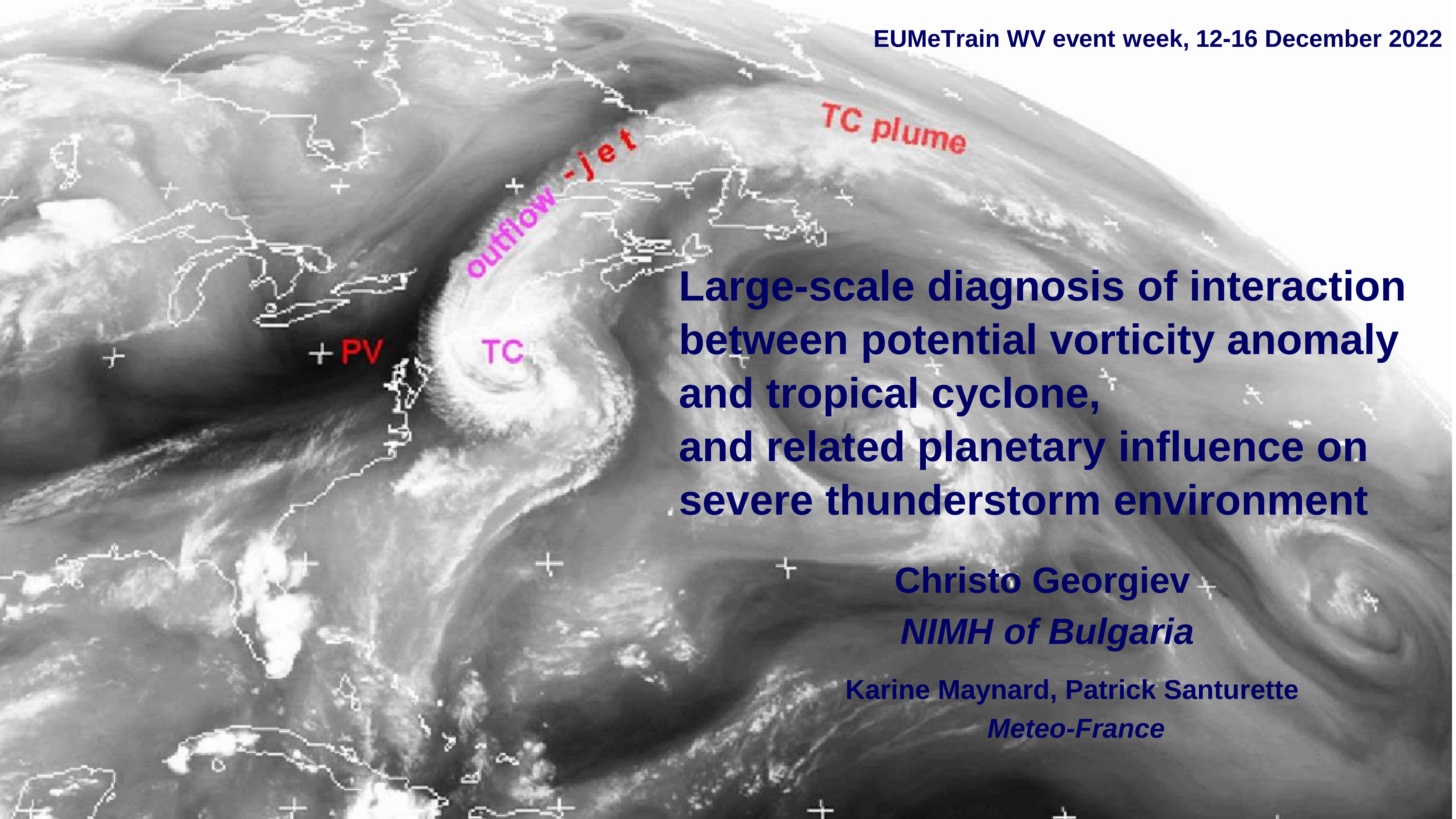
EUMeTrain WV event week, 12-16 December 2022



Large-scale diagnosis of interaction between potential vorticity anomaly and tropical cyclone, and related planetary influence on severe thunderstorm environment

Christo Georgiev
NIMH of Bulgaria

Karine Maynard, Patrick Santurette
Meteo-France

OUTLINE

✓ **Use of WV channel images in operational forecasting environment**

1. As a diagnostic tool in the process of prediction of Extratropical Transition (ET) of a Tropical cyclone (TC), a gradual process in which a TC loses tropical characteristics and becomes more extratropical in nature;
2. To identify thunderstorm potentials while the convective system is still in a pre-convective state.

1. Extratropical transition (ET) of a TC

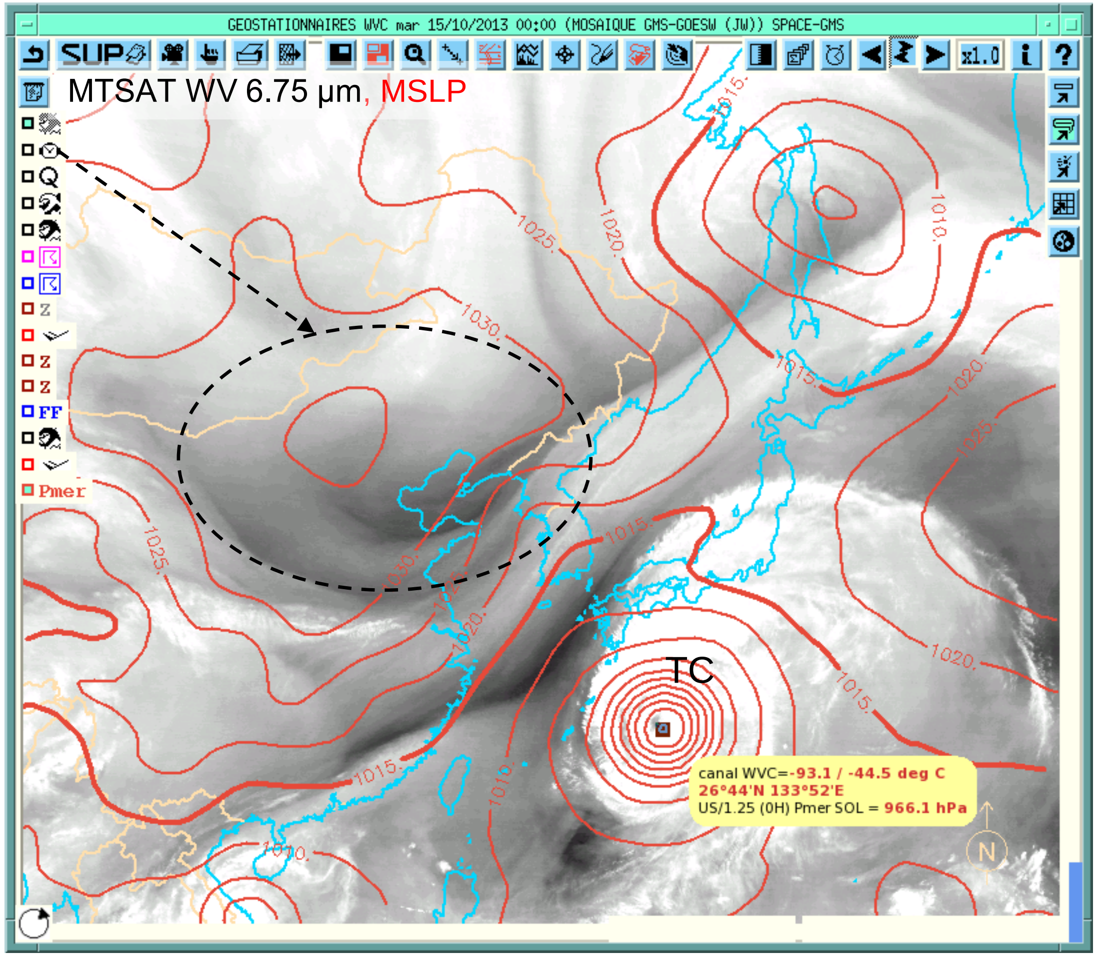
Typhoon_WIPHA 2013 , western Pacific:

- 12-14 October 2013: Persistent tropical intensification of the storm, growing to a very large system.

Approaching the mid-latitudes, the ocean waters surrounding is cooling down, but the storm carries its tropical origin of a much deeper surface low than any mid-latitude system (*in the MSLP field, red contours*).

- Transitioning to an extratropical (ET) system may be governed by much stronger (than tropical) mid-latitude upper-level dynamics:
- 15-16 October: ‘‘ Explosive “ extratropical transition and rapid deepening as a result of interaction with a mid-latitude trough and potential vorticity (PV) anomaly.

WIPHA , 15 Oct 2013 00 UTC



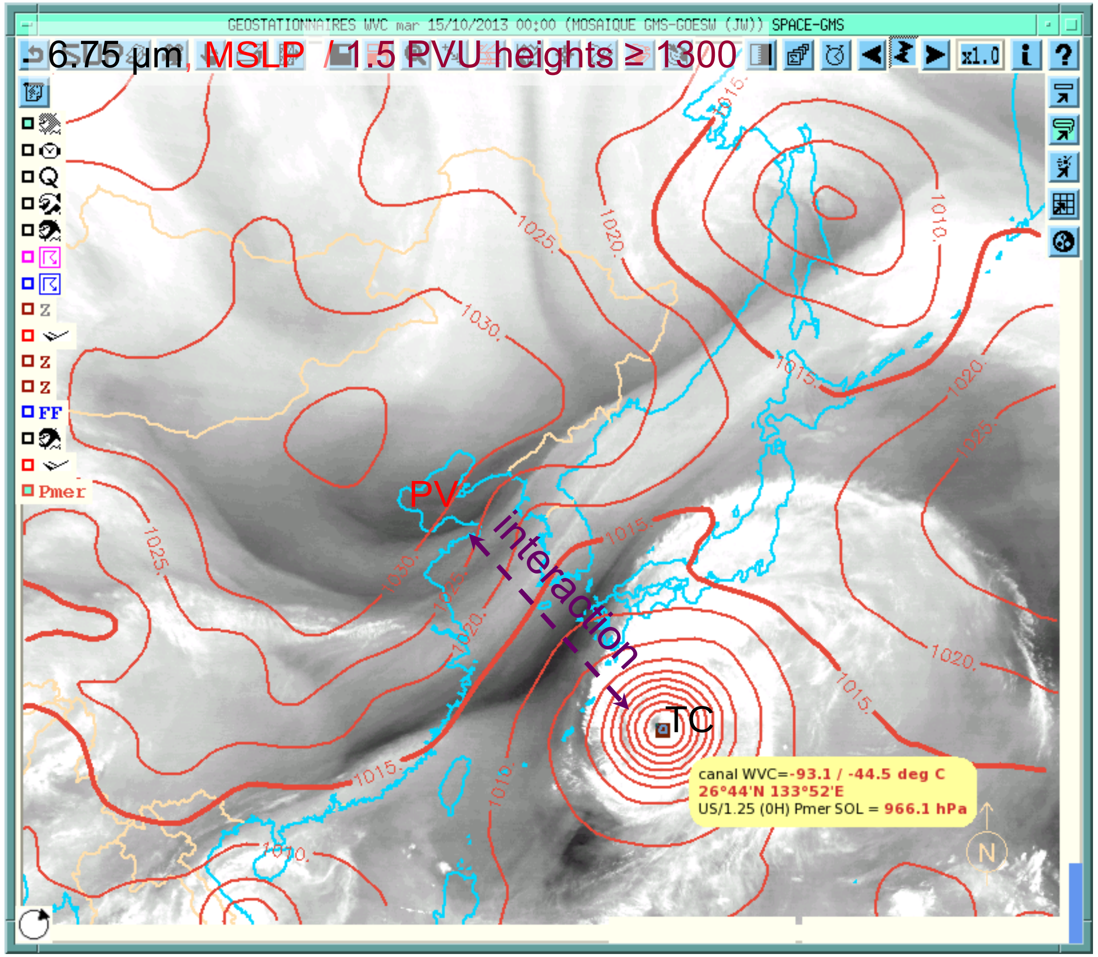
Extratropical transition (ET) of TCs

PV anomaly can influence and control the ET process (Agustí-Panareda et al., 2004; Santurette and Georgiev, 2005; Georgiev, Santurette, Maynard, 2016).

To evaluate the role of the PV anomaly advection at the onset of ET and the efficiency of using WV imagery to check on the validity of the NWP forecasts.

Sensitivity study: Using the PV inversion method coupled to the ARPEGE model (Meteo-France, Arbogast et al., 2008) for modification of the initial conditions.

