

# Measurement of Aircraft Wake Vortices Using Doppler 1.5 micron LIDAR

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- Cooperation for wake vortex research at Sendai Airport
- Doppler lidar at Sendai airport in Japan
- Our research for several years
- Advection database of wake vortices
- Data mining
- Conclusion





# Corporative structure of our activity at Sendai Airport

## Wake Vortex Advisory System

Organizer : Japan Aerospace Exploration Agency (JAXA)

Partner : Electronic Navigation Research Institute (ENRI), Tohoku University



Sendai Airport in Japan



### JAXA

- Evaluation of airplane's behavior under wake vortices



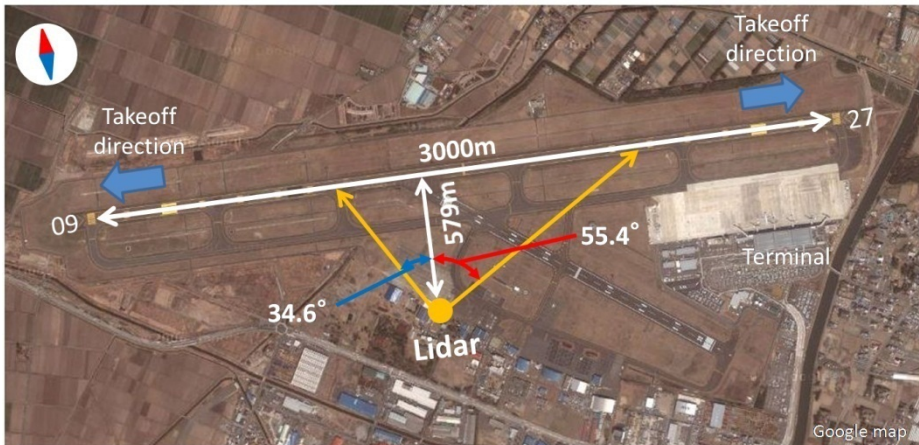
### ENRI

- Development of Doppler LIDAR
- Application to GBAS

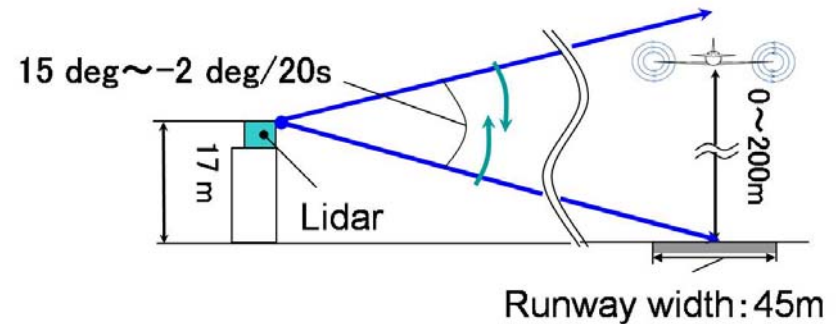
### Tohoku University

- Observation
- Simulation (CFD)

# Doppler lidar at Sendai airport in Japan



Sendai airport, Japan

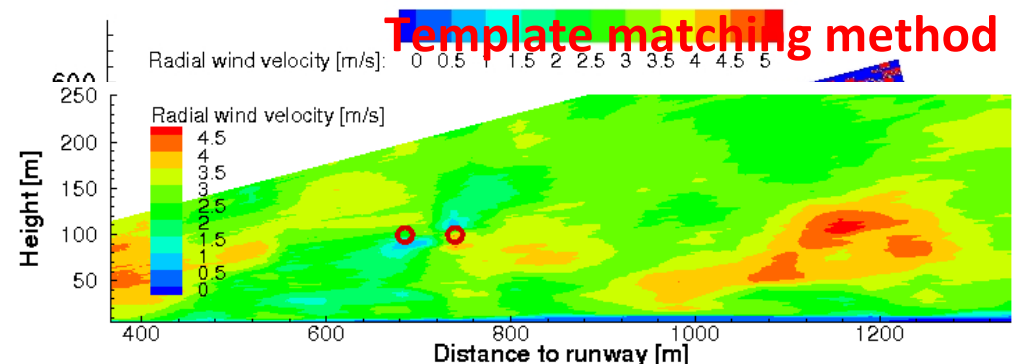


Schematic of measurement plane



Doppler lidar (ENRI)

