SnT 2019

CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

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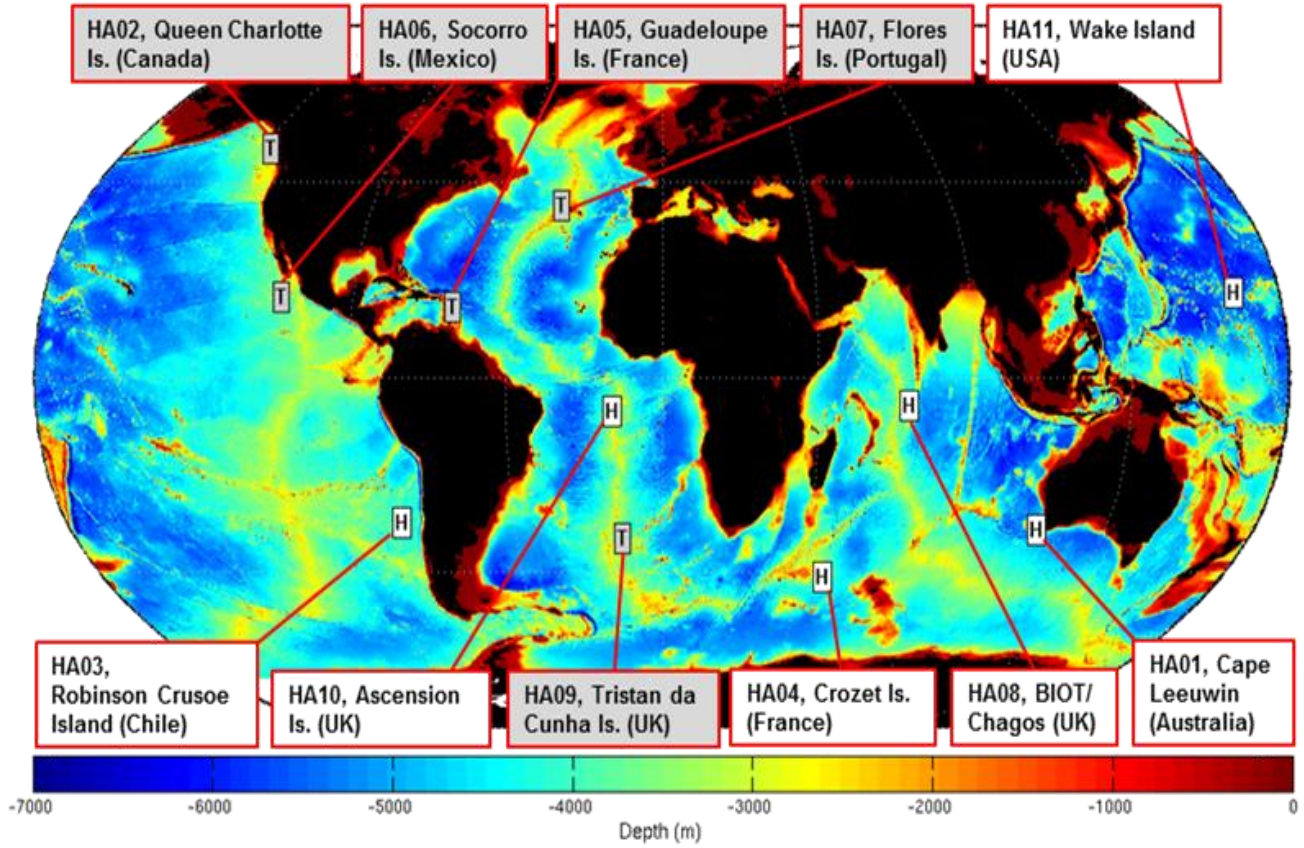
Monte Carlo simulation tool for maritime operations risk reduction and enhancement of IMS hydroacoustic network sustainment

Introduction

- The IMS Hydroacoustic (HA) Network
- Schematic of an IMS HA hydrophone station
- Ocean conditions at IMS HA hydrophone station locations
- First use of operations simulations to evaluate HA04 Crozet risks
- Monte Carlo Mission Time Simulator (MMTS) to support weather risk-based planning of maritime operations relevant to CTBTO
- Conclusions

