The mesoscale structure of a mature polar low
Airborne measurements and numerical simulations

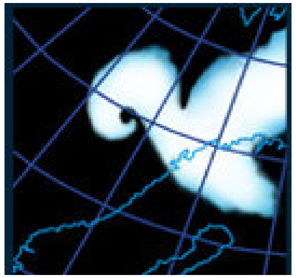
Andreas Dörnbrack[1], Johannes Wagner[2], Alexander Gohm[2] and Andreas Schäfler[1]

(1) Institut für Physik der Atmosphäre,
Deutsches Zentrum für Luft und Raumfahrt (DLR),
Oberpfaffenhofen, Germany

(2) Institute of Meteorology and Geophysics,
University of Innsbruck, Innrain 52,
A-6020 Innsbruck, Austria

in cooperation with the Norwegian IPY-THORPEX project
lead by J. E. Kristjánsson and the Norwegian Met Service

DLR



INTERNATIONAL 2007 2008 POLAR YEAR

universität innsbruck

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Campaign: IPY THORPEX 2008

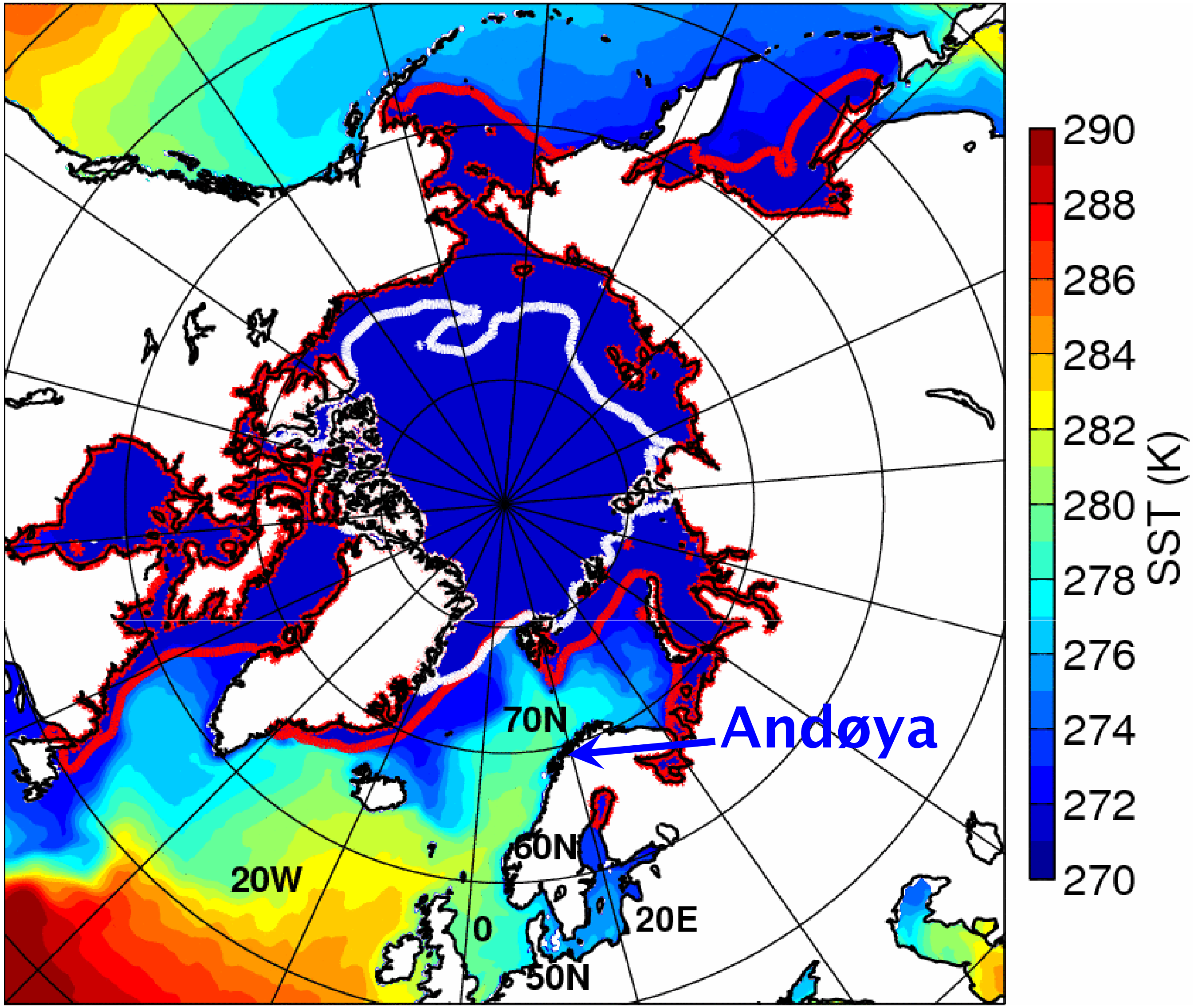
- IPY: International Polar Year (March 2007 to 2009)

- THORPEX: The Observing System Research and Predictability Experiment

- Airborne in-situ and remote-sensing observations over the Norwegian and Barents Seas

→ Focus on Arctic fronts, polar lows and terrain-induced flow disturbances

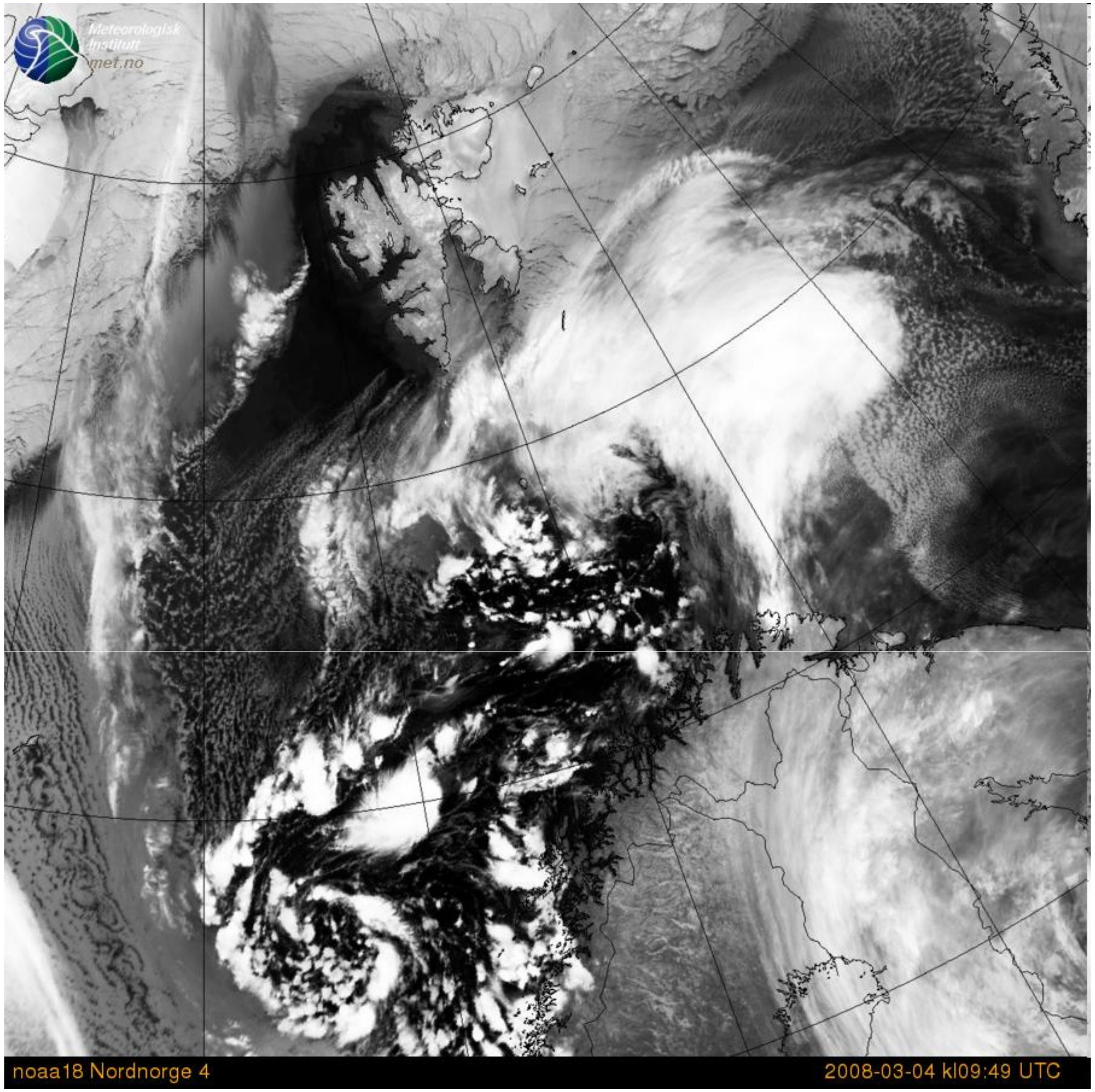
Objective: Improved forecasting of adverse weather in the Arctic region – present and future



Monthly mean SST for March (2006-2010)

Vilhelm Bjerknes on the quay at Bergen (R. Groven, 1983)

"The northernmost part of Norway in winter is one of the stormiest locations on Earth, and the terrible accidents that occur from time to time, when large parts of the fishing fleet with crew and tools are lost, are only too well known. A look at the climatological conditions show [that] the reason for the frequency of the storms [is that] the mean temperature in January by the outermost Lofoten islands is 27 degrees Celsius higher than the mean for the same latitude around the globe. This is the effect of the warm waters of the Gulf Stream. At the same time a Siberian winter cold reigns on the Finnmark plateau. Nature has, in other words, put an immense steam kettle side by side with an immense condenser. This steam engine must always work, and that is what it does, with great, irregular strokes." (1904)

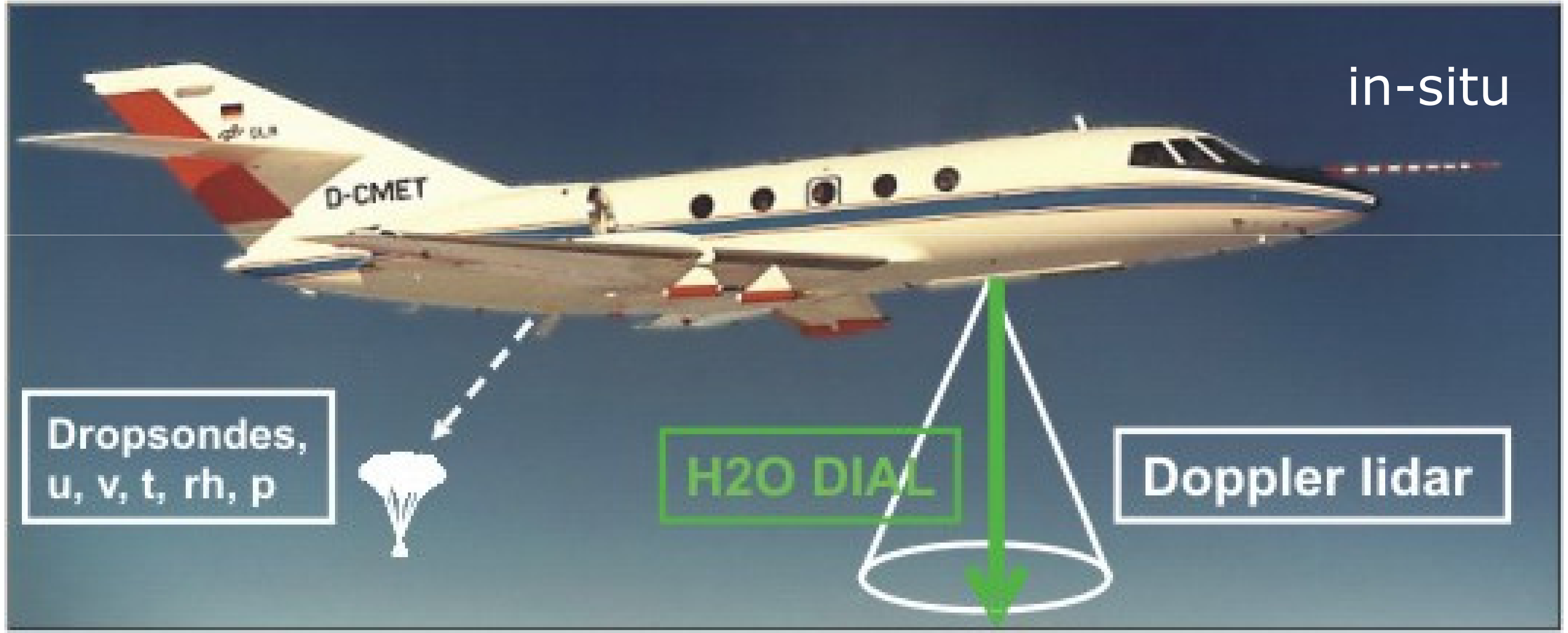


NOAA IR - 4 March 2008

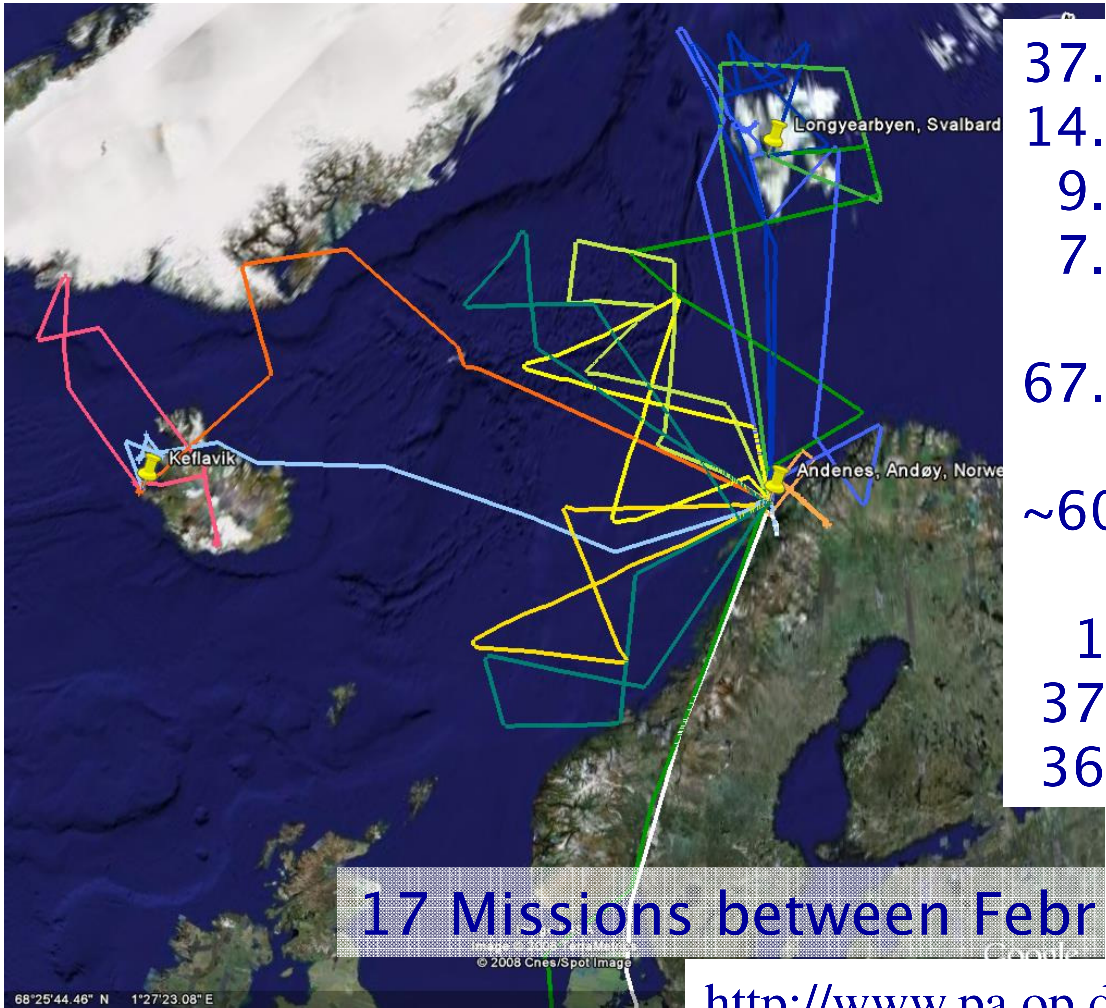
Andøya, 4 March 2008

DLR Airborne Measurements
IPY-THORPEX Andøya/Norway

February 25 – March 17 2008



DLR Falcon Deployment Feb 25 - Mar 17 2008



37.0 h Uni Oslo
14.0 h EUFAR Island
9.0 h EUFAR Norway
7.0 h DLR-IPA

67.0 h Altogether

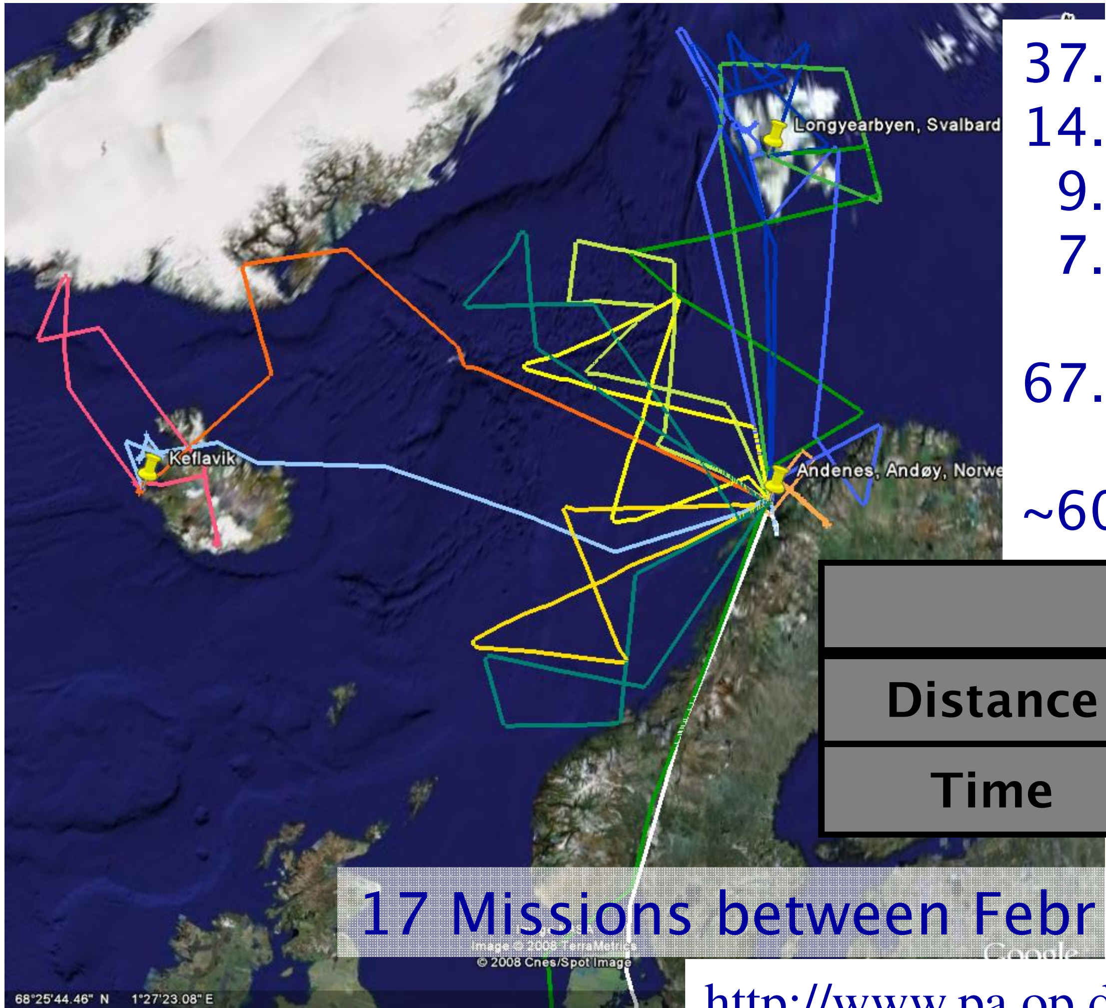
~60 h *in-situ* data

148 Dropsonde Profiles
3779 Wind Lidar Profiles
3673 Water Vapor Profiles

17 Missions between Febr 25 till March 17 2008

http://www.pa.op.dlr.de/ipy_thorpex

DLR Falcon Deployment Feb 25 - Mar 17 2008



37.0 h Uni Oslo
14.0 h EUFAR Island
9.0 h EUFAR Norway
7.0 h DLR-IPA

67.0 h Altogether

~60 h *in-situ* data

	Wind	Water Vapor
Distance	~ 30000 km	~20000 km
Time	37:30 h	24:36

17 Missions between Febr 25 till March 17 2008

http://www.pa.op.dlr.de/ipy_thorpex

Numerical Modelling I

ECMWF Integrated Forecast System (IFS)

- operational analyses:
  delayed cut-off assimilation cycle, T_L799L91, $\Delta \approx 25$ km

  6 hourly meteorological data (u, v, ω, T, q, p, DIV, ...) at standard pressure levels and at model levels interpolated on regular 0.5° × 0.5° lat/lon grid

- use of operational setup March 2008 (T_L799L91, cycle 32r2)
  calculate 1 h forecasts every 6 hours for lead time 5 h
  = pseudo-analyses

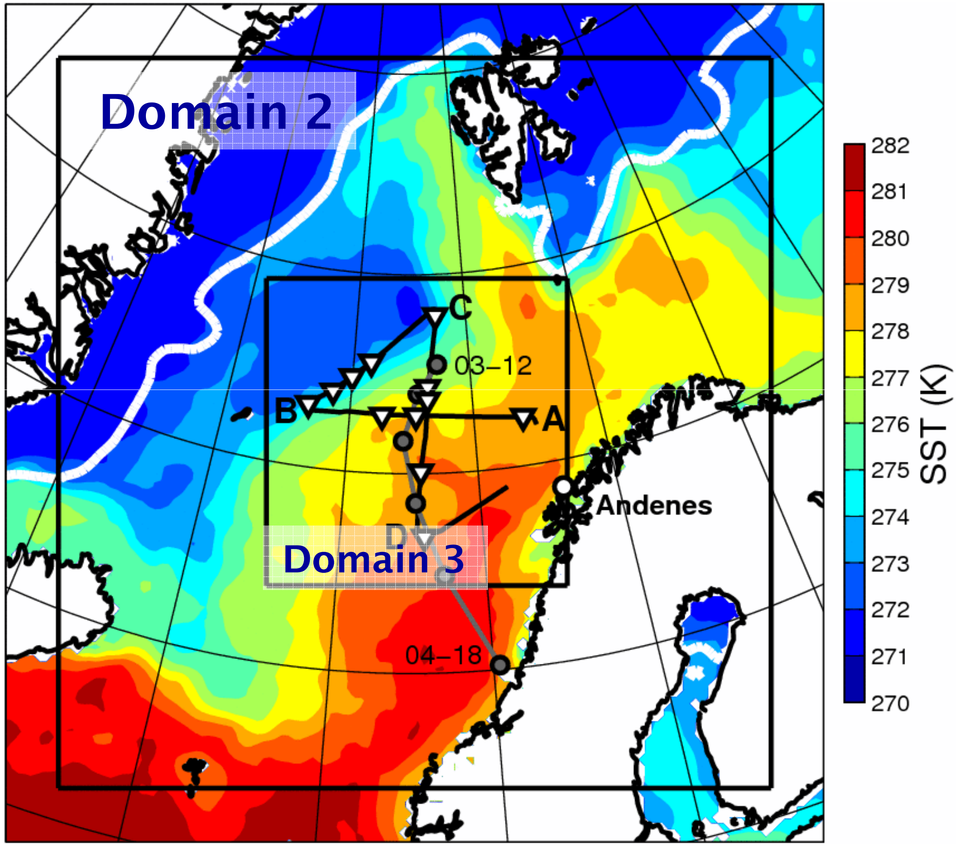
Numerical Modelling II

Polar Version of
Weather Research and Forecasting Model (WRF 3.1.1)

(Polar Meteorology Group of the Ohio State University)

- **Adaptions to polar boundary layer (e.g.: roughness length over ice surfaces)**
- **Implementation of fractional sea ice, fractional snow cover and frozen soil physics in land-surface model**
- **Improved heat transfer and surface energy balance for ice sheets**
- **Initialisation: ECMWF model-level data**
- **OSTIA SST and SEAICE data (daily, global, 0.05° resolution)**
  (Operational Sea Surface Temperature and Sea Ice Analysis,
  National Center for Ocean Forecasting (NCOF), Met Office UK)

