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# Improving the mitigation of wind hazards in ATM operations with Ground-based Wind Doppler LIDARs

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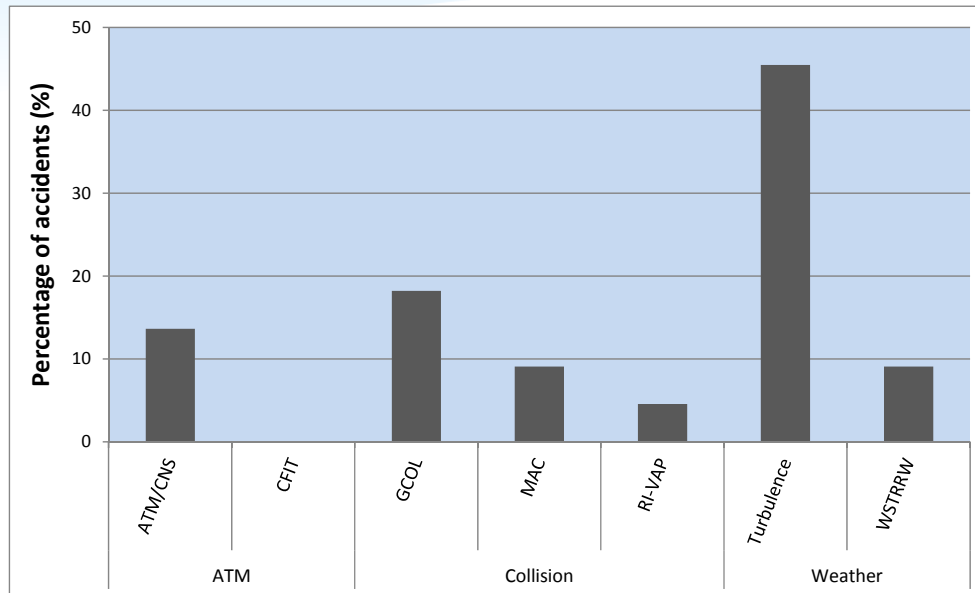


SESAR Innovation Days, 1-3 December, Bologna, Italy

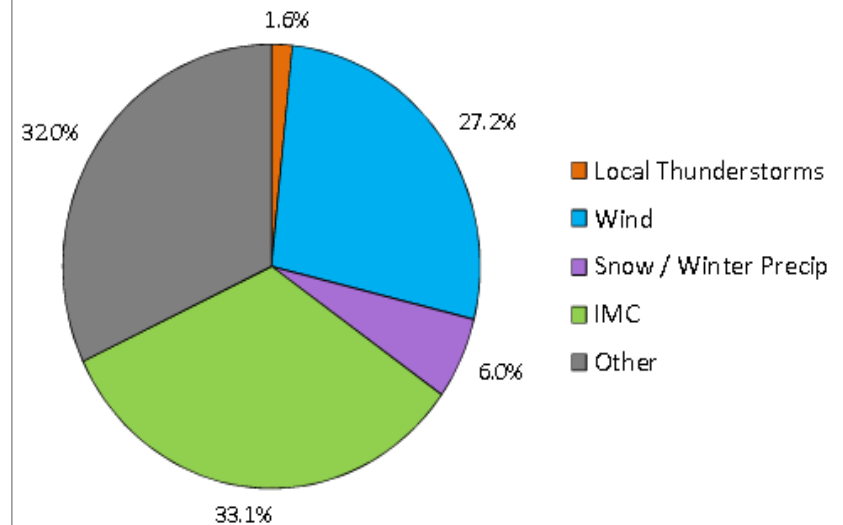


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# Motivation



Source : EUROCONTROL Performance Review Report 2012



Source Klein et al., ATM Seminar 2009, Weather Forecast Accuracy: Study of Impact on Airport Capacity and Estimation of Avoidable Costs

## Weather has a major impact on ATM

- Half of accidents are weather related (turbulence, wind, wind shears, convective weather, icing)
- 20% to 70% of delays are weather related – Cost of 2.5billion in Europe

# Objectives

## ■ Improving Weather awareness by enhancing observations

- Provide more accurate and resolved observations
- Provide relevant and useful real time alerts

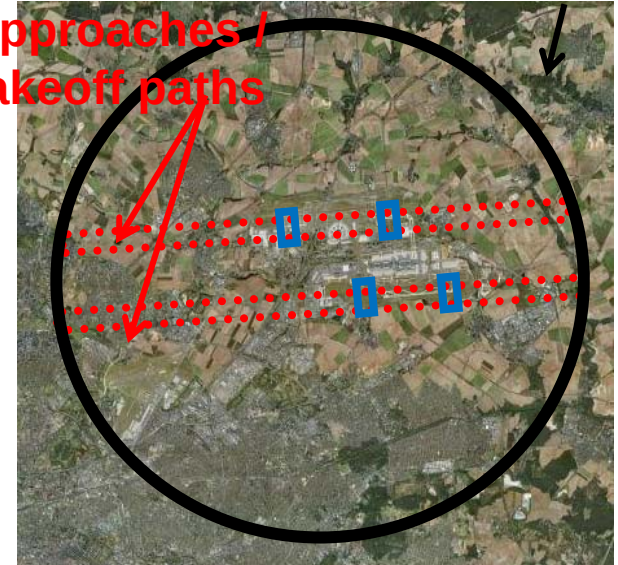
## ■ Improving Weather forecasts

- Develop high resolution NWP models
- Enhance the observations networks for assimilation

## ■ Functional requirements formalized in SESAR

- Headwind, CrossWind, Wind Shears, Turbulence, Cloud coverage
- Three area of interest: 360° / Approaches / Very final
- Focus below 500m (<1500ft)
- Accuracy better than 0.5m/s

