



Koninklijk Meteorologisch Instituut

Institut Royal Météorologique

Königliches Meteorologisches
Institut

Royal Meteorological Institute

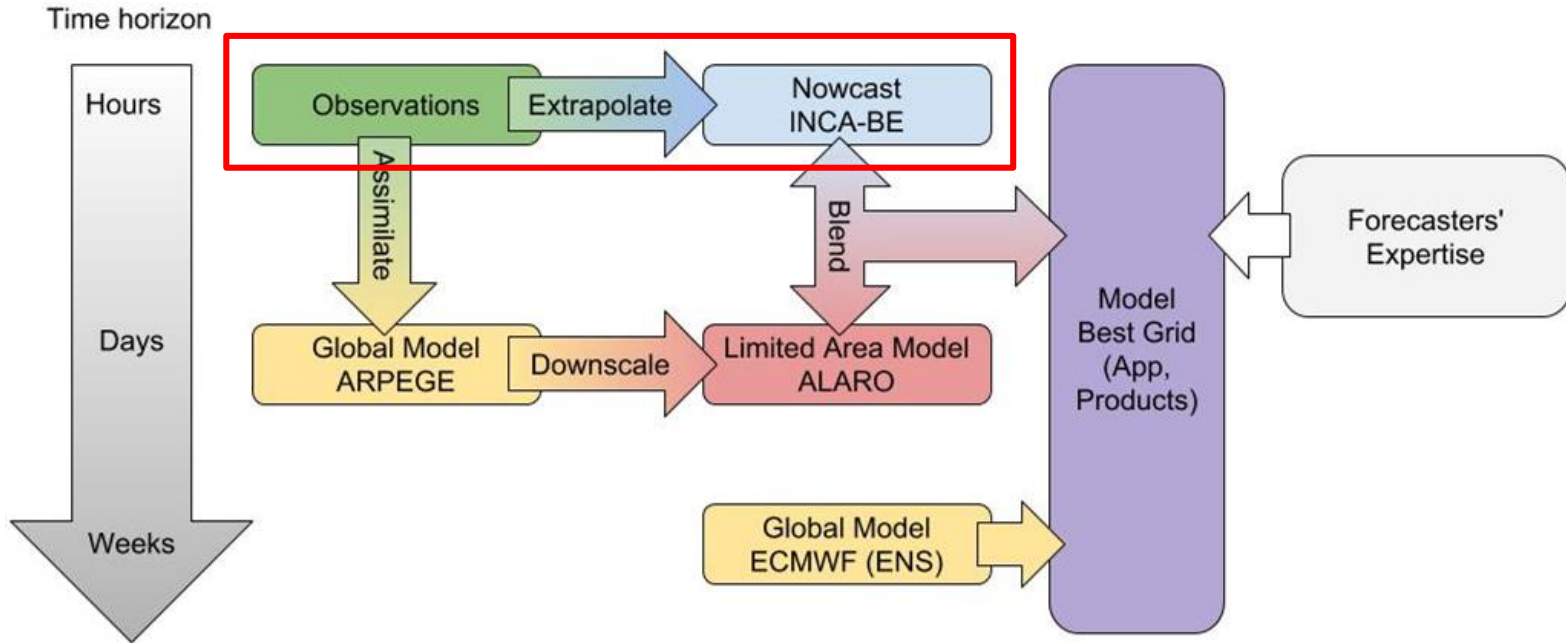
The Seamless Prediction Programme at the Royal Meteorological Institute of Belgium

Maarten Reyniers, Michiel Van Ginderachter, Lesley De Cruz,
and many others

EUMETSAT Integrated nowcasting workshop, 23-25 Jan 2024, Darmstadt, DE

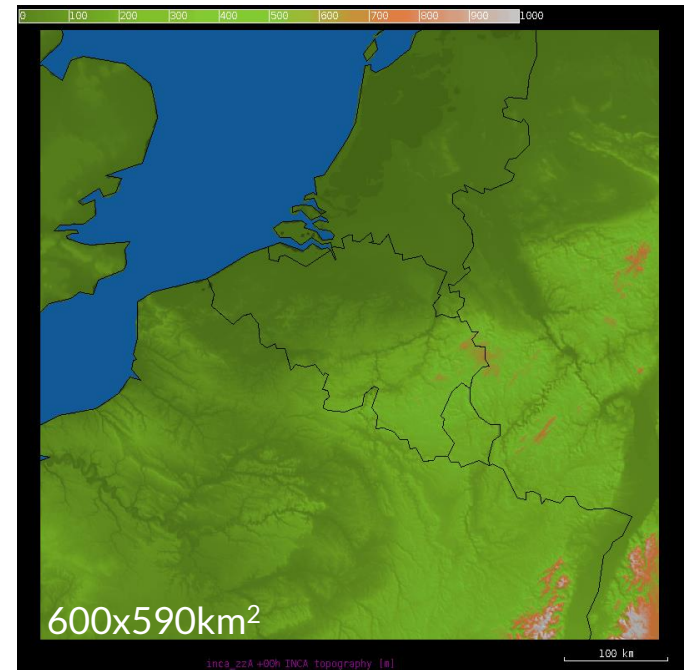
Existing RMI forecasting systems

Existing system: a treasure of forecast products

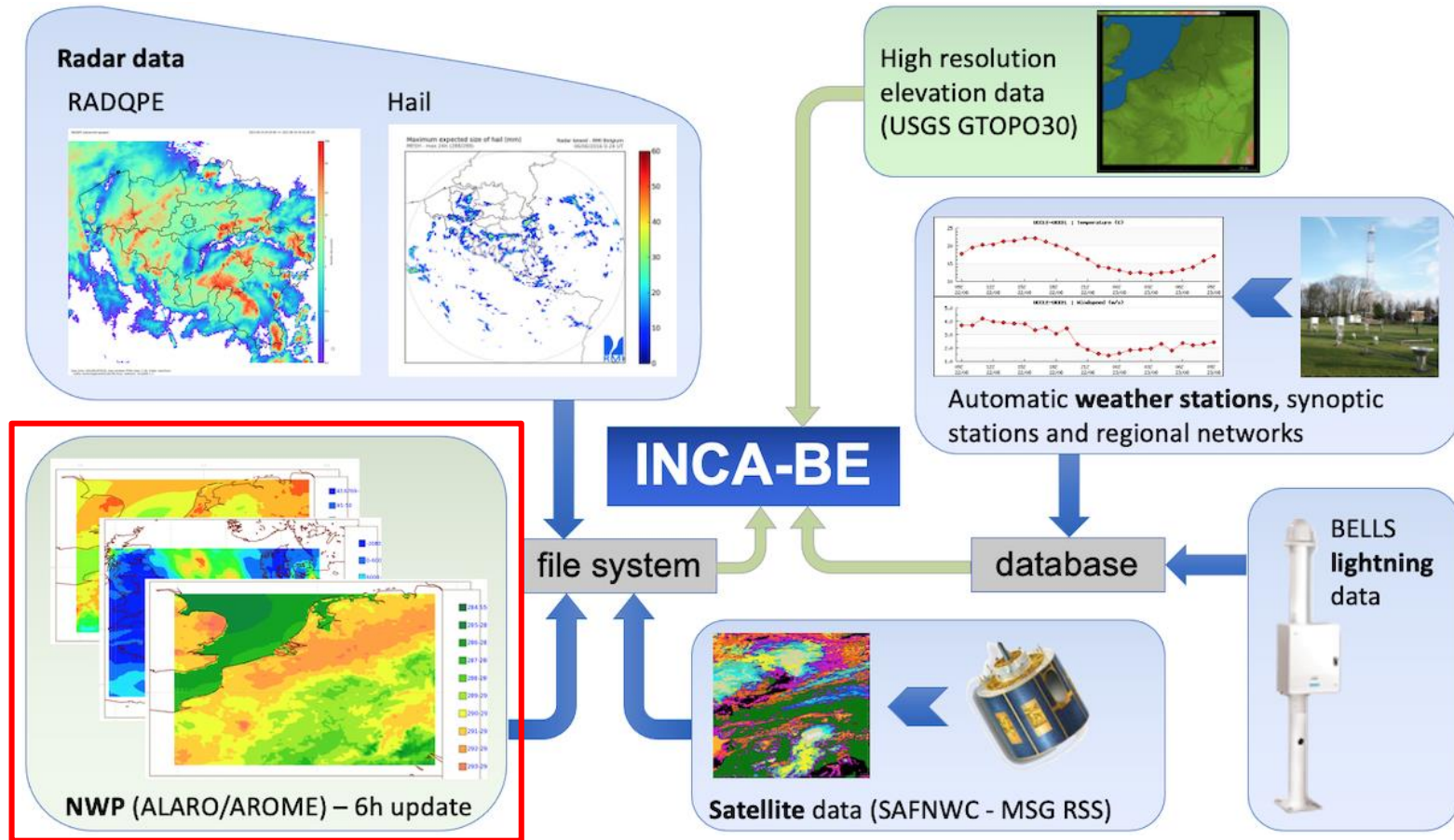


Operational nowcasting: INCA-BE

- INCA = Integrated Nowcasting through Comprehensive Analys
- **Nowcasting system** of several meteorological fields:
temperature, humidity, wind, cloudiness, precipitation, precipitation type
- **High resolution: 1 km**
- **Base code** from GeoSphere, Austria
- Implemented at RMI since 2012 and heavily **adapted/improved** since then
- **Literature:**
“The INCA-BE system: ten years of operational nowcasting and its applications at the national meteorological service of Belgium”
<https://zenodo.org/record/5798952>



