



The Danish Meteorological Institute

Added values with the regional atmospheric reanalyses

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with materials contributed by

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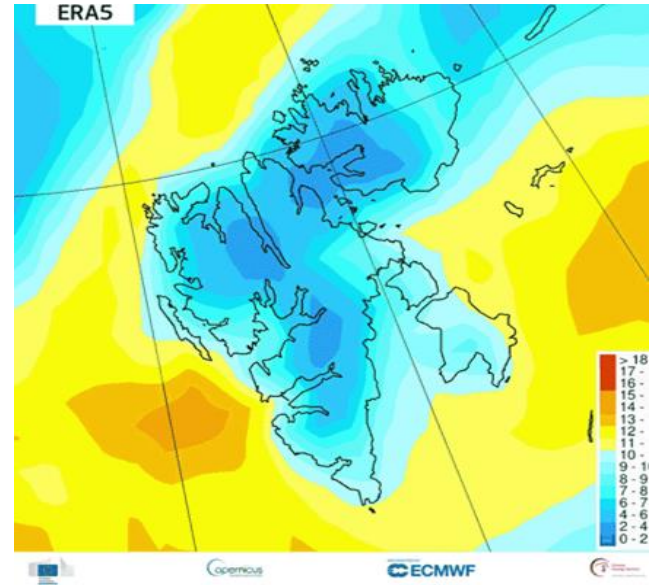
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Carlos Peralta Aros, DMI

&

Copernicus CARRA team

DMI DANRA team



Xiaohua Yang, Nordic Meteorologists Meeting 2022, Helsingki, 15 June 2022



Outlines

- **Harmonie-NWP based reanalyses**
 - CARRA and DANRA
- **Where comes the added values**
 - Added values with regional NWP
 - High fidelity climate reanalysis
- **Further findings**
 - Is LAM intrinsically inferior to global model for large scale properties?
 - Is hydrostatics approximation still acceptable at 2.5 km grid resolution?
 - Cases with analysis bust
- **Outlooks**



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Harmonie-based regional reanalysis

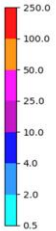
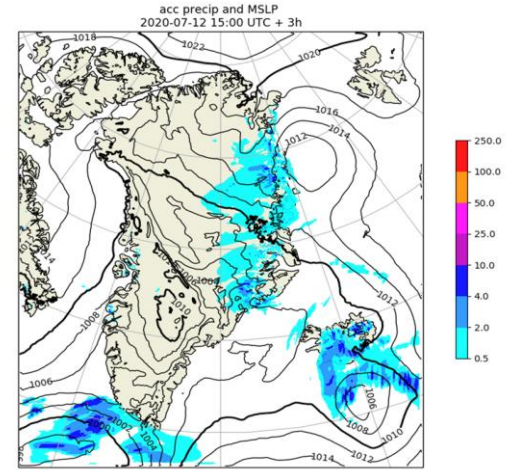
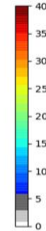
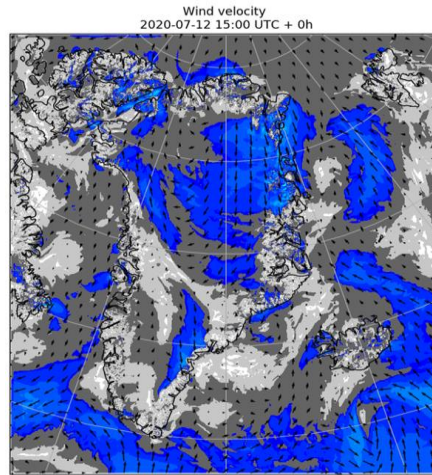
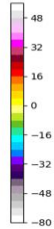
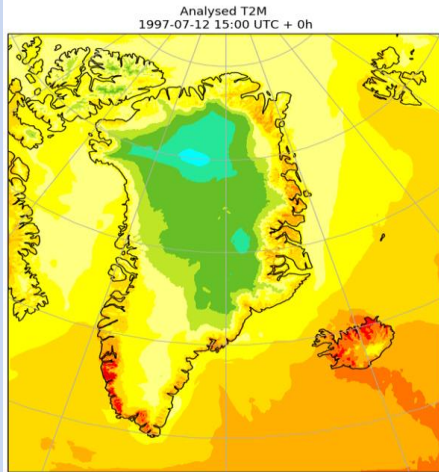
Xiaohua Yang, Nordic Meteorologists Meeting 2022, Helsinki, 15 June 2022



Climate
Change

Climate reanalysis: past weather hour by hour

- Gridded climate dataset produced by state of art weather model and data assimilation
- fixed model version + maximum utilisation of observation: high fidelity dataset
- combination of assimilation and forecast with focus on analysis and short range



temperature on 12 July each
year (note the warm 2012)

Reanalysis provides gap-free, high fidelity, gridded and coherent climate time series



Norwegian
Meteorological
Institute

ECMWF Copernicus
Europe's eyes on Earth



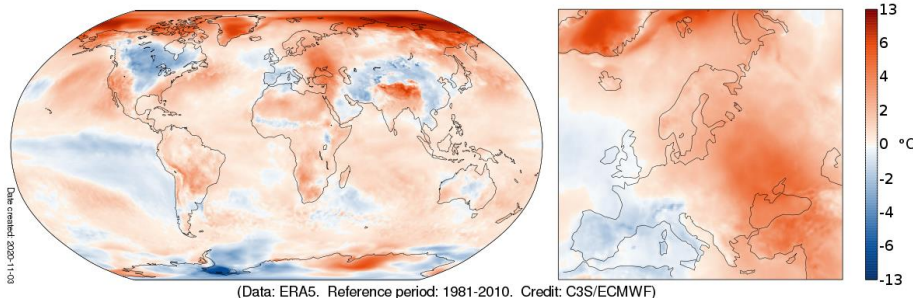


Climate
Change

C3S global and regional reanalyses for the Arctic region

ERA5: Global reanalysis

Surface air temperature anomaly for October 2020



Available in the CDS (> 35,000 users): @ 25 (31 native) km

Atmosphere, land, ocean waves.

- From **1979 to 5 days ago**
- Preliminary back extension (1950-1978) made available recently; for the Arctic the final release will be similar.

Conducted at ECMWF

CARRA: Arctic reanalysis



CARRA1: (red domains)

January 1991 – Dec 2021 @ 2.5km

Proof of concept: (grey domain)

1-year pan-Arctic reanalysis, Sep 2017/18 @ 3.75km

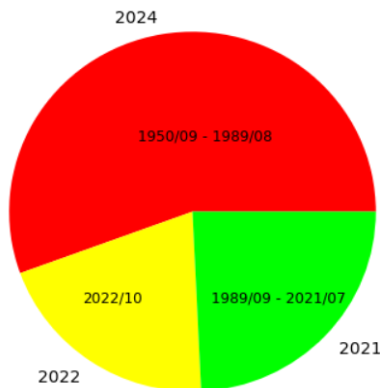
Met Norway, DMI, SMHI, FMI, IMO, Météo-France



DANish ReAnalysis (DANRA)

NCKF (Danish National Center for Climate Research) DANRA

- CARRA reanalysis-adapted
- lateral boundary conditions from ERA5
- maintain close to real time afterwards

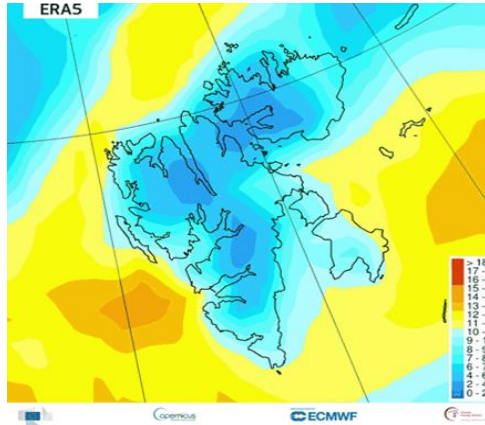


DANRA

2023, 30+ year DANRA 2.5 km (1991-2021)

2025, full 70-year DANRA 2.5 km (1951-2020)

Regional reanalyses, magnifying glasses to ERA5

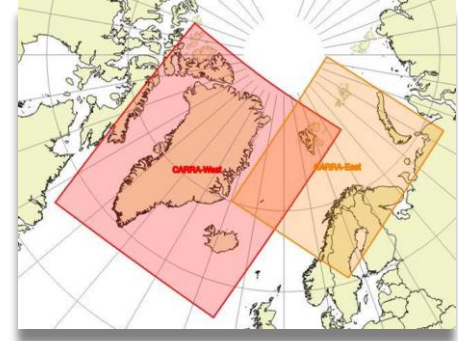


Global Reanalysis:

Copernicus ERA5, 31 km

Regional Reanalysis:

Copernicus CARRA, 2.5 km
DANRA, DMI, 2.5 km



Harmonie Climate Reanalysis System

Adapted from operational NWP Harmonie-arome

CY40

Using ERA5 hourly boundary

3-hourly 3DVAR assimilation with up to 30h fcst

Enhanced representation of high-resolution features through input data and improved surface modelling: local surface observation, satellites data, satellite **snow**, **glacier albedo**, high resolution sea states, and also improved **physiography**



