En-route Road Weather Forecast Service for the Icelandic Meteorological Office

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Author: Hróbjartur Þorsteinsson
Affiliation: bitVinci efh Iceland
Email: thorsteinssonh@gmail.com
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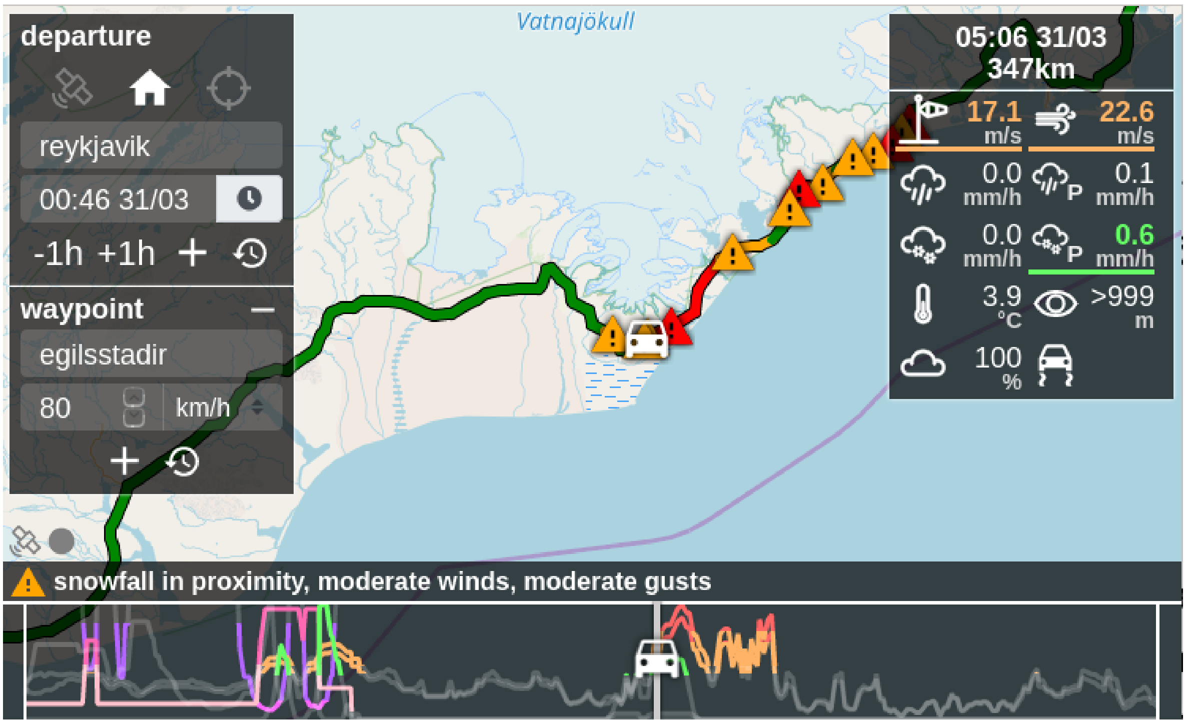

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IS: *Höfundar skýrslunnar bera ábyrgð á innihaldi hennar. Niðurstöður hennar ber ekki að túlka sem yfirlýsta stefnu Vegagerðarinnar eða álit þeirra stofnana eða fyrirtækja sem höfundar starfa hjá.*

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Introduction

In the last years the Icelandic Meteorological Office (IMO) has been working on further expansion and improvements of its weather forecast dissemination through a mobile map based interface. The IMO focuses on unifying access to the IMO weathers services under a single mobile friendly application, the Veður app, that is available in mobile app stores, but is currently being updated with new and improved features.

In 2018, the software company bitVinci ehf was established by a few software and meteorology experts with shared experience in forecasting and product development at the IMO. The first focus of bitVinci was the development of an en-route weather forecast service for ships. This initial work culminated in a web-service called SeaMon-API that provided maritime forecasts to front-end applications such as webpages and smartphone apps.

Through discussions and interaction with the IMO, it became clear that there was significant software and infrastructure overlap of the SeaMon-API system with a more general en-route weather forecast service that would also be able to include forecasts on roads. This opportunity, and declared interest of participation and support from the Icelandic Meteorological Office, culminated in this research and development proposal to the Icelandic Road and Coastal Administration (IRCA).

The project and results presented within this report address adapting and expanding the SeaMon-API service to en-route road weather forecasts and the development of a mobile friendly (responsive) user interface for trials with users in Iceland. The new web-service and the results of this initial user interface development are being adapted by Stokkur ehf for inclusion as a component in the IMO Veður app. Furthermore, the new SeaMon-API en-route weather service has been made public for Iceland, and can be accessed and used as a component in other services, such as any future applications developed for or by the Icelandic Road and Coastal Administration.

