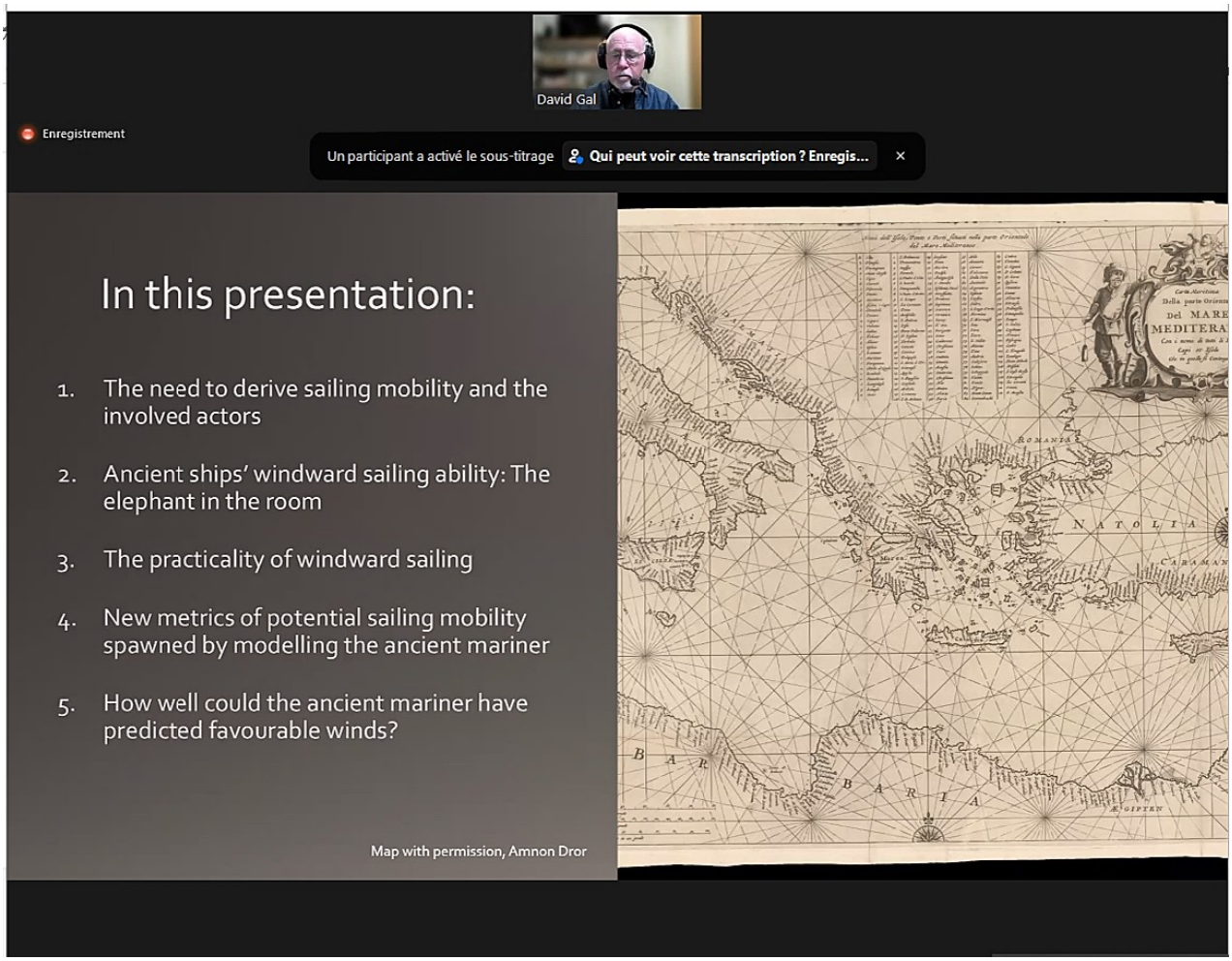
David Gal
Enregistrement
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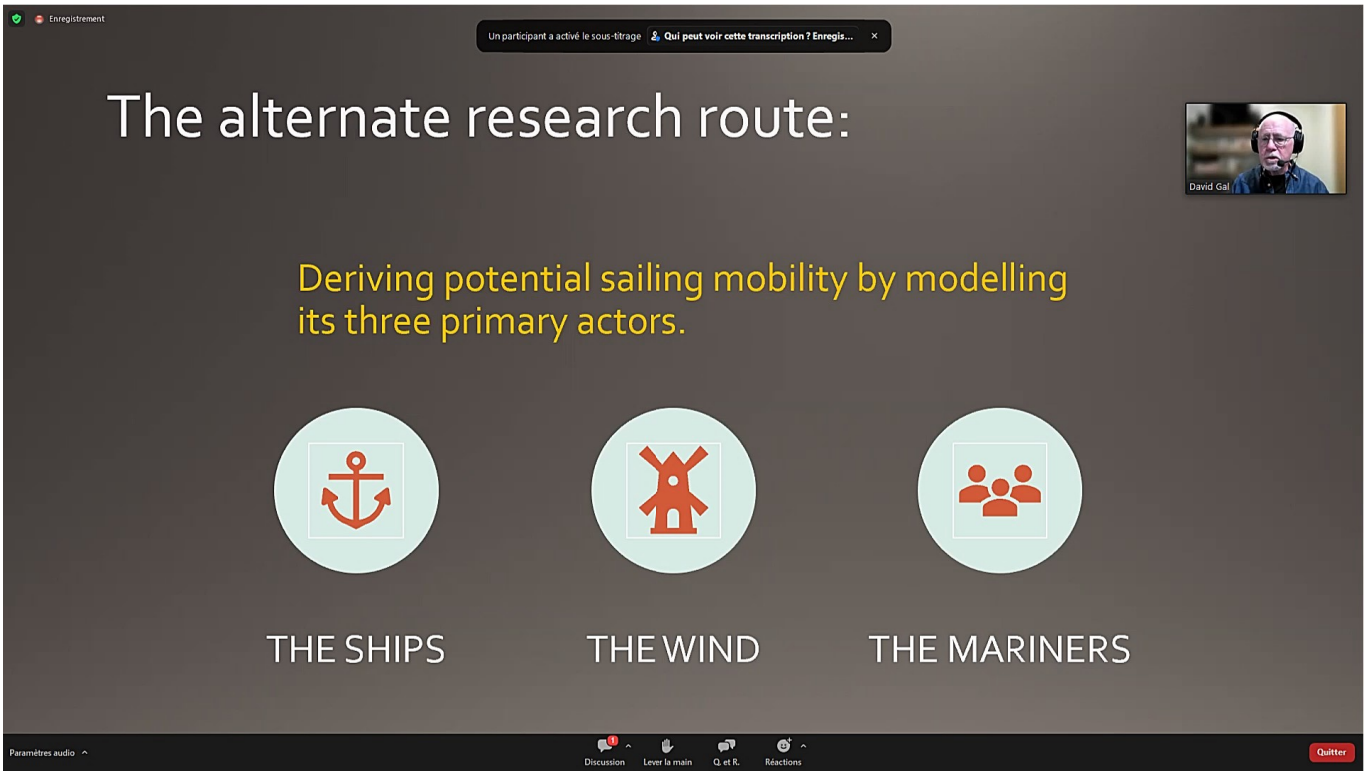
Qui peut voir cette transcription ? Enregis...
In this presentation:
1. The need to derive sailing mobility and the involved actors
2. Ancient ships' windward sailing ability: The elephant in the room
3. The practicality of windward sailing
4. New metrics of potential sailing mobility spawned by modelling the ancient mariner
5. How well could the ancient mariner have predicted favourable winds?
Map with permission, Amnon Dror


Enregistrement
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Qui peut voir cette transcription ? Enregis...
The alternate research route:
David Gal
Deriving potential sailing mobility by modelling its three primary actors.
THE SHIPS
THE WIND
THE MARINERS
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter

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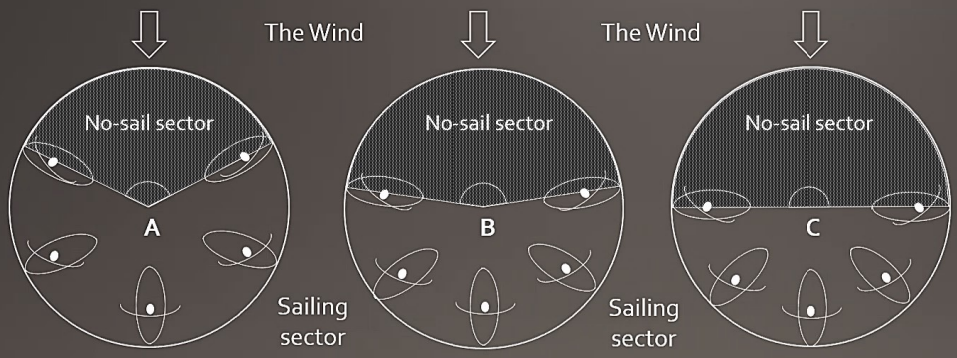
Windward sailing: Three scholarly camps



Practical windward sailing | Limited windward ability | No windward ability

Paramètres audio | Discussion | Lever la main | Q. et R. | Réactions | Quitter

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A reassessment of Mediterranean ships' windward ability in Antiquity

1. Conducting a critical review of influential scholarly sources
2. Revisiting the theory of windward sailing
3. Studying inputs from experimental archaeology

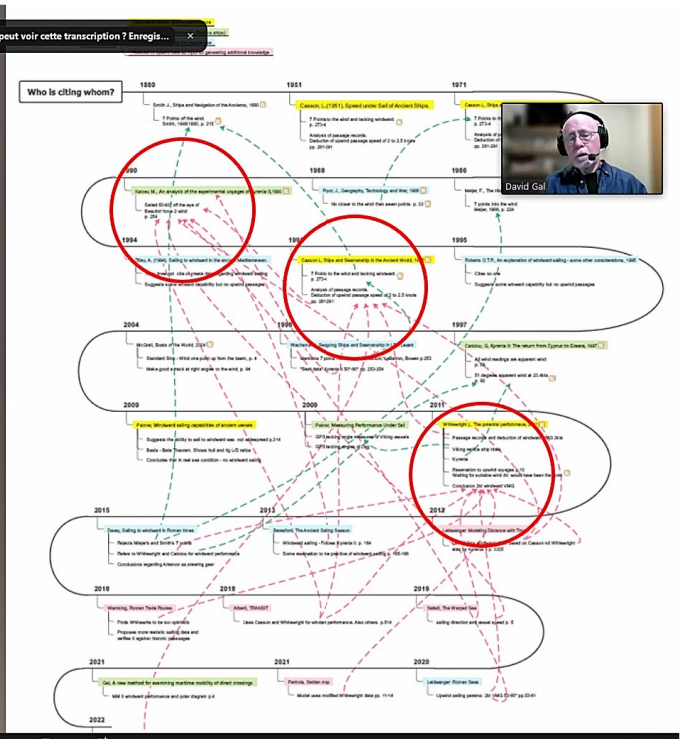
Paramètres audio | Discussion | Lever la main | Q. et R. | Réactions | Quitter

The three most cited "suppliers"

M. Katzev (1990)
An Analysis of the Experimental Voyages of Kyrenia II

L. Casson (1995)
Ships and Seamanship in the Ancient World

J. Whitewright (2011)
The Potential Performance of Ancient Mediterranean Sailing Rigs



L. Casson's method to derive ships' speed

Historic non-stop passages with given durations

Passages conducted with favourable wind

Average passage speed made good

"4 – 6 knots with the wind"

"Unfavourable or foul winds are those that blow from some point ahead [of the ship]."