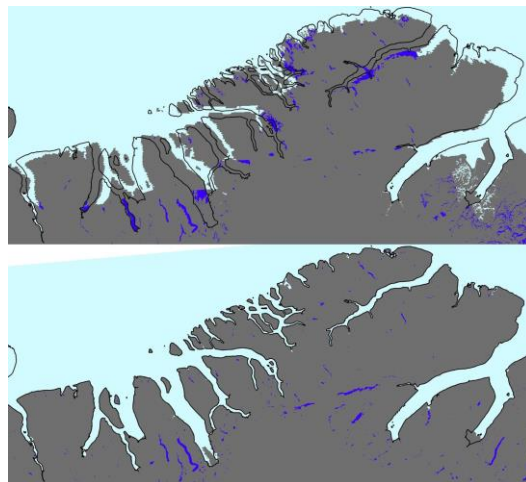
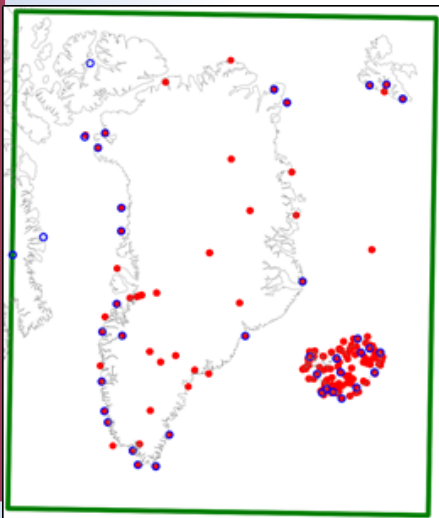


Enhanced surface representation: database and characteristics

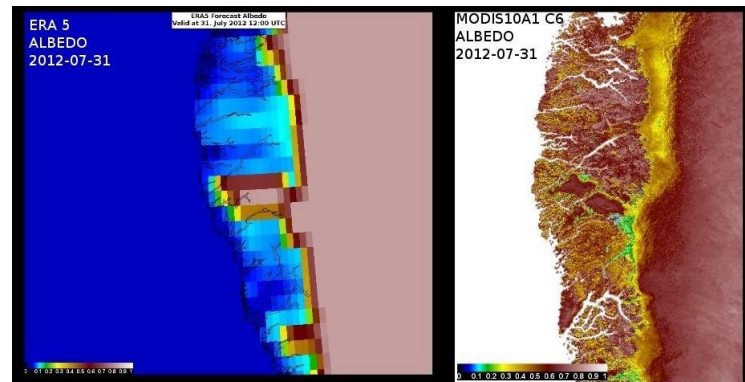
Example use of **local surface observation** archives available in the partner countries.

Blue: Obs in ERA5

Red: Extra local obs in CARRA (e.g. PROMICE, GC-NET, ASIAQ)



North Greenland physiography:
Upper: Uncorrected Ecoclimap
physiography
Lower: Corrected physiography
using sat. data.



West Greenland albedo representation:
Left: ERA5 glacier albedo
Right: Albedo derived from MODIS

Also use of 5 km resolution historical satellite (AVHRR) based data set for snow cover (CryoClim)



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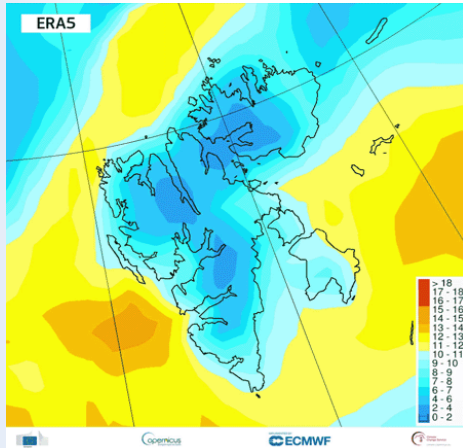
Manifestation of added values

Xiaohua Yang, Nordic Meteorologists Meeting 2022, Helsinki, 15 June 2022



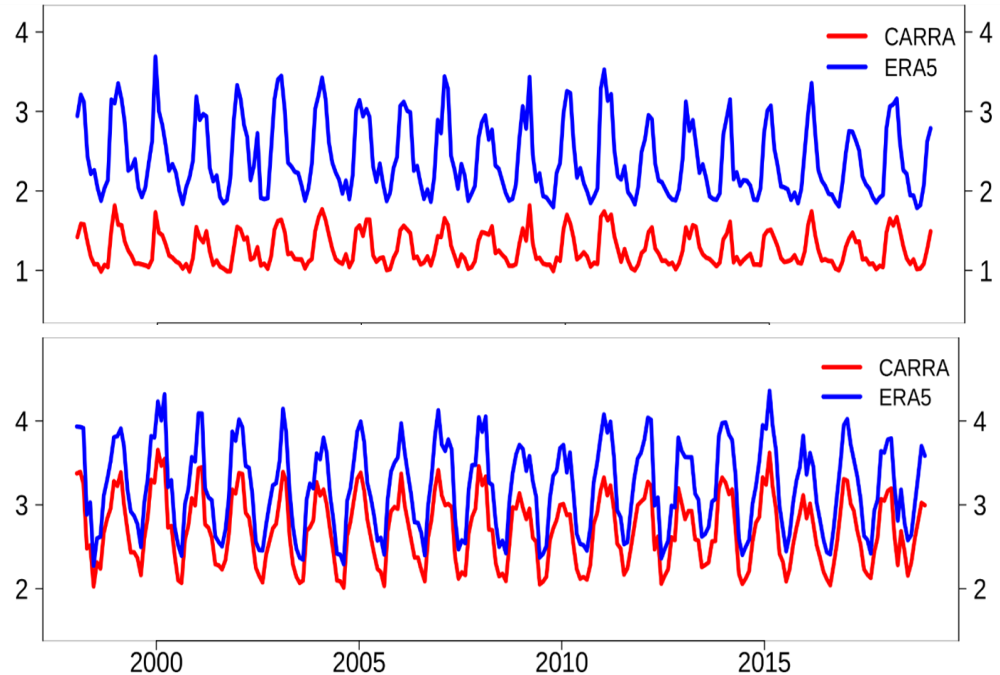
Climate
Change

General verification intercomparison clearly in favor of CARRA



Added values with the km-scale CARRA data

- higher data resolution
- improved fidelity for ECVs
- better representation of extreme features and small scale climatology



T2/W10 error time series for **CARRA** and **ERA5**.



Norwegian
Meteorological
Institute

ECMWF

Copernicus
Europe's eyes on Earth



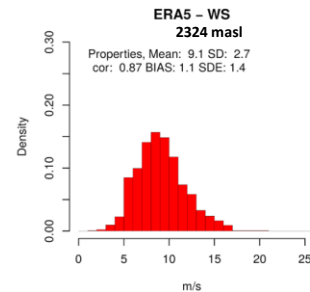
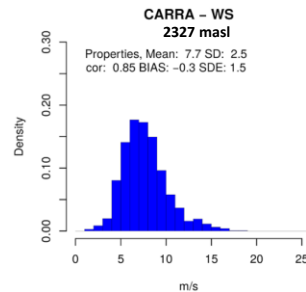
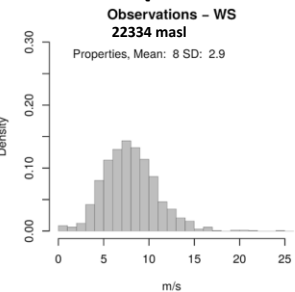
Overall climate statistics: DJF 10m wind speed

NASA-U (4443)

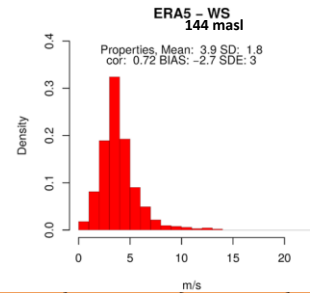
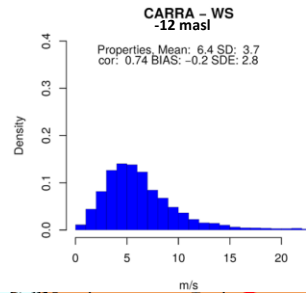
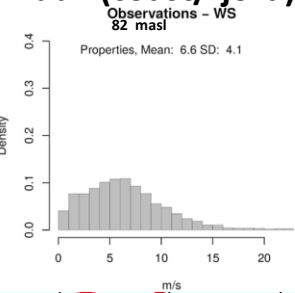
Nuuk
(4249)

Reykjavik
(4030)

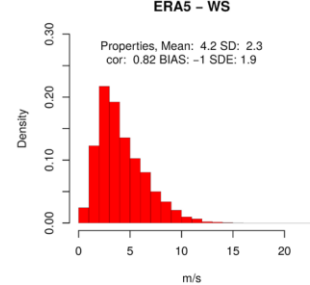
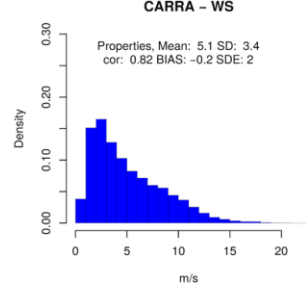
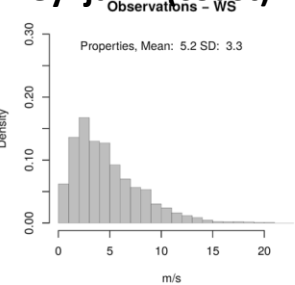
NASA-U (inland ice)



