Prediction of sea ice thickness clusters in the Northern Hemisphere

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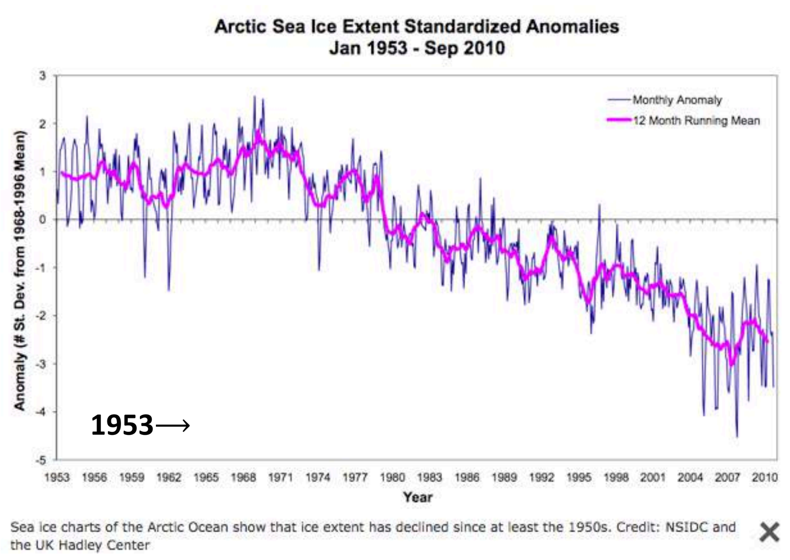
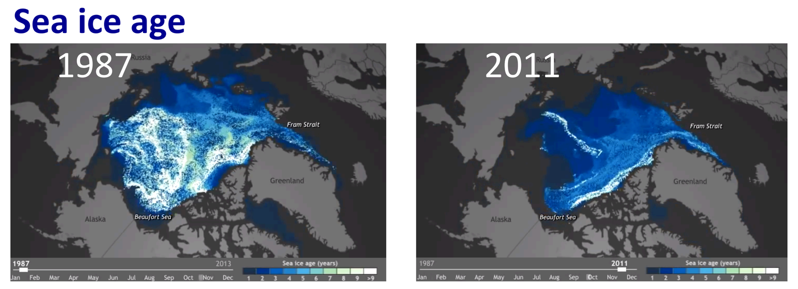
• NH sea ice cover has experienced a long-term decline superimposed on a strong internal variability



Sea ice charts of the Arctic Ocean show that ice extent has declined since at least the 1950s. Credit: NSIDC and the UK Hadley Center

Sea ice age



→ This study *i)* **identifies physically relatable patterns of the NH sea ice variability on seasonal to interannual time scales** disentangled from a long-term climate change, *ii)* **explores their predictability with a state-of-the-art coupled climate model**

• **Principal component analysis (PCA)** produces a low-dimensional representation of the data that summarizes key properties of variability

→ linear decomposition in a set of uncorrelated (orthogonal) principal components or modes that successively maximize the variance captured

→ its limitations: symmetry between positive and negative phases, suppresses nonlinearity by using a linear covariance matrix, PCA modes do not necessary represent physical modes, …

• **Clustering methods** partition data into groups or clusters based on their distance – they can be hierarchical or non-hierarchical

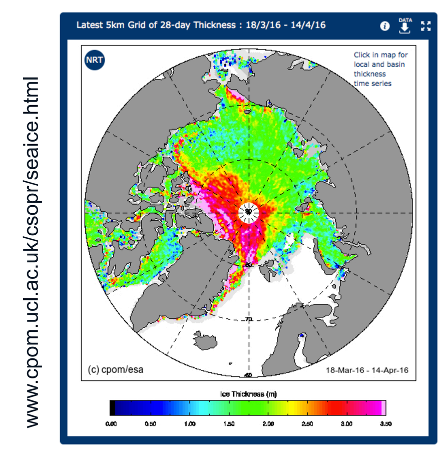
→ aims to simultaneously minimize the distance between members of a given cluster or mode and maximize the distance between the centers of the clusters

