Introduction to Conceptual Models

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From Cloud systems in satellite images to Conceptual Models

- If we look into all small details of cloud systems in satellite image – there is an unlimited number of configurations

- If we look from a more distant point of view ignoring smaller details – there is a limited number of re-appearing configurations

- These configurations must have a common physical background

- This is the starting point of „Conceptual Models“
Elements of a Conceptual Model

- Physical processes in the troposphere lead to a CM comprising:
  - Typical configurations in satellite images
  - Typical weather events
  - Typical features in typical numerical parameter fields
    - Basic Parameters:
      - Pressure, humidity, temperature and so on
    - Derived Parameter:
      - Vorticity, vorticity advection, potential vorticity, temperature advection, convergence and so on
  - Typical features in vertical cross sections
Let us „construct“ a Conceptual Model on the breadboard
typical features in RGBs + Diffs + SAFs

typical configuration in satellite images

Conceptual Model
Conceptual Model

- typical features in RGBs + Diffs + SAFs
- typical configuration in satellite images
- responsible physical processes
Conceptual Model
eg. "Comma"

- Characteristic life cycle
- Typical weather events
- Typical features in RGBs + Diffs + SAFs
- Typical configuration in satellite images
- NWP parameters: relevant parameters, typical configurations
- Vertical cross sections: relevant parameters, typical configurations
- Responsible physical processes
- Radarechos typical structures
There are physical processes in the atmosphere which:
- produce cloudiness
- form cloudiness

Two assumptions for the existence of cloudiness are:
- enough humidity
- Upward vertical motion:
  - \( \omega = \frac{dp}{dt} \)

Fundamental mathematical relation for describing vertical motion:
- Omega equation:
Omega equation in a quasi-geostrophic system:

- 2 important assumptions
  - 1.) in the vertical exists hydrostatic equilibrium
  - 2.) pressure and vorticity field are in geostrophic equilibrium

\[
\left(\sigma \nabla^2_p + f_0 \frac{\partial^2}{\partial p^2}\right) \omega = -f_0 \frac{\partial}{\partial p} \left[ -V_g \cdot \nabla_p (\zeta + f) \right] - \frac{R}{p} \nabla^2 \left[ -V_g \cdot \nabla_p T \right] - \frac{R}{p c_p} \nabla^2 H
\]

- The right-hand side of this form of the omega equation consists of three terms:
  - 1.) the vertical change of vorticity advection
  - 2.) the Laplacian of temperature advection (the change of the horizontal gradient of temperature advection)
  - 3.) the Laplacian of the diabatic warming (the change of the gradient of diabatic warming) → not treated in these lectures
\[
\left( \sigma \frac{\nabla^2}{p} + f_0 \frac{\partial^2}{\partial p^2} \right) \omega = -f_0 \frac{\partial}{\partial p} \left[ -V_g \cdot \nabla_p (\zeta_g + f) \right] - \frac{R}{p} \frac{\nabla^2}{p} \left[ -V_g \cdot \nabla_p T \right] - \frac{R}{p_c} \frac{\nabla^2}{H}
\]

\[\downarrow\]
\[\infty \rightarrow -\infty\]

\[\downarrow\]
1

Vorticity-advection

\[\downarrow\]
2

Temperature-advection

\[\downarrow\]
3

(Diabatic Heating)

\[\downarrow\]
Not treated
In these lectures

\[\text{\textbf{c}}_p\] specific heat at constant pressure
\[\text{f}\] Coriolis parameter
\[\text{p}\] pressure
\[\text{H}\] diabatic heat transfer
\[\text{R}\] universal gas constant
\[\text{T}\] temperature
\[V_g\] geostrophic wind vector
\[\zeta_g\] relative geostrophic vorticity
\[\sigma\] static stability
\[\omega\] vertical motion
Temperature and Temperature Advection

- Laplacian of temperature advection

\[- \frac{R}{c_p} \nabla^2 \left[ - v_g \nabla p T \right]\]

- Upward motion takes place where the (relative) strongest warm advection exists
- WA - Warm Advection
- CA - Cold Advection

- WA takes place in the areas of fronts, especially in warm fronts
Which kind of weather systems do you connect with WA?

