



Royal Netherlands  
Meteorological Institute  
*Ministry of Transport, Public Works  
and Water Management*

# On the development and application of weather models for wind energy

Part 1: Ine Wijnant KNMI

“EUROS for wind energy”  
11-10-2017

# KNMI weather and climate models



Good computer models are essential for the production of high-quality weather warnings and climate information. They are an indispensable tool in the creation of weather forecasts and climate scenarios. KNMI is continually working to improve these models and to keep up with the latest insights and technology. But how does such a model work?

## 1 What is a model?

As the **SUN** warms the earth it becomes warmer around the equator than at the poles. This causes large-scale **air movement** and transport of heat and humidity in the atmosphere. These weather and climate processes are simulated by computers in **numerical models**.



## 2 Calculations

In the model the atmosphere is divided up in **grid cells**



In each 3-dimensional grid cell, quantities are maintained, such as:

- temperature
- pressure
- humidity
- wind
- radiation
- etc.

The actual values of these quantities are constantly changing as radiation is reflected, water evaporates, turbulence causes mixing, etc.



These changes are calculated by the model in **modules** that describe the physical processes.

Each calculation moves the model forward in 60 second steps:



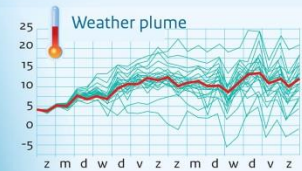
In a **column** of grid cells we encounter modules for condensation, precipitation, radiation, turbulence, evaporation and surface processes.



## 3 Weather forecast

The initial conditions of the quantities in each grid cell in the forecast model are determined from observations by weather satellites, ground stations, weather balloons and other measurements.

The observations and the model are not perfect. A slight deviation from the initial state leads to different weather situations. By slightly changing the initial conditions and the physical modules a 'weather plume' is created.



Narrow plume: **fairly certain weather forecast**  
Wide plume: **uncertain forecast**



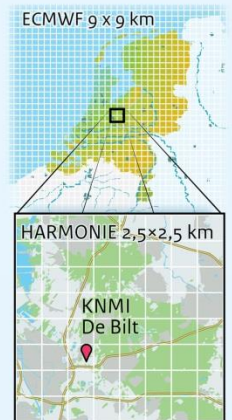
## 4 Climate scenarios

For climate simulations the model calculates far ahead. Factors that affect the climate, such as greenhouse gases, are taken into account.

### Models used at KNMI

#### ECMWF

Global model from the European Weather Centre in Reading (UK). Used for forecasts up to 2 weeks on a grid of **9 x 9 km** (around 600 cells for The Netherlands).



#### HARMONIE

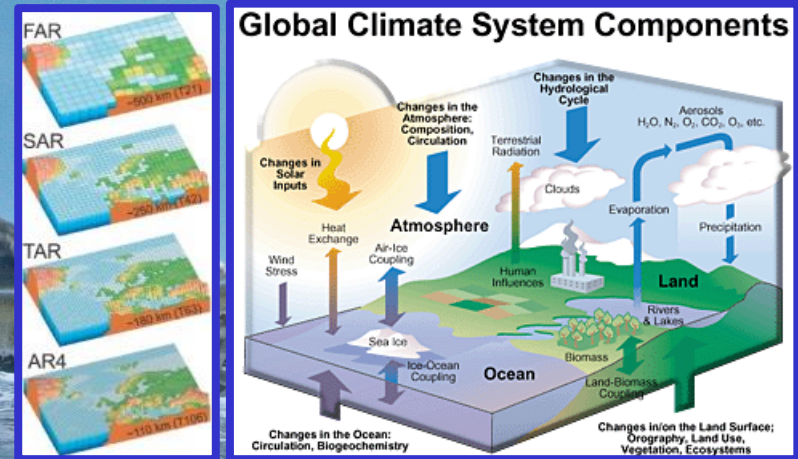
Model for The Netherlands and surroundings. In use since 2012 for forecasts up to 2 days with cells of **2.5 x 2.5 km** (around 10000 cells for The Netherlands).