- ✓ Resolution (line-of-sight direction) : 29.9 [m]
- ✓ Resolution (Angle) : 0.05 [deg.]
- ✓ Range : 2.4 [km]



# Our research for several years

Data assimilation (4DVar)

Simulation (CFD) considering  
actual weather condition



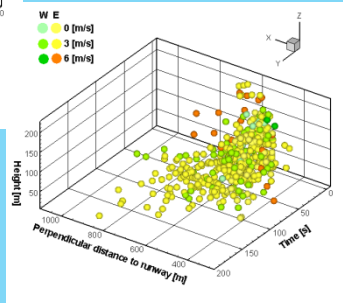
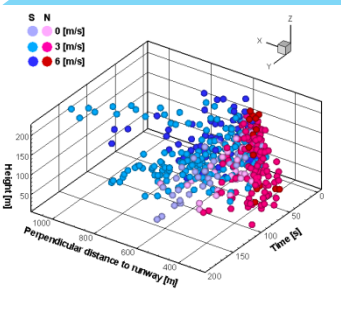
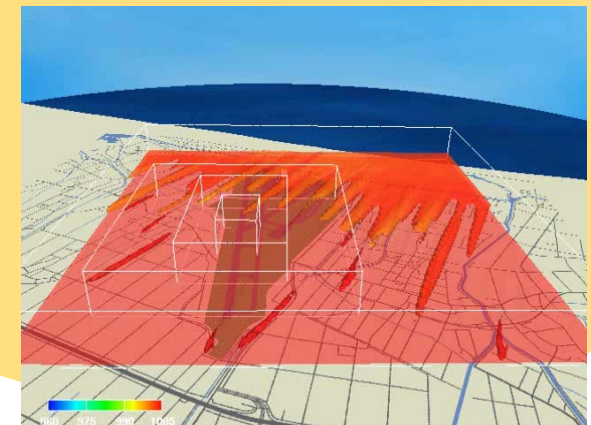
Observation

Advection database  
of wake vortices



Doppler Lidar at Sendai Airport  
(By Mitsubishi Electric Corporation)

Nested regional numerical  
weather model





# Advection database of wake vortices

- Target aircrafts in regular operation at Sendai airport

Model	B767-300	Airbus 320	MD-81/90	Boeing 737-400/-500/-700/-800
Number of data	230	145	121	124
Category	Heavy	Medium		

Measurement : April 2006 - May 2009

- Measurement and weather conditions in advection database

Measurement	Aircraft size (Strength of wake vortices)		Initial height (vortex position)	
Weather	Average wind velocity <sup>1</sup>	Mean wind direction <sup>1</sup>	Humidity <sup>2</sup>	Atmospheric pressure <sup>2</sup>
	Temperature <sup>1</sup>	Air density <sup>2</sup>	Sky condition <sup>2</sup>	Dew-point temperature <sup>2</sup>
	Visibility <sup>2</sup>	Showalter stability index (SSI) <sup>3</sup>	Vertical gradient of potential temp. <sup>3</sup>	The Brunt-Väisälä frequency <sup>3</sup>
	Static stability <sup>3</sup>	Richardson number <sup>3</sup>	<sup>1</sup> : JMA database, <sup>2</sup> : METAR, <sup>3</sup> : MSM-GPV	

