Characterising extreme sea state severity using absolute spatial dependence

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Background

- Extreme waves in tropical cyclone (TC) dominated region *rare*
- Estimates of 100-year significant wave height (SWH) using data from a single location have large epistemic uncertainty
- Using *spatial information* can reduce this uncertainty
- Key modelling idea is to characterise (1) peak storm severity (STM) and (2) its absolute spatial dependence (ASD)

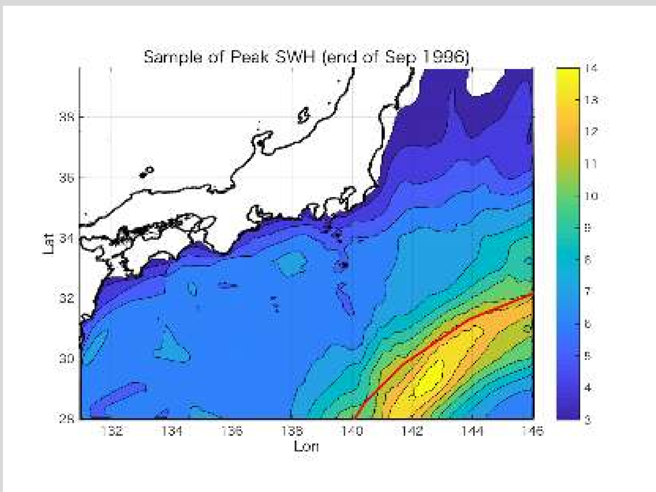
Purpose of Study

TO improve accuracy of extreme wave estimation
BY deriving a novel stochastic method
USING ideas of spatial statistics

Methodology

- **Space-time maximum (STM):** The maximum value of SWH at any location in the region for any time during a TC event.
- **Absolute spatial dependence (ASD):** For each location on a fixed spatial grid over the region, and a TC, ASD gives the maximum value of SWH for any time during the TC as a fraction of STM for that TC.
- **Assumptions:** (1) STM is spatially stationary (i.e. its distribution does not depend on location), and (2) STM and ASD are independent.

Extreme wave during a TC event



Ex) TC in Sep. 1996 largest SWH during TC event

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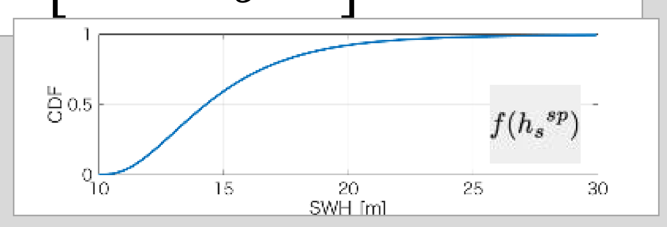
Space-time maximum (STM)

Extreme value distribution of storm peak is modelled with General pareto distribution for POT

$$F(x) = 1 - \left[1 + \frac{\xi(x-\mu)}{\sigma}\right]^{-1/\xi}$$



Extreme value estimation = Extrapolation in time (LWM [1])

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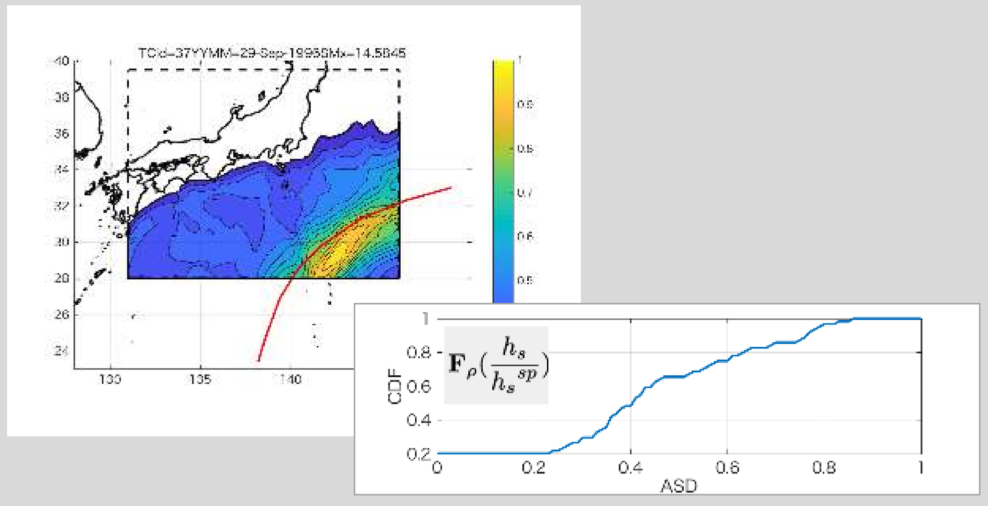
Absolute spatial dependence (ASD)



