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The Extratropical Transition of Hurricane Debby (1982) and its re-development into an Intense Windstorm Mauri over Finland

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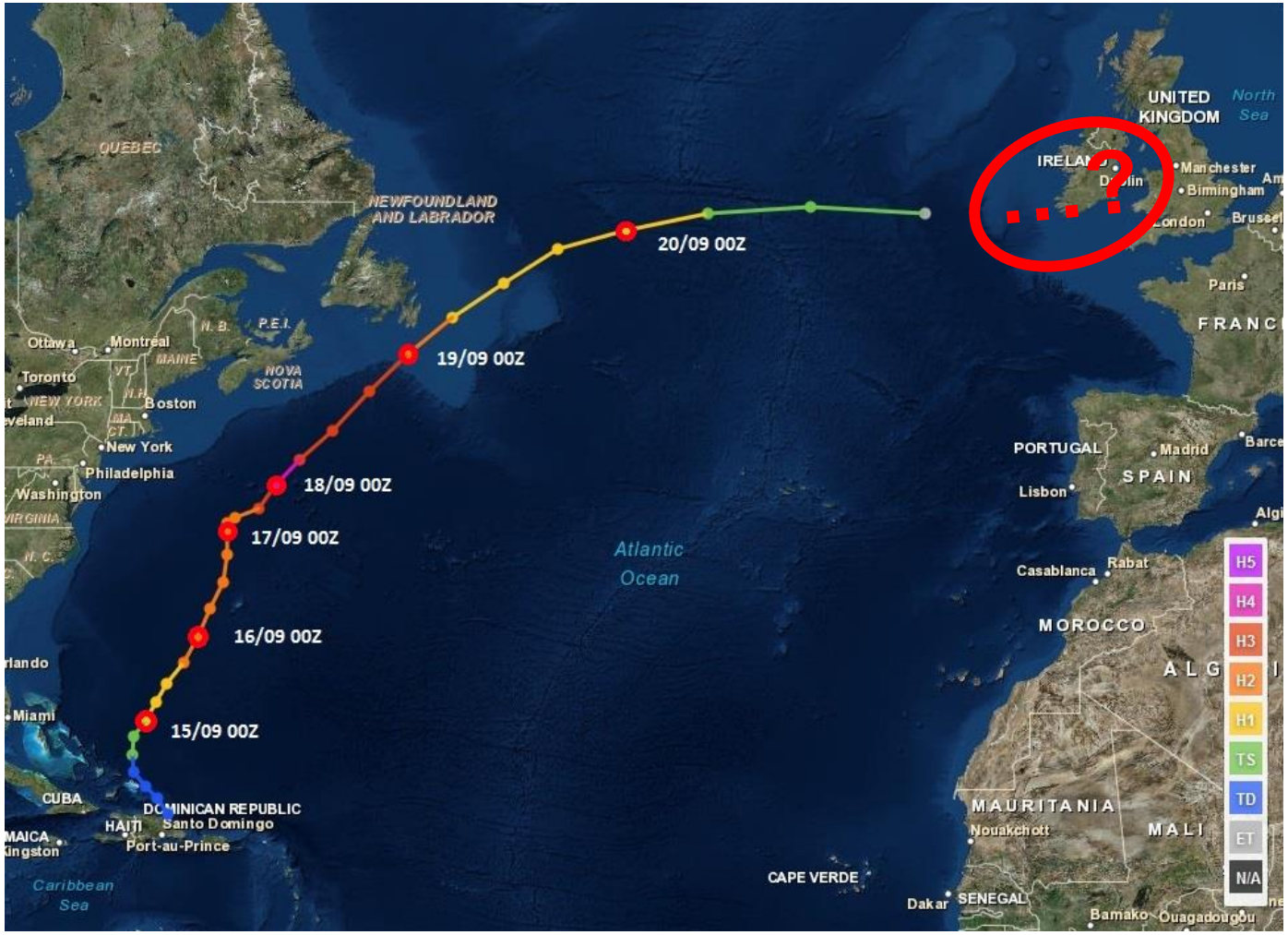
Why Debby / Mauri?

- One of the **most intense windstorms** in Finland
  → 2 fatalities and 3 milj. m^3 of forest damage
- Probably the **only Finnish storm to originate from a hurricane**
  → Speculated at the time but never investigated before

Fallen trees in Lapland in Sep 1982.
Picture: YLE

Hurricane Debby (1982)

- **15 Sep**: category 1
- **18 Sep**: category 4
  → max. winds 58 m/s
  → min. pressure 950 hPa
- **19-20 Sep**: extratropical transition (ET)
- NHC tracks only the tropical part



Outline

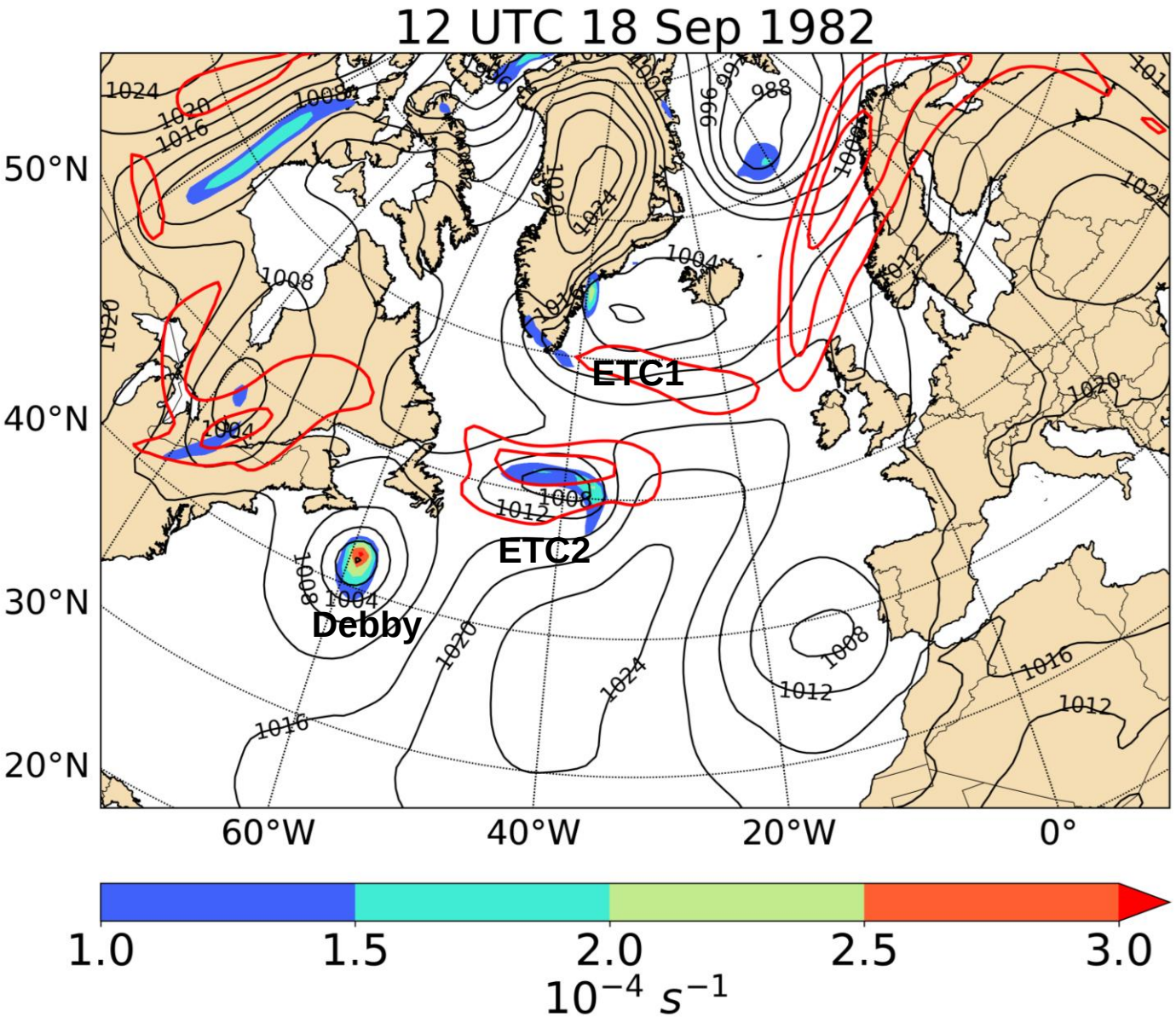
Synoptic overview

→ **ERA-Interim reanalysis** (*T255: ~ 80 km, 60 levels*)

Meso- and synoptic-scale dynamic evolution

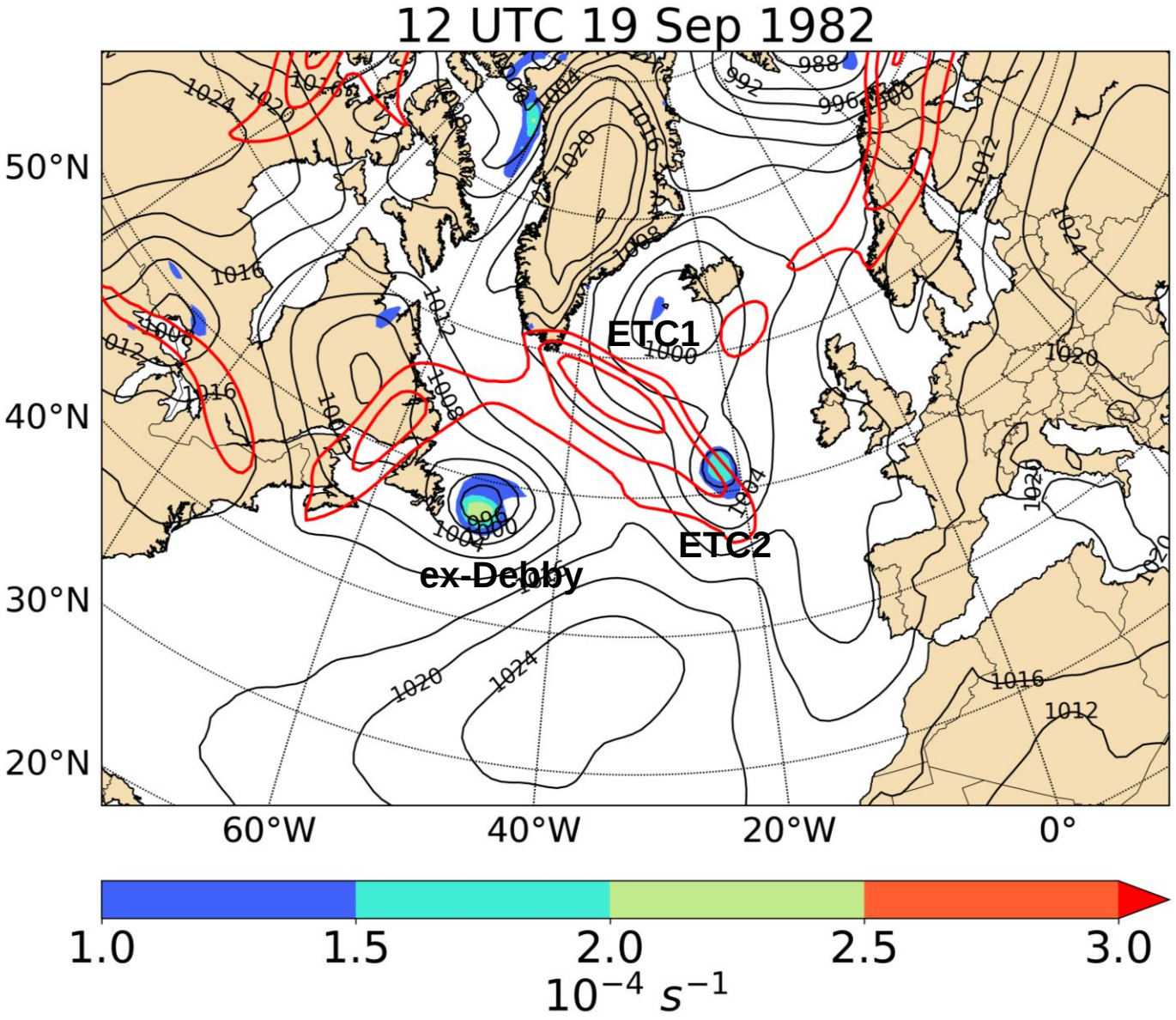
→ **OpenIFS simulations** (*T1279: ~ 16 km, 137 levels*)

1. Why did ex-Debby travel across the Atlantic?
2. Why did ex-Debby re-intensify over the UK?
3. What were the reasons for strong winds over Finland?



