Convection and Severe Weather

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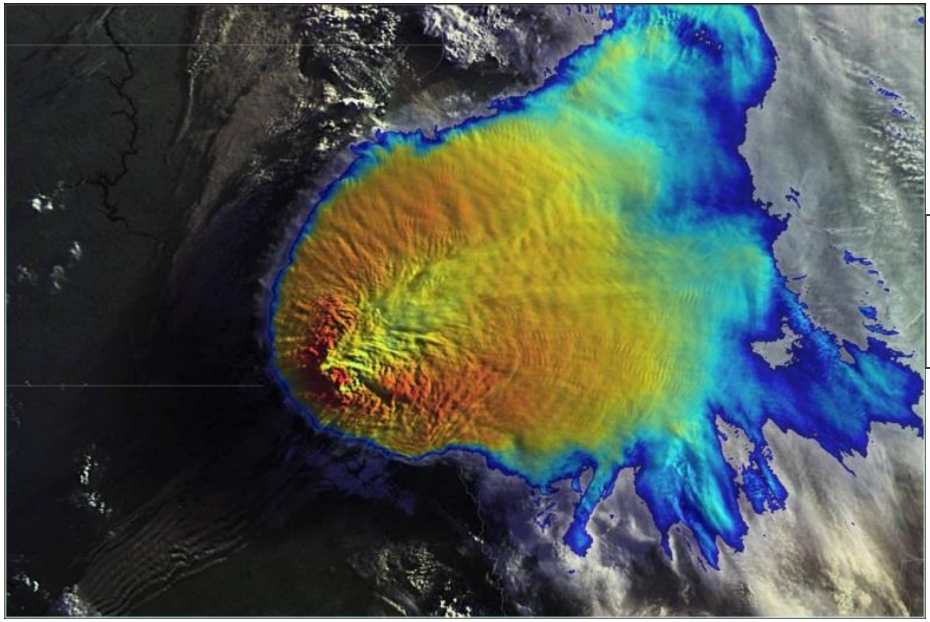
In this lecture…

- How do thunderstorms interact with environmental wind?
- Why does such an interaction increase the risk of severe weather (large hail, damaging winds, tornadoes)?
- Vertical wind shear and storm-relative helicity as predictors for thunderstorm organization
- Case examples

„Organized thunderstorms“

Storm organization:

- Interaction of updraft and downdraft with environmental winds
- Separation of updraft and downdraft
- Longer lifetime
- Higher severe weather risk
- In particular: storm can start to rotate as a whole!



Organized thunderstorm over the Great Plains; „sandwich product“ of GOES-R satellite data (© Martin Setvák, 2010)

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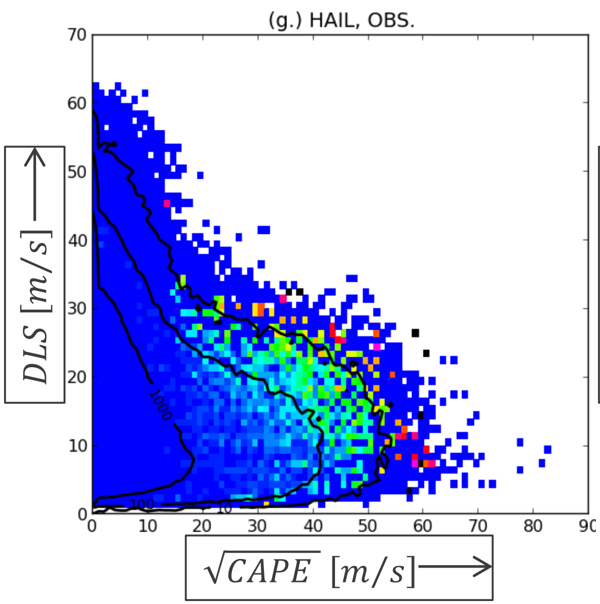
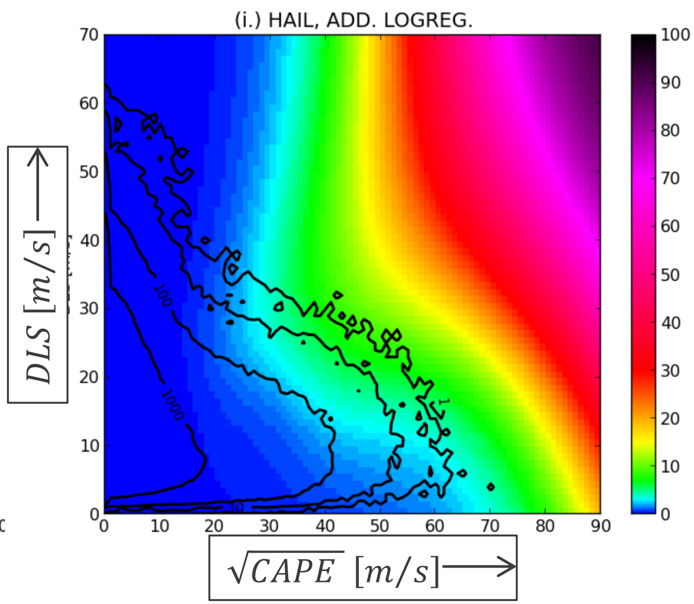
Ambient conditions and severe weather

Severe weather risk rises with inreasing…

- Convective Available Potential Energy (CAPE)
- Vertical wind shear (most commonly used: 0-6 km bulk shear = deep-layer shear, DLS)
- Example: Probability of large hail (>2 cm) per 6h and 0.75° x 0.75°





Data:
- ERA-Interim
- ESWD
- central Europe
- 2006-2013

Left: observations
Right: statistical model

Storm modes

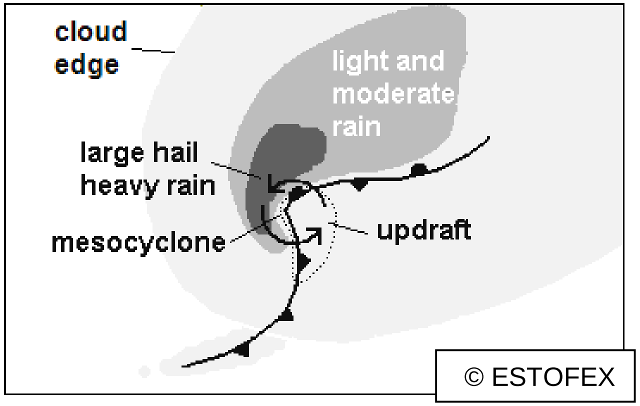
Storm mode:	Single cell	Multicell	Supercell
Vertical wind shear:	weak ($DLS \lesssim 10\ m/s$)	moderate ($10\ m/s \lesssim DLS \lesssim$	strong ($DLS \gtrsim$
Updraft characteristics:	only one updraft	repeated pulses of new updrafts on one preferred side	continuous new updrafts on one particular side
Updraft maintainment:	none	interaction of cold pool with environment	upward perturbation pressure gradient

- **Increasing organization!**
- **Increasing lifetime!**
- **Increasing severe weather risk!**

Supercell

„A supercell is a storm that contains a deep, persistent mesocyclone.“
(Charles Doswell III)

- Mesocyclone: rotating column of air on scales of a few kilometers to a few tens of kilometers
- „Persistent“: long time period compared to timescale of convection (say, at least 30 minutes)
- „Deep“: a significant fraction of the depth of a cumulonimbus cloud (say, at least its lower half)



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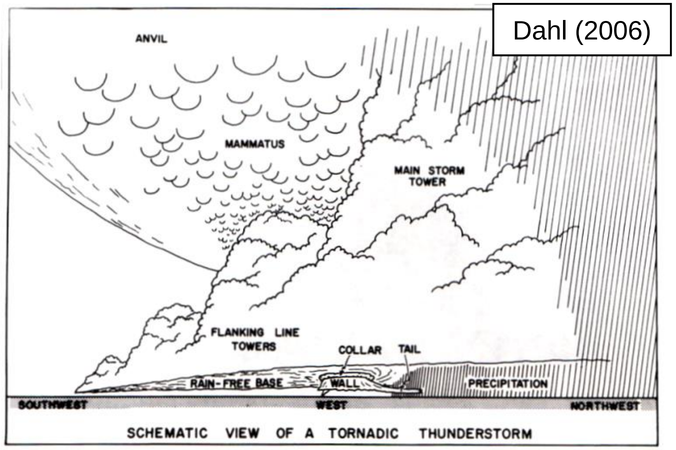

Dahl (2006)

From vertical wind shear to supercell rotation

Crosswise and streamwise vorticity

Crosswise vorticity:

- Axis of spin normal to the flow
- Proportional to wind speed shear
- Analogy: a car or bike wheel

Streamwise vorticity:

- Axis of spin parallel to the flow
- Proportional to directional wind shear
- Analogy: a perfectly thrown American football

(In reality: always a mixture of both)

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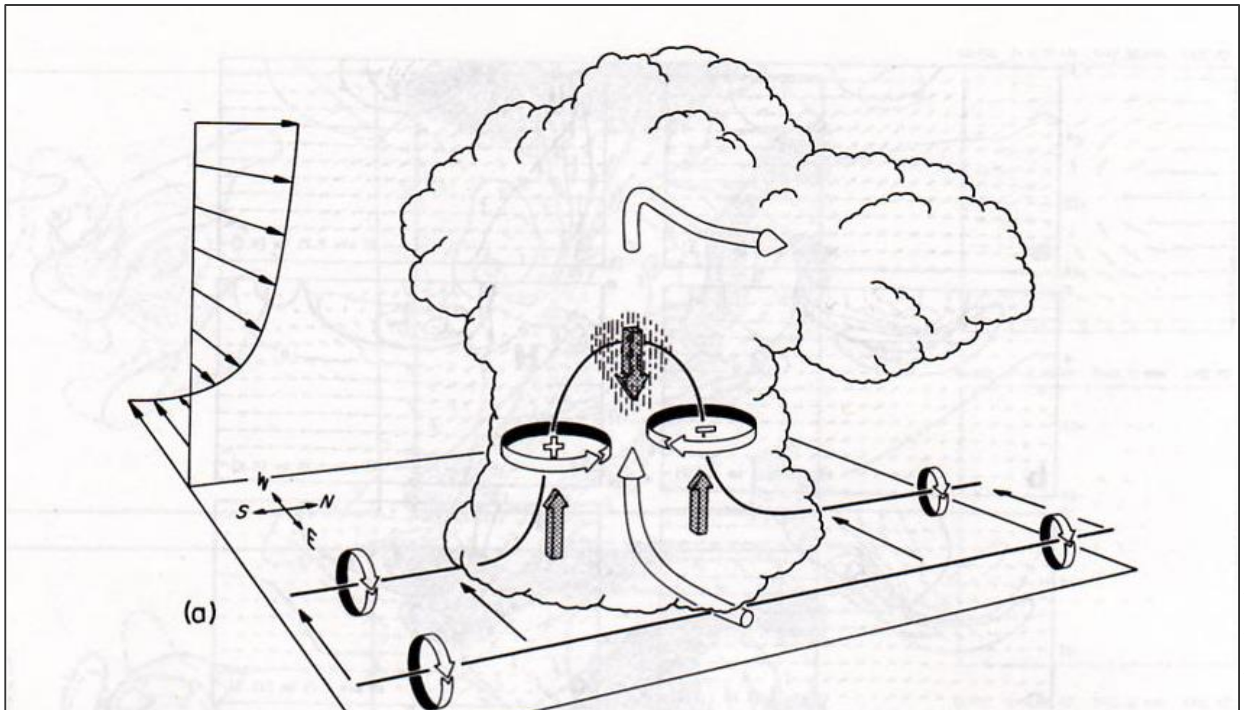
Speed shear ⇔ crosswise vorticity

