



PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



# WIND ENERGY NETWORK FOR DISTRIBUTED GENERATION IN URBAN ENVIRONMENTS (REGEDIS)

**Workshop on Urban Wind Resource Assessment**  
**November 29 and 30, 2022**

**Challenges towards real-  
time urban Wind forecast**

Jaime Milla Val  
[jmilla@nabladot.com](mailto:jmilla@nabladot.com)

**NABLA DOT :: ()**  
INGENIERÍA COMPUTACIONAL DE FLUIDOS



PROGRAMA IBEROAMERICANO DE CIENCIA Y TECNOLOGÍA PARA EL DESARROLLO



GOBIERNO DE ESPAÑA

MINISTERIO DE CIENCIA E INNOVACIÓN



Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas



Laboratório Nacional de Energia e Geologia, I.P.



# NablaDot

- SME that offer simulation services and digital technologies
- Sectors: energy, industry 4.0, Civil engineering, Water, Smart Cities

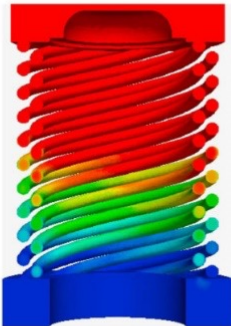
CFD

Engineering Apps

Digital twin

Gas temperature (°C)

Vapor mass fraction



RESET		APRIL 11												APRIL 11																			
		1.0				100				1.0				100				1.0				100				1.0				100			
		in_A				548				in_A				548				in_A				548				in_A				548			
DATOS DE ENTRADA	QUEMADORES PARED TRASERA																																
	Aperturas compuestas (°)		A3	B3	E3	A1	B2	F3	F4	B1	A2	E4	B3	A4																			
	OFAs		25	25	25	25	25	25	25	25	25	25	25	25	25																		
	COFA		25	25	25	25	25	25	25	25	25	25	25	25	25																		
	Ala Terciario		50	50	50	50	50	50	50	50	50	50	50	50	50																		
	LÍQUIDOS		0	0	0	0	0	0	0	0	0	0	0	0	0																		
	SUPERIOR		0	0	0	0	0	0	0	0	0	0	0	0	0																		
	Ala Secundario		0	0	0	0	0	0	0	0	0	0	0	0	0																		
	MEDIO		0	0	0	0	0	0	0	0	0	0	0	0	0																		
	INFERIOR		0	0	0	0	0	0	0	0	0	0	0	0	0																		
DATOS DE SALIDA	QUEMADORES PARED FRONTAL																																
	Aperturas compuestas (°)		C3	D1	E1	C2	D2	F1	F2	D4	C1	E2	D3	C4																			
	OFAs		25	25	25	25	25	25	25	25	25	25	25	25	25																		
	COFA		25	25	25	25	25	25	25	25	25	25	25	25	25																		
	Ala Terciario		50	50	50	50	50	50	50	50	50	50	50	50	50																		
	LÍQUIDOS		0	0	0	0	0	0	0	0	0	0	0	0	0																		
	SUPERIOR		0	0	0	0	0	0	0	0	0	0	0	0	0																		
	Ala Secundario		0	0	0	0	0	0	0	0	0	0	0	0	0																		
	MEDIO		0	0	0	0	0	0	0	0	0	0	0	0	0																		
	INFERIOR		0	0	0	0	0	0	0	0	0	0	0	0	0																		
Equipar		A												B																			
		10												10																			
TRABAJOS																																	
		FRONTAL												TRASERA																			
		P3												P4																			
		30.0												30.0																			
		52.79												52.79																			
		120												120																			
		150												150																			
		180												180																			
		210												210																			
		240												240																			
		270												270																			
		300												300																			
		330												330																			
		360												360																			
		390												390																			
		420												420																			
		450												450																			
		480												480																			
		510												510																			
		540												540																			
		570												570																			
		600												600																			
		630												630																			
		660												660																			
		690												690																			
		720												720																			
		750												750																			
		780												780																			
		810												810																			
		840												840																			
		870												870																			
		900												900																			
		930												930																			
		960												960																			
		990												990																			
		1020												1020																			
		1050												1050																			
		1080												1080																			
		1110												1110																			
		1140												1140																			
		1170												1170																			
		1200												1200																			
		1230												1230																			
		1260												1260																			
		1290												1290																			
		1320												1320																			
		1350												1350																			
		1380												1380																			
		1410												1410																			
		1440												1440																			
		1470												1470																			
		1500												1500																			
		1530												1530																			
		1560												1560																			
		1590												1590																			
		1620												1620																			
		1650												1650																			
		1680												1680																			
		1710												1710																			
		1740												1740																			
		1770												1770																			
		1800												1800																			
		1830												1830																			
		1860												1860																			
		1890												1890																			
		1920												1920																			
		1950												1950																			
		1980												1980																			
		2010												2010																			
		2040												2040																			
		2070												2070																			
		2100												2100																			
		2130												2130																			
		2160												2160																			
		2190												2190																			
		2220												2220																			
		2250												2250																			
		2280												2280																			
		2310												2310																			
		2340												2340																			
		2370												2370																			
		2400												2400																			
		2430												2430																			
		2460												2460																			
		2490												2490																			
		2520												2520																			
		2550												2550																			
		2580												2580																			
		2610												2610																			
		2640												2640																			
		2670												2670																			
		2700												2700																			
		2730												2730																			
		2760												2760																			
		2790												2790																			
		2820												2820																			
		2850												2850																			
		2880												2880																			
		2910												2910																			
		2940												2940																			
		2970												2970																			
		3000												3000																			
		3030												3030																			
		3060												3060																			
		3090												3090																			
		3120												3120																			
		3150												3150																			
		3180												3180																			
		3210												3210																			
		3240												3240																			
		3270												3270																			
		3300												3300																			
		3330												3330																			
		3360												3360																			
		3390												3390																			
		3420												3420																			
		3450												3450																			
		3480												3480																			
		3510												3510																			
		3540												3540																			
		3570												3570																			
		3600												3600																			
		3630												3630																			
		3660												3660																			
		3690												3690																			
		3720												3720																			
		3750												3750																			
		3780												3780																			
		3810												3810																			
		3840												3840																			
		3870												3870																			
		3900												3900																			
		3930												3930																			
		3960												3960																			
		3990												3990																			
		4020												4020																			
		4050												4050																			
		4080												4080																			
		4110												4110																			
		4140												4140																			
		4170												4170																			
		4200												4200																			
		4230												4230																			
		4260												4260																			
		4290												4290																			
		4320												4320																			
		4350												4350																			
		4380												4380																			
		4410												4410																			
		4440												4440																			
		4470												4470																			
		4500												4500																			
		4530												4530																			
		4560												4560																			
		4590												4590																			
		4620												4620																			
		4650												4650																			
		4680												4680																			
		4710												4710																			
		4740												4740																			
		4770												4770																			
		4800												4800																			
		4830												4830																			
		4860												4860																			
		4890												4890																			
		4920												4920																			
		4950												4950																			
		4980												4980																			
		5010												5010																			
		5040												5040																			
		5070												5070																			
		5100												5100																			
		5130												5130																			
		5160												5160																			
		5190												5190																			
		5220												5220																			
		5250												5250																			
		5280												5280																			
		5310												5310																			
		5340												5340																			
		5370												5370																			
		5400												5400																			
		5430												5430																			
		5460												5460																			
		5490												5490																			
		5520												5520																			
		5550												5550																			
		5580												5580																			
		5610												5610																			
		5640												5640																			
		5670												5670																			
		5700												5700																			
		5730												5730																			
		5760												5760																			
		5790												5790																			
		5820												5820																			
		5850												5850																			
		5880												5880																			
		5910												5910																			
		5940												5940																			
		5970												5970																			
		6000												6000																			
		6030												6030																			
		6060												6060																			
		6090												6090																			
		6120												6120																			
		6150												6150																			
		6180												6180																			
		6210												6210																			
		6240												6240																			
		6270												6270																			
		6300												6300																			
		6330												6330																			
		6360												6360																			
		6390												6390																			
		6420												6420																			
		6450												6450																			
		6480												6480																			
		6510												6510																			
		6540												6540																			
		6570												6570																			
		6600												6600																			
		6630												6630																			
		6660												6660																			
		6690												6690																			
		6720												6720																			
		6750												6750																			
		6780												6780																			
		6810												6810																			
		6840												6840																			
		6870												6870																			
		6900												6900																			
		6930												6930																			
		6960												6960																			
		6990												6990																			
		7020												7020																			
		7050												7050																			
		7080												7080																			
		7110												7110																			
		7140												7140																			
		7170												7170																			
		7200												7200																			
		7230												7230																			
		7260												7260																			
		7290												7290																			
		7320												7320																			
		7350												7350																			
		7380												7380																			
		7410												7410																			
		7440												7440																			
		7470												7470																			
		7500												7500																			
		7530												7530																			
		7560												7560																			
		7590												7590																			
		7620												7620																			
		7650												7650																			
		7680												7680																			
		7710												7710																			
		7740												7740																			
		7770												7770																			
		7800												7800																			
		7830												7830																			
		7860												7860																			
		7890												7890																			
		7920												7920																			
		7950												7950																			
		7980												7980																			
		8010												8010																			
		8040												8040																			
		8070												8070																			
		8100												8100																			
		8130												8130																			
		8160												8160																			
		8190												8190																			
		8220												8																			



PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO

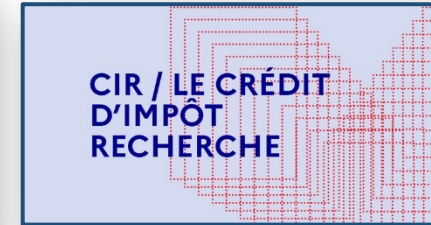


**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



## NablaDot (key facts)

- Innovative SME (Spanish Ministry of Science)
- Innovative Company (French Ministry of higher education, research and innovation)
- Finalists of I4MS Disruptor Awards - 2018 (Fortissimo 2)
- Participation in R&D projects (European, National) > 20
- Energy Cluster of Aragón
- Digital Innovation Hub Aragón
- Strong innovative & multidisciplinary character





PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



## Background projects: FORTISSIMO2

- European H2020 Project (2018)
- **PROBLEM:** Urban wind assessment tools are costly in relation to the cost of a small wind turbine.
- **SOLUTION:** cloud-based tool for optimal placement of urban turbines including:
  - GIS (Geographic Information System)
  - NWP (Numerical Weather Prediction)
  - CFD (Computational Fluid Dynamics)
  - Analytics software to accurately simulate the urban environment

*More info:* <https://www.fortissimo-project.eu/en/experiments/807/cloudbased-micrositing-of-small-wind-turbines>



PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



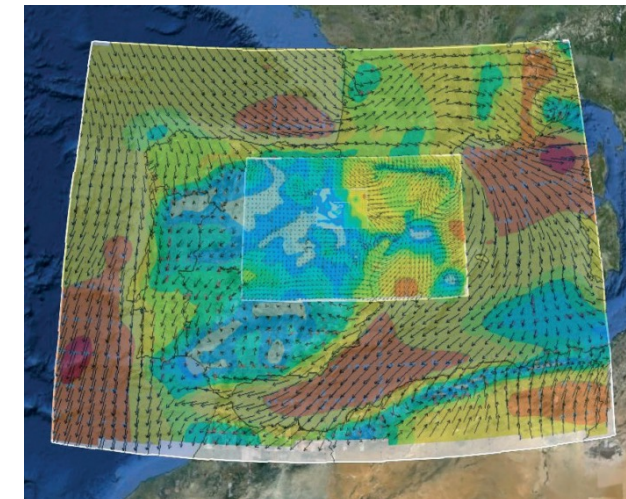
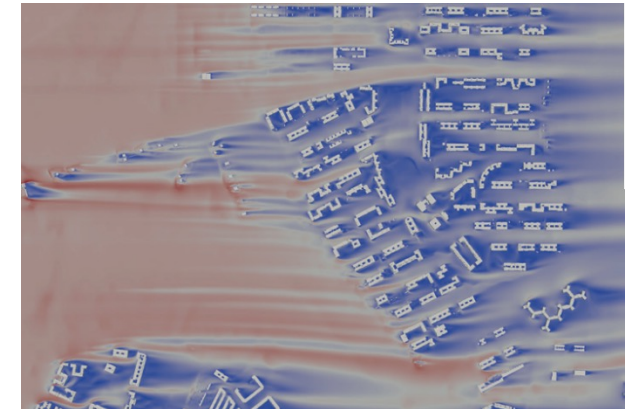
**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



## Background projects: FORTISSIMO2

### RESULTS

- Modelled urban area (city of Zaragoza) of about  $2 \text{ km}^2$
- Simplified approach (limited resources and time) but promising results
- First proof of concept and starting point of our activity in this field
- Industrial PhD
- New project starting in 2023!







PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



## PhD thesis: DEVELOPMENT OF AI MODELS FOR HIGH RESOLUTION WIND FIELDS PREDICTION

- **FLUID MECHANICS PhD at the University of Zaragoza**
- **Industrial oriented:** developing the thesis in a company, NablaDot
- **Funded by the Spanish Government (Ministry of Science and Innovation)**



PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



# Motivation

## OBJECTIVE

- Get a high fidelity/detailed wind field over a region without the need of expensive CFD simulations

## WHAT FOR?

- Wind energy (new locations, forecast, digital twin..)
- Ski stations (snowfall prevention)
- Urban fluxes (legislation, building planning, dispersion...)
- Security (rescue operations, fires...)