WIPHA , 15 Oct 2013 00 UTC

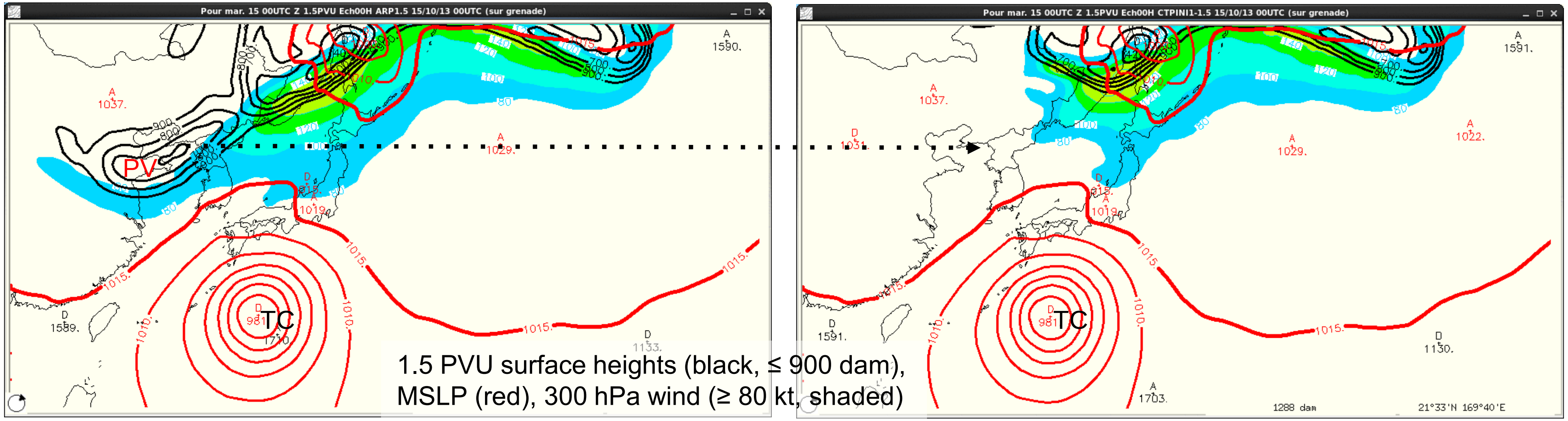


PV anomaly , (low geopotential of 1.5 PVU, which represent the dynamical tropopause surface, brown contours) seen as a dark dry feature in the WV image

PV modification *(Georgiev, C., Santurette, P., Meynard, K., 2016)*

CONTROL (operational) RUN

MODIFIED RUN



1.5 PVU surface heights (black, ≤ 900 dam), MSLP (red), 300 hPa wind (≥ 80 kt, shaded)

NWP initial state, 15 Oct 2013 00 UTC

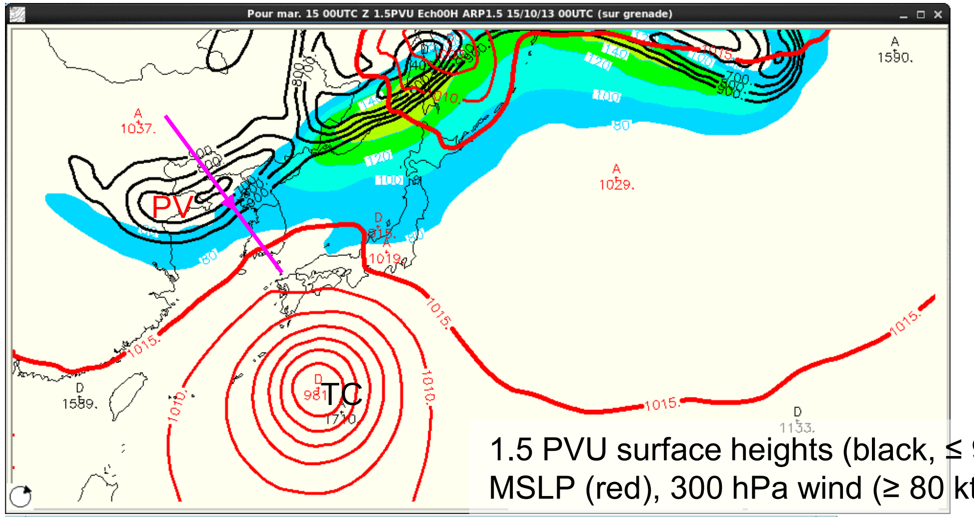
The PV modification:

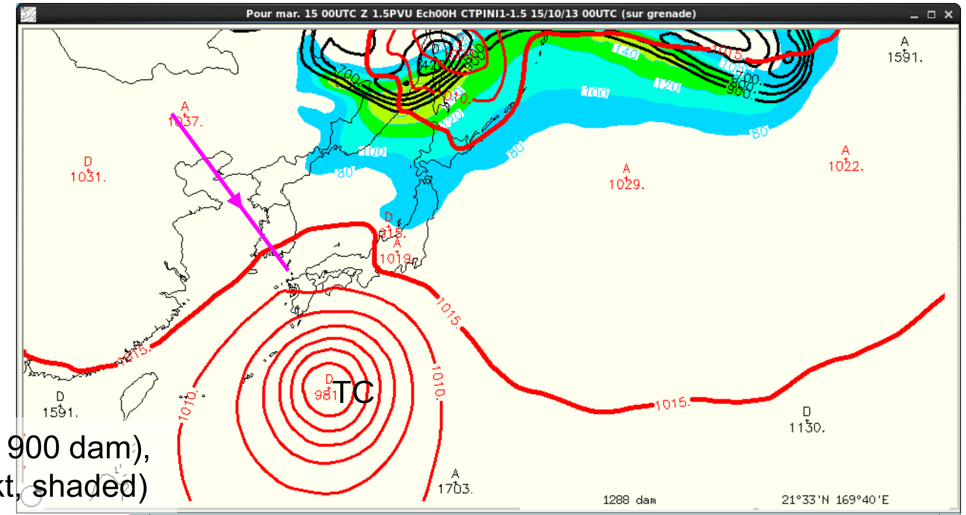
- The active part of the upper-level PV anomaly at most equatorward side of the trough is removed.
- This has an effect of removing related jet stream (colour shaded area) Northwest of the TC.

PV modification *(Georgiev, C., Santurette, P., Meynard, K., 2016)*

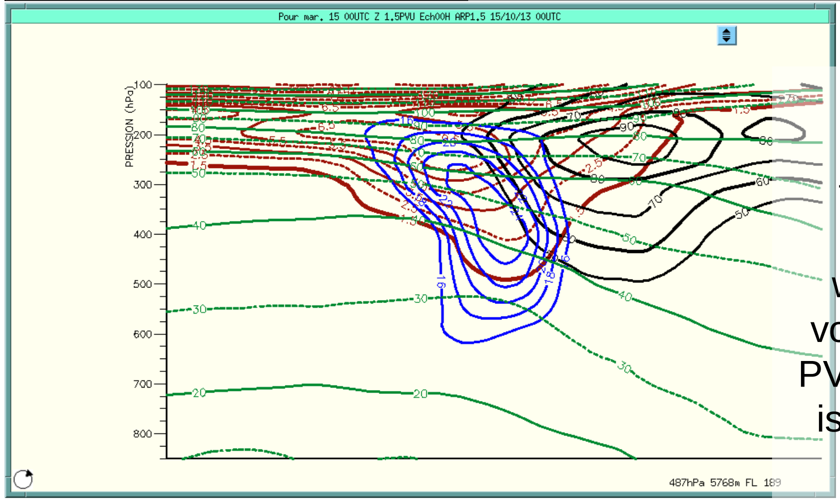
CONTROL (operational) RUN

MODIFIED RUN

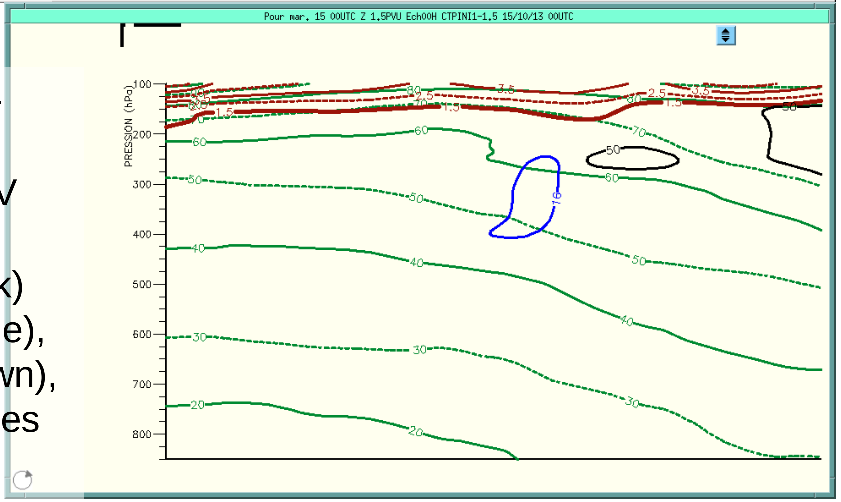




1.5 PVU surface heights (black, ≤ 900 dam), MSLP (red), 300 hPa wind (≥ 80 kt, shaded)



Vertical cross-sections at the removed PV anomaly:
wind max (black)
vorticity max (blue),
PV anomaly (brown),
isentropic surfaces (green)



Effects in response of the PV modifications:

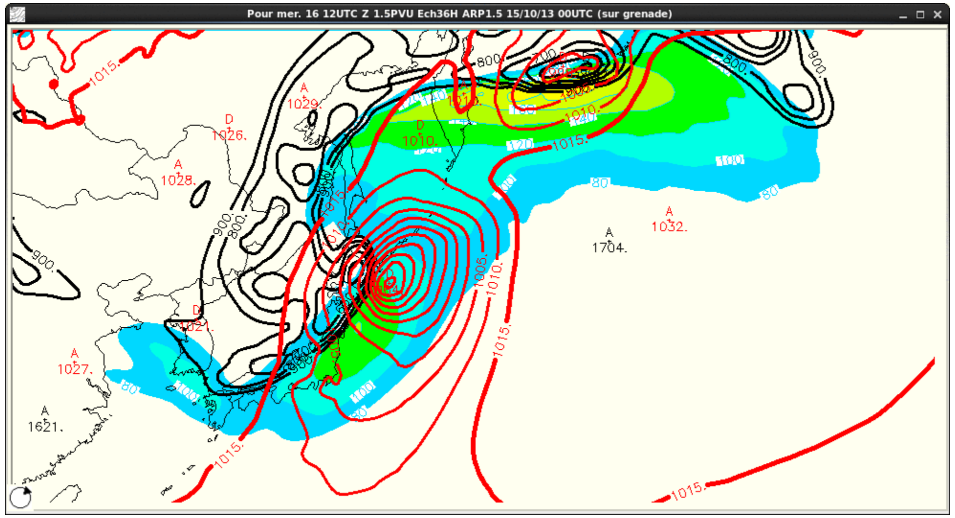
- The static stability is decreased between 500 hPa and 200 hPa (weaker vertical gradient of potential temperature, green contours that is determined by the new level of tropopause.
- Mid/upper-level relative vorticity (blue contours) is significantly decreased.

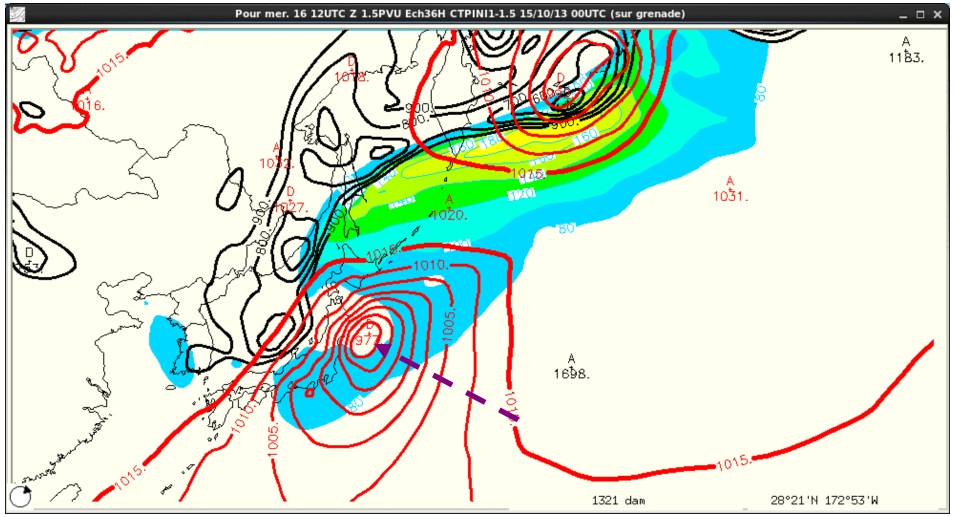
PV modification: 36-h NWP forecast

CONTROL (operational) RUN

MODIFIED RUN

1.5 PVU surface heights (black, ≤ 900 dam), MSLP (red), 300 hPa wind (≥ 80 kt, shaded area)





In the forecasts for periods longer than 30 h, differences between the operational and modified forecasts have increased significantly.

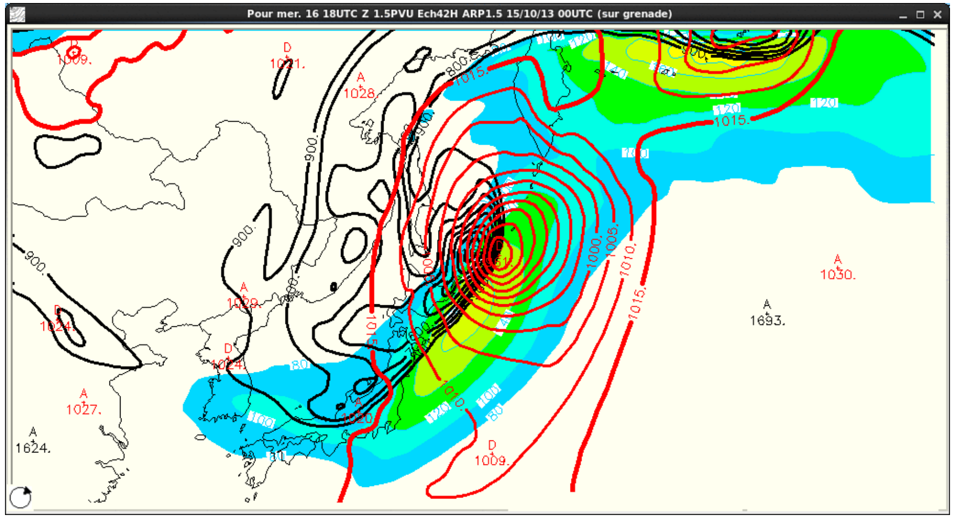
At the 36-h forecast, <u>in the modified run</u> the Extratropical Development is not well captured**:**

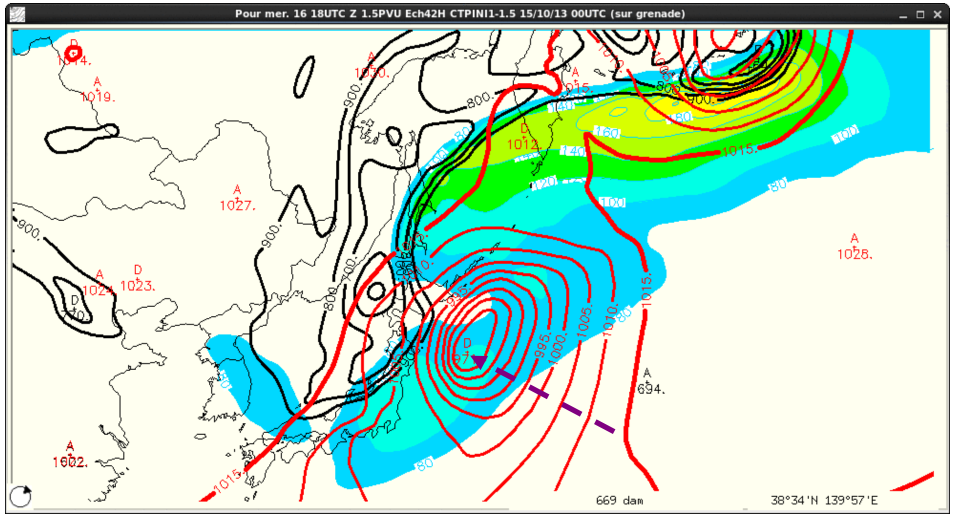
- **The northward movement of the cyclone is not simulated due to much weaker PV anomaly advection in the rear side of the TC.**
- **The surface low depth is underestimated by more than 15 hPa.**

PV modification: 42-h NWP forecast

CONTROL RUN | MODIFIED RUN

1.5 PVU surface heights (black, ≤ 900 dam), MSLP (red), 300 hPa wind (≥ 80 kt, shaded area)





At the 42-h forecast, <u>in the modified run</u>:

- The low depth is underestimated by more than 20 hPa.
- The modified run was different in track and position of the low center due to the simulated much weaker upper-level southwesterly flow (colour shaded).

