Modeling ocean-atmosphere coupled feedbacks over the tropical oceans

Charlotte A. DeMott

Department of Atmospheric Science, Colorado State University

photo: western Pacific from R/V Vickers, TOGA COARE (C. DeMott)

Atmospheric Convection and Air-Sea Interactions over the Tropical Oceans Workshop, 7-9 May 2019, Boulder CO

Modeling ocean-atmosphere coupled feedbacks over the tropical oceans: an MJO perspective

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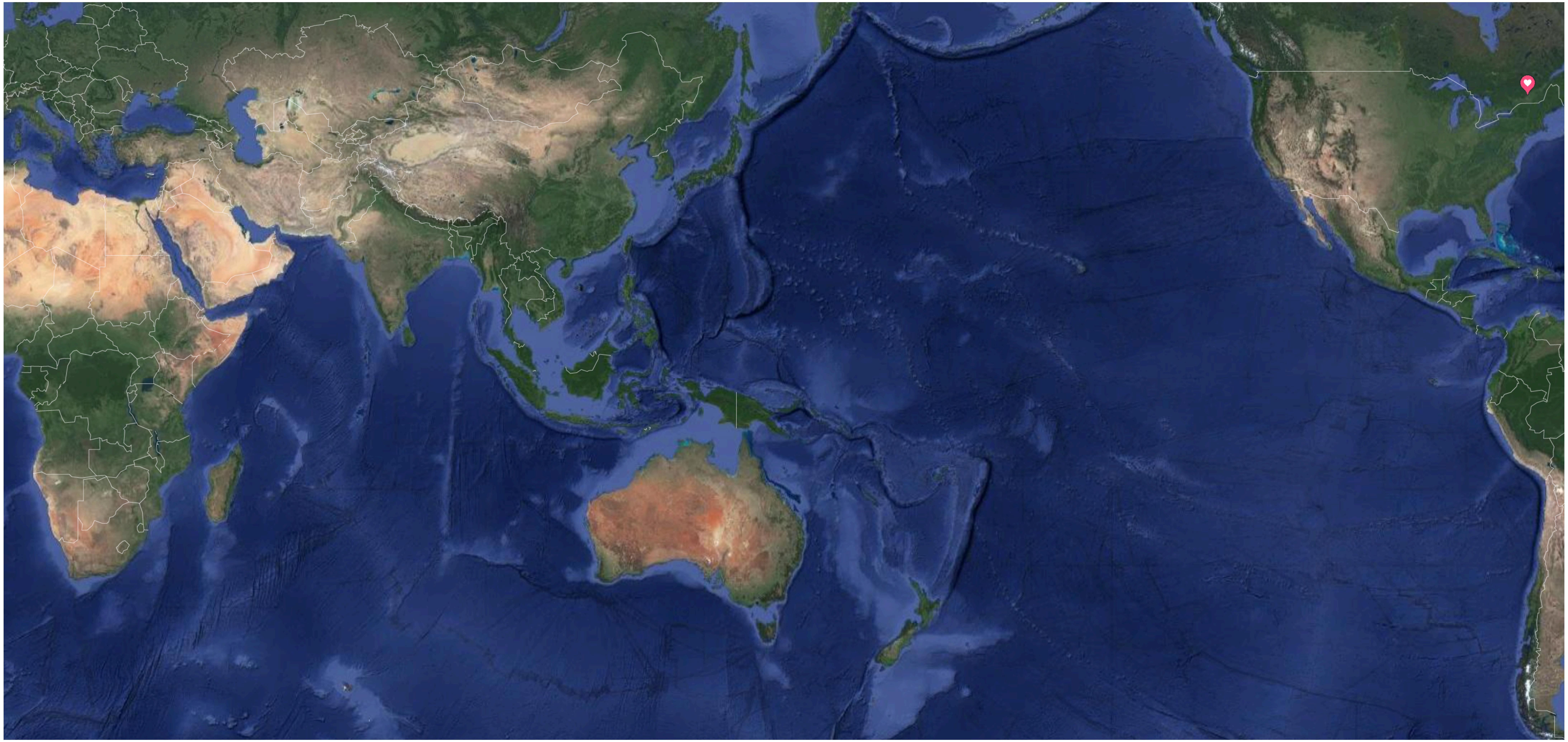
why the MJO?

- 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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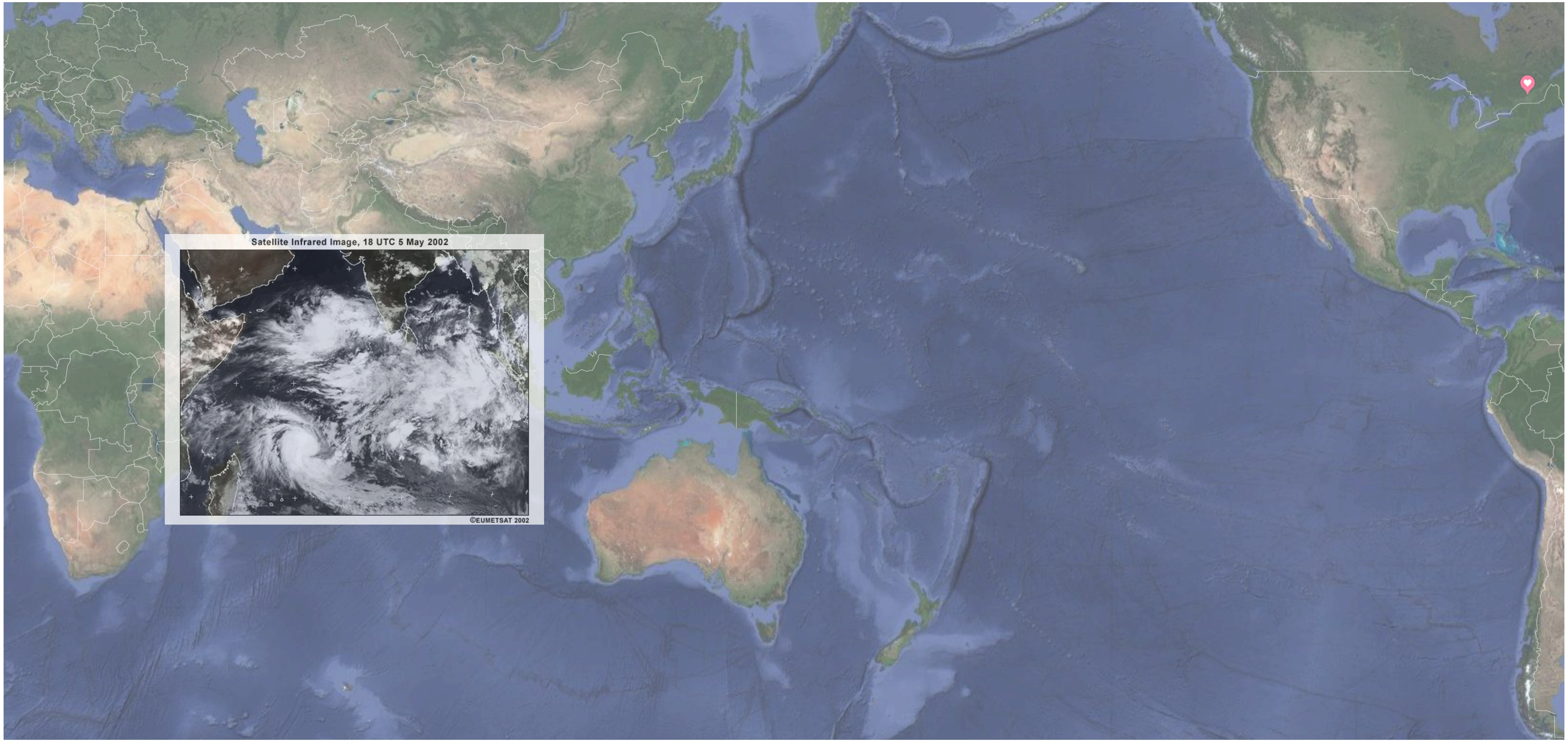

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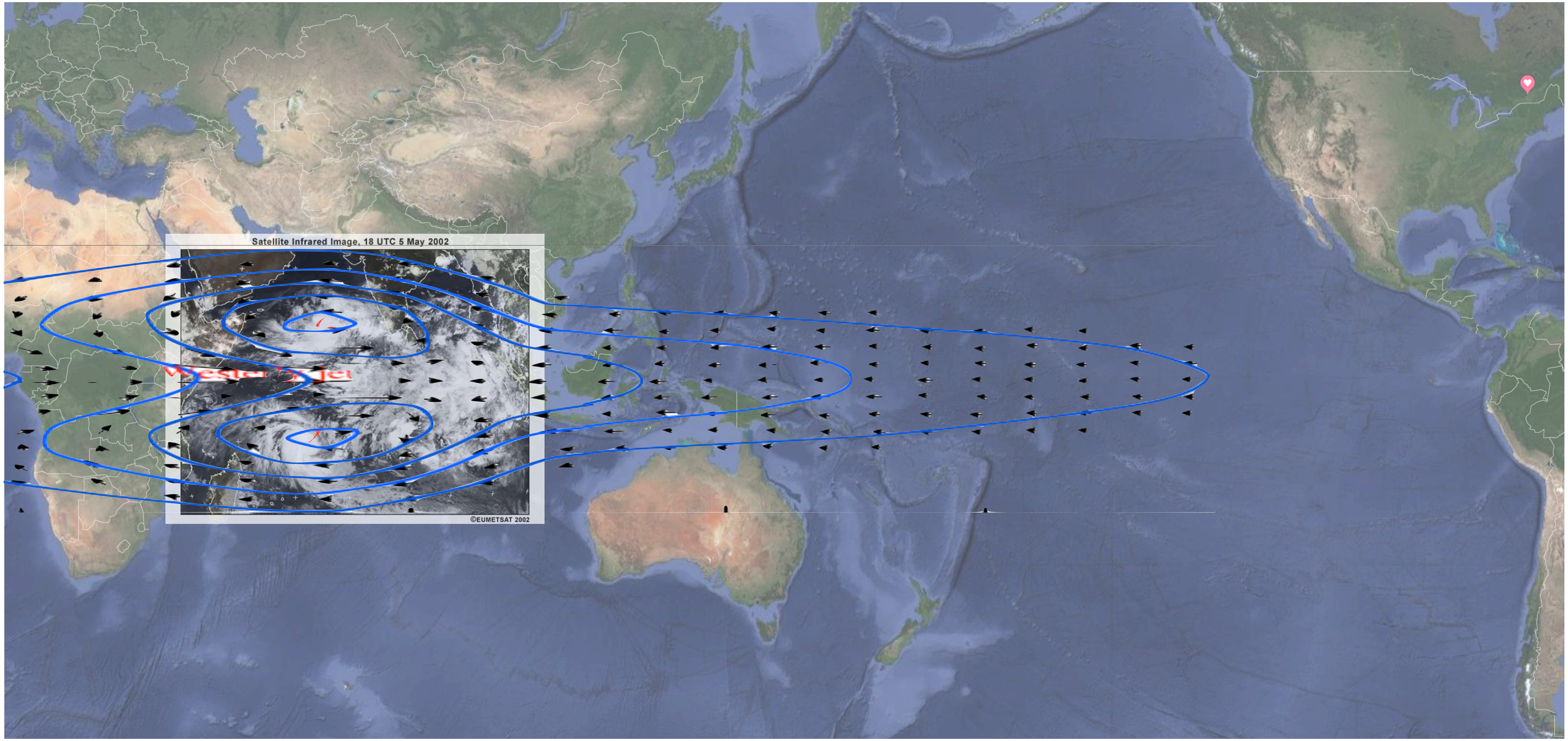

