MOOS IvP Helm Based Simulations of Collision Avoidance by an Autonomous Surface Craft Performing Repeat-Transect Oceanographic Surveys

Michael A. Filimon
Dept. of Ocean Engineering

Daniel L. Codiga
Grad. School of Oceanography

University of Rhode Island

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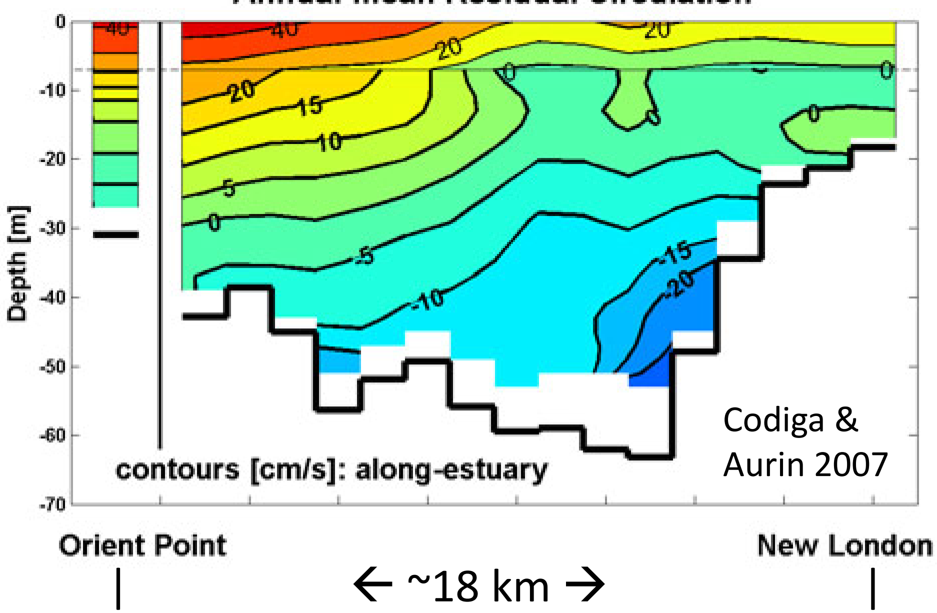
Today’s talk

- Potential for autonomous surface crafts (ASCs) to advance coastal/estuarine oceanography
- Design of the SCOAP (Surveying Coastal Ocean Autonomous Profiler) ASC
- MOOS IvP Helm simulations of collision avoidance (CA) during repeat-transect oceanographic sampling
- Initial examples of CA based on COLREGS (USCG 1972 Collision Avoidance Regulations)

Key field sampling GOALS in coastal & estuarine oceanography

- **To directly measure material transport**
  - salty/fresh water; harmful algal blooms; suspended sediments; oil spills; etc

Eastern Long Island Sound
Annual-mean Residual Circulation



- Measure <u>currents</u> *and* <u>concentrations</u>
- Capture **spatial** structure and variability
  - Horizontal: Resolution 1-2 km; cover 10s of km
  - Vertical: Sample from surface to seafloor
- Capture **temporal** variability
  - Separate tidal and longer-timescale variations
  - Persistence of **~weeks**!

Field sampling CHALLENGES in coastal & estuarine oceanography

- Strong currents (typically tidal)
- Shallow and variable bathymetry
- Irregular coastlines
- Heavy commercial, recreational, and fishing vessel traffic
- Fixed fishing gear

Traditional platforms

- Research vessel surveys
  - ***Good spatial coverage*** BUT …
  - ***Insufficient temporal coverage*** (too costly to operate for long durations)

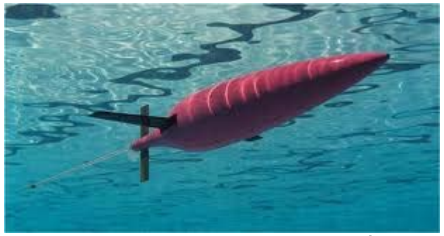
- Moorings
  - ***Good temporal coverage*** BUT …
  - ***Insufficient spatial coverage*** (too costly for high numbers; also unsafe/unpermitted to litter heavily trafficked waterways with moorings)

Classes of newer mobile platforms

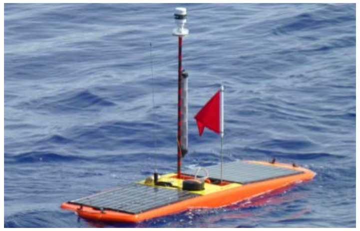
e.g., REMUS (Hydroid)

- **AUVs**
  - Good propulsion
  - Insufficient durations

- **Subsurface gliders**
  - Good persistence
  - Insufficient propulsion to stem currents



e.g., Seaglider (iRobot/Kongsberg)



Wave Glider (Liquid Robotics)

- **Wave-driven ASCs**
  - Excellent persistence
  - Propulsion irregular; marginal to stem currents

