GENESIS outline of conceptual approach

2 October 2017

1. Introduction

From the GENESIS proposal: "This project aims to develop a new, unified **genesis scheme** for convective triggering and updraughts for use in the current Met Office convective parametrisation scheme and applicable to new parametrisations. The genesis scheme will, at every timestep, determine the updraught characteristics to be fed to the other parts of the convection scheme and will integrate aspects of sub-cloud and updraught dynamics in consistent equations. We will achieve this by integrating and further advancing a body of research on the physics and fluid dynamics of deep convection, with a particular focus on the initiation and development of updraughts. We will consider behaviour both at the cloud and the cloud-system scale, with representations derived from large numerical simulations, and using novel statistical measures."

We anticipate:

I. Characterising the statistics of those aspects of the sub-cloud field which provide the lower boundary condition to convective clouds, as functions of environmental parameters; and
II. Evaluating the contribution of the existing convective cloud field to these statistics.

2. What determines the conditions for genesis of convection?

a. "Meteorological" phenomena

A successful scheme will need to be able to capture the relationships between moist convection and a number of related physical phenomena, notably including.

- Boundary layer state and turbulence; Convective, sheared and nocturnal boundary layers;
- Surface forcing (including topography / heterogeneity).
- Pre-existing cloud above the BL
- Cold pools;
- Gravity waves, including nocturnal coherent structures in the NBL;
- Convergence lines;

In practice, these phenomena must influence convection, and a convection scheme, through associated physical processes and measures of them. Such physical quantities are more universal, but the range of these meteorological phenomena directs us to what those physical processes maybe, and directs our evaluation of convection schemes.

b. Physical quantities and processes

In practice, the phenomenological view of convection forcing needs to translate into generic physical quantities (e.g. temperature) and processes (e.g. turbulence) which can be analysed in the convective environment. The lists that follow propose processes, and some measures of these.

i. Boundary layer processes and structures

- Spatial distribution

  - Distribution of “triggering” BL perturbation length-scales (narrow vs wide distribution of length-scales);
  - Representative horizontal length-scale of BL perturbations (mean / percentile value of above);
  - Horizontal (x-y) aspect ratio to BL horizontal length-scale distribution (lines versus localised thermals? Rolls, convergence lines, gust fronts etc);
  - Horizontal distribution or arrangement of BL perturbations (uniform vs organised);
  - Vertical distribution of perturbation;
  - Topology of structures (thermal versus plume?).
- Thermodynamics
  - Magnitude of BL perturbations in T, q and tracers;
- Dynamics
  - Perturbation in vertical velocity;
  - Spatial structure in relation to mixing, transport etc;
  - Vorticity, helicity.
- Joint distributions of these quantities.

ii. Deep convective processes

- “Convective (Bernoulli?) suction”
- Entrainment
- Detrainment

c. Convective response

In order to make use of improved knowledge of the sub-cloud conditions, we need to better understand how these influence the resulting clouds, in measures such as:

- Horizontal size of convective updrafts (within cloud), mass flux etc.
- Higher-order measures of cloud structure, e.g. morphology of updraught, plume vs thermal etc.
- Tendency of clouds to have multiple updrafts;
- Depth of convection;
- Convective organisation …

3. Implementation

Implementation of quantitative information on sub-cloud “triggering” conditions depends on the scheme in question, but for example we can consider the Plant-Craig scheme in which a number of clouds, N, and their mass-fluxes, m_i, is computed in order to derive a plume calculation.

- We would in this case do away with the CAPE closure and derive the statistics of the number and mass-flux as determined quantitatively from the sub-cloud conditions (and modified by “suction” if pre-existing cloud is present).
- This information would also be fed to a modified cloud model in which the existing “plume” calculation is replaced by calculations taking account of new aspects of the lower boundary / initial condition to the cloud (e.g. size and aspect ratio).
- Stochasticity may be explored by sampling the fields N and m_i from a physically-based distribution.
- We are interested to consider creating cloud objects which have their own lifetimes: for instance, cloud objects such as thermals may be generated in each timestep, labelled, and given a time-dependent evolution in the following steps.

