Clouds and precipitation in NWP models

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We all know what clouds are. To some extent.

From the literature, people have argued about cloud properties for a long time already:

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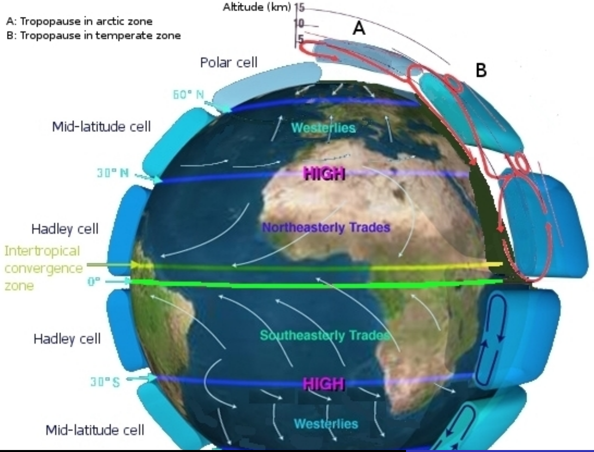
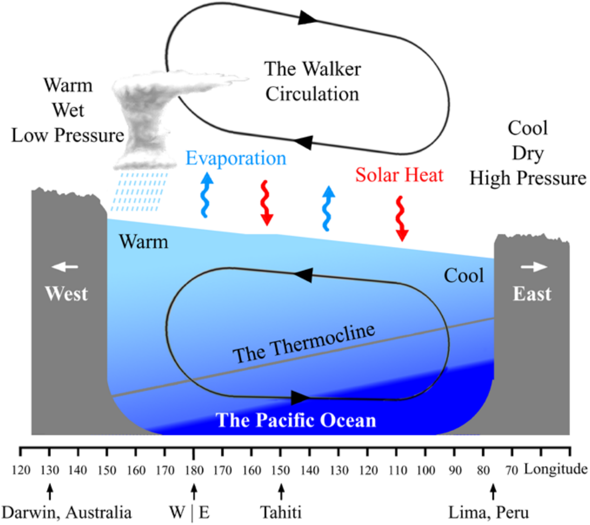
HAMLET
    Do you see yonder cloud that's almost in shape of a camel?
LORD POLONIUS
    By the mass, and 'tis like a camel, indeed.
HAMLET
    Methinks it is like a weasel.
LORD POLONIUS
    It is backed like a weasel.
HAMLET
    Or like a whale?
LORD POLONIUS
    Very like a whale.
```

Models do not care about shape of clouds, important properties are: cloud water content, cloud cover, phase, albedo, precipitation etc.

Spatial and temporal scales

Life of a single cloud varies from few minutes to many hours. Size varies from few hundred meters to several tens of kilometres. Deep convection drives global processes like Hadley and Walker cells (ENSO cycles).




The Walker Circulation
Warm
Wet
Low Pressure
Cool
Dry
High Pressure
Evaporation
Solar Heat
Warm
Cool
West
East
The Thermocline
The Pacific Ocean
120 130 140 150 160 170 180 170 160 150 140 130 120 110 100 90 80 70 Longitude
Darwin, Australia
W | E
Tahiti
Lima, Peru

Clouds in NWP models- Purpose

Very much dependent on scale. Global circulation or weather tomorrow. Models usually manage convective and large scale clouds differently, but this may change.

Climate models

modification of large scale circulation, control of radiation budget and precipitation distribution

Limited area NWP model

Peoples everyday weather + extreme events.

In any case, clouds are integral part of the model and mutually interact with:

- dynamics
- turbulence
- convection
- radiation
- microphysics
- aerosols and chemistry

Classification

According to Mapes (1997), convection schemes can be divided into two general types based upon the vertical extent of the atmospheric forcing that controls the convection.

Deep-layer control

Supply-side approach, removal of CAPE which comes from large scale.

Low-level control

Initiation related to removal of CIN.

Another possibility, how environmental changes due to convection are defined.

Static scheme

determines the final state after convection is done and adjusts model fields

Dynamic scheme

Myriad of physical processes trying to estimate the final state.

Some examples of convection schemes

Deep layer control schemes

- Arakawa-Schubert scheme (1974)
- Betts-Milles scheme (1986,1993)
- Kuo scheme (1965) - static, moisture control

Low level (activation control) convective schemes

Dynamical, mass flux convective schemes

- Tiedke (1989)
- Gregory and Rowntree (1990)
- Kain and Fritch (1993)
- Emanuel (1991)

Low level convection schemes more dependent on local conditions.

Convective parametrization in HIRLAM

Two alternative schemes available. Both have long development history, KF/RK seems to be better documented and has uses outside HIRLAM, STRACO is more internal project.

STRACO - Soft TRAnsition COndensation

Moisture budget closure, similar to Kuo, which is deep-layer control.

Kain-Fritch/Rach-Kristjansson

Kain-Fritch for convection, Rach-Kristjansson for grid scale condensation. KF - mass-flux scheme, based on CAPE removal (deep layer control), but activation of convection is based on low-level forcing.