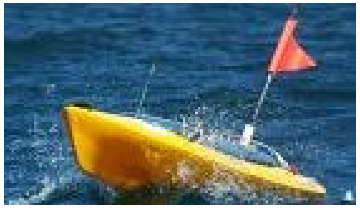
ALL THREE:

- **Require miniaturized/low-power sensors**
- **Not well suited for water depths of ~5-10 m or less**

Examples of ASCs for shallow water

- Q-Boat (OceanScience)

- SCOUT (Maribotics)



- Kingfisher (Clearpath)

- Proven: hours-days durations; rivers, protected harbors
- **Not designed for:**
  - **Stability in open coastal water sea states**
  - **Persistence of more than hours (~days max)**

Larger Catamaran ASC "SCOAP"

- Customized SeaRobotics design guided by URI
- Sufficient size (11m length, 5m beam) for:
  - Stability in sea states of open coastal waters
  - Hosting winch system for vertical profiling
  - Battery bank, diesel generator, large fuel tanks
  - Mounting USCG-required lighting (2m-high mast)
- Ready for very shallow water
- Communications to shore via LOS RF (remote control) or Iridium (supervised autonomy)

(Cont.)

- Sufficient energy reserves for:
  - Propulsion (electric thrusters) to stem currents (8 knots peak)
  - ~Weeks-long persistence at average speed 5 knots
  - “Everyday” (NOT miniaturized/low-power) sensors
- Vessel detection sensors for collision avoidance
  - Automatic Identification System (AIS): in place
  - For non-AIS vessels: Broadband radar next goal; potentially visual/thermal imagery as well
- Oceanographic sensors
  - Current profiler & meteo in place; winching system next goal
- Cost-effective compared to research vessel

(More info at: http://www.po.gso.uri.edu/~codiga/scoap/SCOAP.htm)

Repeat-transect oceanographic sampling: SCOAP-feasible

- ***Transect: ~20 km long, stations every ~2km***
  - ***~5 knots avg speed, 10 min each station***
  - ***sample at all stations ~4 times/day***
- At stations: surface-to-bottom vertical profiles
  - Currents: acoustic Doppler current profiler (ADCP)
  - Water properties: winched sensor package
- **Operational advantages of repeat transects:**
  - "Moving buoy" concept: suitable for approval by Coast Guard (~as for oceanographic moorings)
  - ASC always on same transect, other vessels informed (via, e.g., CG Notice to Mariners)

Main remaining impediment:
Safe on-board collision avoidance system

- Must be overcome before long-term ASC deployments can be realized
- Suitable challenge for MOOS IvP Helm (MIH) to solve
- MIH in backseat/payload role on SCOAP
- Motivates MIH simulations presented here

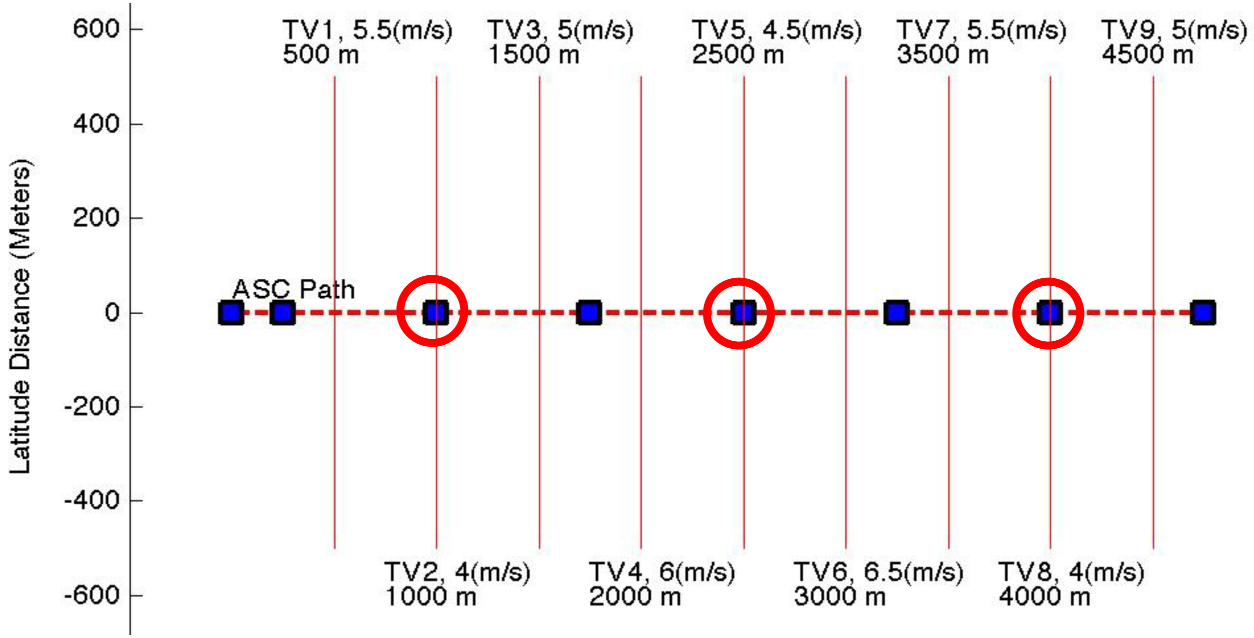
Long-term goal:

- COLREGS-based collision avoidance (CA)
- Inputs from on-board sensors (AIS, radar, visual/thermal imagery)

Configuration of 24-hr simulations

- **ASC travels East-West** at 2.5 m/s (~5 knots)
  - 8 stations each 750 m apart; 10 min stop at each
- **9 Traffic Vessels moving North-South**
  - Transects 500 m apart; speeds 4-6.5 m/s
  - 3 traffic vessels ○ are aligned with ASC stations

(Plan view map)



Two CA Algorithms

- **Neutral: "BHV_AvoidCollision"** (in standard MIH release)
  - Vehicle alters course in most convenient direction
- **COLREGS: "BHV_AvdColregs"**
  - Currently under development by Benjamin & Woerner
  - Vehicle alters course asymmetrically based on USCG 1972 Collision Avoidance Regulations (COLREGS):

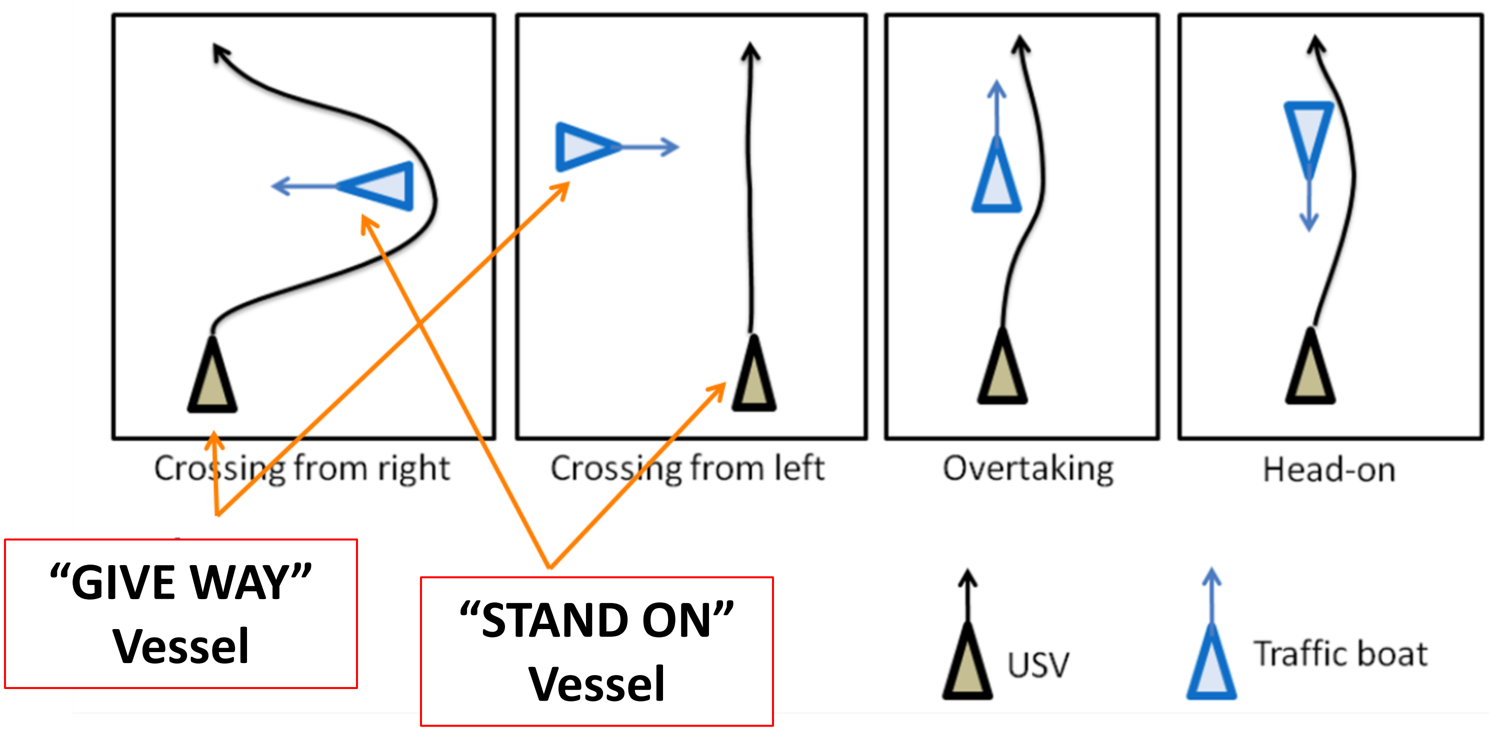


Fig. modified from Kuwata et al., 2011

Runs Presented Today

	Type of CA	
Run name	**ASC**	**Traffic vessels**
BASE :	Neutral	**None***
Traffic CA :	Neutral	Neutral
COLREGS :	COLREGS	**None***

