Industry use of Marine Environmental Prediction Services

Shawn Allan
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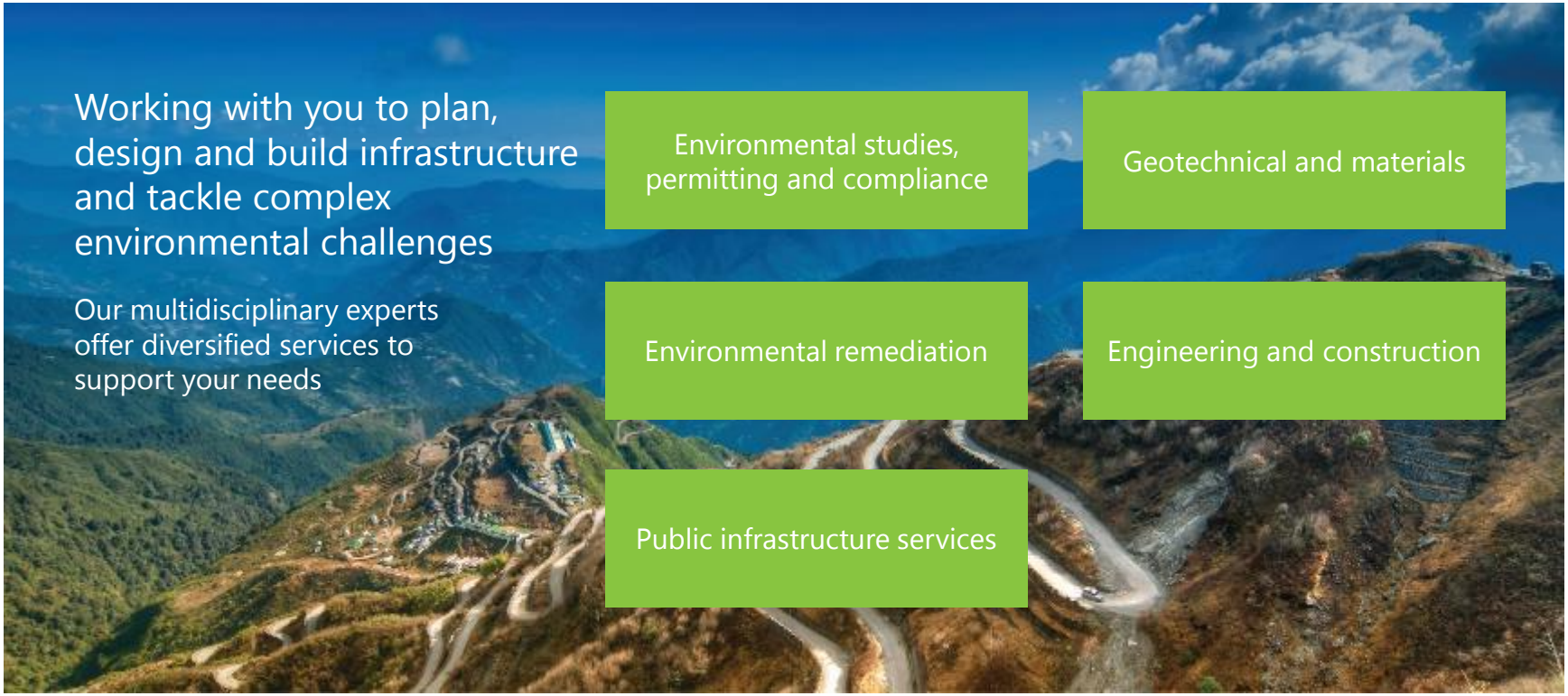
Environment and Infrastructure Solutions



Environment and Infrastructure Solutions

Wood Metocean Services

Weather and ocean experts mitigating financial and safety risks for clients whose businesses are sensitive to high impact weather events or severe ocean conditions

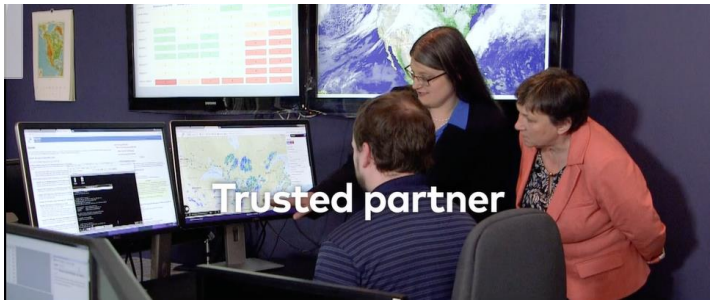
24/7 anywhere in the world

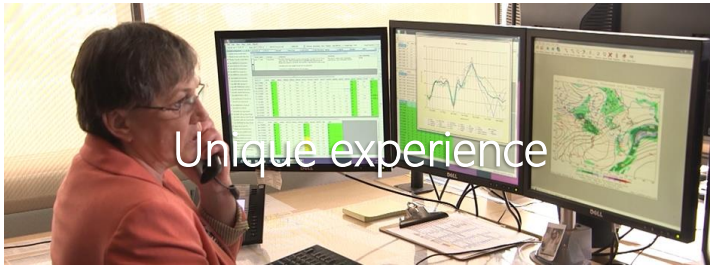
Over 60 full time meteorologists, oceanographers, climate and data scientists

Approx. 2,500 users for our Information Management Tools and Services

Met-Ocean Office Locations

St. John's, NL ● Halifax, NS ● Ottawa, ON

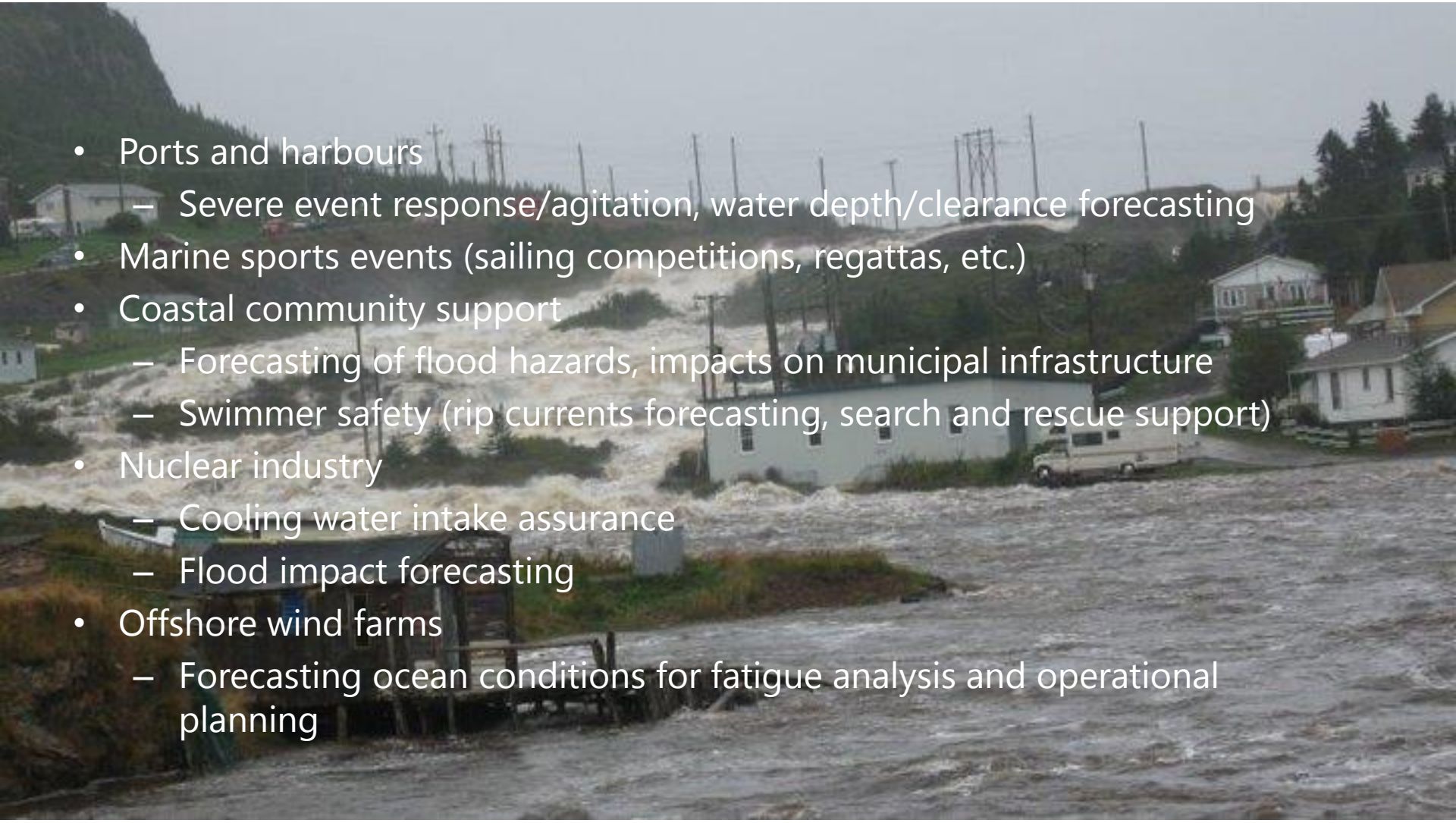




Themes to remember

- *Common Operating Picture*
- *What threshold triggers a change in decision?*
- *Quantification of uncertainty*
- *Access to data*

Operational use cases in a range of industries

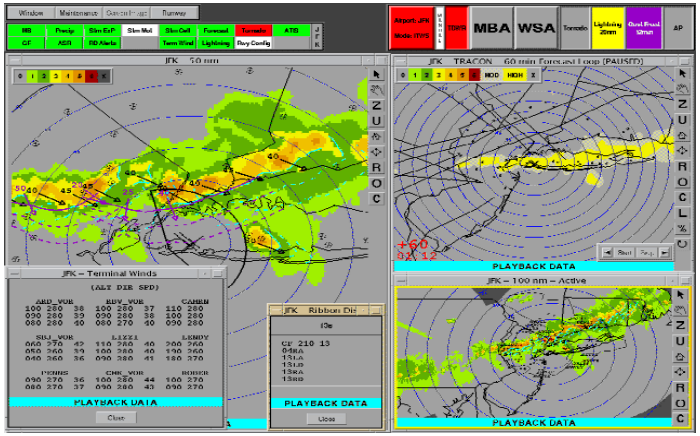


- Ports and harbours
  - Severe event response/agitation, water depth/clearance forecasting
- Marine sports events (sailing competitions, regattas, etc.)
- Coastal community support
  - Forecasting of flood hazards, impacts on municipal infrastructure
  - Swimmer safety (rip currents forecasting, search and rescue support)
- Nuclear industry
  - Cooling water intake assurance
  - Flood impact forecasting
- Offshore wind farms
  - Forecasting ocean conditions for fatigue analysis and operational planning

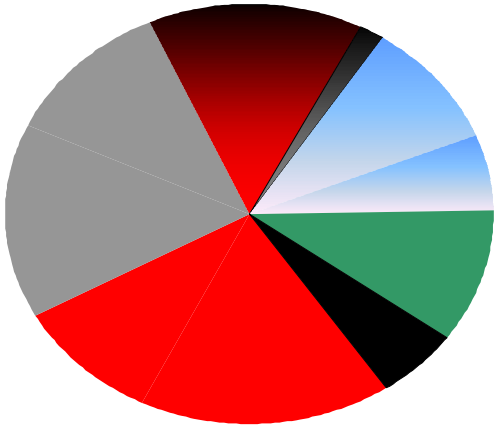
Looking Back in Time: A Different Field of View

Using Prediction Systems in Aviation Setting

New York Prototype Integrated Terminal Weather System (ITWS)