Idealized case 1: only speed shear

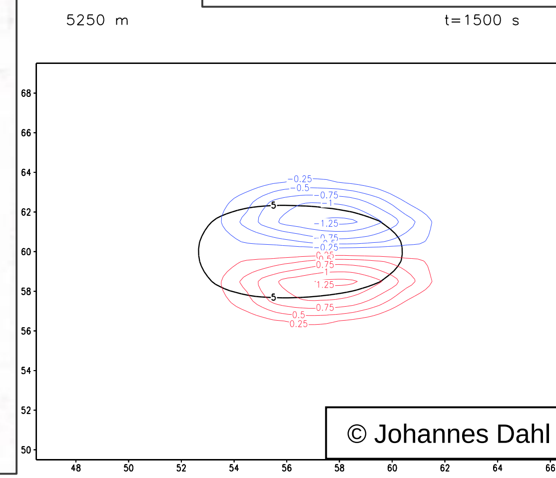
⇒ Only crosswise vorticity

⇒ Vertical vorticity not collocated with updraft



Dahl (2006), modified from Klemp (1987)

updraft
anticyclonic vorticity
cyclonic vorticity



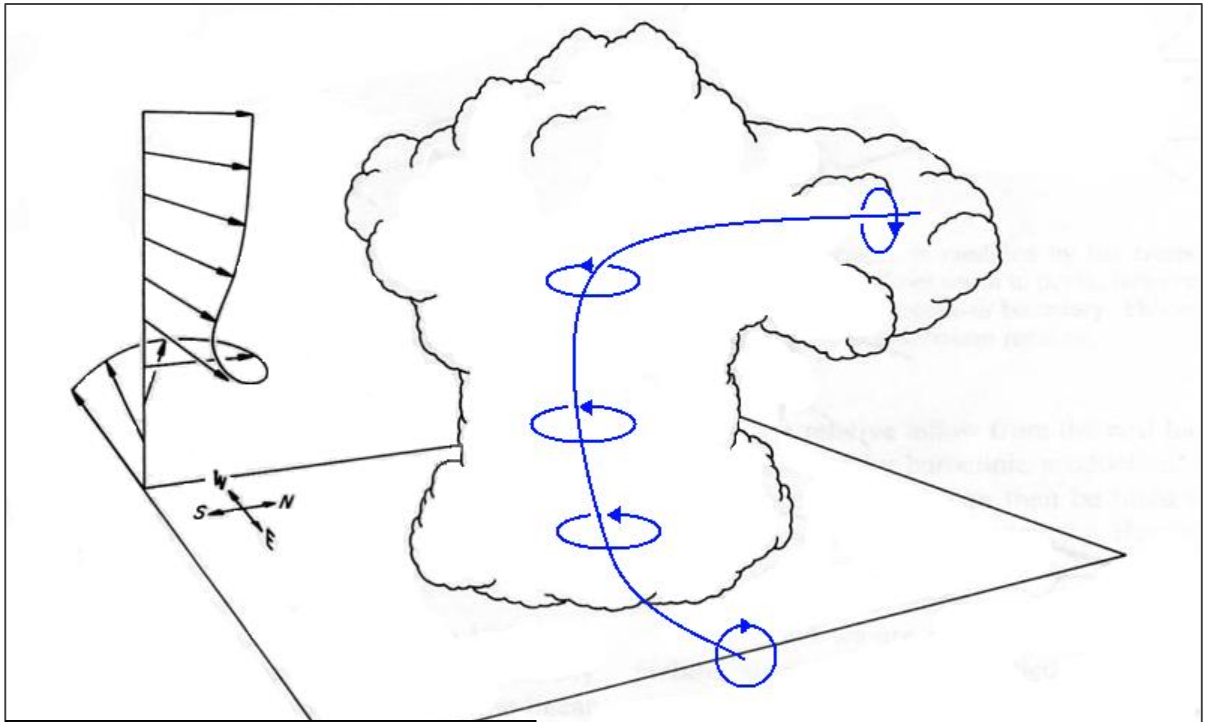
© Johannes Dahl

Directional shear ⇔ streamwise vorticity

Idealized case 2: only directional shear

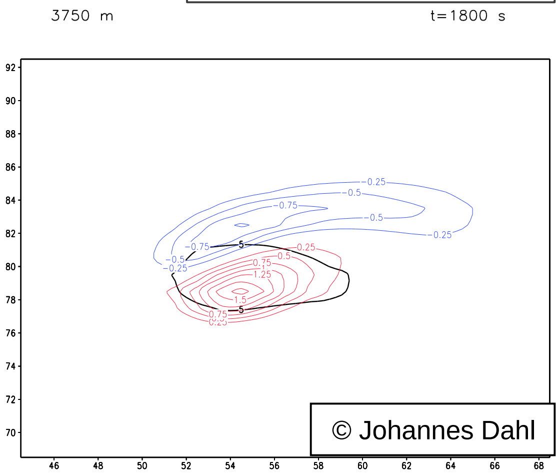
⇒ Only streamwise vorticity

⇒ Vertical vorticity collocated with updraft



Dahl (2006), modified from Klemp (1987)

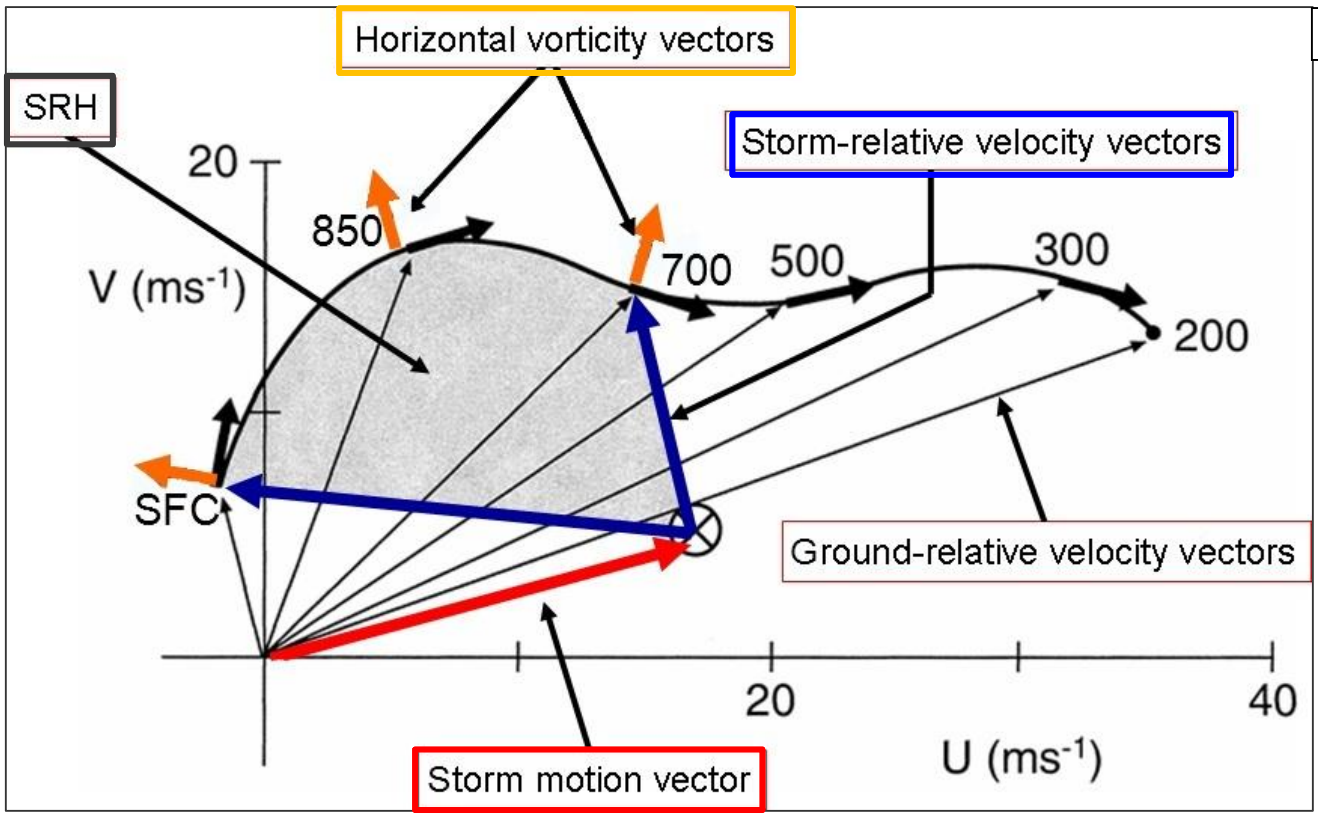
updraft
anticyclonic vorticity
cyclonic vorticity



© Johannes Dahl

Storm-relative helicity (SRH)

- SRH is proportional to area between storm-relative wind vectors and hodograph (positive for clockwise turning of wind with height, negative otherwise)
- Roughly: $100\, m^2/s^2 < |SRH| < 200\, m^2/s^2$ in the lowest 3 km is moderate, $|SRH| > 200\, m^2/s^2$ is a lot!



Dahl (2006)

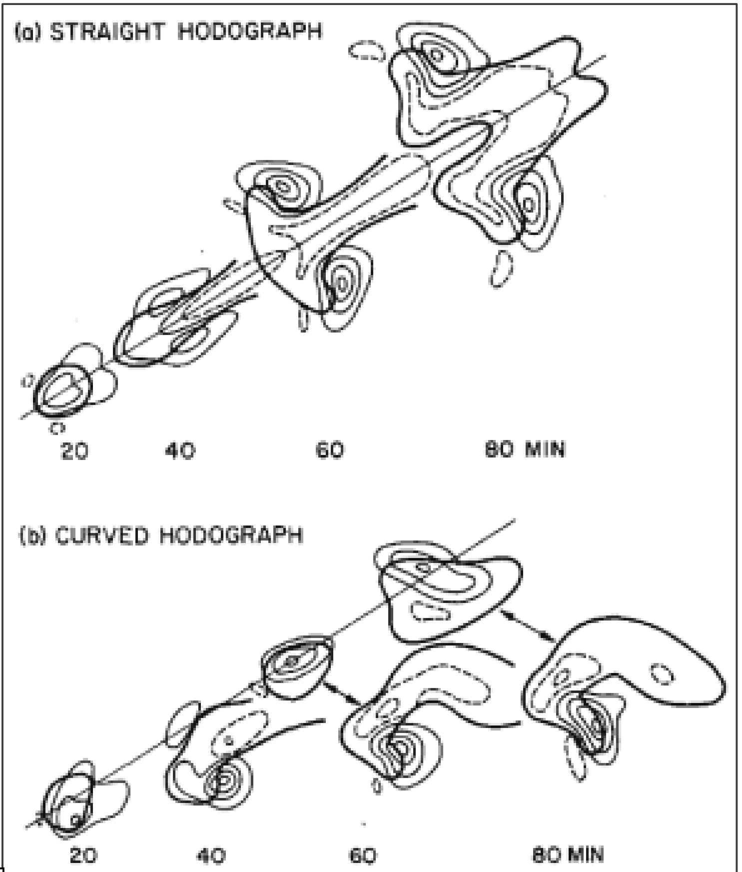
Storm behavior under straight and curved hodographs

Straight hodograph ⇔ speed shear:

- Storm splits into pair of „left mover“ and „right mover“
- Crosswise vorticity turns streamwise in case of deviant motion

Curved hodograph ⇔ directional shear:

- One storm (on low-level inflow side) is favored, the other one decays
- Streamwise vorticity is further enhanced in case of deviant motion



from Rotunno and Klemp, 1982.

