Progress in impact-based forecasting across timescales: from impact data to risk forecasts

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With contributions from the Weather Impacts Team and University of Exeter

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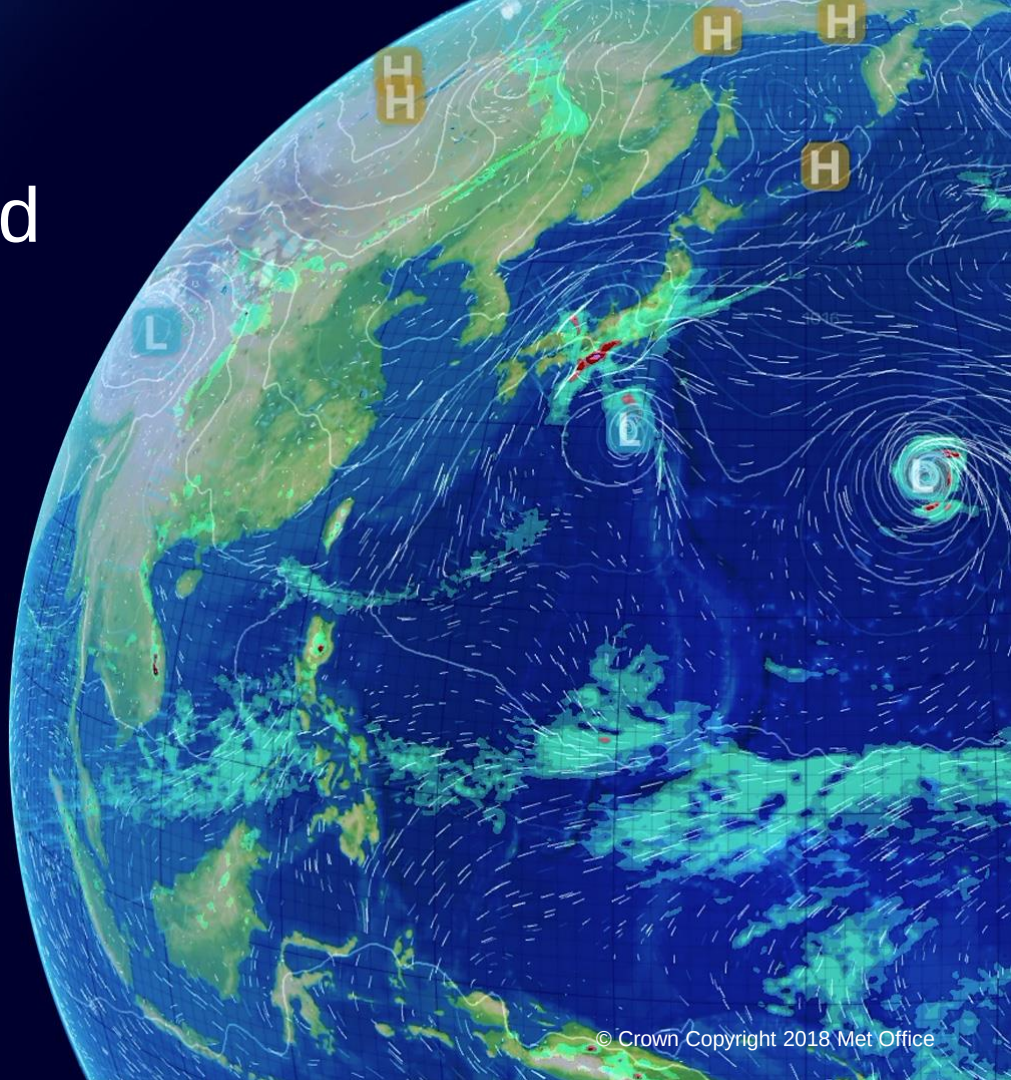
Bureau of Meteorology R & D Workshop 2020



Outline and context

- Understanding the value of different IbF approaches
- Better clarity on the sensitivity and uncertainty in vulnerability and semi-dynamic exposure indices
- Developing methods for impact data collection for evaluation and model development
- Identifying ways to enhance pre-preparedness using extended-range forecasts

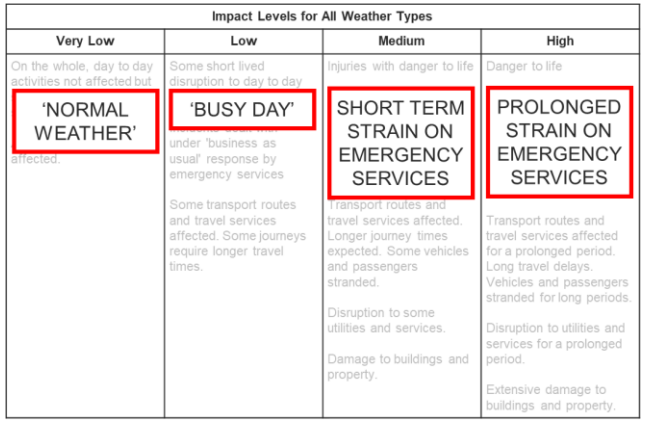
"What the weather will be" → "What the weather will do"

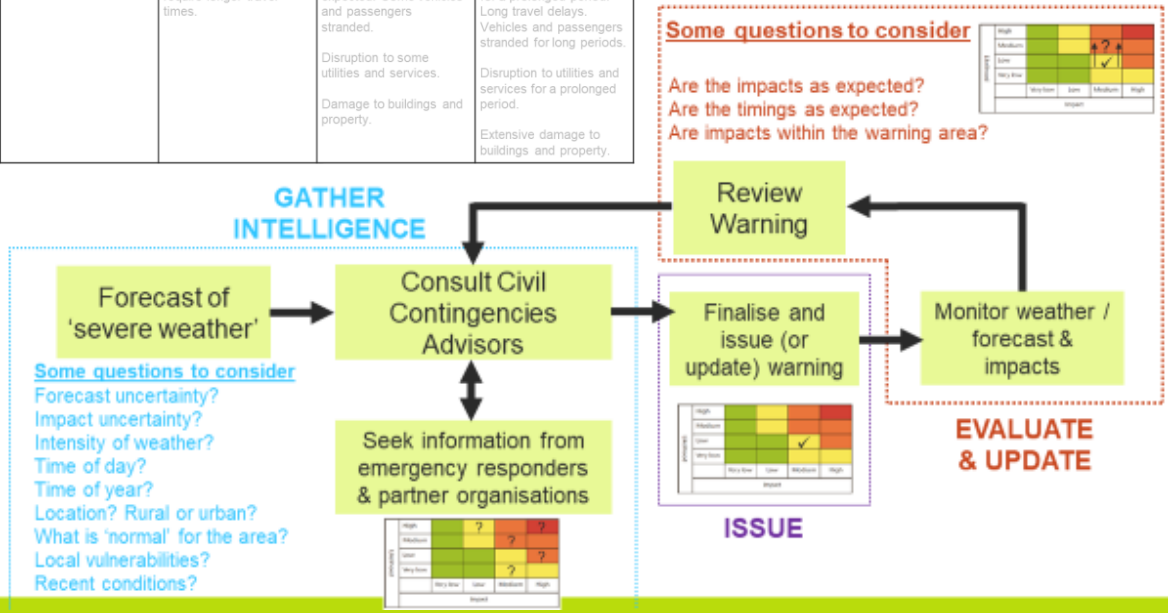
- The science and technology supporting this transition are still evolving
- WMO guidelines on multi-hazard impact-based forecast and warning services (WMO, 2015)
- The future of forecasts: Impact-based Forecasting for Early Action (IFRC, Met Office and others, 2020)

