Strategic Ship Routing with Satellite Altimeter-Based Dynamic Ocean Current Information : Impacts of Temporal Coverage

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OVERVIEW

- **Introduction**
  Study area: North Atlantic Gulf Stream Region

- **Selection of O-D pairs and Starting Dates**
  Starting dates are defined as the day a ship leaves the origin
  EastBound =the ship primarily traveling **with** the currents
  WestBound =the ship primarily traveling **against** the currents

- **Effect of Satellite Ground Track Accumulation**
  Does the strategy for accumulation of daily current estimates along the ground tracks really matter for the purpose of ship routing?

  If it does, how many days of ground track information should we accumulate to obtain the greatest fuel savings in routing ships when we accumulate daily current information along the ground tracks?

  What is the temporal coverage impact on ocean current routing as the information gets old?

- **Effect of Satellite Supply**
  What is the increased magnitude of fuel savings due to having two different ERP satellites simultaneously compared to having only one ERP satellite?

- **Effect of Information Scheme**
  Where should we concentrate research efforts for better routing performance when we utilize the satellite altimeter-based ocean current information?

- **Conclusion & Future Research**
  Spatial coverage effect and an accurate geoid model were most important in overall mean fuel savings. These effects were followed by the time lag effect and the satellite supply effect. Thus, we need to concentrate future research efforts on developing an accurate spatial interpolation model and an accurate geoid model for better routing performance.

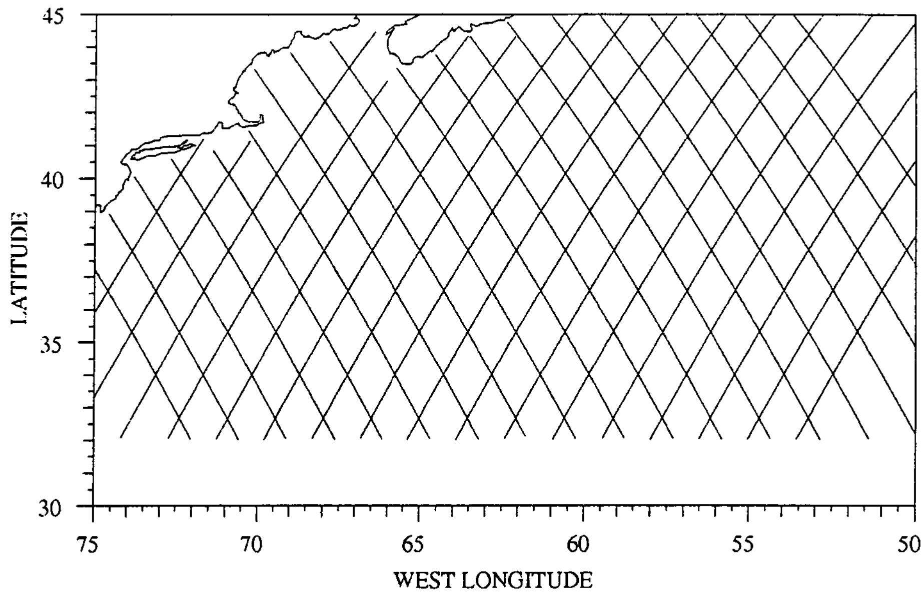

Figure 1: All Ground Tracks of a 17-day ERP Satellite in the Study Region.