- **The sensitivity experiment confirms that the interaction with a cyclonic upper-level PV anomaly is a critical factor in the ET process.**
- **Any uncertainties in the initial simulation of upper-level dynamics may amplify and result in significant NWP errors in the forecast of ET development of the storm.**

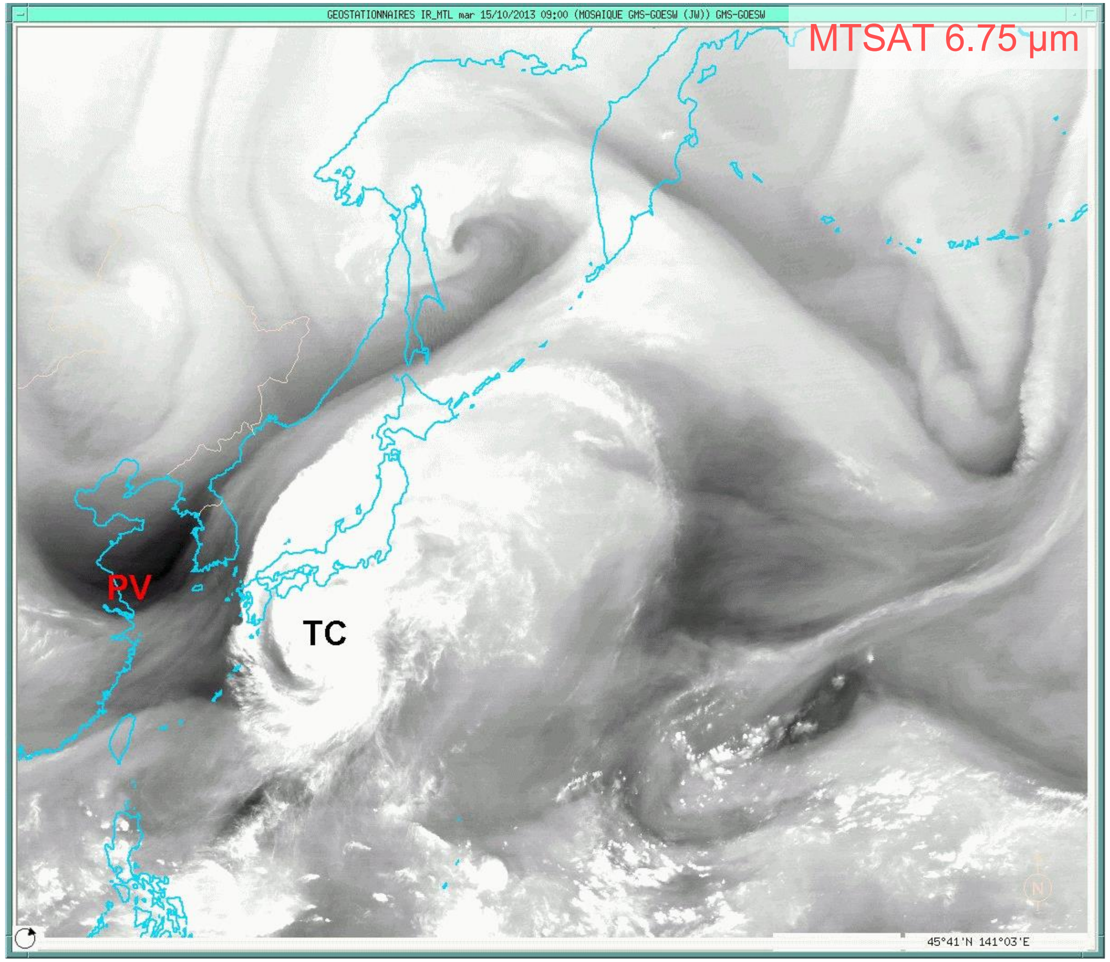
Extratropical transition of TCs
Interaction with mid-latitude PV anomalies

WV imagery analysis:

During the extratropical transition (ET), the tropical cyclone (TC) loses its convective core.

Than it develops a frontal structure of a extratropical cyclone (EC), or in other cases with no additional forsing it may continue to decay.

Surging of a dry dark feature on the WV imagery is a sign that PV anomaly advection can influence and control the ET process (Agustí-Panareda et al., 2004).



Summary

WV imagery can be used–in terms of the PV concept–as a diagnostic tool in the process of prediction of ET and to check on the validity of the NWP model forecasts.

2. Thunderstorm forecasting

- Ingredients for thunderstorms and forecasting criteria at different scales.
- Usefulness of MSG imagery in WV channels for diagnosis:
  - Upper level forcing for convection: PV-anomaly advection, diffluent upper-level flow, deformation zones.
  - Global scale interactions/connections that increase atmospheric moisture in the convective storm environment as seen in WV imagery. Organised Transport of Moisture originated from a Tropical cyclones may play critical role in processes associated with heavy precipitations and other severe weather over the mid-latitudes (Kusselson et al., 2022).

	Ingredients for thunderstorms	Forecasters criteria
Essential (Doswell et al., 1996)	(a) potential instability (moderate at least)	➢ MU CAPE[1] > 700 j/kg
	(b) Warm moist air in low- or mid-levels	➢ > ϑ'_w, layer ~1000 m, >= 16°C and Moist air up to 700 hPa
	(c) Lifting the parcel to the LFC	➢ Low-level convergence, orography
Essential for severe thunderstorms	(c) Pronounced lifting in the layer of instability	> Pronounced convergence line, or area with strong convergence
	(d) (d1) Upper-level positive vorticity advection (d2) Upper-level divergence, even weak, or at least, zero-divergent flow at the upper-troposphere	> Ahead of a PV anomaly, or > left exit or right entrance of a jet-streak > Weak, no convergent upper-level wind,
	(e) Low-level jet, or at least a corridor of organised wind	➢ At least a "tube" of organised wind (>=15 kt) in the layer 100 - 1000 m
	(f) Mid-level Jet for moisture transport	➢ organised wind (>=30 kt) about 600 hPa
	(g) Cold air in mid- troposphere, a dry layer just above the boundary layer for convection inhibition.	> Low values of ϑ'_w in mid-level (relatively cold), above moist layers (ϑ'_w ~3 to 6°C less than in low-level).
	(h) Vertical wind shear	> *Helicity surface-3000 m >= 100 m^2/s^2; not essential, but important factor of potential for cyclonic updraft rotation in a supercell*

[1] : "Most Unstable CAPE", CAPE of the most unstable parcel between surface and 700 hPa.

Satellite information for severe thunderstorm forecasting

Essential for extremely severe thunderstorms forecasting

WV imagery
- WV Plumes
- Atmospheric rivers

GLOBAL SCALE > 12 000 km

Global scale interactions/ connections (Thiao et al., 1993; Ralph et al., 2005).
- Identify transfer of moisture in a deep layer

(to 5 days)

WV imagery
- PV anomaly
- Upper-level Jet
- Mid-level Jet
- Blocking regime, Deformation zone
- Upper-level Diffluent flow
- Mid/upper level flow of moist air

SYNOPTIC SCALE > 2500 km

Prepare the environment for thunderstorms
- Synoptic scale forecast (12 – 48 hours)

WV (6.2/7.3),/IR imagery, RGBs,NWC SAF
- Mid-level dry/cold air advection
- Low-level moist air, Moisture convergence
- Differential heating
- Convection Inhibition
- Potential instability

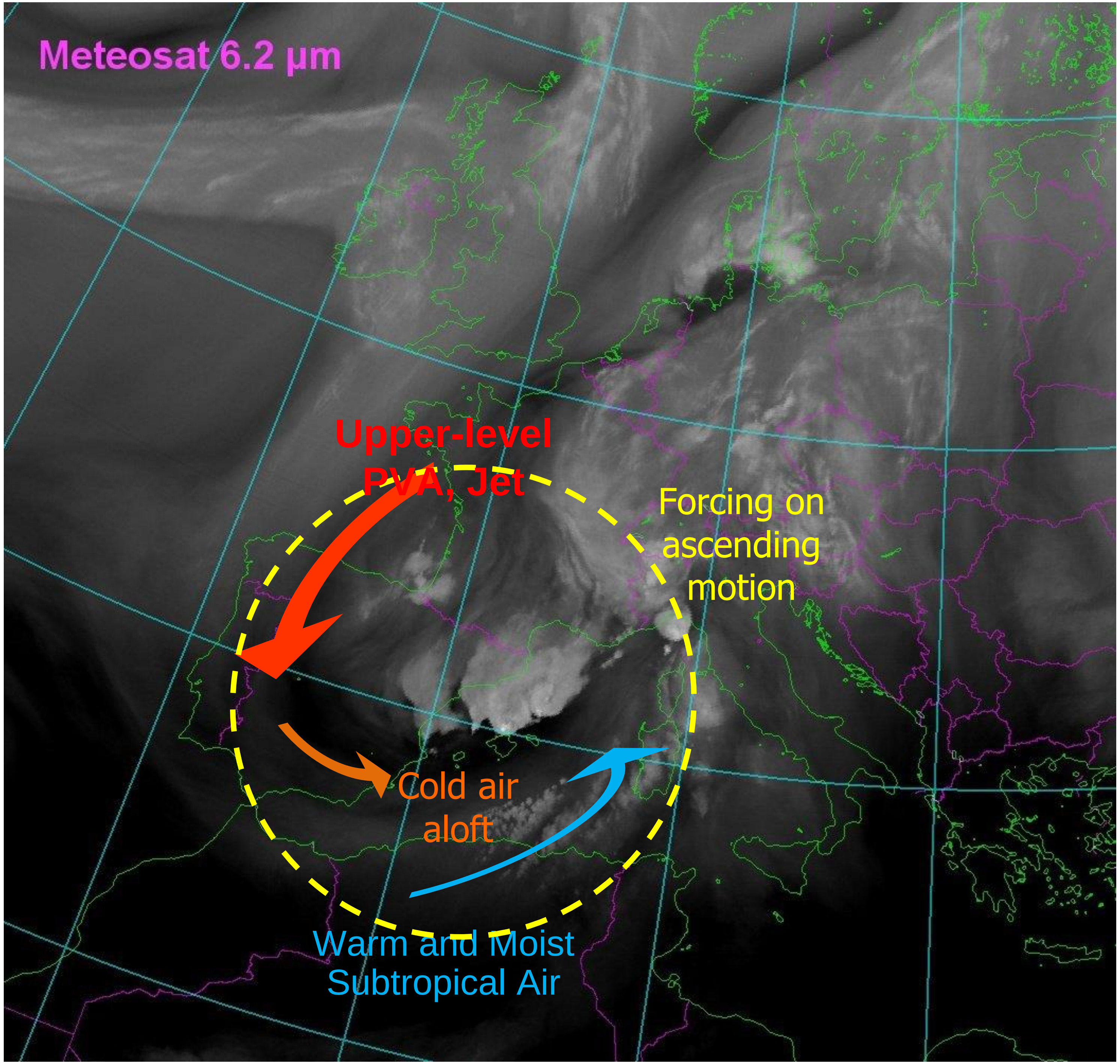
MESSOSCALE > 250 km

Determines where and when thunderstorms may develop
- Mesoscale forecasting (3 - 12 hours)

IR/VIS, RGBs NWC/H- SAFs, WV
- Cloud top features
- Rainfall estimation
- Propagation (movement, development)
- Convection inhibition

STORM SCALE > 2.5 - 25 km

Determines the severity and where the storm will move
- Nowcasting (0 - 3 hours)



Typical circulation pattern favourable for a strong convective development in Southern Europe, seen in WV imagery

18 August 2022 00 UTC

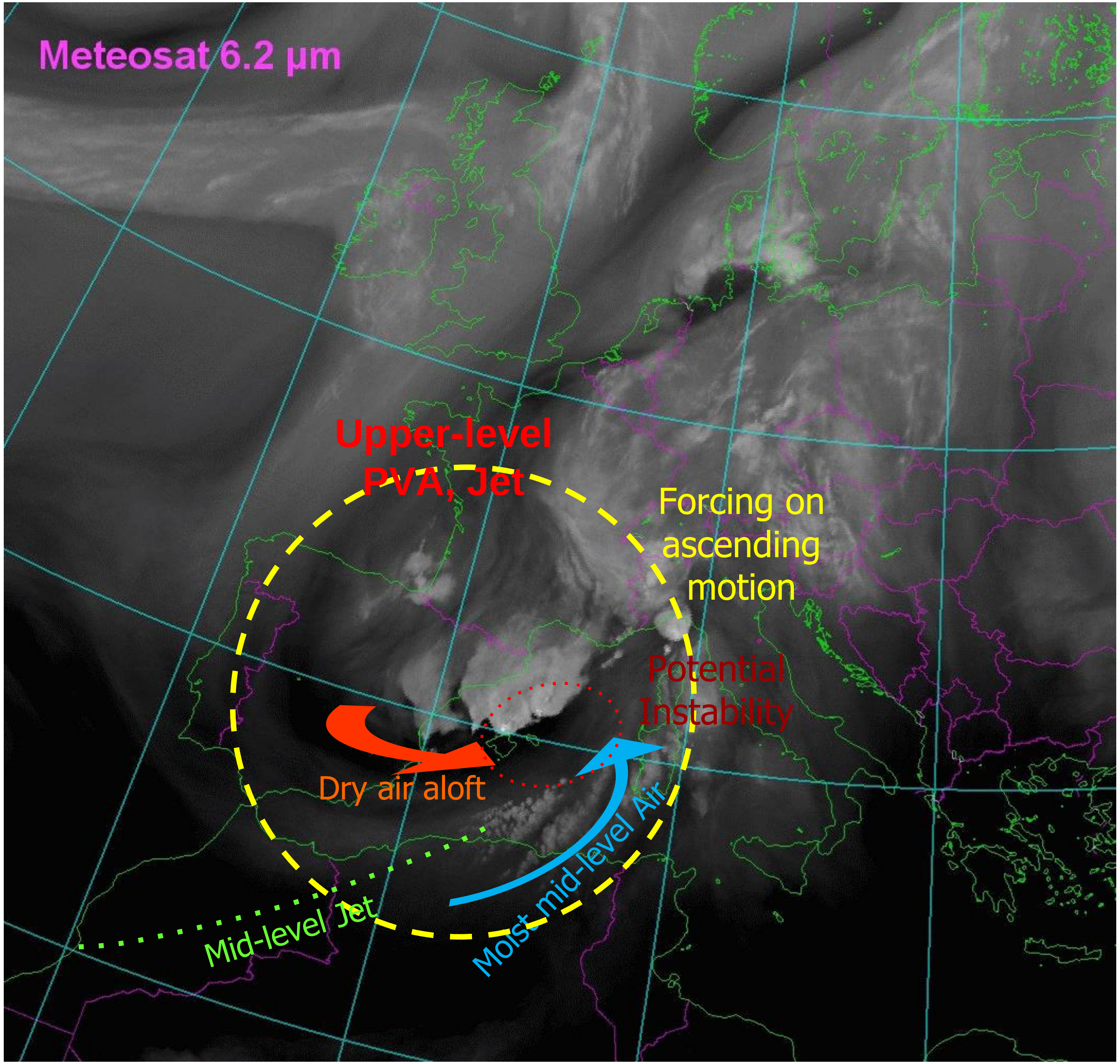
WV imagery 6.2 µm

- **PV anomaly**
- **Upper-level Jet**
- **Upper-level Diffluent flow**
- **Blocking regime**
- **Mid-level Jet (7.3 µm)**

