2020 BREAK-UP STUDY
OF ARCTIC SEA ICE IN THE
ALASKAN BEAUFORT AND CHUKCHI SEAS
APPENDIX A: DRAWINGS

Prepared for:

U.S. Dept. of the Interior
Bureau of Safety and
Environmental Enforcement
Washington, D.C.

Coastal Frontiers Corporation
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FLITH PATH LEGEND
Flight Path C1 on June 15, 2020
Flight Path C2 on June 16, 2020
C1-13 Location of Photo C1-13 on Flight C1
C2-V07 Location of Video C2-V07 on Flight C2
ICE LEGEND
Type:
FYI First Year Ice (_%)
MYI Multi-Year Ice (_%)
OW Open Water (<10% ice)
SIF Sea Ice Free (also)
Form:
BSH Brash Ice (<2 m)
CAK Ice Cake (2-20 m)
MED Medium Floe (100-500 m)
BIG Big Floe (500-2000 m)
Edge:
CIE Compact Ice Edge
DIE Diffuse Ice Edge
LFI Landfast Ice Edge
Feature/State:
BKN Broken Ice
CRK Crack
ISL Inactive Shear Line
SMP Small Melt Ponds
MMP Medium Melt Ponds
LMP Large Melt Ponds
RTN Rotten Ice
RDG (_m) Ridge (height in m)
RBL (_m) Rubble (height in m)
P/U (_,_m) Pile-Up (height, encroachment in m)
P/U (relict) Pile-Up (Relict Pile-Up)
PLY Polynya
The prefixes g and m are used to indicate grounded features and multiple features, respectively.
NOTES
1. Flights conducted using Aero Commander 690.
2. Horizontal datum is Universal Transverse Mercator, Zone 4 (UTM04N), NAD 83 (meters). Geodetic coordinates are provided relative to NAD 83.
Scale (nautical miles)
Scale (kilometers)
2020 BREAK-UP STUDY
JUNE 2020 AERIAL RECONNAISSANCE
OF THE CHUKCHI SEA
FLIGHT PATH, PHOTO LOCATIONS, AND ICE FEATURES
Scale: 1:500,000
Checked by: CBL
Drawn by: APC
Date: 18 June 2020
Sheet: 1 of 1
Revised:
Prepared for: BSEE
Prepared by: COASTAL FRONTIERS CORPORATION
Drawing No.: CFC-1070-02-001
Rev. 0
Hanna Shoal
Hanna Shoal Prospects
Burger Prospects
Crackerjack Prospects
West Prospects
Devil's Paw Prospects
Utqiagvik
Skull Cliff
Pt. Franklin
Seahorse Islands
Peard Bay
Pt. Belcher
Wainwright
Kugrua River
Kuk River
Icy Cape
Nokotlek River
Avak River
Utukok River
Kasegaluk Lagoon
Point Lay
Kokolik River
72° 00.00' N
71° 00.00' N
70° 00.00' N
167° 00.00' W
163° 00.00' W
159° 00.00' W
N: 8,000,000
N: 7,950,000
N: 7,900,000
N: 7,850,000
N: 7,800,000
N: 7,750,000
E: 200,000
E: 250,000
E: 300,000
E: 350,000
E: 400,000
E: 450,000
E: 550,000
10% MYI; BIG; mRDG (2m); RBL (2m)
RDG (3m)
mRDG (2m); RBL (2m)
50% FYI; 20% FYI; 20% MYI; LMP; RDG (2m); RBL (2m); BKN
RBL (20m)
40% FYI; 30% MYI; BIG; MMP; mRDG (2m); RBL (2m)
60% FYI; 30% MYI; MED; S-MMP; mRDG (2m); RBL (2m); BKN
RDG (5m); RBL (5m)
70% FYI; 20% MYI; MED; SMP; mRDG (3m); RBL (3m)
70% FYI; 20% MYI; BIG; SMP; mRDG (2m); RBL (2m); BKN
60% FYI; 20% MYI; BIG; MMP; mRDG (2m); RBL (2m)
50% FYI; 20% MYI; MED; MMP; mRDG (2m); RBL (2m)
60% FYI; 20% MYI; BIG; BSH; S-MMP; mRDG (2m); RBL (2m)
40% FYI; 20% MYI; MED; SMP; mRDG (2m); RBL (2m); BKN
50% FYI; 50% MYI; SMP; mRDG (2m); RBL (2m)
20% FYI; 10% MYI; MED; mRDG (2m); RBL (2m)
ISL; RDG (3m); RBL (3m)
50% FYI; 30% MYI; BIG; BSH; S-MMP; mRDG (1m); RBL (1m)
70% FYI; 30% MYI; SMP; mRDG (3m); RBL (3m); BKN
70% FYI; 10% MYI; MED; MMP; mRDG (2m); RBL (2m); BKN
70% FYI; 20% MYI; S-MMP; mRDG (2m); RBL (2m)
80% FYI; 10% MYI; BIG; S-MMP; mRDG (2m); RBL (2m); BKN
100% MYI; M-LMP; mRDG (3m); RBL (3m)
50% FYI; 20% MYI; S-MMP; mRDG (3m); RBL (3m); BKN
60% FYI; 20% MYI; S-MMP; mRDG (2m); RBL (2m); BKN
60% FYI; 30% MYI; MMP; mRDG (2m); RBL (2m)
OW; BSH; CAK
ISL; RDG (7m)
70% FYI; 30% MYI; MMP; mISL
90% FYI; 10% MYI; MMP; mRDG (2m); RBL (2m)
100% FYI; LMP; mRDG (3m); RBL (3m)
100% FYI; MMP; mRDG (2m); RBL (2m)
80% FYI; 20% MYI; MMP; mRDG (2m); RBL (2m)
80% FYI; 20% MYI; LMP; mRDG (3m); RBL (3m); BKN
100% FYI; MMP; mRDG (1m); RBL (1m)
100% FYI; M-LMP; mRDG (1m); RBL (1m); RTN
100% FYI; RBL (1m)
100% FYI; UDI; MMP
10% FYI; MED; mRDG (2m); RBL (2m); RTN
70% FYI; RBL (2m); BKN
100% FYI; MMP; mRDG (2m); RBL (2m); mCRK
60% FYI; UDI; RTN
90% FYI; 10% MYI; mRDG (2m); RBL (2m); BKN
50% FYI; UDI; RTN

1: 500,000

PEER REVIEW UNDER APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN
FORMALLY DISSEMINATED BY BSEE. IT DOES NOT REPRESENT AND SHOULD NOT BE
CONSTRUED TO REPRESENT ANY BSEE DETERMINATION OR POLICY.”


Weller Bank
Stamukhi Shoal
Harrison Bay Prospects
Camden Bay Prospects
Harrison Bay
Thetis Is.
Spy Is.
Nikaitchuq
OoogurUk
Oliktok Point
Jones Is.
Northstar Prod. Is.
Reindeer Is.
Cross Is.
Dinkum Sands
McClure Is.
Narwhal Is.
Stefansson Sound
Jeanette Is.
Liberty Is. Site
Prudhoe Bay
Deadhorse
Stockton Is.
Maguire Is.
Flaxman Is.
Brownlow Point
Mikkelsen Bay
Camden Bay
Anderson Point
Barter Is.
Colville River
Kuparuk River
Sagavanirktok River
Canning River
N: 7,900,000
N: 7,850,000
N: 7,800,000
N: 7,750,000
E: 350,000
E: 400,000
E: 450,000
E: 500,000
E: 550,000
E: 600,000
E: 650,000
ICE LEGEND
Type:
FYI First Year Ice (_%)
MYI Multi-Year Ice (_%)
OW Open Water (<10% ice)
SIF Sea Ice Free
Form:
CAK Ice Cake (2-20 m)
SML Small Floe (20-100 m)
MED Medium Floe (100-500 m)
BIG Big Floe (500 m-2 km)
Edge:
CIE Compact Ice Edge
DIE Diffuse Ice Edge
Feature/State:
LMP Large Melt Ponds
RTN Rotten Ice
TIH Through-Ice Holes
RDG (_m) Ridge (height in m)
RBL (_m) Rubble (height in m)
P/U (relict) Relict Pile-Up
The prefixes g and m are used to indicate grounded features and multiple features, respectively.
FLITH PATH LEGEND
Flight Path B2 on July 10, 2020
B2-19 Location of Photo B2-19 on Flight B2
B2-V10 Location of Video B2-V10 on Flight B2
Subsea Pipeline
Scale (nautical miles)
Scale (kilometers)
NOTES
1. Flight B2 conducted on July 10, 2020, using Aero Commander 690.
2. Horizontal datum is Universal Transverse Mercator, Zone 6 (UTM06N), NAD 83 (meters). Geodetic coordinates are provided relative to NAD 83.
2020 BREAK-UP STUDY
JULY 2020 AERIAL RECONNAISSANCE
OF THE CENTRAL BEAUFORT SEA
FLIGHT PATH, PHOTO LOCATIONS, AND ICE FEATURES
Scale: 1:400,000
Checked by: CBL
Drawn by: APC
Date: 13 July 2020
Sheet: 1 of 1
Revised:
Prepared for: BSEE
Prepared by: COASTAL FRONTIERS CORPORATION
Drawing No.: CFC-1070-02-003
Rev. 0

APPENDIX B

POST-REMOTE IMAGING ACQUISITION REPORTS

2019-20 Freeze-Up and 2020 Break-Up Studies of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas

Contract 140E0119C0011

Post-Remote Imaging Acquisition Progress Report No. 11

May 20, 2020

This report describes the first pair of RADARSAT-2 images obtained from MDA in support of the 2020 Break-Up Study of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas under Contract 140E0119C0011. Processed versions of the images, representing derivative products that may be transmitted to BSEE in accordance with MDA's End User License Agreement, are attached as Figures 1 and 2. A description and assessment of each image is provided below.

Image of Beaufort Sea

Date of Acquisition: May 17, 2020

Area of Observation: Alaskan Beaufort Sea extending from Barter Island to west of Point Barrow, and north of the 74°N parallel.

Principal Objective: Document the early stages of break-up, with particular emphasis on the condition of the landfast ice and pack ice, and the distribution of multi-year ice.

Findings: The landfast ice zone, although relatively narrow, did not display any obvious signs of deterioration. Farther offshore, the polar pack was well-consolidated with concentrations approaching 100%. Multi-year ice was present in the pack ice, with the largest floes and highest concentrations located to the east of Harrison Bay. The only significant lead was an extension of the Chukchi Sea flaw lead that stretched to the northeast of Point Barrow.

Assessment: The image is of good quality and suitable for its intended purpose. Publicly-available ice charts and satellite images will be used to provide supplemental information on the deteriorating ice canopy until the next RADARSAT-2 image is obtained in approximately two weeks.

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Image of Chukchi Sea

Date of Acquisition: May 15, 2020

Area of Observation: Alaskan Chukchi Sea extending from east of Point Barrow to west of the 170°W meridian, and from Ledyard Bay to the vicinity of the 74°N parallel.

