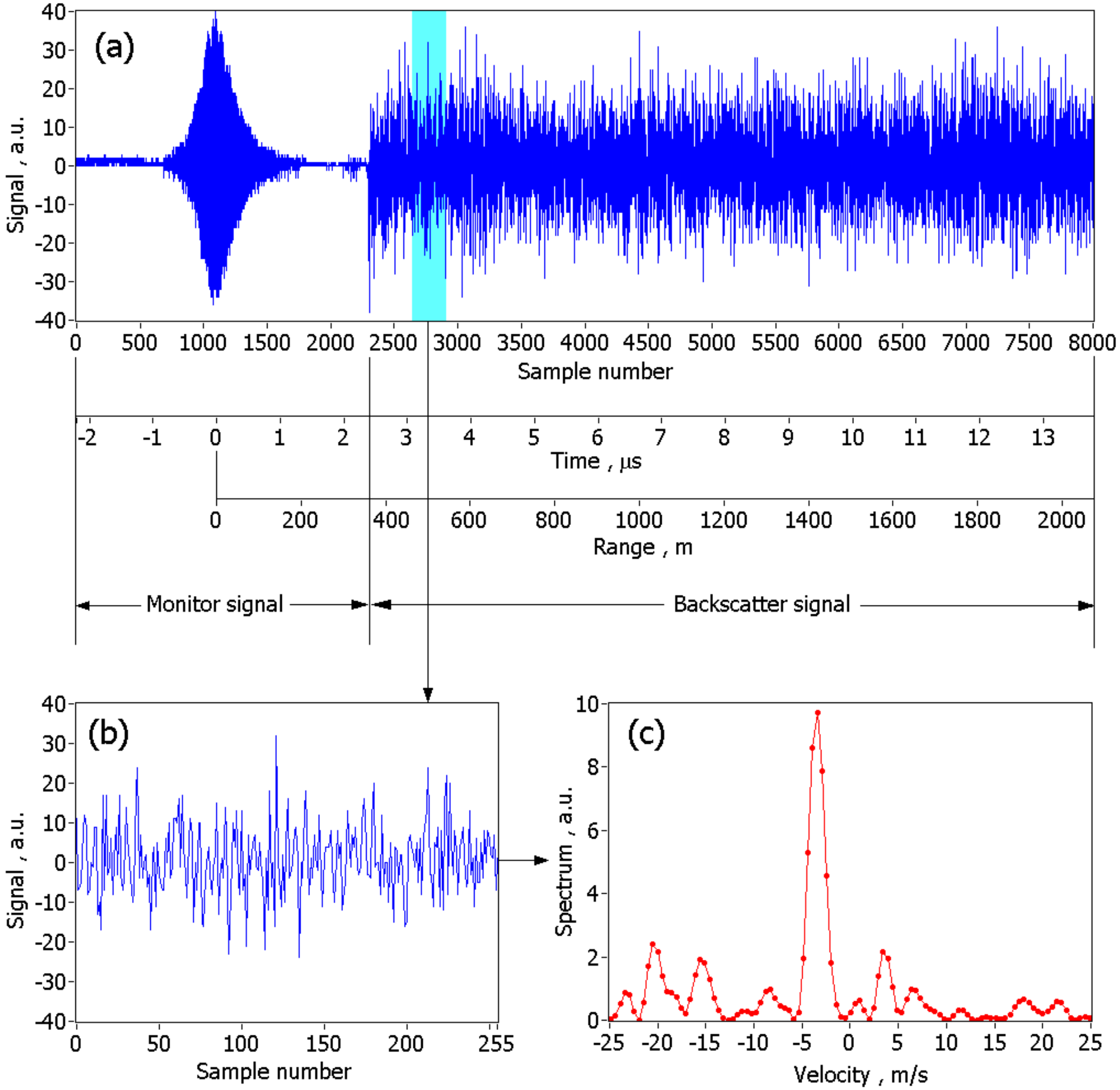
early digitising	500 MHz
with quick-look	

Signal processing:

four-stage algorithm



Evaluation steps for wake vortex characterisation

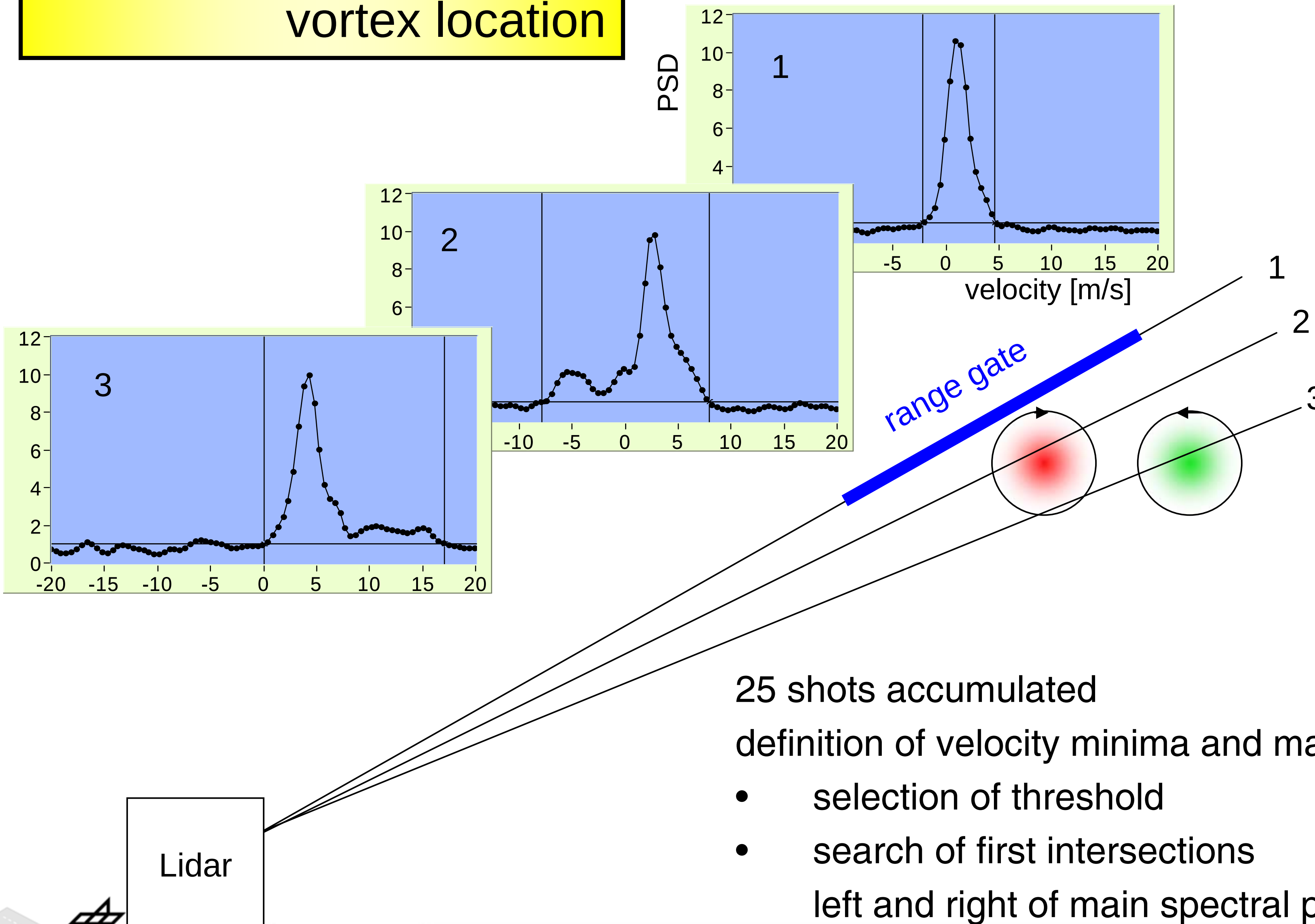


Four-stage process:
Stage 0

raw data:
- heterodyne signal of laser pulse
- atmospheric backscatter signal (2 ns/sample)

Doppler spectra:
Fourier transform (256 samples) with zero padding (768 samples)