Casson 1951, p.137

Passages conducted with unfavourable wind

Average passage speed made good

"2 – 2½ knots against the wind"

L. Casson's method to derive ships' speed

Historic non-stop passages with given durations

Passages conducted with favourable wind

Average passage speed made good

"4 – 6 knots with the wind"

"...could probably point no closer to the wind than seven points [78.75°] ...When his destination lay well to windward he resorted ... to tacking"

Casson 1995, p.274

Passages conducted with unfavourable wind

Average passage speed made good

"2 – 2½ knots against the wind"

"...record of voyages made under unfavourable wind conditions"

Voyage	Distance (nm)	Duration (days)	Overall Speed (knots)
Cyrene-West point of Crete	160	2	3.3
Ascalon-Thessalonica	800	13	2.6
Rhodes-Gaza	410	7	2.4
Alexandria-Marseilles	1,500	30	2.1
Puteoli-Ostia	120	2½	2.0
Gaza-Byzantium	855	20	1.8
Rhodes-Byzantium	445	10	1.8
Caesarea-Rhodes	400	10	1.8
Alexandria-Cyprus	250	6½	1.6
Sidon-Chelidonian Islands	350	9½	1.5

Following Casson, 1995, p. 289

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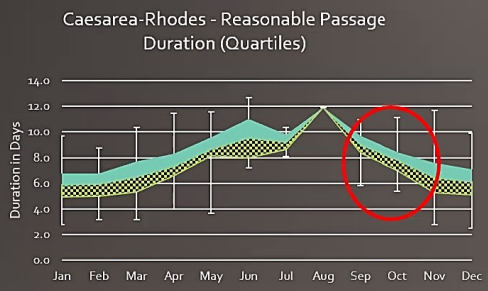
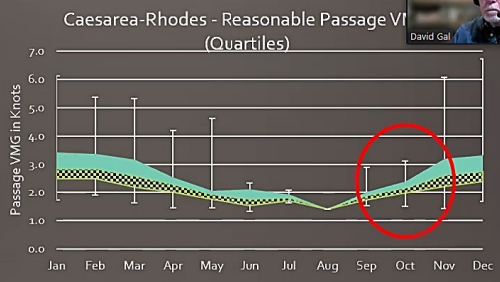
Caesarea to Rhodes in October: Sailing characteristics





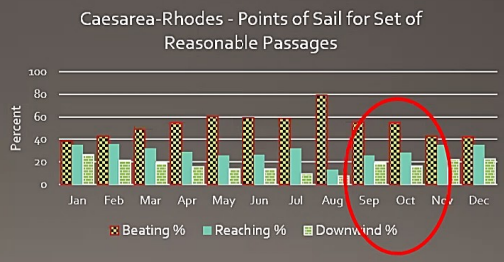
Median Coefficient of Mobility 0.23

Median Passage Duration ..... 8 days

Median Passage VMG ..... 2.2 knots

Destination in No-Sail sector 14%

Reaching and Downwind PoS 45%



Paramètres audio Discussion Lever la main Q. et R. Réactions Quitter

Enregistrement

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J. Whitewright's method (2011)

Followed Cason for unfavourable wind passages' VMG

"Tally"

Max. VMG of reconstructed ship trials

"Max. VMG to windward 2 knots"

"This study uses the concept of 'velocity made good' (Vmg) as central to the comparative assessment of appropriate sailing vessels [...] Analysis of Vmg allows the absolute performance of two vessels to be compared independent of factors ..."

Whitewright, 2011 p. 3

Paramètres audio Discussion Lever la main Q. et R. Réactions Quitter

Enregistrement

Un participant a activé le sous-titrage Qui peut voir cette transcription ? Enregis...

J. Whitewright's method (2011)

Followed Cason for unfavourable wind passages' VMG

"Tally"

Max. VMG of reconstructed ship trials

"Max. VMG to windward 2 knots"

"In the majority of cases it is unlikely that such performance would have encouraged ancient mariners to set out on a voyage against the wind. The practice of waiting for a suitable wind direction must have been the norm."

Whitewright, 2011 p. 10

Paramètres audio Discussion Lever la main Q. et R. Réactions Quitter

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M. Katzev
An Analysis of the Experimental Voyages of Kyrenia II, (1990)

"Later in the afternoon the wind shifted to the southwest. During a two hour period around sunset *KYRENIA II* sailed 50° to 60° off the eye of a 2 Beaufort wind, close hauled, port tack, making over 2 knots speed – evidence of her ability to sail effectively into the wind"

Katzev, 1990, p. 254

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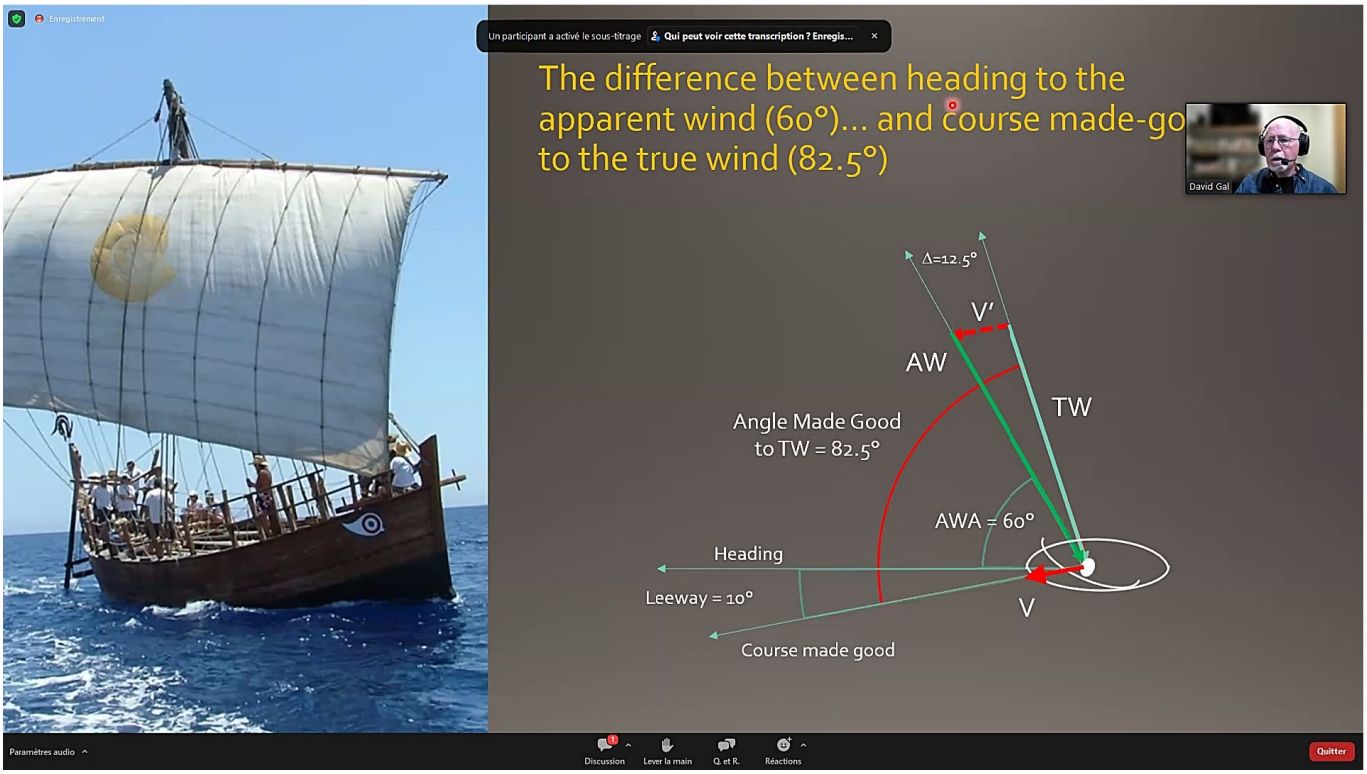
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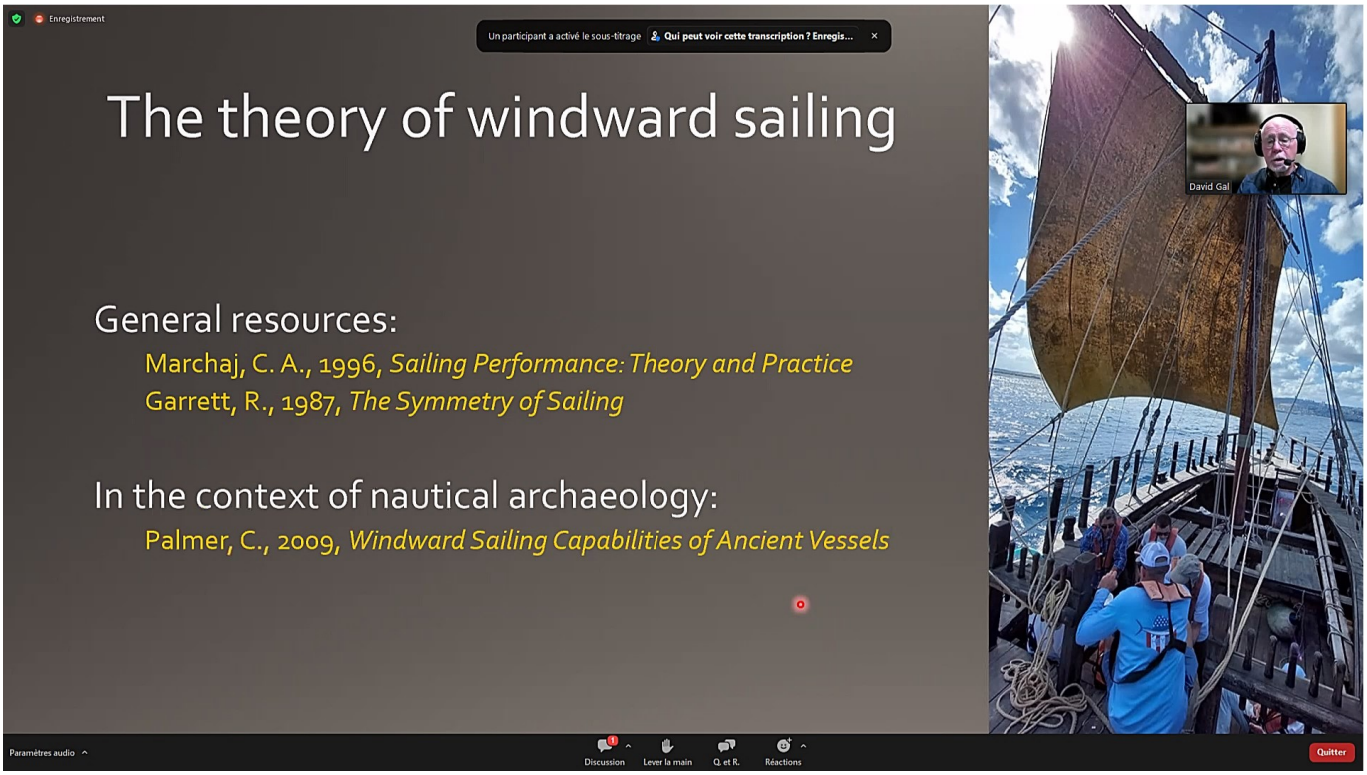
Qui peut voir cette transcription ? Enregis...
The difference between heading to the apparent wind (60°)... and course made-go to the true wind (82.5°)
David Gal
Δ=12.5°
V'
AW
TW
Angle Made Good to TW = 82.5°
AWA = 60°
Heading
Leeway = 10°
V
Course made good
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter


Enregistrement
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Qui peut voir cette transcription ? Enregis...
The theory of windward sailing
General resources:
Marchaj, C. A., 1996, Sailing Performance: Theory and Practice
Garrett, R., 1987, The Symmetry of Sailing
In the context of nautical archaeology:
Palmer, C., 2009, Windward Sailing Capabilities of Ancient Vessels
David Gal
Paramètres audio
Discussion
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The β (Beta) Theorem

When sailing close-hauled the force of the sail applies a sideways force on the vessel.

