Diagnosis of convective parameterisation schemes in extratropical cyclones

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DIAMET project
DIAbatic influences on Mesoscale structures in ExTratropical storms

• Consortium constituted by four UK universities (Manchester, Leeds, Reading and East Anglia) and the Met Office

• Three Work Packages
  • WP A. Structure of mesoscale anomalies and their wide-scale consequences
  • WP B. Physical processes and their parameterisation
  • WP C. Predictability
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DIAbatic influences on Mesoscale structures in ExTratropical storms

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• Three Work Packages
  • WP A. Structure of mesoscale anomalies and their wide-scale consequences
  • WP B. Physical processes and their parameterisation
    1. Improving convective parameterisation
    2. Air-sea fluxes and their influence on storm development
    3. Microphysical processes
  • WP C. Predictability
Budget diagnostics

- Tracers (affected by advection) for potential temperature ($\theta$), specific humidity ($q$), cloud liquid water ($q_{cl}$) and cloud ice content ($q_{cf}$)

- The variables of interest ($\theta$, $q$, $q_{cl}$ and $q_{cf}$) are decomposed in the following way:
  \[
  \varphi = \varphi_0 + \Delta \varphi
  \]  
  (1)

- In turn the total increment to the variable is decomposed as follows:
  \[
  \Delta \varphi(x,t) = \sum_{i=\text{proc}} \Delta \varphi_i(x,t)
  \]  
  \[
  \text{proc} = \{\text{parameterised processes}\}
  \]  
  (2)

- These processes depend on the variable under consideration. For example,
  - For potential temperature:
    - Microphysics, mixing in BL, latent heating in BL, convection, radiation
  - For specific humidity:
    - Microphysics, boundary layer, convection
Budget diagnostics

• For each tracer there is an evolution equation of the form

\[
\frac{D\varphi_0}{Dt} = \frac{\partial \varphi_0}{\partial t} + \mathbf{v} \cdot \nabla \varphi_0 = 0
\]  

(3)

• The initial field (\(\varphi_0\)) satisfies the following equation

\[
\frac{D\Delta \varphi_i}{Dt} = \frac{\partial \Delta \varphi_i}{\partial t} + \mathbf{v} \cdot \nabla \Delta \varphi_i = S_{\varphi_i}
\]  

(4)

• Rewriting equation (3) and (4) as

\[
\frac{\partial \varphi_0}{\partial t} = -\mathbf{v} \cdot \nabla \varphi_0
\]

(5)

\[
\frac{\partial \Delta \varphi_i}{\partial t} = -\mathbf{v} \cdot \nabla \Delta \varphi_i + S_{\varphi_i}
\]

(6)
Budget diagnostics

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(6)

Only affected by advection.

Affected by sources/sinks of the relevant variable.
Budget diagnostics

• The evolution equation for the relevant variables can then be written as

\[
\frac{\partial \varphi}{\partial t} = \frac{\partial \varphi_0}{\partial t} + \frac{\partial \Delta \varphi_i}{\partial t} = -\mathbf{v} \cdot \nabla \varphi_0 - \mathbf{v} \cdot \nabla \sum_{i = \text{proc}} \Delta \varphi_i + \sum_{i = \text{proc}} S_{\varphi_i}
\]  

(7)
Budget diagnostics

- The evolution equation for the relevant variables can then be written as

\[
\frac{\partial \varphi}{\partial t} = \frac{\partial \varphi_0}{\partial t} + \frac{\partial \Delta \varphi_i}{\partial t} = \nabla \cdot \varphi_0 - \nabla \cdot \sum_{i = \text{proc}} \Delta \varphi_i + \sum_{i = \text{proc}} S_{\varphi_i}
\]  

(7)

Redistribution of conserved component

Advection of conserved component
Budget diagnostics

• The evolution equation for the relevant variables can then be written as

\[
\frac{\partial \varphi}{\partial t} = \frac{\partial \varphi_0}{\partial t} + \frac{\partial \Delta \varphi_i}{\partial t} = -\mathbf{v} \cdot \nabla \varphi_0 - \mathbf{v} \cdot \nabla \left( \sum_{i = \text{proc}} \Delta \varphi_i \right) - \sum_{i = \text{proc}} S_{\varphi_i}
\]  