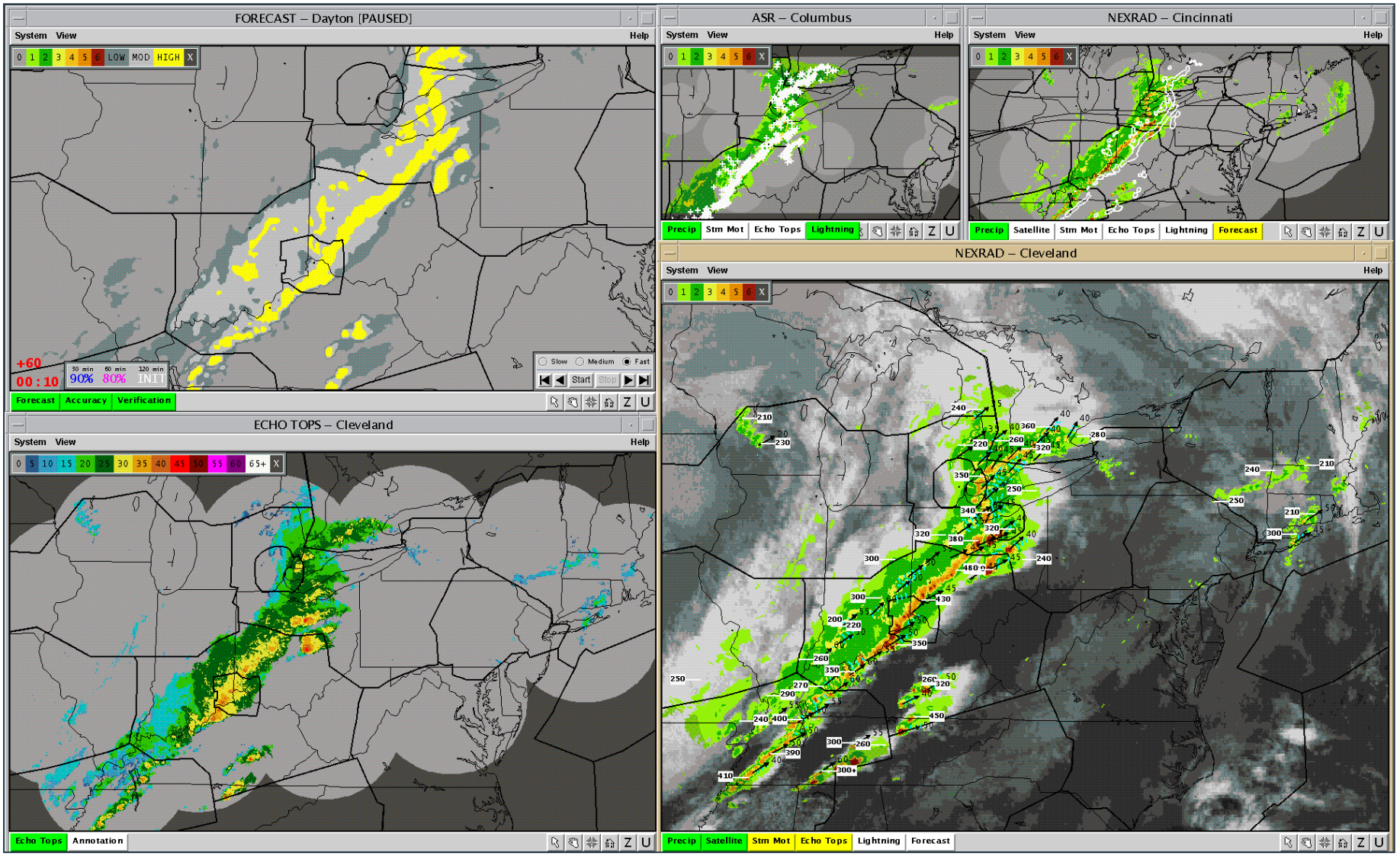


Relative proportion of weather type to annual arrival delay at EWR

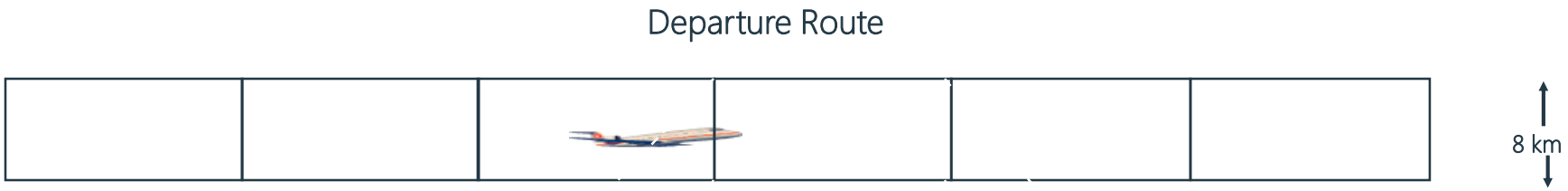


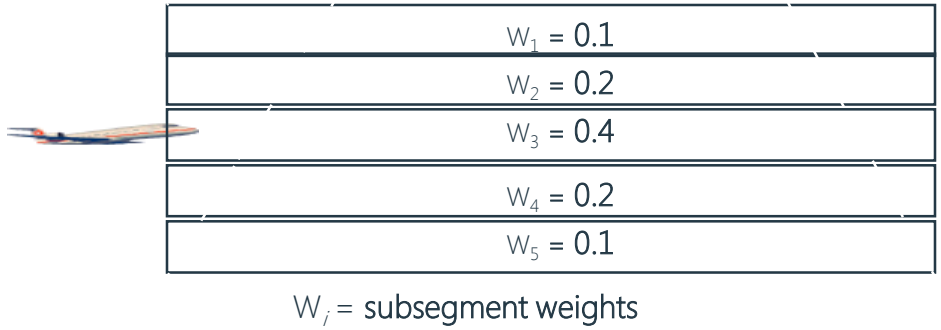
- Lincoln study ATC-291 - departures benefit the most from NY ITWS
- NY air traffic controllers operate within most complex airspace in USA
- Relationship drove new areas of research

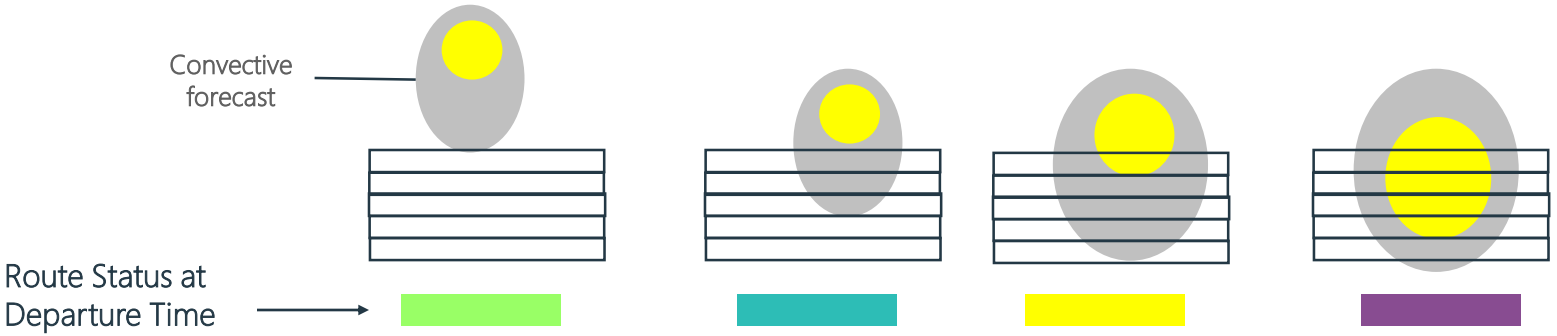
Growing Up: Corridor Integrated Weather System



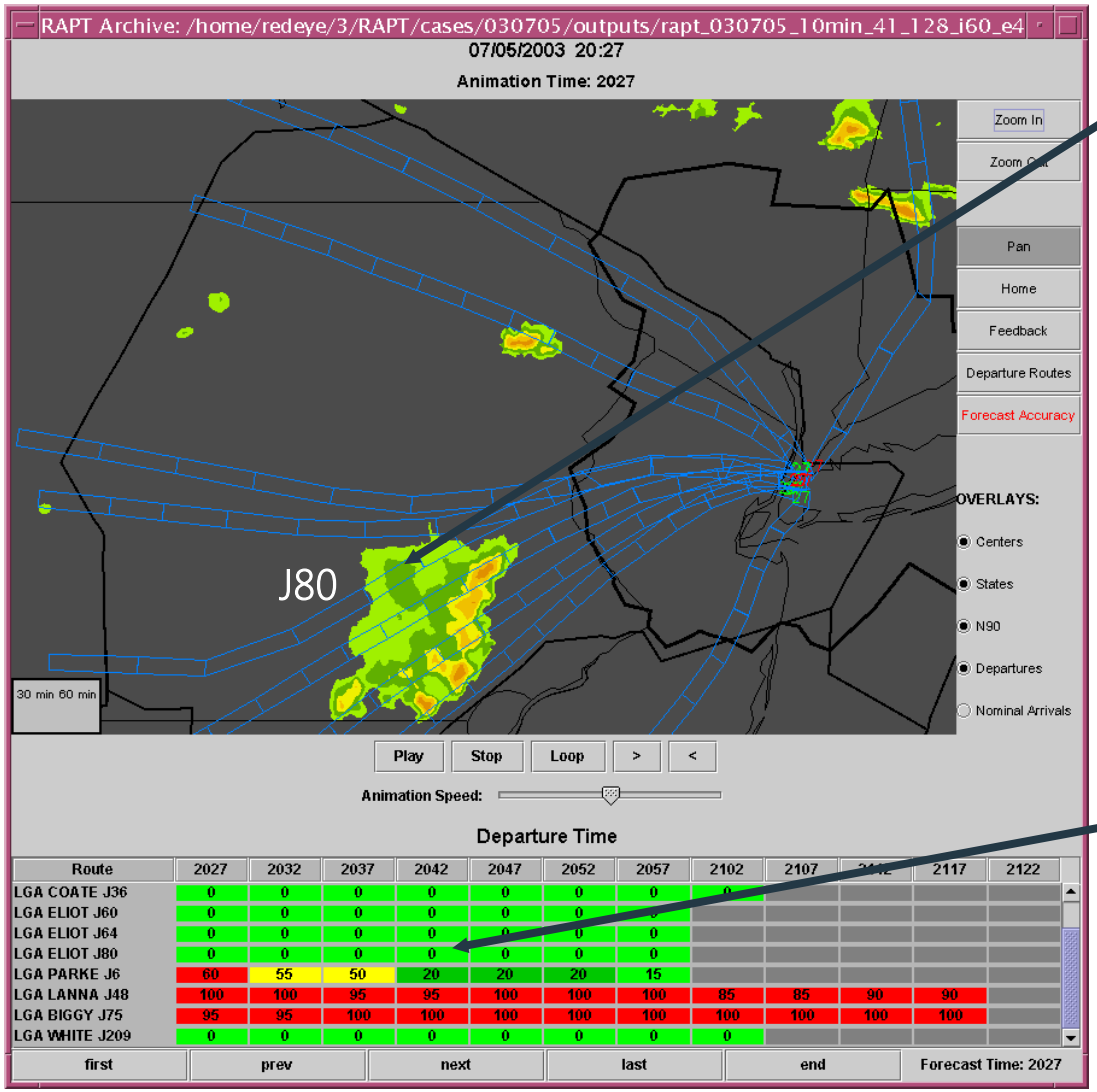
Route Availability Planning Tool Algorithm







The RAPT Display



Controllers wanted J80 to remain closed. Managers used RAPT plus storm tops to convince them otherwise.

Managers estimated 30 extra NY departures were able to take off based on this decision.

From Boston/New York to Newfoundland: Aviation to Metocean

That was then…

ConocoPhillips Canada

Marine Site Forecast for ConocoPhillips
Sample AMEC Forecast
Issued Tuesday April 21, 2009, 15:30 NDT

amec

AMEC Warning (for 10 m height): STORM WARNING FOR THURSDAY
MSC Warning (N. Grand Banks): STORM WARNING FOR THURSDAY

Synopsis

Moderate southeasterly winds today as a weak low approaches from the south. Winds drop to light early Tuesday in the wake of the low. Winds freshen to moderate to strong northerlies Wednesday as a low approaches from the south. Wind Freshens to storm strength Wednesday night as the low passes east of the Bay. Generally good visibility drops to fair to poor Wednesday.

2 Day Forecast Starting Tuesday, April 21, 15:30 NDT

Date/Time (NDT)	Tue/21 15:30	Tue/21 21:30	Wed/22 03:30	Wed/22 09:30	Wed/22 15:30	Wed/22 21:30	Thu/23 03:30	Thu/23 09:30	Thu/23 15:30
Derrick (82m) Wind Direction (true/from)	270	260	250	230	210	200	210	210	220
Derrick Wind Speed (kt)	17	19	25	42	48	52	58	60	55
Derrick Maximum Wind Speed (kt)	20	20	30	45	55	57	63	65	60
10m Wind Speed (kt)	12	12	12	35	40	45	47	50	45
10m Maximum Wind Speed (kt)	15	16	17	40	45	50	55	57	52
Wind Wave Height (m)	0.8	0.8	0.8	2	5	4	6	8	9
Wind Wave Period (s)	4	4	4	4	4	5	6	7	7
Primary Swell Direction (true/from)	360	10	10	10	NIL	NIL	NIL	NIL	NIL
Primary Swell Height (m)	3.7	3.5	3.2	2	NIL	NIL	0	0	0
Primary Swell Period (s)	11	11	11	11	NIL	NIL	0	0	0
Secondary Swell Direction (true/from)	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Secondary Swell Height (m)	0	0	0	0	0	0	0	0	0
Secondary Swell Period (s)	0	0	0	0	0	0	0	0	0
Combined Sea Significant Height (m)	3.8	3.6	3.3	2.8	2.4	2.2	2.3	2.6	2.8
Combined Sea Maximum Height (m)	7.2	6.8	6.3	5.3	4.6	4.3	4.4	4.9	5.3
Weather	CLR	FEW	BKN	OVC	BKN	MIST	R-	R-	R+
Visibility (nm)	6+	6+	6+	6+	6+	3	5/8	3/8	1/8
Temperature (C)	-2.6	-2.3	-1.9	-1.5	-0.5	0.5	1	2	2
Freezing Spray (NIL/LGT/MDT/HVY)	LGT	LGT	LGT	NIL	NIL	NIL	NIL	NIL	NIL
Freezing Spray (cm/h)	0.3	0.3	0.3	0	0	0	0	0	0
Pressure (mb)	1026	1027	1027	1020	1010	996	984	992	996

Vessel Motion, Issued at Tuesday, April 21, 15:30 NDT

Date/Time (NDT)	15:30	21:30	03:30	09:30	15:30	21:30	03:30	09:30	15:30
MODU Heading (true)	290	290	290	290	290	290	290	290	290
Maximum Helideck Heave (m)	3.1	2.8	2.6	2.2	2.2	2.5	3.5	4	5
Maximum Helideck/Rig Floor Pitch (deg)	0.5	0.5	0.5	0.4	1	1	1	1.5	1.5
Maximum Helideck/Rig Floor Roll(deg)	1.4	1.2	1	0.9	1	1	1	1.5	1.5
Maximum Rig Floor Heave (m)	2.3	2	1.9	1.6	2	2.2	2.8	3.5	4