Numerical Modelling II



- 3 Domains: Δx=18, 6, 2 km
- 70 vertical, terrain-following levels

Δz~15 m near ground
Δz~400 m for z>4 km to p_{TOP}= 50 hPa

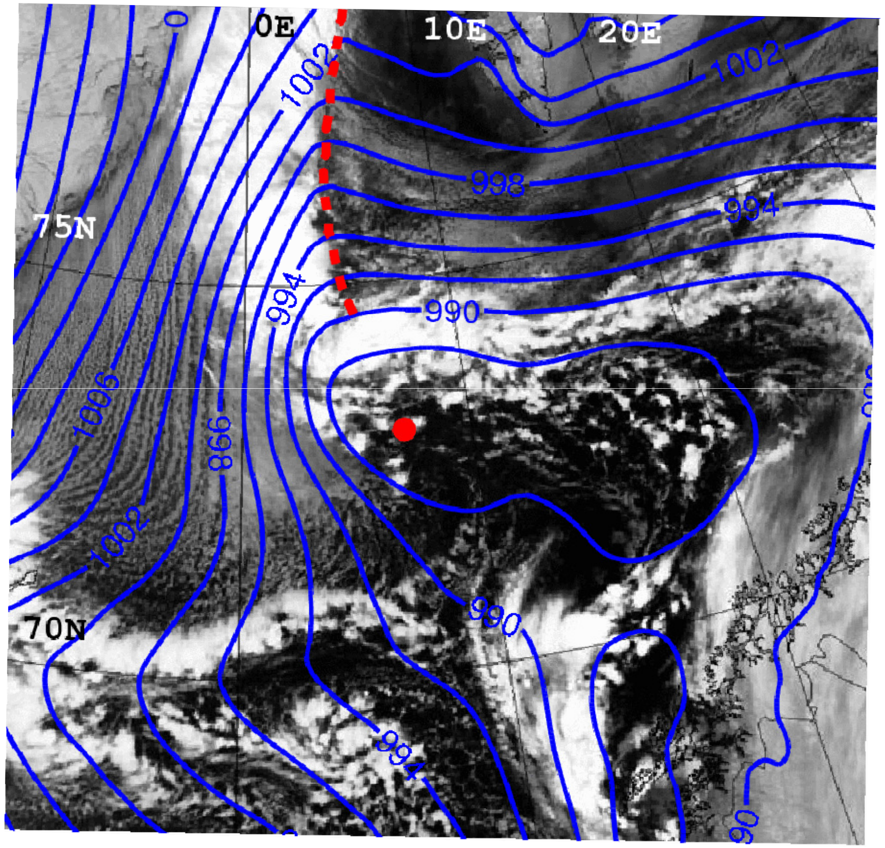
- Rayleigh damping layer: above 10 km
- carefully selected parametrisations:
  - ice, snow, graupel microphysics;
  - polar landsurface model,
  - prognostic TKE scheme in BL
  - cumulus parametrisation (not in D3)

Evolution of the Polar Low

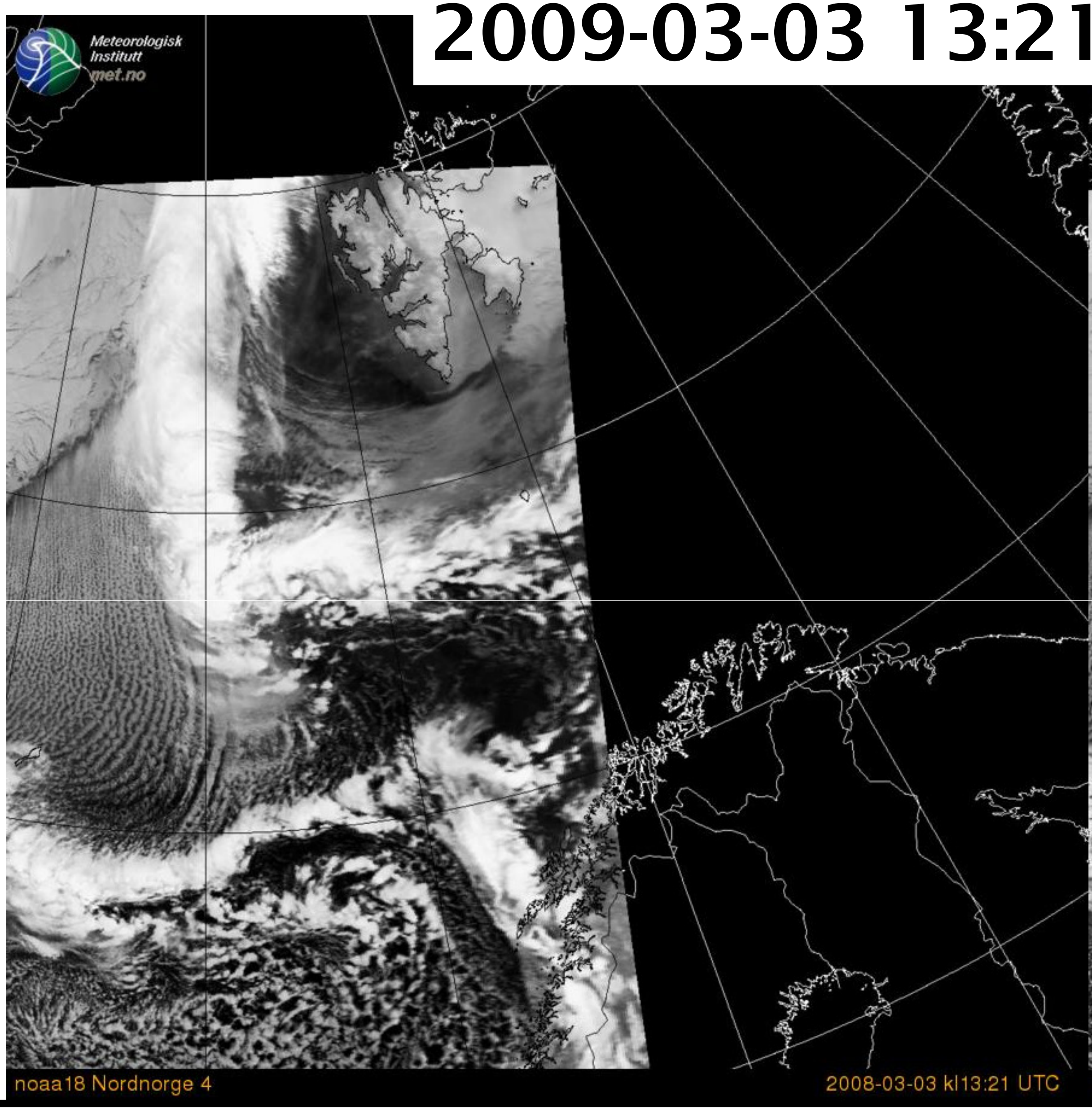
- sequence of NOAA AVHRR infrared satellite images covering the early development of the observed polar low on 3/4 March 2008
- start of development: 3 March 2008 00 - 12 UTC
- landfall: 4 March 2008 18 UTC

  Lifetime: about 36 hours
- flight during mature stage: 3 March 2008 1515 - 1800 UTC

2009-03-03 10:01 UTC



2009-03-03 13:21 UTC



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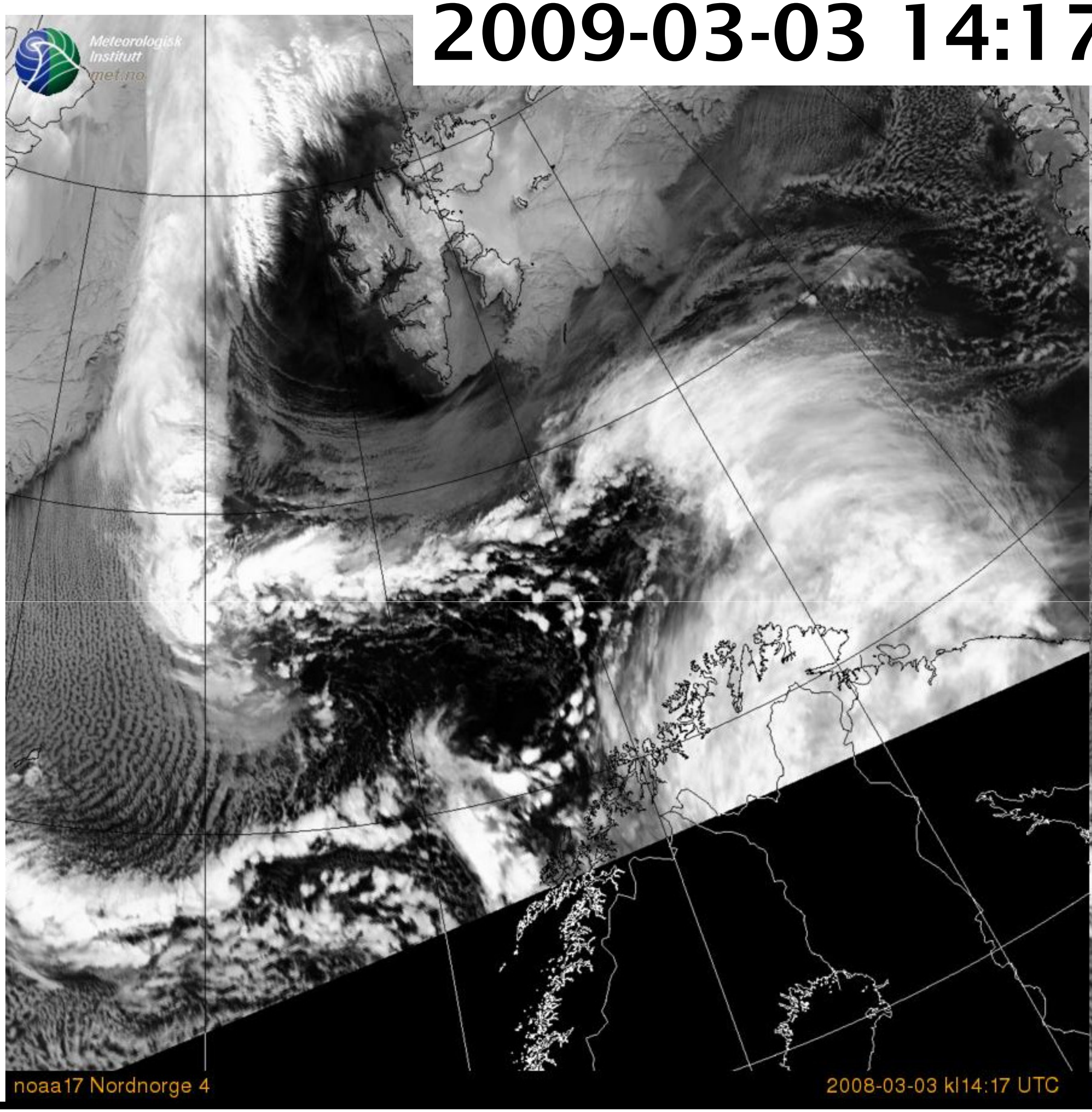
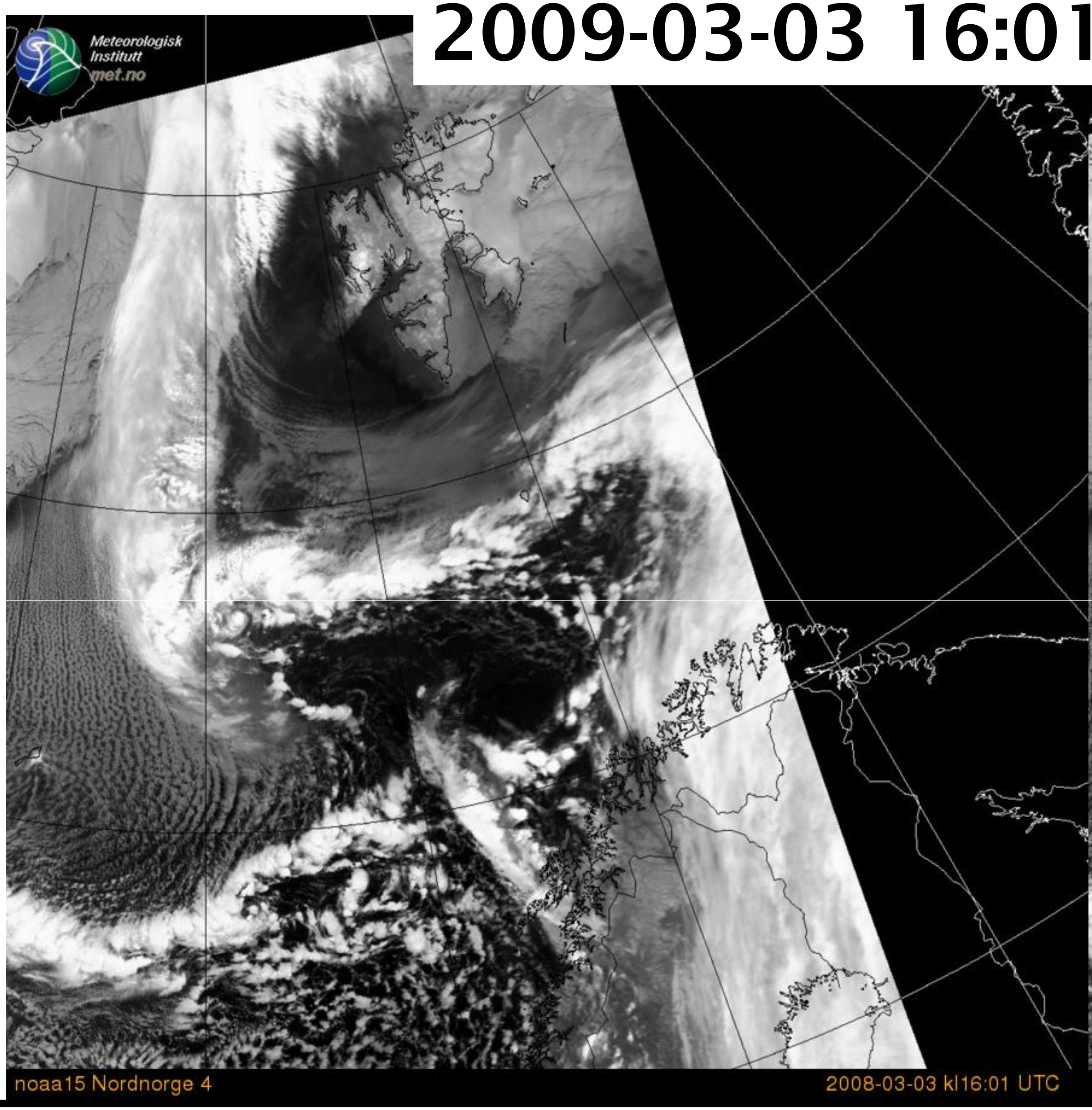
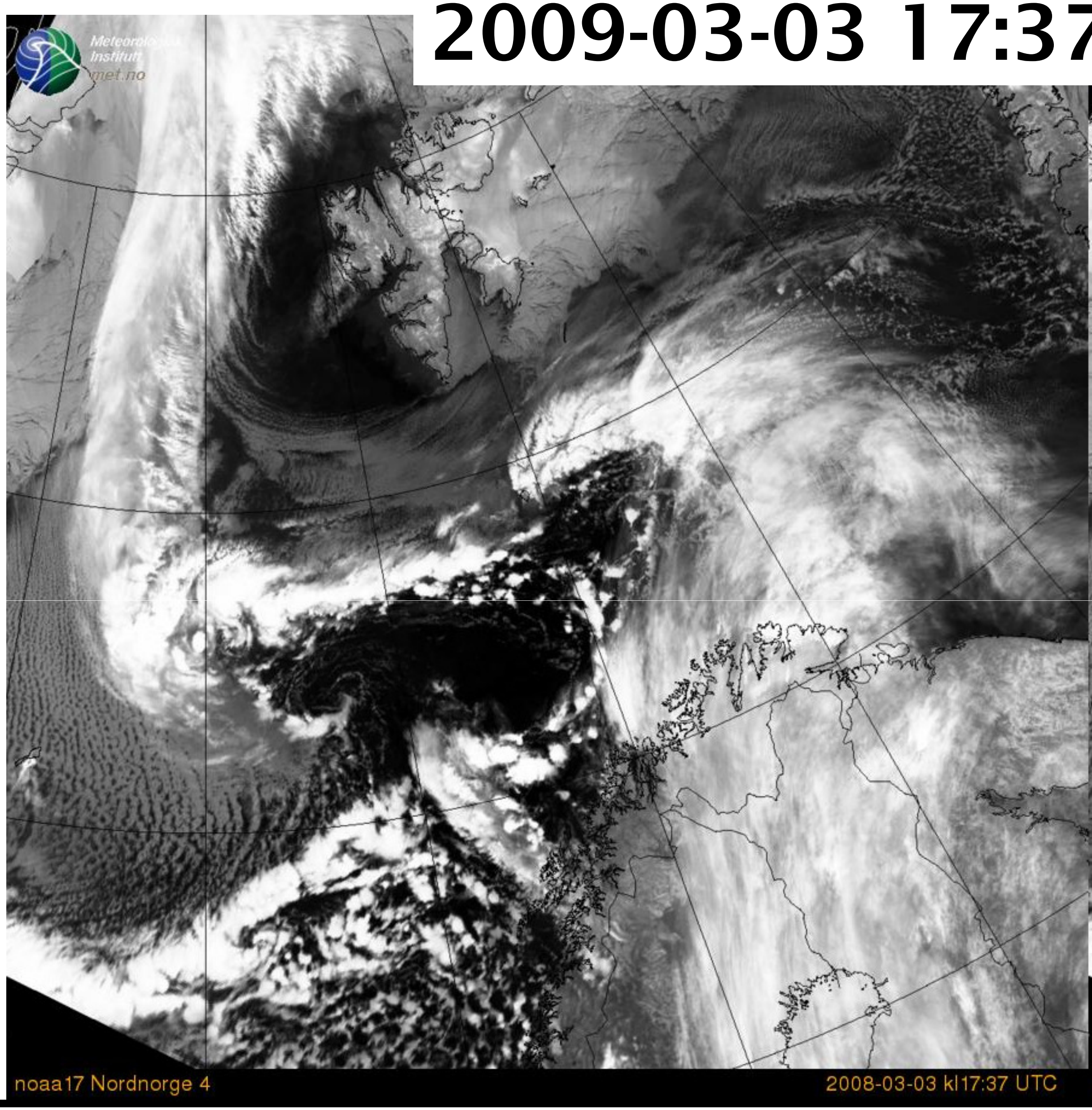


2009-03-03 16:01 UTC



2009-03-03 17:37 UTC



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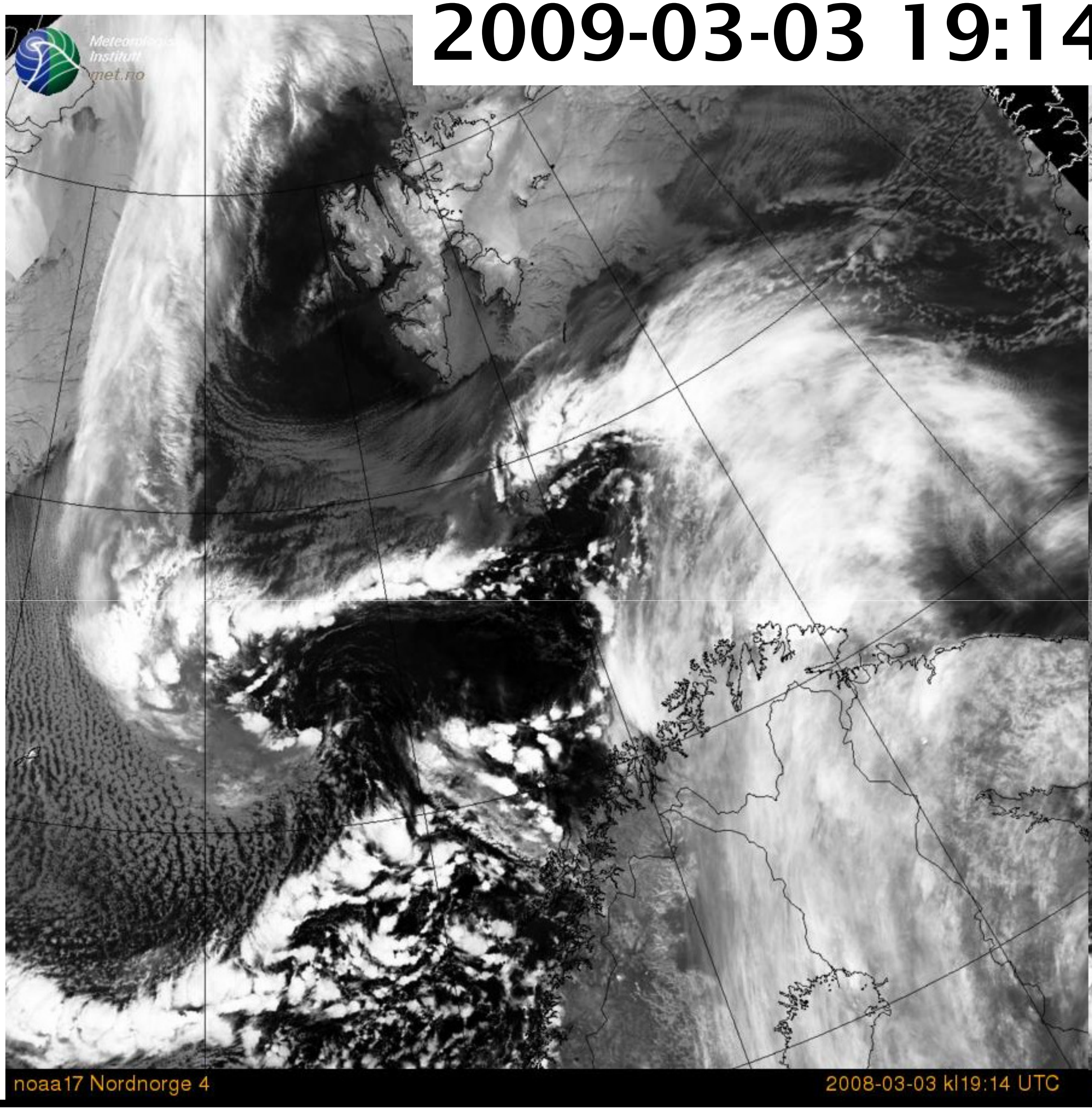