Operational nowcasting: INCA-BE input

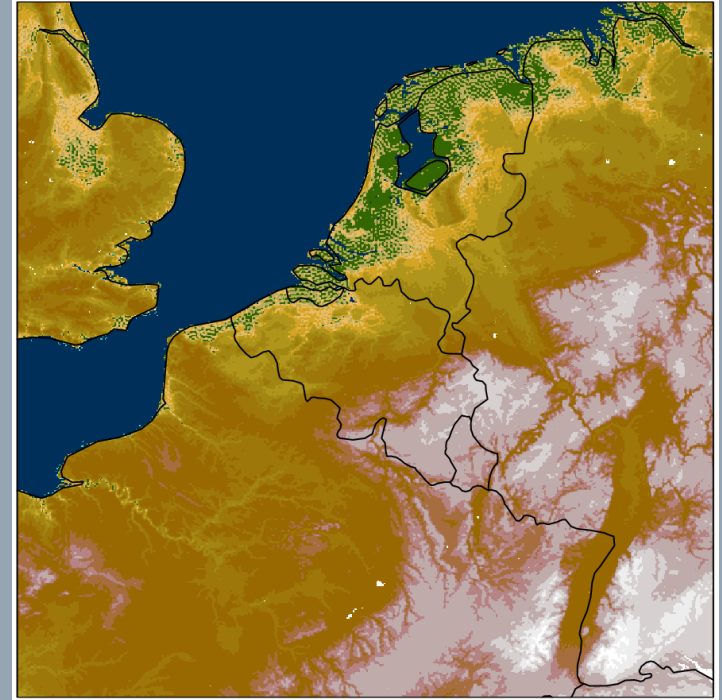


Two parallel INCA-BE versions

- INCA-ALARO: background model **ALARO**
- INCA-AROME: background model **AROME**

2 ACCORD MODELS (ALARO | AROME)

- coupled to ARPEGE (MF) | IFS (ECMWF)
- *in-house* models (= full control)
- 4 runs/day (0, 6, 12, 18 UTC)
- 3h data assimilation cycle (AROME)
- +48h forecast range
- 45s timestep
- 1.3 km horizontal resolution



- Dynamics part of the models are identical
(= equations of the atmosphere and how to solve them)
- Difference in the physics parameterisations
(= source and sinks in the equations of the atmosphere)

	ALARO	AROME
deep convection	scale-aware parameterisation	no parameterisation
microphysics	less sophisticated (water, ice, snow, rain)	sophisticated (+ graupel and hail)
surface interactions	less sophisticated	sophisticated
developments	contributions by RMI	no contributions by RMI
applicability	~ between 15 - 1 km	~ < 3 km

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FORTHCOMING DEVS	ALARO	AROME
deep convection	scale-aware parameterisation	no parameterisation
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surface interactions	sophisticated	sophisticated
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Operational nowcasting: INCA-BE output

Basic fields

forecast up to +12h, 1h step

Temperature, dewpoint, relative humidity, snowfall level, freezing level, wind, wind gust speed, wind chill, ground temperature

Precipitation fields

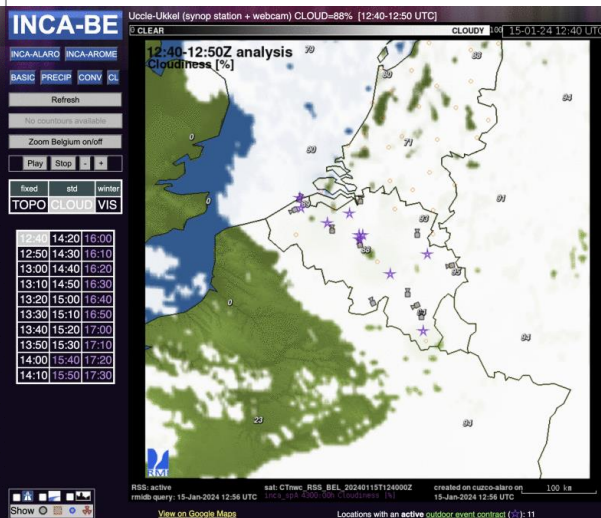
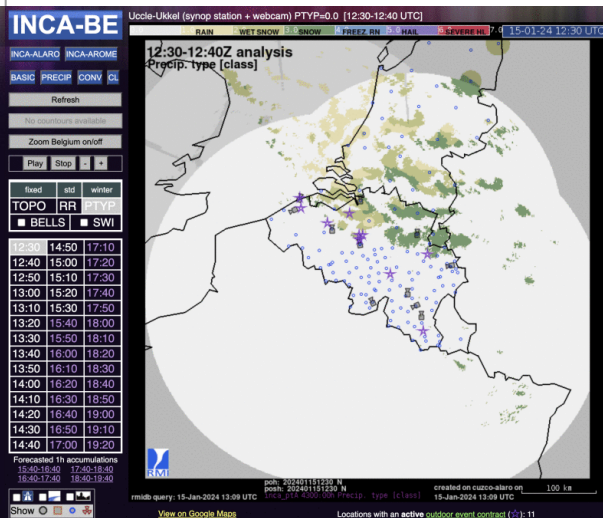
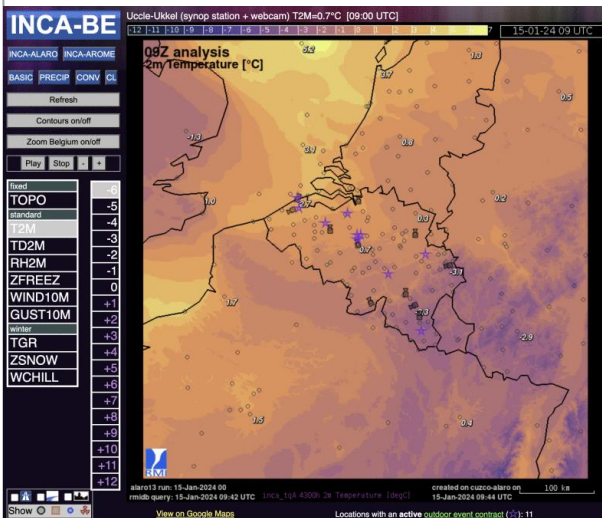
forecast up to +4h, 10' step

