GSWARM: AN EXAMPLE OF MAKING A GIS MODEL FOR EVERYDAY USE

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ABSTRACT: Modeling snow processes over terrain with a Geographic Information System (GIS) takes a specific set of skills and a lot of computer processing power and time. These factors are often at odds with how such a model would be used for, say, daily avalanche forecasting. We used the near-surface snow warming statistical and empirical model SWarm as a basis for designing a simple and fast GIS tool. This simple GIS-based warming model, called GSWarm, resulted from (a) published user comments on existing snow and avalanche computer tools, (b) published graphic design principles, and (c) direct forecaster feedback. Using GSWarm as an example, we present key ideas used to provide a simple interface to a complex GIS model, including: (1) Calculating many possible scenarios ahead of time, so hypothesis testing of different weather and snow conditions can be done quickly. (2) Allowing small previews of many results to be seen on one screen, for selection of specific conditions without using input boxes. (3) Providing scaling and visualization help to the user rather than giving a single final result. These ideas represent a unique perspective on snow and avalanche computer model design.

KEYWORDS: Computer assisted forecasting, Geographic Information Systems (GIS), Modelling

1. INTRODUCTION

An inspiring attribute of our field is that, on the whole, we all work to exchange and use information for safety and the common good. Research plays an even deeper role in this by finding new information to exchange, and even finding new ways to obtain information.

When describing the process to do that, a researcher might split the job up into four steps: (1) Pick a subject that matters. (2) Carefully study the subject enough to characterize some new aspect of it. (3) Disseminate your results to an interested audience. (4) Gather enough feedback from that audience to return to step two if needed, and step one to begin something new.

Most research papers fulfill the need for communication in step three, and they do so by talking about the field research that happened in steps one and two. In other words, a typical paper is a method of communication, and the content is the field study and its results.

This paper, on the other hand, *talks* about step three: communication. We as authors came to the realization that although the mathematical models developed by our research group such as SWarm (Bakermans and Jamieson, 2009) and SAWLEM (Zeidler et al., 2006) enjoy use by practitioners, the amount of use is not necessarily what we expect given that a wider audience has expressed interest in the subjects. And so the question – and challenge – seemed to be whether a mathematical model could be made accessible to additional audiences.

To do this, we adapted the near surface warming model called SWarm (Bakermans and Jamieson, 2009) to another presentation medium: digital terrain data. Many complications and difficult decisions arose from this process, such as: *limit the area, or require long processing times?* Or: *provide one single result, or let the user choose?* This paper outlines our process, the decisions we made for these questions, and the resulting system – a GIS-based implementation of SWarm now called GSWarm.

2. PREVIOUS WORK

Computers play a multicoloured and somewhat unclear role in avalanche forecasting. Looking at existing systems shows almost as many design philosophies as systems themselves.

There are programs which provide a forecast answer for the day such as a danger rating. These systems include Merindol et al. (2002), Giraud et al. (2002), Floyer and McClung (2002), and Zeidler and Jamieson (2004), and Schirmer et al. (2010) as a few examples.

Other systems provide insight into physical snow conditions without providing a direct forecasting an-

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swer, and these include SNOWPACK (Bartelt and Lehning, 2002), SWarm (Bakermans and Jamieson, 2009), SAWLEM (Zeidler et al., 2006), and CROCUS and SAFRAN (Giraud et al., 2002), among many more.

Still others organize data – such as weather information, or history data for an avalanche path – into a recognizable and readable format. These include Cornice (Purves et al., 2002), and GeoWax (McCollister et al., 2003). This category also includes *spatial notepads*, which allow recording of conditions over terrain and time. Although spatial notepads exist (Canadian Avalanche Association, 1991), others have been called for, such as for surface hoar layers (Davis, 2010).

Some models fill a category in a specific culture, locale, or regime well. These include the Mammoth Mountain binary decision trees (Rosenthal et al., 2002) and the local-expert-weighted system in Gassner and Brabec (2002), among others.

