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Overview of current operational sub-seasonal and seasonal forecast products and services and how they are used at StormGeo and MET Norway

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Abstract The report is providing a baseline overview of current operational sub-seasonal and seasonal forecast products and services and how they are used at StormGeo and MET Norway. This is part of a deliverable in work package 3 in the Centre for Research-based Innovation Climate Futures.	
Keywords sub-seasonal forecast, seasonal forecast, probabilistic forecast, forecast uncertainty, teleconnections	

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Responsible signature

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1 Introduction

Issuing seamless weather – climate forecasts require prediction data from short-term weather forecasting and up to decadal predictions. These data are available from numerous sources. The confidence in the predictions varies depending on the source of - and the location of the predictions, in addition to the lead time. In traditional weather forecasting there is a general consensus that there is predictability up to around 14 days ahead. That there is predictive power also on longer time scales, has been shown in multiple studies (Hoskin, 2013; Mariotti et al., 2018; Meehl et al., 2021; Merryfield et al., 2020; Vitart et al., 2018; White et al., 2022). However, it is required to compile and present the predictions in new ways than what is done in the short- and medium-range forecasting (e.g., White et al., 2017, van Straaten et al., 2020). Seamless weather and climate prediction can improve the decision-making and planning across all timescales, contribute to protection of life and property together with facilitating a more sustainable environment, in addition to an enrichment of socio-economic well-being (White et al. 2017).

This report is written as part of a deliverable in Climate Futures, with the purpose to provide an overview of sub-seasonal and seasonal forecast products and how they are currently used operational in Norway. Climate Futures is a Centre for Research-based Innovation (duration 2020 – 2028, and partly funded by the Norwegian Research Council, see www.climatefutures.no) where the Centre is tailoring 10 days to 10 years climate predictions for various partners in climate- and weather-sensitive sectors. StormGeo and MET Norway, partners in Climate Futures as user and research partner, respectively, are the only two institutions in Norway that today are issuing public weather forecasts operationally. StormGeo is producing daily forecasts up to day 10, and in addition optimising weather-exposed operations for various clients (e.g. shipping, energy, etc., see http://www.stormgeo.com). MET Norway is responsible for the public meteorological services for civil and military purposes in Norway, and they work with authorities, industry, institutions, and the public with the mission to protect life and property (http://www.met.no). MET Norway is also tailoring forecasts for the energy sector. Note that as part of Climate Futures, seasonal predictions are launched semi-operationally on https://klimavarsling.no. These predictions are described in a separate publication (see Lenkoski et al., 2022).

The report is first presenting an overview over the available prediction data and the various sources of predictability on sub-seasonal and seasonal timescales. Then a more detailed description of the use of these predictions at StormGeo and MET Norway is given. The report ends with a summary and outlook about how the use and tailoring of sub-seasonal and seasonal predictions can be done in collaboration between Climate Futures, MET Norway and StormGeo.

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2 Models

Weather and climate predictions from days to seasons are produced by various global prediction centres and available to the weather services and forecasters from several different data and products. We are here describing the prediction models (and the source of data) used at MET Norway and StormGeo for the medium-range, extended-range and long-range forecasting:

- Medium-range: 10-15 days forecast, providing weather information on sub-daily timescales.
- Extended-range: 6 weeks forecast, providing weather (and climate) information on monthly or sub-monthly timescales. Also called monthly or sub-seasonal to seasonal predictions (S2S).
- Long-range: 6 month predictions, providing climate information on monthly and seasonal timescales. Also called seasonal forecast.

The model data used for the different time periods are described briefly below.

2.1 10 to 15 days forecast models

For the 10 to 15 days forecast, deterministic and ensemble data from the European Centre of Medium-Range Weather Forecast (ECMWF) model are used as the main data source, and the American GFS model is used as a supplement. Both models are updated four times a day (00, 06, 12 and 18 UTC), but the model run at 06 and 18 UTC from the ECMWF model only covers the first 72 hours. The forecasters have access to these forecasts through in-house downloaded data (only the ECMWF-simulations), but also the chart browsers at https://www.ecmwf.int/en/forecasts and https://www.wetterzentrale.de can be used.

2.2 Monthly data models

The extended-range forecast, referred to as sub-seasonal-to-seasonal (S2S) timescale, is aiming to fill the gap between short- to medium-range weather prediction and long-range seasonal predictions. Large databases of sub-seasonal hindcasts and forecasts are produced through projects such as S2S (Vitart et al. 2018) and SubX (Pegion et al. 2019). These databases are easily accessible for research purposes, but to get the real time forecast from the multi-models is more challenging. Meteorologists often choose only one model to use operationally, and forecasts from the Integrated Forecasting System (IFS) produced at European Centre for Medium-Range Weather Forecast (ECMWF; EC - extended) is typically used. EC - extended generates a 46 day forecast twice a week (on Mondays and Thursdays), and the first 15 days of the ensemble forecast is in line with the medium-range forecast (at resolution about 16 km), then from day 15 the forecast is re-initialized by the IFS at a lower resolution (about 32 km) and extended out to 46 days. Note that in 2023 it is expected that the EC - extended forecast will be updated to be produced on a daily basis (see ECMWF in focus, April 2022). The forecast can easily be accessed through the ECMWF forecast chart page, where the model fields are typically shown as weekly anomalies or with some probability distribution for certain events. The NCEP-CFSv2 is another model that is producing sub-seasonal predictions. Even though the update frequency of CFSv2 is higher (run 4-times per day), it is mainly used as a supplement to the ECMWF forecast. Moreover, the graphical products published on the official site are not tailored towards Europe (but can be good to assess teleconnections and other regions). Some privately run sites, like www.tropicaltidbits.com, have better graphical representations of the NCEP-CFSv2 model. The EC - extended forecast is part of the S2S database, and the NCEP-CFSv2 is part of the SubX-ensemble.

2.3 Seasonal data models

The World Meteorological Organization (WMO) has designated 14 centres that provide global seasonal forecasts on a monthly basis: ECMWF and UK Metoffice (England), ECCC (Canada), NCEP (US), JMA (Japan), Meteo-France

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(France), CMCC (Italy), DWD (Germany), HMCR (Russia), BCC (China), KMA (South-Korea), South African Weather Service (South-Africa), CPTEC (Brasil) and BoM (Australia) (see Bojovic et al. 2022). The seasonal data are available at the WMO Lead Centre for Long-Range Forecast Multi-Model Ensembles webpage: https://www.wmolc.org. On this web page the seasonal forecasts are published as soon as they are available and cover the next six months. The user can choose to look at anomalies for a one or multiple months either from a single model or multi-models of two or more models.

Seasonal forecast data are also available at the Copernicus Climate Change Service (C3S) webpage: https://climate.copernicus.eu/seasonal-forecasts. This webpage includes seasonal data from the following eight data centres: ECMWF and UK Metoffice (England), ECCC (Canada), NCEP (US), JMA (Japan), Meteo-France (France), CMCC (Italy) and DWD (Germany) and is available on the 13th of each months. The model fields are shown only as three month anomalies, and as multi-model of all eight models or as single models.

