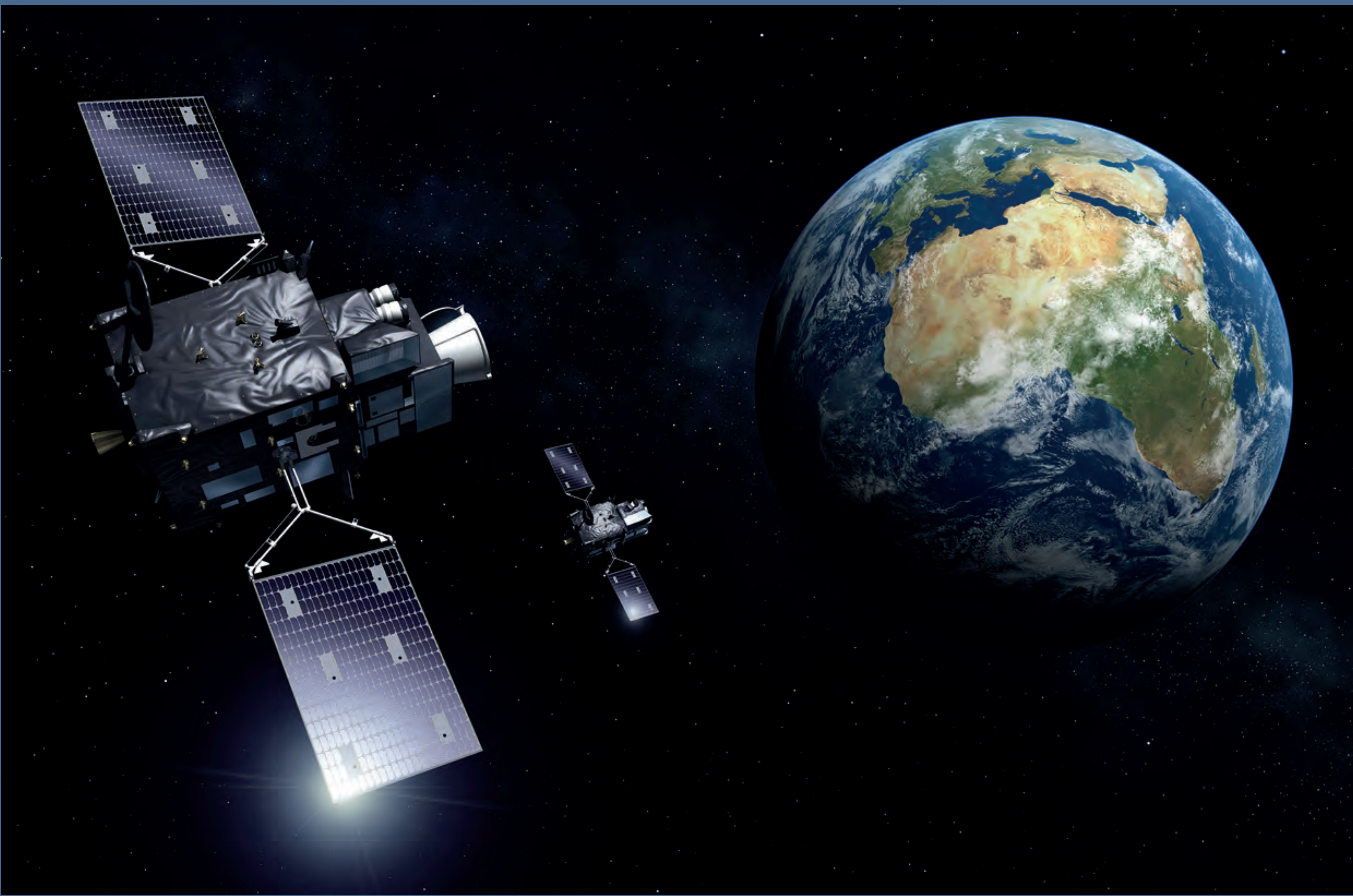
# The European Forecaster



*Newsletter of the WGCEF N° 28*
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**Cover:**
*MTG, a new step in weather observation*


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# Introduction

*Dear Readers and Colleagues,*

*It's a great delight and honour to introduce the 28th edition of our newsletter 'The European Forecaster'. The success of a publication on a regular yearly basis is only possible because of the excellent work of many colleagues. Therefore we would like to say thank you to Mr. Bruno Gillet-Chaulet and his colleagues at Météo-France for printing the newsletter. Many thanks go to Mr. Nicholas Roe for reviewing the incoming articles. We kindly address our warmest gratitude to all the authors for writing articles about new ideas, recent developments and interesting case studies in the field of weather forecasting. Last but not least, we want to thank Mr. Andre-Charles Letestu for updating our WGCEF website www.euroforecaster.org continuously.*

*Severe weather hazards have strong impact on humans, infrastructure, vegetation and ground. Therefore precise severe weather warnings in time, location and intensity can minimize or even prevent damages, save lives and reduce financial loss. This is one major -even the most important- mission of weather forecasters. With their expertise, knowledge and experience forecasters are able to provide excellent advice to the public, stakeholders and all kind of weather-depending users by issuing impact-oriented weather and warning information. Various requirements are necessary to be able to do this job accurately: regular training, good IT-infrastructure, intelligent tools, sufficient meteorological and non-meteorological data sources, scientific exchange and cooperation.*

*To keep or even improve the high quality of forecasts, cooperation and scientific exchange between the different NMSs is essential, which is one important goal of our working group WGCEF.*

*In this newsletter we have tried to make an interesting compilation of articles dealing with the above mentioned critical aspects of the forecaster's job. As always, our warning systems are under continuous construction and new developments are presented. Furthermore the possibilities of the 3rd generation Meteosat satellites are being discussed. There is also room for an article about the more "soft" psychological site of dealing with forecasts and warnings. Also interesting articles about wind farms and arctic forecasting challenges are included.*

*We hope that you will find this newsletter interesting, enjoyable and informative and we wish you a nice reading!*

*Best regards,*

**Jos Diepeveen (KNMI) and Christian Csekits (Geosphere, ZAMG)**
Chairpersons, WGCEF

# News and updates from a selection of NMSs

## AEMET (Spain – Jesus Barroso)

Since last spring, forecasters have been allowed to work from home for up to 60 % of their shifts. This organisational scheme is intended to become permanent, if approved by the Aeronautical Supervision Authority.

Regarding operational applications and tools, a team is working on the implementation of a new meteorological workstation, VisualWeather software by IBL being the preferred option, though other systems are still under consideration.

As for the meteorological events, the Atlantic storms Fien and Gérard brought strong winds and high amounts of snowfall to the Pyrenees, where the snow season has been short and scarce anyhow. Juliette, a Mediterranean storm, caused a historical snowfall episode on the Balearic Islands, even at sea level and low altitudes, especially in Majorca. On the other hand, most of the country faces drought conditions, due to the lack of precipitation during the spring. April 2023 was the hottest and driest in record, causing widespread damage to growing crops.

## ARSO (Slovenia – Veronika Hladnik- Zakotnik)

We bought TriVis for weather graphics.

We released our 100th Podcast about weather and weather related topics.

Start of new big project Sovir in autumn - a plan to renew prognostic system.

We remain on national TV every day, also have every day at 5 pm, a live 3 minute talk about weather with news presenter.

A lot of activities for our new web site.

Recruitment of new forecasters continues, now 2 are in training.

## CHMI (Czech Republic – Marjan Sandev)

**New organizational structure**

From 1 January 2023, a new Forecasting Service Division was established, separated from the Meteorology and Climatology Division. This division incorporates the Meteorological Forecasting Section, the Hydrological Forecasting Department and the Forecasting Service Development Department. The director of Forecasting Service Division is Mgr. Radek. The aim of this change is to focus on the expertise of forecasting offices and communication both between departments and sections, as well as towards the public and customers.

**Warning System updates**

Changes of display alerts on the CHMI websites. Approved version of two maps: the first map displays information about all severe phenomena, and second map shows observed severe phenomena which requires extraordinary attention and possibly a quick response to protect property and the health of the population.

From 1 May 2022 an expert team, The Convective Group, started working to help operational forecasters with decision making during forecasting and nowcasting severe convective storms. In the convective season (from May to September) forecasters from the Convective Group have shifts on days when storms are expected. They prepare alerts and summary reports for media and social networks, explain forecast uncertainty, prepare case studies and train the forecasters. Members of the Convective Group also personally ensure and coordinate cooperation with other meteorological entities on research after storms with extraordinary impact (e.g., F4 tornado on 24 June 2021).

The working group for a new (Impact based/ oriented) warning system has been working since the summer of 2022. A group is split to look at different factors i.e. limits, impacts, hydrology, CAP, Alert Editor (meteorological workstation), distribution, education, and communication.

CHMI developed a mobile app: SMS alerts for mayors. Access to the application is only for mayors and external employees of the regions. It also distributes alerts to state and local government organizations through many other apps operated by partners.

### Innovations

International and national cooperation with organizations and customers this year have included: Preparation for international exchange and visualization of 10 min data with Austria (Geosphere). Preparation of interdepartmental cooperation in the rental of drones for terrain/damage survey activities, the purchase drones and training of pilots is planned. Cooperation with an Amateur Meteorological Society, who are building an app for reporting severe weather phenomena from the field (similar to ESWD of ESSL). Preparation of a cooperation with the Mountain Rescue Service on sharing warnings (avalanches probably will be a part of the NMS warning system and distributed to Meteoalarm).

HAMR (Hydrology – Agronomy – Meteorology - Retention) – as part of the PERUN project (Prediction, Evaluation and Research for Understanding National sensitivity and impacts of drought and climate change for Czechia) was developed. The goal of HAMR is drought status information, at a regional level resolution, on surface and underground waters with a prediction out to 1 week, not currently part of the warning system. The CAP protocol that will be offered to end users is required for the next growing season.

FROST – a part of TAČR grant, a cooperative project with Institute of Atmospheric Physics. The aim is for better prediction of surface temperatures and conditions on the Czech motorway network. The project supposes the use of new data sources, especially satellite measurements, which will be used for a cloud extrapolation. The forecast will be calculated on all sections of Czech motorways and their connections.

In cooperation with the organization CzechGlobe, the FIRERISK model was innovated. FIRERISK is a forecast model for predicting the risk of occurrence and spread of wildfires. Based on the experience of the fire in the Czech Switzerland National Park, the model was updated. It uses the outputs of the ALADIN model (from 00 UTC). The overall risk is a combination of the Haines index, drought conditions, and the FWI Fire Danger Index itself.

Automatic creation and distribution of products at the request of customers from the energy suppliers (ČEZ, ČEPS), transport (road – ŘSD, railway – SŽ) and public services segments (WOLT). Data, text, graphic forecasts of severe weather phenomena with a large impact - e.g. wind gusts, storms, snowfall, icing, rime.

### Education and Training

Preparation and creation of online meteorological courses in MOODLE (for mandatory and optional training) for newcomers as well as operational forecasters. Examples of courses: Convective storms (mandatory), Road meteorology (mandatory), Integrated warning system and meteorological workstation Visual Weather – Alert Editor (mandatory). Other optional courses: Basics of synoptic meteorology, Satellite and radar meteorology, numerical weather forecast etc.

## CNMCA (Italy – T.Col. Alessio Canessa)

On July 20th 2022 the CNMCA and COMet Centers were reorganized into a single new one, called "Centro Nazionale di Meteorologia e Climatologia Aerospaziale". The new Centre will therefore maintain the acronym of the historical Centre, the CNMCA, where the final "A" intends to emphasize its "Aerospace" capacity in the context of space weather forecasts.

The website www.meteoam.it and the "Meteo Aeronautica" APP, managed by the Air Force Meteorological Service, have been renewed and updated. New products and new tools for accessing meteorological information are available.

The long roadmap to make "ItaliaMeteo" Agency operational is progressing well. "ItaliaMeteo", the new Italian civil meteorological service based in Bologna, will play a coordinating role of the weather agencies already active at national and regional level. (www.agenziaitaliameteo.it)

## DWD (Germany – Robert Hausen)

Forecasters are more now involved in project work and education but at the expense of other work, e.g. the zoomed analyses charts for central Europe issued every 3 hours, now retired.

Forecasting staff numbers have now become limited at regional offices due to issues hiring suitable candidates (shift work not attractive enough anymore despite home office and dislocated work being established in recent years for some shifts).

A new warning project "RainBow" started which will see: automatization of warning process for some events, tailored warning information for key customers/ expert users, harmonization of thresholds between general, aviation and maritime warnings and consideration of impact with improved communication.

Finally some significant rainfall during winter and spring with slow recovery of groundwater the table, but now drought returned since mid of May.

## ECMWF (Tim Hewson)

Operational ECMWF forecast production moved to the new ATOS supercomputer in Bologna in October 2022.

Work continued apace on the next forecast upgrade (cycle 48r1) due for implementation in June 2023 - some key points are:

1. Upgrade to ENS resolution (18km to 9km); no upgrade to HRES resolution (run will be renamed).

2. Extended Range will be separate system, 36km resolution, running daily from 00UTC, day 1-46, 101 members.

3. Two reforecast streams rather than one to support medium and extended range suites, one at 9km to day 15, the other at 36km to day 46.

