GASS perspectives

Ben Shipway on behalf of the GASS SSC and all the GASS community

March 2014
GASS perspectives

- Overview of GASS
  - Different to GCSS?
- (Selected) relevant GASS projects
  - Grey-zone
  - WTG
- Philosophical approach to development
- Why do intercomparisons?
- Microphysics/KiD-A
A community who carry out and use observations, process studies and model experiments with a focused goal of improving the representation of the atmosphere in weather and climate models.
Some highlights of GASS 2012/2013

GASS has 13 current and planned projects; one project was completed in the past year. Newer projects of note include:

- a collaboration with GLASS on land-atmosphere interactions (DICE project)
- moist processes parameterizations interactions with the large-scale circulation – the Weak-Temperature Gradient approximation. (joint with WGCM/EUCLIPSE)
- the cold air outbreak project looking at convection in the so called “Grey-Zone”
- GABLS project to study the ability of models to simulate the very stable boundary layers seen over Antarctica
- The examination of cloud radiation errors and associated surface temperature biases occurring in model over the central United States in summertime
Active participant in the WCRP Climate Sensitivity Grand Challenge project

- GASS co-chairs have helped to write the white paper for the project
- GASS SSC members Robert Pincus and Pier Siebesma are co-leaders of initiatives
- GASS projects will be an active part of this Grand Challenge including an anticipated project to study the accuracy of the radiative forcings simulated by climate models.
- Other projects that will continue to be this Grand Challenge include the current project on Low-Cloud Feedbacks and the new project on the Weak Temperature Gradient. The Grey Zone and Microphysics projects are also expected to play a role in this Grand Challenge.
GASS links

Links to other WCRP projects and groups

• The vertical structure and diabatic heating of the MJO project is conducted jointly between GASS and the WCRP-WWRP MJO task force
• GASS presents reports to the annual WGNE meetings
• The Low-Cloud Feedbacks project (CGILS) has been conducted jointly with the CFMIP project of WGCM
• Gunilla Svensson (SSC member) represents GASS on the Polar project initiatives of WWRP and WCRP.
• Steve Woolnough (SSC member) represents GASS on the joint WWRP/WCRP seasonal prediction project.
Working with many model types
bringing together observations, modelling and understanding in intercomparison projects

GASS methodologies

SCMs/offline (eg CIRC/KiD)  Weather and Climate Models

LAMs  LES/CRMs

Field campaigns  Instrumented sites  Earth observations

Atmospheric physics under climate change
Accomplishments in last 20 years

Often in collaboration with other groups, there have been over 40 projects in the last 20 years.

<table>
<thead>
<tr>
<th>Area</th>
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<tr>
<td>Boundary layer clouds</td>
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<td>Fire stratocumulus, smoke cloud case, Astex Lagrangians (2), Astex stratocumulus, Bomex, ATEX, ARM Shallow Cu, Eurocs FIRE diurnal cycle, DYCOMS (2), RICO stratocu-&gt;trade cu transition, climate change (CGiLS)</td>
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<td>Deep convection</td>
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<td>ICMCP, Parcel Model, 9 March 2000 ARM, sparticus</td>
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<td>Australian cold front, FASTEX, ARM March 2000 IOP (2)</td>
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<td>GABLS cases</td>
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<td>Radiation</td>
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<td>CIRC – now GASS/GDAP joint</td>
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<td>Microphysics</td>
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<td>KiD</td>
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Changes since GCSS

- No longer specific working groups (BL, deep convection, polar clouds etc.)

- Anyone can lead a project, GASS-SSC act as sponsors.