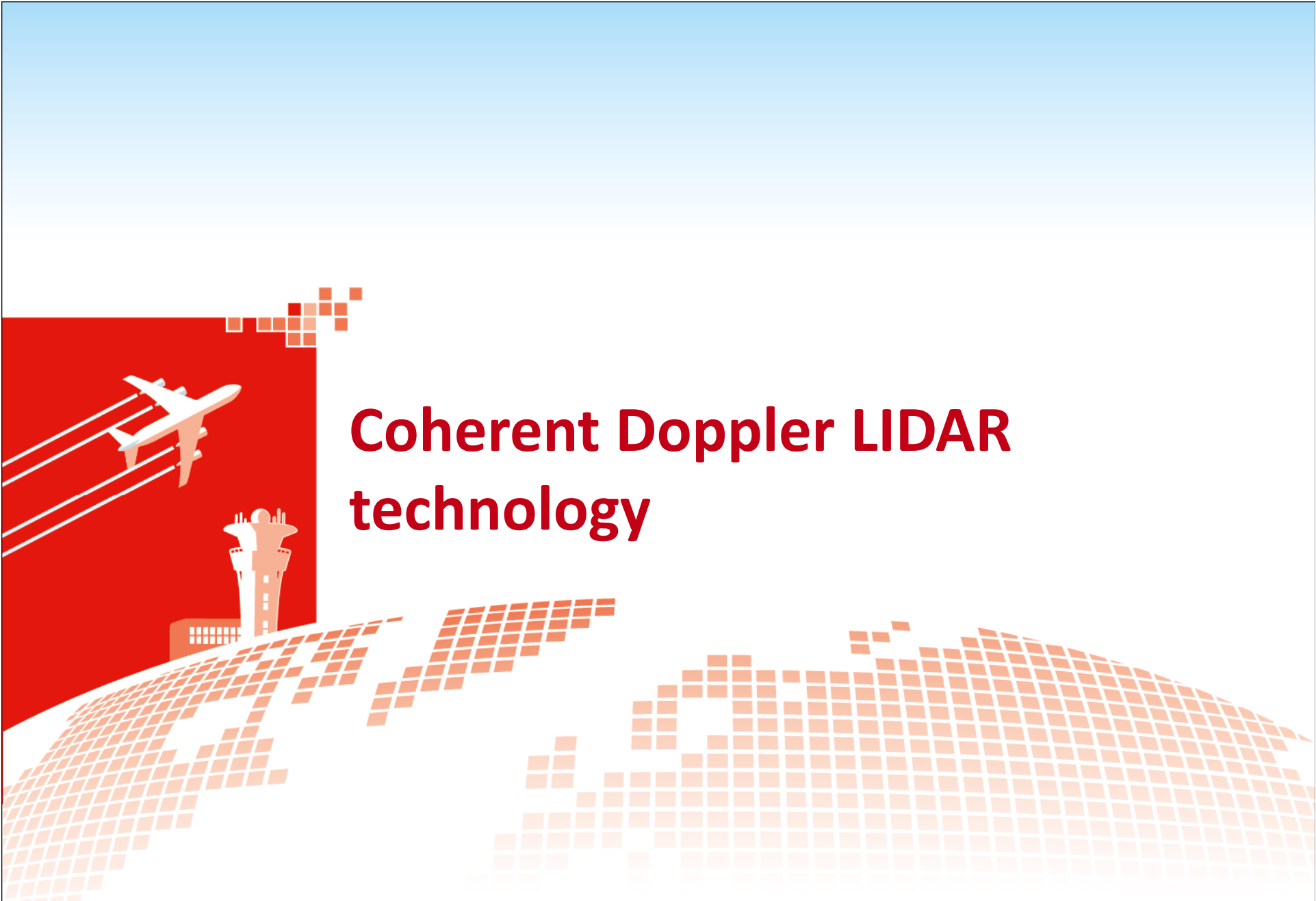
Approaches /  
takeoff paths



360°  
warning

## ■ New LIDAR technologies are now available

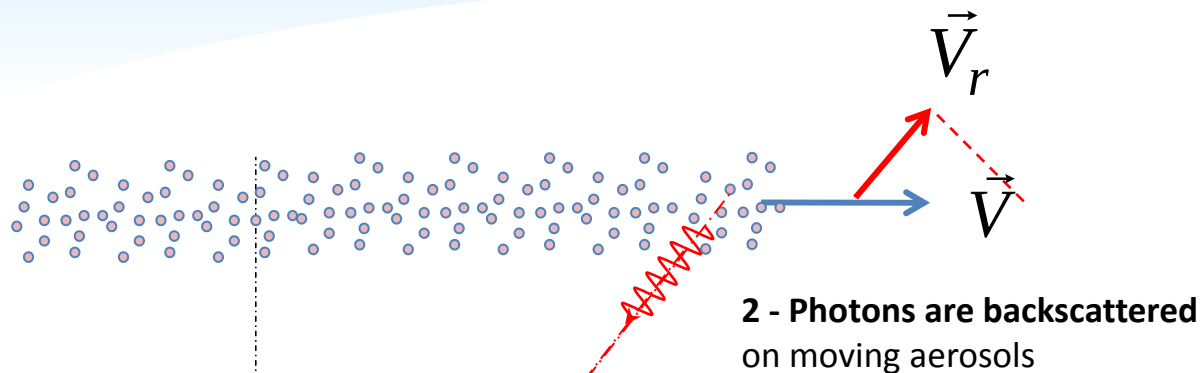
- What are their capabilities for measuring wind and wind hazards?
- What are their benefits for ATFM / ATM applications ?



