A transition matrix for a stochastic modeling of the population dynamics of convective clouds

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Background

Convective clouds populations cover a spectrum of sizes and lifetimes and are often in transition (Courtesy of NASA).

Current conceptual models underpinning parameterizations of the interaction between convection and the environment have relied on an unrealistic assumption that slowly varying large-scale environment is in statistical equilibrium with a large number of small and short-lived clouds.

Objective

Informed by analysis of radar observations, cloud permitting model simulations and theory, the study aims to develop probabilistic models of non-equilibrium dynamics of cloud populations for:

- Testing hypotheses regarding the roles of various physical processes and
- Parameterizing the spectrum of convective clouds (from isolated to MCSs) in a unified framework.

The Stochastic Framework

$$\frac{dn_i}{dt} = \sum_{j \neq i} W_{ji} n_j - W_{ij} n_i$$

n_i is the number of cells of size $a_i = ia_1$

$a_1 = 6.25km^2$ is the size of a pixel (the smallest cell).

Transition to size a_i Transition from size a_i

A simplification:

If a convective pixel is to be added to (removed from) the domain, the probability that a convective cell of size a_i will gain (lose) that pixel such that:

$$n_{i+1} = n_{i+1} + 1, \text{ and } n_i = n_i - 1 \quad \text{for addition}$$
$$\text{and}$$
$$n_{i-1} = n_{i-1} + 1, \text{ and } n_i = n_i - 1 \quad \text{for removal}$$

is given by

$$p_i = \sum_j \boldsymbol{T}_{ji} n_j \qquad (1)$$

$\boldsymbol{T}$ is the transition matrix.

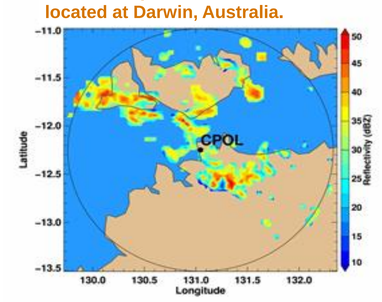
The Transition Matrix

(a) Development

C-Pol observation at Darwin

- 12 winters of C-Pol radar scans are used to identify convective cells.
- Steiner et al. (2005) algorithm is used to identify convective cells and stratiform areas.

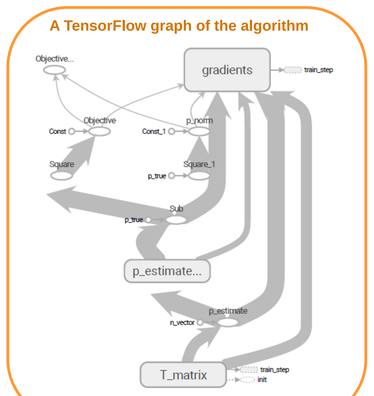
A snapshot of convective cells observed by C-POL radar located at Darwin, Australia.



Machine learning

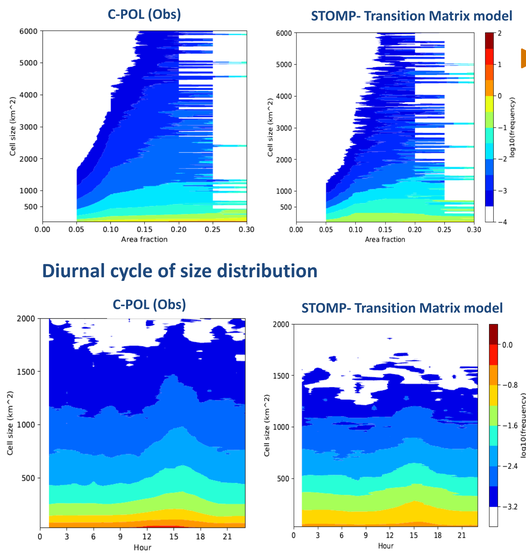
- A simple machine learning algorithm is constructed using TensorFlow. With the C-Pol radar observed time series of convective cell size distributions as an input, the algorithm uses Adaptive Moment Estimation (ADAM) optimizer to solve Eq. (1) for $\boldsymbol{T}$.

A TensorFlow graph of the algorithm



(b) Validation

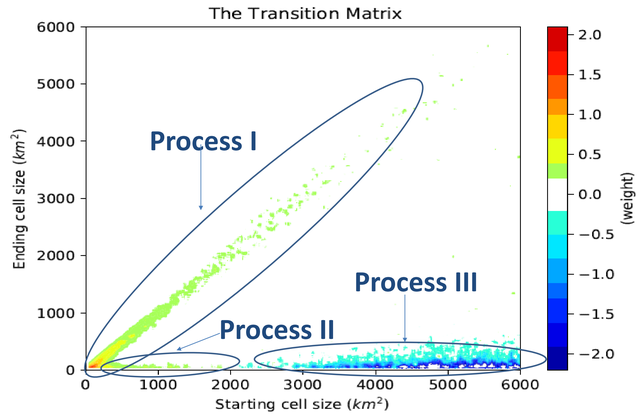
Size distribution vs area fraction



Diurnal cycle of size distribution

- When forced by the rate of change of area fraction. The transition matrix model predicts the size distribution as a function of area fraction and diurnal cycle well.

(c) Interpretation



The population dynamics is governed by primarily three processes:

- **Process I Lifecycle of convection:** Cells form, grow and decay.
- **Process II Positive feedback:** The presence of large cells favors the formation of new small cells possibly through cold pool dynamics.
- **Process III Negative feedback:** The presence of very large cells suppresses the formation and growth of small cells possibly through stabilization of the environment.

Summary and Future Work

- Convective cloud population from C-band radar observations at Darwin and a machine learning algorithm are used to construct a transition matrix for stochastic modeling of population dynamics of cloud populations. The matrix represents lifecycle of convection as well as direct cloud-cloud interactions.
- The framework will be extended to include stratiform area and hence of formation of MCSs and will be implemented into a mass flux scheme.

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