Climate Change and Polar Regions: Implications for Shipping and Resource Extraction

Scott R. Stephenson
University of Connecticut, Storrs, CT

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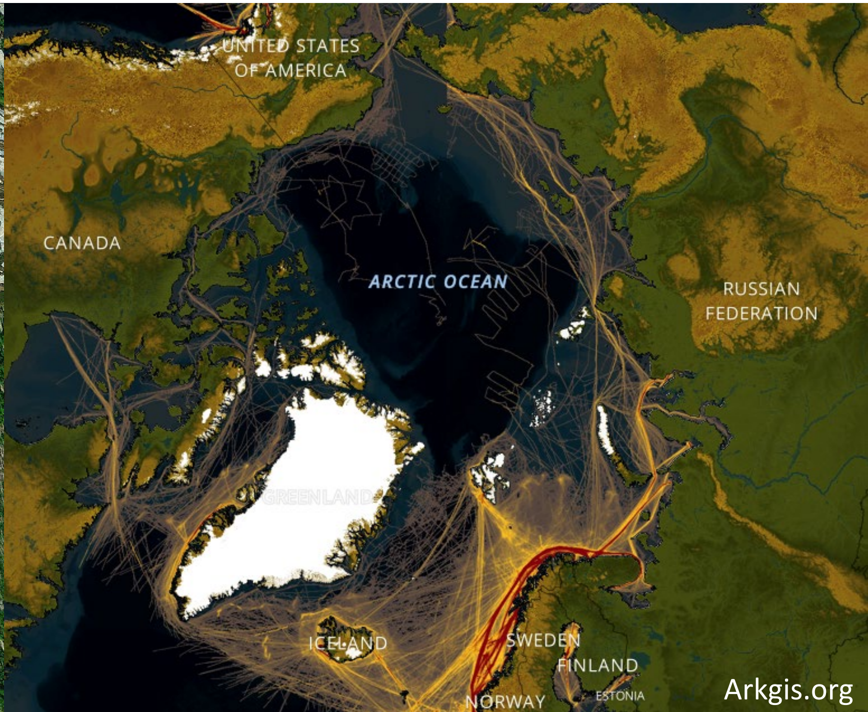
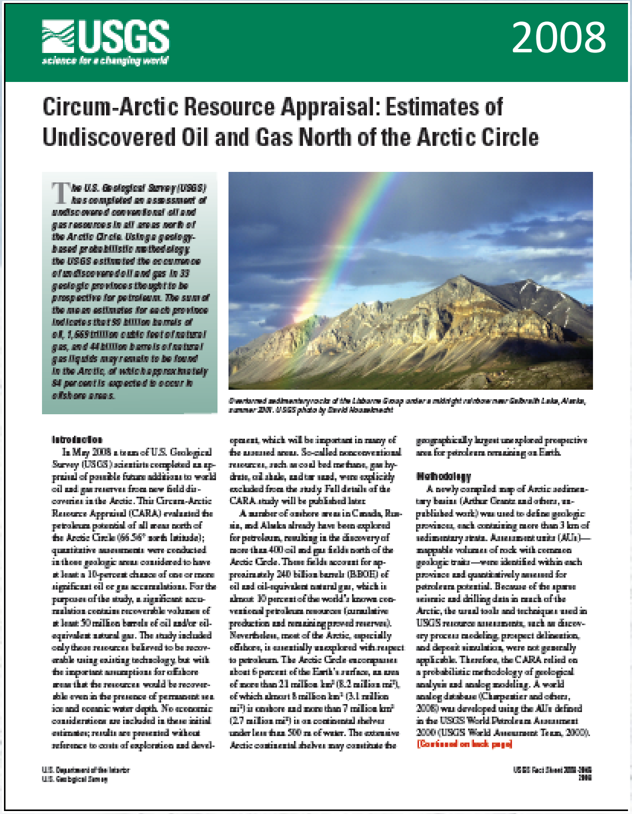
stephenson@uconn.edu



1. How will climate change realistically enable access to the Arctic?
2. To what extent do these predictions depend on model choice?
3. How do oil and gas resources shape economic development in the Arctic?



USGS
science for a changing world

2008

Circum-Arctic Resource Appraisal: Estimates of Undiscovered Oil and Gas North of the Arctic Circle

The U.S. Geological Survey (USGS) has completed an assessment of undiscovered conventional oil and gas resources in all areas north of the Arctic Circle. Using a geology-based probabilistic methodology, the USGS estimated the occurrence of undiscovered oil and gas in 33 geologic provinces thought to be prospective for petroleum. The sum of the mean estimates for each province indicates that 90 billion barrels of oil, 1,669 trillion cubic feet of natural gas, and 44 billion barrels of natural gas liquids may remain to be found in the Arctic, of which approximately 84 percent is expected to occur in offshore areas.

Overturned sedimentary rocks of the Lisburne Group under a midnight rainbow near Galbraith Lake, Alaska, summer 2001. USGS photo by David Houseknecht

Introduction

In May 2008 a team of U.S. Geological Survey (USGS) scientists completed an appraisal of possible future additions to world oil and gas reserves from new field discoveries in the Arctic. This Circum-Arctic Resource Appraisal (CARA) evaluated the petroleum potential of all areas north of the Arctic Circle (66.56° north latitude); quantitative assessments were conducted in those geologic areas considered to have at least a 10-percent chance of one or more significant oil or gas accumulations. For the purposes of the study, a significant accumulation contains recoverable volumes of at least 50 million barrels of oil and/or oil-equivalent natural gas. The study included only those resources believed to be recoverable using existing technology, but with the important assumptions for offshore areas that the resources would be recoverable even in the presence of permanent sea ice and oceanic water depth. No economic considerations are included in these initial estimates; results are presented without reference to costs of exploration and development, which will be important in many of the assessed areas. So-called nonconventional resources, such as coal bed methane, gas hydrate, oil shale, and tar sand, were explicitly excluded from the study. Full details of the CARA study will be published later.

A number of onshore areas in Canada, Russia, and Alaska already have been explored for petroleum, resulting in the discovery of more than 400 oil and gas fields north of the Arctic Circle. These fields account for approximately 240 billion barrels (BBOE) of oil and oil-equivalent natural gas, which is almost 10 percent of the world's known conventional petroleum resources (cumulative production and remaining proved reserves). Nevertheless, most of the Arctic, especially offshore, is essentially unexplored with respect to petroleum. The Arctic Circle encompasses about 6 percent of the Earth's surface, an area of more than 21 million km² (8.2 million mi²), of which almost 8 million km² (3.1 million mi²) is onshore and more than 7 million km² (2.7 million mi²) is on continental shelves under less than 500 m of water. The extensive Arctic continental shelves may constitute the geographically largest unexplored prospective area for petroleum remaining on Earth.

Methodology

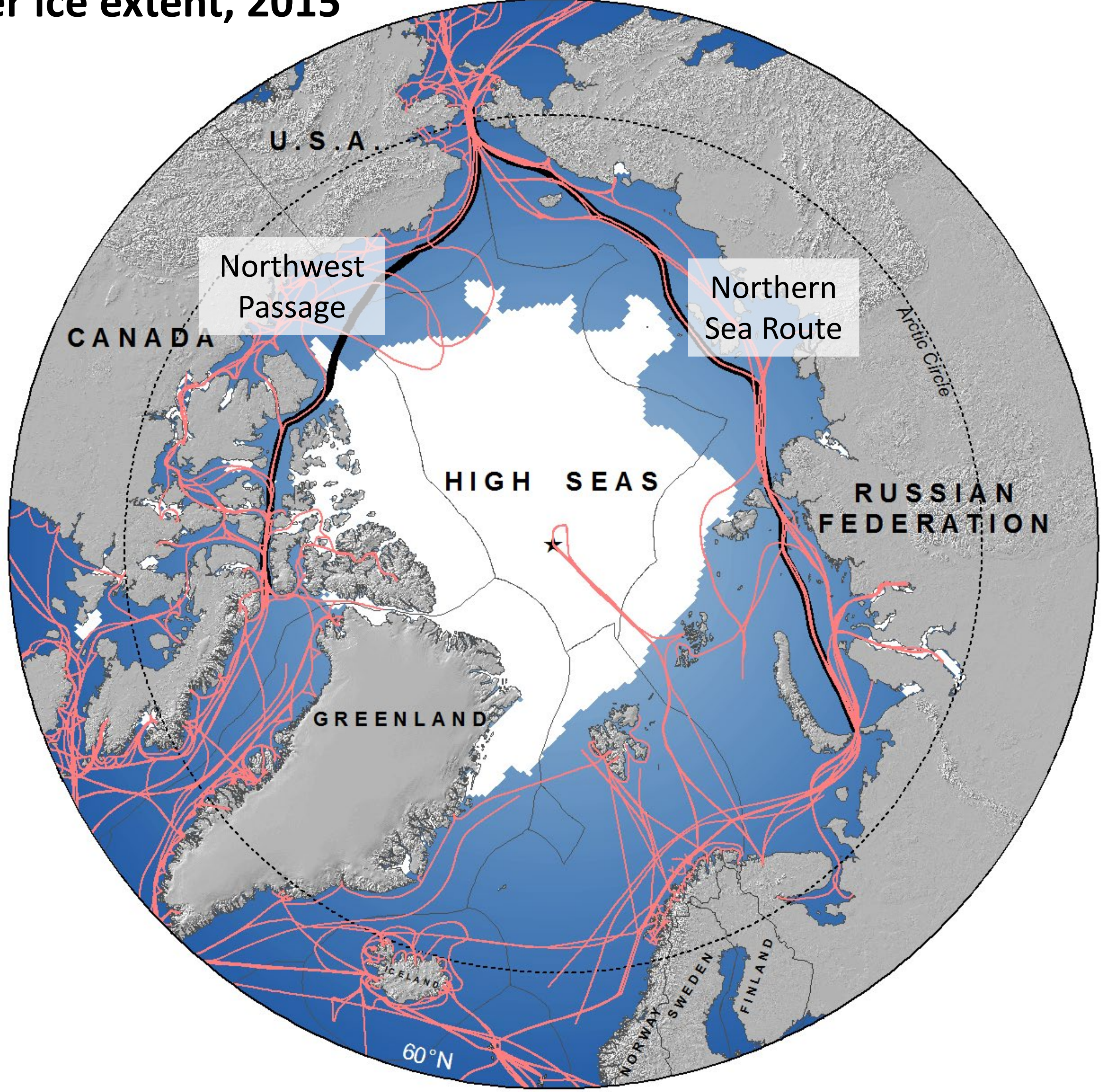
A newly compiled map of Arctic sedimentary basins (Arthur Grantz and others, unpublished work) was used to define geologic provinces, each containing more than 3 km of sedimentary strata. Assessment units (AUs)—mappable volumes of rock with common geologic traits—were identified within each province and quantitatively assessed for petroleum potential. Because of the sparse seismic and drilling data in much of the Arctic, the usual tools and techniques used in USGS resource assessments, such as discovery process modeling, prospect delineation, and deposit simulation, were not generally applicable. Therefore, the CARA relied on a probabilistic methodology of geological analysis and analog modeling. A world analog database (Charpentier and others, 2008) was developed using the AUs defined in the USGS World Petroleum Assessment 2000 (USGS World Assessment Team, 2000).

