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Waves and surface ocean circulation for least-carbon ship routes

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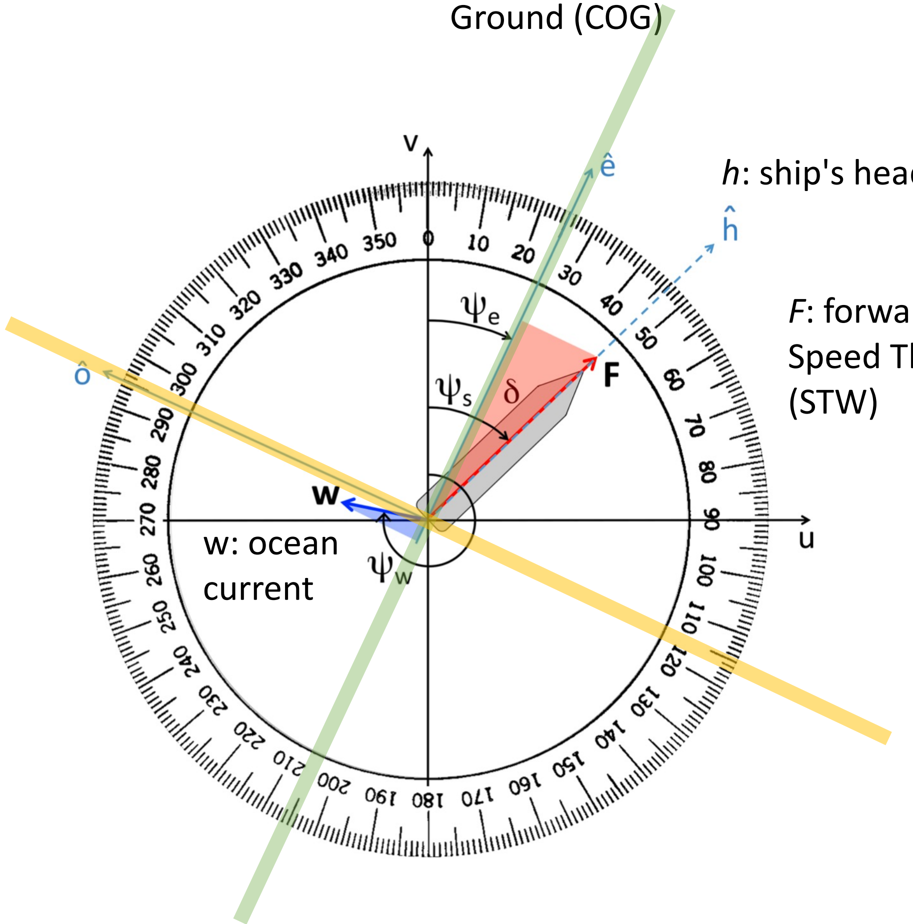
Motivations

- Decarbonisation of shipping
  - IMO initial strategy (to be reviewed in 2023)
  - EU fitfor55 legislative package (now in trilogue)
  - UN/COP26 - Clydebank declaration ("green corridors" for zero-carbon bunker)

- role of voyage optimization
  - applies to both newbuilds and retrofits
  - relevant also in medium- (pricing of emissions) and long-term (expensive fuels)

- need for open-source, community models
  - transparency, inter-comparisons, verification
  - connect to open-access datasets from both Copernicus, WOC, and others
  - easily add-on new features

Ocean currents and ship's speed



Linear superposition of velocities
& motion constrained along $\hat{e}$ ➔

$$SOG = w_{\parallel} + \sqrt{F^2 - w_{\perp}^2}$$

$w_{\perp}$

cross flow always detrimental to Speed Over Ground (SOG)

$w_{\parallel}$

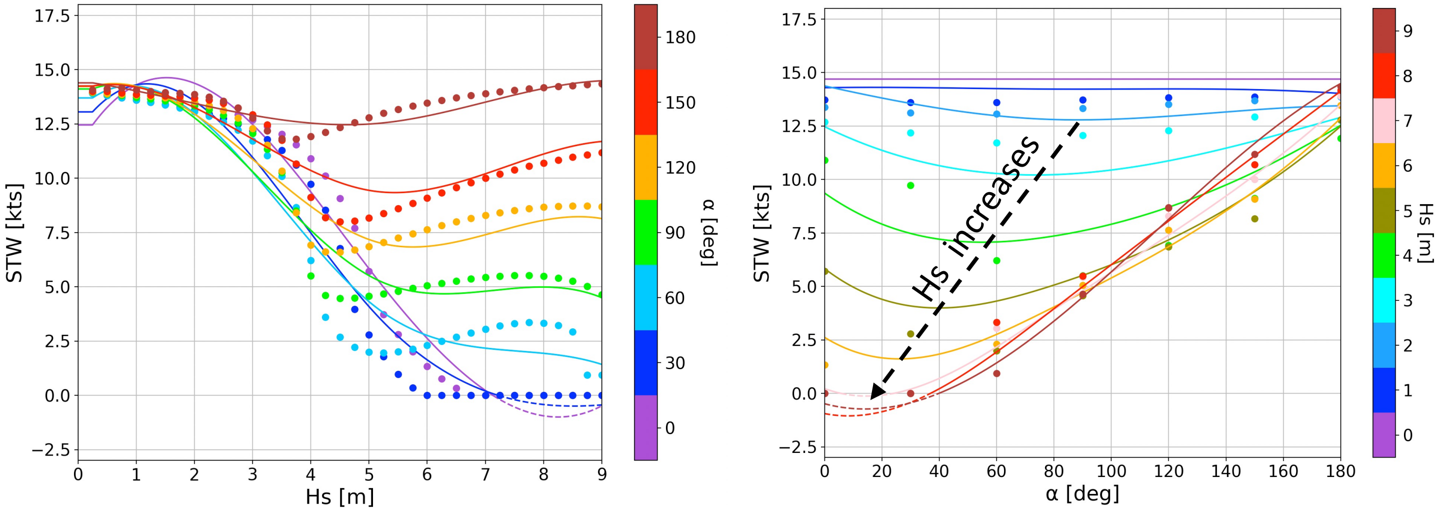
longitudinal flow can either increase or decrease SOG

Mannarini and Carelli, 2019, Geoscientific Model Development. https://doi.org/10.5194/gmd-12-3449-2019

Vessel Speed Trough Water (STW)

bulk carrier

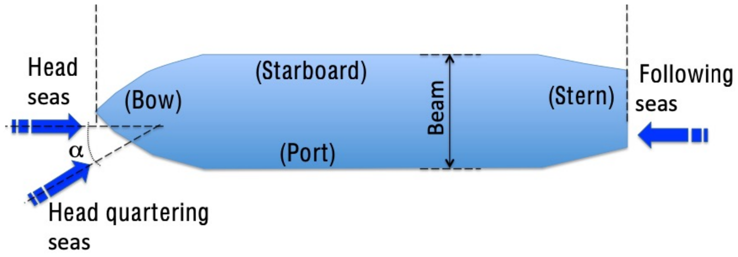
parameter	symbol	value	units
length between perpendiculars	L_{pp}	196	m
breadth	B	32	m
draught	T	13	m
block coefficient	C_B	0.83	-
propeller diameter	D_p	6.5	m
main engine power	P_{SMECR}	13,760	kW



modeling approach(*):

