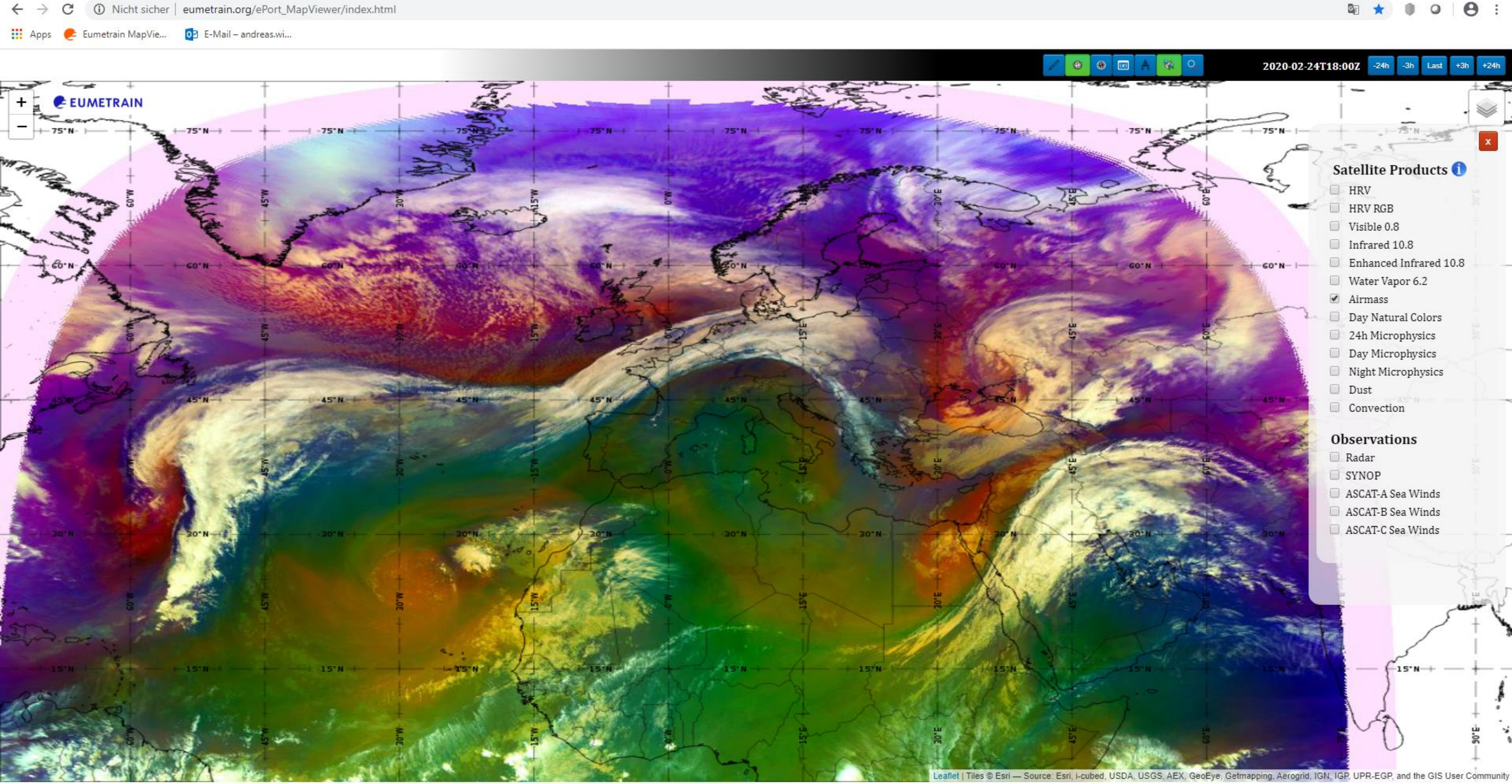
Introduction to Cyclones

Front types and frontal analysis

SEEMET 2020 – Online Classroom

Andreas Wirth (ZAMG)



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Satellite Products

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- ☐ Day Natural Colors
- ☐ 24h Microphysics
- ☐ Day Microphysics
- ☐ Night Microphysics
- ☐ Dust
- ☐ Convection

Observations

- ☐ Radar
- ☐ SYNOP
- ☐ ASCAT-A Sea Winds
- ☐ ASCAT-B Sea Winds
- ☐ ASCAT-C Sea Winds

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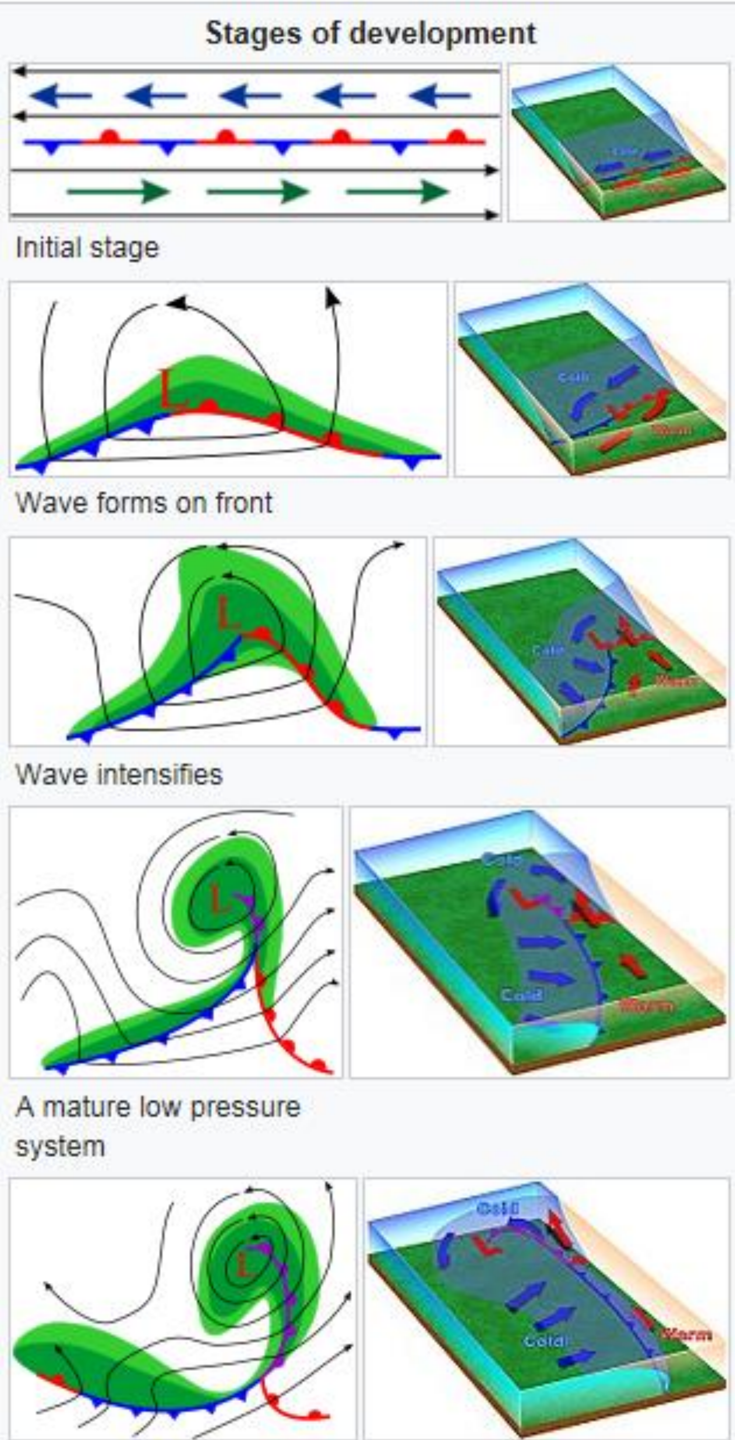
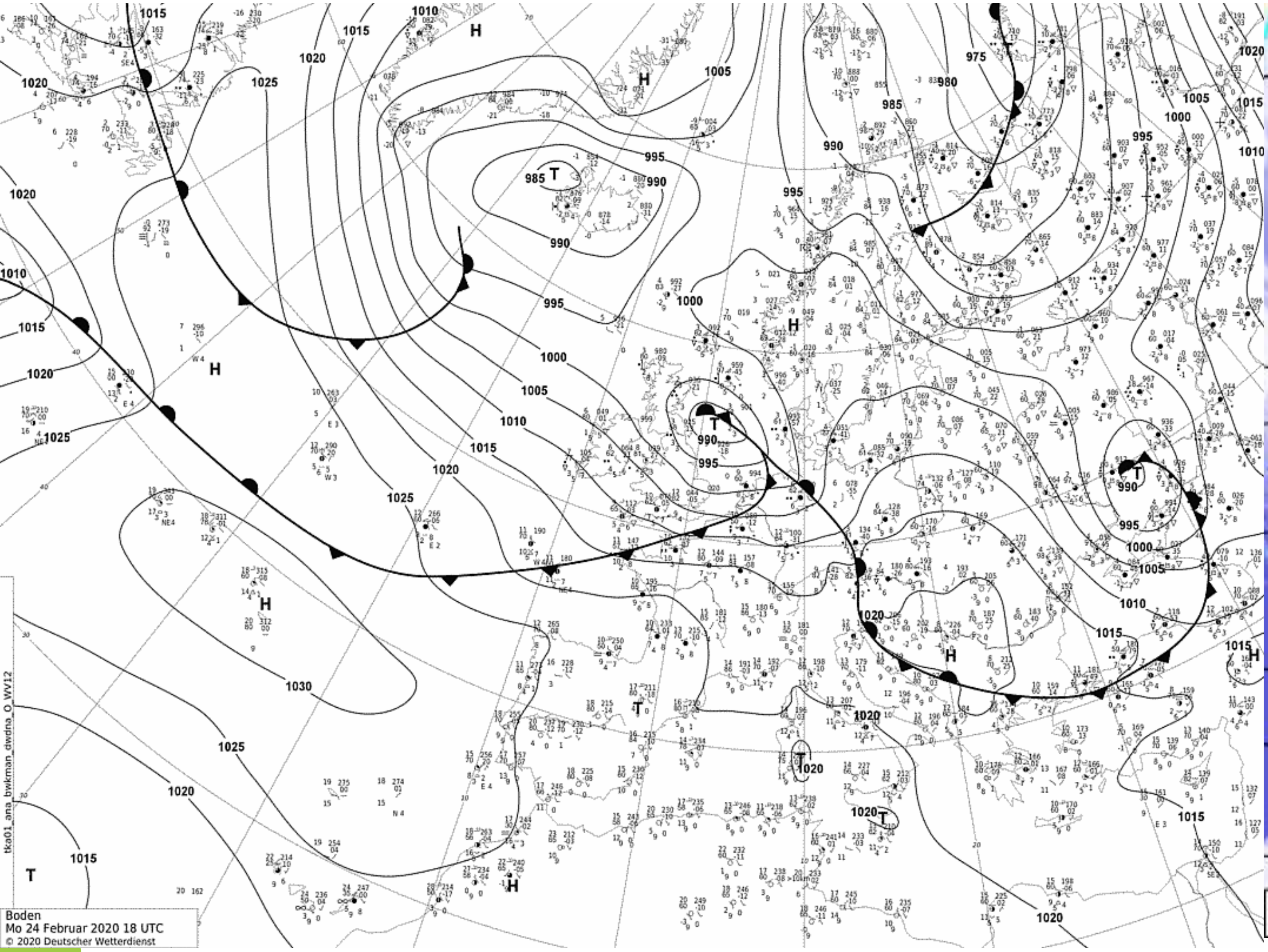
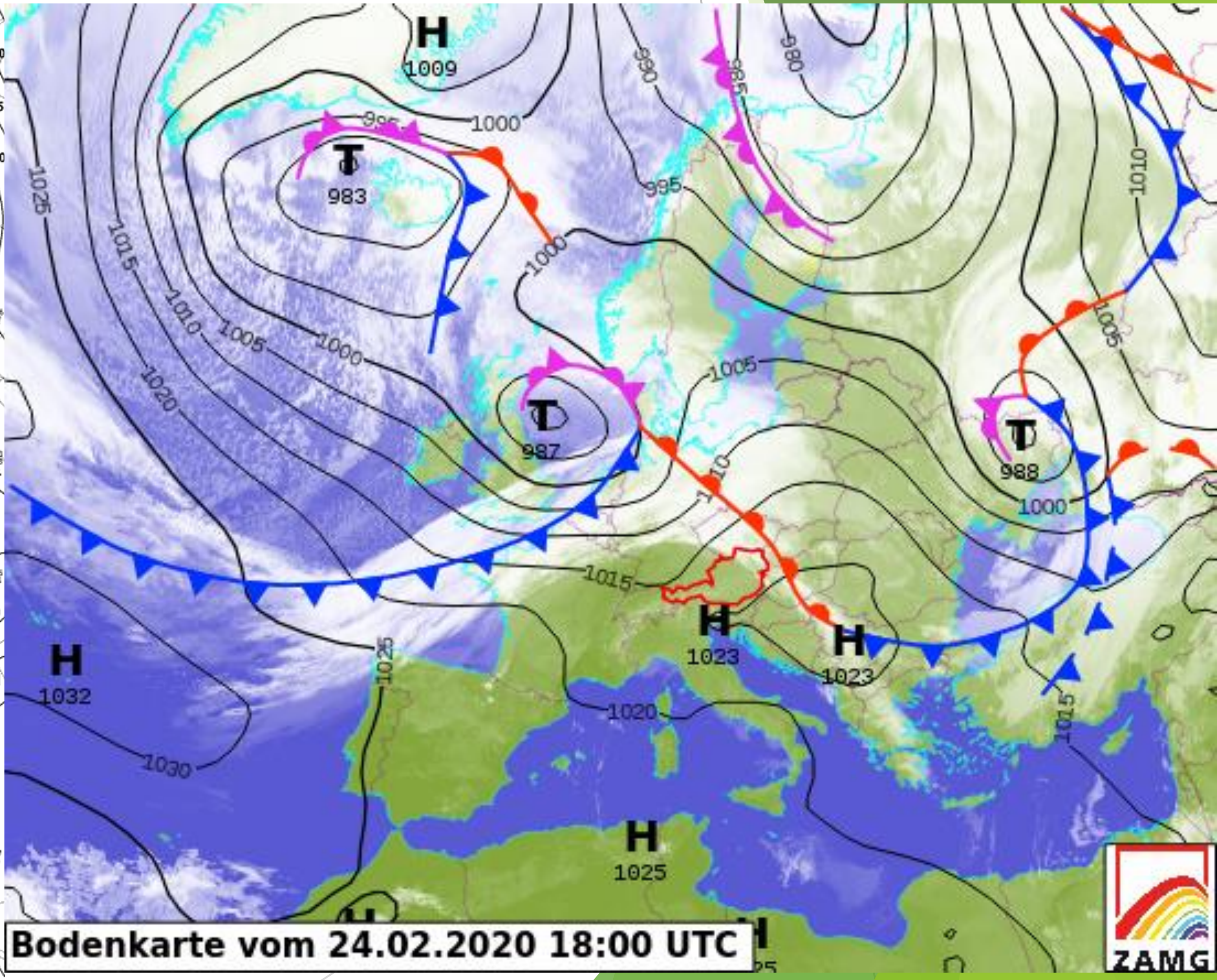
When we are asked to do a frontal analysis, we all think first about the classical Norwegian Model

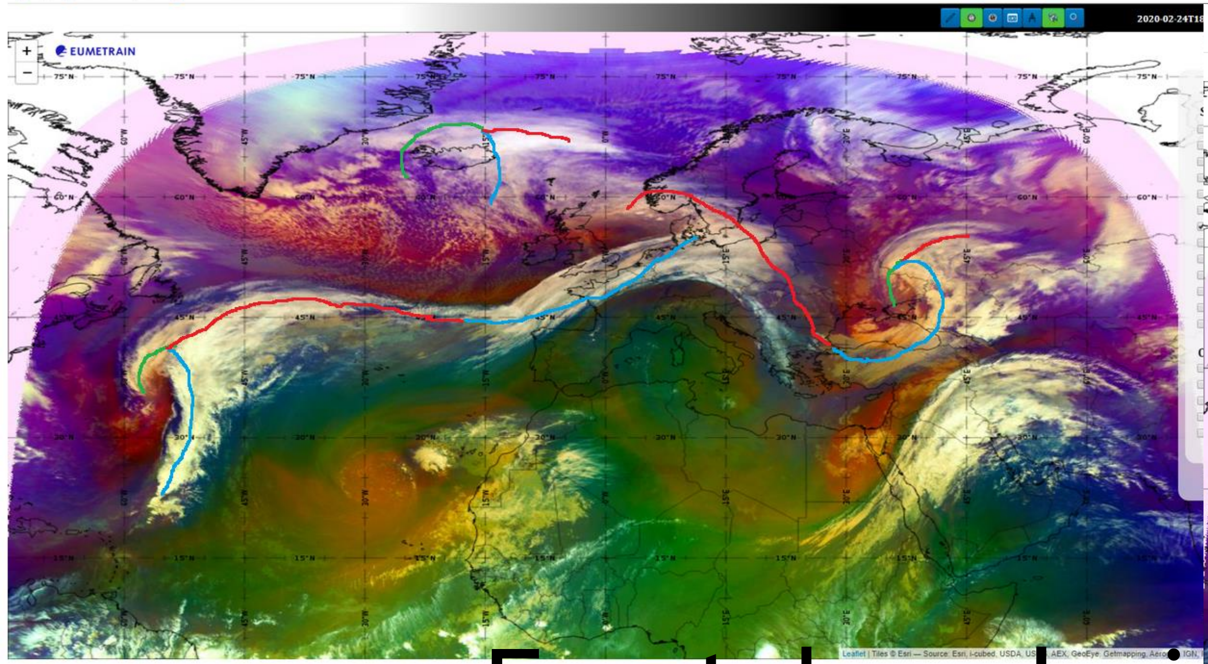


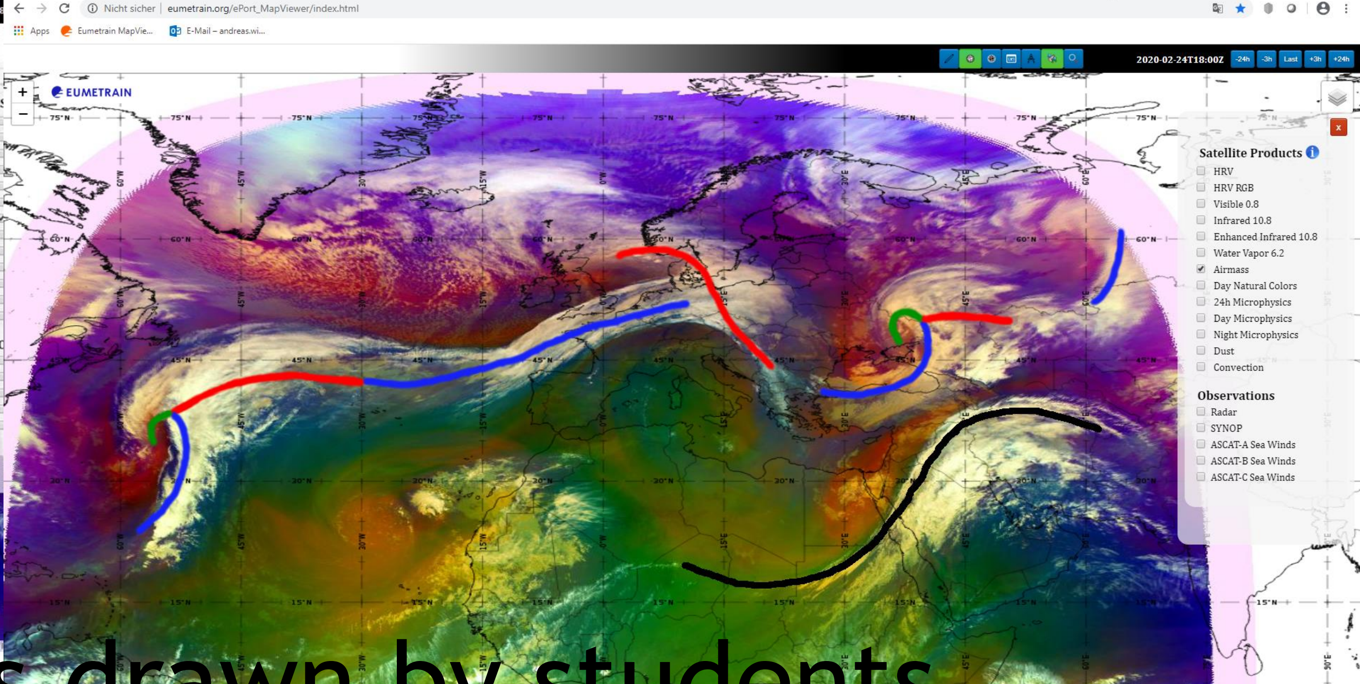
Are these cyclones all the same? Just in different stages of development?





Frontal analysis drawn by students

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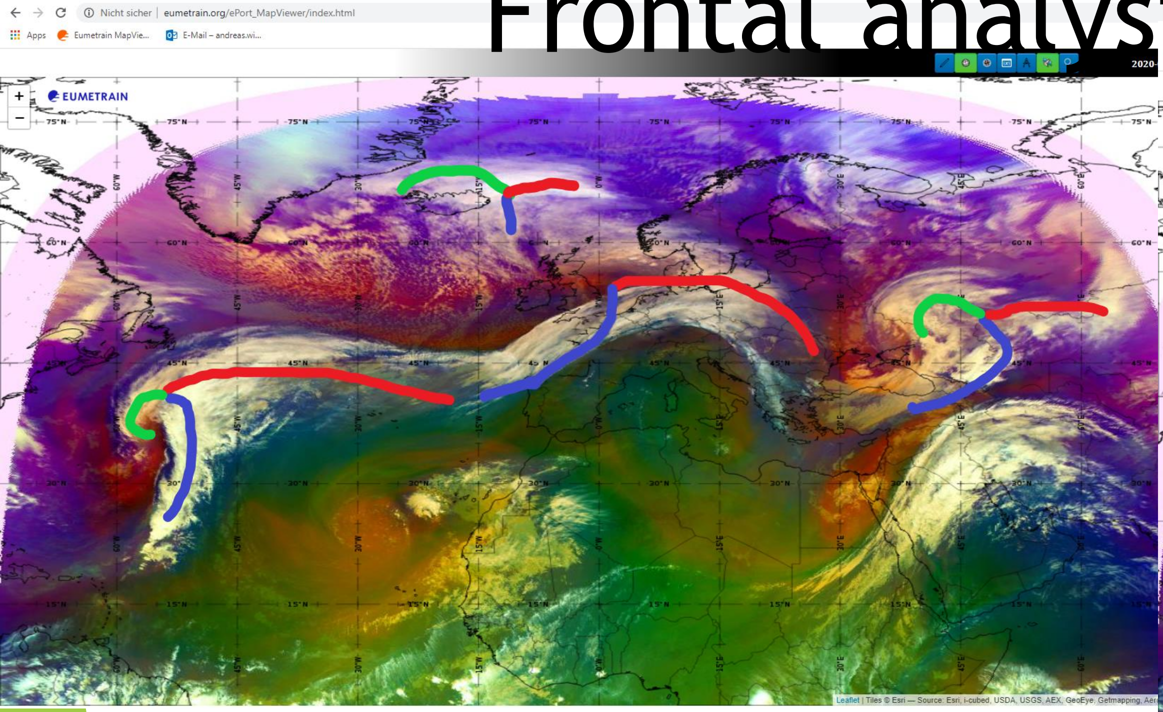
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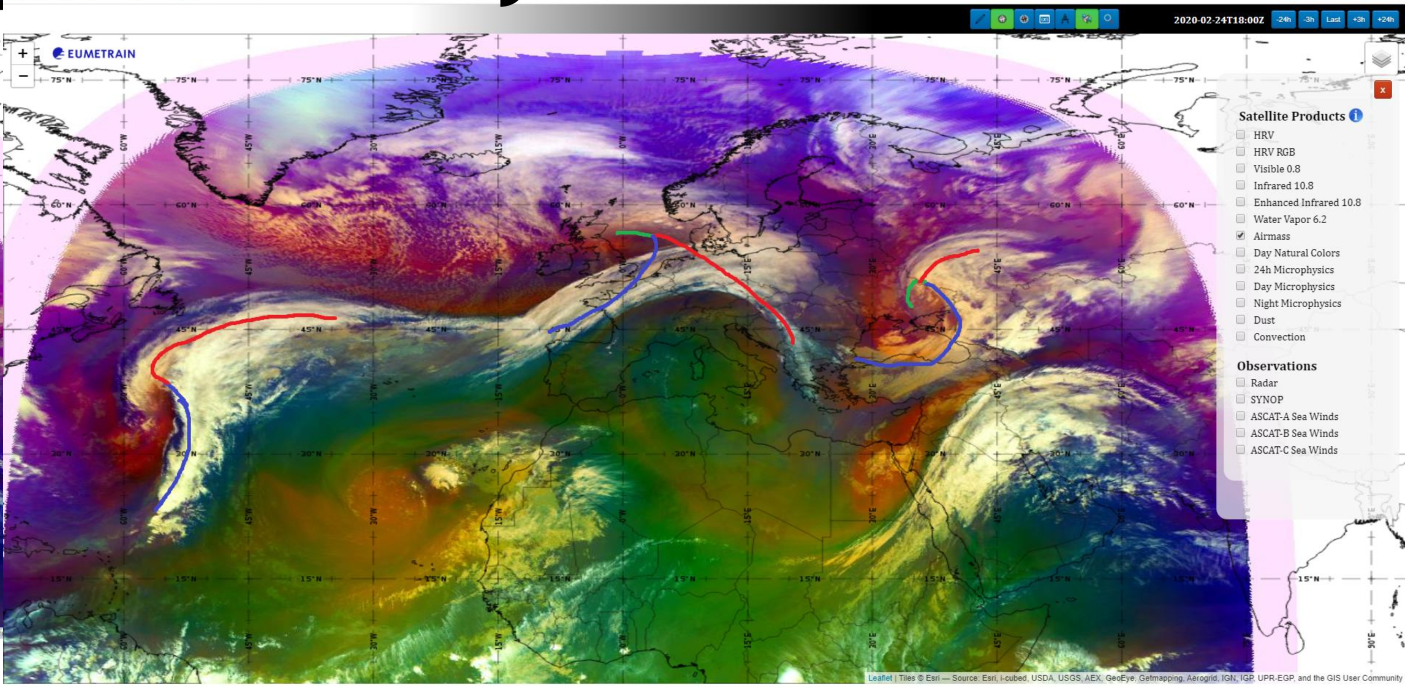
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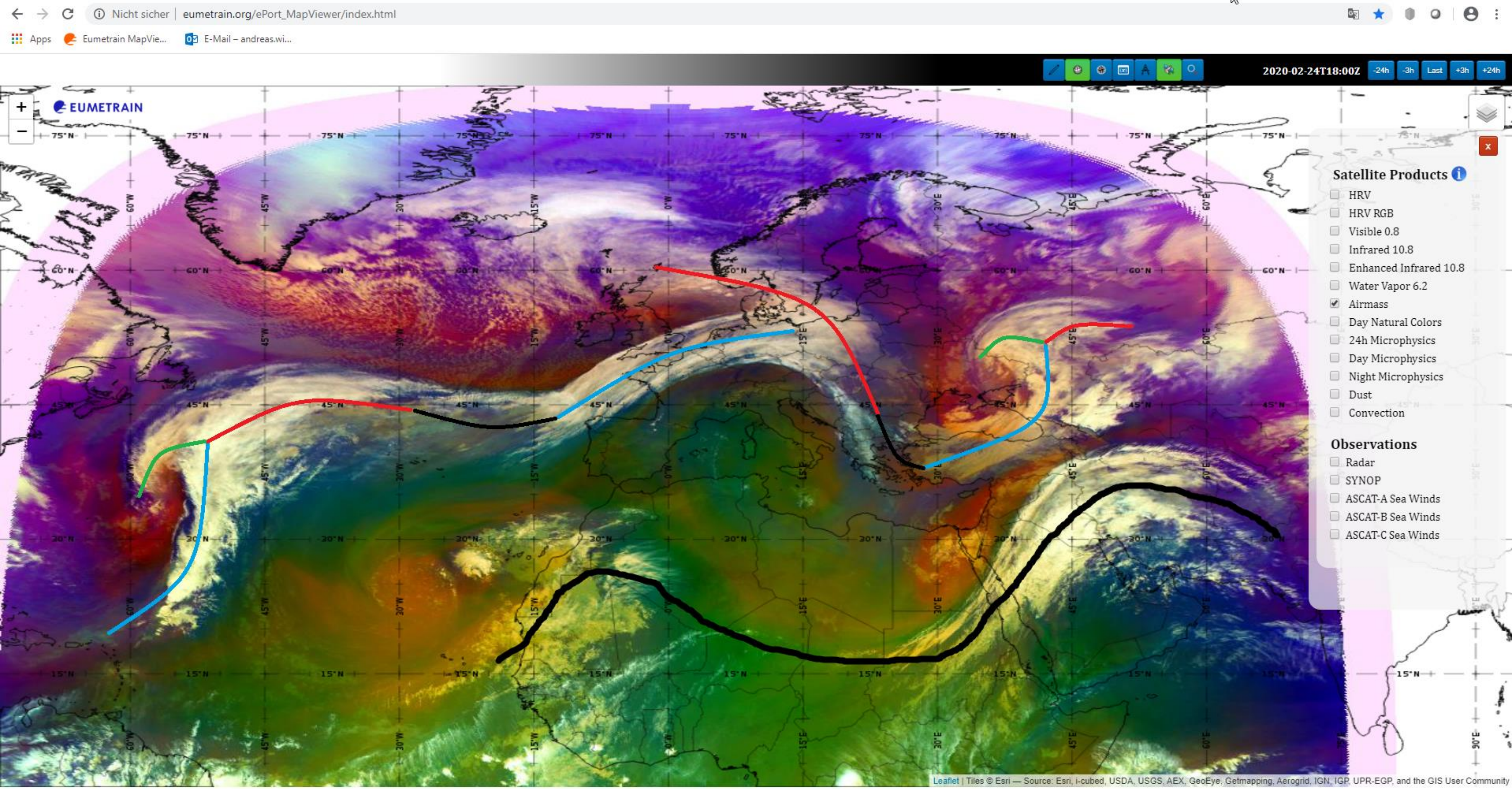

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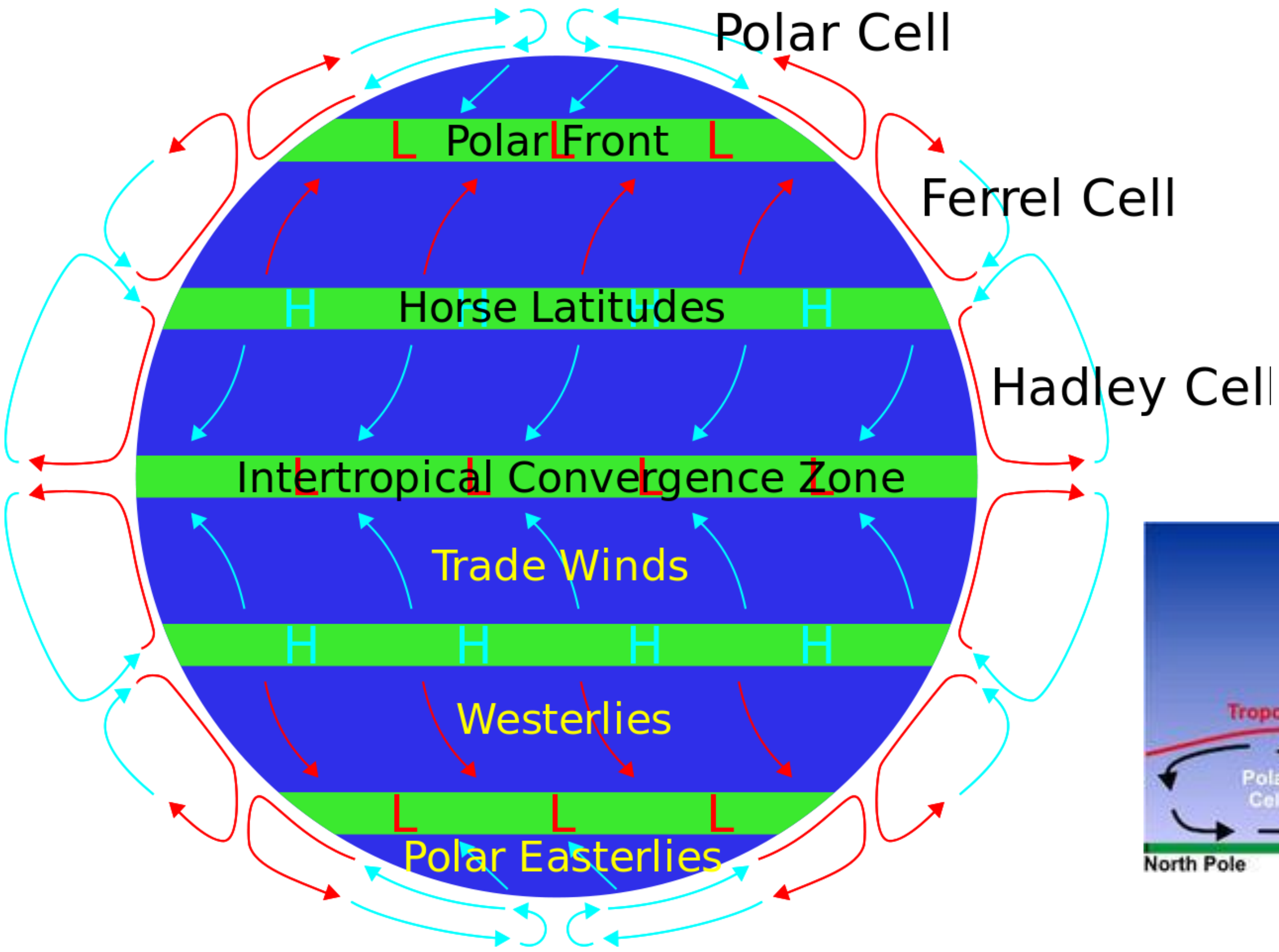
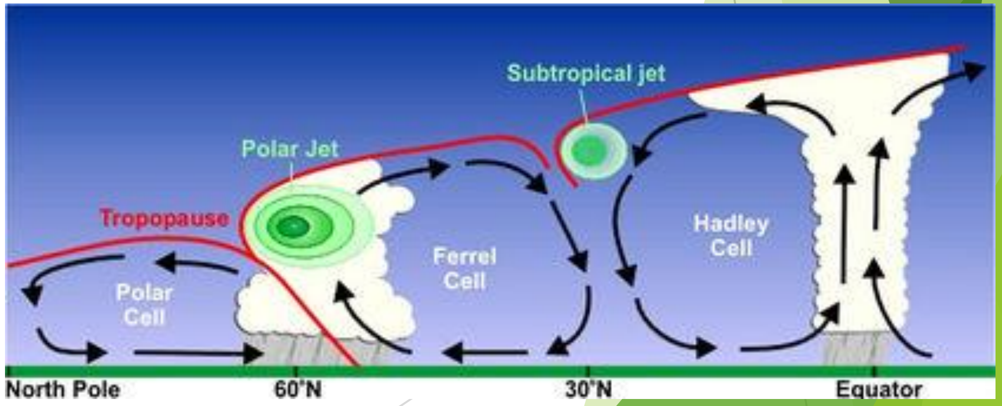
Is this the correct analysis? I don‘t know! It is more important that you can justify your decision.

