

Tropical Moisture Linkages to Intense Arctic Cyclones in June 2018

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Case Overview

- **Two sequential intense Arctic cyclones, AC1 and AC2, occurred in early June 2018**
- **AC1 forms northeast of the Caspian Sea within a frontal trough**
- **AC2 forms east of Greenland and may be linked to the remnants of Tropical Storm (TS) Alberto**
- **AC1 and AC2 strengthen over western Eurasia as they interact with tropopause polar vortices (TPVs)**
- **AC1 and AC2 undergo a cyclonic rotation over the Arctic Ocean, during which AC2 absorbs AC1**

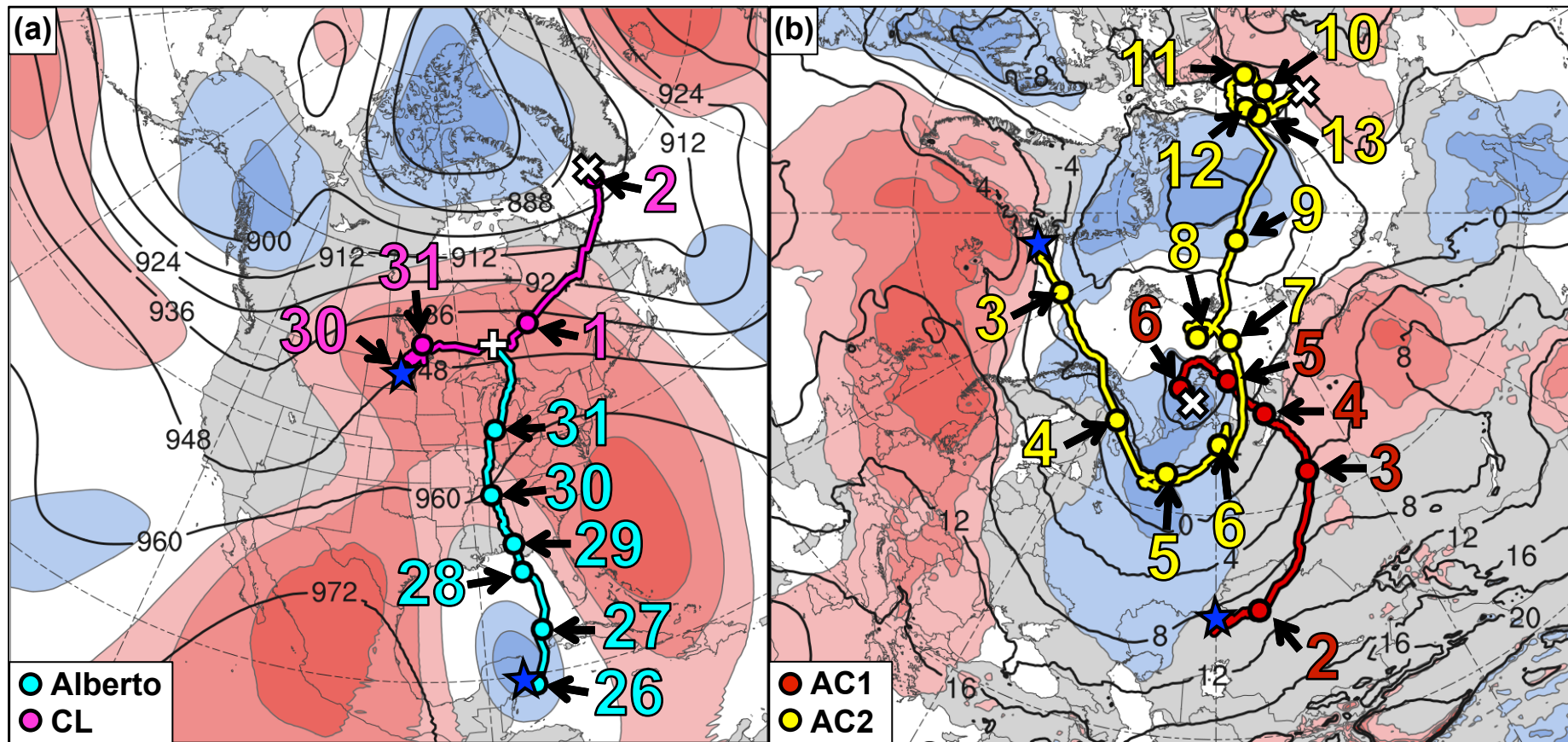
Data and Methods

- **Obtained gridded analyses from ERA-5 (Hersbach and Dee 2016) at 0.25° resolution**
- **Tracked cyclones manually by following locations of minimum sea level pressure (SLP)**
- **Identified and tracked TPVs objectively by utilizing a TPV tracking algorithm (Szapiro and Cavallo 2018)**
- **Computed backward trajectories by using NOAA HYSPLIT trajectory model**

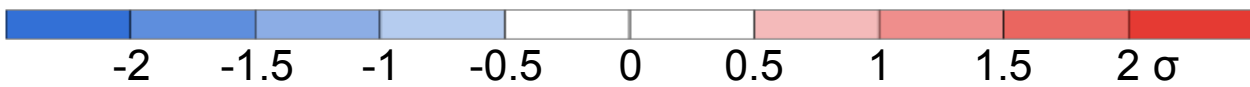
Big Picture

- **Depict AC1 and AC2 tracks and intensities**
- **Show relevant TPV tracks**
- **Illustrate large-scale flow evolution**

Track and Intensity of Cyclones



★ Genesis + Merger
⊗ Lysis ○ 0000 UTC positions

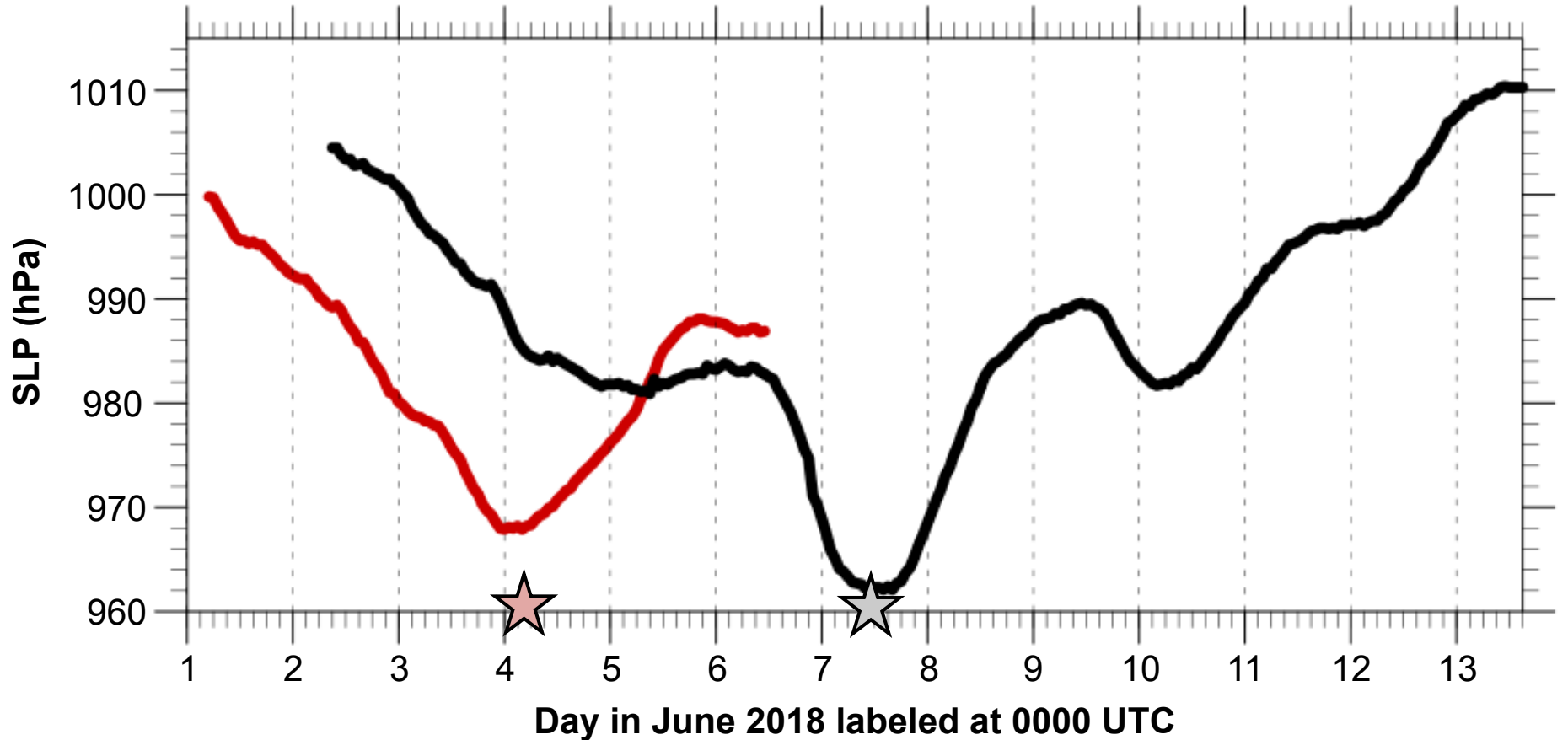


(a) 26 May–1 June 2018 time-mean 300-hPa geopotential height (dam, black) and standardized geopotential height anomalies (σ , shaded); (b) 1–7 June 2018 time-mean 850-hPa temperature ($^{\circ}\text{C}$, black) and standardized temperature anomalies (σ , shaded).

Cyclone	Genesis	Lysis	Lifetime
AC1	1 June	6 June	~5 d
AC2	2 June	13 June	~11 d

Track and Intensity of Cyclones

Hourly minimum SLP time series of AC1 and AC2



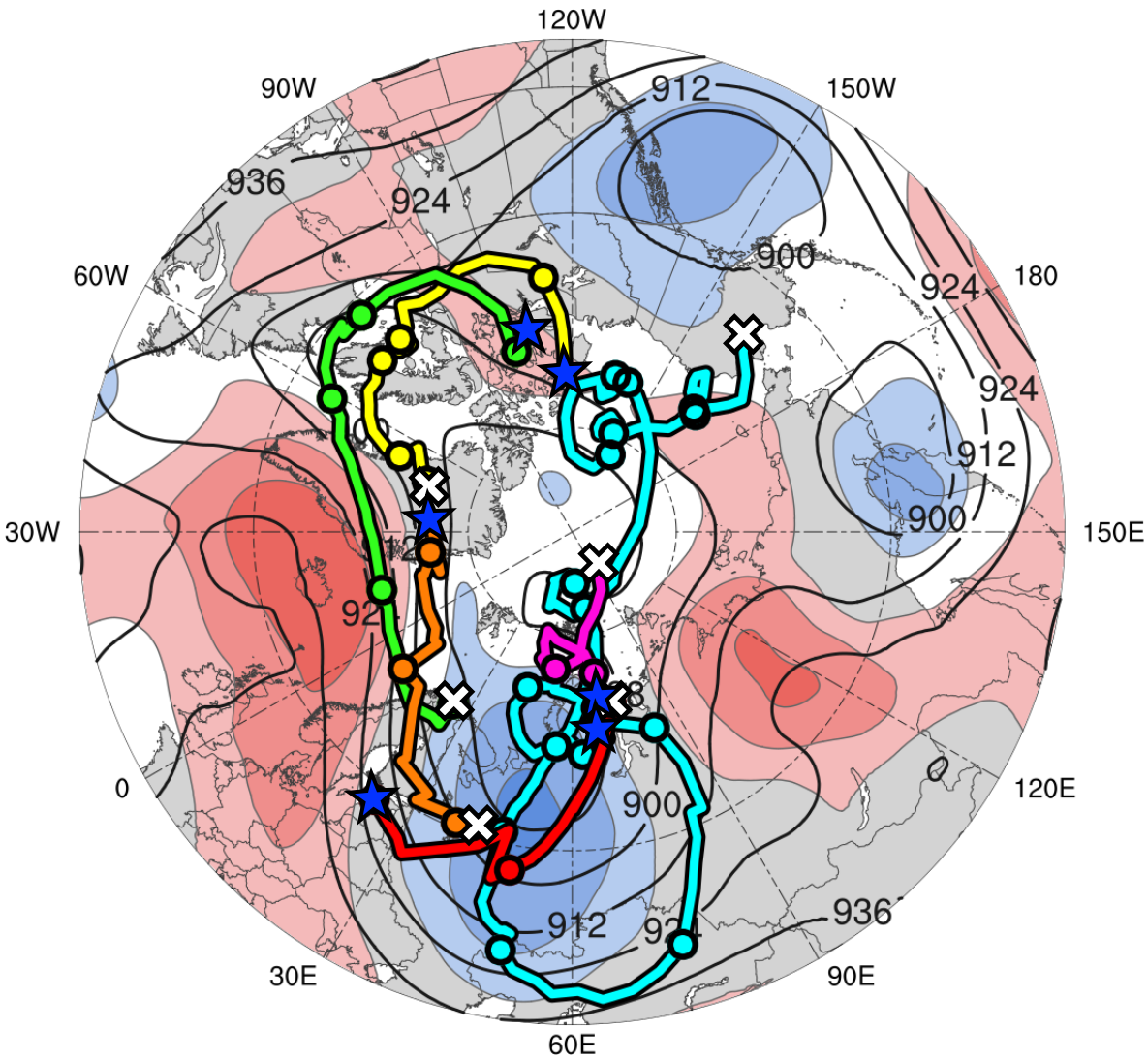
— AC1

— AC2

★ Peak intensity of AC1 at
0400 UTC 4 June 2018 (967.9 hPa)

★ Peak intensity of AC2 at
1100 UTC 7 June 2018 (962.0 hPa)

Tracks of TPVs



TPV	Genesis	Lysis	Lifetime
TPV 1a	29 May	3 June	~5.4 d
TPV 1b	2 June	5 June	2.5 d
TPV 1c	5 June	7 June	~2.4 d
TPV 1d	6 June	8 June	2 d
TPV 2	30 May	4 June	~4.4 d
TPV 3	30 May	15 June	~17 d

- TPV 1a
- TPV 1b
- TPV 1c
- TPV 1d
- TPV 2
- TPV 3

- ★ Genesis
- ⊗ Lysis

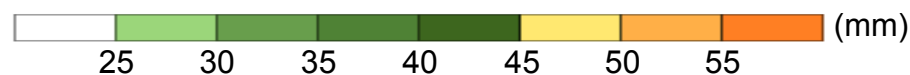
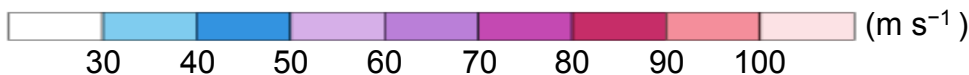
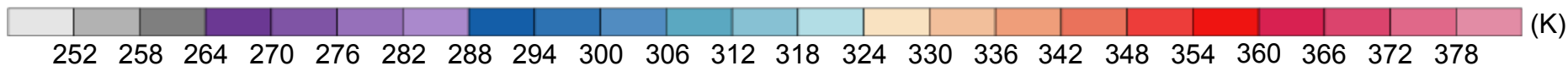
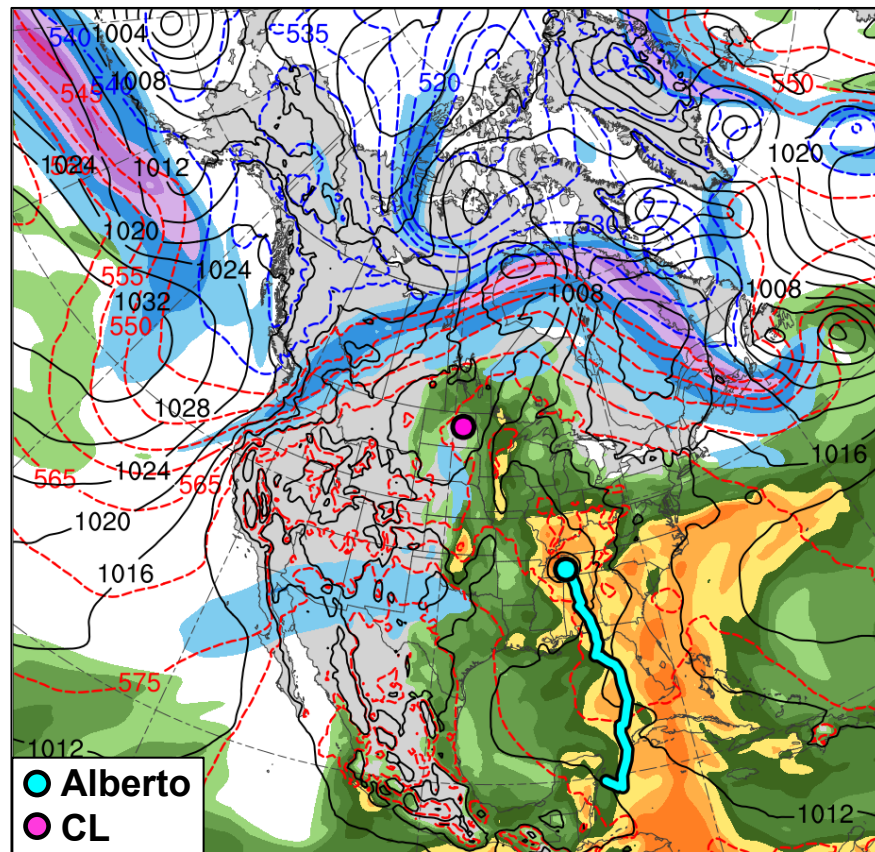
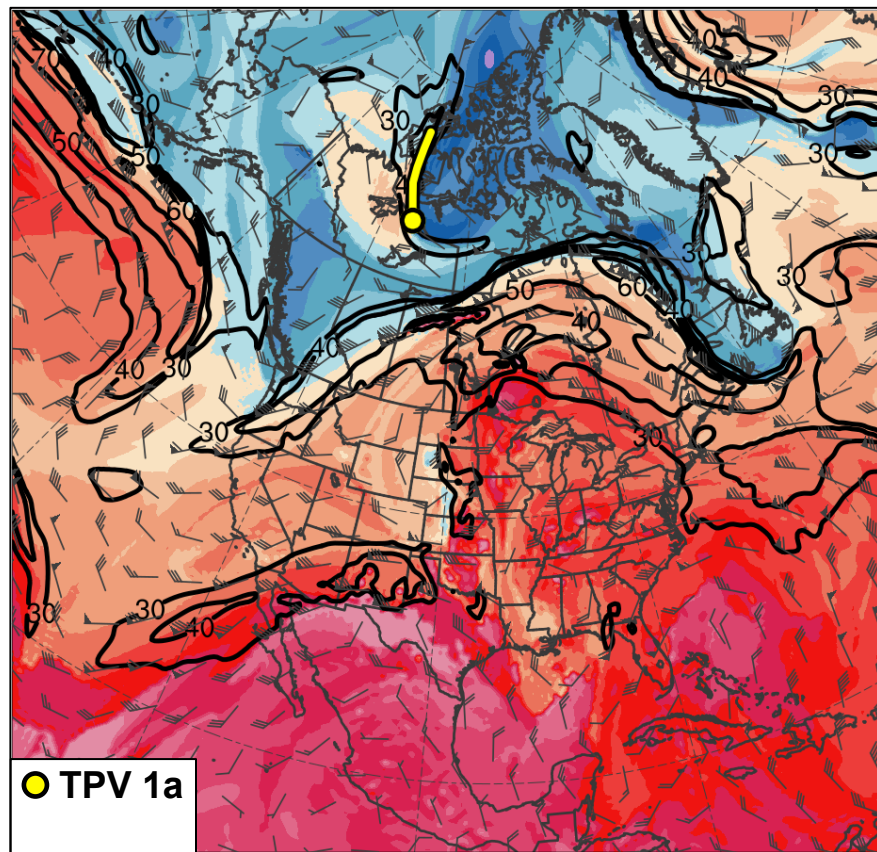
○ 0000 UTC positions

-2 -1.5 -1 -0.5 0 0.5 1 1.5 2 σ

1–7 June 2018 time-mean 300-hPa geopotential height (dam, black) and standardized geopotential height anomalies (σ , shaded)

**Synoptic-Scale Flow Evolution:
North America and North Atlantic
30 May–2 June 2018**

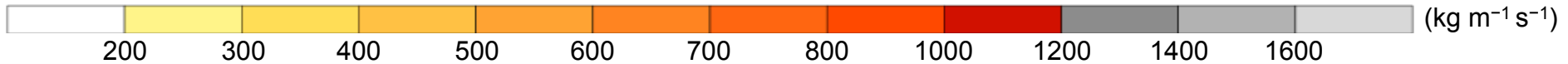
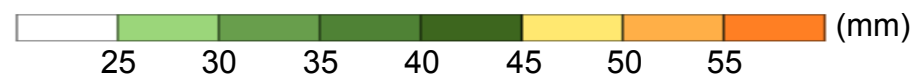
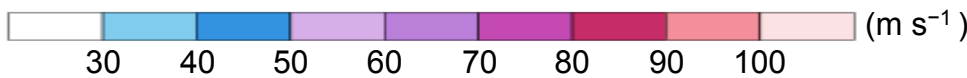
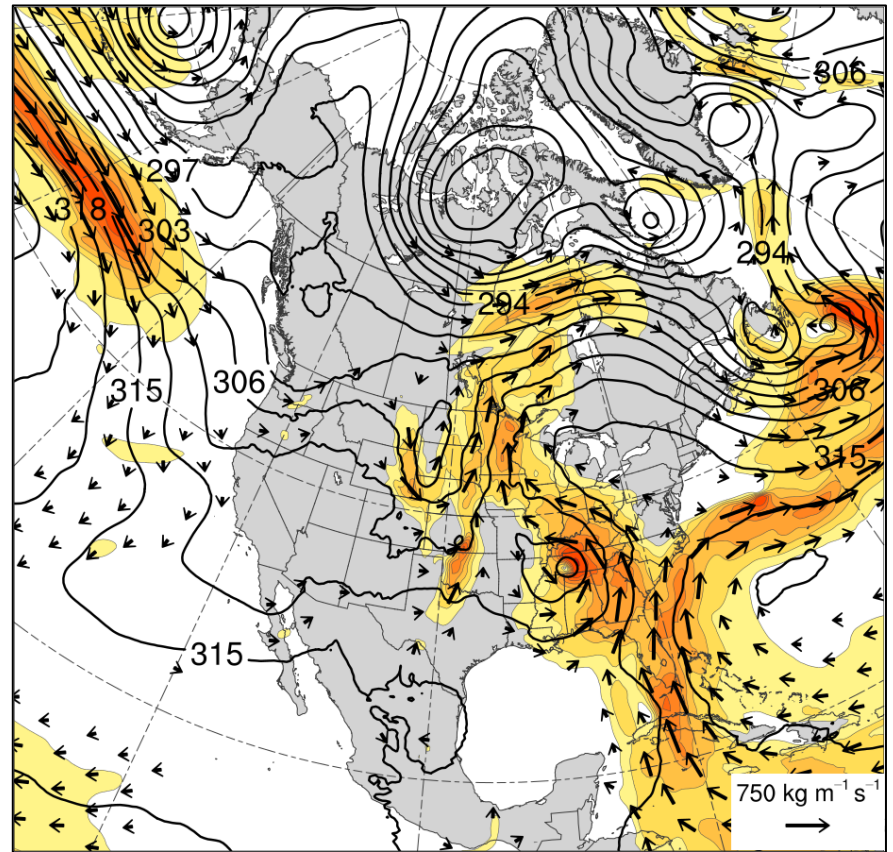
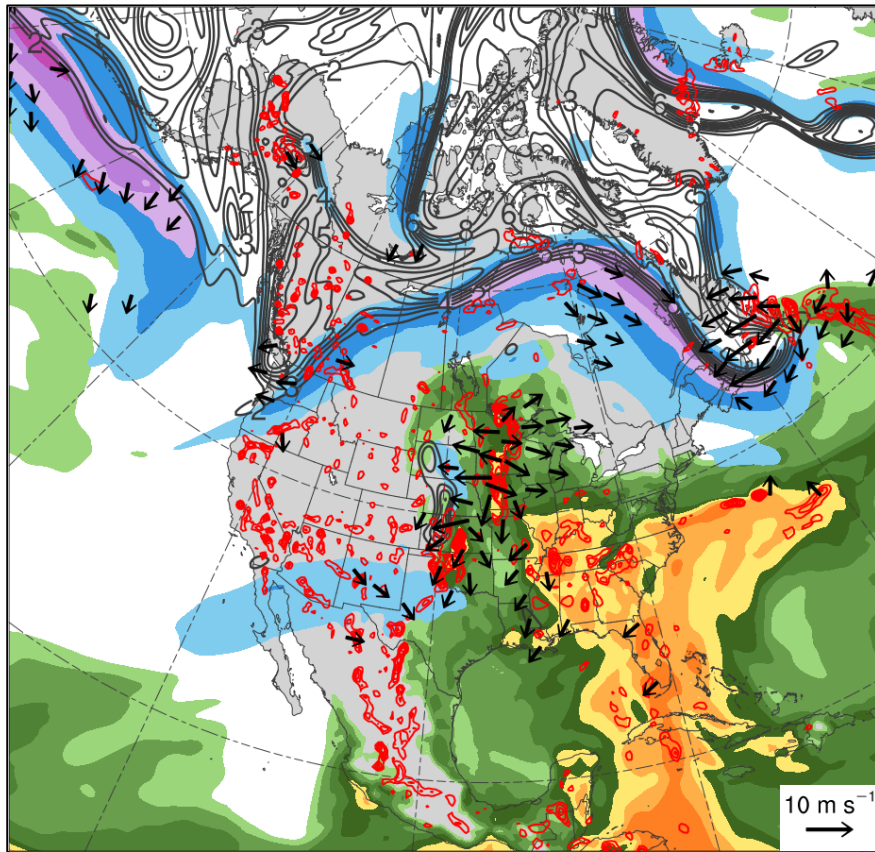
0000 UTC 30 May 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

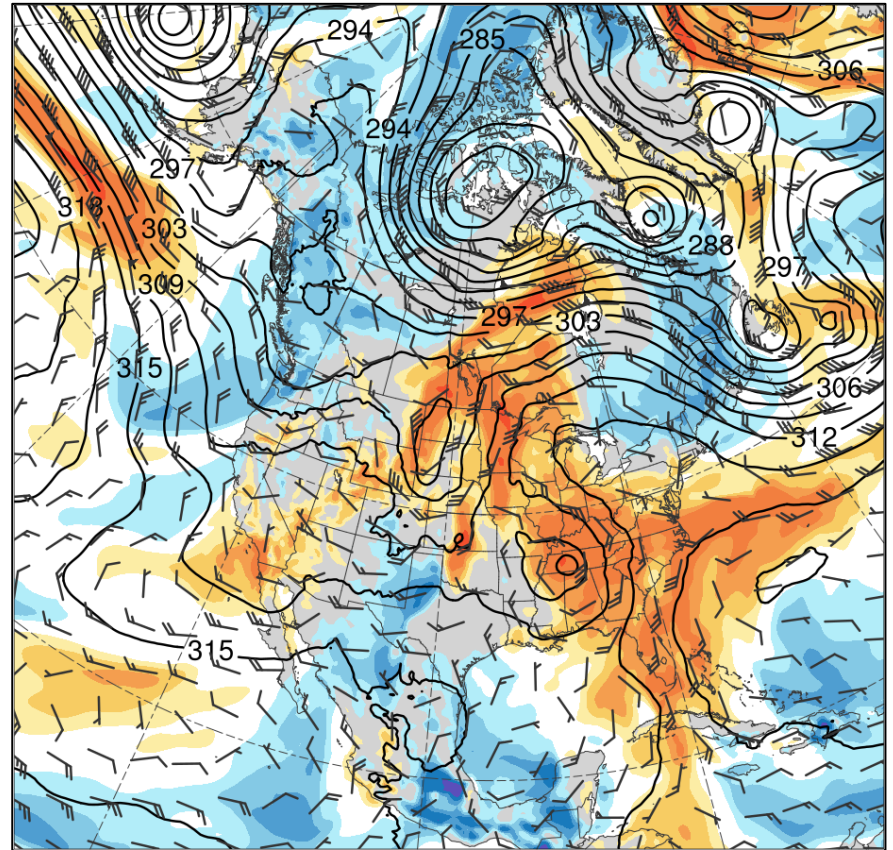
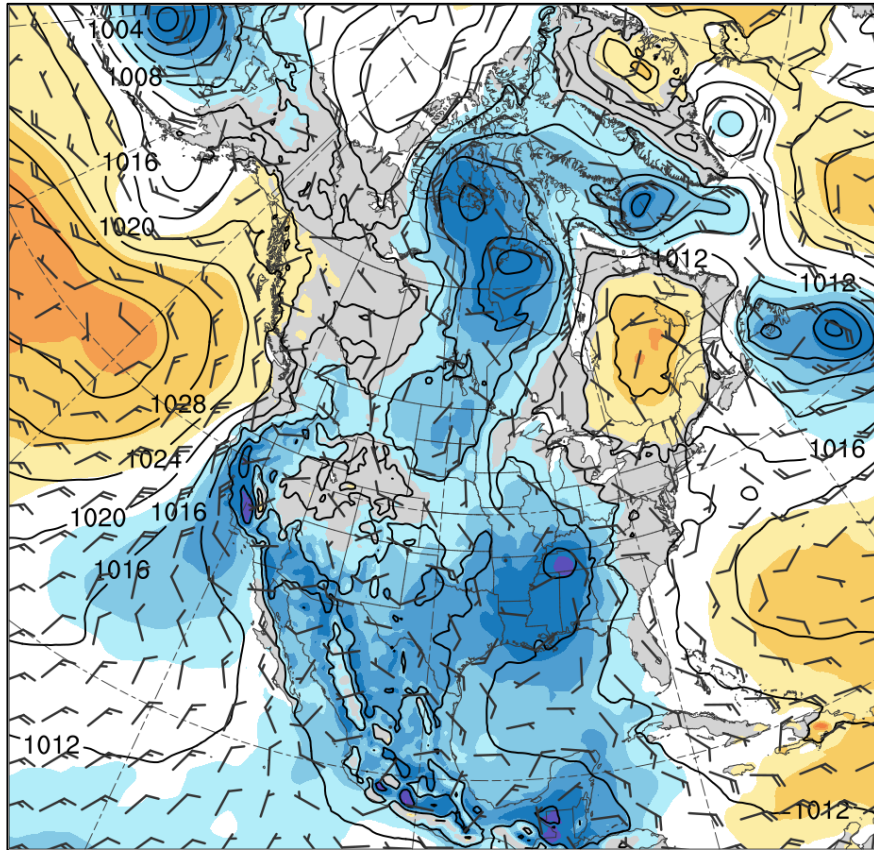
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350–250-hPa PV (PVU, gray) and irrotational wind (m s⁻¹, vectors), 300-hPa wind speed (m s⁻¹, shading), 800–600-hPa ascent (every 3×10^{-3} hPa s⁻¹, red), and PW (mm, shading)