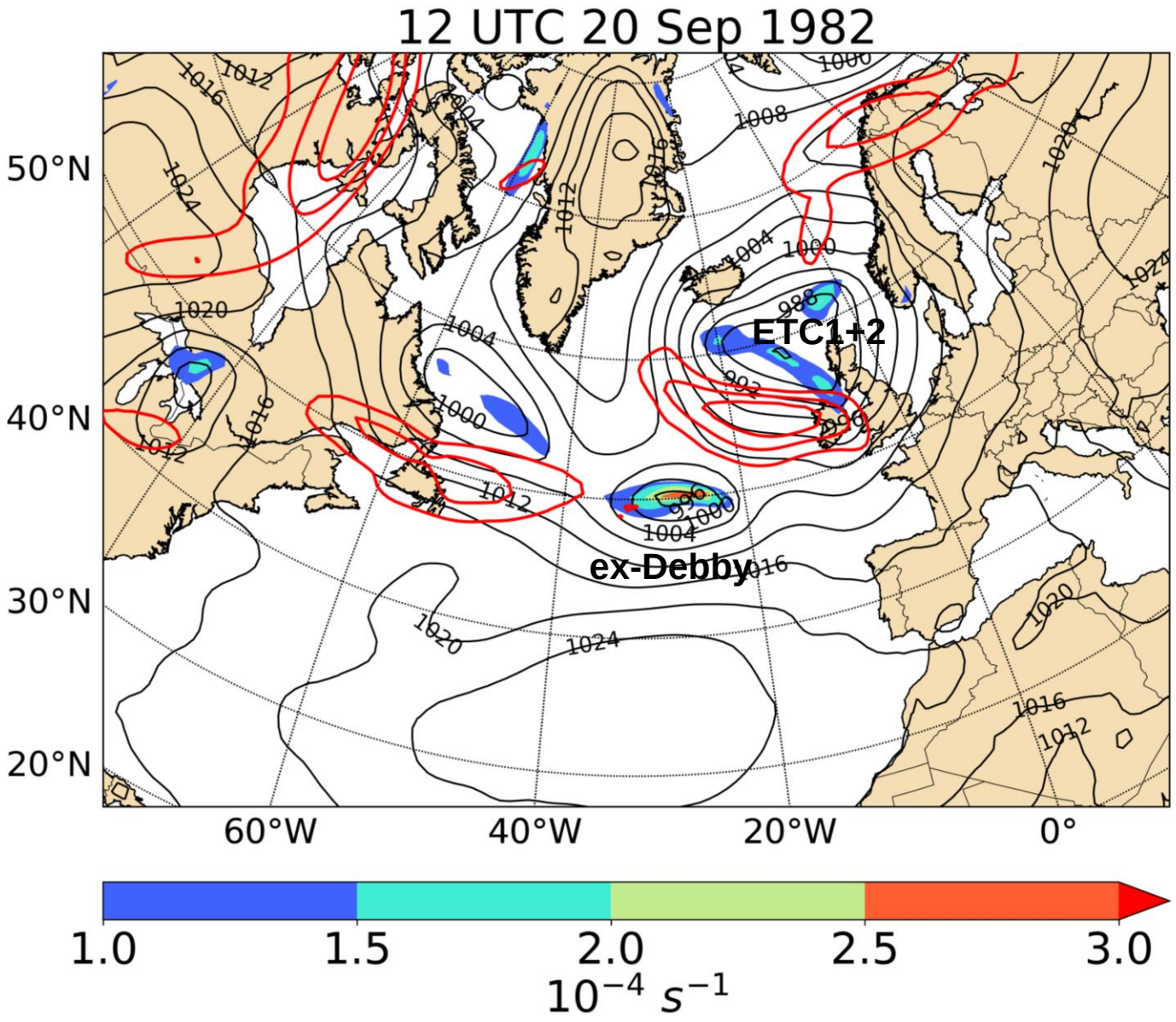
- Debby still a hurricane
- Two extratropical cyclones (ETC1 and ETC2) present
- Jet streaks over northern Europe and north-eastern Atlantic

850-hPa relative vorticity (colors),
mean sea level pressure (black contours),
300-hPa wind speed (red contours at 40,50,60 m/s)



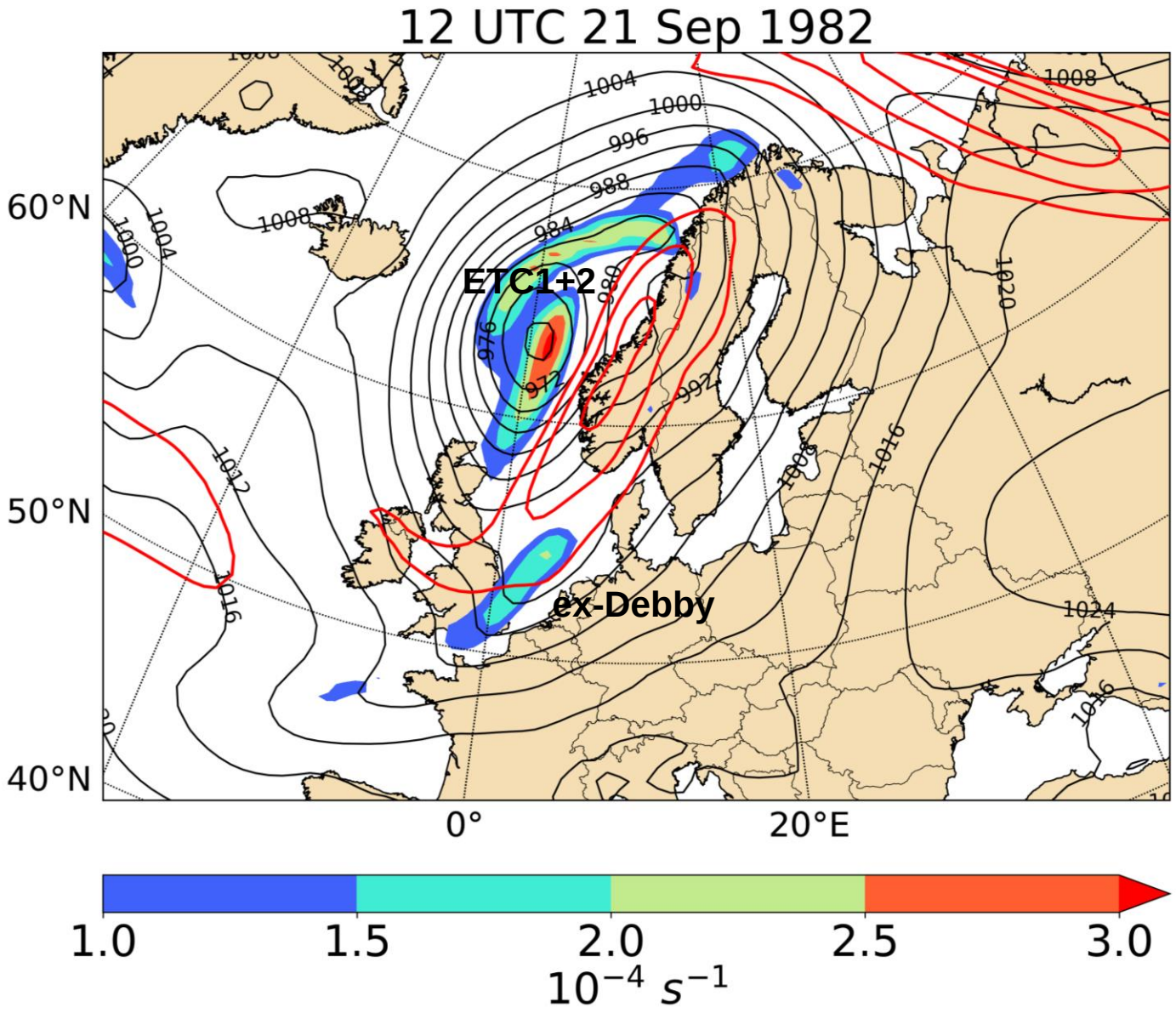
- Debby undergoes ET → ex-Debby
- ETC1 intensifies
- ETC2 reaches the left exit of the jet

850-hPa relative vorticity (colors),
mean sea level pressure (black contours),
300-hPa wind speed (red contours at 40,50,60 m/s)



