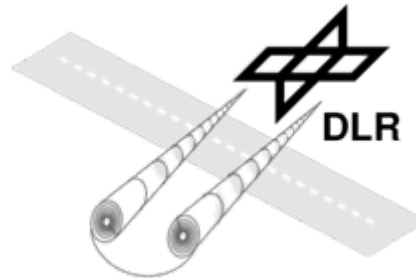


# The Wake-Vortex Prediction & Monitoring System

## WSVBS – Capacity Aspects

see Air Traffic Control Quarterly, Vol. 17, No. 4, 2009



Frank Holzäpfel

Institut für Physik der Atmosphäre

Deutsches Zentrum für Luft- und Raumfahrt

Oberpfaffenhofen, Germany

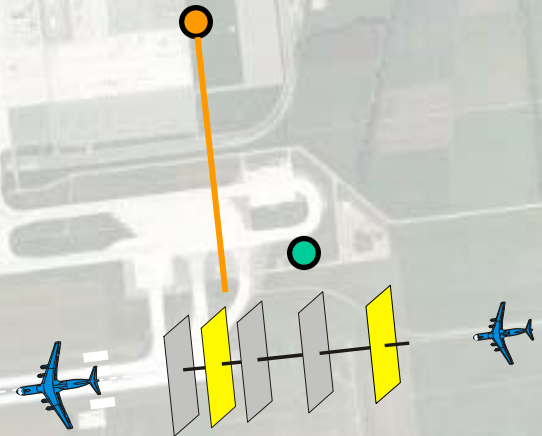
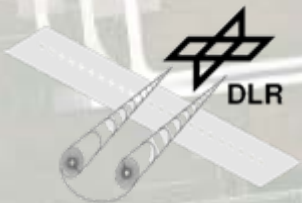
T. Gerz, K. Dengler, M. Frech, F. Holzäpfel, K. Kober, S. Rahm, A. Wiegele

C. Schwarz, K.-U. Hahn, Institut für Flugsystemtechnik, Braunschweig

W. Gerling, A. Scharnweber, Institut für Flugführung, Braunschweig

## the WSVBS

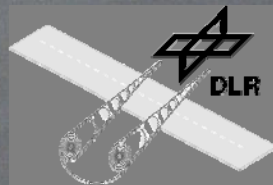
- supports weather dependent dynamic separations
  - on closely-spaced parallel runways
  - and single runways
  - for weight class combinations
  - or dynamic pairwise separations
- demonstration campaigns at
  - Frankfurt airport (winter 06/07)
  - Munich airport (summer 10)





DLR-Projekt Wirbelschleppe (1999 – 2007)  
DLR-Projekt Wetter & Fliegen (2008 – 2011)

AWIATOR, ATC-Wake, CREDOS,  
C-Wake, FAR-Wake, FLYSAFE,  
S-Wake, WakeNet3-Europe, Wavenc





special thanks for the support go to:

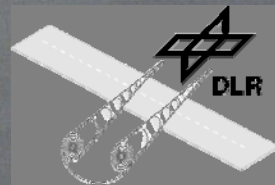
DFS Deutsche Flugsicherung GmbH

DWD Deutscher Wetterdienst

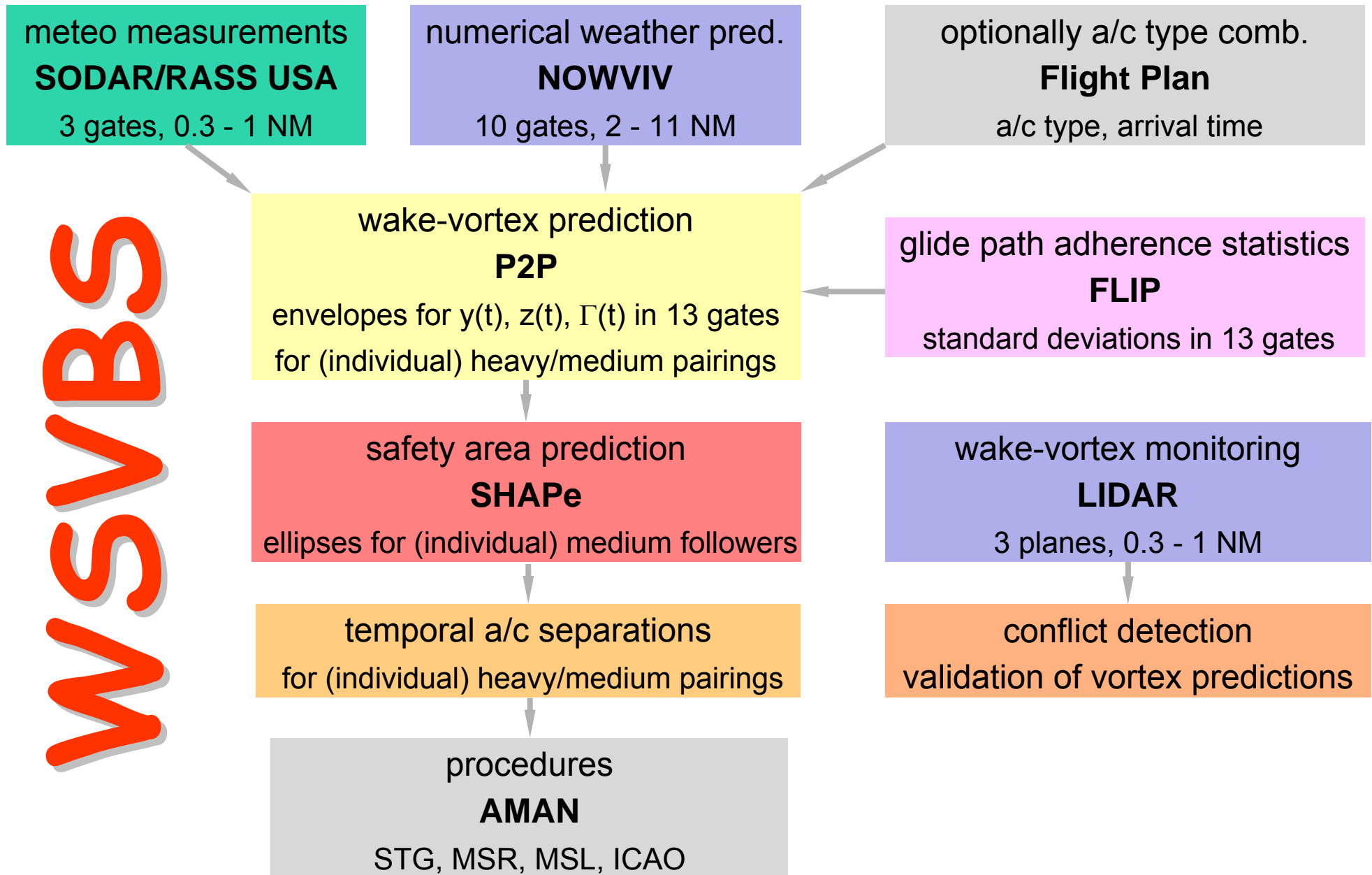
Fraport AG

Flughafen München GmbH

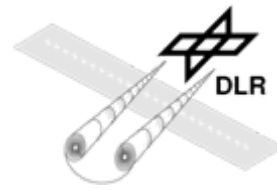
Metek GmbH



# WSVBs

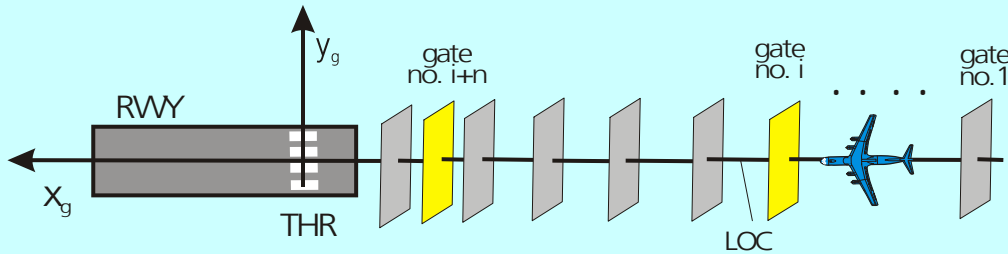


# WSV Topology

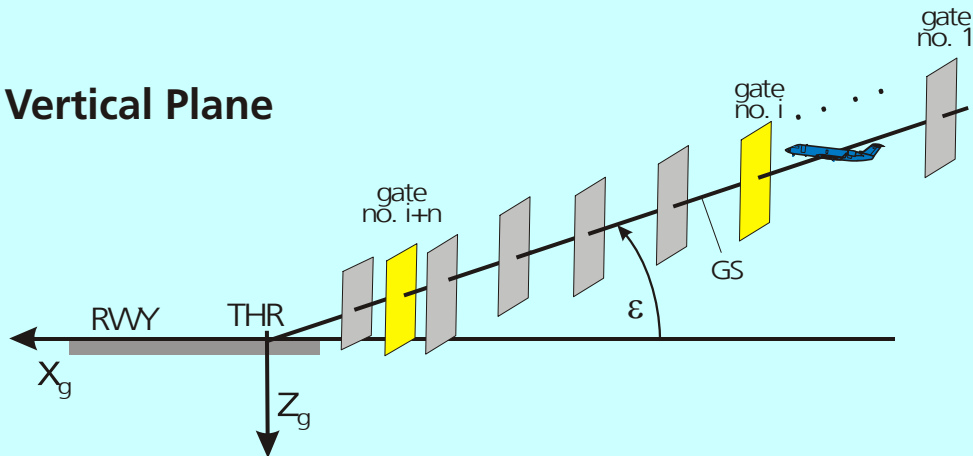


13 Gates Along Nominal ILS Flight Path ( $\Delta x = 1/3 \text{ NM} - 1 \text{ NM}$ )

## Horizontal Plane

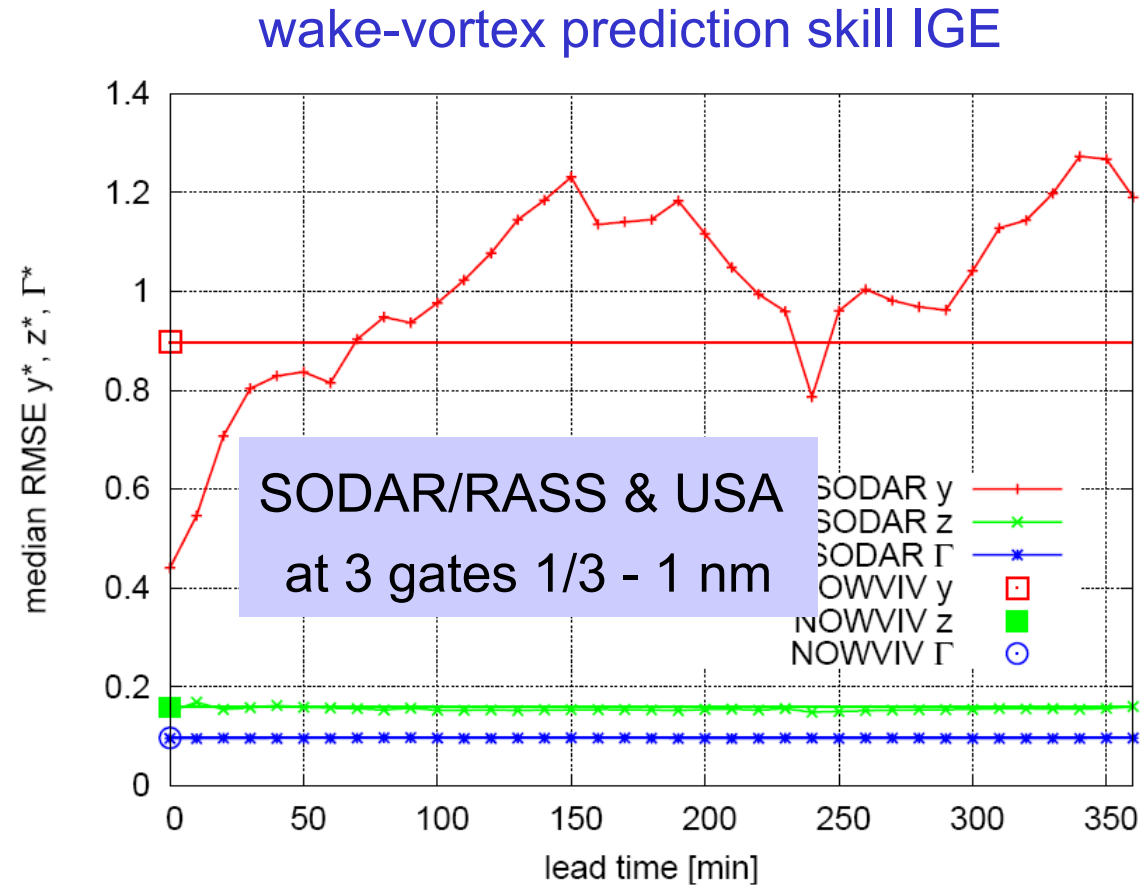
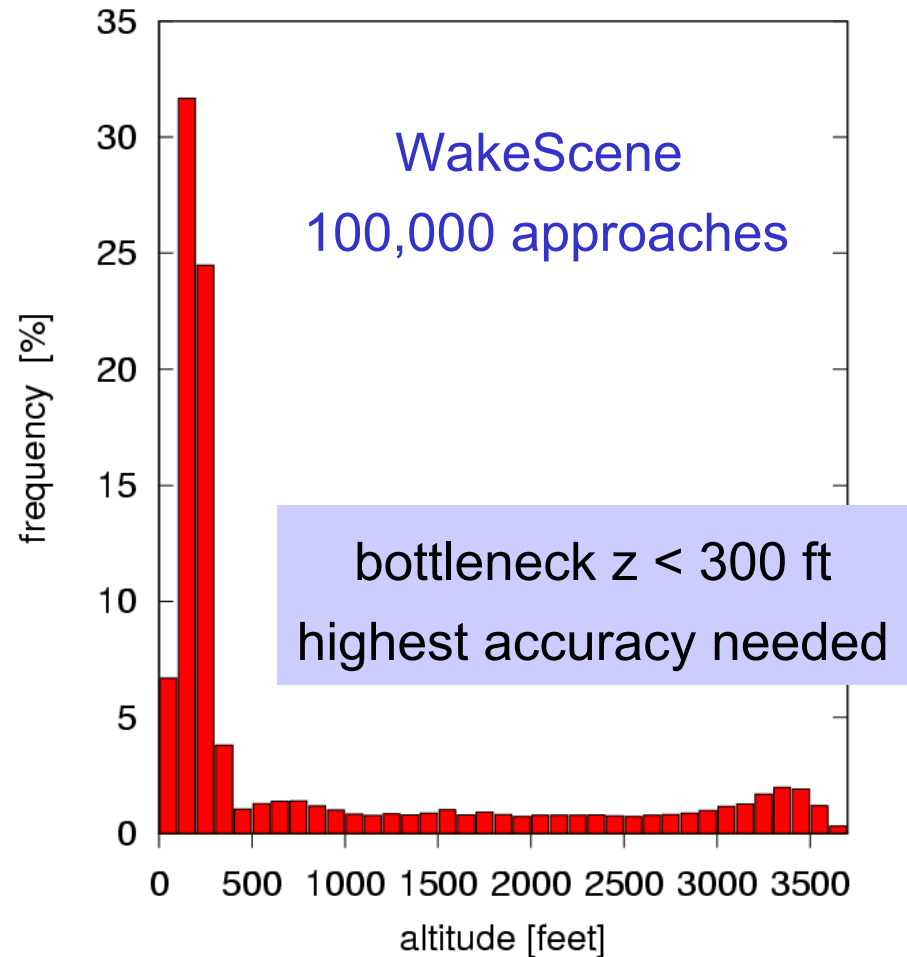
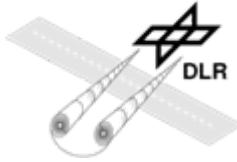