→ without orthogonality or linearity constraints inherent in PCA

→ **K-means method** is non-hierarchical clustering analysis that allows reassignment of members between different clusters (not possible in hierarchical clustering):

⟶ **optimal number of clusters K** (possible to determined via hierarchical approach) **has to be specified in advance**

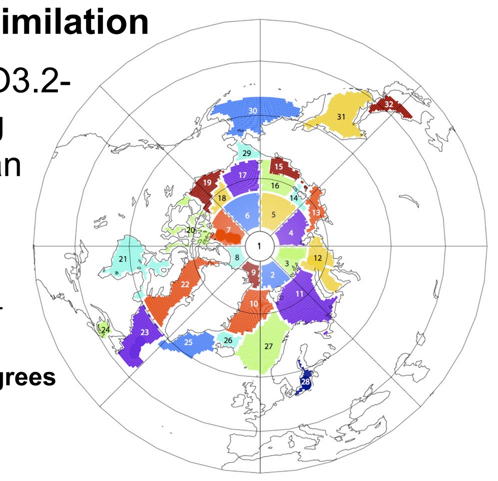
⟶ **produces** representation of the spatial and temporal variability with **K patterns of cluster centers and time series of cluster occurrences**



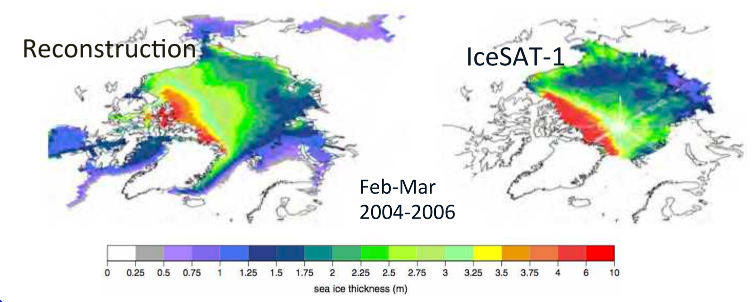
→ focus on **sea ice thickness (SIT)** – likely a key medium of the sea ice system memory on longer time scales

Measuring **SIT** is a demanding task at any scale ⇒ use **reconstruction = GCM + data assimilation**

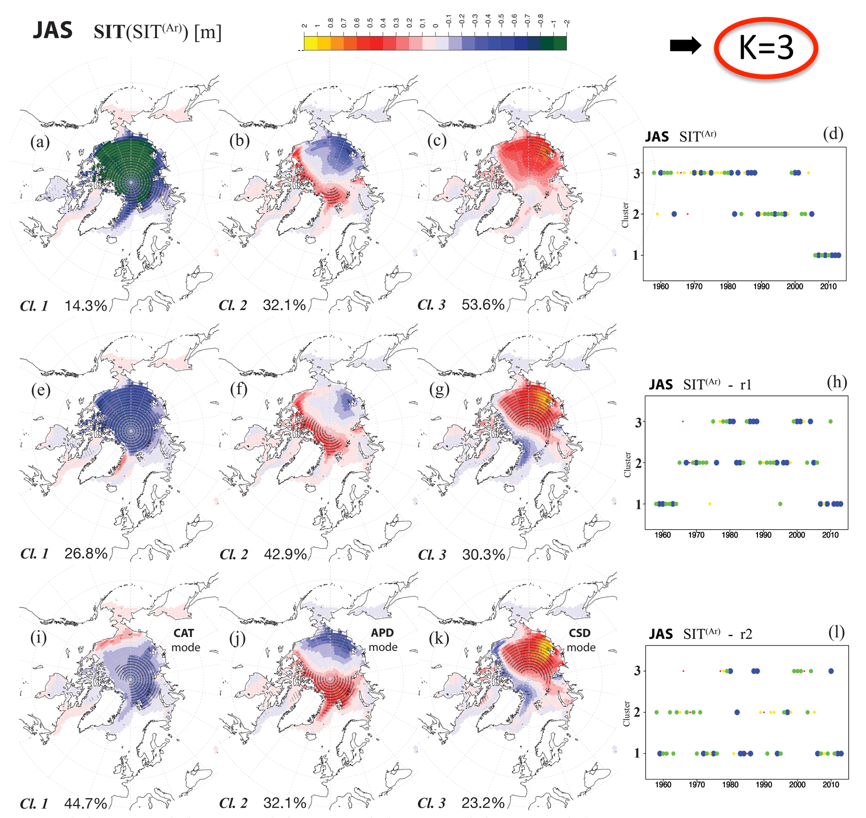
Combined two multi-member NEMO3.2-LIM2 reconstructions (surface forcing fileds DFS4.3 and ERA-Int, and ocean restoring: ORAS4) to get continuous **SIT** over the 1958-2013 period