4. New snow scheme - up to 5 layers depending on snow depth (was 1). Will improve 2m temperatures over snow and other aspects.

5. Higher resolution than hitherto for part of the analysis cycle.

6. Improvements to some CAPE-related variables.

7. A new precipitation type of "freezing drizzle" is to be diagnosed and predicted.

Visibility meteograms (in bar chart format) are being introduced to our output products.

The Destination Earth (DestinE) Digital Twin initiative is expected to have a second phase, lasting 21 months (team based in Bonn).

ECMWF is actively exploring the topic of Machine Learning ("data driven") forecasts, which, when fed with a good analysis, have become very competitive versus standard operational NWP, at least for predicting broadscale flow. Externally, there has been a big surge of activity in this area in the last year or so.

## FMI (Finland – Juha Sihvonen)

FMI stopped running our HIRLAM model in December 2022. We had been one of its first adopters and it had been in use for nearly 33 years.

During the fall the sea model NEMO was taken into use.

A neural network based total cloud cover nowcast has been implemented as part of FMI's automated nowcasting/very short-range weather forecast.

For the winter 2022-2023 a simple energy weather forecast for the general public was quickly implemented. It took into account heating needs, availability of wind power and other factors.

The safety weather services group has also increased cooperation with the road authority.

In aviation weather we piloted a new product for the winter season with the aircraft deicing services at Helsinki-Vantaa Airport (EFHK). It consists of a tailored weather forecast up to ~24h ahead twice daily, delivered via email and phone briefing.

In the north, avalanche warnings were unified to European EAWS standards.

In June 2023 our "edited" meteorologist's weather forecast had been added to our open data service. The service already included our weather warnings, real-time observations, daily and monthly values for historical observations, values for past 30-year climate normal periods, forecasts from the ECMWF and Nordic MEPS/HARMONIE models, air quality and sea models, and climate change forecasts from the ECMWF and Nordic.

Work on the GeoWeb workstation continues together with KNMI and MET Norway. Currently at FMI it is used operationally primarily for viewing radar and satellite images, but other data like lightning and ceilometer observations or model data are often included as well.

## LVGMC (Latvia – Valerija Kostevica)

We continue to improve our warning system by turning it into an impact-based warning system. Starting this summer (2023) a new heat wave warning criteria and guidelines for forecasters will be introduced.

In 2022 December we introduced new warning criteria for high water level in rivers (in cooperation with municipalities). Now warnings are sent directly not only to civil protection authorities but also to municipalities.

MODES data from airplanes are now visualized for operational work use allowing us to see more frequent vertical observation data for temperature and wind.

Over the last year we've improved collaboration with the Radiation Safety Centre. Due to the war in Ukraine we offer additional information about the potential spread of nuclear pollution.

Two new aviation forecasters and two general forecasters started to work, training of few more trainees is continuing.

Extreme floods in East part of Latvia in January 2023 (issued red warning).

## Met Éireann (Ireland – Liz Coleman)

The incomparable Head of Forecasting, Evelyn Cusack retired at the start of June after 42 years of service and we welcomed our new Head of Forecasting, Eoin Sherlock.

High-resolution version of Harmonie called HECTOR, has been made available to forecasters in a test environment. HECTOR has a horizontal grid resolution of 750m.

Works have commenced on the installation of the first of five planned dual polar radars for Ireland. The first installation will be in Shannon Airport, Co. Clare.

We have been working with Climate services to develop climate lines for our forecasters as media interviews tend towards a climate context for current weather.

ANYWHERE Multi-Hazard portal has been rolled out to stakeholders, allowing stakeholders real time information on potential hazards in their areas.

Met Eireann continues to collaborate on the UWC-W project. Forecasters are using operational comparisons between Harmonie and UWC models informing forecasting decision.

A review of Met Éireann's warnings guidelines has begun, with help and input from colleagues in Climate Services Division to review threshold values for warnings.

Met Éireann is currently tendering for a new text-based forecasting system, with further tenders for visualisation of model output and the website and app development planned.

Three new forecasters have joined the team.

## MET Norway (Geir Ottar Fagerlid)

Focusing on the weather since the last member meeting, Norway has experienced a fairly normal weather year. The country is quite elongated, so it is common to have areas with a bit of everything throughout the year. The summer of 2022 was seen as poor. The average temperature for the whole country ended 0.7 °C above normal. Large parts of the country were classified as "Very wet" or "Extremely wet". For the country as a whole, 15% more precipitation fell than normal. As a result of a lot of maritime air throughout the summer, few convective danger warnings were sent. Only one orange warning was sent at the end of the season. Normally there are usually some more.

The winter season was seen as warm in the northern parts of Norway. In the rest of the country's season was mainly within normal, but an area in the north of Eastern Norway could be classified like "Cold". The national temperature was 0.3 °C above normal.

Since last summer, focusing only on more serious alerts (amber/red), one warning was sent for torrential rain, 7 warnings sent for persistent rain, 2 warnings sent for strong winds, and 4 amber warnings sent for heavy snow. A part of the country also experienced an "undetected" polar low pressure, which in an ideal world would have had a more serious warning.

## Met Office (UK – Nick Roe)

The Combination of the defence and civil forecasting departments continues with a joint management team now in place. To streamline products a product catalogue is being compiled to identify similar items and reduce the duplication of effort, there is also a project ongoing to identify and decommission products that are no longer required by the users. There will be greater sharing with third party companies when it is judged that this will 'help the public make better decisions to stay safe and thrive' e.g. UKV data is now available on windy.com.

The office has now aligned with the governmental Civil Service pay grades and talent spotting process as well moving ministries from the now defunct Department of Business, Energy and Industrial Strategy to the Department for Science, Innovation and Technology. The Met Office has also been recognised as an official Category 2 Responder to acknowledge the importance of forecasts during extreme weather emergencies.

Many working groups have started as Future of Operational Meteorology (FoOM) project continues to gather pace. These are looking at strategic workforce planning, demand management, future ways of working, manager to staff ratios and change management.

The technical side of FoOM has started to deliver with the work around the new data visualisation package in the Beta stage. This will be a completely online, cloud based, system called Vortex which will combine the current IBL Vistual Weather with all the data on internal websites. All operational meteorologists have been tasked with testing various elements and fill in questionnaires to help shape what it will look like and do.

It was a challenging spring/early summer with stretched staffing resources and industrial action resulting in several strikes (now resolved). Training courses to get meteorological technicians qualified into operational forecasters sooner will help with resourcing. It was found that doing these courses remotely was not completely effective so remote learning will blended with more learning in person on future courses. The value of experienced meteorologists as well as other staff has also been recognised with the implementation of a long service award.

## Météo-France (France - Bruno Gillet-Chaulet)

NWP: New version of ARP/AROME on new computers (June 2022). Ensembles (PEARP/PEARO): members resolution now matches HR deterministic runs. Testing a 500 m resolution version of AROME to be operational for the Paris Olympic Games 2024.

Weather Warnings: New version of "Vigilance" (November 2022) with 2 maps (D and D+1), infra-departmental (French administrative division) information for Avalanches and Storm Surges.

Climate: new references (1991/2020). New tools for Climate Change Adaptation ("Climadiag"/ "Climsnow") and trainings for local elected/authorities.

Celebrations: 100 years of the French Meteorological School (ENM) and 40 years of the National Research Center (CNRM) (October 2022).

Trade: New commercial policy refocused on high value-added customers

Staff: Number of employees on the rise! With 17 new dedicated forecasters hired. Recruitment policy: 23 hires.

Observations: New buoys planned to be implemented in the Mediterranean Sea.

New Météo-France "motto": "At your side in a changing climate".

Weather Events: Exceptional "wildfires" season (Summer 2022: 72 000 hectares burnt) due to exceptional heatwaves (earliest ever seen in June 2022) and drought, resulting in a new national weather production ("Forest Weather") to help prevent such situations. Early and intense forest fire for a month of April (2023) at the French-Spanish border (Catalonia). Numerous solicitations for water resources management, electricity consumption...

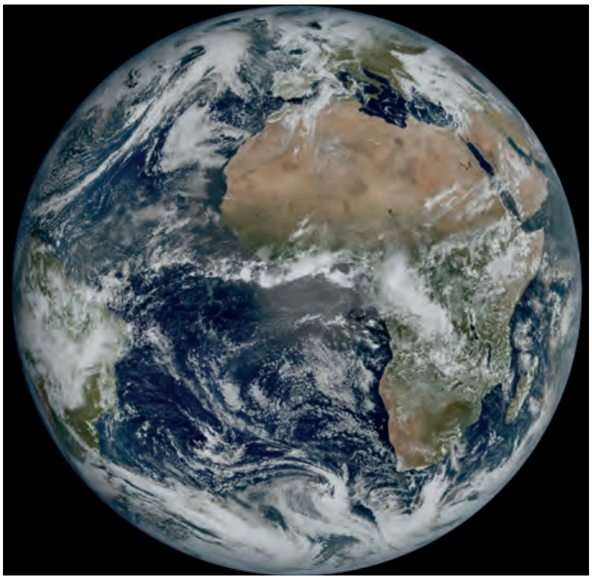
## OMS (Hungary – Zoslt Patkai)

After the 2022 national vote, HMS has been transferred from the Ministry of Agriculture to the newly created Ministry of Technology and Industry. Just some weeks before the end of the year this Ministry was dissolved, the Met. Service was transferred next to Ministry of Energy. Meanwhile, after the poor NWP forecast on National Day (August 20$^{th}$), the president and vice-president were fired. Later, vice-president could be returned to the Service. These rapid changes stalled, for a long time, the most important goal of the Service: the transformation from a state administration body into a state-owned company. This transformation would solve many problems: staff limit, salary limits, complete financial and human resource management dependence on the state, etc. At the time of writing the transformation process has finally started. In addition to these, our Service has not had an officially appointed senior management since the end of August. As if there weren't enough problems, in May an unexpected 10% downsizing had to be implemented at all state administration bodies.

# Meteosat Third Generation Data: Users' Needs Come First

sylvain.lemoal@meteo.fr, **Météo-France (DIROP/CMS)**

On the 24th of December 1963, the Météo France Meteorological Satellite Centre (CMS) received a Christmas present that forecasters had long been dreaming of: the first weather satellite image ever processed by a European centre **(figure 1)**. Sixty years after this first step, meteorologists were eagerly awaiting the next big moment in European weather forecasting history – the arrival of the first image of Meteosat Third Generation (MTG) on to their workstations **(figure 2)**. The launch of the first MTG satellite (13th December 2022) was another major step forward for European meteorology, as witnessed every couple of decades. MTG observations enrich the information available for forecasters and make numerical weather predictions more accurate. They will provide observations that can speed-up storm warnings, track lightning, pinpoint fire hotspots, and enhance emergency response.



▲ *Figure 2: 18/03/2023 at 1150 UTC – MTG-I1*
*First image from Meteosat Third Generation – Photo: Eumetsat/Esa*

The Meteosat Third Generation system is the most complex and innovative geostationary meteorological system ever built. The MTG space segment will eventually comprise a total of six satellites: four MTG-I (imaging spacecraft) and two MTG-S (sounding spacecraft) delivering 50 times more data than Meteosat Second Generation (MSG). This satellite complex will provide at least 20 years of operational service. By 2026 the first three satellites will be deployed, this fully operational constellation will include two MTG-I and one MTG-S satellites.


▲ *Figure 1: 24/12/1963 at 1229 UTC – Tiros-8*
*First image received in Europe at the Météo-France Meteorological Satellite Centre – Photo: Météo France*

| | | MTG | MSG |
|---|---|---|---|
| + | Better temporal resolution | 10 min (full disk)<br>2 min 30 s (Europe) | 15 min (full disk)<br>5 min (Europe) |
| + | Better spatial resolution | 500 m to 2 km | 1 to 3 km |
| + | Better spectral resolution | 16 channels | 12 channels |
| + | More instruments | FCI – LI<br>IRS – Sentinel-4 | SEVIRI – GERB |

## MTG-I

The priority of the MTG programme with the Flexible Combined Imager (FCI) will be to continue to support nowcasting and very short-term forecasting. Made possible by major enhancements to the Meteosat imagery mission, with images available much more frequently, every 10 minutes for full disk imagery (vs 15 min for MSG) and every 2.5 minutes (vs 5 minutes for MSG) for the rapid scanning service over Europe and adjacent seas. The number of spectral channels increases from 12 to 16, to deliver additional information on semi-transparent cirrus clouds, cloud microphysics, aerosols, volcanic ash, fog, air mass characteristics and wildfires. The spatial resolution varies from 500 m to 2 km, depending on the channels **(figure 3)**. FCI data continues the 40-plus-years of data series from Meteosat satellites.

On the same platform (MTG-I), for the first time over Europe and Africa, the Lightning Imager (LI) provides real-time data on the location and intensity of lightning flashes. The imager detects all types of lightning: cloud-to-cloud, cloud-to-ground and intra-cloud flashes, day and night. Data from LI enables more precise forecasts of severe thunderstorms and allow meteorologists to monitor, track and extrapolate where lightning strikes. Better knowledge of the state of electrification improves air navigation services and gives pilots more opportunity to avoid electrically active thunderstorms.

## MTG-S

The new geostationary sounding service is based upon requests from the numerical weather prediction (NWP) community to frequently deliver spectral information and/or retrieved products. It will also support nowcasting applications, such as early detection of areas prone to convective initiation, and improved warnings on location and intensity of convective storms.