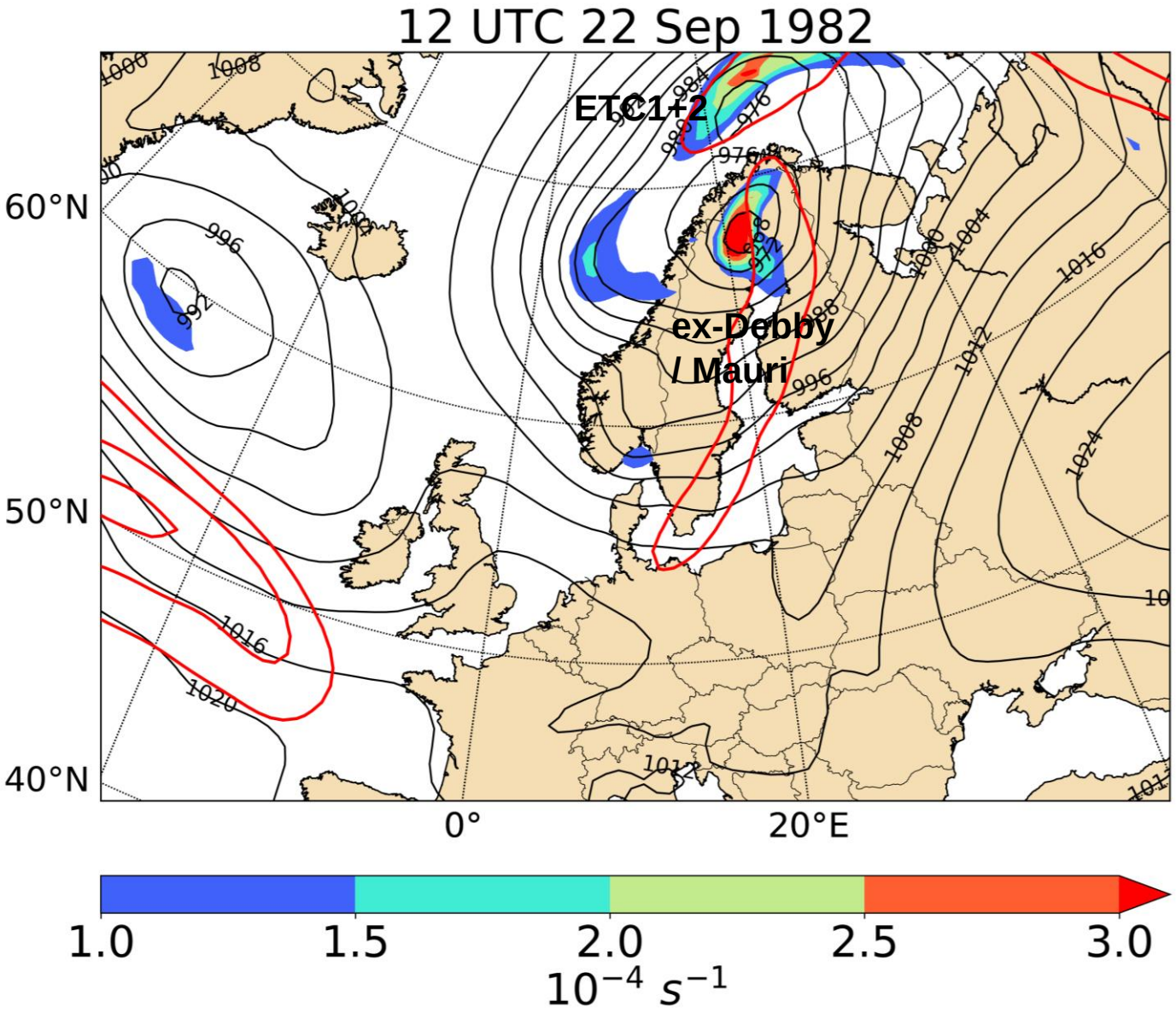
- Ex-Debby travels rapidly across the Atlantic
- ETC2 merged with ETC1 → large and intense low pressure system
- ETC1+2 stays in the left exit of the jet

850-hPa relative vorticity (colors),
mean sea level pressure (black contours),
300-hPa wind speed (red contours at 40,50,60 m/s)



- Ex-Debby resembles a frontal trough rather than a closed low
- Ex-Debby reaches right entrance of the jet
- ETC1+2 intensifies
- T-bone structure: bent-back warm front and cold front

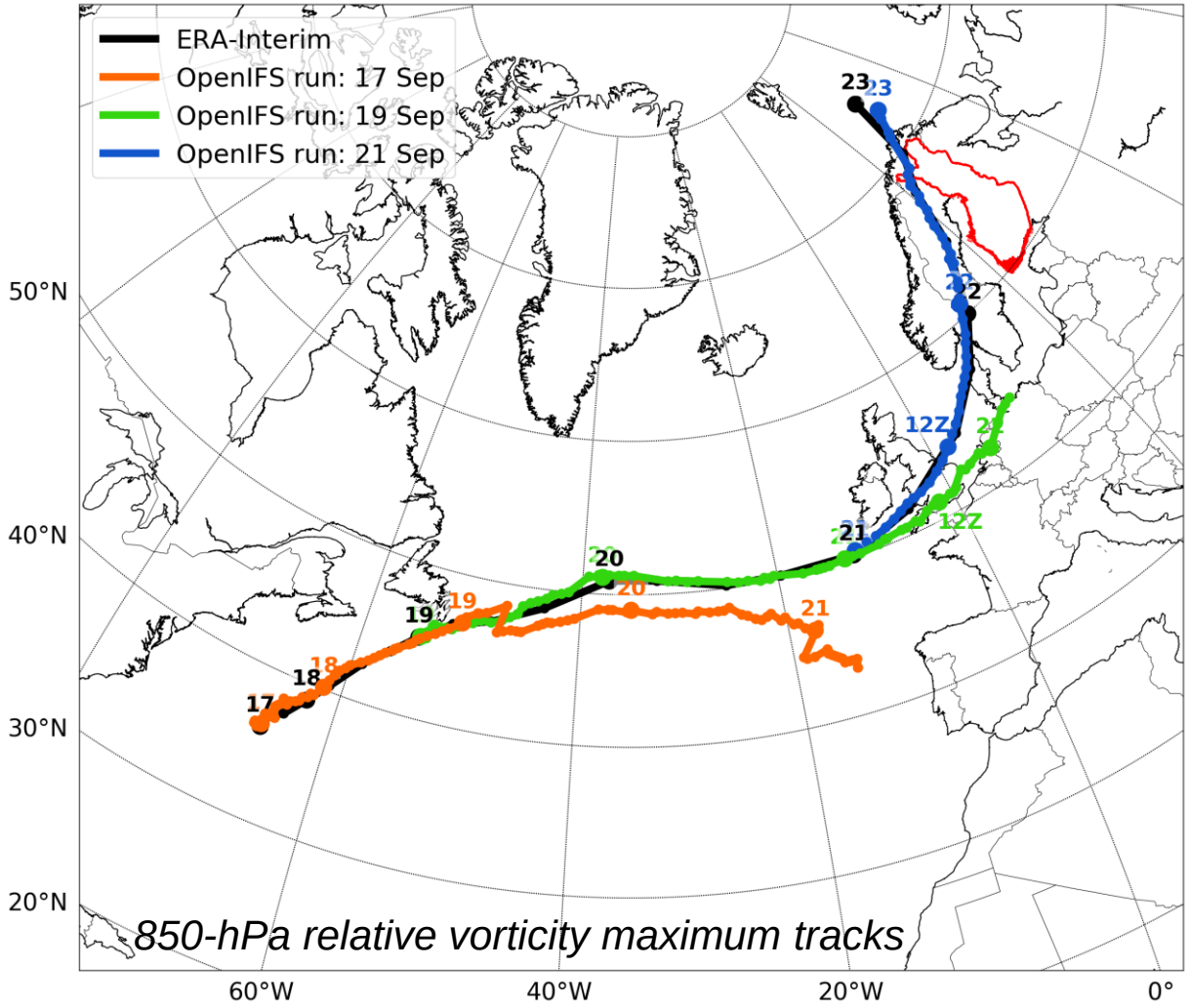
850-hPa relative vorticity (colors),
mean sea level pressure (black contours),
300-hPa wind speed (red contours at 40,50,60 m/s)



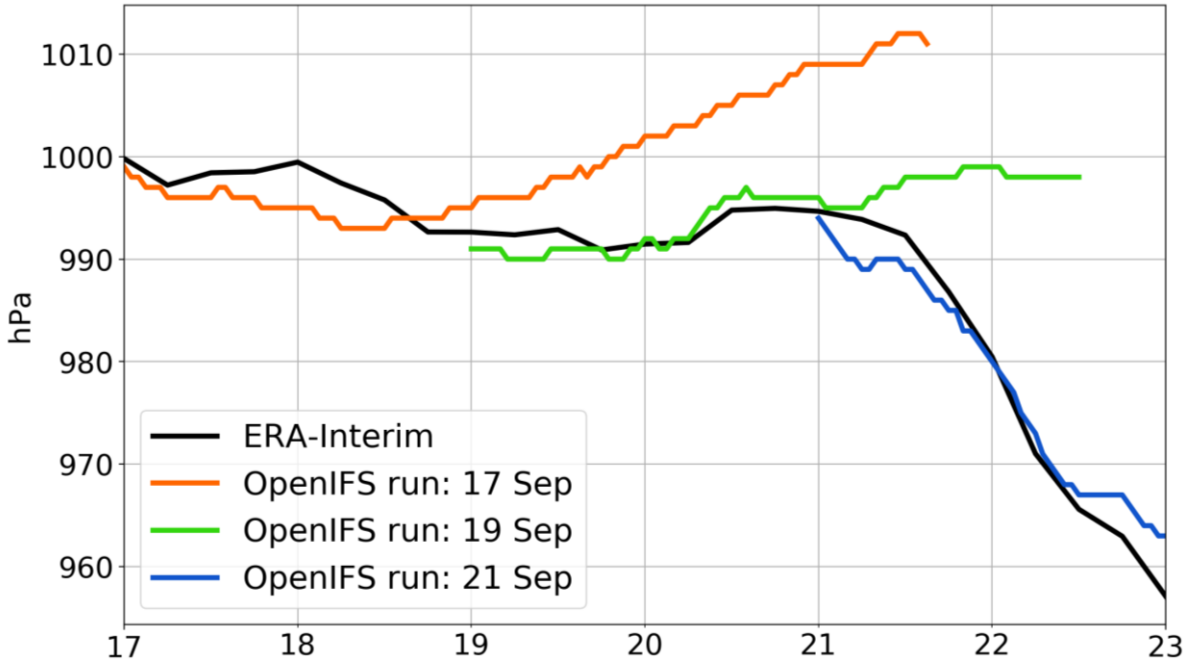
- Ex-Debby over Finland → Mauri
- Other low centre near the warm front
- Ex-Debby more intense of the two

850-hPa relative vorticity (colors),
mean sea level pressure (black contours),
300-hPa wind speed (red contours at 40,50,60 m/s)

