Analysis and Modelling of the September 2023 flood-inducing precipitation in Greece due to cyclone Daniel

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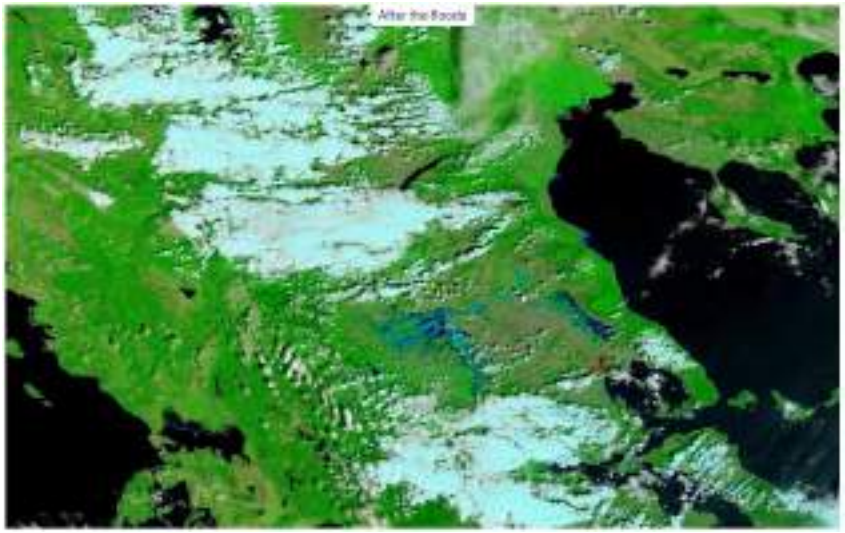
Storm Daniel 4-11 Sept 2023

- Casualties:
  Libya > 12000
  Greece 17
  Turkey 4
  Bulgaria 4
- Damages:
  Libya > US $ 6.2 bn
  Greece > € 2 bn

Terra Modis RGB

Before the floods
31 Aug 2023

After the floods
8 Sep 2023



Source: Roberto et al., EUMETSAT

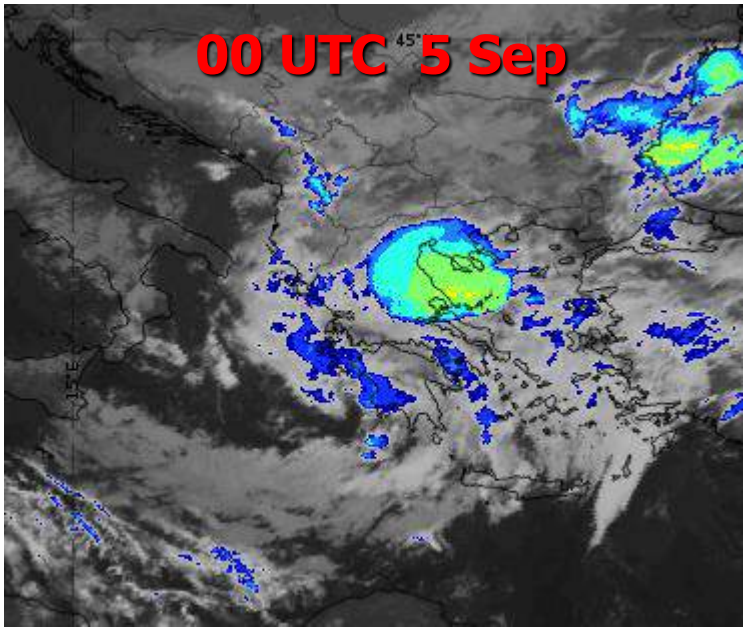
5 Sep 2023
Zagora (NOA) = 760 mm
Portaria (NOA) = 762 mm
LGBL (HNMS) = 348 mm

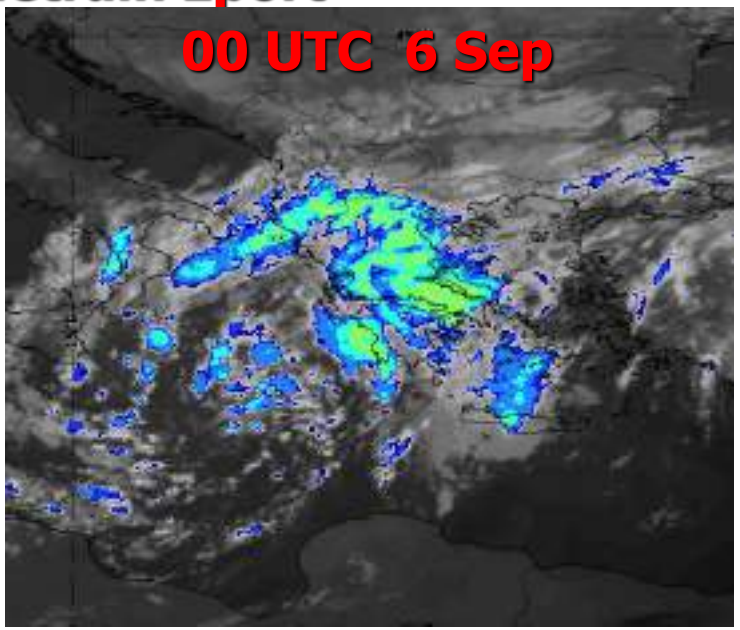
4-7 Sep 2023
Zagora (NOA) = 1096 mm
LGBL (HNMS) = 639 mm (clim. 495 mm/year)

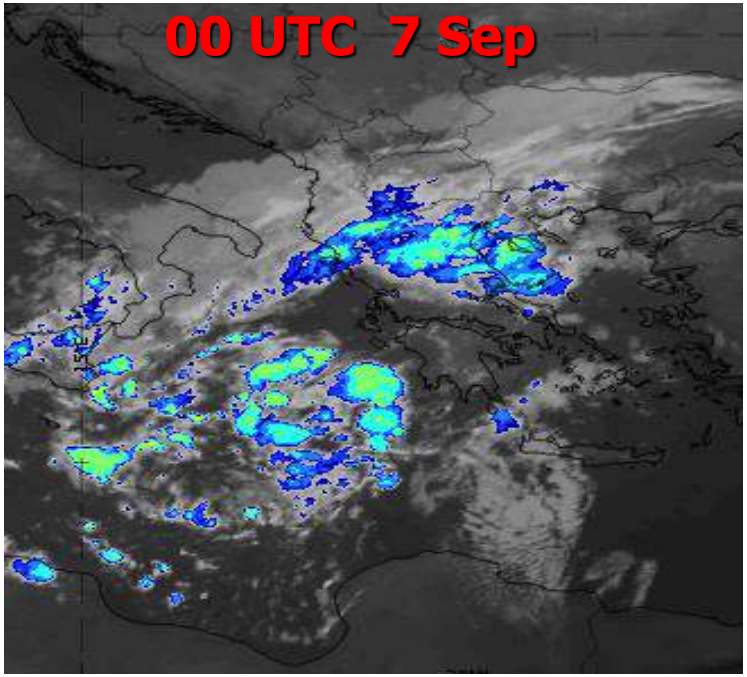
Aims:

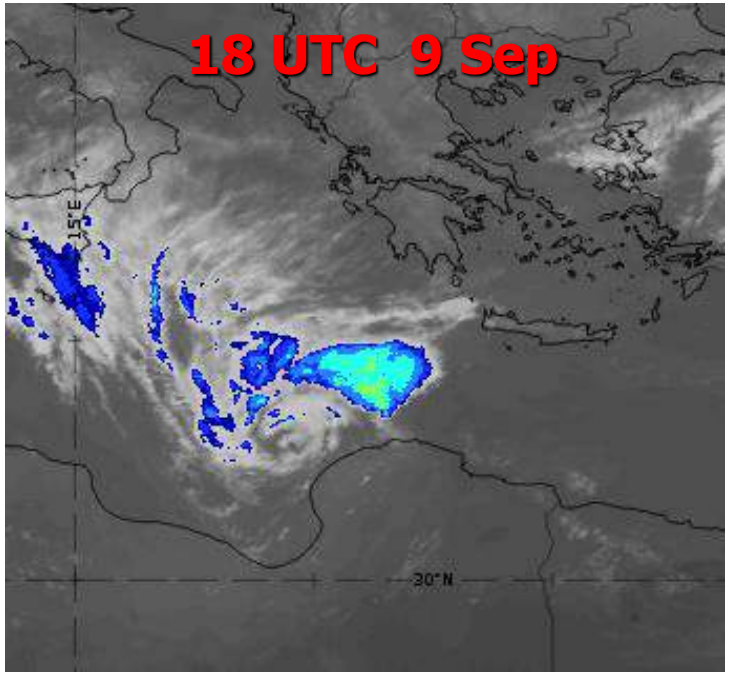
- Meteorological analysis
- Investigate its sensitivity to the surface conditions