Precipitation, precipitation type, lightning, severe weather index

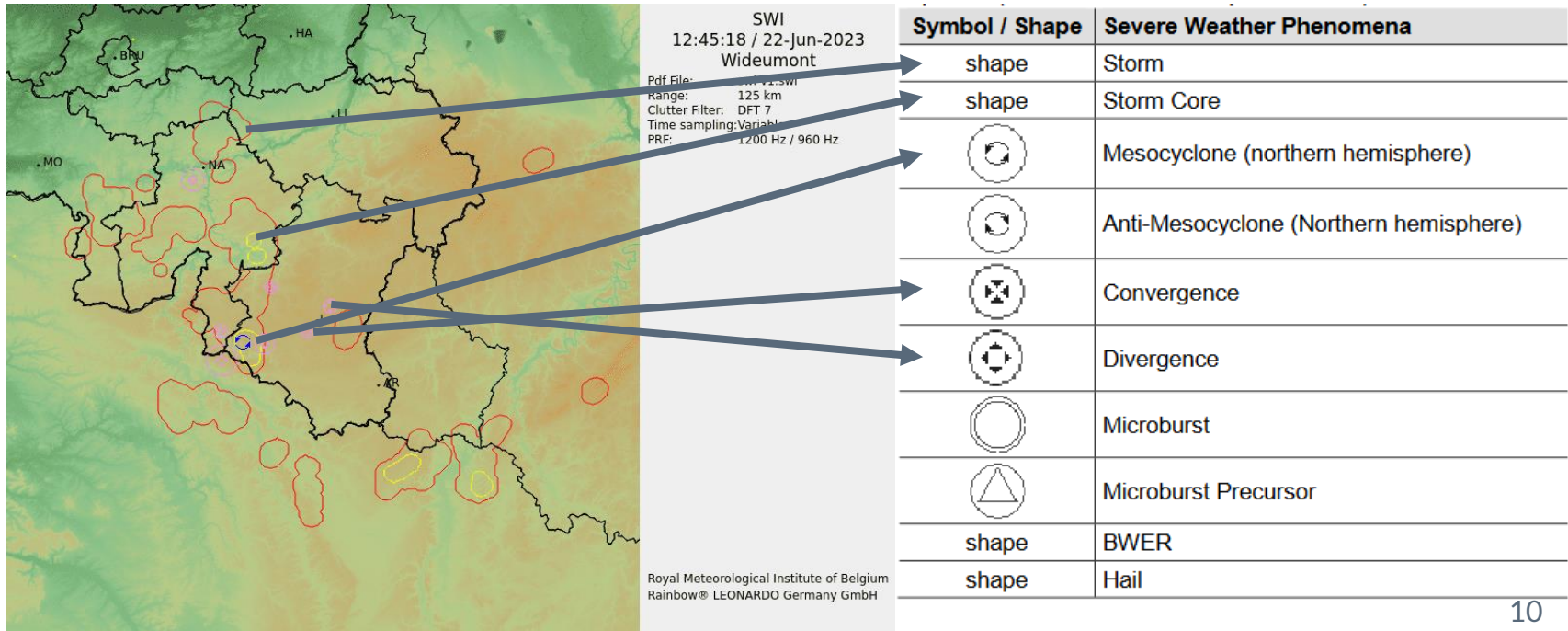
Cloudiness fields

forecast up to +2h, 10' step

Cloudiness, visibility



- New INCA-field “Severe Weather Index” (SWI)
- Starting point: radar-based severe weather contours and rotation detection (MC)



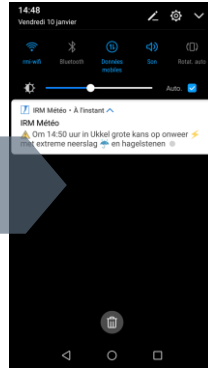
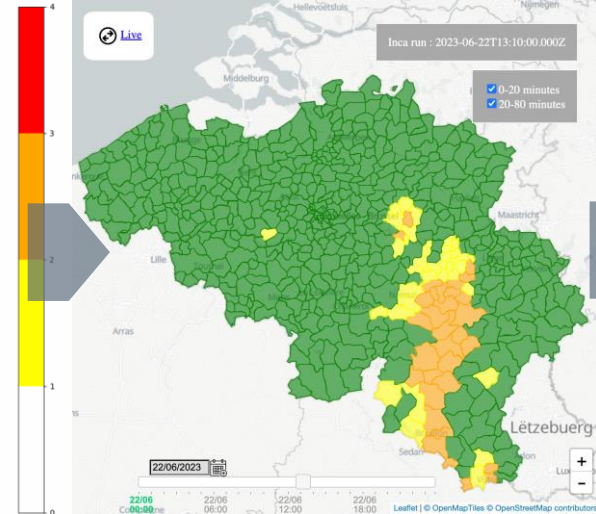
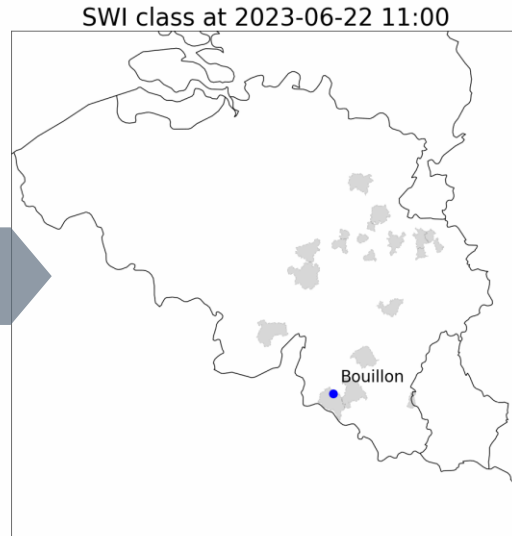
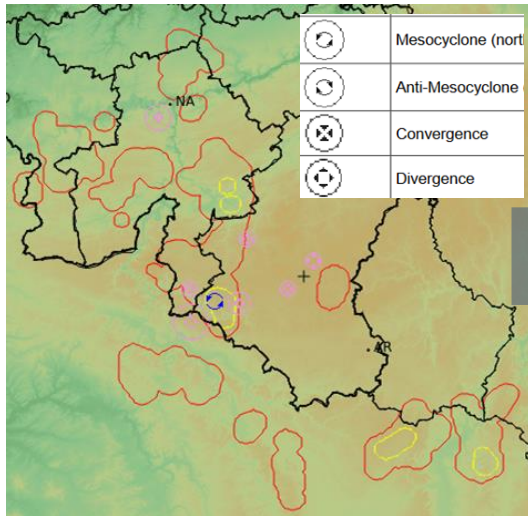
SWI = input for **Wind Gust notifications** in **RMI smartphone app** (2024)

Radar

INCA-BE

Micro-warnings

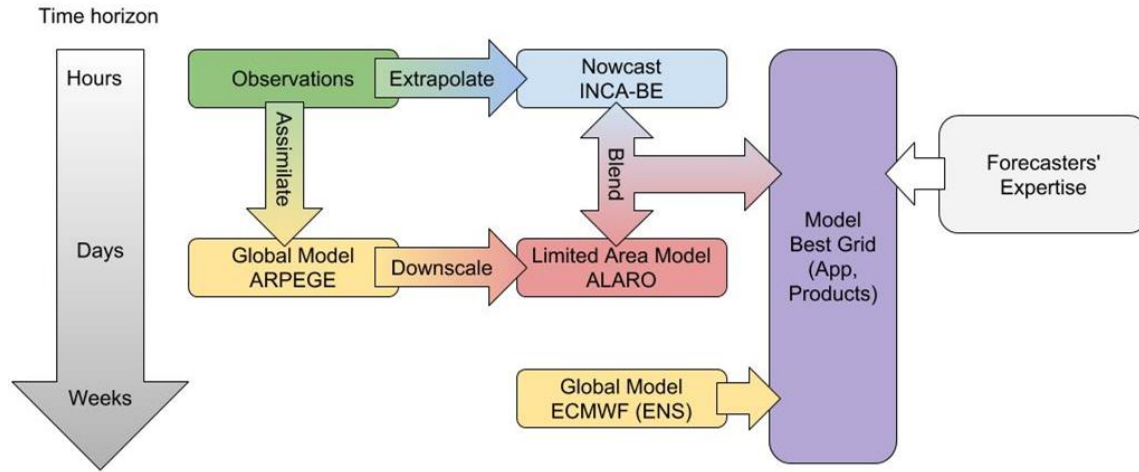
RMI app



2023

2024

Existing systems: a treasure of forecast products



Works well, but :

- **heterogeneous** in terms of time horizon, resolution, update frequency, ...
→ unclear which product is best for which lead time/application
- mostly **deterministic**
→ lacks reliable uncertainty information

Requirements of a next-generation forecasting system:

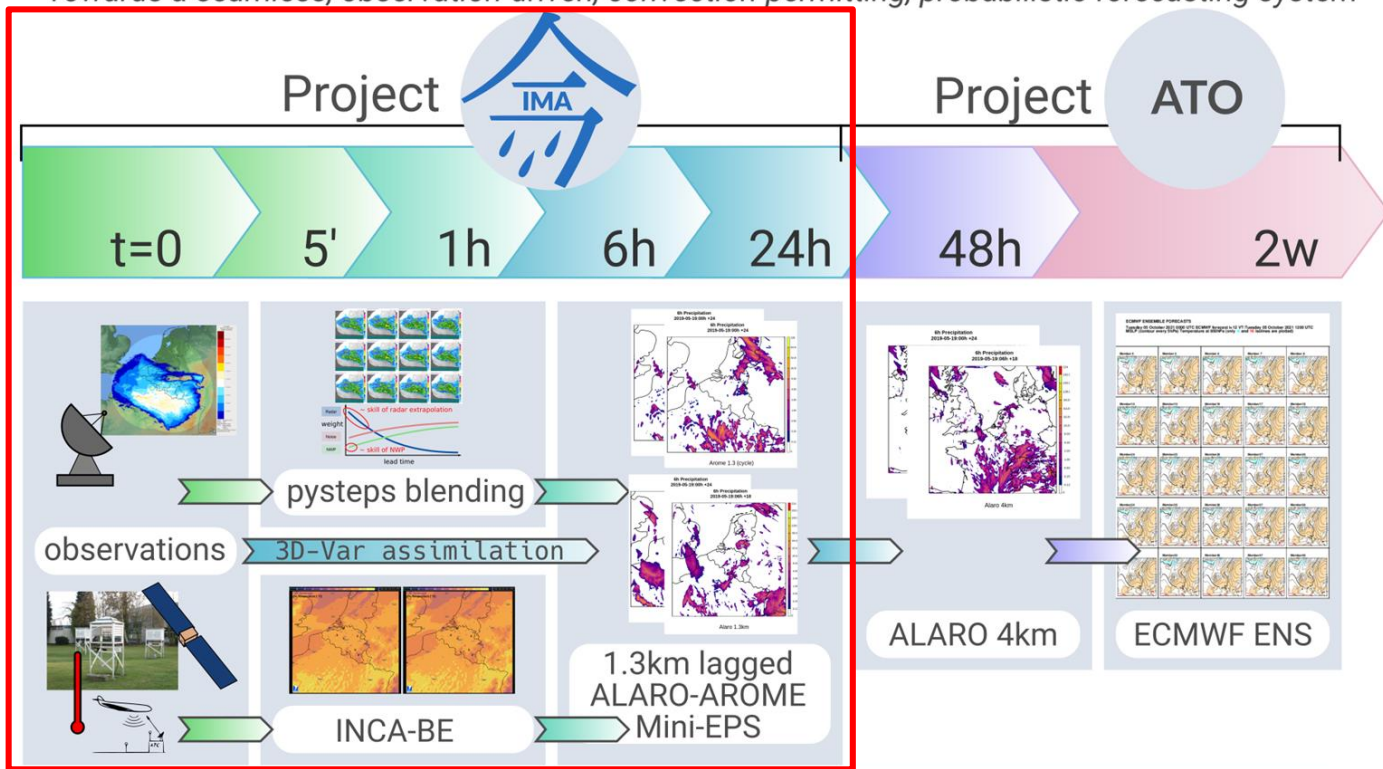
- **Ensemble** prediction system → uncertainty propagation
- **High** spatial and temporal **resolution**
- **Observation-driven** and rapidly updating (nowcasting)
- Based on state-of-the-art **numerical weather prediction** models
- **Seamlessly** combining available forecasts to **maximize skill** at all times
- **Robust** and **user-oriented**