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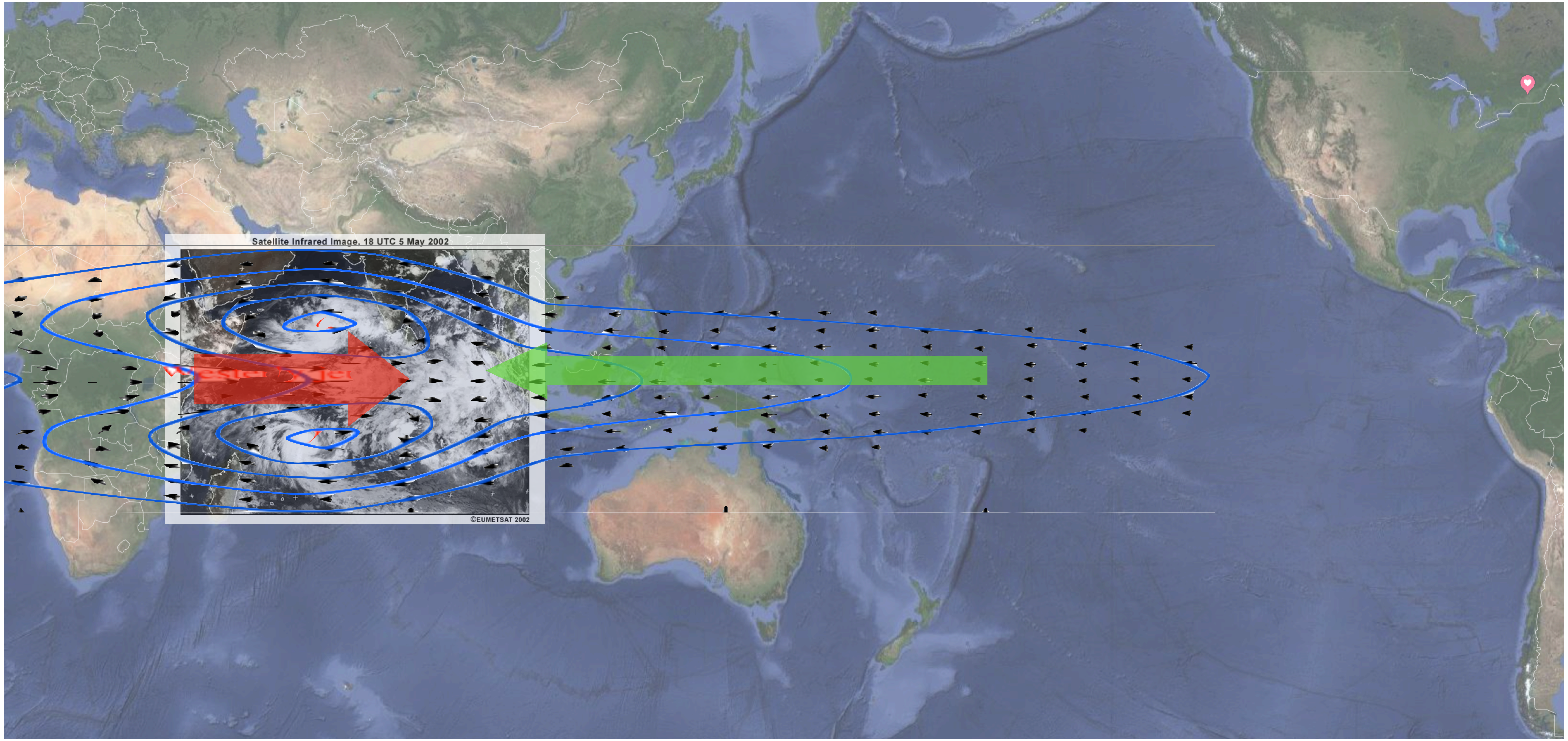
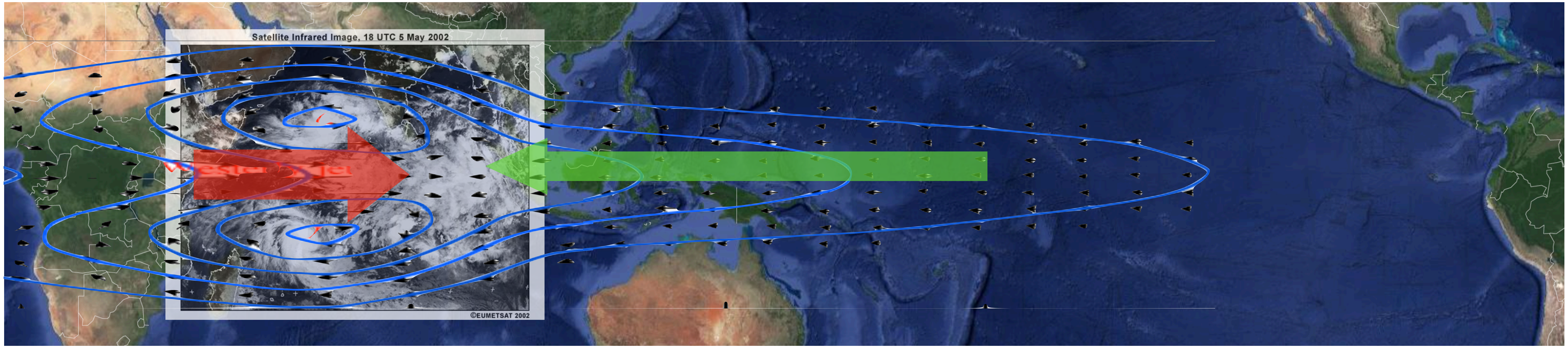


scale of the Madden-Julian oscillation

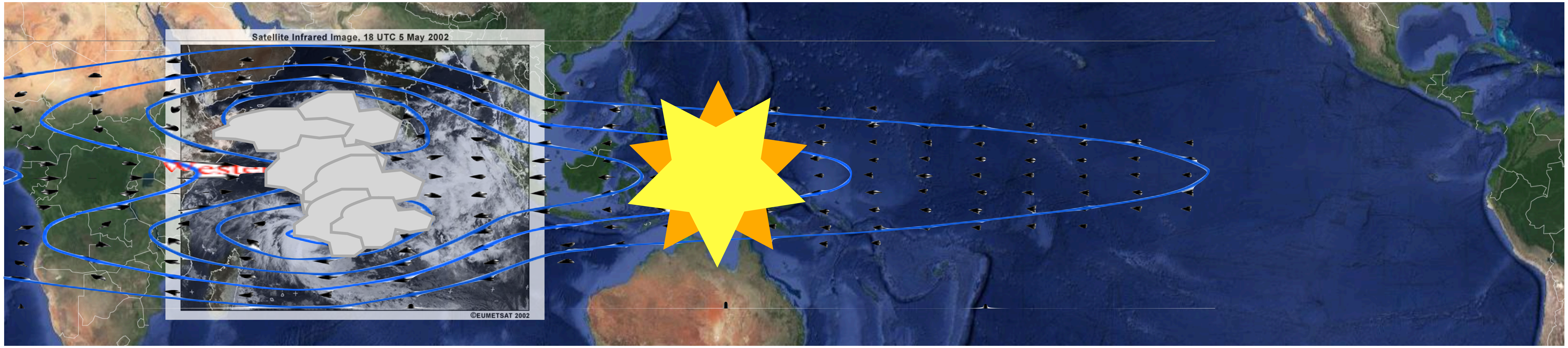
30N



30S

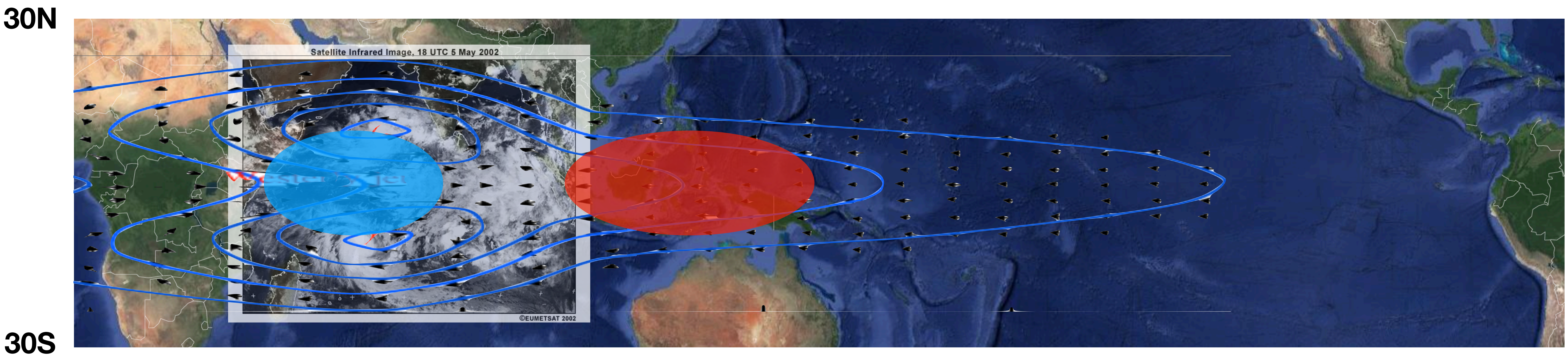
scale of the Madden-Julian oscillation

30N



30S

scale of the Madden-Julian oscillation



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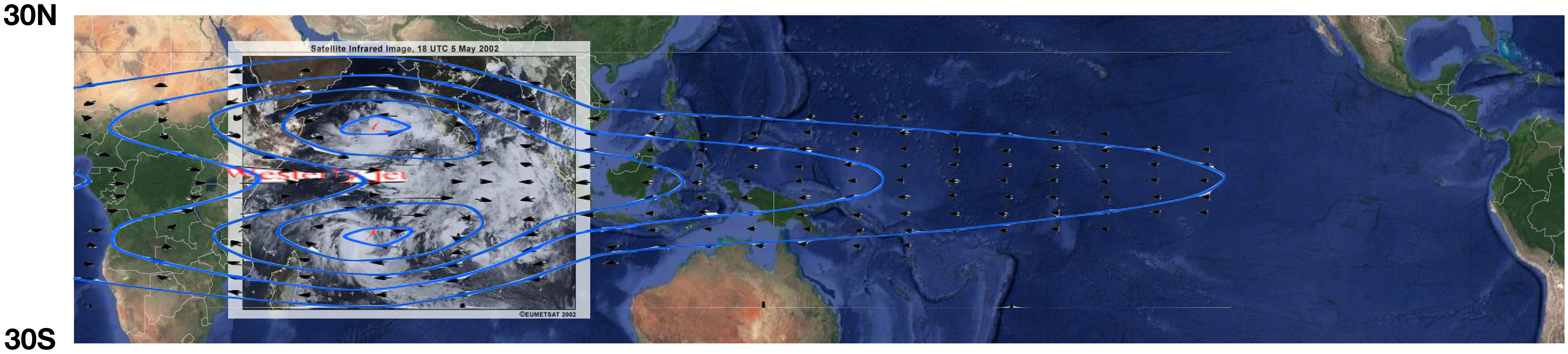
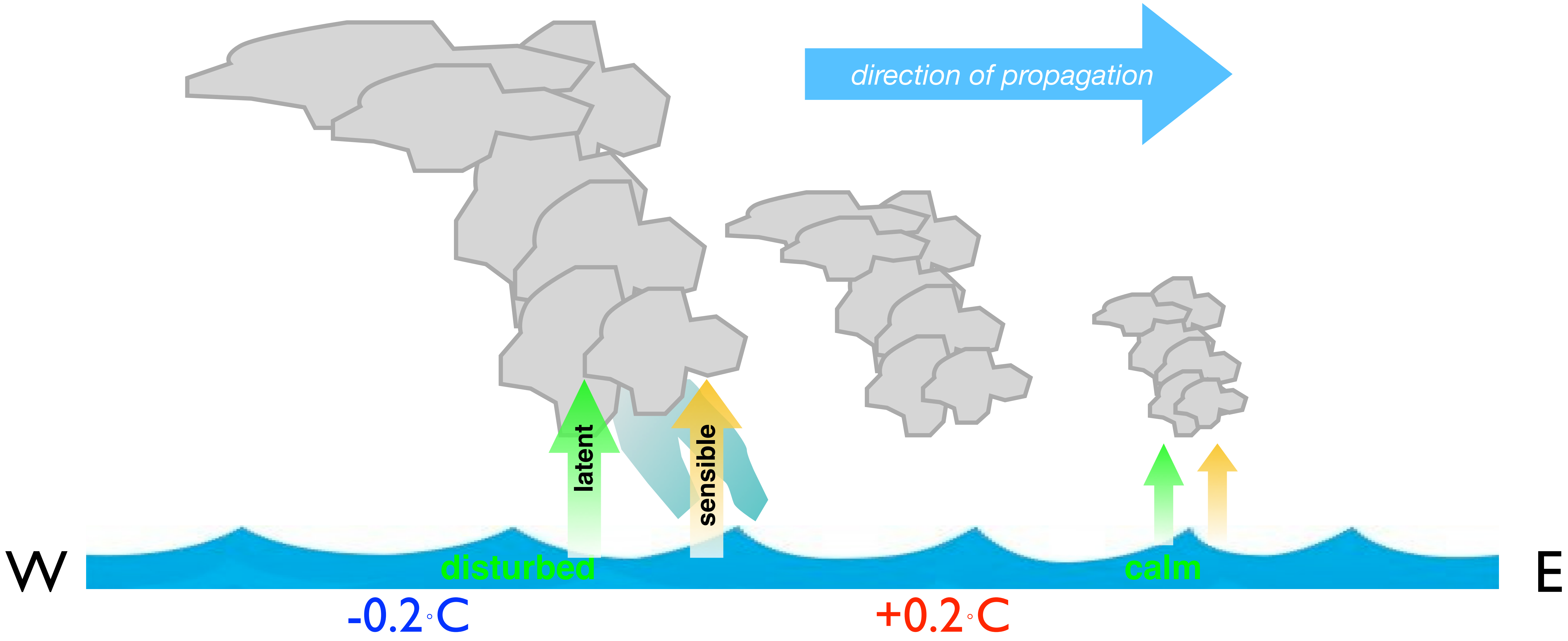
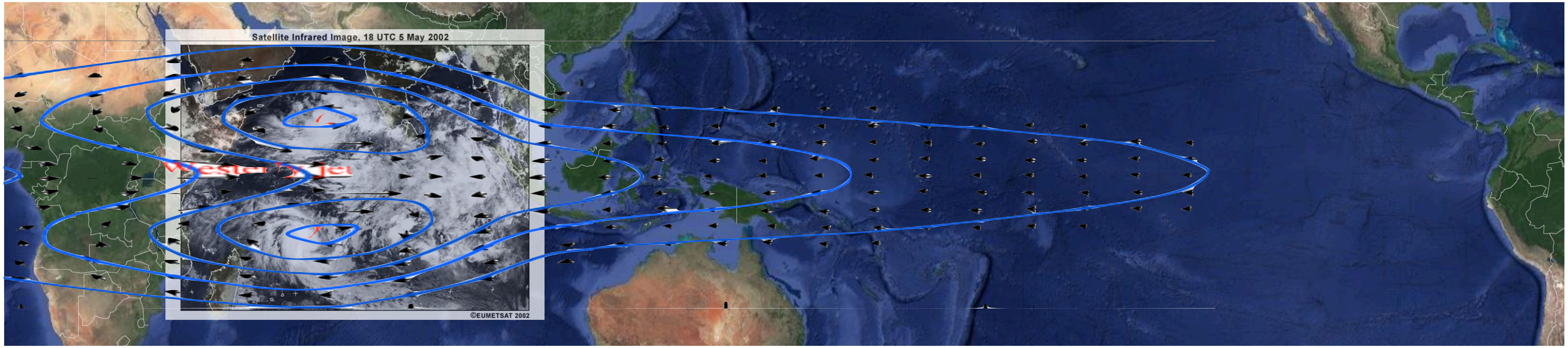