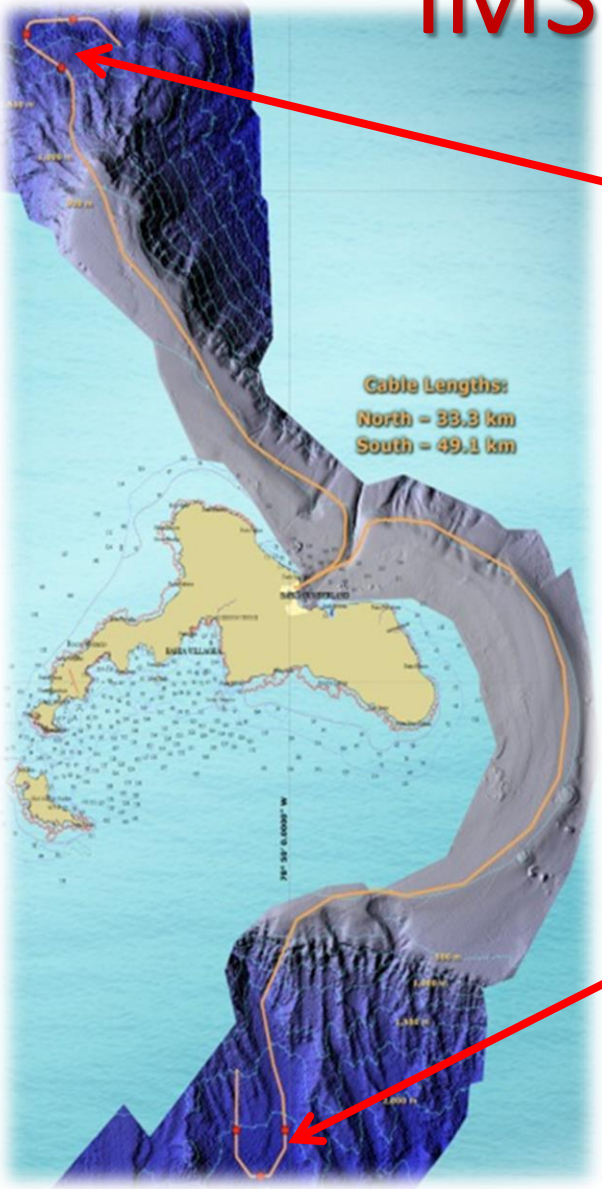
The CTBT IMS HA Network

Hydrophone Station		Water depth (m)	Hydrophone depth (m)
HA01	**W**	**1550**	**1100**
HA03	**N**	**1866**	**824**
	S	**2071**	**830**
HA04	**N**	**1310**	**541**
	S	**1309**	**535**
HA08	**N**	**2300**	**1250**
	S	**1800**	**1350**
HA10	**N**	**2000**	**850**
	S	**1700**	**850**
HA11	**N**	**1400**	**750**
	S	**1150**	**750**



- (Grey boxes) 6 T-phase stations: near-shore seismometers, which record waterborne hydroacoustic waves coupled upslope into the earth's crust.
- (White boxes) 5 Hydrophone stations: moored hydrophones pick up hydrocaoustic waves in the water column.