# Advection database of wake vortices

## Purpose of advection database of wake vortices

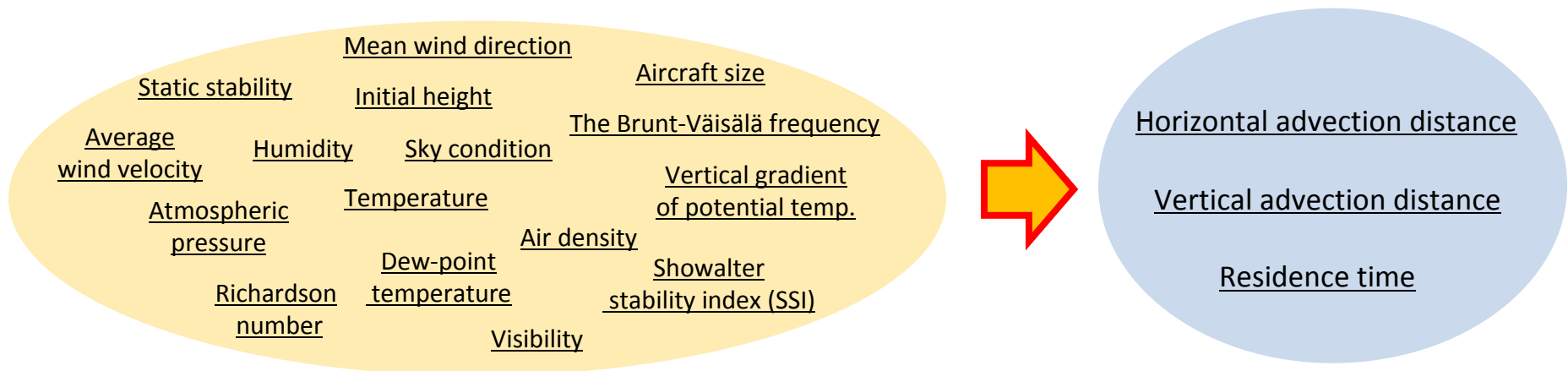
Identify measurement and weather factors that influence behavior of wake vortices

## Behavior of wake vortices

**1.Horizontal advection distance** : an