Model process-based evaluation using high-frequency multi-variate observations at the Arctic and Antarctic supersites during the Year of Polar Prediction: the YOPPsiteMIP

Barbara Casati, Gunilla Svensson, Jonathan Day, Taneil Uttal, Oystein Godoy, Zen Mariani, Jason Milbrandt, Gabrielle Gascon, Morten Koltzow, ...
**NWP process-based evaluation** against high frequency multivariate observations **at the YOPP super-sites.**

Leads: Gunilla Svensson (U Stockholm), Barbara Casati (ECCC)

**Arctic and Antarctic supersites:**
have suites of instruments, using both direct and remote techniques (such as lidars, radars, ceilometers, radiometers), that provide detailed measurements of the vertical column of the atmosphere as well as the surface conditions and energy fluxes.

**NWP model output:**
are archived at high frequency (~ minutes) for a beam of grid-points surrounding the super-site location (20km radius), for the physical variables supported by the observations at the site.

**Target processes include:**
the representation of (surface and upper-air) energy and momentum fluxes; the closure of the radiation budget, turbulence and energy balance; cloud micro- and macro-physics (vertical profiles of water vapor, liquid and ice water content); aerosols and hydro-meteors micro-physics.

[Canadian Autonomous Arctic Aerosol Lidar – Iqaluit ECCC supersite (photo courtesy of Daniel Coulombe)]
The Arctic supersites include the International Arctic Systems for Observing the Atmosphere (IASOA, https://www.esrl.noaa.gov/psd/iasoa/dataataglance) stations at Barrow, Oliktok Point, Eureka, Alert, Summit, Ny-Ålesund-Zeppelin, Pallas-Sodankylä, Tiksi, Cherskii, Baranova, as well as the ECCC sites Iqaluit and Whitehorse (ecpass.ca).

The Antarctic supersites include Alexander Tall Tower, Casey, Davis, Dome-C, Dumont D'Urville, Halley IV, King Sejong, Georg Von Neumayer, Mawson, Syowa, Jang Bogo, Amundsen-Scott / South Pole, Byrd, Rothera, Vostok, McMurdo / Scott base, Troll.

These sites span the diversity in climatology and topography found in the polar areas and thus represent a variety of challenges for NWP systems.
The IASOA Merged Observatory Data Files (MODF)  Lead: Taneil Uttal (IASOA, NOAA)

IASOA: www.IASOA.org
Consortium of scientists that work with measurements made at observatories that encircle the Arctic Ocean

IASOA Data Portal: https://www.esrl.noaa.gov/psd/iasoa/dataataglance

MODF: in support to the YOPPsiteMIP, IASOA aims to provide a **unified file format**, with **standardized quality controls and data processing**, which **includes all measurements** at the IASOA observatories.

- Focus on Special Obs Periods (SOPs)
- Variables and time frequency (15’) align with YOPP NWP time-series model output
- Each variable will be processed consistently for all observatories, by a single individual/team
- Uncertainty estimates will be included
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Points to global network archives, developed for a narrow range of instruments and variables ...
Iqaluit super-site
(63.74N, 68.51W, 11 m)

- Radiosondes
- Airport Terminal
- City of Iqaluit
- Weather office
- Ka-Band weather radar
- Present weather detection
- Ceilometer
- Precipitation Imaging Package
- Doppler lidar
- Water vapour lidar
- CAAAL Raman water vapour lidar
- And 4 time-lapse cameras

