Prediction of Dynamic Pairwise Wake Vortex Separations for Approach and Landing – the WSVBS

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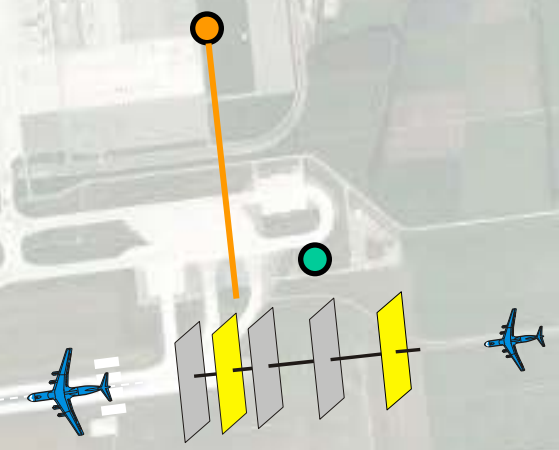
Wake Vortex Advisory System “WSVBS”

- supports weather dependent dynamic separations

  - on closely-spaced parallel runways
  - and single runways

  - for weight class combinations
  - or dynamic pairwise separations

  - demonstration campaigns at
    - Frankfurt airport (winter 06/07)
    - Munich airport
      (summer 10, spring 11)



Wake Vortex Advisory System “WSVBS”

- supports weather dependent dynamic separations
  - on closely-spaced parallel runways
  - and single runways

special thanks for the support go to:

- DFS Deutsche Flugsicherung GmbH
- DWD Deutscher Wetterdienst
- Fraport AG
- Flughafen München GmbH
- Metek GmbH

WSVBS

meteo measurements
SODAR/RASS USA
3 gates, 0.3 - 1 NM

numerical weather pred.
COSMO-Airport
10 gates, 2 - 11 NM

optionally a/c type comb.
Flight Plan
a/c type, arrival time

wake-vortex prediction
P2P
envelopes for y(t), z(t), Γ(t) in 13 gates
for (individual) heavy/medium pairings

glide path adherence statistics
FLIP
standard deviations in 13 gates

safety area prediction
SHAPe
ellipses for (individual) medium followers

wake-vortex monitoring
LIDAR
3 planes, 0.3 - 1 NM

temporal a/c separations
for (individual) heavy/medium pairings

conflict detection
validation of vortex predictions

procedures
AMAN
STG, MSR, MSL, ICAO

Deutsches Zentrum
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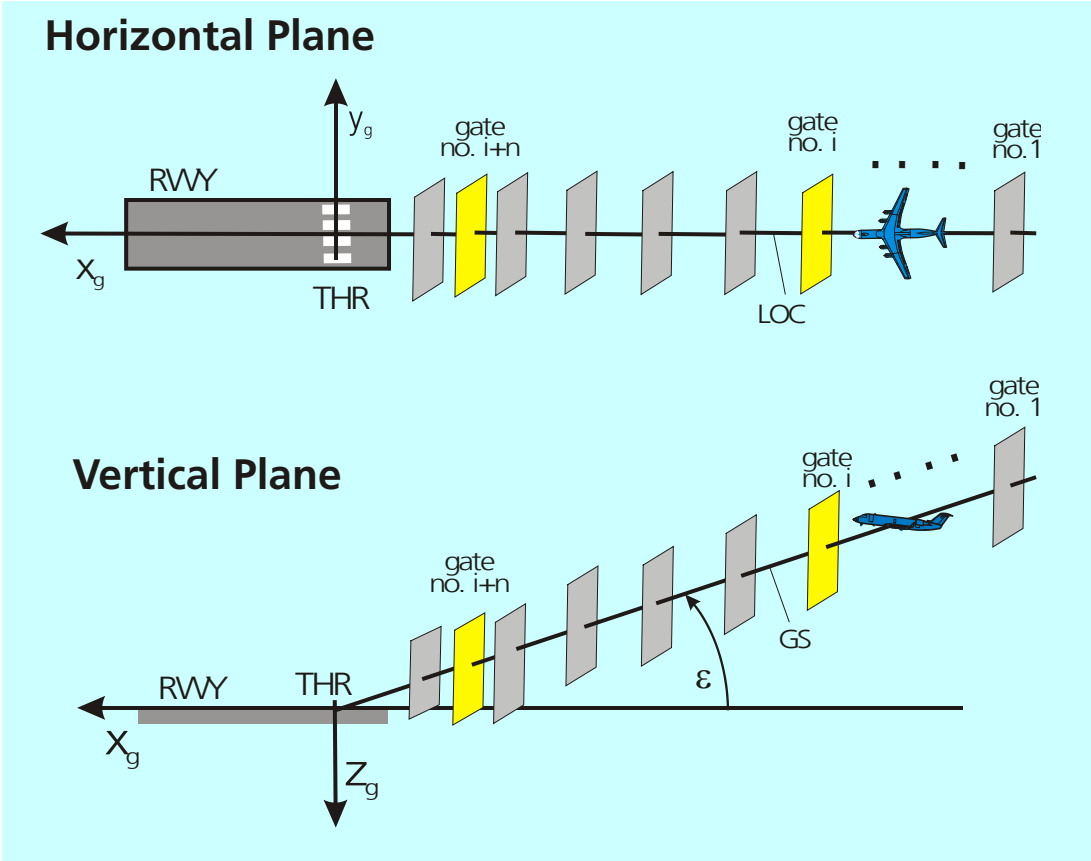
in der Helmholtz-Gemeinschaft