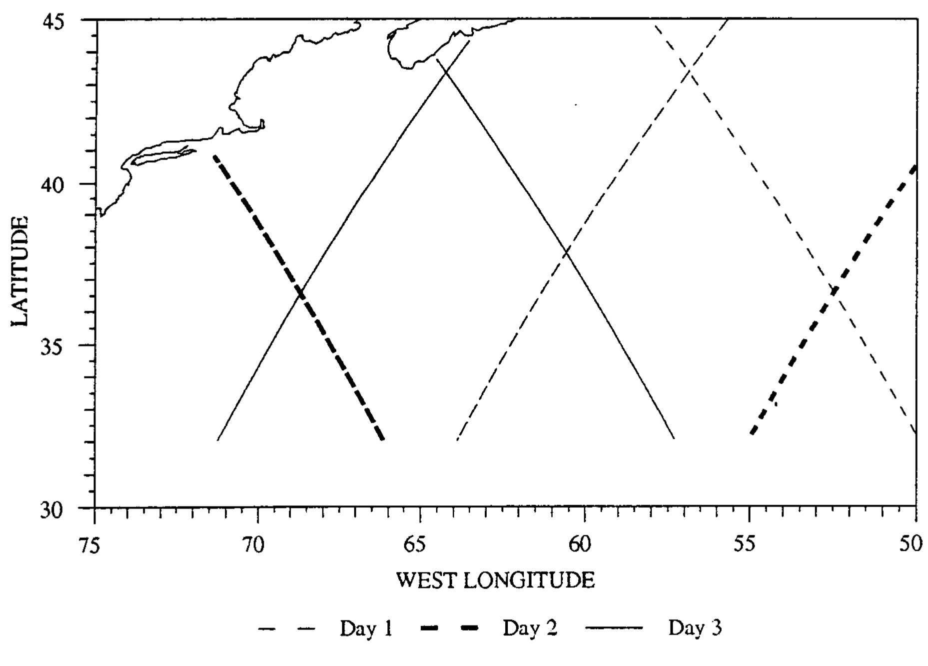

Figure 2: The 17-day ERP Ground Tracks for Three Consecutive Days in the Study Region.

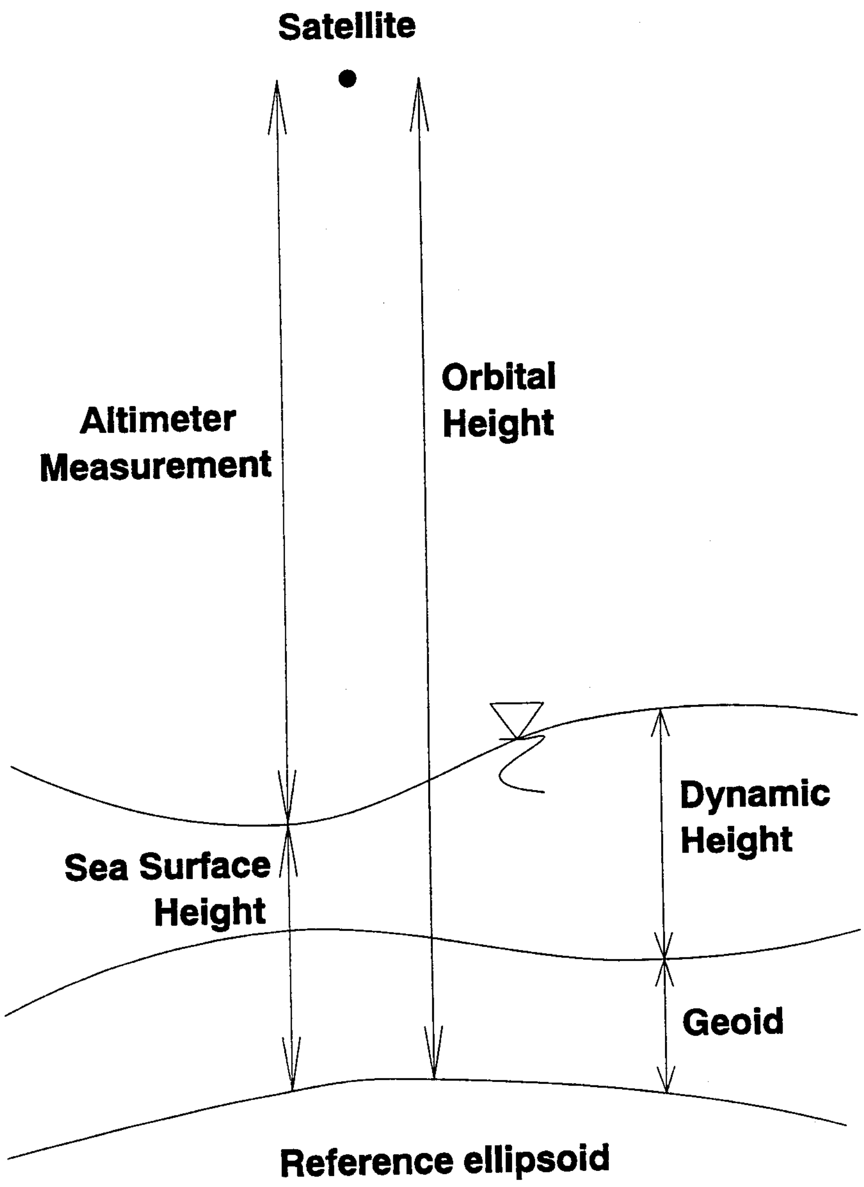

Figure 3: A schematic Diagram of an ERP Satellite Altimeter Measurement.

