Impact of revised snow cover on NWP and plans for ERA6

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David Fairbairn, Ewan Pinnington, Dinand Schepers and many others

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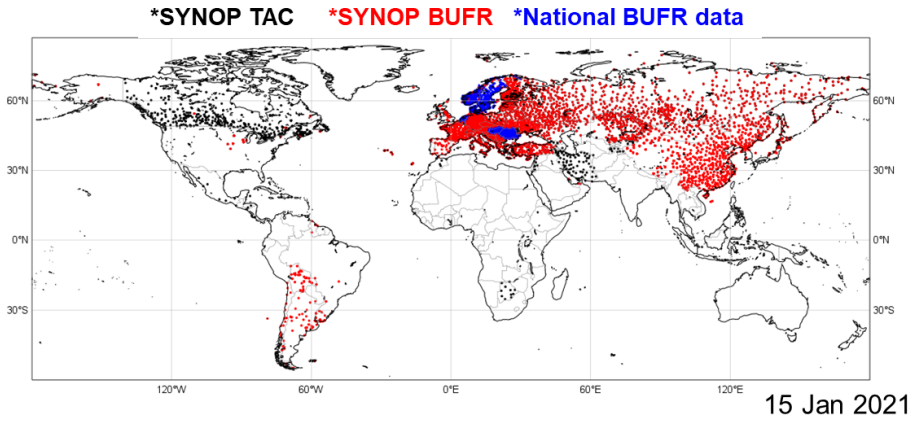
ECMWF 気象庁 Japan Meteorological Agency

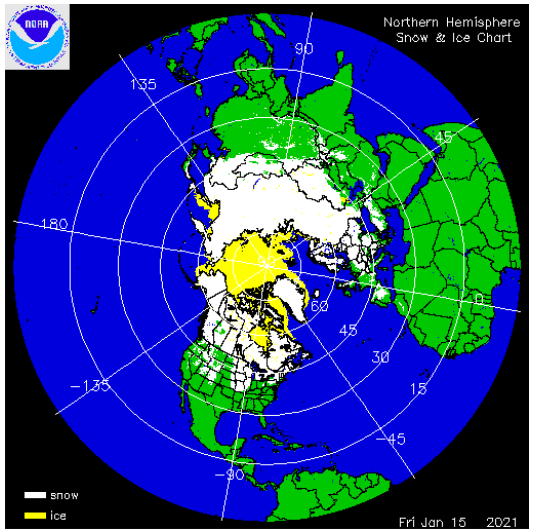
Outline

- Impact of revised snow data assimilation and snow cover parameterization
  - Implemented in the CY49R1
- ESA CCI snow cover assimilation for reanalysis
  - Plans for snow data assimilation in ERA6
- Other work on snow data assimilation in 2 years

Snow data assimilation at ECMWF



- **Observations:**
  - Conventional snow depth data: **SYNOP and National networks**
  - Snow cover extent: **NOAA NESDIS/IMS daily product** (4km)
    - Available daily at 23 UTC, assimilated in the next analysis at 00UTC



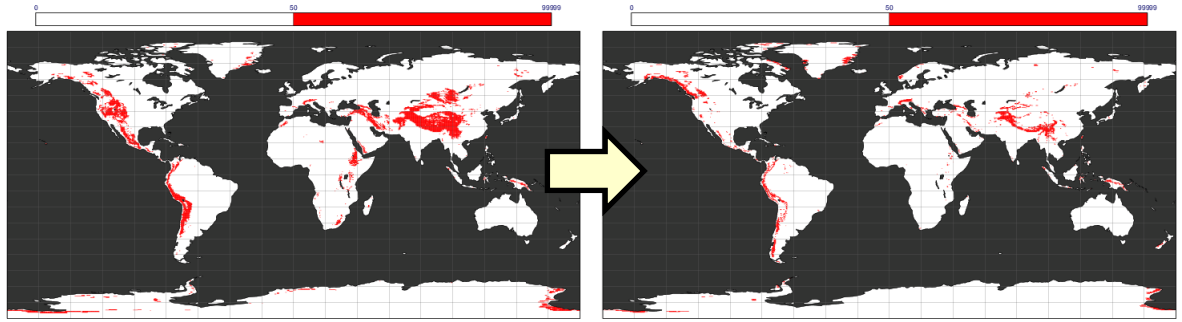
- **Data assimilation:**
  - **Optimal Interpolation (OI)**
    - Based on horizontal and vertical structure function in Brasnett (1999)
  - The result of the data assimilation is used to initialize NWP

- **One of current issues:**
  - IMS is assimilated at the grids lower than 1500m, leading to excess snow depth on high mountains
  - Especially on the Tibetan Plateau (Orsolini et al, 2019)

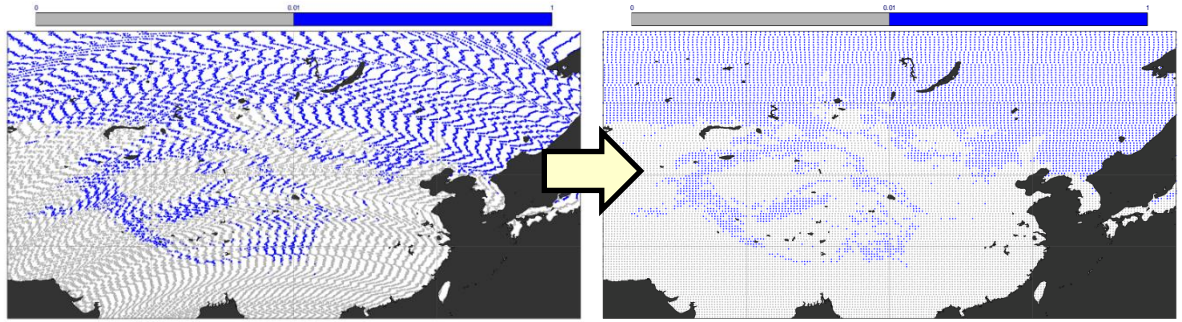
Revised snow DA for the CY49R1

	Current system (CNTL)	Revised snow DA (TEST)
IMS assimilation area	Altitude < 1500m	SDFOR < 250m
IMS thinning	Select 1 from every 36	Select closest 1 to a gaussian grid of 40km
Condition to assimilate SD_{IMS}	IMS=1 & SD_{model} < 10^{-9}cm	IMS=1 & SD_{model} < 1cm
Vertical correlation length	800m	500m
Upper limit for snow depth	1.4m	3.0m

IMS is not assimilated on the red shading



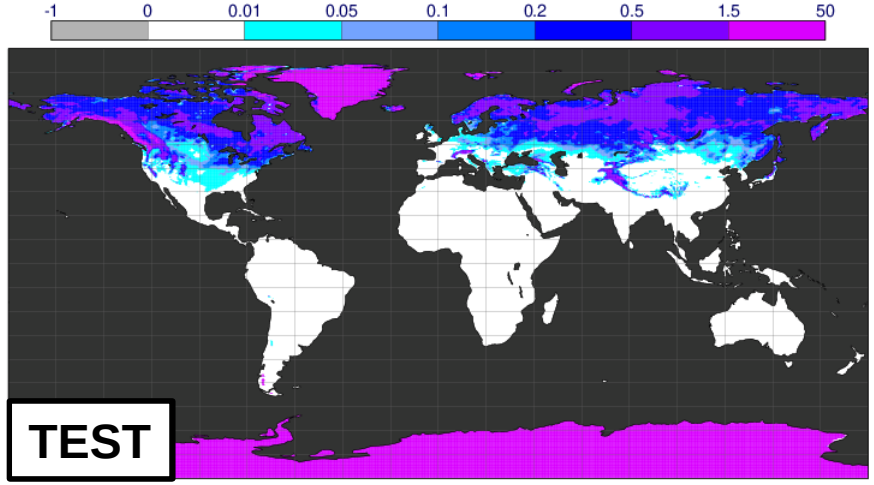
Revised thinning for IMS

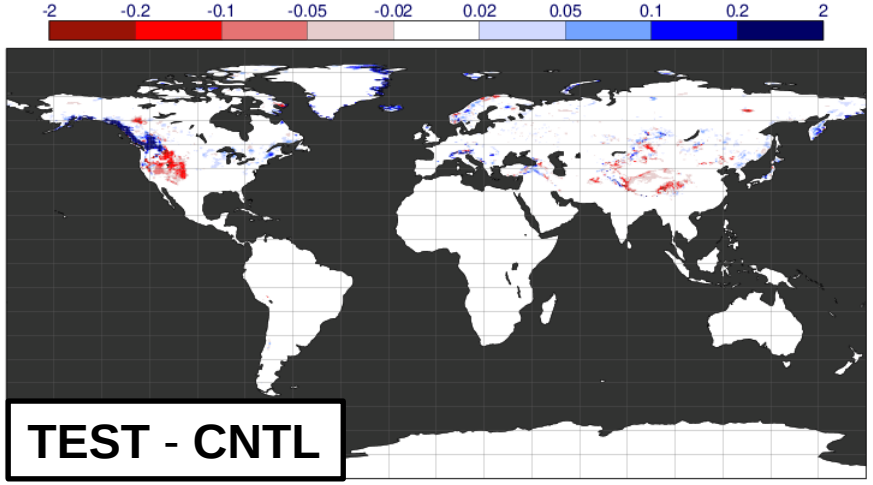


In this presentation, I will show results based on the CY48R1.1 for 2 winter seasons

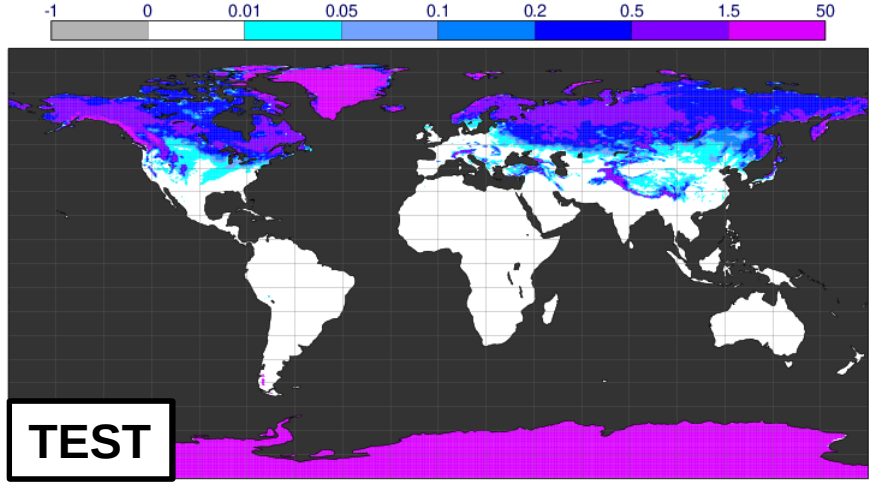
Impact of revised snow DA on snow depth

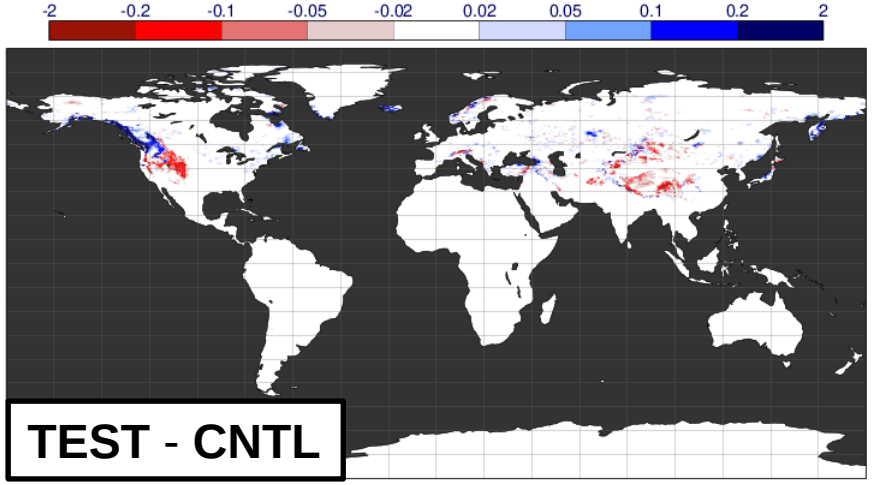
Feb 2021





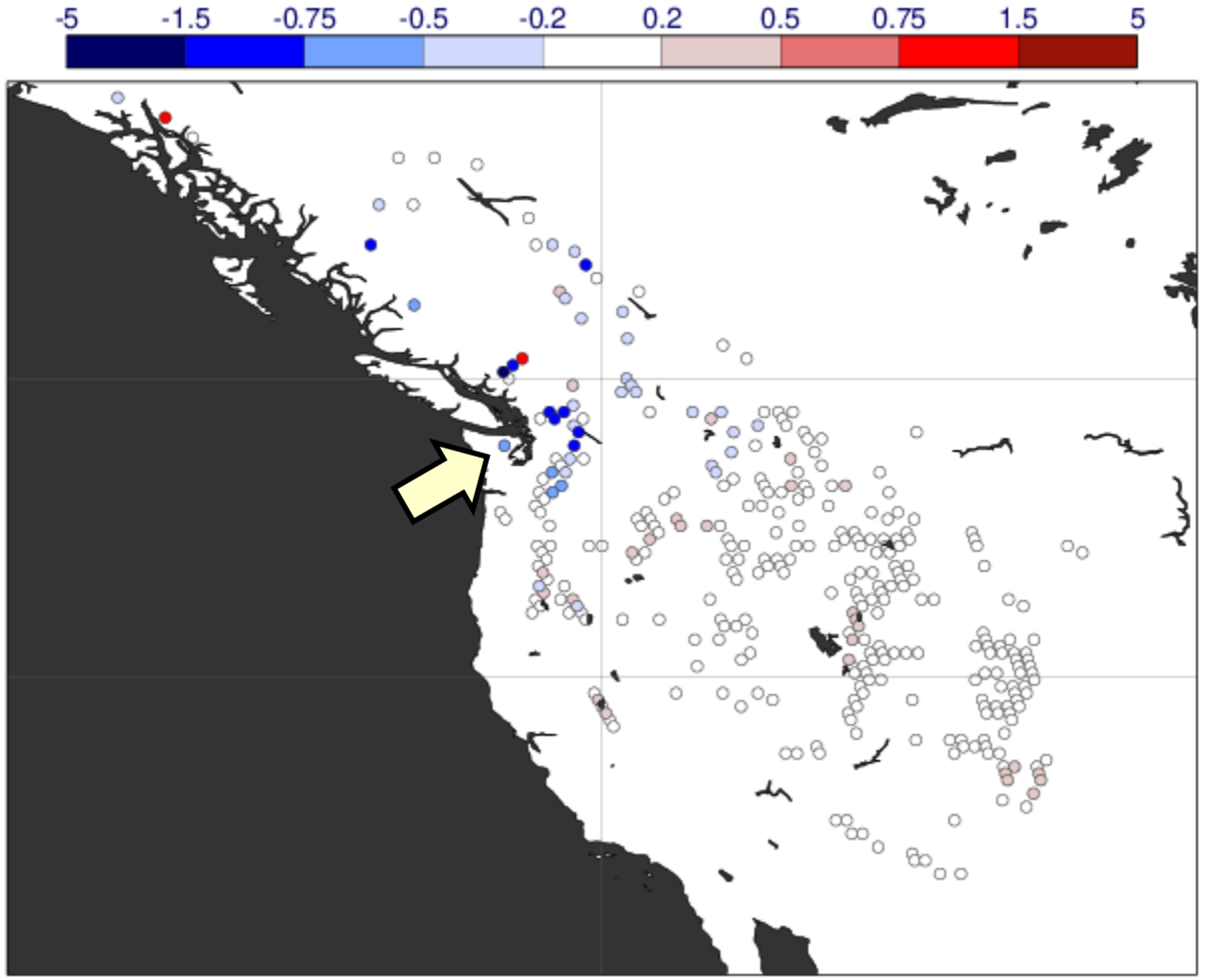
Feb 2022





- Snow depth is reduced on mountainous areas by assimilating IMS (except the Northern Rockies)
- Almost similar impact for winter 2020/21 and 2021/22