Principal Objective: Document the early stages of break-up, with particular emphasis on the condition of the landfast ice and pack ice, and the occurrence of river overflood onto the sea ice.

Findings: Landfast ice was present along the entire length of the Chukchi Sea study area. The width varied substantially, from more 17 nautical miles (nm) off Skull Cliff to just over 1 nm immediately south of the Kuk River inlet. River overflood onto the sea ice was evident in that portion of Kasegaluk Lagoon that lies to the south of Icy Cape. Offshore, the pack ice was separated from the landfast ice by an extensive flaw lead whose width increased from less than 5 nm off Utqiagvik to more than 30 nm off Icy Cape.

Assessment: The image is of good quality and suitable for its intended purpose. Publicly-available ice charts and satellite images will be used to provide supplemental information on the deteriorating ice canopy until the next RADARSAT-2 image is obtained in approximately two weeks.

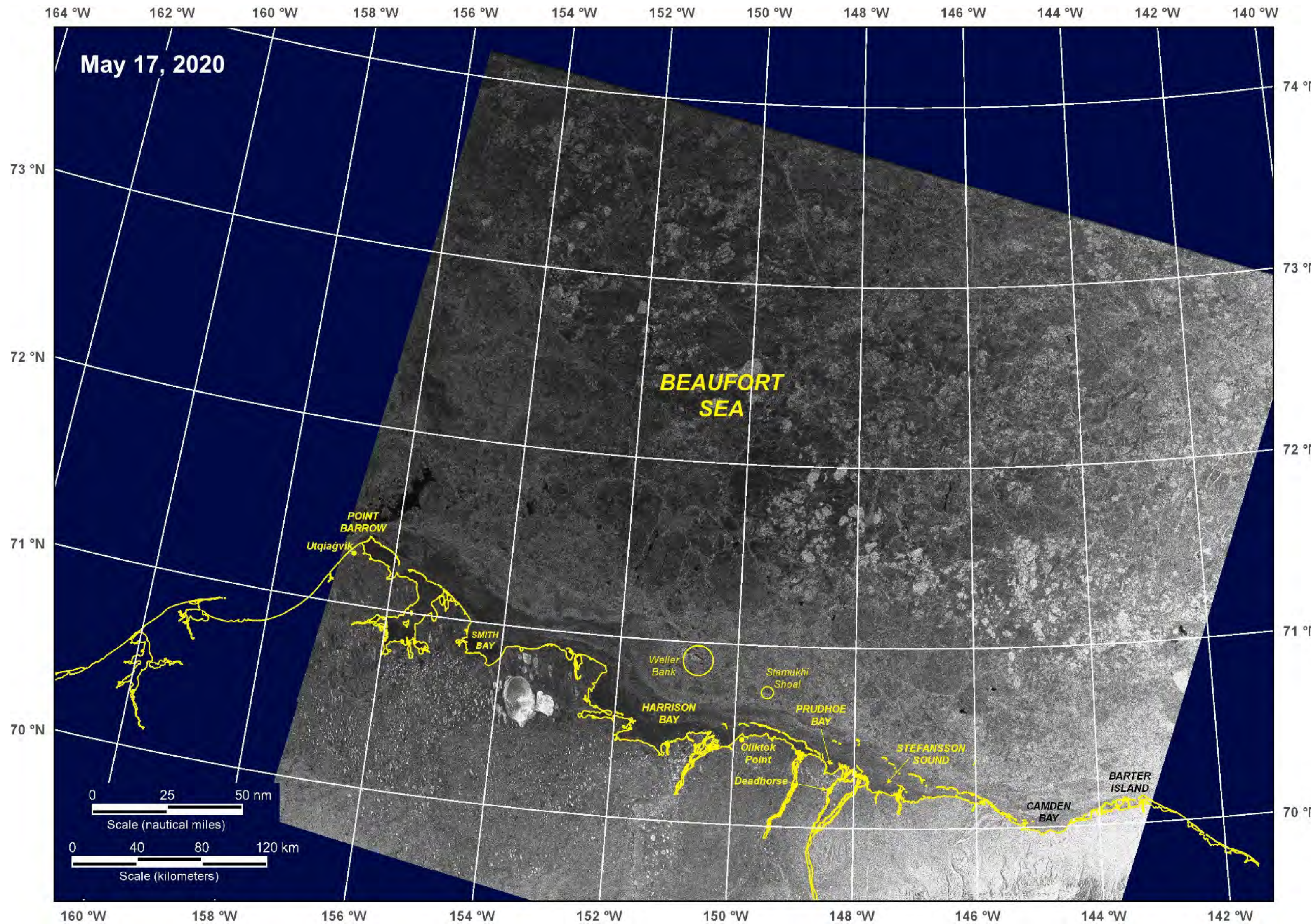

Figure 1. RADARSAT-2 Image of Beaufort Sea

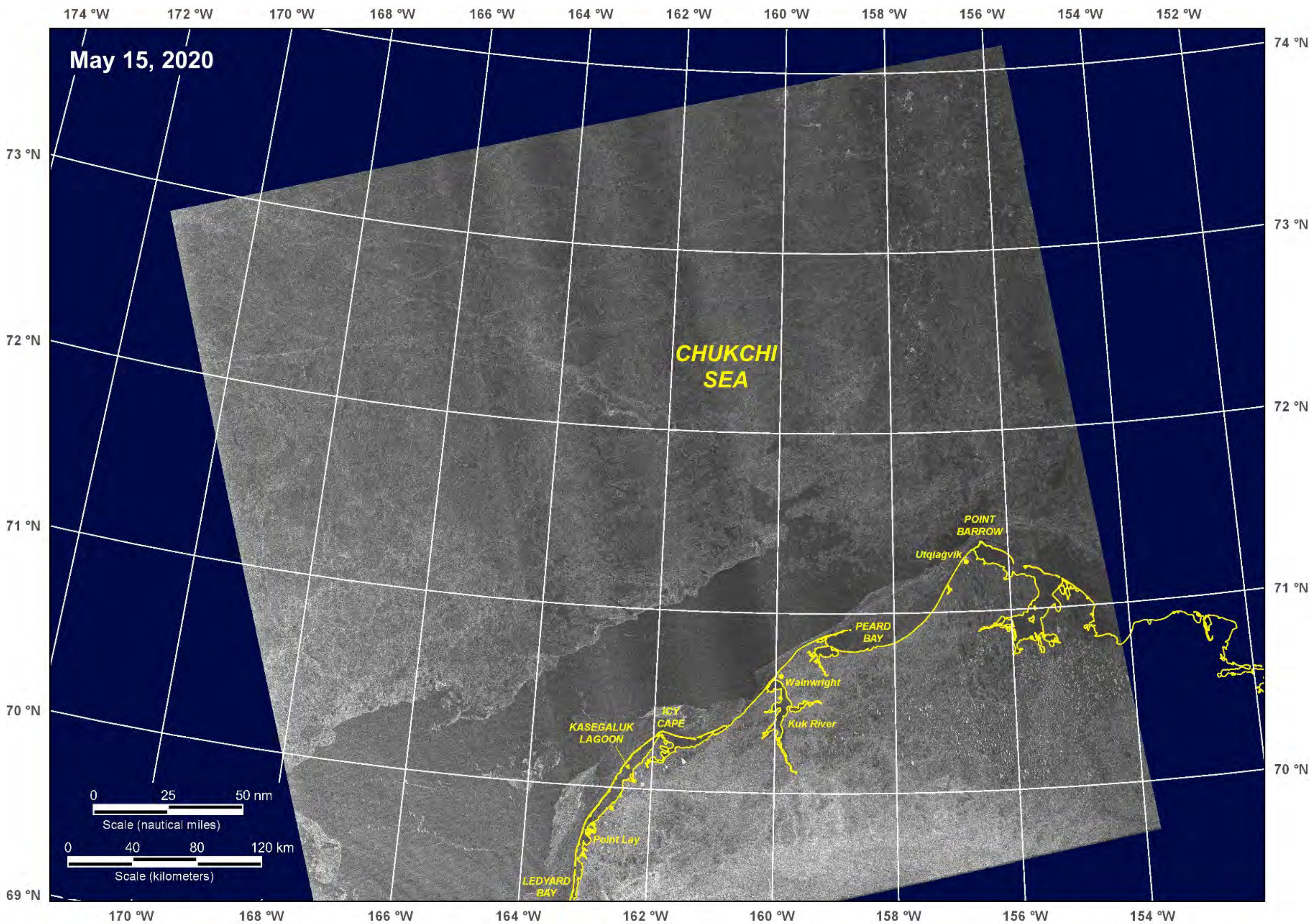

Figure 2. RADARSAT-2 Image of Chukchi Sea

COASTAL FRONTIERS

2019-20 Freeze-Up and 2020 Break-Up Studies of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas

Contract 140E0119C0011

Post-Remote Imaging Acquisition Progress Report No. 13

June 24, 2020

This report describes the third pair of RADARSAT-2 images obtained from MDA in support of the 2020 Break-Up Study of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas under Contract 140E0119C0011. Processed versions of the images, representing derivative products that may be transmitted to BSEE in accordance with MDA's End User License Agreement, are attached as Figures 1 and 2. A description and assessment of each image is provided below.

Image of Beaufort Sea

Date of Acquisition: June 20, 2020

Area of Observation: Alaskan Beaufort Sea extending from central Camden Bay to west of Point Barrow, and north of the 74°N parallel.

Principal Objective: Document the progress of break-up, with particular emphasis on the condition of the landfast ice and pack ice, the distribution of multi-year ice, and the convergence of warm-water plumes from the Mackenzie River and Alaska Coastal Current.

Findings: The most significant change from the prior image acquired on June 3rd was the appearance of open water to the north and east of Point Barrow and to the north and west of Camden Bay. The former reflects the arrival of warm water from the Alaska Coastal Current in the Chukchi Sea, while the latter reflects the arrival of warm water from the Mackenzie River in Canada. The landfast ice zone remained largely intact despite nearshore melting caused by river discharge onto the surface of the ice. The polar pack was well-consolidated, with multi-year ice scattered throughout much of the study area.

Assessment: The image is of good quality and suitable for its intended purpose. Publicly-available ice charts and satellite images will be used to provide supplemental information on the deteriorating ice canopy until the next RADARSAT-2 image is obtained in approximately two weeks.

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Image of Chukchi Sea

Date of Acquisition: June 18, 2020

Area of Observation: Alaskan Chukchi Sea extending from Point Barrow to west of the 173°W meridian, and from Ledyard Bay to the vicinity of the 74°N parallel.

Principal Objective: Document the progress of break-up, with particular emphasis on the condition of the landfast ice and pack ice, and the growing expanse of open water that separates the two masses of ice.