SYNOPTIC SCALE > 2500 km

- **Mid-level cold air advection**
- **Convection Inhibition**
- **Potential instability (7.3 µm and 6.2 µm).**

MESSOSCALE > 250 km



Typical circulation pattern favourable for a strong convective development in Southern Europe, seen in WV imagery

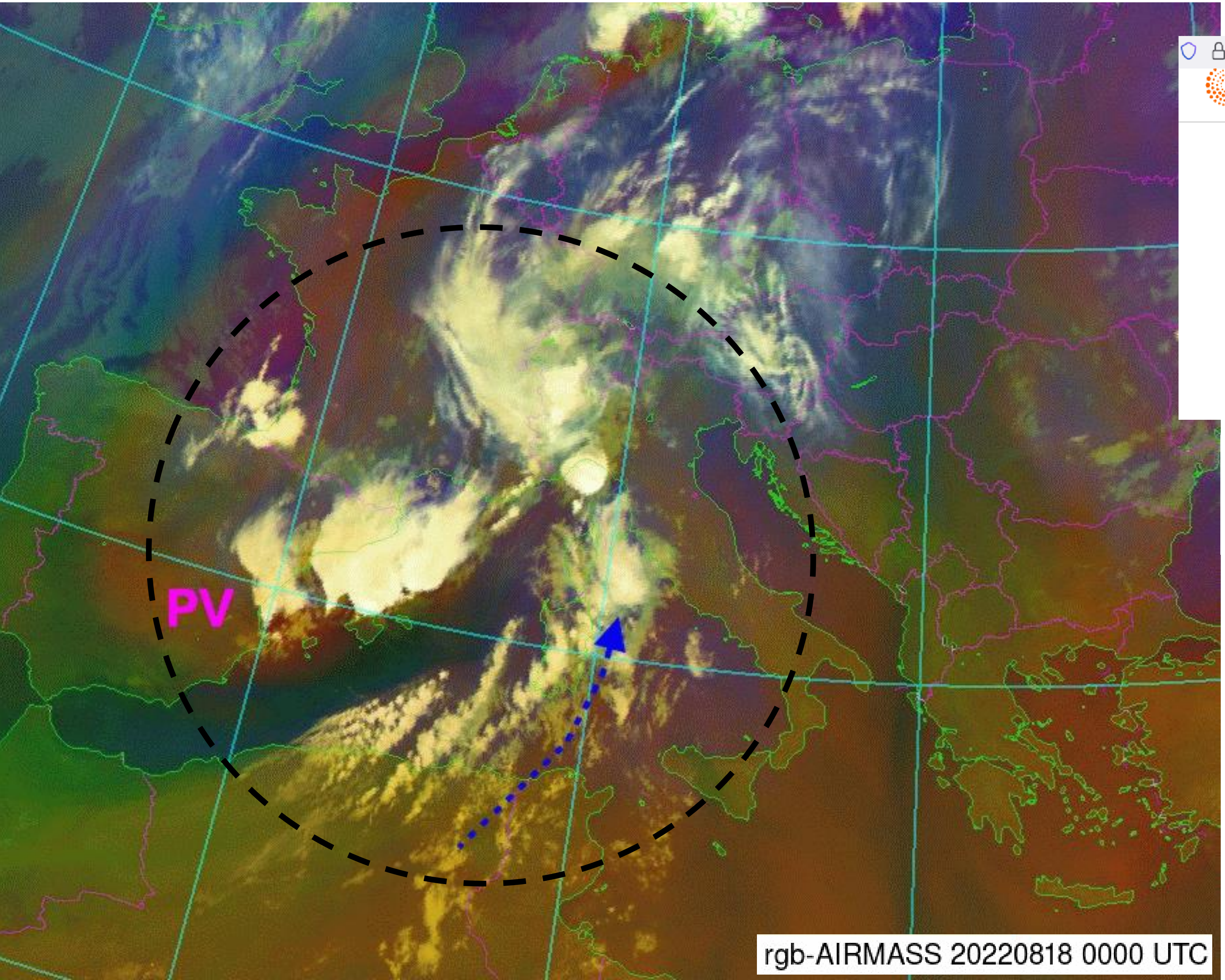
18 August 2022 00 UTC

Usually, the most severe convection in the Southern Europe develops in **strong blocking regime.**

Potential instability seen in comparison of 7.3 and 6.2 µm images.

Mid-level jet (around 600 hPa level**) for Moisture Transport, seen as a moisture boundary in WV 7.3 µm** (Georgiev and Santurette, 2009).

RGB Air Mass Meteosat Product 0000 - 2000 UTC 18 August 2022




https://www.reuters.com/world/europe/one-dead-many-households-off-electri

REUTERS

World Business Legal Markets More

Europe

3 minute read · August 18, 2022 9:34 PM GMT+3 · Last Updated 3 months ago

Violent storm kills six on Corsica as island raises new alert

By Marc Angrand and Benoit Van Overstraeten

https://www.reuters.com/world/europe/one-dead-many-households-off-electricity-thunderstorms-hit-southern-france-2022-08-18/

The strong blocking regime persistently maintain a convective environment of

- Convection Inhibition associated with the PV anomaly.
- Convective instability
- Upper-level forcing of ascent
- Advection of moist, warm subtropical airmass at low- and middle levels

Damaging hailstorm in Sofia, Bulgaria, 8 July 2014

An exceptional case

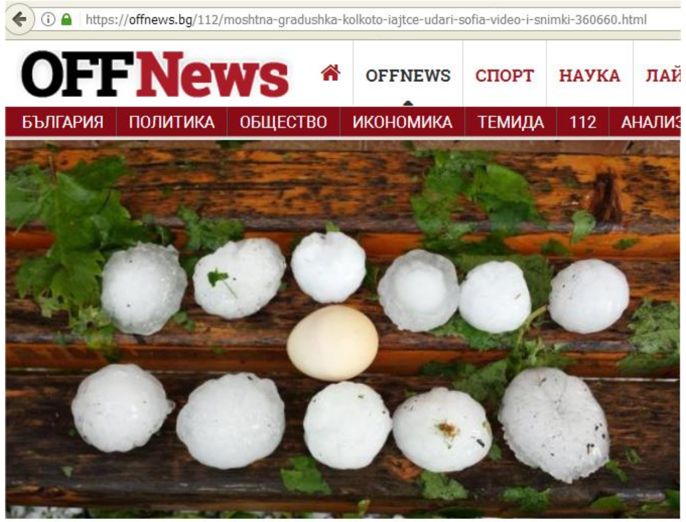
GLOBAL
SCALE
> 12 000 km

Planetary transfer of humidity from tropical origin at middle/upper troposphere

strong moisture transport into mid/upper troposphere of a mid-latitude convective environment that result in very high CAPE and updraft buoyancy in a deep tropospheric layer.

https://www.youtube.com/watch?v=5fH1CcvjSd4

https://offnews.bg/112/moshtna-gradushka-kolkoto-iajtce-udari-sofia-video-i-snimki-360660.html



Снимка: Филипа Филипова

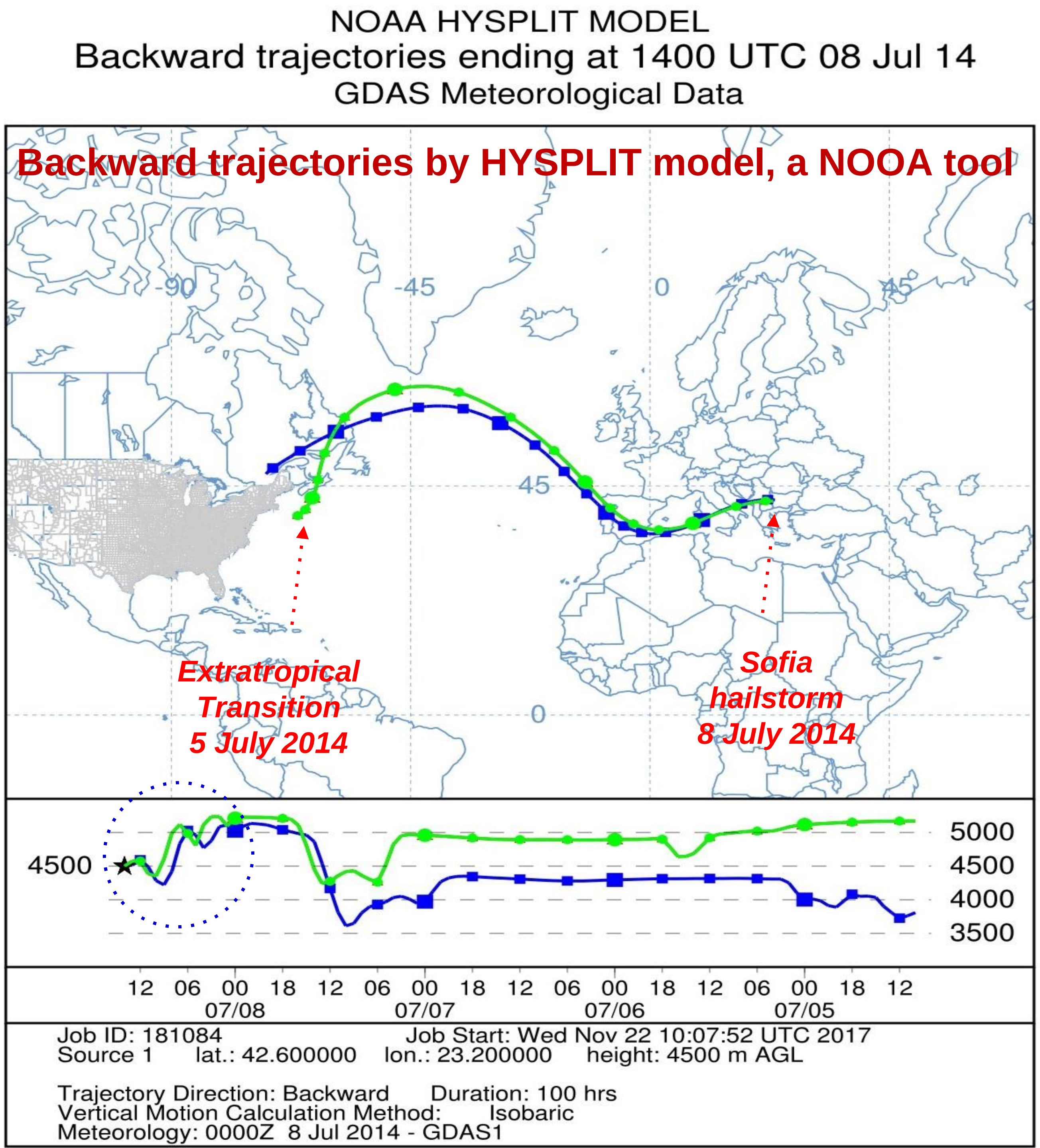
TC Arthur, Western Atlantic
1- 4 July 2014

GLOBAL
SCALE
> 12 000 km

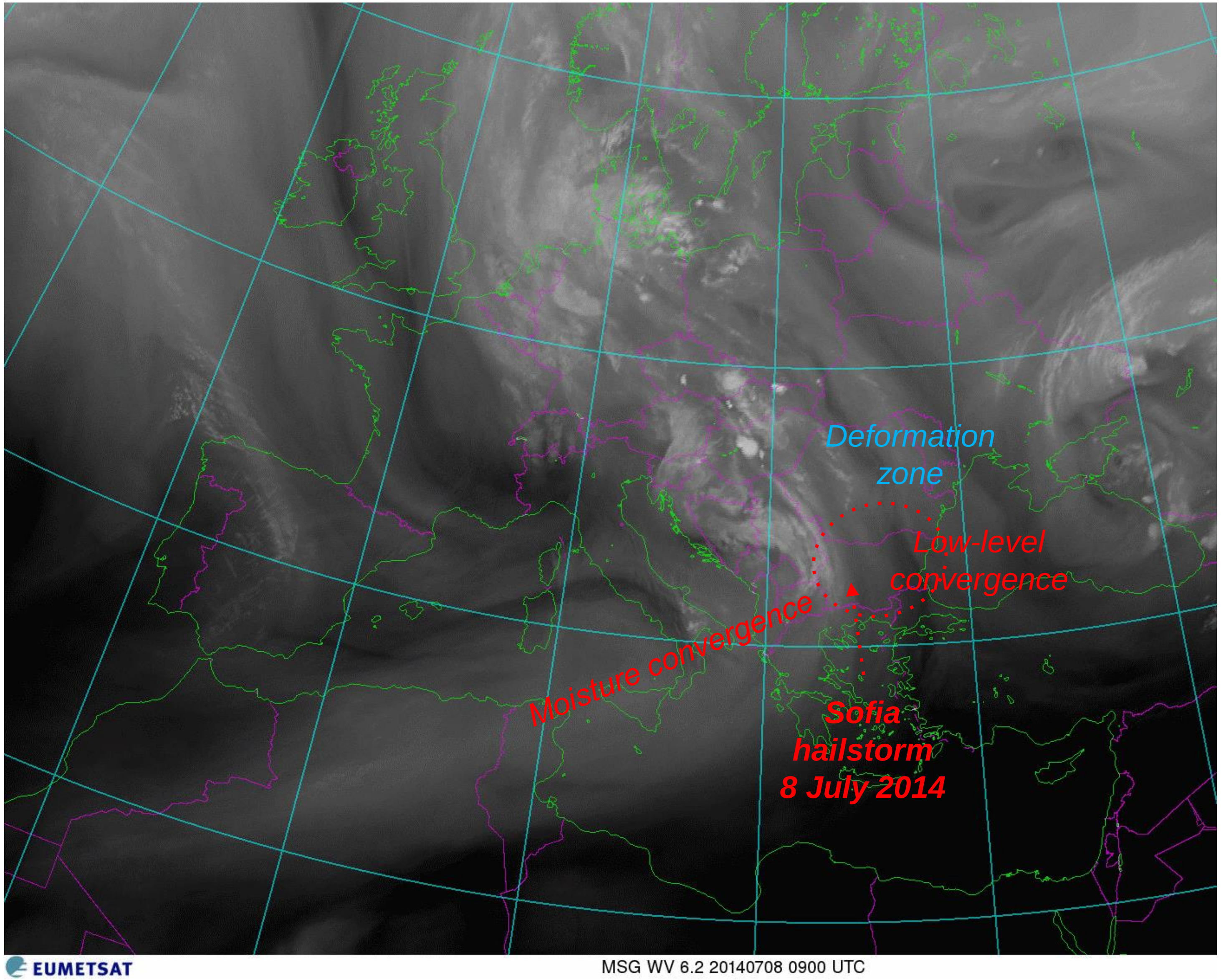
Convective environment, SE Europe
8 July 2014

Simulated trajectories show a link between the extreme hailstorm in Sofia on 8th of July and TC Arthur, developed on 1-4 July 2014.
The large amount of moisture supply comes partially from the Extratropical Transition and development of Hurricane Arthur (the green trajectory) .

