Convective parameterization:
- Arakawa-Schubert, Grell, Tiedtke, Zhang-McFarlane
- Explicit convection
- Review for MT exam

Reminders/announcements:
- Midterm Thu 3/3 (2014 exam posted on www page)
  - Part of exam will be take-home, summarizing CP papers
  - See BMJ “lab review exercise” on class web page: Practice for exam
- Project hypothesis assignment, due (presented) Tue 3/15
- Intel-compiled version of WRF is *extremely* fast compared to gcc version… efficiency of linear algebra libraries?
- Let’s not use the gcc build anymore
Semester Outline

Model Physics:
1.) Land-Surface Models (LSM)
2.) Turbulence parameterization & the planetary boundary layer (PBL)
3.) Convective parameterization
4.) Cloud and precipitation microphysics
5.) Parameterization of radiation

Project:
1.) Topic selection, case identification
2.) Hypothesis development
3.) Control simulation, hypothesis presentation
4.) Experiments and final presentation

Technical:
1.) Running SCM
2.) Running WPS, WRF, postprocessing for real-data cases
3.) Model experiments: Terrain and physics modifications
4.) Analysis and diagnosis of model output

Done
Doing
Not yet
Convective Parameterization

Outline for convective parameterization (CP) section:

A. Concept
   1.) Thought experiment
   2.) Concepts and processes

B. Why CP schemes are needed and matter
   1.) Types of NWP problems affected by CP schemes
   2.) Convective momentum adjustment
   3.) Explicit convection and the “stratus problem”

C. CP Scheme Fundamentals
   1.) Adjustment versus mass-flux schemes
   2.) The Betts-Miller-Janjic CP scheme
   3.) The Fritsch-Chappell and Kain-Fritsch schemes
   4.) Arakawa-Schubert, Grell, Tiedtke, other WRF schemes

D. Modifications to CP schemes, model experiments (to be assigned)
Summary from last class

- BMJ shallow mixing scheme can overpower even stout inversion layers; watch for telltale “smoking gun” 200-mb deep “mixing lines” in model output soundings

- Running without CP can have unintended consequences, especially in moist environments (“stratus problem”)

- Fritsch-Chappel and Kain-Fritsch mass-flux schemes utilize 1-D entraining/detraining plume models

- Designed for mesoscale grid spacing (10-30 km)

- KF trigger function utilizes grid-scale vertical motion, but other options are now available (set in namelist)
Find cloud-top (mixed moist adiabat)

Shallow

Compute reference (mixing line)

Specify shallow cloud-top

Correct to satisfy \[ \int C_p T' - \int Lq' = 0 \]

Adjust \( T, q \) \((\tau)\)

Deep

Compute reference \( (fT_{wv} \text{ to } 0^\circ C, \ P \text{ specified downdraft BL}) \)

Correct to satisfy \[ \int C_p T' + Lq' = 0 \]

Precip < 0

Precip = \( \int Lq' \)

Precip > 0

Adjust \( T, q \) \((\tau, \tau_{BL})\)

Large-scale model

Fig. 9.9. Flowchart for Betts–Miller convection scheme.
Control vs. No-Shallow

Without shallow mixing scheme, stratus deck holds!

Shallow convection “smoking gun” footprint ~ 200 mb
Schematic of Kain-Fritsch scheme, from N. Seaman, COMET Faculty NWP course, 1999

- Detrainment of condensate in anvil
- Compensating subsidence
- Entrainment and detrainment in up and downdraft
- Downdrafts
Model results can be very sensitive to CP scheme choice

- Choice of CP scheme can influence location, strength of coastal cyclones (e.g., Mahoney and Lackmann 2006)

- Betts-Miller-Janjic (BMJ) CP scheme tended to produce closed low centers in regions of strong CP activity, while Kain-Fritsch (KF) produced more continuous inverted trough

- Moral of the story: If a simulated meteorological feature forms in association with activity from a specific physics scheme, we should have lower confidence in its veracity
Important CP Considerations

What are key “differentiating aspects” of CP schemes?