What is a front? Trivial question or not?





What physical parameters define a front?

- Temperature gradient (e.g. 8°C/220 km or at least 6°C/500 km)?
- Temperature advection?
- Humidity gradient?
- A change of windspeed and direction?
- Pressure and pressure change?
- Clouds and precipitation?

ITCZ

Is it a front?

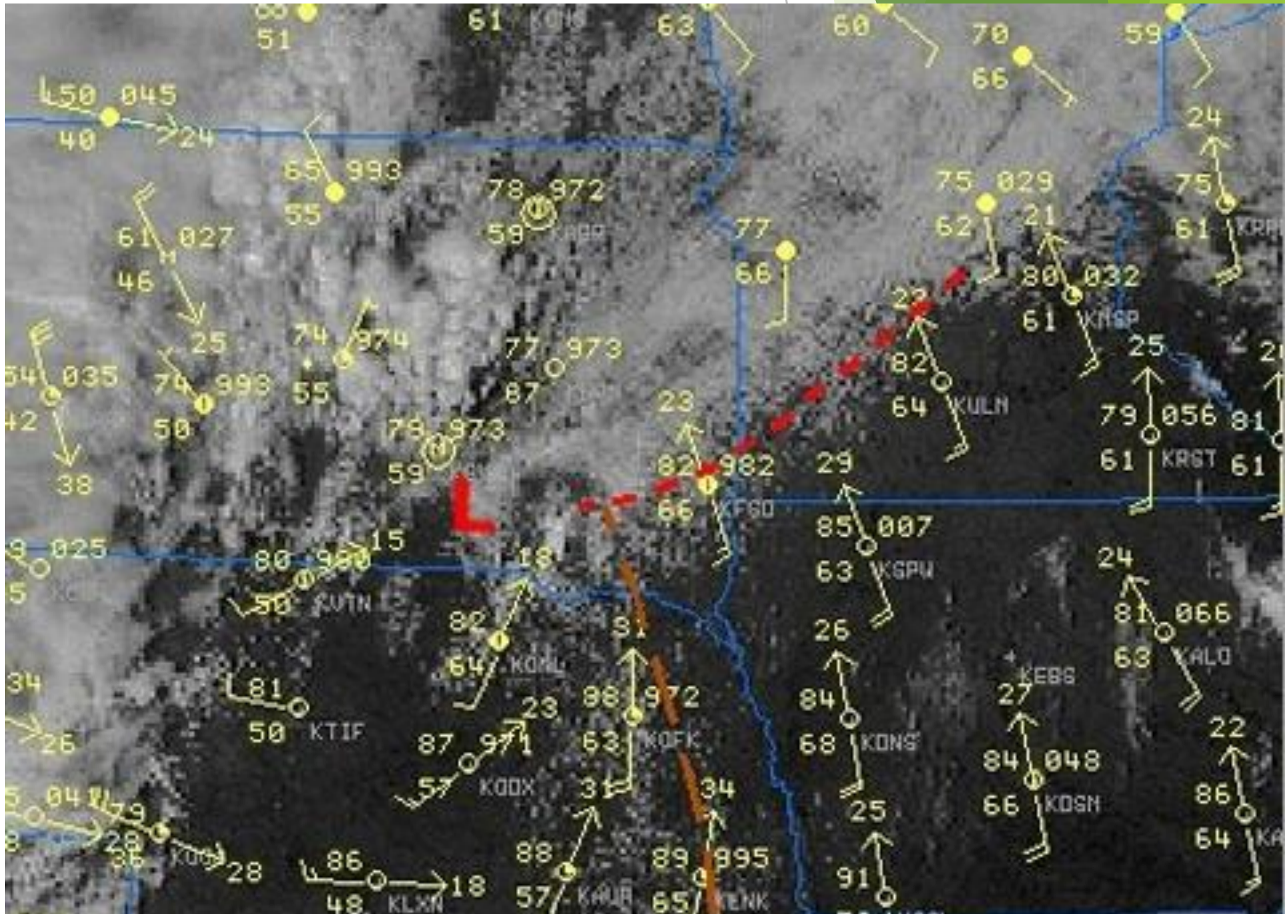
What makes a front a front?

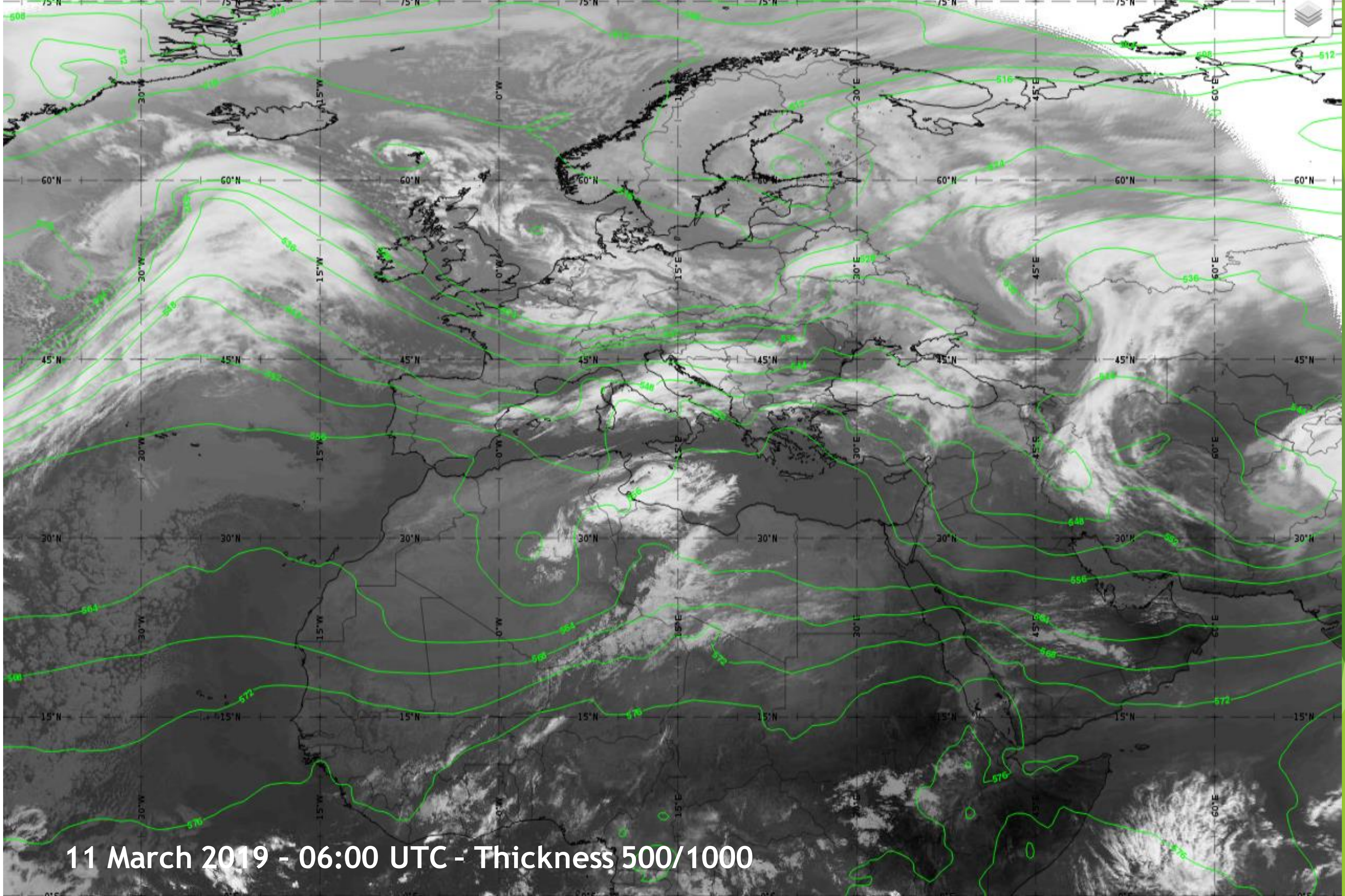
The ITCZ was originally identified from the 1920s to the 1940s as the "Intertropical Front" ("ITF"), but after the discovery in the 1940s and the 1950s of the significance of wind field convergence in tropical weather production, the term *ITCZ* was then applied*.

***Barry, Roger Graham; Chorley, Richard J: Atmosphere, weather, and climate (1992)*

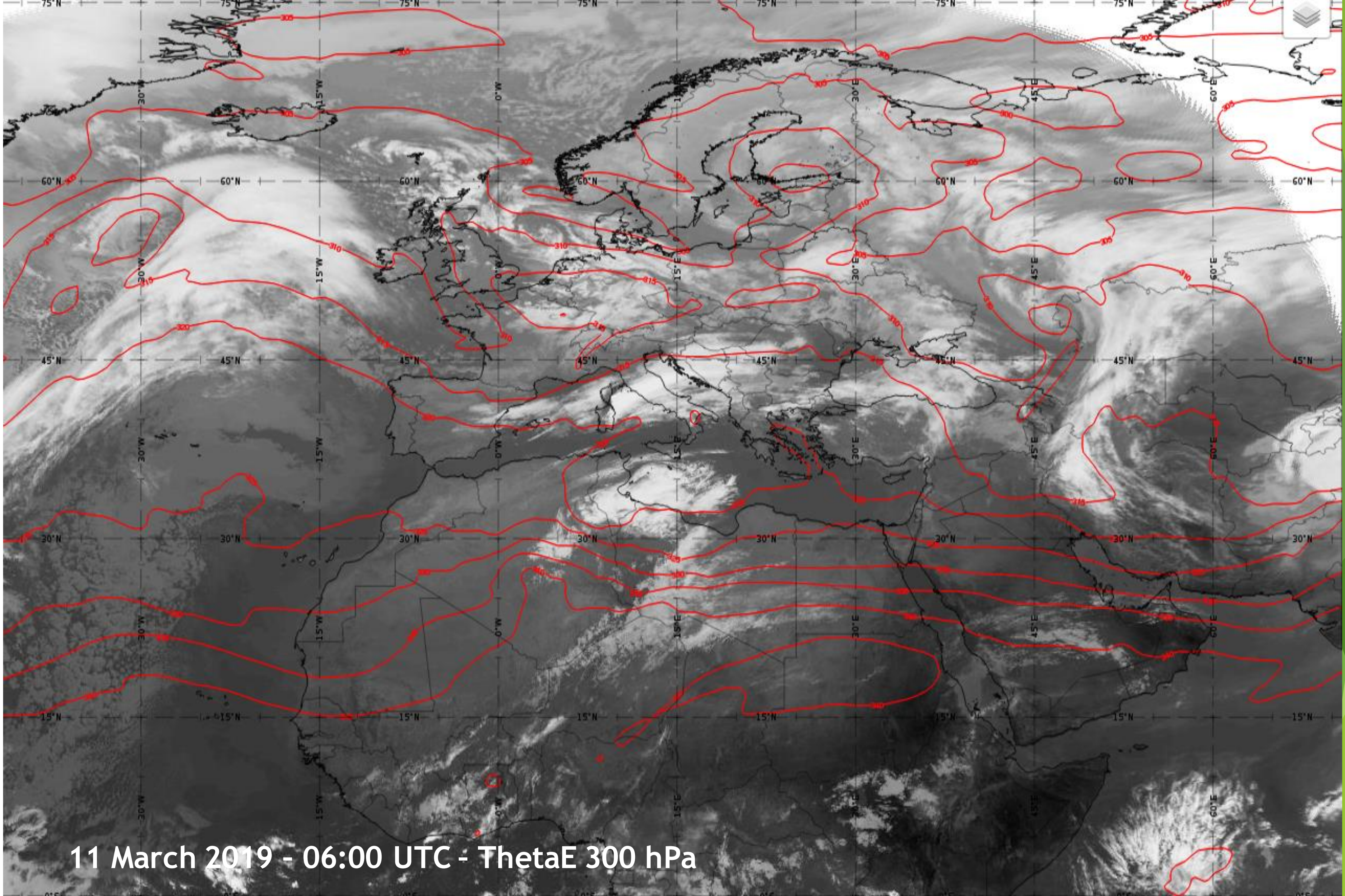
The Dry Line

- Appearance: North-Amerika / India
- The dry line is located in the warm sector of an extra-tropical cyclone
- Orientation: North to South
- No Temperature gradient, just a humidity gradient and a directional wind change
- Has an influence on the appearance of thunderstorms



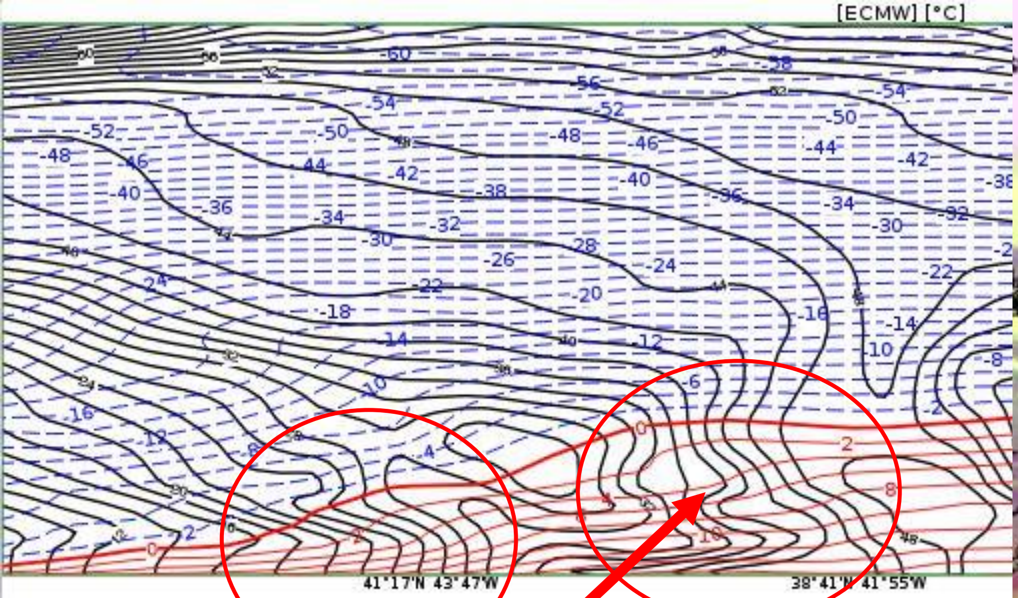


11 March 2019 – 06:00 UTC – Thickness 500/1000



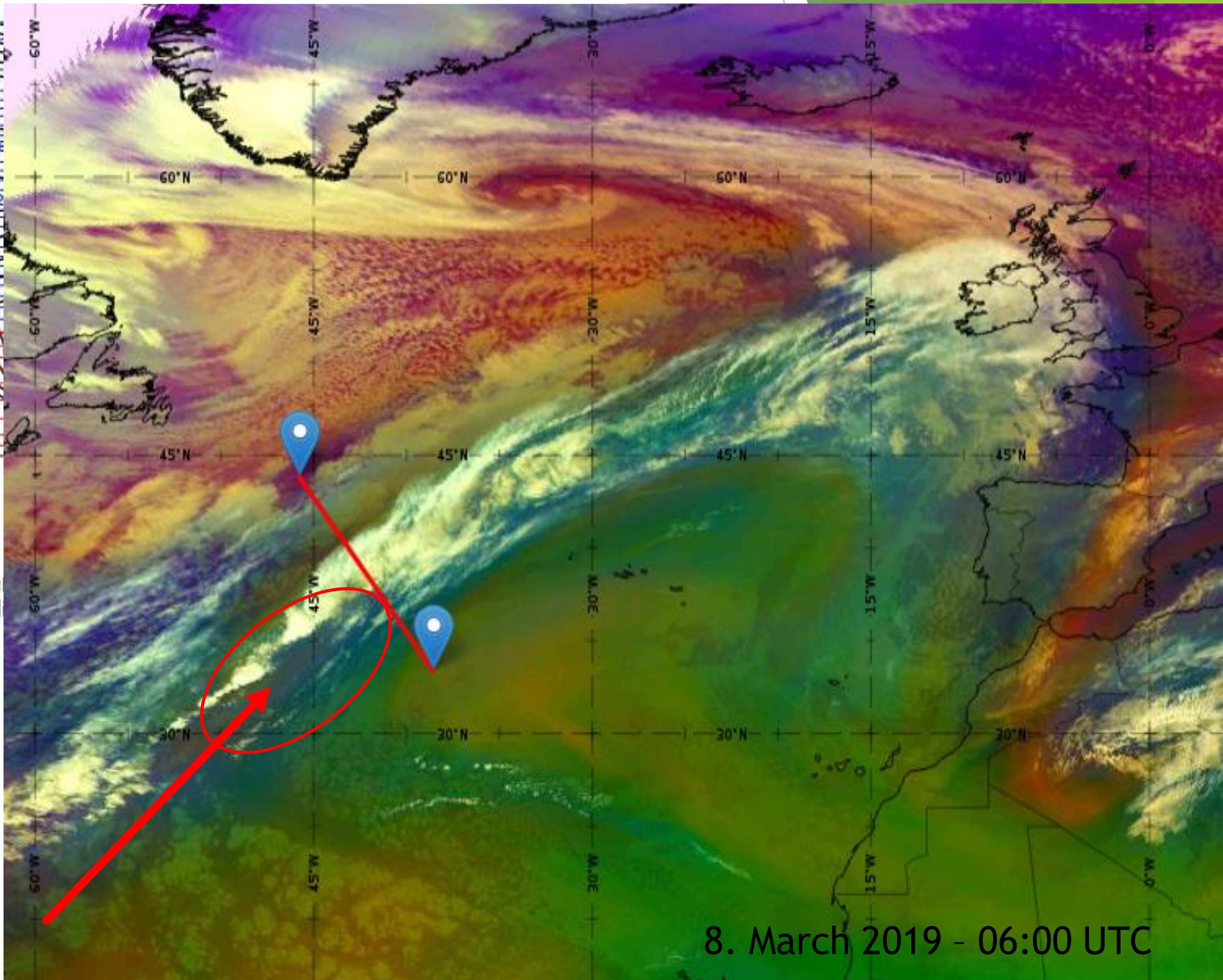
11 March 2019 – 06:00 UTC – ThetaE 300 hPa

Cold fronts



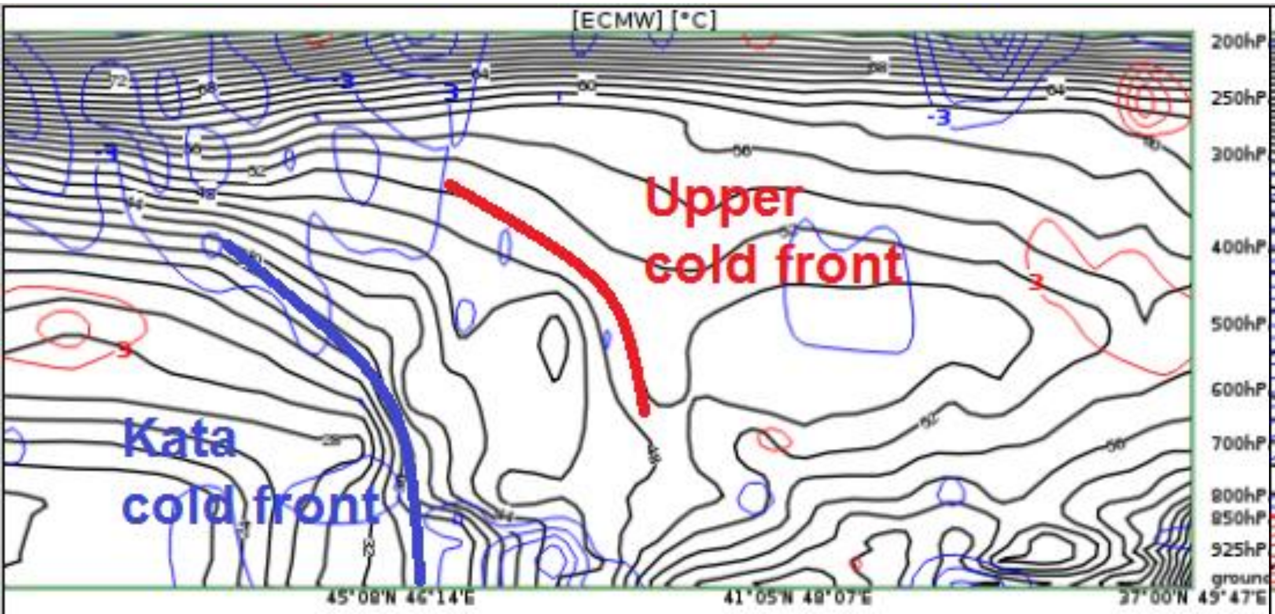
Cross Section from map **Equivalent Potential Te**
for 43°52'N 45°47'W - 33°24'N 38°35'W, val

The frontal zone is steeper near the ground. (frictional effect, orography, …) The shape of the cold front is due to the density difference between warm and cold air. Convection forms ahead of the surface front.



8. March 2019 – 06:00 UTC

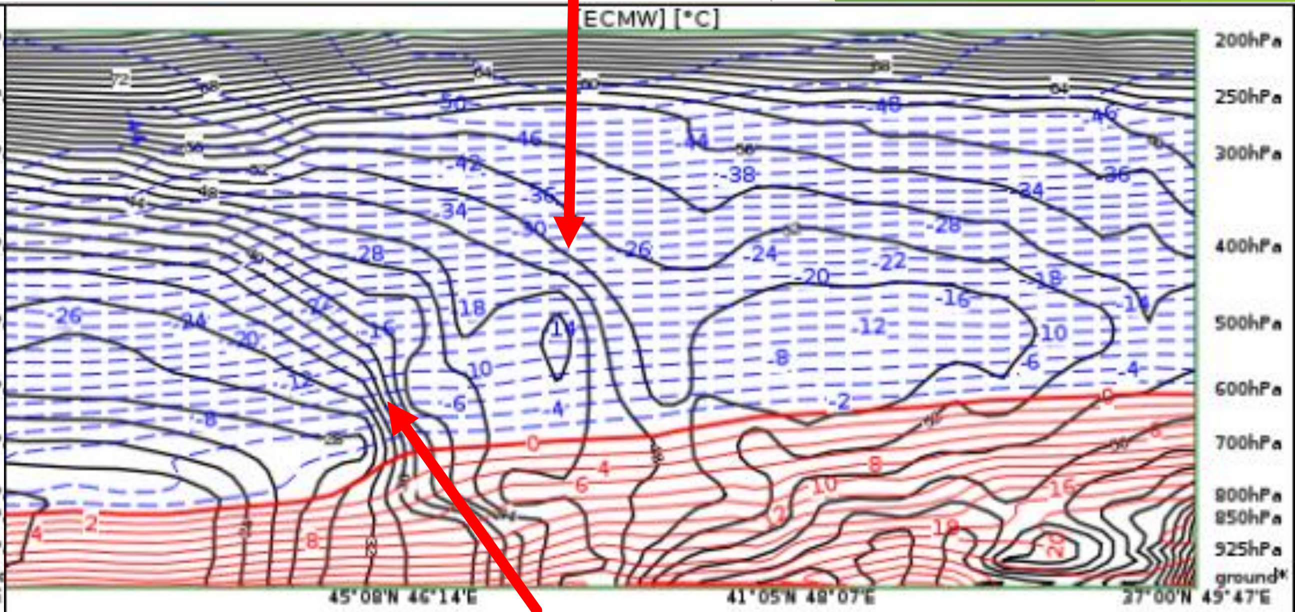
Upper front or upper boundary?



Upper cold front

Kata cold front

Cross-Section from map **Equivalent Potential Temperature** and **Temperature Advection**
for 49°09'N 44°04'E - 37°00'N 49°47'E, valid 01.06.2018 12:00

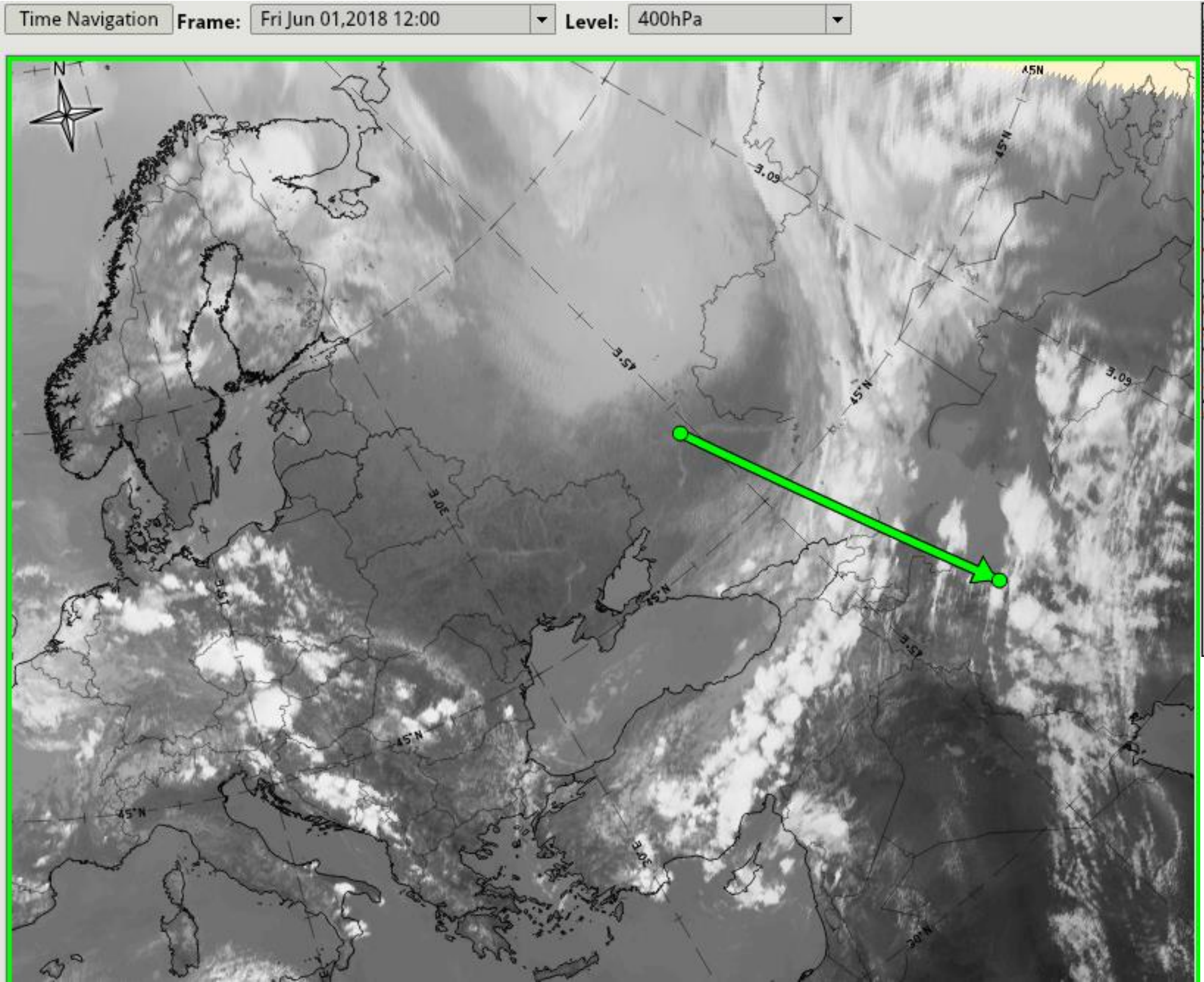


No temperature gradient

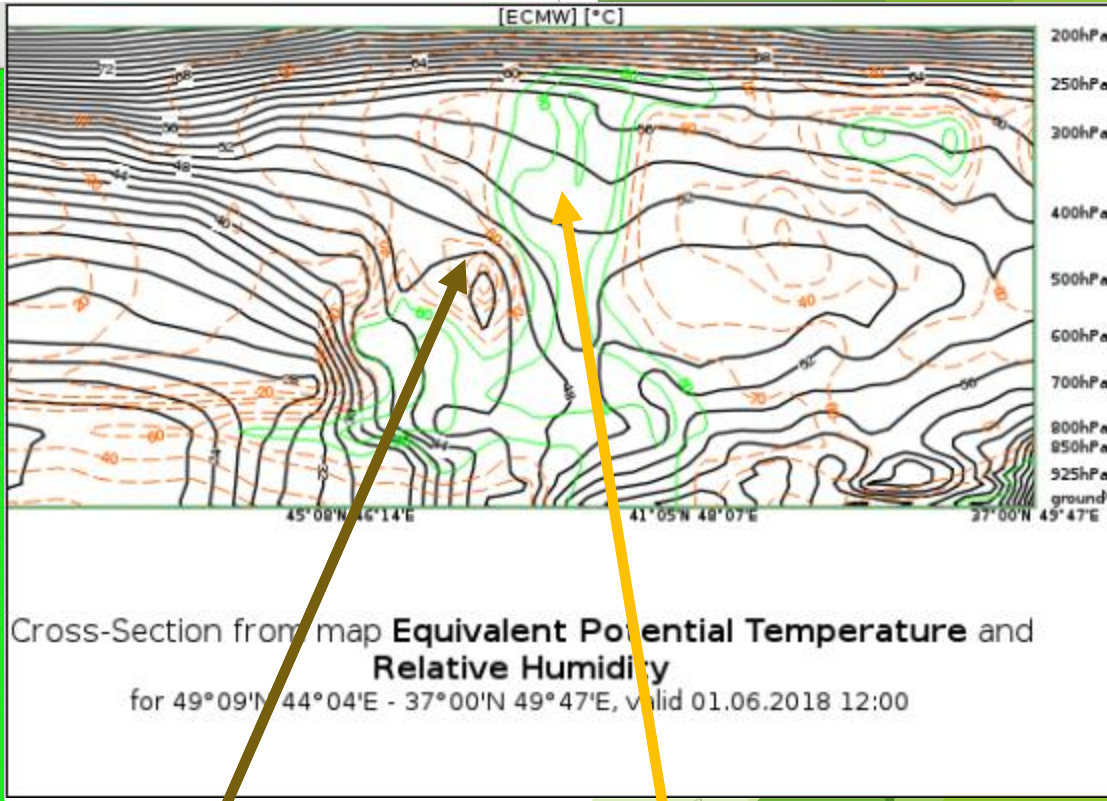
Temperature gradient

Cross-Section from map **Equivalent Potential Temperature** and **Temperature**
for 49°09'N 44°04'E - 37°00'N 49°47'E, valid 01.06.2018 12:00

- In fact, most upper level fronts are just moisture boundaries and not thermal boundaries. The term **upper level front** is misleading.