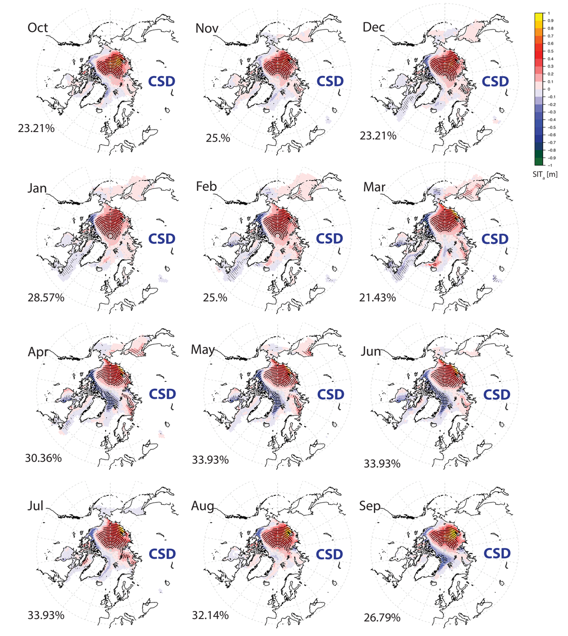
Use regional SIT averages: **~1000 → 32 degrees of freedom**



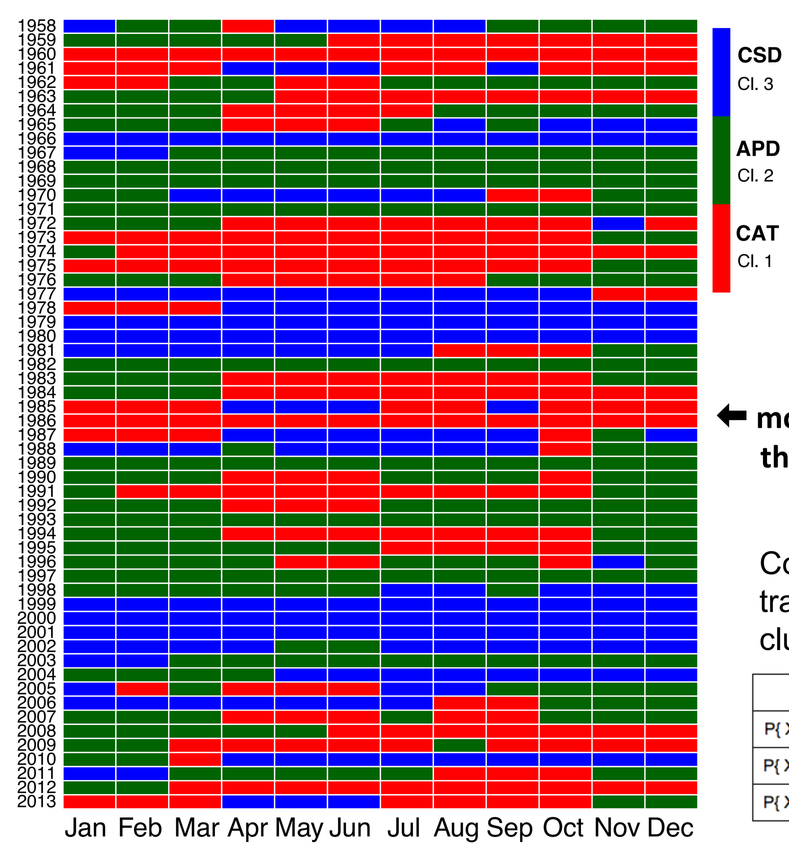
Guemas V, Doblas-Reyes FJ, Mogensen K, Tang Y, Keeley S (2014) Ensemble of sea ice initial conditions for interannual climate predictions. Clim Dyn. doi:10.1007/s00382-014-2095-7