## Vertical Plane

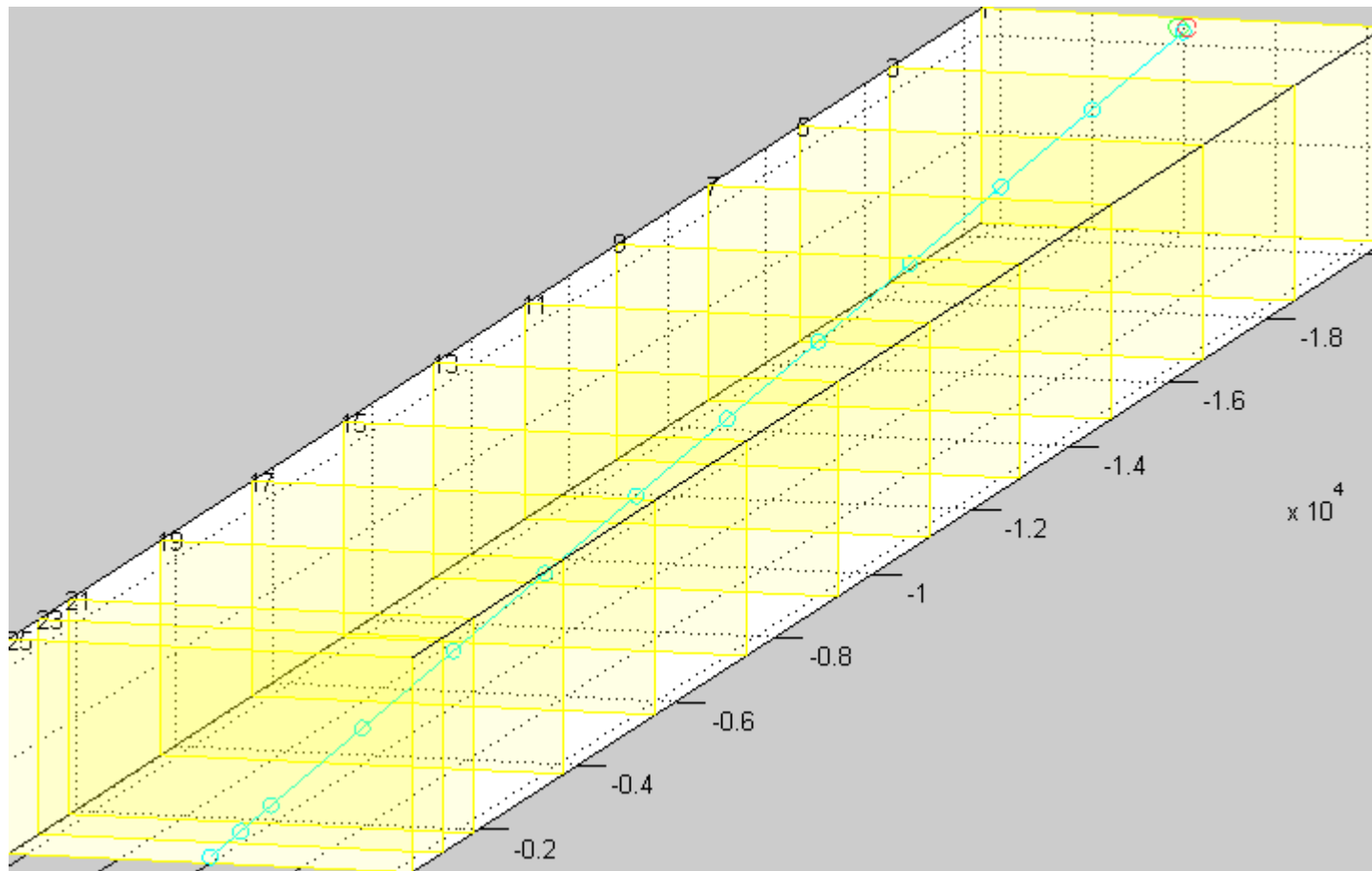
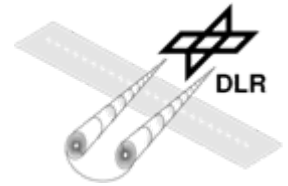


| gate No | $x_{\text{gate}}$ [m] | $z_{\text{gate}}$ [m] |
|---------|-----------------------|-----------------------|
| 1       | -20372                | -1077                 |
| 2       | -18520                | -979                  |
| 3       | -16668                | -880                  |
| 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                   |

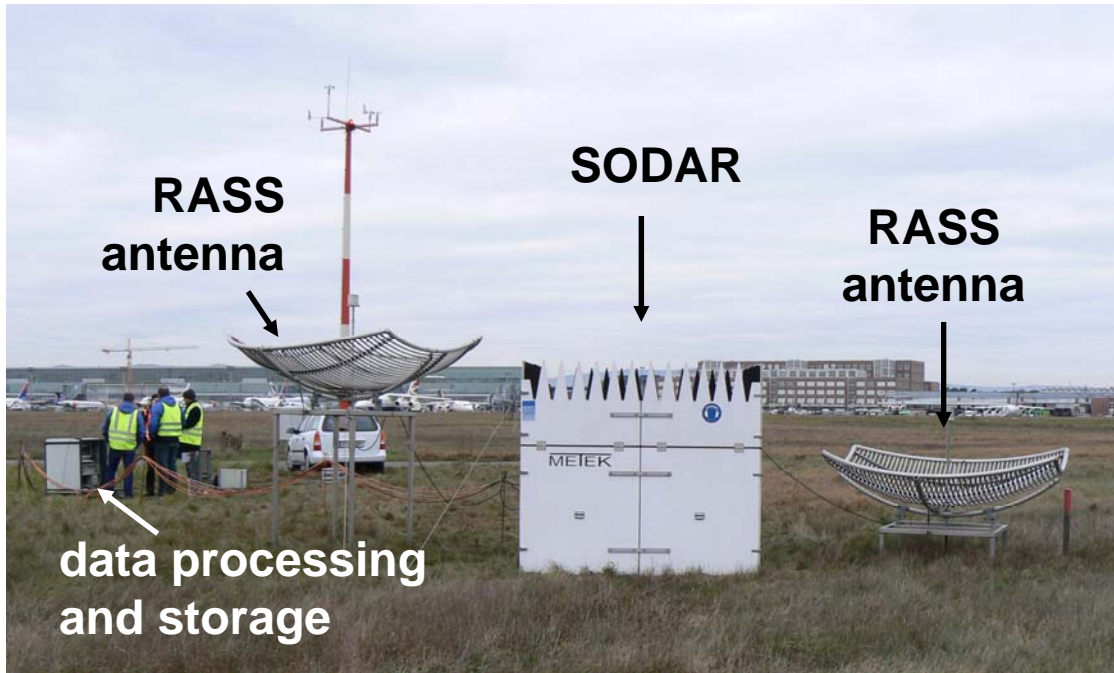
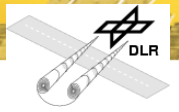
# meteo data input – strategy



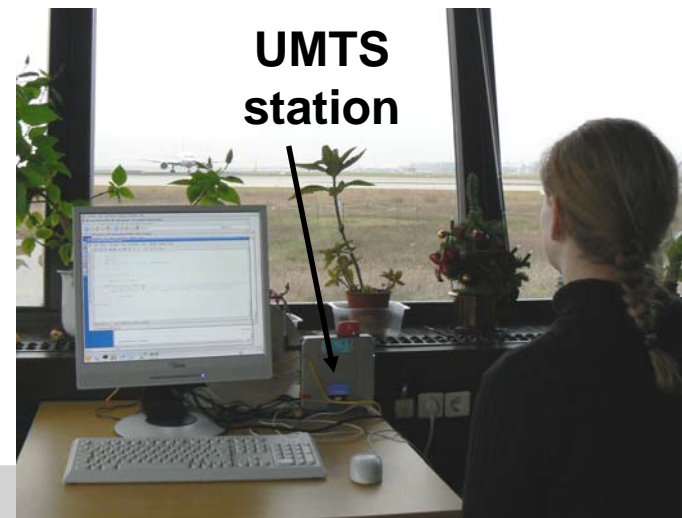
# approach scenario – WakeScene



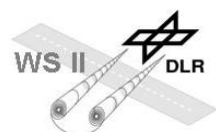
# Instrumentation at Frankfurt airport: SODAR/RASS/USA



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

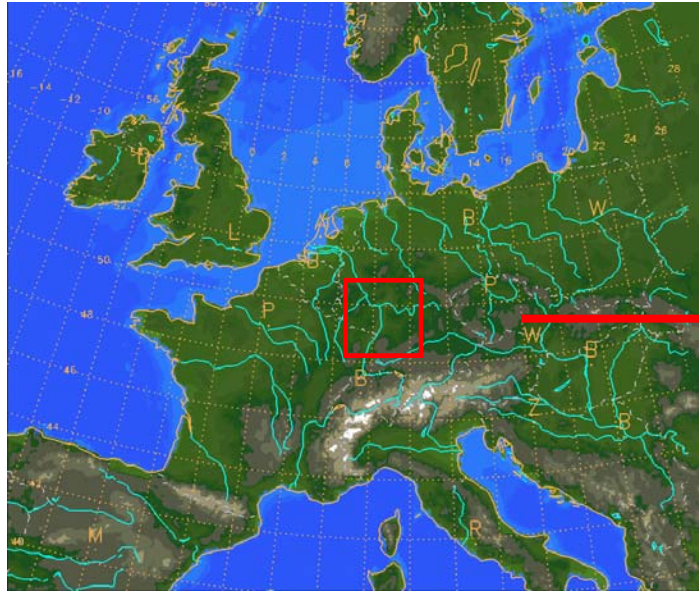


**LOZ-PC**

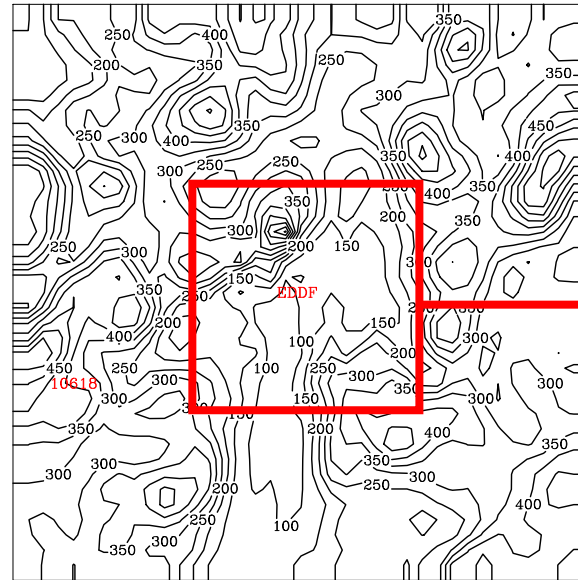


Deutsches Zentrum  
für Luft- und Raumfahrt e.V.  
in der Helmholtz-Gemeinschaft

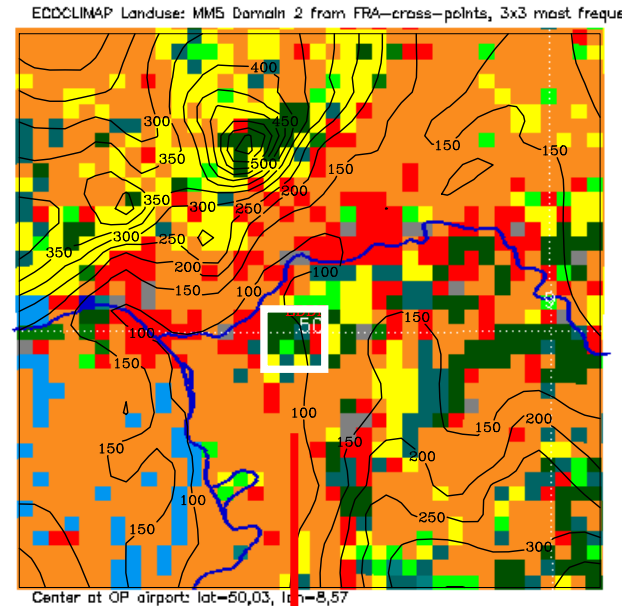
## Forecasting for airports: model chain with nesting – NOWVIV



