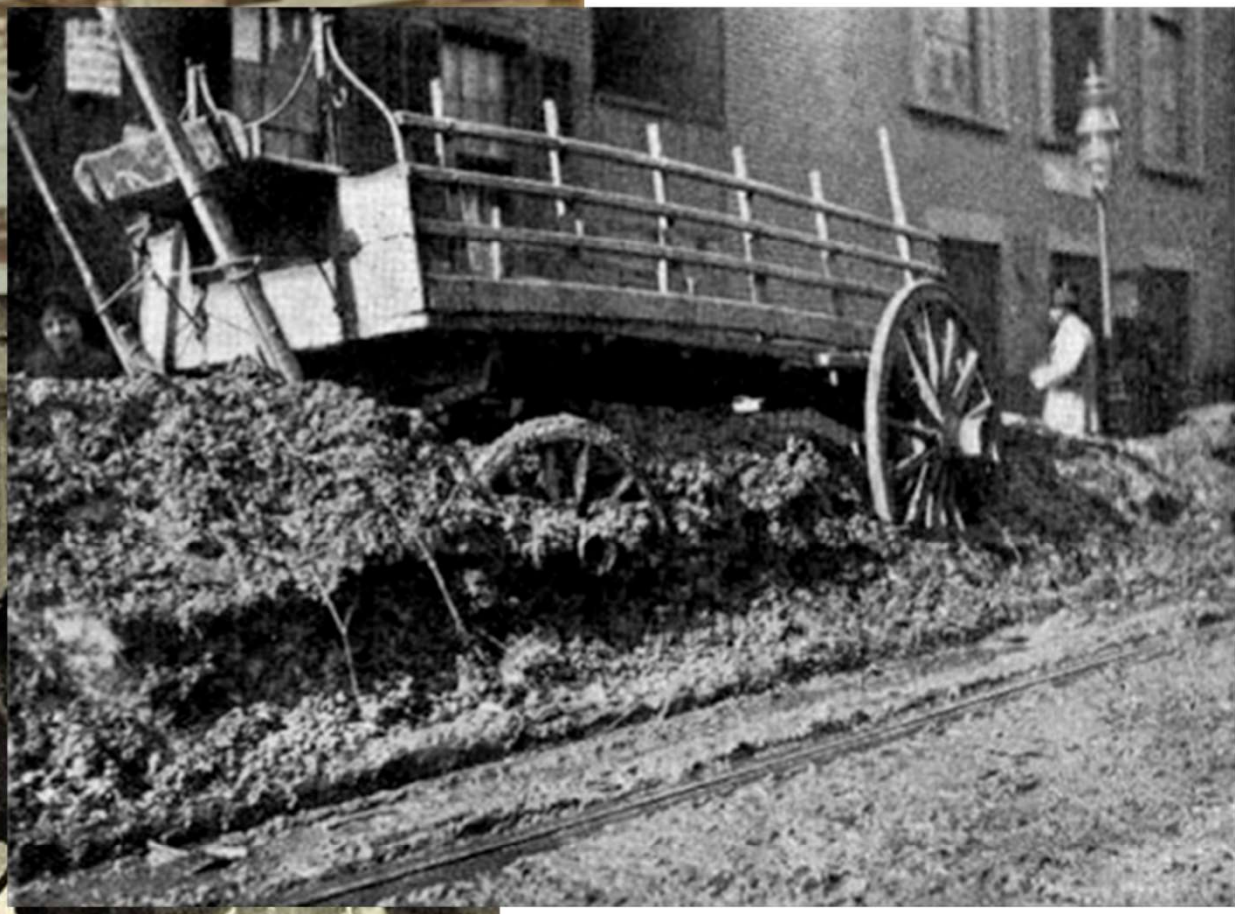
Artificial Intelligence based Real-Time Sea Surface Currents Quantification and Dissemination Framework

Professor Vladan Babovic

National University of Singapore



The First Machine Age

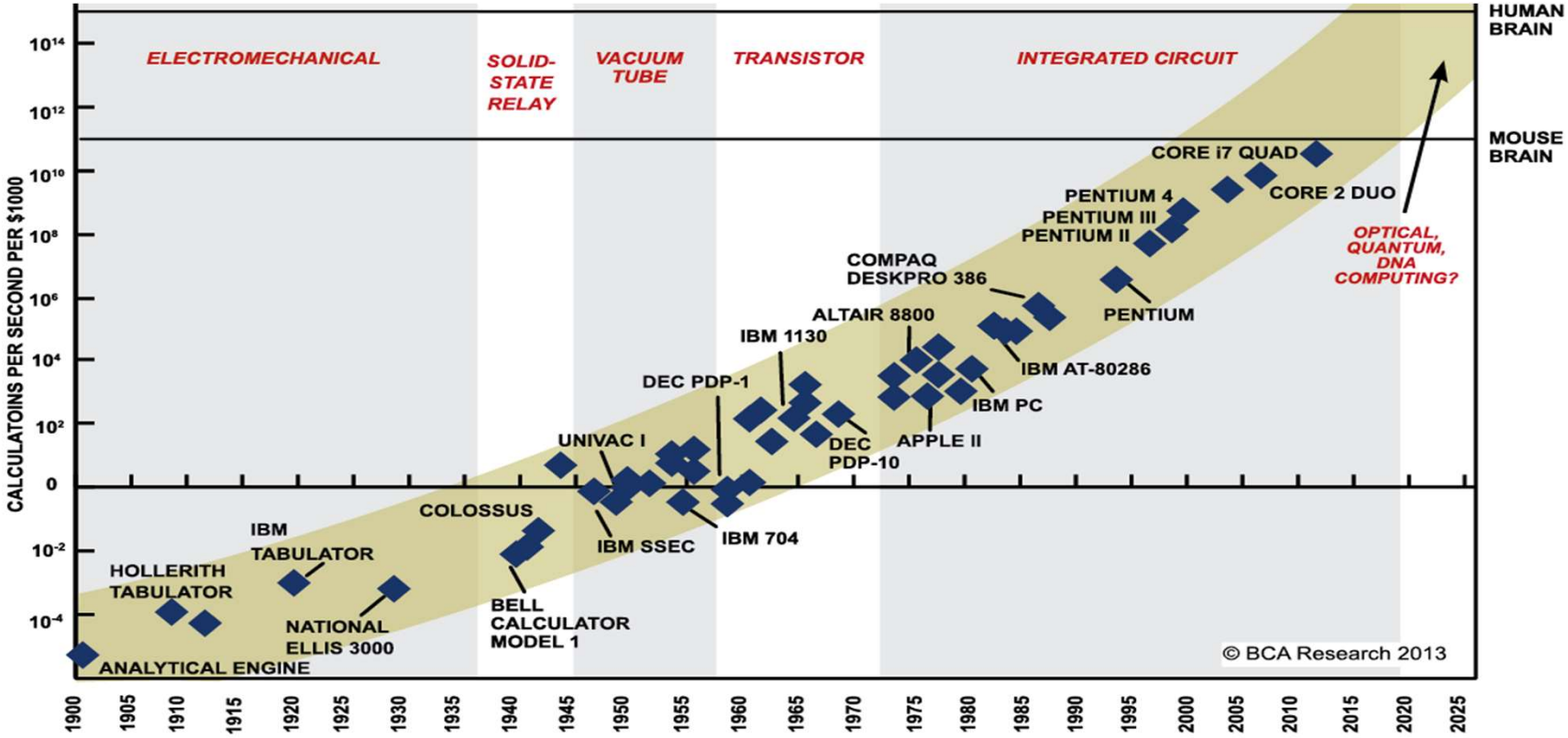
- Changing the world requires:
  - Physical power: move or transform the things
  - Mental power: decide where and how
- Industrial Revolution = Physical Power
  - Steam engine (internal combustion engine, electricity)
  - Mostly a complement to humans
- Not entirely without social resistance