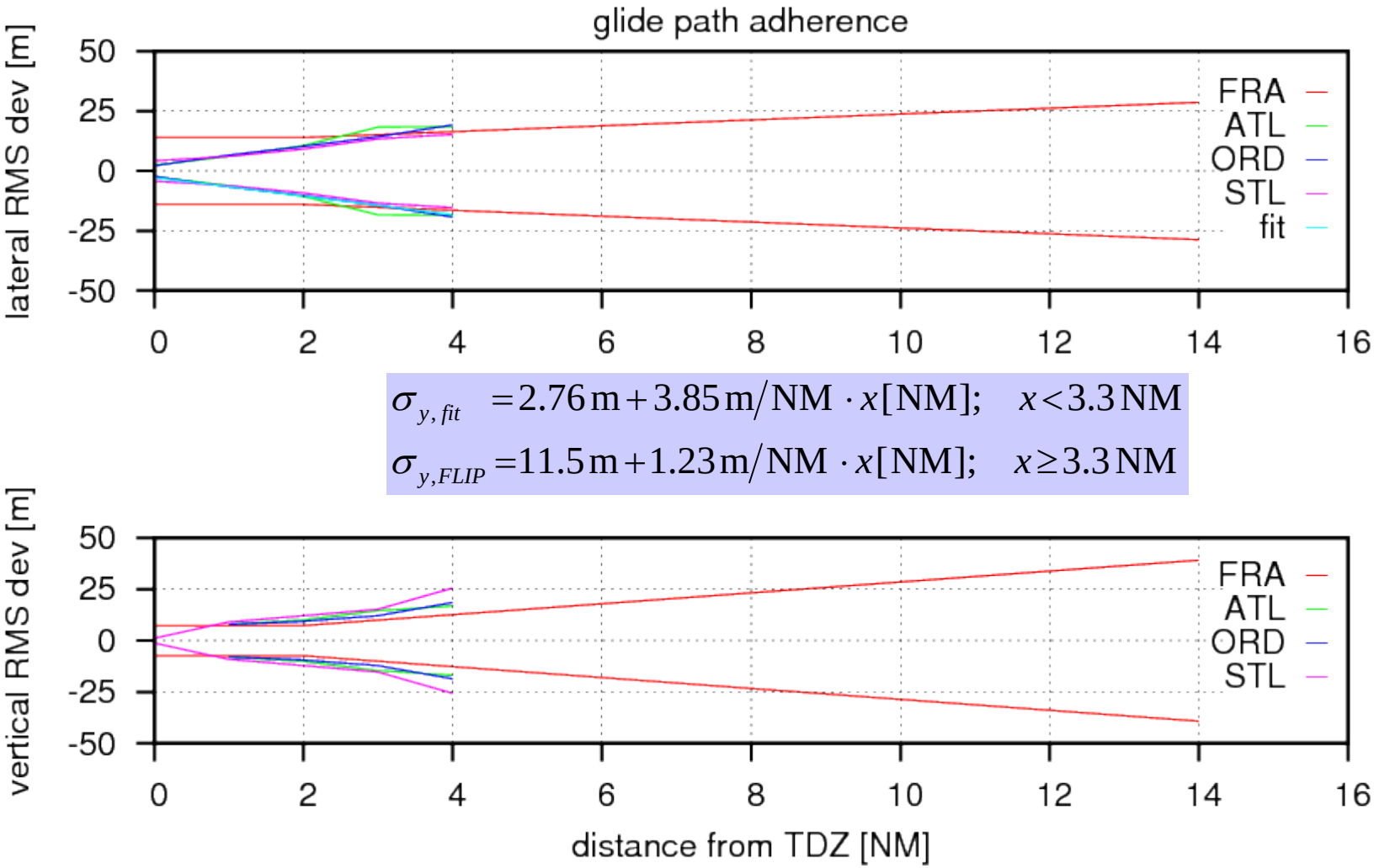
WSV Topology

13 Gates Along Nominal ILS Flight Path (Δx = 1/3 NM - 1 NM)



gate No	x_{gate} [nm]	z_{gate} [m]
1	-11	-1077
2	-10	-979
3	-9	-880
4	-8	-781
5	-7	-683
6	-6	-584
7	-5	-486
8	-4	-387
9	-3	-289
10	-2	-191
11	-1	-94
12	-2/3	-61
13	-1/3	-29

Approach Corridor Dimensions



35,691 approaches
3,394 approaches
1,112 approaches
x,xxx approaches

$$\sigma_{y,fit} = 2.76\,\mathrm{m} + 3.85\,\mathrm{m/NM} \cdot x[\mathrm{NM}]; \quad x < 3.3\,\mathrm{NM}$$

$$\sigma_{y,FLIP} = 11.5\,\mathrm{m} + 1.23\,\mathrm{m/NM} \cdot x[\mathrm{NM}]; \quad x \geq 3.3\,\mathrm{NM}$$

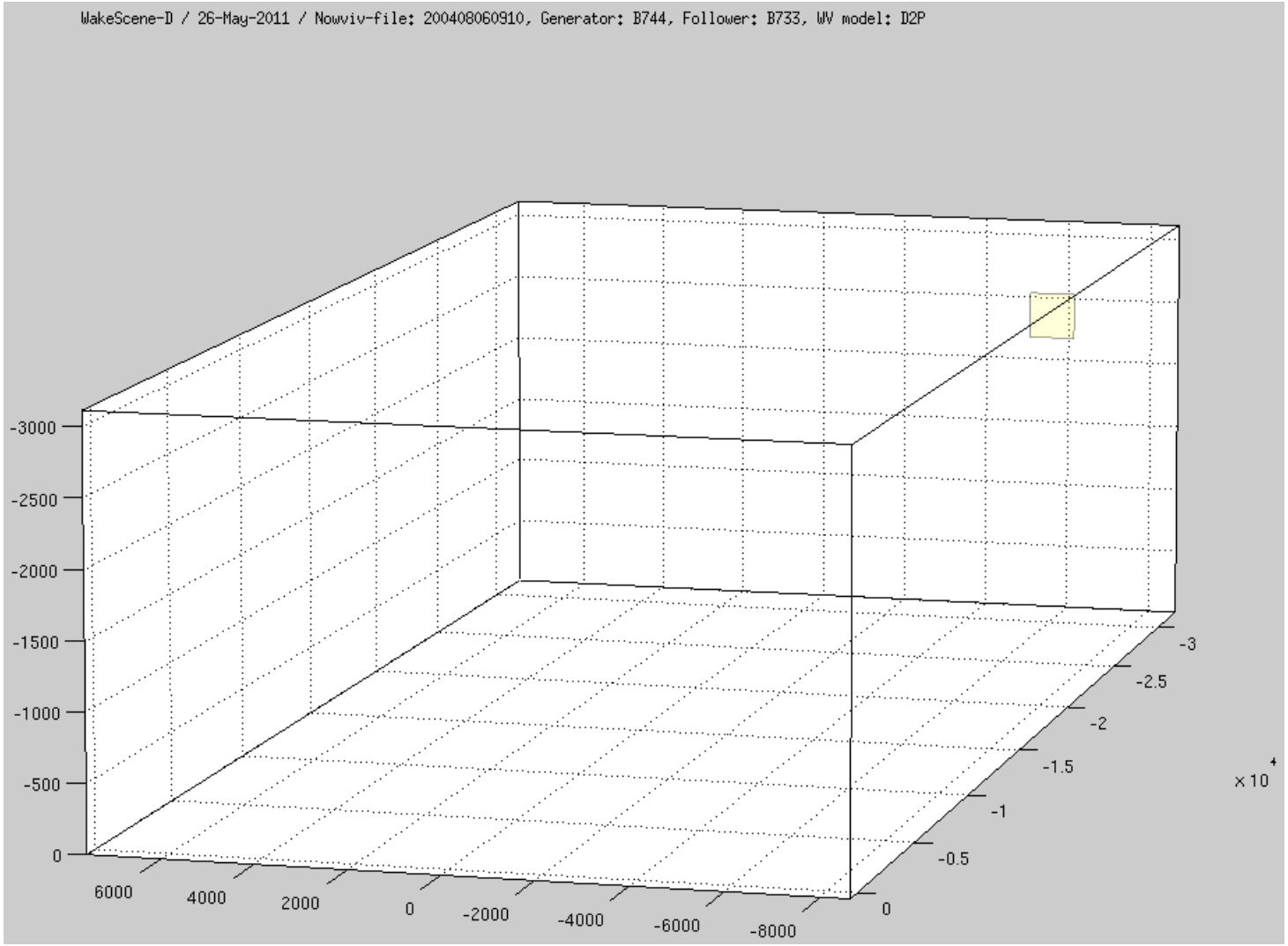
FRA: Frauenkron, H., Maiss, M., Nalpanis,P.: FLIP - Flight Performance using Frankfurt ILS, DFS German Air Navigation Services, 2001.