- Cold Fronts
- Warm fronts
- Waves
- Features in the upper level trough
- Features in the upper level ridge
- Features connected to the jet stream
- Others
Different WF cloud configurations

- Meteorologists identify different features as warm fronts or warm-front like cloud system
- Are these different cloud configurations also different CMs?
Please indicate the WF cloud system With yellow star!
WF Band

WF Shield

Detached WF

TA=0 along leading edge of frontal cloud band
Max of WA within frontal cloud band

two maxima of WA in front of TFP and within warm sector

detached WF cloud under separate (detached) WA max
Vorticity and Vorticity advection as cloud producing and forming parameters

- Vorticity is a streamfield quality - It describes rotation
- Vorticity is a parameter which is important for cloud formation
- Vorticity advection has as connection to upward motion: 1st term in the omega equation

Vorticity
- Relative Vorticity
- \( \zeta = \text{rot}_z \mathbf{v} = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \)
  - \( \zeta > 0 \) ... zyklonal
  - \( \zeta < 0 \) ... antizyklonal

Vorticity = Curvature vorticity + shear vorticity
- \( \zeta = \text{VK}_s - \frac{\partial V}{\partial n} \)
- \( \zeta_s = - \frac{\partial V}{\partial n} \)
  - \( \text{KS} \) ... Curvature of the streamlines
  - \( \text{V} \) ... Velocity

Vorticity advection
- Advection of rel. Vort.
  - \( VA = - \mathbf{v} \cdot \nabla \zeta \)
- positive Vorticity advection
  - PVA: \( VA > 0 \)
  - Upward motion
- negative Vorticity advection
  - NVA: \( VA < 0 \)
  - Downward motion
In the 1st term of the $\omega$ – equation there is the vertical change of the vorticity advection

- $\partial/\partial p \cdot (-v_p \cdot \nabla \eta)$

A contribution to upward motion is given if:

- PVA increases with height
- NVA decreases with height

Useful simplification:

- Wind typically increases with height $\rightarrow$ also vorticity increases typically
- Instead of the vertical change of vorticity advection only the distinct maxima in upper levels (500 or 300 hPa) are inspected
Which kind of weather systems do you connect with PVA

- Cold Fronts
- Warm fronts
- Waves
- Features in the upper level trough
- Features in the upper level ridge
- Features connected to the jet stream
- Others
Typical co-operation of shear and curvature vorticity

Typical for troughs, lows

Typical for jet streams
Different Cold air cloud configurations

- Meteorologists identify different features in the cold air
- Commas with and without cloud enhancement
- Enhanced cloudiness without spiral configuration
- Are these different cloud configurations also different CMs?
comma Enhanced Cumuli

- Comma in front of upper level trough
- PVA max above comma cloud
- PV = 2 units low down in troposphere

EC ahead of upper level trough
- PVA max in the area of EC-Cloud
Comma cloud in PVA max in left exit region of a jet streak
PV = 2 units low down in troposphere

EC cloud in left exit region of a jet streak
PVA max in left exit region of a jet streak
Potential Vorticity and features in WV images

The potential vorticity (PV) is the absolute circulation of an air parcel that is enclosed between two isentropic surfaces.

\[ PV = -g \left( \zeta_e + f \right) \frac{\partial \Theta}{\partial p} \]

- \( f \): Coriolis parameter
- \( g \): gravitational acceleration
- \( p \): pressure
- \( PV \): potential vorticity
- \( \Theta \): potential temperature
- \( \zeta_e \): relative isentropic vorticity

PV is the product of absolute vorticity and static stability.

Two factors: a dynamical and a thermodynamical element.
There is a clear relation between PV and water vapour imagery.

A low tropopause can be identified in the WV imagery as a dark zone.

- Circular WV eddies
- Elongated dark stripes
Presentation of PV in connection with satellite images

- PV has low values in troposphere: values < 1 unit
- PV has high values in stratosphere: values > 2 units or more
- Usually the transition between tropospheric and stratospheric air is at values between 1 and 4 units

- 1 PV Unit = 10^{-6}m^2K(s kg)^{-1}

- Two different presentations of PV:
  - As direct values on isentropic surfaces
  - As height of PV = 2 units
Another group of Conceptual Models