⇒ nonlinear forced response of the Arctic requires removing 2nd order polynomial approximation of the long-term climate change to determine robust SIT variability clusters



• **NH SIT cluster patterns are consistent in different months and seasons**



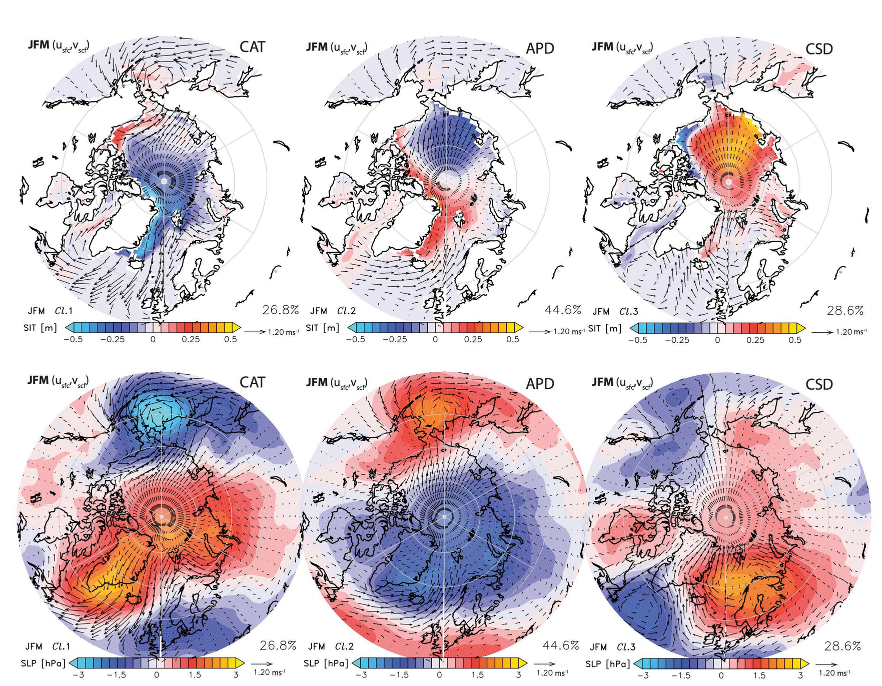
→ 3 identified SIT clusters: Central Arctic Thinning (CAT) mode, Atlantic Pacific Diploe (APD) mode, and Canadian Siberian Dipole (CSD) mode often show persistence reaching into interannual time scales

⬅ **monthly occurrences of the NH SIT clusters**

Conditional probability of the transition between the NH SIT clusters (1958-2013)

X(t+1)	CAT	APD	CSD
P(X(t+1) | CAT(t))	81.36%	13.18%	5.45%
P(X(t+1) | APD(t))	10.69%	85.12%	4.20%
P(X(t+1) | CSD(t))	6.87%	5.82%	87.30%

• **Key influence of surface wind in winter**

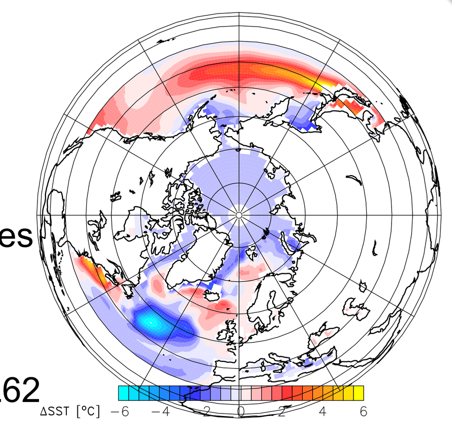


Fučkar, N.S., V. Guemas, N.C. Johnson, F. Massonnet, and F.J. Doblas-Reyes. (2015) Clusters of interannual sea ice variability in the northern hemisphere. Climate Dynamics. Online publication date: 28-Nov-2015.