IVT (kg m⁻¹ s⁻¹, shaded and vectors) and 700-hPa geopotential height (dam, black)

0000 UTC 30 May 2018

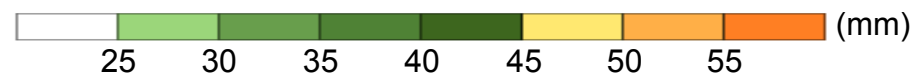
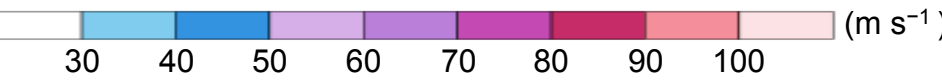
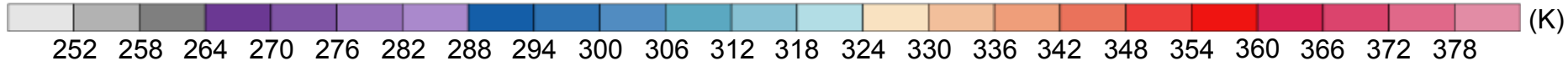
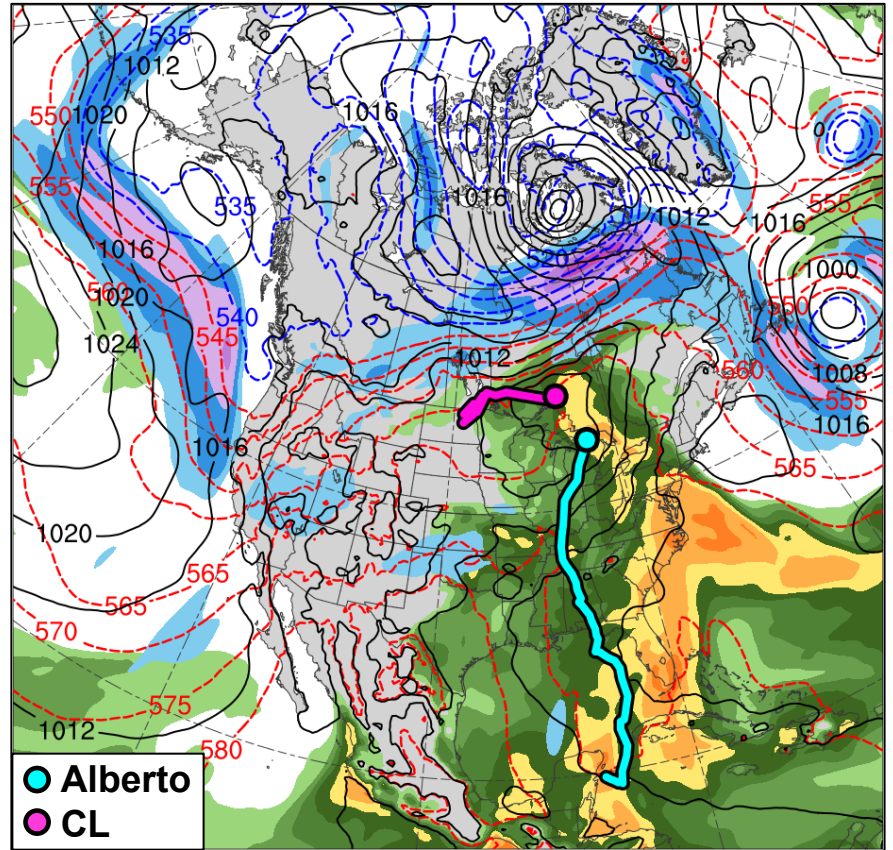
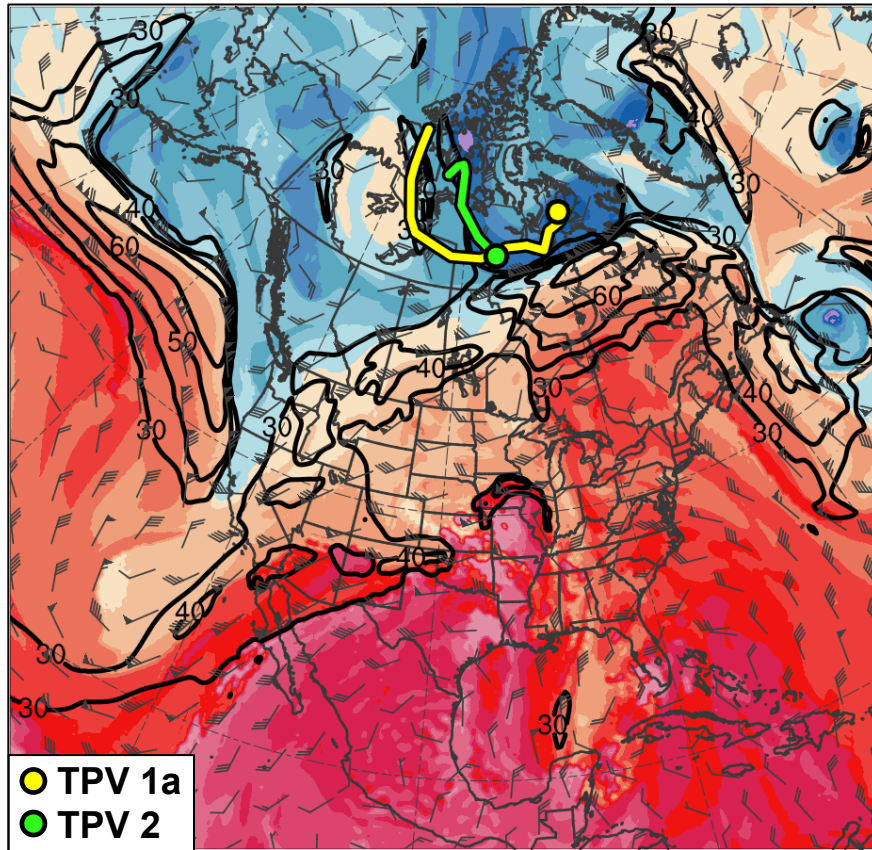


-6 -5 -4 -3 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5 6

SLP (hPa, black), 10-m winds (m s^{-1} , flags and barbs), and standardized SLP anomalies (σ , shaded)

700-hPa geopotential height (dam, black) and winds (m s^{-1} , flags and barbs), and standardized PW anomalies (σ , shaded)

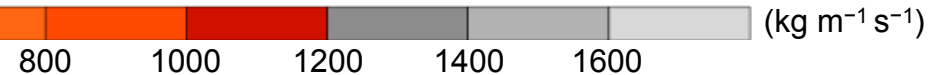
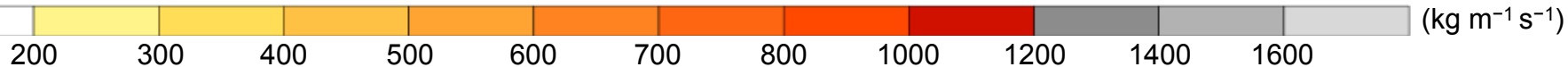
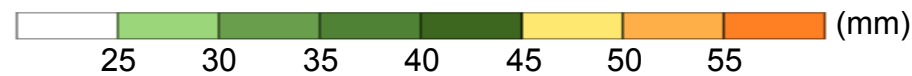
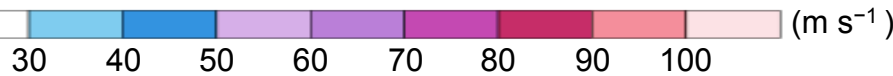
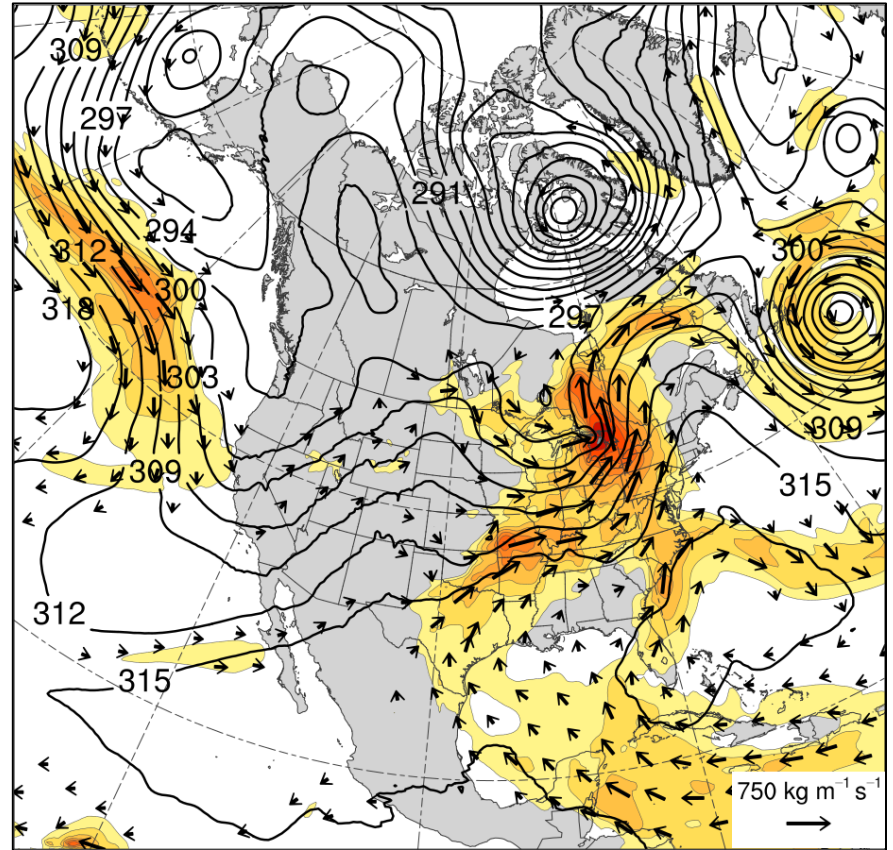
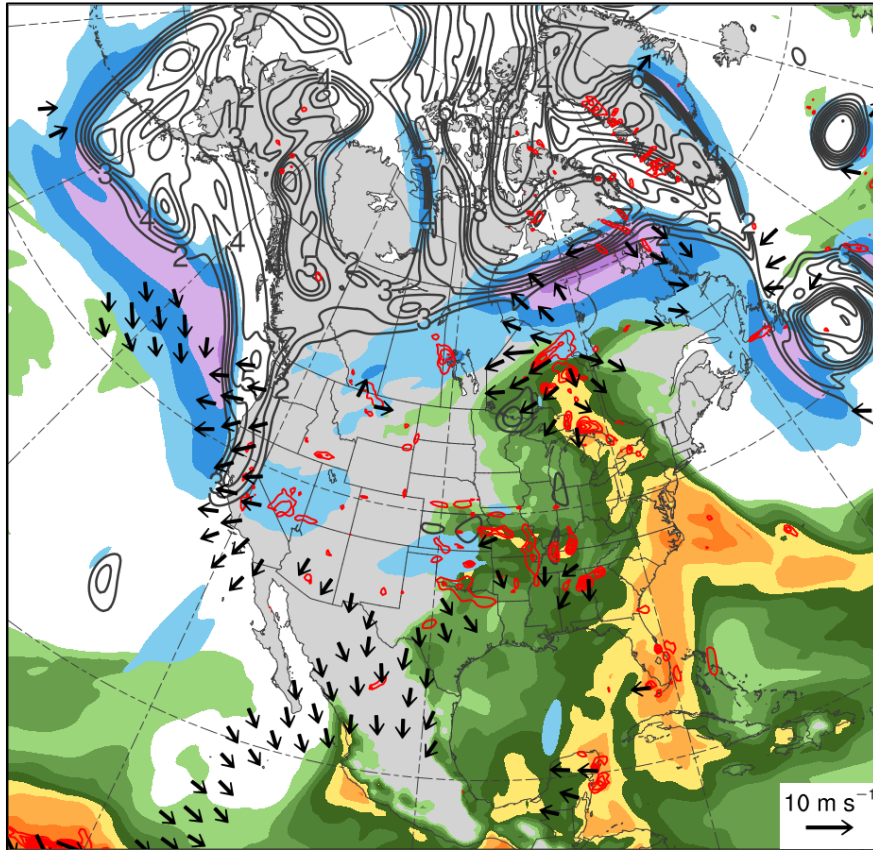
1200 UTC 31 May 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

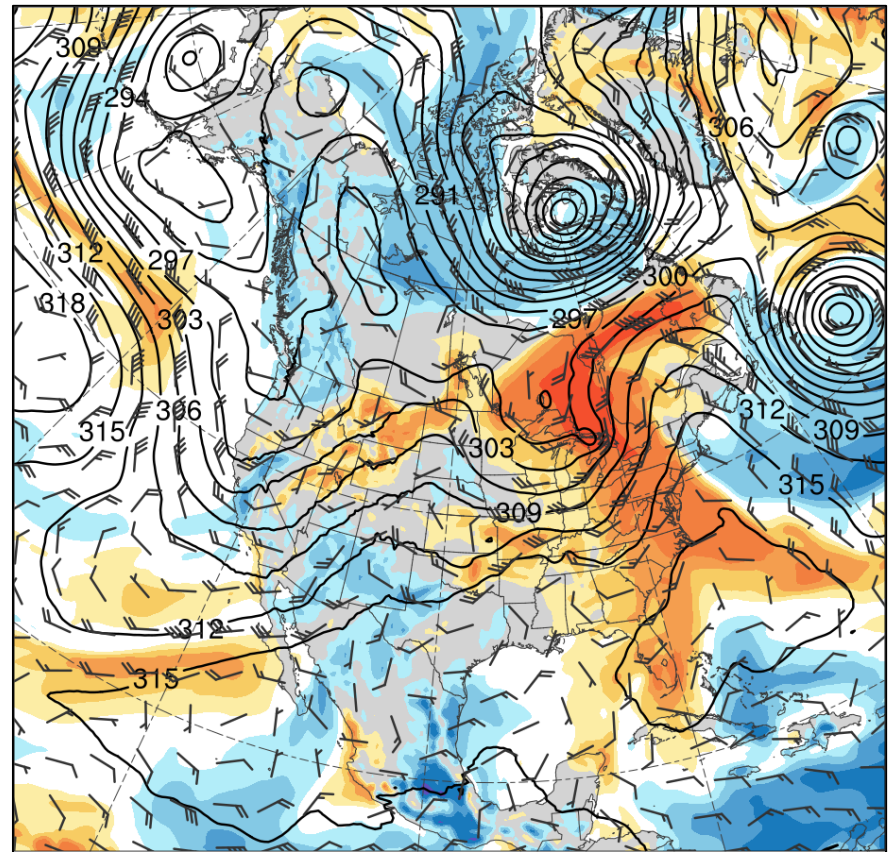
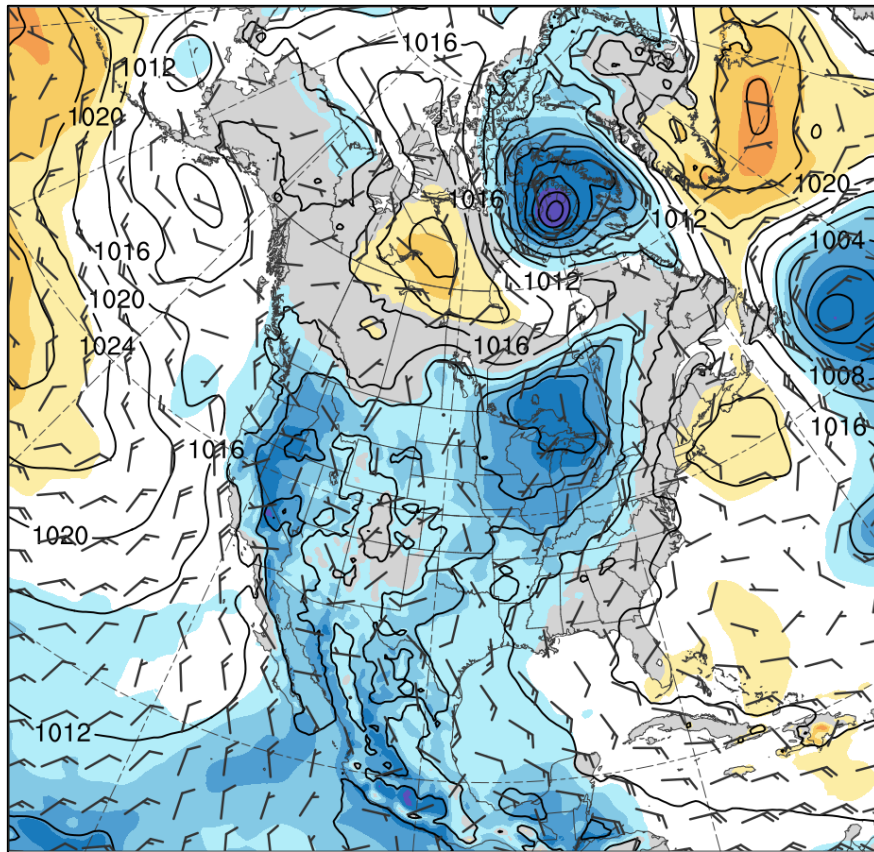
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350–250-hPa PV (PVU, gray) and irrotational wind (m s^{-1} , vectors), 300-hPa wind speed (m s^{-1} , shading), 800–600-hPa ascent (every $3 \times 10^{-3} \text{ hPa s}^{-1}$, red), and PW (mm, shading)

IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and 700-hPa geopotential height (dam, black)

1200 UTC 31 May 2018

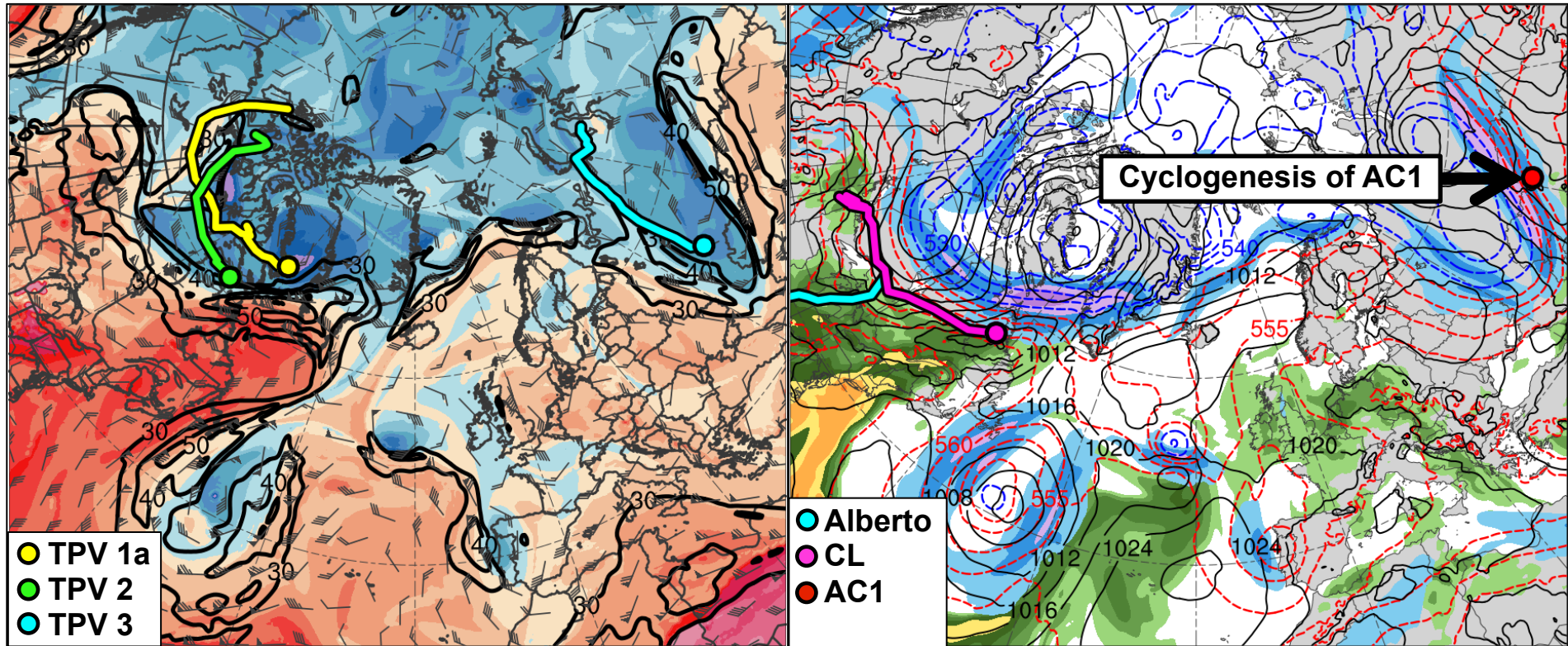


-6 -5 -4 -3 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5 6

SLP (hPa, black), 10-m winds (m s^{-1} , flags and barbs), and standardized SLP anomalies (σ , shaded)

700-hPa geopotential height (dam, black) and winds (m s^{-1} , flags and barbs), and standardized PW anomalies (σ , shaded)

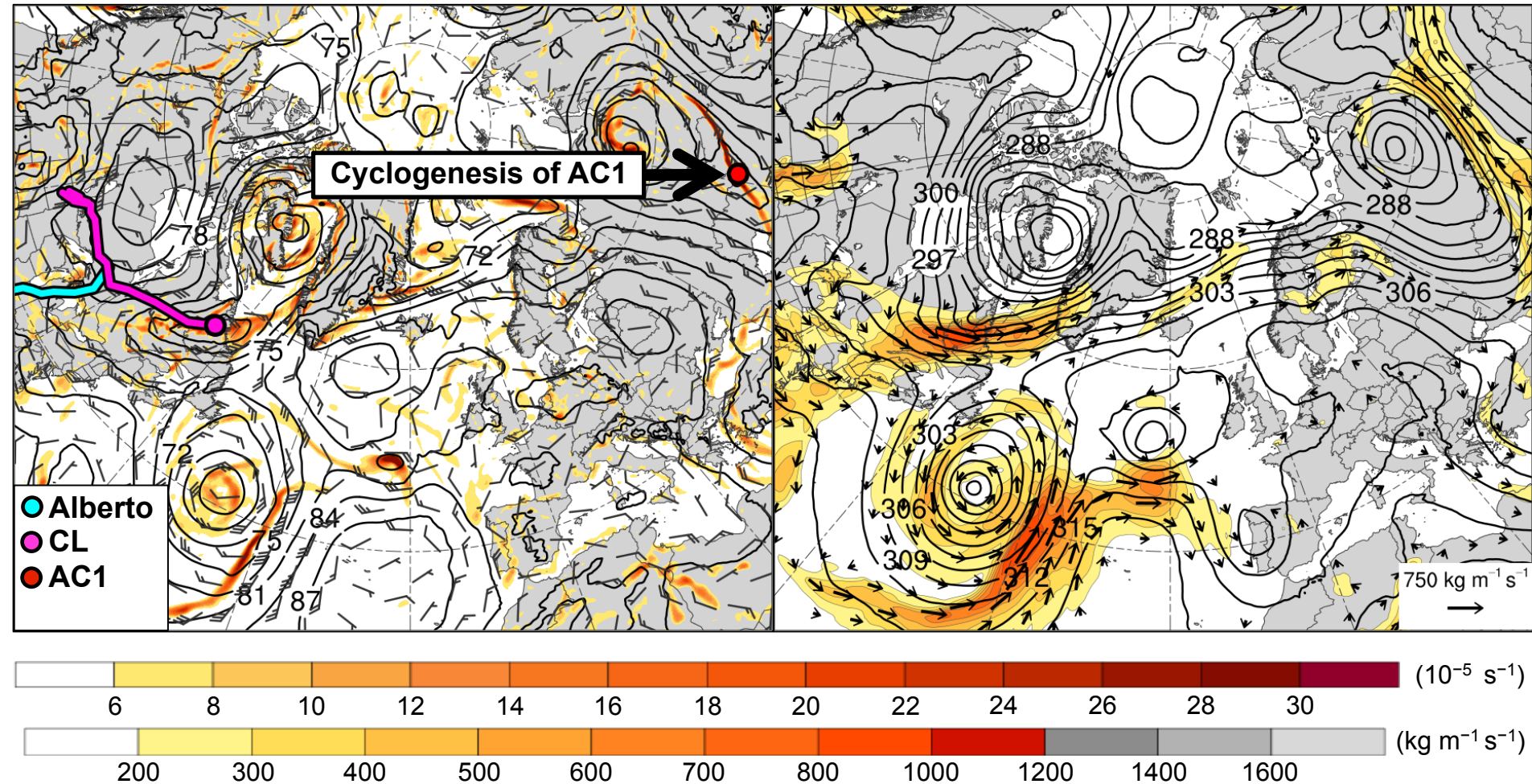
1200 UTC 1 Jun 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s^{-1} starting at 30 m s^{-1}), and wind (m s^{-1} , flags and barbs) on 2-PVU surface

300-hPa wind speed (m s^{-1} , shaded), 1000-500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