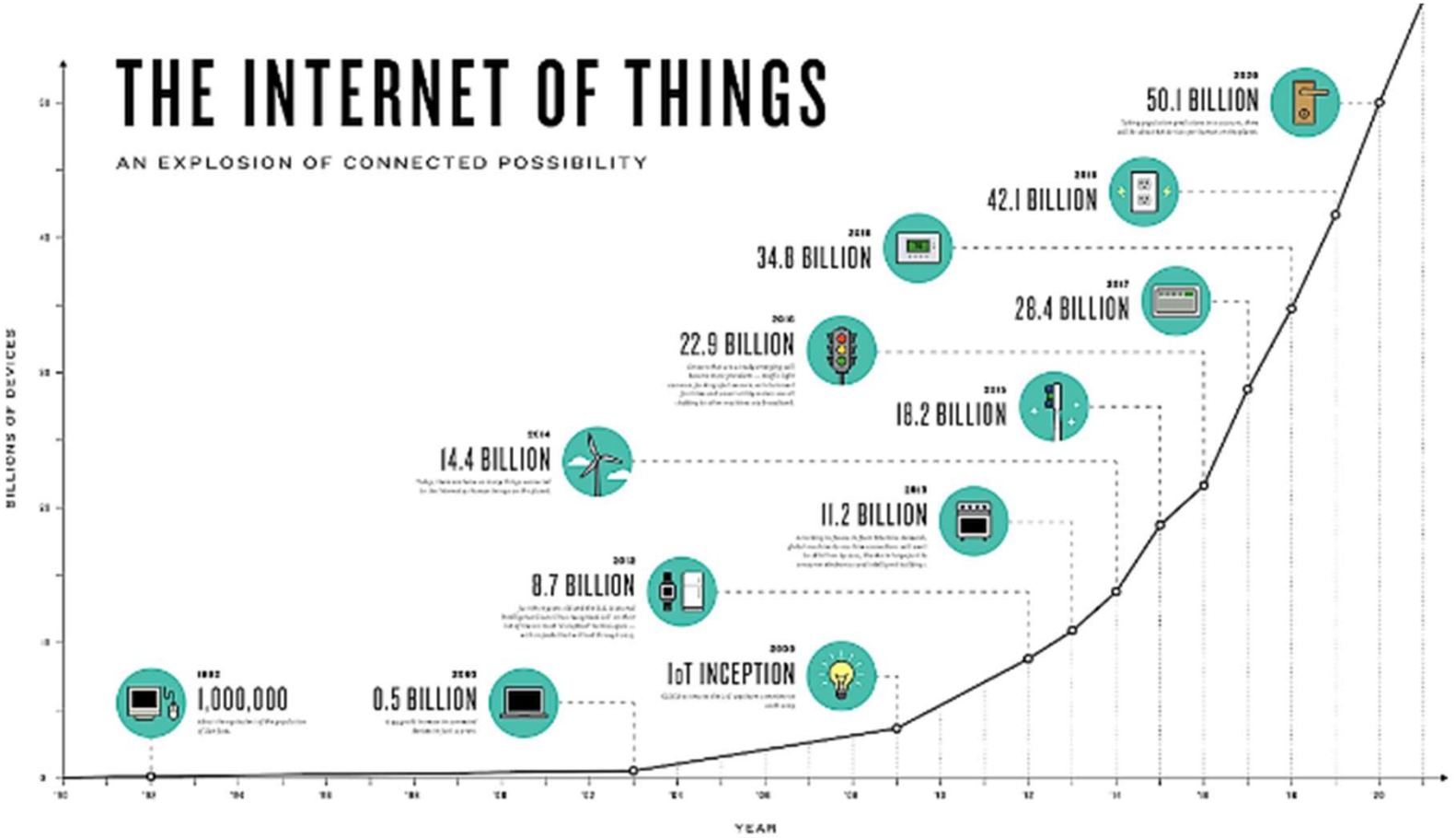
The Second Machine Age

(Brynjolfsson and McAfee, 2014)

Data, Computers, Knowledge -> Mental power

Moore's Law



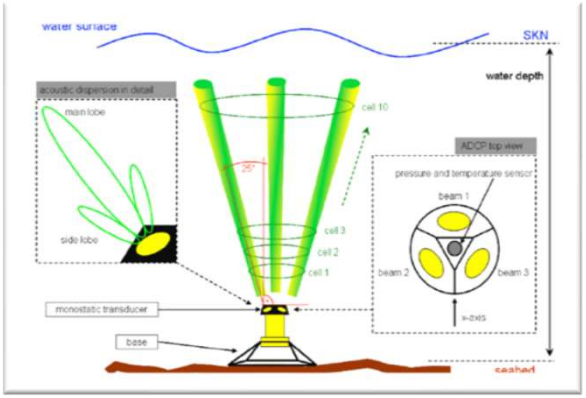


Coastal Currents

How are currents measured traditionally?

- Acoustic doppler current profiler (ADCP)

http://oceanexplorer.noaa.gov/technology/tools/acoust_doppler/media/adcp.html



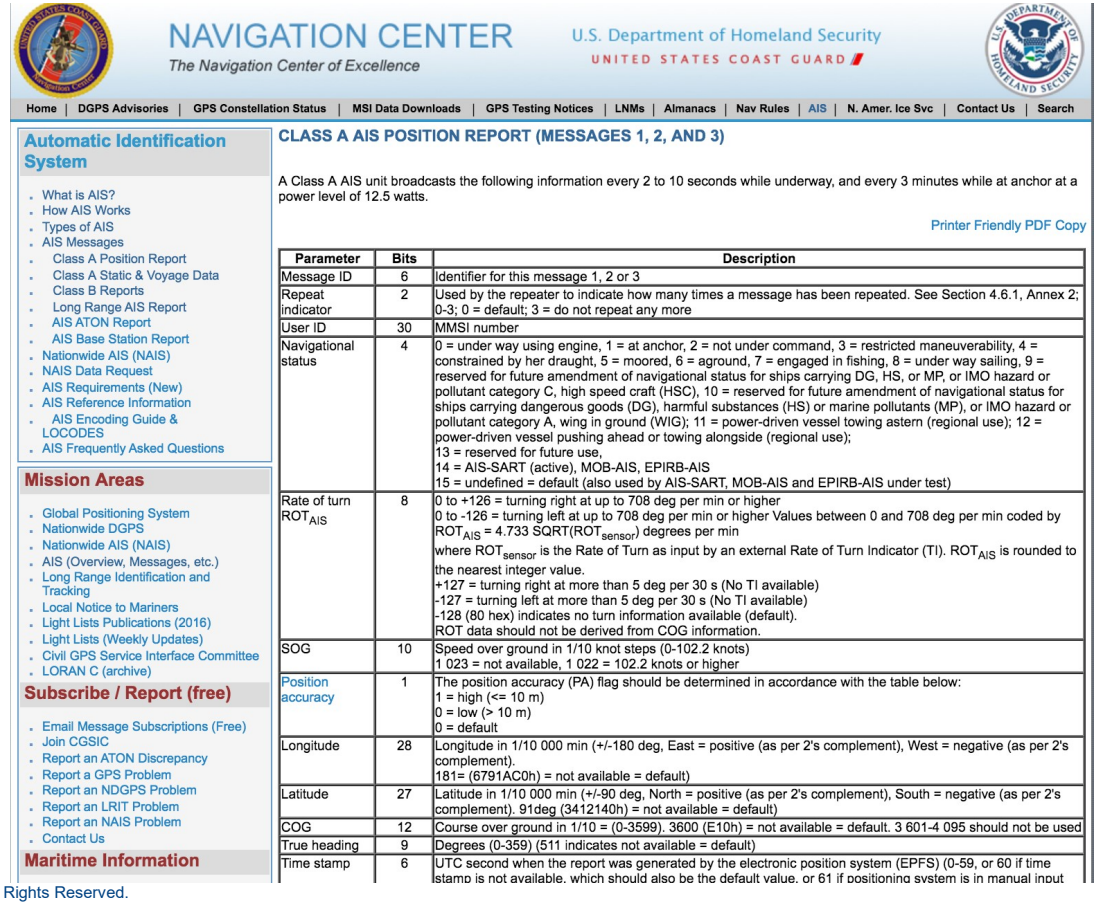
Zhao et al. (2016)

Direct insitu measurement at a single location

Cost for one ADCP:

- About S$ 31,900 to acquire
- About S$ 6,000 to deploy and retrieval
- About S$ 8,400 per month to maintain
- Total of **S$ 100,800** per year + one-time cost of **S$ 37,900**

International Maritime Organisation (IMO) imposes Automatic Identification System (AIS) messaging



NAVIGATION CENTER
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Automatic Identification System

- What is AIS?
- How AIS Works
- Types of AIS
- AIS Messages
  - Class A Position Report
  - Class A Static & Voyage Data
  - Class B Reports
  - Long Range AIS Report
  - AIS ATON Report
  - AIS Base Station Report
- Nationwide AIS (NAIS)
- NAIS Data Request
- AIS Requirements (New)
- AIS Reference Information
- AIS Encoding Guide & LOCODES
- AIS Frequently Asked Questions

Mission Areas

- Global Positioning System
- Nationwide DGPS
- Nationwide AIS (NAIS)
- AIS (Overview, Messages, etc.)
- Long Range Identification and Tracking
- Local Notice to Mariners
- Light Lists Publications (2016)
- Light Lists (Weekly Updates)
- Civil GPS Service Interface Committee
- LORAN C (archive)

Subscribe / Report (free)

- Email Message Subscriptions (Free)
- Join CGSIC
- Report an ATON Discrepancy
- Report a GPS Problem
- Report an NDGPS Problem
- Report an LRIT Problem
- Report an NAIS Problem
- Contact Us

