Aggregation Methodology for the Circum-Arctic Petroleum Assessment*

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Abstract

In May 2008 a team of U.S. Geological Survey scientists completed an appraisal of possible future additions to world oil and gas reserves from new field discoveries in the Circum-Arctic. In this appraisal, 48 assessment units (AUs) were identified as having at least a 10-percent chance of one or more significant oil or gas accumulations. The AUs are mappable units of rock with common geologic traits. The distribution of resources within AUs was determined by simulation from geologic inputs, including expert opinion. The AUs were aggregated to higher levels, including volume by province, total volume by resource category, off-shore volume and off-shore volume by country. In some previous assessments, plays or AUs were considered independent or totally dependent. This aggregation methodology incorporated perceived dependencies by asking assessors to specify ordinal values representing high, medium or pairwise correlations between AUs for charge, rocks and timing. These ordinals were converted to numerical values. In addition, a lower level of correlation was specified to account for general geologic similarities among provinces and the correlation induced by having a common assessment team. The charge, rocks and timing correlations were averaged. The resultant matrix was examined and a biasing constant was added to ensure a correlation structure. An analysis was conducted to determine sensitivity of results to the specified values of correlations. The 48 AU simulation files were sampled from the bias adjusted correlation matrix (ACM) so that the correlation structure in the aggregation results reflected the ACM to within sampling error. Because the size distributions of oil and gas fields are highly skewed, sampling to achieve aggregation was based upon ranks of field sizes. The variables sampled were oil in oil fields and gas in gas fields. A review of results by members of the assessment team indicated that the aggregation achieved an appropriate level of dependency.

References

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U.S. Geological Survey, 2008, Circum-Arctic Resource Appraisal: Estimates of Undiscovered Oil and Gas North of the Arctic Circle, Fact Sheet 2008-3049 (download at http://pubs.usgs.gov/fs/2008/3049)

Aggregation Methodology for the Circum-Arctic Petroleum Assessment

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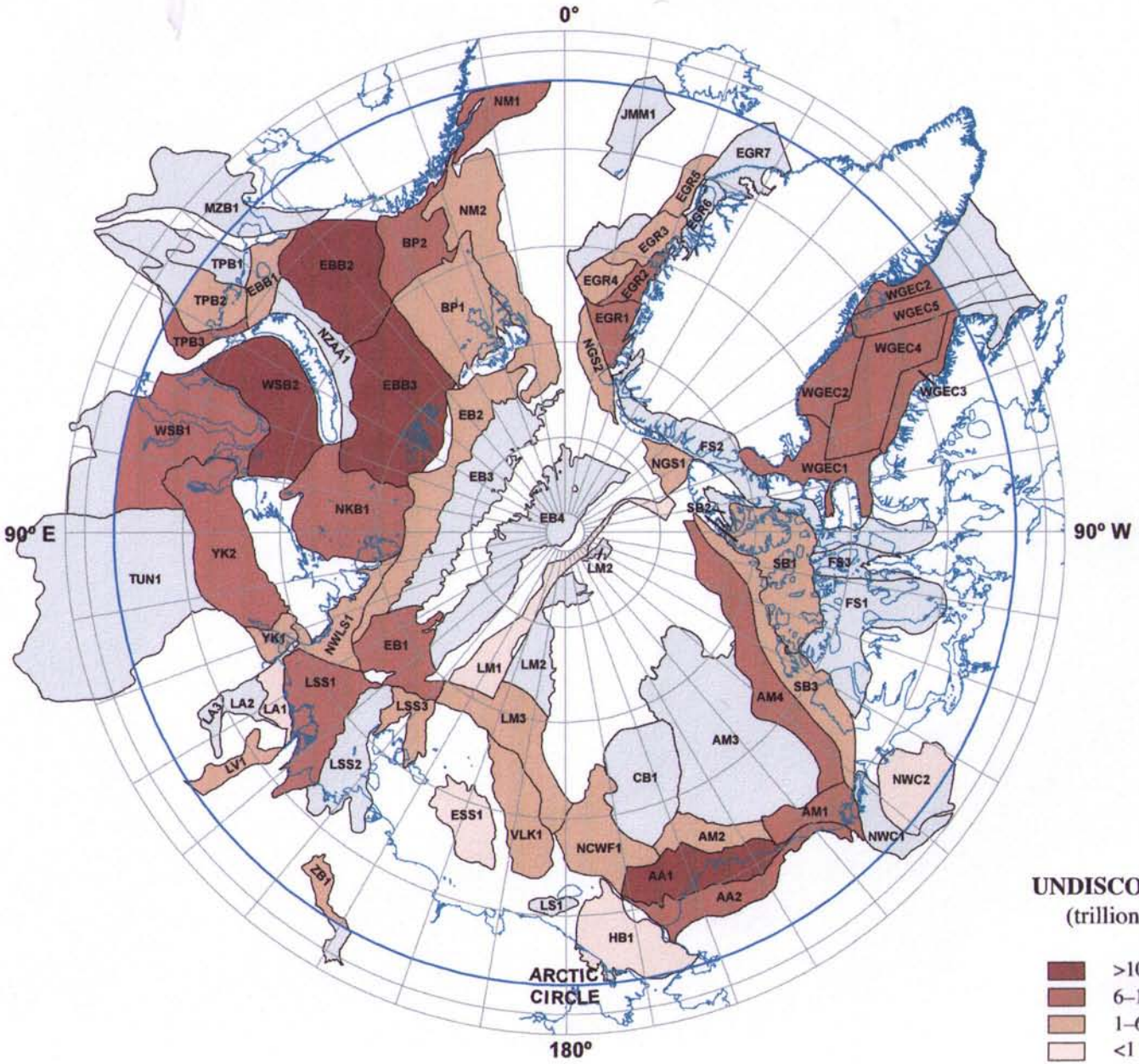
The Task