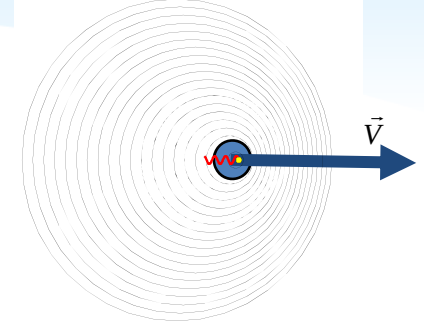
# Coherent Doppler LIDAR technology



# Principle of new Pulsed Doppler LIDARs

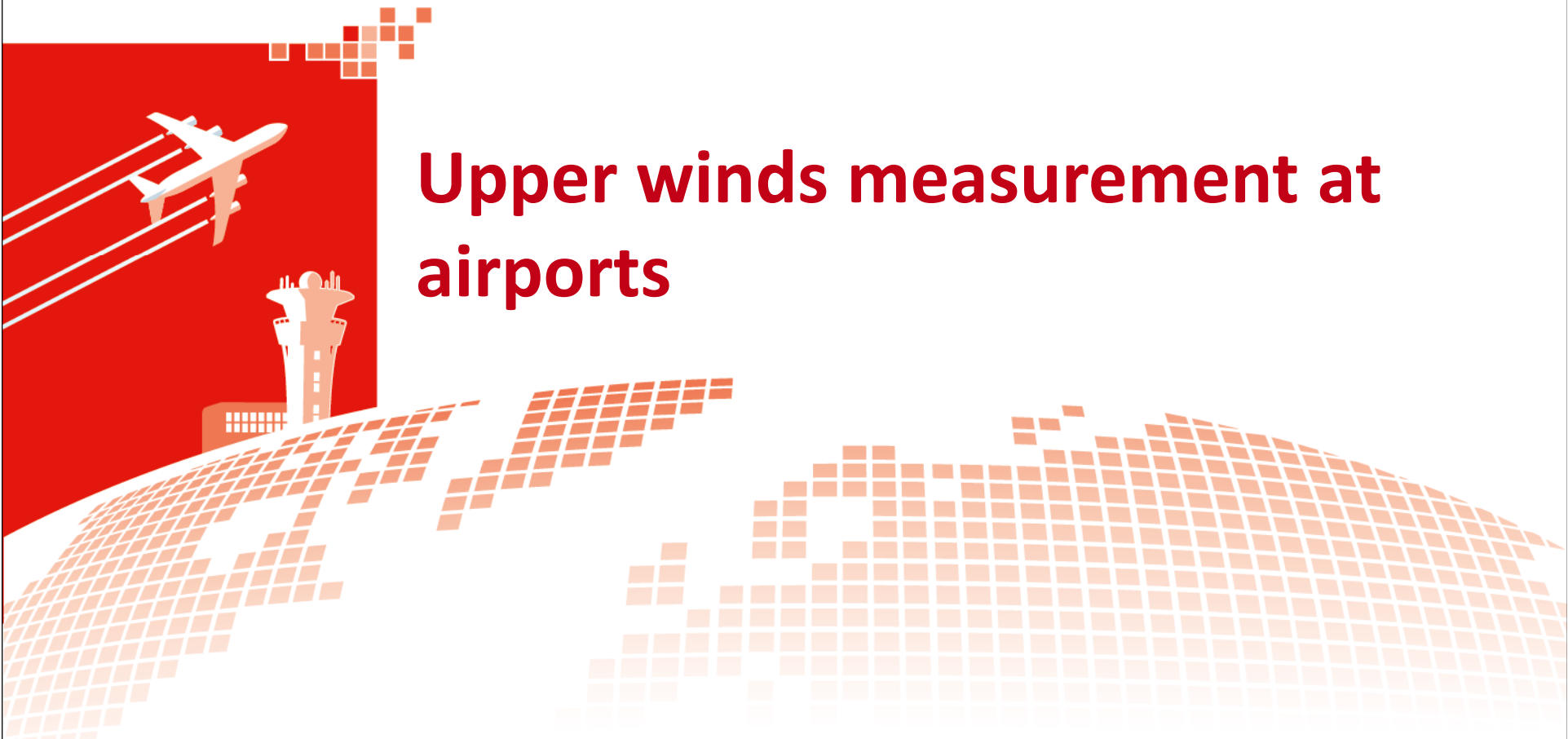


Doppler effect



$$fd = 2V_r/\lambda$$

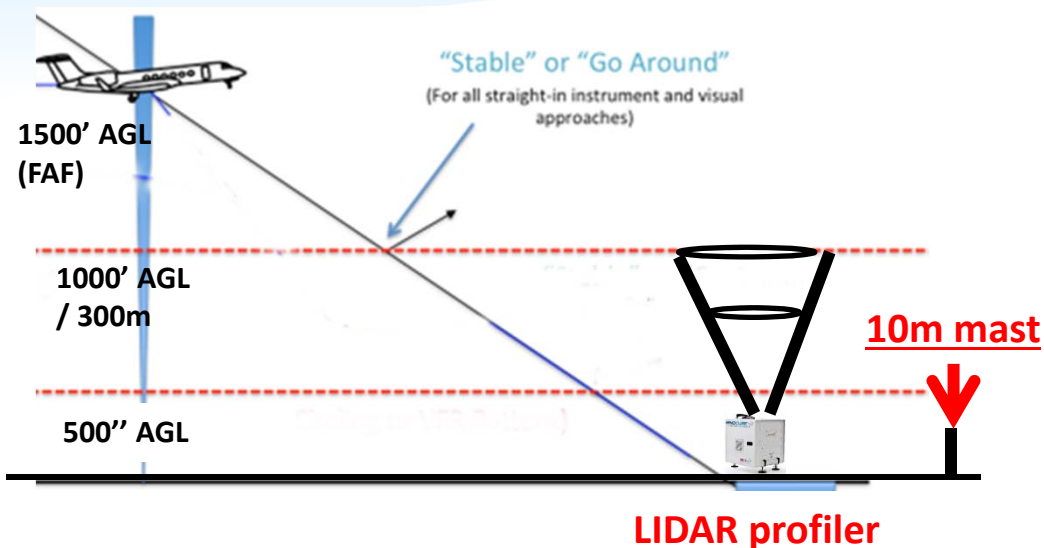
- Measure **remotely** and **accurately** winds at **precise** locations
- Detect aerosol / cloud layers
- Reduction of costs with LIDARs based on fiber technology
- Limitations: nominal performances under clear air / light rain conditions + Range compared to radars