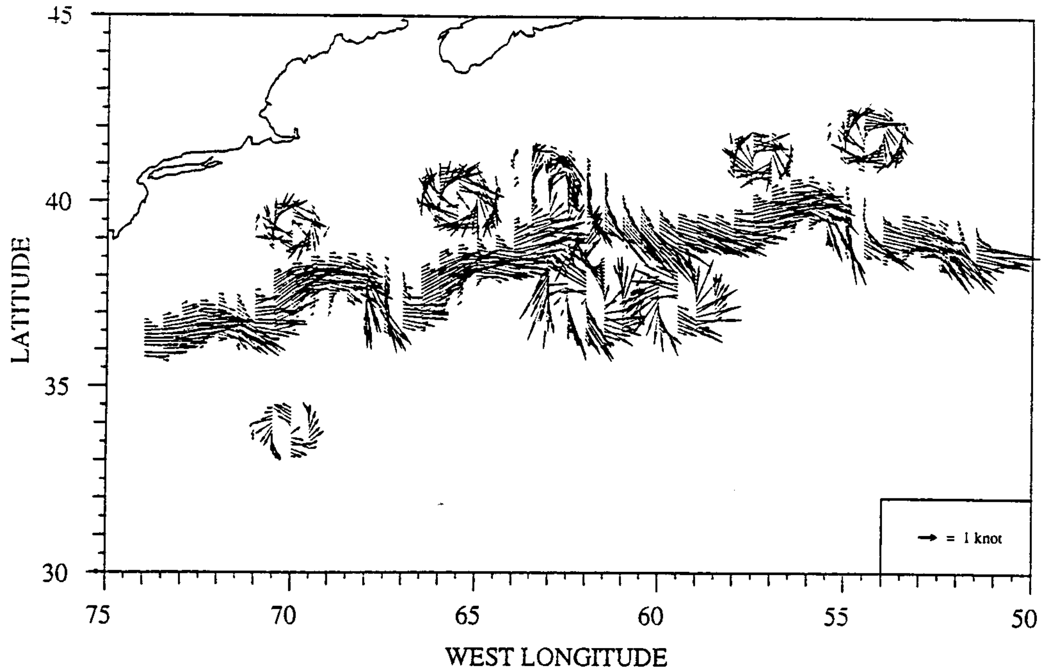

Figure 4: "True" Current Pattern on 5/21/88 based on Harvard Data

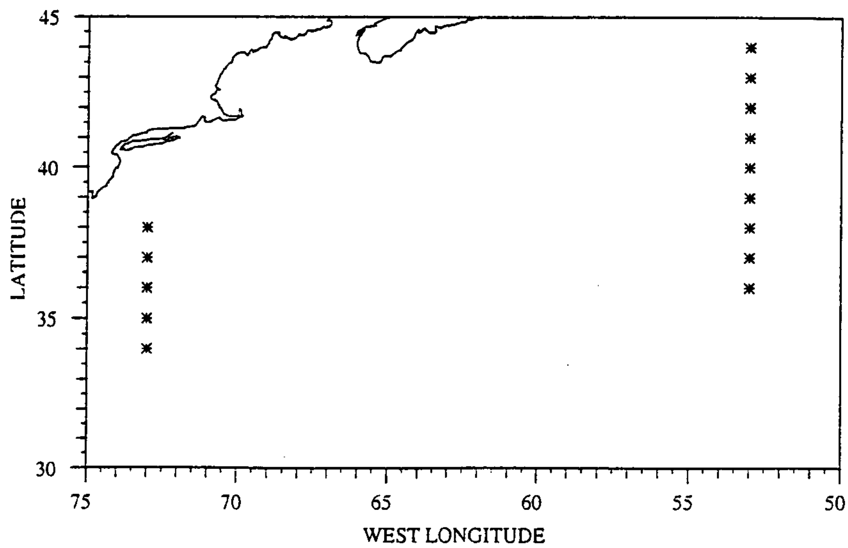

Figure 5: Origins and Destinations Forming Initial 45 O-D Pairs in the Study Region.

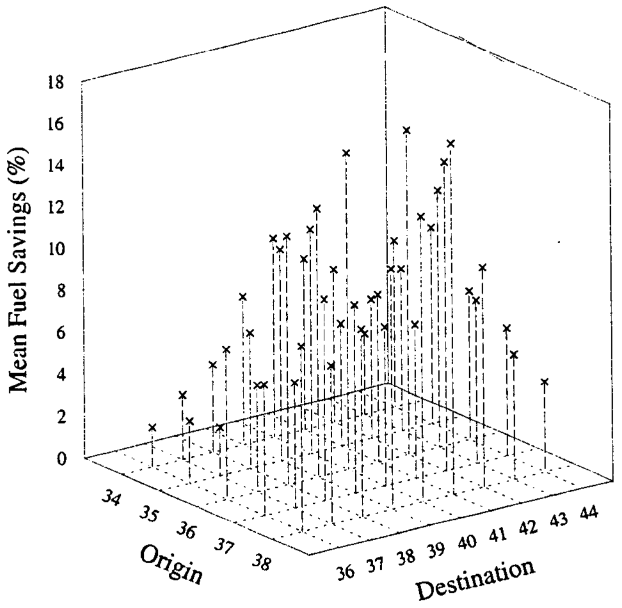

Figure 6: Eastbound MFS's of Each O-D Pair.