* "Traffic vessel not performing CA" is important, challenging case: an inattentive recreational boater or unmonitored auto-pilot

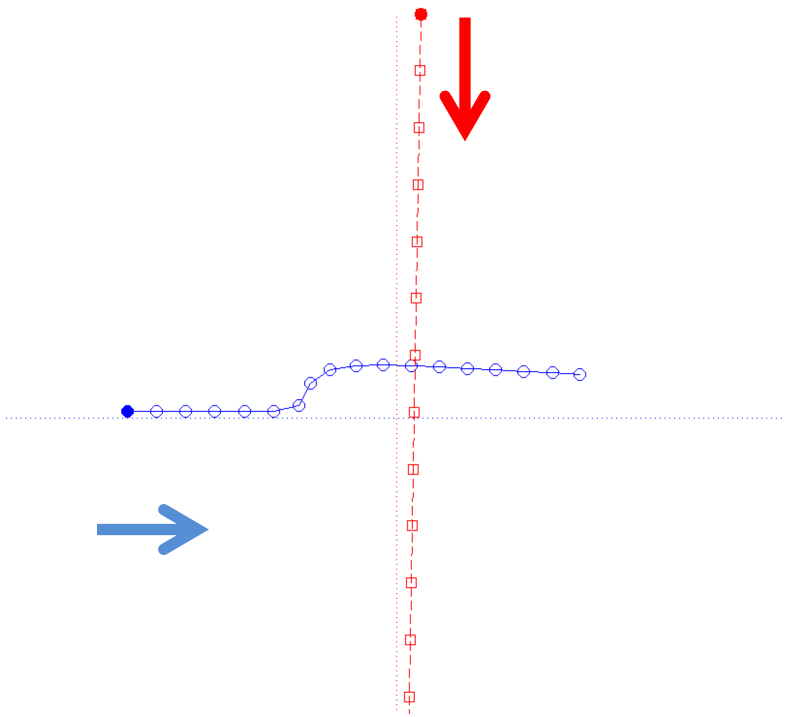
Results: BASE & Traffic CA

- BASE: three types of ASC maneuvers
  - *Large deflection*
  - *Course reversal*
  - *Leave/return to station-keep*
- Traffic CA: two types of ASC maneuvers
  - *Modest deflection*
  - *Modest leave/return to station-keep*
  - Both less dramatic than BASE, as expected; *course reversal* not seen

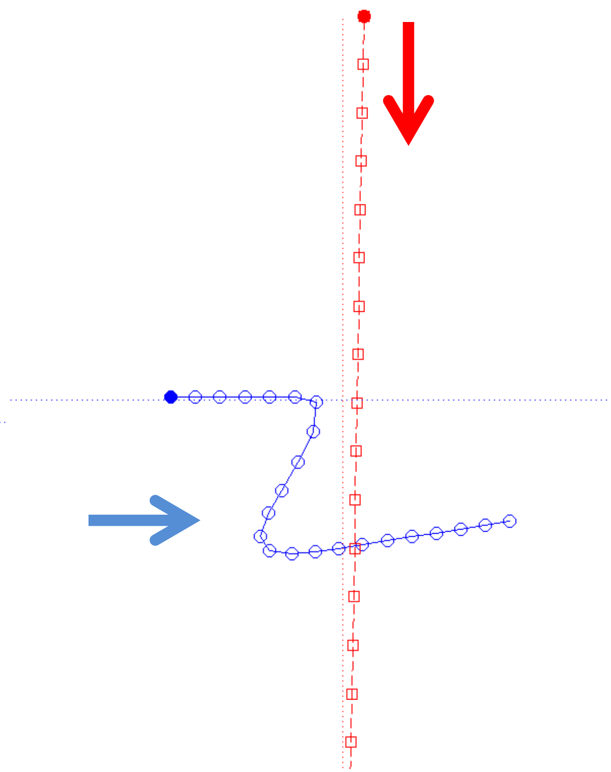
See: Filimon, Michael A., 2013. "Site Planning and On-Board Collision Avoidance Software to Optimize Autonomous Surface Craft Surveys" University of Rhode Island, M.S. Thesis. http://digitalcommons.uri.edu/theses/56