Approaches to Impact-based Forecasting

NSWWS Impact-based Warnings

- Co-produced warning levels based on experiences of emergency responder community
- Interactive process of dialogue and knowledge exchange to formulate warnings
- Impact severity changes based on spatial and temporal variability of exposure and vulnerability and the magnitude of the interacting hazard
- Operational meteorologists and advisors working with responders for several years develop expertise in how risk varies for the areas they warn for





Vehicle Overturning Hazard Impact Model Risk Forecasts

Identify wind gust accident thresholds for different vehicle types & critical wind directions for vehicle overturning

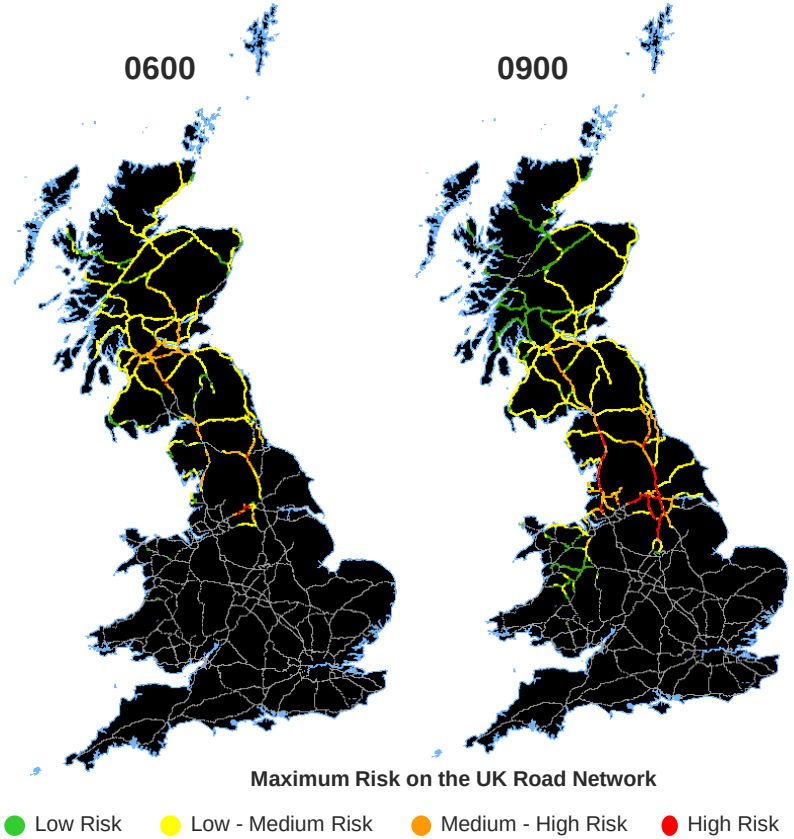
Hazard

Road vulnerability to wind
- Bridge or tunnel
- Orientation
- Altitude
- Number of lanes

Vulnerability Index

What are the elements on the road that are exposed?
- Unloaded goods vehicles
- Cars
- Loaded goods vehicles

Exposure Index



Hemingway & Robbins, 2020. Meteorological Applications

Review of VOT model forecasts

Method

- Reproduced a consistent archive of VOT model risk forecasts for all wind events between January 2016 and August 2019 (inclusive).
- Digitised all NSWWS wind (and combined) warnings for 2018 to produce a set of geospatial objects that describe the timing, location and warning category assignments for the issued warnings.
- Compared the NSWWS wind warnings spatially and temporally with the VOT risk forecasts using geospatial software.
- Vulnerability and Exposure are nationally scaled. Certain routes haven't exceeded certain risk categories.

Generalised behavior of the model

UHGV exposure for 09:00 on a weekday in mid-May

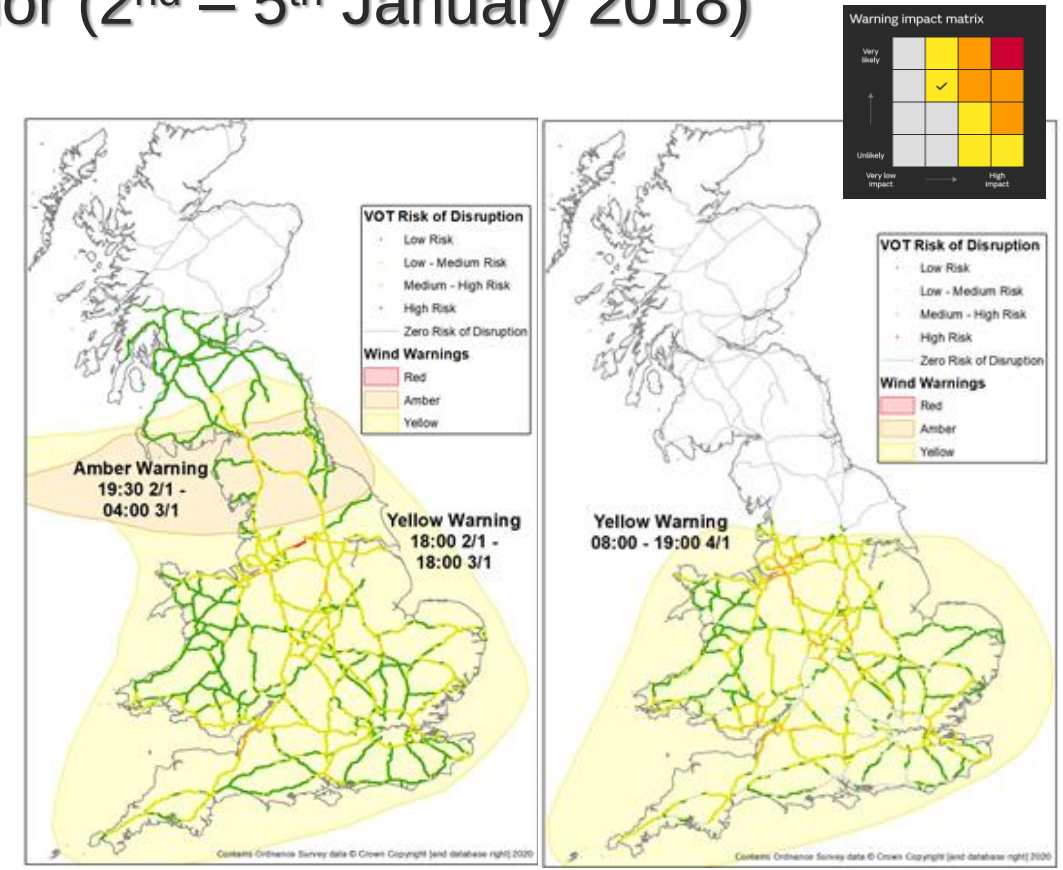
Maximum risk score distribution based on VOT risk forecasts in period Jan 2016 to Aug 2019

Storm Eleanor (2nd – 5th January 2018)

- Yellow wind warning issued from 18:00 on 2nd Jan to 18:00 on 3rd Jan with a low likelihood and medium impact assignment.
- Amber wind warning issued from 19:30 on 2nd Jan to 04:00 on 3rd Jan with likelihood and impact assignment of medium.
- Yellow wind warning issued from 08:00 to 19:00 on 4th Jan with a medium likelihood and low impact assignment.