<u>"active" phase:</u>
cloudy
windy
cooling/cold SSTs

<u>"suppressed" phase:</u>
fewer clouds
calm
warming/warm SSTs

scale of the Madden-Julian oscillation





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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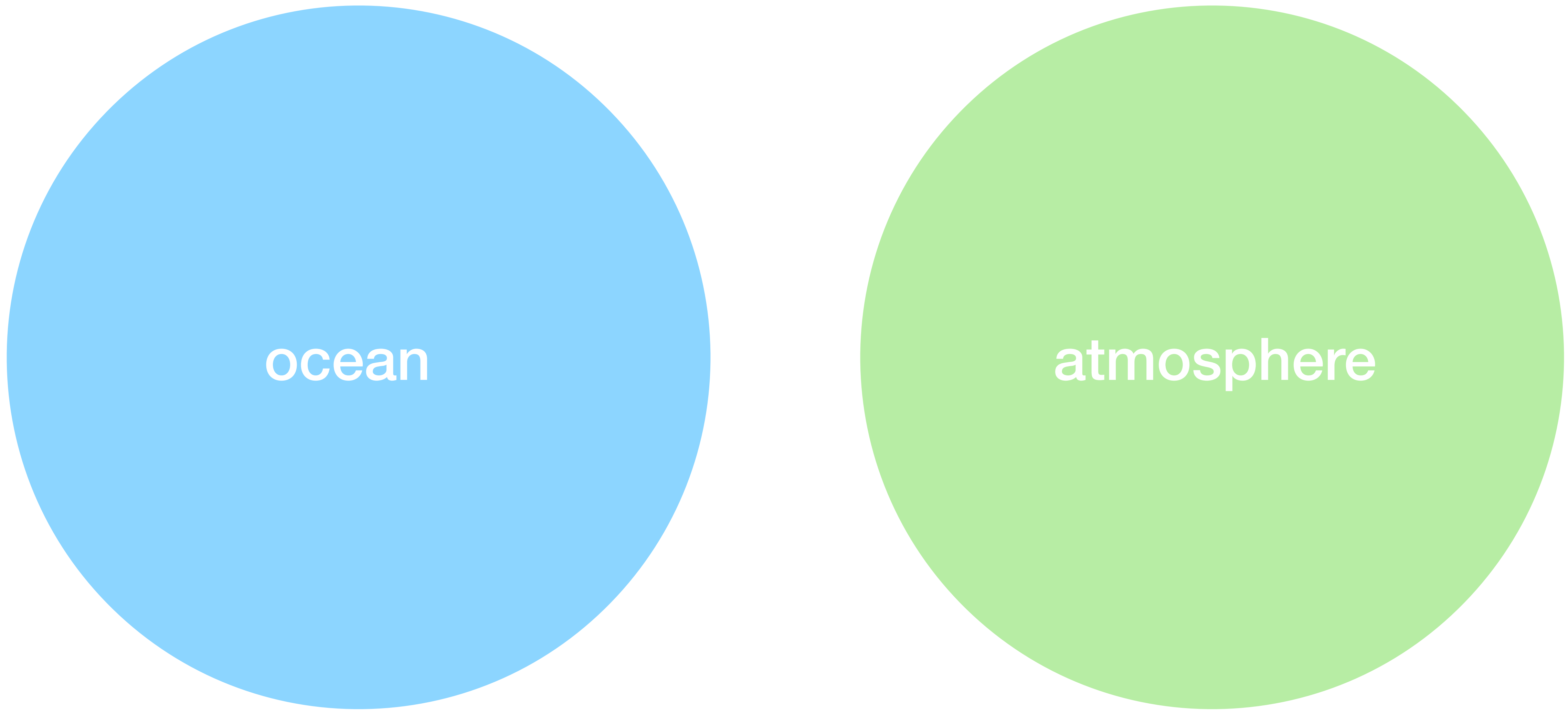

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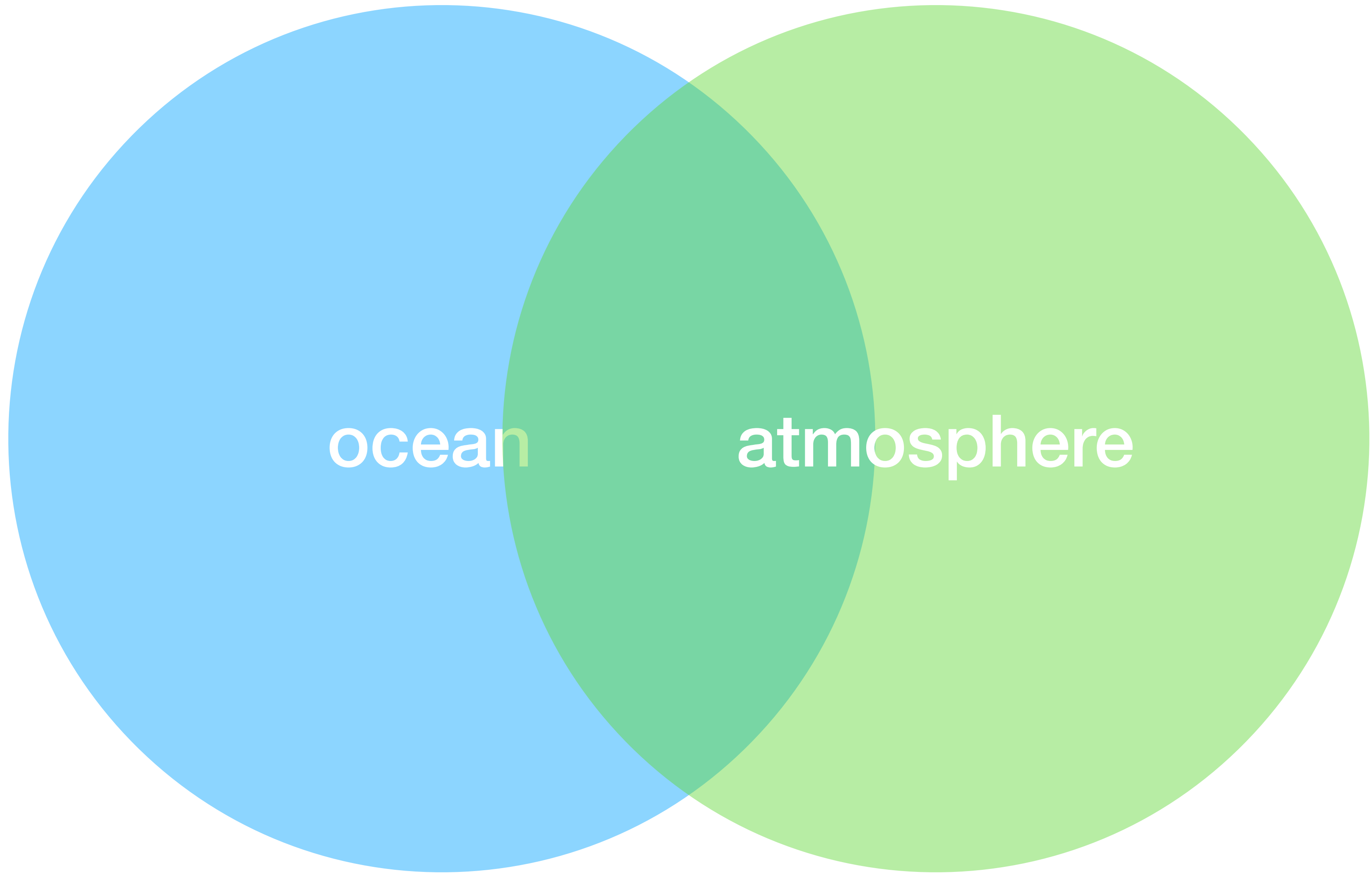
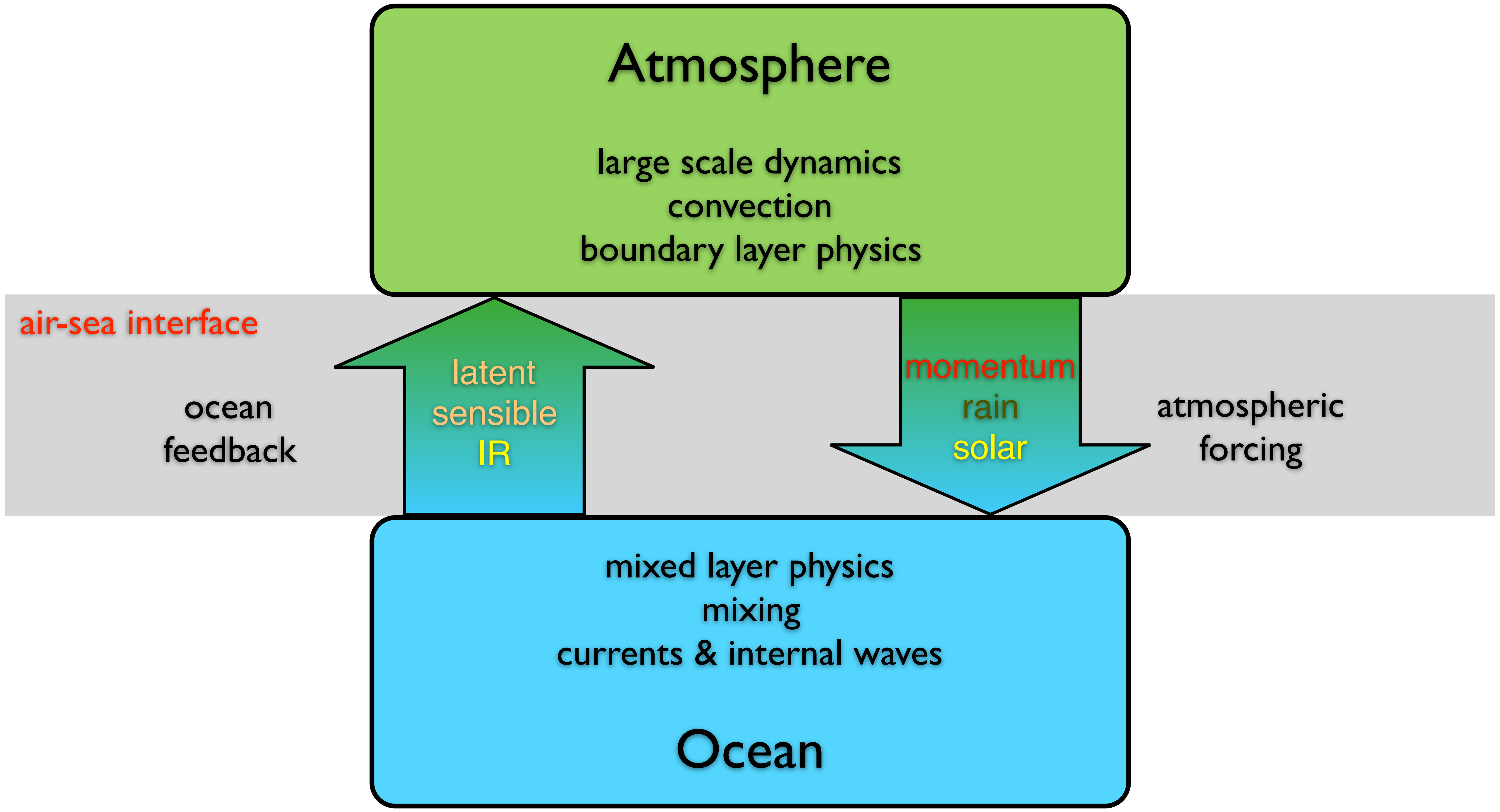