Findings: The landfast ice was deteriorating rapidly when the image was acquired, as evidenced by large pieces drifting offshore as well as a complete absence of ice along approximately 25% of the coastline in the Chukchi Sea study area. Offshore, the pack ice was separated from the landfast ice by a growing expanse of open water whose width exceed 75 nm off Peard Bay and 100 nm off Point Lay.

Assessment: The image is of good quality and suitable for its intended purpose. Publicly-available ice charts and satellite images will be used to provide supplemental information on the deteriorating ice canopy until the next RADARSAT-2 image is obtained in approximately two weeks.

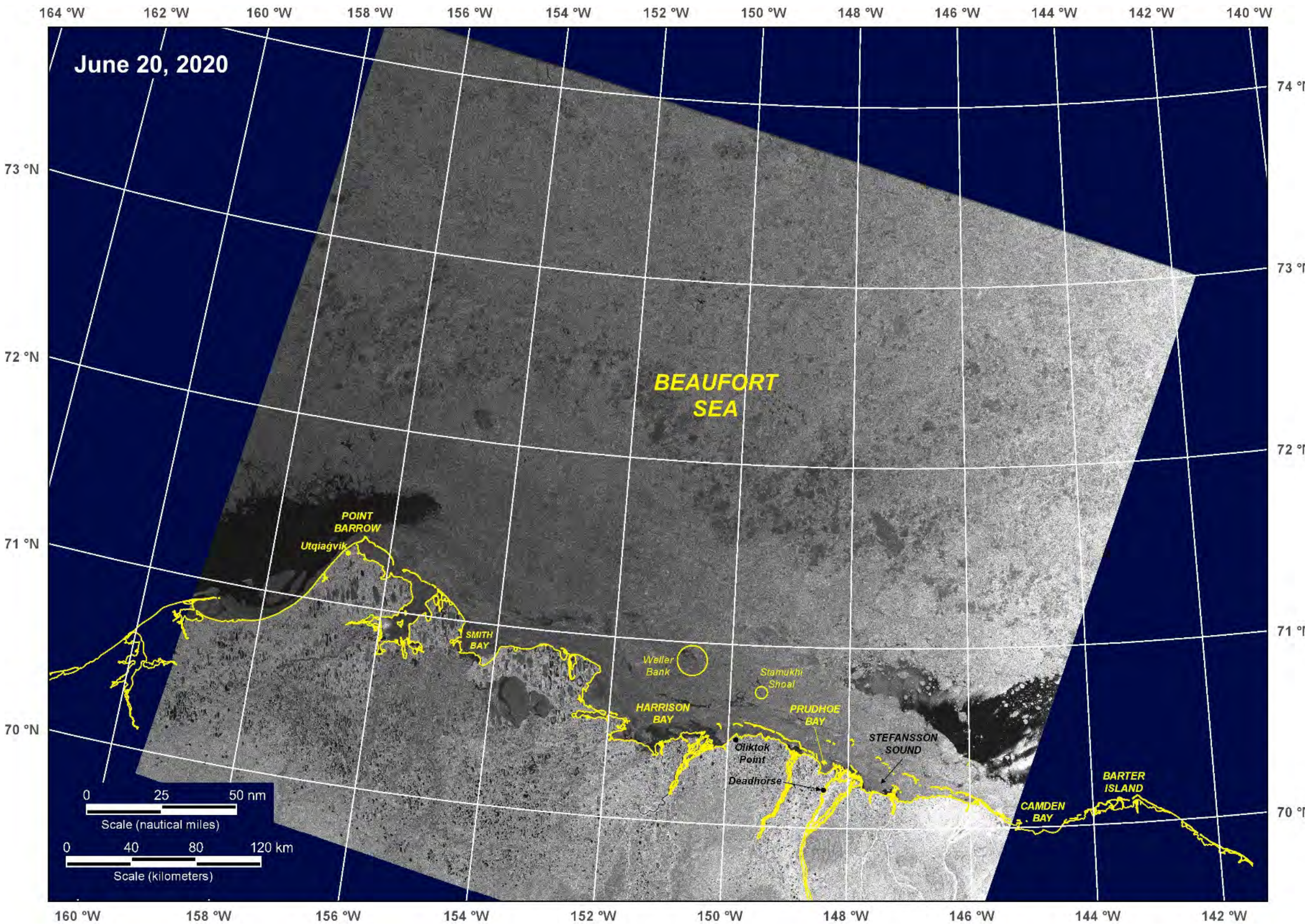

Figure 1. RADARSAT-2 Image of Beaufort Sea

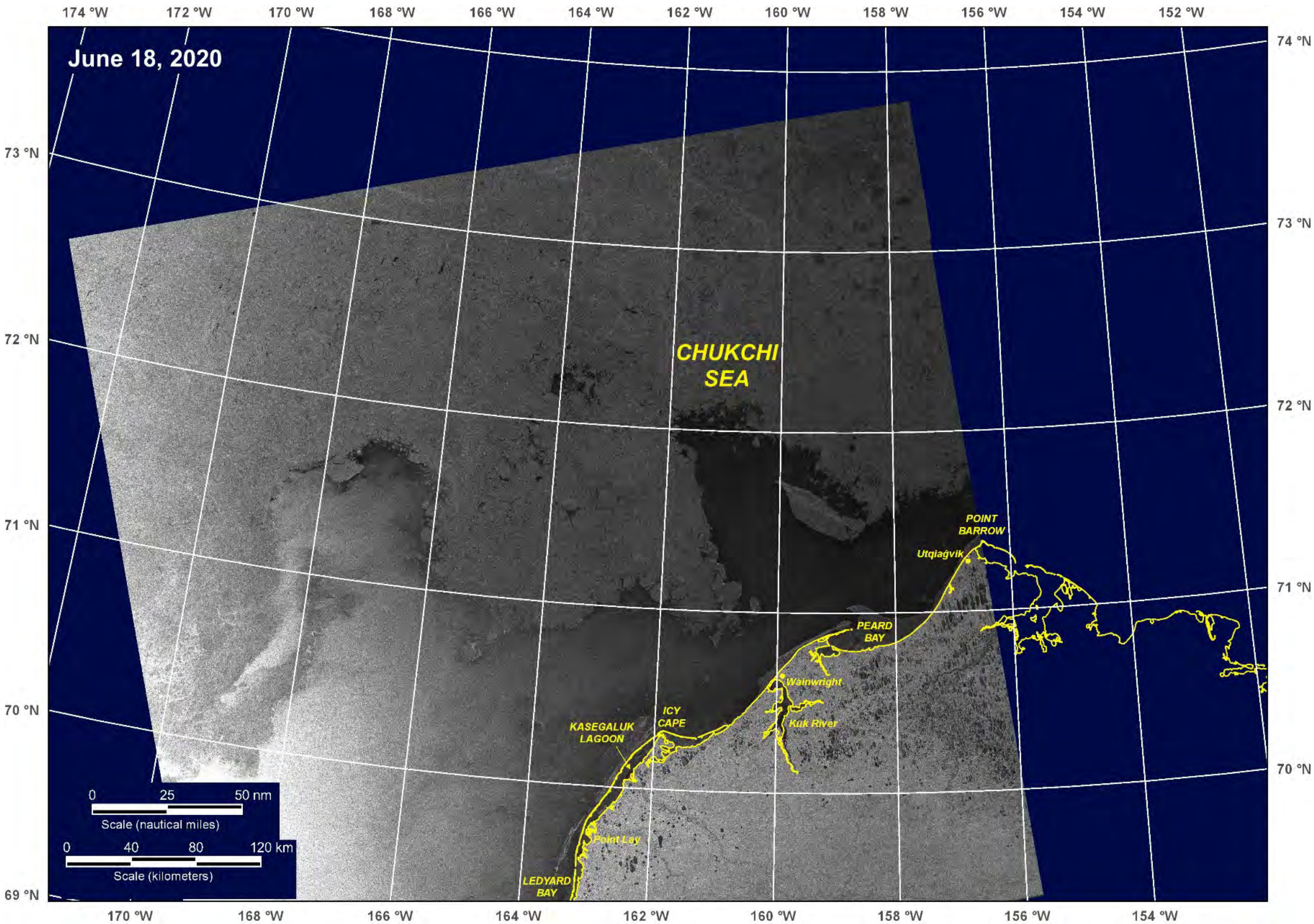

Figure 2. RADARSAT-2 Image of Chukchi Sea

COASTAL FRONTIERS

2019-20 Freeze-Up and 2020 Break-Up Studies of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas

Contract 140E0119C0011

Post-Remote Imaging Acquisition Progress Report No. 14

July 2, 2020

This report describes the fourth pair of RADARSAT-2 images obtained from MDA in support of the 2020 Break-Up Study of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas under Contract 140E0119C0011. Processed versions of the images, representing derivative products that may be transmitted to BSEE in accordance with MDA's End User License Agreement, are attached as Figures 1 and 2. A description and assessment of each image is provided below.

Image of Beaufort Sea

Date of Acquisition: June 27, 2020

Area of Observation: Alaskan Beaufort Sea extending from eastern Camden Bay to west of Point Barrow, and north of the 74°N parallel.

Principal Objective: Document the convergence of warm-water plumes from the Mackenzie River and Alaska Coastal Current, and the deteriorated condition of the ice canopy.

Findings: Since the prior image was acquired on June 20th, the warm-water plumes from the Mackenzie River and Alaska Coastal Current continued to converge, the landfast ice zone experienced substantial losses due to a combination of nearshore melting and calving at its seaward edge, and large areas of broken ice and open water appeared in the region immediately offshore of the landfast ice.

Assessment: The image is of good quality and suitable for its intended purpose. Publicly-available ice charts and satellite images will be used to provide supplemental information on the deteriorating ice canopy until the next RADARSAT-2 image is obtained in approximately two weeks.

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Image of Chukchi Sea

Date of Acquisition: June 25, 2020

Area of Observation: Alaskan Chukchi Sea extending from east of Point Barrow to west of the 172°W meridian, and from Ledyard Bay to the vicinity of the 74°N parallel.

Principal Objective: Document the final stage of break-up, with emphasis on the diminished extent of the landfast ice zone and the extent of open water.

Findings: Whereas Kasegaluk Lagoon and the Kuk River Entrance contained small amounts of sea ice, the coverage in Peard Bay remained high at approximately 80%. In the exposed waters adjacent to the coast, landfast ice was confined to three regions: (1) between Point Barrow and Utqiagvik, (2) between Skull Cliff and Point Belcher, and (3) the vicinity of Icy Cape. Pack ice was concentrated in the region north of the 70°N 30' parallel, leaving a large expanse of open water in the southern portion of the study area.

Assessment: The image is of good quality and suitable for its intended purpose. Publicly-available ice charts and satellite images will be used to provide supplemental information on the deteriorating ice canopy until the next RADARSAT-2 image is obtained in approximately two weeks.