Key Points:

- Warning area maps provide general assessment of where and at what severity likely impacts might occur.
- Geographic areas are assigned a warning level for a set validity time.
- Warnings don't use specific wind thresholds to identify whether the wind is hazardous to a specific asset (e.g. transport)

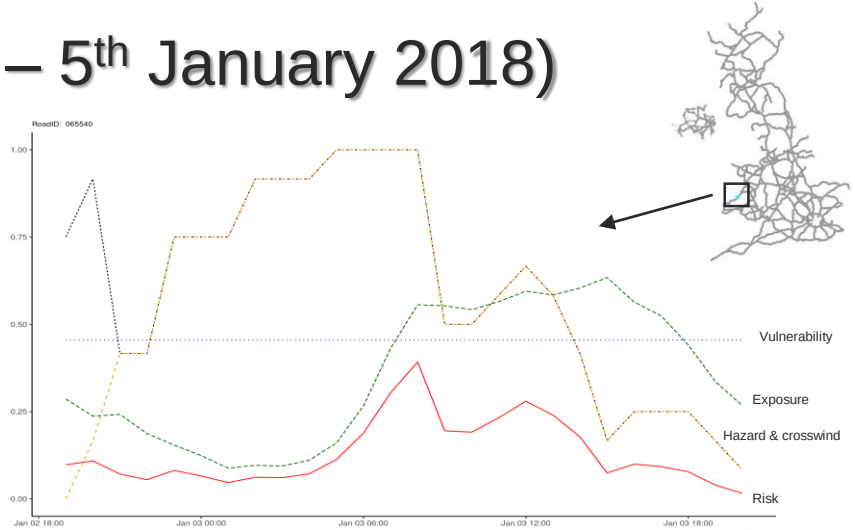


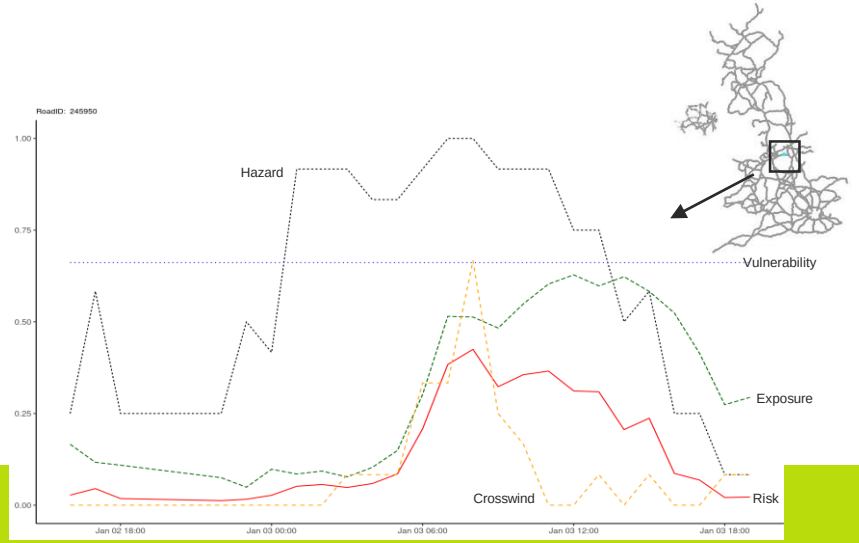
Storm Eleanor (2nd – 5th January 2018)

- Able to see the breakdown of the risk forecast for specific points in the network.
- Hazard (between 0 and 1) = probability of wind gust exceeding accident wind gust threshold
- Vulnerability (between 0 and 1) is partially dynamic and consists of 3 indicators which are static in time and a fourth (crosswind) which is variable based on the wind direction forecasts from MOGREPS-UK
- Exposure (between 0 and 1) describes the number and type of vehicles using that section of road over time.
- Risk score is then a function of these three components.

Key points:

- VOT risk forecast provides information on temporal and spatial risk variability.
- Will not always match the impact-based warnings issued as VOT risk forecasts are automated with no intervention.



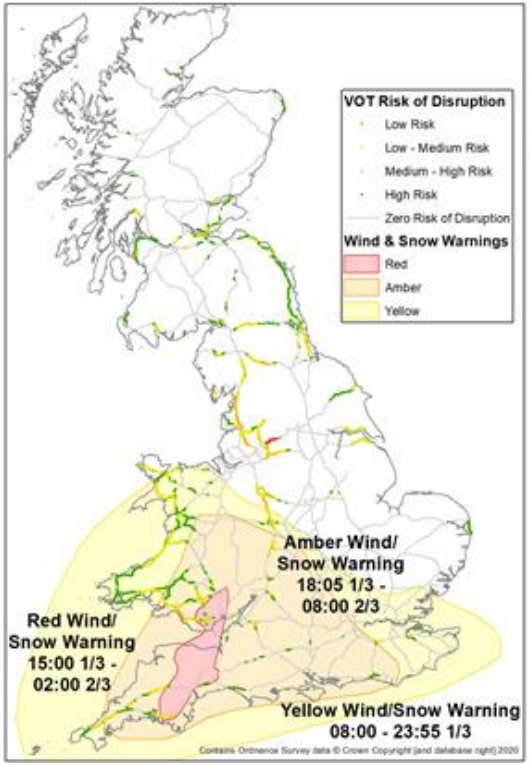


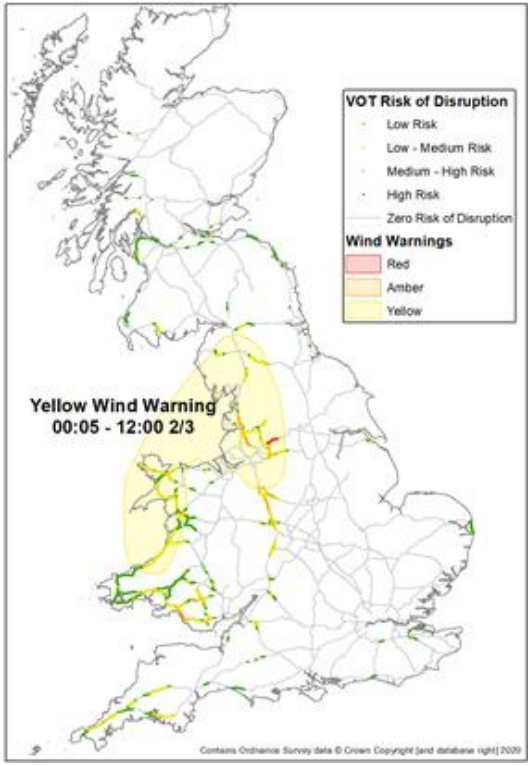
Storm Emma (1st – 2nd March 2018)