- calm water resistance (Holtrop&Mennen, 1982)
- wave-adde resistance (Lang et al, 2021)
- DPM method for power estimation (MAN, 2011)
- sustained speed (ITTC-7.5-02-07-02.8)

- for given α, speed loss initially increases with Hs
- peak drifts to smaller α as Hs increases

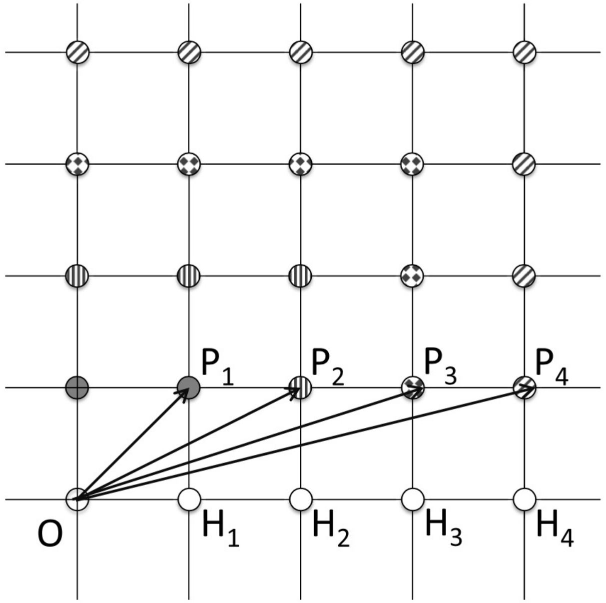


*) A. Salhi, 2023. Ship performance modeling for least-CO_2 routes, University of Bologna, PhD thesis - in preparation

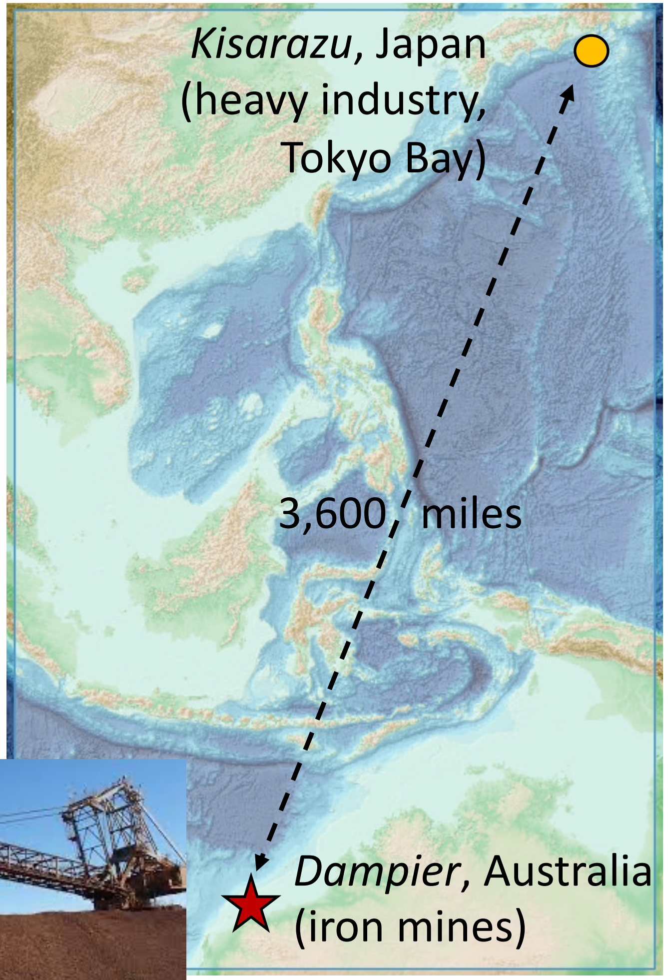
Mannarini et al, 2016, https://doi.org/10.5194/gmd-9-1597-2016

Static data – bathymetry, graph, ports

VISIR graph parameter	value	unit
grid size	1/12.5	deg
connectivity	4	
min depth	8	m
#nodes	102,097	
#edges	4,507,732	
#coast points	677,584	



graph with 4^{th} order connectivity

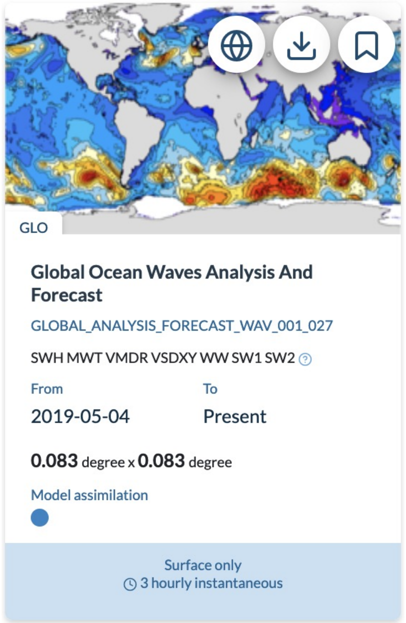


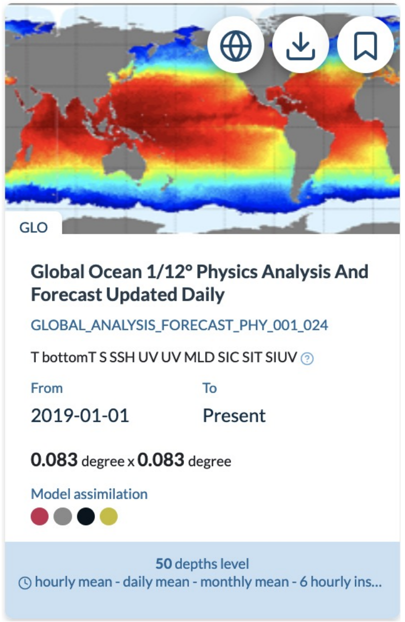
*) Mannarini, et al., IEEE Transactions on Intelligent Transportation Systems, https://doi.org/10.1109/TITS.2019.2935614

Dynamic data - Copernicus Marine Service

CMEMS spatial resolution:
1/12 degree
(=5 nmi in meridional direction)