Validation of snow depth against the SNOTEL and CanSWE

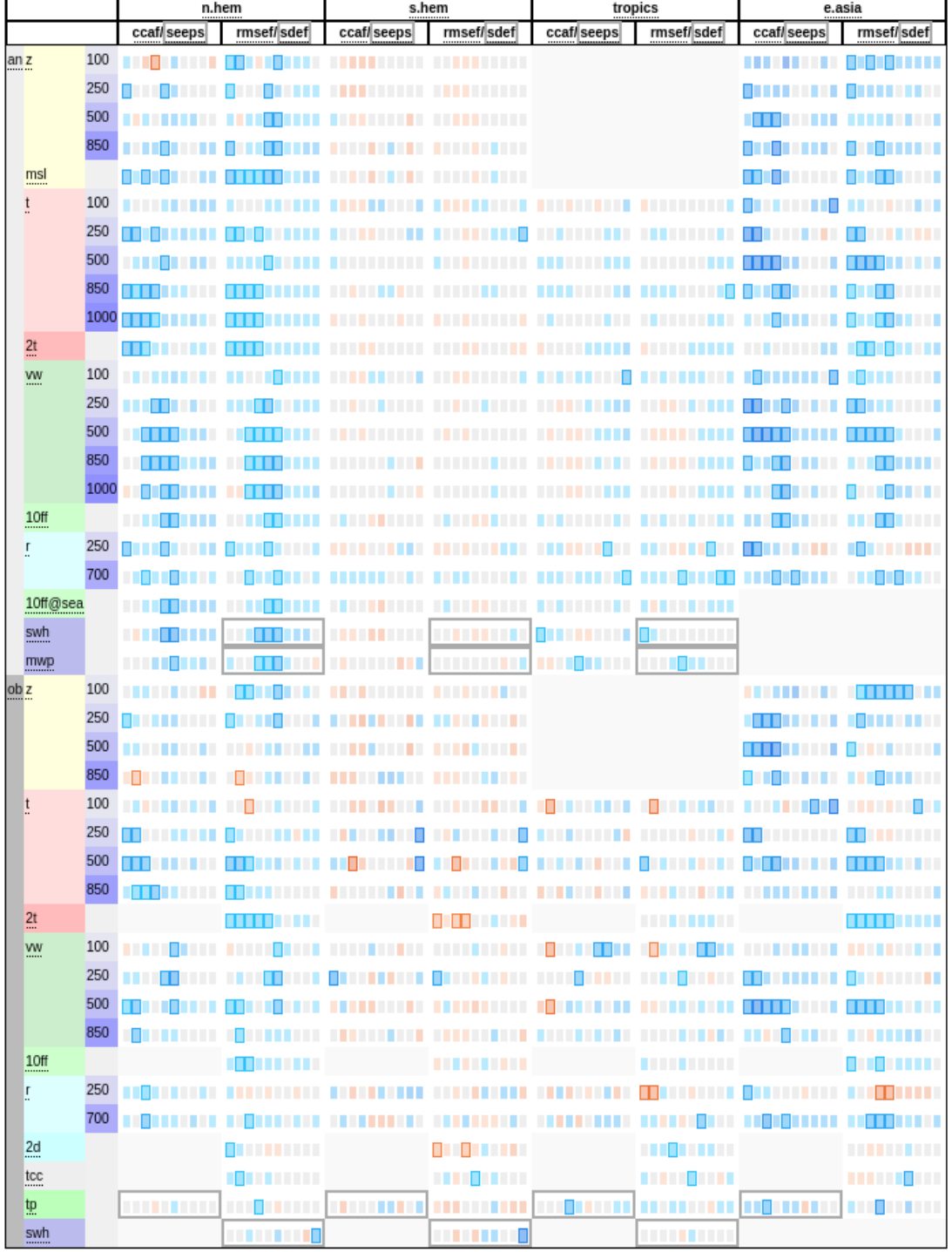


Mean absolute errors for Feb 2021 and 2022

SNOTEL: Serreze et al. (1999)
CanSWE: Vionnet et al. (2021)

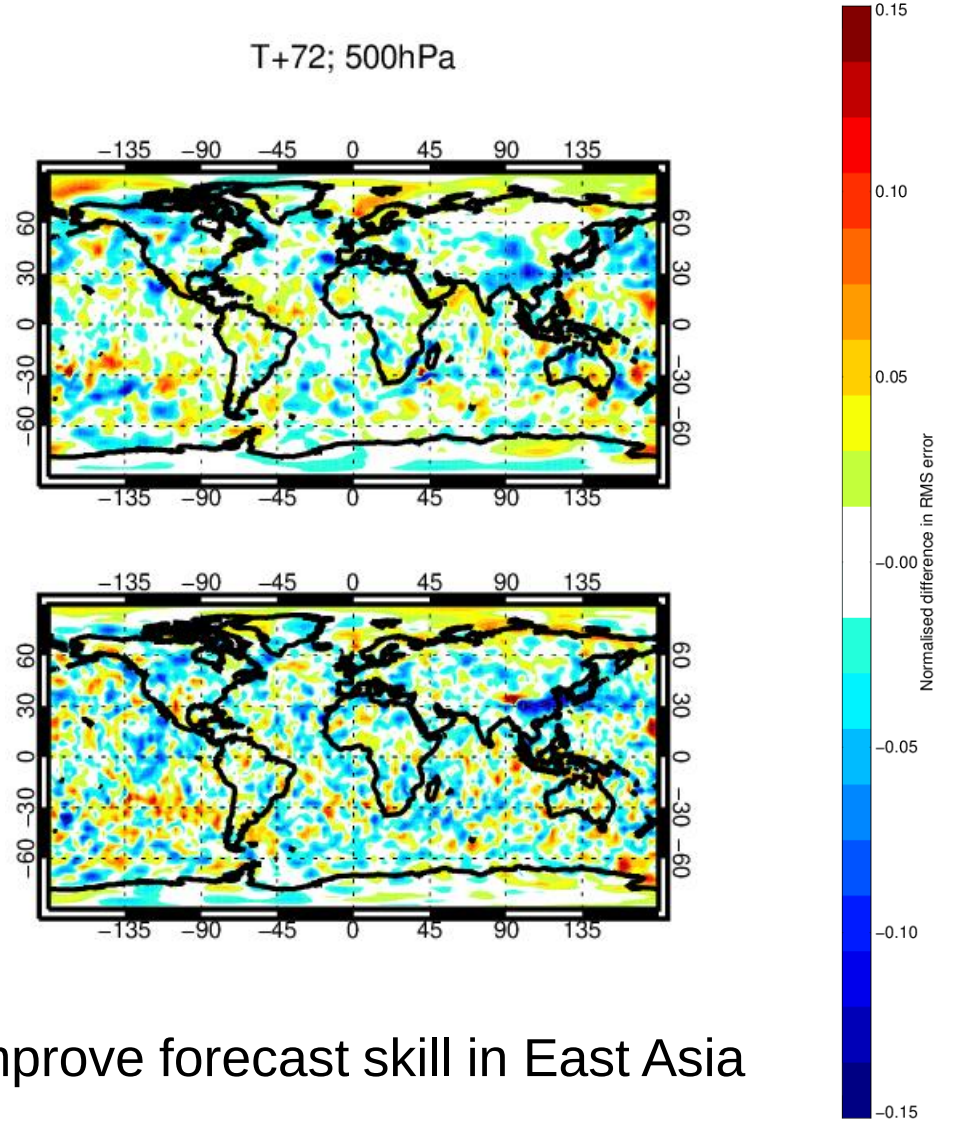
- Snow depth is increased on the Northern Rockies by the upper limit change
- Mean absolute errors are much reduced against in situ observations on the area

Scorecard for winter 2020/21



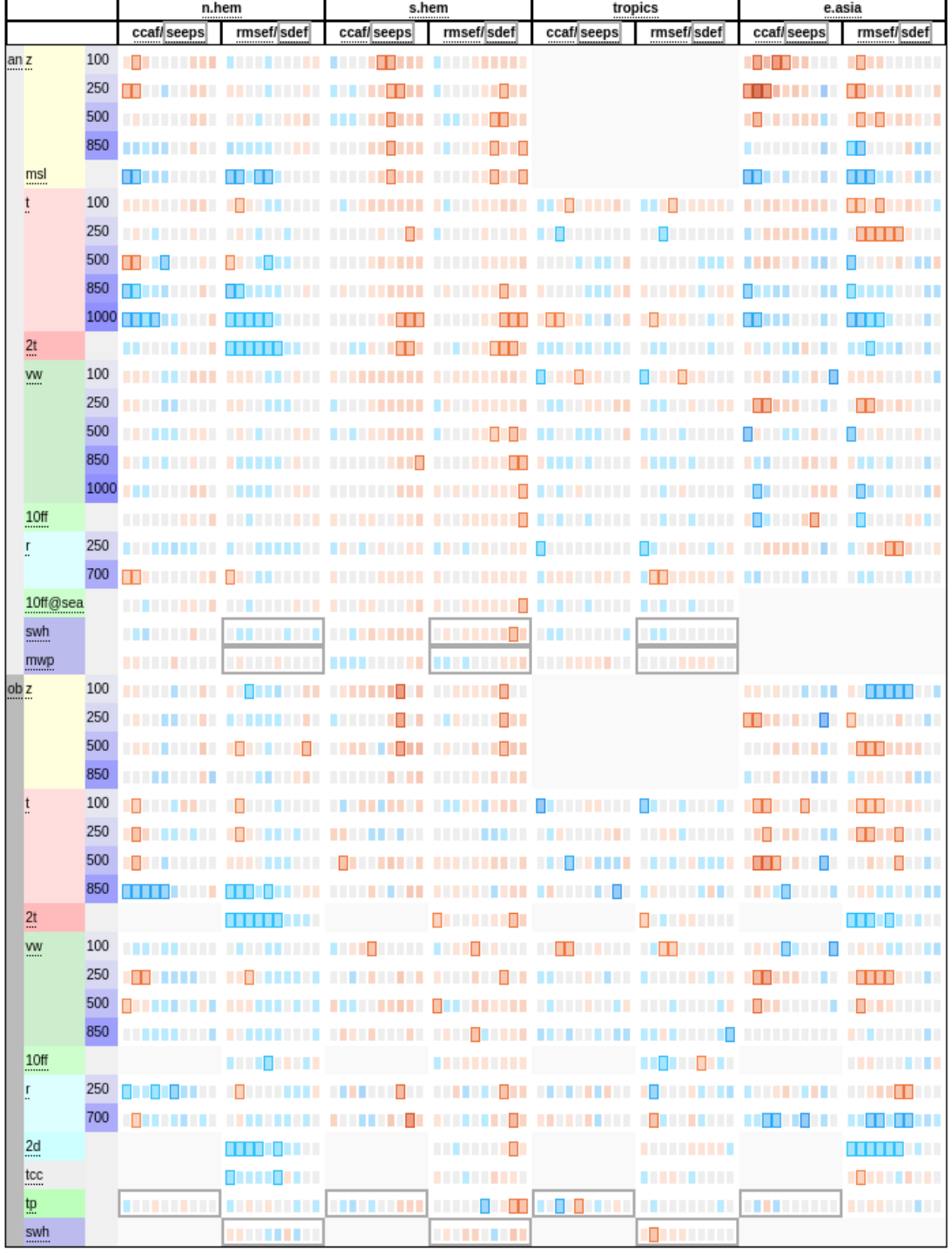
Z500

T500

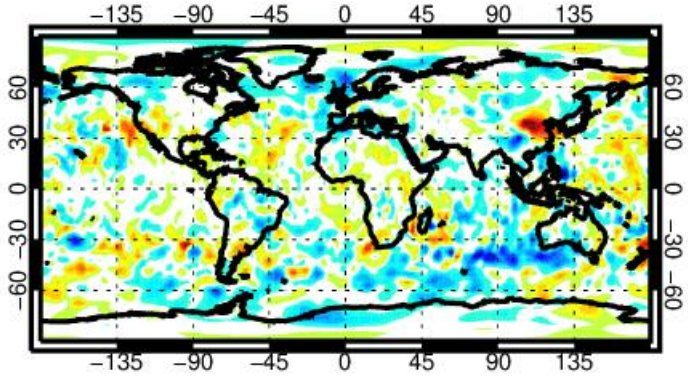


Improve forecast skill in East Asia

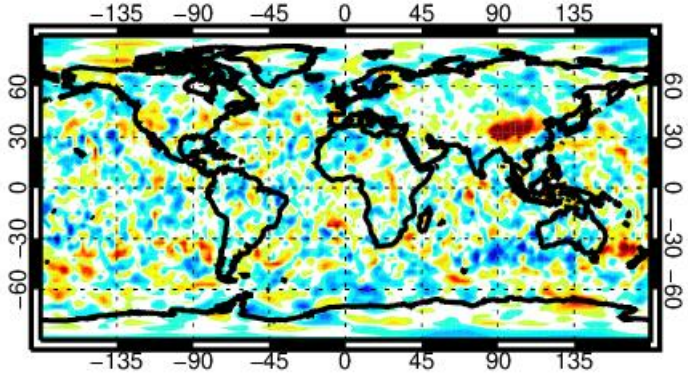
Scorecard for winter 2021/22



Z500



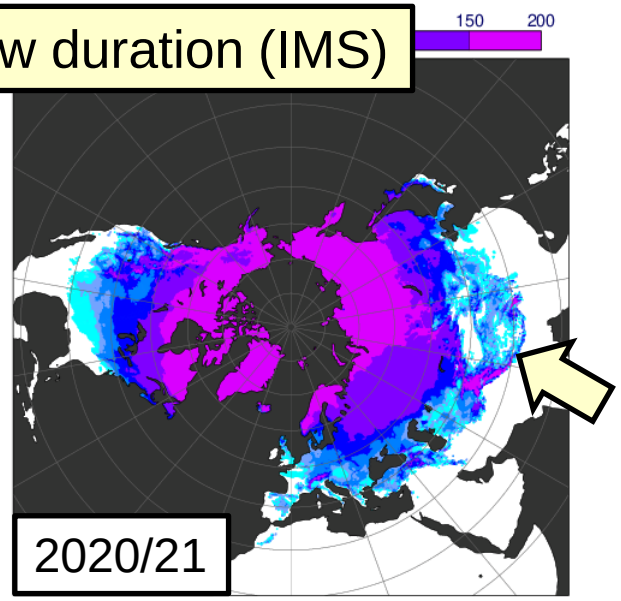
T500

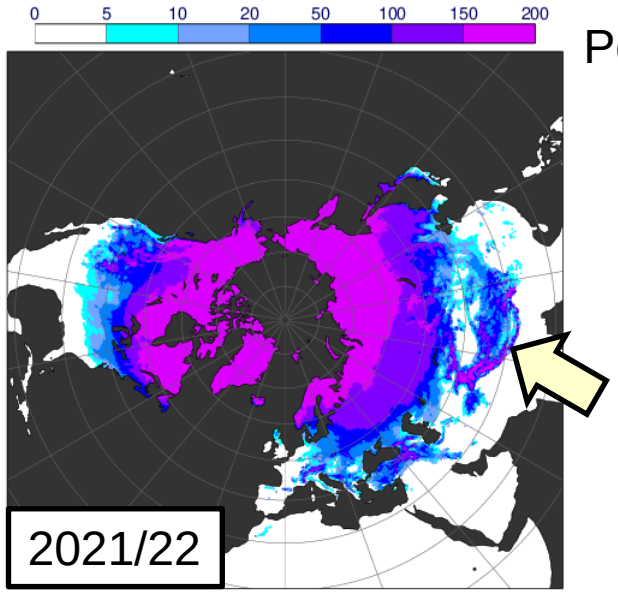


Degrade forecast skill in East Asia

What's the difference between 2020/21 and 2021/22?