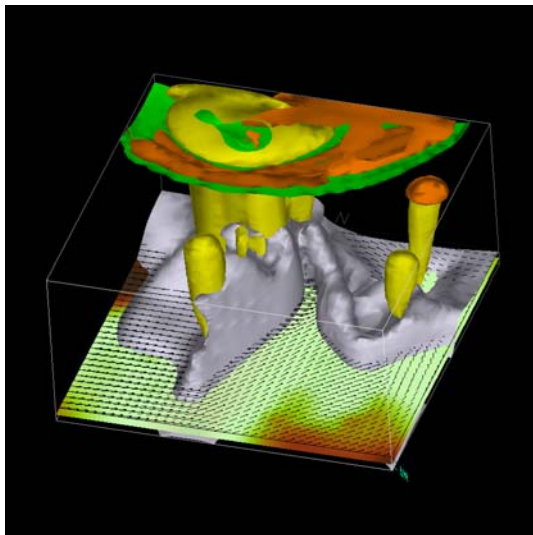
LM forecasting domain



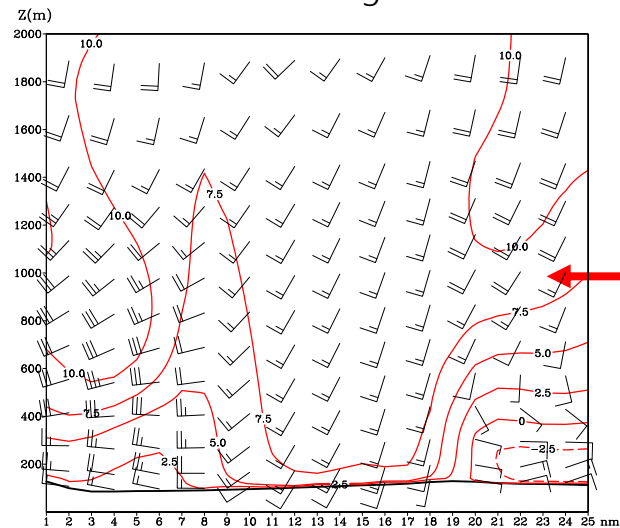
MM5 forecasting domain 1



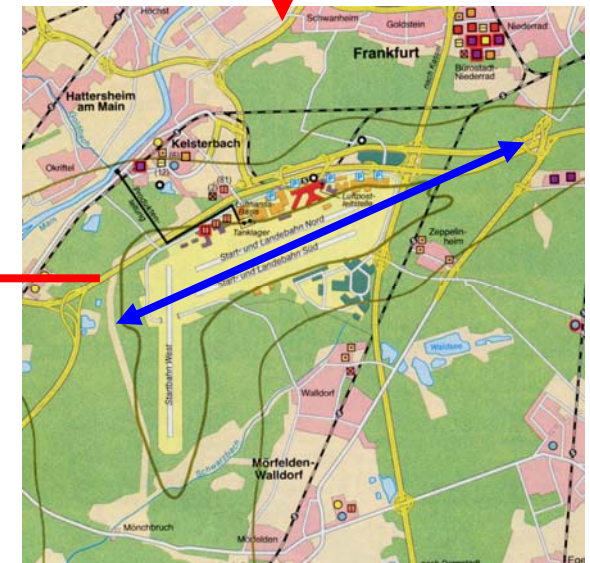
MM5 forecasting domain 2



### 3D view of storm crossing airport

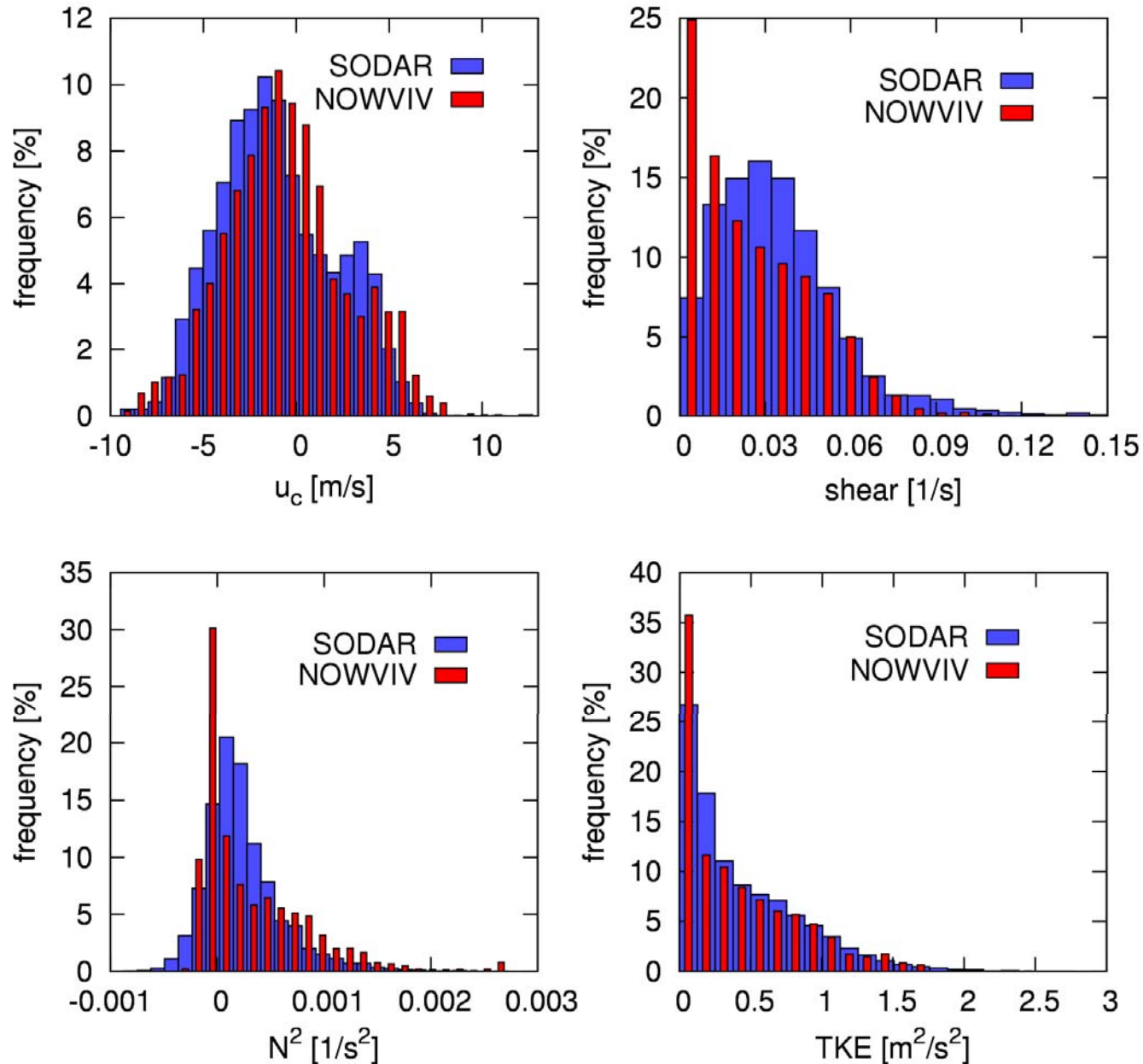
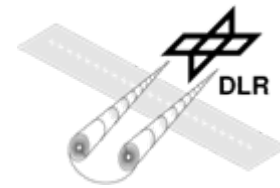


Cross section along glideslope



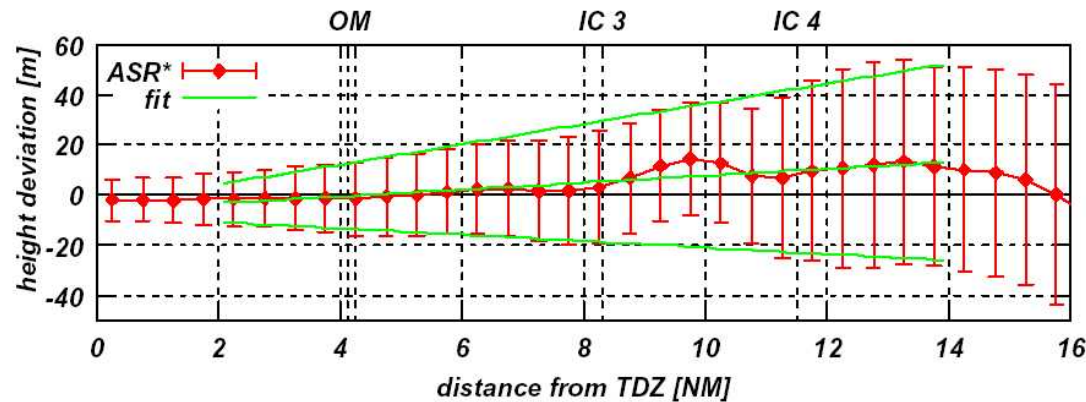
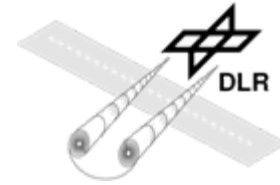
Airport area

# Meteorological Data Base – Validation

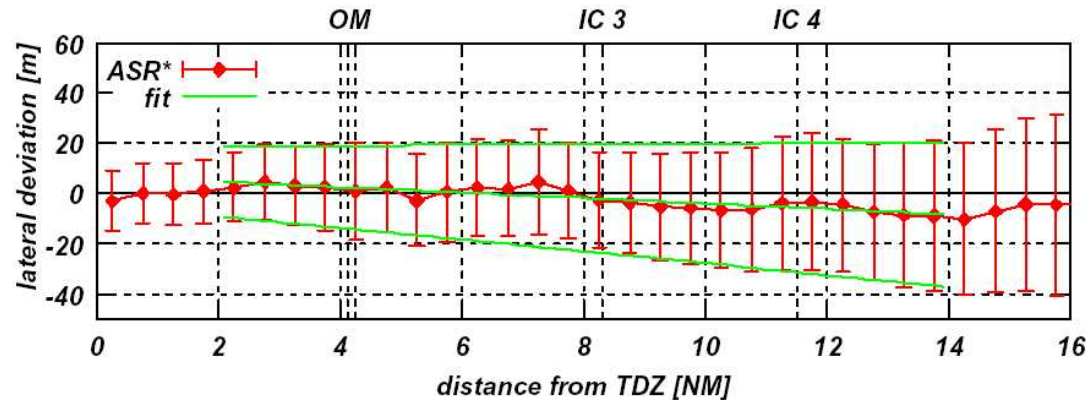


40 days  
 $z = 100$  m

# Approach Corridor Dimensions – FLIP



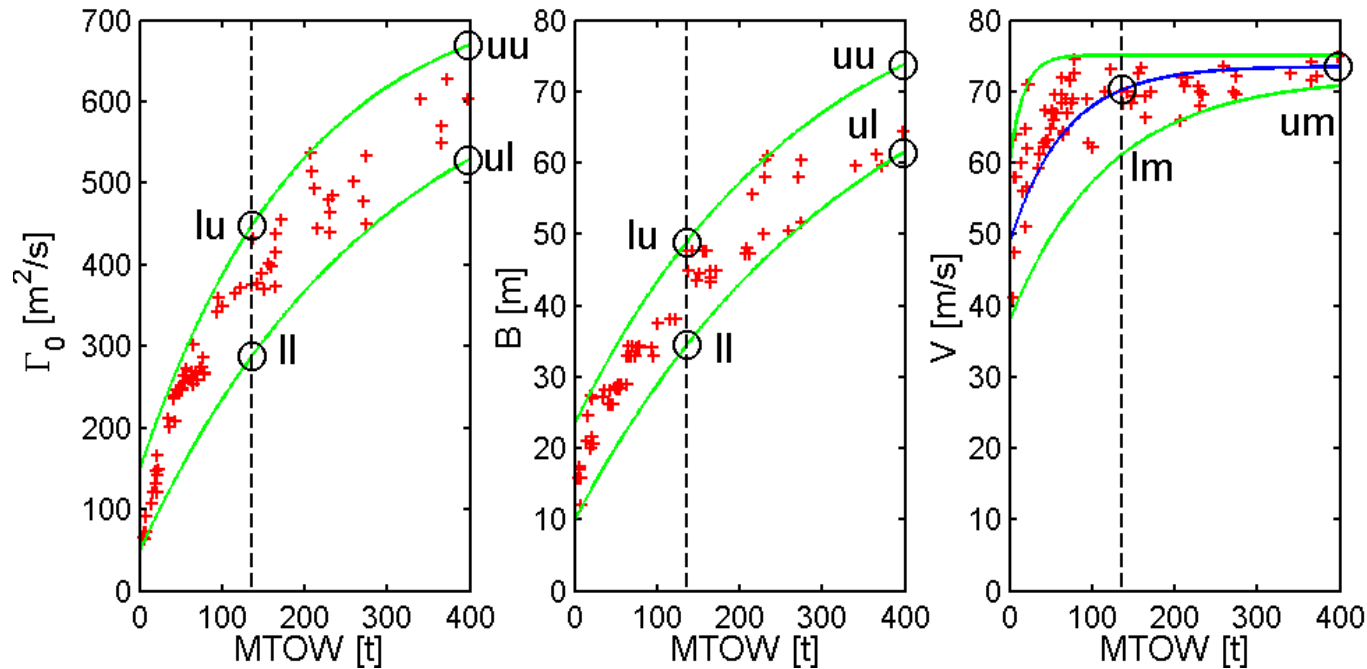
(35,691 a/c-approaches)



