Impact of extreme weather events on global shipping - Team D

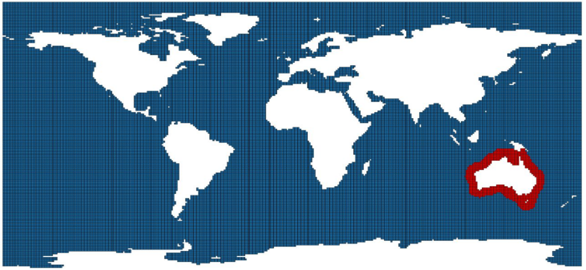


Figure 1 - Ocean Grids (Blue - Worldwide, Red - Australian Study Area)

Modelling Movement Around the Ocean

The first step in conducting our project was modelling how trade moves around the ocean. To do this, we split the world into 1-degree boxes. If the intersection of the largest ocean polygon and a given grid was non-empty, the grid was designated an ocean grid, reducing 63536 grids to 45851 ocean grids, as seen in Figure 1. The centroid of each of the ocean grids gave the nodes for our network, as seen in Figure 3. If the corresponding polygons of two nodes touched, then an edge between the nodes was created, with a weighting equal to the haversine distance between the two centroids latitude and longitude coordinates.

To reduce complexity, our study area was restricted to the ocean grids surrounding Australia, giving 750 ocean grids for our study. The full network for the australian study area can be seen in Figure 4.

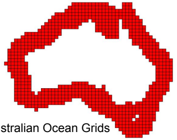


Figure 2 - Australian Ocean Grids

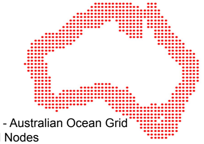


Figure 3 - Australian Ocean Grid Centroid Nodes

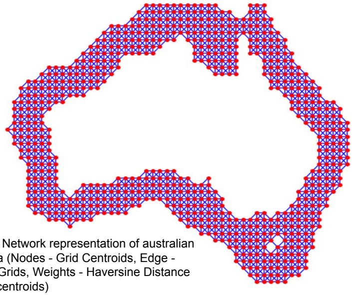


Figure 4 - Network representation of australian study area (Nodes - Grid Centroids, Edge - Adjacent Grids, Weights - Haversine Distance between centroids)

Modelling A Single Ship - Dynamic Analysis

In Figure 5 the red nodes represent the ocean grids centroids in the Australia study area. The green circle represents the origin of the ship, the green cross the destination, and the blue star the ships current location. The blue line through the nodes represents the shortest path by edge weight from the ship's current location to the destination, using all active nodes. Each time step, the ship moves a given distance, with the movement costs being £1 per km travelled. The first row, Figure 5a/b/c shows the movement through the network while all nodes are active. Figure 6b shows the path of the wallace cyclone in 2019 that in our model would cause some nodes to become untraversable, the impact of which can be seen by the missing red nodes in the top right of Figure 5d/e.

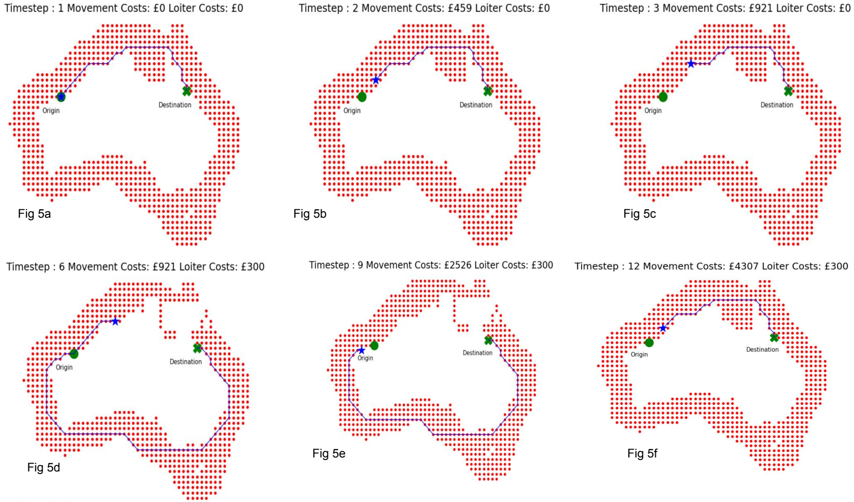
In this example, the ship then has a choice. The ship can either wait for the cyclone to pass, incurring a £100 loiter cost when a timestep passes but it does not move or begin to make the journey on the new current shortest path. In this example, the ship loitered for three timesteps (Fig 5d) and then moved for the next three timesteps (Fig 5e). However, at this point, time step 9, the cyclone passed, and the nodes are available to traverse again, meaning the new shortest path is again through the previously cyclone-affected region, as seen in Figure 5f. However, depending on the movement and loiter costs, and the time period the cyclone affects the network will determine whether to loiter or move is the most economical decision. This model allows for the effective modelling of future scenarios to inform decision making by seafarers.

