Initiation of Deep Moist Convection at WV-Boundaries

Vienna, Austria

For the operational forecaster one important precondition for the diagnosis and prediction of convective activity is the availability of observation tools with high temporal and spatial resolution. Remote sensing facilities mostly used by operational weather services are satellites, weather radar and lightning detection. Satellite images from the operationally used MSG are updated every 15 minutes, and every 10 minutes within a rapid scan – mode of METEOSAT-8.

The visible channels show the earliest stages of convection as soon as the convective cell exceeds the spatial image resolution.

The onset of deep moist convection (DMC) can be observed in the WV channels which represent the humidity in a layer above approximately 600 hPa.

It is possible to derive information about the atmospheric flow within this layer of the troposphere even when clouds are absent. Features in the WV image like grey and white zones and black stripes are caused by processes including differential advection in both the horizontal and vertical directions in different scales. Both large-scale and small-scale patterns may create conditions favourable for convection: cyclonic perturbation, cyclonic rotation centres and deformation zones.

The physical concepts behind synoptic and mesoscale cloud configurations shown in the WV satellite image can be well described with the non-hydrostatic quasigeostrophic theory using well-known parameters like relative vorticity and its advection, potential vorticity and many others.

For small-scale features like the convective cells investigated here, hydrostatic considerations are more relevant.

Under the synoptic situation of an upper-level pressure ridge and a thermal ridge (”fair weather”), shallow convection (in the sense of “not deep”, a capping inversion is not a necessary condition) appears especially over mountainous regions if a sufficiently moist surface layer and initial instability is existent. As comprehensive observations with the METEOSAT 7 WV channel showed, DMC developing from this shallow convection, preferably appears first at the transition zones between areas with dark/dry and bright/humid pixels, the so-called WV Boundaries (Krennert and Zwatz - Meise, 2003). It became clear, that different processes favour the onset of deep moist convection at boundaries in the WV image.

A possible approach towards an understanding of the mechanism is the separation of various components responsible for the onset of deep convection:

- The vertical stratification of the air column
- Entrainment
- Dynamic initiation
- Incoming solar radiation, diabatic heating

The vertical stratification of the air column

A basic item necessary for the understanding of the physical process of deep convection is the vertical stratification, especially in association with the vertical decrease of humidity.

A comprehensive investigation has shown that the critical area is widespread conditional instability in the low and middle troposphere. Near the surface a shallow layer of absolute instability can be found in nearly all cases. Often the high reaching conditional instability in the layer above is interrupted by very thin stable layers or weak inversions.

Usually radiosondes are not available at the exact location of deep convection, the temporal and spatial resolution of the soundings is far too coarse. Here, the use of WV channels can contribute significantly to the knowledge about upper tropospheric dynamics.

Since September 2003 two new MSG water vapour channels have become operationally available, offering better spatial and temporal resolution than the METEOSAT-7 WV channel. In this way an investigation of the differential vertical and horizontal moisture distribution (qualitatively) becomes possible. The MSG WV channels 5 and 6 display the humidity content in two different layers. Channel 5 has a maximum absorption at a wavelength around 6.2 µm, with the maximum signal being received from around 350 hPa. The WV channel 6 has maximum absorption at 7.3 µm, with a maximum signal from around 500 hPa. See the schematic in fig.1.

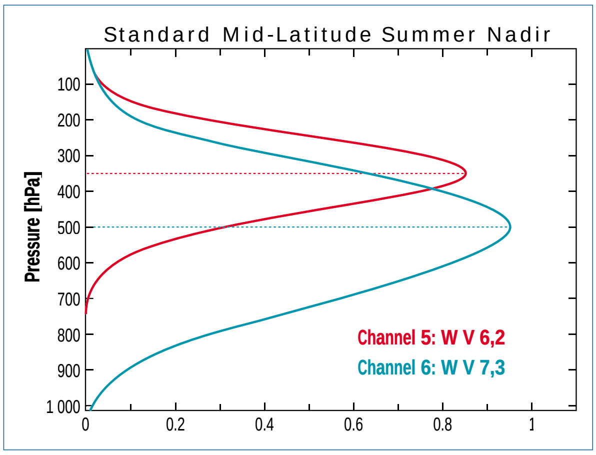


Figure 1: Weighting function of the 6,2 µm band (Channel 5) and the 7,3 µm band (Channel 6), respectively, representing the height of the maximum signal for both WV channels.