# Upper winds measurement at airports



# LIDAR Wind Profiler



|                   |             |
|-------------------|-------------|
| Measurement range | 40 to 300 m |
|-------------------|-------------|

|           |      |
|-----------|------|
| Frequency | 1 Hz |
|-----------|------|

|                         |                   |
|-------------------------|-------------------|
| Measurement range gates | 12 simultaneously |
|-------------------------|-------------------|

|                     |        |
|---------------------|--------|
| Wind speed accuracy | 0.1m/s |
|---------------------|--------|

|                  |             |
|------------------|-------------|
| Wind speed range | 0 to 60 m/s |
|------------------|-------------|

|                         |    |
|-------------------------|----|
| Wind direction accuracy | 2° |
|-------------------------|----|

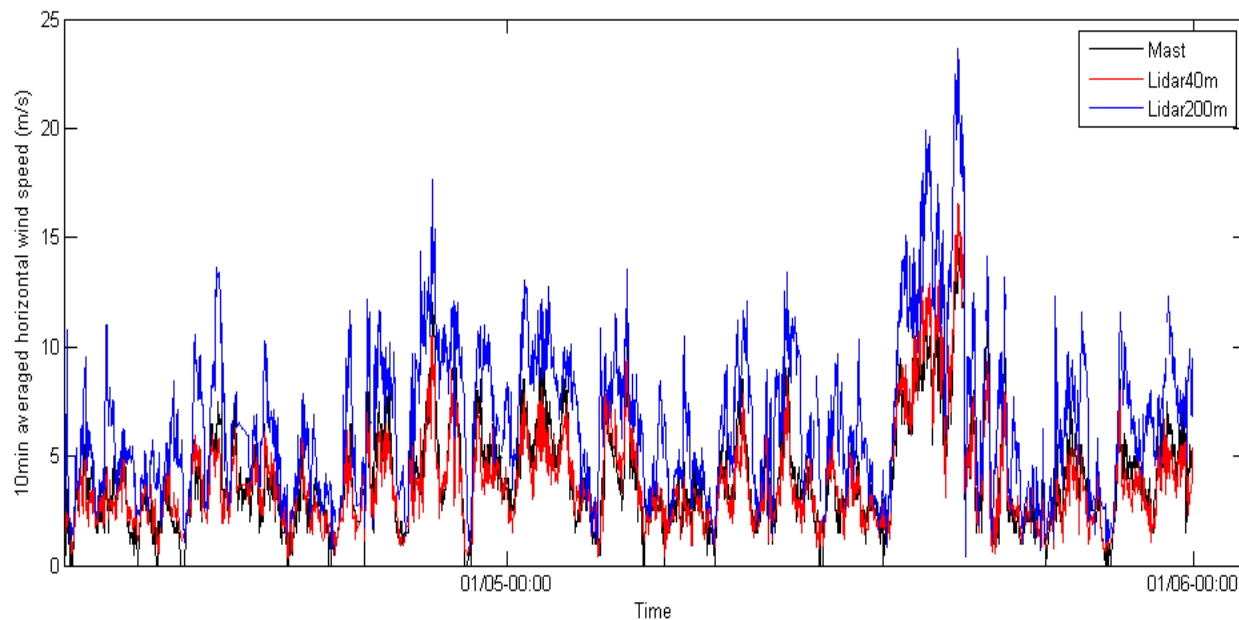
|             |      |
|-------------|------|
| Consumption | 45 W |
|-------------|------|

|        |       |
|--------|-------|
| Weight | 45 kg |
|--------|-------|

- Surface wind standardized in ICAO Annex 3 are not well representative of winds affecting aircrafts
- LIDAR Profiler can provide upper measurements up to 1000feet
  - 1s wind speed and direction
  - Averaged wind speed and direction, and wind standard deviations (usually 10min)
  - Optional: EDR, TKE, fog layer detection

# Application of LIDAR Wind Profiler at Toulouse-Blagnac airport

- Trial in April/May 2014 at Toulouse-Blagnac airport (UFO project)
- Data availability ~98% at 200m
- Mean difference between wind at 200m of LIDAR and surface wind of anemometer ~2.7m/s and standard deviation of 4.5m/s