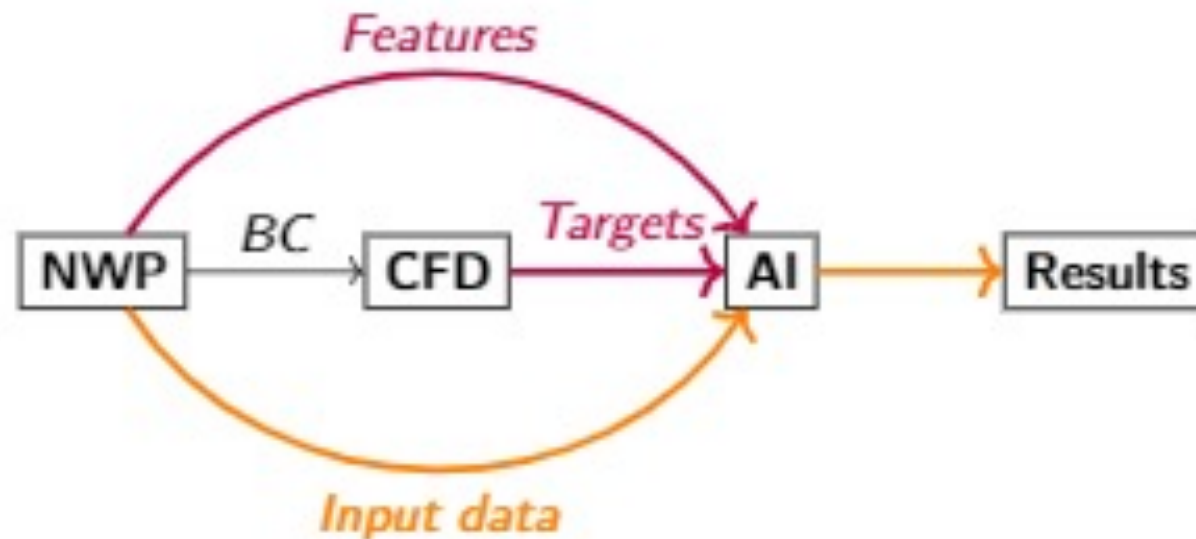
## HOW?

- Using emerging AI/ML techniques jointly with more traditional CFD and NWP (mesoscale simulations).



## Application case - General idea

- Use **NWP**, **numerical weather predictions** (mesoscale simulations) to feed **AI** models with **CFD** as targets. At the end -  
-> get rid of CFD (operational mode).
- Map mesoscale-like results to CFD-like results.







PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



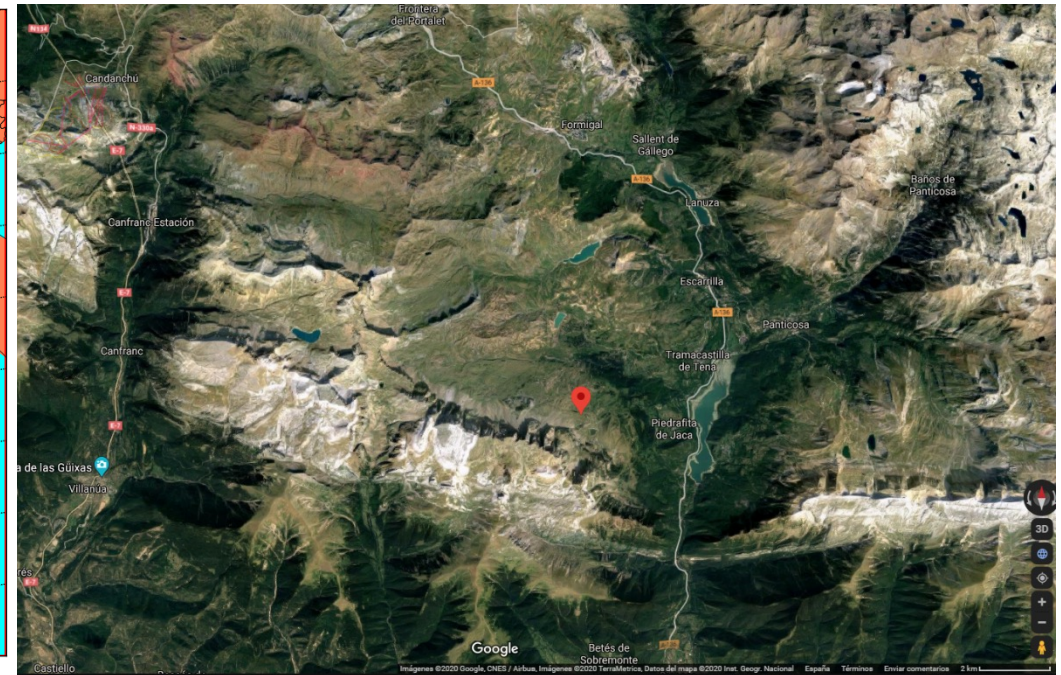
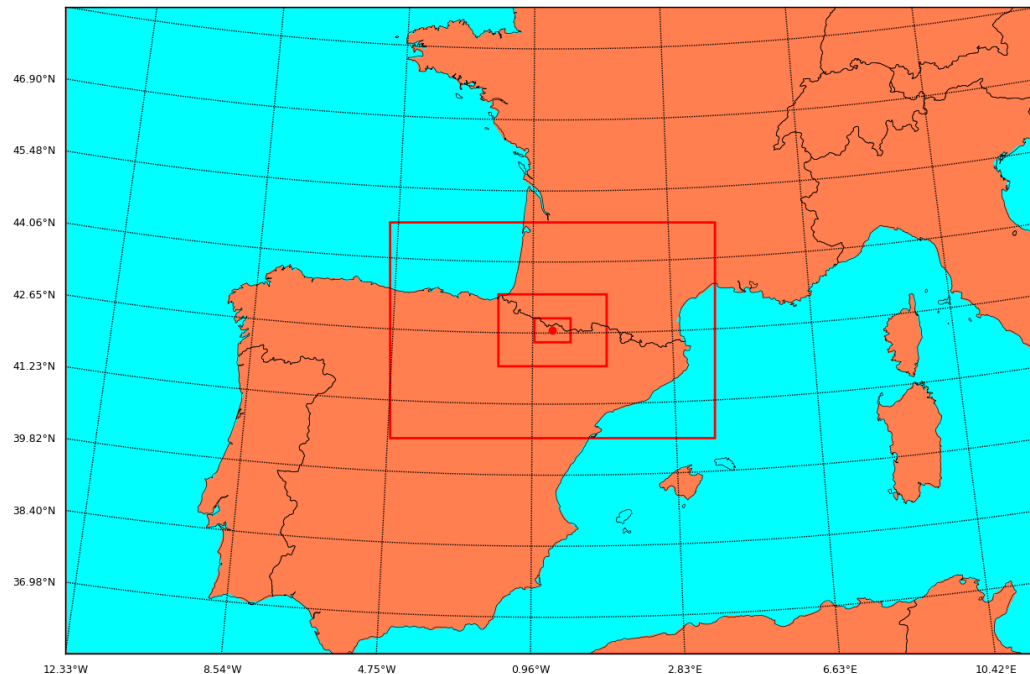
**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