In stratiform phase, precipitation creation is similar to Sundqvist scheme. STRACO uses similar methods for precipitation release also for convective mode. At current stage, KF/RK has both cloud water and cloud ice available as prognostic variables.

For more information, B. Sass presentation from 2008 YSSS

Explicit convection

Hypothesis

Explicit microphysics on grid scale is enough to produce reasonable convective events on most cases

Example

AROME, explicit convection at 2.5km and 40(60) vertical levels. Still need for shallow cumulus parametrization.

- It is not clear, what resolution is enough (25m - 1000m)
- dependence on other parts of the model (dynamics, physics, turbulence)
- Microphysics
- dynamics - MesoNH (euler) vs ALADIN (sisl) dynamics

Microphysics

Physical processes:

- cloud particle formation
- growth
- dissipation

Common set of cloud particles:

- cloud water
- pristine christals
- snow
- rain
- precipitating ice (graupel, sleet, hail)

Warm microphysics - cloud water and rain only.

Reasonable number of possible processes between (5) particles and vapour is around 30.

size distributions, Marshall-Palmer distribution

$$n(D) = n_0 e^{-\lambda D}$$

D - diameter, n - number of particles per unit volume, λ - slope parameter, n_0 - maximum number of droplets per unit volume.

Types of condensed matter

- Cloud droplets - exist on temperatures down to -40 Celsius. Require CCN to form. Condensational growth not enough to form rain, other processes needed. Usually no vertical velocity.
- Raindrops, growth by collision and coalescence is enhanced by different fall velocities of different drop sizes. Rain may develop 15min after cloud formation. Fall speed >0
- Ice cristals and aggregates. Saturation pressure over ice lower than over water. At temperatures warmer than -40, freezeng requires that "ice nucleus" are available. Aggregates - snow.
- Rimed ice particles, graupel and hail. Form when ice cristals collide and coalesce with supercooled water droplets or ice cristals.

Typical evolution equation

$$\frac{\mathrm{d}q_x}{\mathrm{d}t} = -ADV(q_x) + TURB(q_x) + (P_1 + P_2 + P_3 + P_4 + ...)$$

CCN - cloud condensation nuclei

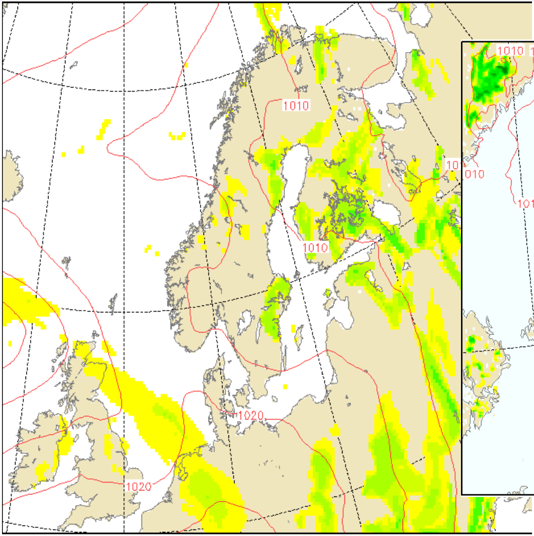
- CCN - clouds will not form without.
- Simple parametrization in HIRLAM, more CCN over land and less over ocean.
- This is where "integrated modelling" comes into the game.

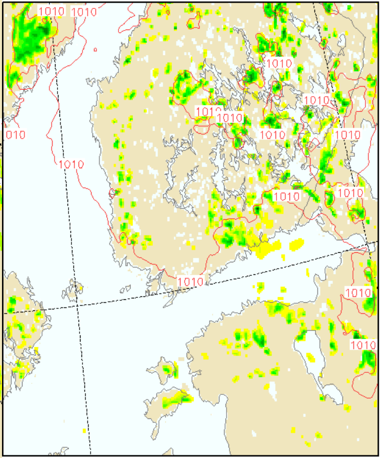
Example

Precipitation release in warm clouds. Small number of CCN - bigger droplets, faster precipitation generation.

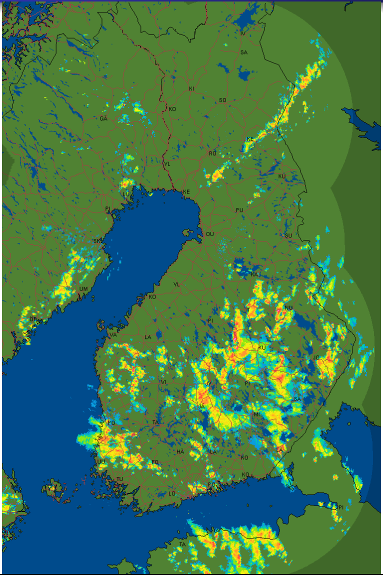
$$q_{rain} = q - q_{critical}, \;\; q_{critical} = f(CCN)$$

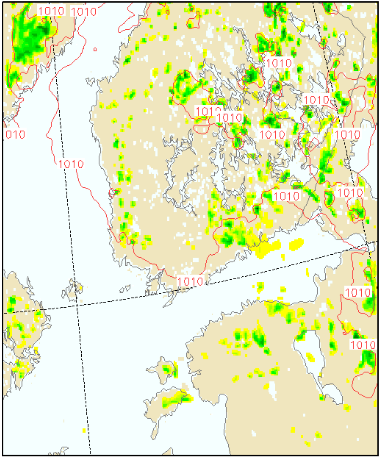
HIRLAM vs AROME precipitation forecast





Radar measurement and AROME precipitation forecast





Shallow convection

Gets less attention than deep convection, but:

- most frequently observed tropical cloud
- influence BL depth and parameters
- strongly influence global radiation budget
- AROME has, HIRLAM has test version?

Interesting ongoing developments

- Assimilation of radar reflectivities in HARMONIE
- 3D radiation parametrization
- GLAMEPS - Grand Limited Area Model Ensemble Prediction System (HIRLAM - ALADIN, glameps.org, members only access).

Remarks

- Cloud modelling depends on scale and purpose
- Clouds depend on and influence other components/processes of the model
- Clouds depend on (fine scale) data assimilation
- Clouds are chaotic
- HIRLAM will see its last release this year, but as a stable and mature environment will continue to be used for some time.