

Clustering Event

HPC & Big Data Technologies
for Global Challenges

PIVOTAL

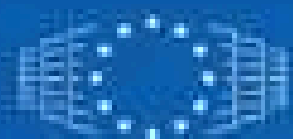
Global Challenges and HPC: The Case of Wildfires

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04.11.2025



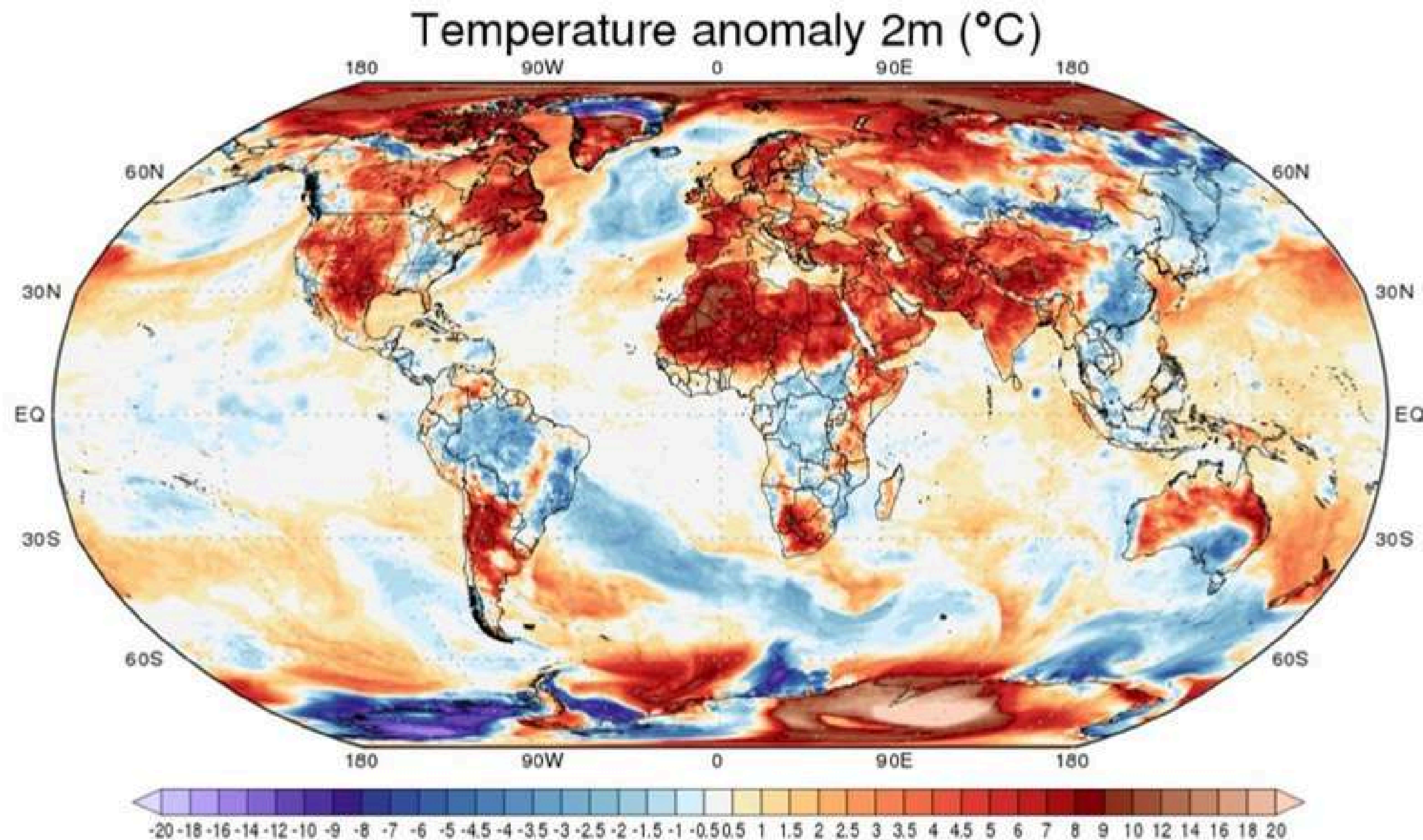
EuroHPC
Joint Undertaking

Grant number: 101093457

A warming world

NCEP GFS forecast vs CFSR reanalysis @0.5deg
Run: 17 Oct 2025 06z

Forecast: +138h
Valid: 23 Oct 2025 00z



Anomaly global: 1.083K

NH: 1.643K

SH: 0.522K

90N-60S: 1.002K

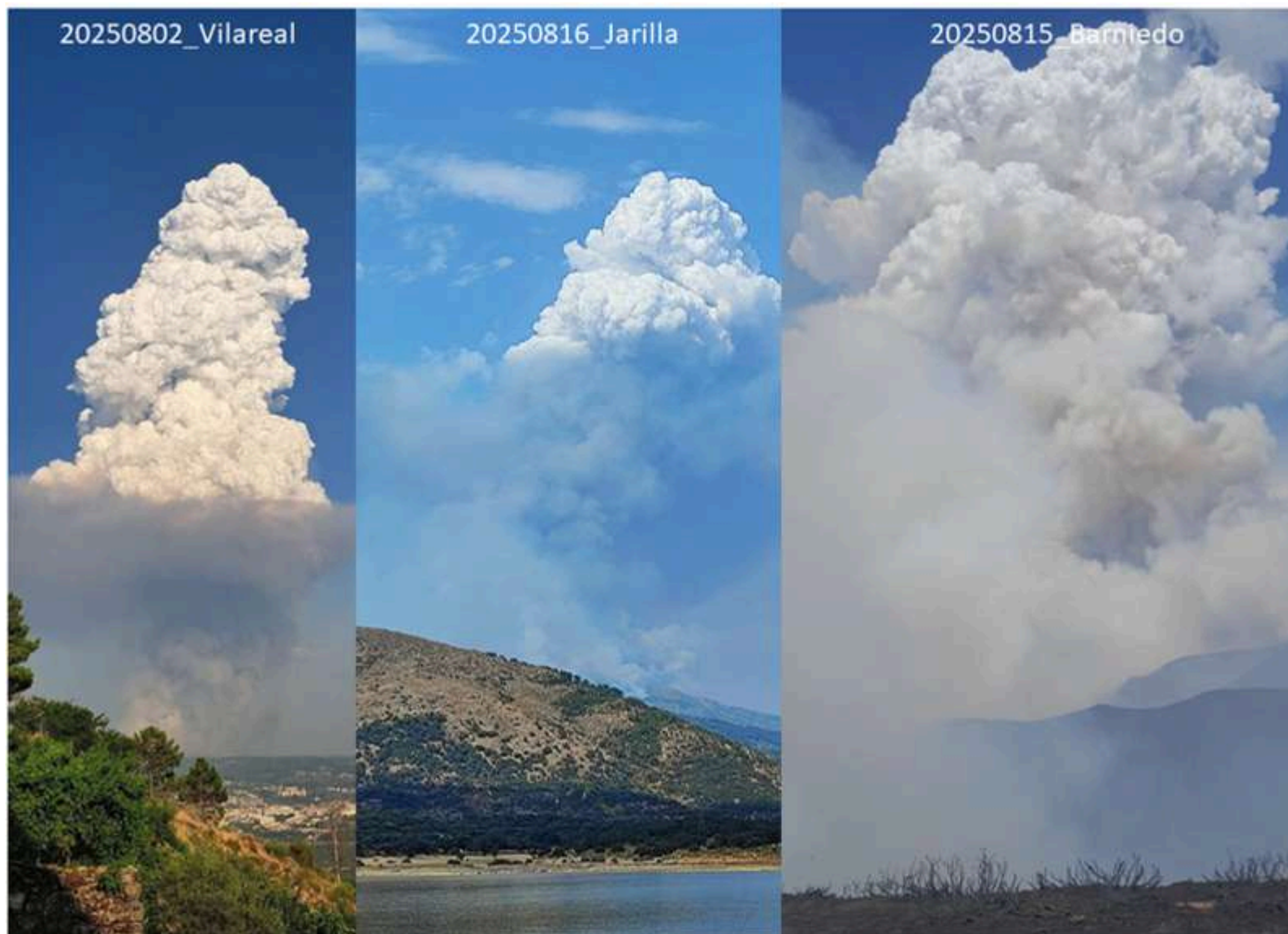
10/23/2025 00:00 UTC

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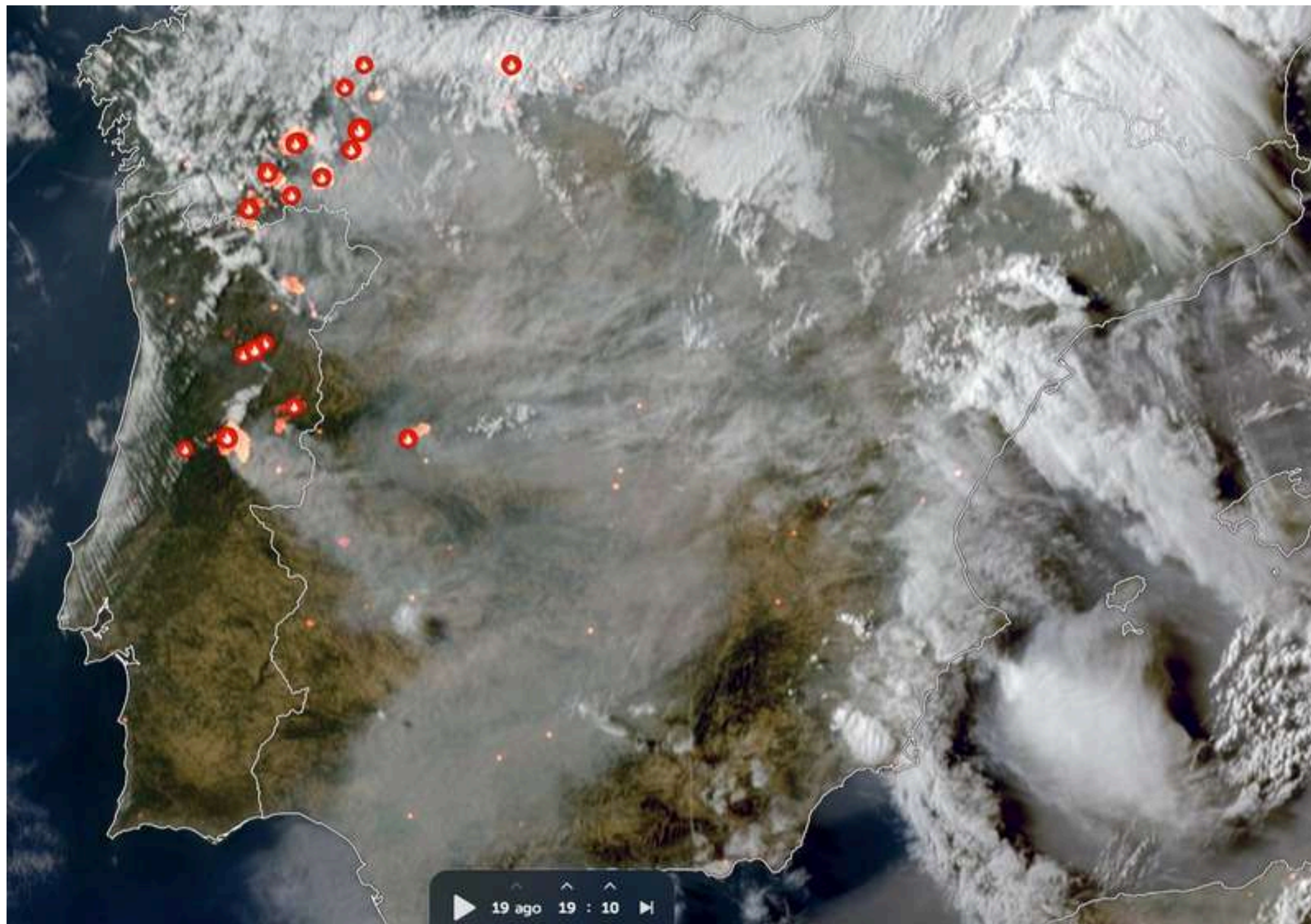
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The challenge of wildfires



The challenge of wildfires



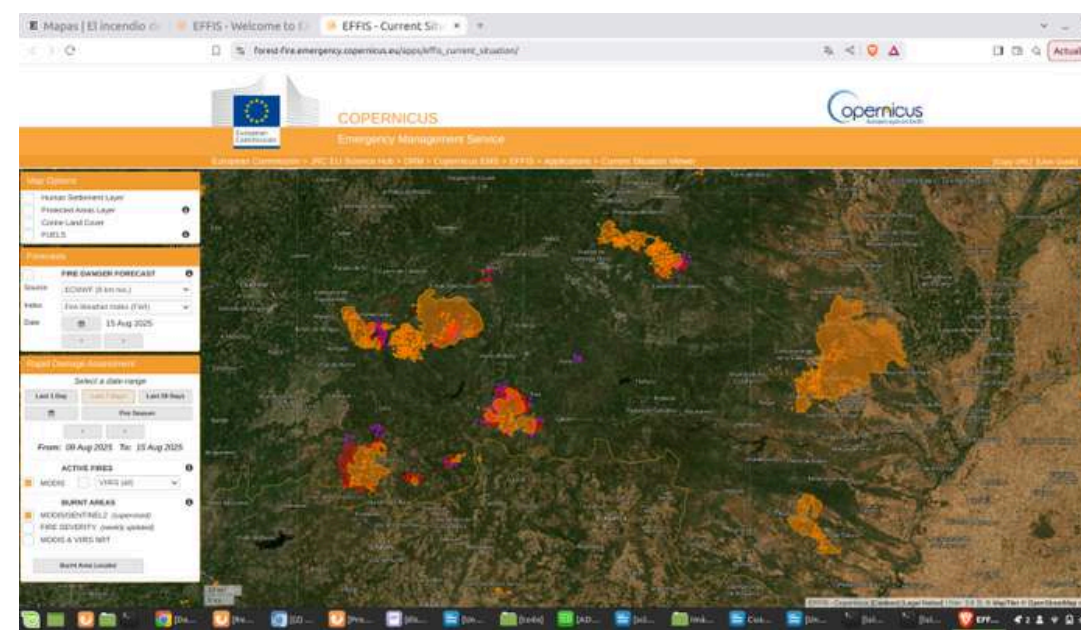
The challenge of wildfires



The challenge of wildfires

Wildfires are a major concern in the EU due to more energetic conditions linked to climate change. New **tools** are needed:

- To help **decision making**
- To assess **fire front** spread
- To understand **fire-atmosphere** interactions
- To evaluate **smoke** dispersion
- To estimate potential **impacts** on populated areas



Fire-atmosphere interaction and extreme fire behavior overwhelms fire fighters and threatens populated areas
Smoke dispersion linked to large fires and fire-complexes events

- A reliable simulation is needed for operations planning and health impact assessment



Wildland-Urban Interface (WUI) and transport networks are most vulnerable to wildfires.

- Risk assessment and environment planning
- Information is needed to assist decision making for sheltering and evacuation



Two use cases with two specific scales

Scene 1. **Landscape** scale

- To provide simulations of wildfire progression, energy release and coupled **atmosphere-fire interactions**.
- To estimate **perturbation of wind fields**.
- To simulate generation of **pyro-convective** movements.
- To model **smoke** release and dispersion. Generation and transport of **flying embers**.
- Calculation domain is **50 x 50 x 3 Km**. Target spatial resolution 20 m. Target temporal resolution 5-10 min

Scene 2. **Wildland-Urban Interface** scale

- To provide simulations of the local fire behavior and local fire-atmosphere interactions
 - Local flame front **propagation**
 - Local combustion **heat release**
 - Local combustion **smoke release** and dispersion
- To estimate local effect of **vegetation** on air flow and fire behaviour
- To estimate local effect of **buildings** on air flow and fire behaviour
- To simulate generation, transport and emission of **flying embers**
- Calculation domain is **3 x 3 x 1 Km**; Target spatial resolution 1 m; Target temporal resolution 1 min

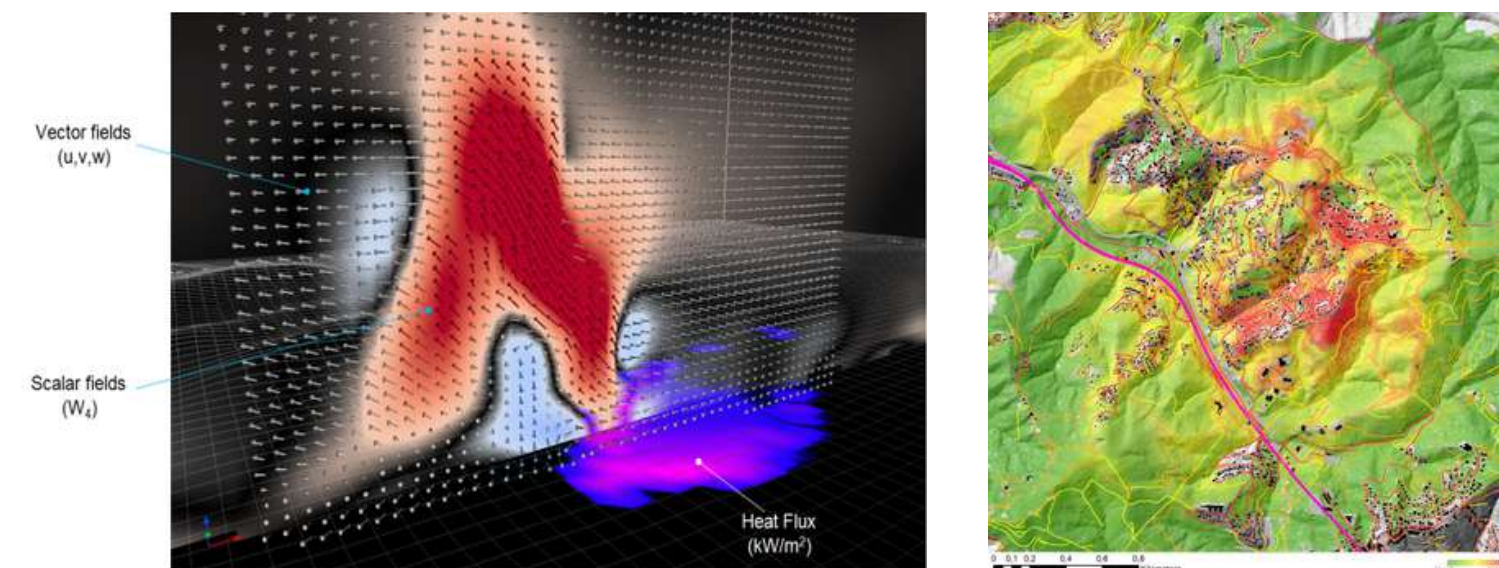
Objective: Provide simulations of large wildfire progression, energy release and coupled atmosphere-fire interactions, including fire front spread, smoke dispersion and pyroconvective movements

Practical Application: Operational analysis of large fires and fire-complexes events:

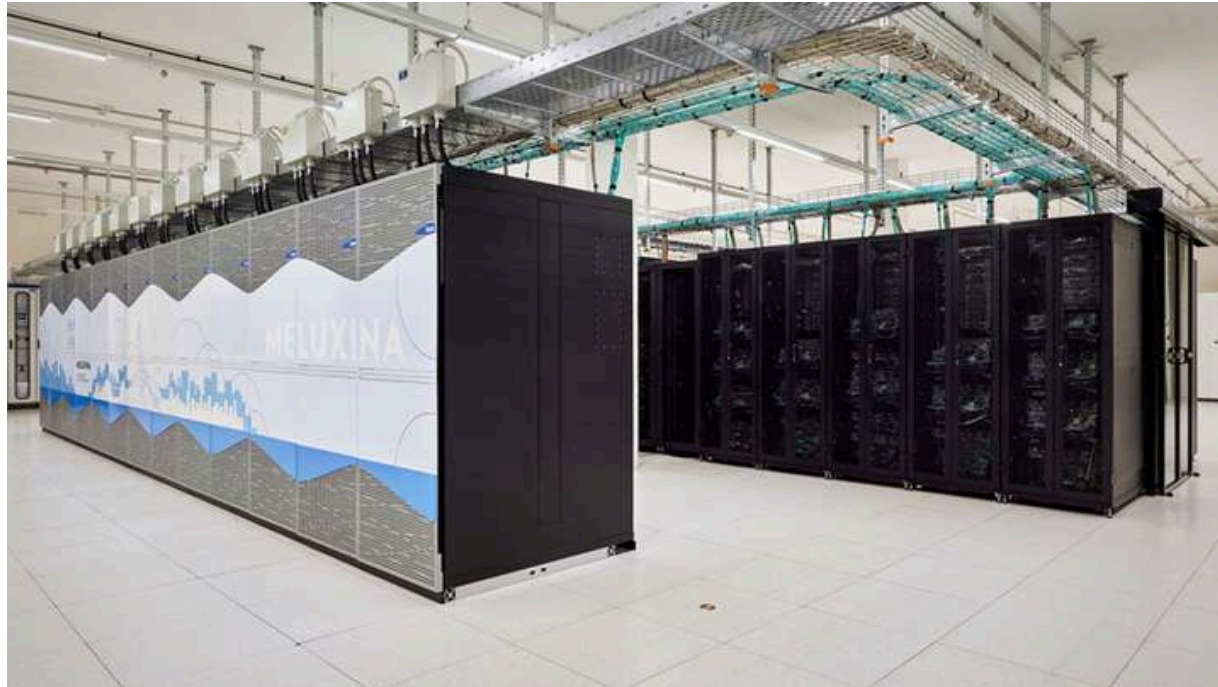
- Fire front spread forecast
- Analysis of pyroconvective movements
- Impact of smoke on urban environments
- Assessment on resources allocation

Practical Application: Probabilistic spread and landscape risk assessment:

- Identification of potential landscape hotspots
- Planning of WUI prevention and mitigation strategies
- Verification of protection measures

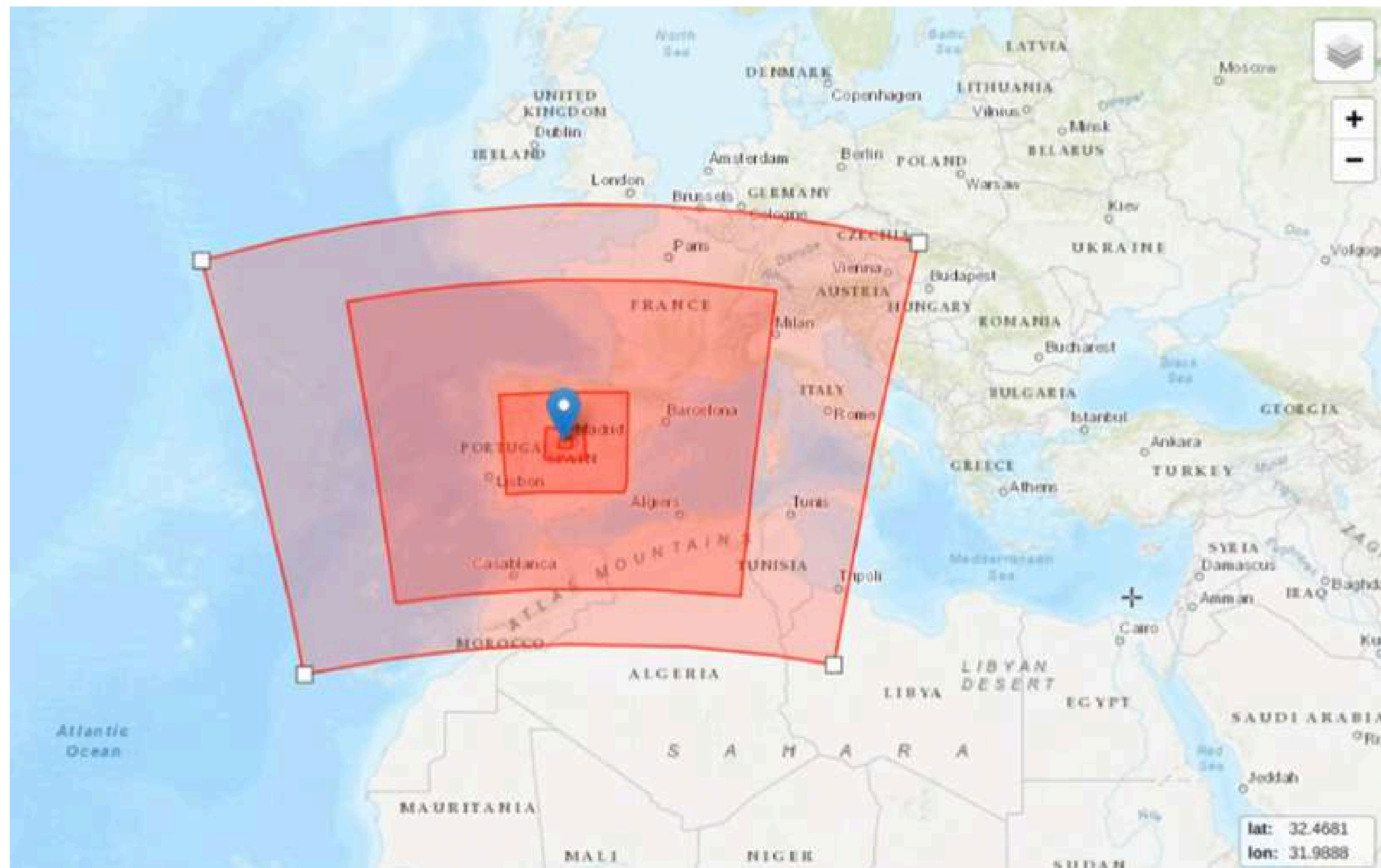


Use of EuroHPC JU resources

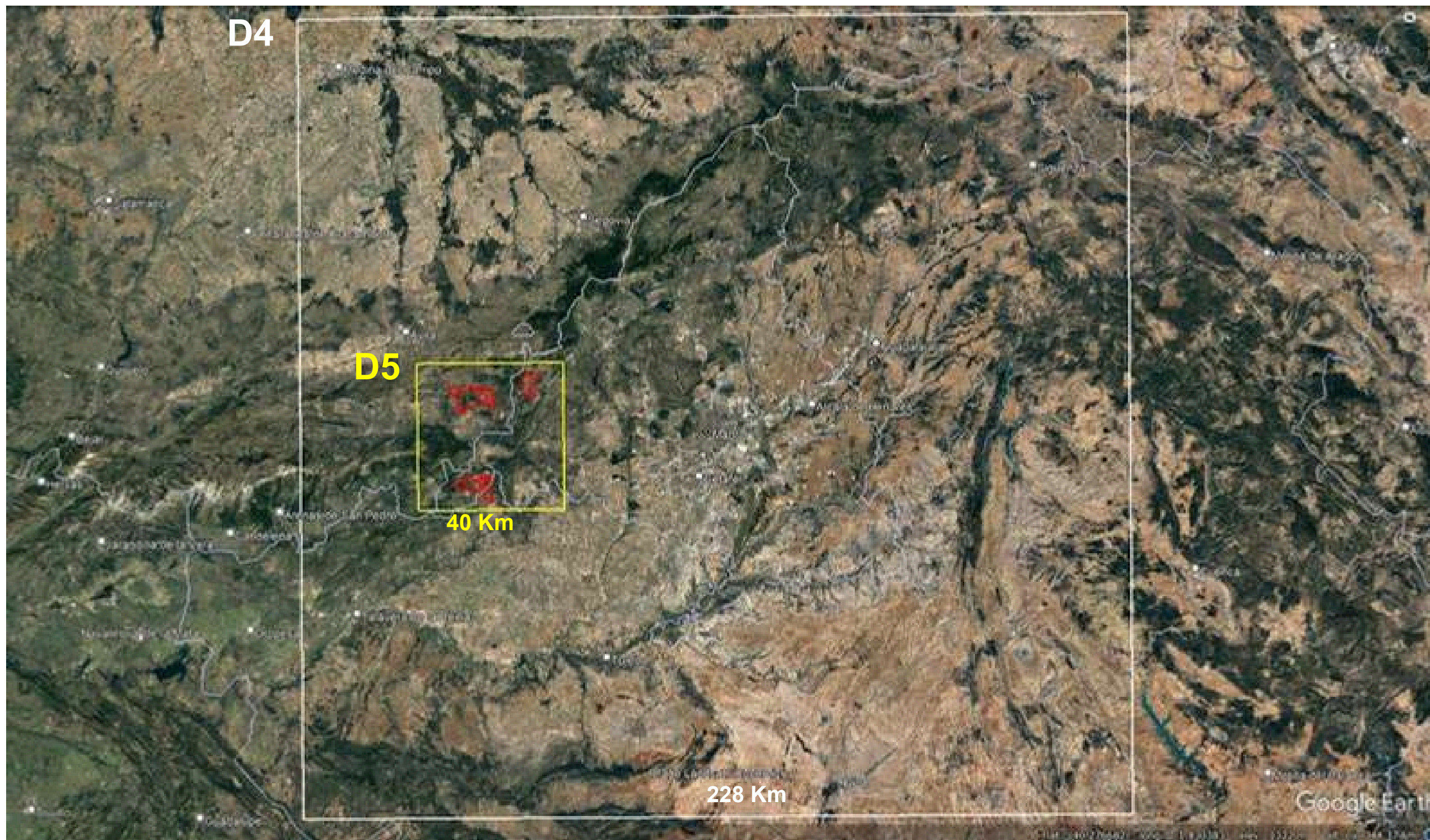


HPC simulation of Fire-Atmosphere interaction

High resolution – Downscaling
Up to 5 nested domains
WRF – mesoscale model
SFIRE coupled fire spread model