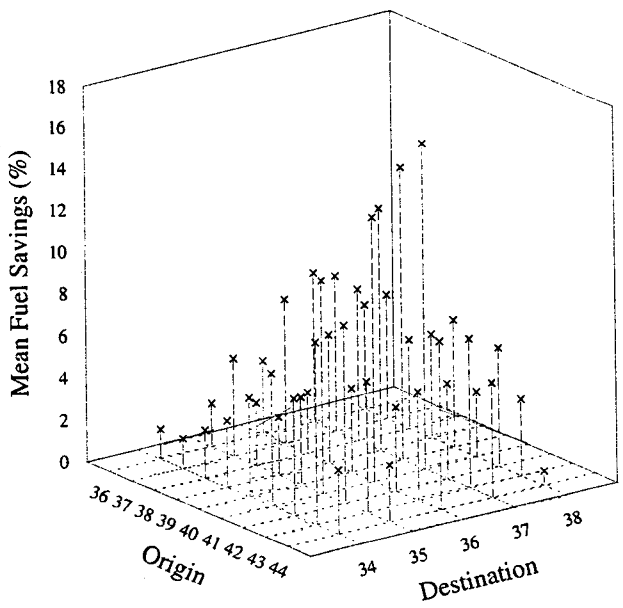

Figure 7: Westbound MFS's of Each O-D Pair.

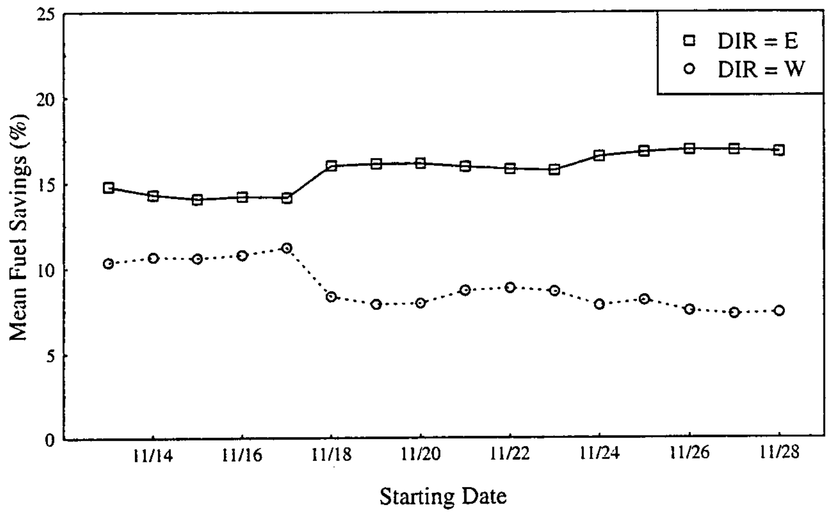

Figure 8: MFS of Possible Starting Dates in 1987.

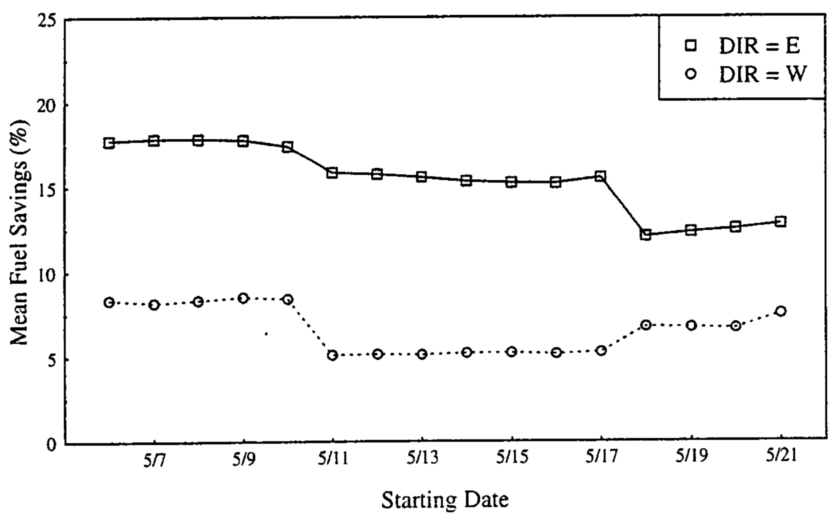

Figure 9: MFS of Possible Starting Dates in 1988.