• **EC-Earth2.3 forecast system**

Seamless Earth System Model

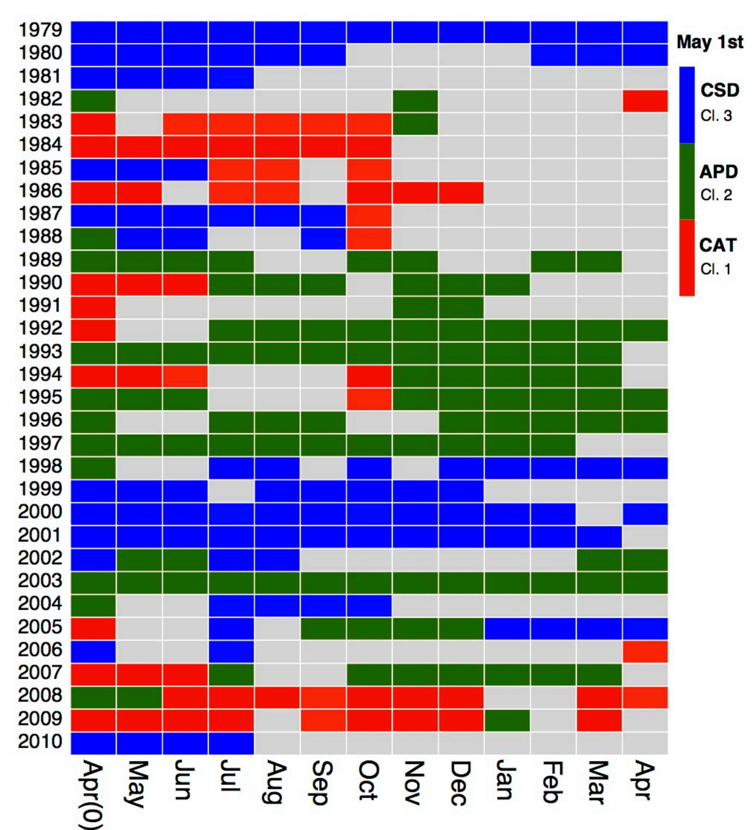
→ aims to forge weather and climate forecasting, and climate change studies in a single dynamical framework



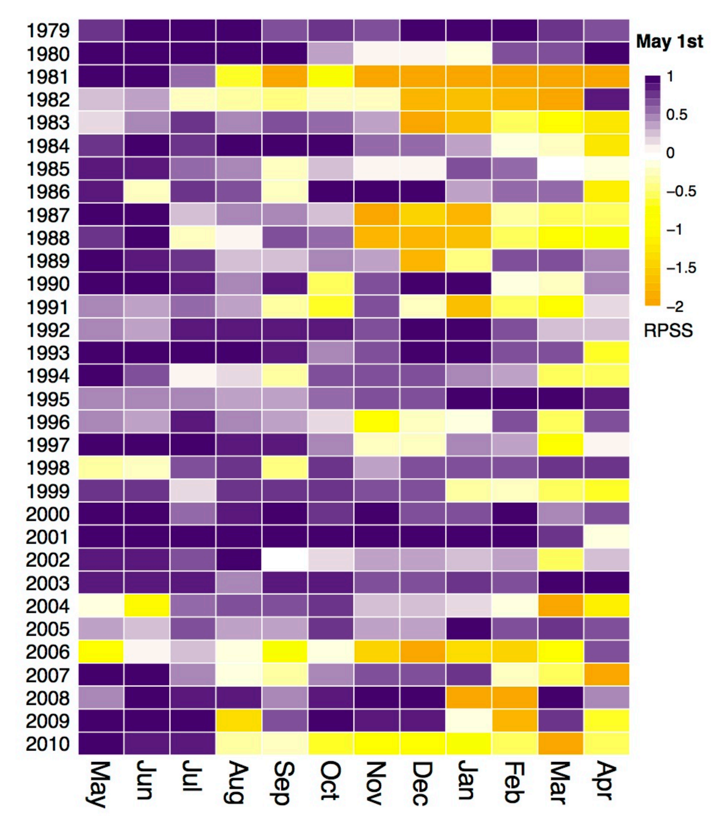
Atmosphere: ECMWF's Integrated Forecasting System (IFS) T159 and L62 (up to 5 hPa)
Land: H-TESSEL (part of IFS)
Ocean: Nucleus for European Modeling of the Ocean (NEMO) v3.2 in ORCA1L42
Sea ice: Louvain-la-Neuve sea Ice Model (LIM) V2 (part of NEMO)

