Improving the ECMWF model’s representation of supercooled layers in Arctic mixed-phase clouds

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ECMWF
The model’s cloud scheme

OLD cloud scheme
(Tiedtke scheme operational 1995-2010)

NEW Cloud Scheme
(operational from 9th Nov 2010, Cy36r4 onwards)

More prognostic variables – physical processes for conversion between water species individually parameterized

One condensate variable with diagnostic split
The old cloud scheme: Diagnostic split between cloud ice and liquid

- One prognostic variable for condensate
- Liquid/ice split is temperature dependent
- Not well-suited to represent mixed-phase Arctic clouds

Example: -10°C
OLD: 35% liquid, 65% ice
NEW: any liquid-to-ice ratio possible
M-PACE single layer cloud

CMBE Cloud Fraction
- 99% cloud fraction contour

Shupe in-cloud LWC
- supercooled liquid layer

Shupe in-cloud IWC
- sedimenting/precipitating ice

ECMWF Cloud Fraction

ECMWF gridbox LWC
- condensate primarily in ice phase

ECMWF gridbox IWC
- multiple layers
Prognostic liquid and ice variables

- CMBE Cloud Fraction
- Shupe in-cloud LWC
- Shupe in-cloud IWC
- ECMWF Cloud Fraction
- ECMWF gridbox LWC
- ECMWF gridbox I+SWC

NEW model: improved ratio of liquid to ice, but liquid layer not maintained
Processes involved in maintaining supercooled liquid layer

- Radiative cooling, leading to destabilization and small scale ascent
- Water saturation, source of liquid
- Ice nucleation and small ice crystal growth
- Water depletion
- Ice crystals fall out

Model doesn’t represent the small-scale mixed-phase cloud top processes of water production from convective overturning, ice nuclei activation and depletion, and fall-out of growing ice crystals separating ice and liquid in a shallow layer.
Reduce deposition rate near cloud top

CMBE Cloud Fraction

Shupe in-cloud LWC

Shupe in-cloud IWC

ECMWF Cloud Fraction

ECMWF gridbox LWC

ECMWF gridbox I+SWC

Liquid layer maintained

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M-PACE single layer cloud LWP/IWP

Observations: A aircraft, W Wang retrieval, S Shupe

- SCM 2007
- CY36R1 diagnostic split for condensate
- CY36R4 prognostic ice/liquid
- CY37R3 enhanced liquid layers

Klein et al. QJRMS 2009
What about radiation?

[Graphs showing Surface Irradiance and Downward Longwave with different lines for OBS, OLD, NEW, and LAYERS]
Global results:

Change in 2m Temperature: warmer across North America and Europe
Reduced 2m T error, improved T1000hPa scores

TOA SW bias (ECMWF-CERES) reduced around Antarctica due to increased column liquid water

yellow: 15-30W/m^2
Conclusion

• ARM data very useful to guide model development
• Prognostic liquid and ice variables give the model a framework to better represent mixed-phase processes
• Some of these processes remain unresolved, but a simple parameterization improves persistence of liquid layers
• Surface radiation is improved, and so are 2m temperatures over the northern hemispheric continents
• This improvement is reflected in the model scores (T1000hPa)
• Improved TOA net SW bias in the southern hemisphere associated with increased supercooled liquid water in low clouds around Antarctica
• Future: keep working on linking parameterization more directly to physical processes