Stage 1: Spectra at wake vortex location

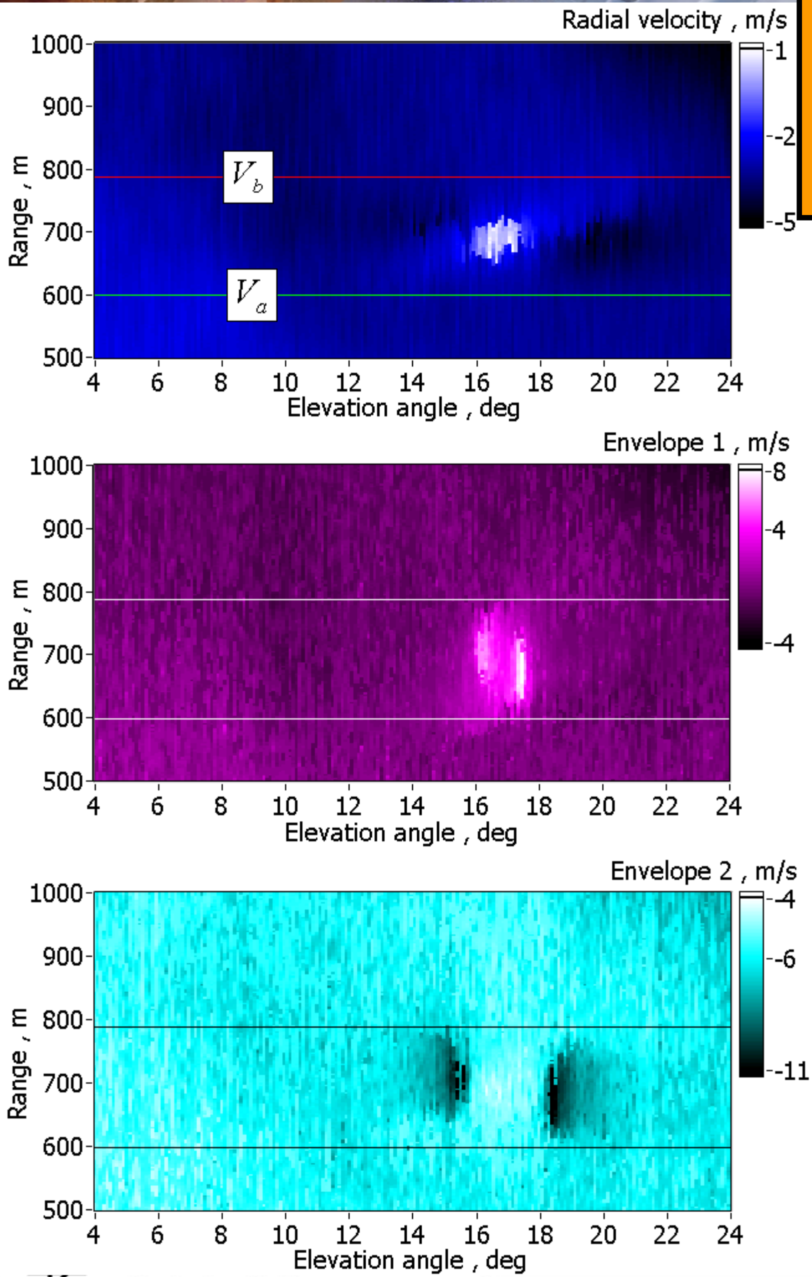


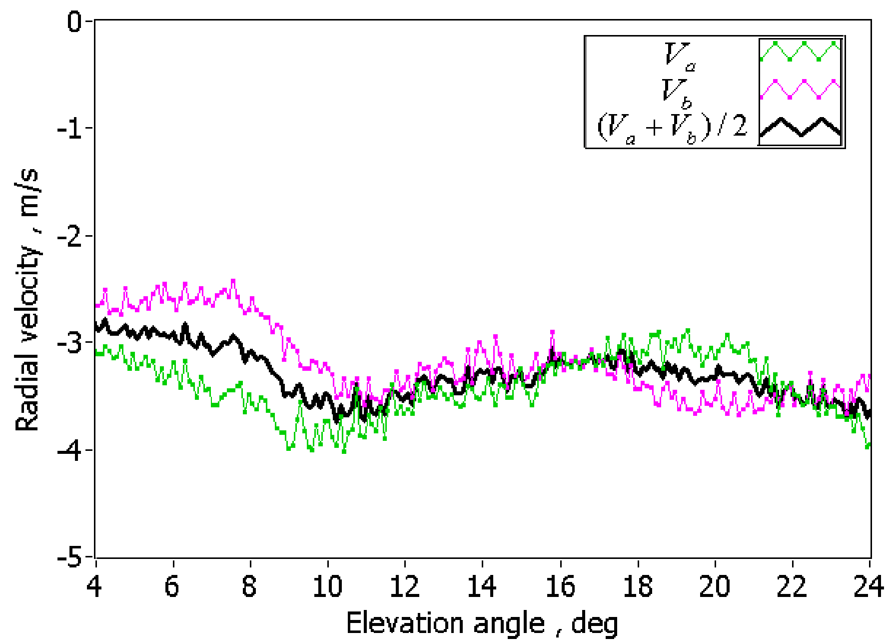
25 shots accumulated

definition of velocity minima and maxima:

- selection of threshold
- search of first intersections
  left and right of main spectral peak

Stage 2:
- eliminate background wind
- determine envelopes

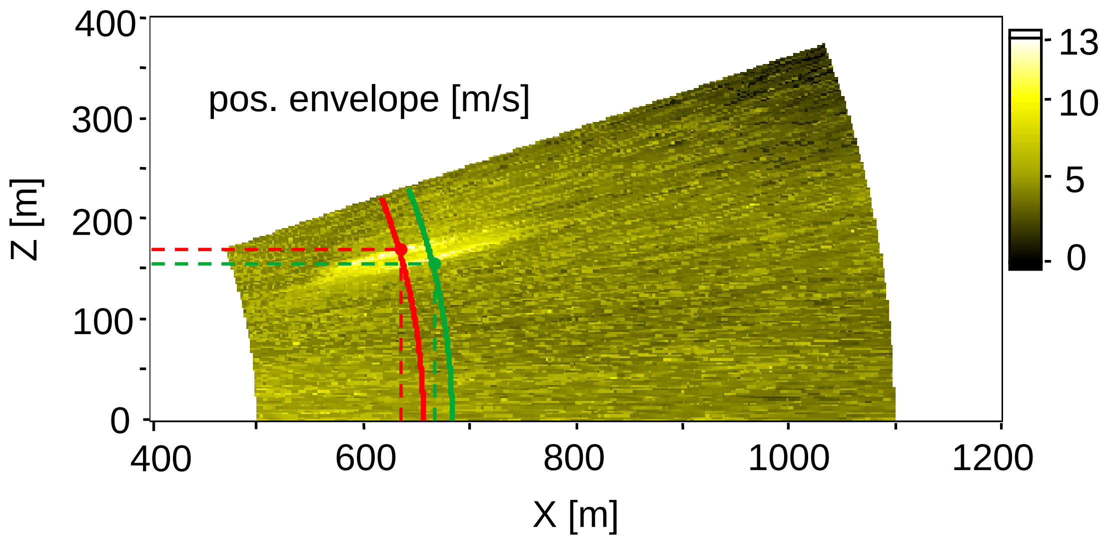


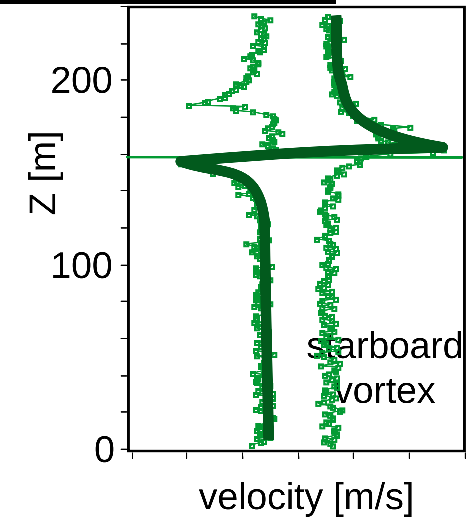


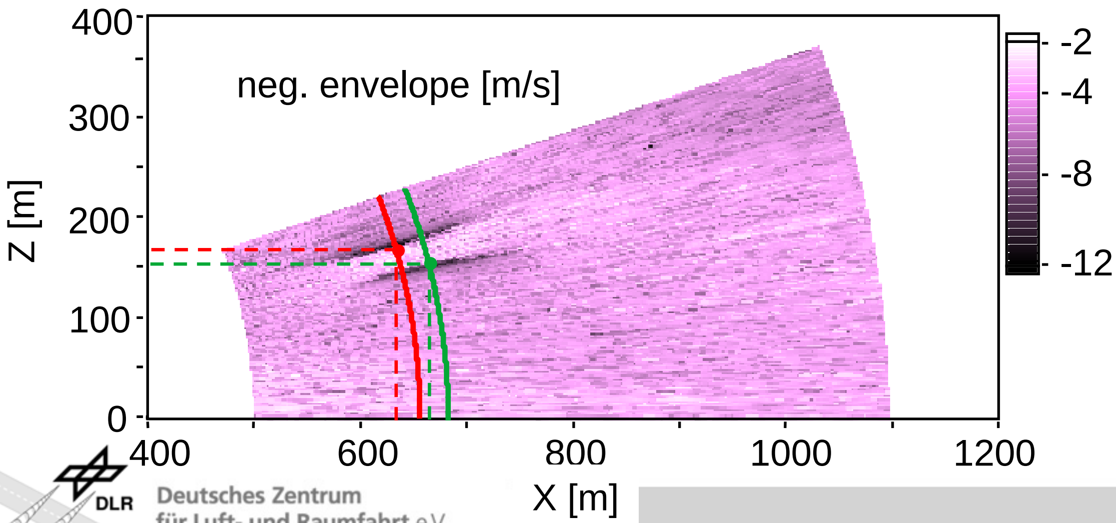
background wind

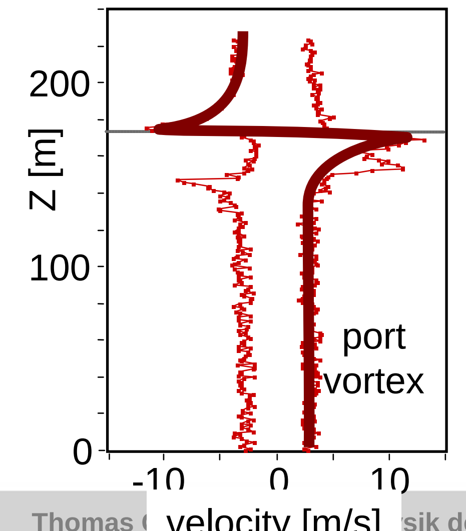
positive and negative envelopes
of radial (LOS) velocities