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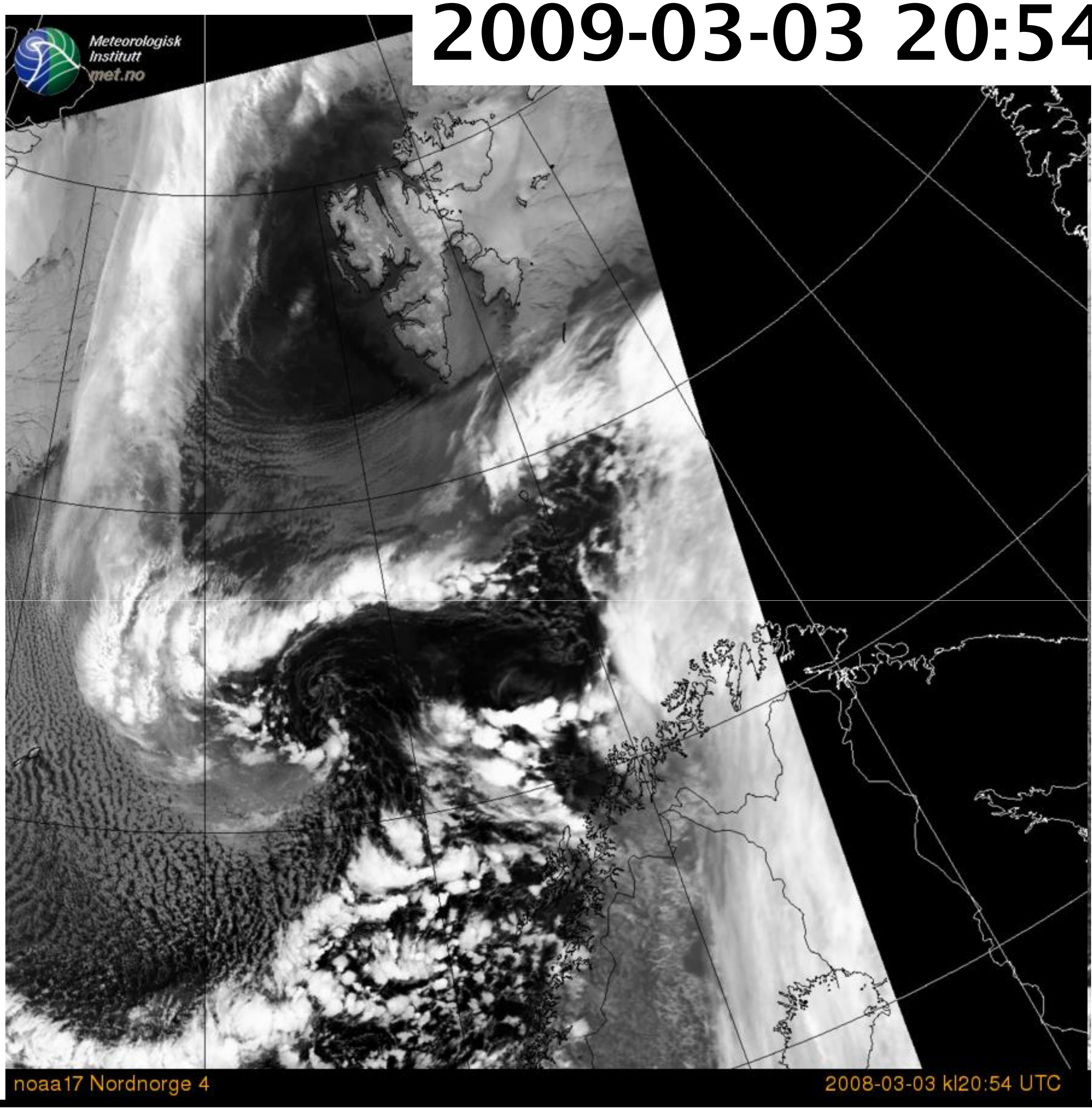
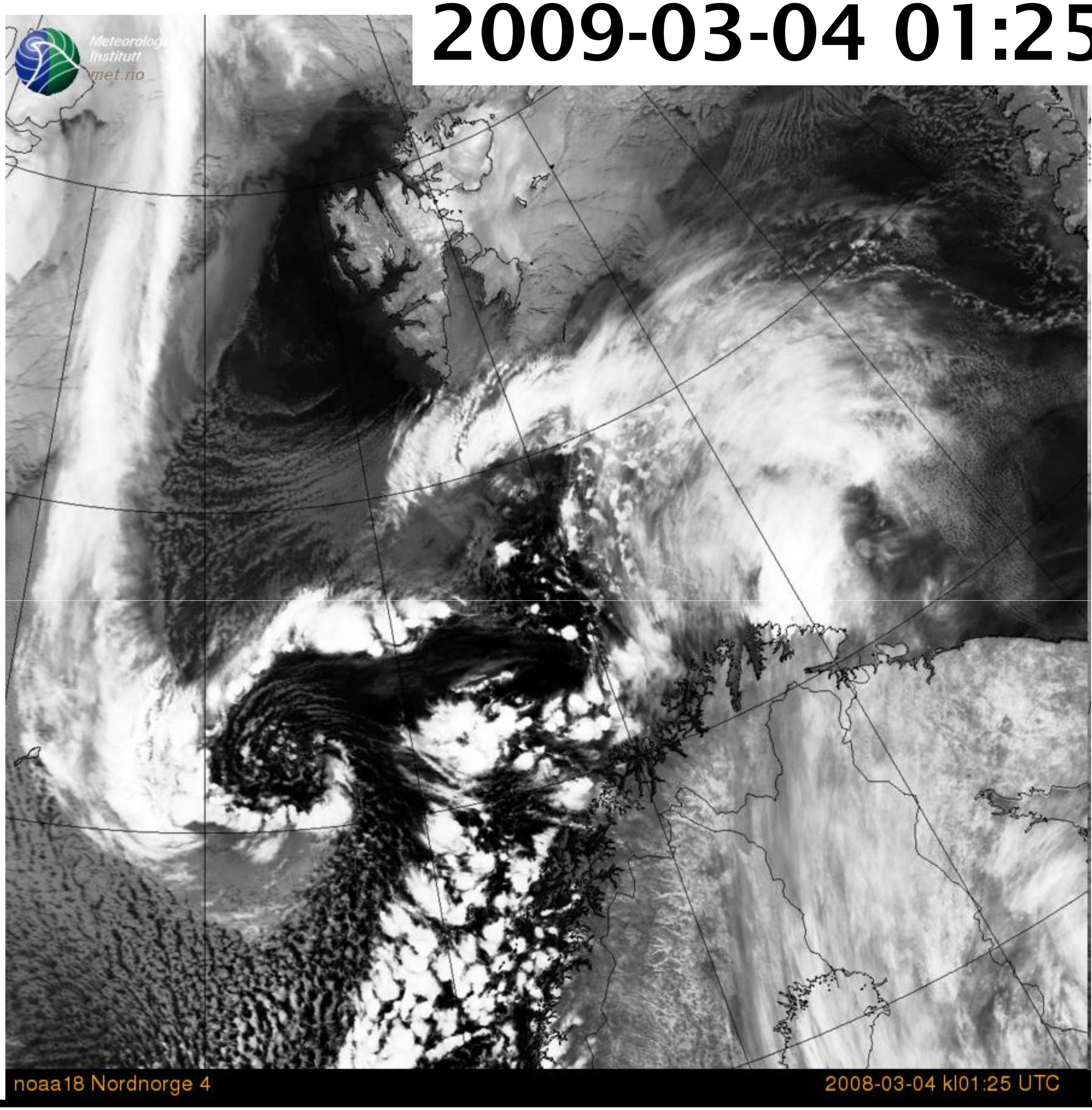
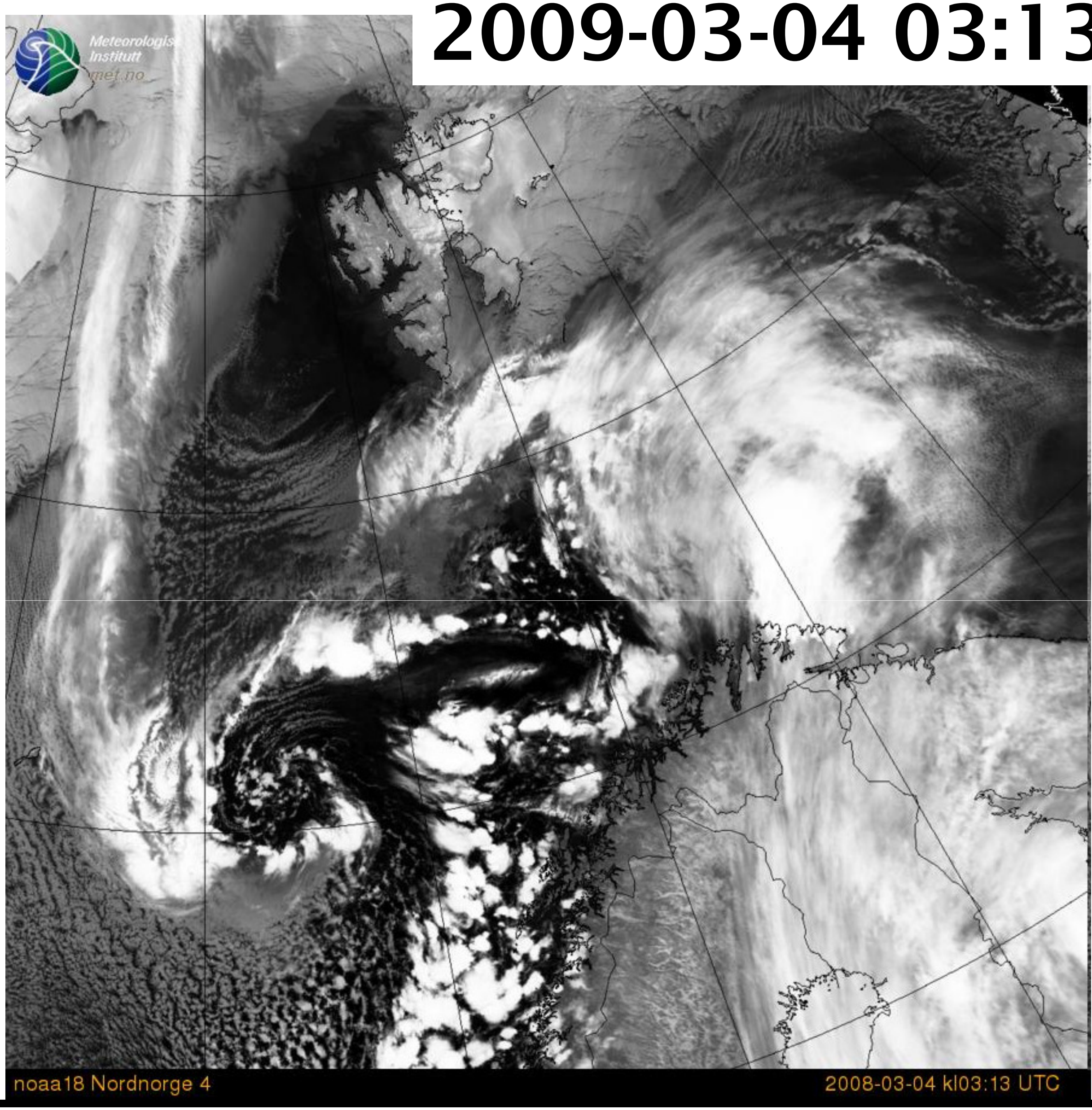


2009-03-04 01:25 UTC



2009-03-04 03:13 UTC



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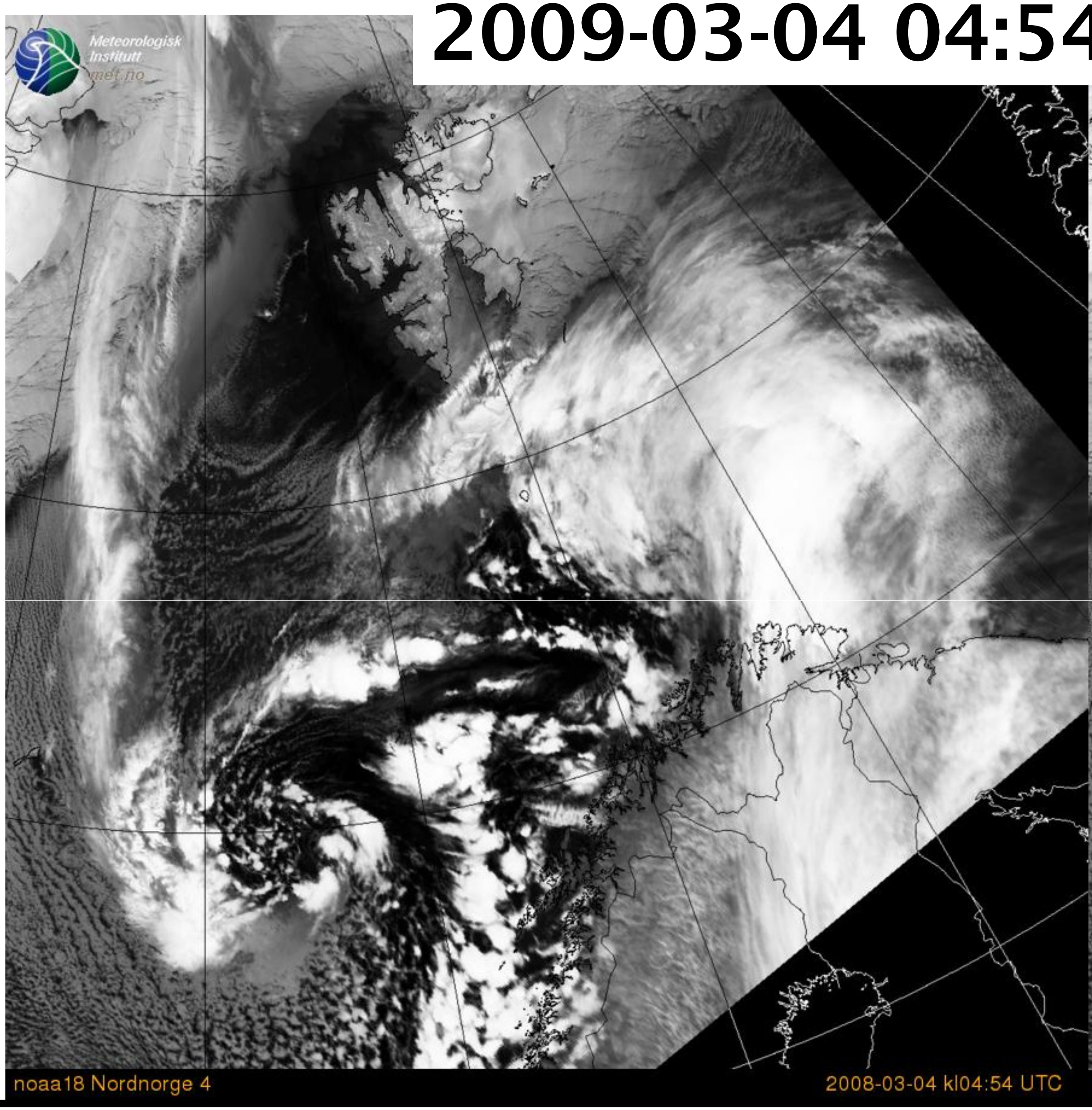

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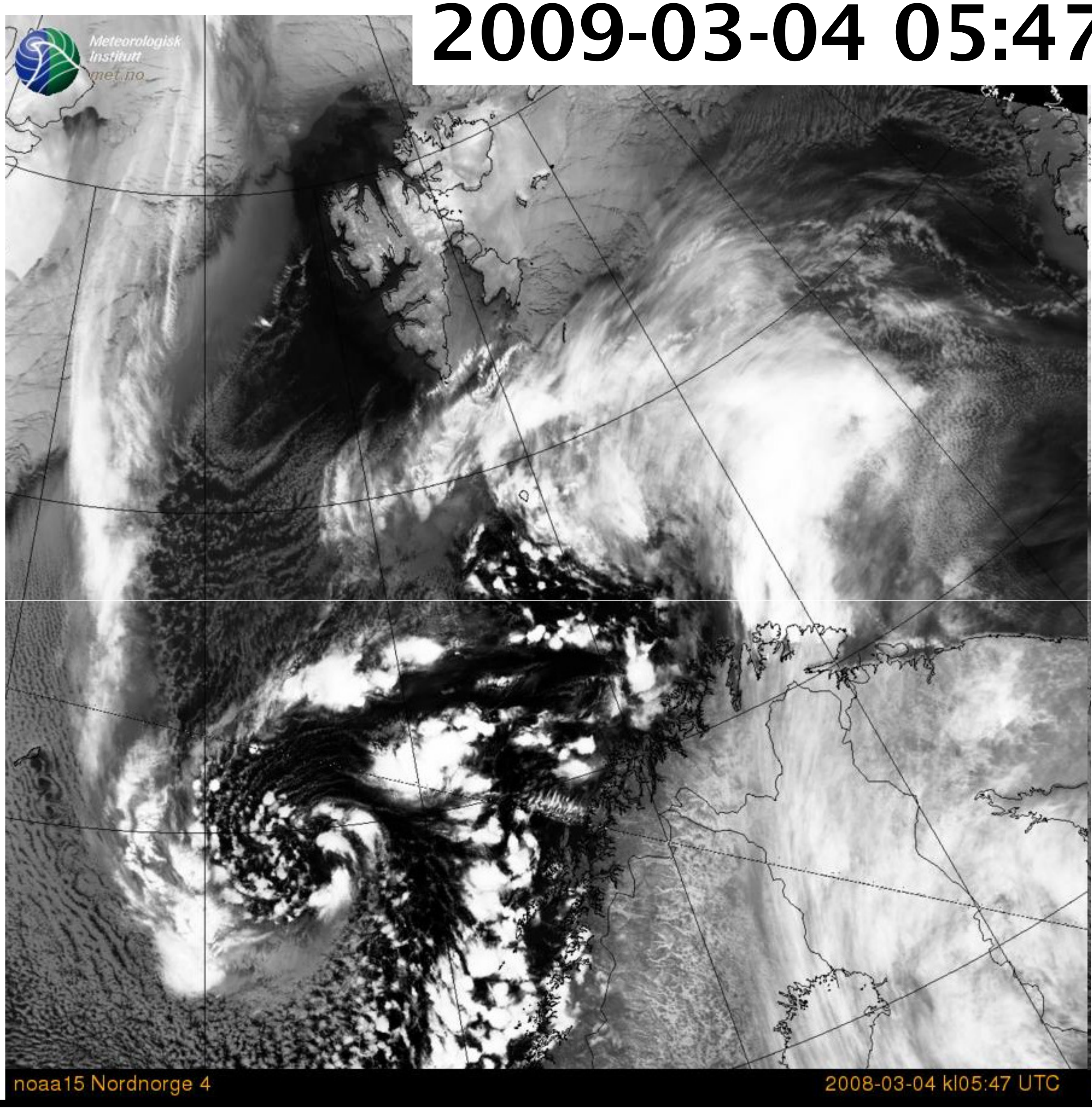

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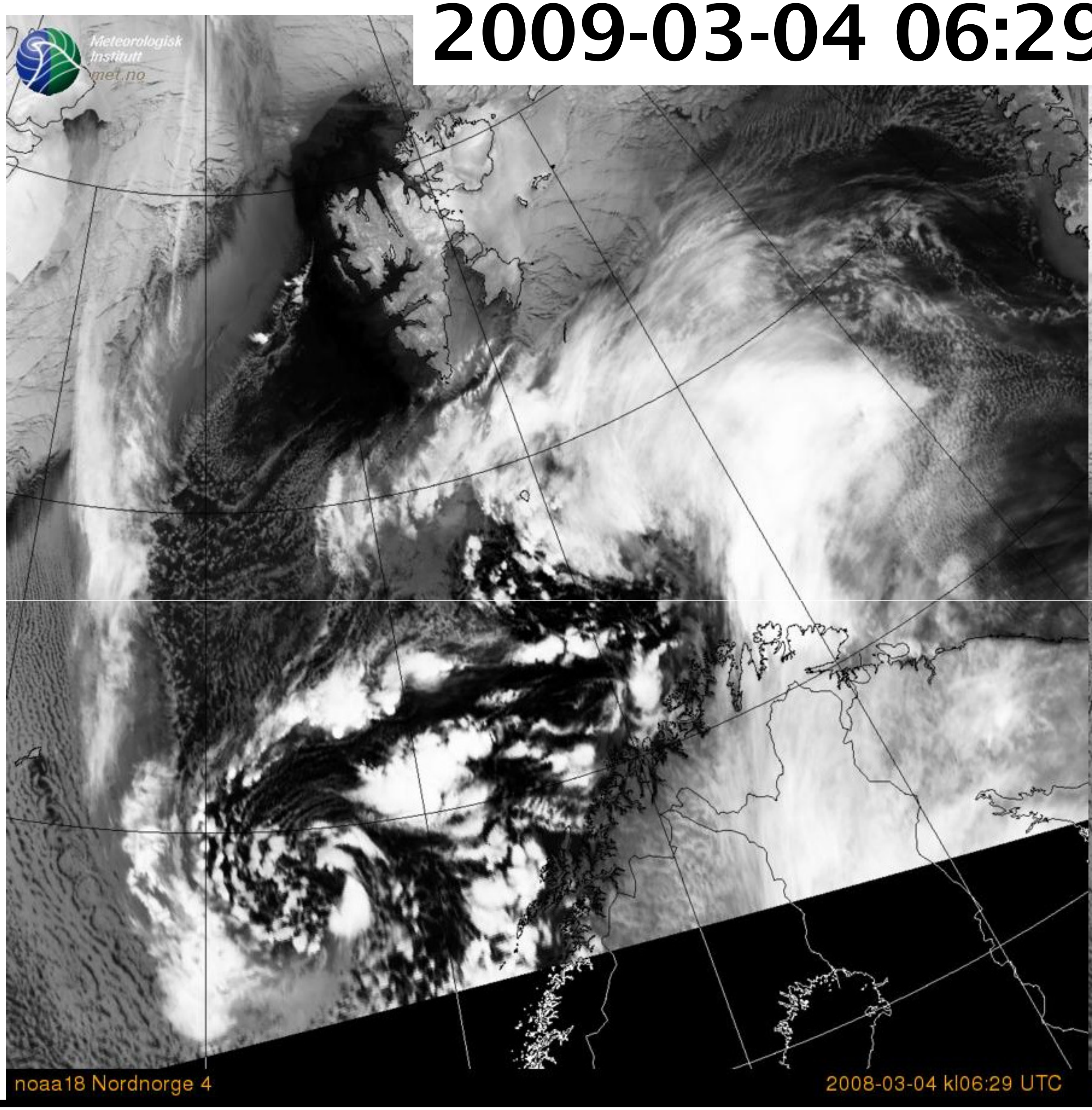

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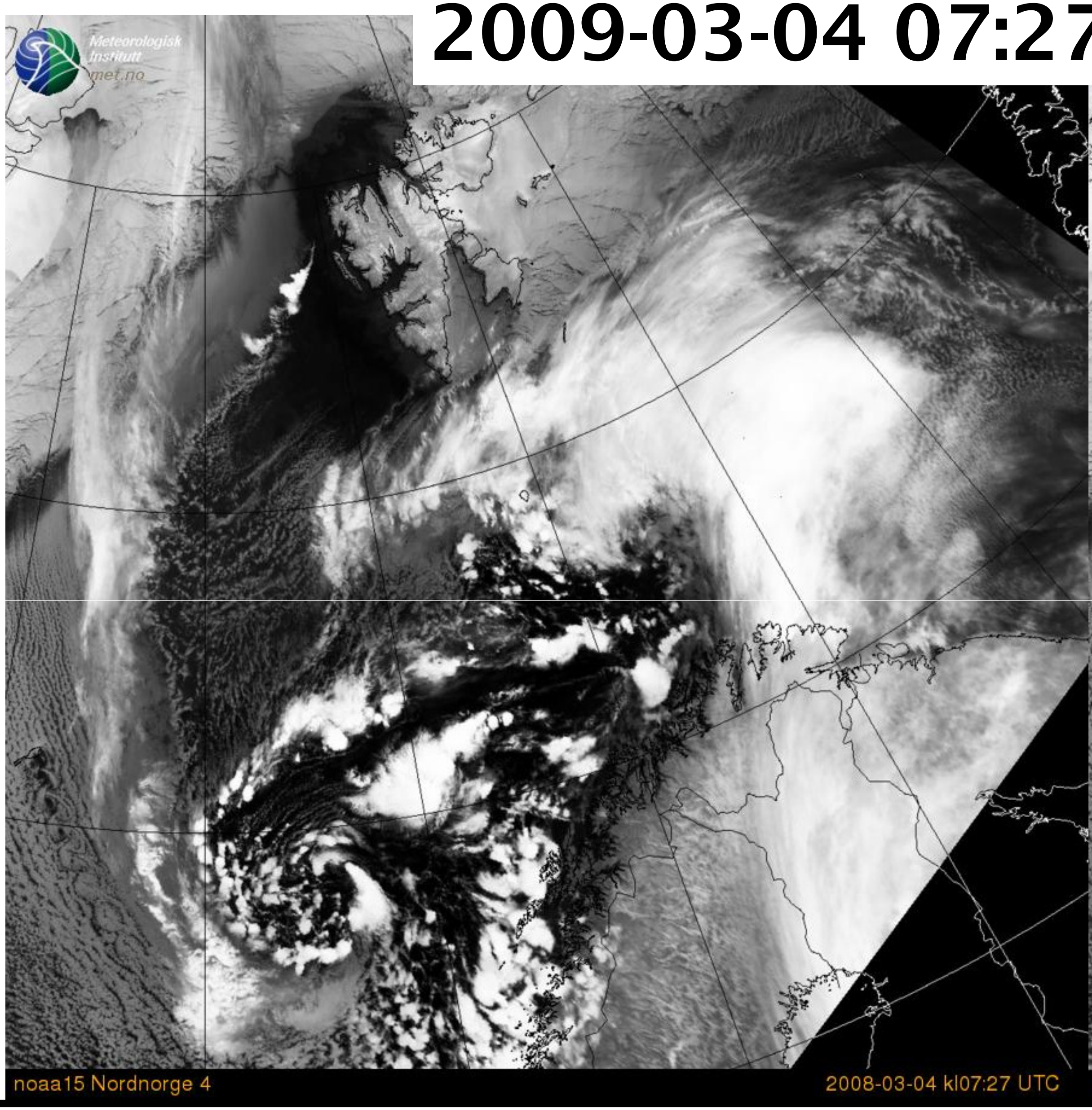

