Optimising shipping decisions subject to sea level uncertainty in tidal areas

Probabilistic *vs* Possibilistic approaches

UNIVERSITY OF LIVERPOOL — EPSRC & ESRC Centre for Doctoral Training in Risk & Uncertainty

Noémie Le Carrer[1,2], Scott Ferson[1], Peter L. Green[1]

[1]Institute for Risk and Uncertainty, School of Engineering, University of Liverpool

[2] nlc@liverpool.ac.uk

EPSRC Engineering and Physical Sciences Research Council

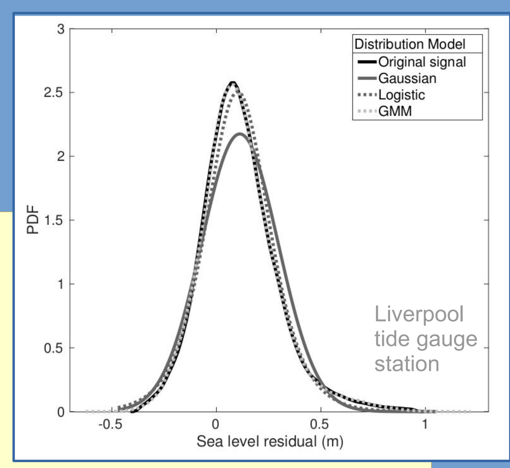
1. Towards robust and optimal shipping decisions?

- Traditional harmonic tide predictions remain the most commonly used data for ship scheduling in tidal areas.
- However **actual sea depths deviates from these predictions**: the residuals show a root-mean-square (rms) error of 10 cm averaged along tide gauge stations of the UK coast and even 29 cm for the high tidal range ports.

  More accurate hydrodynamic model predictions driven by weather forecasts (e.g. the MetOffice/NOC CS3 storm surge model) slightly lower this score to a **rms error of 8 cm** for 48h lead-time predictions [1]. In some American estuaries, the residual amounts to 30% of the predicted sea depth [2].
- **1 cm of available under keel clearance can be turned into an additional load of 30 tons** for a small bulk carrier of dimensions 136m x 21 m, which amounts to an **additional cargo value** ranging from ~US$ 2,000 (coal) to ~US$ 500,000 (tin).

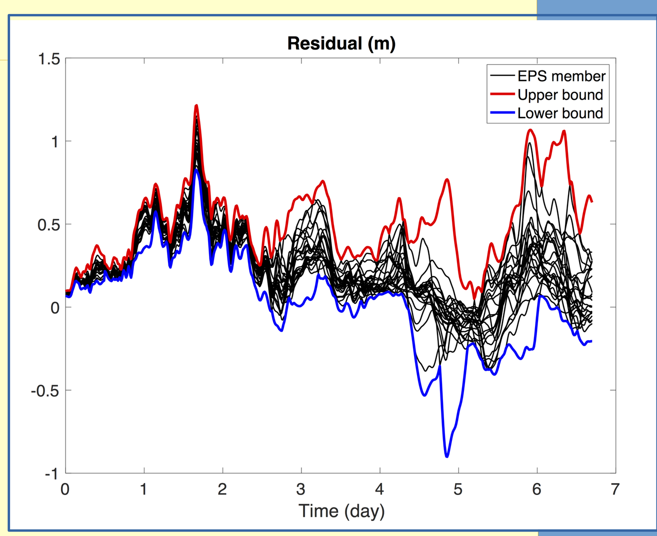
  In standard weather conditions, the fuel consumption increase is comparatively very limited (< US$ 100).
- **Large safety margins** have to be taken into account to prevent grounding and adapt to busy port conditions . Little work has been done on their optimisation, as they are most often added to a deterministic solution based on tide predictions only.
- A **robust and optimal solution** to this problem would allow shipping companies to make **extra profit** and port authorities to improve **safety** in seaways, increase port throughput and limit **port congestion**.