Snow duration (IMS)



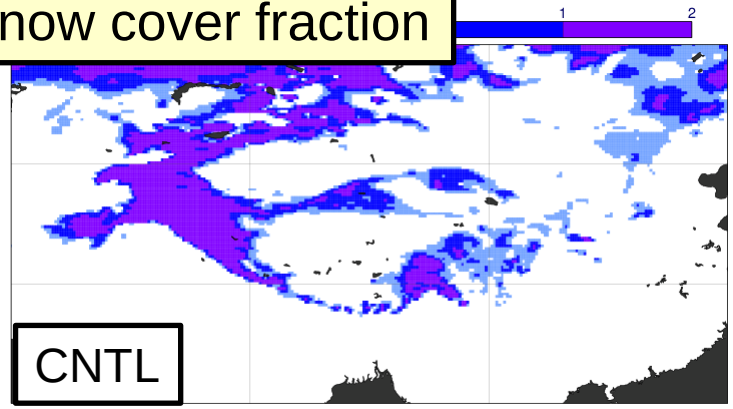


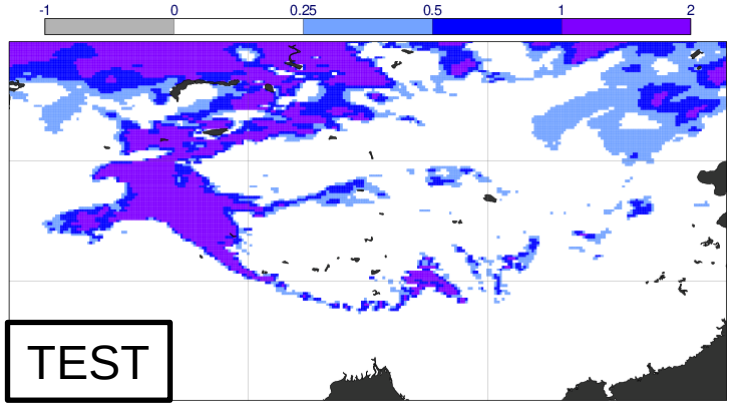
Period: Dec to May for each year

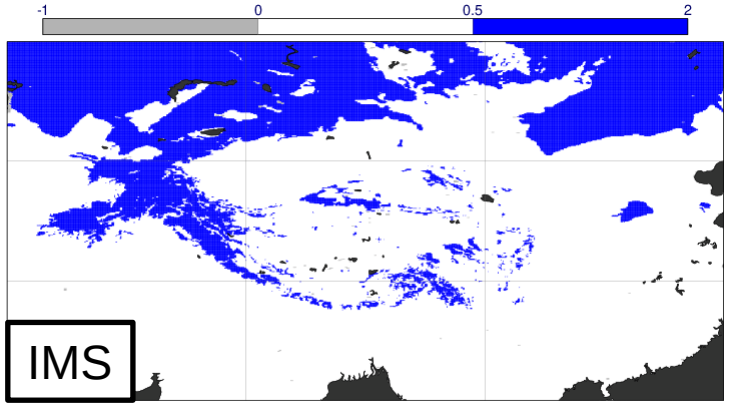
In 2021/22, snow-covered area on the Tibetan Plateau was much larger for a longer period than 2020/21

28th Feb 2021

Snow cover fraction



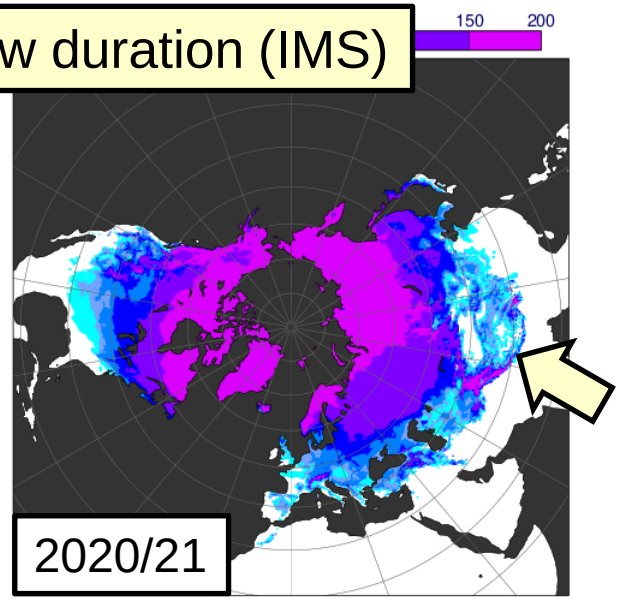


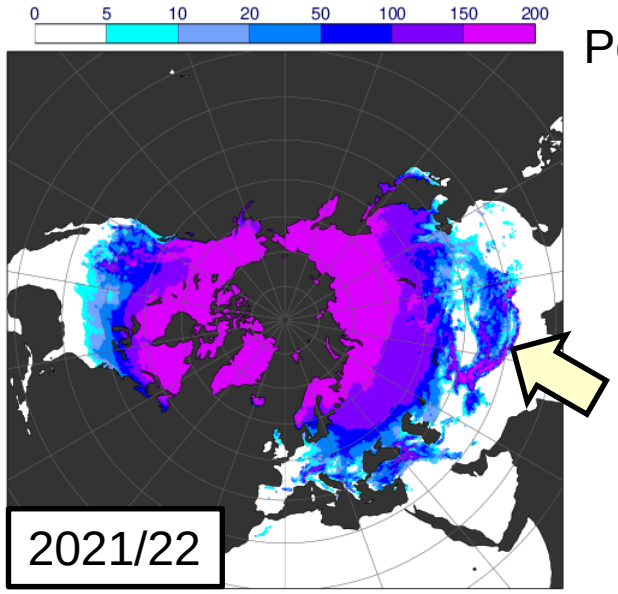


Snow cover fraction is improved by assimilating IMS in 2020/21, but…

What's the difference between 2020/21 and 2021/22?

Snow duration (IMS)



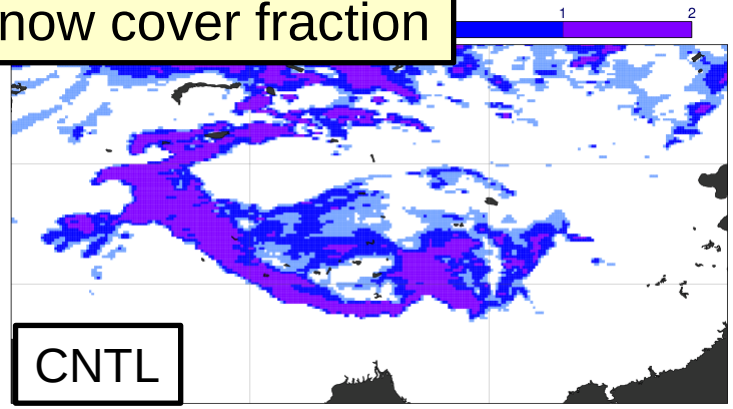


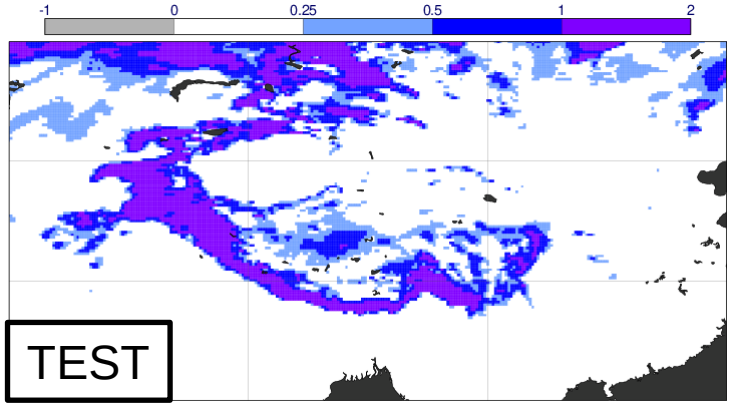
Period: Dec to May for each year

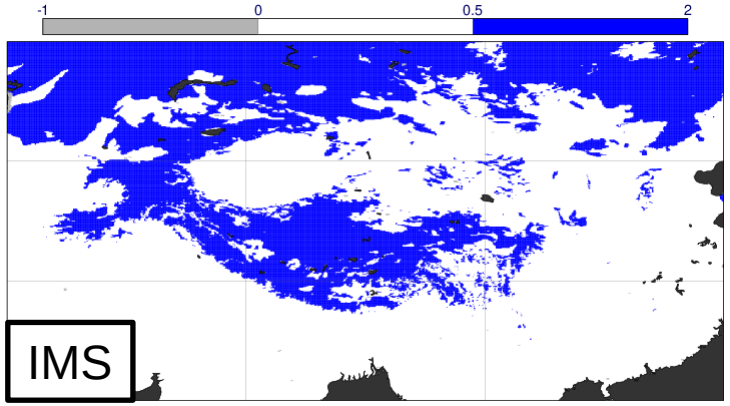
In 2021/22, snow-covered area on the Tibetan Plateau was much larger for a longer period than 2020/21

Snow cover fraction

1st Jan 2022







Insufficient snow cover fraction for shallow snow → **Need to improve SCF parameterization in the IFS**

Revised snow cover parameterization for the CY49R1

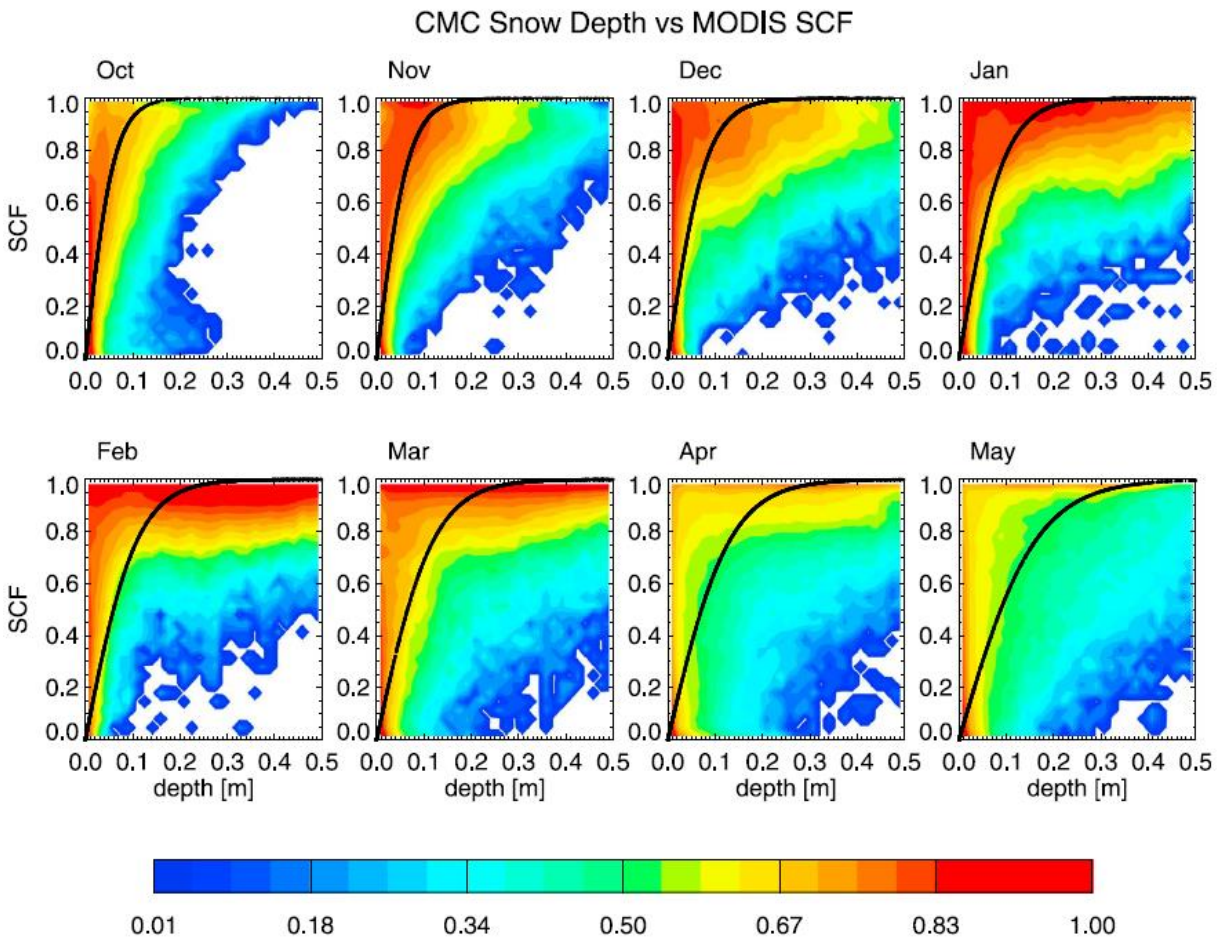
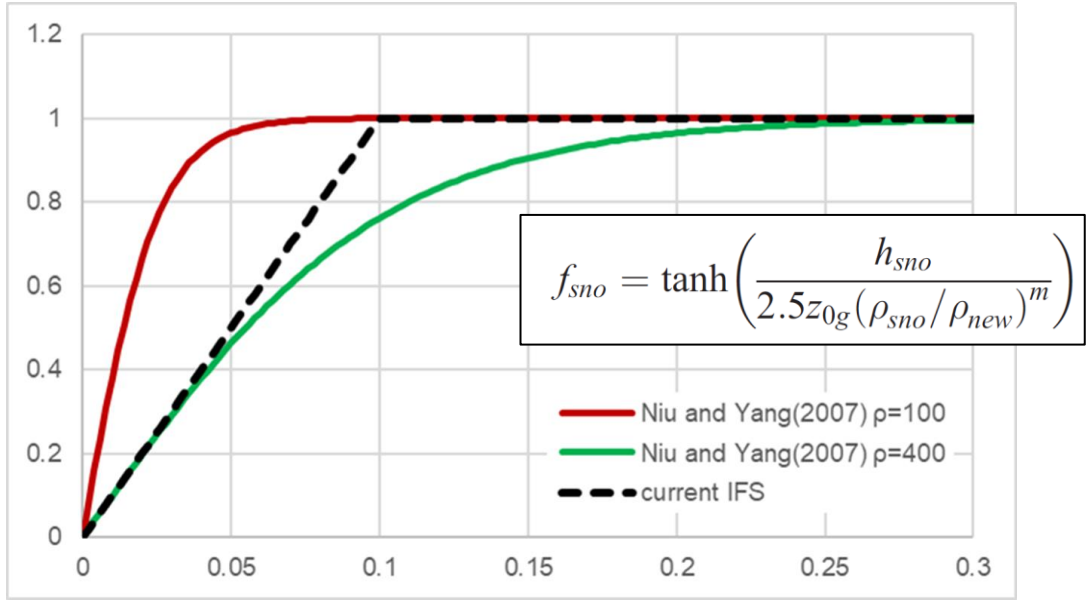


Figure 2. Same as Figure 1 except daily averaged data were used to generate the histograms.