Sea Wave Height





Sea Level
In-Situ TS Profiles
SST
Sea Ice Concentration and/or Thickness

global-analysis-forecast-wav-001-027

3-hourly instantaneous fields

VHM0, VHM0_DIR
(Spectral significant wave height)

global-analysis-forecast-phy-001-024-3dinst-uovo

6-hourly instantaneous fields

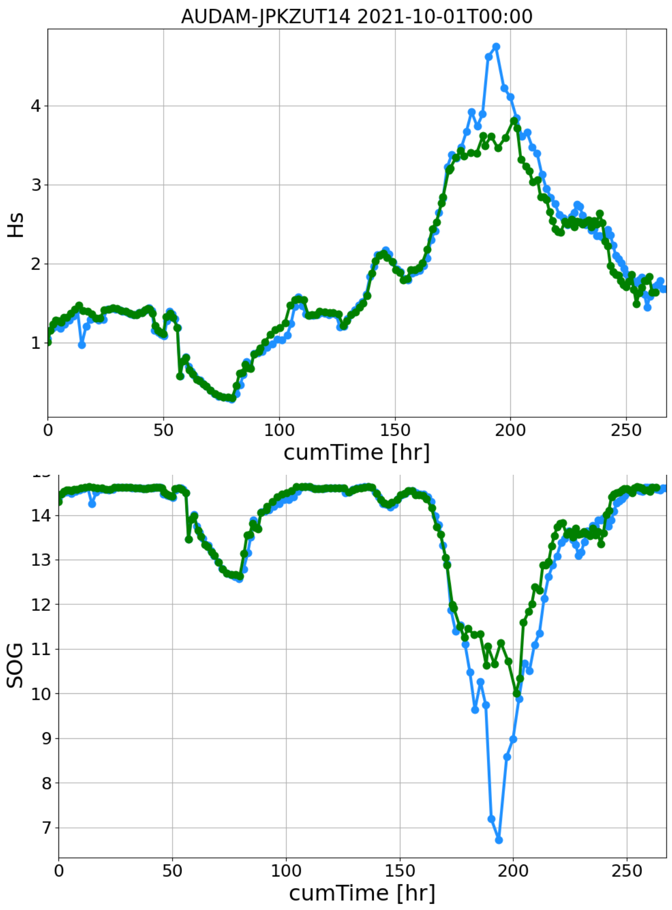
UO, VO
(ocean current velocity)

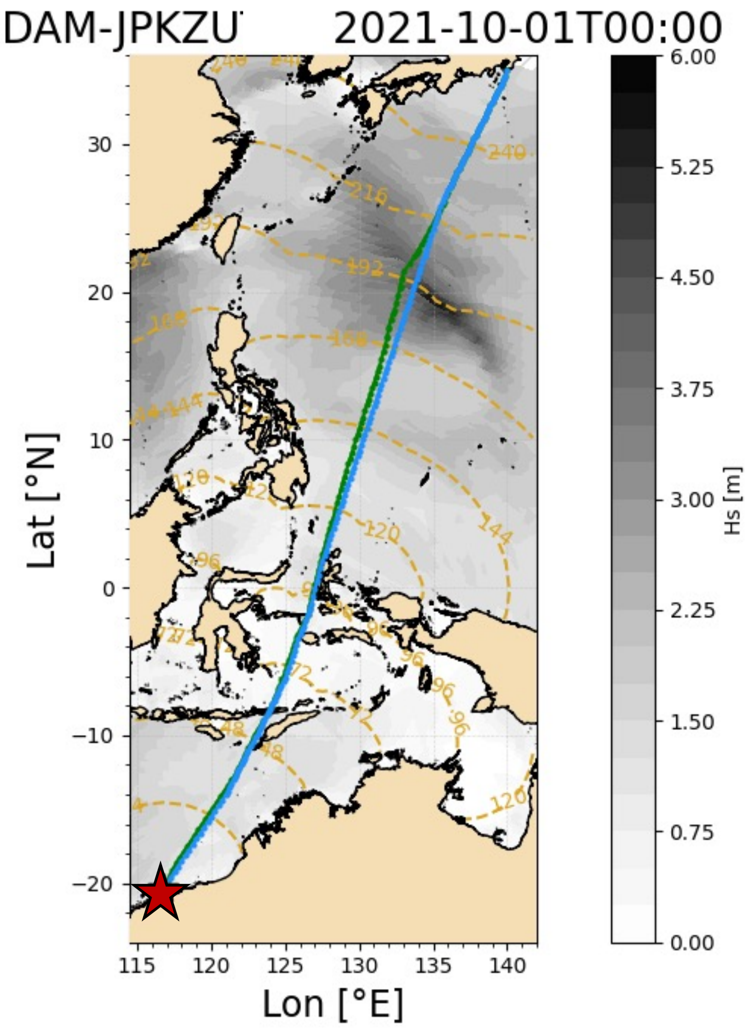
Results from VISIR-2 model

$<Hs>_{gdt}$ = 1.77m
$<|\alpha|>_{gdt}$ = 91.5°

Duration [hrs]: 262.7
dLength [%]: +0.2
CO_2 [t]: 477
dCO_2 [%]: -1.7

- wave height only





least distance route ("geodetic")
CO_2-optimal route

- reduced speed loss along the CO_2-optimal route
- wave field visualized via concentric shells at three-hourly timesteps *)

*) Mannarini, et al, 2021, Journal of Marine Science and Engineering, https://doi.org/10.3390/jmse9020115

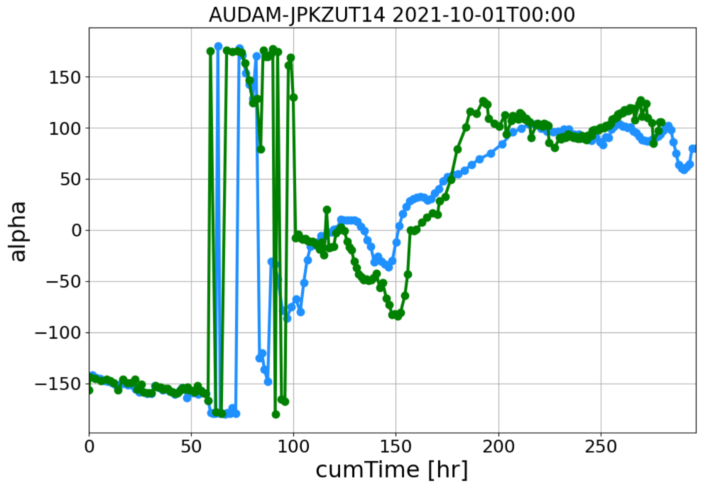
Results from VISIR-2 model

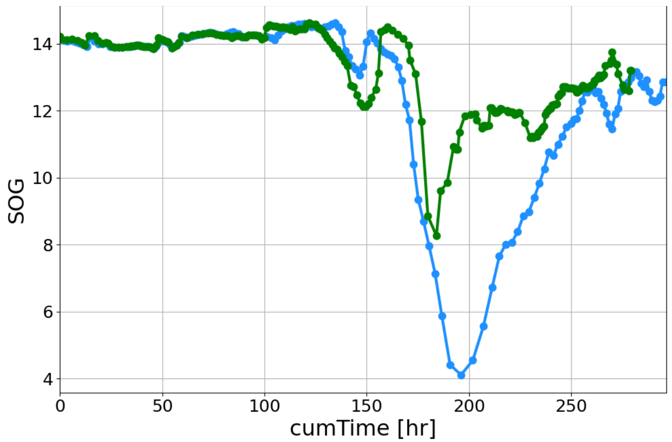
$\langle Hs \rangle_{gdt}$ = 1.83m
$\langle|\alpha|\rangle_{gdt}$ = 94.9°