3 Day Outlook Starting Friday, April 24, 03:30 NDT

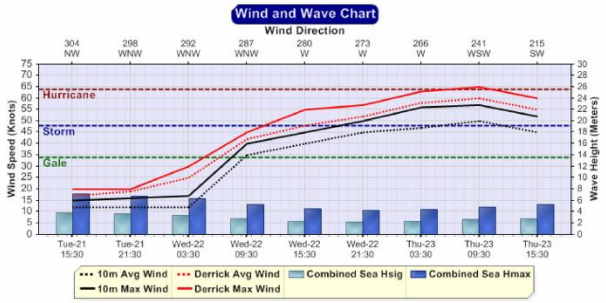
Date/Time (NDT)	Fri/24 03:30	Fri/24 15:30	Sat/25 03:30	Sat/25 15:30	Sun/26 03:30	Sun/26 15:30
10m Wind Direction (true/from)	163	266	265	263	257	258
10m Wind Speed (kt)	19	35	25	30	25	20
10m Maximum Wind Speed (kt)	30	45	30	35	30	25
Combined Sea Significant Height (m)	2.5	3	3	4	3	2.5
Combined Sea Maximum Height (m)	5	6	6	8	6	5
Visibility (nm)	2	3	1/2	6+	6+	6+

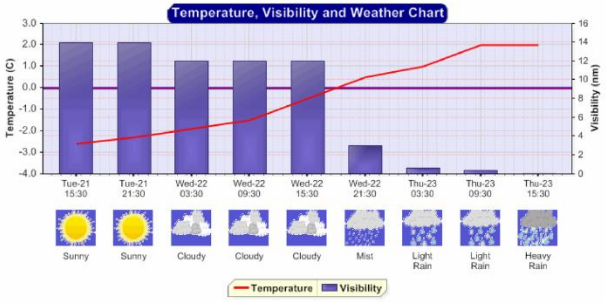
Next Forecast Issue Time: Tuesday April 21, 2009, 21:30 NST
Contact Information: Duty Forecaster at 709 739-7775 (Phone); 709-753-2799 (Fax), weather@amec.com (Email)

ConocoPhillips Canada

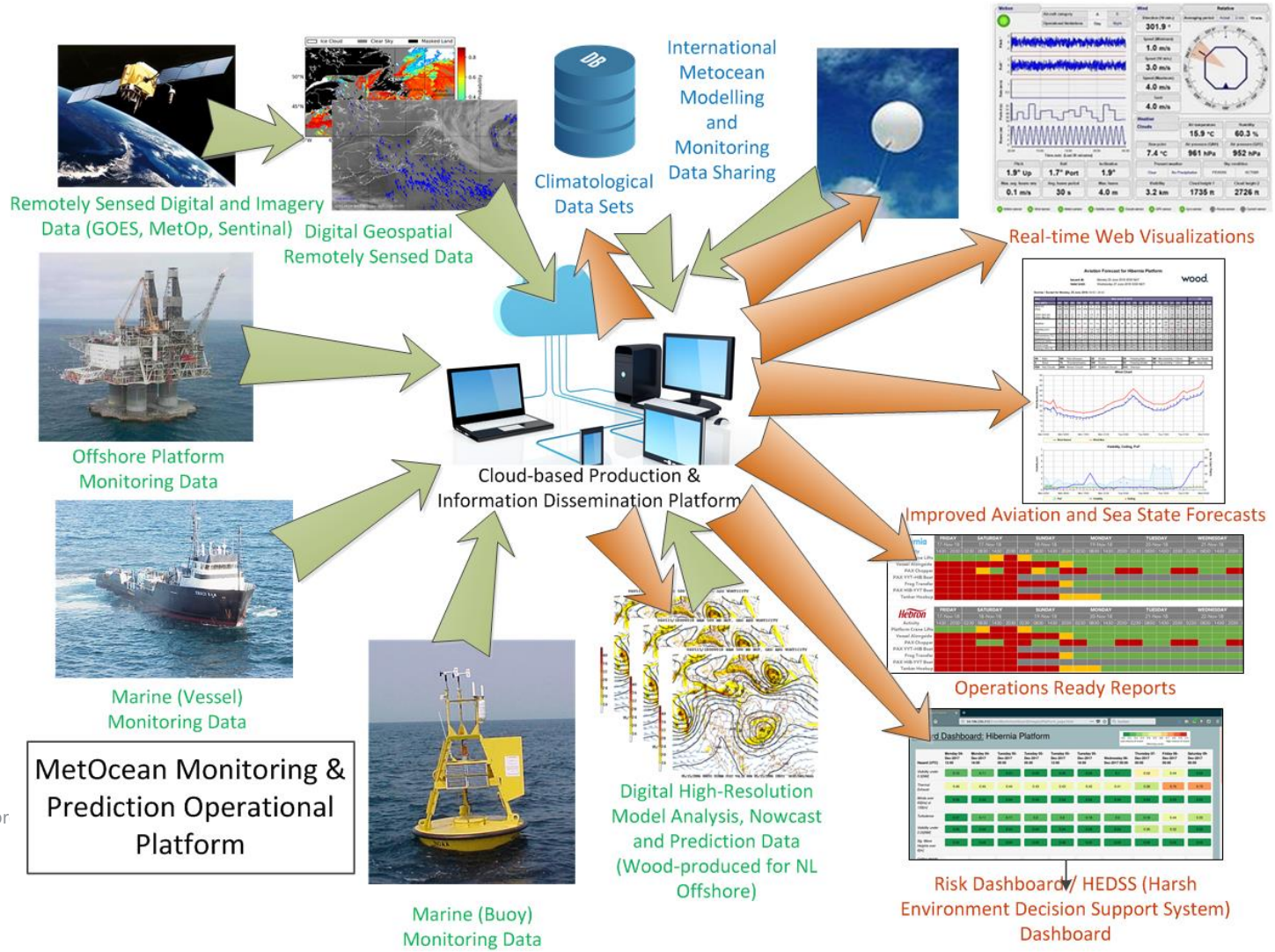
Marine Site Forecast for ConocoPhillips
Sample AMEC Forecast
Issued Tuesday April 21, 2009, 15:30 NDT