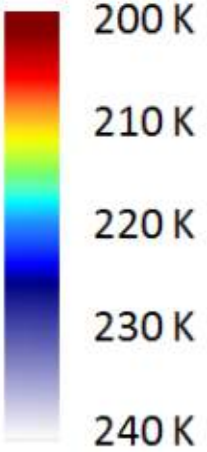
MSG – 10.8µm
Eumetrain Eport



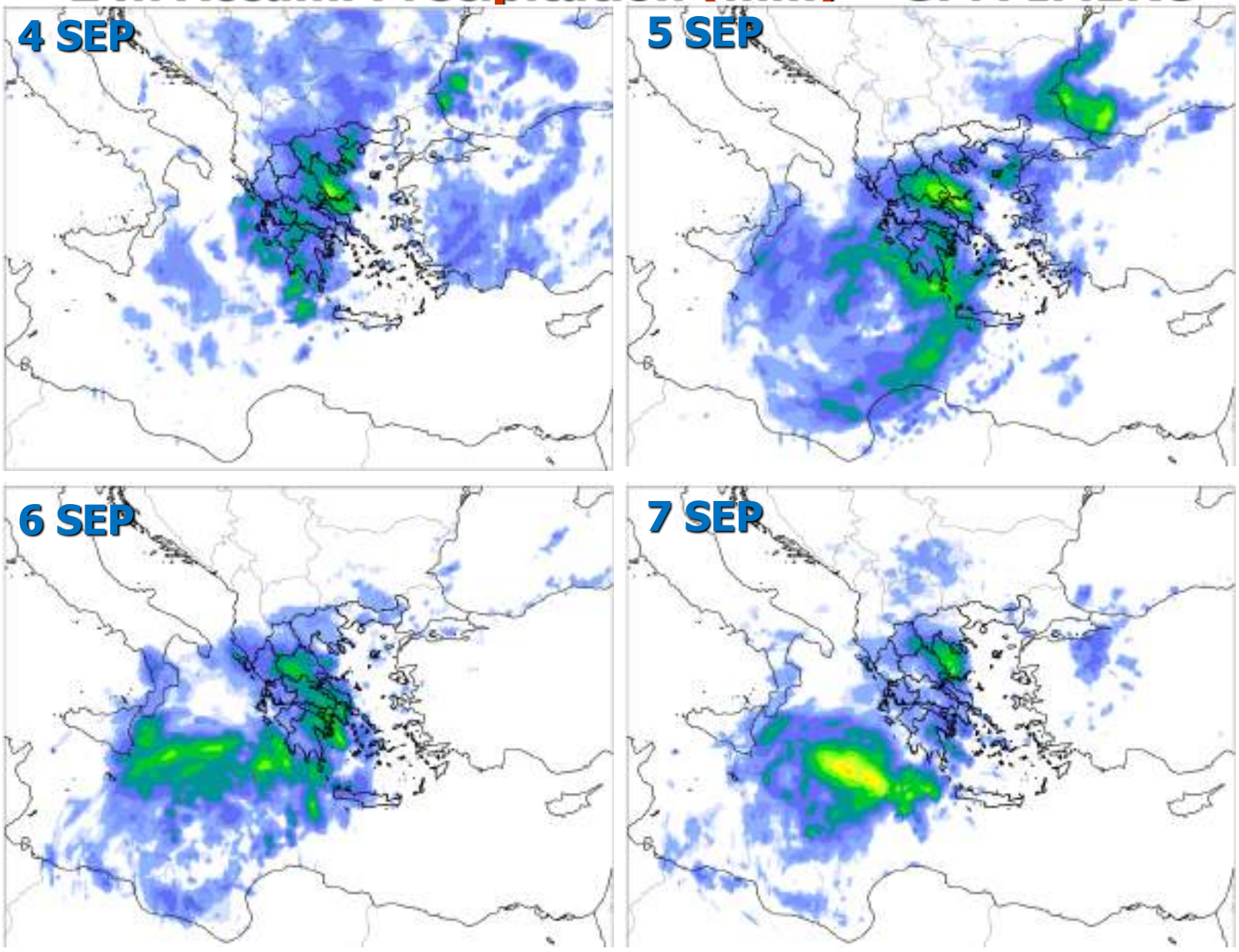




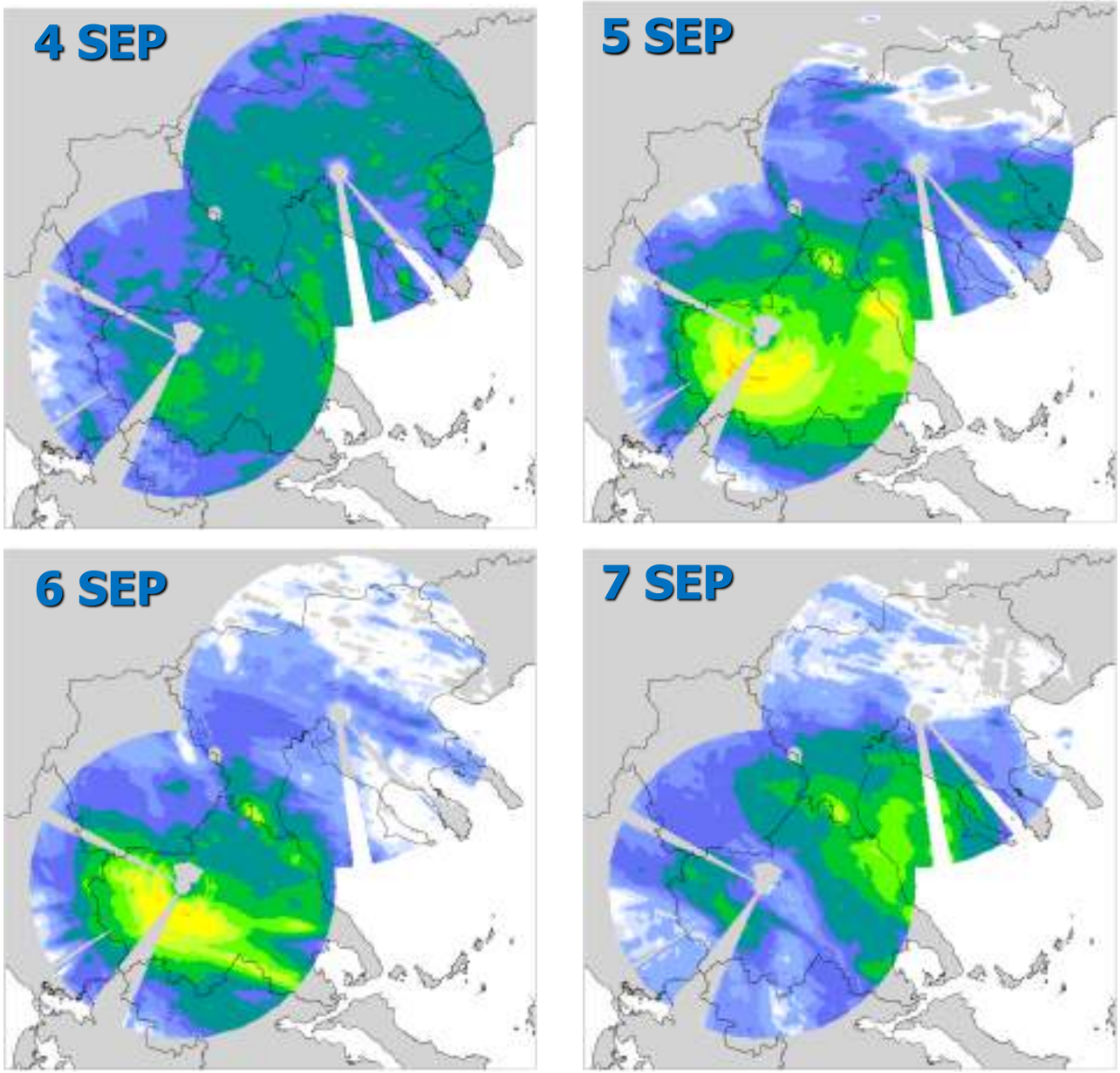




24h Accum. Precipitation (mm) – GPM IMERG



24h Accum. Precipitation (mm) - Radar



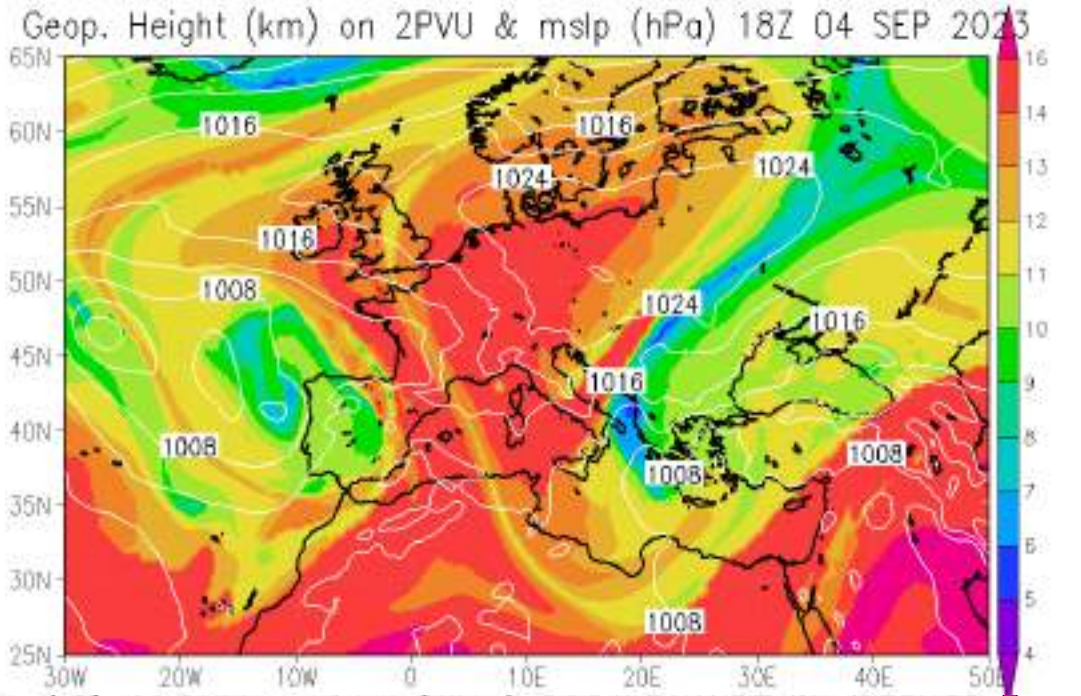
Hellenic Agricultural Insurance Organization

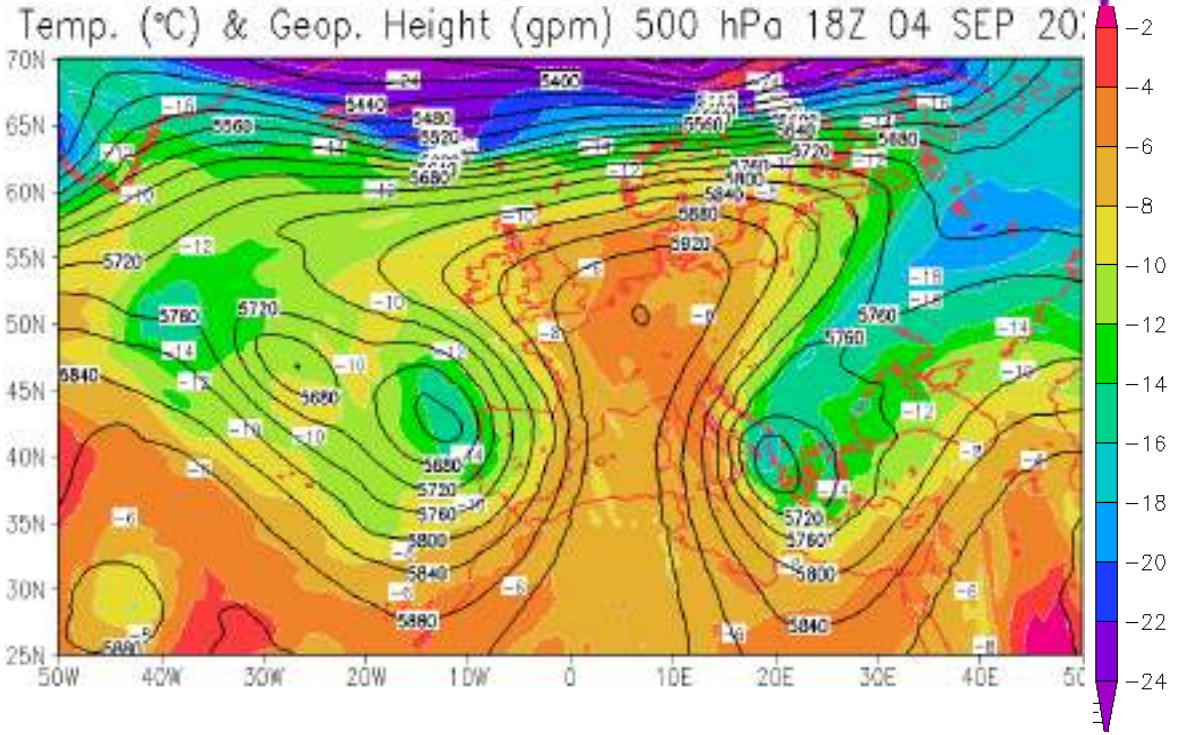
& 3D S.A.