- Yellow wind warning issued from 08:00 to 23:55 on 1st March
- Amber wind warning issued from 18:05 on 1st March to 08:00 on 2nd March
- Red wind warning issued from 15:00 on 1st March to 02:00 on 2nd March
- Yellow wind warning issued for 00:05 to 12:00 on 2nd March

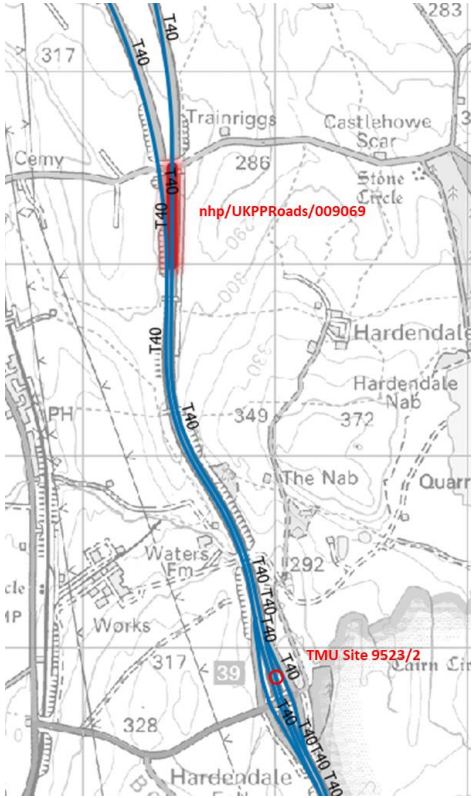
Key points:

- Purpose of the Impact-based Warning being issued
- Multi-hazard interactions have a downstream effect on impact assessment
- In this example the VOT risk forecasts are less coherent. Strongly related to the driving hazard forecast from MOGREPS-UK





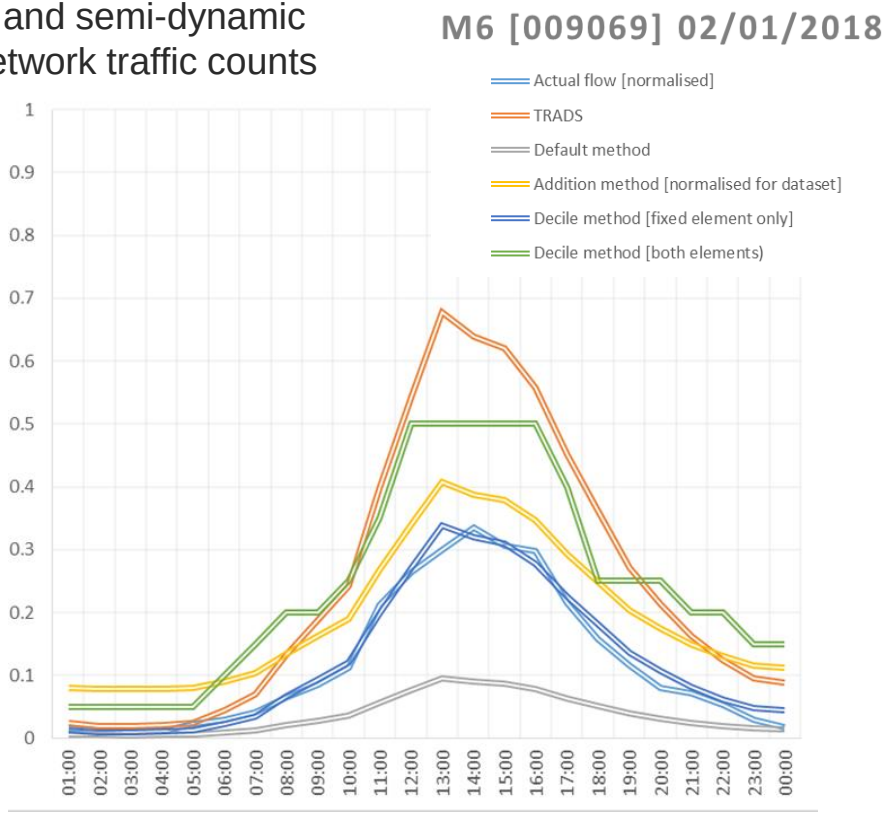
Assessing robustness of the exposure index



Combination of static and semi-dynamic exposure from road network traffic counts

nhp/UKPPRoads/122850 [EXP3 = 0.1263160] is a slip road. The adjacent main carriageway nhp/UKPPRoads/122766 has the same EXP3 value and road type.

Sample station about 4km east.

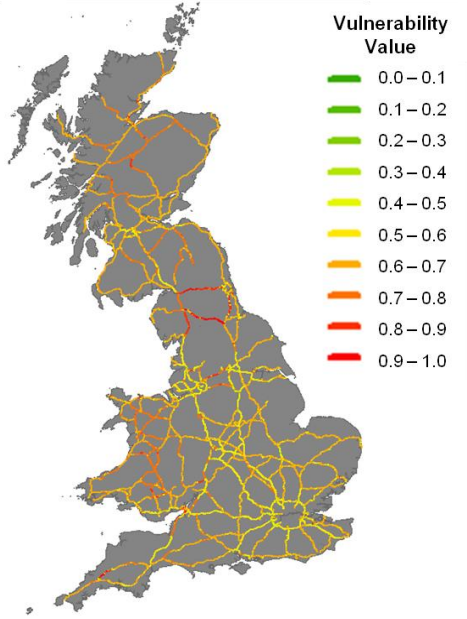


Assessing robustness of the vulnerability index

- Vulnerability Indicators:
  - Wind direction relative to road section orientation (WD)
  - Road section attribute (RAtt)
  - Road section altitude (Ratt)
  - Number of Lanes (NL)