Stage 3: (i) range and elevation of max/min signal strength: estimation of core position
(ii) profiles of tangential velocity at identified ranges

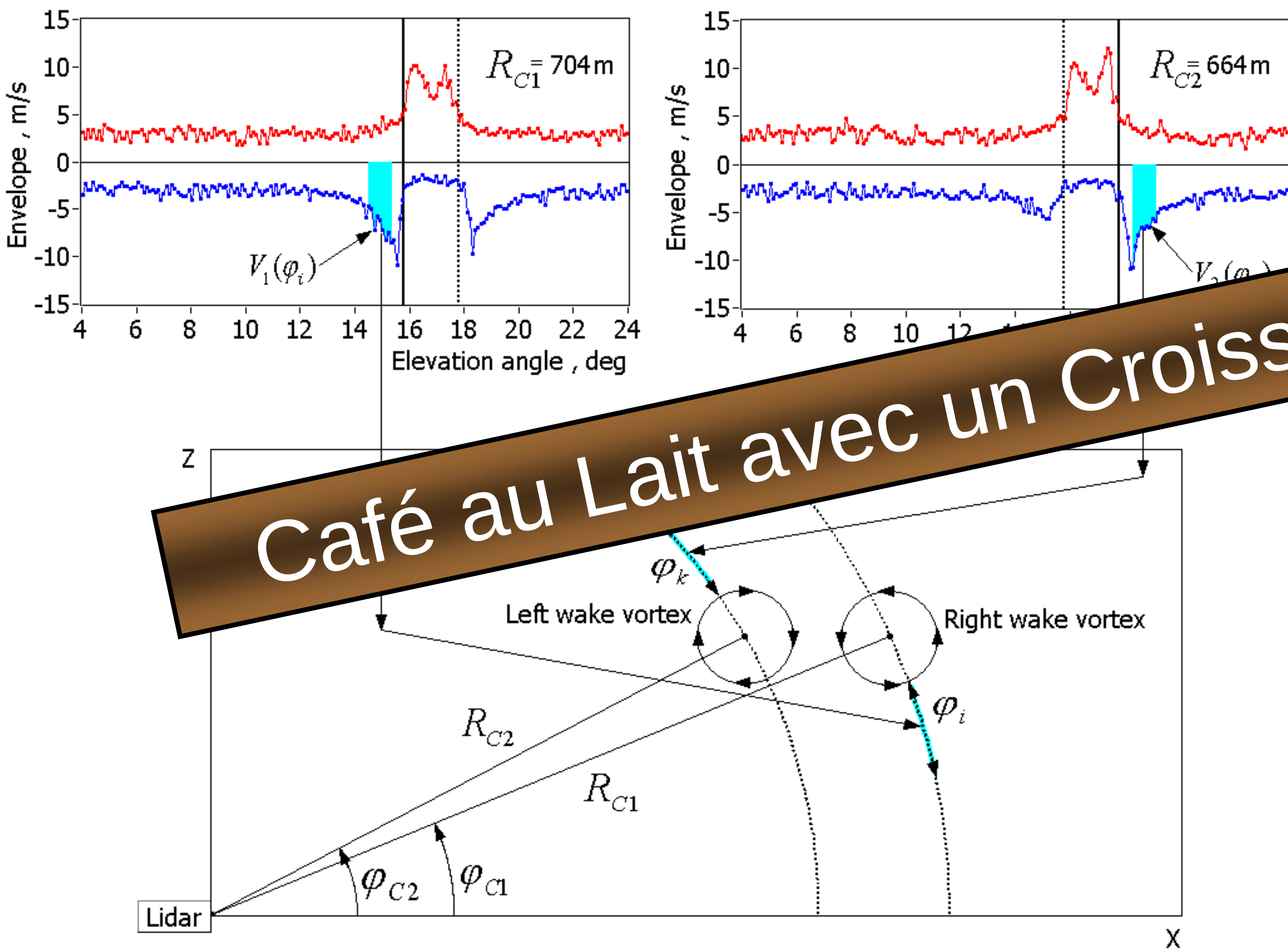








Stage 4: compute circulation

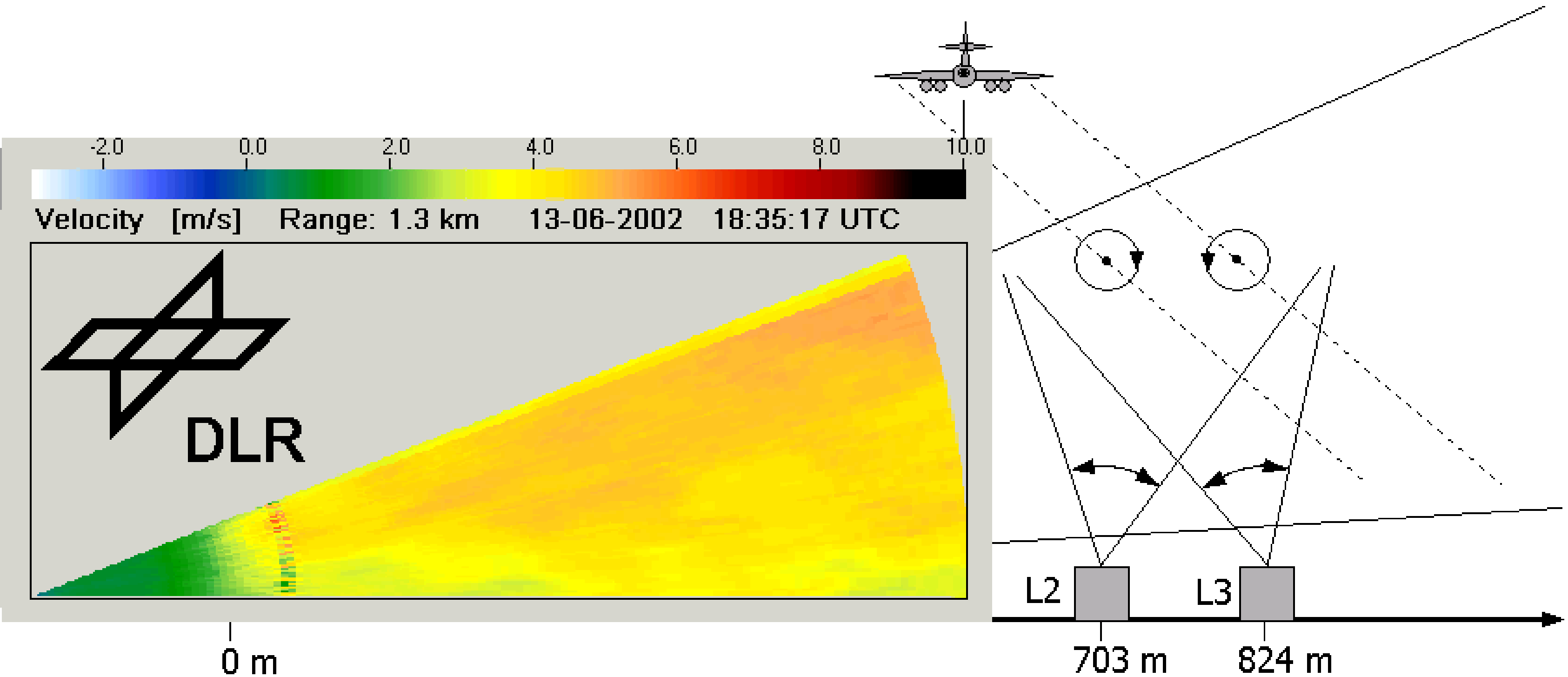


Café au Lait avec un Croissant

vortex circulation:
integration method
e.g. 5 - 15 m for
vortices of large a/c

Pulsed Lidar as a vortex characterising field instrument

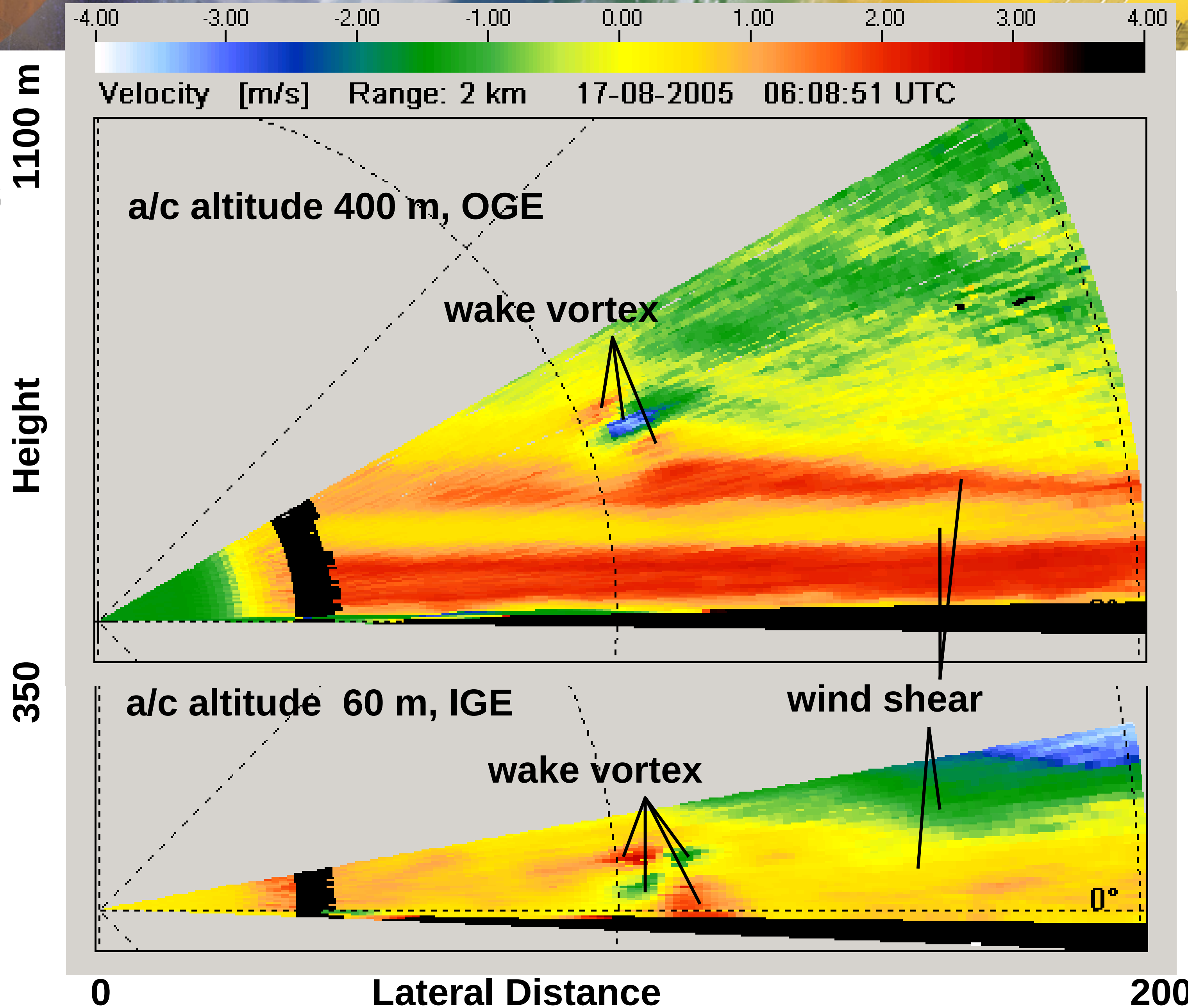