BASE: Large deflection, Traffic from left

Traffic vessel earlier



Traffic vessel later



Key: **ASC**

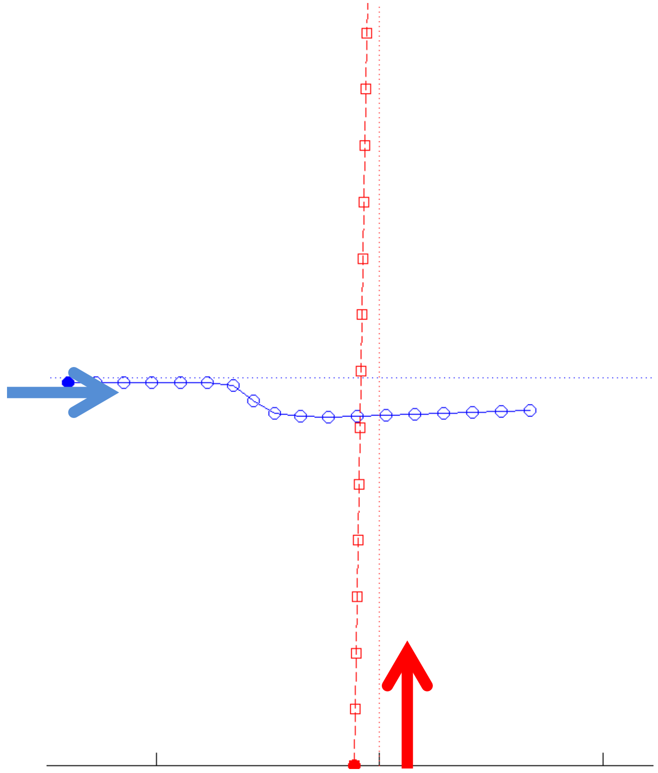
(Solid symbol =initial location)

Traffic vessel

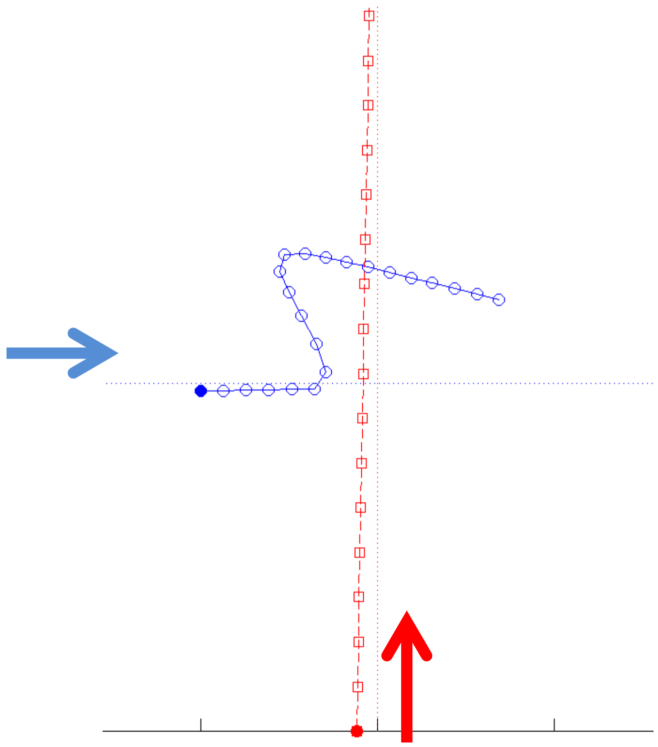
BASE: Large deflection, Traffic from right

- Very similar to prior case but reversed
  - No left/right asymmetry, as expected for *neutral*