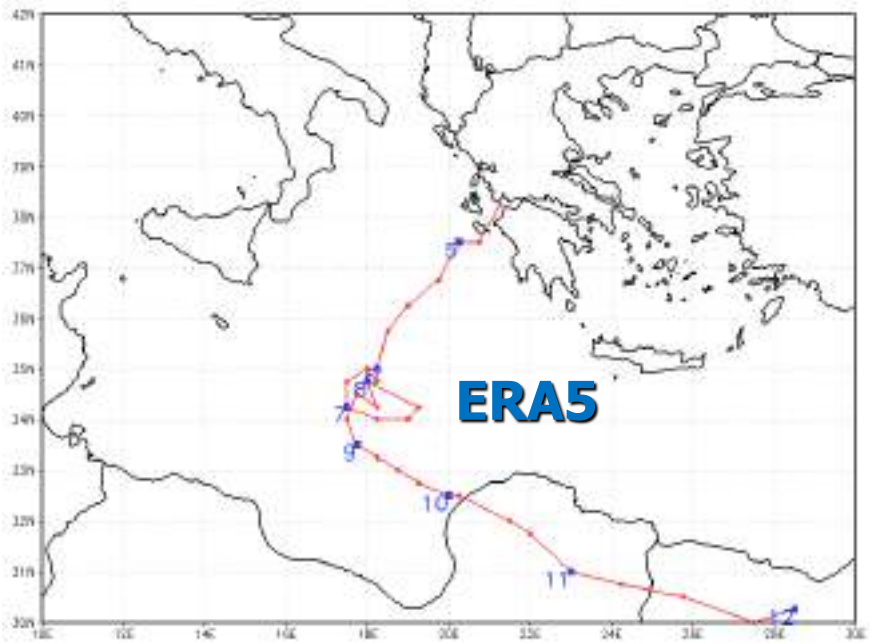
ERA5

18 UTC

4 SEP 2023



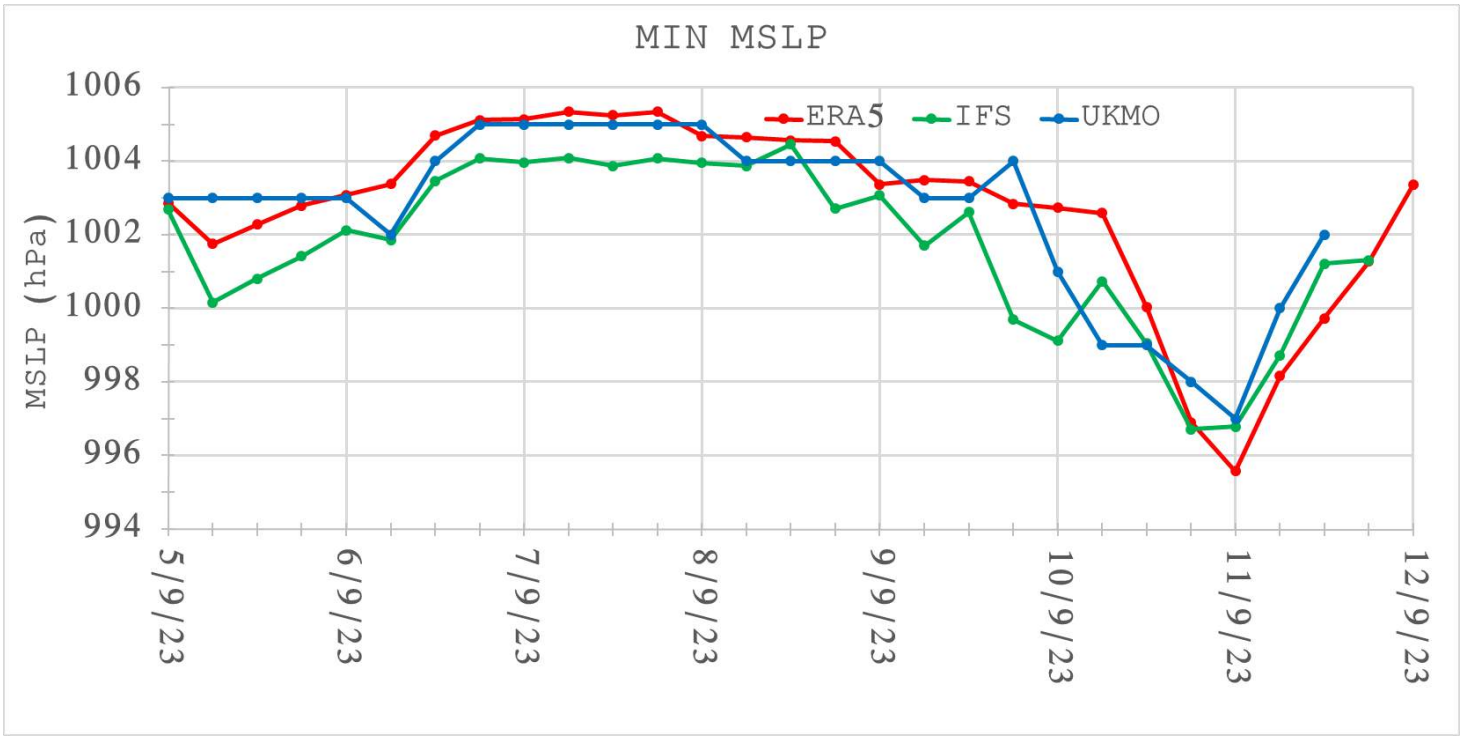


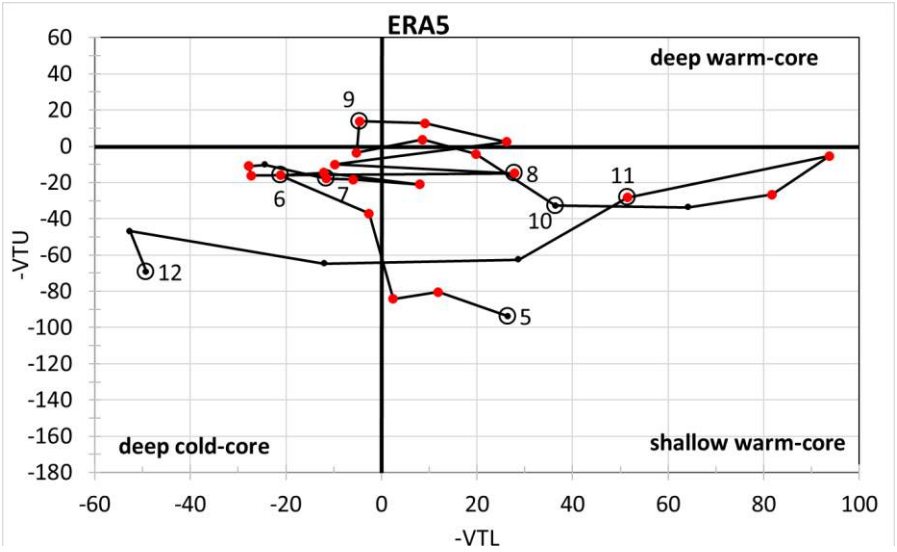


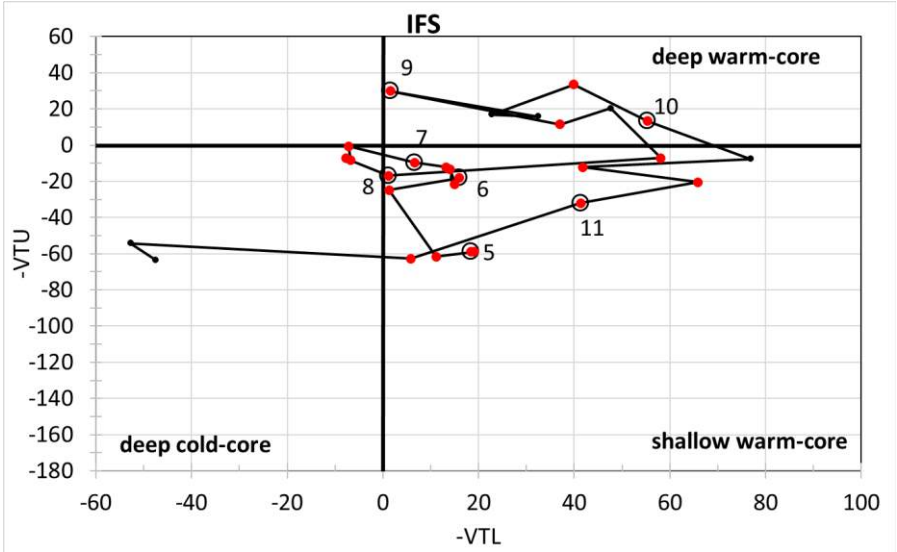
Max ASCAT wind speed:

37 kt at 20:21 UTC 8 Sep

40 kt at 19:30 UTC 9 Sep
(Roberto et al. EUMETSAT)







Sym. Deep Warm Core

ERA5
12 UTC 8 Sep
18 UTC 8 Sep
12 UTC 9 Sep

Radius: 200km

Layers:

600-300 hPa

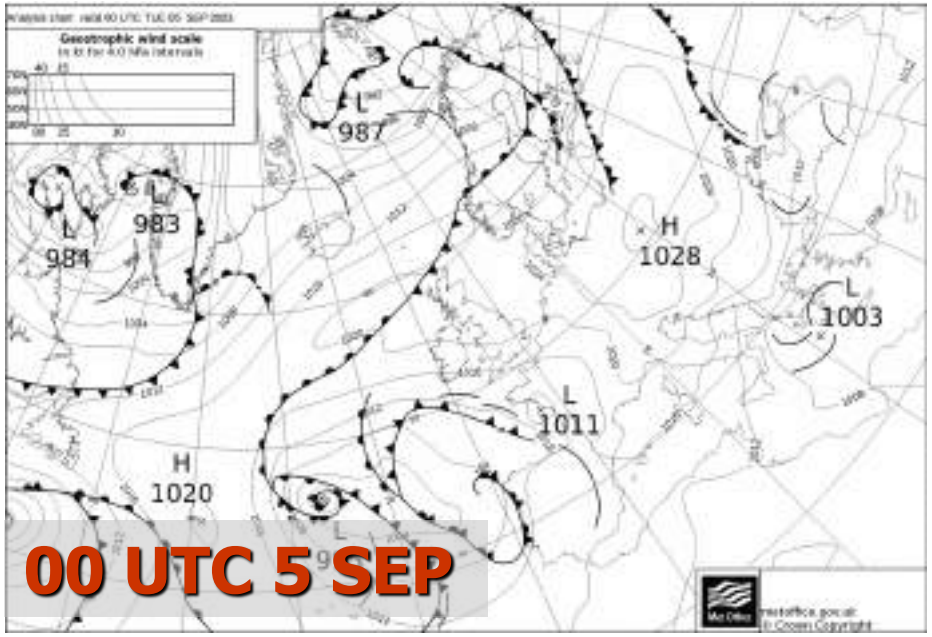
900-600 hPa

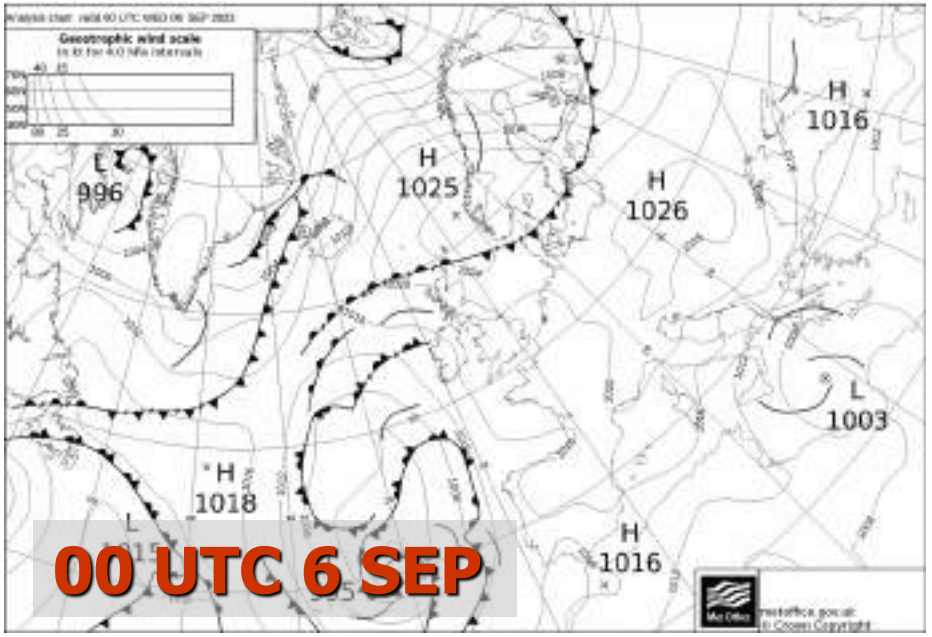
Red dots: |B|<10 m

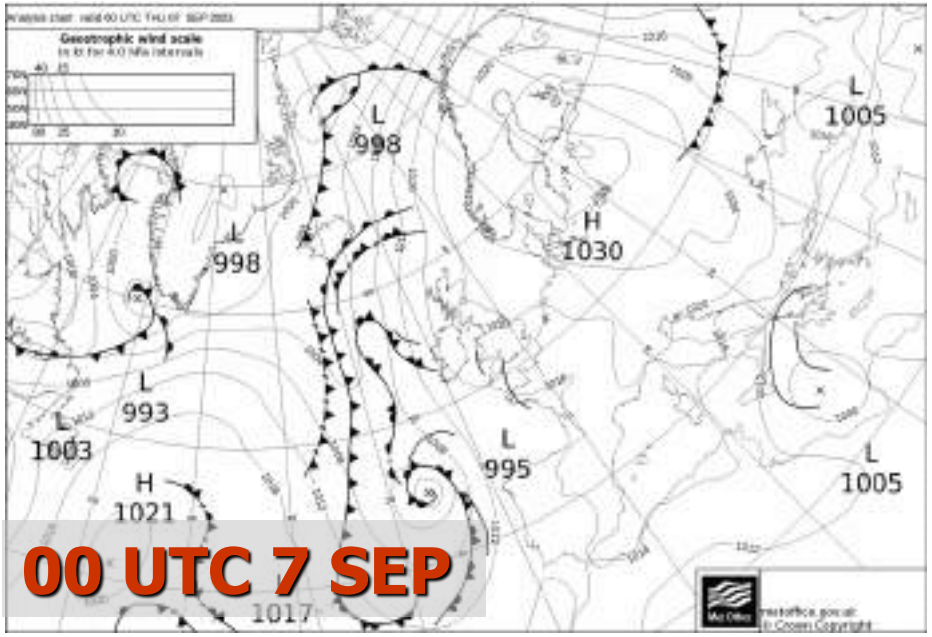
Sym. Deep Warm Core

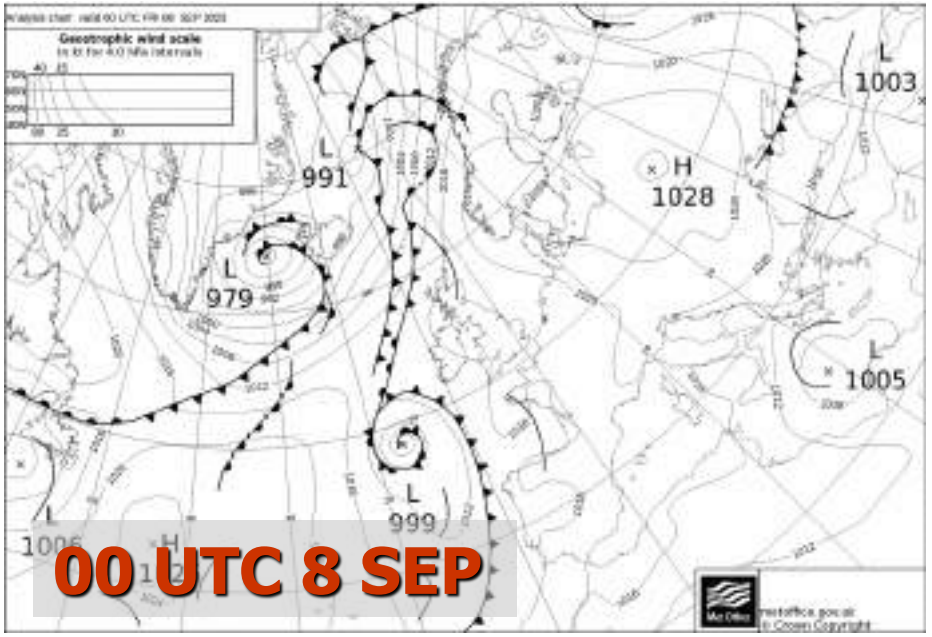
IFS
18 UTC 8 Sep
00 UTC 9 Sep
18 UTC 9 Sep
00 UTC 10 Sep

UKMO


Geostrophic wind scale
L 987
L 983
L 984
H 1028
L 1003
L 1011
H 1020
00 UTC 5 SEP

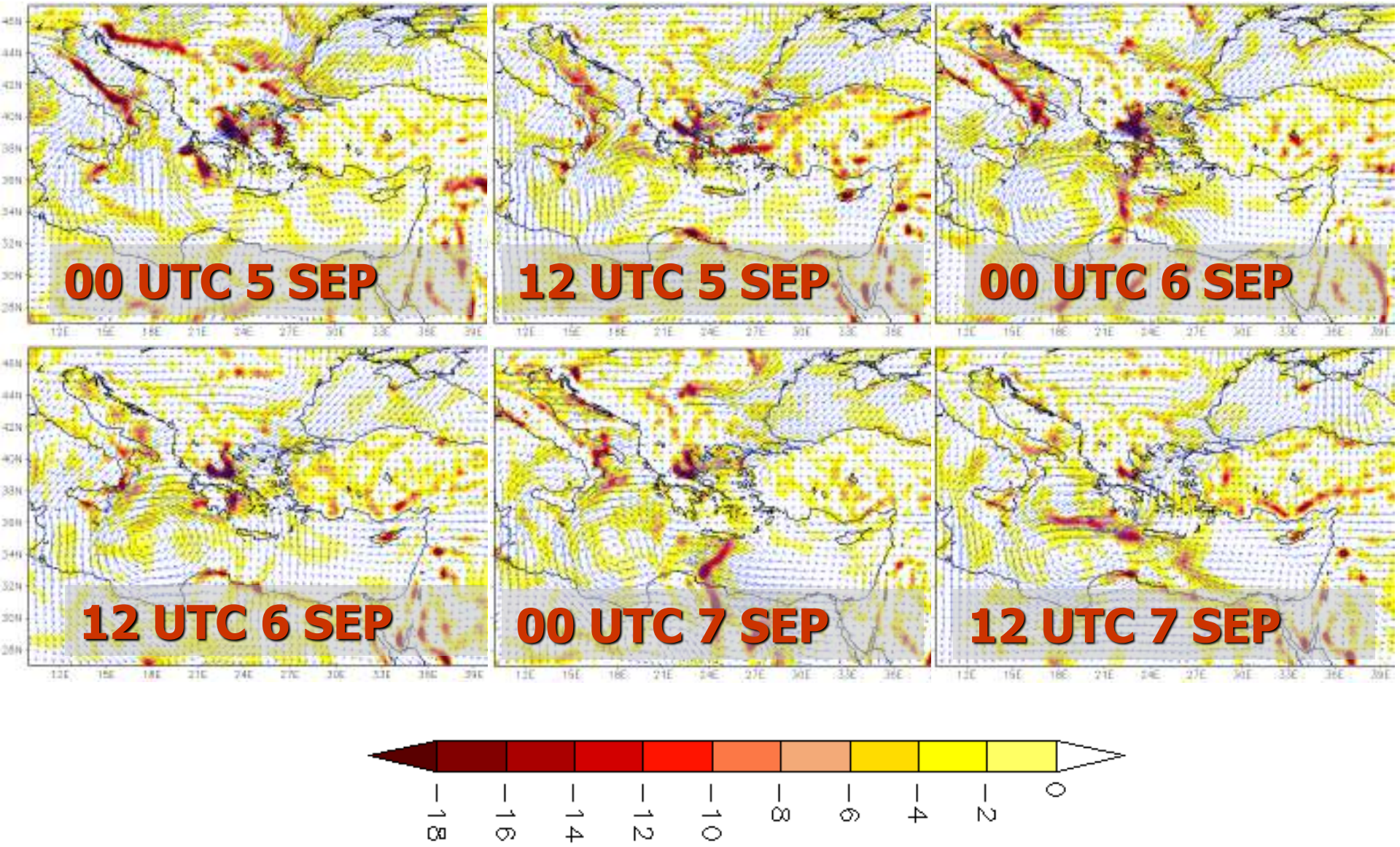

Geostrophic wind scale
H 1016
H 1025
H 1026
L 996
L 1003
H 1018
H 1016
00 UTC 6 SEP