- Aggregate conventional oil and gas resource assessment results of the Circum-Arctic
- Assessment was conducted by the U.S. Geological Survey in 2008
- Basic unit of assessment was the assessment unit (AU) – mappable volume of rock with common geologic traits


0°
90° E
90° W
180°
ARCTIC CIRCLE
NM1
JMM1
EGR7
EGR5
EGR6
EGR3
EGR4
EGR2
EGR1
NGS2
MZB1
TPB1
TPB2
TPB3
EBB1
EBB2
BP2
NM2
BP1
NZAA1
WSB2
EBB3
WSB1
EB2
EB3
EB4
NKB1
YK2
TUN1
YK1
NWLS1
EB1
LSS1
LA3
LA2
LA1
LV1
LSS2
LSS3
LM1
LM2
LM3
ESS1
VLK1
ZB1
LS1
HB1
NCWF1
AA1
AA2
AM2
CB1
AM3
AM4
AM1
NWC1
NWC2
SB3
SB2
SB1
FS3
FS2
FS1
NGS1
WGEC1
WGEC2
WGEC3
WGEC4
WGEC5
WGEC2
UNDISCOVERED GAS
(trillion cubic feet)
>100
6–100
1–6
<1
Area not quantitatively assessed
Area of low petroleum potential

Dependency Concerns

- Many past oil, gas and other resource assessments have assumed:
  - AU's (or plays, basins) were pairwise independent
  - AU's (or plays, basins) were totally dependent