amec



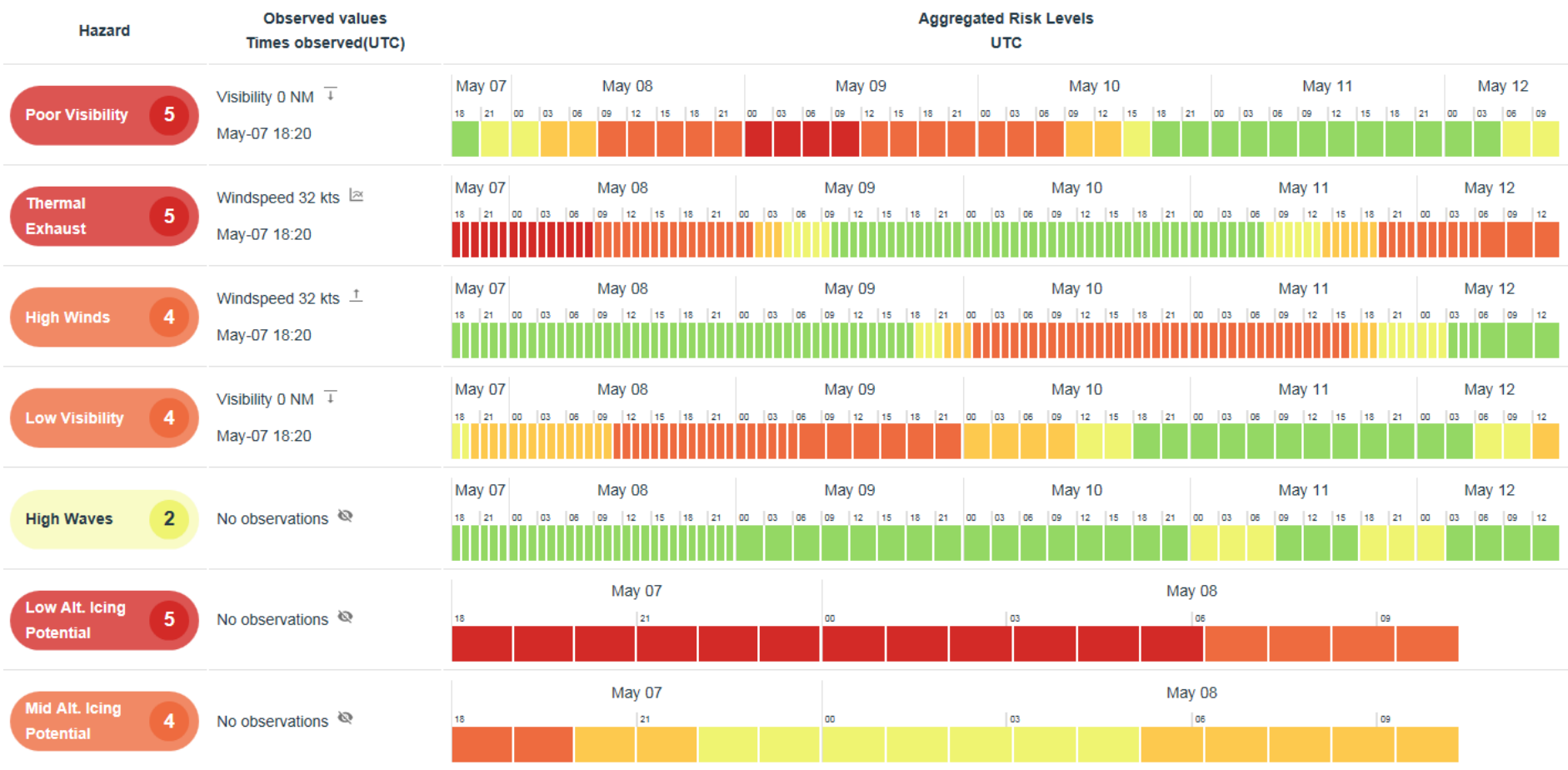


Beyond tables—Harnessing a world of data



This is now…Threshold based risk prediction

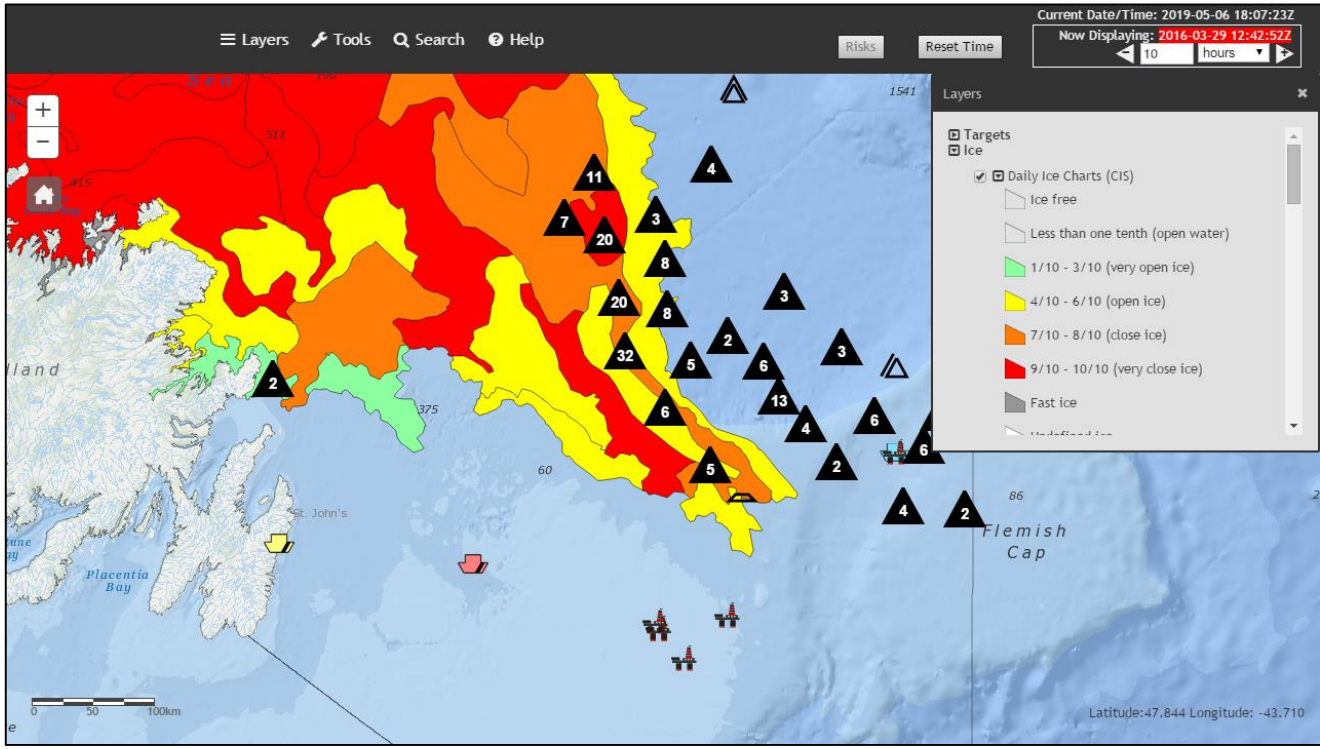
- Risk Dashboard



Common Operating Picture for Ice Management Decision Making

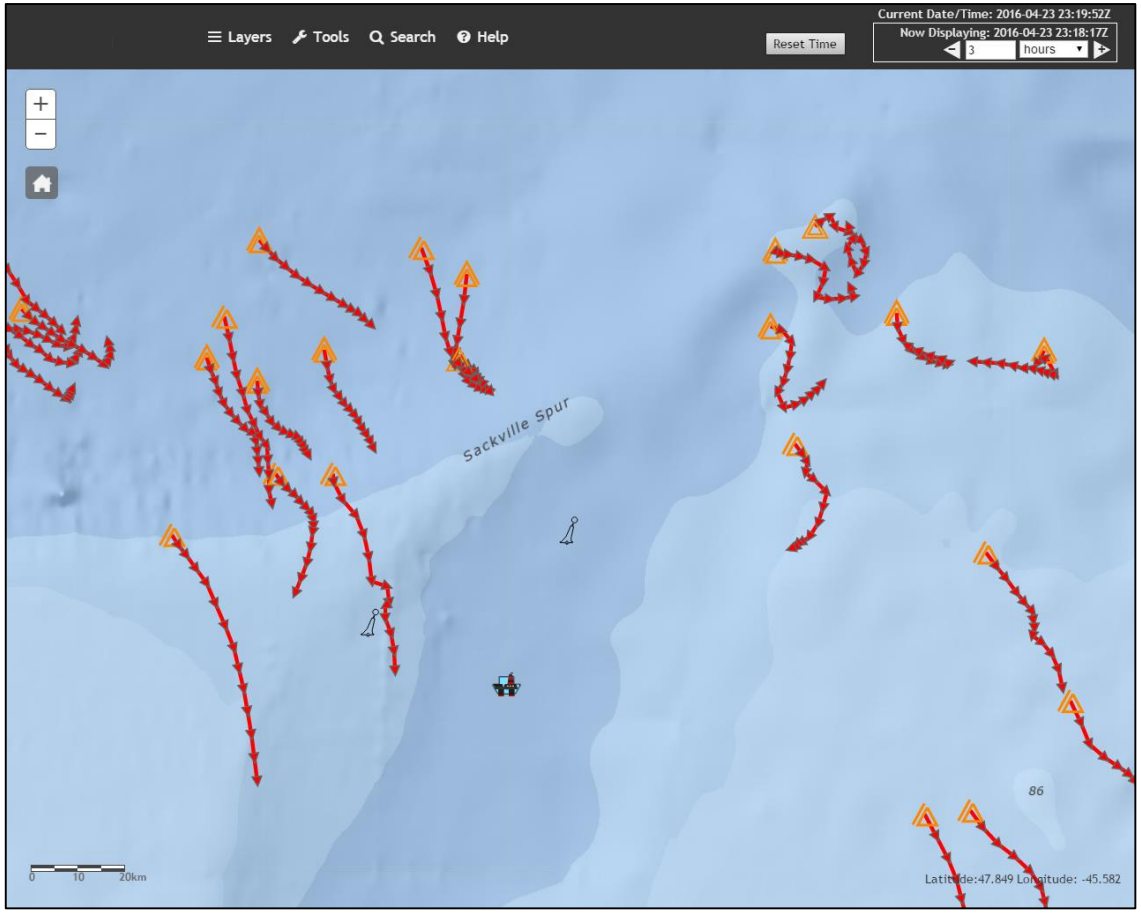
Met-Ocean-Ice Data for Operational Decisions

- Met-Ocean-Ice *observation* data is used as inputs to making operational decisions related to:
  - Proximate ice "threats" that require tactical activities to mitigate risk (e.g. iceberg towing)
  - Severe conditions that prevent operational activities (helicopter transport, crane lifts, oceanographic deployments, etc.)



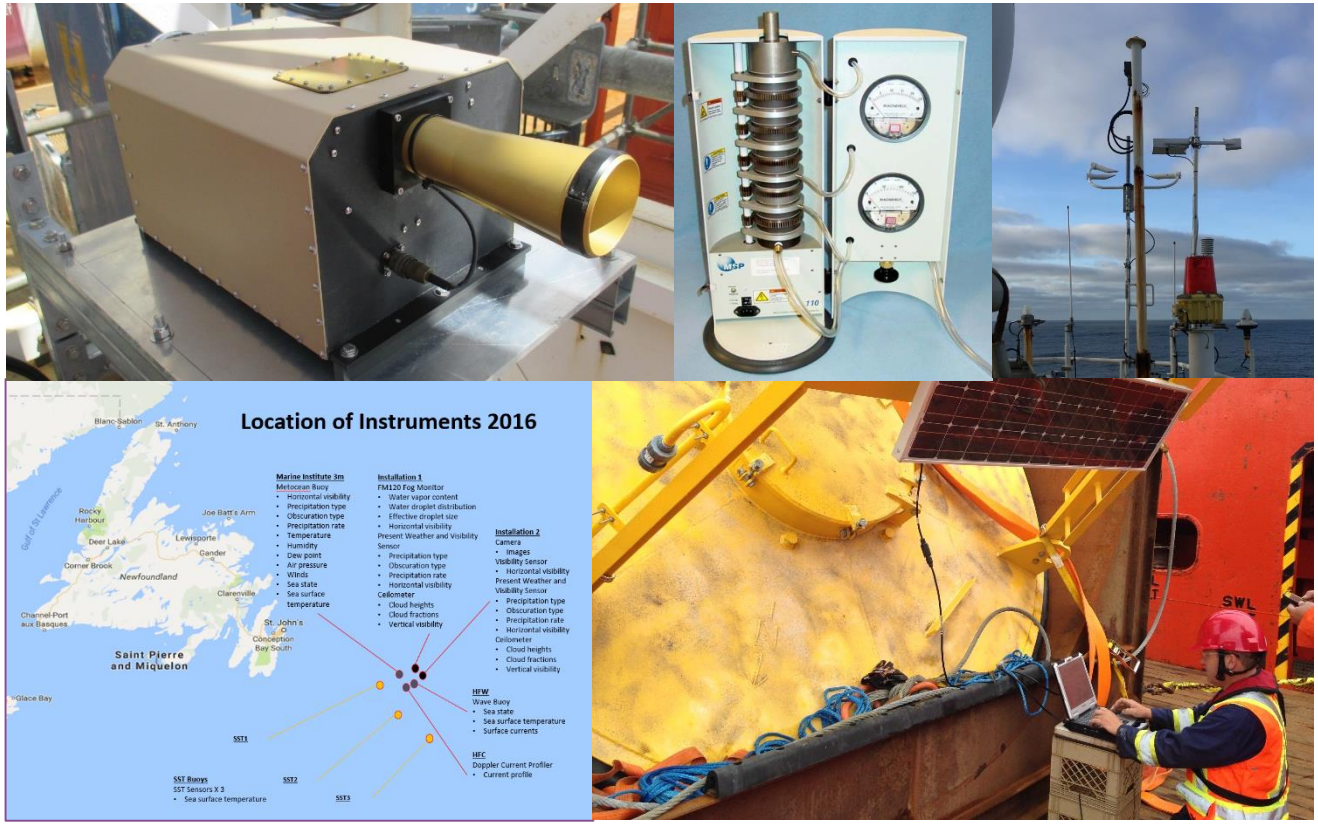
Met-Ocean-Ice Data for Operational Decisions

- Observations (iceberg positions) and model data (current, wave and wind models) are integrated in iceberg drift models to generate predictions of future positions and risk posed by icebergs
- Information is used to identify threats and take actions, e.g.:
  - Tow iceberg
  - Disconnect from well
  - Move platform



Visibility Prediction on the Grand Banks

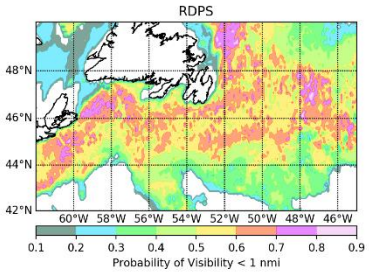
Collecting data in a harsh environment

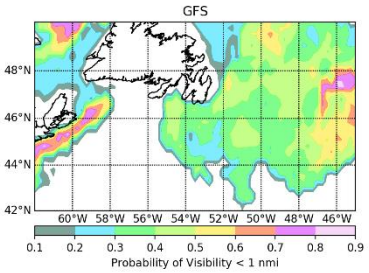


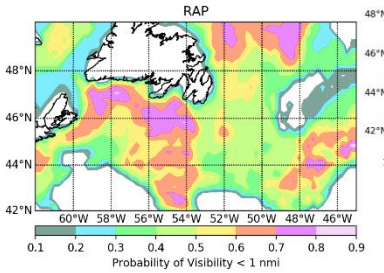
Random Forest Method applied to Model Data

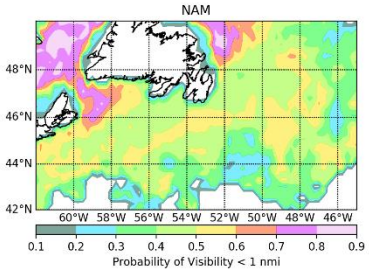
Six probabilistic fog forecasts

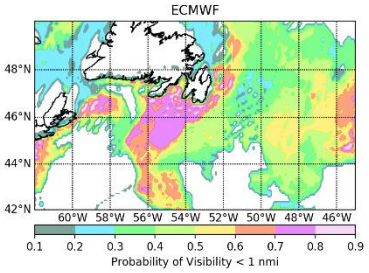
(We use RIOPS/GIOPS for SST forecast)

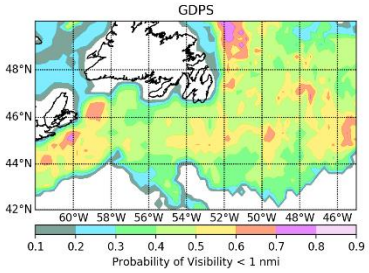


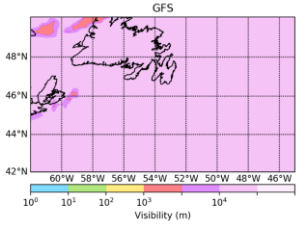


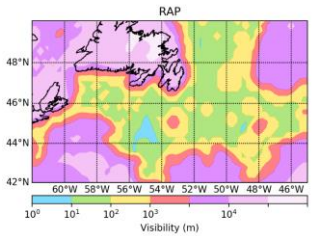


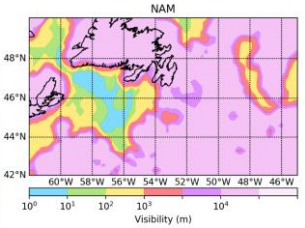


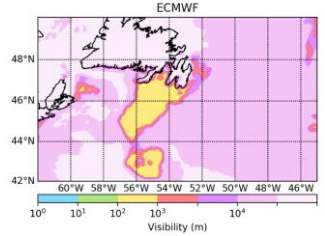


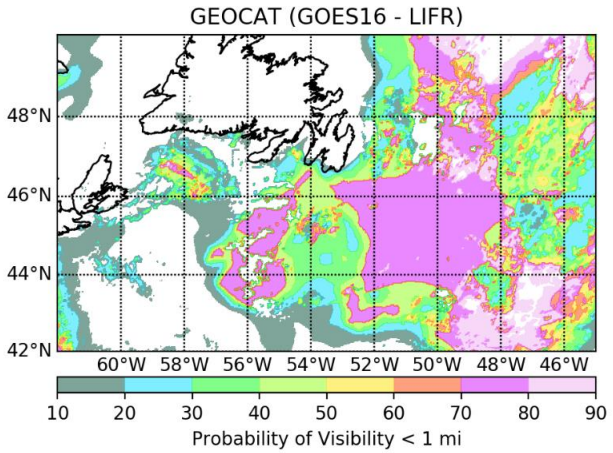








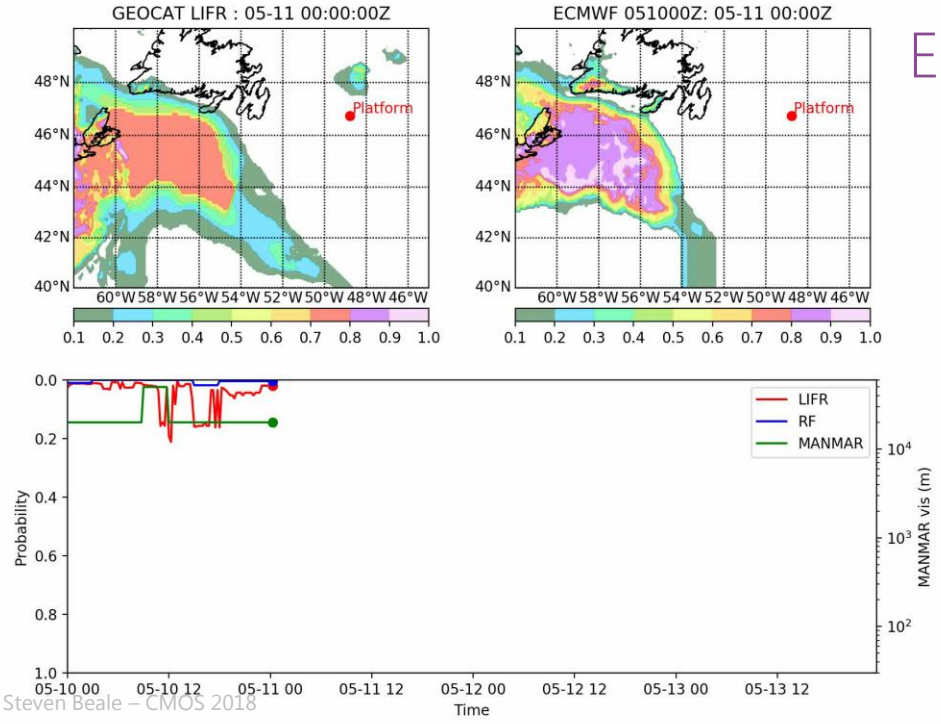




presentation by Wood.