Supercells as dominant severe weather producers

Why do supercells frequently produce severe weather?

- Updraft and downdraft are enhanced by local perturbation pressure gradients
- Helical flow in updraft reduces entrainment
- The architecture of the storm cloud allows hailstone trajectories which favor more rapid growth
- Supercell rotation may be concentrated into tornadoes under certain conditions

Forced lift due to perturbation pressure gradients

Forced lift is occasionally made visible by laminar clouds near the updraft, when environmental air is lifted alongside

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Severe storm forecasting in a nutshell

- **If we want to forecast large hail, severe wind events, or tornadoes, we first and foremost need to identify environments favorable for organized storms!**

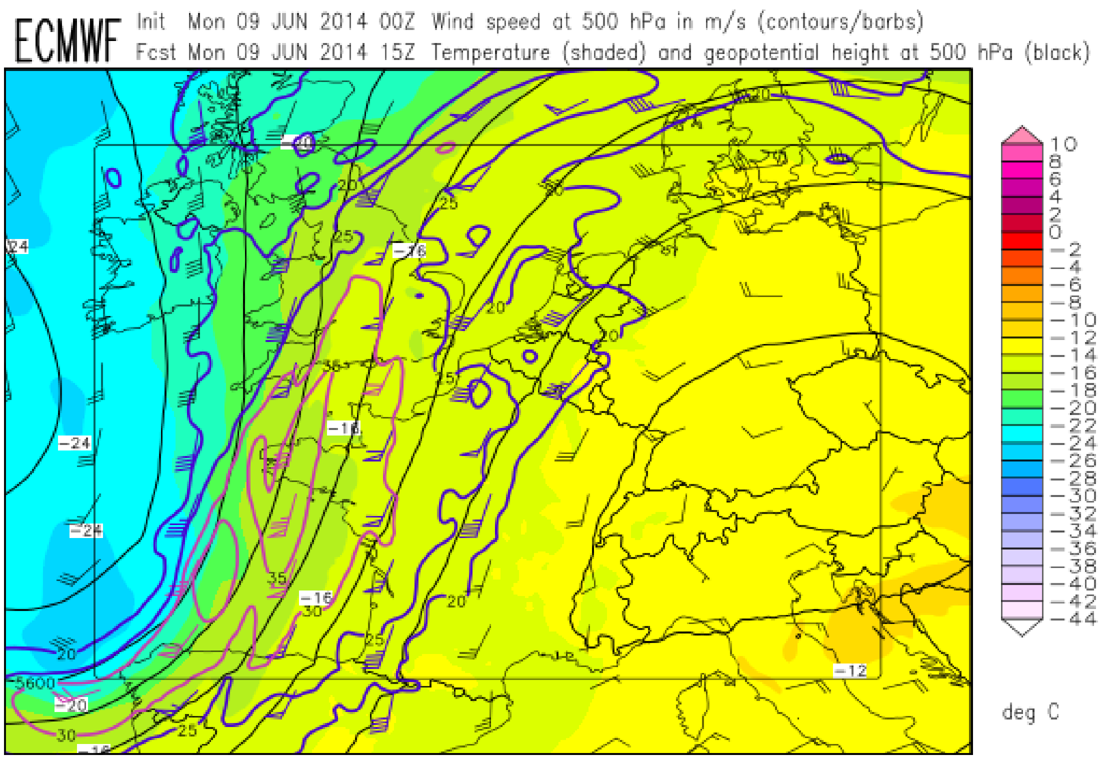
- **If vertical wind shear is strong and the hodograph is straight, watch out for storms whose motion deviates from the mean wind!**

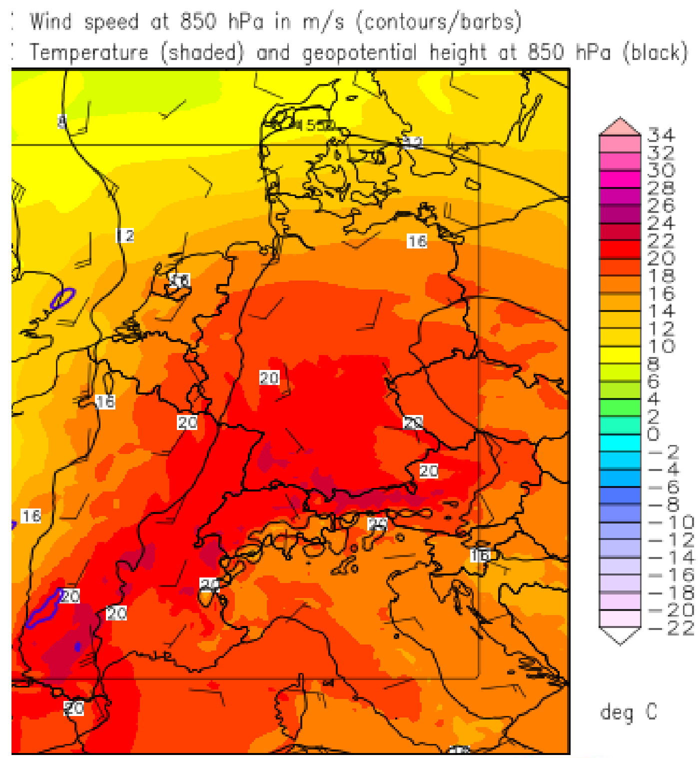
- **If vertical wind shear is strong and the hodograph is curved, watch out for any storm that forms!**

Case study: 09 June 2014, N France

ECMWF forecasts for 15 UTC

- Deep SW-erly flow at 500 hPa geopotential (left)
- Strong warm air advection from the S at 850 hPa (right)

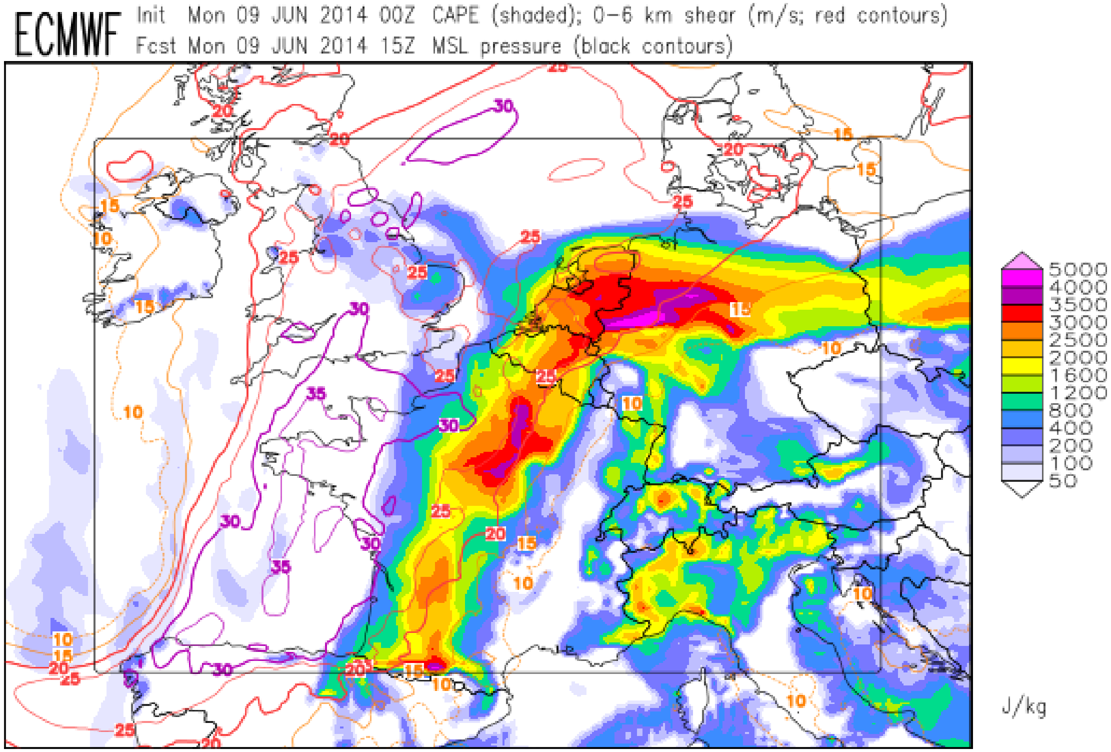


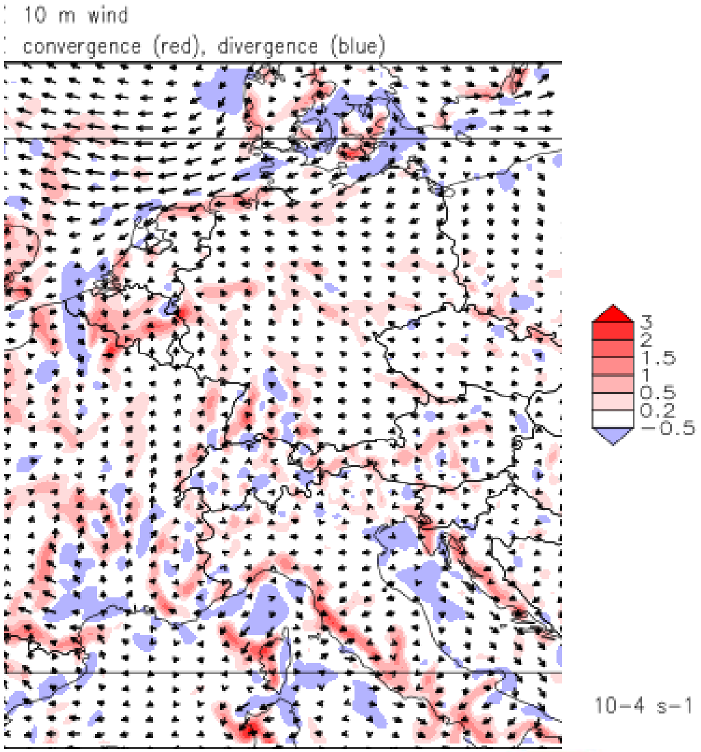


Case study: 09 June 2014, N France / 2

ECMWF forecasts for 15 UTC (cont'd)

- High CAPE and strong deep-layer shear (left)
- Diffuse cold front / sea breeze front in the 10m wind field (right)