- Control = standard vulnerability metric using the 4 proxy indicators

- One-At-A-Time (OAT) sensitivity analysis

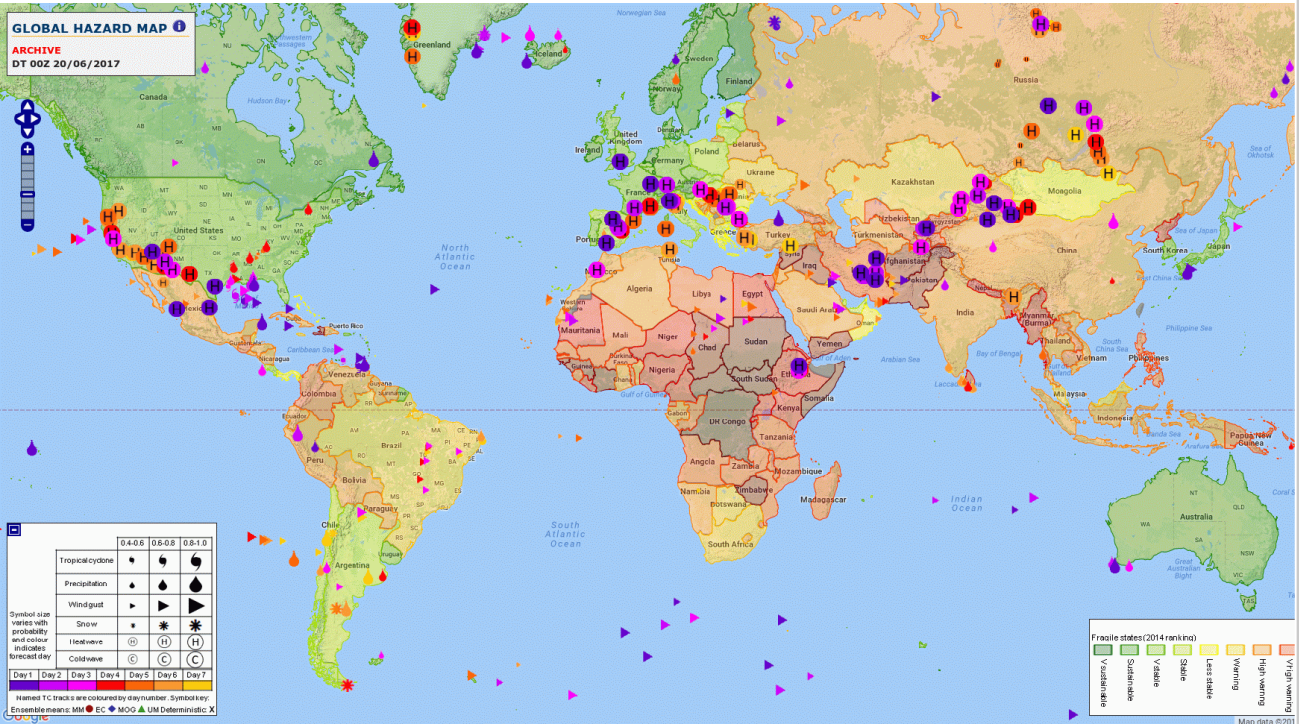


		E1_3A	E1_3B	E1_3C	E1_3D
		WD	RAlt	RAtt	NL
E1_3A	WD		✓	✓	✓
E1_3B	RAlt	✓		✓	✓
E1_3C	RAtt	✓	✓		✓
E1_3D	NL	✓	✓	✓	

Impact data for evaluation and model design

Met Office

Global Hazard Map



Met Office

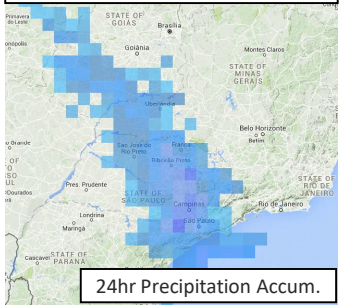
Global Hazard Map

- GHM is a GIS Web Map Service created by the Weather Impacts team for Global Guidance Unit forecasters
- Aims to summarise where high-impact weather is forecast across the globe out to 7 days using global ensembles
- Web Map Service – easy to overlay info, zoom/pan, flexible format for data layers
- Symbol-based summary map, coloured by lead time, sized by probability, to give an “at a glance” view of all hazards and lead times
- Can then drill down to particular variables / days / models / areas of interest
- Can overlay vulnerability and exposure layers to give information on likely impact

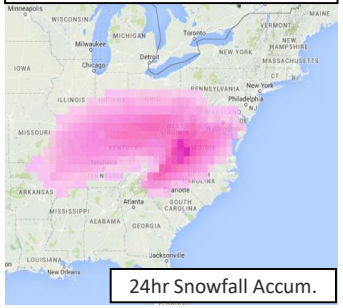
GHM forecast layers: Creation of summary map

ECMWF ENS; MOGREPS-G; Multi-model ensemble

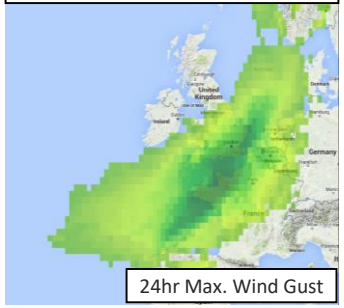
Day 3 forecast from 00Z 09/03/2016



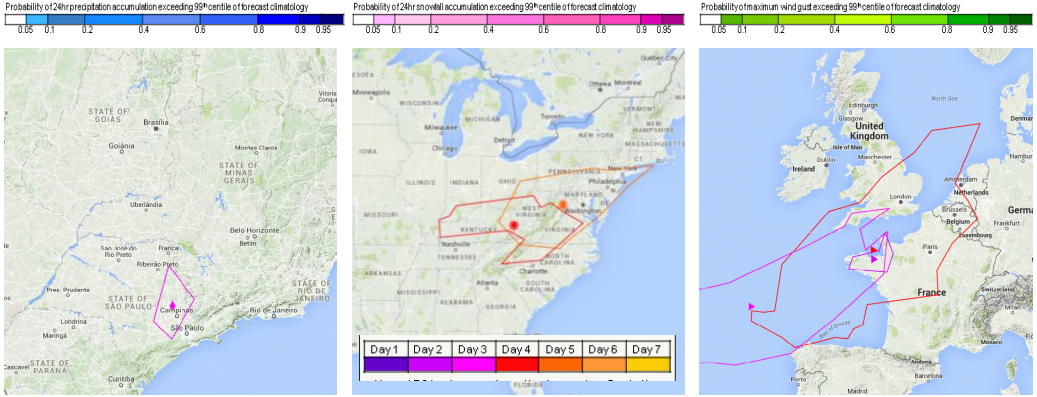
Day 4 forecast from 00Z 19/01/2016



Day 4 forecast from 00Z 25/03/2016

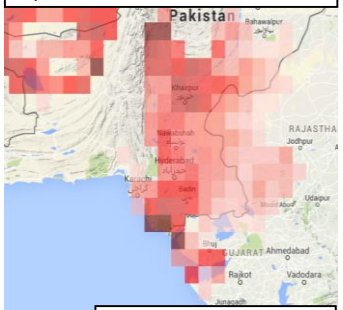


For each of these it shows the probability of exceeding the 99th centile of forecast climatology

