Dynamic Coast

Erosion Enhanced Flooding

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Erosion Enhanced Flooding

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Project Managers: Emily Hastings (2017), Nikki Dodd (2018), Sophie Beier (2019-2021). Centre of Expertise for Waters/James Hutton Institute.

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The cover image shows: (Top) Storm waves reflecting and undermining artificial defences at Golspie, Highland. Copyright: A. MacDonald (2020). (Bottom left) coastal erosion of the beach crest adjacent to the World Heritage Site at Skara Brae, Bay of Skaill in Orkney. Copyright: A Rennie / NatureScot (2019). (Bottom right) an oblique aerial image of the Splash play park at Montrose looking north. In the 1980s the play park was set-back within the dune, due to the subsequent coastal erosion, now it is in a more exposed position relying on artificial coastal defences. Copyright: F. McCaw (2021).

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WS1a Erosion Enhanced Flooding (Technical Annex)

Context

Coastal erosion, erosion enhanced flooding and coastal flooding are expected to be amongst the early impacts of climate change affecting mid-latitudes. Despite erosion and flooding often occurring together, they have in the past been considered as separate risks. This separation represents a fundamental gap that Dynamic Coast set out to address. Whilst more detailed local modelling has been undertaken within the Dynamic Coast Super Sites, the juxtaposition of anticipated coastal erosion and coastal flood polygons allows the identification of flood-prone areas whose flood frequency and extent may increase due to the erosional loss of protective features, such as coastal dune cordons with low-lying hinterland areas. In parallel, such an analysis also identifies areas where flood risk is not expected to be influenced by coastal erosion. Accordingly, a prioritisation of such areas has been developed based on coincidence of both erosion and flooding areas and then provided to SEPA and Local Authorities (LAs) to support their duties under the FRM(S) Act.

SEPA have national responsibility for national flood risk assessment, which aims to identify risks posed from coastal, fluvial and surface water flooding. SEPA works with LAs to take forward and appraise the identified risks at a local level via Flood Risk Strategies. However, at a national level much of the coastal flood mapping is derived from a simplified understanding of the anticipated flood level, reflected by an anticipated still water-surface flood level compared against terrestrial land-levels, to identify which areas are at risk. A number of urban shores have improved mapping where the offshore wave characteristics have been appraised alongside detailed topographic mapping to better understand wave overtopping risks. Whilst these approaches are pragmatic, neither approach incorporates the additional flood risks caused by the loss of natural protective features by coastal erosion, both locally and at a national level, hence SEPA's interest and support of Dynamic Coast (phase one and two). Since 2017 the Dynamic Coast mapping has been available for SEPA and Local Authority staff to read alongside their flood risk assessments, however a prioritised assessment of the locations where erosion was most likely to exacerbate flooding was required and this was investigated within Work Stream 1 of Dynamic Coast 2.

Flood risk can be enhanced on both natural and artificially defended shores by the loss of beach sediment that then leads to foreshore lowering and/or coastal steepening. Coastal steepening occurs where the positions of MHWS and MLWS migrate at different rates, with the most common condition being where MLWS migrates landward at a faster rate than MHWS. This occurs naturally, for example where resistant rocks outcrop at MHWS and arrest its migration, yet any landward movement at MLWS remains unaffected due to the mobility of sediments at that position. Artificial coastal defences act in the same way as a rocky shore or cliff and allowed Talyor et al. (2004) to identify an association between coastal steepening and coastal defences around the English and Welsh coasts. Such an effect, mainly due to wave reflection effects, is not unexpected and has prompted international recognition of the reducing extents of foreshores around the globe. This has been recognised as a high priority issue internationally with Sustainable Development Goal (SDG) Indicator 6.6.1 calling for changes in the extent of water-related ecosystems over time to be monitored. The nature and geometry of the nearshore is particularly important in the dissipation of wave energy and is a critical factor in forecasting wave overtopping (SEPA FRM assessments).