Time Navigation **Frame:** Fri Jun 01,2018 12:00 **Level:** 400hPa

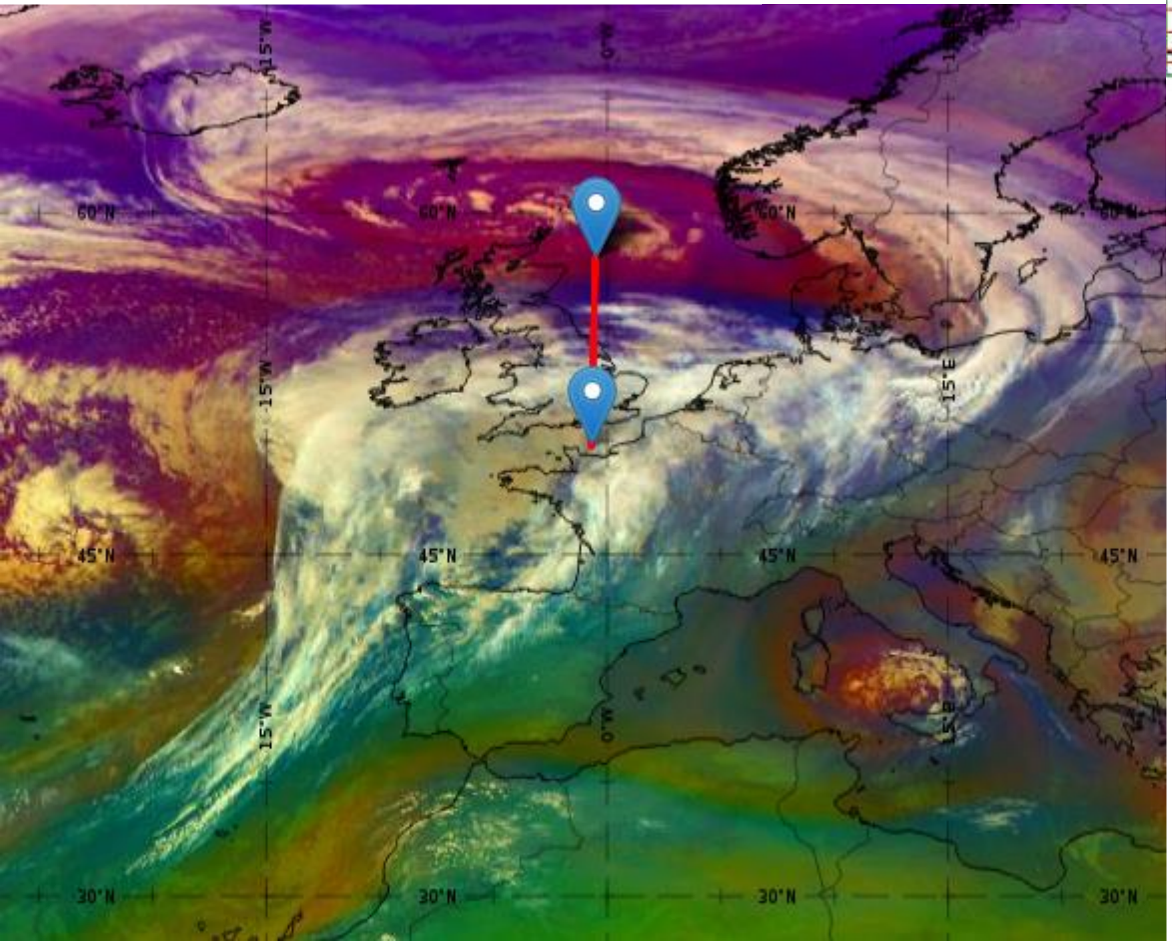


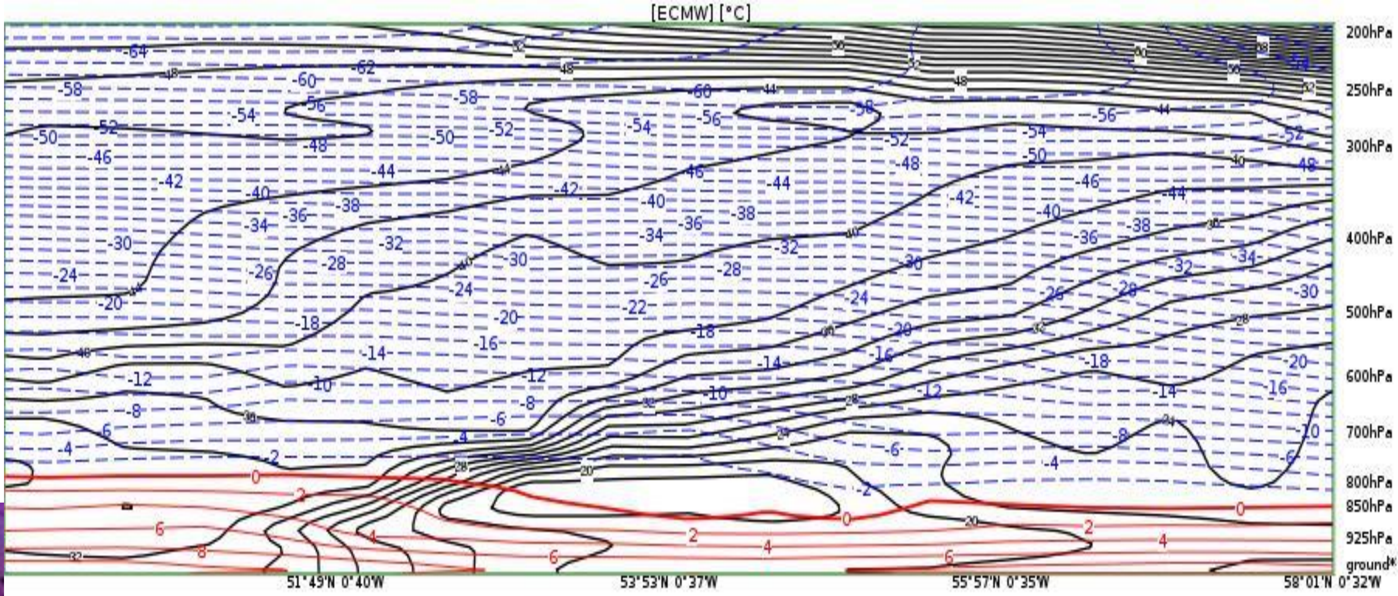
Cross-Section from map **Equivalent Potential Temperature** and **Relative Humidity**
for 49°09'N 44°04'E - 37°00'N 49°47'E, valid 01.06.2018 12:00

Dry intrusion

High reaching humidity

Warm fronts

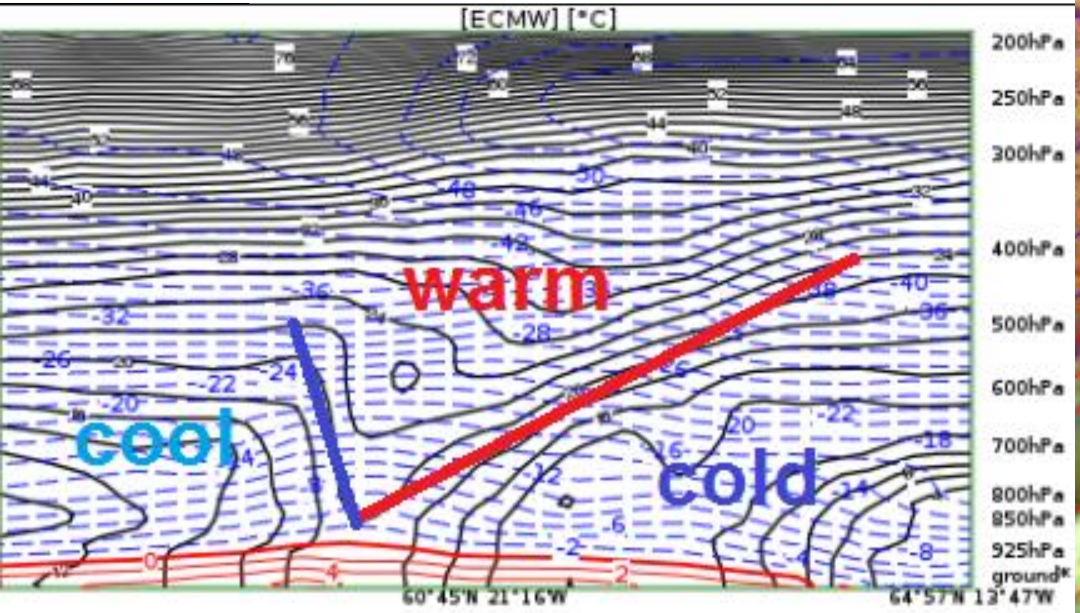




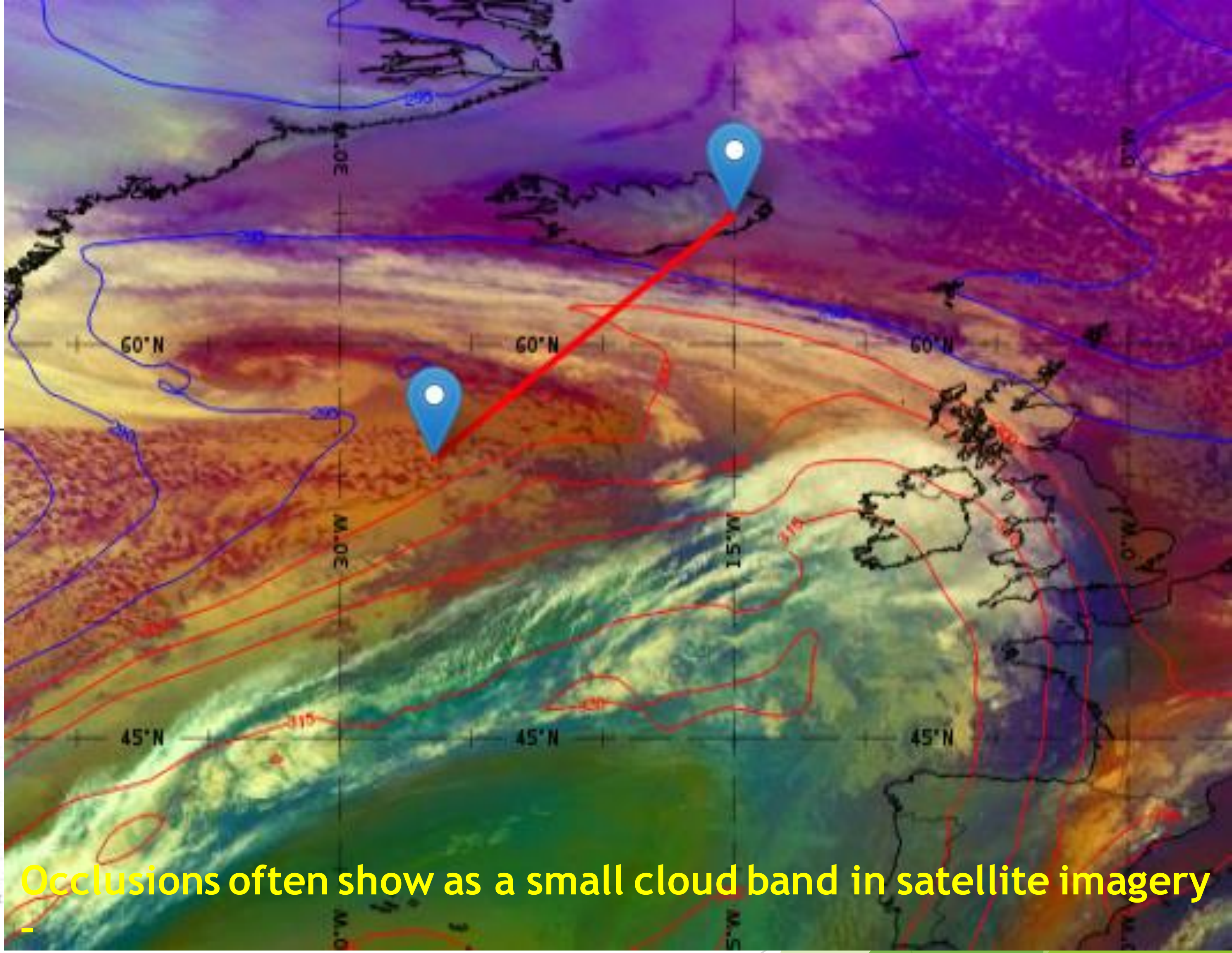
Cross-Section from map **Equivalent Potential Temperature** and **Temperature**
for 49°45'N 0°42'W - 58°01'N 0°32'W, valid 03.03.2019 06:00

- Warm fronts are mostly seen in satellite imagery as broad bands whose cloudiness often mixes with warm sector clouds.
- The inclination of the front is rather low: 0.5° bis 1°
- Precipitation starts ahead of the surface front. Precipitation is uniform and long lasting – high probability for freezing rain.
- Warm fronts move slower than cold fronts.

Occlusions



Cross-Section from map **Equivalent Potential Temperature** and **Temperature**
for 56°13'N 26°58'W - 64°57'N 13°47'W, valid 08.03.2019 06:00



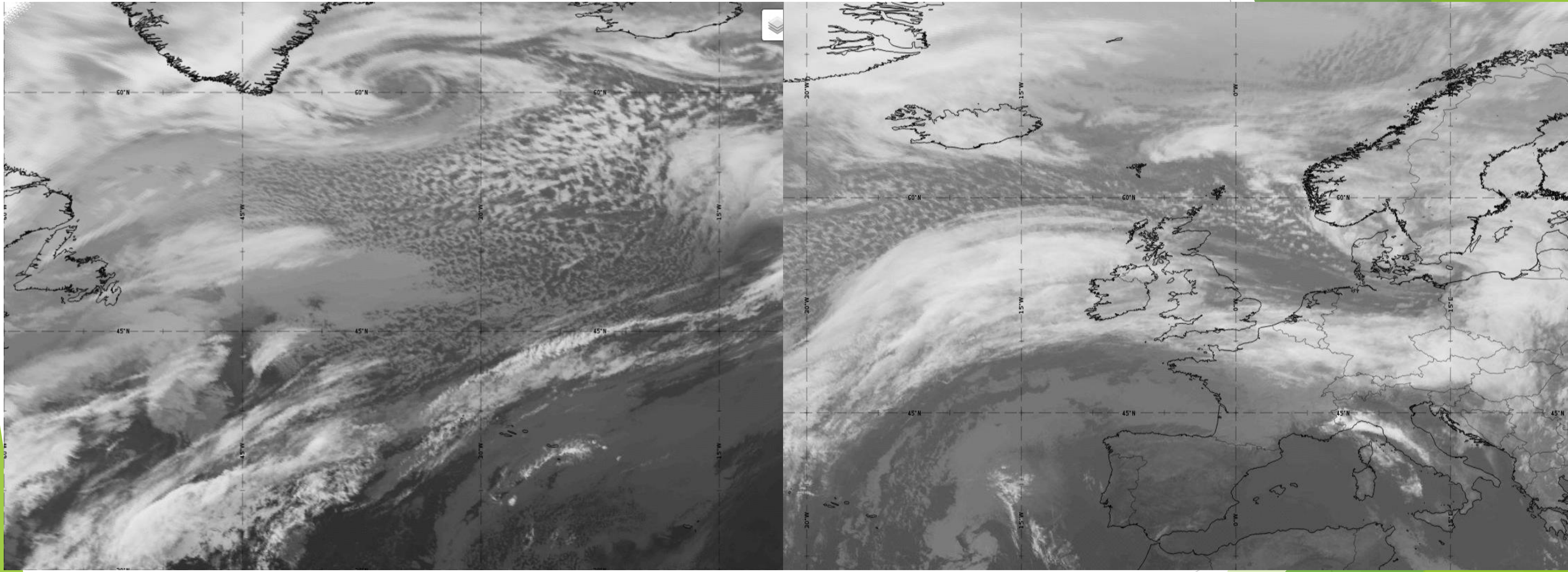
Occlusions often show as a small cloud band in satellite imagery -

Very similar to cold fronts.

Within the occlusion cloud band, warm air protrudes in between two colder air masses.

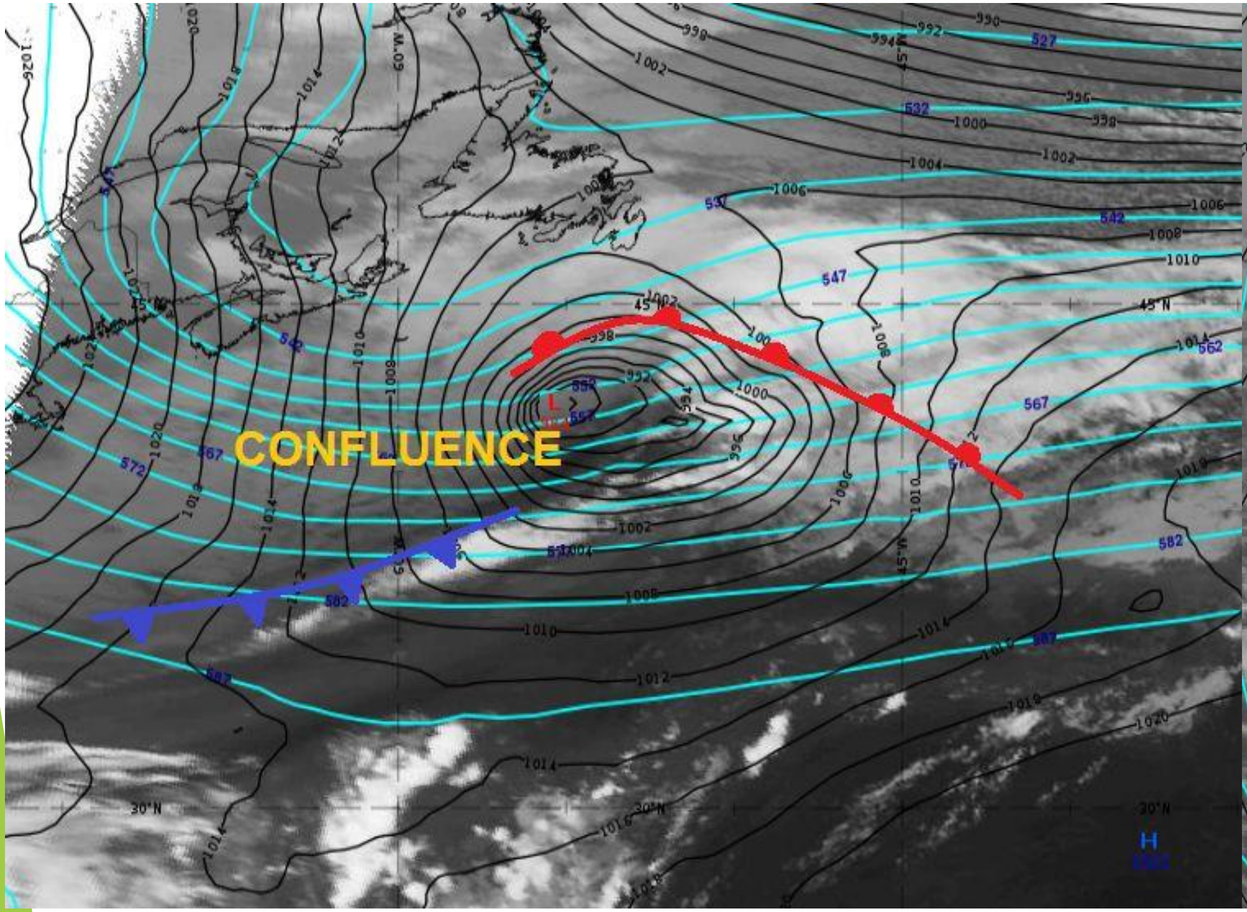
Airmass RGB: the occlusion cloud band separates cold polar air (blue) from sinking air masses behind the cold front (red).

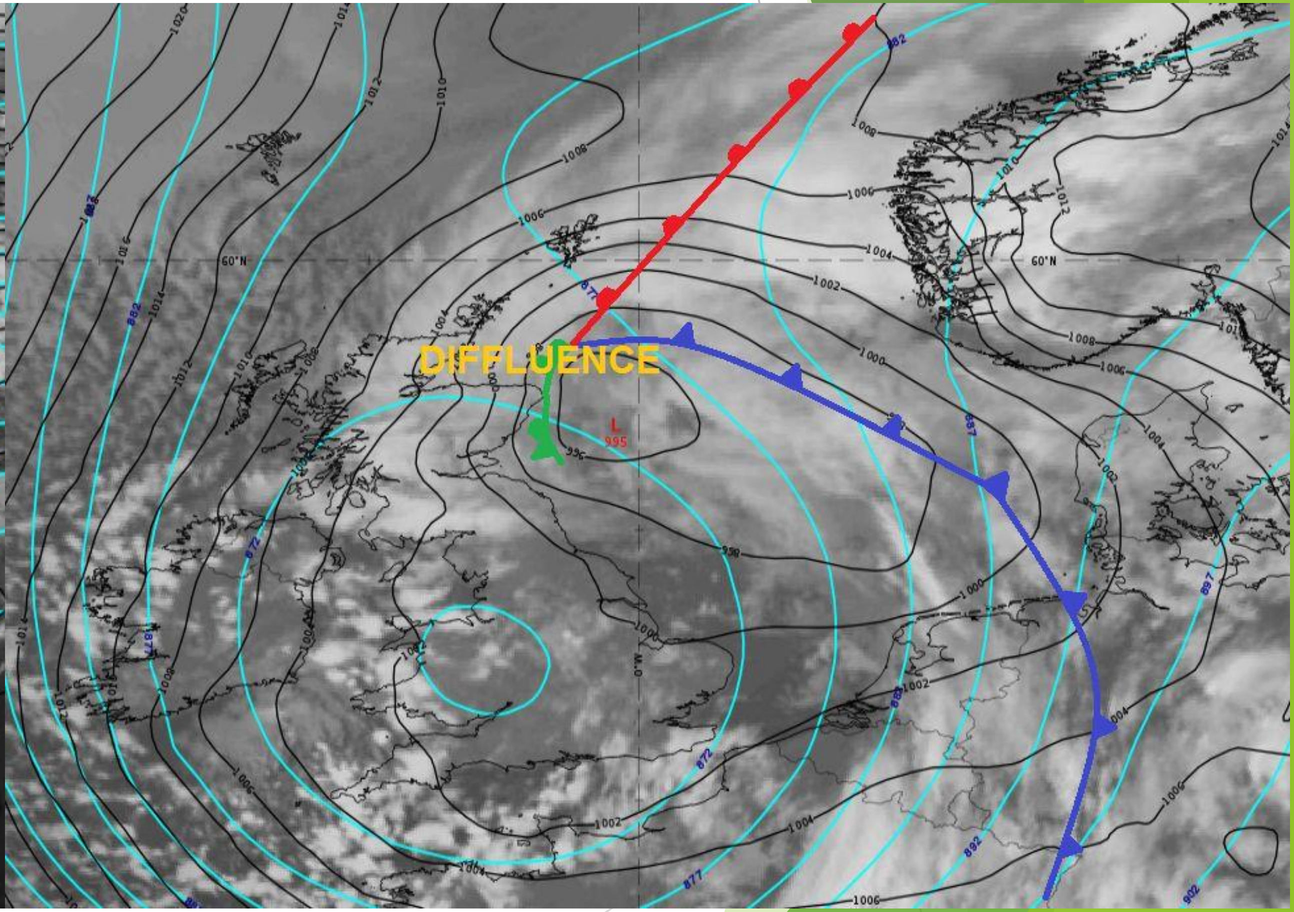
Two developing cyclones - two different frontal analyses.

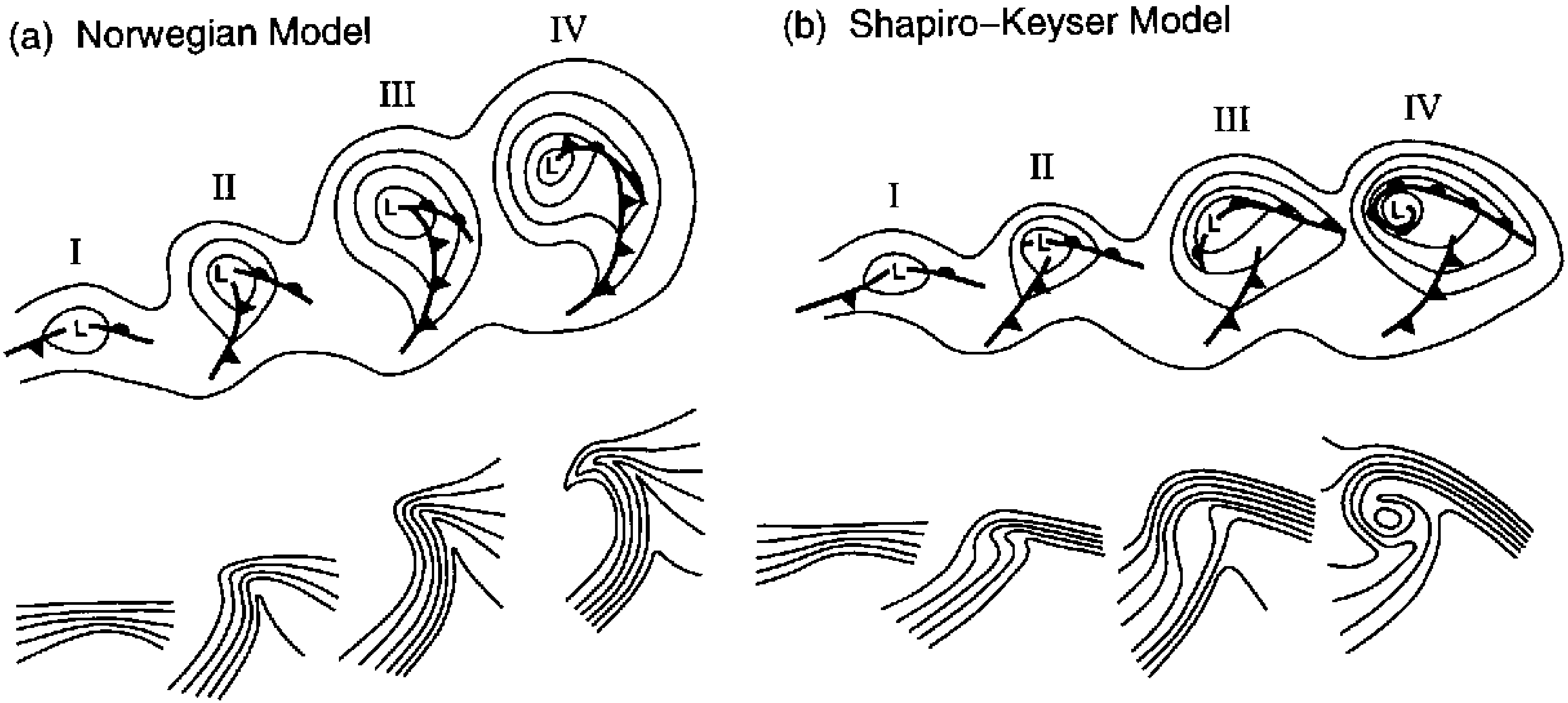


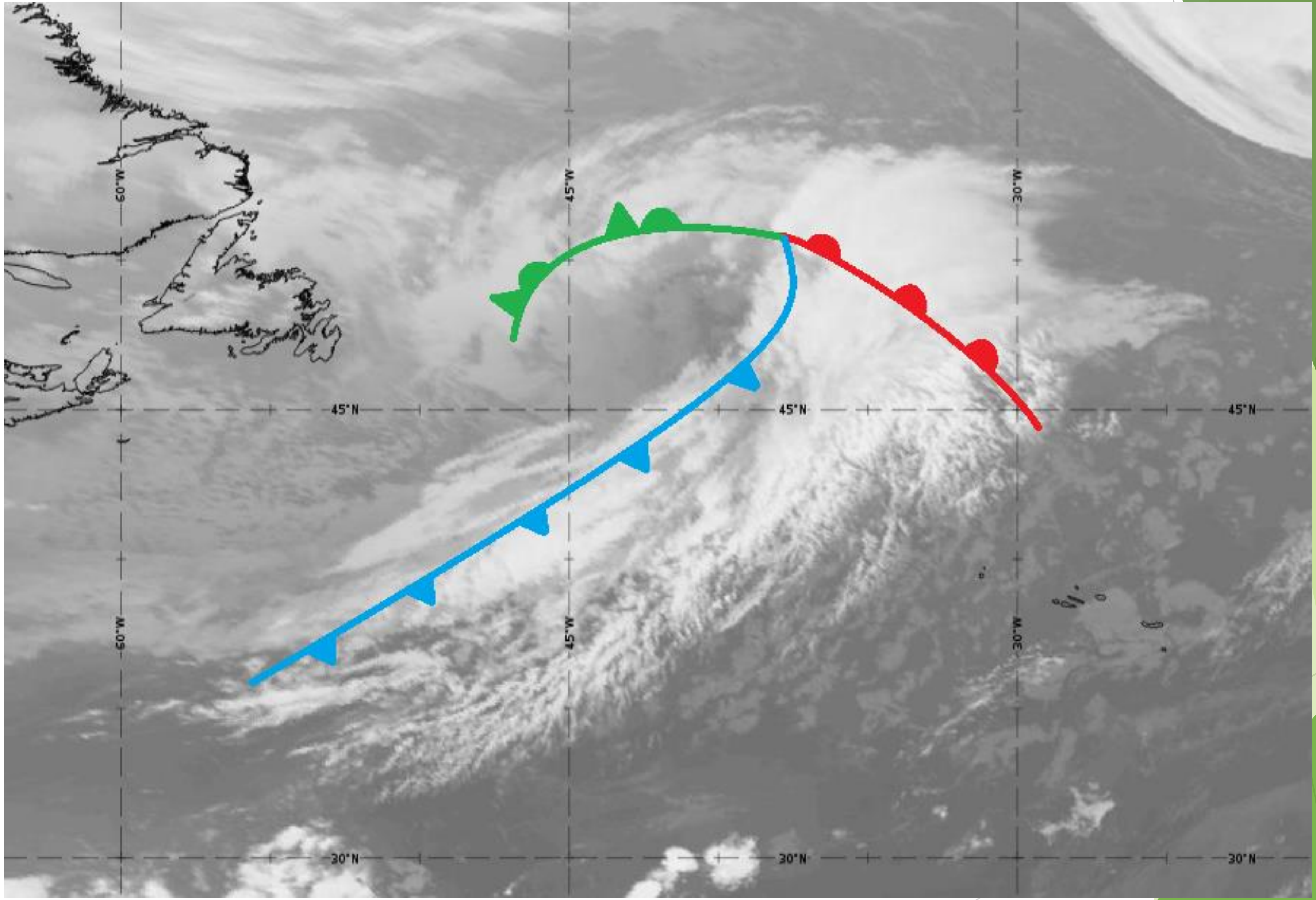
It is nearly impossible to discriminate Shapiro-Keyser cyclones from Norwegian cyclones from visual inspection of satellite images.

Nevertheless there are some clues from the large scale flow.