Notation

$$FS = f(DIR, RT, LAG, INFO, SD, SAT, ACC, TRK)$$

where

FS = relative fuel savings
DIR = direction of voyage
RT = O-D pair for the routing
LAG = time lag of acquiring the current info
INFO = info scheme for estimating the current profile
SD = starting date
SAT = supply of the satellite
ACC = accumulation of daily info
TRK = # of ground track & the sequence

DIR ∈ **{E, W}**
RT ∈ **{RT_1(*A-A*), RT_2(*A-B*), RT_3(*I-I*), RT_4(*B-B*)} for DIR = E**
∈ **{RT_5(*I-I*), RT_6(*B-B*), RT_7(*B-A*)} for DIR = W**
LAG ∈ **{0, 7}**
INFO ∈ **{M, P, F, Nt, Ft}**
SD ∈ **{SD_1(11/15/87), SD_2(11/22/87), SD_3(11/28/87), SD_4(5/6/88), SD_5(5/11/88), SD_6(5/21/88)}**
SAT ∈ **{T, G, C}**
ACC ∈ **{5, 8, 11, 14, 17} for SAT = G**
∈ **{4, 7, 10} for SAT = T**
∈ **{T_4G_5, T_4G_8, …, $T_{10}G_{14}$, $T_{10}G_{17}$}**
TRK ∈ **{1, 2, …, 16, 17} for SAT = G**
∈ **{1, 2, …, 9, 10} for SAT = T**
∈ **{1, 2, …, 29, 30} for SAT = C**

Simulation Framework

1. Choose the starting date.

2. Select the "true" currents patterns.

3. Extract the ground tracks of each ERP satellite.

4. Extract velocities depending on the information schemes along the ground tracks.

5. Aggregate the data from Step 3 to produce a single "snapshot" of 0.1° latitude by 0.5° longitude gridded current vectors.

6. Run the optimization with the "estimated" currents in Step 4 to find estimated minimum fuel consumption/time route.

7. Use the "true" currents patterns to get travel time T on this minimum time route.

8. Use the "true" currents pattern to get Vwo on the great circle route to arrive at T.

9. Compute the relative fuel savings.

Table 4: Mean Relative Fuel Savings (%) for a 10-day ERP Satellite with Real- and "Near" Real-time Information.

DIR	LAG	INFO	ACC	MFS	Std. Dev.	Number of Cases
E	0	M	4	2.36	4.22	240
			7	2.76	4.94	240
			10	2.98	5.19	240
		P	4	3.10	4.44	240
			7	4.11	5.19	240
			10	4.51	5.64	240
		F	4	3.37	4.55	240
			7	4.07	5.37	240
			10	4.48	5.76	240
W	0	M	4	0.43	2.65	180
			7	0.83	3.34	180
			10	0.97	3.73	180
		P	4	0.86	2.67	180
			7	1.73	3.22	180
			10	2.40	3.08	180
		F	4	1.16	2.96	180
			7	2.04	3.37	180
			10	2.41	3.52	180
E	7	M	4	0.68	4.65	240
			7	0.83	5.32	240
			10	0.76	5.71	240
		P	4	1.65	4.72	240
			7	2.44	5.78	240
			10	2.59	6.23	240
W	7	M	4	-0.66	3.83	180
			7	-0.11	4.12	180
			10	-0.22	4.37	180
		P	4	0.63	2.57	180
			7	1.29	3.26	180
			10	1.57	3.54	180

Table 7: Mean Relative Fuel Savings (%) for a 17-day ERP Satellite with Real-time Information.

DIR	LAG	INFO	ACC	MFS	Std. Dev.	Number of Cases
E	0	M	5	2.41	4.33	408
			8	2.72	4.68	408
			11	2.63	5.03	408
			14	2.52	5.18	408
			17	2.15	5.17	408
		P	5	3.64	4.72	408
			8	4.21	4.81	408
			11	4.51	4.97	408
			14	4.64	4.78	408
			17	4.23	4.88	408
		F	5	3.95	4.66	408
			8	4.61	4.96	408
			11	4.99	4.88	408
			14	4.70	4.97	408
			17	4.18	5.03	408
W	0	M	5	-0.15	3.69	306
			8	-0.13	4.20	306
			11	-0.34	4.39	306
			14	-0.15	4.96	306
			17	-0.29	5.10	306
		P	5	0.45	3.57	306
			8	1.21	3.87	306
			11	1.83	4.03	306
			14	1.94	4.12	306
			17	1.83	4.26	306
		F	5	0.72	3.22	306
			8	1.29	3.71	306
			11	2.04	3.91	306
			14	2.47	3.92	306
			17	2.11	4.26	306

Table 8: Mean Relative Fuel Savings (%) for a 17-day ERP Satellite with "Near" Real-time Information.