Erosion enhanced flooding

Methods

SEPA's coastal flood maps show the areas of land below anticipated flood levels, extended from a buffer set 500m seaward of MHWS. Such an approach hinders the visualisation and analysis of erosion enhanced flooding as the depiction of time-series future erosional shorelines moving landward intersects with areas of anticipated flooding on both foreshore and offshore and produces a cluttered output. Thus, an initial step was required to identify only the inland areas of anticipated flooding, excluding the shore-face and 500m seaward buffer.

Identification of inland flood areas & exclusion of the foreshore and offshore

Following consultation with SEPA the Medium Probability Climate Change (1:200yr event & UKCP09 HES 95% sea level rise) flood polygon was extracted from the current version (V2) of the SEPA flood maps[1]. This was clipped with a 1:250k polygon dataset of Scotland. This removes the anticipated flooding within the sea, intertidal area and leaves a narrow slice along the upper beach, along with the inland areas. The polygon dataset was then converted from multipart to single-part geometries to enable each individual 'flood polygon' to be analysed separately. Unique identifiers were created prior to the extraction of the centroid location from each flood polygon. The distance from each centroid to the shoreline of the 1:250k dataset was calculated to allow the area of each flood polygon and the coastal distance from its centroid to be established. These were manually reviewed and an 'inner' description was assigned to polygons which extended inland, whist 'edge' areas were the null condition (where polygons were limited to the shoreface). An intersect of coastal flood prone areas with 'roads' was also undertaken and labelled as 'inner roads'. The resultant dataset reflects the inland extent of coastal flooding based on a 1:200 year ('Medium') annual probability of flooding, including the UKCP09 High Emissions 95 percentil sea level rise figure.

Proximity of inland flood polygon to future MHWS

A proximity analysis was carried out on the areas of anticipated inland coastal flooding (prepared above) alongside the anticipated future shoreline positions established in Dynamic Coast Work Stream 2, at each decadal interval between 2020 & 2100. Inland areas of flooding were included when they lay within 30m of the anticipated 2100 MHWS line, and then labelled within an Erosion Year of 2100. This process was repeated for the anticipated 2090 MHWS line, overwriting those also selected for 2100 and so on for all future decadal MHWS lines. It is acknowledged that whilst this represents a simplification of the relative protection potentially offered by any flood protection feature (dune ridge etc), it does provide a first order assessment of erosion enhanced flooding extents at a national level. Such an

[1] Whilst UKCP18 data has been used throughout out this research, SEPA had not updated their earlier climate change flood mapping. For this reason we were advised to use the pre-existing UKCP09-based maps. See SEPA (2020) Future Flood Map Summary document, for more information.

approach assumes the erosion and demise of the original position of the flood protection feature and does not reflect any 'roll-over' processes, where sediment is carried landward and possibly upward but with the feature remaining intact, albeit now further landward than before. This process is commonly associated with coarse sediment shores. A possible future refinement of this approach might employ the DEFRA shore face habitat map as an additional step to identify the shore face type and assess the likelihood of roll-over of that type of shore. Since the typical distance between the position of MHWS and the vegetation edge (the point when erosion of land/dune etc starts, as opposed to loss of beach) lies between 15m and 30m nationally, a nominal distance of 30m inland from the MHWS position was used to identify when inland flood areas were expected to be at risk of breaching and then included within the flood envelope. Figure 1 shows an example of this from South Uist, where areas of identified flood risk are symbolised based on the proximity of future erosion; for example, areas shaded red lie within 30m of MHWS in 2020, areas shown in yellow lie within 30m of MHWS in 2060, areas shown in light green lie within 30m of MHWS in 2070 and so on.