Nuuk (coast/fjord)

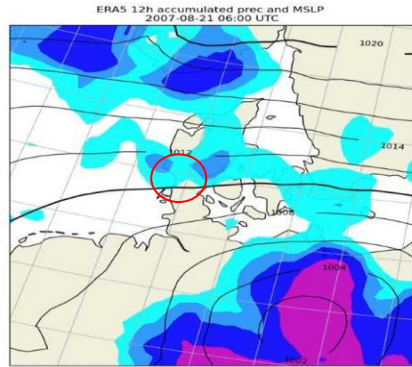
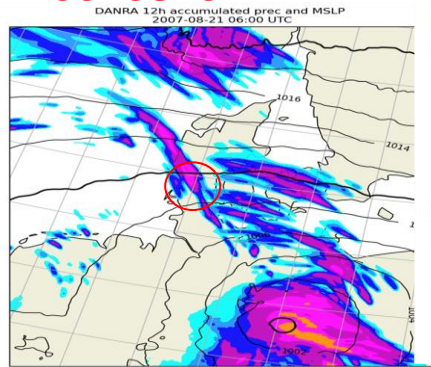


Reykjavik (coast)

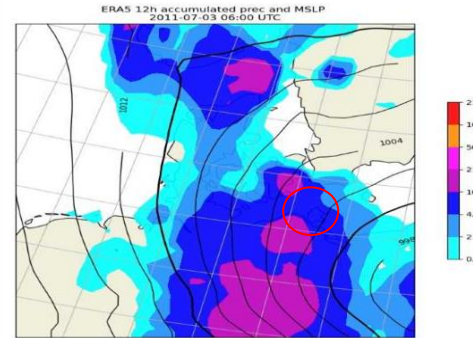
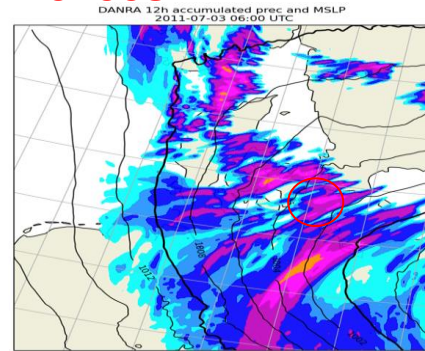


KM-scale reanalysis resolves major flashfloods

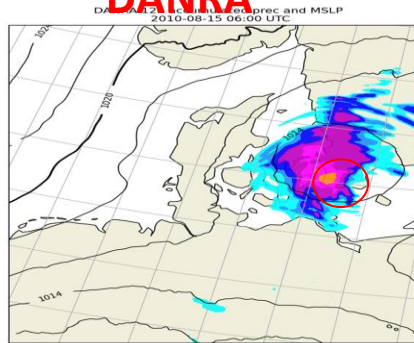
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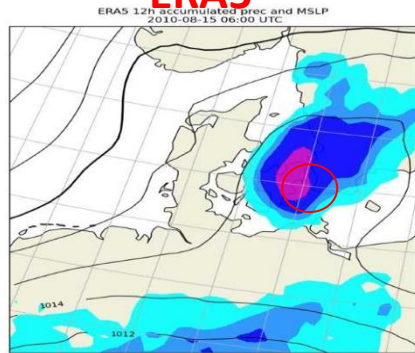
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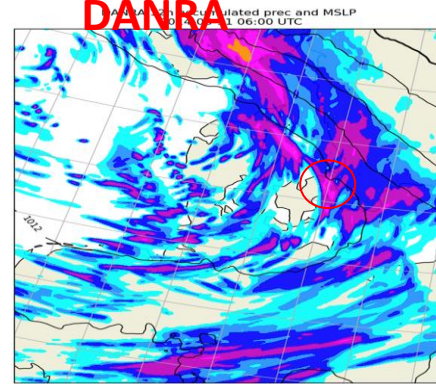
DANRA



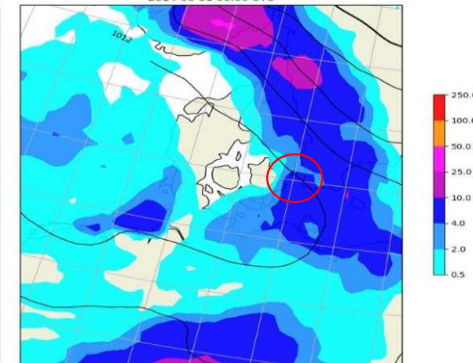
ERA5



DANRA



ERA5



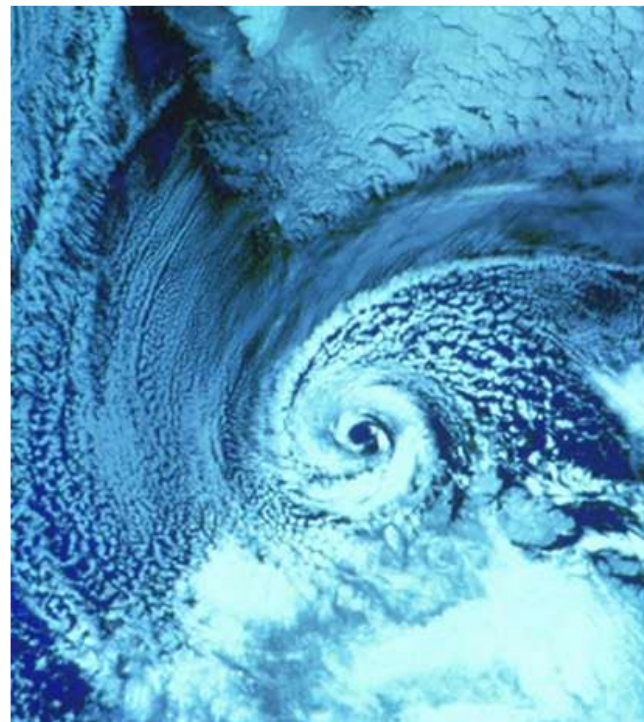
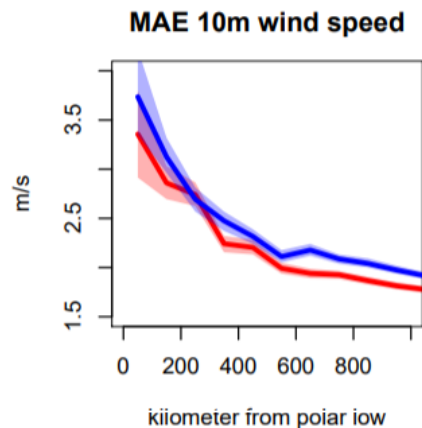
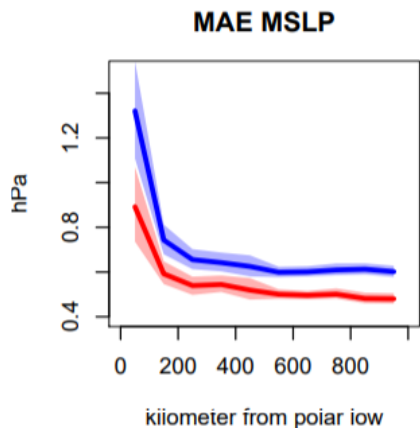
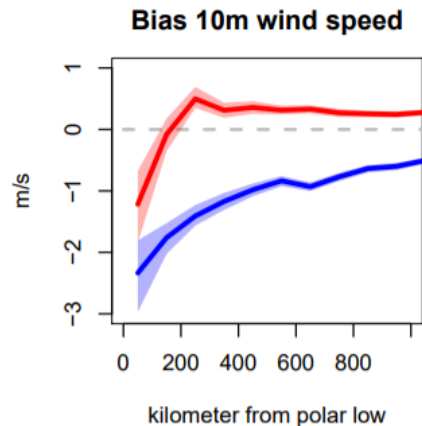
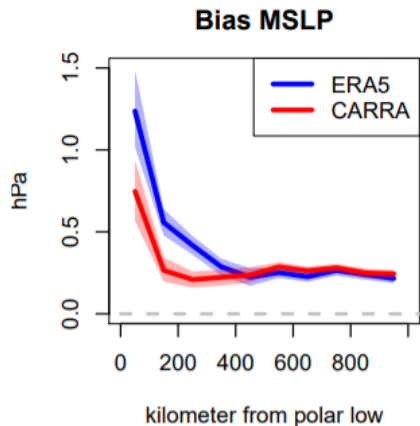
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20140830



Climate
Change

Polar lows 1999-2019



Data set: **Rojo, Maxence; Noer, Gunnar; Claud, Chantal (2019):** Polar Low tracks in the Norwegian Sea and the Barents Sea from 1999 until 2019. *PANGAEA*, <https://doi.org/10.1594/PANGAEA.903058>,



Better replica of historical Danish storms

Danish <u>category 4</u> storms	Wind Speed Maxima [m/s]		
	OBSERVED	DANRA	ERA5
1981-11-24	35.0	28.5	26.2
1983-01-18	31.4	27.4	23.2
1990-02-26	31.0	28.6	23.6
1991-01-09	33.0	29.9	24.5
1999-12-03	41.2	39.5	27.5
2013-10-28 "Alan"	38.0	33.7	23.6
2013-12-05 "Bodil"	31.4	31.2	25.8

Peak mean wind as observed and simulated in the Danish (DANRA) and global reanalysis (ERA5) for hurricane events in the last three decades.