Swenson and Lawrence (2012)

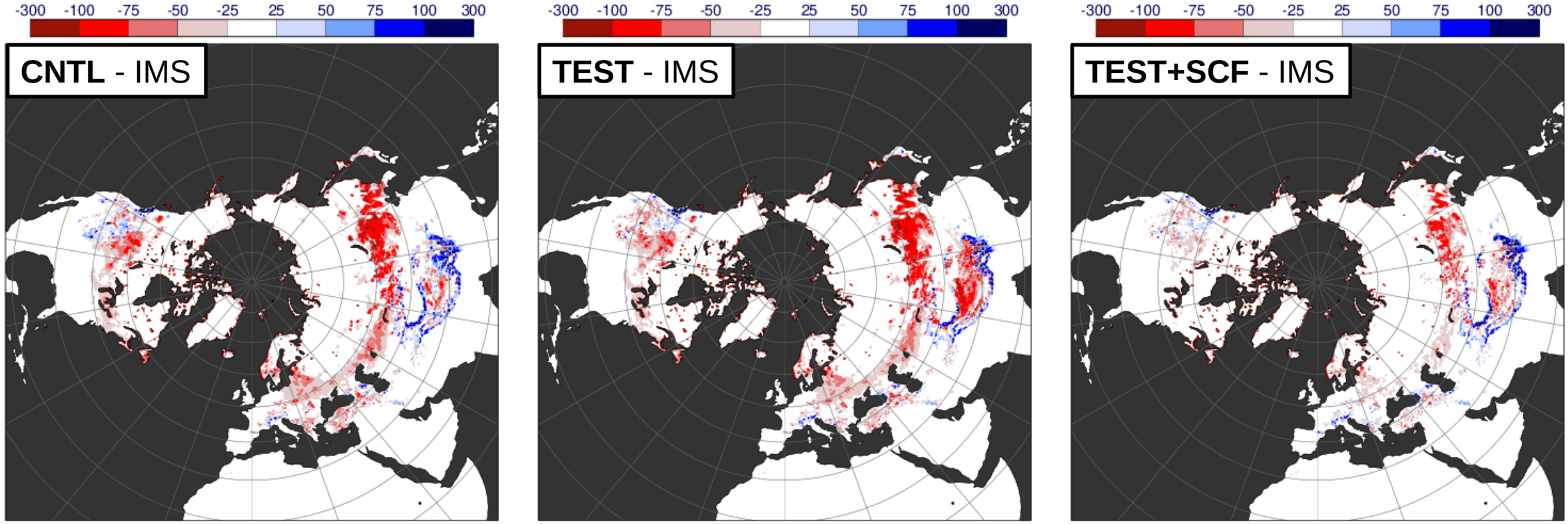
- SCF doesn't depend on snow depth only
  - Accumulation or melting, vegetation, etc…
  - Described in Niu and Yang(2007), Swenson and Lawrence (2012), Nitta et al. (2014)
- The Niu and Yang (2007) SCF has been tested



  - SD_{IMS} is also changed from 5cm to 3cm

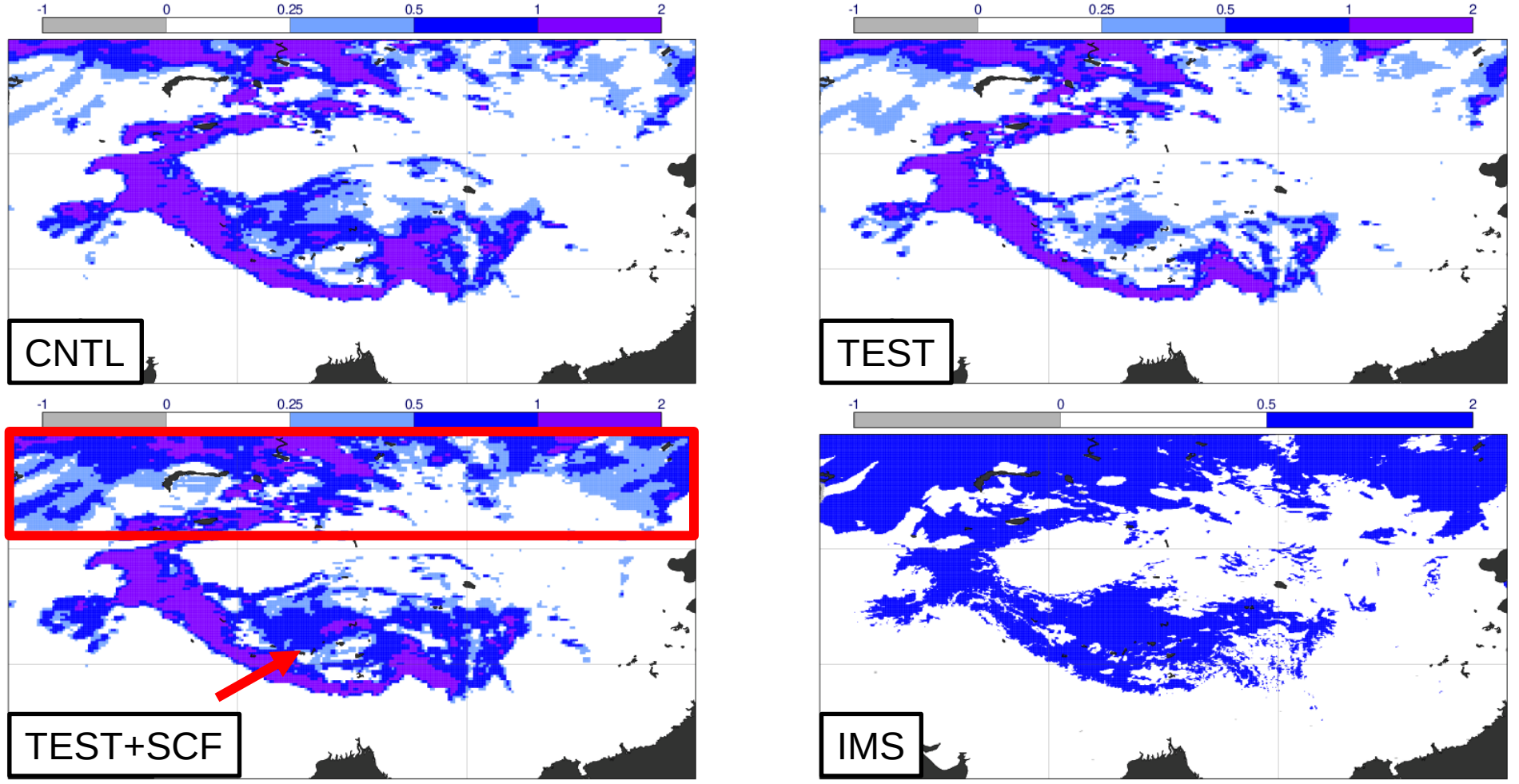
Validation of snow cover duration against IMS

Period: Dec 2021 to May 2022



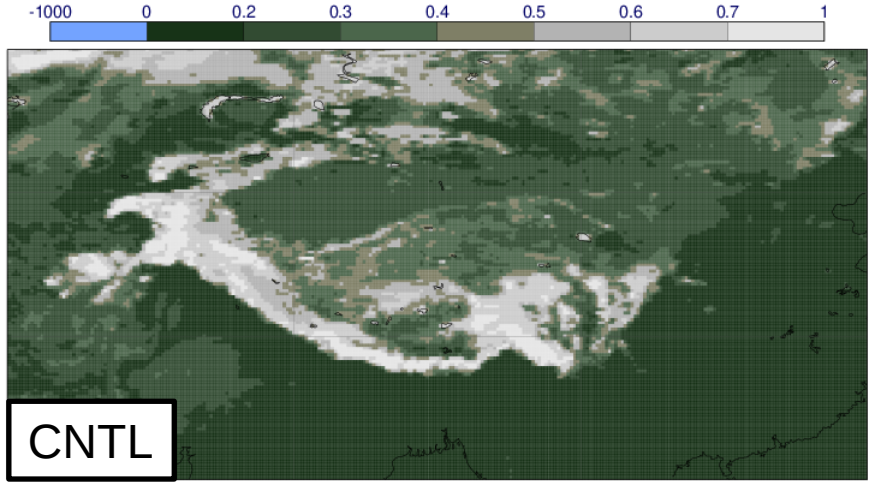
- **CNTL** has negative biases of snow cover duration (number of days when SCF>50%)
  - Worse on the Tibetan Plateau in **TEST**, although looks better for snow depth
- The negative biases are improved by the revised SCF parameterization (**TEST+SCF**)

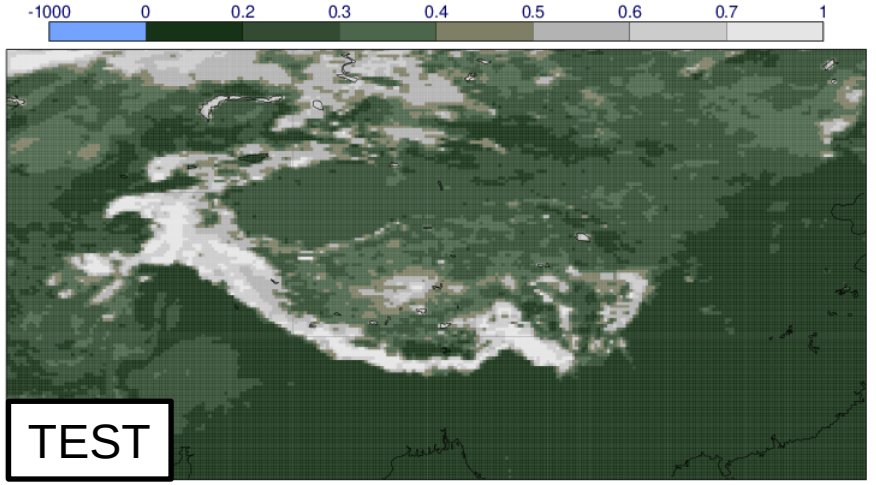
An example of snow cover fraction on 1st Jan 2022

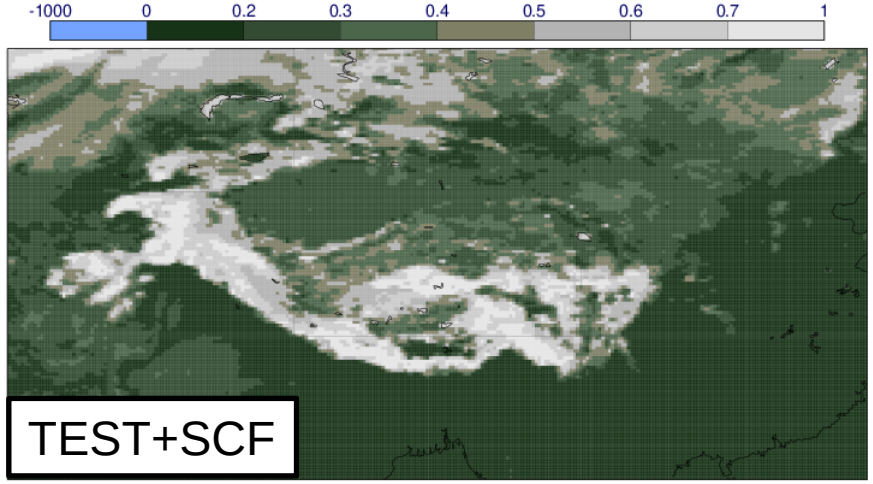


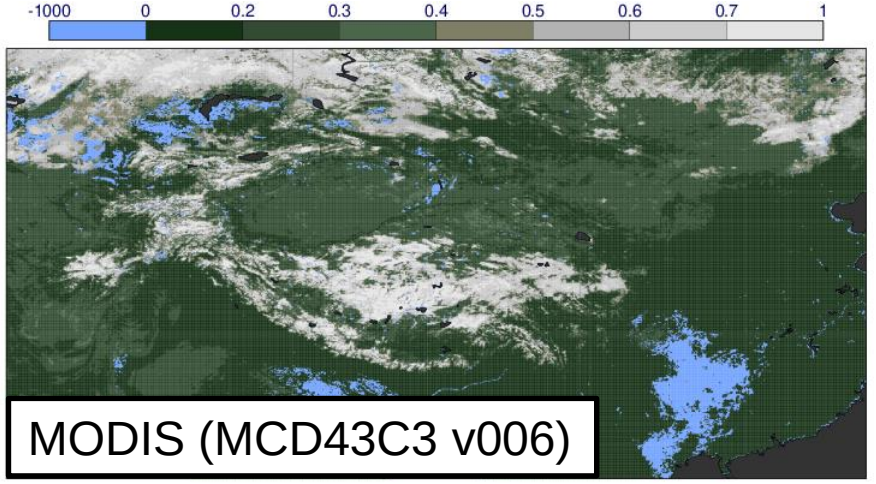
- SCF is increased for shallow snow by the revised SCF parameterization

An example of albedo on 1st Jan 2022







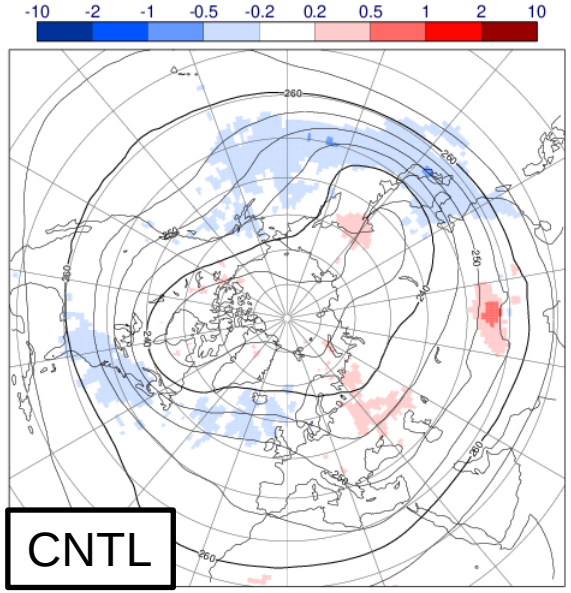


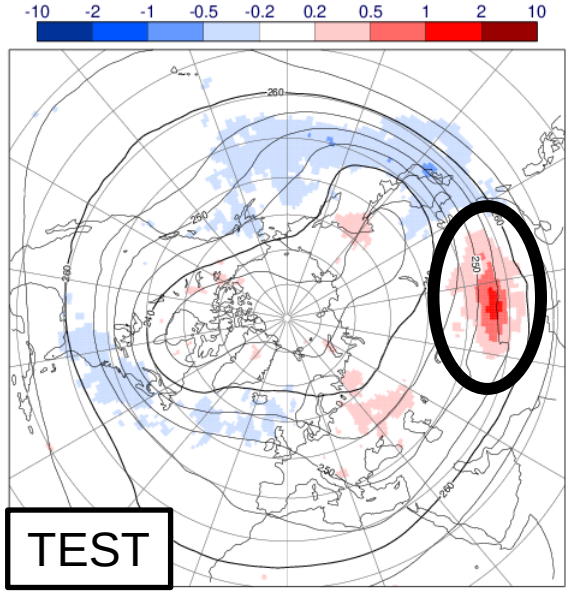
- Albedo is also increased especially on the Tibetan Plateau