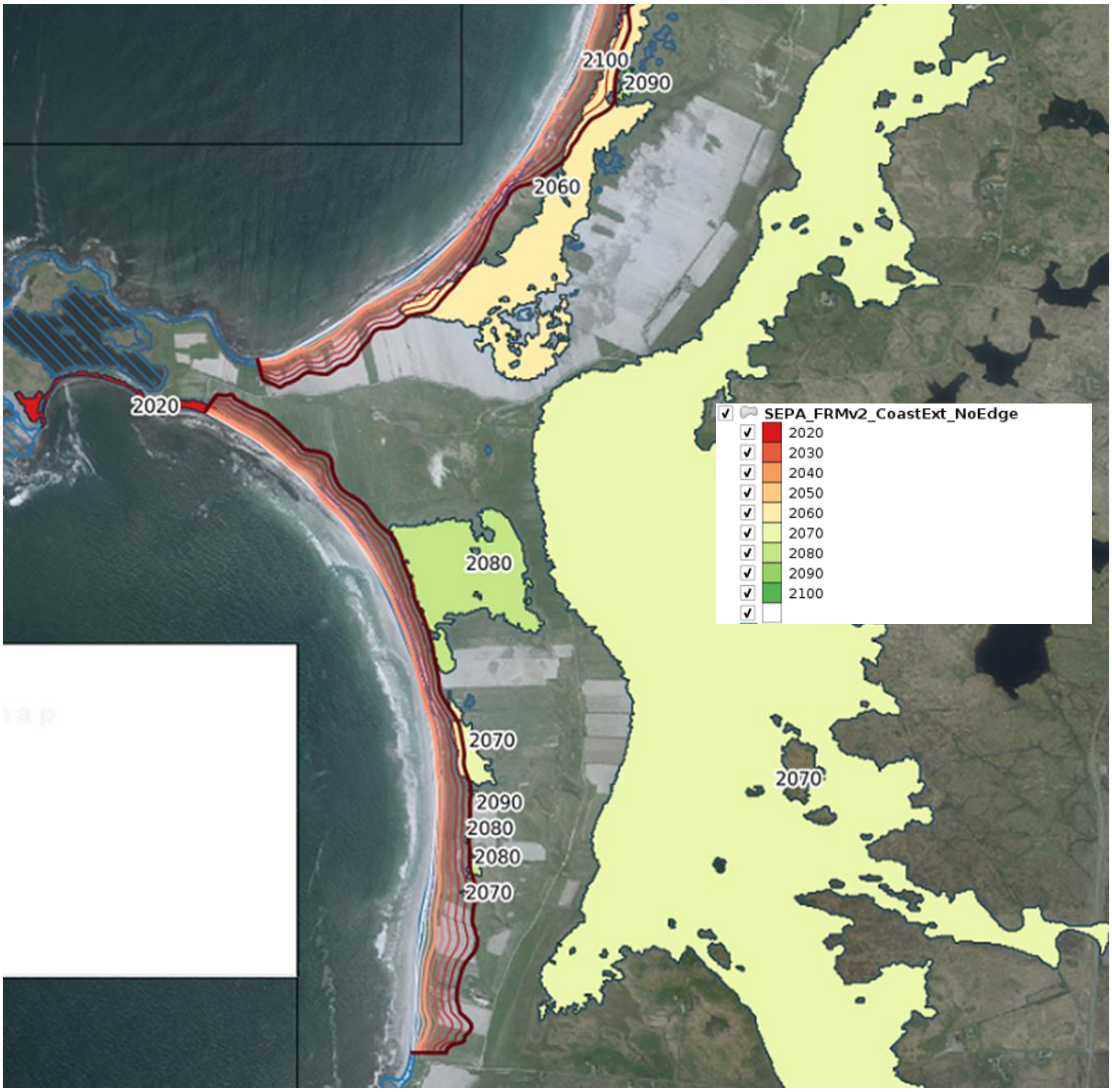


Figure 1 Example of proximity analysis of areas at flood risk and anticipated erosion. South Uist.©SEPA flood risk maps.

Proximity of erosion enhanced flood prone areas to assets

The flood prone areas were compared with SEPA's residential property (polygon) dataset, road and rail dataset to inform the presence or absence of asset data. Further analysis by SEPA and LA partners can be carried out, by subdividing the polygons further, and considering the overlap with assets to further inform potential erosion enhanced flood risks.

