Wake-Vortex Prediction and Monitoring System

Design and Performance at Frankfurt Airport

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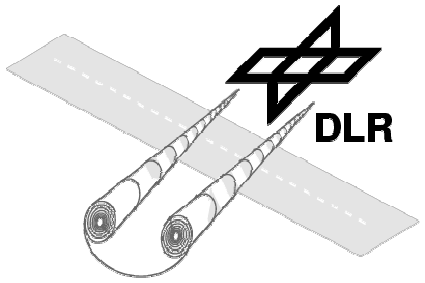
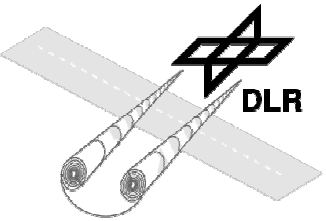



DLR-Projekt Wirbelschleppe
(1999 – 2006)
AWIATOR, ATC-Wake, Credos,
C-Wake, FAR-Wake, FLYSAFE,
S-Wake, WakeNet,
WakeNet2-Europe, Wavenc
DLR



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

numerical weather prediction
NOWVIV
10 gates, 2 - 11 NM

wake-vortex prediction
P2P
envelopes for y(t), z(t), Γ(t) in 13 gates
for 8 a/c parameter classes (heavy)

glide path adherence statistics
FLIP
standard deviations in 13 gates

safety area prediction
SHAPe
ellipses in 13 gates for HH, HM

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

temporal a/c separations
for 6 a/c-class combinations

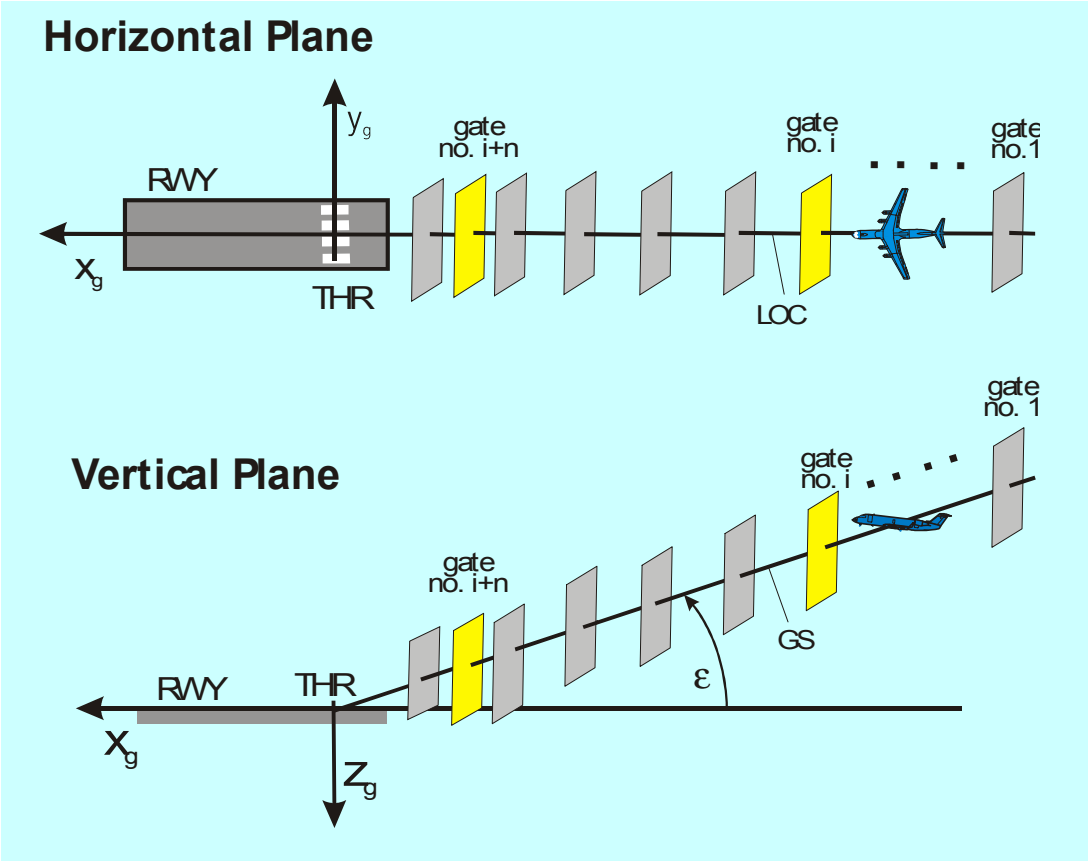
conflict detection
issue warning / adapt predictions

procedures
AMAN
STG, MSR, MSL, ICAO

WSVBS

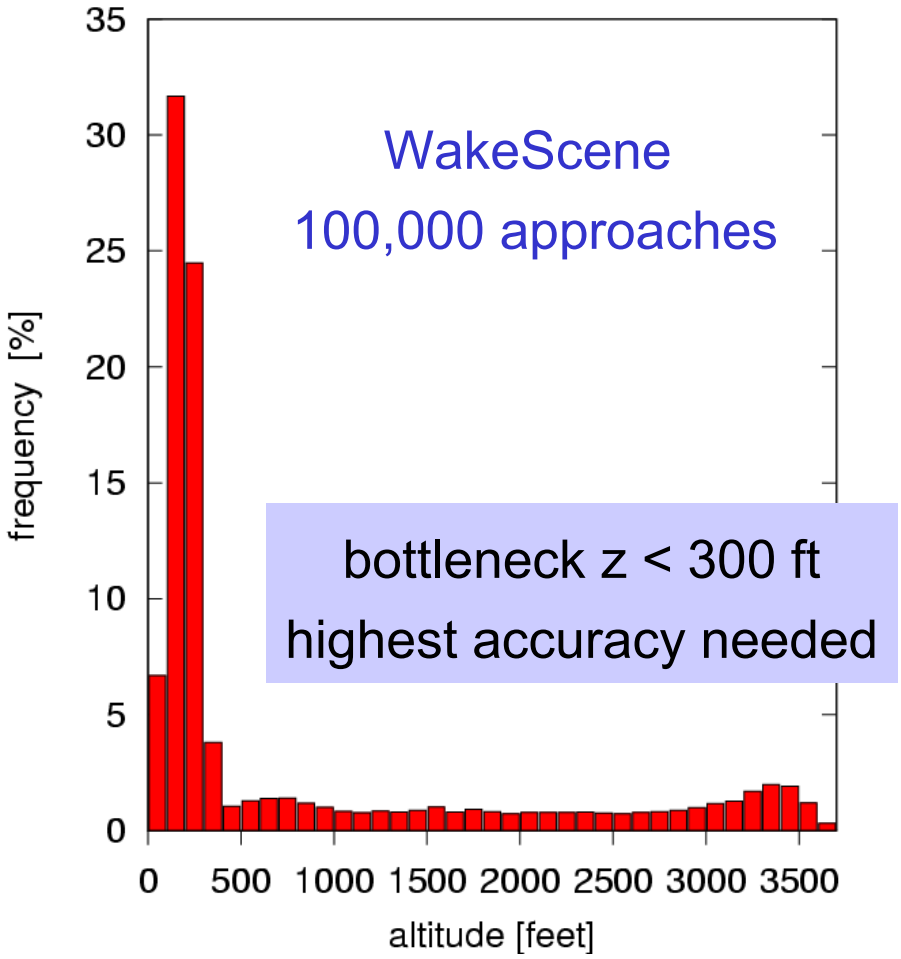
WSV Topology

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



gate No	x_{gate} [m]	z_{gate} [m]
1	-20372	-1077
2	-18520	-979
3	-16668	-880
4	-14816	-781
5	-12964	-683
6	-11112	-584
7	-9260	-486
8	-7408	-387
9	-5556	-289
10	-3704	-191
11	-1852	-94
12	-1235	-61
13	-617	-29