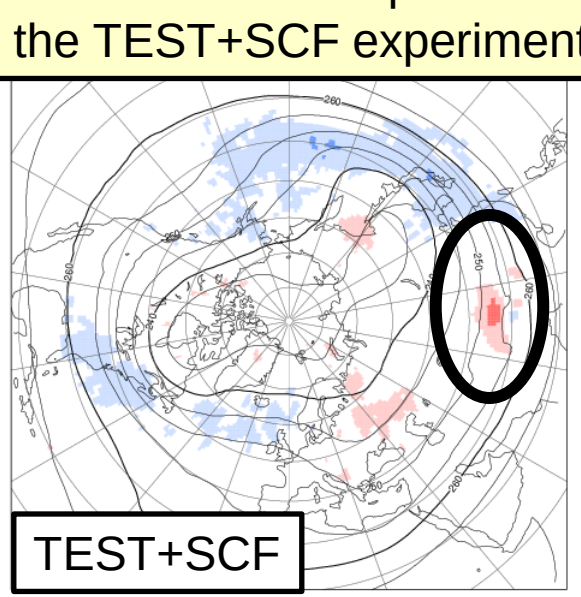
Mean biases of T850 and T500 at T+48

Warm biases of temperature are reduced in the TEST+SCF experiment

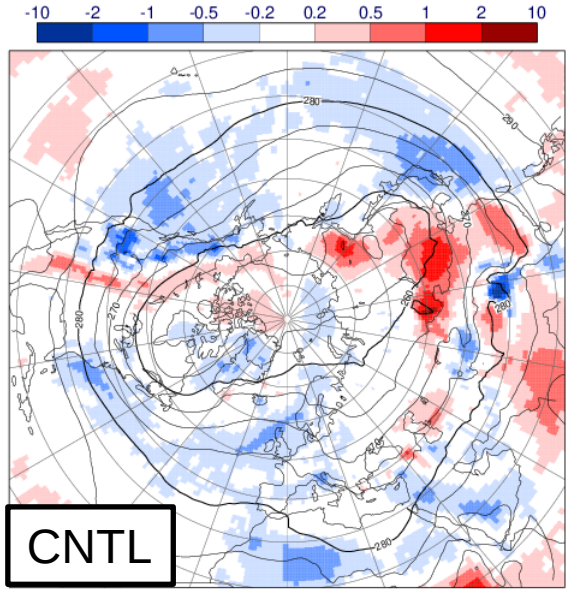
T500

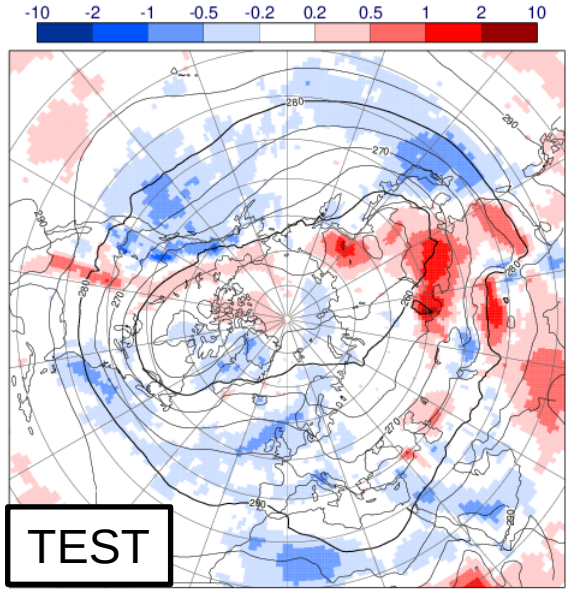


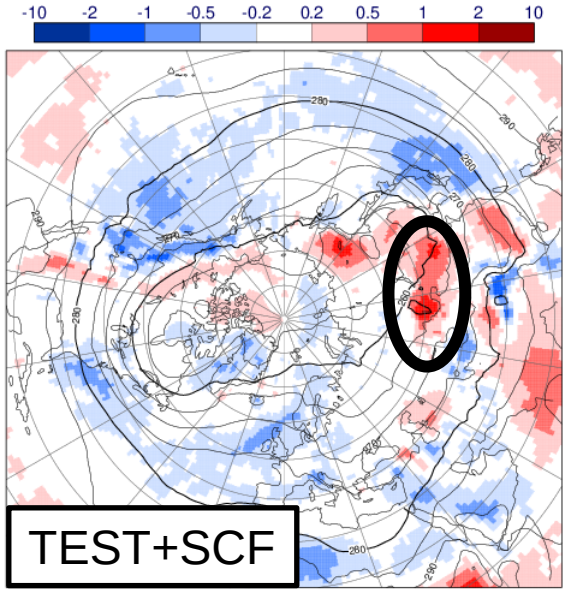




T850

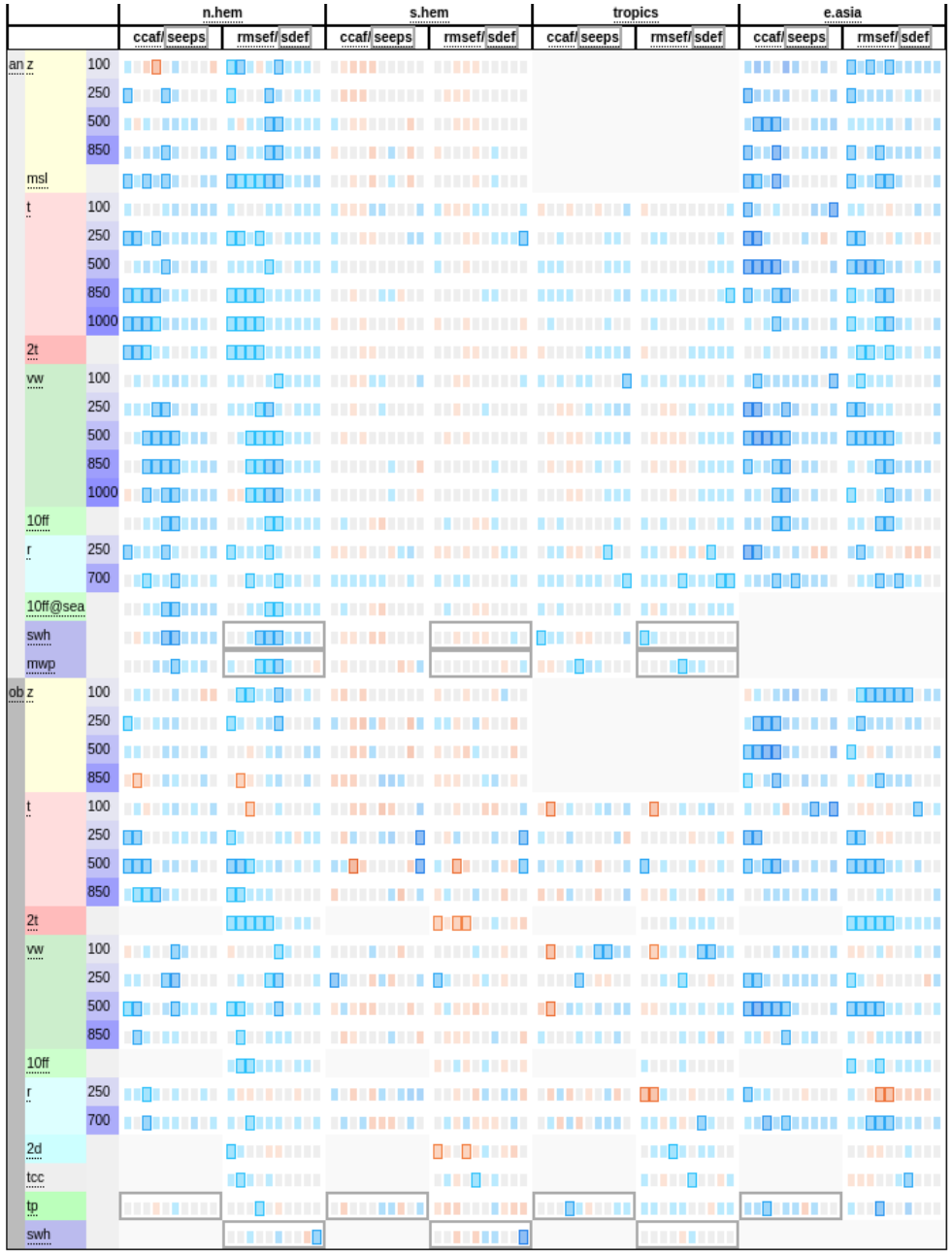




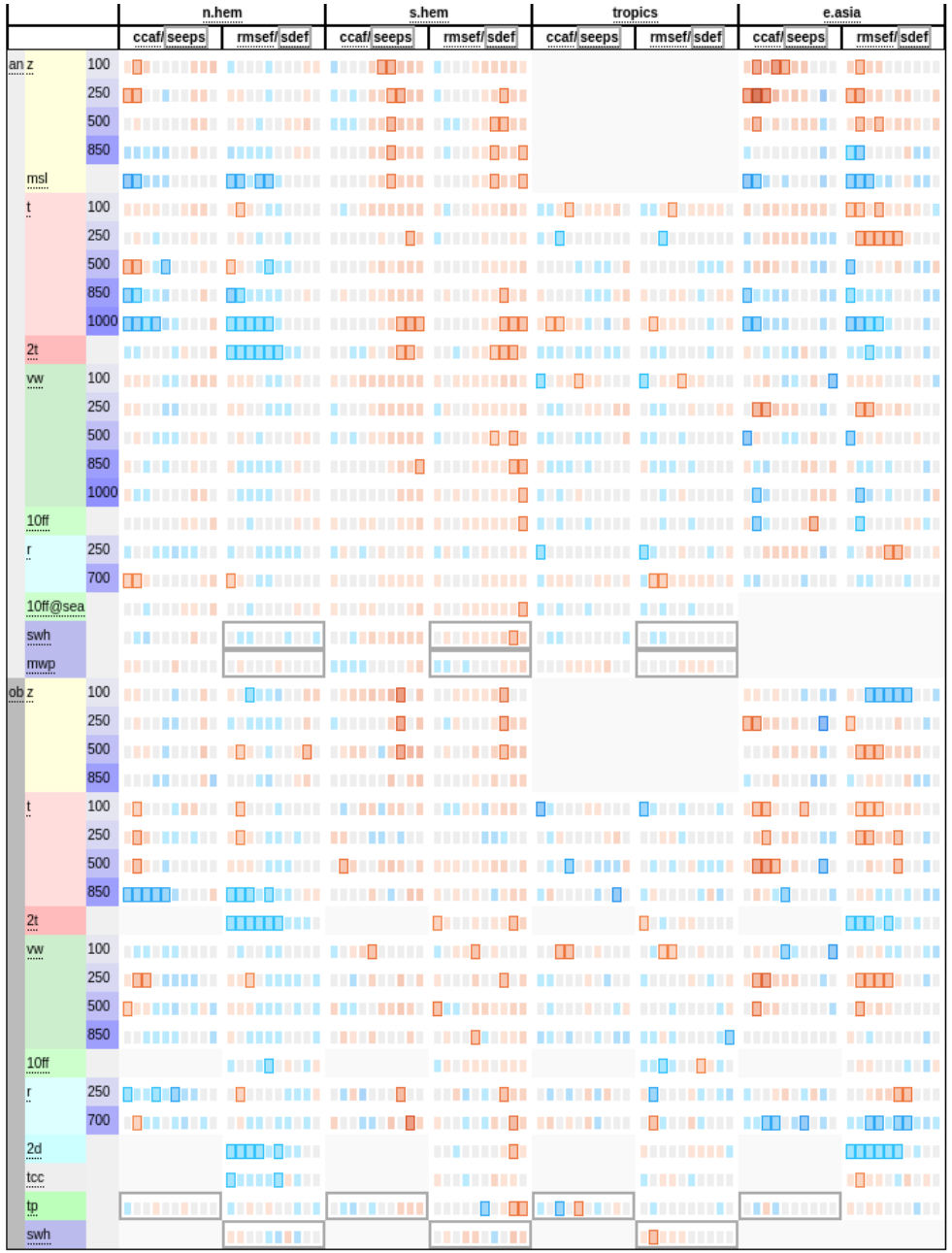


Winter 2021/22

Scorecards of TEST against CNTL

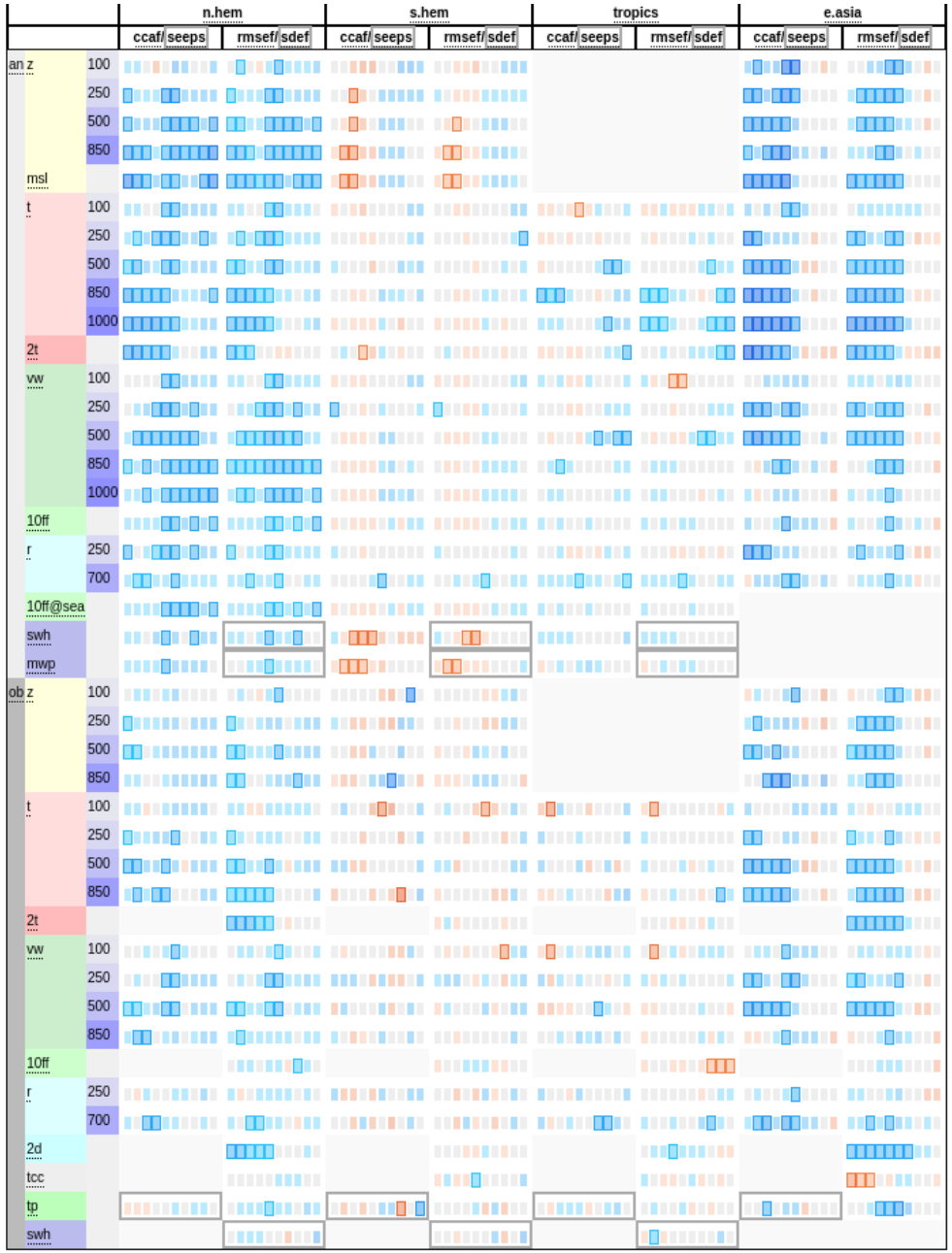


Winter 2020/21

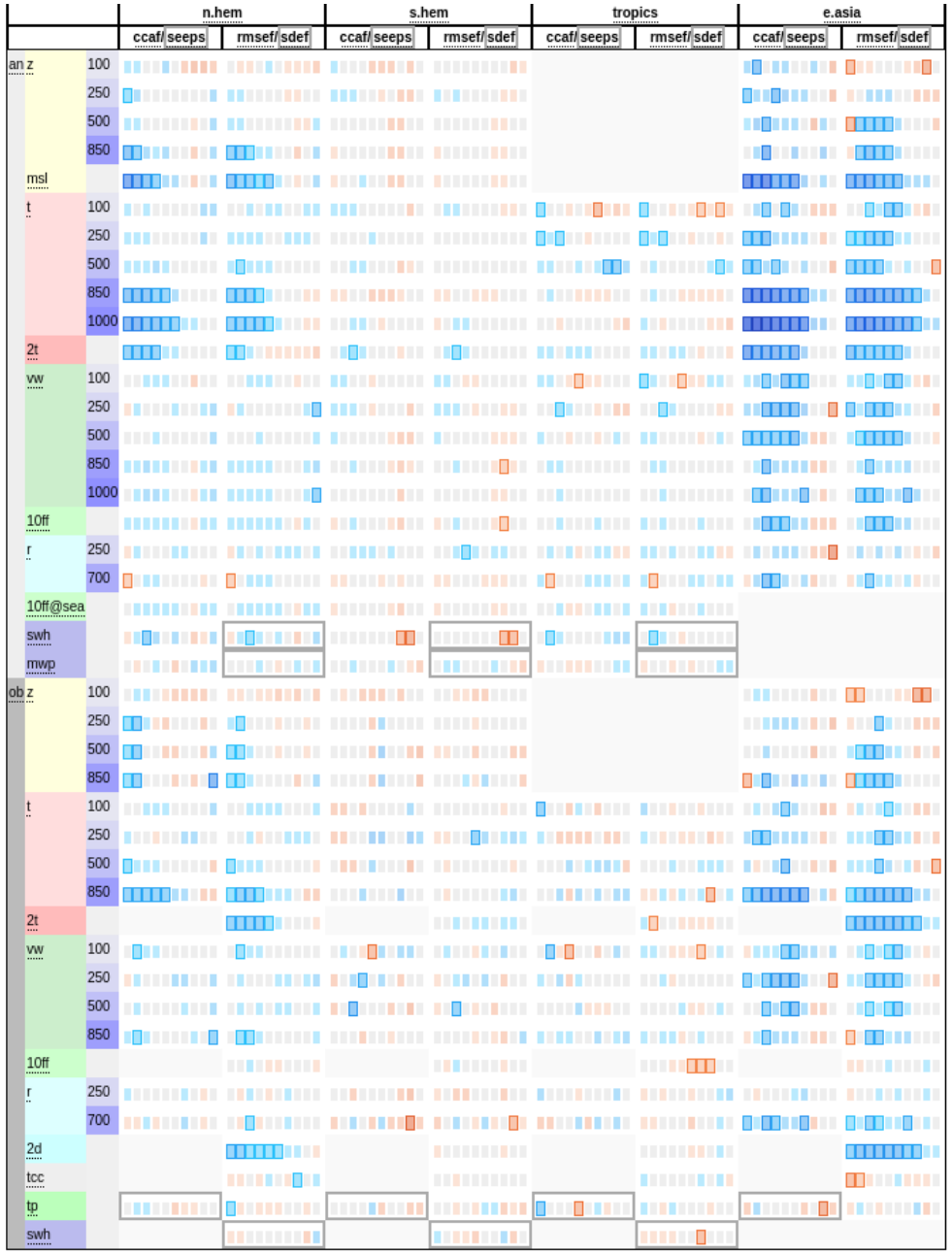


Winter 2021/22

Scorecards of TEST+SCF against CNTL



Winter 2020/21



Winter 2021/22

Summary

- **Snow cover has large impact on NWP, especially around East Asia**
  - Not only near surface temperature, but also in the mid-to-upper troposphere
- **Importance of collaboration between modeling and assimilation team**
  - Crucial for addressing error compensation
- **We can sometimes obtain a clue from experiments for different years**
  - In the case of snow changes, also important to have a look at spring

* You can see the details based on CY49R1 at the IWG page.