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

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

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

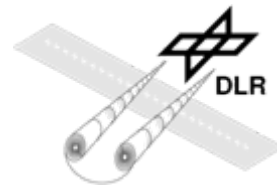


representation of  
heavy leader a/c

|                        | $\Gamma_0$<br>[m <sup>2</sup> /s] | $b_0$<br>[m] | $V$<br>[m/s] | characteristic<br>time scales $t_0$ | descent<br>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         | <b>39.9 s (max)</b>                 | 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         | <b>10.3 s (min)</b>                 | <b>2.63 m/s (max)</b>               |
| $\Gamma_{0ll} b_{0lu}$ | 288.2                             | 38.4         | 70.3         | 32.1 s                              | <b>1.19 m/s (min)</b> <sup>1)</sup> |
| $\Gamma_{0ll} b_{0ll}$ | 288.1                             | 27.1         | 70.3         | 16.0 s                              | 1.69 m/s                            |

8 a/c-parameter  
combinations

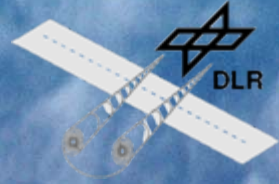
# representation of ind. a/c types – dynamic pairwise



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

all a/c types in MUC & FRA

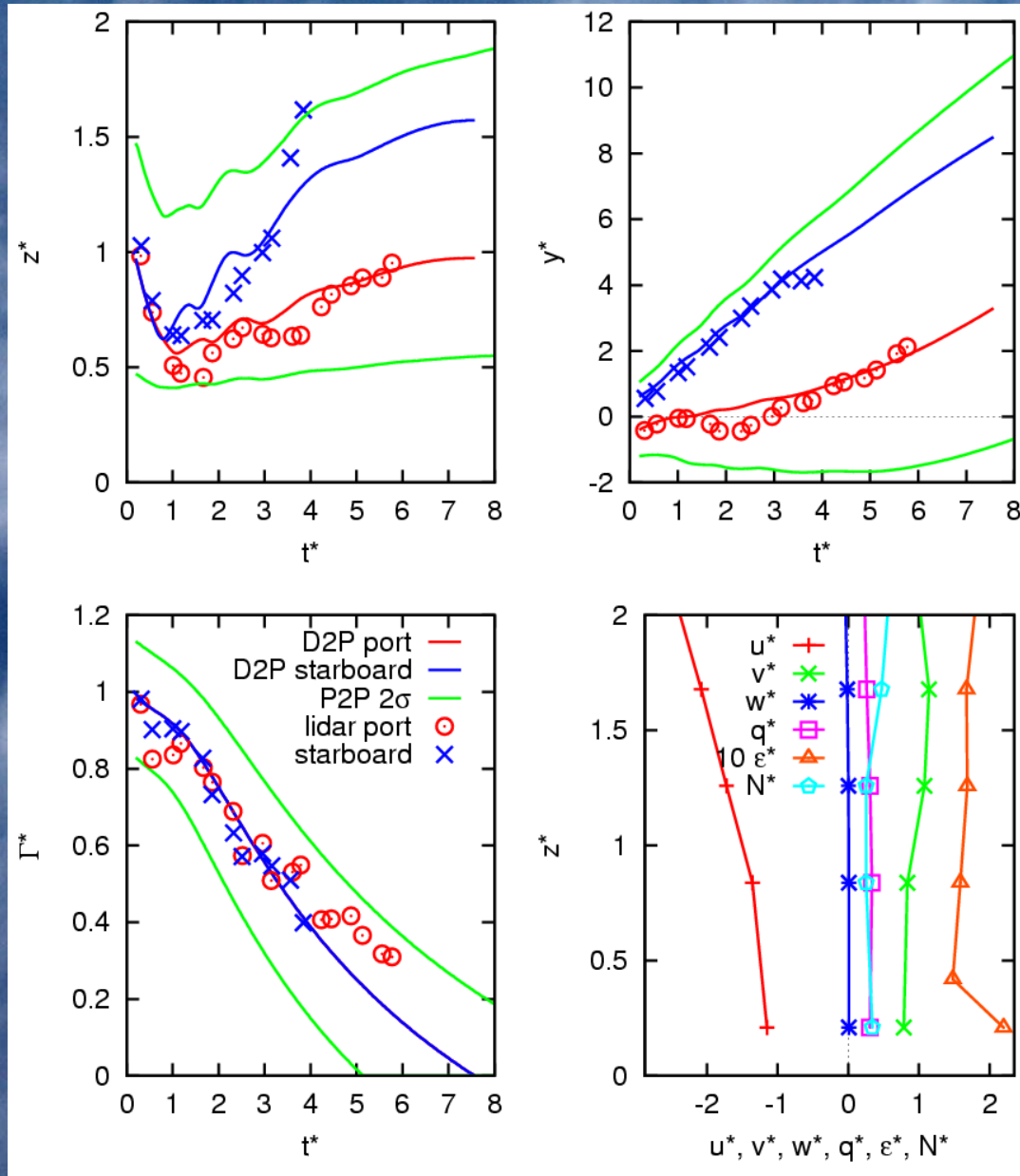
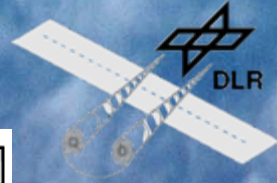
# Probabilistic Two-Phase Wake-Vortex Transport and Decay model



- P2P accounts for effects of a/c configuration, wind, wind shear, turbulence, stable stratification, and ground proximity
- provides envelopes for  $y$ ,  $z$ ,  $\Gamma$  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

# Probabilistic Two-Phase Wake-Vortex Transport and Decay model

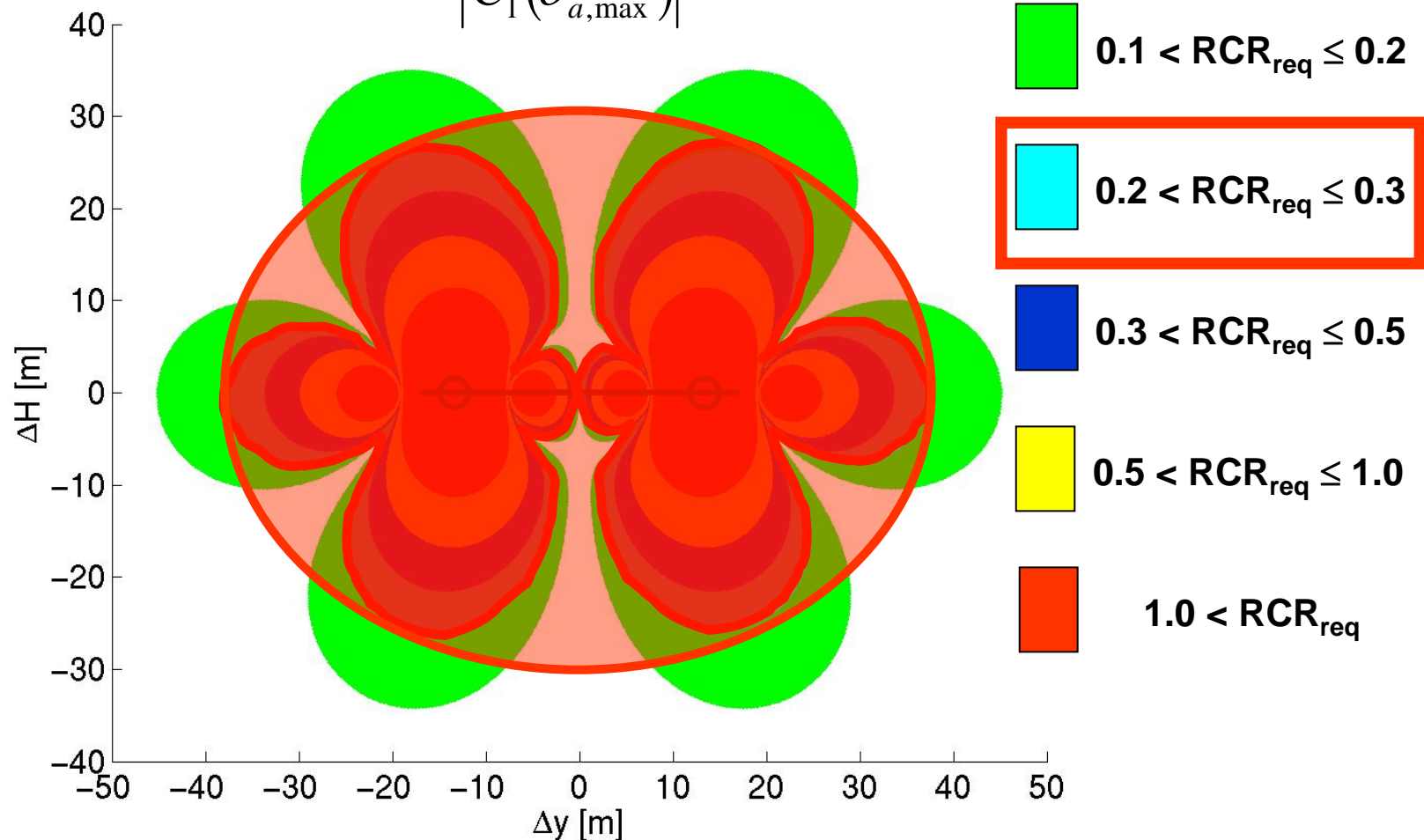


# Simplified Hazard Area (SHA)

req. roll control ratio

$$RCR_{req} = \left| \frac{C_{1,WV}}{C_1(\delta_{a,max})} \right|$$

approach:  
safe and undisturbed operations  
possible outside the hazard area

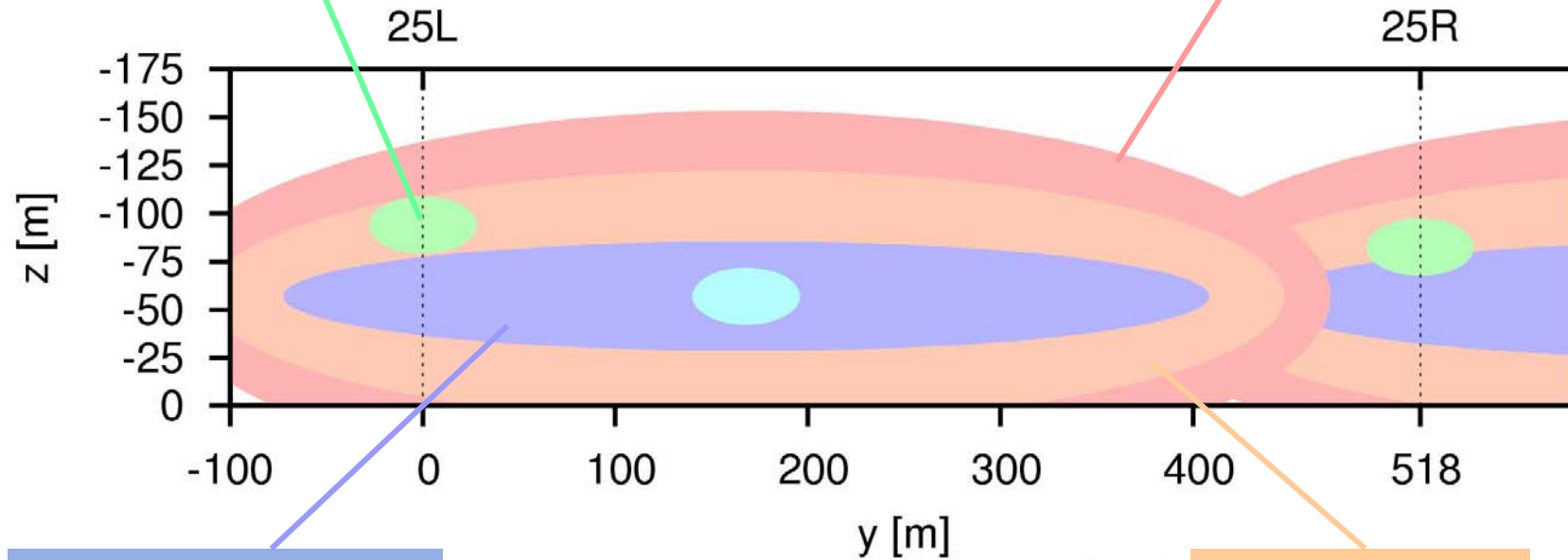


# WSV Strategy

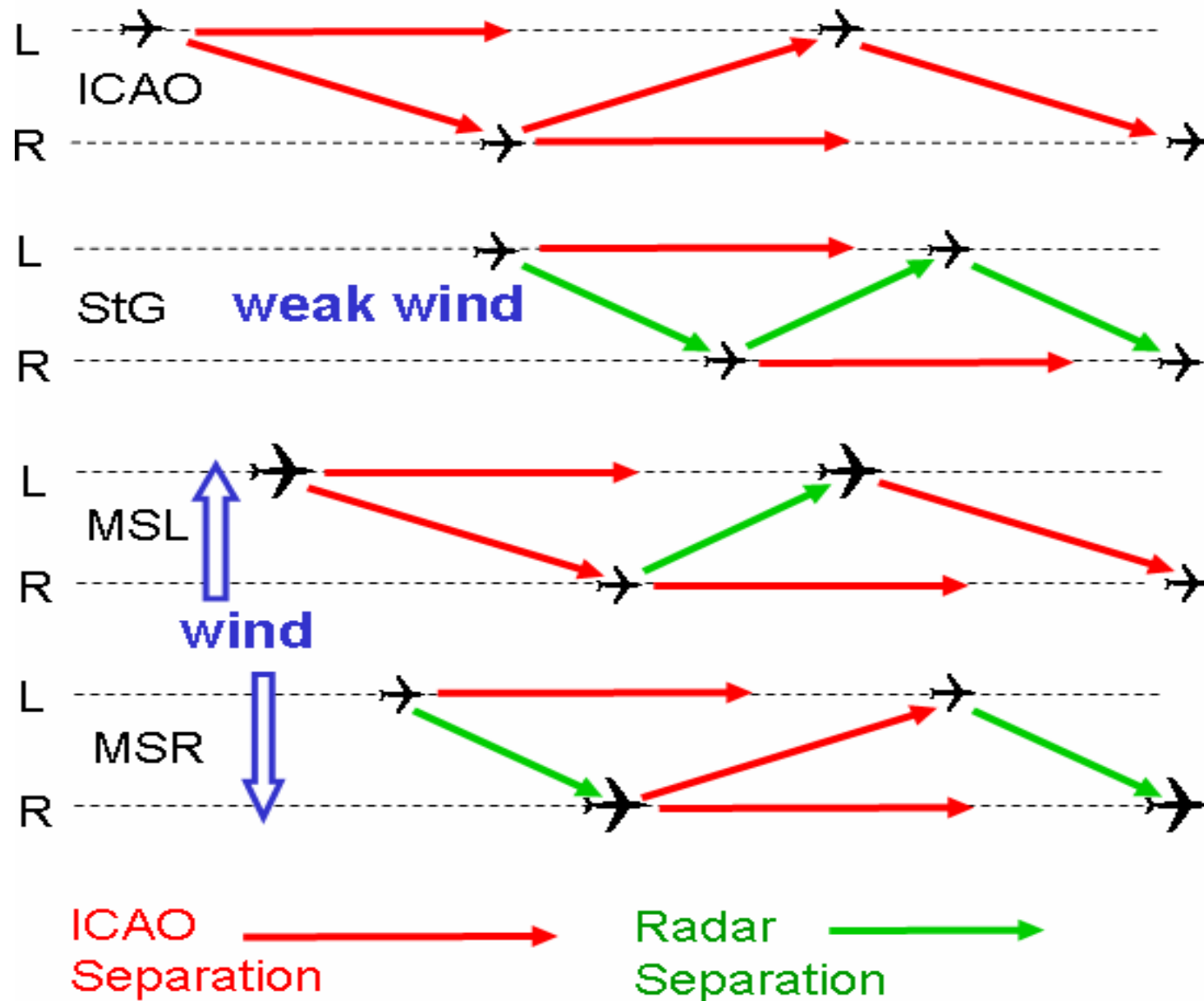
approach corridor (95.4%)