[Continued on back page]

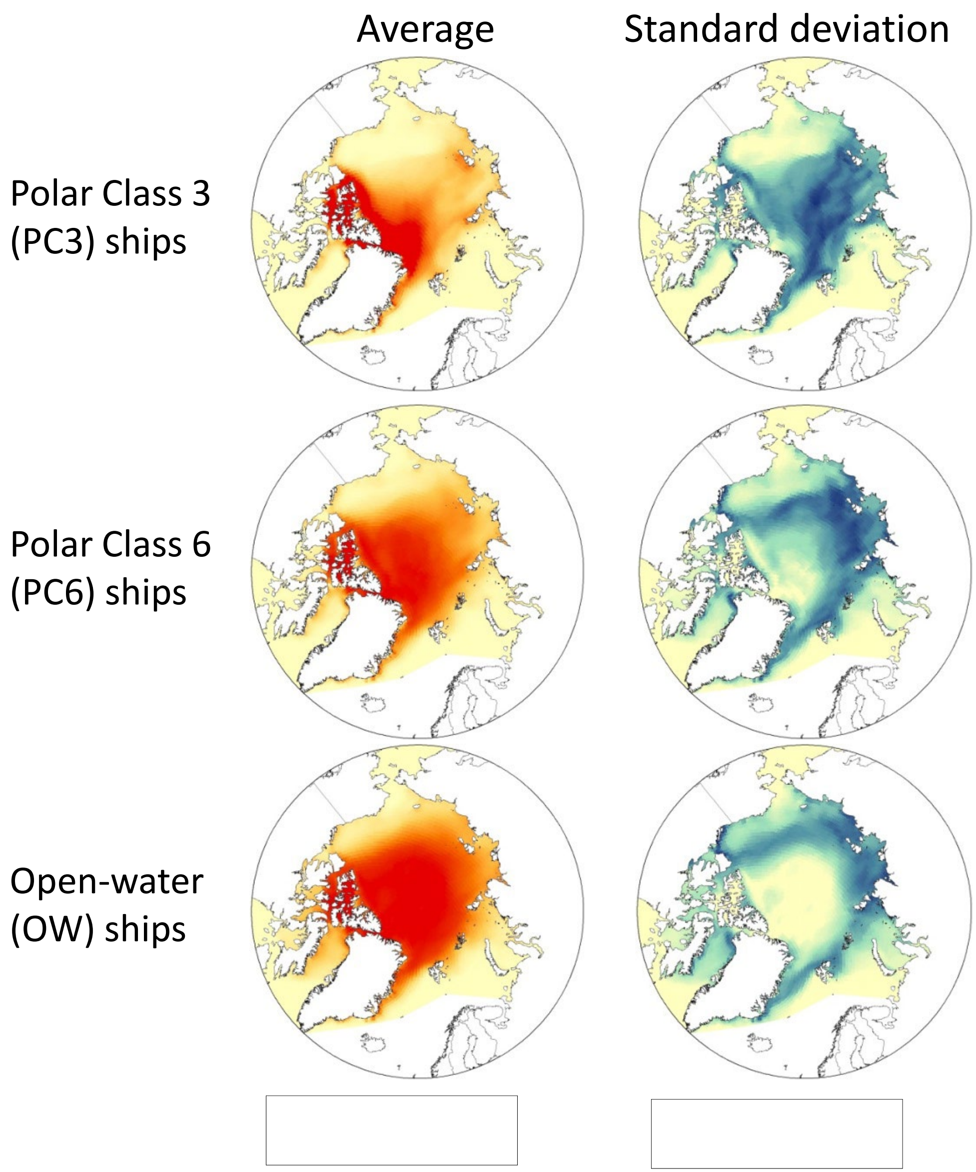
U.S. Department of the Interior
U.S. Geological Survey

USGS Fact Sheet 2008-3049
2008

September ice extent, 2015

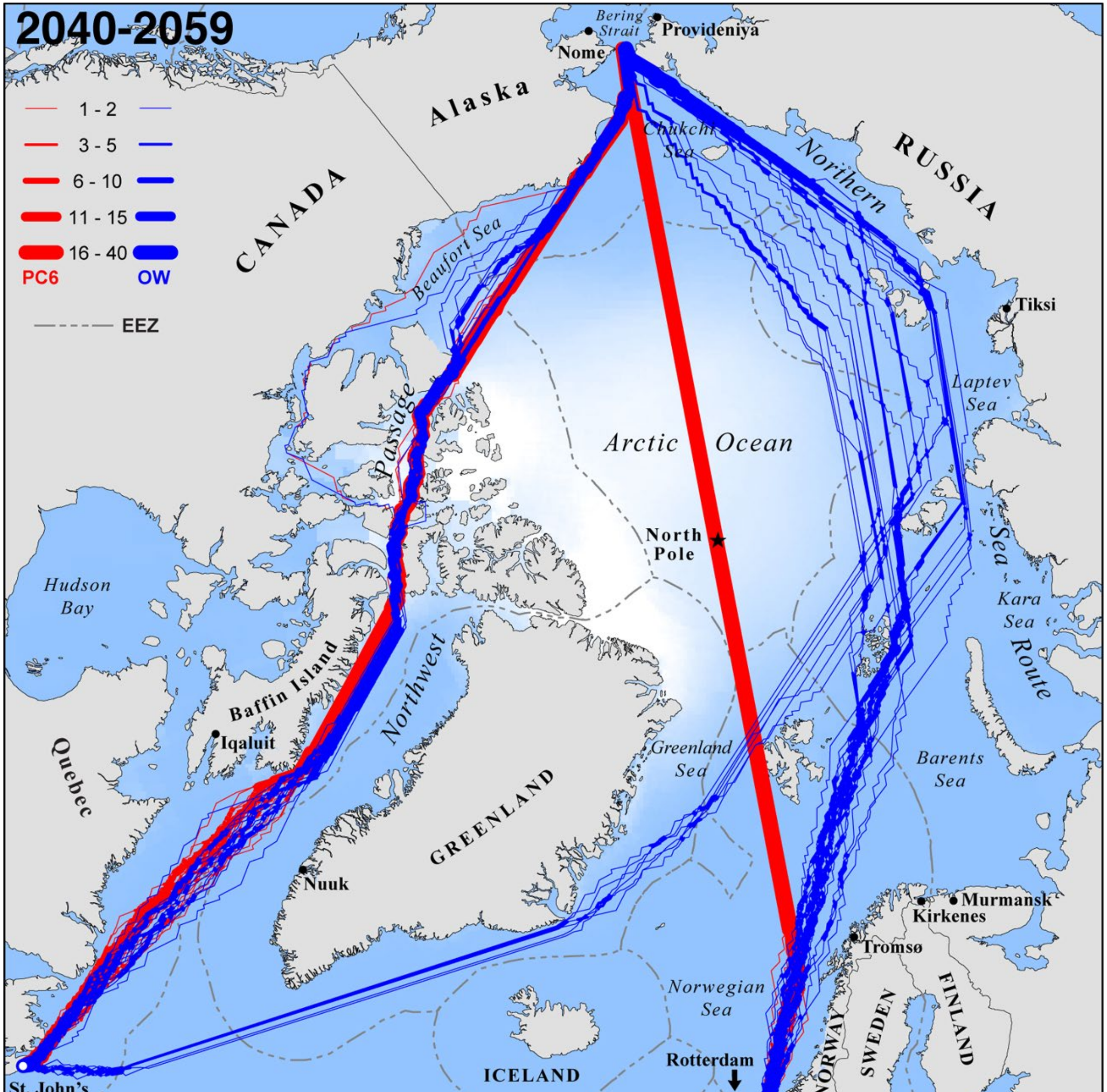


Number of ship-accessible days July-October for Polar Class and open-water vessels (red: average; blue: standard deviation) for 2011-2030 under a medium climate change scenario (RCP 6.0)