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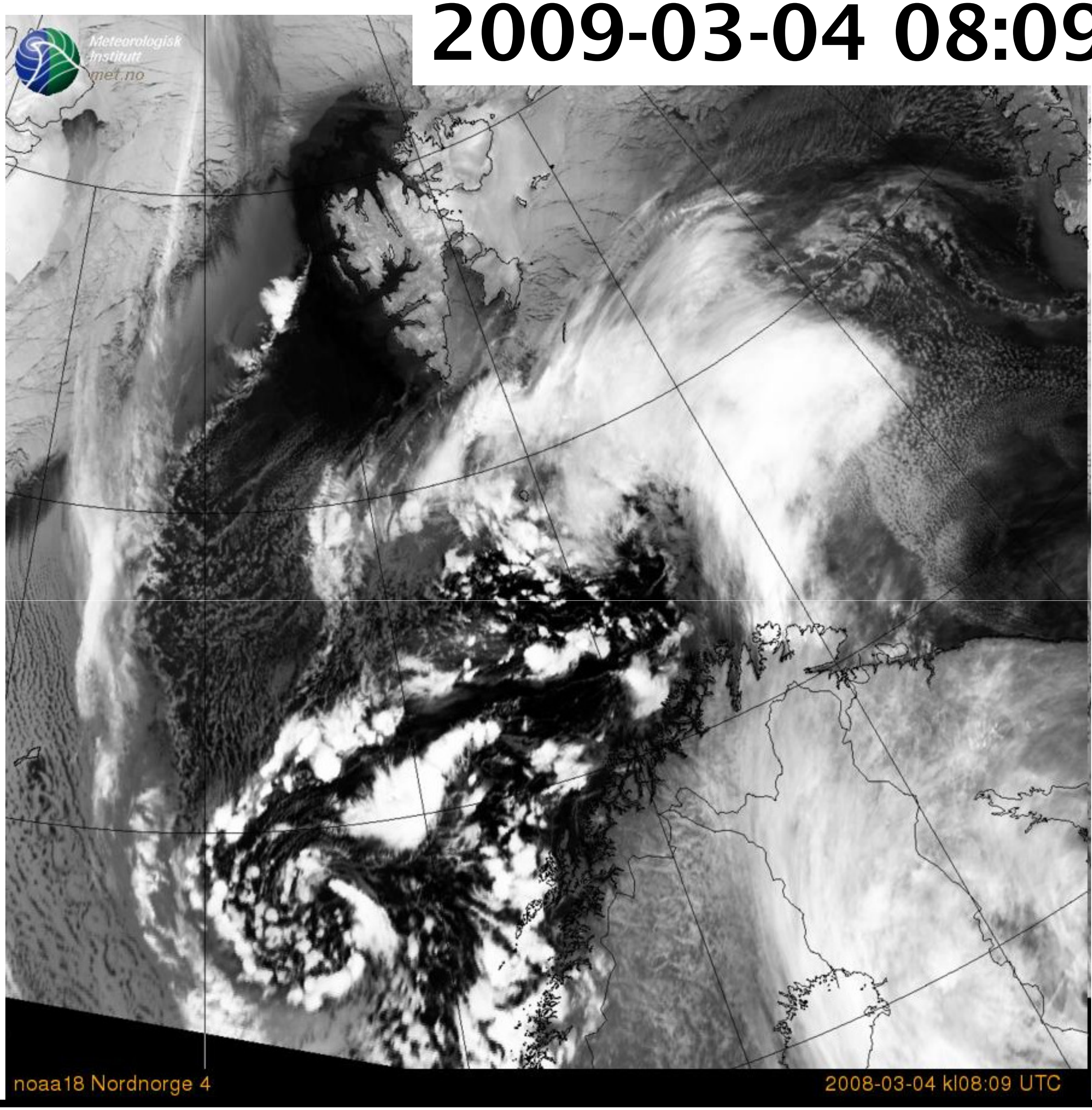

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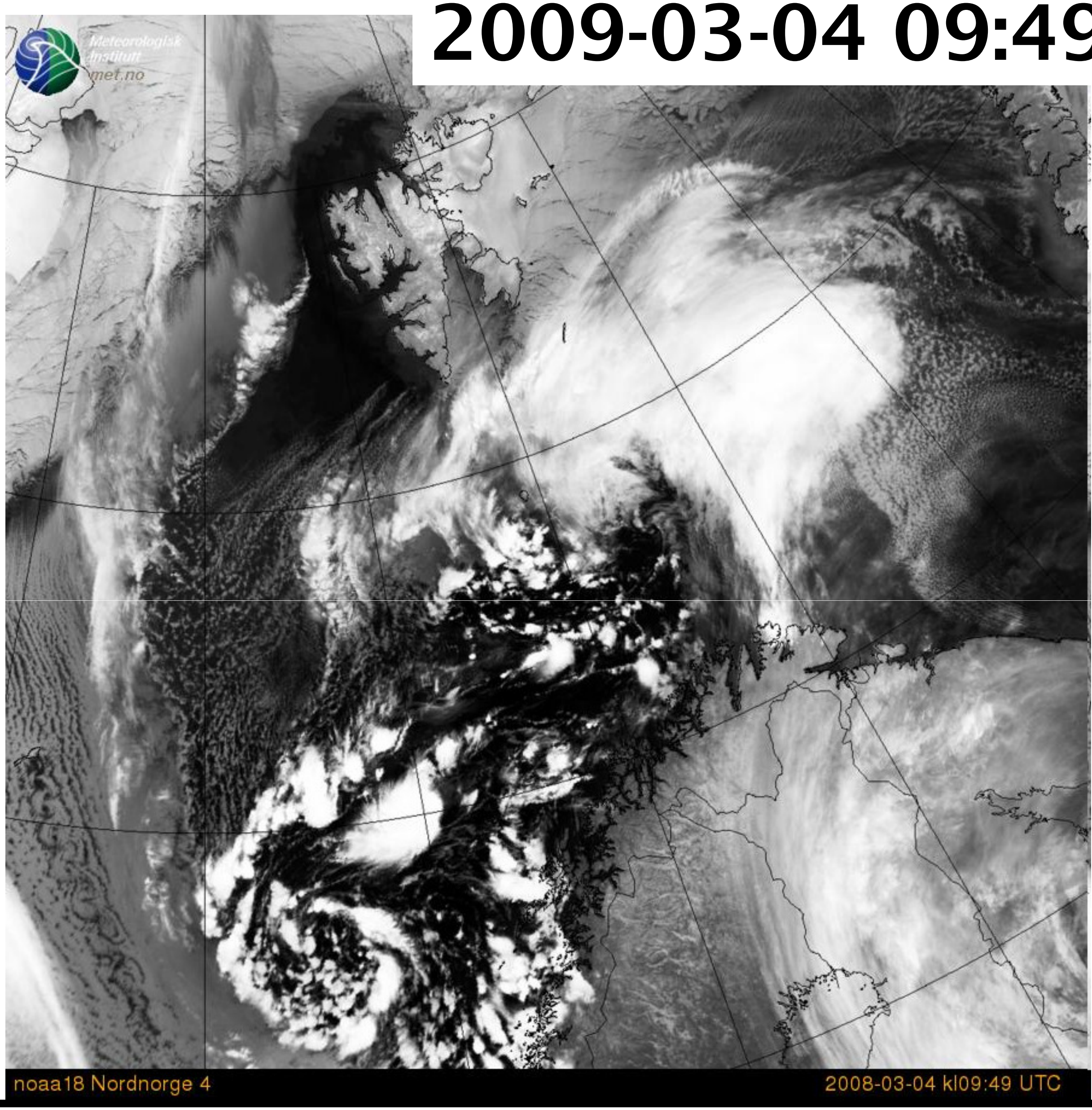
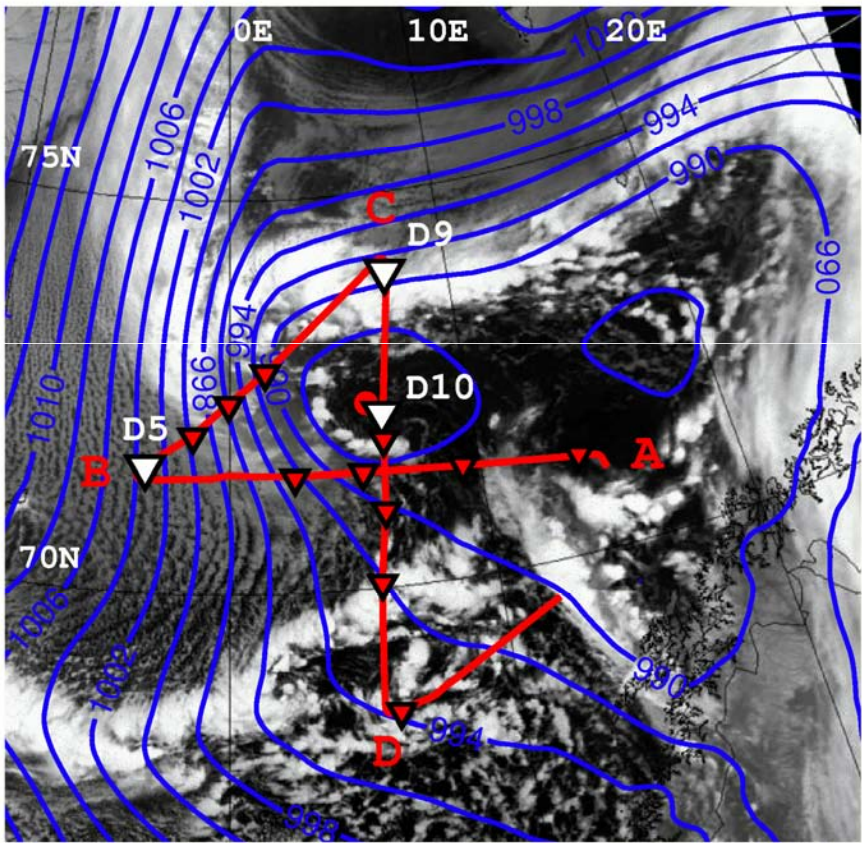
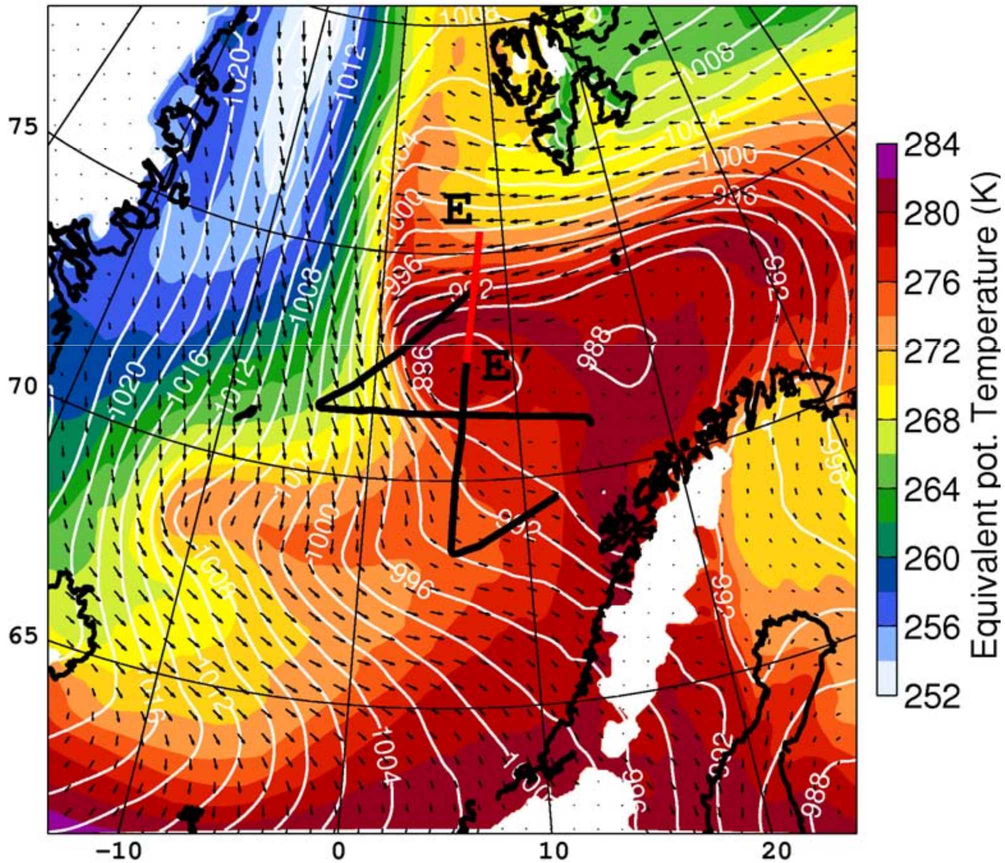


Synoptic Situation

3 March 2008 16 UTC



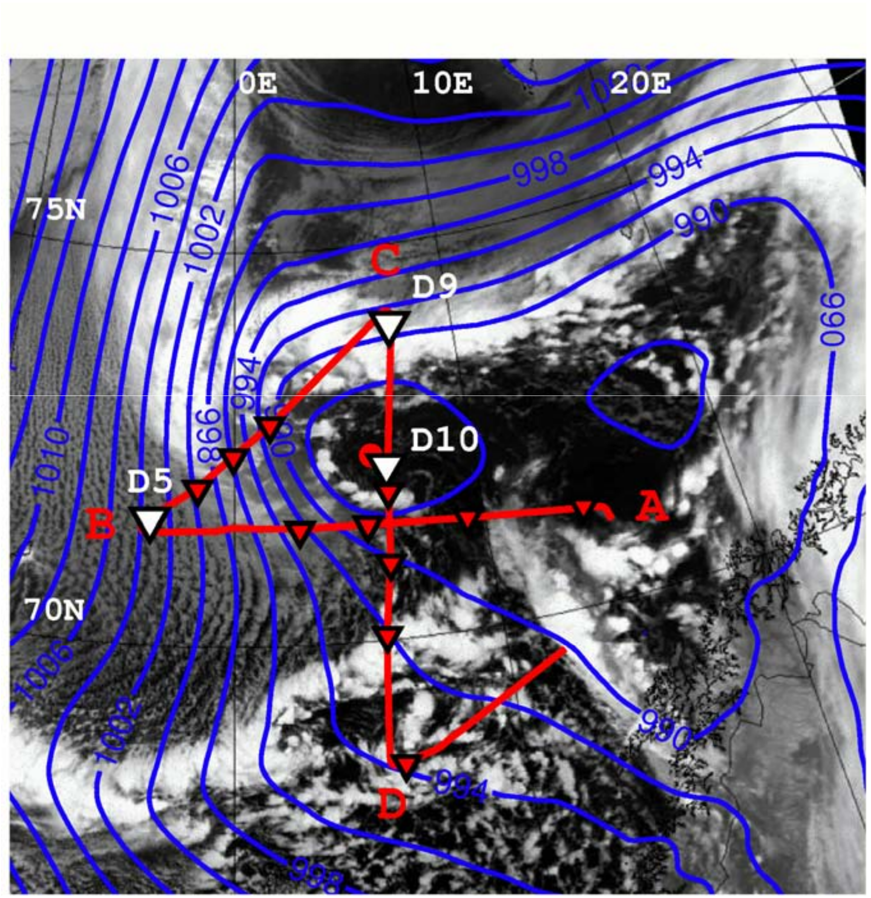
NOAA AVHRR IR & SLP (hPa)



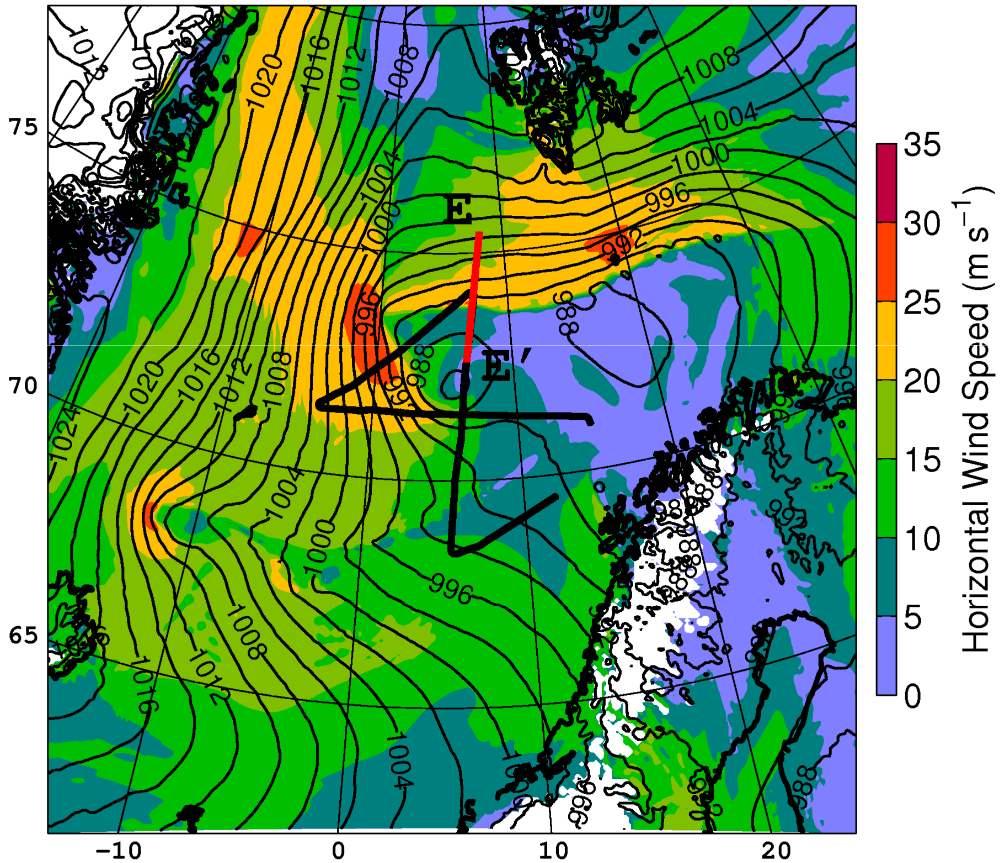
Θ_e at 925 hPa & SLP (hPa)

Synoptic Situation

3 March 2008 16 UTC

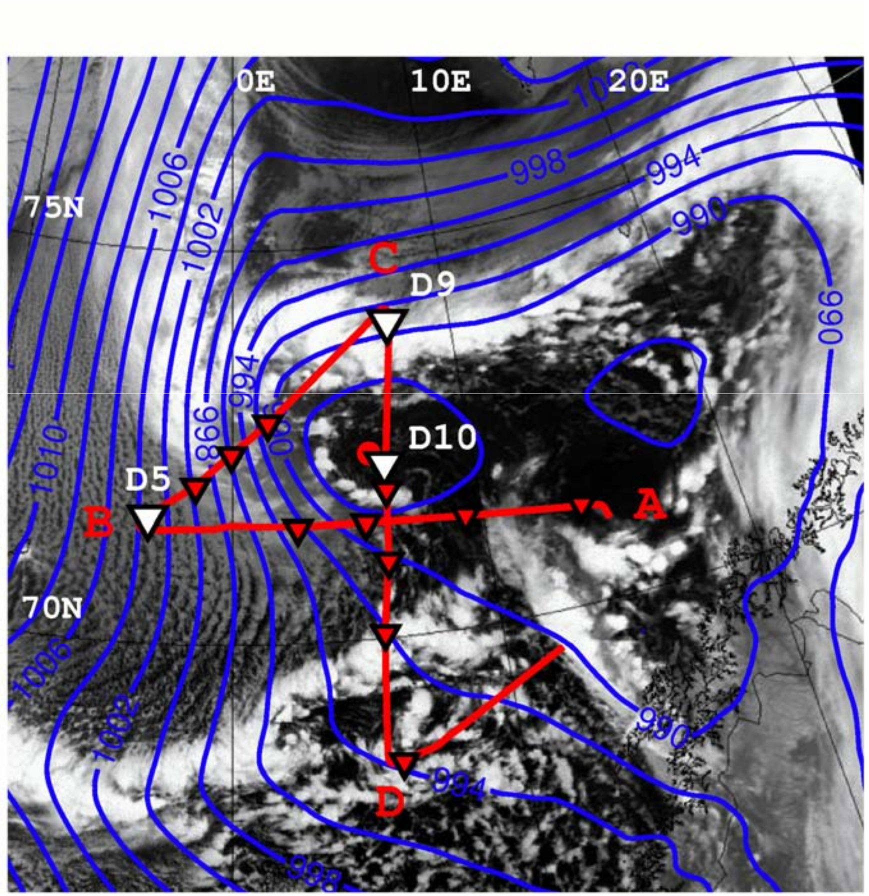


NOAA AVHRR IR & SLP (hPa)

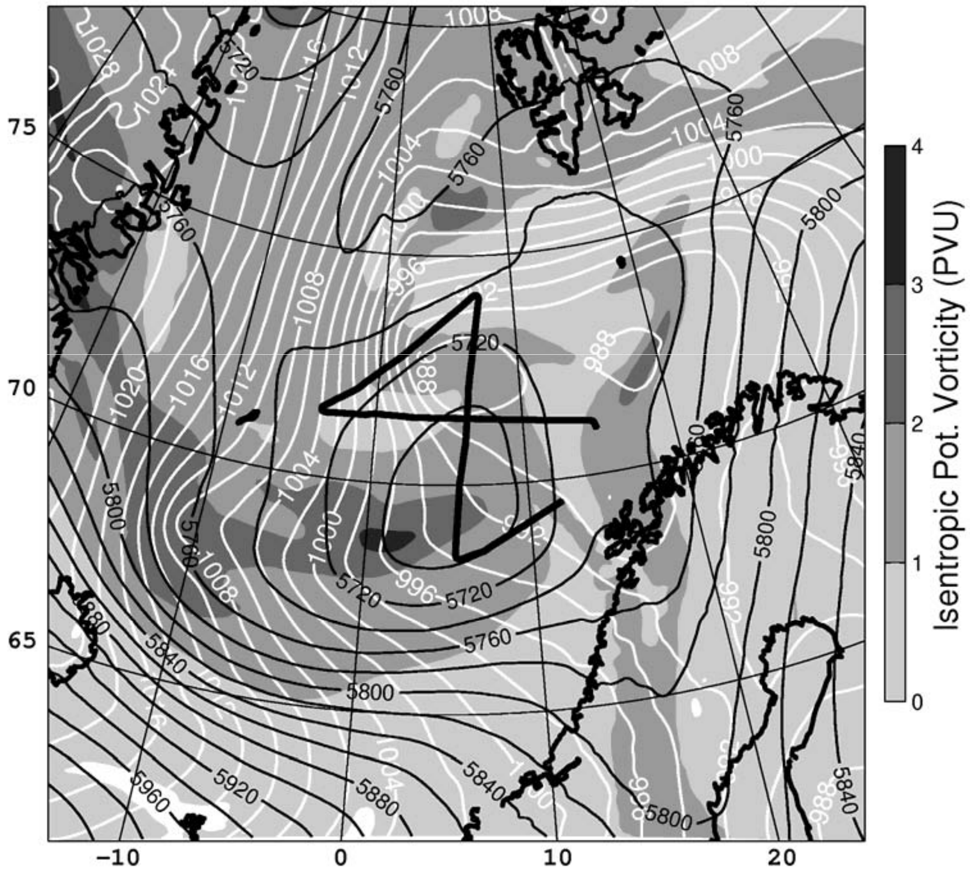


Wind at 925 hPa & SLP (hPa)

Synoptic Situation
3 March 2008 16 UTC



NOAA AVHRR IR & SLP (hPa)



PV at 285 K, Z at 450 hPa, & SLP (hPa)

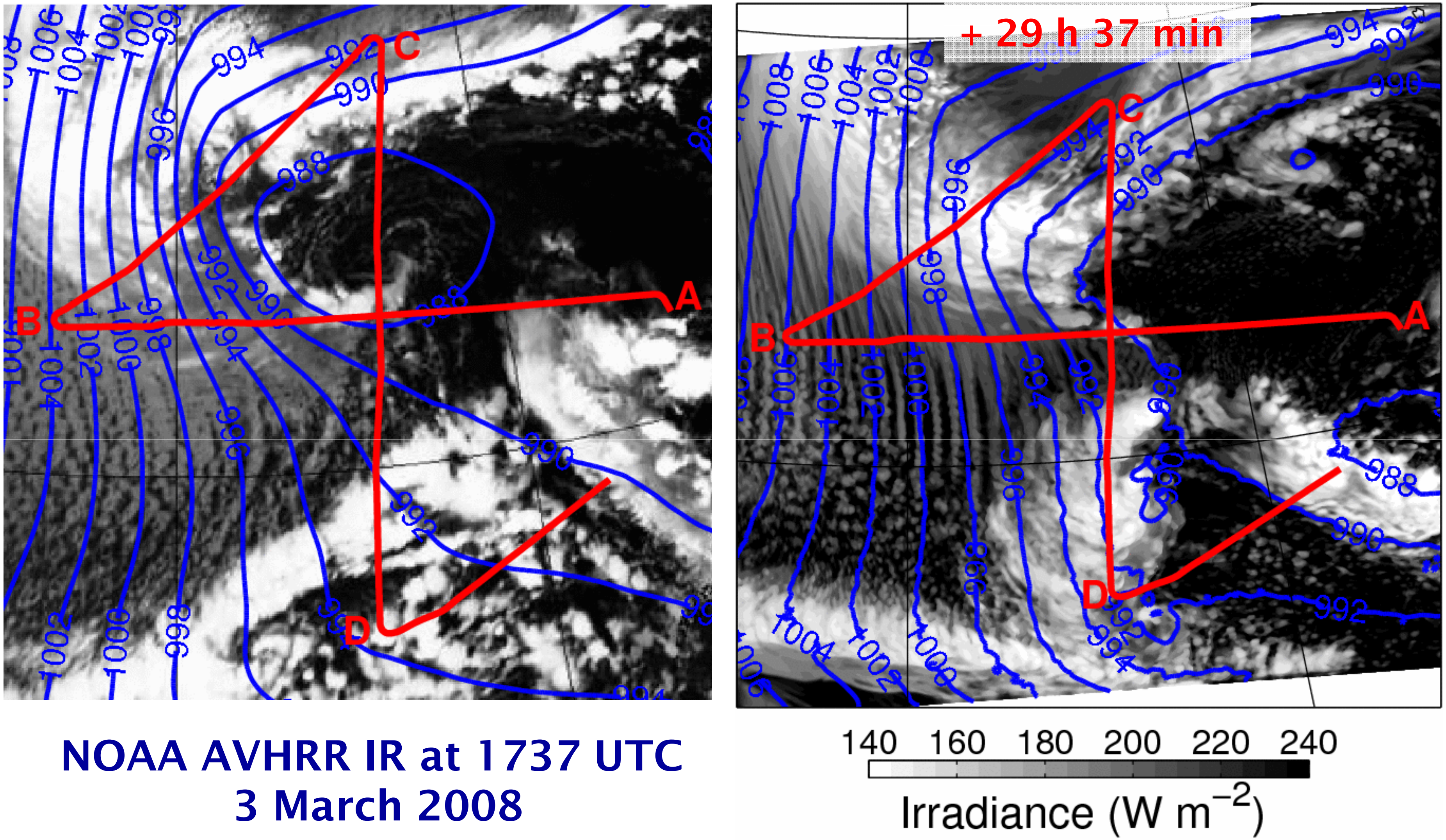
WRF sensitivity tests

Case	Physics	Start time
CTRL	full physics	0600 UTC 03 Mar
FPH-1202	full physics	1200 UTC 02 Mar
FPH-0003	full physics	0000 UTC 03 Mar
FPH-1203	full physics	1200 UTC 03 Mar
NOSFLX-1	no surface fluxes	0600 UTC 03 Mar
NOSFLX-2	surface fluxes switched off at 0000 UTC 04 Mar	0600 UTC 03 Mar

