Sea Ice Trends and Variability

US-Canada Northern Oil & Gas Research Forum 2017

Anchorage Alaska

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Oct 11-13, 2017

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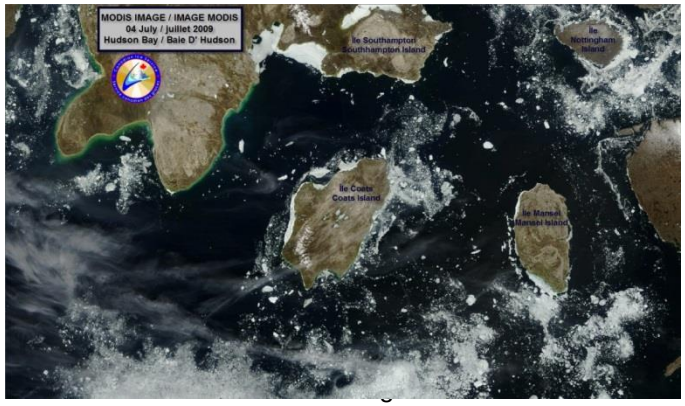
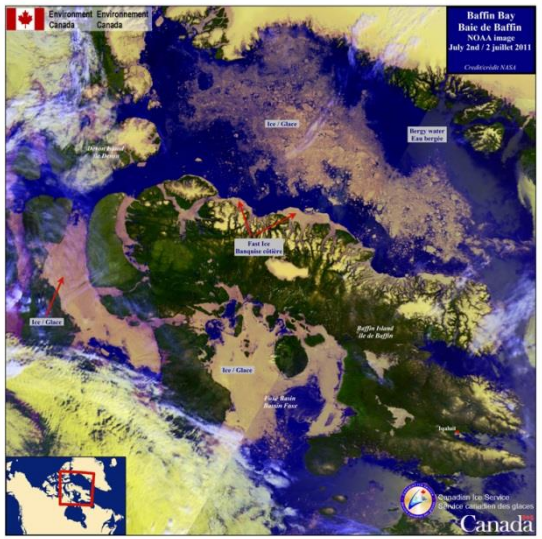
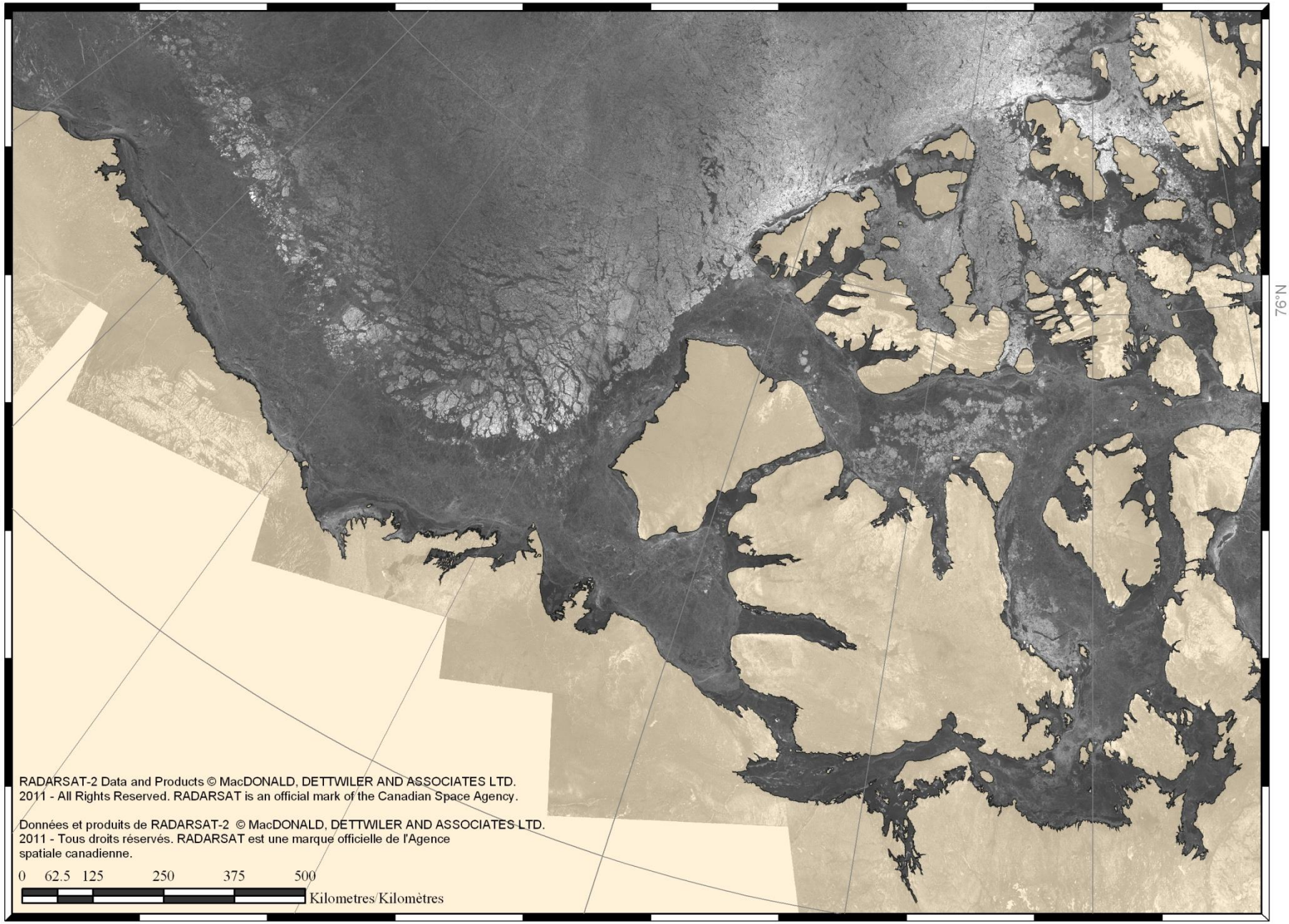
Data Sources - Concentration

- Data sources
  - CIS human interpretation of ice conditions
    - 1968 to 1996
      - NOAA AVHRR satellites
      - Aircraft patrols
    - 1996 to present
      - Addition of Synthetic Aperture Radar satellites
        - » RADARSAT-1, Envisat, RADARSAT-2, Sentinel