Spatial Dependence = Empirical based on TC events

Extreme distribution for each TC event

$$\mathbf{P}(\rho H s^{sp} \le h_s) = \int \mathbf{F}_\rho\left(\frac{h_s}{h_s{}^{sp}}\right) f(h_s{}^{sp})\, dh_s{}^{sp}$$

Extreme distribution for N-year event

$$\mathbf{P}_{\mathbf{Nyears}}(\rho H s^{sp} \le h_s) = \sum_{k=0}^{\inf} \frac{\lambda^k e^{-\lambda}}{k!} \mathbf{P}^k(\rho H s^{sp} \le h_s) = exp(-\lambda(1 - \mathbf{P}(\rho H s^{sp} \le h_s)))$$

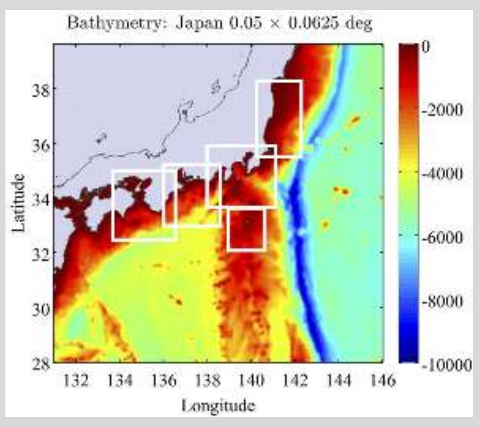
Application to North West Pacific using hindcast wave dataset

Data

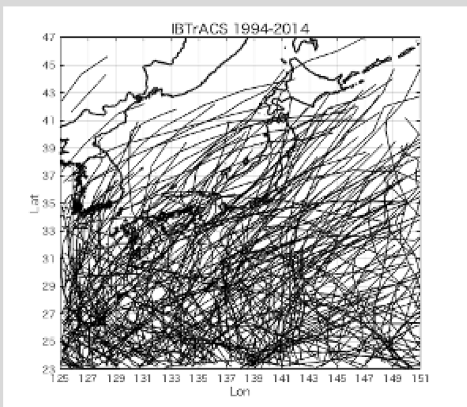
Wave Hindcast: Todai Wavewatch 3 [2]
- ✓ 21-year (1994-2014) hindcast
- ✓ High resolution (0.01degree) grid

Tropical cyclone tracks: IBTrACS [3]
- ✓ Track data merged from many agencies
- ✓ Indicates storm center location

Storm peak extraction
- ✓ 10m threshold for storm peak SWH
- ✓ 63 TCs during 1994-2014 (3 per year)
  - > STM data peak per storm
  - > ASD data per storm per location