(7)
Data and model

- Case from DIAMET first field campaign:
  - 30 September 2011
  - Low-pressure system centred to the south-west of Iceland
  - Long trailing active cold front

- Model:
  - Met Office Unified Model (MetUM) version 7.3
  - North-Atlantic—Europe (NAE) domain
  - Grid spacing 0.11° (~12 km)
  - 38 vertical levels (lid ~40 km)
  - (MetUM Modified) Gregory—Rowntree convection scheme
DIAMET field campaign
0600 UTC 30 September 2011

850-hPa equivalent potential temperature

Mean sea-level pressure
DIAMET field campaign
0600 UTC 30 September 2011

Model-derived OLR

Model derived Total precipitation

850-hPa equivalent potential temperature
Comparison with observations

Radar image

Model derived Total precipitation
0600 UTC 30 September 2011
Convective – Large-scale rain split

Total precipitation

Convective rain
0600 UTC 30 September 2011
Convective – Large-scale rain split

Total precipitation

Diagram showing total precipitation with labeled points A and B.
Preliminary results

- Integration starting on 1200 UTC 28 September 2011
- The following slides show cumulative increments on 0600 UTC 30 September 2011 (T+42)
Sources/sinks of potential temperature
850 hPa (~1300 m height)
Sources/sinks of potential temperature
850 hPa (~1300 m height)

Total change  Microphysics  Long-wave radiation

Convection  BL latent heat  BL mixing

Shallow convection behind the cold front
Sources/sinks of potential temperature
850 hPa (~1300 m height)

Competing processes along the cold front and below the cloud head
Sources/sinks of specific humidity  
850 hPa (~1300 m height)

- Total change
- Microphysics
- Shallow convection behind the cold front
- Convection
- Boundary layer

Competing processes along the cold front and below the cloud head
Sources/sinks of potential temperature
600 hPa (~4000 m height)
Sources/sinks of potential temperature
600 hPa (~4000 m height)

Total change  Microphysics  Long-wave radiation

Deep convection active along the cold front

Convection  BL latent heat  BL mixing
Sources/sinks of potential temperature
600 hPa (~4000 m height)

Competing processes along the cold front and below the cloud head
Sources/sinks of potential temperature
600 hPa (~4000 m height)

Cloud head formed by air from the boundary layer
Sources/sinks of specific humidity
600 hPa (~4000 m height)

Recall that the component evolution includes advection
Sources/sinks of potential temperature
250 hPa (~10000 m height)
Sources/sinks of potential temperature
250 hPa (~10000 m height)

Action of short-wave radiation become important
Sources/sinks of potential temperature
250 hPa (~10000 m height)

- Total change
- Microphysics
- Convection
- BL latent heat
- Short-wave radiation

Strong cumulative effect in upper (anticyclonic) branch of the warm conveyor belt
Sources/sinks of specific humidity
250 hPa (~10000 m height)

Total change  Microphysics

Convection  Boundary layer

Strong cumulative effect in upper (anticyclonic) branch of the warm conveyor belt
Concluding remarks

- One tool for the analysis of convection in large-scale atmospheric models have been presented:
  - Budget of energy (heating/cooling) and moisture (drying/moistening)
- It represents an integral view of the processes acting during a simulation (cumulative action/cumulative increments)
  - It is useful not only for the evaluation of convection but for a complete assessment of processes in the model
  - It does not provide instantaneous information about sources and sinks
- It can be coupled with other budget diagnostics such as that for potential vorticity
Concluding remarks

- Instantaneous information about the generation/destruction of the different variables can be obtained
  - By reformulating the approach to output instantaneous increments (perhaps averaged over a predetermined period) or
  - By combining the present approach with trajectories to study the changes due to parameterised processes along trajectories
Concluding remarks

• This method could be useful for
  o The analysis of balance between convective and large-scale achieved by
    ▪ Different spatial model resolutions
    ▪ Different parameterisation schemes (with a focus on convection schemes).
  o The analysis of a broader range of phenomena not restricted to convection parameterisation schemes