- Isolating processes and looking at wider impacts (reductionism/holism)

- Projects are cross-cutting, interdisciplinary
<table>
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<th>Current and future projects</th>
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<tr>
<td>Stable boundary layers: Antarctic case</td>
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<td>The role of cloud and radiation processes in models US warm bias</td>
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<td>Weak temperature gradient</td>
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<td>Grey-zone project</td>
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<td>Microphysics modelling (KiD)</td>
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<td>DICE: LoCo/SGP Testbed (GLASS project)</td>
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<td>Marine Boundary Layer Cloud Feedbacks (CGILS)</td>
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<td>Land-Atmosphere Interactions (GLASS/GABLS joint project)</td>
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<td>CIRC – the continuous intercomparison of radiation codes</td>
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<td>Cirrus</td>
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<td>Tropical Convection observed during CINDY/DYNAMO</td>
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<td>Polar Clouds (ISDAC)</td>
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<td>Stratocumulus-to-trade cumulus transition</td>
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<td>Vertical structure and diabatic heating of the MJO</td>
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Summary

• GASS still remains a very active group with 13 active projects
  • Tackling all timescales – weather through to climate
  • Isolating processes in great detail
  • Working with observations
  • Truly supporting model development – not just evaluation
• 4 papers from TWP-ICE comparison were an ASR featured research article
• Links to GLASS with the new DICE project
• Links to WCRP Grand challenge on Clouds/climate sensitivity
• Links with WMAC and work on a physics summer school
• Continued relationship with WGCM though cloud-feedback project and the new WTG project and WCRP G.C.
Grey-Zone (Cold-air outbreak)
Grey-Zone (Cold-air outbreak): Another new perspective...
The Grey Zone Project:

First Case: CONSTRAIN: A cold air outbreak

A WGNE initiative

A. Pier Siebesma KNMI & Technical University Delft

siebesma@knmi.nl

on behalf of the

Grey Zone committee: Martin Miller, Andy Brown, Jeanette Onvlee, Pier Siebesma
Case Coordinators: Paul Field, Adrian Hill, Stephan de Roode, Axel Seifert, Lorenzo Tomassini, Pier Siebesma

1. Introduction on the Grey Zone
2. The Case Constrain, a cold air outbreak
3. Status and Results
4. Next Steps & Discussion Points
1. Grey Zone Project: Intro & Motivation
Motivation

• Increased use of (operational) models in the “grey zone” \((\Delta x = 1 \sim 10\text{km})\)

• Models operating in this resolution range resolve some of the “aggregation of convective cells” but certainly no individual convective cells.

• This has led to the “wrong” perception that these “grey-zone” models, when operating without (deep) convection parameterizations, can realistically represent turbulent fluxes of heat, moisture and momentum.

• Hence there is a urgent need of a systematic analysis of the behavior of models operating in the “grey-zone”:

“The Grey Zone Project”
Proposal (from WGNE 2010 meeting)

- Project driven by a few expensive experiments (controls) on a large domain at a ultra-high resolution ($\Delta x=100\sim500m$) ($\sim2000\times2000\times200$ grid points).

- Coarse grain the output and diagnostics (fluxes etc) at resolutions of 0.5, 1, 2, 4, 8, 16, 32 km. (a posteriori coarse graining: COARSE)

- Repeat CONTROLS with 0.5km 1km, 2km, 4km, 8km, etc without convective parametrizations etc (a priori coarse graining: NOPARAMS)

- Run (coarse-grain) resolutions say 0.5, 1km, 2km, 4km and 8km with convection parametrizations (a priori coarse graining: PARAMS)

- Preference especially from the mesoscale community for a cold air outbreak
Aims

• Show how faithfully fluxes, variances, cloud structures, etc can be represented by comparing COARSE, NOPARAMS and PARAMS depending on all aspects of set-ups.

• Guide improvements in current schemes especially at these resolutions - essential for future progress

• Gain some insight and understanding of what can be achieved without parametrizations

• Clarify what cannot/should not be done without parametrization also!!

• Explore the importance/relevance of stochastics

• .......and ultimately provide guidance for the design of scale aware parameterizations

Strong Support from both the international NWP and Climate community
The Case: CONSTRAIN: A Cold Air Outbreak.
The Mesoscale Community is interested to start with an extra-tropical case.

Cold-air outbreaks are of general interest for various communities.

Proposal: “Constrain” cold-air outbreak experiment
31 January 2010

Participation of global models, mesoscale models but also from LES models !!