advection distance from the center of runway and an advection direction by a residence time

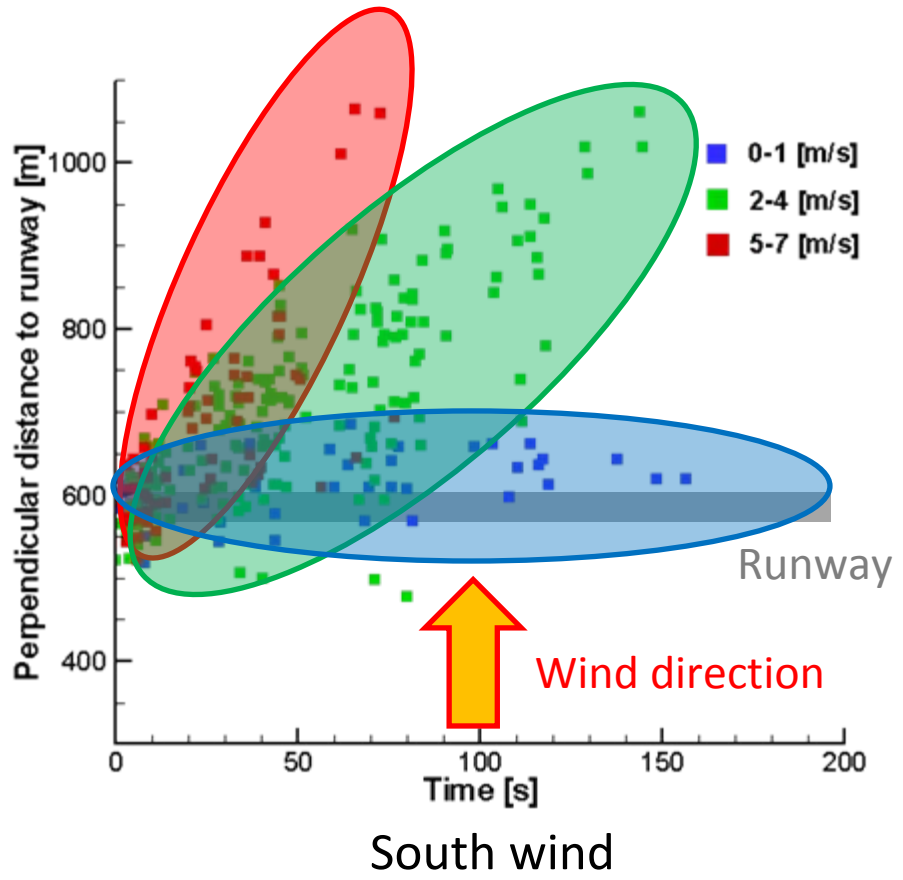
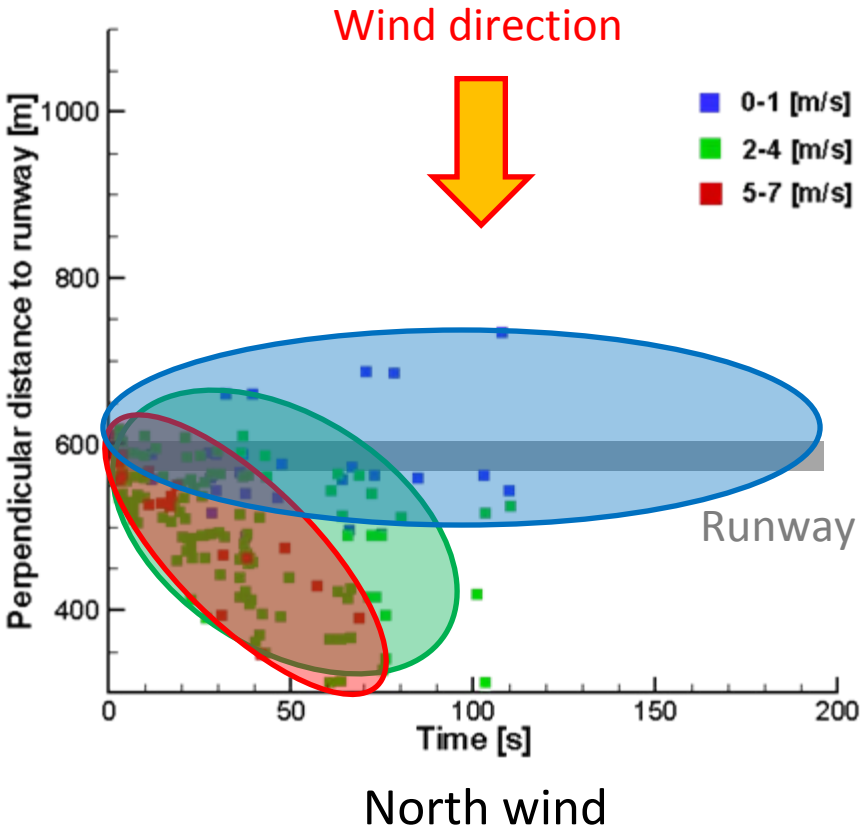
**2.Vertical advection distance** : an advection distance from the initial height by a residence time