Other sources to seasonal predictions are the North American Multi-Model Ensemble, which is an experimental multi-model seasonal forecasting system consisting of coupled models from US modelling centres including NOAA/NCEP, NOAA/GFDL, IRI, NCAR, NASA, and Canada's CMC.

In May 2022 The Norwegian Climate Prediction Model (NorCPM) started to produce seasonal predictions operationally, with the goal to be part of the C3S seasonal prediction models. These predictions are available through its own web-platform.

3 Sub-seasonal and seasonal predictability

3.1 Sources of predictability

Forecasting of the weather is an initial value problem, while climate projection is a boundary value problem. In between is climate prediction, which depends on both initialised processes and the boundary conditions. In this report, the focus is on sub-seasonal and seasonal predictions, and for this timescale the prediction skill depends on the model complexity and the initialised components. Predictions on sub-seasonal and seasonal timescales need to have the ocean and land coupled with the atmosphere, and each component should be initialised with the best estimate of the current state (Meehl et al., 2021).

Large-scale anomaly patterns in for instance sea surface temperature (SST) or atmospheric circulation, and how this is connected with the variability of weather and climate in remote geographical areas, is referred to as teleconnections. These anomaly patterns are typically given as time series and defined as climate indices (see here for a list of climate indices) which can be used as predictors to predict weather and climate in remote regions together with the dynamical models.

3.2 Predictions based on teleconnections and other predictors

In Figure 1, the sources of predictability (or predictors) for various timescales are shown. In the following we will briefly describe some of the phenomena and how they are connected to the sub-seasonal and seasonal weather in our

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region. For a more detailed description of the various sources of predictability, the reader is referred to Merryfield et al. (2020) or Meehl et al. (2021).

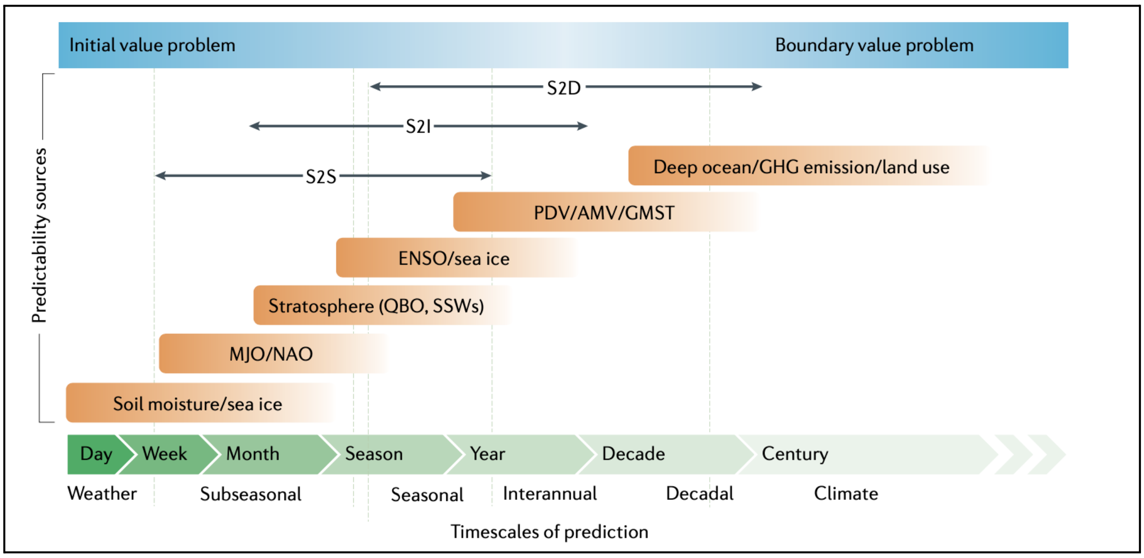

Figure 1 (from Meehl et al. 2021): Timescales and sources of predictability for sub-seasonal to seasonal (S2S), seasonal to interannual (S2I) and seasonal to decadal (S2D) timescales. Lighter green shading indicates larger uncertainty. AMV, Atlantic multi-decadal variability; ENSO, El Niño–Southern Oscillation; GHG, greenhouse gas; GMST, global mean surface temperature; MJO, Madden–Julian Oscillation; NAO, North Atlantic Oscillation; PDV, Pacific decadal variability; QBO, Quasi-Biennial Oscillation; SSW, sudden stratospheric warming.

3.2.1 El Niño-Southern Oscillation (ENSO)

The ENSO-system refers to the sea surface temperature in the tropical part of the Pacific Ocean. When the SST in certain parts of the tropical Pacific is warmer than 0.5 degrees of the normal, it is defined as an El Niño phase, and when it is cooler than 0.5 degrees of the normal it is defined as a La Niña phase. Despite the distance to Europe, there are some indications that there is a connection in the two different phases and strengths of the ENSO-system to the European climate, especially during the winter.

3.2.2 North Atlantic Oscillation (NAO)

NAO is a pressure index related to the pressure difference between Iceland and the Azores/Portugal area. A negative NAO tends to reduce low pressure activity into the Nordic and typically shift the low pressure track toward the continent, while a positive NAO tends to enhance the low pressure activity toward the Nordic (see Figure 2).

This is a popular teleconnection to use in Europe, though it should, as with all teleconnections, be used with caution. There are examples of a strong positive NAO and solid blocking high pressure over the Nordic (like in October 2016). Furthermore, NAO is very dependent on the pressure systems, which means that when it is forecasted, it has relied on where the model has positioned its low and high pressures. This means it is no more predictable in the monthly and seasonal aspects of the forecasts than the models' capability of forecasting the low pressure tracks and strengths correctly.

Still, it is a good indication of the main trends in the model and is one of the indices that are available in the seasonal models.

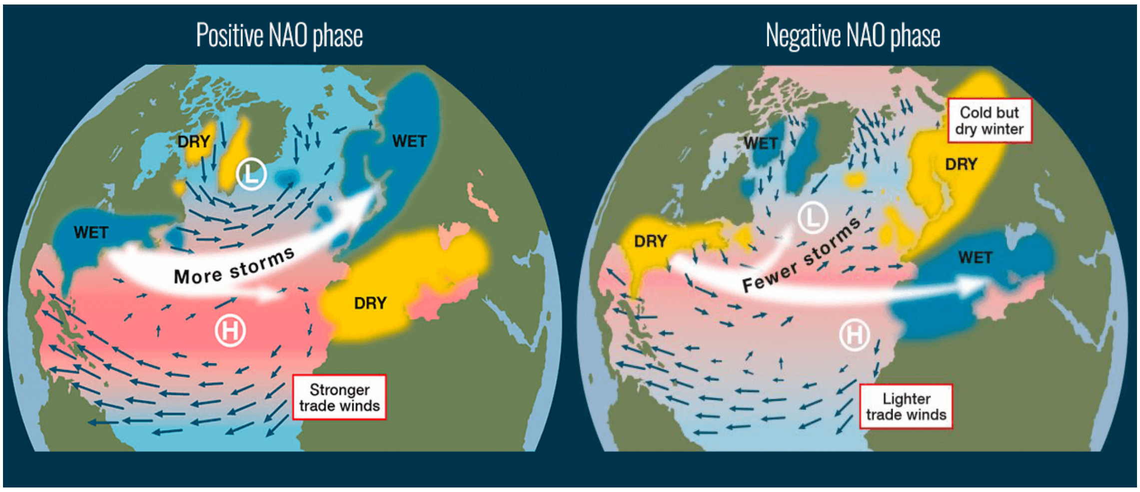

Figure 2: NAO-index and how the two different phases affect the weather in Europe. The figure is from the Severe Weather Europe webpage, available at the following link: https://www.severe-weather.eu/europe-weather/north-atlantic-nao-index-storm-mk/

3.2.3 Arctic Oscillation (AO)

AO is in many ways similar to the NAO, but is more general, as it relates to the pressure differences between higher and lower latitudes in the northern hemisphere. In a way, the NAO is a regional variant of the AO. Its phases give similar trends as the NAO phases, where a positive AO tends to favour more low pressure activity into Northern Europe, and a negative AO tends to favour less low pressure activity (Figure 3). It is also well correlated to the NAO, and they often move into the same phases, but not always.