Use Cases

The first thing to consider before embarking on the development of a new type of service and software application, in this case a novel approach to presenting weather forecast to road travelers, is the question 'why?', why this new product and approach. What problems does this new product attempt to solve and for what kind of users.

In the case of the proposed en-route route weather forecast service, we can be divide potential users into two categories:

- **End-users** : Public users, wanting to get direct information about road weather conditions.
- **Third-party users** : Service providing entities such as road administrations, national weather services, and software companies wanting to provide or develop an improved or composite service based on the new product.

The **end-user** will require a complete and functioning application of the service, from data provisioning (web-service) to a complete front-end client application that helps the user visualize and interact with the service.

Third-party users will usually only require the data provisioning part of the solution, wanting to integrate the new data into their own portfolio of services and applications.

In the below lists we attempt to identify at least some of the envisioned applications of the service and improvements that an en-route weather forecast system can provide:

End-user

- Trip planning and expediency
  - Users want to plan their travels based on weather conditions along route without having to mentally envision their travel progress while flicking through multiple types of weather maps. The traditional weather map only holds about 3 types of weather parameters, and can only show each time step along route as a single image. Road conditions and dangers can however involve up to 10 or more forecast parameters. With an en-route weather service, the problem of identifying road conditions along route can be presented in a single visualization / forecast request.
- Information efficiency
  - Depending on the Internet connectivity, accessing and browsing traditional forecast maps can in some cases be difficult, especially in remote locations. En-route forecasts only fetch the relevant forecast data along the planned route, therefore reducing the data transfers by many orders of magnitude.
- Vans, trailers and special vehicles
  - En-route forecasts can be tuned to take account, and to highlight dangers specific to certain types of vehicles and modes of transportation.

Third-party

- Planning
  - Certain types of services rely heavily on weather conditions along road segments. A good example is planning for plowing of roads in the event of heavy snowfall and snowdrift along road segments. An en-route weather forecast service has the necessary features to help identify problems ahead of time along road segments without relying on shifting through traditional weather maps.
- Logistics

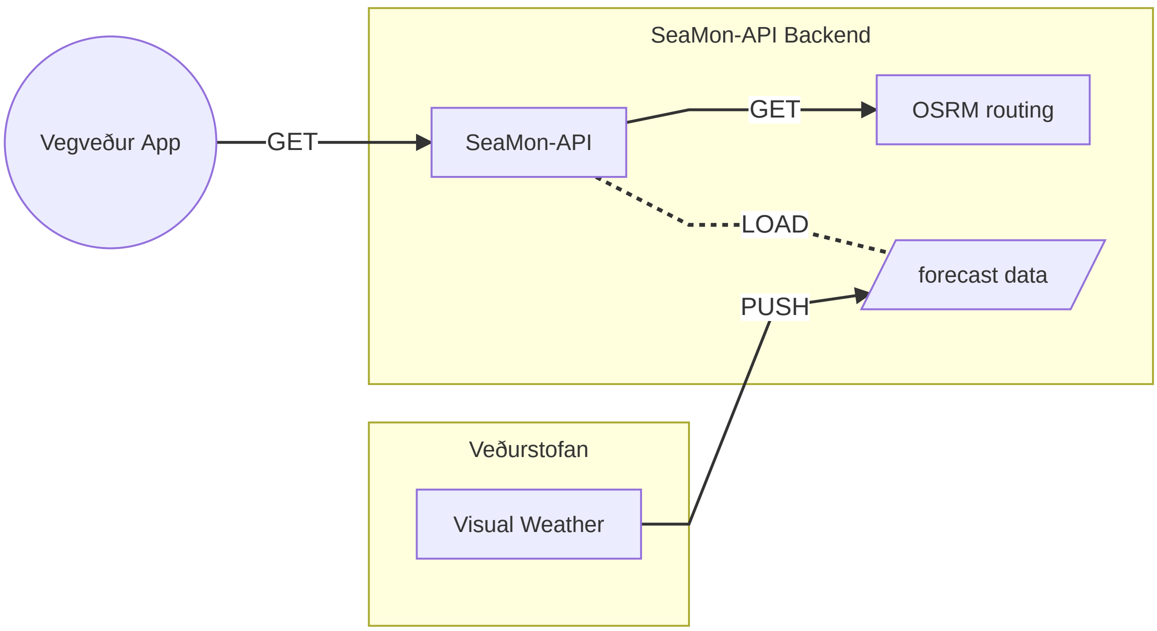
- Certain types of service providers transfer products and passengers along roads, and can benefit from forecasting delays or closures along certain routes in their transportation networks. Delays due to weather along one particular route can for example cause cascading effects on other transportation connections.
- National Weather Services (NWPs)
  - NWPs would like to improve access to their forecast products both for public end-users and other third-party customers.
- Road Authorities
  - Road authorities can benefit from being able to forecast road closures or delays in their road networks.
- Weather routing
  - Vehicle navigation providers (such as TomTom) can build more advanced routing applications that take account of detailed weather forecasts along road networks.
- Autonomous driving
  - Autonomous vehicles are currently under heavy development by many leading software and car manufacturers. Autonomous vehicles can be made more safe by being 'aware' of forecasted weather conditions along driving routes.