Maritime Information

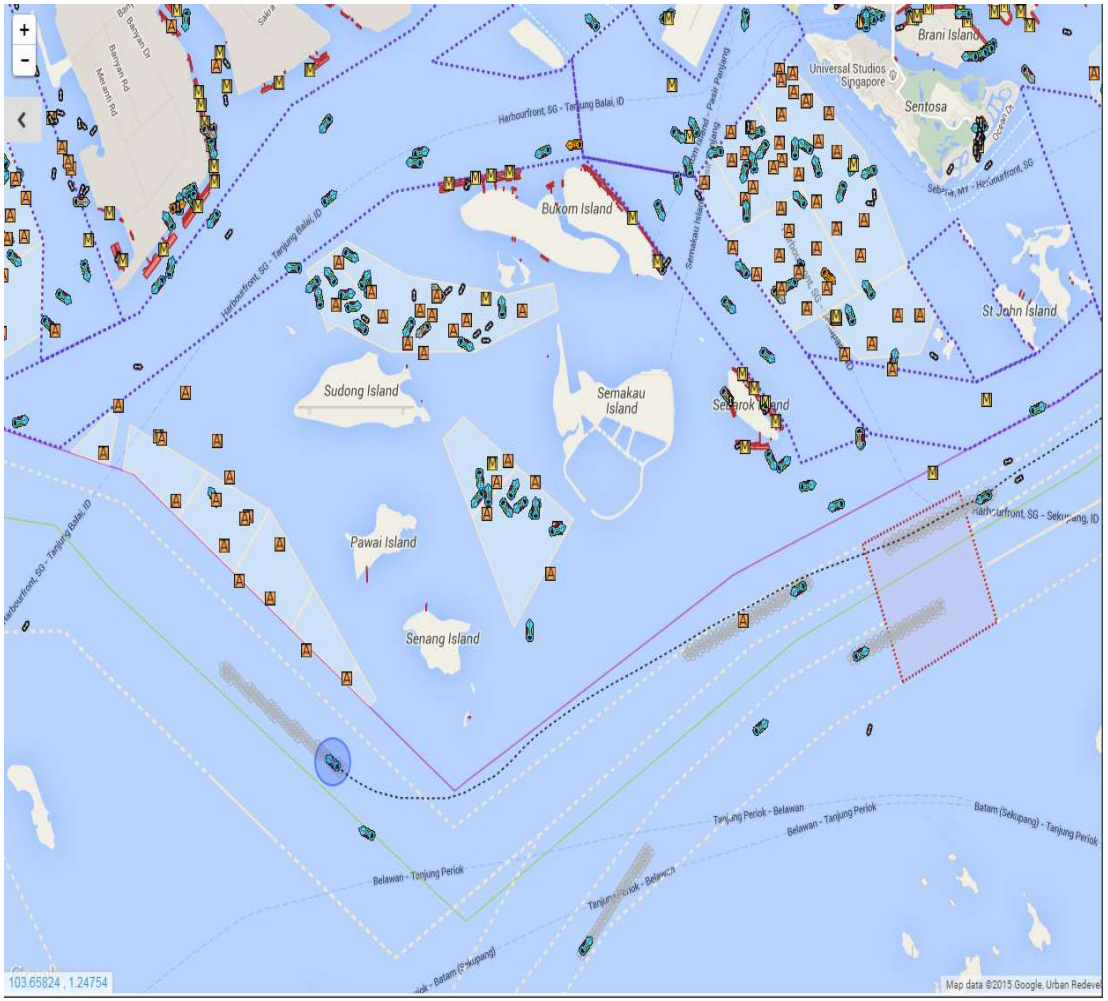
CLASS A AIS POSITION REPORT (MESSAGES 1, 2, AND 3)

A Class A AIS unit broadcasts the following information every 2 to 10 seconds while underway, and every 3 minutes while at anchor at a power level of 12.5 watts.

Printer Friendly PDF Copy

Parameter	Bits	Description
Message ID	6	Identifier for this message 1, 2 or 3
Repeat indicator	2	Used by the repeater to indicate how many times a message has been repeated. See Section 4.6.1, Annex 2; 0-3; 0 = default; 3 = do not repeat any more
User ID	30	MMSI number
Navigational status	4	0 = under way using engine, 1 = at anchor, 2 = not under command, 3 = restricted maneuverability, 4 = constrained by her draught, 5 = moored, 6 = aground, 7 = engaged in fishing, 8 = under way sailing, 9 = reserved for future amendment of navigational status for ships carrying DG, HS, or MP, or IMO hazard or pollutant category C, high speed craft (HSC), 10 = reserved for future amendment of navigational status for ships carrying dangerous goods (DG), harmful substances (HS) or marine pollutants (MP), or IMO hazard or pollutant category A, wing in ground (WIG); 11 = power-driven vessel towing astern (regional use); 12 = power-driven vessel pushing ahead or towing alongside (regional use); 13 = reserved for future use, 14 = AIS-SART (active), MOB-AIS, EPIRB-AIS 15 = undefined = default (also used by AIS-SART, MOB-AIS and EPIRB-AIS under test)
Rate of turn ROT_{AIS}	8	0 to +126 = turning right at up to 708 deg per min or higher 0 to -126 = turning left at up to 708 deg per min or higher Values between 0 and 708 deg per min coded by $ROT_{AIS} = 4.733\ SQRT(ROT_{sensor})$ degrees per min where ROT_{sensor} is the Rate of Turn as input by an external Rate of Turn Indicator (TI). ROT_{AIS} is rounded to the nearest integer value. +127 = turning right at more than 5 deg per 30 s (No TI available) -127 = turning left at more than 5 deg per 30 s (No TI available) -128 (80 hex) indicates no turn information available (default). ROT data should not be derived from COG information.
SOG	10	Speed over ground in 1/10 knot steps (0-102.2 knots) 1 023 = not available, 1 022 = 102.2 knots or higher
Position accuracy	1	The position accuracy (PA) flag should be determined in accordance with the table below: 1 = high (<= 10 m) 0 = low (> 10 m) 0 = default
Longitude	28	Longitude in 1/10 000 min (+/-180 deg, East = positive (as per 2's complement), West = negative (as per 2's complement). 181= (6791AC0h) = not available = default)
Latitude	27	Latitude in 1/10 000 min (+/-90 deg, North = positive (as per 2's complement), South = negative (as per 2's complement). 91deg (3412140h) = not available = default)
COG	12	Course over ground in 1/10 = (0-3599). 3600 (E10h) = not available = default. 3 601-4 095 should not be used
True heading	9	Degrees (0-359) (511 indicates not available = default)
Time stamp	6	UTC second when the report was generated by the electronic position system (EPFS) (0-59, or 60 if time stamp is not available, which should also be the default value, or 61 if positioning system is in manual input

There are thousands of vessels within port limits at any point in time …
… giving us tens of thousands of AIS messages in real time



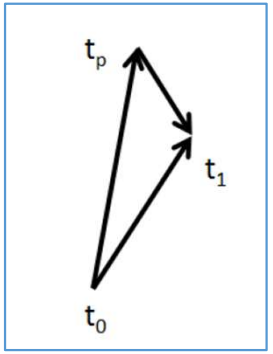
A snapshot of AIS messages in Singapore waters

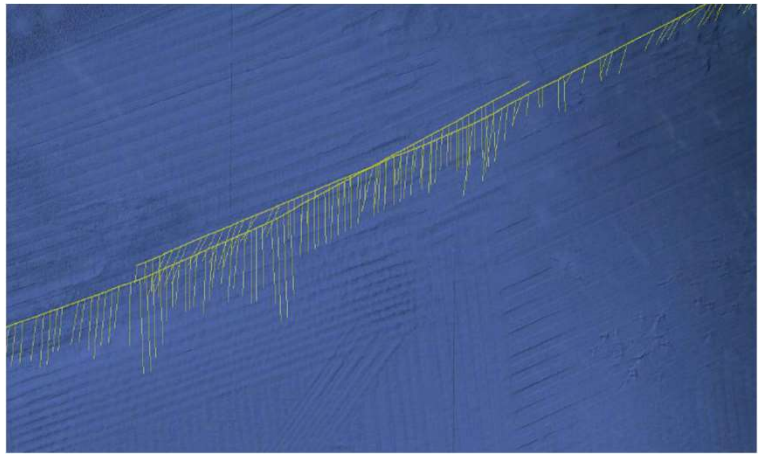
Data Driven AIS Modelling

There are 27 kinds of AIS messages. The most relevant here are listed below

MessageID	*Name*	Description
1	Position Report	Scheduled position report
2	Position Report	Assigned scheduled position report
3	Position Report	Special position report, response to interrogation
4	Base Station Report	Position, UTC, date and current slot number of base station
5	Static and Voyage Related Data	Scheduled static and voyage related vessel data report
10	UTC/Date Inquiry	Request UTC and date
11	UTC/Date Response	Current UTC and date if available
17	DGNSS Broadcast Binary Message	DGNSS corrections provided by a base station
21	Aids-to-Navigation Report	Position and status report for aids-to-navigation
27	Long Range AIS Broadcast Message	A subset of position report data

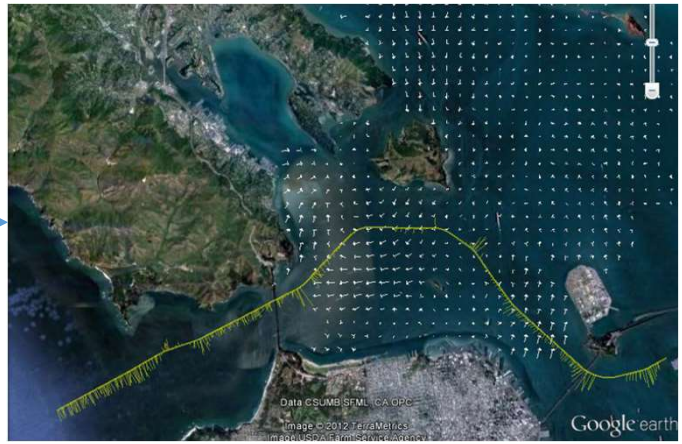
Cloud





Raw AIS messages

Surface Currents from AIS



Data Driven AIS Modelling

Cloud

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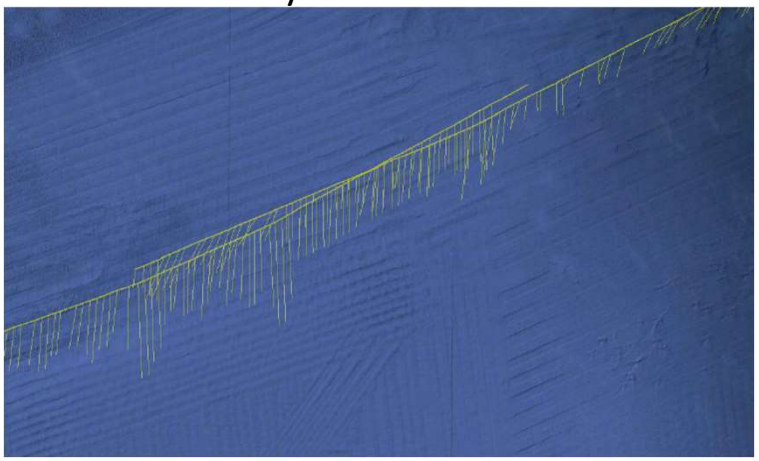
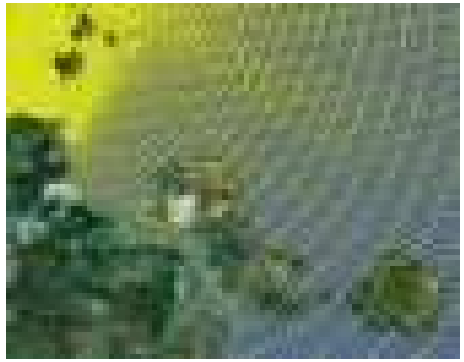
Raw AIS messages