Case study: 09 June 2014, N France / 3

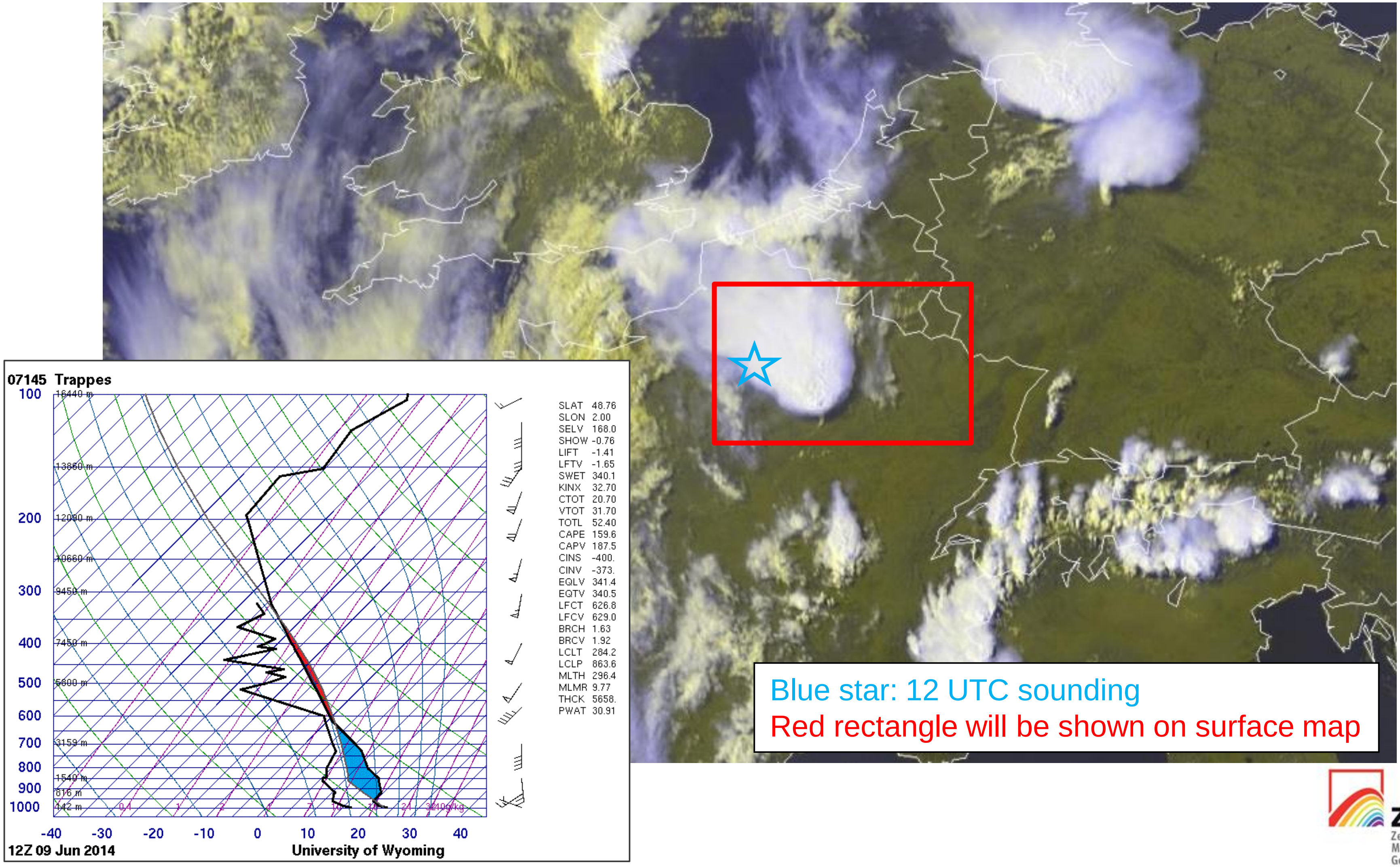
- Severe weather outbreak with numerous supercells
- Hailstones up to 9 cm in the Loiret department around 15 UTC

© Vincent Deligny

© Cédric Guivarch

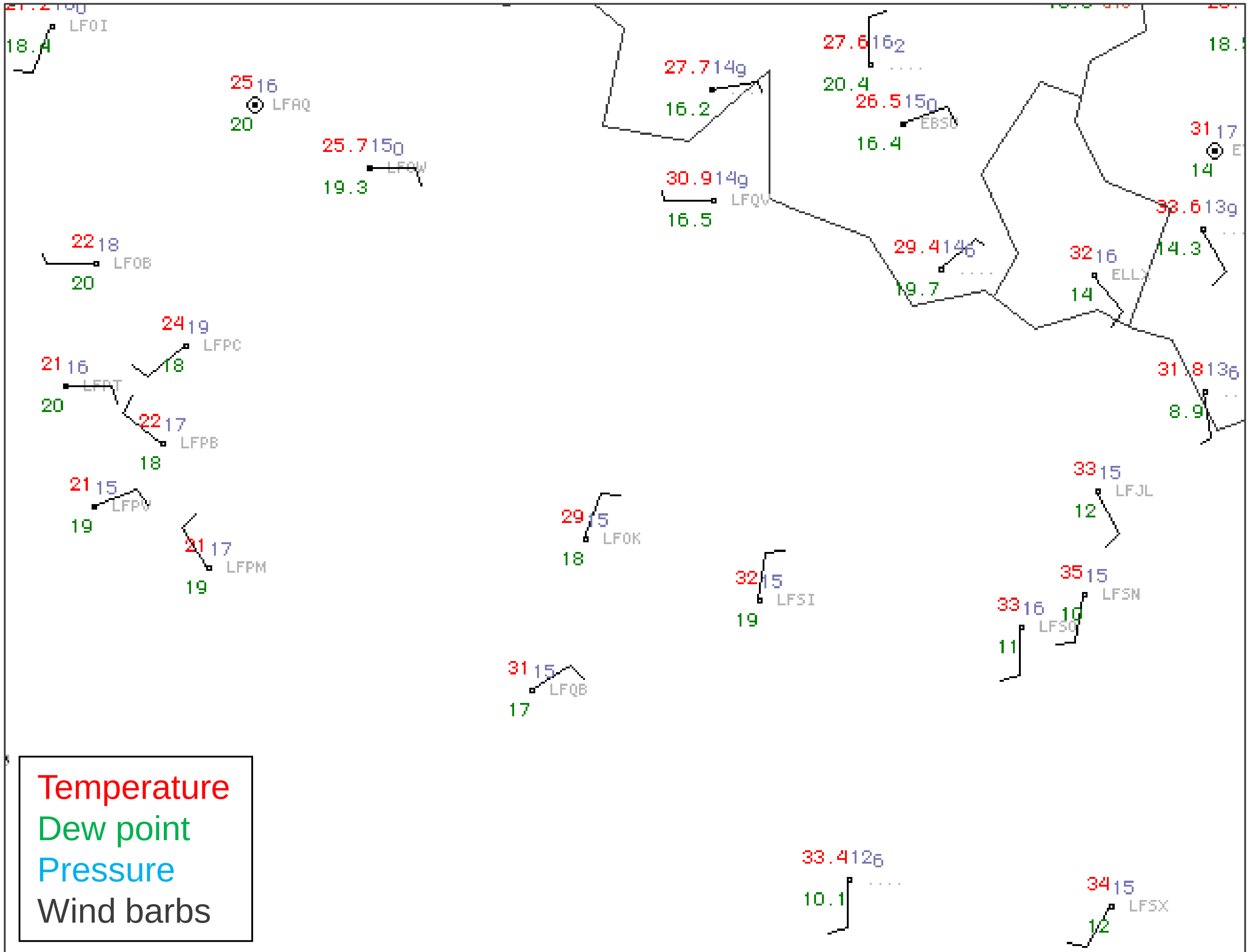
Case study: 09 June 2014, N France / 4

1500 UTC Meteosat E-view display



Case study: 09 June 2014, N France / 5

14 UTC surface observations



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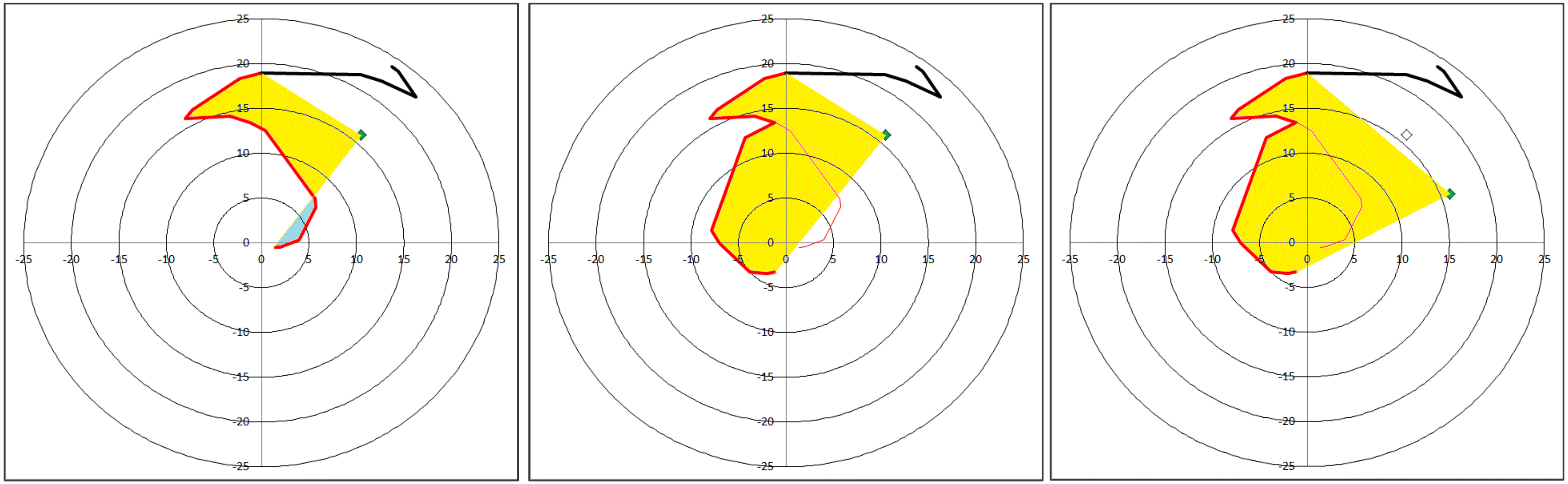
Case study: 09 June 2014, N France / 6