- What is the basis of their fundamental closure assumption?
- Do they adjust momentum?
- Do they include a shallow mixing component?
- To what extent do they facilitate, versus preclude, grid-scale precipitation?
- What is the basis of their trigger function?
# WRF CP scheme summary (V371)

<table>
<thead>
<tr>
<th>Cu_physics</th>
<th>Scheme</th>
<th>Uphys feedback</th>
<th>Momentum</th>
<th>Shallow</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>KF</td>
<td>Cloud, rain, ice, snow</td>
<td>No</td>
<td>Yes, with weak</td>
</tr>
<tr>
<td>2</td>
<td>BMJ</td>
<td>None</td>
<td>No</td>
<td>Yes, stronger</td>
</tr>
<tr>
<td>3</td>
<td>Grell-Freitas</td>
<td>Cloud water, ice</td>
<td>No</td>
<td>Yes (namelist)</td>
</tr>
<tr>
<td>4</td>
<td>Old SAS</td>
<td>Cloud water, ice</td>
<td>No (off)</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Grell 3-D</td>
<td>Cloud water, ice</td>
<td>No</td>
<td>Yes (namelist)</td>
</tr>
<tr>
<td>6</td>
<td>Tiedtke</td>
<td>Cloud water, ice</td>
<td>Yes, linear</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Zhang-McF</td>
<td>Cloud water, ice</td>
<td>Yes, better</td>
<td>No</td>
</tr>
<tr>
<td>11</td>
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<td>Cloud, rain, ice, snow</td>
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<td>Yes</td>
</tr>
<tr>
<td>14</td>
<td>New SAS</td>
<td>Cloud water, ice</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>16</td>
<td>New Tiedtke</td>
<td>Cloud water, ice</td>
<td>Yes, better?</td>
<td>Yes</td>
</tr>
<tr>
<td>93</td>
<td>GD-ens</td>
<td>Cloud water, ice</td>
<td>No</td>
<td>Yes (namelist?)</td>
</tr>
<tr>
<td>99</td>
<td>KF (old)</td>
<td>Cloud, rain, ice, snow</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

12 choices, only 6 *unique* choices (multiple variations of 4)
Arakawa-Schubert (AS) & Simplified AS

- Mass-flux type scheme, envisions ensemble of clouds within each grid cell
- Two versions in WRF (shallow updated, only new adjusts momentum), both “simplified”

How can we determine with certainty whether old SAS adjusts momentum or not?
Arakawa-Schubert Scheme (old)

1) Look at code
2) Output tendencies
Arakawa-Schubert Scheme

• 1-D model includes entrainment detrainment
  – Clouds of different sizes: Large entrainment for short clouds, small for tall
  – All detraining moisture at cloud top
  – Compensating subsidence outside of updrafts
Arakawa-Schubert Scheme

Cloud B

Volume contains little environmental air / lots of cloud air. Slightly reduces buoyancy resulting in detrainment below cloud top.

Volume contains lots of environmental air / little cloud air. Greatly reduces buoyancy resulting in nearby detrainment.

Some Precipitation Evaporates in Downdraft

Evaporatively Driven Cooling of Updraft Source Layer

The COMET Program
Arakawa-Schubert Scheme
Arakawa-Schubert Scheme

- Closure focus on large-scale \textit{destabilization rate}: “Quasi-equilibrium” scheme
- Trigger requires CAPE, but does not eliminate it, just prevents build-up
- Scheme classically viewed as “treadling lightly” on model atmosphere
- Not really designed for small grid length (cloud ensemble idea)
- Computationally expensive in original formulation
- Simplified version: Only 1 cloud type, random cloud top height assigned
Hurricane Sandy case: Precipitation – Total vs Conv. (Allison Michaelis, Jennifer Tate)