Surface Currents from AIS

Overlapping trajectories reduce error and uncertainty of surface currents



Multiple vessels within computational cell reduce error and uncertainty



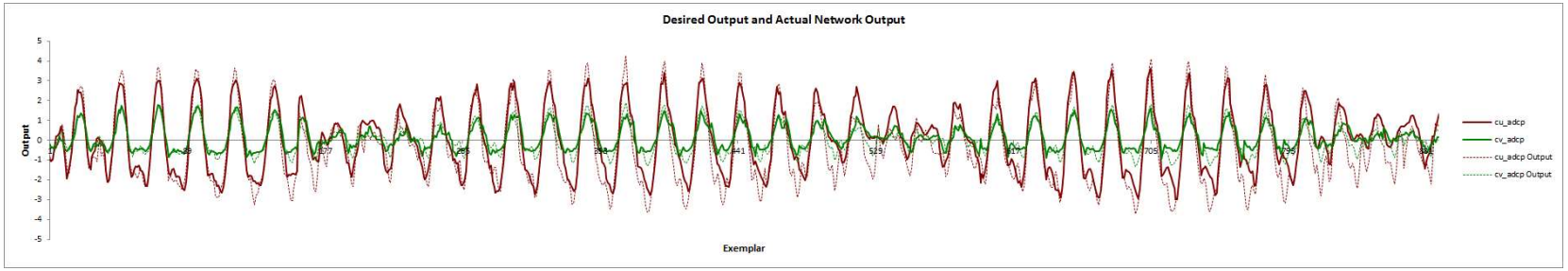
Gusong ADCP

AIS derived currents vs ADCP Observations

hourly data between March 14, 2017 14:00 and June 19, 2016 16:00

Gusong AIS data and Tidal Constituents as inputs

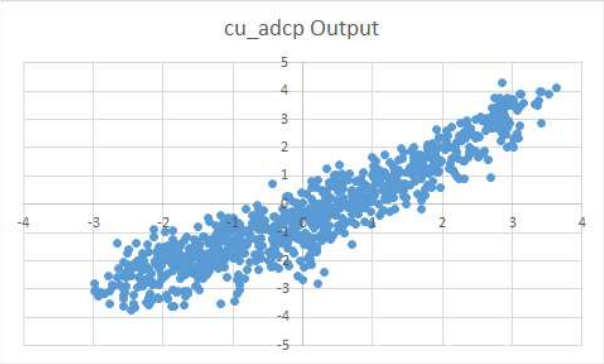
(out of sample test period: May 24, 2017 – July 31, 2017)

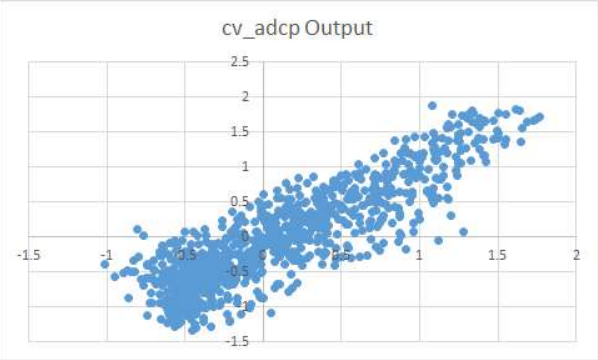


Performance	*cu_adcp*	*cv_adcp*
RMSE	0.788923387	0.361661089
NRMSE	0.137611701	0.147847436
MAE	0.614890853	0.281181943
Min Abs Error	3.8508E-05	0.000887763
Max Abs Error	2.991904153	1.214060269
r	0.926597271	0.876333929

Gusong
AIS data and Tidal Constituents as inputs

(out of sample test period: May 24, 2017 – July 31, 2017)





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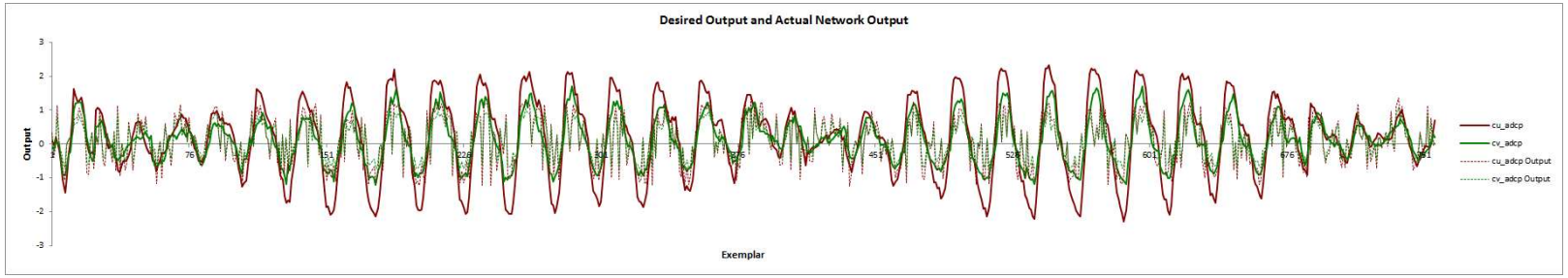
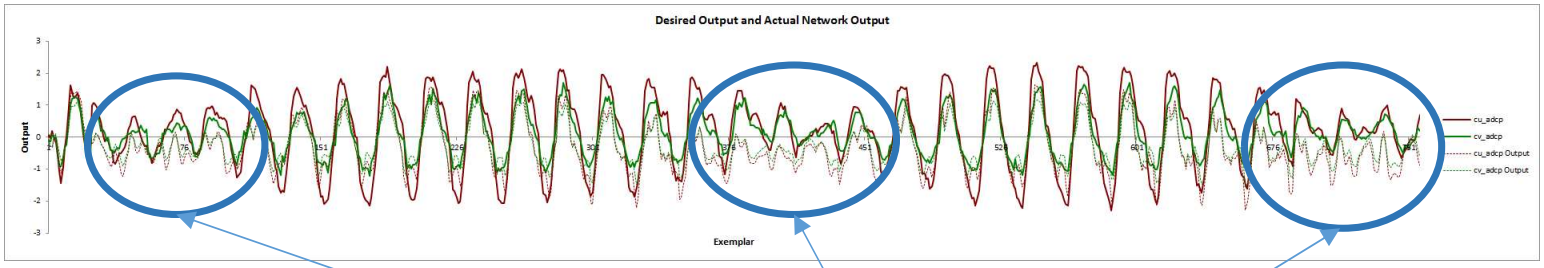
Banyan Beacon
AIS as the only inputs
(out of sample test period: May 24, 2017 – July 31, 2017)



Performance	*cu_adcp*	*cv_adcp*
RMSE	0.836770508	0.510765261
NRMSE	0.191725681	0.15138711
MAE	0.641437834	0.387127342
Min Abs Error	0.000593128	0.001107938
Max Abs Error	3.054024041	2.010778689
r	0.671913839	0.659261042

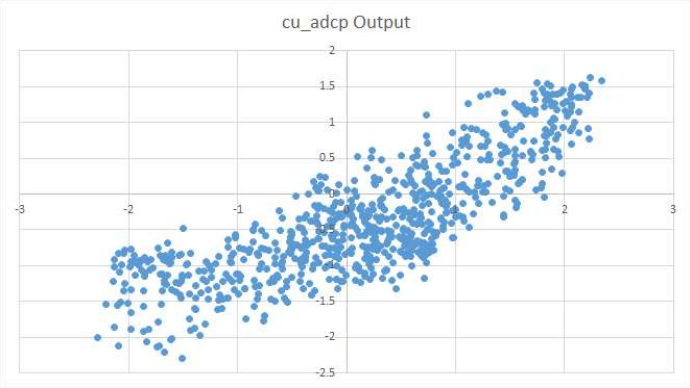
Banyan Beacon AIS data and Tidal Constituents as inputs