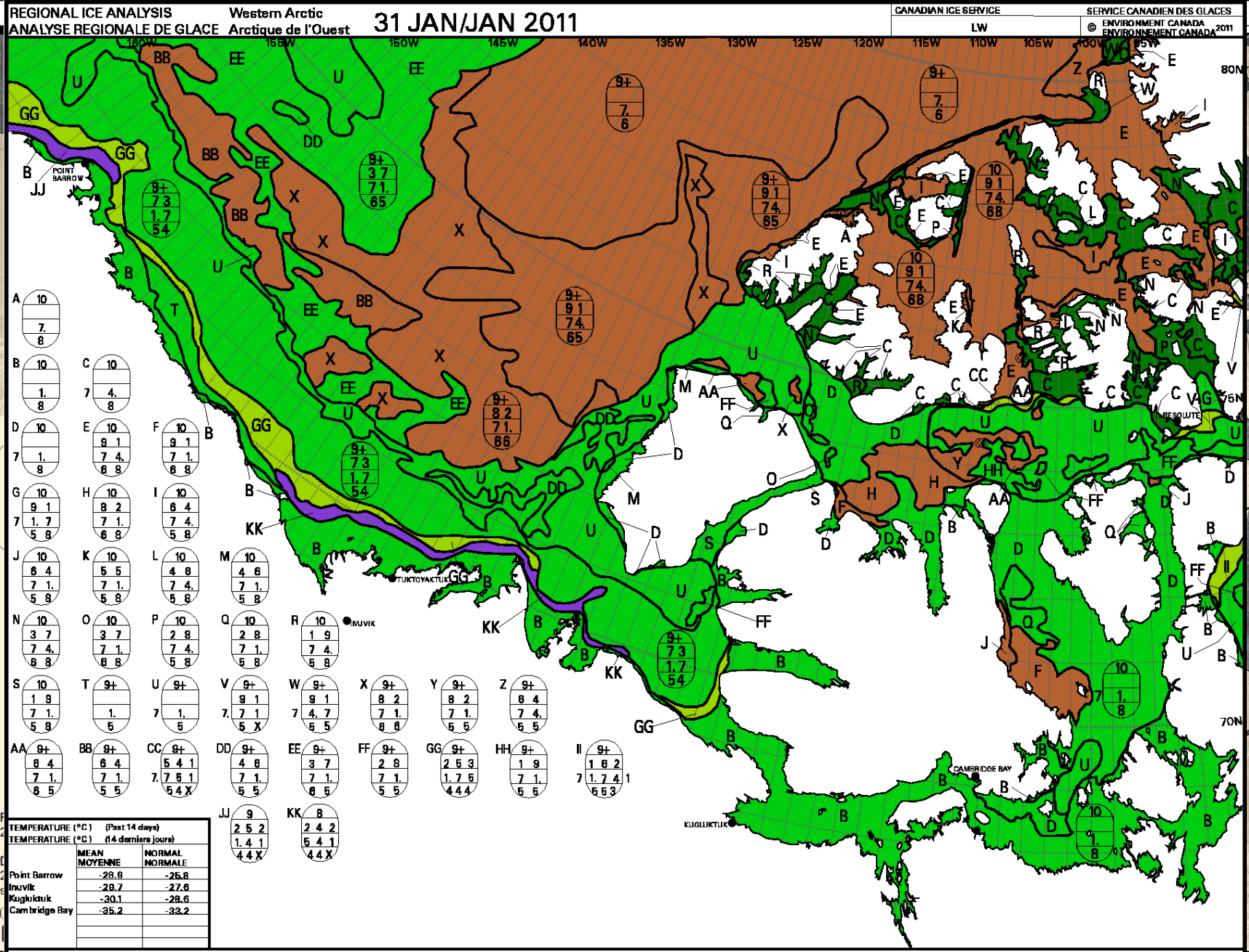




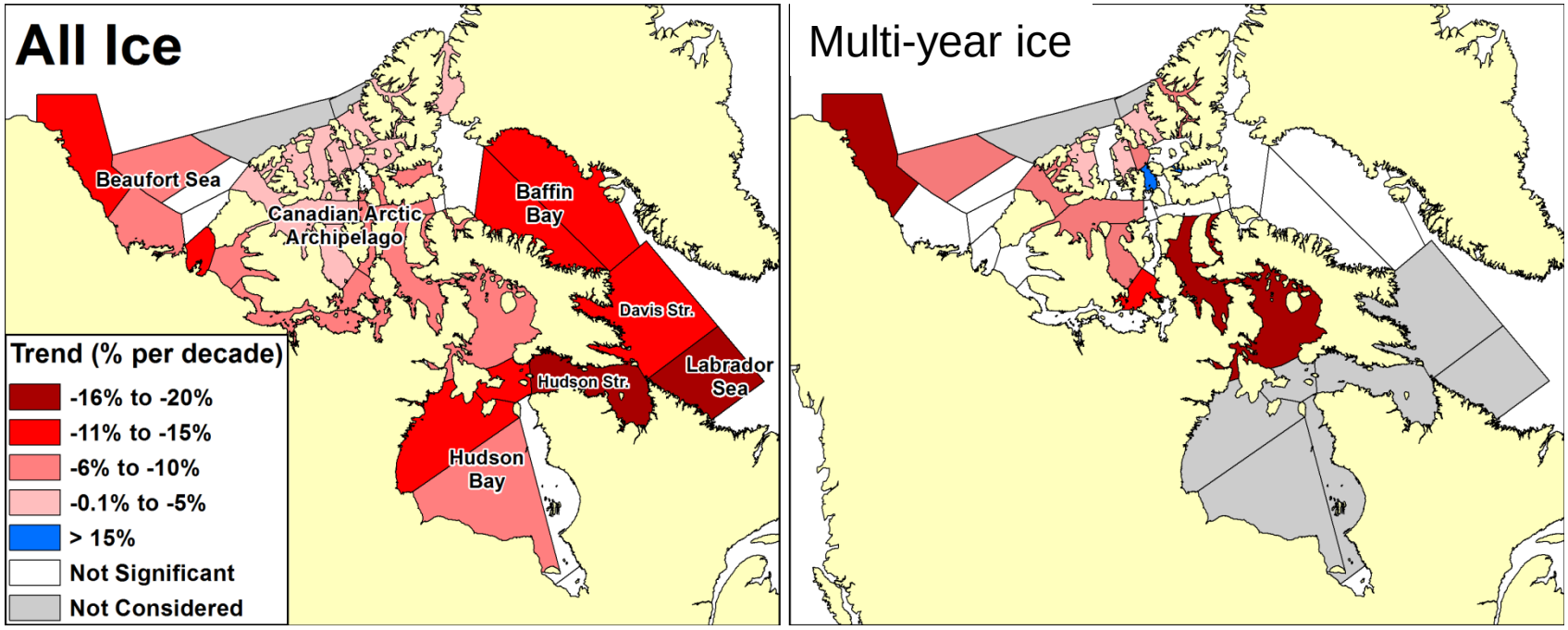


01/28/2011 - 01/31/2011

Western Arctic / Arctique de l'Ouest


REGIONAL ICE ANALYSIS
ANALYSE REGIONALE DE GLACE
Western Arctic
Arctique de l'Ouest
31 JAN/JAN 2011
CANADIAN ICE SERVICE
SERVICE CANADIEN DES GLACES
LW
© ENVIRONMENT CANADA ENVIRONNEMENT CANADA 2011
POINT BARROW
INUVIK
TUKTOYAKTUK
KUGLUKTUK
CAMBRIDGE BAY
RESOLUTE
80N
75N
70N
76°N
66°N
TEMPERATURE (°C) (Past 14 days)
TEMPERATURE (°C) (14 derniers jours)
MEAN MOYENNE
NORMAL NORMALE
Point Barrow -28.9 -25.8
Inuvik -28.7 -27.6
Kugluktuk -30.1 -28.6
Cambridge Bay -35.2 -33.2
WMO Colour Code - Stage of Development
Code de couleurs de l'OMM - Stade de formation
Ice Free
Libre de glace
Open Water
Eau Libre
Icebergs
New
Nouvelle
Grey
Grise
Grey-white
Blanchâtre
First-year
Première année
Thin First-year
Mince de première année
Medium First-year
Moyenne de première année
Thick First-year
Epaisse de première année
Old Ice
Vieille glace
Second-year
Deuxième année
Multi-year
Plusieurs années
Undefined Fast Ice
Indéfini Banquise côtière
Ice Shelf
Plateau de glace
Undefined
Indéterminée