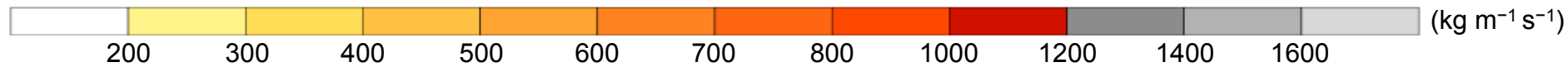
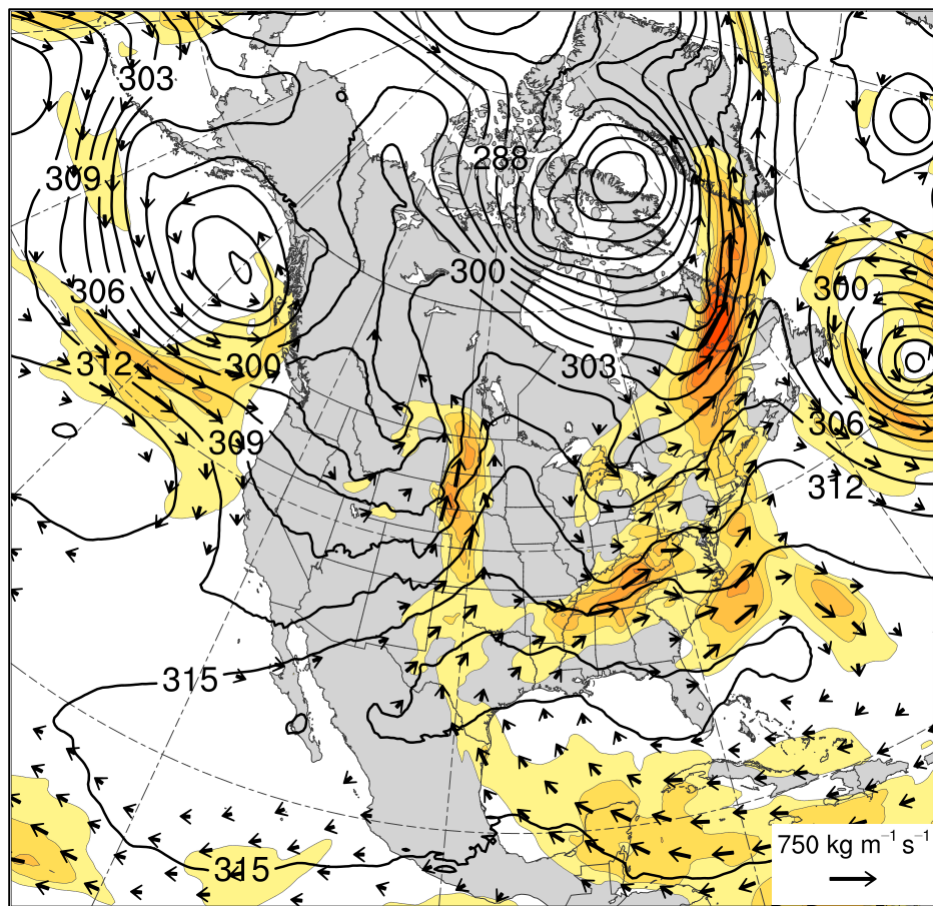
1200 UTC 1 Jun 2018



925-hPa relative vorticity (10^{-5} s^{-1} , shaded),
geopotential height (dam, black), and
winds (m s^{-1} , flags and barbs)

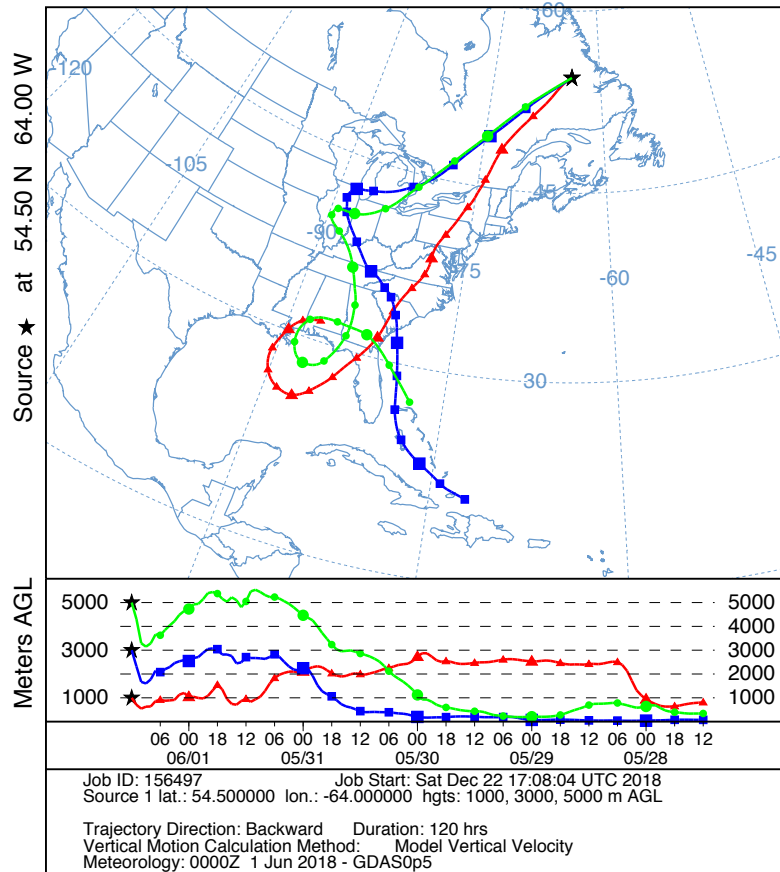
IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

1200 UTC 1 Jun 2018



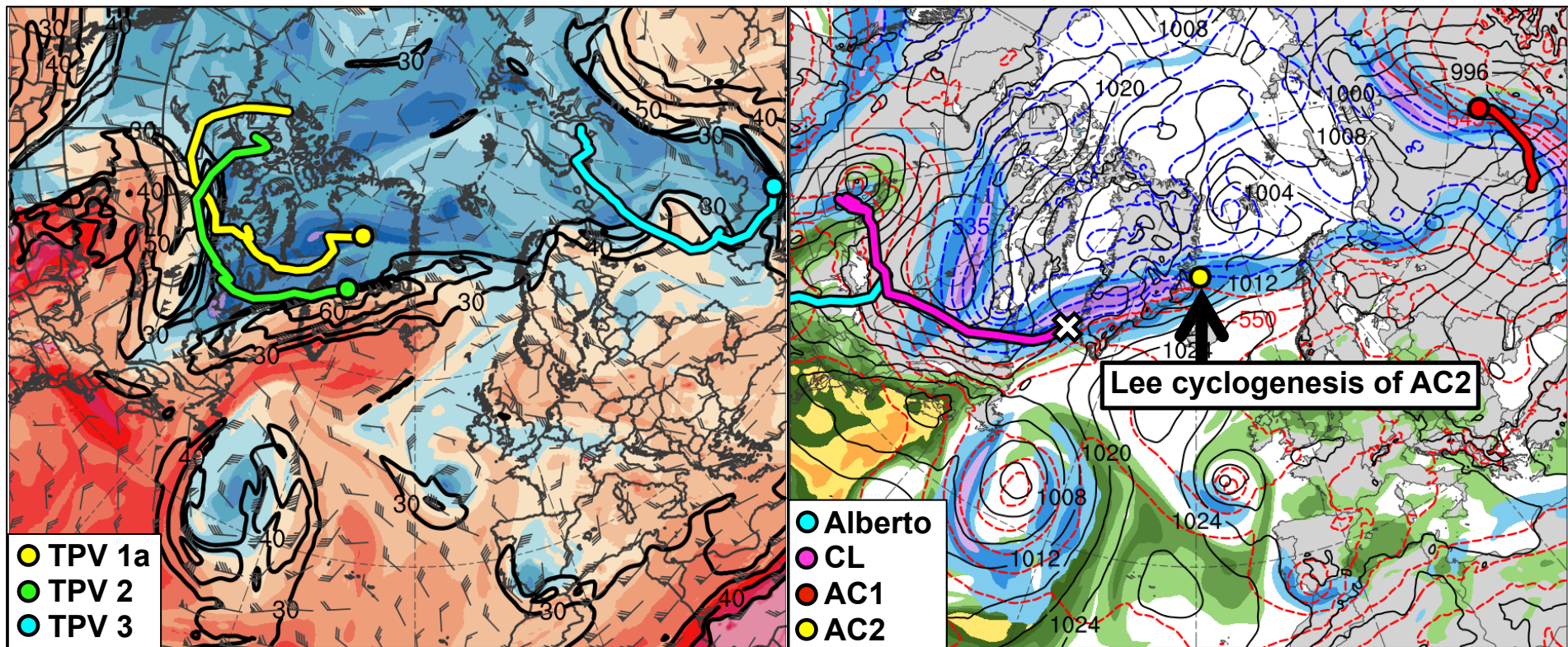
IVT ($\text{kg m}^{-1} \text{s}^{-1}$, shaded and vectors) and 700-hPa geopotential height (dam, black)

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 01 Jun 18
GFSG Meteorological Data



NOAA HYSPLIT 5-d backward trajectories ending at 1200 UTC 1 June 2018

1200 UTC 2 Jun 2018



252 258 264 270 276 282 288 294 300 306 312 318 324 330 336 342 348 354 360 366 372 378 (K)

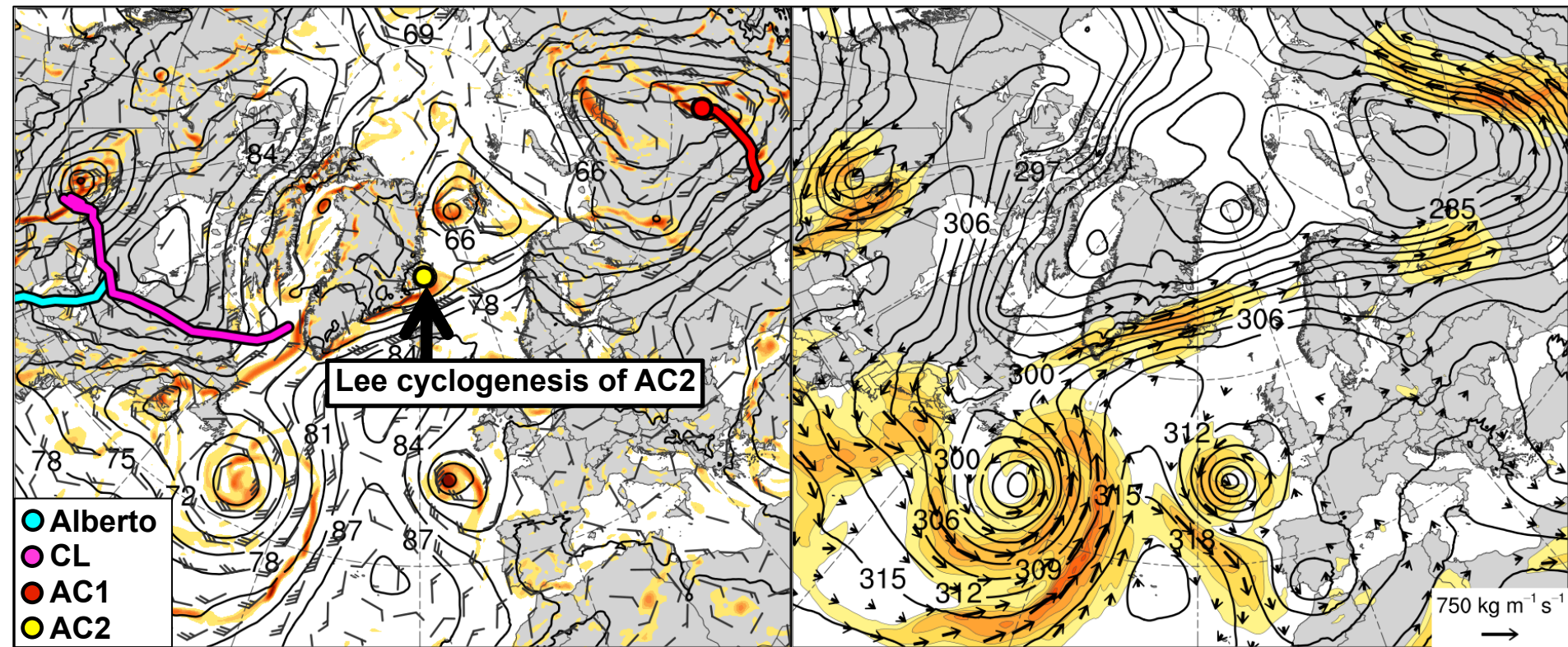
30 40 50 60 70 80 90 100 (m s⁻¹)

25 30 35 40 45 50 55 (mm)

Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

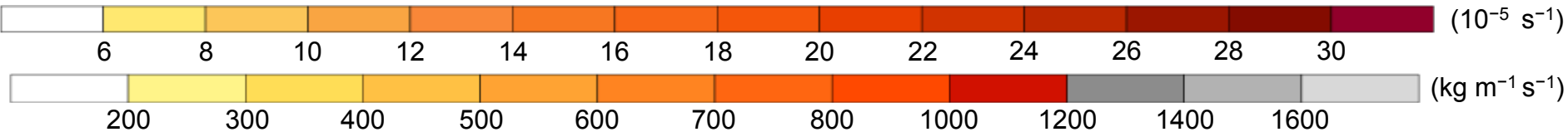
300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

1200 UTC 2 Jun 2018



Lee cyclogenesis of AC2

- Alberto
- CL
- AC1
- AC2

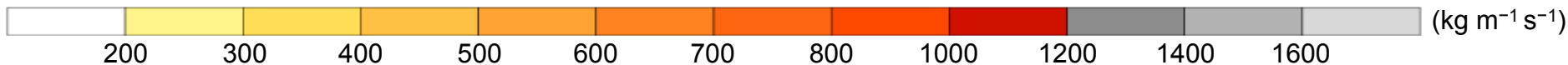
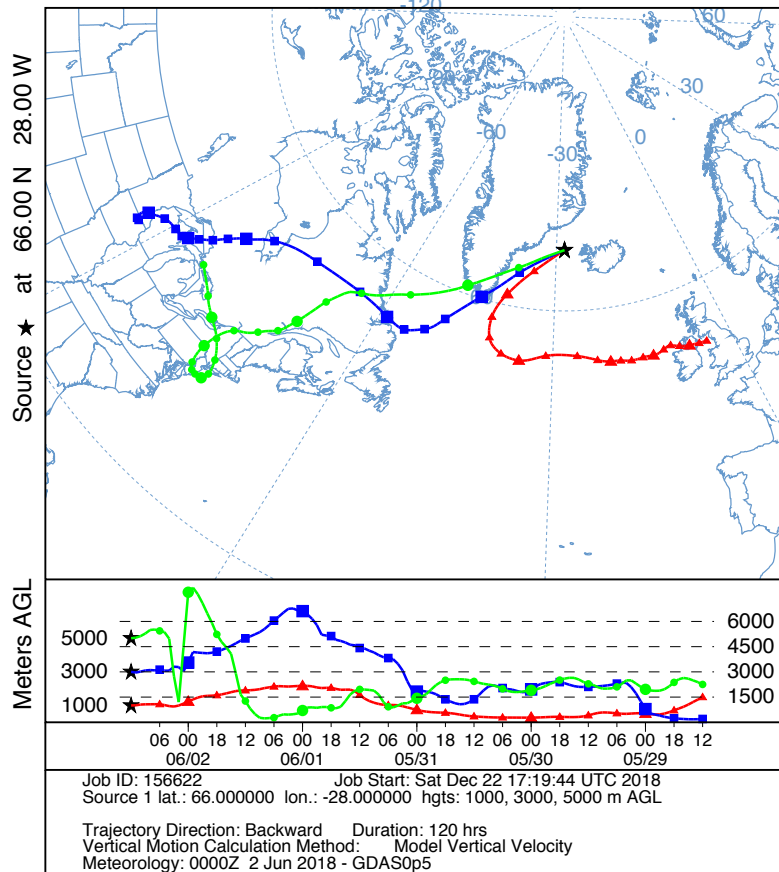
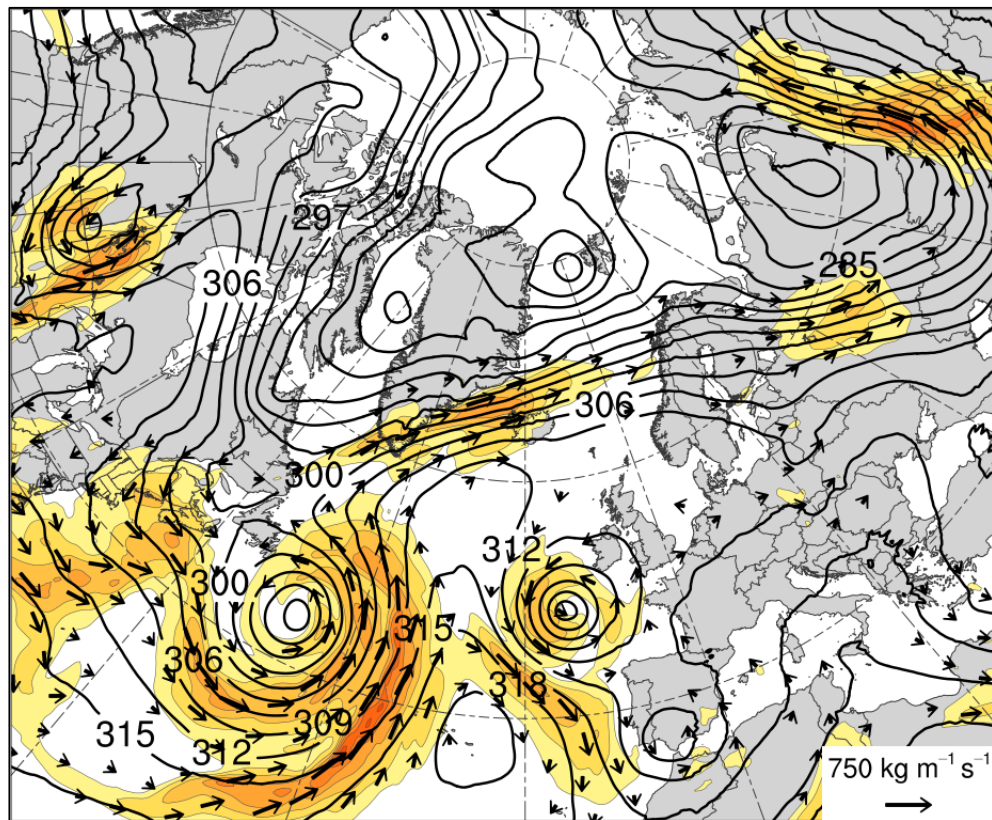


925-hPa relative vorticity (10^{-5} s^{-1} , shaded),
geopotential height (dam, black), and
winds (m s^{-1} , flags and barbs)

IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

1200 UTC 2 Jun 2018

NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 02 Jun 18
GFSG Meteorological Data

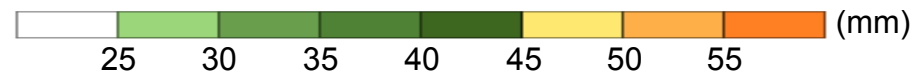
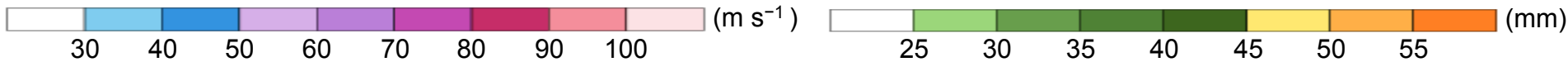
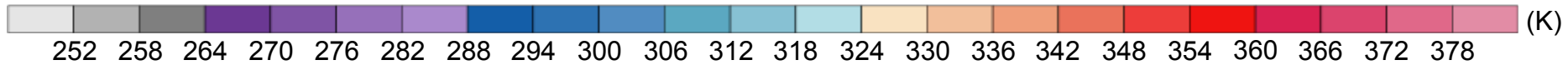
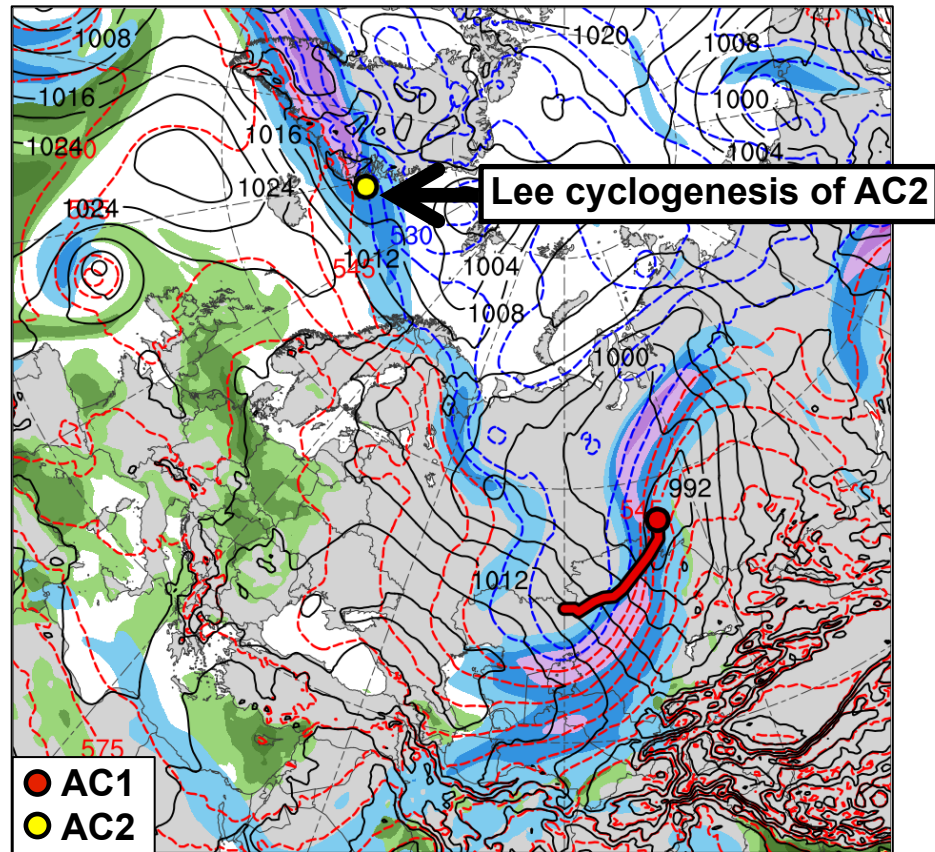
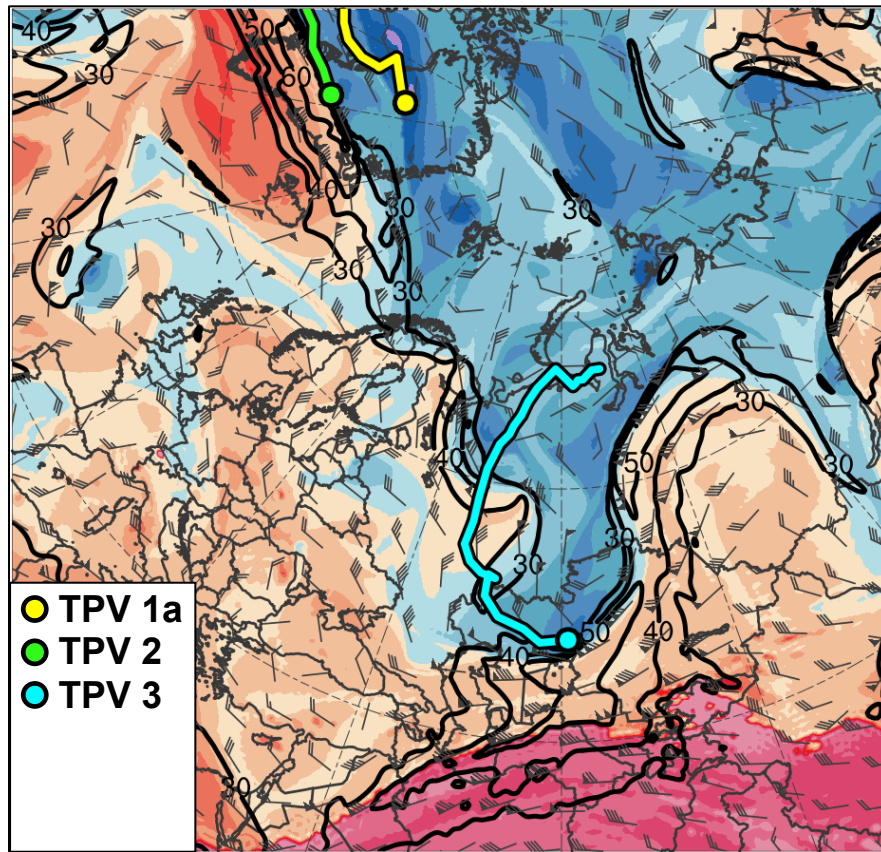


IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

NOAA HYSPLIT 5-d backward trajectories
ending at 1200 UTC 2 June 2018

Synoptic-Scale Flow Evolution: Europe and Western Asia 2–7 June 2018

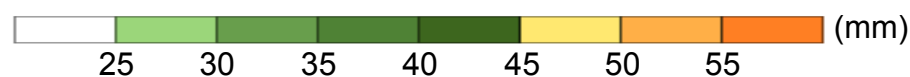
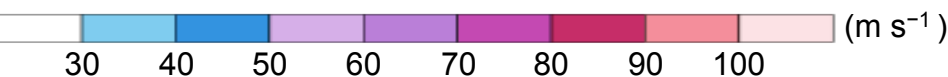
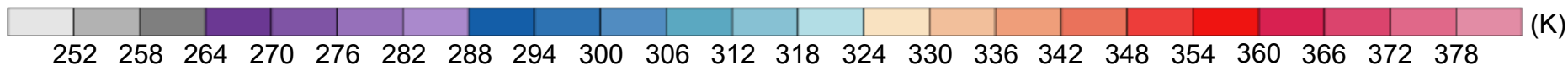
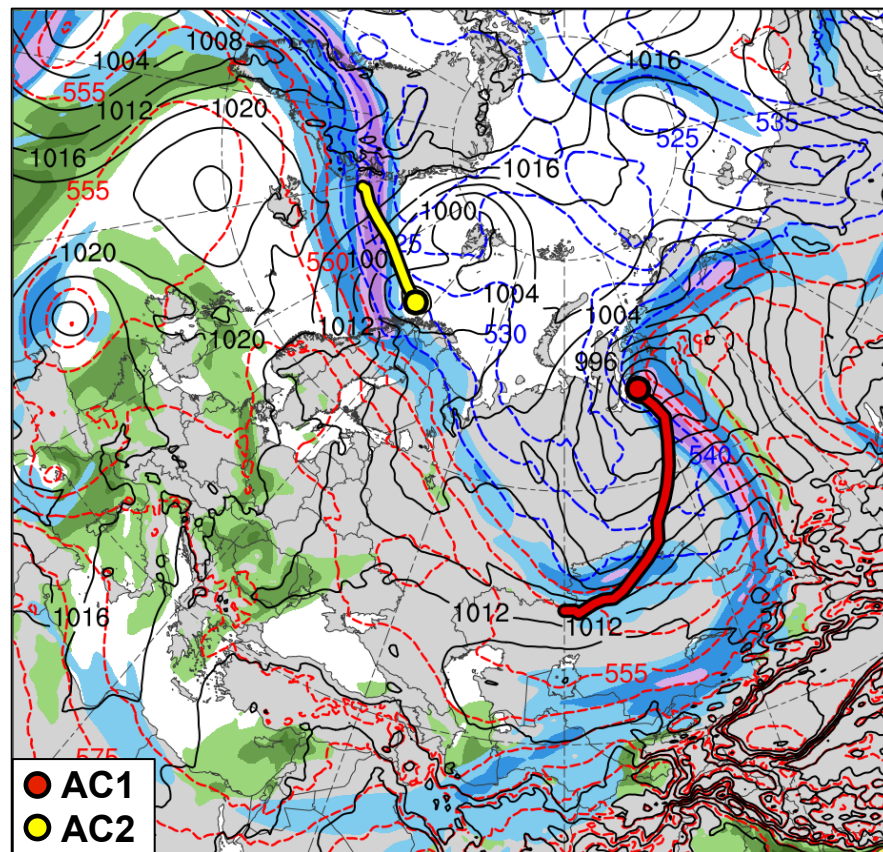
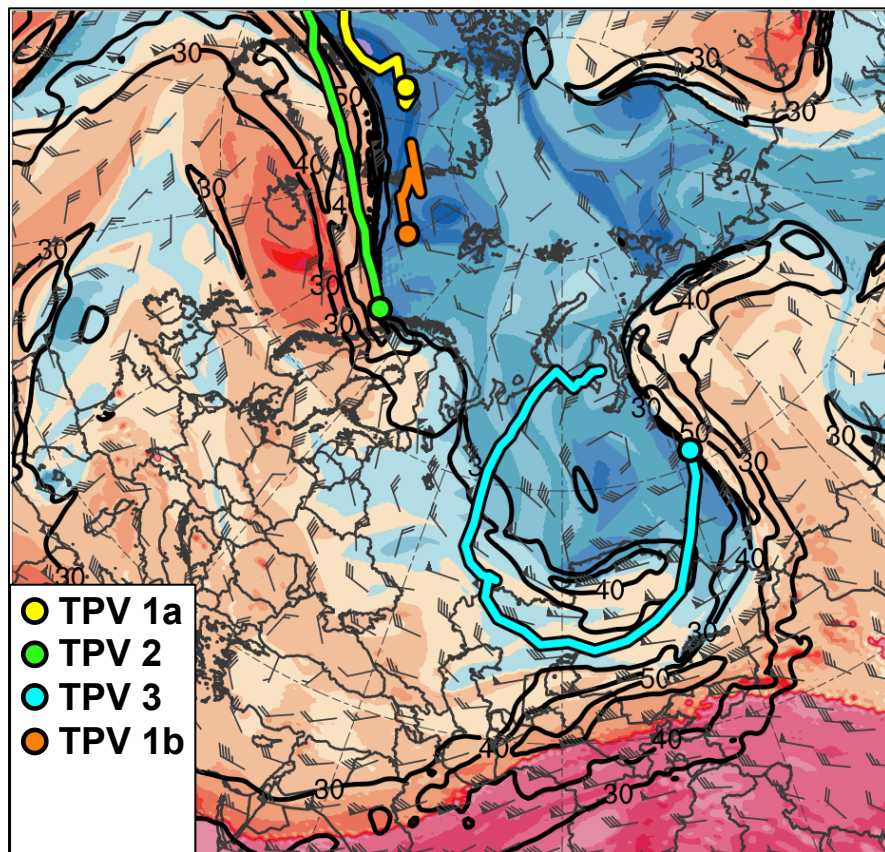
1200 UTC 2 Jun 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