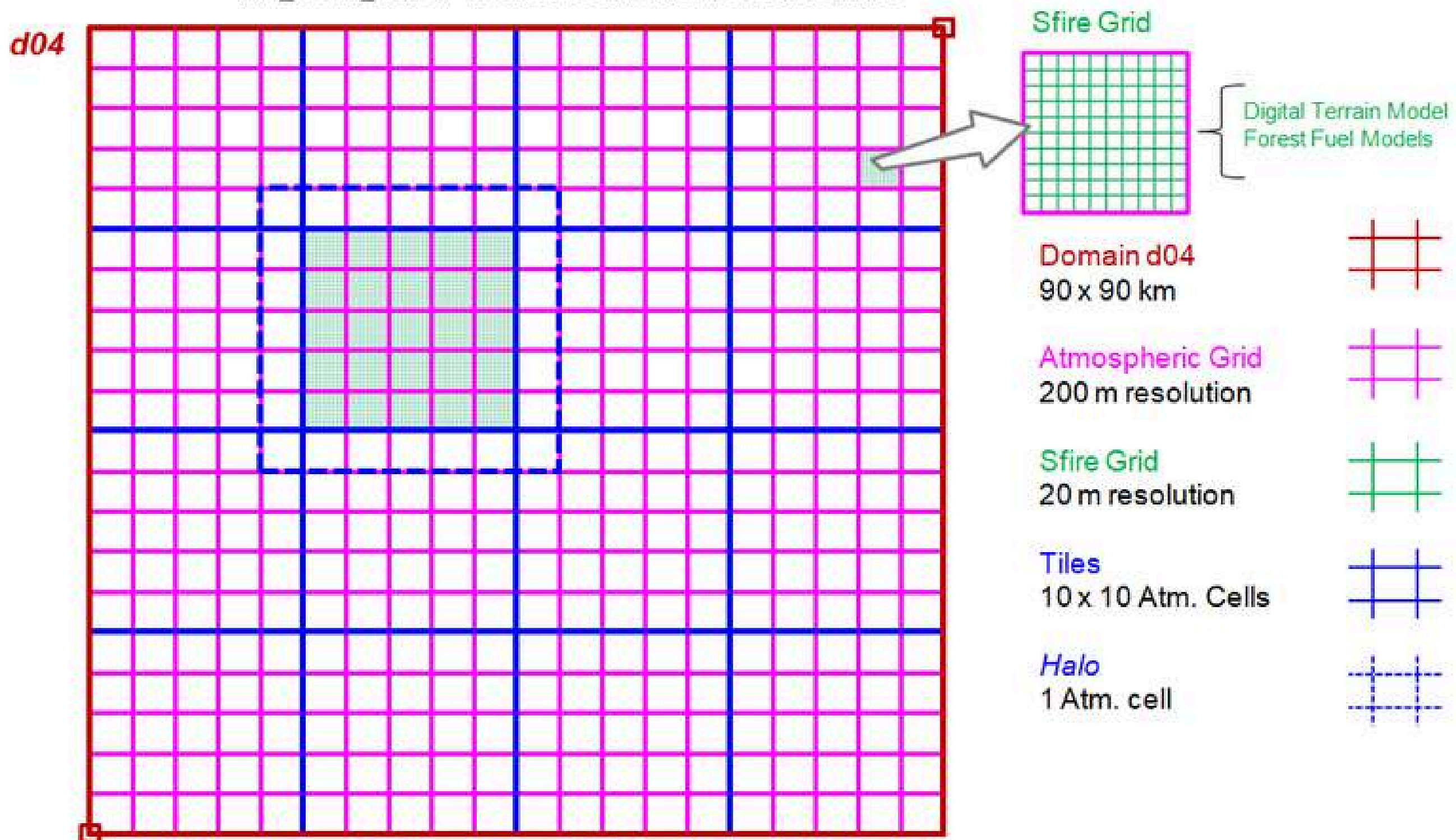


HPC simulation of Fire-Atmosphere interaction



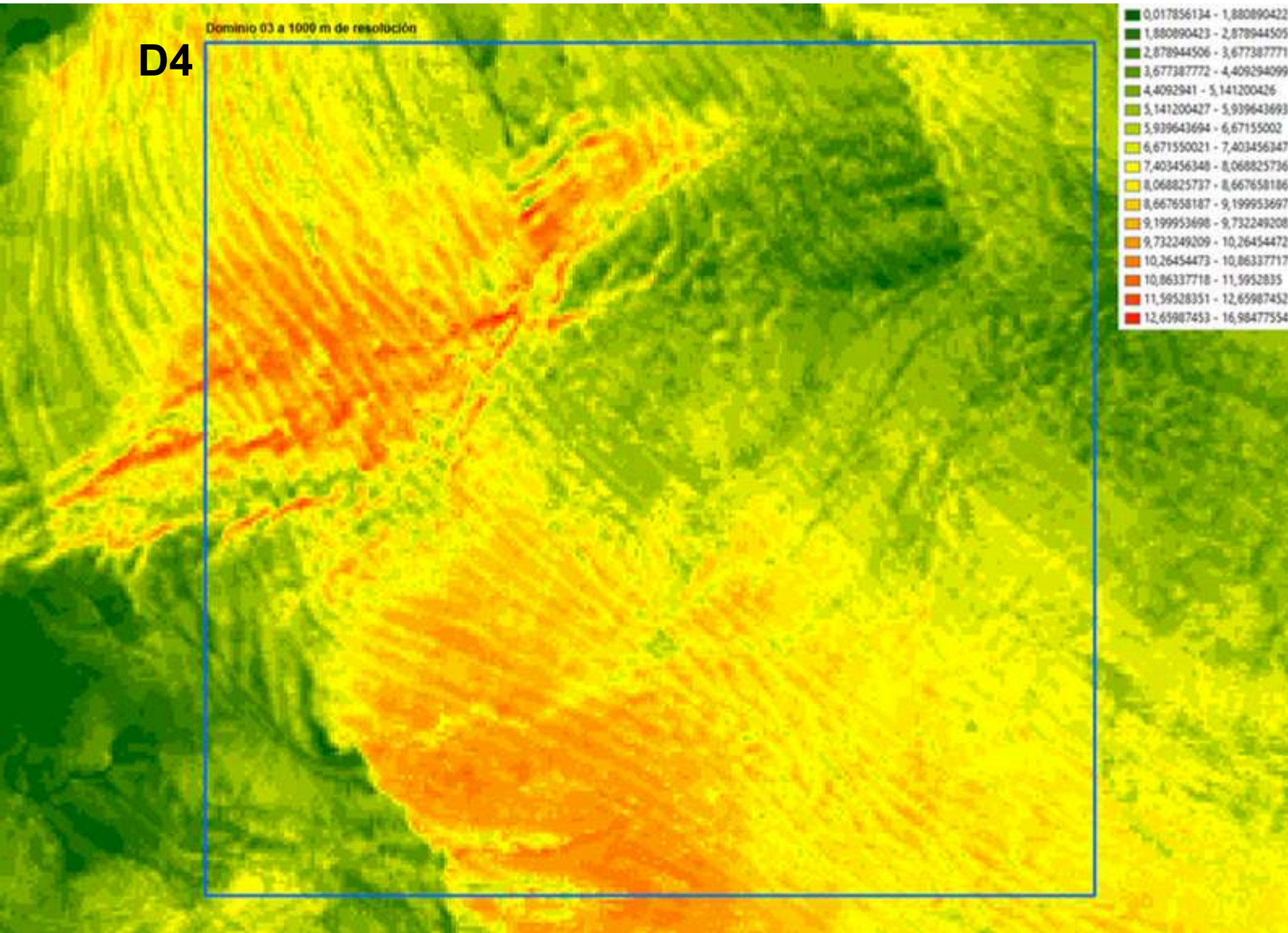
HPC simulation of Fire-Atmosphere interaction

MPI_CART_CREATE = To create this division into tiles
 MPI_CART_SHIFT = To enable communication between tiles

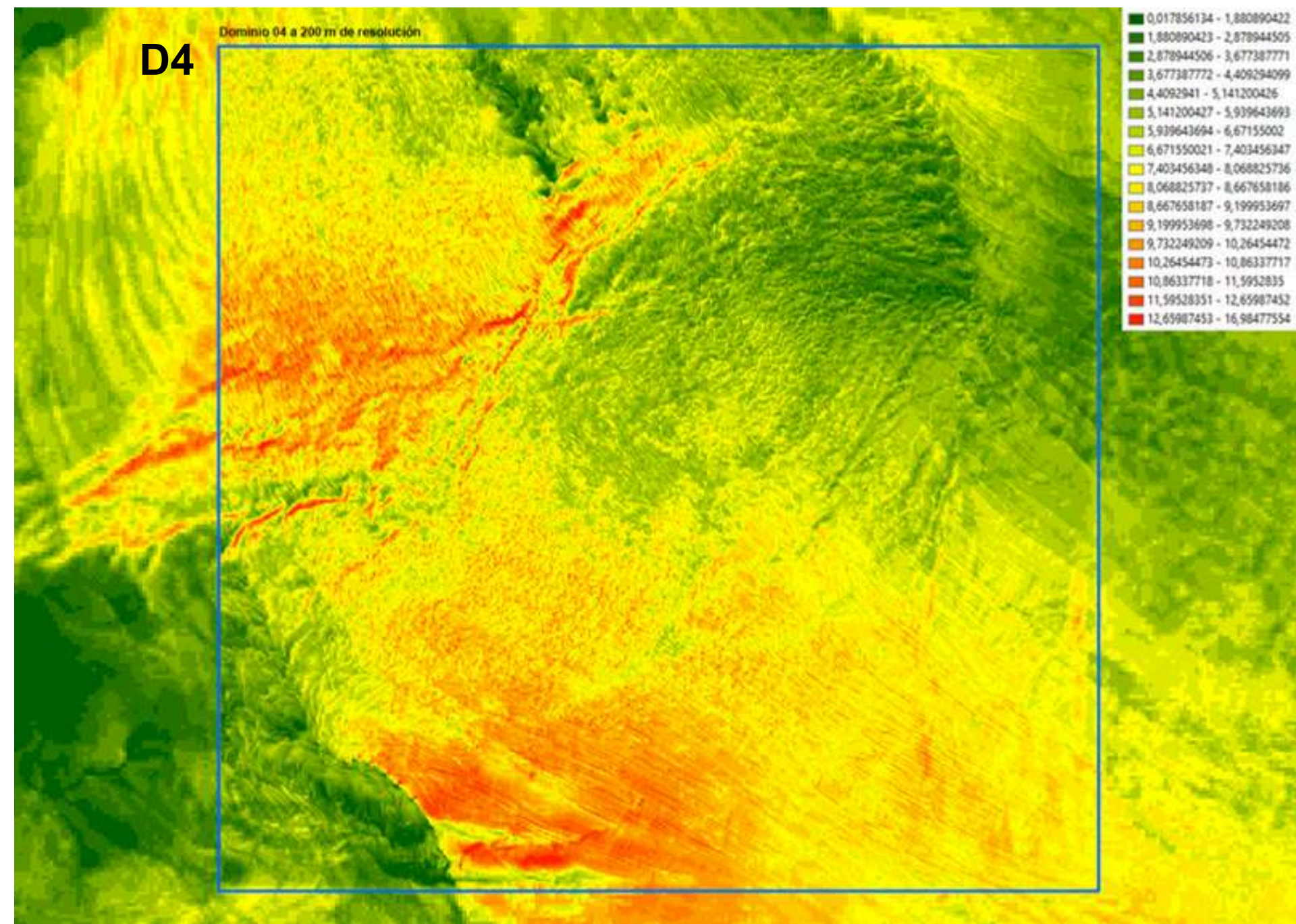


HPC simulation of Fire-Atmosphere interaction

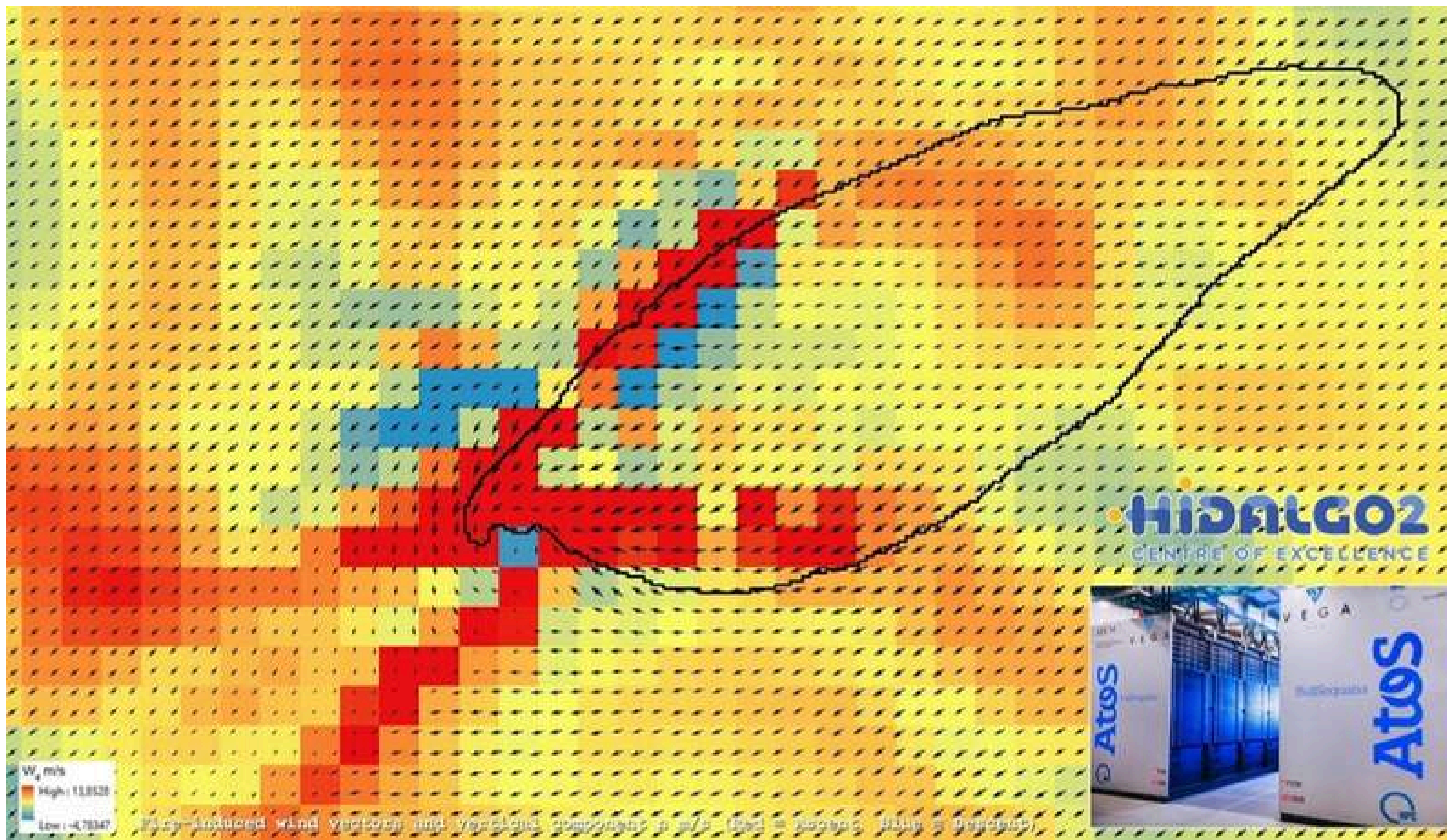
1000 m resolution



200 m resolution



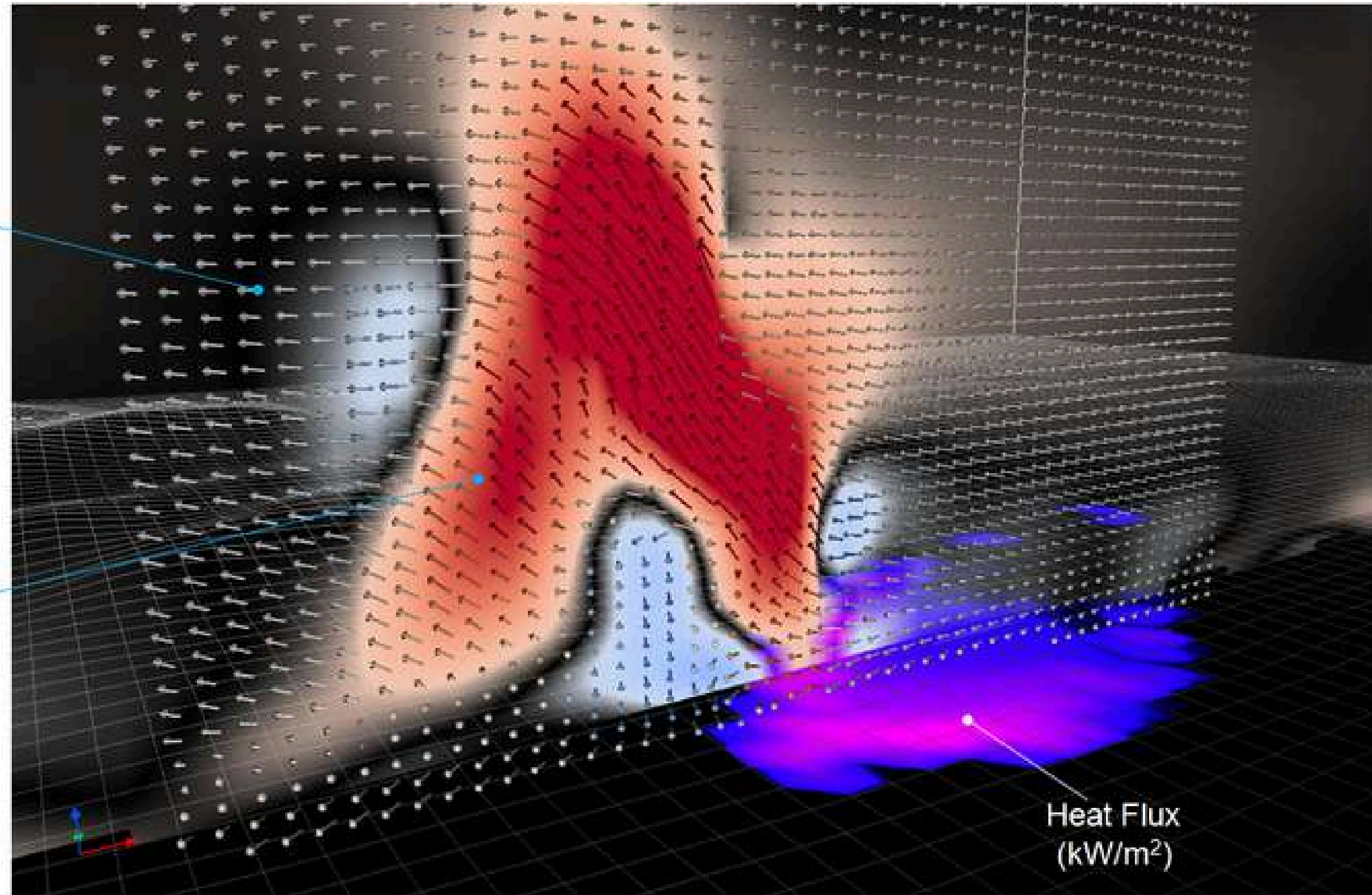
HPC simulation of Fire-Atmosphere interaction



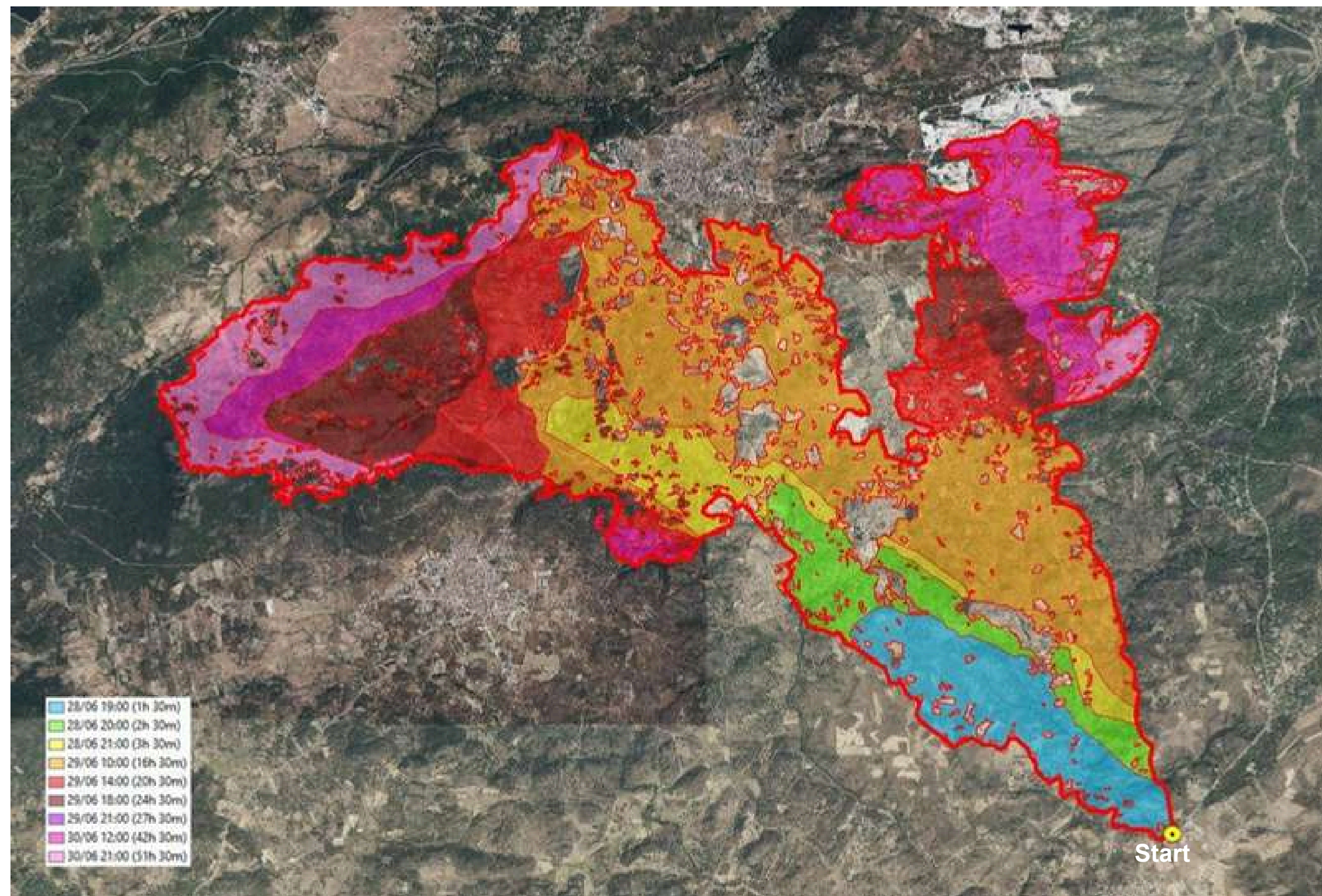
HPC simulation of Fire-Atmosphere interaction

Vector fields
(u, v, w)

Scalar fields
(W_4)



Application – Simulation of real wildfires



Source: Regional Forest Firefighting Service of Castilla-La Mancha

Application – Simulation of real wildfires

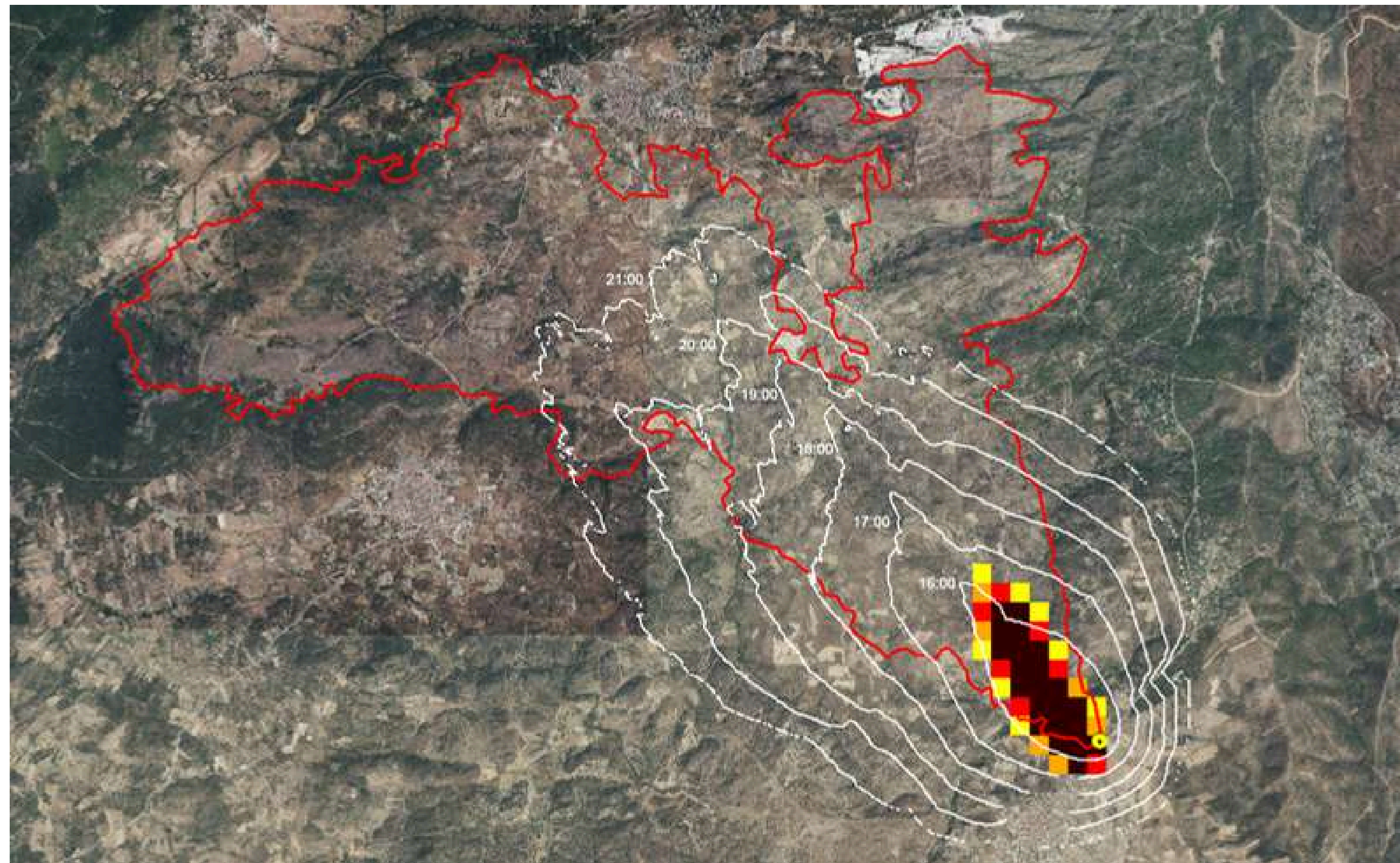
28/06/2019 19:04 (17:04 UTC)