coupled processes within the MJO



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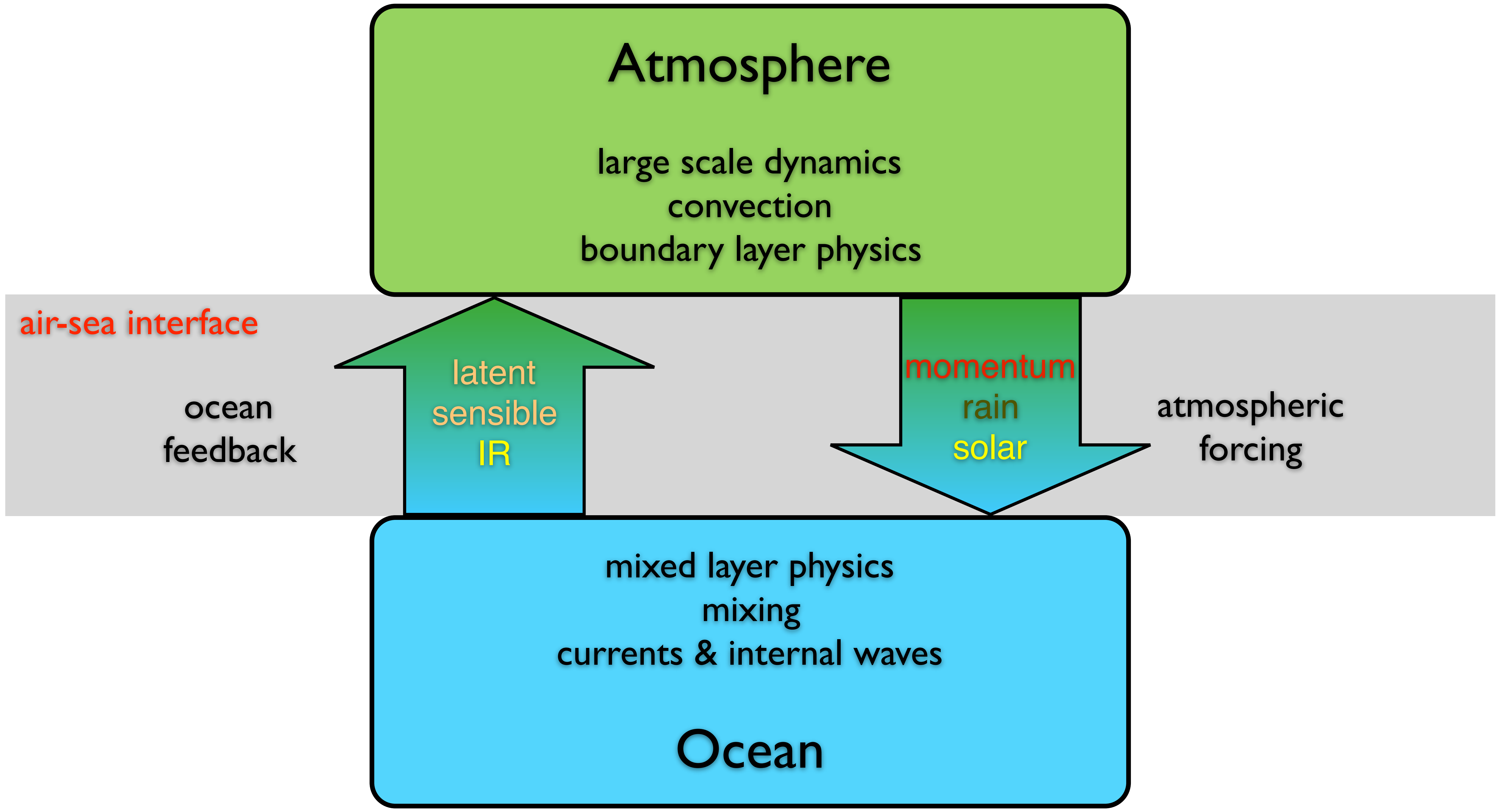

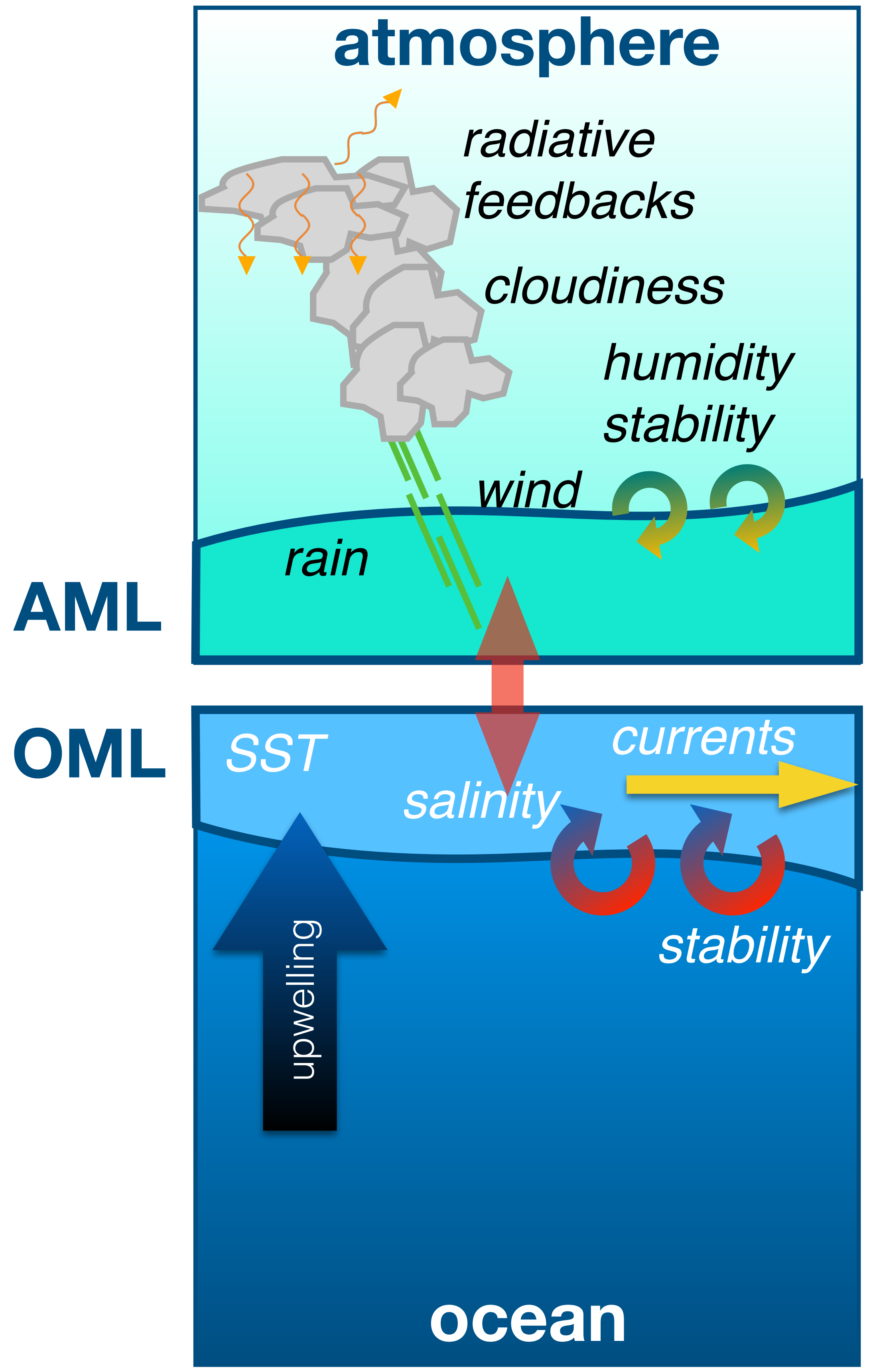

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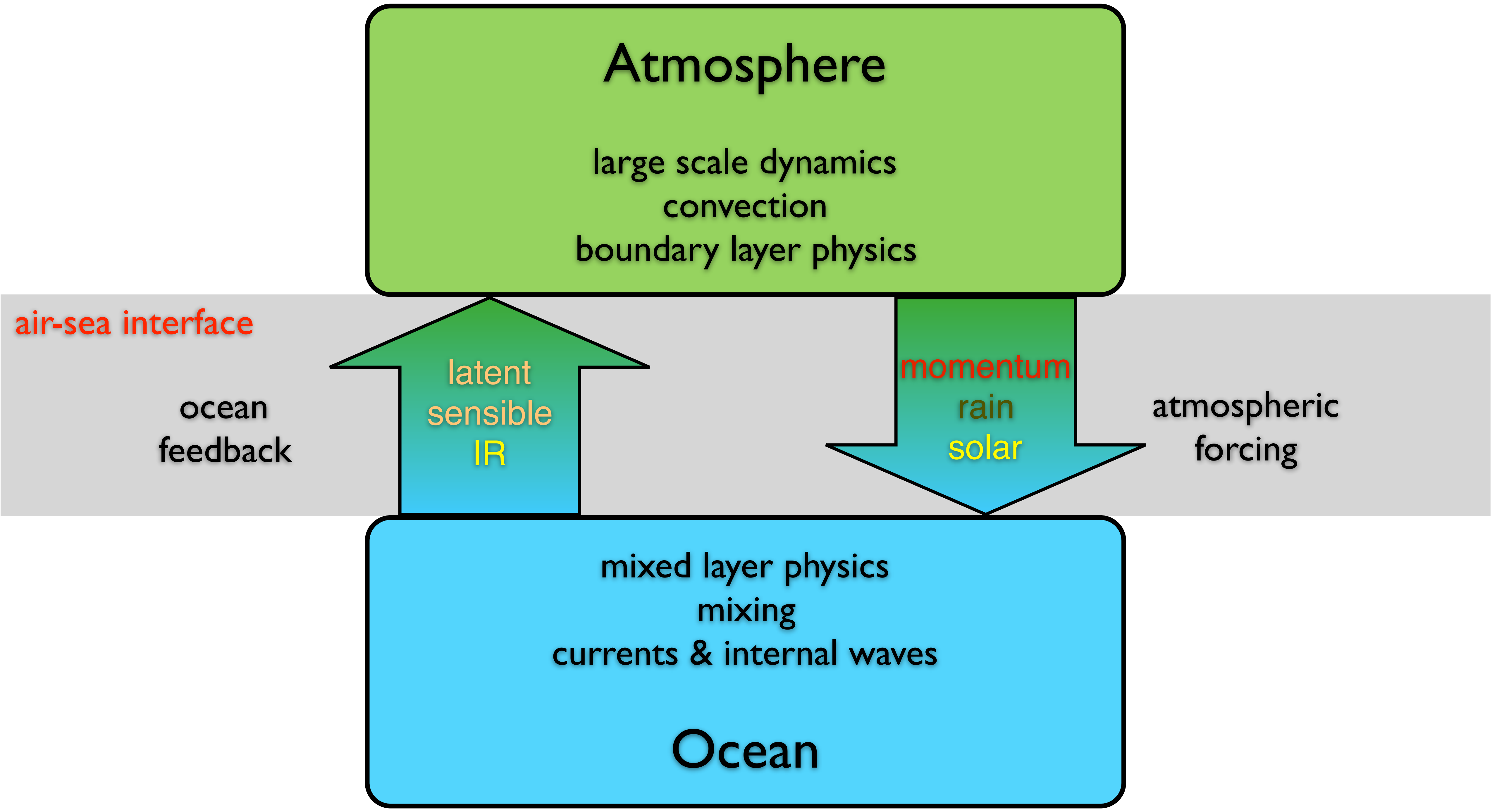

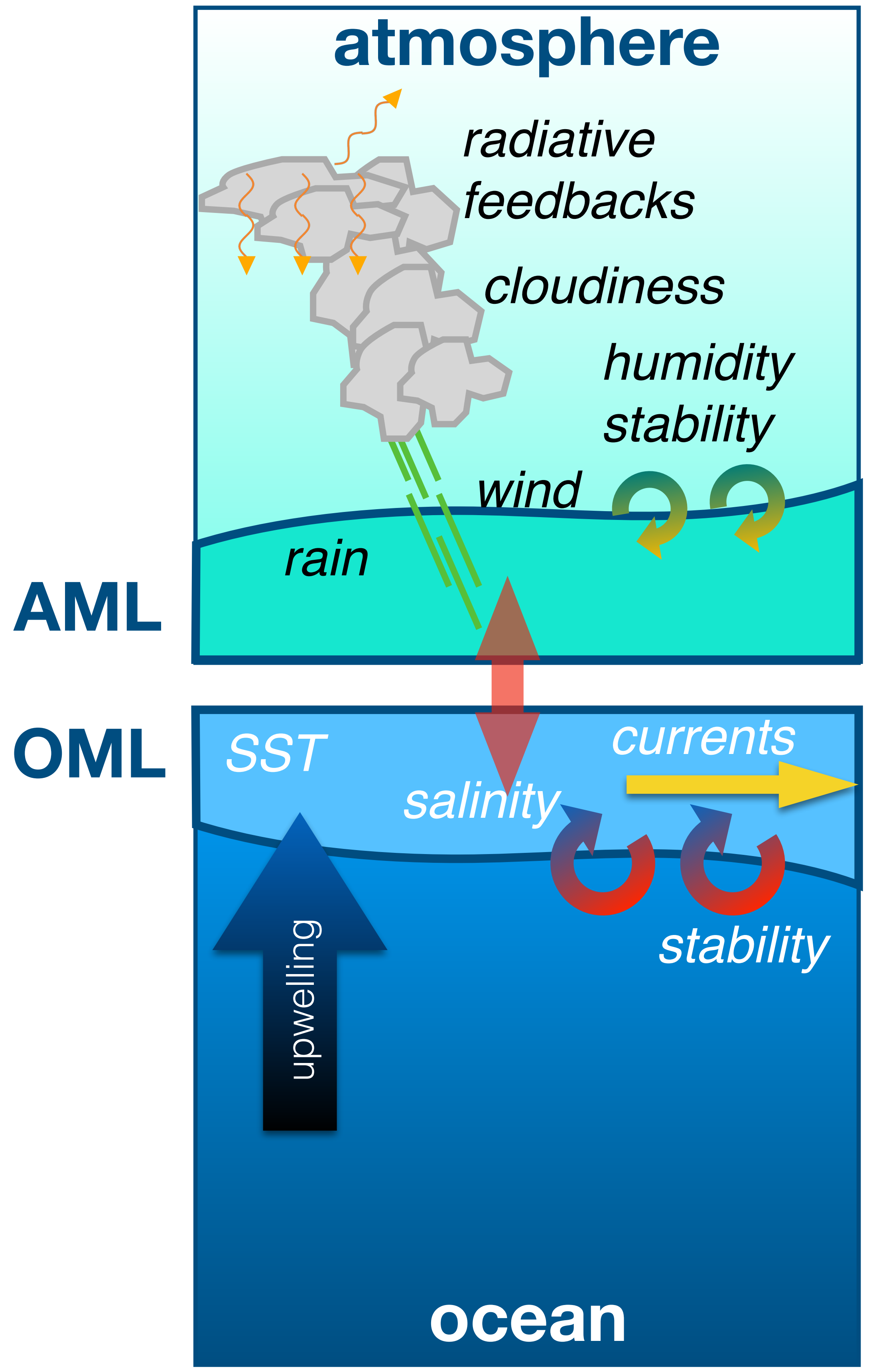

- Ocean and atmosphere communicate via surface fluxes
- AML and OML thermodynamic properties regulate the fluxes