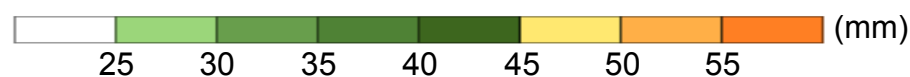
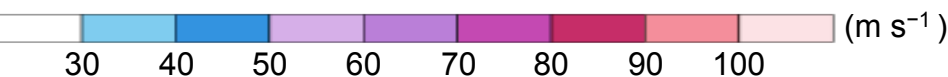
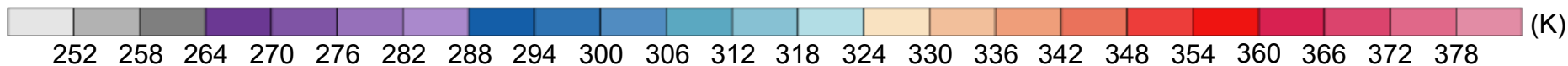
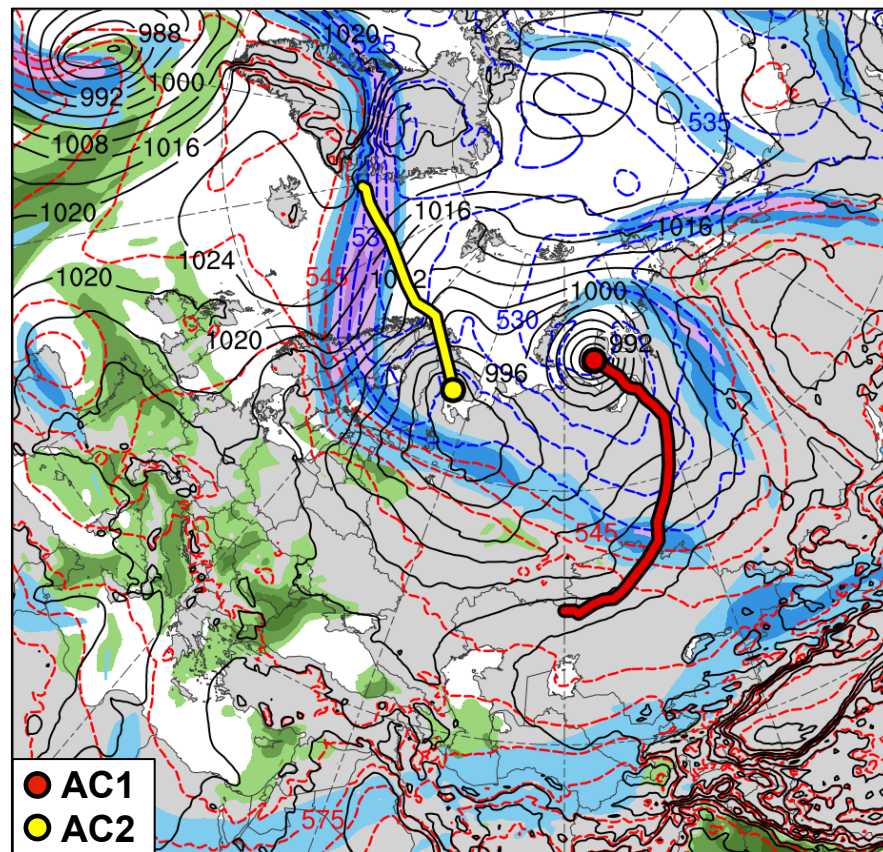
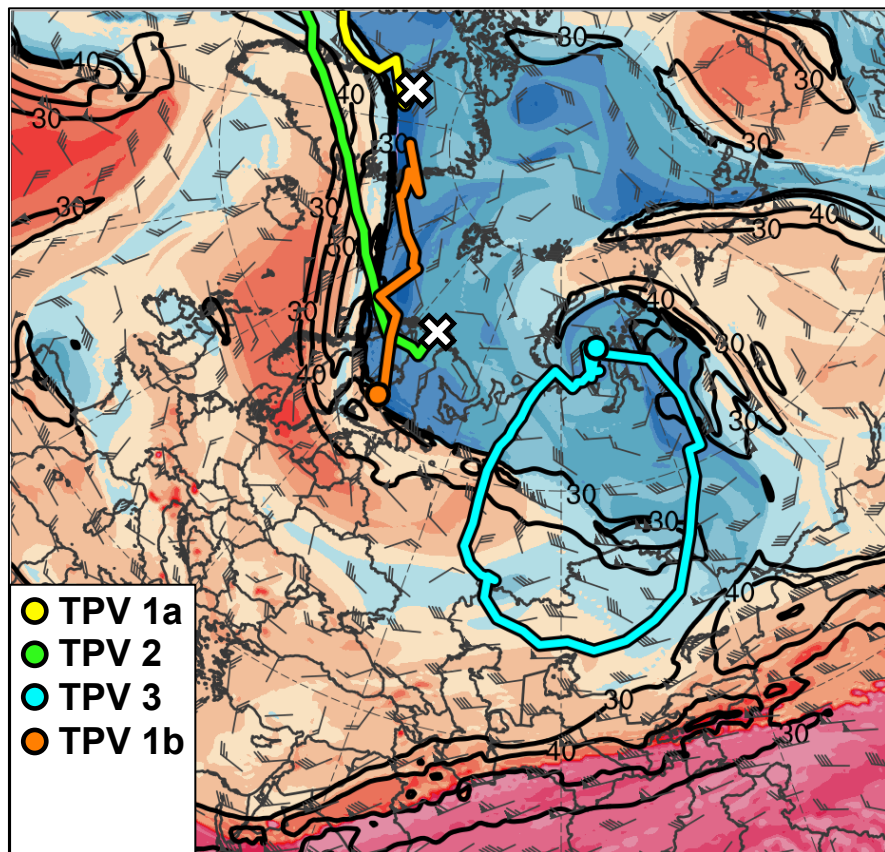
1200 UTC 3 Jun 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

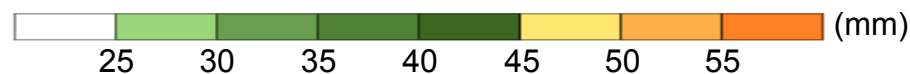
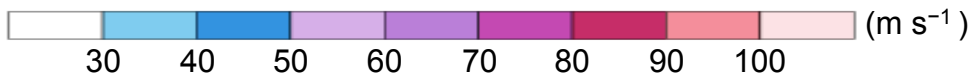
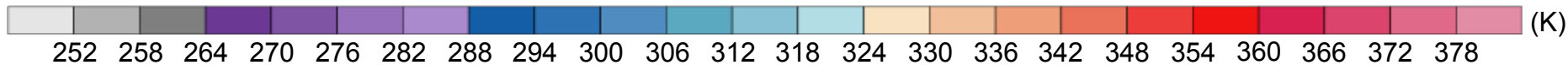
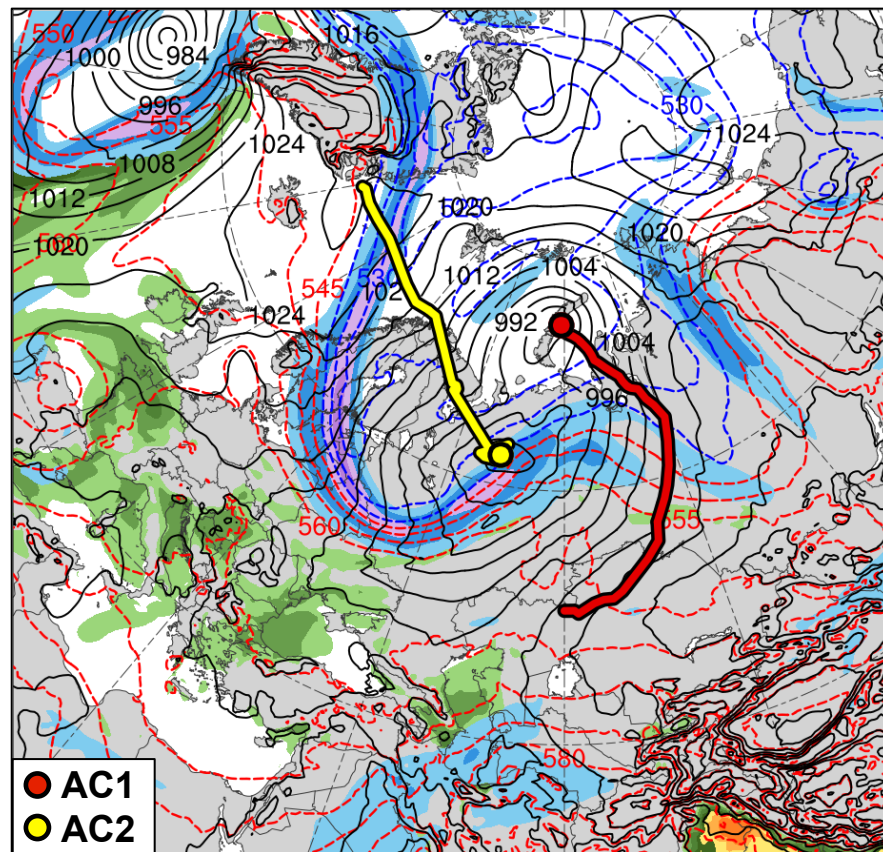
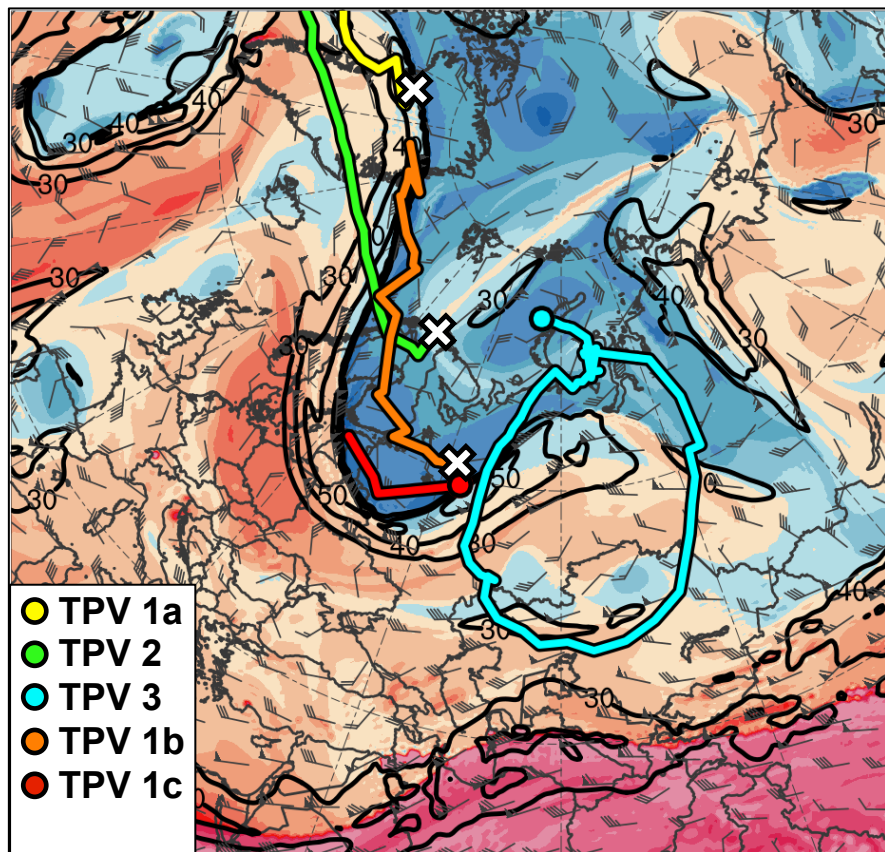
1200 UTC 4 Jun 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

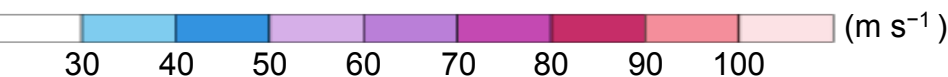
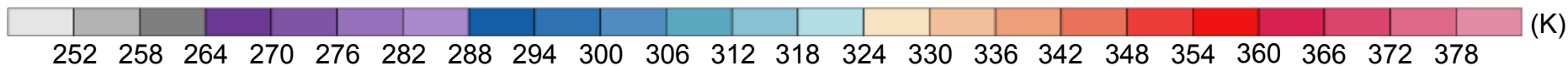
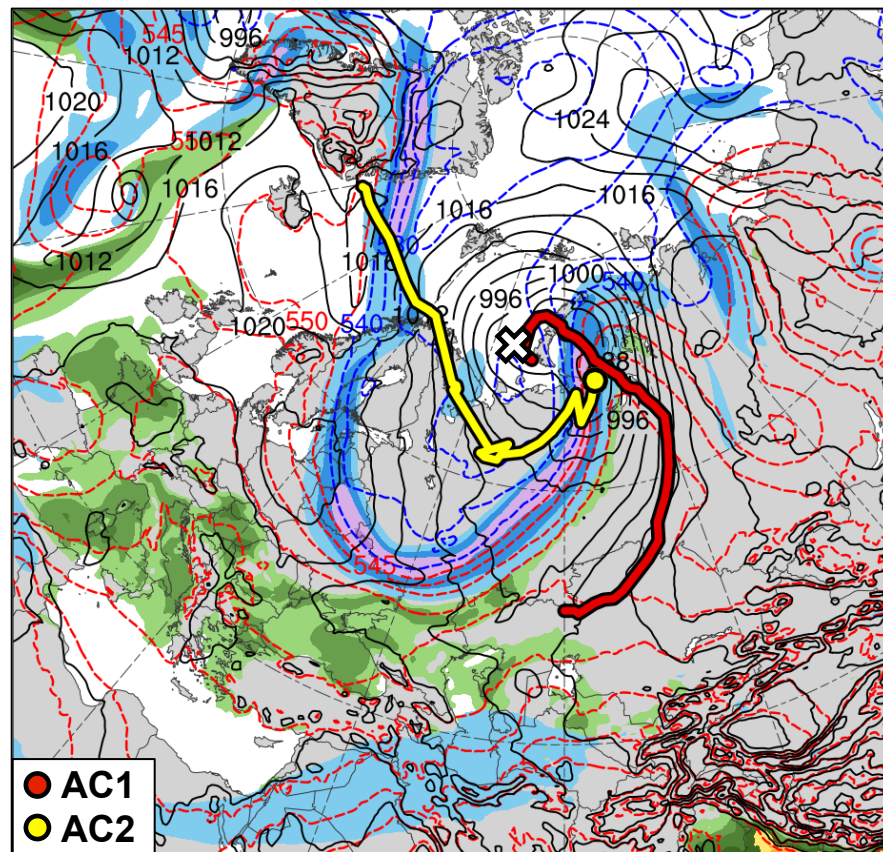
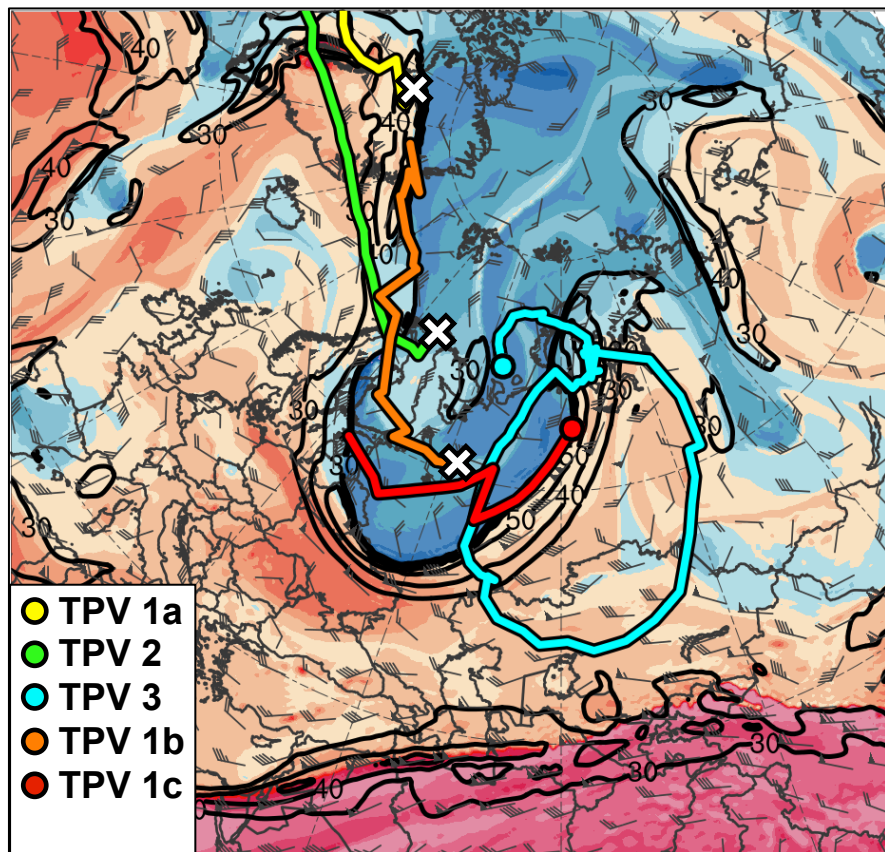
1200 UTC 5 Jun 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

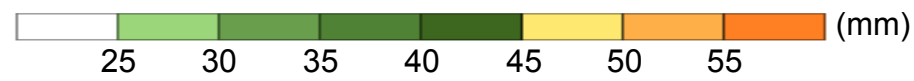
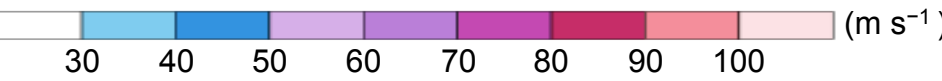
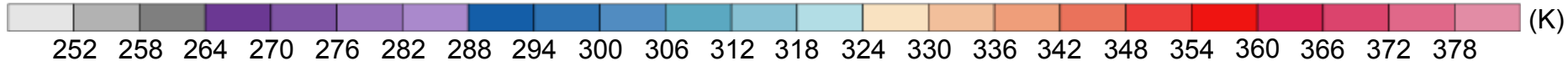
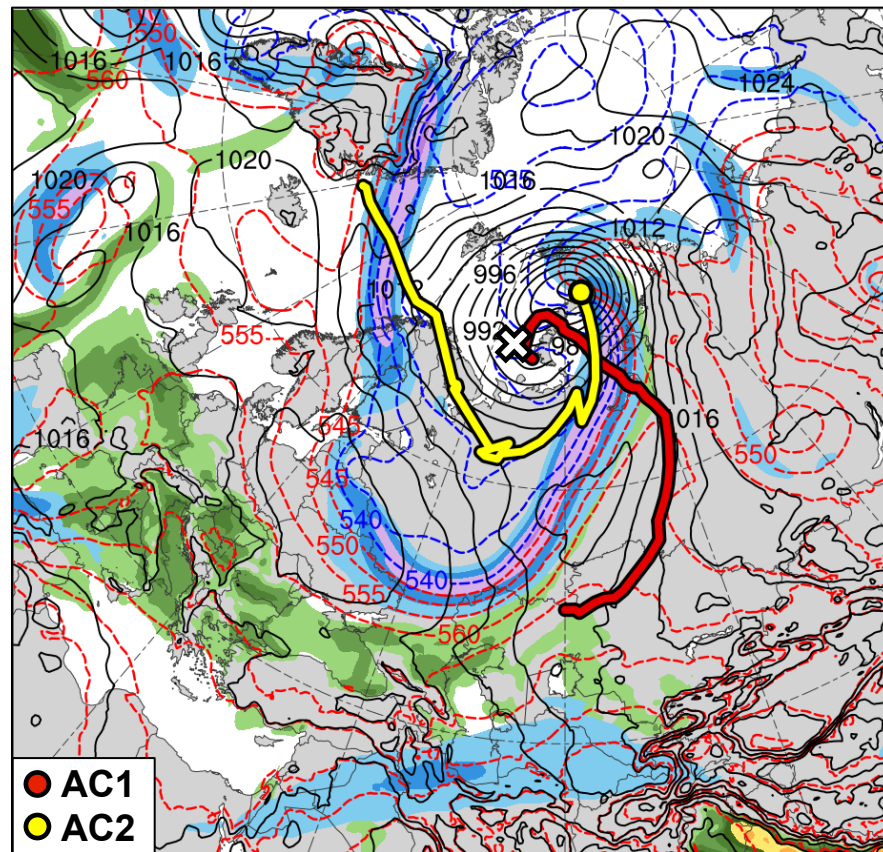
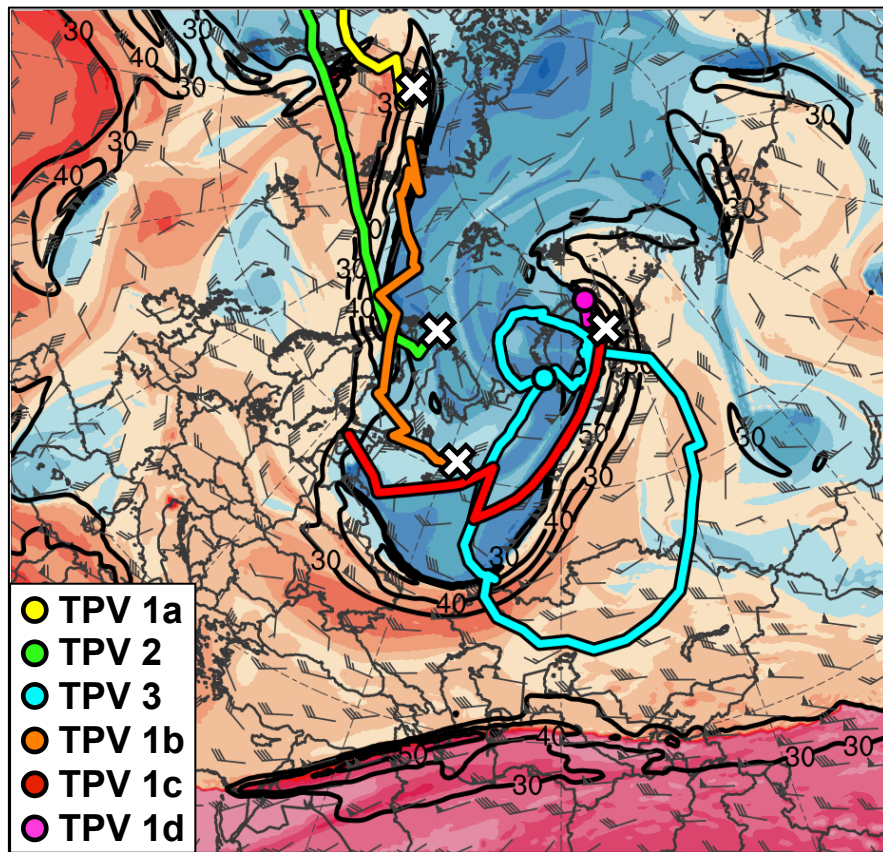
1200 UTC 6 Jun 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

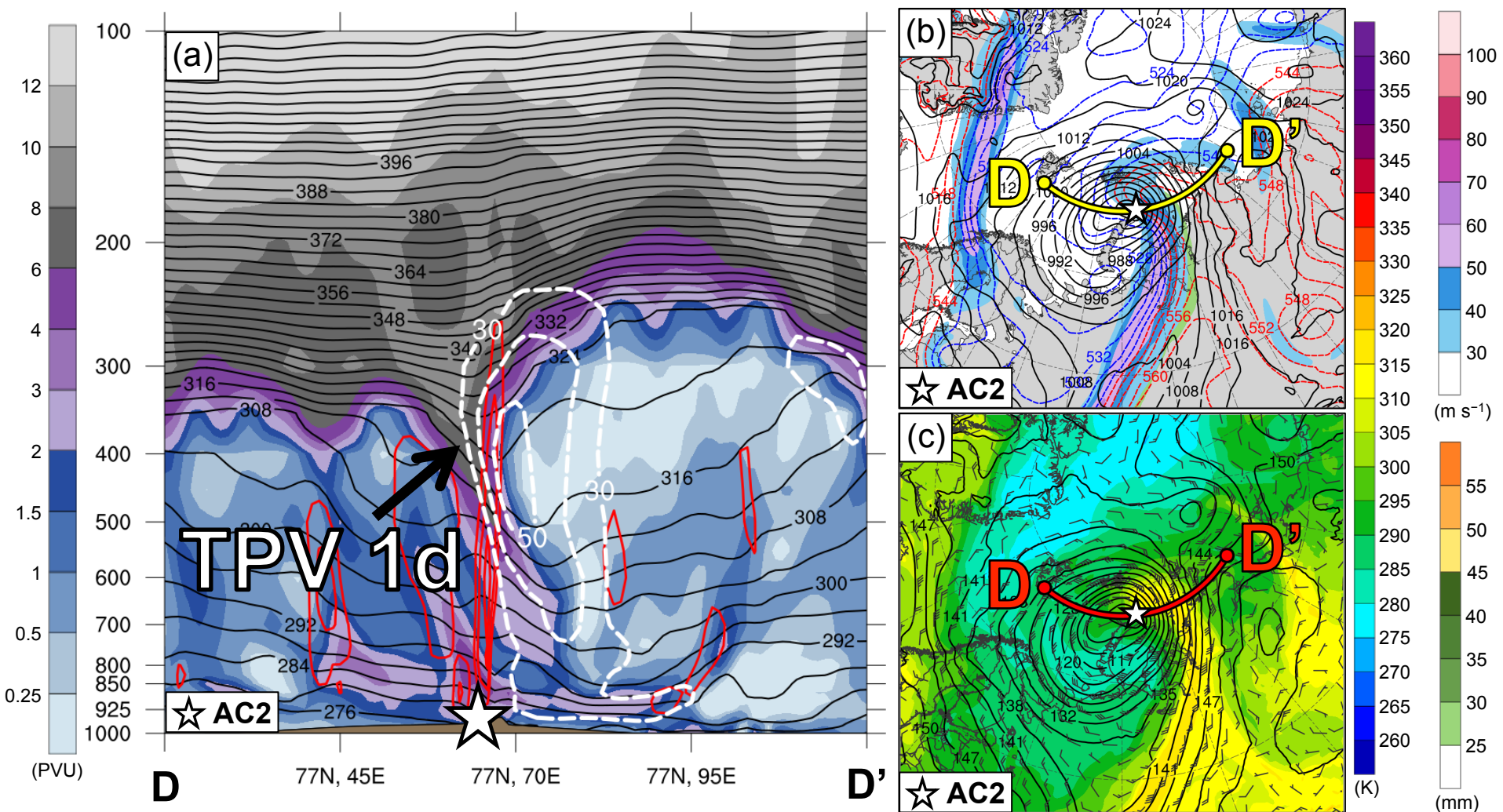
0000 UTC 7 Jun 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