Source: Regional Forest Firefighting Service of Castilla-La Mancha

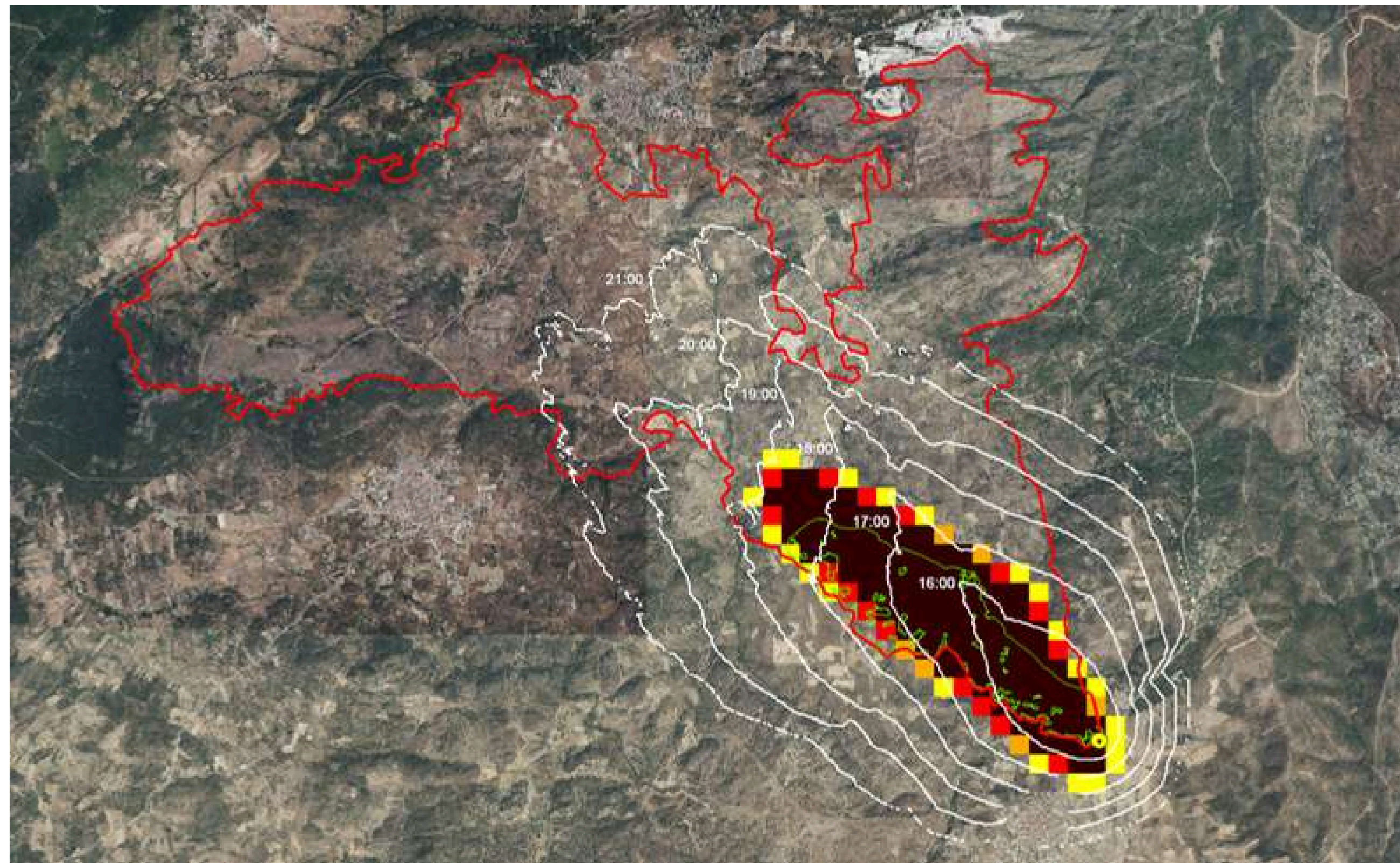
Simulation of fire propagation

16:00 UTC



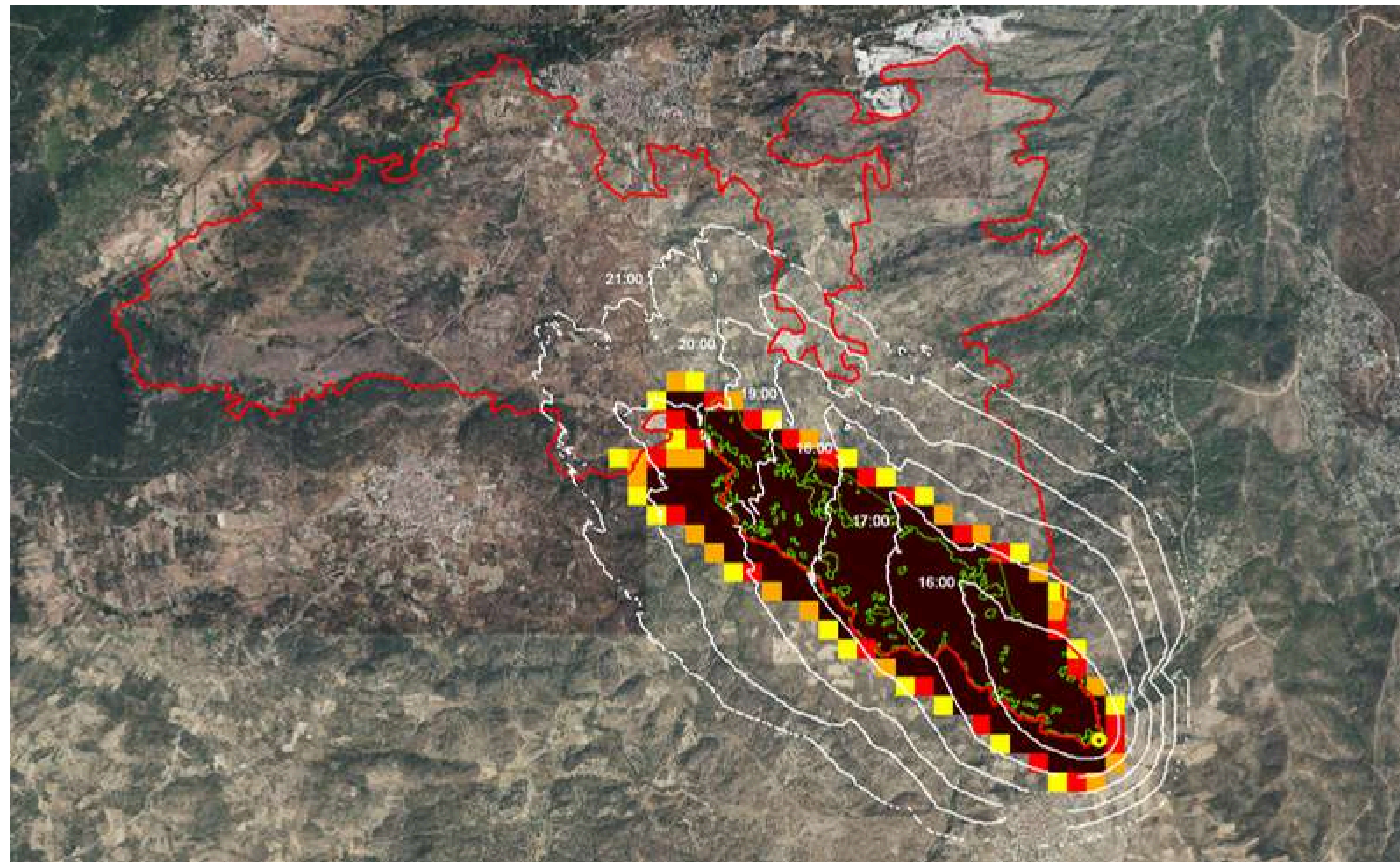
Simulation of fire propagation

17:00 UTC



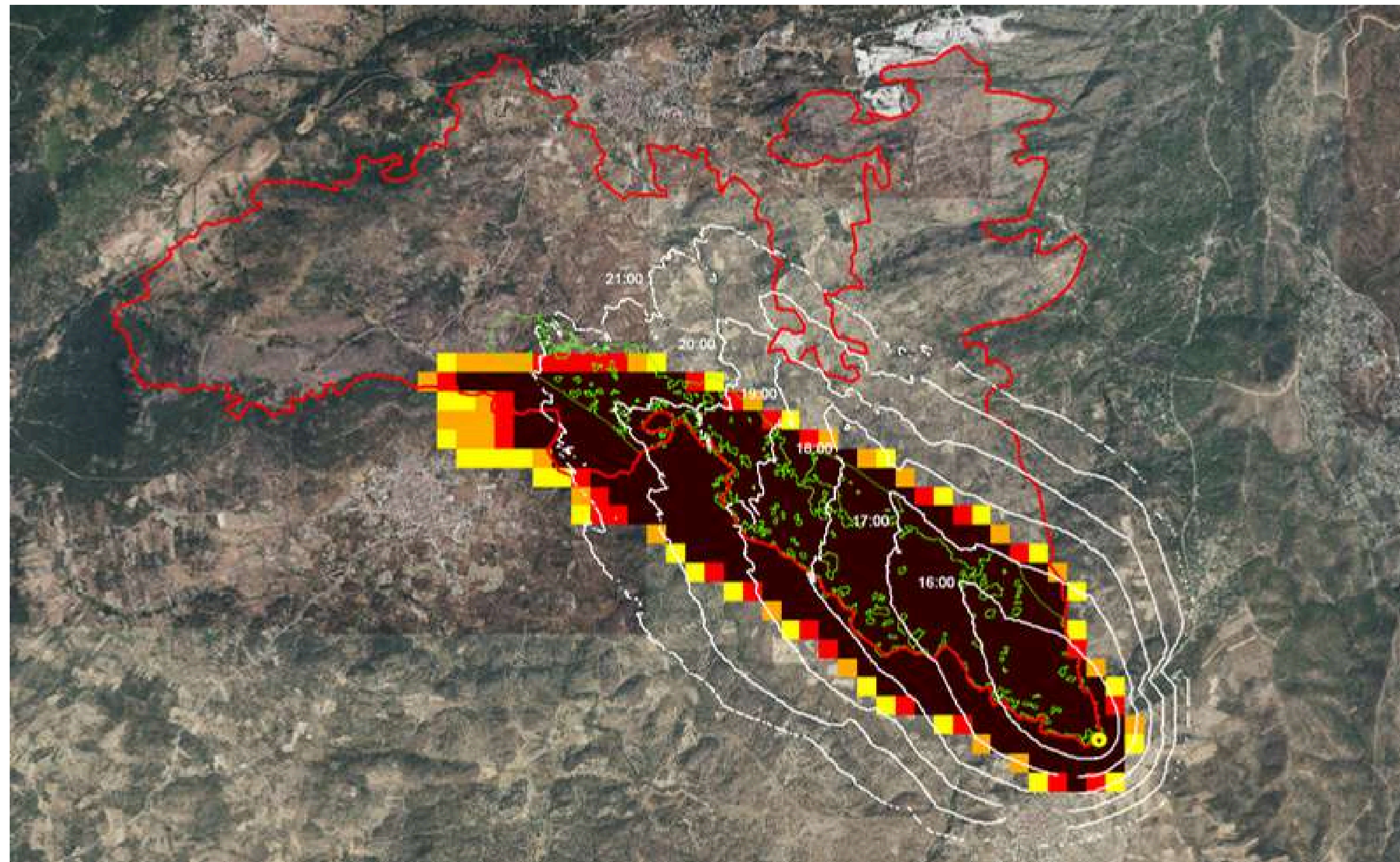
Simulation of fire propagation

18:00 UTC



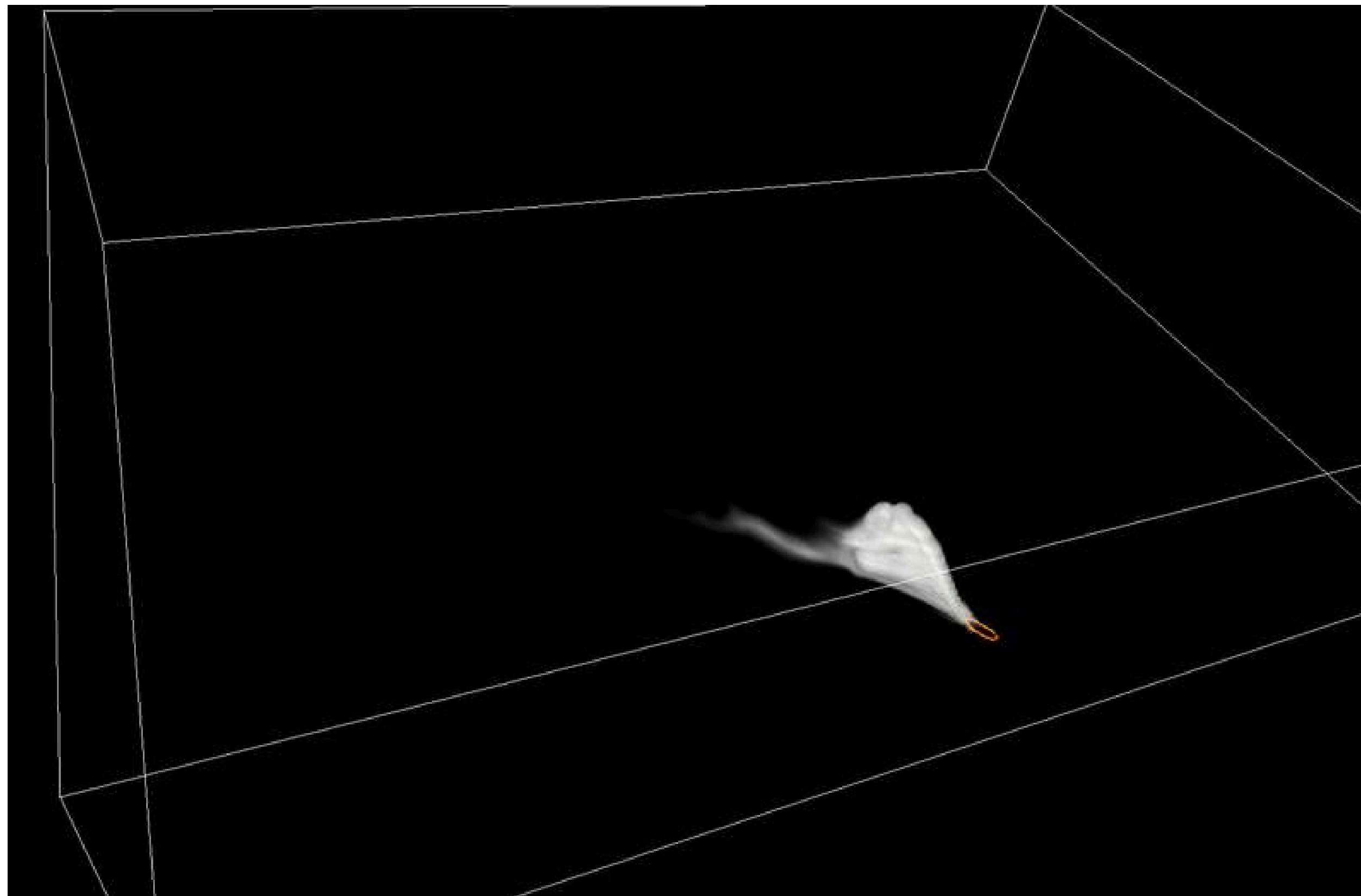
Simulation of fire propagation

19:00 UTC



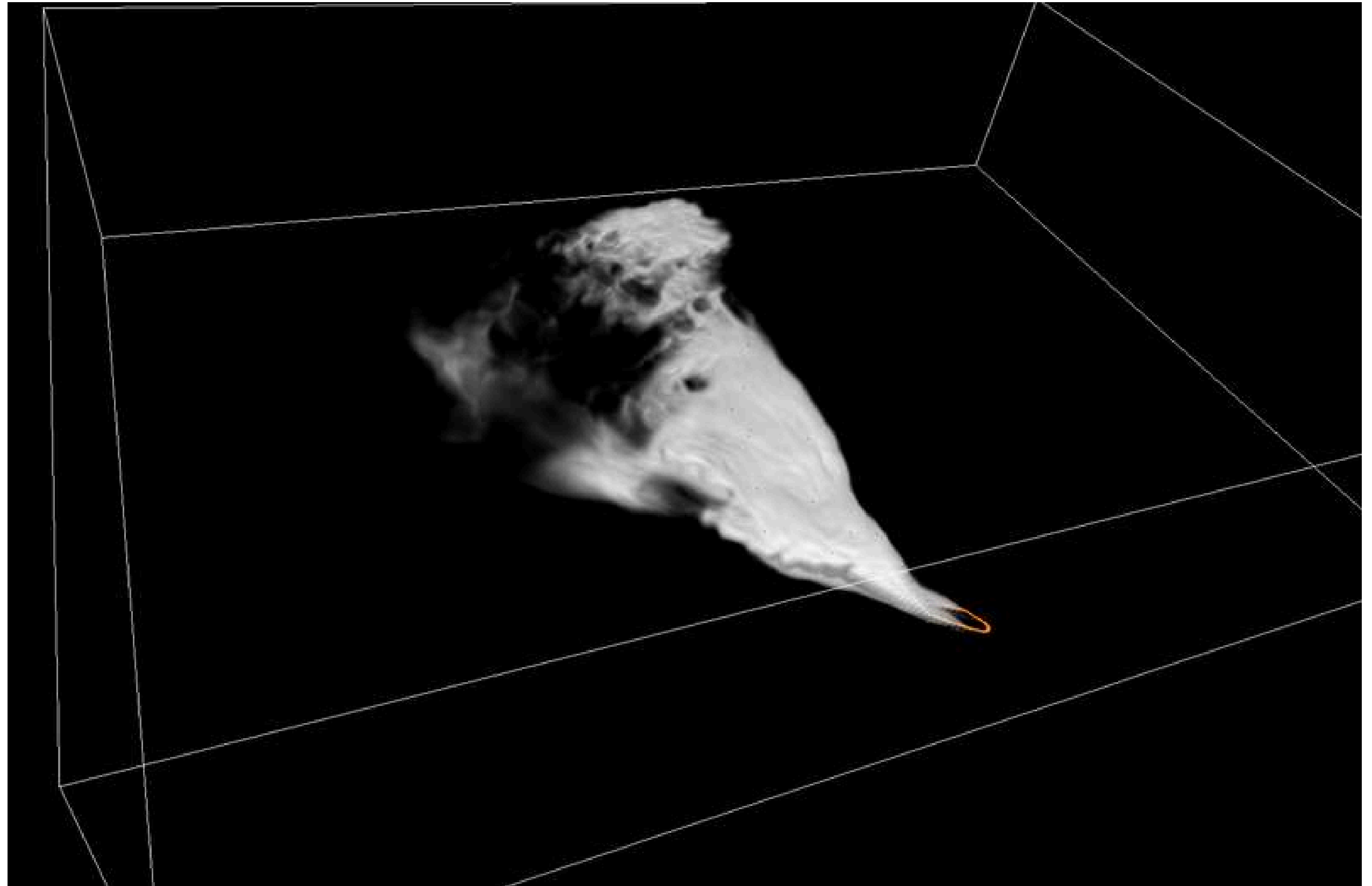
Simulation of smoke dispersion

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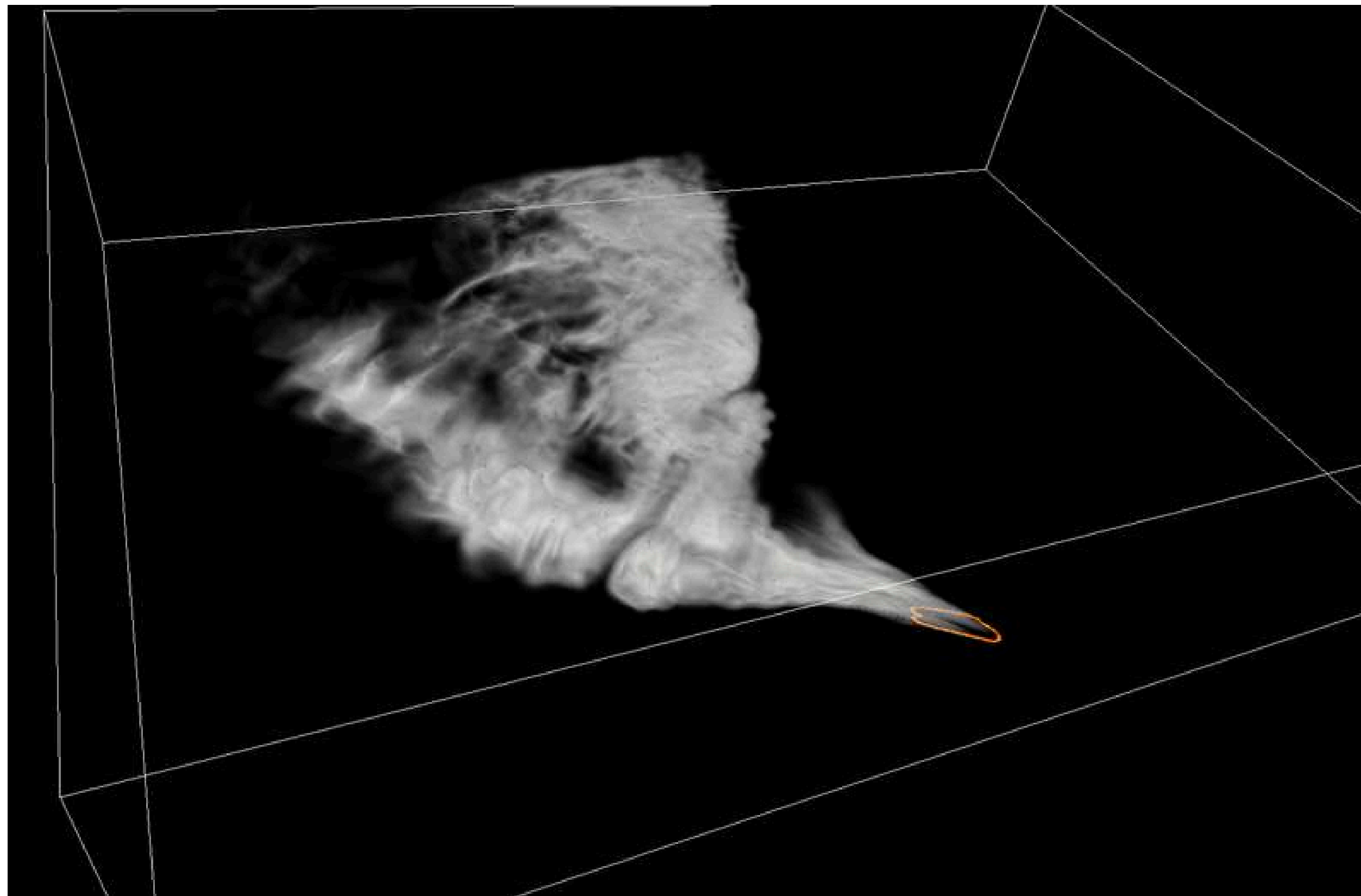
Simulation of smoke dispersion

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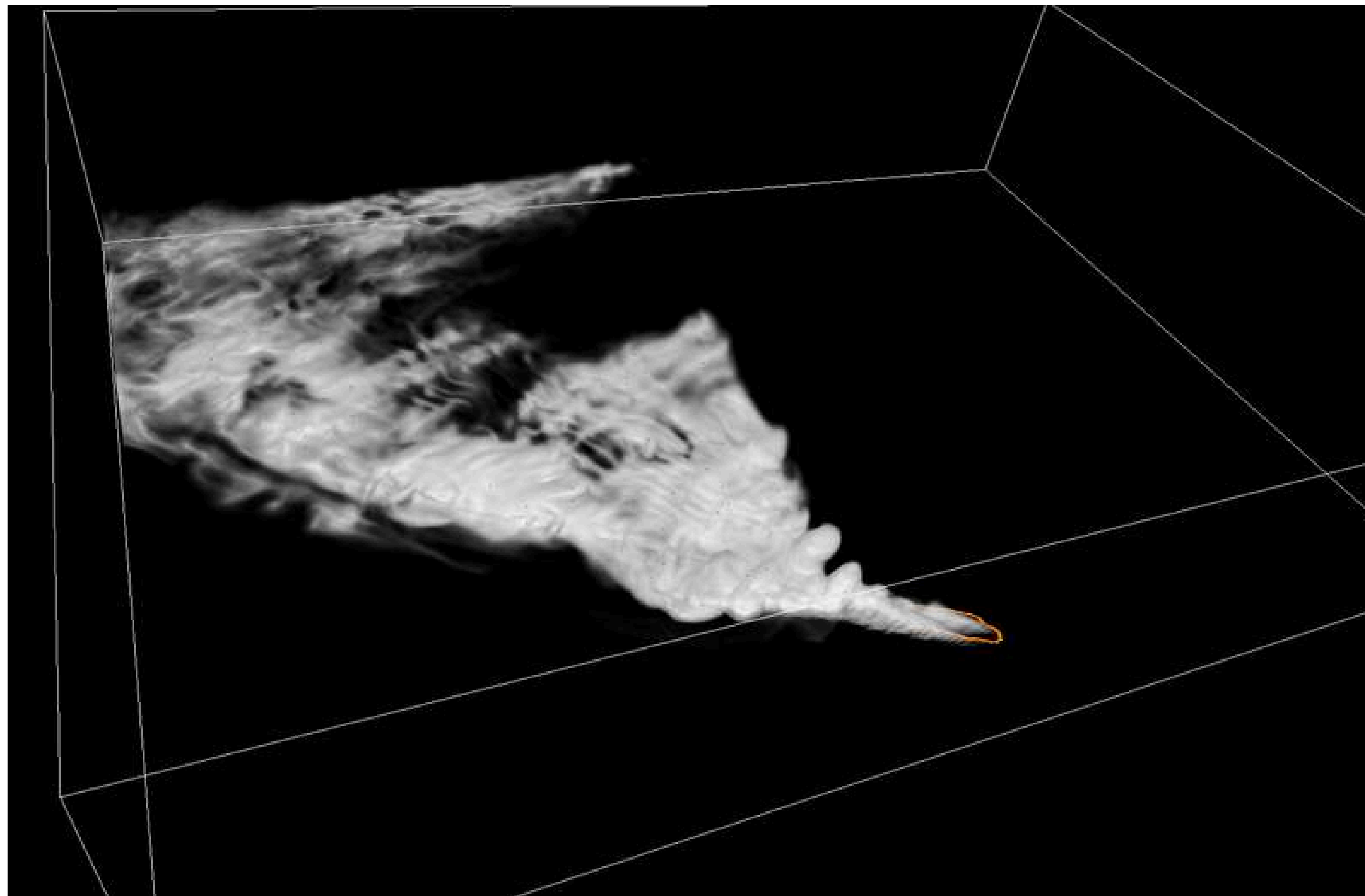
Simulation of smoke dispersion