The hull creates lift in the opposite direction balancing the sail's sideways force.

The more efficient the sail and/or the hull, the vessel can sail effectively closer to the wind.

This can be calculated

Paramètres audio | Discussion | Lever la main | Q. et R. | Réactions | Quitter

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How efficient is my sail and hull?

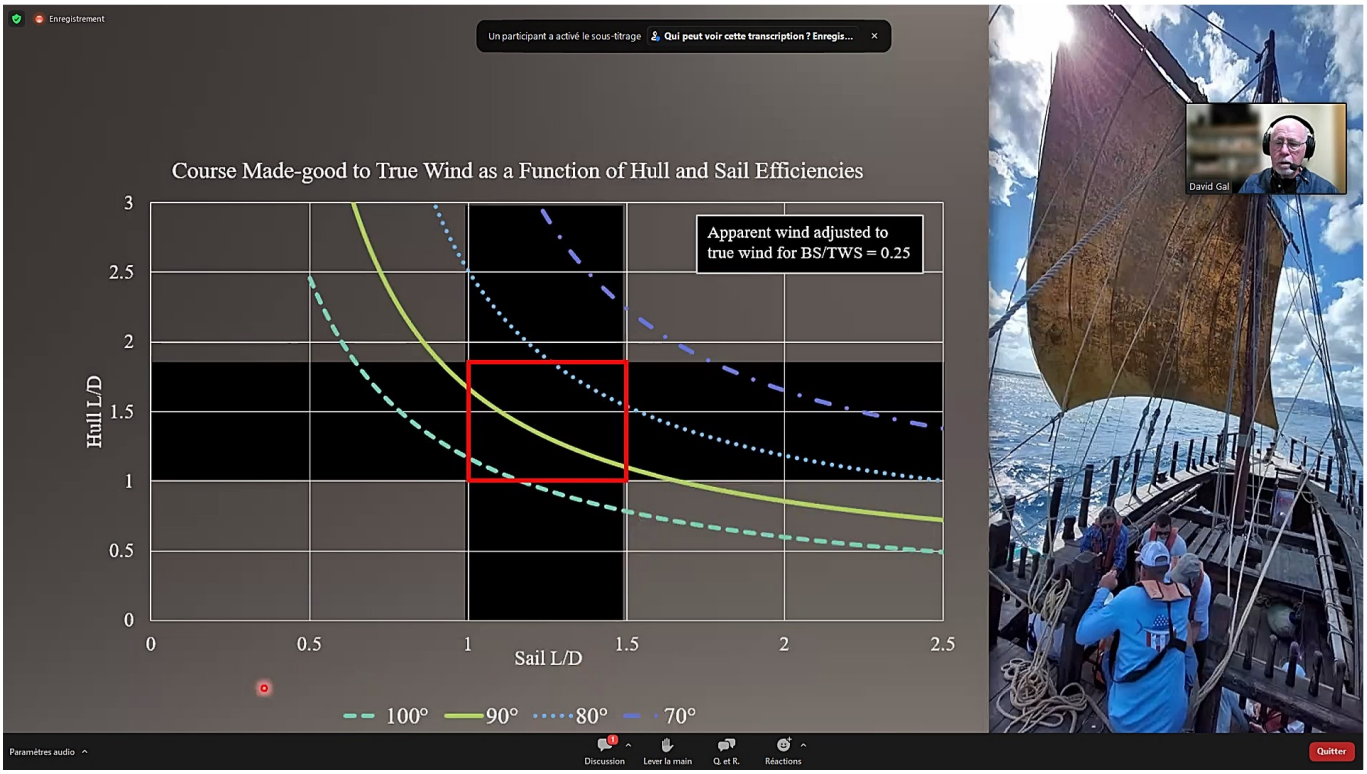
Practical measurements require a wind tunnel and a tow tank

Expressed in terms of Lift to Drag Ratio (L/D)

Palmer (2009) provided a range of measures from tests on representative models

Palmer also provided measures of L/D degradation by various factors

Paramètres audio | Discussion | Lever la main | Q. et R. | Réactions | Quitter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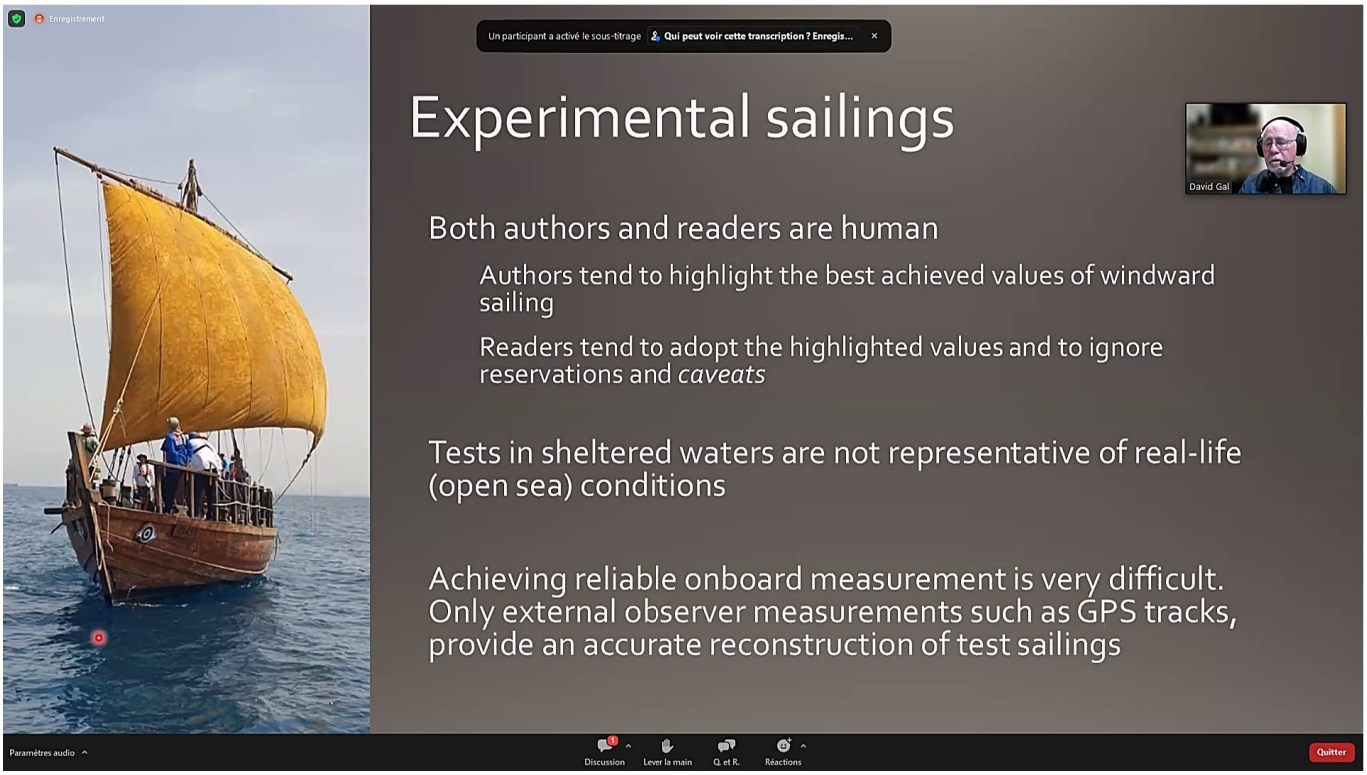
Qui peut voir cette transcription ? Enregis...
Course Made-good to True Wind as a Function of Hull and Sail Efficiencies
Apparent wind adjusted to true wind for BS/TWS = 0.25
Hull L/D
Sail L/D
0
0.5
1
1.5
2
2.5
3
100°
90°
80°
70°
David Gal
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter


Enregistrement
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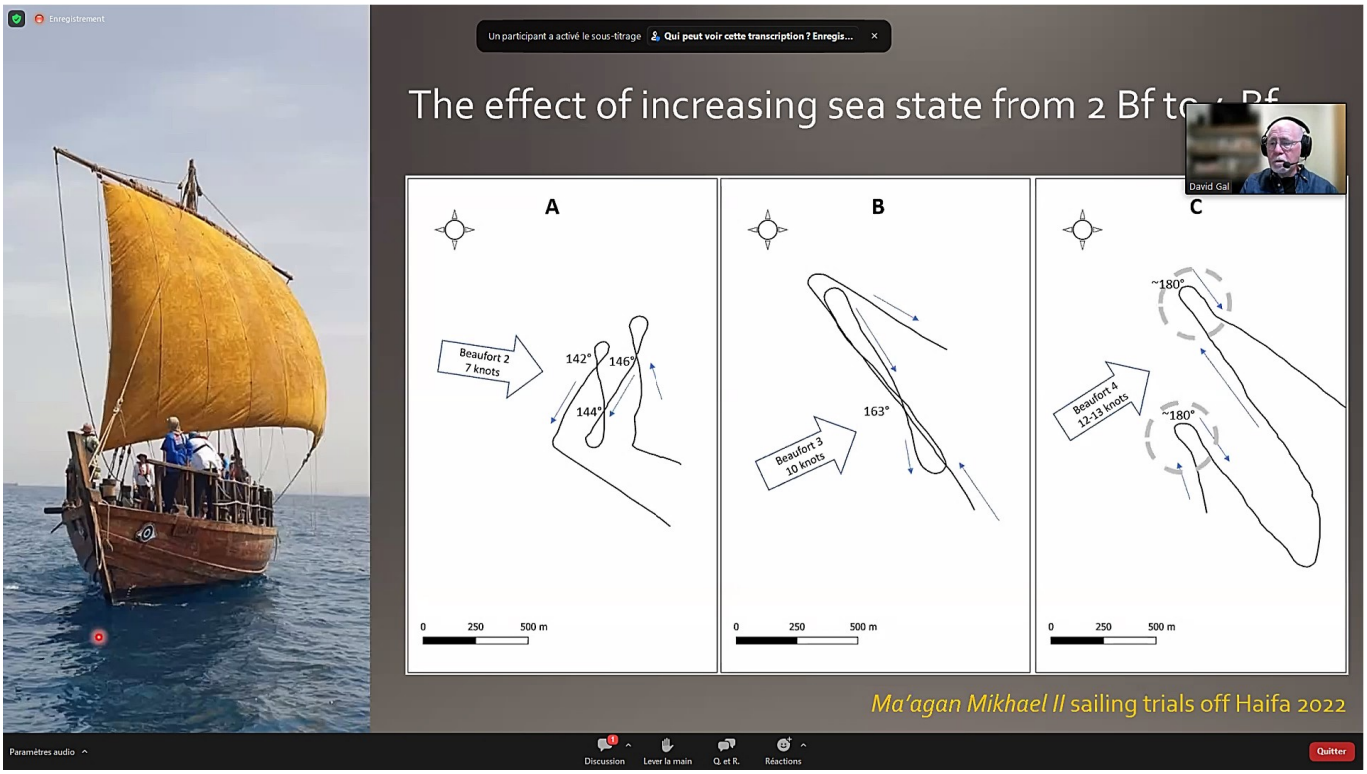
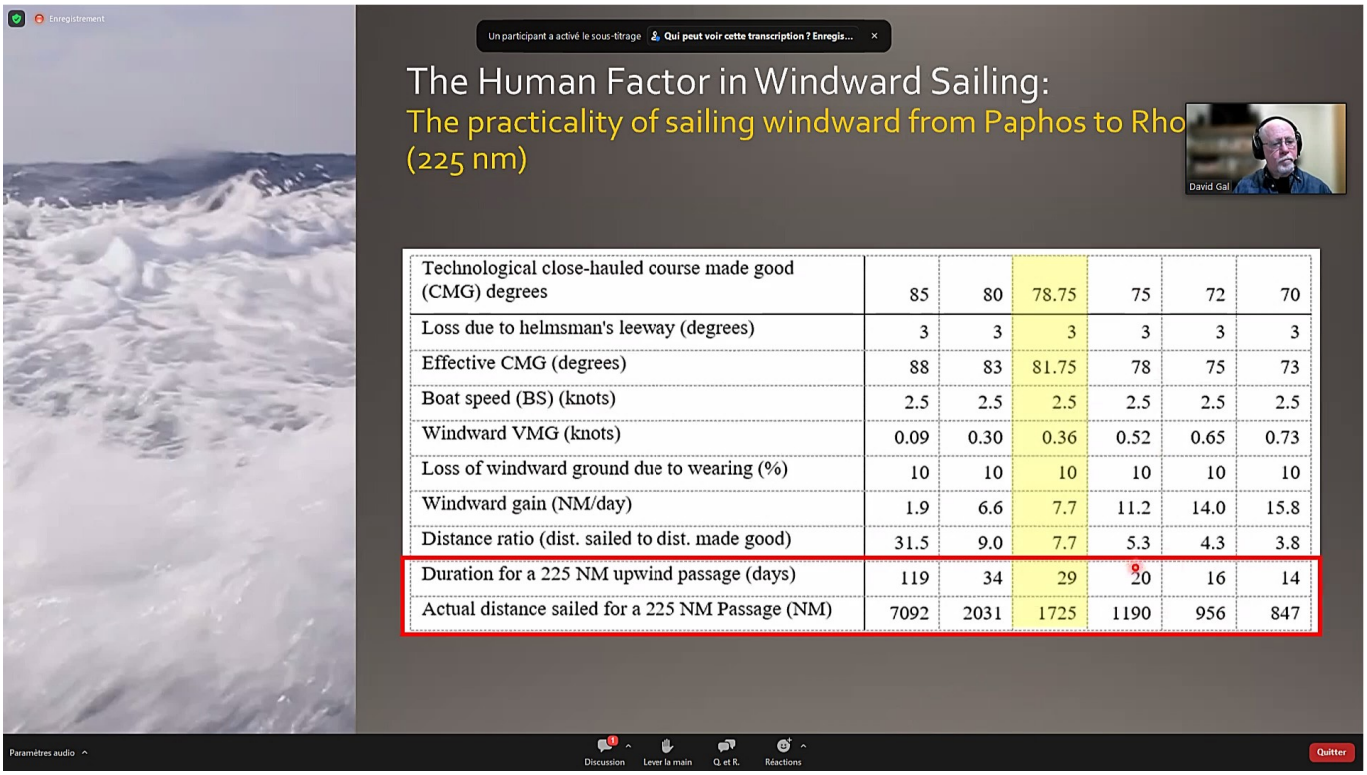
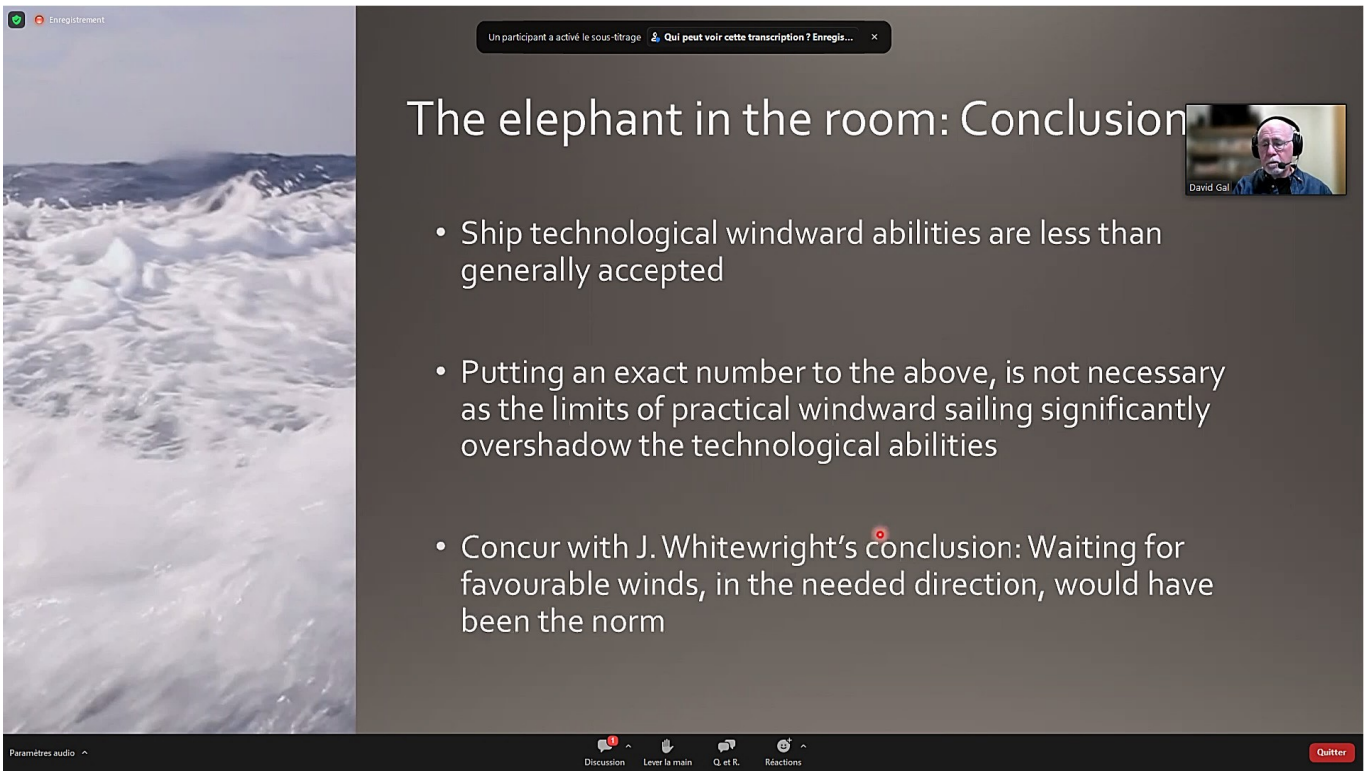
Qui peut voir cette transcription ? Enregis...
Experimental sailings
David Gal
Both authors and readers are human
Authors tend to highlight the best achieved values of windward sailing
Readers tend to adopt the highlighted values and to ignore reservations and *caveats*
Tests in sheltered waters are not representative of real-life (open sea) conditions
Achieving reliable onboard measurement is very difficult. Only external observer measurements such as GPS tracks, provide an accurate reconstruction of test sailings
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter





Technological close-hauled course made good (CMG) degrees	85	80	78.75	75	72	70
Loss due to helmsman's leeway (degrees)	3	3	3	3	3	3
Effective CMG (degrees)	88	83	81.75	78	75	73
Boat speed (BS) (knots)	2.5	2.5	2.5	2.5	2.5	2.5
Windward VMG (knots)	0.09	0.30	0.36	0.52	0.65	0.73
Loss of windward ground due to wearing (%)	10	10	10	10	10	10
Windward gain (NM/day)	1.9	6.6	7.7	11.2	14.0	15.8
Distance ratio (dist. sailed to dist. made good)	31.5	9.0	7.7	5.3	4.3	3.8
Duration for a 225 NM upwind passage (days)	119	34	29	20	16	14
Actual distance sailed for a 225 NM Passage (NM)	7092	2031	1725	1190	956	847


Enregistrement
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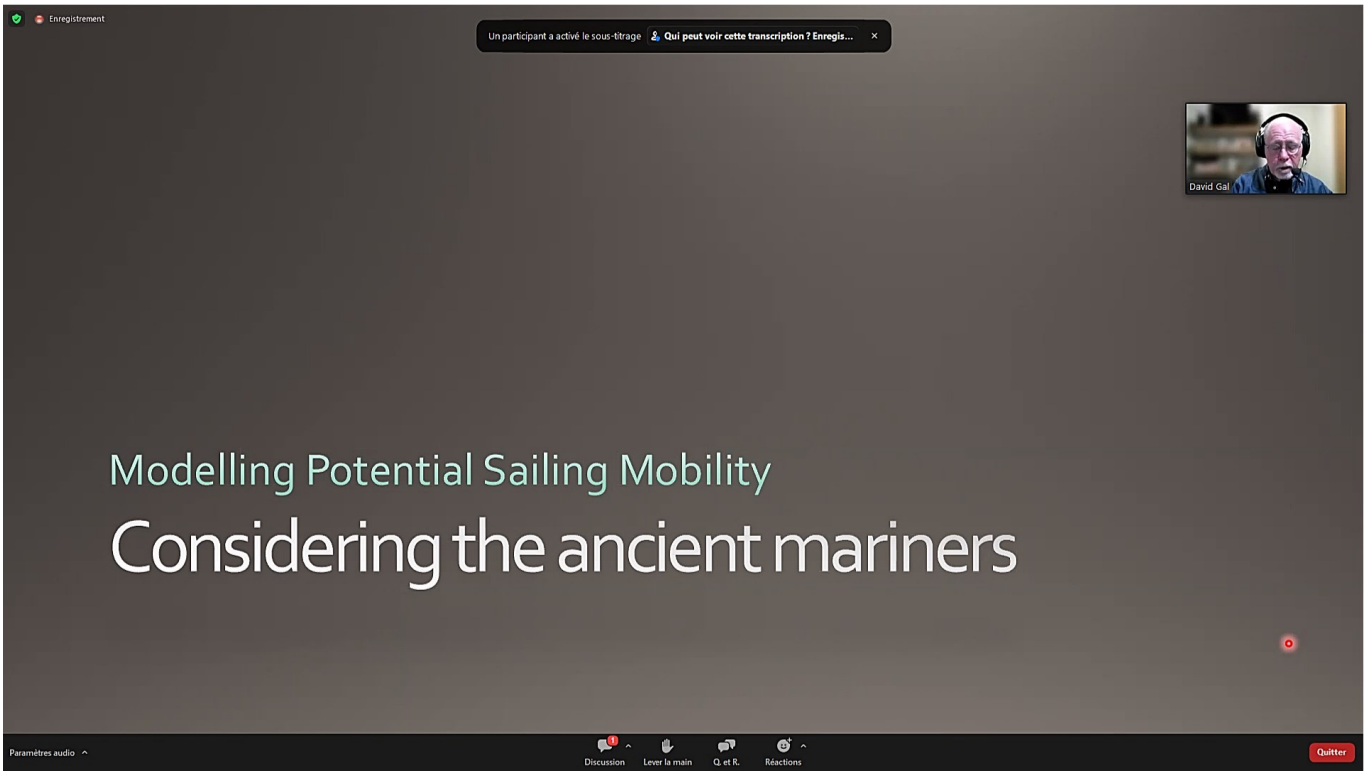
The elephant in the room: Conclusion
David Gal
• Ship technological windward abilities are less than generally accepted
• Putting an exact number to the above, is not necessary as the limits of practical windward sailing significantly overshadow the technological abilities
• Concur with J. Whitewright's conclusion: Waiting for favourable winds, in the needed direction, would have been the norm
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter


Enregistrement
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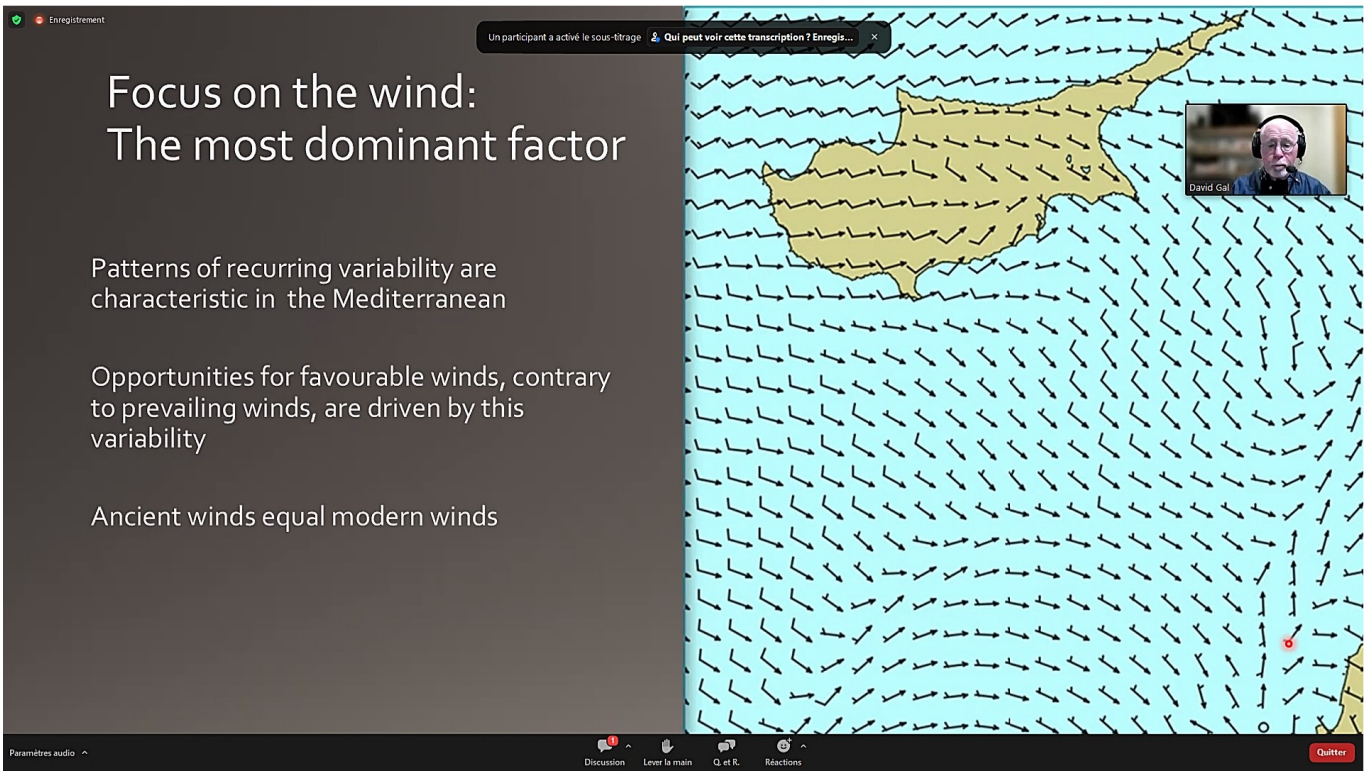
David Gal
Modelling Potential Sailing Mobility
Considering the ancient mariners
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter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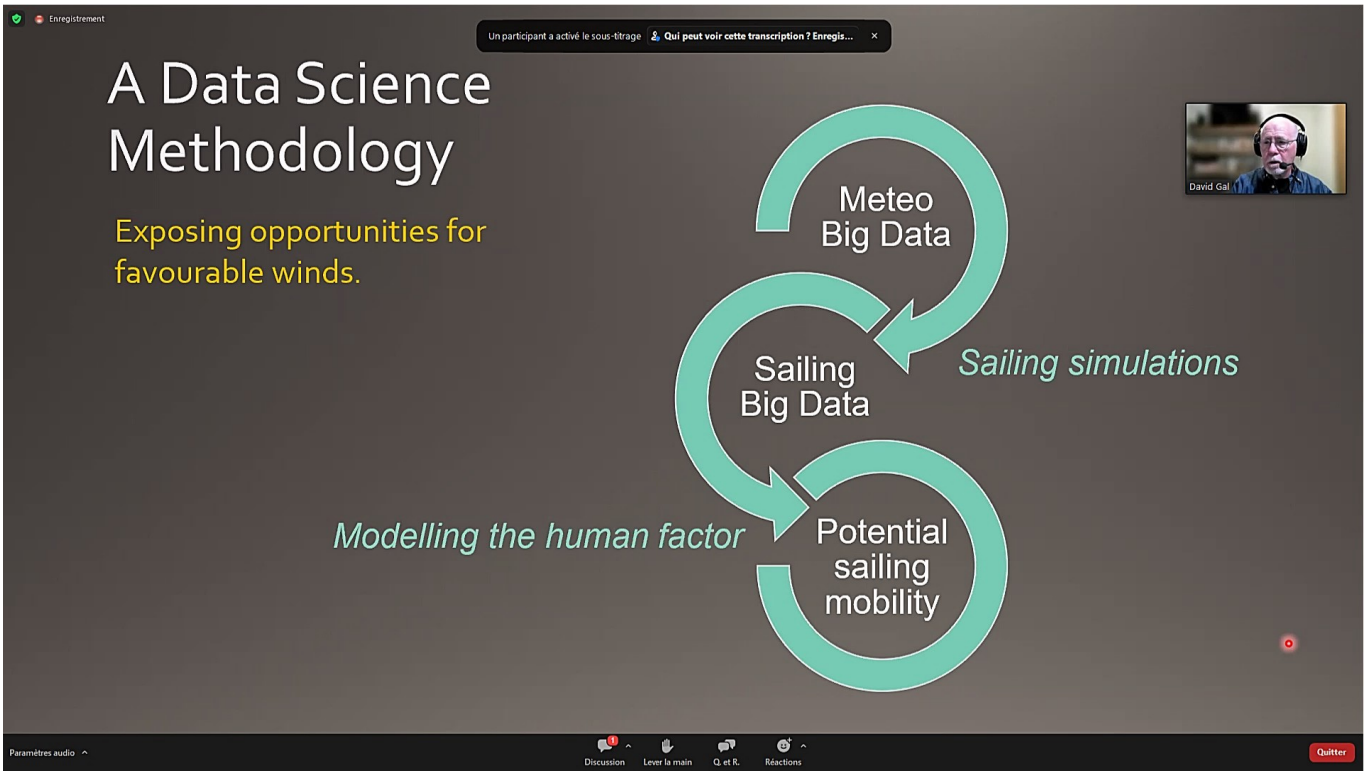
Qui peut voir cette transcription ? Enregis...
Focus on the wind:
The most dominant factor
Patterns of recurring variability are characteristic in the Mediterranean
Opportunities for favourable winds, contrary to prevailing winds, are driven by this variability
Ancient winds equal modern winds
David Gal
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter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Qui peut voir cette transcription ? Enregis...
A Data Science Methodology
Exposing opportunities for favourable winds.
Meteo Big Data
Sailing Big Data
Potential sailing mobility
Sailing simulations
Modelling the human factor
David Gal
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter

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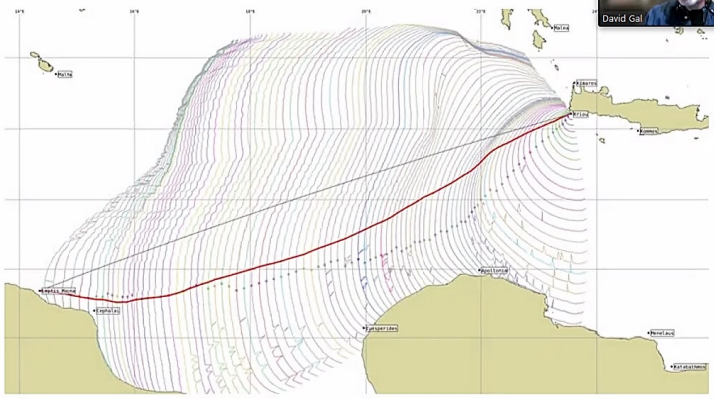
Weather Routing Simulations

- Least Cost Path routing between two points based on isochrones
- One simulated sailing departing every day on each passage for 15 years = 5479 simulations
- For 224 direct passages = 1.2 million simulated sailings



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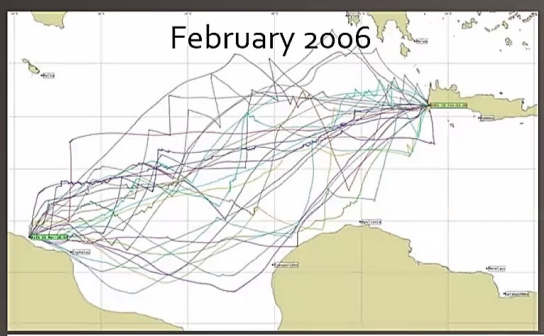
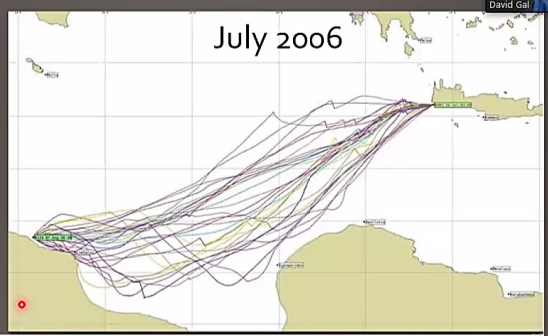
Seasonal effects on sailing: Crete to Leptis Magna
The practicality of the simulated passages?