Image courtesy of Zen Mariani
<table>
<thead>
<tr>
<th>Instrument and Manufacturer</th>
<th>Operation</th>
<th>Measurement(s)</th>
<th>Temporal and spatial resolution and range</th>
<th>Model output</th>
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<tr>
<td>Ka-Band Radar (METEK)</td>
<td>Pulsed dual-polarization Doppler Radar</td>
<td>Line-of-sight wind speed and direction; aerosol-hydrometeors (cloud and fog) backscatter; depolarization ratio (% ice versus water ratio); precipitation rate</td>
<td>10 min; vertical profile at 10 m res. up to 3-7 km a.g.l.; 15-25 km radius range</td>
<td>Vertical profiles of the horizontal and vertical wind components; cloud base height [weaker: opacity and thickness]; water vapor (specific humidity) and liquid-ice water profiles; microphysic hydrometeors (particles class, size and shape); precipitation rate.</td>
</tr>
<tr>
<td>Ceilometer (VAISALA)</td>
<td>Pulsed (8 kHz) diode laser Lidar</td>
<td>Cloud octa and height; cloud intensity (opacity and thickness), aerosol-hydrometeors (cloud) profiles; Mixing Layer Height</td>
<td>5 min; vertical profile at 5 m res. up to 7.5 km a.g.l.</td>
<td>Total / true cloud cover and cloud base height; [weaker: cloud opacity and thickness]; water vapor (specific humidity) and liquid-ice water profiles; microphysic hydrometeors; [weaker: Mixing Layer Height].</td>
</tr>
<tr>
<td>PWD 52 Visibility Sensor (VAISALA)</td>
<td>Forward-scatter measurement</td>
<td>Surface (1.5m) visibility, precipitation type, luminance</td>
<td>1 min; surface obs.</td>
<td>Visibility at the surface; precipitation types; surface downwards Short Wave (SW) radiation.</td>
</tr>
<tr>
<td>Doppler Lidar (HALO)</td>
<td>Pulsed (10 kHz) scanning at 1.5 µm (Mie scattering)</td>
<td>Line-of-sight wind speed and direction, aerosol-hydrometeors backscatter, depolarization ratio (% ice versus water ratio); precipitation rate</td>
<td>5 min; vertical profile at 3 m res. up to 4 km a.g.l.; 2-4 km radius range</td>
<td>Vertical profiles of the horizontal and vertical wind components; cloud base height [weaker: opacity and thickness]; water vapor (specific humidity) and liquid-ice water profiles; microphysic hydrometeors (particles class, size and shape); precipitation rate.</td>
</tr>
<tr>
<td>2nd Doppler Lidar (HALO), located 100 m a.g.l. 3km NE of the main site on top of a hill</td>
<td>Pulsed (10 kHz) scanning at 1.5 µm (Mie scattering)</td>
<td>Line-of-sight wind speed and direction, aerosol-hydrometeors backscatter, depolarization ratio (% ice versus water ratio); precipitation rate</td>
<td>5 min; vertical profile at 3 m res. up to 3-4 km a.g.l.; 5 km radius range</td>
<td>Vertical profiles of the horizontal and vertical wind components; cloud base height [weaker: opacity and thickness]; water vapor (specific humidity) and liquid-ice water profiles; microphysic hydrometeors (particles class, size and shape); precipitation rate.</td>
</tr>
<tr>
<td>Particle Imaging Probe (PIP) (NASA / Wallops)</td>
<td>Automated back-lit camera</td>
<td>Snowflake images</td>
<td>1 min; surface obs.</td>
<td>Precipitation type / microphysic hydrometeors: snow density, size, phase.</td>
</tr>
<tr>
<td>Surface meteorological observations (Miscellanea)</td>
<td>Temperature, relative humidity, wind, surface pressure, precipitation accumulation</td>
<td>1 min; surface obs.</td>
<td>Horizontal wind components, temperature, relative humidity, surface pressure, precipitation accumulation.</td>
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</tr>
<tr>
<td>Radiosondes (VAISALA)</td>
<td>temperature, relative humidity, wind, pressure</td>
<td>12 hours; vertical profile at 15 m res. up to 30 km a.g.l.</td>
<td>Vertical profiles of horizontal wind components, temperature, relative humidity, geopotential height.</td>
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</table>
## Iqaluit super-site (63.74N, 68.51W, 11 m)