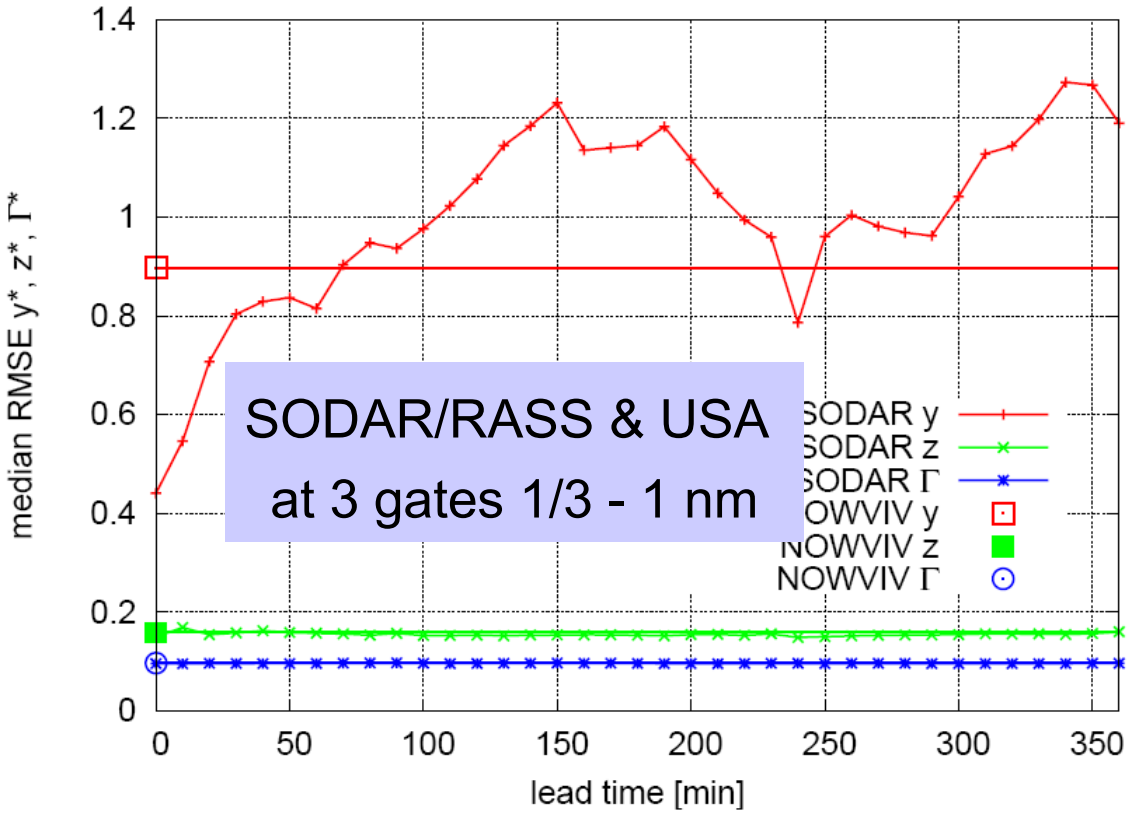
meteo data input – strategy



WakeScene
100,000 approaches

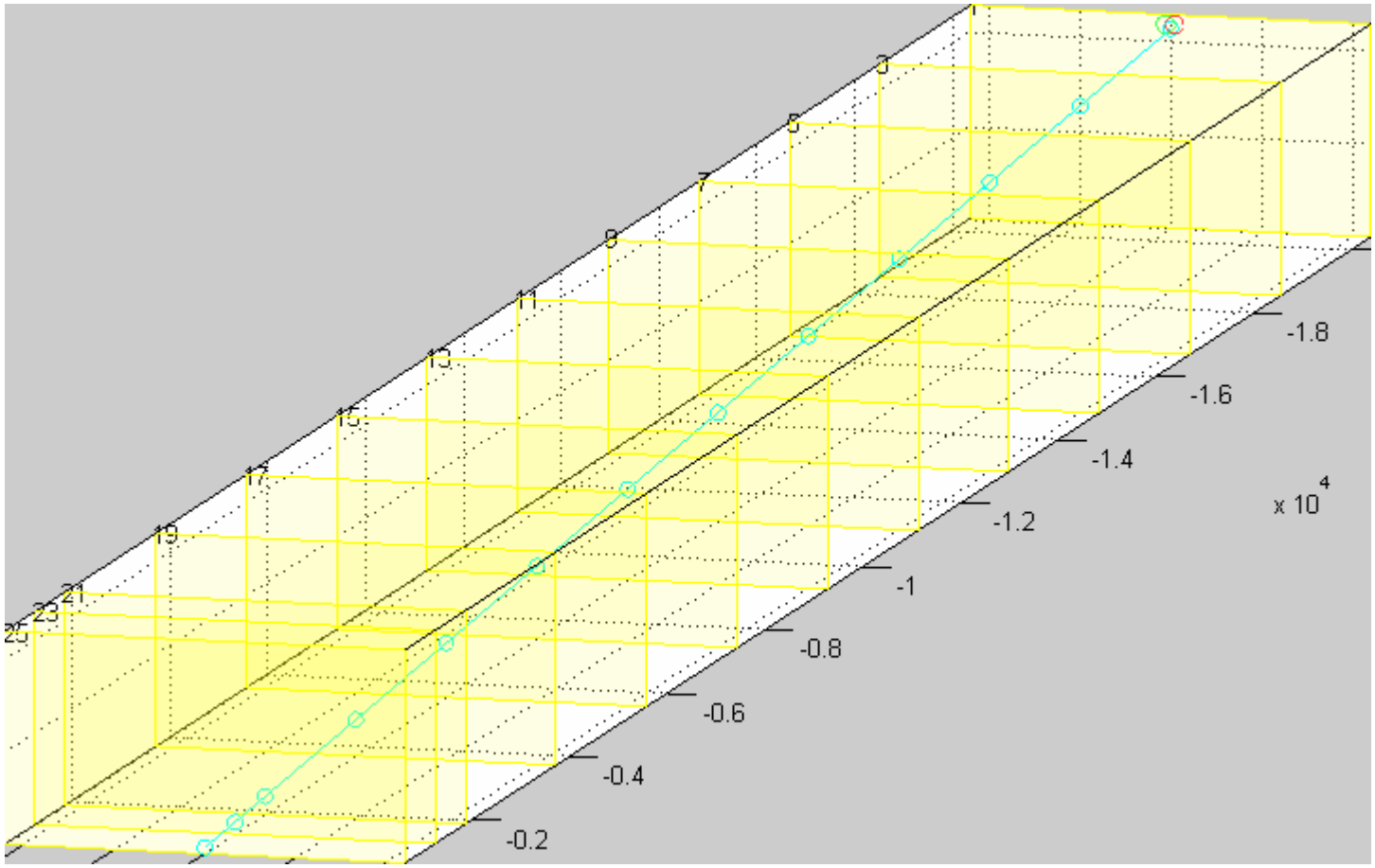
bottleneck z < 300 ft
highest accuracy needed

wake-vortex prediction skill IGE



SODAR/RASS & USA
at 3 gates 1/3 - 1 nm

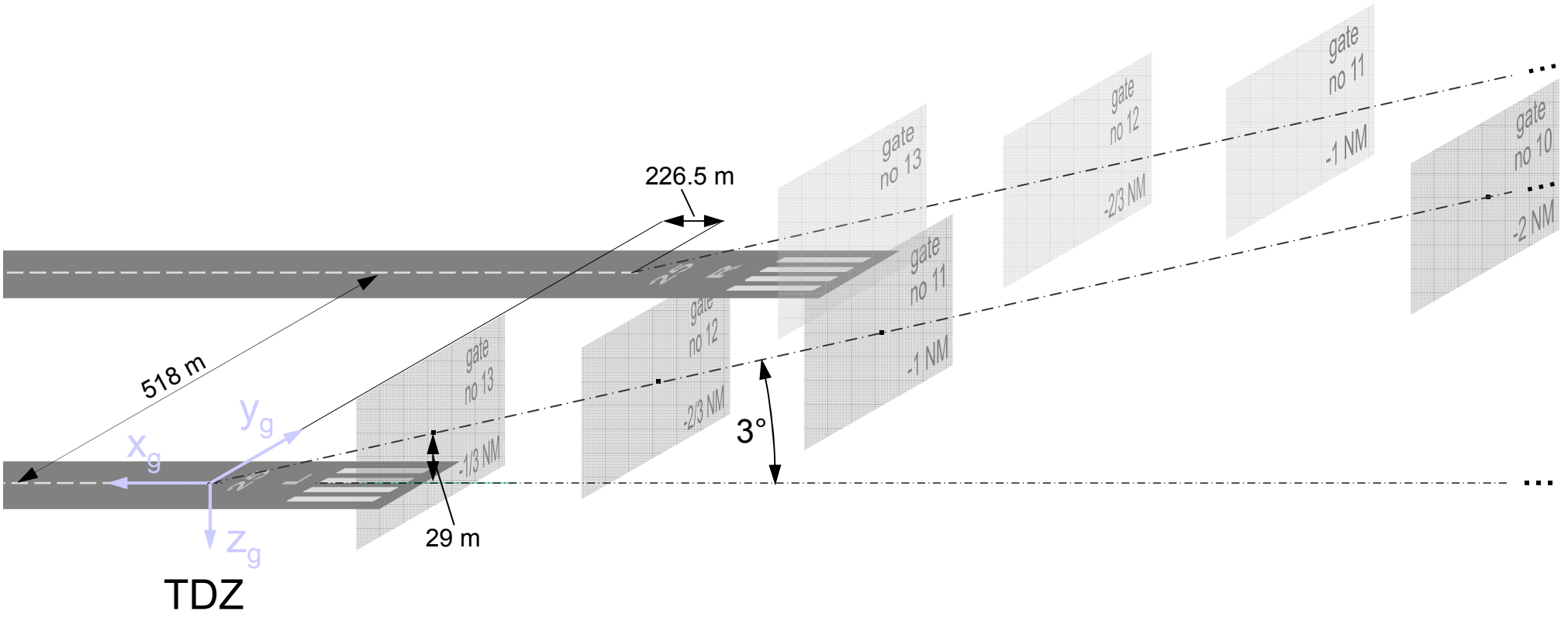
approach scenario – WakeScene

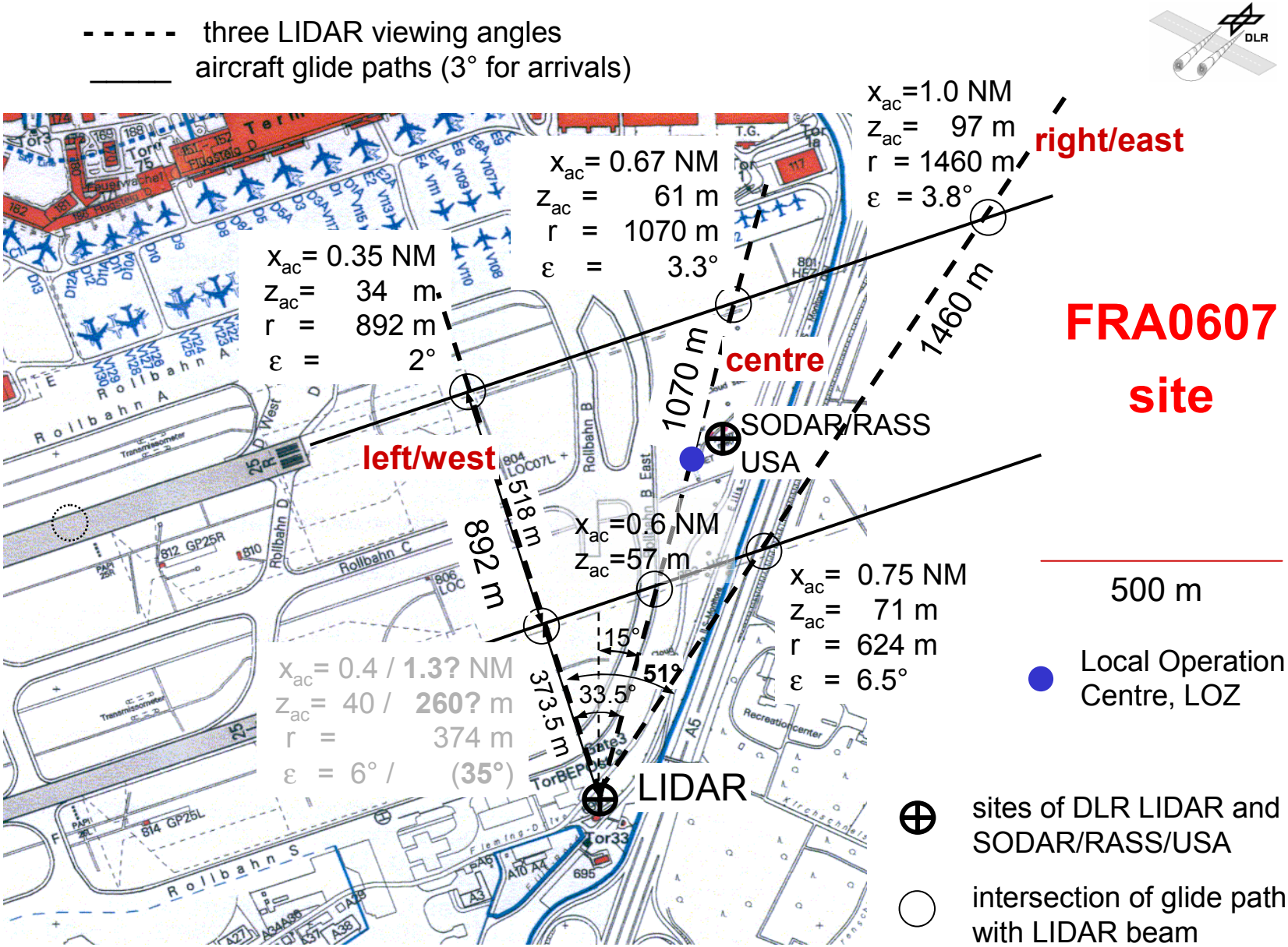


Holzäpfel et al., ICAS 2006

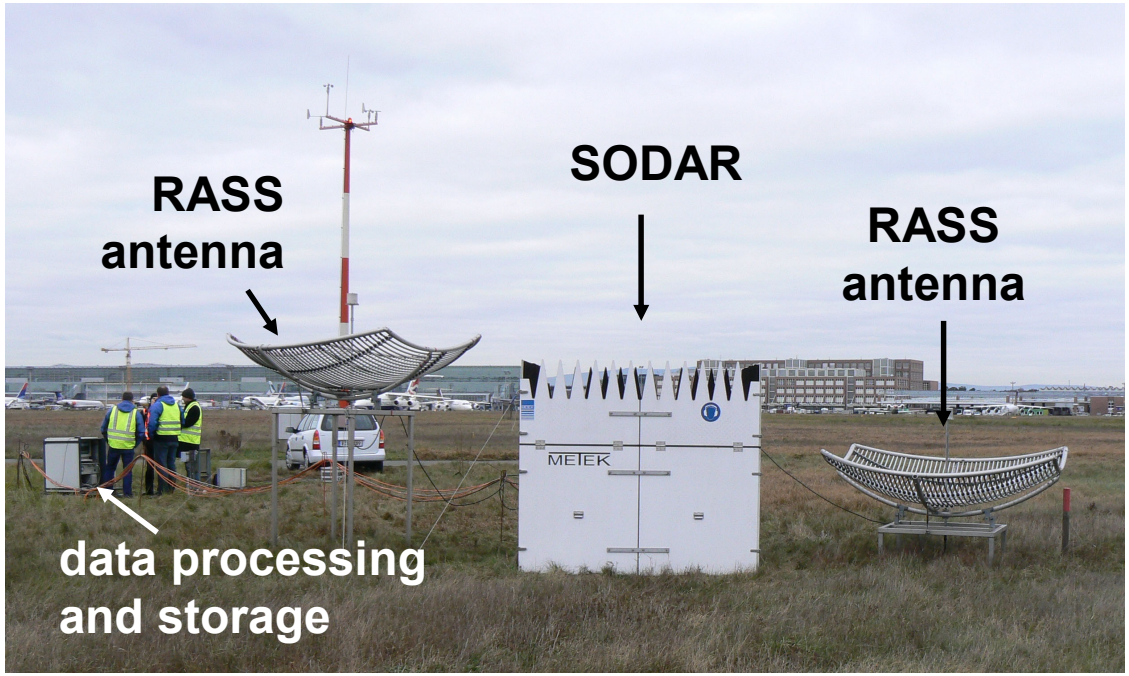
WSV Topology – Perspective View

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

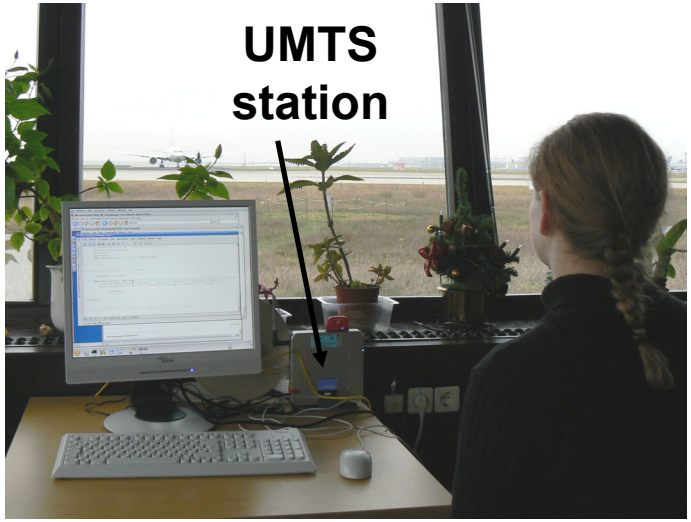



- - - - - three LIDAR viewing angles
_____ aircraft glide paths (3° for arrivals)
x_{ac}=1.0 NM
z_{ac}= 97 m
r = 1460 m
ε = 3.8°
right/east
x_{ac}= 0.67 NM
z_{ac} = 61 m
r = 1070 m
ε = 3.3°
x_{ac}= 0.35 NM
z_{ac}= 34 m
r = 892 m
ε = 2°
1460 m
1070 m
centre
SODAR/RASS
USA
left/west
518 m
892 m
x_{ac}=0.6 NM
z_{ac}=57 m
x_{ac}= 0.75 NM
z_{ac}= 71 m
r = 624 m
ε = 6.5°
15°
519
33.5°
373.5 m
x_{ac}= 0.4 / 1.3? NM
z_{ac}= 40 / 260? m
r = 374 m
ε = 6° / (35°)
LIDAR
FRA0607
site
500 m
Local Operation Centre, LOZ
sites of DLR LIDAR and SODAR/RASS/USA
intersection of glide path with LIDAR beam