Summer sea ice trends- 1968-2016

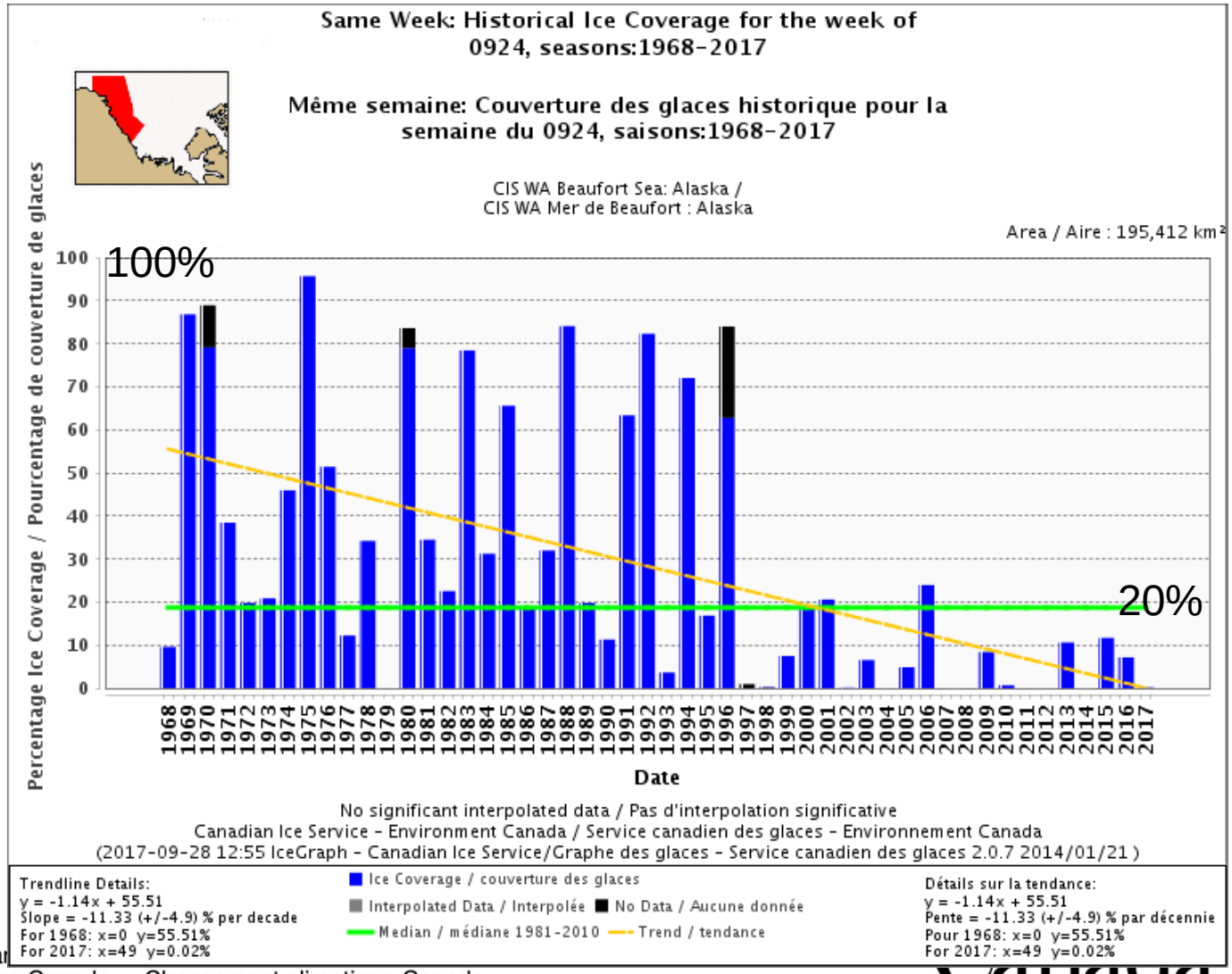


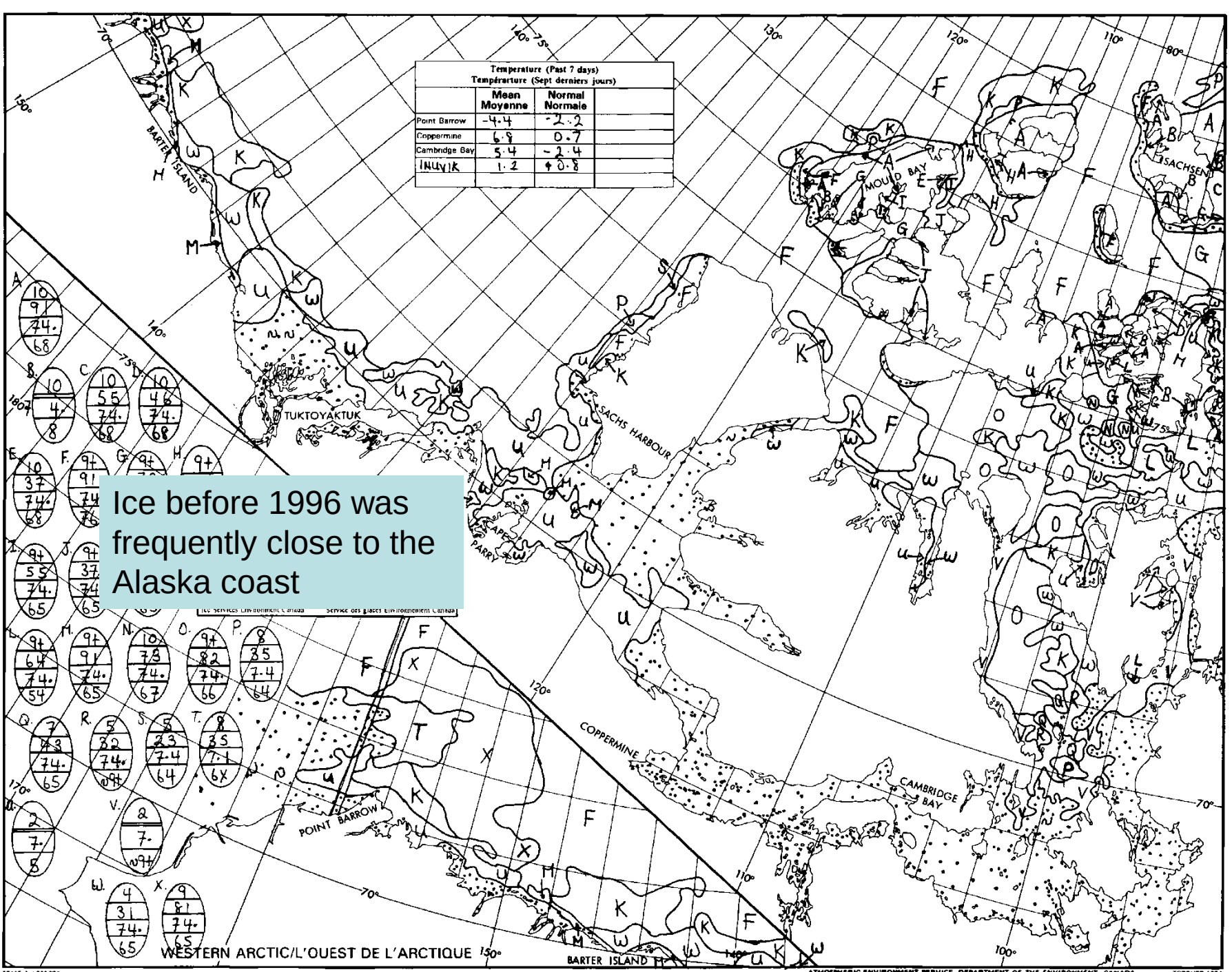
Tivy et al., 2011, updated

- Almost all regions in the US and Canadian Arctic had decreases in total ice concentration
- Multi-year ice (MYI) concentration decreases are not as wide-spread as total ice
  - in the last 10 years the MYI trend has doubled

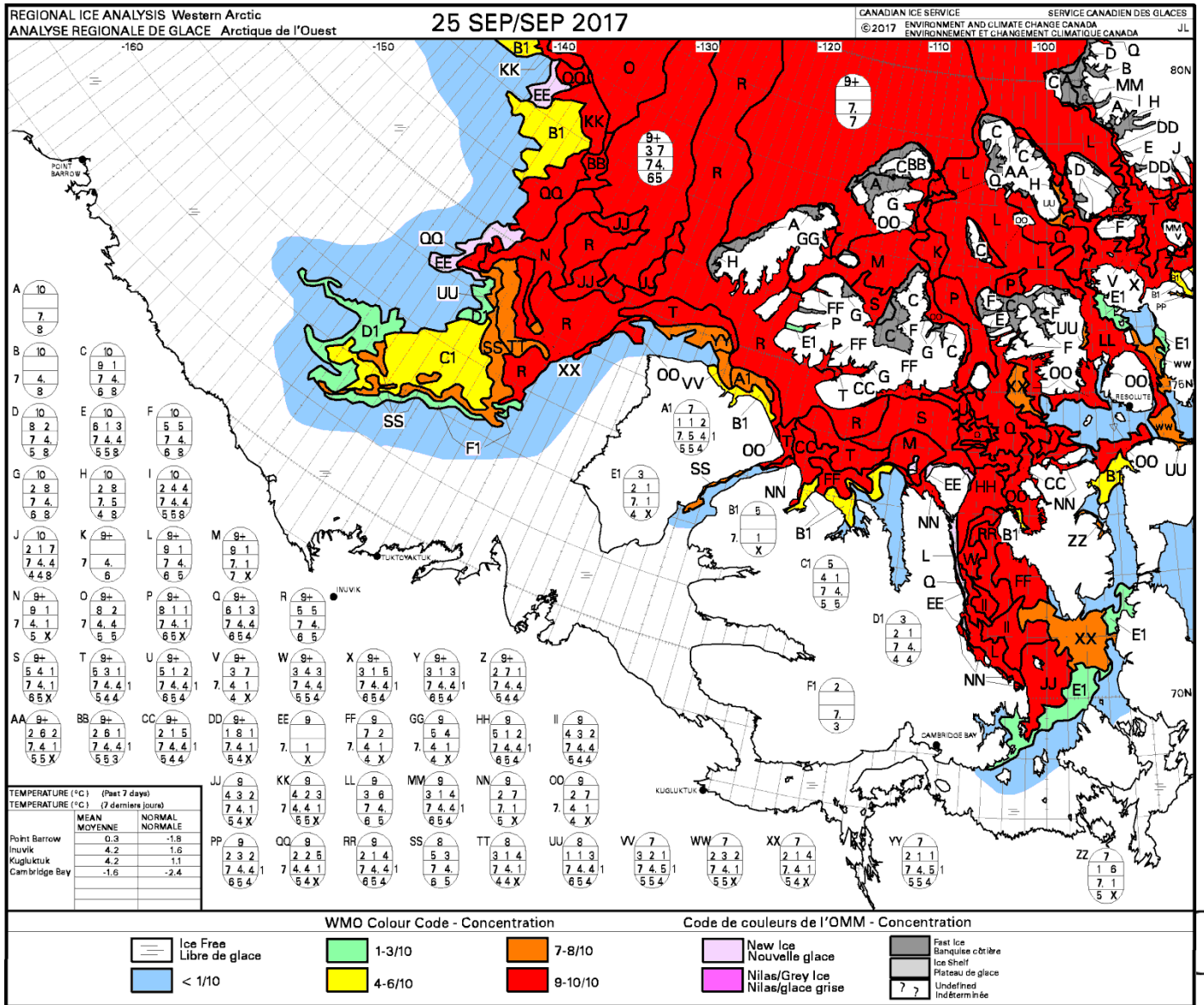
Alaska Coast – Ice Concentration Week of Sept 24