C-Wake and _AWIATOR_ (F/T-1) campaigns in Tarbes 2002/2003



2 µm pulsed Lidar (DLR)

10 µm, cw Lidars (QinetiQ 2002 & ONERA 2002-03)

Signatures in LIDAR quick-looks



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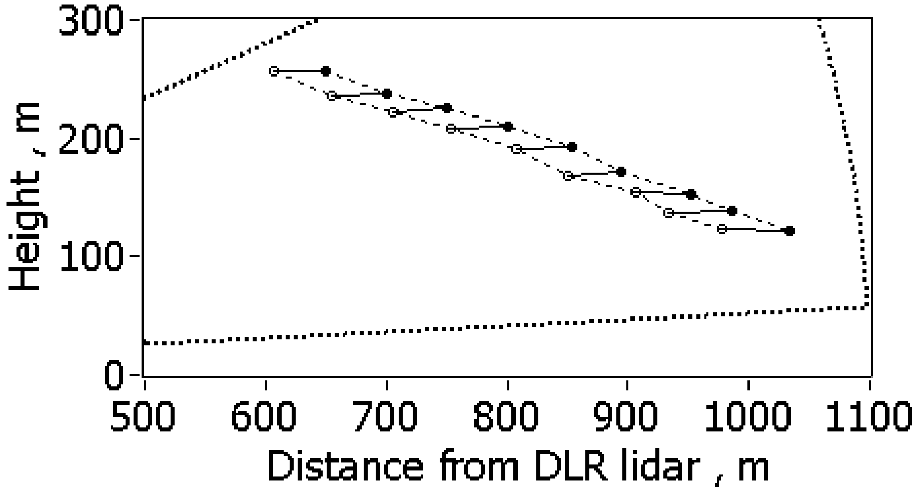
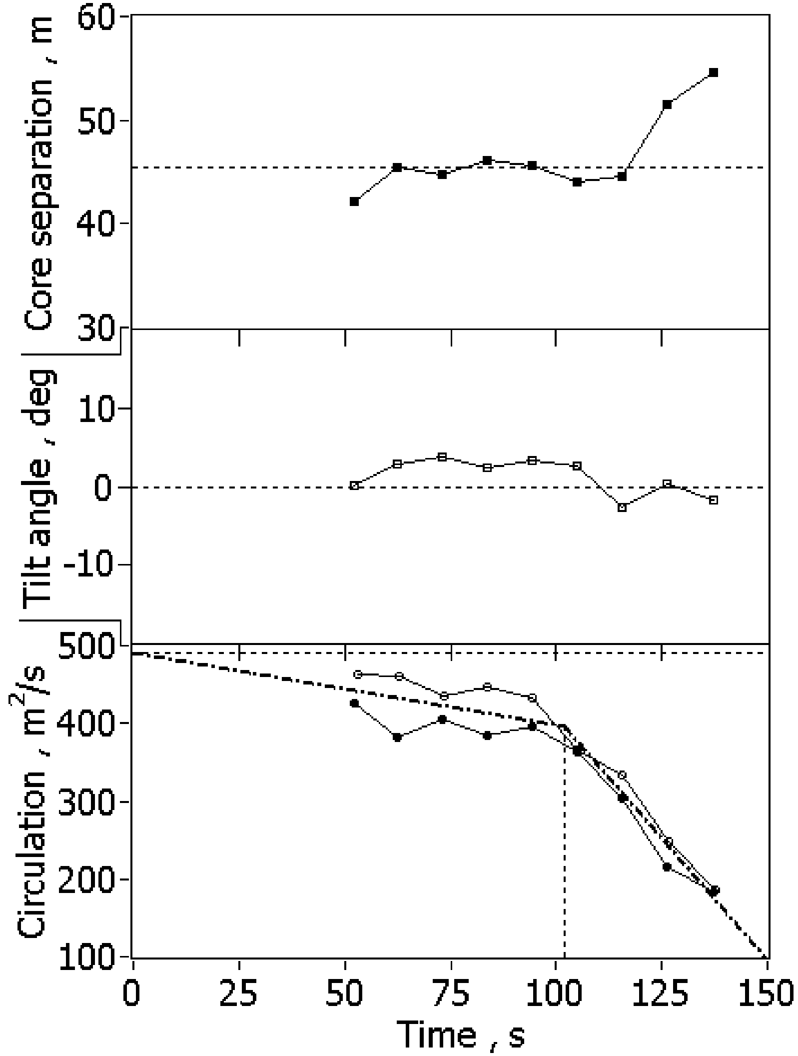
Wake vortices of A340-300 over-flight 4-22



⇑ Trajectories of the vortex pair

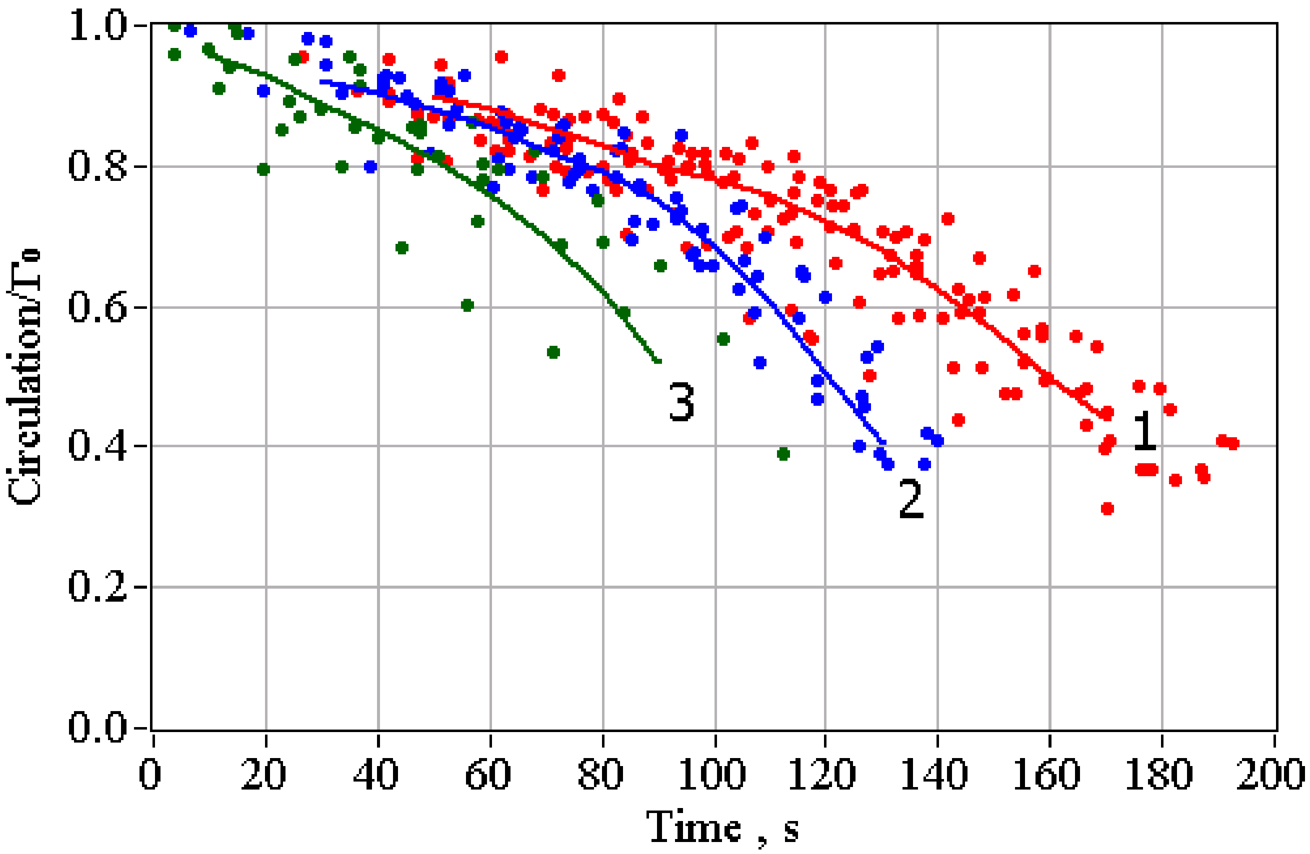
Time dependence of core separation, tilt angle and vortex circulation ⇒