(a) Norwegian Model
I
II
III
IV
L
L
L
L
(b) Shapiro–Keyser Model
I
II
III
IV
L
L
L
L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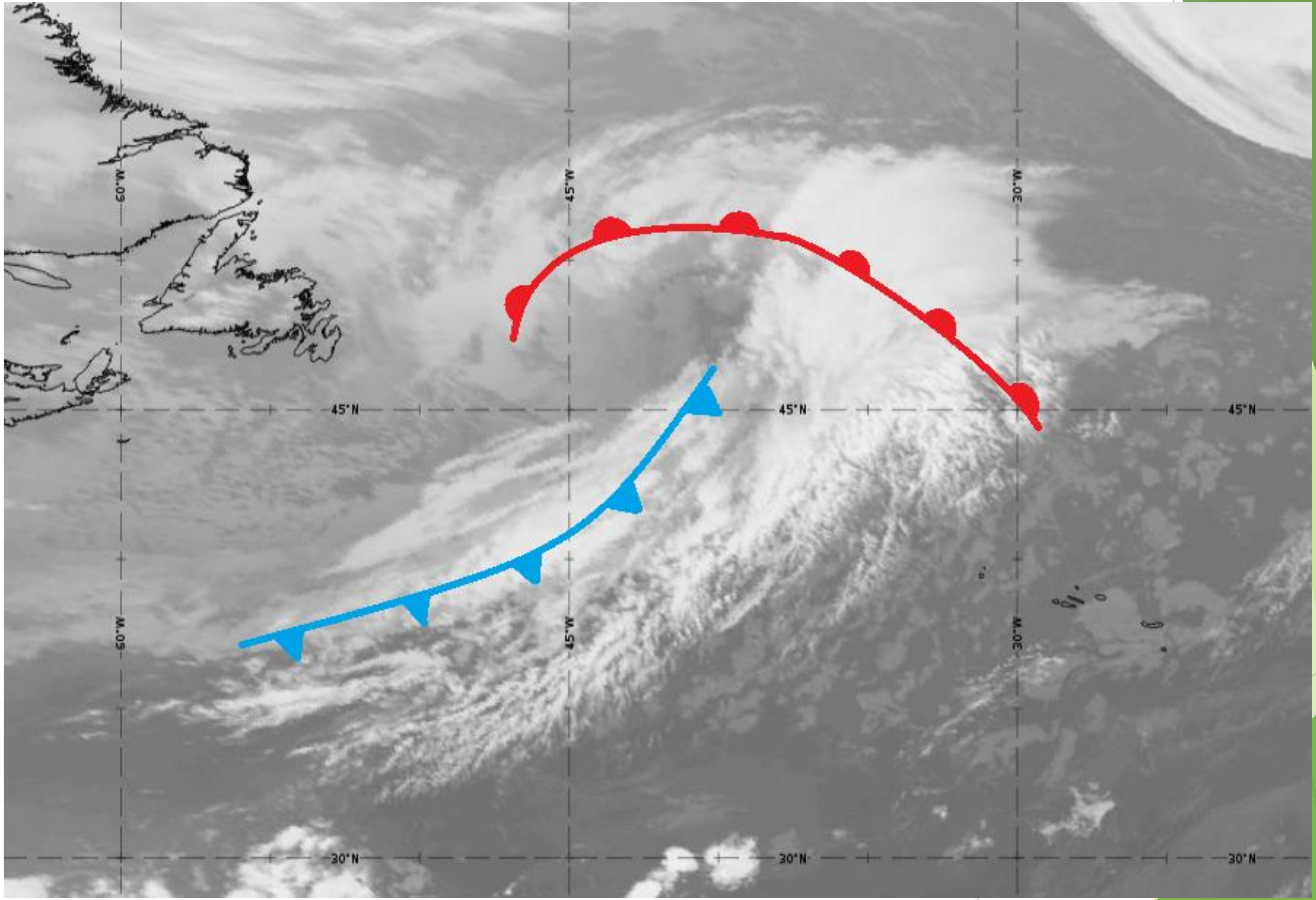
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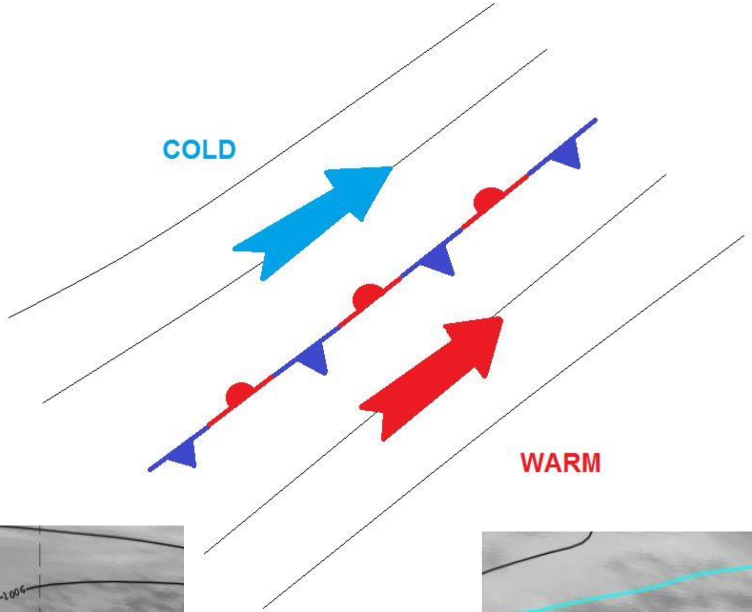
Let‘s see the main differences between the classical Norwegian and the Shapiro-Keyser model

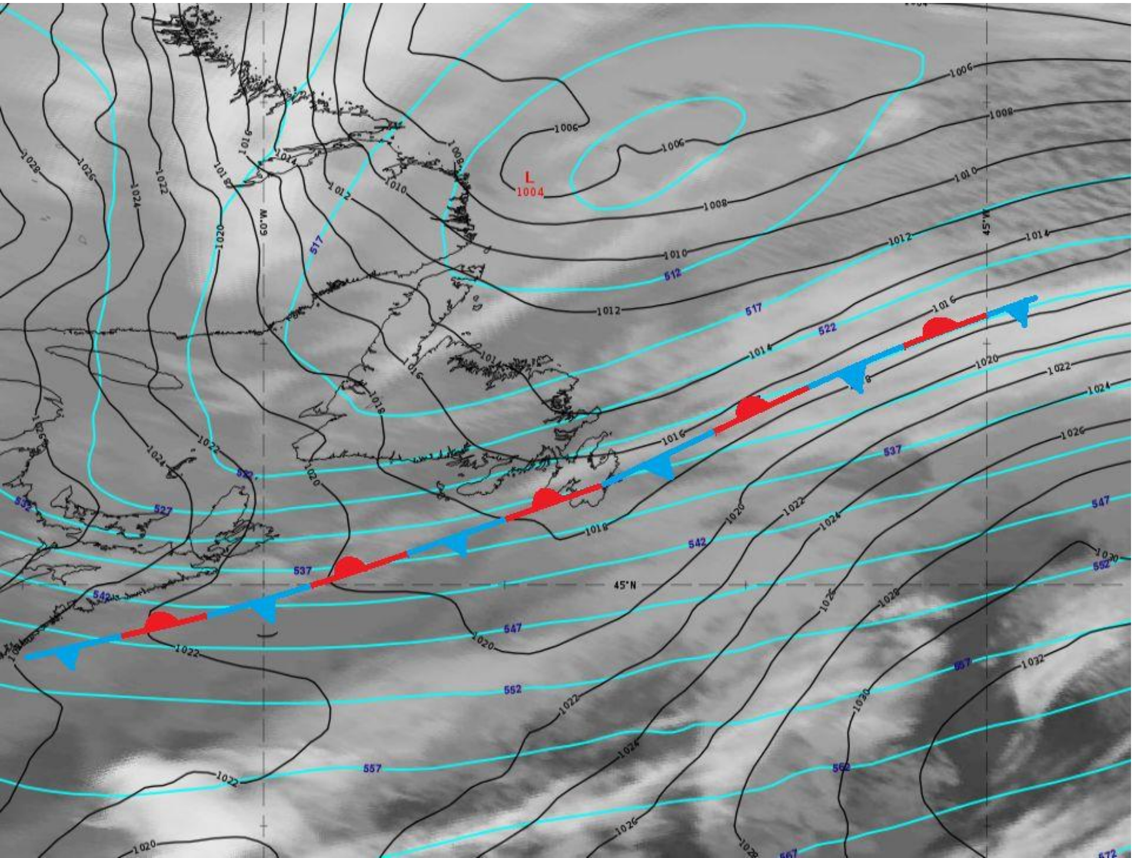
A. Initial stage	similar
B. Developing wave	similar
C. Intensification stage	deviating development
D. Maturity stage	deviating development
E. Dissipating stage	converging development

Initial stage:

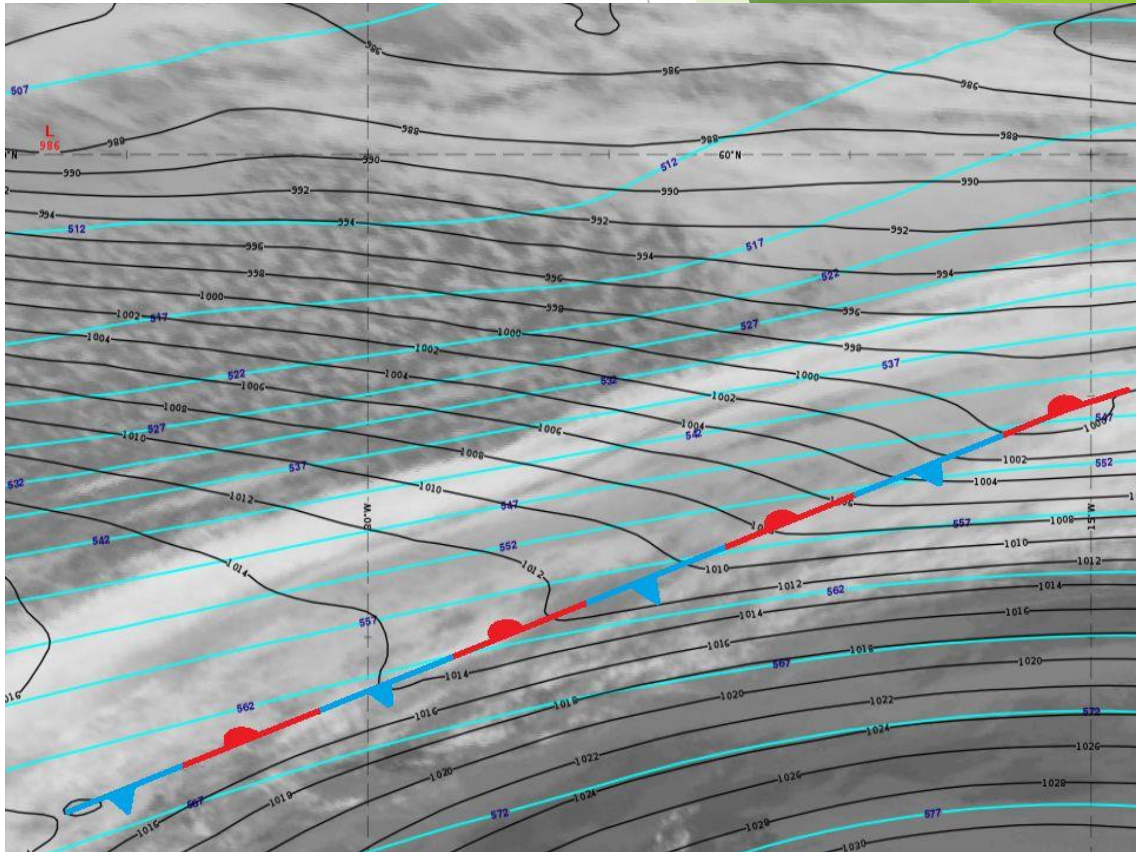
A horizontal temperature gradient in an undisturbed flow along a baroclinic boundary.



Norwegian cyclone

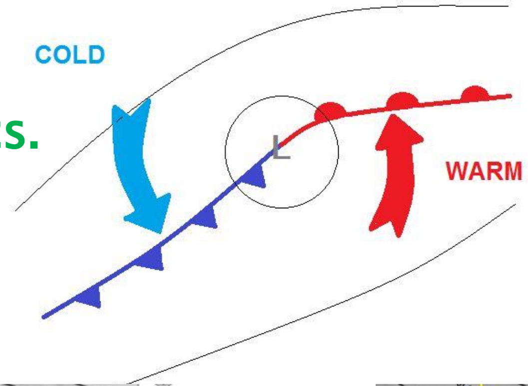


Shapiro-Keyser cyclone

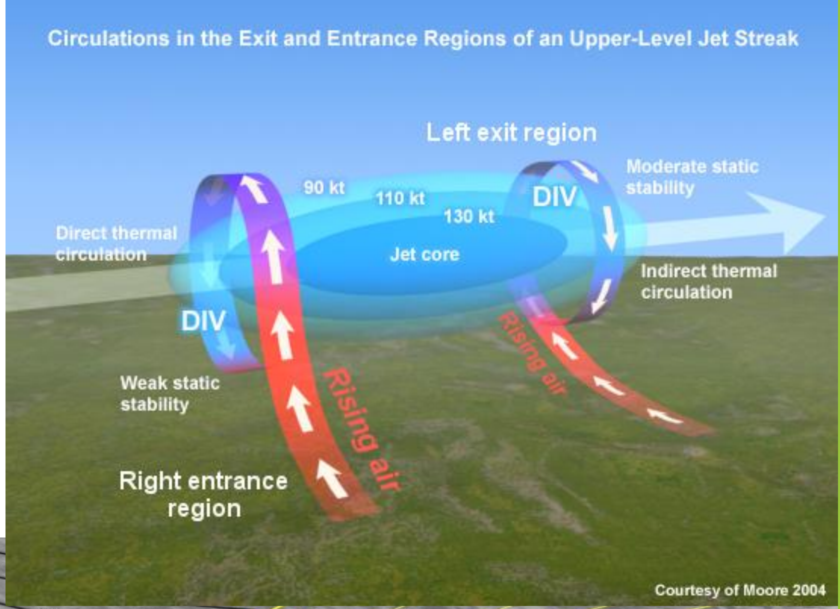


Developing wave:

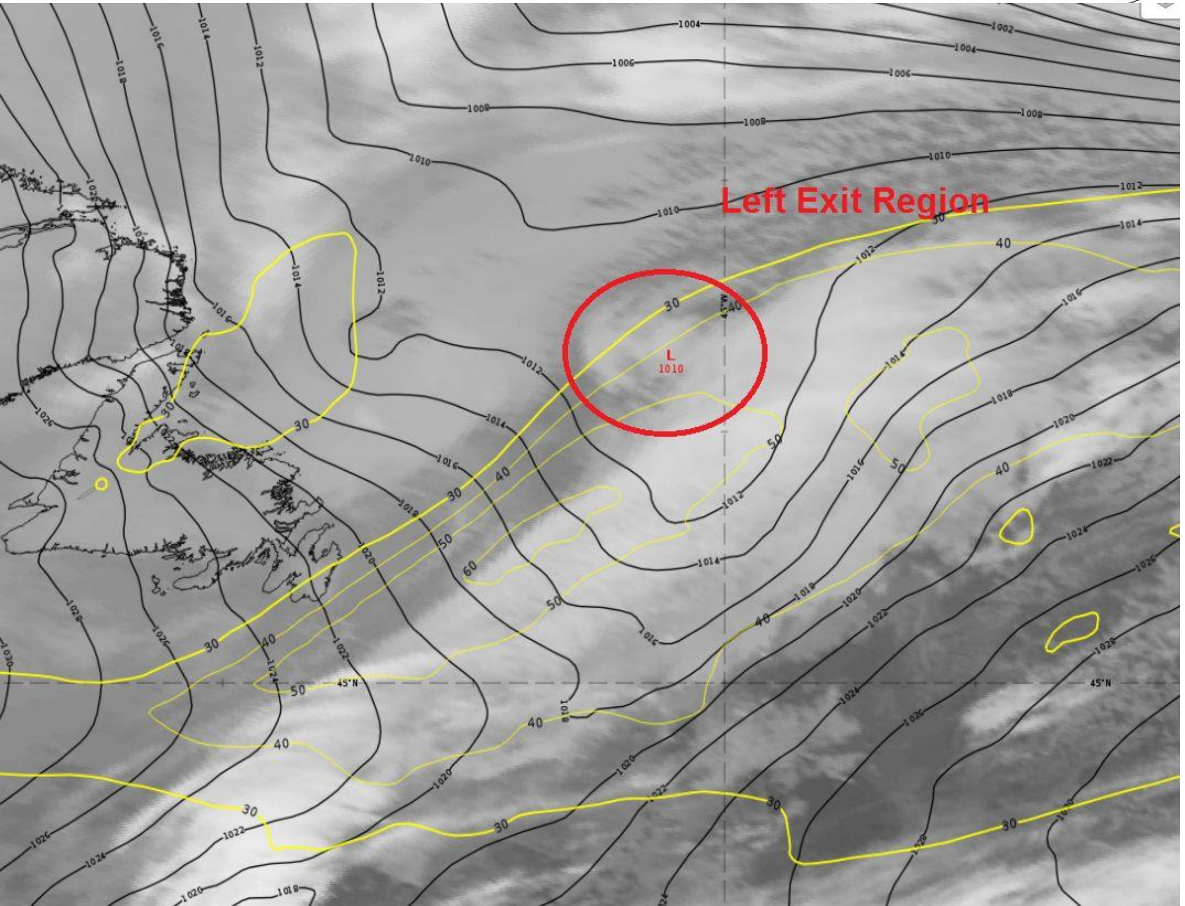
The development of the surface low
is triggered by the upper-level dynamics.

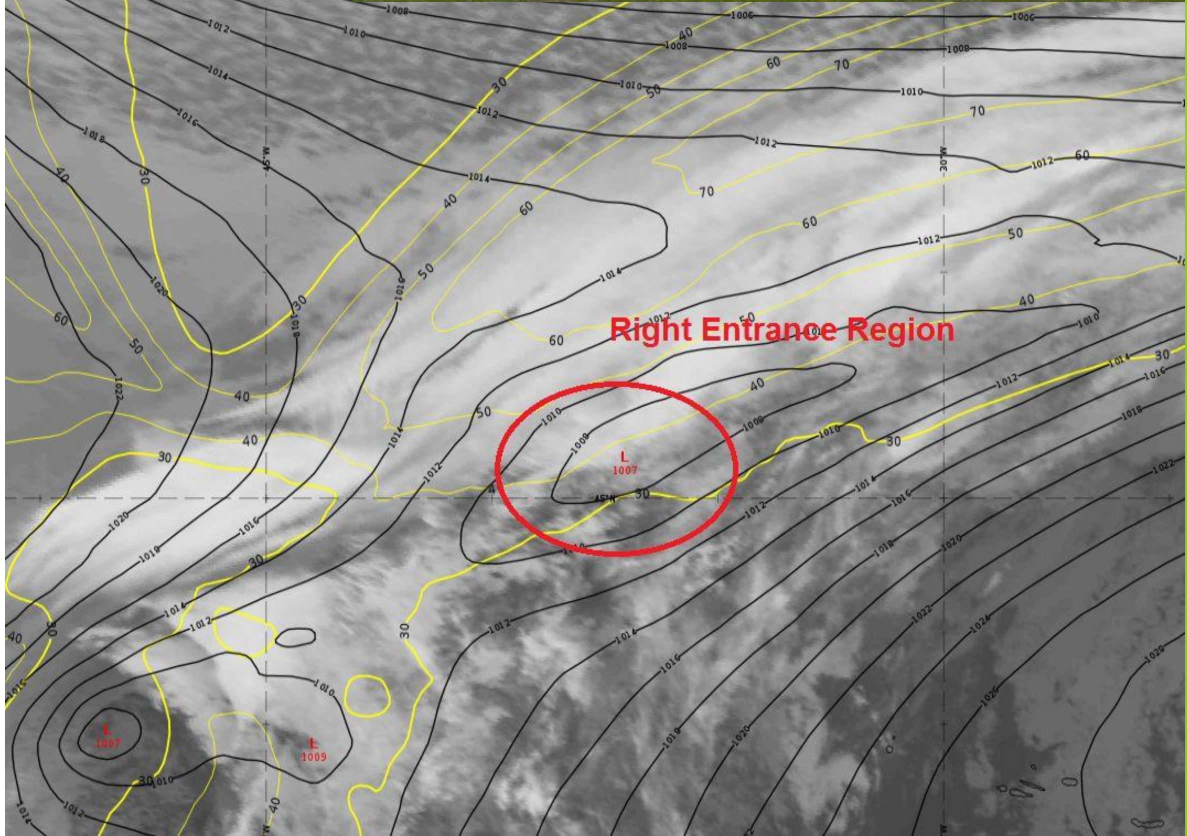


Norwegian cyclone


Circulations in the Exit and Entrance Regions of an Upper-Level Jet Streak

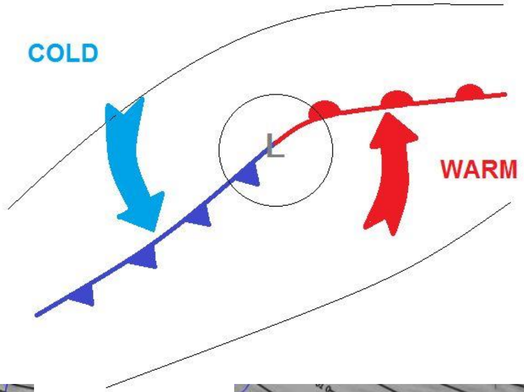
Courtesy of Moore 2004



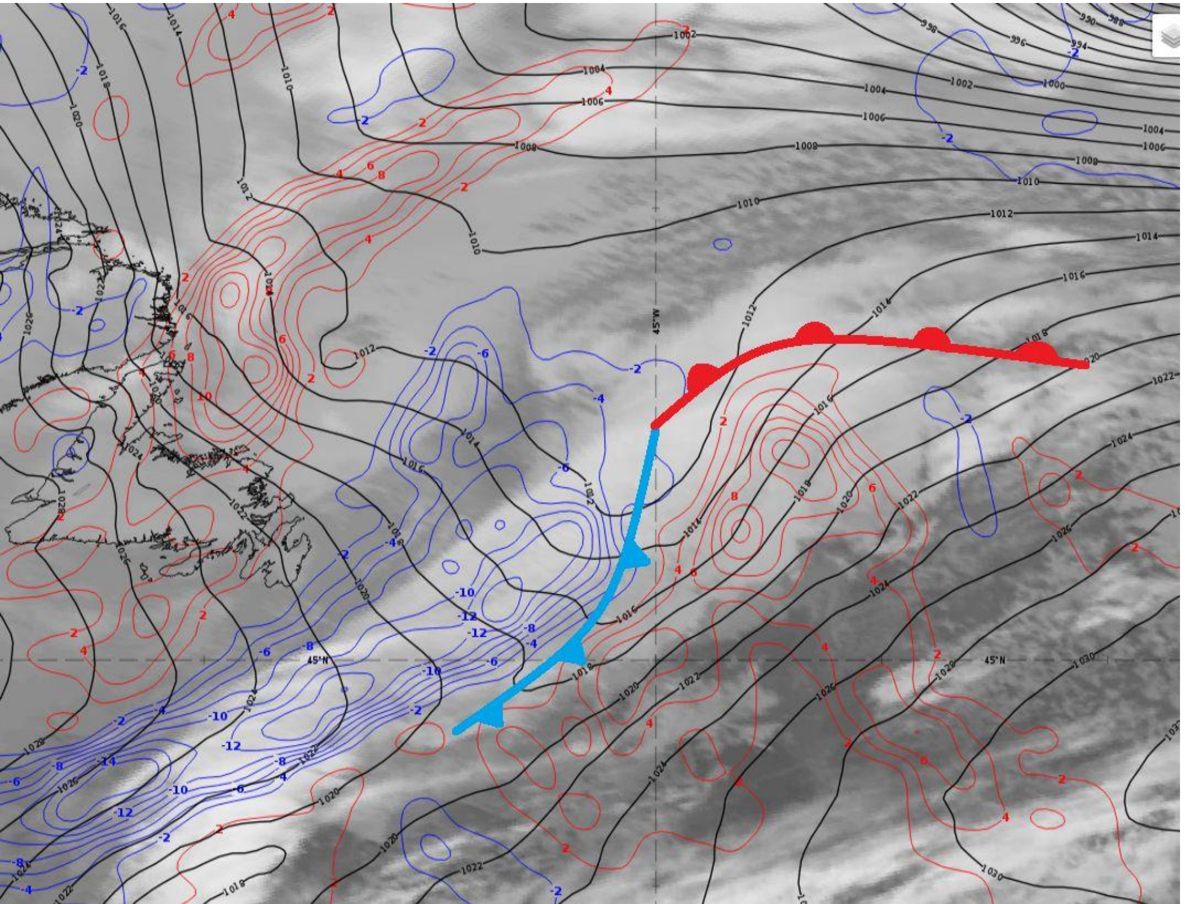


Developing wave:

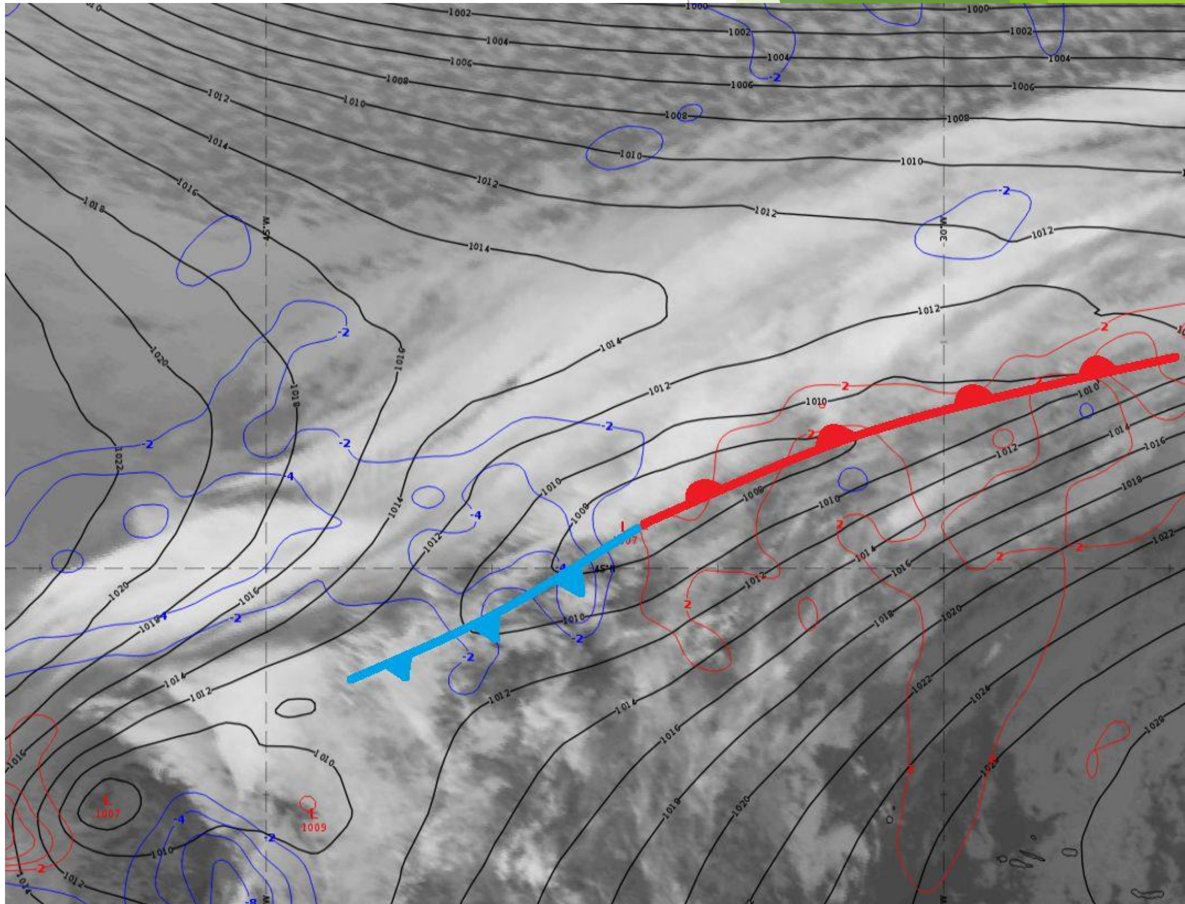
The temperature advection field indicates protruding warm and cold air masses and developing fronts.



Norwegian cyclone

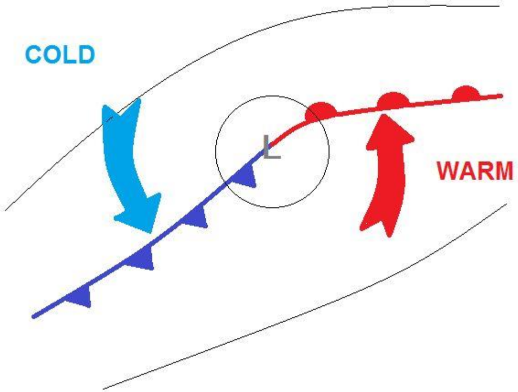


Shapiro-Keyser cyclone

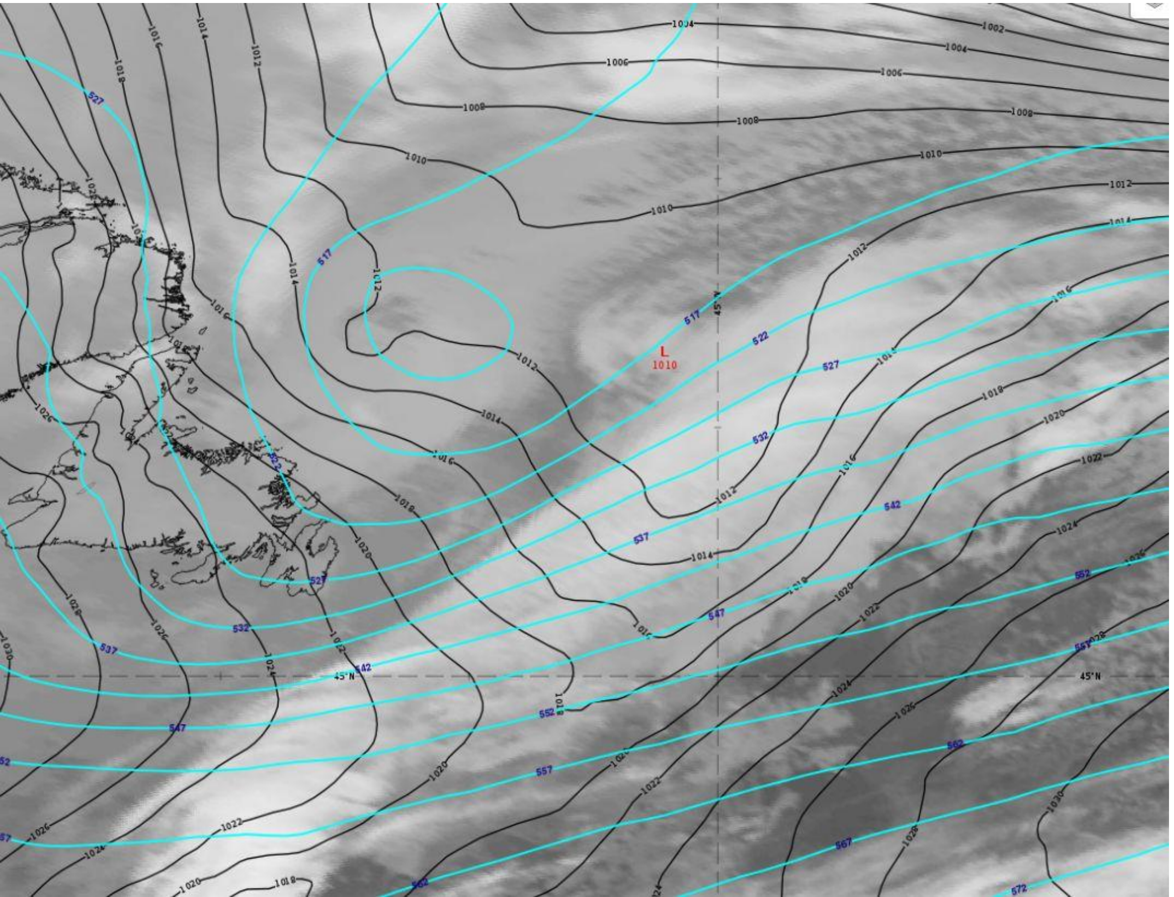


Developing wave:

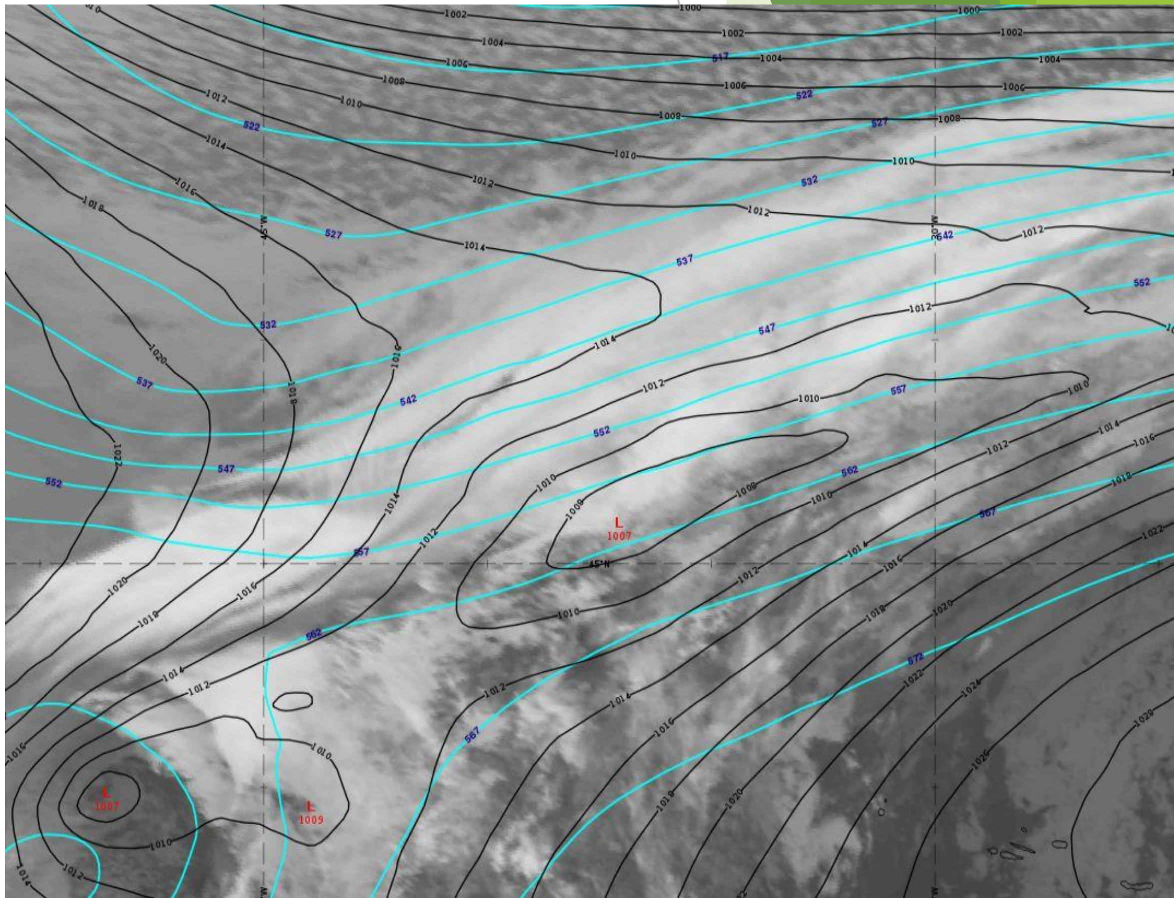
The only difference between N and S-K can be seen in the large-scale flow and results from the high/low index situation.