→ Creation of the RMI's transversal **Seamless Prediction Programme**



Seamless Prediction Programme

Towards a seamless, observation-driven, convection-permitting, probabilistic forecasting system



communication



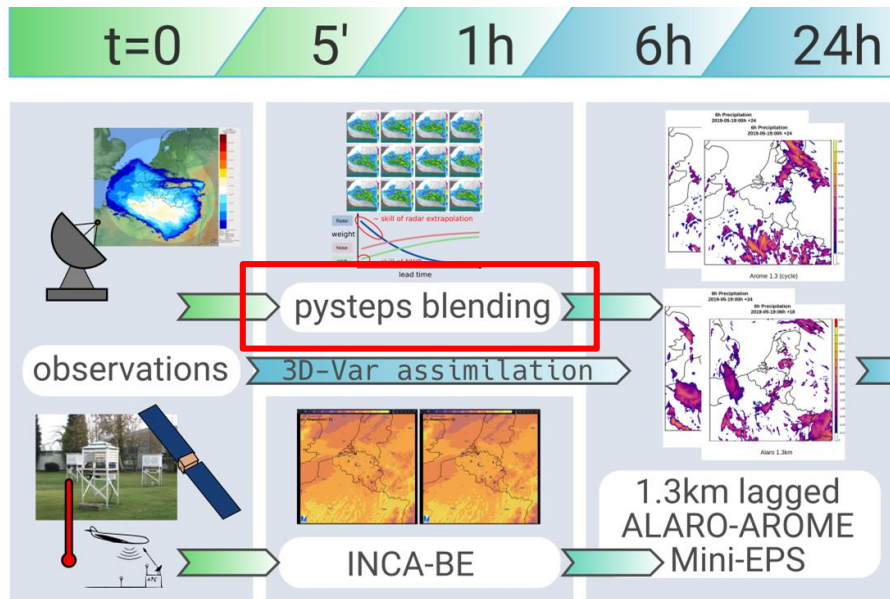
quality assurance



availability

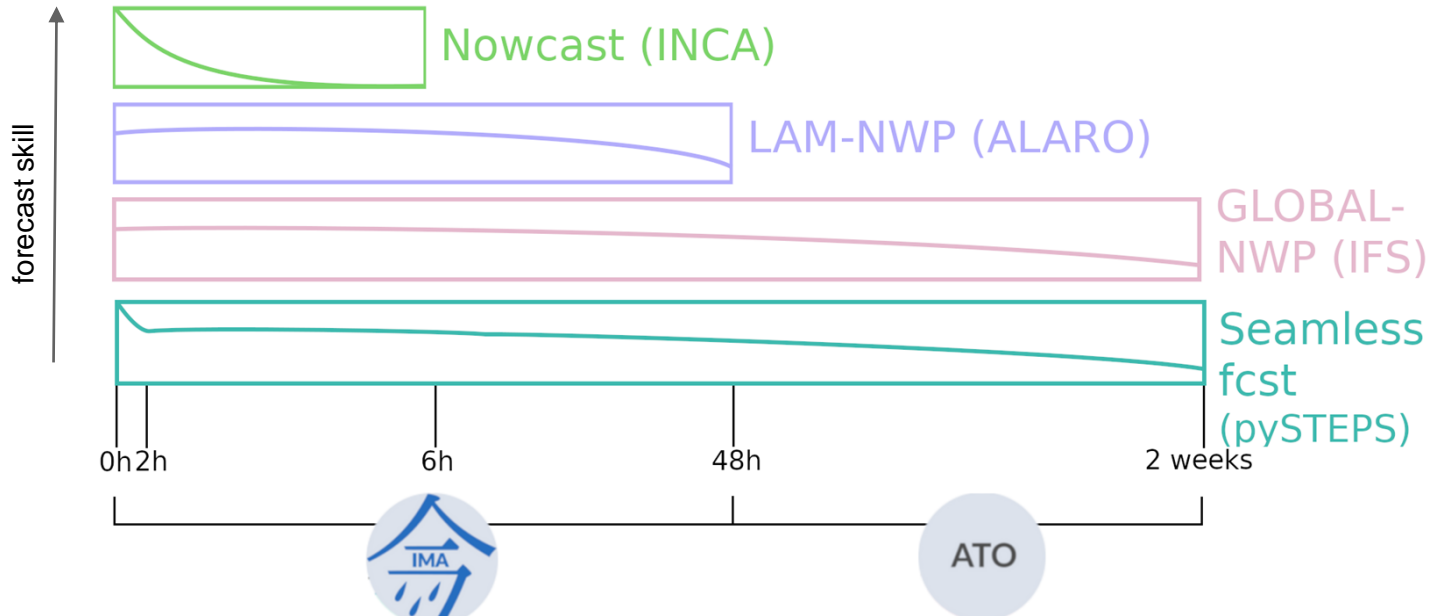
USER-ORIENTED

Short-term Seamless Probabilistic Prediction: Project IMA



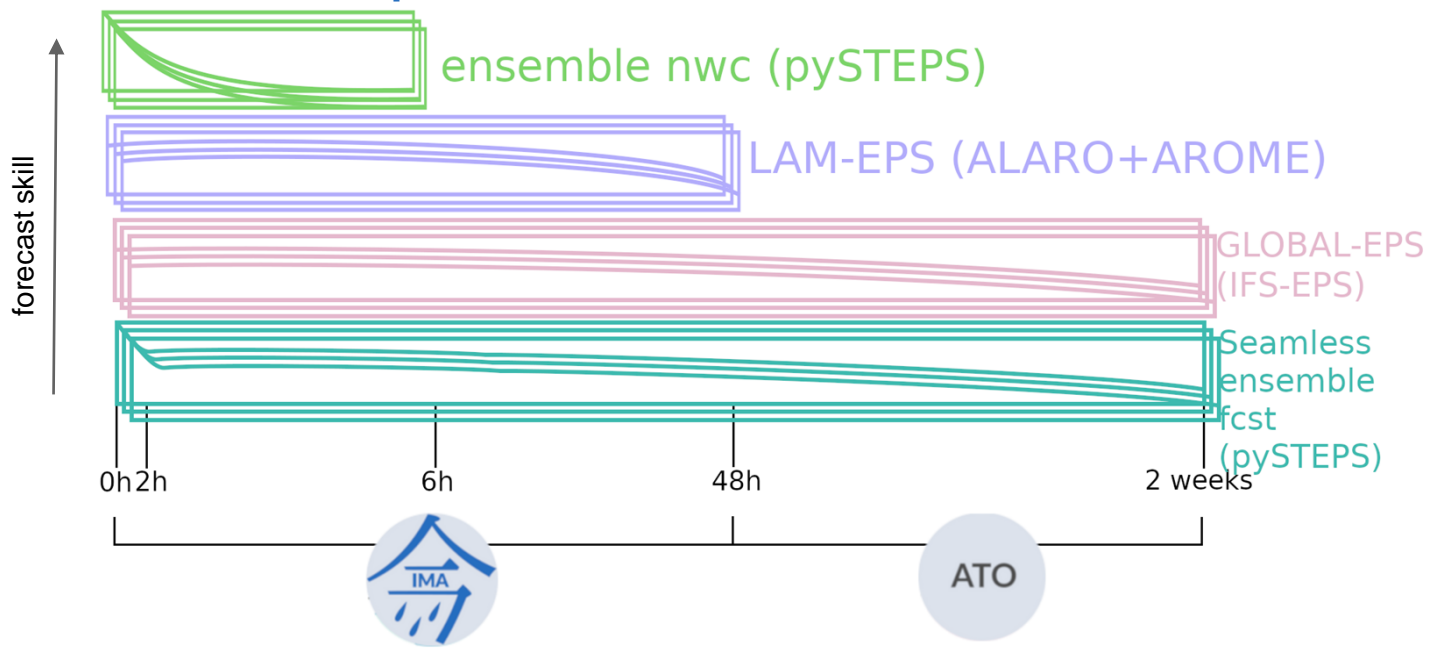
Seamless forecast:

forecast without discontinuities, using an **optimal combination** of all information sources



