Organized Tropical Convection and the Weather-Climate Intersection

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Discrete spectrum of organized tropical convection

- Diurnal Cycle
- Seasonal Cycle
- MJO

Upscale organisation?

Modulates activity

MJO Suppressed Phase?

Monsoon Onset?

Mesoscale systems (1-100 km, Hours)

Synoptic systems (100's km, Days)

MJO (1000's km, Weeks)

Adapted from Moncrieff et al. (2007)

Weather: Extended Prediction (WWRP)

Climate: Variability on timescales up to seasonal (WCRP)
Year of Tropical Convection (YOTC)

Collaborative research at the intersection of weather and climate (timescales up to seasonal) with emphasis on multi-scale convective organization and its interaction with the large-scale circulation

A focused contribution to Seamless Prediction
ECMWF Global Database
(25 km)
May ‘08 – Apr ‘10

Focus Areas
- MJO & CCEWs
- Easterly Waves & TCs
- Trop-ExtraTrop Interaction
- Monsoons
- Diurnal Cycle
WCRP Aqua-planet model intercomparison project

Courtesy: Dave Williamson and Mike Blackburn
Large-scale precipitation bias
Similar at weather and climate timescales; linked to global circulation features

Courtesy: Jim Boyle, Steve Klein
Role of organized moist convection
Multiscale convective organization $O(1 \text{ – } 1000 \text{ km})$

- Moist convection organizes into mesoscale convective systems (MCS), superclusters, and other phenomena; interacts with atmospheric waves, notably in the Tropics

- Mesoscale convective organization:
  - Is missing from climate models – insufficient resolution, organized dynamics not represented in parameterizations
  - Is explicit in cloud-system resolving models (CRMs), and as 2D CRMs in superparameterized global models
  - Is explicit but under-resolved in high-resolution global NWP models
  - Its properties are quantified by theoretical-dynamical models

- Vertical shear has a fundamental effect on convective organization, but shear is not taken into account in convective parameterizations
Cumulus convection
Riehl & Malkus (1958)

Parameterization:
Arakawa & Schubert (1974)

Weakly interacting cumulus

Organized convection
(e.g., MCS; Houze (2004))

Key dynamical properties not represented by parameterization

< 10 km

> 100 km
Convective parameterization assumes a gap between parameterized cumulus (~1 km) and resolved scales (>100 km).

But the scale-gap does not exist in nature: Organized convection occupies the gap.

Addressing this key problem is high the YOTC research agenda via theory, numerical modeling and observations.

Horizontal scale:
- Large Eddy Simulation ($\Delta \sim 100$ m)
- CRM ($\Delta \sim 1$ km)
- Global NWP ($\Delta \sim 10$ km), climate models by 2020
- Contemporary climate models ($\Delta \sim 100$ km)

‘Scale-gap’
- Satellite & field-campaign data
- Mesoscale organization
Projected changes in precipitation (2090-2099 compared to 1980-1999) from IPCC AR4 climate models for most populated regions: low confidence especially in the summer hemisphere

Due to the absence of organized convection in climate models?
MCS: A world-wide phenomenon

Satellite analysis: Laing and Fritsch (1997)
Elevated solar heating determines start position & start time of convection

$\text{Mesoscale downdraft}$

$\text{MCS: a family of cumulonimbus}$

$\text{c} \approx 17 \text{ ms}^{-1}$

$\approx 1000 \text{ km}$
Meridionally averaged rain-rate

NEXRAD analysis
Carbone et al. (2002)

3-km explicit

10-km explicit

10-km Betts-Miller

Moncrieff and Liu (2006)
Grid-scale circulations represent propagating systems.
Upscale evolution of MCS

Stage 1: Onset
Stage 2: Multicell formation
Stage 3: Mesoscale organization

Stratiform ascent
Mesoscale downdraft

Δp

Convective parameterization
Mesoscale heating / momentum transport

Dynamic triggering

Missing from parameterizations
Parameterizing mesoscale overturning
*Stratiform heating and mesoscale downdraft cooling*

\[ Q_m(p, t) = \alpha_1 Q_c(p, t) \left[ \sin \pi \left( \frac{p_s - p}{p_s - p_t} \right) - \alpha_2 \sin 2\pi \left( \frac{p_s - p}{p_s - p_t} \right) \right] \]

\[ Q = Q_c + Q_m \]

- \( Q_m \) = Heating by slantwise mesoscale overturning
- \( Q_c \) = Cumulus heating
- \( \alpha_1 \) = Heating by slantwise mesoscale overturning/cumulus heating
- \( \alpha_2 \) = First-baroclinic heating/second-baroclinic heating
- \( p_t \) = Cloud-top pressure
- \( p_s \) = Surface pressure
Weather Prediction (T1279, ~15 km) compared with Satellite Observations

ECMWF predictions and Meteosat observations

Courtesy: Martin Miller
Multiscale Tropical Convective Organization:

Progress with the MJO, from coupled climate models to dynamical theory
Tropical MCS observed by TRMM

Tao and Moncrieff (2009)
Upscale cascade of energy: organized tropical convection
Downscale control: waves and shear

Superclusters: $L \sim 1000$ km
Cumulonimbus: $L \sim 10$ km
MCS: $L \sim 100$ km

$L \sim 10000$ km
Improved Intraseasonal Variance Community Atmospheric Model (CAM4)

Courtesy: Rich Neale
Improved MJO in ECMWF model
Scale-invariant structure of superclusters (~1000 km) and MCS (~100 km)

Moncrieff and Klinker (1997)
MJO in a superparameterized global model

Courtesy: Marat Khairoutdinov
MJO-like systems & propagating organized convection in idealized superparameterized global model

Superparameterized convention in a global model (Grabowski 2001)

Organized convective overturning interlocked with MJO (Moncrieff 2004)
Upscale effects of organized convective momentum transport

**Planetary-scale equations**

\[
\begin{align*}
\bar{U}_t - y\bar{V} + \bar{P}_x &= F^U - d_m \bar{U} \\
y\bar{U} + \bar{P}_y &= 0 \\
\bar{\theta}_t + \bar{W} &= F^\theta - d_\theta + \bar{S}_\theta \\
\bar{P}_z &= \bar{\theta} \\
\bar{U}_x + \bar{V}_y + \bar{W}_z &= 0
\end{align*}
\]

**Synoptic-scale momentum convergence**

\[
\begin{align*}
F^U &= - (v'u')_y - (w'u')_z \\
F^\theta &= - (v'\theta')_y - (w'\theta')_z
\end{align*}
\]

Biello, Majda & Moncrieff (2006)
Multiscale theory of the MJO

a) MJO “skeleton” – global-scale cloud envelope
   - Majda & Stechmann (2010)

   Neutrally stable interaction between:
   i) Planetary-scale lower-tropospheric moisture and
   ii) Planetary-scale envelope of synoptic-scale convective activity
   explains slow eastward phase speed; dispersion relationship $d\omega/dk \sim 0$; horizontal quadrupole vortex

b) MJO “muscle” - convection
   - Majda & Stechmann (2011)

Consistent with:

i) Positive effect of lower-tropospheric humidity in global models

ii) MJO satellite observations,

iii) Dynamics of coupling between organized convection/ and large-circulation
Summary

• We are at an interesting juncture:

- Progress being made with theory, modeling and observations of organized moist convection, e.g., orogenetic convection over continents and MJO

- Applying this knowledge to advance prediction and understand predictability

WCRP/WWRP-THORPEX YOTC Project: Global effects of organized tropical convection on time scales up to seasonal (intersection of weather and climate)
www.ucar.edu/yotc

Thanks for your attention