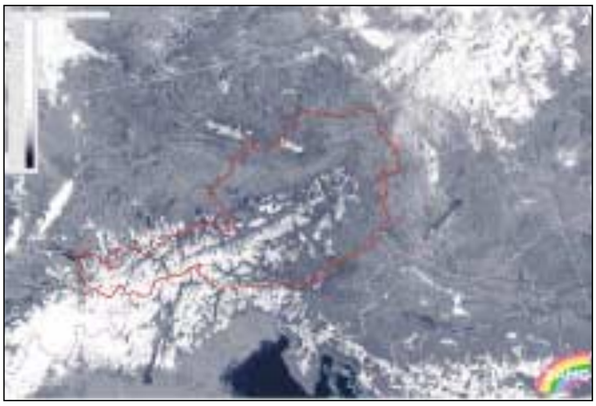


Figure 2: MSG high resolution visible image (HRVIS) channel 12, 0945 UTC. The image shows a mostly cloud free area over the eastern part of Austria and its neighbour states. First signs of shallow convection appear over the mountainous region of the eastern Alps (centre of image).

The example of 28 April 2004 represents a typical case for the process of the onset of deep moist convection at WV - boundaries. The MSG high-resolution visible image (Fig.2) shows a nearly cloud free environment with no frontal disturbance (in the “classical” sense) over the eastern part of Austria at 0930 UTC. Yet, shallow convection has already set in over the eastern Alpine mountains.

WV channel 6 is also able to display the position of shallow convection. Medium grey shading along the eastern alpine flank indicates the increase of relative humidity at middle tropospheric levels through convection and further convective transport of humidity to the upper levels of the troposphere (Fig. 3 and 5, 1115 UTC and 1230UTC). Within two consecutive time steps three areas of deep moist convection, A, B and C, can be observed over the eastern Alps (Fig. 7). The MSG WV channel 5 represents the distribution of relative humidity at upper levels of the troposphere. The dark “dry” zones can be clearly distinguished from the brighter “humid” parts in the image. Higher potential instability is usually connected to an increasing vertical gradient of humidity, e.g. when a dry zone (dark in WV channel 5) is situated above a relatively moist zone (light grey in WV channel 6). Comparing Fig. 4 and Fig. 3 this initial condition is given over the eastern part of Austria. In Fig. 6 - 8 the growth of DMC at WV boundaries is shown.

Finally, the convective transport of moisture above 350 hPa can be seen in Fig. 8 (areas A, B and C).

The combination of the two MSG WV channels within a RGB composite demonstrates the mechanism more clearly. An area of increased potential instability can be identified qualitatively by the distribution of the horizontal humidity gradient at the two levels (Fig. 10, see also the colour table in Fig. 9 for interpretation). Along the transition zone between “dry” and “moist” upper air, deep convection occurs at the expense of the surrounding areas (fig. 10 - 12).