**3.Residence time** : an elapsed time until wake vortices disappear from lidar measurements



# Advection database of wake vortices

Influence of mean wind direction and average wind velocity on horizontal advection distance



Advection distance of wake vortices depends on averaged cross wind velocity

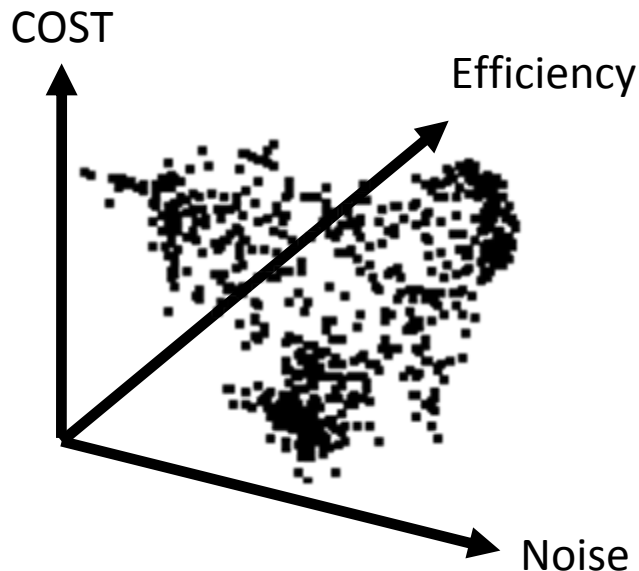


# Data mining

Extraction of cross-correlation from multi dimensional data

✓ Visualization is most simple and most useful method

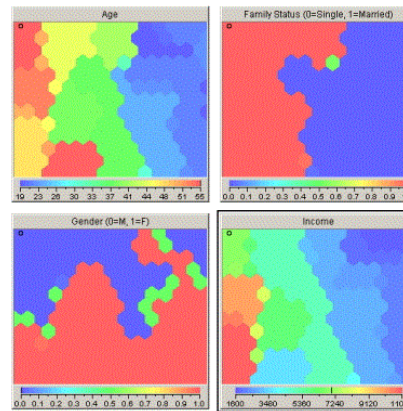
Less than equal to  
3 dimension



More than 3 dimension

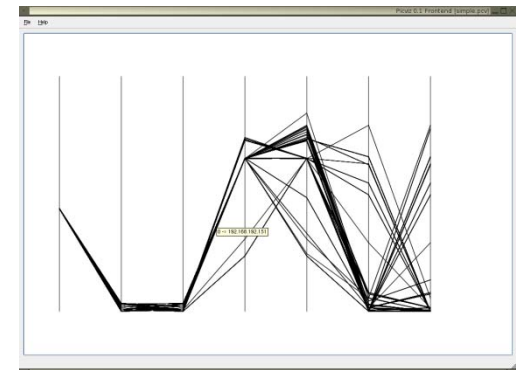
## Data mining

- Self-Organizing Map
- Parallel Coordinate



Viscovery SOMine 5.0, Mindware Inc.

