Polar NWP - Norwegian activities

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Mt. Lønahorgi, Norway, April 1961
Overview of talk

• What is special about NWP in the polar regions?
• The IPY-THORPEX-Norway project – The 2008 Andøya campaign
• Polar NWP at the Norwegian Met. Institute
• In-cloud icing and NWP
• Recommendations for future activities
Lessons from the past

- Fishermen knew how to interpret weather signs such as *cirrus uncinus*, a *halo*, changes in wind direction, etc.
- Polar Lows come more abruptly than synoptic-scale systems, often catching fishermen off guard.

30 fishermen from Andenes died at sea on 6 February 1821.
Thoughts about the future

- Oil and Gas Exploration
- New Shipping Lanes
- Tourism
- Climate Change
8 January 2010: A First-Ever Wintertime Polar Low North of Svalbard
### Forecast errors as a function of latitude

<table>
<thead>
<tr>
<th>Station</th>
<th>LAT</th>
<th>Mean error</th>
<th>STD</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ny Ålesund</td>
<td>78.9</td>
<td>0.6</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>Bjørnøya</td>
<td>74.5</td>
<td>0.5</td>
<td>1.4</td>
<td>1.5</td>
</tr>
<tr>
<td>Heidrun</td>
<td>65.3</td>
<td>0.2</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>Ekofisk</td>
<td>56.5</td>
<td>0.0</td>
<td>1.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

Error statistics for MSLP for selected SYNOP stations in the North Sea, Norwegian Sea and the Barents Sea in units of hPa. The table shows a composite of all forecast lengths from +18 to +42 hours with the Norwegian operational limited area model HIRLAM between 1 Jan 2010 and 30 Sept 2010.
Forecast error in ECMWF model

Jung & Leutbecher (2007: QJRMS)
The 2008 Andøya Campaign

Jón Egill Kristjánsson

Trygve Aspeli en, Idar Barstad, Gudmund Dalsbø, Andreas Dörnbrack, Ivan Føre, Emma Irvine, Trond Iversen, Erik Kolstad, Torsten Linders, Harold McInnes, Gunnar Noer, Thor Erik Nordeng, Roger Randriamampianina, Melvyn Shapiro, Thomas Spengler, Øyvind Sætra, Johannes Wagner

+ Norwegian Research Council
+ DLR
+ EUFAR
+ Cicero
+ Andøya Rocket Range
+ *******
The Field Campaign

- Base of operations: Andenes, Norway (69°N, 16°E)
- **DLR Falcon aircraft**: 56 flight hours; 150 dropsondes
- Coast Guard vessels: KV Senja, KV Svalbard
- Unmanned Aerial Vehicles (UAV) at Spitzbergen
- Additional radiosondes at Norwegian and Russian sites
- Drifting buoys
- Approximate cost: 1.2 M€
Polar Lows – NWP challenges:

• Small scale (~ $10^2$ km)
• Poor observational coverage in the Arctic
• How well are the physical processes represented in the models?

Polar Lows develop in marine cold-air outbreaks aided by an upper-level trigger
Sea Surface Temperatures and Altimeter Synergy (STARS)

- ESA funded project to investigate the potential of combining altimeter and SST observations from microwave and IR sensors during polar low events
- Building a database of relevant satellite data over a 5 year period
- Use the STARS database to investigate polar low climatology
- Use the STARS database to investigate the ocean response to polar low events

Polar low yearly frequency from STARS data
Falcon payload for IPY-THORPEX-Norway 2008

Dropsondes: \( u, v, P, T, q \)

Doppler lidar:
- Horizontal & vertical wind

DIAL:
- \( H_2O, \) Aerosols

\( u, v, w, TAS \)

\( T, P, q \)
3-4 MARCH 2008: POLAR LOW
Polar low in the Norwegian Sea 3 March 2008

1st flight
Polar low in the Norwegian Sea 3 March 2008
Polar low in the Norwegian Sea 4 March 2008
W-E sections at 11:40 UTC 3 March

Potential Temperature

Horizontal Wind Speed

Sloping frontal surface

Low-level jet of 27 m s$^{-1}$
SW-NE sections at 11 UTC 4 March

Relative Humidity

Potential Temperature

- Dry slot (eye of the PL)
- Warm air in the eye (descent?)

Kristjánsson et al. (2010: BAMS, submitted)
Pronounced **Warm Core** (Potential Temperature at 925 hPa)
16-17 MARCH 2008: POLAR LOW
Air Mass Transformation on 15 April

80.8°N, 2.5°E

Sharp surface inversion
Ground temperature: -30°C

79.9°N, 6.5°E

Well-mixed cloud-topped PBL
Ground temperature: -10°C
Air Mass Transformation on 15 April

79.9°N, 6.5°E

Well-mixed cloud-topped PBL
Ground temperature: -10°C

76.4°N, 9.0°E

Deep convection
Ground temperature: +3°C
36 h forecasts at 12 UTC 16 March

* indicates observed position
L indicates predicted position
The 16 March 2008 Polar Low

- The Polar Low developed overnight from 15 – 16 March
- Operational models had indicated a possible polar low development hundreds of km further SW

Kristjánsson et al. (2010: BAMS, submitted)
Is there a Reservoir of CAPE in Polar Low Environments?