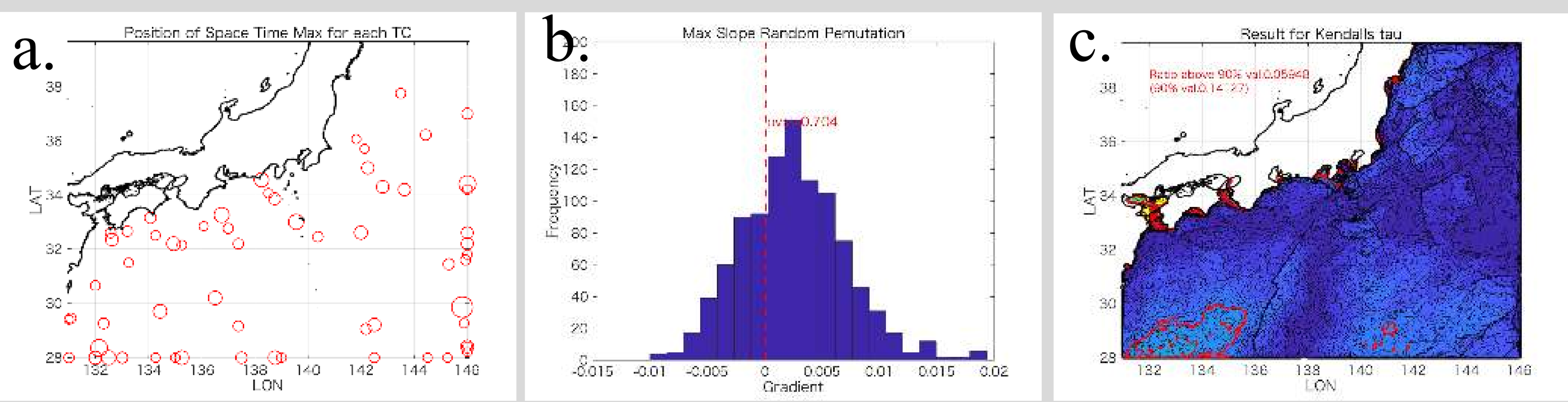
Todai WW3 (region J02)



TC tracks during 1994-2014 (IBTrACS)

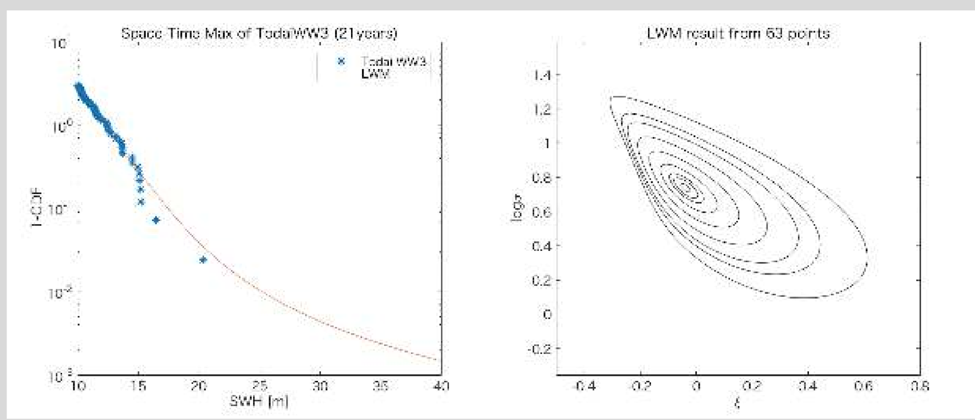
Justification of modelling assumptions

a. Location and magnitude of STM value
b. Random permutation result for spatial linear trend for STM
c. Kendall's rank test for exchangeability for STM and ASD