open circles: port vortex,
full circles: starboard vortex



Influence of Atmospheric Turbulence on Vortex Decay

EDR =
(0.5-2)
(2-5)
(5-20)
x10^{-4} m²/s³



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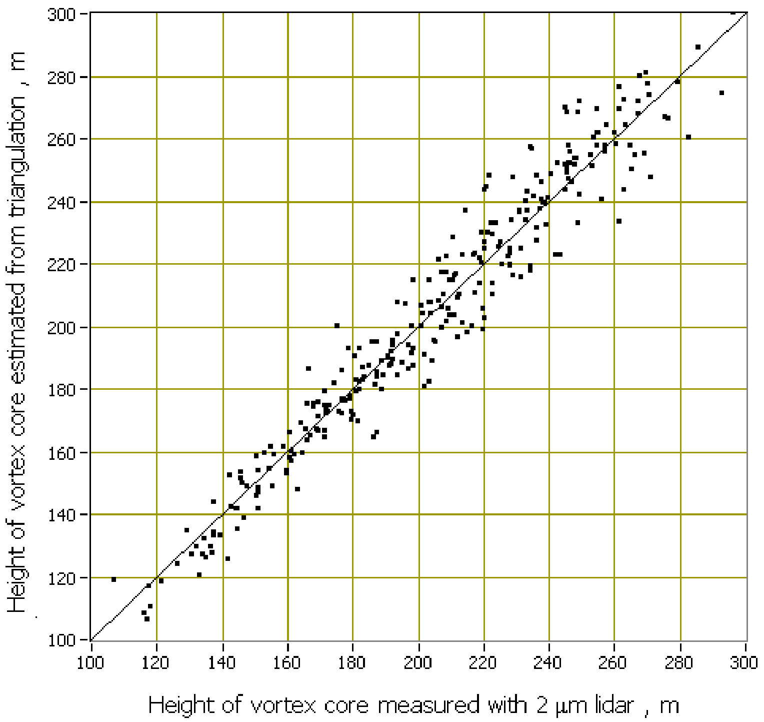
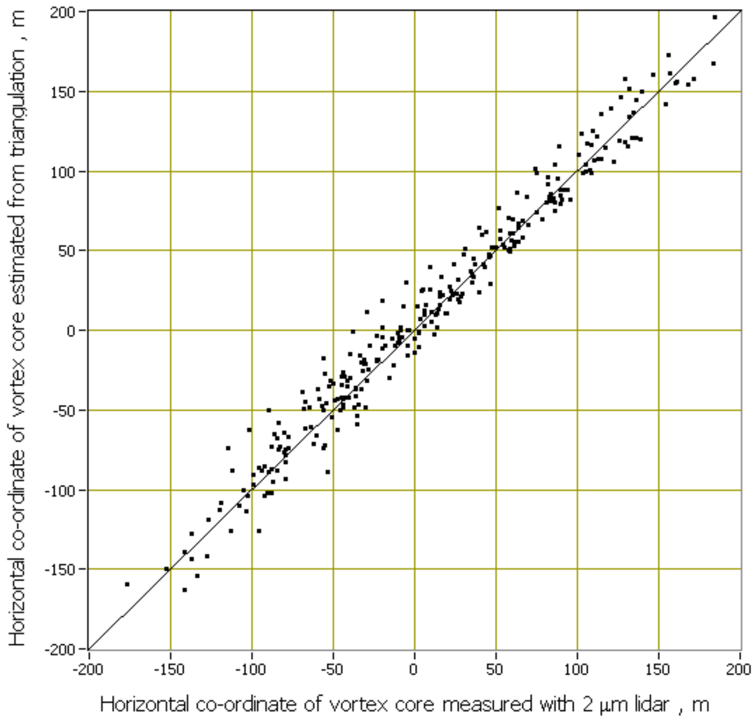
Core trajectories

Comparison of cw-lidar triangulation data and pulsed-lidar data

(ONERA, QinetiQ, DLR)



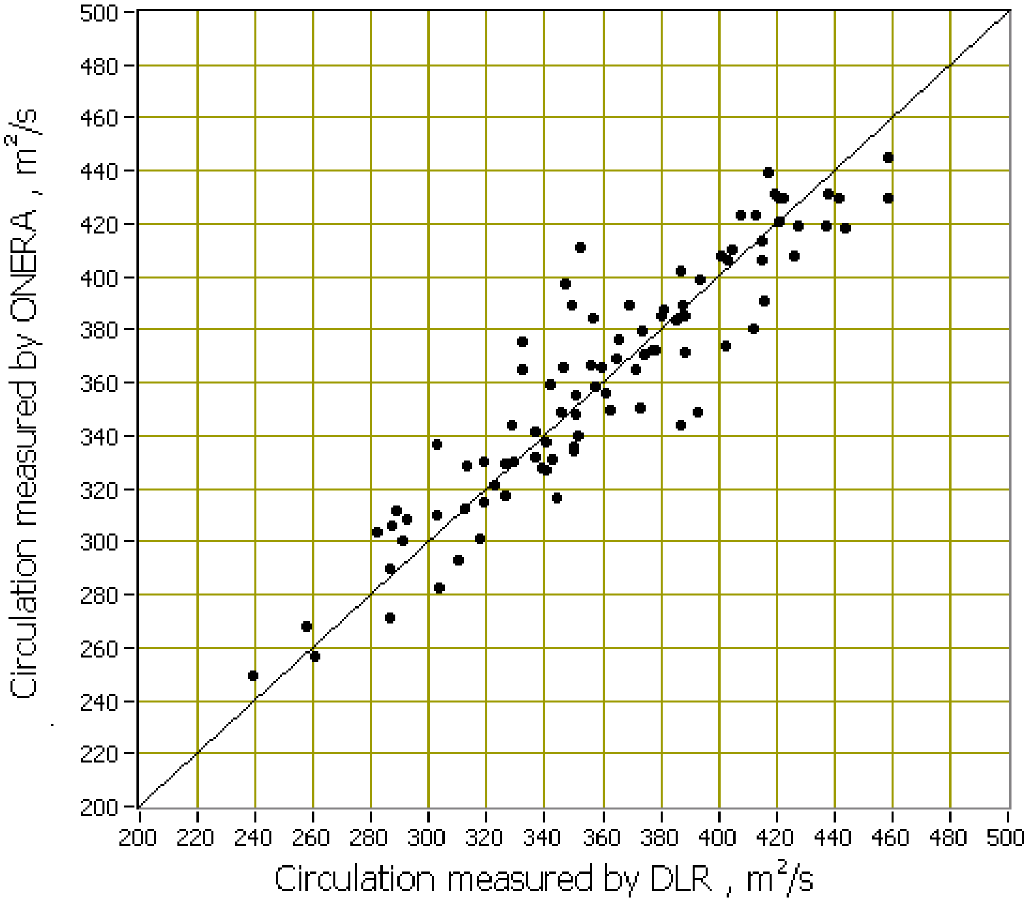


data scatter:
height: σ **= 9 m**

lateral posiiton: σ **= 13 m**

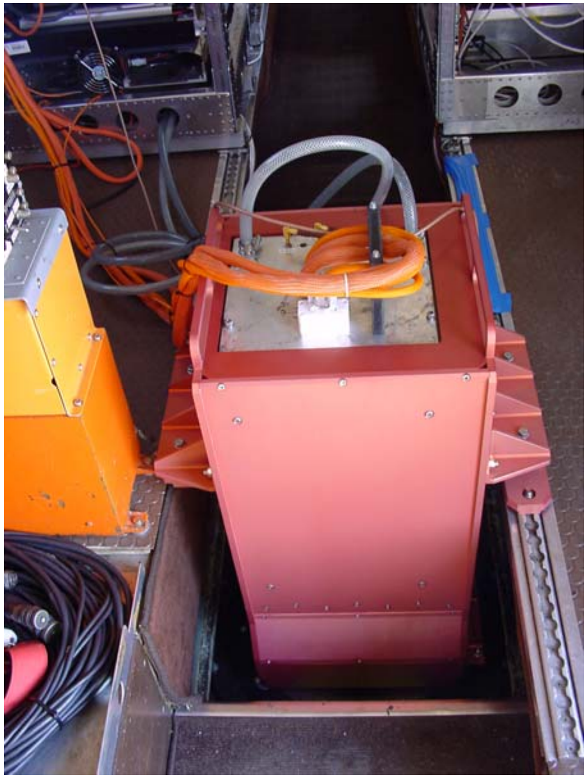
Circulation

Comparison of cw and pulsed lidar data (ONERA, DLR)