Geostrophic wind scale
L 998
L 1005
H 1030
L 998
L 993
L 1003
H 1021
L 995
L 1005
1017
00 UTC 7 SEP


Geostrophic wind scale
L 1003
L 991
H 1028
L 979
L 1005
L 999
1006
00 UTC 8 SEP

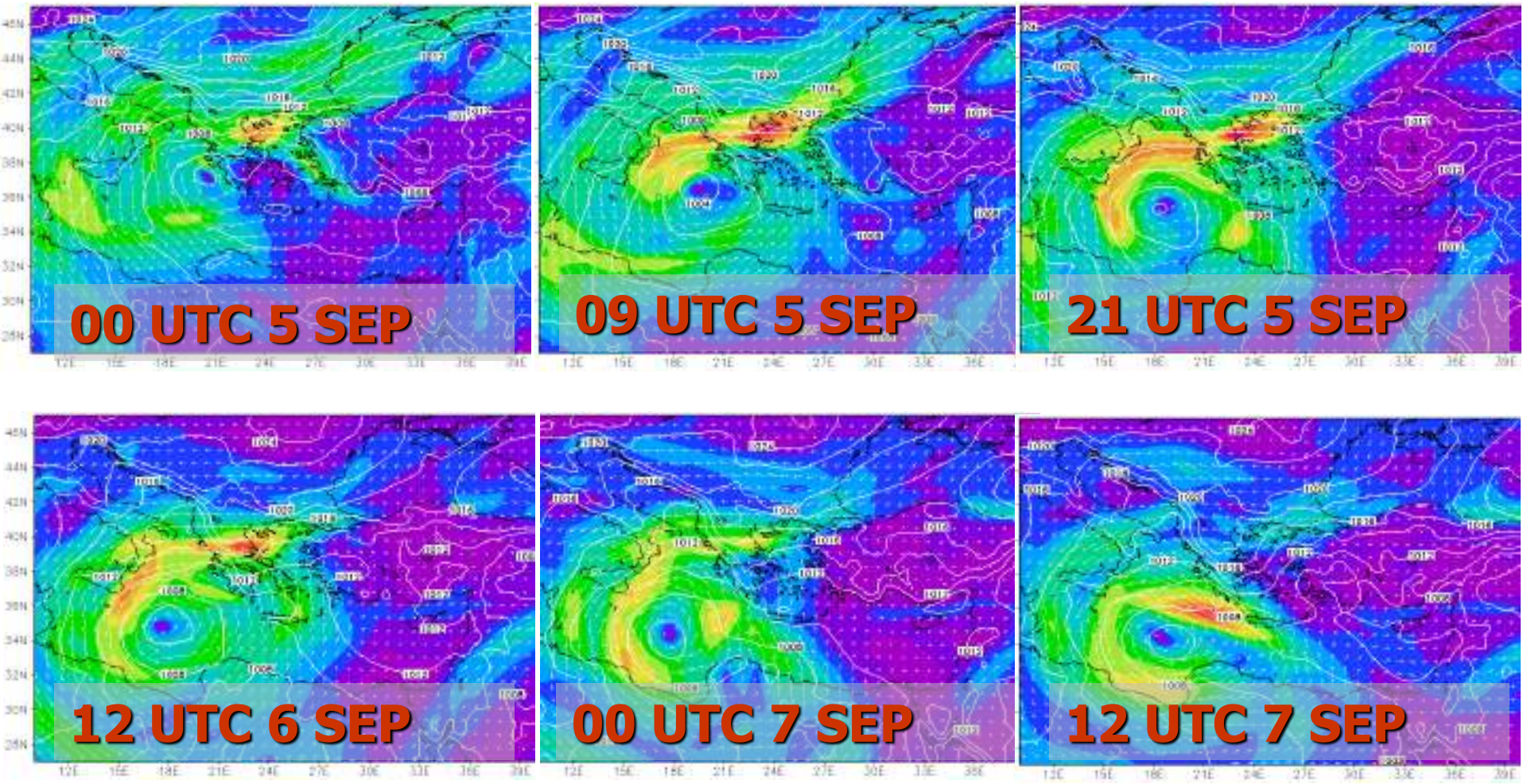
ERA5

950 hPa Divergence (10^{-5} s^{-1}) & wind

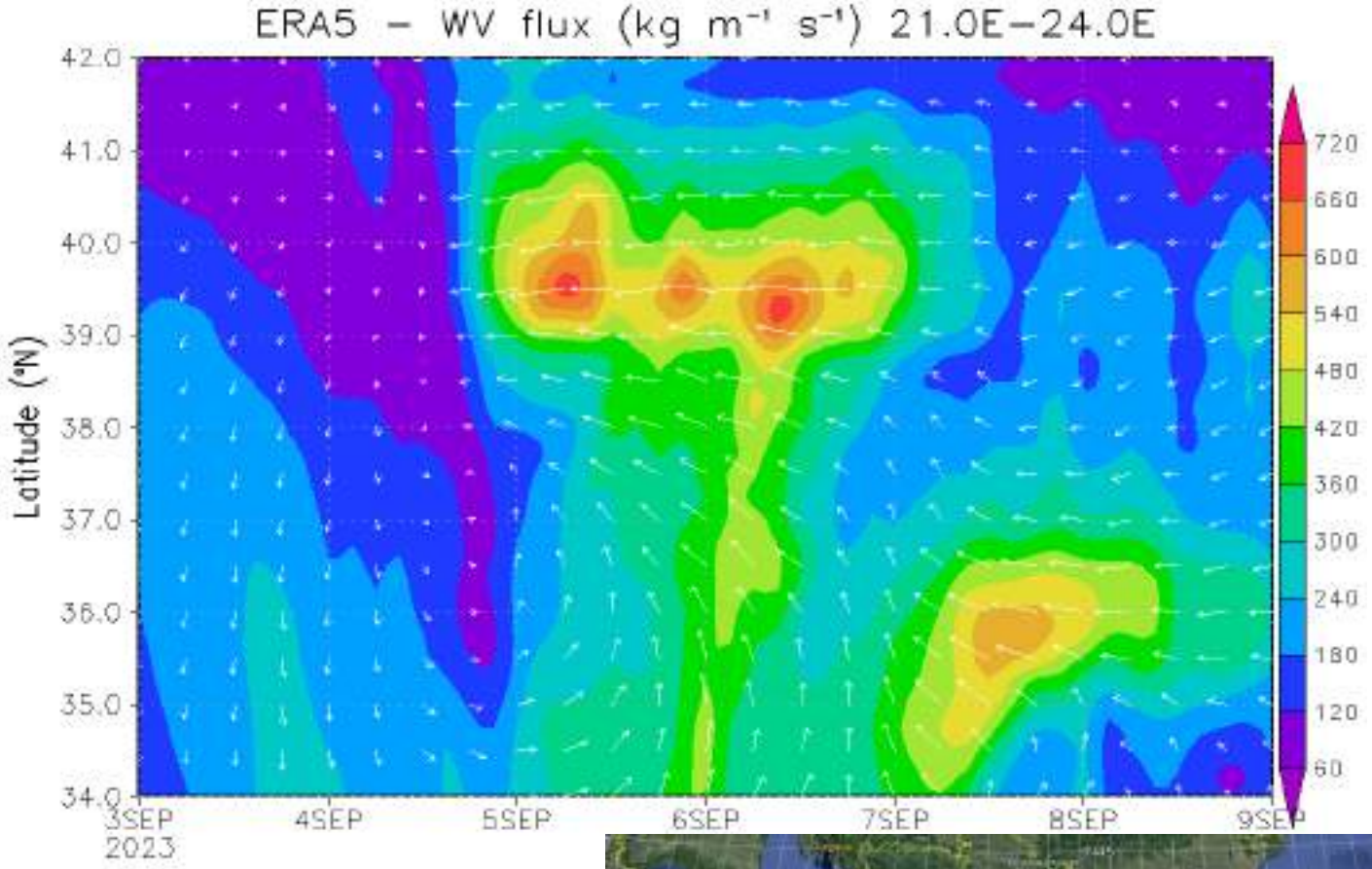


ERA5

MSLP & IVT (kg m^{-1} s^{-1})

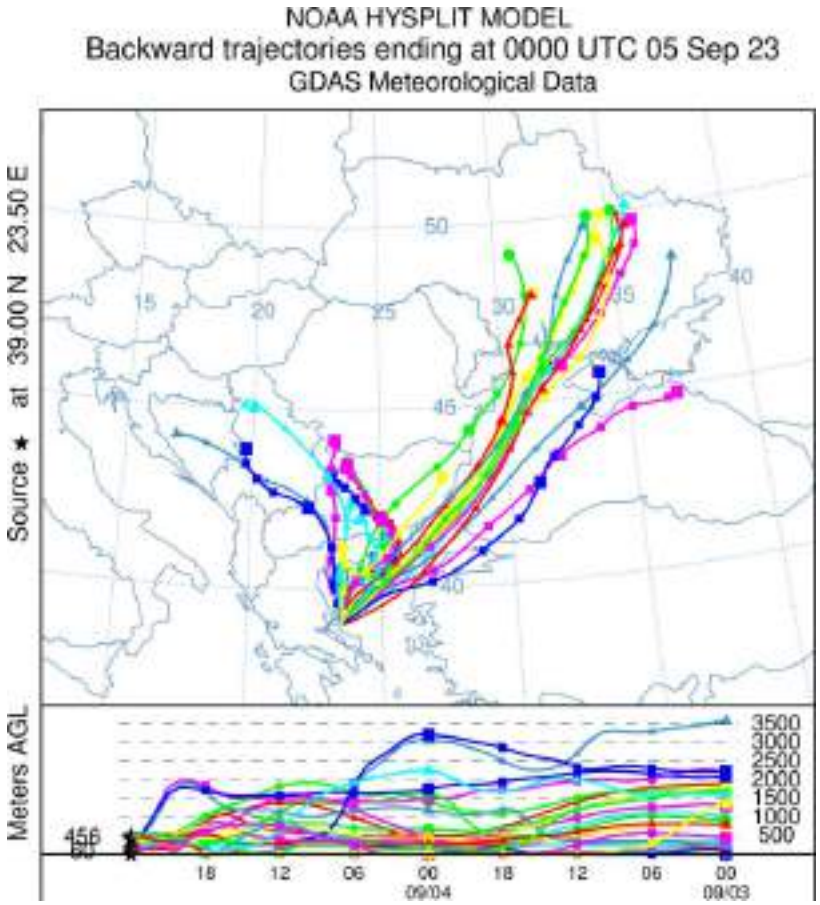


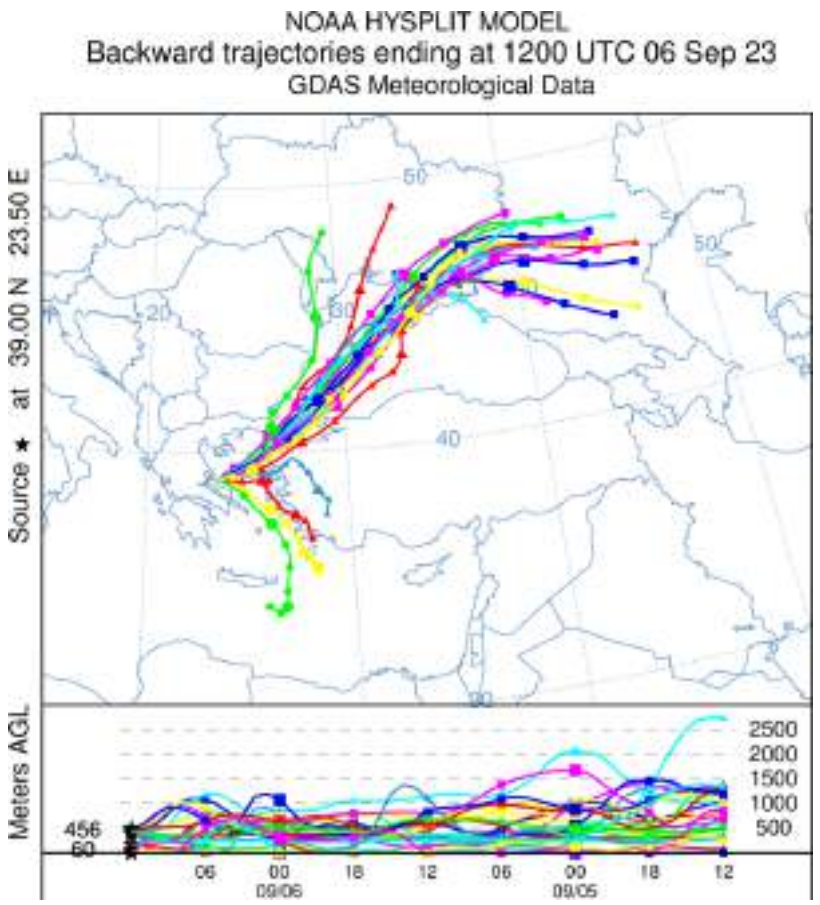
ERA5


ERA5 – WV flux (kg m⁻¹ s⁻¹) 21.0E–24.0E
Latitude (°N)
42.0
41.0
40.0
39.0
38.0
37.0
36.0
35.0
34.0
3SEP
2023
4SEP
5SEP
6SEP
7SEP
8SEP
9SEP
720
660
600
540
480
420
360
300
240
180
120
60