Stephenson et al.,
Climatic Change (2013)

Optimal September navigation routes from Rotterdam/St. John's to the Bering Strait from 2040-2059 as driven by ensemble-average climate model projections



Vessel Classes:

Polar Class 6

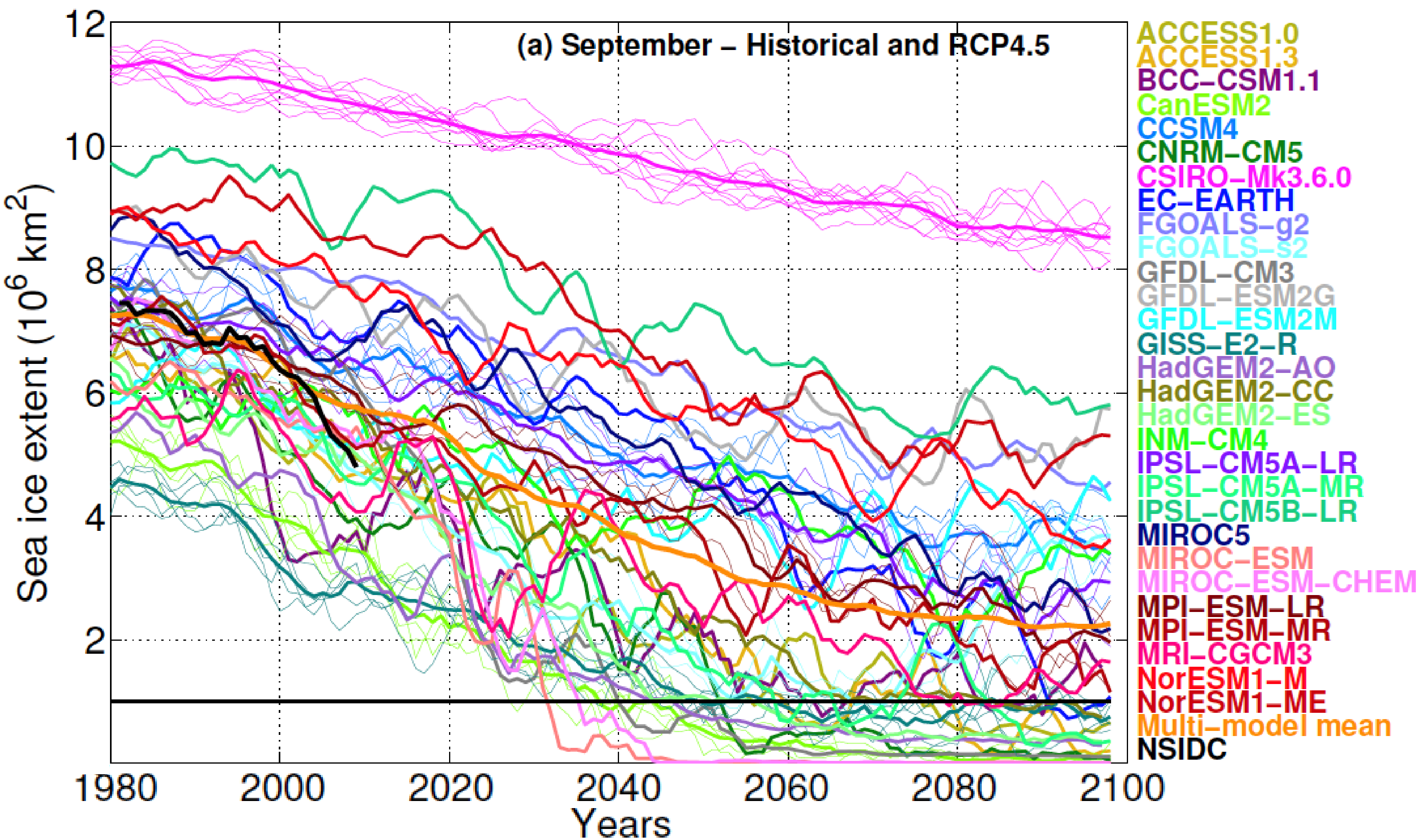
Open-water

Climate scenario:

RCP 4.5

Smith & Stephenson, *PNAS* (2013)

September Arctic sea ice extent as simulated by 29 climate models

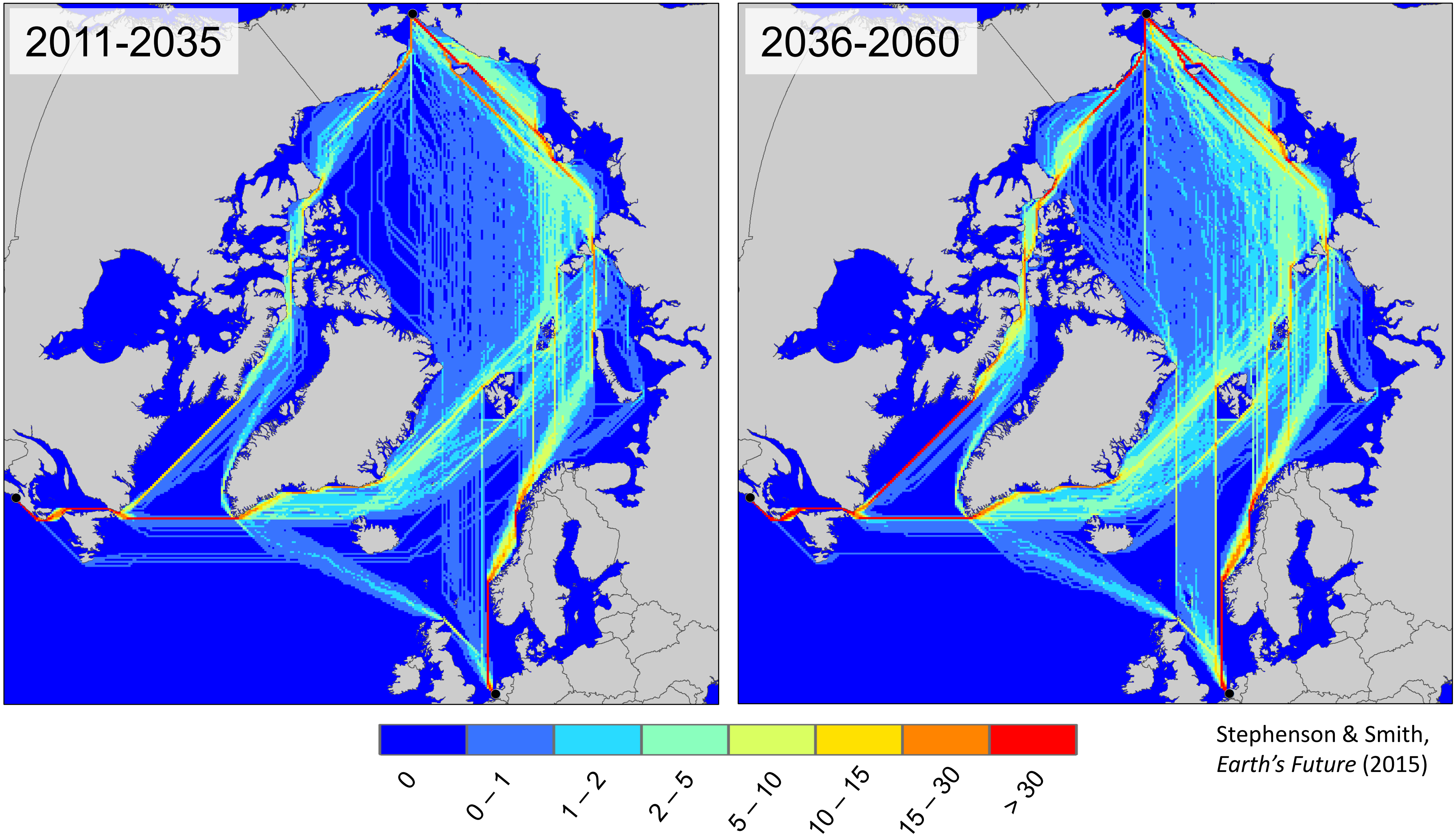


Observations: black

Multi-model average (unweighted): orange

Massonnet et al. (2012)