OpenIFS simulations

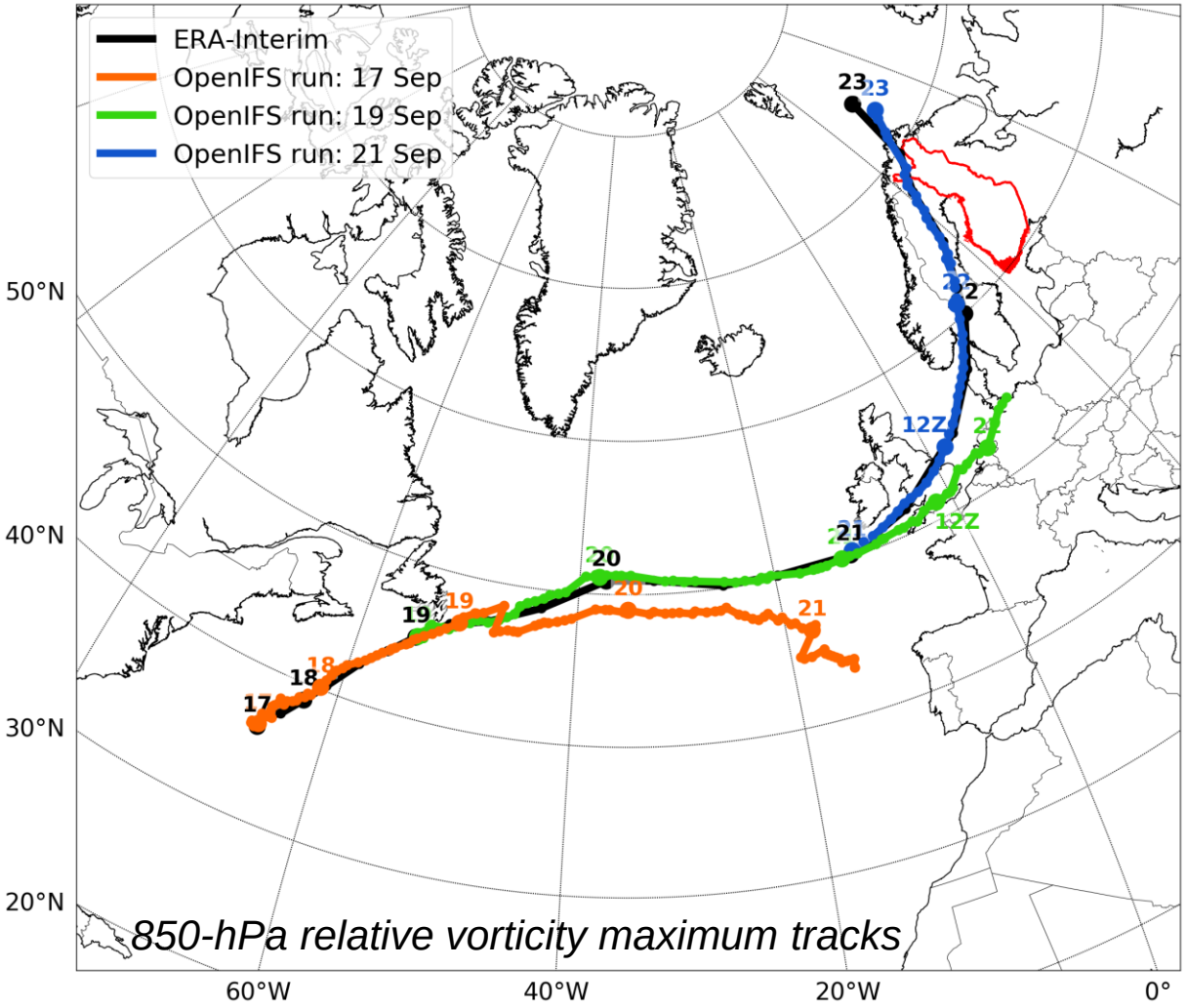


- **High resolution** (T1279) simulations
  → coarser resolutions did not capture
- **Three runs** with different initialization dates
  → forecast skill ~2 days

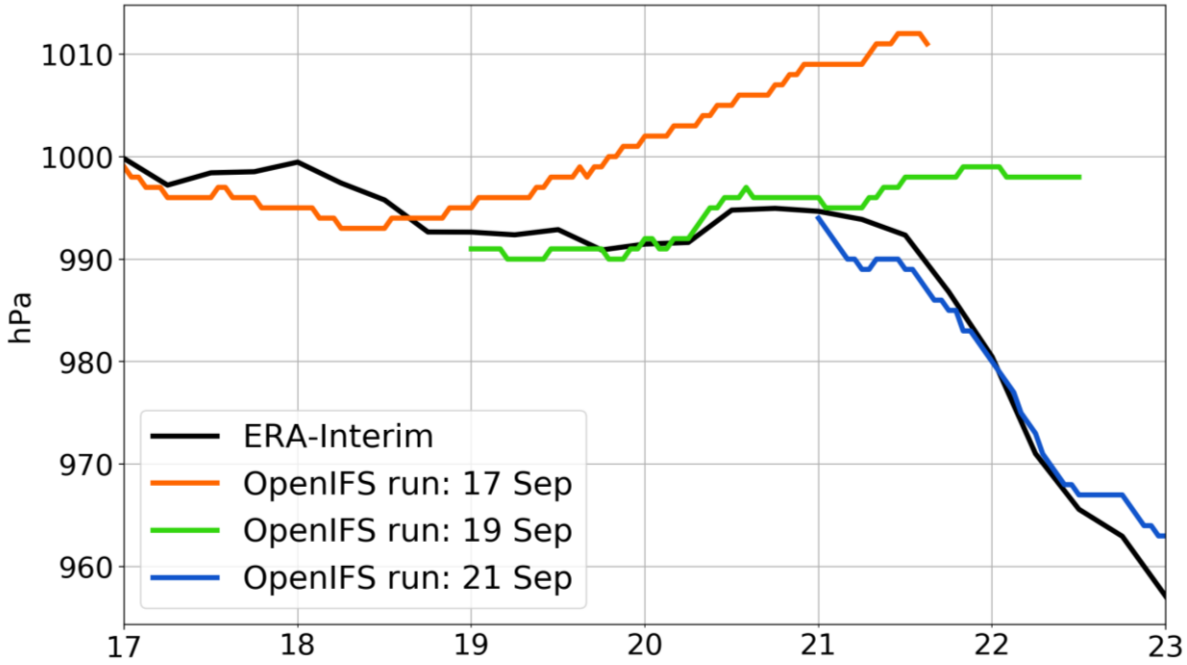


Time series of minimum pressure

OpenIFS simulations

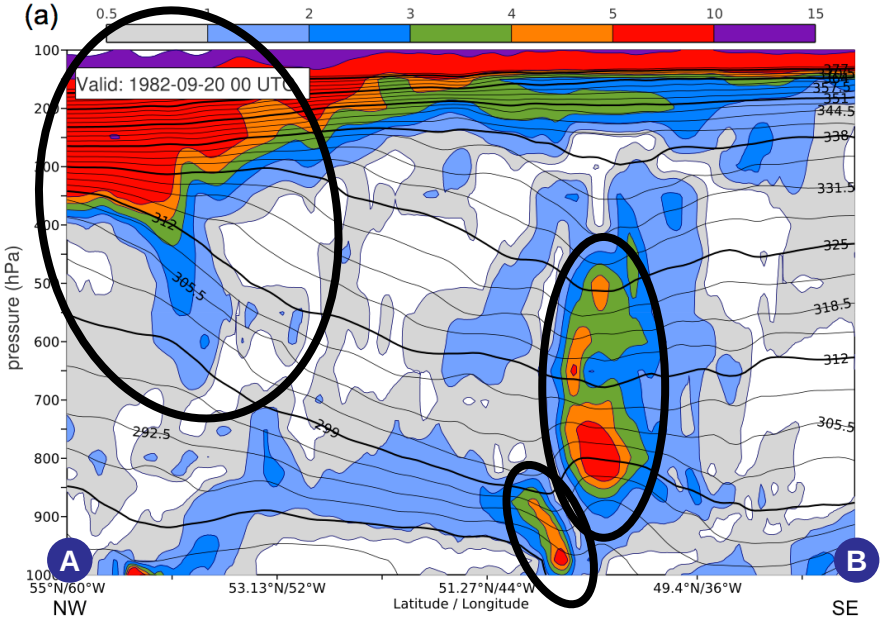


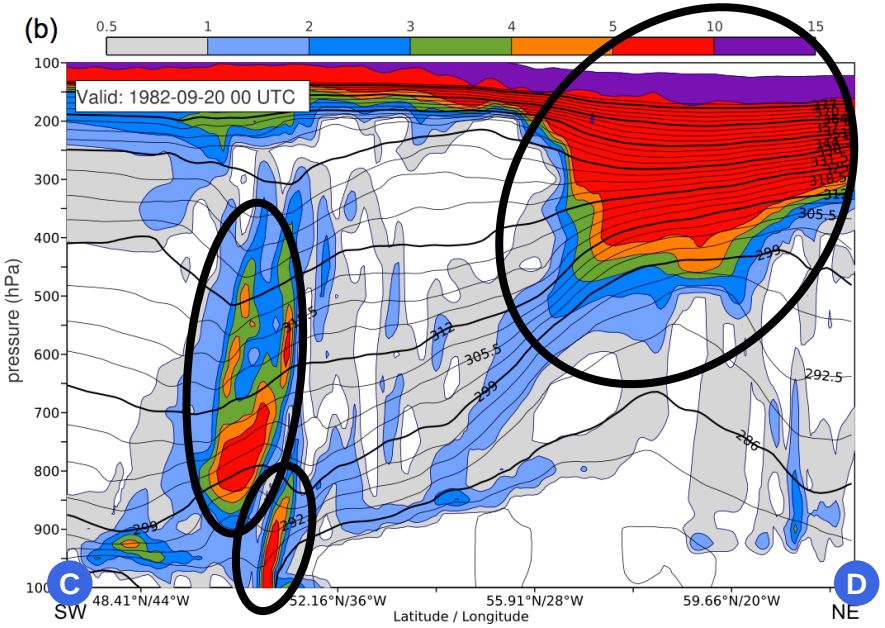
1. **Why did ex-Debby travel across the Atlantic?**
   → 19th forecast
2. **Why did ex-Debby re-intensify over the UK?**
   → 21st forecast (compared to 19th forecast)
3. **What are the reasons for strong winds over Finland?**
   → 21st forecast

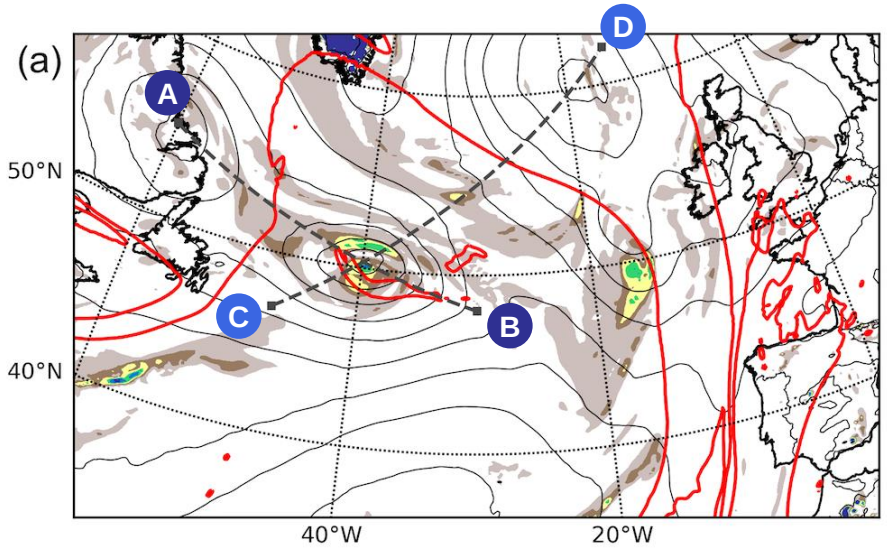


Time series of minimum pressure

Why did ex-Debby travel across the Atlantic?