	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Name	Start Date	Start Date (raw)	ETA	ETA (raw)	Duration	Duration (raw)	Ortho distance	Ortho distance (raw)	Sailed Distance	Sailed Distance (raw)	Avg BS	Avg BS (raw)	Max BS	Max BS (raw)	Min BS	Min BS (raw)
2	Knou-Leptis_Magna_200602_010 18 Feb-03:00	18/02/2006 03:00	1140231600	15/03/2006 13:35	1142429700	25 d 10 h 35 m	2198100	482.99 NM		482.99	1,430.16 NM		1430.16	2.34	6.53	0.24	
3	Knou-Leptis_Magna_200602_004 24 Feb-03:00	24/02/2006 03:00	1140750000	11/03/2006 02:50	1142045400	14 d 23 h 50 m	1296400	482.99 NM	975.35 NM				975.35	2.71	6.32	0.07	
4	Knou-Leptis_Magna_200602_003 25 Feb-03:00	25/02/2006 03:00	1140836400	12/03/2006 03:40	1142134800	15 d 0 h 40 m	1296400	482.99 NM	942.16 NM				942.16	2.61	6.58	0.33	
5	Knou-Leptis_Magna_200602_000 28 Feb-03:00	28/02/2006 03:00	1141096600	11/03/2006 10:55	1142074500	11 d 7 h 55 m	978900	482.99 NM	859.22 NM				859.22	3.16	7.56	0.43	
6	Knou-Leptis_Magna_200602_006 22 Feb-03:00	22/02/2006 03:00	1140572200	03/03/2006 22:45	1141425900	9 d 19 h 45 m	848700	482.99 NM	819.83 NM				819.83	3.48	8.21	0.85	
7	Knou-Leptis_Magna_200602_024 04 Feb-03:00	04/02/2006 03:00	1139022000	13/02/2006 22:25	1139869500	9 d 19 h 25 m	847500	482.99 NM	712.76 NM				712.76	3.02	6.71	0.76	
8	Knou-Leptis_Magna_200602_022 06 Feb-03:00	06/02/2006 03:00	1139194800	13/02/2006 22:40	1139870400	7 d 19 h 40 m	675600	482.99 NM	643.29 NM				643.29	3.42	7.49	1.00	
9	Knou-Leptis_Magna_200602_023 05 Feb-03:00	05/02/2006 03:00	1139108400	13/02/2006 22:05	1139868300	8 d 19 h 5 m	759900	482.99 NM	685.65 NM				685.65	3.25	6.49	0.82	
10	Knou-Leptis_Magna_200602_025 03 Feb-03:00	03/02/2006 03:00	1138935600	12/02/2006 14:55	1139756100	9 d 11 h 55 m	820500	482.99 NM	733.70 NM				733.7	3.22	7.54	1.59	
11	Knou-Leptis_Magna_200602_021 07 Feb-03:00	07/02/2006 03:00	1139281200	13/02/2006 22:45	1139870700	6 d 19 h 45 m	589500	482.99 NM	629.18 NM				629.18	3.84	8.51	1.51	
12	Knou-Leptis_Magna_200602_007 21 Feb-03:00	21/02/2006 03:00	1140490800	28/02/2006 14:05	1141135500	7 d 11 h 5 m	644700	482.99 NM	657.71 NM				657.71	3.67	7.82	1.00	
13	Knou-Leptis_Magna_200602_027 01 Feb-03:00	01/02/2006 03:00	1138762800	07/02/2006 05:00	1139288400	6 d 2 h 0 m	525600	482.99 NM	587.24 NM				587.24	4.02	7.89	1.46	
14	Knou-Leptis_Magna_200602_012 16 Feb-03:00	16/02/2006 03:00	1140058800	24/02/2006 02:20	1140747600	7 d 23 h 20 m	688800	482.99 NM	599.36 NM				599.36	3.13	7.21	0.72	
15	Knou-Leptis_Magna_200602_008 20 Feb-03:00	20/02/2006 03:00	1140404400	27/02/2006 08:55	1141030500	7 d 5 h 55 m	626100	482.99 NM	609.32 NM				609.32	3.5	7.12	0.38	
16	Knou-Leptis_Magna_200602_011 17 Feb-03:00	17/02/2006 03:00	1140145200	24/02/2006 18:05	1140804300	7 d 15 h 5 m	659100	482.99 NM	608.16 NM				608.16	3.32	7.38	0.42	

One summary record for each sailing

Paramètres audio Discussion Lever la main Q. et R. Réactions Quitter

Enregistrement

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Modelling the human factor: New mobility metrics

No longer the sole metric of passage speed

Coefficient of Potential Sailing Mobility

The proportion of a month having favourable winds to depart on a practical passage

Quantifiable waiting time

Factoring waiting time into passage duration reflects true link costs

Paramètres audio | Discussion | Lever la main | Q. et R. | Réactions | Quitter

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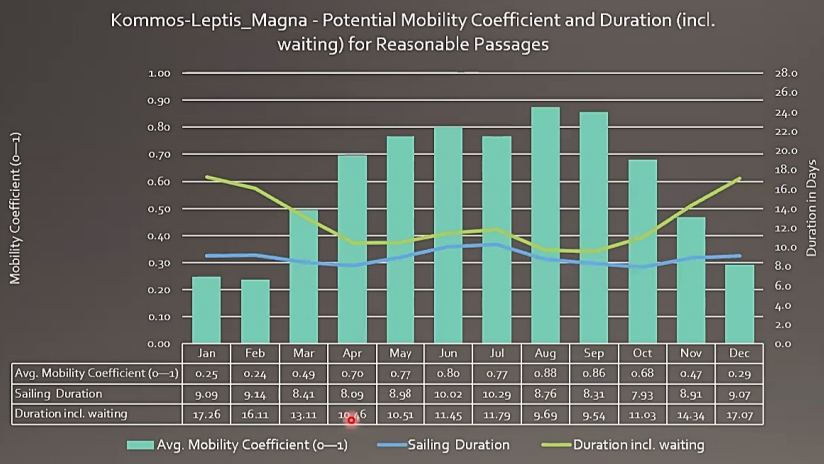
Potential Sailing Mobility from Kriou to Leptis Magna:
Probability of a reasonable passage and total duration (incl. waiting time)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg. Mobility Coefficient (0—1)	0.25	0.24	0.49	0.70	0.77	0.80	0.77	0.88	0.86	0.68	0.47	0.29
Sailing Duration	9.09	9.14	8.41	8.09	8.98	10.02	10.29	8.76	8.31	7.93	8.91	9.07
Duration incl. waiting	17.26	16.11	13.11	10.66	10.51	11.45	11.79	9.69	9.54	11.03	14.34	17.07

Summary Chart: Mobility Coefficient (0—1) and Duration including time spent waiting (days) averaged over 15 years (2004—2018)

Paramètres audio | Discussion | Lever la main | Q. et R. | Réactions | Quitter

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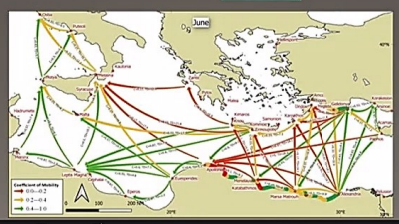
From measurements to case study:
Assessing the potential envelope of sailing mobility for a historic scenario

- Seasonal routing options
- Bottlenecks
- Coastal sailing options
- Sailing durations
- Time spent waiting
- Annual round trip planning