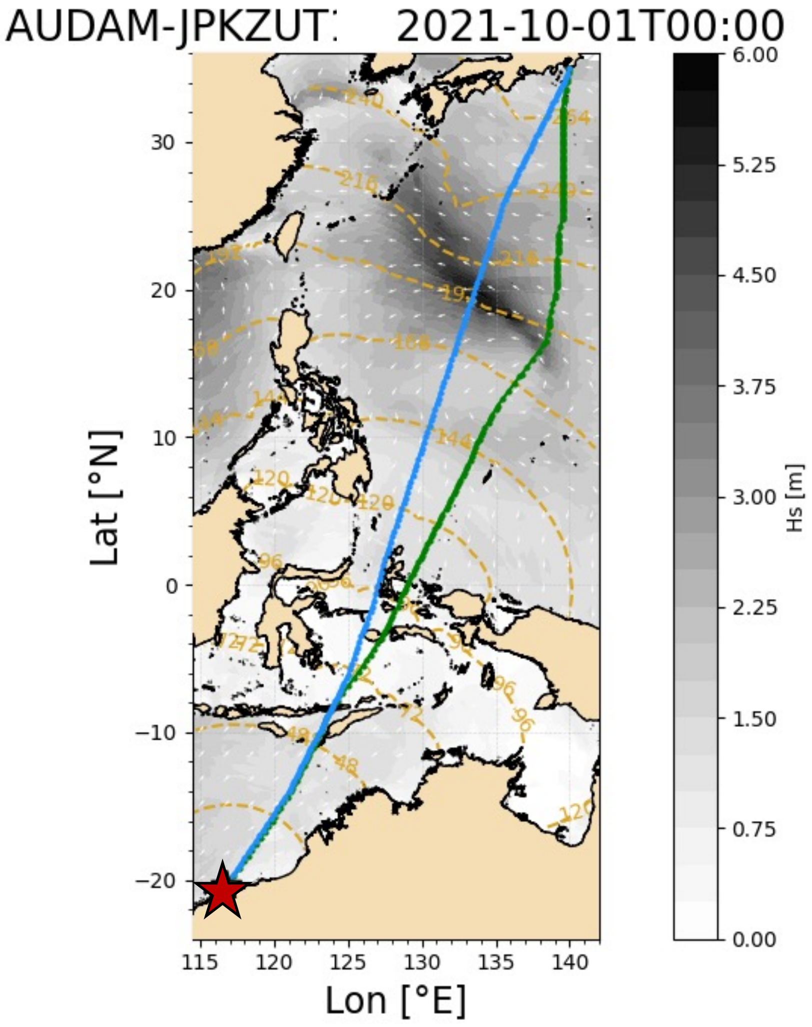
Duration [hrs]: 279.3
dLength [%]: +2.5
CO_2 [t]: 507
dCO_2 [%]: -5.8

- wave height and direction

α







waves of ~5m encountered at α=50° ➔ peak speed loss along geodetic at 192 hours

CO_2-optimal route avoids both rough and head sea

(ship sails at larger α than along geodetic)

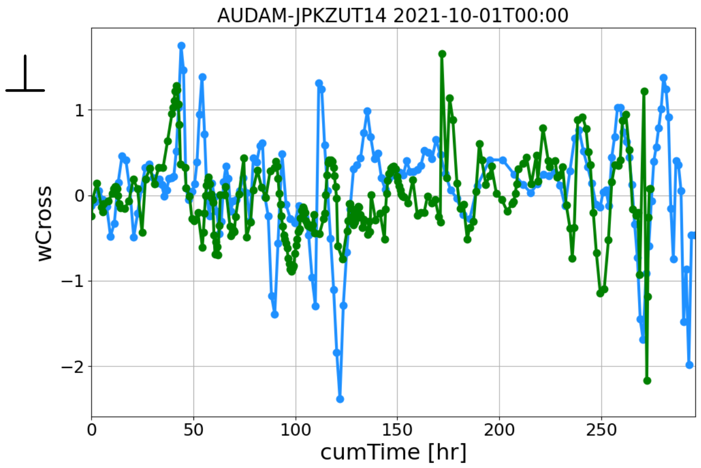
Results from VISIR-2 model

$\langle Hs \rangle_{gdt}$ = 1.83m
$\langle|\alpha|\rangle_{gdt}$ = 94.8°

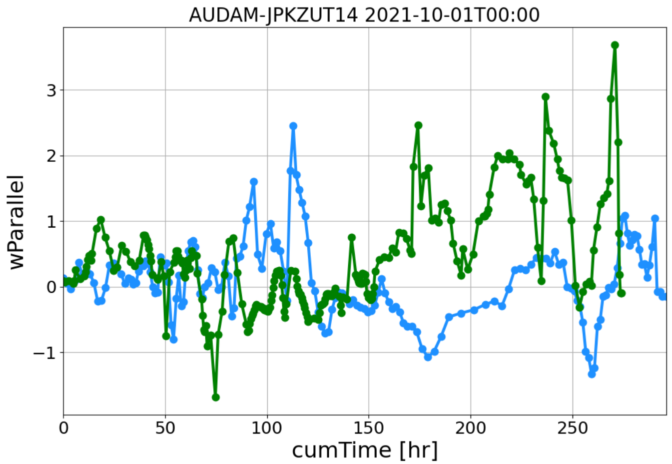
Duration [hrs]: 274.3
dLength [%]: +8.1
CO_2 [t]: 498
dCO_2 [%]: -7.4