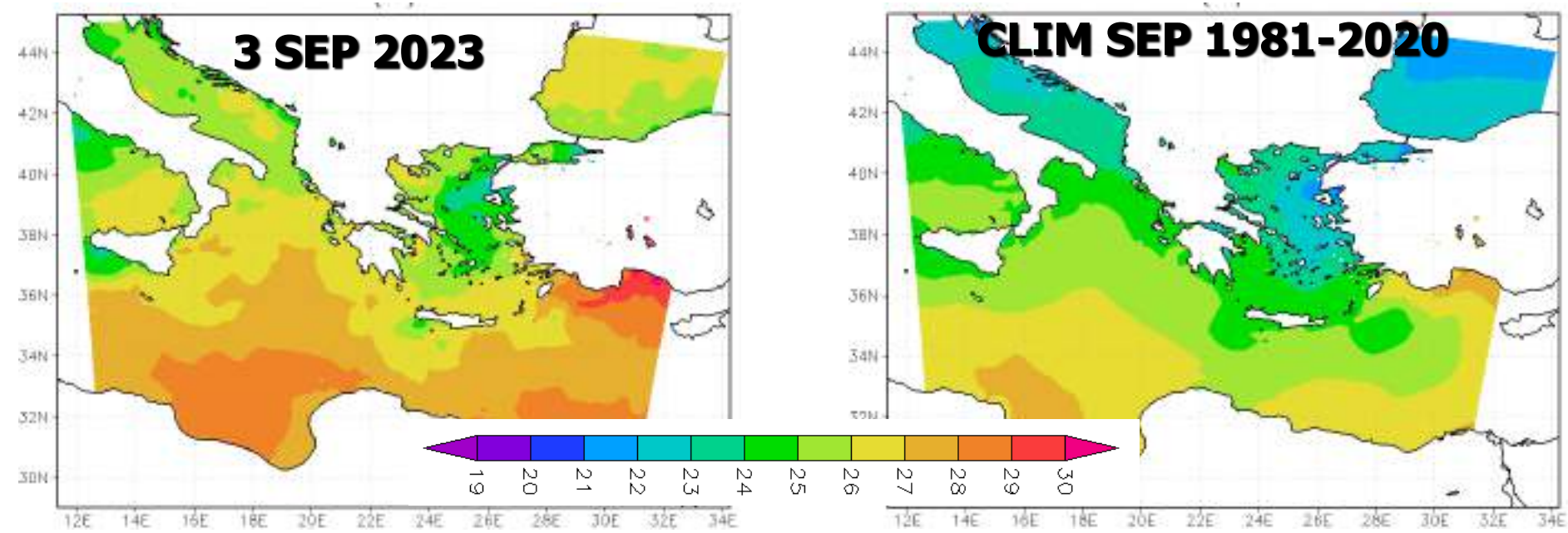

42°N
34°N

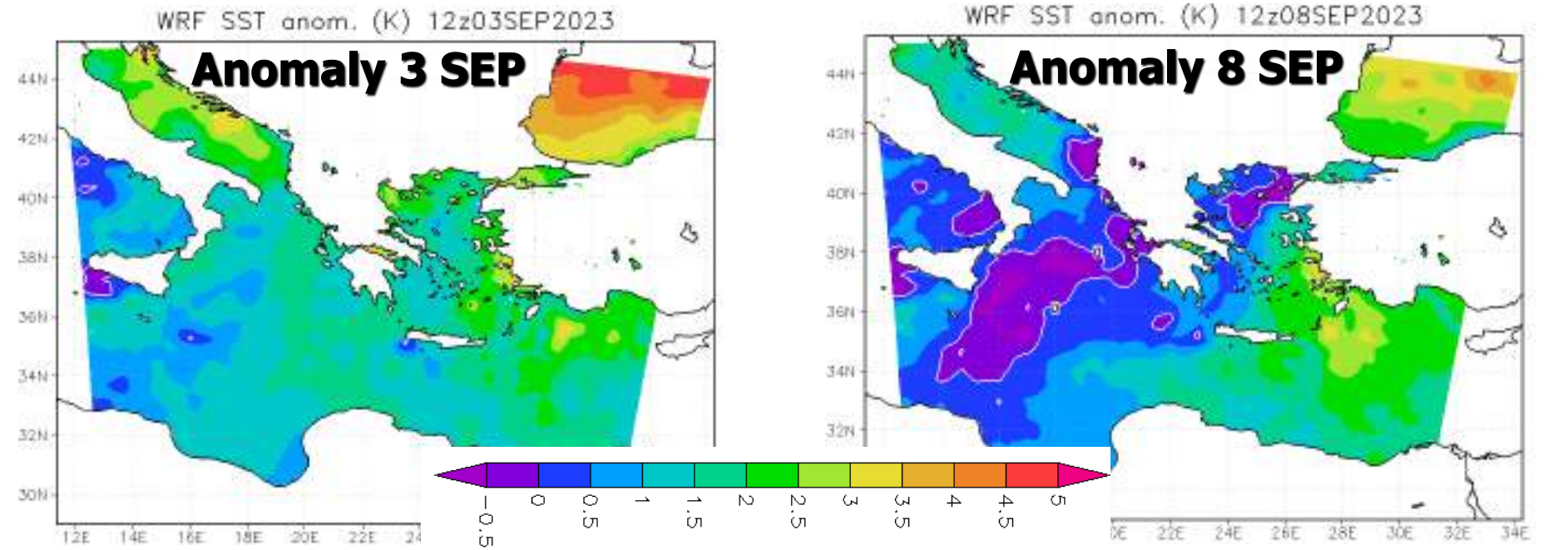
HYSPLIT -GDAS



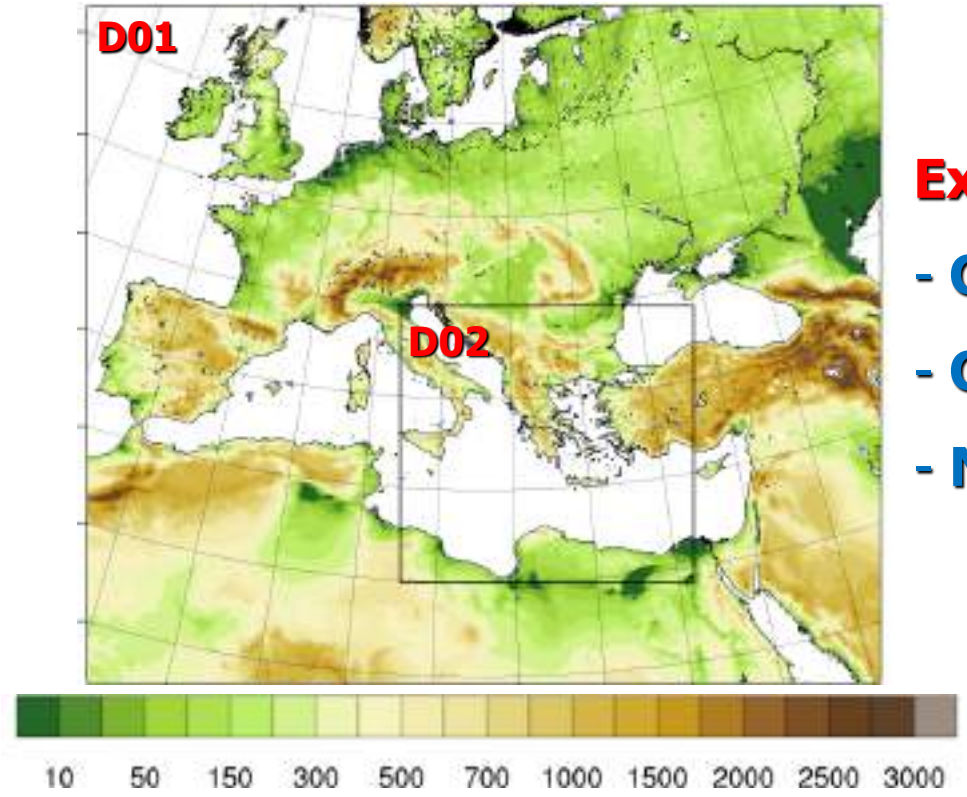


ERA5 SST


3 SEP 2023
CLIM SEP 1981-2020
19 20 21 22 23 24 25 26 27 28 29 30


WRF SST anom. (K) 12z03SEP2023
Anomaly 3 SEP
WRF SST anom. (K) 12z08SEP2023
Anomaly 8 SEP
−0.5 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5

WRF-ARW model V4.3.3



Experiments

- **CTRL**: control run
- **CLIM**: clim ERA5 SST, Sep 1981-2020
- **NOFLX**: no surface fluxes

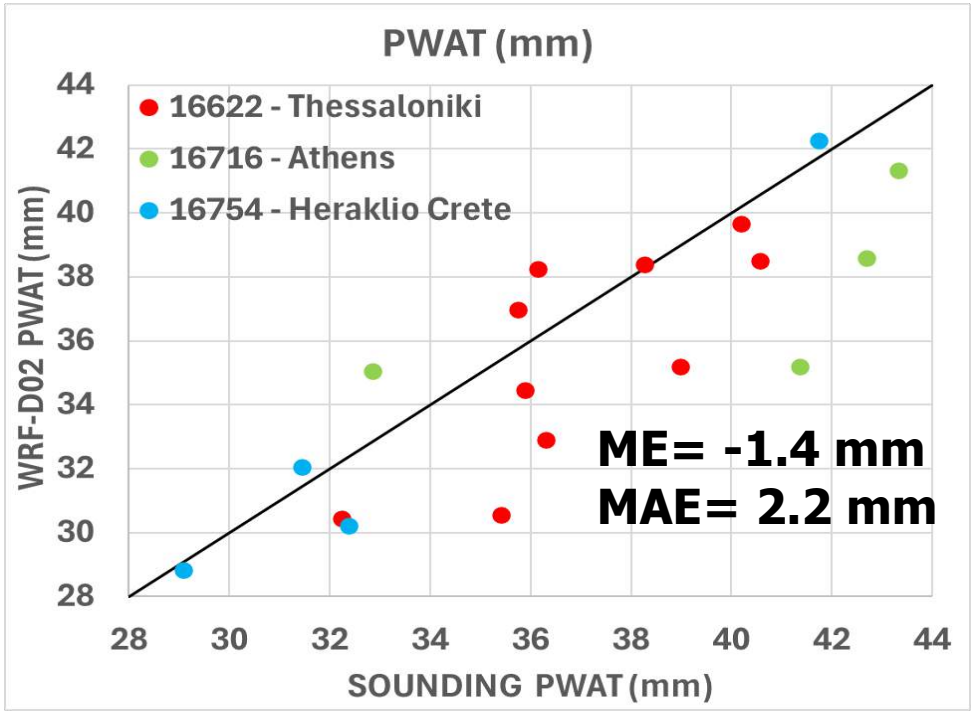
- Horizontal grid-spacing: 10 km x 10 km (D01), 3.3 km x 3.3 km (D02), 2-way
- 51 sigma levels up to 50 hPa
- Initial and boundary conditions: 0.25° x 0.25° 3-hourly ERA5
- SSTs: ERA5 updated or climatological
- Init: 12 UTC, 03 SEP 2023
- WSM6 microphysics, Kain-Fritsch convection (D01), YSU pbl, MM5 surface layer

Model Verification – WRF D02

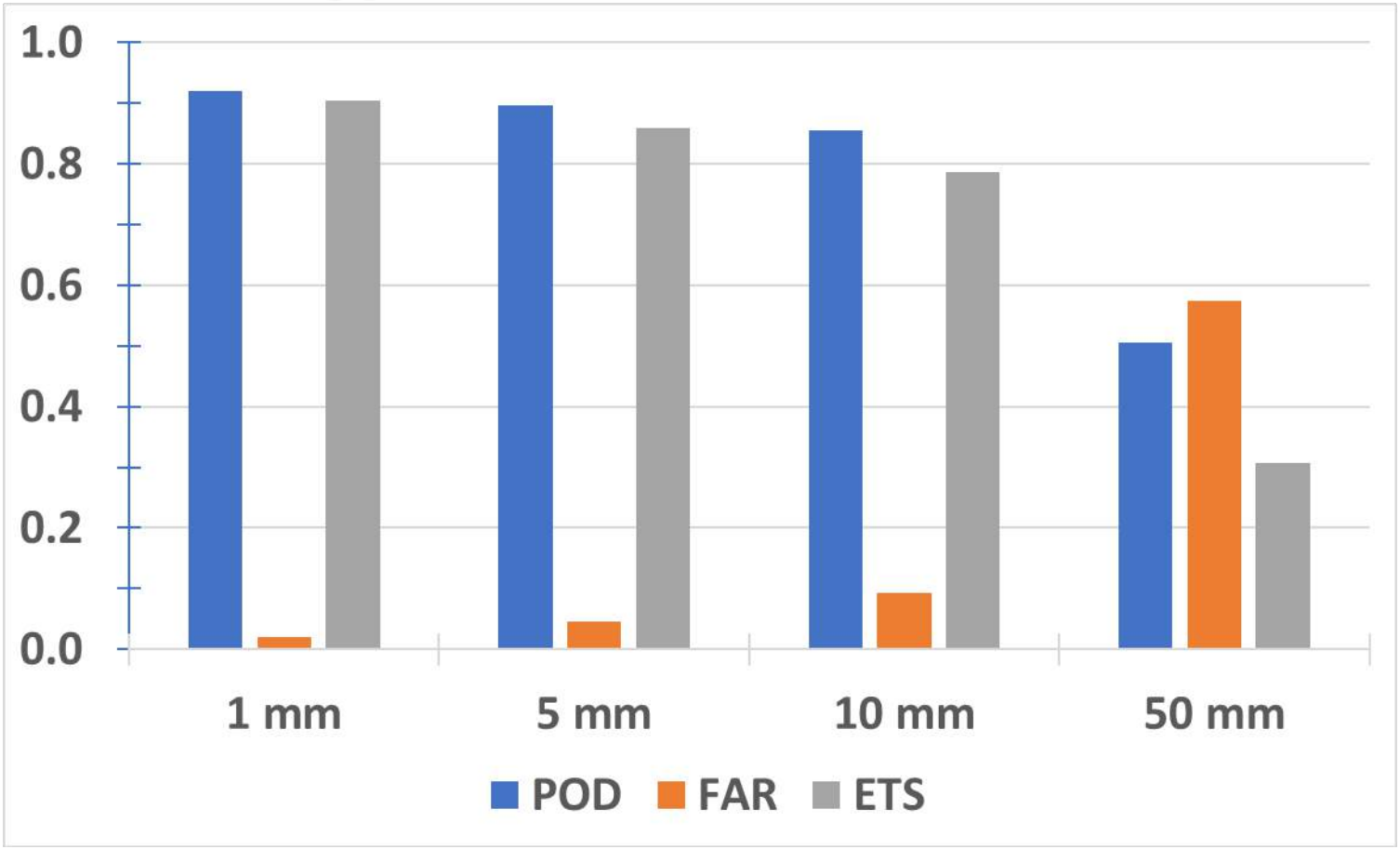
Stats: T+12 to T+120 hrs, 3hr (00 UTC 04 Sep – 12 UTC 08 Sep 2024)

29 Greek stations of HNMS

Parameter	Mean Error	Mean Absolute Error
mslp (hPa)	0.0	0.9
Temp. 2m (K)	-0.4	1.6
Rel. Hum. 2m (%)	-0.8	10.0
Wind speed (m/s)	1.6	2.4



Precipitation - Neighborhood based verification (methodology of Clark et al. 2010, Wea. & Forecast.)