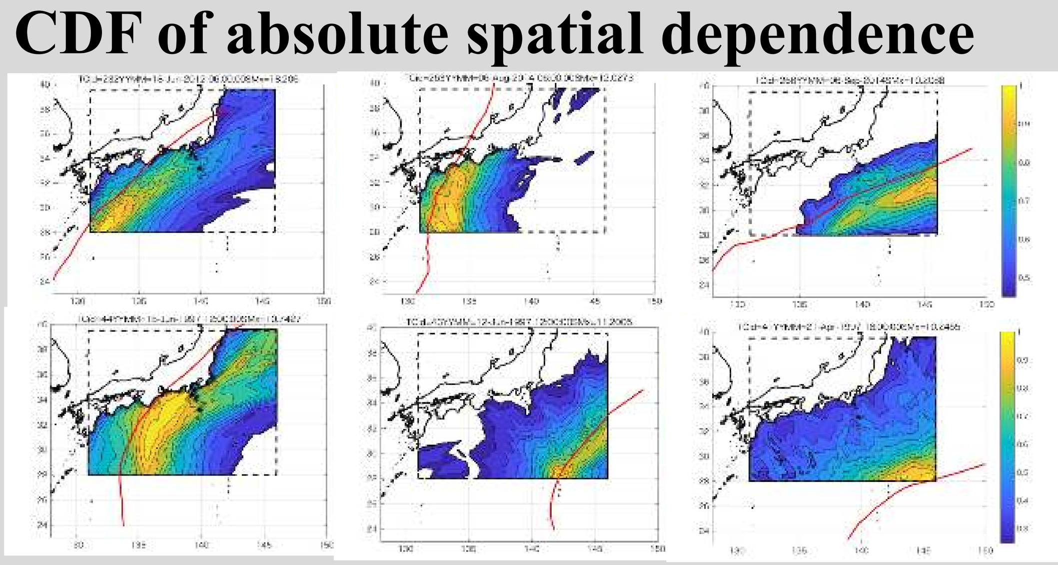
Results

CDF of space-time maximum (STM)

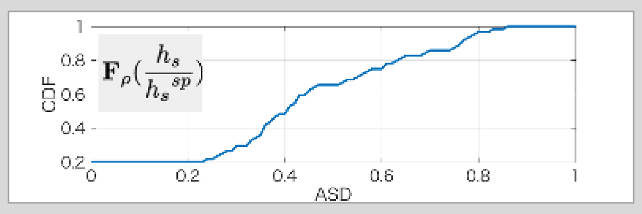


Extreme of STM
- 100 yr RP is around 33m
- Shape param. is ξ = -0.02 at maximum likelihood
- Still has large uncertainty from 63 TCs

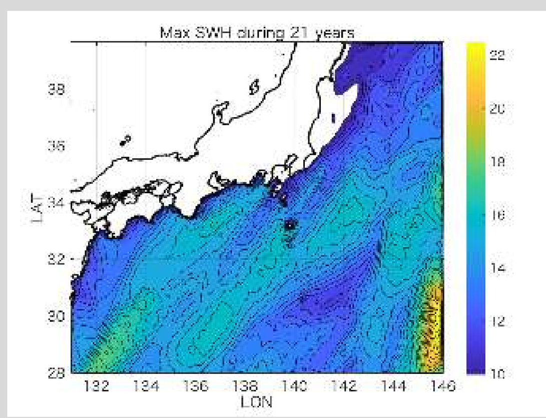
CDF of absolute spatial dependence



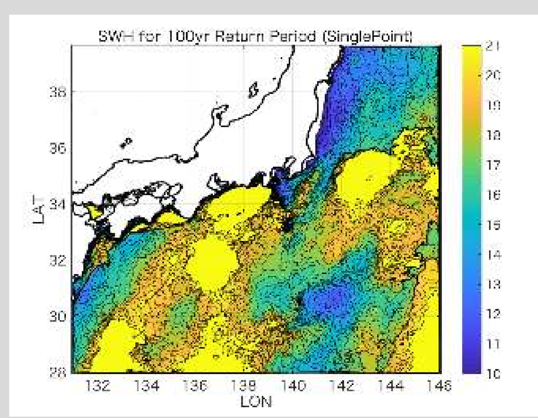
Typical storm track
- Moves towards North East
- Waves are larger on the right of storm track due to stronger wind forcing



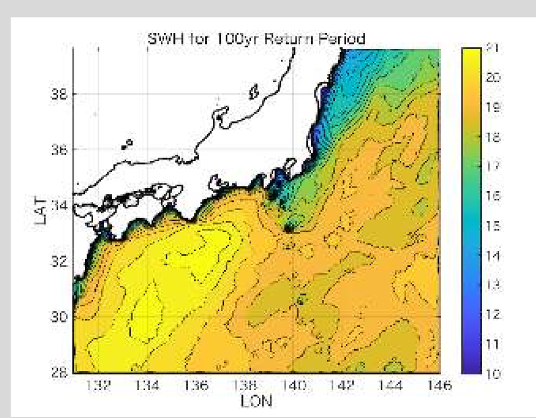
Comparison: Single point estimation vs spatial inference