Indicative Results

Of the 9,067 coastal flood-prone inland polygons analysed by Dynamic Coast, almost one quarter of these are likely to be influenced by coastal erosion by 2100. The bulk of these contain some areas close to the anticipated MHWS positions, however as MHWS retreats inland the number of additional polygons increases (Table 1).

Table 1 Summary describing the influence of erosion on areas of inland flood risk and adjacent assets.

Description	# of flood polygons within 30m of anticipated position of MHWS	# of flood polygons with Residential Property within 30m of anticipated position of MHWS	# of flood polygons with roads within 30m of anticipated position of MHWS	# of flood polygons with rail within 30m of anticipated position of MHWS
2020	1,760	371	629	50
2030	10	1	3	0
2040	26	0	1	0
2050	38	3	5	0
2060	33	1	2	0
2070	45	4	5	0
2080	46	2	5	0
2090	43	1	1	0
2100	46	3	4	1
Total (2020-2100)	2,047	386	655	51

See the link below for an interactive web-map of the results:

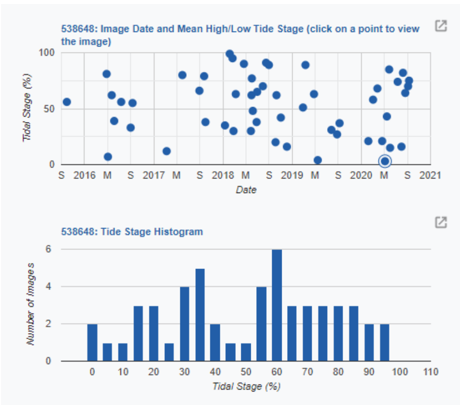
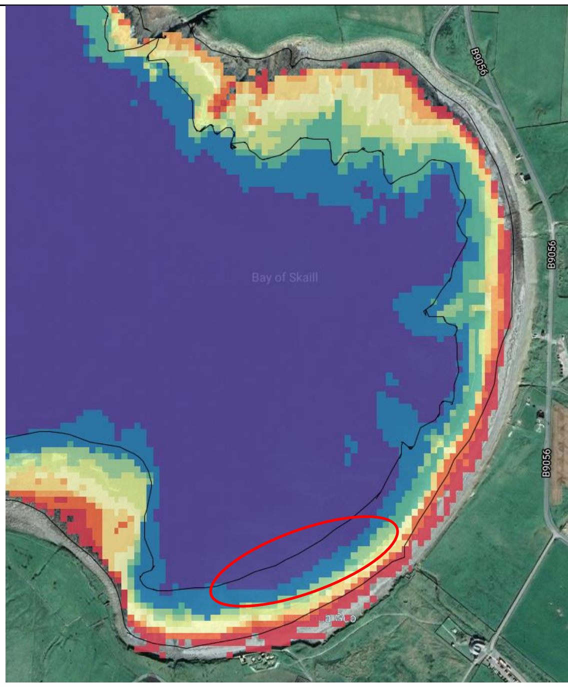
Browser link
www.dynamiccoast.com/webmaps.html