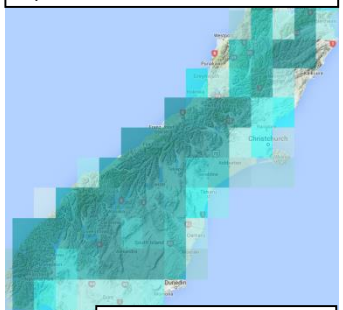


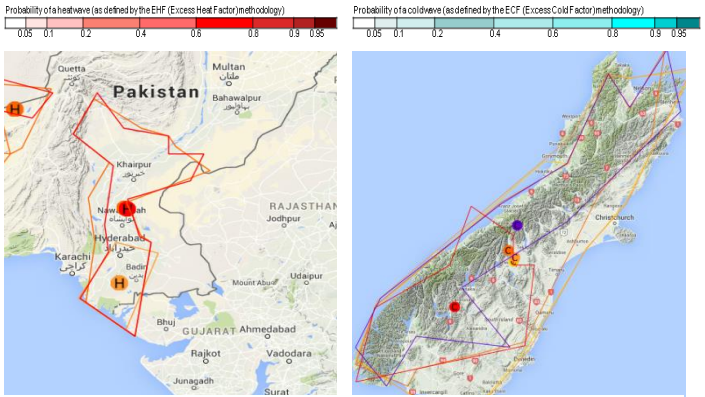
ECMWF ENS only

Day 5 forecast from 12Z 15/06/2015



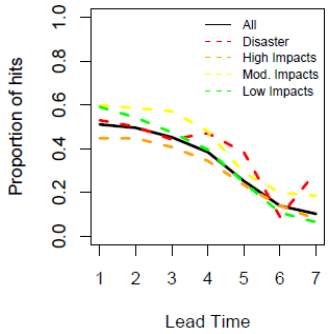
Day 6 forecast from 00Z 15/06/2015





Summary polygons, coloured by lead time, show the areas where the probabilities are significant for that lead time and hazard

Evaluating high-impact forecasts



How does GHM perform in meeting its key aim “to summarise the risk of high-impact weather for the week ahead”?

(1) Did the forecast weather at a certain level of severity occur?

Traditional ensemble-based verification against weather observations

Comparing gridded hazard forecasts against station-based weather observations to create contingency based verification statistics as to whether or not the weather event occurred

(2) Did the forecast weather result in a high-impact event?

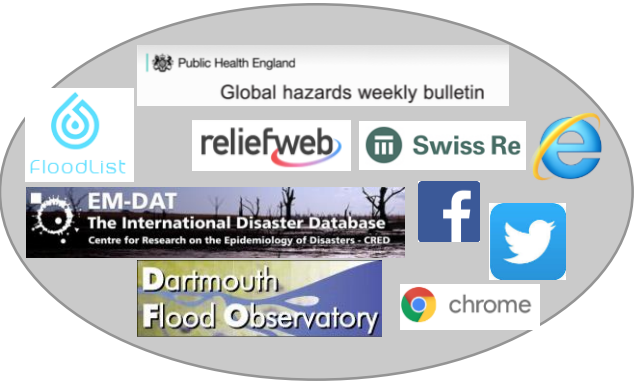
Newly developed impact-based evaluation method

Aims to evaluate how well the Global Hazard Map summary polygons relate to records of community impacts (e.g. fatalities, injuries, displacement, evacuation, receipt of aid, disruption, denial of access, hardship)

Robbins and Titley, 2018. Meteorological Applications

Impact Databases: benchmark comparison testing

Met Office manually curated database

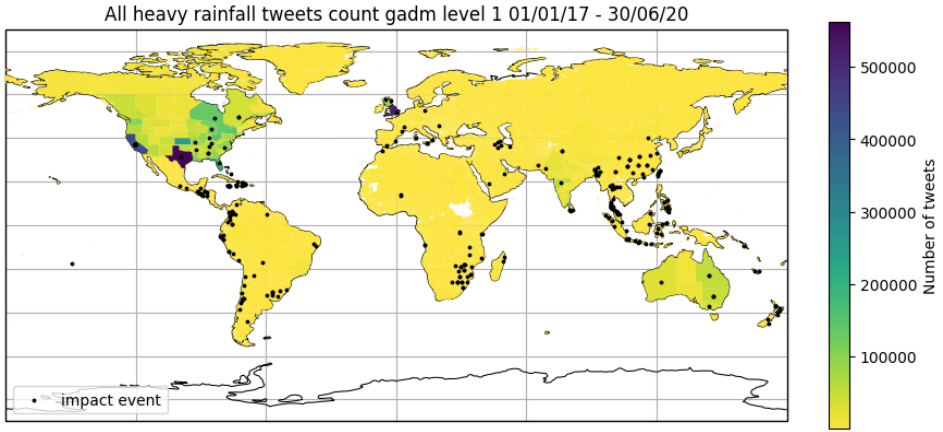


Heavy Rainfall Database
Spatial_ID (entry ID)
Event_ID (hazard event ID)
Record Date
Start Date
End Date
Hazard Type ('Heavy rainfall')
Trigger/Cause
Secondary Hazards
Hazard Notes
Country Name
Region/State/Province Name
Region/State/Province Latitude
Region/State/Province Longitude
Settlement Name
Settlement Latitude
Settlement Longitude
Impact Information
Impact Categorisation
References

- Labour-intensive
- Significant amount of detail in the impact information
- Good accuracy in temporal and spatial location of each record
- Increased likelihood of events not being captured due to the resource required for manual curation

Database using social sensing

- Filtering tweet data to remove retweets, quotes, bots and other non-relevant data
- Location inference of the tweets
- Matching to GADM level 1 locations for comparison with the manually curated dataset
- ***Aim to test social sensing method as an event detector***