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Both NAO and AO are primarily used in the shorter range of the long-range forecasts (10-15 days and monthly).

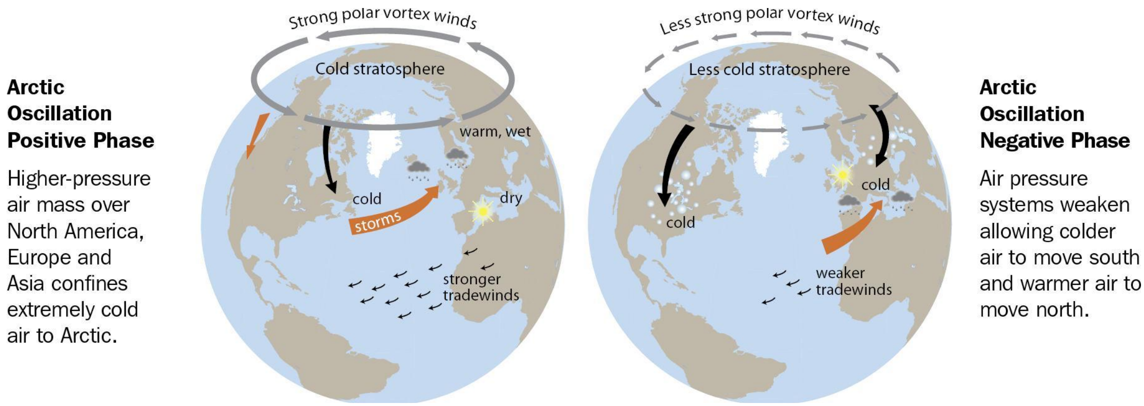

Figure 3: AO-index and how the two different phases affect the weather in Europe. This figure is from the Arctic Monitoring & Assessment Programme, available at the following webpage: https://www.amap.no/documents/doc/the-arctic-oscillation-and-circulation-positive-and-negative-phase/947

3.2.4 Atlantic Tripole

The Atlantic Tripole is a pattern in the sea surface temperature in the Atlantic. Like the ENSO-system it changes slowly and is fairly predictable over at least the next few months. Figure 4 shows an example of a negative Atlantic Tripole phase. For a positive phase, the warm and cool anomaly areas switch places (cool in the middle, warmer in the north and south).

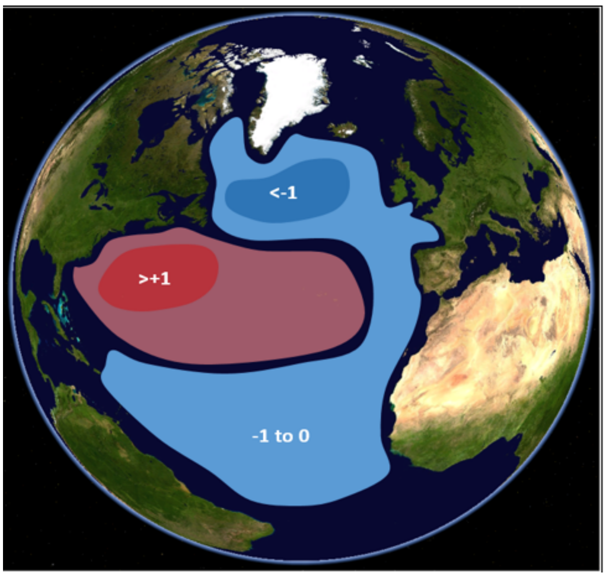

Figure 4: Negative Atlantic Tripole-pattern. Source: StormGeo.

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The negative phase tends to enhance low pressure activity (NAO more positive). A positive phase tends to decrease low pressure activity (NAO more negative), and increase the frequency of high pressures near Iceland, which gives more frequent cold events in Scandinavia.

The Atlantic Tripole is primarily used in the monthly and seasonal forecast.

3.2.5 Madden Julian Oscillation (MJO)

The MJO is referring to an area of enhanced convection and precipitation, moving east along the equator and using 30-60 days on a full round around the globe. The equator is split into 8 different geographical areas, and the phase of the MJO is defined by its geographical position. The strength of the MJO is defined by the strength of the convection. The phases and the strength of the MJO is displayed in a phase diagram as shown in Figure 5.

Despite this being a tropical feature, it can at times have strong connections to the weather development in Europe. The effect a particular phase can have on the weather is varying with the time of the year, and the effect can go from being very weak and non-existing to having a great impact on the weather development.

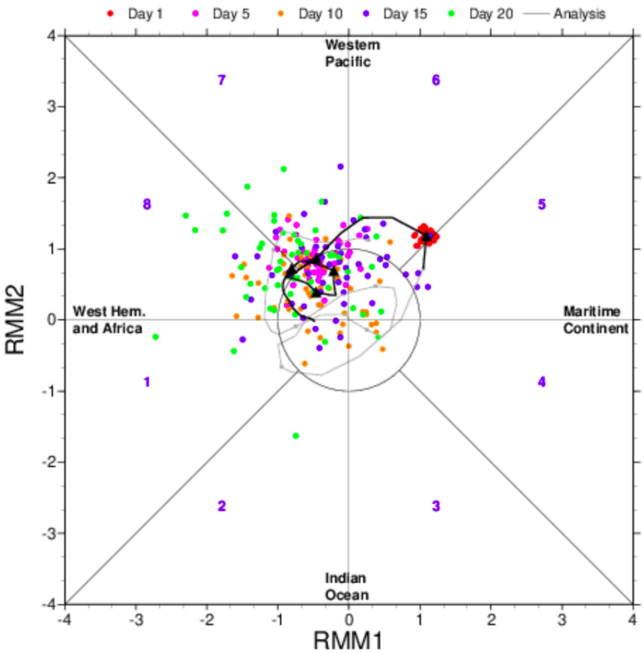

Figure 5: Phase diagram of the Madden Julian Oscillation (MJO). The figure is based on the ECMWF extended-range forecast and is available at the following webpage: https://apps.ecmwf.int/webapps/opencharts/products/mofc_multi_mjo_family_index.