OLR (W/m^2) and SLP (hPa)

ECMWF SLP (hPa)

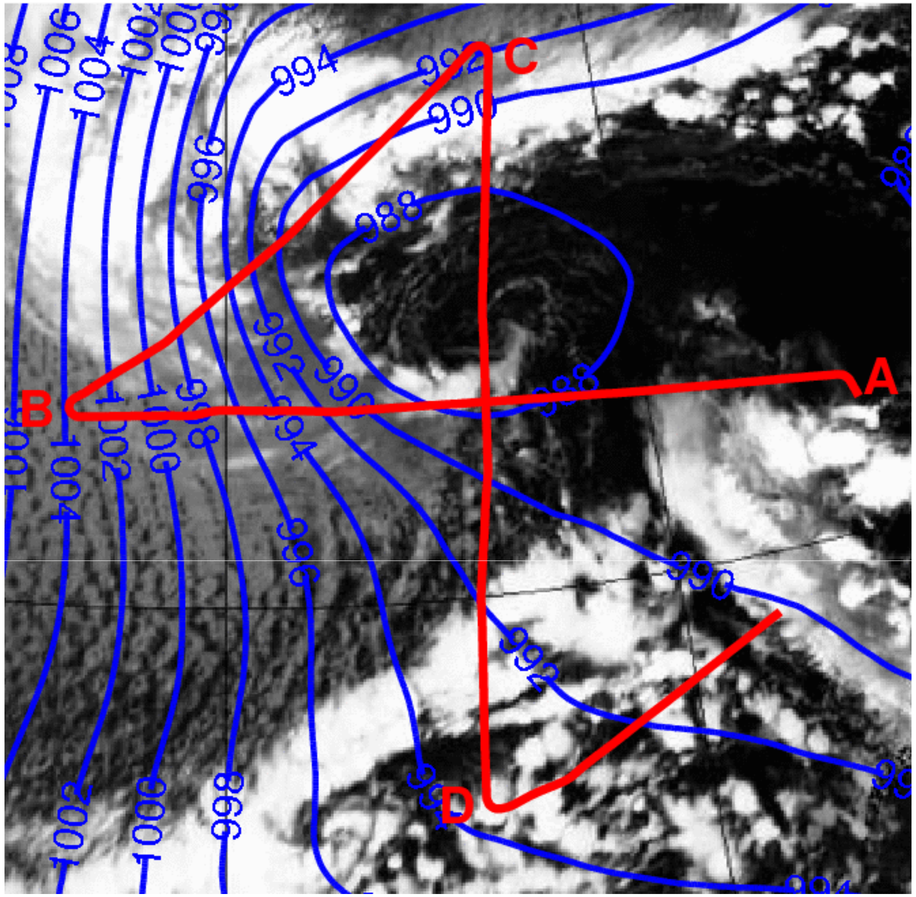
WRF full physics: 2 March 12 UTC

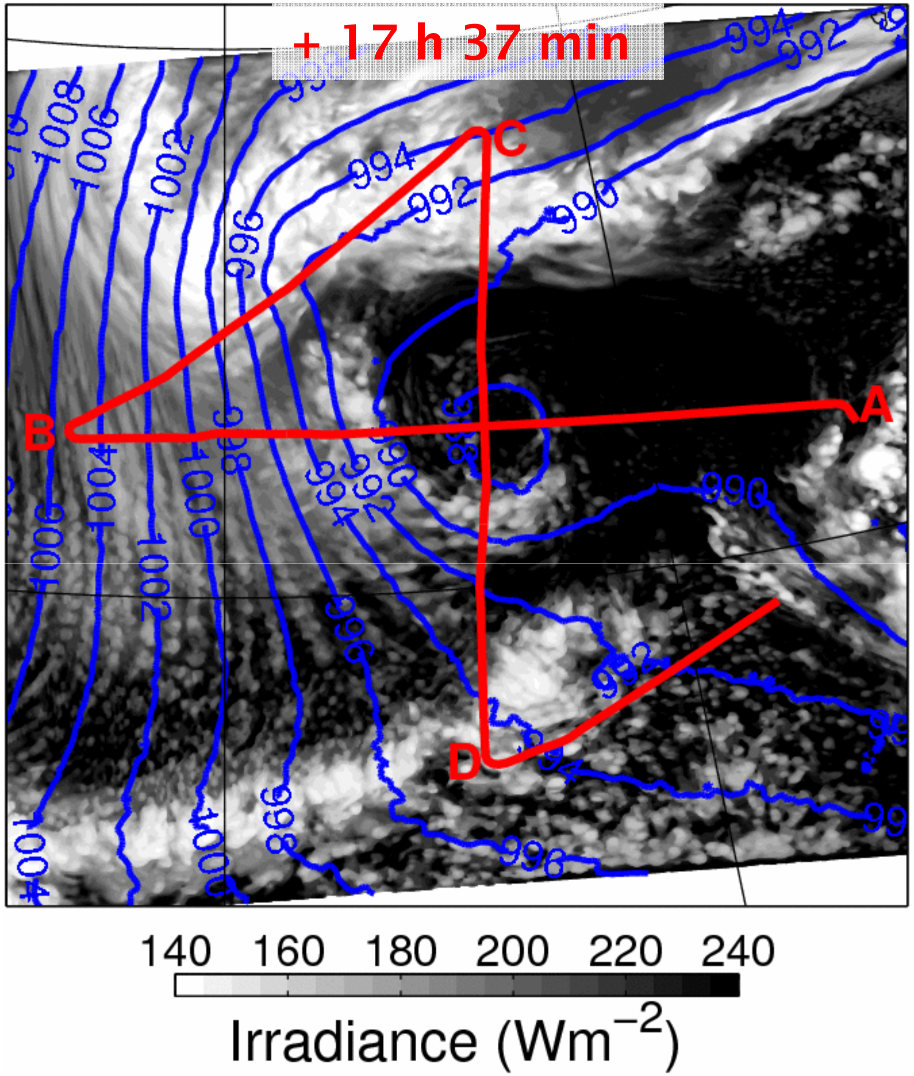


NOAA AVHRR IR at 1737 UTC
3 March 2008

ECMWF SLP (hPa)

WRF full physics: 3 March 00 UTC

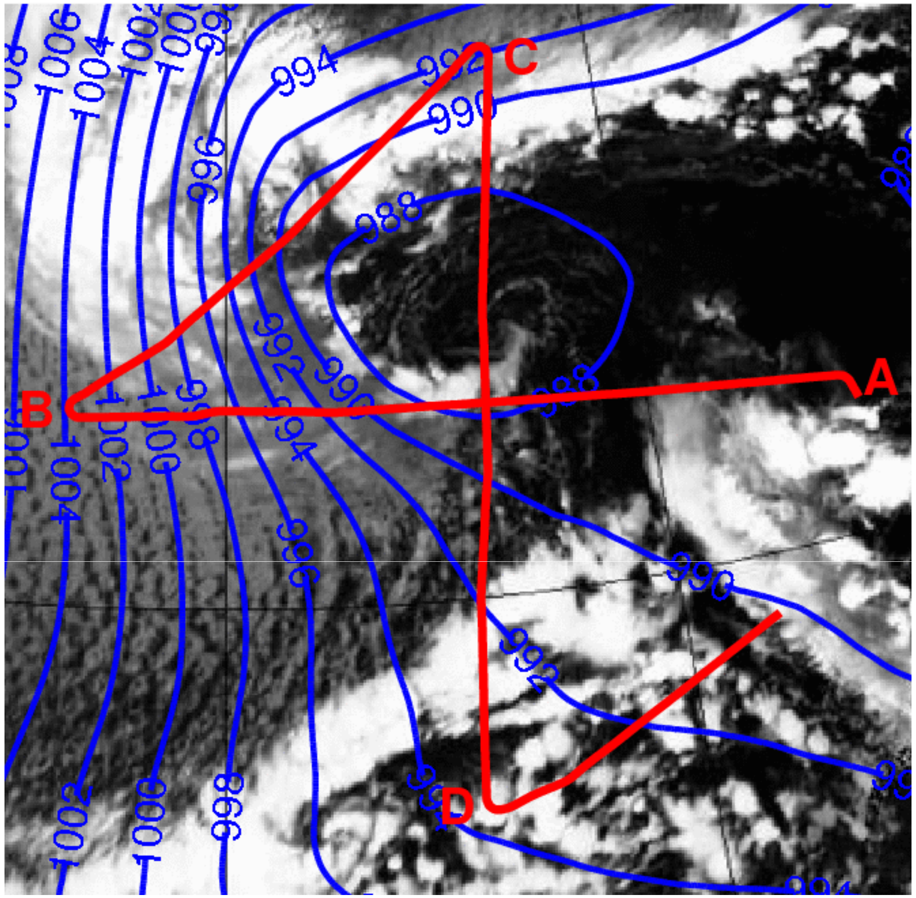




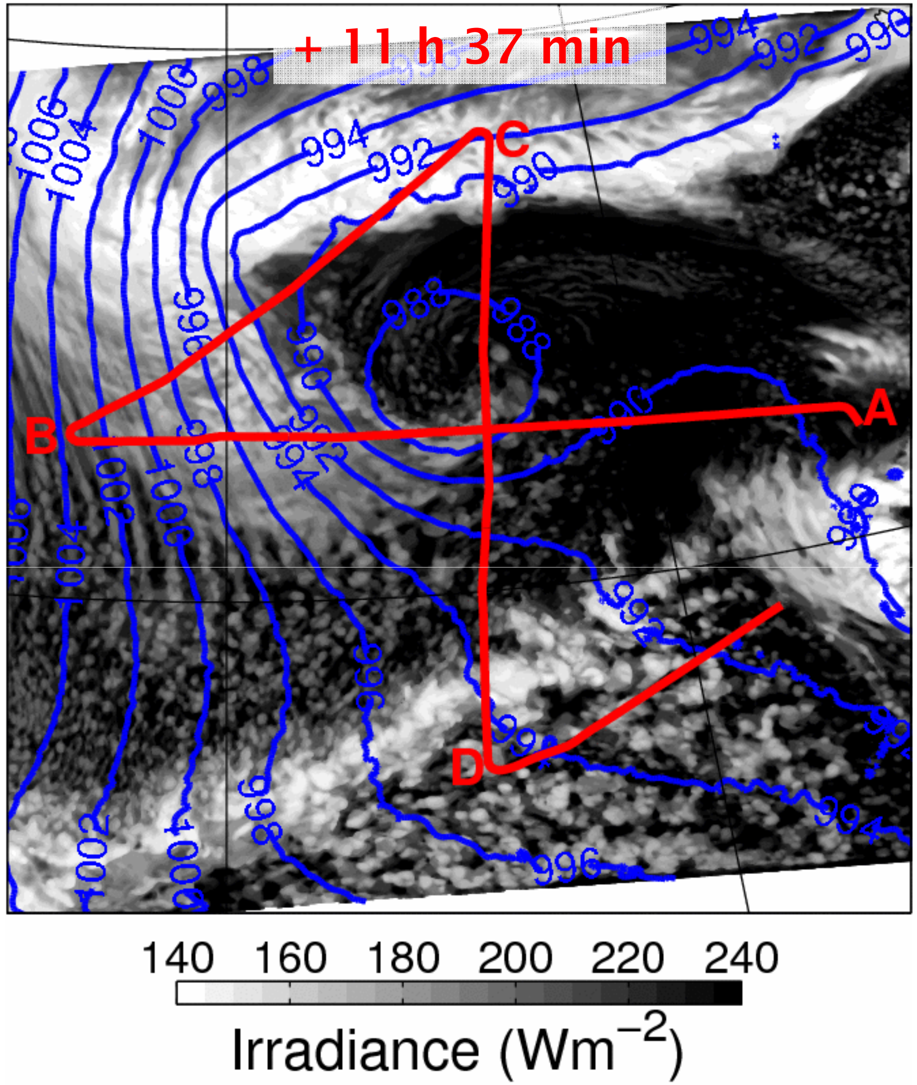
NOAA AVHRR IR at 1737 UTC
3 March 2008

ECMWF SLP (hPa)

WRF full physics: 3 March 06 UTC

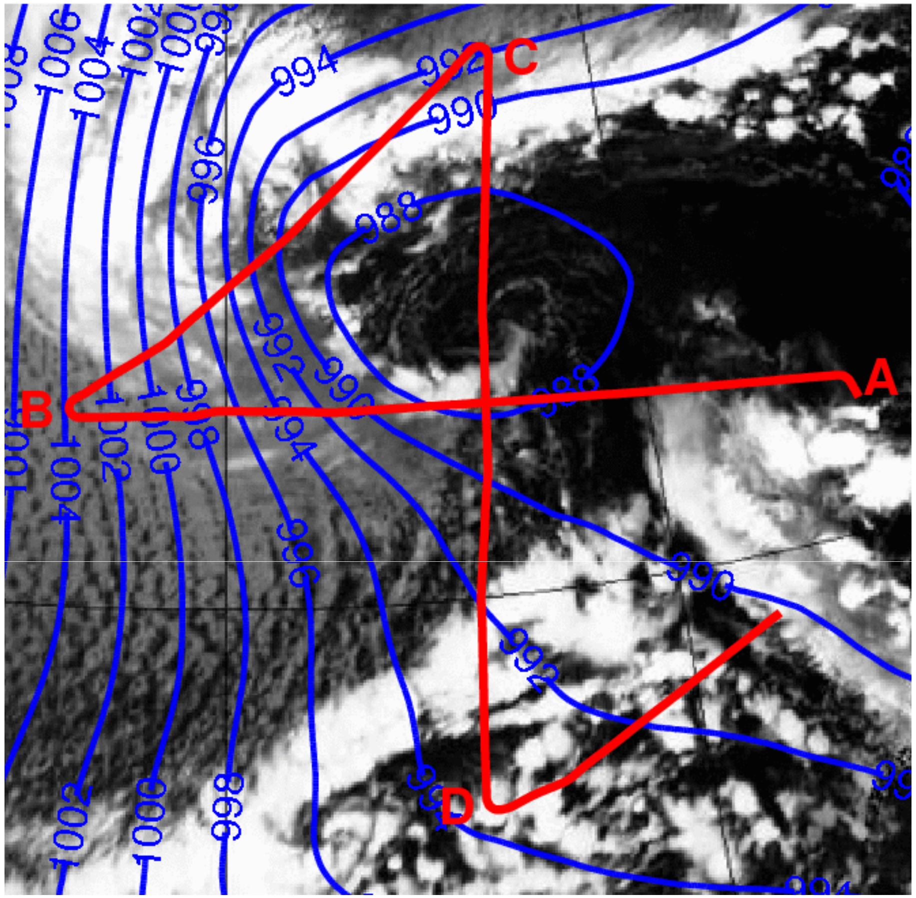


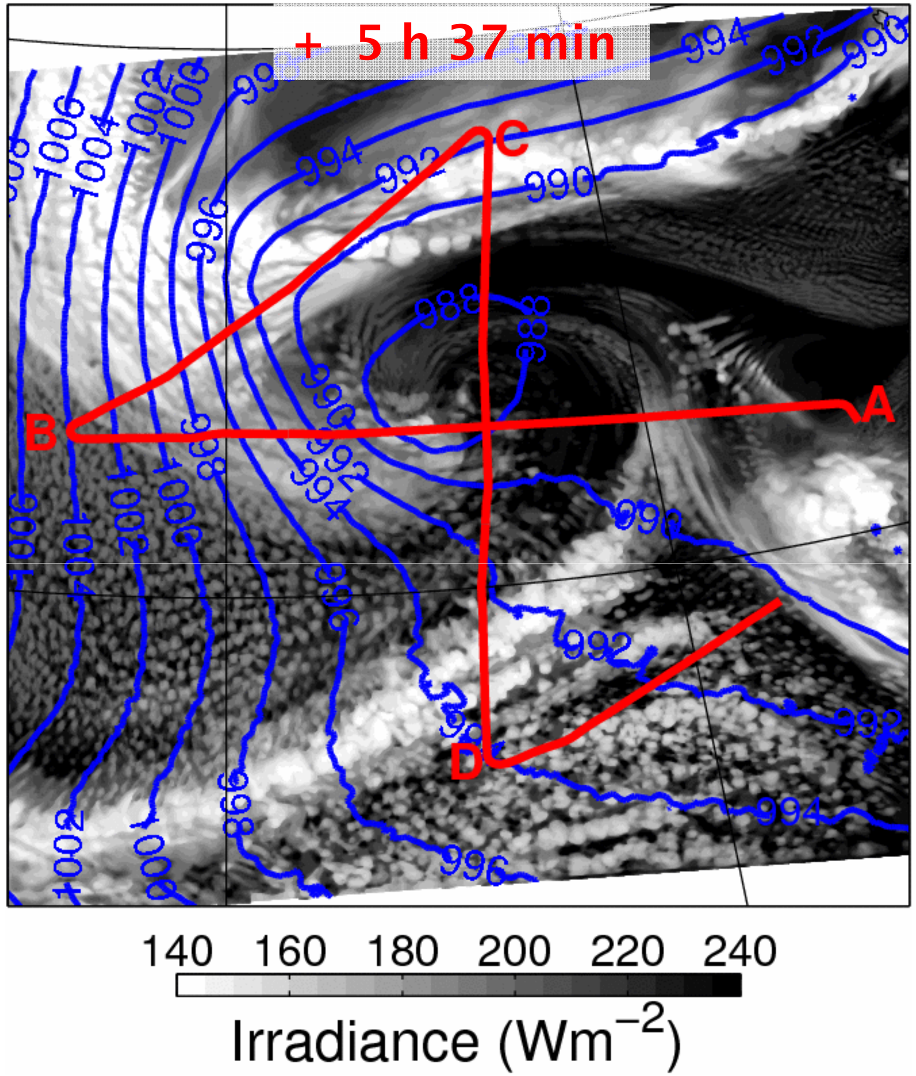
NOAA AVHRR IR at 1737 UTC
3 March 2008



ECMWF SLP (hPa)

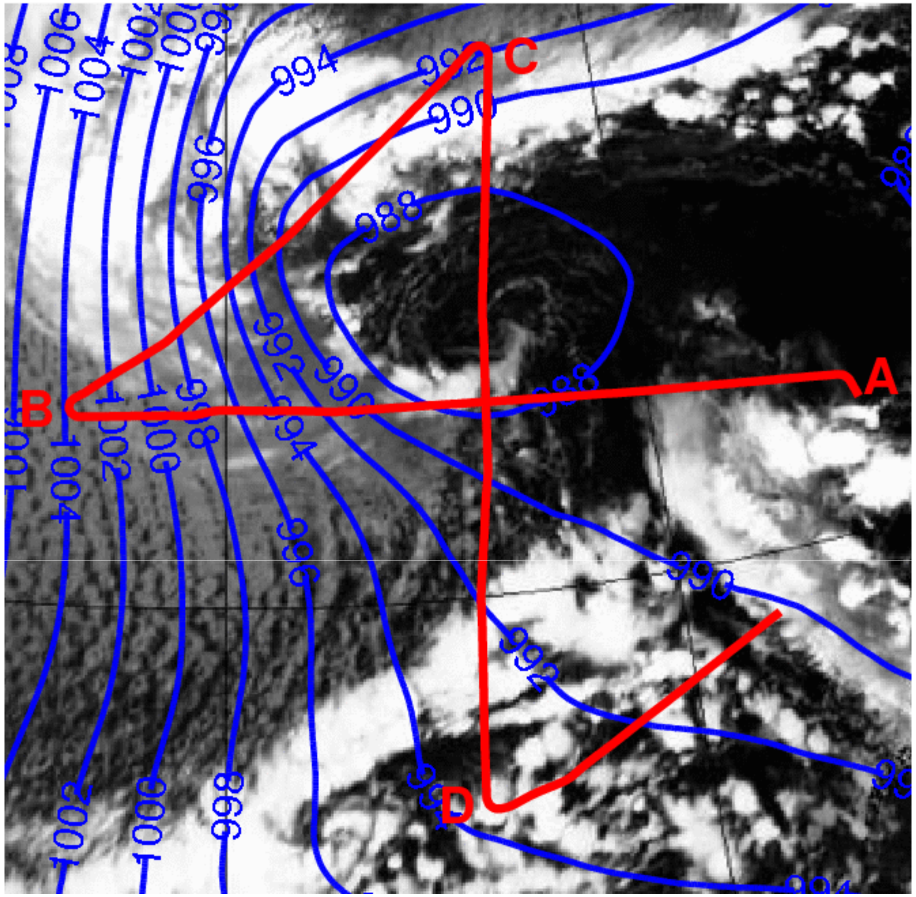
WRF full physics: 3 March 12 UTC





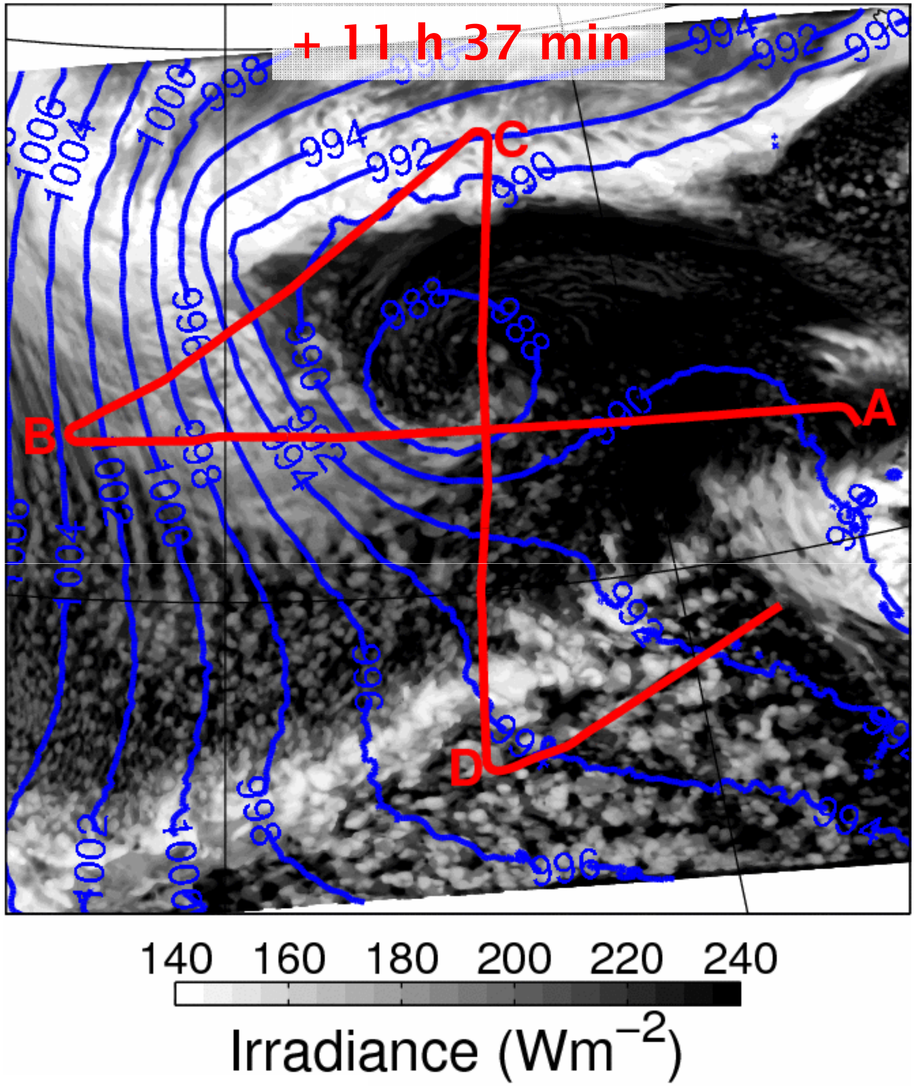
NOAA AVHRR IR at 1737 UTC
3 March 2008

ECMWF SLP (hPa)