Seamless forecast:

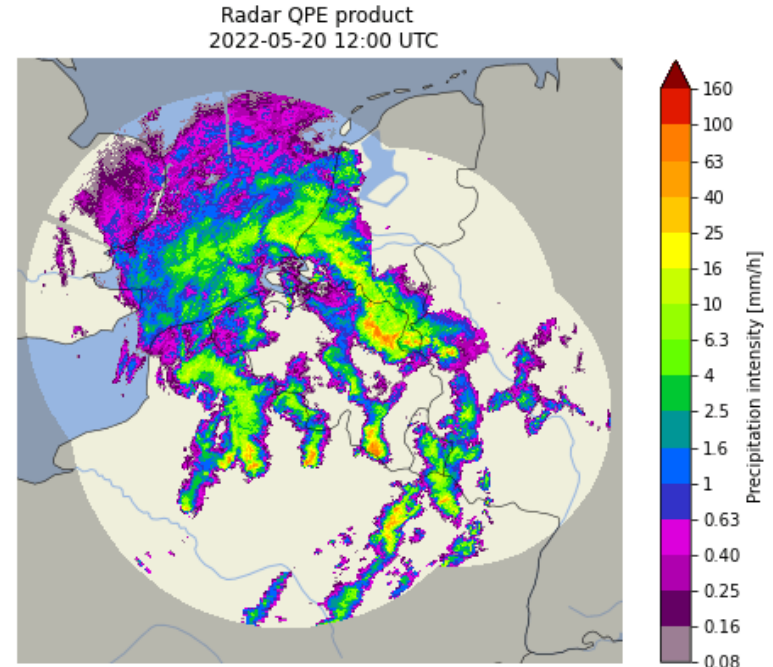
probabilistic forecast without discontinuities, using an optimal combination of all information sources



Nowcasting and blending in pySTEPS

Rainfall patterns show scaling behaviour:

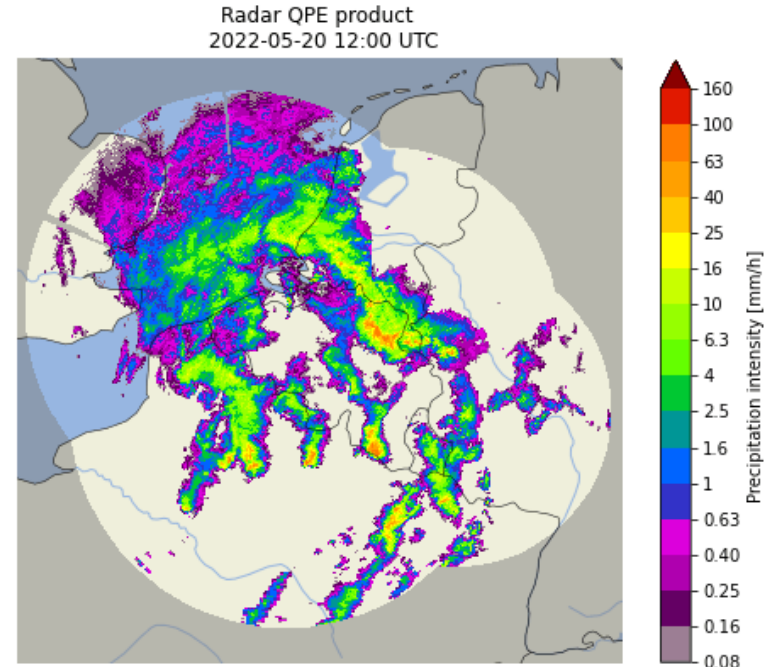
- rain fields are not organized as a collection of cells but are a **continuum of structures** over a broad range of scales (~ 200 km - 100m)
- each scale has a characteristic lifetime (limits predictability)



Start from radar image/product

1. Derive **advection vectors**
2. **Decomposition** into different scales (cascade)
3. **Lagrangian evolution** of the rainfield and **noise generation**
4. **Blending** with **NWP forecast** and **noise**

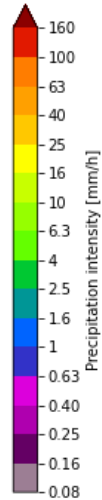
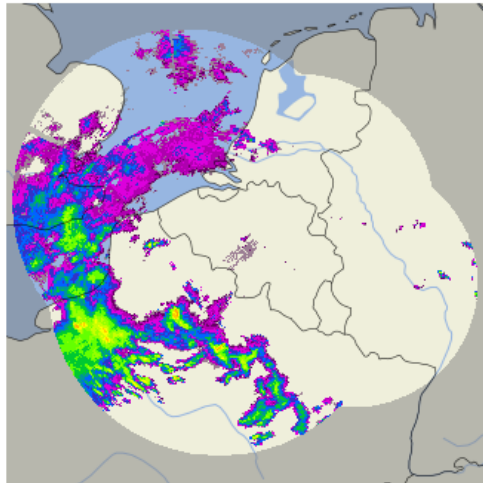
Original concept by Seed, 2003, Journal of Applied Meteorology, 42, 381



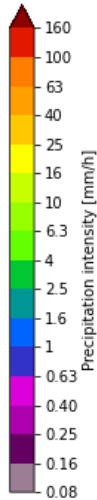
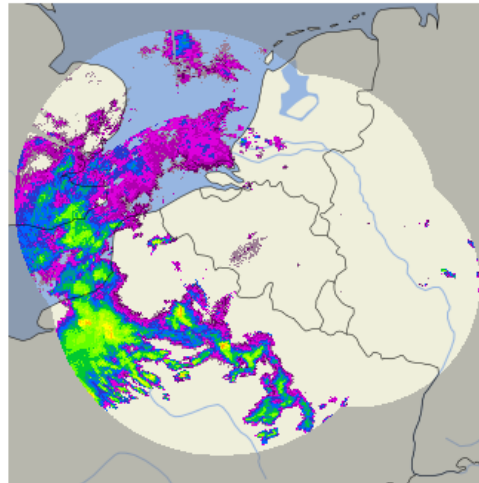
(1) Derive advection vectors

Using optical flow algorithms (Lucas-Kanade) on sequence of radar images/products

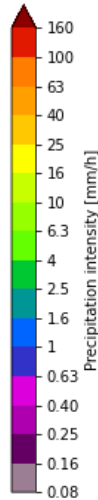
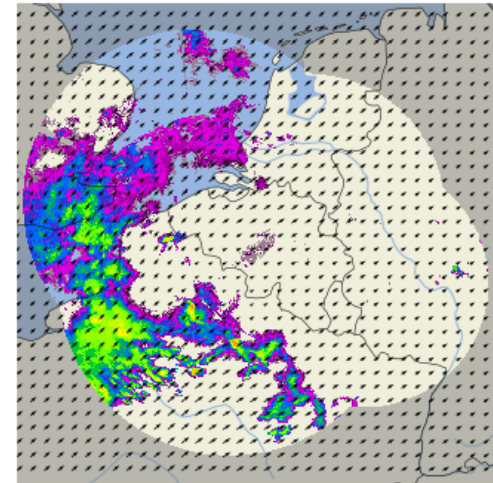
Radar QPE product
2022-05-20 07:50 UTC



Radar QPE product
2022-05-20 07:55 UTC



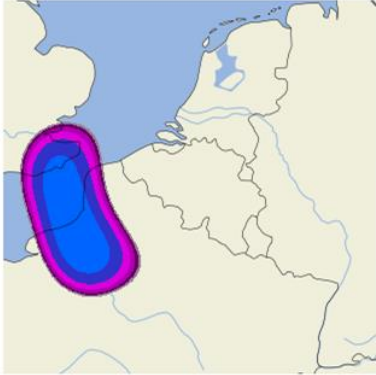
Radar QPE product
2022-05-20 08:00 UTC



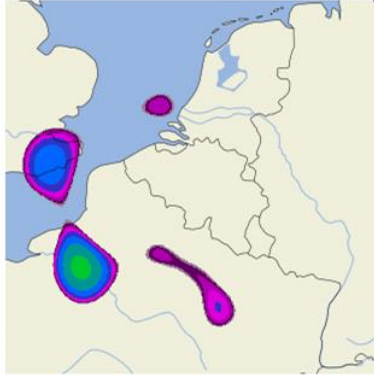
(2) Decomposition into “cascade”