Studied by Yordan Katsarov, air force meteorologist, Bulgaria



Convective environment over Bulgaria   8 July 2014



MSG WV 6.2 20140708 0900 UTC

Preparation the environment for thunderstorm

GLOBAL SCALE > 12 000 km

WV Plumes / Atmospheric rivers of moisture

- Transfer of moisture by planetary (Rossby) waves, normally related to synoptic-scale extratropical cyclones that can give rise to **a narrow region of strong meridional water vapor flux**.
- Large amounts of water vapor**, originated by a tropical cyclones** may be involved

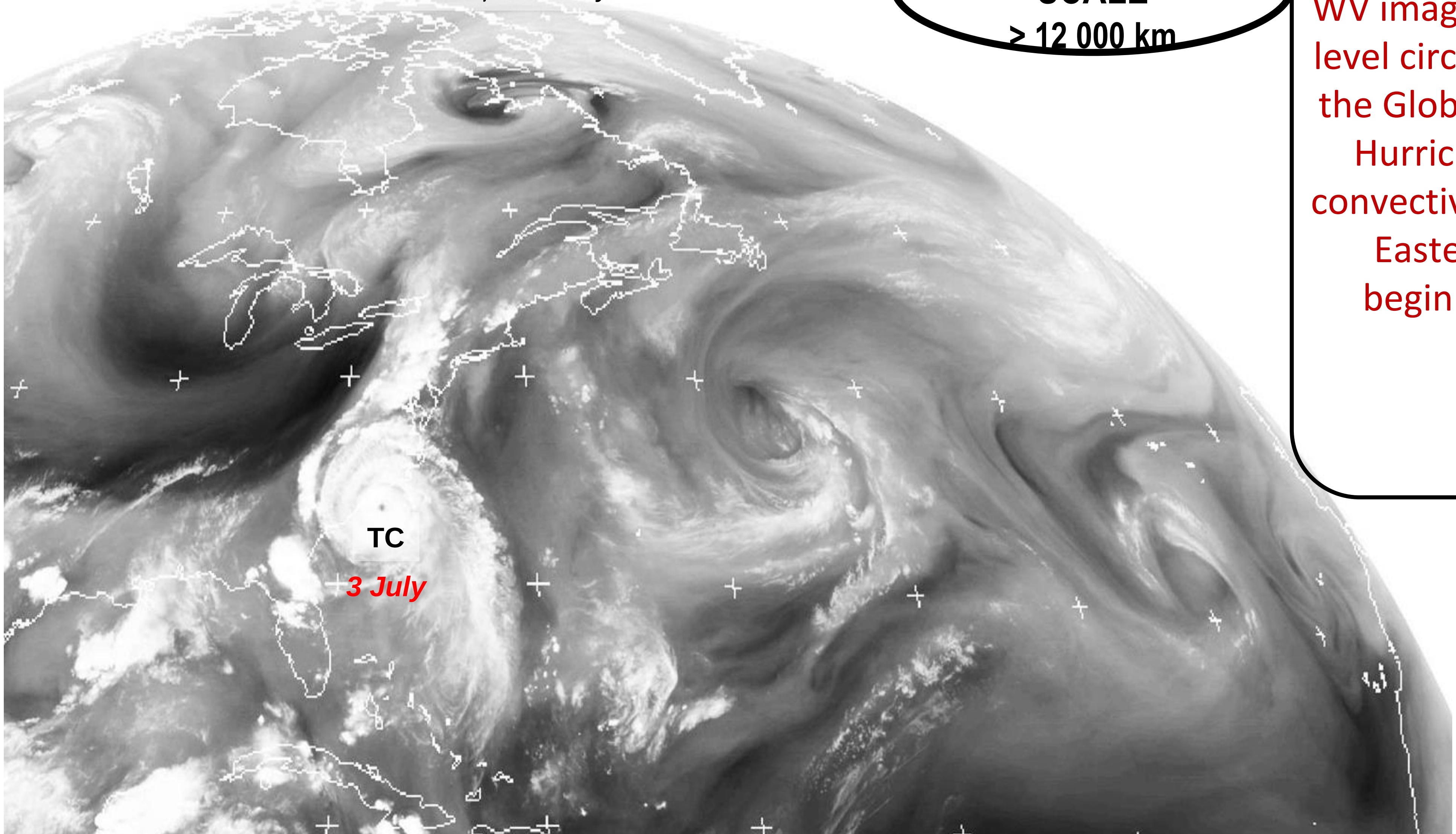
SYNOPTIC SCALE > 2500 km

- **Mid-upper level subtropical moist flow**
- **Deformation zone**
- **Moisture convergence**
- **Low-level convergence line**

Large scale upper-level interactions and their remote influence on deep moist convection

GOES-13 Satellite 6.55 µm, 3 July 2014 2100 UTC

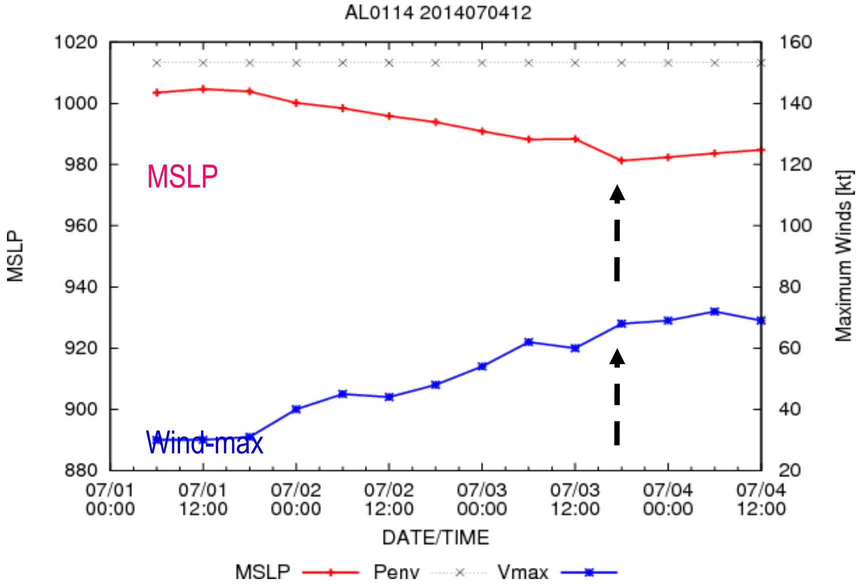
GLOBAL SCALE
> 12 000 km



WV imagery analysis of uper-level circulation that governs the Global scale influence of Hurricane Arthur on the convective environment over Eastern Europe in the beginning of July 2014.

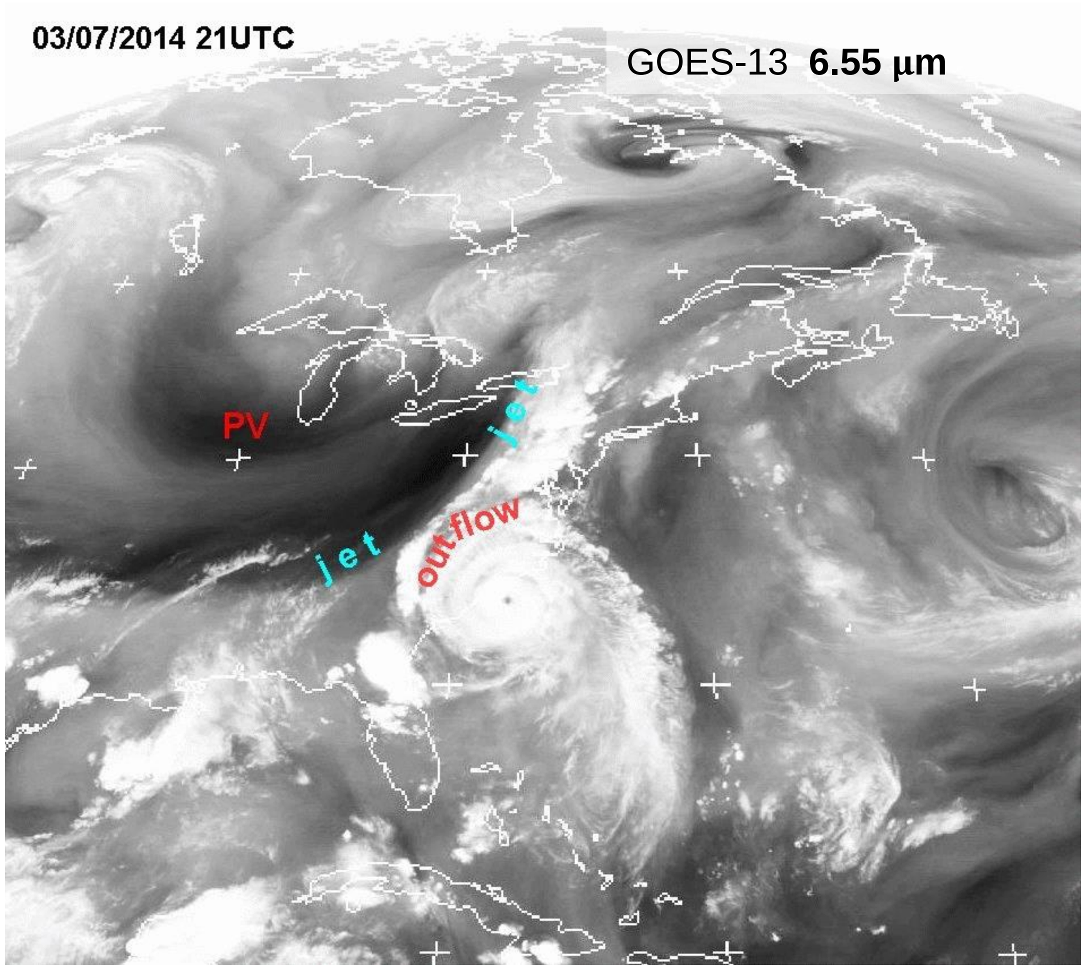
Intensification of TCs on the anticyclonic shear side of jets

Hurricane ARTHUR , 1-4 July 2014



Track data from NOAA NESDIS Center for Satellite Applications and Research.

A positive fluctuation of the TC intensity (increasing maximum surface winds) over the subtropical latitudes ,



WV Imagery signatures for storm intensification by TC - subtropical jet interaction (Georgiev et al. 2016):

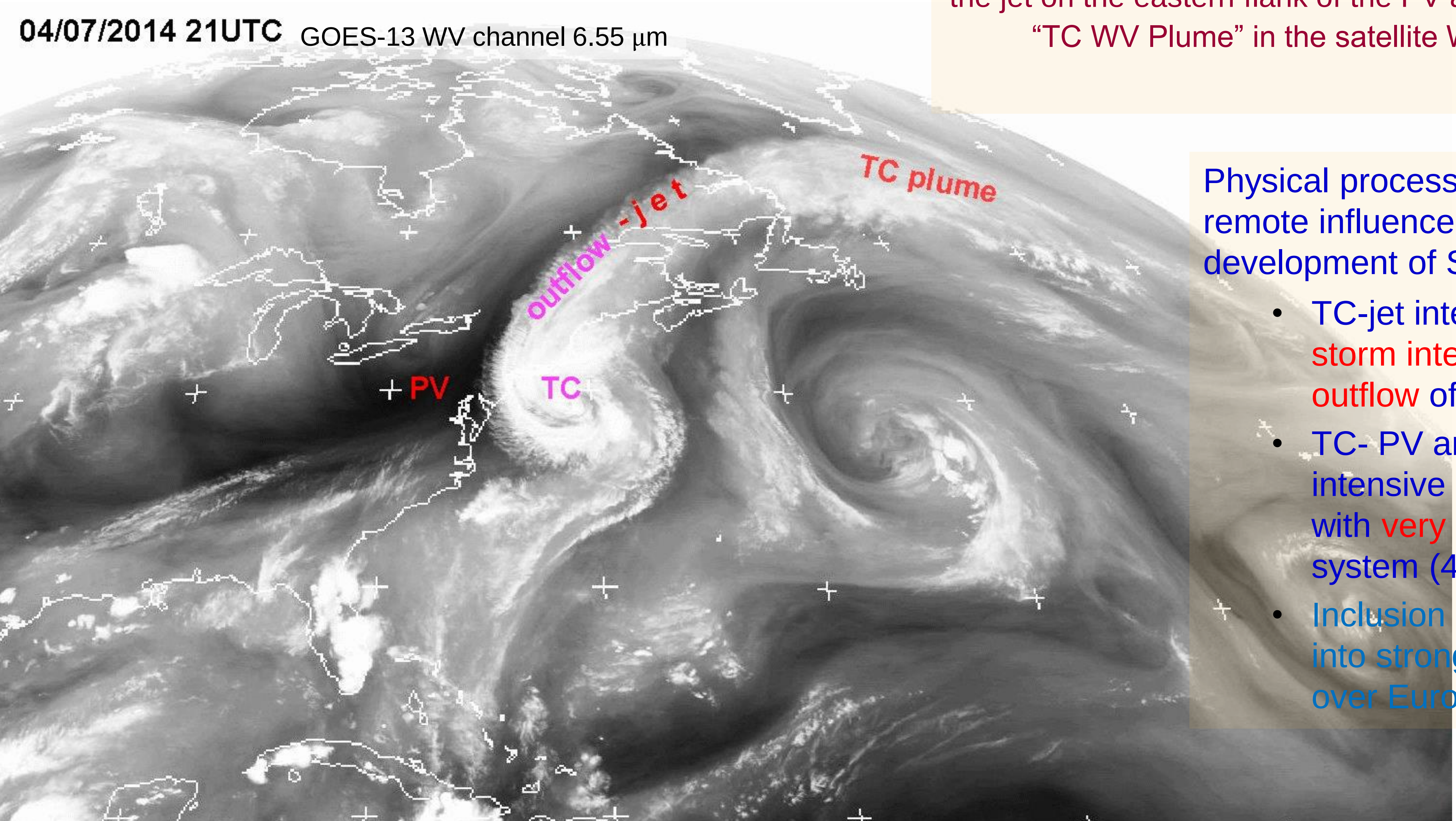
Elongation of the spiral outflow band and strengthening the convection at the polerward side of the TC.