High-level System Design

In order to provide an expedient and usable en-route road weather forecast, three main components are necessary:

1. **High resolution weather forecast provided by a National Weather Service (Veðurstofan/IMO in Iceland)**
2. **Web-service back-end that accepts queries for weather data along a route, and handles fast lookup of parameters along the the route, both in space and time (SeaMon-API)**
3. **Web or application front-end that interacts with a user, generating queries to the online service and displays the forecast results (e.g. the Vegveður App).**

The following high-level schematic outlines the flow of information between these three components in the SeaMon-API road weather system that has been developed:



A key component in adapting the original en-route marine weather service to routes along roads was the addition and tuning of a roads routing solver. For the purposes of this project the Open Source Routing Machine (OSRM) was selected and currently runs alongside the SeaMon-API server in the cloud. For every road weather request, the SeaMon-API deligates the OSRM server instance, which holds road network data for Iceland, to calculate the shortest path between two waypoints on the Icelandic road network. This path is then used by the SeaMon-API to pick out weather data along the path, returning it as a response to the requesting application.

> In testing, significant inaccuracies and inefficiencies in routing along specific routes in Iceland were discovered, seemingly due to out of date road network data that is currently available for OSRM. A notable example is the route calculated between Reykjavik and Ísafjörður, which results in a path up Þorskafjarðarheiði, while the more correct route is via Hólmavík up to Steingrímsfjarðarheiði. In order to improve such routing issues, it is planned to replace OSRM with the Google Routes engine, which performs much better for Iceland.

REST-API Design

Modern web-service components usually serve data with a publicly accessible Application Programming Interface (API) via a HTTP or HTTPS web-protocol. This interface is commonly referred to as a REST-API, and is the interface adopted for the SeaMon-API server. The current REST-API service endpoints are summarized in the below table:

HTTP endpoint	Method	Description
api.seamon.io/forecast	GET	returns weather forecasts along route
api.seamon.io/models	GET	lists available forecast models and parameters
api.seamon.io/version	GET	lists the version id of the SeaMon-API service
api.seamon.io/saved/{id}	GET	fetches previously saved forecast results by unique id

In order to encrypt and conceal all route requests from users, the SeaMon-API server only responds to request via a secure HTTP protocol (HTTPS).

The en-route road weather forecast service developed within this project is an extension to the `/forecast` service endpoint that was originally provided for great circle arc ship routes. The following section outlines briefly how this extension has been implemented. For more in-depth information about the REST-API please refer to the SeaMon-API docs at http://docs.seamon.io/api_overview

The REST-API drive request

The `/forecast` endpoint originally only queried weather forecast parameters along great circle arc paths defined with the argument `?waypts=(...),(...)...`.
The new feature added in this project, appropriate for road networks, was the option of calculating the shortest route using the argument `?drive=(...),(...)...` .

The following example demonstrate a HTTP request for a weather forecast while driving from Þorlákshöfn towards Akureyri at 80 kph average speed, with the addition of a 2 hour stop in Staðarskáli:

```
https://api.seamon.io/forecast?drive=(Thorlakshofn;now),(Stadarskali;80kph),
(Stadarskali;prev_plus_2h),(Akureyri;80kph)&params=igb|wind,temp
```

The following table summarizes important argument that are available to the request:

Parameter	Value	Description
drive	array of waypoints	Routes between waypoints are resolved using a routing engine for shortest distances between locations along a road network.
params	array of parameters	Forecast model and weather parameters to query, see params options in docs
view	view name	Data presentation options, see view options in docs
token	string	Unique access key, see authorization API in docs
save	boolean [true/false]	Stores forecast data response so that can be recalled and shared using the `saved/{id}` endpoint

