iea-isgan.org

ISGAN – International Smart Grid Action Network

Matthias Lange, Quentin Libois, Remco Verzijlbergh

23 March 2021

ISGAN Academy webinar #27
Recorded webinars available at: https://www.iea-isgan.org/our-work/annex-8/

ISGAN in a Nutshell

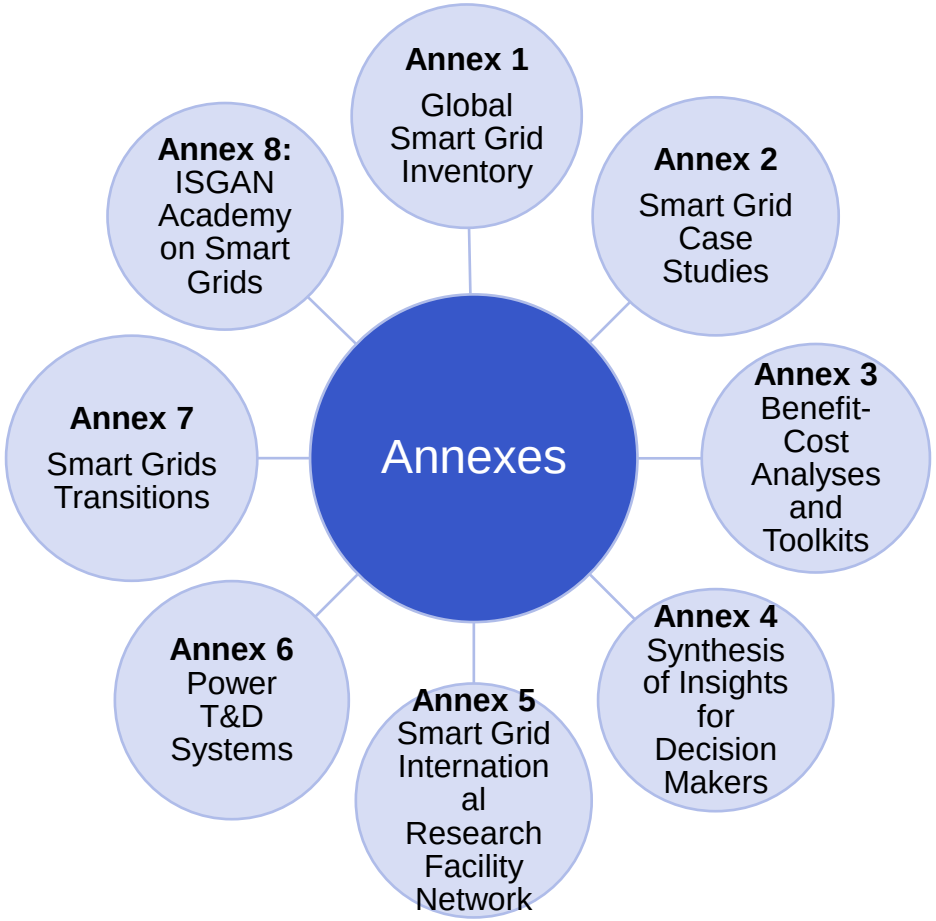
Created under the auspices of:

the Implementing Agreement for a Co-operative Programme on Smart Grids

an initiative of the Clean Energy Ministerial (CEM)

Strategic platform to support high-level government knowledge transfer and action for the accelerated development and deployment of smarter, cleaner electricity grids around the world

International Smart Grid Action Network is the only global government-to-government forum on smart grids.



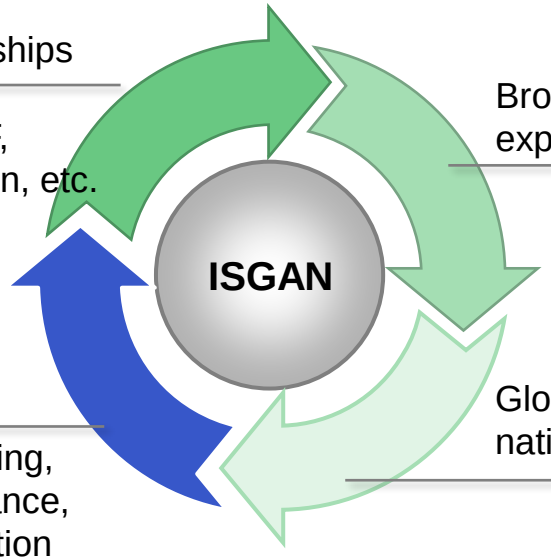
ISGAN's worldwide presence

ISGAN
INTERNATIONAL SMART GRID
ACTION NETWORK

Value proposition

Strategic partnerships

IEA, CEM, GSGF, Mission Innovation, etc.



Broad international expert network

Global, regional & national policy support

Knowledge sharing, technical assistance, project coordination

Visit our website:
www.iea-isgan.org

iea-isgan.org

ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

Advanced weather forecasting for RES applications

Smart4RES developments towards high-resolution and Numerical Weather Prediction solutions to improve RES forecasting models

Matthias Lange, Quentin Libois, Remco Verzijlbergh

23 March 2021

iea Energy Technology Network

CLEAN ENERGY MINISTERIAL

Agenda

- Smart4RES in a nutshell
- Challenges in forecasting of renewables
- Towards Numerical Weather Prediction models dedicated to Renewables Energy Sources
- High-resolution weather models

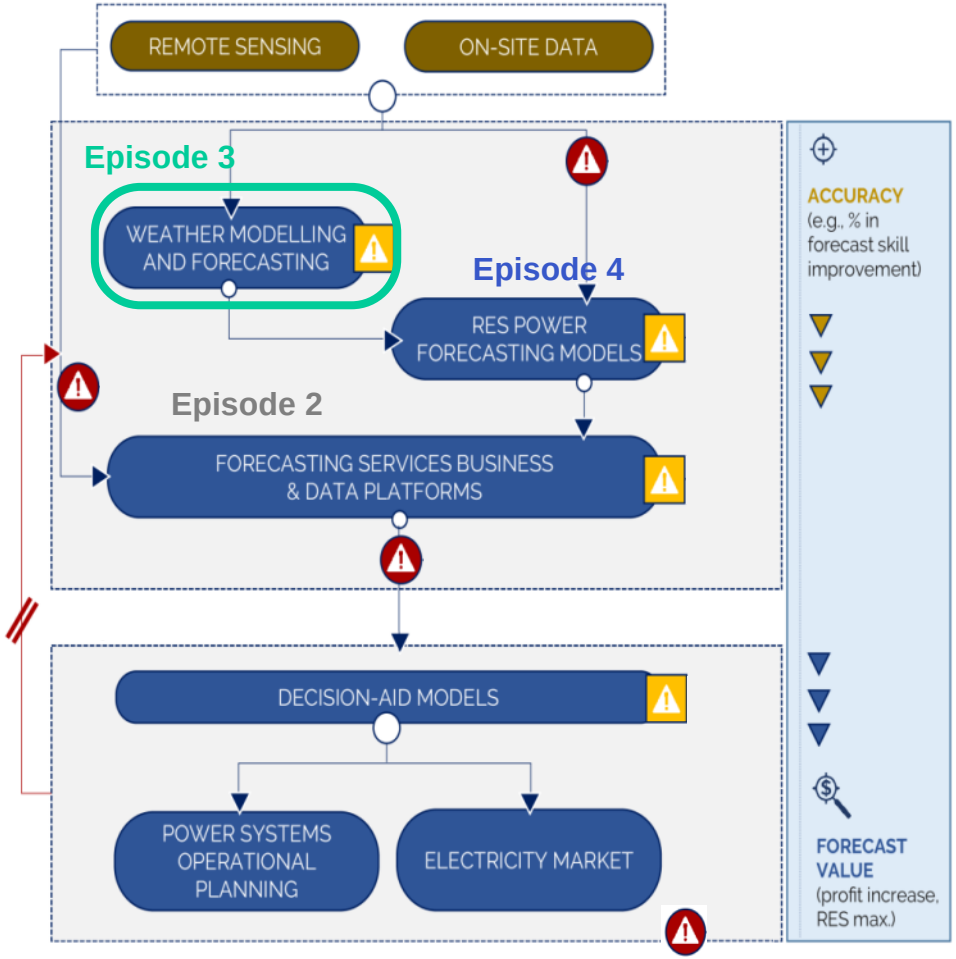
Smart4RES in a nutshell

Smart4RES in a nutshell

- RES forecasting is a mature technology with operational tools and commercial services used by different actors
- However, we want to make progress to improve the forecasting accuracy and to reduce costs of RES integration

Smart4RES vision

Science and industry closely co-operate to achieve outstanding improvements of RES forecasting by considering the whole model and value chain.



Smart4RES webinar series

Season1: Towards a new Standard for the entire RES forecasting value chain

#1 June 2020	#2 Dec 2020	#3 March & April 2021	#4 May 2021	#5 July 2021	#6 September 2021
Replay on Youtube	Replay on Youtube				
Introduction to Smart4RES - Data science for renewable energy prediction	Extracting value from data sharing for RES forecasting	Advanced weather forecasting for RES applications 3.1 NWP & High-resolution models 3.2 Data observations & assimilation	Optimising participation of RES generation in electricity markets: new opportunities and the role of forecasting	Optimizing the value of storage in power systems and electricity markets	Modelling tools for integrating RES forecasting in electrical grids
ARMINES, DTU	INESCTEC, DTU	energy&meteo systems, WHIFFLE, DTU, DLR, METEO FRANCE	energy&meteo systems, DTU, ARMINES	ARMINES, NEW ENERGY WORLD	INESCTEC, ARMINES