NOAA AVHRR IR at 1737 UTC
3 March 2008

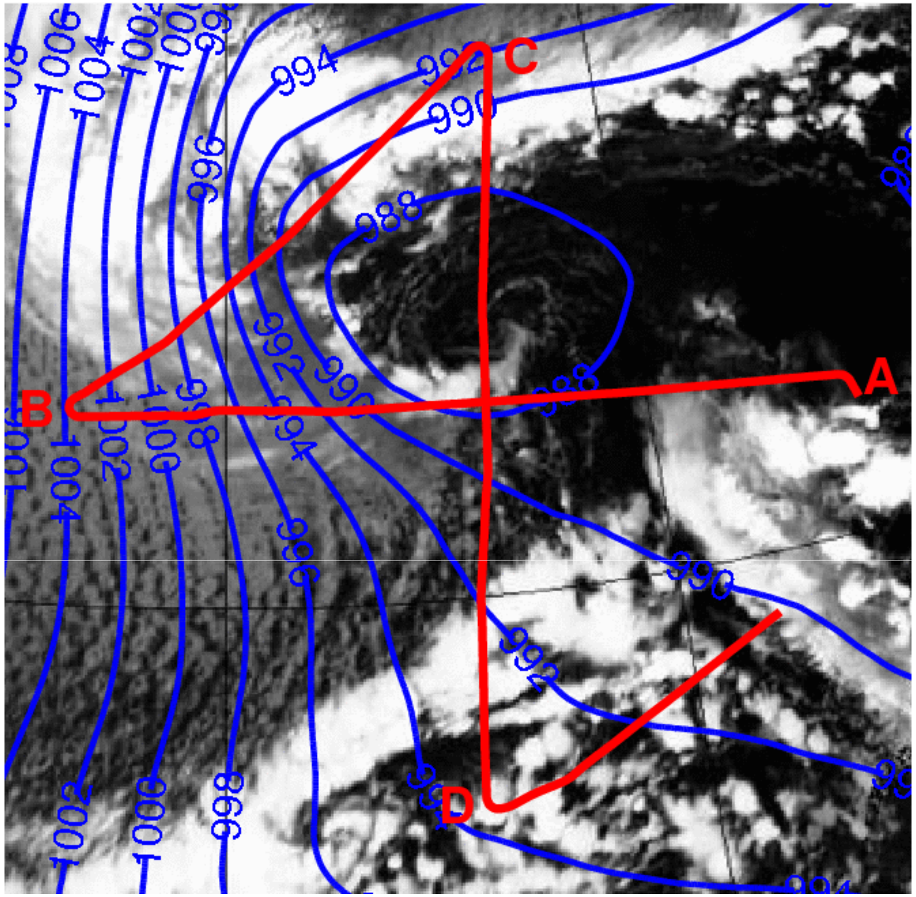
WRF full physics: 3 March 06 UTC

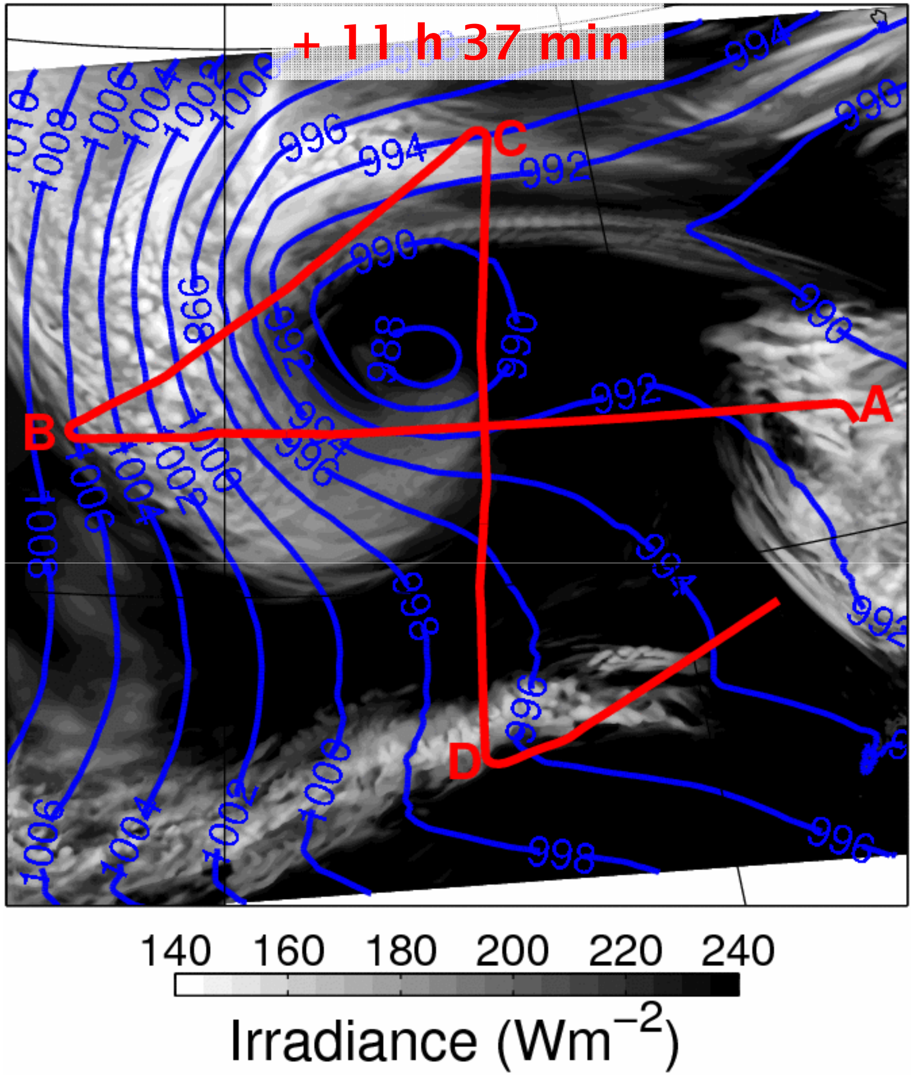


Reference (CTRL) Run

ECMWF SLP (hPa)

WRF no s-fluxes: 3 March 06 UTC



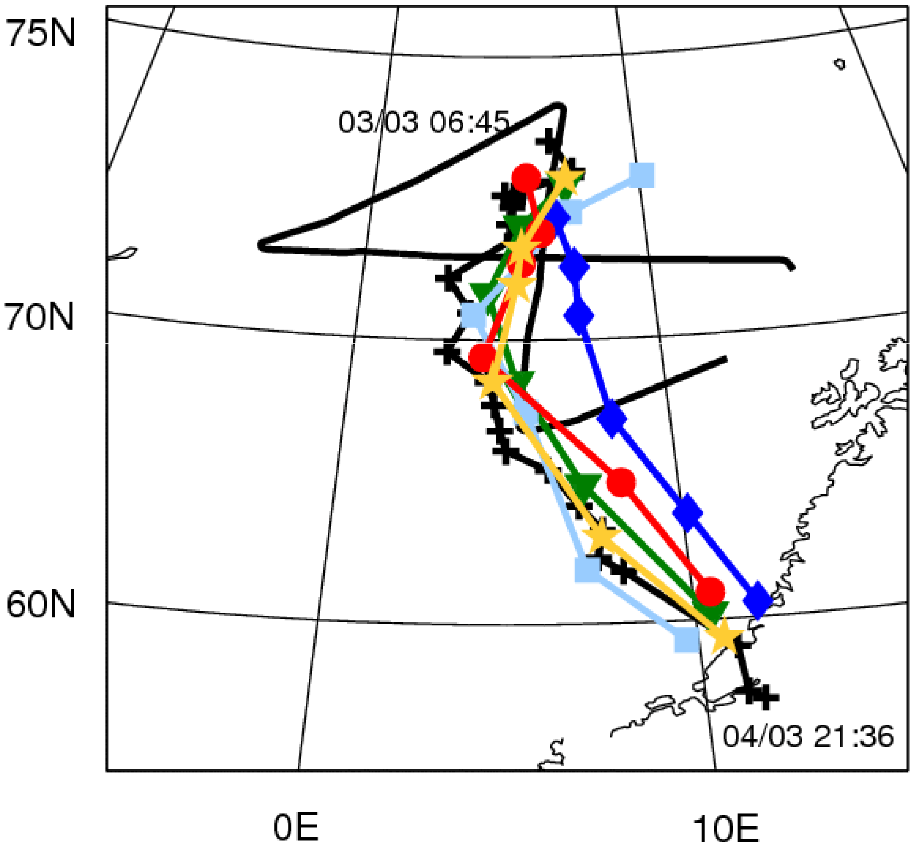


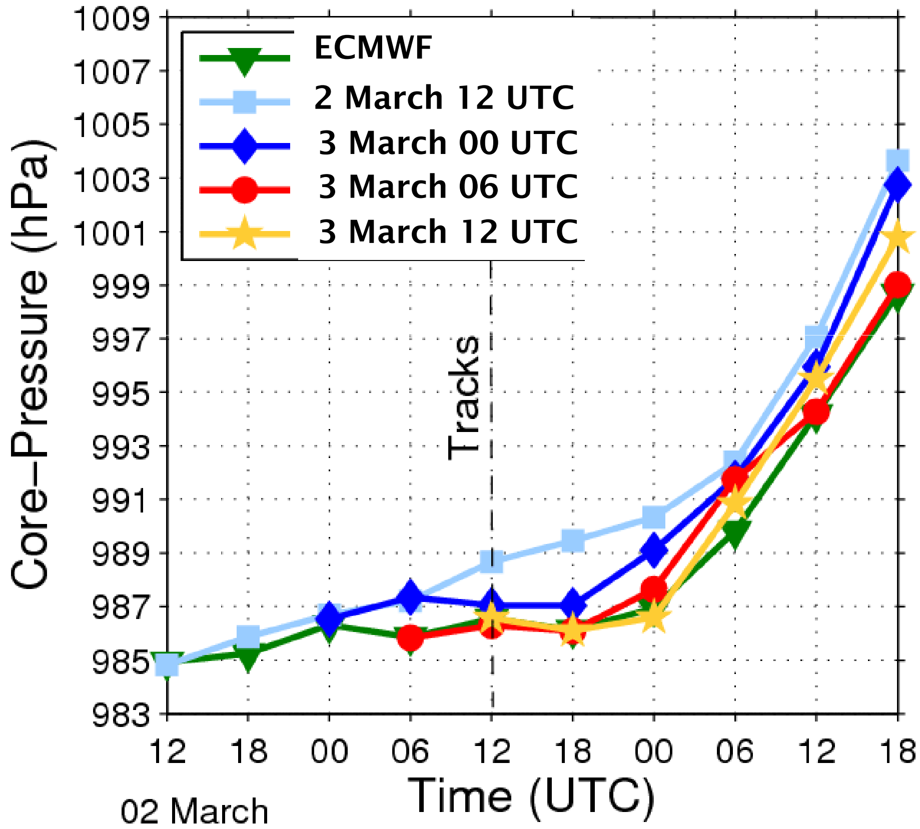
NOAA AVHRR IR at 1737 UTC
3 March 2008

WRF sensitivity tests

Track and Core Pressure (hPa)

Initialisation Time Dependence

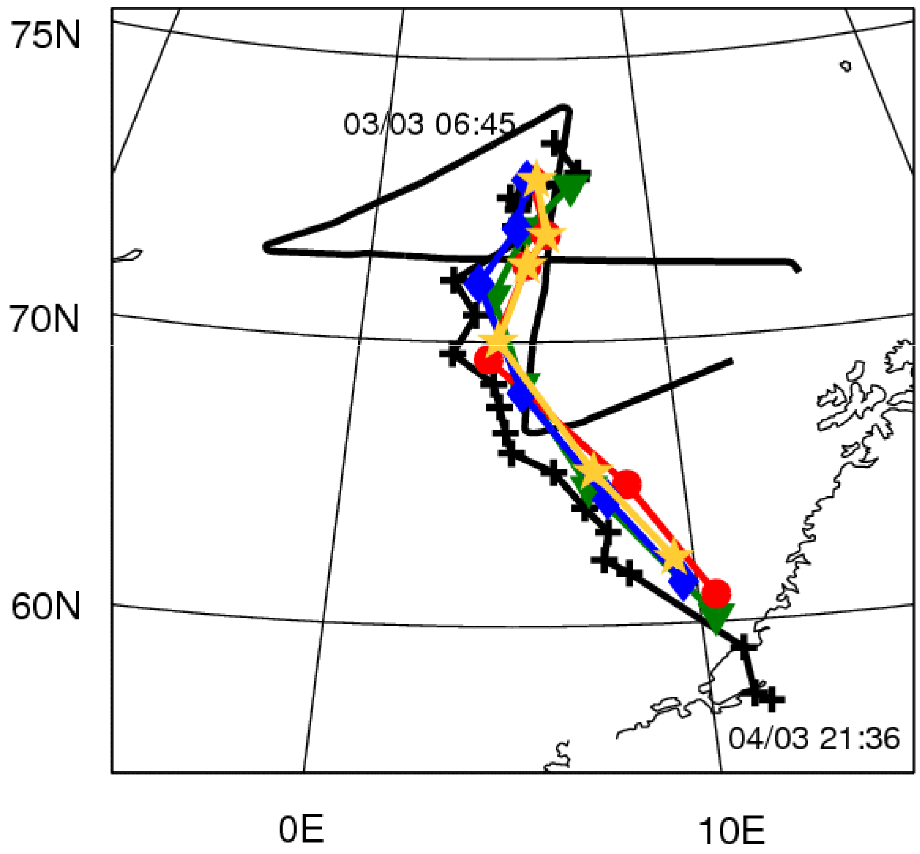


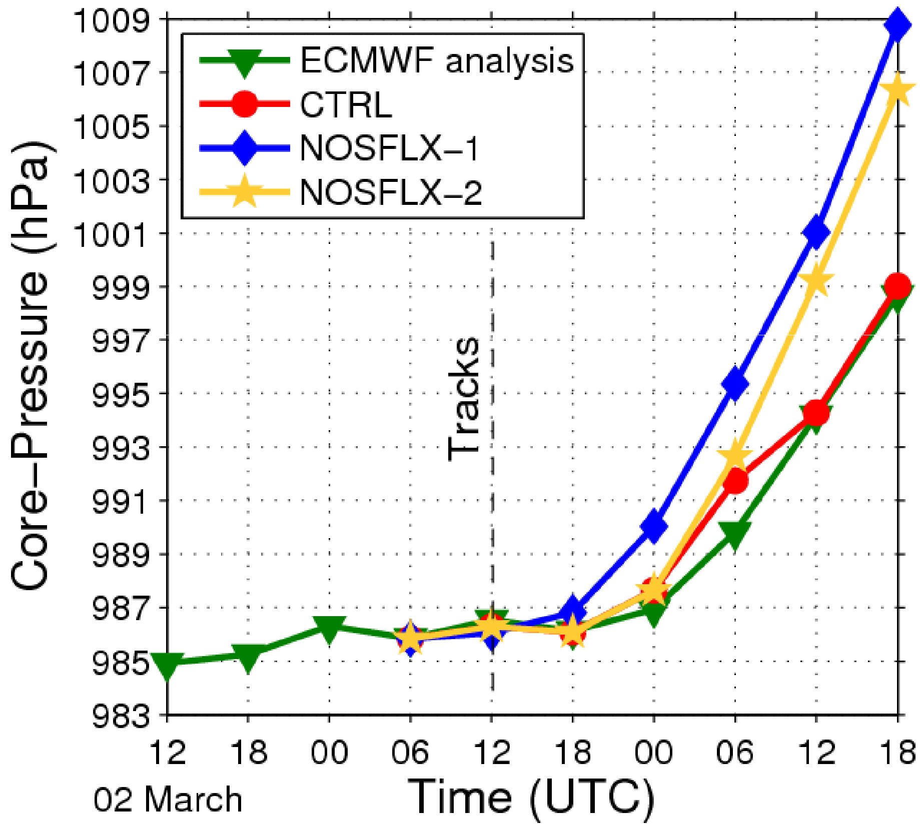


WRF sensitivity tests

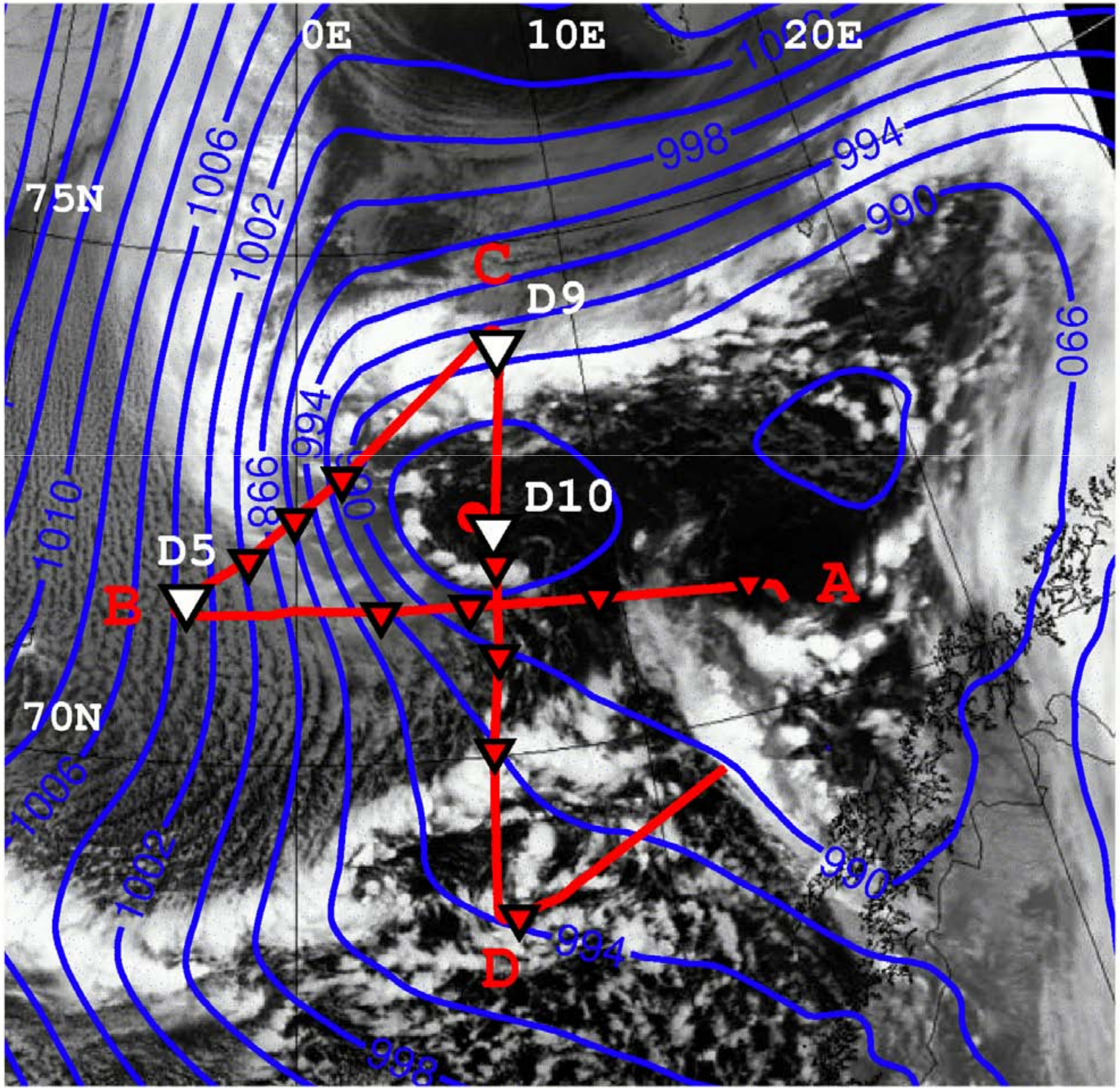
Track and Core Pressure (hPa)

