Modeling ocean-atmosphere coupled feedbacks over the tropical oceans

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photo: western Pacific from R/V Vickers, TOGA COARE (C. DeMott)
Modeling ocean-atmosphere coupled feedbacks over the tropical oceans: an MJO perspective

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why the MJO?

• it’s a nice “laboratory” for studying air-sea interactions
  • not a land-sea breeze phenomenon
  • not a shallow water (gravity) wave
  • moisture is essential: surface fluxes, advection, cloudiness, rainfall

• MJO convection affects and responds to oceanic processes on multiple scales
scale of the Madden-Julian oscillation
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“active” phase:
- cloudy
- windy
- cooling/cold SSTs

“suppressed” phase:
- fewer clouds
- calm
- warming/warm SSTs
scale of the Madden-Julian oscillation

direction of propagation

-0.2 C
+0.2 C

disturbed
latent
sensible
calm
goals of this talk

• to present scales of ocean-atmosphere interactions important to the MJO

• to introduce model requirements for representing these processes
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• to introduce model requirements for representing these processes
coupled processes within the MJO

Atmosphere
- large scale dynamics
- convection
- boundary layer physics

Ocean
- mixed layer physics
- mixing
- currents & internal waves

Air-sea interface
- ocean feedback

Latent
- sensible
- IR

Momentum
- rain
- solar

Atmospheric forcing
coupled processes within the MJO

Atmosphere
- large scale dynamics
- convection
- boundary layer physics

Ocean
- mixed layer physics
- mixing
- currents & internal waves

air-sea interface
- ocean feedback

Atmosphere
- latent
- sensible
- IR

Ocean
- momentum
- rain
- solar

atmospheric forcing

AML
- radiative feedbacks
- cloudiness
- humidity
- stability
- wind
- rain

OML
- SST
- salinity
- currents
- stability
- upwelling

ocean
coupled processes within the MJO

- Ocean and atmosphere communicate via surface fluxes
- AML and OML thermodynamic properties regulate the fluxes
buoyancy flux:
- the combined flux of heat and moisture into a volume of air or water
- buoyancy fluxes alter parcel density
the buoyancy flux

- buoyancy flux:
  - the combined flux of heat and moisture into a volume of air or water
  - buoyancy fluxes alter parcel density

\[
F_b \sim Q_{net} + (P - E)
\]

- heating
- moistening

\[
Q_{net} = SW \downarrow + LW \uparrow + LH \uparrow + SH \uparrow
\]
the buoyancy flux

- **buoyancy flux:**
  - the combined flux of heat and moisture into a volume of air or water
  - buoyancy fluxes alter parcel density

\[
F_b \sim Q_{net} + (P - E) \quad F_b = SH + (0.61C_pT/L_v)LH
\]

- heating
- moistening

\[
Q_{net} = SW \downarrow + LW \uparrow + LH \uparrow + SH \uparrow
\]
buoyancy fluxes, stability, mixing

\[ Q_{net} \approx SW \downarrow + LH \uparrow \]
buoyancy fluxes, stability, mixing

\[ Q_{net} \approx SW \downarrow + LH \uparrow \]
buoyancy fluxes, stability, mixing

\[ Q_{\text{net}} \approx SW \downarrow + LH \uparrow \]

calm/suppressed

OML

strong mixing
MLD ~constant
weak stability

water advection
SSH perturbations

P − E

OML

weak stability
vertical mixing
ML deepening

OML

strong stability
water advection
SSH perturbations

ocean

ocean
buoyancy fluxes, stability, mixing

\[ Q_{\text{net}} \approx SW \downarrow + LH \uparrow \]

- Calm/suppressed
- Disturbed/active

The net effect on SST regulates the ocean feedback to the atmosphere.
time scales of air-sea coupled processes
time scales of air-sea coupled processes

Bellenger and Duvel 2009
time scales of air-sea coupled processes

Bellenger and Duvel 2009
Hendon and Glick 1997
time scales of air-sea coupled processes

-0.2 C  +0.2 C

diurnal

intraseasonal

intraseasonal

Bellenger and Duvel 2009

Hendon and Glick 1997

Moum et al. 2014
time scales of air-sea coupled processes

W

-0.2 °C

disturbed

diurnal

sensible

-0.2 °C

E

calm

intraseasonal

seasonal

diurnal warm layer

Bellenger and Duvel 2009

Hendon and Glick 1997

Moum et al. 2014

Rydebeck and Jensen 2017

intraseasonal

Bellenger and Duvel 2009

Hendon and Glick 1997

Moum et al. 2014

Rydebeck and Jensen 2017

seasonal

Bellenger and Duvel 2009

Hendon and Glick 1997

Moum et al. 2014

Rydebeck and Jensen 2017
time scales of air-sea coupled processes

- Diurnal: Bellenger and Duvel 2009
- Seasonal: Rydbeck and Jensen 2017
- Interannual: McPhaden 2004
buoyancy fluxes, stability, convection

calm/suppressed

atmosphere

AML
buoyancy fluxes, stability, convection

\[ F_b \sim SH + 0.1LH \]
buoyancy fluxes, stability, convection

\[ F_b \sim SH + 0.1LH \]

calm/suppressed

• diurnal convection
• SST gradient-driven convergence
buoyancy fluxes, stability, convection

\[ F_b \sim SH + 0.1LH \]

calm/suppressed

- diurnal convection
- SST gradient-driven convergence

disturbed/active
buoyancy fluxes, stability, convection

\[ F_b \sim SH + 0.1LH \]

calm/suppressed

disturbed/active

- diurnal convection
- SST gradient-driven convergence

• convection primarily regulated by large-scale atmospheric circulations
buoyancy fluxes, stability, convection

\[ F_b \sim SH + 0.1LH \]

calm/suppressed

disturbed/active

AML

atmosphere

the interaction of convection with atmospheric humidity strongly modulates ocean feedbacks

• diurnal convection
• SST gradient-driven convergence

AML

atmosphere

• convection primarily regulated by large-scale atmospheric circulations
convective moistening by rainfall rate

- Suppressed: 0.1-1 mm/day
- Transition: 3-5 mm/day
- Active: 10+ mm/day

100 hPa

Surface
convective moistening by rainfall rate

- warm and cold SST anomalies shift the distribution of rainfall rates and the height of moistening/drying.
- in models, the convective response to SST-modulated buoyancy fluxes is quite sensitive to cumulus parameterization.
- these processes affect tropical mean state moisture distributions.
model requirements for coupled processes

- **ocean**
  - finely resolved upper ocean
  - sub-daily coupling with atmosphere
  - adequate horizontal resolution to simulate oceanic equatorial Rossby waves, equatorial jets

- **atmosphere**
  - realistic surface fluxes (mean state; variability)
  - “correct” convective initiation
  - “correct” sensitivity of convection to column humidity
  - a better understanding of what “correct” looks like from observations
direct observations for constraining models
extra slides
uncoupled

d. Atmosphere-only, CGCM SST

e. KPP-coupled, CGCM SST

weak mixing

f. Atmosphere-only, high entrainment
g. KPP-coupled, high entrainment

strong mixing

coupled
SST cooling: fluxes vs dynamics

Halkides et al. (2015)
**summary of MJO coupled processes**

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