### Supercomputer

HARMONIE requires around 3 quadrillion calculations. KNMI has a computer with a capacity of 50 trillion calculations/sec (50 teraflops) that is used to make 8 weather forecasts per day.



# Differences weather and climate models



**Spatial-temporal resolution:** grid-spacing most climate models 100-150 km (next generation 25 km) and decennia, weather models about 3 km and hourly. Weather models solve processes that are parametrized in climate models (e.g. convection).

**Modelling the ocean:** climate models are coupled models. KNMI's climate model EC-Earth includes ECMWF weather model, dynamic ocean model, sea ice model and soil model (coupled every 1-3 hours). Research version also other earth system models (ocean biochemistry, dynamic vegetation, atmospheric chemistry, carbon cycle components and dynamic ice sheets). If aspects of the above are included in weather models, than not calculated, but parametrized (e.g. how sea surface roughness changes with wind and how SST changes with season).

**Data assimilation:** measurements play key part in weather models, but not in climate models

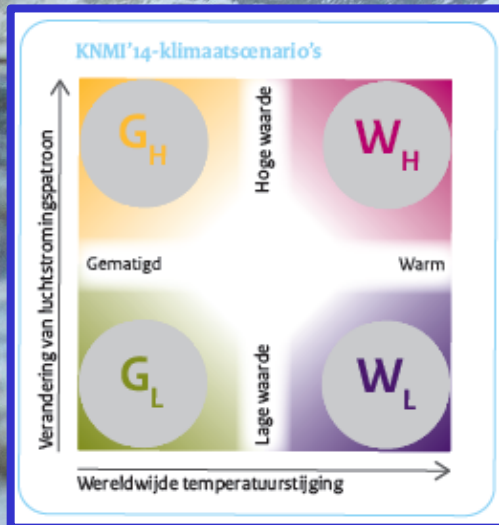
# Scenario's based on climate models



## CMIP5 (IPCC):

- 30 global climate models (ensemble) simultaneously run with same green-house gas forcing
- Measurements only used for the initialization of models for 1850 (pre-industrial)
- Control-run: > 500 runs for 1850 to guarantee atmosphere and deep ocean are in balance
- All models then forced with the same (measured) greenhouse gas concentration until 2006
- All models forecast future for different greenhouse gas concentration scenarios

Based on IPCC: "KNMI klimaatscenario's voor Nederland" (2014, update 2021):



KNMI14 scenarios	Reference 1981-2010	GL 2036-2065	GH 2036-2065	WL 2036-2065	WH 2036-2065
Average wind speed winter	6.9 m/s	-1.1 %	+0.5 %	-2.5 %	+0.9 %
Highest daily average wind speed winter	15 m/s	-3.0 %	-1.4 %	-3.0 %	0 %
Number of winter days with wind direction between Sand W	49	-1.4 %	+3.0 %	-1.7 %	+4.5 %
KNMI14 scenarios	Reference 1981-2010	GL 2071-2100	GH 2071-2100	WL 2071-2100	WH 2071-2100
Average wind speed winter	6.9 m/s	-2.0 %	+0.5 %	-2.5 %	+2.2 %
Highest daily average wind speed winter	15 m/s	-2.0 %	-0.9 %	-1.8 %	+2.0 %
Number of winter days with wind direction between Sand W	49	-1.6 %	+6.5 %	-6.5 %	+4.0 %

Changes in wind speed small, but natural variability wind and storm climate large.

In two (GH/WH) of the four climate scenarios winters with more westerly winds.

# Forecasts based on weather models



Up to minutes ahead: forecasts using LES (100m; 10sec)

Turning nacelle, pitching blades

Up to 48 hours ahead: forecasts using mesoscale model e.g. Harmonie (2.5 km; hourly) + ensembles

Match energy supply and demand. Energy trade.