Case Study

Fog Event May 11 2018; Forecast from May 10 00:00Z



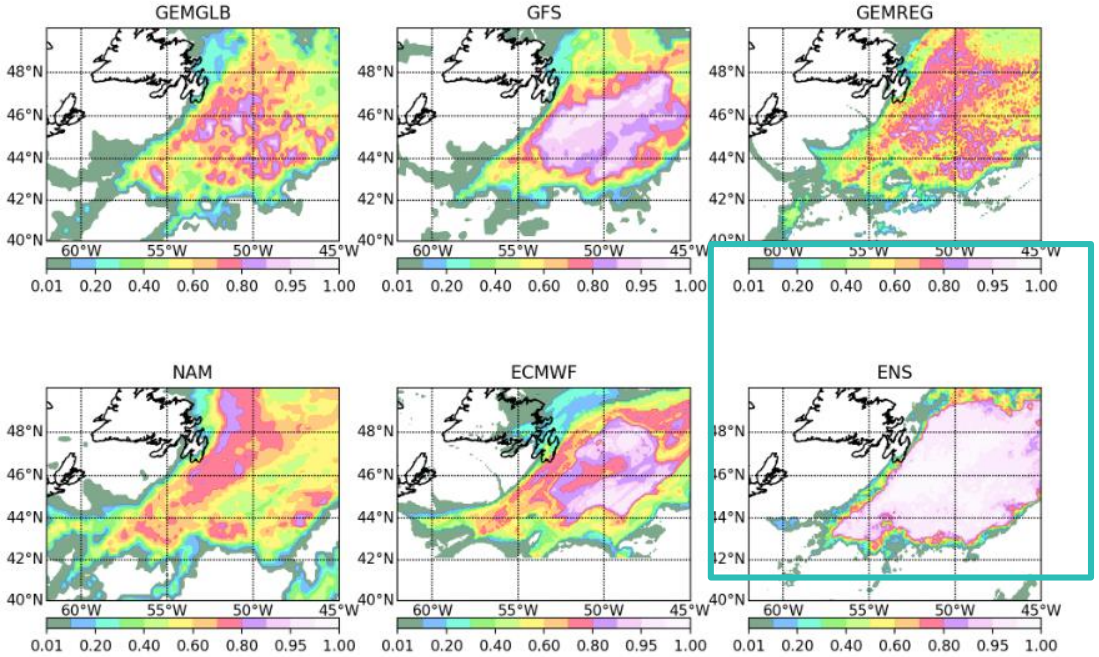
ECMWF

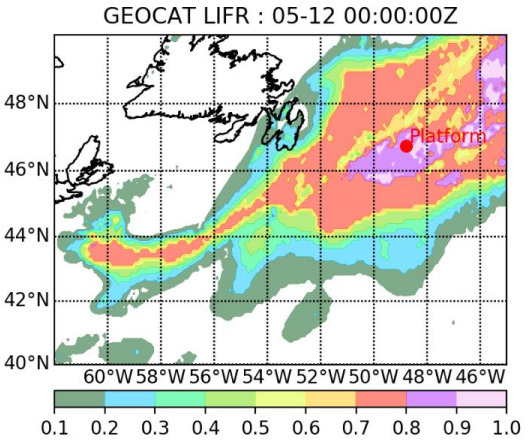
Ensemble techniques for visibility prediction

$$P(S\,|\bar{E}) = P(\bar{E}|S)\frac{P(S)}{P(\bar{E})}, where\ S = State, \bar{E}\ is\ set\ of\ forecasts$$

Bayesian Approach:

This example: Ensemble is +48hrs probability that GEOCAT probability > 50%





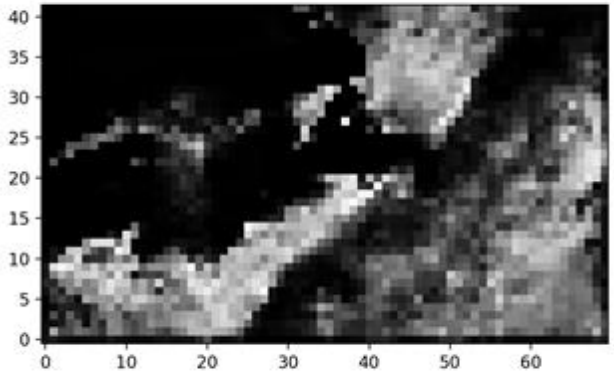
Extracting more value from prediction systems

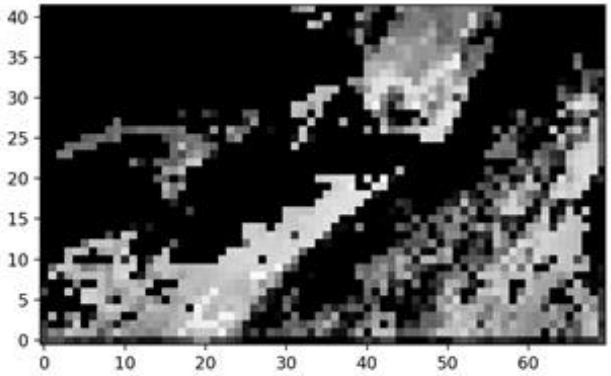
Categorical Visibility Forecast/Model Validation

0-6 Hour Rankings	BIAS	POD	FAR	HSS	Rank Score	Rank
FORECAST	1	2	4	1	2.33	1
ECM_BDEA	3	5	5	2	4.17	2
RDPS_BDEA	9	9	2	3	5.67	3
RAP_STWA	4	3	10	5	5.83	4
GFS_BDEA	13	11	1	4	6.83	5
NAM_STWA	11	1	11	9	7.33	6
GFS_WOOD	7	8	7	8	7.50	7
GDPS_BDEA	12	12	3	7	8.17	8
MMB_NATV	6	7	12	6	8.33	9
GFS_STWA	8	10	8	10	9.00	10
NAM_BDEA	10	4	13	12	9.33	11
RAP_NATV	14	6	14	11	10.83	12
RAP_BDEA	2	13	16	15	12.50	13
NAM_NATV	5	14	15	13	12.67	14
GFS_NATV	16	16	6	16	12.67	14
ECM_NATV	15	15	9	14	12.83	16

- Study Period 1 June 2018 to 31 August 2018: "Advection Fog Season"
- Fog versus No-fog
- Best POD ~90%, FAR ~10%
- Human skill best at short range
- Native visibility models have poor skill in fog versus no-fog discrimination (are not applicable to Grand Banks)
- Best 7 models have been developed for this project!

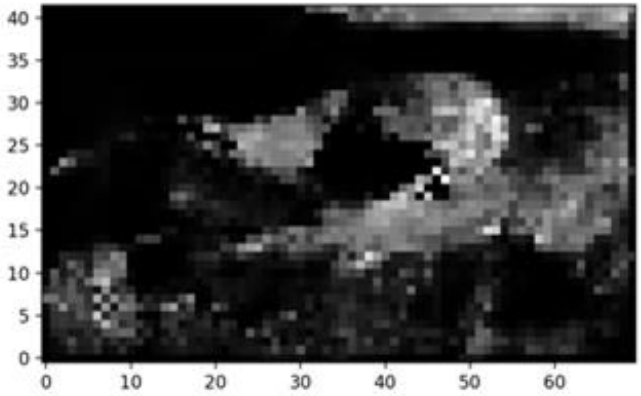
The Future: Deep Learning and other methods