## Application case - Localization

Over a complex terrain

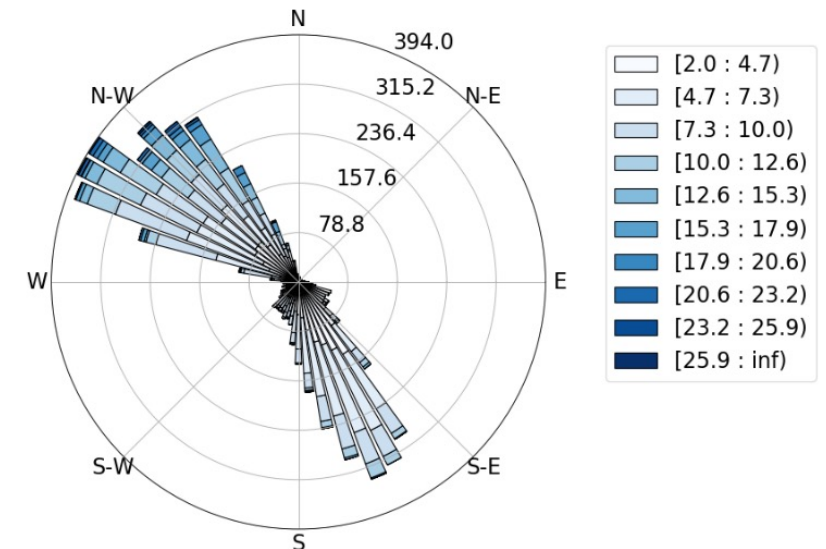
- Spanish Pyrenees, between Aragón and Tena rivers, "sierra de la Partacua"





## Application case - Simulations

- Mesoscale simulations with **WRF** --> hourly data over 2018 (8760 events)
- Windrose at central point of the location --> frequency based selection of 193 events for training
- CFD simulation with **OpenFOAM**:
  - Steady state
  - SIMPLE algorithm for velocity-pressure coupling
  - Isothermal flux
  - RANS equations for continuity and momentum





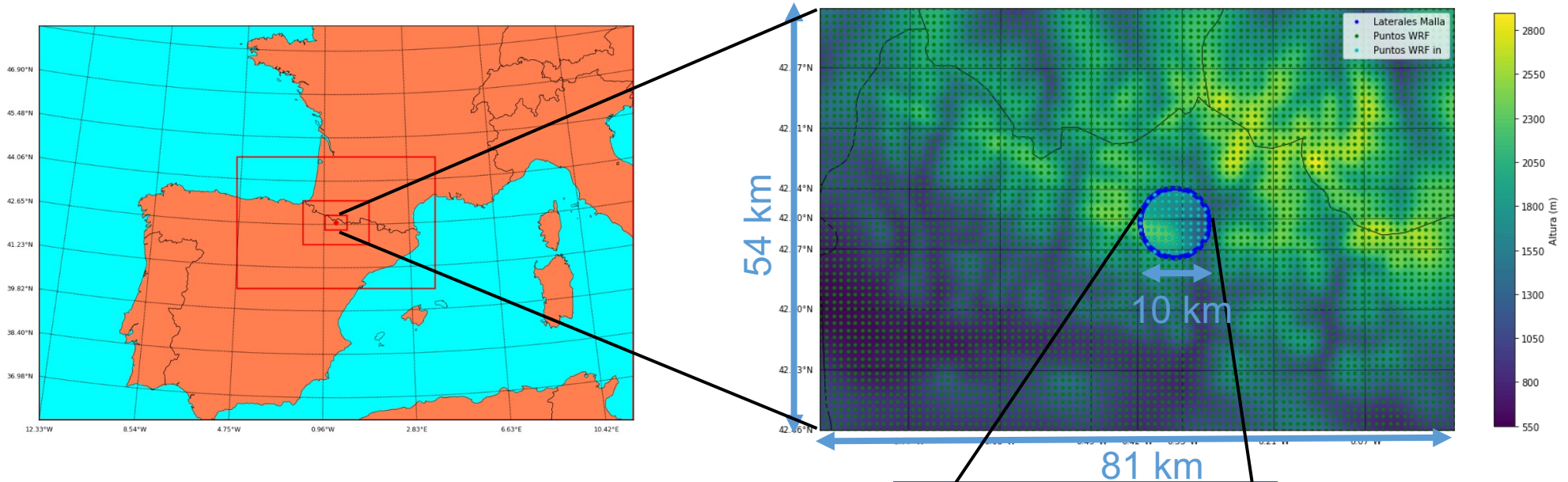


PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO

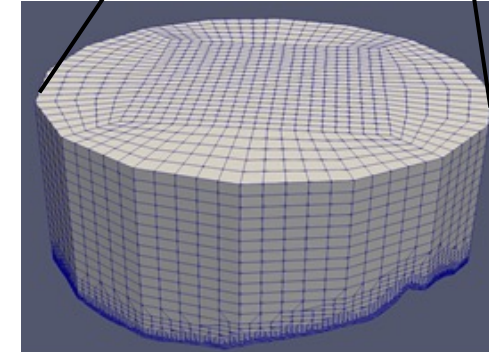
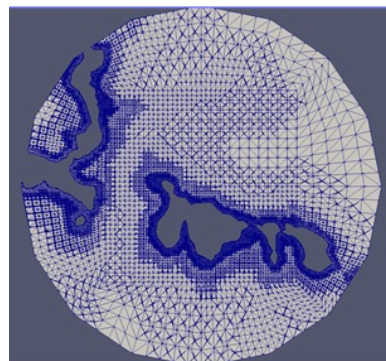
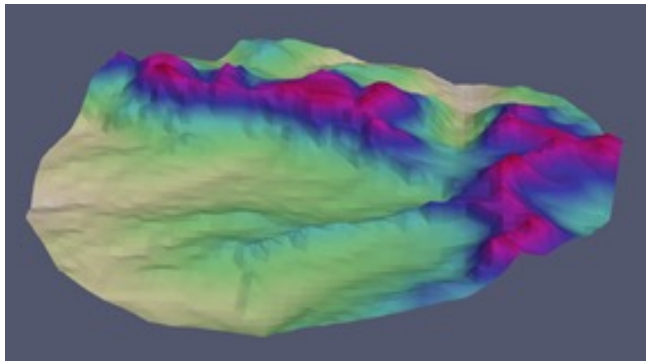