Up to 72 (some parameters 240) hours ahead: forecasts using global model e.g. ECMWF (9 km; 6 hourly) + ensembles

Weather windows for maintenance and installation work

Up to 4 weeks ahead: extended or inter-seasonal forecasts (work in progress)

Weather windows for maintenance and installation work

Seasonal forecasts: not much skill in Europe

E.g. reliable forewarning cold calm winters

# Hindcasts based on weather models



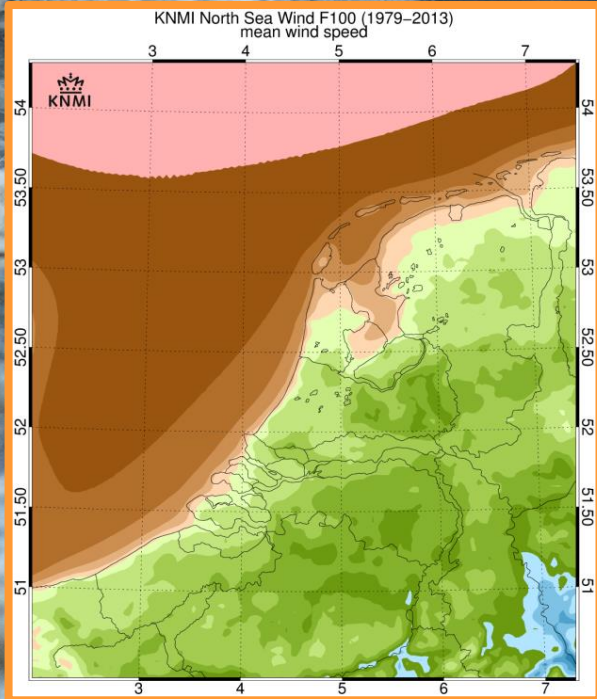
**Re-analysis** = 3D global information on meteorological parameters consistent with laws of physics and a lot of measurements (e.g. ERA-Interim 5 million/12 hrs):

Re-analysis	Period	Frequency	Horizontal grid-spacing	Vertical grid-spacing	Remark
ERA-interim	1979-now	6 hourly	80 km	60 levels up to about 80 km	
ERA5	1950-now (available 2010-2016)	hourly	31 km	137 levels up to about 80 km	+ 3 hourly uncertainty info (grid 62 km) + extra parameters including 100 m wind
MERRA-2	1980-now	6 hourly	50 km	72 levels up to about 80 km	
NCEP/NCAR	1948-now	6 hourly	209 km	28 levels	
...					