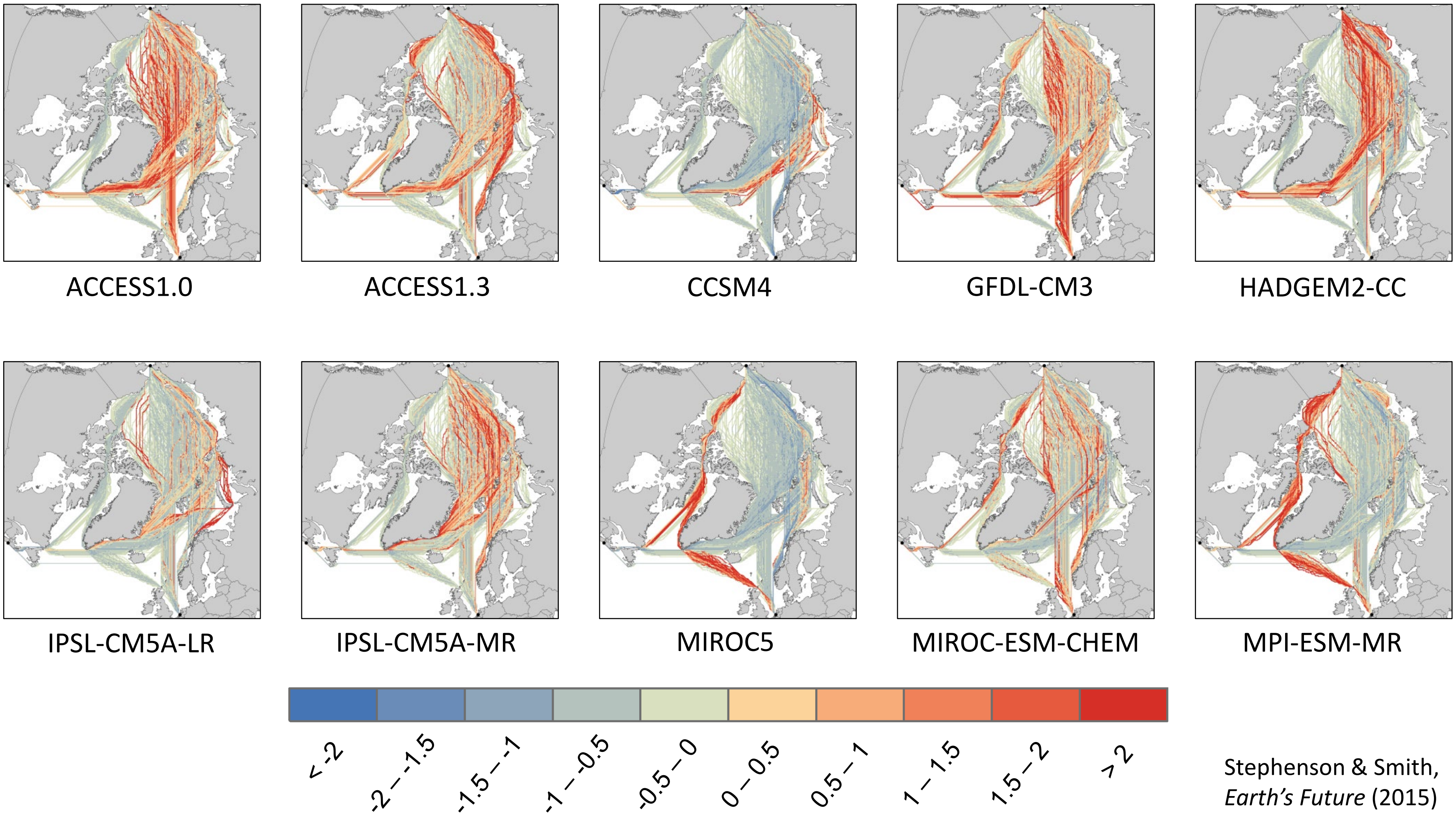
10-model average of year-round density of least-cost navigation routes from Rotterdam, The Netherlands and Halifax, Nova Scotia to the Bering Strait by open-water vessels under RCP 4.5



Stephenson & Smith, *Earth's Future* (2015)

By 2060, eastern/central Arctic encompasses 70% of total routes

Single-model deviation from 10-model average least-cost route density for open-water vessels in standard deviation units (2036-2060, RCP 4.5)



Stephenson & Smith, *Earth's Future* (2015)

- By 2060, only two models (CCSM4, MIROC5) project no "trans-polar" routes
- Northwest Passage robustly accessible in only 2 models (MIROC5, MPI-ESM-MR)

Number of months in which an eastern/central Arctic route (E/C; includes the NSR) or the Northwest Passage (NWP) was projected to be the least-cost route from Rotterdam, Halifax, or both, under RCP 4.5

No NWP routes projected in 4 models

3 models account for 11% of total routes

RCP 4.5

	2011-2035				**2036-2060**			
	OW		PC6		OW		PC6	
	E/C	NWP	E/C	NWP	E/C	NWP	E/C	NWP
ACCESS1-0	68	0	155	0	102	0	187	0
ACCESS1-3	86	15	153	77	113	39	190	121
CCSM4	13	0	48	0	22	0	89	0
GFDL-CM3	84	22	200	131	130	82	270	197
HADGEM2-CC	68	0	135	0	90	0	156	0
IPSL-CM5A-LR	19	0	67	0	52	0	120	1
IPSL-CM5A-MR	51	0	136	0	99	8	211	15
MIROC5	2	15	5	19	22	49	51	68
MIROC-ESM-CHEM	69	20	157	108	116	83	221	168
MPI-ESM-MR	26	56	116	138	56	78	151	150
Average	49	13	117	47	80	34	165	72