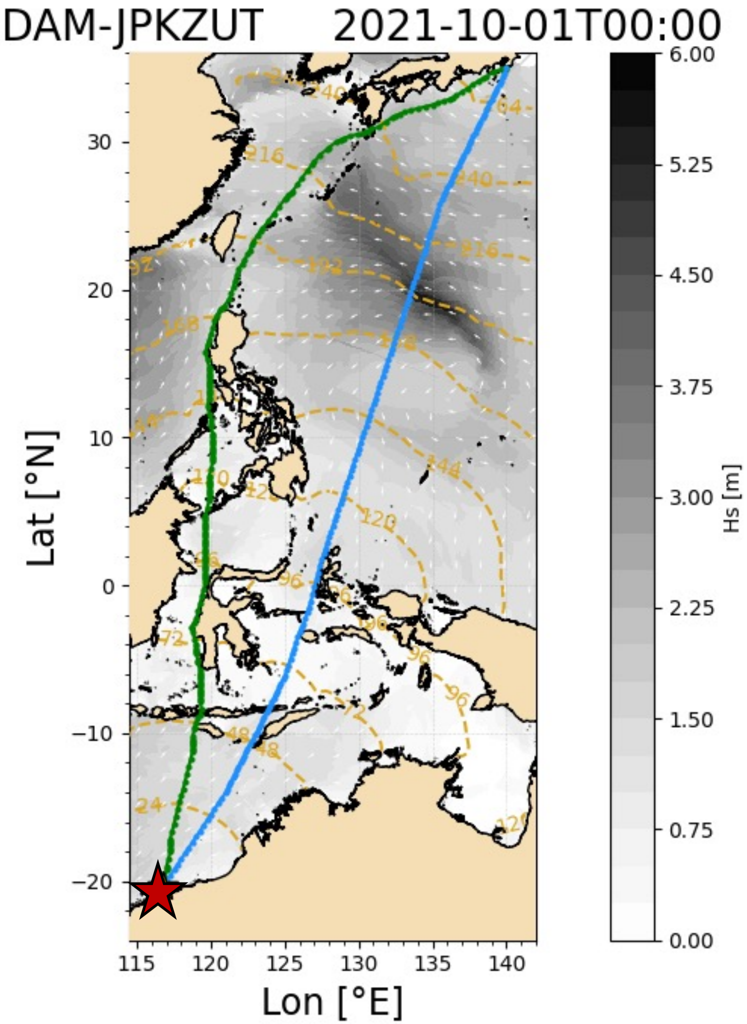
- wave height, dir. and currents

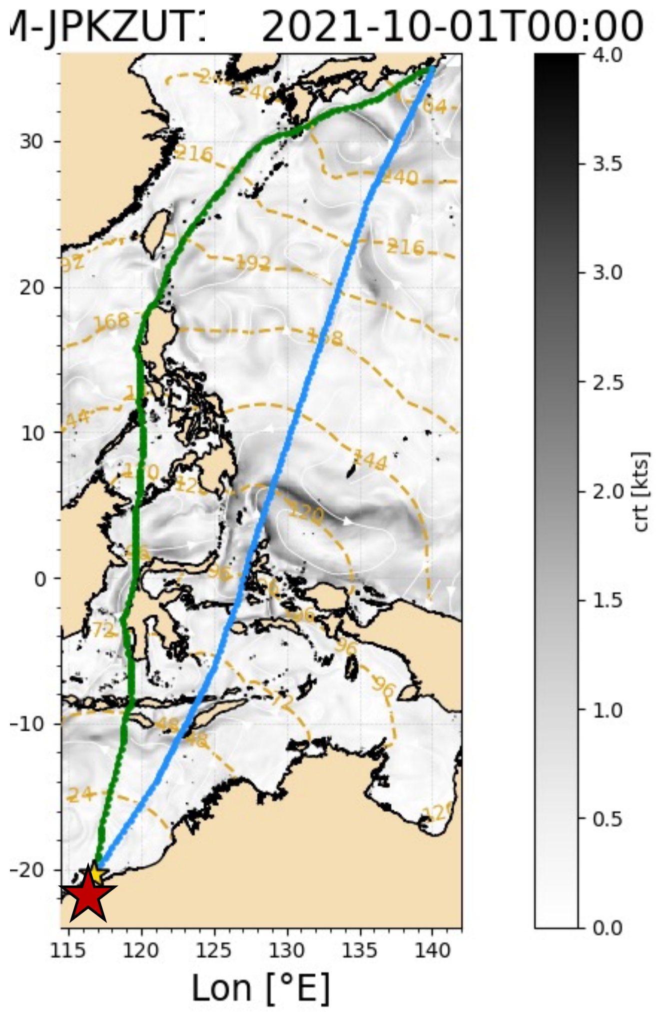
$w_\perp$



$w_\parallel$







exploitation of North Equatorial Current is more effective than flow around Halmahera eddy

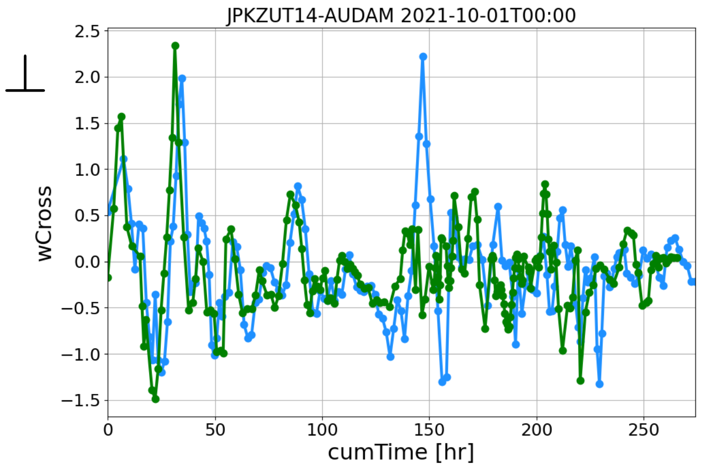
Results from VISIR-2 model

$\langle Hs \rangle_{gdt}$ = 1.84m
$\langle |\alpha| \rangle_{gdt}$ = 109.1°

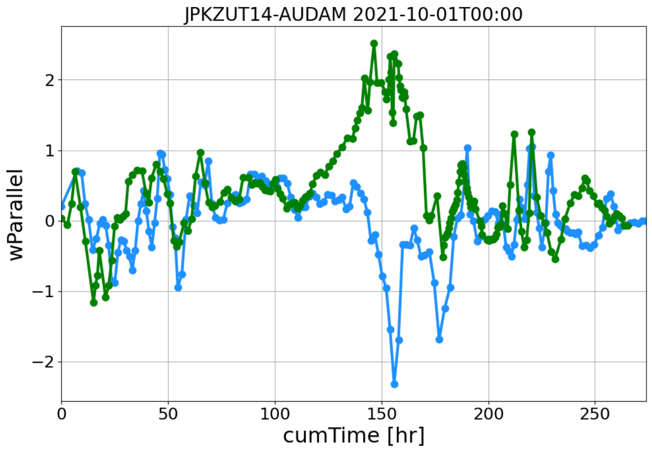
Duration [hrs]: 265.4
dLength [%]: +1.5
CO_2 [t]: 482
dCO_2 [%]: -3.1