⟶ focus on seasonal (12-month) prediction using full-field initialization (using ERA-Interim for atmospheric IC, ORAS4 for oceanic IC and sea ice IC from reconstruction used to identify SIT clusters) with May 1st and November 1st start dates from 1979 to 2010

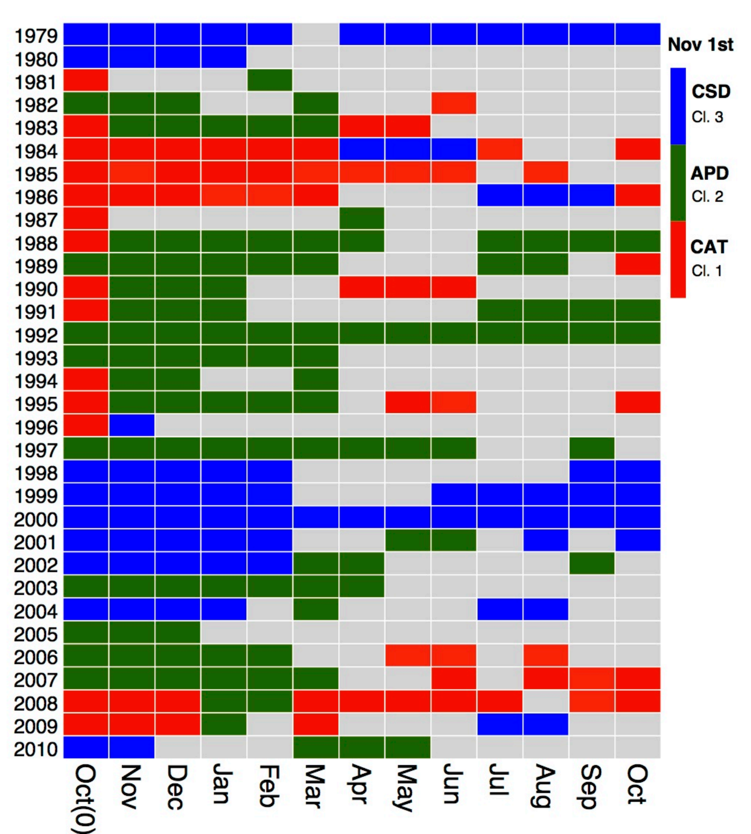
• **May 1st IC** **Accuracy** (saturated at 0.6)



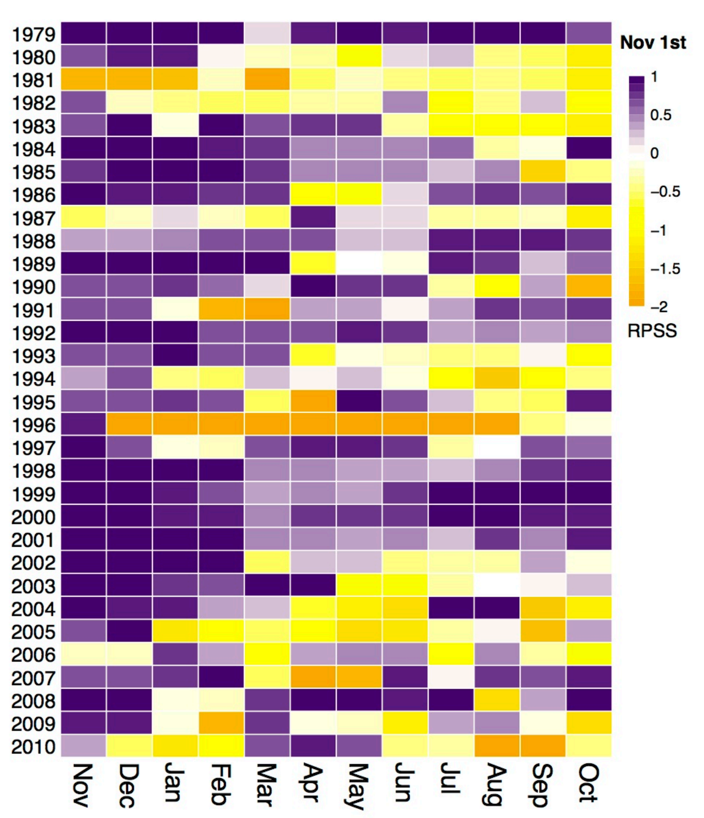
Ranked Probability Skill Score (1st order Markov chain)