Domain of interest: 800X1600 km

Quick Transition : ~ 36 hours
3 Different Flavours

1. Global Simulations (at the highest possible resolution up to 5 km)

2. Mesoscale Models (Eulerian)
   At various resolutions (up to 1 km )
   LAM-set up

3. Mesoscale/LES Models (Lagrangian)
   Idealized with periodic BC
   highest resolution (~100m)
   LES set up
The Case (3)
Full case description see: www.knmi.nl/samenw/greyzone
3. Status & Results
# Global Models

(coordination: Lorenzo Tomassini (MPIHamburg & Axel Seifert (DWD))

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Global Models (2)
(coordination: Lorenzo Tomassini (MPI Hamburg & Axel Seifert (DWD))

- No data has been submitted so far, but several groups have performed preliminary test simulations.
# Mesoscale Models

(coordination: Paul Field & Adrian Hill Met Office)

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Mesoscale Models (2)
(coordination: Paul Field & Adrian Hill Met Office)

- 1,2,4,8,16km grid resolution
- 800km x 1600km domain
- 36h simulation
- Convection on/ convection off at all resolutions
- 5 models have submitted results so far
## LES Models

(coordination: Stephan de Roode / Pier Siebesma (TU Delft))

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• 250m, 500m, 1km, 4km grid resolution
• 100km x 100km domain
• 14h simulation
• 4 models have submitted results so far
Standard Case (DALES)
Prescribed droplet number concentration: N=50 cm$^{-3}$.  

Liquid Water Path (kg/m$^2$)
Spatial patterns

Cloud fraction and liquid water profiles

2 h
6 h
10 h
13 h
Strong Sensitivity to Cloud Microphysical Details

Cloud Droplet Number Concentration

Open Cells

Half open Cells

Closed Cells
Summary

• Cold Air Outbreak Case:
  • of intrinsic interest for atmospheric modelling
  • mesoscale structures makes it relevant for “grey zone” purposes
  • Complicated because of microphysics-dynamics interactions

• Unique combination of LES (5), mesoscale models (5+) and global models (4+)

• Cell broadening well resolved by turbulence resolving modeling
Outlook

- A cloud resolving (Eulerian) simulation (200m) is still lacking.
  (GPU version of DALES would need ~2000 GPU’s for a 100m resolution run for the 800x1600 km domain. Oakridge Titan Machine has 16000 GPU’s)

- Workshop is planned for October 2014.

- Still time to participate and send in results

  visit the website for more info: [www.knmi.nl/samenw/greyzone](http://www.knmi.nl/samenw/greyzone) and contact:

  Global Models: Lorenzo Tomassini : lorenzo.tomassini@mpimet.mpg.de
  Mesoscale Models: Paul Field : paul.field@metoffice.gov.uk
  LES models Stephan de Roode: S.R.deRoode@tudelft.nl
Weak-Temperature Gradient (WTG)
Weak temperature gradient (WTG): Interactions with the large scale
Background

- Weak Temperature Gradient (WTG) and similar approaches are becoming widely used to study a range of problems in which the two-way interactions between tropical convection and the large-scale dynamics play a central role.
  - These approaches have been used with varying degrees of difference.
  - These approaches have been used with a range of difference CRMs and SCMs.

- The combination of the above makes it difficult to understand to what extent various aspects of the formulation of these approaches are responsible for the agreements and discrepancies seen in the published results.
GASS has initiated a new international intercomparison project in early 2014.

GASS-WTG project will explore two parameterization frameworks:

- Weak Temperature Gradient (WTG), as in Sobel and Bretherton (2000) with PBL treated separately with fixed PBL top
- Weak Pressure Gradient (DGW)/Wave methods, as in Kuang (2011)
Project Outline

• look at simulations of convection with a parametrization of the large-scale dynamics
  • Use a number of models CRMs and SCMs
  • Perform a set of common simulations of convection:
    • Sensitivity to SST/surface fluxes
    • Sensitivity to initial conditions (multiple equilibria)

• Compare the WTG and DGW approaches
  • Simulation with the WTG approach versus analogous simulation with the DGW approach