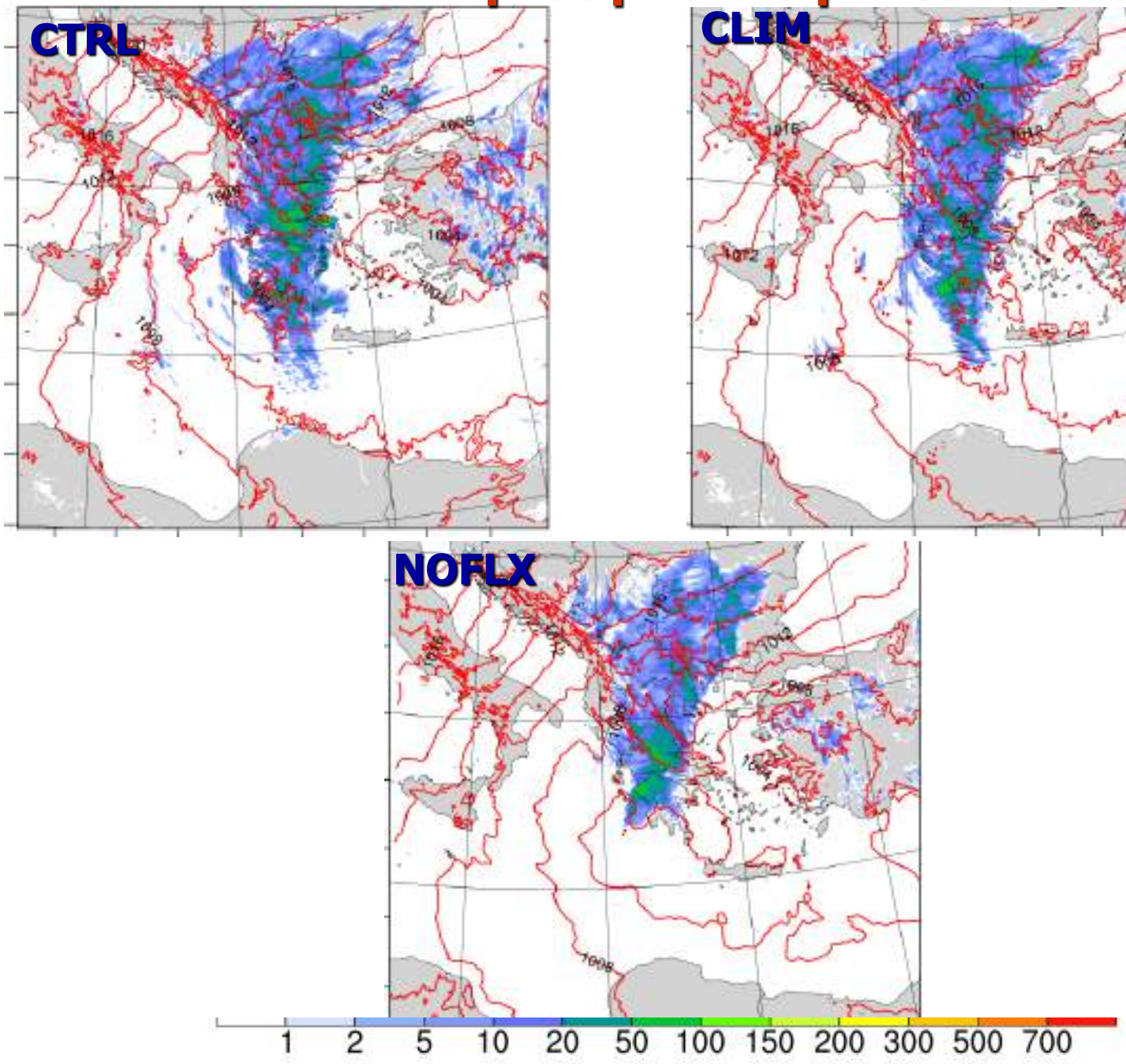


WRF-D02 vs Radar

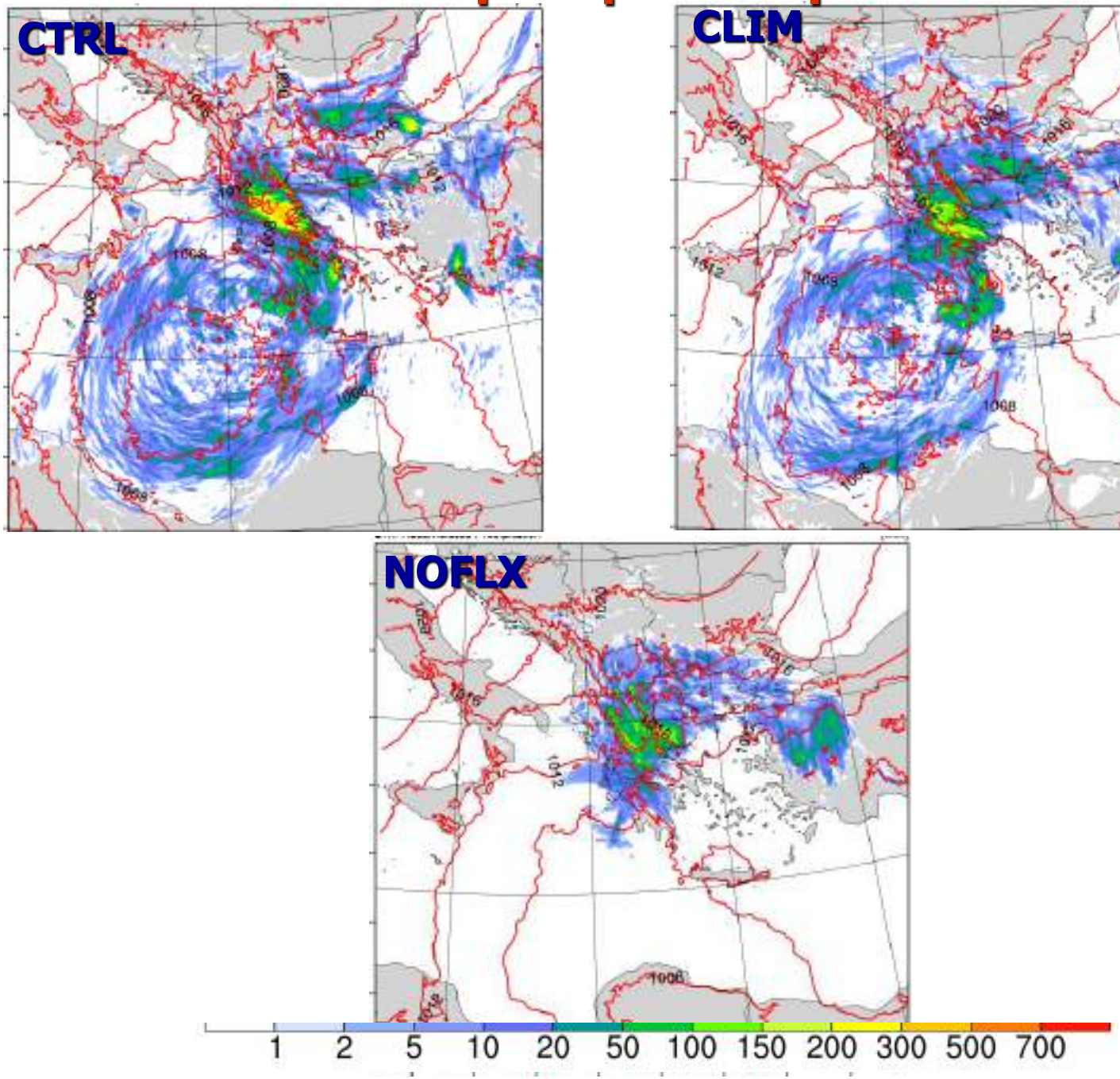
24 hr intervals:

00 UTC 4 Sep – 00 UTC 5 Sep
00 UTC 5 Sep – 00 UTC 6 Sep
00 UTC 6 Sep – 00 UTC 7 Sep
00 UTC 7 Sep – 00 UTC 8 Sep

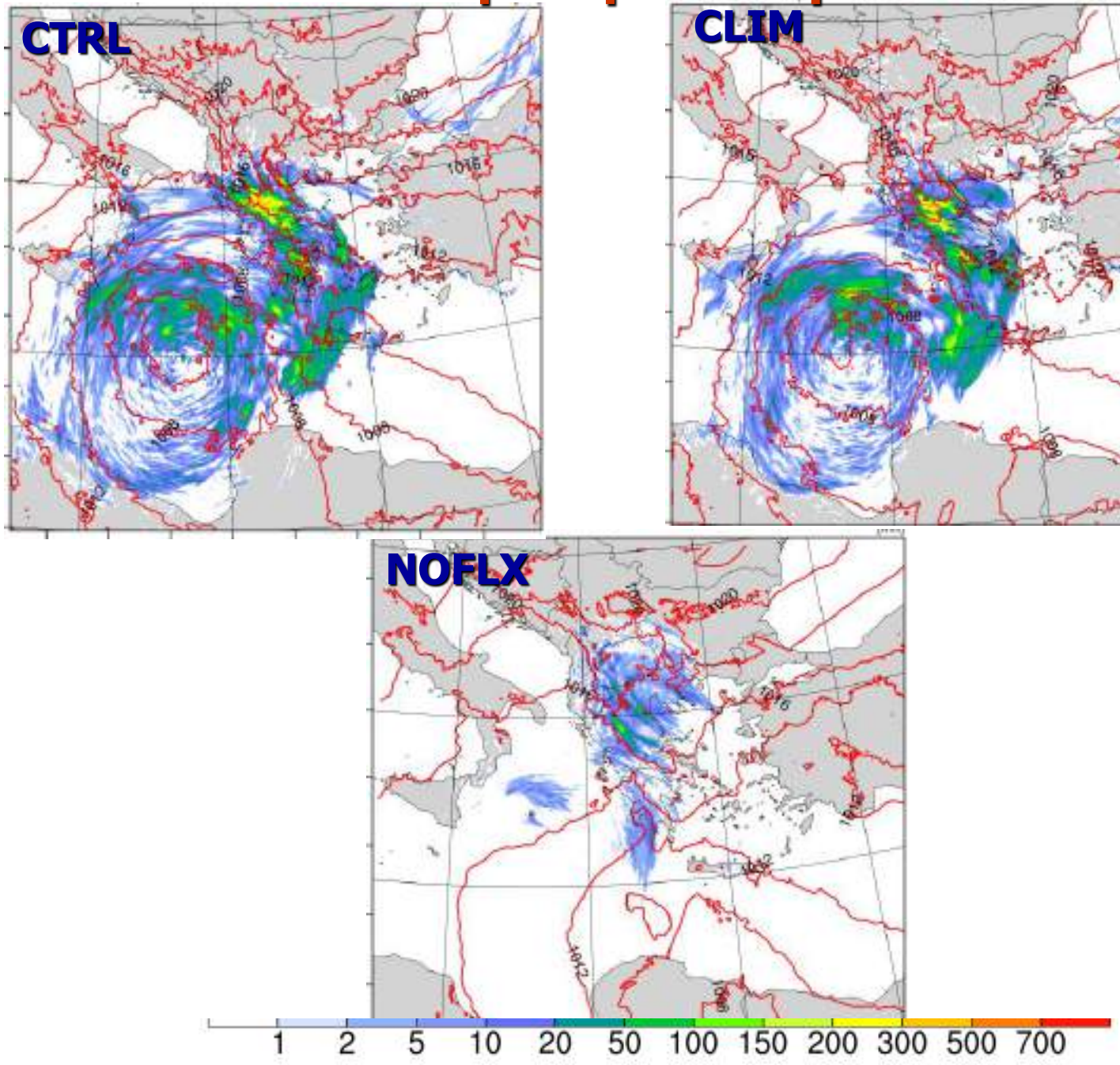
WRF D02 – 24hr precip & mslp – 00 UTC 5 Sep