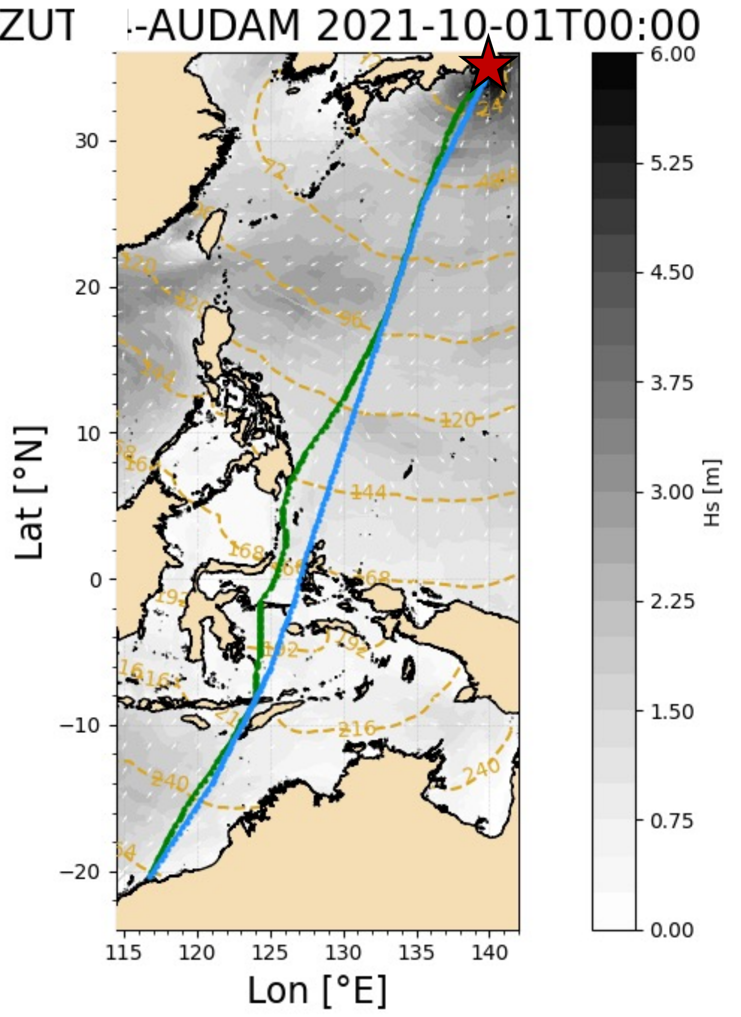
- wave height, dir. and currents

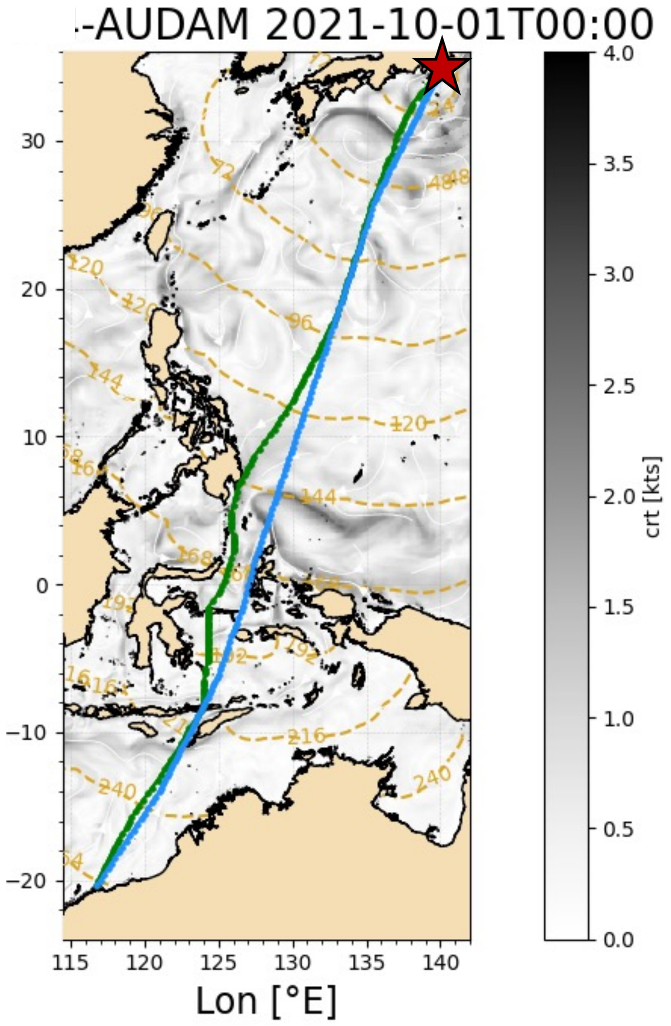
$w_\perp$



$w_\parallel$





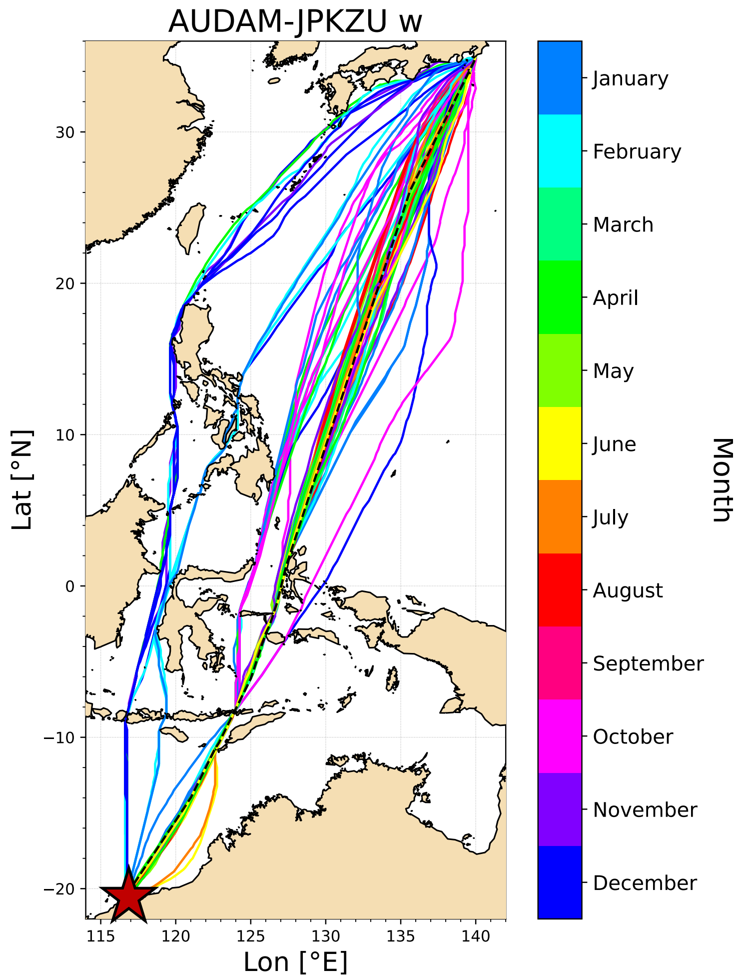


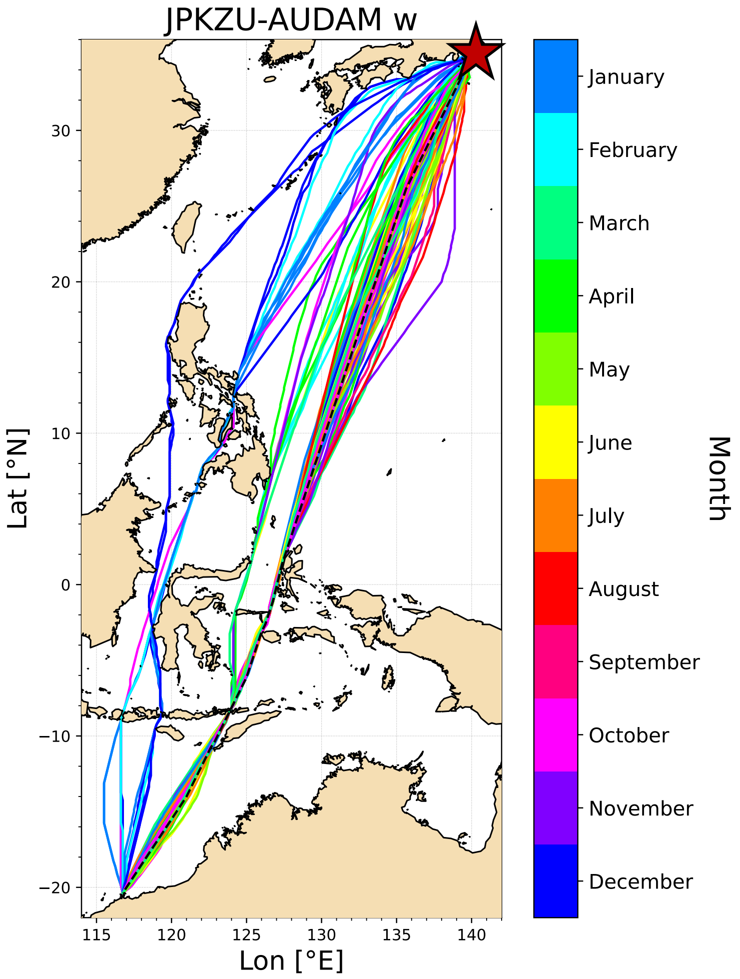
avoiding Halmahera & exploiting branch of Mindanao eddy