The above request results in a JSON data object that the client side application processes and displays to the user:


```
{
  "forecasts": {
    "igb": {
      "source": "IGB 2020-03-27T1800",
      "dists": [0.0, 1102.45, ..., 419995.33, 421666.08],
      "lats": [63.8562, 63.8659, ..., 65.6687, 65.6591],
      "lons": [-21.3866, -21.3905, ..., -18.1804, -18.2085],
      "times": [1585622455, 1585622495, ..., 1585639742, 1585639817],
      "members": {
        "igb": {
          "temp": [1.89, 1.89, ..., 1.74, 0.41],
          "wind": [8.82, 9.06, ..., 19.43, 20.14]
        }
      }
    }
  },
  "units": {"temp": "°C", "wind": "m/s"},
  "waypts": {
    "route": [{"label": "Þorlákshöfn",
               "lat": 63.8562,
               "lon": -21.3866,
               "time": 1585622455.0}, ...,
              {"label": "Akureyri",
               "lat": 65.6591,
               "lon": -18.2085,
               "time": 1585639817.4877}]
  }
}
```


Note that the requested temperature and wind data, `temp` and `wind` tags, in the above response are contained within a `members` tag. This is a feature of the SeaMon-API allowing for multiple statistical weather forecast runs, so called ensemble model runs, to be returned and/or processed for statistical likelihood of weather conditions. In this initial implementation, ensemble member forecasts were not necessary, but is an important and novel feature already incorporated into the SeaMon-API that can be expanded upon in future versions of the Vegveður app.

Another feature that should be pointed out in the data response is that significant figures have been limited in order to speed up and reduce the amount of data transfer on each request to the service. A forecast request for 10 weather parameters amounts to only 10 kilobytes of data between Þorlákshöfn and Akureyri, and 2 kilobytes of data for Reykjavik to Selfoss . This feature greatly improves the responsiveness of the service on slow network connections.

JavaScript SDK

Alongside the REST-API service, language native methods have been developed to simplify the use of the service for software developers. The SeaMon-API Software Development Kit (SDK) has been expanded to include the new `/forecast/?drive` REST-API feature outlined above.

The current SDK is currently only available for development in JavaScript, JavaScript being the most commonly used language for client side software development today.

> Other software languages can easily be supported depending on software development needs. We would be happy to assist any developers in their use of the service by providing support for other languages as the need arises.

The current version of the SeaMon-SDK toolkit is public and can be downloaded here:
https://api.seamon.io/sdk/js/seamon-sdk-min.js
The SDK is documented in detail on the SeaMon-API docs site:
http://docs.seamon.io/sdk_overview/

It's worth noting, that in addition to providing a programmable interface to the REST-API, some graphical functionalities have also been included for plotting weather charts and routes on maps as currently implemented in the Vegveður app:
http://docs.seamon.io/sdk_overview/#graphical-tools

The SeaMon.forecast.drive SDK request

For the purposes of this report we will only briefly review the `.drive(...)` functionality that has been added to the SDK. The `SeaMon.forecast.drive()` method fetches a SeaMon forecast between waypoints along a road network. Routes between waypoints are resolved using a road routing engine for shortest distances between waypoint locations. The method returns a JavaScript promise object for handling responses and exceptions (errors):

```
function SeaMon.forecast.drive(waypts,
                               params,
                               opts={server="https://api.seamon.io",
                                     token="",
                                     save=false})
```

The following table summarizes argument options that are available to the request using the SDK:

Parameter	Value	Description
waypts	array of waypoints	See waypoint definitions in docs, e.g. `[['Reykjavik','now'], ['Akureyri','80kph']]`
params	array of parameters	Forecast model and parameters to query. See parameter definitions in docs.
server	string	Sets SeaMon-API server if other than default.
token	string	Unique access key, see authorization API in docs.
save	boolean [true/false]	Stores forecast data response so that can be recalled and shared using the `saved/{id}` endpoint.

The following JavaScript example demonstrates a typical SDK function call in order to fetch a weather forecast en-route between Reykjavík and Akureyri:

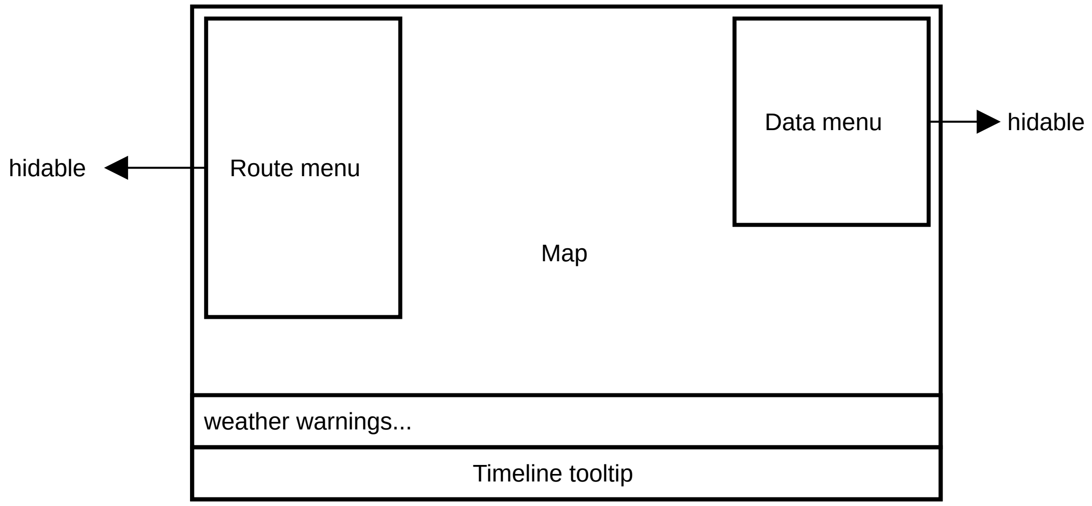
```
SeaMon.forecast.drive([['Reykjavik','19-05-01T12:00'], ['Akureyri','80kph']],
                       ['igb|wind', 'igb|temp'])
  .then(data => {
    doSomething(data);
  })
  .catch(err => {
    console.error('cought exception:', err);
  });
```

The JavaScript programming pattern used in this case is called a promise and ensures that the request is handled asynchronously, avoiding blocking of program flow while the data request is being processed.

User Interface Design

The aim was to develop a responsive user interface layout that would work well on multiple platforms, including web-browsers, tablets and mobile phones. Responsive user interface design is popular in modern app development as it reduces code overhead, work effort and maintenance of the app for for support across multiple platforms.

The most challenging problem with responsive apps is the lack of space for menus, data, buttons and text. While web browsers and tablets have very usable space, the smaller devices, such as Android phones and iPhones, have severely limit space, and this affects most design decisions.



After multiple iterations of the front-end interface, a layout depicted in the above schematic was adopted for the first release of the application.

Map widget

The map widget plots the route defined in the route menu (see description below). It also indicates weather warnings along the route and the position of the vehicle along the route set by the draggable timeline widget (see description below).

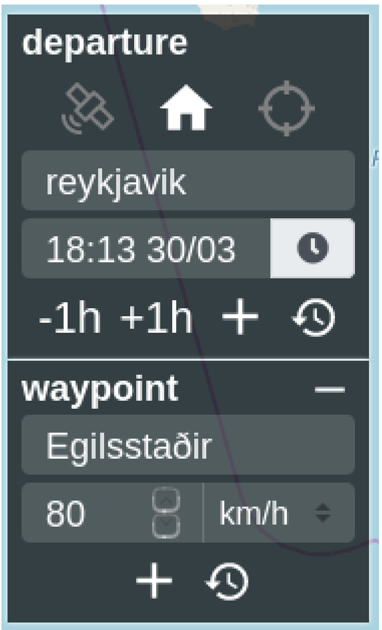
The route path is color coded in relevance to severity of weather conditions, so that the user can get a fast overview of the conditions along his plan. The warnings are color coded in 4 levels of severity:

- **Good conditions (Green)**
- **Moderate conditions (Yellow warning)**
    - Most well equipped vehicles will be able to handle these conditions, but the driving experience will be difficult in many cases. Those vehicles with trailers, and inexperienced drivers should take special care.
- **Bad conditions (Red warning)**
    - Recommended to take extreme care under these conditions, and sometimes only the most well equipped vehicles will be able to drive. Danger of road closure is high if due to heavy snow precipitation. Those with trailers should also think twice if due to heavy winds or snow.
- **Extreme conditions (Purple warning)**
    - The purple warning is rare, but was necessary in order to indiciate unusually extreme and dangerous winds and gusts - hurricane force winds and gusts.

Note that 3 or 4 level color coding to summarize conditions for all types of vehicles and drivers is a very difficult task that will require ongoing improvements and tuning. It is possible that eventually different types of vehicles and driver experiences should be made configurable by the user to take account of these differences between users. This is food for further study and trials.

Route menu widget

The route menu allows the user to insert the point of departure, location and time. Optionally, depending on the device, the current GPS location can be used (setellite icon) as point of departure. The '+' button is used to add waypoints for the route. The waypoints take destination place names and average speed of travel towards those locations.