• Basic formulation is mass-flux type (offshoot of Arakawa-Schubert, but 1 cloud type)

• Describes CP in terms of three concepts:
  – **Dynamic control**: Modulation of convection by environment (instability, moisture, trigger, vertical wind shear)
  – **Feedback**: Modulation of environment by convection
  – **Static control**: Cloud model used to determine parameterized convective cloud properties
Conceptual picture of Grell scheme

From http://nldr.library.ucar.edu/repository/assets/technotes/asset-000-000-000-214.pdf
Grell scheme

- Original Grell (1993) scheme: mass-flux type, updrafts + downdrafts, cloud + ice detrainment
- Grell (1993) recognized sensitivity to closure assumptions in CP scheme
- Grell and Devenyi (GD, 2002) propose novel approach – ensemble of closure assumptions
- Two versions of GD available in WRFV3.7, plus aerosol-aware Grell-Freitas scheme
Grell-Devenyi ensemble scheme

- `cu.physics=3`: Ensemble Grell-Devenyi (GD) scheme

- Four different types of closure assumption, different CIN tolerance, efficiency – can set ensemble size in namelist (ensdim, default = 144)

- Ensemble mean fed back to solver

- Parameters are tunable (I have not tried varying ensemble size)

```
<table>
<thead>
<tr>
<th>maxiens</th>
<th>= 1,</th>
<th>Grell-Devenyi only</th>
</tr>
</thead>
<tbody>
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<td>maxens</td>
<td>= 3,</td>
<td>G-D only</td>
</tr>
<tr>
<td>maxens2</td>
<td>= 3,</td>
<td>G-D only</td>
</tr>
<tr>
<td>maxens3</td>
<td>= 16</td>
<td>G-D only</td>
</tr>
<tr>
<td>ensdim</td>
<td>= 144</td>
<td>G-D only</td>
</tr>
</tbody>
</table>

These are recommended numbers. If you would like to use any other number, consult the code, know what you are doing.
Grell-Devenyi 3-D ensemble scheme

• `cu_physics= 5`: Newer version of GD scheme

• Smaller ensemble

• Distributes compensating subsidence over neighboring grid cells – can specify
  – Designed for smaller grid lengths – great feature!