Smart4RES consortium

6 countries
12 partners

End-users
Industry
Research
Universities
Meteorologists

Funds: H2020 programme
Budget: 4 Mio€
Duration: 3.5 years

11/2019-4/2023

Denmark — DTU

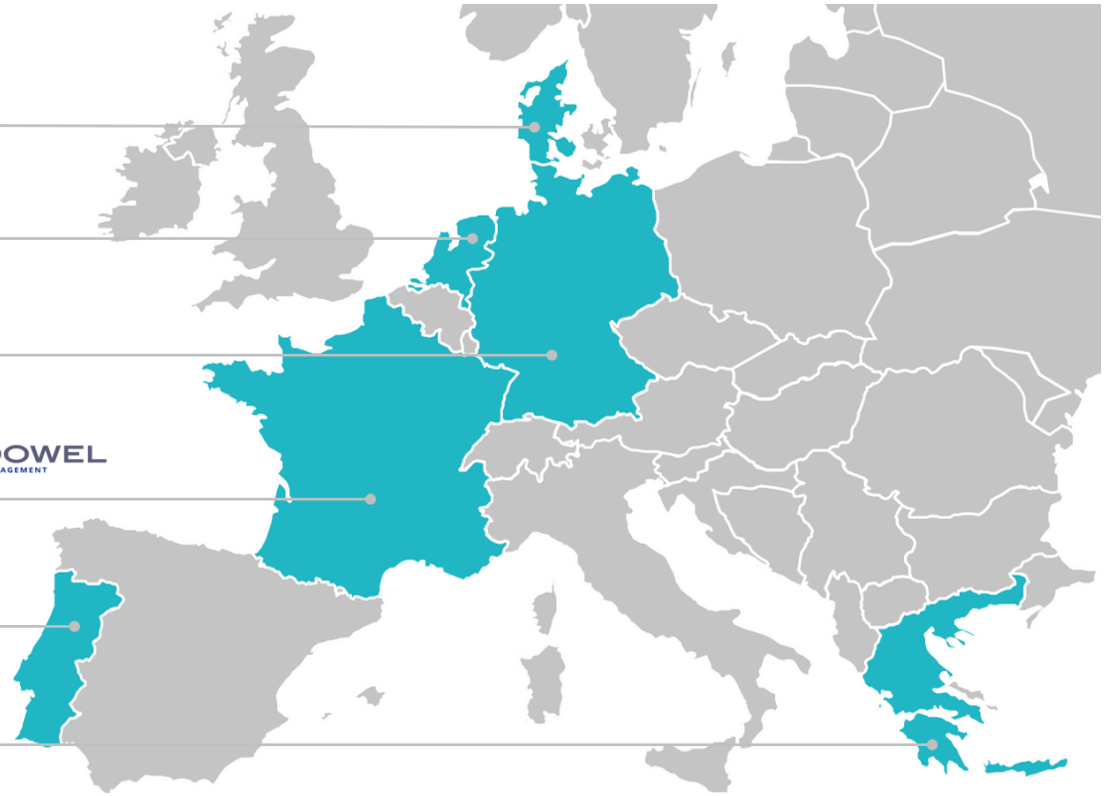
Netherlands — WHIFFLE, DNV·GL

Germany — DLR, energy & meteo systems

France — ARMINES, MINES ParisTech, METEO FRANCE, DOWEL MANAGEMENT

Portugal — INESCTEC, NEW ENERGY WORLD

Greece — HEDNO, ICCS



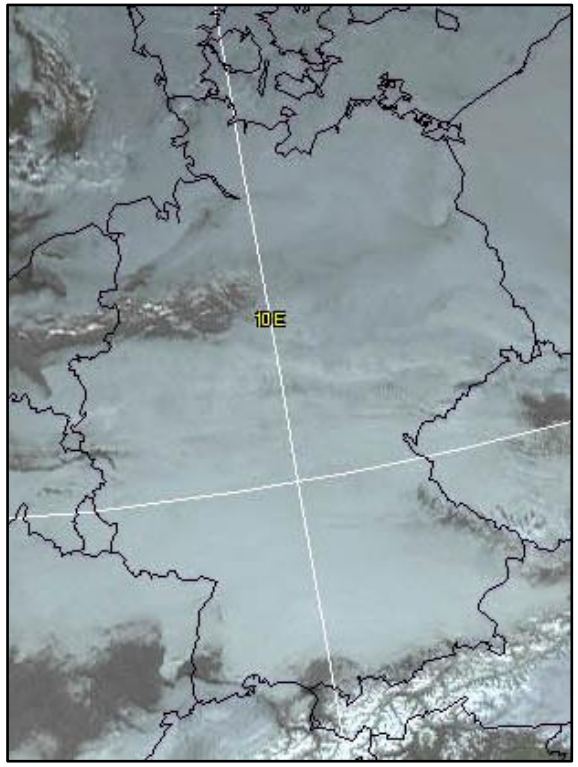
➲ **Follow us!**
www.smart4res.eu

Challenges in forecasting of renewables

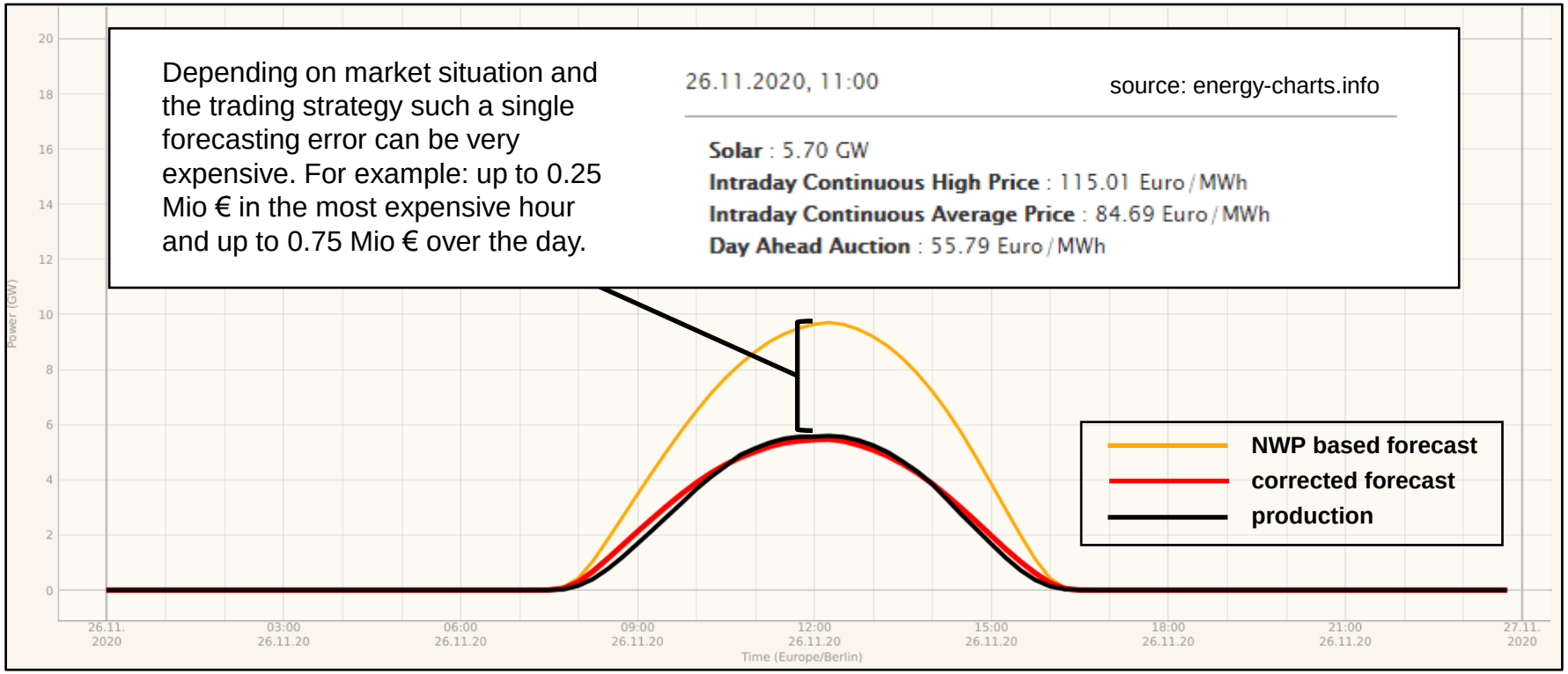
Challenges in forecasting of renewables

- Solar power prediction: the fog situation

fog seen from satellite



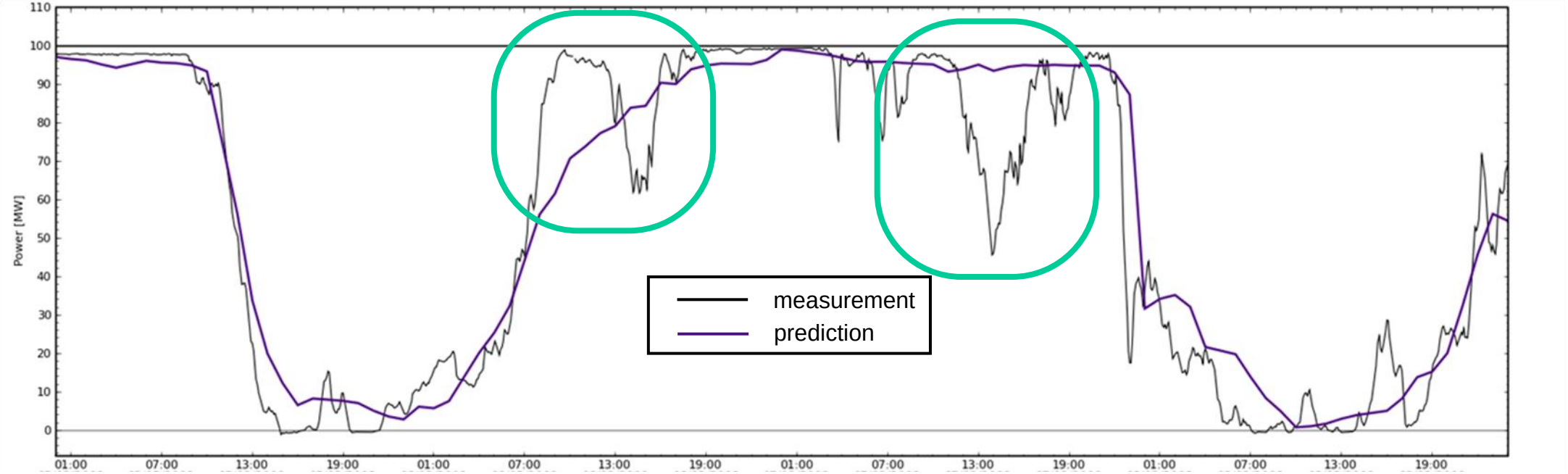
impact of fog on solar power forecast for Germany:
individual weather models with large forecasting errors



Challenges in forecasting of renewables

- Wind power prediction: fluctuations and ramps

State-of-the-art weather models provide a time resolution of 1 hour and do not predict fast changes



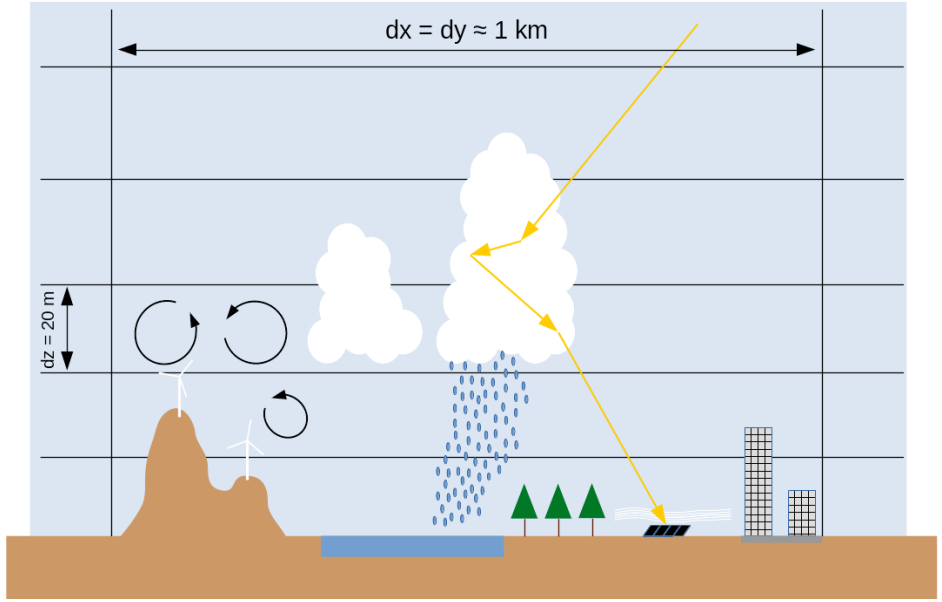
Towards Numerical Weather Prediction (NWP) models dedicated to Renewable Energy Sources (RES)

Innovative weather forecasts for RES – Challenges and Solutions

ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

Why is weather forecasting so difficult ?

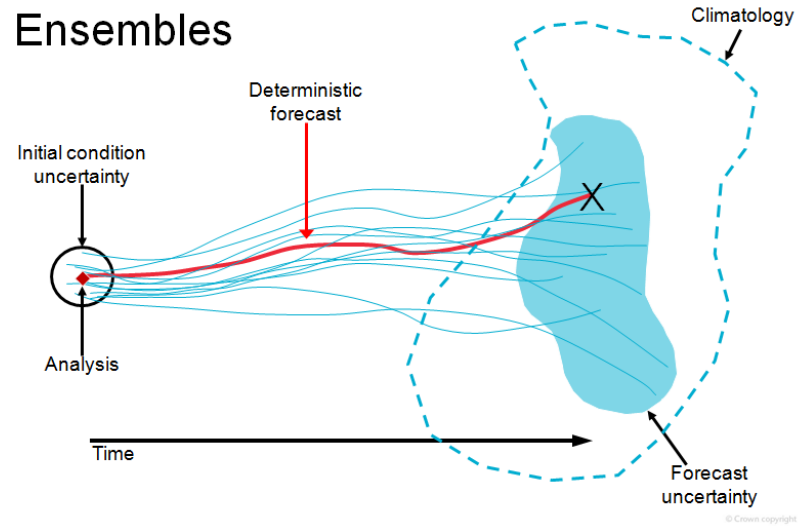
- atmosphere is **chaotic** *(initial state is critical)*
- NWP models have coarse resolution while physical processes **occur at very small scales** *(clouds, rain, wind gusts, etc.)*
  → **Parameterizations needed**



Many physical processes occur at scales smaller than the model grid, and are not explicitly simulated. They are parameterized based on explicitly simulated large scale variables

What are the solutions ?