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3.2.6 Stratospheric conditions

For the stratosphere, primarily the polar vortex from October to March/April are investigated. The strength and position, and partly the shape of the polar vortex influence the general weather across the Northern hemisphere, including Europe. Typically, when the polar vortex is strong and solid, there are more low pressure activity and stormy conditions, while the opposite is the case for a weak polar vortex. The extreme case is the sudden stratospheric warming (SSW) when the polar vortex becomes strongly disrupted and can lead to abrupt changes in the weather regimes to a typically calmer and more high pressure dominated type of weather regimes.

It is not only in times of SSWs that the polar vortex influences the weather. The low pressure tracks tend to follow the position of the polar vortex. If the polar vortex shifts toward Europe, it tends to push the lows in a more southern track, and if the polar vortex shifts toward Canada and Alaska, it tends to pull the general low pressure track northward.

Assessment of the polar vortex is used mostly for the monthly forecast from October to March, and to some degree in the 15-day period, especially if there are clear signs of changes in the polar vortex, like an SSW.

In addition to the polar vortex, also the Quasi-Biennial Oscillation (QBO), which refers to the stratospheric wind system over the tropics, are assessed. This changes direction around every second year (quasi-bi-annual), and can have a slight influence on the weather. Its signals are never particularly strong, but the two different phases (easterly phase or westerly phase) do to some degree influence the likelihood of SSWs. It is also fairly predictable into the seasonal aspect of the forecasts, and is a parameter that is used primarily in seasonal forecasting.

3.2.7 Solar radiation

The amount of solar radiation that the Sun emits, and the Earth absorbs, oscillates in an approximate 11-year cycle, thus changing very little from month to month. The forecasts are based on predictions from NASA, although the main trends are relatively predictable. The impact on the weather is generally quite low, but there are tendencies that vary through the year depending on where in the cycle we are. Typically, cold winters are seen slightly more often in the years of low solar activity, especially the more “extreme” winters.

3.2.8 October snow cover

The October snow cover extent in Siberia has shown to have possible impacts on the winter weather. Thus, this is only applicable for the winter season. Years of high snow cover in Siberia has a tendency of increasing the chance of a colder weather development in January/February, where complicated processes lead to changes in the stratosphere and the result is often a weaker polar vortex or a sudden stratospheric warming (SSW). Years of low snow cover in Siberia has the opposite effect, often resulting in a stronger polar vortex and milder/wetter conditions near the surface.

3.3 Analog method for forecasting

Analysing different teleconnections one by one to see if they return any usable signals is one thing, but what do we do when different teleconnections return conflicting signals, and also when the teleconnection signals differ from the dynamical models? The various teleconnections are not independent, meaning that some teleconnections might be interwoven in such a way that the phase or strength of one teleconnection defines or influences another.

One possible way is to look at teleconnections in relation to each other and find previous years that have had teleconnections in similar phases and strengths that we expect to see over the next few months, or are currently seeing. This must be used with caution for several reasons. As a rule, there will be very few years that have similar phases and strengths for all teleconnections we assess. Usually there will be one or two that do not fit any previous years. Another reason is that if these years are far back in time (especially before 1990, and perhaps even before 2000), one must ask oneself how much value these analog years have in a rapidly changing climate.

As for all teleconnections, analog years is a tool for the forecaster that must be used with caution, and mostly as a potential means to slightly change the probabilities of the different outcomes in a seasonal forecast.

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4 How sub-seasonal and seasonal data are used at StormGeo

Long-range forecasting in StormGeo is primarily focused on clients within the energy industry, especially traders and energy producers. Due to this, the main focus of interest has historically been Norway, Sweden, Finland and Denmark, but through the years increasingly more of the European continent as well, as the energy flow becomes more interconnected between countries.

StormGeo splits the long-range forecasting into three different time periods.

1. 15-day forecasts that are produced several times daily based on daily ensembles from ECMWF and GFS, in combination with any other relevant information.
2. 6-weeks (45 days) forecasts, historically the “monthly forecast” (4-week), that are produced twice weekly, following the cycle of ECMWF extended range model forecasts. These model runs are used in combination with other relevant information. StormGeo’s main sub-seasonal product is called Foresight45.
3. Seasonal forecasts, Foresight 180, that covers the next 6 months, or 180 days, based on a range of different seasonal models and other relevant information. This is produced once monthly.

Due to the uncertainty in long-range weather models, StormGeo is also putting a lot of emphasis on teleconnections and statistical measures to potentially identify scenarios and weather regimes that occur more frequently than others.

StormGeo's clients in the energy industry are well aware of the limitations in long-range forecasts. Even in situations where there really is no statistical significance for any given weather scenario or weather regime, or the general trend (e.g. milder than normal, normal temperature, or cooler than normal), the forecaster is expected to pick one scenario or trend that he or she believes to be more likely than others. The clients accept the uncertainties in long range forecasts, and that the forecaster's choice at times can be near impossible to make and very well can be wrong. The uncertainty in long range forecasts is usually communicated to the end user, usually by putting a percentage of likelihood on the different weather regimes or trends.

Producing forecasts for the three main time ranges (15-day, monthly and seasonal) are somewhat similar, but also quite different, and all of them involve a combination of interpreting model data, teleconnections and historical data. Typically, the 15-day forecasts rely much more on model data than teleconnections and the seasonal forecasts rely more on teleconnections than model data. For the monthly forecasts it can be more fifty-fifty but variable from week to week.

StormGeo indices

The energy industry is the main user of StormGeo's long-range forecasts. The focus of interest is precipitation and temperature, and increasingly also solar radiation and wind. In addition to displaying precipitation and temperature as anomaly charts, the results are displayed as calculated indices for both temperature and precipitation parameters.

This results in one single precipitation index and one single temperature index for all the Nordic, and another set of indices for the European continent. The precipitation index is based on areas that produce power. The value of each millimetre is transformed into a number in GWh using HBV models in different discharge areas, that considers elements as evaporation and runoff, and then the total number of GWh produced is calculated for all of the Nordic/Scandinavia region. This is presented either as GWh or as a percentage of the normal. The percentage of the normal is only using precipitation alone.

For temperature, StormGeo computes a weighted average, where the average is weighted against large population areas. This means that the temperature in southern parts of the Nordic will have much more weight than the northern parts as it has a higher population.

A wind index for the European continent is also computed.

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The single indices that are produced makes it quite easy to get a quick overview of how different weather regimes and teleconnections impact Scandinavia as a whole compared to the normal.

4.1 Models for different forecasting ranges

4.1.1 15-day forecasts

The 15 day-forecasts are produced at least twice daily and are focusing mainly on the last week of the forecast period. Already for this period there are variations that can lead to different weather scenarios that impact different parts of Scandinavia (and the European continent) differently. It relies heavily on the model ensembles, which StormGeo uses to create their own clusters. The reason StormGeo stopped using the automatically created clusters from ECMWF is that they are not consistent enough or clear enough for Scandinavia from one model run to the next. The clusters are created by analysing each single member of the ensemble, with focus on precipitation and temperature compared to the normal, combined with a visual interpretation of the main weather regimes in each member. For example, different low pressure tracks may give the same amount of precipitation in Scandinavia as a total, but will give large regional differences. Members that have a similar weather regime, giving a similar result in precipitation and temperature end up in the same cluster. Typically, there will be 4 to 6 clusters per model run.