Mathematical models, computers, and GIS use have gained a stronger foothold in non-forecasting applications such as predicting avalanche runout, impact, and designing defenses and structures for avalanche terrain. Furthermore, in meteorology – which may be viewed as our sister field of study – computers, analytical models, and physics have all established themselves as indispensable to both forecasting and general understanding.

Few systems are different adaptations of existing models with new perspectives. One such system is a cellular automata model developed by Kronholm and Birkeland (2005) designed to show the conditions that create large avalanches.

GSWarm is this last type of system: a re-adaptation of an existing model to fill a new use niche.

3. GOALS

First, GSWarm needs to be distinguished from SWarm, as they do not compete. SWarm is simply an empirical model – a mathematical description of field research results. SWarm as most *users* think of it is a spreadsheet which allows the user to obtain expected warming down 10 cm in the snowpack based on latitude, longitude, date, current cloud cover, and days since snowfall. The user of the spreadsheet is then presented with expected warming for different slopes and aspects, and the data is presented on a familiar rose aspect graph, on a Cartesian graph, and in a table. Figure 1b shows a screenshot of SWarm in use.

SWarm takes specific input and presents tangible numbers, but only at a single point. GSWarm, on the other hand, takes no input and instead allows the user to *drill down* into results. In addition, GSWarm does not give numbers as a result, instead it presents *warming maps* which display expected warming by using colour. One such map and its key are provided in Figure 1a.

Hence, these two programs, although using essentially the same model, answer different types of questions. SWarm answers definite questions easily, such as: *what is the average warming on north slopes today?* GSWarm cannot easily answer these definite, numerical questions, but it can, at a glance, give intuitive answers for questions such as: *which slopes along a route will warm significantly today?*

With the help of preliminary releases and user feedback, the goals of GSWarm became clear:

- ○ Primarily visual rather than numeric results
- ○ Minimal time and computer skills needed to use
- ○ Easy to compare results from different inputs
- ○ Free to the end user
- ○ More spatial information, such as terrain shading
- ○ Keep “experimental” feel for future changes

The last goal motivated this paper. It is our hope that by outlining the efforts needed to create a large-scale spatial implementation of SWarm that future designs of spatial models can improve upon the process.

4. CHALLENGES AND METHODS

Design of a usable interface begins with the data. Rather than collecting the data one wishes to display and then scrambling to figure out how to display it well, the two steps should be one step. Ideally, the data will fit directly into its own display. This is not only complicated to do, but the end result can also take many forms. We describe our methods in designing GSWarm below to help show but one streamlining process of many.

4.1 Platform challenges

To generate a spatial map as a result, the designer needs to use some type of Geographic Information System. Even before choosing the type of data to be produced, the platform choice seemed clear: choosing an open source and free GIS platform removed any cost to the end user. The GIS system used in the development of GSWarm was GRASS, a free and open source Linux-based GIS system. GRASS is a stable and mature system that lends itself to research and has established documentation both online and in print form (Neteler and