Traffic vessel earlier

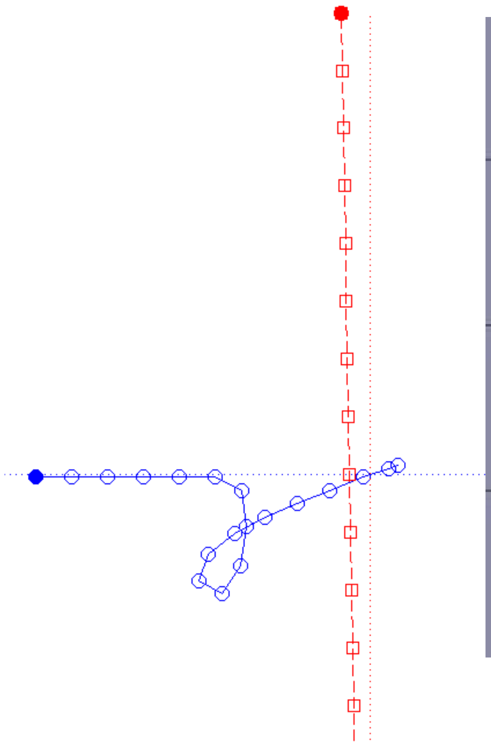


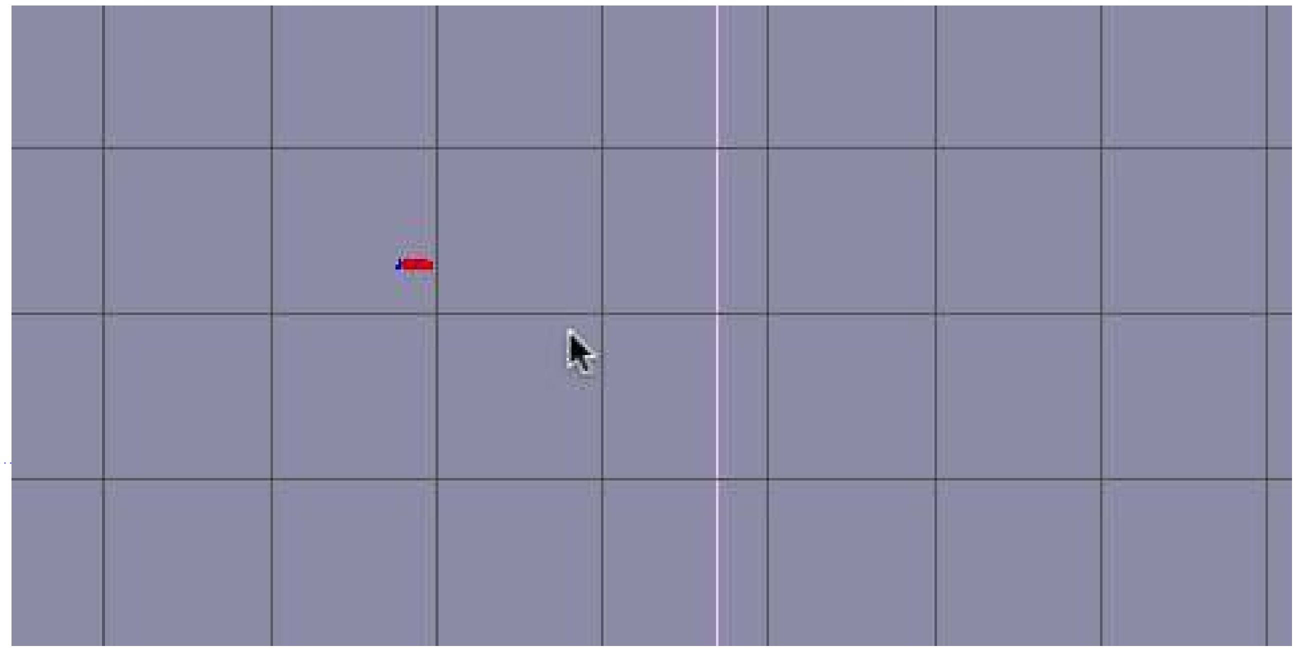
Traffic vessel later



BASE: Course reversal

“just between early and late”