Figure 3: MSG WV 6, 28 April 2004, 1115 UTC

Figure 4: MSG WV 5, 28 April 2004, 1115 UTC

Figure 5: MSG WV 6, 28 April 2004, 1230 UTC

Figure 6: MSG WV 5, 28 April 2004, 1230 UTC

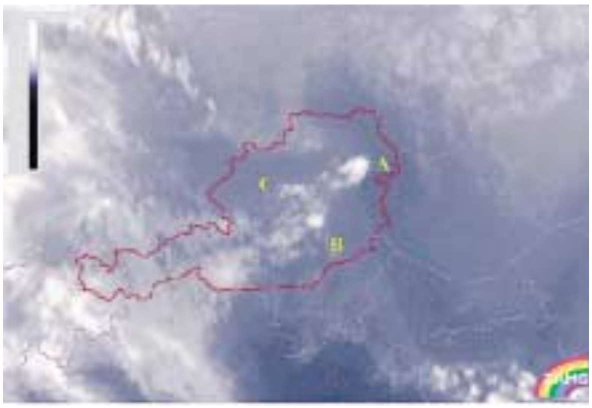


Figure 7: MSG WV 6, 28 April 2004, 1345 UTC

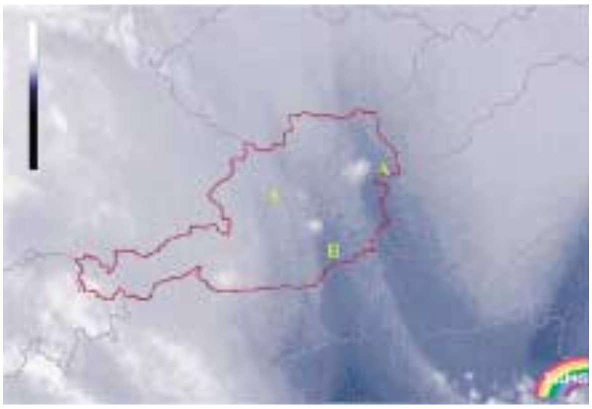
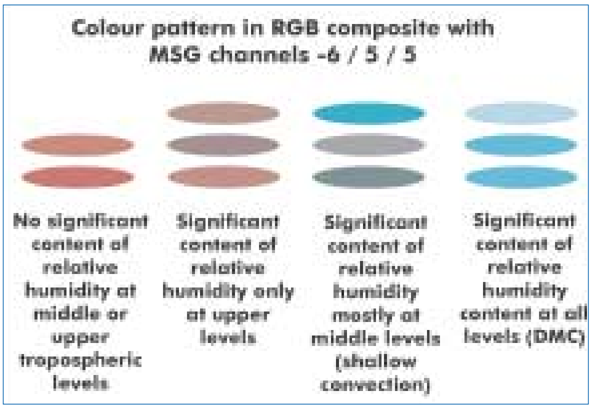


Figure 8: MSG WV 5, 28 April 2004, 1345 UTC



Colour pattern in RGB composite with MSG channels -6 / 5 / 5

No significant content of relative humidity at middle or upper tropospheric levels	Significant content of relative humidity only at upper levels	Significant content of relative humidity mostly at middle levels (shallow convection)	Significant content of relative humidity content at all levels (DMC)

Figure 9: Colour table

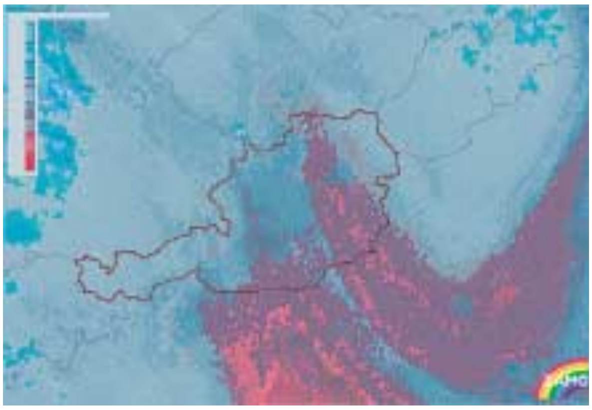


Figure 10: MSG WV RGB -6/5/5, 28 April 2004, 1115 UTC

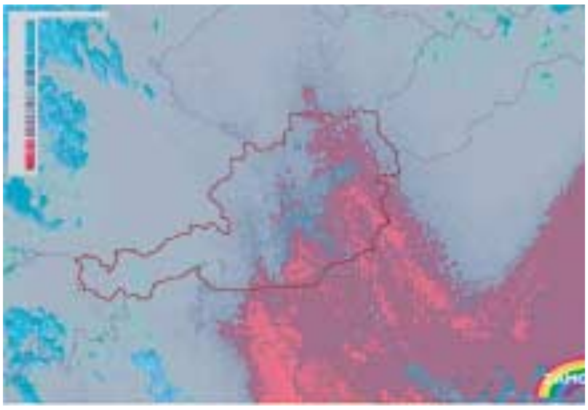


Figure 11: MSG WV RGB -6/5/5, 28 April 2004, 1230 UTC

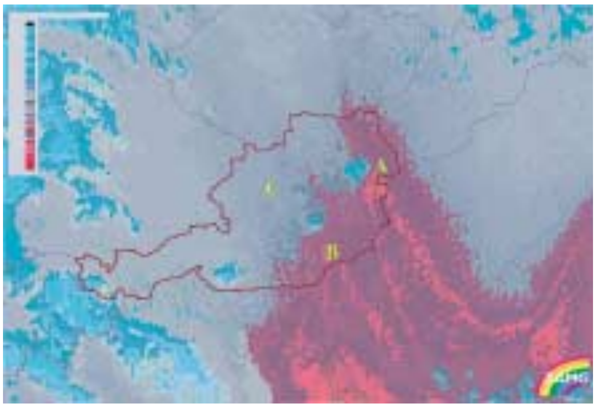


Figure 12: MSG WV RGB -6/5/5, 28 April 2004, 1345 UTC

The MSG WV- images provide primarily qualitative information about the humidity distribution, both vertical and horizontal.