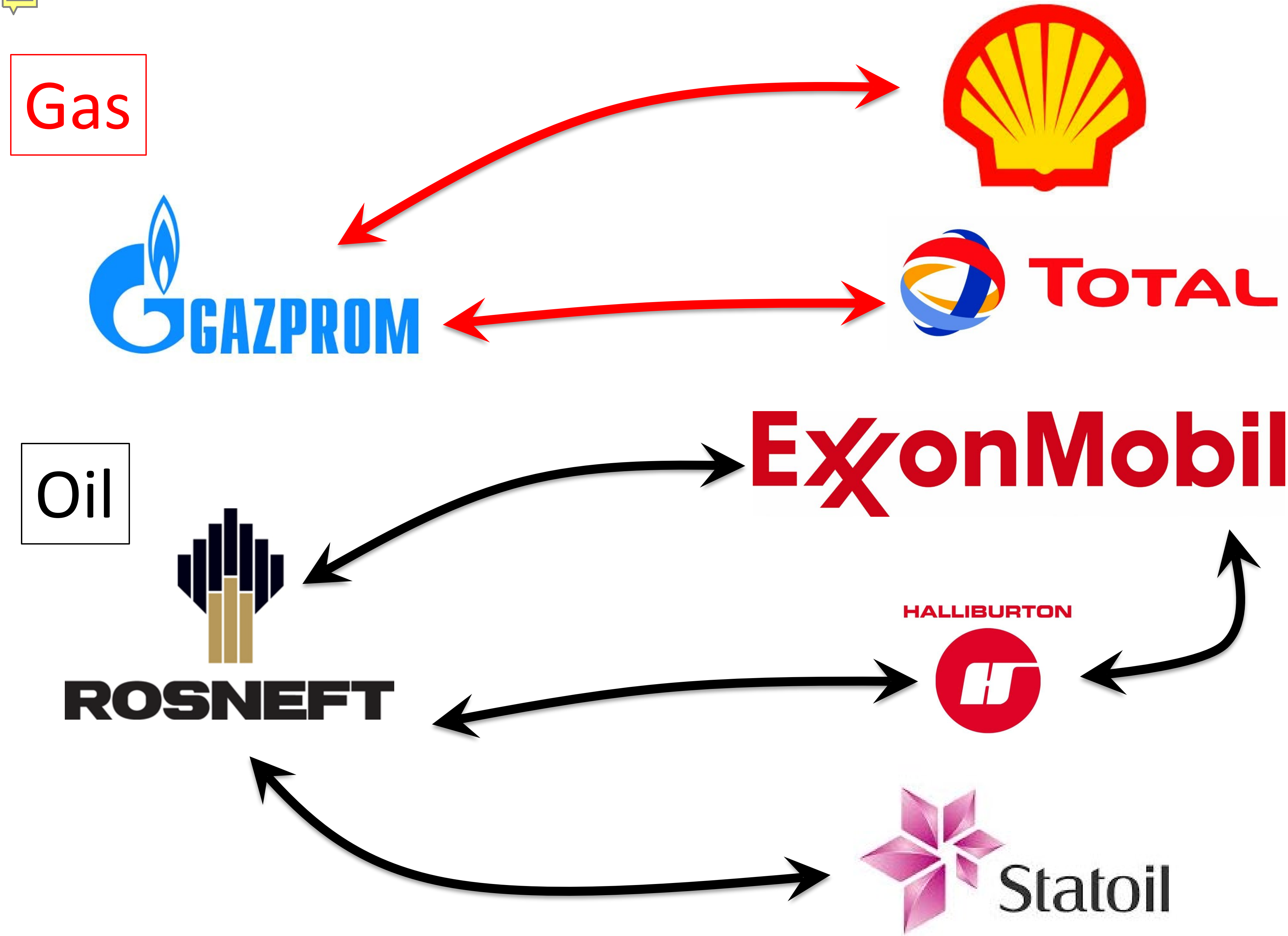
3 models account for 73% of NWP routes

> 1 SD below average

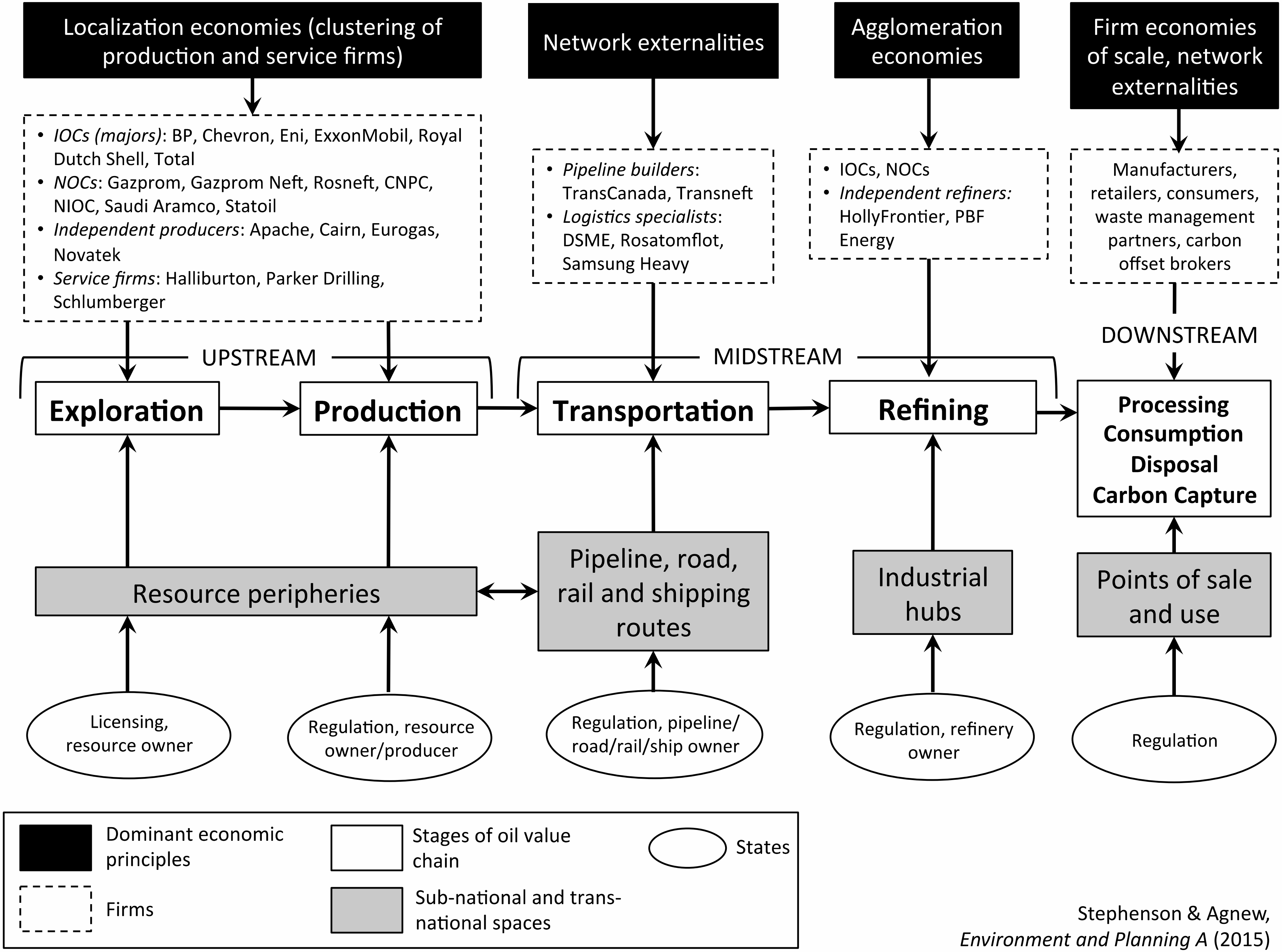
> 1 SD above average

> 2 SD above average

3 models account for 49% of total routes

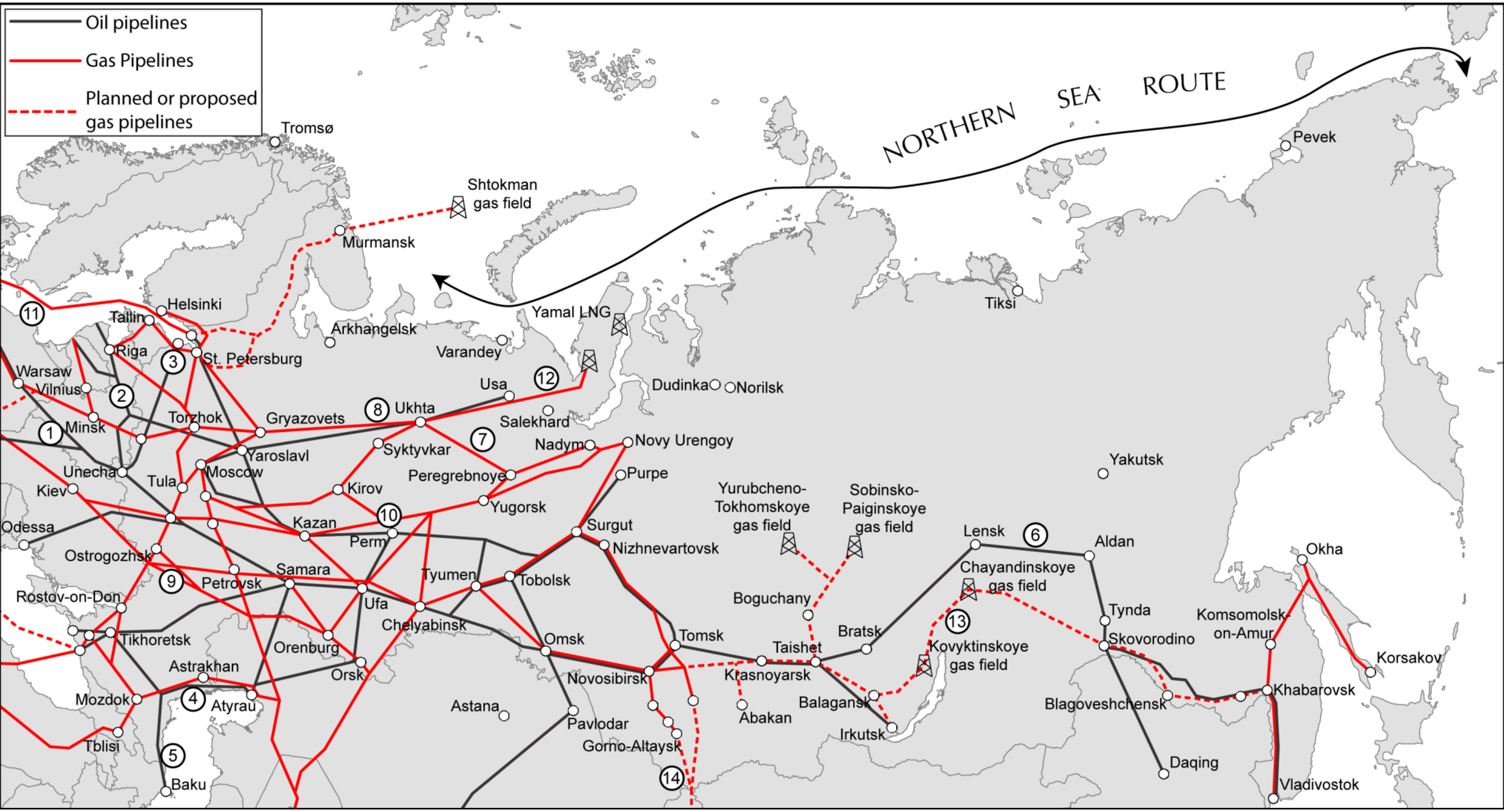


Gas
GAZPROM
TOTAL
Oil
ExxonMobil
HALLIBURTON
ROSNEFT
Statoil


Localization economies (clustering of production and service firms)
Network externalities
Agglomeration economies
Firm economies of scale, network externalities
• IOCs (majors): BP, Chevron, Eni, ExxonMobil, Royal Dutch Shell, Total
• NOCs: Gazprom, Gazprom Neft, Rosneft, CNPC, NIOC, Saudi Aramco, Statoil
• Independent producers: Apache, Cairn, Eurogas, Novatek
• Service firms: Halliburton, Parker Drilling, Schlumberger
• Pipeline builders: TransCanada, Transneft
• Logistics specialists: DSME, Rosatomflot, Samsung Heavy
• IOCs, NOCs
• Independent refiners: HollyFrontier, PBF Energy
Manufacturers, retailers, consumers, waste management partners, carbon offset brokers
UPSTREAM
MIDSTREAM
DOWNSTREAM
Exploration
Production
Transportation
Refining
Processing Consumption Disposal Carbon Capture
Resource peripheries
Pipeline, road, rail and shipping routes
Industrial hubs
Points of sale and use
Licensing, resource owner
Regulation, resource owner/producer
Regulation, pipeline/ road/rail/ship owner
Regulation, refinery owner
Regulation
Dominant economic principles
Firms
Stages of oil value chain
Sub-national and trans-national spaces
States
Stephenson & Agnew, Environment and Planning A (2015)

Major oil and gas pipelines in Russia

Stephenson & Agnew, *Environment and Planning A* (2015)