The infrared sounder (IRS) on-board MTG-S is set to revolutionise weather forecasting by tracking the four-dimensional (over time and space) structure of atmospheric water vapour and temperature, for the first time on an operational basis. In addition, IRS is expected to provide information on ozone, carbon monoxide and volcanic ash composition.

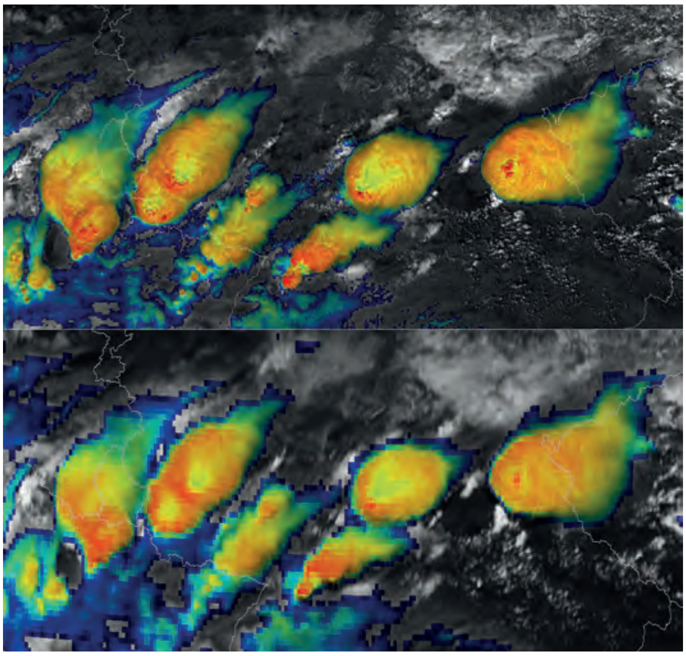
Copernicus Sentinel-4 instrumentation will monitor air quality, trace gases and aerosols over Europe on an hourly basis and with high spatial resolution. Sentinel-4 covers the need for continuous monitoring of atmospheric composition. The mission will focus on air quality, with the main data products being ozone ($O_3$), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), formaldehyde (HCHO) and aerosol optical depth.

## At Météo-France

It's been a long time in the making, to provide data that has never been available over Europe before. Alongside other member states, Météo-France takes part in the MTG user preparedness group (MTGUP!) and in a wide range of initiatives and workshops that has allowed it to account for the needs of users such as forecasters, researchers and, more generally, all the customers of satellite data **(figure 4)**.

Météo-France already has experience in processing data for French overseas territories from next-generation satellites currently in operation, such as Japan's Himawari-8 and -9 and United States' Goes-16, -17 and -18. They have given a tantalizing taste of what is to come.

Inside Météo-France, users' needs come first, so a new working group lead by the end users has been created to discuss their requirements with the specialists of the Meteorological Satellite Centre and so the GUSAT was born (in French: "Groupe des utilisateurs des données satellitaires"). At the same time, the CMS has been delivering specialist training courses in collaboration with the French National School of Meteorology.



◄ *Figure 3: Spatial resolution of the sandwich product using VIS and IR channels to characterise thunderstorms – MTG vs MSG – Photos: Eumetsat*

To broadcast these new products in real time and to be sure that end users are ready to hit the ground running as soon as MTG goes operational, all the elements of the operational chain, the processes and the hardware required improvements and testing. Additionally, telecommunications lines, antennas, EumetCast systems and algorithms were set up and checked under the guidance of the Météo France MTG-I1 project.

▲ *Figure 4: Meteorological Satellite Centre – Photo: Météo France*

# Wind farms and the weather

Yorick de Wijs, **meteorologist at the KNMI**

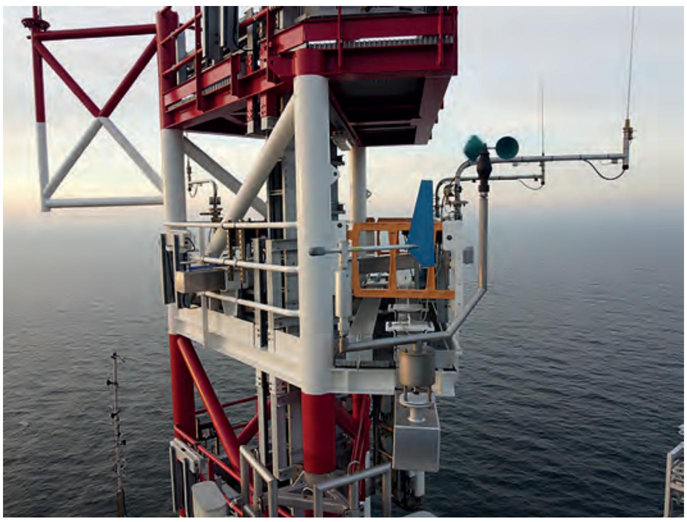
***The KNMI ('Royal Dutch Meteorological Institute') is responsible for providing weather forecasts and issuing weather warnings for the Amsterdam FIR (Flight Information Region), which not just extends above Dutch territory but also includes a large part of the Southern North Sea. As a result, oil rigs and offshore wind farms play an important role in our operations as a weather office. Observations from weather stations on these rigs and farms are crucial in the process of making accurate weather forecasts for this region, however, as they disturb radar signals and affect the weather itself, the increasing number of wind farms could become a challenge in the future.***

## From oil rigs to wind farms

For more than half a century oil and gas have been extracted from the sediments under the North Sea, generating the need for oil rigs and other platforms. The KNMI has been responsible for providing weather forecasts and warnings for ships and offshore personnel since the nineties, with some of the platforms equipped with meteorological instruments. Observations from these offshore weather stations became essential for meteorologists, not just to monitor the local weather conditions, but also because they can provide a strong indication of future weather conditions over land when weather systems approach from the west or north.


▲ *Figure 1: present and planned wind farms offshore the Dutch coast, source: windopzee.nl*

With the transition to sustainable energies and therefore the gradual decommissioning of the platforms used for oil and gas extraction, two offshore weather stations have already been taken down, with more expected to be retired in the future. Fortunately, the deployment of wind farms in the North Sea has opened up a way to continue these measurements. The first wind farm, a group of wind turbines in the same location used to produce electricity, came online in 2007, just offshore from Egmond aan Zee. Since then, five more farms have been built and during the next decade many more wind farms are scheduled to be built offshore the Dutch coast **(figure 1).** As part of the Maritime Information Service Point (MISP) project, the KNMI will be allowed to place meteorological instruments on the accompanying platforms. An example of this is shown in **figure 2.**



▲ *Figure 2: anemometer, windvane and other instruments attached to a tower on a wind farm platform, source: KNMI*

## Anomalous propagation echoes

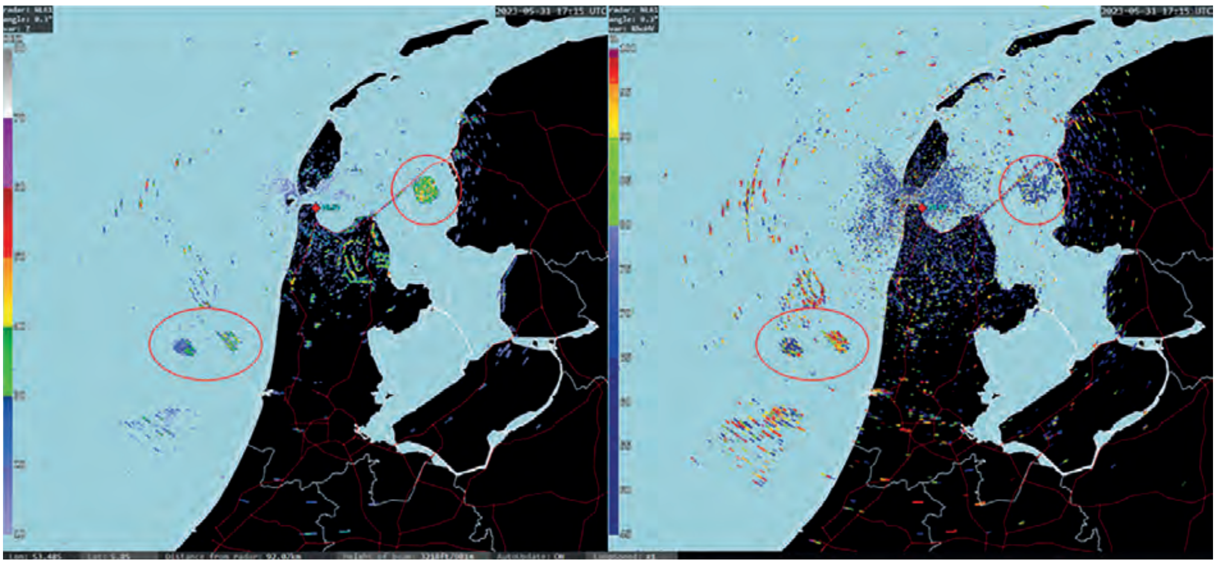
The presence and planned future expansion of wind farms in the North Sea does pose a challenge when using radar images under certain atmospheric conditions. When radar beams pass through a layer that has a high atmospheric stability, for example due to a strong temperature inversion, the beams will bend downward more than normal (this is called super-refraction). In some cases a process called 'ducting' can occur; a special super-refractive condition such that the radar beam gets trapped or 'ducted' within this layer. This can cause the radar beams to hit the wind farms and show their reflections as stationary false radar echoes (or anomalous propagation echoes). An example of such echoes is shown in **figure 3**.

With the future wind farms becoming much bigger, they will likely generate a lot more reflections on the radar products used by our meteorologists as well as our clients. This will happen especially during spring time when warm (continental) airmasses are moving over the cold North Sea water, creating a stable boundary layer, similar to a nocturnal boundary layer over land. Although Dual Polarization Radar products are actually able to determine whether reflections are caused by precipitation or anthropogenic objects, one has to be careful to not filter too much or aggressively in cases where there are actual (isolated) storms active in the area. Therefore meteorologists should always be aware of the locations of these wind farms, in order to not make a wrong assessment.

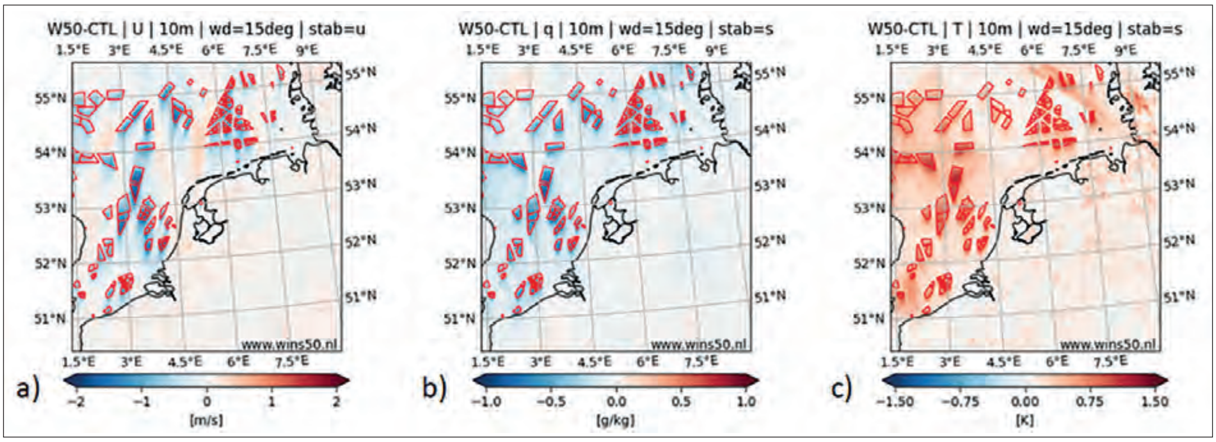
## Affecting the weather

The increasing number of wind farms also poses another challenge. As much as we know about their yield generated under certain wind conditions, our knowledge on how wind farms or single wind turbines affect weather conditions themselves is limited. Last year however, a study was performed together with the Wageningen University, using our local high resolution weather model Harmonie, which showed some interesting results. They compared year-long model runs with and without parameterized wind farms, in order to determine how to improve local wind forecasts, power production and the effects on the near-surface wind, temperature and humidity.

They found a significant decrease in wind speed as far as 50-150 kilometers downstream of the wind farms **(figure 4a),** especially during conditions with a high stability (warm air over a cold surface). Additionally the wind turbines caused an increase in turbulence, enhancing the atmospheric mixing in the boundary layer. This will inevitably also change the temperature and humidity profiles of the affected downstream atmospheric layer. For example, in a stable boundary layer with cold and moist air near the surface, increased mixing would result in higher temperatures and lower humidity close to the surface (**figure 4b & c**), potentially causing visibilities to improve or low clouds (stratus) to dissolve. On the other hand, adding mixing to a stable but very moist layer trapped below an inversion, could also result in the formation of stratus clouds. The satellite images in **figure 5** show an example of the first process.