Beach lowering at defences and possible increase of flood risk

Methods

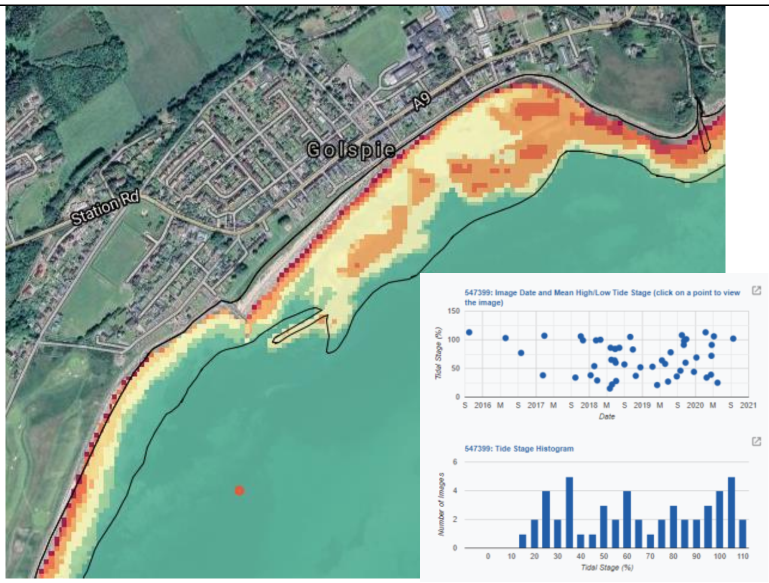
In order to develop a methodology to establish the extent of beach lowering and its association with coastal defences, it is necessary to assemble three datasets: the national distribution of coastal defences, (both natural and artificial) and the observed time-series positions of both OS MHWS position and OS MLWS position. The currency and dating of OS MHWS positions is robust and is used throughout Dynamic Coast, however the currency of OS MLWS is less complete with intermittent updating on a national scale. In view of this Dynamic Coast has employed our Coast X-Ray tool (https://jamesmfitton.users.earthengine.app/view/coastxraytides, link to WS7 paper) to compare the published position of OS MHWS and MLWS alongside the observed tidal extent visible within the Sentinel 2 back-catalogue of satellite images. Several artificially defenced shores were included to test the method in the expectation of a national roll-out in due course. It should be noted that nationally the distribution, extent and condition of coastal defences remains incomplete and any meaningful national roll-out of this method awaits enhanced data on the coastal defence estate. However, since the Coast X-Ray coverage is national, as are the OS MHWS and MLWS positions, then a national picture of beach lowering is possible, albeit at a relatively coarse level of granularity.

Indicative Results

Location & Observation	Extract from Coast X-ray
Bay of Skaill, Orkney [Good tidal spread of observations] X-ray suggests that MLWS in Southern third of the Bay has moved landward and suggested associated increase in flood risk. 	

Golspie, Highland

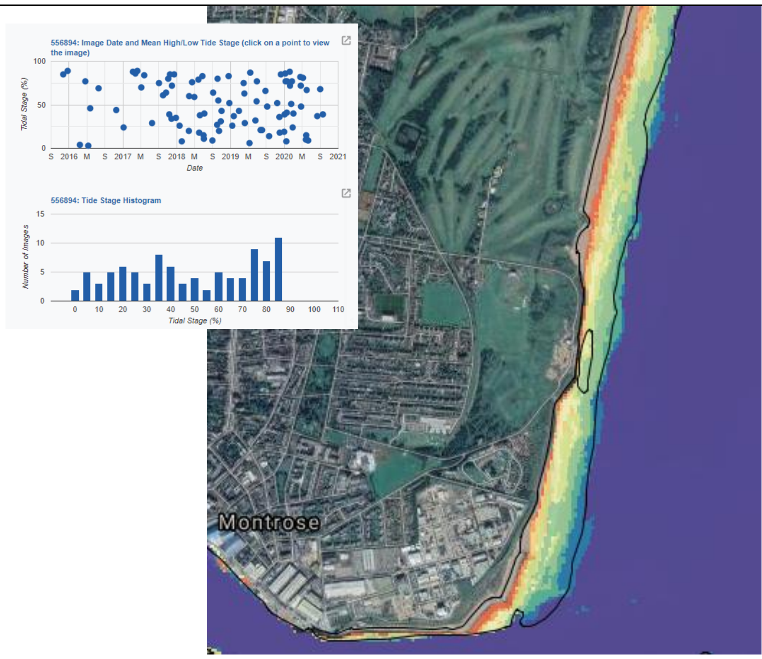
[Limited low-water observations] therefore possible retreat of MLWS south of Goslpie Pier is inconclusive. Upper beach accretion north of Golspie Pier, reducing flood risk.