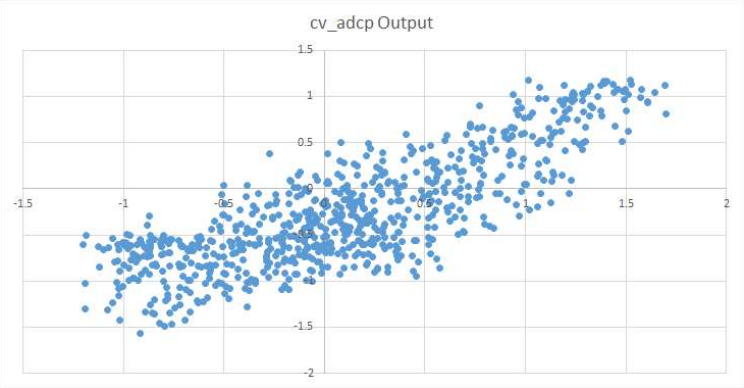
(out of sample test period: May 24, 2017 – July 31, 2017)



Performance	*cu_adcp*	*cv_adcp*
RMSE	0.826199976	0.542396373
NRMSE	0.189303699	0.160762342
MAE	0.702207967	0.448761405
Min Abs Error	0.002430004	0.001260911
Max Abs Error	1.882363894	1.435863182
r	0.826798846	0.814947272

Banyan Beacon
AIS data and Tidal Constituents as inputs
(out of sample test period: May 24, 2017 – July 31, 2017)





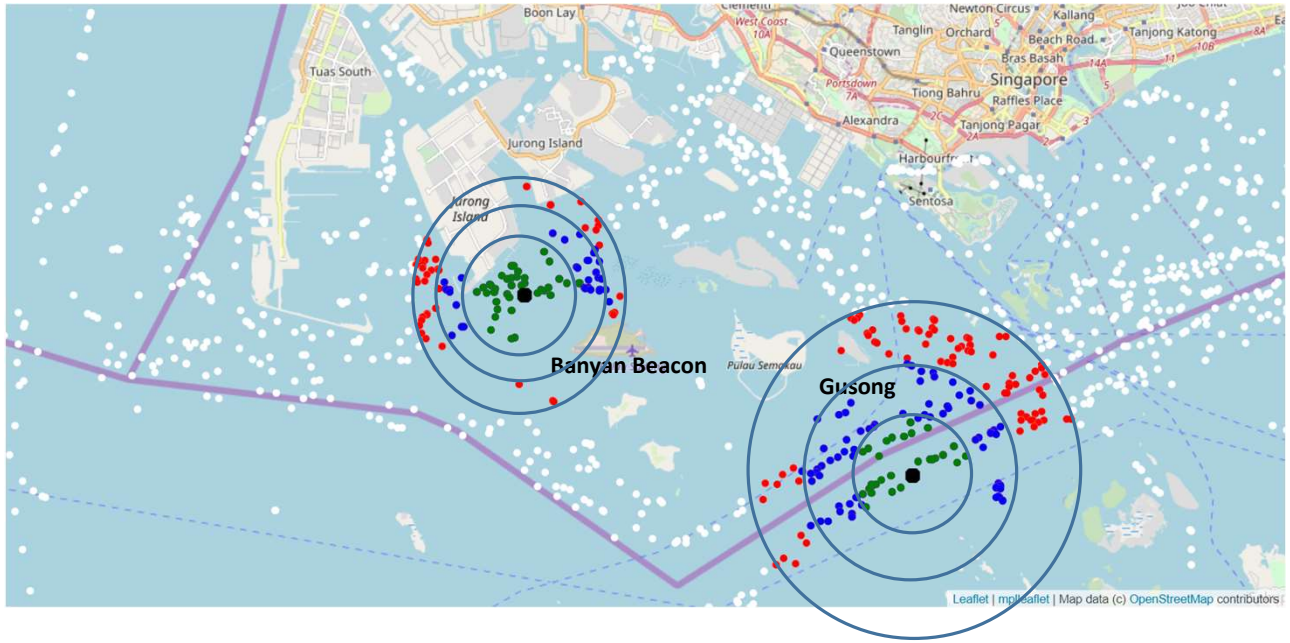
Performance	*cu_adcp*	*cv_adcp*
RMSE	0.905192135	0.591899841
NRMSE	0.207402838	0.17543481
MAE	0.749783592	0.497895892
Min Abs Error	0.000425132	0.00087303
Max Abs Error	2.274965446	1.430509447
r	0.841467116	0.872818795

Gusong and Banyan Beacon ADCP

Algorithm Refinements: AIS derived currents vs ADCP Observations

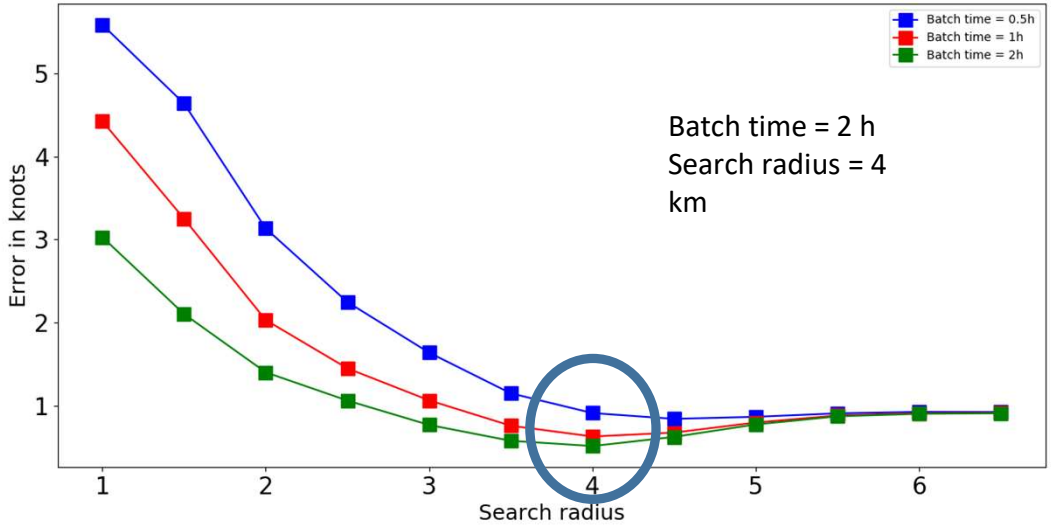
hourly data between March 14, 2017 14:00 and June 19, 2016 16:00

Algorithmic Refinements
Radius based ship selection



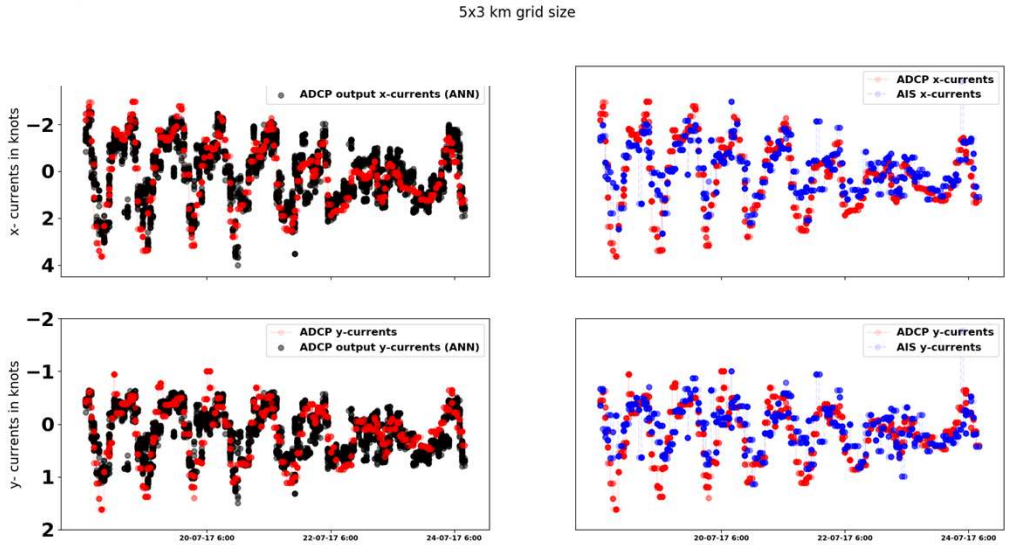
* Locations are moved slightly to allow better selection of vessels

Computing optimal search distance and time aggregation (Gusong ADCP)



Banyan Beacon
Adaptive Radius Based vessel selection (validation data)

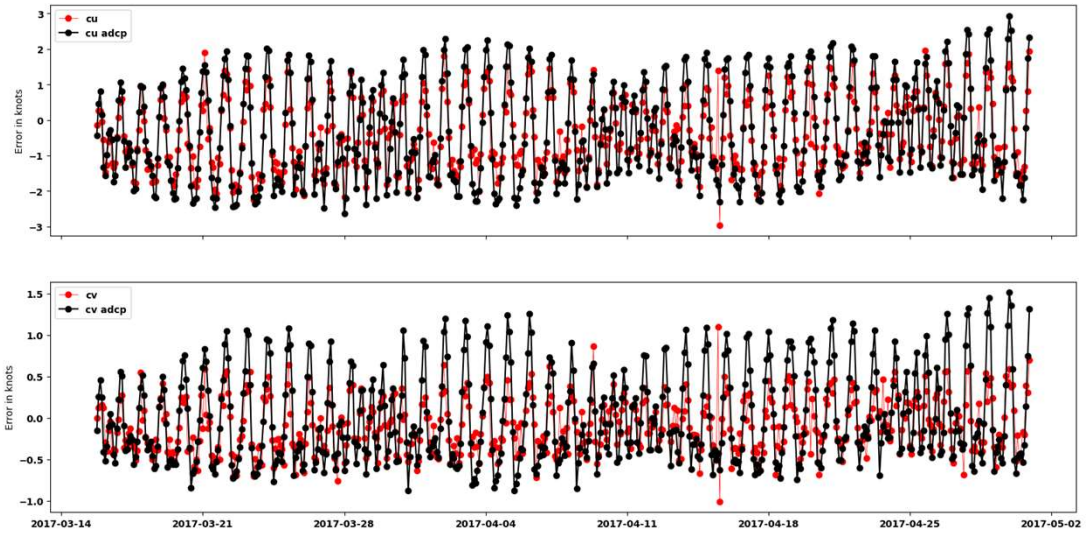
Performance	Surface_x_currents_adcp	Surface_y_currents_adcp
RMSE	0.578331284	0.259786214
NRMSE	0.095907459	0.009599736
MAE	0.416348961	0.206893833
Min Abs Error	0.000239331	4.38E-05
Max Abs Error	1.466300729	0.94092846
r	0.920814343	0.869661262