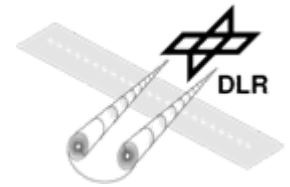
safety area HM

WSV - gate 11 - leader a/c:  $\Gamma_{0uu}$ ,  $b_{0uu}$  - separation time = 100 s

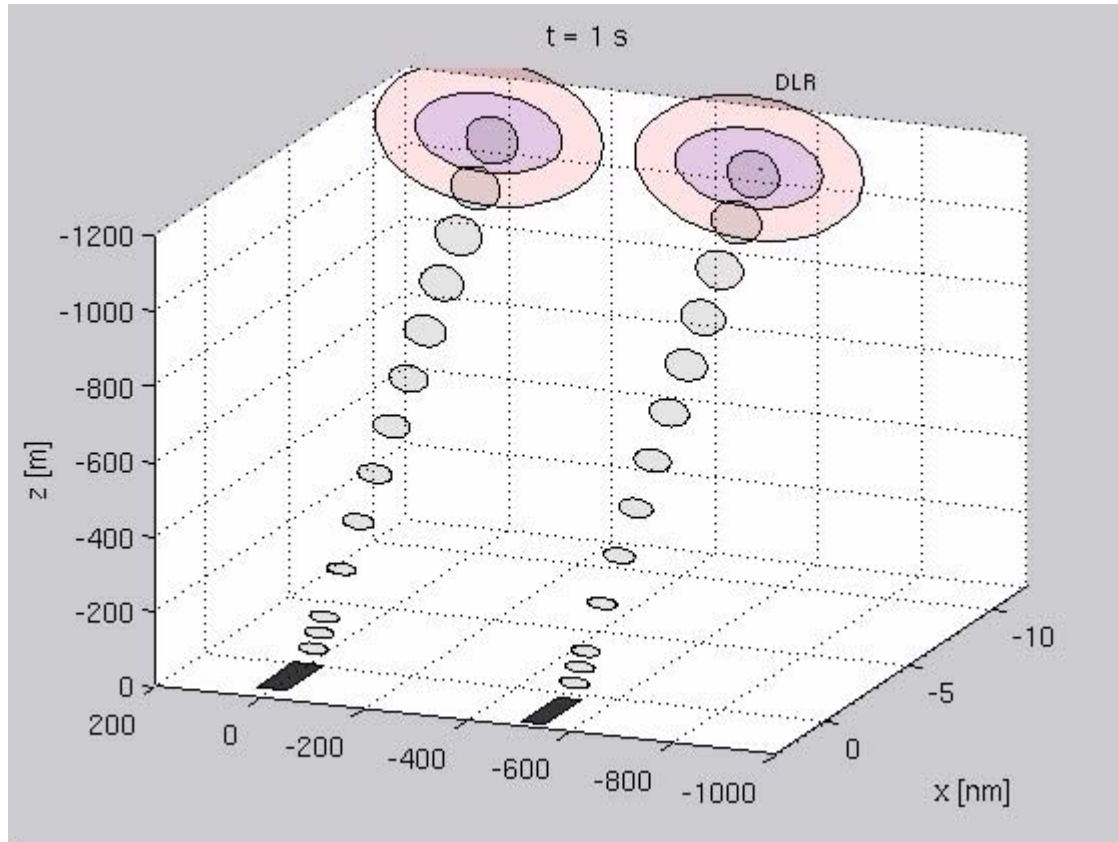


# Frankfurt Airport: DFS' Concepts of Operation for CSRP





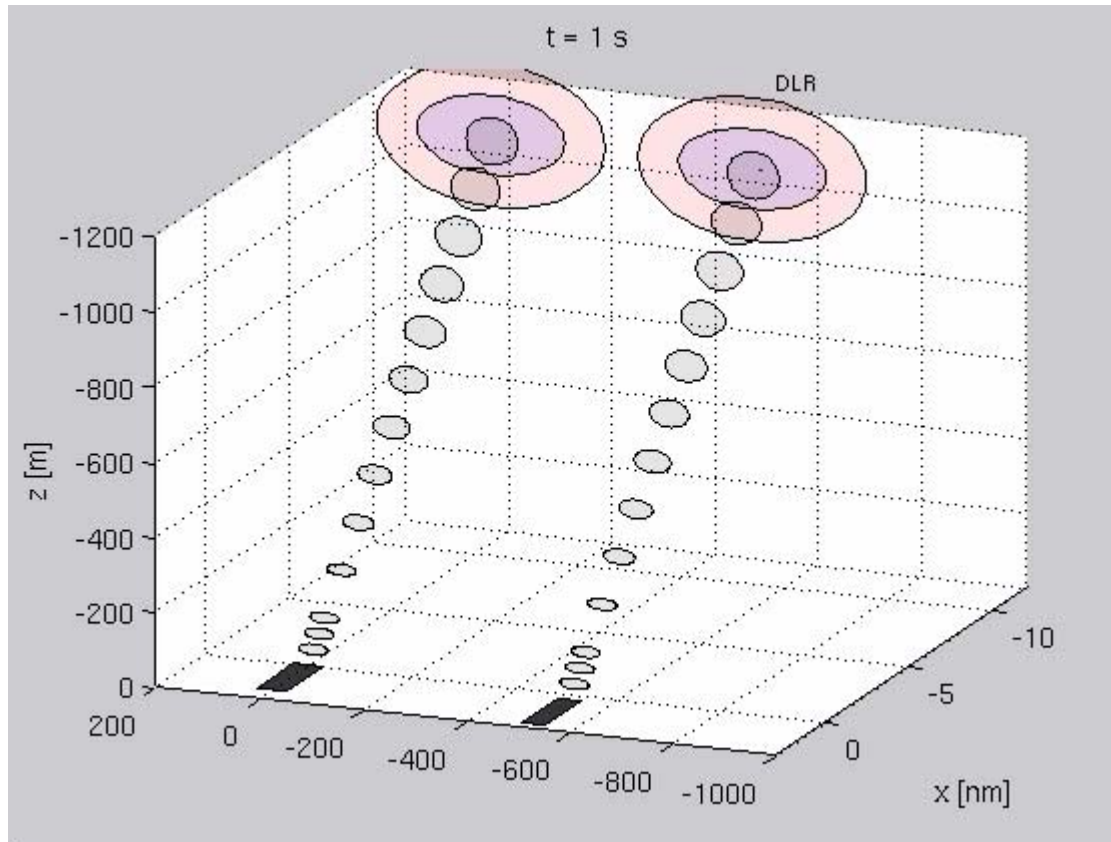
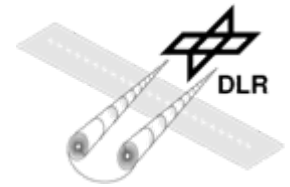
# WSV Strategy Animated veering light winds



- 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

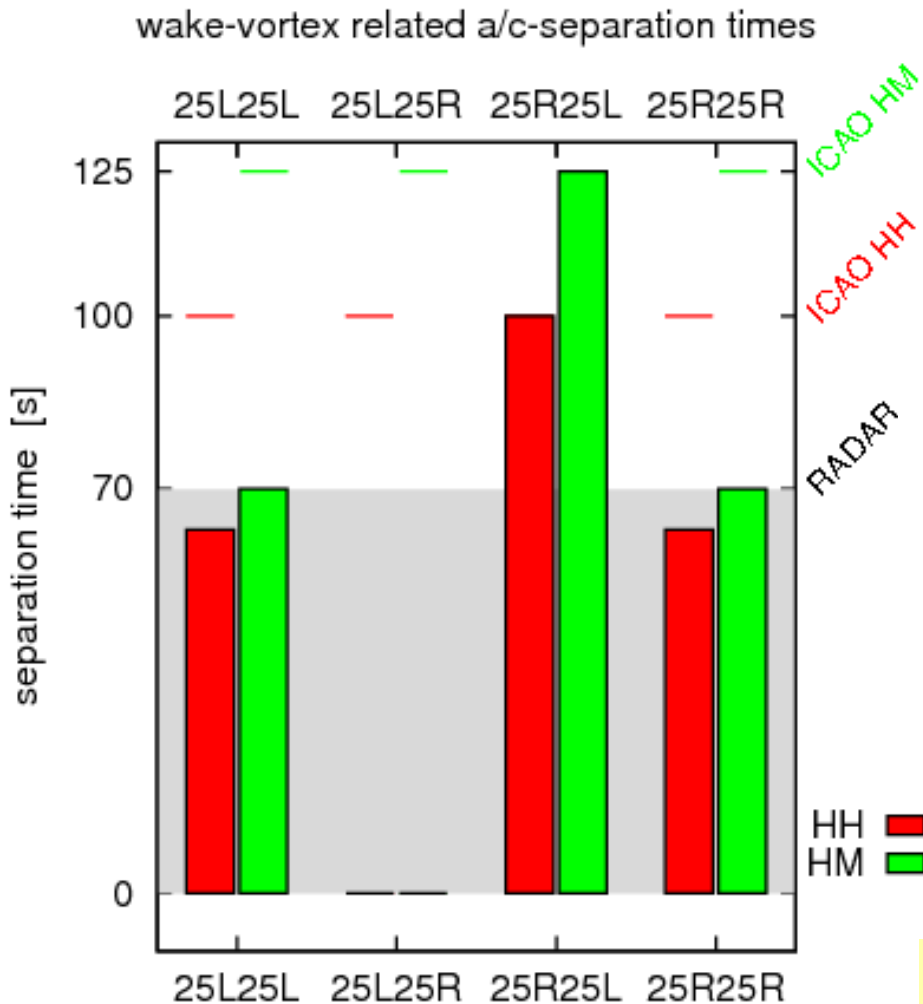
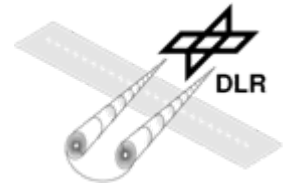
- 2004/09/10 19:10
- generator 2 shown  
which determines sep.
- heavy-medium

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

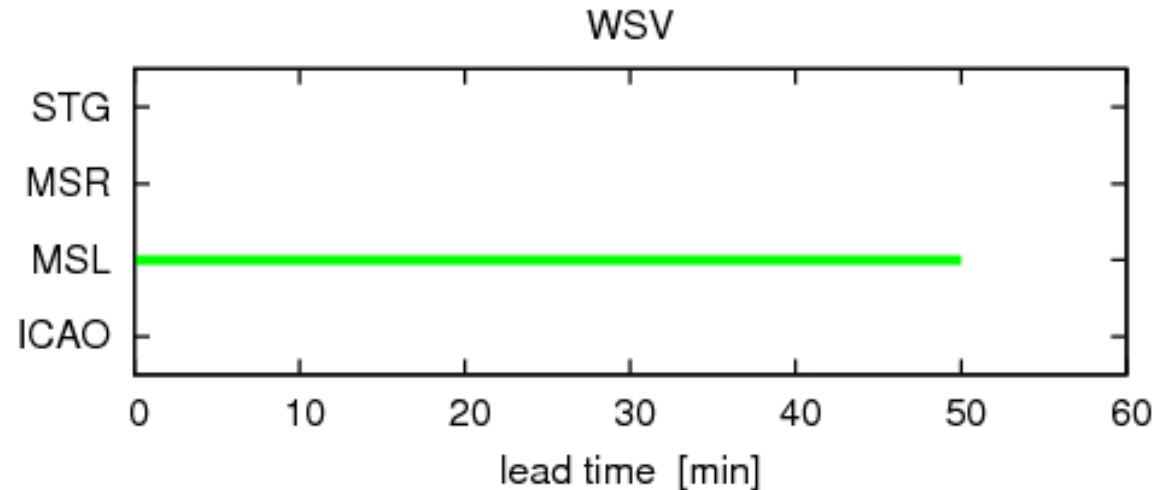
- modified staggered left
- reduced sep. single rwy