https://confluence.ecmwf.int/pages/viewpage.action?pageId=327671988

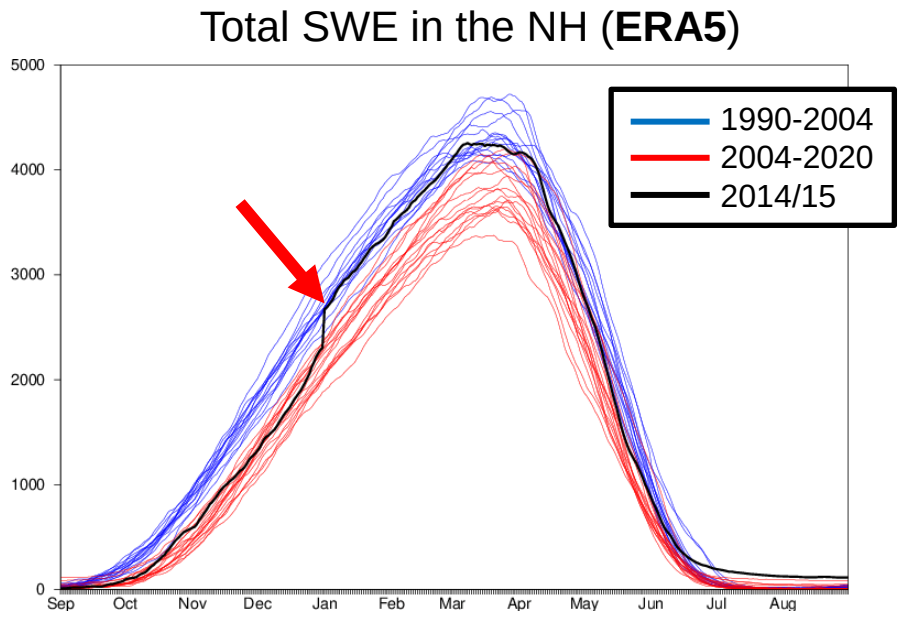
Outline

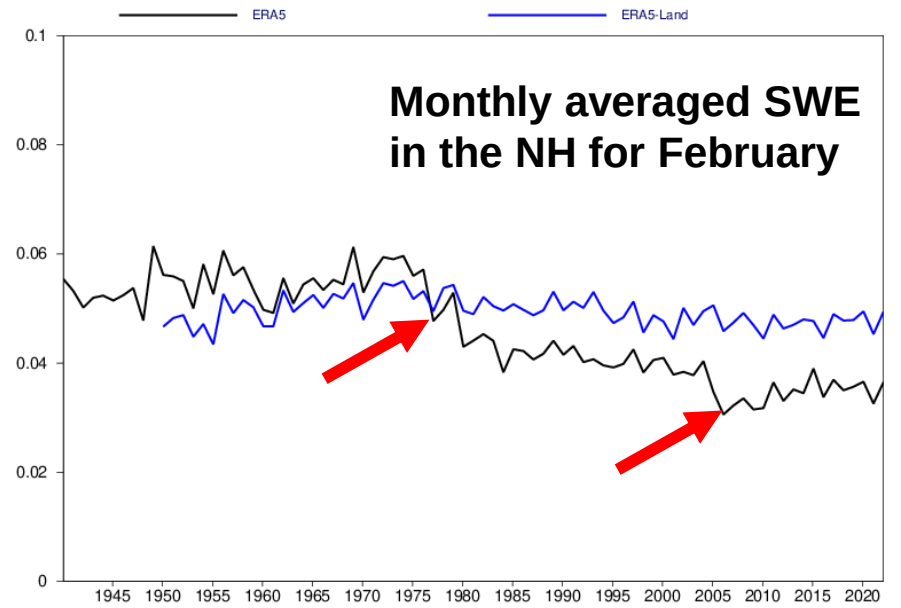
- Impact of revised snow data assimilation and snow cover parameterization
  - Implemented in the CY49R1
- ESA CCI snow cover assimilation for reanalysis
  - Plans for snow data assimilation in ERA6
- Other work on snow data assimilation in 2 years

Issues of snow analysis in ERA5

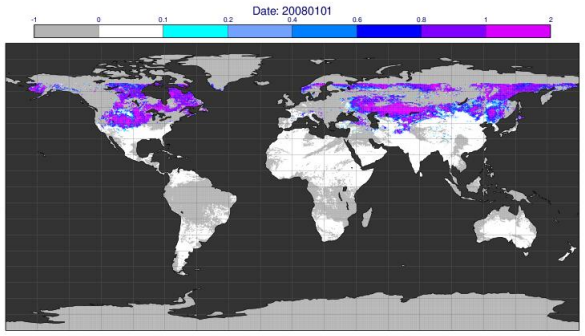
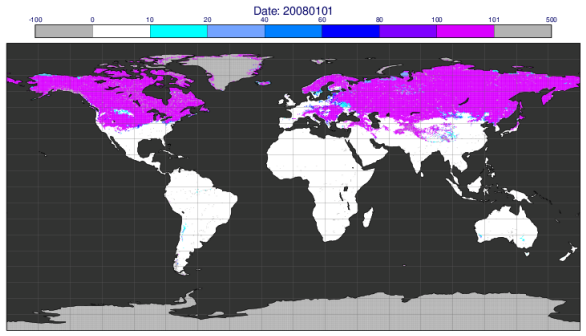
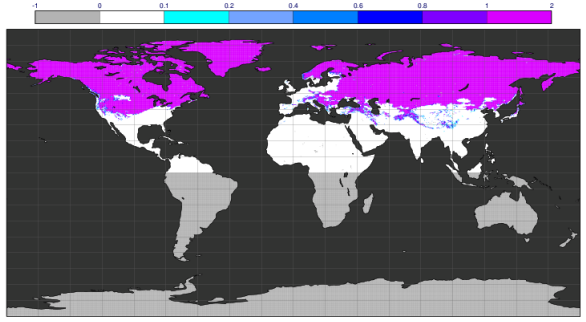
- Inconsistency between before and after 2004
  - IMS has been assimilated since 2004
  - The difference of ERA5 and ERA5-Land looks particularly large between 2004 and 2010 (inconsistency of IMS?)
- Discontinuity between 2014 and 2015
  - Due to a stream change
- Inconsistency around 1970's
  - Upper limit for snow depth didn't work without observations

To be more consistent for longer years in ERA6, possibility of using the ESA CCI Snow have been explored





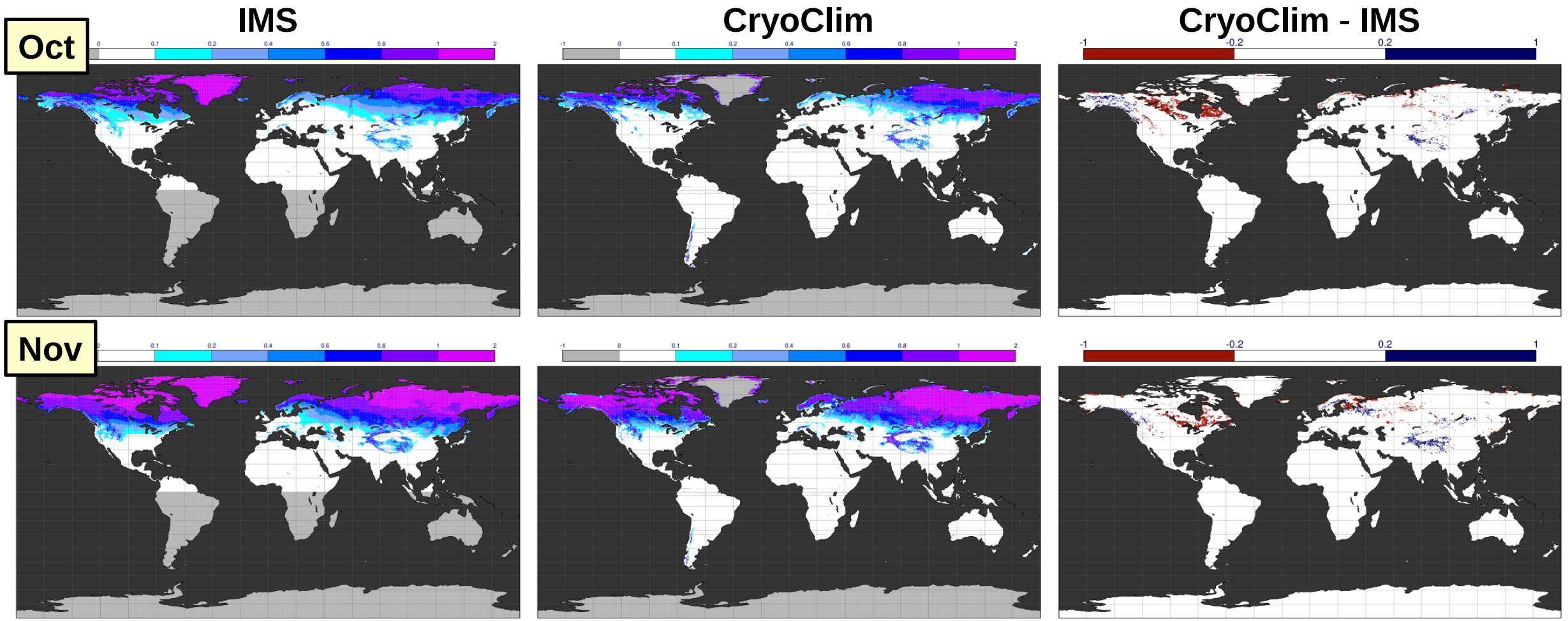
Comparison among satellite-derived snow cover products

