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

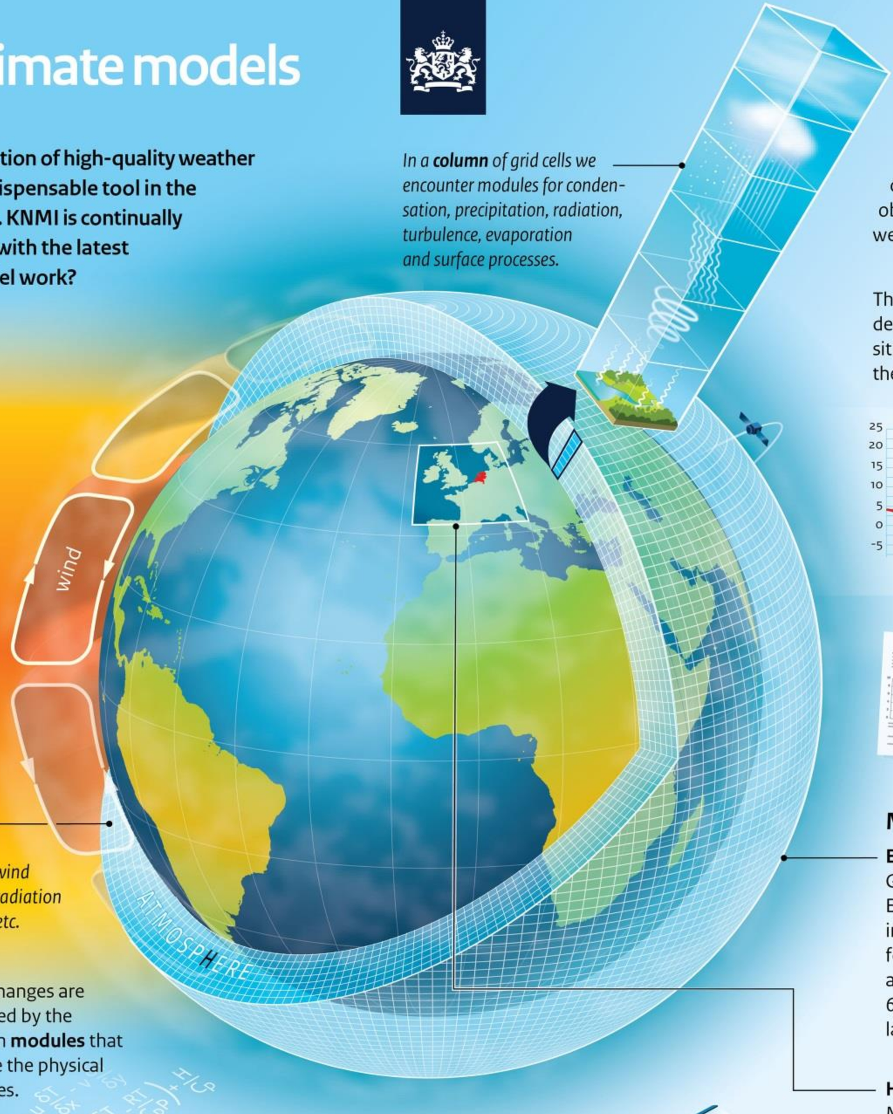
On the development and application of weather models for wind energy

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?



❶ 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**.

SUN

❷ 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.

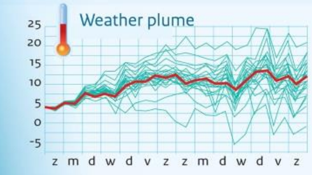
These changes are calculated by the model in **modules** that describe the physical processes.

Each calculation moves the model forward in 60 second steps:

❸ 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***

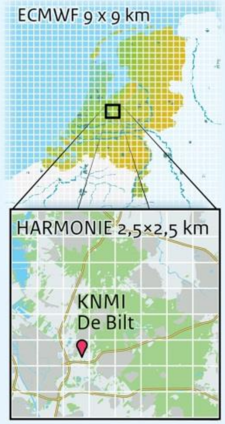
❹ Climate scenarios

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.

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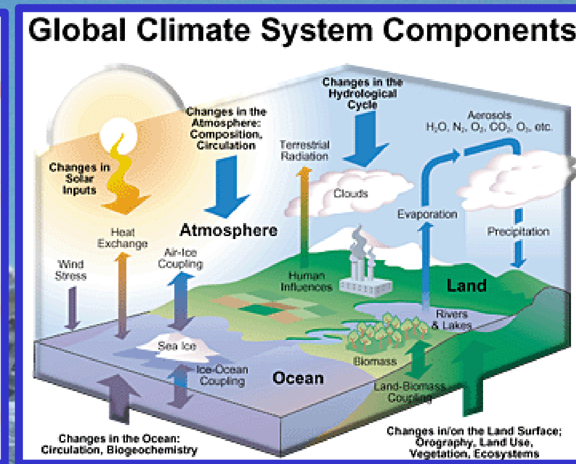
Differences weather and climate models



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).