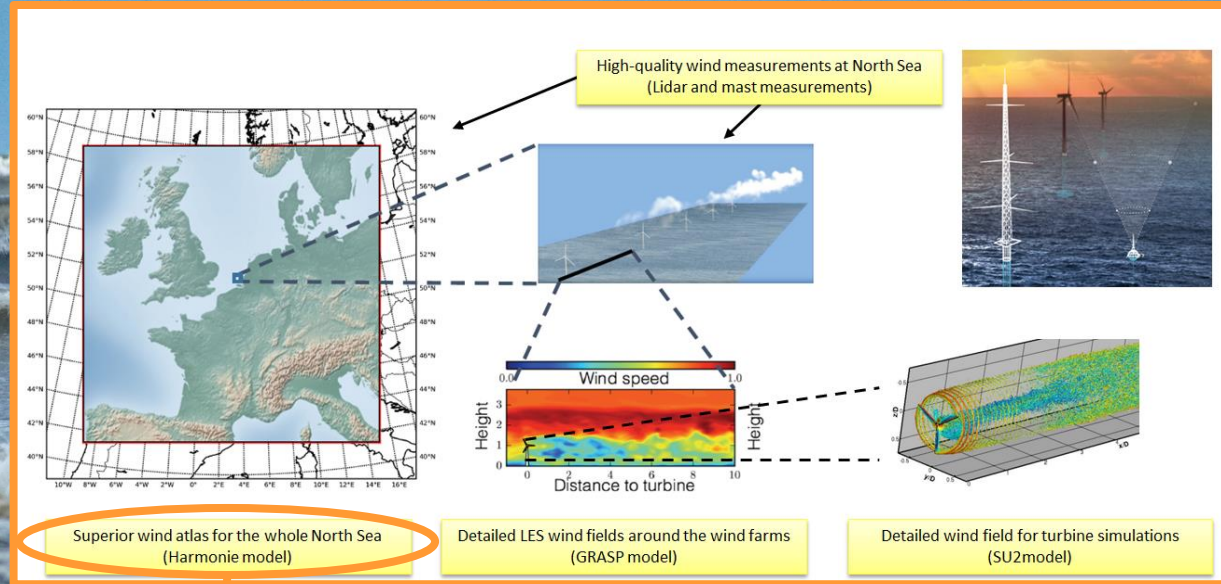
# Wind Atlas based on hindcasts



KNMI Noordzee Wind (**KNW**) Atlas: based on ERA-Interim downscaled with Harmonie Cy37 (wind climatology on a 2.5x2.5 km grid up to 200m)  
<http://projects.knmi.nl/knw/>