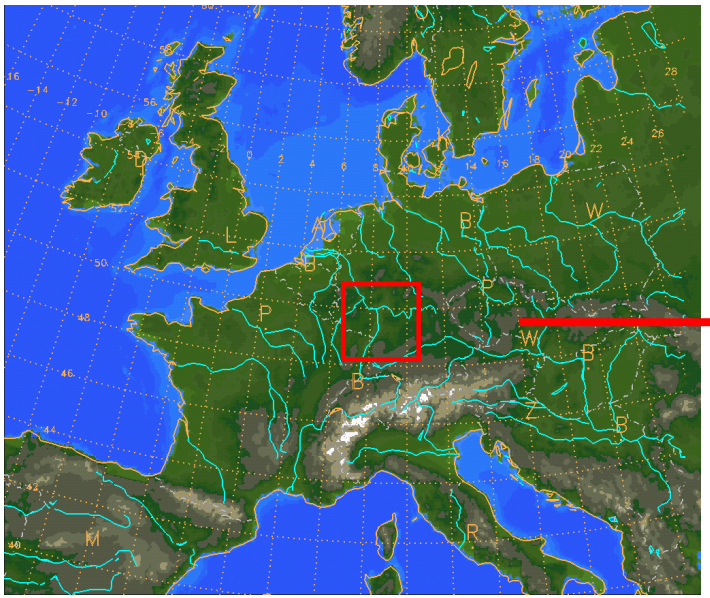
Instrumentation at Frankfurt airport:
SODAR/RASS/USA



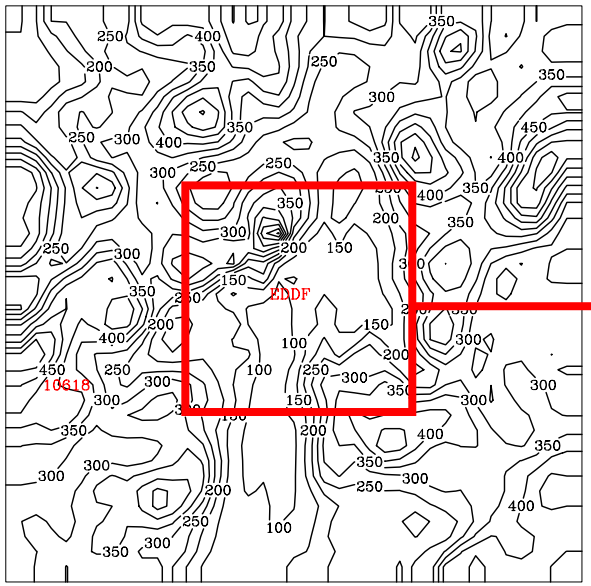
Lokales Operationszentrum LOZ in the German Weather Service's observer house.



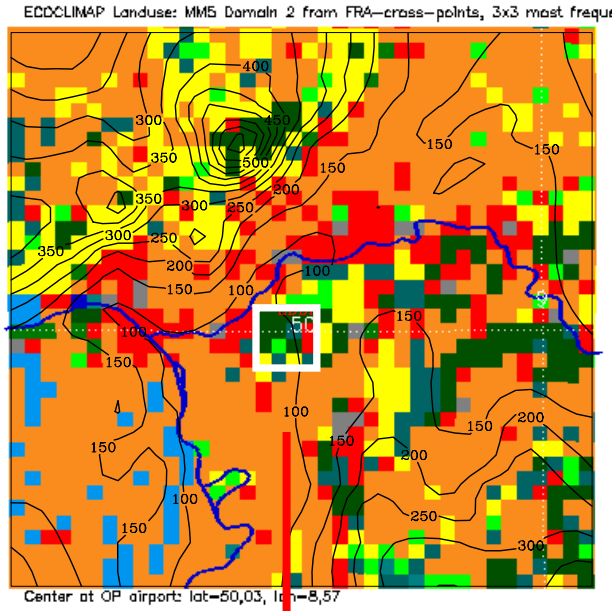
Forecasting for airports: model chain with nesting – NOWVIV