Map: 850-hPa potential vorticity (colors), 250-hPa potential vorticity at 2 PVU (red contour), mean sea level pressure (black contours)

Cross sections: potential vorticity (colors), potential temperature (contours)

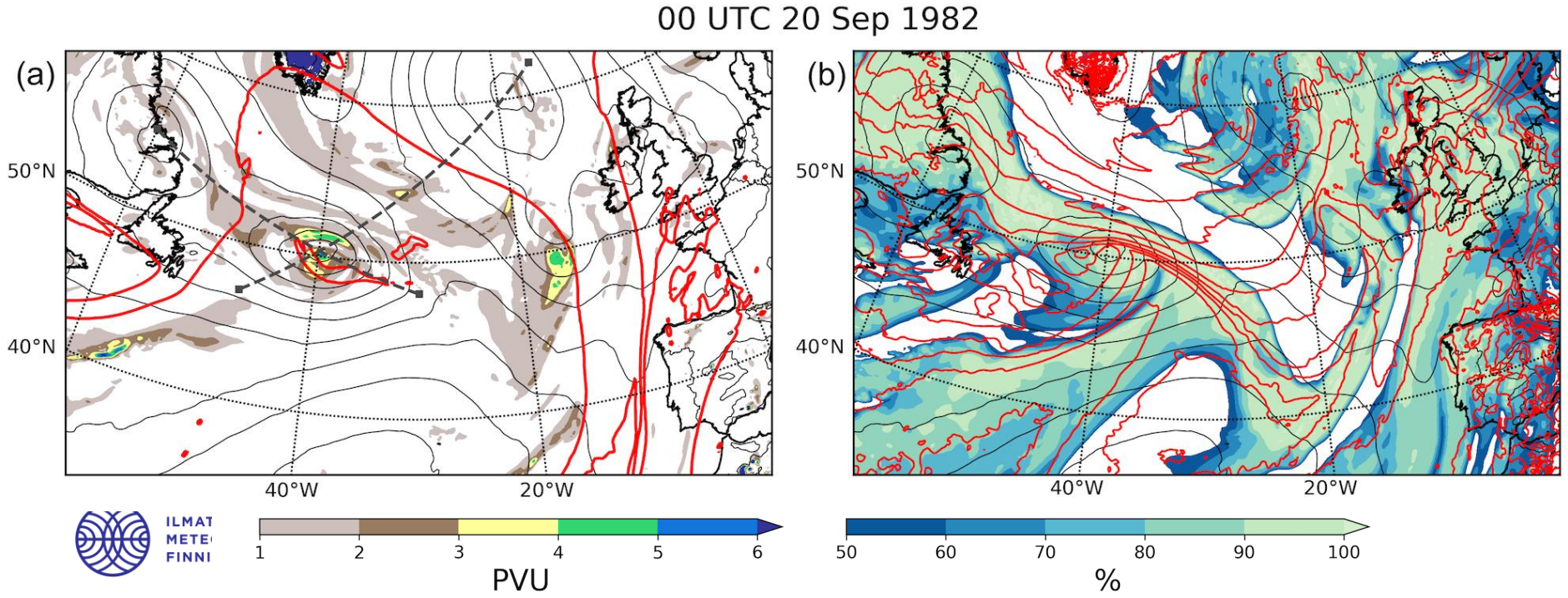
- **PV tower** remaining from ET process
- **Surface PV** anomaly from the bent-back warm front
- **Upper-level PV** anomaly from the trough

→ Upper levels not interacting with low-level PV
→ No upper-level forcing
→ <u>Ex-Debby did not intensify</u>

Why did ex-Debby travel across the Atlantic?

- **Diabatic Rossby wave** can maintain itself by constant diabatic PV generation
- Criteria by Boettcher and Wernli (2013):
  1. Closed surface pressure contour → **yes**
  2. Positive low-level PV anomaly → **yes** (> 5PVU)
  3. Substantial low-level baroclinicity → **yes** (15.5K > 5K)
  4. Fast propagation → **yes** (510km / 6h > 250km / 6h)
  5. Sufficient moisture → **yes** (850-hPa RH > 90%)
  6. Very weak upper-level forcing → **yes**

→ Ex-Debby travelled rapidly across the Atlantic as a diabatic Rossby wave

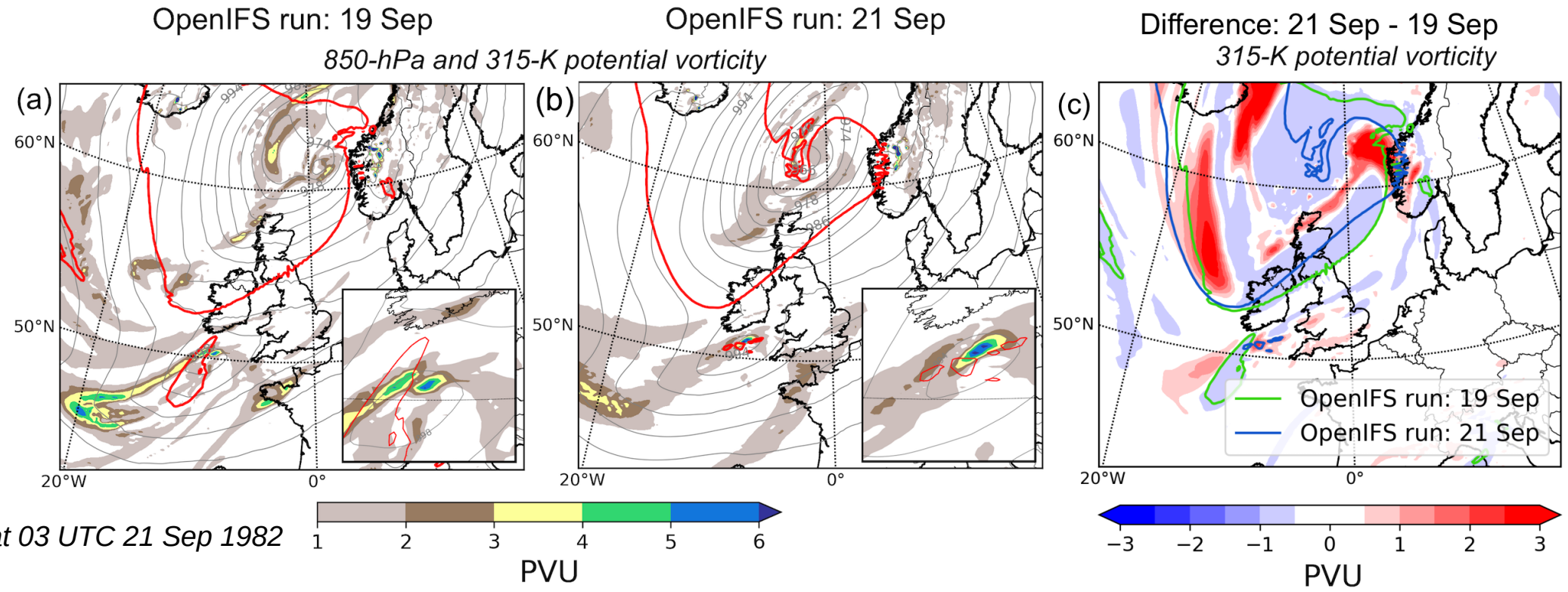


(a) 850-hPa potential vorticity (colors), 250-hPa potential vorticity at 2 PVU (red contour), mean sea level pressure (black contours)

(b) 850-hPa relative humidity (colors), 950-hPa potential temperature (red contours), mean sea level pressure (black contours)

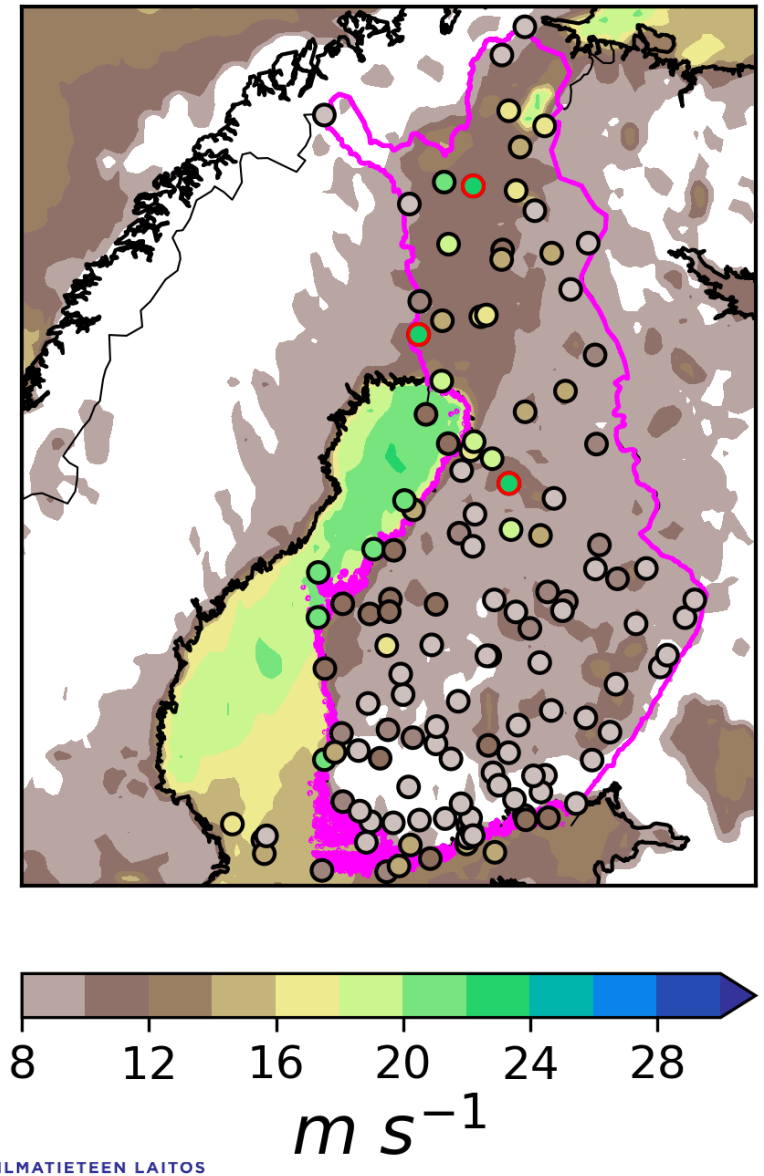
Why did ex-Debby re-intensify over the UK?

- **21st forecast**: sharp upper-level trough just west of the low-level PV anomaly of ex-Debby
- **Differences in low-level PV**: in 19th ex-Debby weaker, less coherent and farther south and west
- **Differences in phasing**: in 19th upper and low-level PV anomalies vertically stacked
  → Upper-level trough intensified ex-Debby in 21st but not in the 19th forecast



Valid at 03 UTC 21 Sep 1982

Reasons for strong winds over Finland?