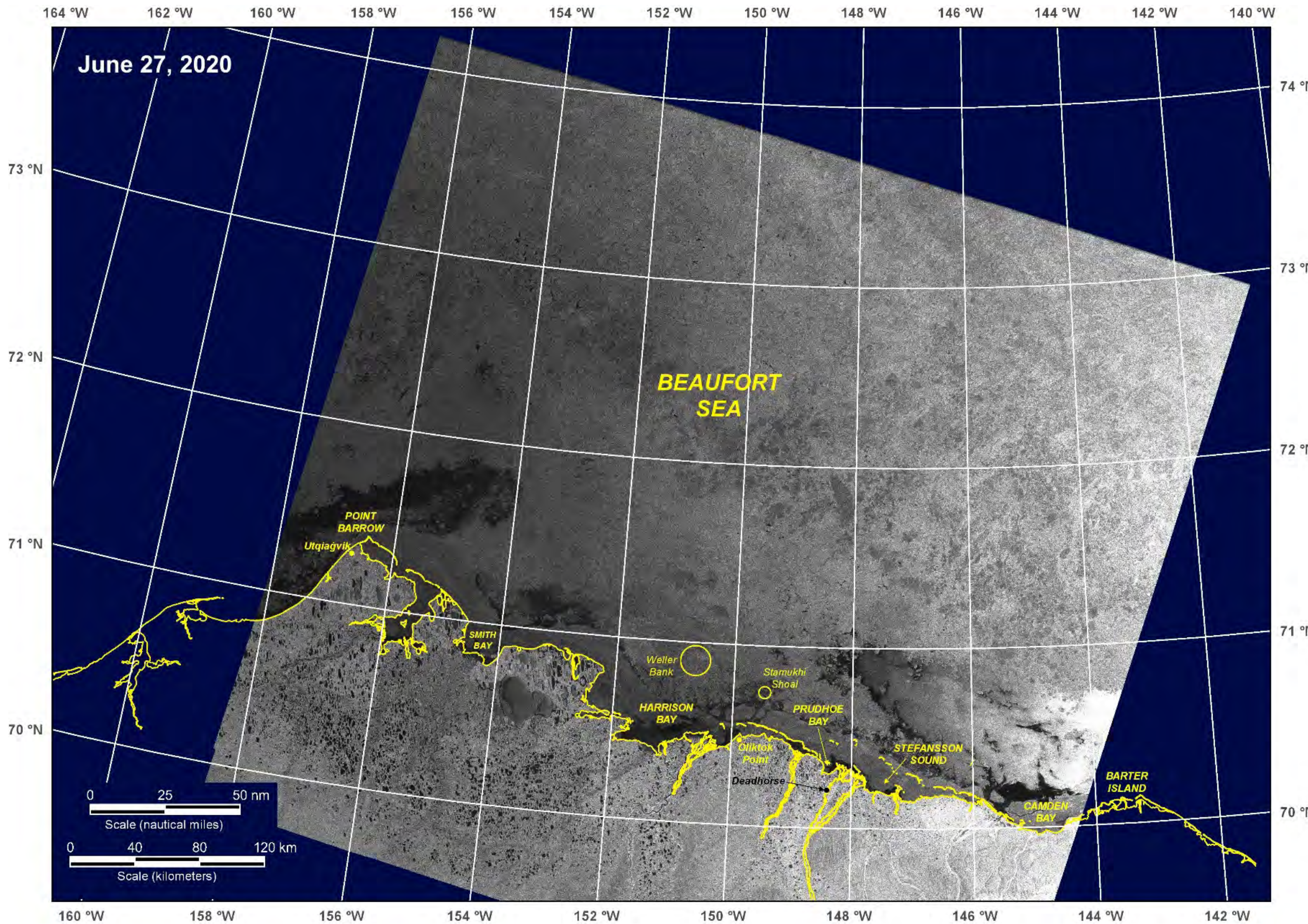

Figure 1. RADARSAT-2 Image of Beaufort Sea

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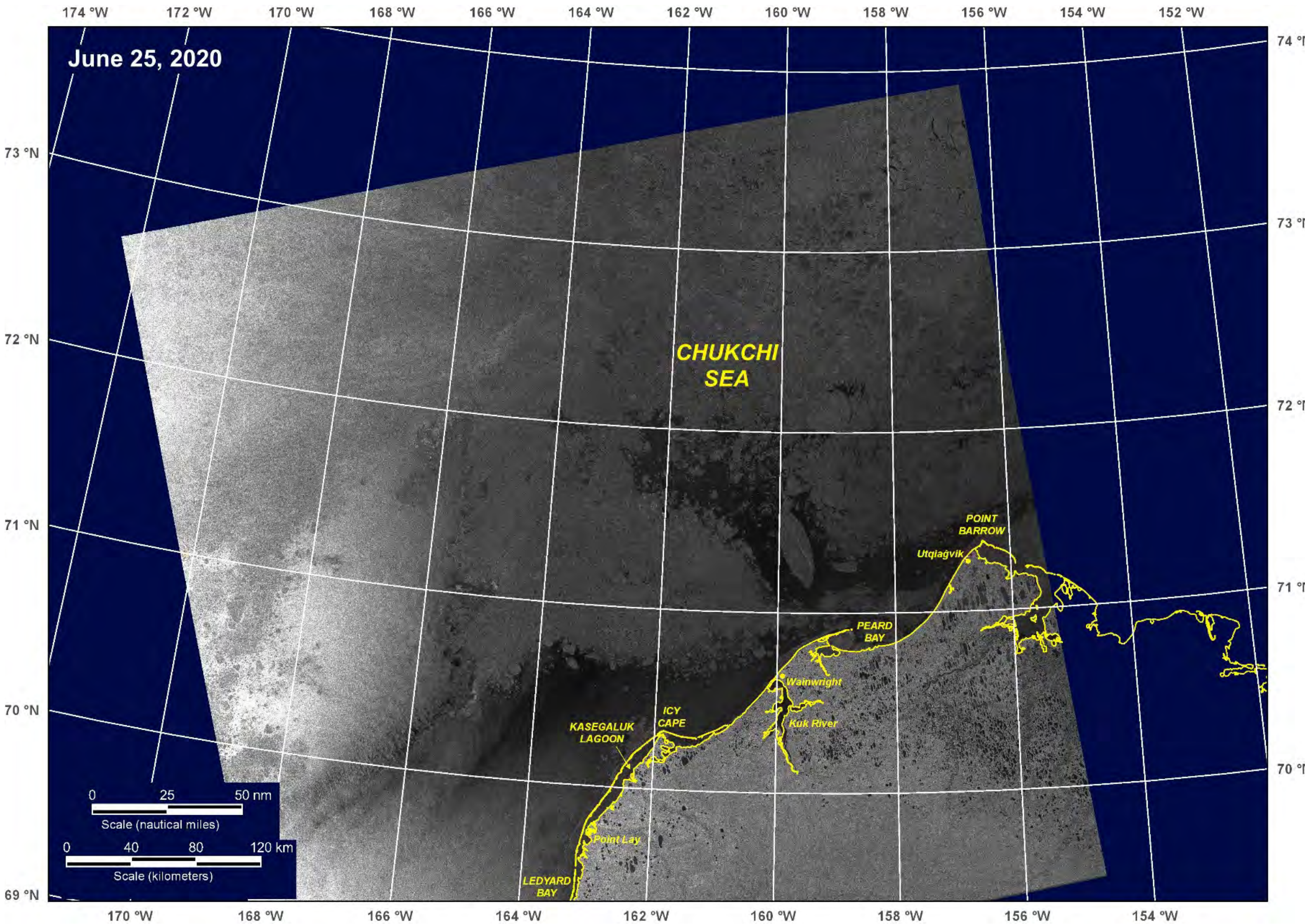

Figure 2. RADARSAT-2 Image of Chukchi Sea

COASTAL FRONTIERS

2019-20 Freeze-Up and 2020 Break-Up Studies of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas

Contract 140E0119C0011

Post-Remote Imaging Acquisition Progress Report No. 15

July 20, 2020

This report describes the fifth and final pair of RADARSAT-2 images obtained from MDA in support of the 2020 Break-Up Study of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas under Contract 140E0119C0011. Processed versions of the images, representing derivative products that may be transmitted to BSEE in accordance with MDA's End User License Agreement, are attached as Figures 1 and 2. A description and assessment of each image is provided below.

Image of Beaufort Sea

Date of Acquisition: July 14, 2020

Area of Observation: Alaskan Beaufort Sea extending from central Camden Bay to west of Point Barrow, and north of the 74°N parallel.

Principal Objective: Document the final stage of break-up including the southern boundary of the pack ice.

Findings: Since the prior image was acquired on June 27th, the warm-water plumes from the Mackenzie River and Alaska Coastal Current have converged, most of the remaining landfast ice has been dislodged from the nearshore region, and the pack ice has retreated to the north. When the image was acquired on July 14th, the southern edge of the pack ice was located approximately 50 nautical miles north of the mainland coast.

Assessment: The image is of good quality and suitable for its intended purpose. Publicly-available ice charts and satellite images will be used to provide supplemental information on the final stage of break-up until the period of data acquisition ends on July 31st.

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Image of Chukchi Sea

Date of Acquisition: July 12, 2020

Area of Observation: Alaskan Chukchi Sea extending from Point Barrow to the 173°W meridian, and from Ledyard Bay to the vicinity of the 73°45'N parallel.

Principal Objective: Document the final stage of break-up including the southern boundary of the pack ice.

Findings: When the image was obtained on July 12th, all of the landfast ice had been removed from the nearshore region with the exception of two small patches to the west of Peard Bay. The pack ice had retreated to the north and west, leaving the region south of the 71°N parallel and east of the 168°W meridian virtually ice-free. The southern edge of the pack ice was diffuse, while the eastern edge was compact.

Assessment: The image is of good quality and suitable for its intended purpose. Publicly-available ice charts and satellite images will be used to provide supplemental information on the final stage of break-up until the period of data acquisition ends on July 31st.