- Significant shift after 1996
- Variability has decreased
- More years with less ice

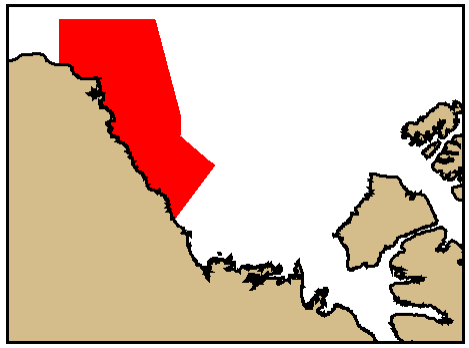


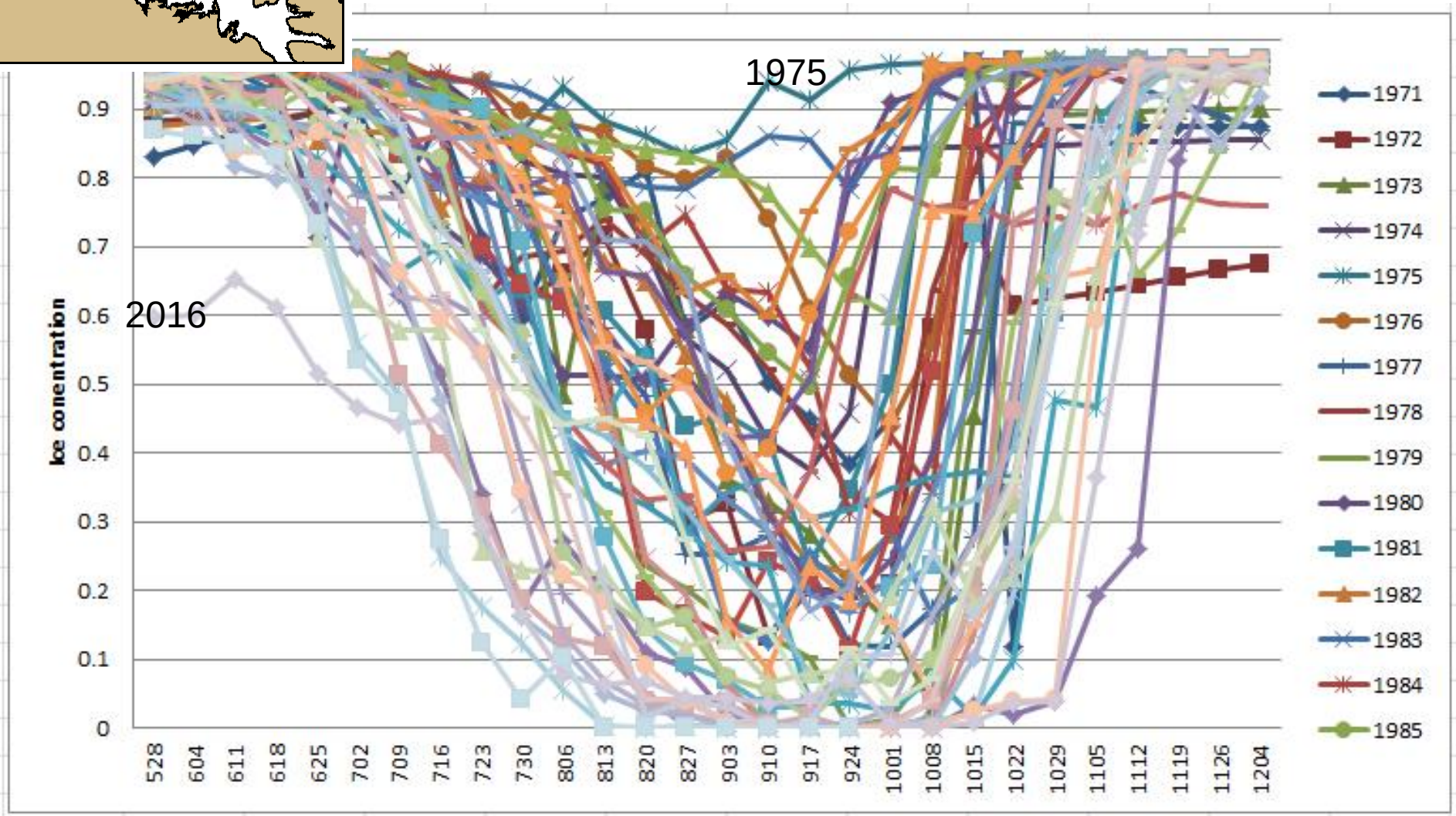

Temperature (Past 7 days)
Température (Sept derniers jours)
Mean Moyenne
Normal Normale
Point Barrow -4.4 -2.2
Coppermine 6.8 0.7
Cambridge Bay 5.4 -2.4
INUVIK 1.2 +0.8
Ice before 1996 was frequently close to the Alaska coast
WESTERN ARCTIC/L'OUEST DE L'ARCTIQUE
BARTER ISLAND
TUKTOYAKTUK
SACHS HARBOUR
SACHSEN
MOULD BAY
CAPE PARRY
POINT BARROW
COPPERMINE
CAMBRIDGE BAY
SCALE 1:4,000,000
ATMOSPHERIC ENVIRONMENT SERVICE–DEPARTMENT OF THE ENVIRONMENT–CANADA
SERVICE DE L'ENVIRONNEMENT ATMOSPHÉRIQUE–MINISTÈRE DE L'ENVIRONNEMENT–CANADA
TORONTO 1994
0062-9181

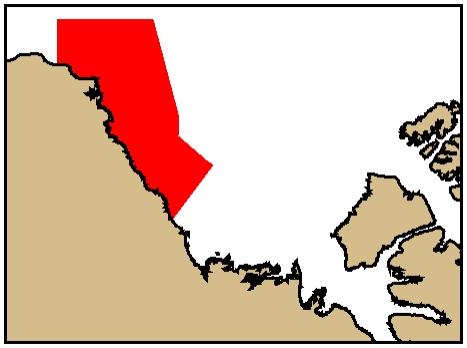
Western Arctic – Ice Concentration 24 Sept 2017