Hodographs from Paris/Trappes 12 UTC sounding

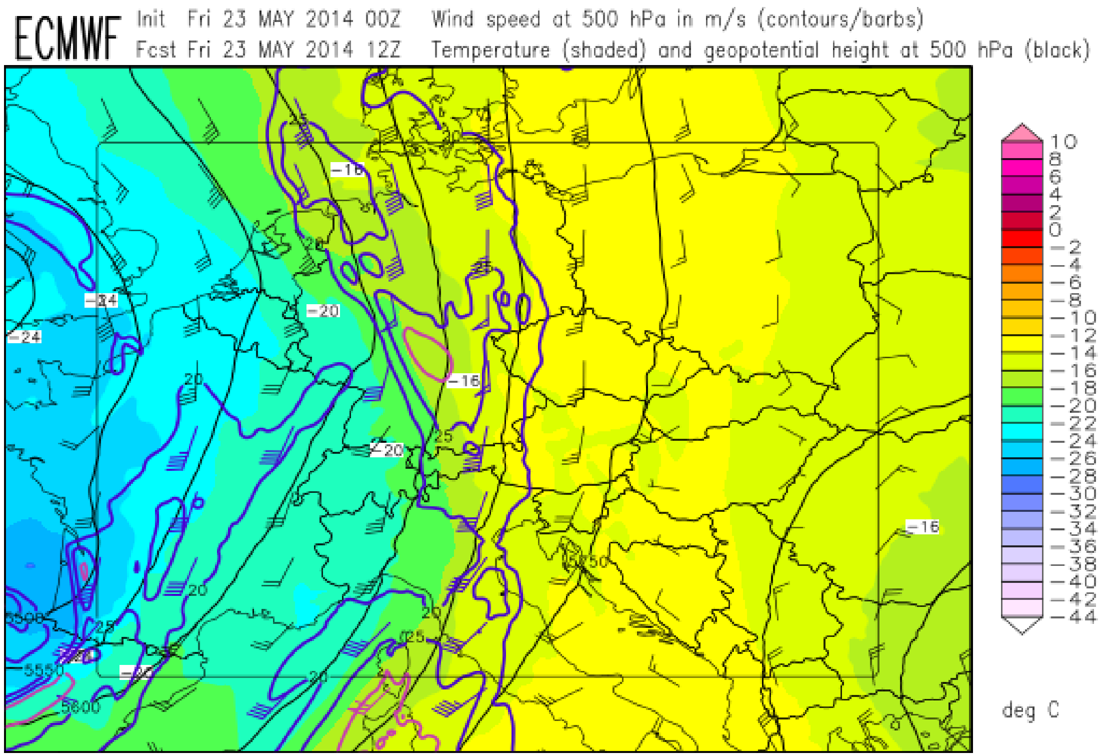


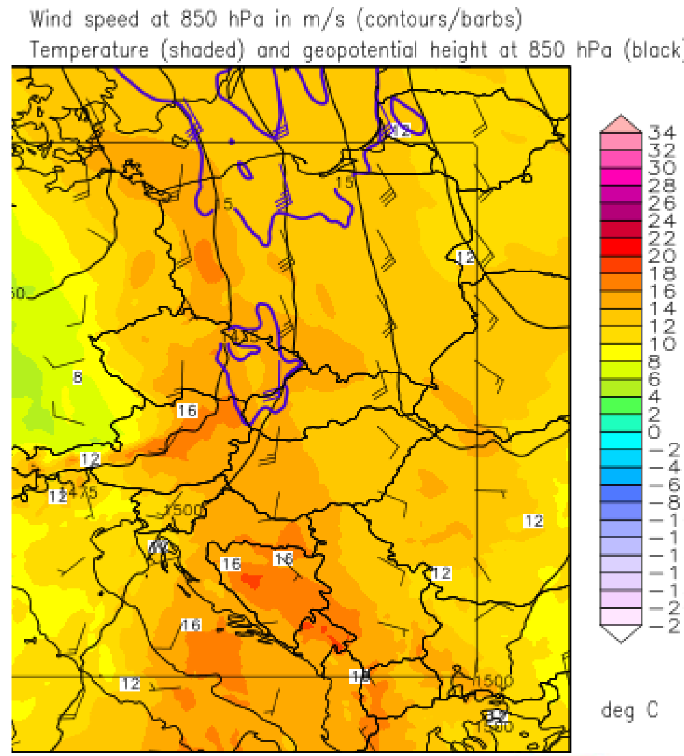
Original: $SRH = 176\, m^2/s^2$	With modified low-level winds: $SRH = 457\, m^2/s^2$	…and with adjusted storm motion: $SRH = 566\, m^2/s^2$

Case study II: 23 May 2014, E Austria

ECMWF forecasts for 12 UTC

- SSW-erly flow at 500 hPa (left)
- S-erly low-level jet at 850 hPa (right)





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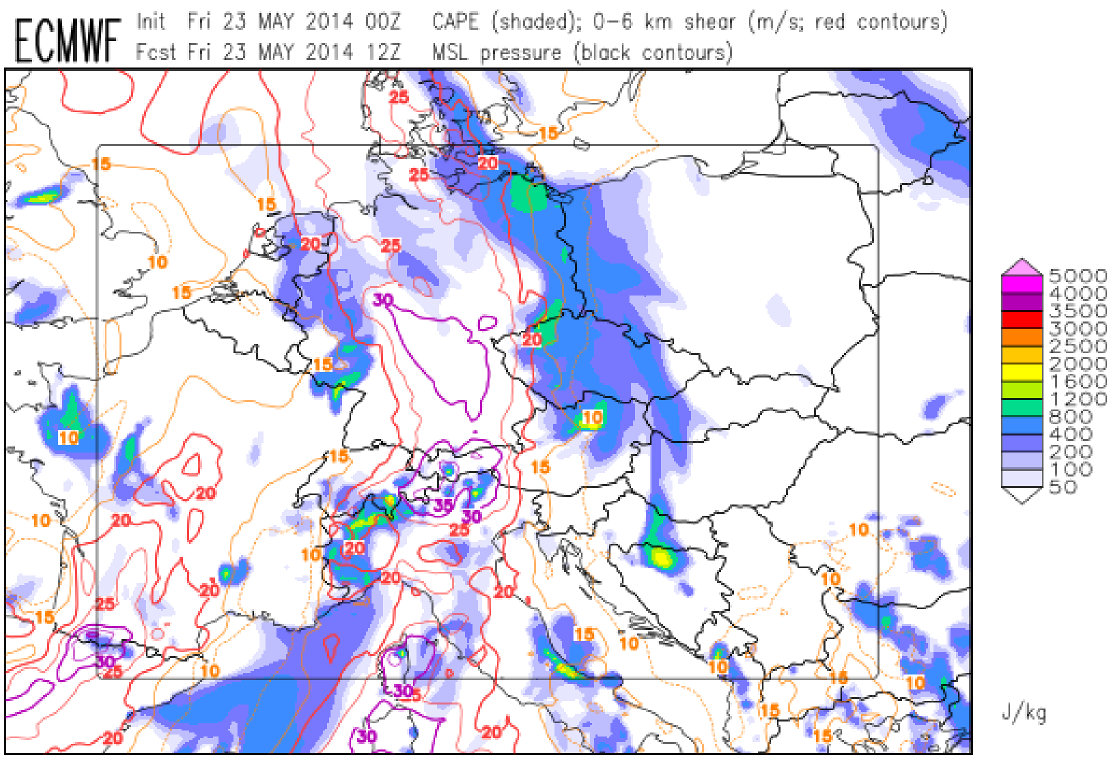
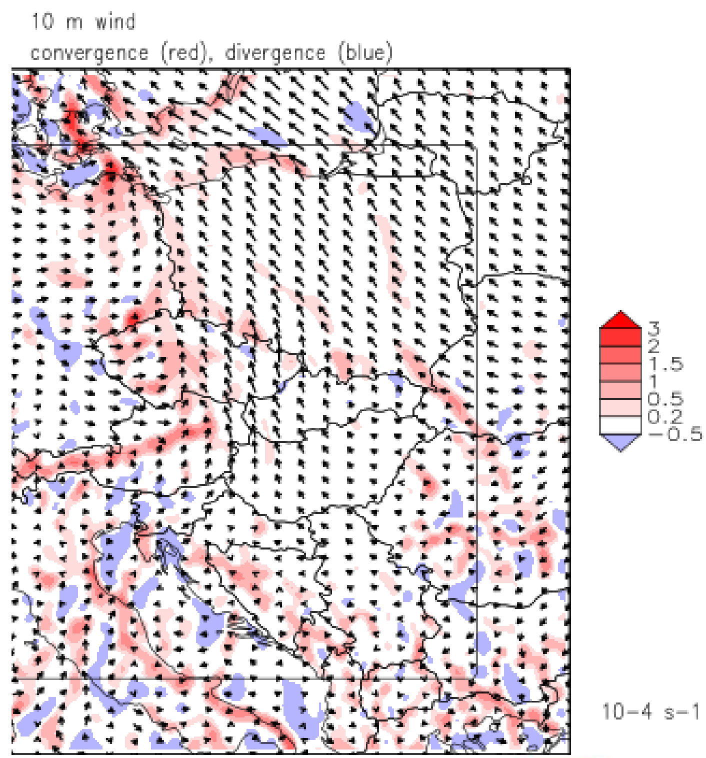
Case study II: 23 May 2014, E Austria / 2

ECMWF forecasts for 12 UTC (cont'd)

- Moderate CAPE, moderate deep-layer shear (left)
- Convergence line in 10m wind field (right)





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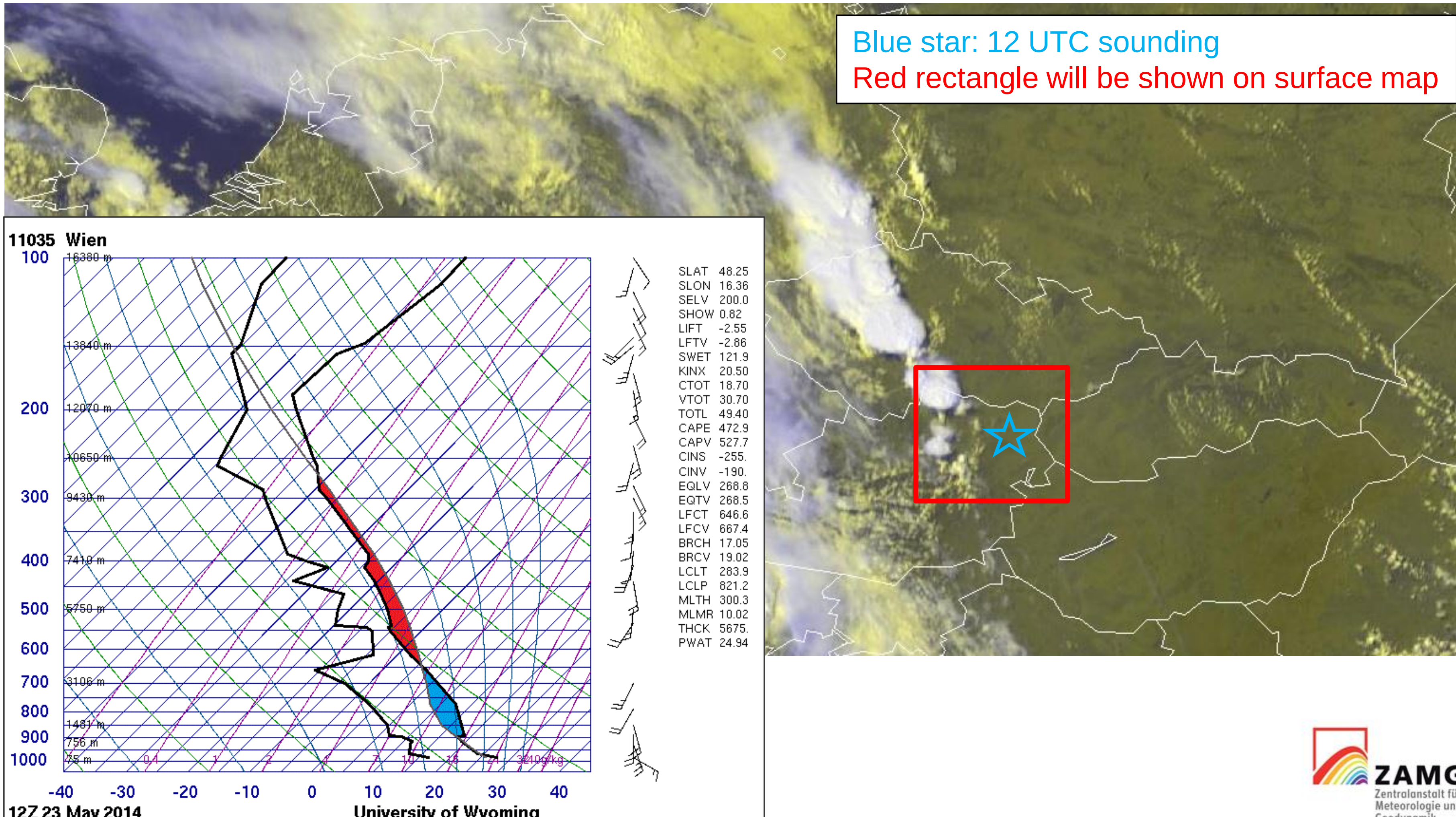
Case study II: 23 May 2014, E Austria / 3