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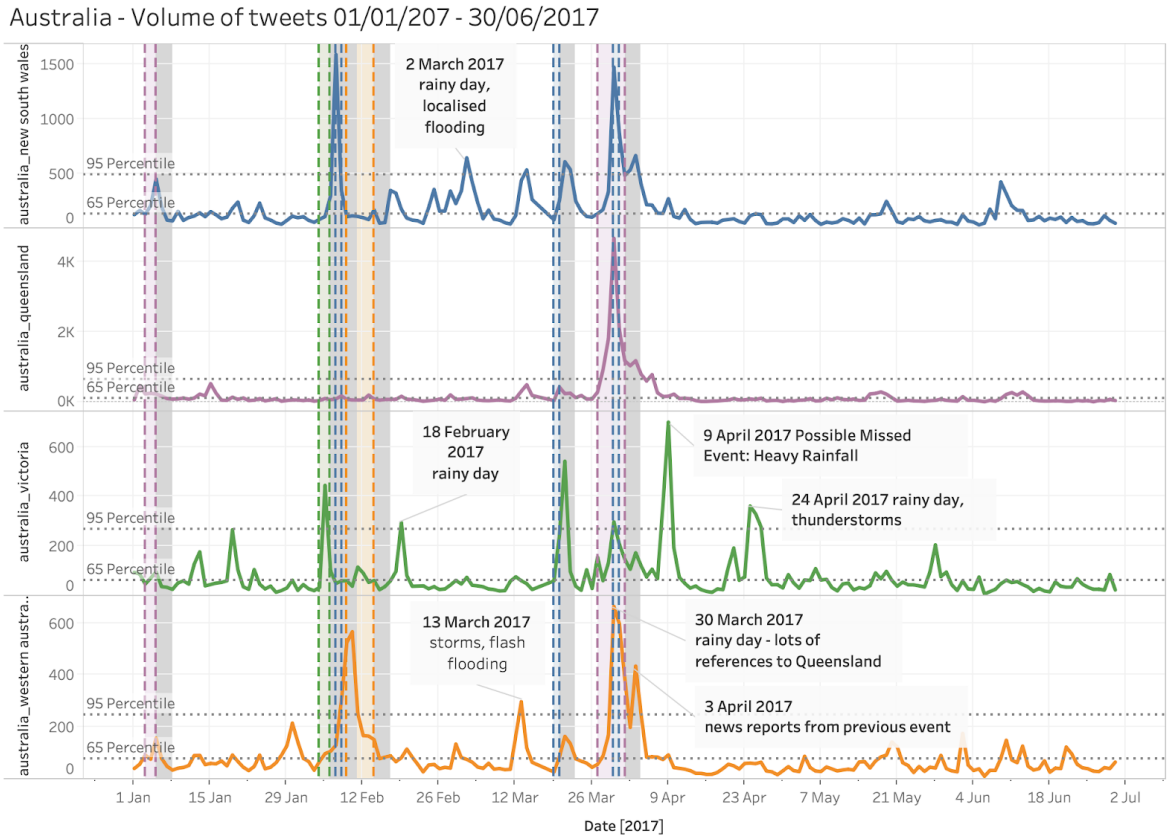
Impact Databases: benchmark comparison testing



- Good correspondence between the volume of tweets and identified events in the MO database
- Several peaks in tweet data (greater than 65th & 95th percentile) that do not correspond to events in the MO database – these represent potentially missed events
- Still need to identify optimal tweet percentile thresholds that could be used for event identification – likely to be spatially and severity variable

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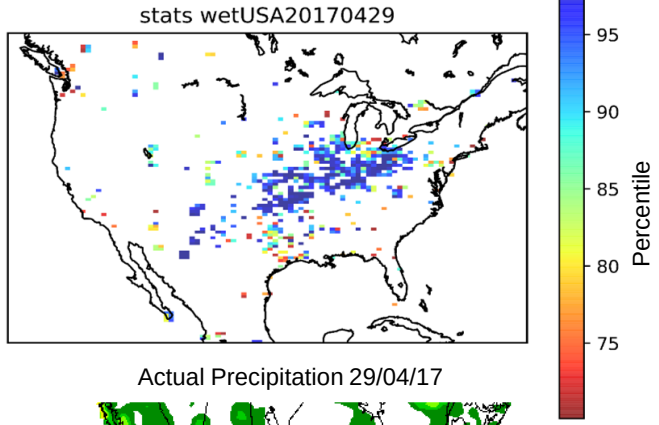
Impact Databases: benchmark comparison testing

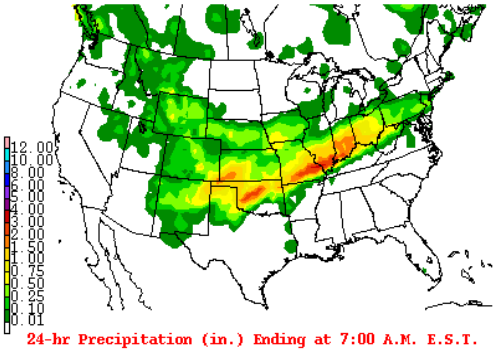
Key findings:

- Performance greatest for native English-speaking countries. Reasonable performance for countries which speak other languages which is encouraging
- Tweet data aggregated over a 3-day window yielded the best results when compared to the Met Office database
- Number of tweets does not necessarily improve the performance of the social sensing method
- Method achieves high coverage (few false negatives)
- False positives suggest the social sensing method could enhance our impact database collection
- More work needed to understand what tweets can offer in terms of impact detail and how this aligns with impact severity categorisation

‘Heavy Rainfall’ USA Tweet Activity 29/04/17



Actual Precipitation 29/04/17



http://www.wpc.ncep.noaa.gov

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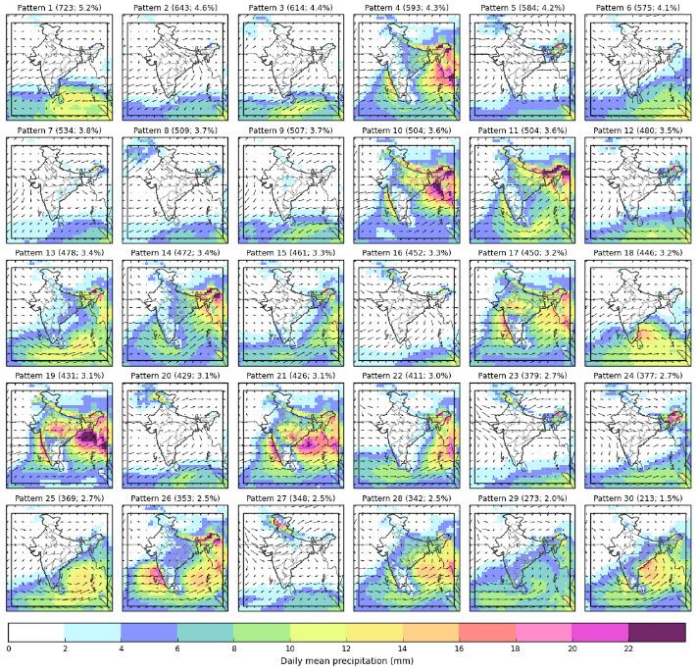
Extended-range forecasts for preparedness

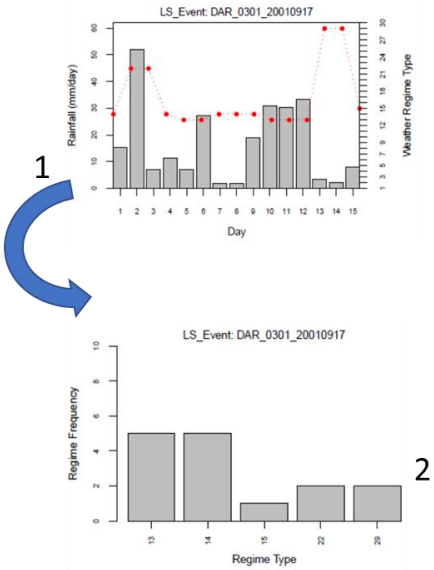
Understanding what forecasts to use when, to inform guidance