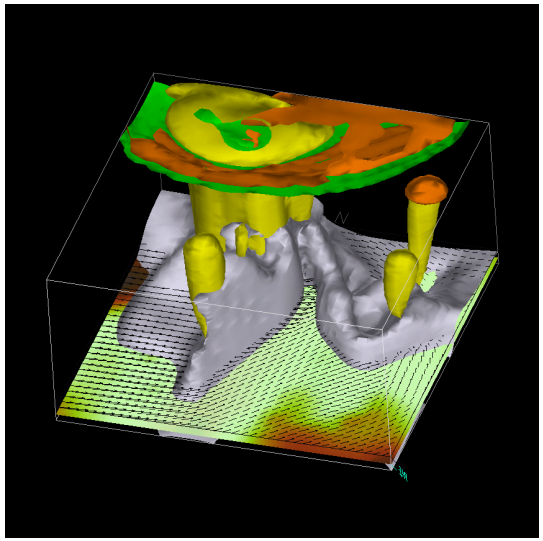
LM forecasting domain



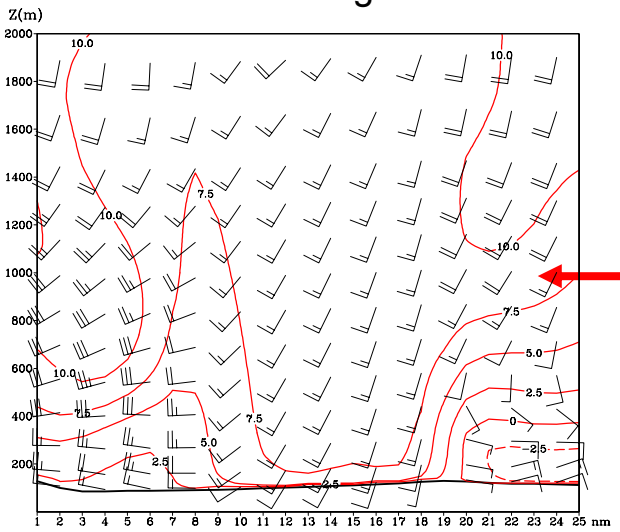
MM5 forecasting domain 1



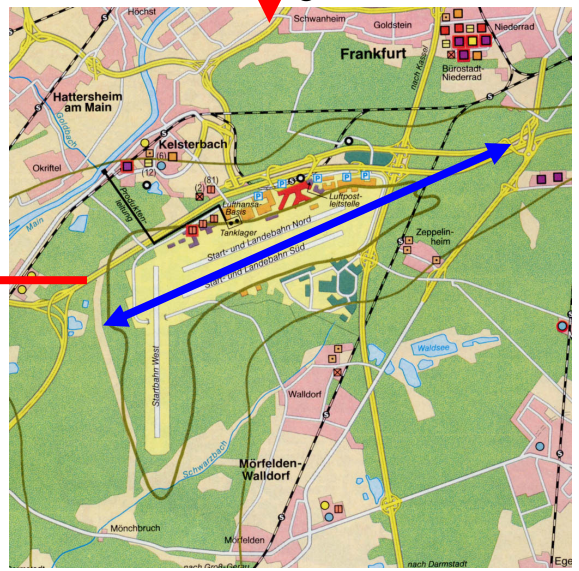
MM5 forecasting domain 2



3D view of storm crossing airport



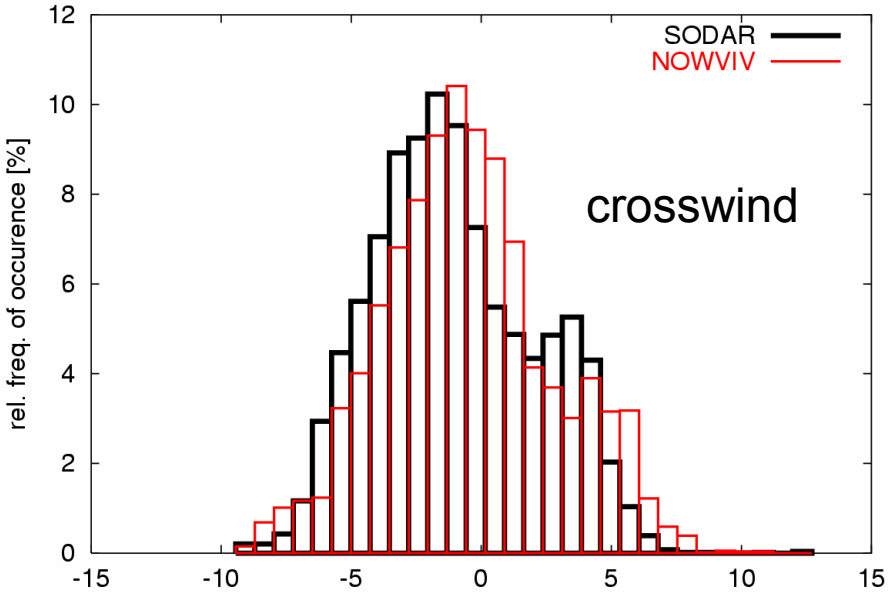
Cross section along glideslope

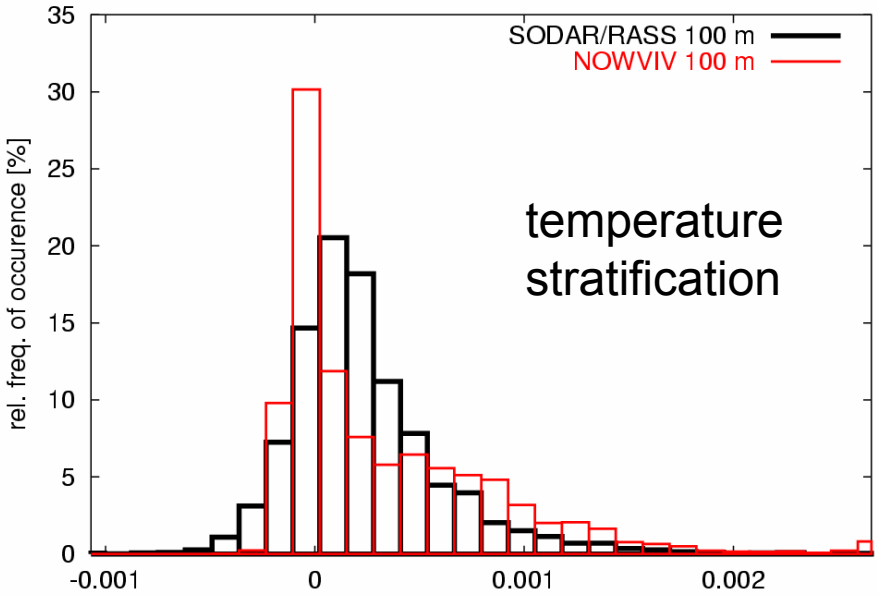


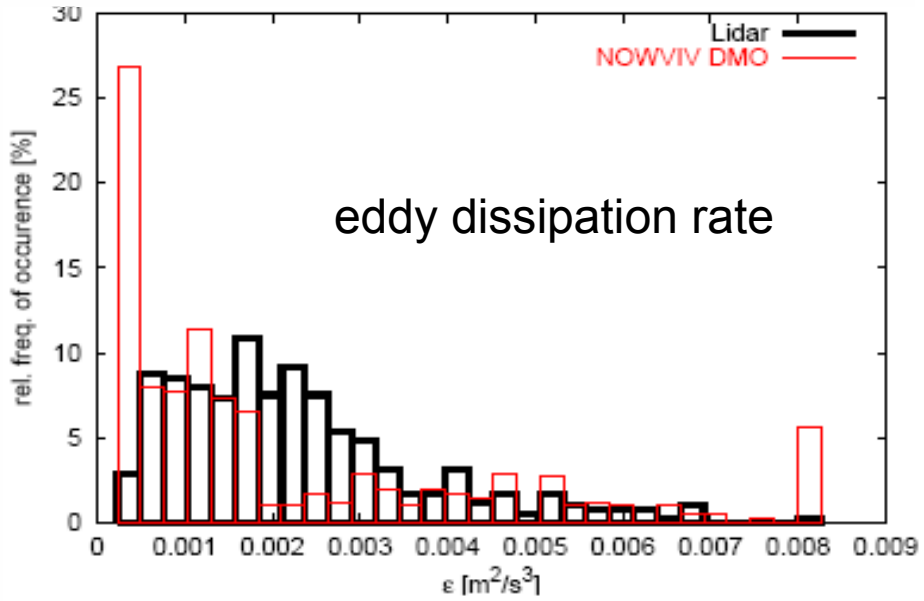
Airport area

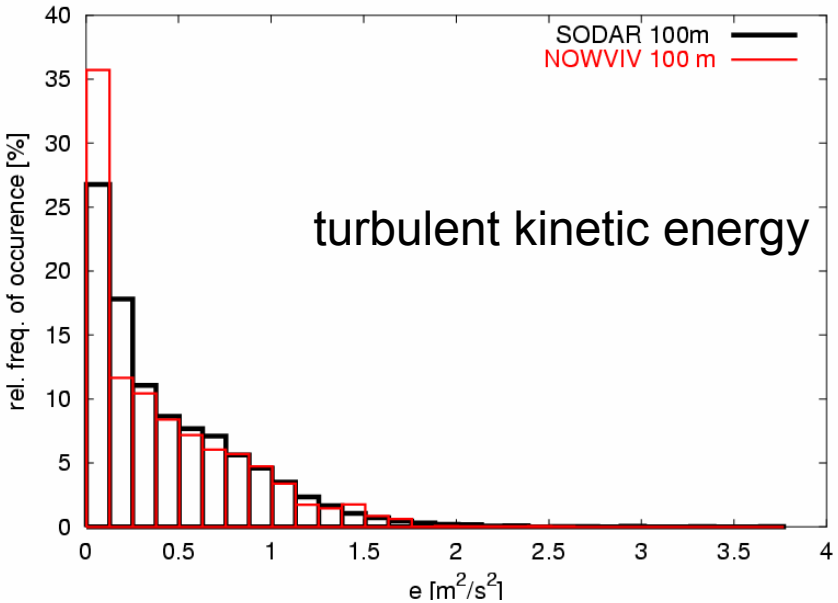
Meteorological Data Base – Validation

(26.8.04 - 5.10.04, NOWVIV - SODAR/RASS, z = 100 m)

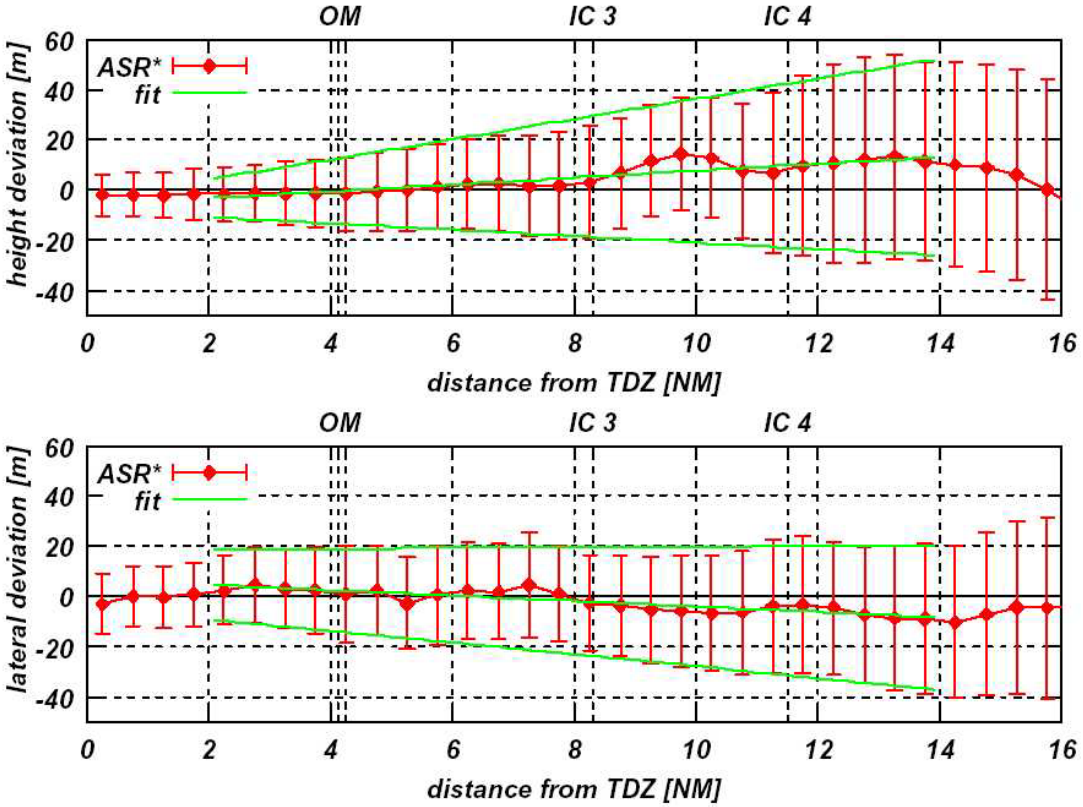








Approach Corridor Dimensions – FLIP



(35,691 a/c-approaches)

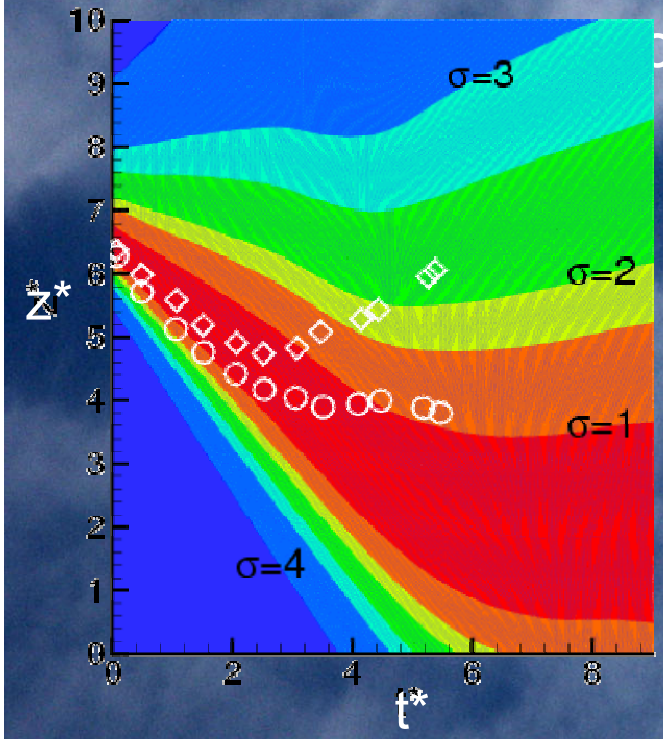
Frauenkron, H., Maiss, M., Nalpanis,P.: FLIP - Flight Performance using Frankfurt ILS, DFS German Air Navigation Services, 2001.

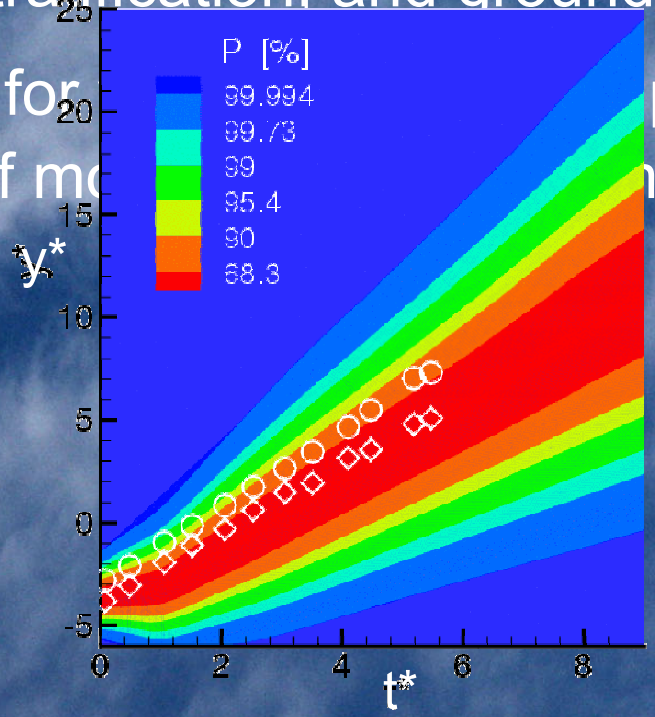
$$\sigma_{\Delta y_g} = 11.5\,\mathrm{m} - 6.634 \cdot 10^{-4} \cdot x_g$$

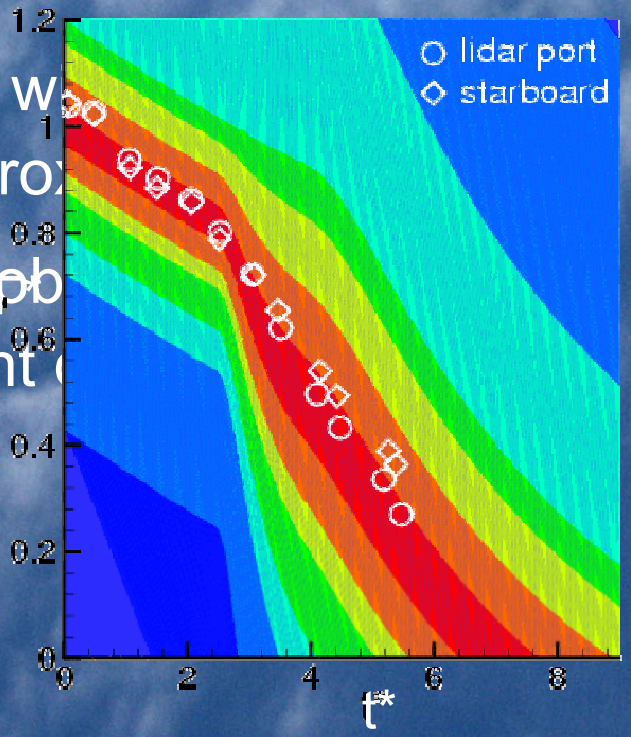
$$\sigma_{\Delta z_g} = 2.1\,\mathrm{m} - 1.430 \cdot 10^{-3} \cdot x_g$$

Probabilistic Two-Phase Wake-Vortex Transport and Decay model

- P2P accounts for effects of a/c configuration, w
  turbulence, stable stratification, and ground pro
- provides envelopes for prob
  of m ment