In the context of the convection scheme being developed by Mike Whitall at the MetOffice, in which the same updraft model is being used to represent both vertical transport in the boundary layer and in convective clouds, it appears that the most useful insight GENESIS can provide is through:

- Defining as a function of height in the boundary layer what the mean vertical heat and moisture flux is and over what area fraction of the domain this vertical transport takes place

- Studying the physical mechanisms which cause different convective and forcing phenomena (squall lines, coldpools, topographic uplifing, large-scale convergence) to affect the boundary layer structure and how the change in the boundary layer structure creates changes in the coherent structures which lead to the formation of convection. This will lead of insights which may inform new processes which should be represented in convective updraft models or new prognostic fields which should be evolved to represent in-boundary layer variations which are not captured by the horizontal mean.

4. Examples

The examples below are based on analysis of a dx=25m (domain: 50km x 50km x 6km) simulation of the RICO test case (vanZanten 2011) which represents precipitating marine shallow cumulus in Radiative Convective Equilibrium performed with UCLALES.

Length-scales of variability

Within GENESIS it is the aim to characterise the length-scales of coherent structures which transport moisture and heat through the boundary layer cause the formation of convective clouds. Here this was investigated by calculating the variance retained in patches of decreasing size compared to the variance across a domain-wide cross-section.

In Figure 1 the variance retained for the vertical velocity, water vapour and virtual potential temperature and for comparison for a randomly generated field are plotted. The figure shows that the variance falls off more rapidly for the moisture and buoyancy fields as compared to vertical velocity, indicating that the structures in vertical velocity a narrower in size (larger patches are necessary to capture the variance in moisture and buoyancy). This has implications for how distributions in space for these scalar fields may be parameterised as it may not be adequate to assume the same length-scale for all scalar fields making it challenging to define the boundaries of coherent structures uniquely.

In Figure 2 the evolution in time of the length-scales of variability for the vertical velocity is plotted. In the RICO simulation the convection has become organised at t=1440min, causing the vertical velocity variability to concentrate in coherent structures with larger horizontal extent. The boundary-conditions (i.e. large-scale forcing) for this simulation does not vary over time and so this indicates the need to investigate how the boundary layer state changes over time and how this influences the scales of coherent structures carrying vertical transport.

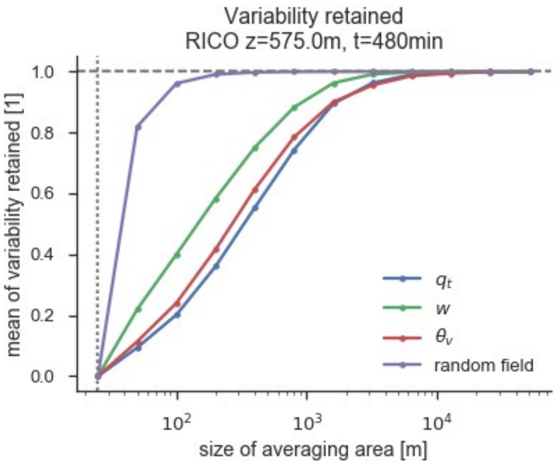

Figure 1: Retained variability (with varying patch size) is different size for vertical velocity, moisture and buoyancy suggesting that vertical velocity is concentrated in narrower features

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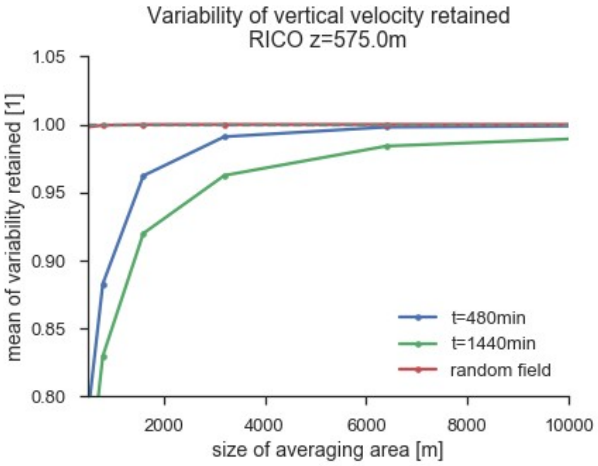

Figure 2: Retained variability in patches of increasing size shows that as convection becomes organised (t=1440min) the variability of vertical velocity is concentrated in regions with larger area

Distributions through the boundary layer

As a direct input to the use of current convection schemes GENESIS aims to characterise the dynamic and thermodynamic properties of air that causes the formation of convective clouds. In Figure the distributions of potential temperature (left) and water vapour (right) have been extracted through horizontal cross-sections at characteristic heights in the boundary layer, as well as at points immediately below clouds within 6min of the formation of these clouds. By comparing the surface and mid-boundary layer (z~350m) distributions it appears that predominantly the warmest and drier parcels rises from the surface, however by looking at the distributions at cloud-base the colder and moister parcels appear to be what trigger convection.