- using **ensembles** to explore all possible states
- **increasing spatial resolution to get rid of parameterizations**
- **improving parameterizations**

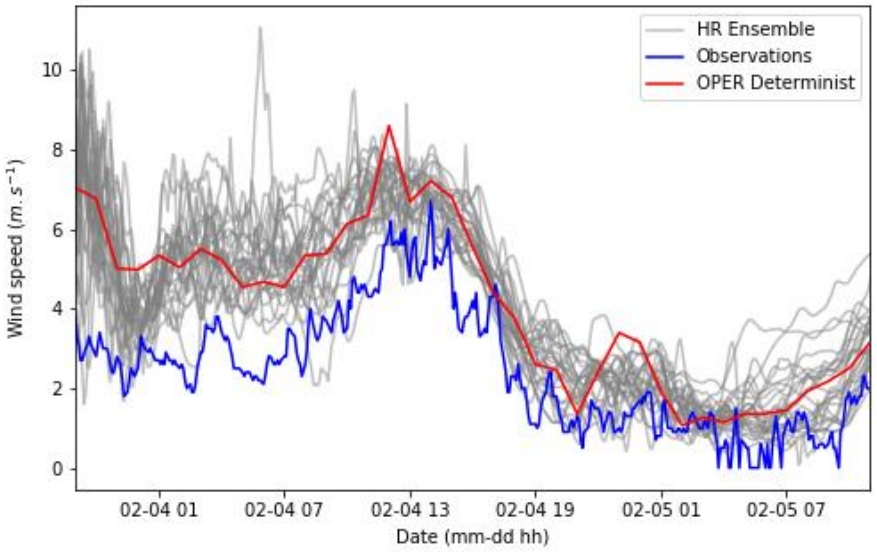


Schematic illustration of the use of ensembles in weather forecasts (UK Met Office)

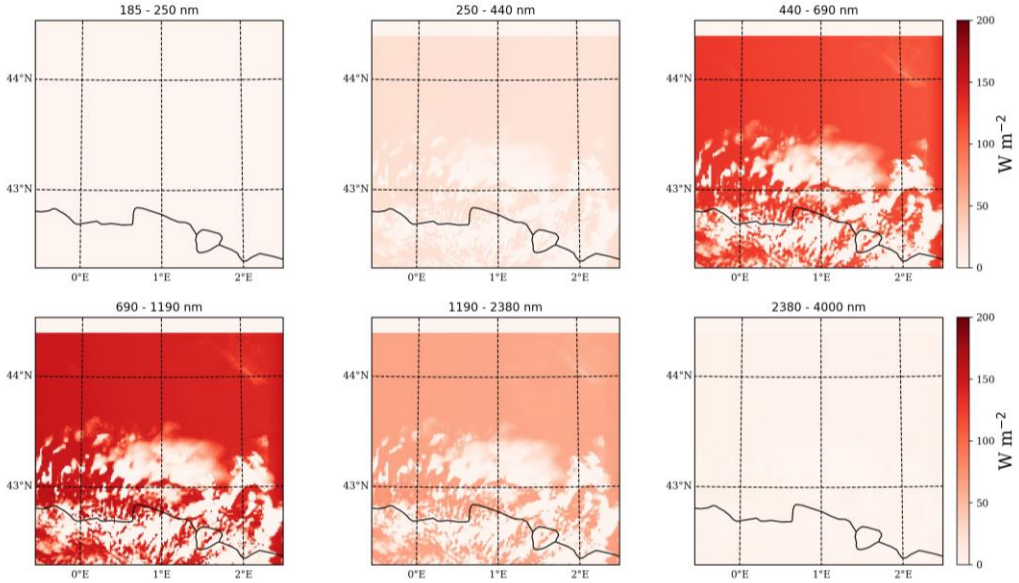
Towards NWP models dedicated to RES

Paths to improved RES forecasts

- providing higher temporal resolution outputs (*NWP models have a ~1 min time step but standard output is 1 hour*)
- extracting additional relevant variables for RES
  (cloud optical thickness, direct/diffuse partition, spectral distribution of radiation, rapid wind fluctuations)
- evaluating and calibrating NWP models accounting for RES scores and developing specific forecasters capabilities



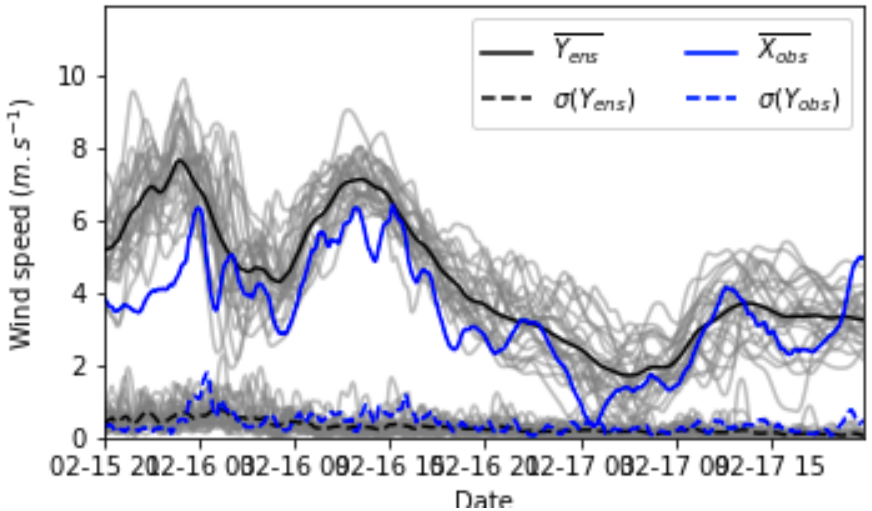
Comparison between 1-hour (operational) and 5-min resolution outputs for wind speed forecasts *(courtesy B. Alonzo)*



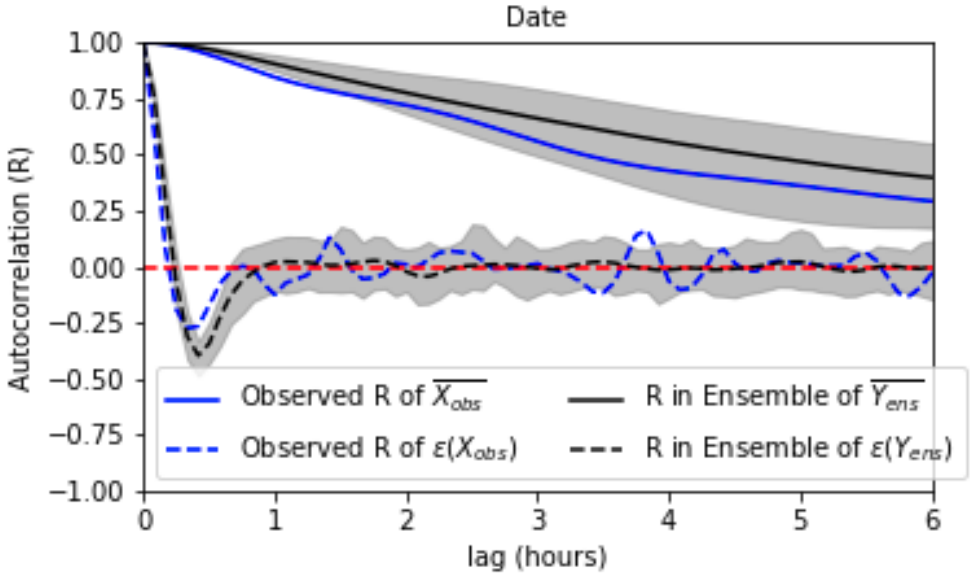
Direct solar radiation in 6 spectral bands simulated by AROME around Toulouse (France)

High temporal resolution outputs

- **High frequency fluctuations in simulated wind speed are consistent with observations**
- **Slight underestimation of these fast fluctuations in the ensemble mean**
  but some members do capture them better
- **Autocorrelation demonstrates the forecast capability**



Low frequency variations and intra-hourly standard deviation of wind speed. Comparison between ensemble simulations and observations *(courtesy B. Alonzo)*



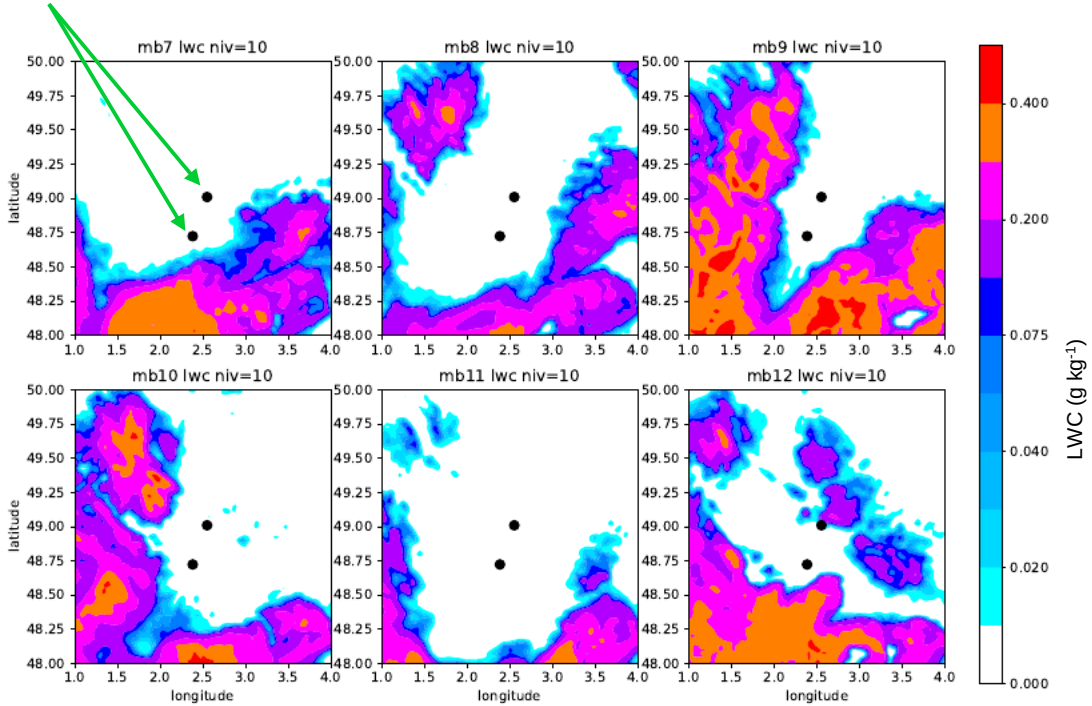
Autocorrelation functions of low and high frequency wind fluctuations *(courtesy B. Alonzo)*

The power of ensembles – fog

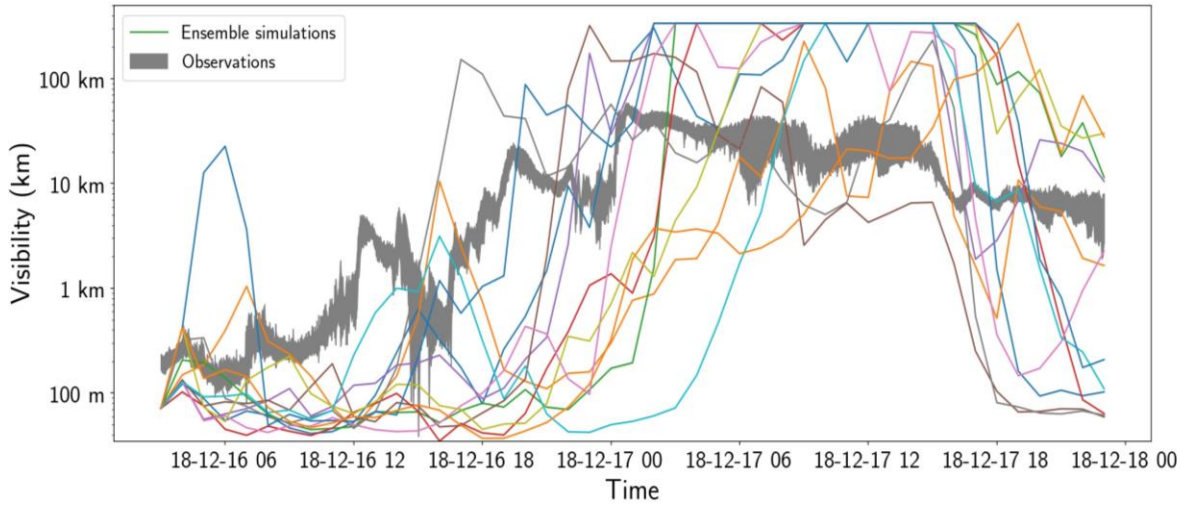
Ensembles (perturbed initial conditions, lateral forcing, surface or parameterizations) highlight how the atmospheric state can vary a lot from a member to another