- Almost stationary supercell near Allentsteig (Austria) at ~14 UTC
- Hailstones 4-6 cm in size, nearly tornadic circulation at the ground

Case study II: 23 May 2014, E Austria / 4

1355 UTC Meteosat E-view display



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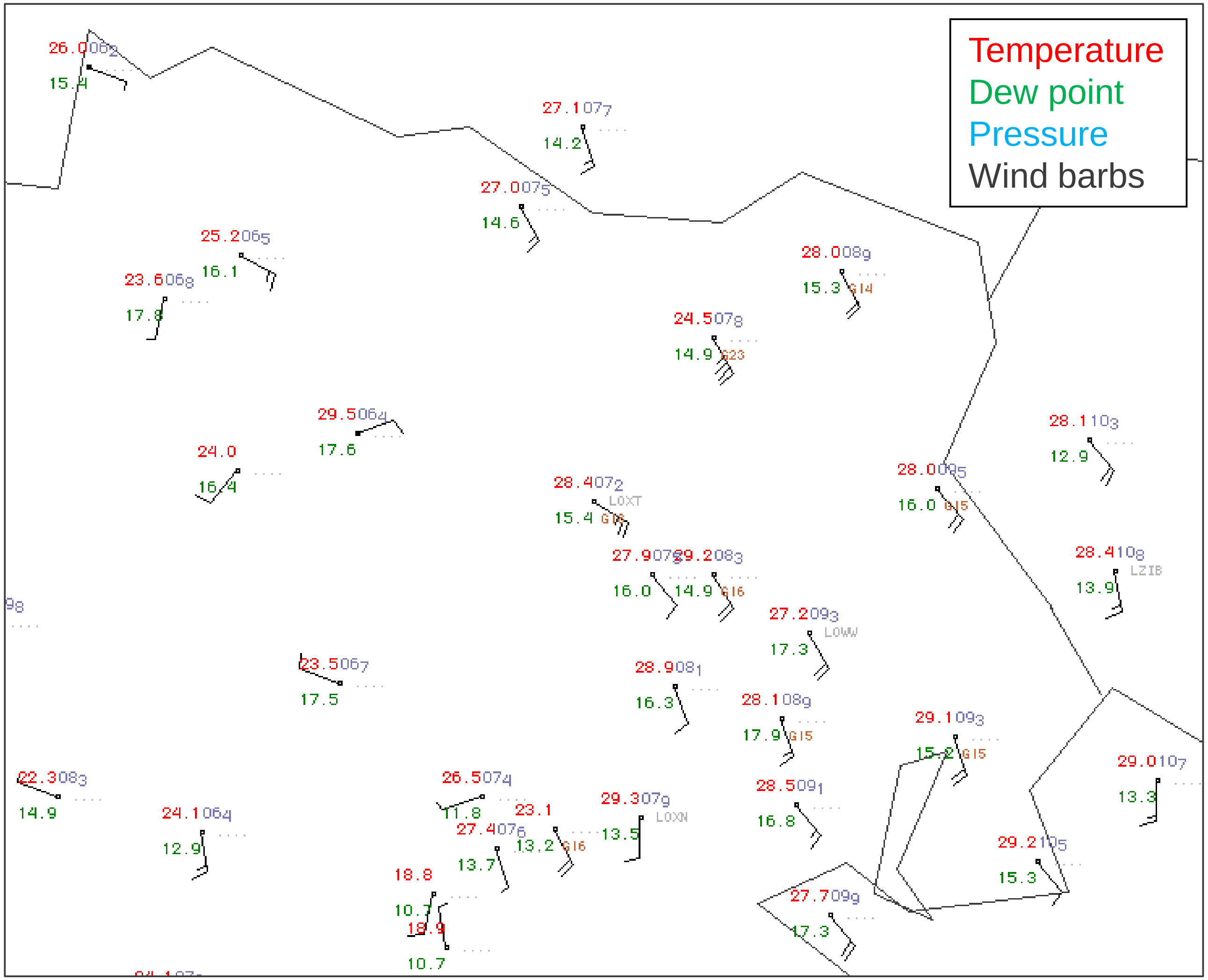
Case study II: 23 May 2014, E Austria / 5

EUMETSAT Convection Week
23 June 2015
Folie 25

13 UTC surface observations



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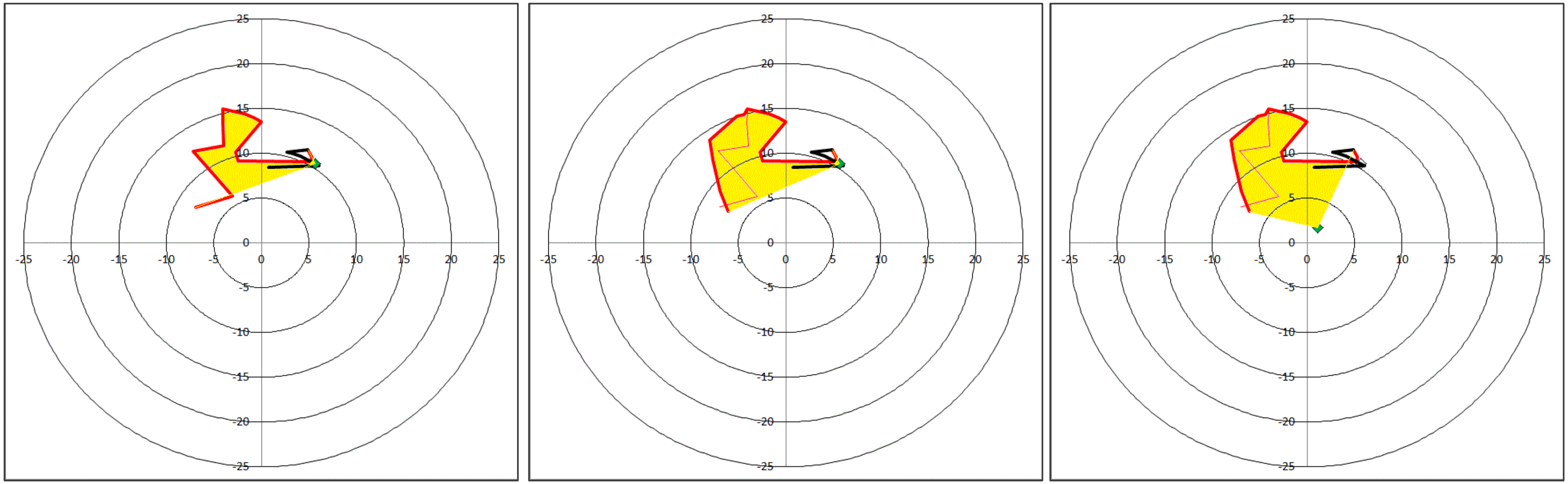
Case study II: 23 May 2014, E Austria / 6

Hodographs from Vienna 12 UTC sounding



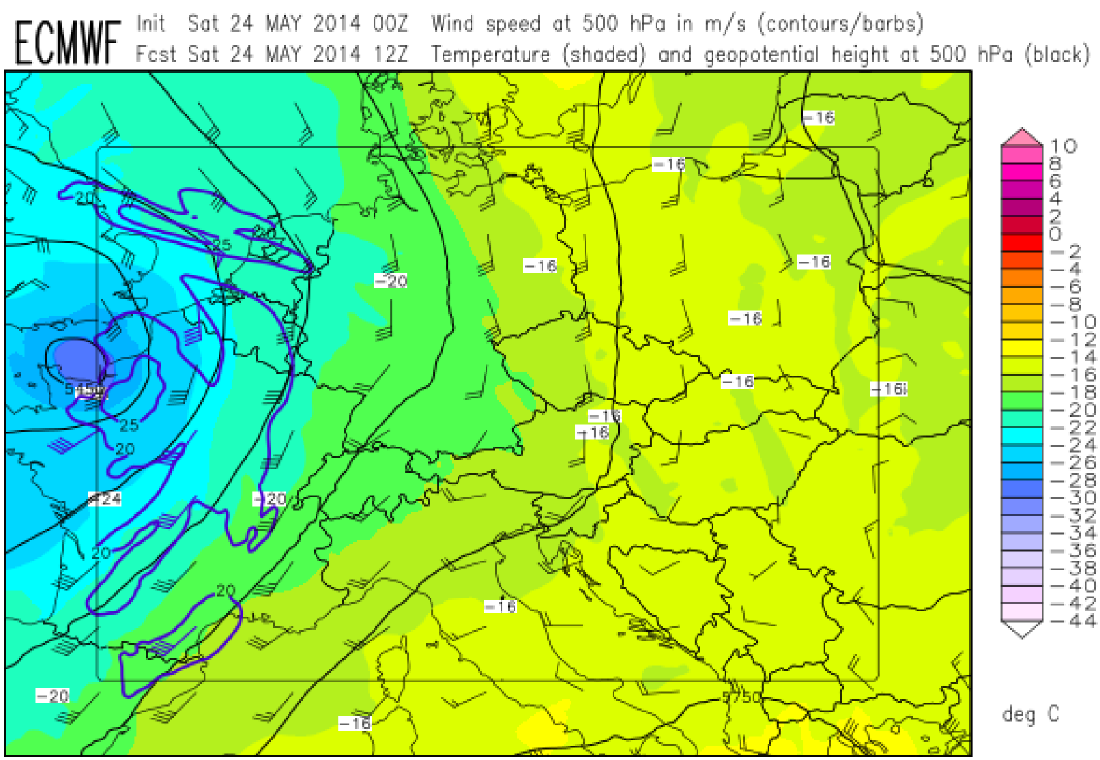
Original: $SRH = 82\, m^2/s^2$	With modified low-level winds: $SRH = 140\, m^2/s^2$	…and with adjusted storm motion: $SRH = 186\, m^2/s^2$

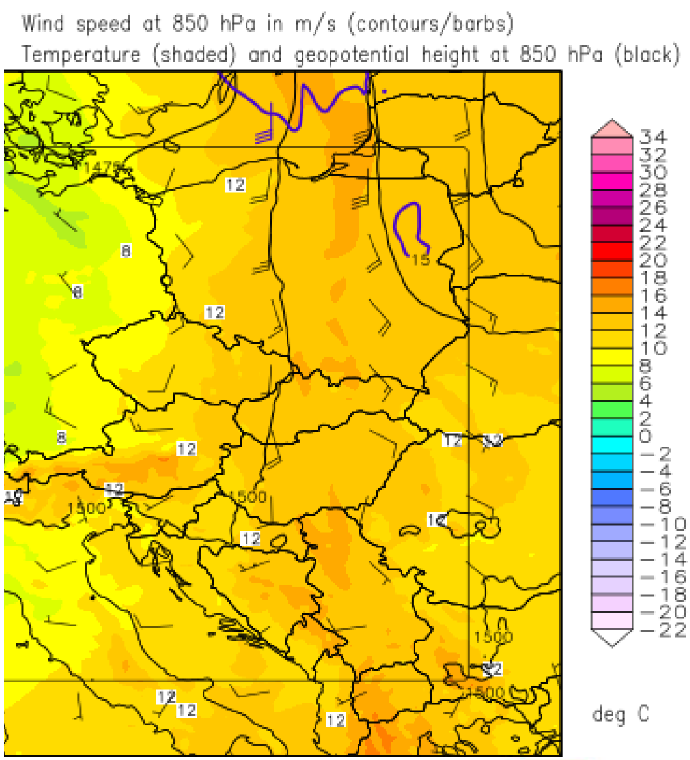
Case study III: 24 May 2014, E Austria

EUMETSAT Convection Week
23 June 2015
Folie 27

ECMWF forecasts for 12 UTC

- Weakening S-erly flow at 500 hPa (left)
- 850 hPa turning from S to W (right)