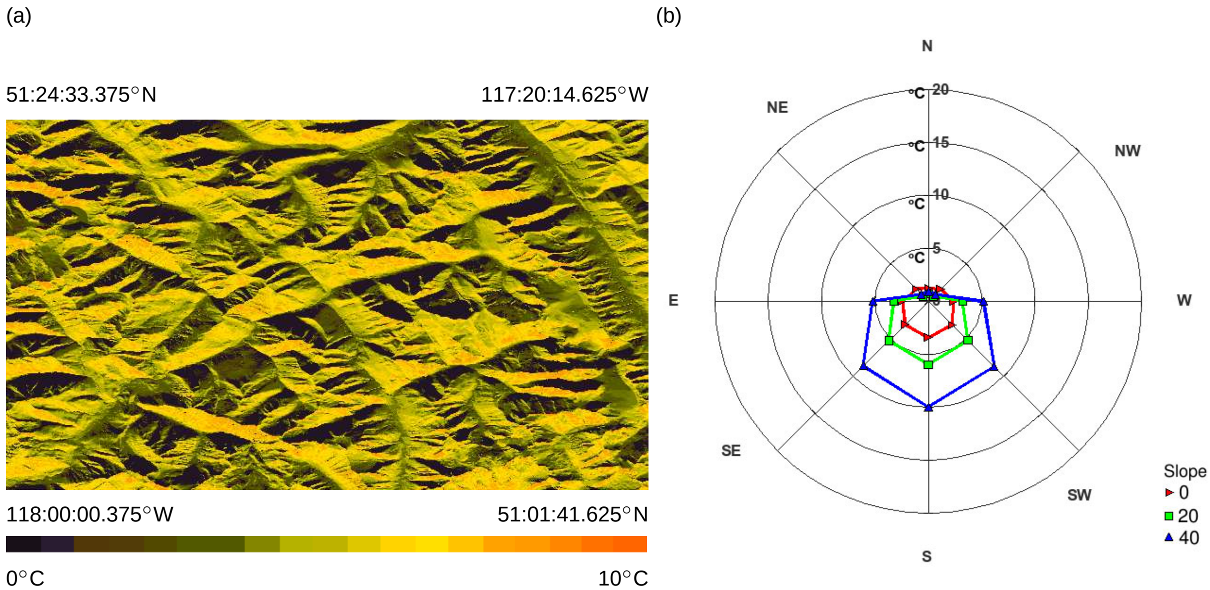

Figure 1: Output of expected warming 10 cm down from (a) GSWarm and (b) SWarm for a single day (October 29), albedo (one day of no snow), and cloud cover (4/8). A full size GSWarm warming map is 2272 x 1306 pixels for the Rogers Pass area. The legend in SWarm (b) has been moved and scaled to fit. SWarm also provides a table and Cartesian coordinate graph, both also containing expected warming listed by slope and aspect.

Mitasova, 2008)

GRASS can be driven from the command line, and so GSWarm was created by batch scripting. GRASS also contains the shortwave modelling program `r.sun` (Hofierka, 1997) which allows for beam (direct), diffuse, and reflected shortwave radiation calculations over terrain and minimizes memory use by utilizing pre-calculated horizon shading maps.

4.2 Time challenges

Ideally, a GIS-based warming model would return a map of expected warming for arbitrary conditions, an arbitrary location, and an arbitrary date.

However, SWarm uses the maximum shortwave input in a day, and hourly estimates of incoming shortwave must be made in order to find that maximum value. To perform twelve of these calculations on 3181 x 1829 pixels and produce one day of warming maps on a server-grade machine takes 45 minutes of processing time and 1.3 GB of computational hard drive cache space.

Given this time and computing power requirement, it made more sense to limit GSWarm to preset areas of high interest or use. This way, images could be pre-calculated for an entire year all at once and only the time to download the images would be needed when running GSWarm. For this first redesign, the region we selected was that surrounding Rogers Pass, British Columbia, Canada, from 51:01:41.625° north to 51:24:33.375° north, and 118:00:00.375° west to 117:20:14.625° west in NAD83 with a resolution of 00:00:00.75 degrees (about 40 m) per pixel. Figures 1a and 3 show different warming maps with geographic extent labels.

4.3 Data challenges

Although pre-calculating the images ahead of time solved many of the time challenges, it introduced a new data space challenge. Each full warming map takes up 4 MB of space, and for the nine different cloud cover values (0/8–8/8) and eight different albedo values (0–7 days since snowfall) offered by SWarm, this produces 63 images and over 250 MB of images per day. Ideally, as the model depends on the Julian day for the date, one year could be calculated and used for every year, but with eight months of interest (October through May) and around thirty days per month, a full image solution for just Rogers Pass would take up 60 GB of space.