Different members can have very distinct behaviours

Paris airports



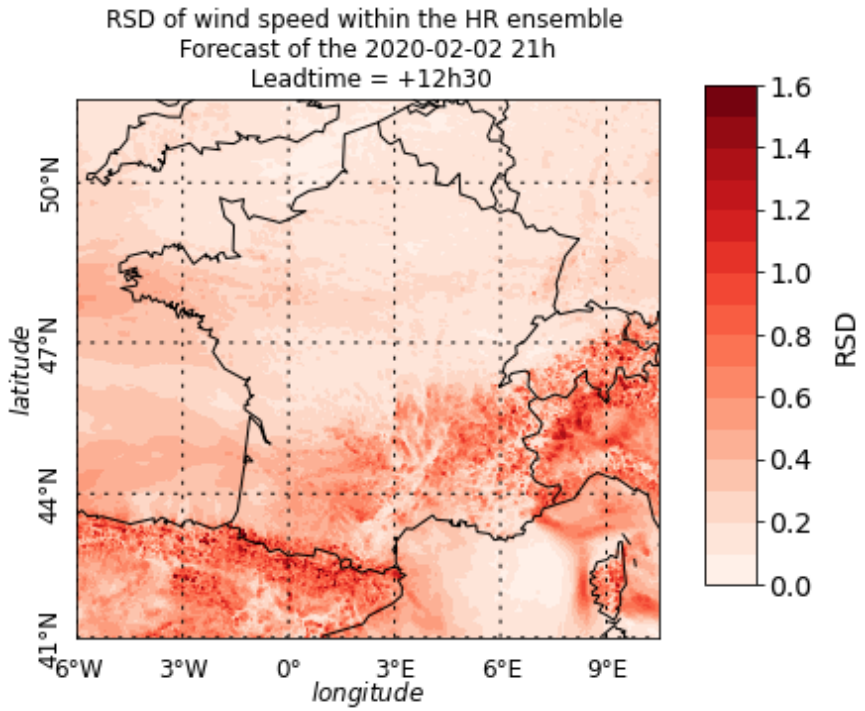
Fog prediction (maps of liquid water content at level 1, 10 m high) around Paris for 6 members of an ensemble *(courtesy T. Bergot)*

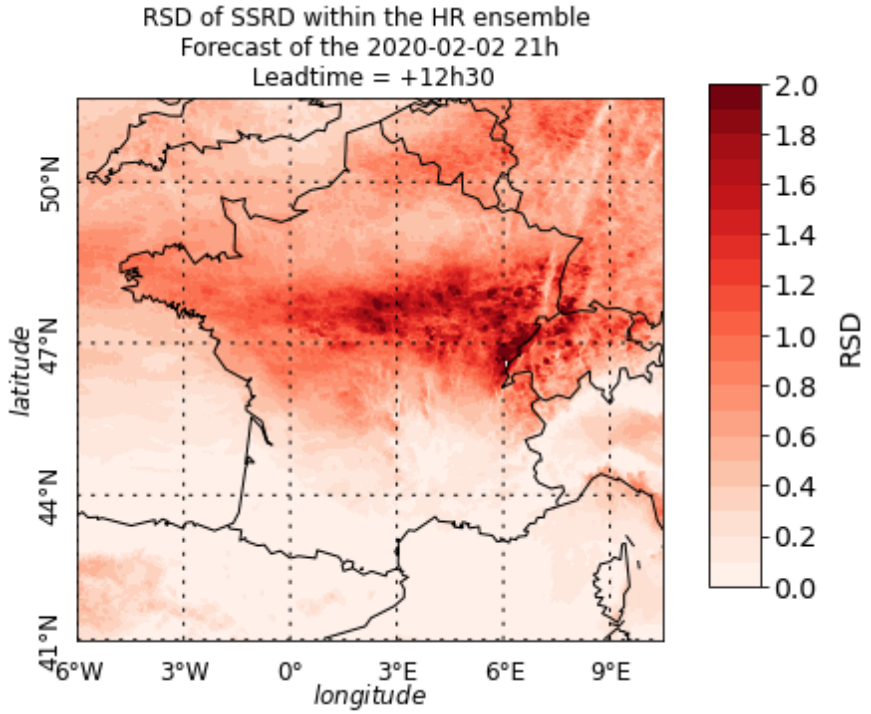


Fog predictions (operational 12 members ensemble simulations) and observations (12 measurements) at CdG airport (Paris) in December 2018 *(courtesy T. Bergot, R. Lestringant)*

The power of ensembles – wind, solar

- **Ensembles are useful to estimate the uncertainty associated with a forecast**
- **Uncertainties in RES relevant variables can be significant**



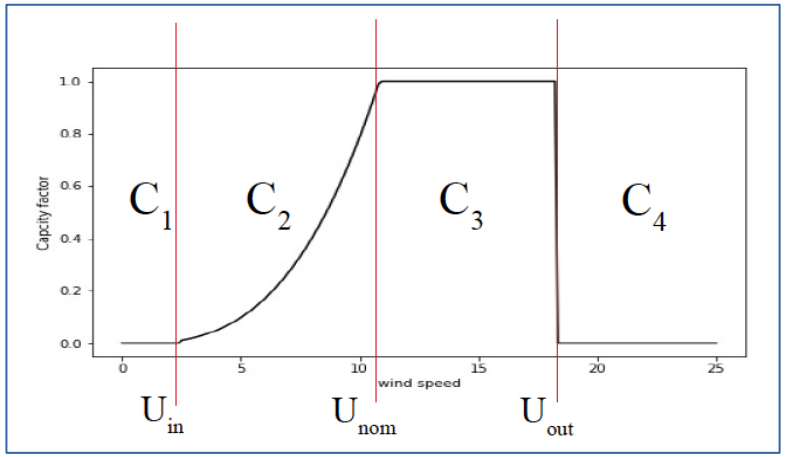


Relative standard deviation (standard deviation/mean) for wind (left) and global horizontal irradiance (right) across an ensemble of 25 members (*courtesy B. Alonzo*)

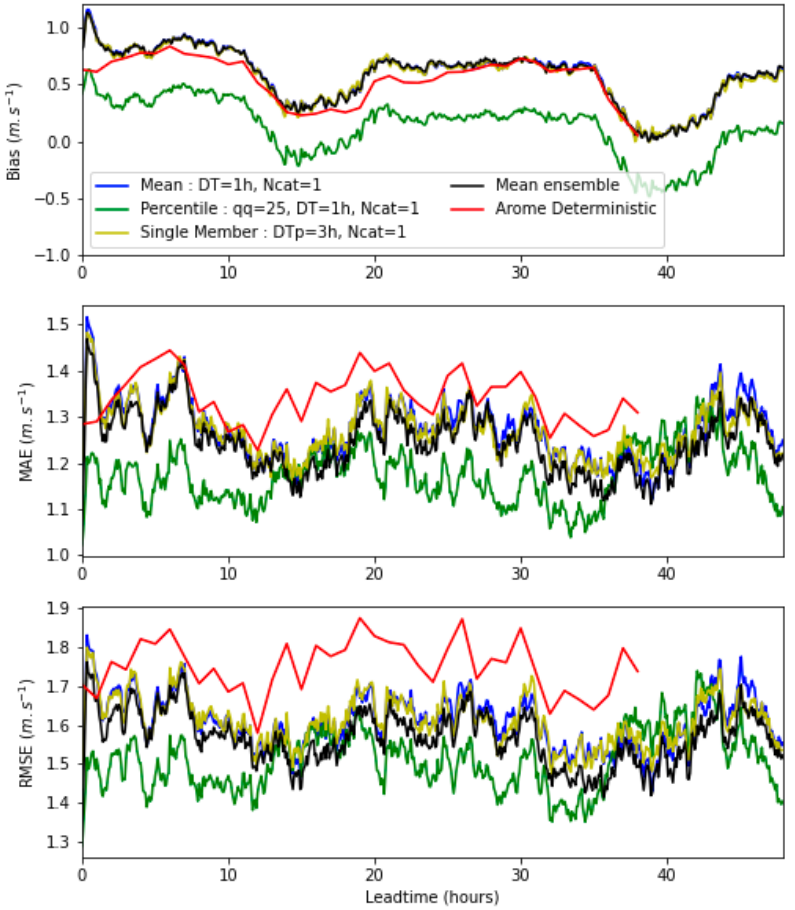
The power of ensembles – Pseudo-deterministic simulations

ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

- **Ensembles can be used to build pseudo-deterministic simulations (that look like deterministic simulations to the end-user)**
- **These pseudo-deterministic simulations can be built in various ways, and can be very specific to the end-user needs**
- **Pseudo-deterministic simulations can exceed ensemble mean forecasting performances**



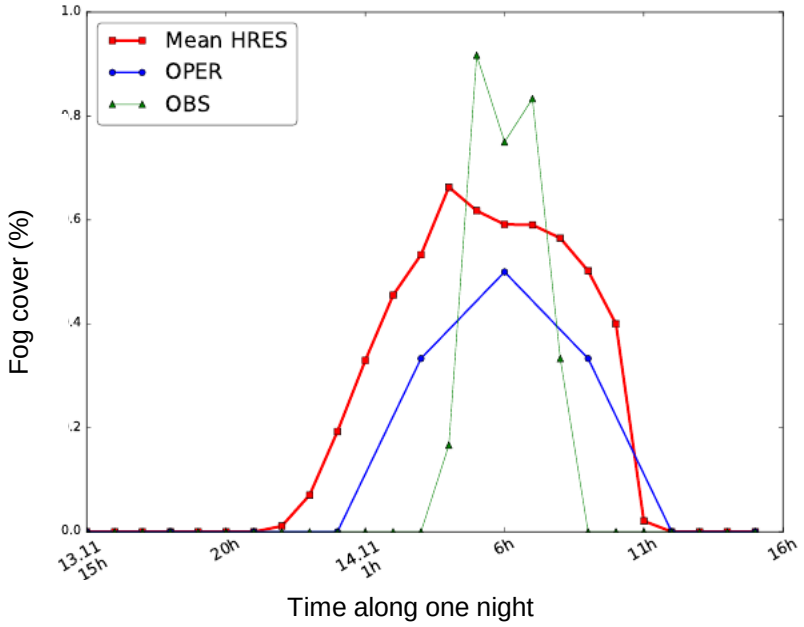
Definition of categories for wind speed, used to build pseudo-deterministic runs for wind power forecasts. Over each period, the most represented category across the ensemble is used.