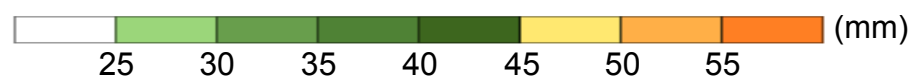
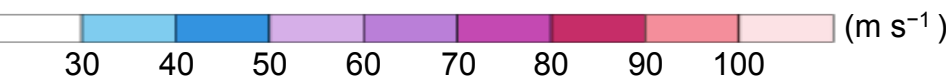
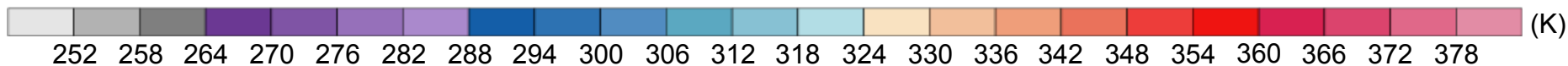
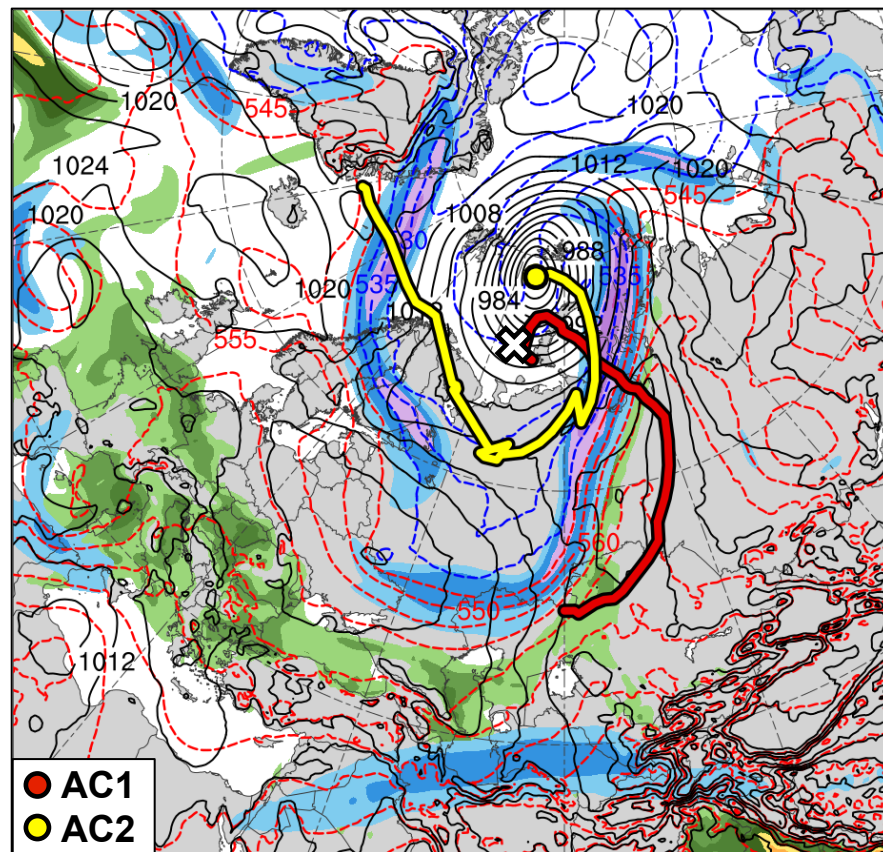
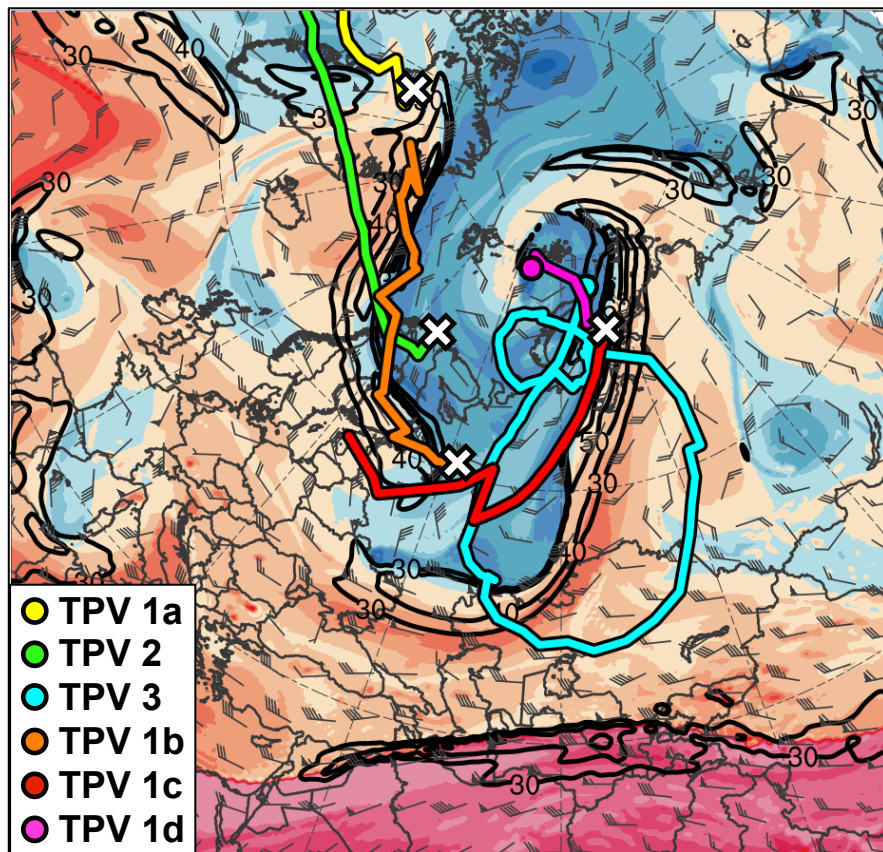
300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

0000 UTC 7 Jun 2018



(a) PV (PVU, shaded), θ (K, black), ascent (red, every $5 \times 10^{-3} \text{ hPa s}^{-1}$), and wind speed (white, every 10 m s^{-1} starting at 30 m s^{-1}); (b) 300-hPa wind speed (m s^{-1} , shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded); (c) 850-hPa θ_e (K, shaded), geopotential height (dam, black), and wind (m s^{-1} , flags and barb)

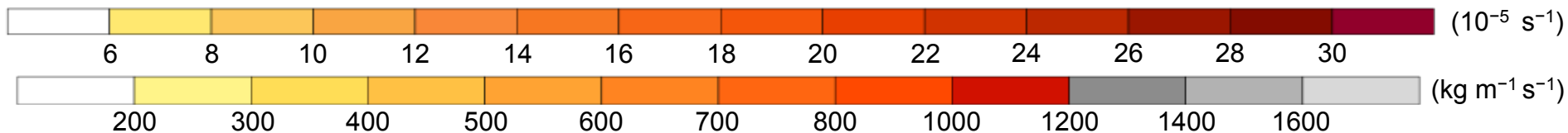
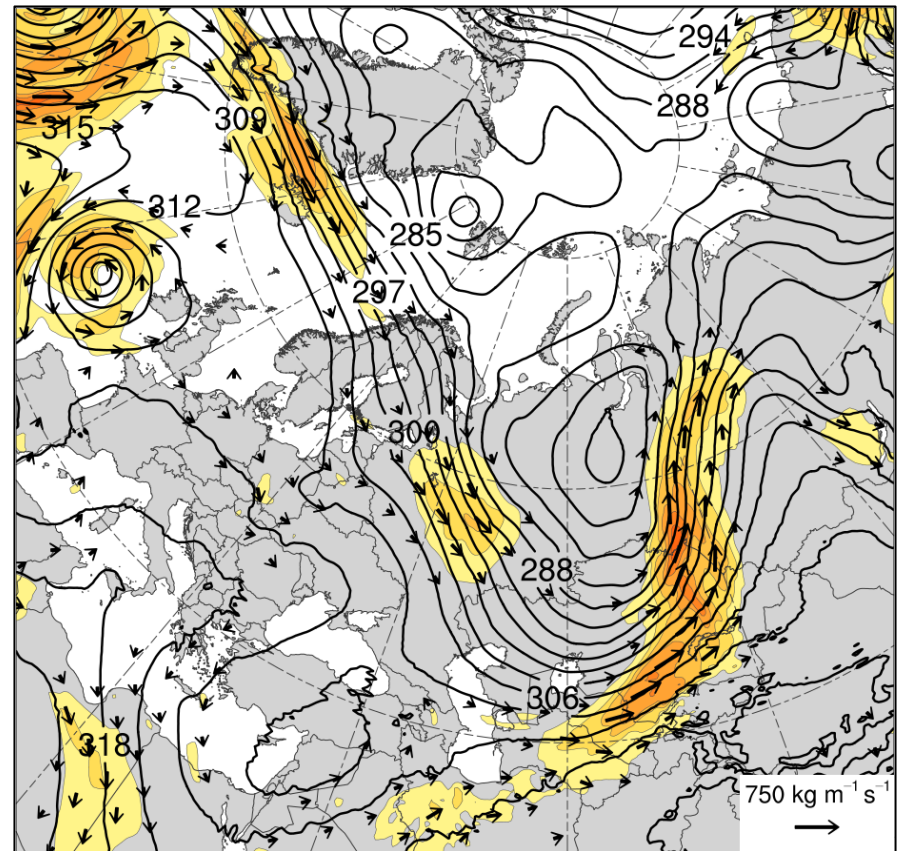
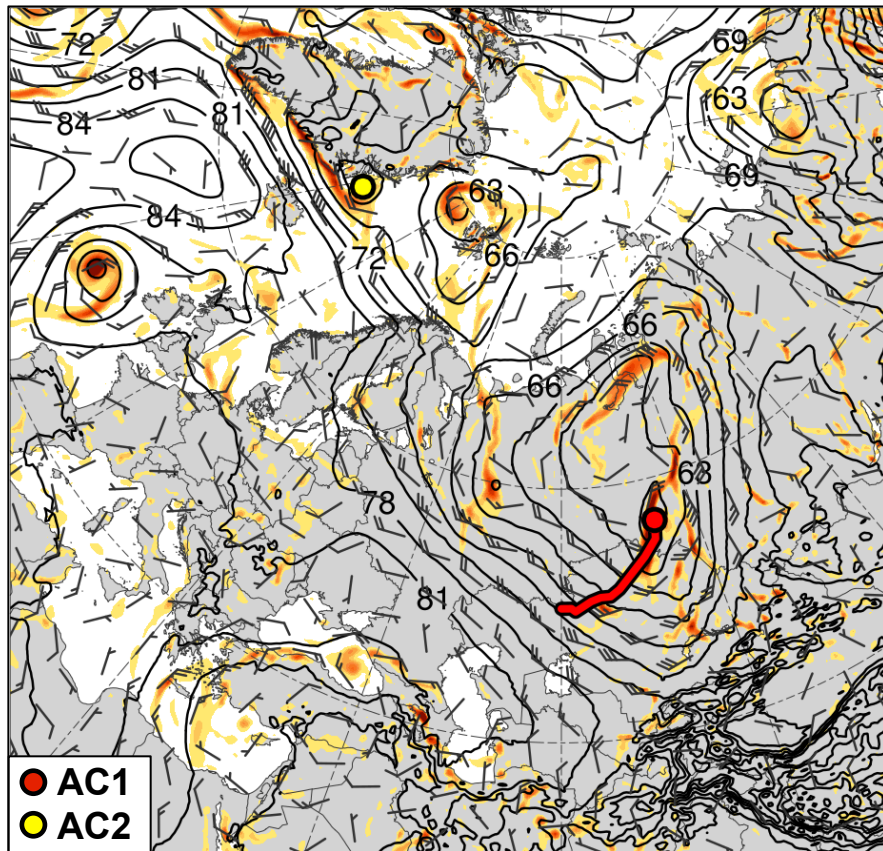
1200 UTC 7 Jun 2018



Potential temperature (K, shaded), wind speed (black, every 10 m s⁻¹ starting at 30 m s⁻¹), and wind (m s⁻¹, flags and barbs) on 2-PVU surface

300-hPa wind speed (m s⁻¹, shaded), 1000–500-hPa thickness (dam, blue/red), SLP (hPa, black), and PW (mm, shaded)

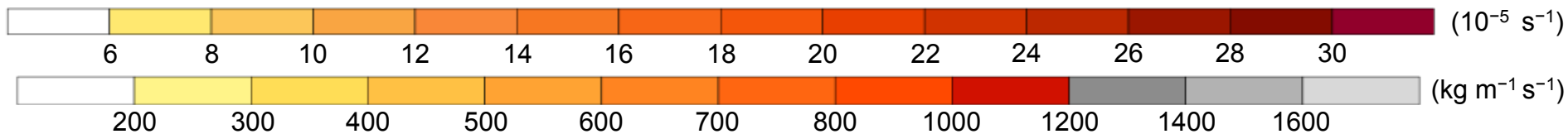
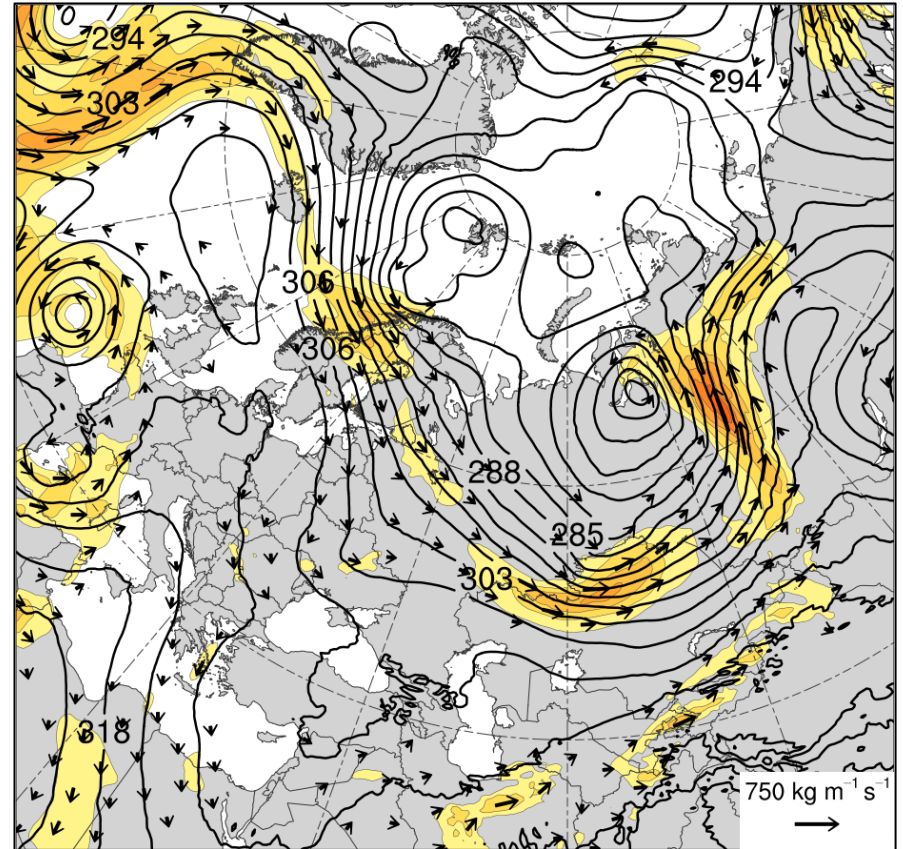
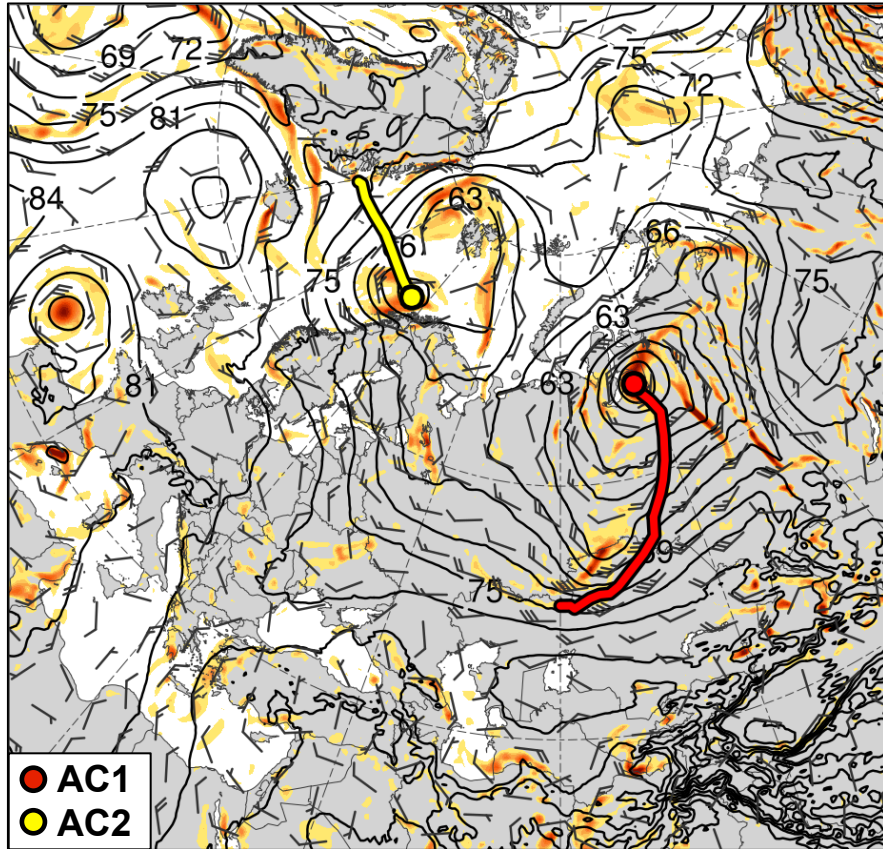
1200 UTC 2 Jun 2018



925-hPa relative vorticity (10^{-5} s^{-1} , shaded),
geopotential height (dam, black), and
winds (m s^{-1} , flags and barbs)

IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

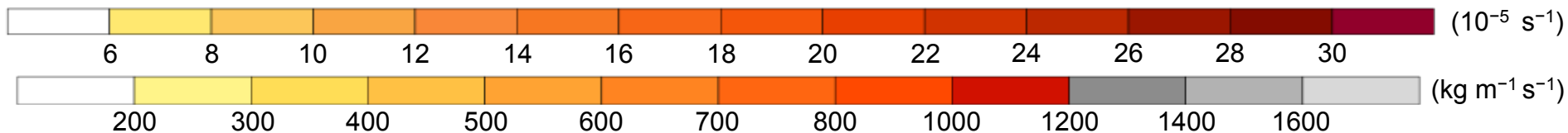
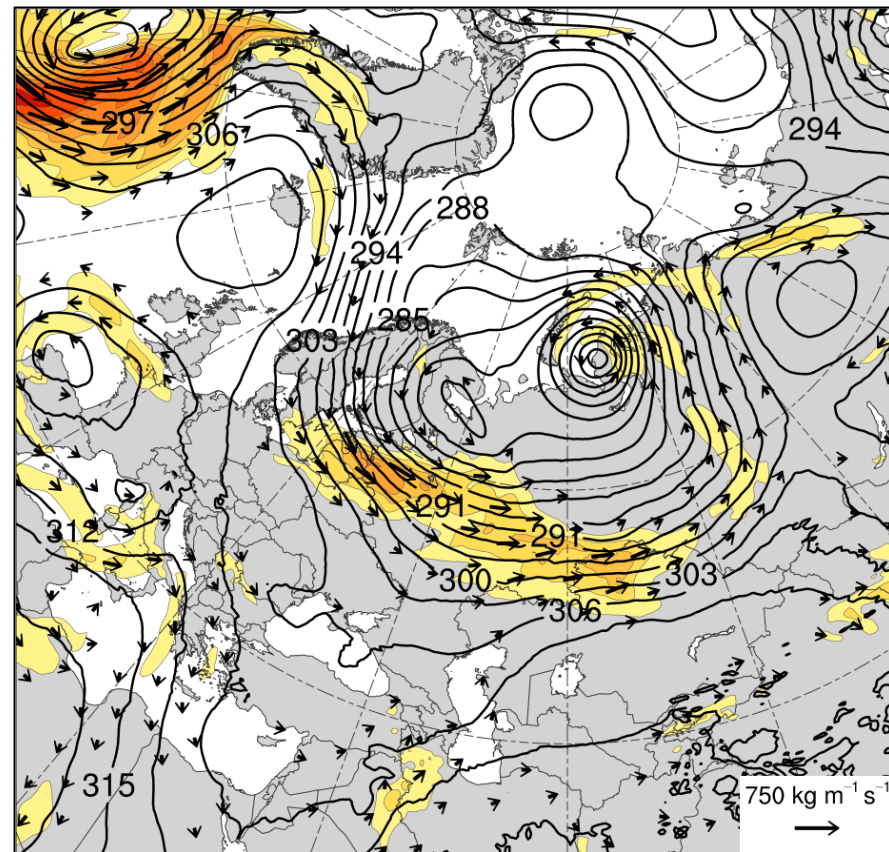
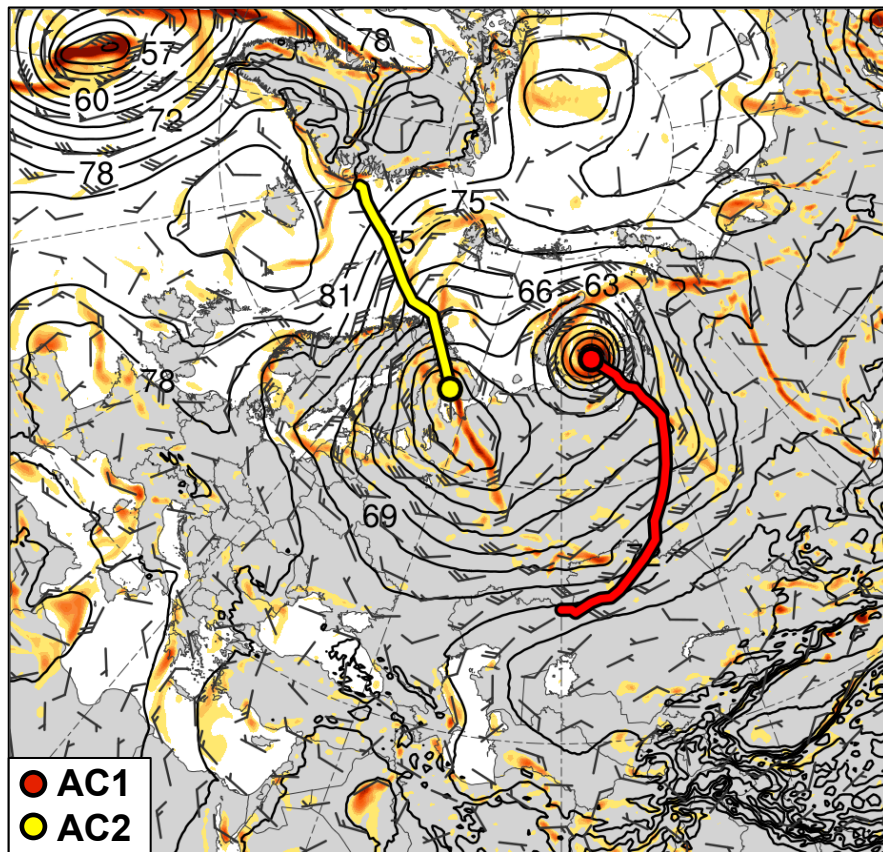
1200 UTC 3 Jun 2018



925-hPa relative vorticity (10^{-5} s^{-1} , shaded),
geopotential height (dam, black), and
winds (m s^{-1} , flags and barbs)

IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

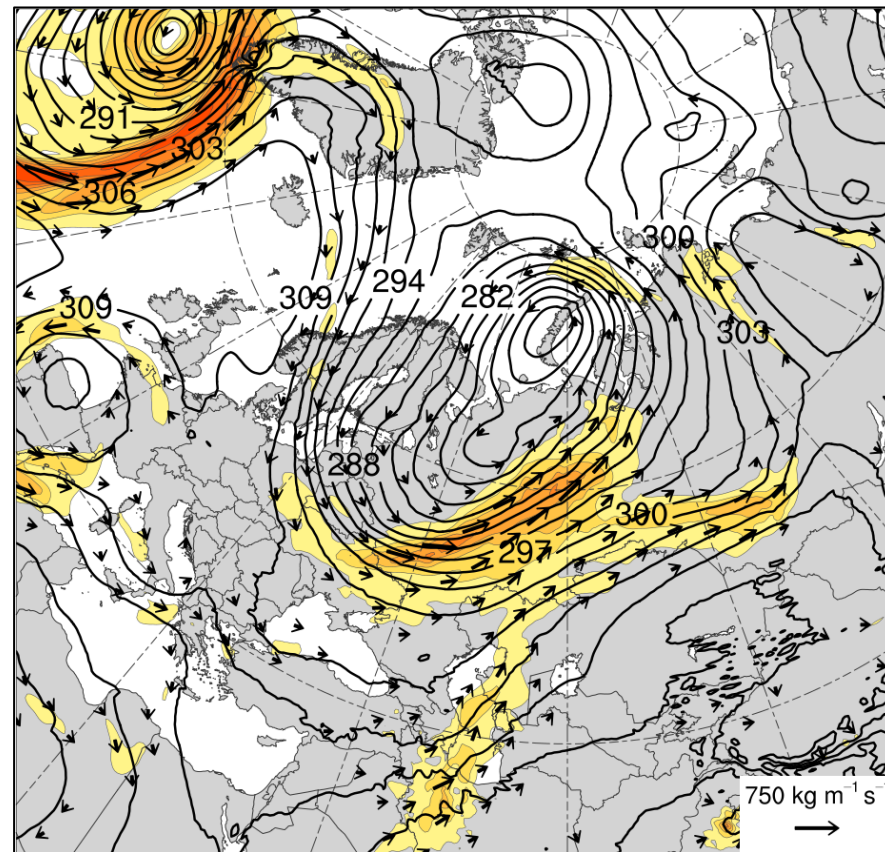
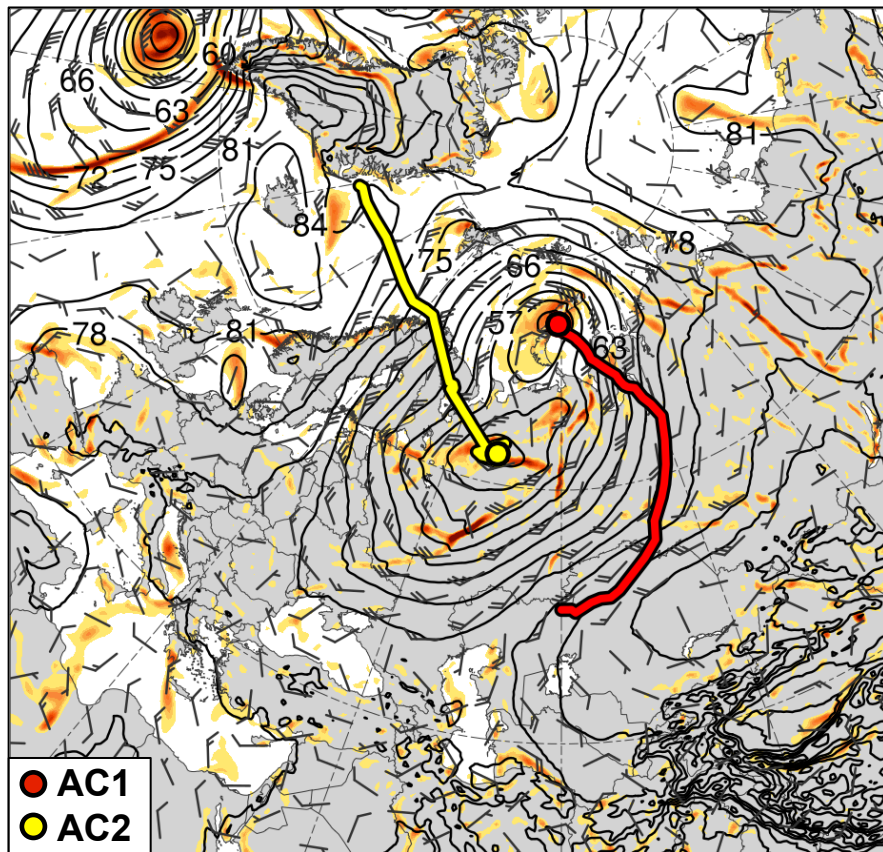
1200 UTC 4 Jun 2018



925-hPa relative vorticity (10^{-5} s^{-1} , shaded),
geopotential height (dam, black), and
winds (m s^{-1} , flags and barbs)

IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

1200 UTC 5 Jun 2018



6 8 10 12 14 16 18

(10^{-5} s^{-1})