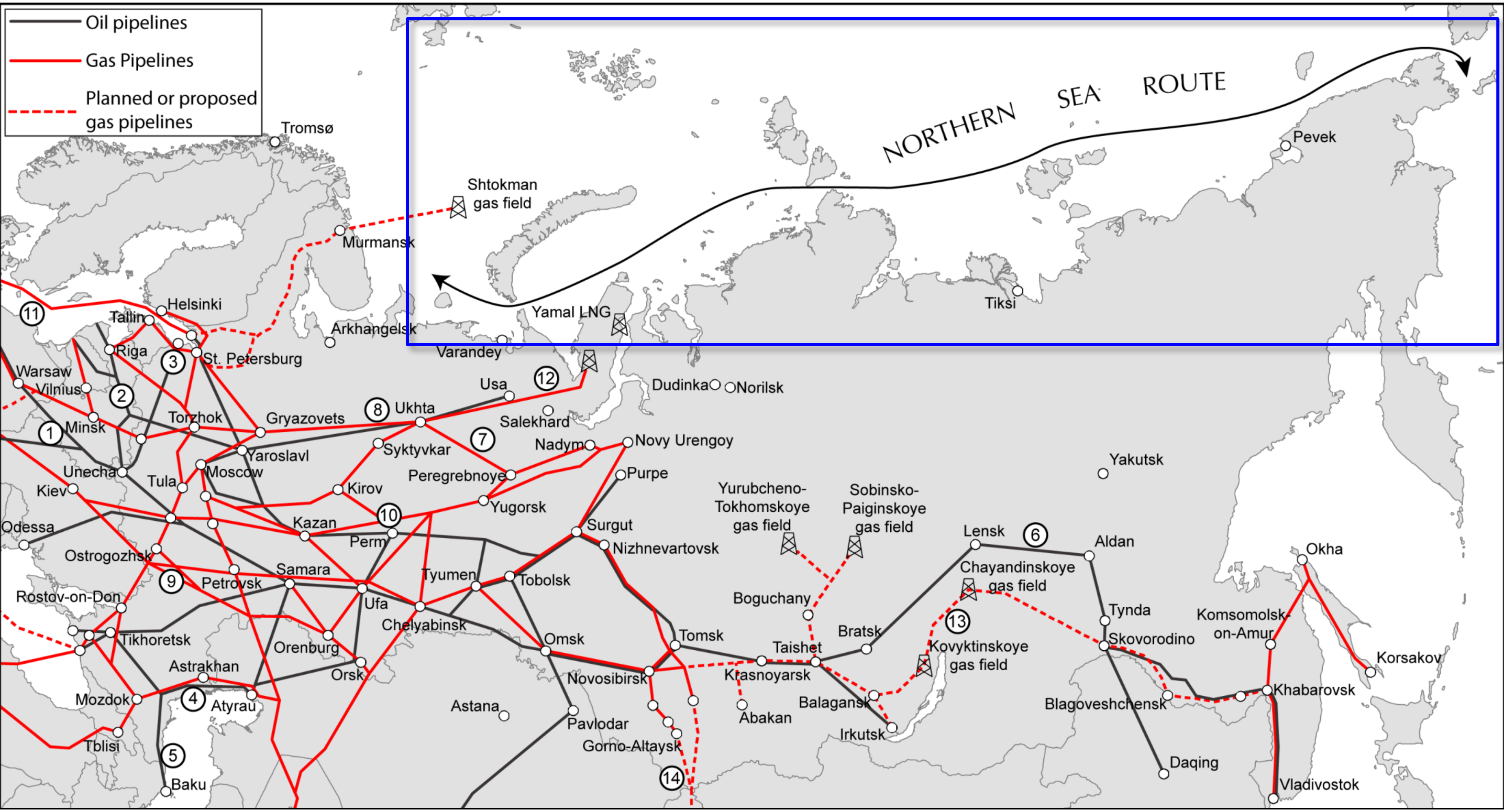
Oil Trunklines

1. Druzhba
2. Baltic 1 & 2
3. North-West
4. Caspian
5. Baku-Novorossiysk
6. East Siberia-Pacific Ocean (ESPO)

Gas Trunklines

7. Northern Lights
8. Yamal-Europe I
9. Soyuz
10. Bratstvo
11. Nord Stream
12. Bovanenkovo-Ukhta
13. Power of Siberia
14. Altai

The Northern Sea Route: a new LNG transport corridor?



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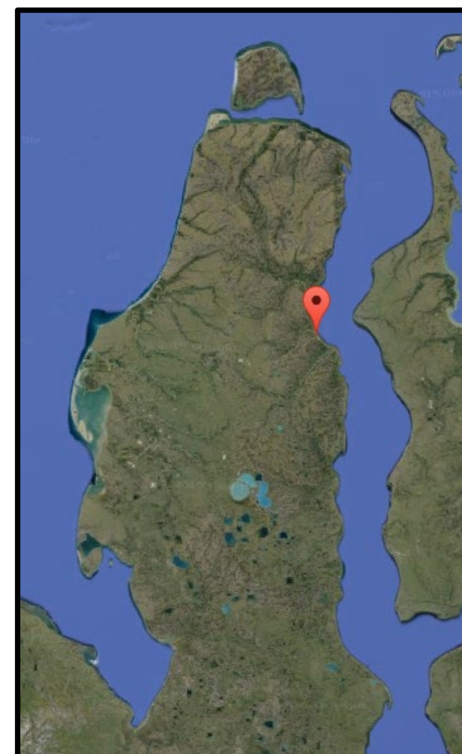
YAMAL LNG
SABETTA



Stated Local Economic Impacts of Yamal LNG

Source: Novatek

Local Stakeholder	Impact
Business owners, providers of goods and services within YNAO	Employment, business opportunities
Residents of Seyakha (closest settlement)	Employment, educational opportunities, construction and upgrade of infrastructure and housing
Residents of other rural settlements (Yar-Sale, Novy Port, Panavevsk, Salemal)	Employment, long-term improvement of regional social and transport infrastructure

However:

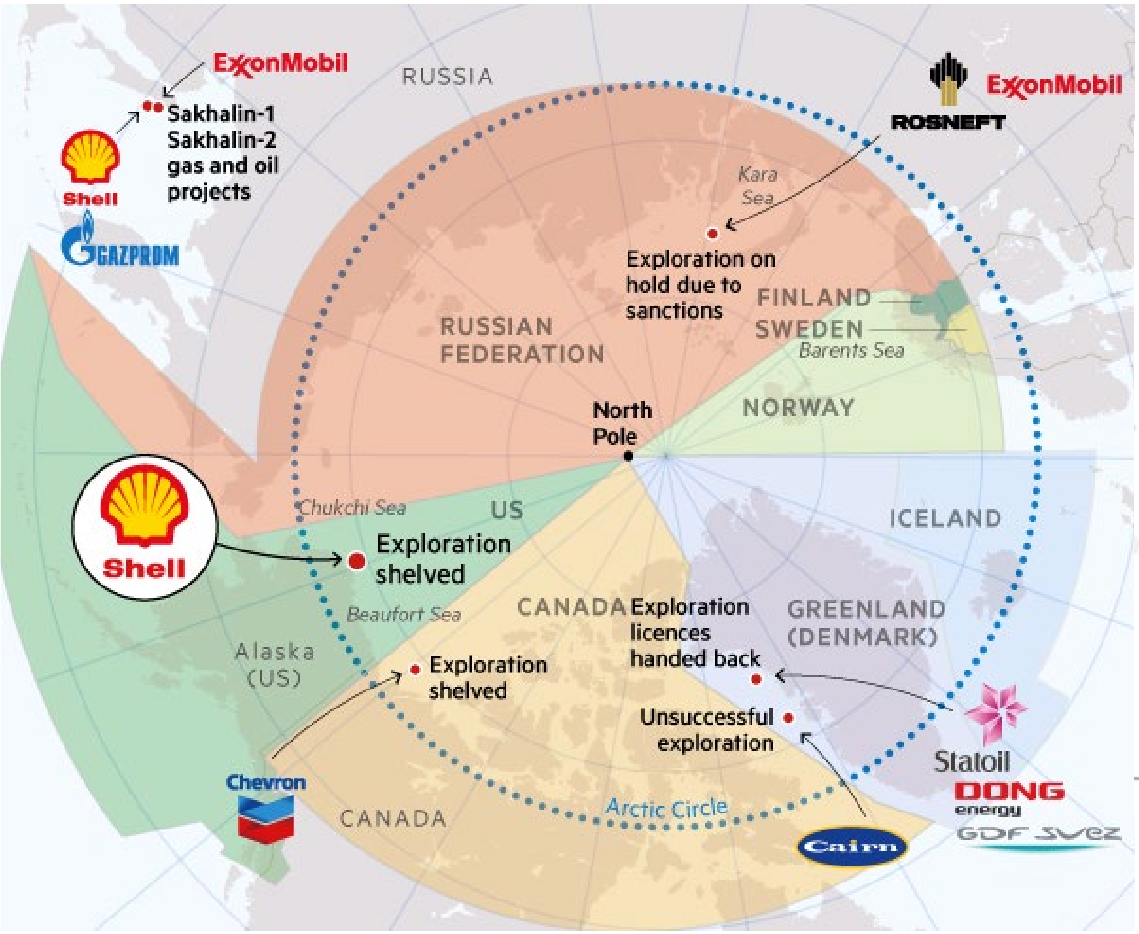
- No permanent settlements near Yamal LNG, so no local employment effect
- Workers will most likely originate from throughout Russia and abroad
- Most contracting companies are foreign (e.g. Germany, Japan, Korea, U.S.)