- Suggested by Rasmussen (1979)
- Central to the Hypothesis of CISK as a Driving Mechanism for Polar Lows

- Counter-hypothesis: Instability Due to Heating from Below Rapidly Released
- Consistent with the WISHE Mechanism
CAPE and CIN from all PL dropsondes

- CAPE values always below 350 J kg$^{-1}$
- In most cases CAPE is below 100 J kg$^{-1}$

*Linders & Saetra (2010: J. Atmos. Sci.)*
Are Polar Lows “Arctic Hurricanes”? 

A weak sensitivity to SST is found

Linders, Saetra, Bracegirdle (2010: QJRMS, accepted)
Operational models at *met.no* covering *(parts)* of the Arctic: HIRLAM, UM and LAMEPS
HIRLAM
(hydrostatic model)

• **H12** (0.108°=12km, 864x698x60 gridpoints, Δt=300s) 3DVAR-FGAT analysis, ECMWF boundaries, runs 00/06/12/18 UTC to +66h.

• **H08** (0.072°=8km, 344x555x60 gridpoints, Δt=200s) 3DVAR-FGAT analysis, ECMWF boundaries, runs 00/06/12/18 UTC to +66h.

• **H04** (0.036°=4km, 300x500x60 gridpoints, Δt=100s) Surface analysis, otherwise initial condition and boundaries from H08. Runs 00/06/12 /18UTC to +66h.
The UNIFIED MODEL
(non-hydrostatic model)

• UM 4km
  covering same area as HIRLAM 4 km (mainland Norway)

• UM 4km for the Barents Sea
  UM 4km for the Barents Sea was set in production in December
  2007, mainly for the IPY (International Polar Year) 3 week
  campaign in February-March 2008. The model continued to run
  to support the forecasters in Northern Norway (VNN, Tromsø).
  Nested into Hirlam12 (as the grid is not covered by Hirlam8).
  Hirlam12 writes the necessary hourly model fields for a sub area
  covering the UM4 Barents grid.
  640*440*38 grid, currently running for 48 hours at 12utc only
NORLAMEPS, The Norwegian ensemble prediction system
A simple “multi” model, multi initial condition ensemble. 42 ensemble members [2 times (20+control)]

Two components:
1) Targeted EPS (TEPS) and Limited Area Model (HIRLAM) \rightarrow LAMEPS
2) NORLAMEPS=Combination of TEPS and LAMEPS
Model domains

1 LAMEPS (12 km grid spacing)
2 UMEPS-big (4 km grid)
3 UMEPS-small (4 km grid)
4 UMEPS-big (4 km grid)
Probability of severe winds
12 UTC 4 March (T+42)
Probability for precipitation
2.5 mm/3h; 0900-1200 UTC 4 March (T+39->T+42)

UMEPS-big (colour)
Radar observations (grey)

LAMEPS
Strike Probability Maps
Icing on Power Lines

Canada 1998
Millions without power

Germany 2005
250,000 homes without power
Icing event of 14 September 2005

Unexpected severe icing encountered by aircraft at 3000-4300 m height near Mt. Folgefonn (1450 m) in SW Norway – Pilots observed heavy rain at -10°C
The former tropical cyclone Marta starts deepening as an extra-tropical cyclone

8 Sept 2005

10 Sept 2005
Subtropical air heading for Norway

13 Sept 2005

14 Sept 2005

★ Location of Mt. Folgefonn
* Location of Stavanger sounding
14 Sep 2005: Extremely high tropopause and saturated air from the surface to 8 km

0°C isotherm at 3200 m
A near-disaster for flight CST602 due to icing around 4000 m height at 05:20 UTC

Figure 3: The flight profile for CST602 during the period 07:22:20 to 07:25:12 (based on Mode C every 5 seconds).
The WRF nested grid domains
Different time evolutions of cloud microphysical parameters

**Thompson scheme**

- 0.2-0.4 g m$^{-3}$ supercooled cloud liquid water + rain at 04 and 05 UTC

**Ferrier scheme**

- No supercooled cloud liquid water!
- No rain above 3600 m
05 UTC

Thompson scheme

Ferrier scheme

SLW up to 6000 m height upwind of and over the mountain

Snow depletes the SLW!
Summary

• New insight into mesoscale Arctic weather phenomena, especially **polar lows** was gained during IPY-THORPEX

• A new LAMEPS has been developed

• New satellite data are being exploited (IASI)

• Case-to-case differences in predictability not understood

• **Improved model physics** needed to predict icing episodes
Recommendations

• **Improved Observational Coverage** in the Polar Regions Needed

• This includes both continuous observations and dedicated field campaigns

• Enhanced international collaboration is needed in the Arctic
Thank you for your attention!