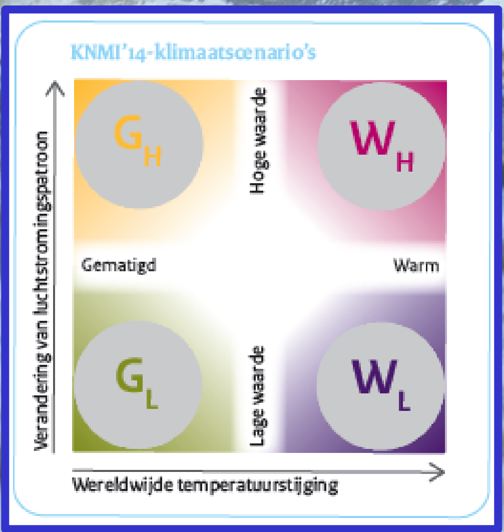
Data assimilation: measurements play key part in weather models, but not in climate models

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 S and 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 S and 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

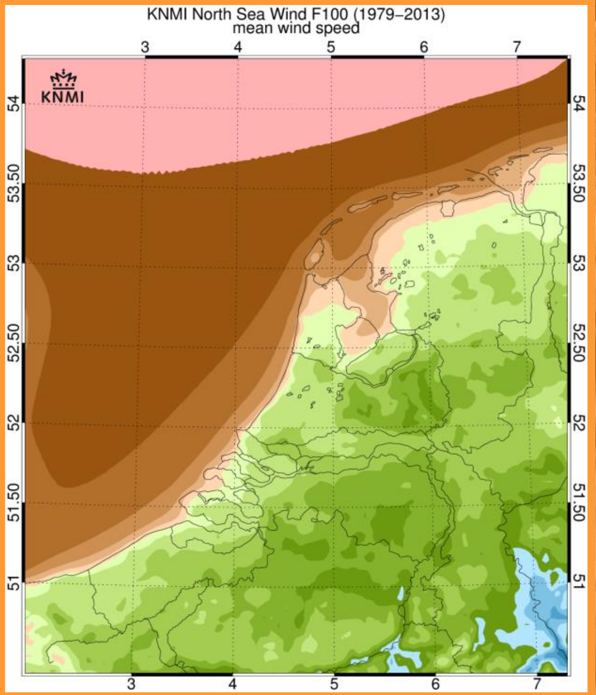
Hindcasts based on weather models

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):

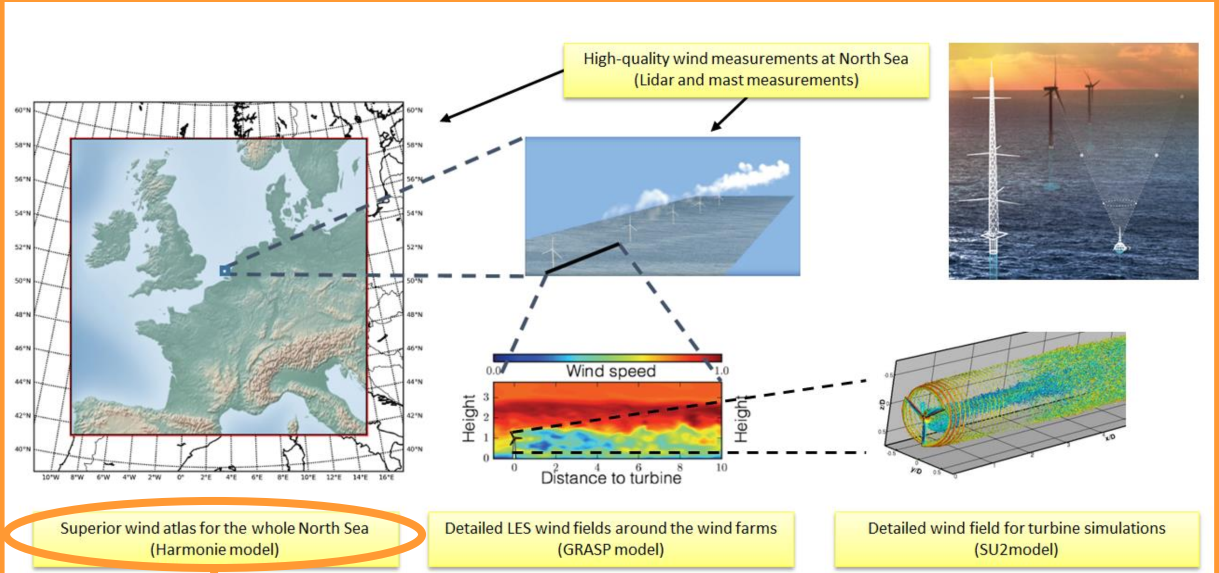
Re-analysis	Period	Frequency	Horizontal grid-spacing	Vertical grid-spacing	Remark
ERA-interim	1979-now	6 hourly	80 km	60 levels up to about 80 km	
ERA5	1950-now (available 2010-2016)	hourly	31 km	137 levels up to about 80 km	+ 3 hourly uncertainty info (grid 62 km) + extra parameters including 100 m 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/