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<tr>
<td>4k Pantilt Camera (Axis)</td>
<td>Automated pivoting camera, provides high-resolution images of the site in all directions</td>
<td>visibility, precipitation type, cloud cover</td>
<td>5 min; surface obs.</td>
<td>Surface visibility, precipitation type, total cloud cover.</td>
</tr>
<tr>
<td>Canadian Autonomous Arctic Aerosol Lidar (CAAAL) (ECCC)</td>
<td>355/532/1064 nm transmitter &amp; 6 ch. receiver</td>
<td>Temperature, relative humidity, pressure, water vapor mixing ratio; profiles of aerosols-hydrometeors (particle microphysics: phase-state, i.e. water vs ice, size &amp; shape).</td>
<td>1 min; vertical profile at 3 m res. up to 15 km a.g.l.</td>
<td>Temperature, Relative humidity, geopotential height, water vapour mixing ratio profiles; cloud base height [weaker: opacity and thickness]; liquid-ice water profiles; microphysic hydrometeors (particles class, size and shape).</td>
</tr>
<tr>
<td>Scintillometer (x2) (Scintec)</td>
<td>Large-aperture optical transmitter/receiver</td>
<td>Temperature, relative humidity, surface pressure; turbulence (structure parameter of refracted index fluctuation, structure parameter of temperature fluctuation, H-convection) and crosswind; sensible heat flux (W/m²)</td>
<td>5 min; max 6 km path length; surface obs.</td>
<td>Temperature, relative humidity, surface pressure; horizontal wind components; upward surface sensible heat flux.</td>
</tr>
<tr>
<td>Fog Measuring Device (FMD) (Droplet Measurement Technology)</td>
<td>Fog sensor</td>
<td>Fog intensity, water vapor</td>
<td>TBD; surface obs</td>
<td>Surface visibility; water vapor (screen level specific humidity)</td>
</tr>
<tr>
<td>Far-IR Radiometer (FIRR) (LR Tech)</td>
<td>Zenith/Nadir-viewing infrared radiometer</td>
<td>Long Wave (LW) downwards radiation (at surface), and cloud microphysics (thin ice cloud water structure)</td>
<td>10 min; NA – surface and profiles</td>
<td>Long Wave (LW) downward radiation (at surface); water vapor (specific humidity) and liquid-ice water profiles; microphysic hydrometeors; Effective Cloud Cover (partitioned for low, medium and high clouds).</td>
</tr>
<tr>
<td>Surface radiation fluxes (TBD)</td>
<td>Surface radiation sensors (diffuse and direct)</td>
<td>SW and LW upwards and downwards radiation</td>
<td>TBD ; surface obs.</td>
<td>SW and LW upwards and downwards radiation</td>
</tr>
<tr>
<td>Water Vapour Lidar (TBD)</td>
<td>Pulsed Lidar system</td>
<td>Temperature, relative humidity, pressure, water vapor mixing ratio; profiles of aerosols-hydrometeors (particle microphysics: phase-state, i.e. water vs ice, size &amp; shape)</td>
<td>TBD; vertical profiles</td>
<td>Temperature, relative humidity, geopotential height, water vapour mixing ratio profiles; cloud base height [weaker: opacity and thickness]; liquid-ice water profiles; microphysic hydrometeors (particles size, shape).</td>
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<tr>
<td>Category</td>
<td>Description</td>
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<tr>
<td>Upper-air atmospheric variables</td>
<td>Geo-potential height (m); temperature and dew point temperature (K); horizontal and vertical wind components (m/s); specific humidity (kg/kg); [(model parameters for the direct calculation of) Mixing Layer Height].</td>
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<tr>
<td>Cloud microphysics, hydrometeors vertical profiles</td>
<td>Water vapor and cloud liquid-ice water vertical profiles (kg m-3 between levels); [column-integrated liquid and ice water path and precipitable water vapour (kg m-2)]; prognostic microphysic variables (to obtain hydrometeors particles class and phase, size and shape, mass and concentration/density, number and average size per unit volume). For both liquid and solid phase: mixing ratio (kg/kg), concentration (# m-3), effective radius (m)</td>
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<tr>
<td>Clouds macrophysics</td>
<td>cloud fraction (at every level); [Total cloud cover (column-integrated cloud fraction)]; [cloud base height (m); cloud top height (m)]; cloud opacity and thickness (clouds optical properties): vertical profile [and column-integrated] liquid and ice optical depth; [effective cloud cover (TCC with optical depth)].</td>
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<tr>
<td>Surface atmospheric variables</td>
<td>Surface air pressure and Mean Sea Level pressure (Pa); surface skin temperature (K); 2m and 10m temperature and dew point temperature (K); 2m and 10m specific humidity (kg/kg); 2m and 10m wind speed and direction (m/s). Surface visibility (m). Precipitation type (drizzle, rain, snow, graupel, hail, freezing rain, ice pellets), precipitation rate (kg/m2/s) and accumulated precipitation (kg/m2).</td>
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<tr>
<td>Cryosphere, Surface properties</td>
<td>Snow depth (m); snow depth water equivalent (kg m-2); snow surface temperature (K); snow-layer profile temperature (K); Surface roughness for heat and momentum (m); type of soil and vegetation (if applicable); soil surface temperature (K), soil moisture (kg m-2); soil temperature profile (K) and soil moisture profile (kg m-3).</td>
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<tr>
<td>Radiation and energy and momentum fluxes</td>
<td>Surface and vertical profiles of down-ward / up-ward SW and LW radiation (W/m2); Top-of-Atmosphere incoming/outgoing SW and outgoing LW radiation (W/m2); [Surface albedo]. Vertical profiles of moisture, heat and momentum fluxes; surface upward latent and sensible heat flux (W/m2); gravity wave drag, orographic and turbulence surface stress (m2 s-2), [friction surface velocity (m s-1)].</td>
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<tr>
<td>Tendencies (total and due to advection)</td>
<td>Tendency of air temperature (K s-1); tendency of specific humidity (kg/kg s-1); tendency of (u and v components of the) momentum (m s-2).</td>
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</table>
The Canadian Arctic Prediction System (CAPS) supersite time series