```
cugd_avedx = number of grid boxes over which subsidence is spread.
            = 1, default, for large grid distances
            = 3, for small grid distances (DX < 5 km)
```
Grell-Devenyi 3-D ensemble scheme

All Grell: Set ishallow = 1 in namelist (V371) to activate, otherwise off

Nice to have shallow separated and specified in this fashion

Also switch for cloud-radiative feedback (Grell and KF)
Hi Gary,

It was great seeing you as well last week.

I'm not sure there is a clear answer to your question because it involves multiple parameterizations. You're asking from the standpoint of parameterized convection, but as you know the cloud fractions and albedos are handled in radiation, so I can only answer your question from the standpoint of BMJ+GFDL radiation packages that we run in the NAM. Because the BMJ is an adjustment scheme it doesn't deal with condensate, so there are some simple assumptions made in the GFDL for treating convective clouds in isolation, in the presence of stratiform clouds, and in overlap assumptions so that when convection is triggering there is a radiative impact.

Regards,
Brad

Brad Ferrier, NCEP/EMC
Do Parameterized Convective Clouds Affect SWdn?

Convective precipitation, thru 21 UTC 29 Jan 2010
Do CP Clouds Affect SWdn?

Shortwave down at surface, at 21 UTC 29 Jan 2010

What is this odd-looking maximum in surface SWdown?
Do CP Clouds Affect SWdn?
Do CP Clouds Affect SWdn? In NAM, yes
Do CP Clouds Affect SWdn?

So, in WRF NMM (aka NAM model), CP clouds **DO** affect GFDL radiation.

Does it work this way in WRF-ARW?
Hi Gary,

Great, I'm glad you appreciated the graphics. Feel free to refer your class to the web site if you find any of it useful.

“I have an educated guess that it you would see the effect in the WRF NMM but not in the ARW.”

“The 50,000 ft lesson here is that transferring information between different physics packages can be a real challenge, hence the "physics wheel of pain". ”

Regards,
Brad
THE PHYSICS WHEEL OF PAIN

(Modified from Jiayu Zhou, NOAA/OST)

1. Hydrometeor phase, cloud optical properties, cloud fractions, & cloud overlap
2. Precipitation (incl. phase)
3. Subgrid transports, stabilization, detrainment
4. Sfc energy fluxes, LSM
5. Convection, PBL evolution, precipitation

Slide from Dr. Brad Ferrier, NCEP
Recent improvements

• Now, MSKF gives feedback, and namelist option allows for Grell as well

• Others allow sun to shine unabated while its (convective) raining!
Tiedtke (2 choices now)

• Based on operational ECMWF scheme: another mass-flux scheme

• Rooted in tropical, marine field experiments, but also higher-latitude convection

• Trigger also includes grid-scale vertical motion, moisture, instability

• Includes momentum transport

• Shallow mixing component also built-in
Tiedtke (2 choices now)

• Moisture supply is determined by large-scale convergence and PBL fluxes

• Plume entrainment rates related to large-scale convergence as well: Inverse proportionality

• Fundamental idea of moisture convergence “causing” convection has been questioned for Kuo (1965) scheme, also relevant here (Stensrud 2007)

• Despite this, scheme very successful (see, e.g., Bassill 2015 for hurricane Sandy) in ECMWF
Old versus new Tiedtke (cu_physics 6, 16)

- Hurricane Joaquin case
- Two WRF simulations identical, but one uses newer Tiedtke (16), the other uses older Tiedtke (6)
Variations on *same scheme* can give very different results!

**Differences between new and older Tiedtke?**

- New trigger functions for both deep and shallow components
- Different convective time scale for deep convection
- New formulation for entrainment/detrainment rates
- Additional ice processes accounted for
- Differences in cloud-scale pressure gradients (for momentum)

Zhang-McFarlane

- Origin: Canadian GCM
- Mass Flux formulation, similar to Arakawa-Schubert
- Trigger for deep convection: grid-scale CAPE production rate $> \text{threshold}$
- Shallow: non-precipitating
- CAPE consumption rate balances grid-scale production rate
- Best in tropical deep convection
- Includes momentum adjustment
- Causes excessive cooling/drying at lower altitudes, warming/moistening of upper levels
Convection Parameterization, Tropical Pacific Double ITCZ, and Upper-Ocean Biases in the NCAR CCSM3. Part I: Climatology and Atmospheric Feedback

XIAOLIANG SONG AND GUANG JUN ZHANG
Scripps Institution of Oceanography, University of California, San Diego, La Jolla, California

(Manuscript received 21 May 2008, in final form 3 February 2009)

ABSTRACT