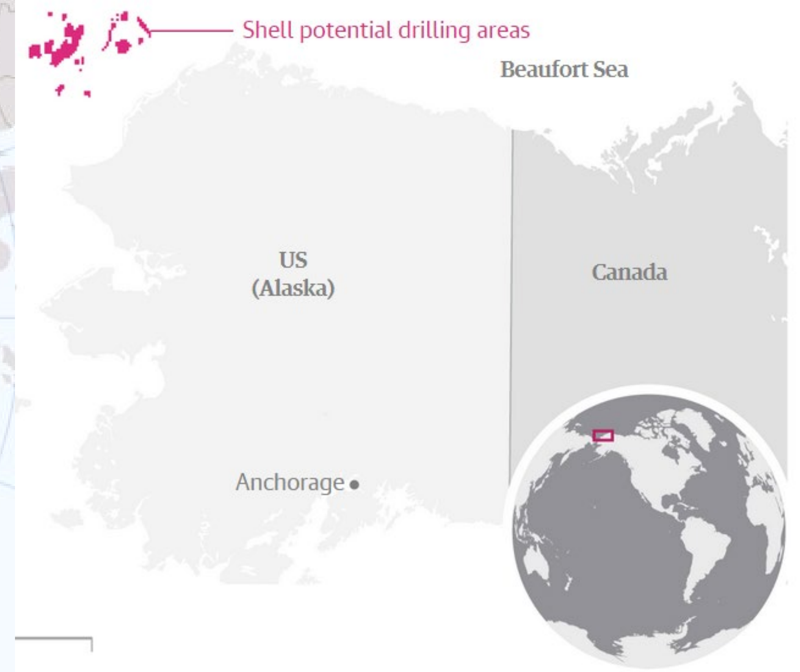
Contractors for Yamal LNG

Equipment	Contractor	Country
EPC	Technip/JGC	France/Japan
Cryogenic heat exchangers	APCI	USA
Turbine cryogenic compressors	General Electric	USA
Boil-off gas compressors	Siemens	Germany
Air cooled heat exchangers	Hamon D'Hont	Belgium
Integrated control & safety system	Yokogawa	Japan
Gas turbines for power plant	Siemens	Germany
LNG tanks	Entrepose/Vinci	France
Power plant	Technopromexport	Russia
Acid gas removal system	BASF	Germany
Arc-7 LNG carriers	Daewoo Shipbuilding & Marine Engineering	Korea

Adapted from Gyetvay, 2013

Shell's retreat "for the foreseeable future"



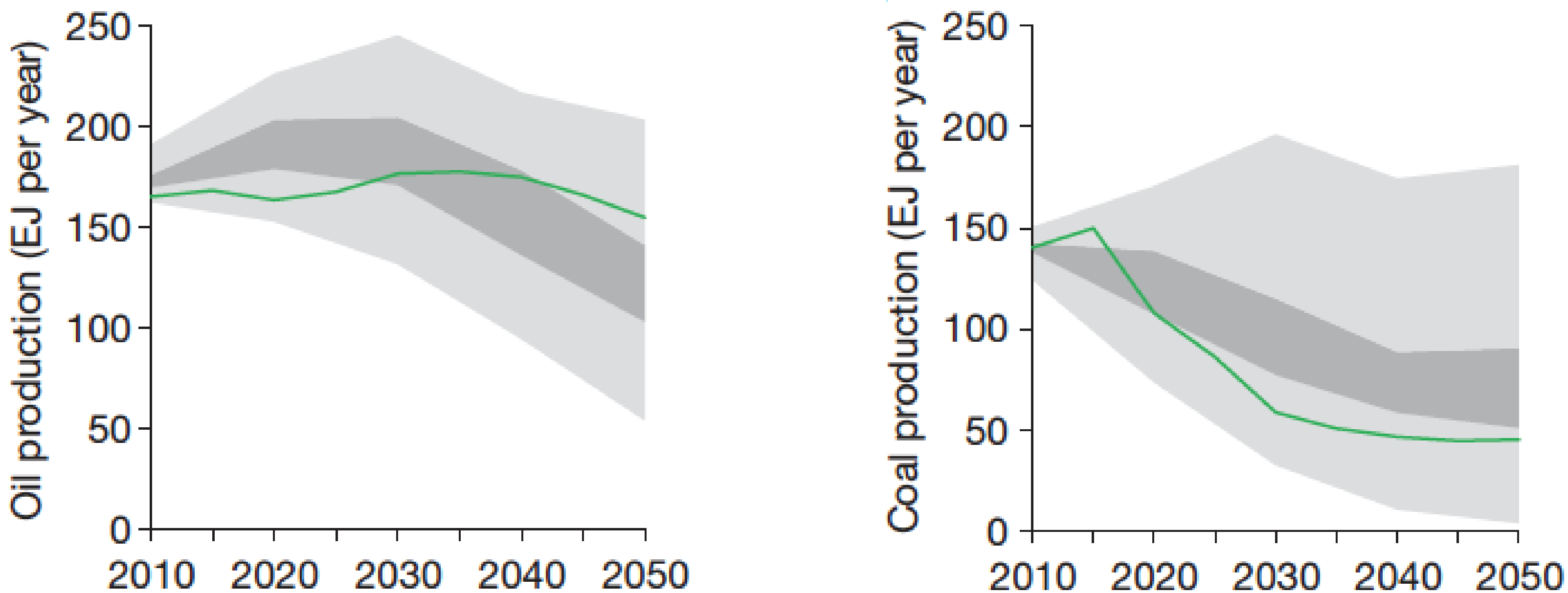


“Kayaktivists,” Seattle 2015

How much fuel is "unburnable" in order to keep warming below 2° C?

McGlade & Ekins (2015)

Projected oil (left) and coal (right) production under a 2° C warming scenario



- Globally, 1/3 of oil reserves and over 80% of coal reserves are unburnable
- 75% of Canada's reserves are unburnable, and 85% of its bitumen (oil sands)
- Coal reserves are the least-used fuel (82% unused by 2050)
- **All Arctic resources are unburnable**

What are the major threats from climate change in the polar regions?

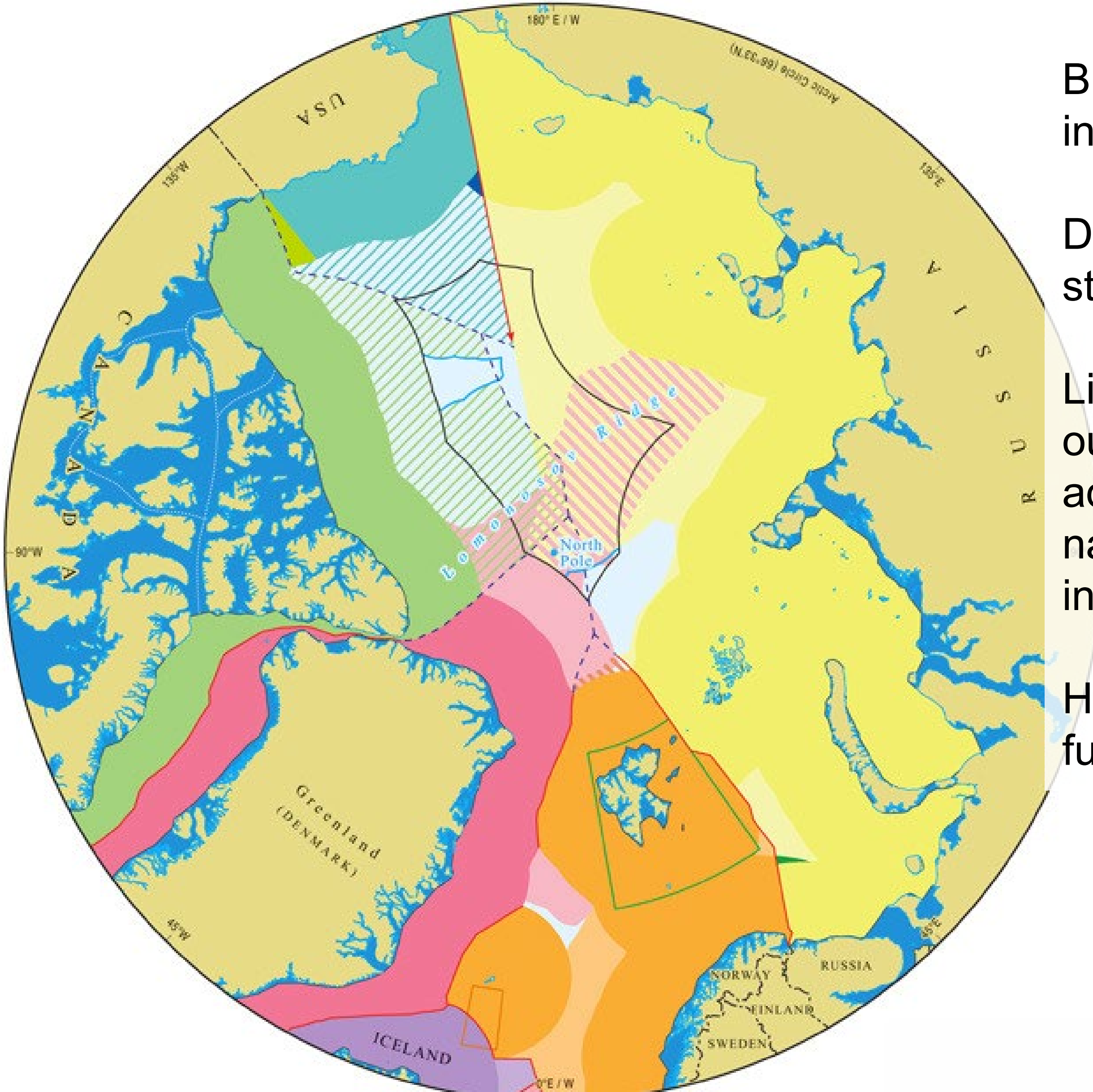
- Access to resources that must stay in the ground if we hope to avoid catastrophic climate change
- Access to central Arctic “trans-polar” routes far from ports and search and rescue stations
- Variability of future Arctic routes pose uncertainties for strategic planning by governments, environmental agencies, and the global maritime industry
- Arctic development offers opportunities for international cooperation and strategic positioning of the Northern Sea Route, but without clear benefits for local populations (Yamal LNG)