Max SWH during 21 years



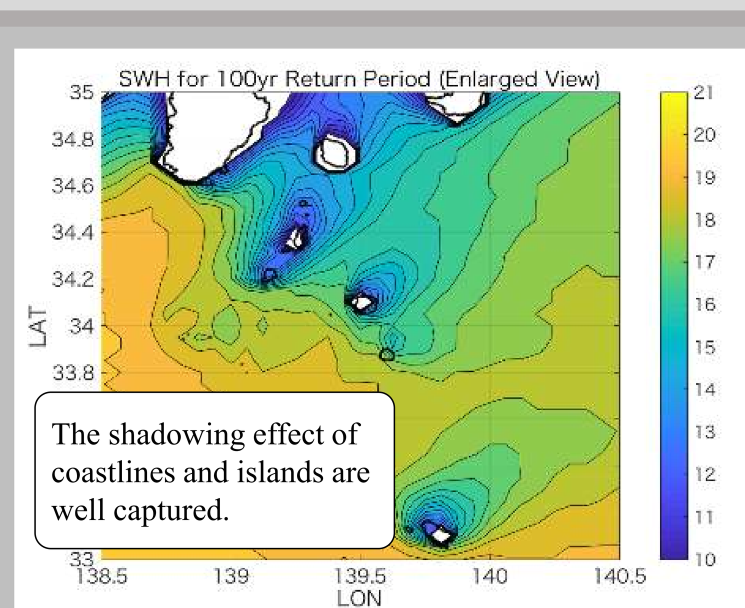
Estimates from single location

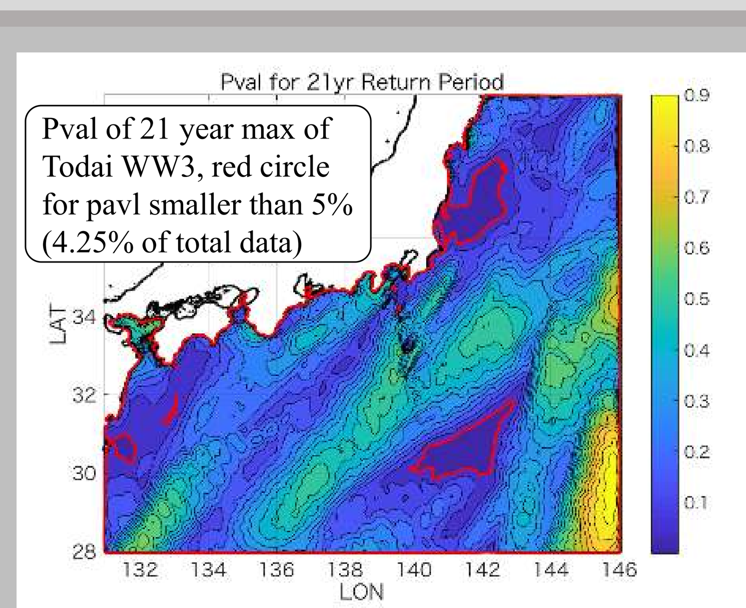


Estimates from STM x ASD

Discussion

- Novel approach to estimation of return values for SWH in TC regions.
- Key assumptions, consistent with data for the current application, are that STM is spatially stationary, and that STM and ASD are independent.
- Improved description compared with location-by-location analysis, reflecting e.g. land-shadow effects clearly.
- Further applications currently under way, and article in preparation.





Reference. [1] Wada, R., Waseda, T., & Jonathan, P. (2016). Extreme value estimation using the likelihood-weighted method. Ocean Engineering, 124, 241-251. [2] Webb, A., Waseda, T., & Kiyomatsu, K. (2016, February). A 20-Year High-Resolution Wave Resource Assessment of Japan with Wave-Current Interactions. In AGU Fall Meeting Abstracts. [3] Knapp, K. R., Kruk, M. C., Levinson, D. H., Diamond, H. J., & Neumann, C. J. (2010). The international best track archive for climate stewardship (IBTrACS) unifying tropical cyclone data. Bulletin of the American Meteorological Society, 91(3), 363-376.

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