Norwegian cyclone

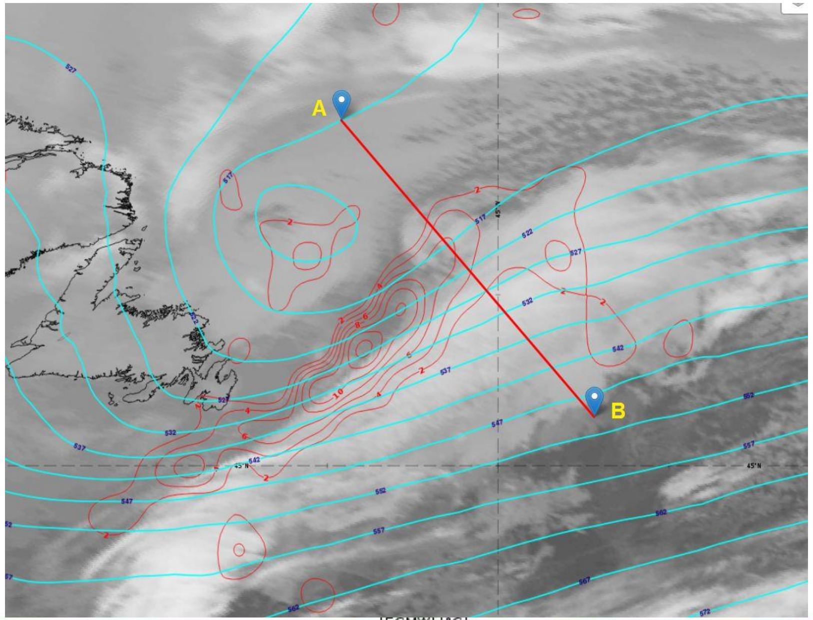


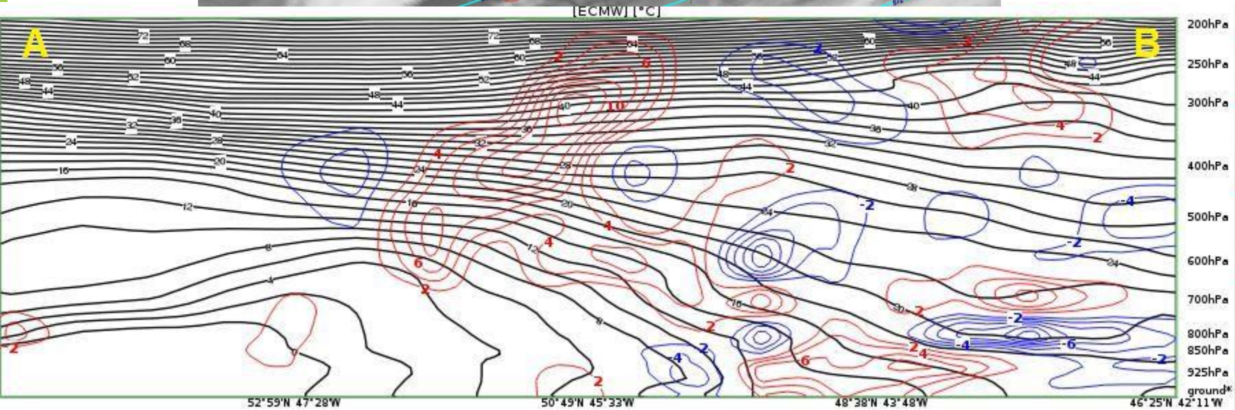
Shapiro-Keyser cyclone



Developing wave: vertical cross sections

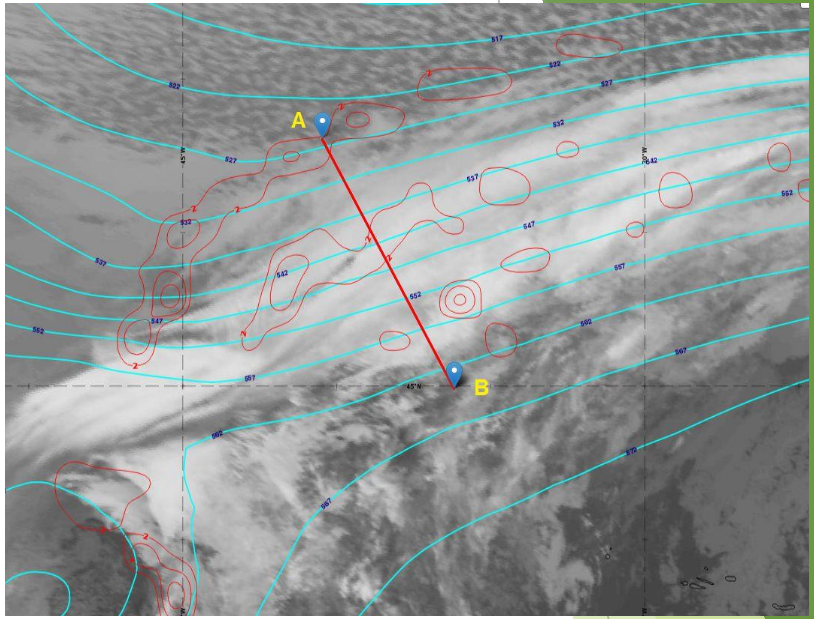
Norwegian cyclone

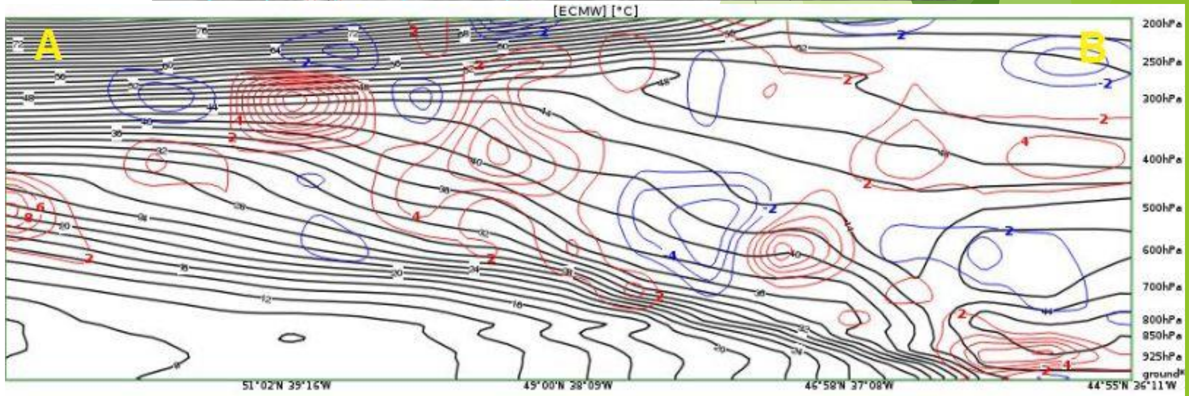




Cross-Section from map **Equivalent Potential Temperature** and **Vorticity Advection**
for 55°06'N 49°35'W - 46°25'N 42°11'W, valid 10.03.2019 06:00

Shapiro-Keyser cyclone

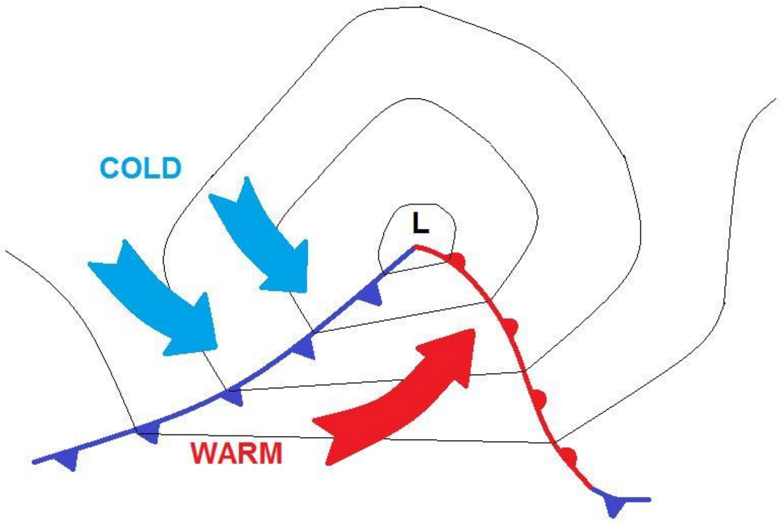




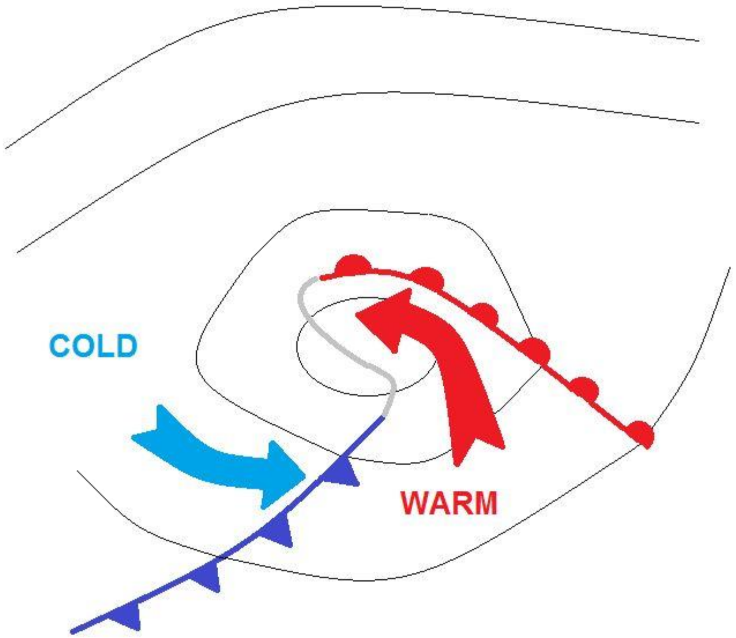
Cross-Section from map **Equivalent Potential Temperature** and **Vorticity Advection**
for 53°03'N 40°29'W - 44°55'N 36°11'W, valid 15.03.2019 06:00

Intensification stage: Deviating development

Norwegian cyclone



Shapiro-Keyser cyclone

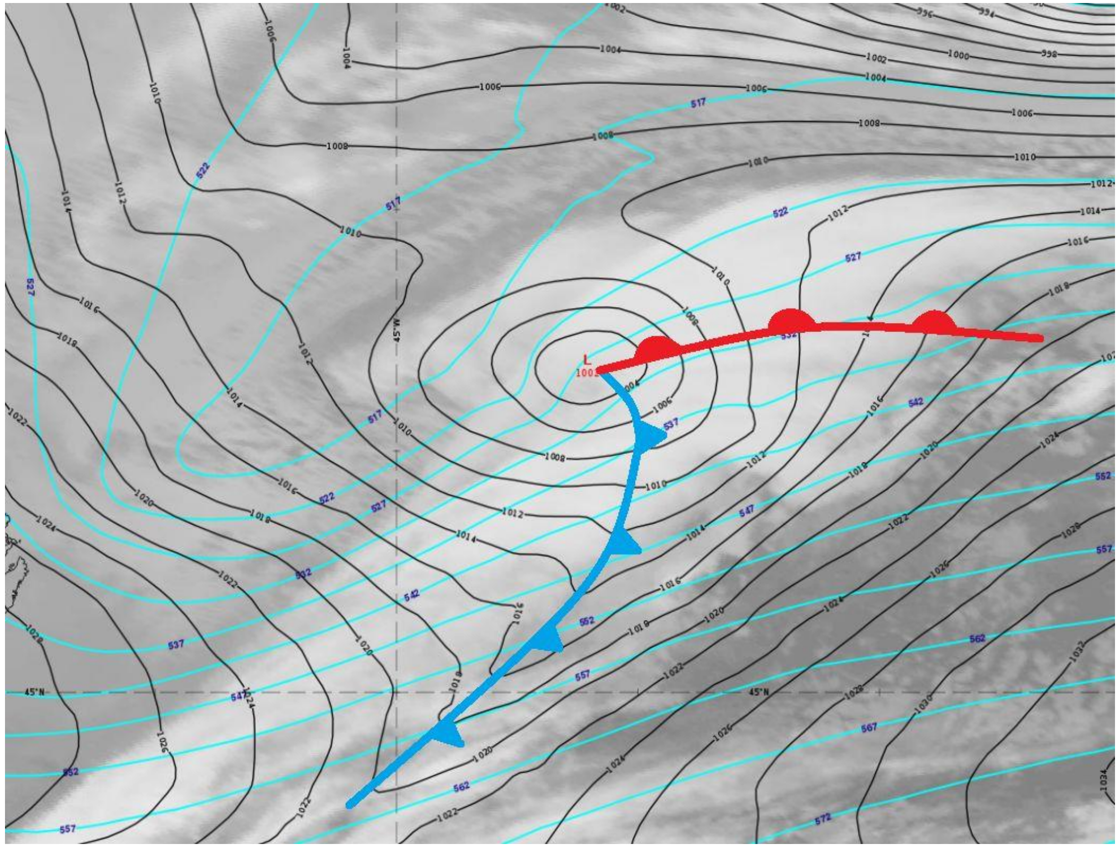


- Warm air invades the low centre
- Cold frontal fracture forms

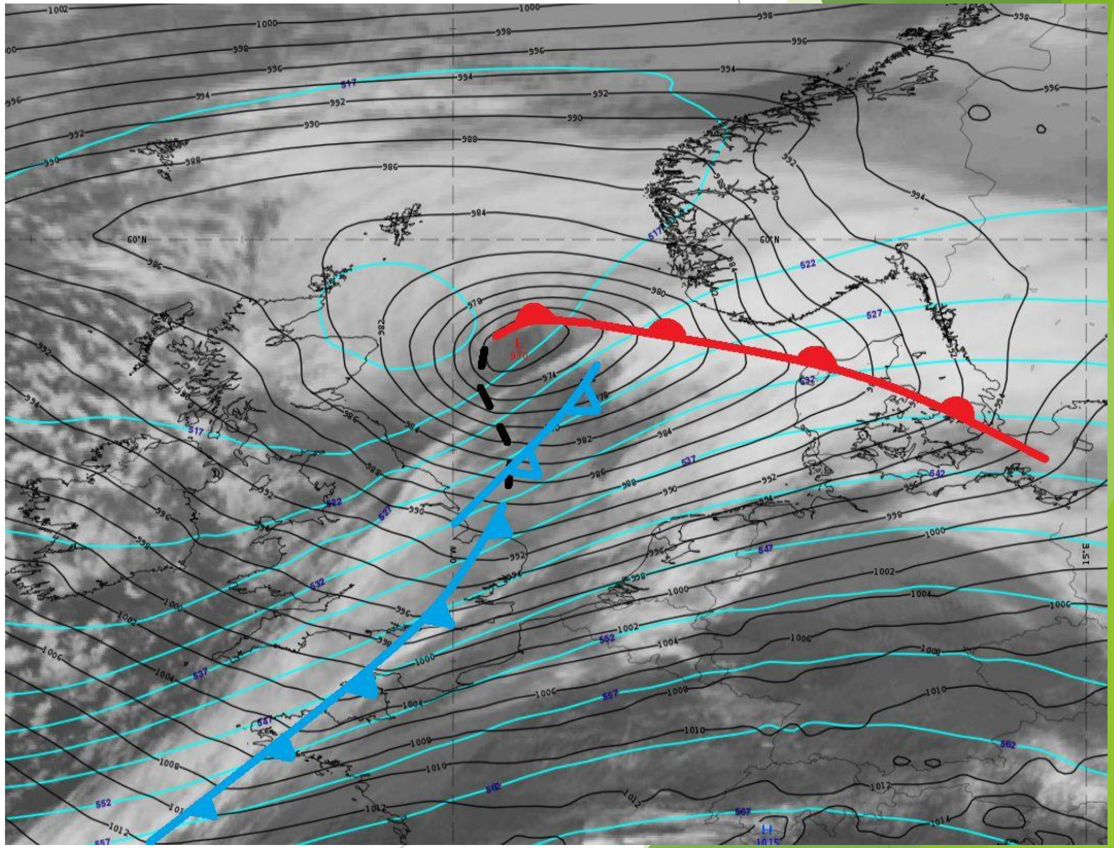
Intensification stage: Deviating development

The surface cold front detaches from the warm front and the so-called **cold frontal fracture** (black dotted line) forms. The upper-level cold front remains unaffected by the low-level warm air advance and moves south-eastward.

Norwegian cyclone



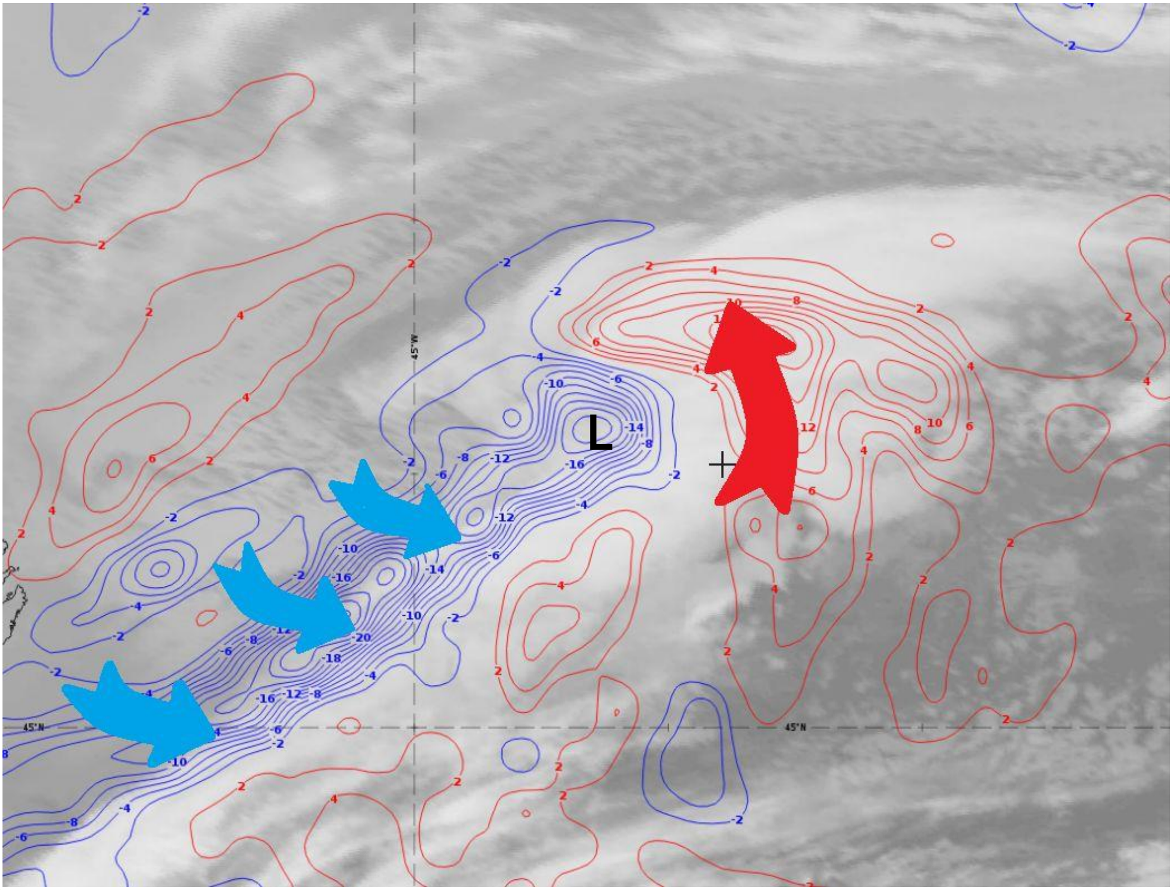
Shapiro-Keyser cyclone



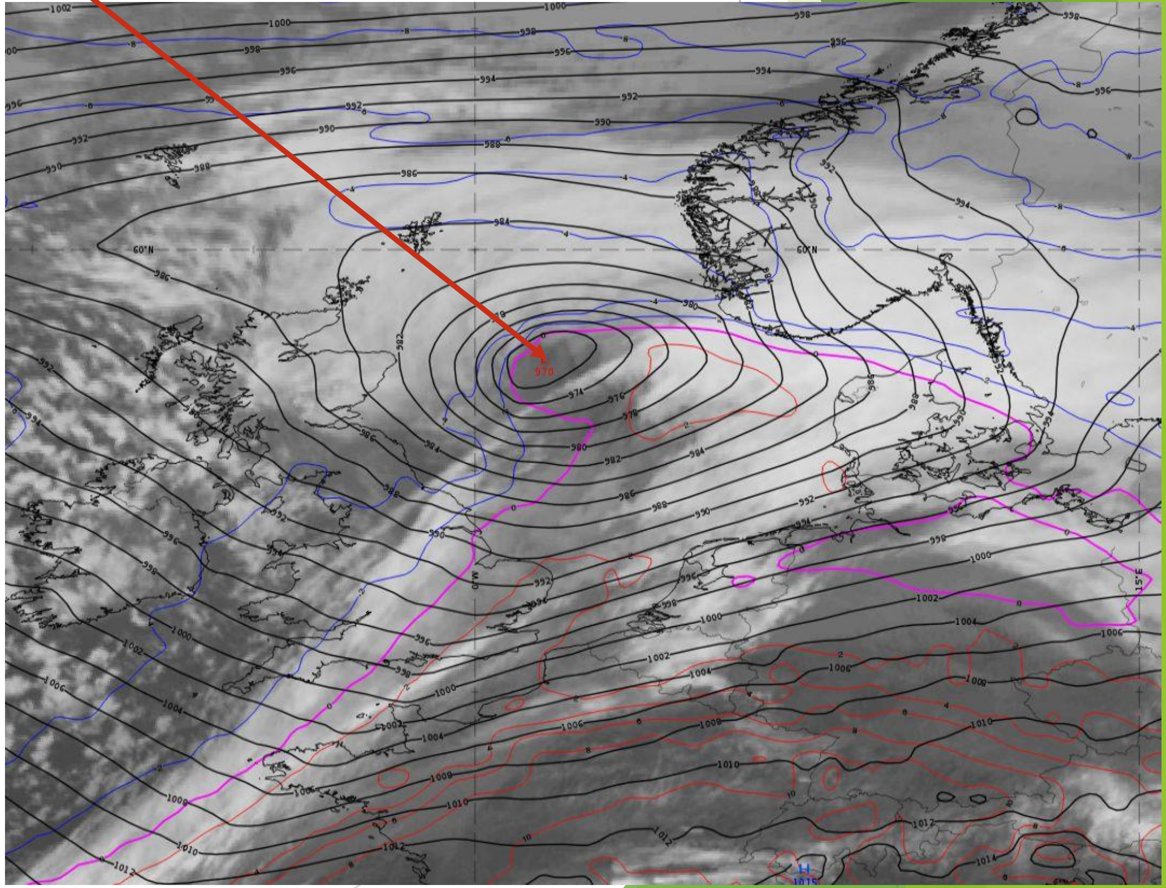
Intensification stage: Deviating development

The temperature field at lower levels shows a pronounced bulge of warm air right at the surface pressure minimum.

Norwegian cyclone

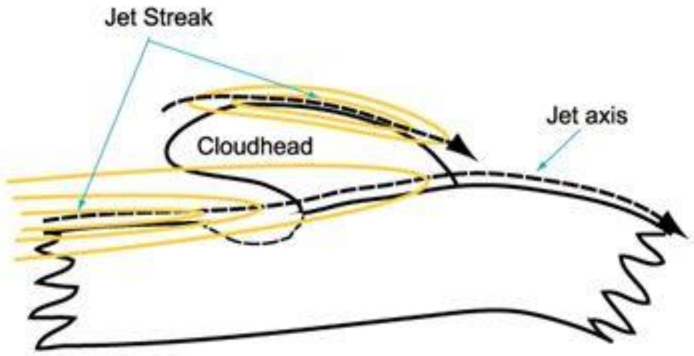


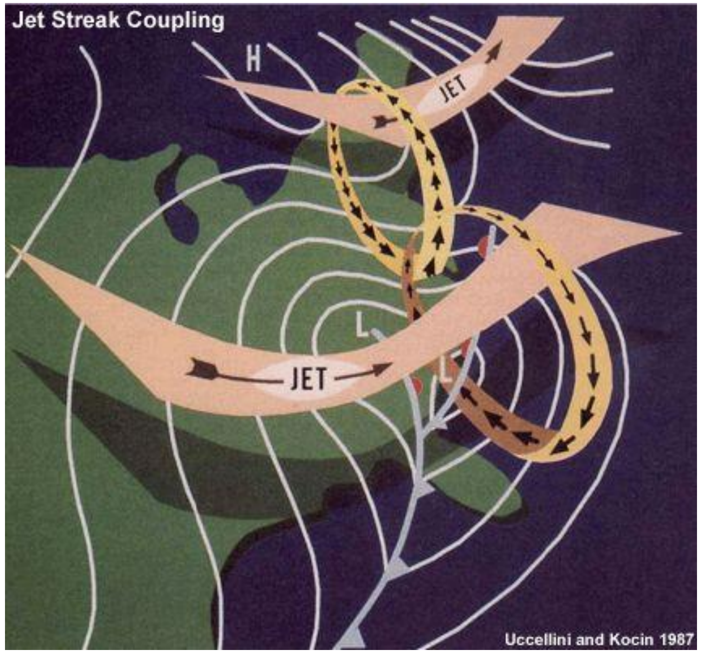
Shapiro-Keyser cyclone



Intensification stage: Deviating development

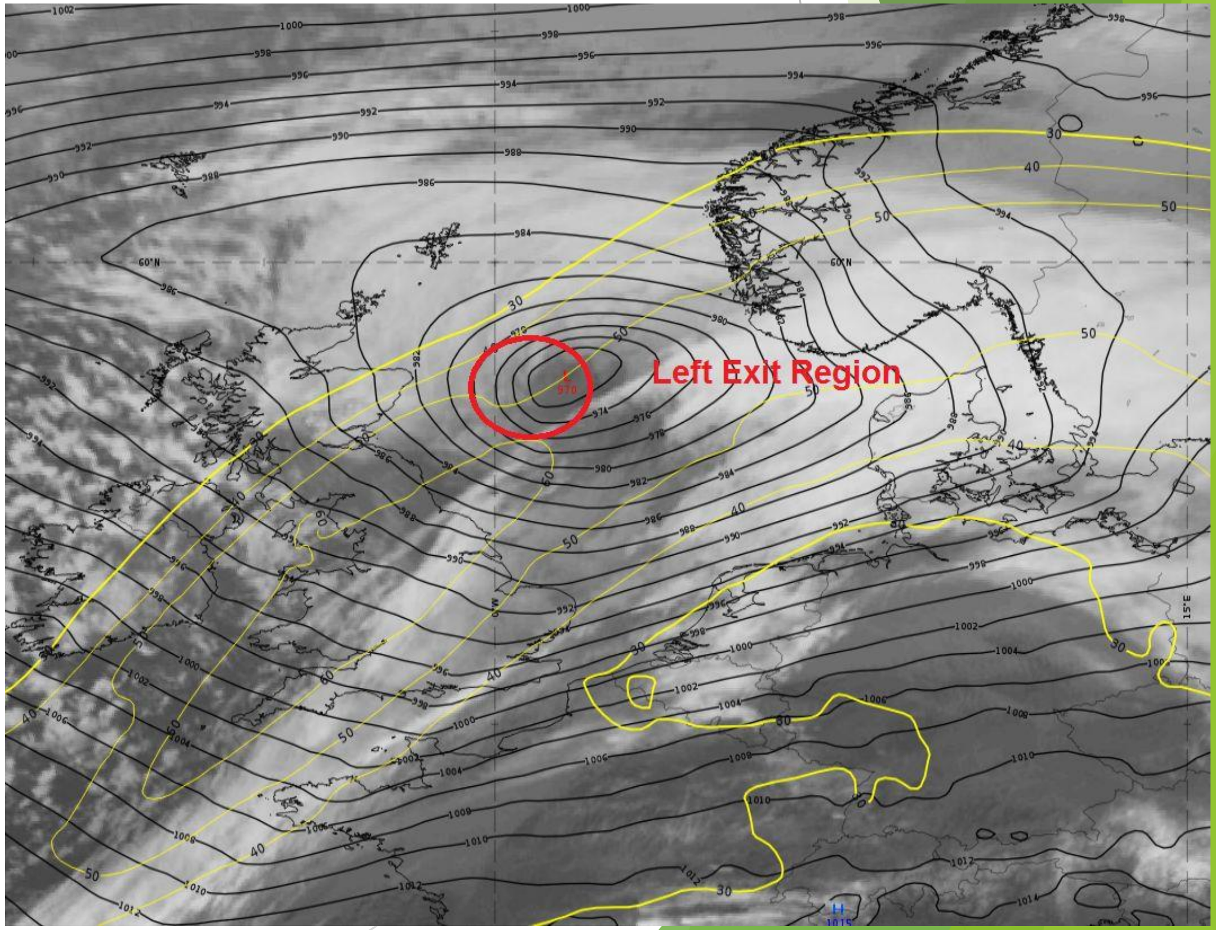
Typical configuration that can be found with Rapid Cyclogenesis





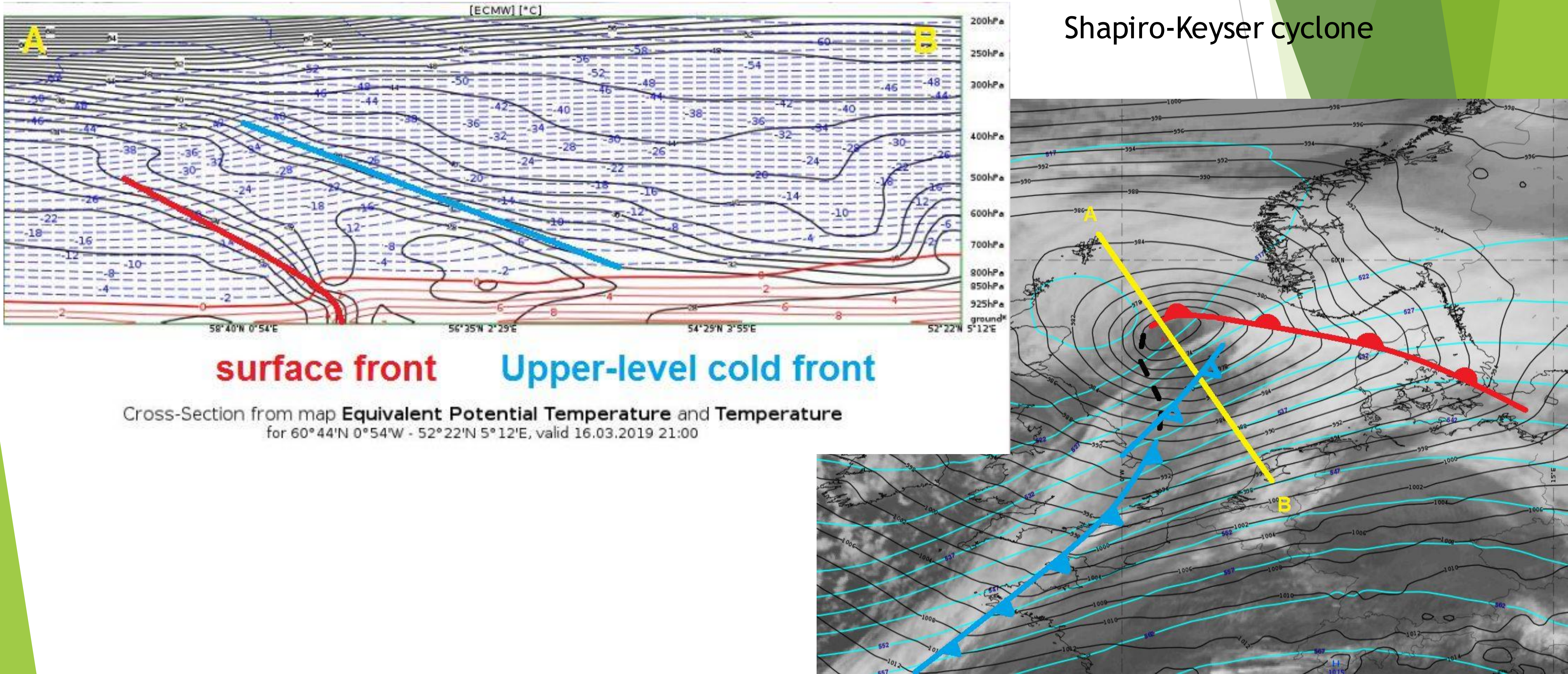
Uccellini and Kocin 1987

Shapiro-Keyser cyclone



Intensification stage: Deviating development

Shapiro-Keyser cyclone

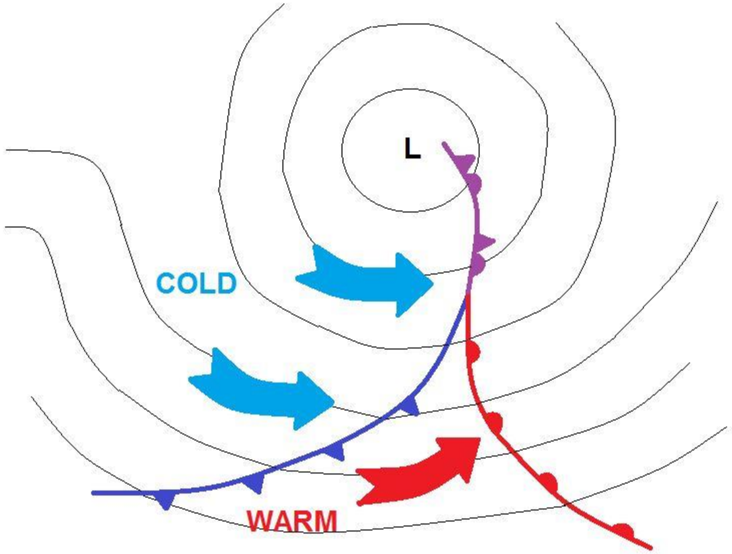


Cross-Section from map **Equivalent Potential Temperature** and **Temperature**
for 60°44'N 0°54'W - 52°22'N 5°12'E, valid 16.03.2019 21:00