ATL, ORD: Zhang Y, Shortle J, Sherry L.: 2010. Comparison of Arrival Tracks at Different Airports. In: Proceedings of 4th International Conference on Research in Air Transportation. Budapest, Hungary.

STL: Hall, T., M. Soares. 2008. Analysis of localizer and glide slope flight technical error. 27th Digital Avionics Systems Conference, St. Paul, MN.

Approach scenario – WakeScene

(animation)



Holzäpfel et al., Aircraft Wake Vortex Scenarios Simulation Package - WakeScene, Aerospace Science and Technology **13,** 2009.

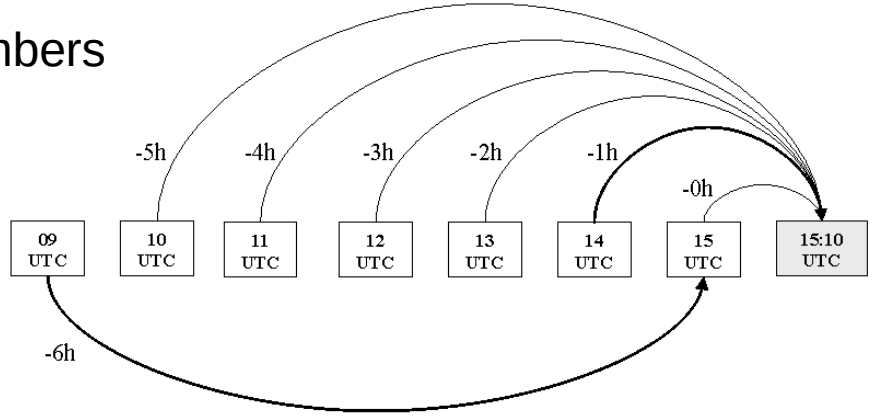
Holzäpfel et al., Aircraft Wake Vortex Scenarios Simulation for TakeOff and Departure, Journal of Aircraft **46**, 2009, 713-717.

Holzäpfel & Kladetzke, Assessment of Wake Vortex Encounter Probabilities for Crosswind Departure Scenarios, J. Aircraft **48**, No. 3, 2011.

Numerical weather prediction and meteorological instrumentation

COSMO-Airport:

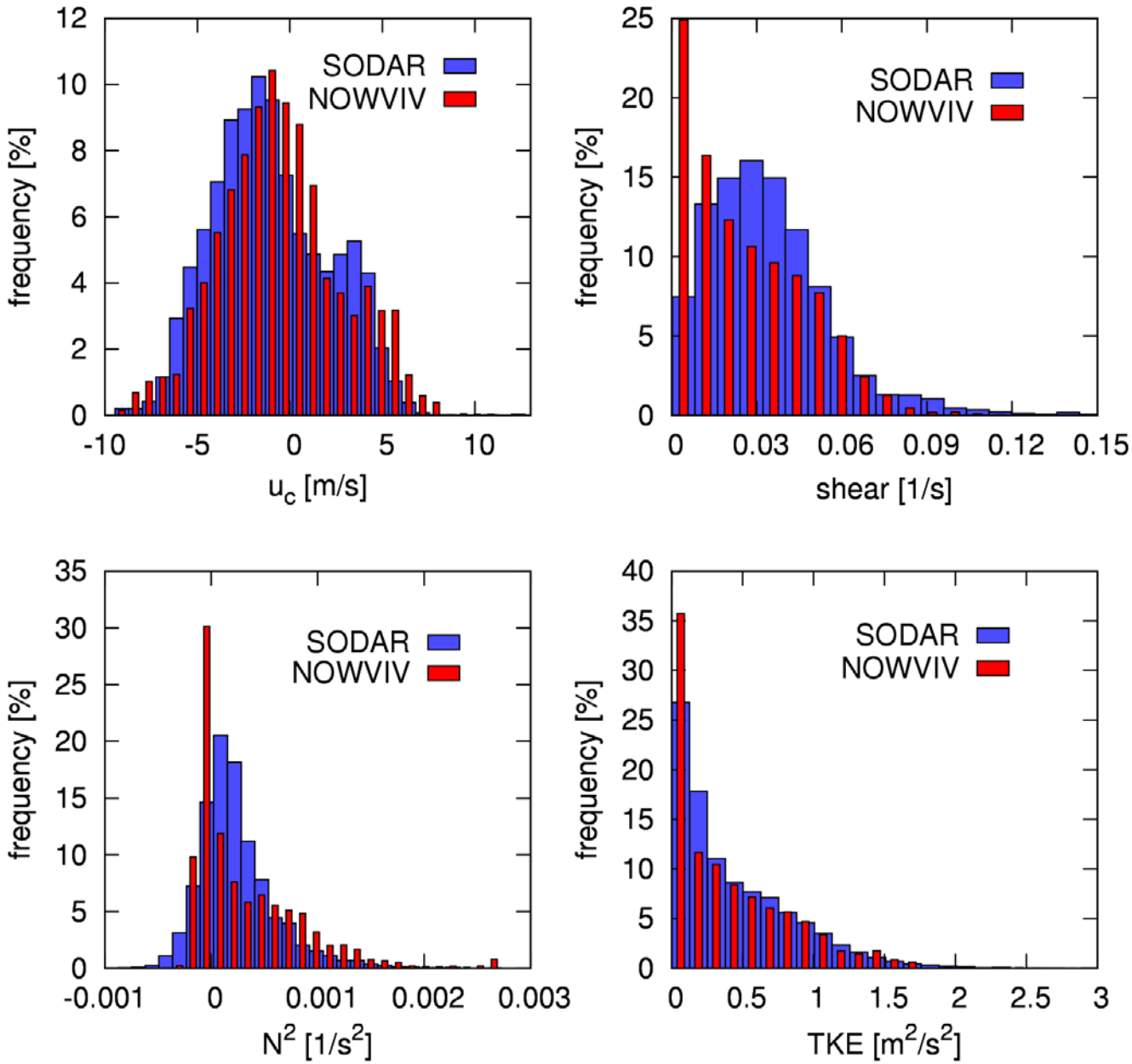
- meteo conditions along glidepath (output every 10 min)
- assimilation of SYNOP, TEMP, AMDAR and precipitation radar
- time-lagged ensemble predictions with 6 members