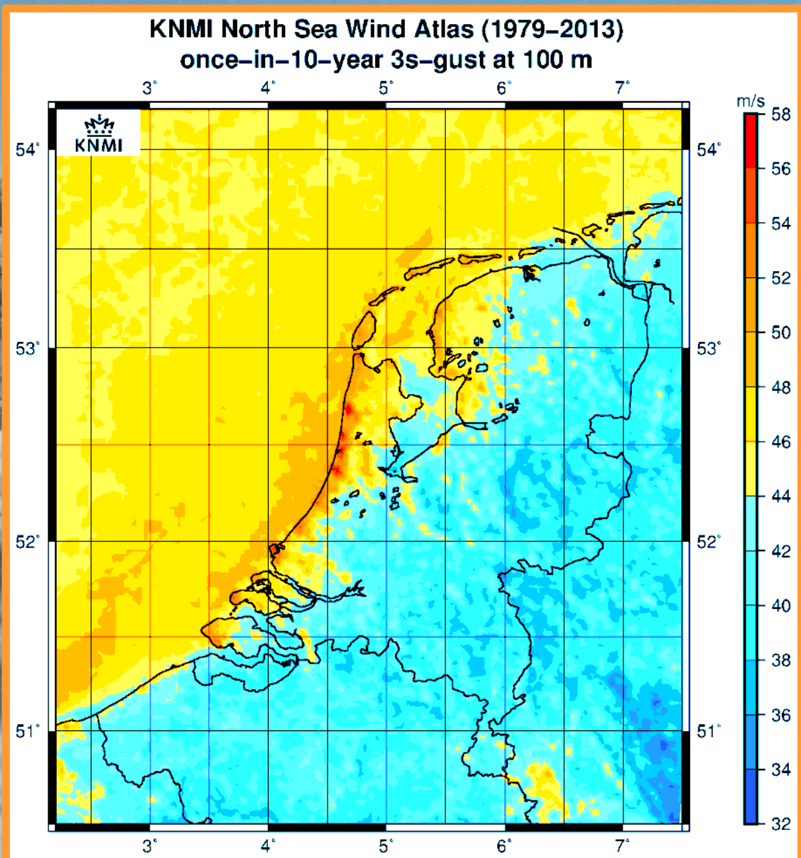


Dutch Offshore Wind Atlas **DOWA** (ECN/Whiffle/KNMI)



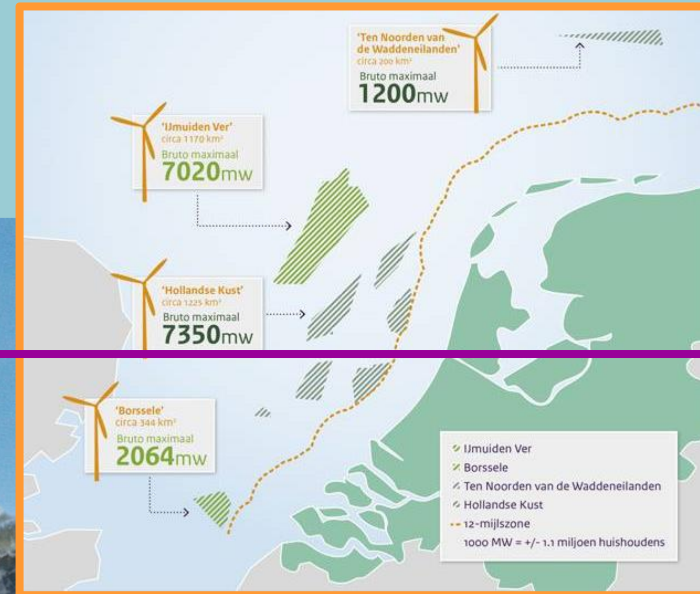
- New models (ERA5/Harmonie Cy40) to produce 10 year climatology (2008-2017) up to 600 m heights
- New method (harmonie + data-assimilation with satellite and aircraft measurements) to improve correlation at smaller time-scales (e.g. diurnal cycle)
- New output parameters that enable LES-downscaling

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

Thank you. Questions?