18:00 UTC



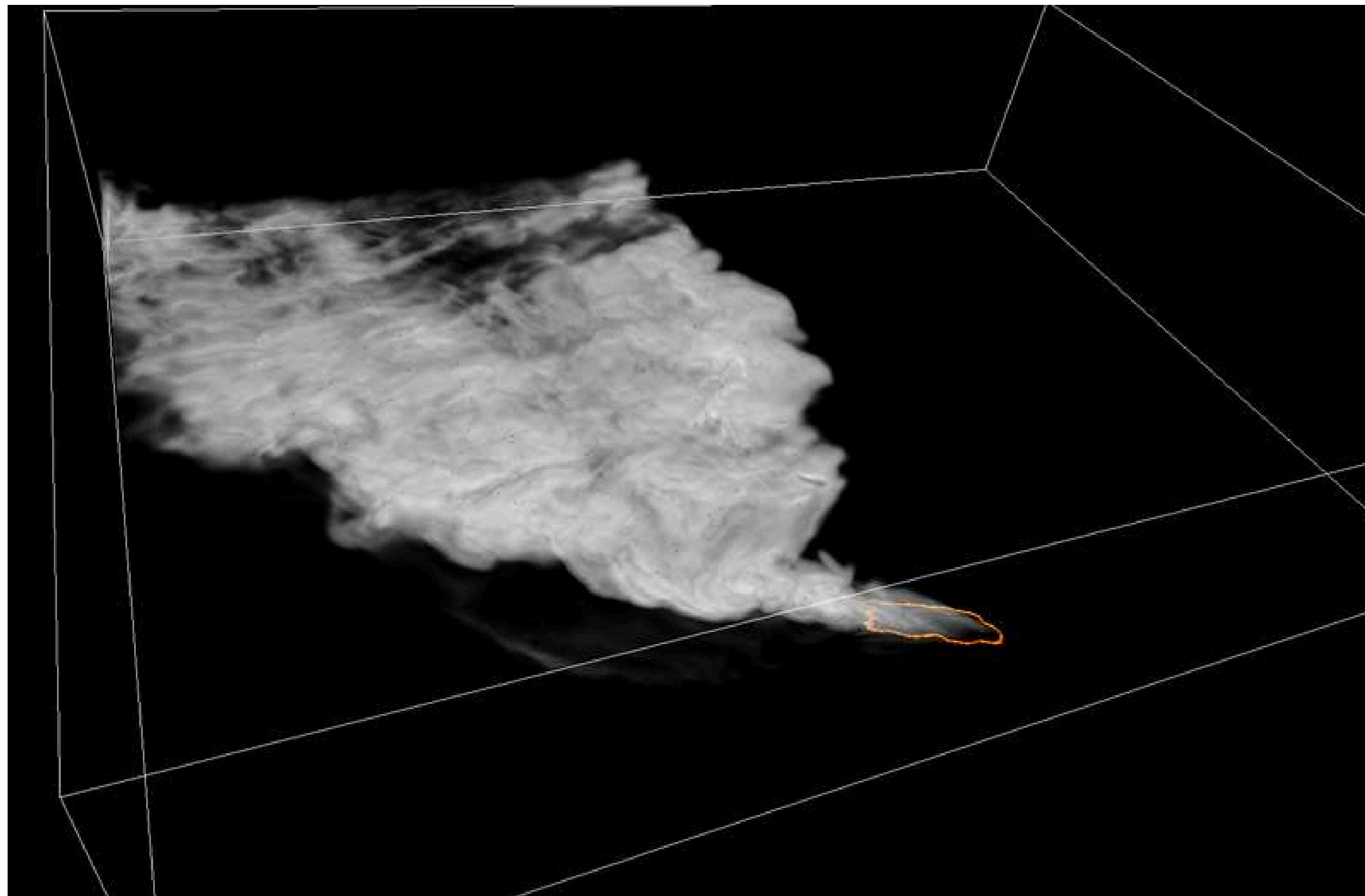
Simulation of smoke dispersion

19:00 UTC

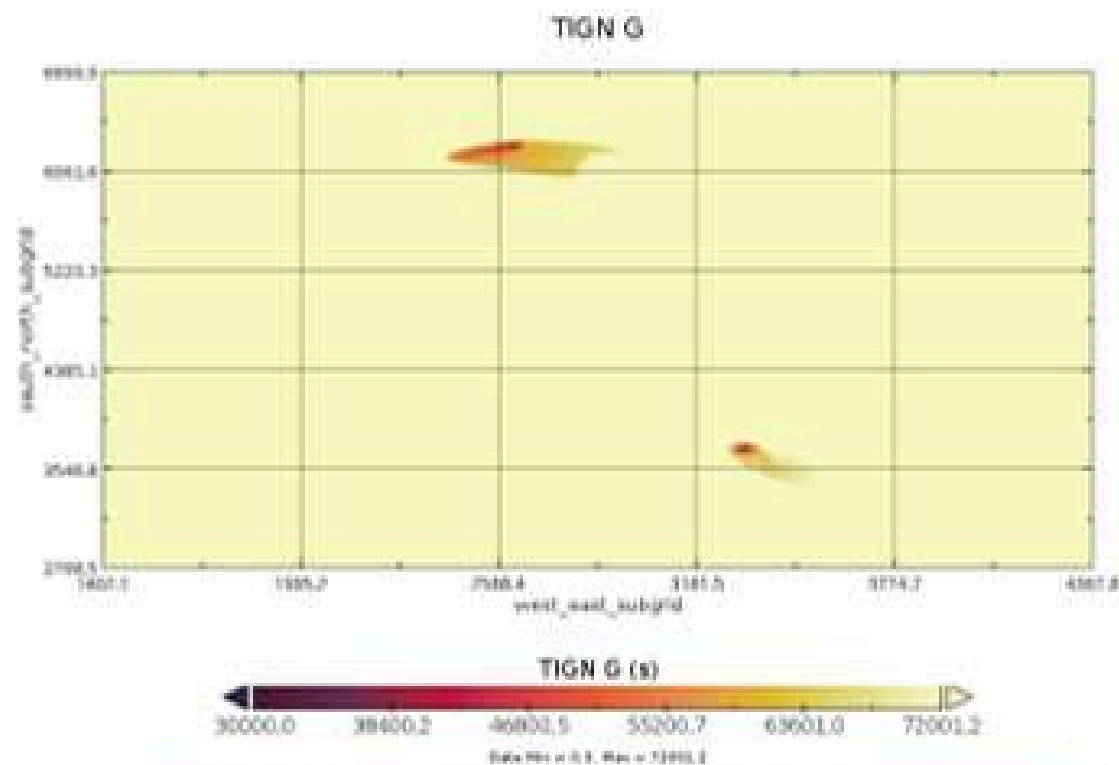
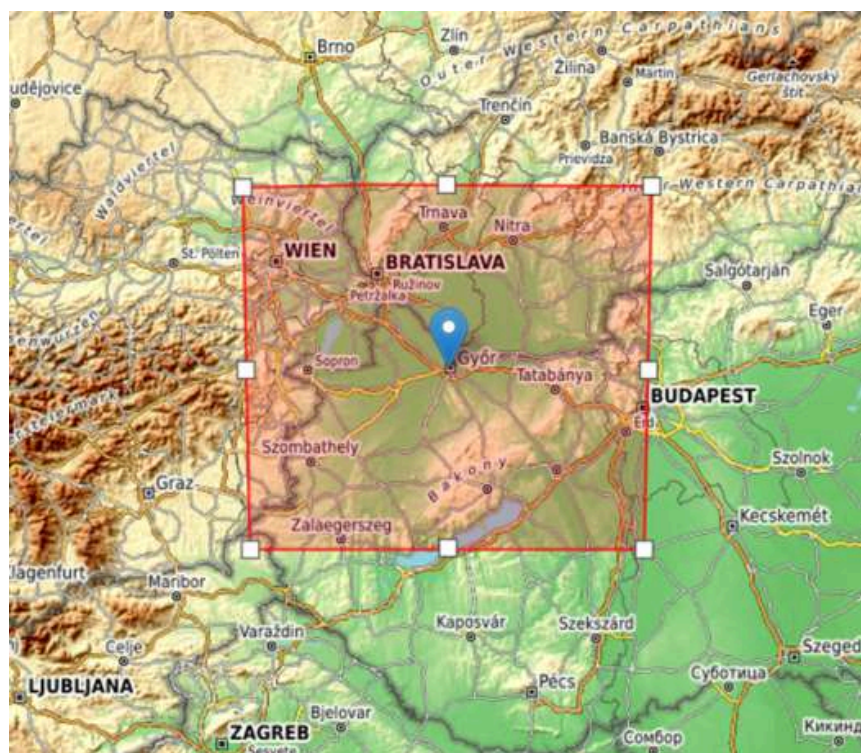


Simulation of smoke dispersion

20:00 UTC

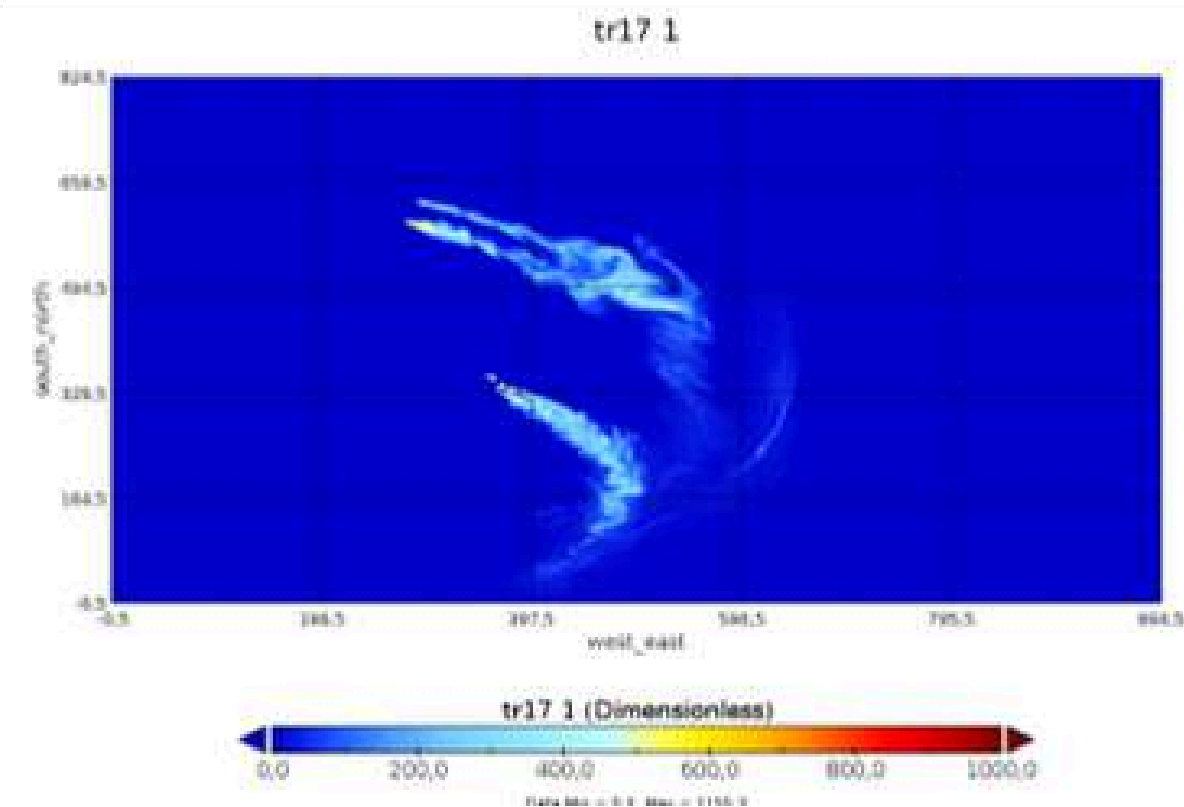
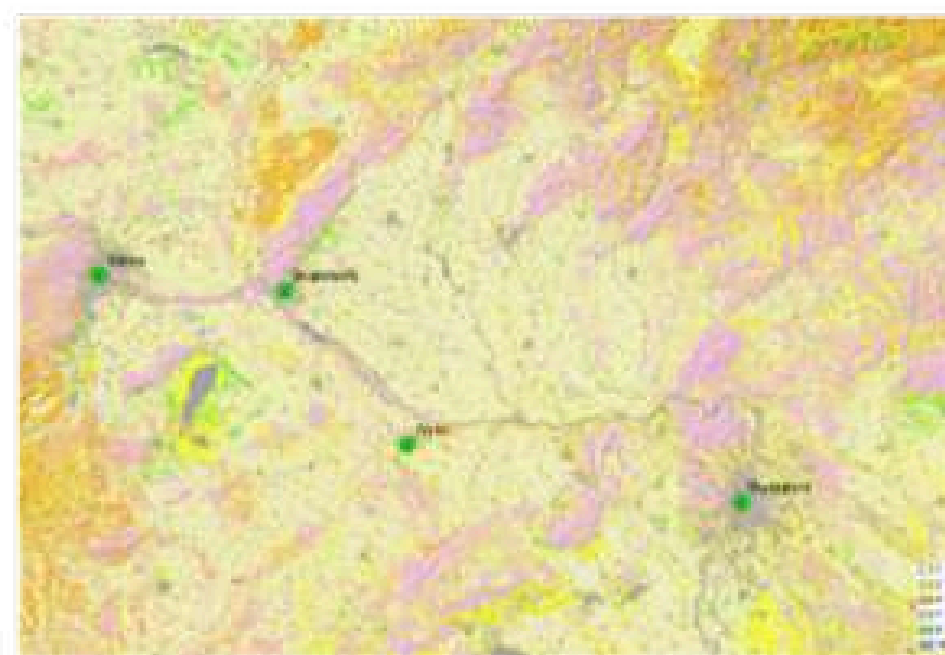
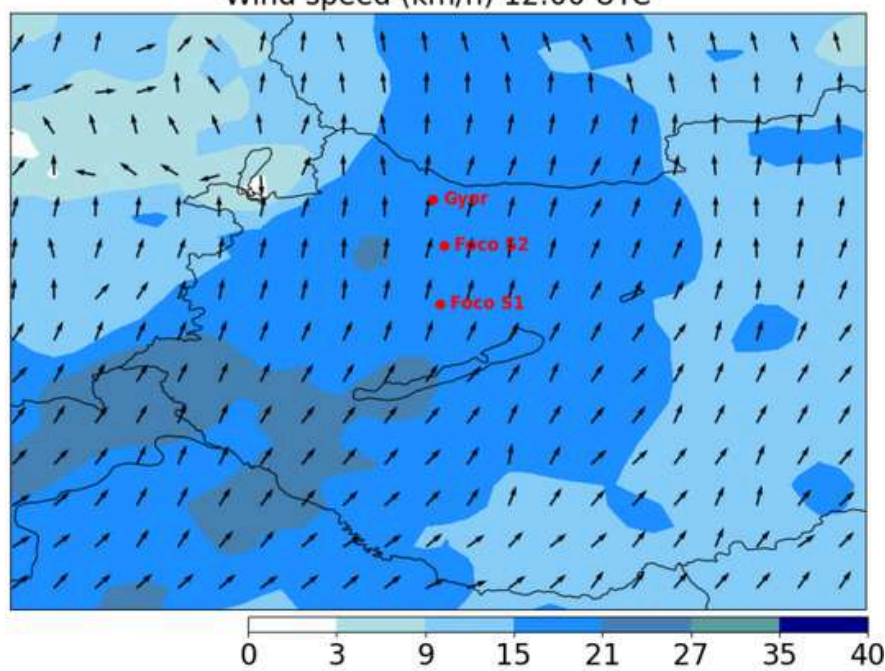


Application - Landscape analysis

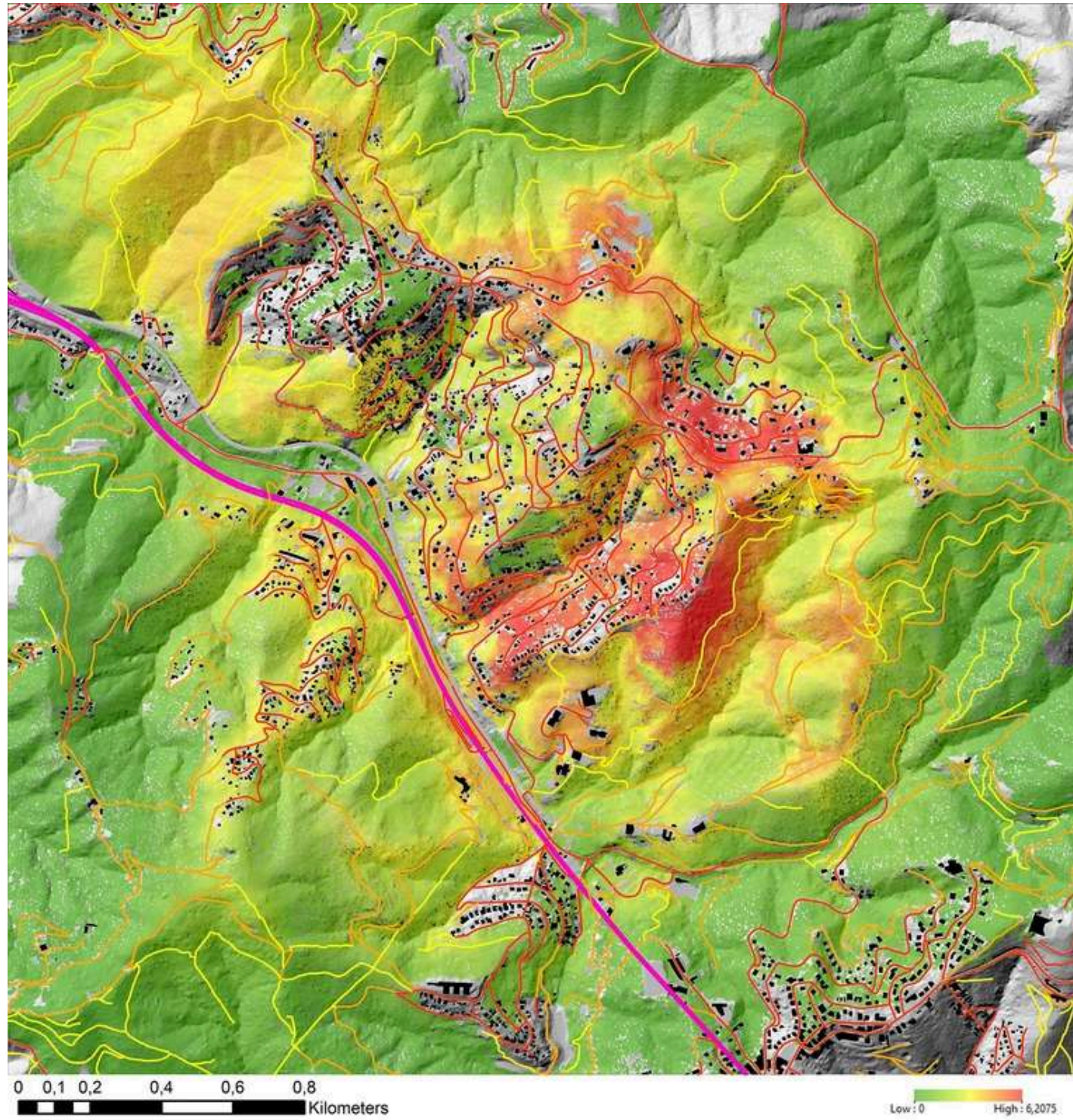


Simulation of fire spread and smoke dispersion of a large fire in a transboundary large fire in the surroundings of Győr (Hungary)

Wind speed (km/h) 12:00 UTC



Application - Landscape analysis



$$BP = 100 \cdot \frac{NF}{NS}$$

- BP Burn Probability, expressed in %
- NF Number of times fire passes through a point in the territory
- NS Total number of simulations

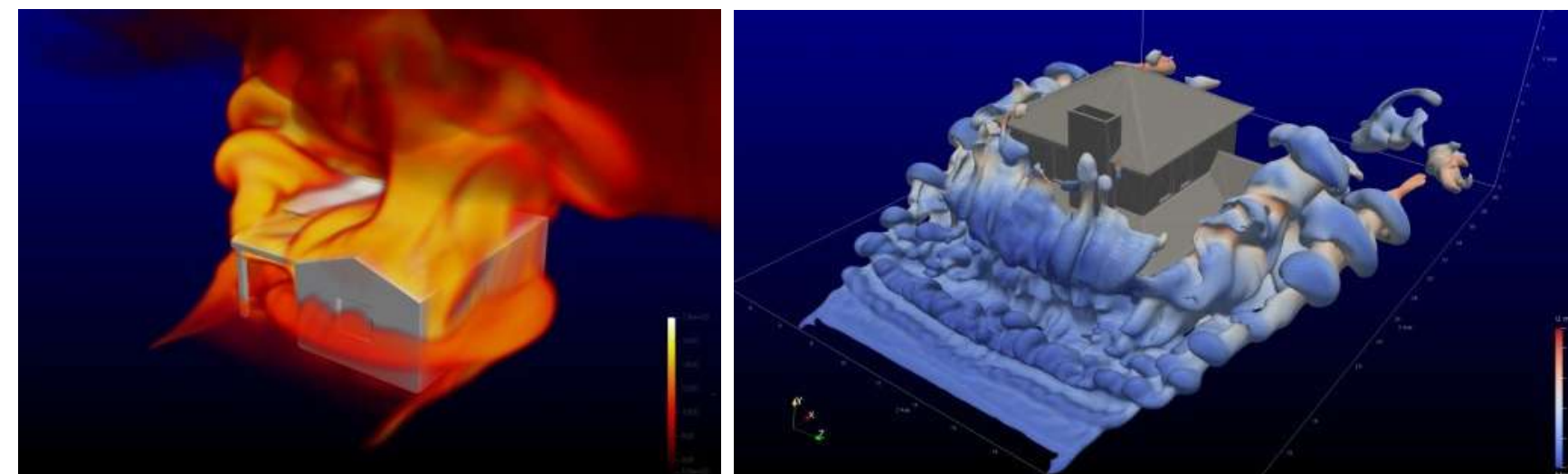
Objective: Simulate wildfire propagation in WUI areas, thermal impact on buildings, and smoke production and dispersion

Practical Application: Fuel mitigation design and vegetation planning:

- Treatments in forested areas surrounding urban zones
- Treatments within residential developments

Practical Application: Performance-Based Design (PBD) applied to buildings

- Identification of the most vulnerable points
- Study of reinforcement strategies
- Verification of protective measures



- **MeluXina** cluster, CPU partition

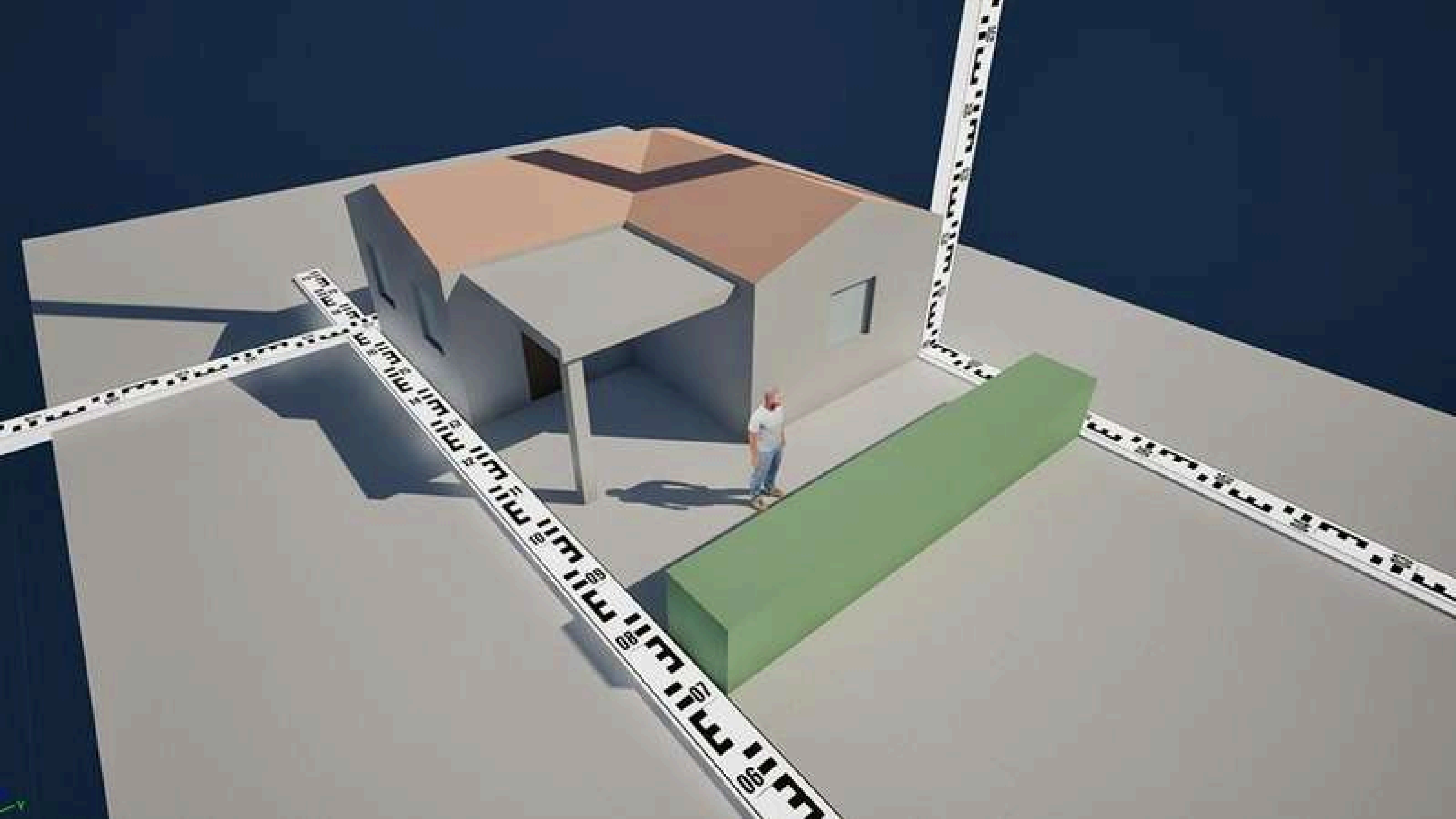
Tools Used Within **OpenFOAM**:

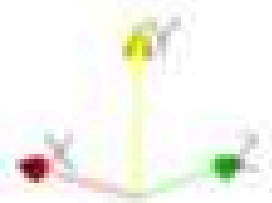
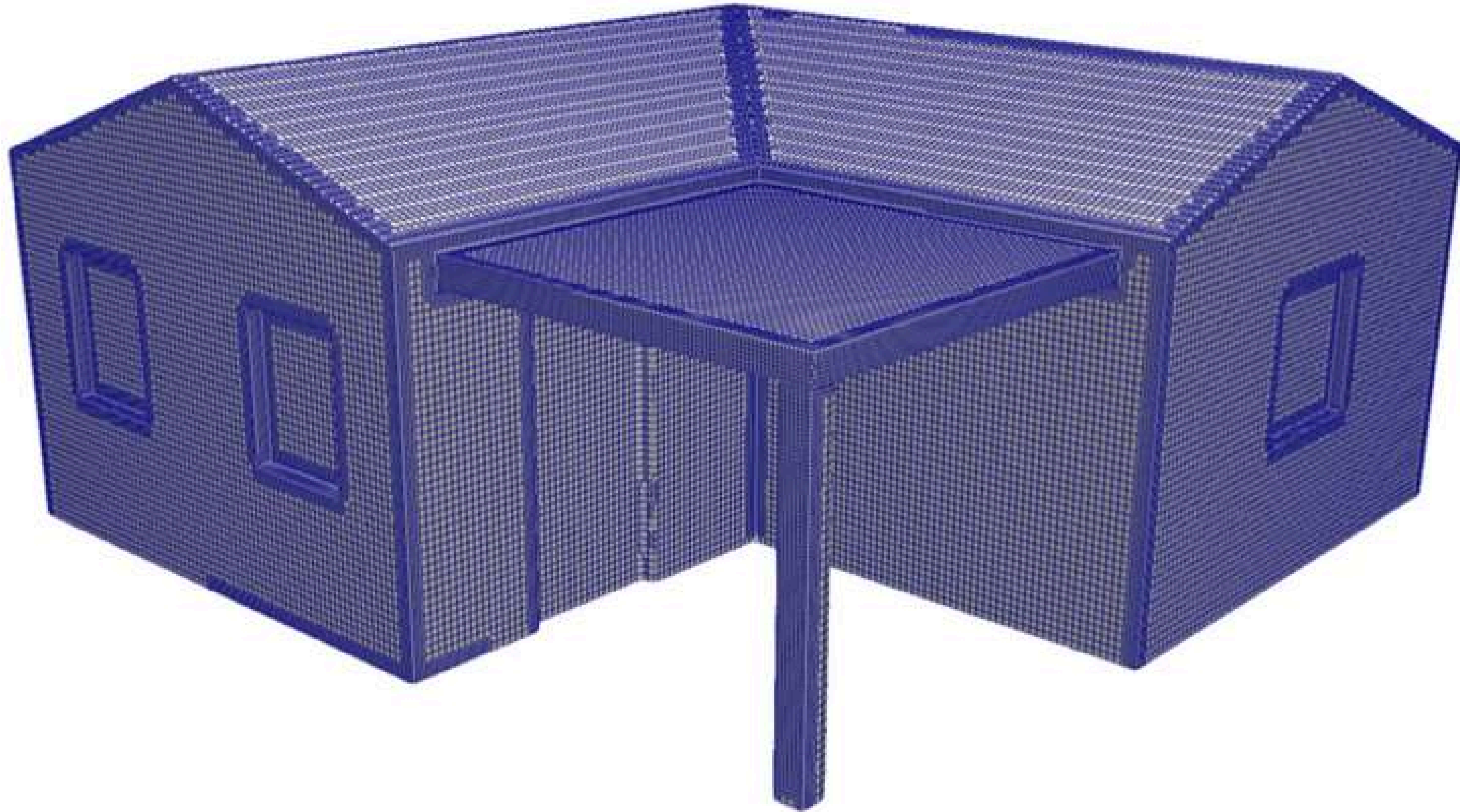
- **PIMPLE** solver for air movement
- **fireFoam** solver (OFv2312) for turbulent flame diffusion
- **porousGasificationFoam** solver (OFv8) for reactive porous media
- **wildfireFoam** solver specifically for forest fuels

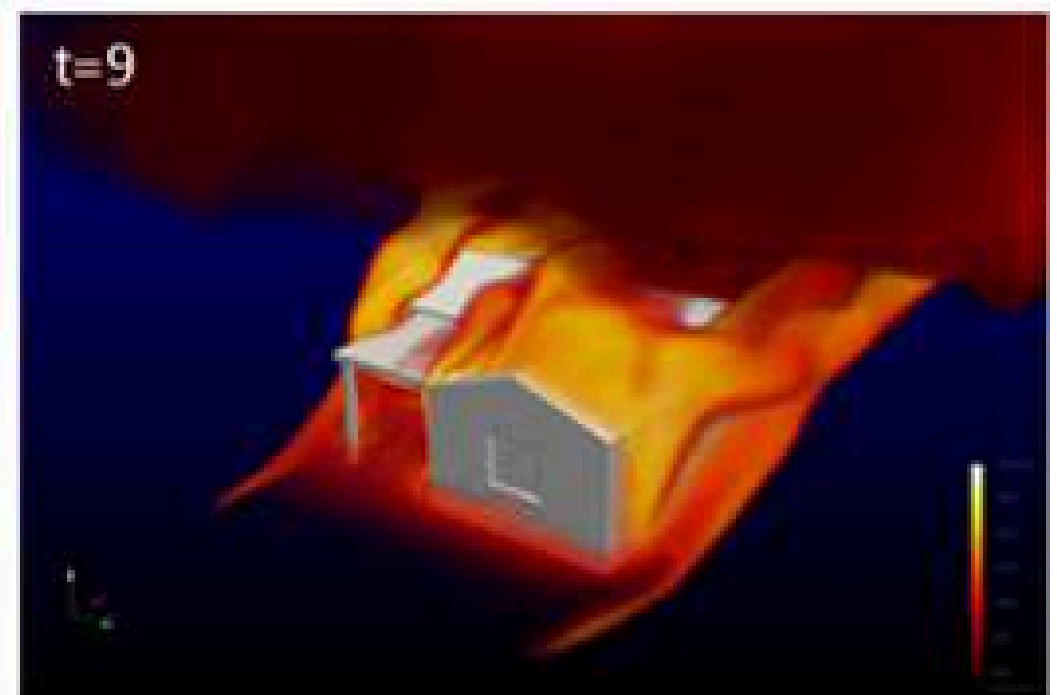
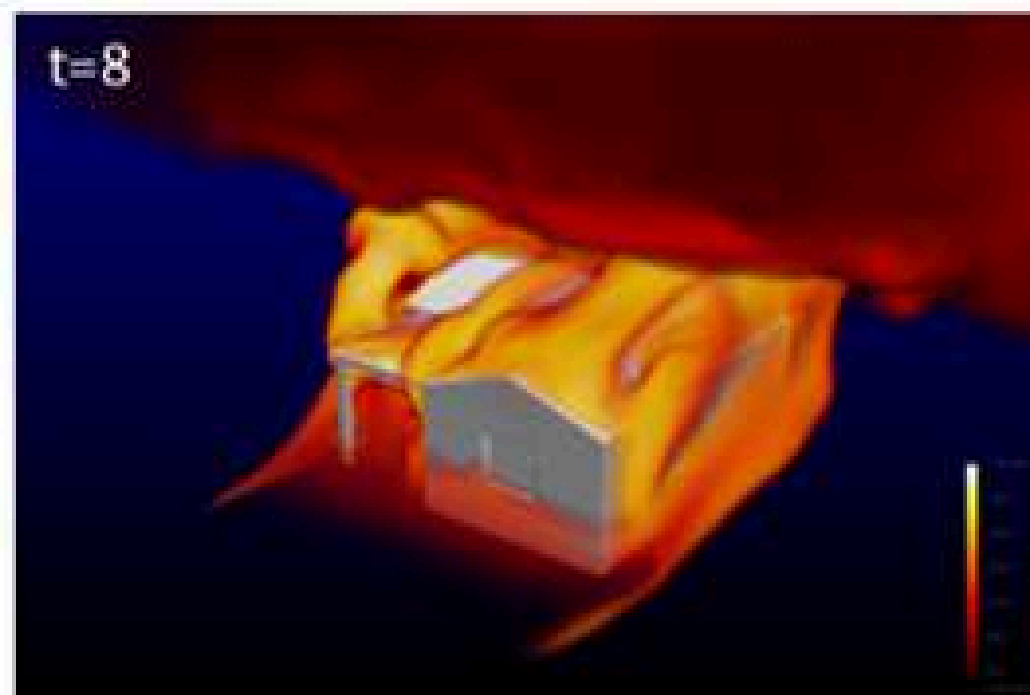
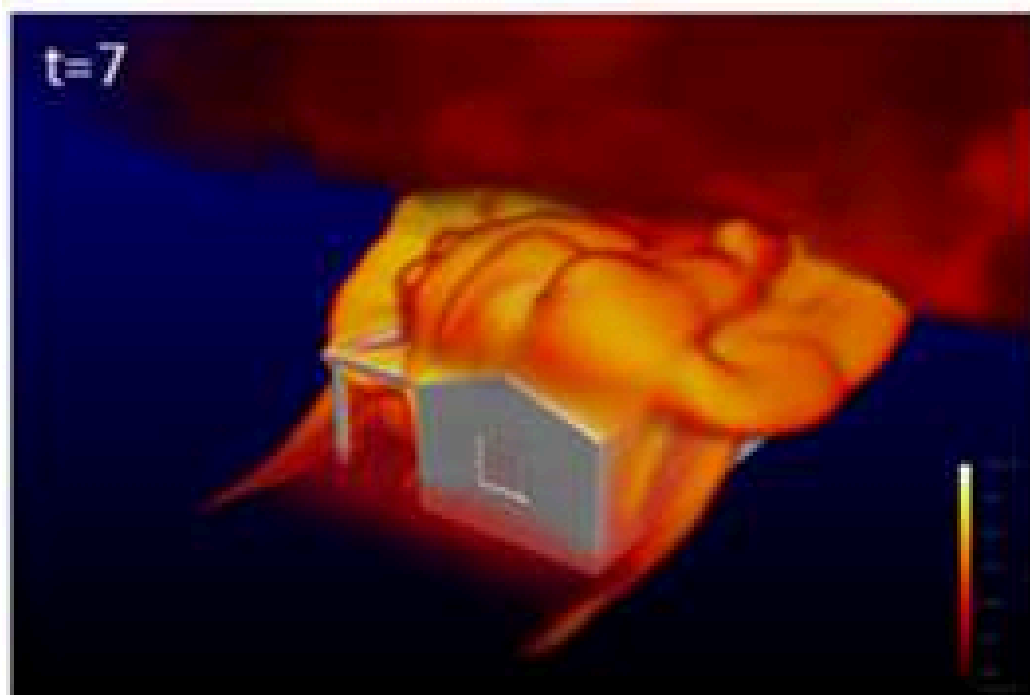
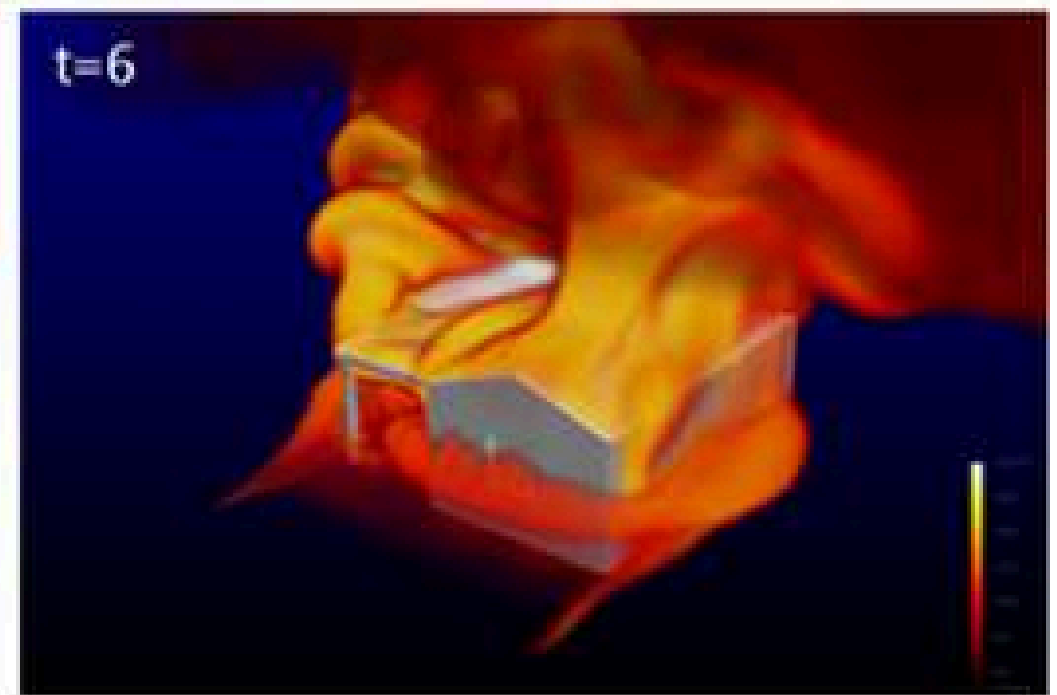
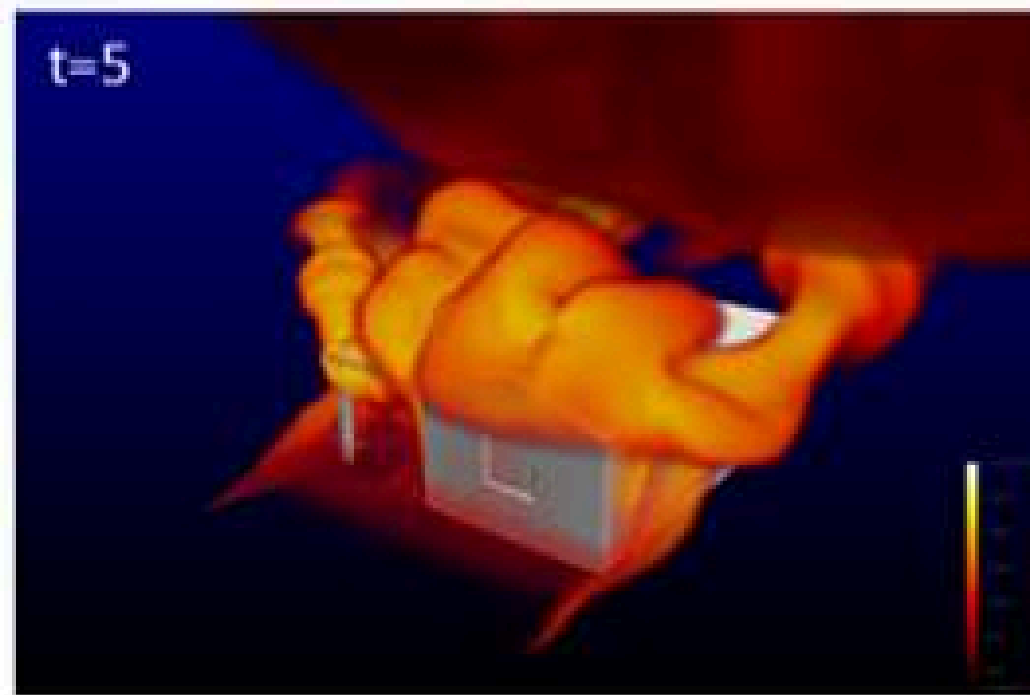
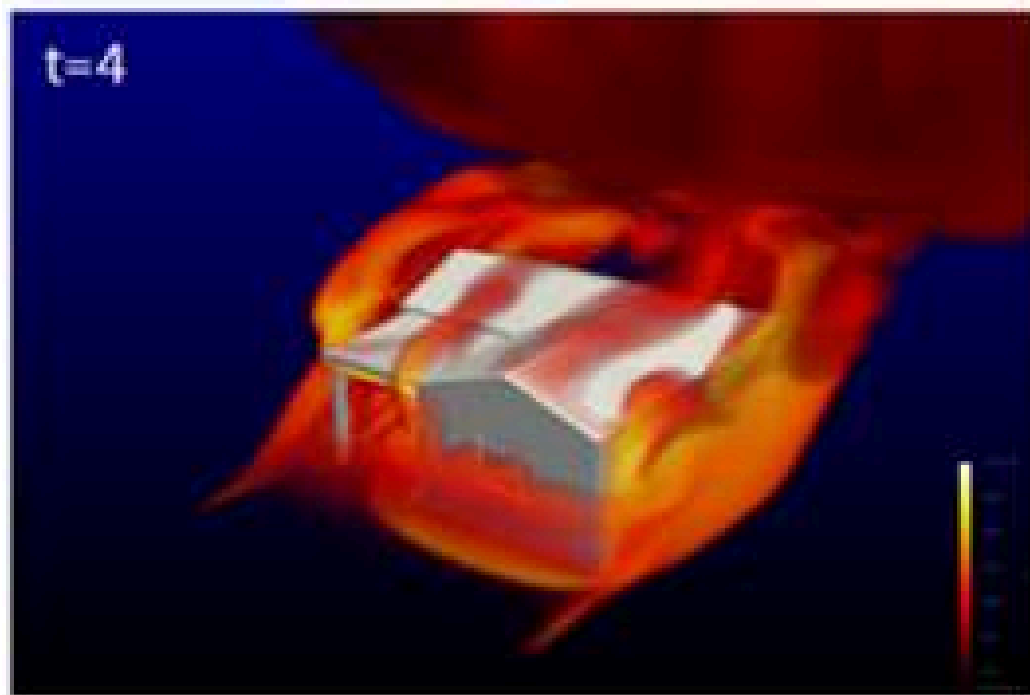
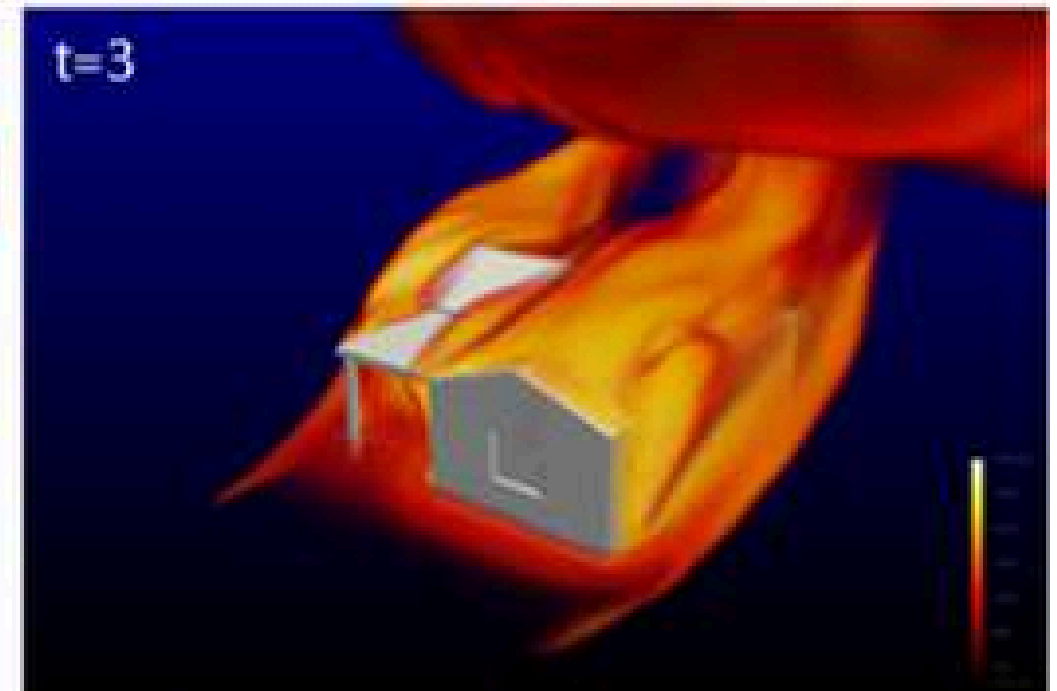
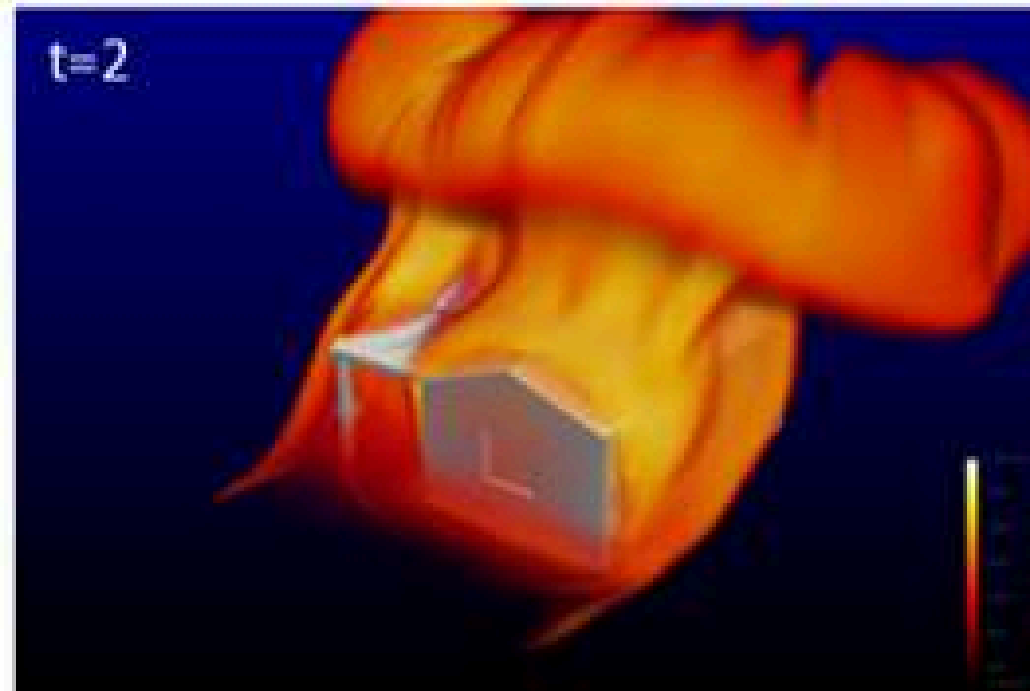
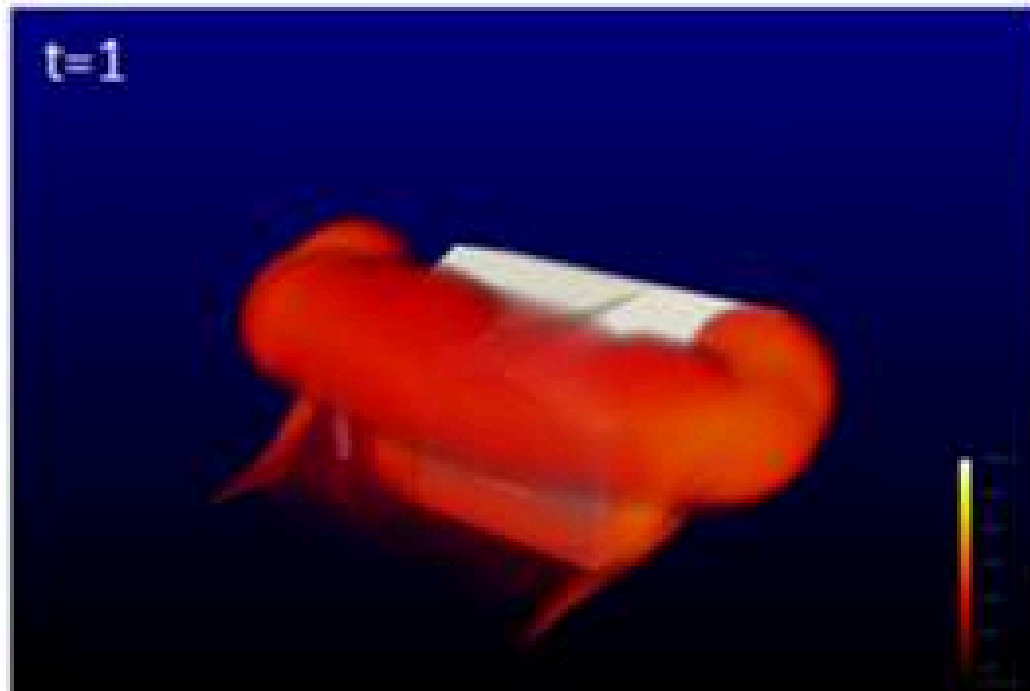
Working Scales:

- **Fuelbed** scale (1x1 m)
- **Household** and surroundings scale (50x50 m)
- **Urbanization** scale (1x1 km)