## Self-Organizing Map



Parallel Coordinate, wikipedia

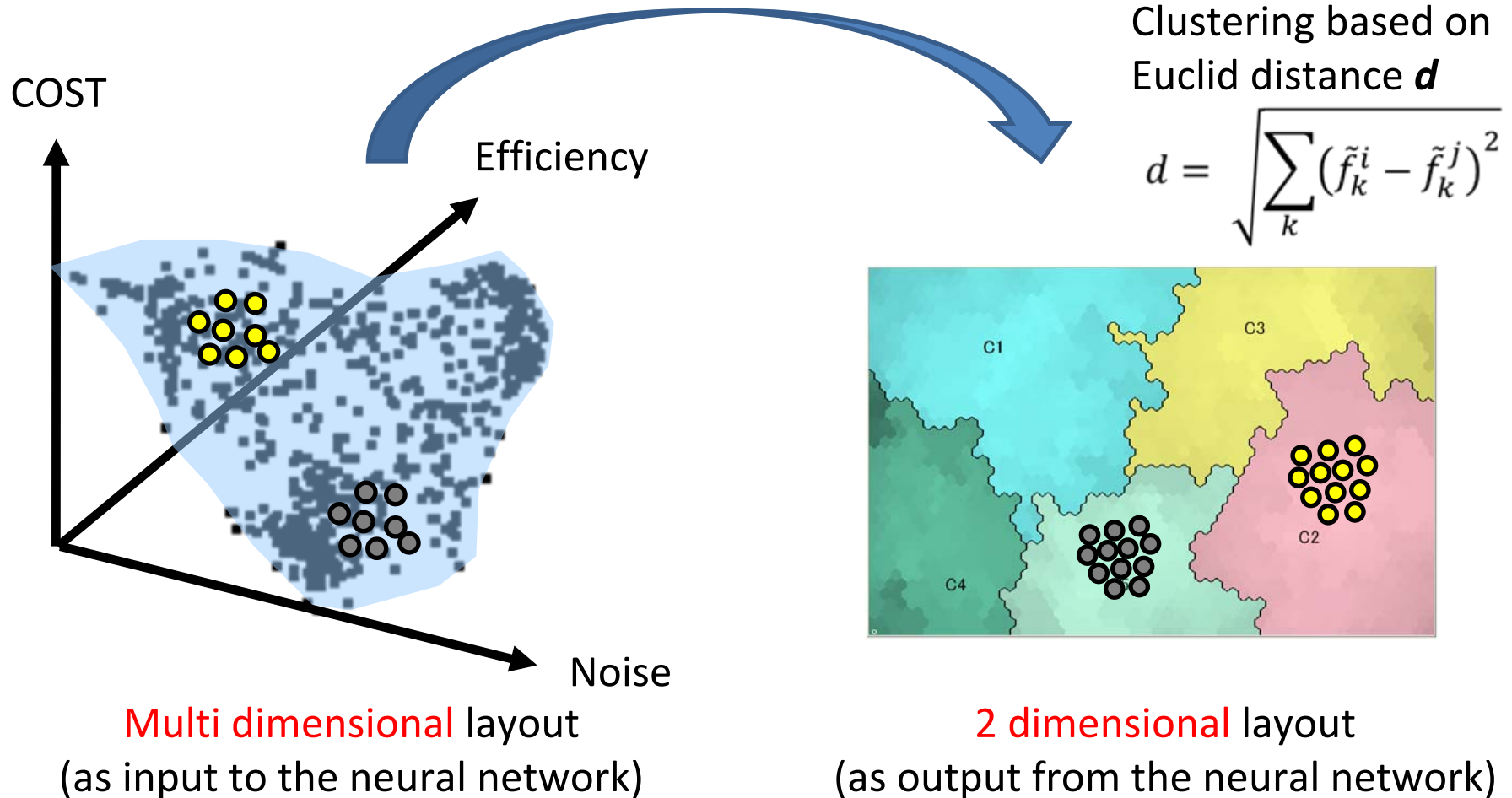
## Parallel Coordinate

SOM is applied to advection database of wake vortices for extraction of the correlations between measurement/weather factors and wake vortex behavior