2. Modelling the uncertainty on sea levels: Probabilities *vs* Possibilities



A. Probabilistic approach

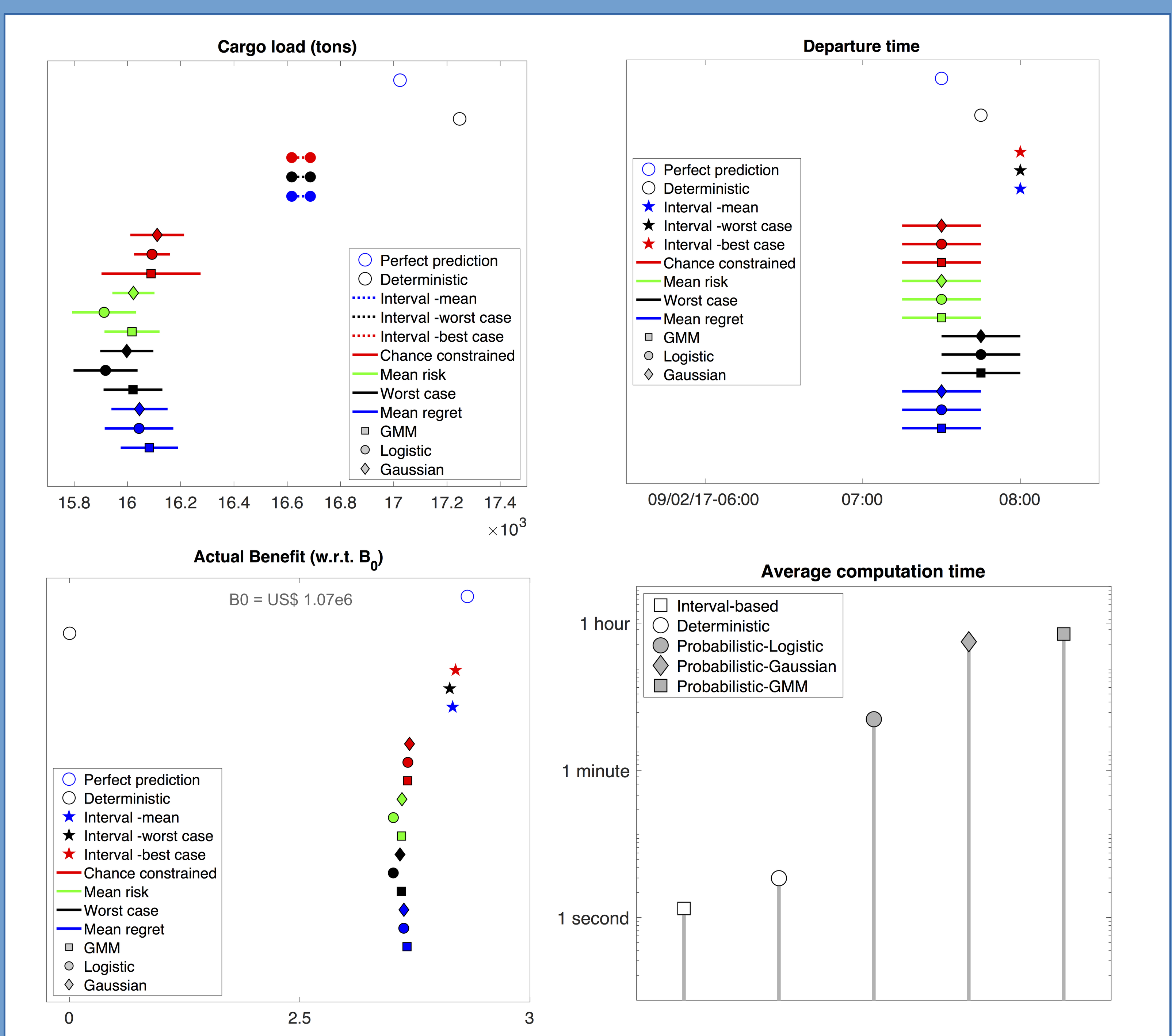
- Uncertainty is modelled via best-fit distributions over 10 years of residuals archives
- 3 distributions are tested: Logistic, Gaussian and Gaussian mixture model (GMM) as more complex models are also more expensive to sample
- 4 standard risk metrics are compared: mean-regret, mean-risk, worst-case, chance-constrained
- A particle swarm optimisation algorithm combined to Monte-Carlo simulations is then used to solve the cargo loading and ship scheduling problem.



B. Possibilistic approach

- The hydrodynamical surge model is run with 23 different weather forcing, issued by the weather ensemble predictions (EPS; MetOffice MOGREPS). This provide a sample of possible future sea level surges.
- Because the probabilistic interpretation of ensemble predictions raises concerns, especially for extreme events [3], we first consider that any value within the bounds of the EPS is possible, without additional information.
- A risk metric (worst case, mean benefit) is chosen and the problem is solved by propagating the bounds through the shipping decision model.