Results from VISIR-2 model

Oct.2021-
Sett.2022

- waves only





route departure any 5th day

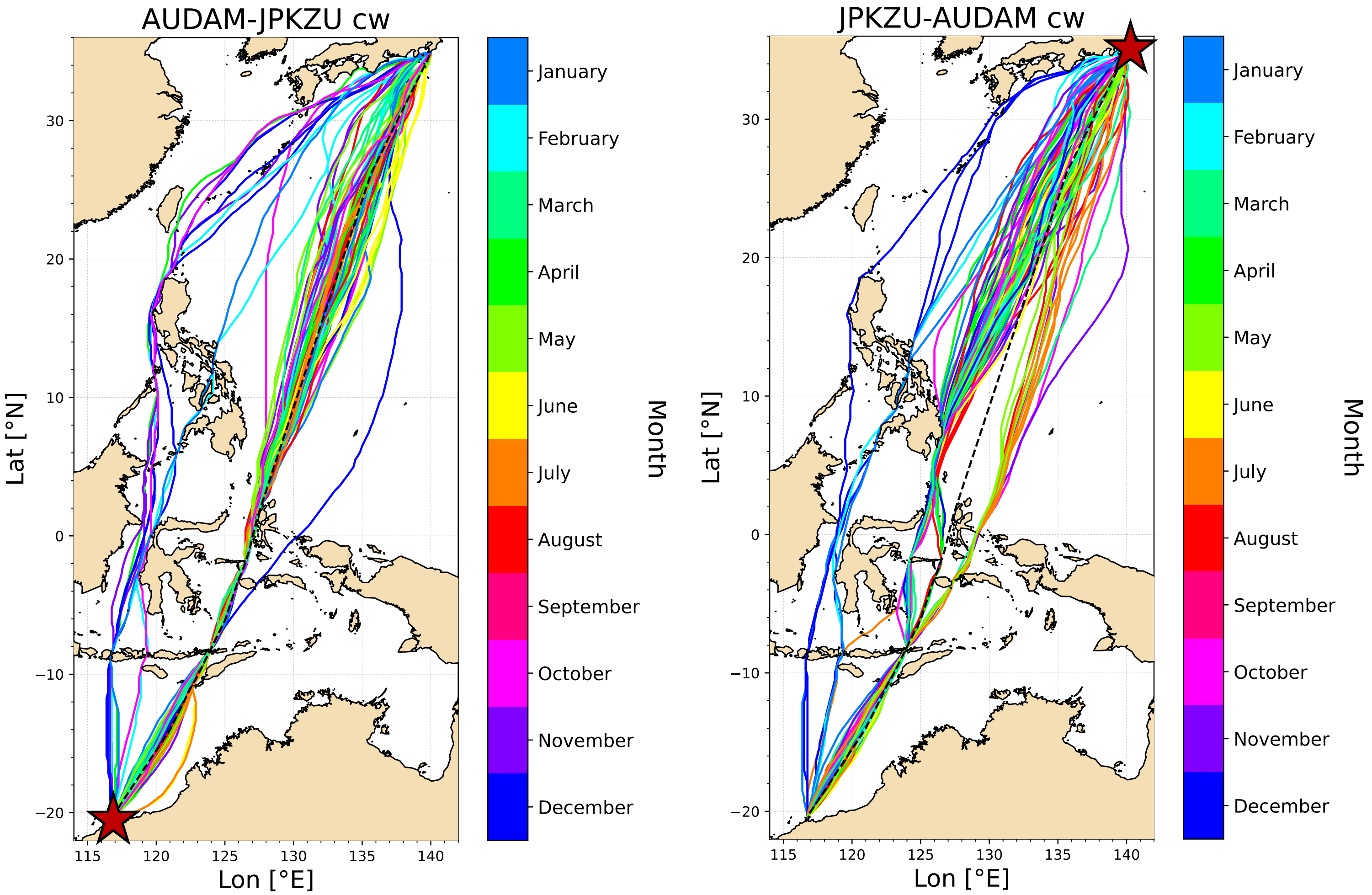
←bundles of optimal routes:

- concentration along the geodetic one (black dashed)
- largest diversions in winter

Results from VISIR-2 model

Oct.2021-
Sett.2022

- waves & currents



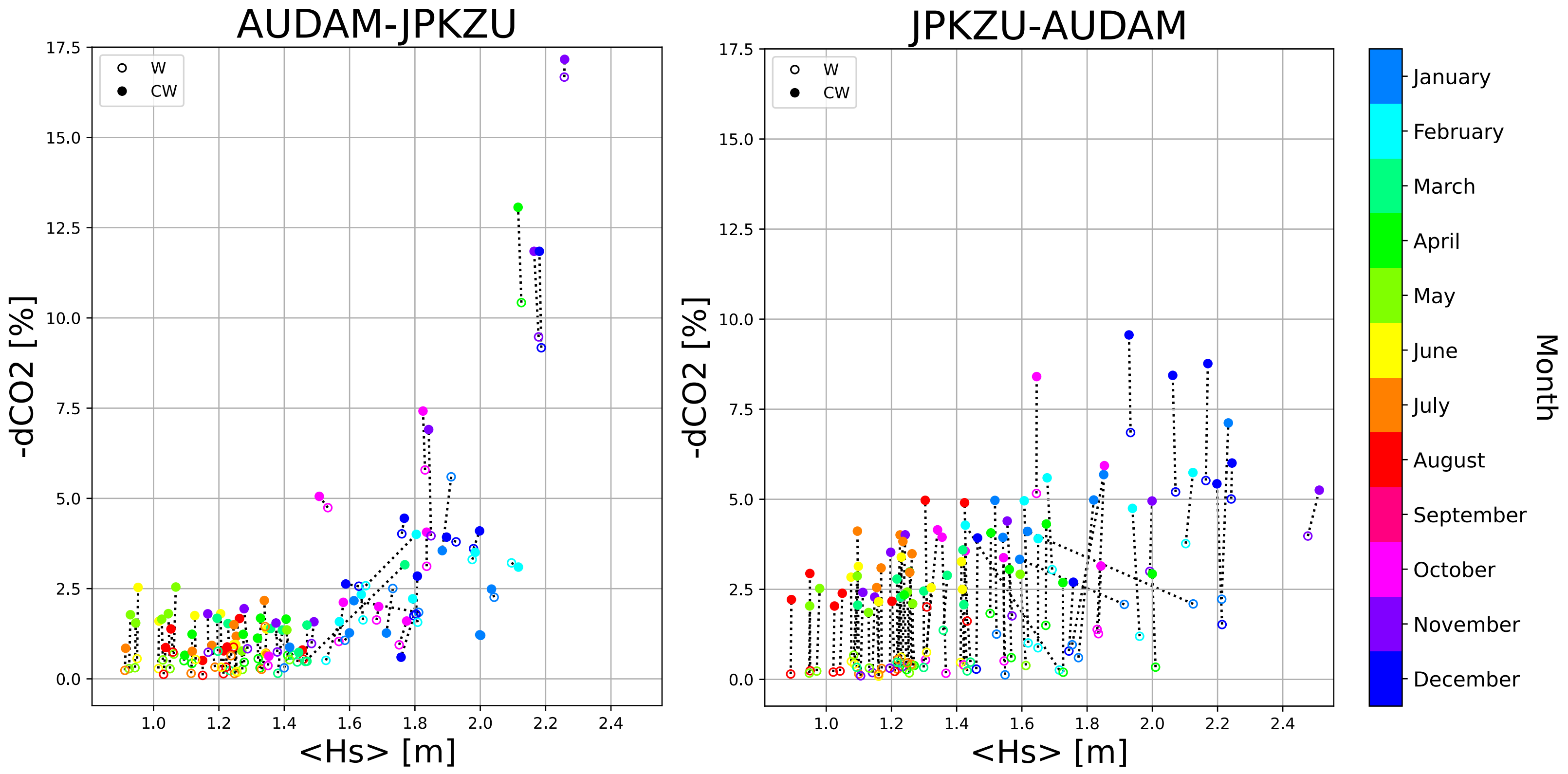
←optimal routes skipping meridional component of Halmahera eddy (northbound)