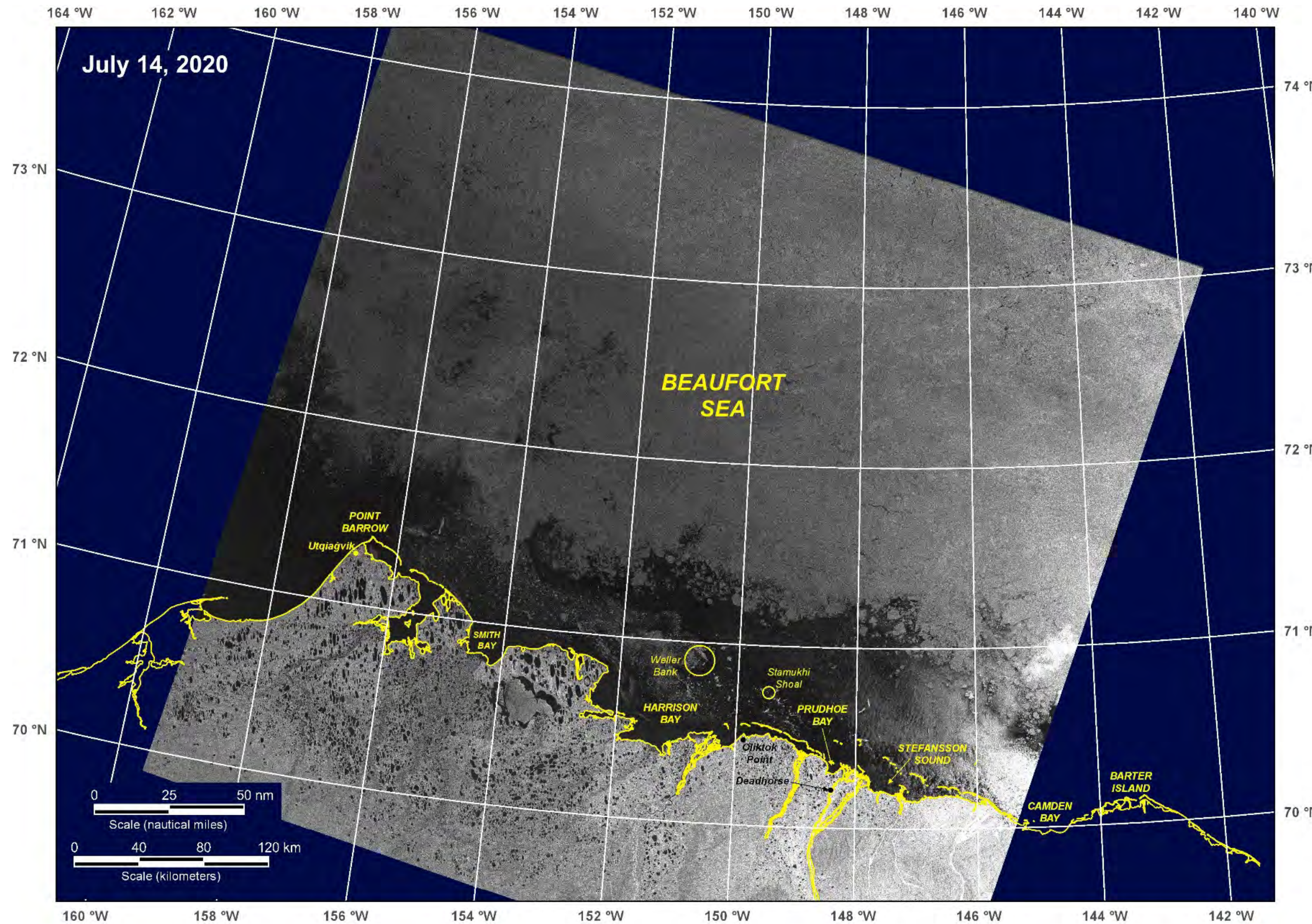

Figure 1. RADARSAT-2 Image of Beaufort Sea

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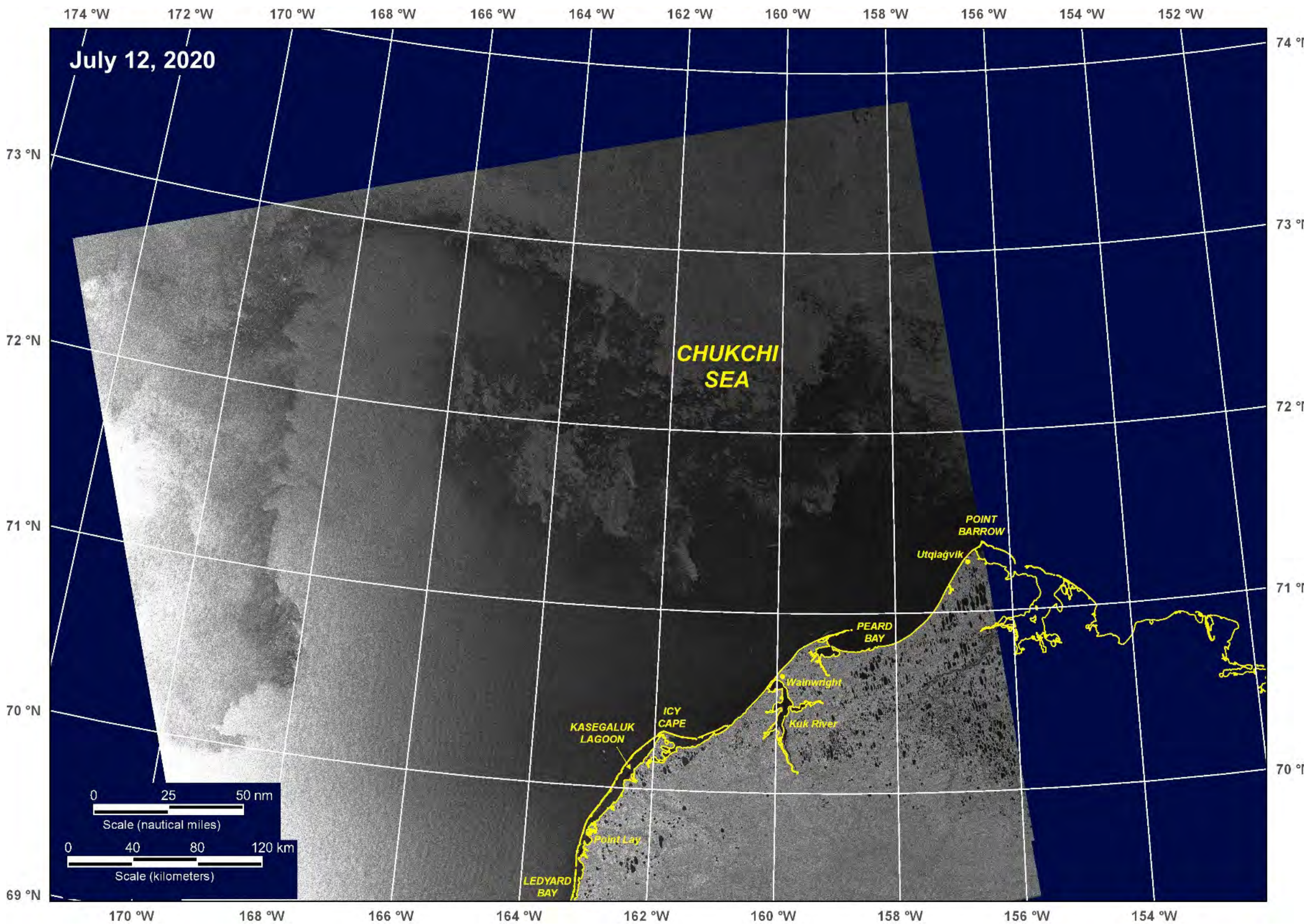

Figure 2. RADARSAT-2 Image of Chukchi Sea

APPENDIX C

POST-OBSERVATION BREAK-UP PROGRESS REPORTS

COASTAL FRONTIERS

2019-20 Freeze-Up and 2020 Break-Up Studies of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas

Contract 140E0119C0011

Post-Observation Break-Up Progress Report No. 1 (Chukchi Sea)

June 23, 2020

Objectives

Two aerial reconnaissance missions were conducted in mid-June 2020 to document the ice conditions that prevailed near the end of the break-up period in the Alaskan Chukchi Sea. The specific objectives of the flights were as follows:

1. Obtain ground truth information to confirm and expand upon the conclusions drawn from satellite imagery;
2. Investigate large-scale features identified in the satellite imagery, including multi-year ice floes and the deteriorating landfast ice zone;
3. Detect, investigate, and document small-scale ice features that were beneath the resolution of the satellite imagery, including shoreline pile-ups, ridges and rubble fields, melt ponds, and multi-year ice fragments.

Area of Observation

The two flights were conducted from Utqiagvik Airport using a twin-engine Aero Commander 690 with two pilots. The flight paths are shown in Figure 1, while details are provided below:

Nearshore Chukchi Sea (June 15th): After departing from Utqiagvik, the aircraft headed southwest over the retreating strip of landfast ice. The aircraft reversed direction at Point Lay, returning to Utqiagvik along the coastline to facilitate the observation of shoreline pile-ups. The flight was conducted under clear skies with excellent visibility until just prior to landing, when dense fog was encountered.

Offshore Chukchi Sea (June 16th): The flight path consisted of a counterclockwise loop that began and ended at Utqiagvik and included Hanna Shoal, the Hanna Shoal Prospects, and the Burger Prospects along with several small deviations to observe the edge of the retreating pack ice as well as pieces of landfast ice that had been dislodged and drifted offshore. With the exception of the region north and west of the Burger Prospects, where fog was present, clear skies and excellent visibility prevailed.

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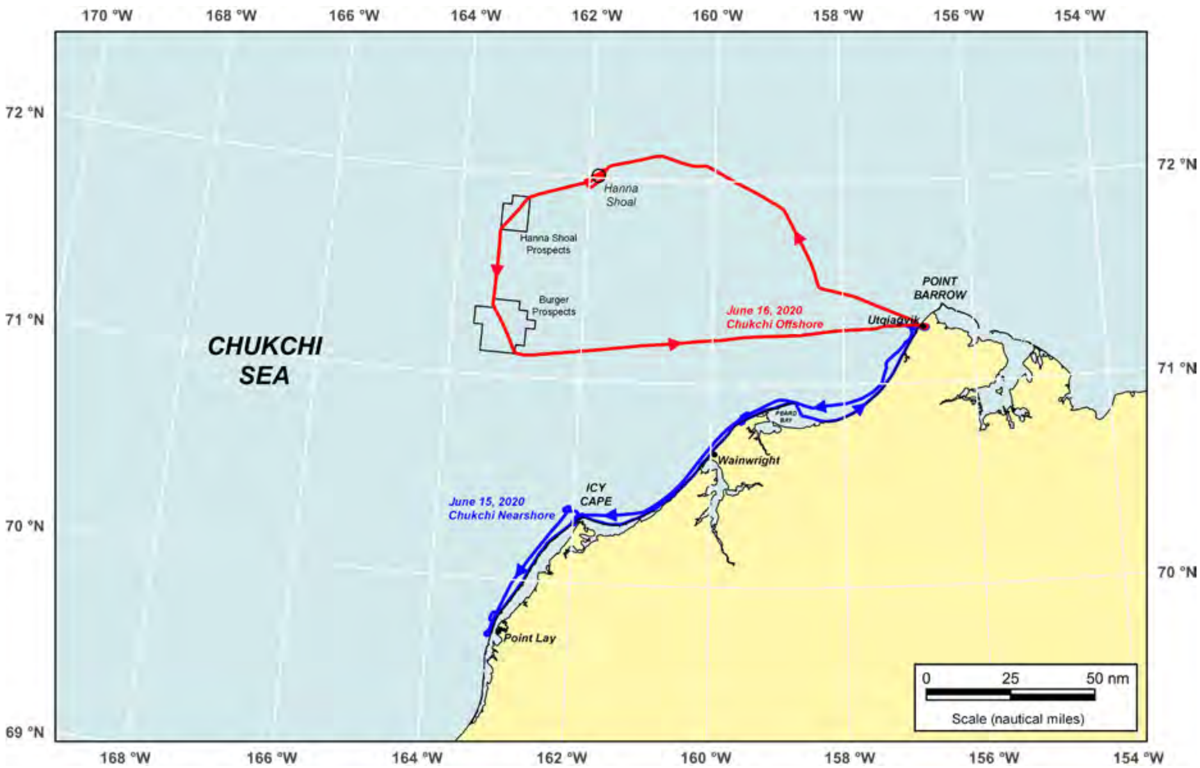

Figure 1. Flight Paths in Alaskan Chukchi Sea

Significant Findings

Lagoon Ice: Ice coverage in the semi-protected lagoons ranged from negligible in portions of South Kasegaluk Lagoon and the Kuk River Entrance Channel to 10/10s in Peard Bay. In all instances where ice was present, it was badly deteriorated as evidenced by numerous melt ponds and through-ice holes (Plate 1).