After postprocessing using Machine Learning:
Good phase, improved magnitude

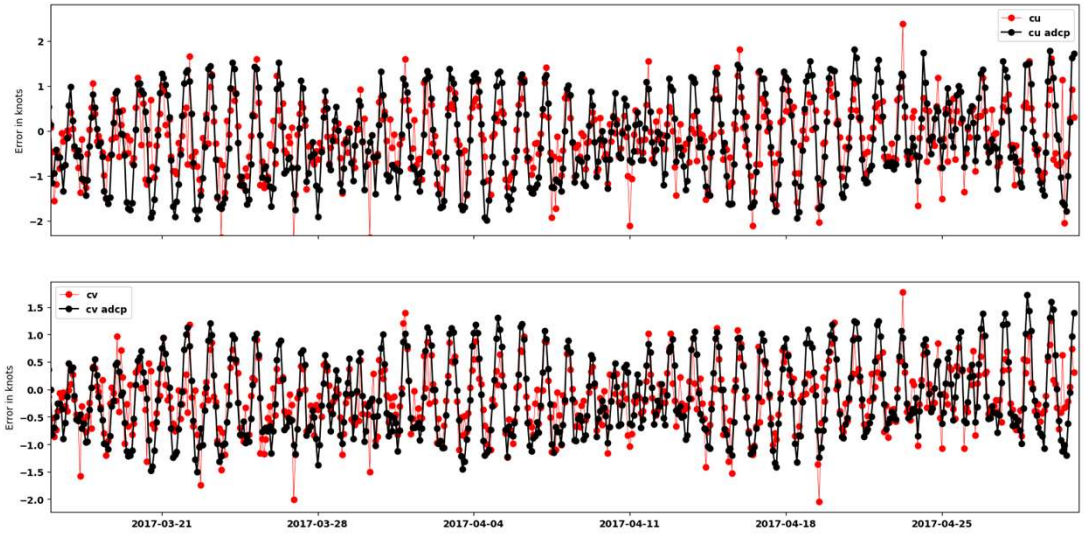
Initial Estimate:
Good trade off

Gusong data time series



Batch time = 2 h
Search radius = 4 km

Banyan Beacon data time series

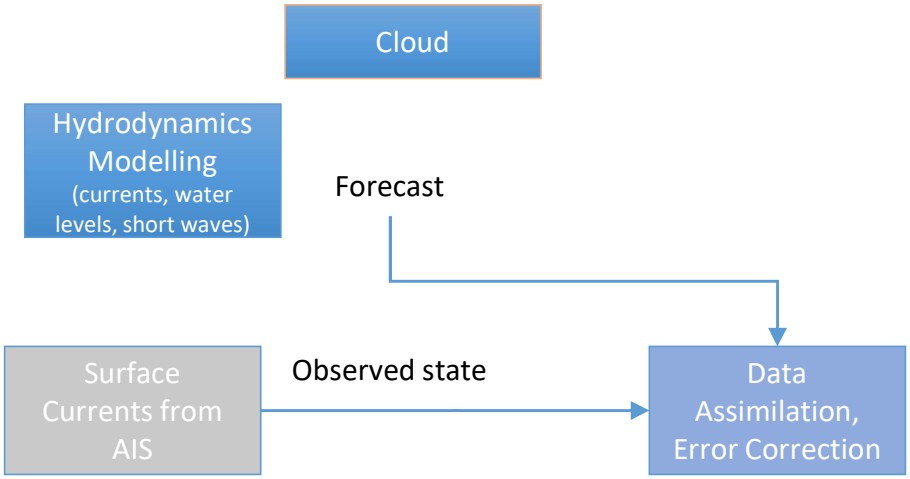


Batch time = 2 h
Search radius = 2 km

Hydrodynamic model

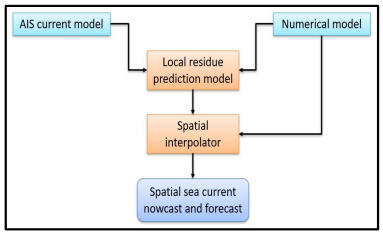
- Hydrodynamic model provides operational **forecast** of current flows
- It also provides the 3rd dimension (vertical flow velocity distribution)
- Usually well calibrated against water levels
- Currents direction and intensity validated only against (few!) ADCP observations
- Now, we have means to access thousands of observations collected in real time derived from AIS
- Unprecedented accuracy