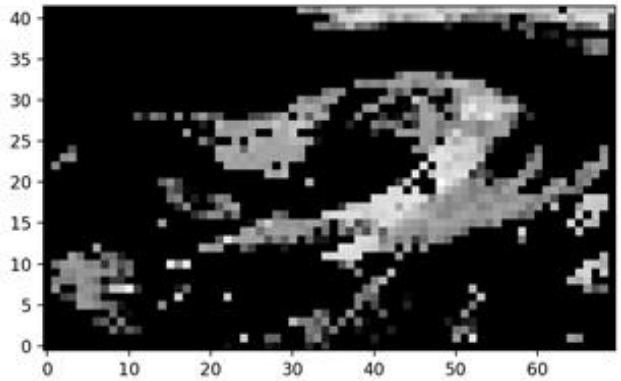




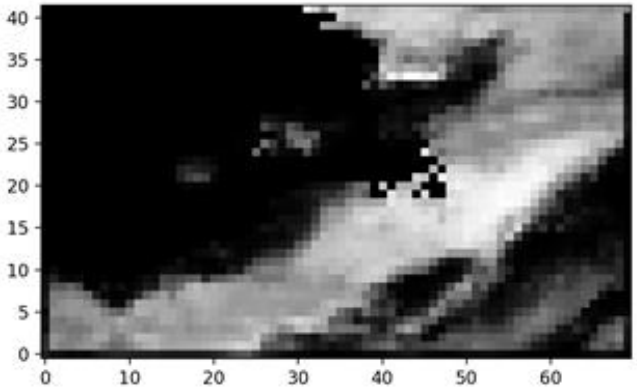
2hrs Predicted

2hrs Observed

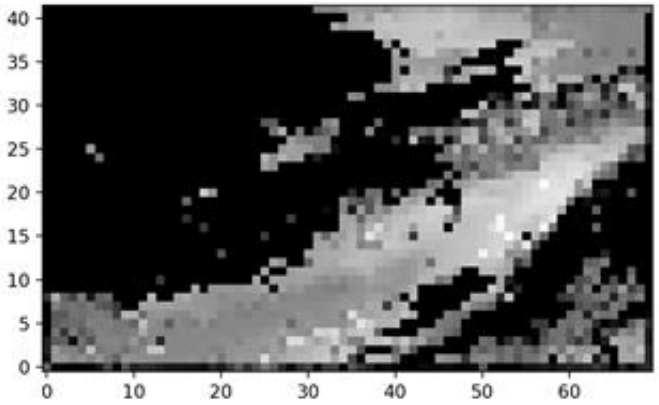


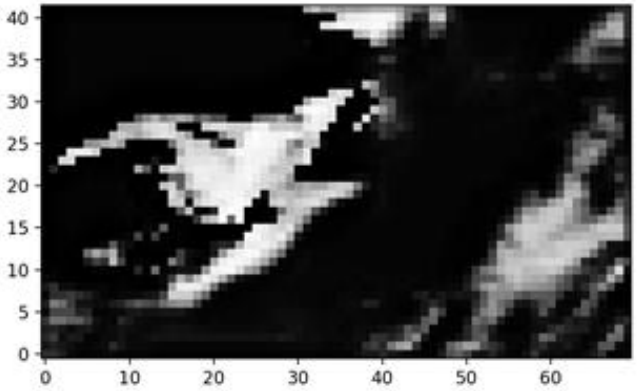


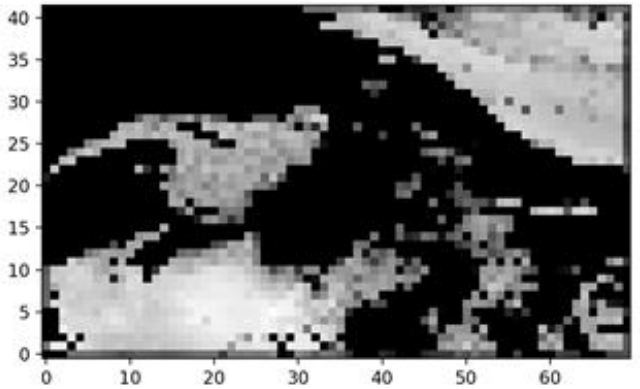
1hr Predicted



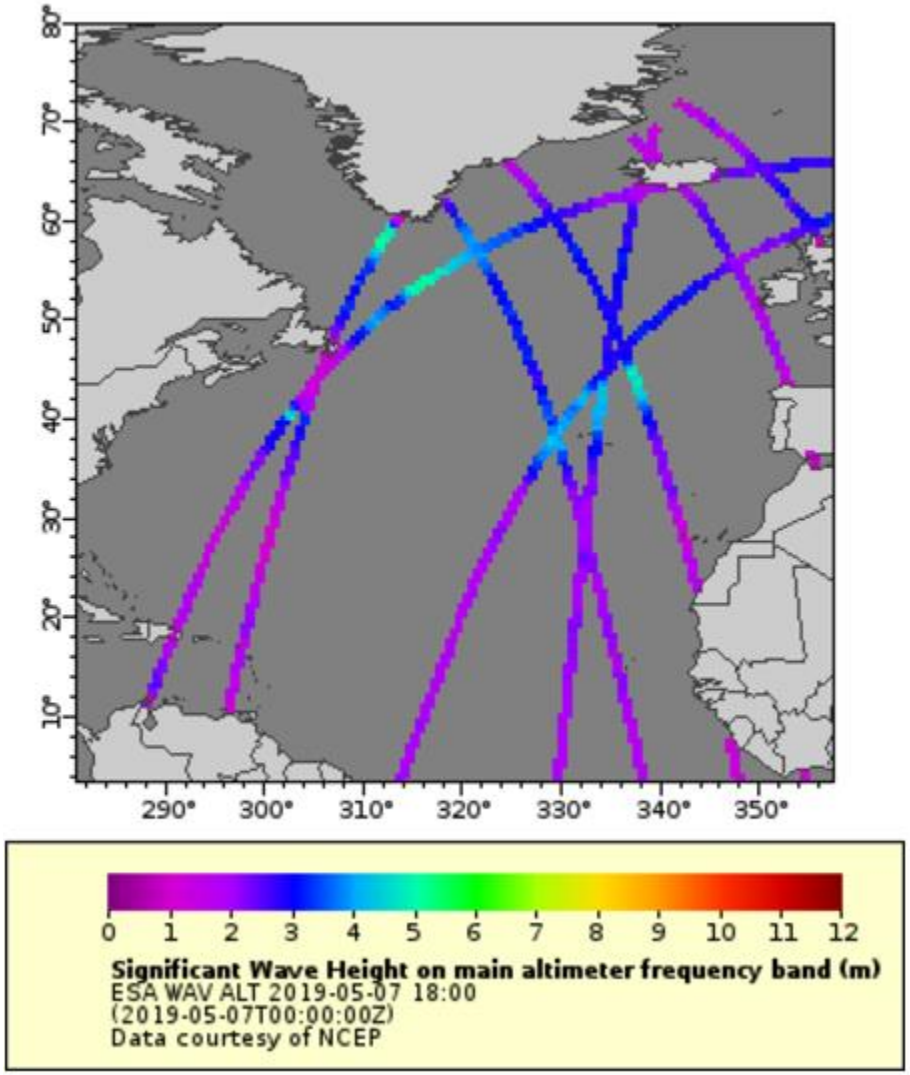
1hr Observed







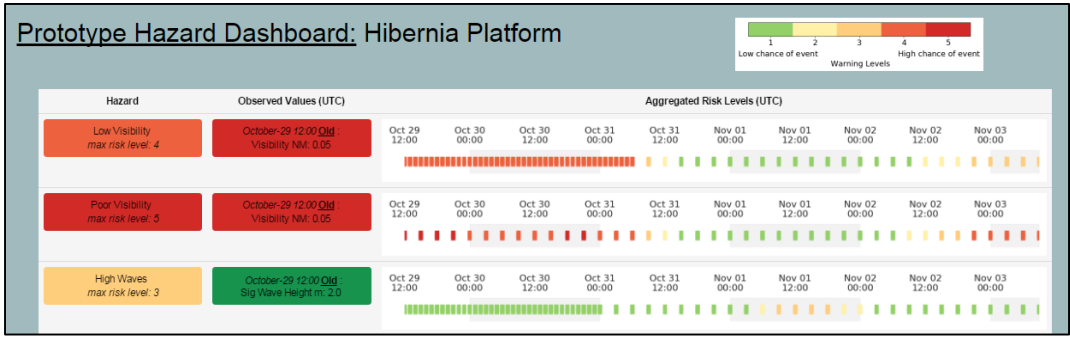
Estimated satellite-based wave height measurements

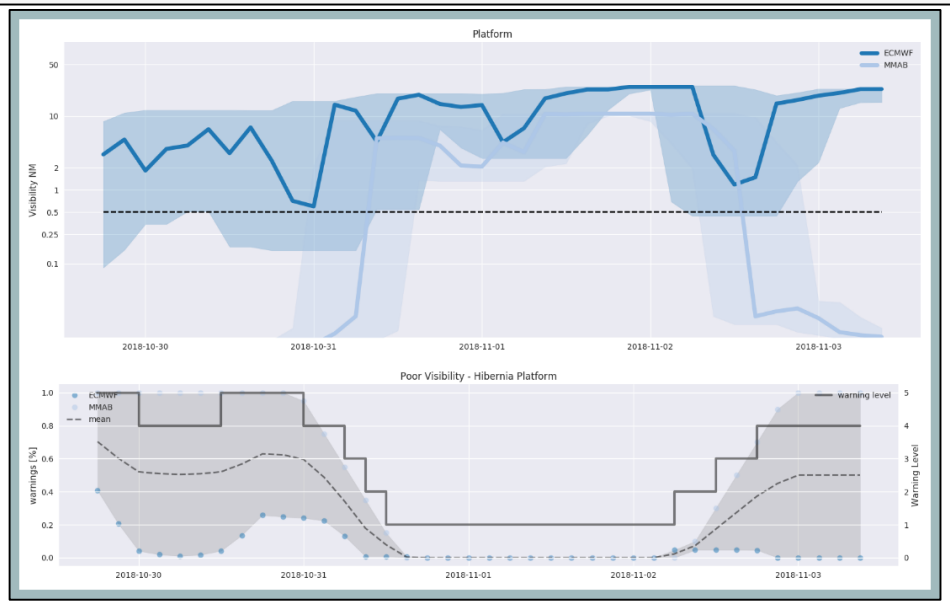


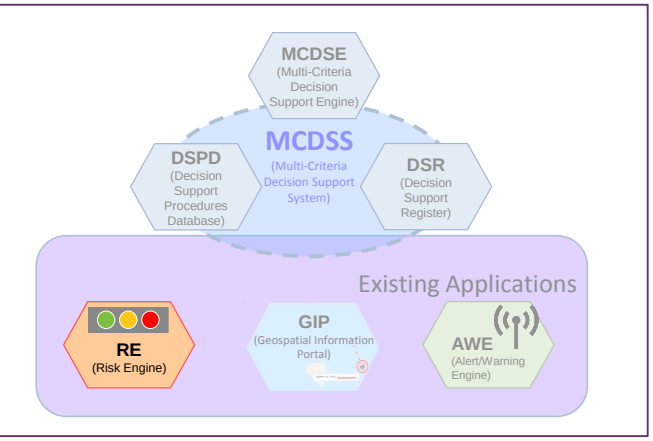
Risk Dashboard R&D

Risk Engine:

Evaluates environmental inputs and predicts potential for met-ocean conditions (visibility, waves) to exceed operational thresholds

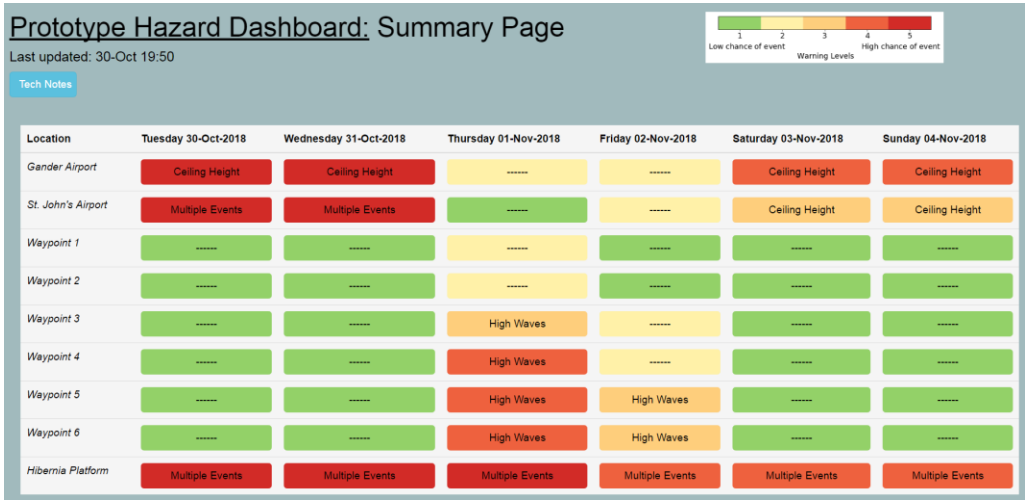






Risk Dashboard R&D

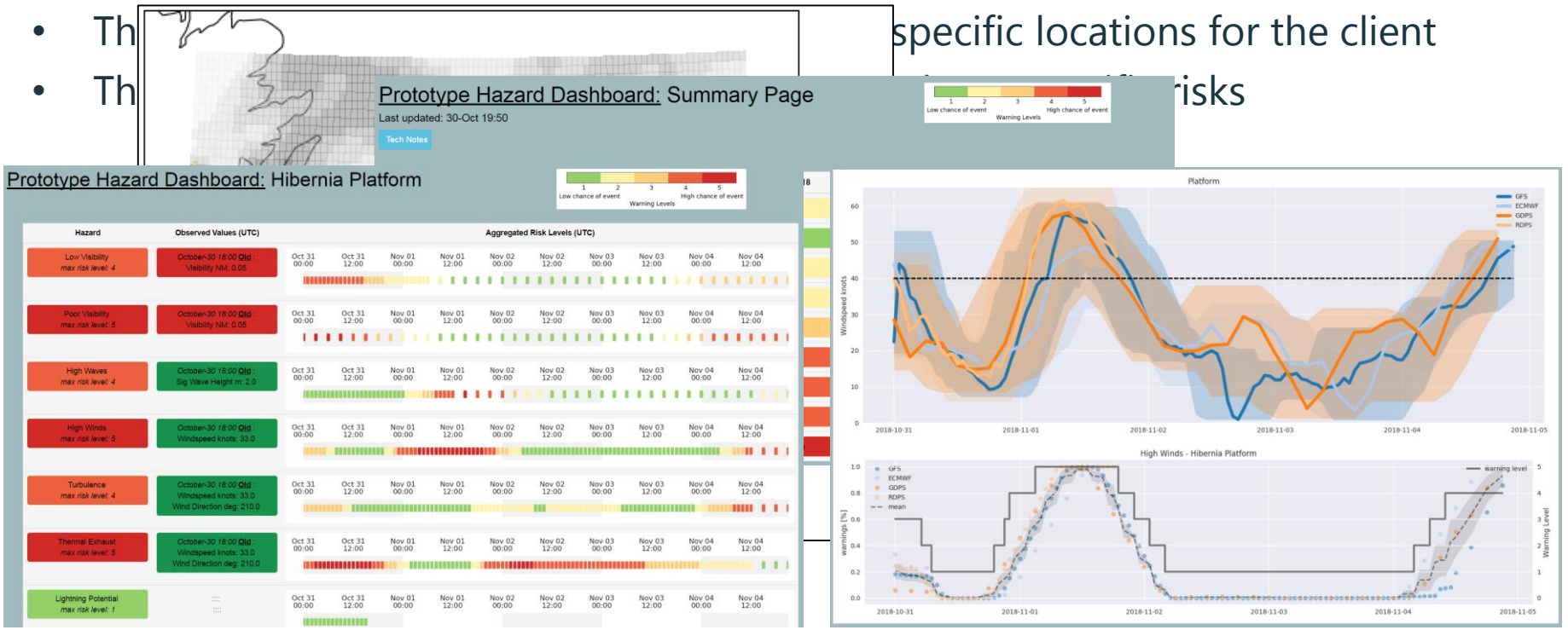
- Risk Dashboard R&D project was self-funded by Wood
- Goal was to create an easy-to-interpret, at-a-glance view for clients to identify their risk
- Risk system is comprised of:
  - Risk Engine: sophisticated statistical analysis and algorithms to predict "probability" of exceeding thresholds
  - Risk Dashboard: Web-based display that communicates an at-a-glance view of potential risks



Location	Tuesday 30-Oct-2018	Wednesday 31-Oct-2018	Thursday 01-Nov-2018	Friday 02-Nov-2018	Saturday 03-Nov-2018	Sunday 04-Nov-2018
Gander Airport	Ceiling Height	Ceiling Height	------	------	Ceiling Height	Ceiling Height
St. John's Airport	Multiple Events	Multiple Events	------	------	Ceiling Height	Ceiling Height
Waypoint 1	------	------	------	------	------	------
Waypoint 2	------	------	------	------	------	------
Waypoint 3	------	------	High Waves	------	------	------
Waypoint 4	------	------	High Waves	------	------	------
Waypoint 5	------	------	High Waves	High Waves	------	------
Waypoint 6	------	------	High Waves	High Waves	------	------
Hibernia Platform	Multiple Events	Multiple Events	Multiple Events	Multiple Events	Multiple Events	Multiple Events

Risk Dashboard R&D

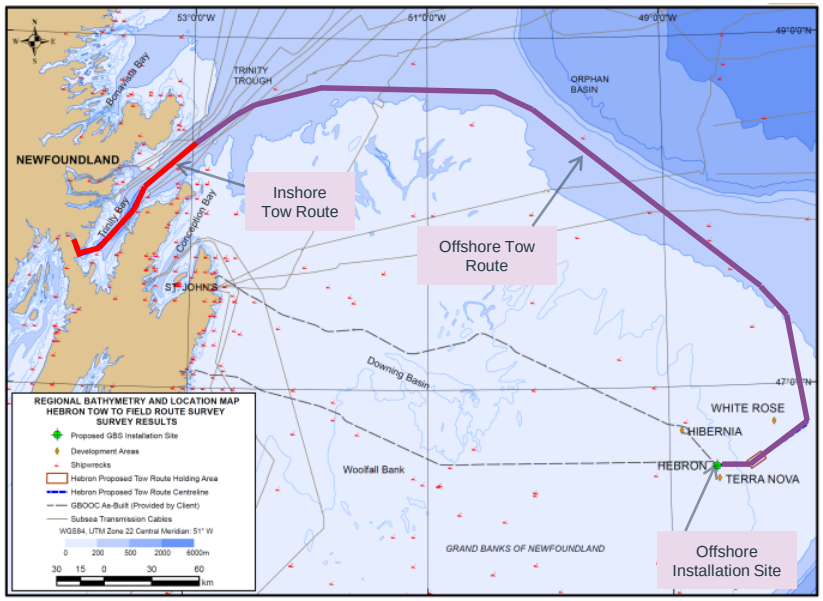
- The risk determination starts with spatial mapping of the risk
- Th specific locations for the client
- Th risks