Thank You

Scott R. Stephenson
stephenson@uconn.edu

Greenpeace's protest and the arrest of the "Arctic 30" (2013)

Maritime jurisdiction and boundaries in the Arctic (IBRU)



Blue areas: Arctic state internal territorial waters

Dark shaded areas: Arctic state EEZ

Light shaded areas: outstanding claims to additional EEZ beyond 200 nautical miles in the international “high seas”

Hatched areas: theoretical future claims

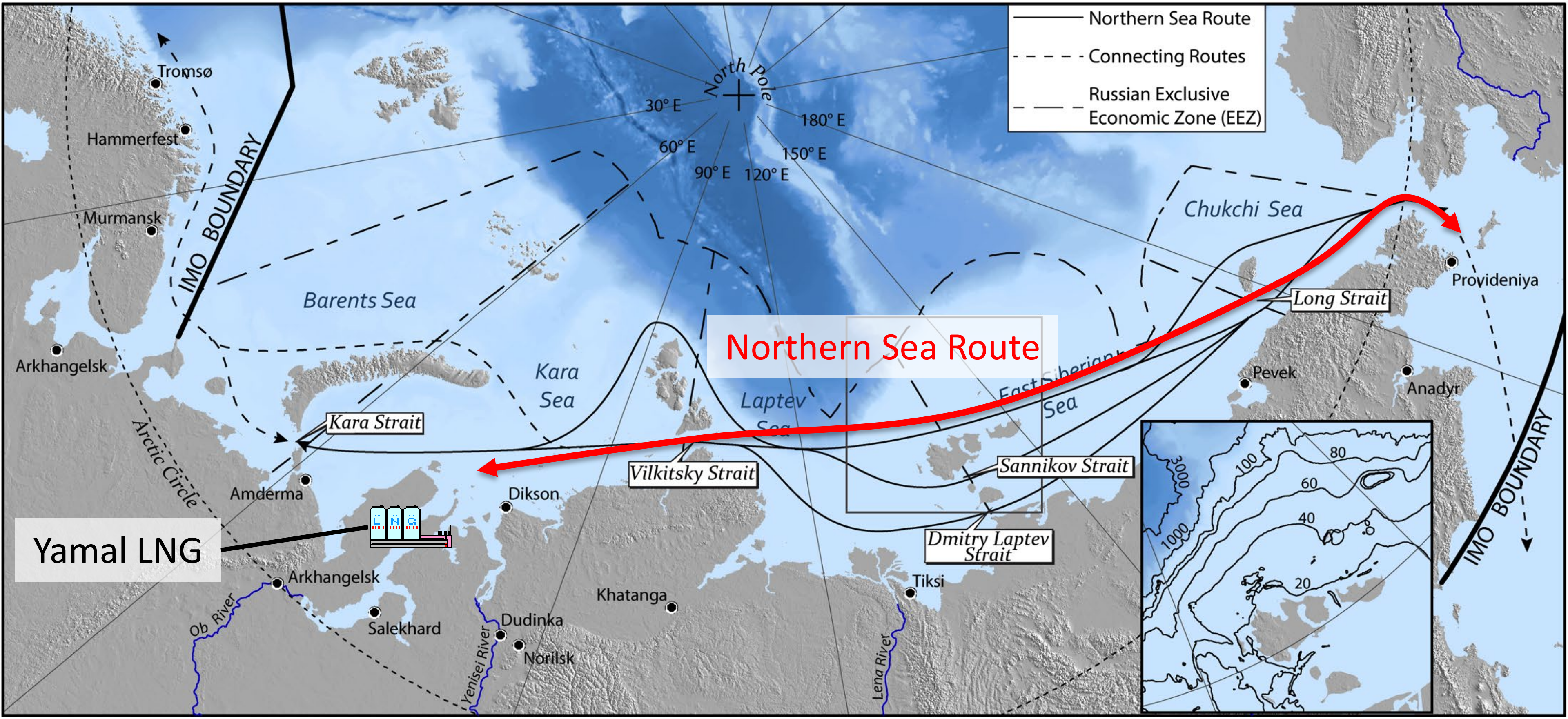
Optimal September navigation routes from Rotterdam/St. John's to the Bering Strait from 2006-2015 as driven by ensemble-average GCM sea ice projections

Trans-Arctic shipping

Vessel Classes:
Polar Class 6
Open-water

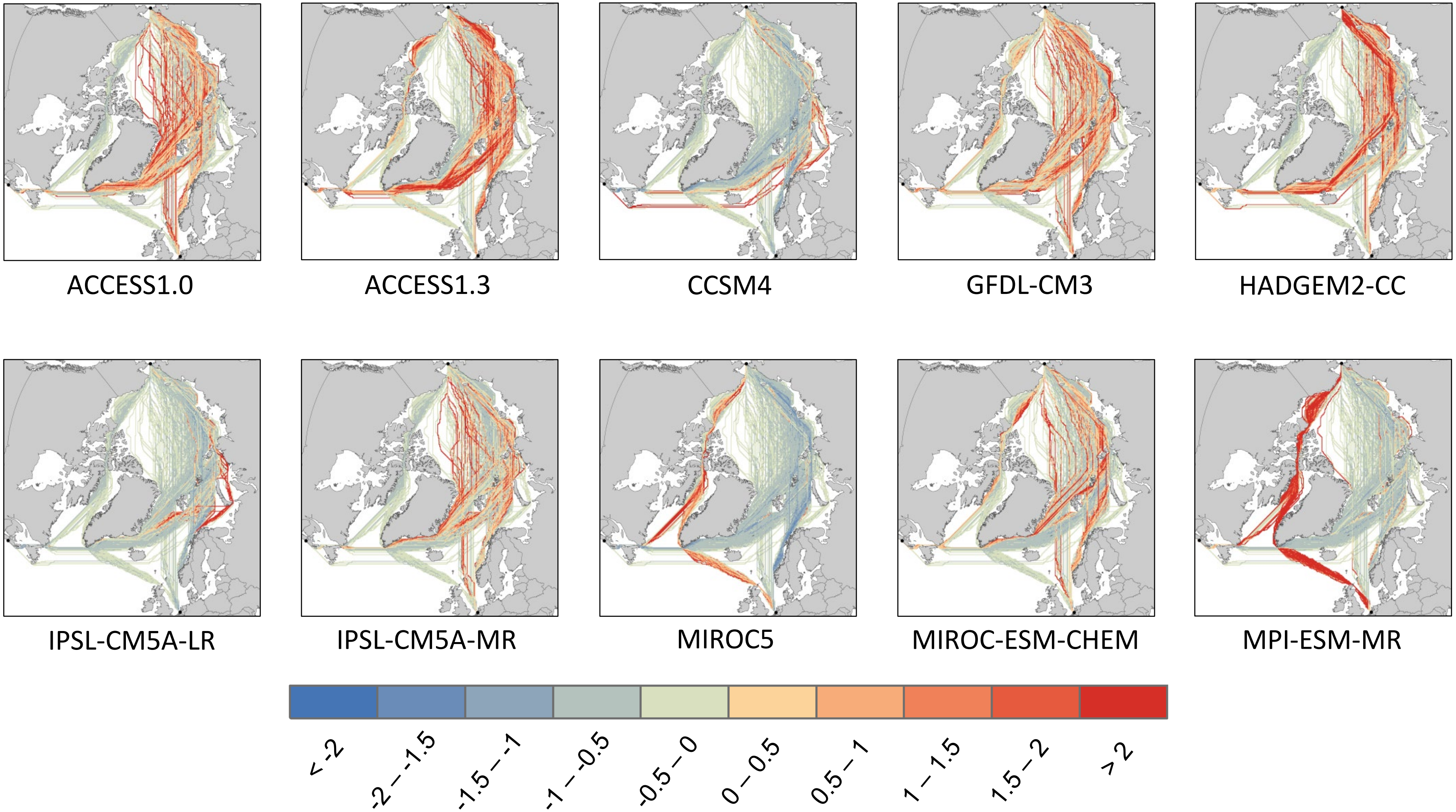
Forcing:
RCP 4.5 W/m^2

Smith & Stephenson, *PNAS* (2013)



Northern Sea Route
Connecting Routes
Russian Exclusive Economic Zone (EEZ)
North Pole
30° E
60° E
90° E
120° E
150° E
180° E
Tromsø
Hammerfest
Murmansk
Arkhangelsk
IMO BOUNDARY
Barents Sea
Kara Sea
Laptev Sea
East Siberian Sea
Chukchi Sea
Northern Sea Route
Kara Strait
Vilkitsky Strait
Sannikov Strait
Dmitry Laptev Strait
Long Strait
Providenlya
Pevek
Anadyr
Amderma
Dikson
Yamal LNG
Arkhangelsk
Salekhard
Khatanga
Dudinka
Norilsk
Tiksi
Arctic Circle
Ob River
Yenisei River
Lena River
3000
1000
100
80
60
40
20
IMO BOUNDARY

Single-model deviation from 10-model average least-cost route density for open-water vessels in standard deviation units (2011-2035, RCP 4.5)



NSR is most reliably accessible, but dominates in only two models (CCSM4, IPSL-CM5A-LR)

Polar Class 6
Summer (JASO)
2011-2030
RCP 6.0

Summer accessible days (JASO average)

Red: n/a
Green: std dev
Blue: average