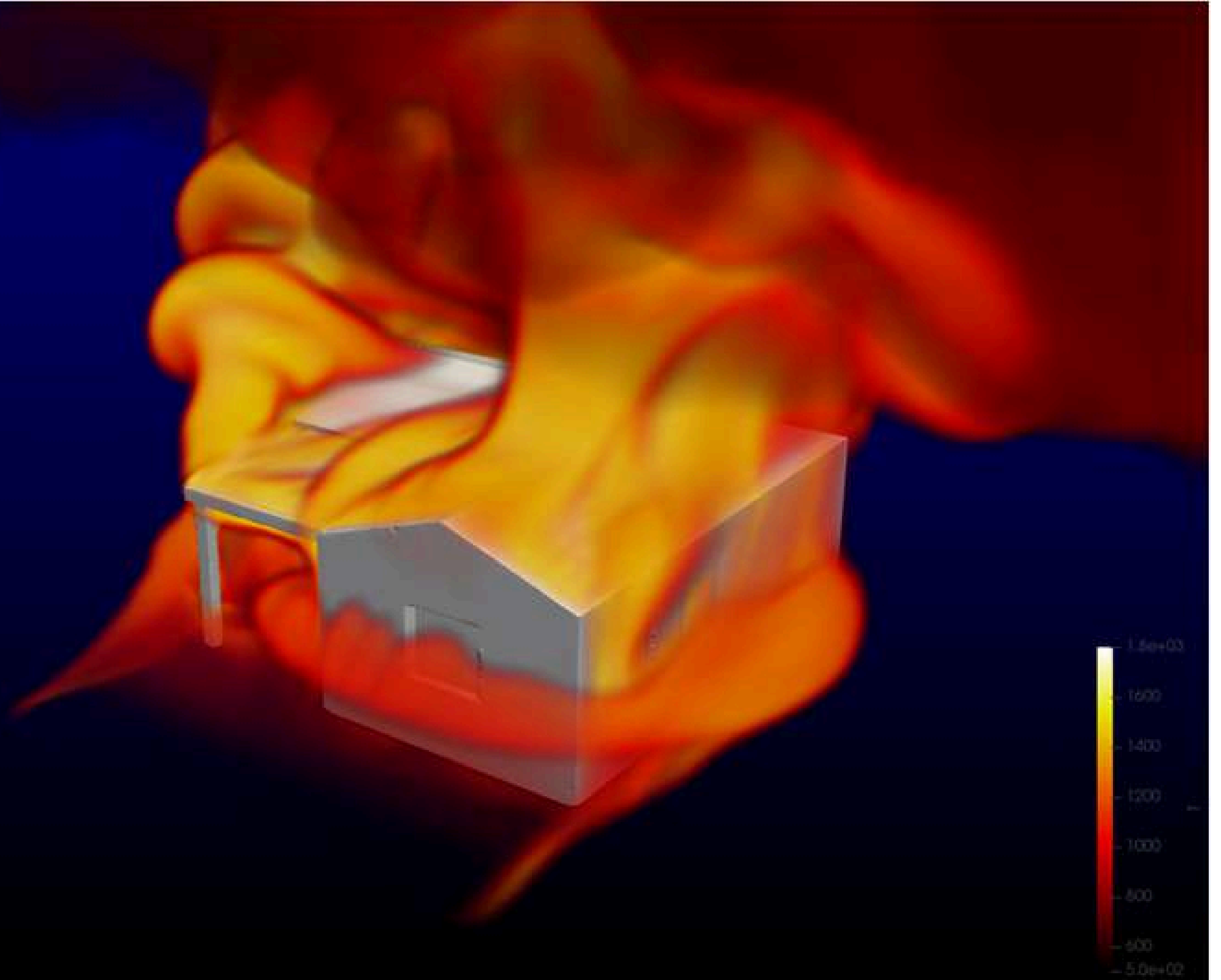




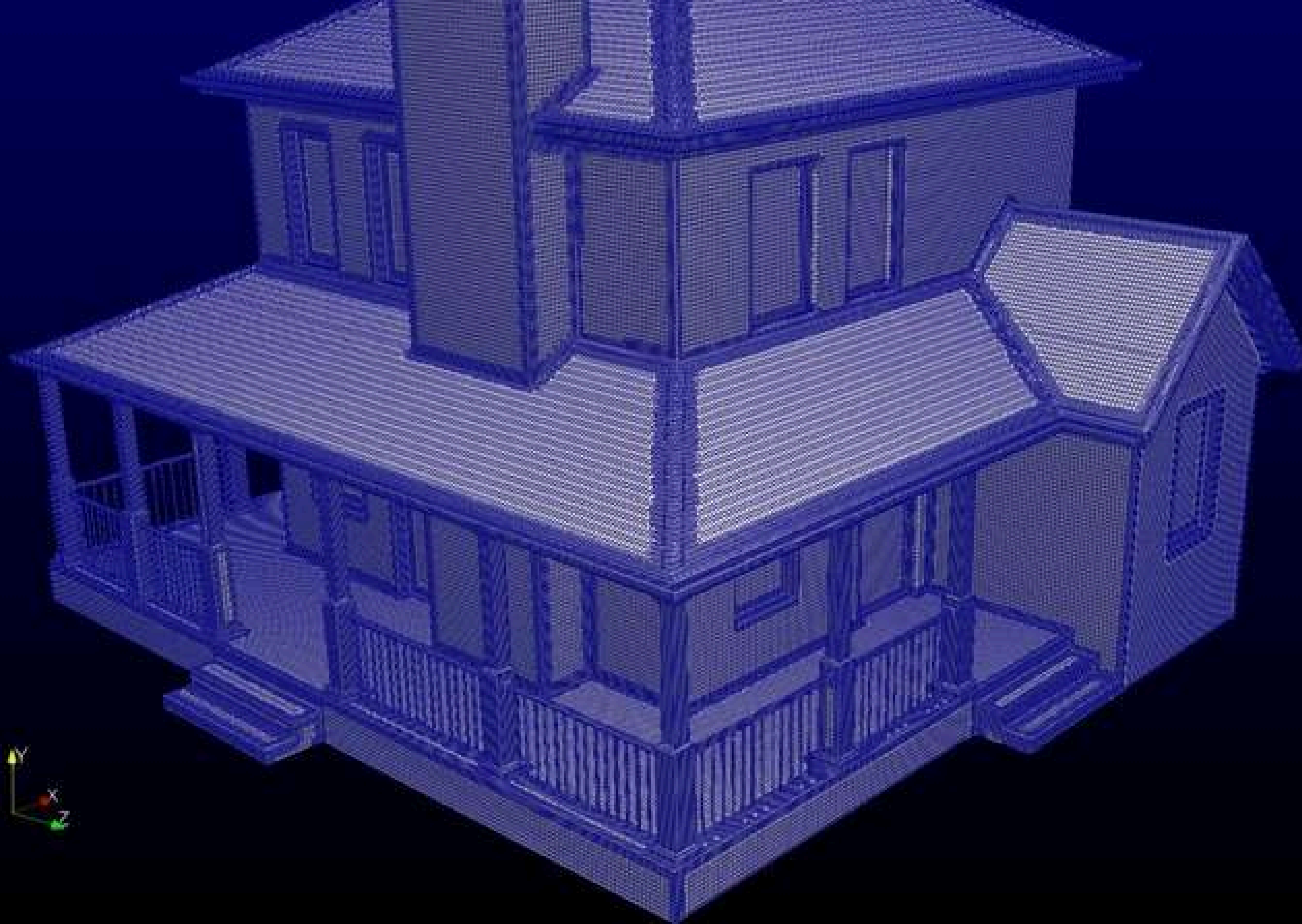


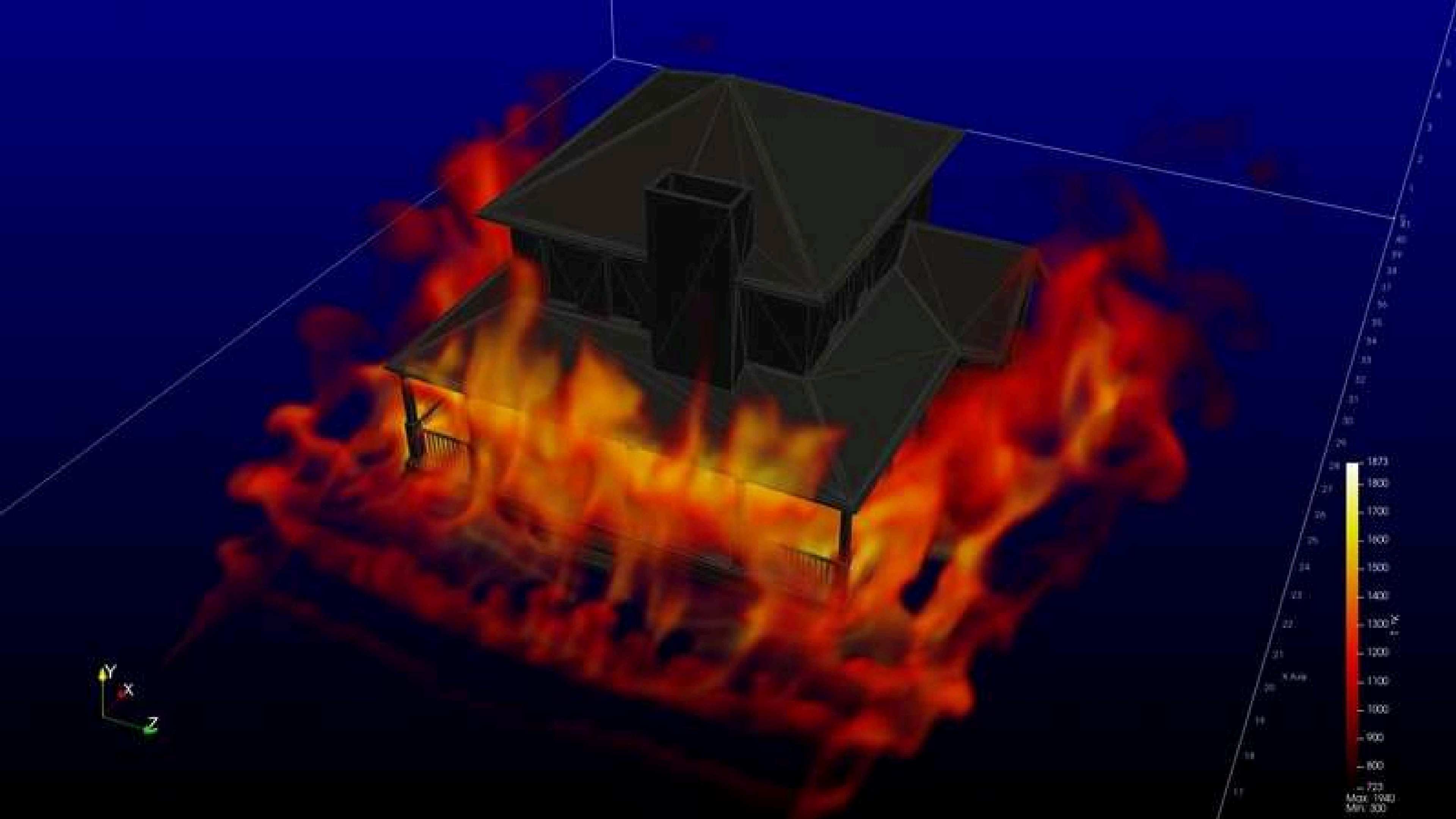


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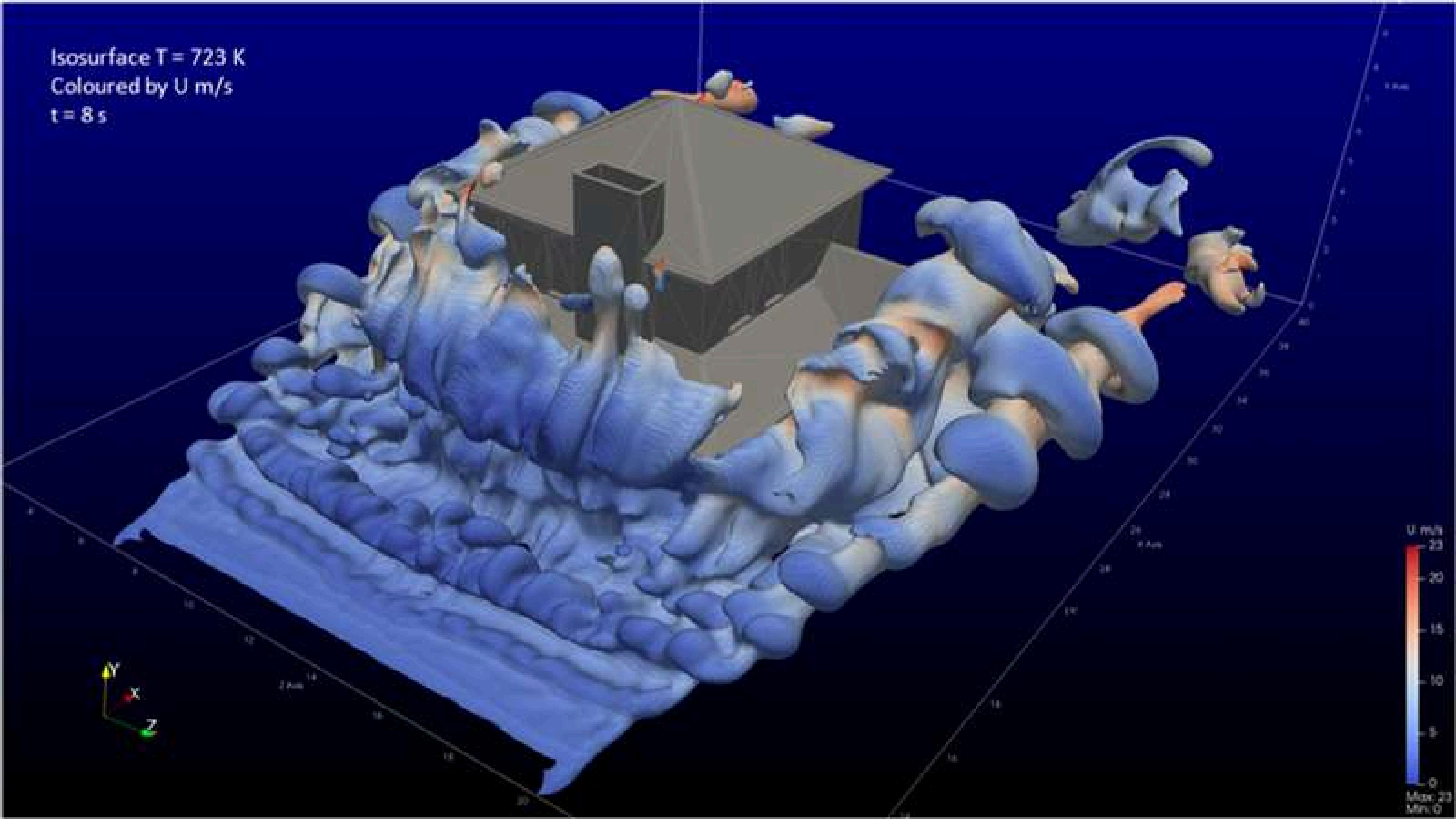


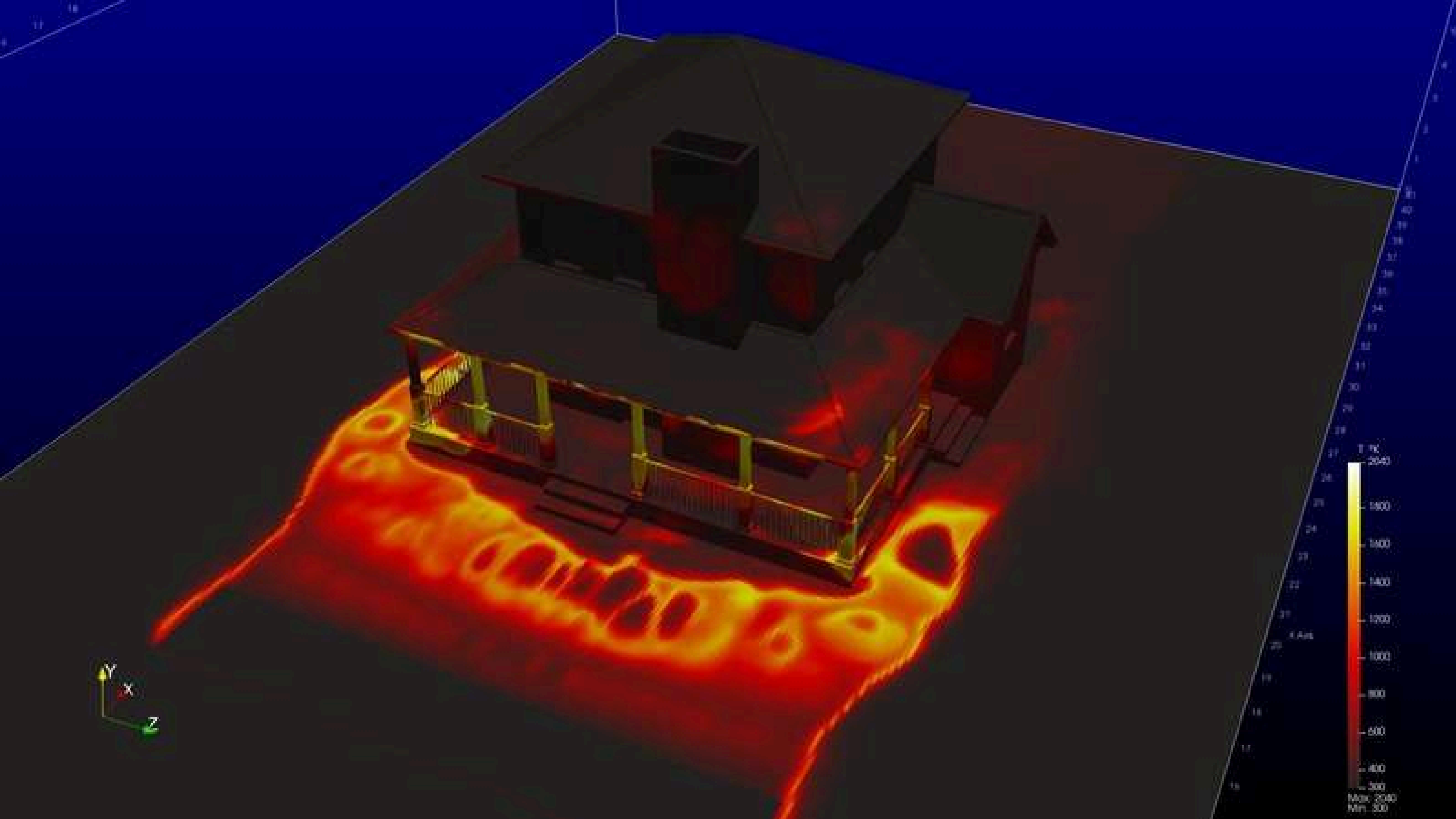




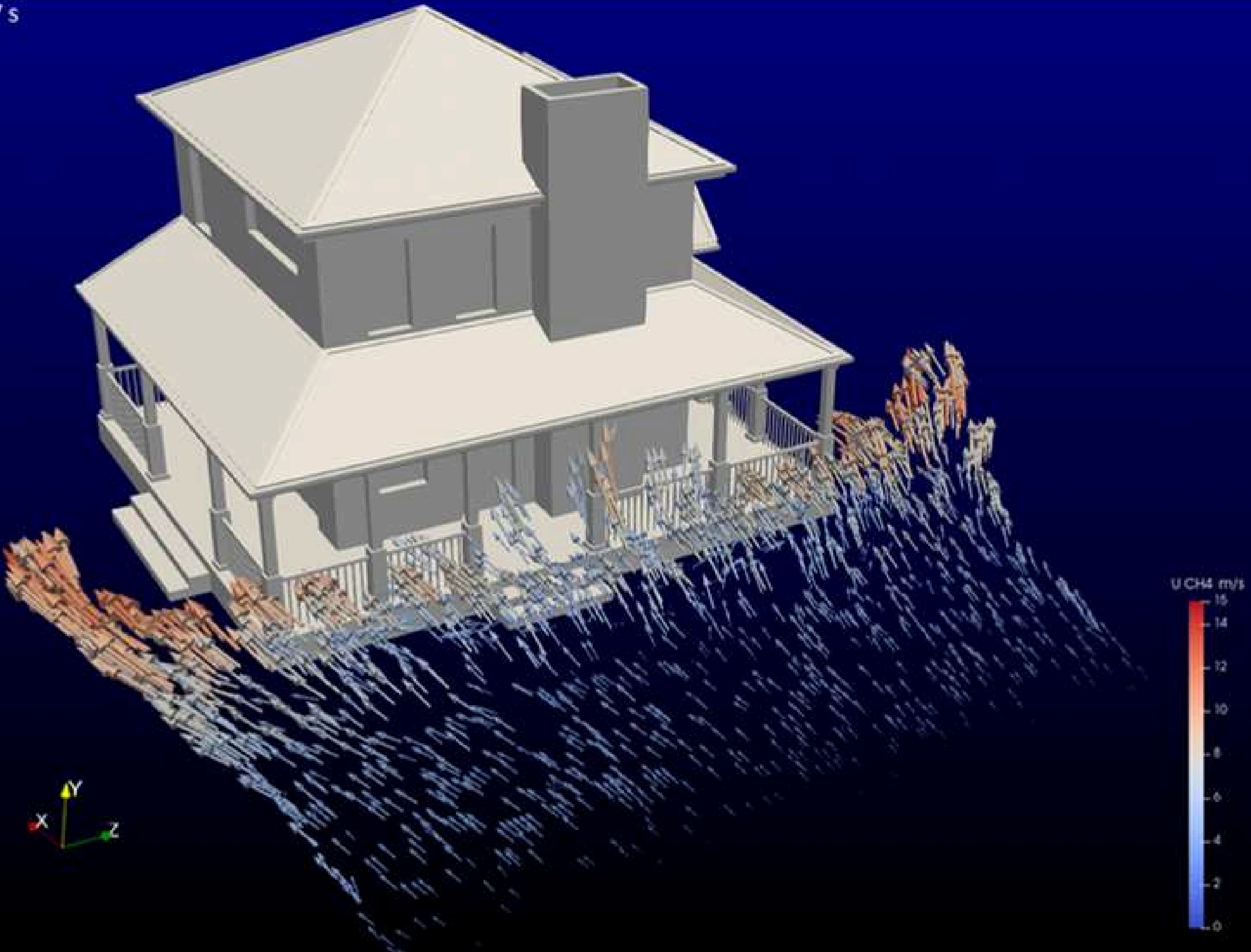


Isosurface $T = 723 \text{ K}$
Coloured by $U \text{ m/s}$
 $t = 8 \text{ s}$





$t=7s$

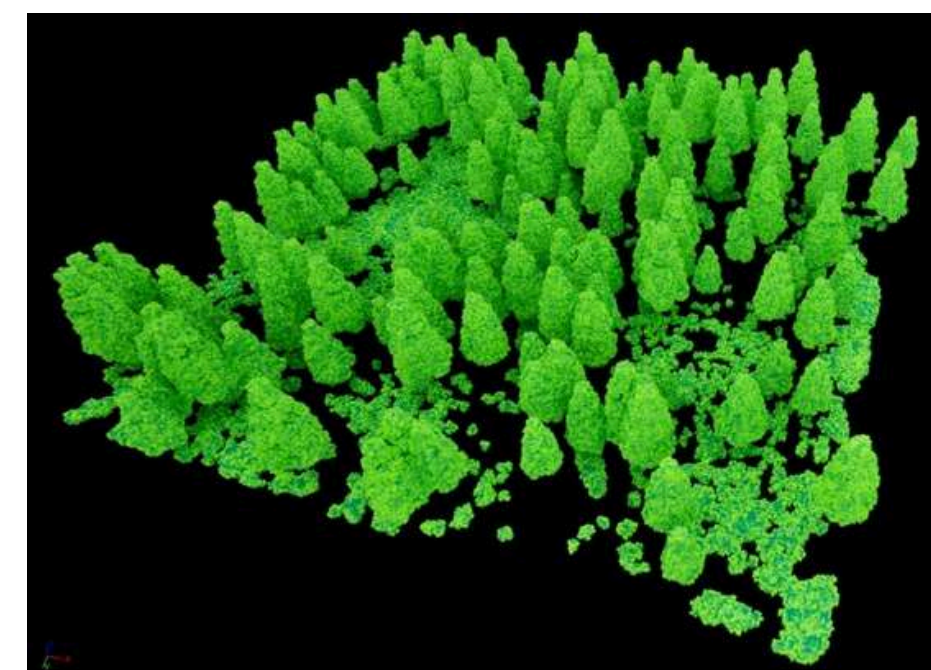
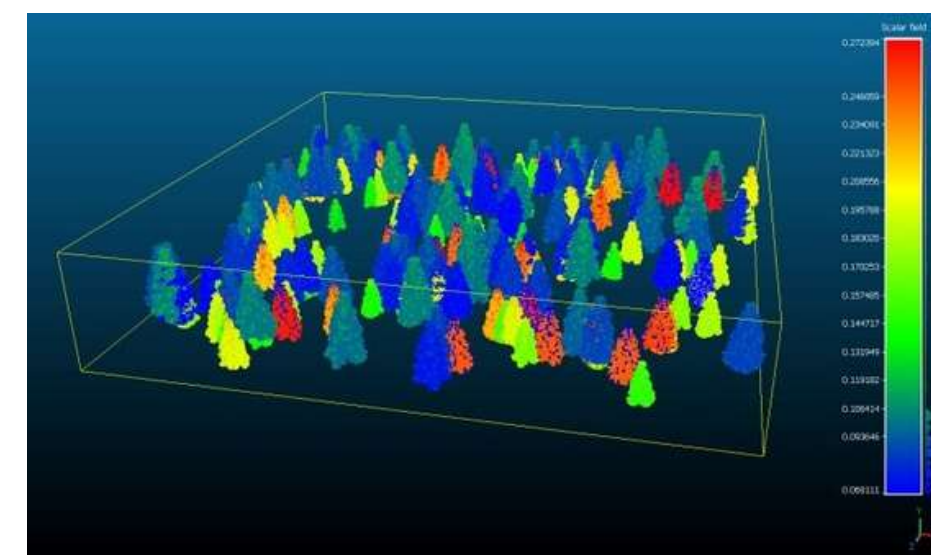
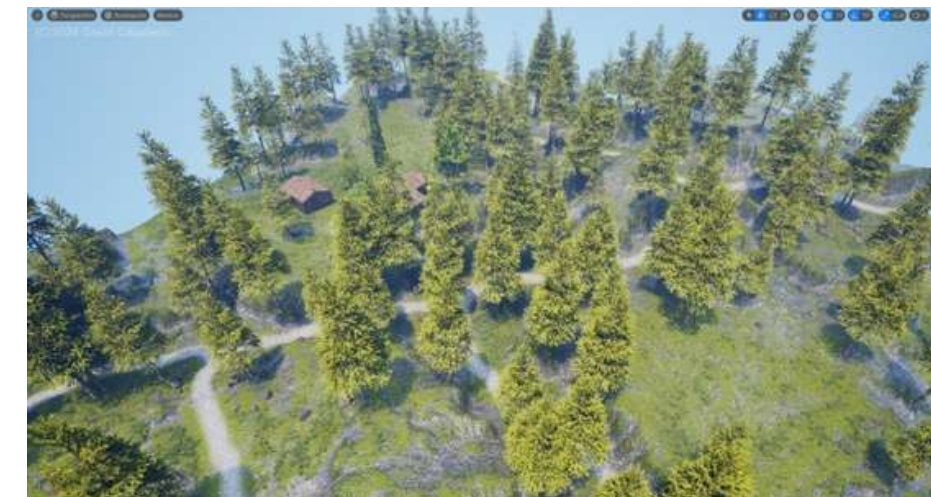


Vegetation description

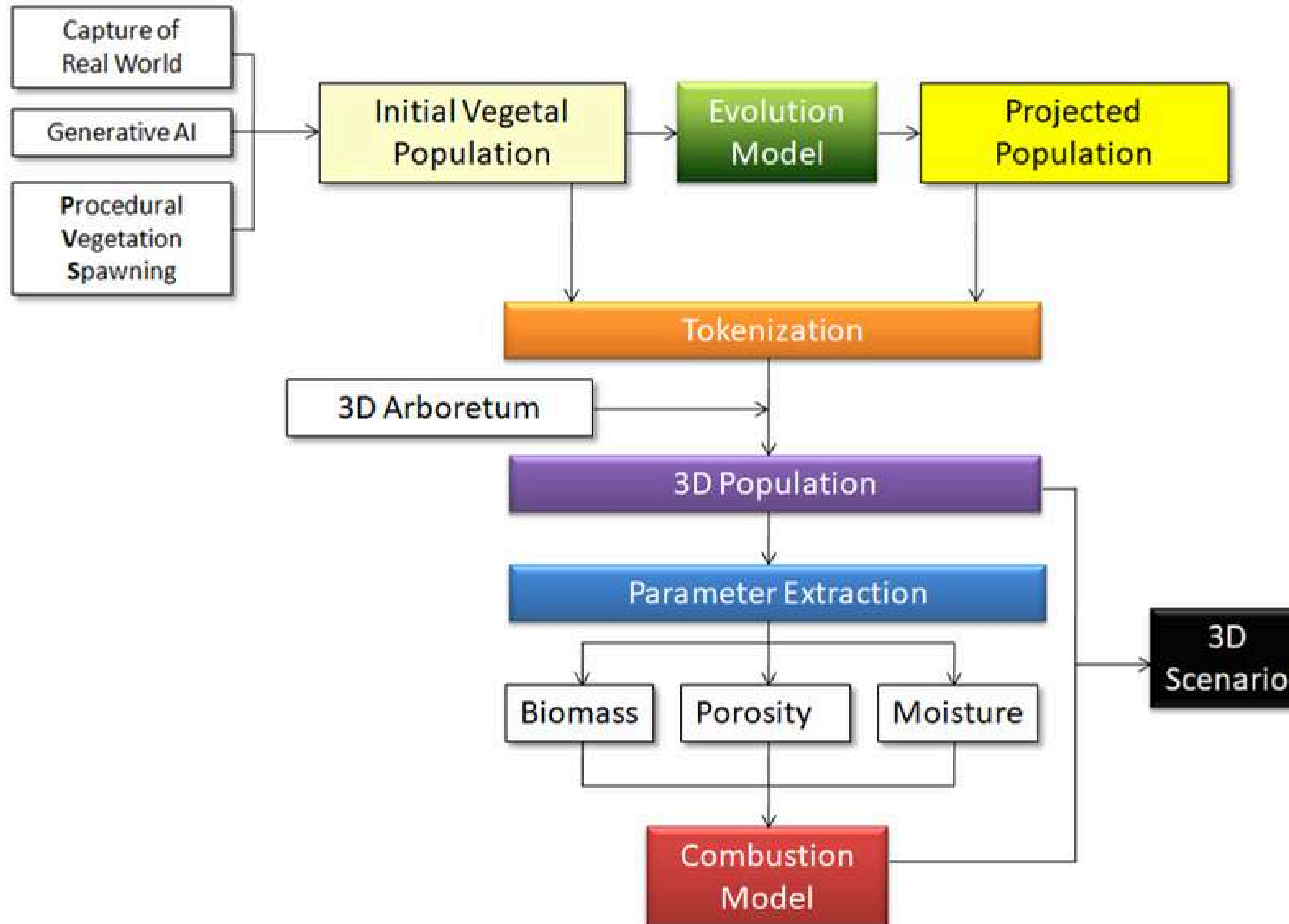
- Vegetation identification process – individual-based
- **Tokenization** (position, species, age, condition)
- Use of standardized formats for vegetation description
- Population interpretation for **WF pilot**:
 - Linking tokens to detailed 3D models (library)
 - Generation of point clouds
 - Biomass distribution
 - Voxelization and creation of OpenFOAM fields (*Ywood*, *porosityF*, *hum*)

This approach enables the reuse of vegetation populations:

- In **other pilots** through reinterpretation
- Coupled with vegetation growth models like **SORTIE**
- To quantify **fuel mitigation** actions
- To facilitate and automate **photorealistic visualization**
- To support the development of advanced **Digital Twins**