Ra
Fo
Ga
Tr

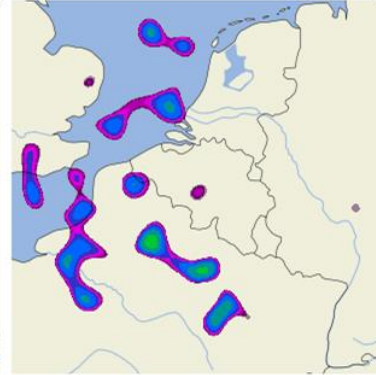
Cascade level 1
2022-05-20 08:00 UTC



Cascade level 2
2022-05-20 08:00 UTC



Cascade level 3
2022-05-20 08:00 UTC



Cascade level 4
2022-05-20 08:00 UTC



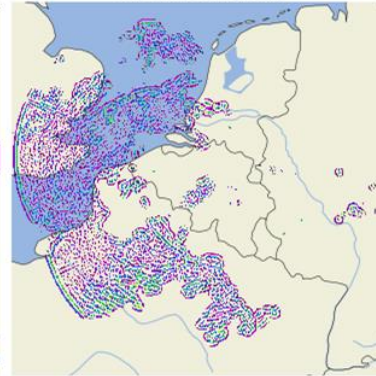
Cascade level 5
2022-05-20 08:00 UTC



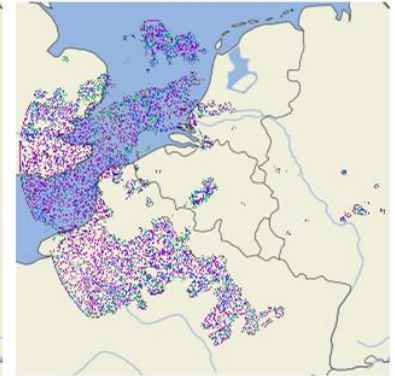
Cascade level 6
2022-05-20 08:00 UTC



Cascade level 7
2022-05-20 08:00 UTC



Cascade level 8
2022-05-20 08:00 UTC



(3) Lagrangian evolution & creation of noise

Evolution of each cascade level modelled with AR-2 process

$$Y_k(t + 2\Delta t) = \Phi_{k,1} Y_k(t + \Delta t) + \Phi_{k,2} Y_k(t)$$

Parameters (ϕ) are function of Lagrangian autocorrelation and regressed to climatological values

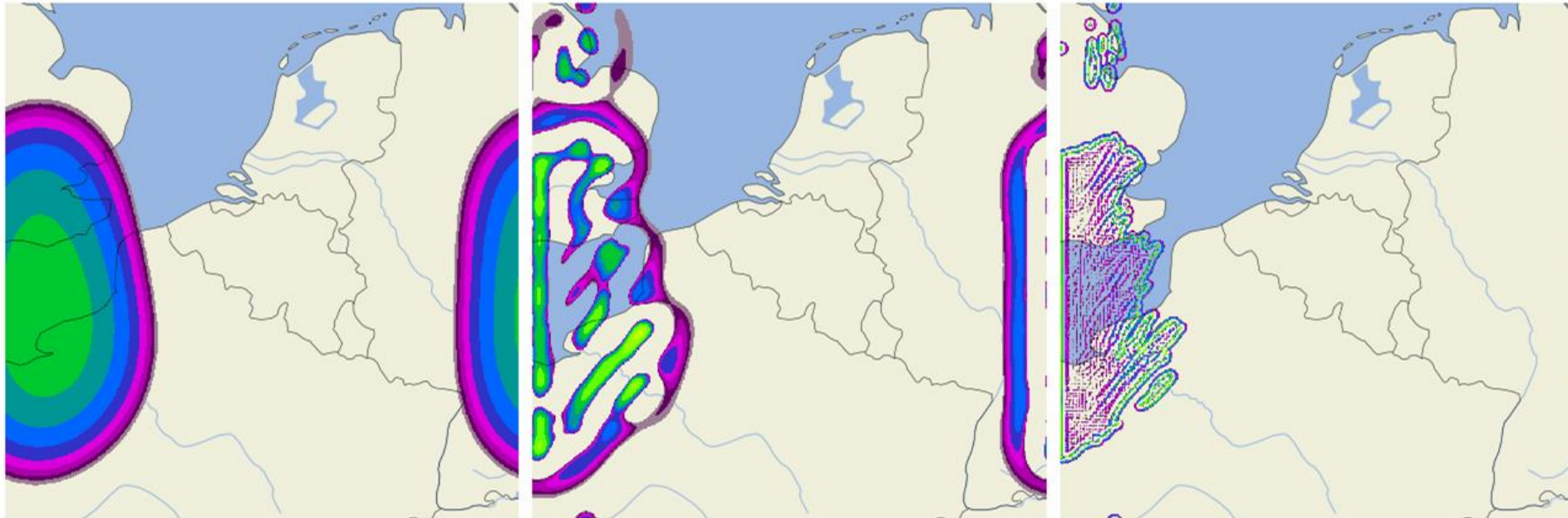
Create noise cascade with appropriate spatial correlation for each scale (Gaussian filtering) and evolve using same AR-2 model

(3) Lagrangian evolution & creation of noise

ALARO NWP cascade level 0
2022-05-20 08:00 UTC + 5 min

ALARO NWP cascade level 3
2022-05-20 08:00 UTC + 5 min

ALARO NWP cascade level 6
2022-05-20 08:00 UTC + 5 min



(4) Blending the cascades

Combining the EXTRAPOLATION, NOISE and NWP cascades

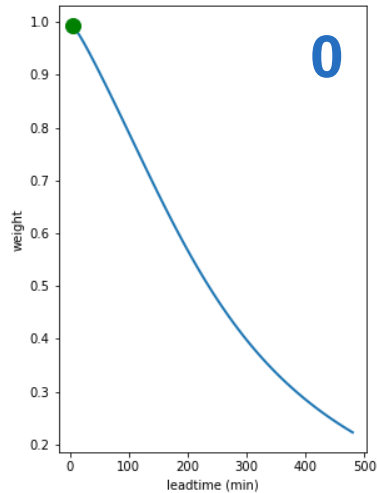
$$Y_k = \omega_k^e Y_k^e + \omega_k^n Y_k^n + \omega_k^m Y_k^m$$

Weights are depended on the skill of each component

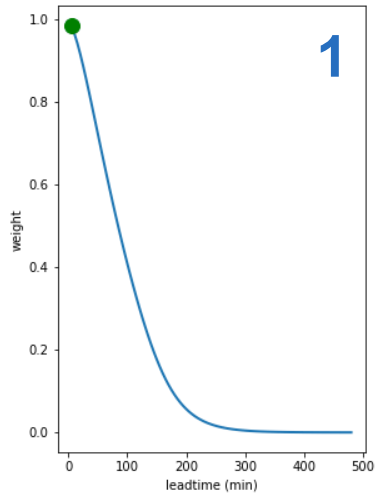
- Extrapolation: start from perfect skill and evolve according to AR-2 model
- NWP: start from skill w.r.t. most recent radar image and evolve towards skill of past days



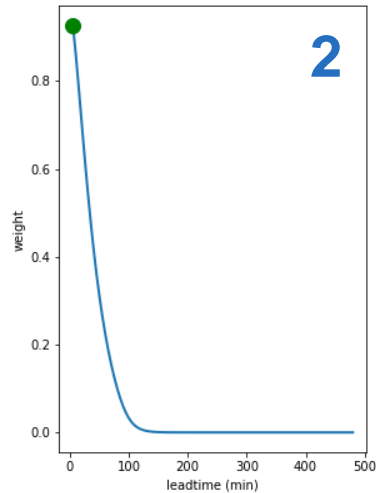
Weights of NWC cascade level 0
2022-05-20 08:00 + 5 min



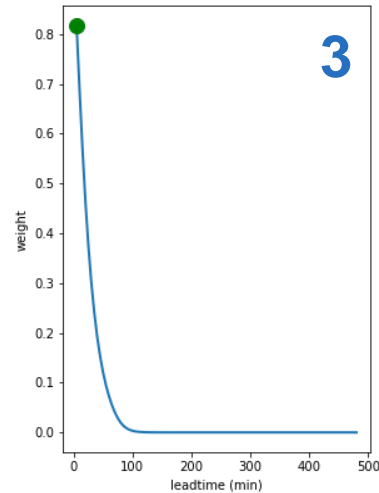
Weights of NWC cascade level 1
2022-05-20 08:00 + 5 min