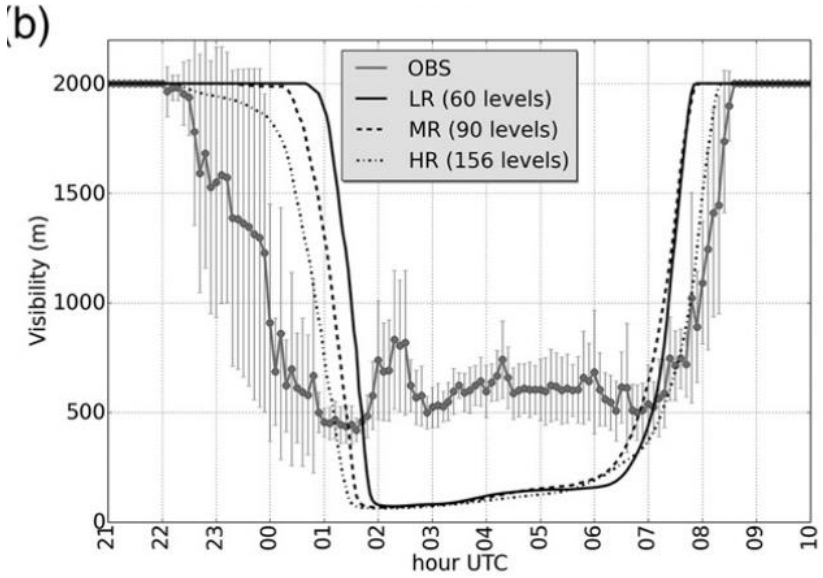
Performances of various simulations with respect to observations. Here, the dedicated pseudo-deterministic simulation performs best (*courtesy B. Alonzo*)

Increasing spatial resolution

- **Fog formation is very sensitive to the state of the atmosphere close to the surface**
- **Increasing vertical and horizontal resolution modifies turbulence and dynamics**



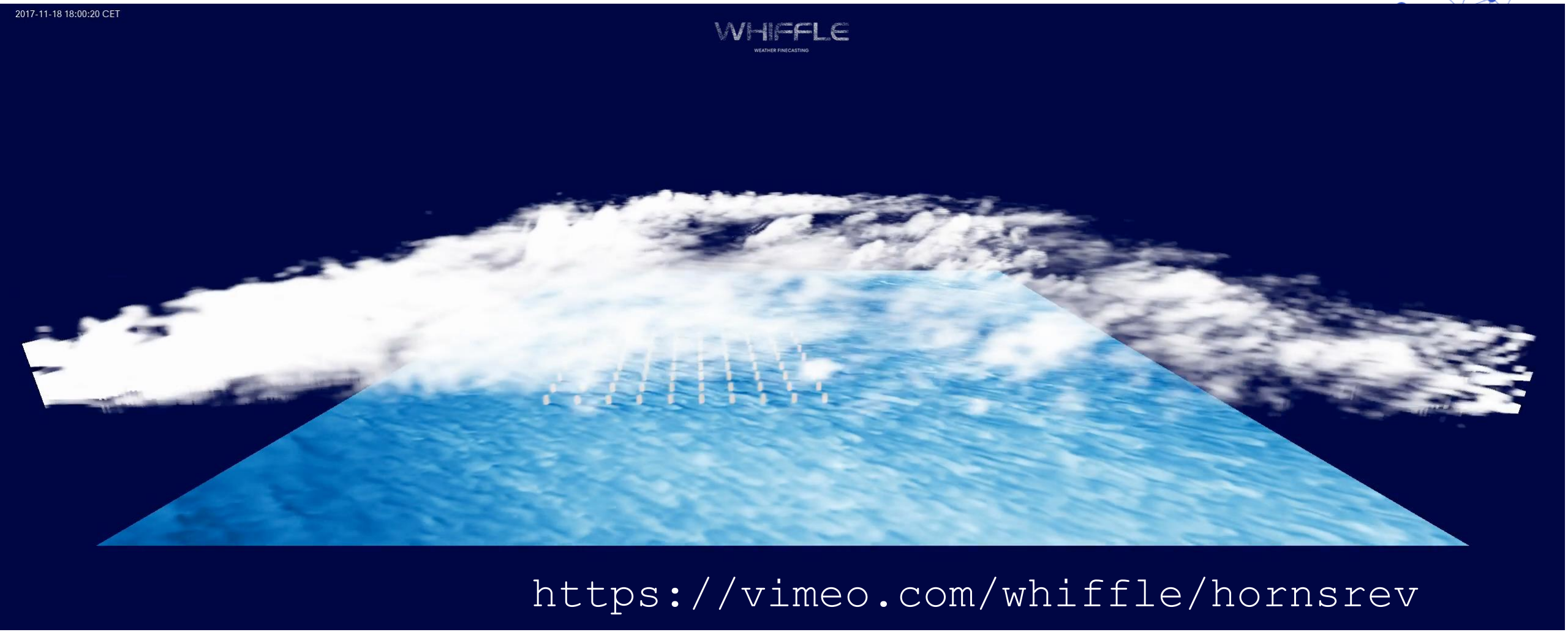
Differences in fog prediction for different spatial resolutions (2,5 km, 60 levels vs 1 km, 156 levels ; *Ragon, 2020*)



Higher vertical resolution better reproduces fog daily cycle near Paris airport (*Philip et al., 2016*)

High-resolution weather models
Large Eddy Simulation (LES): the future

Operational LES model of the HornsRev offshore wind farm

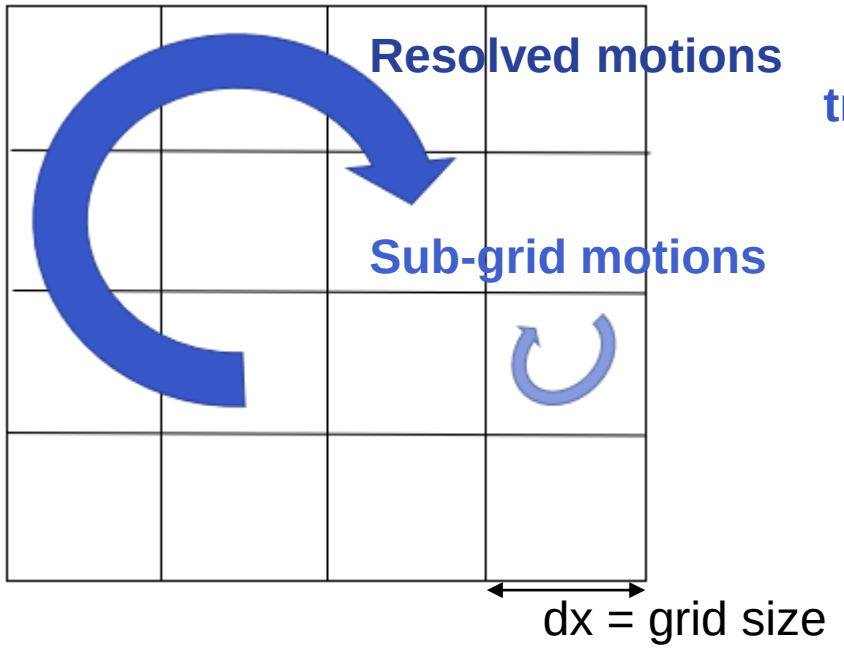


Gilbert, C., Messner, J. W., Pinson, P., Trombe, P., Verzijlbergh, R., Dorp, P. Van, & Jonker, H. (2019). Statistical Post-processing of Turbulence-resolving Weather Forecasts for Offshore Wind Power Forecasting. *Wind Energy*, 1–16. https://doi.org/10.1002/we.2456

The energy spectrum of turbulent flow in Large Eddy Simulation (LES)

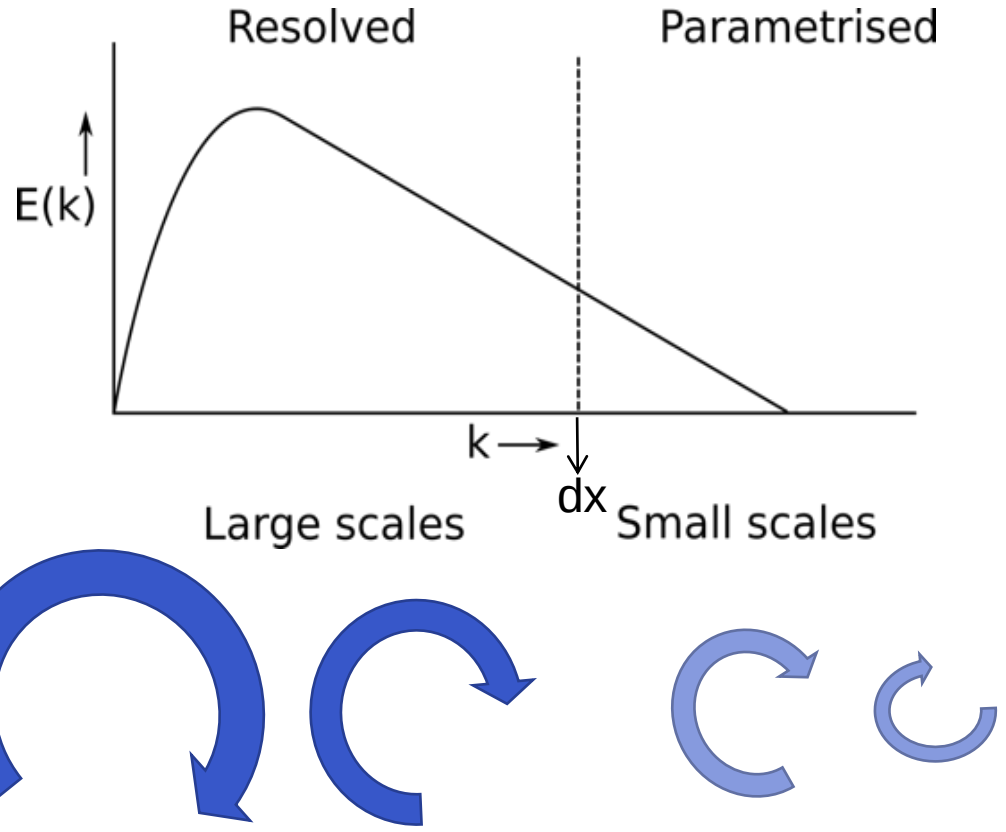
ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

Large Eddy Simulation



Fourier transform

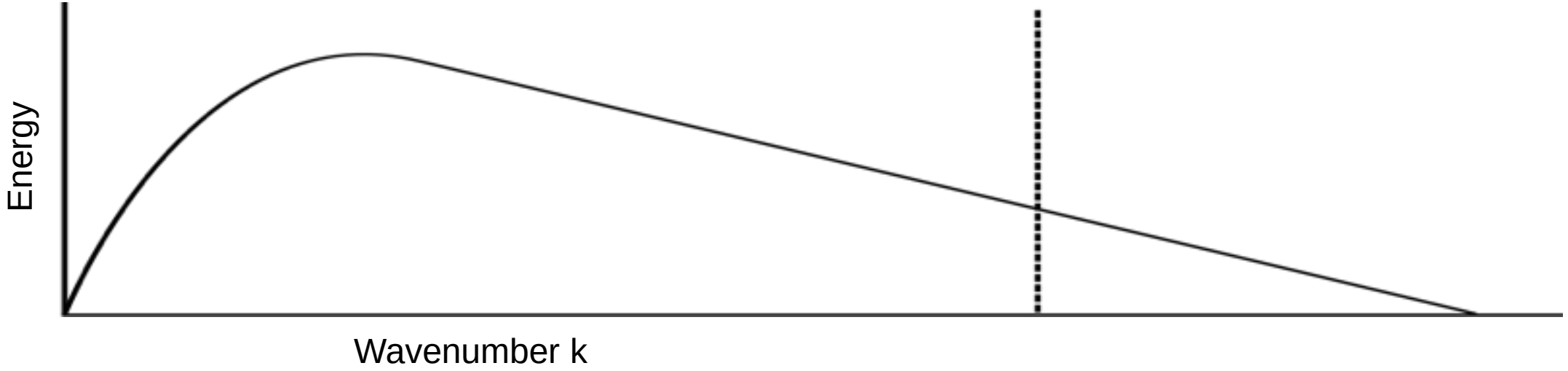
A turbulent spectrum: energy as function of wavenumber

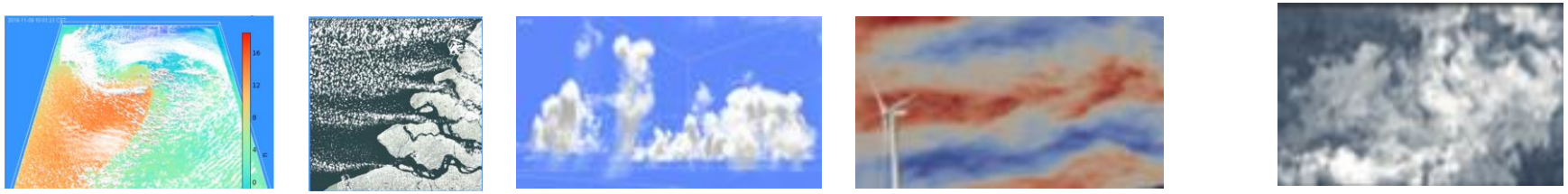


Model grid in *physical space* showing schematically the turbulent motions *(eddies)*

In *spectral space* the energy of different eddies peaks around a certain size (small wavenumber *k* are the largest eddies)

The energy spectrum of turbulent flow in Large Eddy Simulation (LES)





Flow dependent

Flow independent

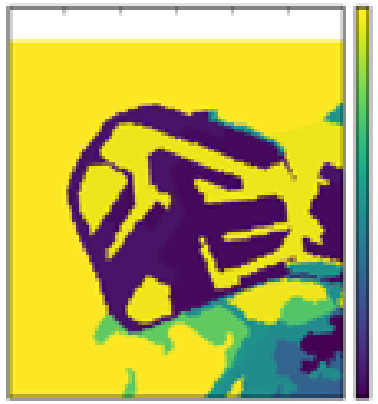
LES resolves all relevant physical processes and only parametrizes homogeneous turbulence