Verification of winds:

- Strongest observed winds **23 m/s** (red circles)
- Strongest simulated winds over sea **22 m/s** and over land **14 m/s**
- OpenIFS underestimates the wind speeds (mainly over land) but correctly locates the strongest winds

Max. 10-m wind speed during 22 Sep 1982 from FMI observations (circles) and OpenIFS run of 21st Sep (colors)

Reasons for strong winds over Finland?

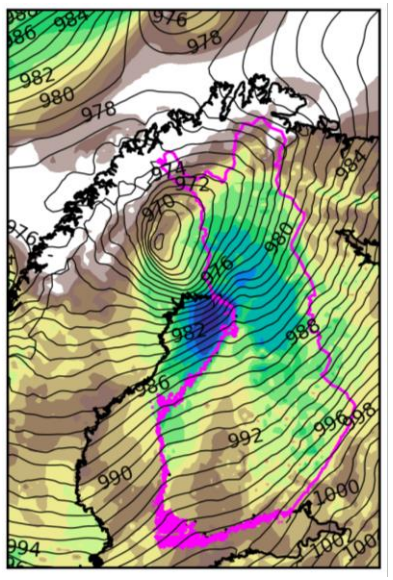
Wind gust in OpenIFS:

$$F_{gust} = F_{10} + C_{ugn}u_* + C_{conv}\max(0, U_{850} - U_{950})$$

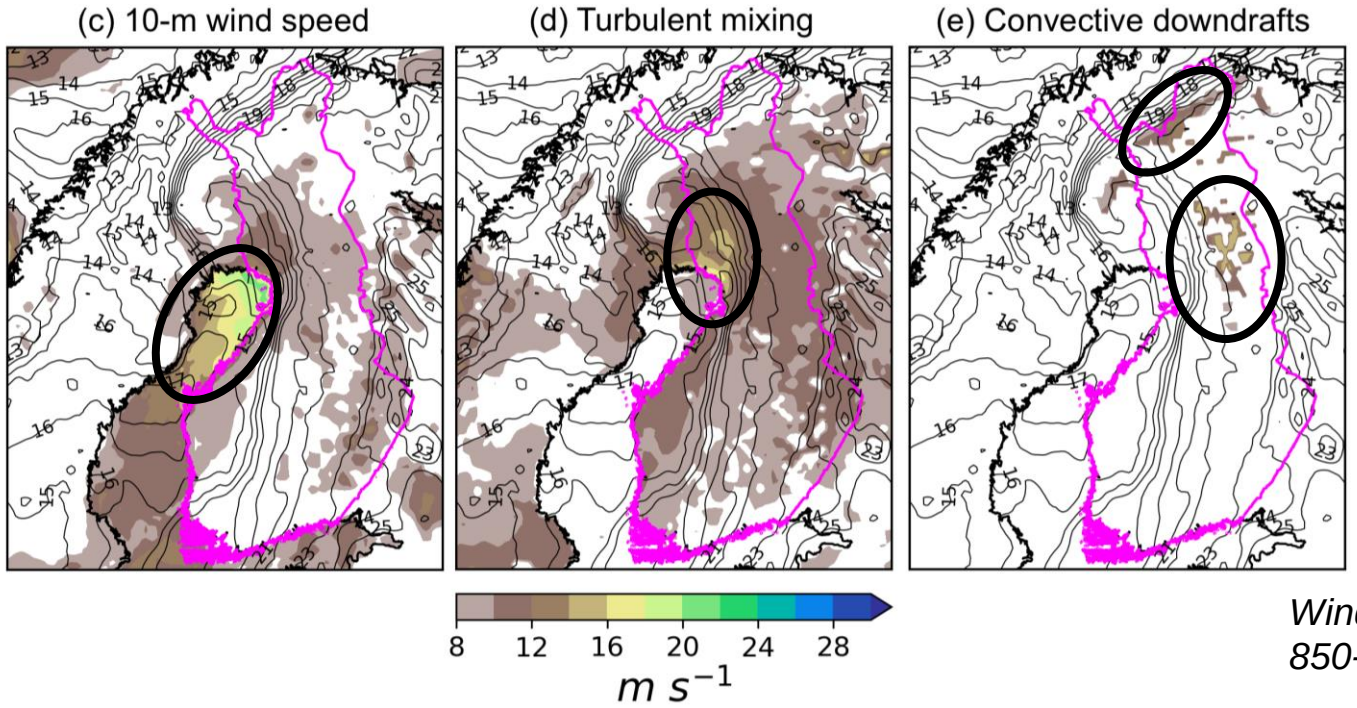
gust = 10-m wind + turbulent mixing + convective downdrafts

surface friction, boundary layer stability

vertical wind shear, convection



Wind gust (colors) at 12 UTC 22 Sep, mean sea level pressure (contours)



- Strong winds due to <u>strong pressure gradient and low surface roughness</u>
- <u>Turbulent driven gusts</u> behind the cold front
- <u>Gusts due to convective downdrafts</u> in the warm sector

Wind gust components (colors) at 12 UTC 22 Sep, 850-hPa potential temperature (contours)

Conclusions

- **Why did ex-Debby travel across the Atlantic?**
  → *Maintained itself as a diabatic Rossby wave.*
- **Why did ex-Debby re-intensify over the UK?**
  → *Phasing with other extratropical cyclone was crucial.*
- **What are the reasons for strong winds over Finland?**
  → *Strong pressure gradient and low surface roughness caused strongest winds but turbulent mixing and convective downdrafts enhanced the gusts.*

- Complex case, three high resolution simulations needed to cover whole evolution.
- OpenIFS correctly located but underestimated the 10-m wind speeds.