Yearly Variation – Ice Concentration







Alaskan Coast
3/10 or less of ice

1974

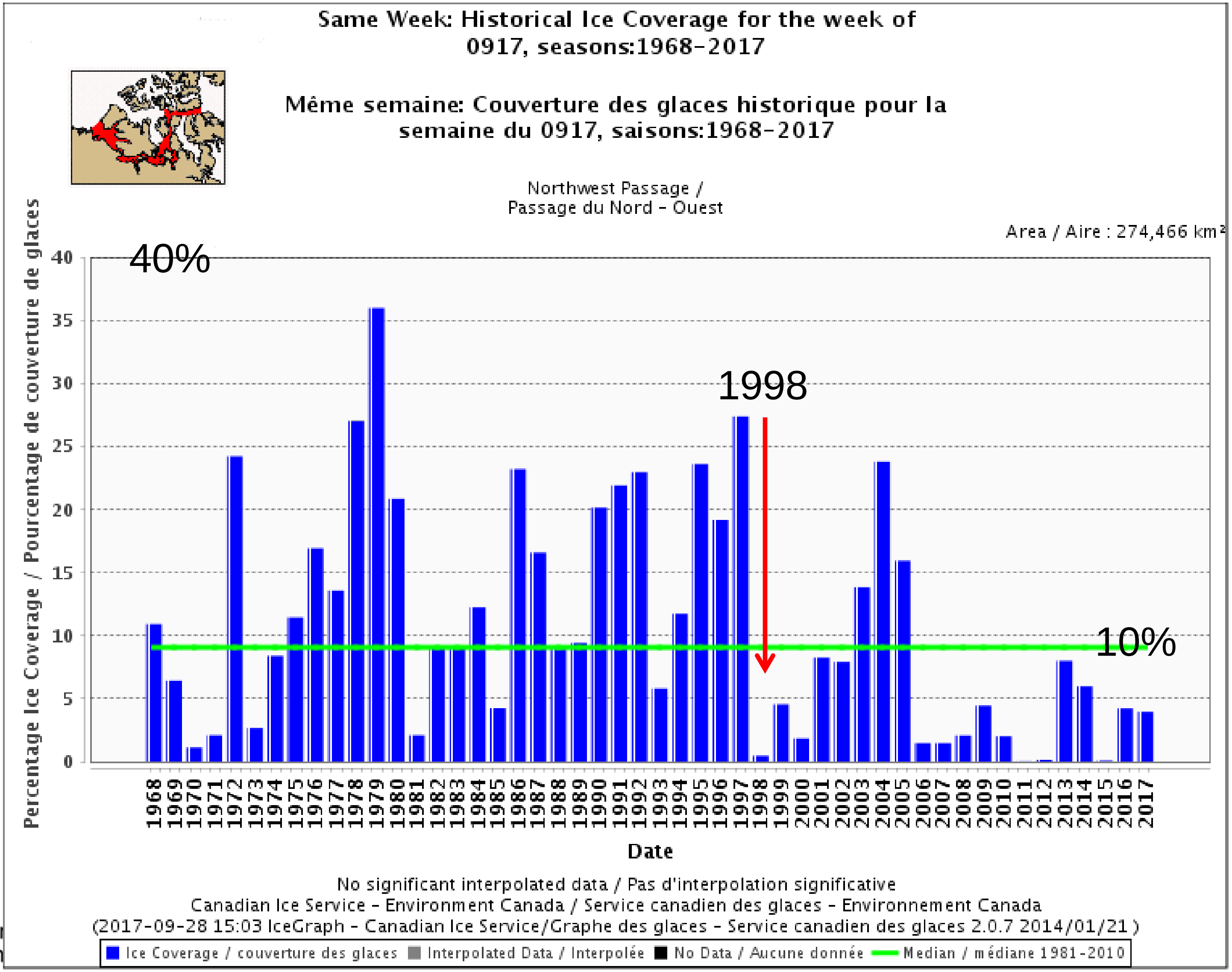
1998

2017

	716	723	730	806	813	820	827	903	910	917	924	1001	1008	1015	1022	1029	1105	1112	1119	1126	1204
1971	0.8831	0.7139	0.5943	0.7417	0.7714	0.8117	0.5794	0.621	0.501	0.4506	0.3844	0.4507	0.9499	0.9524	0.1189	0.8736	0.874	0.8743	0.8747	0.875	0.8754
1972	0.9133	0.8964	0.6175	0.6601	0.7146	0.5802	0.2982	0.3265	0.1326	0.2024	0.1978	0.2103	0.582	0.7358	0.6146	0.6248	0.6349	0.6451	0.6552	0.6654	0.6756
1973	0.92	0.8981	0.859	0.4855	0.7767	0.7271	0.5826	0.3613	0.329	0.2825	0.2085	0.1526	0.0292	0.4543	0.7991	0.8916	0.8938	0.896	0.8981	0.9003	0.9025
1974						0.6999	0.5684	0.5215	0.417	0.3751	0.4593	0.8418	0.8434	0.8451	0.8467	0.8483	0.85	0.8516	0.8533	0.8549	0.8565
1975	0.9165	0.8975	0.8694	0.9321	0.8837	0.8608	0.8339	0.8555	0.9414	0.9141	0.9567	0.9646	0.9677	0.9564	0.9716	0.9714	0.9714	0.9713	0.9713	0.9712	0.9712
1976	0.9439	0.9393	0.896	0.8802	0.8664	0.8178	0.7976	0.8277	0.7406	0.6104	0.5141	0.4406	0.5592	0.9474	0.9472	0.9647	0.9643	0.964	0.9636	0.9632	0.9629
1977	0.8884	0.8355	0.7764	0.781	0.5554	0.4837	0.2521	0.2527	0.2807	0.2318	0.122	0.1194	0.1744	0.2772	0.8813	0.8778	0.9534	0.9323	0.9112	0.8902	0.8691
1978	0.8781	0.6198	0.6855	0.6953	0.7416	0.6877	0.6316	0.5867	0.5207	0.435	0.3419	0.2988	0.6364	0.8094	0.9402	0.9699	0.9713	0.9718	0.9708	0.9715	0.9751
1979	0.9075	0.8664	0.7788	0.6597	0.538	0.2359	0.205	0.1577	0.1344	0.1036	0	0.0154	0.093	0.5762	0.8076	0.9538	0.9656	0.972	0.9716	0.9679	0.9701
1980	0.7333	0.687	0.6184	0.5135	0.5127	0.5072	0.5859	0.6345	0.5973	0.5533	0.7902	0.911	0.9285	0.9058	0.9022	0.9022	0.9708	0.9718	0.9716	0.9719	0.9717
1981	0.8753	0.891	0.6356	0.6188	0.6065	0.5384	0.4401	0.4564	0.4199	0.2403	0.3449	0.4991	0.9381	0.9689	0.9706	0.9576	0.9652	0.9683	0.9716	0.9664	0.9671
1982	0.7573	0.8035	0.7998	0.7704	0.6779	0.6489	0.5434	0.4738	0.3158	0.2404	0.2252	0.2826	0.3924	0.9681	0.9691	0.9718	0.9724	0.9725	0.9731	0.9734	0.9735
1983	0.943	0.9417	0.9299	0.8992	0.8015	0.7863	0.7839	0.822	0.8613	0.8554	0.7842	0.8693	0.9284	0.9698	0.9704	0.9717	0.9757	0.9668	0.9697	0.966	0.9639
1984	0.9516	0.9357	0.8597	0.8372	0.82	0.7	0.7465	0.639	0.6333	0.5229	0.3119	0.4267	0.3425	0.8639	0.9183	0.9619	0.9717	0.9679	0.9697	0.9723	0.9703
1985	0.9291	0.8985	0.8377	0.8866	0.7539	0.7523	0.6576	0.6086	0.5473	0.4954	0.6558	0.8149	0.811	0.9489	0.9408	0.9716	0.9744	0.9517	0.9687	0.9718	0.9725
1986	0.9201	0.8505	0.7599	0.6109	0.5829	0.5	0.5157	0.4341	0.3145	0.2053	0.1861	0.2448	0.4021	0.5799	0.9551	0.9452	0.9621	0.9561	0.972	0.9719	0.9692
1987	0.663	0.7026	0.6171	0.6592	0.4298	0.3534	0.3255	0.2865	0.3428	0.369	0.3059	0.3197	0.3477	0.3659	0.3731	0.365	0.5941	0.8822	0.9435	0.9639	0.9716	0.9717
1988	0.9067	0.904	0.9009	0.8604	0.8406	0.8294	0.7334	0.6325	0.6581	0.5974	0.751	0.8407	0.8773	0.9496	0.969	0.9706	0.9707	0.9712	0.9716	0.9723	0.9724	0.9724
1989	0.8588	0.8227	0.771	0.7466	0.629	0.5286	0.4514	0.3302	0.1556	0.1262	0.2507	0.1978	0.2898	0.1652	0.2081	0.4283	0.965	0.9591	0.9719	0.9722	0.9729	0.9725
1990	0.8324	0.7938	0.6983	0.6443	0.6211	0.4853	0.1988	0.1659	0.1334	0.2419	0.2168	0.1131	0.2952	0.5192	0.8596	0.8084	0.8802	0.9574	0.9345	0.9715	0.9724	0.9724
1991	0.9319	0.9225	0.9032	0.8722	0.8575	0.8494	0.8433	0.8342	0.8148	0.7796	0.6992	0.6335	0.6007	0.8342	0.9476	0.9717	0.9725	0.9723	0.9725	0.9725	0.9727	0.9727
1992	0.8945	0.7975	0.7857	0.7864	0.8052	0.6628	0.6572	0.5738	0.4226	0.4252	0.5074	0.8229	0.8358	0.9352	0.9673	0.8108	0.9287	0.9567	0.9665	0.9699	0.9728	0.967
1993	0.7272	0.6875	0.6412	0.547	0.4339	0.4538	0.5519	0.2868	0.2409	0.2359	0.0357	0.0362	0.0248	0.0739	0.0186	0.0983	0.4764	0.4672	0.9254	0.9713	0.9708	0.9711
1994	0.7938	0.8577	0.8485	0.7767	0.564	0.4592	0.5106	0.3707	0.4077	0.6011	0.7201	0.8199	0.9612	0.9671	0.9719	0.9403	0.9594	0.9721	0.9722	0.9724	0.9724
1995	0.7785	0.7715	0.5696	0.4268	0.3853	0.4047	0.3928	0.3329	0.2852	0.1953	0.1685	0.2192	0.341	0.4986	0.8272	0.9727	0.9712	0.9713	0.9692	0.9674	0.9695
1996	0.8623	0.6086	0.5548	0.4568	0.3842	0.3322	0.3377	0.2577	0.2636	0.3747	0.6274	0.7836	0.7583	0.7665	0.7312	0.7426	0.7311	0.7603	0.7757	0.7632	0.7597
1997	0.7349	0.6304	0.54	0.3694	0.3132	0.2198	0.1507	0.0646	0.0081	0	0	0	0	0.2093	0.5912	0.6985	0.831	0.6572	0.7231	0.8399	0.9567
1998	0.7	0.3405	0.1803	0.2717	0.2007	0.1108	0.0874	0.0195	0.0029	0.0021	0.0017	0.0007	0	0.0328	0.0206	0.0405	0.1939	0.2617	0.8248	0.9694	0.9632
1999	0.9065	0.9022	0.7078	0.4474	0.2784	0.1448	0.0937	0.0691	0.0319	0.0324	0.0745	0.2035	0.2376	0.72	0.834	0.9328	0.9707	0.9719	0.9721	0.9724	0.9726
2000	0.8778	0.8416	0.8071	0.6558	0.4465	0.4466	0.4072	0.157	0.0853	0.2353	0.1882	0.4566	0.7541	0.7487	0.835	0.937	0.9709	0.9709	0.971	0.9675	0.9711
2001	0.8585	0.8585	0.8719	0.8318	0.7112	0.7081	0.6546	0.418	0.285	0.1698	0.2055	0.6168	0.8584	0.9322	0.9601	0.9646	0.9719	0.9724	0.9724	0.9724	0.9724
2002	0.8732	0.8149	0.7411	0.7242	0.4906	0.2475	0.1947	0.0635	0.0012	0.0024	0.0007	0	0	0.1368	0.7386	0.7709	0.7319	0.9414	0.9517	0.9306	0.9711
2003	0.8269	0.6343	0.5727	0.2567	0.1919	0.1455	0.1632	0.0756	0.055	0.0139	0.0653	0.0724	0.0992	0.2173	0.323	0.7698	0.76	0.9187	0.9697	0.9328	0.9655
2004	0.6286	0.5946	0.3895	0.1958	0.1256	0.0464	0.003	0.0008	0.0019	0.0024	0	0.0002	0.0178	0.1925	0.5026	0.8965	0.9714	0.9538	0.9639	0.9497	0.9356
2005	0.6863	0.6629	0.5558	0.4522	0.4262	0.378	0.3177	0.2471	0.1796	0.0766	0.0484	0.1445	0.313	0.3325	0.4061	0.7183	0.7869	0.9246	0.9655	0.9711	0.9713
2006	0.895	0.8813	0.7721	0.7437	0.5537	0.5313	0.4942	0.4326	0.3671	0.3074	0.2392	0.1535	0.0515	0.1517	0.2271	0.6553	0.6663	0.8561	0.9003	0.9505	0.9436
2007	0.4782	0.2837	0.1622	0.1155	0.0503	0.0254	0.0198	0.0005	0	0	0	0	0.0049	0.1027	0.2623	0.6063	0.86	0.9139	0.9258	0.8479	0.9185
2008	0.4119	0.3217	0.1859	0.1318	0.1198	0.038	0.0349	0.0359	0.0072	0.0161	0	0.0082	0.0405	0.1919	0.4601	0.8854	0.8449	0.9506	0.961	0.9713	0.9715
2009	0.5797	0.2592	0.2311	0.2259	0.2246	0.1484	0.1193	0.1354	0.0663	0.0807	0.0841	0.1924	0.3244	0.1818	0.22	0.3144	0.6574	0.7449	0.916	0.9549	0.9495
2010	0.6196	0.5519	0.3257	0.1379	0.0698	0.0349	0.0202	0.0091	0.0101	0.0057	0.0063	0.029	0.166	0.274	0.3647	0.6384	0.8488	0.9688	0.9661	0.9709	0.9698
2011	0.2514	0.1767	0.1236	0.0563	0.0032	0.0003	0.0038	0	0	0	0.0001	0.0025	0.0129	0.019	0.1941	0.6816	0.8204	0.9436	0.9704	0.9715	0.9709
2012	0.5945	0.5444	0.3452	0.2222	0.1843	0.0921	0.0379	0.0098	0.0025	0.001	0	0	0	0.0265	0.0396	0.041	0.5923	0.9632	0.9707	0.9708	0.9708
2013	0.7236	0.6639	0.5324	0.4254	0.2082	0.0167	0.0429	0.0305	0.0013	0.0095	0.106	0.1082	0.2595	0.1598	0.2639	0.5822	0.877	0.7309	0.9424	0.9556	0.9654
2014	0.6308	0.5263	0.451	0.3386	0.1469	0.0409	0.0419	0.0121	0.0076	0.002	0	0	0.0428	0.2407	0.3423	0.6184	0.94	0.9624	0.9648	0.9352	0.9712
2015	0.7008	0.5788	0.4928	0.4412	0.451	0.4242	0.2759	0.1194	0.1429	0.0396	0.1164	0.0353	0.0716	0.2404	0.3599	0.6174	0.792	0.8262	0.9581	0.9501	0.9665
2016	0.4493	0.2928	0.1643	0.0777	0.0646	0.0706	0.0455	0.0440	0.0364	0.0425	0.0715	0.0077	0.0013	0.0091	0.0366	0.0392	0.3644	0.7191	0.8923	0.9612	0.9477
2017	0.2749	0.124	0.0411	0.101	0.002	0.0016	0	0	0.0003	0	0.0012										