Summary: Added values due to resolution, observations, model representations

Improved fidelity and capability manifested through

- case-to-case and near-surface quantities
- high-impact situations (polar lows/storms, convective events, winter warming events)
- local climate statistics in presence of physiographic features
- MSLP and large scale properties no exceptions!

Added value from combination of

- model set-ups which benefit from state of art operational configuration with experiences
- extended use of observations data in data assimilation including local data
- higher horizontal model resolution and enhanced description about forcing
 - physiography
 - sea surface temperature; sea ice
 - snow cover
 - glacier albedo



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Further findings

Xiaohua Yang, Nordic Meteorologists Meeting 2022, Helsinki, 15 June 2022



For years it has been a common experience that LAM models (HARMONIE...), while outperforming those of the global models (ECMWF) in screen level quantities (T2, W10m... ..) thanks to better resolved surfaces, the skill scores on 'large scale weather parameters' (surface pressure, upper air quantities) usually lag behind those of ECMWF.

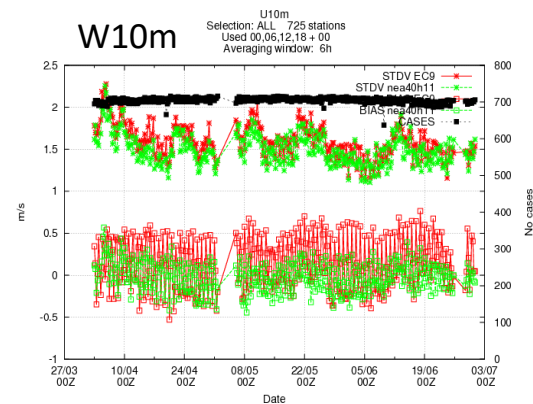
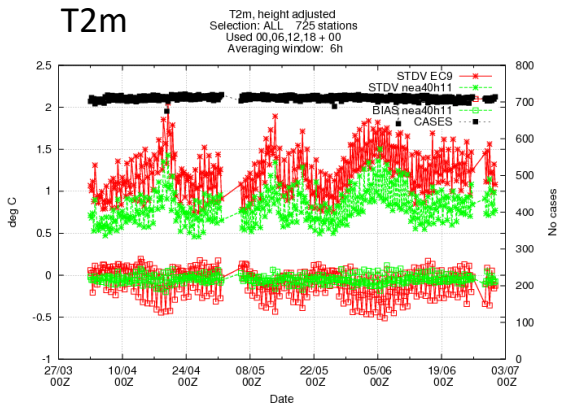
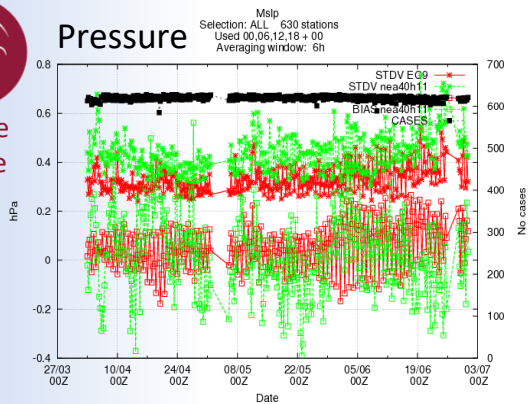
Why?

Shortcomings in data assimilation algorithm and capability??

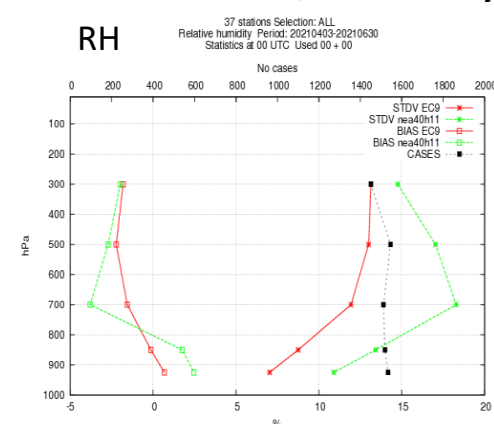
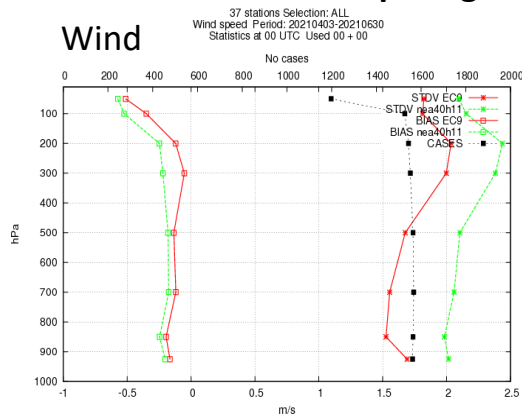
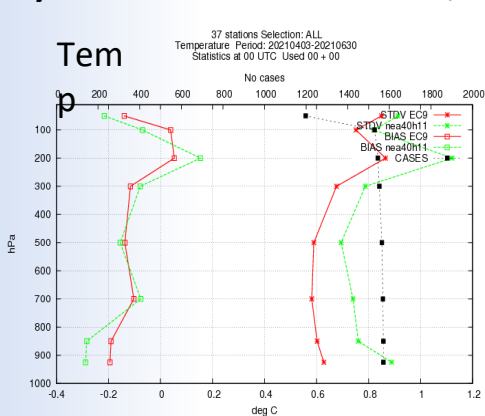
Limited model domain to take into account important observations outside??



Climate Change

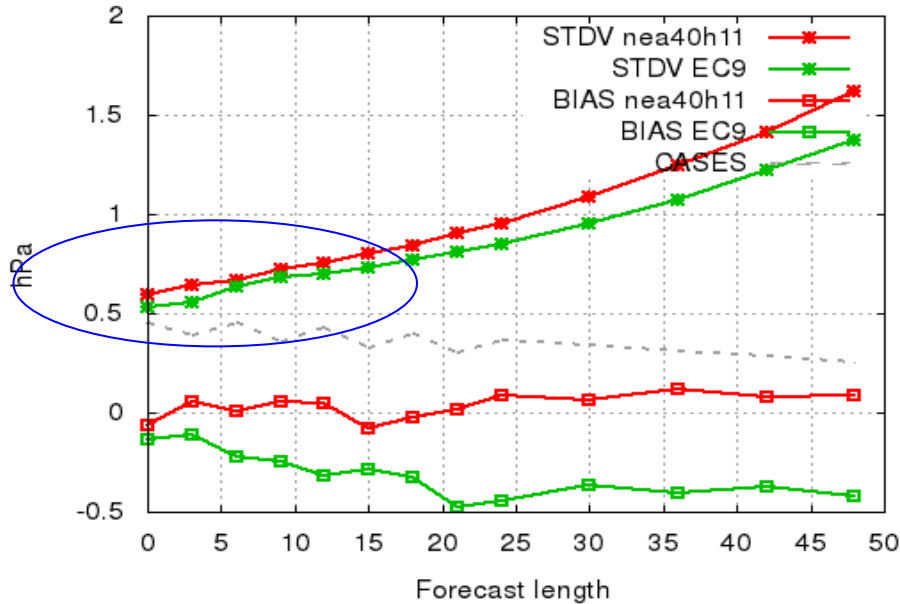


Daily error time series of MSLP, T2m and W10m forecasts comparing ECMWF and DMI-HARMONIE, March-May 2021



Averaged errors with T, W and RH along pressure levels ECMWF and DMI-HARMONIE, March-May 2021

Selection: ALL using 1168 stations
 Mslp Period: 20190128-20190226
 Hours: {00,06,12,18}



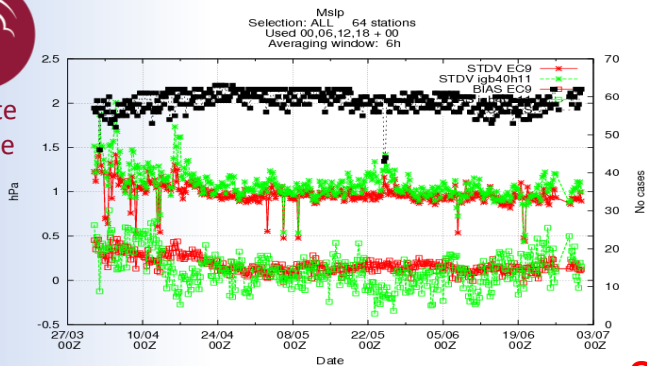
DMI-HARMONIE

ECMWF HRES

ECMWF HRES normally verifies better in MSLP than DMI-NEA. Note the latter is driven by a 6h older forecast. ECMWF-HRES delivers 3 to 9 h later than DMI-NEA. Taking into account delivery time, NEA could be better!!!
 Delivery time is a quality indicator.