Re-forming of the TC eye.

TC convective cloud system is organized into more distinct "spiral bands“.

Extratropical Development of Tropical Cyclone:
Interaction with mid-latitude upper-level trough and related positive PV anomaly

The TC **large-scale moist air mass** in the warm side of the jet on the eastern flank of the PV anomaly is seen as a "TC WV Plume" in the satellite WV channel imagery.



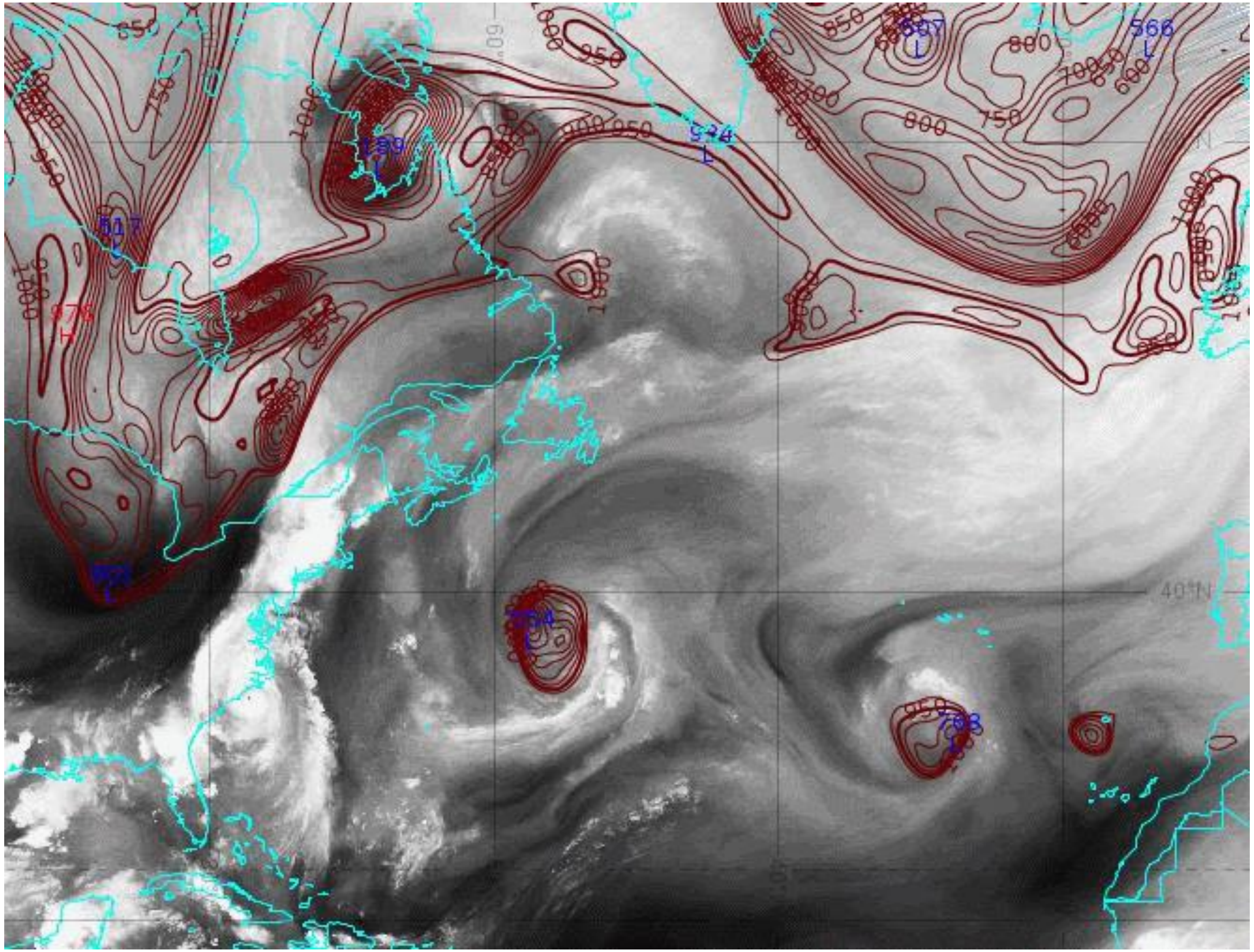
Physical processes which enabled remote influence of TC Arthur on the development of Sofia hailstorm:

- TC-jet interaction leading to storm intensification and its outflow of 3 July.
- TC- PV anomaly interaction and intensive extratropical transition with very strong jet-outflow system (4-5 July).
- Inclusion of the TC WV plume into strong cyclonic circulation over Europe on 6 July.

Extratropical Development of Tropical Cyclone: Interaction and related Large Scale Jet on the eastern flank of the PV anomaly

GLOBAL SCALE
> 12 000 km

GOES-13 WV 6.55 µm, ARPEGE analyses of 1.5 PVU surface heights <1000 dma



Atlantic 4-5 July 2014

PV-WV imagery analysis

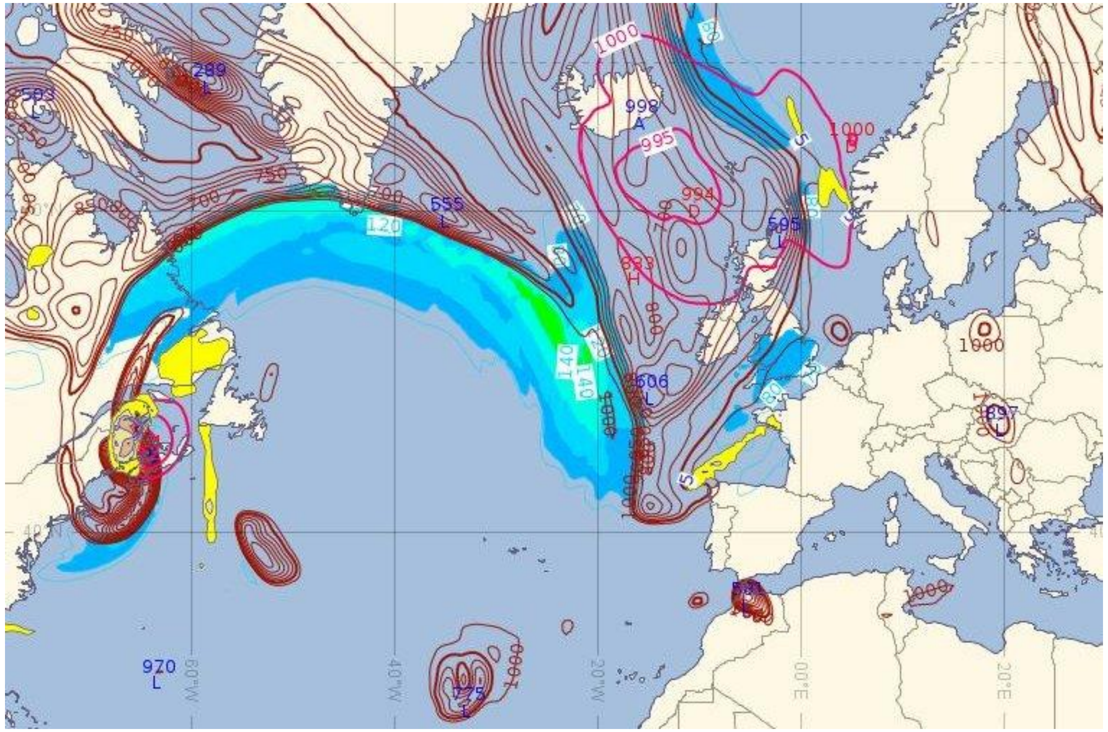
The PV anomaly advection governs the process of explosive ET development with the large cyclone's outflow and strong upper-level jet on the eastern flank of the PV anomaly.

Building of a huge high-level ridge from Atlantic coast of US and Canada through Greenland to Eastern Atlantic and Iberian Peninsula in Europe.

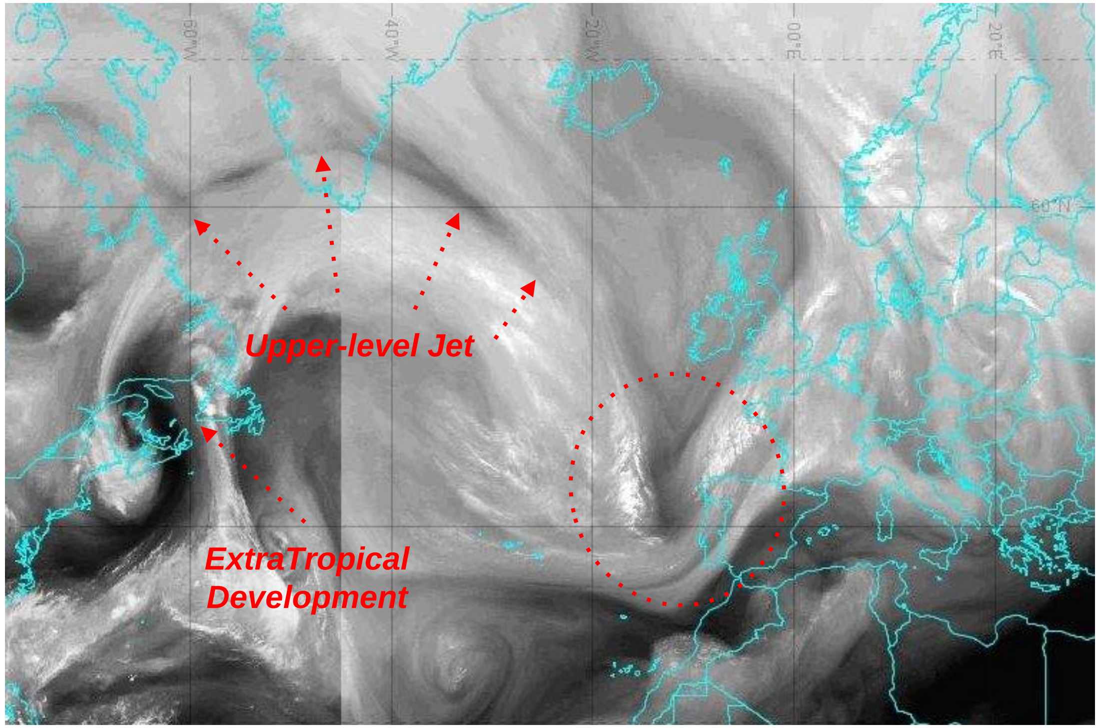
And associated upper-level jet at the polar side of the ridge (Strong Gradient Zone in the field of 1.5 PVU surface heights).

PV-WV imagery Interpretation 5 July 2014 21 UTC

ARPEGE NWP 1.5 PVU surface heights <1000 dma MSLP <1000 hPa) wind speed at 1.5Pvu > 70kt



GOES-13 WV channel 6.55 µm + Meteosat WV channel 6.2 µm



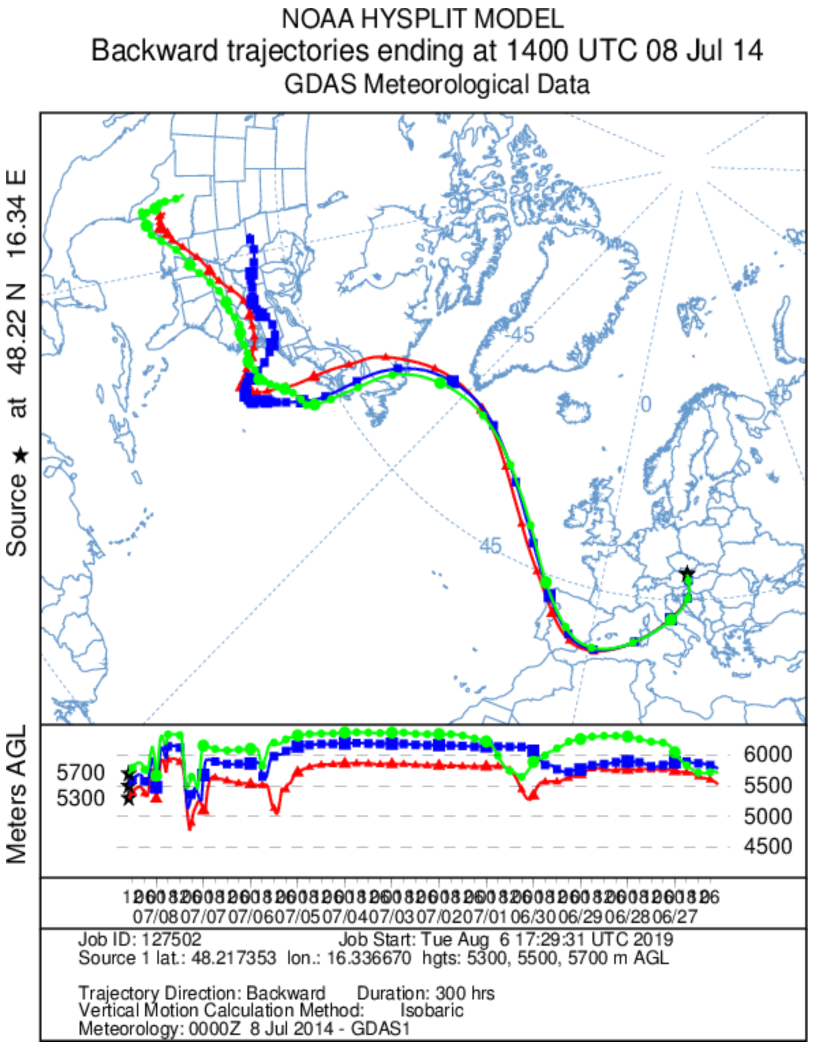
- The upper-level jet at the polar side of the ridge: Strong Gradient Zone in the heights of the dynamical tropopause and related Anticyclonic Moisture Boundary in the WV imagery.