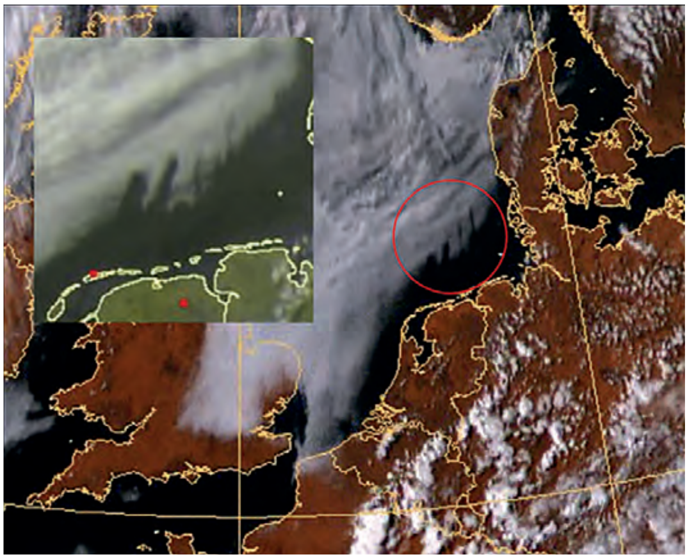
▲ *Figure 3: radar reflectivity (left) and correlation coefficient (right), red circles indicate the location of the wind farms, blue colors (or any other colors except red) for the correlation coefficient indicate non-meteorological echoes. Source: KNMI*




▲ *Figure 4: model output wins50, showing the anomalies of the 10 m wind (left), specific humidity (center) and temperature (right), source: [https://wins50.nl/imagelibrary/](https://wins50.nl/imagelibrary/)*

## Induced lightning?

A final challenge, something we still have very little experience with, is the possibility of wind turbines inducing lightning. During cases with isolated showers containing supercooled droplets/ice, the presence of wind turbines could, similarly to AIL (Aircraft Induced Lightning), have an effect on the triggering of lightning. In addition to their impressive height of about 200 meters (including the blade), the rotation of the blades and the used materials could also play a role in altering the electric fields. Although there have been instances where wind farms or even individual turbines seemed to have played a role in the onset of lightning, there is still ongoing debate about this.



▲ *Figure 5: visible satellite image around 14:00 UTC on the 13th of May 2023, source: Meteosat (edit)*

# The warning service at MET Norway

Geir Ottar Fagerlid, **Norwegian Meteorological Institute**

**The warning service at MET Norway is currently organized as follows.** MET Norway is tasked with the main purpose of preventing damage to life and society, and it is responsible for providing a weather warning service for Norway. This responsibility, described in the guidelines, is to notify and report to the coordination channel managed by the Norwegian Directorate for Civil Protection (DSB). All types of crises are handled by the principles of responsibility, equality, closeness, and cooperation. The municipalities, county commissioner offices, the Norwegian Directorate for Civil Protection and the Ministry of Justice and Emergency Preparedness (JD) are especially responsible for the preparedness and response in Norwegian society when a crisis, such as a weather event, occurs.

Operational forecasters at three regional offices in Tromsø, Bergen and Oslo have a 24/7 responsibility to monitor, analyze and issue weather warnings for a range of phenomena (in Norwegian: https://www.met.no/vaer-og-klima/ekstremvaervarsler-og-andre-farevarsler/vaerfenomener-som-kan-gi-farevarsel-fra-met). On a daily basis, there is a video meeting with NVE (the Norwegian Flood and Energy directorate) to discuss precipitation and the possibility of flash floods, flooding and landslides etc. In a situation with a (possible) orange or red event, an additional forecaster is added to the team and contact with local authorities are established. The role of this senior forecaster is to coordinate the tasks and stakeholders involved, to ensure that the situation is well handled. The warnings and the warning system are, with a varying degree of systematization, evaluated, surveyed, and reported post-event. Based on these insights, several groups have the responsibility to follow-up suggestions and recommendations. One group has the superior responsibility for following-up the reports mentioned above (*Farevarseloppfølgningsgruppen*), and to follow-up and coordinate the expert teams that are responsible for specific phenomena (*Fenomengruppene*). In addition, there is a group with members from MET Norway, NVE, and the public broadcaster (NRK), which focuses on how the warnings are communicated and presented from the weather service to the public (Yr.no).

All orange and red incidents are evaluated, with written reports for both internal and public use. At the yellow warning level, evaluation is performed on a weekly basis but only for selected cases for some phenomena. However, wind, rain, icing, polar low, storm surge and forest fire warnings are evaluated based on easily available data.

▲ *Rockslide in W-Norway in November 2022.*

**Several changes have also been made in Norway over the last five years.** The warnings are now issued in both Norwegian and English, and include a color/warning level, advice, expected impacts, illustrations and probability information. The warning dissemination is also made available through a broader range of media and specifically in social media channels. MET Norway also disseminates warnings in the CAP protocol, ensuring that all warnings can be made available for all users regardless of the platform. MET Norway is heavily involved in risk assessments regarding probabilities of weather exceeding given thresholds (i.e. traditional forecasting) and now also routinely participates in video conferences on incident handling. Gradually more phenomena have been included in the warning service.

**Despite ongoing improvements, there are still some known potential shortcomings.** Advice is, in general, not coordinated with authorities and civil protection, but more empirically based. Criteria is mainly meteorologically based, varying in time and place. Exposure and vulnerability are considered in some degree but MET Norway doesn't necessarily have insight into relevant information owned by contingency actors. Several projects have seen the light to address these issues:

• The K2S project at MET Norway will contribute to advancing socio-economic gains of society through improved preparedness, as well as increasing its resilience across various societal levels against shocks and impacts from an increasingly variable and extreme climate. In a situation with severe weather conditions, *everyone* should know and understand their responsibilities and what to do. Thus, the overall outcome that this project aims for the Norwegian society to get (improved) access to and (better) understand impact-based weather warnings so that protective measures, such as safeguarding life and property, can and will be made. The main impact of the project will be to better support both the public and societal actors in their preparedness and response when facing hazardous weather conditions based on the premise that impact-based warning information is tailored to a local context and therefore feels more relevant and is more understandable.

• The Norwegian Flood and energy directorate (NVE) has recently started a project named FlomRisk (eng: FloodRisk) where the main aim is to focus on the risk and impacts at a local municipality level for floods. MET Norway will cooperate with NVE on this project where five municipalities are chosen to set up a system for warnings based on the local risk potential. When using the risk of impact in the warning level, it will be easier to allocate resources and take measures to protect the most vulnerable areas. The purpose of these types of warnings is to make people understand the severity and impacts better, they therefore will be more prepared and take proper actions to save lives and secure properties. The project will make available a decision-making tool for the municipalities in case of warnings (rain and flood).

• In the Stimulab project - *En Fare - Lokal innsats* - the focus is on the interplay between various actors in a community and to evaluate which services the different actors need to secure life and property when severe weather is expected. Here, the user journey after a warning is received and until a protective action (decision or measure) is taken will be explored and mapped. The project

▲ *A polar low pressure affected Trondheim in March 2023, Norway's fourth largest city.*

aims to uncover and map different user journeys within the context of selected local communities by getting to know key public and private actors, as well as their habits and needs better. An ongoing project at MET Norway – Varseltavle or Warning Tables – is an internal pre-warning alert system. The system is regionally based and has a wide range of meteorological parameters. The forecaster/user is alarmed by a color when specific thresholds are exceeded. This is a system specifically aimed to monitor a weather situation before an official warning is sent. Although the system originally was intended for internal use, it will be tested externally to evaluate whether it can be a useful tool for preparedness purposes in the municipalities.

# The Meteorological Vigilance: Météo-France Warning System
## *Brief history, Description and Reflections*

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## Introduction

Established in 2001, the Meteorological Vigilance (Calmet, 2018) is the facility used by Météo-France to warn* the authorities and the population of the occurrence of dangerous weather phenomena or floods. It is deployed in metropolitan France and in the French overseas territories. This article gives a brief history of the system, describes its operation, and offers some thoughts on its development and use.

## Brief history

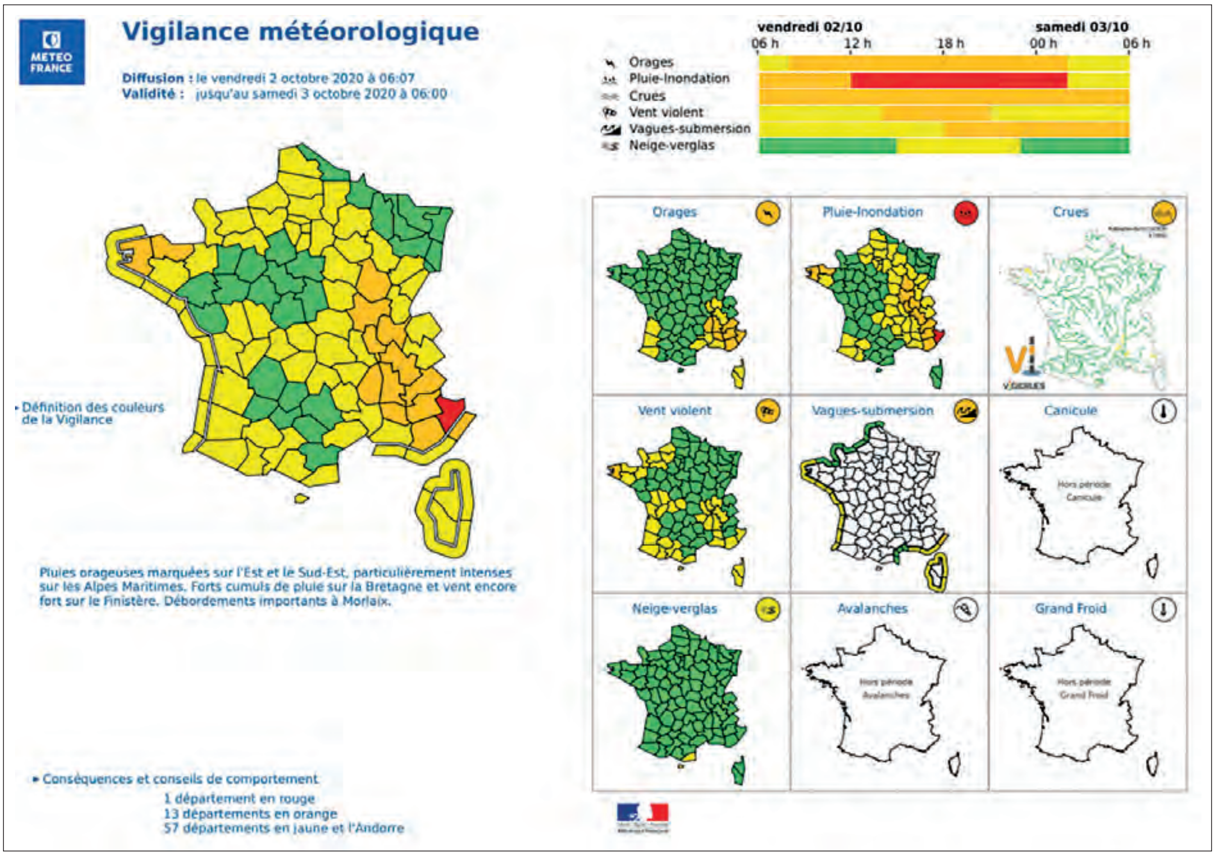
In December 1999, the consequences of the windstorms *Lothar* and *Martin* (92 casualties in France) highlighted the ineffectiveness of the meteorological/weather warnings at that time. These consisted of specific "text" bulletins issued to the authorities on the one hand and special "communiqués" sent to the media on the other (Lepape, 2004). A lack of "meteorological risk culture" clearly appeared during these episodes.

This observation led to the idea of a simpler system, giving the authorities AND the general public the same level of information, describing the expected consequences of the predicted meteorological events and prescribing the behaviours to adopt in order to cope with them. The stated aim was to involve the citizen in their own safety (and that of others). This system was inspired by those already in place in the French overseas territories, used and tested for the management of recurrent risks linked to tropical cyclones. It took advantage of the development of the Internet to allow graphics to become a more important constituent of the information available. Called "Meteorological Vigilance" (https://vigilance.meteofrance.fr/fr), this system was implemented on October 1, 2001 based on the main principles described below. It has undergone evolutions and has been improved to adapt itself permanently to the needs. Some of the milestones are presented below. Originally designed to cover 5 different phenomena (Wind, Rain, Thunderstorm, Snow or Ice and Avalanches), it was extended in 2004 to cover High Temperature and Low Temperature. In 2007, the Central Service of Hydro-meteorology and Flood Forecasting Support (Schapi) of the Ministry of Ecological Transition produced the Flooding Vigilance (Météo-France now relays information from the "Vigicrues" network of rivers monitored by the State, https://www.vigicrues.gouv.fr/), and the Rain phenomenon became Rain-Flood to integrate this new element. Since 2011, the Vigilance has also provided information on the phenomenon Coastal Event (storm surge), produced with a contribution from the Hydrographic and Oceanographic Service of the Navy (Shom). Initially valid for the coming 24 hours, the time-frame covered by the Vigilance was extended in 2022 to the entire next day in the form of a "double map" showing the days "Today" (D) and "Tomorrow" (D+1) **(figure 1)**.

In France, this system is regulatory i.e. it is the subject of an inter-ministerial "circular" (https://www.legifrance.gouv.fr/circulaire/id/45225?origin=list&page=4, involving the Ministries of Ecological Transition, the Interior and Solidarity and Health) which "specifies and reaffirms the guiding principles of the Vigilance and its articulation with crisis management systems".