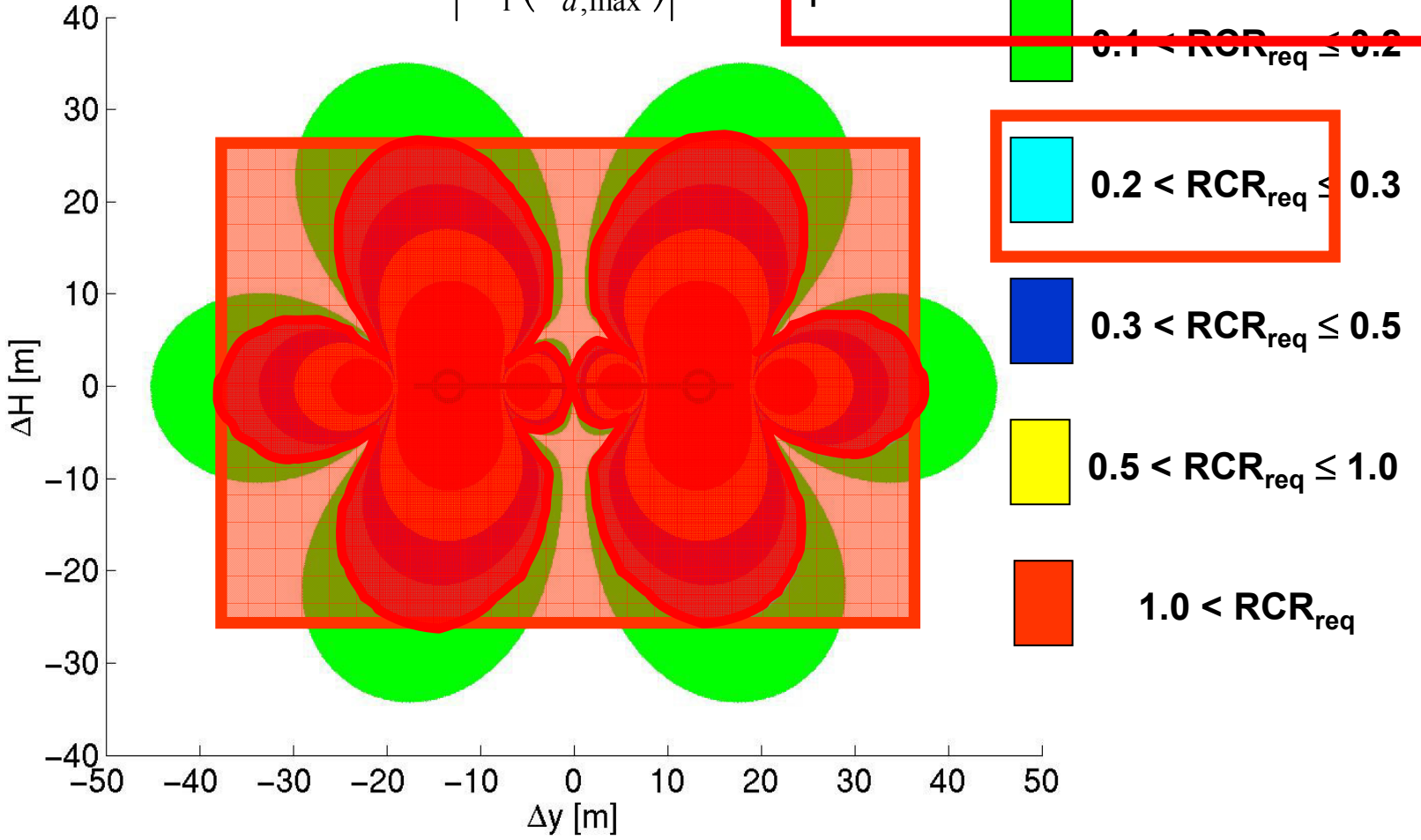




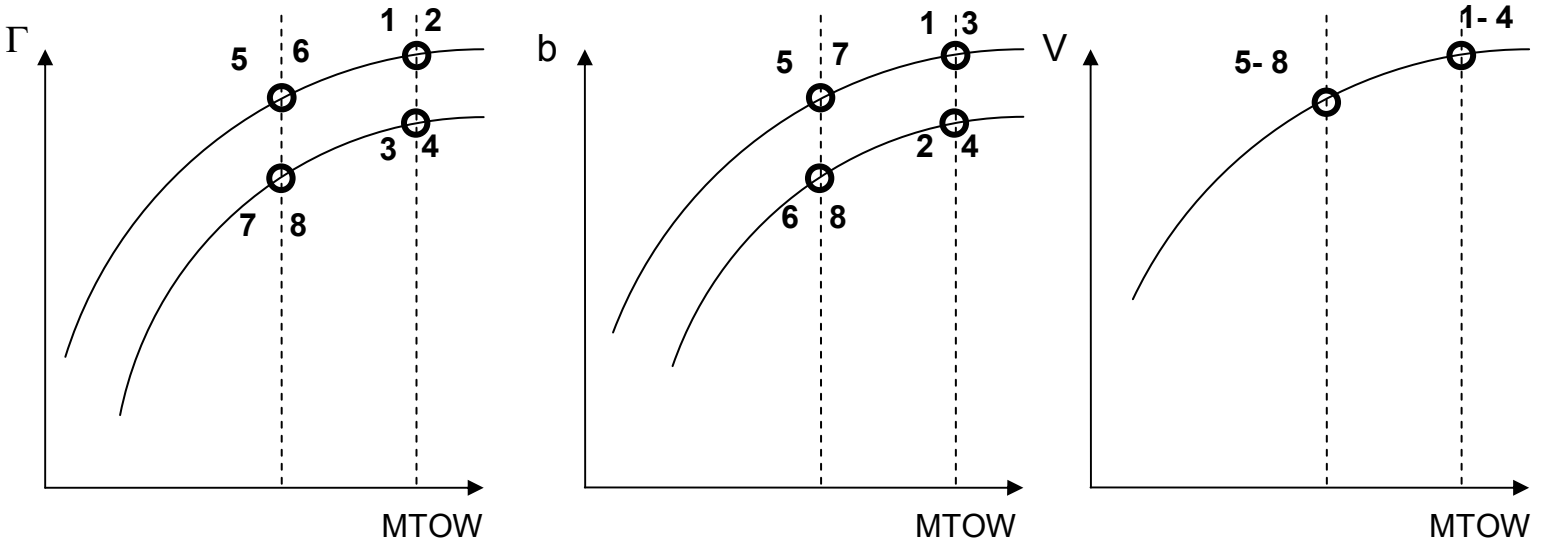
Simplified Hazard Area (SHA)

req. roll control ratio $$RCR_{req} = \left| \frac{C_{l,WV}}{C_l\left(\delta_{a,\max}\right)} \right|$$

approach:
$RCR_{req} < RCR_{nom}$ $RCR_{nom} = 0.2$
safe and undisturbed operations possible outside the hazard area



Representation of heavy-class leader a/c

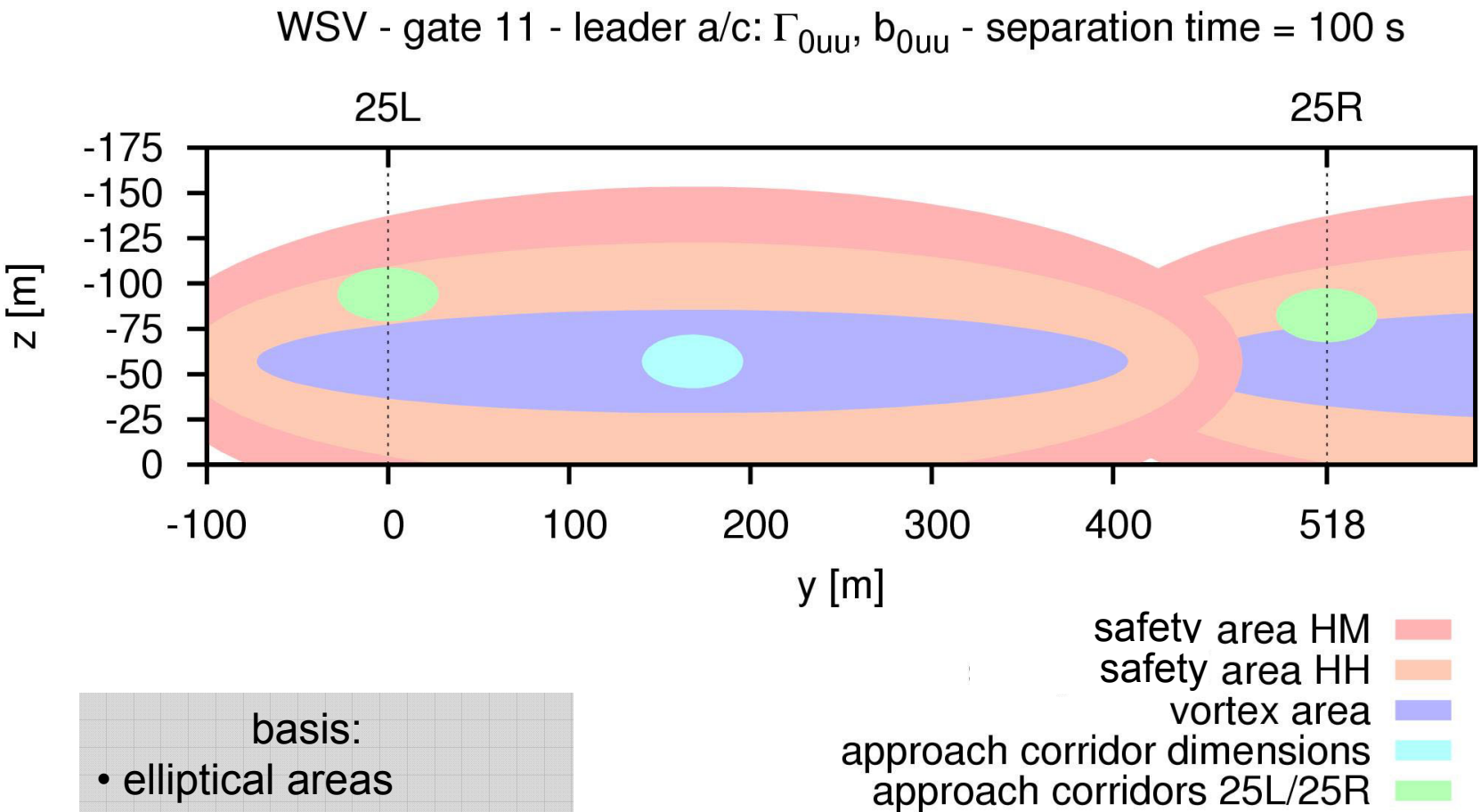


				contributes to envelope of	characteristic time scales t_0	descent speed w_0
1	Γ_{0uu}	b_{0uu}	V_{Lum}	Γ, y, z_u (IGE)	31.5 s	1.84 m/s
2	Γ_{0uu}	b_{0ul}	V_{Lum}	z_l	21.8 s	2.21 m/s
3	Γ_{0ul}	b_{0uu}	V_{Lum}	Γ, y, z_u	39.9 s (max)	1.45 m/s
4	Γ_{0ul}	b_{0ul}	V_{Lum}	-	27.6 s	1.75 m/s
5	Γ_{0lu}	b_{0lu}	V_{Llm}	-	20.7 s	1.86 m/s
6	Γ_{0lu}	b_{0ll}	V_{Llm}	-	10.3 s (min)	2.63 m/s (max)
7	Γ_{0ll}	b_{0lu}	V_{Llm}	z_u	32.1 s	1.19 m/s (min)
8	Γ_{0ll}	b_{0ll}	V_{Llm}	z_u	16.0 s	1.69 m/s

8 a/c-parameter combinations

[1]

WSV Strategy



basis:
- elliptical areas
- 2σ-probabilies (95.4%)

independent consideration of:

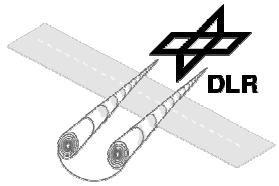
2·13 gates × 8 a/c-comb. × 3 rwy-comb. × 2 weight-class-comb. = 1248 cases

⇒ maximum separation times for 3 rwy-comb. × 2 weight-class- comb.