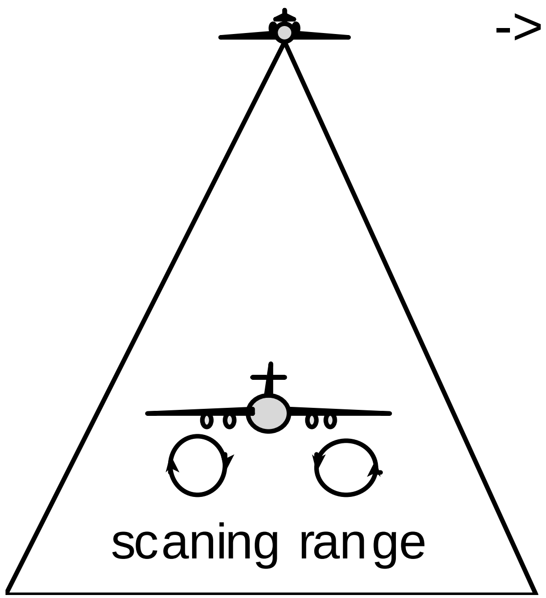
data scatter for circulation: **18 m²/s**

Wake vortex characterisation by airborne lidar measurements



Strategy of airborne lidar measurements

At measurement altitudes only few aerosols expected
-> seeding of the vortices with smoke is prerequisite
-> flight pattern (circuit vs. chase flight) to be optimised



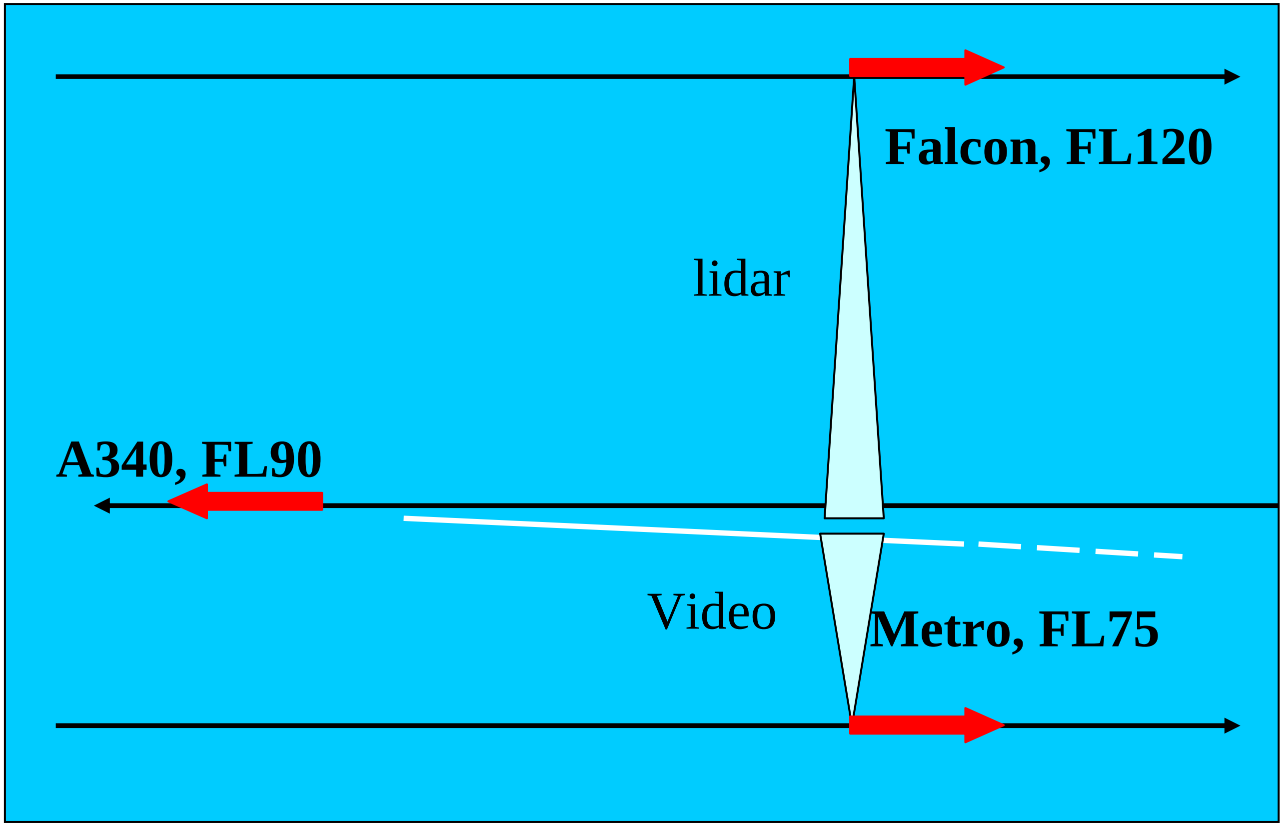
Three campaigns for AWIATOR:

- ATTAS Try-out Oberpfaffenhofen 2005
- A340 Toulouse 9. + 15. Nov. 2006
- ATTAS Oberpfaffenhofen 24. Nov. 2006

plus three campaigns for Airbus

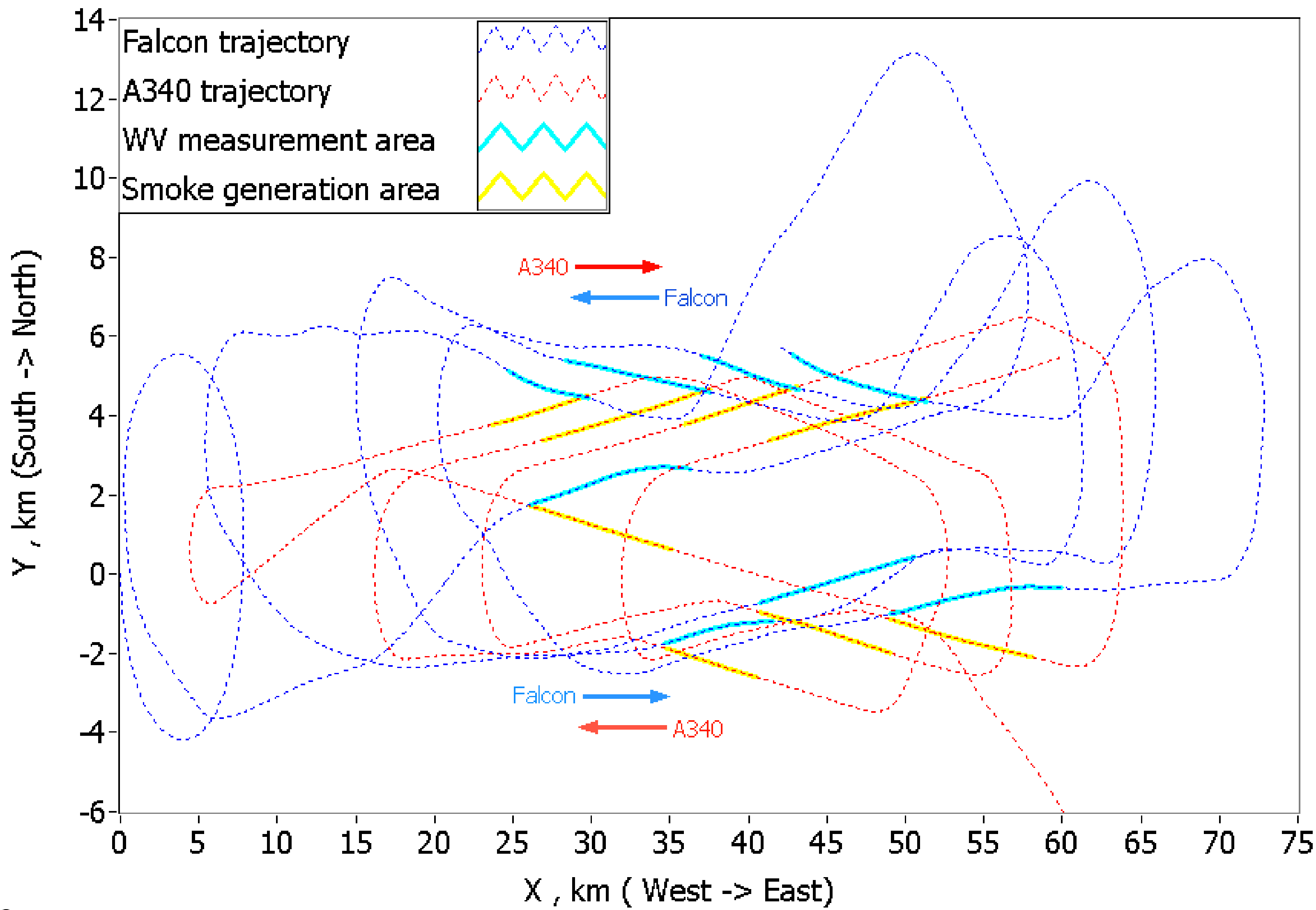
- A380 side by side with A340-600 or B747-400