SODAR/RASS:

- meteo conditions close to threshold
- wind, turbulence, and temperature
- output every 10 min up to 500 m (Δz = 20 m)

Comparison of measured and predicted meteo data



40 days
z = 100 m

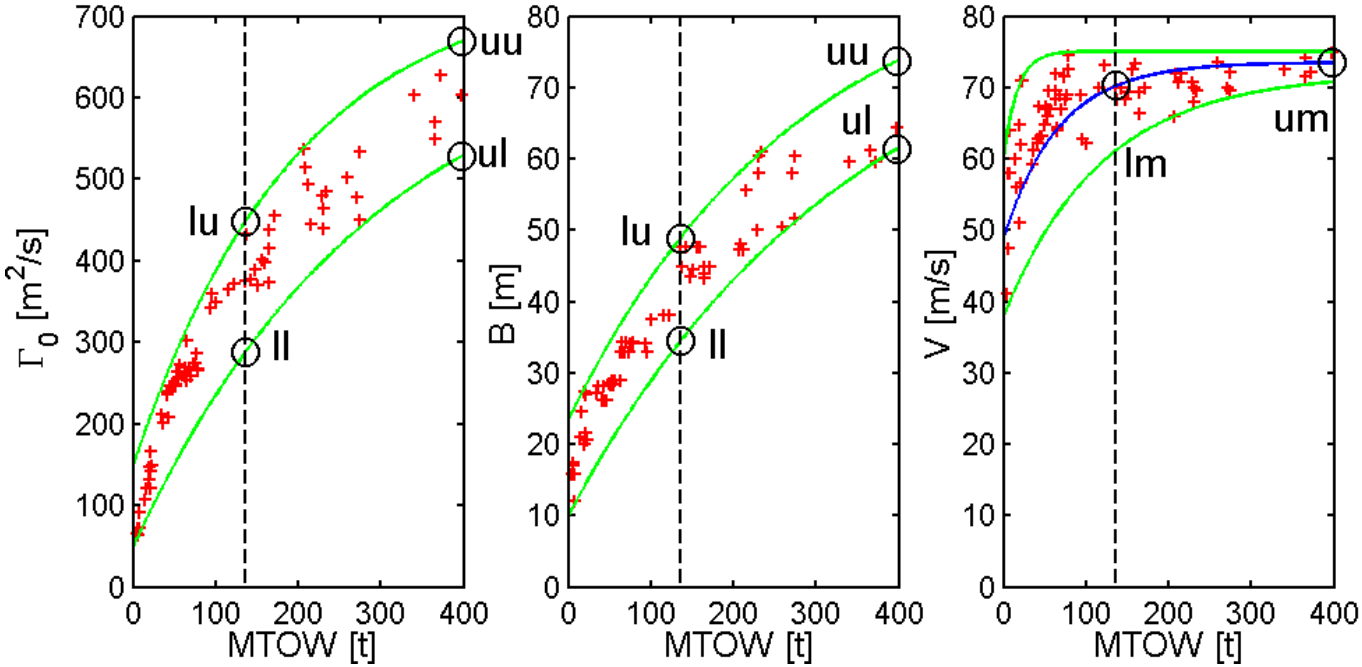
Representation of individual a/c types – dynamic pairwise

- a/c pairings according to flight plan in 5 min increments:

- HEAVY (15):
  A306, A310, A332, A333, A343, A346, B744, B762, B763, B764, B772, B773, B77W, IL96, MD11

- MEDIUM (34):
  A319, A320, A321, AT43, AT45, AT72, B462 , B463, B712, B733, B734, B735, B736, B737, B738 , B752, B753, CRJ1, CRJ2, CRJ7, CRJ9, D328, DH8D, E145, E170, E190, F100, F70, MD82, MD83, RJ1H, RJ85, SB20, SF34

- Γ_{min}: m = OEW + 1 h fuel + 0,1 PAX 100 kg; V = 200 kts at FAF
- Γ_{max}: m = MLW; V = 70 m/s (landing speed)