StormGeo creates clusters for both ECMWF and GFS, but uses ECMWF as the main source, as it is proven to be more accurate. GFS can still be better than ECMWF in predicting certain weather regimes.

An example of the clusters is given below – the percentages next to the models refers to the number of members in that particular cluster, while the numbers next to the precipitation refers to the percentage of precipitation compared to the normal:

CLUSTERS DAYS 8-15

Cluster 1:

Northerly winds dominate. Nordics cold and dry all period. Conti cold or slightly cold, variable precipitation.

EC12: 49% EC00: 55%

GFS12: 42% GFS18: 45% GFS00: 45%

Weighted average: 49%

Scandinavia: Precipitation 10-70% - cluster mean 40% (days 8-10: 40% - days 11-15: 40%). Temperatures slightly below normal (days 8-10: near normal - days 11-15: slightly below normal)

…

Cluster 5:

Low pressure dominated with more than 200% of normal precipitation in the Nordics, wet on Conti as well. Cold or slightly cold.

EC12: 0% EC00: 2%

GFS12: 10% GFS18: 0% GFS00: 3%

Weighted average: 2%

Scandinavia: Precipitation 120-310% - cluster mean 230% (days 8-10: 130% - days 11-15: 310%). Temperatures slightly above normal (days 8-10: slightly above normal - days 11-15: slightly above normal)

4.1.2 Monthly forecast

ECMWF's 6-weeks forecasts are used as the basis for the Foresight45 product StormGeo produces twice weekly.

Regular anomaly charts for precipitation, temperature and mslp are assessed and used to get the main trend from the model. Quite often these anomalies will show the main trend of the models, but they also leave out plenty of important details regarding the certainty of the forecast. For instance, if the anomaly charts show a weak wet trend, is it because the majority of the forecasts are slightly wet or is it because a relatively low number of members are very wet, and the others normal to slightly dry? Or if there are no signals in the anomaly charts, is it because the model has near normal conditions as the main trend or is it just so uncertain that the average of anything from wet (or warm) to dry (or cold) cancel each other out?

Due to this StormGeo also looks at the individual ensemble members to get an overview of how the ensemble members are distributed. The image below shows an example of this. In this example we can see that 33% of the ensemble has a precipitation level around 50-80% of the normal, or that 59% of the ensemble in general is drier than normal, while only 24% of the ensemble

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members are wetter than normal weather. StormGeo does not create any clusters for the monthly forecasts apart from breaking it down into these intervals.

EC ENSEMBLE FOR SCANDINAVIA

Precipitation (% of the normal)	Ens.	Temperature (ºC of the normal)	Ens.
<20	2%	<-5	4%
20-50	24%	-5 to -2.5	24%
50-80	33%	-2.5 to -1	41%
80-100	12%	-1 to 0	12%
100-120	6%	0 to +1	6%
120-150	14%	+1 to +2.5	14%
150-200	8%	+2.5 to +5	0%
>200	2%	>+5	0%
Dry	**59%**	Cool	**69%**
Near normal	**18%**	Near normal	**18%**
Wet	**24%**	Mild	**14%**

EC ENSEMBLE FOR EUROPE

Precipitation (% of the normal)	Ens.	Temperature (ºC of the normal)	Ens.
<20	2%	<-5	4%
20-50	0%	-5 to -2.5	22%
50-80	6%	-2.5 to -1	22%
80-100	10%	-1 to 0	10%
100-120	10%	0 to +1	16%
120-150	12%	+1 to +2.5	20%
150-200	29%	+2.5 to +5	8%
>200	31%	>+5	0%
Dry	**8%**	Cool	**47%**
Near normal	**20%**	Near normal	**25%**
Wet	**73%**	Mild	**27%**

The tables indicates how the precipitation and temperatures are distributed in the ensemble members for this week.

Figure 6: Table of model ensemble distribution for precipitation and temperature in Scandinavia and Europe.

Other models are also taken into consideration, like the NCEP-CFSv2 model, but only the anomaly and/or probability charts are assessed.

4.1.3 Seasonal forecast

For the seasonal forecasts, or Foresight180, StormGeo uses a range of different weather models. These are all based on anomaly or probability charts that are available on the web, and includes the European ECMWF, the NCEP CFSv2, the UK Met Office model, the German DWD, the French Meteo-France model, the Canadian CMC, the European blend of models, C3S, and the North American blend of models NMME.

There are no additional details available for these models apart from the charts and to some degree some teleconnections, so individual ensemble members are not assessed. Figure 7 below shows a snippet of how this may look like.

MODEL	NORDIC			CONTINENT	
	T	P		T	P
ECMWF	SA	SA		A	N
CFSv2	A	A		SA	SB
Met Office	SA	SA		SA	SB
DWD	SA	SA		SA	SB
Meteo-France	SA	SA		A	SB
CMC	SA	A		SA	SB
C3S	SA	SA		A	SB
NMME	A	SA		A	SB
Forecaster	SA	N		SA	SB

Figure 7: Table of main trends for temperature and precipitation for a range of models, and the forecaster's conclusion at the bottom (SA = Slightly Above normal, A = Above normal, SB = Slightly below normal).

4.2 Teleconnections

Due to the model uncertainties in long-range forecasting, StormGeo also analyses teleconnections and statistics related to the different phases of each teleconnection.

Some teleconnections appear to have strong connections to different weather patterns all over the globe, including Europe. A certain phase of a teleconnection never gives a one-to-one relationship with a certain weather scenario, but can significantly increase the likelihood of the occurrence of a specific weather pattern when the conditions are right. Knowledge of when to use a certain teleconnection and when not to use it, is required.

Some of the teleconnections are changing slowly, or are changing in quite predictable patterns, which can make them fairly predictable into the long-range aspects of the forecast. This way they can be used to give additional information on the long-range forecasts, especially in times when the model signals are weak.

Monday to Friday StormGeo produces a Daily Teleconnection product that basically looks at a selection of teleconnections, their current phases and how they are expected to develop in the next 6 weeks. For each week, StormGeo looks at the historical weather for the same time of the year, 30-40 years back in time, to see if there are any dominant trends that tend to repeat itself.

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Each teleconnection is assessed by themselves, but StormGeo also looks at the combination of the teleconnection to see if there are analog years that can give an indication of how the dominant trends have been in years of several similar teleconnections.

4.3 The full assessment

Whether it is a 15-day forecast, a monthly forecast or a seasonal forecast, all relevant information is assessed together before the forecaster makes his/her choice. As mentioned before, it will more or less always be more than one possible weather regime that is outlined by the models and teleconnections for all the time periods, but occasionally some of the regimes will stand out as more likely, or at least have more support from both models and teleconnections, than others. At other times there are no clear trends at all, but in both cases, it is important to understand the uncertainty of the long-range forecast, and that it is all down to probabilities, and that even if one particular regime stands out, it does not necessarily need to be the one that end up being the correct one.

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5 How sub-seasonal and seasonal data are used at MET Norway

At MET Norway sub-seasonal and seasonal predictions are primarily used for two purposes; briefings for the energy sector with focus on relevant weather for the energy industry, and for internal briefings at MET.