This analysis can provide for parcels that trigger convection an estimate for their deviation in thermodynamic variables from the boundary-layer mean state which, which is typical necessary input for convection schemes. This analysis will be extended by studying how the distributions vary with height (which will help constrain updraft schemes which operate in the boundary-layer) and how coherent structures with different characteristics contribute to these distributions.

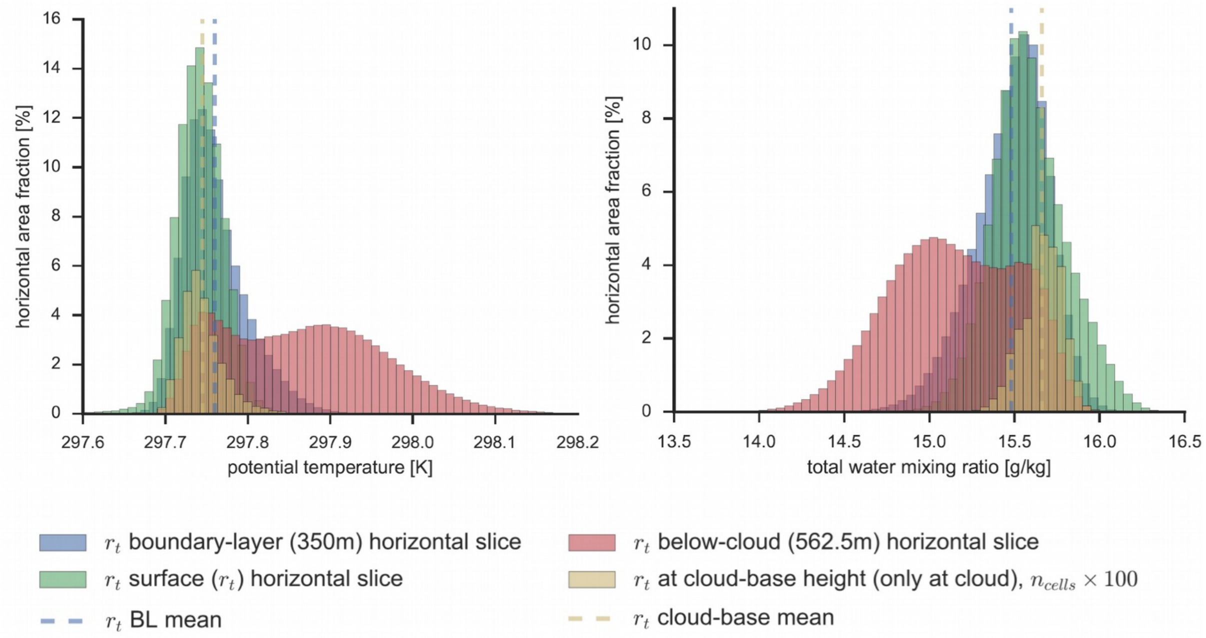

Figure 3: Distributions of potential temperature (left) and water vapour concentration (right) in horizontal cross-sections through the boundary layer at varying heights, as well as for points extracted just below cloud-base. Differences between the mean in the well-mixed boundary layer center (z~350m) and immediately below cloud base indicates that convective clouds in RICO are triggered by cold moist parcels.

5. Summary spreadsheets

In GENESIS the study of interactions between large-scale features, boundary-layer coherent structures and convection is being mapped out by creating a number of spreadsheets which can guide which interactions to focus on (by indicating existing knowledge in the literature and open questions). Below these are included in their current state to given an indication of literature review to date.