Entrainment

Another effect that has to be taken into consideration is strong upward motion that causes turbulent entrainment, resulting in negative buoyancy (evaporation). It can be assumed that within the dry upper layer there is stronger entrainment than within the moist area.

Dynamic initiation

One possible source for DMC at WV - Boundaries can be found in the dynamic processes. Indeed some of the WV structures resemble cyclonic eddies being connected to vorticity and vorticity advection of the same magnitude as synoptic-scale frontal systems.

Operationally used models (like ECMWF) cannot resolve the structures on the scale under discussion, even though the WV-features are of a quite extended scale. A solution to this problem may be the use of operational LAM models like ALADIN. Here the parameters mostly show a better resemblance to the features in the WV images. However, the first appearance of deep convection at the narrow zone of the WV–boundaries cannot be explained properly with the help of numerical model fields alone.

Martin et al. (1999) describe cyclonic circulation which is only indicated in the WV image where favoured and non – favoured areas for deep convection are specified. But the problem under discussion concerns a different scale. Here, processes within a much smaller scale, namely the narrow transition zone between dry and wet areas in water vapour, seem to be of importance.

In this respect it can be summarised that:
- Convection in “fair weather” situations shows a distinct diurnal cycle of development and decay.
- The cells of DMC are initiated in the lower levels of the troposphere.
- Deep convection develops and decays much faster than the WV structures in which they are embedded.

A further approach towards the scale problem could be the derivation of the vorticity directly from the WV channels 5 and 6, respectively. Atmospheric motion vectors (AMVs), calculated from the two WV channels, show the dynamic behaviour in two different layers. In the case of fig. 13, no significant horizontal motion can be seen in the middle troposphere (green arrows). The dark stripes in WV channel 5 show a more distinct horizontal vector field in comparison to the layers below (fig. 14). This means that a zone of increasing potential instability at higher levels is moving over a nearly stationary dome of humid air at middle levels. Additionally, a distinct cyclonic curvature is seen in the vicinity of the DMC. This mechanism is represented in all investigated cases.

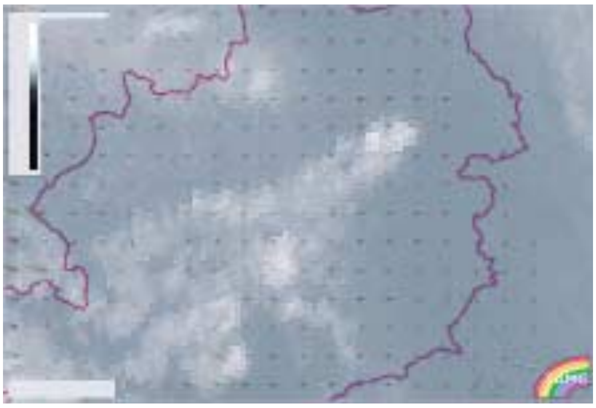


Figure 13: MSG WV 6, 28 April 2004, 1230 UTC

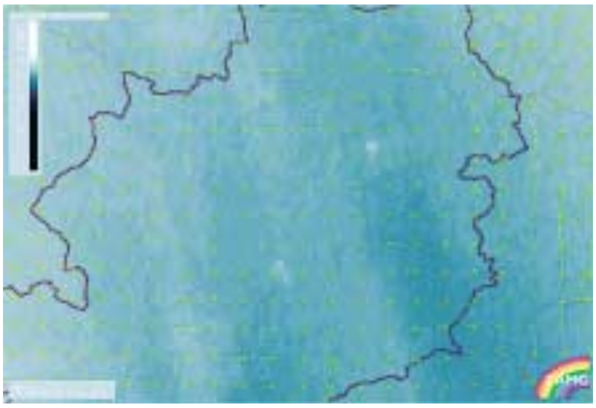


Figure 14: MSG WV 5, 28 April 2004, 1230 UTC

AMVs, computed at two different levels of the troposphere, enable a new approach to investigate the dynamics of deep convective onset in relation to WV-boundaries. The behaviour of vertical and horizontal shear, vorticity and advection could be discussed and calculated independently from numerical models.