Similar effect was found next to Gulf Stream (*)

*) Mannarini and Carelli,. Geoscientific Model Development, 2019. https://doi.org/10.5194/gmd-12-3449-2019

Results from VISIR-2 model

Statistics of CO_2 savings (empty markers: waves only, full: waves & currents)



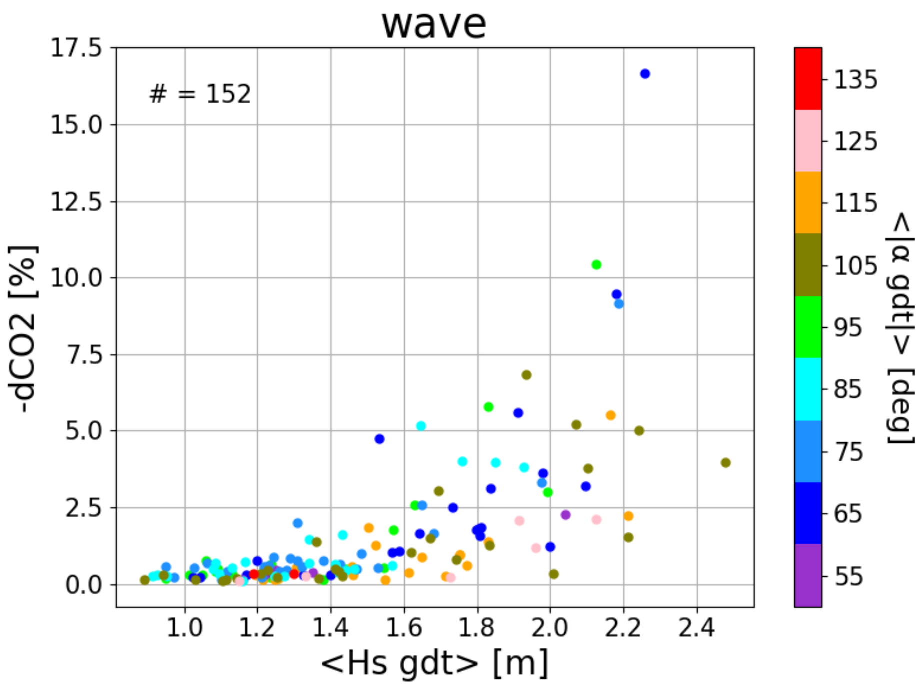
mean saving increase due to currents:

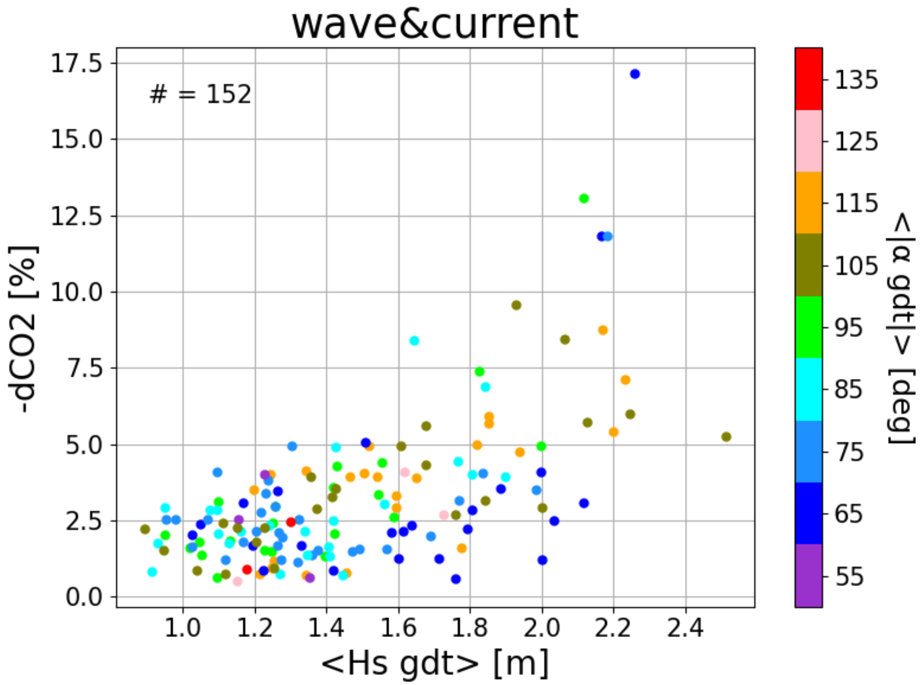
+0.8%

+2.7%

Results from VISIR-2 model

Statistics of CO_2 savings (routes from and to Australia)





"annual" mean savings: 1.4% 3.2%

ocean currents enhancing CO_2 savings for Hs < 1.6 m

Conclusions and Outlook

- Both currents and waves from Copernicus used in VISIR-2 for least-CO_2 routes
- modeling a bulk carrier along a proposed green corridor (Australia-Japan iron ore route)
- 152 routes computed for the (October 2021- August 2022) time frame
- effect of wave direction highlighted
- CO_2 savings due to waves up to more than 16%
- currents can be exploited for enhancing CO_2 savings when waves are small
- annual average CO_2 savings without (with) currents: 1.4 (3.2) %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