## Application case - Setup

WRF



CFD

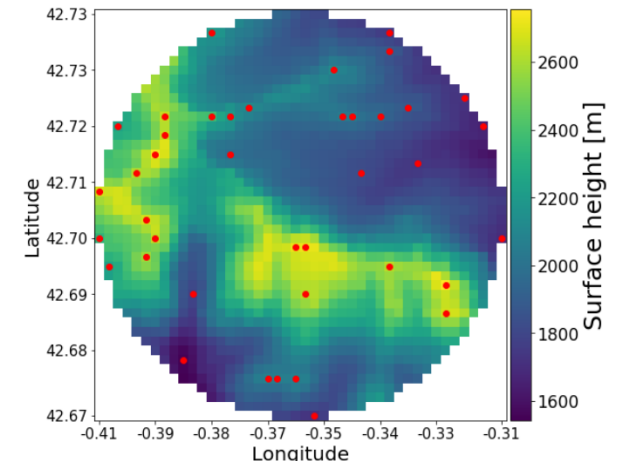
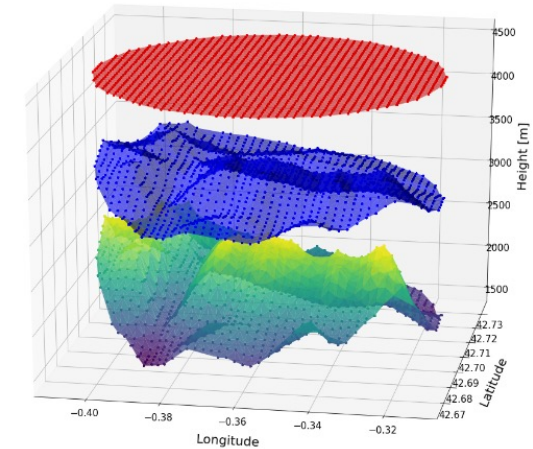


- Cell resolution up to 12 m
- 250k cells



## Application case - AI models

- Bring CFD and NWP results together --> auxiliary mesh
- Train a model for each point individually:
  - **Linear regression**
  - **Support Vector Machine (SVM)**
  - **Random Forest (RF)**
  - **K-nearest neighbors (KNn)**
- Features:
  - Wind components, from NWP, of the point (U, V, W)
  - U, V, W of the point + U, V, W of the **red points**
- Targets:
  - Wind components from CFD (U<sub>x</sub>, U<sub>y</sub>, U<sub>z</sub>)





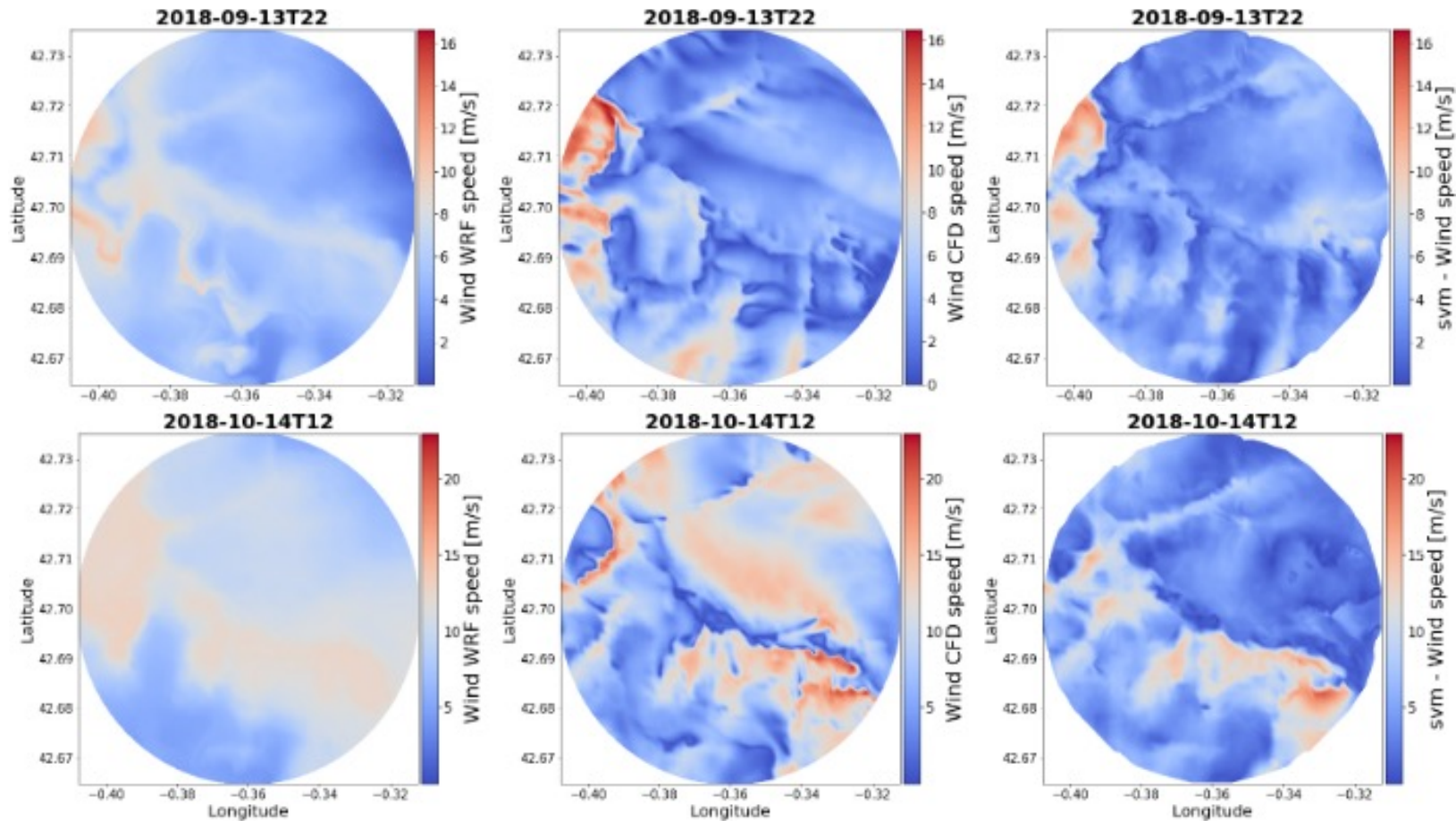
PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