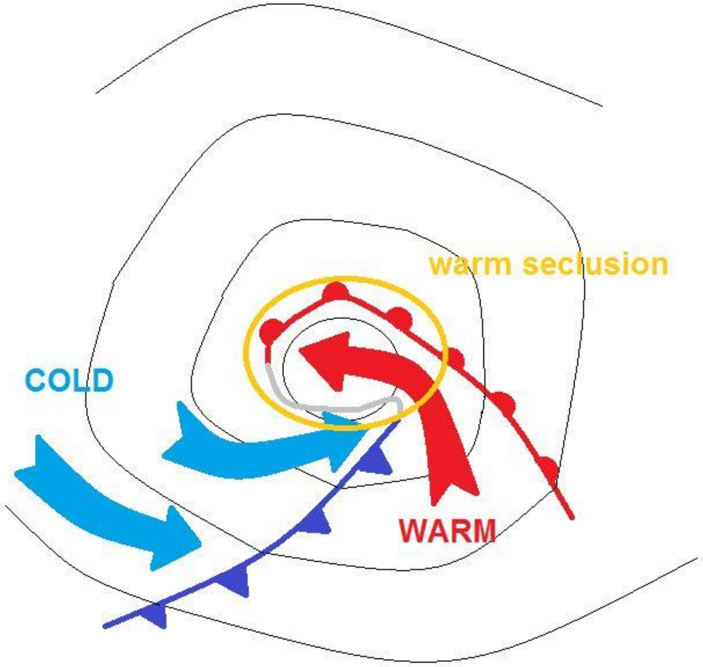
Intensification stage: Deviating development

- Formation of the warm seclusion
- T-bone pattern

Norwegian cyclone



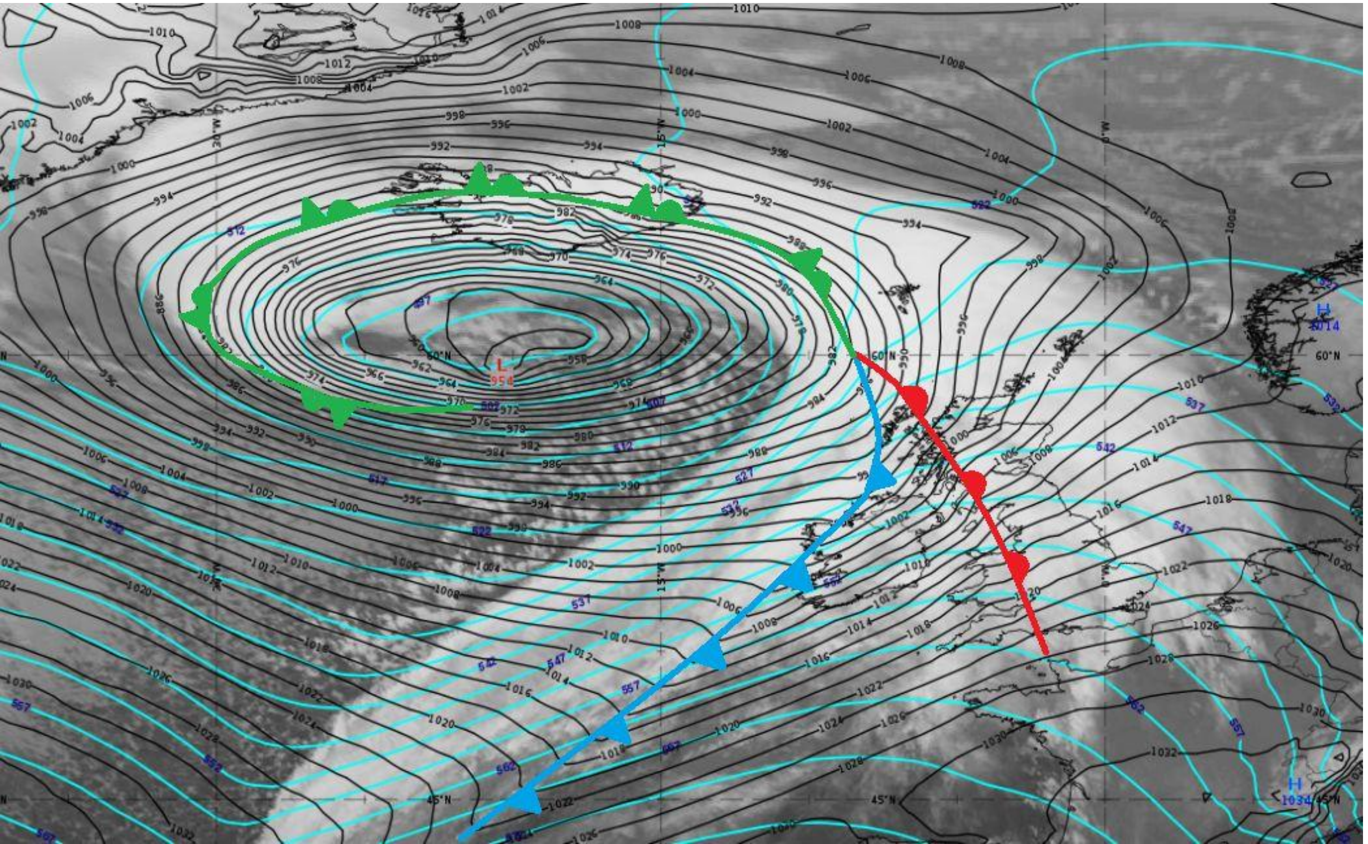
Shapiro-Keyser cyclone



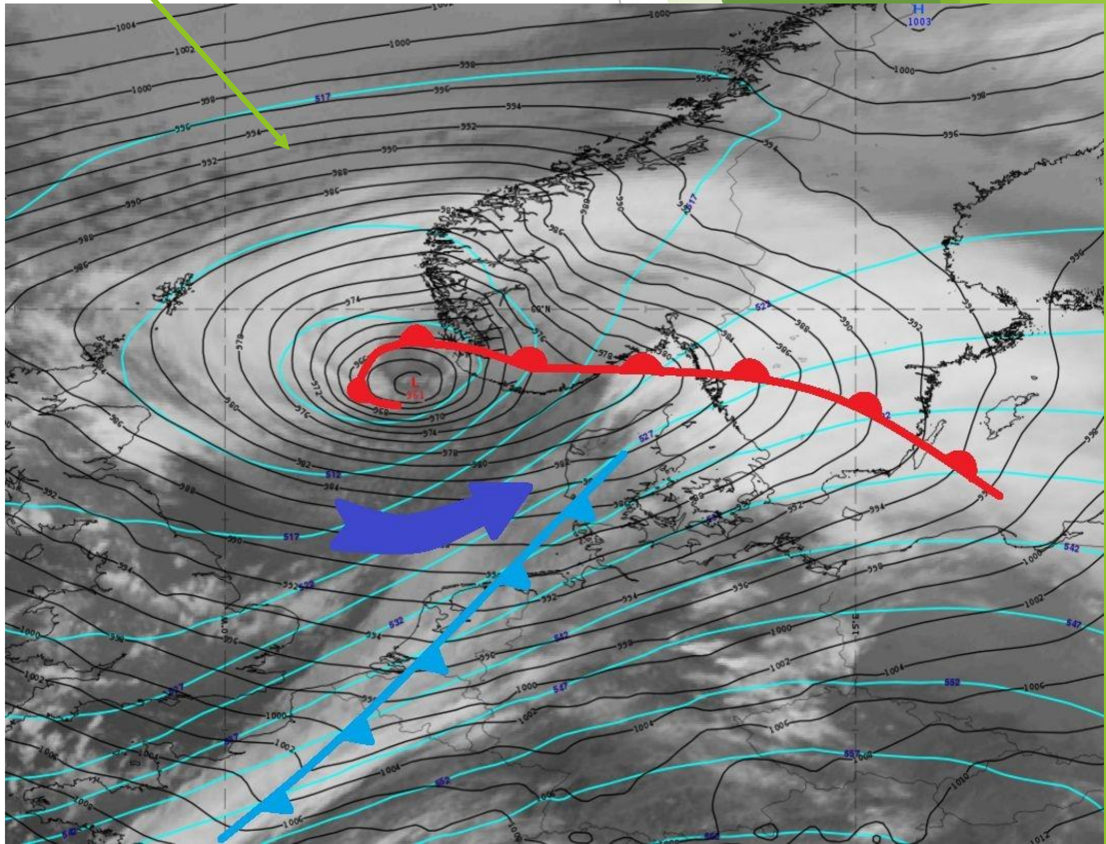
Mature stage: Deviating development

Cold air from behind the cold front starts wrapping around the warm core of the cyclone
The cold frontal gap closes
The upper-level cold front again builds a surface cold front

Norwegian cyclone



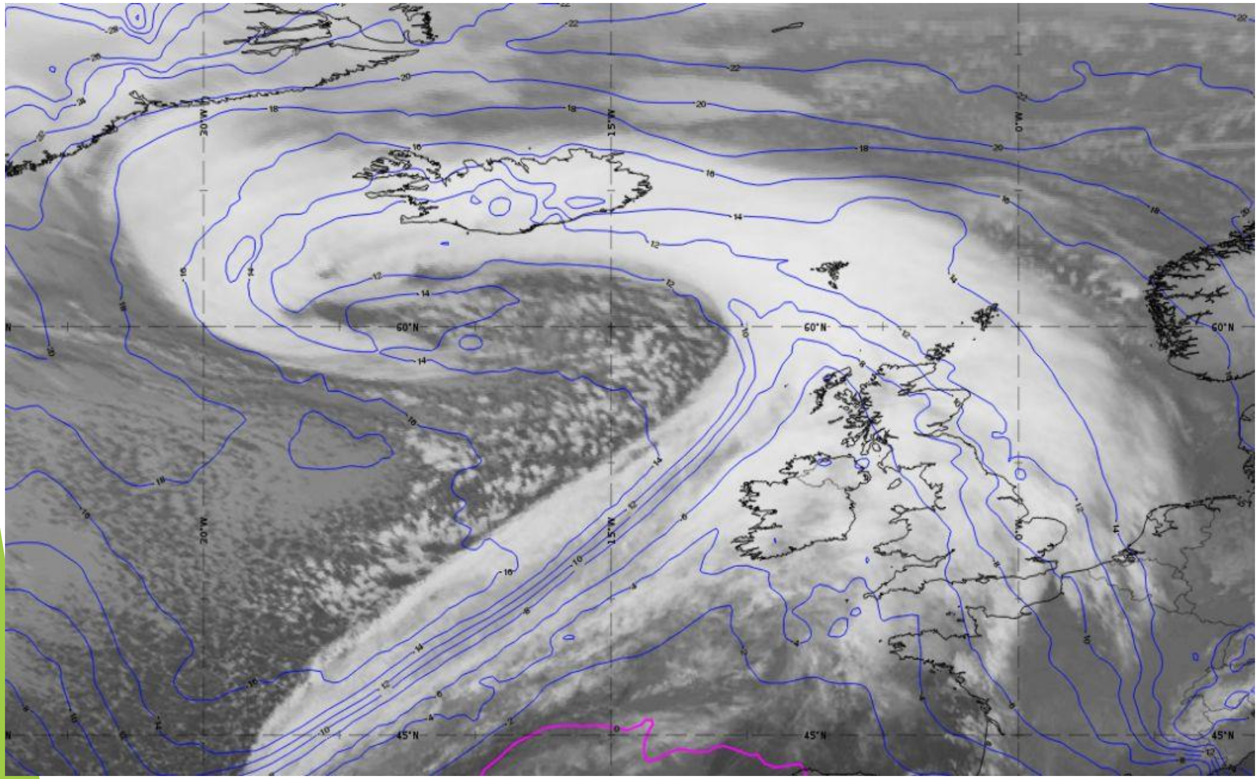
Shapiro-Keyser cyclone



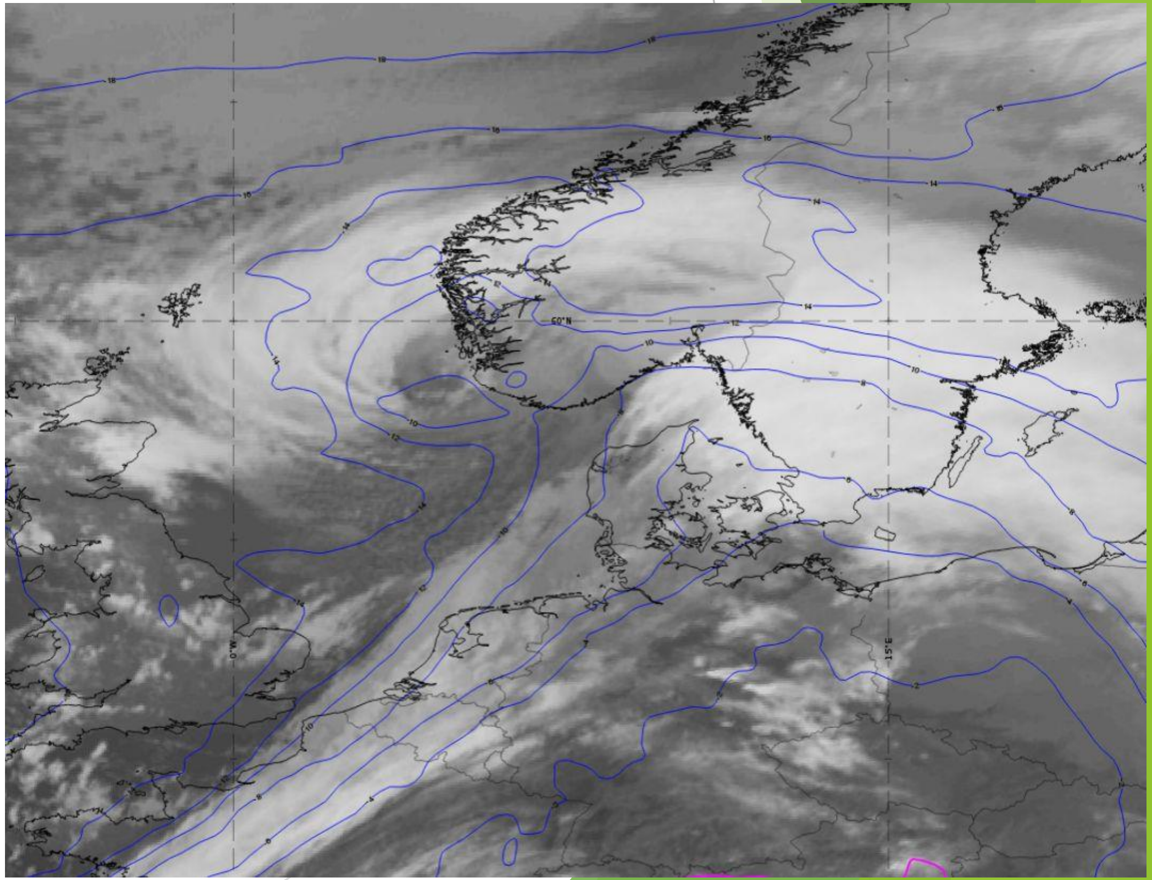
Mature stage: Deviating development

- Cold core
- Warm core

Norwegian cyclone



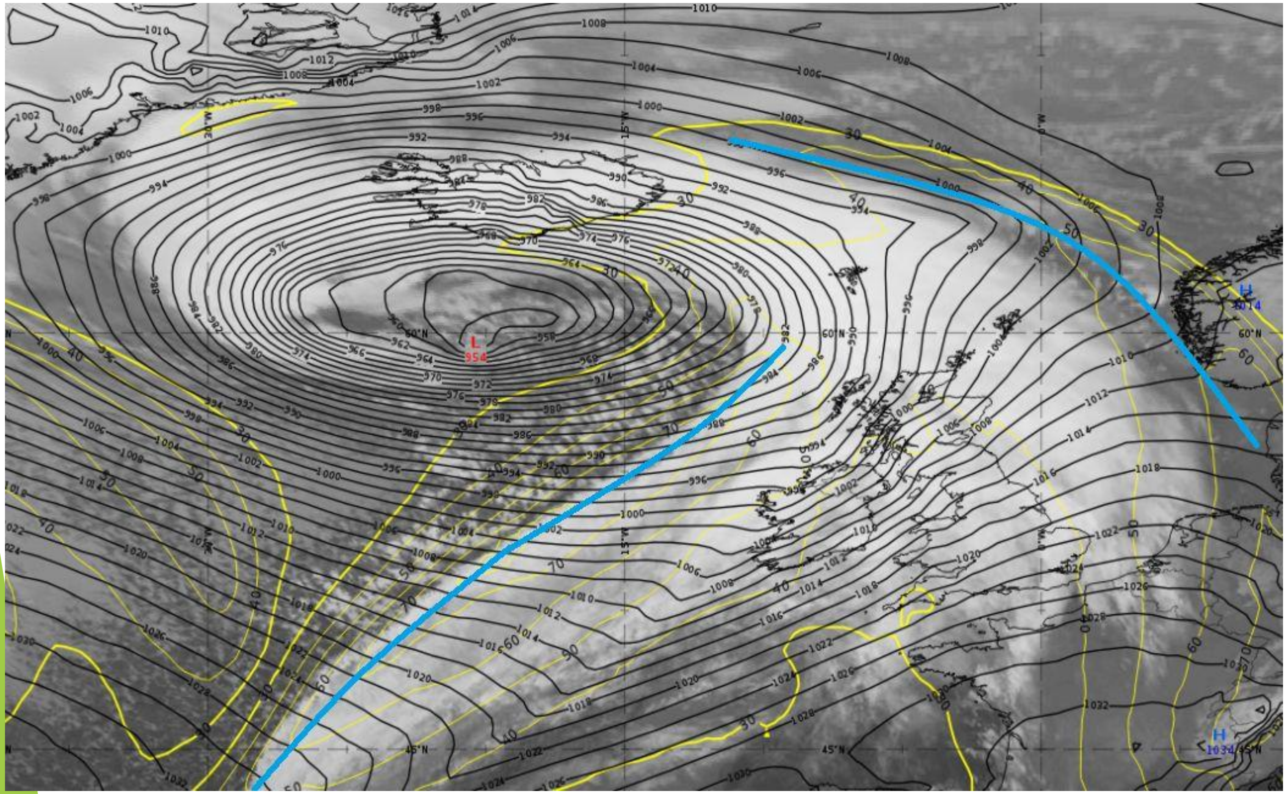
Shapiro-Keyser cyclone



Mature stage: Deviating development

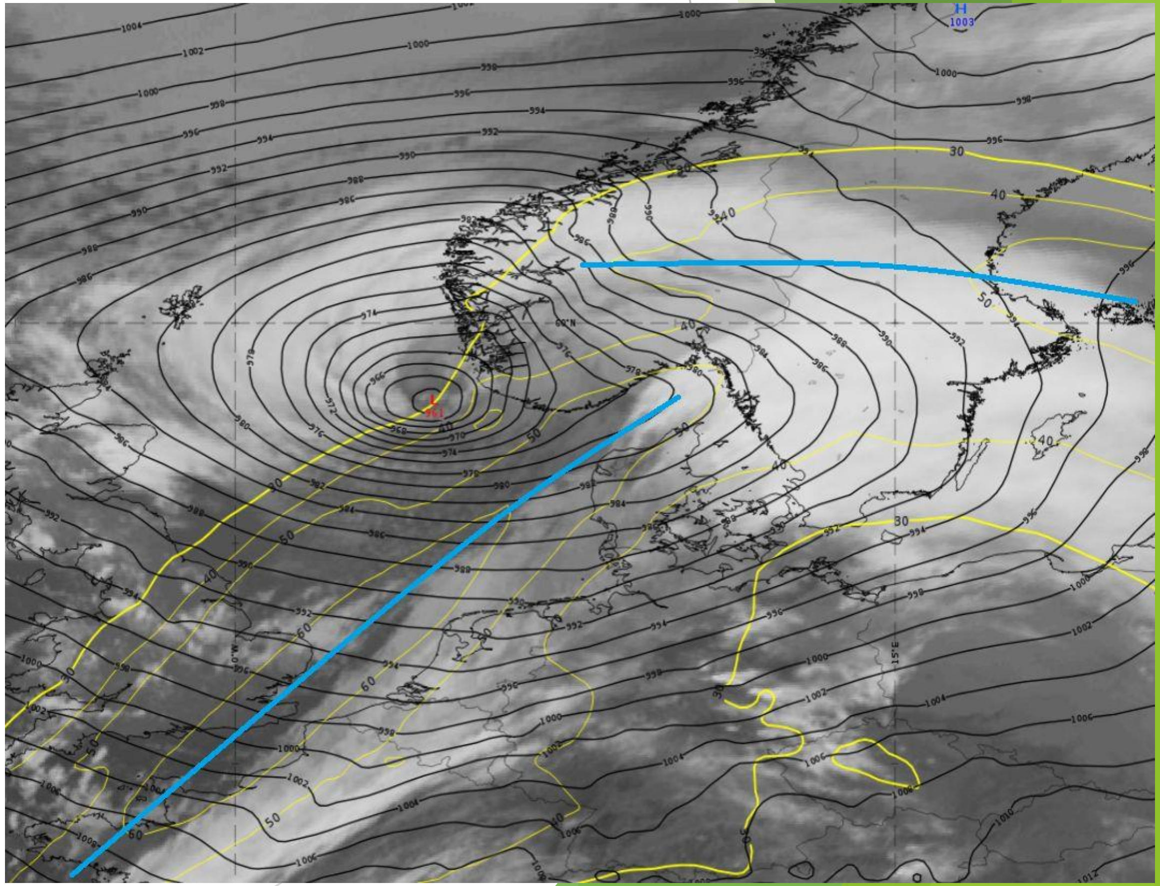
- **The axes of the two branches of the jet are perpendicular to each other.**

Norwegian cyclone



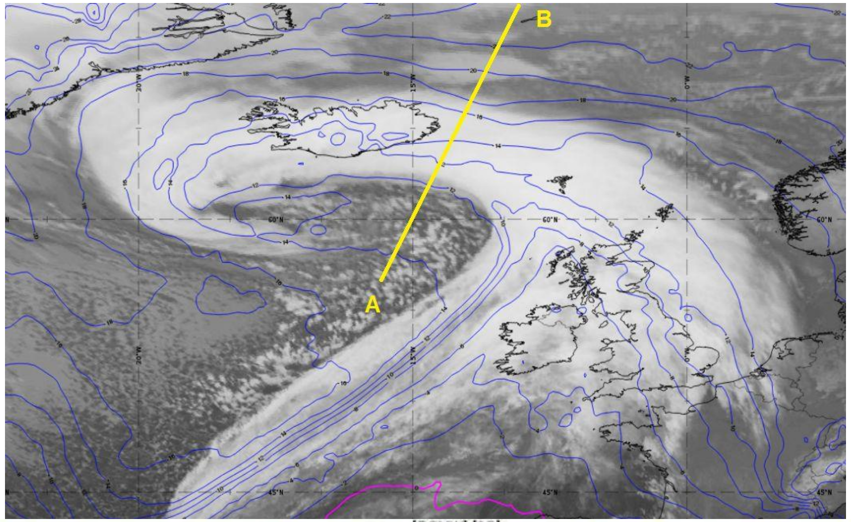
- **The jet axes are almost in line with each other.**

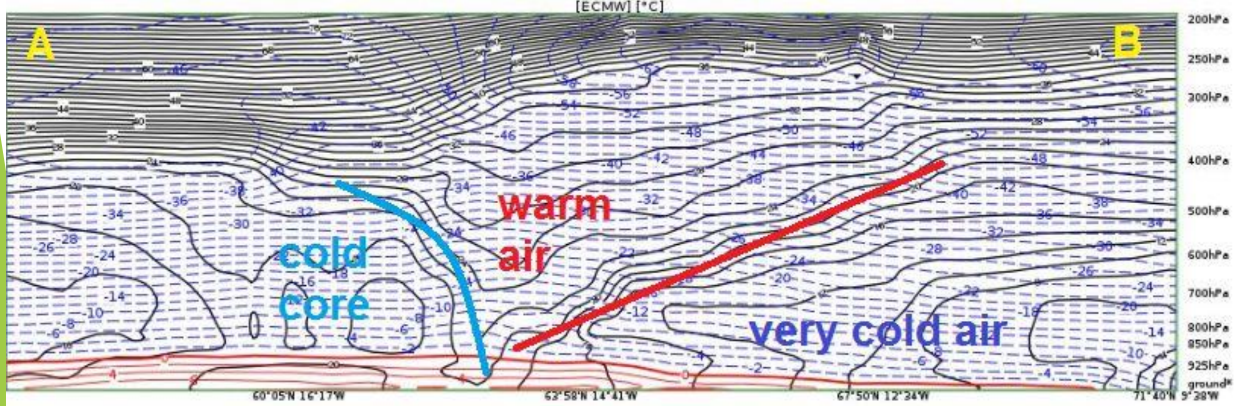
Shapiro-Keyser cyclone



Mature stage: Deviating development

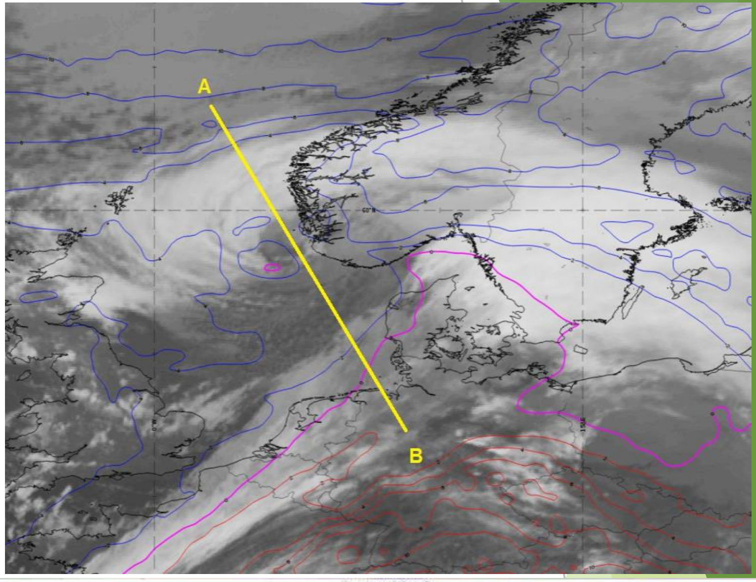
Norwegian cyclone

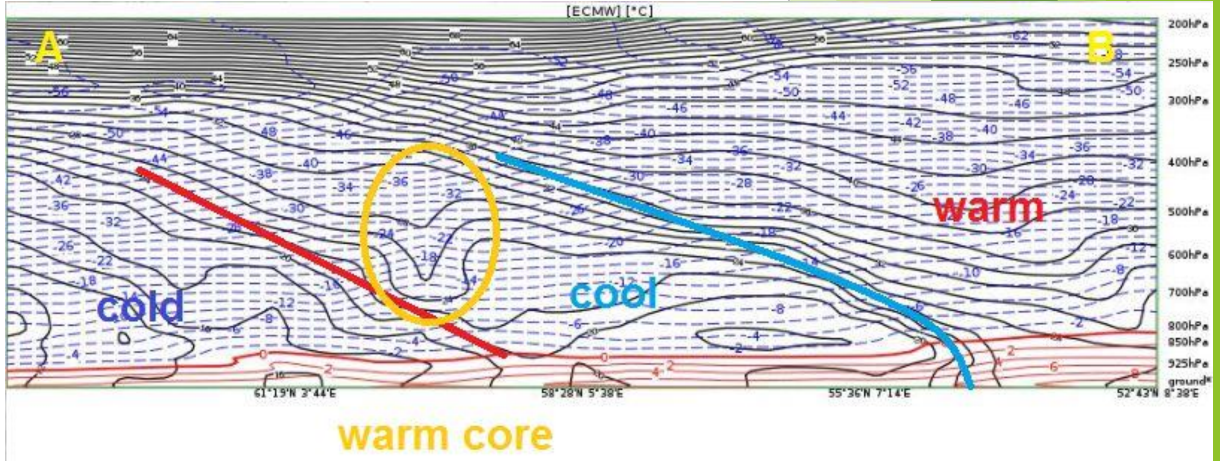




Cross-Section from map **Equivalent Potential Temperature** and **Temperature**
for 56°11'N 17°32'W - 71°40'N 9°38'W, valid 11.03.2019 21:00

Shapiro-Keyser cyclone



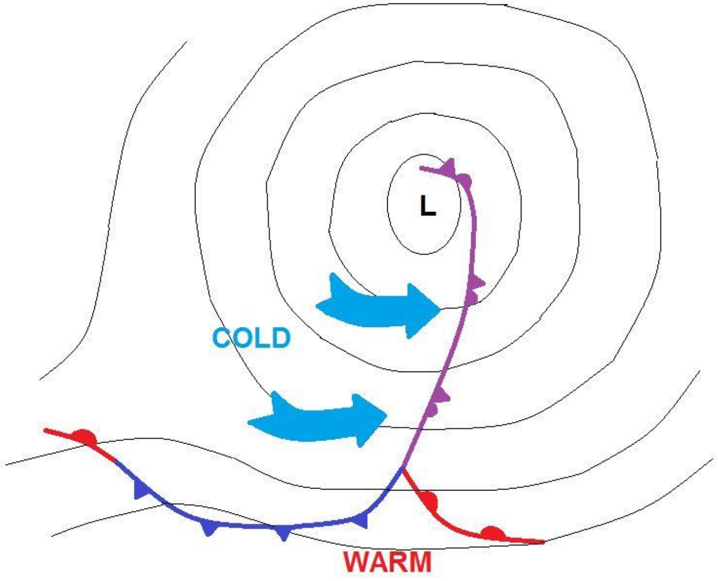


Cross-Section from map **Equivalent Potential Temperature** and **Temperature**
for 64°08'N 1°27'E - 52°43'N 8°38'E, valid 17.03.2019 03:00

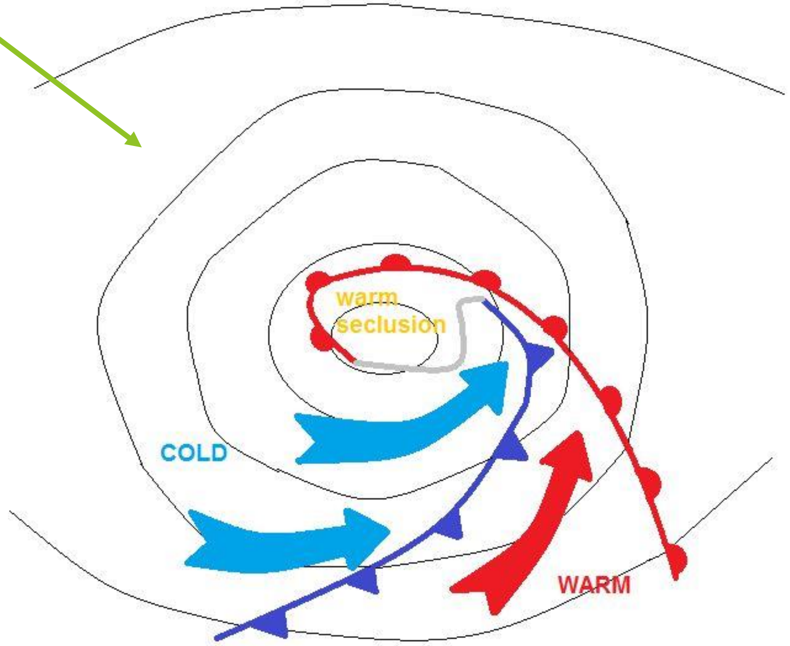
Dissipating stage: Converging development