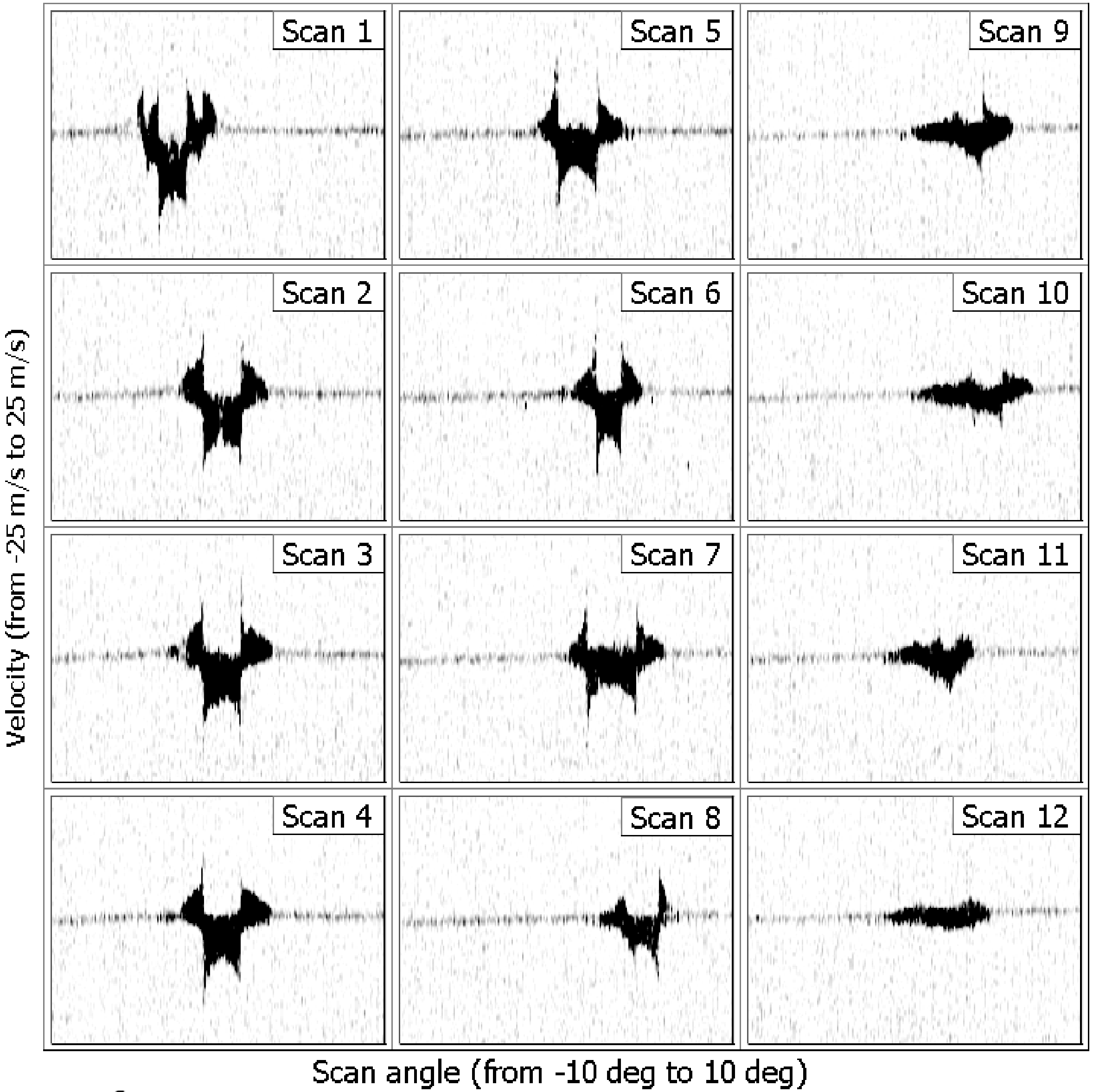
AWIATOR strategy of airborne lidar measurements



The nominal flight paths of the A340, NLR Metro and DLR Falcon, side view, from D1.1.3-19, 15.01.07 (NLR report NLR-CR-2006-770)

AWIATOR A340 and Falcon Flight Pattern 15.11.06 /3



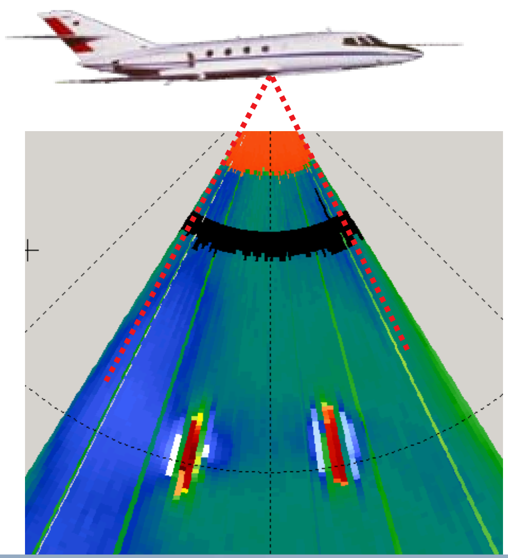


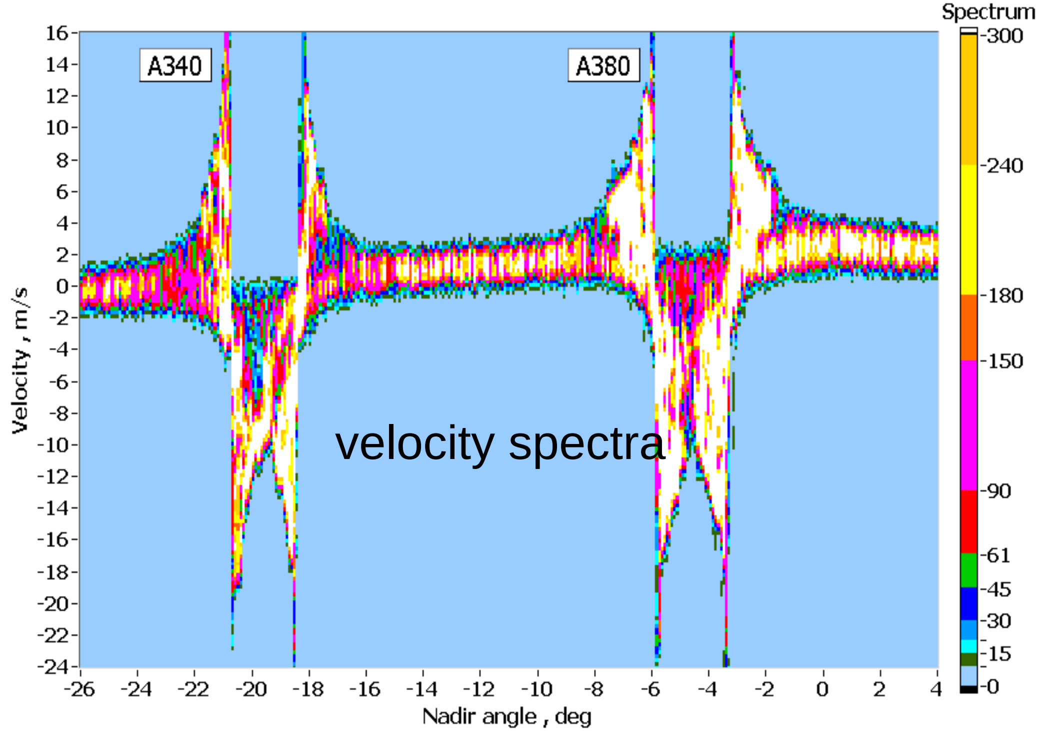
Measured Doppler Spectra

AWIATOR flight 1, leg 1
9.11.06, 13:59 UTC

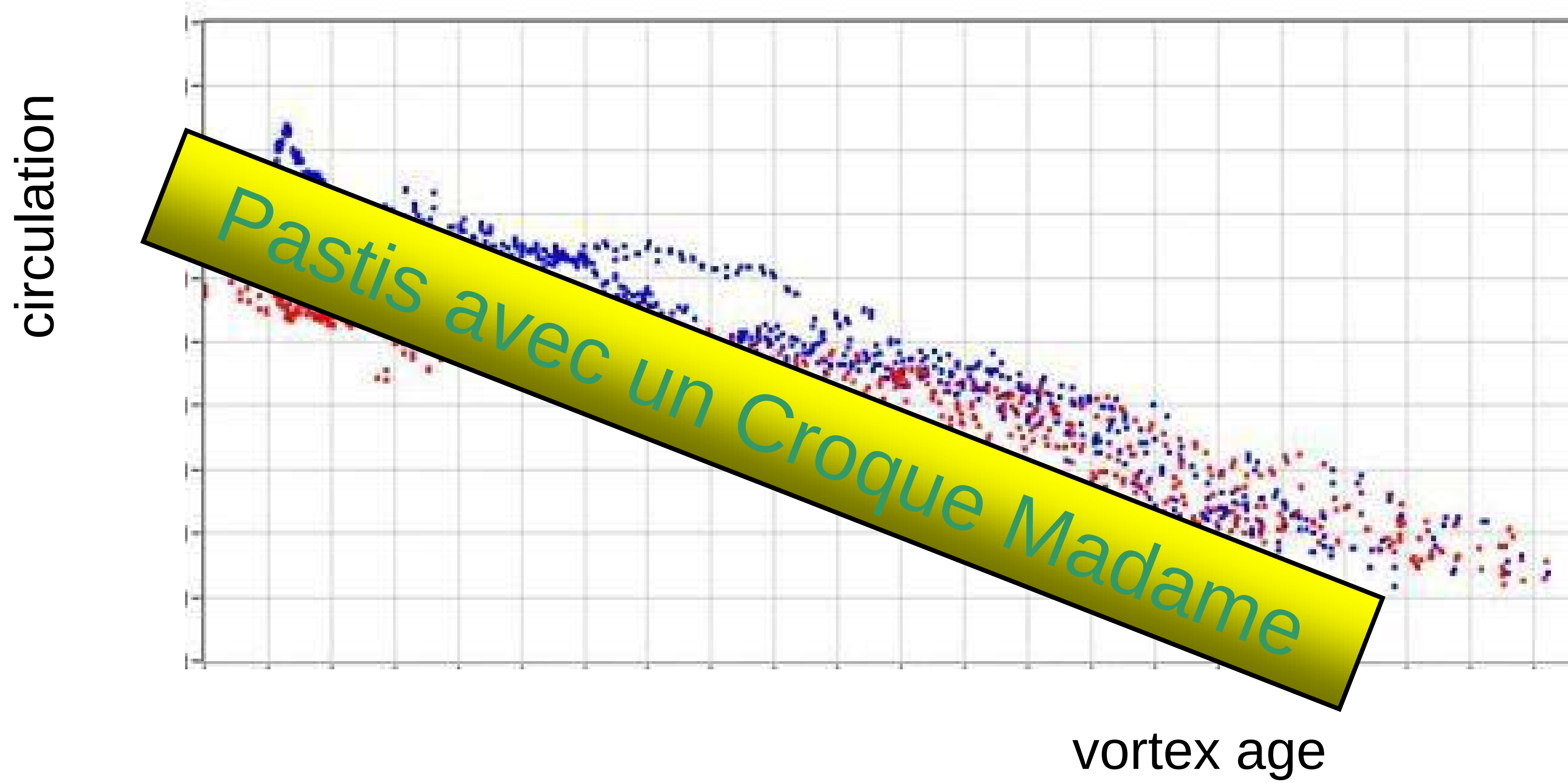
Airbus strategy: A340 and A380 side by side in cruise