- There is a group of Conceptual Models which belong to both physical states:
  - Upward motion through WA and through PVA
- Waves at Coldfronts
- Meteorologists identify different cloud configurations as waves
- Are they also different Conceptual models?
Please indicate the Wave area!
With yellow star!
height contours at 1000 hPa

cloud bulge at rear side of frontal cloud band
trough in low level height (surface); minimum immediately to the rear of cloud bulge
cloud bulge at rear side of frontal cloud band
trough in low level height (surface);

zeroline of TA extends across wave feature;
WA max within (near to) cloud bulge
CA max behind cloud bulge
Upper level trough behind frontal cloud band
PVA max above downstream of cloud bulge

Curvature Vorticity

Curvature Vorticity at upper levels crossing frontal cloud band at wave bulge distinct Advection of Curvature Vorticity at 300 hPa over the cloud bulge of upper wave

Height contours at 1000 hPa

Height at 500 hPa

Height at 1000 hPa

Height contours at 500 hPa

Height contours at 1000 hPa

WV black stripe

Jet axis along rear side of CF-WF system
Jet streak with left exit region at cloud head
PVA max in left exit region of jet streak over cloud head
From where can you learn more?
Manuals, Methods and Programs

- **SatManu**
  - [www.eumetrain.org](http://www.eumetrain.org)
  - Manual of Conceptual Models: detailed descriptions, short versions, exercises

- **SatRep**
  - [www.knmi.nl/satrep](http://www.knmi.nl/satrep)
  - Daily operational application of Conceptual models

- **SatRep/online**
  - [www.satreponline.org](http://www.satreponline.org)
  - [www.eumetrain.org](http://www.eumetrain.org)
  - Daily Satrep cases with numerical fields for training
  - Monthly online sessions

- **EUMeTrain**
  - [www.eumetrain.org](http://www.eumetrain.org)
  - Many Cases demonstrating the CM approach
Some exercises about:

Upper waves
Waves
Rapid cyclogenesis
comma
Based only on the satellite features:
Where do you see „waves“? Indicate by „star“
Key parameters for waves: surface height:
Where do you assume: an upper wave (yellow star) – a wave (red star)?
Key parameters for waves: temperature advection:
Where do you assume: an upper wave (yellow star) – a wave (red star)?
Supporting parameters for waves: upper level height:
Where do you assume: an upper wave (yellow star) – a wave (red star)?
Additional parameters for the different wave models:
key parameters for upper waves: curvature vorticity maximum in 300 hPa
Where do you assume: an upper wave (yellow star) – a wave (red star)?
Additional parameters for the different wave models:
key parameters for rapid cyclogenesis: PVA max in left exit region of a jet stream.
Where do you assume: a beginning rapid cyclogenesis (yellow star)?
Based only on the satellite features:
Where do you see „waves“? Indicate by „star“
Based on the water WV satellite image:
Where do you see „waves“? Indicate by „star“
Key parameters for waves: surface height:
Do you assume: an upper wave – a wave – a rapid cyclogenesis?
Key parameters for waves: temperature advection:
Do you assume: an upper wave – a wave – a rapid cyclogenesis?
Key parameters for rapid cyclogenesis: Jet streak and PVA
Do you assume: a rapid cyclogenesis?
Key parameters for rapid cyclogenesis: Jet streak and PVA maximum
Do you assume: a rapid cyclogenesis?
Key parameters for rapid cyclogenesis: low stratospheric PV
Do you assume: a rapid cyclogenesis?
Based only on the satellite features:
Do you see a comma? Indicate by yellow „star“
Key parameters for a comma: upper level height:
Indicate the relevant feature in the 500 hPa Height contours (by star)

- comma in front of upper level trough
- PVA max above comma cloud
- PV = 2 units low down in troposphere
Key parameters for a comma: PVA Maximum at height levels
Where do you expect a PVA Maximum at 500 hPa? Indicate by star.
Key parameters for a comma: maximum of PV down to low levels
Where do you expect a PV Maximum? Indicate by star

- Comma in front of upper level trough
- PVA max above comma cloud
- PV = 2 units low down in troposphere
Key parameters fora comma: Jet streak and PVA maximum

Where do you expect a left exit region of a jet streak?
Enough for today – have you any questions

- Thank you for your co-operation!

- Useful Exercises till our Langen workshop:
  - I would like you to go through SatManu and the exercises (at least from all CMs which we have treated today)
  - I would like you to prepare a „Mini“ SatRep for the week in Langen. I will put the material in the course page.
Thanks for your attention!