The role of convection parameterization in the formation of double ITCZ and associated upper-ocean biases in the NCAR Community Climate System Model, version 3 (CCSM3) is investigated by comparing the simulations using the original and revised Zhang–McFarlane (ZM) convection schemes. Ten-year model climatologies show that the simulation with the original ZM scheme produces a typical double ITCZ bias, whereas all biases related to the spurious double ITCZ and overly strong cold tongue in precipitation, sea surface temperature (SST), wind stress, ocean thermocline, upper-ocean currents, temperature, and salinity are dramatically reduced when the revised ZM scheme is used. These results demonstrate that convection parameterization plays a critical role in the formation of double ITCZ bias in the CCSM3. To understand the physical mechanisms through which the modifications of the convection scheme in the atmospheric model alleviate the double ITCZ bias in the CCSM3, the authors investigate the impacts of convection schemes on the atmospheric forcing and feedback in the uncoupled Community Atmospheric Model, version 3 (CAM3). It is shown that the CAM3 simulation with the original ZM scheme also produces a signature of double ITCZ bias in precipitation, whereas the simulation with the revised ZM scheme does not. Diagnostic analyses have identified three factors on the atmospheric side (i.e., the sensitivity of convection to SST, the convection–shortwave flux–SST feedback, and the convection–wind–evaporation–SST feedback) that may contribute to the differences in the coupled simulations.
WRF CP schemes & operational models

• Kain-Fritsch (some SREF members)
• Betts-Miller-Janjic (NAM)
• Grell schemes – use ensemble of triggers, closures (RAP)
• Simplified Arakawa-Schubert (old and new versions) (GFS)
• Tiedtke – used in ECMWF model, some climate
• Zhang-McFarlane – climate model scheme (CESM)

Why might knowing operational CP be helpful in “research mode” simulations?
EC vs. CP Model Runs: Organized convection

What are advantages/disadvantages of running with small grid length and explicit convection (EC)?

Here, an example (but note that CP runs did not include momentum transport)
29 January 2001 Case

MM5 forecasts of cold-frontal squall line

Domain: 36:12:4 km grid spacing nested domains

CP on outer grids, EC or BMJ CP on 4 km grid

Compare *PV structure* between EC, CP (BMJ) runs:
- Is EC run faster with progression of frontal squall line?
- See Reeves and Lackmann (2004) for more on this case
- Model runs by Kyle Pressel
- Interested in low-level jet (LLJ) as well – examine potential vorticity (PV)
Cold-frontal squall line case
Cold-frontal squall line case
Cold-frontal squall line case
EC vs BMJ CP

Even EC run still too slow (although better than other runs)

Also noted for other case studies

Why? 3 possible candidates:
- Spinup issues?
- Try with 1-km grid?
- Microphysics sensitivity?
- “Stratus issue”?
29 January 2001 Case

Output temperature tendencies from each physics package (e.g., CP, PBL, etc.)

Used diabatic tendencies to compute PV budget

For PV, tendencies, other fields, spatial averaging along axis of squall line (80 km)

Temporal averaging as well - 20 minutes

Following plots are 20-min along-line averages at 18-27 h forecast lead times
4-km, **BMJ** CP scheme: temperature tendency (all physics)

18-h Fcast

PV (shaded), PV tendency, meridional wind (brown)
4-km EC: Heating (all physics)

18-h Fcast

PV (shaded), PV tendency, meridional wind
EC run exhibits more pronounced squall line PV maximum, and faster ~100 km. 21-h Fcst
4-km, BMJ (top) EC (bottom) PV and V-wind

27-h Fest

~100 km
31 March 2005 Case

WRF forecasts of similar cold-frontal squall line

Domain: 4 km large-dimension grid

Ran EC and CP (BMJ and KF) comparisons at 4 km

Compare *cold pool structure*, EC, CP (BMJ) runs:
  • Is EC run faster?
  • Structural differences from CP runs?
  • Model runs by Kelly Mahoney
WRF 4 too slow (~ 3 h) with convection, but again major improvement over NAM

WRF 4 valid 00 UTC 2 April

Radar for 21 UTC 1 April
WRF4 cold pool representation?

Cross-section location

WRF 4km EXP Sim Rad, F036
12-km BMJ run
Equivalent potential temperature, vertical velocity
4-km BMJ run
Equivalent potential temperature, vertical velocity
4-km EC run

Equivalent potential temperature, vertical velocity
EC vs. CP Cold Pools

Most realistic cold pool generated in EC run
More complete observational comparisons needed- ongoing

EC run propagated MCS eastward most quickly
CP runs struggle to produce surface-based cold pool
Parameterized precipitation

• CP scheme issues:
  – *Slantwise* convection
    • A few schemes exist, *not* implemented in operational models
    • NAM resolution now sufficient to resolve slantwise convection
  – *Elevated* convection (if base too high)
    • Schemes can do if convection based below ~800 mb (NAM - BMJ)