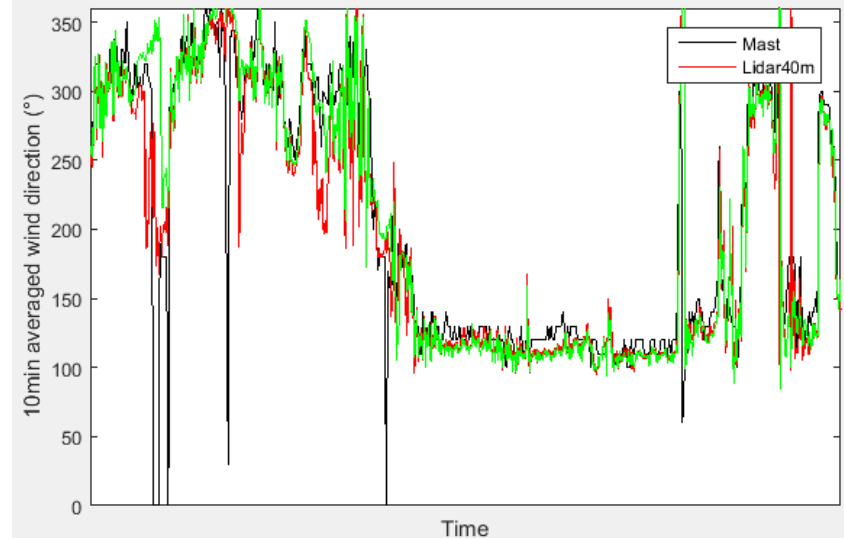


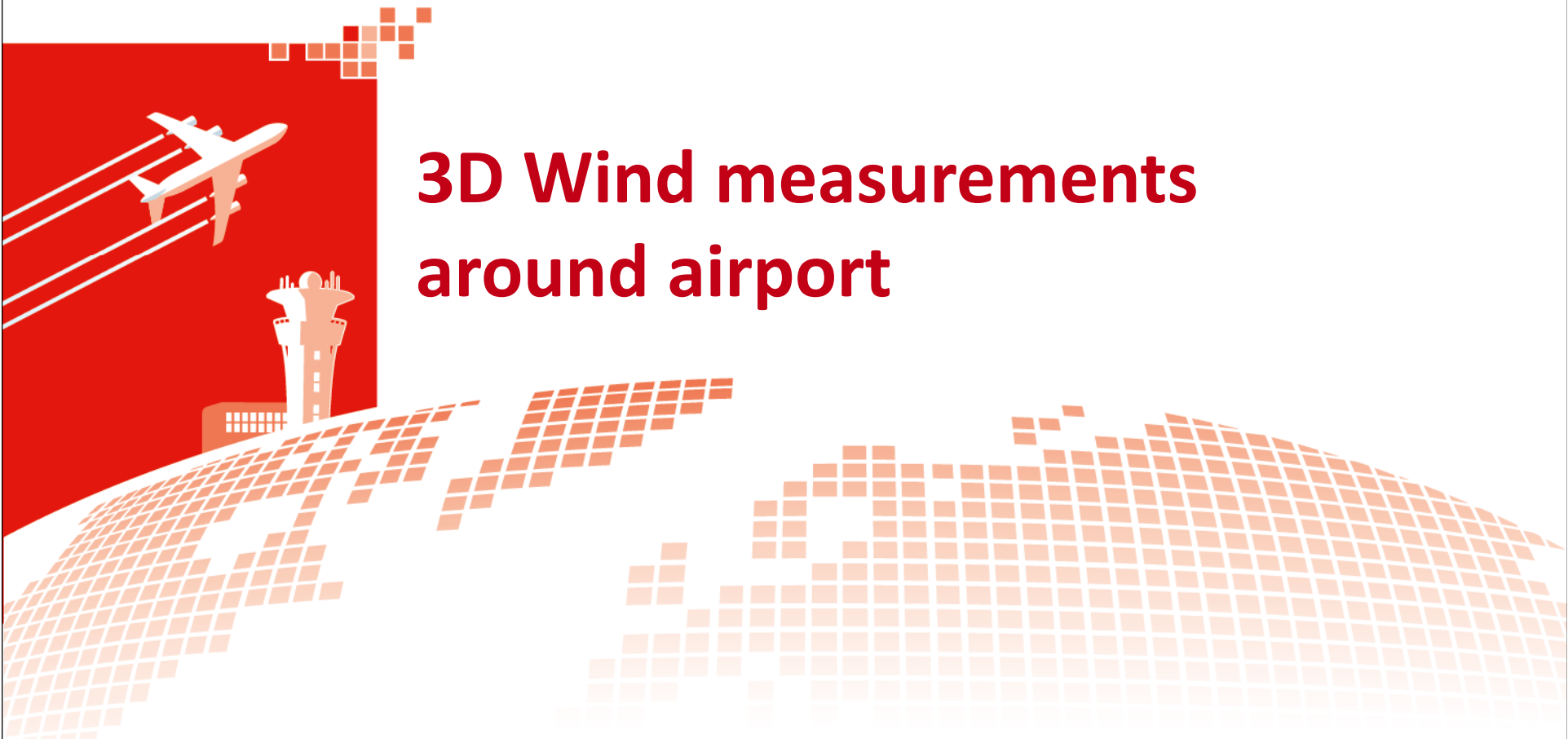
# Application of LIDAR Wind Profiler at Toulouse-Blagnac airport

■ In some cases, wind direction at surface can be very different from wind direction at 40m or 200m

■ Examples of practical applications where surface winds are limiting

- How to manage runway direction if wind direction is known with an uncertainty of  $180^\circ$  ?
- How to inform dangerousness of crosswinds along approach for airports in urban / complex area with only surface winds ?
- At airports in urban area, some procedures for reducing noise are underdevelopments for allowing landings with light tailwinds (5kts), can LIDARs do the job and allow these procedures to go forward ?





# 3D Wind measurements around airport

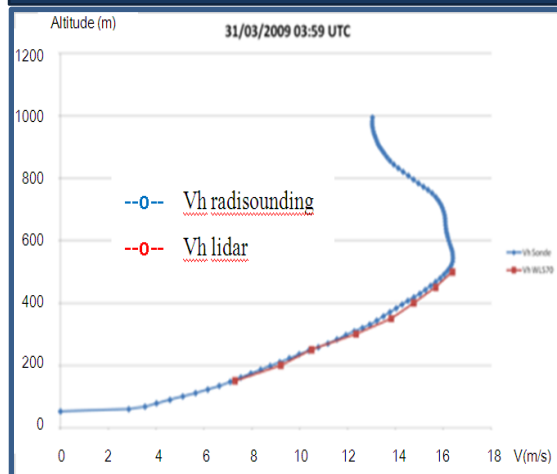


# Scanning Doppler LIDAR features

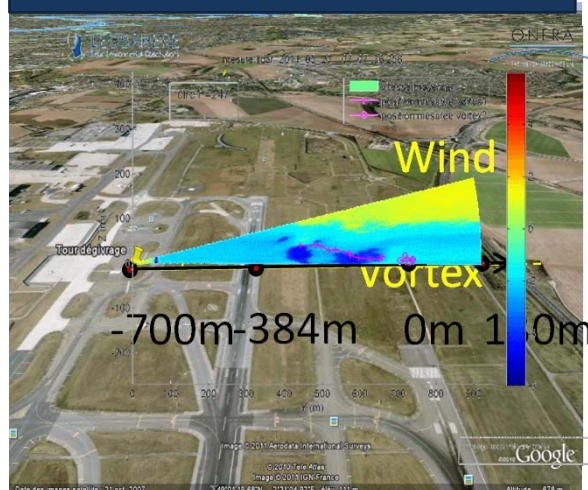


- **Measurement capability :**
  - Raw data: Doppler spectrum, lidar signal (CNR)
  - Wind: radial wind speed, wind barbs, turbulence (TKE, EDR)
  - Backscatter coefficient
- **Range :** up to 10km
- **Scanner rotation speed :** up to 8°/s
- **Angle resolution :** 0,1° resolution
- **Spatial resolution :** between 25m and 200m.