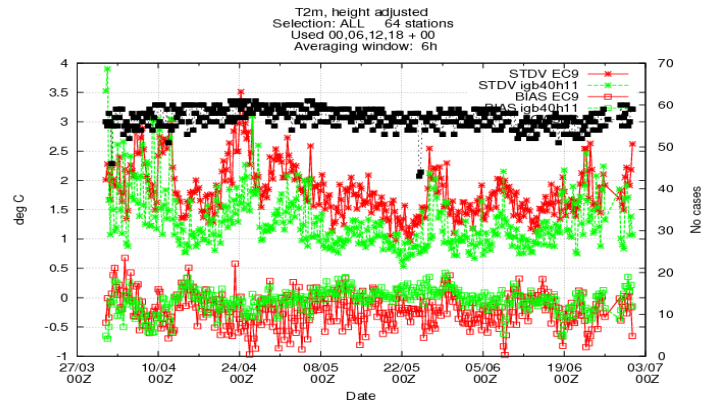


Climate Change

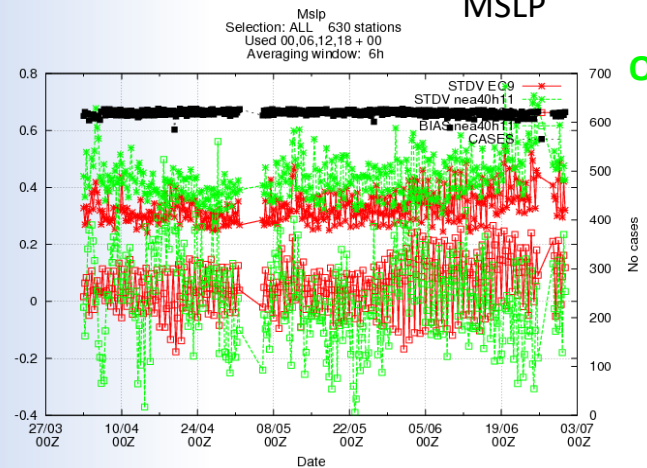


Greenland-Iceland

Operational ECMWF

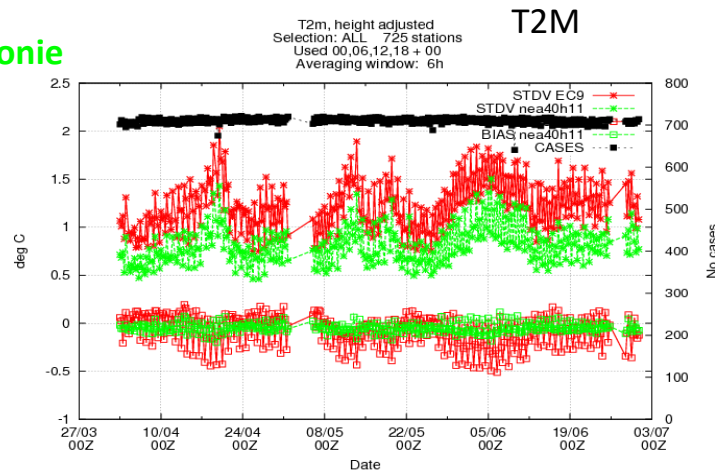


MSLP



Nordic stations

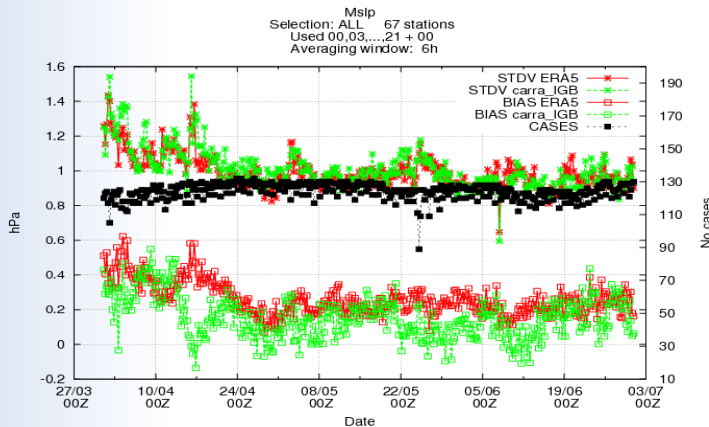
Operational DMI-Harmonie



March-May 2021

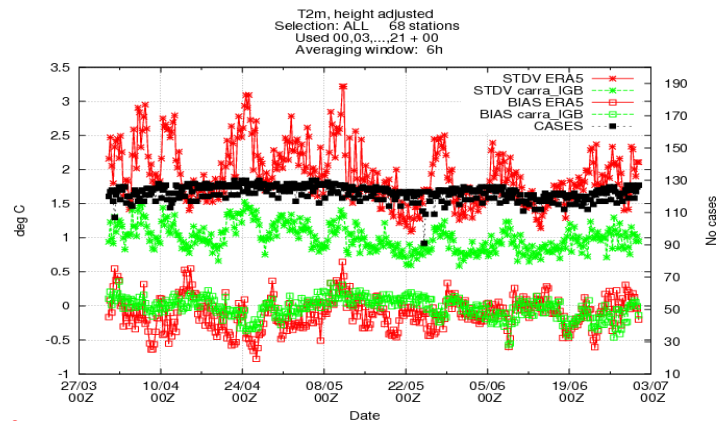


Climate Change



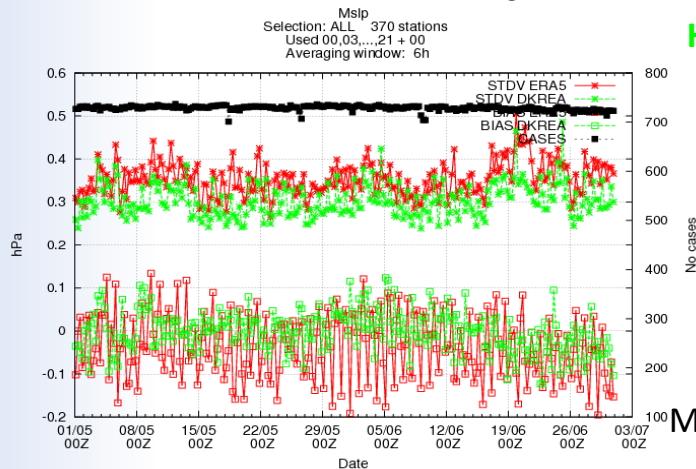
Greenland -Iceland

ERA5 reanalysis



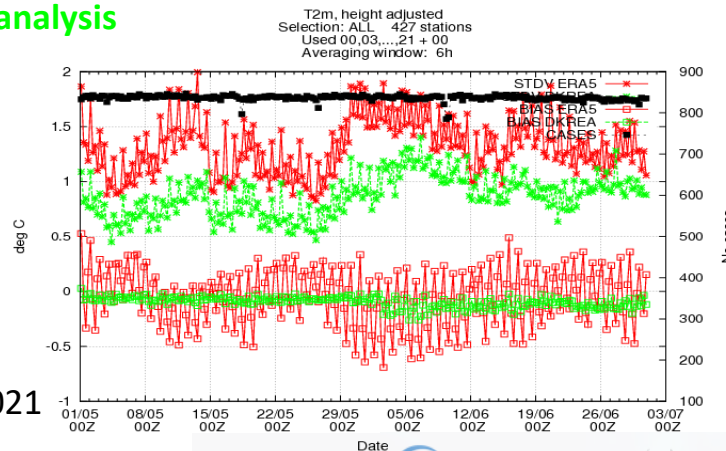
T2m

MSLP



Nordic stations

Harmonie reanalysis



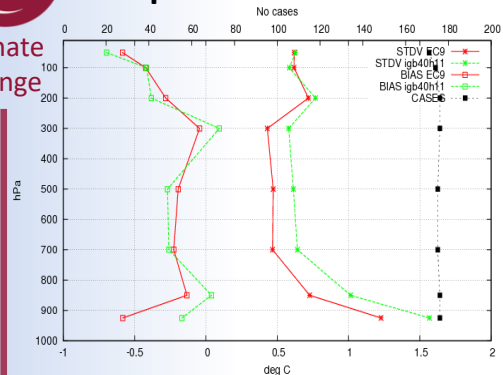
March-May 2021



Climate Change

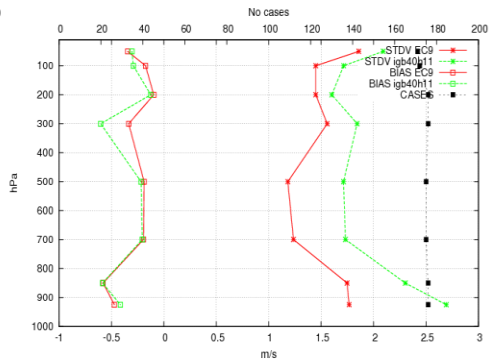
Temp

7 stations Selection: ALL
Temperature Period: 20210401-20210630
Statistics at 00 UTC Used 00 + 00



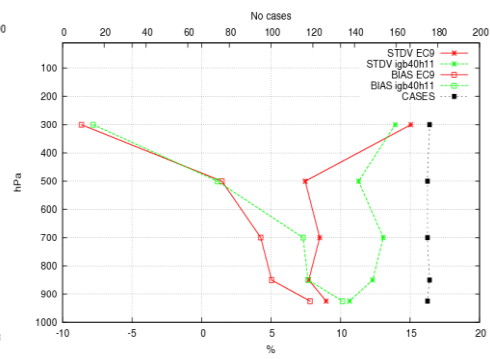
Wind

7 stations Selection: ALL
Wind speed Period: 20210401-20210630
Statistics at 00 UTC Used 00 + 00