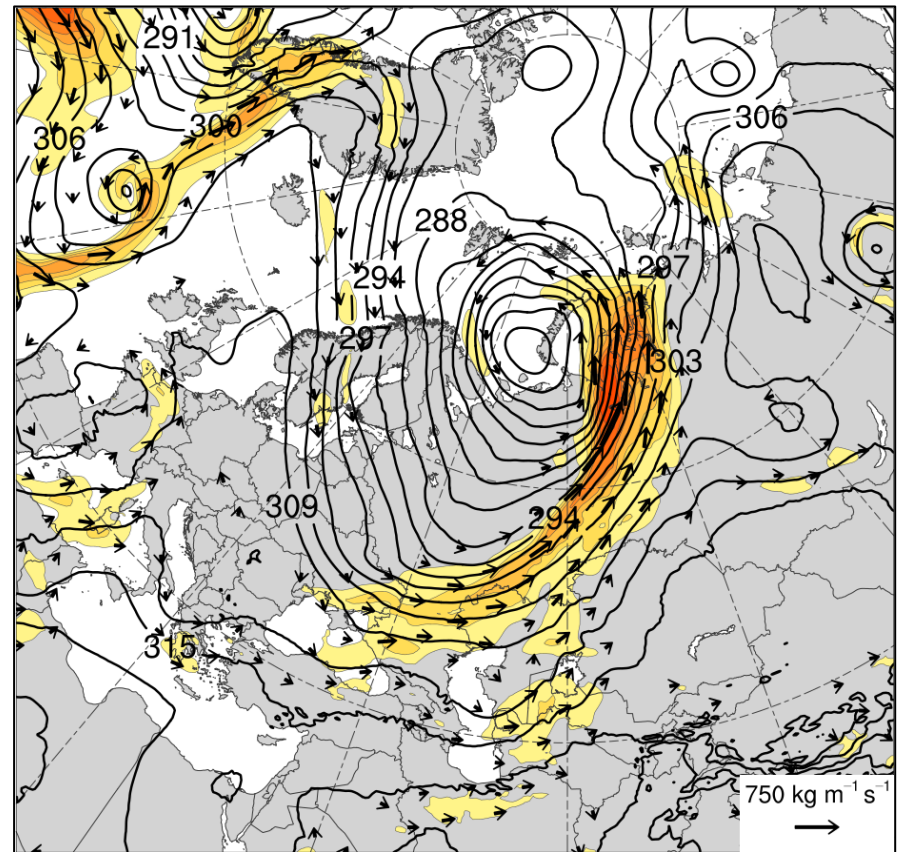
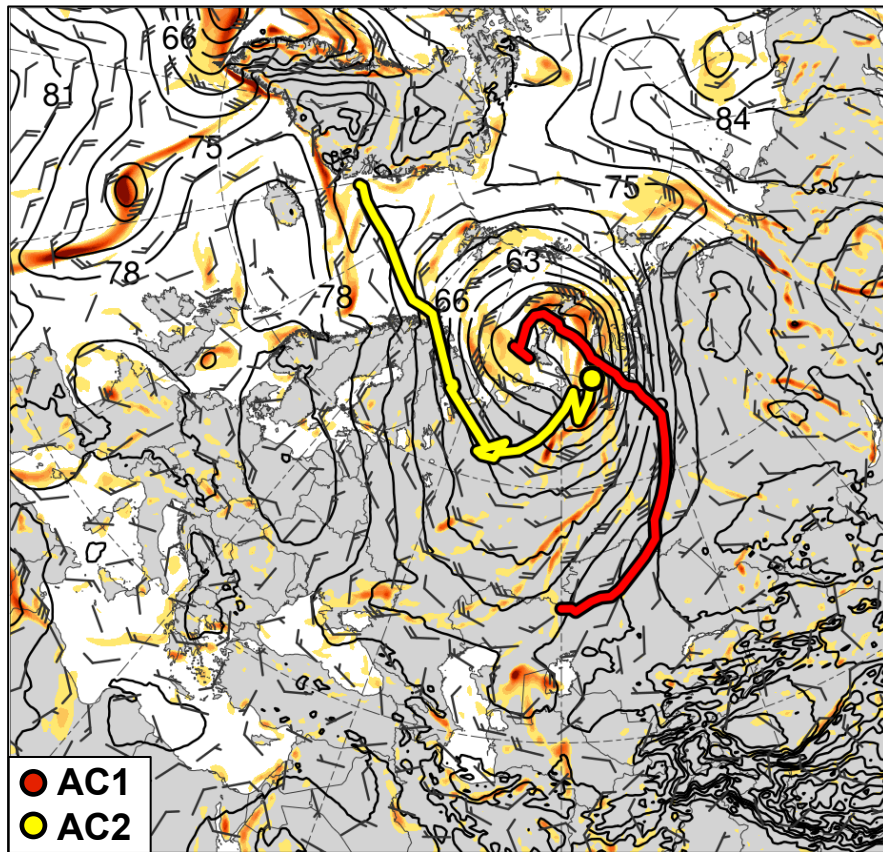
200 300 400 500 600 700

$(\text{kg m}^{-1} \text{ s}^{-1})$

925-hPa relative vorticity (10^{-5} s^{-1} , shaded),
geopotential height (dam, black), and
winds (m s^{-1} , flags and barbs)

IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

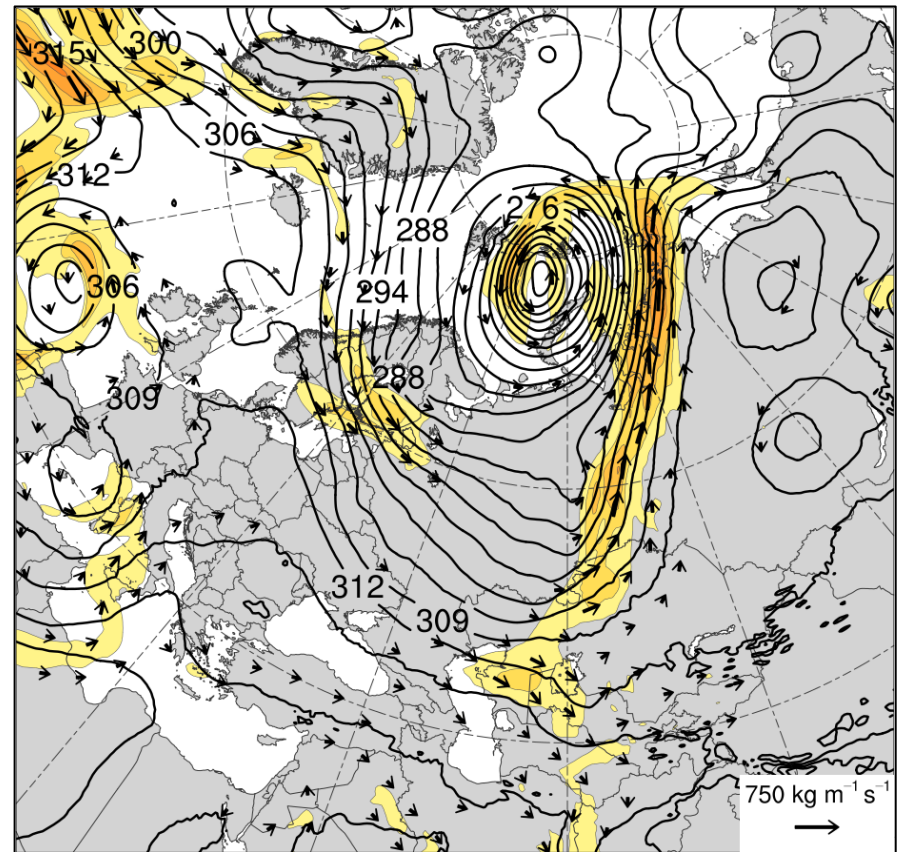
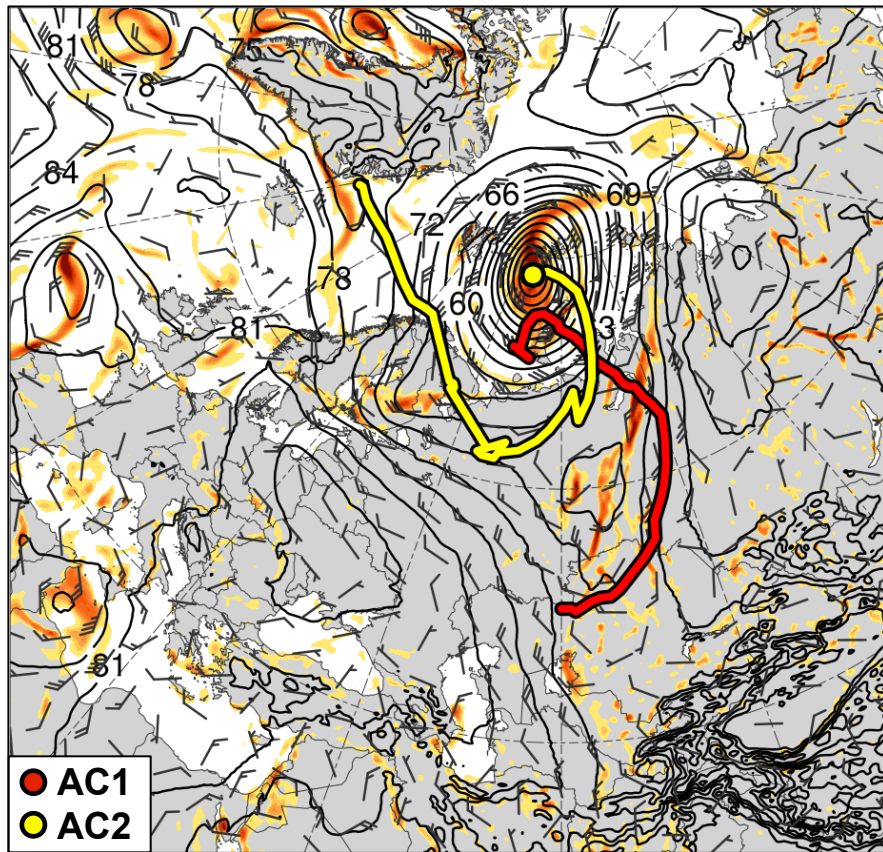
1200 UTC 6 Jun 2018



925-hPa relative vorticity (10^{-5} s^{-1} , shaded),
geopotential height (dam, black), and
winds (m s^{-1} , flags and barbs)

IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

1200 UTC 7 Jun 2018



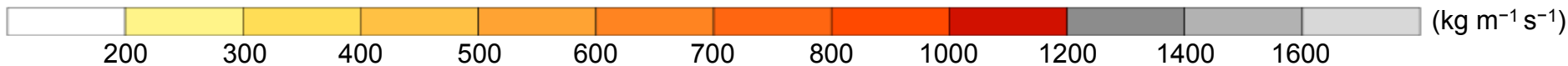
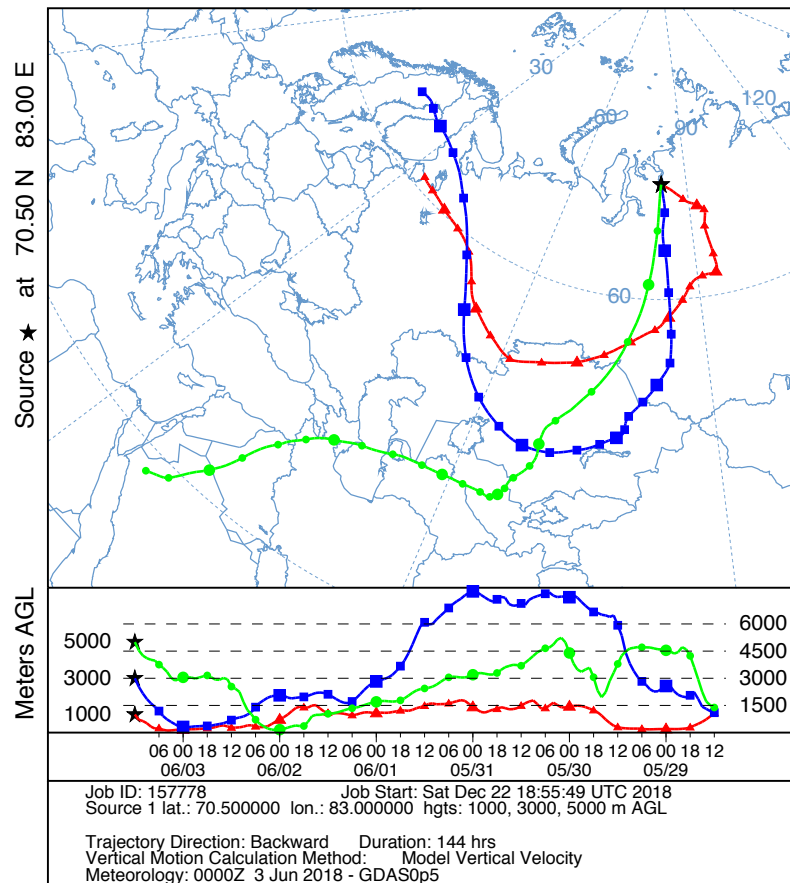
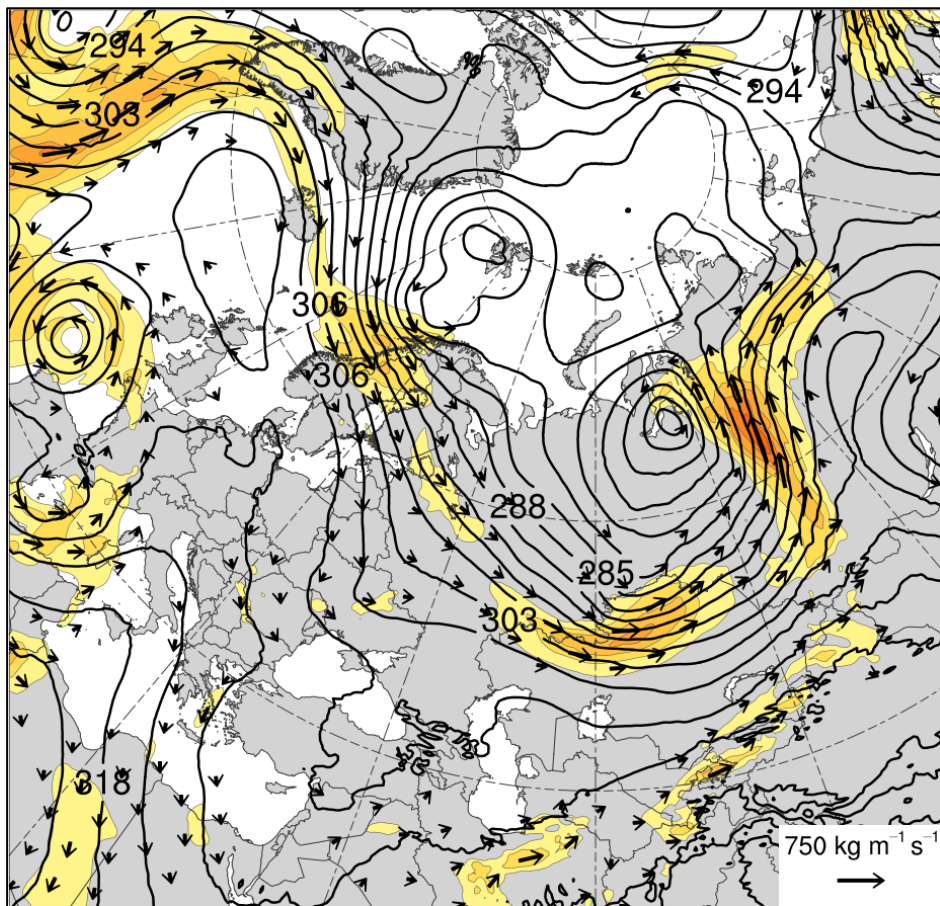
925-hPa relative vorticity (10^{-5} s^{-1} , shaded),
geopotential height (dam, black), and
winds (m s^{-1} , flags and barbs)

IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

Lagrangian Perspective: Selected Trajectories (AC1)

1200 UTC 3 Jun 2018

NOAA HYSPLIT MODEL
 Backward trajectories ending at 1200 UTC 03 Jun 18
 GFS Meteorological Data



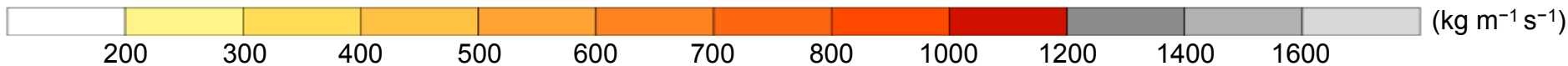
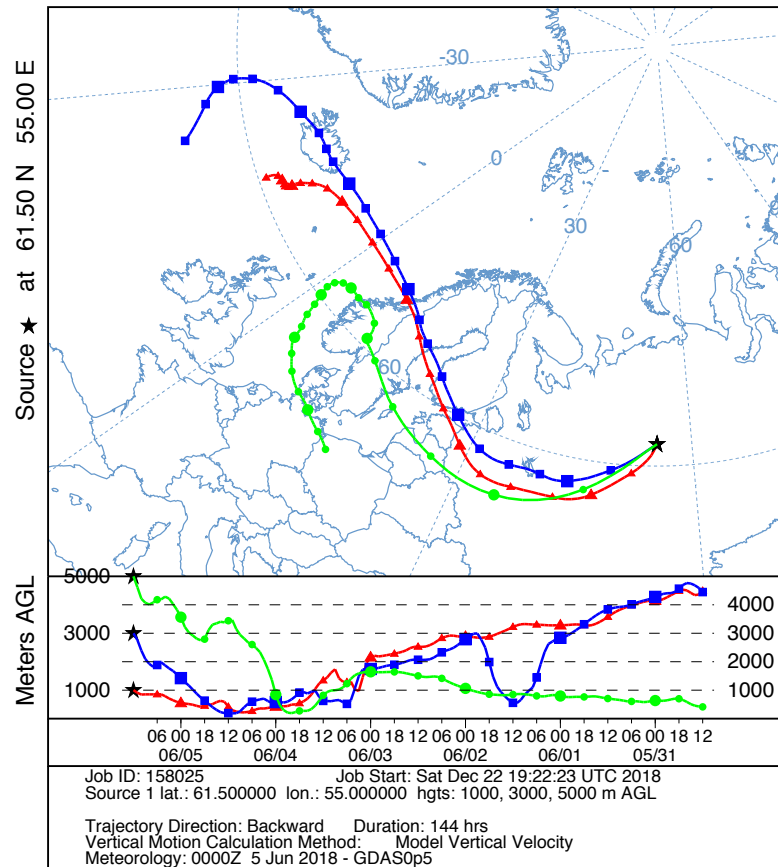
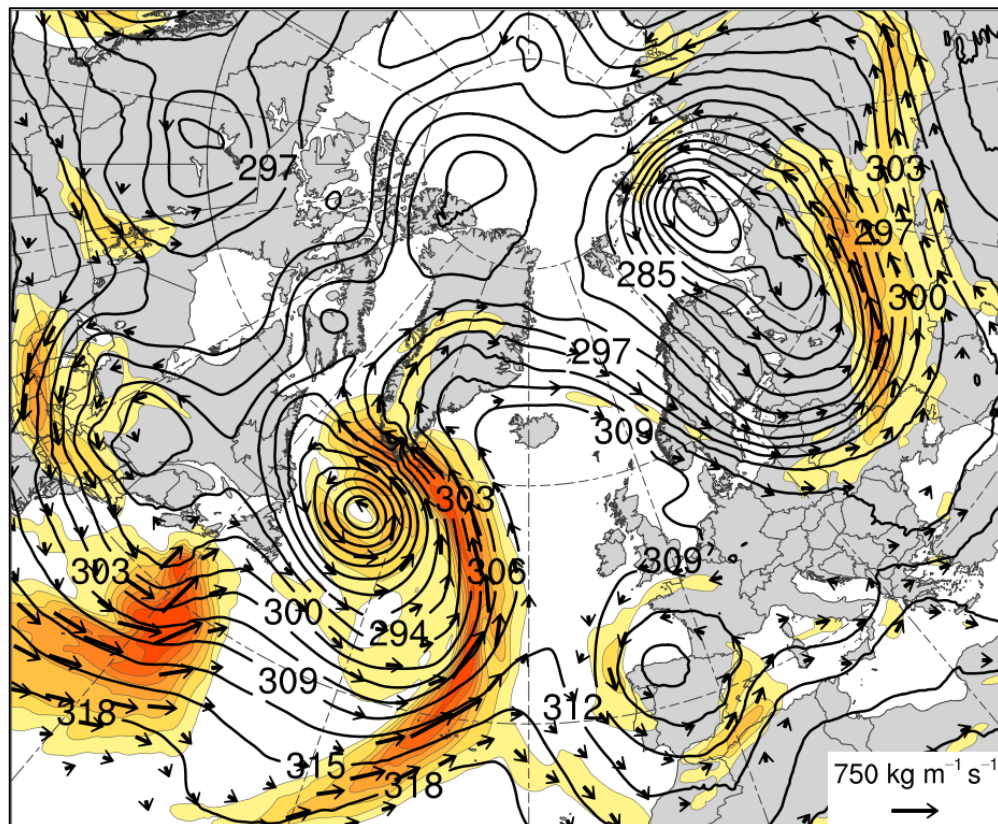
IVT ($\text{kg m}^{-1} \text{ s}^{-1}$, shaded and vectors) and
 700-hPa geopotential height (dam, black)

NOAA HYSPLIT 5-d backward trajectories
 ending at 1200 UTC 3 Jun 2018

Lagrangian Perspective: Selected Trajectories (AC2)

1200 UTC 5 Jun 2018

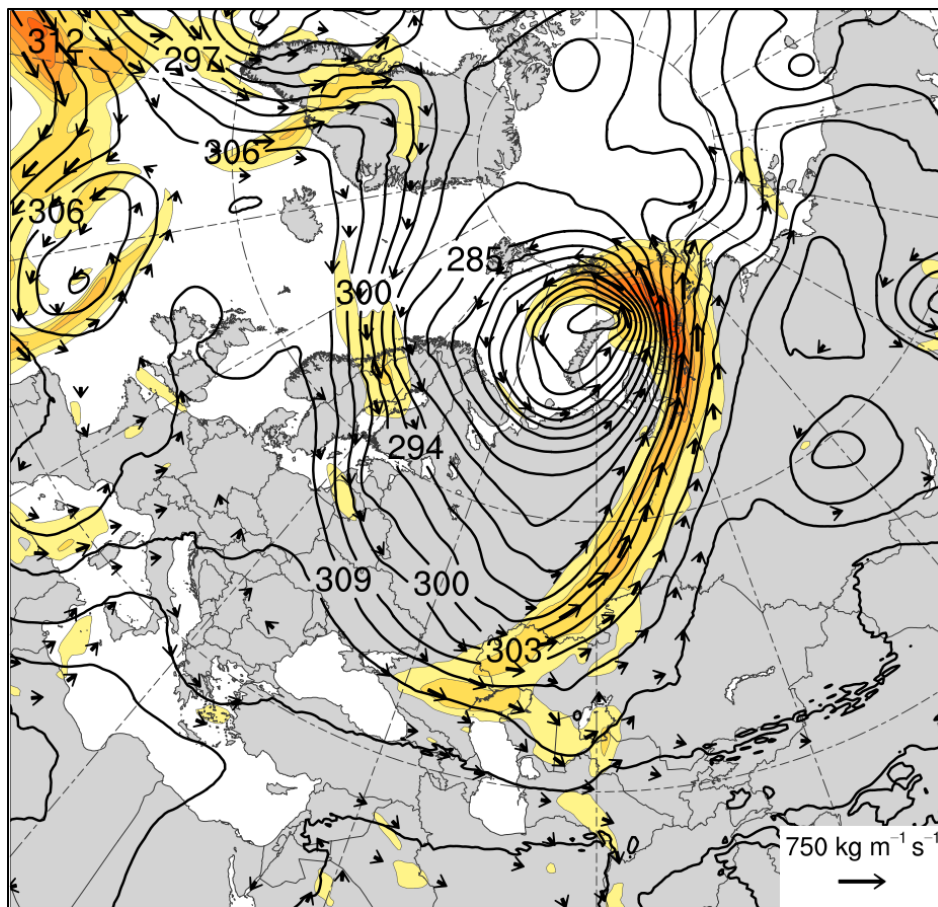
NOAA HYSPLIT MODEL
Backward trajectories ending at 1200 UTC 05 Jun 18
GFSG Meteorological Data



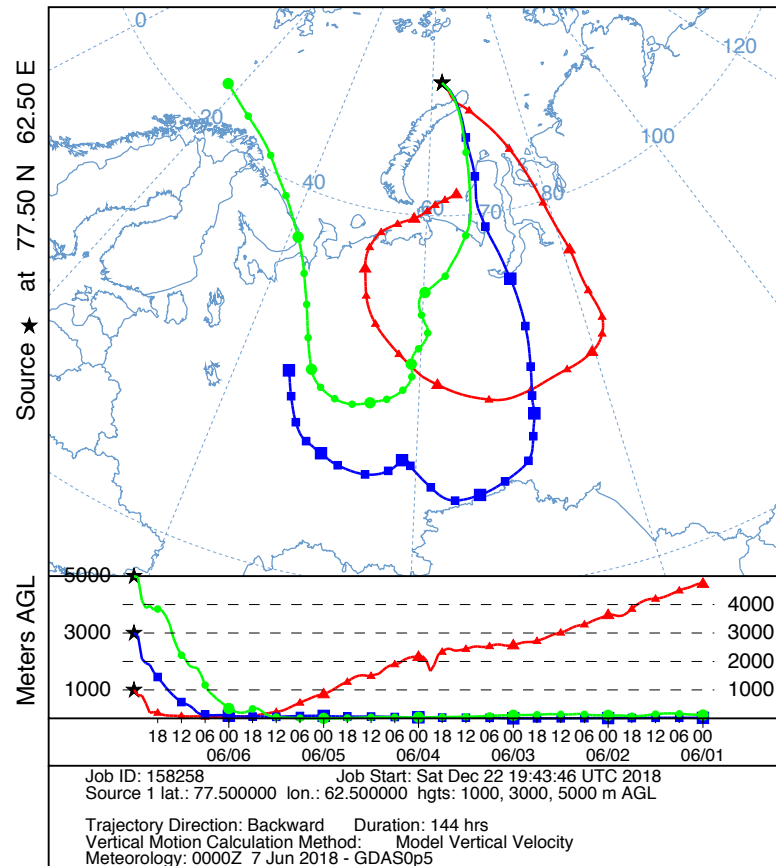
IVT ($\text{kg m}^{-1} \text{s}^{-1}$, shaded and vectors) and
700-hPa geopotential height (dam, black)

NOAA HYSPLIT 5-d backward trajectories
ending at 1200 UTC 5 June 2018

0000 UTC 7 Jun 2018



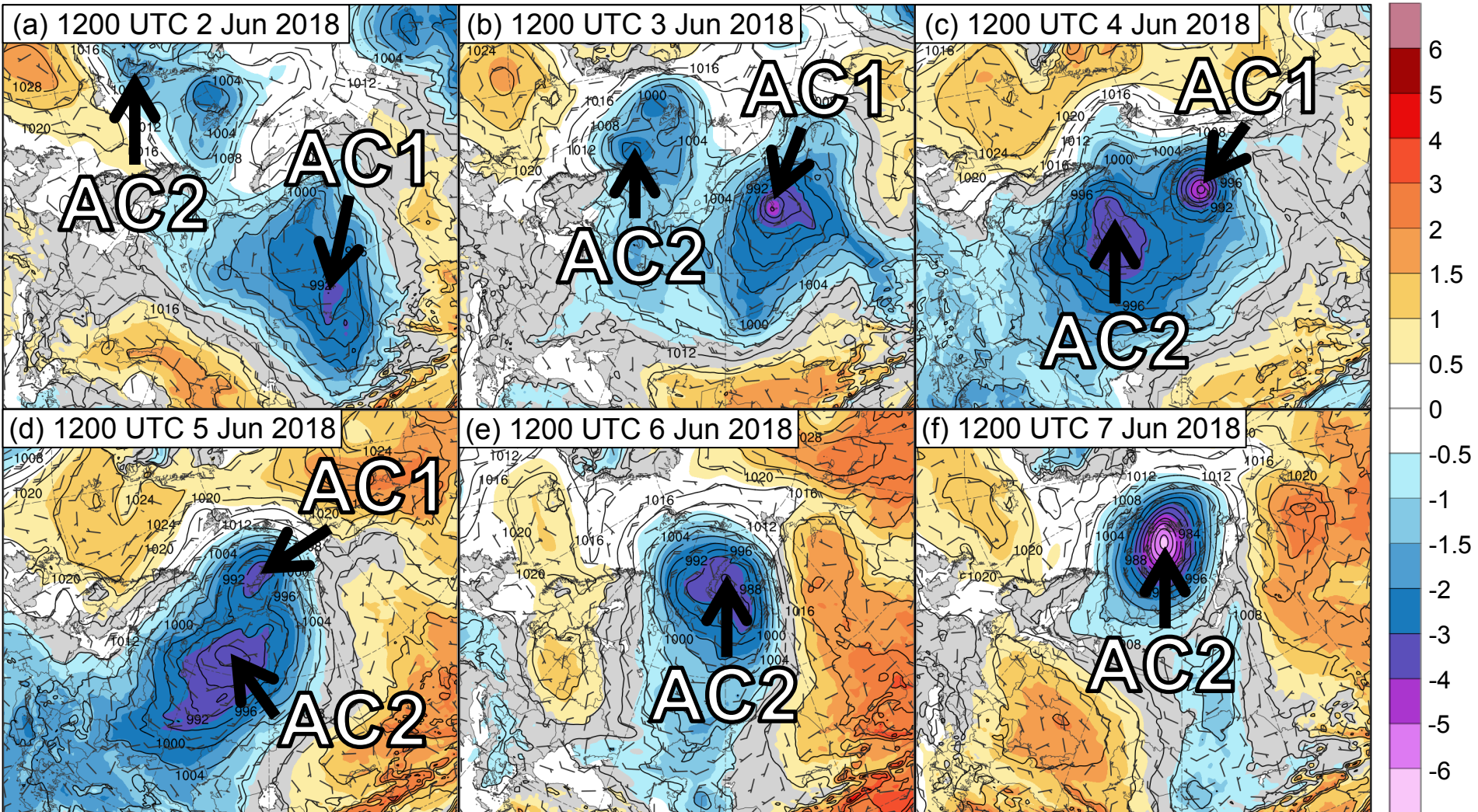
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 07 Jun 18
GFSG Meteorological Data