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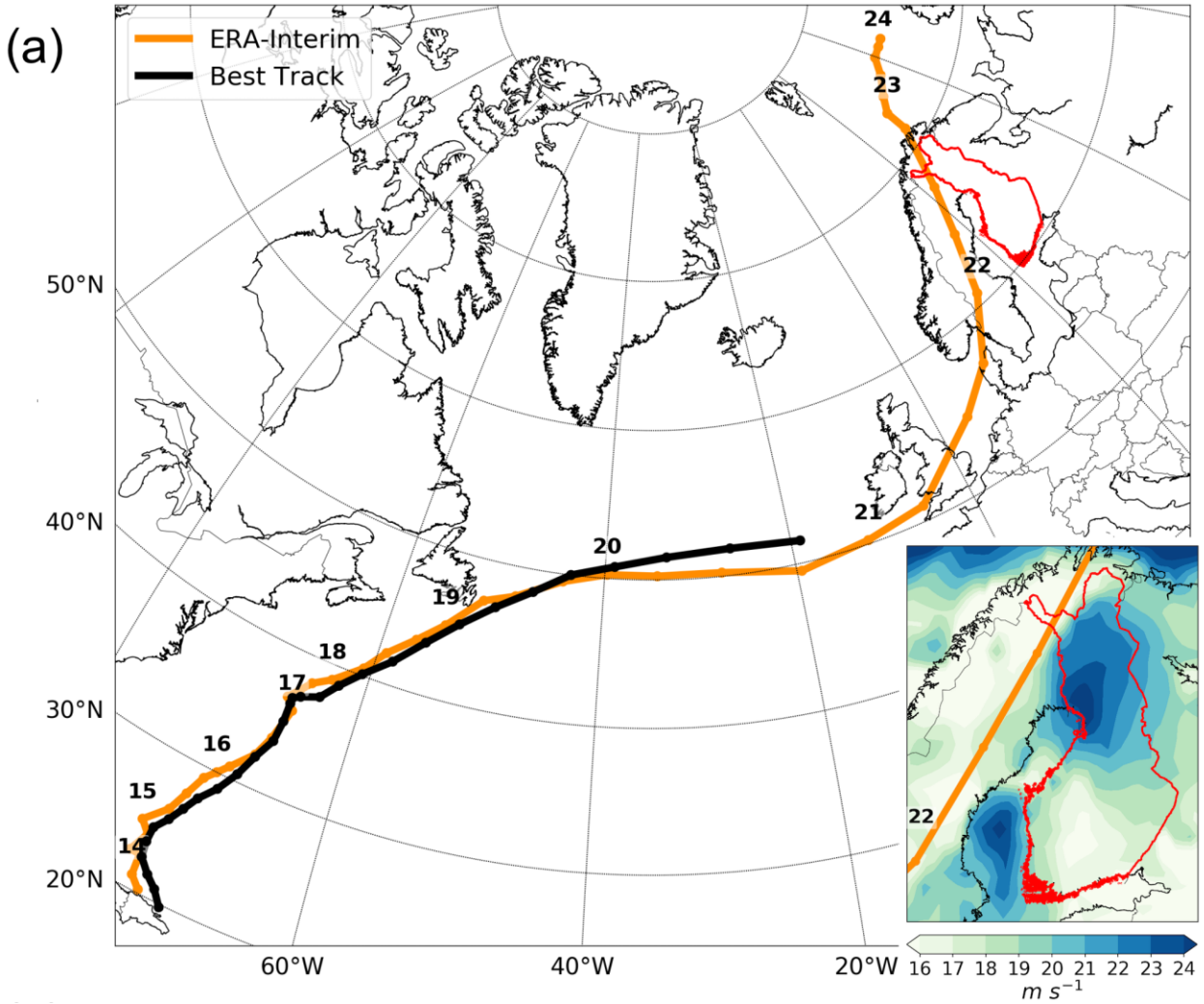
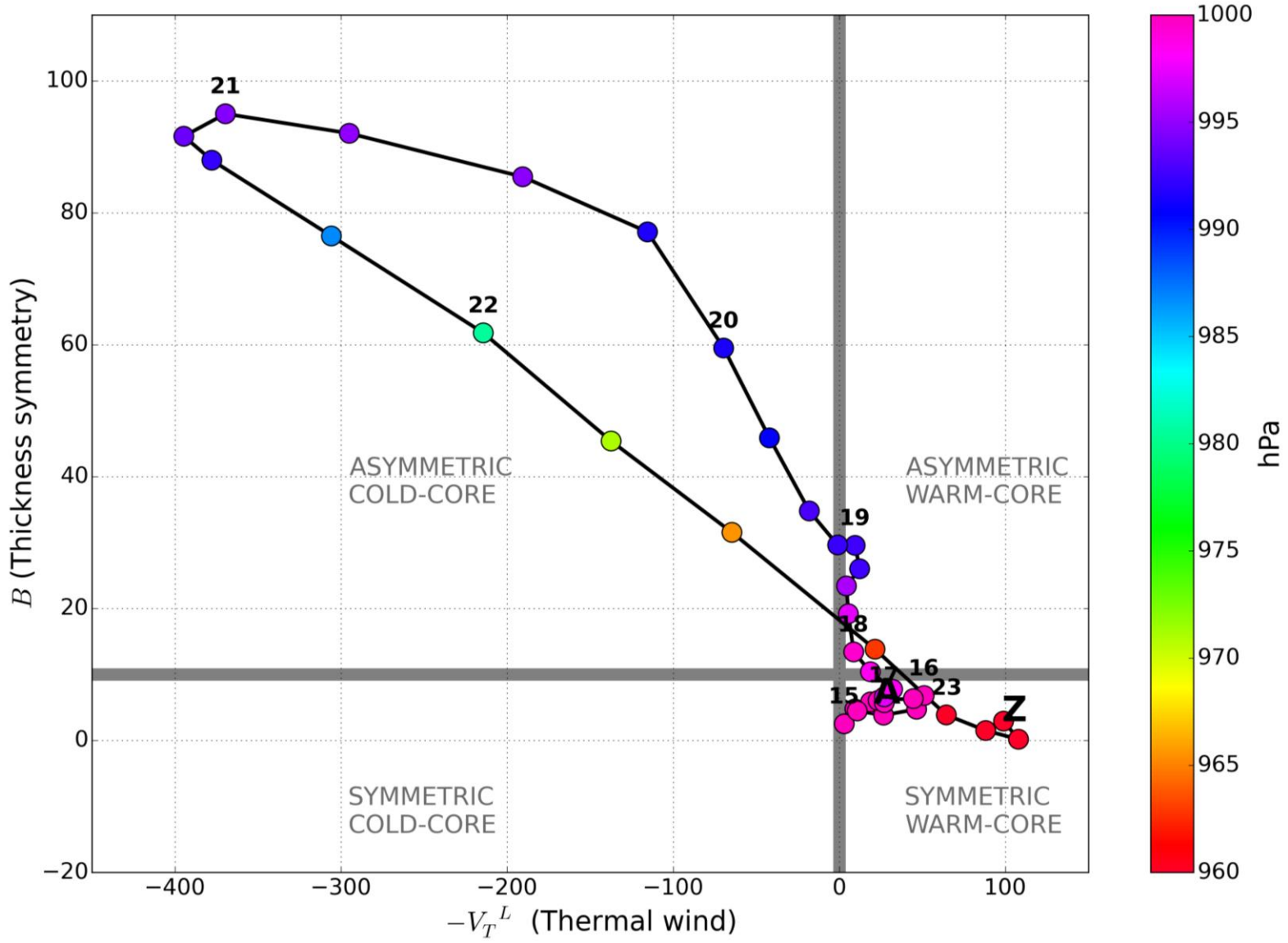
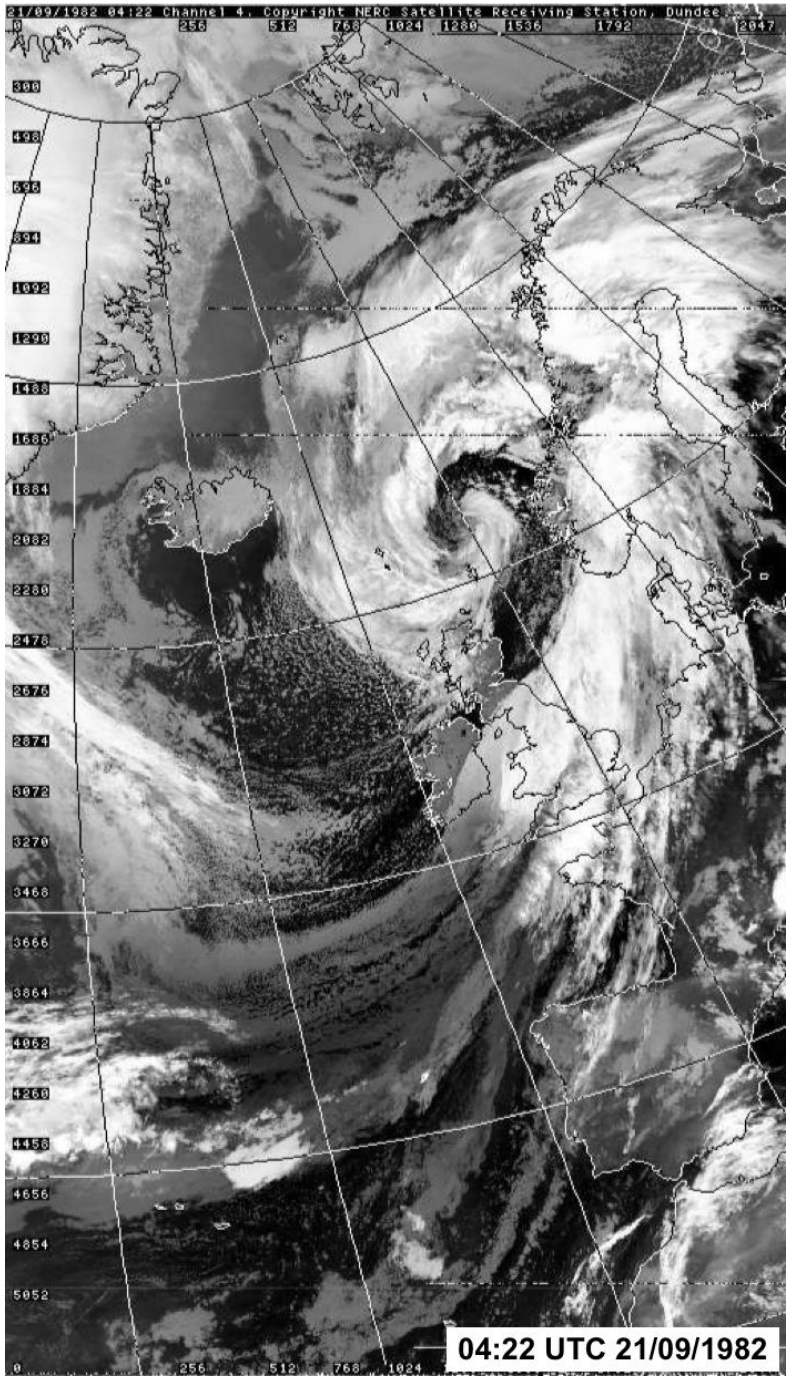
ERA-Interim + NHC tracks



Phase space diagram



Satellite image

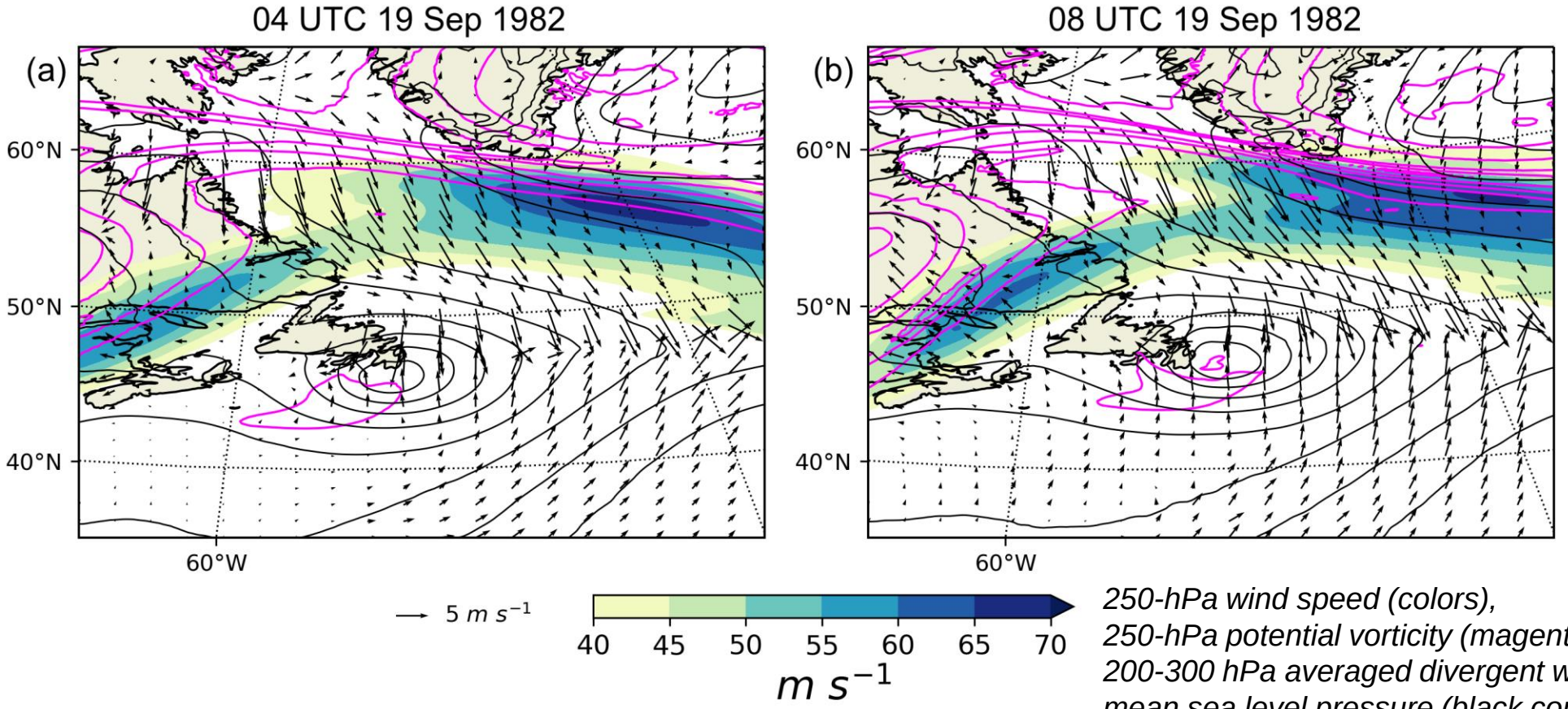


Valid at 0422 UTC 21 Sep 1982

Downstream impacts?