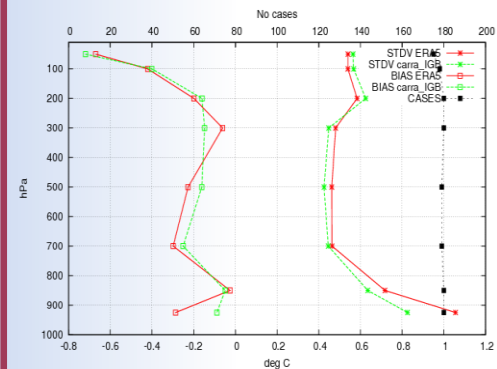


RH

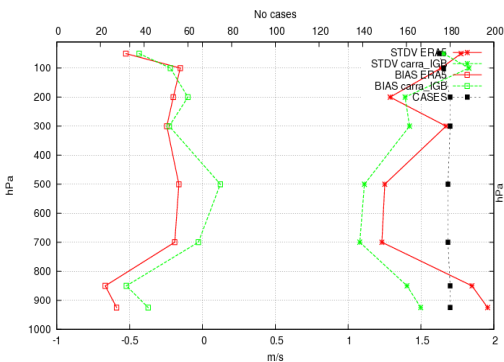
6 stations Selection: ALL
Relative humidity Period: 20210401-20210630
Statistics at 00 UTC Used 00 + 00



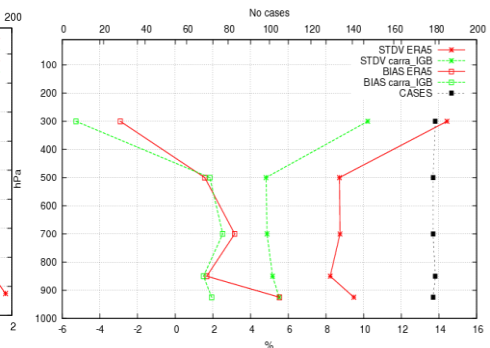
7 stations Selection: ALL
Temperature Period: 20210401-20210630
Statistics at 00 UTC Used 00 + 00



7 stations Selection: ALL
Wind speed Period: 20210401-20210630
Statistics at 00 UTC Used 00 + 00



6 stations Selection: ALL
Relative humidity Period: 20210401-20210630
Statistics at 00 UTC Used 00 + 00



Operational

Reanalyses

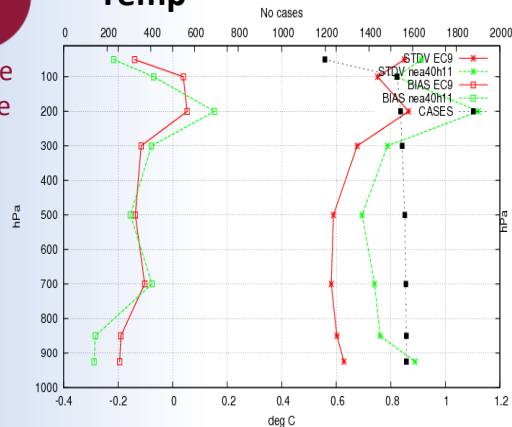
Greenland-Iceland stations, March-May 2021



Climate Change

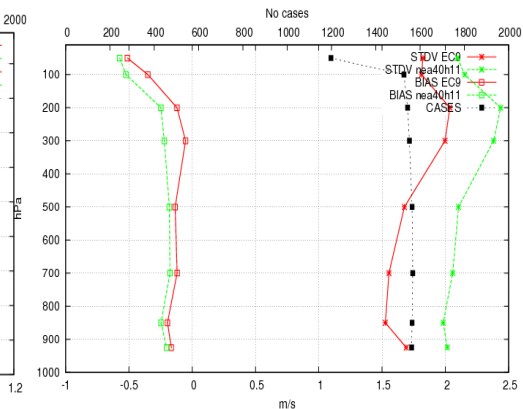
Temp

37 stations Selection: ALL
Temperature Period: 20210403-20210630
Statistics at 00 UTC Used 00 + 00



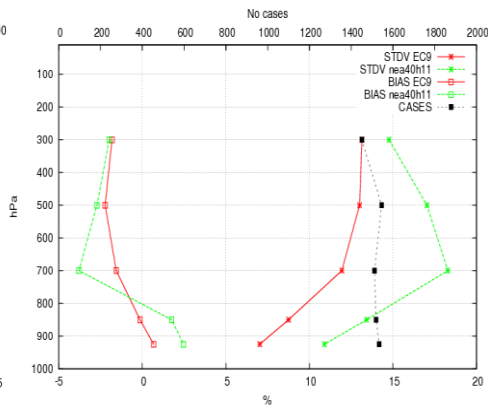
Wind

37 stations Selection: ALL
Wind speed Period: 20210403-20210630
Statistics at 00 UTC Used 00 + 00



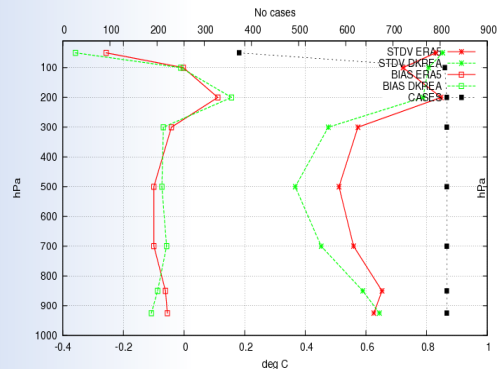
RH

37 stations Selection: ALL
Relative humidity Period: 20210403-20210630
Statistics at 00 UTC Used 00 + 00

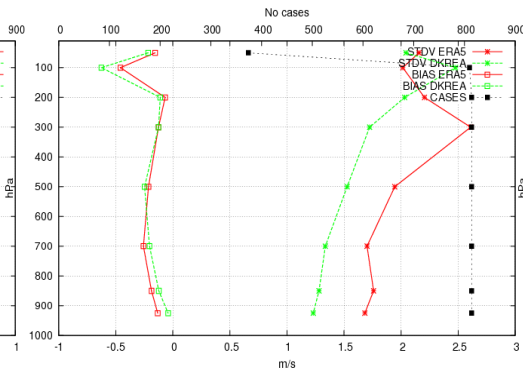


Operational

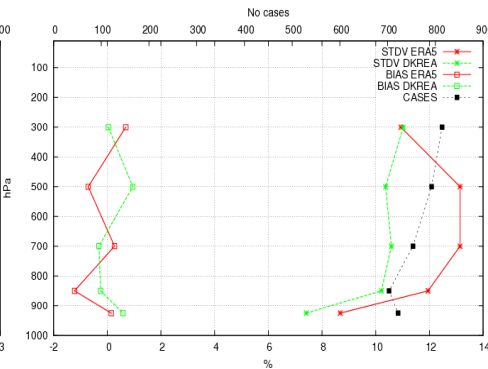
18 stations Selection: ALL
Temperature Period: 20210102-20210331
Statistics at 00 UTC Used 00 + 00



18 stations Selection: ALL
Wind speed Period: 20210102-20210331
Statistics at 00 UTC Used 00 + 00



18 stations Selection: ALL
Relative humidity Period: 20210102-20210331
Statistics at 00 UTC Used 00 + 00



Reanalyses

Nordic stations, March-May 2021



The Danish Meteorological Institute

For years it has been a common experience that LAM models (HARMONIE...), while outperforming those of the global models (ECMWF) in screen level quantities (T2, W10m... ..) due to better resolved surfaces, the skill scores on 'large scale weather parameters' (surface pressure, upper air quantities) usually lag behind those of ECMWF.

Why?