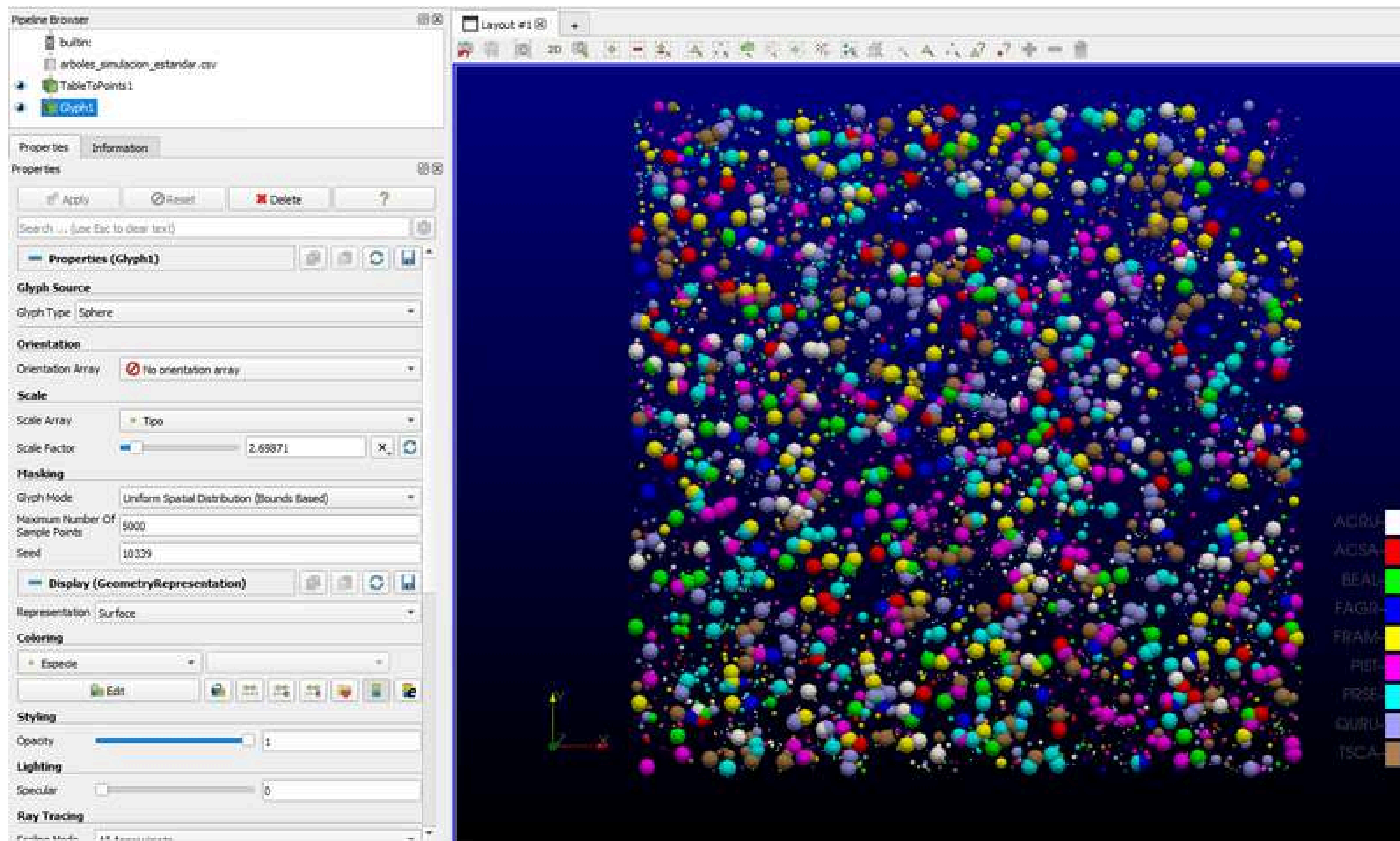
Vegetation modeling



Description of vegetation structures



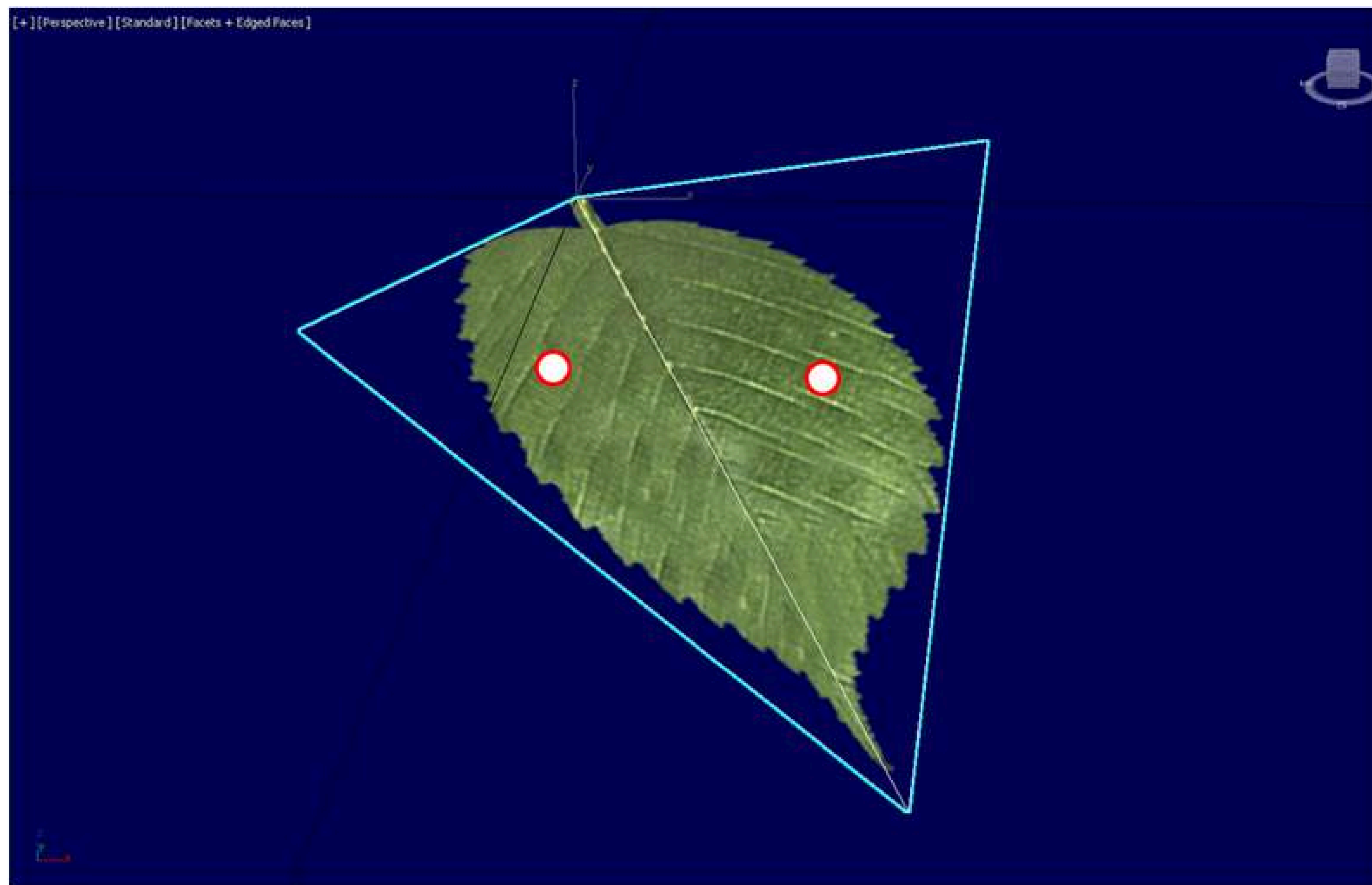
Projection of plants population – SORTIE ND



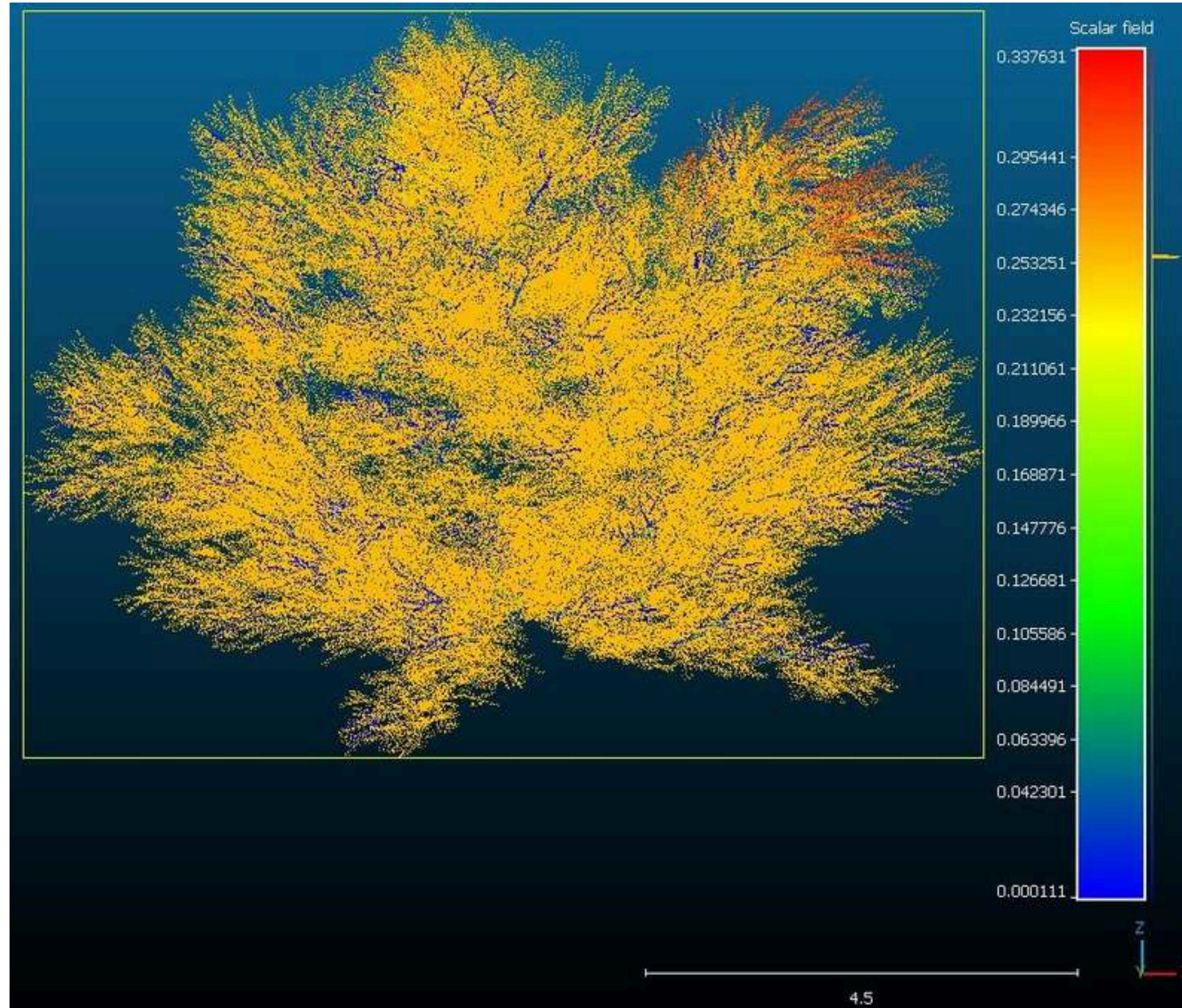
Projection of plants population – SORTIE ND



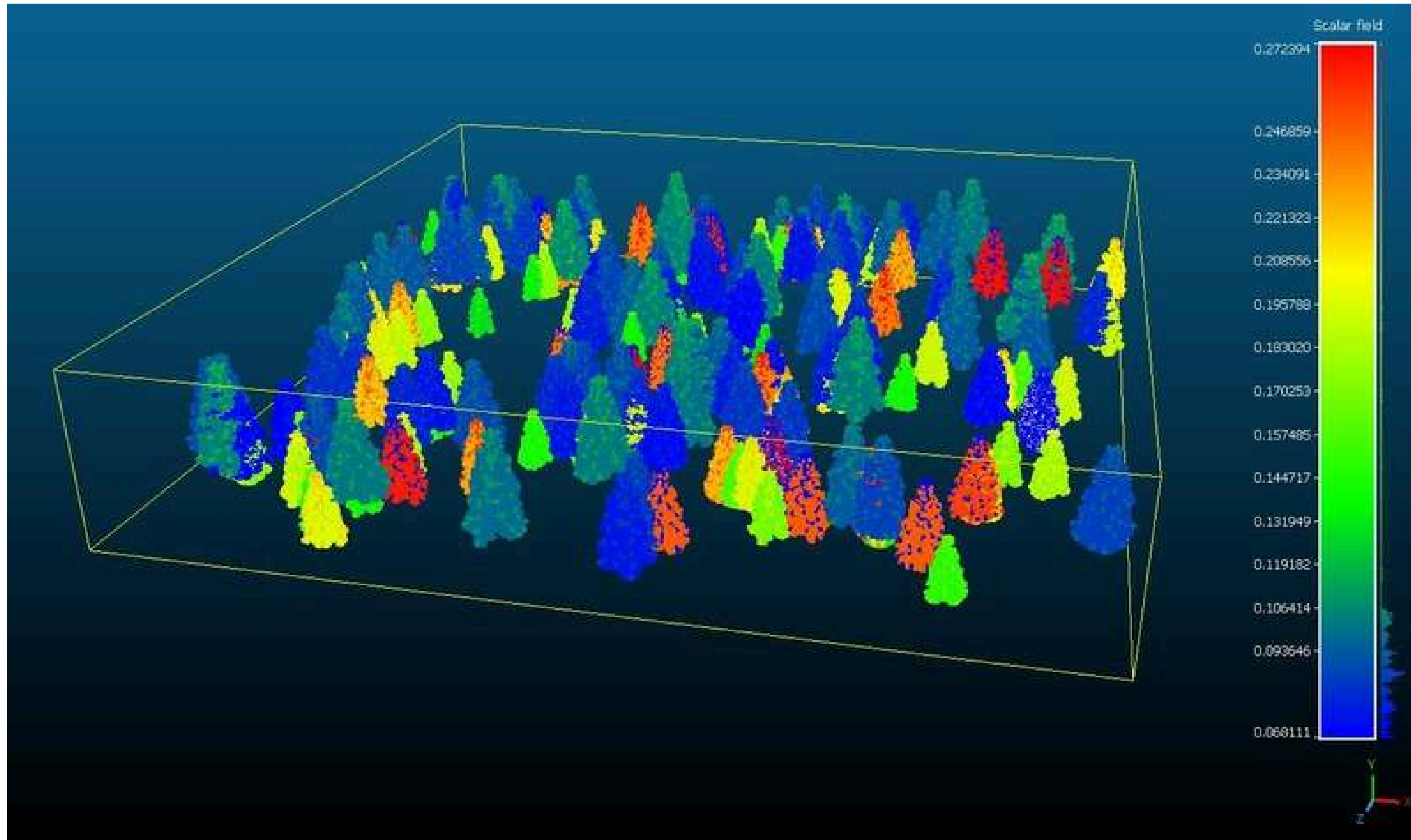
Generation of biomass distributions - Sampling