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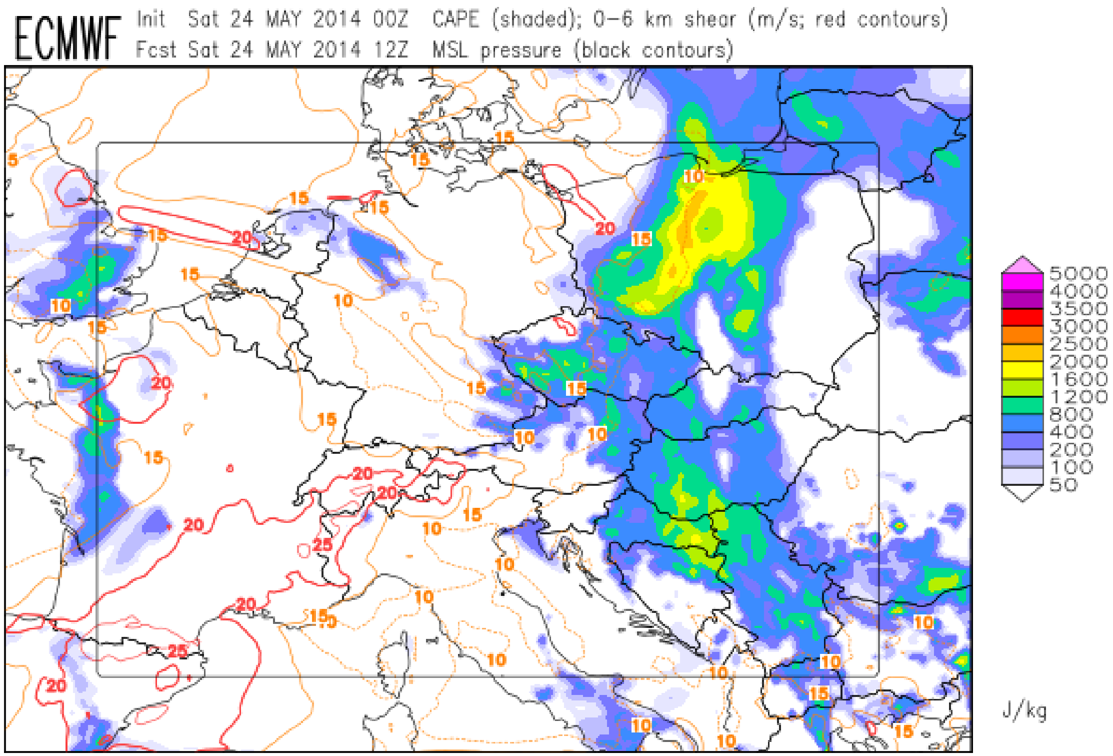
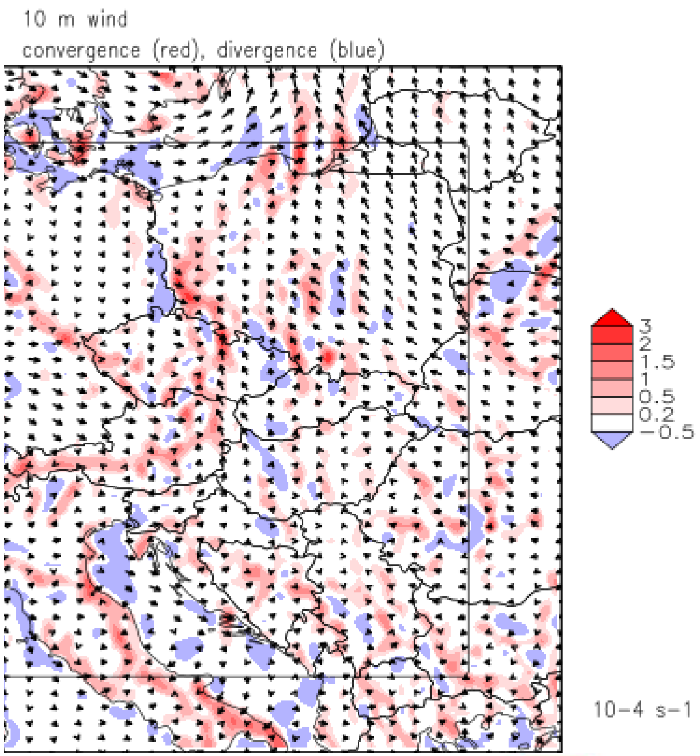
Case study III: 24 May 2014, E Austria / 2

ECMWF forecasts for 12 UTC (cont'd)

- Moderate CAPE, weak deep-layer shear (left)
- Same convergence line still visible in 10m wind field (right)





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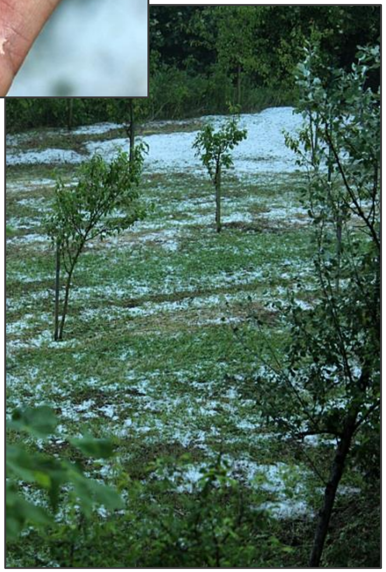
Case study III: 24 May 2014, E Austria / 3

Flash flood in parts of Vienna …

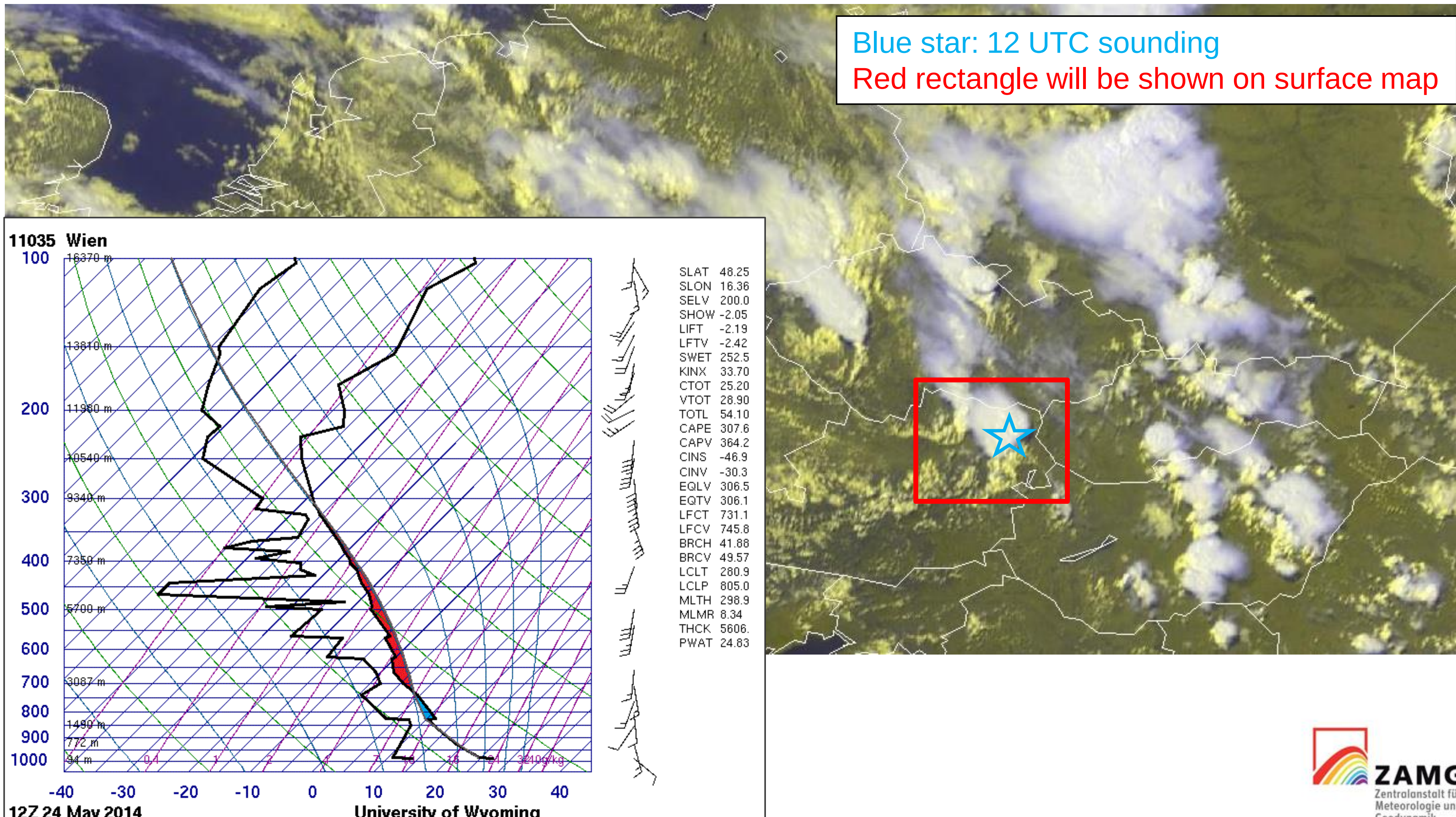
Case study III: 24 May 2014, E Austria / 4

… but also masses of large hail and supercell structures!