Surface Fluxes On/Off

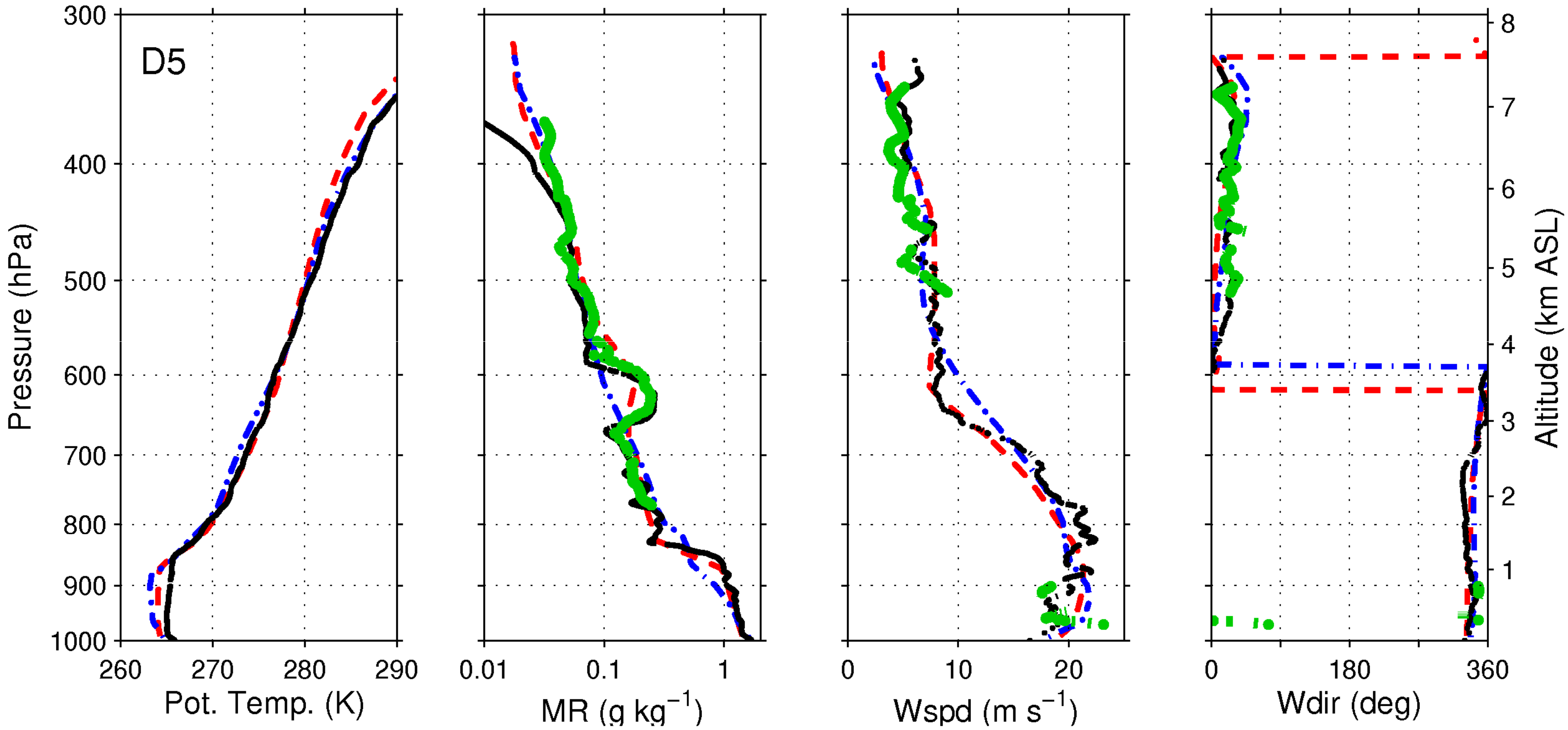




Dropsondes vs Lidar and Model



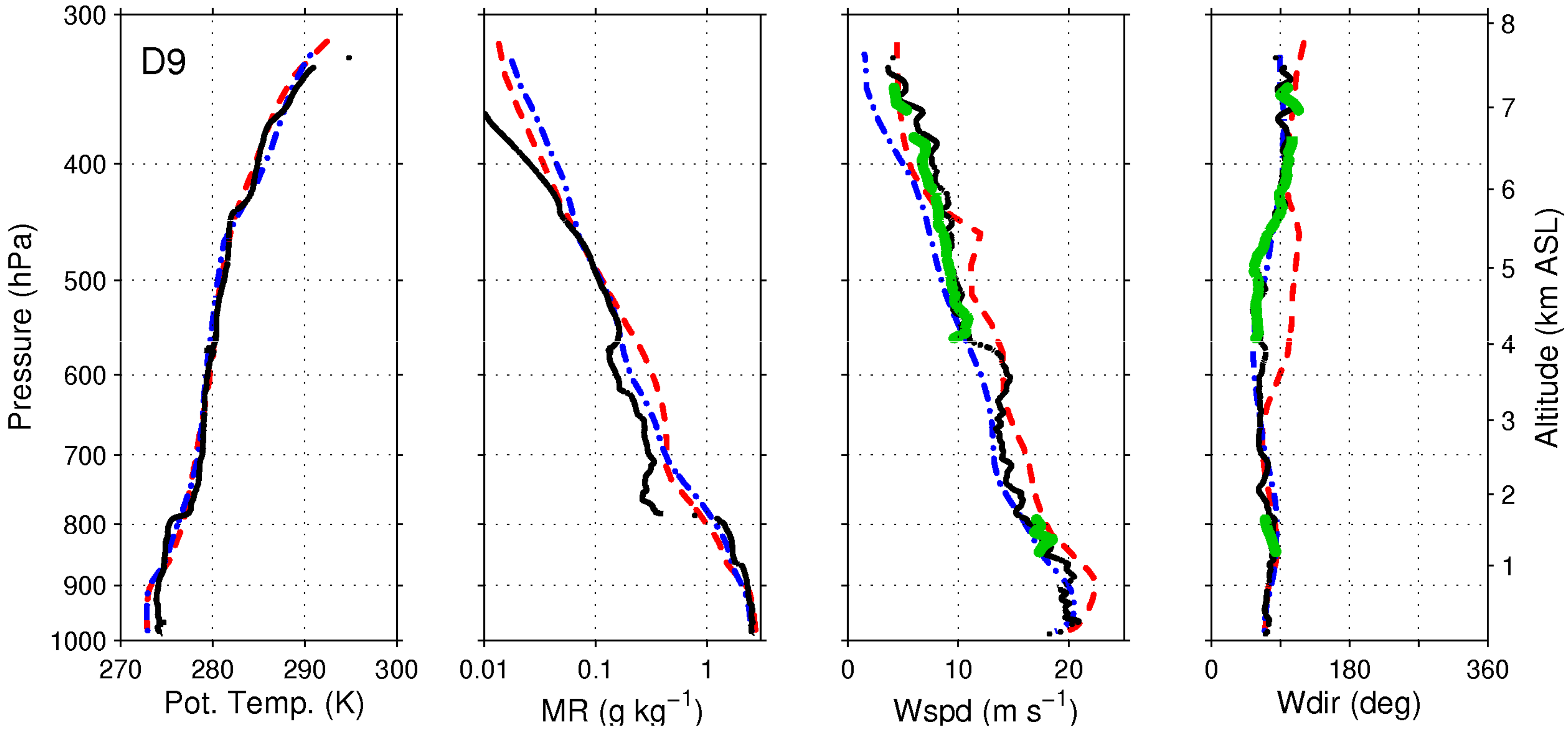
Dropsondes vs Lidar and Model



Dropsonde (thin solid) **Lidar (thick solid),**

WRF CTRL (dashed) **ECMWF (dash-dotted)**

Dropsondes vs Lidar and Model



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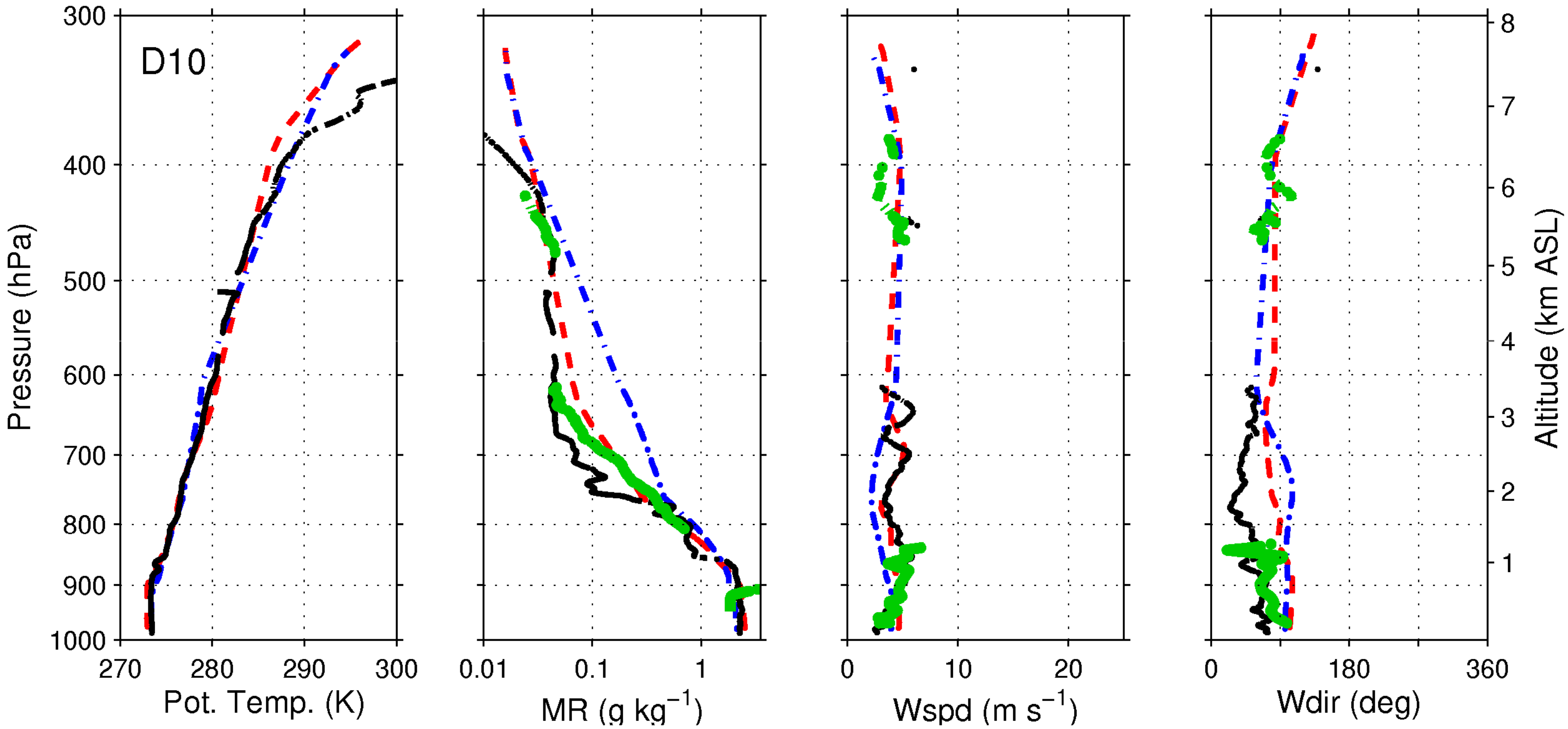
Dropsondes vs Lidar and Model



Dropsonde (thin solid)
WRF CTRL (dashed)
Lidar (thick solid),
ECMWF (dash-dotted)

Airborne Lidar Observations

Backscatter Ratio at 1064 nm

data available ~98 % of flight time

Water Vapor Mixing Ratio (g kg^{-1})

data available ~36 % of flight time

rel. difference to drops ~ 3.8 %

$\Delta x \sim 5$ km, $\Delta z \sim 350$ m

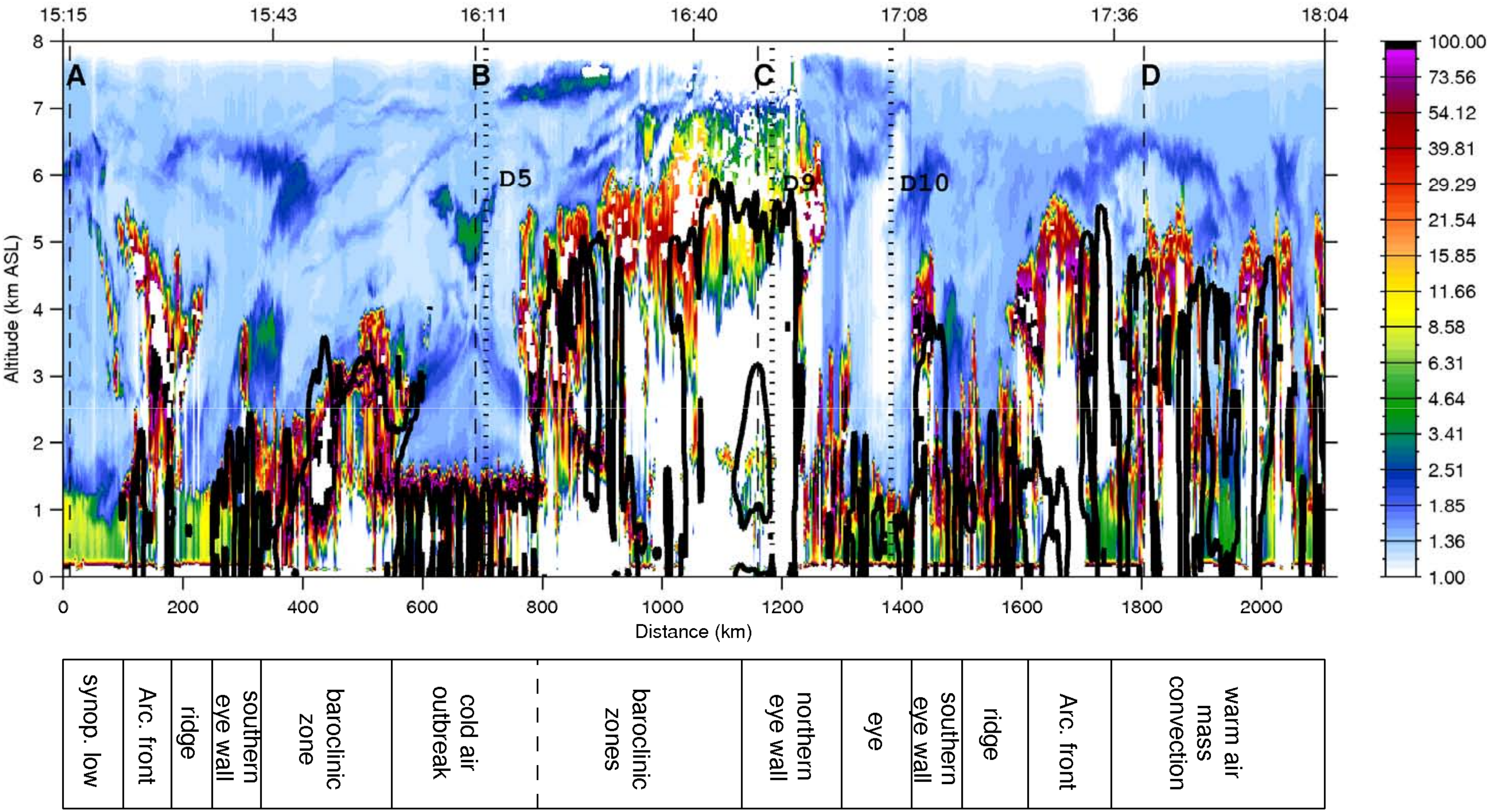
Horizontal Wind Speed (ms^{-1})

data available ~53 % of flight time

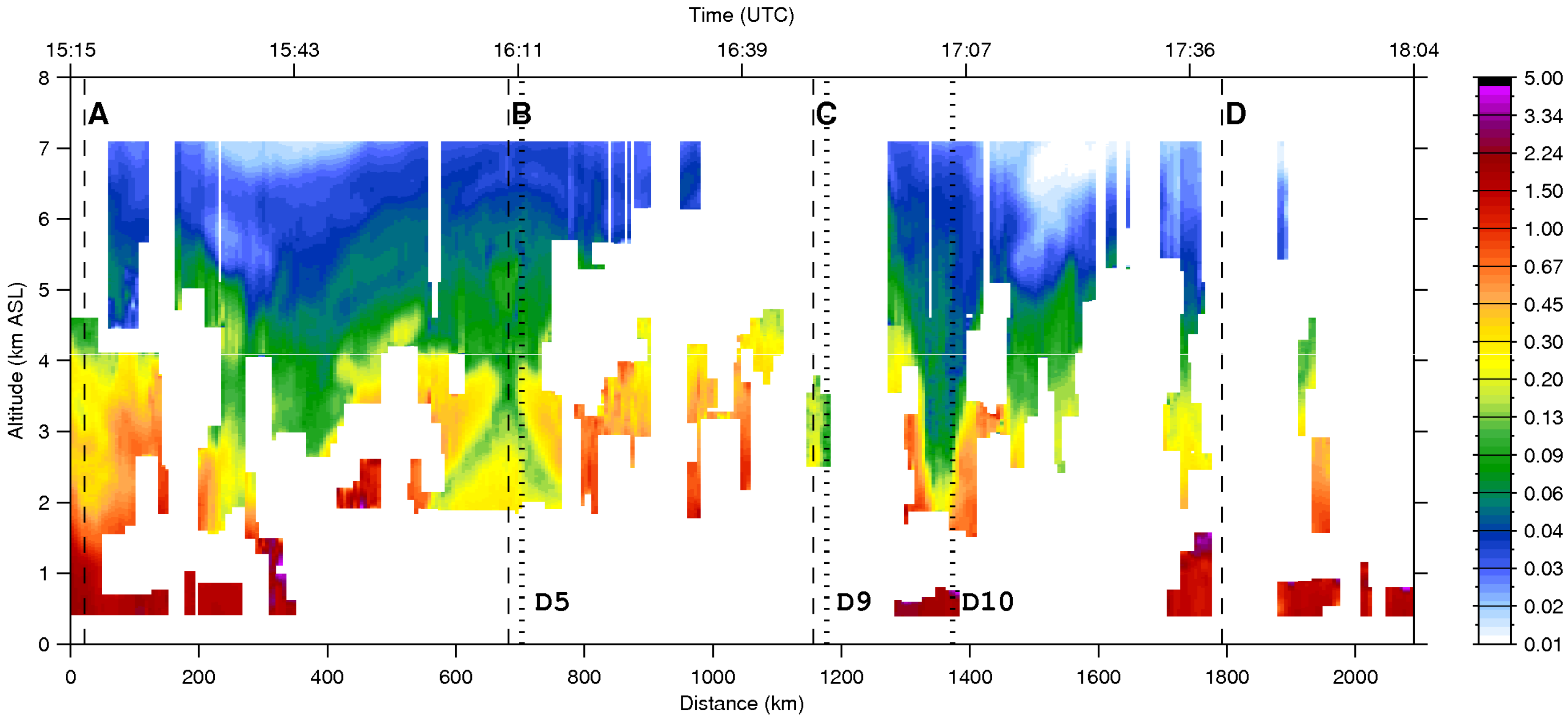
rel. difference to drops ~ 3.5 %

$\Delta x \sim 7$ km, $\Delta z \sim 100$ m

Backscatter Ratio

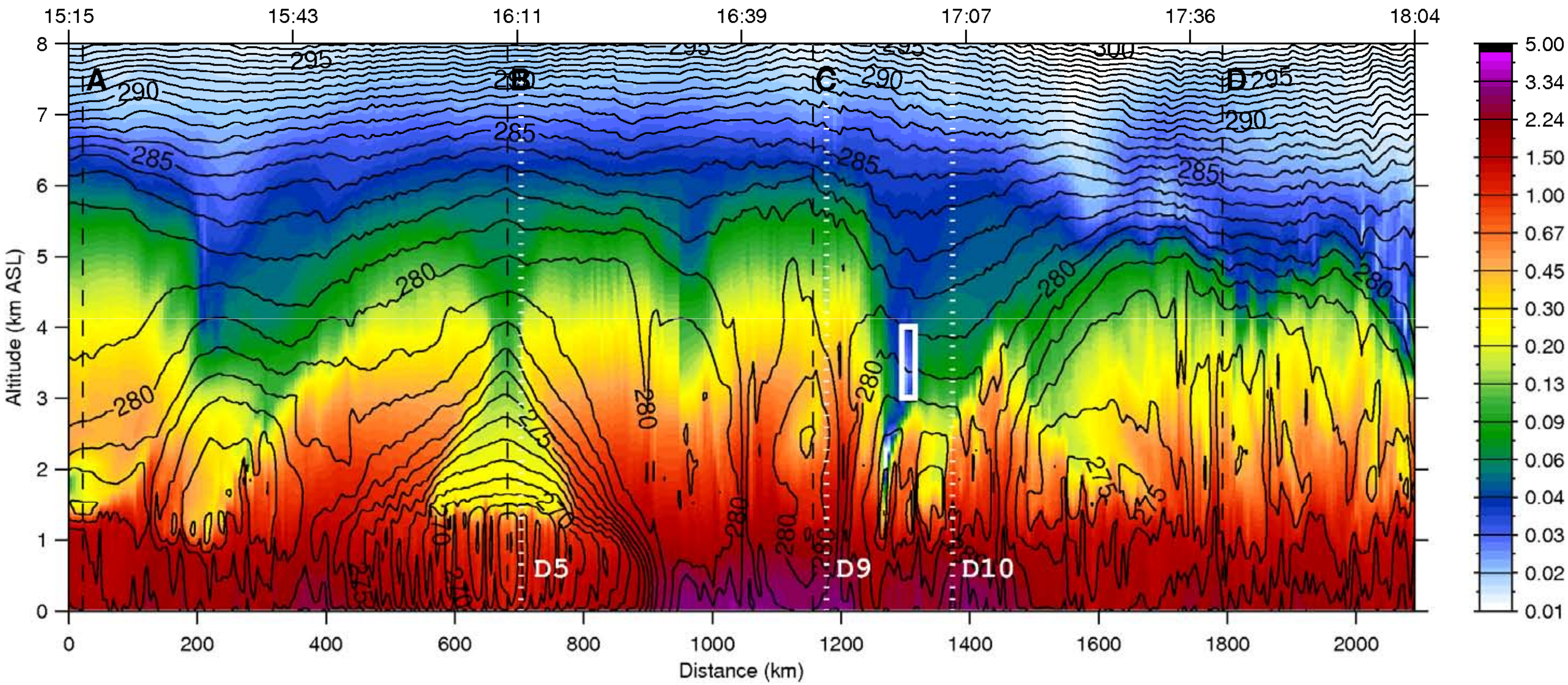


Water Vapor Mixing Ratio (g kg^{-1})



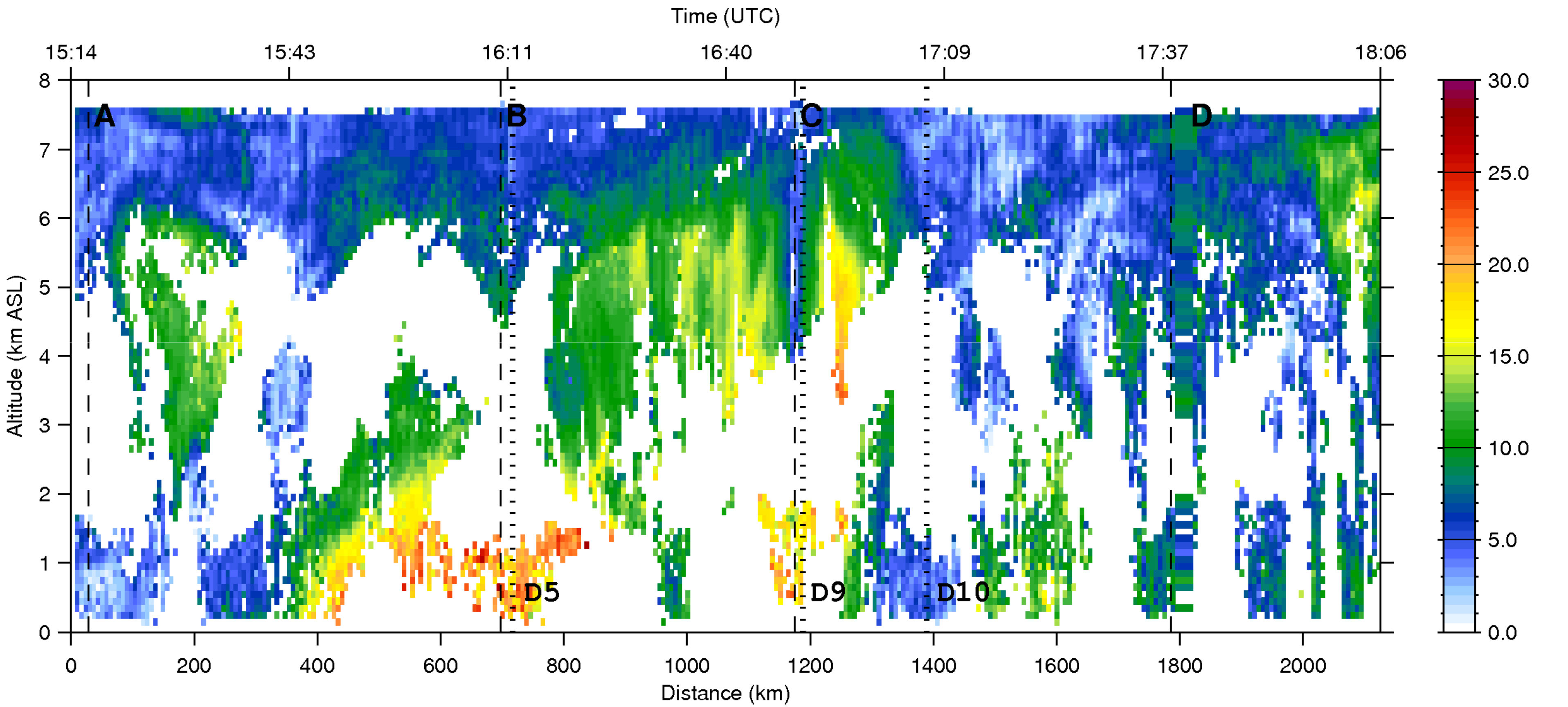
Water Vapor Mixing Ratio (g kg^{-1})

WRF CTRL Simulation



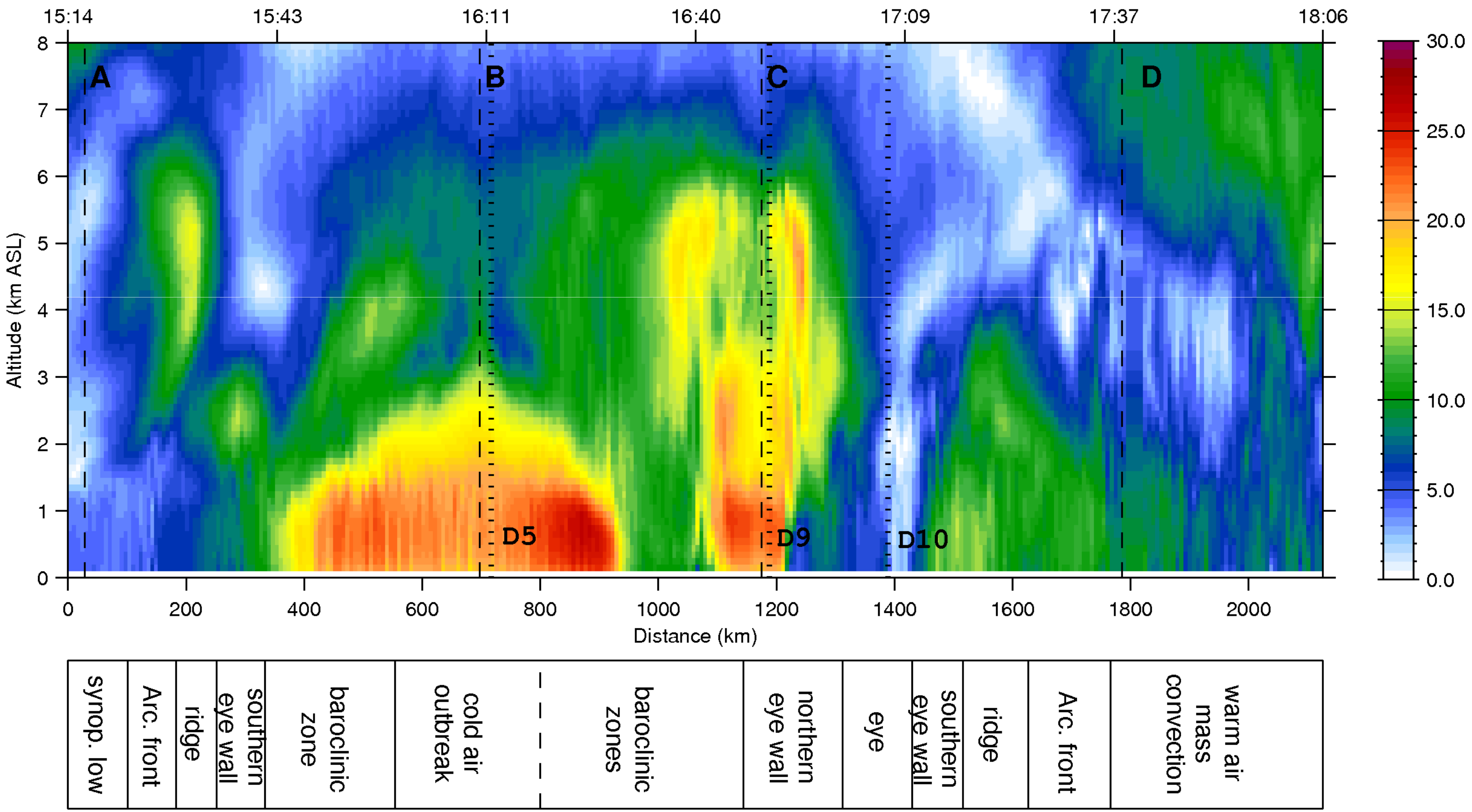
Contour lines: Equivalent Potential Temperature (K)