12 Arctic supersites
The Canadian Arctic Prediction System (CAPS) supersite time series

Time series (every 7.5') for a **beam of grid-points** surrounding the super-sites: enable **neighbourhood** verification (e.g. spatio-timing errors by comparing time series); analysis of **representativeness** (e.g. local effects due to complex topography); ....
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YOPP ongoing projects: NWP process-based evaluation against high frequency multivariate observations at the YOPP super-sites.

Jonny Day and Linus Magnusson (ECMWF): Process Based Verification of EC-HIRES forecasts for Sodankyla (and other YOPP supersites): investigation of IFS winter warm bias; evaluation of vertical profiles of wind, temperature, humidity; coupled diagnostics (radiation, turbulent fluxes etc.) to evaluate multi-level snow scheme.


Morten Køltzow (MET Norway): Verification of AROME Arctic (2,5 km) and IFS HRES at Bjørnøya (74.5167N; 19.0050E).
Summary and Conclusions

- **Arctic and Antarctic observatories**, furnished by suites of instruments that provide detailed measurements characterizing the vertical column of the atmosphere as well as the surface conditions and energy fluxes.
  - IASOA merged observatory data files: what about the Antarctic?

- Modelling centres (ECMWF, ECCC, Meteo France, … ) are providing **NWP model output** at high frequency (on the order of model time-step) on model levels to enable comparison with the multitude of available measurements at the YOPP supersites (over the Antarctic too).

- This unique dataset of paired model output and multi-variate high-frequency observations enables detailed **process-based diagnostics**.
  - Open access via the YOPP data portal: [https://yopp.met.no/](https://yopp.met.no/)

- **Target processes** include the representation of cloud micro- and macro-physics; aerosols and hydro-meteors micro-physics; radiation, turbulence and energy budgets; energy and momentum fluxes.

- Wish to get involved? [barbara.casati@canada.ca](mailto:barbara.casati@canada.ca), [gunilla@misu.su.se](mailto:gunilla@misu.su.se)
Extras
Arctic Ocean Supersites

Ocean supersites were established in order to enable the analysis of ocean-cryosphere-atmosphere coupling processes.

**Supersites at fixed locations:**
- Chukchi Plateau: 165°W, 76°N (Sheba location)
- Arctic Mid-Ocean Ridge: 10°E, 85°N
- Canada Basin: 135°W, 81°N
- North Pole: 0°E, 90°N

**Supersites at changing locations:**
- research icebreaker Oden (expedition during summer 2018)
The Canadian Arctic Prediction System (CAPS)

- Coupled atmosphere ice ocean prediction system (CAPS – RIOPS)
- High Resolution: atmosphere ~ 3km, ice-ocean ~ 3-8 km
- 2 runs each day (00Z, 12Z), up to 48h lead time
- Atmosphere: GEM 4.8, improved microphysics, nested with 25km GDPS.
- Ocean-Ice: NEMO-CICE improved tides, land-fast ice, ice-ocean assimilation
- Open access: available at [http://dd.alpha.weather.gc.ca/yopp](http://dd.alpha.weather.gc.ca/yopp)