The warm seclusion decouples from the warm sector while cold air from behind the cold front wraps around the warm core of the cyclone
The cold frontal gap closes and the cold front catches-up the warm front

Norwegian cyclone

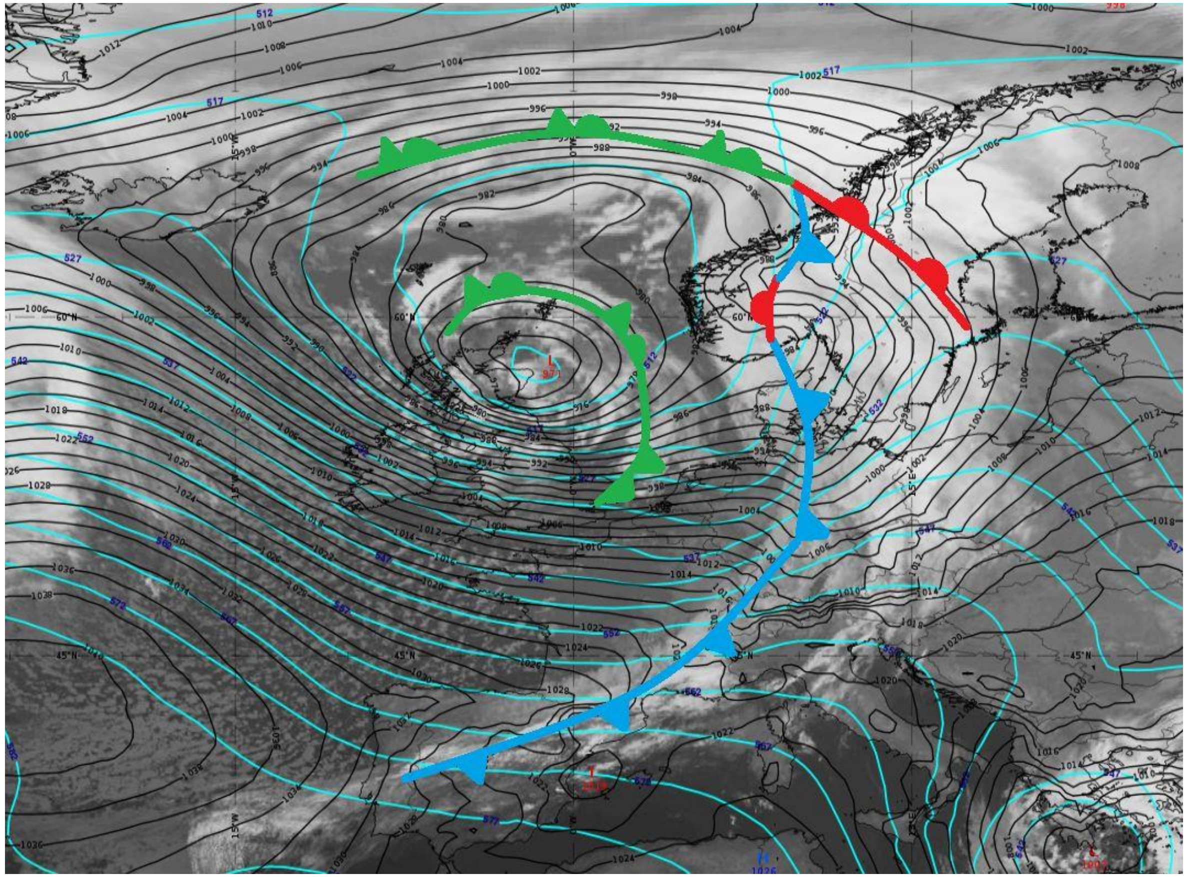


Shapiro-Keyser cyclone

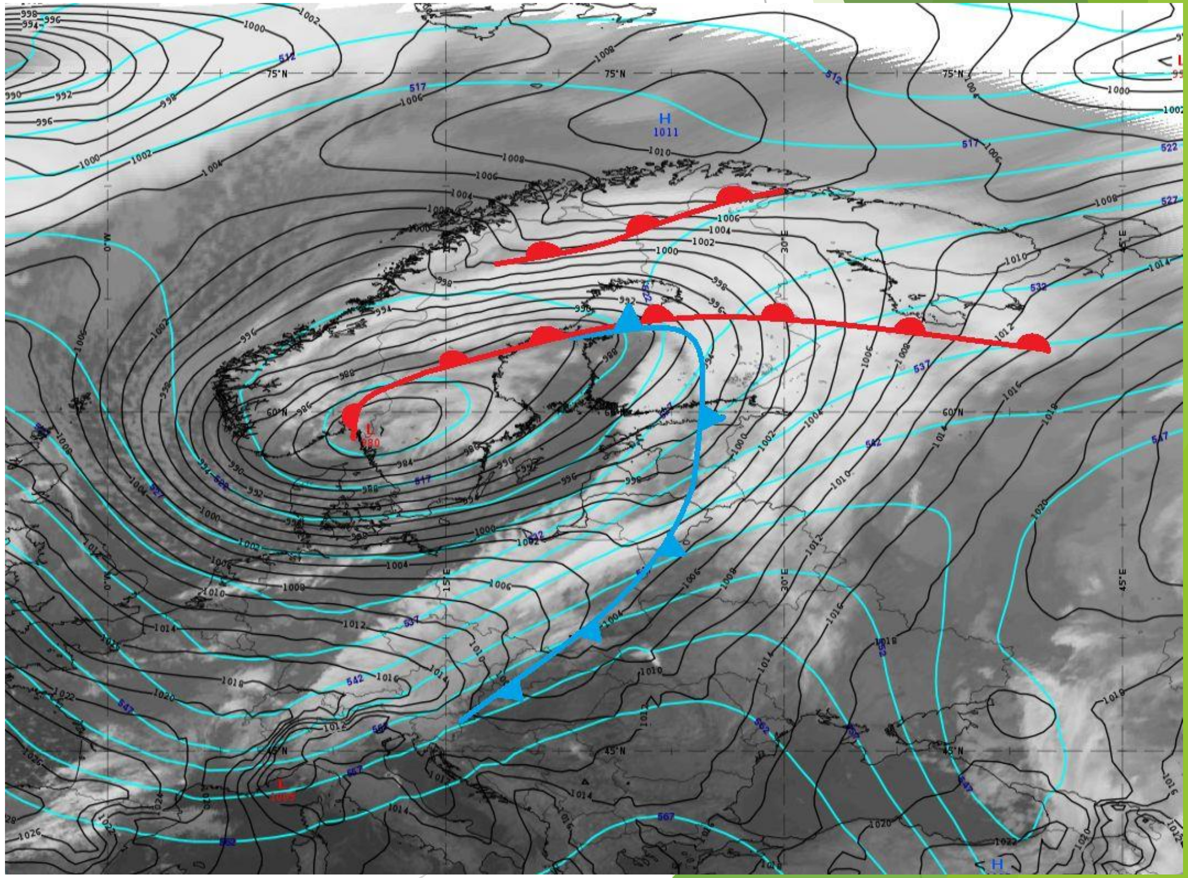


Dissipating stage: Converging development

Aging Shapiro-Keyser cyclones show physical processes typical for Norwegian cyclones, like the merging of the warm and the cold front to form an occlusion.



Norwegian cyclone

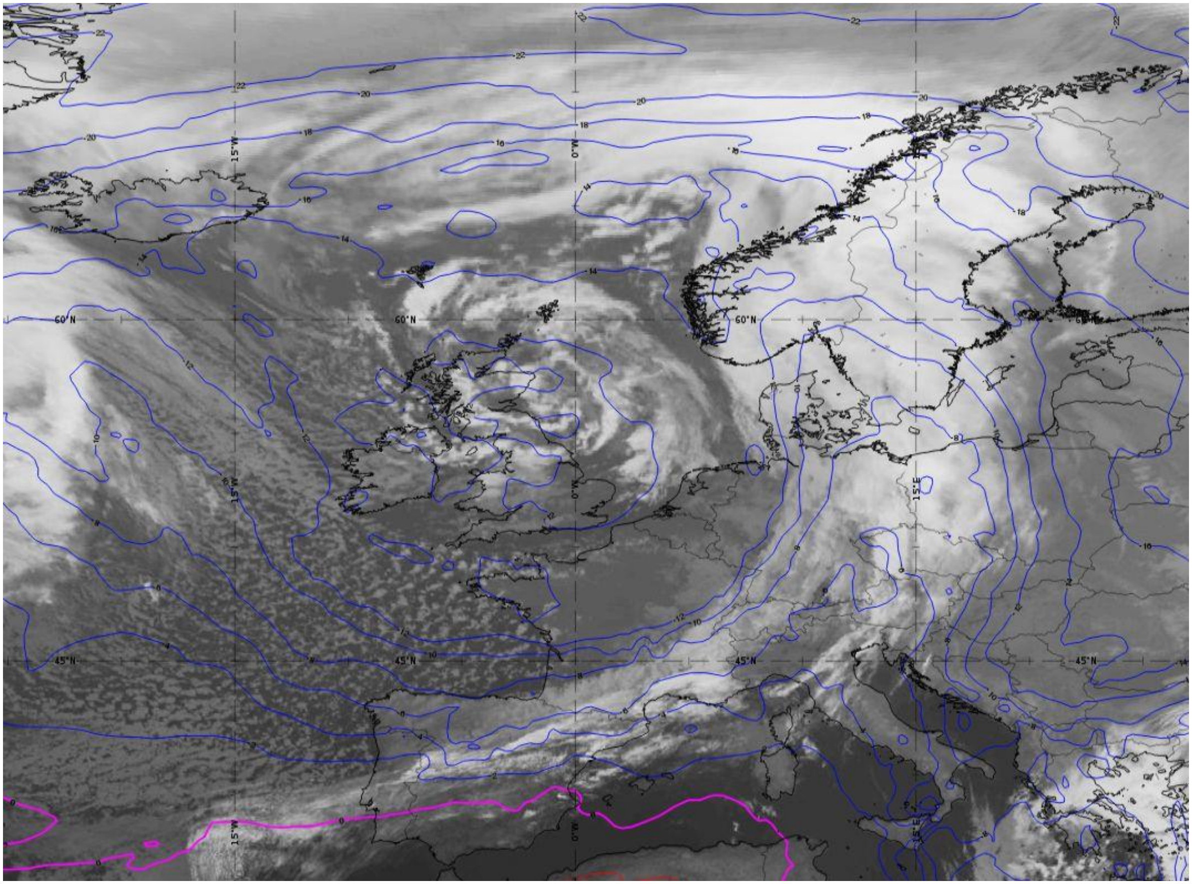


Shapiro-Keyser cyclone

Dissipating stage: Converging development

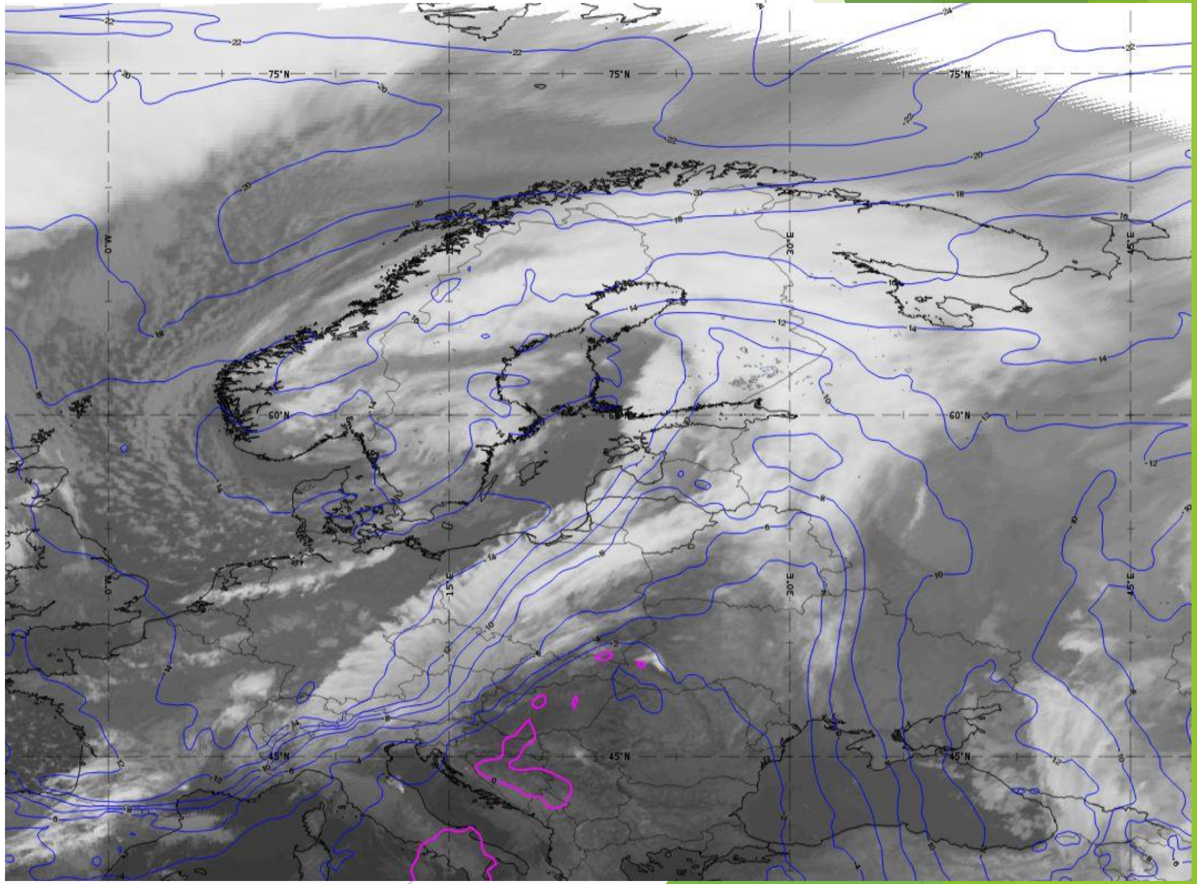
- Warm air in the occlusion cloud band mixes continuously with surrounding cold air

Norwegian cyclone



- Secluded warm air mixes continuously with surrounding cold air

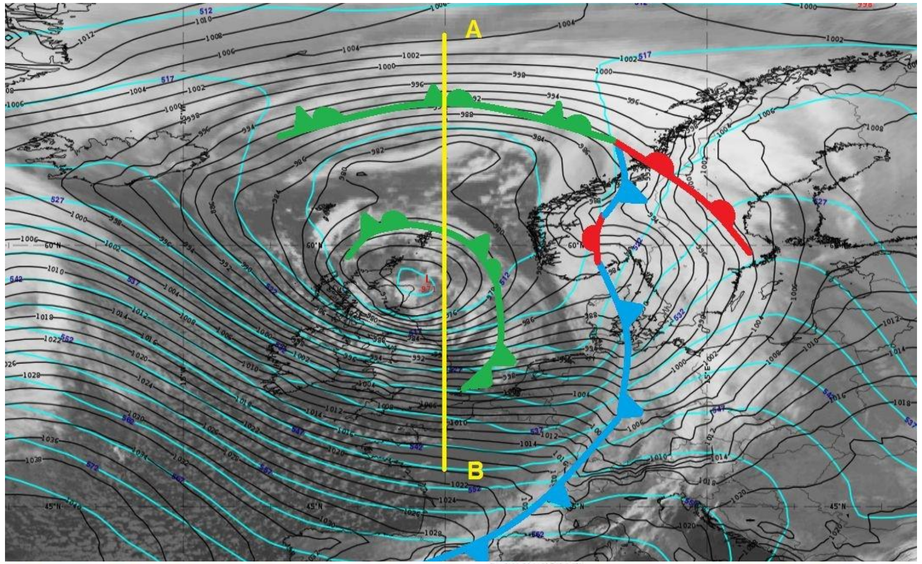
Shapiro-Keyser cyclone

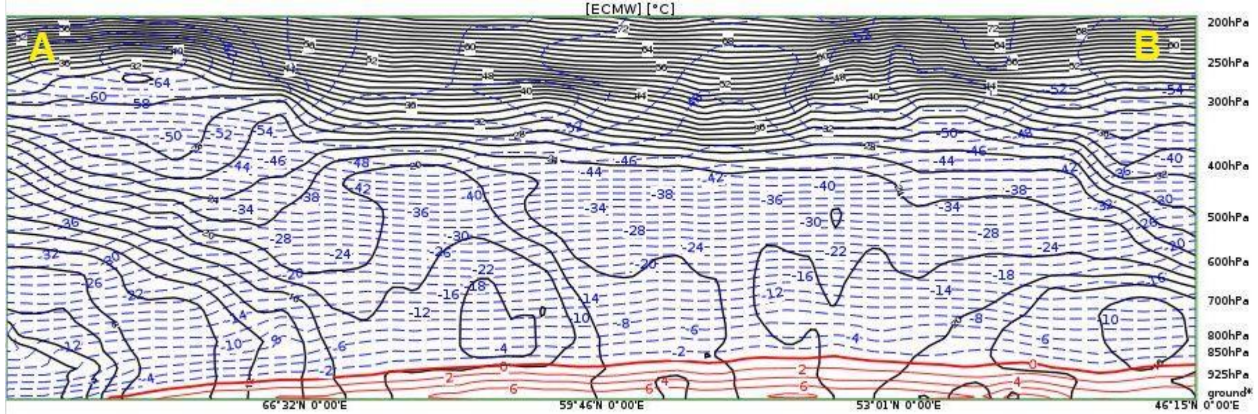


Dissipating stage: Converging development

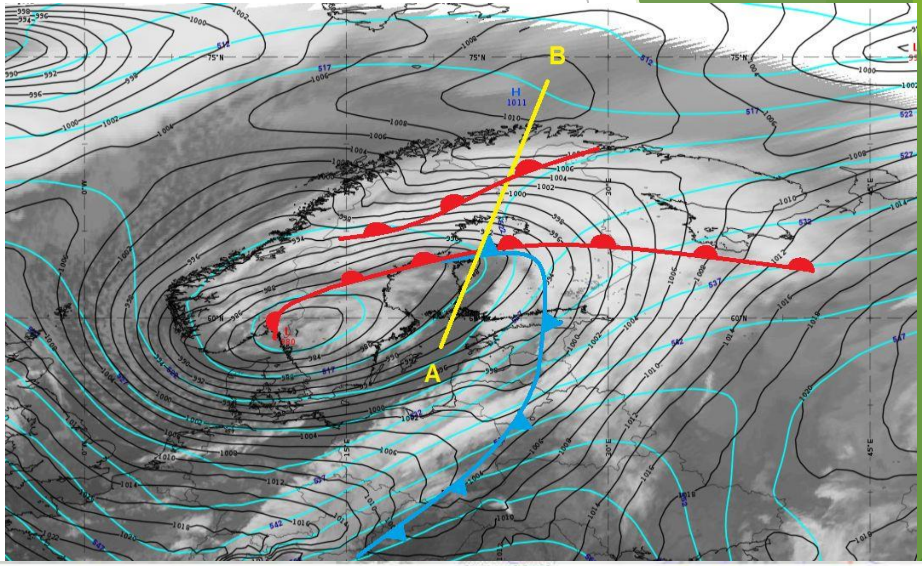
Norwegian cyclone

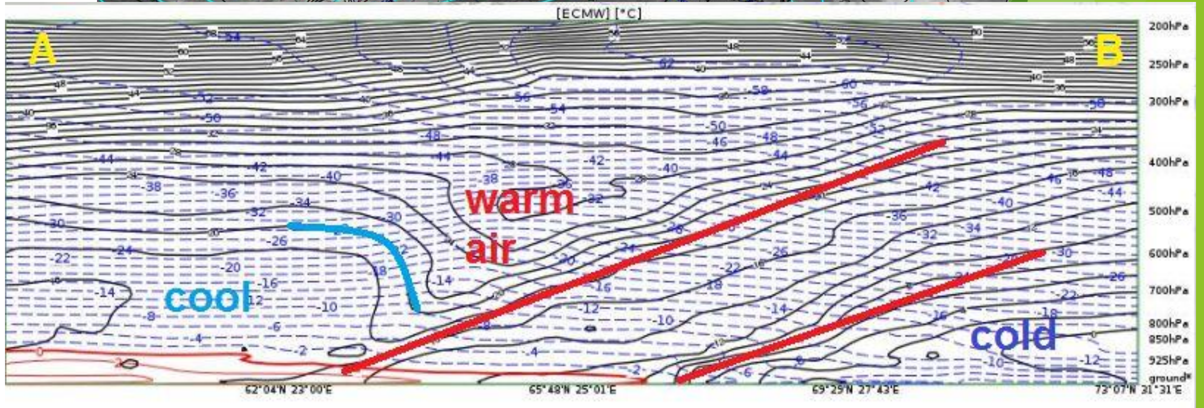
Shapiro-Keyser cyclone





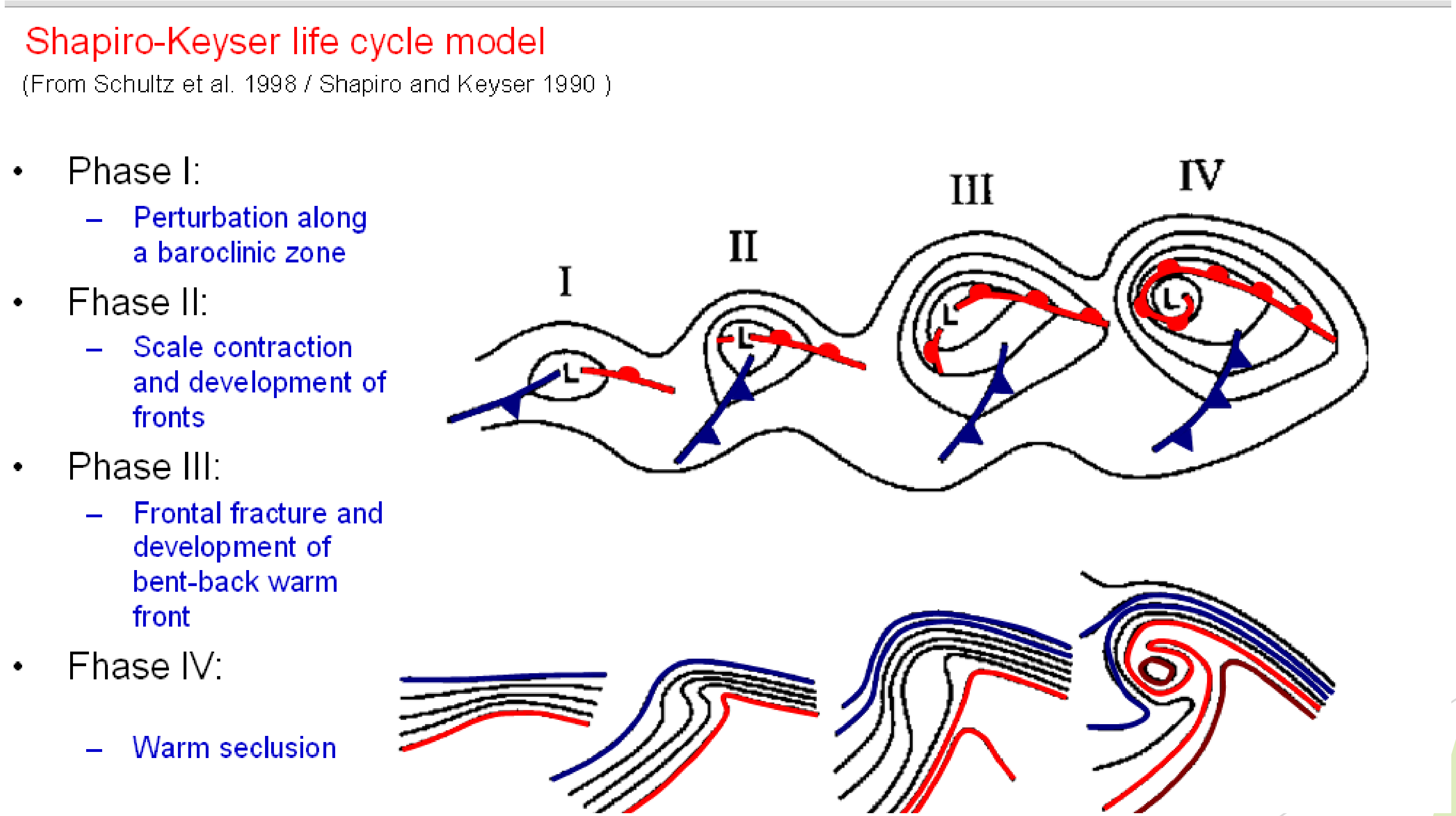
Cross-Section from map **Equivalent Potential Temperature** and **Temperature**
for 73°17'N 0°00'E - 46°15'N 0°00'E, valid 13.03.2019 00:00





Cross-Section from map **Equivalent Potential Temperature** and **Temperature**
for 58°19'N 21°25'E - 73°07'N 31°31'E, valid 18.03.2019 00:00

The Shapiro-Keyser cyclone model



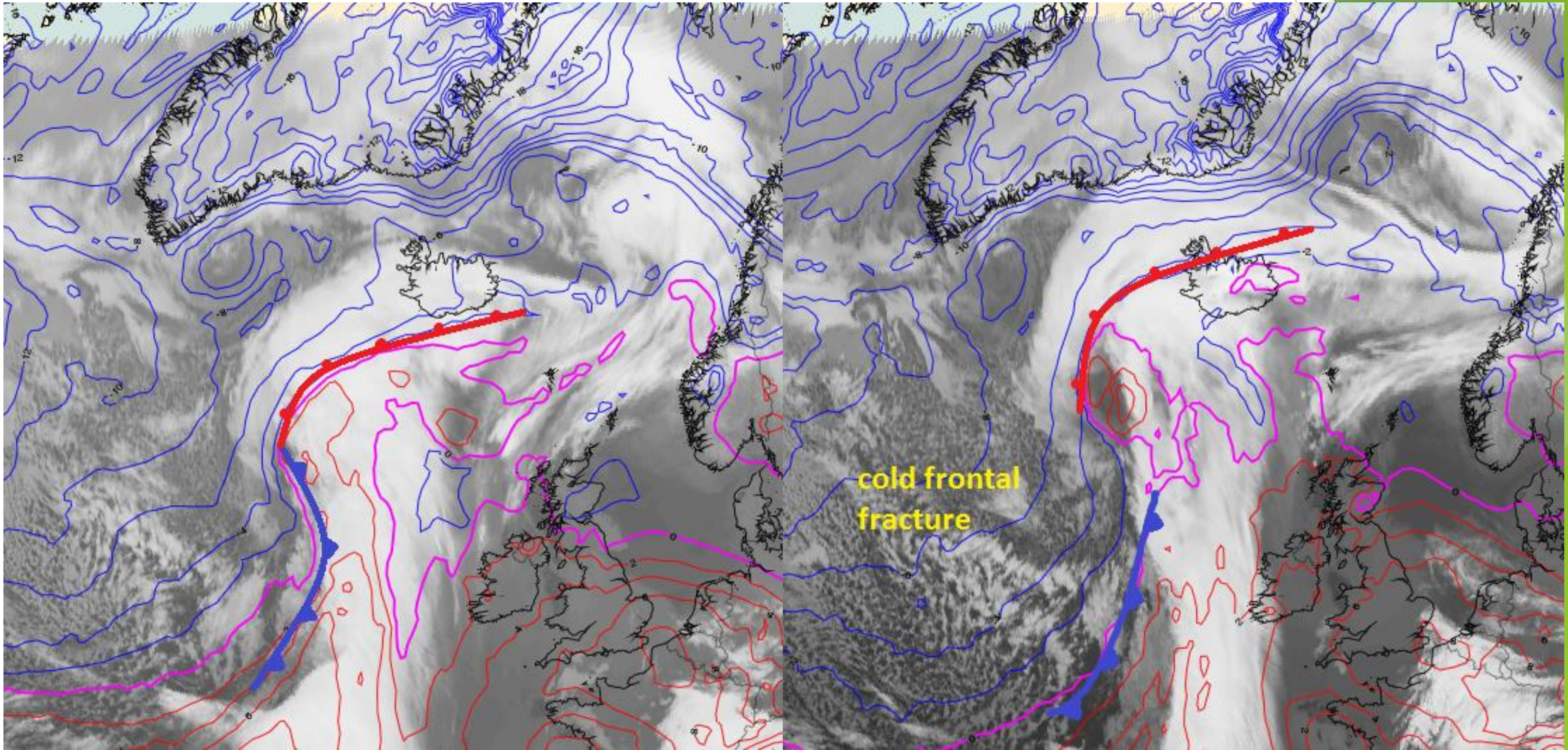
Shapiro-Keyser life cycle model

(From Schultz et al. 1998 / Shapiro and Keyser 1990)

- Phase I:
  - Perturbation along a baroclinic zone
- Phase II:
  - Scale contraction and development of fronts
- Phase III:
  - Frontal fracture and development of bent-back warm front
- Phase IV:
  - Warm seclusion

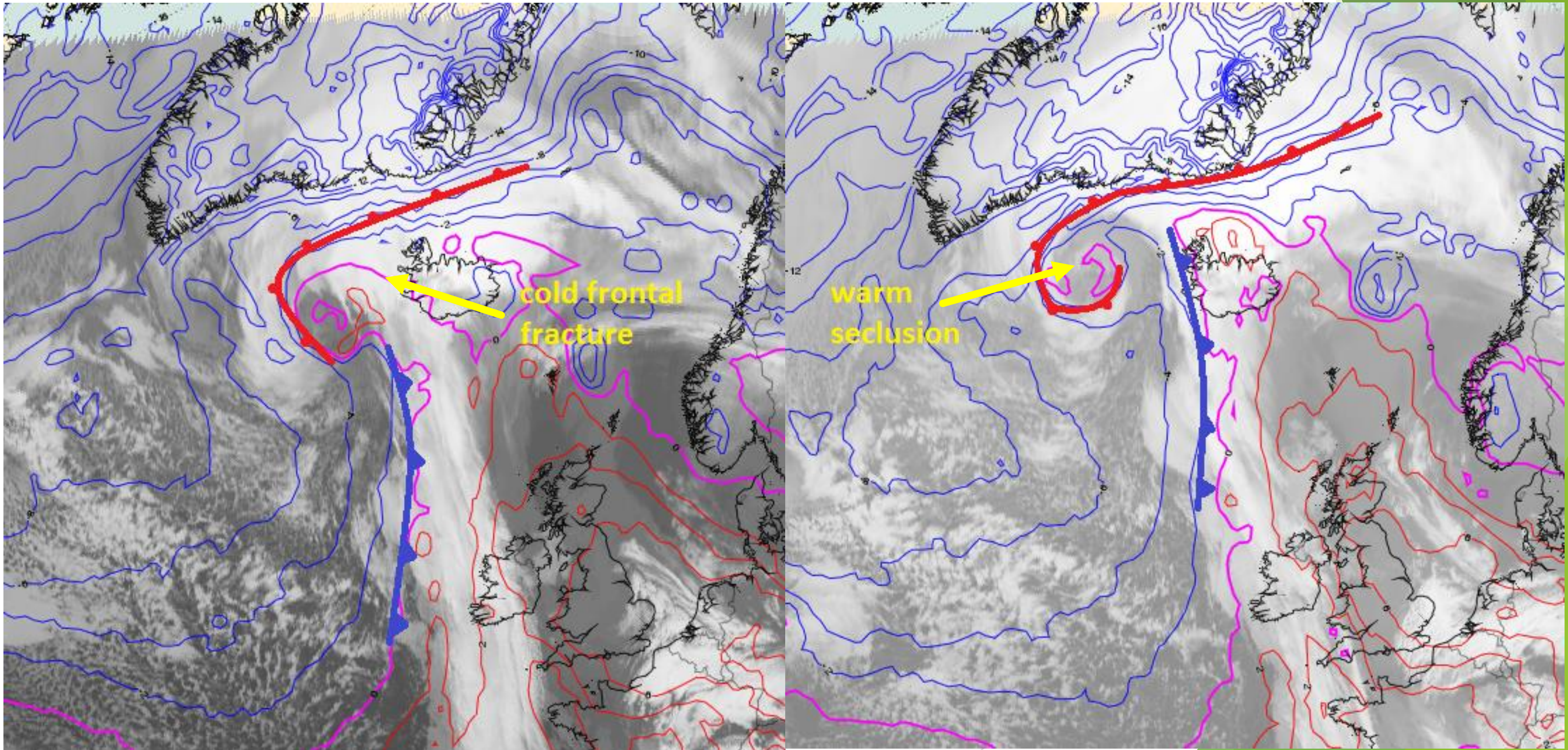
Shapiro-Keyser cyclone

Temperature at 850 hPa on 8 and 9 January 2018 (18:00 and 00.00 UTC)



