A Limited Area Model (LAM) Intercomparison Study of the TWP-ICE Case

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Participating models

Weather Research and Forecast (WRF) model
United Kingdom Meteorological Office (UKMO) model
Consortium for Small-scale Modeling (COSMO) model

WRF has three different configurations

Case Specification

*Monsoon trough: 23-25 Jan 2006 (start on 12:00Z 22 Jan)
  It includes a monsoon deep convective event (Event C, 23.5 – 24.5) and the following outflow cirrus evolution (24.5 – 25.5).

Suppressed monsoon: 28-30 Jan 2006 (start on 12:00Z 27 Jan)
CRM period, 0Z 18 Jan - 0Z 3 Feb (optional)

Forcing data

ECMWF analyses
Model domain

128.891E - 132.891E, 13.923 S - 10.925
Center: 130.891E, 12.425S

Resolution

WRF, UKMO: 1km
COSMO: 2.8km

Nesting

WRF and UKMO used two-way nesting.
COSMO (2.8 km) was forced by a coarser COSMO (7 km), which was nested in the Global model GME.
## Model setup

<table>
<thead>
<tr>
<th></th>
<th>WRF-1</th>
<th>WRF-2</th>
<th>UKMO</th>
<th>COSMO</th>
<th>WRF-3</th>
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<tbody>
<tr>
<td><strong>Levels</strong></td>
<td>92</td>
<td>76</td>
<td>70</td>
<td>50</td>
<td>92</td>
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<td><strong>Surface model</strong></td>
<td>5-layer thermal diffusion</td>
<td>4-layer Noah land model</td>
<td>MOESE (Essery et al. 2003)</td>
<td>7-layer Heise and Schrodin model</td>
<td>5-layer thermal diffusion</td>
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<td><strong>PBL</strong></td>
<td>YSU</td>
<td>YSU</td>
<td>Lock</td>
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<tr>
<td><strong>Microphysics</strong></td>
<td>Thompson</td>
<td>WSM 6-class graupel</td>
<td>Mixed phase (Wilson and Ballard)</td>
<td>Kessler-type class 6</td>
<td>WSM 6-class graupel</td>
</tr>
</tbody>
</table>
1. Can LAM simulations reproduce the observed dynamic and thermodynamic structure during the monsoon event?

2. Can LAMs realistically simulate the observed life cycle of monsoon convective systems?

3. Do models produce consistent cloud properties and structures? How big is the inter-model spread in cloud fields?

4. Do LAMs produce the vertical velocity fields consistent with those derived from CPOL radars?

5. Can LAMs realistically reproduce the diurnal cycle of the convective clouds initiated by the mainland and islands? How does surface heterogeneity, in particular the land/sea contrast, affect the cloud evolution during the monsoon event?

6. How sensitive are the simulated cloud fields to cloud microphysics?

7. Can LAMs statistically produce the similar cloud fields to those simulated by CRMs if they are configured at the similar resolution?
Comparisons of large-scale forcing between Xie, ECMWF, and NCEP
Simulated dynamic and thermodynamic profiles compared with OBS

Averaged from 00UTC, 23 to 00 UTC, 26, January, 2006
Simulated radiative fields compared with observations

(a) Outgoing longwave radiative flux at TOA (W m⁻²)

(b) Downward shortwave radiative fluxes at the surface (W m⁻²)

(c) Downward longwave radiative fluxes at the surface (W m⁻²)

Time (UTC) January 23 - 25, 2006
Simulated surface fluxes and rainfall compared with observations.
What do we see so far?

All models are able to produce similar dynamic and thermodynamic fields consistent with observations. LAMs also simulate the radiative fluxes reasonably well, but they appear to over-estimate surface heat fluxes compared with the ECOR observation.

How do LAMs simulate the cloud systems under the realistic large-scale dynamic and thermodynamic environment?
Simulated cloud fraction compared with observations

(a) Cloud fraction derived from ARSCL

(b) Cloud fraction from DHARMA

(c) WRF-1 Cloud fraction

(d) WRF-2 Cloud fraction

(e) UKMO Simulated Cloud fraction

(f) COSMO Simulated Cloud fraction

2006-Jan 23-25

Total cloud fraction

ARSCL  WRF1  WRF2  UKMO  COSMO  DHARMA

2006-Jan 23-25
Simulated cloud condensate and LWP compared with observations

MMCR Reflectivity (dBZ)

DHARMA cloud Condensate (g/kg)

WRF-1 cloud condensate (g/kg)

WRF-2 cloud condensate (g/kg)

UKMO cloud condensate (g/kg)

COSMO cloud condensate (g/kg)

Liquid water path averaged over clouds compared with MWR observations

Time (UTC), January 23 - 25, 2006
LAM simulated cyclone during the event C

2 km cloud condensate (g/kg) and wind vector at 02:00 UTC, January 24, 2006
Vertical profiles and surface heat fluxes at 02 UTC, 24th