## Application case - Results



(a) Mesoscale

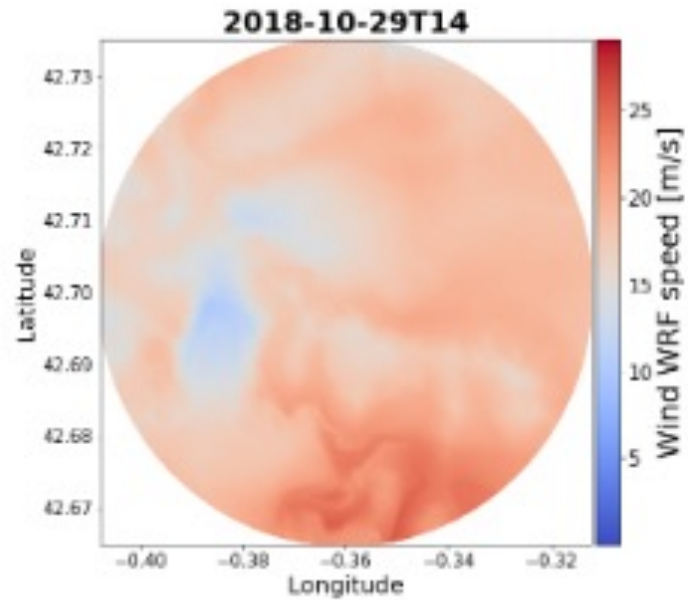
(b) CFD

(c) AI-SVM

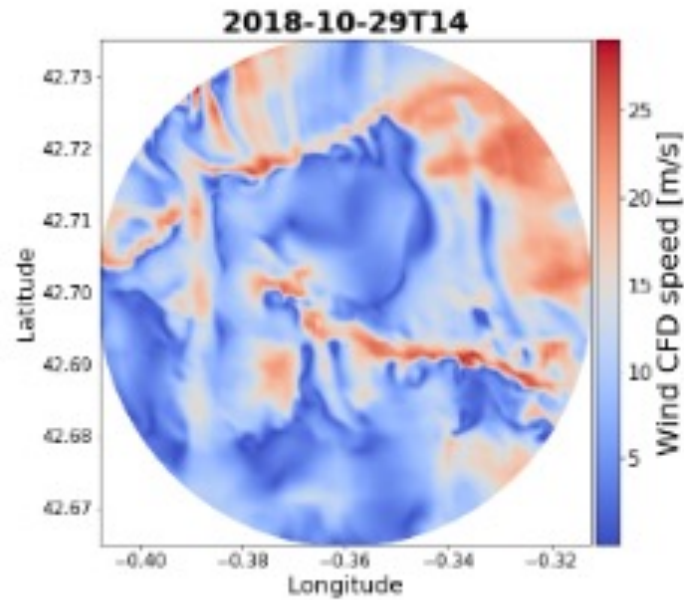




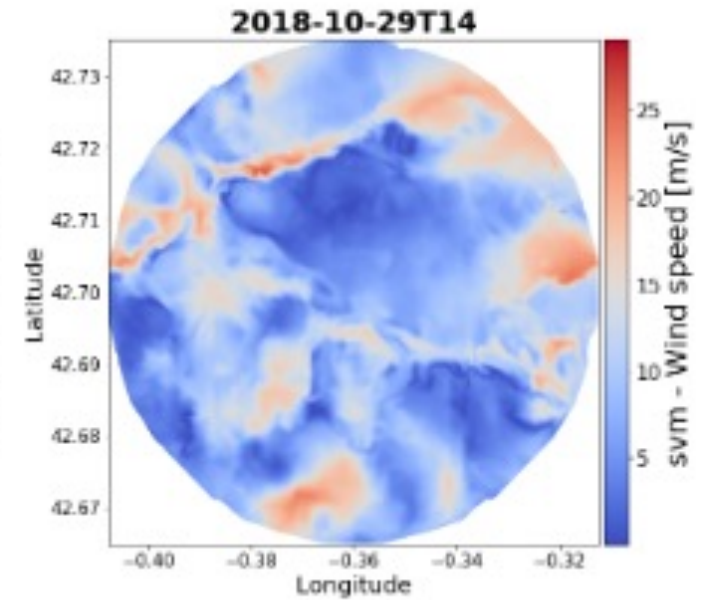
## Application case - Results



(a) Mesoscale



(b) CFD



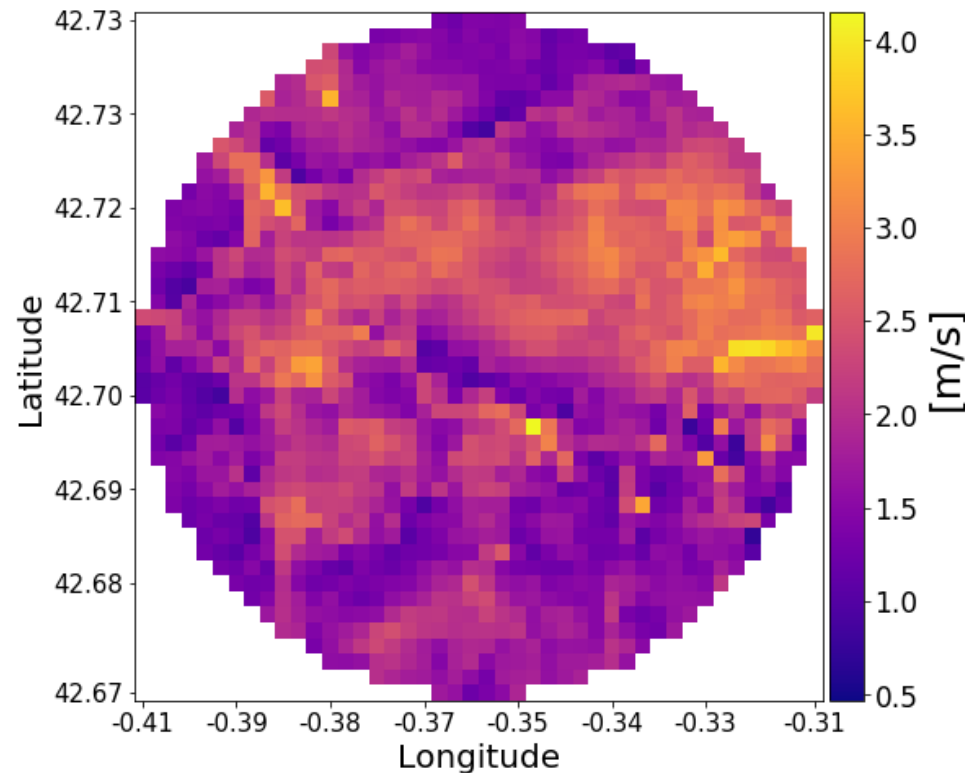
(c) AI-SVM





## Application case - Results

- Mean (over 80 test events) absolute wind speed error [m/s] at surface level
- Simple Features:
  - mean: **1,97** m/s and **44,2** °
- Extended Features:
  - mean: **1,81** m/s and **40,6** °
- **Computational time**:
  - 1 NWP event took ~3 min
  - 1 CFD event took ~1 h
  - Retriving AI data ~ s





PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



## Work in progress - What is ahead?

### Flow assumptions:

- **Transient** instead of steady flow

### Region:

- **Urban area** in contrast with the application case over a mountainous terrain.