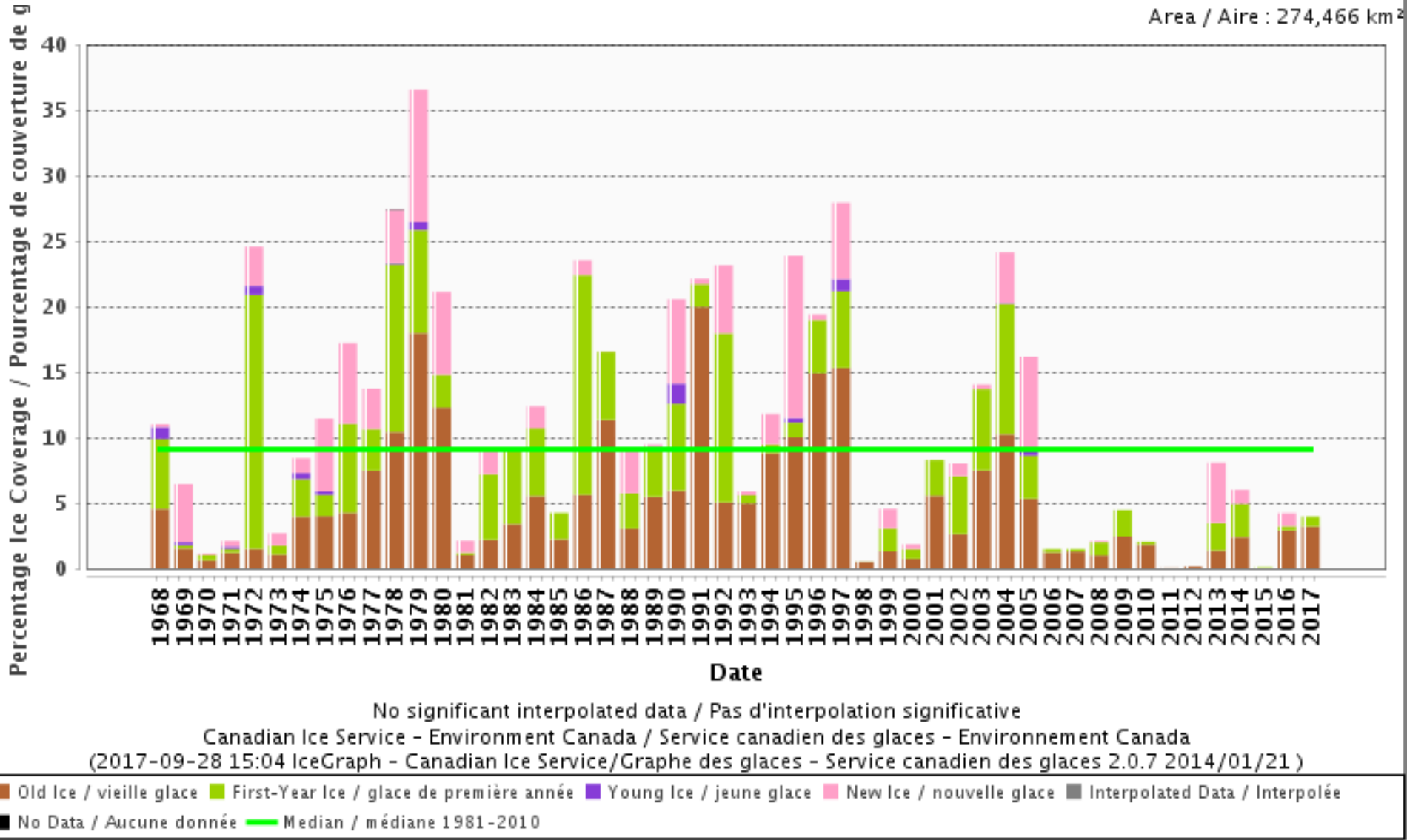
Northwest Passage – Ice Concentration Week of Sept 17