## Fundamental principles

**1.** At any given moment, the Vigilance indicates the level of danger to which a territory is subject for the upcoming deadlines with 4 colours: Green, Yellow, Orange and Red associated with the following definitions:




▲ *Figure 1: Example of a Vigilance map available on the Météo France website. The maximum colour level over the period considered applies to the French "departments". The temporal evolution is displayed at the top with the chronology of the events for each parameter. Case of the memorable "Alex" event of October 2, 2020. This is a simulated "Today" (D) day map for this episode before the implementation of this new presentation in 2022.*

## Green Vigilance:

**No particular vigilance.**

## Yellow Vigilance:

**Be careful.** If you practice activities that are sensitive to meteorological risks or are exposed to floods. Phenomena that are usual in the region but are occasionally and locally dangerous (e.g.: Mistral wind, summer thunderstorm, rising water) are indeed expected. Keep yourself informed of the evolution of the situation.

## Orange Vigilance:

**Be very vigilant.** Dangerous phenomena are expected. Keep yourself informed of the evolution of the situation and follow the safety advice issued by the authorities.

## Red Vigilance:

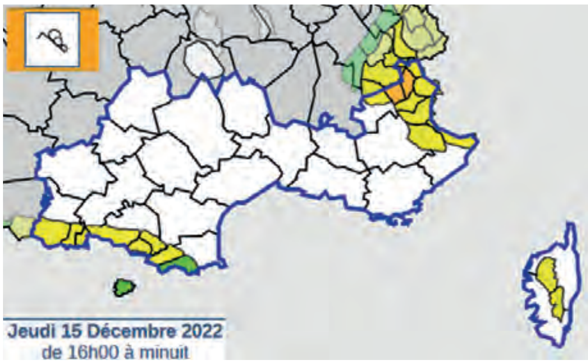
**Absolute vigilance** is required. Dangerous phenomena of exceptional intensity are expected. Keep yourself regularly informed of the evolution of the situation and follow the safety advice issued by the public authorities.

The colour level corresponds to a risk in the sense that it is "a combination of the probability of a meteorological or hydrological event and its consequences" (ISO definition). Thus, decision support criteria have been defined on the basis of thresholds relating to the various parameters monitored and the vulnerability of the concerned territories. These criteria can be modulated according to specific contexts: more intense road traffic during vacation periods, soil moisture, pandemic (as seen with Covid19) etc. This approach is similar to that of an "impact matrix" as proposed in the United Kingdom's weather warnings system ("NSWWS", Suri and Davies, 2021), although the forecast does not explicitly indicate the position of an event in this matrix.

The colour is complemented by text specifying the intensity of the phenomena, their location, their chronology, and the uncertainty inherent in the forecast.

In this system, the meteorological danger information is always available: a territory is constantly placed in a "state of Vigilance". It is not subject to an "alert*" in the sense described by Suri and Davies, 2021. Thus, unfortunately, the Yellow colour (the equivalent of the first "alert" level defined by these authors) is sometimes discredited in France. Indeed, often triggered at very low thresholds, this colour is very frequently used and does not attract the attention it should, especially for events at the limit of the Orange colour. For these events, special messages (called - SPEZF -) are issued to the authorities (they could be considered as similar to the "Yellow Warnings" of the British system). From 2022, for these cases, a highlighting of bulletins on the Vigilance website seeks to overcome this difficulty.

**2.** Vigilance is presented at a departmental scale. In France, the department is the administrative unit that plans and manages crises (under the direction of a Prefect, representing the State). Its spatial scale is adapted to the predictability of the phenomena for the targeted deadlines. However, since administrative boundaries do not necessarily correspond to the contours of meteorological events, a reflection is underway to move away from this departmental constraint. In addition, progress in weather forecasting sometimes allows increased geographical accuracy: for the parameters Coastal Event and Avalanches, a visualization at sub-departmental scale was deployed in 2022 **(figure 2)**. For some overseas territories, a division of the department had already been applied.




▲ *Figure 2: Example of sub-departmental visualization for the Orange Vigilance Avalanches episode of December 15, 2022 in the Alps. The colour applies to the division by "massifs" of the mountain ranges.*

**3.** Determining the level of vigilance is a matter of judgment or decision making (Cadet and Chasseigne, 2009, Klein, 1999). The choice of the colour is made in a collegial manner. It is the result of an exchange between forecasters working at the national level on the one hand, and at the regional level on the other. These players discuss the predicted weather scenario, its uncertainty, the possible consequences and the context of the moment. A representative of the management of Météo-France intervenes when a Red Vigilance is envisaged, this colour being likely to have a significant impact which may place the establishment in the spotlight. In a 2021 "bestseller", Daniel Kahneman and his co-authors (Kahneman and al., 2021) warn against the harmful effects of noise (in the statistical sense) in many fields where these notions of judgment and decision making are involved. We are pleased to note that many of the recommendations advocated by these authors have already been applied through the development of Vigilance at Météo-France: use of objective criteria, aggregation of independent judgements, good knowledge of the "prime rates" (i.e. the climatology of the phenomena), continuous evaluation of situations through active research of new information, training of the operators, systematic feedback on the situations with publication of indicators (described below), etc.

**4.** The Vigilance is updated at least twice a day at 6 a.m. and 4 p.m. and as much as necessary according to the situation. An update of the Flood parameter is carried out daily at 10 a.m. For the Orange and Red colours, accompanying bulletins are mandatory. They are issued from the "time of the Vigilance" (first map with an Orange or Red colour level) until the end of the event requiring this colour level, with a frequency of 3 hours at the regional level, 6 hours at the national level (from the effective beginning of the event).

From an operational perspective, Vigilance management has two distinct moments: 1. Anticipation (the framework established beforehand) and 2. Monitoring (the follow-up of the weather situation) of hazardous weather events (see an example in "The European Forecaster", Newsletter of the WGCEF N°27, September 2022). The monitoring phase sometimes puts forecasters in difficulty. Thus, when an unexpected event goes out of the framework that has been set upstream (because it was not anticipated!), from what level of severity should we trigger the aggravation of the colour level of the Vigilance? The usefulness of a last minute warning must then be weighed against

* In France, a distinction is made between the notions of *warning* and *alert*. Vigilance refers to the first term. It is thus considered as a first level of information (*warning*) which can lead the authorities, if necessary, to take particular measures (*alert*) concerning the population (evacuations, sheltering, traffic bans, etc.). The alert is the responsibility of the crisis management authorities and not of Météo-France.

the complexity of a procedure that impacts many stakeholders. The decision is sometimes delicate.

To carry out the Vigilance (at the anticipation stage), the Numerical Weather Prediction (NWP) is the main tool used by the forecasters. To date, there is no automatic initialization of the Vigilance from the NWP. However, it should be mentioned that automatic products exist and are consulted. In addition, research using Artificial Intelligence (AI) techniques is currently being conducted, crossing weather predictors and data on field consequences. Operational implementations are not envisaged in the short term however.

## Vigilance Evaluation

Vigilance performance is closely monitored. A committee, made up of the stakeholders (see the inter-ministerial circular), meets several times a year for a shared evaluation of the episodes treated with an Orange or Red colour level, or which should have been (we speak of Non-Detection in this last case "ND"). An annual report is published (posted on the Météo France website: https://meteofrance.fr/actualite/publications/documents-institutionnels/les-bilans-vigilance). Indicators have been defined. Some of them have a legal value (i.e. they are taken into account in the French State Budget). More anecdotally, some of them are taken into account in the calculation of the variable part of the remuneration of Météo-France agents! In particular, the following indicators should be mentioned for the phenomena of Wind, Rain, Thunderstorm, Snow or Ice and Coastal Event (on a departmental scale):

**− *The relevance rate.*** It measures the correspondence between the colour issued on a territory and the observation of the phenomenon (intensity, location, chronology). The complementary value corresponds to a False Alarm rate (FA, for example, a department was placed in Orange Vigilance, the expected phenomenon did not occur there or with a lesser intensity). In 2022, the relevance rate amounts to 87% for a target objective ≥ 84% (i.e. a FA rate of 13% for a target ≤ 16%).

**− *The Non-Detection rate.*** Defined above, in 2022 it is 1.4% for a target goal ≤ 2%. FA and ND are in a subtle balance. They depend on the quality of weather forecasts but also on the type of phenomenon, their occurrence (natural annual variability) and their predictability (localized severe thunderstorms are much less well predicted than a large wind-storm...). The target objectives also reflect a social acceptance depending on the state of the art of weather forecasting. Expectations may differ depending on the user! Thus, the general public is particularly sensitive to NDs and these can cause a strong backlash with a questioning of the forecasters' work. Crisis managers are more sensitive to false alarms because of the protection costs that may be incurred (wrongly).

**− *The Detection rates with at least 6 hours and at least 3 hours lead time.*** They reflect the time between the issuance of an Orange or Red Vigilance and the actual onset of an event. In 2022, they are 74% and 90% respectively for targets ≥ 60% and 86%. There is a strong relationship between sufficient anticipation and forecast reliability (in terms of FA and ND). Moreover, finding the right anticipation window can be a challenging issue: is it necessary (or useful) to issue an Orange Vigilance on a Sunday morning at 6 a.m. valid for a wind-storm forecast the next evening (Monday)?

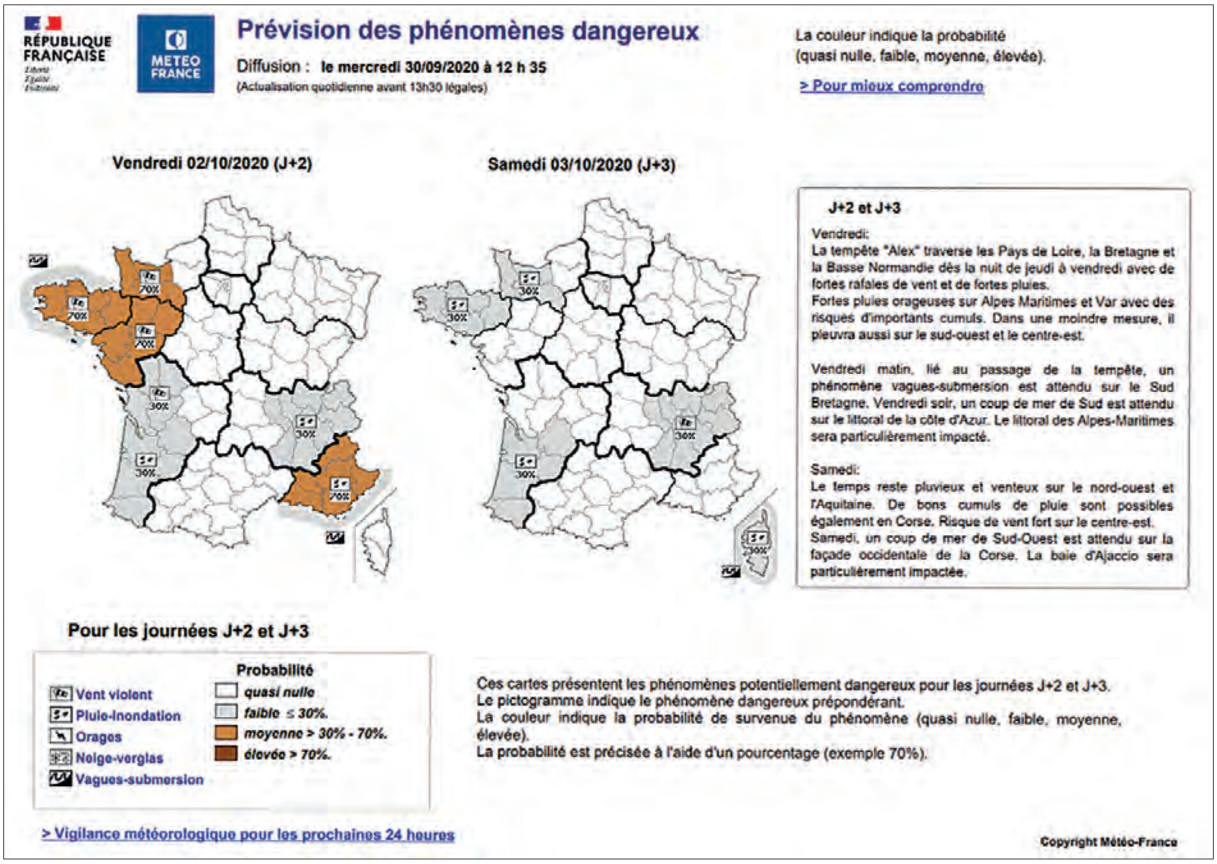
**− *Sub-departmental indicators for the following day (D+1) are currently being developed to take into accou***nt the changes in the Vigilance in 2022.

## Associated products

− The production entitled Hazardous Phenomena Forecast is designed to warn of the risk of *occurrence of hazardous weather phenomena*, defined as situations that may fall under Orange or Red Vigilance levels, in metropolitan France, beyond the deadlines covered by the Vigilance **(figure 3**).