Landfast Ice: The landfast ice was found to be discontinuous, reflecting substantial losses in the weeks preceding the flights. The ice that remained was anchored by grounded ridges and rubble that typically ranged from 2 to 5 m high but peaked at 20 m on Blossom Shoals (Plate 2; Blossom Shoals are located approximately 1 nm north-northwest of Icy Cape). The maximum width of the landfast ice, 10 nm, occurred off Peard Bay (Plate 3), while the region to the east of Icy Cape was found to be completely devoid of such ice (Plate 4). As illustrated in Plate 3, multi-year ice (MYI) was embedded in the landfast ice at concentrations ranging from negligible to 20%.

Flaw Lead: A large expanse of open water that began as a narrow flaw lead and subsequently grew wider in response to a combination of melting and easterly winds separated the pack ice from the landfast ice. The width of the expanded flaw lead ranged from less than 20 nm off Utqiagvik to more than 100 nm off Point Lay.

Plate 1. Rotten Ice in Peard Bay
(June 15, 2020)

Plate 2. 20-m Rubble Pile on Blossom Shoals
(June 15, 2020)

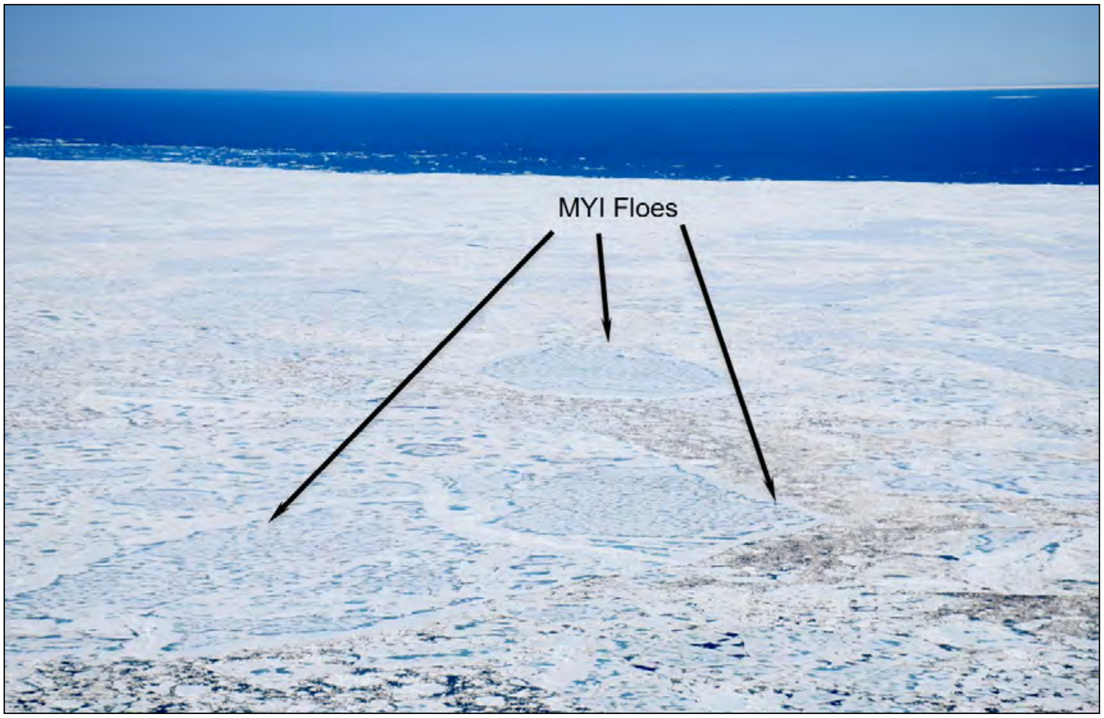

Plate 3. Landfast Ice off Peard Bay
(June 15, 2020)

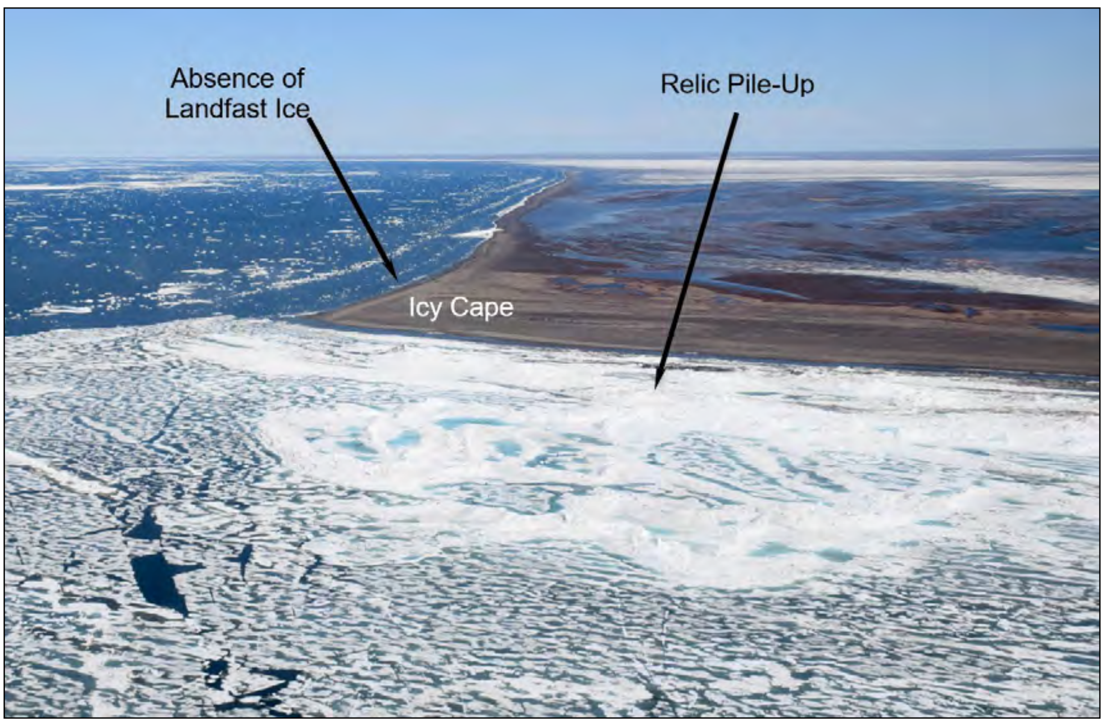

Plate 4. Absence of Landfast Ice East of Icy Cape
(June 15, 2020)

Ice Pile-Ups: Of the 57 ice pile-ups observed on the coast between Point Lay and Utqiagvik during the freeze-up reconnaissance flights in late February, 53 were evident when the nearshore break-up flight was conducted on June 15^{th}. As illustrated in Plate 5, which displays a pile-up that formerly extended 5 m above sea level and encroached 20 m onto the barrier island to the east of Icy Cape, the dimensions of these relict pile-ups had been substantially reduced by melting. The remaining four pile-ups observed during the freeze-up flights were no longer discernible, but five new pile-ups that appeared to have formed during break-up were discovered (Plate 6). The heights ranged from 2 to 5 m and the encroachment distances from 3 to 5 m.

Pack Ice: The pack ice contained a mixture of first-year and multi-year ice, with the concentration of the latter typically ranging from 10 to 30%. Melt ponds were omnipresent. The largest multi-year floe, with an approximate diameter of 12 km, was located at the eastern edge of the pack ice 75 nm west of Utquiagvik (Plate 7).

Katie's Floeberg: Katie's Floeberg, which forms each winter when ice rubble accumulates on Hanna Shoal (Figure 1), measured 5.5 km long and 2.5 km wide, with the major axis oriented northeast-southwest. It was composed of about 80% first-year ice and 20% multi-year ice (Plate 8). The maximum rubble height, 20 m, was located on the southwest side of a multi-year floe near the center of the floeberg. An open-water wake was present on the downwind (west) side, indicating that the feature remained well-grounded at the time of the flight.

Plate 5. Relict Ice Pile-Up on Barrier Island East of Icy Cape (June 15, 2020)

Plate 6. 5-m Pile-Up that Occurred 4 nm Northwest of Point Belcher during Break-Up (June 15, 2020)

Plate 7. Large Multi-Year Ice Floe 75 nm West of Utqiagvik (June 16, 2020)

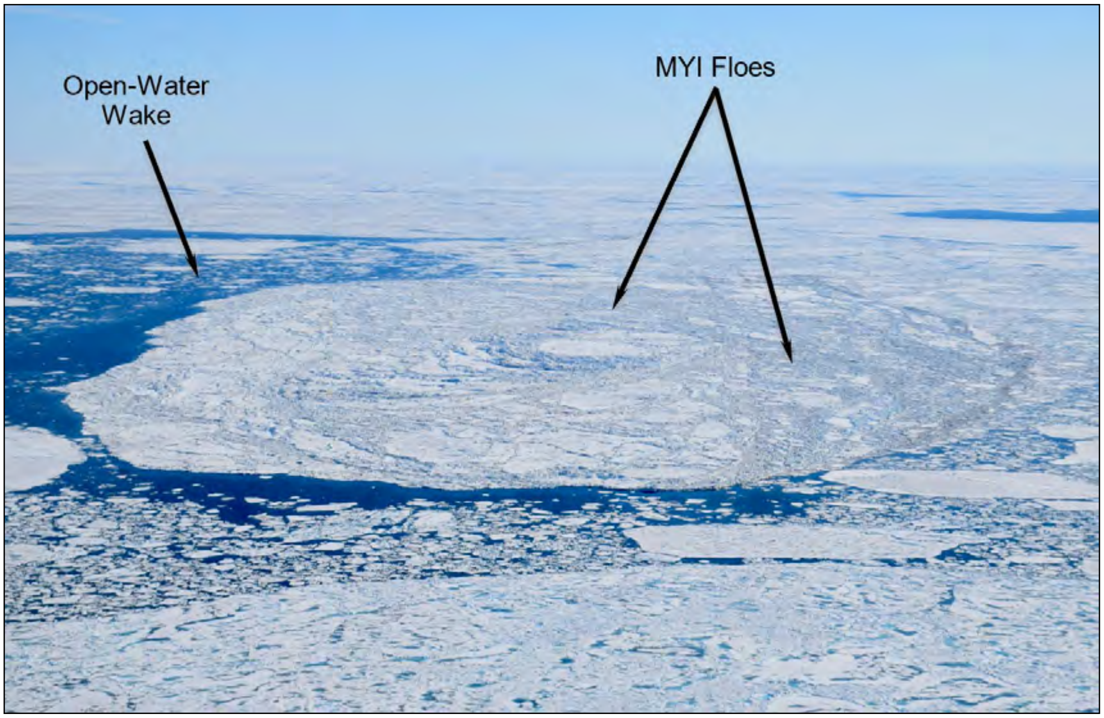

Plate 8. Katie's Floeberg on Hanna Shoal
(June 16, 2020)

Summary and Conclusions

The two aerial reconnaissance missions accomplished the objectives identified at the beginning of this report. No significant technical problems were encountered, and no data gaps have been identified.