IMS HA hydrophone station schematic



North Hydrophone Triplet

South Hydrophone Triplet

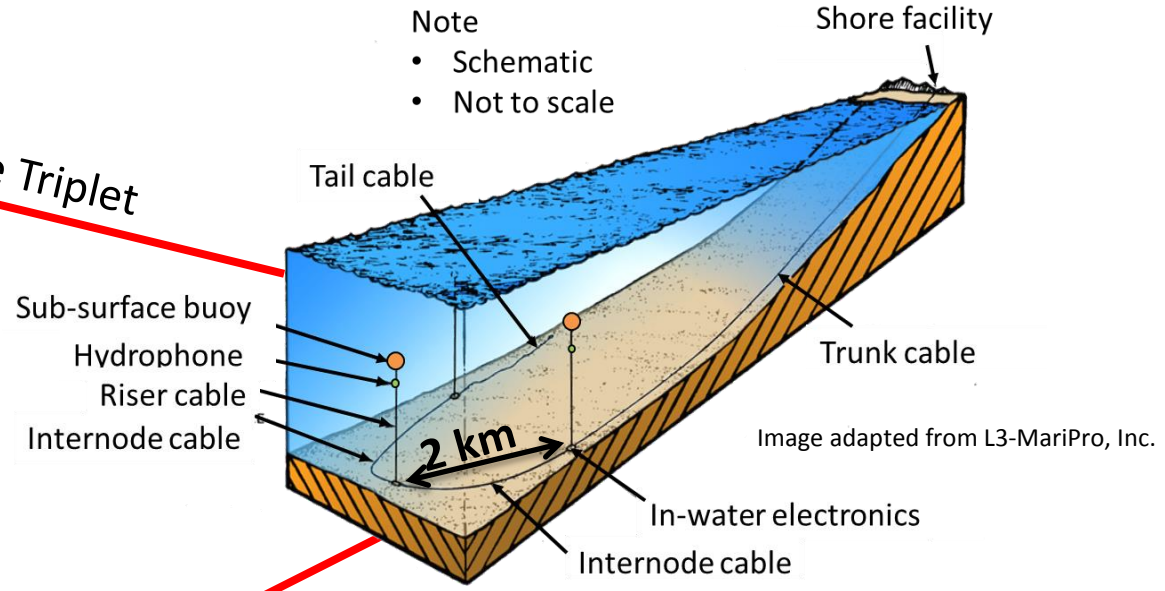
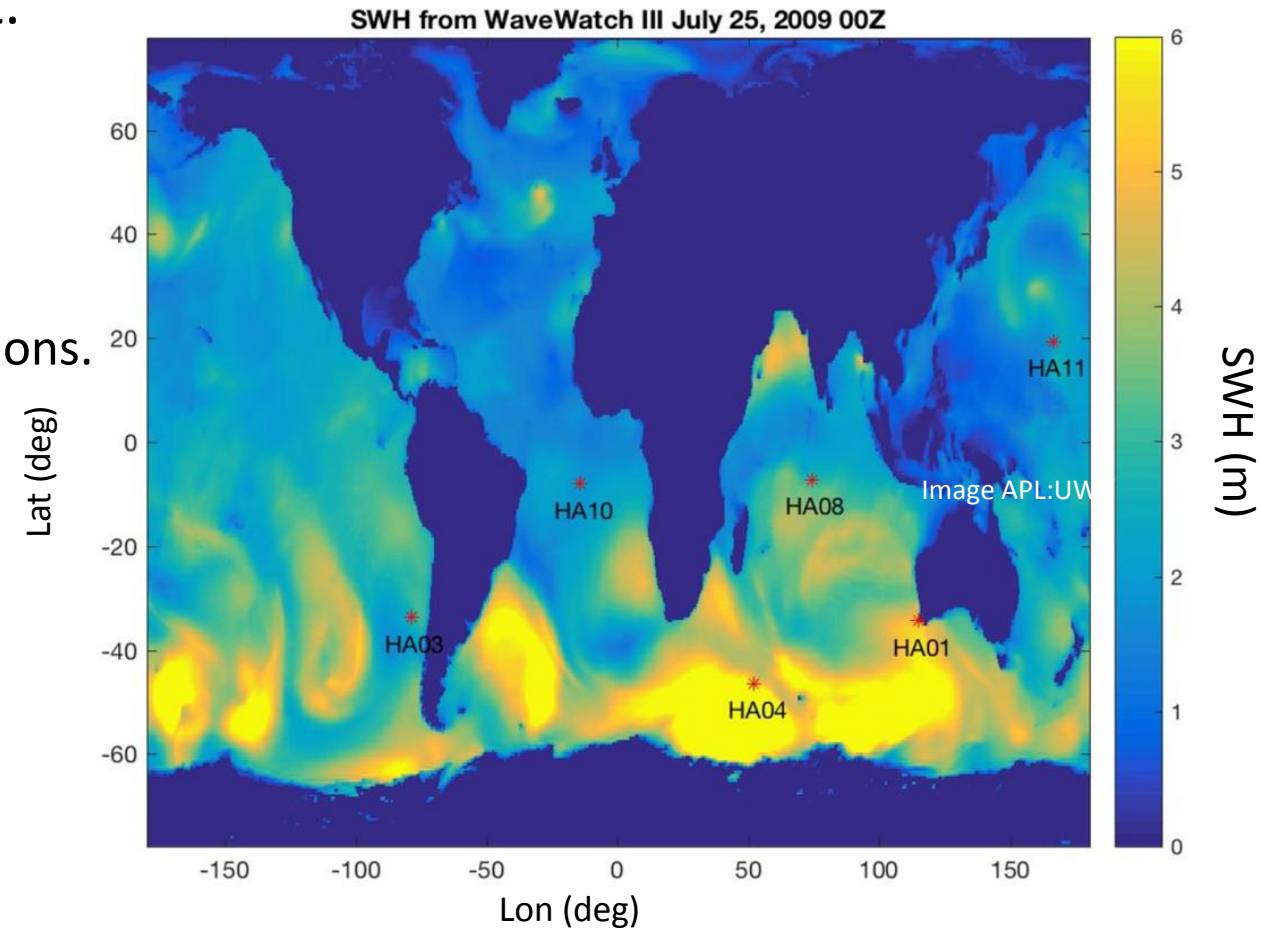


Image adapted from L3-MariPro, Inc.