- The TC WV plume tends to interact with the Polar PV anomaly advected over Europe on 6 July : Dynamic Dry Zone on the WV imagery.

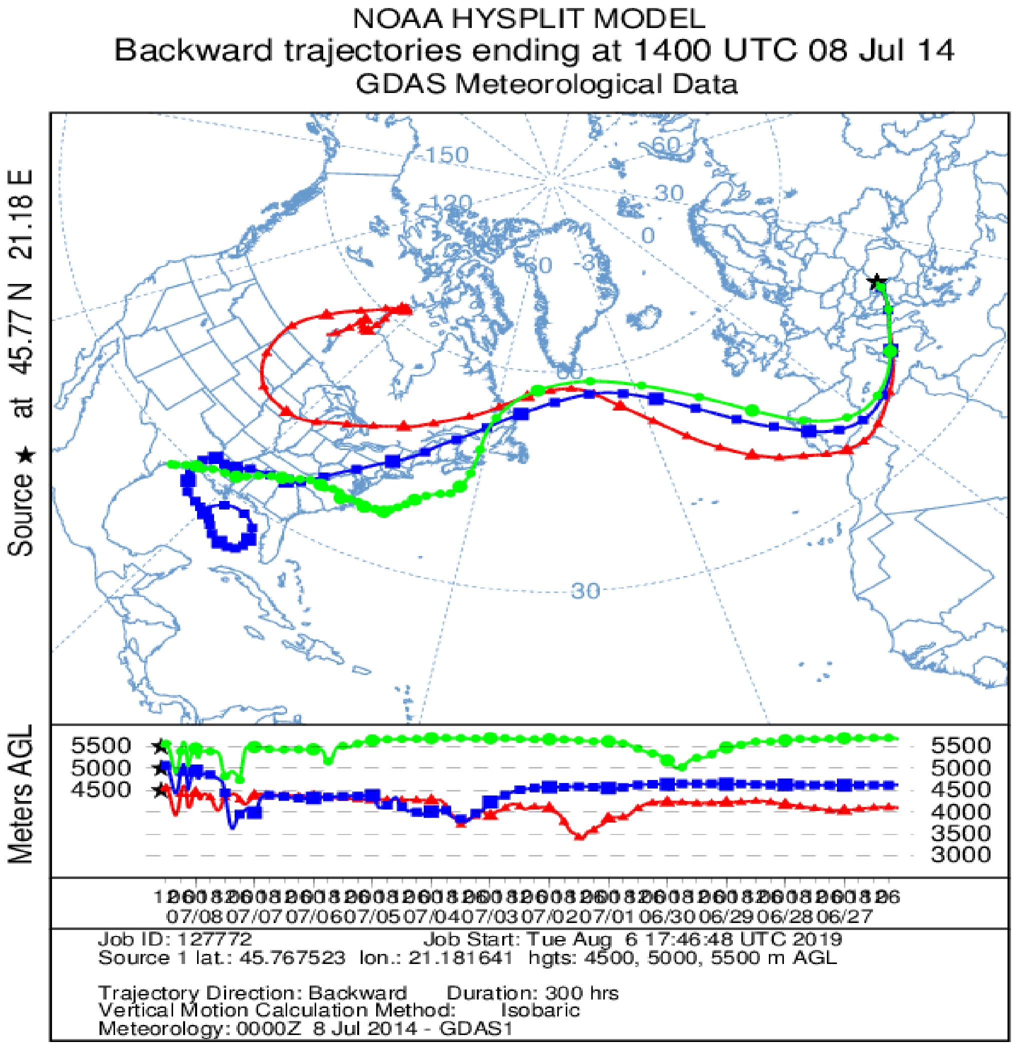
Link between TC Arthur and convective environment over Europe

GLOBAL SCALE
> 12 000 km

Vienna, mainly in the layer 4400-5000 m height (green curve).



Timisoara, Romania, within 4000-6000 m altitude, mainly at 4500-5000 m layer.

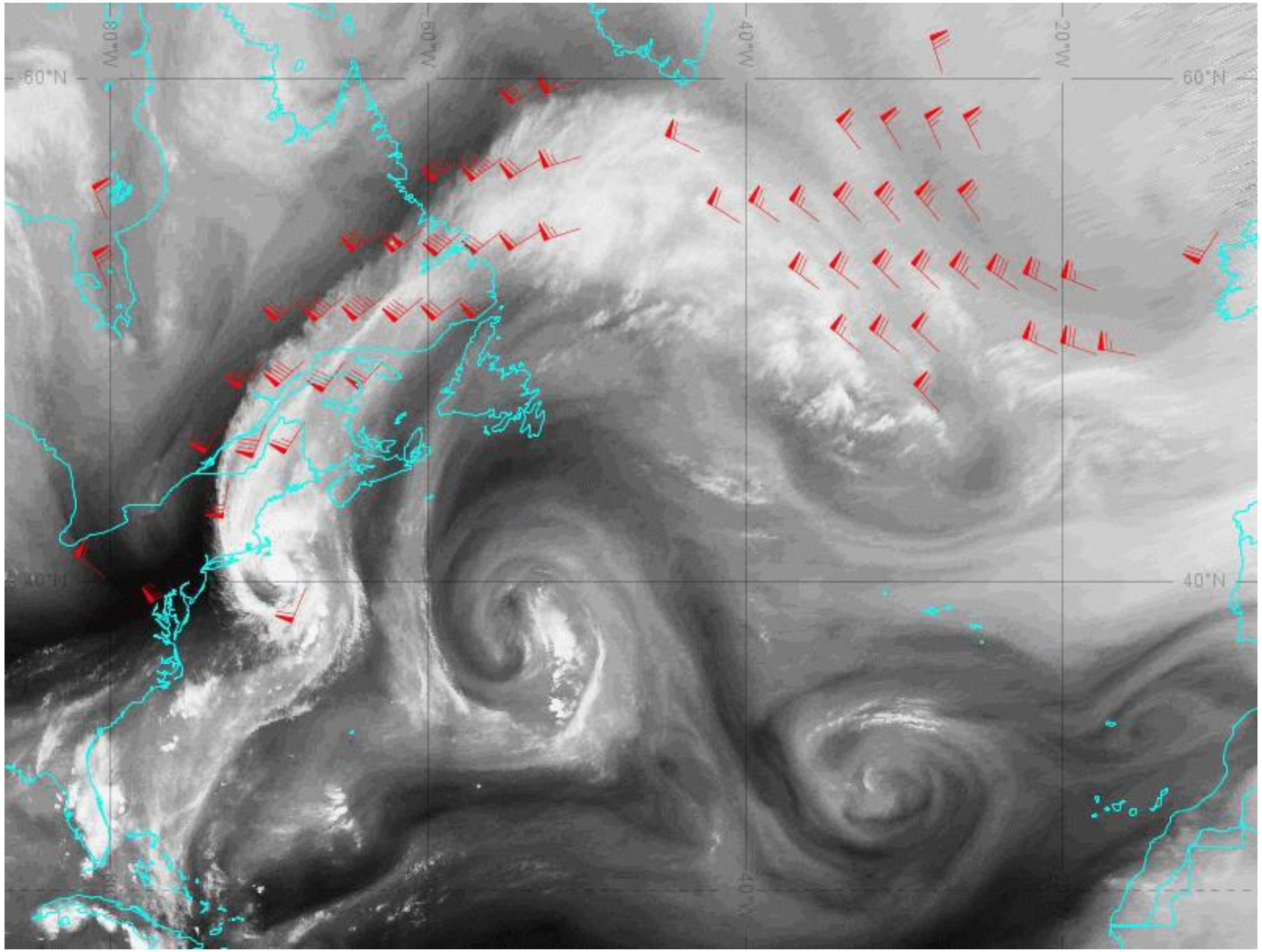


Studied by Yordan Katsarov, air force meteorologist, Bulgaria

The mechanism of TC Plume involvement in the convective environment over Europe

Atlantic 5-6 July 2014

GOES East WV channel 6.55 µm, ARPEGE NWP model analyses of > 60 kt



GLOBAL SCALE
> 12 000 km

WV imagery analysis

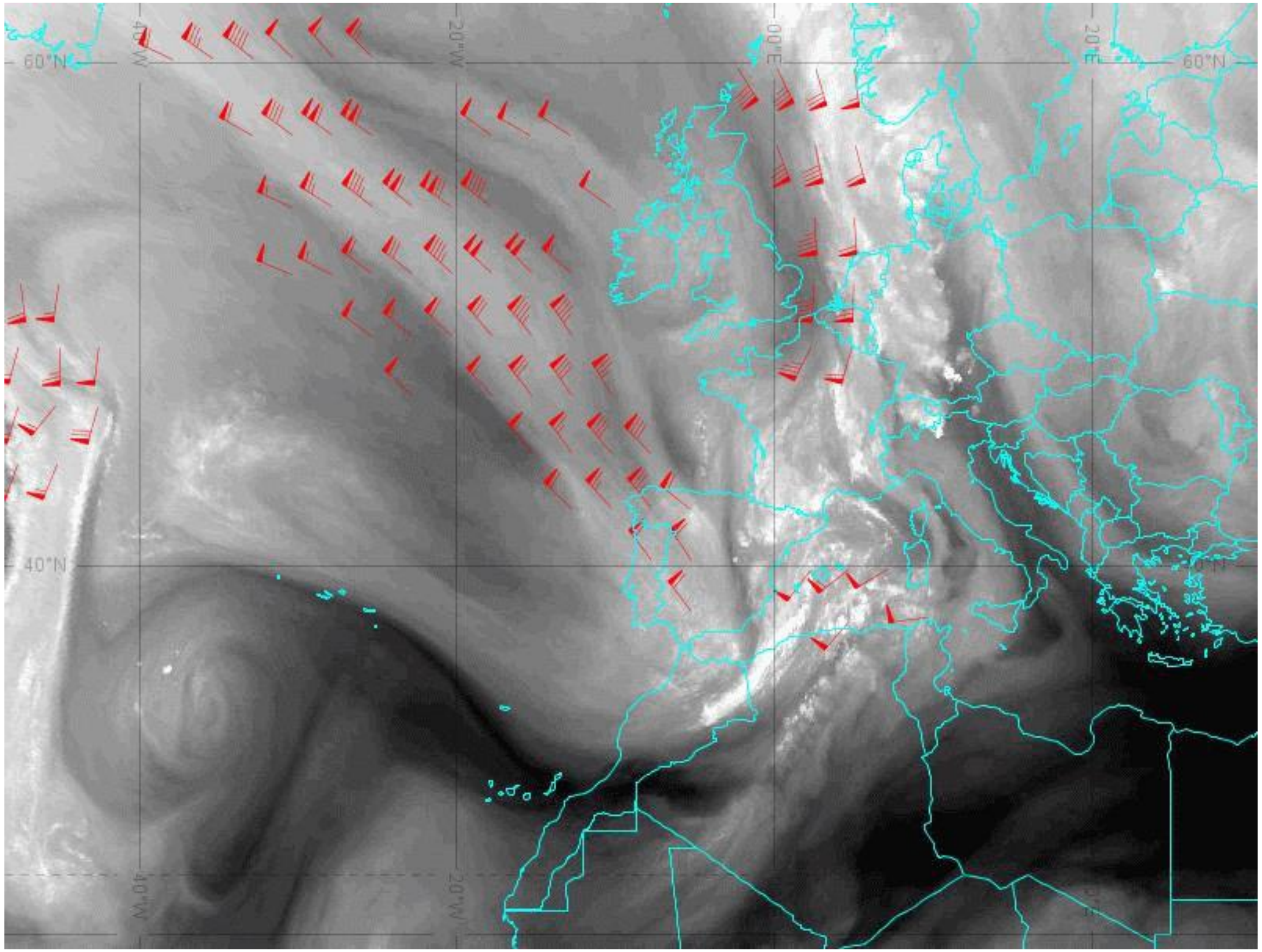
Identify transfer of deep layer moisture

- **WV Plumes**
- **Atmospheric rivers**

1. Explosive " extratropical transition and rapid deepening as a result of interaction with a PV anomaly.
2. With the ET of Arthur, associated planetary ridge, and Jet stream, the TC WV Plume is moving east, crossed the Atlantic Ocean and entered into the circulation of a polar cyclogenesis over the coast of Western Europe on 5 July at 12 UTC.

The mechanism of TC Plume involvement in the convective environment over Europe

METEOSAT 6.2 μm chnnel , ARPEGE NWP model analyses of > 60 kt



GLOBAL SCALE
> 12 000 km

WV imagery analysis

Identify transfer of deep layer moisture

- **WV Plumes**
- **Atmospheric rivers of moisture**

7-8 July 2014

The TC plume seen in the WV imagery represents a fast moving air with the planetary jet, which on the other hand **keep its tropical futures (temperature and moisture).**

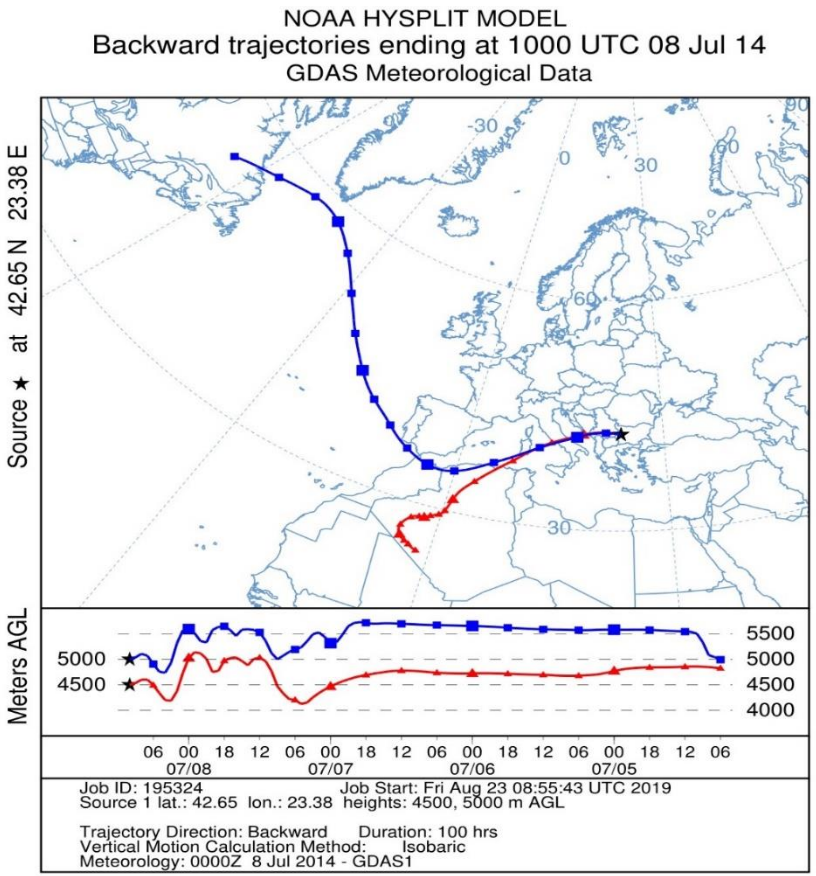
The TC WV Plume entered into cyclonic circulation over the coast of Western Europe on 5 July at 12 UTC.