the buoyancy flux

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

the buoyancy flux

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ocean

$$F_b \sim \underline{Q_{net}} + (\underline{P - E})$$

heating

moistening

$$Q_{net} = SW\downarrow + LW\uparrow + LH\uparrow + SH\uparrow$$

the buoyancy flux

- **buoyancy flux:**
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ocean

$$F_b \sim \underline{Q_{net}} + (\underline{P - E})$$

atmosphere

$$F_b = \underline{SH} + \underline{(0.61 C_p T / L_v) LH}$$

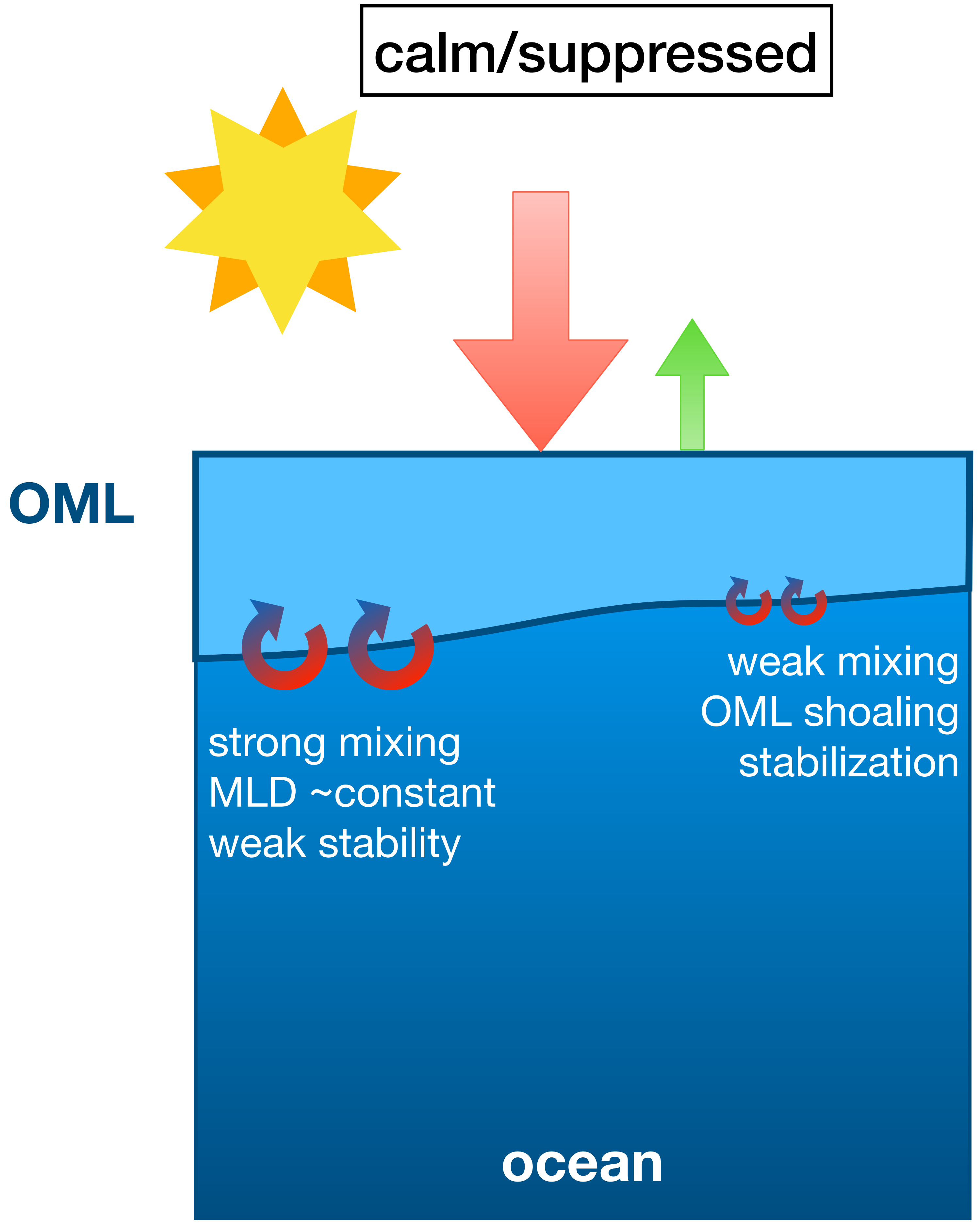
heating (red underline)

moistening (green underline)

$$Q_{net} = SW\downarrow + LW\uparrow + LH\uparrow + SH\uparrow$$

buoyancy fluxes, stability, mixing

$$Q_{net} \approx SW \downarrow + LH \uparrow$$



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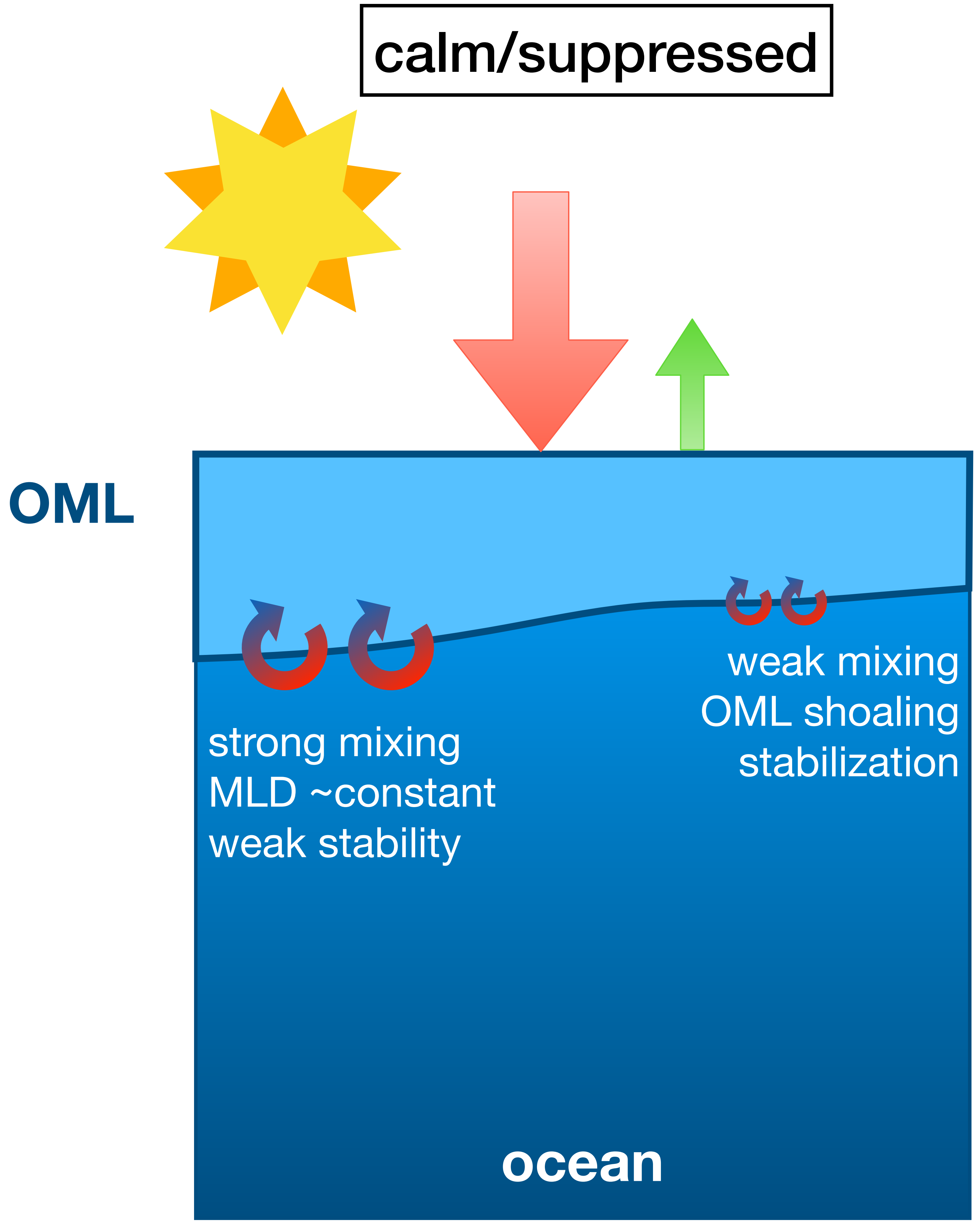