Characteristic	Main Treaty Requirements
Design Life	20 years maintenance-free for the Underwater System (UWS)
Sensor type	Hydrophone with wet end digitiser, no repeater in the fibre-optic trunk cable
Passband	1 – 100 Hz
Number of Sensors	2 Triplets (one North, one South, except for HA01 Cape Leeuwin - Australia)
Sensor location	In the Sound Fixing and Ranging (SOFAR) Channel
System noise	≤ 10 dB below "Urick's deep ocean low noise curve"
Sampling rate	250 samples per second
Data availability	≥ 98% (≥ 97% data received at CTBTO within max. 5 min delay time)
Dynamic range	120 dB
Data transmission	Continuous, raw data for each channel (CD1.1)

Ocean conditions at IMS HA station locations

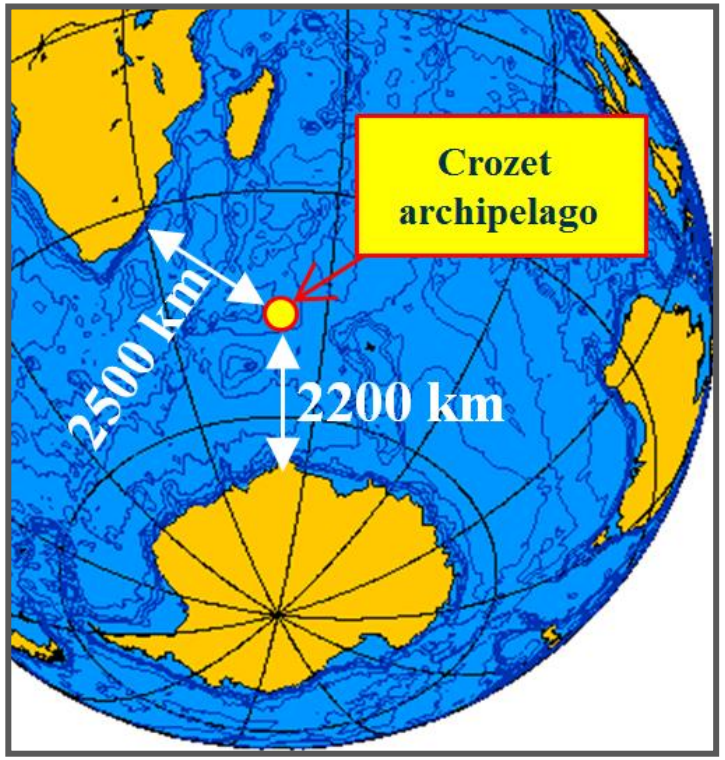
- All at-sea operations are weather dependent.
- Strong variability
  - With the seasons;
  - Rapid and dramatic daily variability at some locations.



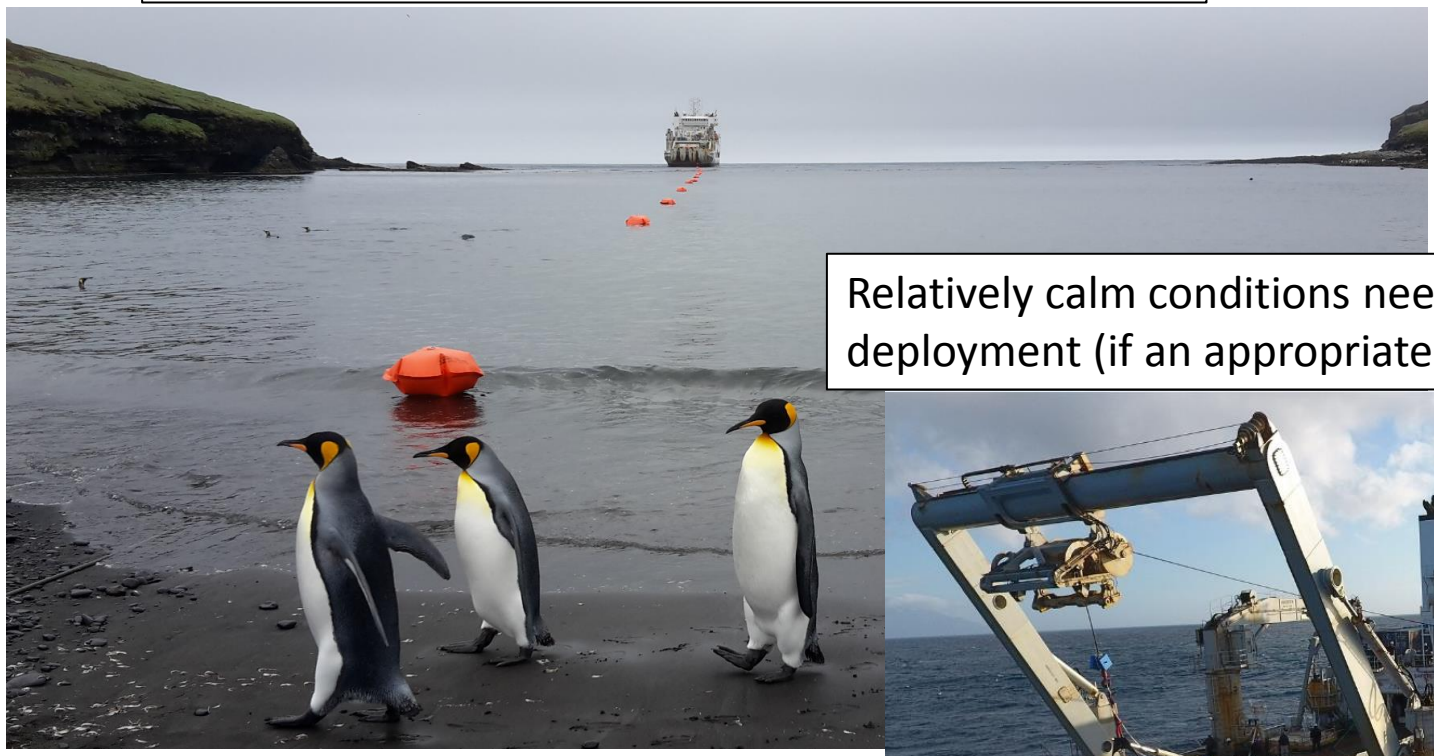
Mean-significant wave heights [SWH (m)], 2-month periods:

	HA01	HA03	HA04	HA08	HA10	HA11
January	2.5 – 3	3 – 3.5	3.5 – 4	1 – 1.5	1.5 – 2	2.5 – 3
March	2.5 – 3	3 – 3.5	3.5 – 4	1 – 1.5	1.5 – 2	2.5 – 3
May	3 – 3.5	3 – 3.5	4.5 – 5	1.5 – 2	1.5 – 2	1.5 – 2
July	3.5 – 4	3 – 3.5	5 – 5.5	2.5 – 3	2 – 2.5	1.5 – 2
September	3.5 – 4	3 – 3.5	4.5 – 5	2 – 2.5	1.5 – 2	1.5 – 2
November	2.5 – 3	3 – 3.5	3.5 – 4	1.5 – 2	1.5 – 2	2 – 2.5

A location with extreme variability – HA04 Crozet



Very calm conditions needed for trunk cable landing



Relatively calm conditions needed for HA node deployment (if an appropriate ship is used)

Drone photo: L-3 MariPro, Inc.
Cable Ship: TE SubCom C/S Decisive

Typical variability at HA04 Crozet

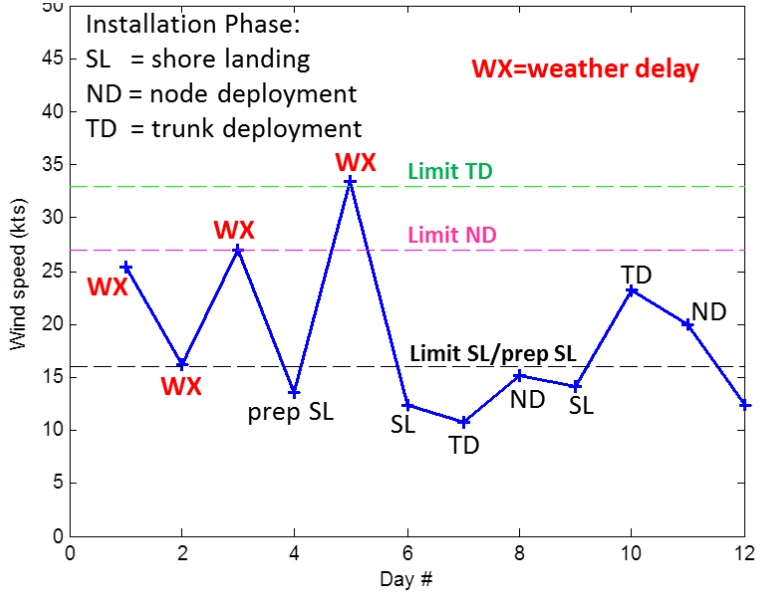
20 Dec 2016 **morning** – perfect conditions for a cable landing

20 Dec 2016 **afternoon** – storm: cable landing done, ship hold on in weather stand-by. No operations possible.

First operations simulations to evaluate HA04 Risks

- Developed in-house during negotiation of HA04 Contract, to analyze risk
- **Input**: Historical wind data (only data available at the time) from Crozet Meteo Station & Operation sequence with maximum wind thresholds.
- **Output**: Probability of encountering a certain number of weather delay days on-site.
- Daily mean winds data available for 2004 – 2013, installation time window 1 Dec – 28 Feb.
- Monte Carlo simulation of installation sequences, evaluating different operational sequences and design options.