The time icon at the bottom of departure and waypoint dialogs allow for adding stop-overs. Stop-overs are pauses in the journey, for example short rest stops or overnight stays. Any number of waypoints and stops can be added along the planned route.

The top right (target) icon can be activated on devices with GPS location, and allows for continuous tracking and updates of the weather forecast while driving. This feature is particularly useful for drivers that wish to continuously monitor weather conditions ahead while driving. It is necessary to use a mobile device holder in the car for this to be safe. When this option is activated the application gives peek in warnings with a bell sound notifying the user of changes in road conditions that lie ahead.

> Note: currently the location input / address works reasonably well, but fails in certain instances. We plan to upgrade the backend geographical location service to the Google-API lookup service to get a much more reliable result.

Data menu widget

The data menu displays weather forecast parameters along the planned journey. It became necessary, due to restricted space, to use descriptive icons to indicate the meaning of these parameters, as opposed to labelling them specifically with text.

Each parameter is higlighted and color coded when the parameter exceeds predefined thresholds that could affect driving conditions. The above example highlights **windy** and **gusty** conditions, **medium snowfall** and **snowfall in proximity**. **Visibility** is also predicted to drop down to 300m. The bottom right **road conditions** icon indicates a the possibility of **snow on road**, but can also hold values for wet road and road icing risk.

> A detailed instructions dialog for the interpretation of these weather parameters is at the time of this report missing from the app, but is of the highest priority to be added in the next test release.

An important feature of responsive apps is the ability to allow the user to discover the meaning of graphics and buttons through experimenting and use of the application. We have made this possible by highlighting these weather parameters, and displaying an associated weather warning summary at the bottom of the screen right above the draggable timeline widget.

Draggable timeline widget

The timeline widget contains a draggable element, the car icon, which allows for exploring weather conditions and warnings along the planned route. In the current version, color coded time series graphs representing different weather parameter thresholds are correspondingly highlighted in the data menu. Weather warnings are summarized for each time location along the graph in a text box sitting directly above the widget.

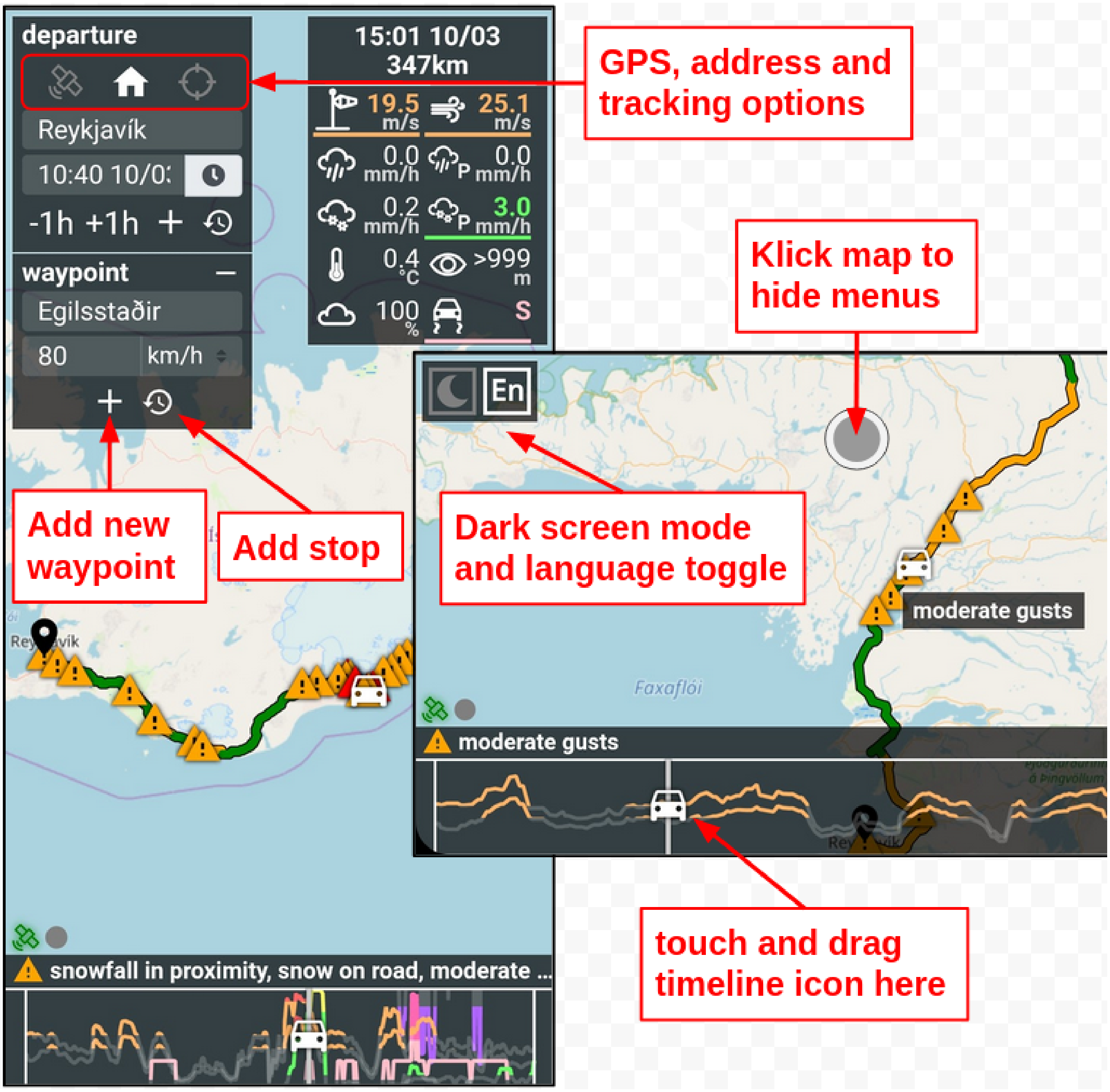
It became quickly apparent that it was not feasible to include meteorological line graphs with textual numbers and units in this first implementation of the layout. Furthermore, the sheer amount of weather parameters that are relevant to driving conditions would have overcluttered the user interface. Instead we limited ourselves to the numeric weather values on each time location along the driving path.