DIR	LAG	INFO	ACC	MFS	Std. Dev.	Number of Cases
E	7	M	5	1.67	4.31	272
			8	1.85	4.80	272
			11	1.59	4.81	272
			14	1.50	4.87	272
		P	5	2.79	4.51	272
			8	3.00	4.73	272
			11	3.22	4.68	272
			14	2.74	4.97	272
W	7	M	5	-0.48	3.42	204
			8	-0.58	4.32	204
			11	-0.90	5.58	204
			14	-1.02	5.32	204
		P	5	0.08	3.29	204
			8	0.39	3.55	204
			11	0.36	3.84	204
			14	0.53	4.01	204

Table 12: Eastbound MFS's(%) with 10- and 17-day ERP Satellites Simultaneously with Real-time Information.

DIR	LAG	INFO	ACC	Mean	Std. Dev.	Number of Cases
E	0	P	T_4G_5	5.05	4.96	720
			T_4G_8	5.29	5.11	720
			T_4G_{11}	5.32	5.15	720
			T_4G_{14}	5.11	4.74	720
			T_4G_{17}	5.07	5.00	720
			T_7G_5	5.05	5.04	720
			T_7G_8	5.25	5.24	720
			T_7G_{11}	5.08	5.17	720
			T_7G_{14}	5.04	4.77	720
			T_7G_{17}	4.92	5.03	720
			$T_{10}G_5$	5.18	5.59	720
			$T_{10}G_8$	5.44	5.53	720
			$T_{10}G_{11}$	5.32	5.38	720
			$T_{10}G_{14}$	5.09	5.22	720
			$T_{10}G_{17}$	4.94	5.12	720

Table 14: Westbound MFS's(%) with 10- and 17-day ERP Satellites Simultaneously with Real-time Information.

DIR	LAG	INFO	ACC	Mean	Std. Dev.	Number of Cases
W	0	P	T_4G_5	2.05	3.37	540
			T_4G_8	2.21	3.55	540
			T_4G_{11}	2.35	3.79	540
			T_4G_{14}	2.51	3.93	540
			T_4G_{17}	2.49	4.06	540
			T_7G_5	2.30	3.55	540
			T_7G_8	2.49	3.58	540
			T_7G_{11}	2.62	3.88	540
			T_7G_{14}	2.57	4.02	540
			T_7G_{17}	2.59	3.88	540
			$T_{10}G_5$	2.84	3.63	540
			$T_{10}G_8$	2.88	3.74	540
			$T_{10}G_{11}$	2.94	3.98	540
			$T_{10}G_{14}$	2.67	4.09	540
			$T_{10}G_{17}$	2.54	4.03	540

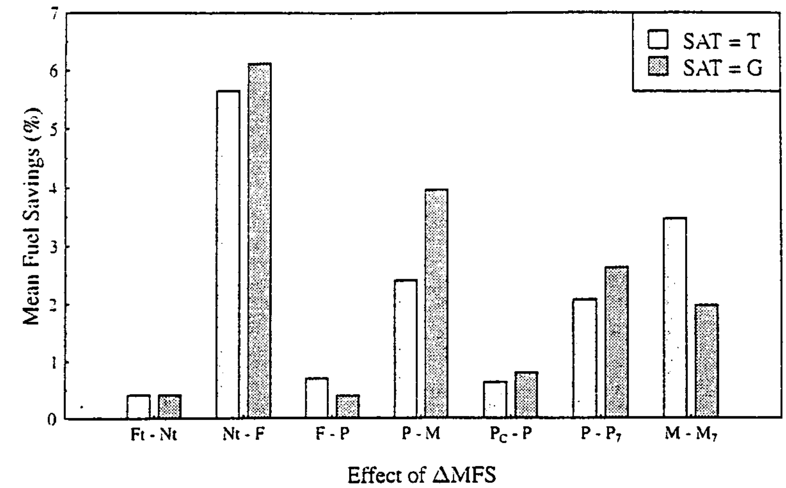

Figure 64: Eastbound ΔMFS's comparison for an O-D Pair *A-A*. Subscript C represents SAT = C, and 7 represents LAG = 7.

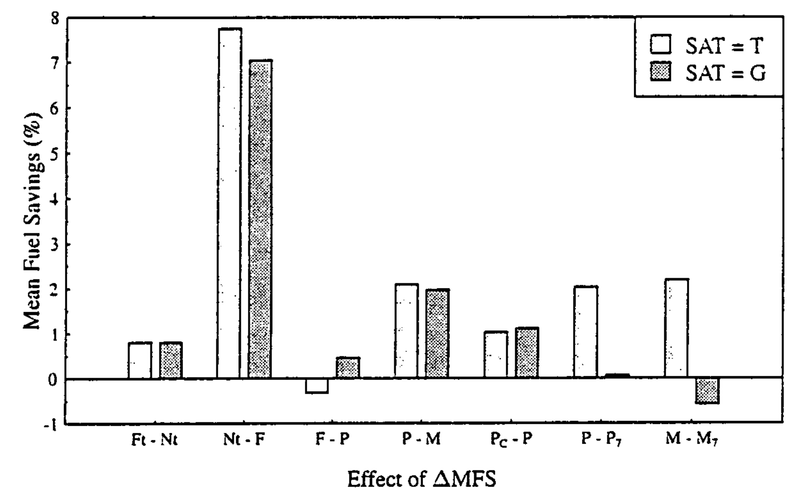

Figure 67: Eastbound ΔMFS's comparison for an O-D Pair *I-I*. Subscript C represents SAT = C, and 7 represents LAG = 7.