High-resolution allows to resolve the surface in detail

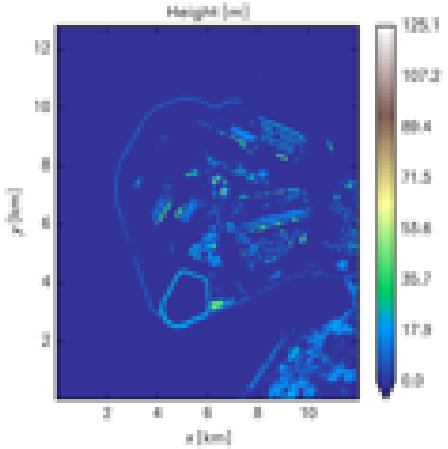
Higher resolution and more explicit modelling of:

- Forest and vegetation resolved in more detail (canopy parameterization)
- Explicitly model obstacles like buildings and wind turbines

Land use



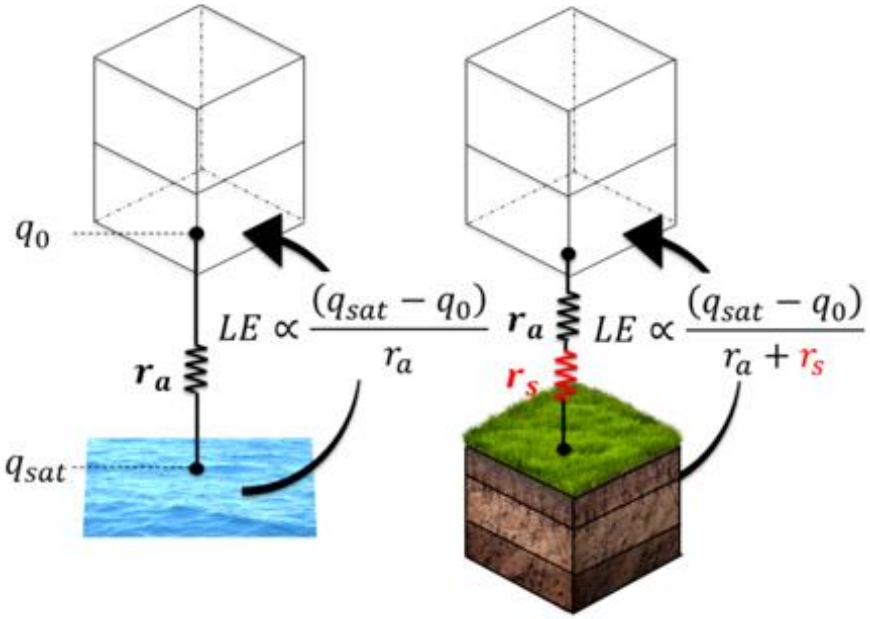
Terrain and buildings



Turbines

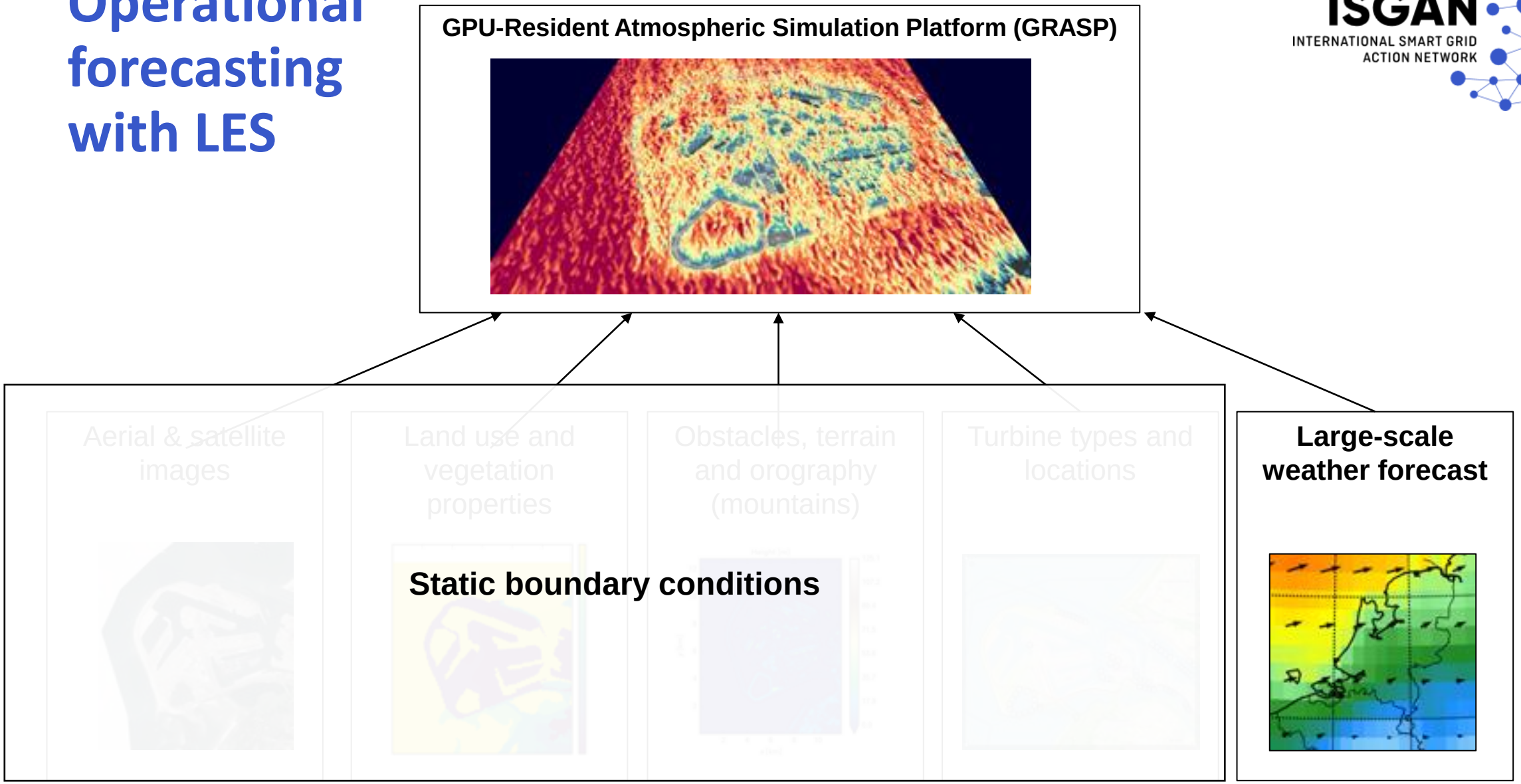
15 km

Surface scheme controls momentum, heat and moisture exchange



Tiggelen, M. Van. (2018). *Towards improving the land- surface-atmosphere coupling in the Dutch Atmospheric Large- Eddy Simulation model (DALES)*. MSc Thesis, Delft University of Technology.

Operational forecasting with LES

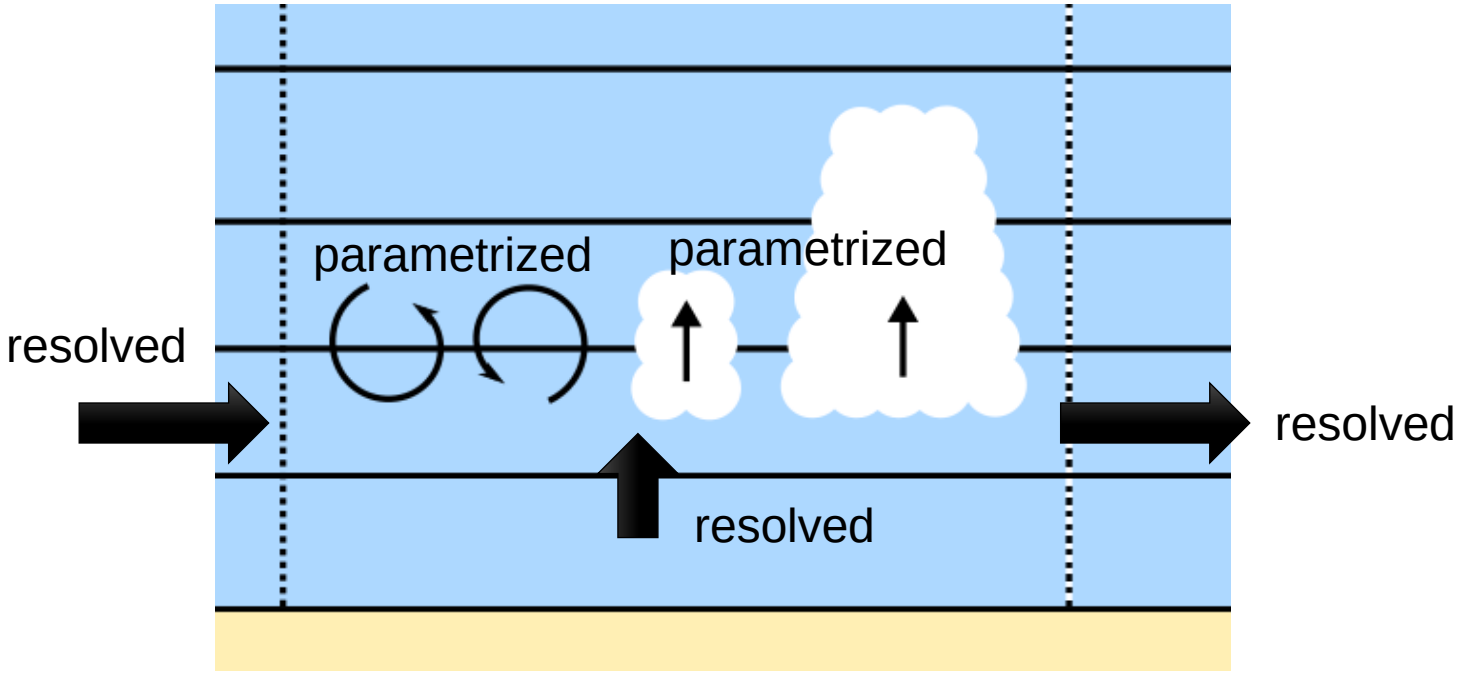


A schematic representation of different inputs to a the LES forecasting model

Physics parameterizations in NWP

Parametrization: **expressing the sub-grid processes in terms of resolved quantities**

Schematic view on transport by sub-grid processes



Typical processes that are parameterized in NWP:

- Turbulence
- Large-scale clouds
- Convective clouds
- Surface drag
- Radiation
- Precipitation
- Surface energy balance

See for example https://www.ecmwf.int/en/elibrary/18714-ifs-documentation-cy45r1-part-iv-physical-processes

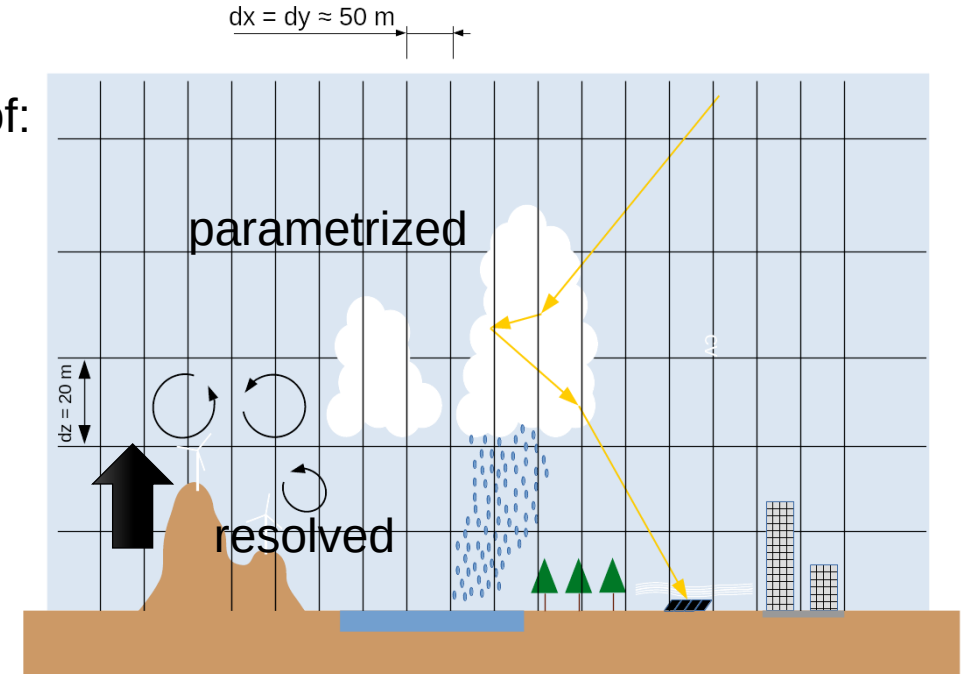
Physics parameterizations in LES

Parametrization: **expressing the sub-grid processes in terms of resolved quantities**