It is provided daily (around 1:30 p.m.) and has been available since June 2020 in the tab "NEXT DAYS" of the website https://vigilance.meteofrance.fr/fr. The maps provide forecasts in the form of probabilities from the first day after the Vigilance covered period (D+2), and up to 7 days (D+7). The spatio-temporal scale is dilated with the deadlines. This approach makes it possible to take into account the uncertainty about the location, chronology and intensity of the targeted phenomena, which generally increases as the deadlines lengthen.

The probabilities are reliable in the sense that the values displayed correspond to the observed frequencies: thus, taking 10 cases with a probability of 30%, there are 3 Orange level Vigilance warnings, for the geographical location and the timeframe considered. The evaluations show very encouraging detection and false alarm rates.



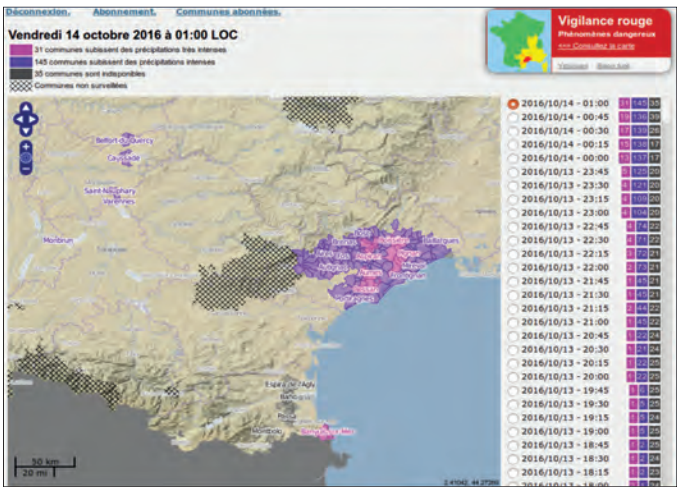

▲ *Figure 3: Example of the production realized on September 30, 2020 for the days D+2 and D+3 ("Alex" event). To be compared with the Vigilance map issued on October 2 at 6:07 a.m. for the corresponding day (Figure 1). Only some phenomena are covered by this production.*

- The Intense Rainfall Warning at a municipality scale (APIC) is an automatic precipitation observation product that aims to warn of an immediate risk of run-off or sudden water rises. It compares, in real time and at high frequency, the rainfall totals deduced from radars and rain gauges to local climatological references (at a kilometre resolution). When thresholds of 10-year (*intense rainfall*) or 50-year (*very intense rainfall*) return periods are exceeded, for time steps ranging from 1 to 24 hours, they are mapped **(Figure 4)** and subscribers are warned. This system must allow for placing the emergency within the framework of a Municipality Safeguard Plan ("Plan Communal de Sauvegarde -PCS-") which each French municipality must legally have. A similar product exists for flash floods (Vigicrues Flash).

## A universal system?

One sometimes wonders why such a simple facility (derived from a traffic light type of signal), immediately understandable and largely universal, did not appear more quickly in the history of weather warnings. This is probably due to a combination of factors, some of which have been mentioned in this article. The fact remains that this type of representation is reproduced (copied!) in many sectors of activity. Air quality, risk of pollen allergy, the Covid-19 pandemic (see "**The European Forecaster", Newsletter of the WGCEF N°25, September 2020**) or forest fire prevention are some examples.

In this last field, at a request of the President of the French Republic, Météo France is inaugurating this year (2023) a new production (called Forest Weather) for the general public. Indeed, in France, after a dramatic 2022 summer in terms of fires in natural areas (an article on this subject

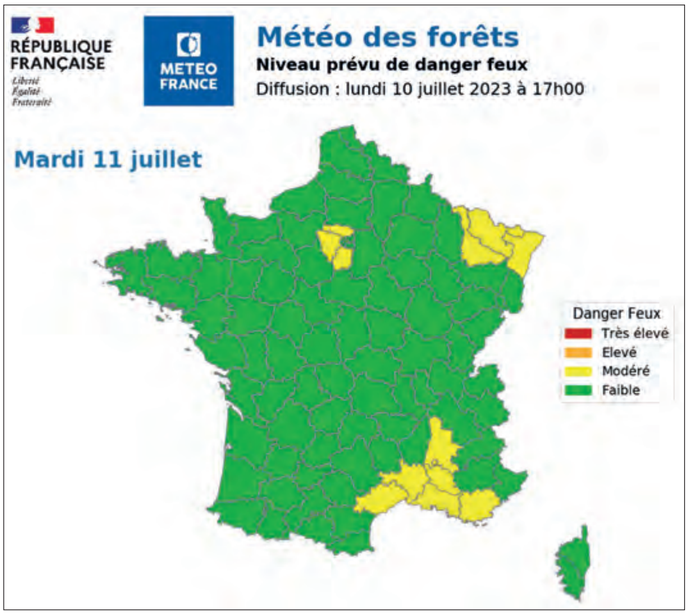



▲ *Figure 4: Example of an "APIC" map during a Red Vigilance episode on October 14, 2016. Municipalities affected by intense precipitation are highlighted with 2 colour levels (intense or very intense rainfall).*

will be eventually published in The European Forecaster) and in a context of increasing risk with climate change, maps adopting the symbolism of the Vigilance will be produced automatically (without human expertise in real time) and published on the institutional site of Météo-France (https://meteofrance.com, tab: Forest Weather). Between June and October, for the next day (D+1) and the day after (D+2), the French departments coloured in Green, Yellow, Orange or Red will warn of the fire danger (**figure 5**). This information should encourage caution in order to avoid fire outbreaks. At this stage, Météo-France does not wish to integrate this parameter into the Vigilance and insists on making it a separate element.

## Conclusion

Vigilance should allow each individual to be warned of his or her exposure to dangerous meteorological or hydrological phenomena and to adopt a behaviour accordingly. The system is an essential part of daily life and is widely known (CREDOC surveys: https://www.credoc.fr/download/pdf/Rapp/R308.pdf). It has become the basic tool for crisis management in meteorology and hydrology. Since its creation, this system has undoubtedly contributed to saving hundreds, perhaps thousands of lives. But as a victim of its fame, it is sometimes criticized for erroneous forecasts while competitors seek to imitate it. In the future, the challenges are numerous. Vigilance will have to maintain the confidence of the authorities and the general public as societal expectations continue to grow. The system will have to keep its simplicity, a guarantee of its effectiveness, despite a complexity that is increasing with more precise forecasts with ever more distant deadlines, but which will always include an element of uncertainty. Taking into account the consequences on the ground will have to be constantly improved. At the heart of this system, forecasters will have to process, with the same efficiency, an ever-increasing amount of data.




▲ *Figure 5: Example of a D+1 Forest Weather map. The presentation is very similar to that of the Vigilance.*

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# Biases in forecasts and being certain about uncertainty – why we need social scientists in meteorology

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When I joined the Met Office twenty years ago as a trainee weather forecaster, the prerequisites were a strong background in physics and maths, and the in-house training gave us a good understanding of the dynamics of the atmosphere. The emphasis was very much on the physical and natural sciences. My career in operational meteorology took to me to a variety of locations, working with a multitude of customers from numerous industry sectors, including military, retail, aviation, sport, energy, construction and media.

The question we were aiming to answer for our customers was 'what is the forecast?' However, as the years progressed so the question subtly changed, what people really wanted to know is what the weather will *do*, rather than what it will *be*. This required a shift from forecasting the weather to forecasting the impact of the weather. But even this does not give the full picture, what we really want to do is neatly summarised in our Met Office purpose, which is 'helping you make better decisions to stay safe and thrive'. This statement of intent puts *people* at the heart of our raison d'etre. When we produce a weather forecast, we're not doing it just for the sake of predicting a future state of the atmosphere, we're doing it because weather impacts us. It determines when we put our washing out, whether we wear a coat, our hobbies, our businesses and their operations, and our safety.

So, we need to use the science of people, something we have been rather slow to acknowledge. But there is now a growing recognition that the social and behavioural sciences are as important as the physical sciences that are more traditionally associated with meteorology. Social and behavioural science can offer insight all the way through the forecast process. Our operational meteorologists have vast amounts of data at their fingertips. How do they decide which data to look at, how to interpret probabilistic data, and what to do when data sources are conflicting? Are there human biases in the process? Answering these questions requires an understanding of decision science and cognition.

Cognitive biases explain ways in which human behaviour differs from rationalism, often in common and predictable ways. Why don't people take preparatory action, for example if they live in a flood risk area? This is called hyperbolic discounting, where people tend to prioritise immediate benefits over bigger future gains. Hick's Law tells us that more options lead to harder decisions, so weather warning advisory action statements must be few, clear and easy. People tune out to things they are repeatedly exposed to, named banner blindness, this is the danger of over-warning. People are more likely to take an action when the effort is small, termed the spark effect or principle of least effort, so in a weather warning we can highlight the easy and free actions first. Social norms mean people adapt their behaviour based on what others do, so if people around them are not following an evacuation order, then they likely won't either. And availability heuristic whereby people favour recent and available information over past information, so someone who has been recently flooded is more likely to take heed of a flood warning.

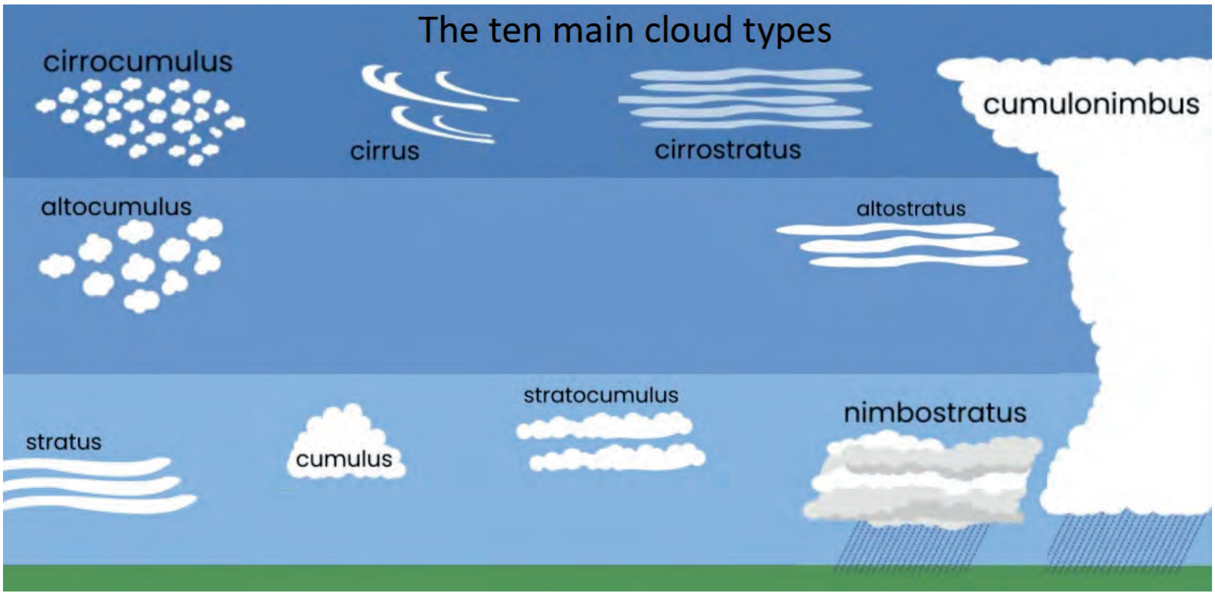
This summer, I took some experiments on the road. This included five Met Office Services Roadshows and the British Science Festival, at which I ran interactive experiments with various audiences to test contextual cognitive biases. Experiment #1 investigates *hyperbolic discounting, or present bias.* Participants are shown **figure 1**, they are told they have (hypothetically) won a holiday and are leaving today. They are at the airport and given the choice of two holiday locations. Both are five-star resorts. Holiday A will look much like the picture on the left when they arrive, with heavy rain today but becoming increasingly sunny through the week. Holiday B will look much like the right-hand picture on arrival, with lots of sunshine, but will gradually turn cloudier with rain by days 4 and 5. They are then asked which holiday they would choose?


▲ *Figure 1: Image used to test hyperbolic discounting.*

My hypothesis was that more people would choose holiday B, taking the sunshine sooner option, despite the fact that they get more sunshine with the first option.

Experiment #2 *tests availability* bias, whereby people draw on recently or easily available information to make decisions. Participants are divided into two groups; group one are asked to draw a cloud, group two are given a graphic showing all main cloud types (**figure 2**) and also asked to draw a cloud. My hypothesis was that group one would tend to draw a cumulus, with group two showing a wider variety of cloud types in their drawings.