Shapiro-Keyser cyclone

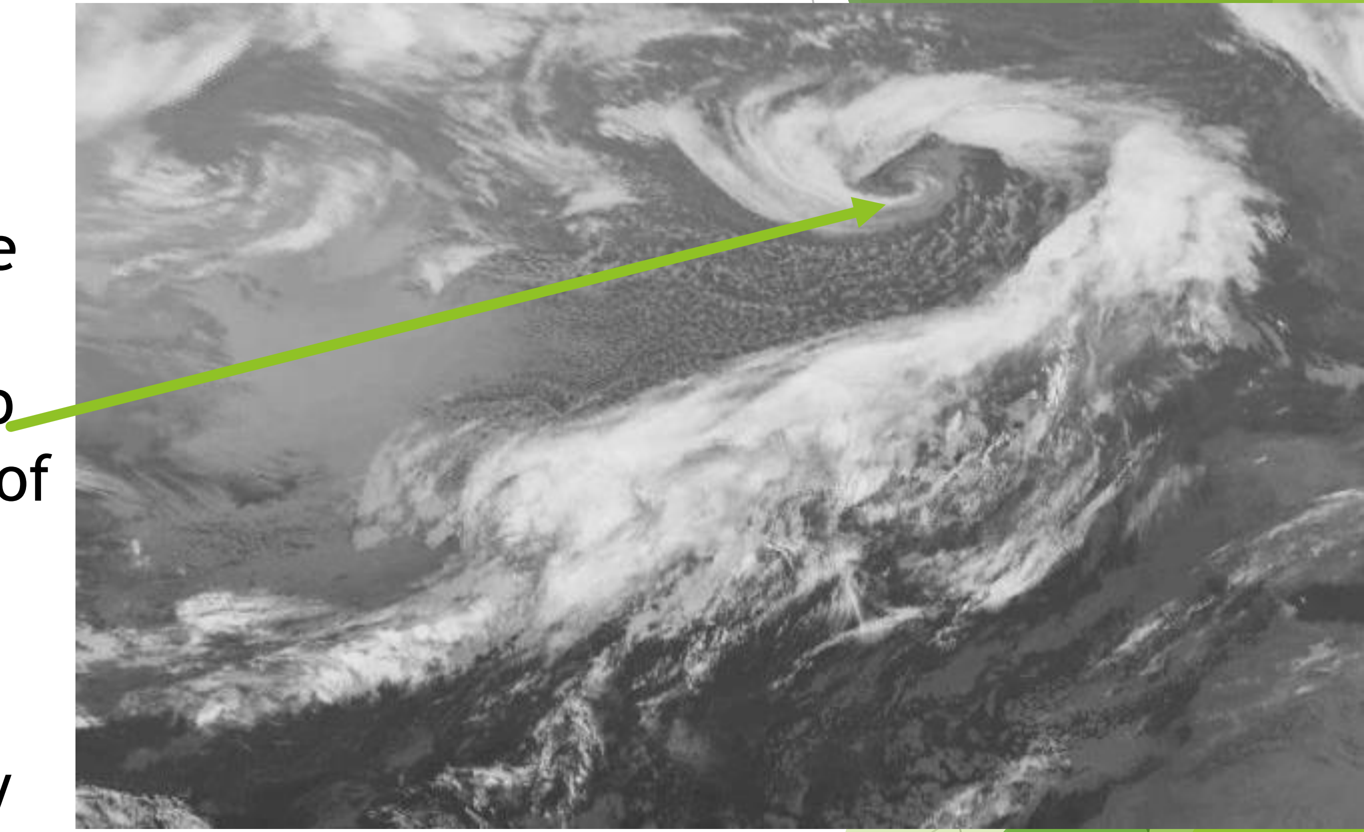
Temperature at 850 hPa on 9 January 2018 (06:00 and 12.00 UTC)

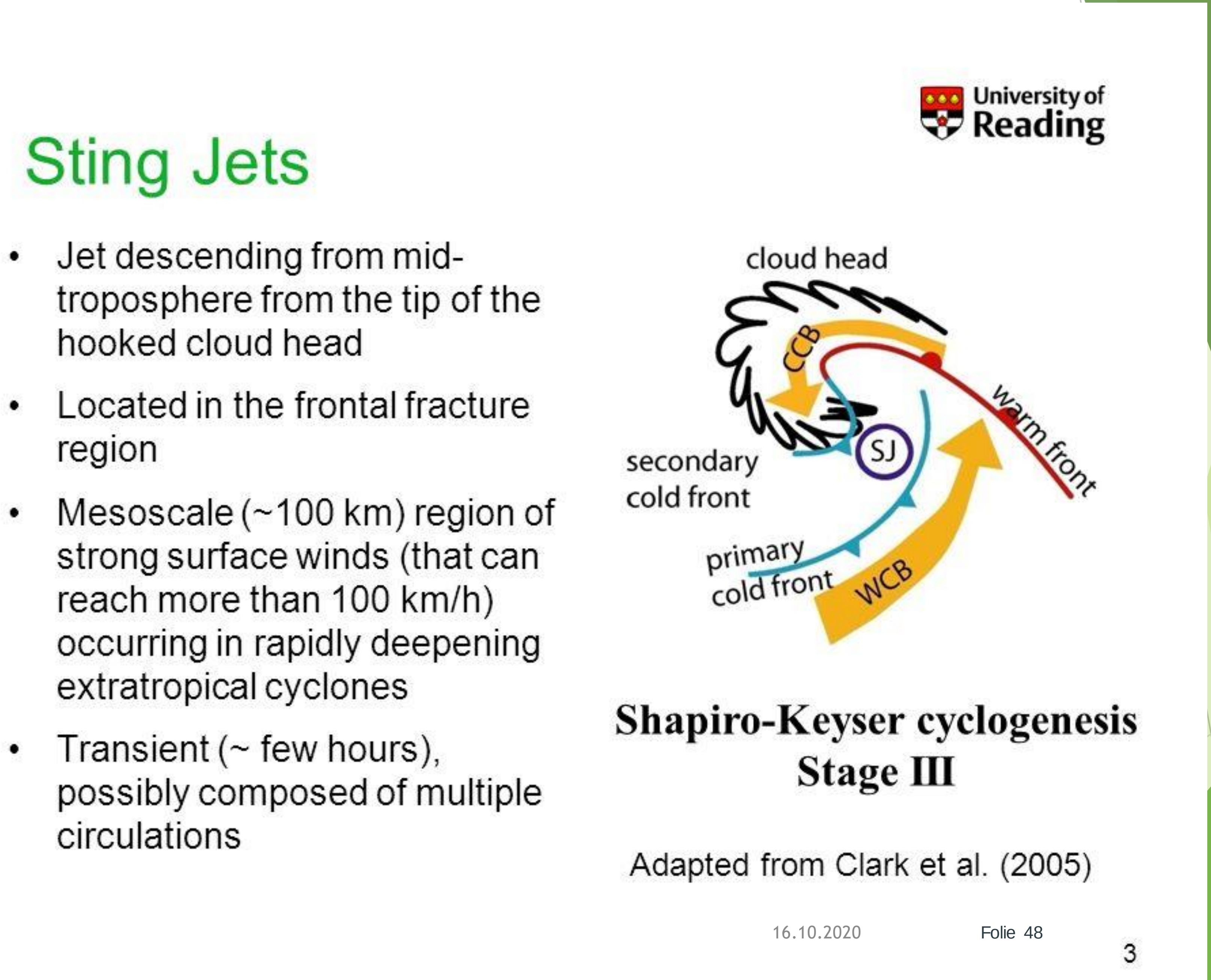


Remember:
It‘s wrap-up not catch-up

Sting Jets

- SJ are strong downdrafts from mid-tropospheric levels (~700 hPa) to the ground.
- High wind speeds at the southern tip of the occlusion cloud band (not all of them are SJ).
- SJ are not exclusively observed with Shapiro-Keyser cyclones.
- Sting jets have a short life time (few hours) and are of limited spatial extent.





University of Reading

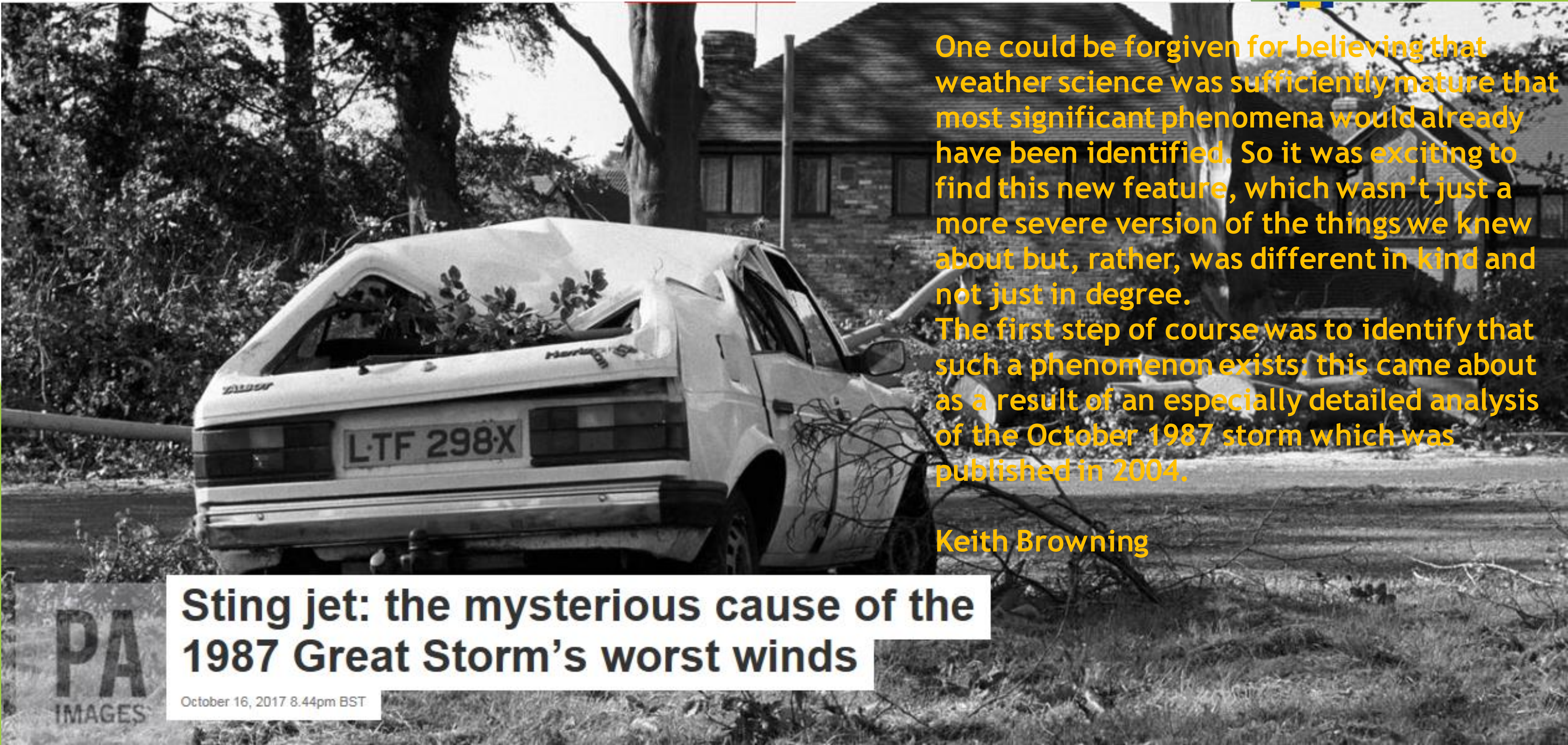
Sting Jets

- Jet descending from mid-troposphere from the tip of the hooked cloud head
- Located in the frontal fracture region
- Mesoscale (~100 km) region of strong surface winds (that can reach more than 100 km/h) occurring in rapidly deepening extratropical cyclones
- Transient (~ few hours), possibly composed of multiple circulations

Shapiro-Keyser cyclogenesis Stage III

Adapted from Clark et al. (2005)

Sting Jets



Sting jet: the mysterious cause of the 1987 Great Storm's worst winds

October 16, 2017 8.44pm BST

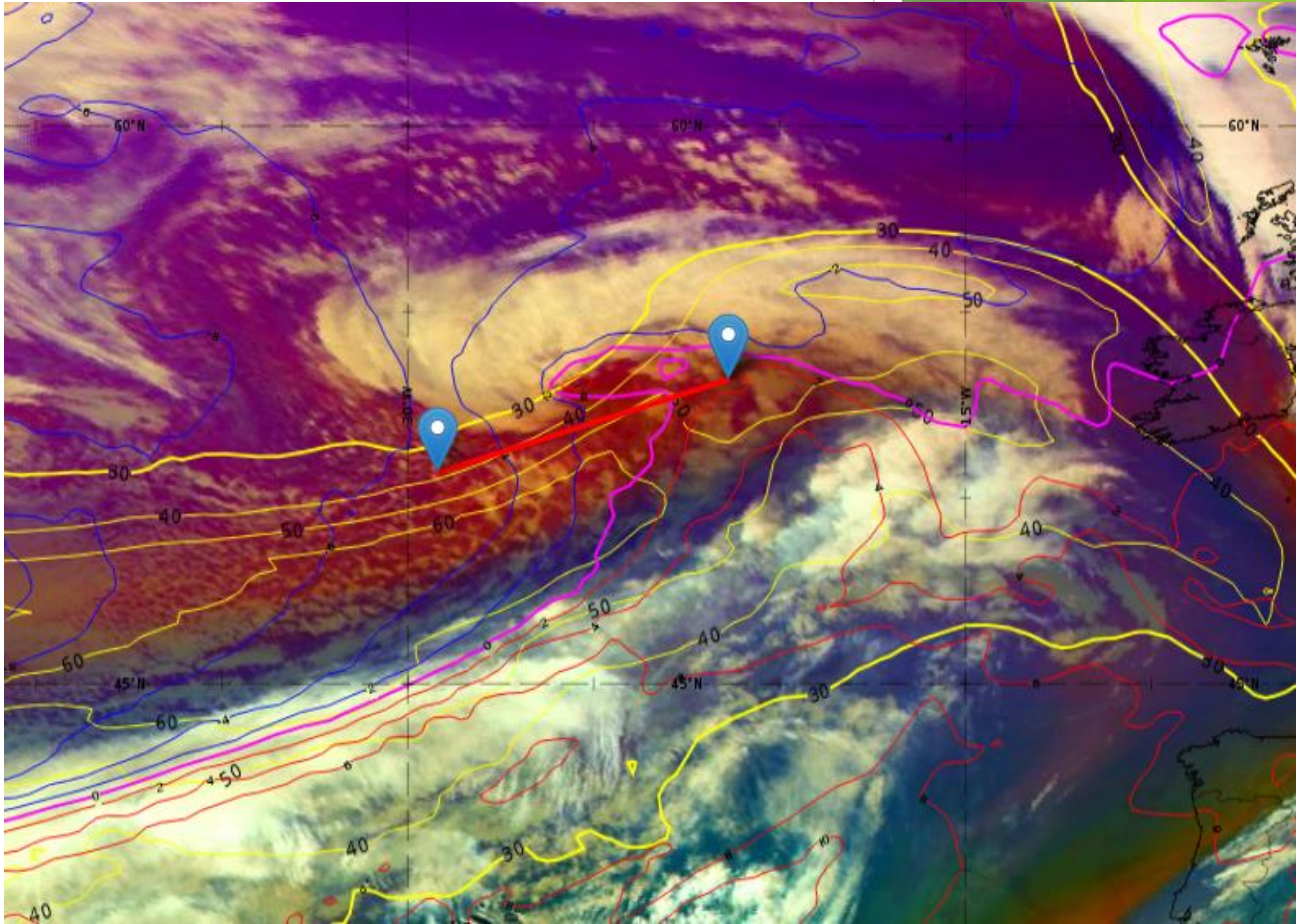
One could be forgiven for believing that weather science was sufficiently mature that most significant phenomena would already have been identified. So it was exciting to find this new feature, which wasn't just a more severe version of the things we knew about but, rather, was different in kind and not just in degree.
The first step of course was to identify that such a phenomenon exists: this came about as a result of an especially detailed analysis of the October 1987 storm which was published in 2004.

Keith Browning

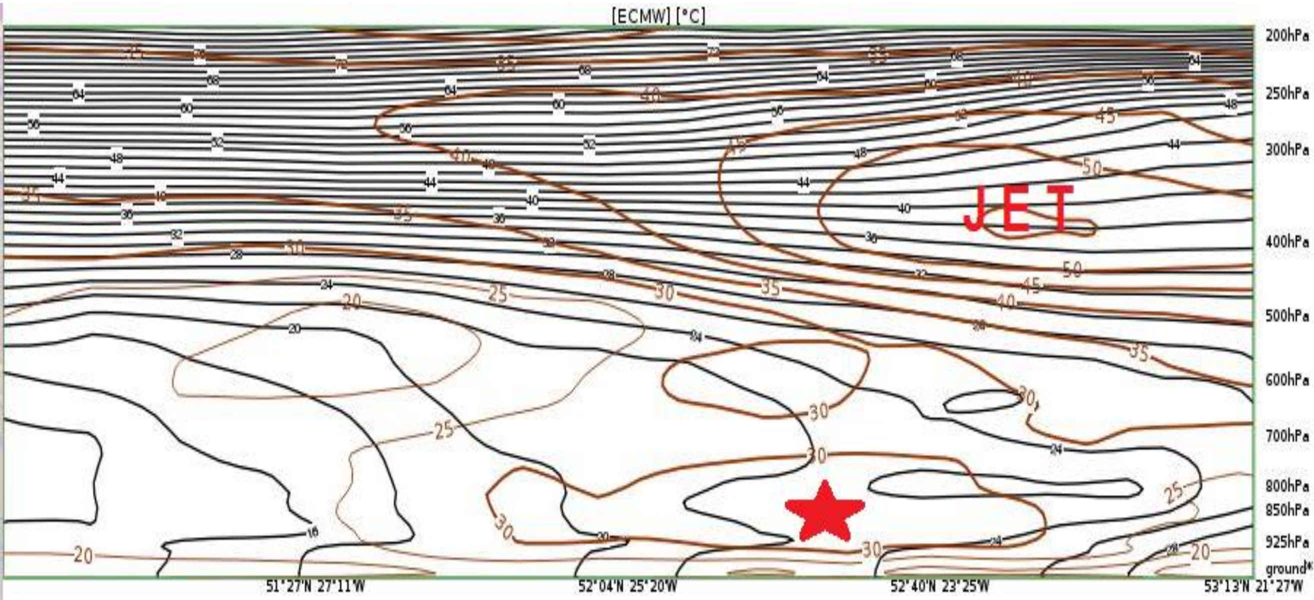
Sting Jets

2 March 2019; 00:00 UTC – Airmass RGB

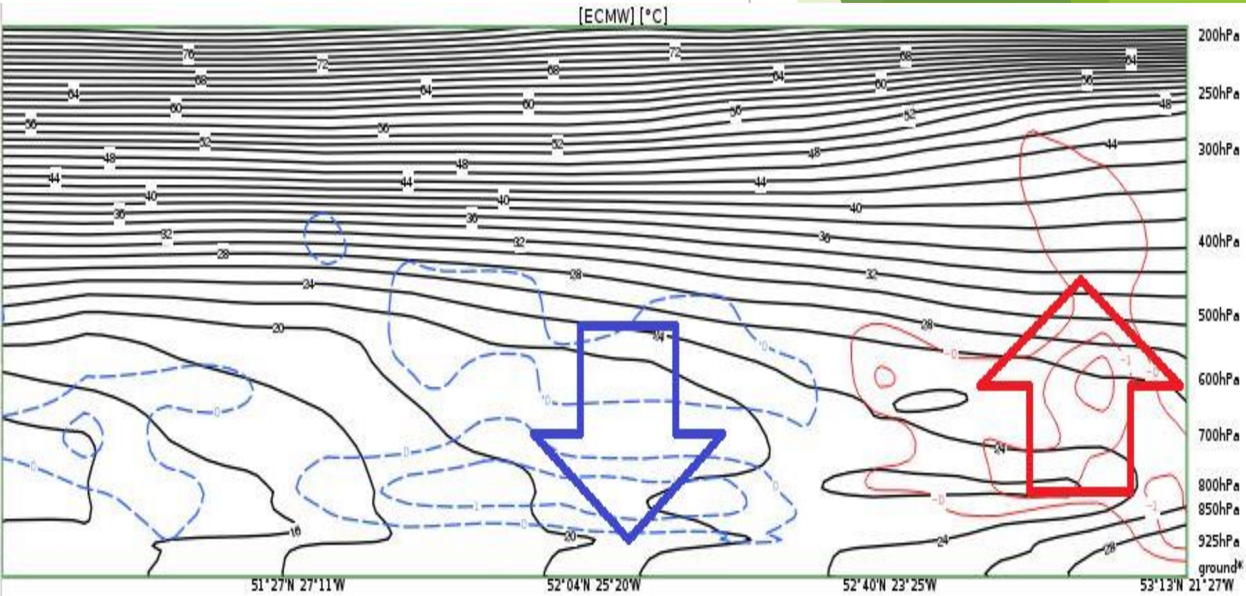
Isotachs 300 hPa (yellow)
Temperature 850 hPa (red/blue)



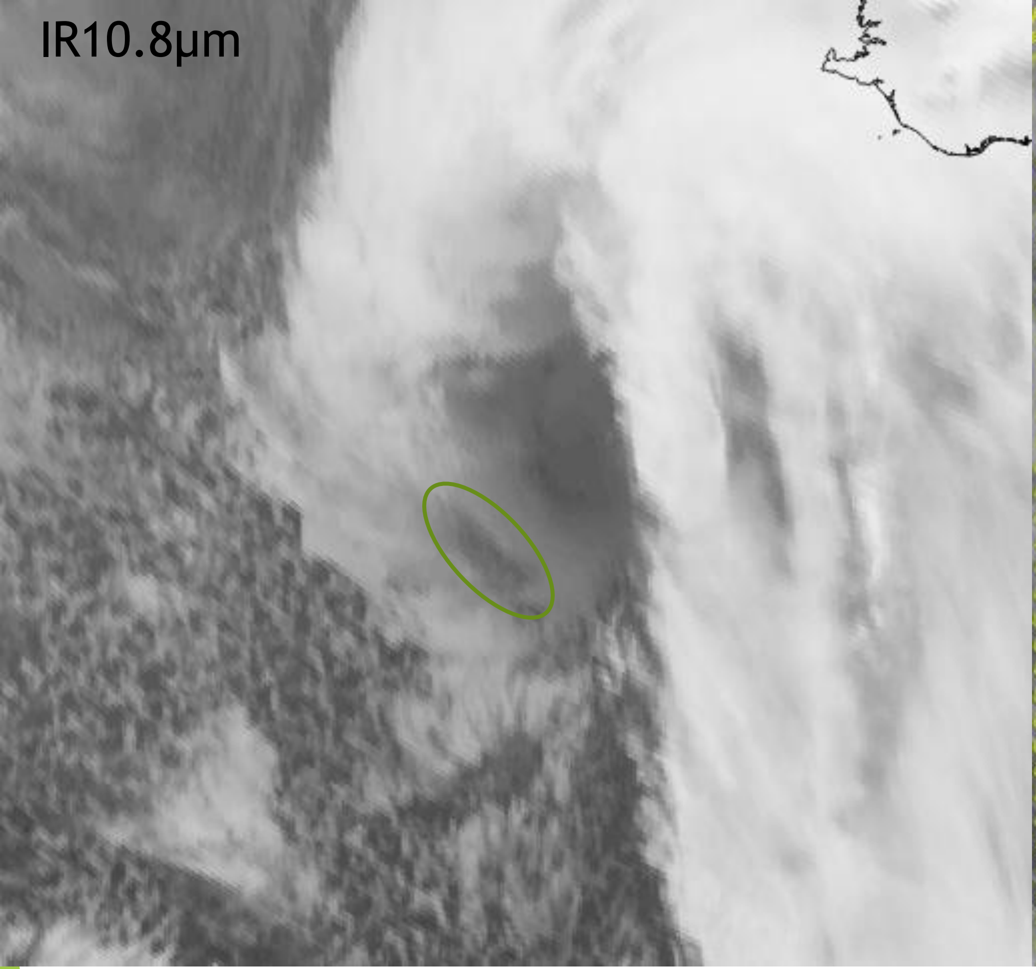
Sting Jets - horizontal cross section

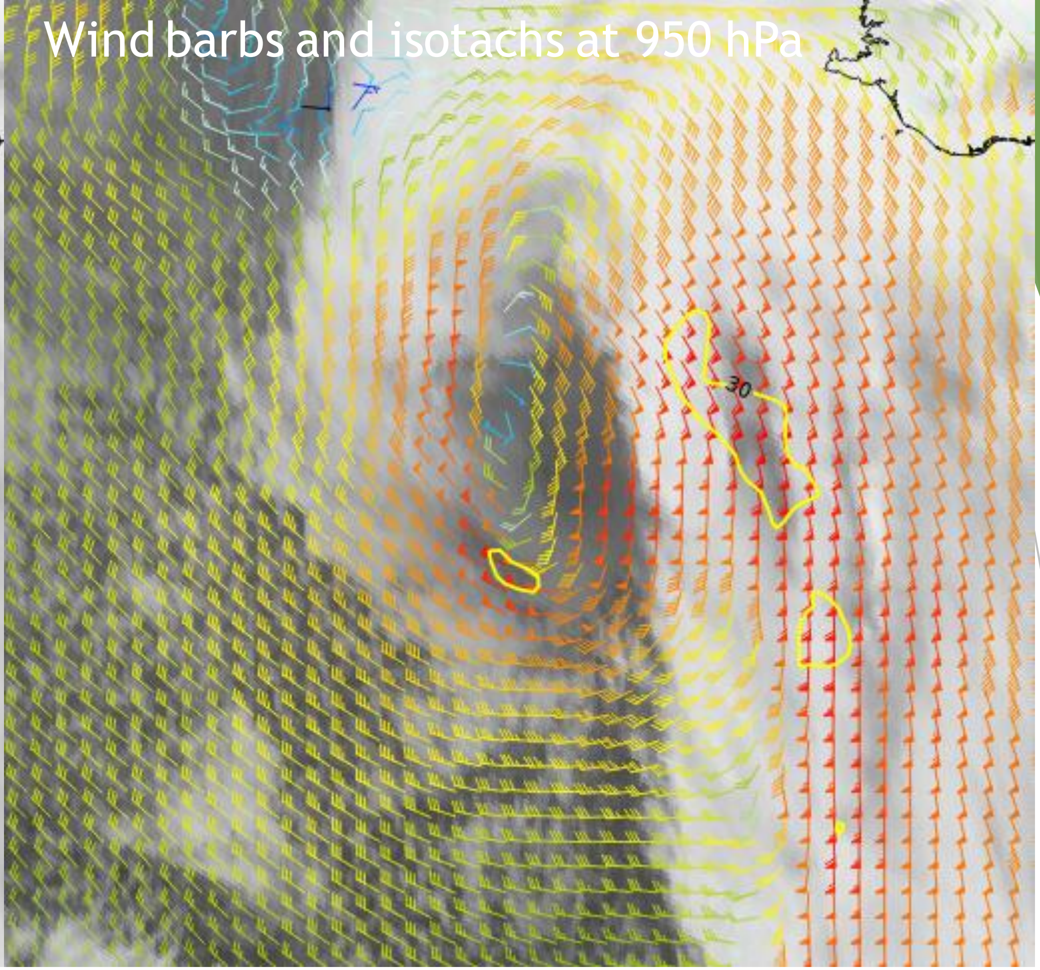


Cross-Section from map **Equivalent Potential Temperature** and **Isotachs**
for 50°48'N 29°00'W - 53°13'N 21°27'W, valid 02.03.2019 00:00



Cross-Section from map **Equivalent Potential Temperature** and **Omega**
for 50°48'N 29°00'W - 53°13'N 21°27'W, valid 02.03.2019 00:00


IR10.8µm

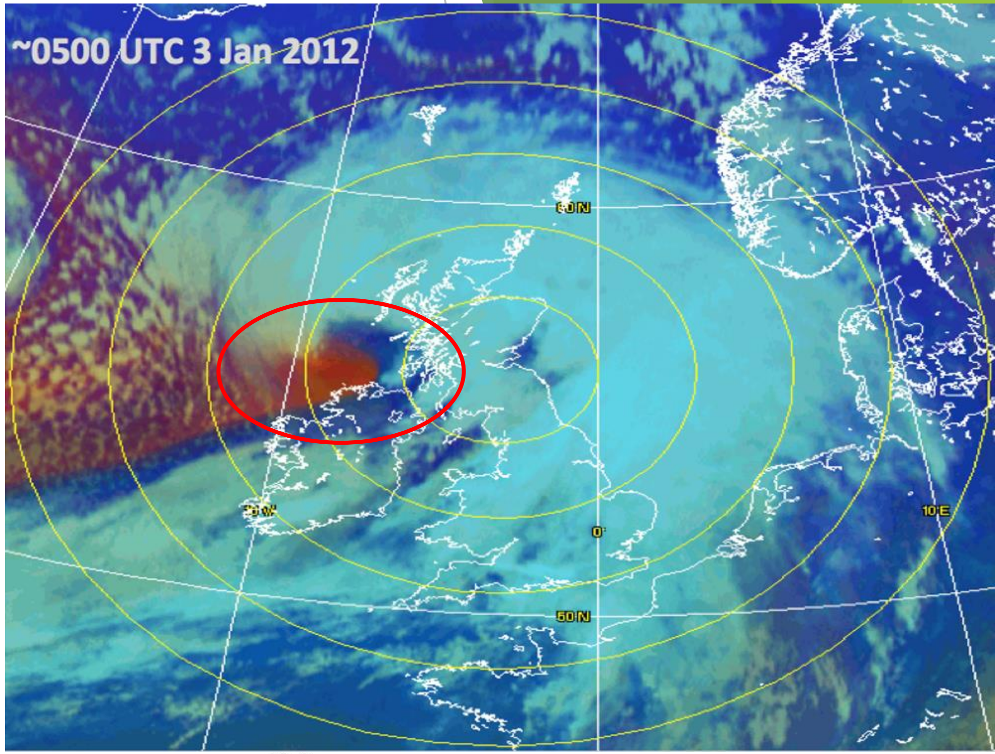

Wind barbs and isotachs at 950 hPa

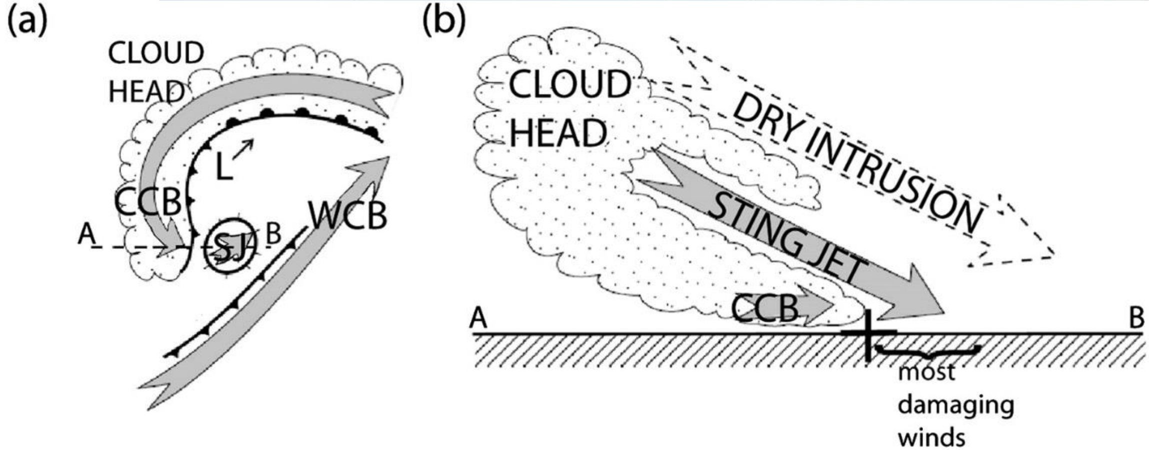
9 January 2018 – 00:00 UTC:

A small cloud free area can be see an the southern tip of the cold conveyor belt. This area corresponds well with a wind maximum at surface level.

Sting Jets – contributing factors

- Mixing of the dry intrusion with the cold conveyor belt (middle and lower tropospheric layers).
- Evaporation of the cloud droplets in the dry air and subsequent cooling reduces the static stability.
- Reduced static stability enhances the vertical momentum transport.
- Resulting small-scale instability gives rise to the observed fingers of cloud (i.e. sloping layers of ascending and descending air).
- SJ can be created by air descending into a region of stronger pressure gradient as it travels around the cyclone center.





… and after the break we will have a look at the **conveyor belt theory**