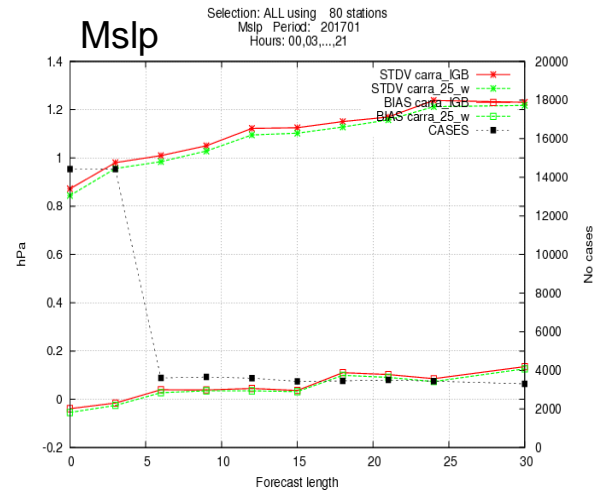
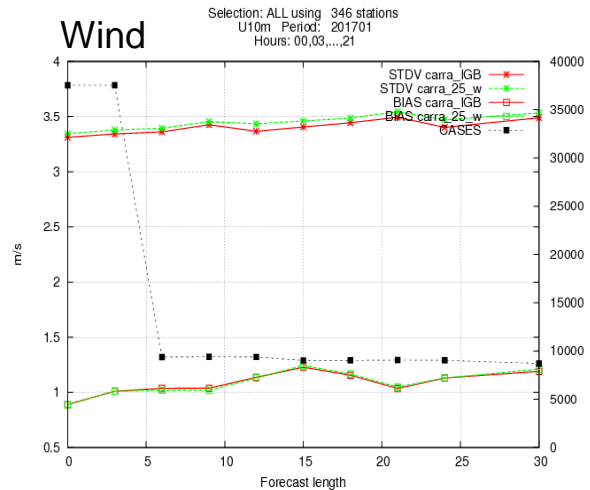
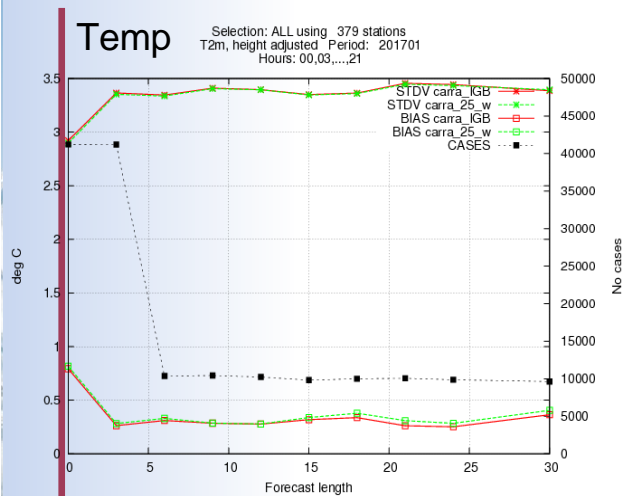
Actually, a quite fundamental deficiency in the LAM forecast is associated with time lagging of lateral forecast boundaries from global model (> 6h time lagging). *In reanalysis scenario, as the lateral boundary is with analysis, the deficiency is gone. LAM parameters for large scale become competitive!*

Thus, LAM model is not intrinsically inferior to global models on predictability of the large scale properties!



Climate
Change

nonhydrostatic effects at 2.5 km?



nonhydrostatic configuration vs **hydrostatic** configurations @ 2.5 km

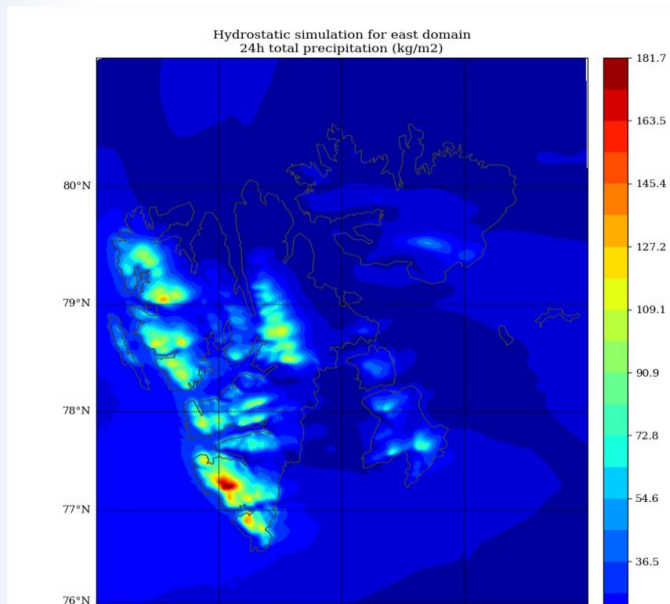




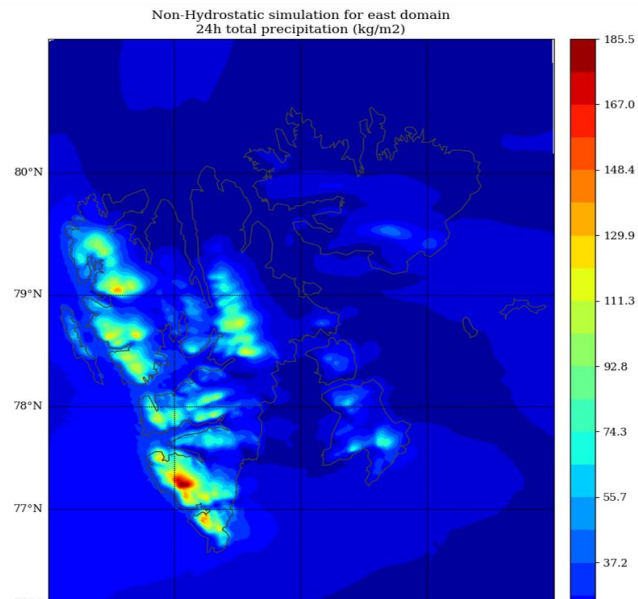
Climate
Change

nonhydrostatic effects at 2.5 km?

Hydrostatic



Non-Hydrostatic



CARRA-simulated extreme rainfall event in Svalbard Nov 8 2016, 06 UTC, 24h accumulated



Norwegian
Meteorological
Institute

ECMWF Copernicus
Europe's eyes on Earth

European
Commission



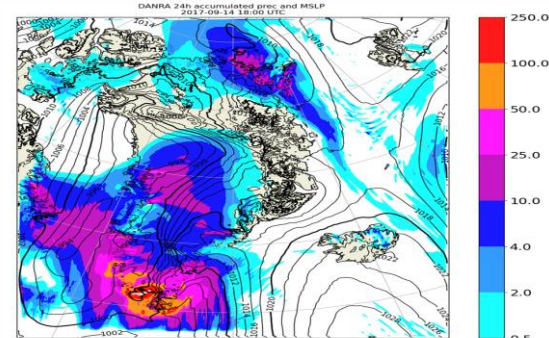
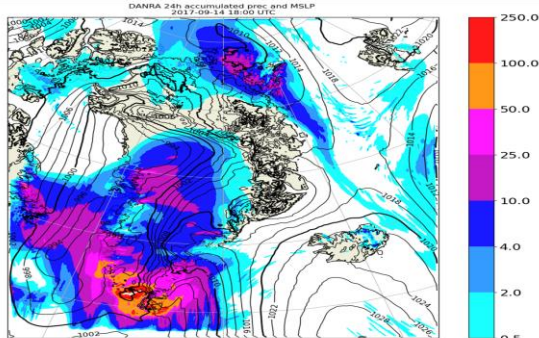
Climate
Change

nonhydrostatic effects at 2.5 km?

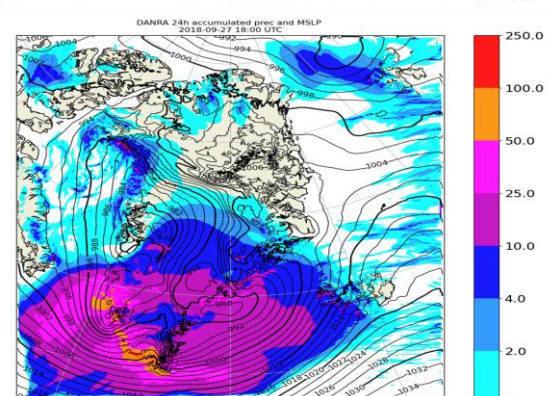
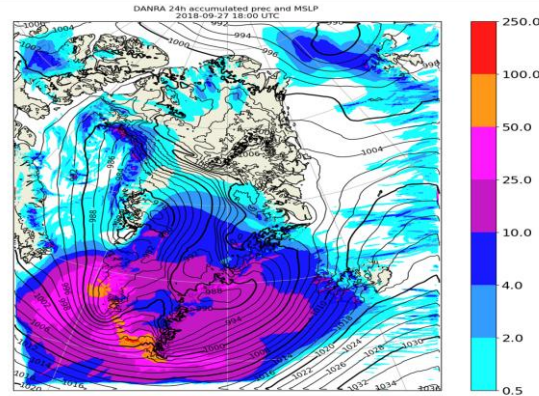
Hydrostatic

Non-Hydrostatic

20170913



20180927



CARRA simulated extreme rainfall events in south Greenland, 24h accumulated



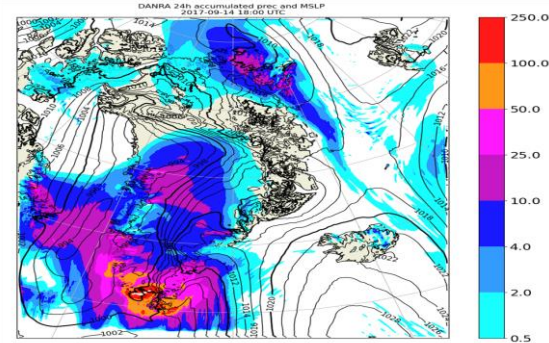
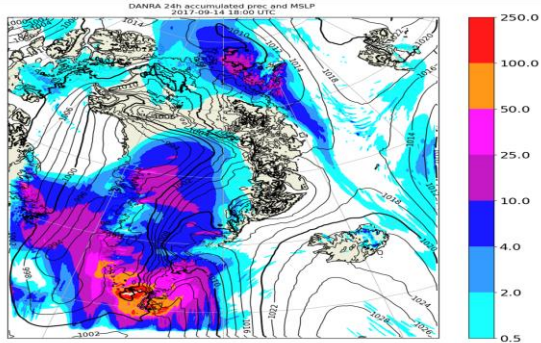
Climate
Change

nonhydrostatic effects at 2.5 km?