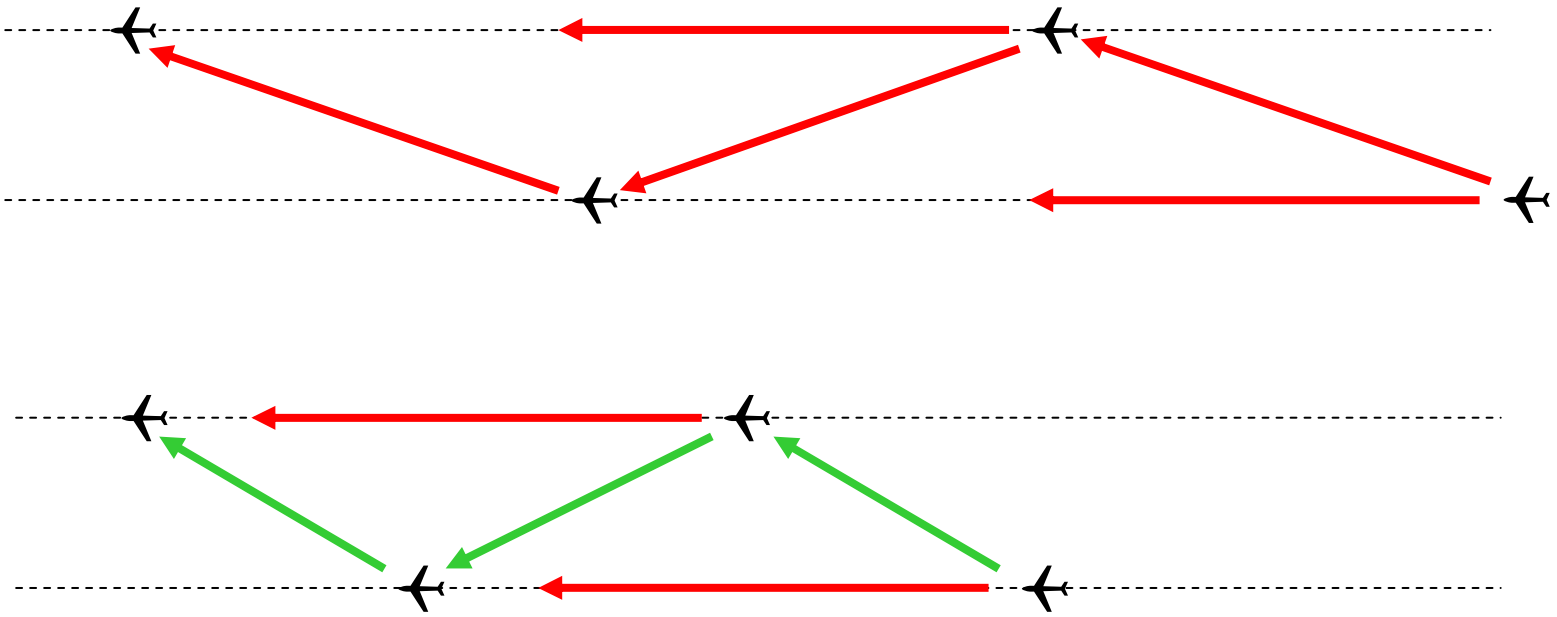
prediction sequence

```
11400  wsvbs_wvu  52
    0 25L25L 100 125
    0 25L25R 100 125
    0 25R25L   0 125
    0 25R25R 100 125
  600 25L25L 100 125
  600 25L25R 100 125
  600 25R25L   0 124
  600 25R25R 100 125
 1200 25L25L 100 125
 1200 25L25R 100 125
 1200 25R25L   0   0
 1200 25R25R 100 125
 ...
```

maximum a/c-separation
HH: 100 s
HM: 125 s
radar separation: 70 s



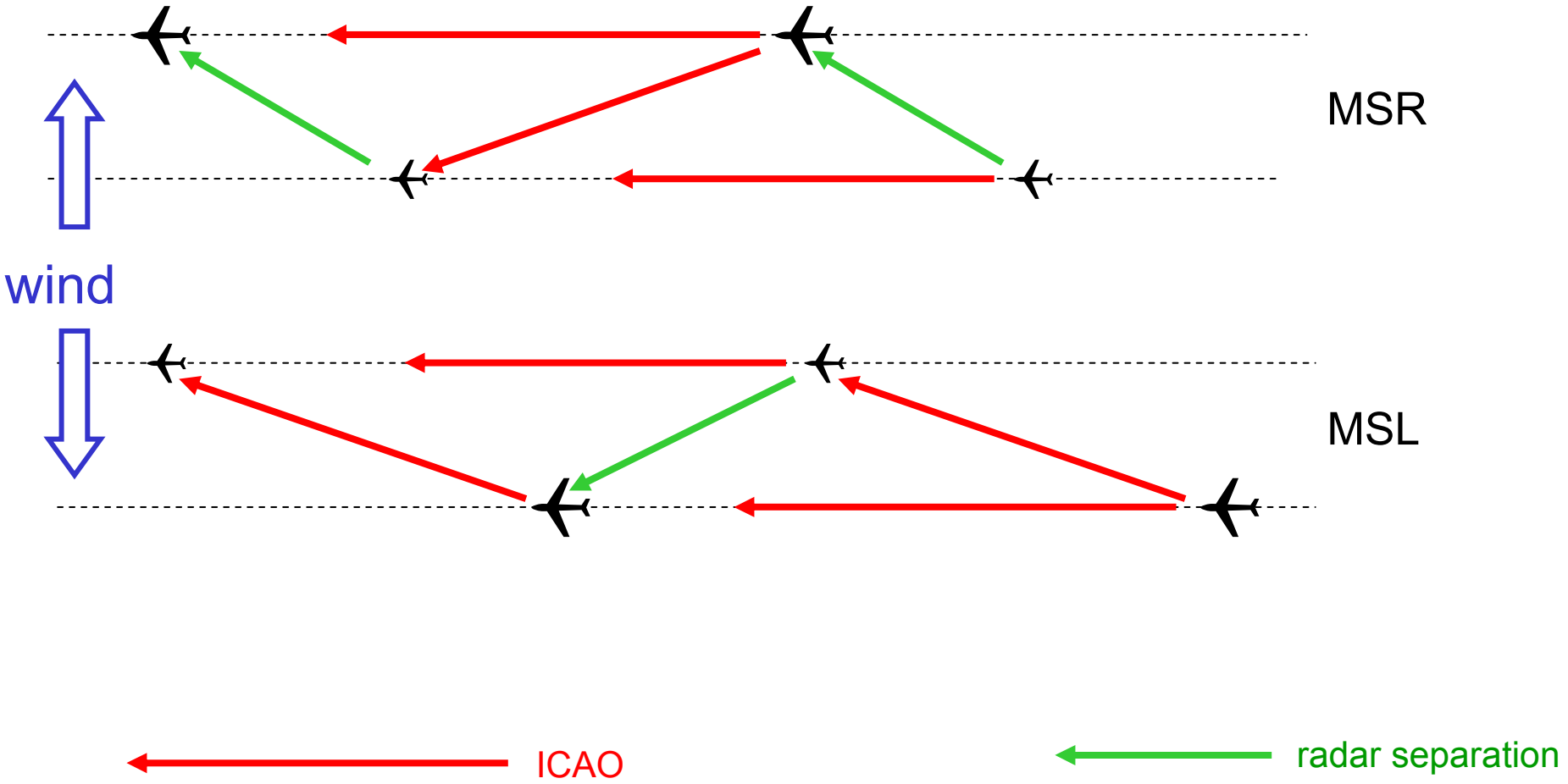
established procedures for closely spaced rwys (WVWS)

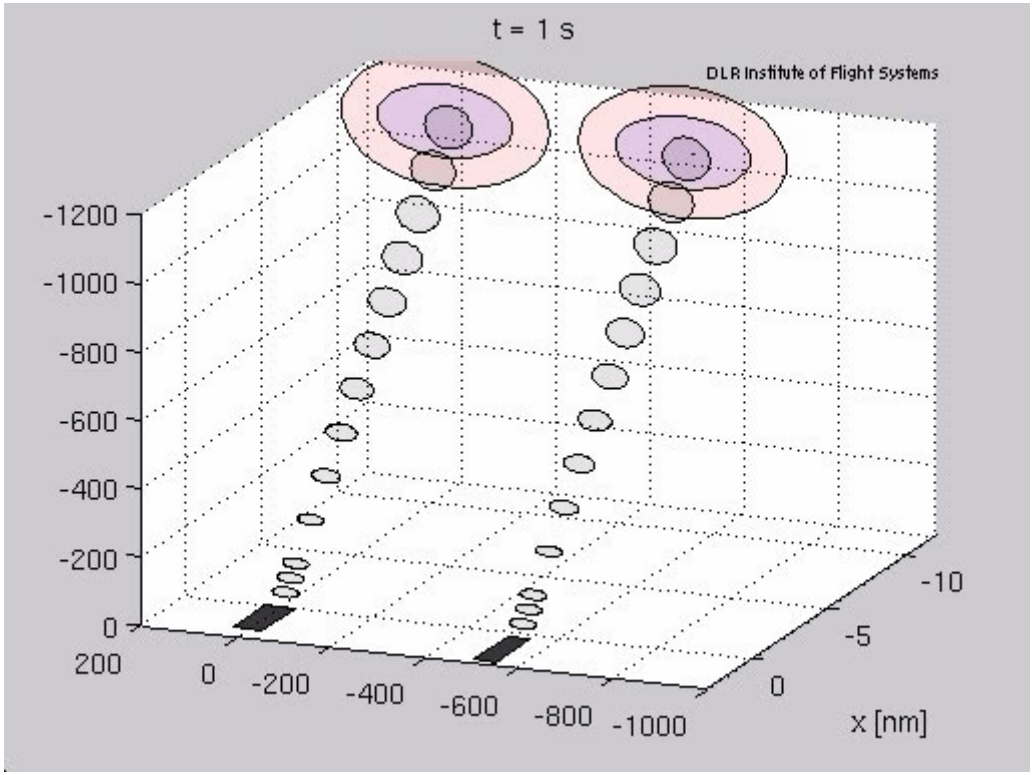


ICAO

radar separation

established procedures for closely spaced rwys (WVWS)