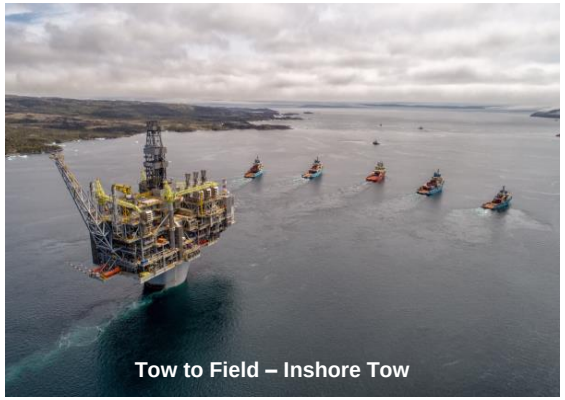


Case Study on Practical Use of Environmental Prediction Systems for Industry Decisions

Marine Operations – Metocean Requirements

Platform Tow & Installation




Tow to Field – Inshore Tow


Tow Fleet Re-configuration & Approach

Marine Operations – Metocean Requirements

Constraints & Criteria

- Critical Path Schedule
- Weather Restricted
- Design ‘Alpha’ Factors
- Limited Weather Window

Solutions & Measures

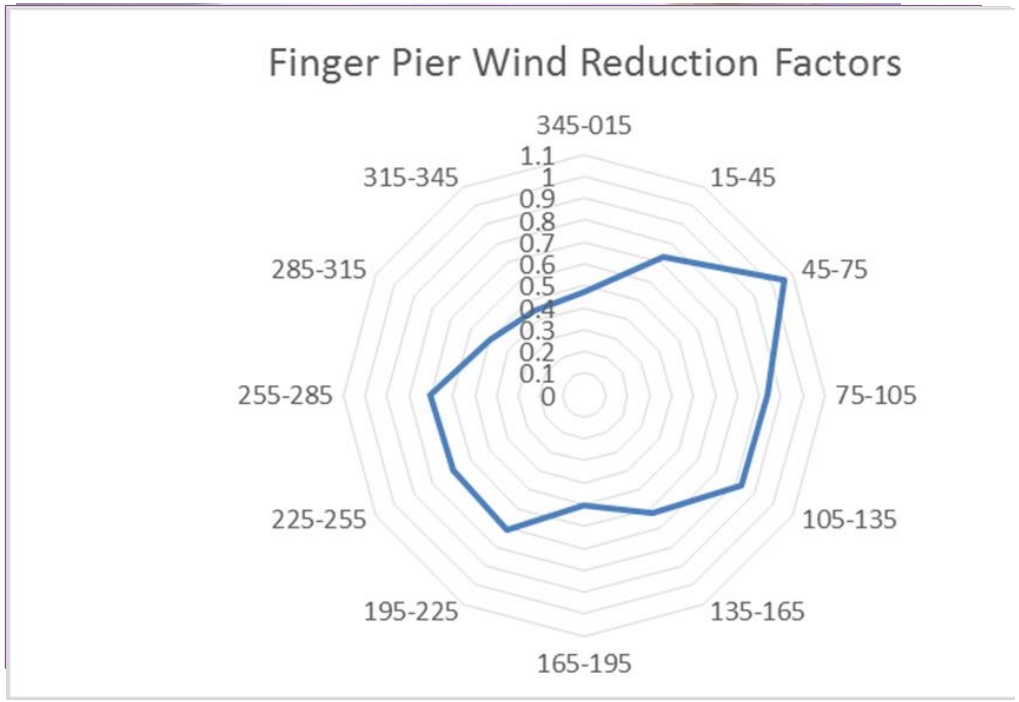
- Experienced Marine Management Team
- Forecaster(s) w/ local expertise & experience
- Forecaster(s) embedded w/ on-site teams
- Qualitative Improvement


Preparing for Towing Operations

Successful Outcomes

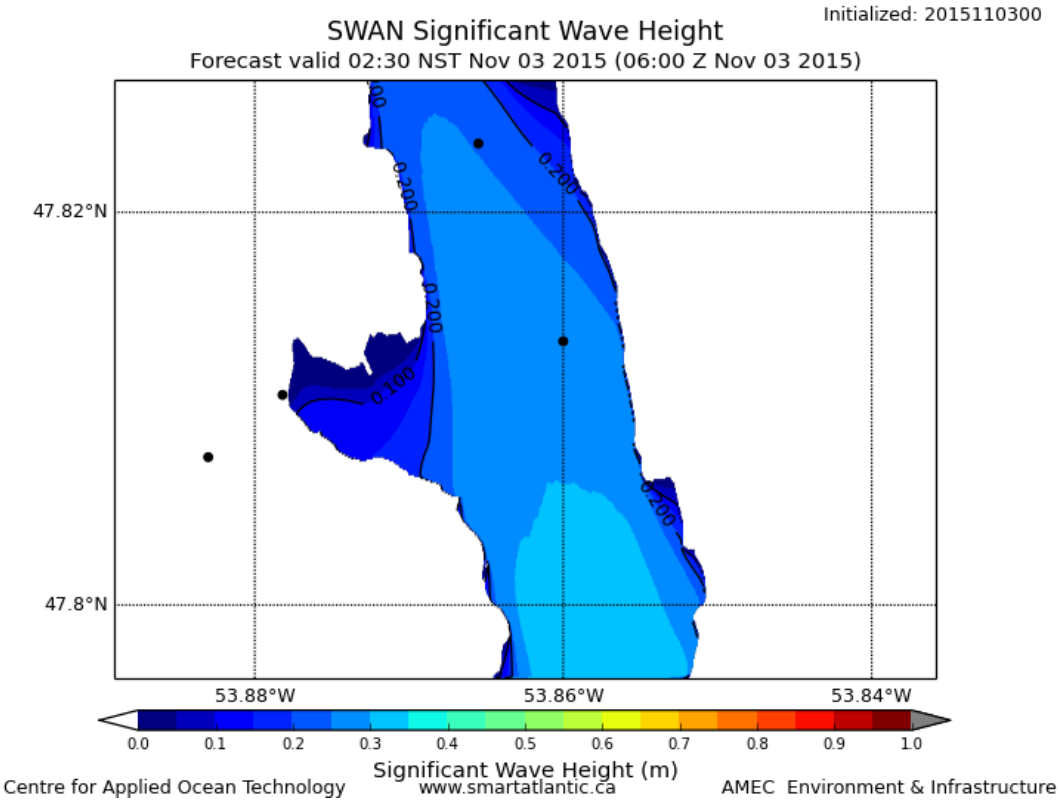
- Confidence for “go / no-go” decision
- Capitalize on Weather Windows
- Minimize waiting on weather

"Tools of the Trade" - Climatology



- Climatology:
  - ✓ Winds
  - ✓ Sea state
  - ✓ Air/sea temperatures
- Observations versus model predictions:
  - ✓ Ambient versus meso/micro model predictions
  - ✓ Mean winds versus gusts
  - ✓ Turning angles and gust factors

"Tools of the Trade" - Modelling

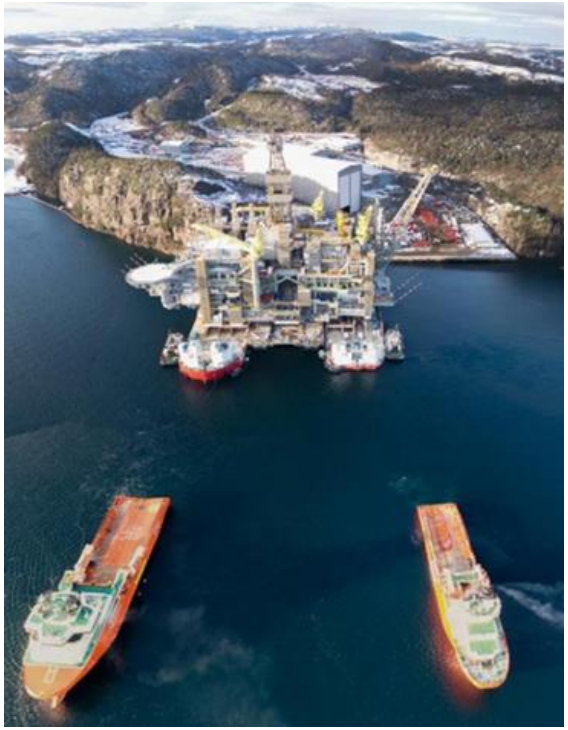


- Meso WRF Model:
  - ✓ Winds
  - ✓ Air/sea temperatures
- Micro LES Model
- SWAN Sea state model:
  - ✓ Coastal / Shallow Water
  - ✓ Hsig/Tp
- Site-specific fetch-limited sea state model best for extreme events

Living Quarters Load Out, Sea Transport and Installation

- Most environmentally sensitive marine operation of project
- 72 hour weather window
- Wind limiting factor as low as 9 m/s (17 knots)
- Forecast procedures developed over the two and ½ year period prior to operation execution

Topsides Lift-off, Transport, Float-over and GBS Mating



- Historically high water levels
- Needed to lift off in a rising tide (added to the weather window constraints)
- Strong jet over region – frequent storms (December in NL)

Tow to Field & Installation

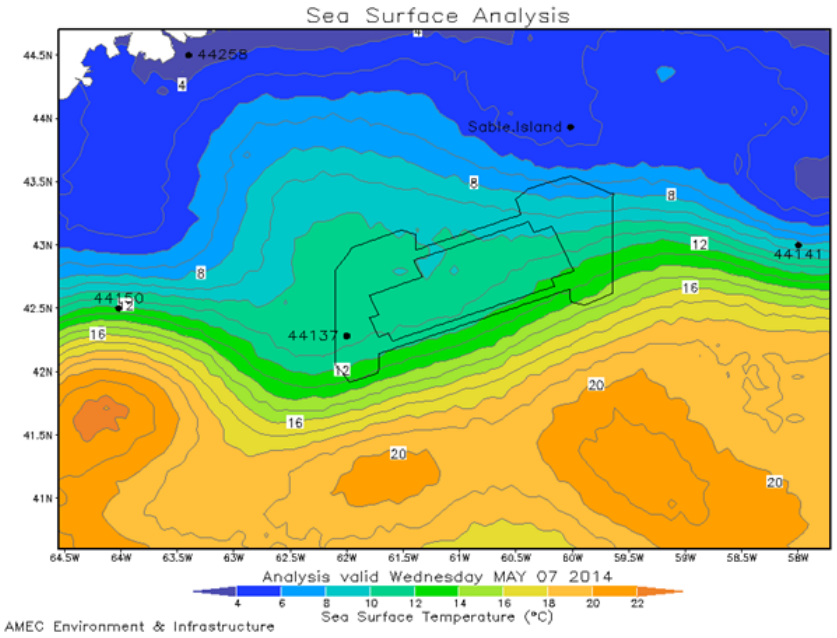
- Historically late / thick sea ice
- Weather restricted operations:
  - ✓ Transit of Trinity Bay (winds)
  - ✓ Installation (winds, visibility and seas)

Prediction of thermocline depth

- Daily oceanographic analysis and forecast of sea surface temperatures and expected variability of thermal structure.
- Predictions based on potential contribution of upcoming weather events toward surface layer mixing or stratification.

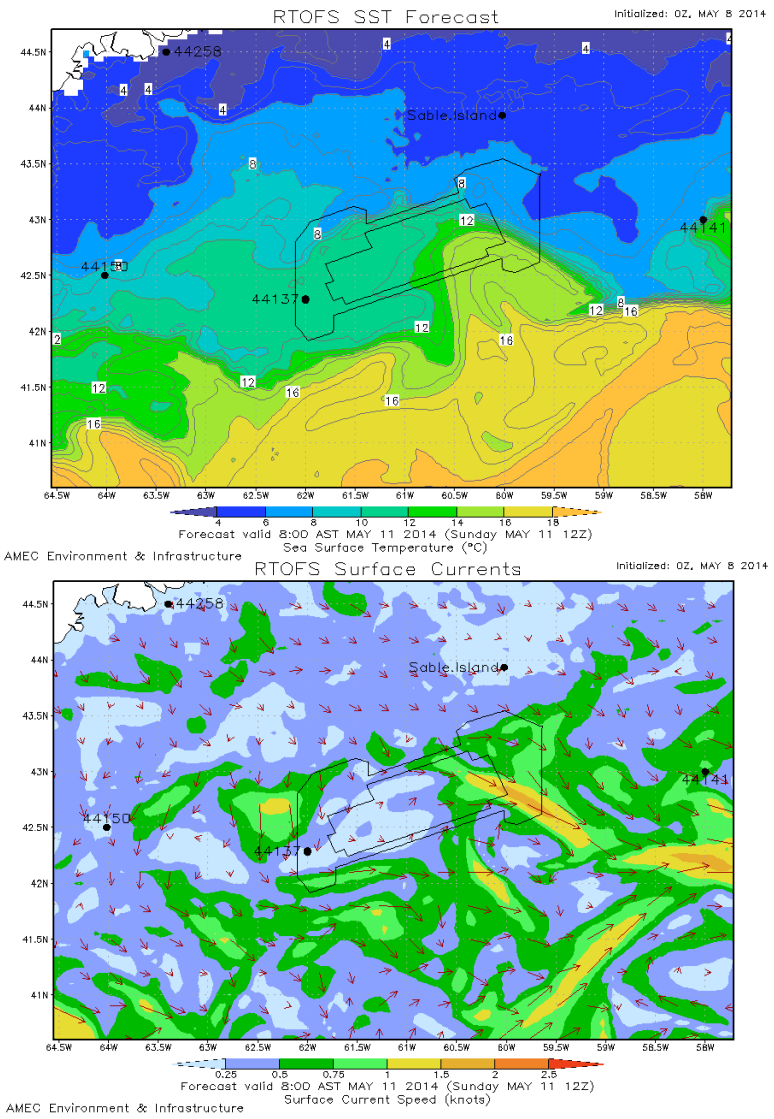
Oceanographic Analysis: Tangier Seismic Survey Area – May 5, 2014

1. Temperature and salinity profiles from May 3 indicate a top mixed layer with a depth of 12 m and temperature around 11 °C. This top layer is slightly stratified, with the temperature in the top 5 m being approximately 0.5 °C warmer than at 12 m. Below the mixed layer the profiles show strong stratification in temperature and salinity down to a depth of 30 m. Overall the profiles indicate a shift in the temperature profile of approximately 3 to 4 °C, and approximately 1 ppt in salinity in the top 30 m.
2. Maps of SST continue to indicate a relatively uniform distribution of temperatures near 11 °C throughout most of the survey area. The forecasts suggest that surface temperatures would remain relatively stable in the next day over most of the survey area, with no significant water mass change expected. The surface warming trend is likely to be temporarily countered by enhanced mixing of the shallow surface layer on Saturday night and Sunday.
3. Winds and seas are expected to be light to moderate with mainly clear skies through Friday. These conditions are expected to promote near-surface warming which is likely to enhance the near-surface stratification. Saturday night into Sunday, strong winds and moderate to rough seas are expected to develop along with fog and mist, leading to a mixing of the shallow warm surface layer.