From measurements to assessments

Paramètres audio Discussion Lever la main Q. et R. Réactions Quitter

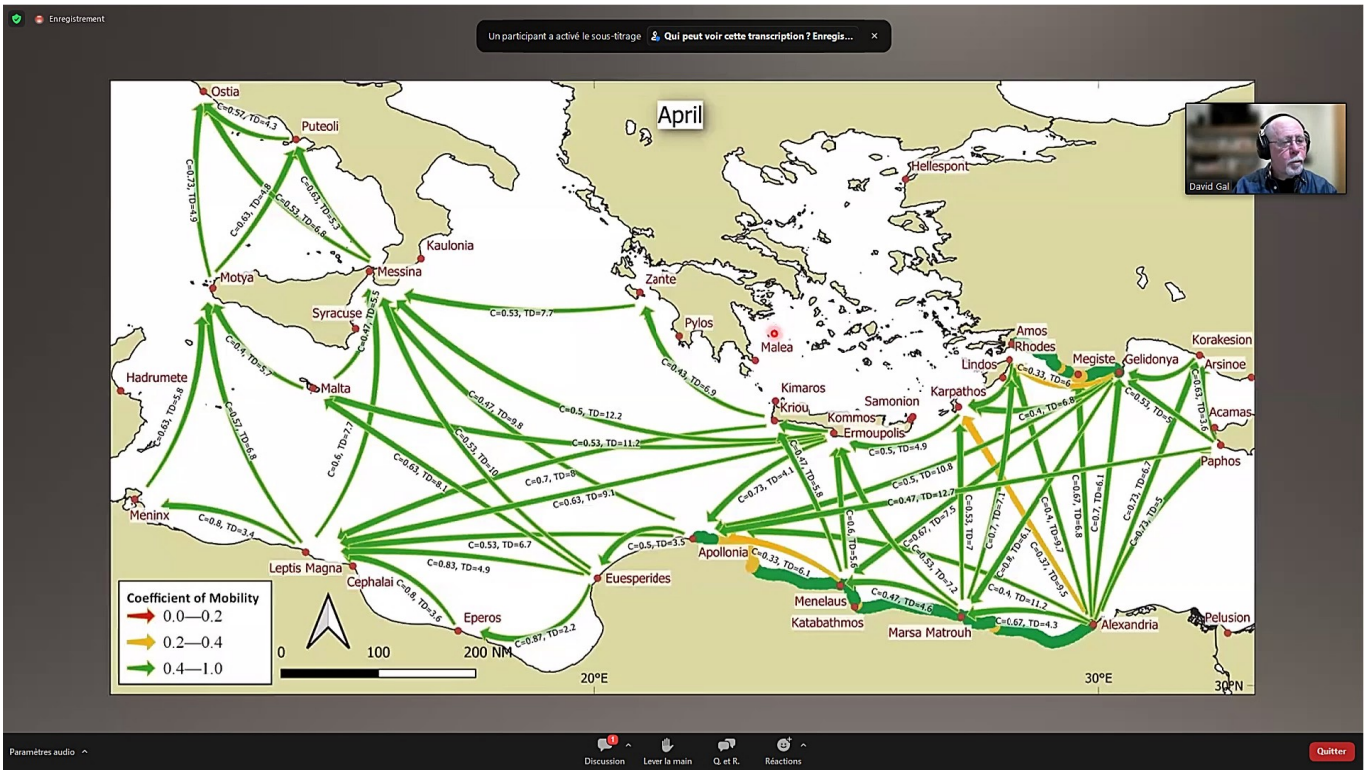
Enregistrement

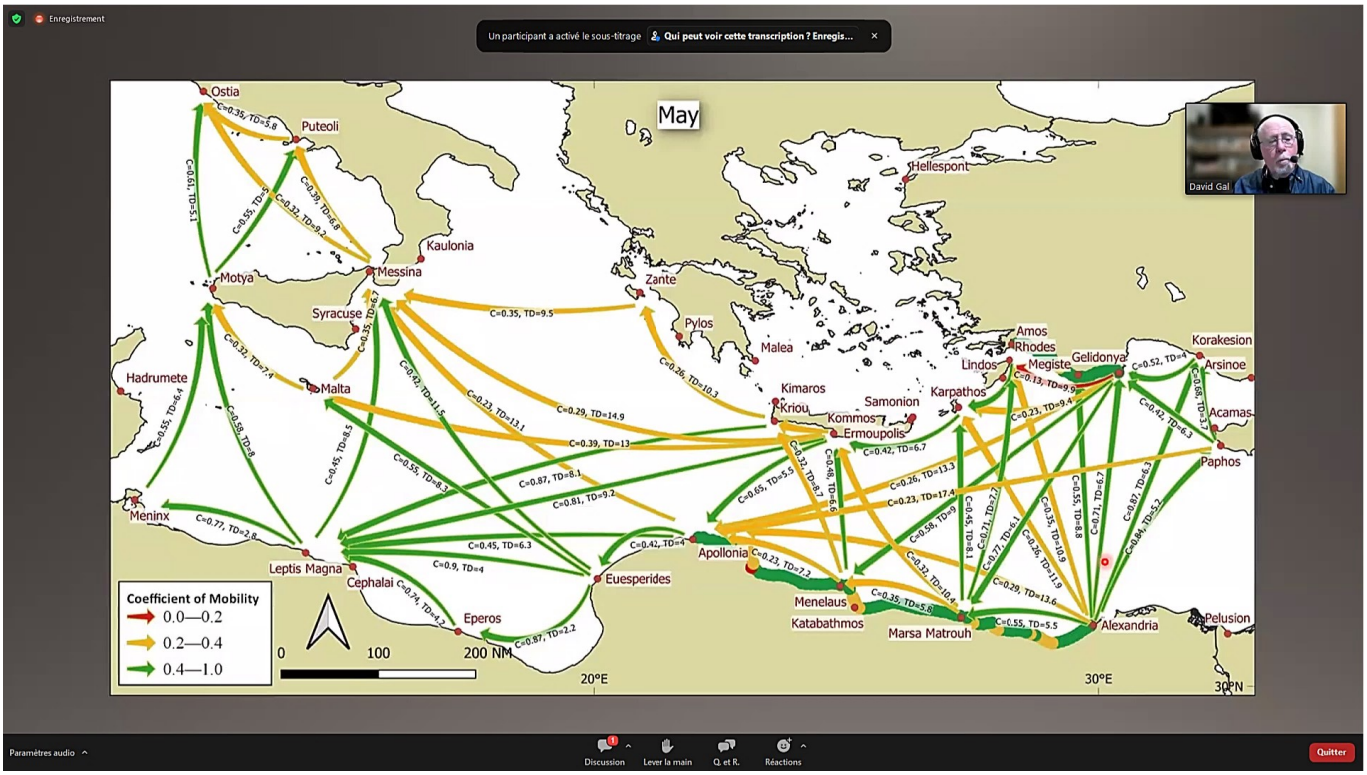
Un participant a activé le sous-titrage Qui peut voir cette transcription ? Enregis...

Potential sailing mobility in historic context

Shipping Egyptian grain to Rome

Paramètres audio Discussion Lever la main Q. et R. Réactions Quitter


Enregistrement
Un participant a activé le sous-titrage
Qui peut voir cette transcription ? Enregis...
April
David Gal
Ostia
Puteoli
Kaulonia
Messina
Motya
Syracuse
Malta
Hadrumete
Meninx
Leptis Magna
Cephalai
Eperos
Euesperides
Zante
Pylos
Malea
Hellespont
Kimaros
Kriou
Samonion
Kommos
Ermoupolis
Amos
Rhodes
Lindos
Megiste
Karpathos
Gelidonya
Korakesion
Arsinoe
Acamas
Paphos
Apollonia
Menelaus
Katabathmos
Marsa Matrouh
Alexandria
Pelusion
Coefficient of Mobility
0.0—0.2
0.2—0.4
0.4—1.0
0
100
200 NM
20°E
30°E
30°N
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter


Enregistrement
Un participant a activé le sous-titrage
Qui peut voir cette transcription ? Enregis...
May
David Gal
Ostia
Puteoli
Kaulonia
Messina
Motya
Syracuse
Malta
Hadrumete
Meninx
Leptis Magna
Cephalai
Eperos
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Zante
Pylos
Malea
Hellespont
Kimaros
Kriou
Samonion
Kommos
Ermoupolis
Amos
Rhodes
Lindos
Megiste
Karpathos
Gelidonya
Korakesion
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Coefficient of Mobility
0.0—0.2
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0
100
200 NM
20°E
30°E
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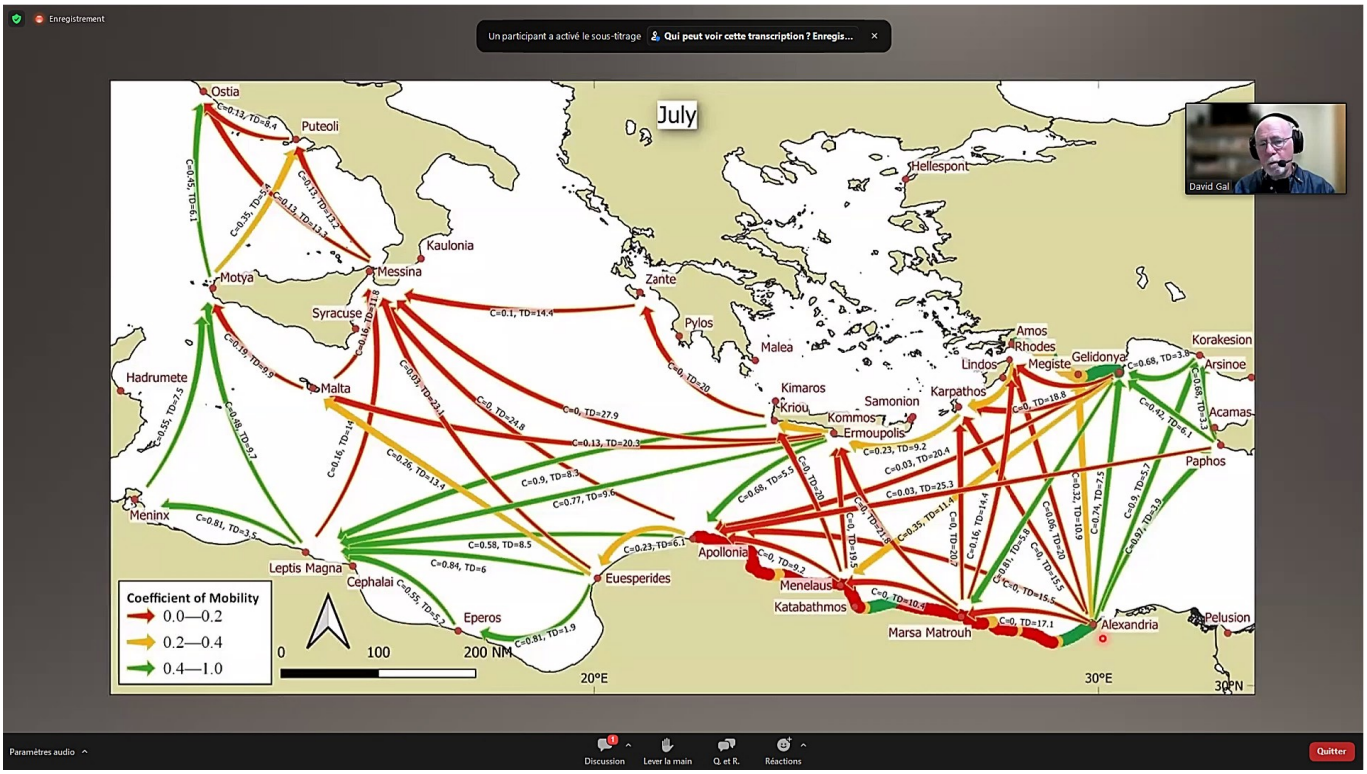
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter


Enregistrement
Un participant a activé le sous-titrage
Qui peut voir cette transcription ? Enregis...
July
David Gal
Ostia
Puteoli
Kaulonia
Messina
Motya
Syracuse
Hadrumete
Malta
Meninx
Leptis Magna
Cephalai
Eperos
Euesperides
Apollonia
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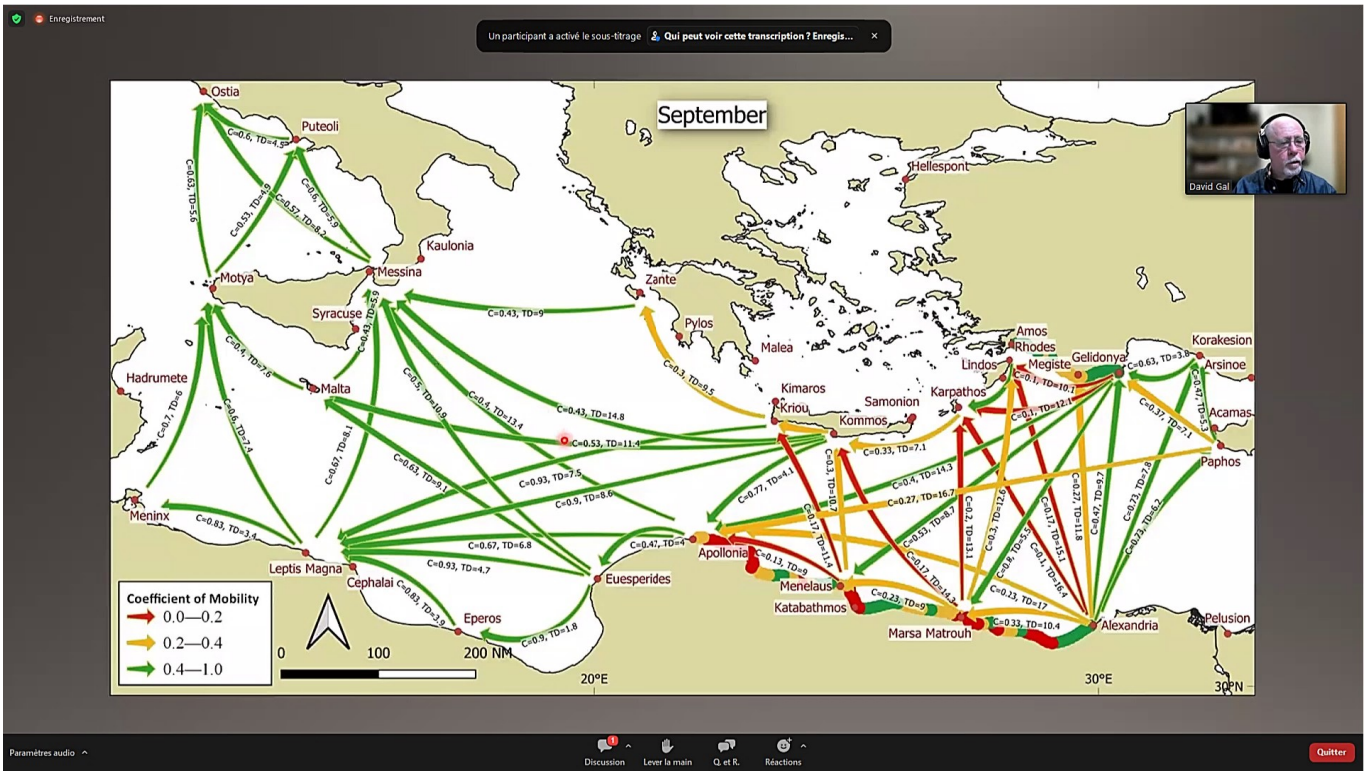
Alexandria
Pelusion
Coefficient of Mobility
0.0—0.2
0.2—0.4
0.4—1.0
0
100
200 NM
20°E
30°E
30°N
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter


Enregistrement
Un participant a activé le sous-titrage
Qui peut voir cette transcription ? Enregis...
September
David Gal
Ostia
Puteoli
Kaulonia
Messina
Motya
Syracuse
Hadrumete
Malta
Meninx
Leptis Magna
Cephalai
Eperos
Euesperides
Apollonia
Zante
Pylos
Malea
Hellespont
Kimaros
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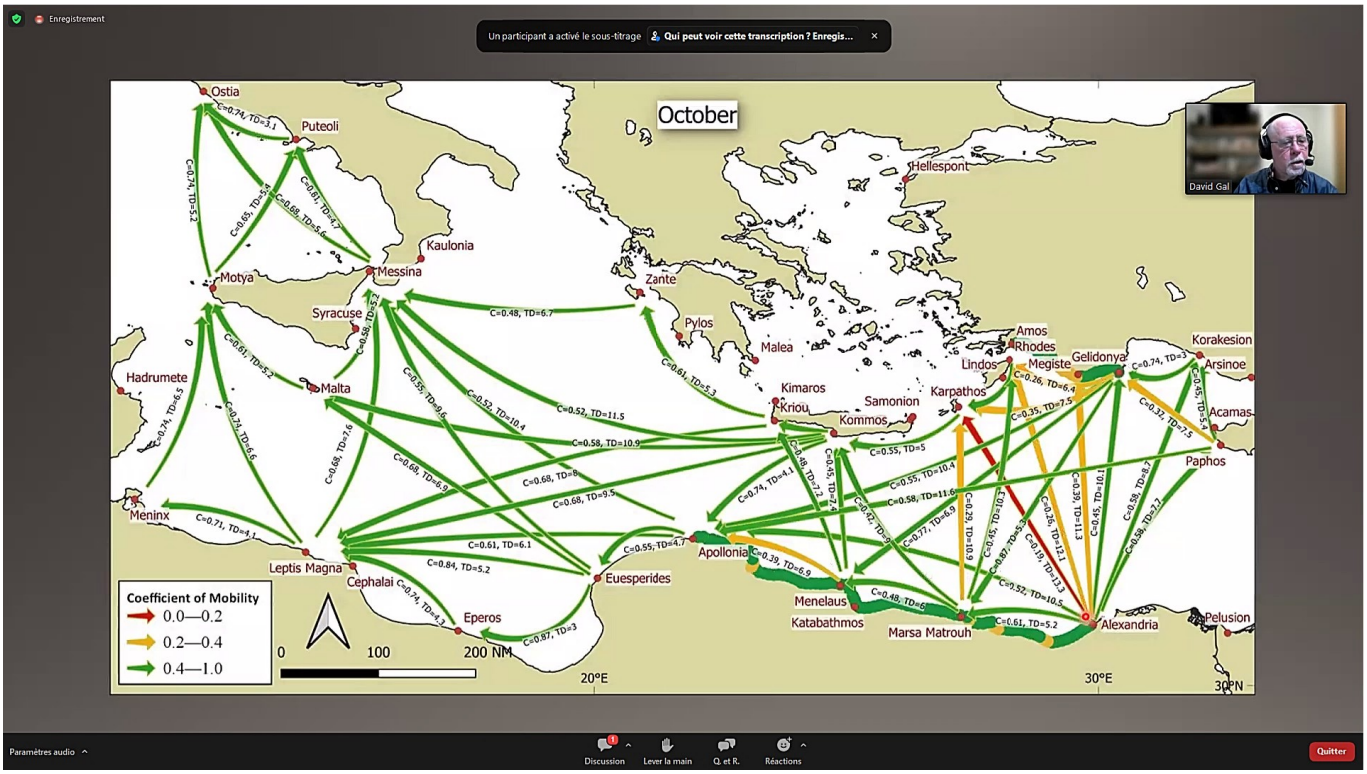
Alexandria
Pelusion
Coefficient of Mobility
0.0—0.2
0.2—0.4
0.4—1.0
0
100
200 NM
20°E
30°E
30°N
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter


Enregistrement
Un participant a activé le sous-titrage
Qui peut voir cette transcription ? Enregis...
October
Ostia
Puteoli
Hellespont
David Gal
Kaulonia
Messina
Motya
Zante
Syracuse
Pylos
Malea
Amos
Rhodes
Korakesion
Arsinoe
Lindos
Megiste
Gelidonya
Hadrumete
Malta
Kimaros
Kriou
Karpathos
Samonion
Kommos
Acamas
Paphos
Meninx
Leptis Magna
Cephalai
Eperos
Euesperides
Apollonia
Menelaus
Katabathmos
Marsa Matrouh
Alexandria
Pelusion
Coefficient of Mobility
0.0—0.2
0.2—0.4
0.4—1.0
0
100
200 NM
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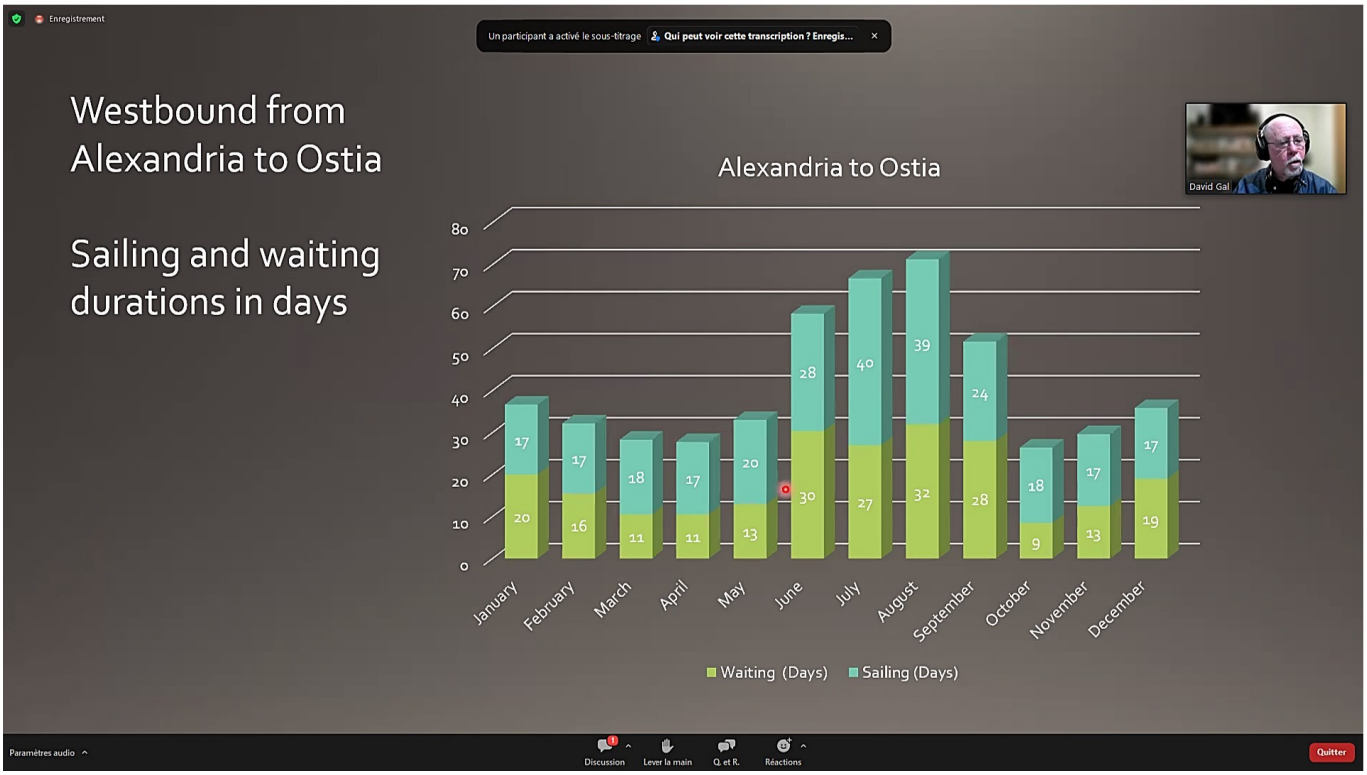
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter


Enregistrement
Un participant a activé le sous-titrage
Qui peut voir cette transcription ? Enregis...
Westbound from Alexandria to Ostia
Sailing and waiting durations in days
David Gal
Alexandria to Ostia
80
70
60
50
40
30
20
10
0
January 20 17
February 16 17
March 11 18
April 11 17
May 13 20
June 30 28
July 27 40
August 32 39
September 28 24
October 9 18
November 13 17
December 19 17
Waiting (Days)
Sailing (Days)
Paramètres audio
Discussion
Lever la main
Q. et R.
Réactions
Quitter

Enregistrement

Un participant a activé le sous-titrage Qui peut voir cette transcription ? Enregis... ×

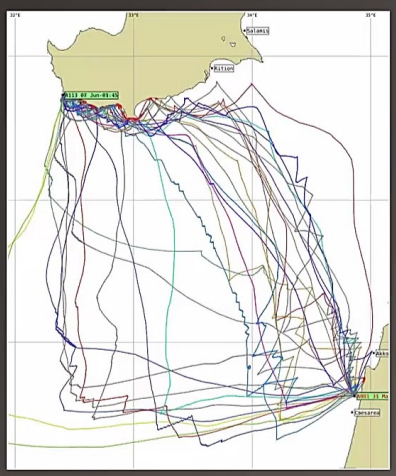
The human factor

Predicting favourable winds for a passage

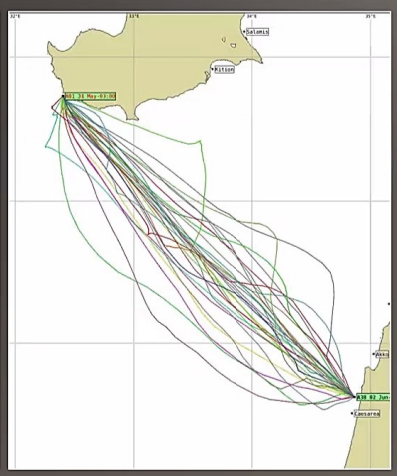
Paramètres audio Discussion Lever la main Q. et R. Réactions Quitter

Enregistrement

Un participant a activé le sous-titrage Qui peut voir cette transcription ? Enregis... ×



Sailings from Dor to Paphos in May 2005.



Sailings from Paphos to Dor in May 2005.

Could the ancient mariner predict when to sail and exploit a window of opportunity for favourable winds?

Could he predict when not to sail?

Paramètres audio Discussion Lever la main Q. et R. Réactions Quitter

Enregistrement

Un participant a activé le sous-titrage Qui peut voir cette transcription ? Enregis... ×

Sailing through history

Thank you

Special thanks to:

- My two supervisors, Debbie Cvikel and Hadas Saaroni
- The crew and volunteers of the replica ship *Ma'agan Mikhael II*

Acknowledgements

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Paramètres audio ^ Discussion Lever la main Q. et R. Réactions Quitter