Small color coded time series graphs are also included underneath the widget, and although they do not give specific numerical information, they can be used to visually connected line-colors to parameters color coded within the data menu. Gray lines indicate good conditions, while colors prompt specific weather related warnings along the route.

> A notable improvement that has be suggested by testers is to allow for a more advanced time series chart with units and numbers, which will peek into the view only when a particular weather parameter is selected in the data menu. This is a very workable solution to the screen space problem and will allow for more advanced exploration of the time series data. This feature has been scheduled to be added to a future release of the application.

User Interface Instructions

The following image gives a brief overview of tactile interactions within the Vegveður user interface:



> Detailed instructions accessible within the application itself are being added, but not yet available at the time of this report.

Field Testing

The Vegveður app and forecast results have been regularly tested and monitored by the author during development, but also bitVinci colleagues, Bolli Pálmason, Hrafn Guðmundsson and Ólafur Stefán Arnarsson.

Two field excursions were performed after the GPS tracking functionality had been added to the app. During the field excursions, the mobile phone was mounted on the windscreen so that the driver could monitor how well the road forecast was corresponding to actual conditions during the trip.

Field testing summaries

- **Reykjavik-Selfoss-Reykjavik, 23 February 2020, Hróbjartur Þorsteinsson:**
  - **Notable success**:
    - Forecast correctly indicated windy and gusty conditions on Hellisheiði
    - Correctly predicted reduced visibility due to low cloud cover when nearing Selfoss.
    - Snowfall indication in the forecast was also reasonably accurate on Hellisheiði and prior to arrival in Selfoss.
  - **Notable fails**:
    - Significant snowfall near Selfoss was however highly inaccurate. After researching the weather conditions in the IMO IGB forecast model, it was found that the convective precipitiation type resulted in inaccurate placement of the precipitation. This is a common limitation in local area forecast models. A future mitigation for this problem will be to keep track of the precipitation type and to indicate likelihoods of snowfall to the users instead.
    - Snow on road greatly reduced the driving experience over Hellisheiði. As a result of this experience a simplified road conditions model was added to SeaMon-API keeping track of snow on road, as well as road wetness and icing risk.
- **Reykjavik-Akureyri-Reykjavik, 18-19 March 2020, Bolli Pálmason / Hróbjartur Þorsteinsson:**
  - **Notable success:**
    - Forecast correctly indicated windy and gusty conditions along route on both days. Noticably accurate were sudden changes in wind conditions near mountains, such as Hafnarfjall.