So, we began cleaning up the display. Rather than nine different cloud cover values, we display five (0, 2, 4, 6, and 8/8). Rather than eight different albedo values, we use five: snowing conditions and 1, 2, 4 and 7 days since snowfall. And rather than calculating every day of the winter, we calculate one day every two weeks October through February, and every week March through May.

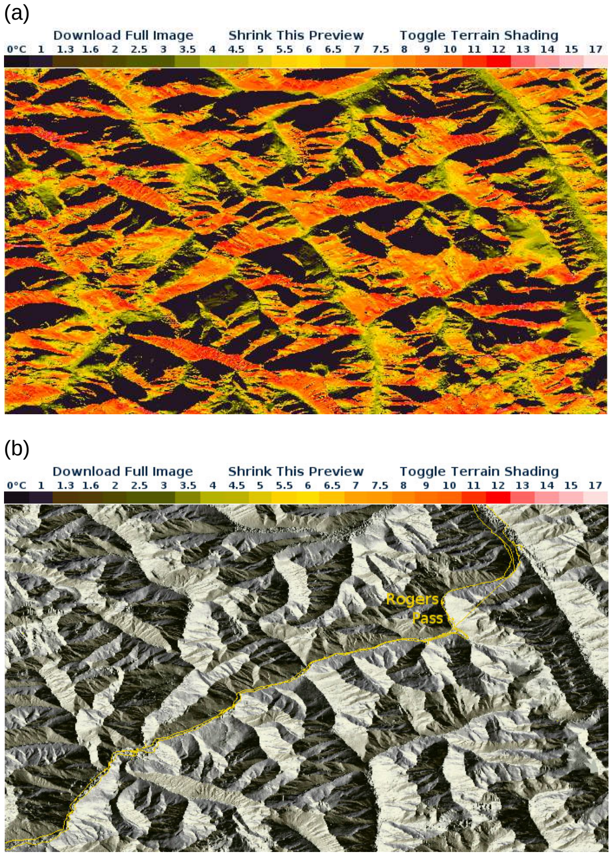

Figure 2: GSWarm views from the 7th of January after seven clear days and current 4/8 cloud. (a) Warming map screenshot, (b) Screenshot of the same map, with terrain shaded relief and landmark overlay. Rogers Pass is located one-third diagonally inwards from the upper right. Map width is approximately 130 km. For latitude and longitude geographical extent, refer to Fig. 1a.

When using GSWarm, the user can visually interpolate between missing days and conditions easily. A day in December and a day in May appear quite different in their warming maps – for an example, see Fig. 3 – but two days in January (even two weeks apart) look quite similar. With this streamlining, GSWarm for Rogers Pass fits in under 3 GB, and this size makes it feasible to compile image maps for many areas.

4.4 Accuracy challenges

The average error in the SWarm model was 1.6 °C over the development dataset. GSWarm, being a re-implementation of an existing model, has not been subsequently tested.

When using the published SWarm model – e.g. the shortwave modification coefficient 0.00542 from Bakermans and Jamieson (2009) – GSWarm overestimates the warming. This is because the GRASS `r.sun` command estimates physical shortwave input using specific physical parameters such as Linke turbidity and albedo in addition to the solar zenith (Hofierka, 1997). Hence, GSWarm uses the coefficient for physically measured maximum shortwave radiation input: 0.00448, also from Bakermans and Jamieson (2009).

In addition, GSWarm uses re-designed aspect and slope corrections which follow local time and apply to the entire estimated beam (direct) shortwave input at each raster pixel:

```
decl = (23.45 * sin((day+284) * 360/365))
hour = 360/24 * (12-localtime)
azimuth = atan((-(cos(hour)) * cos(decl)
   * sin(lat)) +(cos(lat) * sin(decl)),
     sin(hour) * cos(decl))
solarelev = asin((sin(lat)*sin(decl))
   + (cos(lat) * cos(decl) * cos(hour)))
modifier = ((sin(slope) * cos(solarelev)
   * cos(azimuth - aspect))
   + (cos(slope) * sin(solarelev)))
correctedSW = directSW / sin(solarelev)
   * modifier
```