The LES grid is fine enough to resolve turbulence, clouds and the surface. *"Assume less, compute more"*

Explicit modelling of:

- Wind turbines
- Canopies
- Buildings
- Turbulence
- Clouds / fog



Typical processes that are parameterized in LES:

- ~~Turbulence~~
- ~~Large-scale clouds~~
- ~~Convective clouds~~
- ~~Surface drag~~
- Radiation
- Precipitation
- Surface energy balance (in high resolution)

See for example https://www.ecmwf.int/en/elibrary/18714-ifs-documentation-cy45r1-part-iv-physical-processes

Country scale LES already possible on multi-GPU systems

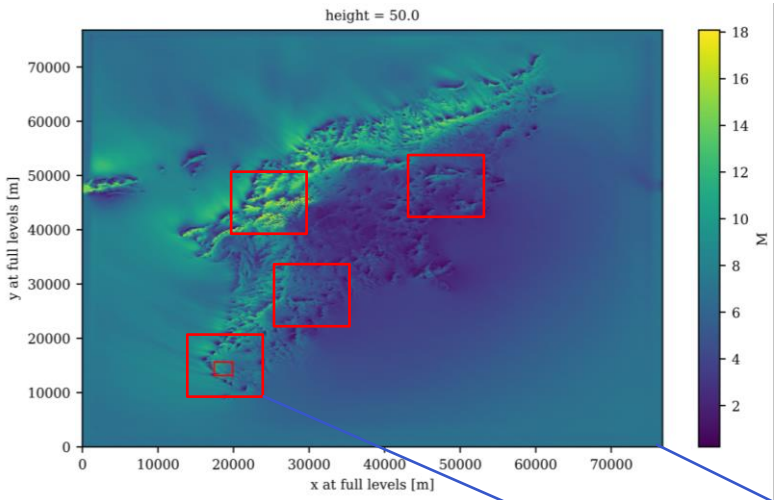
ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

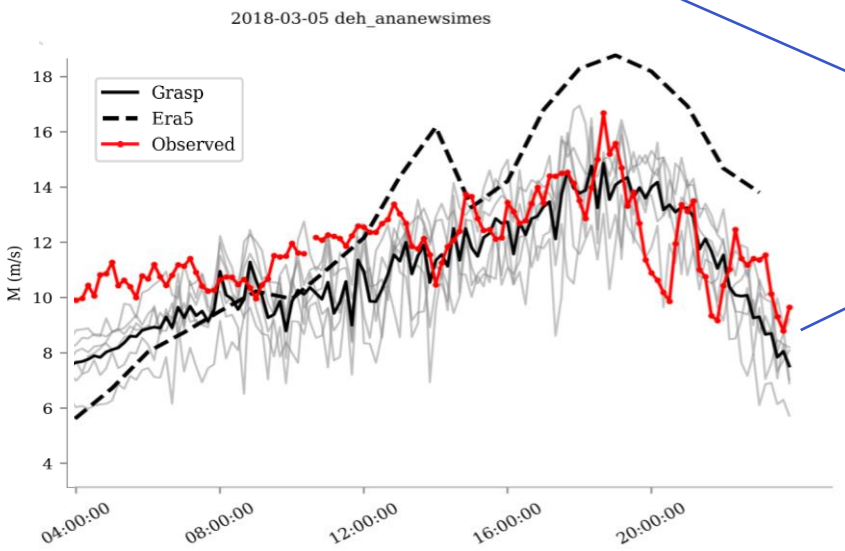
Whiffle forecast

Satellite image

Traditional weather forecast

Smart4RES use case: Rhodes





Important forecast characteristics for smarter grid management:

- Fast fluctuations in wind power
- Spatio-temporal patterns
- Good forecast accuracy on complex terrain

A nested LES forecast is produced

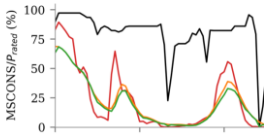
- Outer domain captures Rhodes ~ 100m resolution
- 4 inner domains on wind farms: ~ 40m resolution
- Figure shows variability in individual wind turbine forecasts
- Compare with smooth signal of large-scale weather model (era5)

Planned innovations in Smart4RES

ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

New in Smart4RES: assimilation of local observations in LES

Local observations



- Clouds
- Wind
- Radiation
- Pressure

- Power
- SCADA wind
- SCADA temp
- …

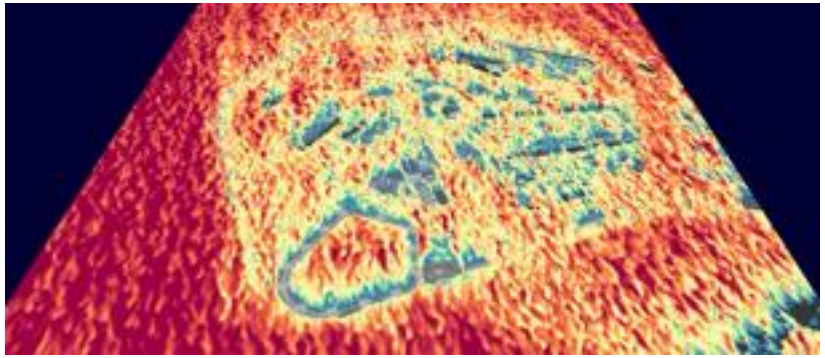
Data assimilation : estimating the state of a system (here: the atmospheric model) given a set of observations and the model dynamics

minimize obj = f (modeled state – observed state)
subject to model dynamics

Large-scale weather model data

Static boundary conditions

GPU-Resident Atmospheric Simulation Platform (GRASP)



The future of numerical weather prediction

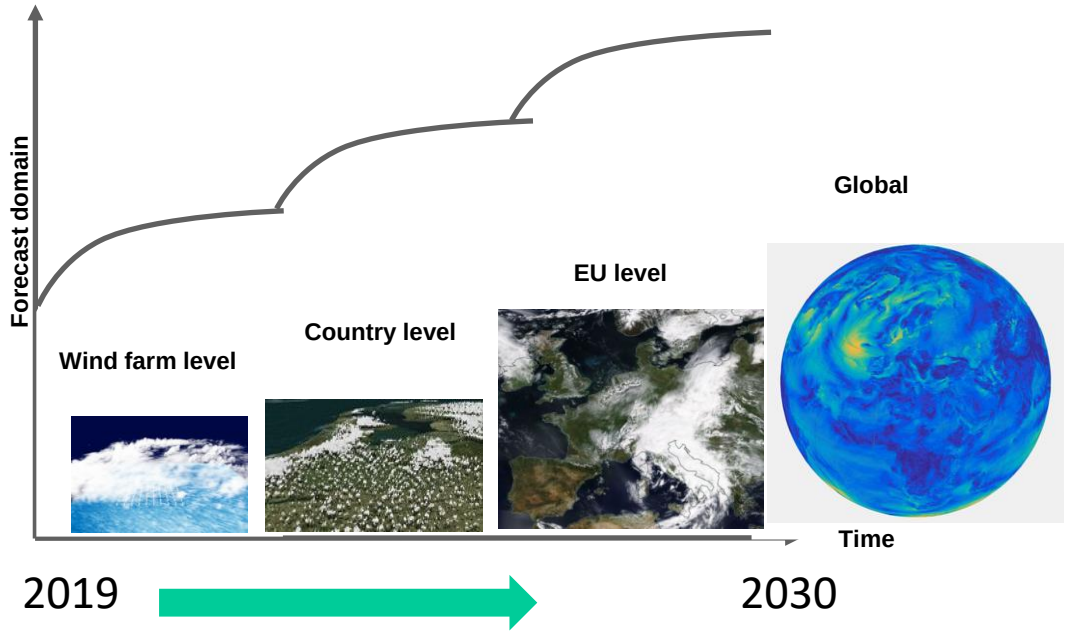
ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

Next generation weather model:

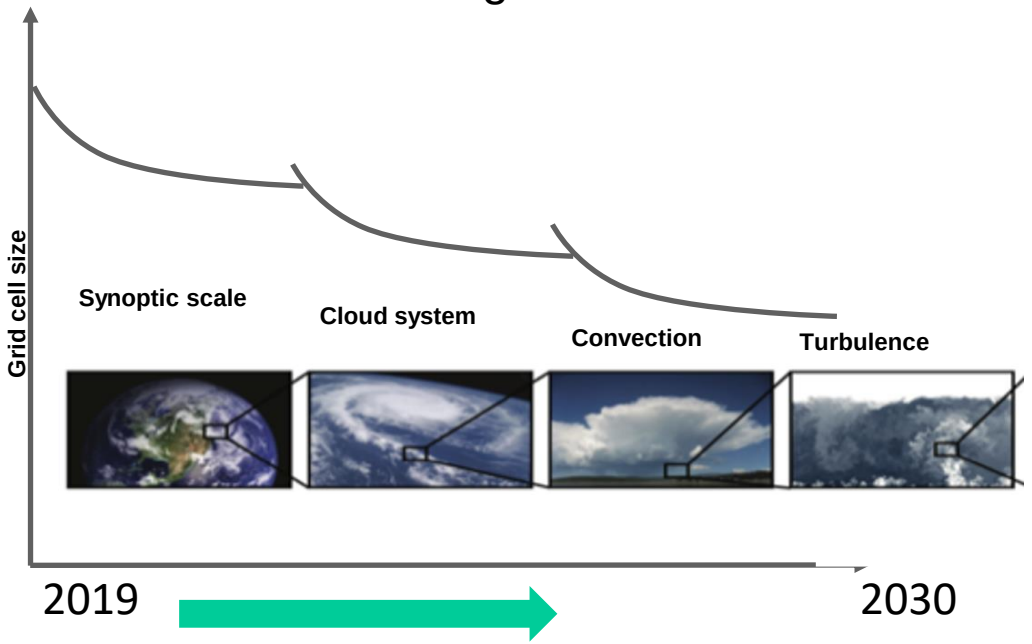
- Turbulence and cloud resolving (= LES !)
- Uses big data and massive computational power
- Supports energy transition and climate adaptation

Who will be first?

LES: scaling up the domain size



NWP: increasing the resolution



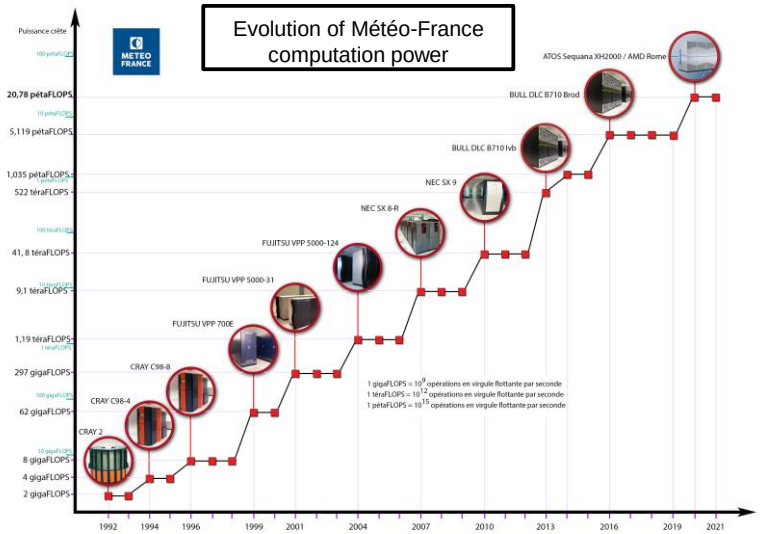
Take-away messages

- Numerical models contain much more than operational outputs
- The natural evolution of NWP is to increase spatial resolution

→ Now at a stage called ***grey-zone turbulence*** in between parameterizations and LES (~ 500 m resolution)

→ LES might be the future of NWP

- Ensembles are becoming the norm to explore uncertainties
- Increasing amount of observations, including non-conventional, are likely to improve forecasts via data assimilation



Attend our next webinar!