Example of a simulated installation sequence



~ 400 installation sequences simulated

Estimated HA04 Crozet Weather delay probabilities

Start of installation	Likelihood of up to 10 Weather Delays	Likelihood of between 11 and 20 Weather Delays	Likelihood of more than 20 Weather Delays	Most likely Weather Delay and its likelihood
Dec	83%	17%	0%	4 days, 14%
Jan	91%	8%	0%	1 day, 13%
Feb	78%	12%	10%	3-5 days, 11%

Baseline installation sequence used for simulations: 8 days
Actual Dec 2016 total days on-site: 11, of which 4 days were weather delays.

MMTS: MonteCarlo Mission Time Simulation

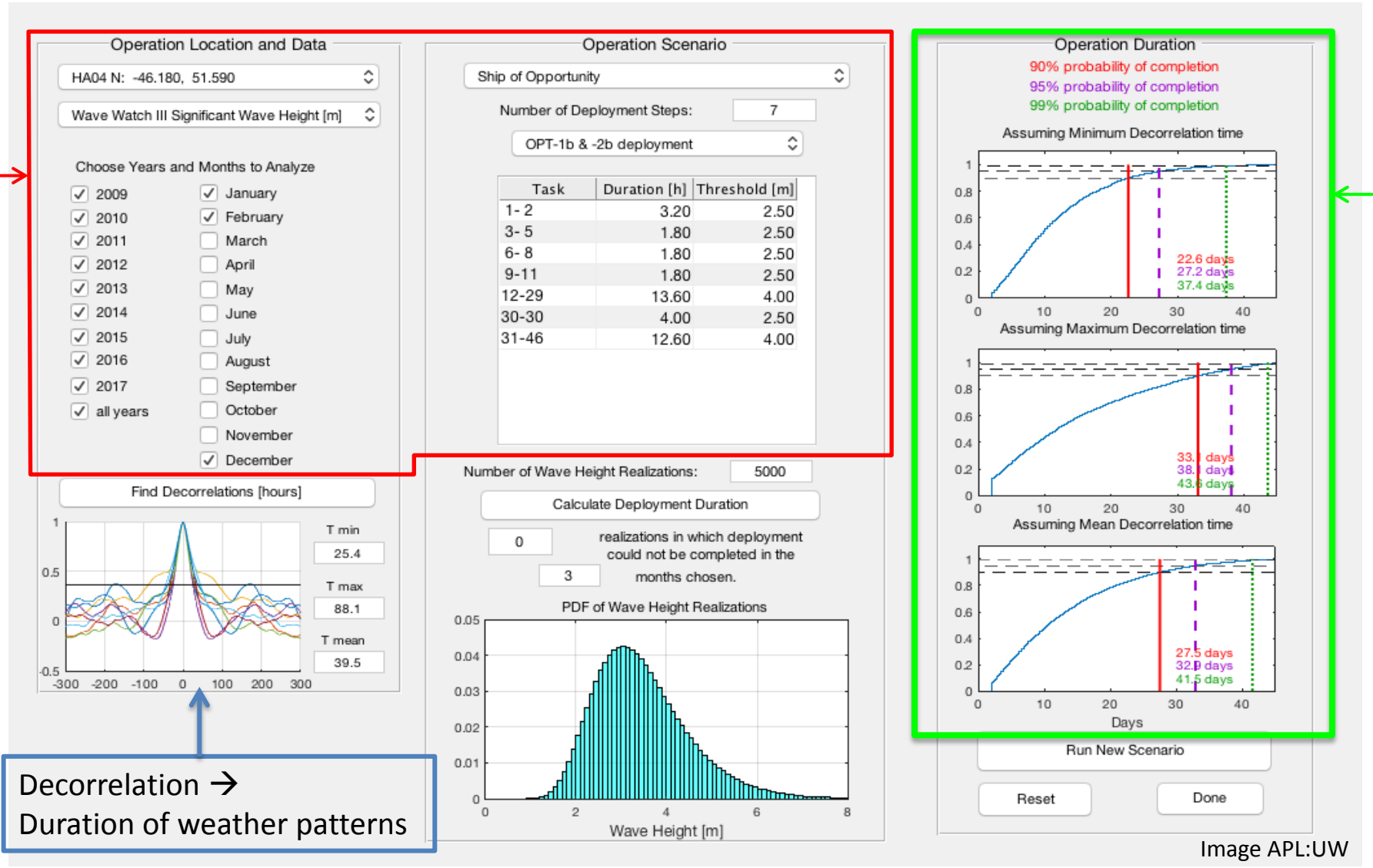
- Developed at APL:UW under Contract with CTBTO.
- **Input**:
  - ***Significant Wave-Height*** (SWH) from NOAA WaveWatch III®:
    - http://polar.ncep.noaa.gov/waves/index2.shtml
    - World-wide wind-wave and ocean swell re-analysis.
    - Uses all data available from metocean buoys, remote sensing, observations.
    - Resolution: 3 hour time intervals, 0.5^{o} x 0.5^{o} grid (~56 x 56 km at the Equator).
  - Tables with durations of at-sea operational sequence steps (installation, cable repair etc.)
  - Type of ship: Vessel of Opportunity (VOO) or Cable Ship (CS)
  - SWH upper limit threshold for each operational step.