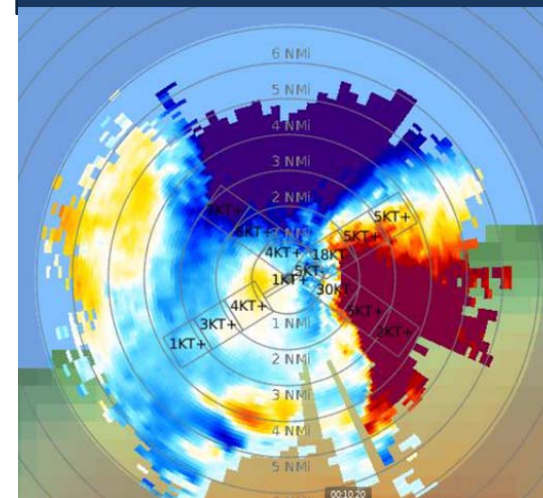
## DBS Mode



## RHI Scan



## PPI Scan





# Wake turbulence separations



# Wake turbulence separations

## ■ Motivation Safety + Airport capacity

- Most accidents during approach at low altitude
- Min Distance separations imposed by ICAO regulations **limit airport capacities** (per runway) (ICAO Doc 4444)

Wake Turbulence  
Accidents per  
Flight Phase

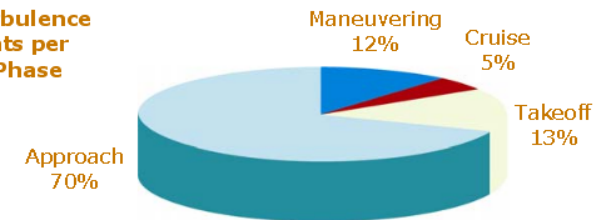


Figure 1

US Wake Turbulence Accidents, 1983-2002

(Source: Flight Safety Foundation – Flight Safety Digest March-April 2002)

## ■ The RECAT project (Wake Turbulence Recategorisation) launched in 2005 initiated by FAA and EUROCONTROL

- Phase 1 : New static distance separation between aircrafts with 6 categories
- Phase 2 : Pairwise distance separation
- Phase 3 : Dynamic pairwise separation or Weather dependent separation

➔ **Strong interest to initiate / implement operationally new wake turbulence regulations like RECAT-EU**

➔ **Still many things to do on the weather dependent separation in WP-E ?**

# RECAT-Phase 1: RECAT-Eu

- Splitting of heavy and medium categories into 2 sub-categories (upper and lower) and define distance separation for each sub-category

| Leader / Follower                  | A380-800 | HEAVY | MEDIUM | LIGHT |
|------------------------------------|----------|-------|--------|-------|
| A380-800                           |          | 6 NM  | 7 NM   | 8 NM  |
| HEAVY<br>MTOM ≥ 136 tons           |          | 4 NM  | 5 NM   | 6 NM  |
| MEDIUM<br>7 tons ≤ MTOM < 136 tons |          |       |        | 5 NM  |
| LIGHT<br>MTOM < 7 tons             |          |       |        |       |



| RECAT-EU scheme   |     | "Super Heavy" | "Upper Heavy" | "Lower Heavy" | "Upper Medium" | "Lower Medium" | "Light" |
|-------------------|-----|---------------|---------------|---------------|----------------|----------------|---------|
| Leader / Follower |     | "A"           | "B"           | "C"           | "D"            | "E"            | "F"     |
| "Super Heavy"     | "A" | 3 NM          | 4 NM          | 5 NM          | 5 NM           | 6 NM           | 8 NM    |
| "Upper Heavy"     | "B" |               | 3 NM          | 4 NM          | 4 NM           | 5 NM           | 7 NM    |
| "Lower Heavy"     | "C" |               | (*)           | 3 NM          | 3 NM           | 4 NM           | 6 NM    |
| "Upper Medium"    | "D" |               |               |               |                |                | 5 NM    |
| "Lower Medium"    | "E" |               |               |               |                |                | 4 NM    |
| "Light"           | "F" |               |               |               |                |                | 3 NM    |

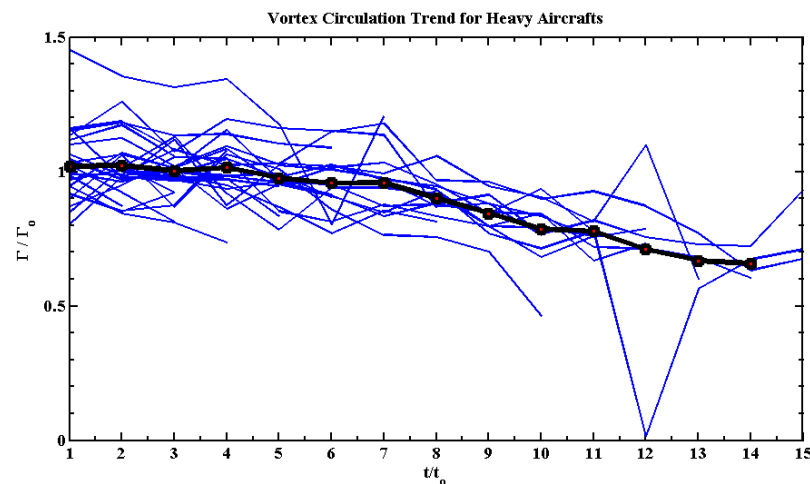
Table 2: RECAT-EU WT distanced-based separation minima on approach and departure

(\*) means minimum radar separation (MRS), set at 2.5 NM, is applicable as per current ICAO doc 4444 provisions.