	ESA CCI Snow AVHRR	ESA CCI Snow CryoClim	IMS
Sensors	AVHRR	AVHRR,SMMR,SSM/I,SSMIS	Many satellites and sensors
Period	1982 - 2019 Longer noise: 1984-1985, 1987 Longer gap: 1994-1995	1982 - 2019	2004 - now
Mask	Cloud, polar night, Greenland, Antarctica	Greenland (except coast), Antarctica	Southern Hemisphere
Example			

- The ESA CCI Snow has a longer period than IMS
- CryoClim has no cloud mask and looks more consistent with IMS

Monthly climatology of IMS and CryoClim

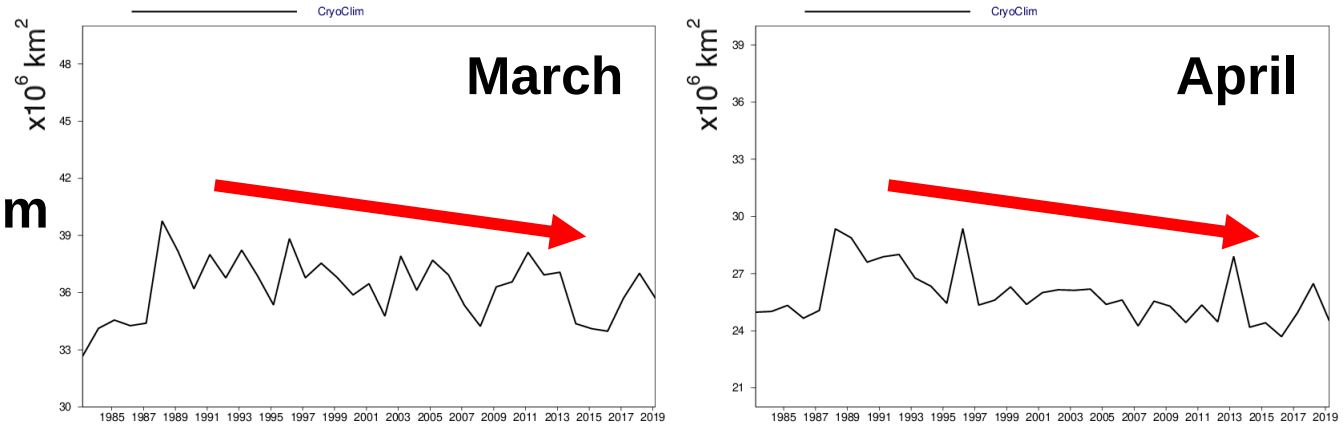
Period: 2006 to 2020

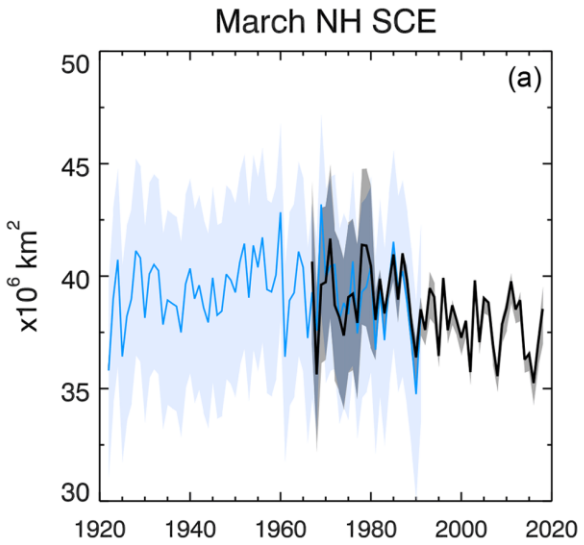


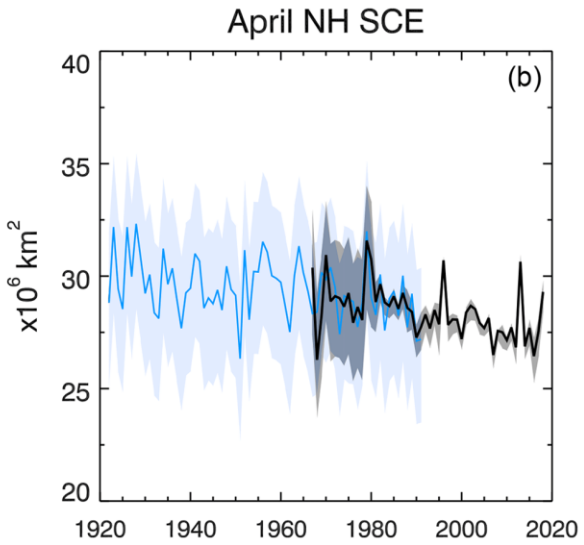
- IMS and CryoClim are consistent in many regions, but not consistent in some regions

Interannual variability of the CryoClim snow cover extent

CryoClim







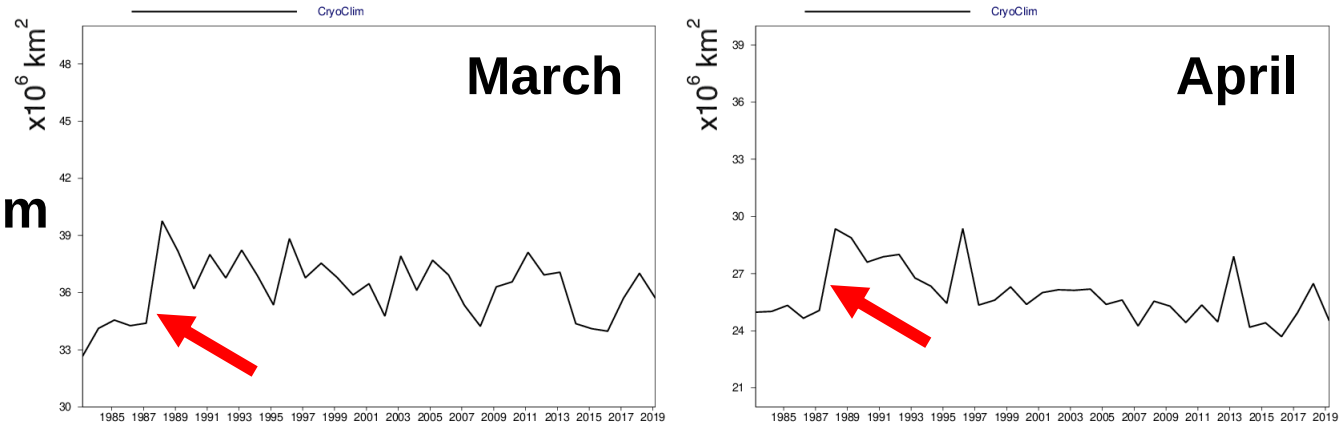
Negative trend for spring in CryoClim
→ Similar to Mudryk et al. (2020)

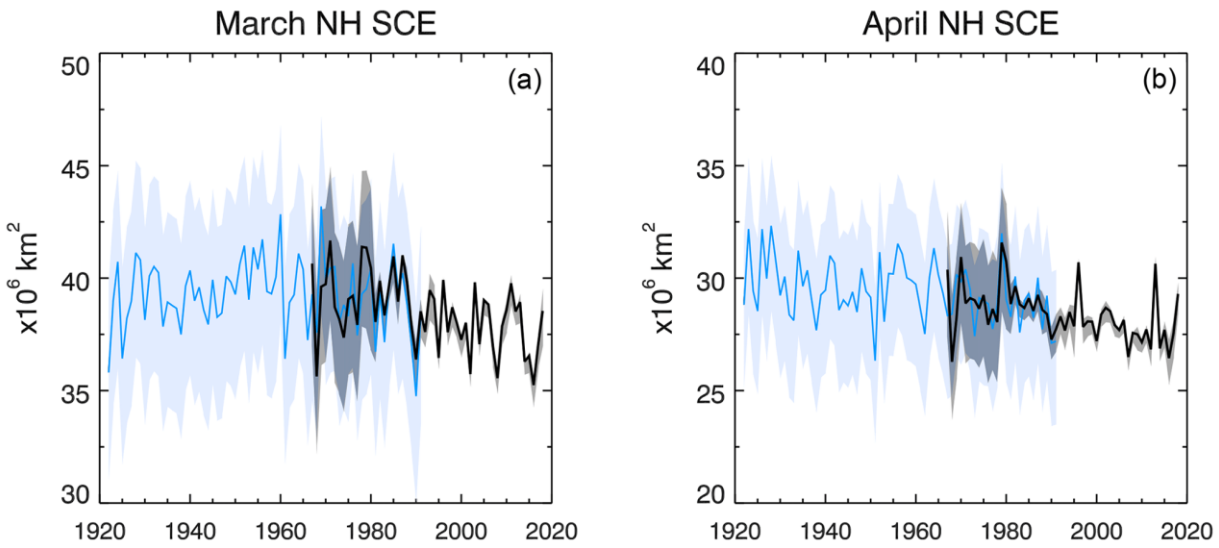
Much less snow-covered area before 1987
→ Corresponding to the SMMR period
→ Looks suspicious

Mudryk et al. (2020): snow cover extent based on multi-dataset

Interannual variability of the CryoClim snow cover extent

CryoClim





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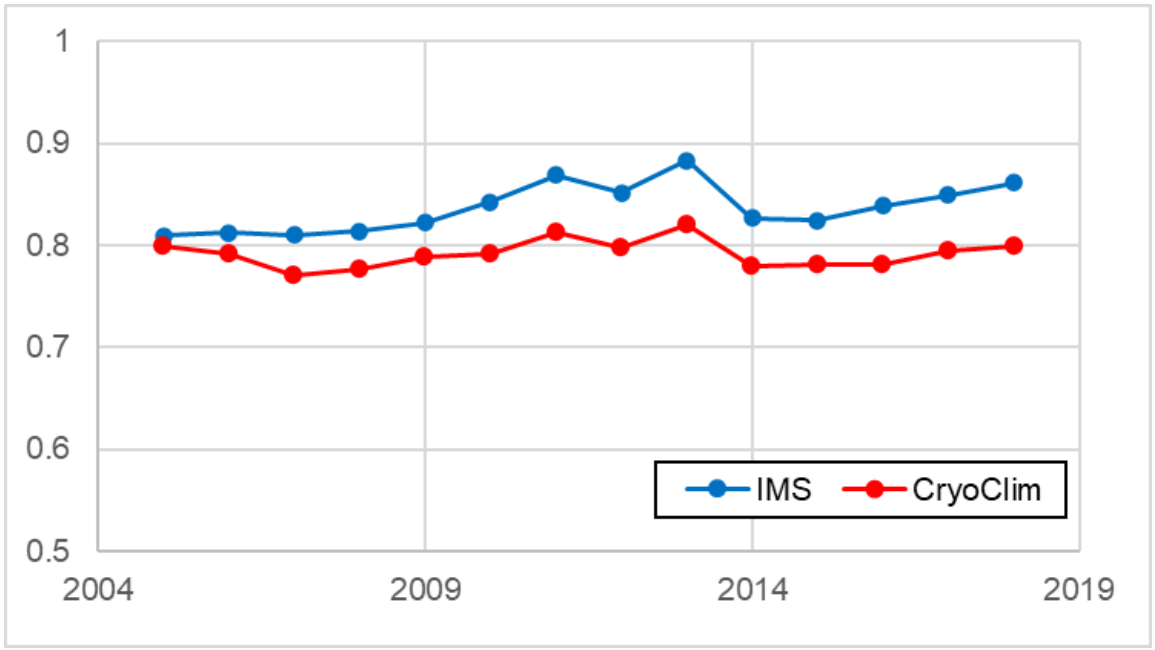
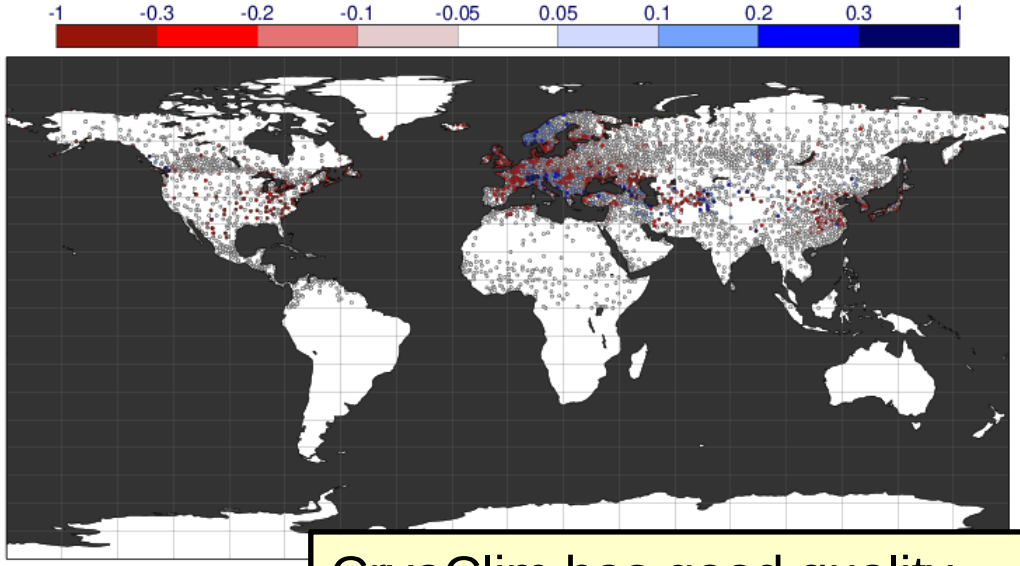
Validation of IMS and CryoClim against in situ observations