Data Assimilation

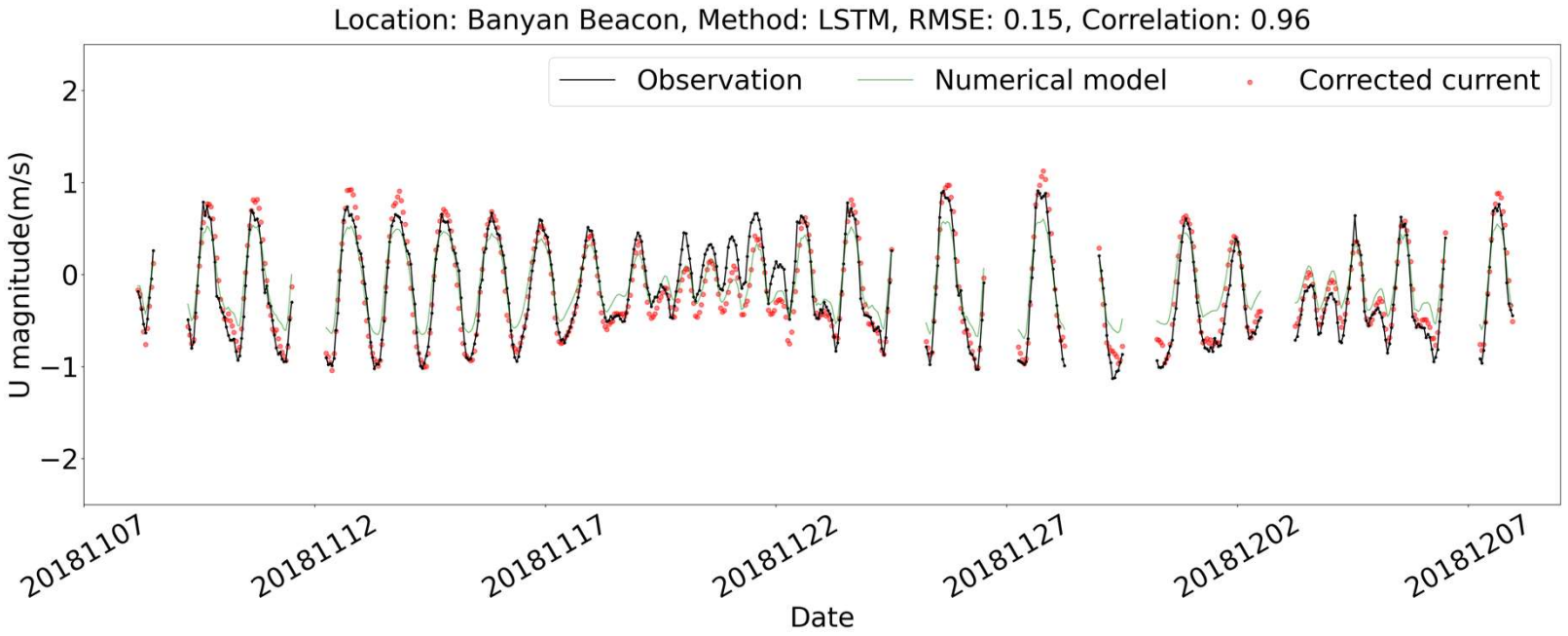


Forecasted currents from hydrodynamics
+
Surface currents from AIS

= significantly improved current forecast over entire entire port limits

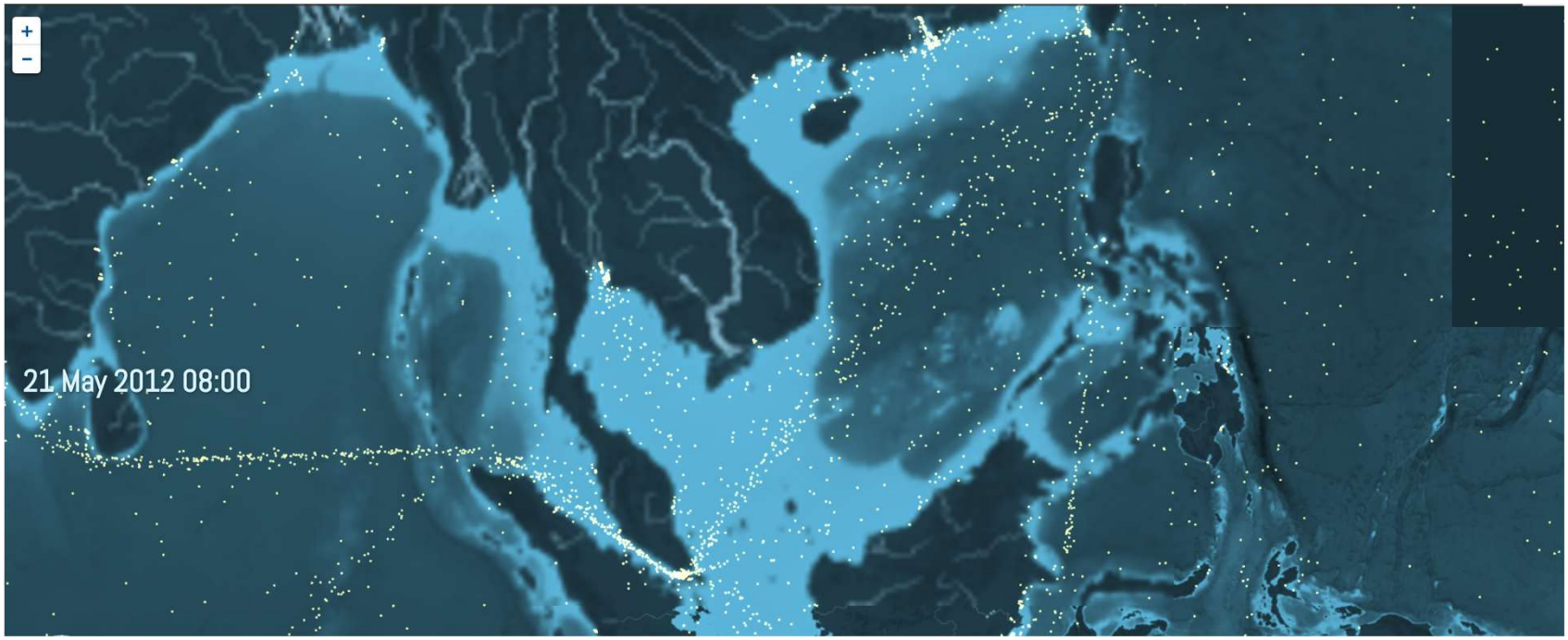


Blended AIS + Hydrodynamic Model at a validation site (Banyan Beacon)