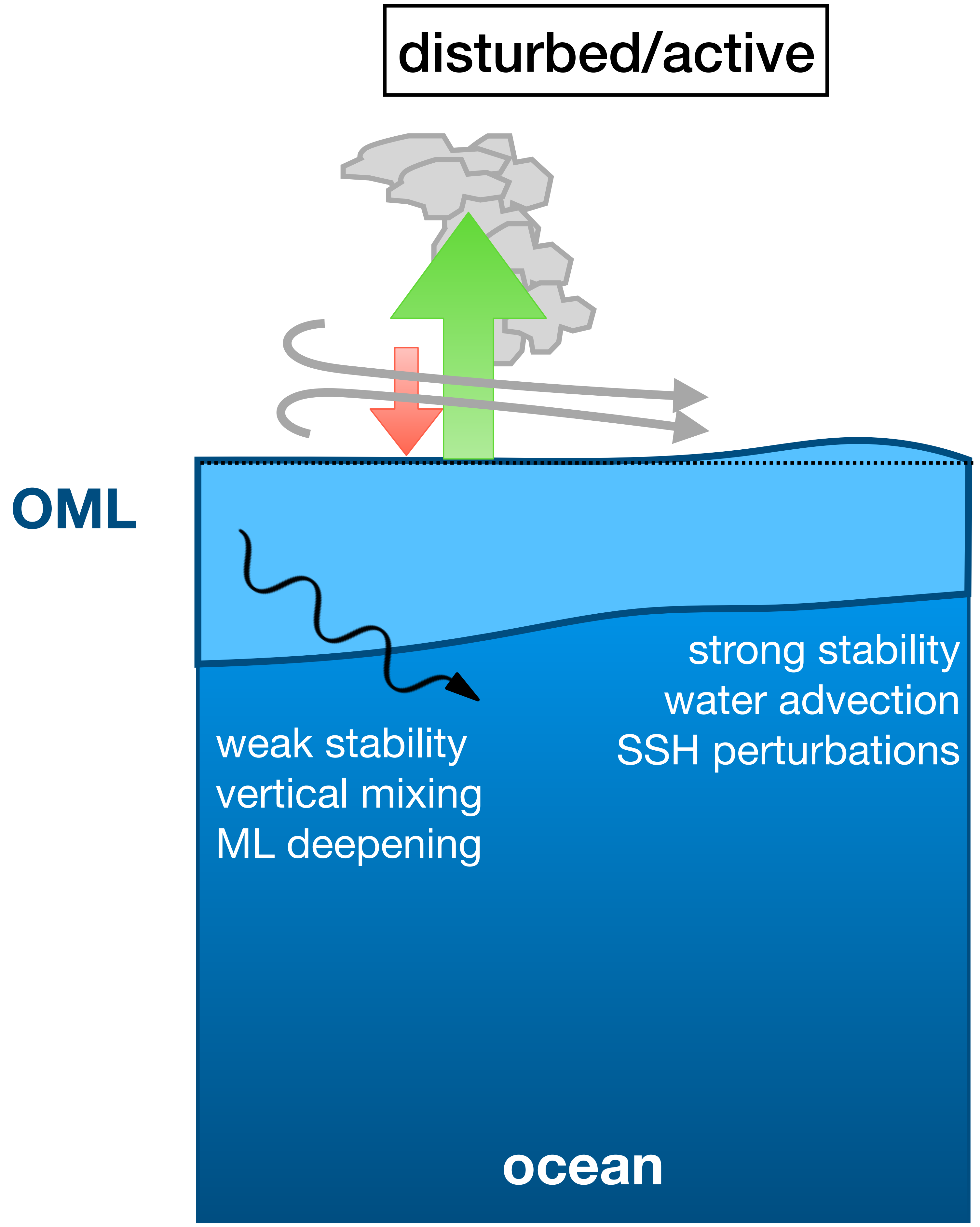

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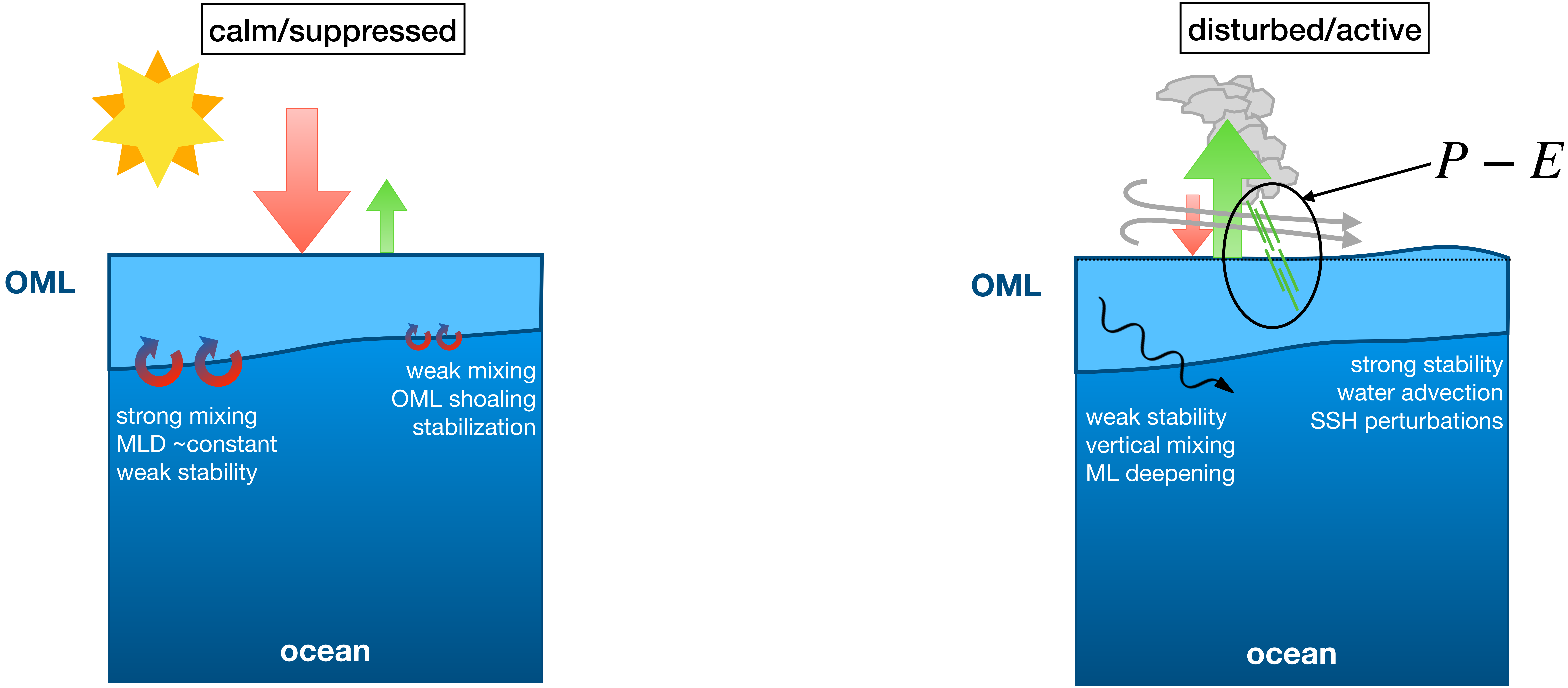

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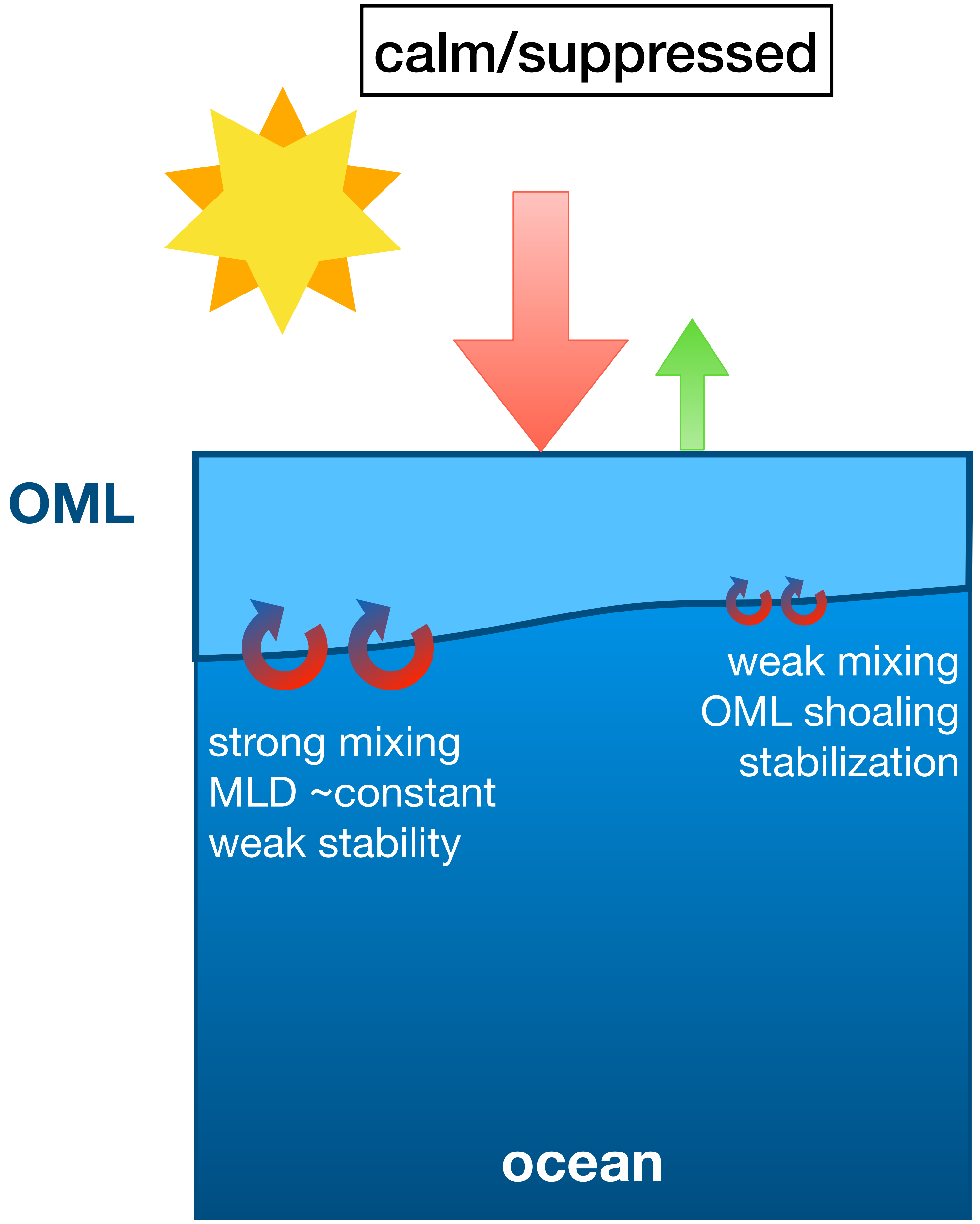
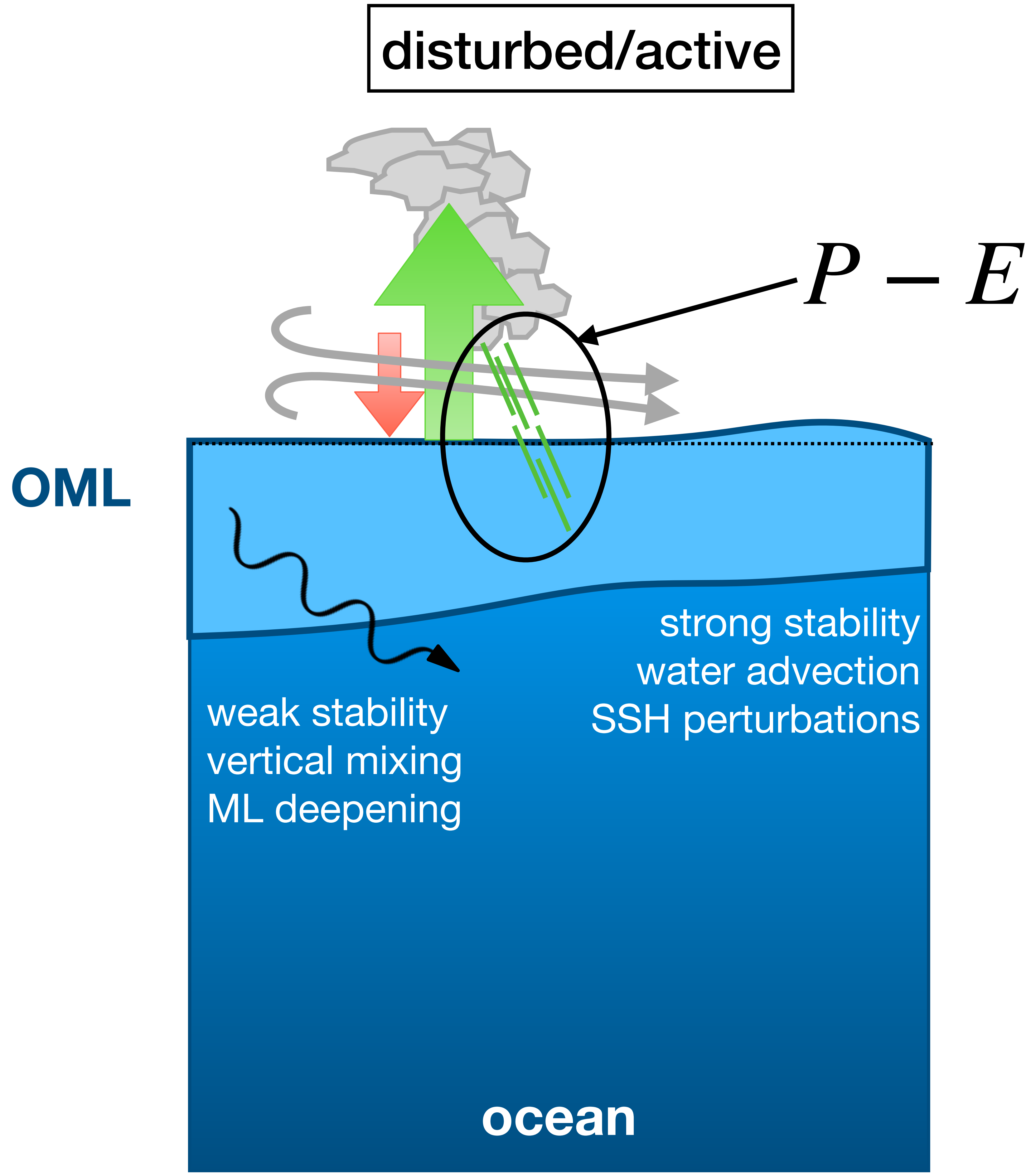
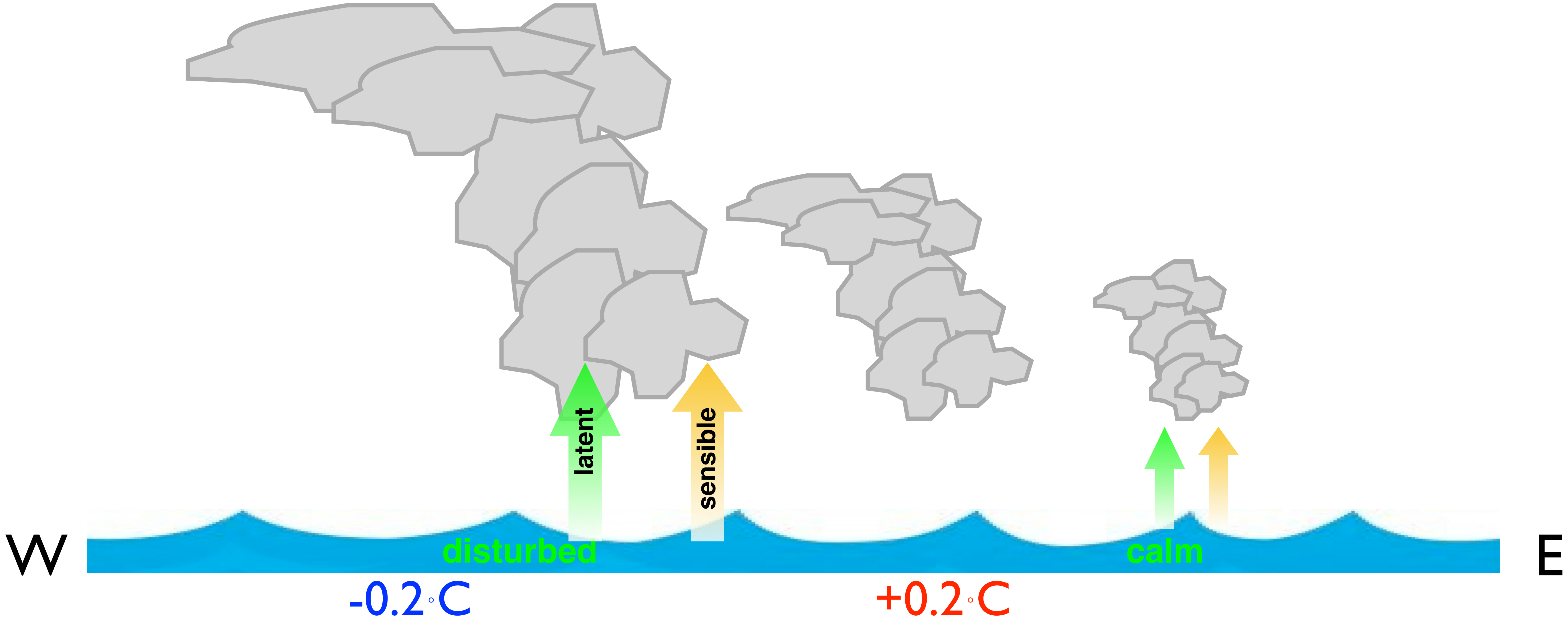