where `day` is the Julian day, `decl` is the solar declination for that day, `localtime` is the local solar time (0-24 hours), `hour` is the hour angle, `azimuth` is the solar azimuth, `solarelev` is the solar elevation, and `slope`, `aspect`, and `lat` are the slope, aspect (azimuth type clockwise from north), and degrees of latitude, respectively. This gives shortwave corrected for slope and aspect (`correctedSW`) from a value of direct beam shortwave (`directSW`). These calculations are not the most precise available, but are a good compromise between computational resources and accuracy. Possible improvements include correcting for leap years and a more accurate declination; these are discussed in Robinson (1966) and other meteorology texts.

These and other changes create deviations from the SWarm values. Other changes include a lower Linke turbidity appropriate for mountainous terrain in the winter, use of albedo in diffuse shortwave calculations, and terrain shading.

Due to these differences, it is difficult to estimate an overall percentage deviation from SWarm values. GSWarm tends to estimate more warming despite using the physical shortwave coefficient as mentioned above. This primarily may be due to GSWarm using a low Linke turbidity, as appropriate for mountainous terrain, but which would be difficult to incorporate in a single point for SWarm. However, this generalization of GSWarm predicting more warming is only a tendency – SWarm can also estimate extreme warming in areas that GSWarm will predict very little due to terrain shading.

As SWarm has also not been independently verified, the absolute numeric value of GSWarm likewise remains unvalidated. However, GSWarm uses physically-based and established concepts (e.g. the `r.sun` routine, horizon shading maps, and solar positions) which give weight to its use as a visual comparative method over different conditions and time.

4.5 Presentation challenges

After carefully designing the data structure for GSWarm, a few additional details were needed to make GSWarm fast and simple for its intended use.

Ensemble presentation. Work already exists on how to display multiple images with similar but slightly different data. Such an image array, called *small multiples* is, in the case of GSWarm, a visual ensemble presentation. The ensemble displays a representative variation in warming over a single day. Figure 4 shows the small multiples that GSWarm uses in its display. Tufte (1990) describes the theory of small multiples and many other minimalist but clear data presentation design practices.

Colouring. Along with the *small multiples* theory, Tufte (1990) emphasizes how colouring on maps should be clear and intuitive. However, what this meant for GSWarm took some experimentation. If the primary goal of GSWarm was to have single, easy-to-understand maps, a many-coloured and fully used colour ramp would be most desirable as it displays the most detail per single map.

However, we felt the real purpose of GSWarm is to allow direct comparison between days, months, albedo values, and cloud cover values. This meant that the GSWarm maps needed one single colour ramp common to all image maps in the entire program. Eventually, we developed a non-linear colour ramp which splits up the small warming values from 0 to 6 °C of expected warming into as many different colours as 6.5 to 17 °C of expected warming. This allows a question of, say, *how much more does terrain create shade in December versus May* to be easily answered with glance, and possible due to a same-colour comparison, as shown in Figure 3.

5. SYSTEM AND USE

The GSWarm user interface is entirely graphical and visual where all options are selected by clicking links rather than selecting items from menus. A good platform for this was a web browser, which already provides a client interface to a web server, and can provide user interactivity via Javascript. The client side for GSWarm was implemented as a web page, and it will run on any system that runs Firefox.