# WSV-Display

## full info & procedures



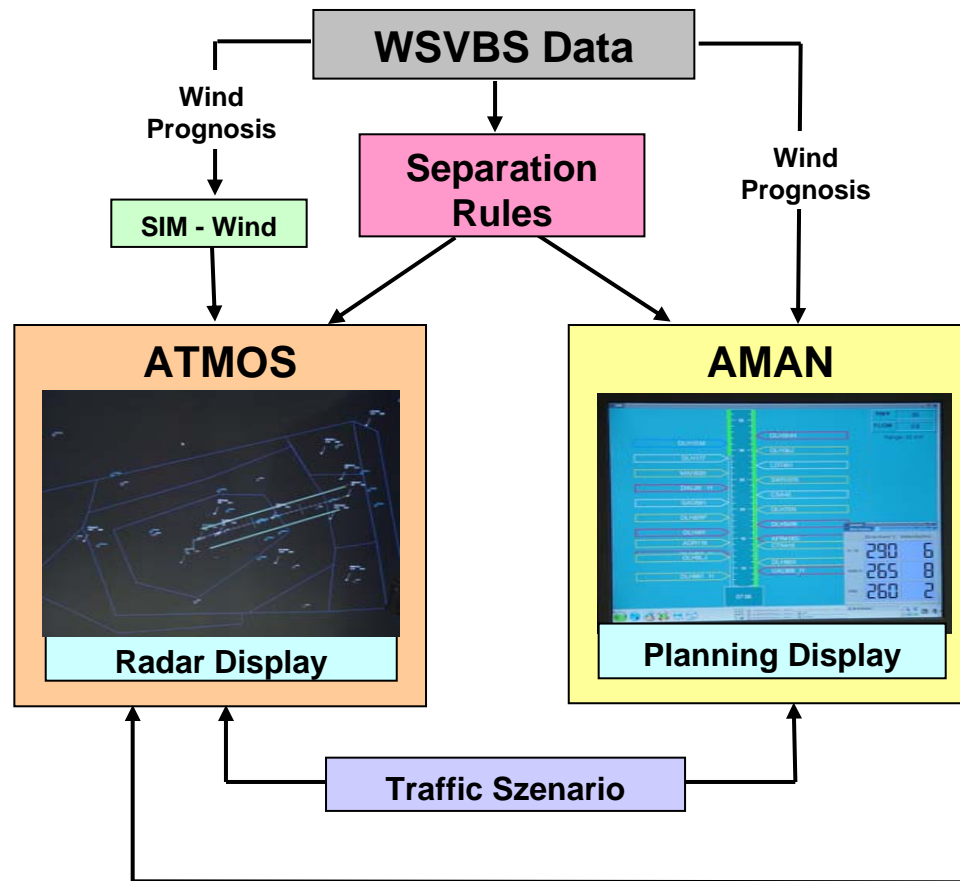
2007-Jan-25 15:10 UTC



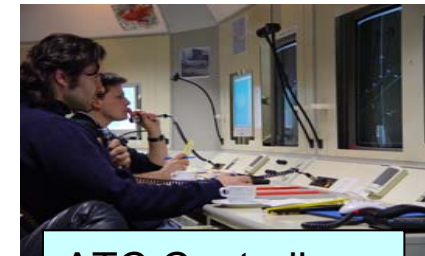
update every 10 minutes  
adjustment to actual time every minute

# Integration in the Air Traffic Control environment

## Real-time simulations



## Structure of WSVBS Simulation



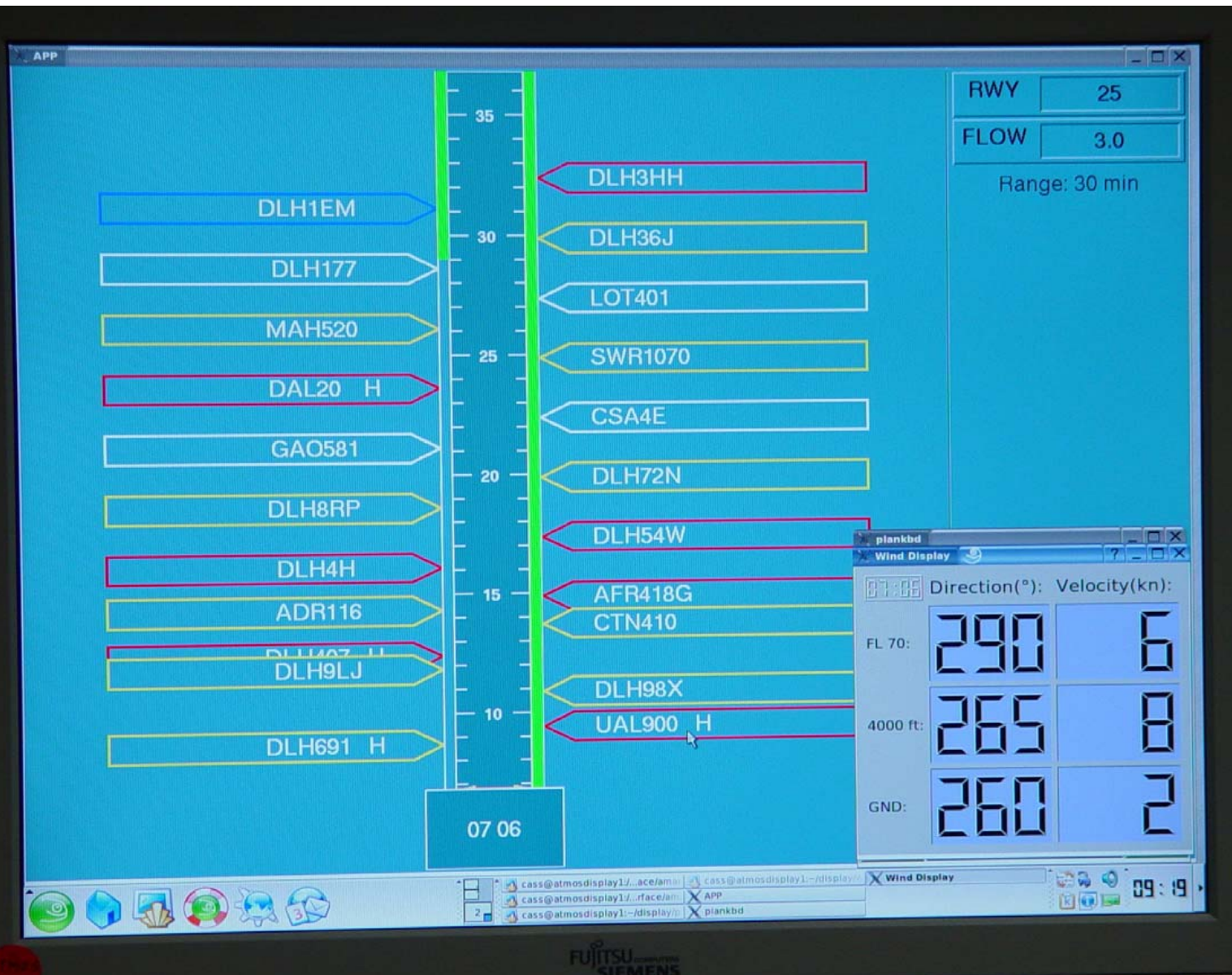
ATC Controller



Pseudo Pilots

# Integration in the Air Traffic Control environment

## ATC controller's planning screen



### Planning Display

A/C on side of green bar may be separated by 2.5 NM

Time horizon 30 min.

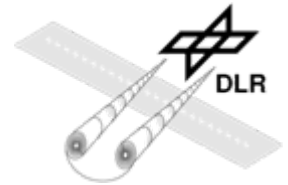
### Wind Information



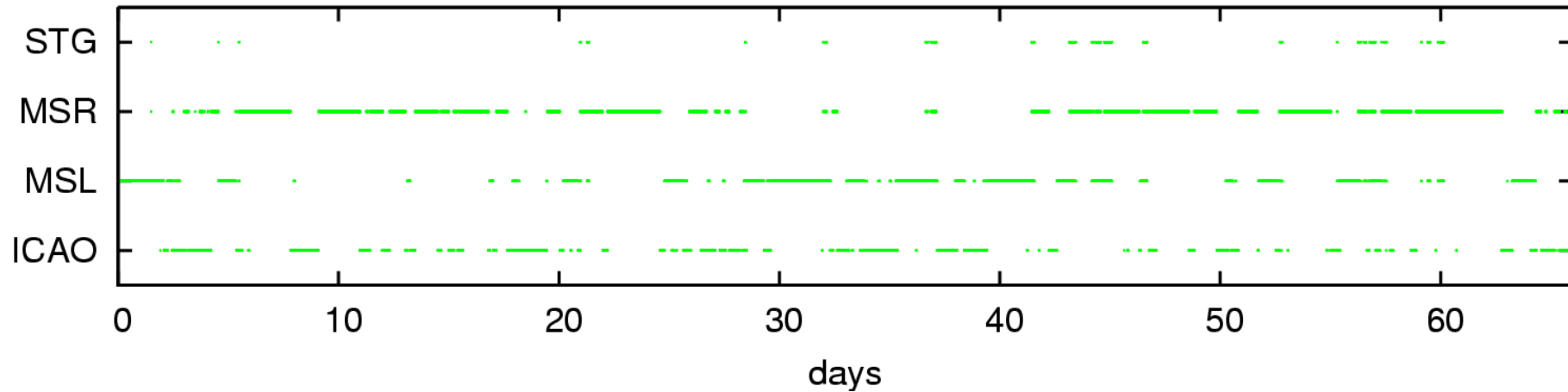
- FL 70
- 4000 ft
- Ground

Time horizon 12 min.

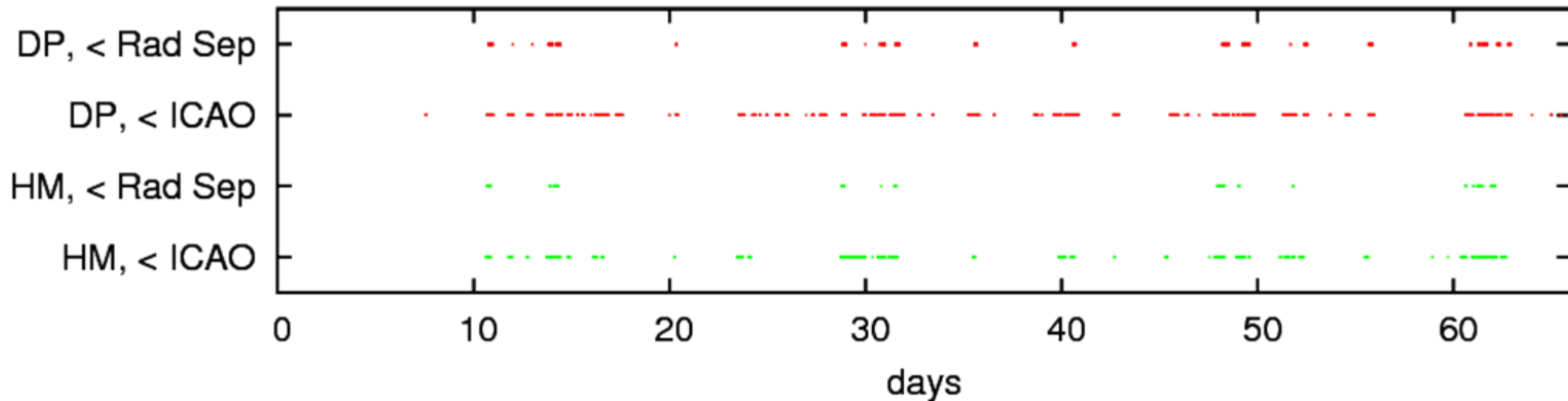
# potential capacity gain (06/12/20 - 07/02/28)



WSV - CSPR - weight classes

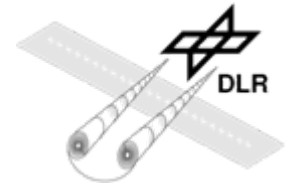


WSV - single rwy - dynamic pairwise



# potential capacity gain offered by WSVBS

(neglecting real traffic, ...)