the net effect on SST regulates the ocean feedback to the atmosphere



time scales of air-sea coupled processes



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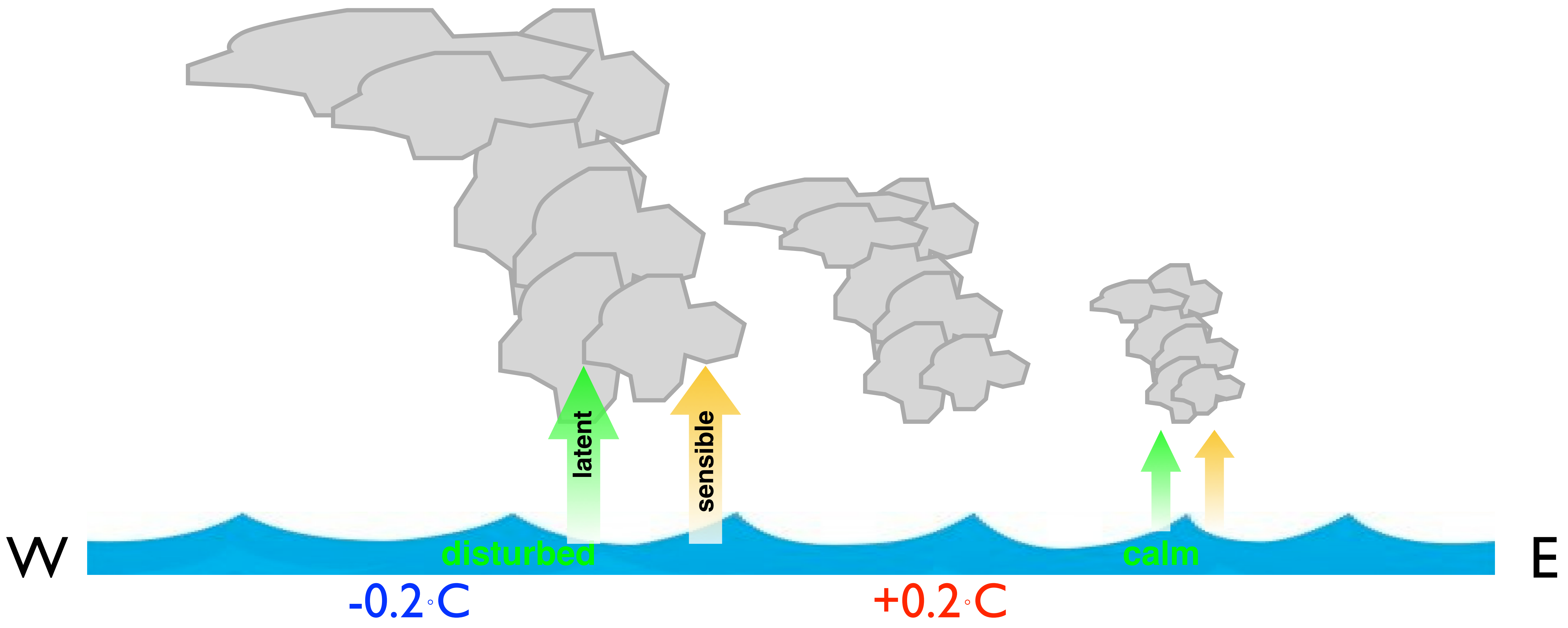
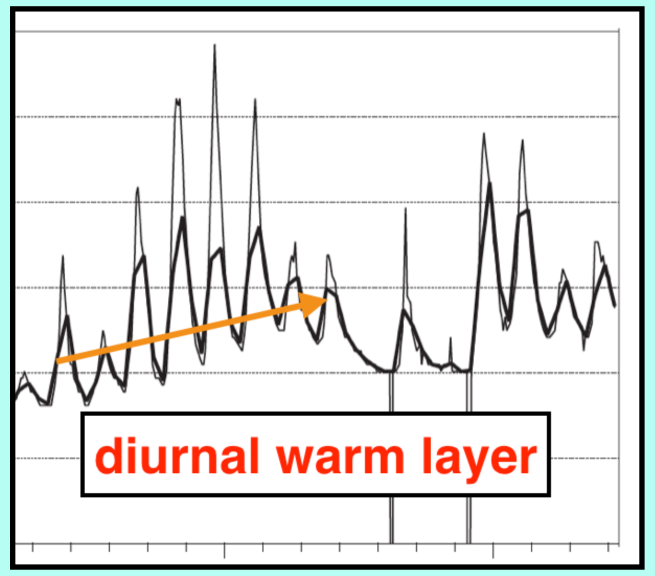


diurnal



Bellenger and Duvel 2009

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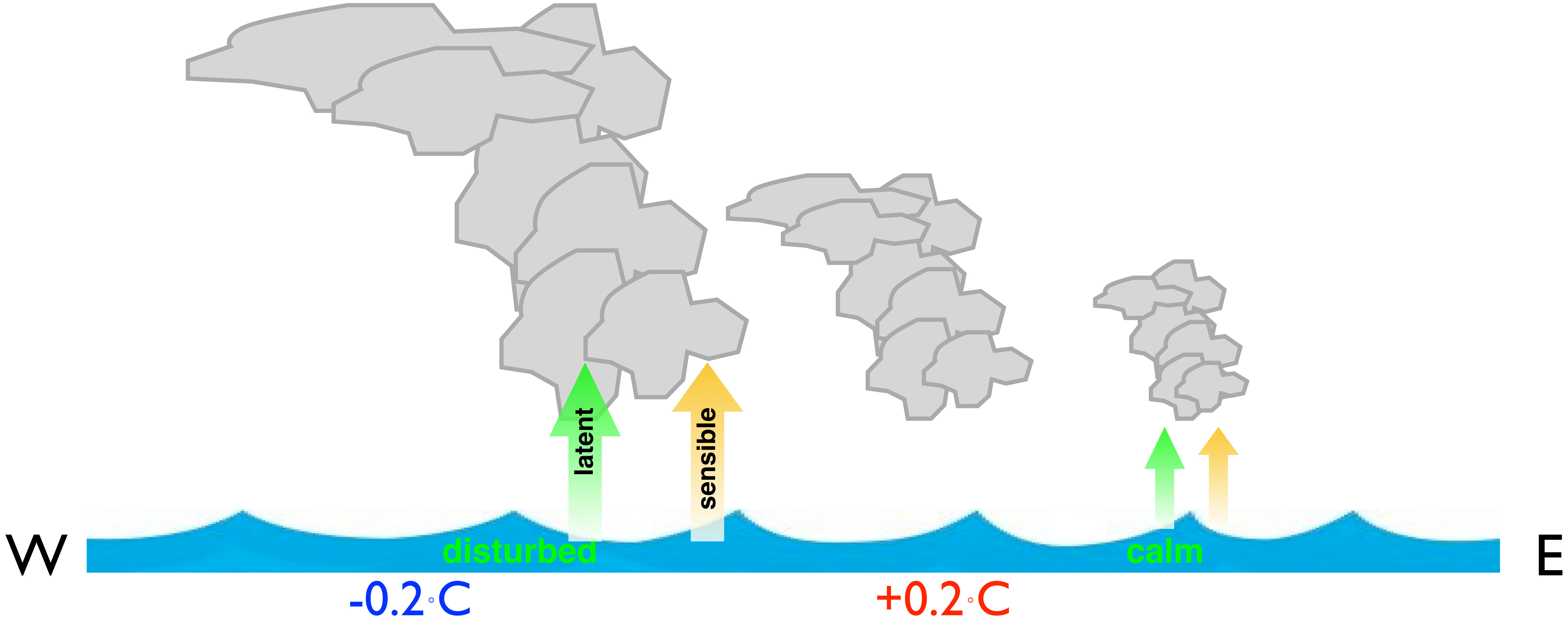

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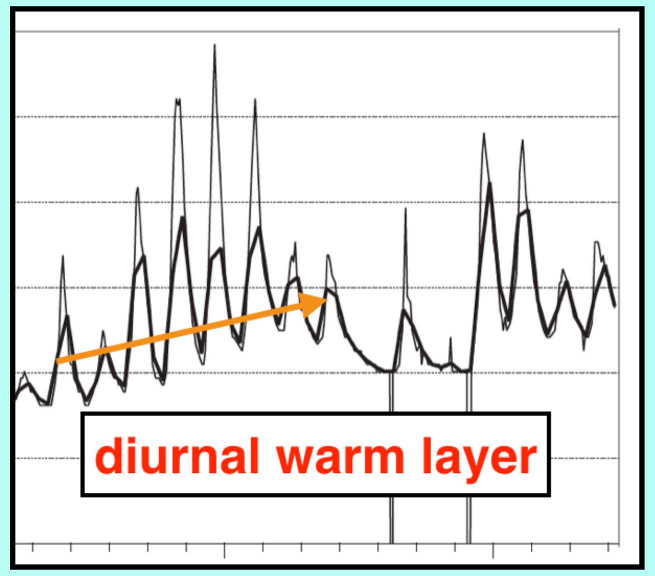
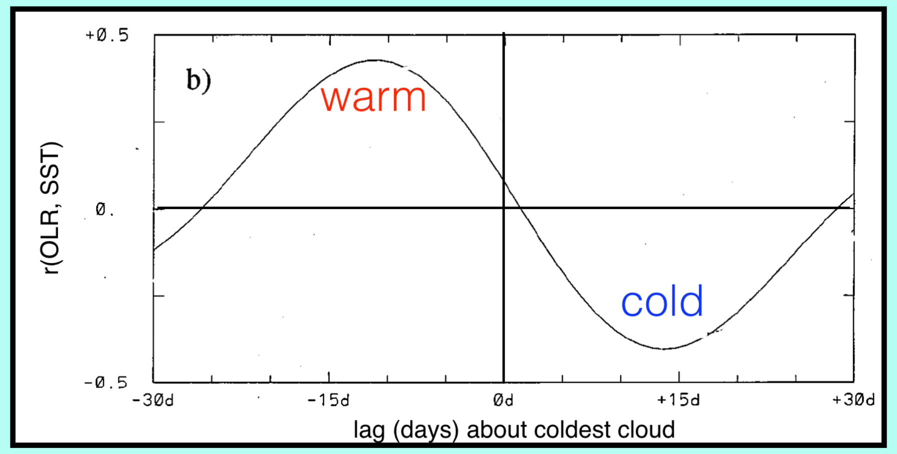


Bellenger and Duvel 2009

intraseasonal



Hendon and Glick 1997

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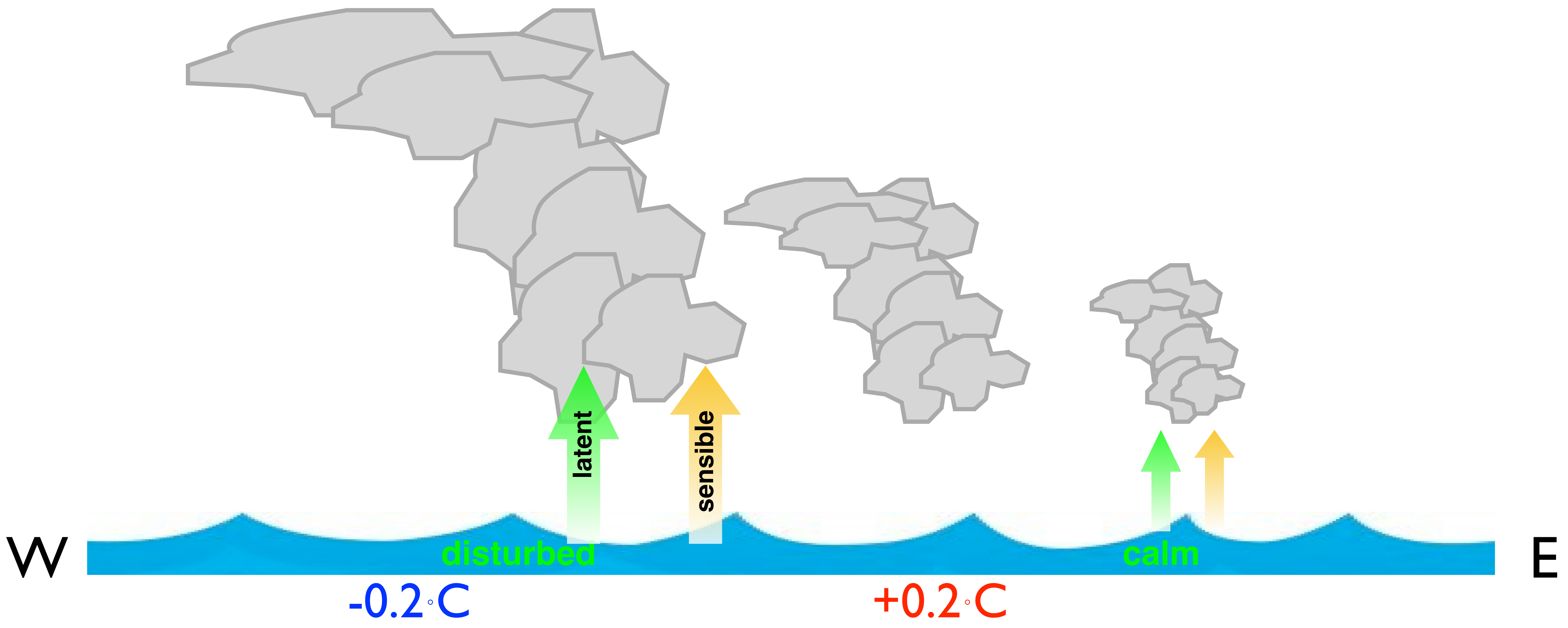