Threat score



CryoClim - IMS

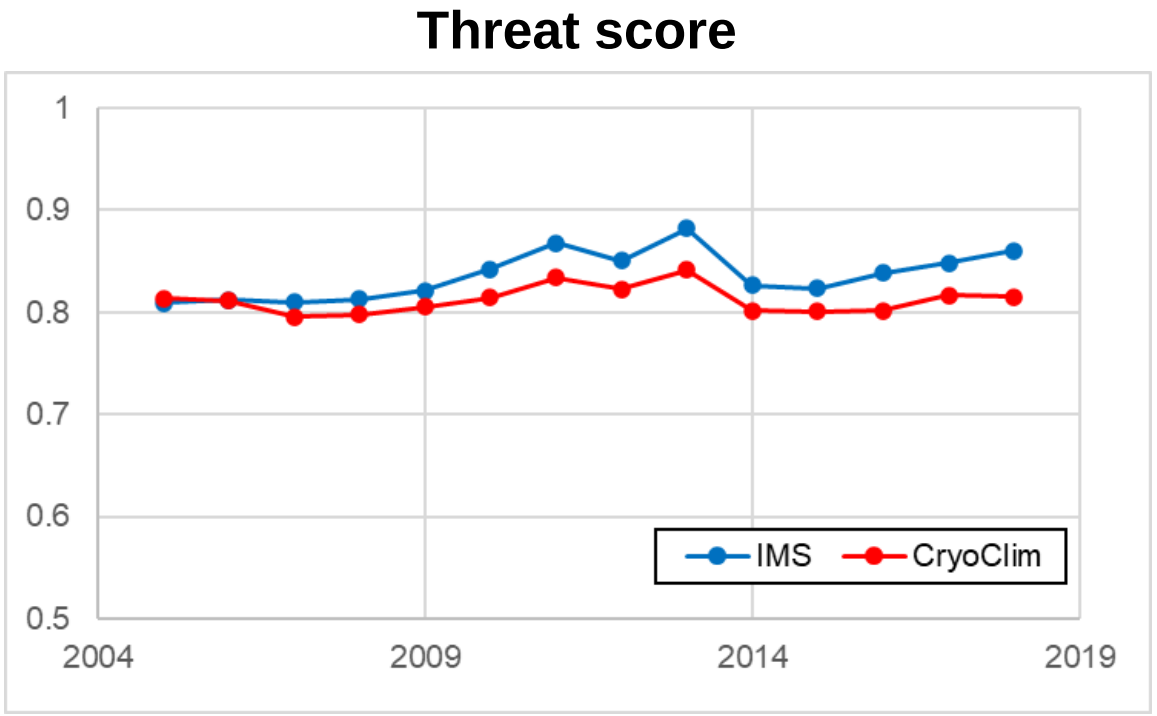


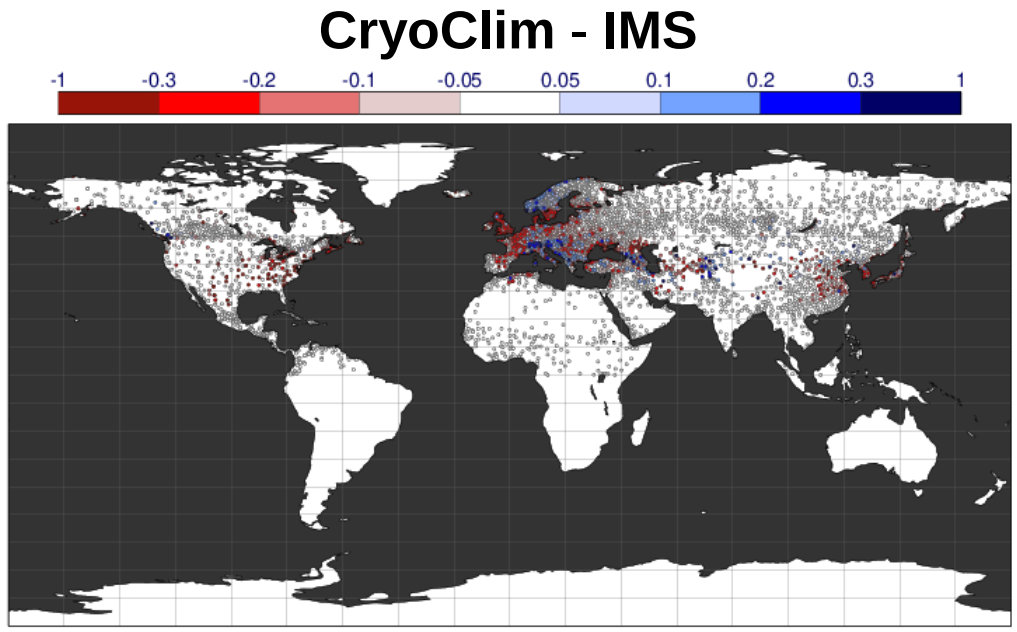
CryoClim has good quality,
but IMS is better than CryoClim

	In situ observed (**SD ≥ 1cm**)	In situ observed (**SD < 1cm**)
Snow-covered (**SCF ≥ 50%**)	a Hit	b False alarm
Snow-free (**SCF < 50%**)	c Miss	d Correct no snow

Threat score = a / (a+b+c)

Validation of IMS and CryoClim after some modifications





- Change a threshold for snow-covered/snow-free from 50% to 30% in CryoClim
- Mask snow-free areas if SCF_{clim} > 80% and $SCF_{CryoClim}$ < 30%

  ⇨ More consistent with IMS and better threat score, but the difference still seen after 2010

Experiment settings

Thanks to Dinand!

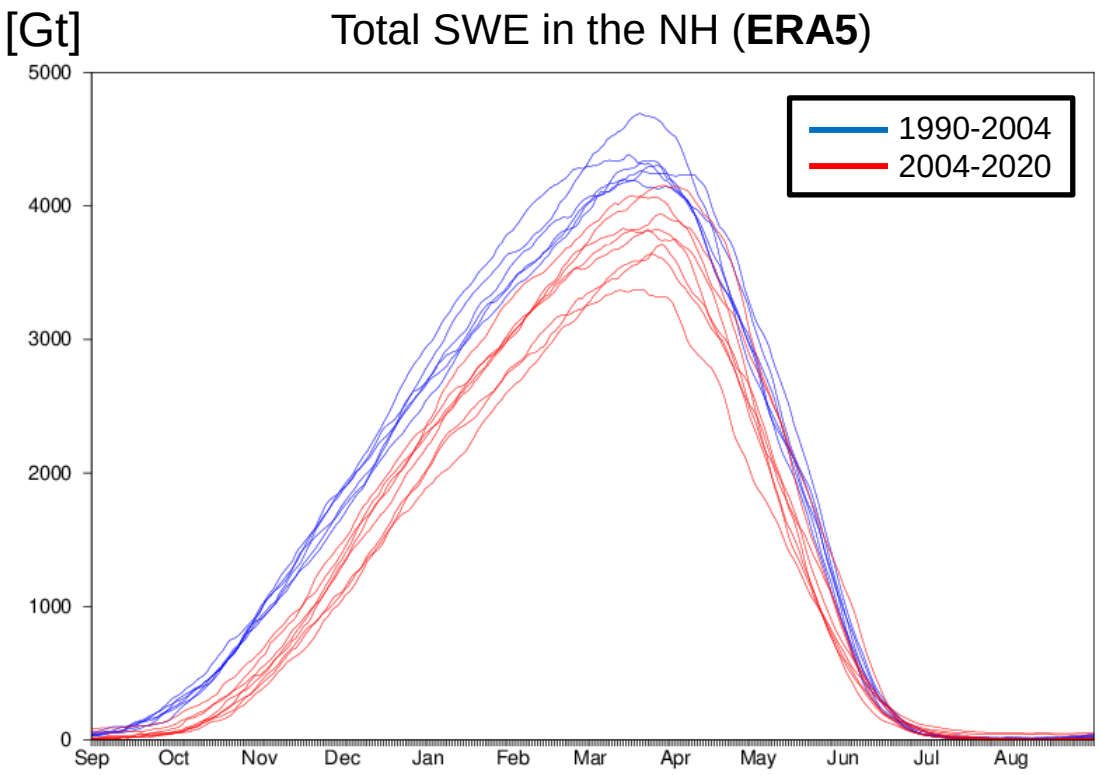
- **Branches**: based on the CY48R1.1 for ERA6 development
  - Including the revised snow DA in CY49R1, upper limit of snow depth for the entire field
- **Exp type**: Stand-alone Surface Analysis only (without atmospheric 4D-Var) at TCo319
- **Period**: Sep 1968 to Aug 2020 (52 years / 13 streams)

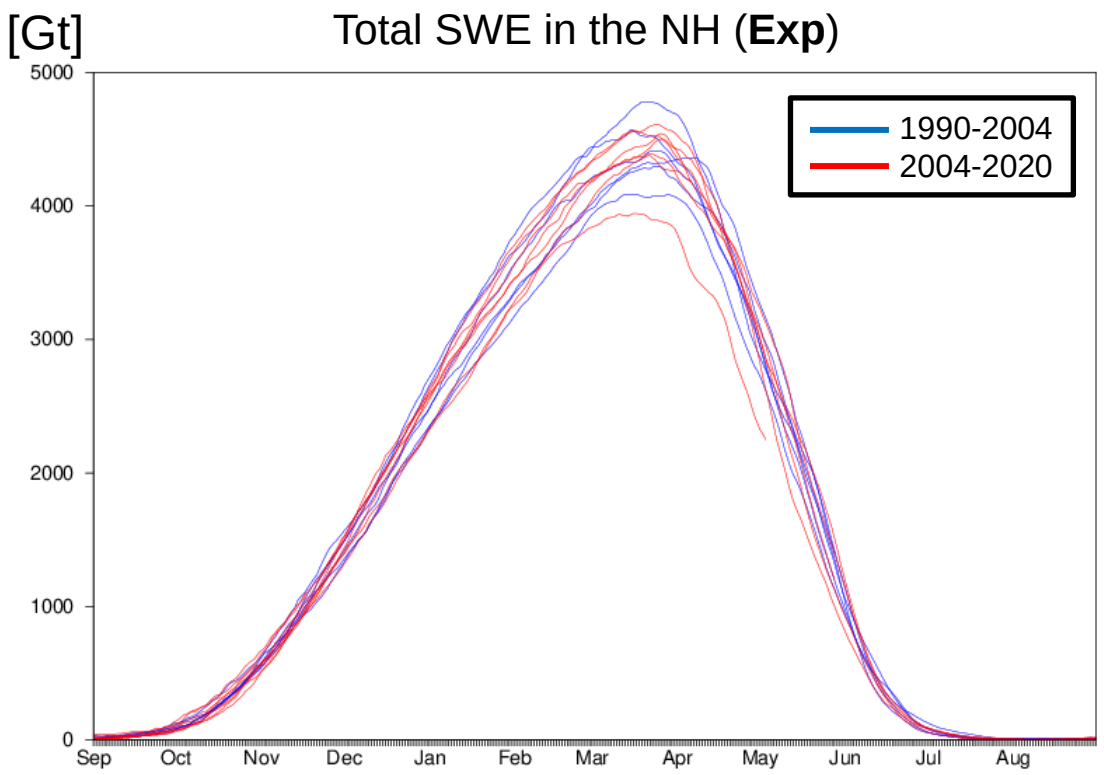
Thanks to Marijana and Peter Lean!

- The CryoClim data was converted from NetCDF to BUFR, then ODB

- Some modifications for CryoClim to be more consistent with IMS
  - Use the snow cover in the NH from 1987 (switch to IMS in 2010)
  - Assimilate binary information of snow-covered/snow-free: the threshold = 30%
  - Climatological QC: reject the snow cover if $SCF_{clim} > 80\%$ and $SCF_{CryoClim} < 30\%$

Time series of SWE in the NH for 1990-2020

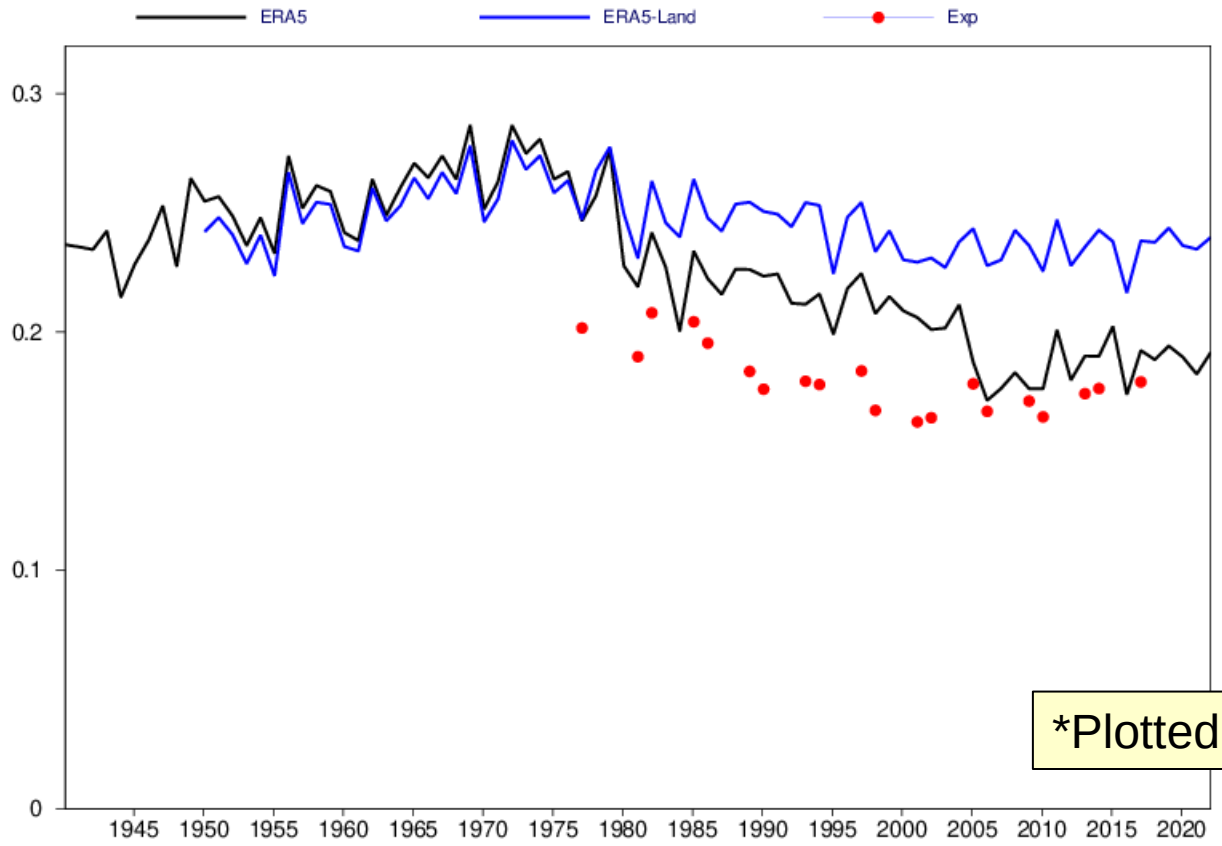




*Plotted from 40% of the experiment

- Looks no gap between before and after 2004 in the experiment

Time series of monthly averaged snow depth in February



*Plotted from 40% of the experiment

- So far, more consistent for a longer period by using the CryoClim snow cover (**Exp**)
  - The multi-layer snow scheme in CY48R1 also contributes to reduction of positive biases

Summary

- **ERA5 has several issues on consistency of the snow analysis**
  - Several gaps in 1970's, 2004 and 2014/15

- **More consistent for longer years by the ESA CCI Snow CryoClim**
  - Contributions from not only DA but the multi-layer snow scheme
  - Will be implemented in ERA6 → Possible to be much more improved than ERA5

- **Future prospects**
  - Possible to provide snow monitoring?
    - Climate Bulletins
    - WMO GCW snow tracker

Other work on snow data assimilation in 2 years

- **Snow QC for fresh snow and SYNOP in China**
  - Implemented in the CY47R3 operational system in Feb 2023
- **Snow fixes in the CY48R1 e-suite**: excessive snow and missing observations
  - with Gabriele, Patricia, Tomas Kral and many others
- **The offline land DA system for extended-range, SEAS6 and ERA6-Land**
  - Implemented snow analysis and worked a bit on real-time system for SEAS6
  - David and Ewan are working hard on the real-time system now
- **The SNOTEL assimilation**: Patricia will continue the experiment
- **Snow analysis in the SEKF towards a unified land DA system**
  - Now possible to assimilate the 2D-OI analysed snow depth in the SEKF

Special thanks to everyone in ECMWF, especially to Coupled Assimilation Team!
I had a great time with you!

Windermere in the Lake District