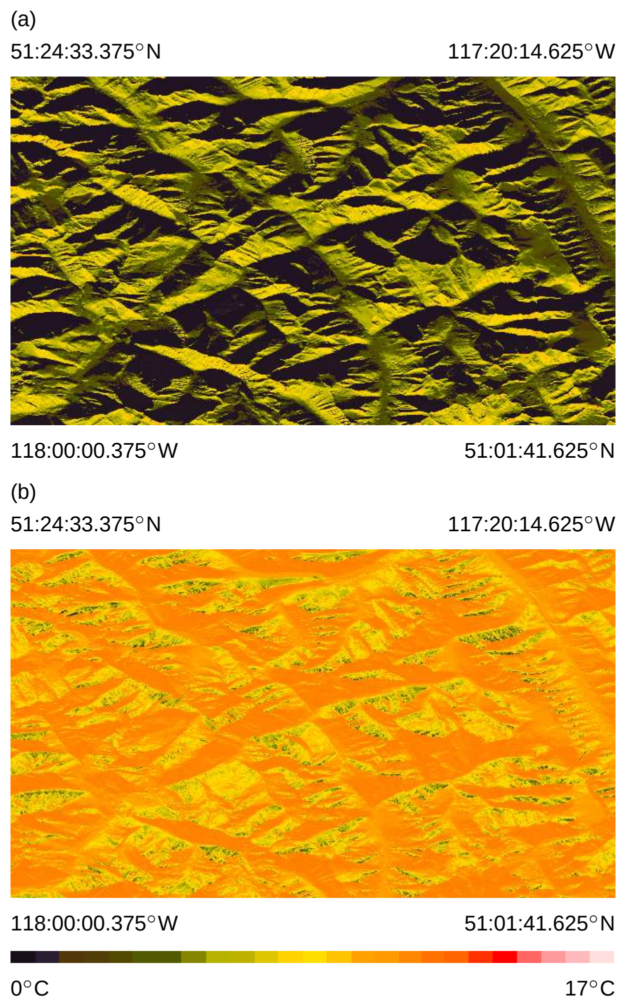

Figure 3: GSWarm warming maps from a clear day with fresh snow from (a) December 24 and (b) May 27, along with their common colour ramp.

We wanted a maximum of three mouse clicks to be needed for most of what GSWarm could do. This is also known as the *three click rule* which is a common website design philosophy. One solution to achieving this is as follows. Upon loading, the user is presented with all available dates as links, and the user need only click on a date to view all 25 preview images for that day. A sample day of image previews is shown in Fig. 4.

Once a user knows what images he or she would like more detail on, another click on a preview image leads to a larger (but still not full size) image. Multiple large images can be viewed in the overview table shown in Fig. 4 at once. Each preview also opens a colour ramp right next to the image, as in the individual screenshots in Fig. 2. From there, the full scale (2232 x 1306 pixel) image may be downloaded via a third click into a new browser tab or window with its own overlay and tools.

The time to “run” the model is then only the time needed to download the images themselves. Preview images as shown in Fig. 4 are approximately 11 KB each, and so an entire day of preview images for viewing the span of possible conditions for that day involves downloading 275 KB, or about one-quarter the byte size of this paper in pdf format. Full images are 3-4 MB. GSWarm may be found at: http://www.ucalgary.ca/asarc/gswarm

6. DISCUSSION AND CONCLUSIONS

The *METHODS* section above showed the level at which decisions must be made in order to follow one single overarching philosophy for ease of use. The decisions we as authors have made can certainly be improved upon; however, few papers in the avalanche field discuss the integration between the needs of the user – i.e. forecasters, recreationalists, guides, etc. – and the design of the system, despite the importance of the topic.

GSWarm fills a niche for users who like thinking spatially, enjoy visual images rather than numbers, want to fly through a lot of data quickly and process it intuitively rather than quantitatively, and have only a small amount of time to do all of this. We (and some users) felt this niche needed filling.

Other users felt that SWarm was just fine as a spreadsheet, why change it? And this variety is just fine. GSWarm could be used for everything from helping new students in recreational avalanche courses visualize how complex warming can be, to intuitively displaying data to spatially-oriented forecasters. SWarm can continue to provide tangible numbers at well-defined locations for those who need them.