• Compare the behaviour of a model when different details of the implementation of the WTG or DGW are applied
  • Parametrization parameters (i.e. strength of circulation coupling to convection)
  • Treatment of moisture advection by the derived large-scale circulation.
Project Timeline

Sep 12: Initial discussion at 1st Pan-GASS meeting
Spring 13: Draft of project specification
Oct 13: Invitation to participate
Jan 14: Project initiation
Spring 14: Initial Data Analysis

Note this project will interact strongly with a WTG-CRM/SCMs comparison led by Gilles Bellon under an EU project EMBRACE
Further details (1)

Parametrization Approaches

• Weak Temperature Gradient
  – as in Sobel and Bretherton (2000),
  – PBL treated separately with fixed PBL top=1.5 km
  – The WTG time scale, $\tau = 3$ hours

\[
\begin{align*}
\overline{w} &= \frac{1}{\tau} \left( \overline{\theta} - \overline{\theta_{Re f}} \right)
\end{align*}
\]

• Weak Pressure Gradient/ Wave methods
  – as in Kuang (2011)
  – The wavenumber, $k = 10^{-06} \; m^{-1}$
  – The wave damping, $\varepsilon = 1 \; day^{-1}$

\[
\begin{align*}
\frac{\partial}{\partial z} \left( \varepsilon \frac{\partial \overline{w}}{\partial z} \right) &= - \frac{k^2 \overline{\rho g}}{T_{Re f}} \left( \overline{T_v} - \overline{T_{Re f}} \right)
\end{align*}
\]

Sensitivity Experiments (as potential follow up project)

• Moisture advection
  – none, relaxation using WTG divergent velocity, relaxation with fixed time scale. Reference profile from RCE?

• Parameters
  – WTG relaxation time (zero for SCMs as one case?), wave number & momentum dissipation in wave method, PBL top/vertical profile in WTG
Convection Experiments (CRMs and SCMs)

- **RCE**
  - Specify SST, surface wind speed, radiative cooling
  - Possible extension to a set of different RCE states

- **Sensitivity to SST under coupling to large-scale circulation**
  - Holding reference profiles fixed change SST/surface wind

- **Sensitivity to initial conditions under coupling to large-scale circulation**
  - Use “dry” and “wet” initial conditions for a range of SSTs to look for multiple equilibria

**Analysis**

- **Compare behaviour across models**
  - Are the results sensitive to choice of parametrization approach within a given SCM/CRM?
  - Are the results sensitive to the choice of CRM/SCM within a given parametrization approach?
  - Is there a systematic difference between the behaviour of CRMs/SCMs within this framework or is the range of behaviour across SCMs different to that in CRMs?
Preliminary Results (1)

Sensitivity to SST under coupling to large-scale circulation
• Model: Large-Eddy Model at version 2.4 of the UK Met
  – Reference profiles fixed to the RCE profiles at 300K
  – Test column initialised with profiles from the reference column

Are the results sensitive to choice of parametrization approach?

DGW simulations are less sensitive to the changes in SST and produce large-scale vertical velocities which are less top heavy
Preliminary Results (2)

Sensitivity to initial conditions under coupling to large-scale circulation

- Use “dry” and “wet” initial conditions for a range of SSTs to look for Multiple equilibria?

Simulation of convection under the WTG (black) and DGW (red) approach. Simulation where initially wet (solid) and initially dry (dashed).

WTG formulation: Precipitating and non-precipitating equilibria for simulations with an SST of 300K

DGW formulation: no multiple equilibria
Preliminary Results (3)

WTG formulation: sensitivity to PBL top

- Uniform SST of 300 K.
- Simulations initially dry with PBL top of 800, 1000 and 1500 m

Multiple equilibria results are sensitive to the PBL top
Development philosophy
Perspective is not about what you’re looking at, but where you’re looking from...
Why do intercomparisons?
Polar clouds: MPACE

(Klein et al, 2009)

- Flow of air off ice sheet onto open ocean
- Significant surface fluxes
Polar clouds: MPACE

![Graph showing ice water path versus liquid water path and ice crystal number concentration.](Image)