Photo: Gudmund Dalsbø during the 2008 IPY-THORPEX campaign
03 March 2008
ETKF Sensitive Area Prediction

Flight 1: 19 sondes in 12Z forecast
Flight 2: 13 sondes in 18Z forecast
T+24 Forecast of Polar Low Landfall

- Improvement to forecast of polar low position and intensity
Polar Low Central Pressure and Track in the 18Z forecast

- Polar low intensity and location are both improved in the 18Z targeted forecast
CAPE and CIN evaluated from dropsondes

CAPE: Convective Available Potential Energy; B: Buoyancy

\[
\text{CAPE} = \int_{\text{LFC}}^{\text{LNB}} g \frac{B}{\theta_{va}} \, dz
\]

\[
B = \theta_v - \theta_{va}
\]

(LFC: Level of Free Convection; LNB: Level of Neutral Buoyancy; LO: Level of Origin)

CIN: Convective Inhibition

\[
\text{CIN} = -\int_{\text{LO}}^{\text{LFC}} g \frac{B}{\theta_{va}} \, dz
\]

Linders & Saetra (2010: J.Atmos.Sci.)
All Cases: Predictions and observations of supercooled LWC

Many missed events at the lowest resolution

Nygaard, Kristjánsson, Makkonen (in prep.)
Ingredients in Polar Low Development

• Large Surface Heat Fluxes (several hundred W m\(^{-2}\))
• Latent Heat Release from Deep Convection
• Low-level Baroclinicity
• Upper-level Trigger

• Relative Role of the Above Processes?
• A spectrum of Polar Low types (Rasmussen & Turner, 2003)
WRF Simulations of the Polar Low Event on 03 March 2008

J. Wagner, A. Gohm, A. Dörnbrack, A. Schäfler

- 3 Domains: $\Delta x = 36$ km, $\Delta x = 12$ km, $\Delta x = 4$ km
- 90 vertical, terrain following $\eta$-Levels; level distance near ground: 15 metres
Model - LIDAR: Wind

WRF: Horizontal Wind Speed [m/s]

Windspeed 925 hPa 16 UTC

LIDAR: Horizontal Wind Speed [m/s]
Model - LIDAR: Vapor

WRF: Water Vapor Mixing Ratio [g/kg]

Mean Vertical Profile

Backscatter Ratio

LIDAR: Water Vapor Mixing Ratio [g/kg]

IR Sat-Image: 03-Mar-2003 17:37 UTC
Model - LIDAR: Vapor

WRF: Water Vapor Mixing Ratio [g/kg]

LIDAR: Water Vapor Mixing Ratio [g/kg]
Water Vapor and Wind Lidar on board the Falcon

- DIAL Filters & Detectors
- 2 high-power DIAL lasers
- 48 cm Telescope
- Two 50 cm aircraft windows
- Newly developed DIAL:
  - 4 wavelengths (3 onlines, 1 offline)
  - To cover whole troposphere + lower stratosphere

2 µm wind lidar
Weather Forecast Quality is poorer in the Arctic than further south

Forecast error over a two year period; the Barents Sea in red and the North Sea in blue.
Where do we find polar lows today?

Red: Marine cold air outbreaks => polar lows

Polar Lows in the Future

Blue: Fewer polar lows than now
Red: More numerous polar lows than now

Note increase in the Barents Sea

Achievements - Legacy

• **Unique Data Set** for Future Research: ‘Cradle to Grave’ Capture of Polar Low on 3-4 March 2008
• A **New Probabilistic Forecasting System** for Wind and Precipitation in the Arctic
• Exploitation of Advanced **New Satellite Data (IIASI)**
• Deployment of **New Weather Observation Stations** at Svalbard
• Deployment of AMDAR instruments on commercial aircraft to Svalbard
• **TEPS – Targeted Ensemble Prediction System**
  TEPS is a dedicated version of ECMWF EPS. 20 + 1 ensemble members, as opposed to 50+1 for EPS. Target area is Northern Europe and adjacent sea areas, as opposed to NH north of 30°N for EPS. TEPS runs at 00utc and 12utc every day. Forecast length is +72h. SV computation with T42 and 48h optimization time. Using ECMWF model IFS with resolution T639L62 (~50km)
  TEPS follows the same model upgrades as ECMWF EPS, hence it always runs the same model cycle as EPS

• **LAMEPS – Limited Area Model Ensemble Prediction System**
  HIRLAM in ensemble set-up. Running since February 2005. Resolution: 12km (0.108°), 60 vertical levels. 20 members + control. Control is based on Norwegian HIRLAM analysis (12km resolution). 20 initial and lateral boundary conditions from TEPS. Lateral boundary conditions every 3 hour. Runs at 06utc and 18utc, 6 hour time lag from TEPS. Forecast length is 60 h. The members use alternating two different physics parameterizations.
Icing on power lines

Mt. Lønahorgi, Norway, April 1961
Probabilistic Forecasting (LAMEPS)

Sea-Level Pressure

Precipitation

Kristjánsson et al. (2010: BAMS, submitted)
Orographic Jets at Svalbard on 27 Feb 2008

Kristjánsson et al. (2010: BAMS, submitted)
Gap Flow at Svalbard on 27 Feb 2008

Kristjánsson et al. (2010: BAMS, submitted)