Authors of other computer forecasting systems have touched on other points of system design. Many of them share the observation that a model need at least be easy to use, fast, and have its basis in quickly comparing lots of data. Here are some pertinent quotes from other papers:

....Our primary goal is to create a tool to visualize, explore, and ask questions of weather and avalanche data sets, thereby allowing us to find spatial patterns and facilitate hypotheses generation. (McCollister et al., 2003)

....Neither of these programs has been widely adopted amongst veteran forecasters because they require substantial time and effort to operate, as well as vast regional backlogs of weather and avalanche data. (Cookler and Orton, 2004)

....The critical point here is that our model of the backcountry forecasting process is one primarily based on hypothesis testing. Thus, the role of the model is not to provide the observer with the avalanche hazard for the following day or to identify the probability of avalanches. Rather, it is another part of the information gathering and hypothesis testing process....(Purves et al., 2002)

Hence, considering the user from the beginning can often make the difference between use or disuse for a computer forecasting system. This is not to say that GSWarm perfects this process; far from it. Rather, GSWarm hopefully will get use enough to, in turn, provide discussion for an even differently designed presentation. Note that the key word here is *different* and not *better*: Different audiences simply require different presentations for communication to be effective. And, addressing each audience carefully and individually will make our tools and thought processes that much more useful.

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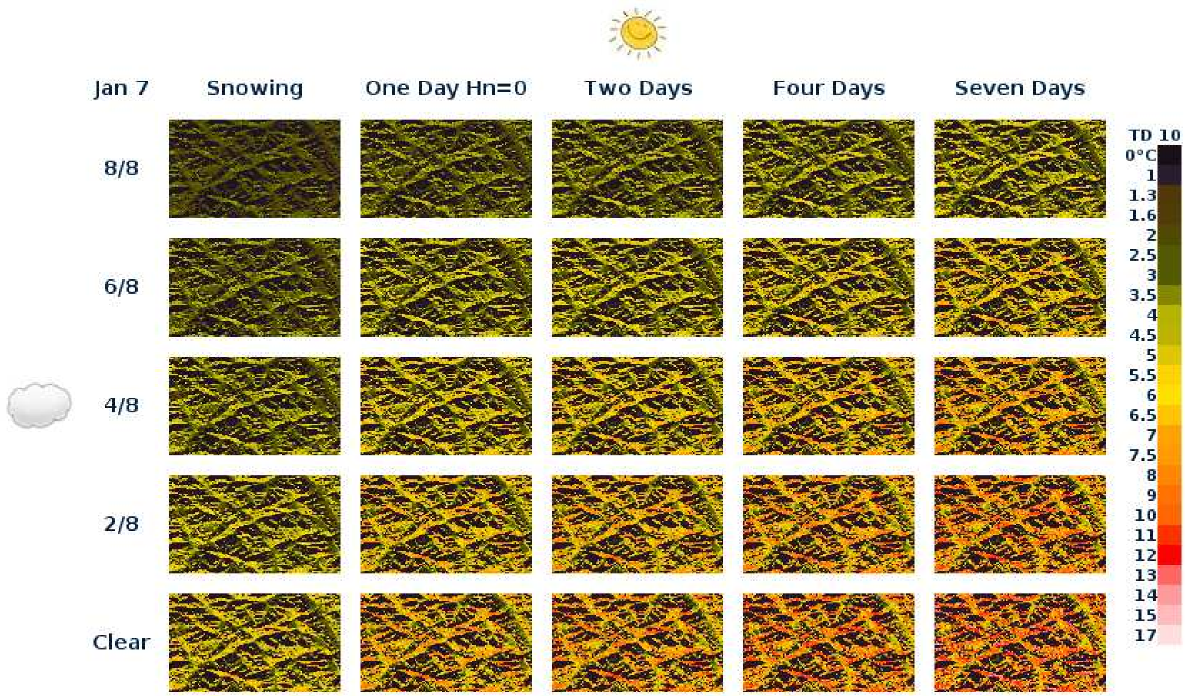

Figure 4: GSWarm's one day view. The preview images show a range of conditions spanning the least and most warming that one could reasonably expect. Clicking on previews allows the user to download images with more detail, i.e. *drilling down*. All images in this paper are best viewed in colour, either in the electronic proceedings or in the online model.

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