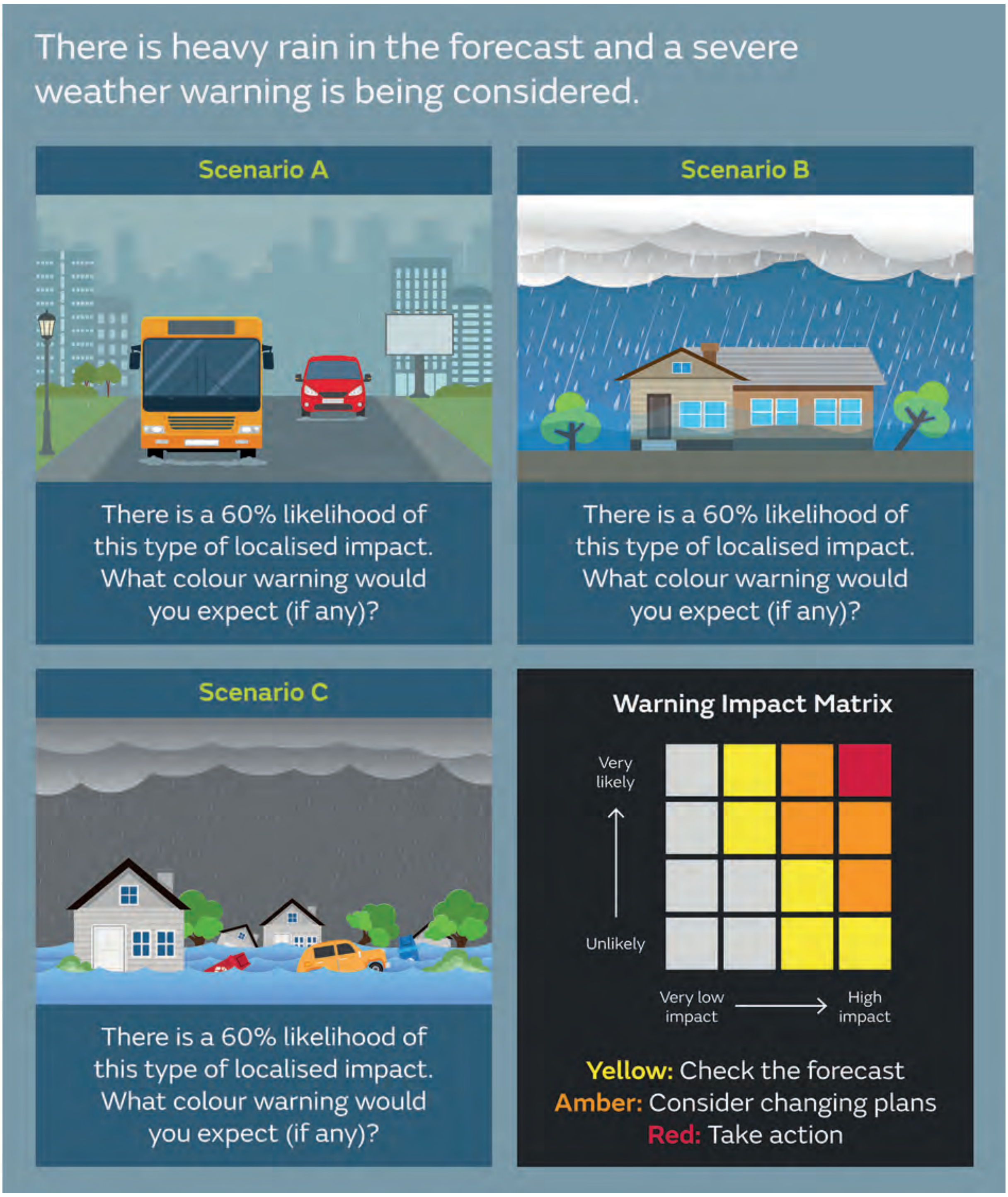
The *severity effect* describes the tendency for people to implicitly interpret probability expressions as more likely when they describe more severe or undesirable outcomes. Someone who




▲ *Figure 2: Image used to test availability heuristic.*

interprets a 'slight chance' of showers to mean a 1%–5% chance will likely interpret a 'slight chance' of a hurricane to mean something closer to a 10%–15% chance (Ripberger et al., 2022). This was tested by showing pictures of impacts varying in severity, accompanied with a probability to keep the base rate the same, and asking people what colour warning (if any) they would expect (figure 3). My hypothesis was that people would conflate severity with likelihood, creating a skew towards amber/red for impactful images regardless of likelihood. (Results will be analysed late 2023).

These are just a few examples of psychological biases, which aren't a problem in themselves, and fortunately we humans are quite consistent in our divergences from rationalism. So as long as we are aware of the biases, we can work around them and even use them to our advantage.




▲ *Figure 3: Image used to test severity bias.*

Behavioural insights research shows that advice should be listed easiest and cheapest first and be specific and actionable. It also tells us that in the case of heat warnings (as opposed to other weather parameters such as wind, snow, rain, fog etc) that people are more likely to act on behalf of someone else, so framing the advice in terms of helping vulnerable relatives and neighbours is most efficacious. This has the additional benefit that once people have taken this action, such as ensuring an elderly relative keeps their curtains closed during the day, drinks plenty of water, and doesn't go outside during peak daytime heating, they are then more likely to take that advice on board themselves.

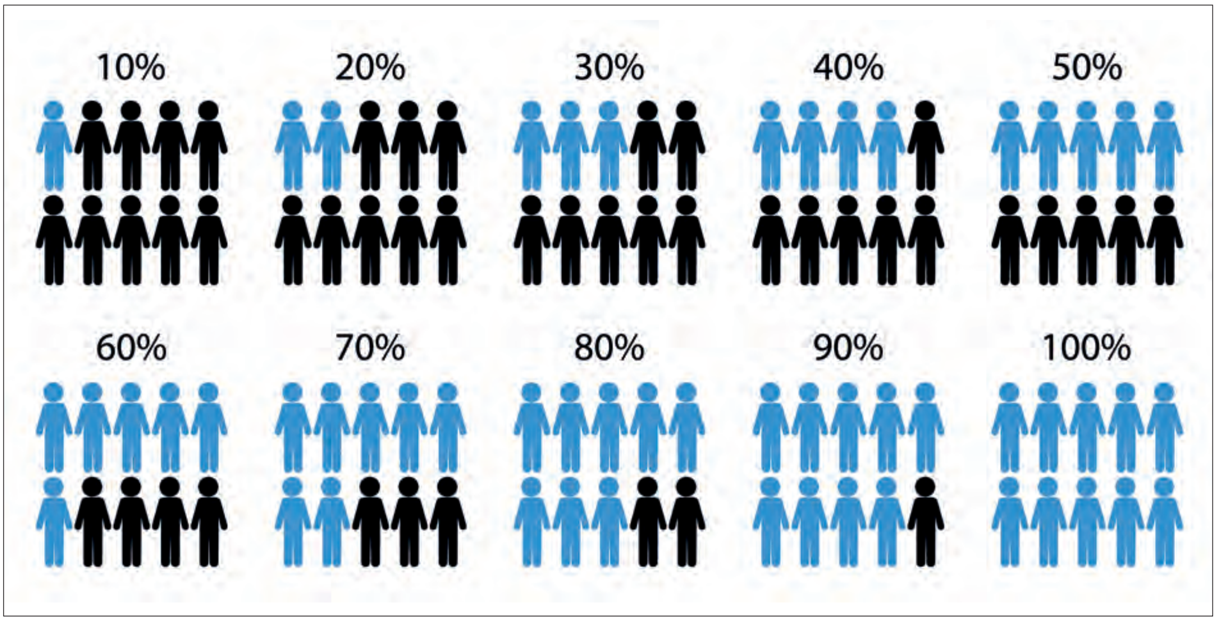
As the meteorological community continues to shift from deterministic numerical weather prediction to probabilistic solutions using ensembles, we continue to grapple with the most effective ways to communicate and visualise uncertainty. Evidence shows that meteorologists hugely underestimate the public's ability to understand and use probabilistic information. In fact, most people intuitively infer uncertainty even when given a deterministic forecast (Savelli and Joslyn, 2012), and as long as the information is presented in an effective way probabilistic information greatly improves decision-making, leads to greater trust and more understanding of forecast information (Ripberger et al., 2020). So it is a win-win. However, those caveats around the method of communication and visualisation are important.

Directionality can influence perception, positive statements that focus the probability that an event *will* happen, such as 'it is possible that the storm will affect town x' can cause people to overestimate the baseline probability of an event, whereas negative statements that focus on the probability that it *won't* happen - 'it is likely that the storm will miss town x' - can cause people to underestimate the likelihood of an event (Honda and Yamagishi, 2017). The trend effect is related to anchoring bias, whereby people are heavily weighted to the first piece of information they see. In the case of the trend effect it can mean people often interpret recent forecasts in light of past forecasts, so a 'moderate' risk, for instance, may cause more worry if it has been *upgraded* from a 'low' risk than if it has been *downgraded* from a 'high' risk (Hohle and Teigen 2015).

When it comes to expressing uncertainty using words and phrases, the literature clearly shows that it is always preferable to include a numeric 'translation' for any verbal probability expressions used, as words such as *possible, likely* etc are very subjective. And ideally, the number should be situated close to, or instead of, the verbal expression, so rather than 'thunderstorms are possible this evening', a better expression would be 'there is a 30% chance of thunderstorms this evening' (Wintle et al., 2019).

Regarding numerical representations of probabilities, the research shows that a simple percentage is most easily understood. Caution should be used against '1-in-x' formats, this is true both for this

▼ *Figure 4: Icon array showing proportion of a population*



context of a weather forecast (Ripberger et al., 2022), but also for framing events in relation to climatology such as a 1-in-100 year flood event, which has also been shown to cause confusion and possible assumptions that if a 1-in-100 year flood happened last year, it won't occur this year (or on fact for another 99 years), which as we know is incorrect. Finally, and perhaps most importantly, what does the research tell us about visualisation of probabilistic information? Unfortunately, the main takeaway is there is no 'best way', one size does not fit all (Ripberger et al., 2022). However, we do know that clarity and simplicity are key, we must not overwhelm the user with cluttered displays. Visualisations should be tested with the relevant audience before rolling out (Ripberger et al., 2022), and they must have explanatory labels and descriptions to avoid ambiguity (Okan et al. 2015).

Gist information is useful, such as icon arrays which provide more transparent representations of risk that generally promote higher comprehension (Dieckmann, Peters and Gregory, 2015). These are not often used in weather but are more common in the medical sector (**figure 4**). There is no reason why we could not find innovative ways to use icon arrays. Pie charts and bar graphs seem to be fairly well understood by the general public as well (Ripberger *et al.*, 2022).

Ensemble or simulation representations (**figure 5**) promote risk comprehension and awareness of unlikely (but possible) outcomes, but they may distract some people from scenarios that forecasters believe are most likely. Therefore, could be useful for high-impact events but less so for more routine weather (Padilla et al., 2017).

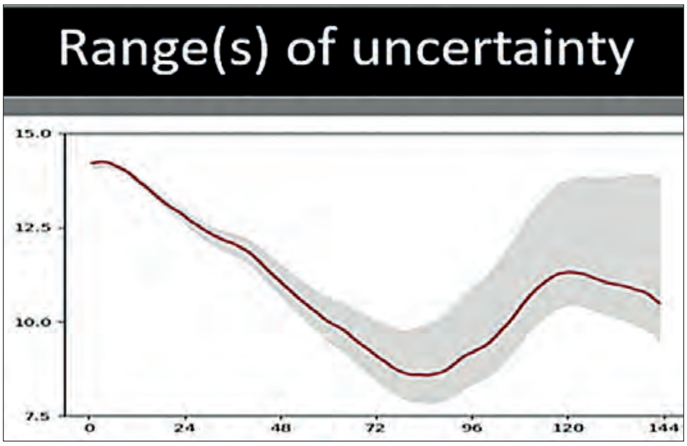
There is some limited evidence that polychromatic schemes work better than monochromatic, and warm colours indicate more risk than cool colours (Klockow-McClain et al. 2020), which makes sense at least in the western world where red is regarded as the colour of danger.

That is the theory, but my role is about putting theory into practice, using these insights and doing our own research to inform improved products and services for our customers. As part of our summer testbed, I was able to compare the decision processes of operational meteorologists who had access to either deterministic model data only, probabilistic (ensemble) only, or both, the results from these experiments will inform our move to ensemble only within the next few years, ensuring a smooth transition for our Operational Meteorologists as well as our customers.

I created a post-event analysis template that can be used after an impactful weather event to summarise the key lessons learned, with a particular focus on decision-making and the behavioural and societal response, which alongside our newly developed climate context documents will ensure we evolve our processes and ways of working so that we and our customers can better plan, prepare for and respond to extreme weather events.

Another key aspect of my job is to raise awareness across our organisation, and the meteorological sector more broadly, of the importance of the social sciences. I am using a multifaceted approach to this, including running a social science community of practice at the Met Office which has been in place for over two years now and has been extremely successful at encouraging engagement with the topic, as well as knowledge sharing and learning. This community is hosting a conference to promote the importance of integrating the social and physical sciences in the environmental sectors and the effective use of the social sciences in meteorology and climatology.

I could go on, but I will leave you to think about additional ways in which social and behavioural science can augment the physical sciences. Suffice to say, this is a rapidly evolving area that combines my three great passions of weather, social science and communication, and I'm delighted to be able to call myself the UK's first Socio-Meteorologist.




◀ *Figure 5: Range of uncertainty visualisation using ensemble data.*

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# Forecasting in the Arctic - Adventure and challenge

Robert Hausen, **German Weather Service**

## Introduction

The Alfred-Wegener-Institute for Polar and Marine Research (AWI) in Bremerhaven and the Maritime Competence Centre of the German Weather Service (DWD) based in Hamburg have forged a reliable and trused partnership, successfully working together for a number of decades studying and monitioring our earth systems. One of their most recent and ambitious ventures was the Multidisciplinary drifting Observatory for the Study of Arctic Climate (MOSAiC) project conducted in 2020.