Interactions between boundary-layer structures an observed physical phenomena

	Phenomena				
Effect on	**Deep convection**	**Shallow convection**	**Coldpools**	**Fronts**	**Convection after sundown**
Horizontal lenght-scale of BL perturbations	Similar to updrafts? I.e. kilometers?	Similar to updrafts/cloud base (equivalent) radius? Height of the boundary layer? Length-scale of overturning?	Characteristic size altered with the appearance of coldpools?	On size of updrafts within front, front width or front length?	Reduce in size a predictable rate (because of energy loss to convective triggering or friction with surface)?
Distribution of BL perturbation horizontal length-scales	Are there more large eddies than for say shallow convection?	?	Restricted in size because of coldpools? Appearance of a second distribution due to thermals lifted from cold pool edge?	?	Reduced as characteristic length-scale reduces?
Horizontal (xy) aspect ratio to BL horizontal length-scale distribution?	No preferential direction (assuming no wind)?	None?	Appearance of more horizontally elongated perturbations?	Appearance of more horizontally elongated perturbations?	None?
Magnitude of BL perturbations	Larger than shallow convection (because clouds are fed by larger eddies) or smaller (because deep convective clouds are self-perpetuating)?	Defined by surface fluxes?	Increased/decreased?	Larger because of downdrafts causing increased circulation in boundary layer?	Reduced in magnitude over time?
Horizontal spatial distribution of BL perturbations	Fewer isolated areas of convection compared to shallow. Is cloud fraction larger or smaller?	Isotropic or clustered?	More closely spaced thermals (because of reduced horizontal area with vertical transport)?	Concentrated along and near front?	Unchanged?
Vertical distribution of perturbations	Concentrated at cloud base (if the clouds are self-perpetuating, “Bernoulli suction”)?	Concentrated at surface (if the thermals are driven by surface fluxes)?	Reduced in vertically in cold pool layer, domain-wide more eddies at higher altitude or fewer eddies?	?	Concentrating at higher altitudes as stable boundary layer grows from the Earth’s surface?
Perturbation in vertical velocity	Larger than shallow because convection is more vigorous?	?	Increased by lifting by cold pool density current?	?	?
Perturbation in water vapour vs temperature	?	Dependent on surface fluxes?	?	?	?

Interactions between boundary-layer structures and observed physical phenomena

	Effect on			
Structure property	**Horizontal size of convective updrafts (within cloud)**	**Tendency of clouds to have multiple updrafts**	**Depth of convection**	**Convective organisation**
Distribution of BL perturbation length-scales (narrow vs wide distribution of length-scales)	Does width of distribution of convective updrafts follow that of the boundary layer thermals?	?	?	?
Horizontal length-scale of BL perturbations (mean value of above)	Larger perturbations leading to larger convective updrafts?	Larger perturbations may trigger updrafts over a larger area, which could cause multiple updrafts instead of a single one. May also be unaffected if larger BL thermals simply create larger updrafts	If larger updrafts are produced these will have a larger undilute core which will lead to deeper convection. If multiple updrafts are formed these could work together to produce deeper convection. http://journals.ametsoc.org/doi/abs/10.1175/JAS-D-16-0221.1	no influence?
Horizontal (xy) aspect ratio to BL horizontal length-scale distribution?	Do oblong BL thermals lead to oblong updrafts?	?	If updrafts with oblong horizontal aspect ratio are formed then these will entrain more which will make convection shallower	no influence?
Magnitude of BL perturbations	Larger horizontal size because larger perturbation (in magnitude) will have larger volume associated which will reach saturation?	?	Larger perturbations will place buoyant parcels on higher moist adiabat, leading to deeper convection	no influence?
Horizontal distribution of BL perturbations (uniform vs organised)	More clustered dry thermals may combine to produce larger convective updrafts?	Do clustered dry thermals combine to produce multiple updraft in a single cloud?	If clustered BL thermals lead to larger convective updrafts or individual clouds with multiple updrafts these will likely lead to deeper convection	no influence?
Vertical distribution of perturbations	?	?	?	?
Perturbation in vertical velocity	If convective updrafts are momentum driven (as compared to buoyancy driven) vertical velocity may determine the size and distribution of convective updrafts			
Perturbation in water vapour vs temperature	?	?	Heating and water vapour loading do not contribute equally to the change in moist adiabat with an equivalent change in density at constant pressure. Does this mean that different cloud-depth is attained?	?