Met Office
Polar clouds: SHEBA

(Morrison et al, 2011)

- Thinner layer
- Weaker surface fluxes
- Weaker motions and lower water contents
- Limited riming and aggregation
- Artificially constrain IN
Polar clouds: SHEBA

Notable sensitivity to vapour deposition rate

Still significant spread
Are we chasing shadows?
Polar clouds: ISDAC

(Ovchinikov et al, 2014)

- Decoupled cloud layer
- Constrain IN
  - Idealized radiation
  - Consistent grid/domain
  - Now also constrain ice particle characteristics
    - Capacitance
    - Fall speeds
    - (density/habit)
Polar clouds: ISDAC

(Ovchinikov et al, 2014)
Polar clouds: ISDAC

(Ovchinikov et al, 2014)

Key findings
- Confirmed **first order importance** of predicting correct **liquid phase cloud** (challenging for GCMs in the Arctic) and **ice number concentration** (always challenging).
- **Constrained setup** revealed the **importance of ice size distribution**
- **Exponential ice size spectrum** (a common default assumption in bulk Schemes) is **too broad** and can underestimate ice water path by a factor of 2.
- Size distribution effects on both **deposition growth** and **sedimentation** are important

Liquid-to-ice partitioning is a strong function of ice size distribution assumption
1.1. *Holism versus reductionism*

A ‘holistic’ approach to investigating the impact of a variety of microphysics schemes, as well as the importance relative to other model components in a full 3-D CRM simulation, is challenging; it is difficult to isolate microphysics effects in the presence of radiative and dynamic feedbacks. Furthermore, 3-D CRMs are computationally expensive, so executing a large number of sensitivity tests is demanding. In an effort to overcome some of these issues and aid development and testing of microphysics schemes some researchers have taken a ‘reductionist’ approach and made use of kinematic frameworks (e.g. Clark, 1974; Petch *et al.*, 1997; Morrison and Grabowski, 2007; Seifert, 2008; Seifert and Stevens, 2010). In a kinematic framework the flow is prescribed, allowing advective transport and particle sedimentation while avoiding the complexity caused by feedbacks between dynamics and microphysics. Although this method does not include an accurate representation of cloud dynamics, research employing such a method has been shown to provide very useful insight. Clark (1974) used both a 1D and a 2D kinematic framework to test an aerosol cloud parametrization. These tests highlighted the importance of considering microphysics and its interaction with other processes.
KiD
(Kinematic Driver)
Getting a grip on the clouds...
Figure 6. Precipitation flux profile (upper-left); ‘bulk’ fall velocity (upper-right); histograms of surface rain rates as a function of intensity (for last hour only, bottom right). In the rain-rate histograms the black lines denote the SPol data converted using either the TRMM (solid) or RICO (dashed) reflectivity vs rain-rate relationship. Lines are otherwise colored following the degrees of freedom available for the microphysical scheme, green for bin, blue for two moment and red for one moment schemes (note because of an output diagnostic problem the UCLA-LES is not included in the ‘bulk’ fall velocity plot).
Kinematic modelling: warm rain