Generation of biomass distributions - Pointcloud



Generation of biomass distributions - Pointcloud



Generation of biomass distributions - Voxelization

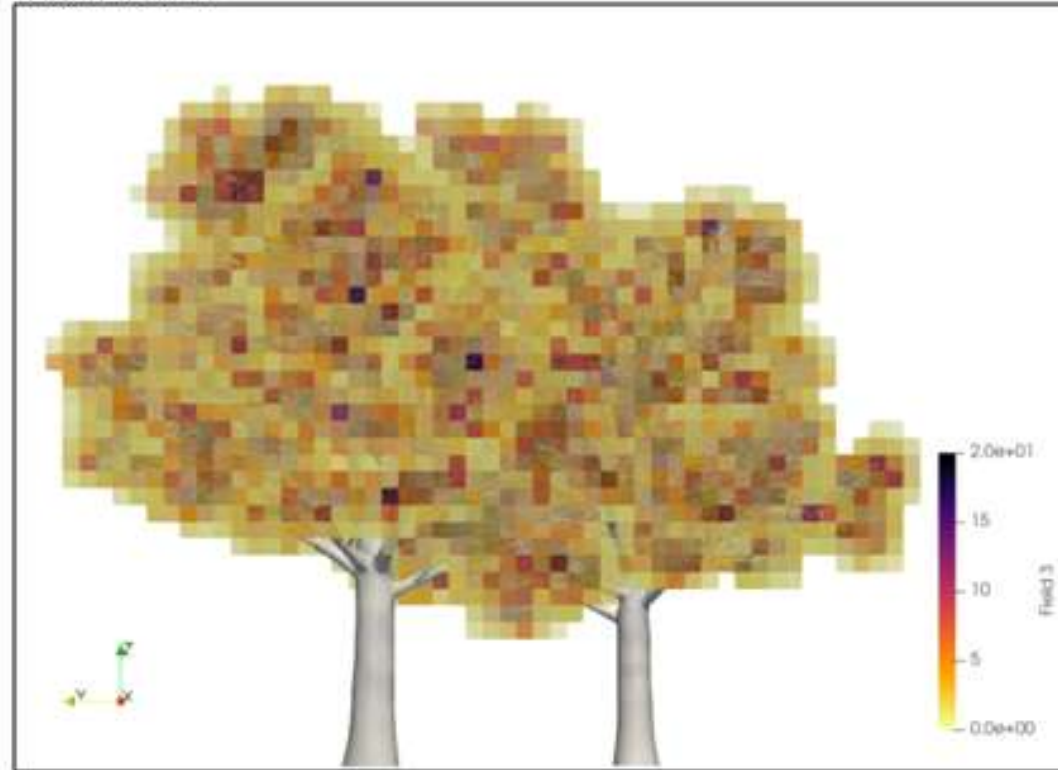
voxel 1.0 m



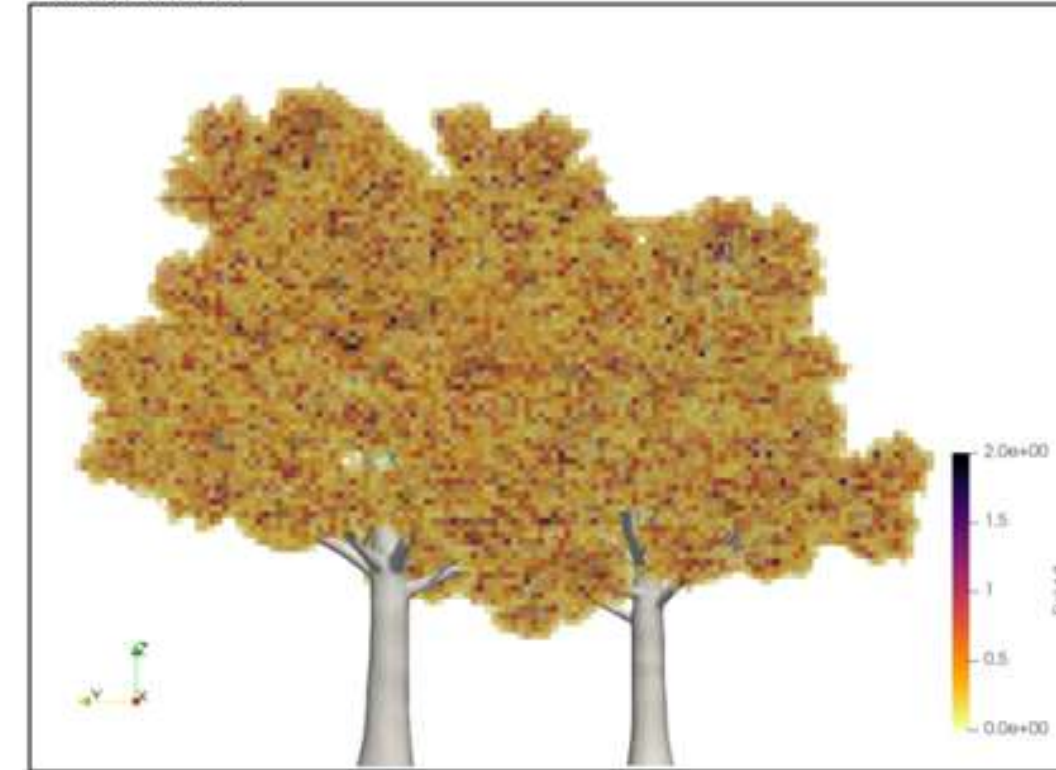
voxel 0.5 m



voxel 0.25 m

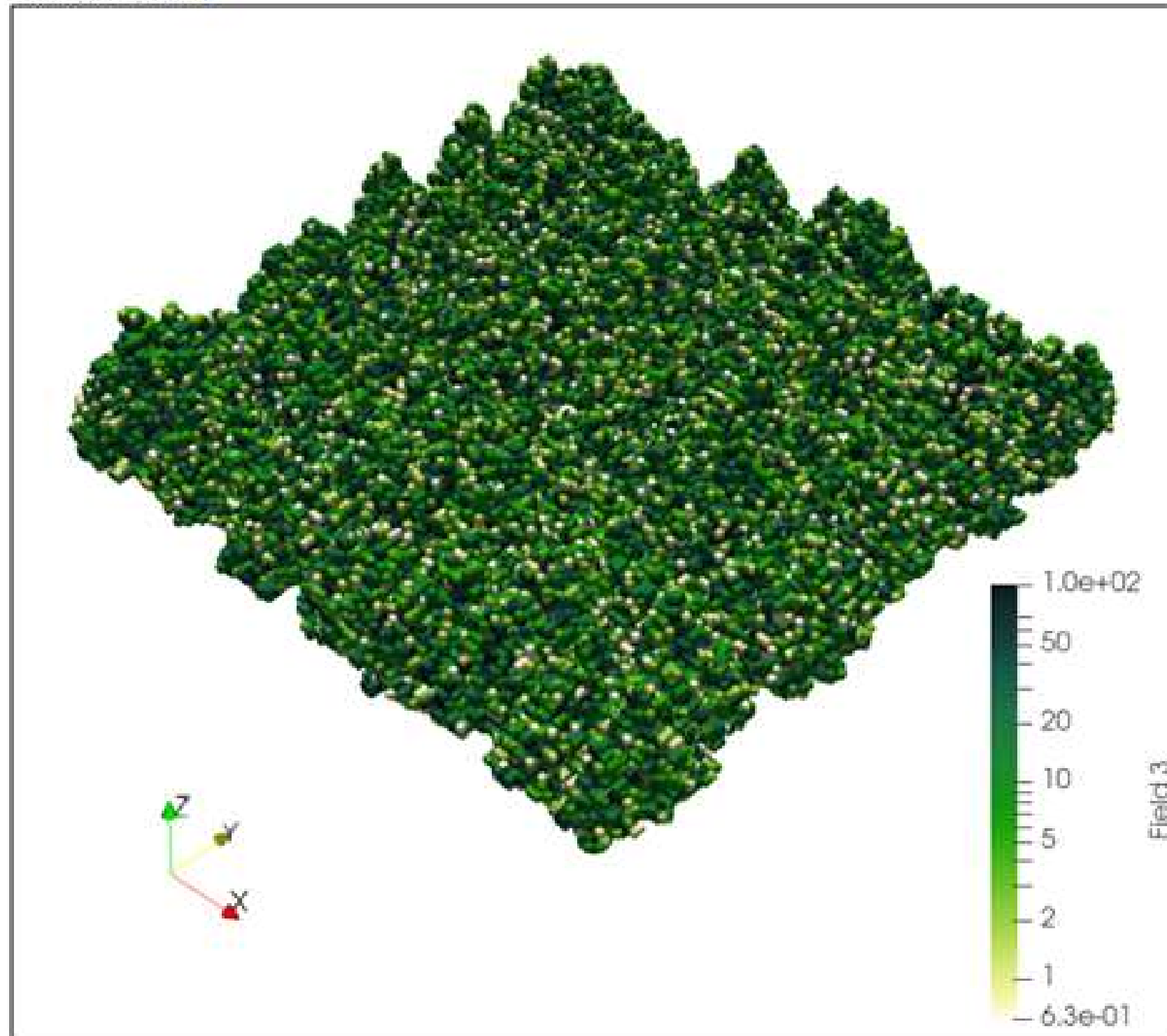


voxel 0.10 m

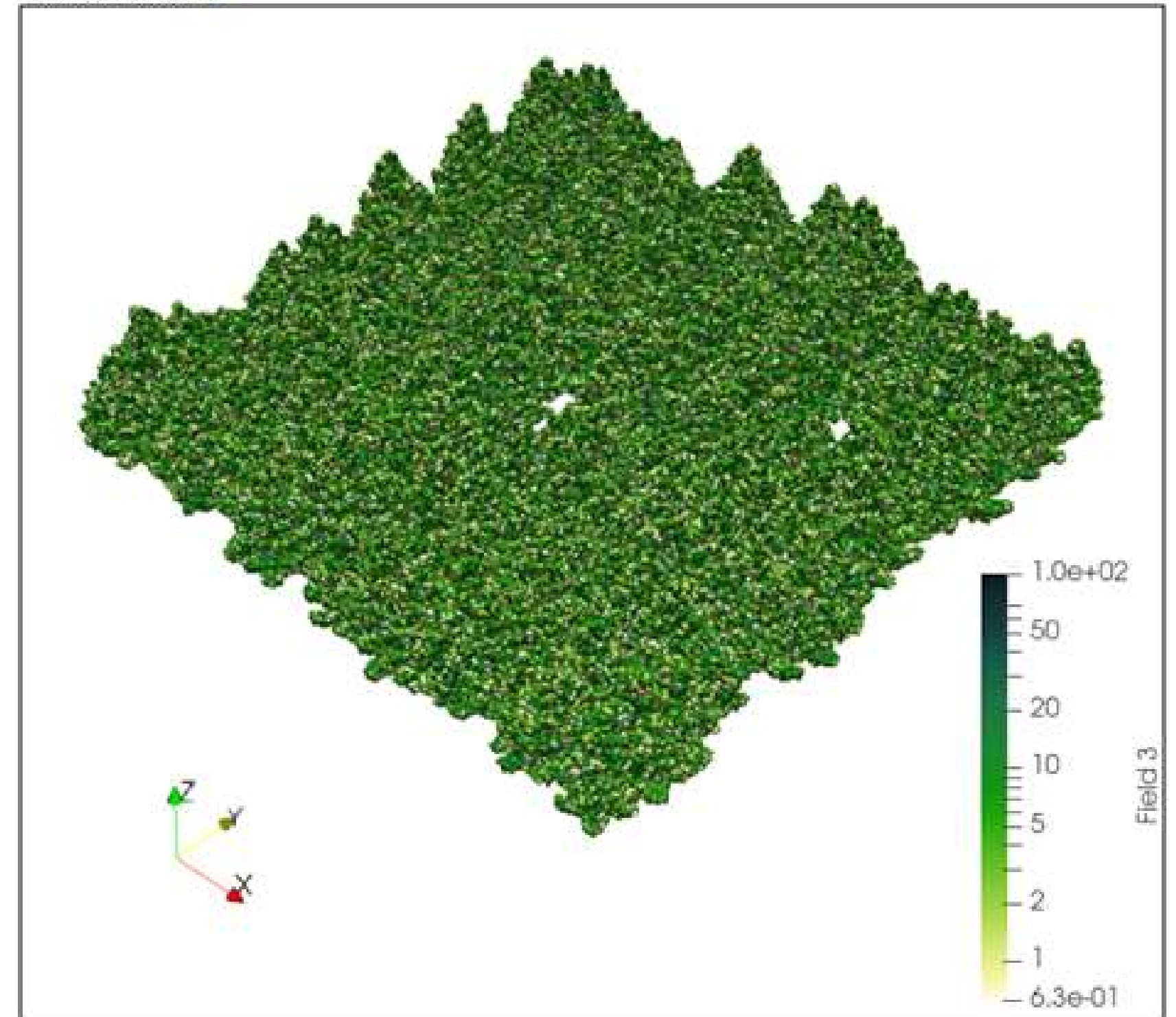


Generation of biomass distributions - Voxelization

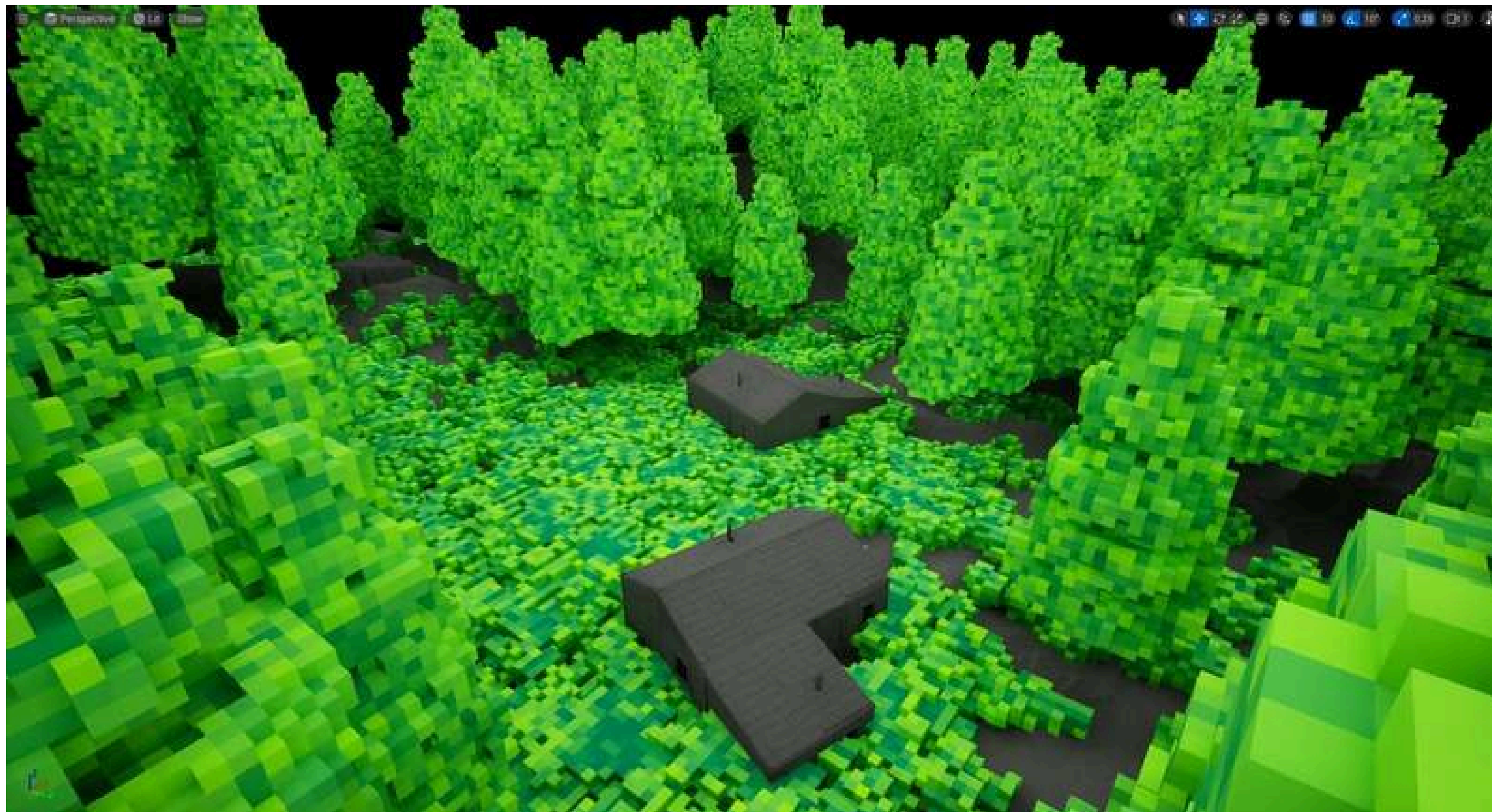
voxel 1.0 m



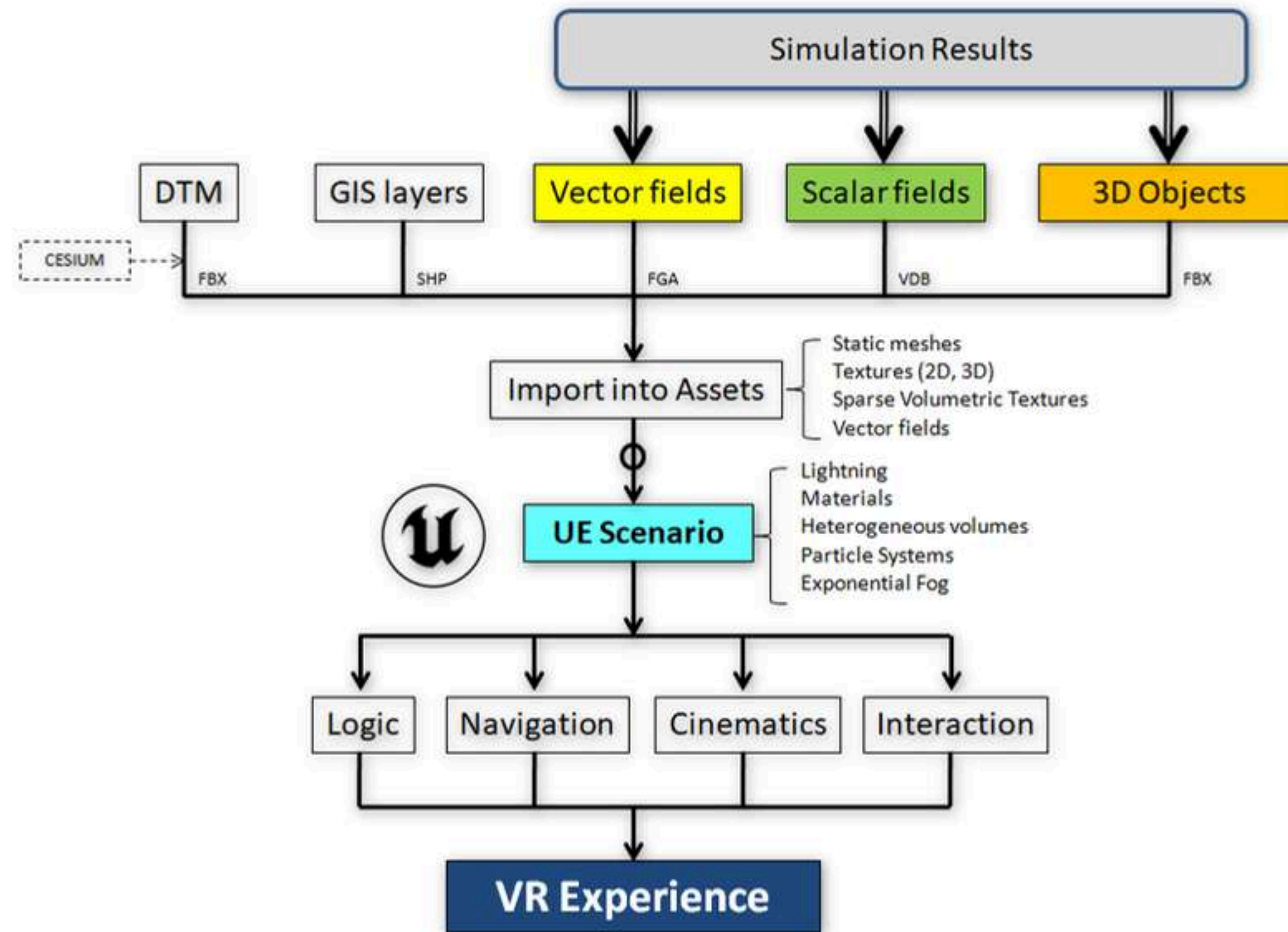
voxel 0.5 m



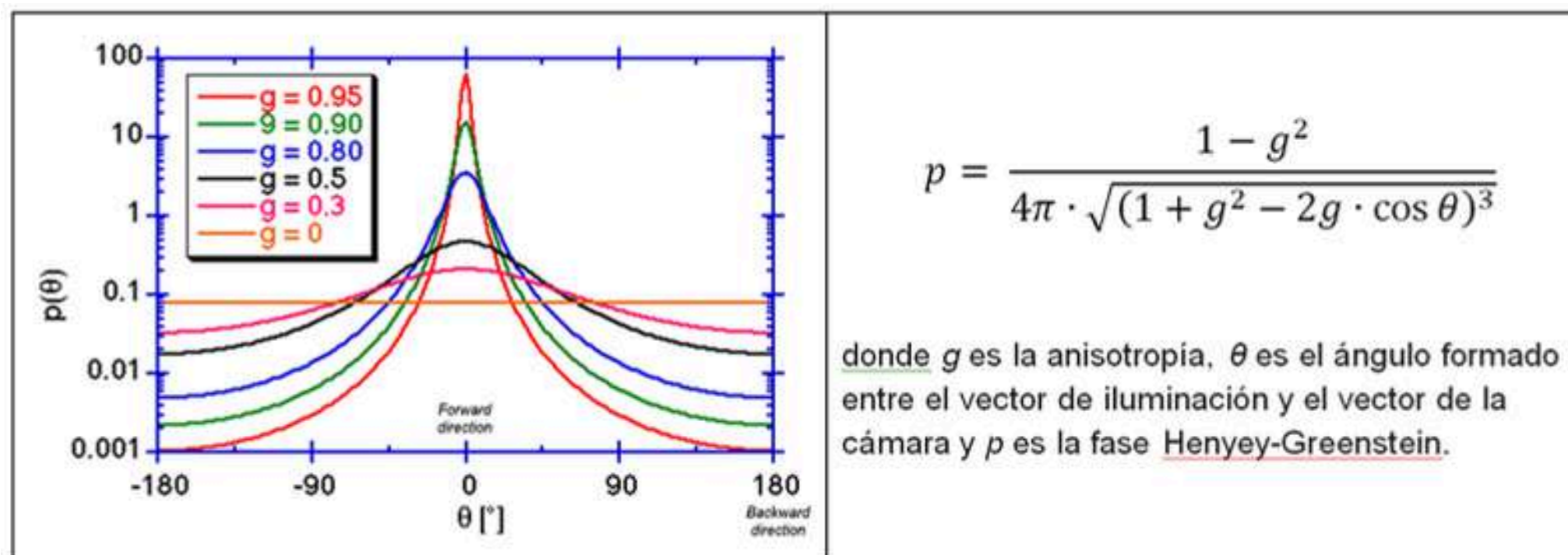
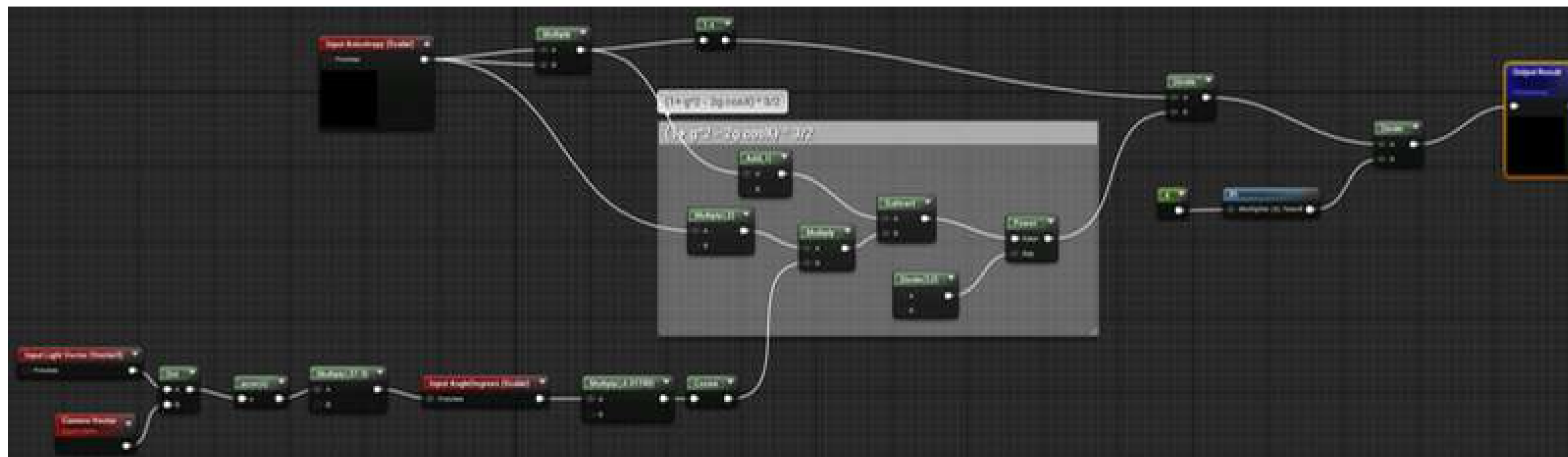
Generation of biomass distributions - Voxelization



Visualization – Integration of numerical simulation



Simulation of optical effects of smoke and flames





Simulation of the optical effect of soot percentage in smoke volume, including light scattering and absorption. Integrated in CEGUM geometry.

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0%

10%

20%

30%

40%

50%

60%

70%

80%

90%

100%

Simulation of the optical effect of soot percentage in smoke volume, including light scattering and absorption. Integrated in Cesium geometry.

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Landscape - Integration of CESIUM Service

- A service offering a 3D model of the world
- Massive high-resolution real-world photogrammetry and 3D content at runtime using 3D Tiles
- Free and open source **plug-in for UE**, fully integrated as objects for interaction
- MTG has integrated Cesium with LiDAR point clouds and wildfire simulations in UE



Landscape - Integration of CESIUM Service







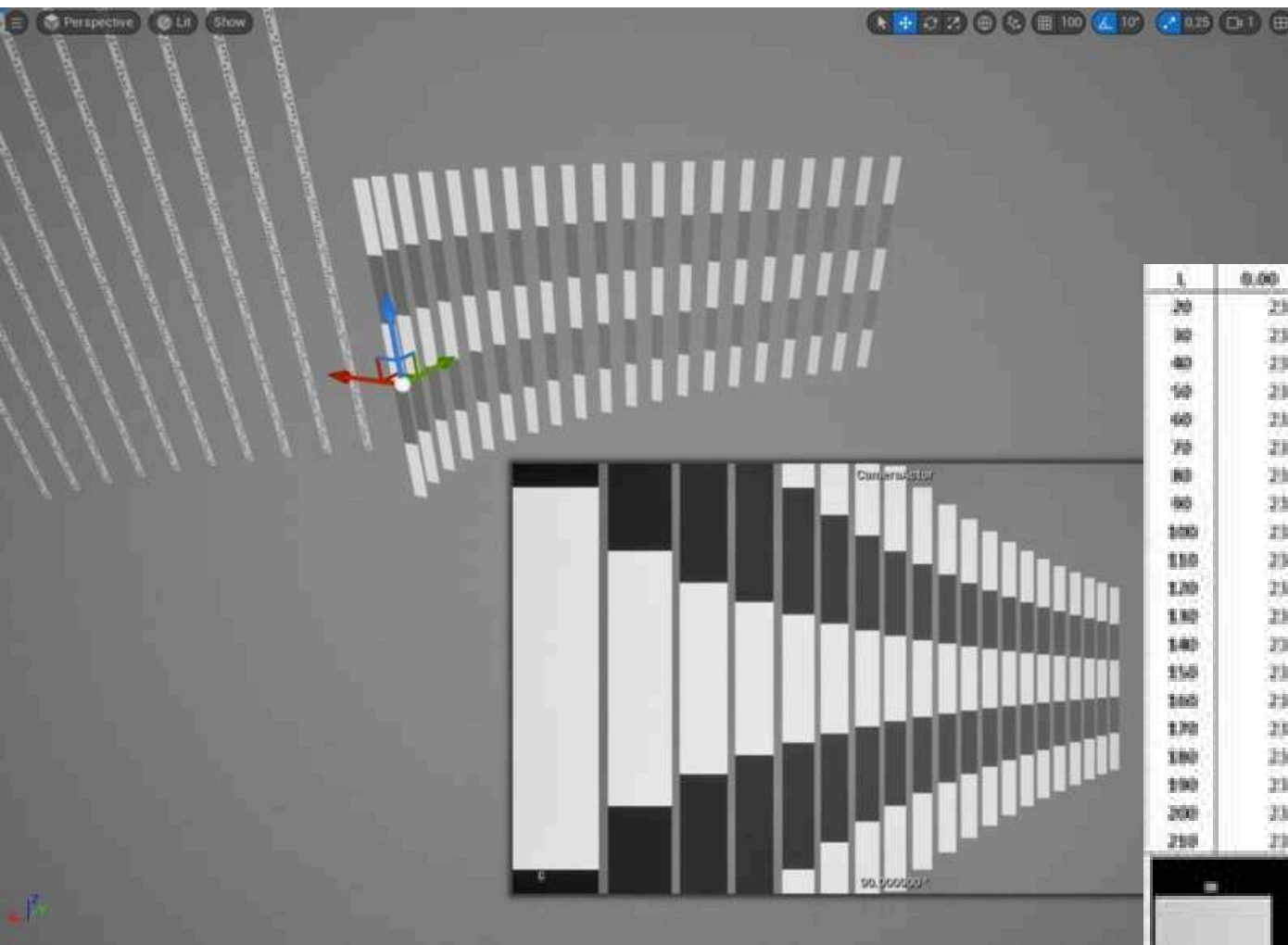
WUI – Integration of vegetation structures



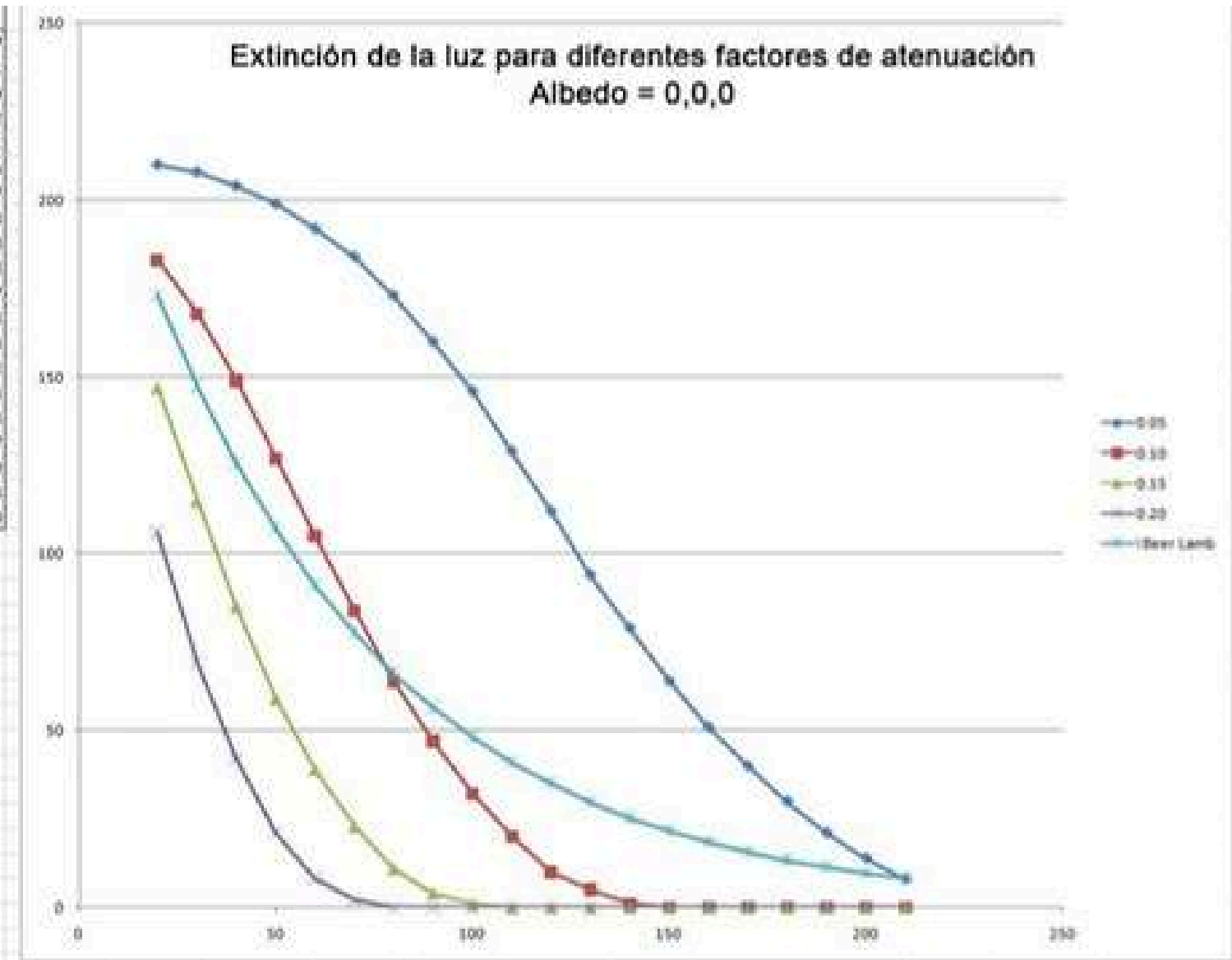
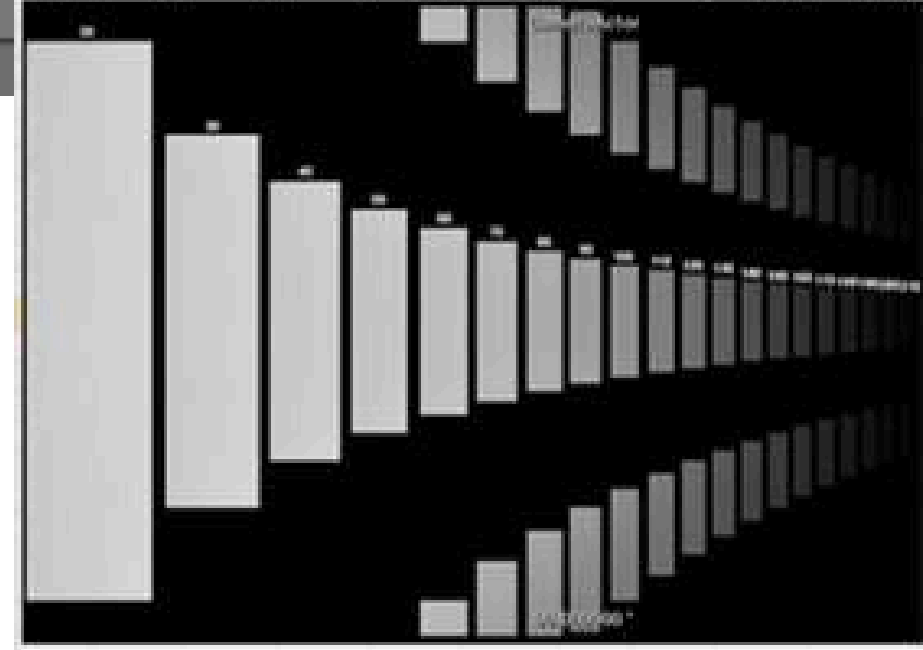
WUI – Integration of vegetation structures

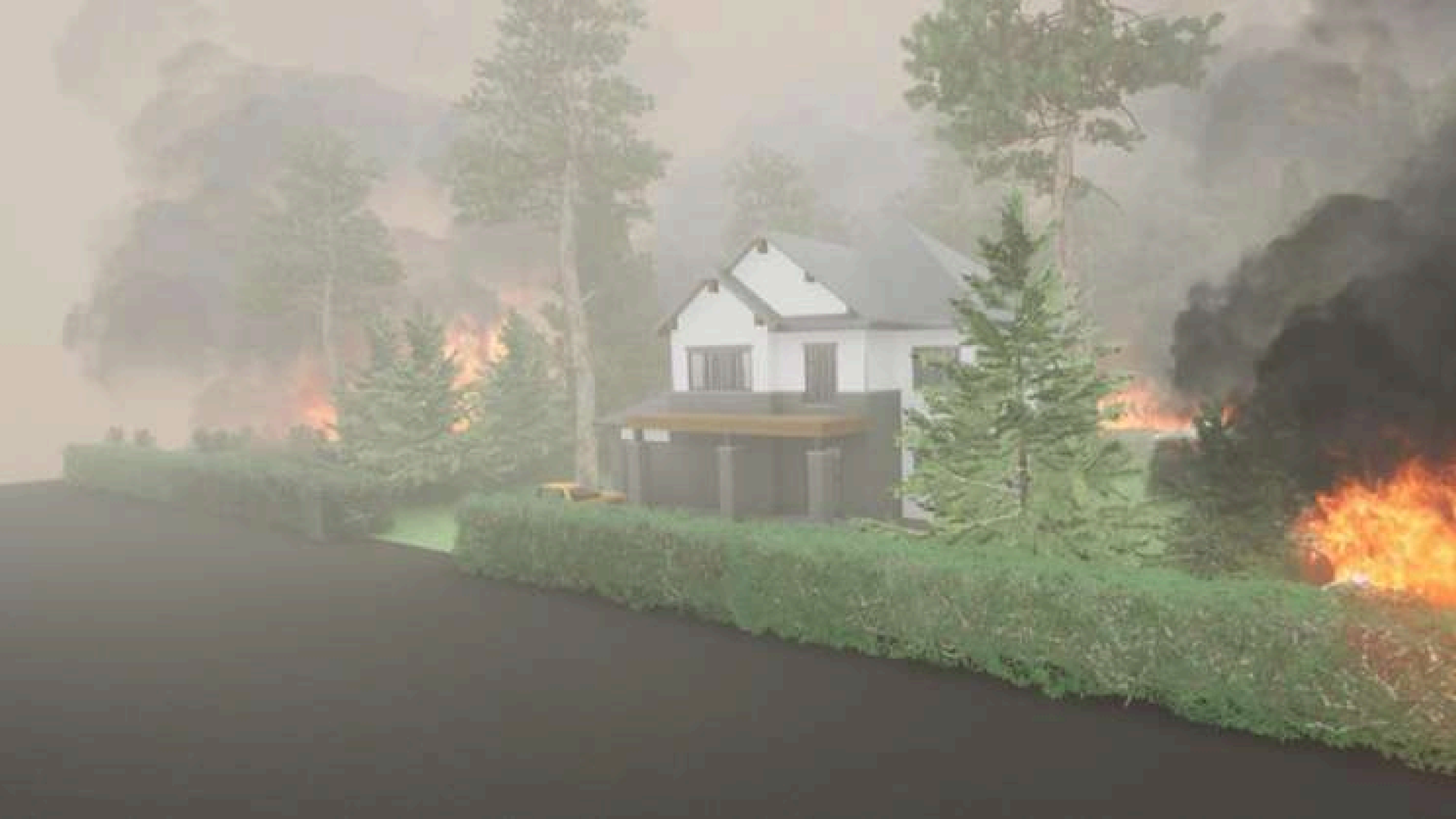


WUI - Simulation of environmental smoke



L	0.00	0.05	0.10	0.15	0.20	UH	B-I	U/σ	Cs	f Beer Lamb	DIF
20	238	210	183	147	106			0,882	0,00626	173	-37
30	238	208	168	115	69			0,874	0,00449	147	-61
40	238	204	149	80	42			0,857	0,00385	125	-79
50	238	199	127	59	21			0,836	0,00358	107	-92
60	238	192	105	39	8			0,807	0,00358	91	-101
70	238	184	84	21	2			0,773	0,00368	78	-106
80	238	173	64	11	0			0,727	0,00399	66	-107
90	238	160	47	4	0			0,673	0,00441	56	-104
100	238	146	32	1	0			0,613	0,00489	48	-98
110	238	129	20	0	0			0,542	0,00557	41	-88
120	238	112	10	0	0			0,471	0,00628	35	-77
130	238	94	3	0	0			0,395	0,00715	30	-64
140	238	79	1	0	0			0,312	0,00788	25	-54
150	238	64	0	0	0			0,269	0,00876	22	-43
160	238	51	0	0	0			0,214	0,00963	18	-33
170	238	40	0	0	0			0,168	0,01049	16	-24
180	238	30	0	0	0			0,126	0,01131	13	-17
190	238	21	0	0	0			0,088	0,01278	11	-10
200	238	14	0	0	0			0,059	0,01417	10	-4
210	238	8	0	0	0			0,034	0,01618	8	0





WUI - Integration of Gaussian Splatting trainings







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Thank
you!

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Thanks!

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