1 Brief Communication: Does it matter exactly when the Arctic
2 will become ice-free?

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6 **Abstract.** Following the 2015 UNFCCC Conference of Parties in Paris there is renewed interest in

7 understanding and avoiding potentially dangerous climate change. The loss of Arctic sea ice is one of the most

8 directly visible aspects of climate change and the question is frequently asked: when can we expect the Arctic to

9 be ice-free in summer? We argue here that this question may not be the most useful one to inform decisions on

10 climate change mitigation or adaptation in the Arctic. The development of a community-wide consensus on a

11 robust definition of 'ice-free', may reduce confusion in the community and amongst the public.

12 **1. Introduction**

13 Arctic sea ice is an iconic feature of the climate system, and its annual retreat to its minimum extent in

14 September provides a regular checkpoint on Arctic climate change. Since 1979 there has been a decline of

15 around 30% in the summer minimum ice extent (Stroeve et al., 2012). However the long term decline is

16 modulated by strong year-to-year variability. The record low extent in 2012 was followed by a strong recovery

17 in 2013 and 2014 (NSIDC, 2015), accompanied by an increase in the volume of the ice (Tilling et al., 2015) , a

18 combination of a cold winter and strong ice convergence to the Canadian Archipelago (Kwok et al., 2015)

19 forming the thick ice .One might then speculation that the Arctic ice cover is more sensitive to fluctuations in

20 temperature than previously thought.

21 In 2015 the minimum ice extent was reached on 11th September and was 4.41 million km2 (NSIDC, 2015),

22 substantially lower than 2013 and 2014 and close to the long term declining trend line since the start of the

23 modern satellite record in 1979. The 2015 melt season was notable for high rates of melting during July, which

24 is generally thought to be caused by anti-cyclonic conditions over Greenland and the central Arctic (Matsumura

25 et al., 2014); this emphasises the important role played by synoptic weather conditions in the year-to-year

26 variations in sea ice. Overall, the internal variability of the Arctic sea ice (Swart et al., 2015) leads to no clear

27 evidence of either a recent slowdown or a speeding-up of the longer term trend of sea ice loss.

28 The long-term decline of Arctic sea ice that has been observed since 1979 is robustly projected by climate

29 models to continue over the coming decades (Collins et al., 2013), and will have substantial impacts on regional

30 ecosystems, indigenous peoples, transport and resource exploitation (Larsen et al.,2014). However, because of

31 internal variability, the appearance of ice-free conditions on a particular date may be of limited significance,

32 depending on the stakeholder. For example the opening of navigation routes for just a few days in an individual

33 year would be of limited value, while particular ecosystems (especially organisms with multi-year life cycles)

34 may be robust to short term variations. It may be more important to know when and where sustained ice-free

35 conditions can be expected.

36

2. Method & Results

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38 We consider four plausible definitions of the date of an 'ice-free Arctic'. We apply the commonly-used
39 threshold, for which northern hemispheric sea ice extent (defined as the total area of ocean with a sea ice
40 fraction greater than 15%) is less than 1 million km2, as the definition of the term 'ice-free'. The threshold of 1
41 million km2, rather than zero, is used because ice can be expected to remain for some time along the northern
42 coast of Greenland, whilst for navigational purposes the central Arctic is ice-free. The 'first ice-free year' is then
43 defined as:

44   A. The first year that at least one day is 'ice free'.

45   B. The first year when the September mean is 'ice free'.

46   C. The first time the final year of a 5 year running mean of September monthly mean extents is 'ice-free'.

47   D. The final year of 5 consecutive September monthly means which are 'ice-free'.

48 A and B are point definitions which, when passed, are likely to evoke significant public interest. However the
49 point at which the threshold is crossed is likely to be strongly dependent on natural year-to-year variability as
50 well as the long-term trend. C and D are attempts to smooth out the effects of interannual variability to produce
51 a more robust measure. Criteria B-D have all been used in the literature and in the IPCC 5th Assessment
52 (Collins et al., 2013). By definition, $A \leq B < C \leq D$. Other, more impact-specific criteria are possible but not
53 considered here.