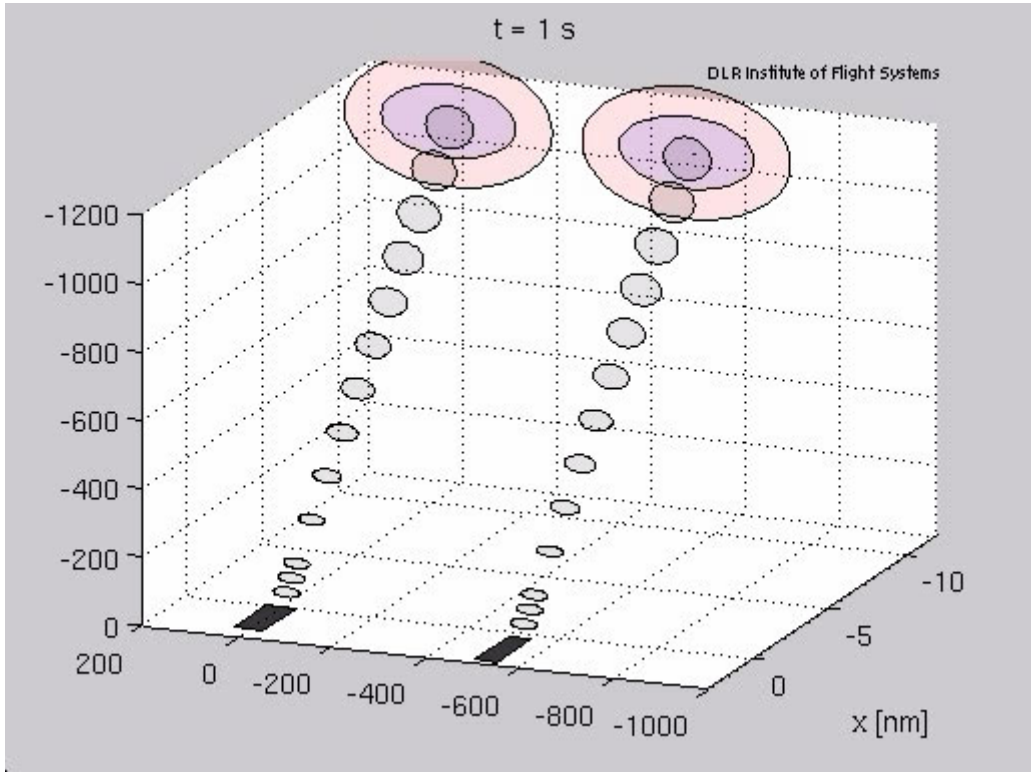


WSV Strategy
Animated
veering light winds

- 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

- 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

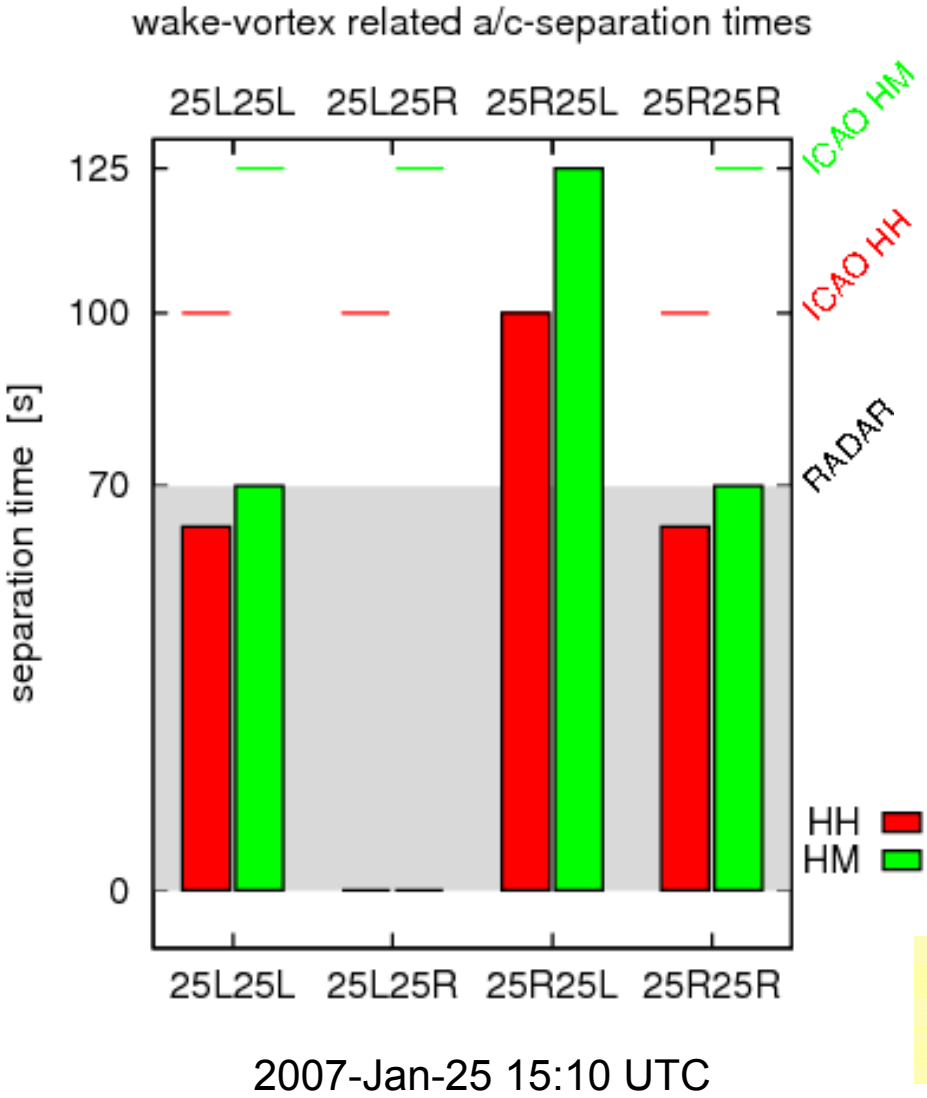
- modified staggered left
- reduced sep. single rwy

WSV Prediction Cycle

- 2 NOWVIV runs per day (launches at 0:00 & 12:00)
- 0:00 run available at about 7:00 to 8:00
- SoRa measurements every 10 min
- WSV predictions for 60 min horizon every 10 min
  (SoRa based: $x \leq 1852$ m, $z \leq 97$ m, NOWVIV based: $x \geq 3704$ m, $z \geq 194$ m)
- last 10 min predictions are not touched

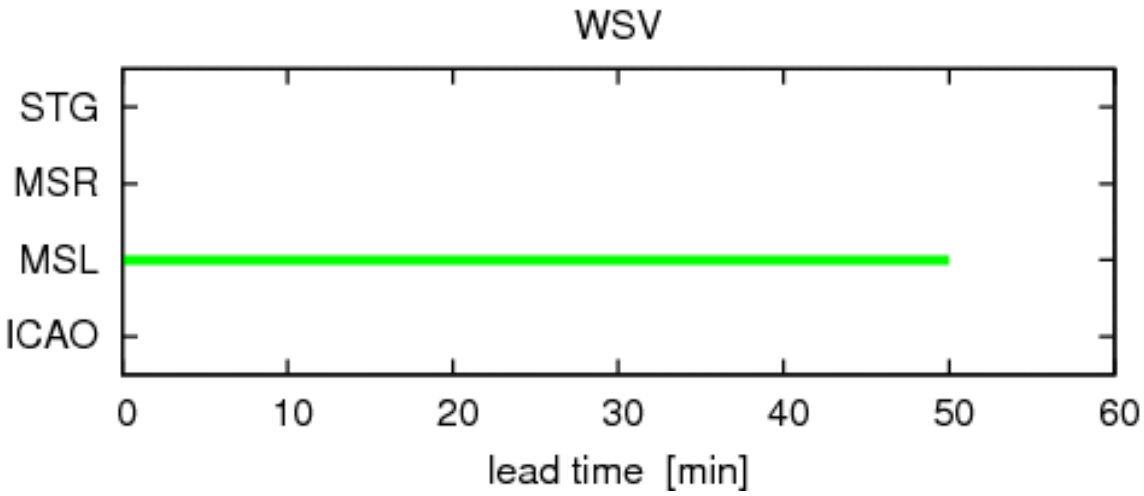
WSV-Display

full info & procedures



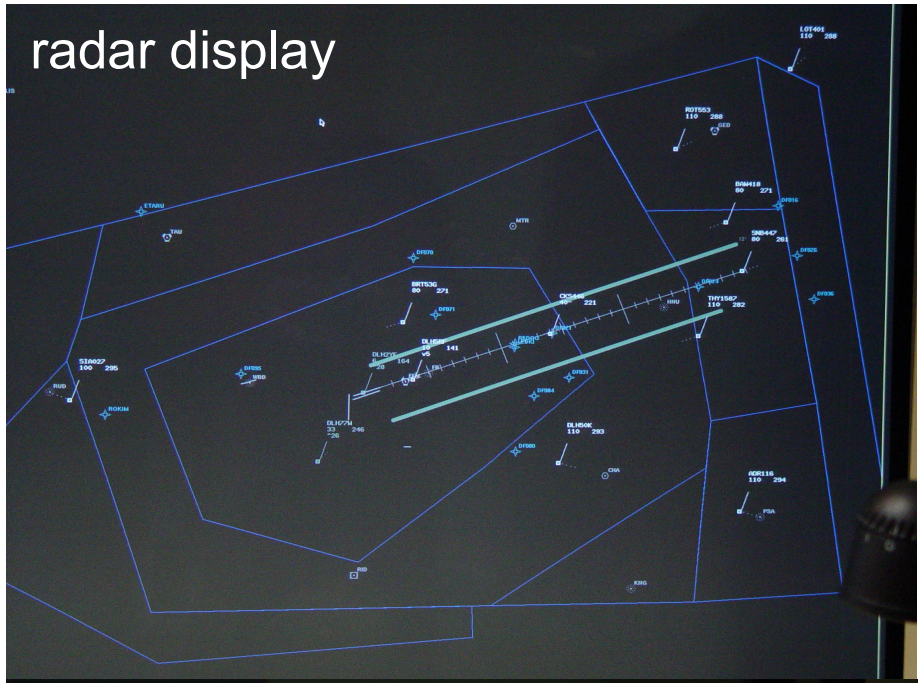
2007-Jan-25 15:10 UTC

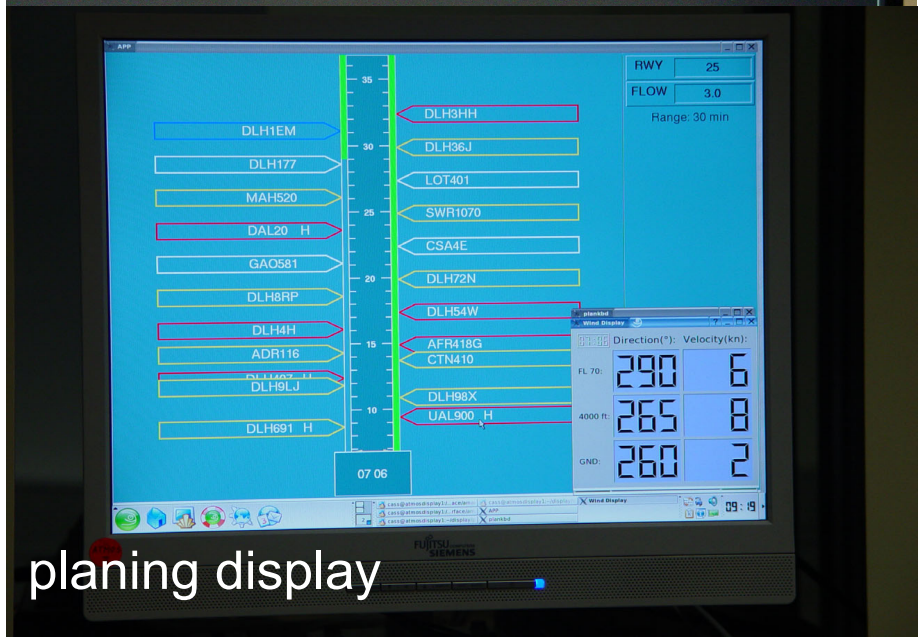
distinguish weight class combinations by two colored bars ?