Representation of heavy leader a/c for weight class combinations

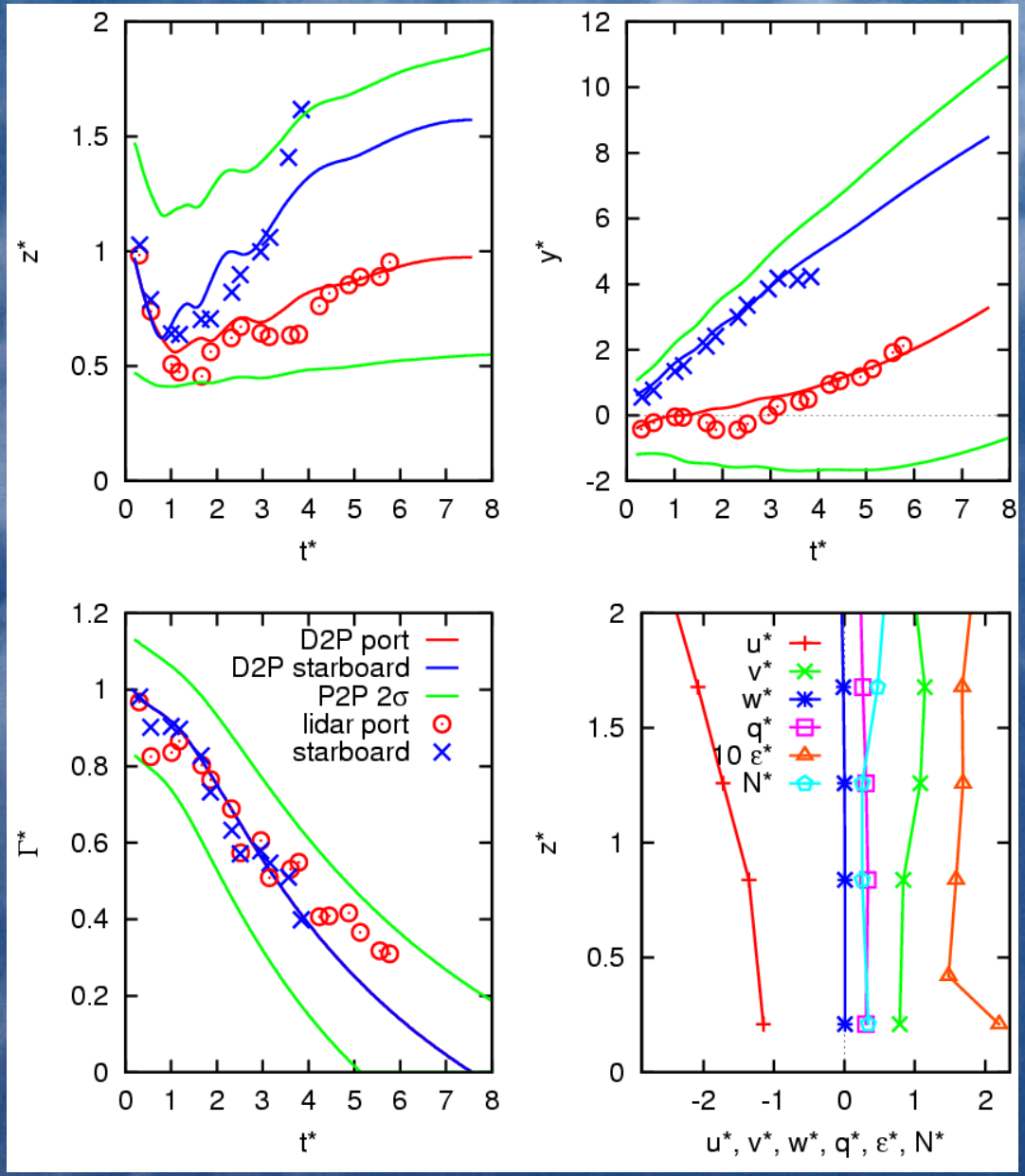
	Γ_0 [m²/s]	b_0 [m]	V [m/s]	characteristic time scales t_0	descent speed w_0
$\Gamma_{0uu}\, b_{0uu}$	669.2	57.9	73.5	31.5 s	1.84 m/s
$\Gamma_{0uu}\, b_{0ul}$	669.2	48.2	73.5	21.8 s	2.21 m/s
$\Gamma_{0ul}\, b_{0uu}$	528.5	57.9	73.5	**39.9 s** (max)	1.45 m/s
$\Gamma_{0ul}\, b_{0ul}$	528.5	48.2	73.5	27.6 s	1.75 m/s
$\Gamma_{0lu}\, b_{0lu}$	448.1	38.4	70.3	20.7 s	1.86 m/s
$\Gamma_{0lu}\, b_{0ll}$	448.1	27.1	70.3	**10.3 s** (min)	**2.63 m/s** (max)
$\Gamma_{0ll}\, b_{0lu}$	288.2	38.4	70.3	32.1 s	**1.19 m/s** (min)[1]
$\Gamma_{0ll}\, b_{0ll}$	288.1	27.1	70.3	16.0 s	1.69 m/s

8 a/c-parameter combinations

Probabilistic Two-Phase Wake-Vortex Transport and Decay model

- P2P accounts for effects of a/c configuration, wind, wind shear, turbulence, stable stratification, and ground proximity
- provides envelopes for y, z, Γ with defined probabilities (based on calibration of model with measurement data)
- validated against data of over 10,000 cases gathered in 2 US and 6 EU measurement campaigns

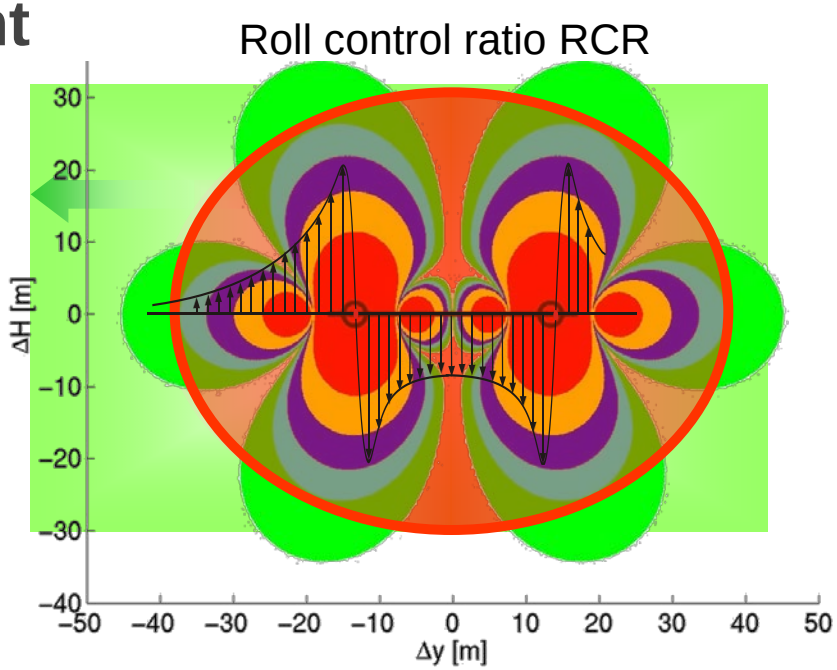
envelopes are wider for predicted meteo than for measured meteo input