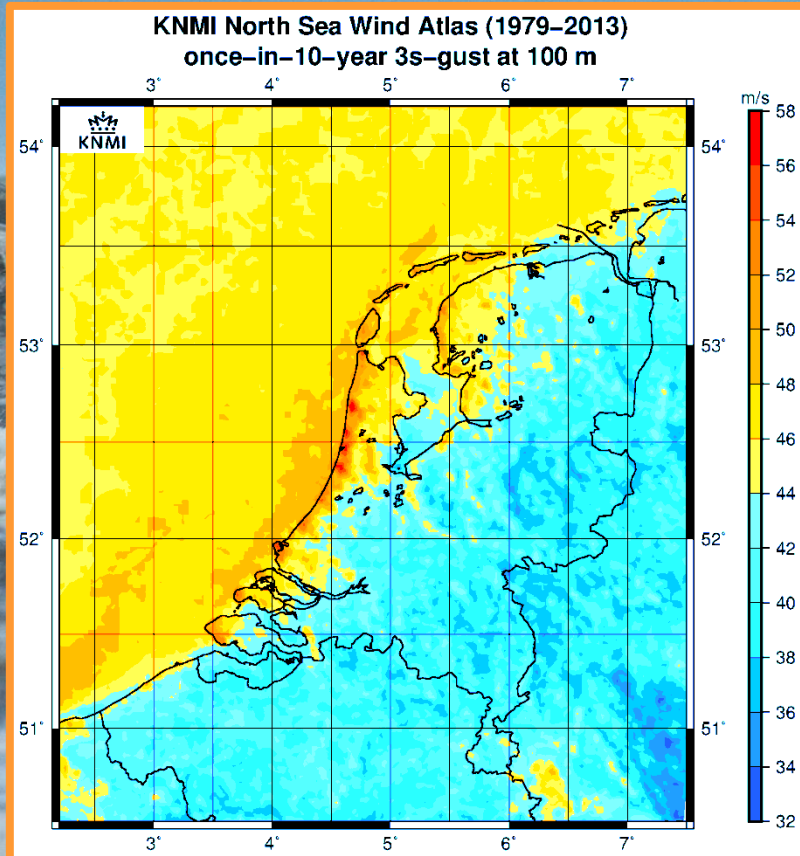


## Dutch Offshore Wind Atlas **DOWA** (ECN/Whiffle/KNMI)



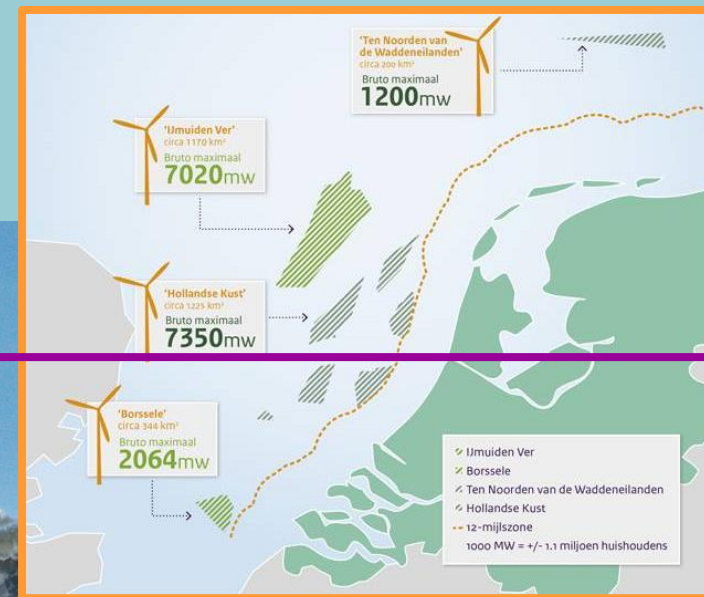
- New models (ERA5/Harmonie Cy40) to produce 10 year climatology (2008-2017) up to 600 m heights
- New method (harmonie + data-assimilation with satellite and aircraft measurements) to improve correlation at smaller time-scales (e.g. diurnal cycle)
- New output parameters that enable LES-downscaling

# Wind Atlas based on hindcasts



IAV 3.5-4%

IAV 4-4.5%



Use KNW-atlas e.g:

1. For wind resource assessment: reference wind speed in Measure Correlate Predict method (MCP)
2. To calculate production capacity
3. To estimate wake effects
4. To assess Inter Annual Variability
5. To derive wind gust climatology



# KNMI and the energy transition



# Thank you. Questions?

The switch to renewable energy is increasing the impact the weather has on our lives. KNMI plays an important role in the transition to a green economy by providing detailed measurements, forecasts, climate change scenarios and scientific research.

## Measurements

Accurate wind or solar radiation assessments make energy yields more predictable and business more profitable. **KNMI measures wind and radiation...**

...in the sky using weather balloons and aircraft

...at or near land/sea surface using automatic weather stations, Cabauw, radars and lidars

...from space with satellites

## Average wind speed

Cross section above the Netherlands (height not drawn to scale)



- Wind farms
- Areas assigned for wind farms

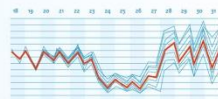


## Work planning

KNMI provides wind and wave information for determining weather windows for installation and maintenance work.

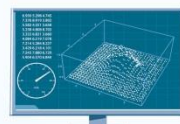
**Weather forecasts are also important for emerging technologies such as:**

- wave energy
- kite power
- tidal energy
- smart grids



## Optimal design

KNMI's expertise on weather extremes like extreme wind gusts, helps to establish the most lean design.



## Sound

Sound and vibration can also be measured, for example to determine the effect of pile driving at sea on porpoises.

The noise from wind turbines is calculated.

## Geothermal energy

KNMI measures vibrations caused by underground works for storage and transport of geothermal energy and waste heat.

Map of the Netherlands:

Annual solar radiation W/m<sup>2</sup>

114 116 118 120 122 124 126 128 130



## Exchanging data: win-win

KNMI can improve the basic weather forecasts with private sector measurements. The private sector benefits from these improvements.

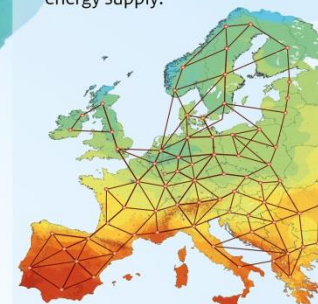
## Supply and demand

Changes in weather cause variations in supply of clean energy. Supply and demand will not always match.



Solutions for this problem are:

1. use of fuels
2. energy storage
3. a large **European electricity grid** which makes it easier to redistribute the available renewable energy supply.



KNMI contributes to security of supply by identifying cloudy and calm periods.

## Big data

By combining information on wind, sun, soil, nature, economy and population, the best areas for harvesting renewable energy can be determined.