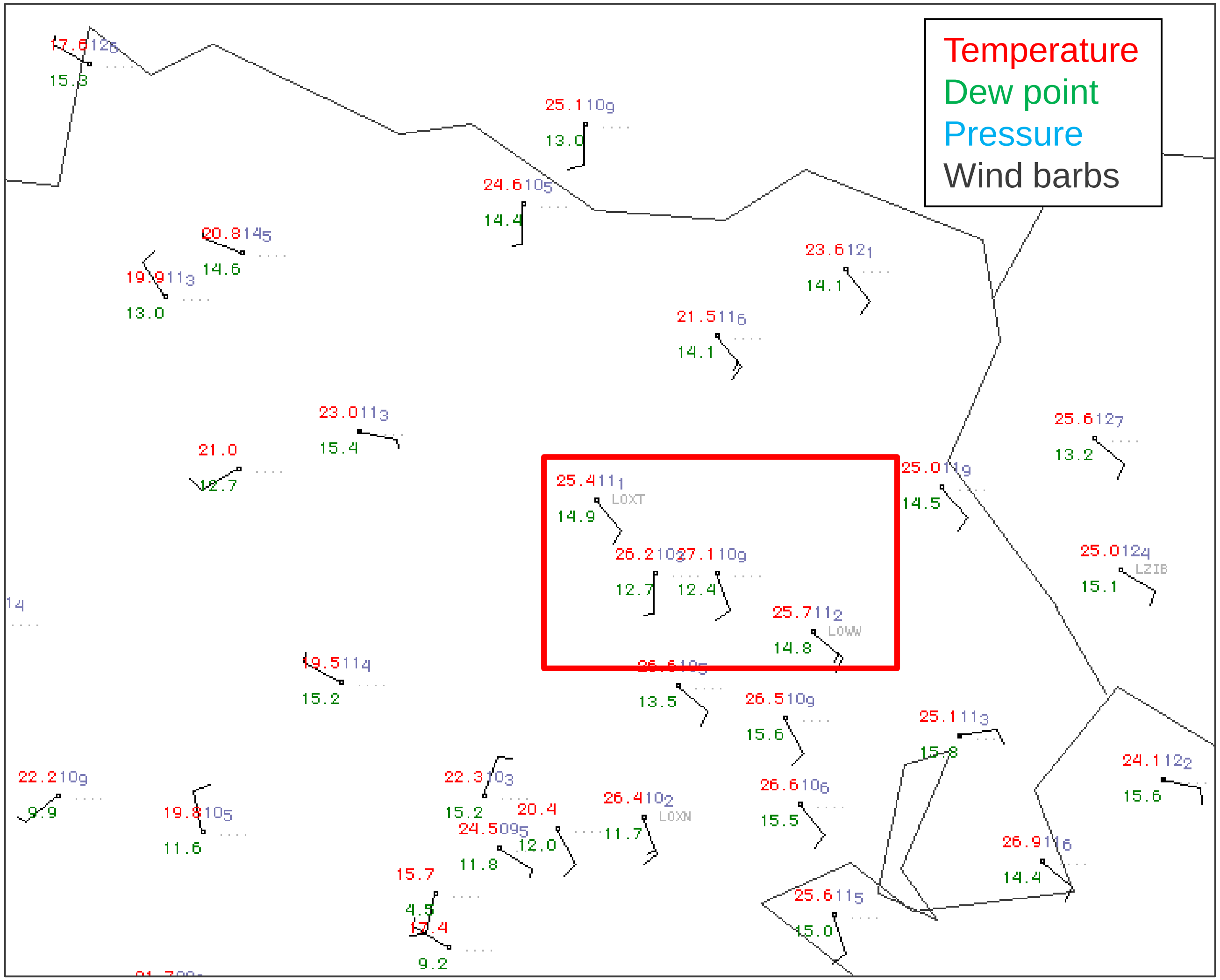
Case study III: 24 May 2014, E Austria / 4

1355 UTC Meteosat E-view display



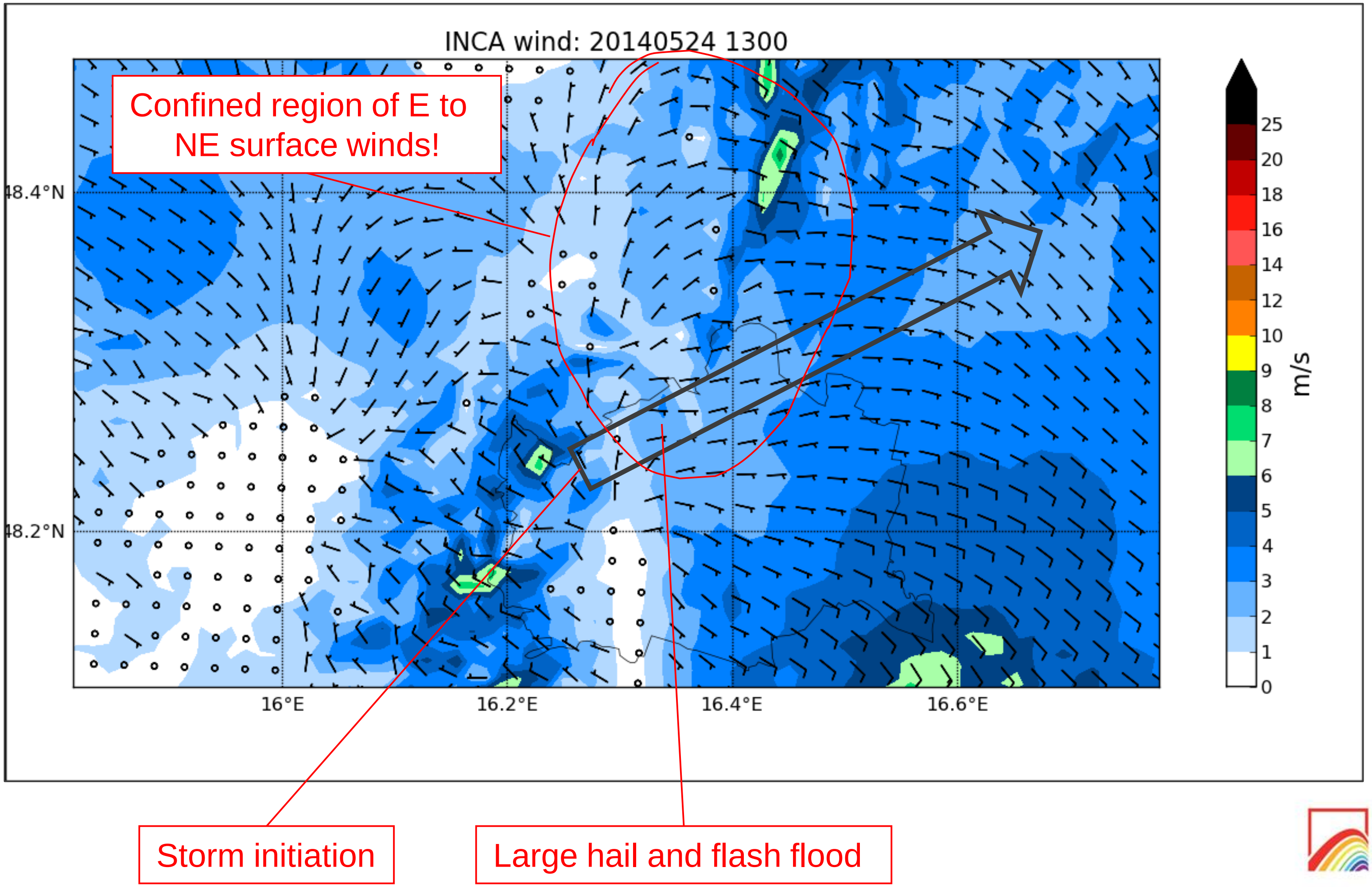
Case study III: 24 May 2014, E Austria / 6

13 UTC surface observations



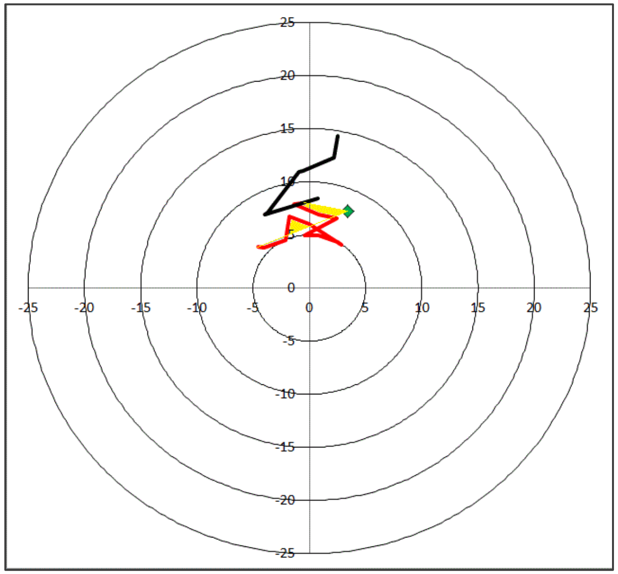
Case study III: 24 May 2014, E Austria / 7

Zoom into 10m wind field over Vienna at 13 UTC (INCA analysis)

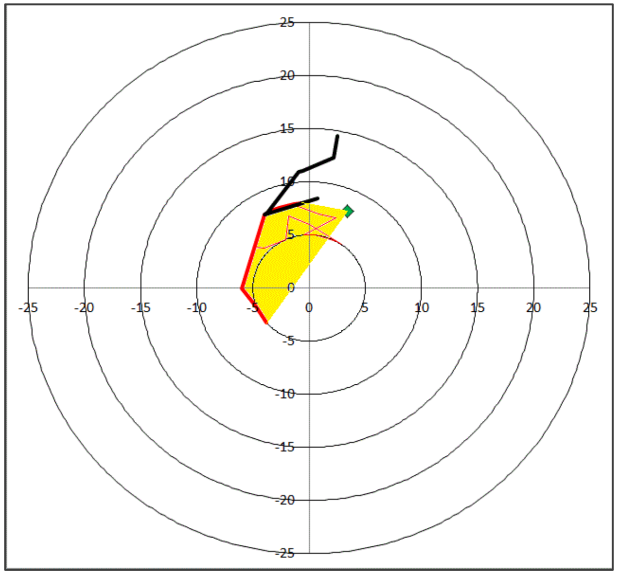


Case study III: 24 May 2014, E Austria / 8

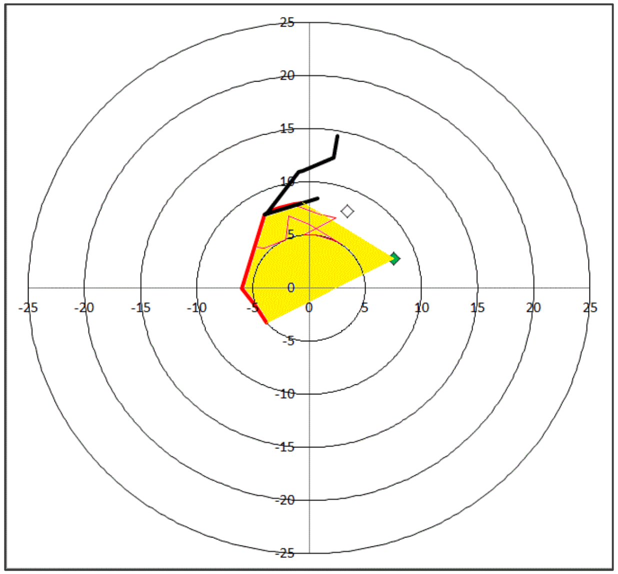
Hodographs from Vienna 12 UTC sounding



Original:
$\boldsymbol{SRH = 8\,m^2/s^2}$



With modified low-level winds:
$\boldsymbol{SRH = 104\,m^2/s^2}$



…and with adjusted storm motion:
$\boldsymbol{SRH = 164\,m^2/s^2}$

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Take-home messages

- Environments favorable for severe thunderstorms are characterized by substantial CAPE and vertical wind shear
- They are less frequent in Europe than in the American Great Plains, but they do occur
- Low-level wind, temperature and moisture may be favorably (or unfavorably) modified by processes over complex terrain
- Such local modifications can easily create supercells when you would not expect them (or prevent supercells when you would expect them)
- **Precise monitoring of observational data is essential!**

Literature and Acknowledgments

Review on severe convective storms:

- Markowski, P., and Y. Richardson, 2010: Mesoscale Meteorology in Midlatitudes. Wiley-Blackwell, 407pp.

Acknowledgments:

- **Johannes Dahl** (Texas Tech University) for discussions and plots
- The **European Severe Storms Laboratory** (ESSL) for most of the material in the case examples

Thank you for your attention!

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