## MOSAiC

The MOSAiC expedition was a € 140 Million scientific research project, designed by an international consortium of leading polar research institutions, to investigate the physical, chemical and biological processes that coupled the Arctic atmosphere, sea ice, ocean, and ecosystem during the freezing to melting season in the Artic circle. The MOSAiC project was a 1 year study that used a modern research icebreaker ship, the Polarstern, laden with scientific instruments to conduct this study.

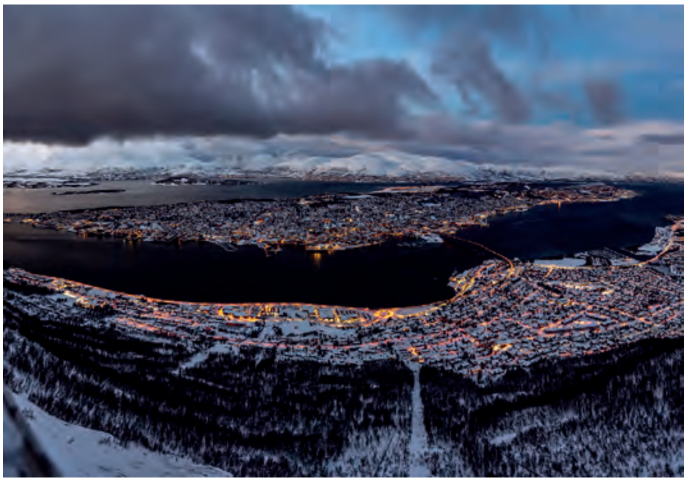
An experienced team of weather forecasters and scientific technicians formed part of the crew on board the expedition the MOSAiC expedition, launching radiosonds, controlling data, maintaining sensors and providing a variety of advisory forecasting products.

It was a win-win situation for both the forecasters and the scientists. The forecasting team provided meteorological advice and guidance to maintain colleague safety on board and allowed scientists to plan future fieldwork activities more effectively, saving time and money. In turn, the forecasters onboard were able to gain real time verification of their own maritime and aviation forecasts seeing for themselves as the changes occurred.

The MOSAiC project was divided into six parts (legs) due to extreme weather conditions. Together with my partner Christian Rohleder, we participated in the Leg 3 of the expedition, running from the end of January until beginning of April 2020.

## Transit to Polarstern

At the end of January 2020, we gathered in TromsØ, Norway in order to get the final instructions before departure. It was the first meeting from all the different disciplines with institues coming from Europe, Asia and the US. I've never been in TromsØ before and must admit I was really impressed. Coming from a mild winter in Frankfurt (Germany) it felt great waking up in a winter wonderland and snow was a great introduction to the wintery conditions to come during our upcoming trip.



▲ *Figure 1: View on TromsØ in the late afternoon, 24.01.2020*

Before we even started we had our first unexpected delay. The ship we expected to take on the expedition was not available and in its place *Kapitan Dranitsyn* ship normally used for tourist trips on Russian rivers during winter was swiftly arranged on short notice as an alternate for us. During this time we met with a number of Russians who were very friendly and polite. In fact, we had a lot of fun with them, competing with them in tough and sweaty table tennis matches. Unfortunately, surreal and unimagenable nowerdays…

After one week we went to sea. It was so bumpy alot of people got seasick. Learning from previous experience, I placed a special plaster behind my ear, which dims the balance feeling and reduces the sickness. One and a half days later we reached the ice edge and the waves stopped immediately. Communication was very restricted. We could WhatsApp, but if you intended to chat, you had to wait. Large photos and videostook a full day or more to come through and this became quite annoying.

During this time when communication was limited, it was best to fill your time with sports, quiz evenings, presentations and movies. The general mood was good and the team spirit grew over time. You could take a walk out on deck but you had to cover your face during these walks  as the outside air temperature was less than -20 degrees! It was permanently dark during the polar night and this made us all very tired. We slept on average 10 to 14 hours per day.

Approximately 200 km away from the North Pole at around 88°N we finally saw a dimmed light near the horizon. That was amazing, we had not seen any light during winter season. On first view the bright spot was rather small but getting closer we realized that we finally made it to the *Polarstern!*

As soon as we disembarked the *Kapitan Dranitsyn* we conducted the meteorological handover with our colleagues from leg 2. They outlined the advantages and disadvantages of the models and shared their experiences in different weather situations which was crucial for our future success in Leg 3.  We were now in charge and it got serious!

▲ *Figure 3: Handover of the forecasters Leg 2 (Julia Wenzel/DWD) to Leg 3 (Robert Hausen/DWD), 02.03.2020*

## On the floe

It was the coldest period of the entire MOSAiC expedition during our leg, and it lasted until the middle of March. The air temperatures fell below -40 degrees centigrade at 2 meters above ground (the all-time record at the "MET-City" part of the Ice Camp was -42.3 degrees on the 4th of March).

Due to a very strong inversion close to the surface the temperatures in the crow’s nest (29 m from the ship surface) there was 5 Kelvin difference between the air temperature at 2 m above the ground surface and the air temperature up in the crows nest, with the nest being warmer.

◄ *Figure 2: Kapitan Dranitsyn in the Arctic during polar night on the way to Polarstern, 06.02.2020*

Despite almost calm conditions, the wind chill was between -50 and -60 degrees (minimum -61.2 degrees) causing frost nips and bites within only a few minutes on unprotected areas of skin. The extremely cold temperatures were threatening cargo and scientific operations and it was challenging for people. The Pistenbullies and Skidoos were not working properly anymore, the oil became solid and stuck. Crane operations were halted below -30 degrees and Helicopters were not able to fly at temperatures below -35 degrees as their temperature operating limits had been reached.

▲ *Figure 4: Exchange between Kapitan Dranitsyn (left) and Polarstern (right) Leg2 to Leg 3 in spring, 05.03.2020*

As we moved into spring, the stormy season started very early. As a result, there was a high demand on weather information on board and we became very busy. Each day started at 6 AM in order that we could successfully prepare materials for the big weather briefing scheduled for quarter past 8 with the captain, chief scientist, logistic managers and pilots. The amount of met work in the morning depended on the planned activities and current weather conditions. After a short break for lunch the evening report with graphical outputs, a PowerPoint presentation for the science meeting and an update on the development in the next days had to be made. You'll never get bored. Day-offs were rare and only happened if you had agreement with the master and chief scientist.

Two types of storm tracks were the most common. Either a storm over the Atlantic Ocean took a swing via Svalbard or Franz-Josef-Land into our direction or it turned southwards from the Bering Strait and passed over northern parts of Canada. No matter the track, it always caused a widespread storm field, horizontally extending over several hundreds of kilometers, which was very impressive. During these storms it took a while for the winds to die down and for blown snow to settle on the ground once more. It was important to carefully consider the winds in the surrounding areas and how they might develop whilst forecasting as these had a direct and major impact on visibility both on the ground and in the air.

## COVID-19 and other challenges

One day an unusual and shocking message from home arrived on the ship. Usually, we received the daily news from the day before  through a common newspaper or via download video of german TV news ('Tagesschau'). But this kind of message changed everything. It was the speach of the former german chancellor Mrs. Angela Merkel explaining the serious spread of a new virus called COVID-19 or CoronaVirus. Regions with higher numbers of infections back home were being locked down causing major restrictions on everyones human rights.

It seemed so surreal as we sat on board our ship at the end of the world  hearing how infections and fatalities were increasing day by day. Some people were kidding that we would be the only ones who would survive. Unbelievable!

After a while we realized that this pandemic would have far reaching consequences even affecting us. The spread of the virus heavily affected our planned return. One by one our planned transport home by either plane or icebreaker boats were cancelled due to this global crisis.

◄ *Figure 5: View on Polarstern with Helideck (green), in behind logistic area und measurements on the floe, 22.03.2020*

We did get some luck. A short part of the runway was repaired during the stable winter season that allowed Twin Otter aircraft to land and were able to evacuate a small number of people that had very urgent issues to return back home immediately. Organizing this evacuation event was a challenge and a masterpiece by all involved authorities.

At the same time as this emergency pick up, the weather conditions had been very challenging. An almost stationary intense low near Spitsbergen caused strong NEly winds of Bft 6 to 7 with multilayered clouds and long-lasting snowfalls were occurring.

The wind speeds exceeded the threshold of 25 knots, causing drifting snow to become blowing snow. This in combination with the snowfall already falling caused whiteouts. Any weather improvements were not expected for days and everybody involved was put on standby which was very stressful and frustrating for some.

▲ *Figure 6: 'Evacuation' of heavy equipment from the floe with helicopter, 25.03.2020*

▲ *Figure 7: Open leads with sea smoke around Met City, 23.03.2020*

As the end of our leg came closer, large amounts of technical equipment on the floe was recovered. There were three weeks of delays in picking up the equipment and as a result some autonomously measuring instruments were left on the floe for Polarstern to take care during leg 4. Helicopters were used to evacuate the heavy huts and to do the final scientific flights.

On Wednesday 13th of May, only a few days before the scheduled departure, a powerful storm hit. The pressure fell to 965 hPa over Spitsbergen. In terms of extreme weather events during MOSAIC it was the dramatic end of the extended leg 3 beating all previous records.

Average 10-minute wind speeds recorded during leg 1 were: of 22.9 m/s (Bft 9) on the 16th of November 2019, and during leg 2:  21.4 m/s (Bft 9) on the 1st of February. We easily exceeded those values with 25.1 m/s (low Bft 10) in the morning hours on the 13th of May.

At this time, persistent easterly winds moved mild and maritime air masses towards the floe, clearing the cold pool over the central Arctic. This was the beginning of the summer season with temperatures now between 0 and -4 degrees. Due to a positive radiation balance the lower troposphere was now only able to produce temperatures above -10 degrees. This rapid increase in temperature caused the breakup of the ice and led to an enhanced risk of fog.

## Return

On our journey to Svalbard an extended zone of high pressure caused only weak winds and enhanced risk of fog and low stratus. Coming closer to the end of May a well-defined low pressure complex established from Iceland towards the Frame Street. Located in front of that system, moderate winds from southeast came up and moved mild air masses with origin west of the Hebrides toward us. Therefore the temperatures rose to positive values with maximums around 2.5 degrees.

Observed precipitation turned from solid into liquid more and more often. Melt ponds formed and the snow layer became heavier but also thinner. It was essential to provide information concerning the ice situation based on satellite images in the visible channel with emphasized contrasts during that period of time. Unfortunately, often cloudy conditions inhibited an undisturbed view to the surface of the ice.

On Tuesday 2nd of June PM, we reached the ice edge and the day after we entered the Isfjord to meet and swap places with our leg 4 colleagues who were waiting on the research vessels 'Sonne' and 'Maria S. Merian'. After a few days handing over to our successors and refilling food and fuel the 'Polarstern' headed off to the MOSAiC floe once more, now filled with fresh scientists and crew on board.

The journey back to the floe for leg 4 was now much easier than it had been for us as the ice started to melt. Leg 4 returned to the original floe and proceeded to collect data until the floe reached the ice edge and finally dissolved finally at the end of July after 300 days of continuous scientific measurement

In the meantime, we headed for home. After a bumpy start with a sharp and nasty trough at the edge of a low near Svalbard coinciding with the schedualed mandatory resuce boat deployment safety exercise. I thought: "Today of all days!". But luckily the rest of our trip home was calm and we enjoyed the sunset view after numerous dark polar days. As we had no more (urgent) tasks to do, all the pressure and stress of the past month released leading into tiredness without any energy. That's why we spent those days watching movies, playing games and extended periods of sleeping. Then it was finally done! We entered the port of Bremerhaven on Monday, the 15th of June 2020 and were sent back to our families and friends. We had originally planned to be absent from home for 2.5 months, but this had turned into nearly 5 months! It was an overwhelming feeling to hug my family after such a long period of time. After a few hours it felt like I've never been away before, but it took a while to adopt and get used to the 'new life' with COVID-19 and all these circulating restrictions.

After we returned home, further north, Leg 5 seized the remaining time at the end of the arctic summer and beginning of autumn to investigate the area around the North Pole more closely, especially in terms of new freezing processes. They returned on the 12th of October which indicated the official end of the MOSAiC campaign.

▲ *Figure 8: View on MOSAiC floe during summer near 82°N, 30.06.2020*

## Summary

During the entire expedition approximately 150Terabytes of data with more than 10, 000 samples of ice, snow , water and air were collected and are under evaluation and will still be analyzed in numerous scientific disciplines and studies. This will take another couple of years. However some initial early conclusions were able to be drawn and were revealed in 2021:

- 25% reduction in ozone concentration, especially in April at 20 km height no ozone was meassured
- Sea ice is melting rapidly
  - Thickness has halved compared to 1880
  - Extent has halved compared to a few decades ago

It hurts to experience the unique environment of the Arctic that closely, knowing that it will most likely be a lost in this rapidly changing region of the world. Despite of all these circumstances, we will never forget this expedition and especially the positive memories, experiences and impressions will remain.

From my experience as a forecaser during leg 3 (March-May 2020): I outline the following pros and cons of the IFS (ECMWF) and ICON (DWD) models for forcasting weather in the extreme northern hemisphere.

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*https://mosaic-expedition.org/expedition/*
*photos: ©Christian Rohleder (technician and meteorological assistence on board/DWD)*

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