    - Snow precipitation, on both days was felt to be fairly accurate, in both location and timing.
    - The newly added 'snow on road' parameter was largely accurate during drive towards Akureyri.
    - Predictions of bad driving conditions on 18 March were felt to be overall very accurate.
    - Predictions of good driving conditions on 19 March were felt to be overall very accurate.
  - **Notable fails:**
    - Reduced visibility was incorrectly indicated by the IGB forecast after reaching the top of Holtavörðuheiði on route to Akureyri.
    - It was noted that the IGB visibility seems to represent fog or low cloud conditions reasonably well, while reduction in visibility due snow precipitation and possible snow-drift conditions often appears to be weak. However this warrants much further investigation. To mitigate this problem it may be required to develop a combined visibility parameter within the SeaMon-API which takes account of these three types of visibility reductions for roads.
    - During return trip to Reykjavik significant amounts of snow on road were encountered on Holtavörðuheiði, mainly due to snow drift. To mitigate this problem, it is necessary to incorporate the IMO / Vegsýn snow drift forecast into the SeaMon-API. However, some necessary work on porting new model runs will first have to take place in collaboration with the IMO.

UI specific issues

Field testing has additionally helped to reveal the following user interface and user experience problems:

- Excessive weather warnings during tracking mode (requires UI improvements)
- Correspondence between route path warning color and current warning sometimes off by one line-step (requires bug-fix)
- GPS tracking sometimes drops due to lack of connectivity and does not re-establish automatically (requires bug-fix)
- Tracking history is not currently retained, so that past forecast history can be viewed while driving (requires UI improvements)

Vegveður in app store and online

At the publication of this report, the SeaMon-API road weather application is available as an online web-page as well as a mobile app in both Google Play store and for Apple TestFlight store. The mobile apps are in testing, meaning that further tweaking and improvements to apps are being worked on based on trial user feedbacks. Recent publication of the project in Icelandic Facebook groups for weather enthusiasts have greatly increased the number of testers and feedback for the app on various devices.

The following page holds up to date instructions on how to install and test the latest Vegveður app for Android and Apple iOS platforms:

https://api.seamon.io/getapps/getapps_is.html

The following Facebook page has been opened for discussion and interaction with test users:

https://facebook.com/vegvedur/

Conclusion

The most important lesson to be taken away from developing a road weather application of any sorts is the multifaceted and complicated nature of driving experiences, application, relevenace to different vehicles and differently experienced drivers. During one particular instance of testing, the author witnessed a tourist driving off the road in fairly good conditions, but with a small layer of compacted snow on the road. Conditions that usually don't pose as much of a problem to drivers that live in Iceland, but this highlights just one of the many challenges in presenting warnings to drivers in a single comprehensive application.

Currently, 11 types of relevant weather parameters have been included in the application in order to give such a comprehensive picture of conditions along roads. These include winds, gusts, rain, rain in proximity, snow, snow in proximity, temperature, visibility, snow on road, wet road and icing risk. Yet we can still foresee the necessity of adding and developing further parameters relating to snow-drift, incorporating the complicated nature of road visibility and providing real time information of road closures from the IRCA. All these weather parameters pose an ongoing challenge in summarizing road conditions so that they will be more readily understood, especially to those users that are less familiar with high latitude weather conditions and interpretation of weather information.

Many aspects of developing an en-route forecast service presented unexpected work load challenges to the author. Besides the significant software development that was necessary for the SeaMon-API data service, the development of a responsive interface and cross platform software in a new programming paradigm was perhaps the greatest learning curve. Other, but less forseen challenges, were complications posed by supporting multiple mobile devices, compiling and submitting apps to both Google Play and the Apple stores. For app distribution, various efforts and costs were inevitably incurred relating to security certifications, registrations and hardware compliances.

The author hopes that the en-route road weather service described in this report, has demonstrated and helped to convince the reader of the significant potential and advantage it can bring in summarizing and previsualizing road weather conditions. Currently the Icelandic Meteorological Office has shown great interest in this approach and are working on incorporating the SeaMon-API service into their current smart device application. Thanks to the IRCA grant, Icelandic administrations, such as the IMO and the IRCA, are now set to take the lead in providing tailor made weather forecast on roads.

Acknowledgements

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Skúli Þórðarsson, road conditions expert and engineer at Vegsýn also provided vital support to the original project proposal, not least confirming the feasibility and attractiveness of the project as an IRCA grant application.

The bitVinci ehf team members, Bolli Pálmason, model expert, Hrafn Guðmundsson, weather forecaster and Ólafur Stefán Arnarsson, software developer have taken significant part in guiding the project with regards to user interface design, data presentation, weather forecast model access and interpretation.

The author would also like to thank numerous testers from friends and family, to the growing number of weather enthusiasts that have now downloaded the Vegveður application and are giving valuable feedback every day on Facebook.

Finally the author would like to give thanks for the gratious grant of 2 million ISK from the Icelandic Roads and Costal Administration, making this project a reality.