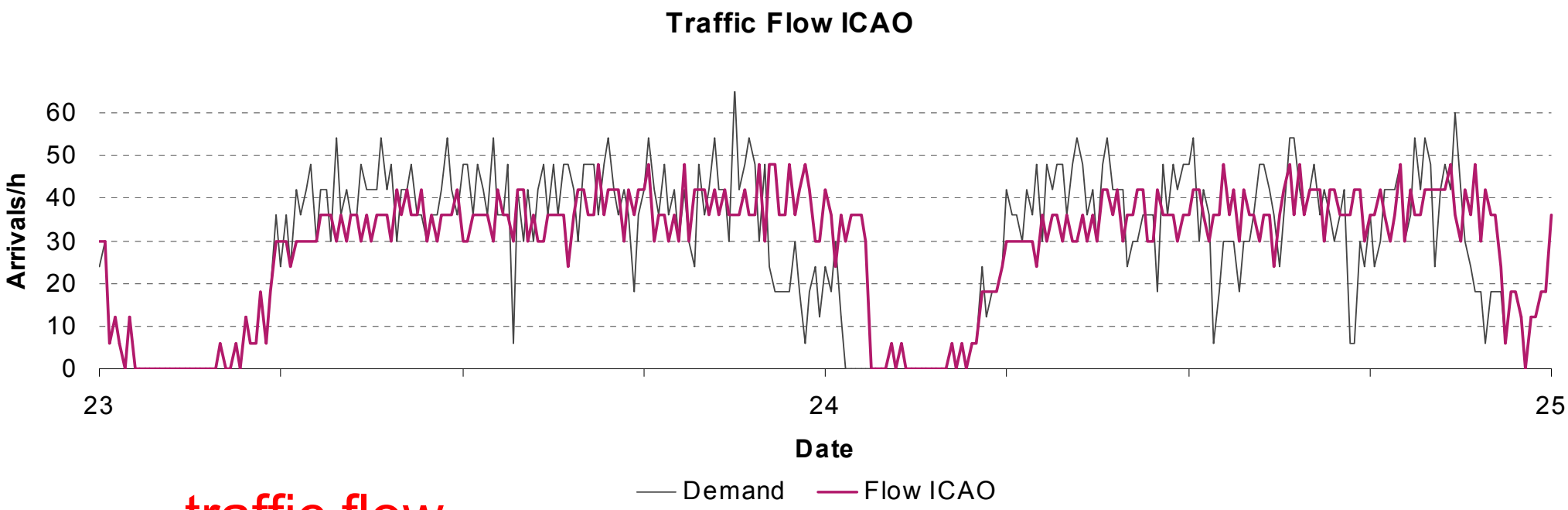


update every 10 minutes
adjustment to actual time every minute

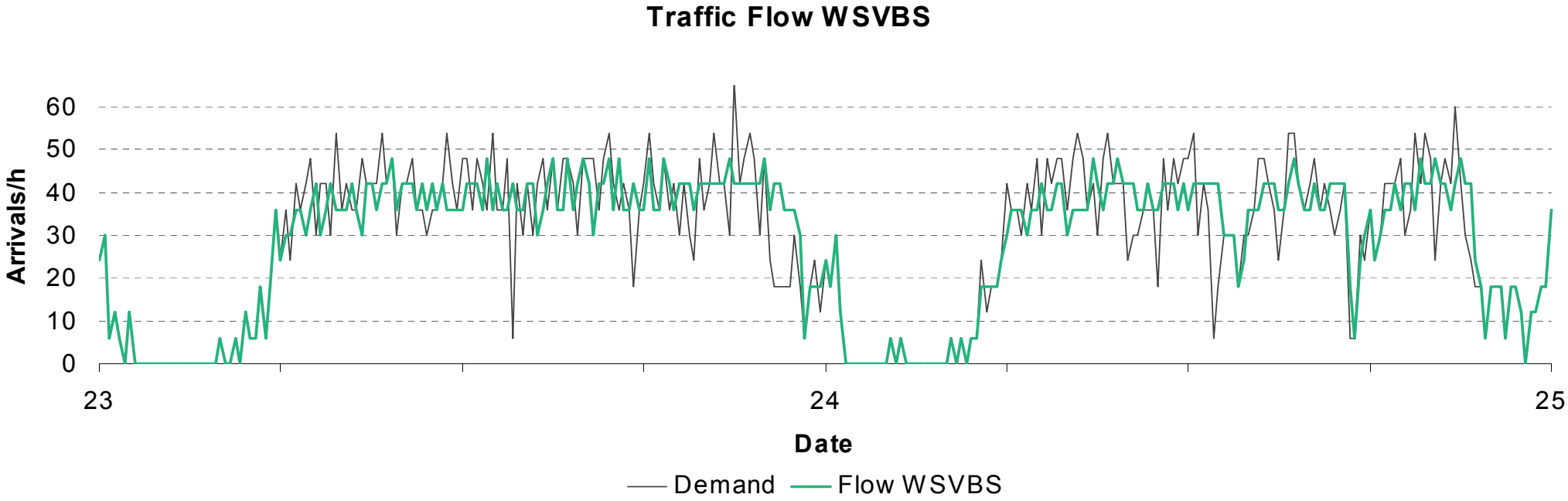
Integration into ATC



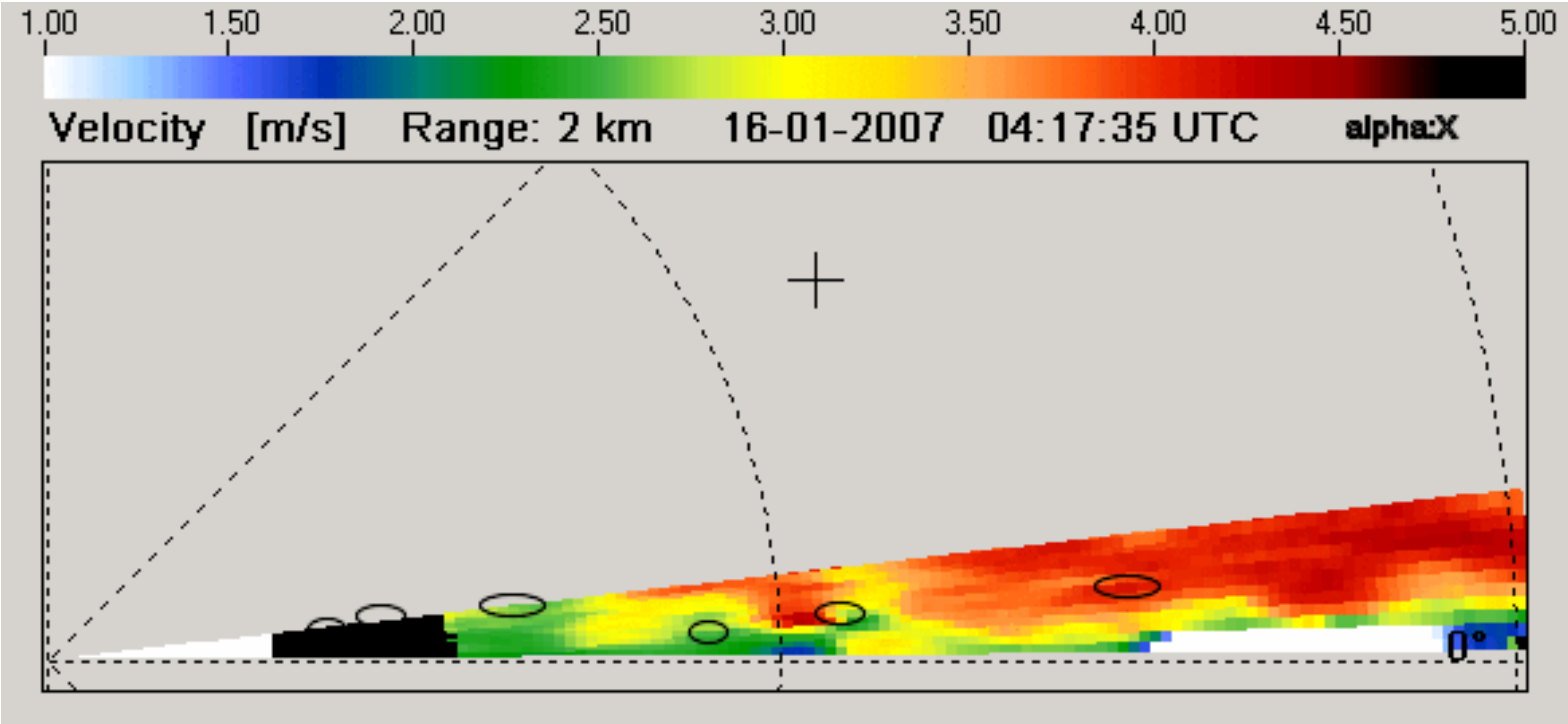




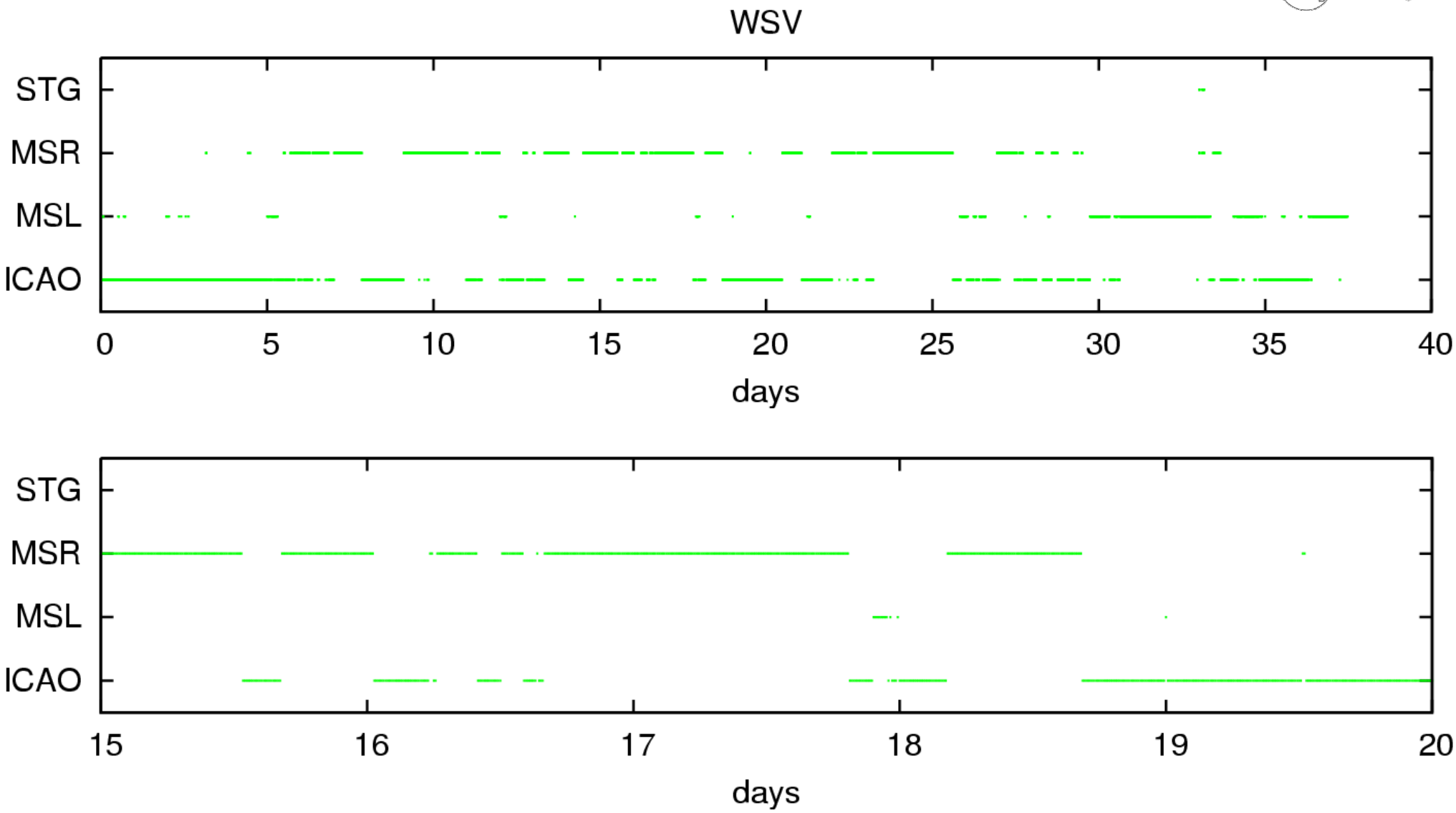
traffic flow



monitoring – lidar



potential capacity gain – stability (06/12/20 - 07/01/30)



synthetic meteo data full year 2004

PROC	MTS	PoU
LLHH	71.7	0.087
LLHM	87.8	0.111
LRHH	0.0	0.478
LRHM	0.1	0.390
RLHH	0.1	0.543
RLHM	1.2	0.436
RRHH	71.7	0.087
RRHM	87.8	0.111
RadLLHH	56.1	0.039
RadLLHM	57.9	0.028
RadLRHH	0.0	0.478
RadLRHM	0.0	0.390
RadRLHH	0.0	0.543
RadRLHM	0.0	0.431
RadRRHH	56.1	0.039
RadRRHM	57.9	0.028
stagHH	0.0	0.161
stagHM	0.0	0.061

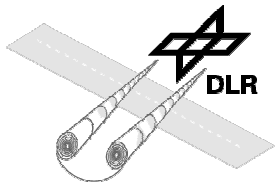
MSL

MSR

STG

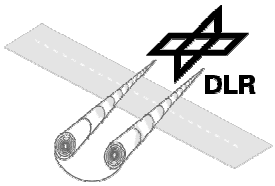
WSV – operating 37.5 days

PROC	MTS	PoU
LLHH	82.2	0.034
LLHM	100.8	0.050
LRHH	0.0	0.240
LRHM	3.9	0.174
RLHH	0.2	0.428
RLHM	2.1	0.373
RRHH	82.2	0.034
RRHM	100.8	0.050
RadLLHH	62.3	0.006
RadLLHM	65.2	0.003
RadLRHH	0.0	0.240
RadLRHM	0.0	0.168
RadRLHH	0.0	0.427
RadRLHM	0.0	0.367
RadRRHH	62.3	0.006
RadRRHM	65.2	0.003
stagHH	0.0	0.008
stagHM	0.0	0.002
ICAO		0.467



potential capacity gain

Conclusions & Outlook



- WSVBS (SODAR/RASS/USA/NOWVIV/FLIP/P2P/SHAPe/AMAN/LIDAR) established & in demonstration phase at Frankfurt airport
- covers glide path from FAF to threshold (11 nm)
- combined use of measured and synthetic meteo data
- all components based on 2-σ confidence levels
- prediction horizon > 45 min; last 10 min not touched
- prediction of established (WVWS) procedures & additional temporal separations
- integrated into AMAN (traffic scenarios simulated with controllers and pseudo pilots)
- stable prediction characteristics - no forecast breakdowns
- (preliminary) period of potential use 53%

- determine predictions skills of WSVBS and its components
- WSV based on WTR-data
- extension to rwys 07
- risk analysis (WakeScene and analytical)
- improved num. weather (& wake-vortex) prediction (data assimilation, ensemble prediction)
- automatic real-time wake vortex monitoring & integration into WSVBS
- consider wake-vortex curvature (LES, P2P, WakeScene, SHAPe, WSVBS, VESA)
- advance implementation of operational system