Montrose, Angus

[Good low-water observations]

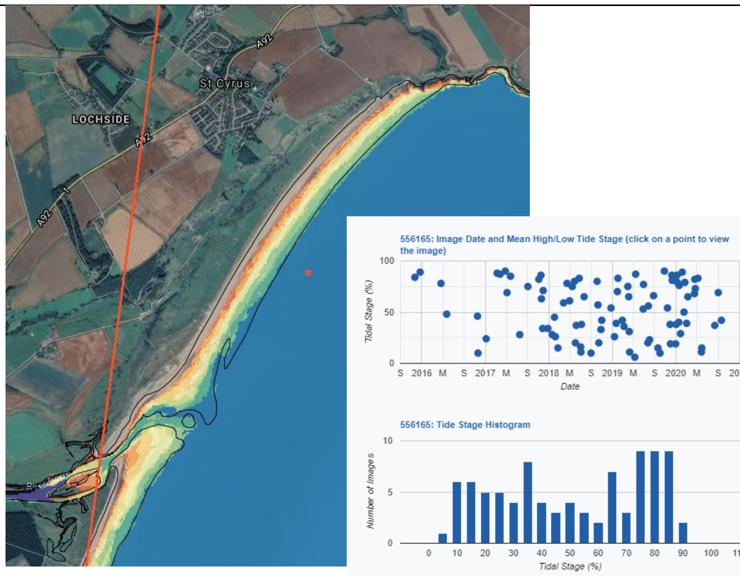
Recent update of OS MLWS means comparisons are unhelpful as there is little time period between data. Historic 1970s MLWS shows retreat of MLWS at Annat Bank and Southern Links.

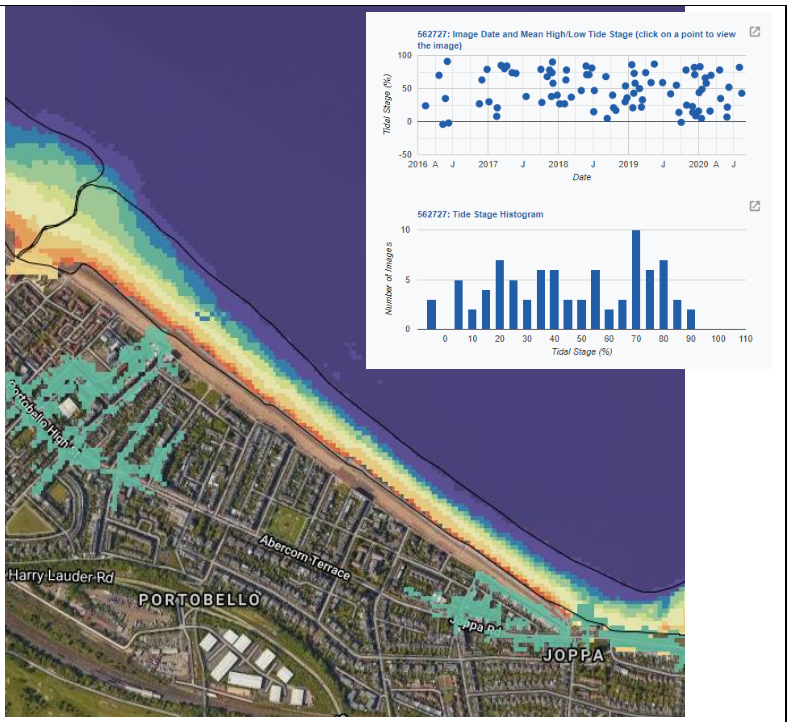
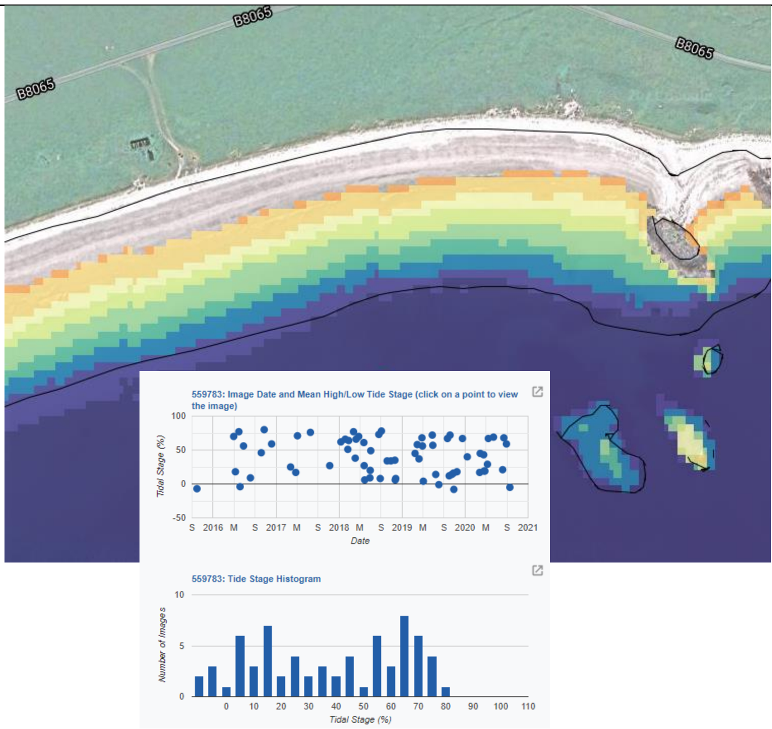