Briefings for the energy sector are every weekday and focus on the weather the next 10 days with extended information on the coming six weeks on Tuesdays and Fridays. A presentation of monthly weather is also prepared and delivered twice a week to a few energy customers and it is also available for governmental agencies at the Halo Webportal.

Internal briefings are split into the monthly and seasonal outlooks/briefings. The monthly briefings take place every Tuesday, with focus on probability of various weather conditions the next 6 weeks. The seasonal briefing takes place once a month (on the third Wednesday of each month), where the probability for how the next months and seasons may develop.

The monthly internal briefings started in October 2020 with the purpose to prepare the meteorologist for what kind of weather to be expected in the coming weeks. The Norwegian Water Resources and Energy Directorate (NVE), the Norwegian Directorate for Civil Protection (DBS) and the Norwegian Public

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Roads Administration (Statens vegvesen) is also invited to these weekly meetings in a preparedness perspective.

The seasonal forecast briefings are rather new, and started in November 2021, and are only open for people at MET Norway. In addition to preparing the meteorologist for possible seasonal climate, these briefings are also considered as a practice for the meteorologist to start to use these data, which has not been part of their work tasks earlier.

5.1 Data sources

For the monthly weather forecast, the extended-range dataset from ECMWF, available at the following webpage: https://www.ecmwf.int/en/forecasts/charts, are used. Predictions from https://www.wetterzentrale.de/ is used as a supplement. For seasonal weather forecasts the ECMWF SEAS5 is the primary data source, but also the other models available at the Copernicus webpage (https://climate.copernicus.eu/seasonal-forecasts) or the multi-model forecasts of all eight models are used.

5.2 Weather variables and regions

The variables that are used for the energy industry depend on the region. Temperature and precipitation are important in Scandinavia, where information about rainfall, snowfall and snowline is important for the water reservoirs and hydropower production, and temperature is important for where people are living (the larger cities) to give information about heating energy demands. Variables that are of interest outside the Nordic countries are incoming solar radiation which is important for solar energy production and wind speed for wind energy production, where the latter is becoming more and more important. Since wind energy cannot be stored in the same way as water for hydropower production, good wind speed predictions are desired.

For the internal briefings, the main focus is on variables such as Mean Sea Level Pressure (MSLP), temperature at 2 metres (T2m) and precipitation.

5.3 Anomalies, clusters and ensemble members

At MET Norway the main focus is on anomalies from the variables described in 5.2, in addition to the geopotential height of at 500 hPa (Z500). Weekly clusters and [probability of weather regimes](#) produced at ECMWF, based on the extended-range predictions are used from week 1 up to there is no signal anymore (typically week 3-4) for the internal briefings. The clusters are split up into six seasonal climatological regimes, and the weather regimes have four predefined climatological regimes (NAO+, NAO-, Blocking and Atlantic ridge) and a no-regime (see [here](#) for an description, and example of the weekly clusters product is given in Figure 8). The advantage with using these products is that the probability of a transition from one weather regime to another can easily be seen. The weather and cluster regime figures are often used as a supplement.

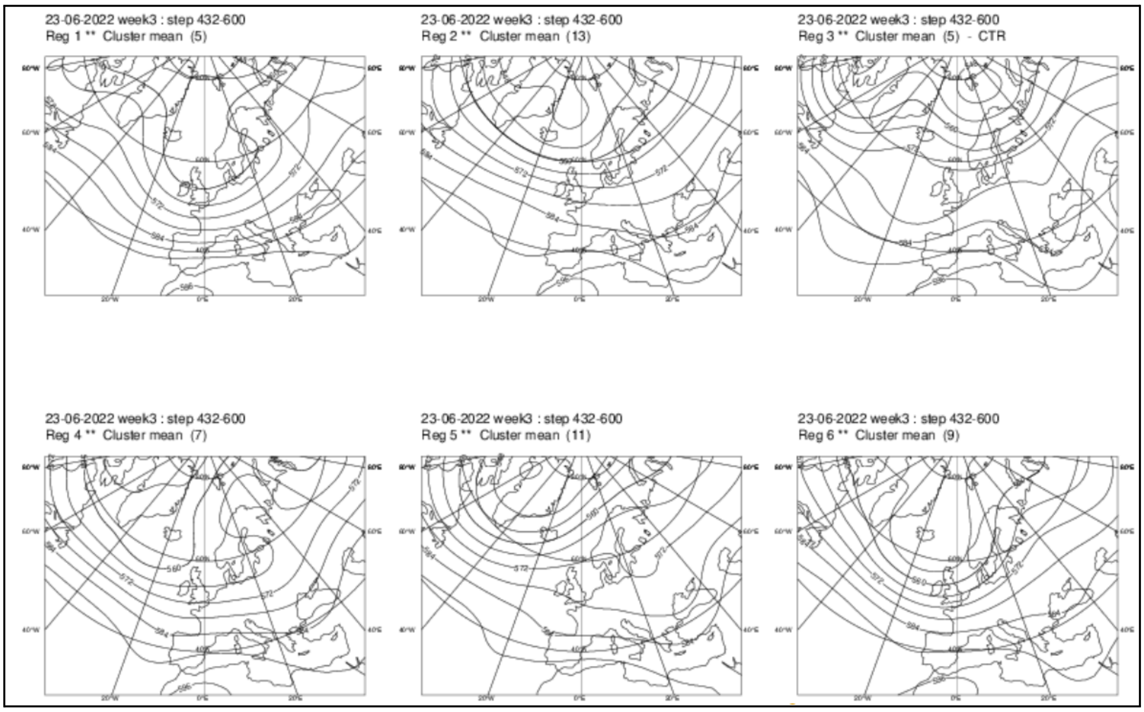

Figure 8: Example of model clusters from the extended-range data from ECMWF.

Individual ensemble members are not investigated for the monthly and seasonal forecast briefings, but the forecasters are taking into consideration the full ensemble by using probability of categorical events/percentiles, ensemble mean and spread and ensemble products such as CDF-plots.

5.4 Data products

For the monthly forecast briefings the plots of weather regimes probabilities and weekly mean anomalies of mean sea level pressure (MSLP), 2m temperature and precipitation are always included. Also products such as the MJO-index, weekly mean anomalies of 10 hPa temperature or 500 hPa height, mean zonal wind at 10hPa, EFI and CDF for temperature and precipitation, ENS extended meteograms and weather regime time series or clusters, are also included from time to time depending on the weather situation, but mainly for the internal briefings. Some of the monthly weather forecast products used are shown in Figure 9.