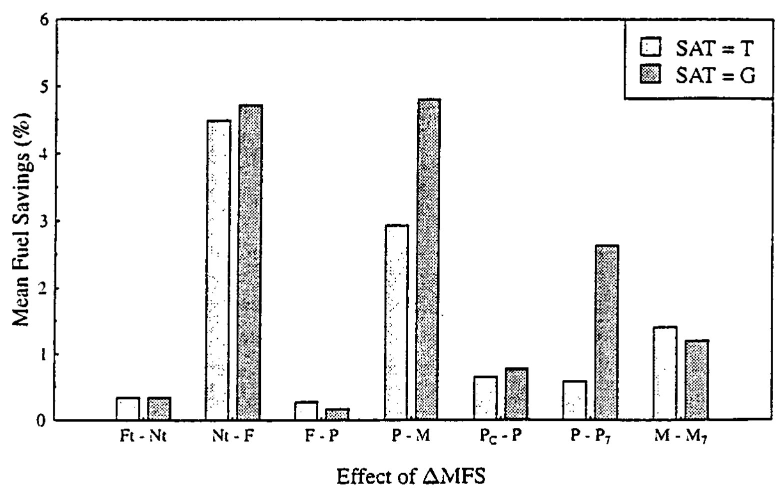

Figure 70: Westbound ΔMFS's comparison for an O-D Pair *I-I*. Subscript C represents SAT = C, and 7 represents LAG = 7.

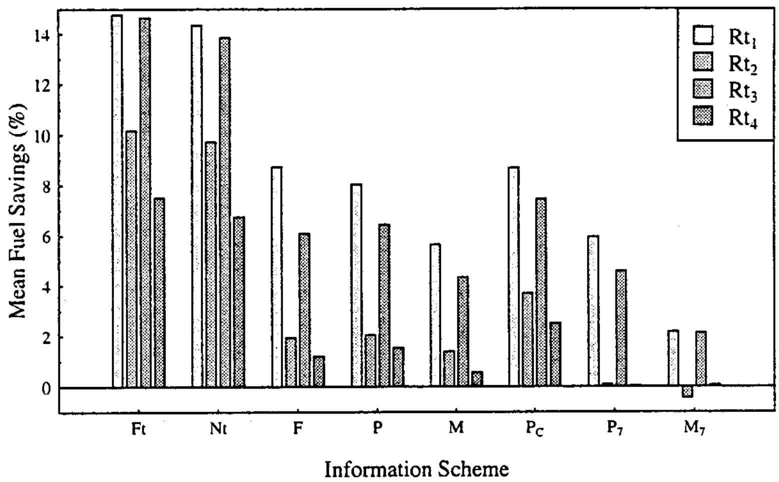

Figure 58: Eastbound MFS's of Each O-D Pair under Each INFO with LAG = 0 for SAT = T. Subscript C represents SAT = C, and 7 represents LAG = 7.

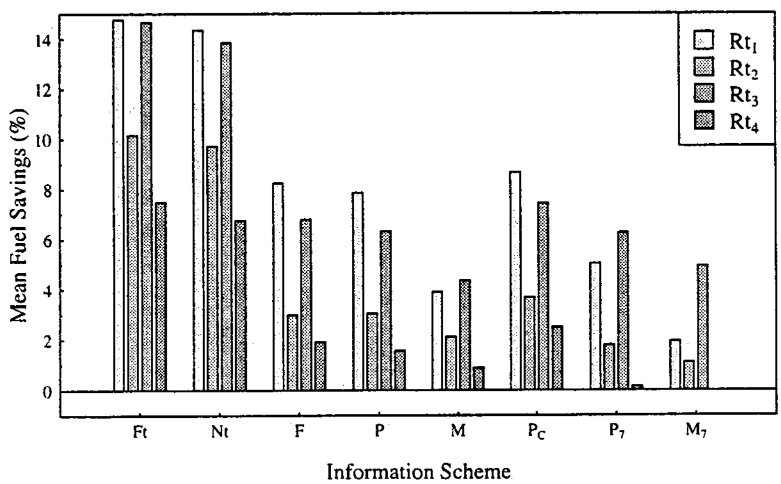

Figure 59: Eastbound MFS's of Each O-D Pair under Each INFO with LAG = 0 for SAT = G. Subscript C represents SAT = C, and 7 represents LAG = 7.