St Cyrus, Aberdeenshire

[Reasonable low-water observations]

Recent update of OS MLWS rendered default X-Ray view unhelpful.



Portobello, Edinburgh [Good low-water observations] MHWS and MLWS align well with Coast X-Ray derived intertidal stage. This suggests limited foreshore change and no apparent change in flood risk / overtopping risk.	
East Hynish Bay, Tiree, Argyll & Bute [Very good low-water observations] MLWS aligns well with Coast X-Ray derived intertidal stage. This suggests limited foreshore change and no apparent change in flood risk / overtopping risk. Possible 30m retreat of lowest foreshore near east.	

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Stornoway, CNES
[Good low-water observations]
To the east of the runway defences MHWS agrees with Coast X-Ray derived upper beach, however MLWS appears to have retreated ca 30-50 m landward with Coast X-Ray lower foreshore. This suggests lower foreshore lowering and coastal steepening with an associated increase in flood risk / overtopping risk.
To the west of the runway defences the MHWS line is out of date, whilst X-Ray and photography reflect recent geomorphology.
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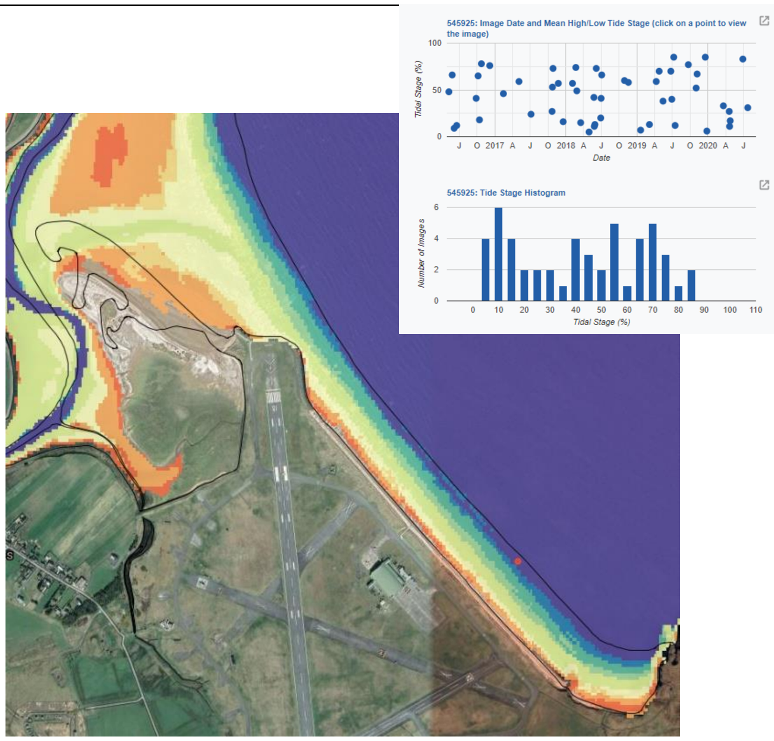