Four Step Transport Model - Modelling Global Trade - Static Analysis

The model created can also be used to analyse aggregate global shipping, providing a view of the impact of extreme weather events over the whole study area. The aggregate shipping effects were modelled using a 4-step transport model framework. The first step is the trip generation, the determination of where is exporting and importing. For this, we used simulated values and the location of real ports, which can be seen as the red crosses in Figure 7. The next step is trip distribution, which determines which import and export go, for which we used a gravity model. The third step is mode choice, which is sailing for this analysis. However, the model can simulate different cargo classes, like reefer (refrigeration), oil tanker, bulk / general cargo etc, all with associated cost function. Finally, the fourth step is route assignment, which is the shortest path in regards to distance in this simulation. The volume on each network edge multiplied by the edge weight gives a value for the total distance travelled to move the cargo units to their needed locations. The thicker the lines edge the more volume on that edge of the network.

In Figure 7a where the network is unaffected, the total distance travelled is 90625 km. In Figure 7b where the network has inactive nodes on a significant shipping route (middle left), the total distance of movement of the goods is 90773 km, an increase of 0.2%. The model shows how a simple case of removing four nodes from the network causes an increase in movement costs. In a more extreme example, if a severe weather event causes a break in the network, visuaslied in Figure 7c then the increase in distance travelled jumped by 26.8% to 114883 km, for which only five nodes need to be removed to achieve.

Figure 5 - Timesteps for single ship model



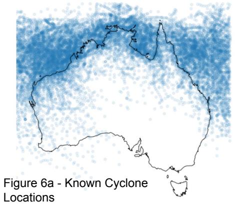


Figure 6a - Known Cyclone Locations Since 1907 [1]

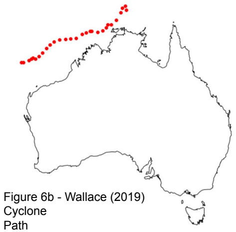


Figure 6b - Wallace (2019) Cyclone Path

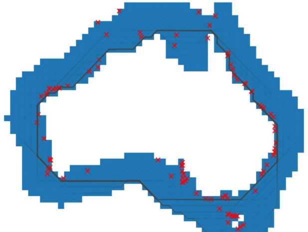


Figure 7a - Shipping Routes (Full Network - 750 Nodes)

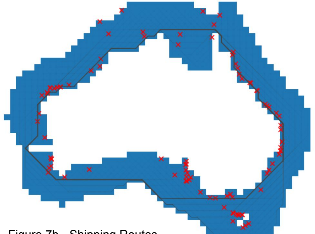


Figure 7b - Shipping Routes (Partial Network - 746 Nodes)

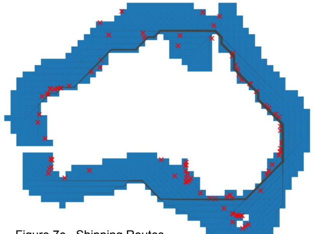


Figure 7c - Shipping Routes (Broken Network - 745 Nodes)

Potential Use Cases

Marine Protected Area (MPA) Placement - The model could be used to inform the location of new MPAs that have a minimal impact on global trade.
Vulnerability Node Identification - The model could be used to identify parts of the network used by a significant proportion of global shipping.
Optimisation - The model could be used for optimisation based on a range of cost functions, such as minimising the distance travelled between ports.

However, a core issue with the above scenarios is the dual use of the model and weaponising the output produced. While optimising for revenue, it could cause an increase in carbon emissions. Likewise, while identifying vulnerable parts of the network to deploy additional security assets, it also gives possible locations for terror attacks.

Moving forward, the development and embedding of safeguards against the situations detailed above will be of critical focus. For example, the entanglement of the model results to ensure that carbon emissions are always taken into account when making recommendations.

References:
[1] Australian Government, B., 2021. *Tropical Cyclone Databases*. [online] Bureau of Meteorology - Australian Govement. Available at: <http://www.bom.gov.au/cyclone/tropical-cyclone-knowledge-centre/databases/> [Accessed 17 June 2021].