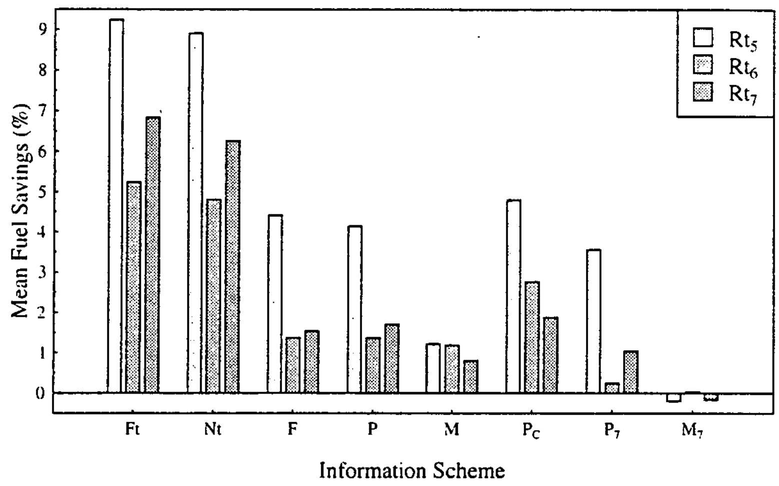

Figure 60: Westbound MFS's of Each O-D Pair under Each INFO with LAG = 0 for SAT = T. Subscript C represents SAT = C, and 7 represents LAG = 7.

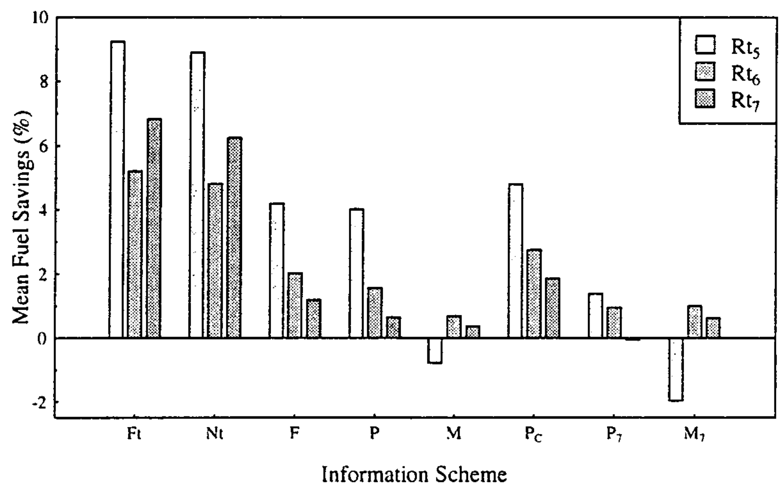

Figure 61: Westbound MFS's of Each O-D Pair under Each INFO with LAG = 0 for SAT = G. Subscript C represents SAT = C, and 7 represents LAG = 7.

Conclusion & Future Research

How many days of ground track information should we accumulate to obtain the greatest fuel savings in routing ships when we accumulate daily current information along the ground tracks?

SAT	DIR	LAG	INFO	MFS(%)	ACC
T	E	0	M	2.98	10
			P	4.51	10
			F	4.48	10
	W	0	M	0.97	10
			P	2.40	10
			F	2.41	10
	E	7	M	0.83	7
			P	2.59	10
	W	7	M	-0.11	7
			P	1.57	10
G	E	0	M	2.72	8
			P	4.64	14
			F	4.99	11
	W	0	M	-0.13	8
			P	1.94	14
			F	2.47	14
	E	7	M	1.85	8
			P	3.22	11
	W	7	M	-0.48	5
			P	0.53	14

- **Effect of Satellite Supply**

  What is the increased magnitude of fuel savings due to having two different ERP satellites simultaneously compared to having only one ERP satellite?

EB:	MFS(SAT=C)	>	MFS(SAT=T)	0.93% more
	MFS(SAT=C)	>	MFS(SAT=G)	0.80% more
WB:	MFS(SAT=C)	>	MFS(SAT=T)	0.54% more
	MFS(SAT=C)	>	MFS(SAT=G)	1.00% more

- **Effect of Information Scheme**

  Where should we concentrate research efforts for better routing performance when we utilize the satellite altimeter-based ocean current information?

  Spatial coverage effect and an accurate geoid model were most important in overall mean fuel savings. These effects were followed by the time lag effect and the satellite supply effect. Thus, we need to concentrate future research efforts on developing an accurate spatial interpolation model and an accurate geoid model for better routing performance.