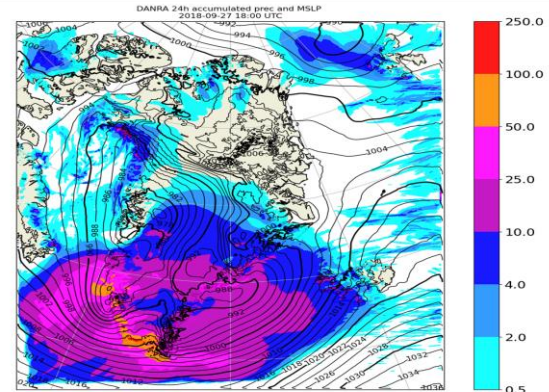
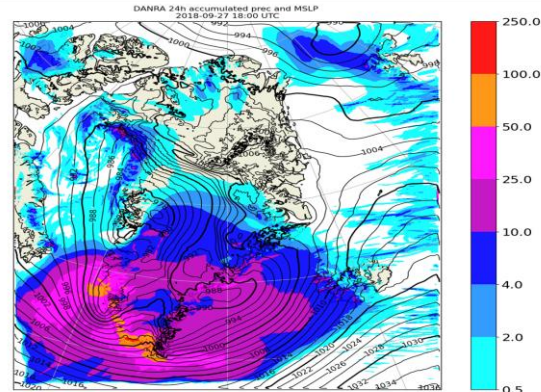
Hydrostatic

Non-Hydrostatic

20170913



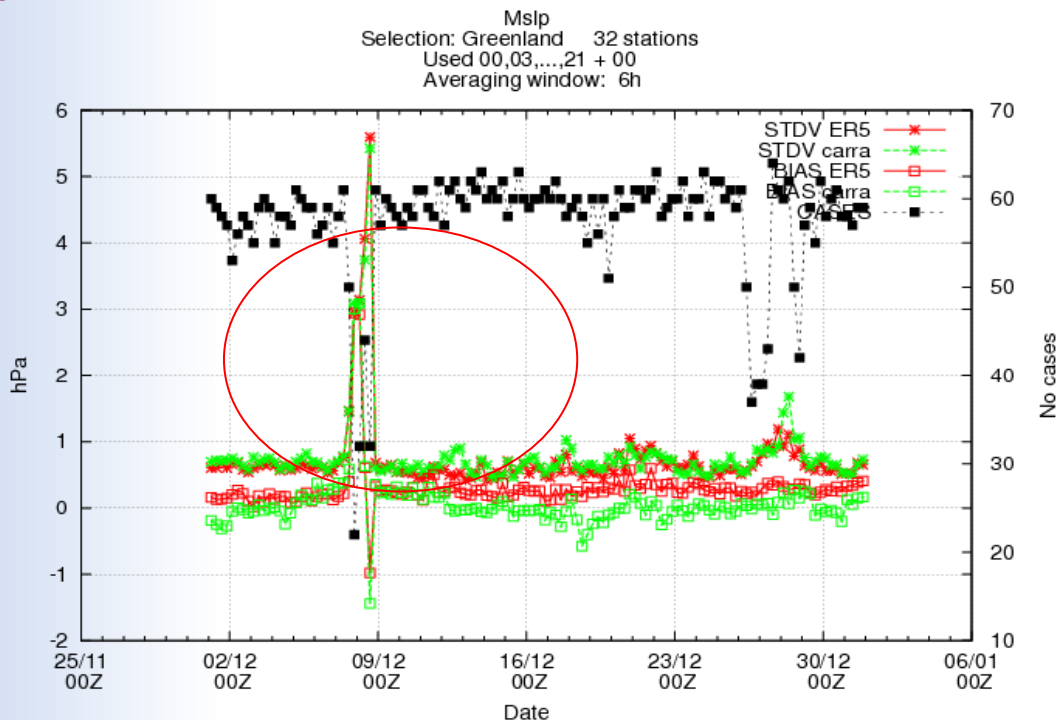
20180927



at 2.5 km, a nonhydrostatic configuration does not appear to add value to hydrostatic!



Known deficiency: analysis bust cases



CARRA data series contain occasionally cases with large deviation to the verifying observations for key parameters (analysis bust cases), where substantial amount of good observation data got rejected due to large model error.

Future phase of CARRA reanalyses shall hopefully improve



Outlook: CARRA2, DANRA-70

DANRA-30 year will be extended to 70 years by 2025.

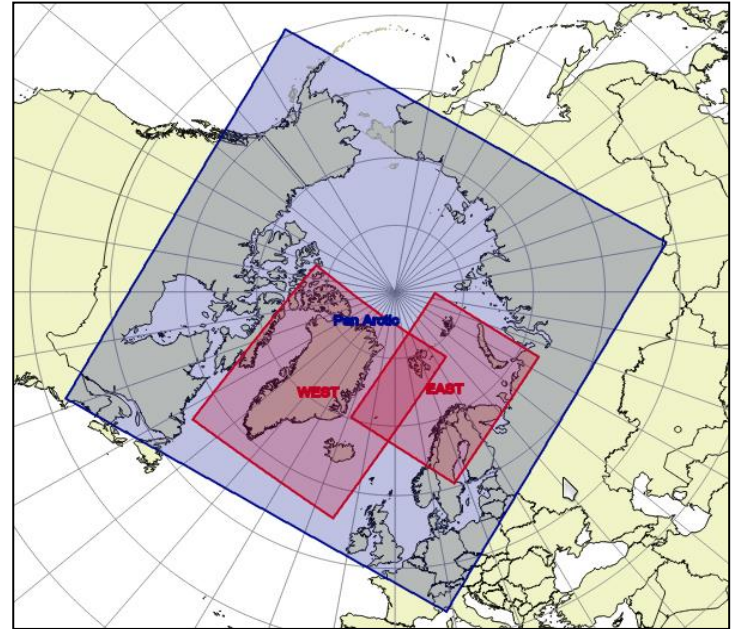
In response to C3S call for next generation Arctic reanalysis, a CARRA2 configuration is currently in preparation, which is for an extended Pan-arctic domain.

Likely configuration

- 2.5 km resolution on Pan-arctic domain
- Possibly an extended reanalysis period with 40+ years
- statistical means produced along production
- Significant updates in surface scheme

Projected production start early 2024, to be complete in 2026

User feedback welcome!





Climate
Change

Where can I get the data?

CARRA

C3S web page, including links to *Climate Data Store* download pages:

<https://climate.copernicus.eu/copernicus-arctic-regional-reanalysis-service>

DANRA

<https://dmidk.github.io/danra-docs/fields.html>

Arctic regional reanalysis on single levels from 1991 to present

WARNING: Variable "surface roughness" is incorrect and should not be used. For traceability and transparency reasons it remains available. Be careful when using the wind component variables - they are pointing to the local grid directions and not to the geographic east-west or north-south directions.

Overview Download data Documentation

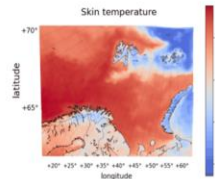
The C3S Arctic Regional Reanalysis (CARRA) dataset contains 3-hourly analyses and hourly short term forecasts of atmospheric and surface meteorological variables (surface and near-surface temperature, surface and top of atmosphere fluxes, precipitation, cloud, humidity, wind, pressure, snow and sea variables) at 2.5 km resolution. Additionally, forecasts up to 30 hours initialised from the analyses at 00 and 12 UTC are available.

The dataset includes two domains. The West domain covers Greenland, the Labrador Sea, Davis Strait, Baffin Bay, Denmark Strait, Iceland, Jan Mayen, the Greenland Sea, and parts of Svalbard. The East domain covers Svalbard, Franz Josef Land, Novaya Zemlya, Barents Sea, and the Northern parts of the Norwegian Sea and Scandinavia.

The dataset has been produced with the use of the HARMONIE-AROME state-of-the-art non-hydrostatic regional numerical weather prediction model. High resolution reanalysis for the Arctic region is particularly important because the climate change is more pronounced in the Arctic region than elsewhere in the Earth. This fact calls for a better description of this region providing additional details with respect to the global reanalyses (ERA5 for instance). The additional information is provided by the higher horizontal resolution, more local observations (from the Nordic countries and Greenland), better description of surface characteristics (high resolution satellite and physiographic data), high resolution non-hydrostatic dynamics and improved physical parameterisation of clouds and precipitation in particular.

The inputs to CARRA reanalysis are the observations, the ERA5 global reanalysis as lateral boundary conditions and the physiographic datasets describing the surface characteristics of the model. The observation values and information about their quality are used together to constrain the reanalysis where observations are available and provide information for the data assimilation system in areas in where less observations are available.

More details about the reanalysis dataset and the extensive input data are given in the Documentation section.



Contact

ECMWF Support Portal *x*

Licence

Licence to use Copernicus Products

Publication date

2020-03-10

Related data

Arctic regional reanalysis on height levels from 1991 to present

Arctic regional reanalysis on model levels from 1991 to present

Arctic regional reanalysis on pressure levels from 1991 to present

DATA DESCRIPTION

Data type Gridset





The Danish Meteorological Institute

Thank you!

Xiaohua Yang, Nordic Meteorologists Meeting 2022, Helsingki, 15 June 2022