Incoming solar radiation, diabatic heating

One source for the initiation of convection is heating of the surface and adjacent air layers by incoming solar radiation during daytime. This heating process causes an absolutely unstable shallow layer near the surface where spontaneous convective overturning becomes likely.

If enough lifting energy is provided, the rising air parcel might reach condensation, leading to strong deep moist convection at the level of free convection in the case of conditional instability. If the lifted parcel starts from higher surfaces, e.g. mountain slopes, less energy is needed to reach the level of free condensation. This implies that shallow convection will start earlier from elevated surfaces.

Incoming solar radiation is absorbed differently in areas of dry or wet upper level humidity. While the visible part of the solar radiation (also known as “atmospheric window”) is not weakened remarkably by water vapour, there is considerable depletion in the near – IR band. According to Liou (2002), water vapour is the primary absorber in the near – IR, which contains about 50% of the incoming solar energy. The amount of solar energy reaching the surface is therefore reduced below the humid area relative to below the dry area in the WV image. Consequently, due to the differential energy of incoming solar radiation below dry and moist upper level layer, decreased diabatic heating at surface levels below a humid region and increased heating below a dry region in the water vapour is to be expected (see also the schematic in fig. 15).

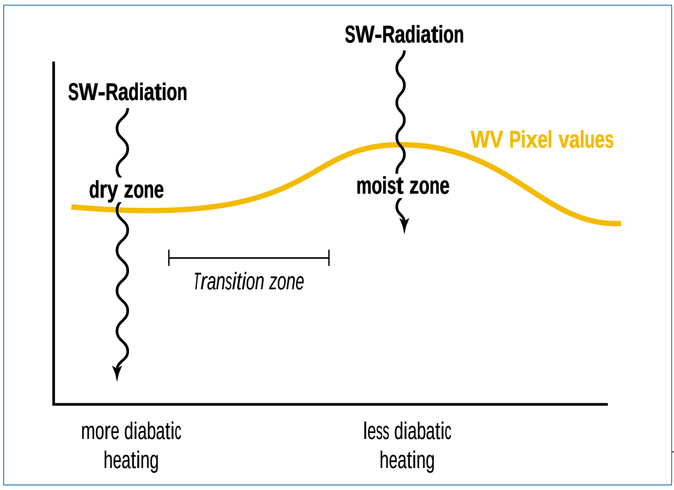


Figure 15.

The combination of all the single components is responsible for the initiation and the onset of DMC in this special synoptic environment. WV images have higher spatial and temporal resolution than the operationally used NWP model fields or the radiosondes. Areas with high probability for convection (diagnosed for example by a stability index) can be superimposed on the WV-image. If there are WV–boundaries in this area, then an even higher probability for the appearance of DMC can be expected and consequently have to be monitored with all available data sources. In this way, an improved technique for nowcasting the exact time and location of thunderstorms in "fair weather" may be provided to the operational forecaster.

References:

Krennert, T., Zwatz-Meise, V., 2003: Initiation of convective cells in relation to water vapour boudaries in satellite images, Atmos. Res., Vol 67-68C pp 353-366.

Liou, K.N., 2002: An Introduction to Atmospheric Radiation. 2nd edition, Academic Press, p87.

Martin, F., Elizaga, F., Riosalido, R., 1999: The Mushroom Configuration in Water Vapour Imagery and Operational Applications. *Meteorol. Appl.*, 6, 143 pp.

Corresponding Author's Address:

Thomas Krennert(1), Alexander Jann(2)

Central Institute for Meteorology and Geodynamics, Vienna, Austria. Hohe Warte 38, A - 1190 Wien

Thomas **Krennert**
and Alexander **Jann**

---

(1) Operational Forecasting Division, E-mail: t.krennert@zamg.ac.at;

(2) Remote Sensing Department, E-mail: a.jann@zamg.ac.at