# Data mining

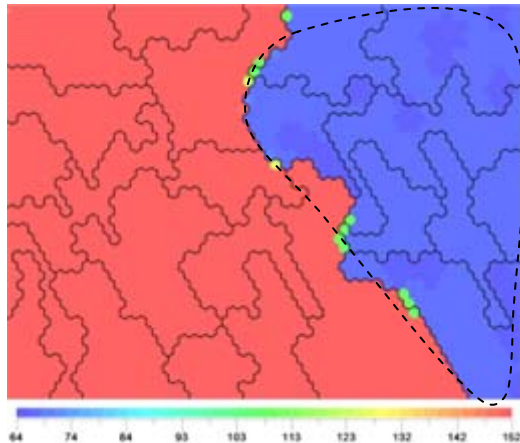
## -Self Organizing Map (SOM) -

Neural network (by Kohonen) used as a clustering method

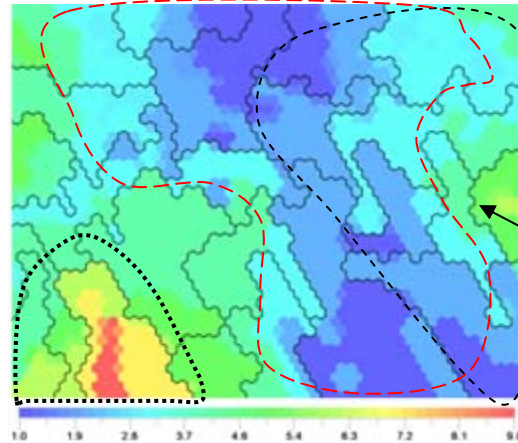


# Data mining

## - Horizontal advection distance -

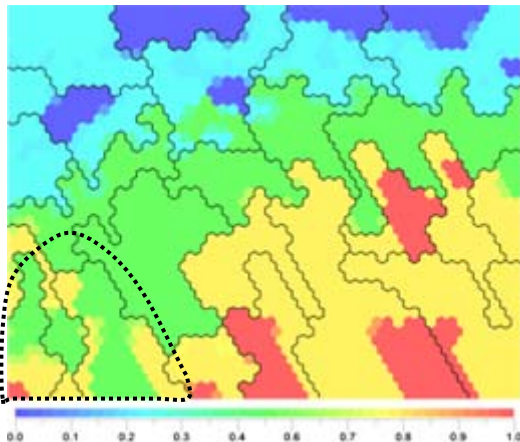


Aircraft size

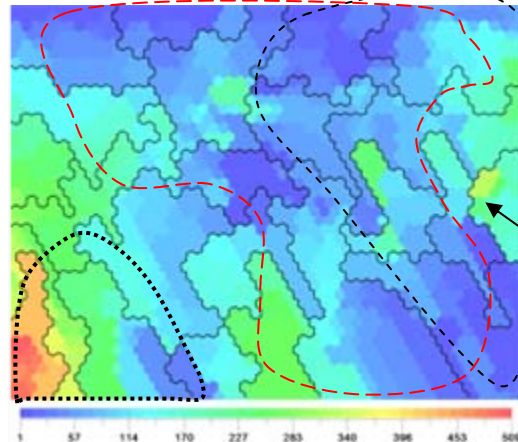


Average wind velocity

Averaged wind velocity ↓  
 Horizontal advection distance ↓



Mean wind direction



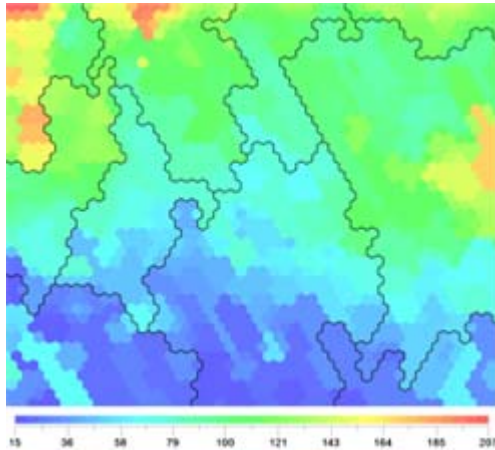
Horizontal advection distance

Averaged wind velocity ↑ .and.  
 Mean wind direction ↑  
 (perpendicular to runway)  
 Horizontal advection distance ↑

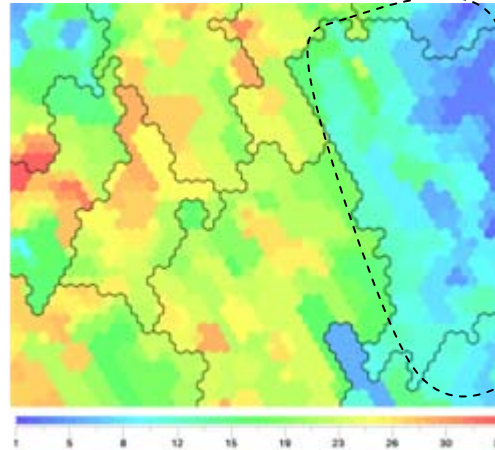
Aircraft size ↓ .and. Averaged  
 wind velocity ↑  
 Horizontal advection distance ↑