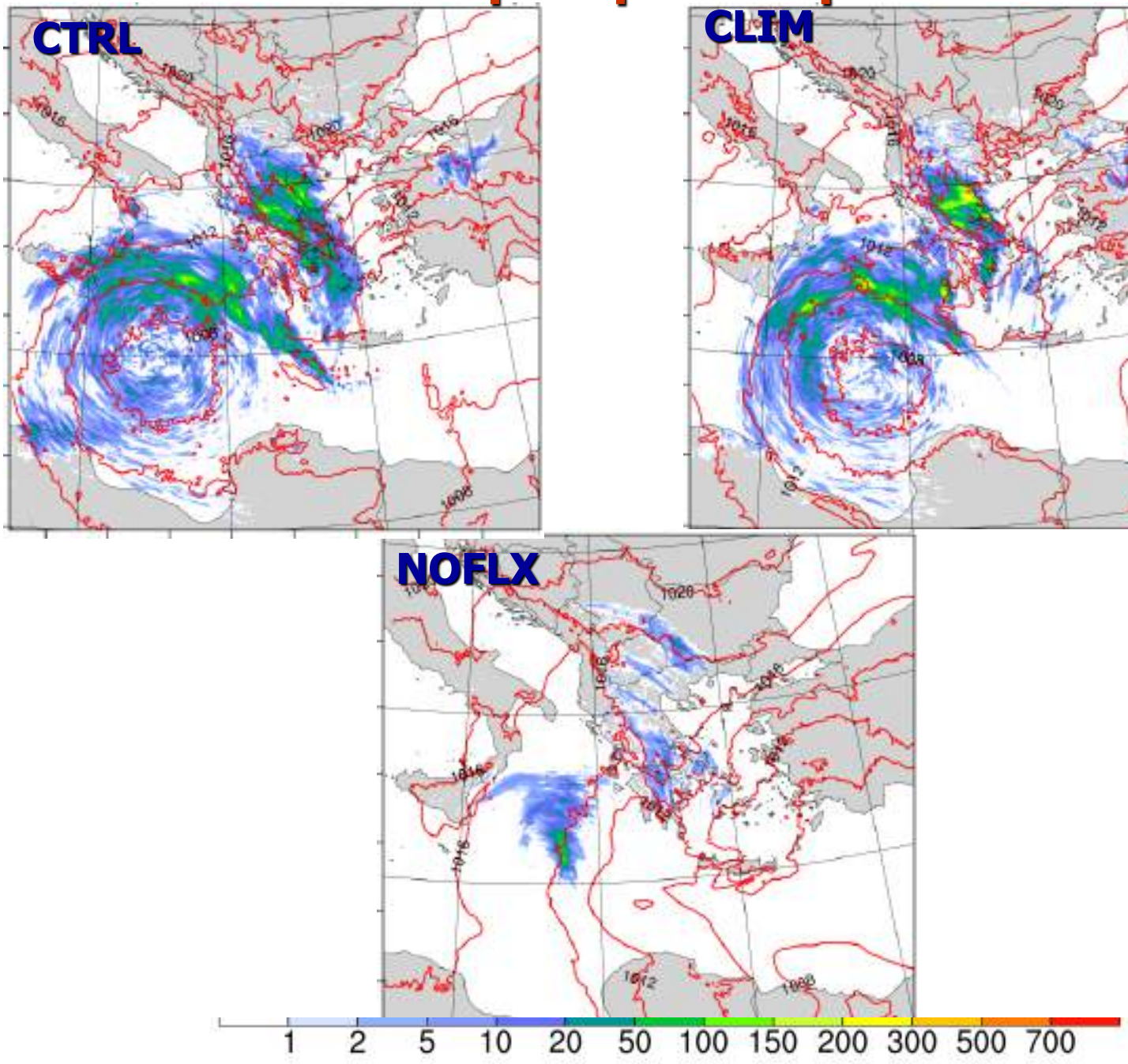
WRF D02 – 24hr precip & mslp – 00 UTC 6 Sep

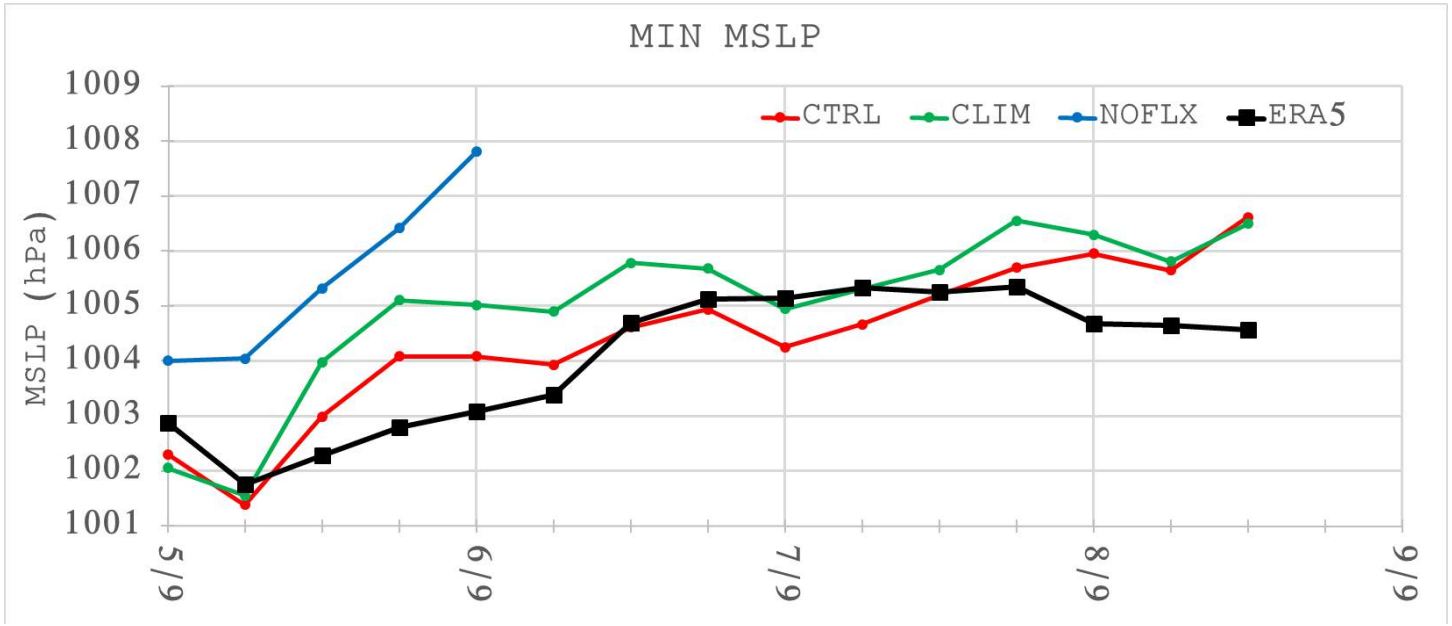


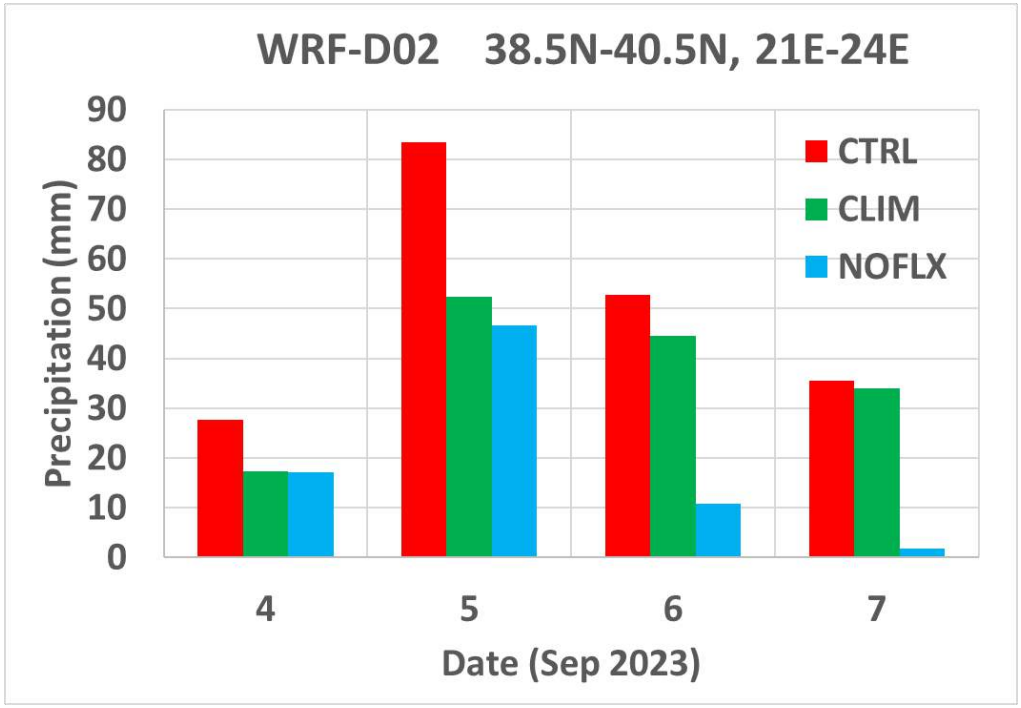
WRF D02 – 24hr precip & mslp – 00 UTC 7 Sep