Horizontal Wind (ms⁻¹)

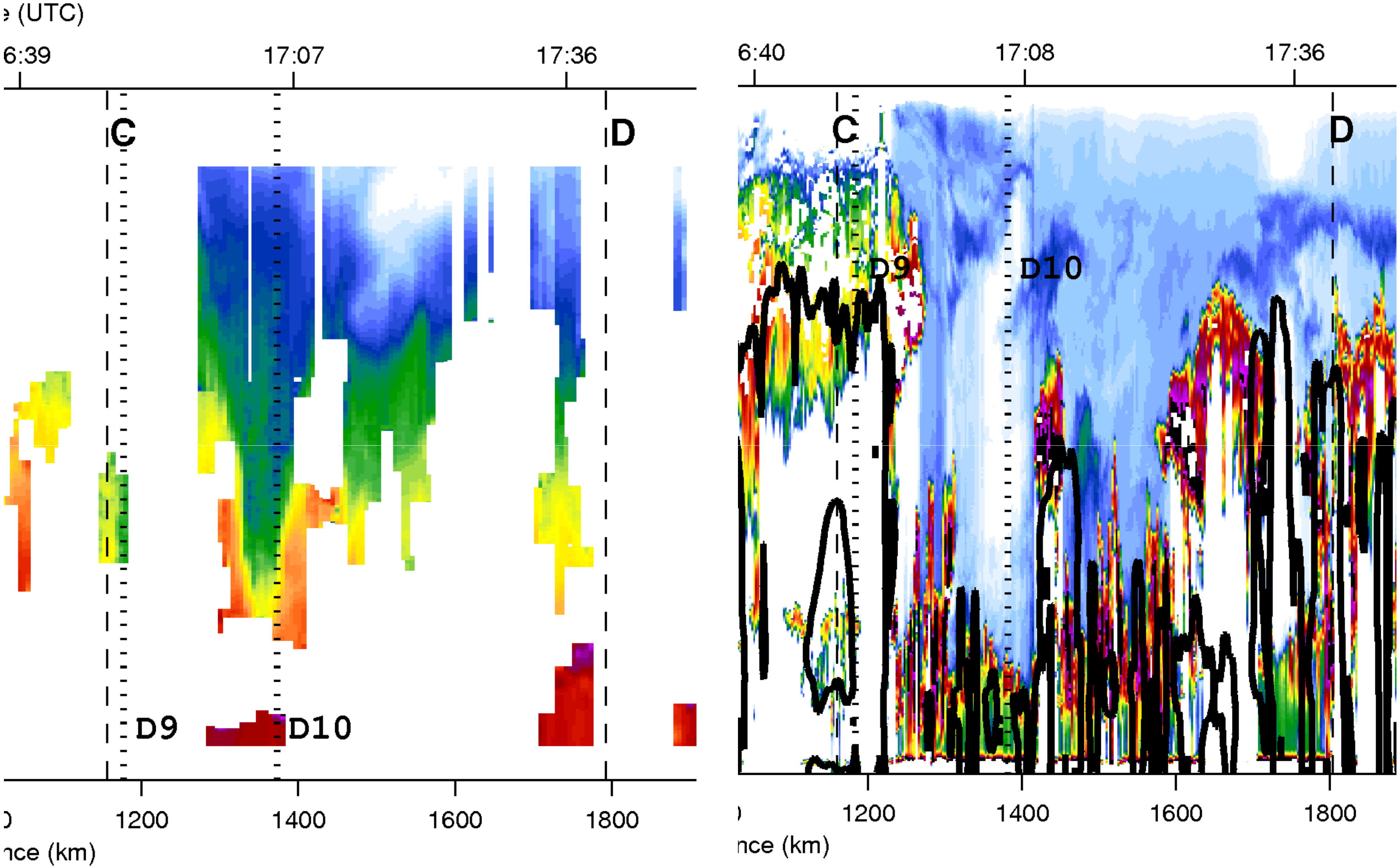


Horizontal Wind (ms^{-1})

WRF CTRL Simulation



Structure of the polar low core



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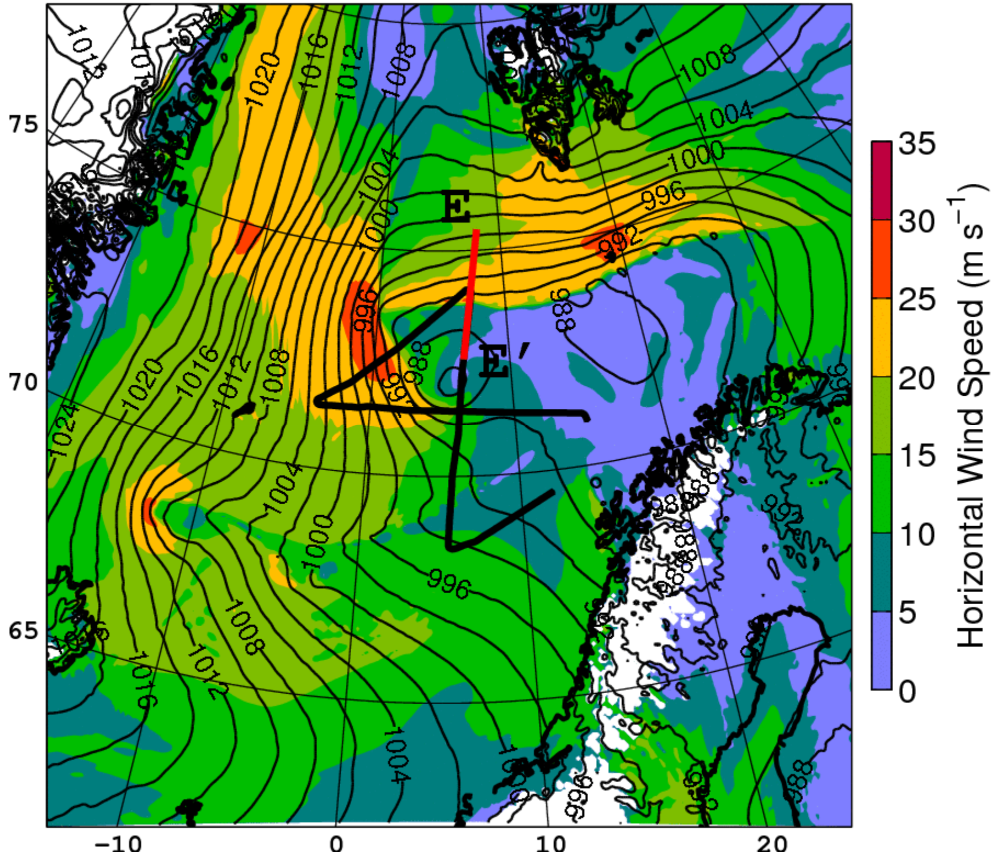
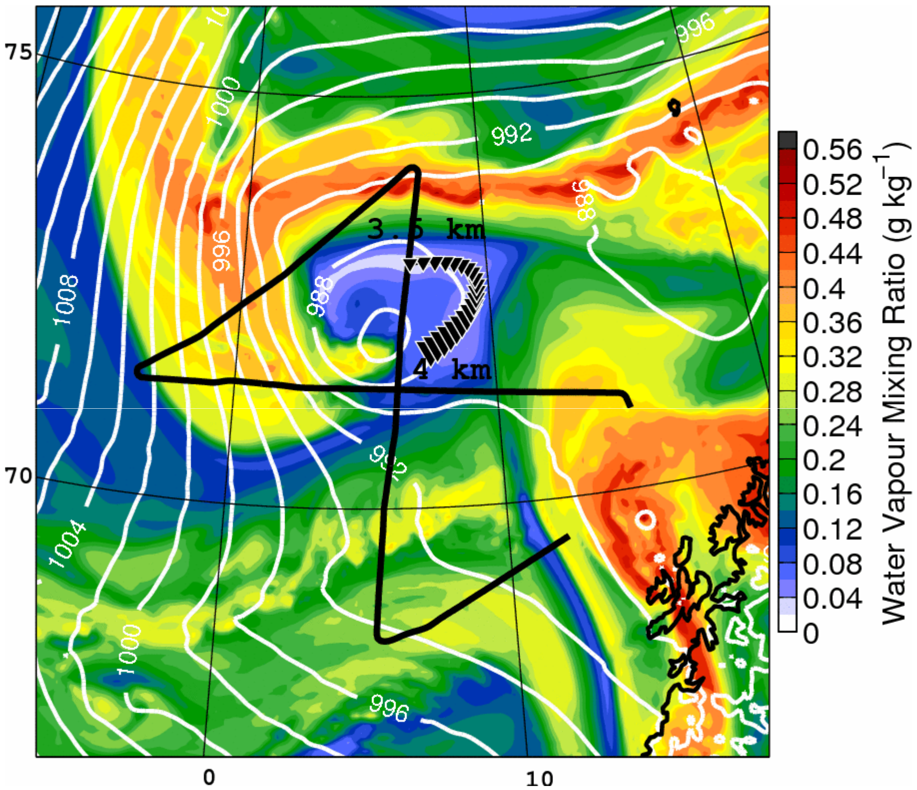


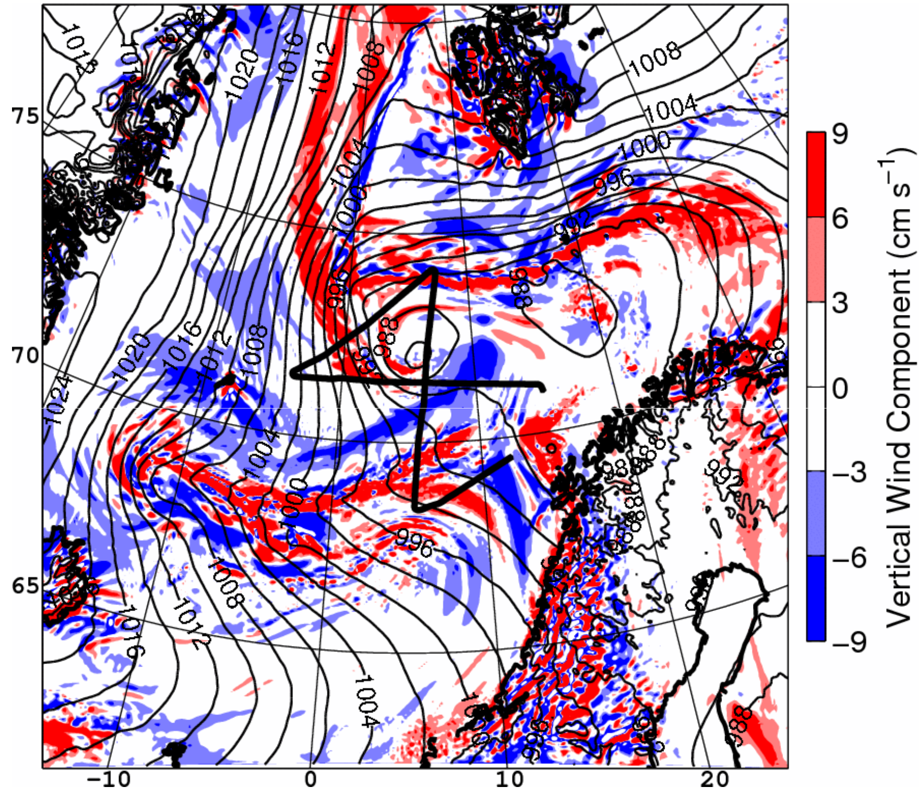
- backward trajectories
- radial wind profile at extended section

Trajectories: subsidence of 500 m/10 h

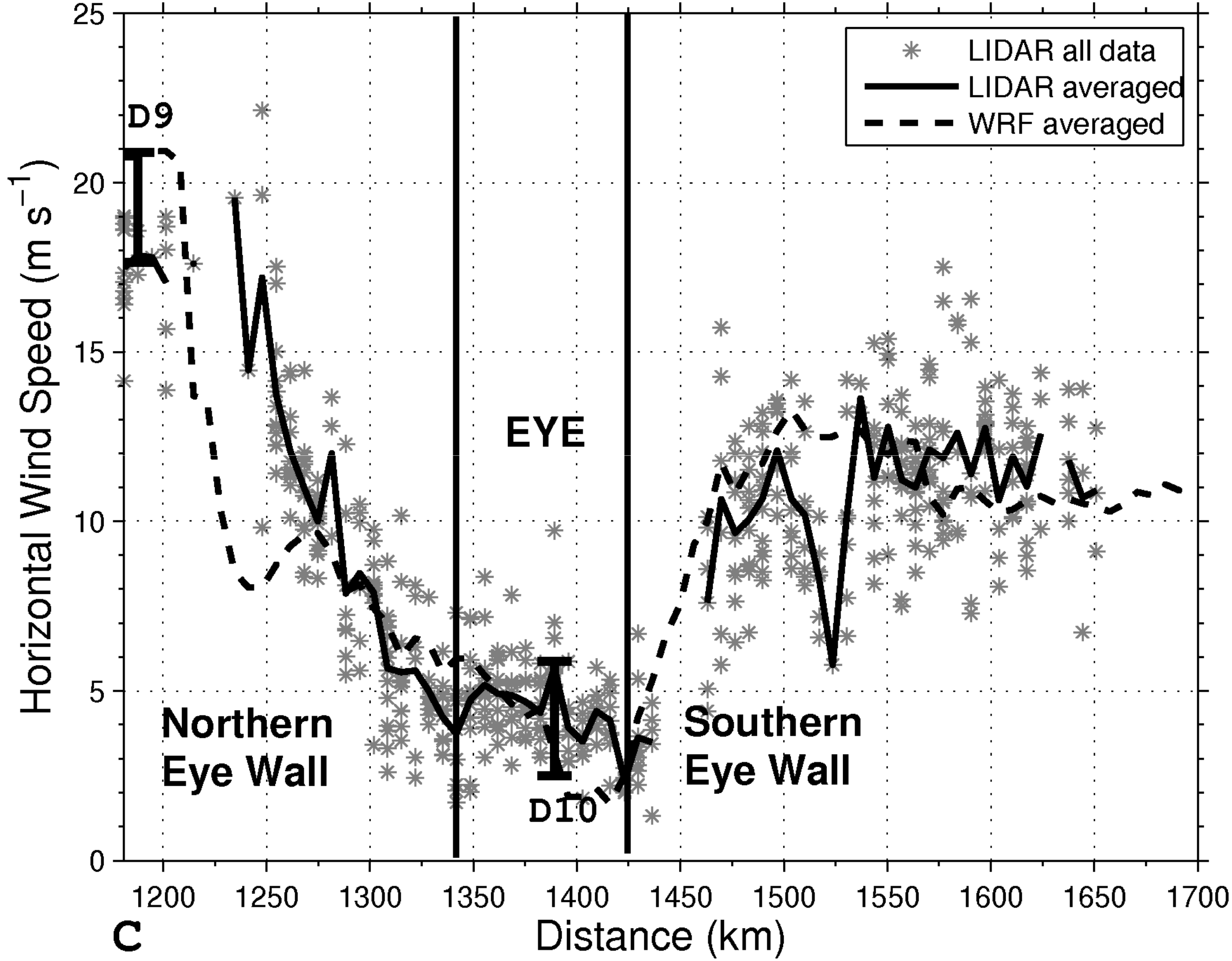
3 March 2008 16 UTC



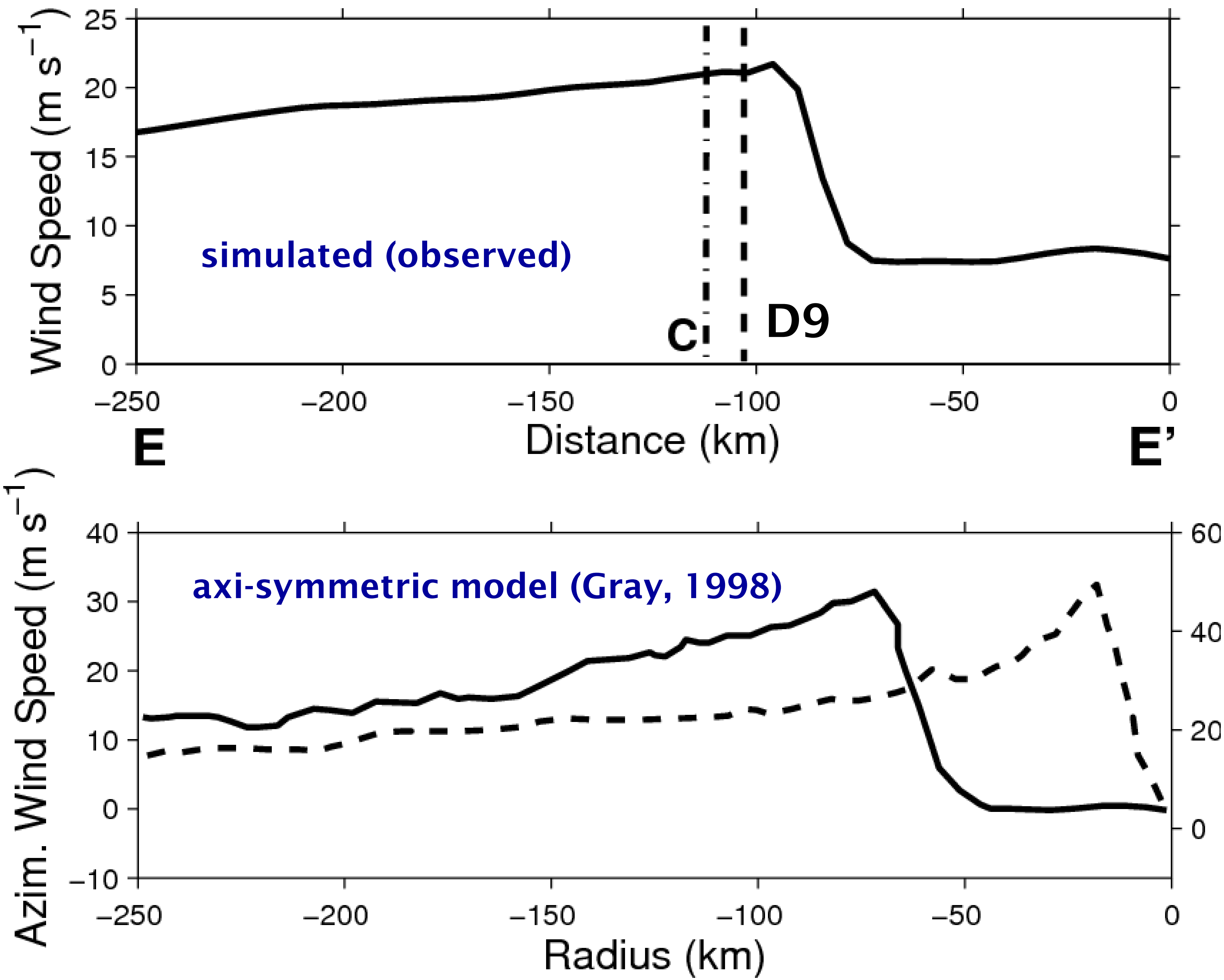
z = 3500 m



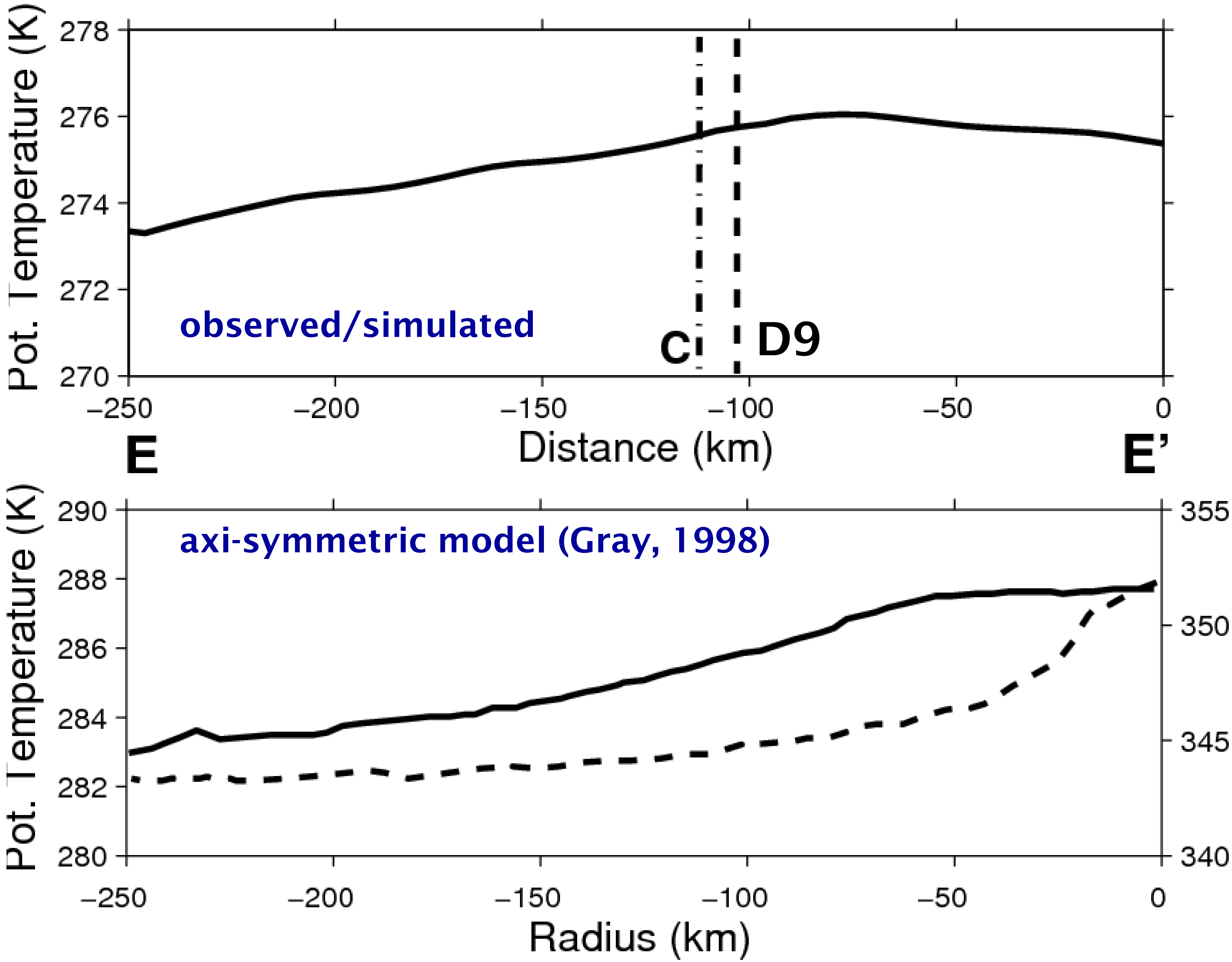
z = 3000 m



LIDAR all data
LIDAR averaged
WRF averaged
D9
D10
EYE
Northern Eye Wall
Southern Eye Wall
Horizontal Wind Speed (m s^{-1})
0
5
10
15
20
25
1200
1250
1300
1350
1400
1450
1500
1550
1600
1650
1700
Distance (km)
C



Wind Speed (m s−1)
25
20
15
10
5
0
simulated (observed)
C
D9
−250
−200
−150
−100
−50
0
Distance (km)
E
E'
Azim. Wind Speed (m s−1)
40
30
20
10
0
−10
60
40
20
0
axi-symmetric model (Gray, 1998)
−250
−200
−150
−100
−50
0
Radius (km)



Pot. Temperature (K)
278
276
274
272
270
observed/simulated
C
D9
−250
−200
−150
−100
−50
0
Distance (km)
E
E'
Pot. Temperature (K)
290
288
286
284
282
280
axi-symmetric model (Gray, 1998)
355
350
345
340
−250
−200
−150
−100
−50
0
Radius (km)

Conclusions

- LIDAR suitable instrumentation to characterize the H_2O, wind and aerosol particle structure above and around Polar Lows (PL), in intrusions and in the PL core

- careful selection of model parameters necessary to obtain reliable simulations to quantify hypotheses and theories
  - WRF and ECMWF IFS runs capture the formation of a PL
  - Model Verification has been done with different types of observational data
  - dignificant dependence of simulation results on initialisation time
  - use of new high resolution SST/SEAICE data set
  - usage of ECMWF model-level data brings great improvements compared to pressure-level data (not shown)

- verification of radial wind structure in the polar low core

Thank you for your attention!