# Data mining

## - Vertical advection distance -

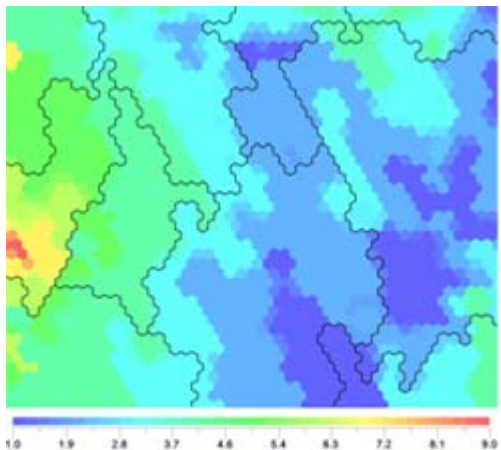


Initial height

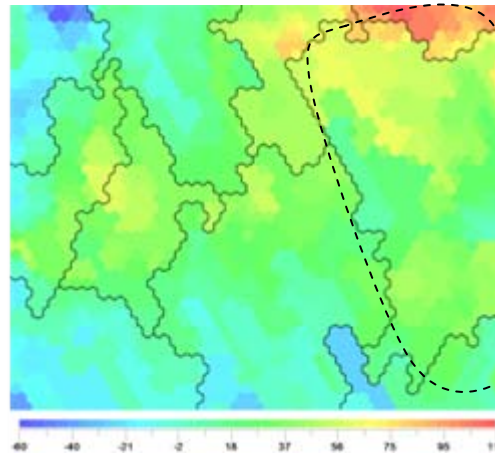


Temperature

Temperature ↑  
 Vertical advection distance ↓



Average wind velocity



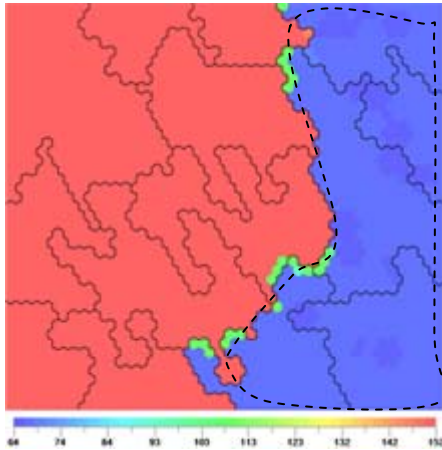
Vertical advection distance

Temperature ↓  
 Vertical advection distance ↑

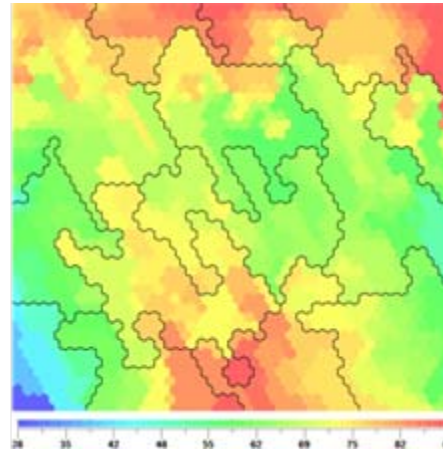


# Data mining

## - Residence time -

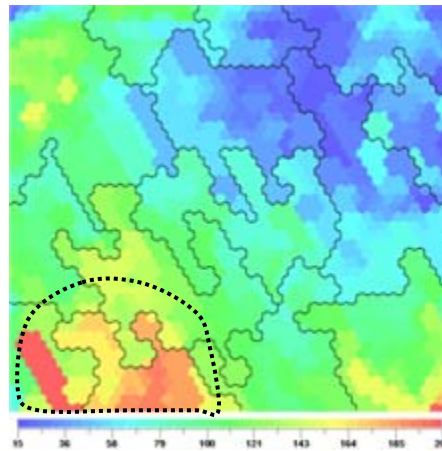


Aircraft size

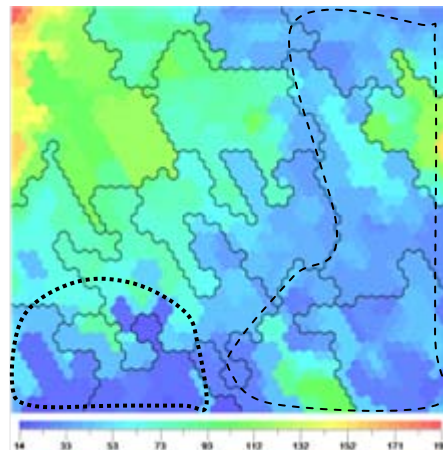


Humidity

Aircraft size ↓  
Residence time ↓



Initial height



Residence time

Aircraft size ↑ .and. Initial height ↑  
Residence time ↓

# Conclusion

**Advection database of wake vortices was constructed based on Lidar measurement.**

➤ Data mining method is applied to the database to understand the cross correlation of multidimensional weather factors.

Factors				Findings	
Averaged wind velocity			↓	Horizontal advection distance	↓
Temperature			↓ ↑	Vertical advection distance	↑ ↓
Aircraft size			↓	Residence time	↓
Aircraft size	↓	Averaged wind velocity	↑	Horizontal advection distance	↑
Averaged wind velocity	↑	Mean wind direction	↑ (perpendicular)	Horizontal advection distance	↑
Aircraft size	↑	Initial height	↑	Residence time	↓

## Future work

- ✓ Extracting more complex correlations from data mining results.
- ✓ Extracting correlations between the another factors which are not considering wake vortex prediction model (ex. humidity, sky condition)

A large commercial aircraft is shown from a low angle, taking off from a runway. The aircraft is white with red and blue stripes. The background features a range of green, forested mountains under a hazy sky. The runway has several red lights visible in the distance.

Thank you for your kind attention