- On-going implementation at Paris CDG
  - 15 other European airports planned until 2020
- Expected benefits: In EU, airport capacities increase from 3 to 8 %
- LIDAR are used before and after the implementation of such new regulations
  - Safety assessment (before) and risk monitoring (after) during one year at airports
  - LIDAR are providing wake vortex databases (localization, circulation) used for statistical analysis

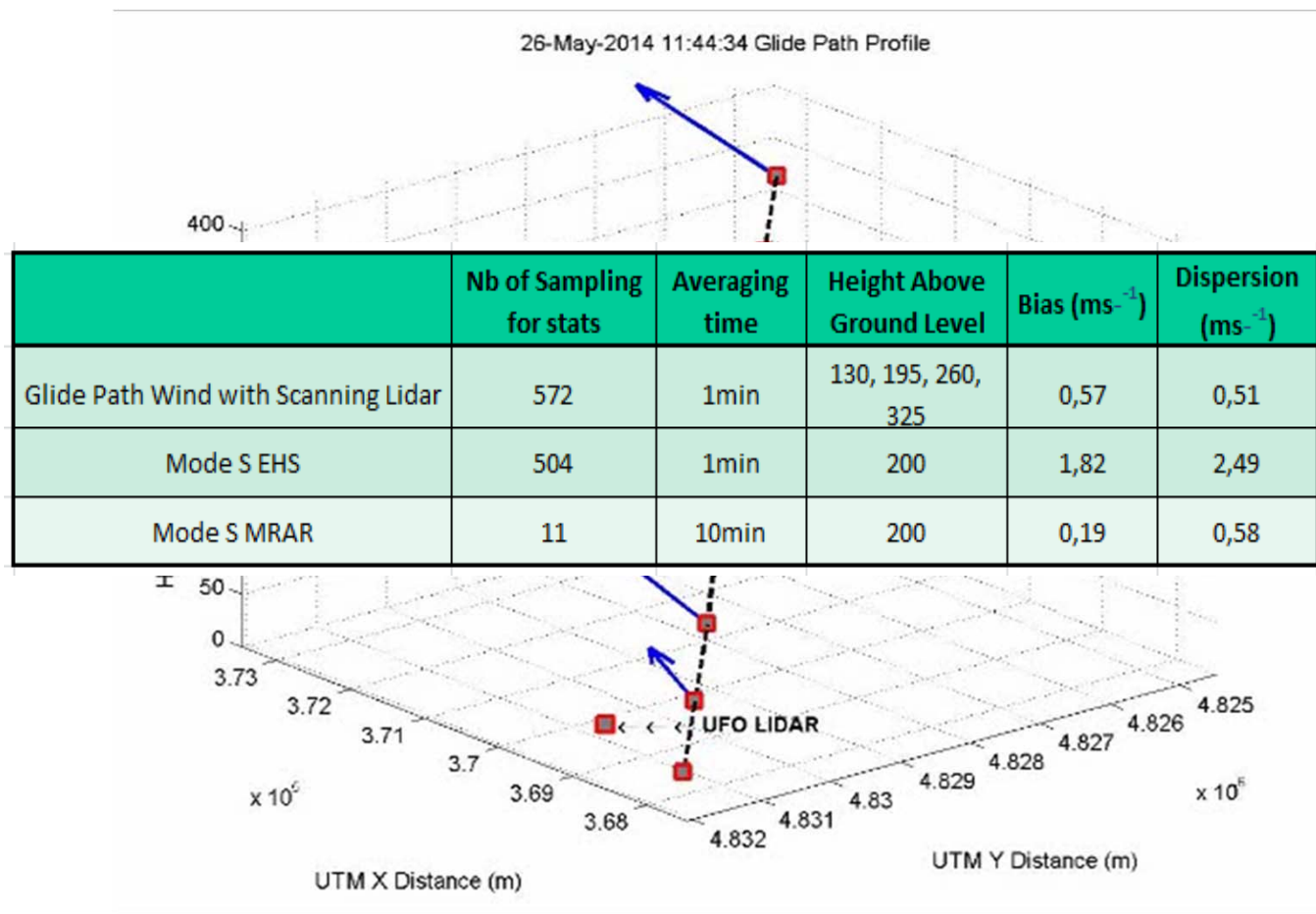
# Wake vortex data collection with Scanning LIDAR systems

| Aircraft data |                  |                   |               |                |                |               | Detection with algorithm |                            |              |                          |                           | Localisation obtained with algorithm |              |              |              |              |              |              |              | Circulation obtained with algorithm |              |              |              |
|---------------|------------------|-------------------|---------------|----------------|----------------|---------------|--------------------------|----------------------------|--------------|--------------------------|---------------------------|--------------------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|-------------------------------------|--------------|--------------|--------------|
| I° Fichie     | Heure            | Real status       | Aircraf t cat | Aircr aft type | Aircr aft spee | Index of scan | Algo detection           | Status of algorithm / real | Statu s      | Aircraft follow-up index | Follow up index per aircr | X ref 1                              | Y ref 1      | X 1          | Y 1          | X ref 2      | Y ref 2      | X 2          | Y 2          | Γ0                                  | Γ5-15 1      | Γ5-15 2      | Γ5-15 moy    |
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| 40            | 19/09/2012 10:54 | PremièreDétection | H             | A343           | 148            | 1             | PremièreDétection        | Pas d'erreur               | ok           | 1                        | 1                         |                                      |              | 370          | 51           |              |              | 429          | 42           | 317,3                               | 421,823      | -318,56      | 370,2        |
| 41            | 19/09/2012 10:55 | Suivi             |               |                |                | 2             | Suivi                    | Pas d'erreur               | ok           | 1                        | 2                         |                                      |              | 376          | 42           |              |              | 440          | 30           | 0,0                                 | 312,409      | -295,54      | 304,0        |
| 42            | 19/09/2012 10:55 | Suivi             |               |                |                | 3             | Suivi                    | Pas d'erreur               | ok           | 1                        | 3                         |                                      |              | 381          | 35           |              |              | 449          | 28           | 0,0                                 | 285,923      | -310,26      | 298,1        |
| 43            | 19/09/2012 10:55 | Suivi             |               |                |                | 4             | Suivi                    | Pas d'erreur               | ok           | 1                        | 4                         |                                      |              | 382          | 26           |              |              | -999         | -999         | 0,0                                 | 310,537      | -999         | 310,5        |
| 44            | 19/09/2012 10:55 | Suivi             |               |                |                | 5             | Suivi                    | Pas d'erreur               | ok           | 1                        | 5                         |                                      |              | 397          | 24           |              |              | -999         | -999         | 0,0                                 | 321,41       | -999         | 321,4        |
| 45            | 19/09/2012 10:55 | Suivi             |               |                |                | 6             | Suivi                    | Pas d'erreur               | ok           | 1                        | 6                         |                                      |              | 405          | 25           |              |              | -999         | -999         | 0,0                                 | 312,625      | -999         | 312,6        |