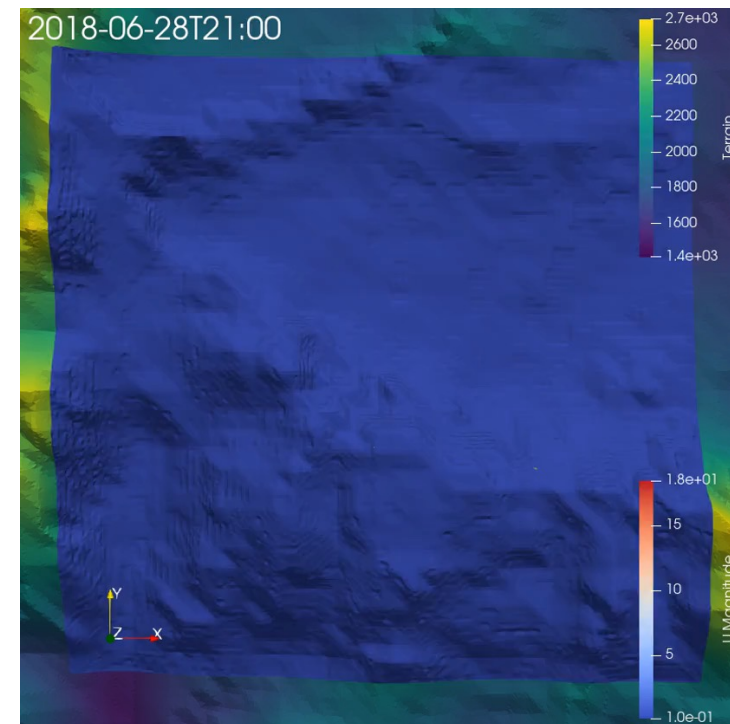
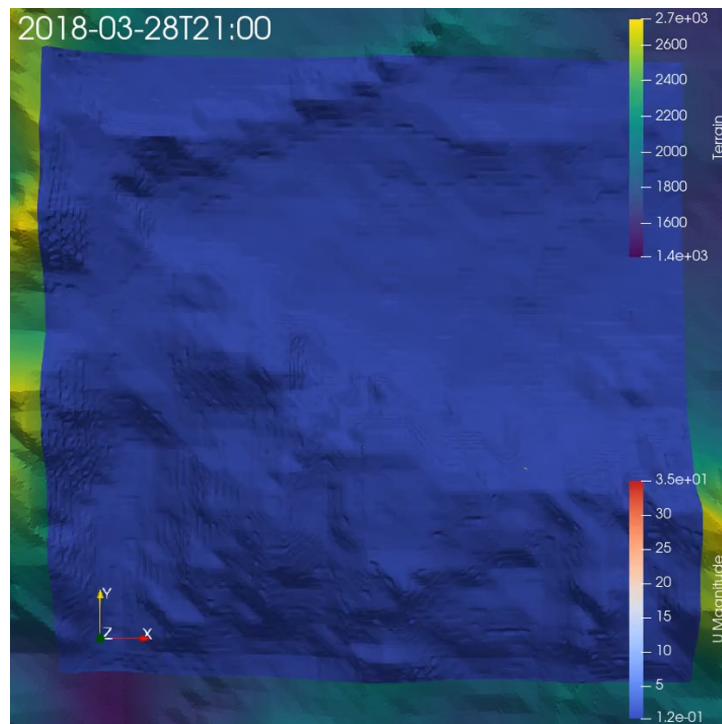
### AI models:

- **Neural Networks.**



## Work in progress - Transient

- Sudden changes in wind velocity
- Are effects of wake development important?
- Temporal dependencies
- Increase training data