Thermocline depth

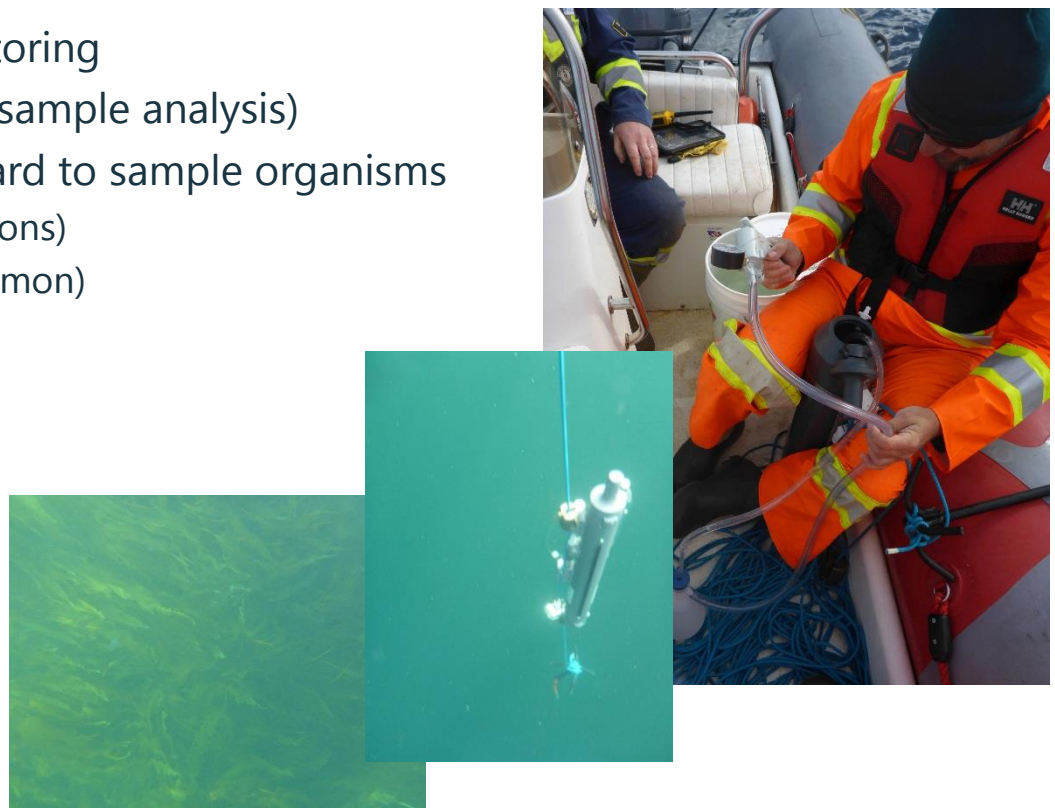
- Assessment based on analysis and interpretation of observations and forecasts:
  - Profiles of temperature and salinity from CTD casts
  - High resolution SST Analysis from NOAA based on real-time, global SST observations from satellite, ships and buoys
  - Wood's weather forecast
  - NOAA's Real-Time Ocean Forecast System (RTOFS) forecasts of surface currents, temperature and salinity structure
  - HYCOM Consortium forecasts of currents, temperature and salinity structure
  - Anticipated improvements with new developments: RIOPS and related models



Marine Environment EEM and Research

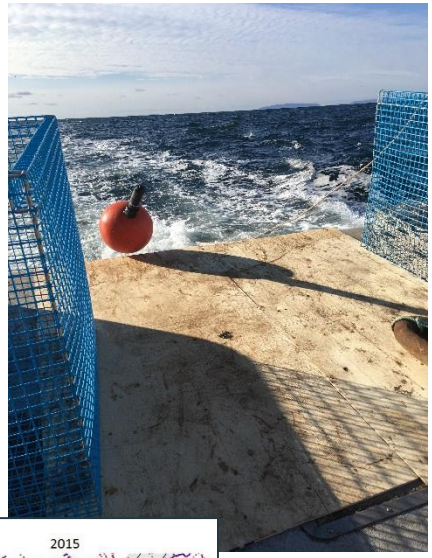
Marine EEM and Research

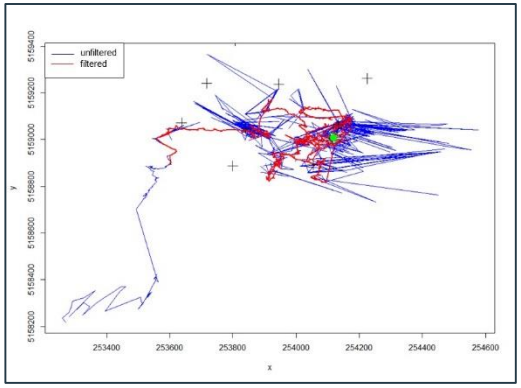
- Environmental DNA (eDNA):
  - New field of research and monitoring
  - Reduces sampling effort (water sample analysis)
  - Especially valuable for rare or hard to sample organisms
    - Invasive Species (vessel inspections)
    - SARA listed Species (Atlantic salmon)
  - Collaboration with CEGA
    - Nunavut / Nalcor
    - DFO
    - PRNL

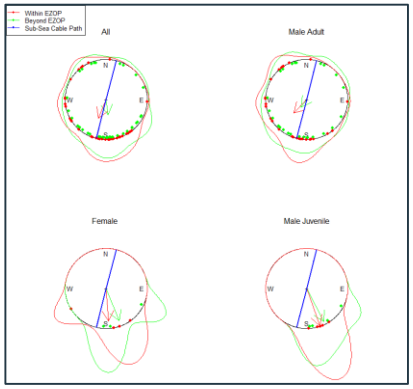


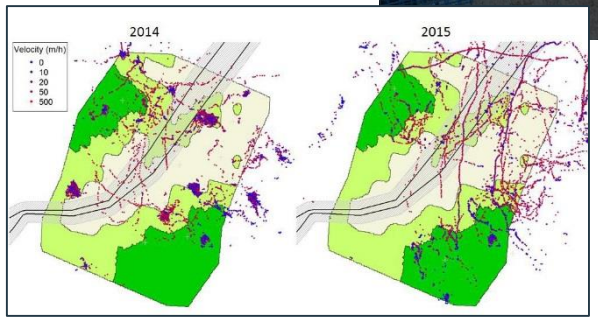
Marine EEM and Research

- Hydro Acoustics:
  - Expanding Capabilities / Distribution
    - Many taggers but not many listeners
  - All tags can be heard
  - Collaboration with DFO, OTN, ASF



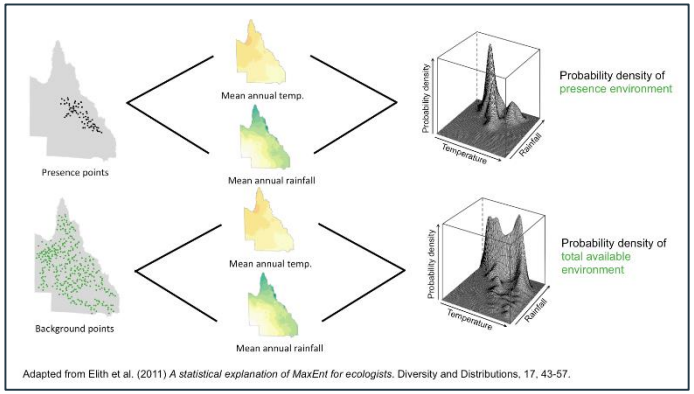




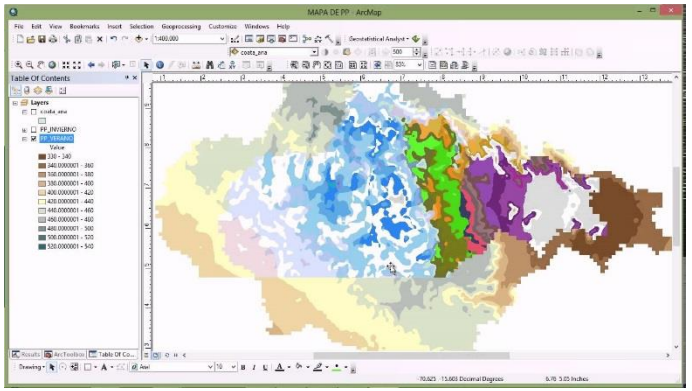


Marine EEM and Research

- Habitat Probability Modelling:
  - Deep Water Corals
    - Can be modified to model any species distribution probability
  - Will Enable more informed assessments and permitting
  - Existing NSERC Industry Grant with MUN
    - Dr. Julissa Roncal

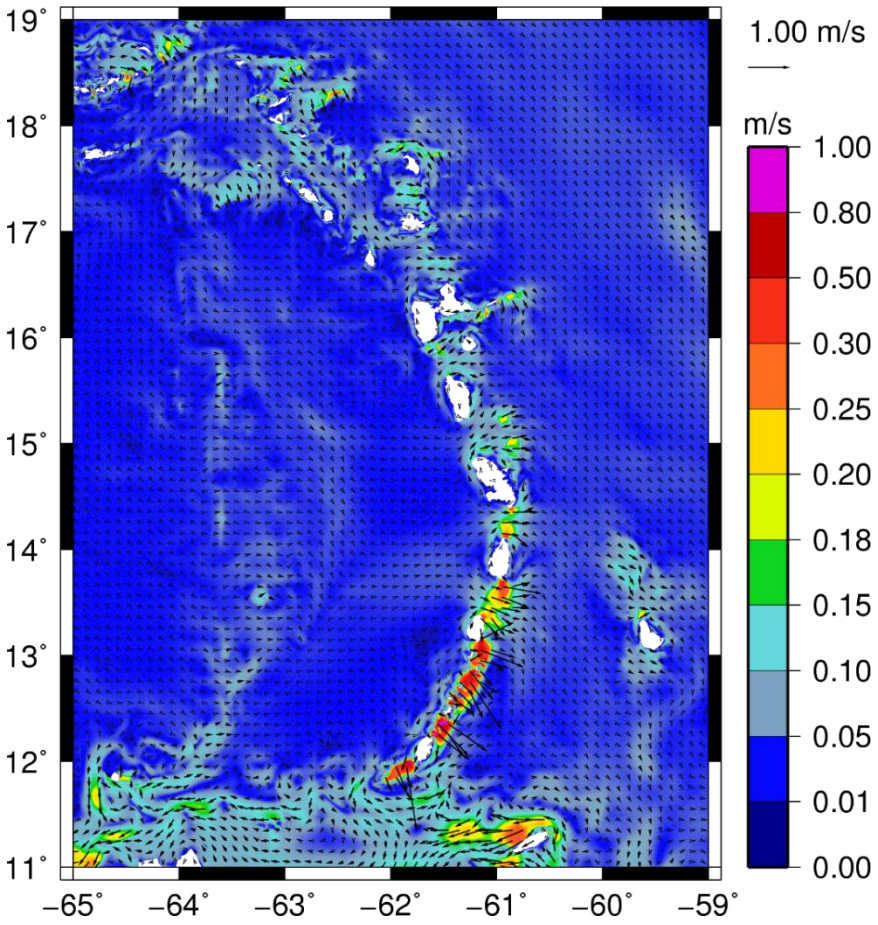


Adapted from Elith et al. (2011) *A statistical explanation of MaxEnt for ecologists*. Diversity and Distributions, 17, 43-57.



Industry Trends in Services and Datasets

- Trend toward open source development of scientific models and software
- Increased access to global and regional datasets and vast computing power
  - benefits industries with a stake in the oceans
- Lowered barriers for industry participation and collaboration
  - Feasible for private consultants to develop local high-resolution flood hazard/impact forecasting systems, leveraging global/regional efforts by academia government agencies
- Availability of in-situ oceanographic datasets and atmospheric inputs still a key challenge
- Example: Wood's (Dr. Juan Gonzalez-Lopez) ongoing engagement with CARICOOS (Puerto Rico) to develop a regional operational modelling system for the Caribbean



Note: Modelled current vectors near Barbados (ADCIRC-SWAN model, by Gonzalez-Lopez et al.)

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