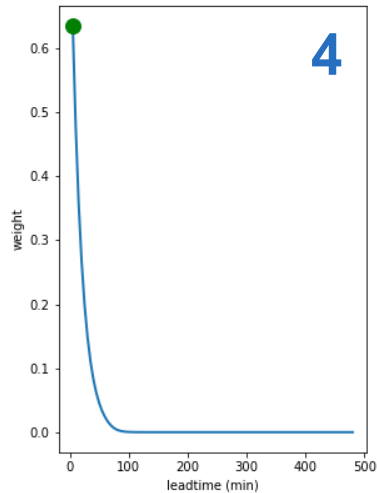
Weights of NWC cascade level 2
2022-05-20 08:00 + 5 min



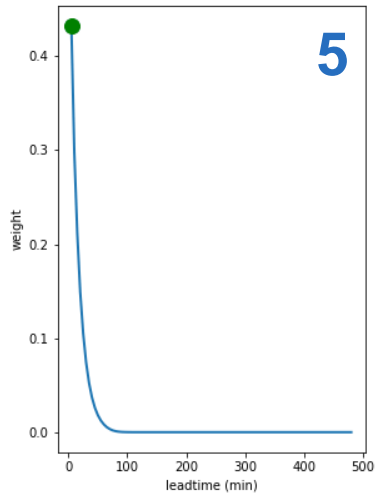
Weights of NWC cascade level 3
2022-05-20 08:00 + 5 min



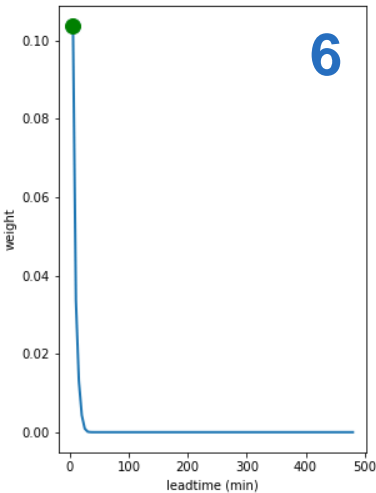
Weights of NWC cascade level 4
2022-05-20 08:00 + 5 min



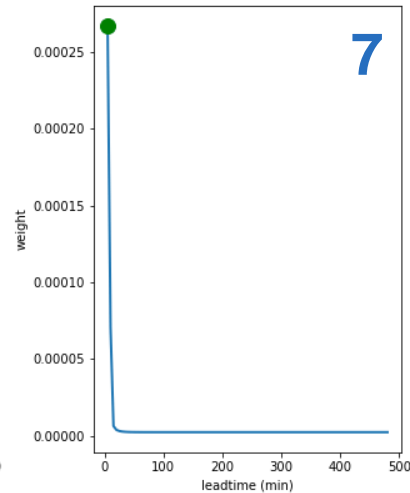
Weights of NWC cascade level 5
2022-05-20 08:00 + 5 min



Weights of NWC cascade level 6
2022-05-20 08:00 + 5 min

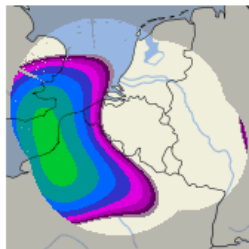


Weights of NWC cascade level 7
2022-05-20 08:00 + 5 min

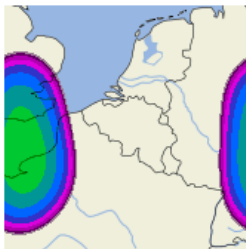


0

NWC cascade level 0
2022-05-20 08:00 UTC + 5 min



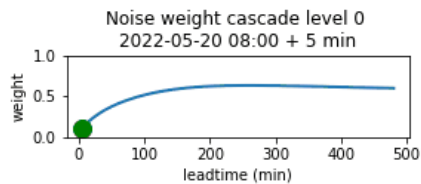
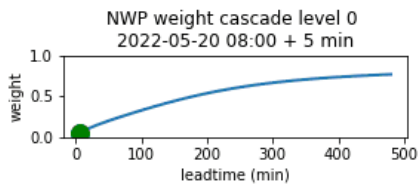
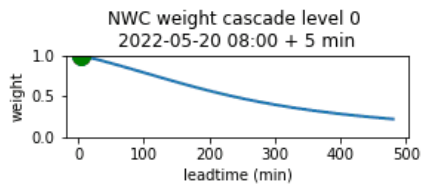
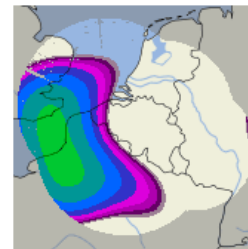
NWP cascade level 0
2022-05-20 00:00 UTC + 485 min



Noise cascade level 0
2022-05-20 08:00 UTC + 5 min

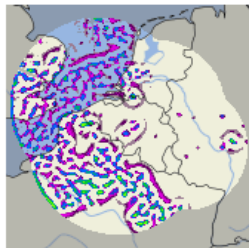


Blended cascade level 0
2022-05-20 08:00 UTC + 5 min

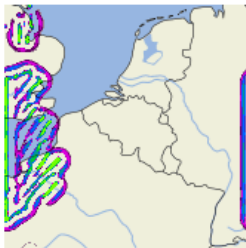


4

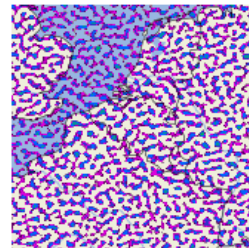
NWC cascade level 4
2022-05-20 08:00 UTC + 5 min



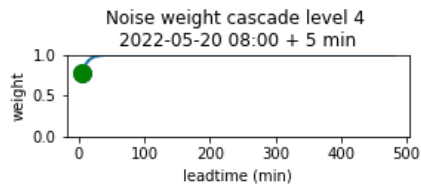
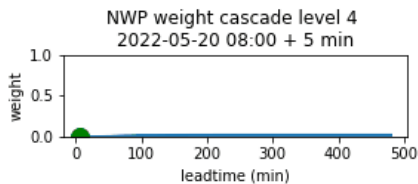
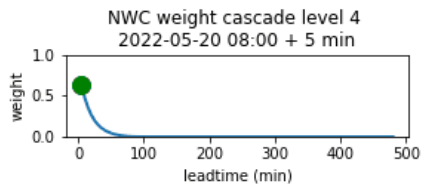
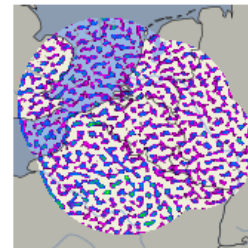
NWP cascade level 4
2022-05-20 00:00 UTC + 485 min