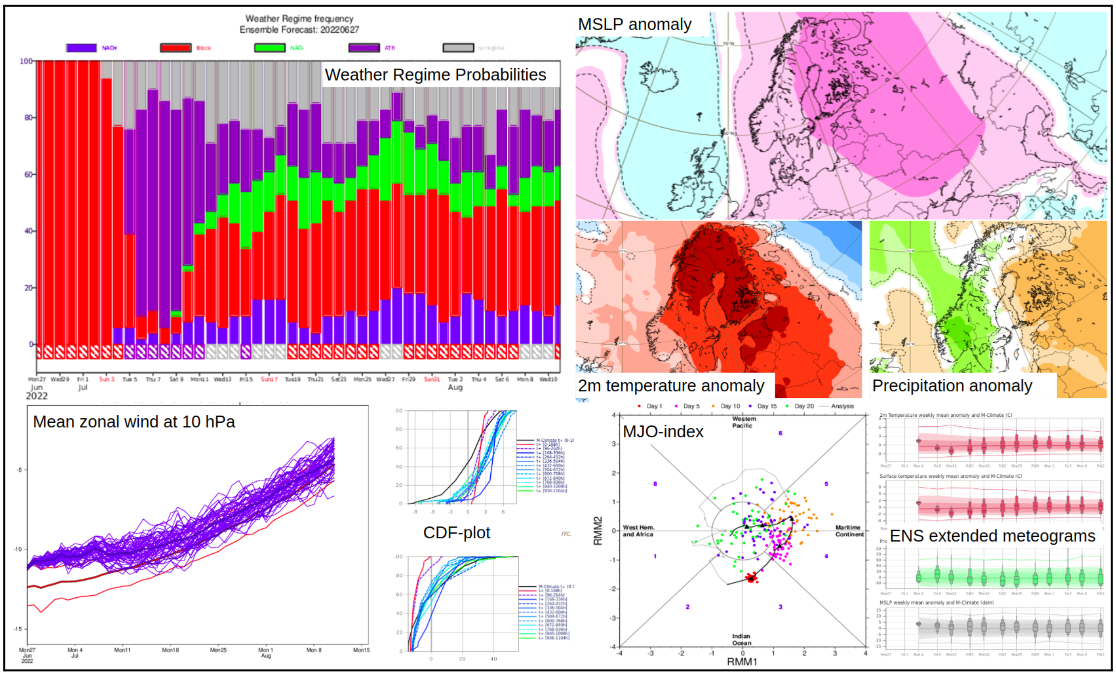

Figure 9: Overview of some of the forecast products used for the monthly forecast briefings. All products are from the ECMWF webpage.

For the seasonal forecast briefings the following products are always included: anomalies or probability (the most likely category) of SST, 2m temperature and precipitation, Niño-plumes and mean zonal wind speed at 10 hPa. In addition, observations and forecasts of the NAO- and AO-index, phase of the QBO-pattern, anomalies or probability (most likely category) of the 500 hPa height, area average precipitation or 2m temperatures and reliability diagrams are shown. Charts based on the ECMWF SEAS5 model are always shown and sometimes also charts from the multi-model ensemble C3S or even some plots from the different models available at the Copernicus webpage. Examples of some of the seasonal weather forecast products used are seen in Figure 10.

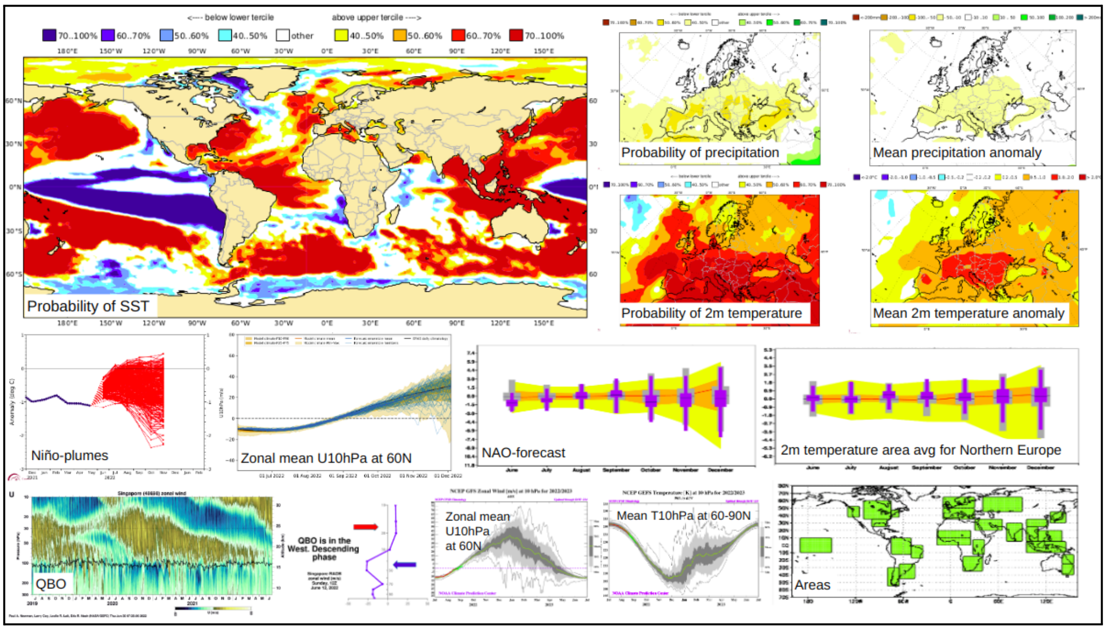

Figure 10: Overview of some of the forecast products used for the seasonal weather briefings. The model predictions are either from the Copernicus or ECMWF webpage, while some of the Teleconnections are from other webpages further described in Section 5.5.

5.5 Use of teleconnections and other predictors

To investigate the predictability, for the monthly forecasts the main focus is on the four weather regimes: NAO+, NAO-, Blocking+ and Atlantic ridge (Blocking-) used in weather regime probabilities (see Figure 11).

The stratospheric conditions are also investigated, especially during wintertime. For the strength of the polar vortex, the mean zonal wind at 10 hPa is used, while the weekly mean anomaly of 10 hPa temperature is used for the stratospheric cooling/warming.

In addition the MJO-index is looked into, but this is mainly included in the weather briefing when there is an interesting phase that is thought to affect the weather in Scandinavia, such as a strong phase 3, which gives a higher probability of a NAO+ regime after some time.

For the seasonal forecasts the main focus is on the ENSO - and NAO - pattern in both summer- and wintertime. For the ENSO-pattern the most likely category of SST anomaly and Niño3 SST anomaly-plumes available on the Copernicus

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web page are normally used. For the NAO-pattern, the six month forecast of the NAO-index available from the ECMWF SEAS5 model is shown.