Implications of Dependency Assumptions

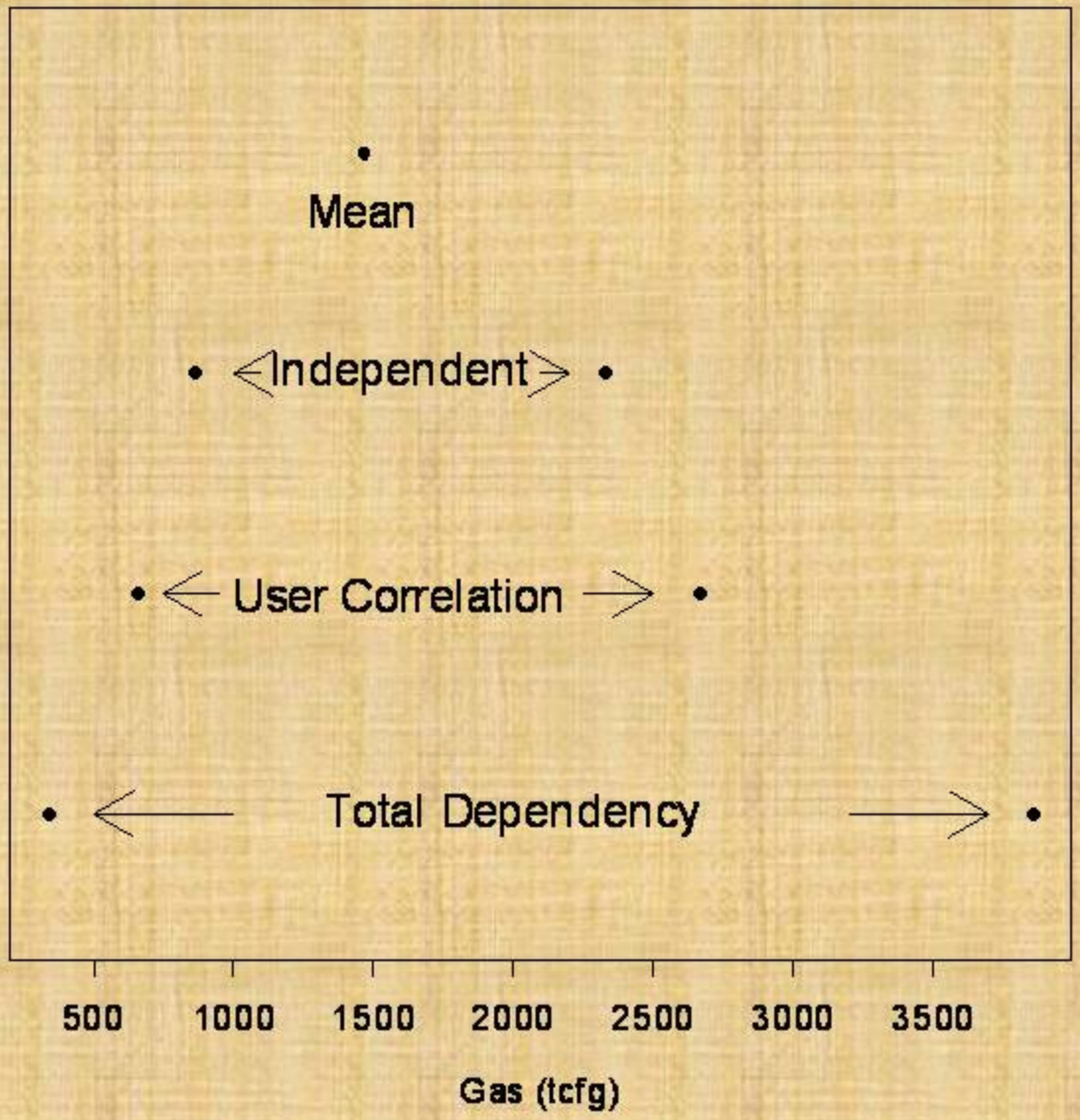
- Effect is on uncertainty of aggregated results
  - pairwise independent – uncertainty of volume of resultant aggregation *too small*
  - totally dependent – uncertainty of volume of resultant aggregation *too large*
- NEITHER ASSUMPTION USUALLY VALID

Aggregation of AU's: Gas in Gas Fields, North of Arctic Circle

Type of Samples	*F95*	*Mean*	*F05*
Independent	**863**	**1,470**	**2,334**
Correlated	**656**	**1,470**	**2,664**
Dependent	**342**	**1,470**	**3,857**

Units = tcfg

North of Arctic Circle, Gas in Gas Fields; F95 to F5



Data -1

- Basic unit – Assessment Unit (AU)

- Assessed quantities –
  - Oil in oil fields
  - Gas in gas fields
  - Liquids in gas fields
  - NGL in oil fields
  - Gas in oil fields

Data -1

Trial	Risked Gas in Gas Fields (BCFG)	Risked Oil in Oil Fields (MMBO)
1	11,567	389
2	6,752	1,487
3	0	0
4	11,669	1,071
5	10,976	678

Data - 2

- Correlation matrix expressing pairwise dependency between AU's

AU Codes	AU Name	00010101	00010202	00020101	00020201	10080102	10080103	10500101	10500102	10500103
00010101	Makarov Basin Margin	1.00								
00010202	Siberian Passive Margin	0.47	1.00							
00020101	Lena Prodelta	0.13	0.18	1.00						
00020201	Nansen Basin Margin	0.13	0.13	0.20	1.00					
10080102	Main Basin Platform	0.13	0.13	0.13	0.13	1.00				
10080103	Foredeep Basins	0.13	0.13	0.13	0.13	0.53	1.00			
10500101	Kolguyev Terrace	0.13	0.13	0.13	0.13	0.53	0.53	1.00		
10500102	South Barents Basin and Ludlov Saddle	0.13	0.13	0.13	0.13	0.40	0.40	0.60	1.00	
10500103	North Barents Basin	0.13	0.13	0.13	0.13	0.33	0.33	0.53	0.60	1.00