IVT ($\text{kg m}^{-1} \text{s}^{-1}$, shaded and vectors) and 700-hPa geopotential height (dam, black)

NOAA HYSPLIT 5-d backward trajectories ending at 0000 UTC 7 June 2018

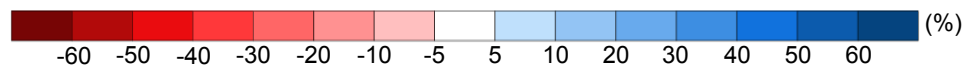
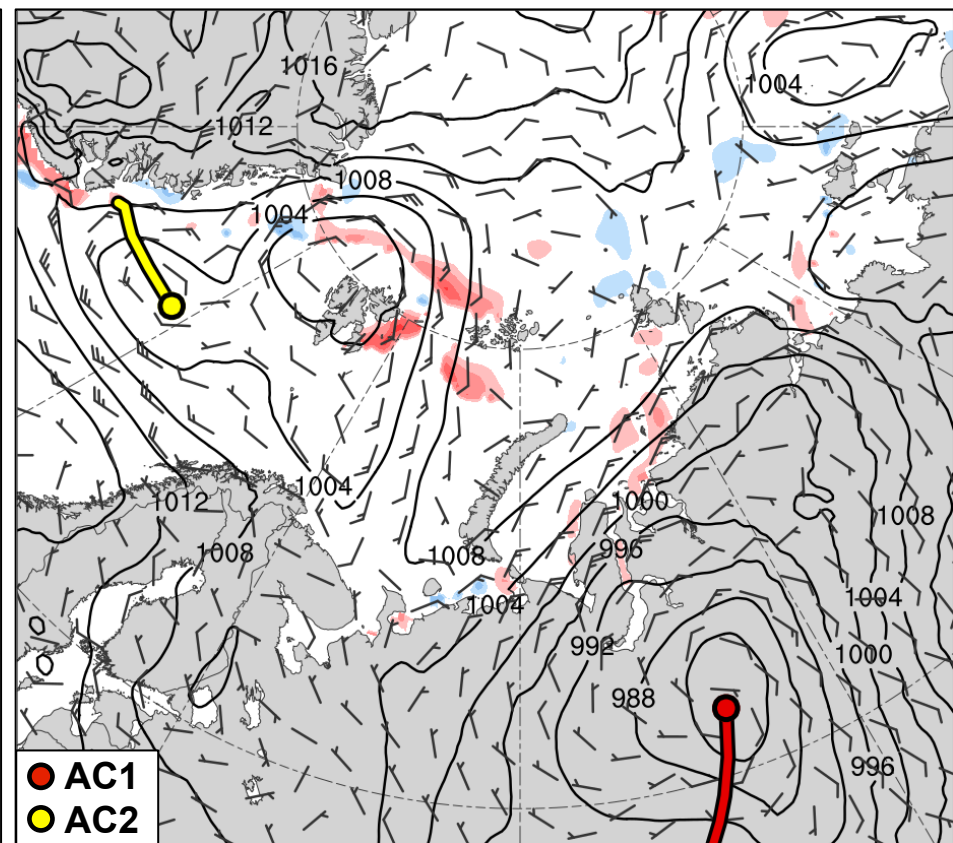
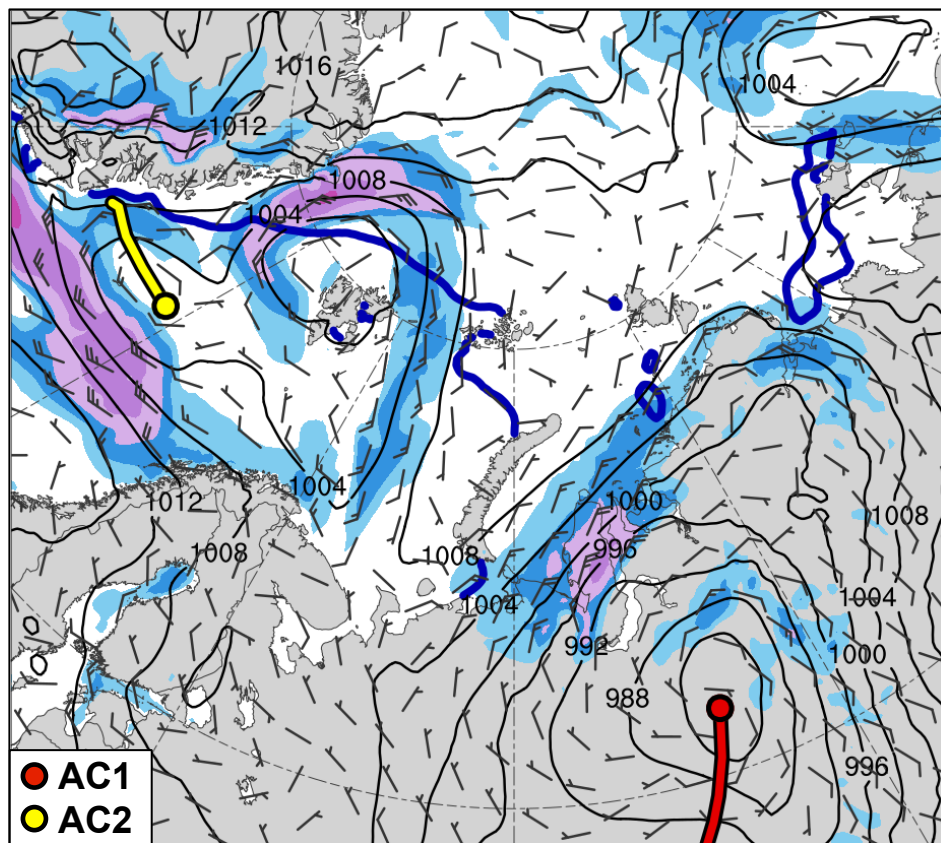
Interactions between Arctic Cyclones



SLP (hPa, black), 10-m winds (m s^{-1} , flags and barbs), and standardized SLP anomalies (σ , shaded)

Impacts of AC1 and AC2 on Arctic Sea Ice

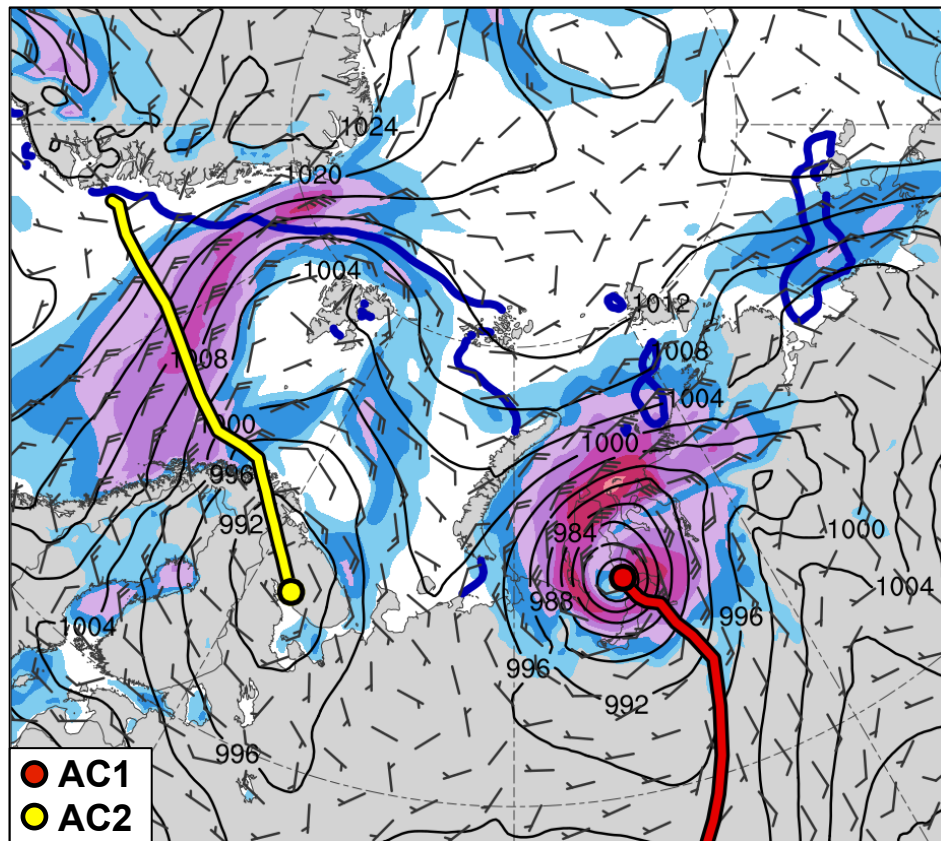
0000 UTC 3 Jun 2018



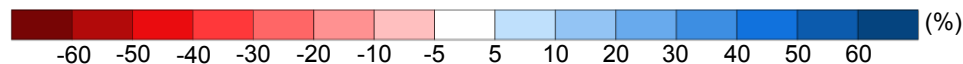
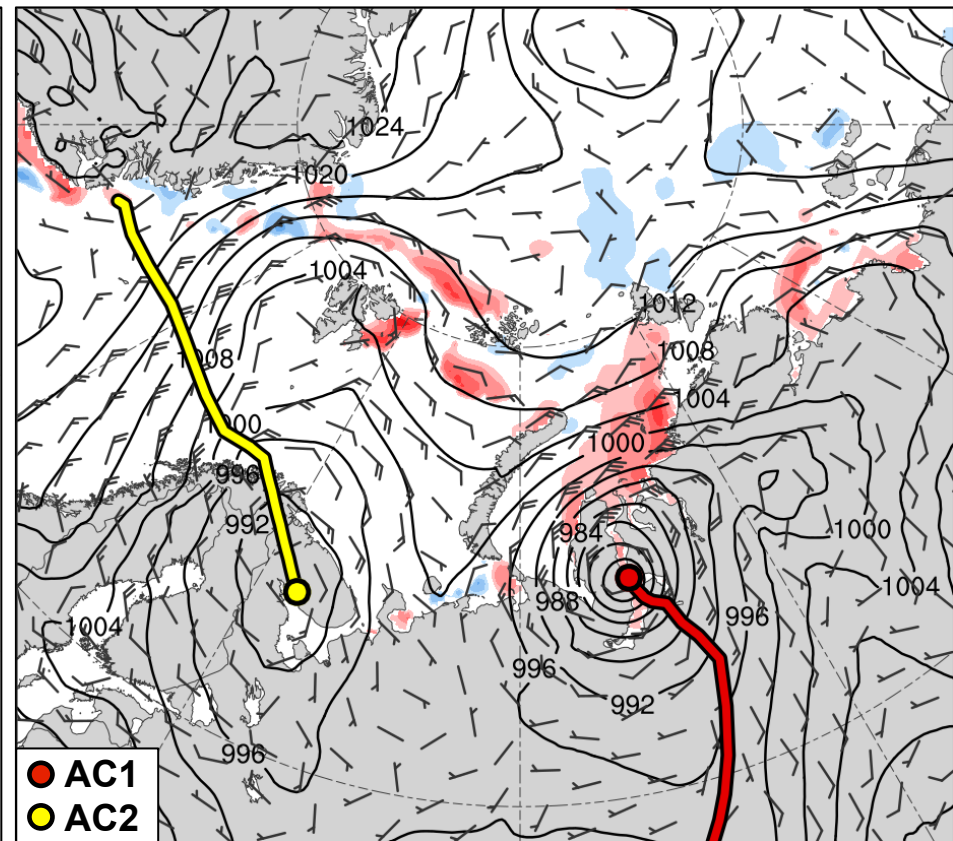
SLP (hPa, black), 10-m wind speed (m s^{-1} , shaded) and wind (m s^{-1} , barbs), and 50% contour of sea-ice concentration (thick blue)

Change in sea-ice concentration (% , shaded) since 0000 UTC 1 June 2018, SLP (hPa, black), and 10-m wind speed (m s^{-1} , shaded)

0000 UTC 4 Jun 2018

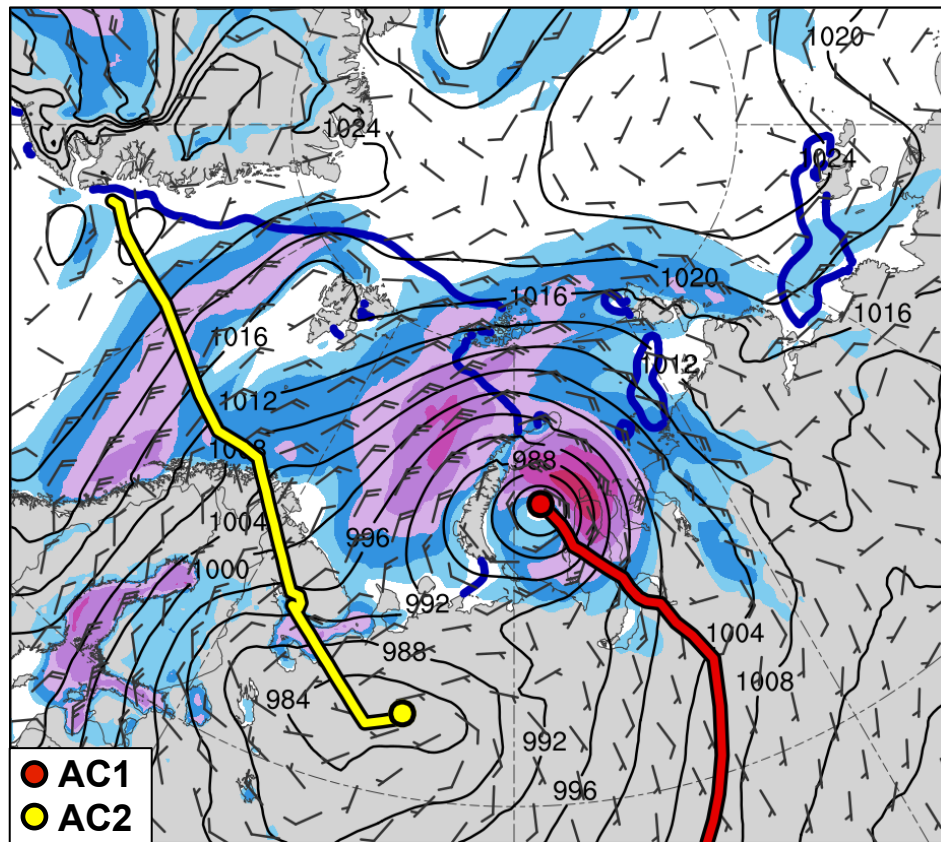


SLP (hPa, black), 10-m wind speed (m s⁻¹, shaded) and wind (m s⁻¹, barbs), and 50% contour of sea-ice concentration (thick blue)

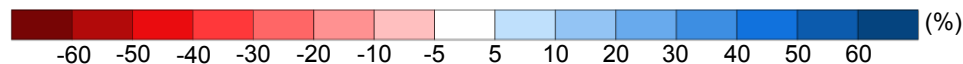
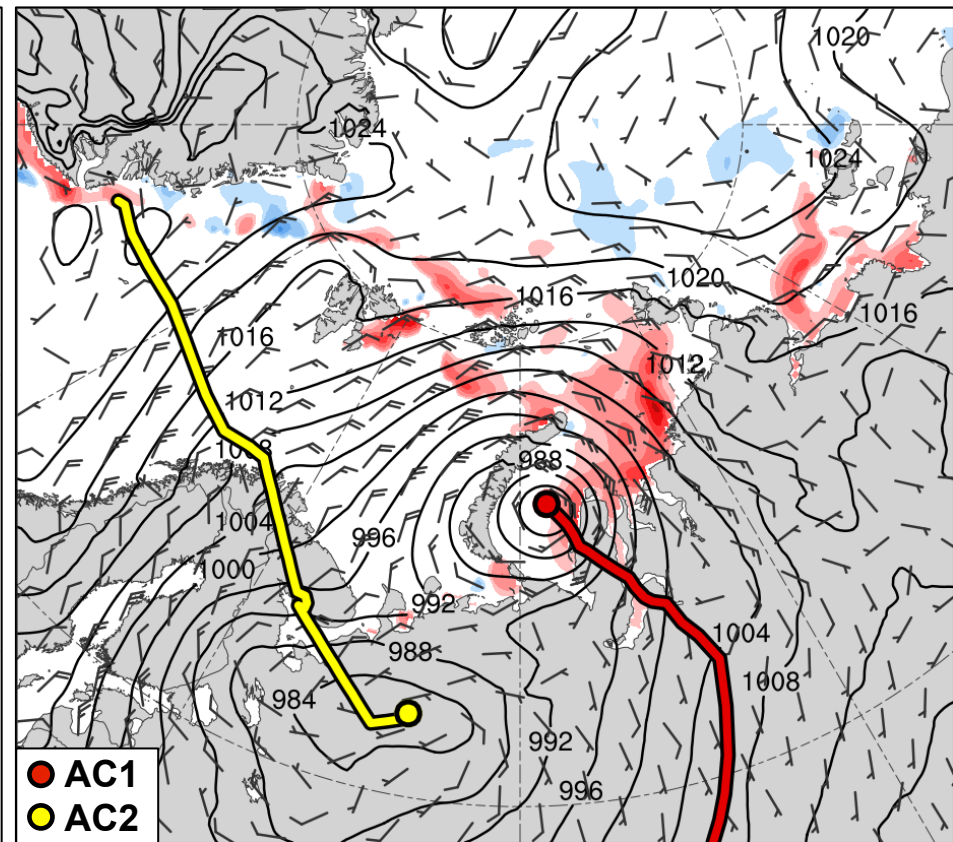


Change in sea-ice concentration (% , shaded) since 0000 UTC 1 June 2018, SLP (hPa, black), and 10-m wind speed (m s⁻¹, shaded)

0000 UTC 5 Jun 2018

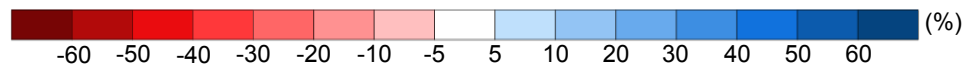
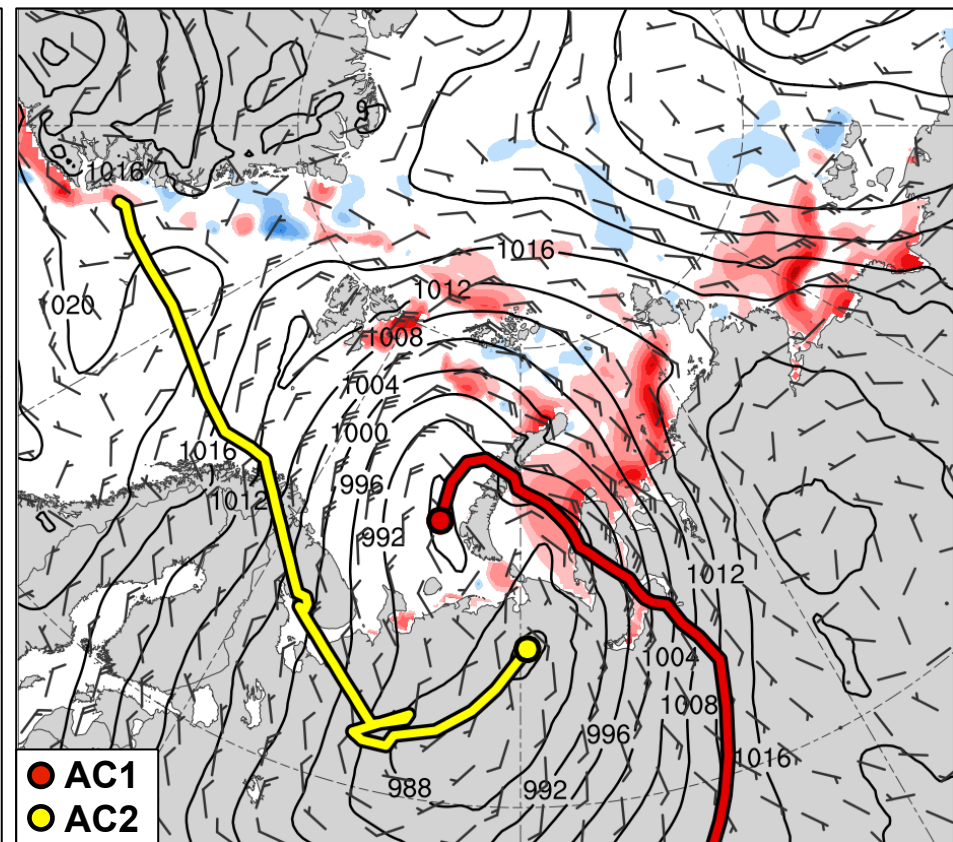
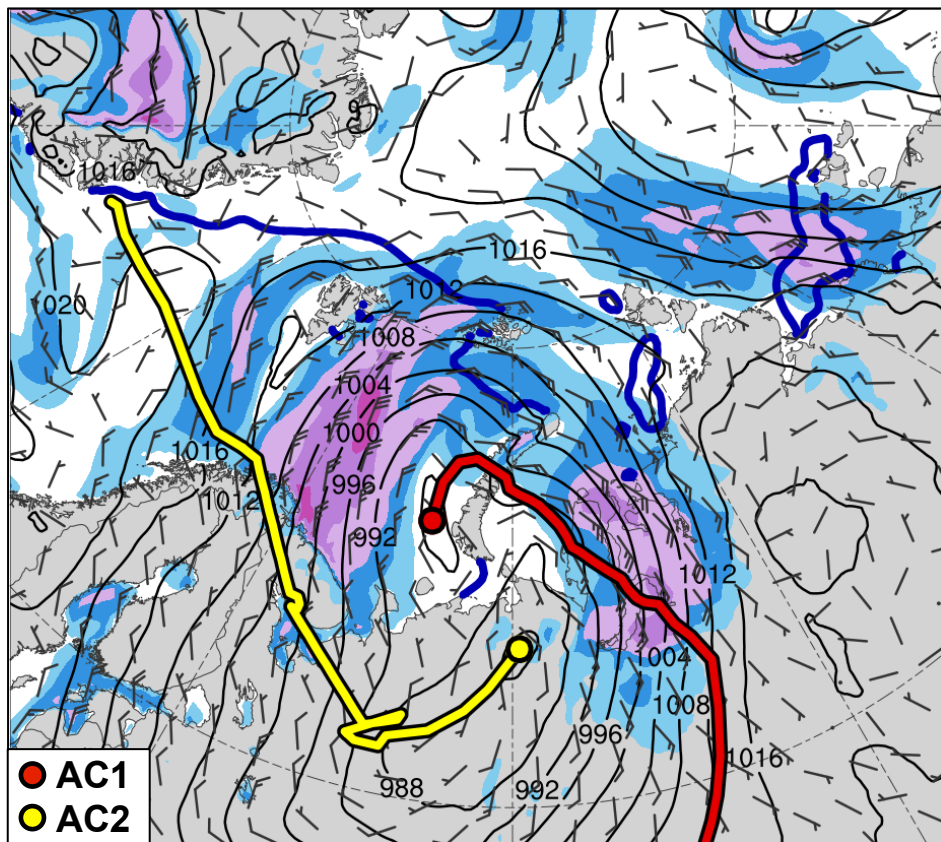


SLP (hPa, black), 10-m wind speed (m s^{-1} , shaded) and wind (m s^{-1} , barbs), and 50% contour of sea-ice concentration (thick blue)



Change in sea-ice concentration (% , shaded) since 0000 UTC 1 June 2018, SLP (hPa, black), and 10-m wind speed (m s^{-1} , shaded)

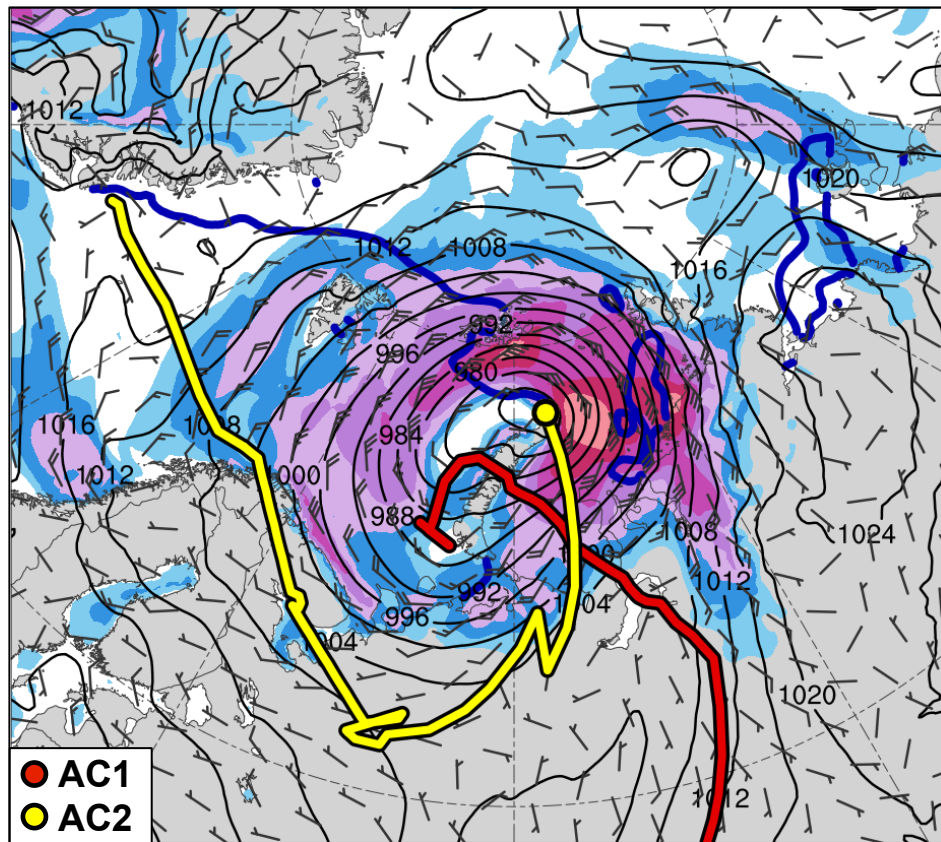
0000 UTC 6 Jun 2018



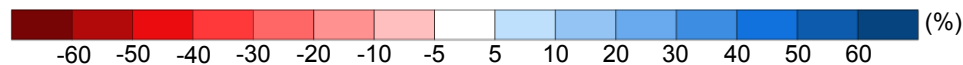
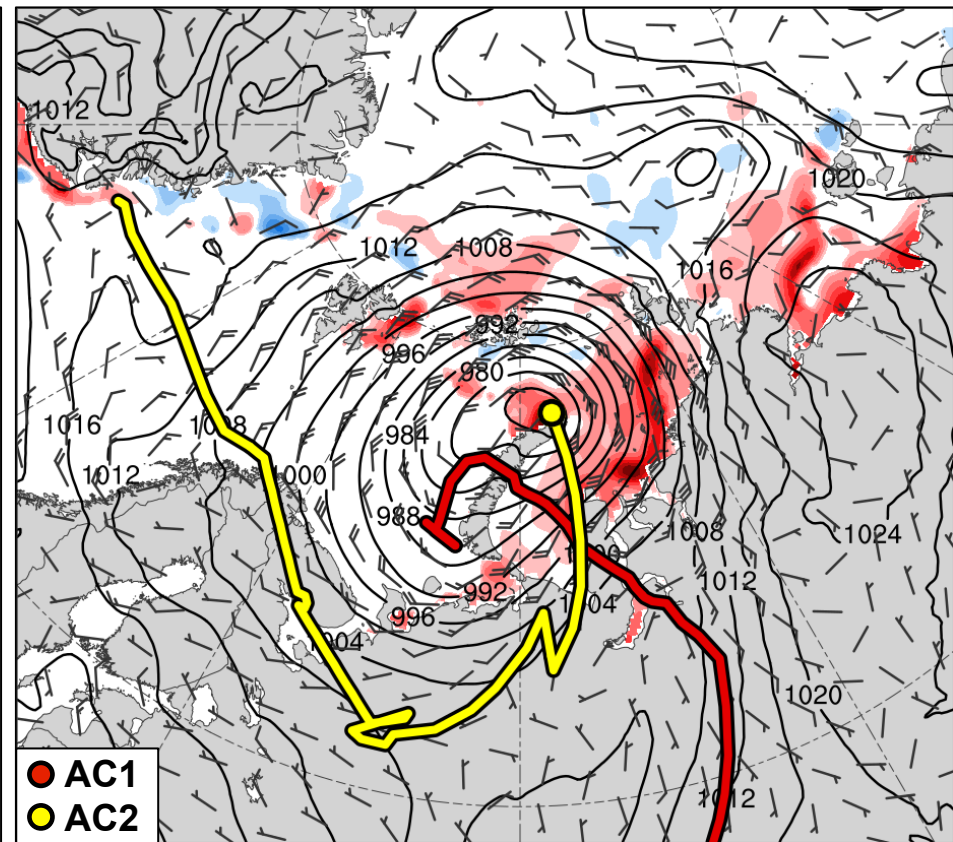
SLP (hPa, black), 10-m wind speed (m s^{-1} , shaded) and wind (m s^{-1} , barbs), and 50% contour of sea-ice concentration (thick blue)