54 We assess the impact of the different definitions in small (4-member) ensembles of climate model projections
55 using the climate model HadGEM2-ES (Martin et al., 2011), for the representative greenhouse gas concentration
56 pathways, RCP4.5 and RCP8.5 (Van Vuuren et al., 2011). Each ensemble member is taken to represent a
57 plausible realisation of the future Arctic and our focus is on the effect of the choice of definitions on the
58 declared 'ice-free date', within each realisation.

59 The dates for which the HadGEM2-ES ensemble depicts the first year with an ice free day range between 2032-
60 2042 for RCP8.5 and 2038-2046 for RCP4.5 (Figure 1). The lag between this first day (criterion A) and the
61 progressively stricter criteria B-D is indicated by a progression of the ice-free dates for each ensemble member.
62 The difference in declared ice-free date between criteria A and D is between 4 and 19 years across all the
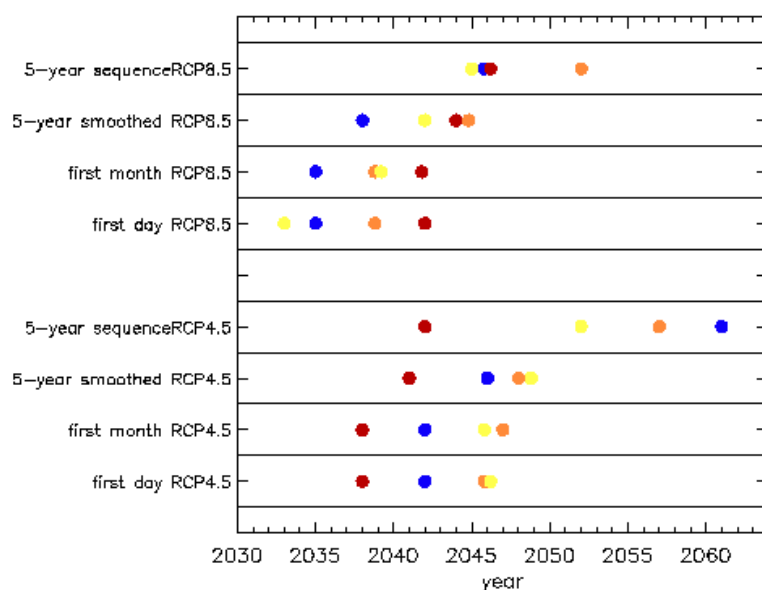63 ensemble members.

64 The ensemble spread in ice-free date, for a given definition of ice-free conditions (an indicator of the importance
65 of interannual variability) is similar in both scenarios and all ice-free definitions, at 8 ± 1 years, except for
66 RCP4.5 criterion D. Thus, the uncertainty in the date on which the Arctic might be declared ice-free may depend
67 as much on the specific criterion for 'ice-free' as on the internal variability or the RCP scenario.

3. Discussion

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69 Our ensembles are too small to sample the full range of interannual variability, and they come from a single
70 climate model. However they are sufficient to illustrate that the choice of definition could have a substantial
71 impact on the date when an 'ice-free' Arctic is declared. In particular we see that the 'AR5' definition D, which
72 might be expected to reduce the effects of interannual variations, can actually amplify them. In RCP4.5 this is
73 because the long-term declining trend becomes quite slow near the threshold (compared with the inter-annual
74 variability), resulting in many crossings and re-crossings.

75   The evidence of summer 2015 is that the Arctic is continuing its progress towards seasonally ice-free conditions.

76   Many of the impacts of decreasing ice cover will be felt irrespective of the precise date when the Arctic is

77   declared seasonally ice-free. Further, both natural systems and human activities will need to operate in an

78   environment of strong year-to-year variability. Recent progress in seasonal forecasting has shown promise that

79   reliable predictions of the year-to-year variations may be possible (Peterson et al., 2014). To inform climate

80   change mitigation and adaptation to the effects of the changing Arctic climate it may be more important to

81   develop seasonal-to-decadal sea-ice predictions, alongside impact-relevant metrics of ice loss, rather than

82   refining projections of the ice-free date.

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84   Figure 1. The dates of ice-free Arctic from various definitions (y-axis) for each of four HadGEM2-ES ensemble

85   members (colours) for the RCP4.5 (lower) and RCP8.5 (upper) scenarios.

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