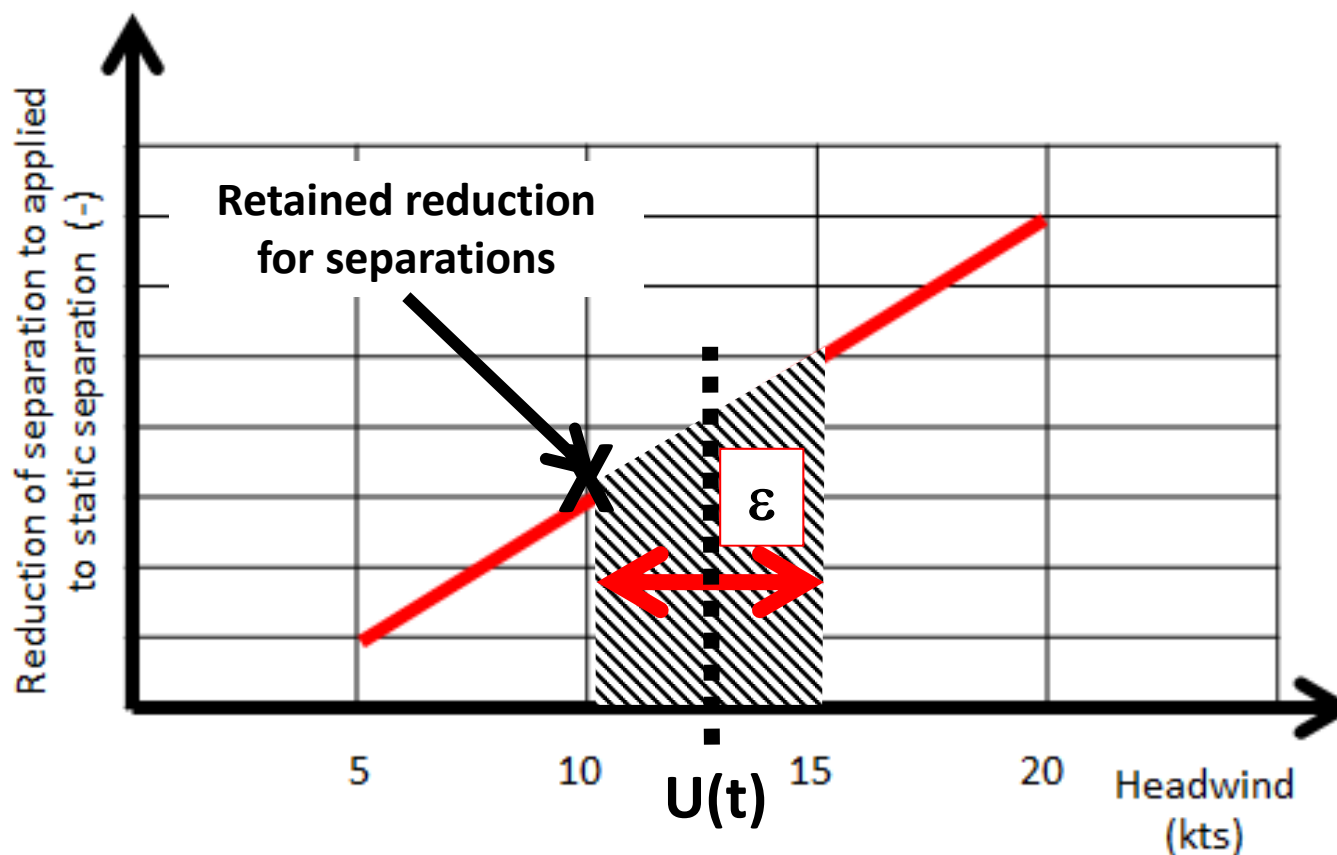


*Decay of circulation for heavy aircrafts during SESAR XP1 Trial*

# Time Based Separation



# Why headwind accuracy matters ?



- Preliminary studies show that a 1 m/s improvement on headwind accuracy correspond to a reduction of 10s of separations

# Conclusions

- ❑ Coherent Doppler LIDAR technology is now a mature technology for operational uses like aviation weather
  - ❑ Measure remotely and accurately winds at precise locations
  - ❑ Limitations: under clear air conditions and range compared to radar
- ❑ Surface winds are not well representative of winds affecting aircrafts
  - ❑ **What could be the interest of upper winds ?**
    - ❑ Runway management, landing under tailwinds, severe crosswinds...
  - ❑ Assimilation into weather forecast models showed improvements of weather forecasts in UFO FP7 project
- ❑ Scanning LIDARs have been tested and are currently used for specific applications
  - Wake turbulence studies and now operational projects (SESAR 12.2.2 and 6.8.1)
  - Wind shear detection when coupled to advanced softwares (SESAR 15.4.9c)
  - Demonstration that LIDARs can provide wind / EDR along glide path (UFO project)
  - ➔ **High potential benefits in using accurate headwind data for reducing TBS**



What's next ?  
Any idea / Question ?