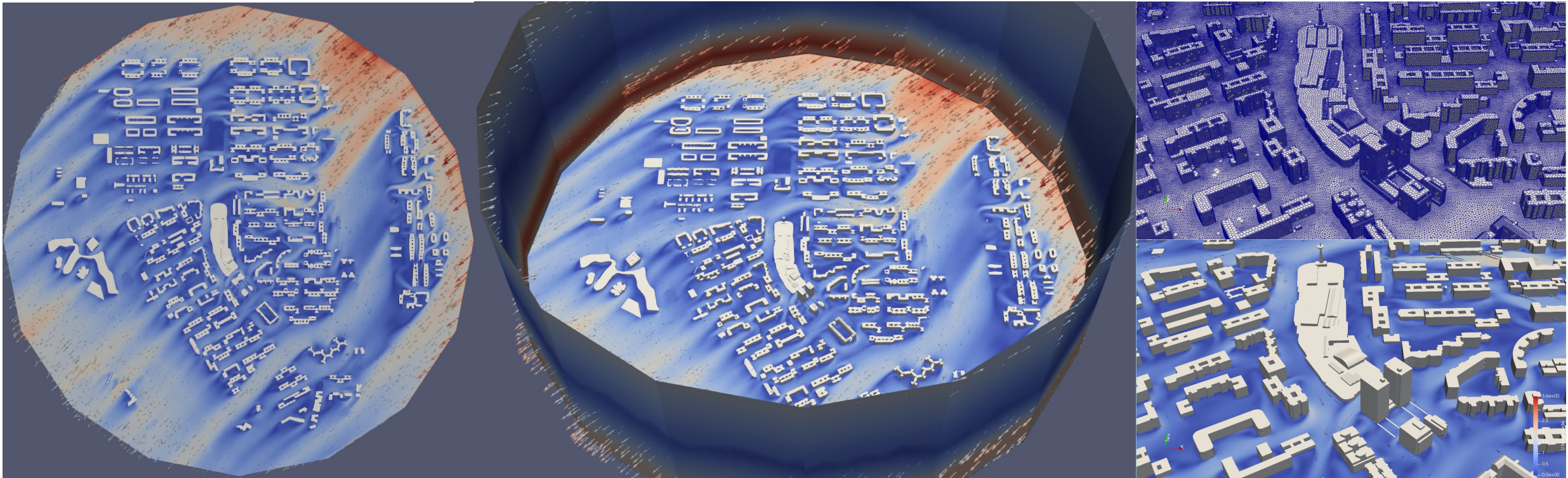


PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



## Work in progress - Urban

### City of Zaragoza (ACTUR neighborhood)

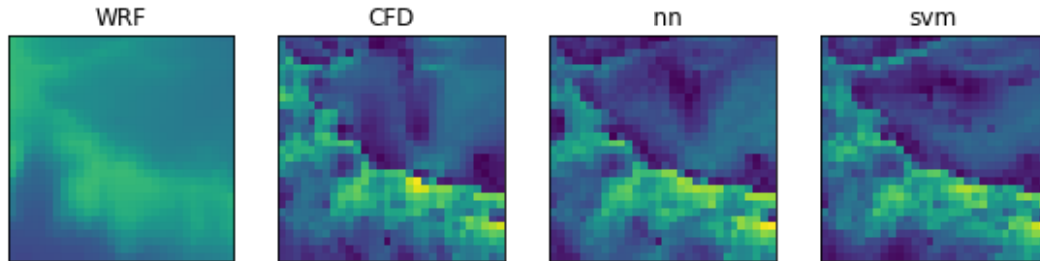




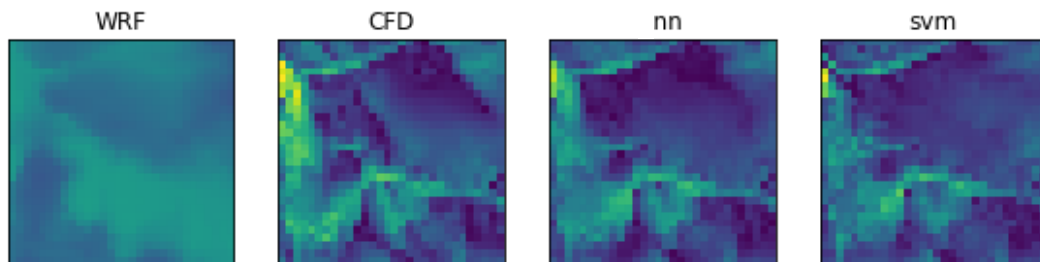
# Work in progress - Neural Networks

More flow-like results

2018-11-05T10		
	R <sup>2</sup>	MAE [m/s]
NN	0,748	2,084
SVM	0,720	2,096

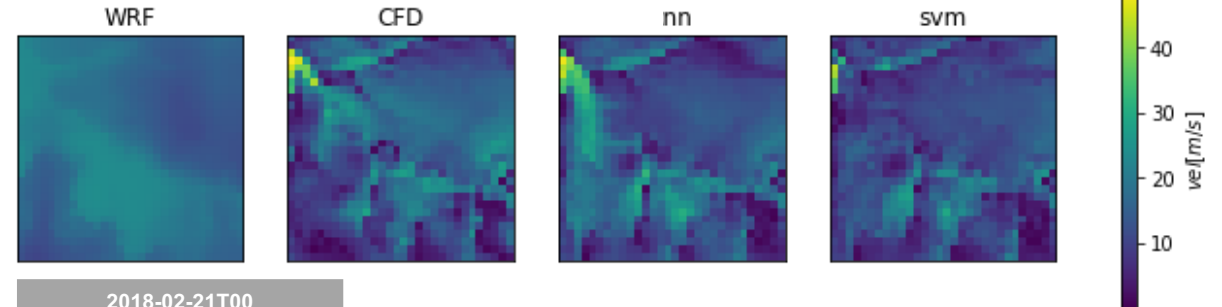


2018-01-18T23		
	R <sup>2</sup>	MAE [m/s]
NN	0,763	2,503
SVM	0,518	3,317

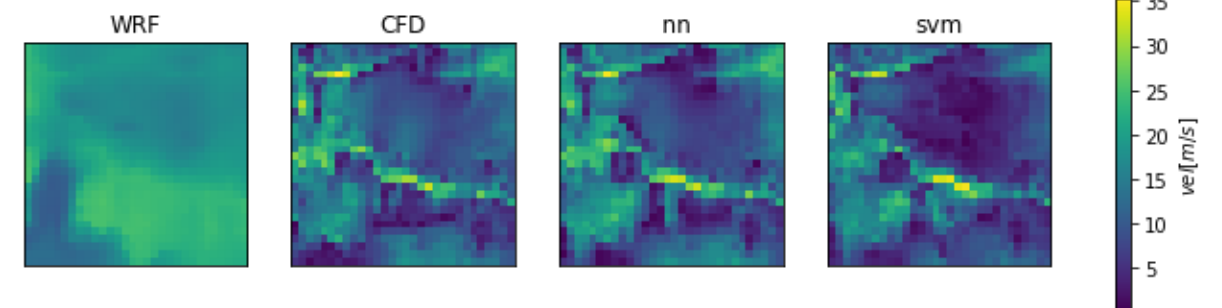


Factual better performance

2018-01-01T03		
	R <sup>2</sup>	MAE [m/s]
NN	0,274	4,569
SVM	0,258	4,333



2018-02-21T00		
	R <sup>2</sup>	MAE [m/s]
NN	0,681	2,464
SVM	0,293	4,079



**\*WORK IN PROGRESS**

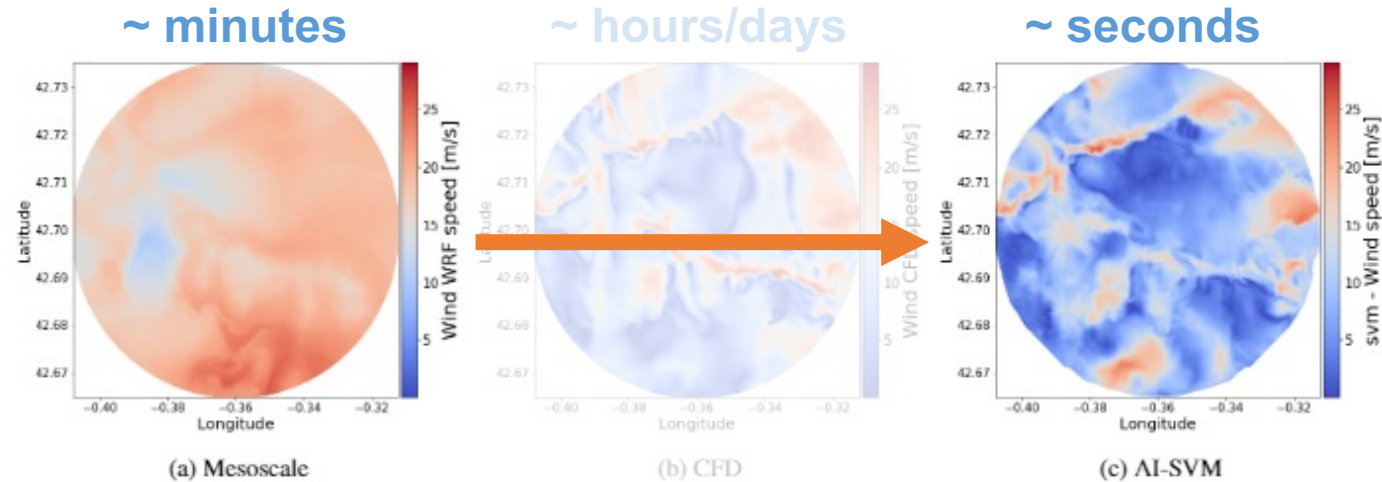
**~4M parameters**





## Conclusions and Perspectives

**AI** model to map **weather data** (NWP) into **high detailed wind** (CFD) simulations



- **Transient** against **steady** state. Temporal dependencies
- **Complex terrain** and (now) testing over **urban areas**
- **NN** promising over traditional ML techniques such as **SVM, RF, KNn...**





PROGRAMA IBEROAMERICANO DE CIENCIA  
Y TECNOLOGÍA PARA EL DESARROLLO



**Ciemat**  
Centro de Investigaciones  
Energéticas, Medioambientales  
y Tecnológicas



# Thanks a lot!

Jaime Milla Val  
jmilla@nabladot.com

**NABLA DOT :: ()**  
INGENIERÍA COMPUTACIONAL DE FLUIDOS