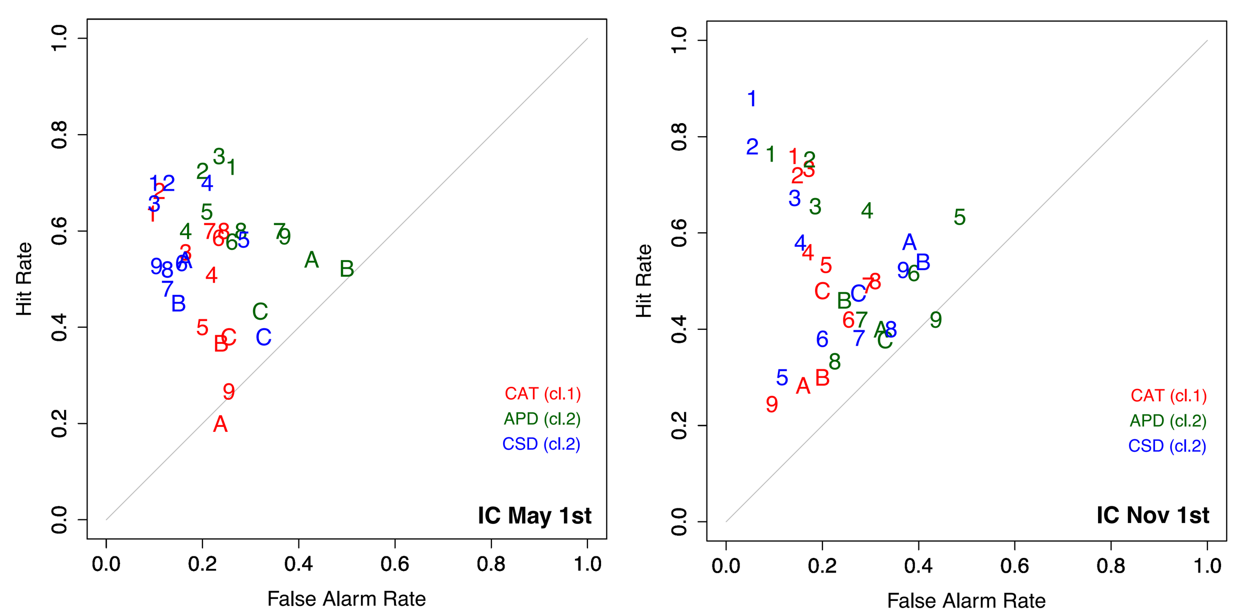
• **November 1st IC** **Accuracy** (saturated at 0.6)



Ranked Probability Skill Score (1st order Markov chain)



Skill of the NH SIT EC-Earth2.3 forecast horizons (marked in hexadecimal order)



➡ Removing quadratic approximation of long-term climate change in the NH yields robust K-means SIT cluster patterns

➡ Optimal number of the NH SIT K-means clusters is **K=3**:
Cl. 1 = **CAT mode**,
Cl. 2 = **APD mode**,
Cl. 3 = **CSD mode**,
with rather consistent patterns in different months and seasons

➡ *Time series of NH SIT cluster occurrences show dominant persistence from seasonal to interannual time scales*

➡ Wind in winter appears as the most crucial for the formation, structure and occurrence of SIT clusters

➡ **EC-Earth2.3 shows substantial prediction skill of the NH SIT clusters indicating that observations-based IC of the NH SIT in summer are more important that in winter**