Sensible heat flux

Latent heat flux
Domain mean cloud condensate

(a) Cloud water (g/kg)
(b) Rain water (g/kg)
(c) Ice (g/kg)
(d) Snow (g/kg)
(e) Graupel (g/kg)
(f) Ice+Snow+Graupel (g/kg)
Variance of cloud condensate

(a) Variance of $q_c$ $(g^2/kg^2)$

(b) Variance of $q_r$ $(g^2/kg^2)$

(c) Variance of $q_i$ $(g^2/kg^2)$

(d) Variance of $q_s$ $(g^2/kg^2)$

(e) Variance of $q_g$ $(g^2/kg^2)$

(f) Variance of $q_i+q_s+q_g$ $(g^2/kg^2)$
Third order moments of cloud condensate
What do we see so far?

1. WRF and COSMO are able to produce the strong deep convective clouds in the monsoon event consistent with observations. The model simulations indicate that these strong deep convective clouds are associated with a cyclone although its strength can vary substantially from model to model. UKMO fails to produce the cyclone, and thus, the deep convective cloud system.

2. Models produced a large discrepancy in cloud fraction and cloud condensate. The inter-model difference in cloud water, ice, snow, and graupel can be as large as a factor of 10.

3. Sensitivity test indicates that the simulated cloud condensates are very sensitive to cloud microphysics, but seem to be less sensitive to vertical resolution as long as it gets sufficiently high.
Convective and stratiform cloud condensate

(a) $w < 1 \text{ m/s}$

(b) $1 \text{ m/s} \leq w < 3 \text{ m/s}$

(c) $w \geq 3 \text{ m/s}$

(d) $w < 1 \text{ m/s}$

(e) $1 \text{ m/s} \leq w < 3 \text{ m/s}$

(f) $w \geq 3 \text{ m/s}$
Convective and stratiform cloud fraction (%)
Convective and stratiform cloud fraction (%) at 5km and 14km
In-cloud vertical velocity distribution

0 – 6 UTC (9:30 -15:30 LST)

12 – 18 UTC (21:30 -03:30 LST)
Excessive Low Level (3km) Convective dBZ and Lack of Stratiform Area
Cloud fraction over land and ocean

Land

Ocean

WRF-1

WRF-2

UKMO

COMSO

Height (km)

Time (UTC), January 23 - 25, 2006
Convective clouds (W>3 m/s) over land and ocean

Cloud condensate

- Land, Qc (g/kg)
- Ocean, Qc (g/kg)
- Land, Qi+Qs+Qg (g/kg)
- Ocean, Qi+Qs+Qg (g/kg)

Cloud fraction

- Land, Fqc (%)
- Ocean, Fqc (%)
- Land, Fqi+Fqs+Fqg (%)
- Ocean, Fqi+Fqs+Fqg (%)
What do we see so far?

1. The inter-model spread is smaller for convective condensate than stratiform condensate. Although cloud condensate shows a great sensitivity to microphysics, microphysics is not a key factor to determine cloud amount.

2. All models are able to produce similar shape of profiles of mean vertical velocity, vertical velocity variance, and the third moment, although there is a large inter-model spread in the magnitude.

3. All LAMs produced compatible continental clouds to their maritime counterparts. The tracer analyses show that the land initiated convection is shallow, generally below 4 km, suggesting that the continental convection is of secondary importance to monsoon deep convective cloud system.
Summary

1. Can LAM simulations reproduce the observed dynamic and thermodynamic structure during the monsoon event?

   Yes, all LAMs are able to produce the dynamic and thermodynamic fields consistent with observations.

2. Can LAMs realistically simulate the observed life cycle of monsoon convective systems?

   Not all models are able to produce the monsoon deep convective clouds associated with cyclones and the following outflow cirrus clouds. The reason is complex. Further investigation is needed.

3. Do models produce consistent cloud properties and structure? How big is the inter-model spread in cloud fields?

   Models show a great discrepancy in the simulated cloud fields. The difference of cloud water, ice, snow, and graupel between models can be as large as a factor of 10.
4. Do LAMs produce the vertical velocity fields consistent with those derived from CPOL radar?

   Only partially consistent. Modeled vertical velocity appears to be too strong. The inter-model spread of velocity statistics is pretty large.

5. Can LAMs realistically reproduce the diurnal cycle of the convective clouds initiated by the mainland and islands? How does surface heterogeneity, in particular the land/sea contrast, affect the cloud evolution during the monsoon event?

   LAMs do produce the diurnal variation of convection initiated by the land, but some of them are not consistent with radar observation. The tracer analyses show that the convection initiated by land is shallow and is of secondary importance to the monsoon deep convective cloud system.

6. How sensitive are the simulated cloud fields to cloud microphysics?

   Cloud condensate shows a great sensitivity to cloud microphysics, but not cloud cover.

7. Can LAMs statistically produce the similar cloud fields to those simulated by CRMs if they are configured at the similar resolution?

   Quite promising.