- **Output:** Probabilistic estimates of HA triplet deployment and repair missions, including weather delays.

- This model is generally useful for the risk analysis of weather-dependent operations.

MMTS simulation example

Input block

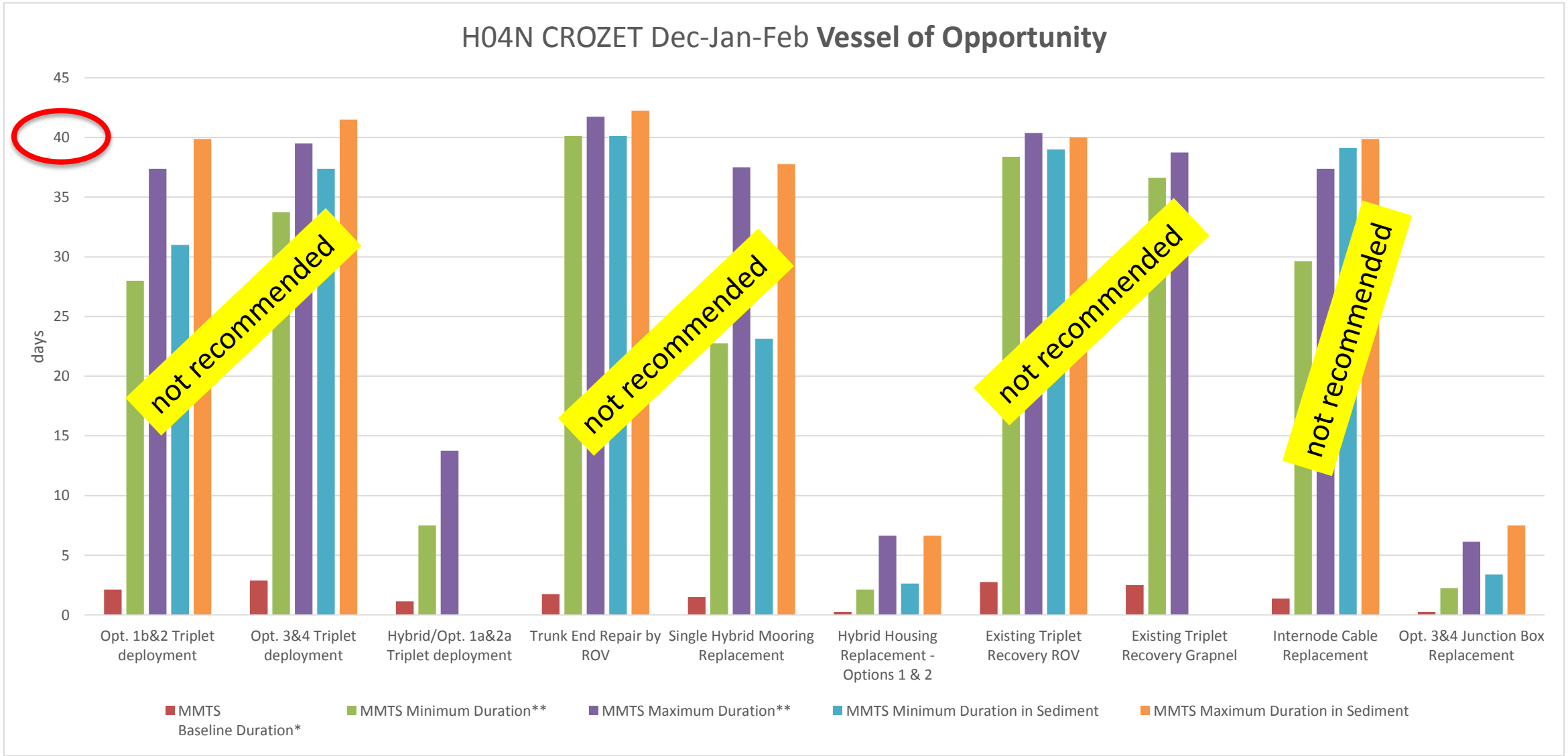


Estimated Mission Duration

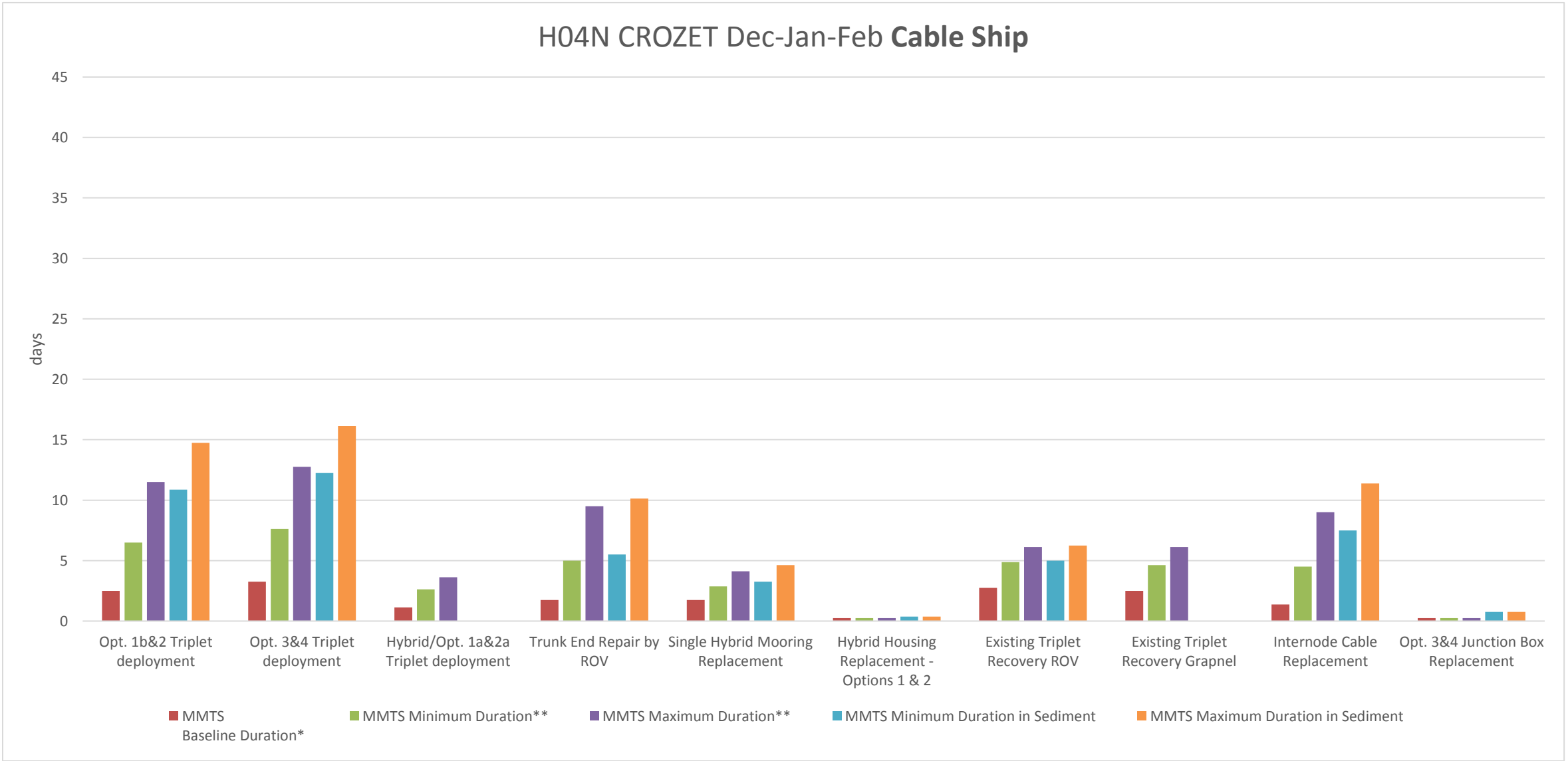
Decorrelation → Duration of weather patterns

Image APL:UW

Evaluation of different designs/sustainment missions



Example: the same designs/missions w/ Cable Ship



Conclusions

- Maritime operations are sensitive to ocean conditions (waves, wind)
- Modern databases, e.g. WaveWatch III®, characterize ocean conditions even at remote ocean locations with high spatial and temporal resolution
- Monte Carlo simulations of maritime operations using such databases can support all stages of CTBTO maritime activities, such as HA station installation and sustainment:
  - Concept stage and evaluation of alternatives
  - Assessment of the feasibility of envisaged maritime activities
  - Detailed mission planning and choice of vessels, mission timeframes.

THANK YOU