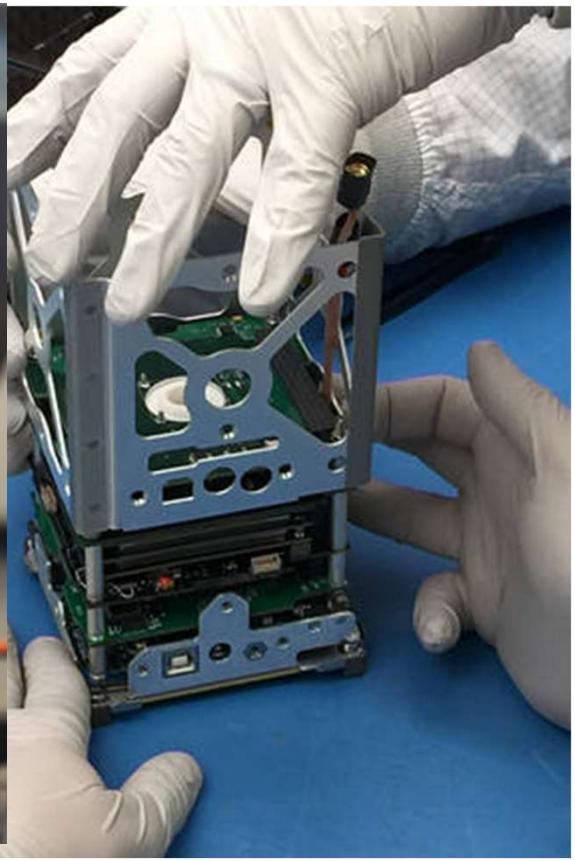


Deep Oceans

Snapshot of AIS messages taken off vessels in South China Sea and Indian Ocean

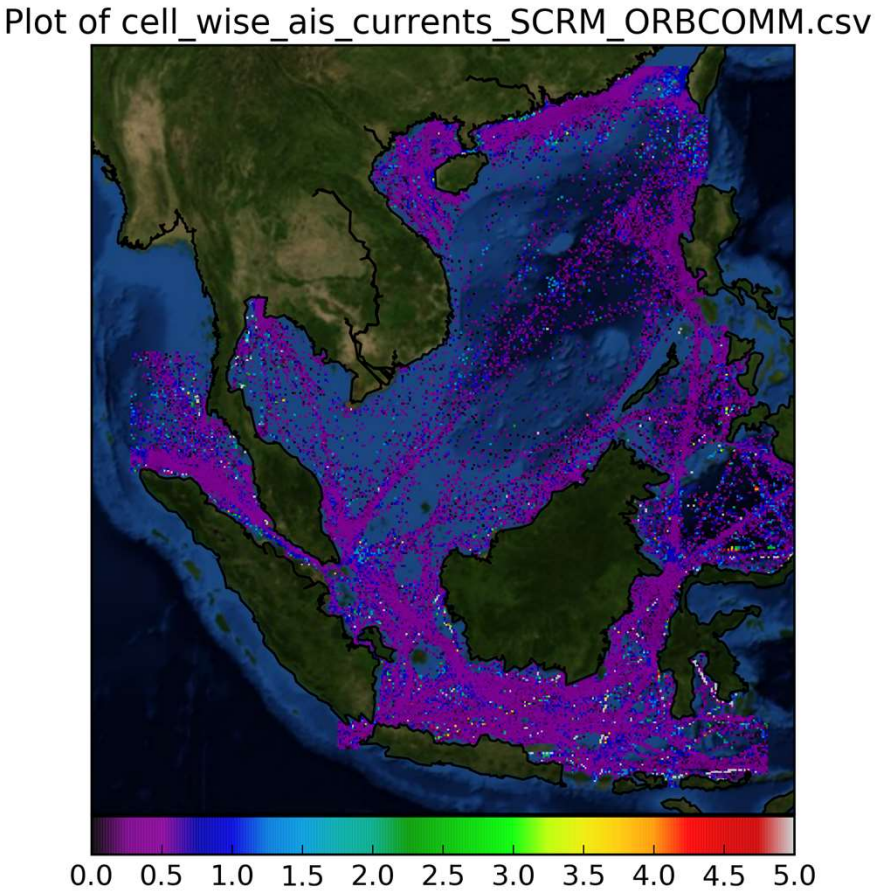


CubeSat

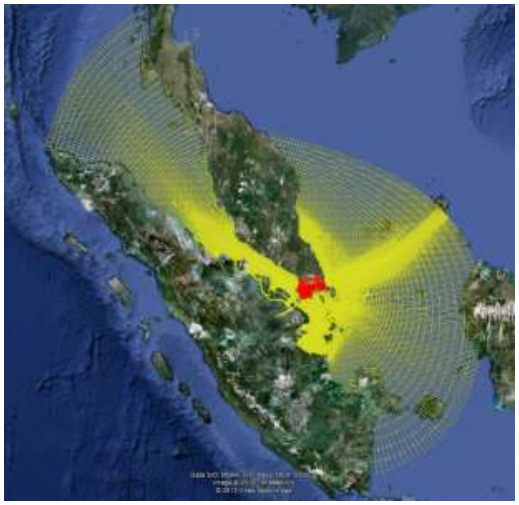


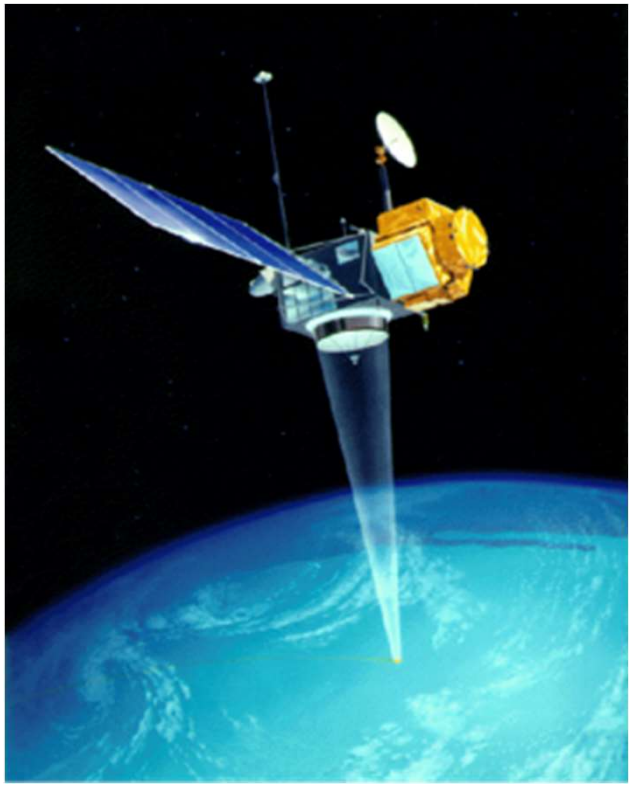
Currents derived from AIS Data

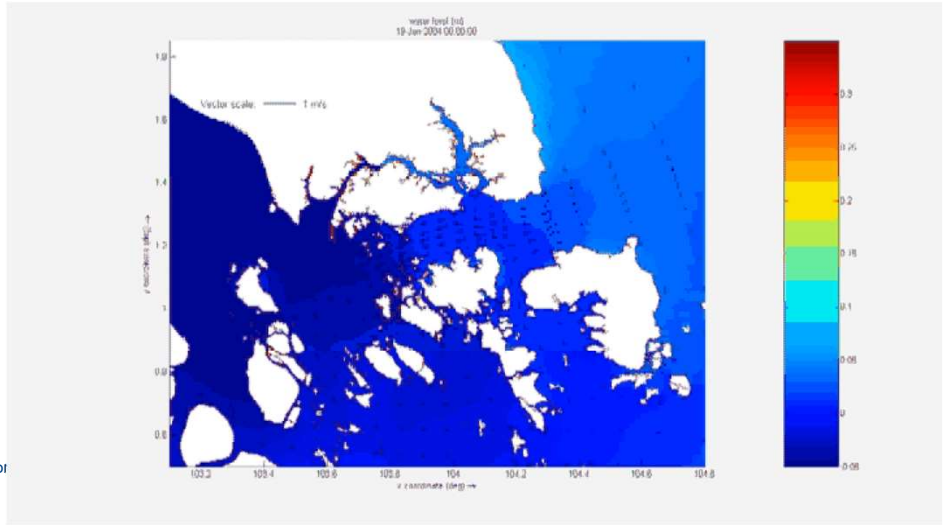
(80 GB per month)



Data + Model Blending

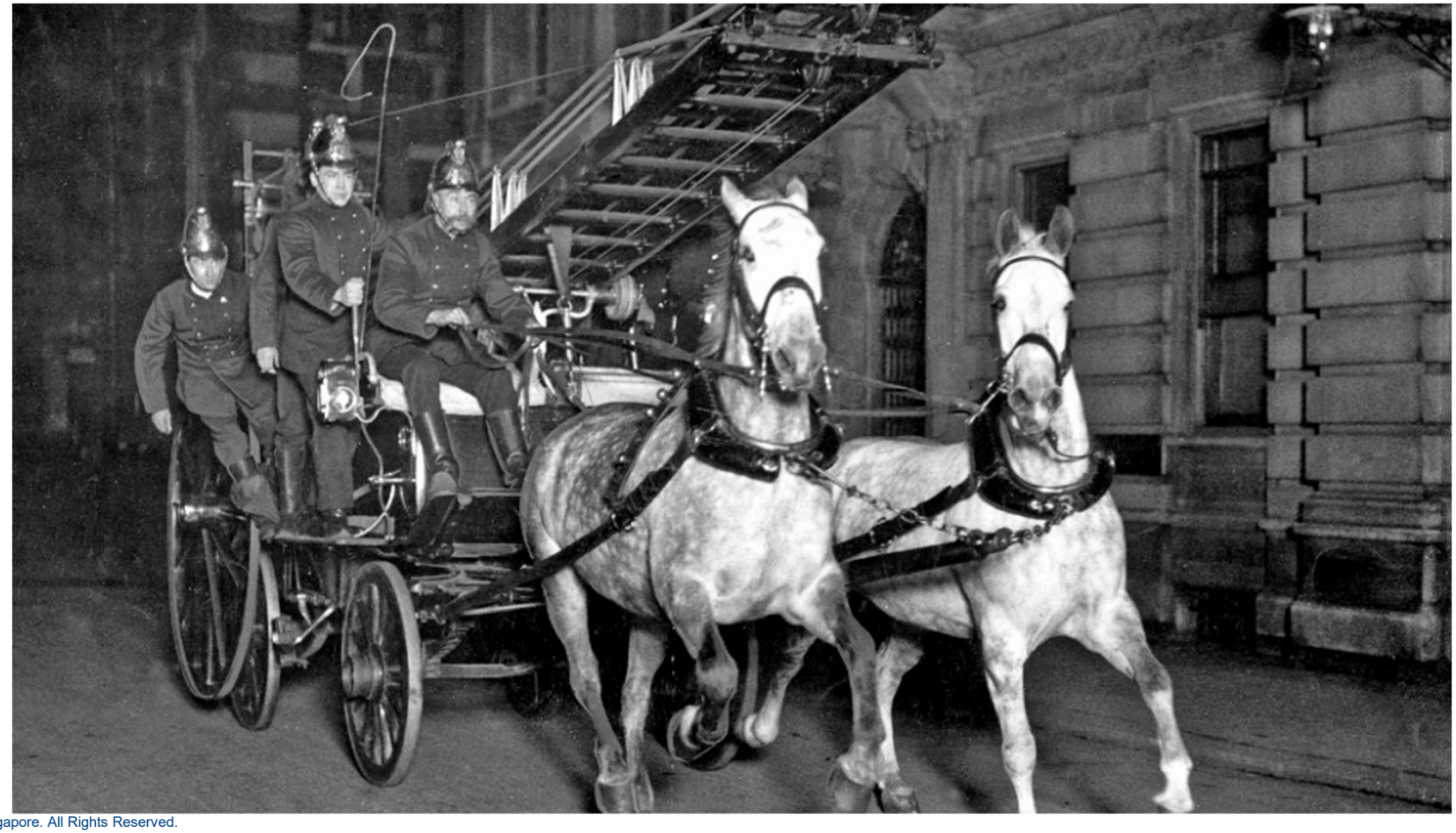






Will Humans Go Way of Horses?

Wassily Leontief, 1983



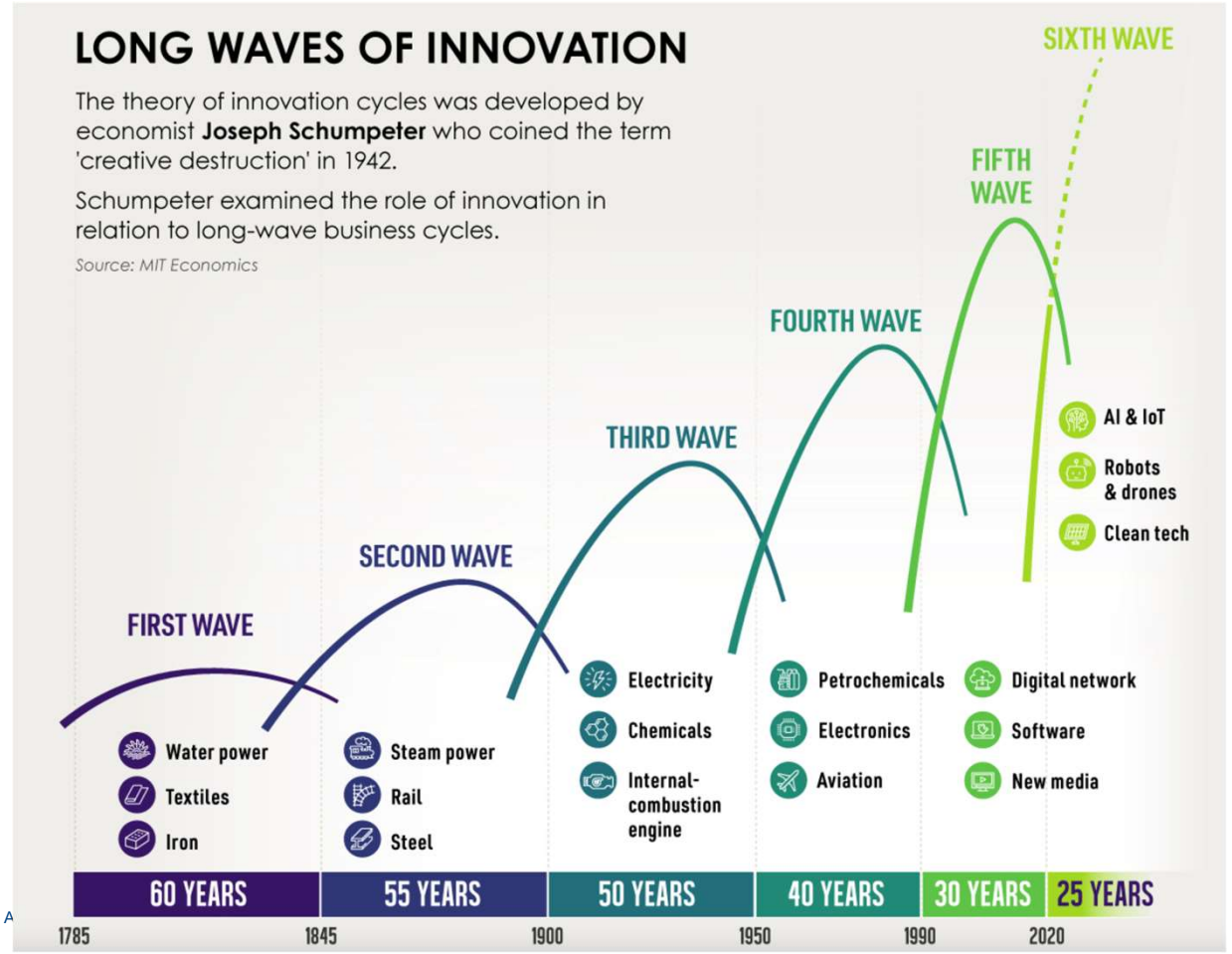
Extended Intelligence

There is a deep fear that human jobs will be replaced by AI.

Rather than racing against the machines, the aim should be to show that a human-AI combination will perform better than humans and AI working alone.

No man is better than a machine for some task

No machine is better than a man with a machine



THANK YOU