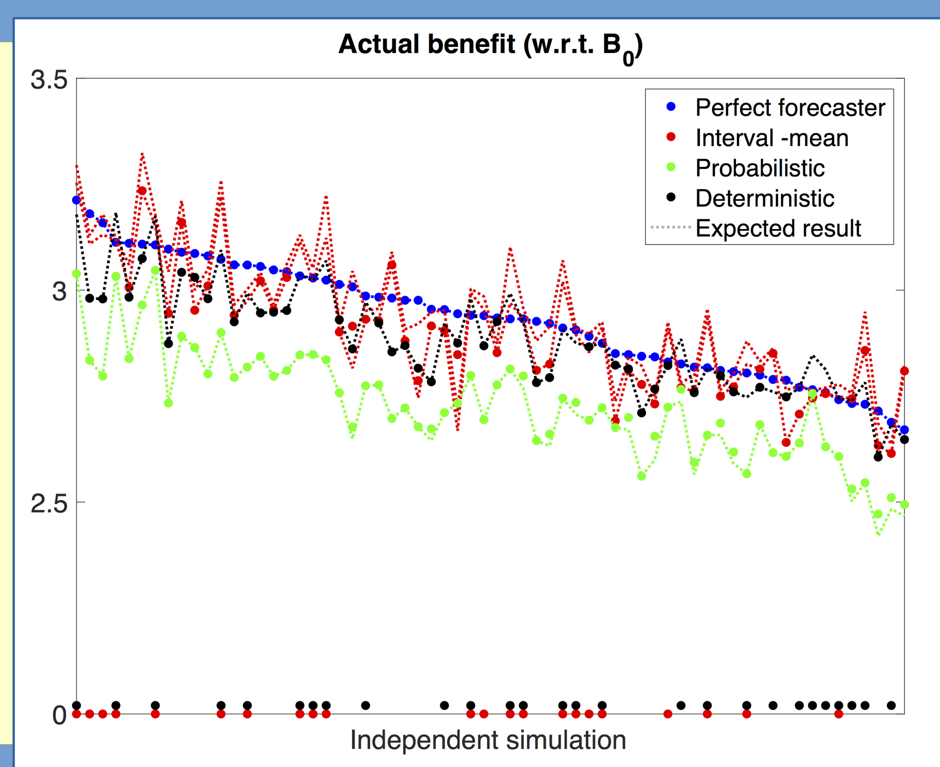
3. Results: a first case study



- The **deterministic** approach is **not robust** to sea level deviations or port delays
- The **probabilistic** approach shows **distributional robustness** (i.e. a simple logistic modelling works is sufficient) and robustness to 4-hour delays
- The **possibilistic** approach is **less conservative** than the probabilistic one, and **much quicker** to compute.

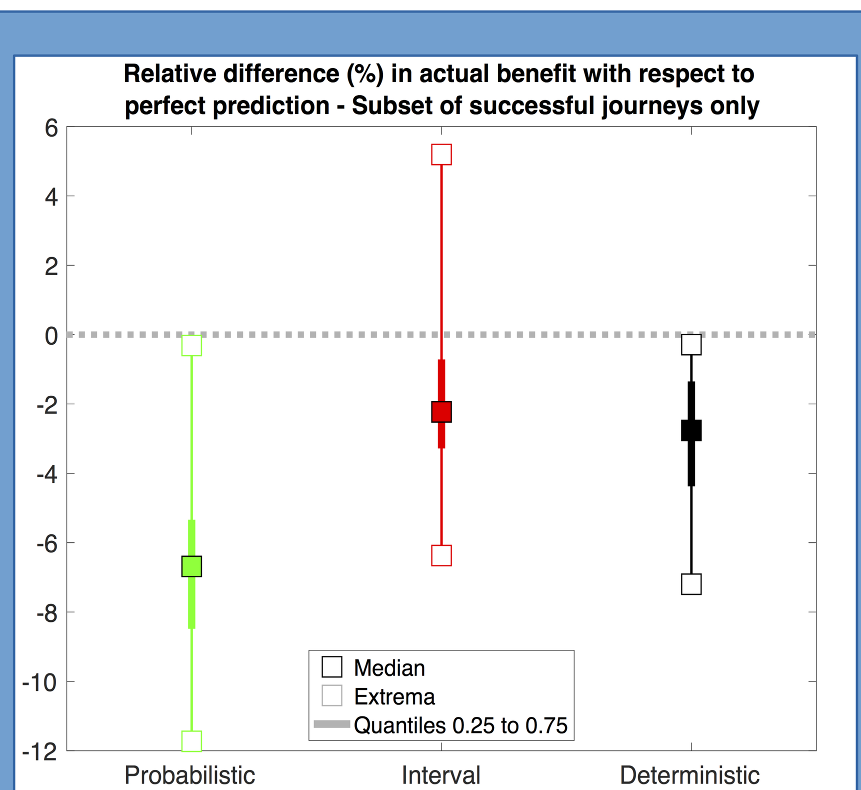
4. Are these results generalisable?

- Both approaches outperform the deterministic solver in average. The latter is **not robust** (failure rate of 42% over 64 independent simulations)
- The **probabilistic approach is the most conservative** but has a zero failure rate
- The interval-EPS approach, when successful (failure rate: 34%), is **much closer to the perfect prediction**.



5. Conclusion

- The **possibilistic EPS-based approach is much cheaper** to compute and has the **strongest potential** as regards predicting the closest-to-optimal solution
- However, the **lack of reliability of the EPS** (i.e. their bound do not contain the true value of the observed residual) remains a barrier for this approach to become operational.



Acknowledgements & References

SEA LEVEL RESEARCH

BODC

[1] Flowerdew *et al.* (2010). *Development and evaluation of an ensemble forecasting system for coastal storm surges.*

[2] Makarynskyy *et al.* (2004). *Predicting sea level variations with artificial neural networks at Hillarys boat harbour, western Australia.*

[3] Legg and Mylne (2004). *Early warnings of severe weather from ensemble forecast information.*