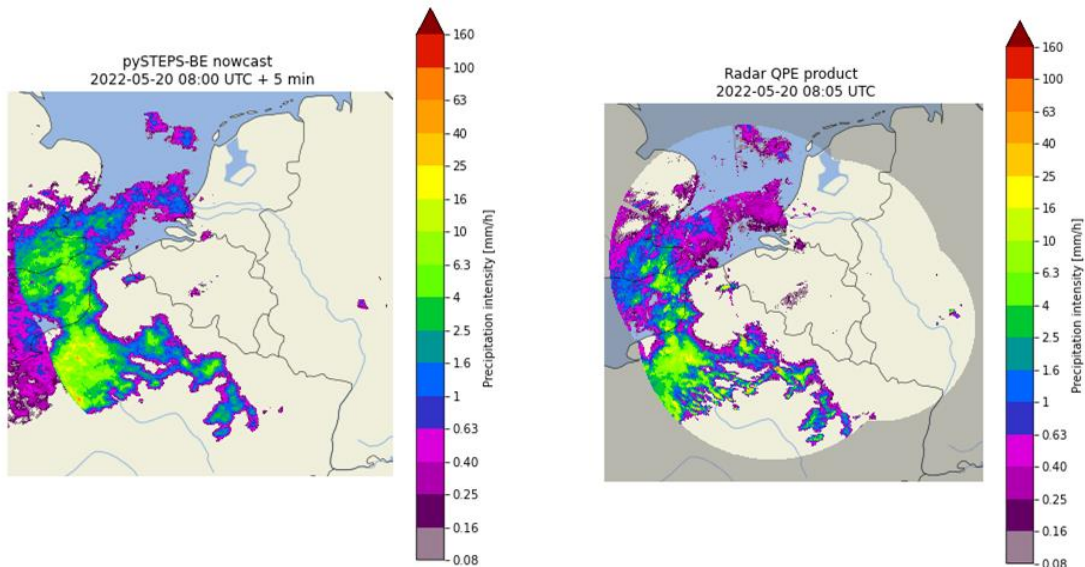


Noise cascade level 4
2022-05-20 08:00 UTC + 5 min



Blended cascade level 4
2022-05-20 08:00 UTC + 5 min





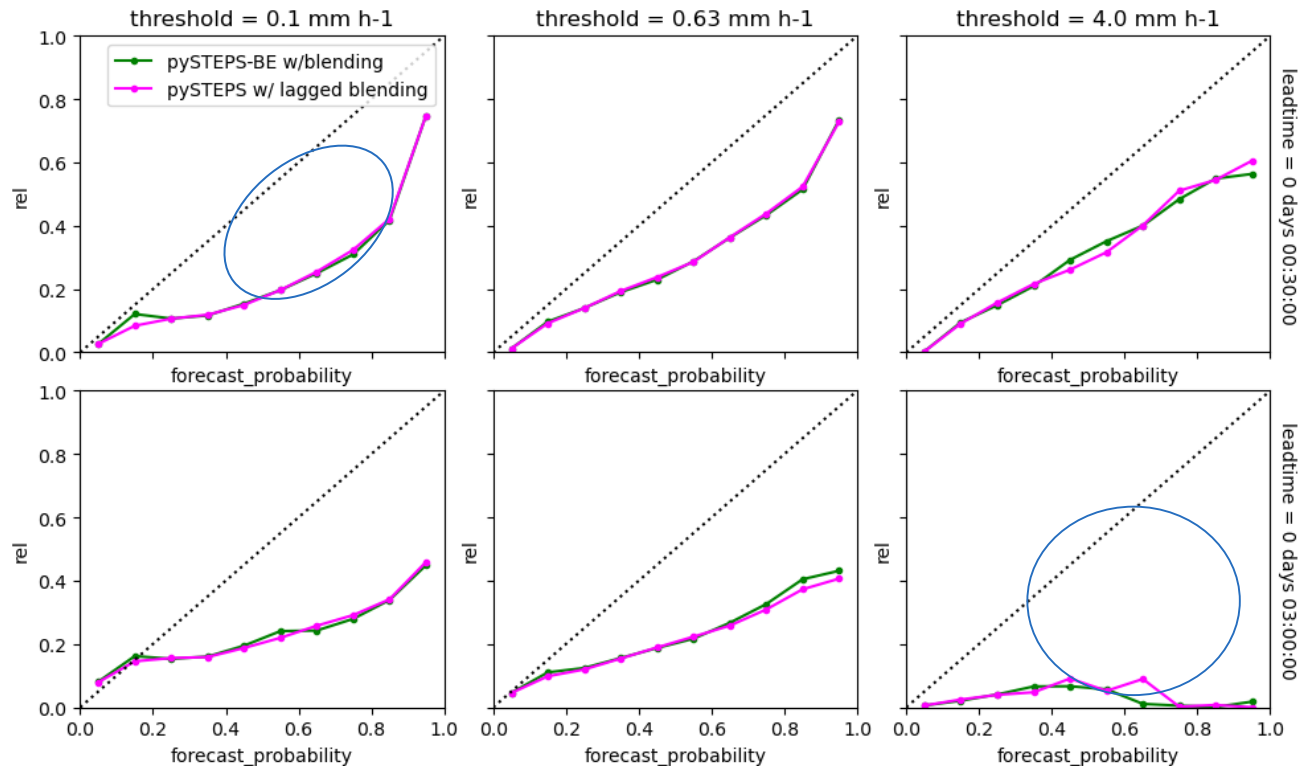
- pySTEPS-BE every 10' in container
 - range: + 6h
 - timestep: 5'
 - 48 members
- Runtime ~ 6'
- Output: netCDF ~ 2 GB

Quality indicators tailored to probabilistic forecasts:

Reliability diagrams

Fractional Skill Score

Skillful Spatial Scale

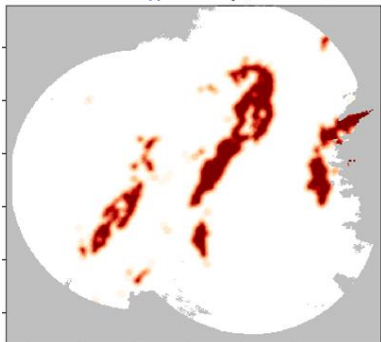




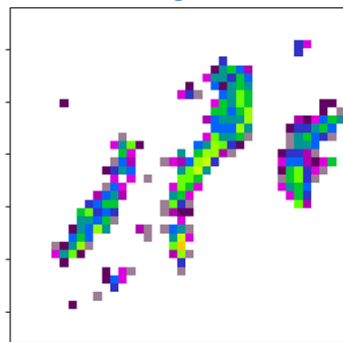
pySTEPS: open source, community driven

<https://pysteps.github.io/>

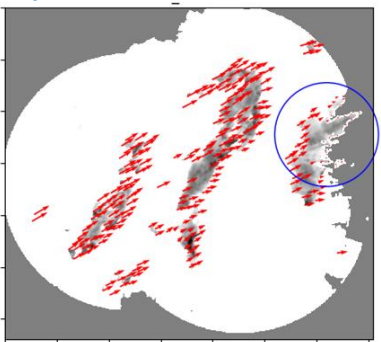
Probability forecast



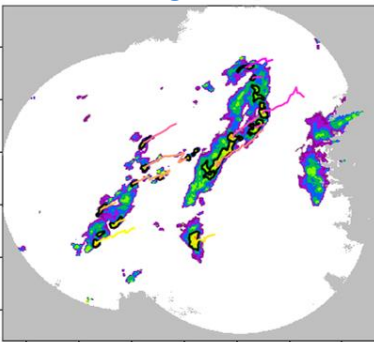
Downscaling



Optical flow



Cell tracking



The screenshot shows the pySTEPS documentation website. At the top left is the pySTEPS logo. Below it is a search bar labeled "Search the docs ...". The main navigation menu is divided into two sections: "FOR USERS" and "FOR DEVELOPERS".

FOR USERS

- Installation
- Gallery
- My first nowcast (Colab Notebook)
- API Reference
- Example data
- Configuration file (pystepsrc)
- Machine learning applications
- Bibliography

FOR DEVELOPERS

- Contributing Guide
- Importer plugins
- Testing
- Building the docs
- Packaging
- Publishing to conda-forge
- GitHub repository

At the bottom of the page, it says "Theme by the Executable Book Project" and "Read the Docs v: stable".

The right side of the screenshot shows the "Example gallery" section. It contains a grid of 16 example scripts and tutorials, each with a small thumbnail image and a title:

- Optical flow
- Advection correction
- Precipitation downscaling with RainFARM
- Probability forecasts
- Extrapolation nowcast
- Generation of stochastic noise
- Thunderstorm Detection and Tracking - T-DaTing
- Data transformations
- Cascade decomposition
- STEPS nowcast
- LINDA nowcasts
- Ensemble verification

Data assimilation in ALARO & AROME
(Mode-S, GNSS, radar, ...)

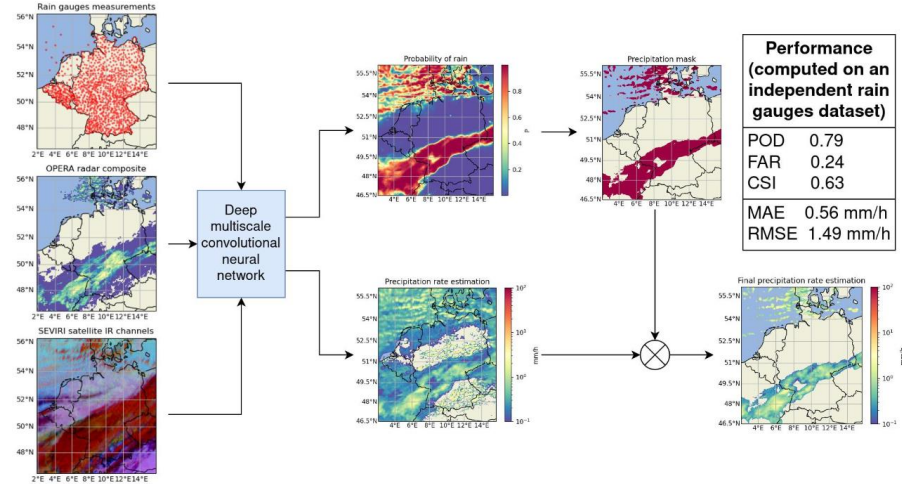
Making project IMA operational

- How often to run the blended/extrapolation-only nowcast?
- How to treat the interval 6-24h?

Move to AI-based multi-modal QPE
(Moraux et al., 2019; 2021)

Future research:

- Investigate AI-based "self-learning" blending and QPN
- Extend beyond the 24h time horizon by blending with ECMWF EPS



Thank you!

**Het Koninklijk
Meteorologisch Instituut**

**L'Institut Royal
Météorologique**

**Das Königliche
Meteorologische Institut**

**The Royal Meteorological
Institute**



Het KMI verleent een betrouwbare dienstverlening aan het publiek en de overheid gebaseerd op onderzoek, innovatie en continuïteit.

L'IRM fournit un service fiable basé sur la recherche, l'innovation et la continuité au public et aux autorités.

Vertrauenswürdige Dienstleistungen für Öffentlichkeit und Behörden begründet auf Forschung, Innovation und Kontinuität.

The RMI provides reliable public service realized by empowered staff and based on research, innovation and continuity.