Wake encounter severity assessment

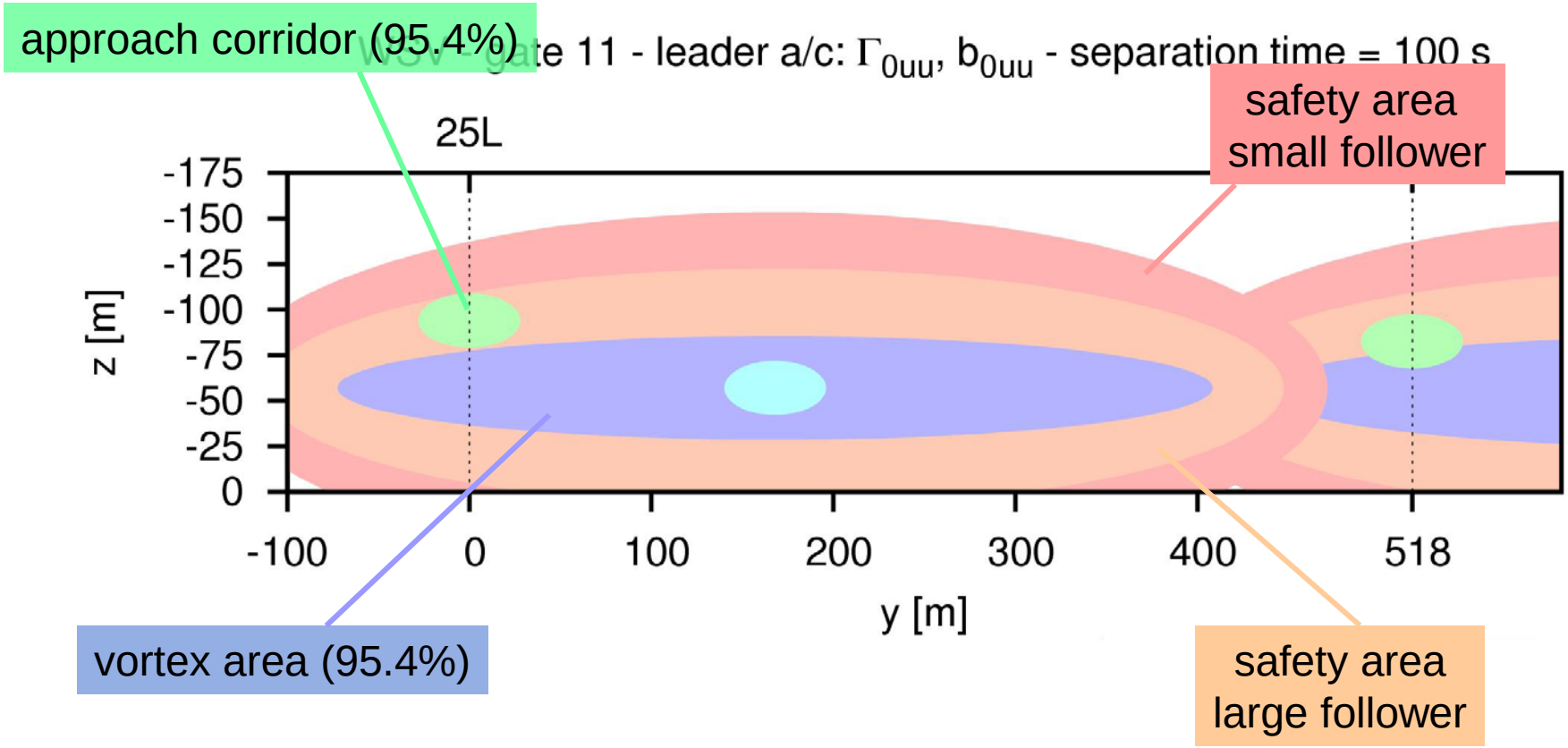
Simplified Hazard Area (SHA)/

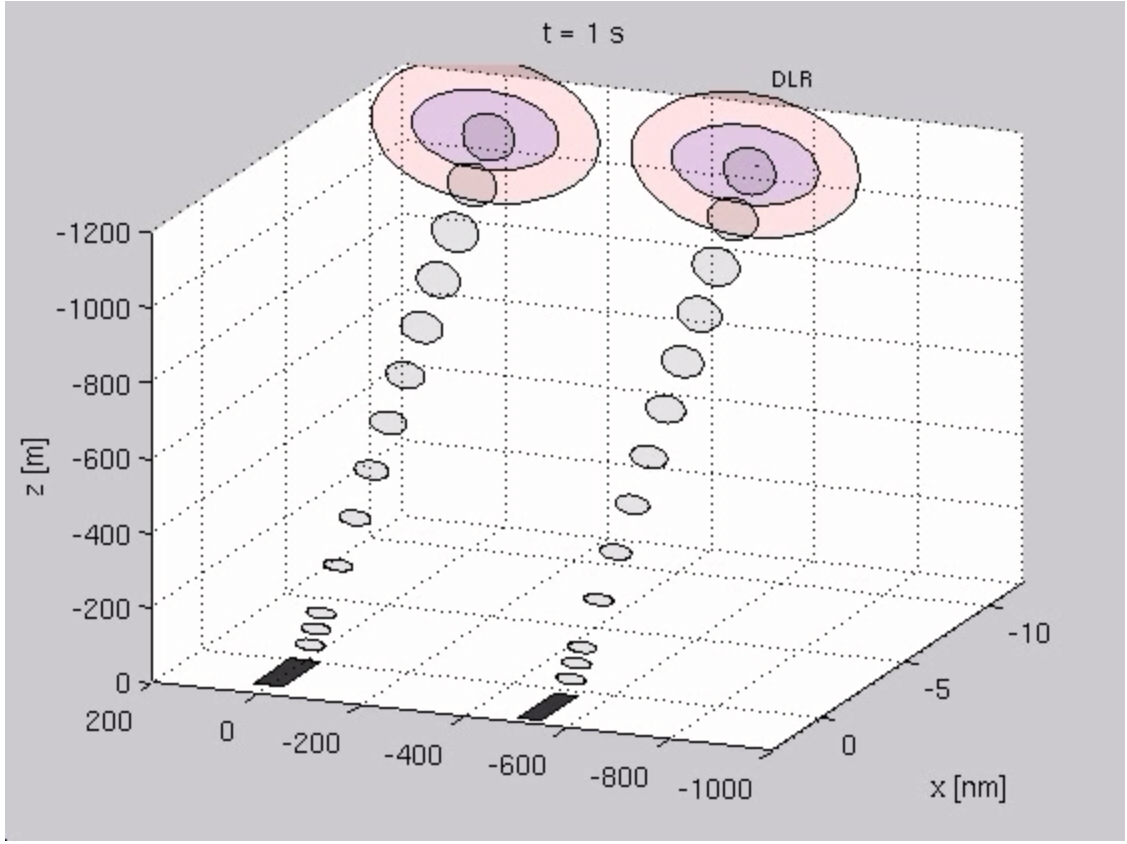
Simplified Hazard Area Prediction (SHAPe)



- „How close can an aircraft fly safely to a wake vortex?“
- DLR concept: Simplified Hazard Area (SHA)
  - conservative/ non-hazard approach, safe and undisturbed operations possible outside the hazard area, no go-arounds
  - simple, robust severity criterion
  - roll control ratio: one parameter to cover complete A/C reaction
  - validated with pilot-in-the loop simulator & flight tests
  - dec
  - nd se
- Simpl Pr) b