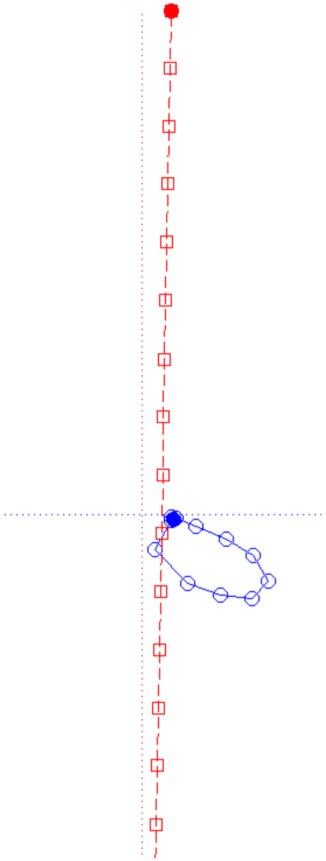




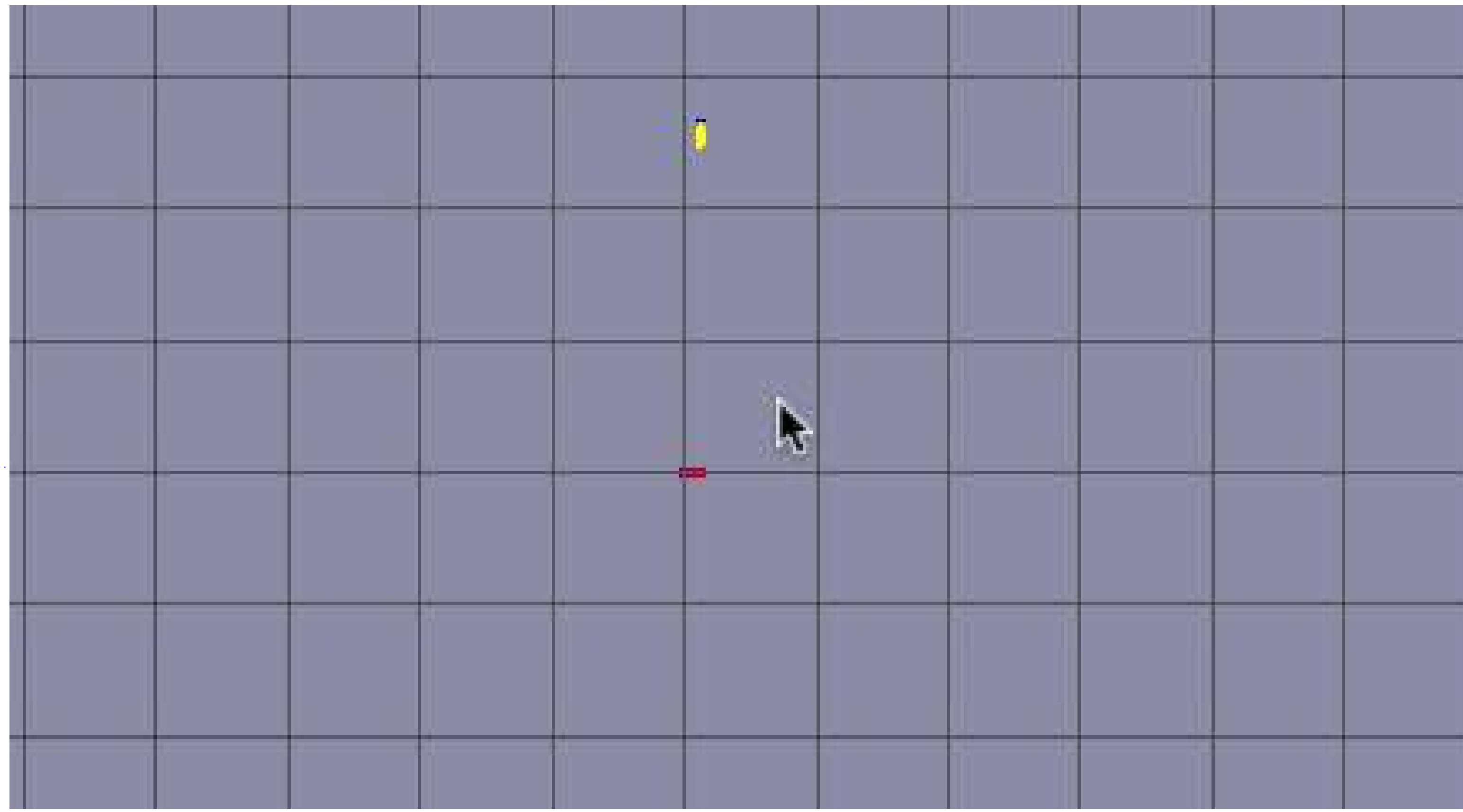
- Did not occur in Traffic CA nor COLREGS simulations

Leave/return to station keep

BASE:

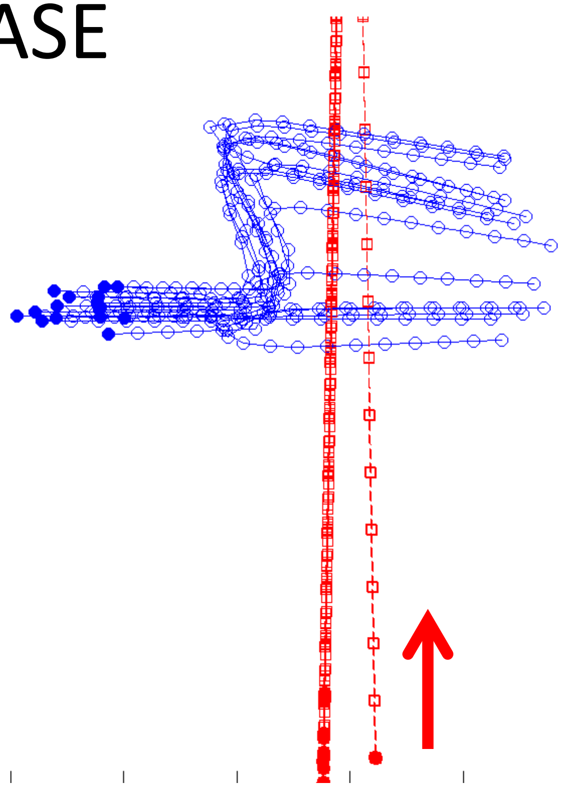


Traffic CA:

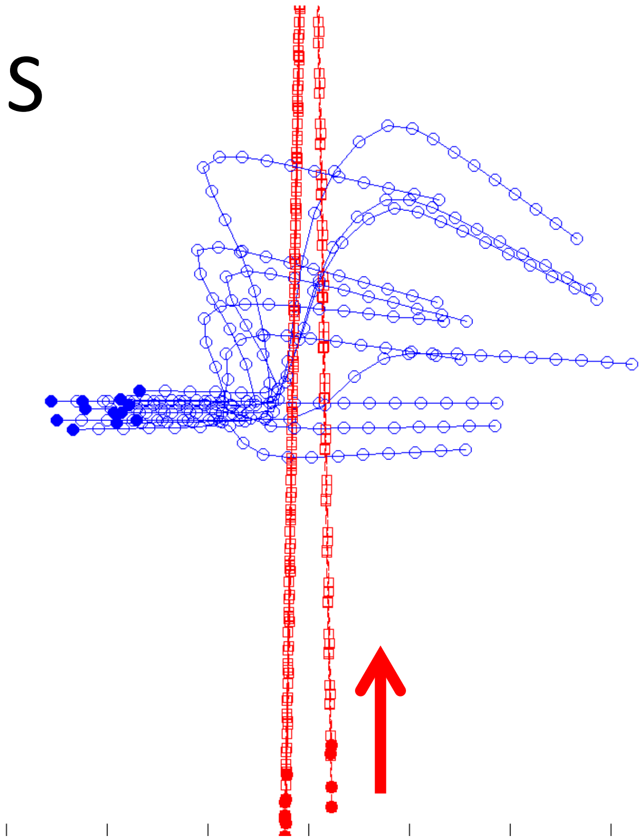


BASE vs COLREGS simulations: Traffic from right

BASE



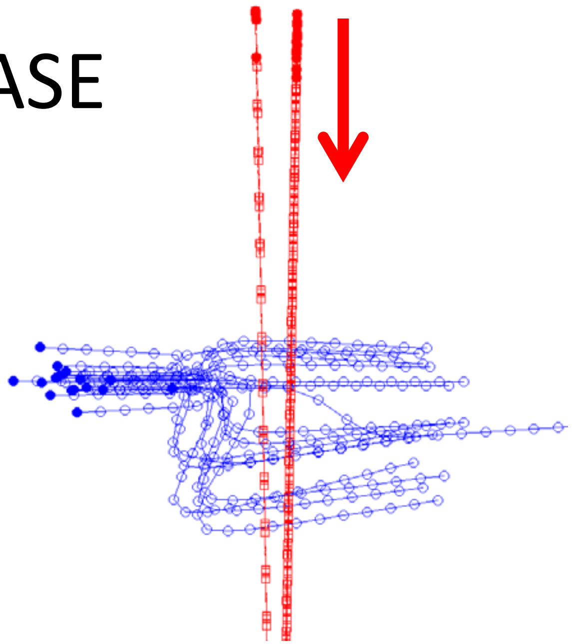
COLREGS



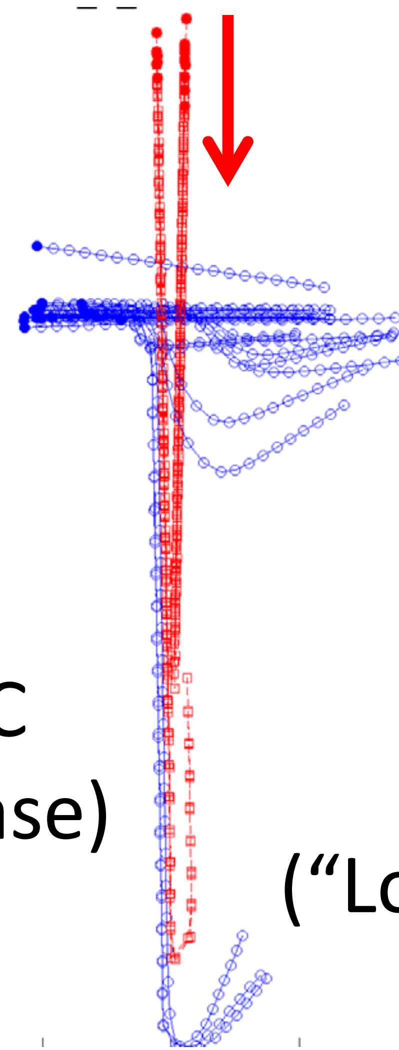
Generally similar: ASC is in GIVE WAY position

BASE vs COLREGS simulations: Traffic from left

BASE



COLREGS



Notably different: in COLREGS ASC takes STAND ON role (not BASE case)

(“Locking”)

“Locking”

- ASC and traffic vessel “lock” in place relative to each other
- Continued motion (e.g. along path of traffic vessel) for extended period before resolving
- Occurs in small percentage of encounters
- Occurs in all three simulations (BASE, Traffic CA, and COLREGS)
- Ways to ameliorate or eliminate it currently being investigated

Challenges / next steps

- ASC using *larger-radius* COLREGS CA together with *smaller-radius* neutral CA:
  – to avoid noncompliant vessel, when COLREGS actions alone will not avert collision
- When holding station, enable STAND ON actions regardless of direction ownship points
- Reduce/eliminate “locking”
- Detection of vessels only in limited range (akin to on-board sensor such as radar)

Conclusions

- For coastal/estuarine material transport measurements, repeat-transect sampling by a large catamaran ASC has many advantages
- A crucial need is on-board autonomy software for reliable COLREGS-based CA using sensor input (AIS, radar, visual/thermal imagery)
- MIH simulations demonstrate sophisticated capabilities of both neutral and COLREGS-based CA behaviors
- Further refinements are necessary but there is strong promise for success in field applications