WRF D02 – 24hr precip & mslp – 00 UTC 8 Sep

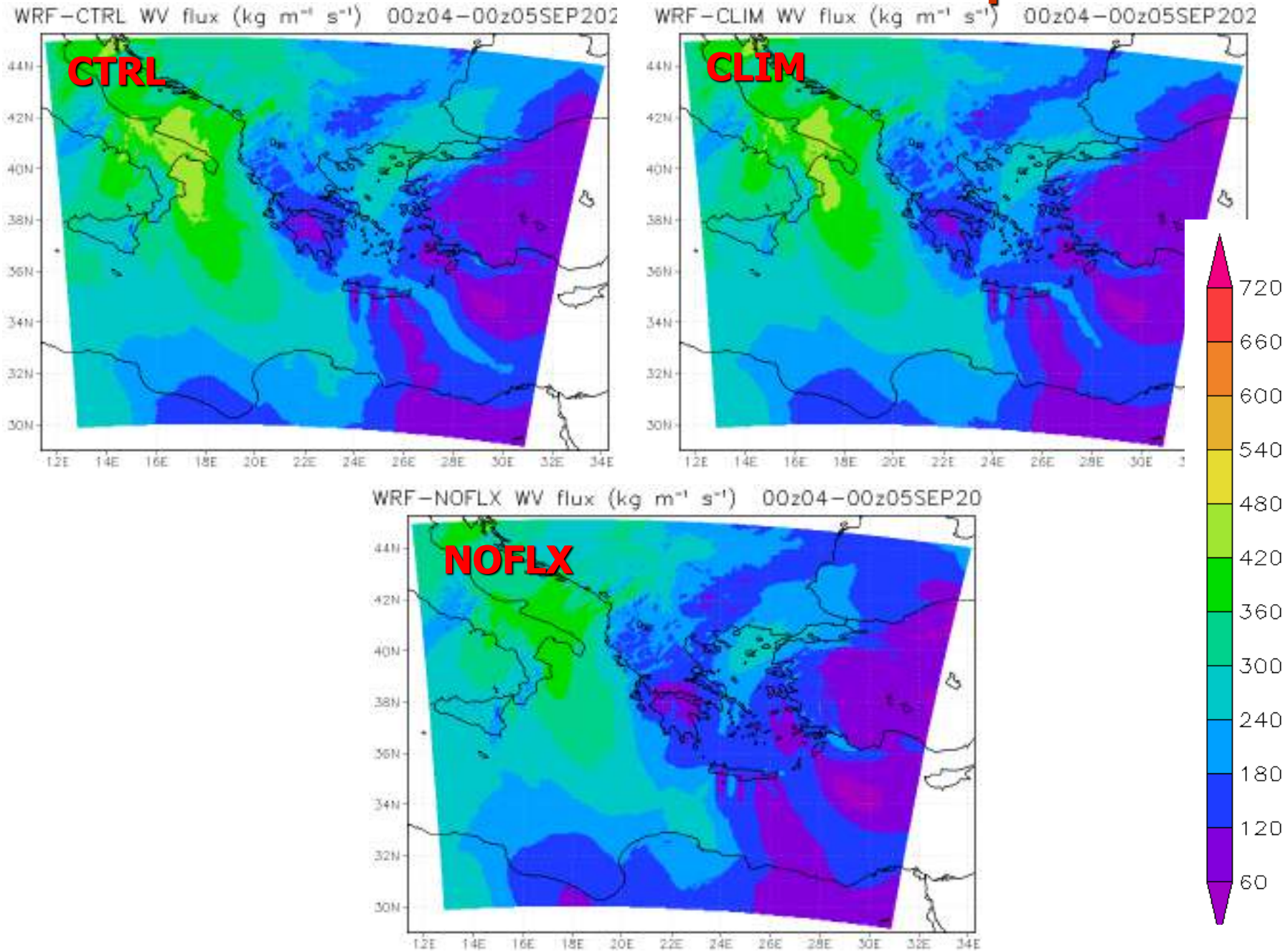



MIN MSLP
CTRL
CLIM
NOFLX
ERA5
MSLP (hPa)
1009
1008
1007
1006
1005
1004
1003
1002
1001
5/9
6/9
7/9
8/9
9/9

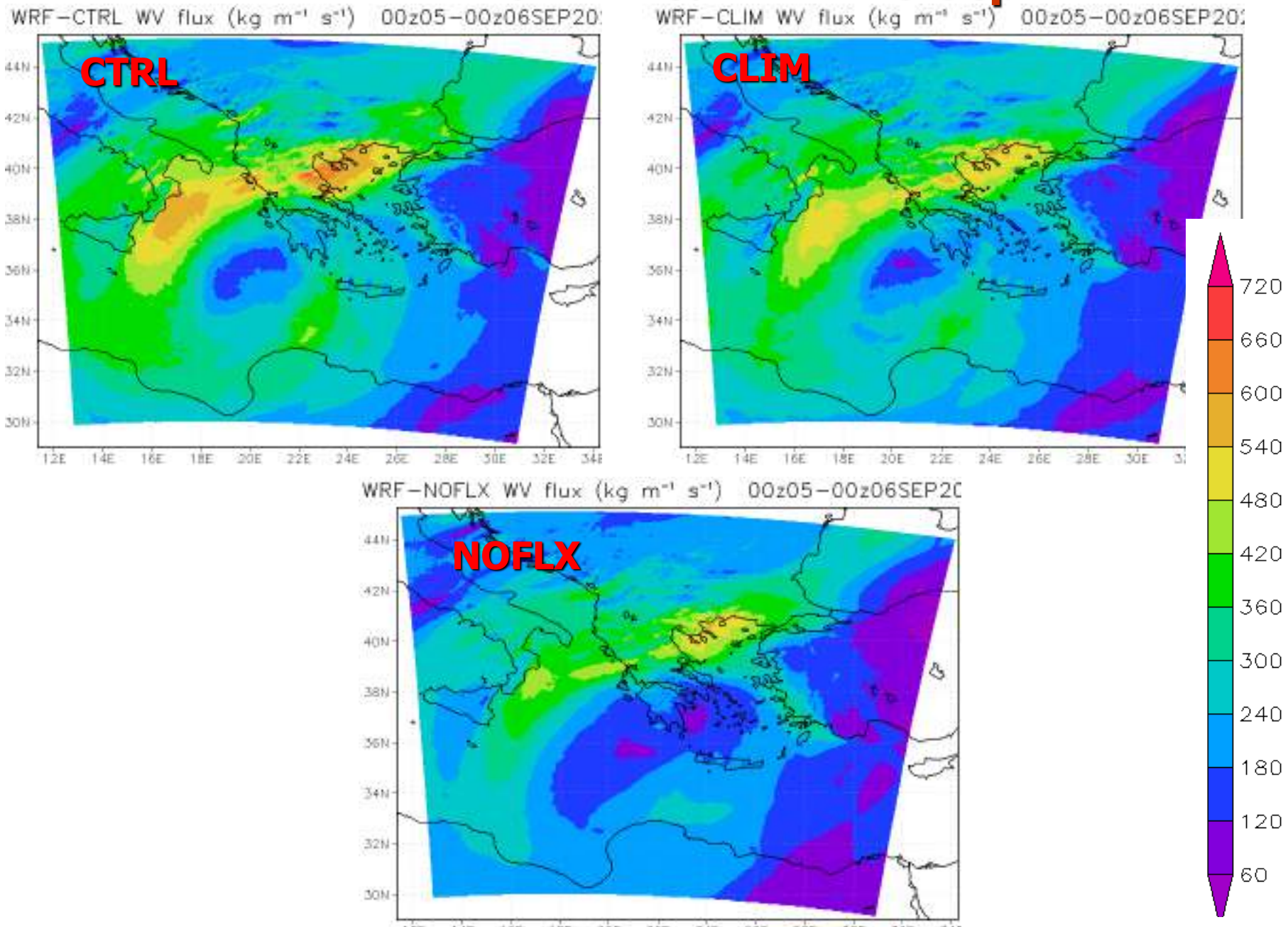

WRF-D02 38.5N-40.5N, 21E-24E
Precipitation (mm)
90
80
70
60
50
40
30
20
10
0
CTRL
CLIM
NOFLX
4
5
6
7
Date (Sep 2023)


North Macedonia
Albania
Greece
N41°
N39°
N37°
N35°
19°
E21°
E25°
E27°

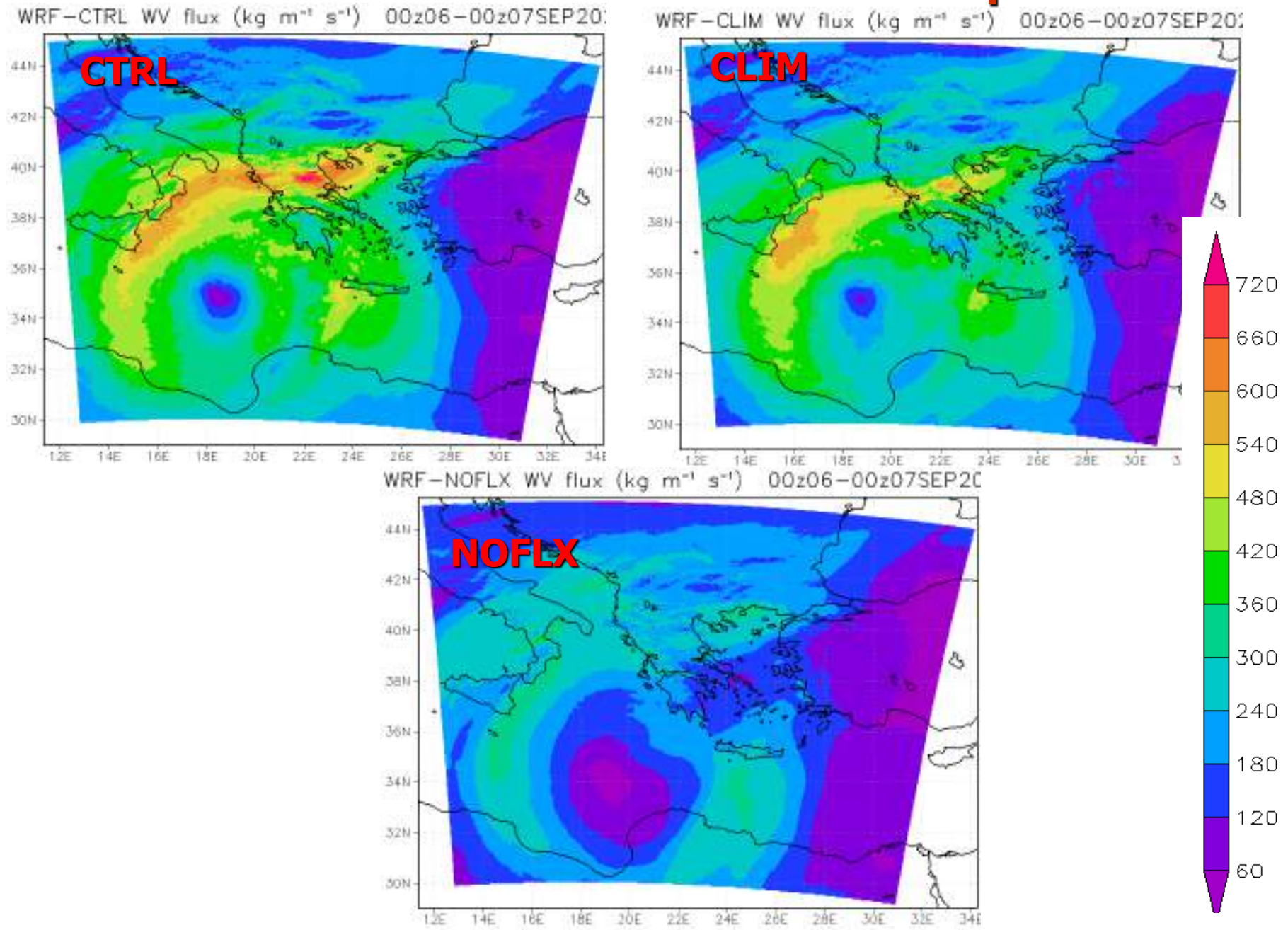
WRF D02 – mean IVT – 4 Sep



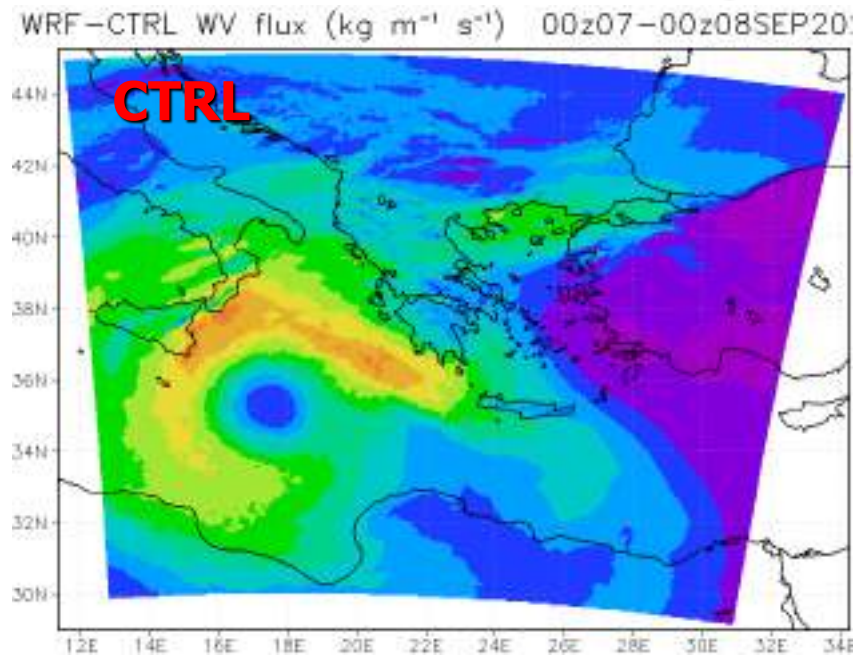
WRF D02 – mean IVT – 5 Sep

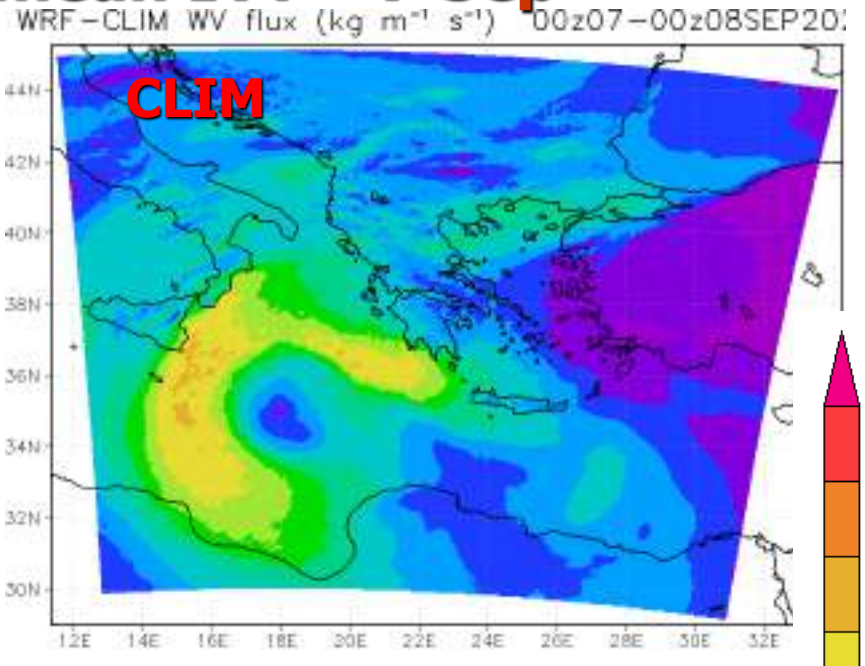


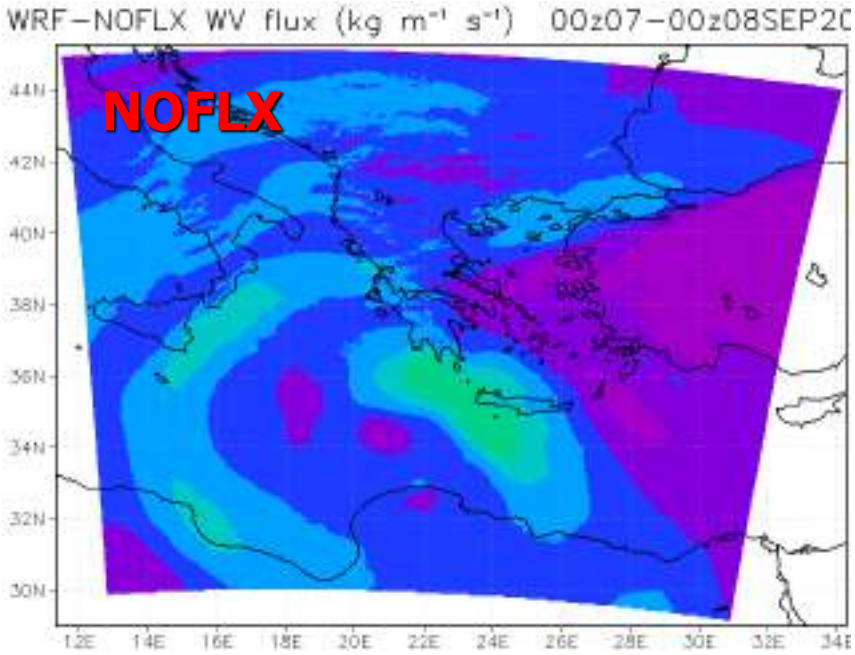
WRF D02 – mean IVT – 6 Sep

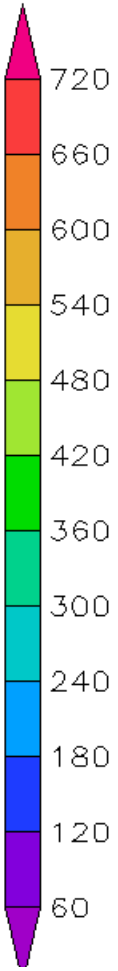


WRF D02 – mean IVT – 7 Sep









SUMMARY - CONCLUSIONS

- Extreme precipitation occurred in the eastern Mediterranean in early September 2023, in association with the development of medicane Daniel.
- Casualties were recorded in Libya, Greece, Turkey and Bulgaria, as well as billions of euros in damages.
- This work focused in Greece where the 4-day precipitation amounts 1000 mm exceeded locally.
- The main drivers of the severe weather were:

  -The development of cyclone Daniel over the Ionian sea due to the penetration of an upper air cold trough located on the eastern flank of an omega blocking.

  - The easterly flow over the Aegean sea due to the combination of an anticyclone over eastern Europe with cyclone Daniel. This flow transported large amounts of moisture, comparable to atmospheric rivers, over the eastern mainland of Greece where strong convergence and updraft occurred.

SUMMARY - CONCLUSIONS

- The warm SSTs that prevailed in the eastern Mediterranean (up to about 2.5 K) and the Black sea (> 2.5-3K) prior to the event appeared to be important for the intensity of the precipitation over Greece.
- The numerical experiments suggested that intense precipitation would occur even with colder climatological SSTs.
- The lack of surface fluxes did not allow the initial cyclone to develop. However, even in this case the transport of the pre-existing moisture would result to intense phenomena in central Greece during the first two days.

Results presented in this work have been produced using the Aristotle University of Thessaloniki (AUTh) High Performance Computing Infrastructure and Resources.