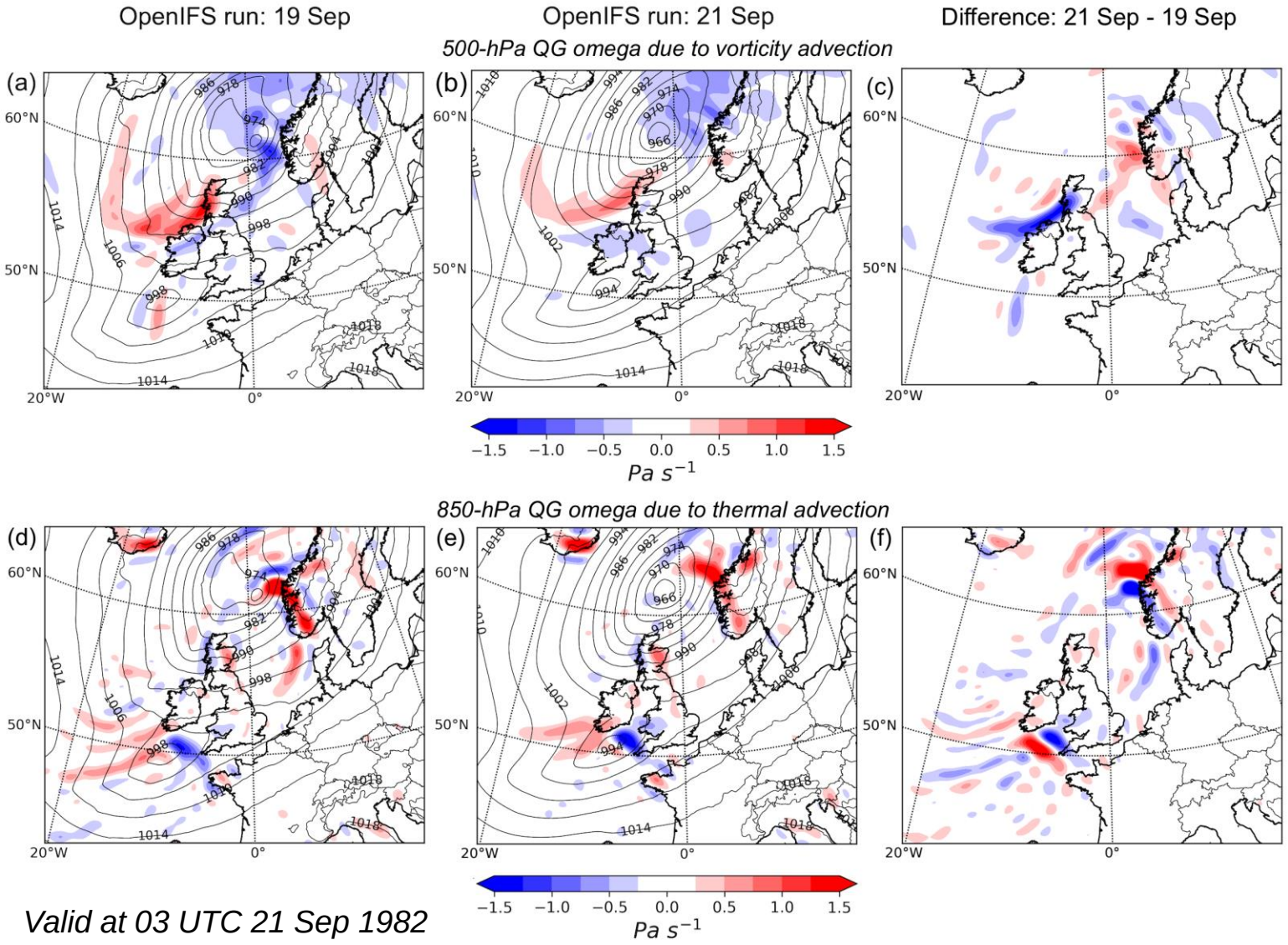
- Upper-level divergent wind of ex-Debby weak
- Upper-level wave guide rather zonal

→ very limited PV advection by divergent outflow of ex-Debby to amplify upper-level ridge



250-hPa wind speed (colors),
250-hPa potential vorticity (magenta contours),
200-300 hPa averaged divergent wind (vectors),
mean sea level pressure (black contours)

Why did ex-Debby re-intensify over the UK?



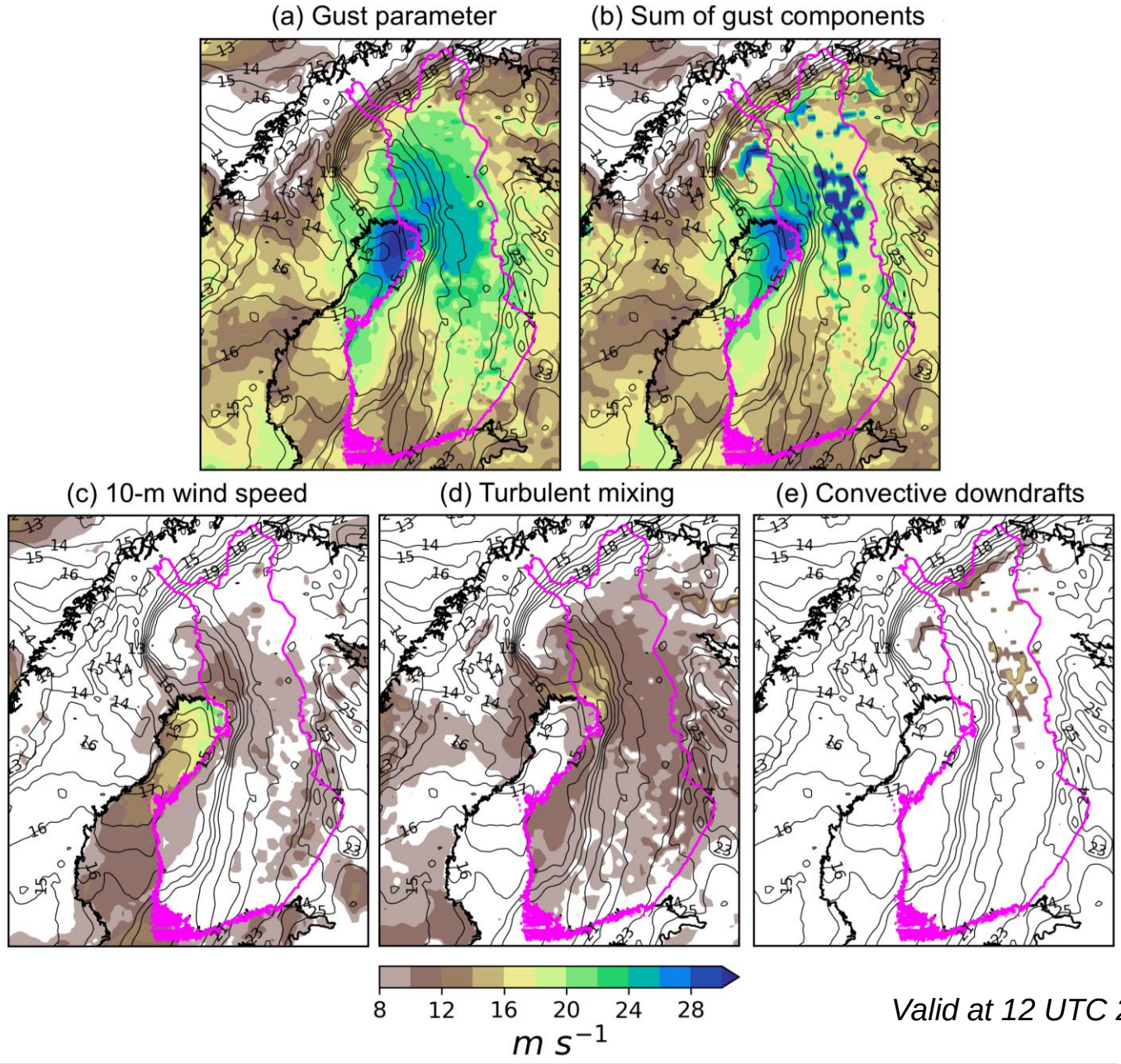
Valid at 03 UTC 21 Sep 1982

ascent = vorticity advection increasing with height + warm-air advection

- **21st forecast**: forcing for ascent near ex-Debby due to vorticity advection and thermal advection
- **Differences in omega due to vorticity advection**: in 19th the descent is farther east
- **Differences in omega due to thermal advection**: stronger in 21st, location shifted

→ Later time steps (06-12 UTC): <u>21st still has favourable phasing while vertical velocities in 19th weaken</u>

Reasons for strong winds over Finland?



Valid at 12 UTC 22 Sep 1982

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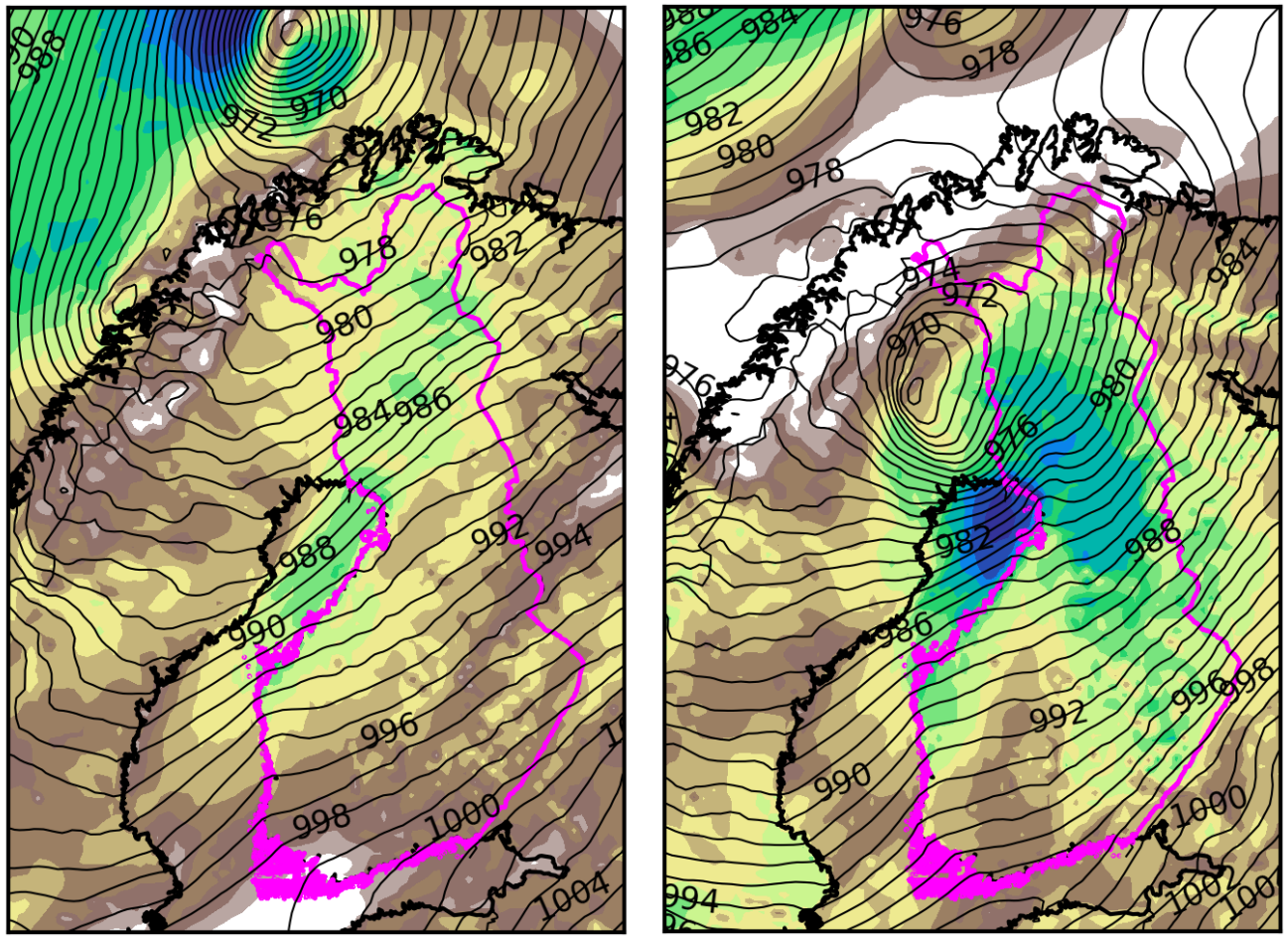
Role of ex-Debby in Mauri's winds

(a) OpenIFS run: 19 Sep

(b) OpenIFS run: 21 Sep



Valid at 12 UTC 21 Sep 1982