(Shipway & Hill, 2012)
Kinematic modelling: warm rain

<table>
<thead>
<tr>
<th>Microphysics scheme</th>
<th>Peak precip. (mm h⁻¹)</th>
<th>$I_{\text{precip}}$ (mm)</th>
<th>$I_{\text{aue}}$ (kg m⁻²)</th>
<th>$I_{\text{aew}}$ (kg m⁻²)</th>
<th>$I_{\text{cond}}$ (kg m⁻²)</th>
<th>$I_{\text{ewp}}$ (kg m⁻²)</th>
<th>$\Delta RWP$ (kg m⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAU [40 μm]</td>
<td>4.95</td>
<td>15.71</td>
<td>0.83</td>
<td>2.37</td>
<td>0.11</td>
<td>0.25</td>
<td>1.20</td>
</tr>
<tr>
<td>TAU [32 μm]</td>
<td>4.95</td>
<td>15.71</td>
<td>0.83</td>
<td>2.37</td>
<td>0.12</td>
<td>0.30</td>
<td>1.20</td>
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<tr>
<td>TAU [25 μm]</td>
<td>4.95</td>
<td>15.71</td>
<td>0.83</td>
<td>2.37</td>
<td>0.16</td>
<td>0.30</td>
<td>1.12</td>
</tr>
<tr>
<td>TAU [20 μm]</td>
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<td>0.83</td>
<td>2.37</td>
<td>0.08</td>
<td>0.09</td>
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<tr>
<td>LEM2.4sm</td>
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<td>16.07</td>
<td>1.08</td>
<td>2.52</td>
<td>0.70</td>
<td>1.13</td>
<td>0.53</td>
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<td>UM7.3</td>
<td>7.74</td>
<td>20.77</td>
<td>1.18</td>
<td>2.70</td>
<td>0.67</td>
<td>1.24</td>
<td>0.63</td>
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<tr>
<td>Thompson07</td>
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<td>17.09</td>
<td>0.17</td>
<td>1.36</td>
<td>0.18</td>
<td>0.42</td>
<td>1.04</td>
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<tr>
<td>LEM2.4dm</td>
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<td>39.66</td>
<td>0.74</td>
<td>2.33</td>
<td>0.19</td>
<td>0.32</td>
<td>1.26</td>
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<tr>
<td>Thompson09</td>
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<td>45.94</td>
<td>0.68</td>
<td>2.26</td>
<td>0.19</td>
<td>0.41</td>
<td>0.98</td>
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<tr>
<td>Morrison</td>
<td>5.39</td>
<td>43.36</td>
<td>0.73</td>
<td>2.38</td>
<td>0.07</td>
<td>0.12</td>
<td>1.06</td>
</tr>
</tbody>
</table>
Kinematic modelling: warm rain
Kinematic modelling: warm rain

\[ w = 2 \text{ms}^{-1} \]

\[ w = 3 \text{ms}^{-1} \]
Kinematic modelling: Flexible 1D or 2D.

- Other standard test cases include:
  - Squall lines
  - Warm and cold stratocumulus
  - Flow over orography
Kinematic modelling: Ice nucleation in wave clouds

- Simple but effective tool for reproducing environmental conditions during the nucleation process.
Kinematic modelling: Ice nucleation in wave clouds
KiD-A
(Kinematic Driver - Aerosols)
How do aerosols affect cloud?
Precipitation sensitivity of bulk microphysics to aerosol
Precipitation sensitivity of bulk microphysics to aerosol

\[ S_0 = -\frac{d \ln R}{d \ln N_d} \]

Feingold & Seibert (2009)
Precipitation sensitivity of bulk microphysics to aerosol

\[ S_0 = -\frac{d\ln R}{d\ln N_d} \]

Feingold & Seibert (2009)

Susceptibility behaviour in (non-convective) precipitation in a GCM
Getting down to the details...
New KiD initiative: KiD-A
[cURRENTLY DEFINING PHASE-I]

- **Lead by:** Adrian Hill (Met Office) & Zach Lebo (NOAA)

- **Phase I-A (kinematic):**
  - Benchmarking/comparison of detailed and bulk microphysics formulations
  - Response to changes in interstitial aerosol

- **Phase I-B (kinematic):**
  - Introduction of aerosol processing by the cloud – how does the growth/washout of aerosol feed back?

- **Phase II (dynamic):**
  - Idealised dynamical modelling of Sc with full aerosol processing capabilities
Example phase I-A with a 1D forcing

1. The Tel-Aviv University (TAU) multi-moment scheme (used in Shipway & Hill (2012))
2. MSSG-Bin – single moment bin scheme described Onishi & Takahashi (2012)
   - \( S1 = 33 \) bins
   - \( S4 = 128 \) bins

Both schemes initialised with aerosol = 50 cm\(^{-3}\)
Example phase II dynamical case with bulk microphysics
Example phase II dynamical case with bulk microphysics
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Example phase II dynamical case with bulk microphysics
Example phase II dynamical case with bulk microphysics
How should any future Action interact with GASS?
That’s something we can discuss over a beer!