Change in sea-ice concentration (% , shaded) since 0000 UTC 1 June 2018, SLP (hPa, black), and 10-m wind speed (m s^{-1} , shaded)

0000 UTC 7 Jun 2018

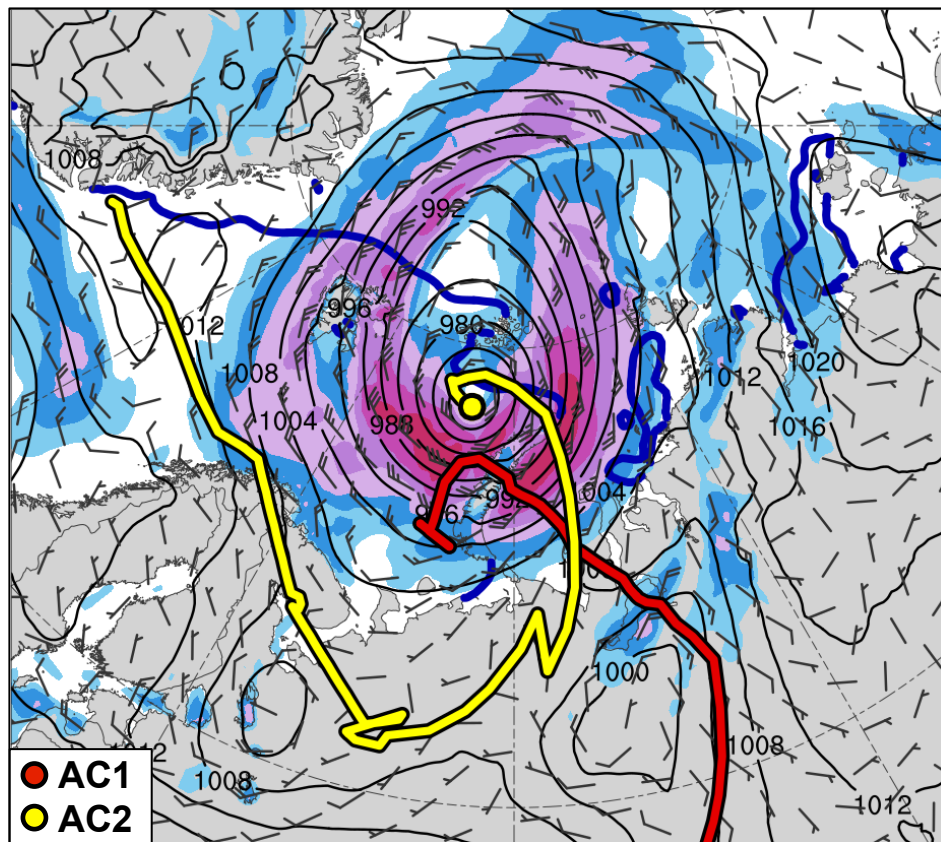


SLP (hPa, black), 10-m wind speed (m s⁻¹, shaded) and wind (m s⁻¹, barbs), and 50% contour of sea-ice concentration (thick blue)

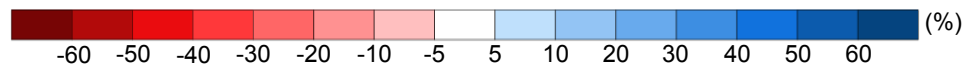
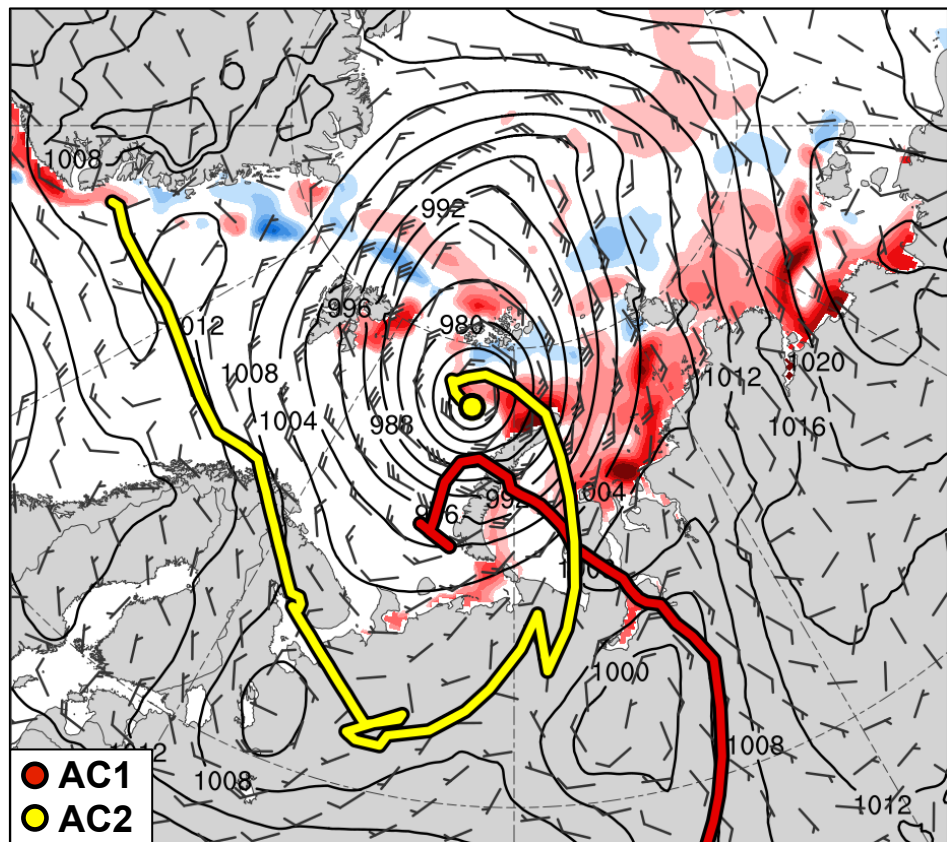


Change in sea-ice concentration (% , shaded) since 0000 UTC 1 June 2018, SLP (hPa, black), and 10-m wind speed (m s⁻¹, shaded)

0000 UTC 8 Jun 2018

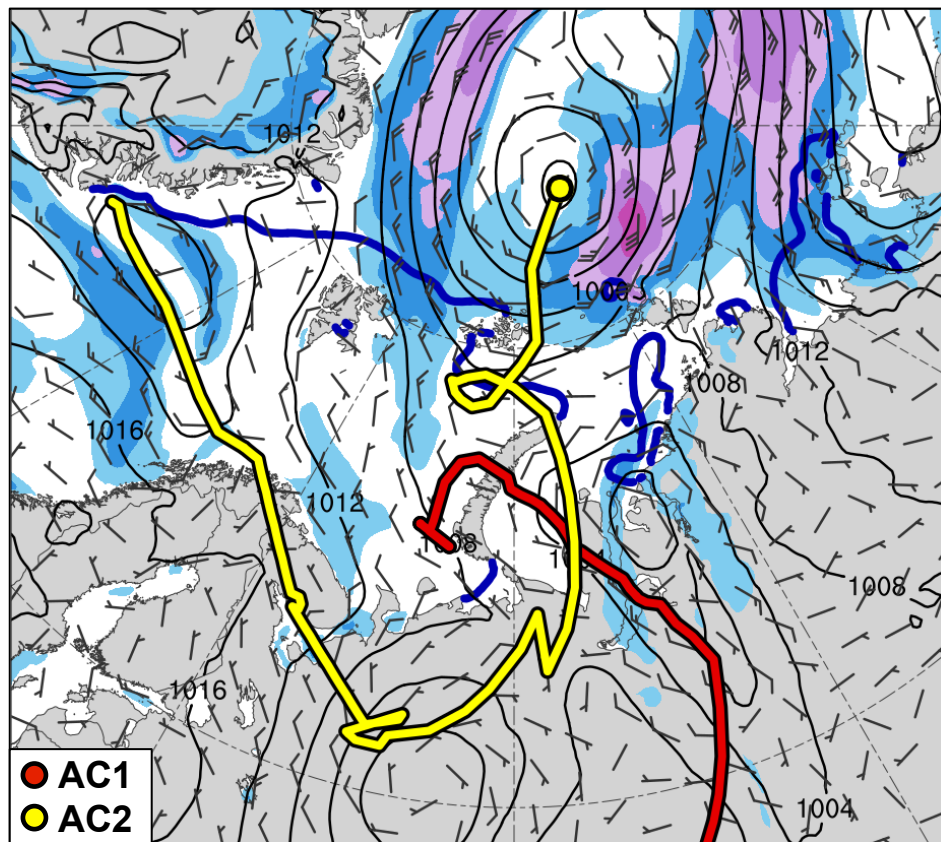


SLP (hPa, black), 10-m wind speed (m s⁻¹, shaded) and wind (m s⁻¹, barbs), and 50% contour of sea-ice concentration (thick blue)

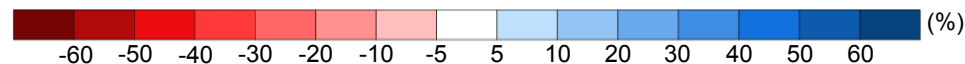
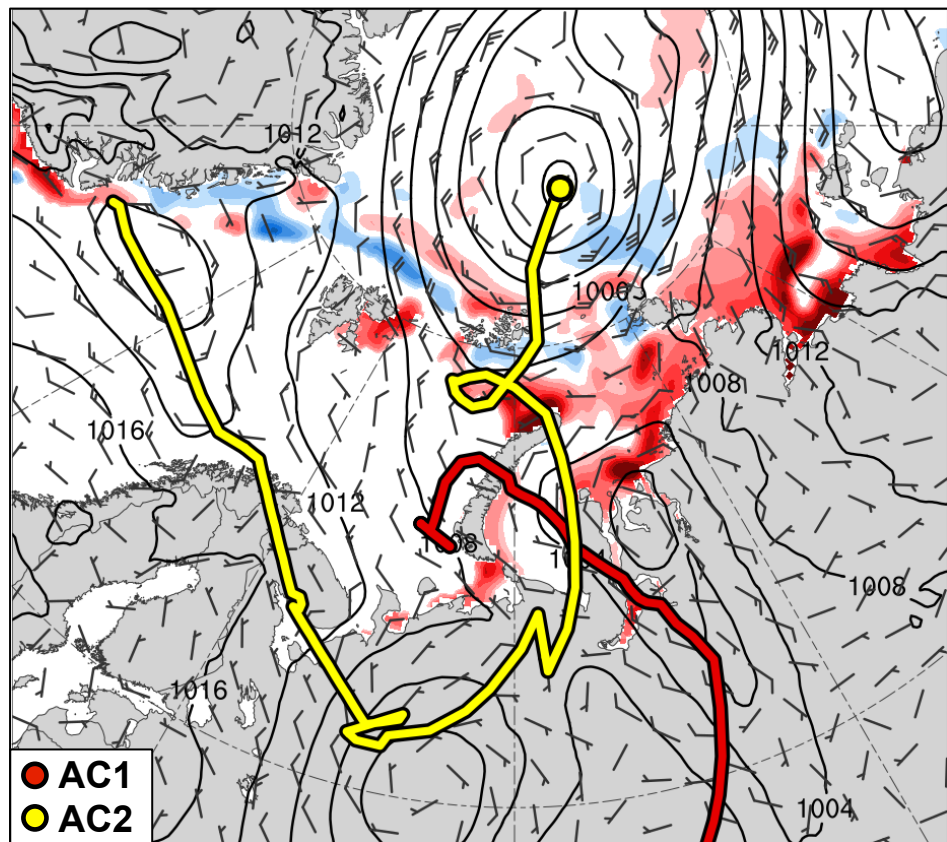


Change in sea-ice concentration (% , shaded) since 0000 UTC 1 June 2018, SLP (hPa, black), and 10-m wind speed (m s⁻¹, shaded)

0000 UTC 9 Jun 2018



SLP (hPa, black), 10-m wind speed (m s^{-1} , shaded) and wind (m s^{-1} , barbs), and 50% contour of sea-ice concentration (thick blue)



Change in sea-ice concentration (% , shaded) since 0000 UTC 1 June 2018, SLP (hPa, black), and 10-m wind speed (m s^{-1} , shaded)

Conclusions:

- **Anomalously amplified flow from eastern North America to Europe permits midlatitude disturbances to reach the Arctic**
- **TS Alberto remnants merge with a Canadian cyclone, move northeastward, and weaken over the Davis Strait windward of Greenland**
- **AC2 forms leeward of Greenland near the nose of a strong upper-level jet and along a moisture axis linked back to the remnants of TS Alberto**
- **AC1 forms along a cold front near the Caspian Sea ahead of an amplified upper-level trough**

Conclusions:

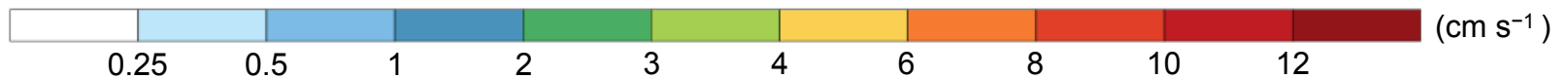
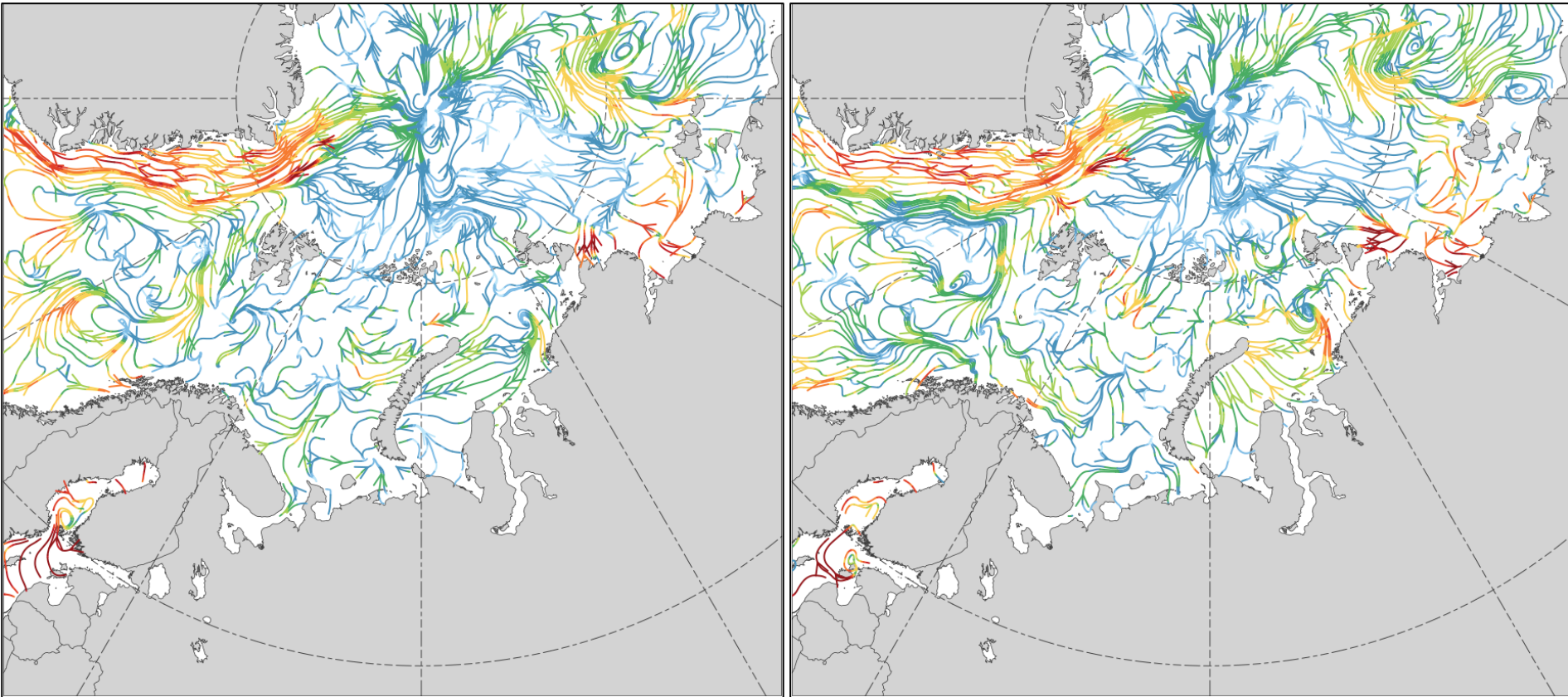
- **Anomalously amplifying flow over western and central Eurasia enables AC1 and AC2 to strengthen and move poleward**
- **TPVs embedded within amplified upper-level troughs foster rapid deepening of AC1 and AC2 in the left-exit regions of jet streaks**
- **AC2 absorbs AC1 after a Fujiwara cyclonic rotation and becomes the dominant Arctic cyclone, with a peak intensity of 962 hPa (SLP standardized anomaly of $< -6 \sigma$)**
- **Warm, moist air and strong low-level winds associated with AC1 and AC2 may contribute to reductions in Arctic sea ice**

Extra Slides

Ocean Currents

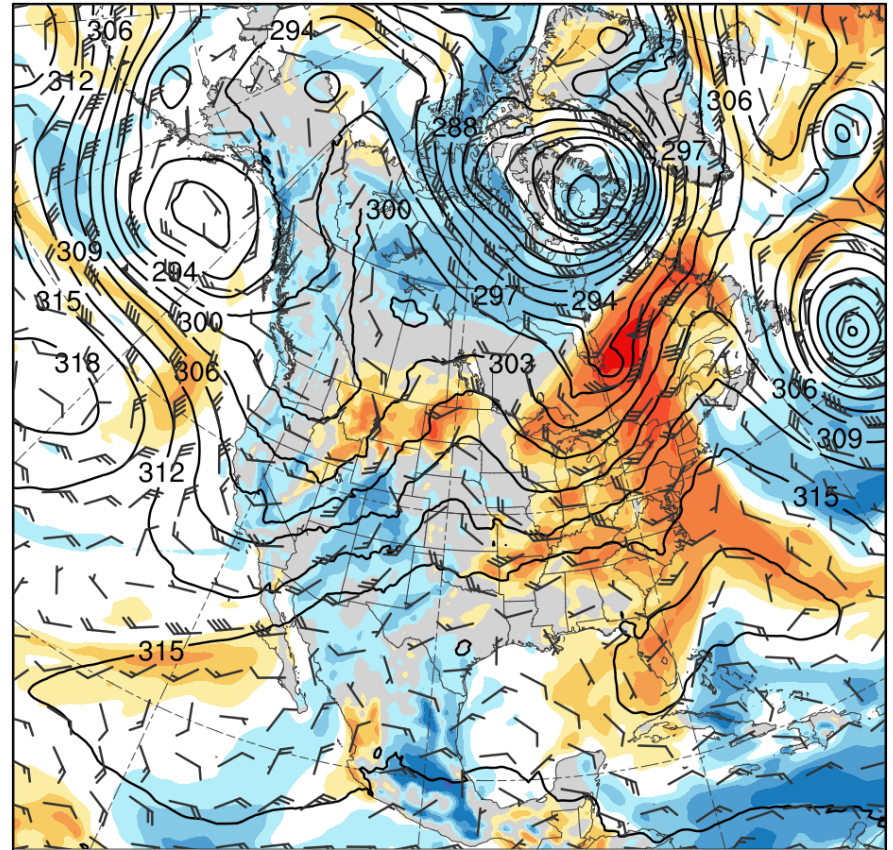
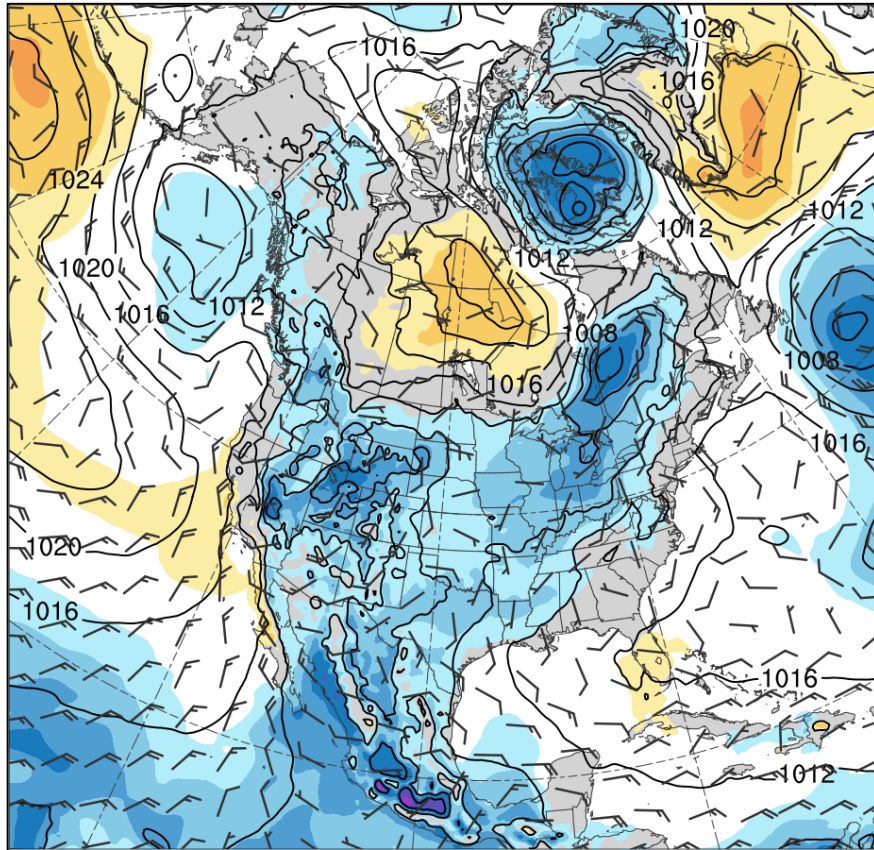
1200 UTC 4 June 2018

0000 UTC 8 June 2018



Ocean current speed and direction (cm s^{-1} , streamlines colored according to speed) at 5 m below sea level (Data source: CFSR)

0000 UTC 1 Jun 2018

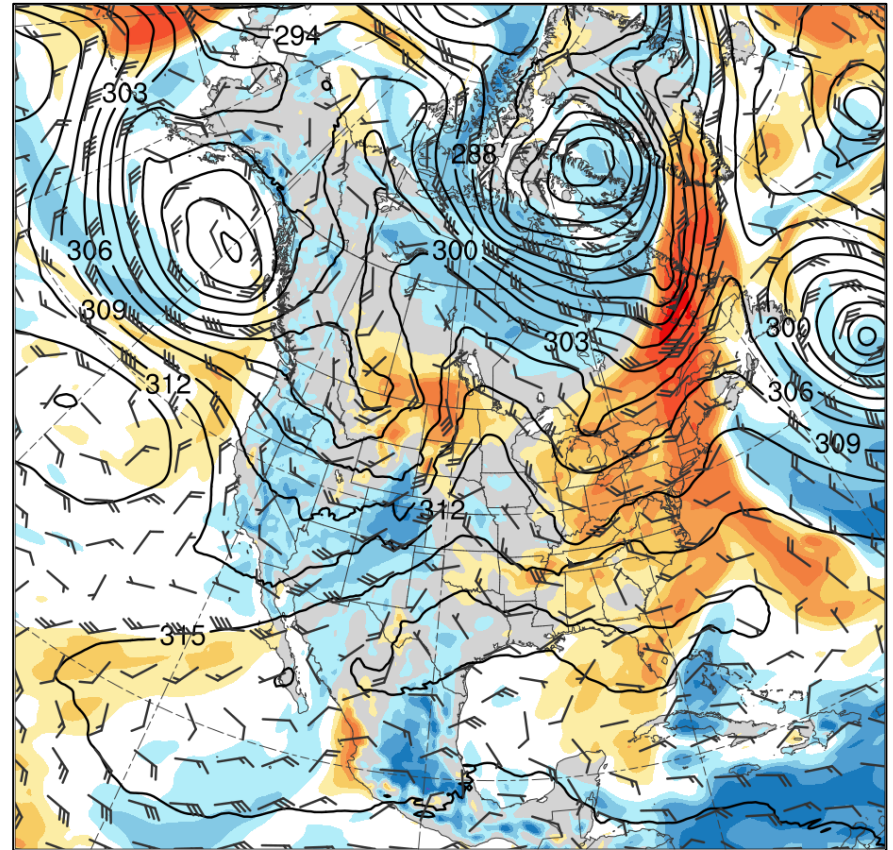
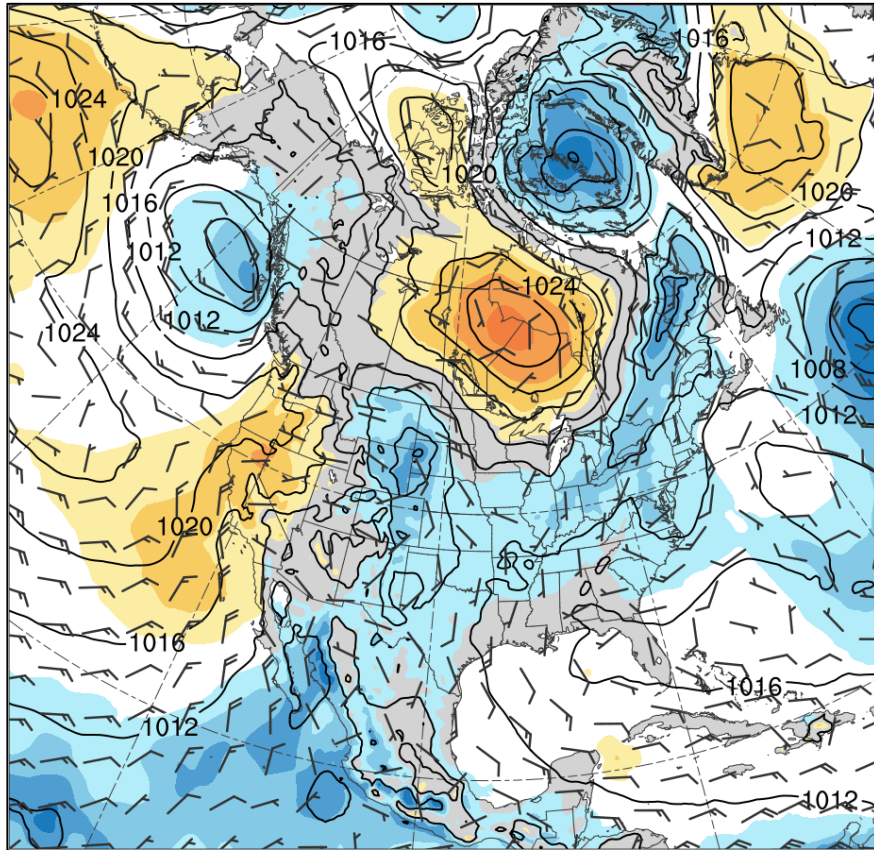


-6 -5 -4 -3 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5 6

SLP (hPa, black), 10-m winds (m s^{-1} , flags and barbs), and standardized SLP anomalies (σ , shaded)

700-hPa geopotential height (dam, black) and winds (m s^{-1} , flags and barbs), and standardized PW anomalies (σ , shaded)

1200 UTC 1 Jun 2018



-6 -5 -4 -3 -2 -1.5 -1 -0.5 0 0.5 1 1.5 2 3 4 5 6

SLP (hPa, black), 10-m winds (m s^{-1} , flags and barbs), and standardized SLP anomalies (σ , shaded)

700-hPa geopotential height (dam, black) and winds (m s^{-1} , flags and barbs), and standardized PW anomalies (σ , shaded)