WSV Strategy





WSV Strategy Animated

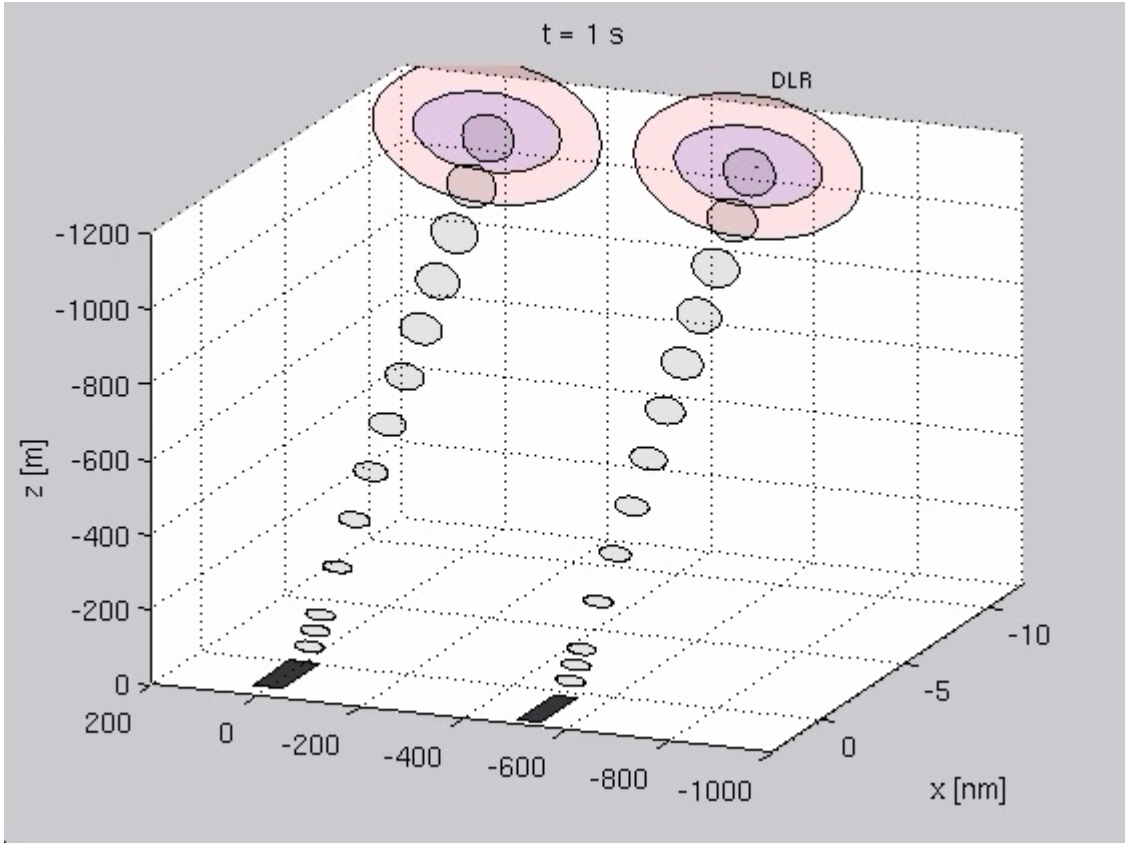
veering light winds

(animation)

- 2004/09/01 08:10
- generator 2 shown
- heavy-medium

25L25L	100	125
25L25R	0	0
25R25L	0	0
25R25R	100	125

staggered approach



WSV Strategy Animated

strong crosswind

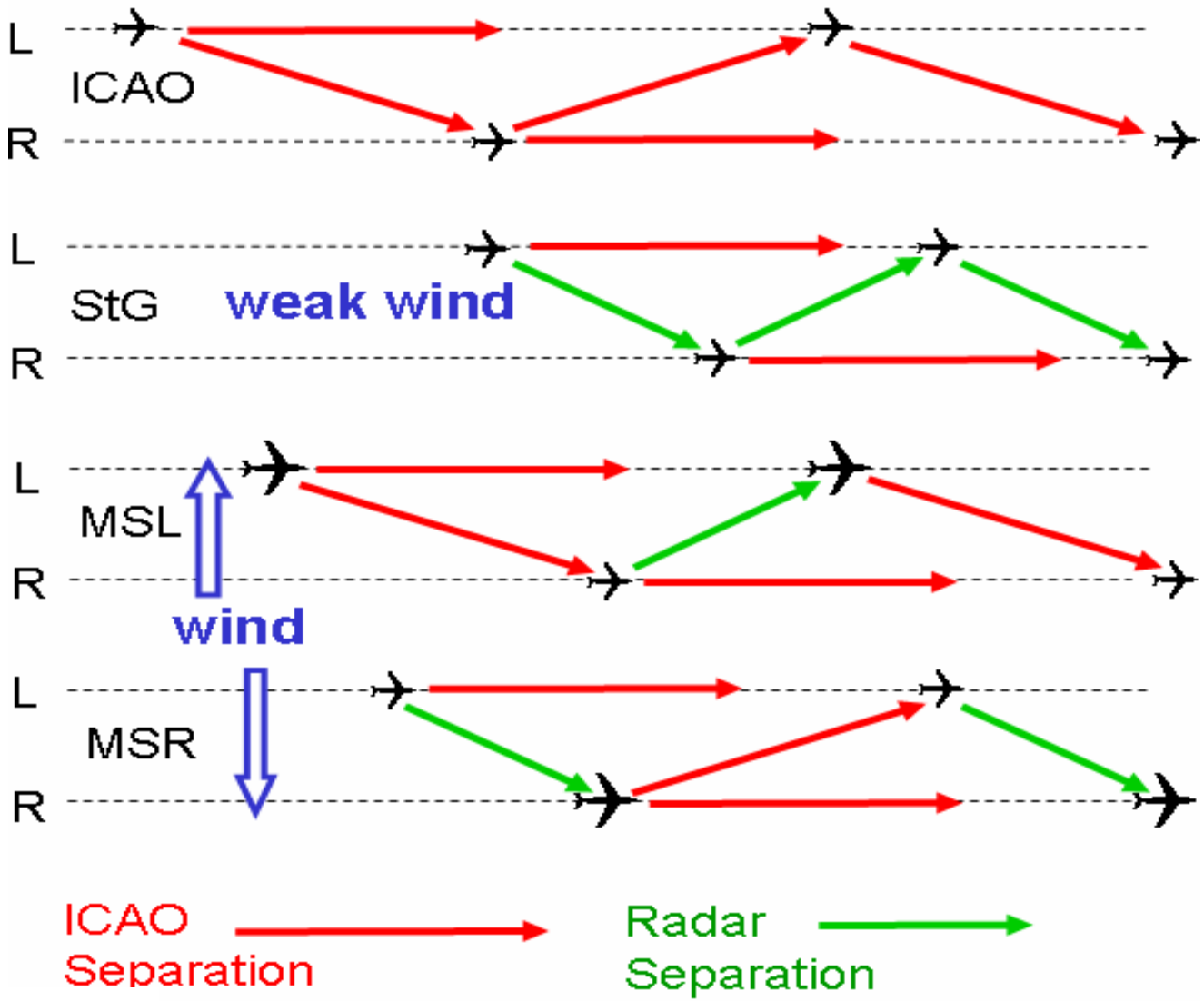
(animation)