The data acquired during the flights will be analyzed in greater detail in the months ahead. Due to the limited nature of the analysis conducted to date, the findings presented in this report should be regarded as preliminary and subject to refinement.

COASTAL FRONTIERS

2019-20 Freeze-Up and 2020 Break-Up Studies of Arctic Sea Ice in the Alaskan Beaufort and Chukchi Seas

Contract 140E0119C0011

Post-Observation Break-Up Progress Report No. 2 (Beaufort Sea)

July 23, 2020

Objectives

Two aerial reconnaissance missions were conducted in early July 2020 to document the ice conditions that prevailed near the end of the break-up period in the Alaskan Beaufort Sea. The specific objectives of the flights were as follows:

1. Obtain ground truth information to confirm and expand upon the conclusions drawn from satellite imagery;
2. Investigate large-scale features identified in the satellite imagery, including multi-year ice floes and the deteriorating landfast ice zone;
3. Detect, investigate, and document small-scale ice features that were beneath the resolution of the satellite imagery, including shoreline pile-ups, ridges and rubble fields, melt ponds, and multi-year ice fragments.

Area of Observation

The two reconnaissance flights were conducted using a twin-engine Aero Commander 690 with two pilots. The flight paths are shown in Figure 1, while details are provided below:

Western Beaufort Sea (July 9th): The aircraft departed from Utqiagvik, cleared Point Barrow, and then proceeded in a southeasterly direction at distances of 10 to 40 nautical miles offshore. After passing over Weller Bank and Stamukhi Shoal, the two customary anchor points for landfast ice in the vicinity of Harrison Bay, it turned southwest into the southeastern portion of the Bay. It then headed east-southeast along the barrier islands between Harrison Bay and Deadhorse. The dense fog that prevailed at the beginning of the flight diminished as the aircraft travelled east, but intermittent fog and poor visibility were encountered on numerous occasions.

Central Beaufort Sea (July 10th): The flight covering the Central Beaufort Sea consisted of a counterclockwise loop that began and ended at Deadhorse. After crossing Stefansson Sound, the aircraft proceeded in an easterly direction along the barrier island chain and across Camden Bay to Barter Island. It then turned back toward the west at distances that typically ranged from 2 to 30 nautical miles off the barrier islands. When the aircraft approached Northstar Production Island, the visibility was severely reduced by fog that prevailed for the remainder of the flight to Deadhorse.

Figure 1. Flight Paths in Alaskan Beaufort Sea

Significant Findings

Lagoon Ice: Open water prevailed in the semi-protected lagoons behind the barrier islands, but widely-scattered ice cakes and small floes at concentrations less than 10% were noted in some areas (Plate 1). In addition, relatively dense accumulations of cakes and small floes were present on the east side of the West Dock Causeway and the Endicott Project (Plate 2), reflecting the easterly winds that prevailed prior to and during the flights. In all instances where ice was present, it was badly deteriorated as evidenced by numerous melt ponds and through-ice holes.

Landfast Ice: Although the landfast ice had been partially removed from some areas and totally removed from others prior to the flights, substantial expanses remained grounded on Weller Bank (Plate 3), where the ridge and rubble heights reached 7 m, and Stamukhi Shoal, where the ridge and rubble heights reached 4 m. In both cases, multi-year ice comprised approximately 20% of the ice that remained. Patches of grounded ice that had become surrounded by open water also were observed immediately east of Point Barrow, between Smith and Harrison Bays, and off Barter Island (Plate 4).

Nearshore Ice: Numerous ice cakes and small floes that appeared to be floating rather than grounded were present on the seaward side of many of the barrier islands (Plate 5). The ice was rotten, with numerous melt ponds and through-ice holes.

Plate 1. Open Water with Widely Scattered Ice Cakes and Floes in Steffanson Sound (July 10, 2020)

Plate 2 Accumulation of Floating Ice on East Side of Endicott Causeway (July 10, 2020)

Plate 3. Landfast Ice Grounded on Weller Bank (July 9, 2020)

Plate 4. Landfast Ice Surrounded by Open Water off Barter Island (July 10, 2020)

Plate 5. Rotten Ice Floating on Seaward Side of Barrier Islands between Oliktok Point and Prudhoe Bay (July 9, 2020)

Ice Pile-Ups: Of the 32 ice pile-ups observed in the Central Beaufort Sea in late February, 16 were evident when the break-up flights were conducted on July 9th and 10th. As illustrated in Plate 6, which displays a pile-up that formerly extended 7 m above sea level and encroached 5 m onto the subaerial beach of Thetis Island, the dimensions of these pile-ups had been substantially reduced by melting. The remaining 16 pile-ups observed during the freeze-up flights were no longer discernible, and new pile-ups or ride-ups that could have formed during break-up were conspicuously absent.

Pack Ice: With the exception of one instance in the Western Beaufort and one instance in the Central Beaufort, the flight paths were located to the south of the pack ice. The exception in the Western Beaufort took place in the vicinity of Weller Bank, where ice concentrations ranging from 20% to 90% were observed in a tongue of ice that extended to the southeast. The concentration of multi-year ice in this tongue ranged from negligible to 30%. All of the ice, both first- and multi-year, was rotten with numerous through-ice holes. In the Central Beaufort, the flight path skirted the diffuse southern edge of the pack ice in the Camden Bay Prospects. Deteriorated first-year ice floes at a concentration of 10% were present in this region.

Multi-Year Ice: As indicated above, multi-year ice floes at concentrations peaking at 30% were observed in the pack ice near Weller Bank. Widely-scattered multi-year floes also were noted between Smith Bay and Weller Bank (Plate 7), seaward of the barrier islands east of Oliktok Point, in the vicinity of Northstar Production Island, and approximately 25 nautical miles north of Camden Bay.

Plate 6. Relict Ice Pile-Up on Thetis Island (July 9, 2020)

Plate 7. Multi-Year Ice Floes Embedded in First-Year Ice 15 nautical miles North of Smith Bay (July 9, 2020)

Summary and Conclusions

The two aerial reconnaissance missions accomplished the objectives identified at the beginning of this report. No significant technical problems were encountered, and no data gaps have been identified.

Conducting the break-up flights in the Beaufort Sea approximately three weeks after those in the Chukchi, as recommended in the 2017 Break-Up Study (Coastal Frontiers and Vaudrey, 2018), represented a substantial improvement over conducting both sets of flights at the same time (as was the case in 2017).

The data acquired during the flights will be analyzed in greater detail in the months ahead. Due to the limited nature of the analysis conducted to date, the findings presented in this report should be regarded as preliminary and subject to refinement.

Reference

Coastal Frontiers Corporation and Vaudrey & Associates, 2018, "2017 Break-Up Study of the Alaskan Beaufort and Chukchi Seas", report prepared for Bureau of Safety and Environmental Enforcement, U.S. Dept. of the Interior, Moorpark, California, 143 pp. + appen.

APPENDIX D

TECHNICAL SUMMARY

2020 BREAK-UP STUDY OF ARCTIC SEA ICE IN THE ALASKAN BEAUFORT AND CHUKCHI SEAS

TECHNICAL SUMMARY

Overview

This study characterizes the processes that occur during break-up in the Alaskan Beaufort and Chukchi Seas. It represents the second such study undertaken in recent years, with the first conducted in 2017. Particular emphasis is placed on comparing and contrasting the break-up processes that occur today with those that prevailed in past decades.

Application

The information developed in this study is suitable for immediate application to the planning, design, construction, and operation of coastal and offshore facilities in the lease sale areas of the Alaskan Beaufort and Chukchi Seas. As an example, the timing and pace of break-up play critical roles in defining the end of the period suitable for on-ice transportation and construction, and the beginning of the period suitable for open-water vessel navigation.

Methods

The study was conducted using a combination of remotely-sensed data and on-site observations. The remotely-sensed data consisted of meteorological data recorded at Deadhorse and Utqiagvik Airports, ice charts prepared by the Canadian Ice Center, National Ice Center, and National Weather Service, satellite imagery acquired using the RADARSAT-2, VIIRS, and MODIS platforms, and drift buoy data available through the International Arctic Buoy Programme. On-site observations were conducted during aerial reconnaissance missions undertaken near the end of the break-up-up season, consisting of two fixed-wing flights in the Chukchi in mid-June followed by two such flights in the Beaufort in early July.

Observations and Conclusions

Air Temperatures: Since the 1970s, progressively warmer break-up seasons have caused the number of accumulated thawing-degree days at Utqiagvik to increase at an average rate of 4.2 per year. The rate of warming has varied widely, however, on time scales ranging from interannual to interdecadal.

Storms: Since the early 1980s, the frequency of storm events during break-up has nearly doubled, from 3.2 to 5.8 storms per year.

River Overflood: The limited data available suggest that the initiation of river overflood onto the sea ice in the Chukchi and Beaufort Seas has been trending earlier at rates ranging from negligible to less than one day per year.

Timing of Break-Up in the Chukchi Sea: The occurrence of break-up appears to be trending earlier, but the rate of change cannot be quantified due to the variability inherent in the timing coupled with a paucity of both historical and recent data.

Timing of Break-Up in the Beaufort Sea: The data acquired in 2017 and 2020, when compared with those from 1953 through 1975, suggest that both break-up and open water are trending earlier, with the occurrence of open water advancing more rapidly than that of break-up. As a result, the duration of the break-up season appears to be decreasing. The rates of change in the timing of break-up and open water appear to be highest for pack ice, intermediate for landfast ice, and insignificant for lagoon ice. It is cautioned, however, that additional data will be required to substantiate and refine these preliminary findings.