Weather patterns over India



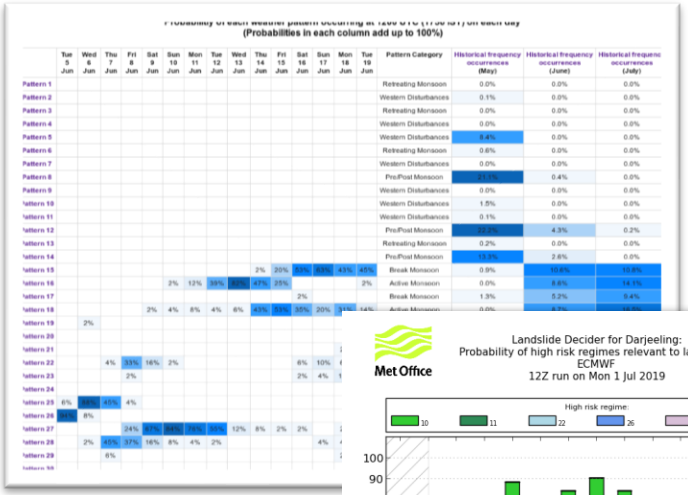
Assess relationship between weather patterns and a range of hazards and hazard-related impacts

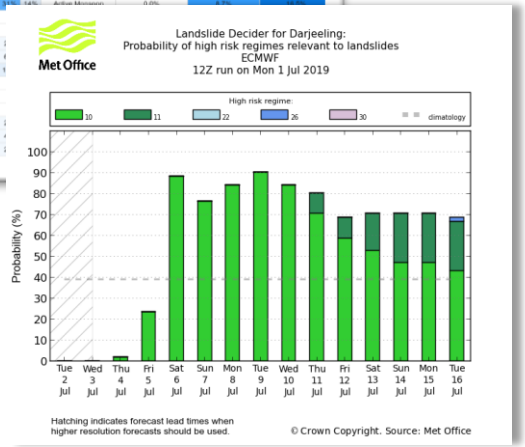
Identifying high-risk weather patterns for rainfall-induced landslides



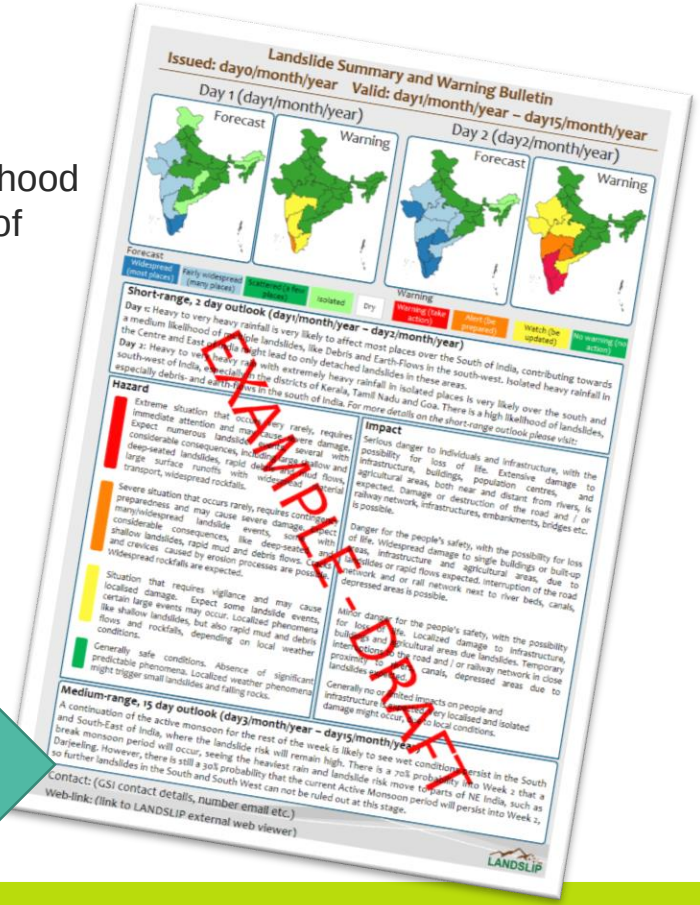
Neal et al. 2020. International Journal of Climatology

Understanding what forecasts to use when, to inform guidance





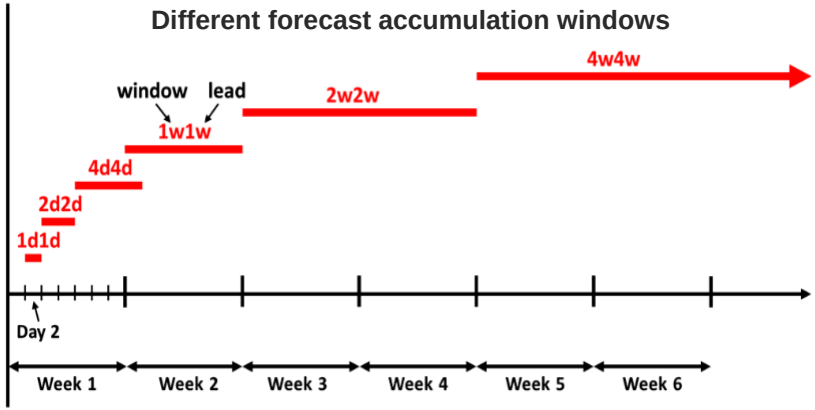
Provides probabilistic information for periods of heightened landslide likelihood based on the occurrence of high-risk weather patterns



Heads-up guidance to inform preparedness

Understanding what forecasts to use when, to inform guidance

For rainfall relevant hazards (e.g. landslides and floods) we need to understand the skill in the rainfall forecasts at different lead times



Wheeler et al. 2017

What does the future look like?

- New & different types of data & ways of processing & analysing them
  - Observations, spatially and temporally dynamic vulnerability & exposure
- Improved impact-orientated evaluation utilising robust and repeatable methods & data
  - Forecasts, warnings & user perception and utility
- Opportunities to understand the hazards through to impacts across forecast lead times; factoring in uncertainty propagation & the controls on predictability for hazards & impacts
- Impact led, multi-hazard ‘event-based’ warning which captures the compound and cascading hazards & impacts to better inform actors of event risk

Met Office

Contributors from Met Office: Lizzy Dyson, Seshu Kolusu, John Mooney, Robert Neal, Helen Titley, Joanne Robbins Anthony Veal, Faye Wyatt

Contributors from University of Exeter: Michelle Spruce, Rudy Arthur, Hywel Williams

References:

Hemingway R. & Robbins J (2020) Developing a hazard impact model to support impact-based forecasts and warnings: The Vehicle OverTurning Model. *Meteorological Applications*, 27, 1, e1819

Neal R., Robbins J., Dankers R., Mitra A., Jayakumar A., Rajagopal E.N. & Adamson G. (2020) Deriving optimal weather pattern definitions for the representation of precipitation variability over India. *International Journal of Climatology*, 40, 1, 342-360

Robbins J & Titley H.A. (2018) Evaluating high-impact precipitation forecasts from the Met Office Global Hazard Map using a global impact database. *Meteorological Applications*, 25, 4, 548-560

Wheeler, M.C., Zhu, H., Sobel, A.H., Hudson, D. and Vitart, F. (2017), Seamless precipitation prediction skill comparison between two global models. *Quarterly Journal of the Royal Meteorological Society*, 143: 374-383

Questions?