Assimilating Cloud-affected Radiances in Idealized Simulations of Deep Convection

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I) Motivation

II) Numerical Configuration
   - Idealized Simulations
   - Variability in Ensemble
   - Data Assimilation Experiments

III) Nature Run
   - Synthetic Satellite Fields of Ice Clouds
   - Lower Boundary Layer Induced Water Clouds

IV) Assimilating Cloud-affected Radiances
   - Brightness Temperature Fields
   - Impact on Ice, Water, Wind & Temperature

V) Conclusions & Outlook
I) Motivation: Why do we assimilate Cloud-affected radiances?

- Early coherent and strong signal
- > 6000 measurements every hour in case study
- Satellite measures radiation at suitable spatial (∼ km) and temporal (15 min) scales

Goal: improve the forecast of
  - Precipitation, Temperature, Wind
    over the whole domain and especially inside convective cells at the convective time scale, for short term weather forecasts
II) Numerical Configuration

Lange & Craig (2014): The Impact of Data Assimilation Length Scales on Analysis and Prediction of Convective Storms, MWR

*Nature Run* for Observation System Simulation Experiments (OSSE), 5 min output
Initial $U(z)$, $V(z)$, $\theta(z)$, ... profile from Radiosonde
(Payerne, Switzerland at 12 UTC, July 20th 2007)
*Cyclic* boundary conditions with $(n, m, l) = (200, 200, 50)$
The increments $dx$ and $dy$ are $\approx 2$ km.
The model levels $dz$ vary from 100 m at the surface to 800 m at domain top.
Overall, $(Lx, Ly, Lz)$ corresponds to (394 km, 394 km, 22 km)
Timestep $dt = 6$ s, can be increased to 12 s, 24 s
120 members are computationally affordable

*new:*

RTTOV 12, for infrared satellite images
MFASIS for solar reflectance
II) Variability in Idealized Ensemble

• Operational local area models comprise large scale variability in initial conditions due to boundary conditions.

In idealized setup so far only spatial variability, i.e., position of cells due to white noise in initial conditions, e.g., after 8 h at 14 UTC (right).

• We add temporal variability by superimposing random large scale perturbations on initial conditions as $T'(z)$, $u'(z)$, $v'(z)$, $rh'(z)$ with standard deviation $0.25 \, \text{K}$, $0.25 \, \text{m/s}$ and 2% relative humidity variation at a vertical wavelength of approximately 8 km, up to $z = 30 \, \text{km}$.
II) Variability in Idealized Ensemble around Nature Run

onset of deep convection varies by more than three hours

nature
II) Data Assimilation Experiments (with LETKF in COSMO-KENDA)

Brightness temperature is simulated with an error of 3 K for WV 6.2 μm, 7.3 μm.

We assimilate every 15 min for 8 cycles, after 8 h lead time with 2 h free forecast. Currently, 40 members run in the cycle.

We do not localize in the vertical.

Horizontal localization is $L_h = 32$ km.

Vertical localization is $L_v = \infty$.

Error model by Harnisch et al. (2016) ranging from $\approx 2$ K in clear sky to $\approx 10$ K in cloud regions for WV 6.2 μm

What is the potential of assimilating cloud-affected radiances?

In the infrared, **ice clouds** are present at later times.

Deep convection sets as **cirrus anvils** develop.

The ice clouds block the view on lower clouds in the infrared.

Lower clouds cause rain as visible in more intermittent radar reflectivity fields.
III) Nature Run: Clouds in Reflectance of Solar Radiation

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In observation system simulations high, medium and low clouds occur as:

- **Ice clouds** in the *water vapor bands*
- **Water clouds** in the *infrared window channels & visible*
- **Lower boundary layer induced clouds** in the *visible* reflectances

*(all in half hour intervals)*
III) Assimilating Cloud-affected Radiances

Member #1
No data assimilation

Member #1
Assimilating Brightness Temperature of Water Vapor 6.2 µm band

Nature Run

$BT(x, y)$ for 6.2 µm
III) Assimilating Cloud-affected Radiances

LETKF creates conditions for clouds to:
• Dissolve, where no clouds exist in nature
• Form, where clouds exist in nature run

What is the impact on other variables?
IV) Impact on Wind, Temperature, Ice, Water Vapor

17-18 UTC (Second hour of free forecast, 4 x 15 min first guesses):
Horizontal and ensemble mean of ...

Overall no significant bias!
IV) Impact on Wind, Temperature, Ice, Water Vapor

14-15 UTC (First hour of data assimilation, 4 x 15 min first guess):
Horizontal and ensemble mean absolute error of ...

- Slight improvement of horizontal velocity
- Clear improvement of temperature at all heights
- Ice clouds begin to form
- W/out ice clouds, clear improvement of water vapor at all heights

Free ensemble
Assimilated ensemble
IV) Impact on Wind, Temperature, Ice & Cloud Water

15-16 UTC (Second hour of data assimilation, 4 x 15 min first guess):
Horizontal and ensemble mean absolute error of...

\[ u \]
\[ T \]
\[ QI \]
\[ QC \]
IV) Impact on Wind, Temperature, Ice & Radar Reflectivity

17-18 UTC (Second hour of free forecast, 4 y 15 min first guess):
Horizontal and ensemble mean absolute error of ...

- **u**
  - **Clear improvement of horizontal velocity remains in forecast**

- **T**
  - **Beneficial where cloud processes are involved**
  - **Gravity waves?**
  - **Ice above**
  - **Rain below**

- **QI**
  - **Impact remains beneficial**

- **Z**
  - **Free ensemble assimilated ensemble**
  - **Clear improvement of radar reflectivity over height of sat weighting function**
V) Conclusions: What is the potential of assimilating brightness temperature?

• The assimilated **brightness temperature** fields improve.
• Radar reflectivity improves significantly over the height of the ice clouds.
• Cloud related quantities as cloud ice and water vapor error decrease.
• Temperature and wind fields improve significantly.
• Improvement depends on cloud impact, i.e., the improvement is largest at times when and at locations where clouds are present (in OSSE).

V) Outlook: What is the most efficient way to assimilate Clouds?

• Longer Forecasts of up to 5 hours
• Update Variables: select cloud variables or only wind & temperature
• Direct assimilation of another instrument, e.g. **visible** 0.6 µm
• Cloud structure, e.g., average cloud cover $<C(x,y)>_{\text{Area}}$, cloud displacement & amplitude score $DAS(x_0,y_0)$, smoothness $\Delta BT(x_0,y_0)$, fractal dimension $D_H$
• Temporal difference of brightness temperature $BT_{\text{diff}}(x_0,y_0)$
Thank you for your attention!