Length of Open-Water Season: Trends toward an earlier occurrence of break-up and a later occurrence of freeze-up are causing the length of the open-water season to increase at rapid rates in both the Chukchi and Beaufort Seas.

Multi-Year Ice: The probability of multi-year ice residing in the Chukchi Sea and nearshore portion of the Beaufort Sea during break-up appears to have decreased since the 1980s. Nevertheless, the possibility of encountering such ice cannot be dismissed.

Detailed technical information specific to the 2020 break-up season is provided in Attachment A.

ATTACHMENT A

TECHNICAL INFORMATION FOR 2020 BREAK-UP SEASON

Entire Study Area

1. ***Air Temperatures:*** The air temperatures during the 2020 break-up season were cold by recent standards. Specifically, 2020 ranked 35th out of the past 51 years in terms of the number of thawing-degree days (TDD) accumulated at Utqiagvik Airport in May, June, and July.
2. ***Ice Thickness:*** The computed thickness of undeformed first-year ice at the end of the 2019-20 winter season was 148 cm in the Chukchi Sea and 162 cm in the Alaskan Beaufort Sea. TDD began to accumulate at Utqiagvik Airport on May 29th, with the computed ice thickness in the Chukchi decreasing to zero on July 26th. In the case of the Beaufort, TDD began to accumulate at Deadhorse Airport on May 23rd. The computed ice thickness decreased to zero on July 8th.

Chukchi Sea

1. ***Late Winter:*** Arctic sea ice attained its maximum extent for the 2019-20 winter season on March 5th. The total area, 15.05 million km^2, although the highest since 2013, was the eleventh lowest since the acquisition of satellite-based data began in 1979. The maximum ice extent approached its median location for the 30-year period from 1981 through 2010 in the Bering Sea but fell short off the coasts of eastern Canada, Greenland, and western Russia. The net result was a deficiency of 590,000 km^2 relative to the average maximum extent over this 30-yr span.
2. ***Wind and Storm Regime:*** Easterlies outnumbered westerlies by substantial margins in each of the three months from May through July. Over the entire period, easterlies occurred 77% of the time versus 23% for westerlies. The monthly average speeds were nearly constant, with values of 11 kt (6 m/s) in May and July, and 10 kt (5 m/s) in June. Storm activity was muted, in that events with daily average wind speeds exceeding 15 kt (8 m/s) occurred on only four occasions encompassing 11 days. Three of the storms were easterlies, with an average duration of 2.7 days/event, while one was a westerly with a duration of three days.
3. ***Coastal Flaw Lead:*** A narrow flaw lead that existed off the Chukchi Sea coast at the end of April expanded throughout May, evolving into a large expanse of open water that was approximately 15 nm (37 km) wide off Point Barrow and 85 nm (158 km) wide off Point Lay at month-end. It continued to expand in June and July.

4. ***River Overflood:*** Of the seven rivers that discharge in or adjacent to the Chukchi Sea study area, the first began overflooding the sea ice on May 12th and the last on June 1st. Most of the flood water was contained in the receiving lagoons, with minimal penetration onto the landfast ice farther offshore.

5. ***Lagoon Ice:*** Break-up in the semi-protected lagoon areas began with South Kasegaluk Lagoon on May 23rd, continued with North Kasegaluk Lagoon and the Kuk River Entrance on June 10th, and concluded with Peard Bay on June 14th. Open water followed in South Kasegaluk Lagoon on June 20th, North Kasegaluk Lagoon on June 27th or 28th, the Kuk River Entrance between June 25th and 30th, and Peard Bay on July 7th.

6. ***Landfast Ice:*** Break-up of the landfast ice occurred on May 13th when an easterly storm dislodged a large piece from the region between Wainwright and Icy Cape, and smaller pieces from the region between Icy Cape and Point Lay. Intermittent losses followed during the remainder of May and first half of June, including a massive piece measuring 74 km long and 19 km wide that broke free from the region between Point Franklin and Utqiagvik. The rate of loss increased in mid-June in response to moderate northeasterly winds and warm air temperatures. At the beginning of July, the landfast ice that remained consisted of intermittent patches spanning the entire length of the study area. The last remnant disappeared in mid-July.

7. ***Pack Ice:*** The pack ice retreated to the northwest at a relatively rapid rate in May. Although the retreat continued in June, it proceeded at a slower pace that reflected occasional reversals. The ice continued to dissipate in July, vacating the Siberian coast during the third week of the month. At the end of July, the southern edge trended northwest from the vicinity of Utqiagvik with the exception of a 50-nm (93-km) wide tongue that extended southwest as far as the Devil's Paw Prospects

8. ***Ice Pile-Ups:*** Of the 57 ice pile-ups observed on the Chukchi Sea coast in late February, 53 were evident in mid-June. In addition, five new pile-ups that had formed during break-up were identified. Two were located on the barrier islands between Point Lay and Icy Cape, while three were located on the mainland shore near the base of the Point Franklin Spit. The heights of the new pile-ups ranged from 2 to 5 m above sea level, the encroachment distances from 3 to 5 m onto the subaerial beach, and the alongshore lengths from 600 to 2,800 m

9. ***Multi-Year Ice:*** Multi-year ice was present in the Chukchi Sea study area throughout the break-up study period. At the beginning of May, relatively small floes were embedded in the landfast ice at concentrations ranging from negligible to 20%. The dispersal of these floes mirrored the break-up of the landfast ice, commencing in mid-May and continuing through mid-July. Multi-year ice also was present in the pack ice, at concentrations ranging from negligible to 30%. The maximum horizontal dimensions of these floes varied from less than 10 m to more than 10 km.

10. ***Ice Drift:*** Two drift buoys embedded in the pack ice attained monthly average speeds of 7.8 and 8.5 nm/day (14.5 and 15.8 km/day) in July. The highest daily average speed, 13.8 nm/day (25.6 km/day), occurred on July 8th.

Beaufort Sea

1. ***Wind and Storm Regime:*** Easterly winds predominated by substantial margins in May, June, and July. Over the entire period, they outnumbered westerlies by a margin of 79% to 21%. The average monthly speeds decreased from 13 kt (7 m/s) May to 12 kt (6 m/s) in June and 9 kt (5 m/s) in July. Only four storm events took place during this period, all of which were easterlies. They produced 18 storm-days, resulting in an average duration of 4.5 days/event.

2. ***River Overflood:*** The Canning and Sagavanirktok began overflooding the sea ice on May 19th, the Colville on May 22nd, the Kuparuk on May 27th, and the Ikpikpuk on May 29th. Most of the flood water remained in the receiving bays and lagoons. The sole exceptions consisted of the discharge of the Canning River onto the sea ice east of Brownlow Point, and small tongues of water from the Kuparuk that pushed past the barrier islands off Gwydyr Bay.

3. ***Lagoon Ice:*** Break-up of the lagoon ice began on or about June 4th when flood water from the Sagavanirktok River melted through the ice in Prudhoe Bay. Through-ice melting followed in Stefansson Sound, South Harrison Bay, South Camden Bay, Gwydyr Bay, and Smith Bay between June 8th and 11th. In Simpson Lagoon, break-up took place on or about June 26th in response to the heat emanating from the mainland coast. Open water in the lagoon areas occurred over a period of several weeks that began with Gwydyr Bay between June 20th and 26th and ended with Stefansson Sound on July 10th. All of the lagoon sites were ice-free by the end of July.

4. ***Landfast Ice:*** Break-up of the landfast ice between Point Barrow and Cross Island occurred on May 23rd when a small loss occurred off Cape Halkett. Farther east, between Cross Island and Barter Island, break-up began with modest losses off Stefansson Sound and Camden Bay on May 27th. In early June, the landfast ice edge tended to lie between the 18- and 11-m isobaths from Point Barrow to Flaxman Island, and to protrude seaward of the 18-m isobath in Camden Bay. In the absence of westerly storms, losses were minimal until the last week of the month. At that time, warm air temperatures, increased wind speeds, and warm sea surface temperatures resulting both from river overflood and from the arrival of warm-water plumes from the Alaska Coastal Current to the west and Mackenzie River to the east, caused substantial losses off Smith Bay and in Harrison and Camden Bays. The accelerated rate of deterioration continued during the first half of July. By mid-month, landfast ice was confined to a patch in Elson Lagoon, narrow strips on both sides of Smith Bay, small patches on the west side of Harrison

Bay, and a narrow, discontinuous strip fronting the barrier islands from Cross to Flaxman. At the end of the month, small patches persisted between Pole and Flaxman Islands.

5. ***Pack Ice:*** The pack ice remained compact during the first three weeks of May. At month-end, however, warm water from the Alaska Coastal Current produced patches of open water adjacent to the landfast ice as far east as Harrison Bay. In analogous fashion, warm water from the Mackenzie River created a patch of open water adjacent to the landfast ice in Camden Bay. In June, unrelenting easterly winds propelled the Mackenzie plume to the west while impeding the easterly progress of the plume from the Alaska Coastal Current. During the final week, the pack ice concentrations in the nearshore region declined markedly in response to the westward progression of the Mackenzie plume to Harrison Bay and the eastern progression of the Alaska Coastal Current plume to Smith Bay. At the end of the month, the only two areas in which dense tongues of pack ice extended as far south as the landfast ice were located off western Harrison Bay and off Admiralty Bay. The deterioration continued in July, with the dense tongues dispersing by mid-month.

6. ***Ice Pile-Ups and Ride-Ups:*** Of the 32 ice pile-ups observed in the central portion of the Alaskan Beaufort Sea in late February, 16 were evident at the time of the break-up flights in early July. In all cases, the dimensions of the relict pile-ups had been diminished by melting. No new pile-ups or ride-ups were discovered in July.

7. ***Multi-Year Ice:*** Multi-year ice was present in the Beaufort Sea study area throughout the break-up study period. At the beginning of May, the concentration tended to be less than 10% in the landfast ice and to range from less than 10% to 50% in the pack ice. The only region lacking multi-year ice was a tongue of first-year ice that extended from the U.S.-Canadian border to the eastern edge of Harrison Bay just offshore of the landfast ice. The multi-year ice embedded in the landfast ice remained in place until late May, when losses began to occur in conjunction with the disintegration of the latter. The dispersal of the embedded multi-year ice paralleled that of the landfast ice, which continued through the end of the study period. With the exception of the nearshore tongue of first-year ice, which closed during the first week in June, multi-year ice remained omnipresent in the pack ice through the end of July. The concentrations ranged from less than 10% to a maximum of 70%. The floe sizes varied over a wide range, from brash ice to maximum horizontal dimensions exceeding 25 km.

8. ***Ice Drift:*** Drift buoys embedded in the pack ice attained monthly average speeds that averaged 5.4 nm/day (10.0 km/day) in May, 4.3 nm/day (8.0 km/day) in June, and 2.9 nm/day (5.4 km/day) in July. The highest daily average speed, 15.4 nm/day (28.5 km/day), occurred on both May 12th and July 28th.