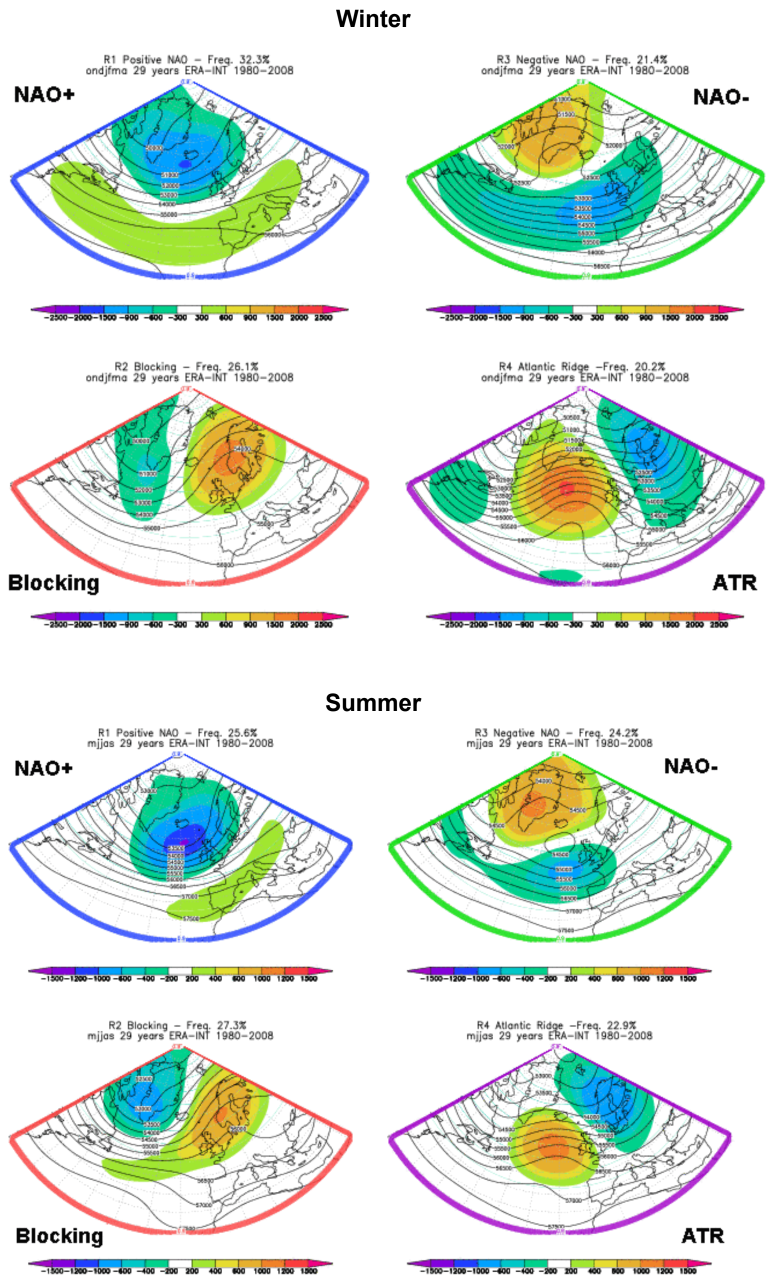

Figure 11: Overview of the four weather regimes: NAO+, NAO-, Blocking+ and Atlantic Ridge (Blocking-) for the winter season (October-April) at the top and summer season (May to September) at the bottom. The figure is from the ECMWF webpage and is available at this link: https://confluence.ecmwf.int/display/FUG/Regime+Charts?preview=/228872302/228872303/4Regimes_2up.gif

During wintertime the phase of the QBO pattern, the strength of the polar vortex and the stratospheric temperature conditions are also looked into. The phase of the QBO is available from the following web page: https://acd-ext.gsfc.nasa.gov/Data_services/met/qbo/qbo.html#singau3.

For the strength of the polar vortex, the forecast of zonal mean 10 hPa wind speed at 60 N is used. This forecast is either taken from the Copernicus web page which shows a six month forecast of 10 hPa wind speed together with the model climatology, or taken from the NOAA Climate Prediction Center (https://www.cpc.ncep.noaa.gov/products/stratosphere/SSW) which shows observations and climatology together with a 16 days forecast of 10 hPa wind speed from the GFS model.

For the stratospheric temperature conditions a forecast of 10 hPa temperature is used. The forecast is either taken from the NOAA Climate Prediction Center which represents a forecast of mean 10 hPa temperature between 60 and 90 N, or weakly forecast anomalies of 10 hPa temperature for the Arctic taken from the ECMWF web page.

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6 Summary and outlooks

In traditional weather forecasting, the meteorologist is considering the time-scale up to around day 14. However, in the context of the seamless weather – climate prediction, all time-scales should be considered (Hawkins, 2012). Even though there is potential predictive skill on all time-scales, the meteorologists rely most on the short-term and medium-range forecasts. Although models play an important part in all forecasting, it has its limits in long-range forecasting. The uncertainty in the forecast quickly increases and each model run produces a range of different scenarios with different probabilities. In contrast with short-range weather forecasts, which are often issued as a deterministic forecast, extended-range and long-range forecasts must be given as probabilistic forecasts. With the current technology and development in meteorology, and at least in the foreseeable future, this will continue to be the case. This means that the end-user will need to understand the difference between a deterministic and probabilistic forecast, which can be a challenge if the end-user is only used to reading deterministic forecasts.

Based on past experience from the meteorologists that have explored extended- and long-range forecasts, they trust the monthly forecasts more than the seasonal predictions. However, at MET Norway the seasonal predictions briefings are rather new, therefore not all of the meteorologists have long enough experience to get an impression about model skill.

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For the extended-range, the general comment is that the monthly forecasts can give useful information up to week three, before they typically converge towards the climatology. However, this is not always the case, therefore the forecast at all timescale needs to be monitored with caution. The forecasts show stronger signals for late fall and winter, while during summer the signals are weaker. There are some systems (e.g., the breakdown of the stratospheric vortex) that induces persistent weather patterns, which then extend the time the forecast can give useful information, but typically this is no longer than up to week four. One suggestion to increase the lead time skill of the monthly forecast, is to combine week 4-6.

One challenge with seasonal predictions is that the forecasts are normally averaged for three months (as on the C3S dataportal). This makes it difficult to communicate the forecast, since during that time period the forecast can hit and fail many times ("a lot of weather during three months"). Nevertheless, the seasonal predictions show some skill for temperature, but no or little skill for precipitation, is one of the comments from the meteorologists. The higher temperature skill can be due to the fact that we are in a warming trend, therefore it is easier to predict warmer than normal conditions.

Another challenge with compiling an extended- and long-range forecasts, is to understand when there is a clear signal in the forecast, and when to make a prediction based on the signals ("In retrospect, it is easy to see that there was a signal, but whether you would make a prediction/act on that signal, is difficult to know"). The signals that are often seen in the models, or even more so in teleconnections, may often not be statistically sound from a scientific perspective. However, some of the end-users, particularly in the energy industry, and even more particularly for energy traders, still need to make decisions based on these forecasts, regardless of the uncertainties. The energy sector, which can be considered as advanced (or expert) users, then turn to the weather forecasters, and expect them to make that choice for them, while understanding the high uncertainty and limitations of these forecasts. In this context, even a slightest weather trend suggested by a model or a teleconnection, or preferably the combination of both, will by these end-users be regarded as important information that they can use in their decisions.
Seasonal (and to a lesser degree sub-seasonal) predictions are perhaps more useful for expert users than for the general public, and it is today not clear how to use these predictions as a supplement to traditional weather forecasting. One

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major challenge in respect to this, is related to the intrinsic uncertainty in the forecasts - the meteorologists find it today difficult to communicate these forecasts in a good way. One goal when it comes to the use of sub-seasonal and seasonal predictions should be to understand when the forecasts have a high degree of certainty so the meteorologist can make a sound prediction and communicate this to the users, who can then make better decisions and plan accordingly. To have an objective toolbox with methodology and words/phrases when preparing and presenting the sub-seasonal and seasonal predictions, would help the meteorologist when compiling the forecasts and communicating the uncertainty and usefulness of these forecasts.

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