- 2004/09/10 19:10
- generator 2 shown which determines sep.
- heavy-medium

25L25L	68	75
25L25R	0	0
25R25L	100	125
25R25R	68	75

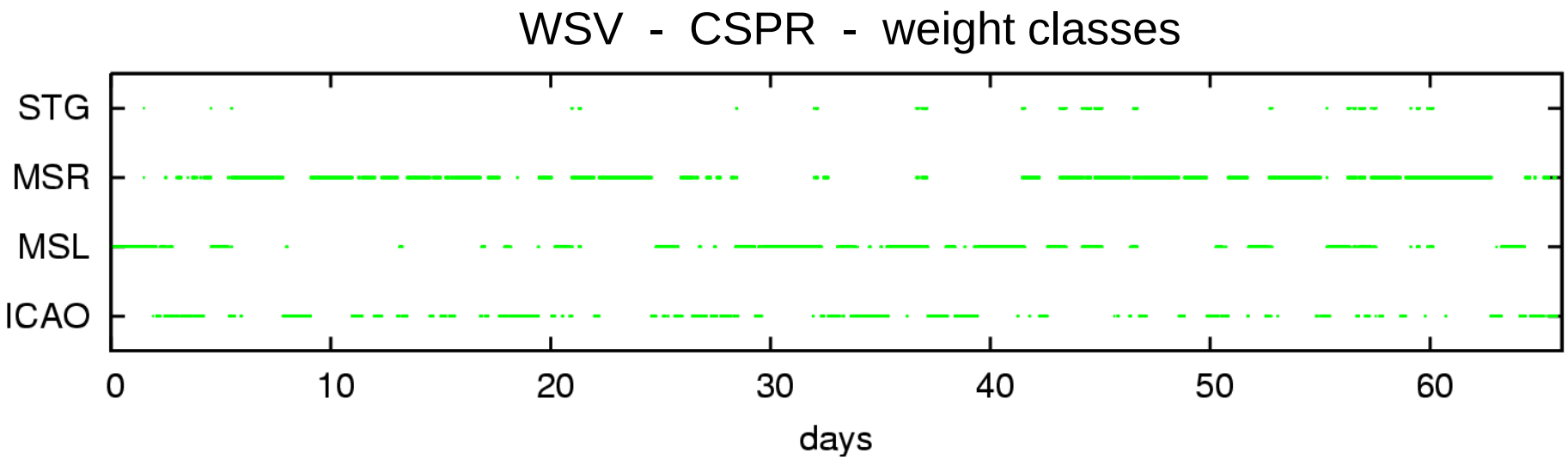
- modified staggered left
- reduced sep. single rwy

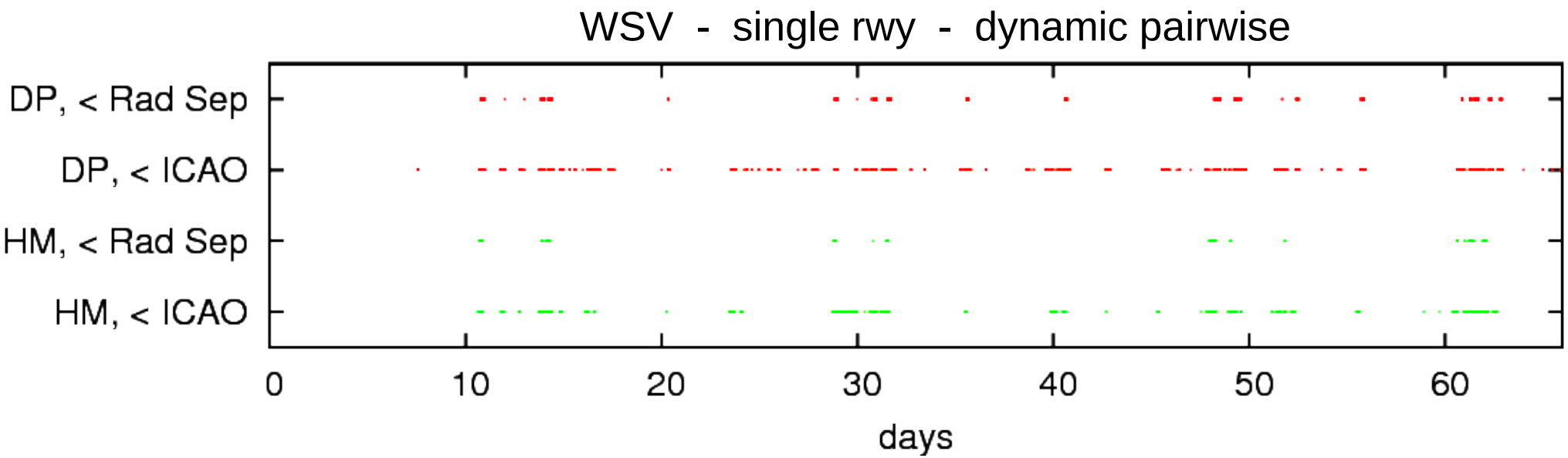
Frankfurt Airport: DFS' Concepts of Operation for CSPR



Potential capacity gain

Frankfurt airport (06/12/20 - 07/02/28)





Potential capacity gain offered by WSVBS

Frankfurt airport

synthetic meteo data
full year 2004

	PROC	MST	PoU
CSPR	MSL	0 s	39%
CSPR	MSR	0 s	43%
CSPR	STG	0 s	6.1%
CSPR	ICAO		24%
SGL RWY:	HM	58 s	2.8%

WSV 06/07
66 days

PROC	MST	PoU
MSL	0 s	31%
MSR	0 s	48%
STG	0 s	3.6%
ICAO		25%
HM	62 s	1.5%
DP	58 s	2.8%

Conclusions I

- The Wake Vortex Prediction and Monitoring System, WSVBS, exists

  components: **SODAR/RASS/USA/COSMO-Airport/FLIP/P2P/SHAPe/AMAN/LIDAR**
- has demonstrated functionality at Frankfurt (12/06 - 02/07) & Munich (6/10 - 9/10) airports
- prediction horizon > 45 min (as required), update every 10 minutes
- predicts the established procedures (WSWS of DFS) for CSPR
- further predicts temporal separations & dynamic pairwise separations also for single rwys
- the LIDAR monitors the crucial altitudes

Frankfurt airport

- potential use of new ConOps (DFS) in 75% of the time
- median durations of procedures amount from 30 min for STG to 90 min for MSR
- potential capacity gain 3 - 4 % (DFS' ConOps only)
- dynamic pairwise (2.8%) almost doubles usage compared to weight class comb. (1.5%)
- the predictions were safe: no warnings from the LIDAR (≈1100 heavy a/c)

Conclusions II

Munich airport (sensitivity analysis dynamic pairwise see AIAA Paper 2011-3037)

- higher sensitivity on heavy leader a/c types than on medium follower a/c types
- WV predictions based on minimum circulation block gates slightly more frequently
- impact of flight corridor dimensions relatively large - improvements of navigational performance may help
- potential capacity gains of dynamic pairwise operations for single runways very small
- WSVBS features very conservative design
- even for perfect weather & WV predictions WV frequently remain in flight corridor
- WSVBS may be further developed as pure warning system