→ for very short-term, direct observations remain very powerful because models give a statistical view of the atmosphere, not perfectly punctual in space and time

→ combination of various inputs is promising, in particular with increased use of artificial intelligence

➲ **Follow us!**

www.smart4res.eu

Further reading

[1] Gilbert, C., Messner, J. W., Pinson, P., Trombe, P. J., Verzijlbergh, R., van Dorp, P., & Jonker, H. (2020). Statistical post-processing of turbulence-resolving weather forecasts for offshore wind power forecasting. Wind Energy, 23(4), 884–897. https://doi.org/10.1002/we.2456

[2] Lindsay, N., Libois, Q., Badosa, J., Migan-Dubois, A., Bourdin, V. (2020). Errors in PV power modelling due to the lack of spectral and angular details of solar irradiance inputs. Solar Energy,197, 266-278 https://doi.org/10.1016/j.solener.2019.12.042

[3] Schalkwijk, J., Jonker, H. J. J., Siebesma, A. P., & Van Meijgaard, E. (2015). Weather forecasting using GPU-based large-Eddy simulations. Bulletin of the American Meteorological Society, 96(5), 715–723. https://doi.org/10.1175/BAMS-D-14-00114.1

[4] E.J. Wiegant, P. Baas, R.A.Verzijlbergh, B.Reijmerink, and S.Caires. The new frontier in numerical metocean modelling: coupled high-resolution atmosphere wave interactions. In Wind Europe Offshore, 2019.

[5] R.A.Verzijlbergh, H.J.J. Jonker, P. van Dorp, E.J. Wiegant, P. Baas, B.M. Meijer, and J. Coeling. Breakthrough weather prediction technology enables wind turbine resolving resource assessments. In Wind Europe, 2019.

Smart4RES webinar series

Season1: Towards a new Standard for the entire RES forecasting value chain

#1 June 2020	#2 Dec 2020	#3 March & April 2021	#4 May 2021	#5 July 2021	#6 September 2021
Replay on Youtube	Replay on Youtube				
Introduction to Smart4RES - Data science for renewable energy prediction	Extracting value from data sharing for RES forecasting	Advanced weather forecasting for RES applications 3.1 NWP & High-resolution models 3.2 Data observations & assimilation	Optimising participation of RES generation in electricity markets: new opportunities and the role of forecasting	Optimizing the value of storage in power systems and electricity markets	Modelling tools for integrating RES forecasting in electrical grids
ARMINES, DTU	INESCTEC, DTU	energy&meteo systems, WHIFFLE, DTU, DLR, METEO FRANCE	energy&meteo systems, DTU, ARMINES	ARMINES, NEWENERGYWORLD	INESCTEC, ARMINES

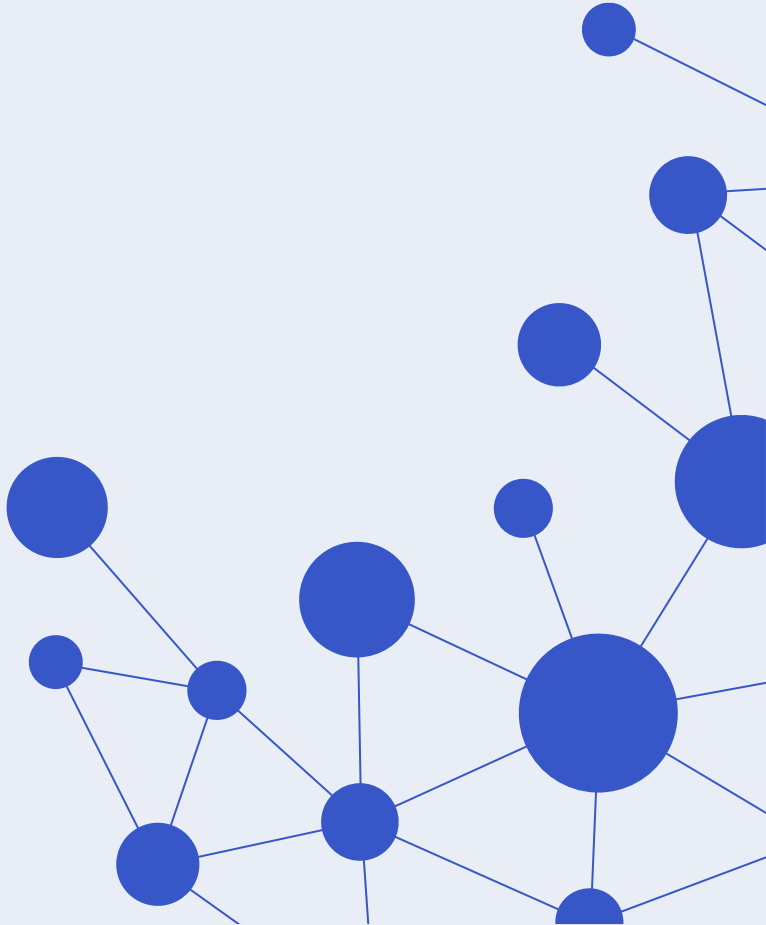
iea-isgan.org

ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

Thank you

info@smart4res.eu

matthias.lange@energymeteo.de
quentin.libois@meteo.fr
remco.verzijlbergh@whiffle.nl

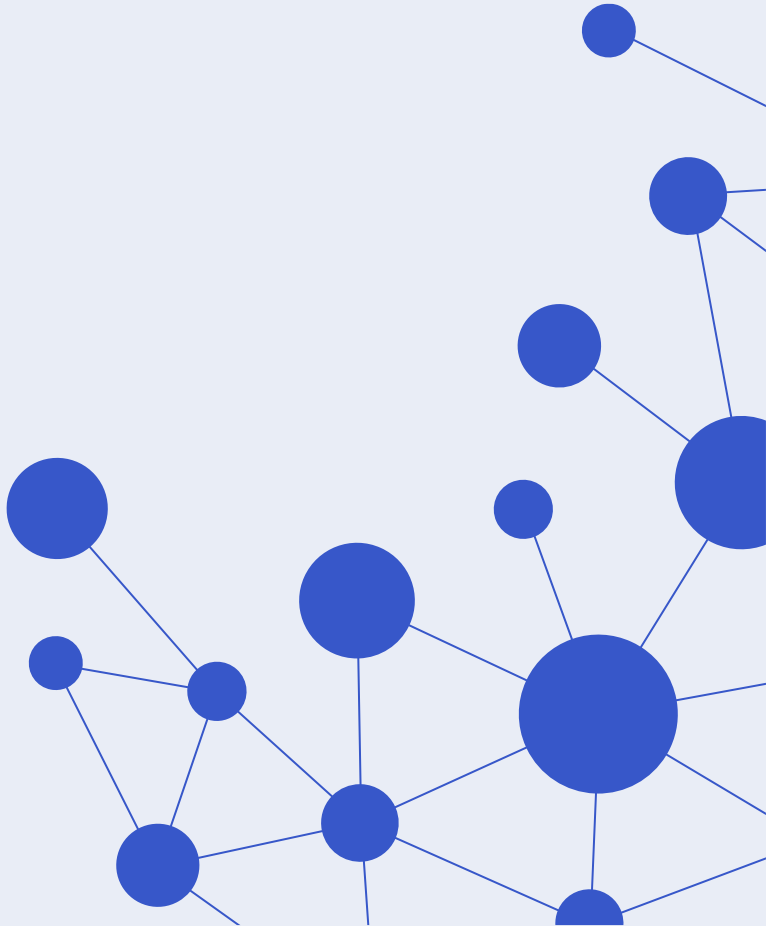


iea Energy Technology Network

CLEAN ENERGY MINISTERIAL

ISGAN
INTERNATIONAL SMART GRID ACTION NETWORK

Back-up slides



iea Energy Technology Network

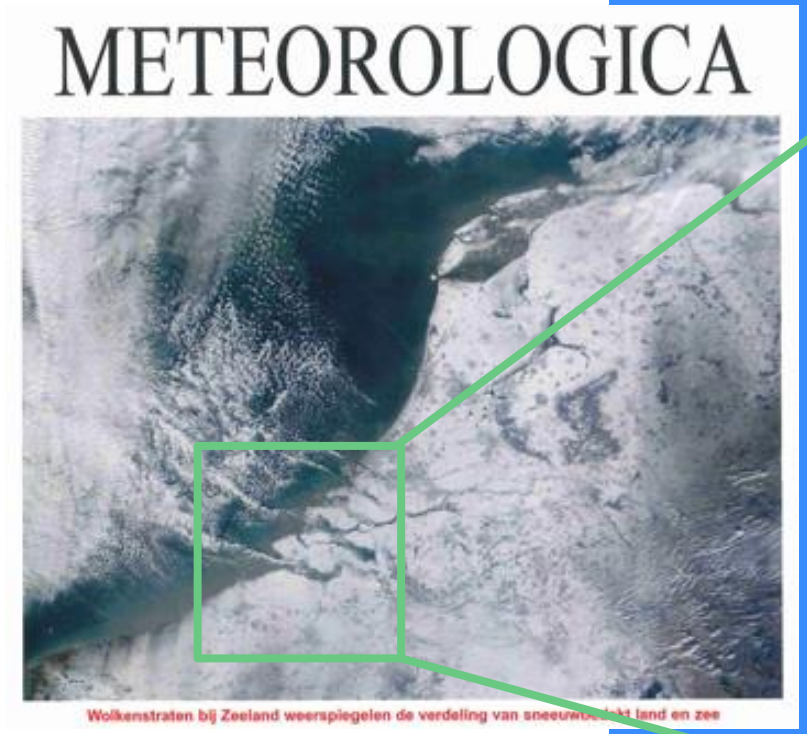
CLEAN ENERGY MINISTERIAL

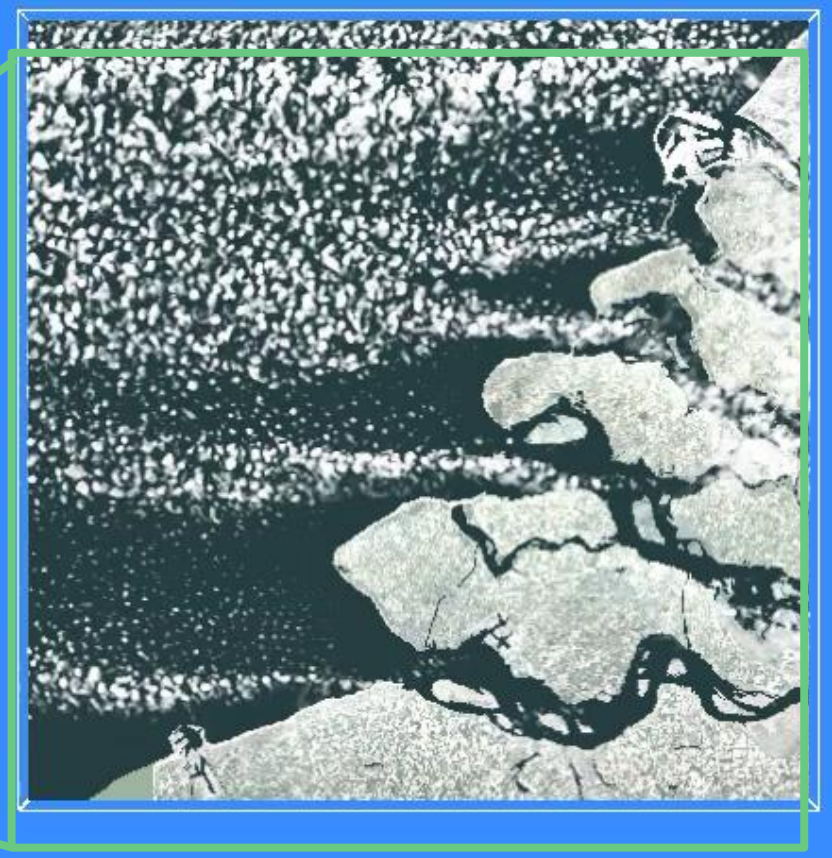
ISGAN
INTERNATIONAL SMART GRID
ACTION NETWORK

2012-02-04 08:00:12 CET

WHIFFLE

WEATHER FINECASTING





https://vimeo.com/whiffle/cloudstreetswinter