Our Approach

- Ask assessors to specify pairwise correlations for charge, trap and rocks in the form of ordinals (high H, moderate M and low L)
- Convert ordinals to numerical values (-1 to 1). Only non-negative values used in Circum-Arctic assessment
- Specify background correlation values

Our Approach (cont)

- See if resultant matrix is a "correlation matrix"
- Add bias factor if necessary to make it a correlation matrix
- Submit resultant matrix to assessment team for review
- Sample from resultant matrix to perform aggregation

Ordinal Correlations for Charge

AU Code	AU Name	00010101	00010202	00020101	00020201	10080102	10080103	10500101	10500102	10500103
00010101	Makarov Basin Margin	1.0								
00010202	Siberian Passive Margin	H	1.0							
00020101	Lena Prodelta			1.0						
00020201	Nansen Basin Margin			L	1.0					
10080102	Main Basin Platform					1.0				
10080103	Foredeep Basins					H	1.0			
10500101	Kolguyev Terrace					M	M	1.0		
10500102	South Barents Basin & Ludlov Saddle					M	M	H	1.0	
10500103	North Barents Basin					L	L	M	H	1.0

Numerical Correlations for Charge; H = 0.9, M = 0.6, L=0.3

AU Code	AU Name	00010101	00010202	00020101	00020201	10080102	10080103	10500101	10500102	10500103
00010101	Makarov Basin Margin	1.0								
00010202	Siberian Passive Margin	0.9	1.0							
00020101	Lena Prodelta			1.0						
00020201	Nansen Basin Margin			0.3	1.0					
10080102	Main Basin Platform					1.0				
10080103	Foredeep Basins					0.9	1.0			
10500101	Kolguyev Terrace					0.6	0.6	1.0		
10500102	South Barents Basin & Ludlov Saddle					0.6	0.6	0.9	1.0	
10500103	North Barents Basin					0.3	0.3	0.6	0.9	1.0

Background Correlation

- Common, low-level geologic traits
- Same assessment team

AU Code	AU Name	00010101	00010202	00020101	00020201	10080102	10080103	10500101	10500102	10500103
00010101	Makarov Basin Margin	1.0								
00010202	Siberian Passive Margin	0.9	1.0							
00020101	Lena Prodelta	0.2	0.2	1.0						
00020201	Nansen Basin Margin	0.2	0.2	0.3	1.0					
10080102	Main Basin Platform	0.2	0.2	0.2	0.2	1.0				
10080103	Foredeep Basins	0.2	0.2	0.2	0.2	0.9	1.0			
10500101	Kolguyev Terrace	0.2	0.2	0.2	0.2	0.6	0.6	1.0		
10500102	South Barents Basin & Ludlov Saddle	0.2	0.2	0.2	0.2	0.6	0.6	0.9	1.0	
10500103	North Barents Basin	0.2	0.2	0.2	0.2	0.3	0.3	0.6	0.9	1.0

Average of Charge, Rocks and Timing Correlation Matrices

AU Code	AU Name	00010101	00010202	00020101	00020201	10080102	10080103	10500101	10500102	10500103
00010101	Makarov Basin Margin	1.00								
00010202	Siberian Passive Margin	0.70	1.00							
00020101	Lena Prodelta	0.20	0.27	1.00						
00020201	Nansen Basin Margin	0.20	0.20	0.30	1.00					
10080102	Main Basin Platform	0.20	0.20	0.20	0.20	1.00				
10080103	Foredeep Basins	0.20	0.20	0.20	0.20	0.80	1.00			
10500101	Kolguyev Terrace	0.20	0.20	0.20	0.20	0.80	0.80	1.00		
10500102	South Barents Basin and Ludlov Saddle	0.20	0.20	0.20	0.20	0.60	0.60	0.90	1.00	
10500103	North Barents Basin	0.20	0.20	0.20	0.20	0.50	0.50	0.80	0.90	1.00

Sample pairwise correlations

	AU1	AU2	AU3
AU1	1	0.6	0.0
AU2	0.6	1	0.9
AU3	0.0	0.9	1

Eigenvalues:		
1	2	3
2.08	1.00	-0.08

Matrix Check

- Minimum eigenvalue of the matrix of pairwise correlations must be > 0 to ensure a correlation matrix
- For the 48 AU's in the Circum-Arctic the minimum eigenvalue = -0.496
- A bias factor of 0.497 is added to the eigenvalues and the matrix reconstituted