Moisture supply in the convective environment of Sofia hailstorm 8 July 2014

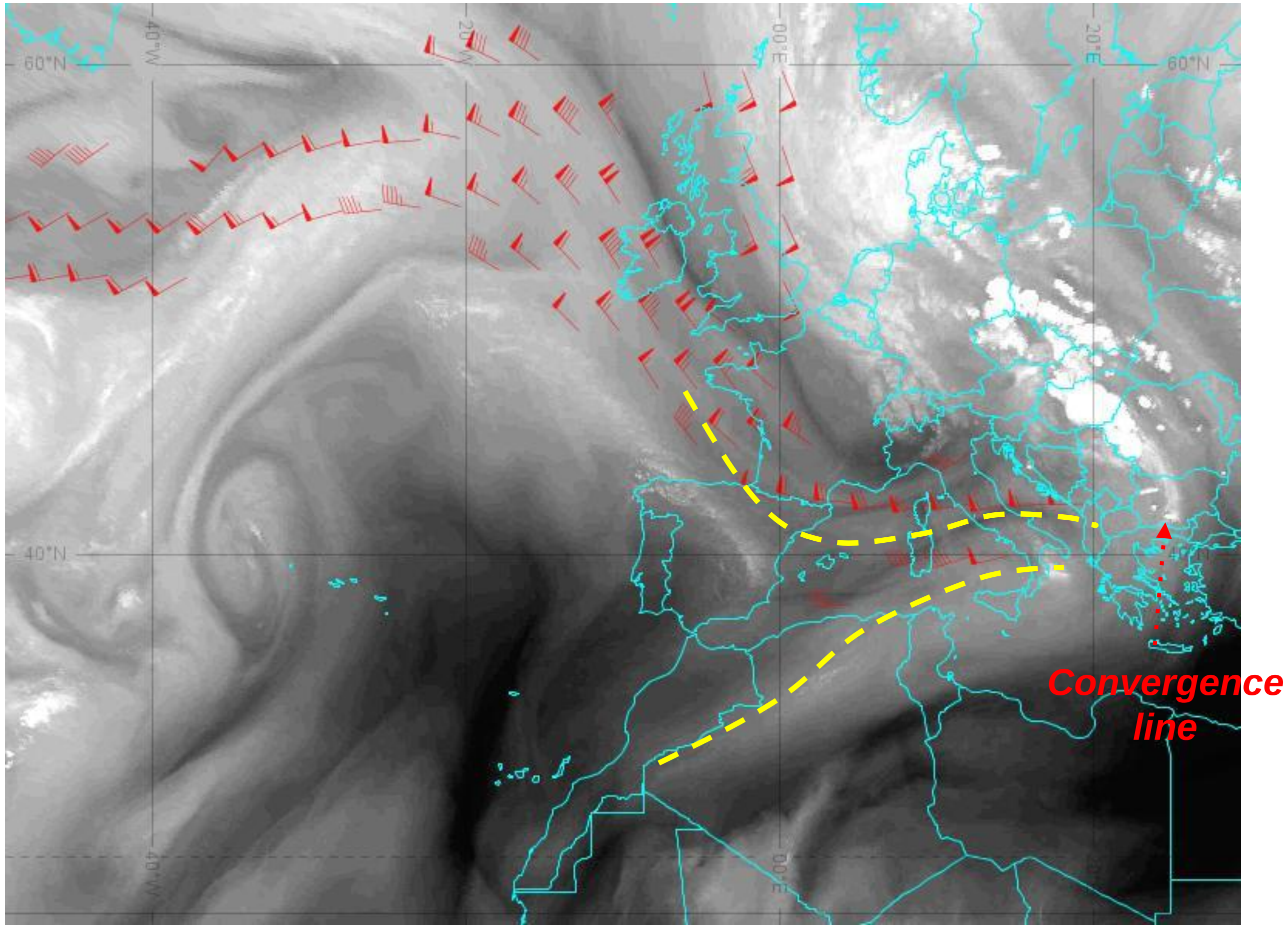
Backward trajectories ending 10 UTC:
Air masses of two different origins are embedded in the pre-convective environment of the storm produced damaging hail in Sofia around 13 UTC.

WV imagery shows moisture convergence of two flows in the rear side of a low-level convergence line, which triggered the convective development:

- From Subtropical Atlantic, Africa and Mediterranean.
- From the Extratropical development of TC Arthur.



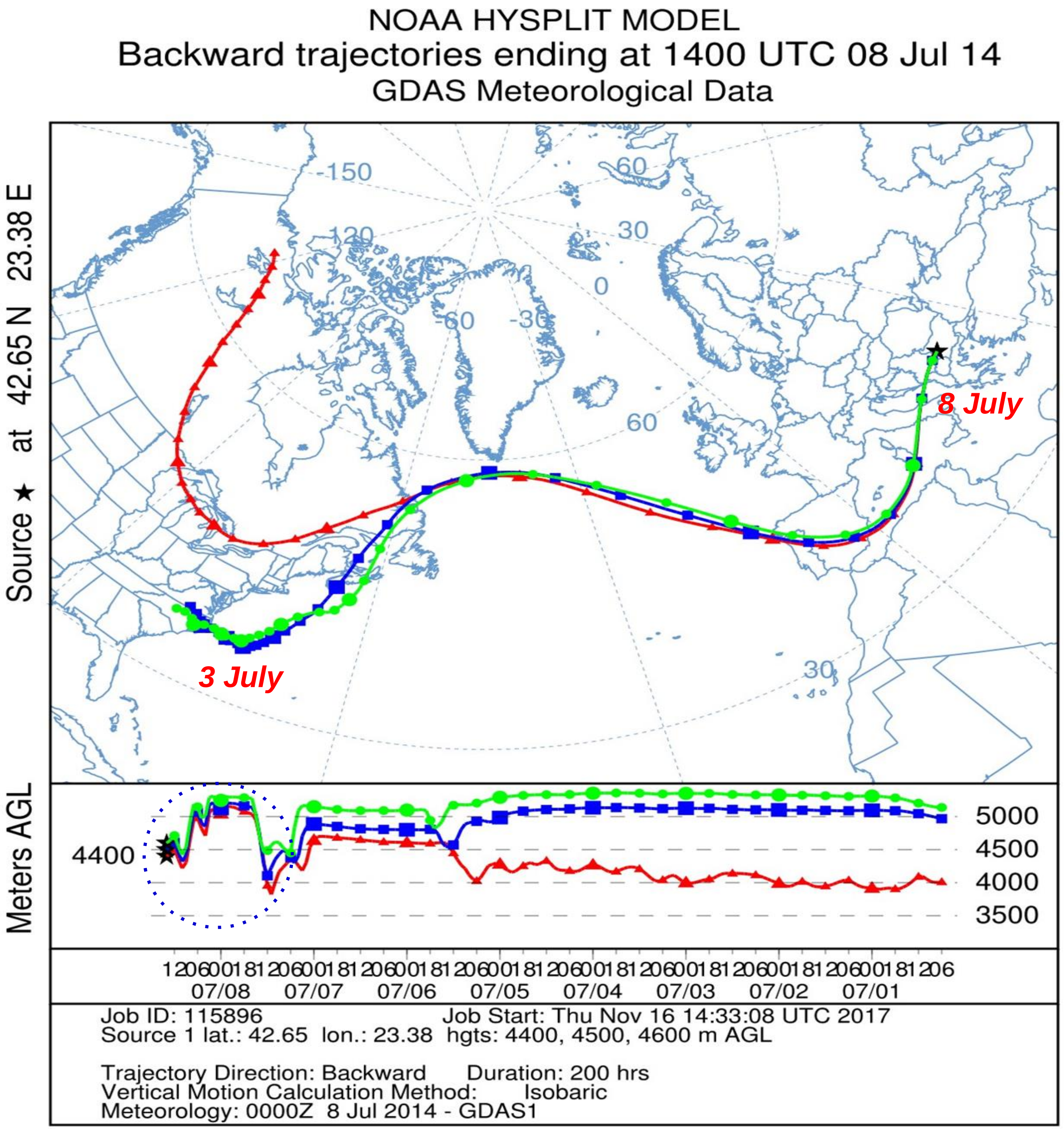
Meteosat WV image 400hPa wind ≥ 45 kt, 8 July 12 UTC



Backward trajectories

GLOBAL SCALE
> 12 000 km

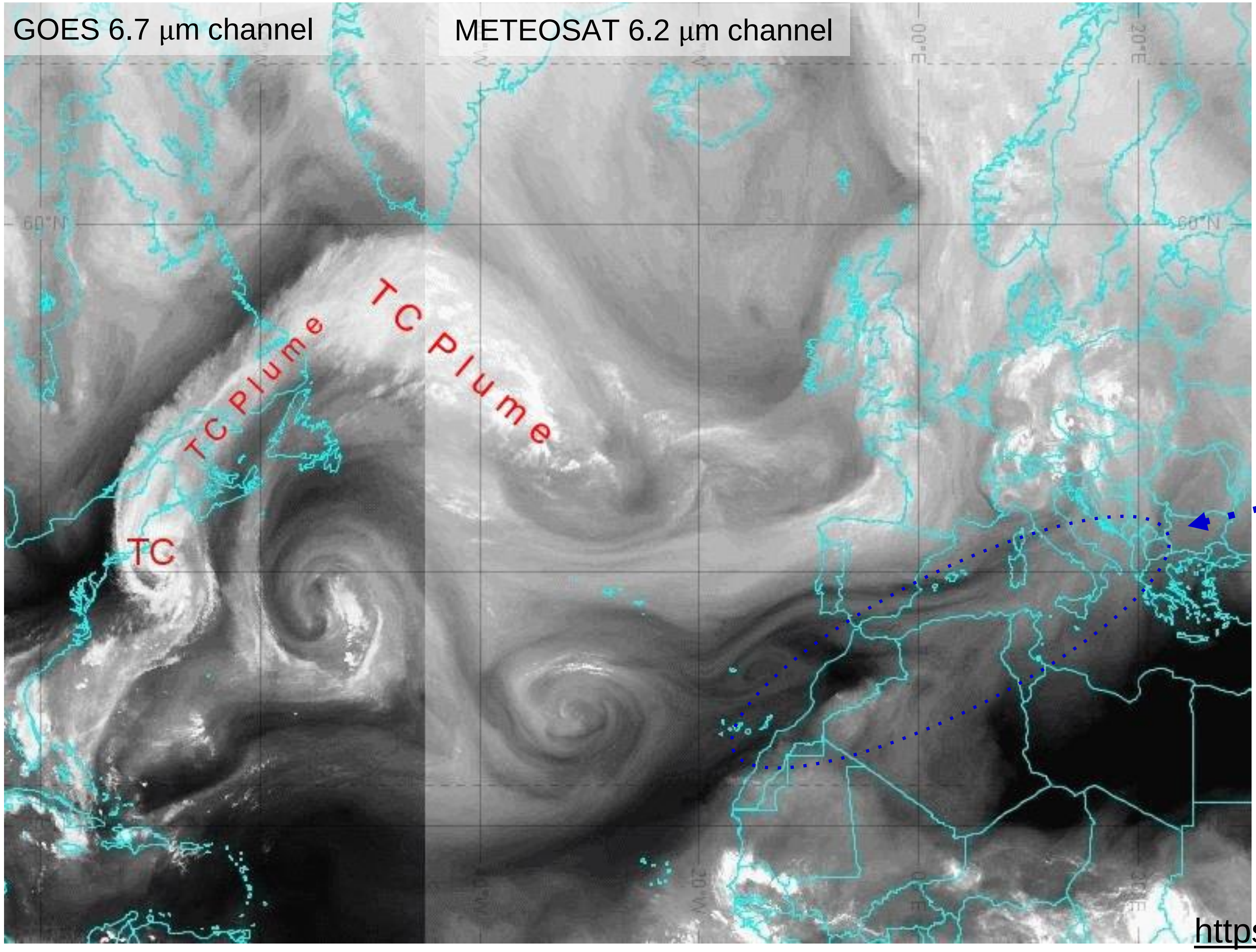
The simulation ending at 14 UTC on 8 July at Sofia shows that the link occurs in the middle troposphere, from 5000 down to 4000 m altitude.



Studied by Yordan Katsarov, air force meteorologist, Bulgaria

TC Plume moves forward and take part on the hailstorm environment

5-8 July 2014



The already existing favourable convective environment has been supplied with additional large amount moisture at middle/upper-level. This result in Strong CAPE up to the upper troposphere and development of an extremely severe hailstorm

The TC WV plume has splitted, a certain portion goes directly to the storm environment and another one after travelling over the subtropical Atlantic, North Africa and Mediterranean sea (accumulated additional CAPE)

https://www.youtube.com/watch?v=5fH1CcvjSd4

Conclusion

Usefulness of WV imagery in severe thunderstorm forecasting

Essential for severe thunder-storms forecasting

WV imagery
- WV Plumes
- Atmospheric rivers

GLOBAL SCALE
> 12 000 km

Global scale interactions/ connections (Thiao et al., 1993; Ralph et al., 2005).
- Identify transfer of moisture in a deep layer (to 5 days)

WV imagery
- PV anomaly
- Upper-level Jet
- Mid-level Jet
- Blocking regime
- Upper-level Diffluent flow

SYNOPTIC SCALE
> 2500 km

- Synoptic scale forecast (12 – 24 hours)

Prepare the environment for thunderstorms

WV/IR, NWC SAF
- Mid-level dry/cold air advection
- Differential heating
- Convection Inhibition
- Potential instability

MESSOSCALE
> 250 km

Determines where and when thunderstorms may develop
- Mesoscale forecasting (3 - 12 hours)

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