measured by downward looking lidar on board of *Falcon*





Circulation of A380 and A340 vortices



Conclusions

- 2 µm **pulsed lidar** used for the first time as a **wake measuring** device
- First **airborne** measurements of aircraft wake vortices
- Transceiver, scanner & data acquisition optimised for **characterisation** of wake vortices: four-stage data-processing algorithm
- Precise vortex trajectory, core separation, tilt angle, and circulation can be derived
- Results of pulsed lidar **verified** by comparison with triangulated cw lidars (based upon vortices from A340 and VFW614 -ATTAS- a/c including atmospheric effects) :

    -standard deviations of vertical and lateral core positions 9 and 13 m,

    -standard deviation of circulation 18 m^2/s
- Augmentation of signal-to-noise ratio is prerequisite for airborne measurements: smoke or contrails

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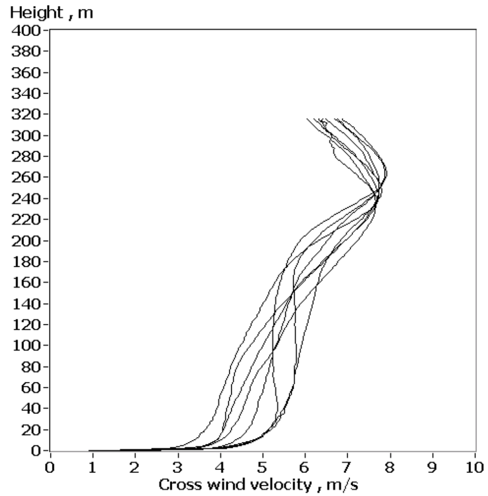
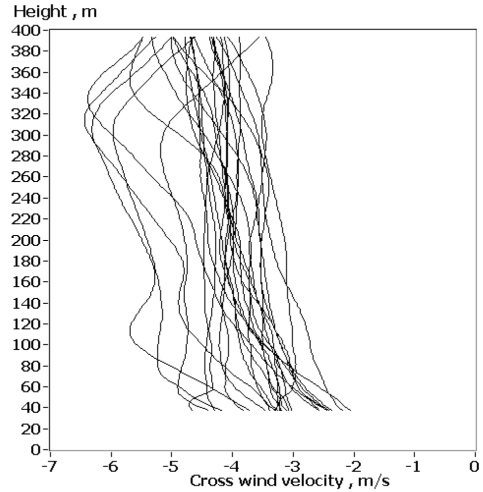
Vertical profiles of cross wind measured by pulsed lidar

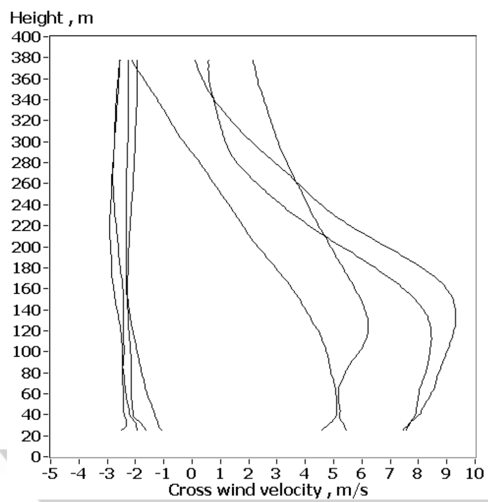
12.06.02
8 profiles (5:46:50 - 6:30:44)



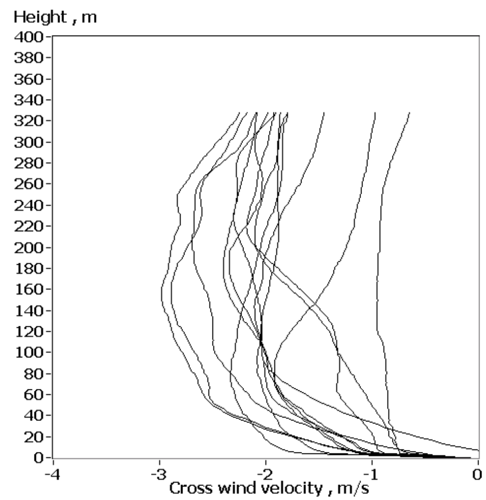
13.06.02
6 profiles (16:37:17 - 17:10:13) + 7 profiles (18:12:08 -18:50:52) +
+ 12 profiles (19:01:51 - 20:07:44) = 25 profiles



14.06.02
2 profiles (16:55:43 - 17:06:40) +
+ 6 profiles (18:13:59 - 18:47:21) = 8 profiles

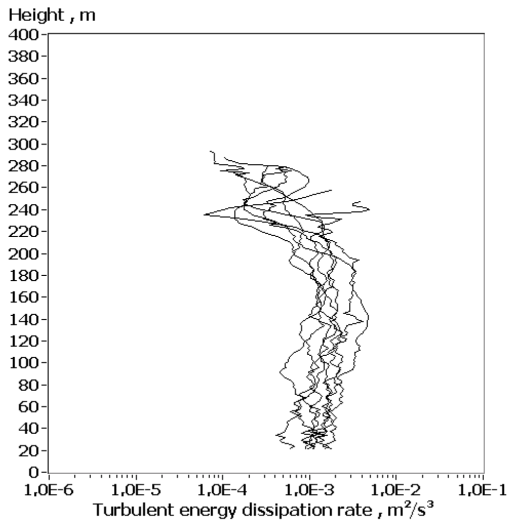


17.06.02
5 profiles (18:10:44 - 18:38:07) + 4 profiles (19:12:11 -19:33:54) +
+ 4 profiles (19:44:45 - 20:07:27) = 13 profiles



Turbulent energy dissipation rate from pulsed lidar wind measurements

12.06.02
8 profiles (5:46:50 - 6:30:44)



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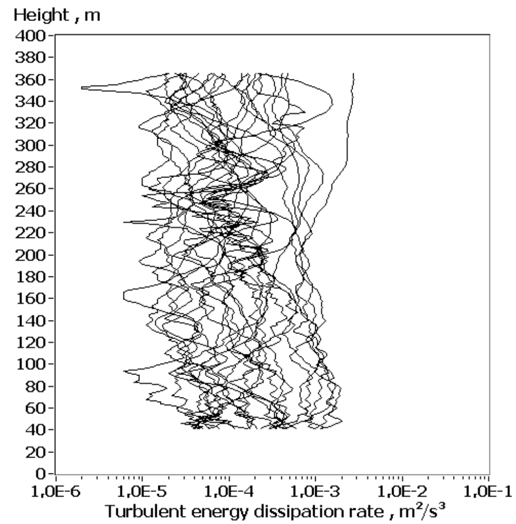


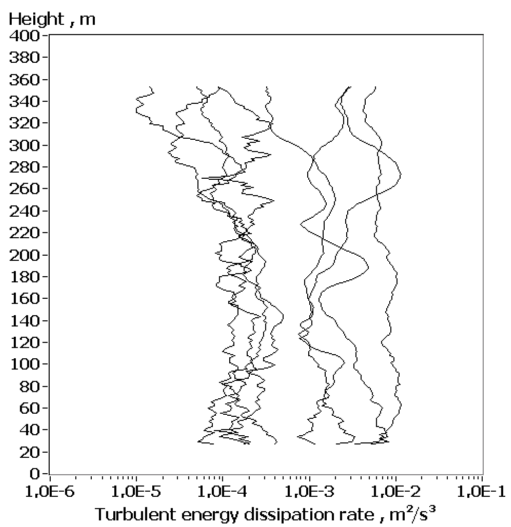
$$\hat{\varepsilon} = \left[\frac{\hat{D}(r_2) - \hat{D}(r_1)}{2(r_2^{2/3} - r_1^{2/3})} \right]^{3/2}$$

where

$$\hat{D}(r_i) = < \left[V_r(R + r_i) - V_r(R) \right]^2 >$$

$i = 1$, 2; $r_1 = 60$ m; $r_2 = 120$ m

14.06.02
2 profiles (16:55:43 - 17:06:40) +
+ 6 profiles (18:13:59 - 18:47:21) = 8 profiles



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