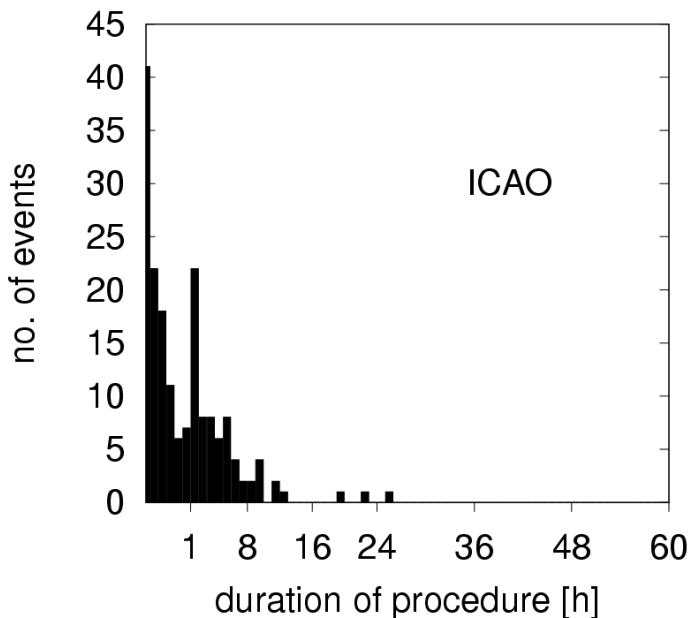
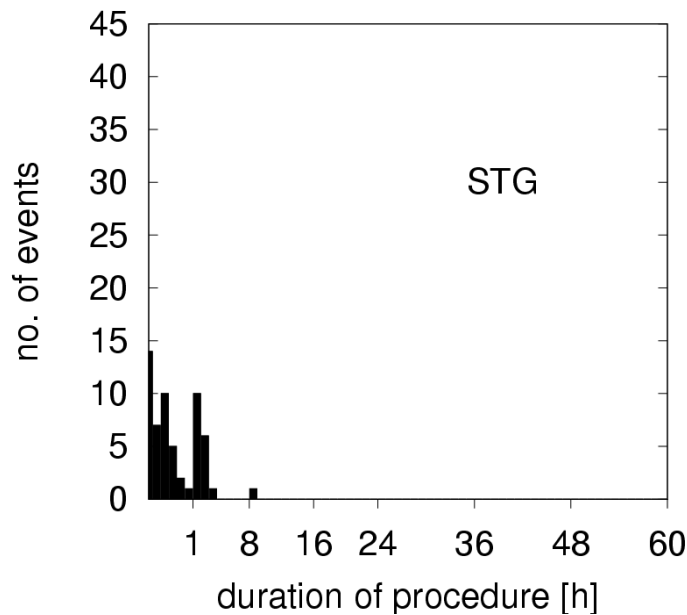
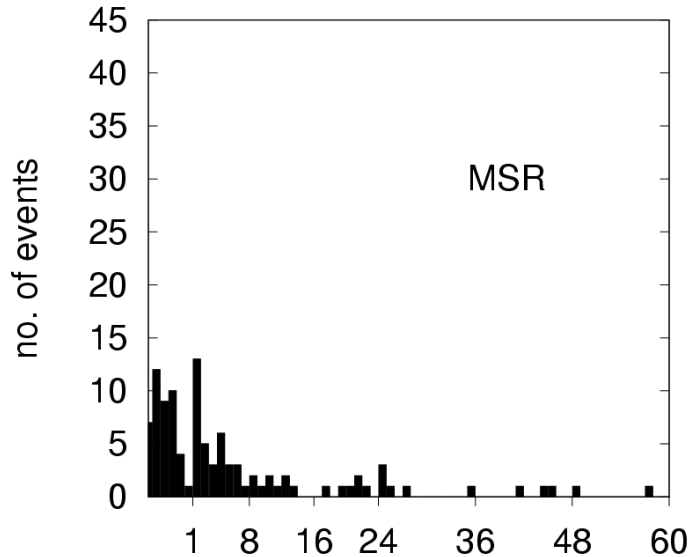
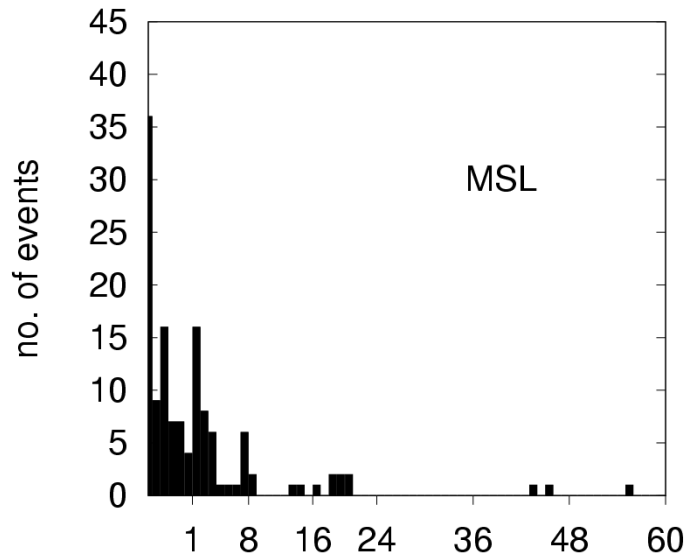
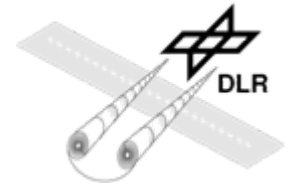
## synthetic meteo data full year 2004

| PROC   | MTS  | PoU  |
|--------|------|------|
| MSL    | 0 s  | 39%  |
| MSR    | 0 s  | 43%  |
| STG    | 0 s  | 6.1% |
| ICAO   |      | 24%  |
| SGL-HM | 58 s | 2.8% |

## WSV 06/07 66 days

| PROC   | MTS  | PoU  |
|--------|------|------|
| MSL    | 0 s  | 31%  |
| MSR    | 0 s  | 48%  |
| STG    | 0 s  | 3.6% |
| ICAO   |      | 25%  |
| SGL-HM | 62 s | 1.5% |
| SGL-DP | 58 s | 2.8% |

# duration of procedures (06/12/20 - 07/02/28)



median durations:

MSL - 40 min

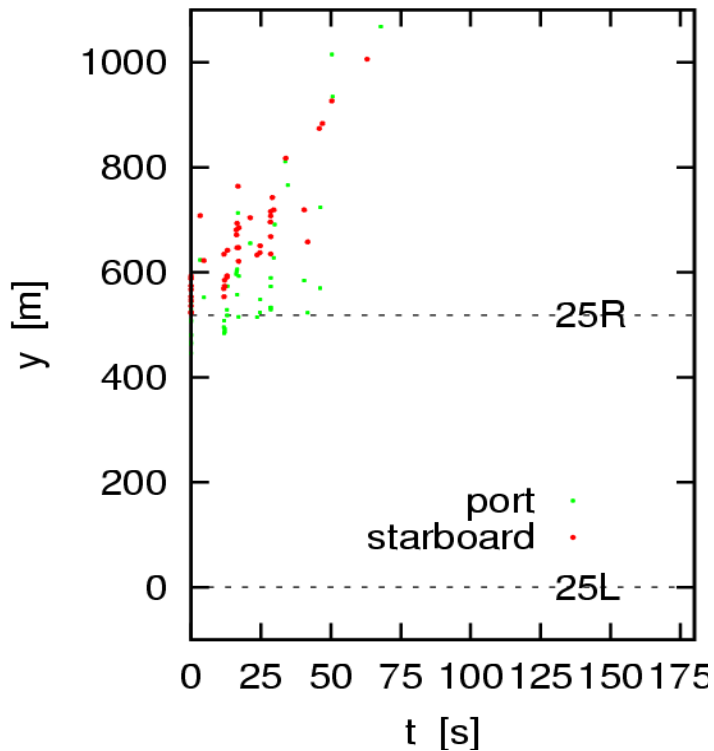
MSR - 90 min

STG - 30 min

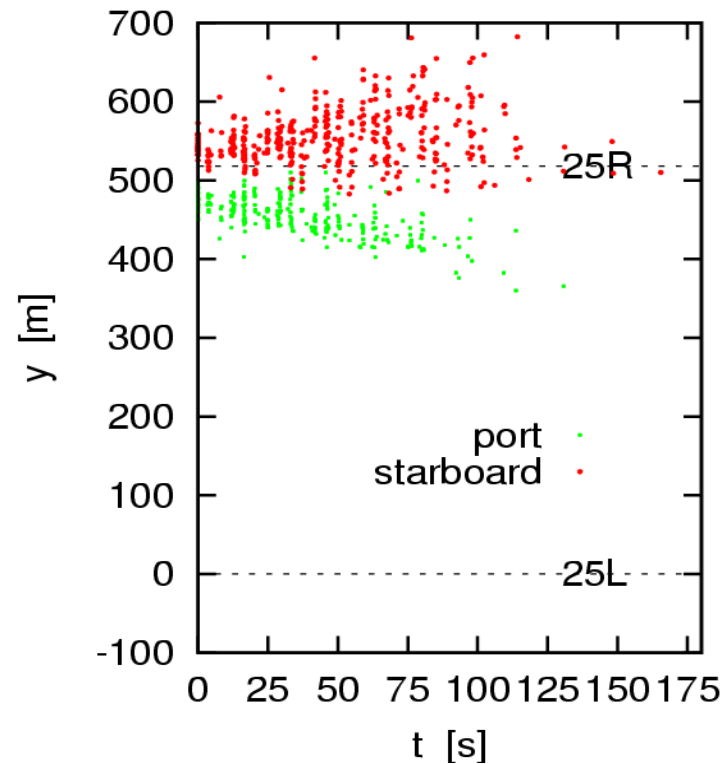
ICAO - 40 min

# Examples of LIDAR monitoring in the last three gates

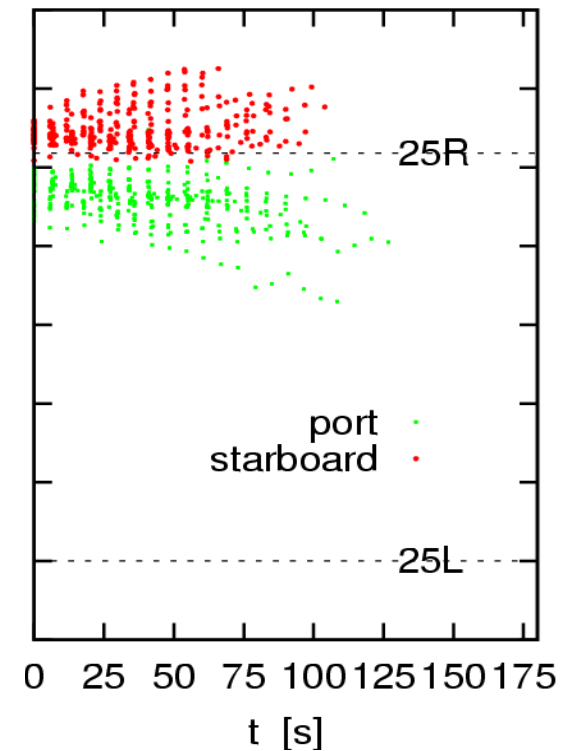
18 Jan 2007 - MSR, SGL in part



30 Jan 2007 - STG, MSL

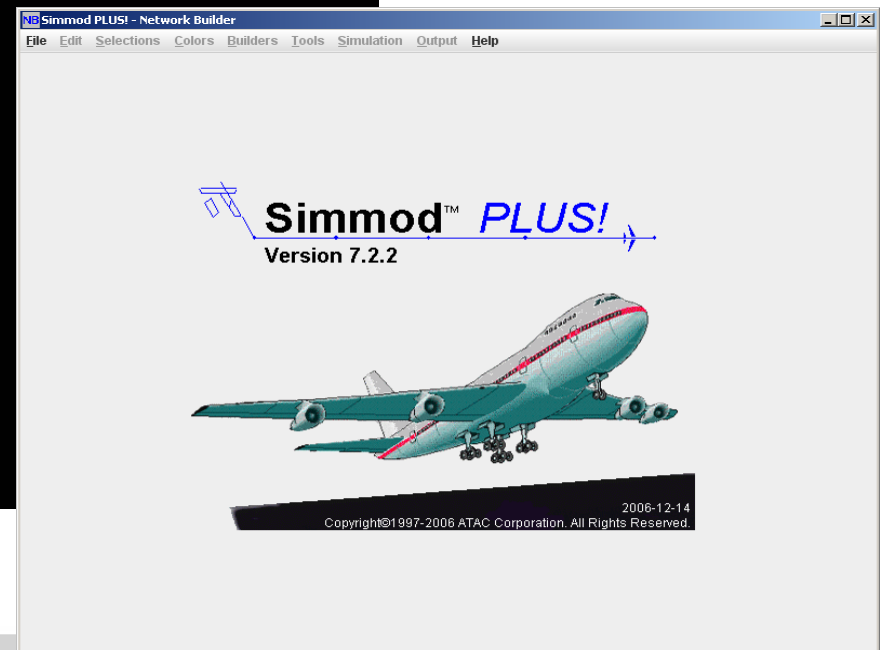


8 Feb 2007 - STG, MSR

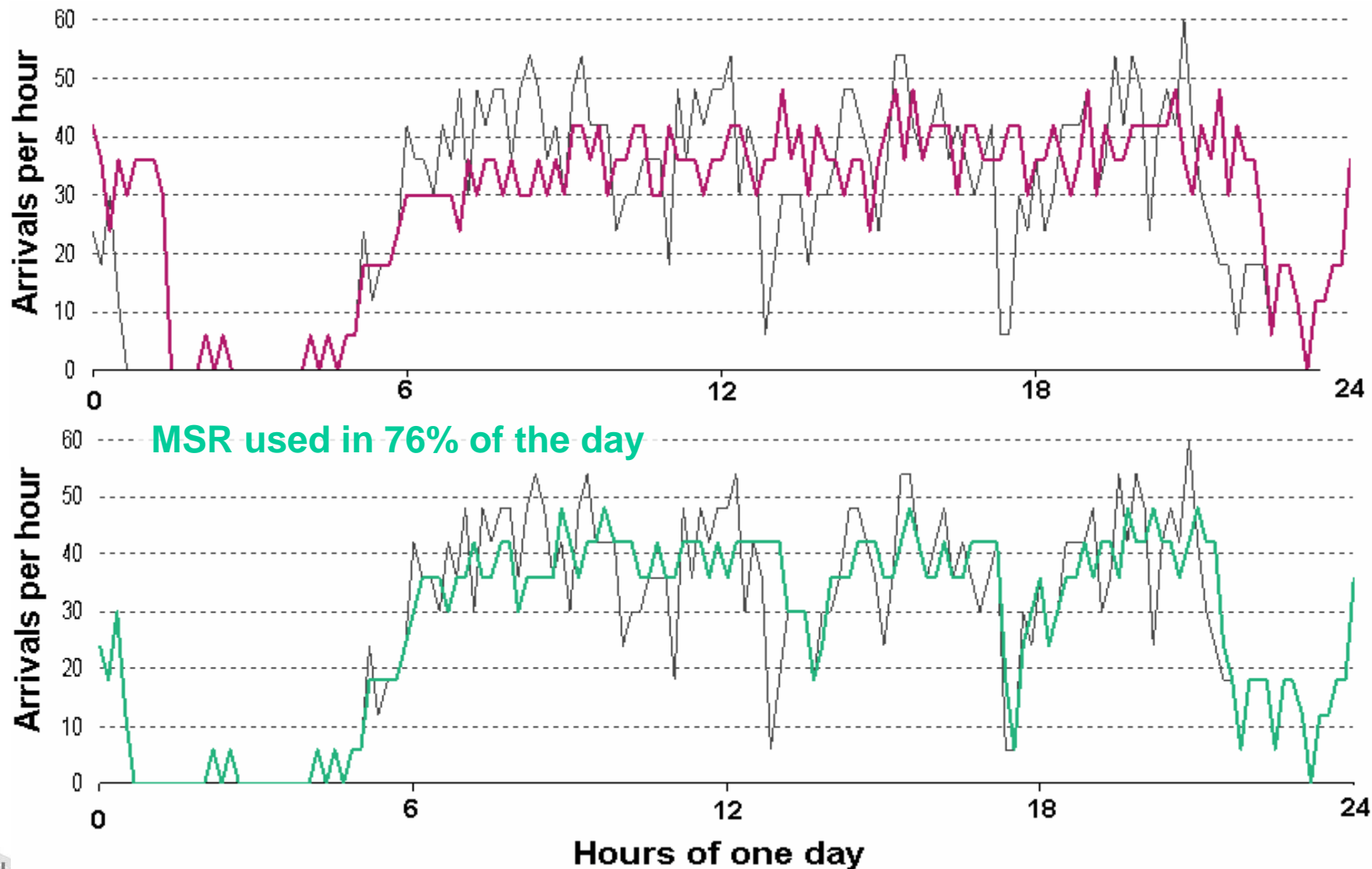


## Fast-time simulations

- 

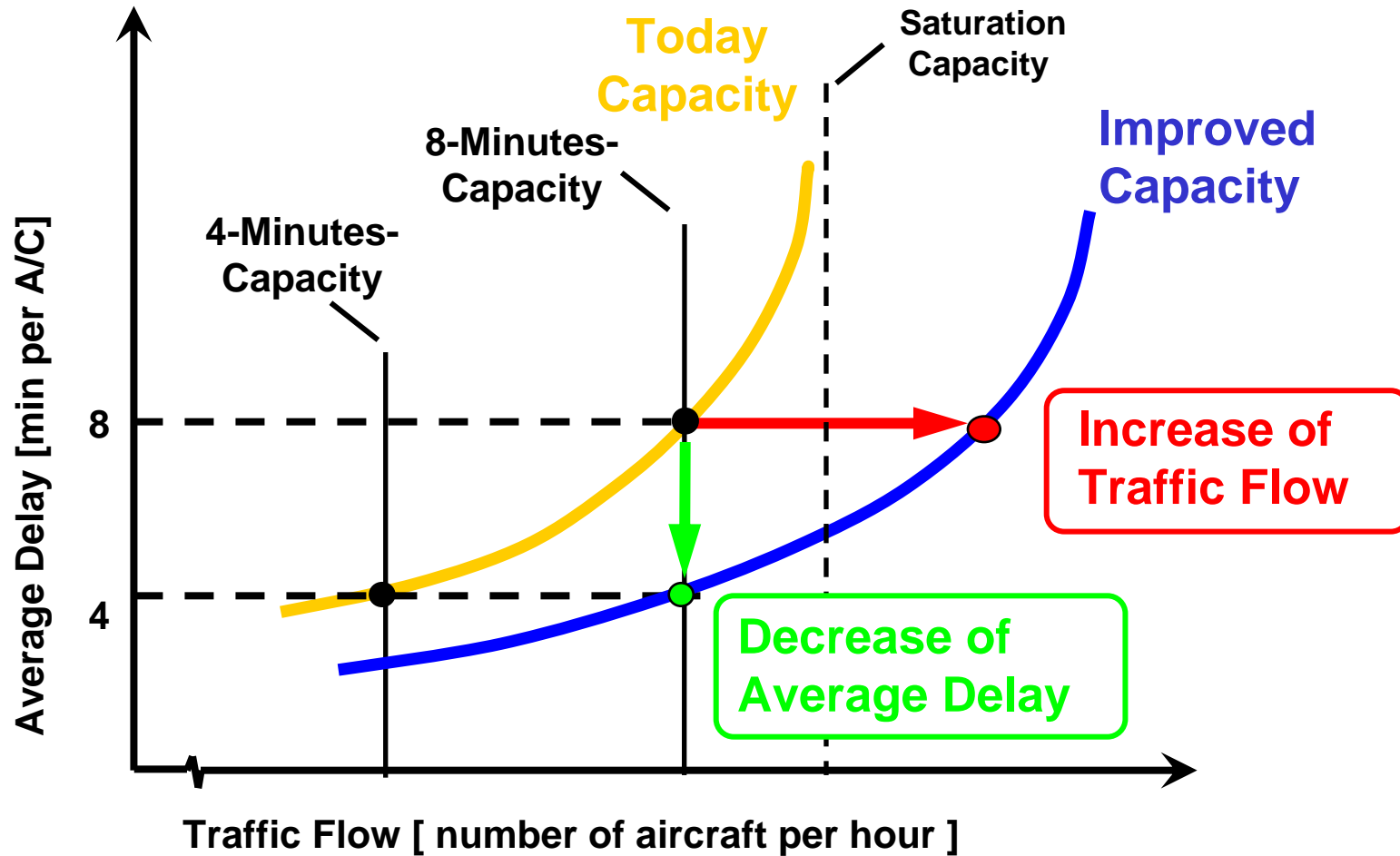


# fast-time simulations: arrivals per hour on a "heavily loaded" day (721 arrivals)



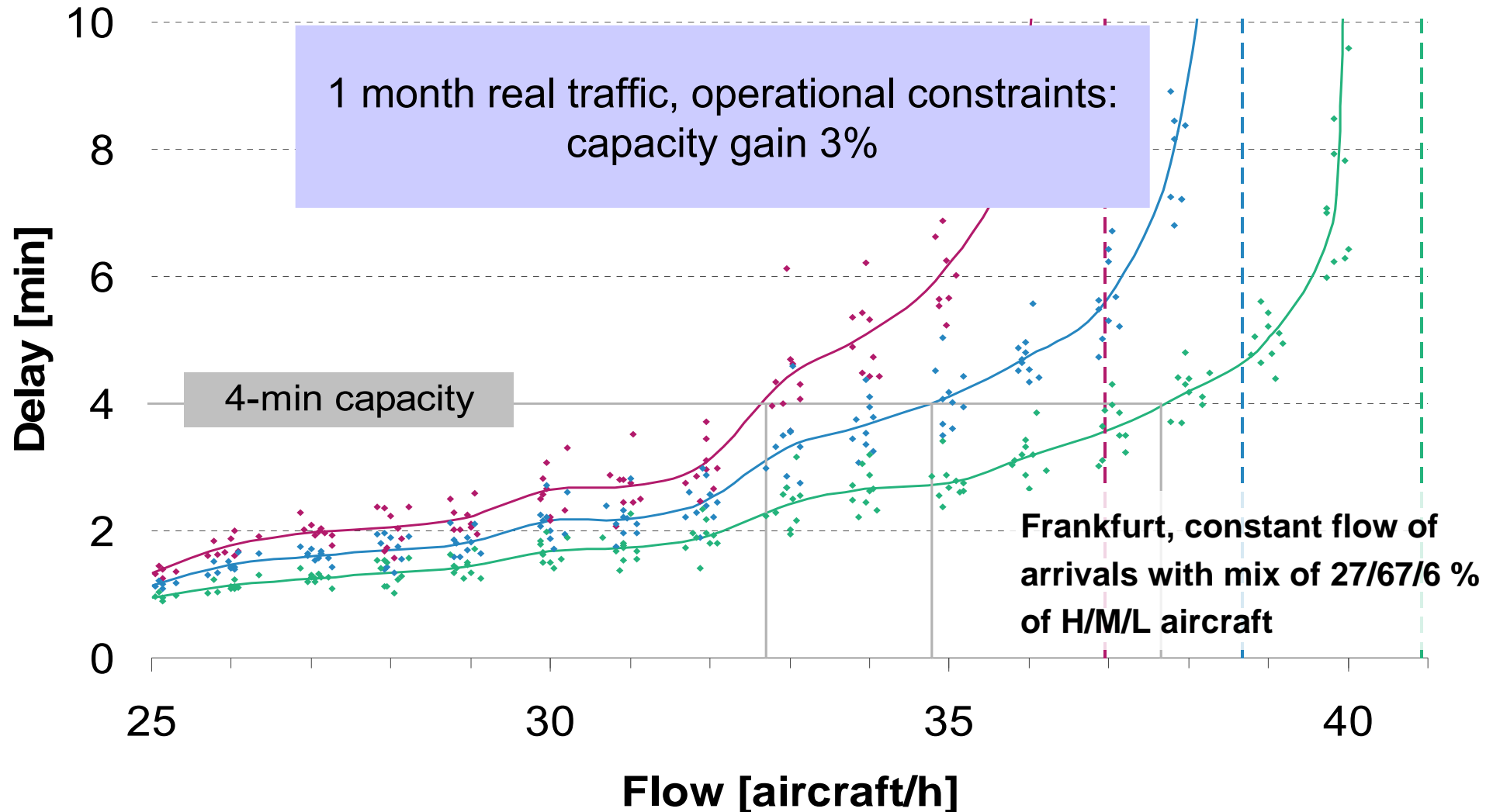
# Integration in the Air Traffic Control environment

Reducing delays or increasing capacity ?



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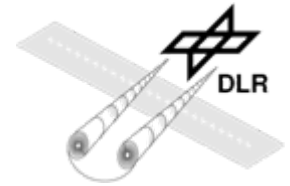


# Conclusions

- The Wake Vortex Prediction and Monitoring System, WSVBS, exists  
components: **SODAR/RASS/USA/NOWVIV/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 runways
- WSV is integrated into AMAN (ATC environment)
- the LIDAR monitors the crucial altitudes

## **From 66 days collected between 06/12/20 and 07/02/28**

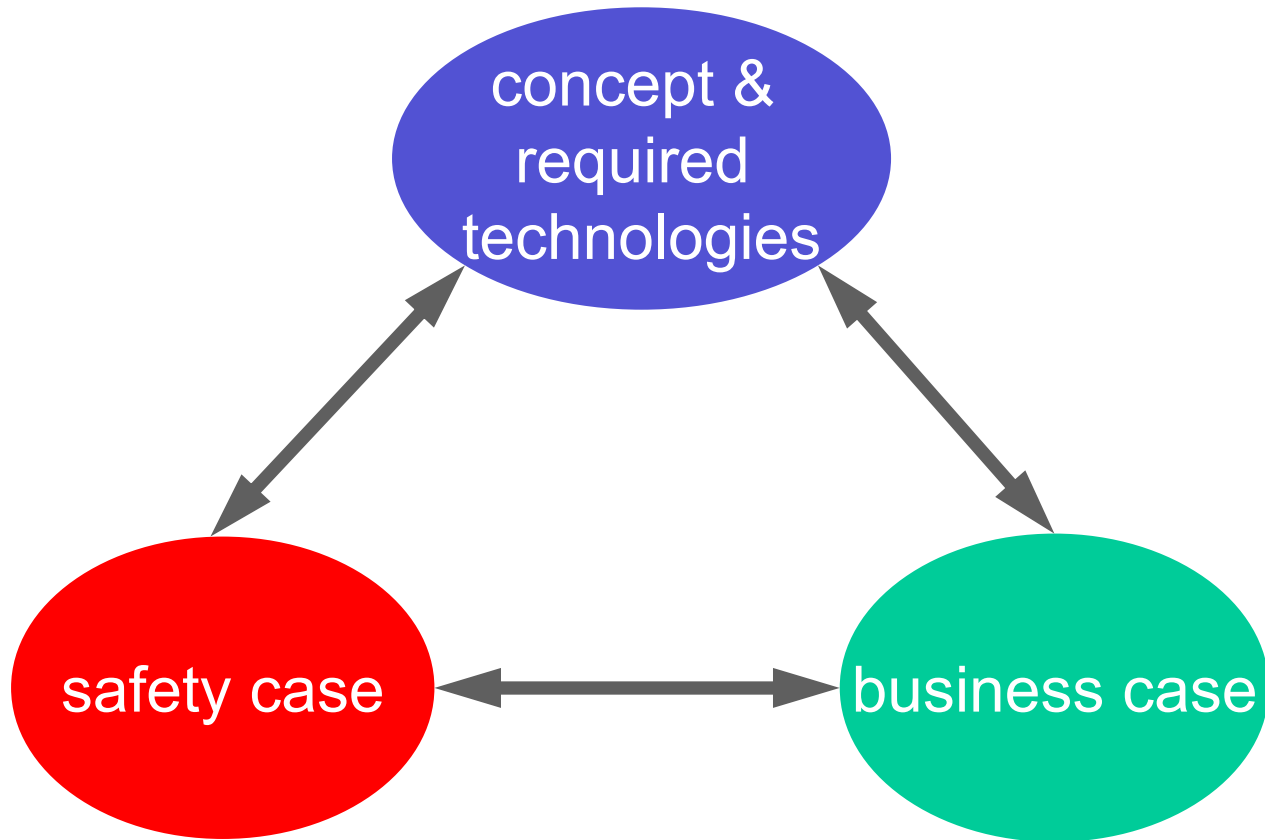
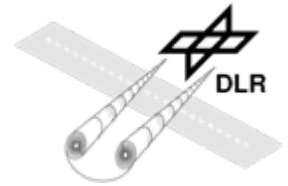
- potential use of new ConOps (DFS) in 75% of the time
- median durations of procedures amount from 30 min for STG to 90 min for MSR
- potential capacity gain 3 - 4 % (DFS' ConOps only)
- dynamic pairwise (2.8%) almost doubles usage compared to weight class comb. (1.5%)
- the predictions were safe: no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



# Research Needs

- identify required accuracy of meteo measurements & predictions  
& of WV predictions  
⇒ defines requirements for improvements; concept feasible & economical?
- ensure that meteo systems developed in SESAR WP11.2 will provide all required parameters (accuracy, coverage, temporal & spatial resolution)
- comprehensive risk analysis to adjust consistent confidence levels  
(also important for business case)
- *WV warning* system for prevention of encounters with currently used a/c seps.

# Research Needs



⇒ iterative refinement