- Since 1998 more years with less ice

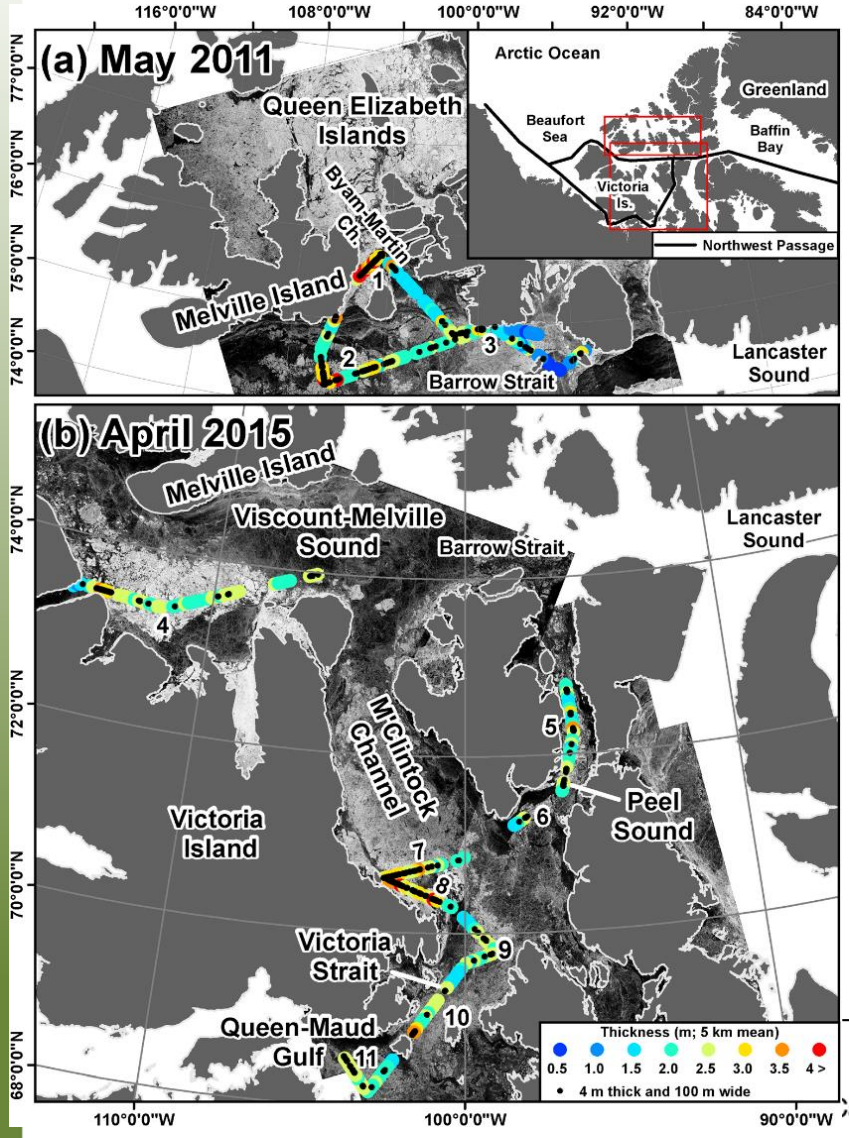


Environme
Climate Ch

Northwest Passage – Stage of Development - Week of Sept 17



Ice Thickness - Northwest Passage



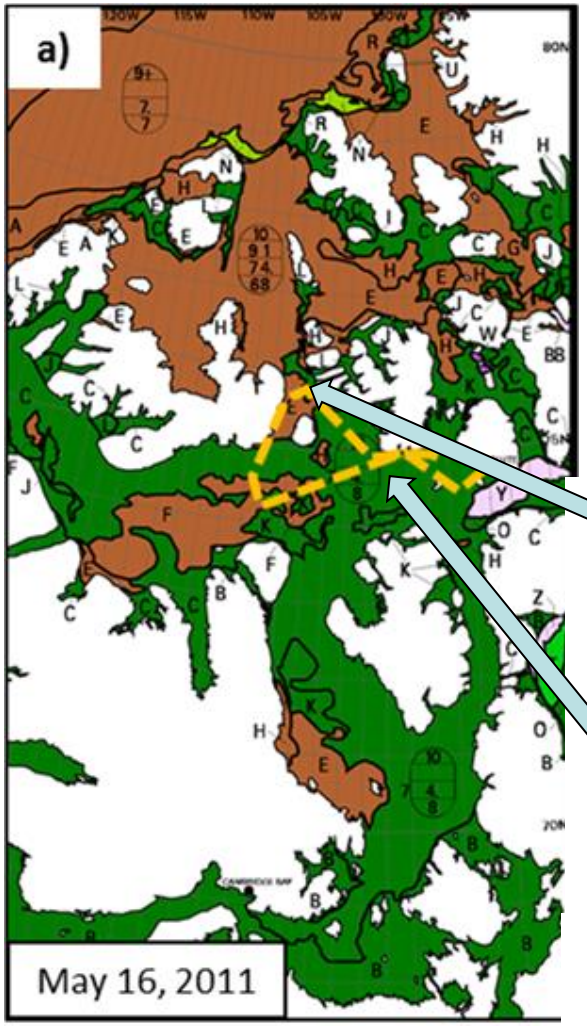
- First ever airborne electromagnetic induction (AEM) ice thickness surveys
  - April and May
  - 2011 and 2015
- Ice very thick (3-4 m)
- Frequently observed ice floes more than 100 m wide and more than 4 m thick