Bias Adjusted Correlation Matrix

AU Codes	AU Name	00010101	00010202	00020101	00020201	10080102	10080103	10500101	10500102	10500103
00010101	Makarov Basin Margin	1.00								
00010202	Siberian Passive Margin	0.47	1.00							
00020101	Lena Prodelta	0.13	0.18	1.00						
00020201	Nansen Basin Margin	0.13	0.13	0.20	1.00					
10080102	Main Basin Platform	0.13	0.13	0.13	0.13	1.00				
10080103	Foredeep Basins	0.13	0.13	0.13	0.13	0.53	1.00			
10500101	Kolguyev Terrace	0.13	0.13	0.13	0.13	0.53	0.53	1.00		
10500102	South Barents Basin and Ludlov Saddle	0.13	0.13	0.13	0.13	0.40	0.40	0.60	1.00	
10500103	North Barents Basin	0.13	0.13	0.13	0.13	0.33	0.33	0.53	0.60	1.00

(Average) – (Bias Adjusted)

AU Codes	AU Name	00010101	00010202	00020101	00020201	10080102	10080103	10500101	10500102	10500103
00010101	Makarov Basin Margin	0.00								
00010202	Siberian Passive Margin	0.23	0.00							
00020101	Lena Prodelta	0.07	0.09	0.00						
00020201	Nansen Basin Margin	0.07	0.07	0.10	0.00					
10080102	Main Basin Platform	0.07	0.07	0.07	0.07	0.00				
10080103	Foredeep Basins	0.07	0.07	0.07	0.07	0.27	0.00			
10500101	Kolguyev Terrace	0.07	0.07	0.07	0.07	0.27	0.27	0.00		
10500102	South Barents Basin and Ludlov Saddle	0.07	0.07	0.07	0.07	0.20	0.20	0.30	0.00	
10500103	North Barents Basin	0.07	0.07	0.07	0.07	0.17	0.17	0.27	0.30	0.00

Sampling Options

- A simulation run for a given AU contains
  - Oil in oil fields
  - Gas in gas fields
  - Derivatives
  - Barrels of oil equivalent (BOE)
- Sample from BOE or from "oil in oil" and "gas in gas" separately

Sampling procedure – gas in gas

- A matrix of 10,000 (the number of simulation runs) by 48 (the number of AUs) was created
- For each AU, gas in gas was sorted in ascending order
- A second 10,000 x 48 matrix was created where independent uniform random numbers in the range -1 to +1 were generated for each element of the matrix

Sampling procedure - continued

- The matrix was combined with the correlation matrix to create a rank order in each column (AU) to induce the specified correlation. Rank ordering was used because the volume of gas in gas fields is a highly right skewed distribution.

Subset of random numbers used to generate correlation

	AU's								
Trial	00010101	00010202	00020101	00020201	10080102	10080103	10500101	10500102	10500103
1	895	6749	231	1286	283	4413	3030	7101	7833
2	1008	2117	3052	5107	7337	7156	8029	2494	4690
3	885	4539	5797	2440	218	2726	3159	2510	1840
4	7544	6901	9821	7128	2976	1214	4523	8576	9072
5	8451	2689	9497	9498	4805	1133	2305	684	6031
6	6835	3379	4111	3131	9496	9140	3575	3277	7829
7	341	8936	4471	7188	1930	2410	1138	585	1096
8	6598	3149	6433	2994	4995	2703	7959	8448	9456
9	2855	6055	1269	5918	5638	1609	1519	4879	5753

Aggregate Results - North of Arctic Circle	
	G.Risked.Gas in Gas Fields
Trials	10,000
Mean	1,469,886.80
Median	1,354,311.27
Standard Deviation	635,029.30
Variance	403,262,208,209.38
Skewness	1.12
Kurtosis	5.11
Coefficient of Variability	0.43
Minimum	277,288.78
Maximum	6,150,605.01
Range Width	5,873,316.23
Mean Standard Error	6350.292971
Fractiles	
F100	6,150,605.01
F95	2,664,182.90
...	
F5	655,544.99
F0	277,288.78

Other Options

- Hierarchical modeling
  - Gordon Kaufman, MIT
  - Uses marginal probability assessment of in-place hydrocarbons in each AU along with elicitation of a few judgments about dependency between on par of AU's.
  - Advantage: fewer expert judgments required

Acknowledgement

- The US Geological Survey supported this activity. Don Gautier and Ron Charpentier of the USGS were especially helpful