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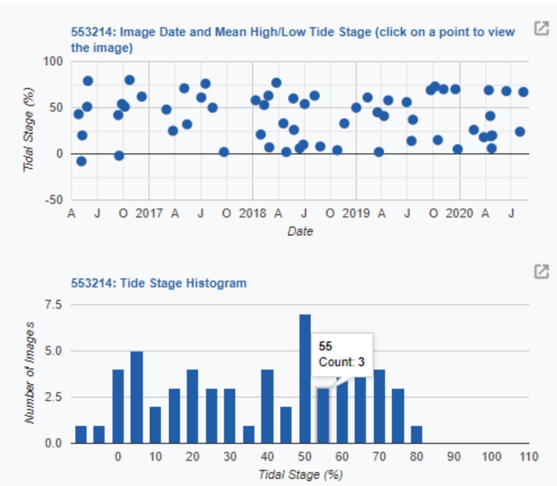
Gualan & South Ford, Uist, CNES
[Very good low-water observations, poor high-water observations]
X-Ray unable to infer upper beach changes, however MLWS appears to have retreated ca >50 m landward. This suggests lower foreshore lowering and coastal steepening with an associated increase in flood risk / overtopping risk.


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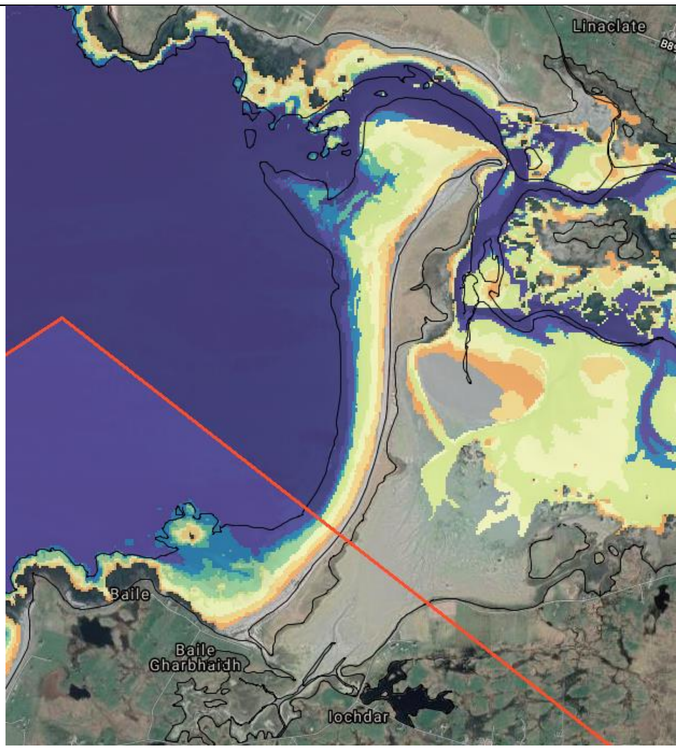

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Wider Implications of This Research

We acknowledge that the initial analysis presented here provides a first impression on the linkages between present and anticipated erosion risk, and coastal flood risk. Nevertheless, the granularity of the analysis could be improved by further inspection of the inland flood envelopes, and further subdivision and then updating the proximity analysis. More detailed understanding of the morphology of natural flood defences at the coast coupled with expectations of whether roll-over will maintain these features as the coast evolves in response to sea level rise, will also help in targeting areas with the greatest compounded future erosion and flood risk.

This work validates concerns over erosion-enhanced flood risk, and the need for more detailed assessment of the relative resilience of the flood protection features. This more detailed assessment, and on-going monitoring and surveillance, is critical for SEPA to fulfil their national flood risk assessment responsibilities and for LAs to deliver any actions on the ground.

References

SEPA NFRA https://www.sepa.org.uk/environment/water/flooding/developing-our-knowledge/#National_Flood_Risk_Assessment

Taylor, Murdock and Pontee (2004) A macroscale analysis of coastal steepening around the coast of England and

End.