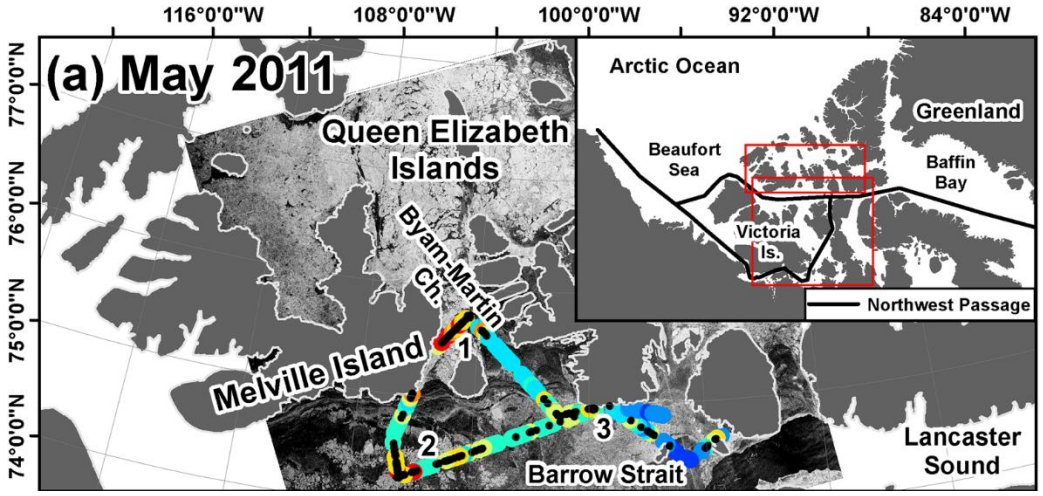
– Octob

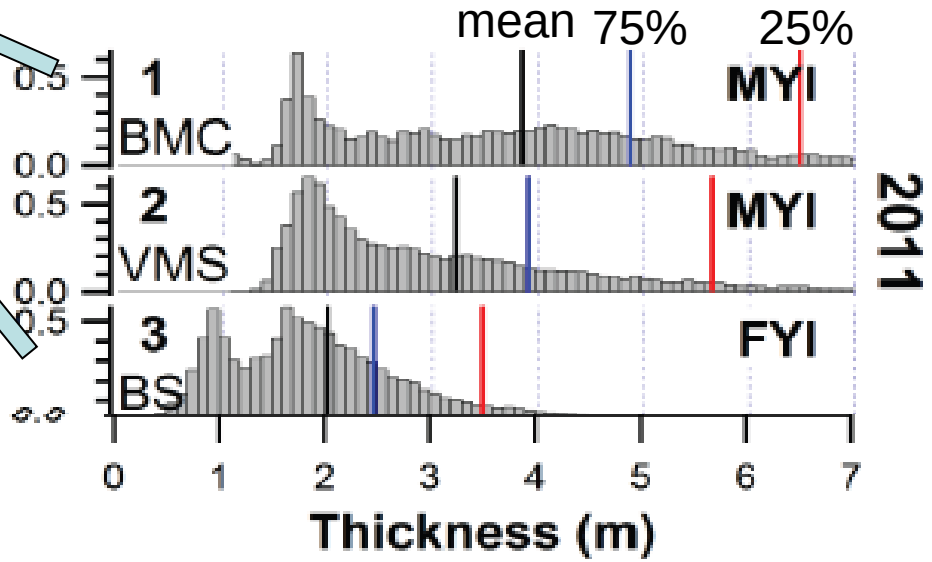
anada

Canada

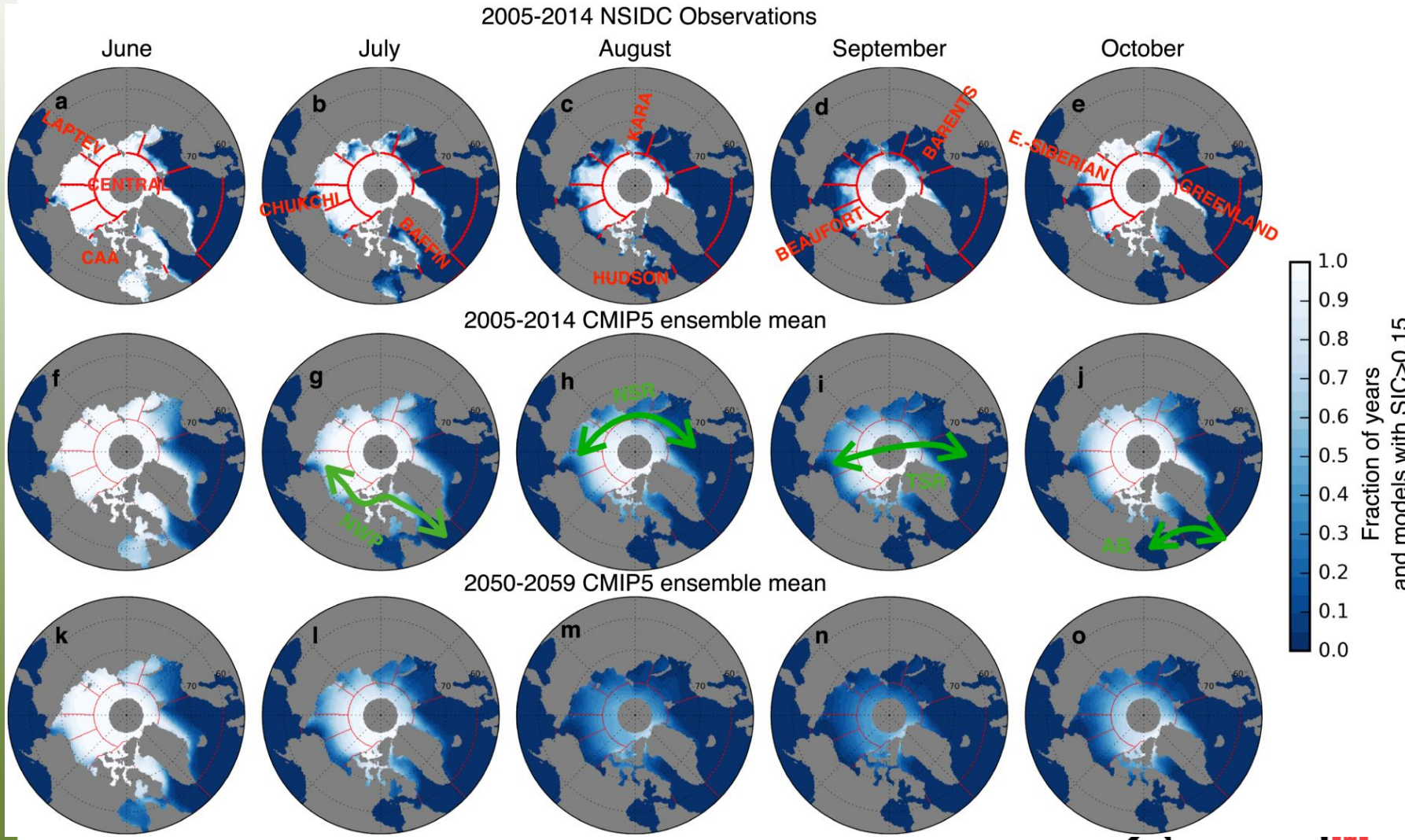
Arctic Ocean Multi-Year Ice – drifting southward







Sea Ice still a hazard for most of the year



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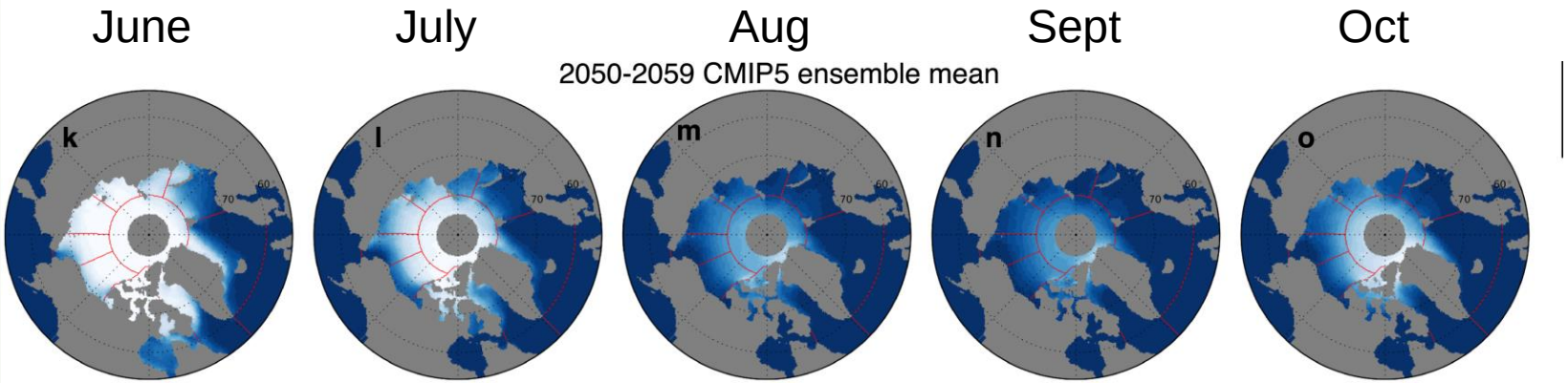
Decadal average forecast – 2050's

- 2050 to 2059
  - Ice could start to clear in Hudson Bay in June
  - Alaska Coast clearing in July
  - Low concentrations of sea ice over the northern hemisphere in August and September.
  - Expect significant variations from year-to-year



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Implications for Marine Operations

- Sea ice concentration has diminished over time but variability means that conditions are not consistent from one year to the next.
- Multi-year ice drifting southward from the Arctic Ocean contains ice floes with significant thickness. These floes drift through the Arctic islands as well as past the Alaskan coast
- Reliable climatological data is available for concentration and stage of development but not for ridges, pressure or measured thickness

Plans and Partners

- Timelines
  - Ongoing work to monitor ice conditions by satellite
  - Use of more detailed data sources
- Partners
  - Other ice services
  - Researchers
- Future work
  - Forecasting improvements
  - More detailed observations
- Potential synergies between USA and Canada
  - Ice modelling groups connect to share results and validation


Thank you
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