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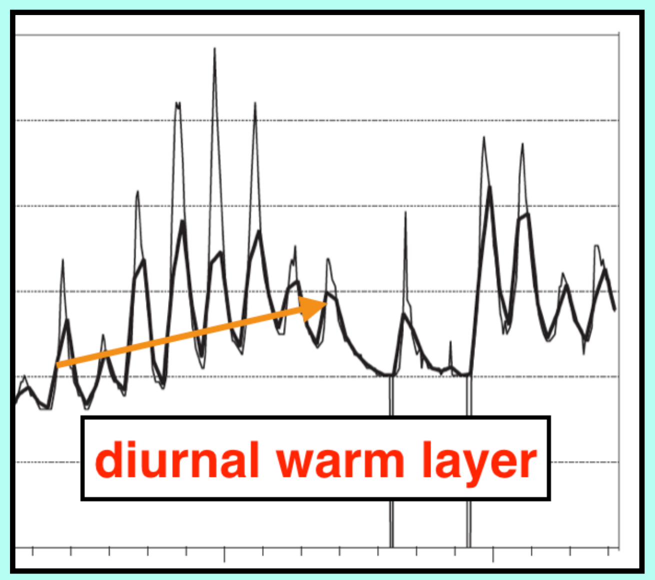

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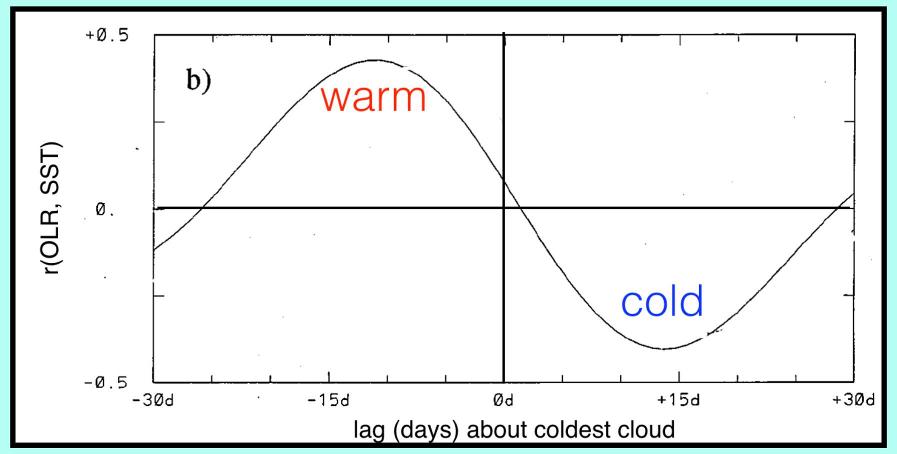

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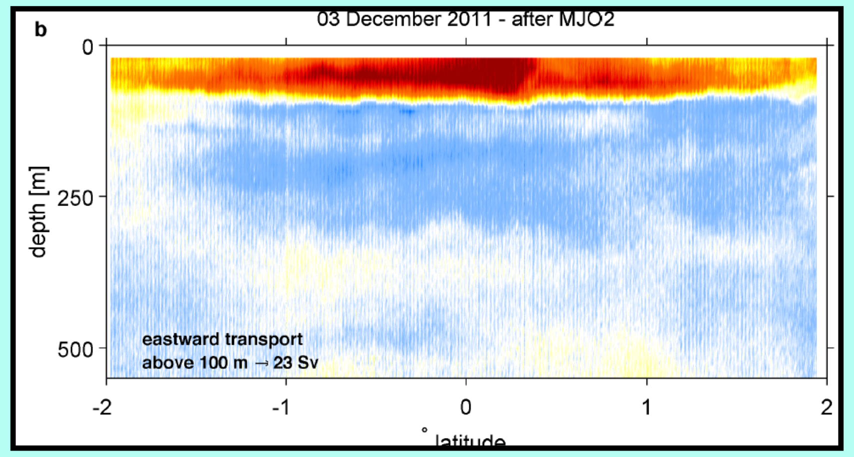

Moum et al. 2014

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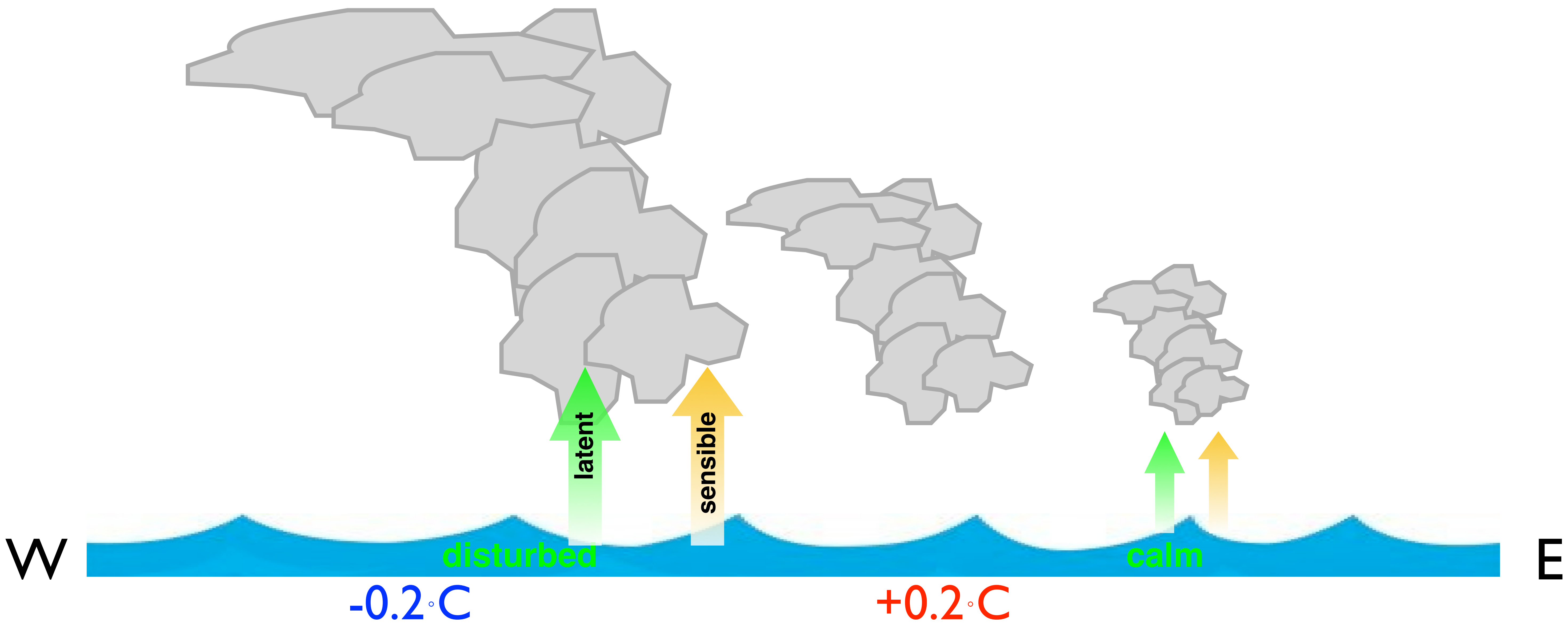

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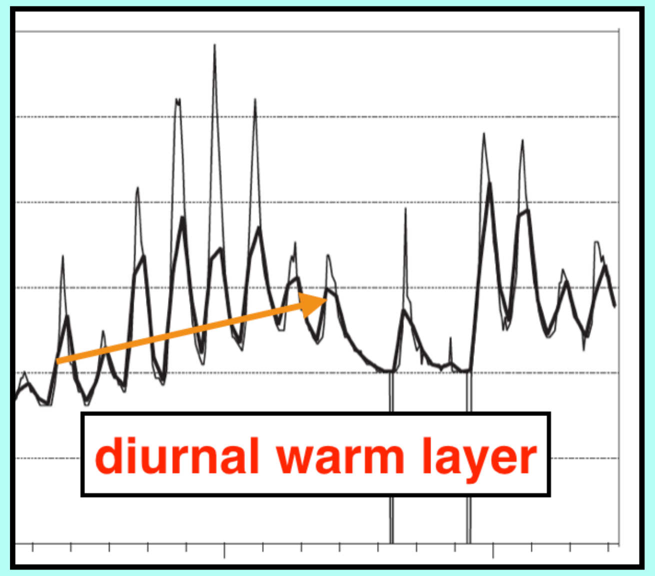

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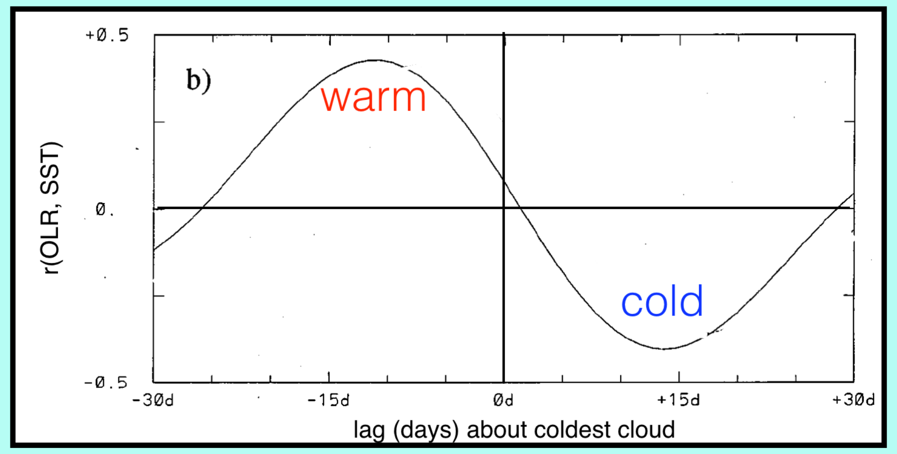

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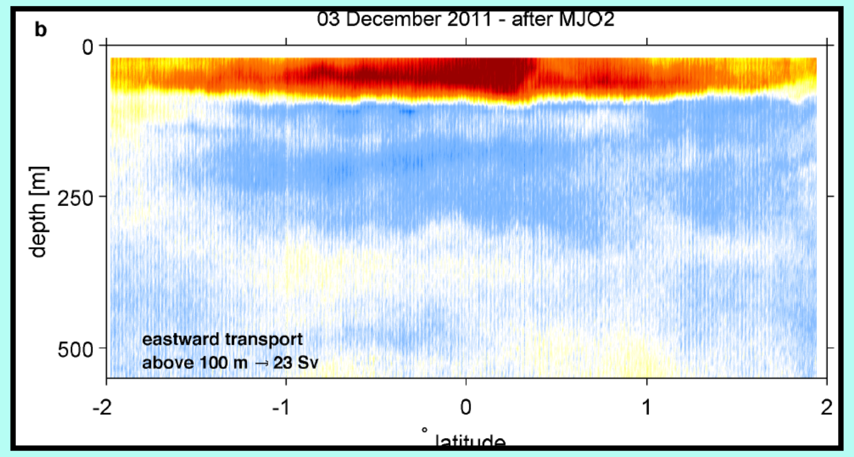
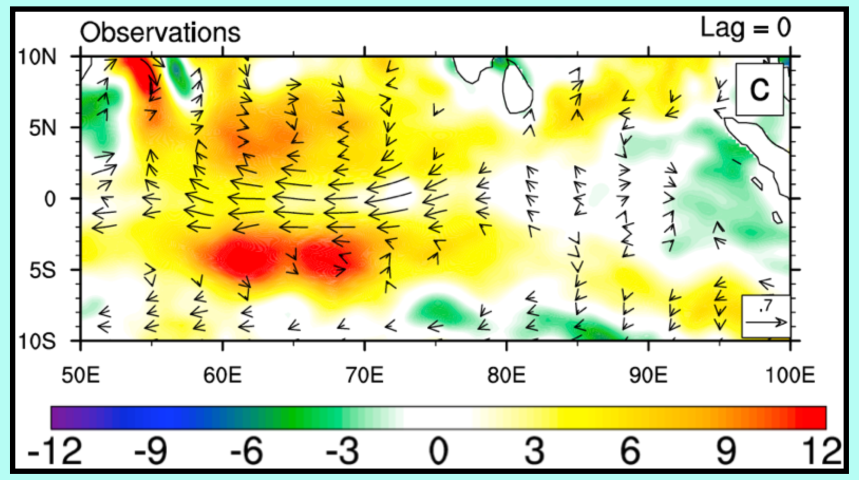


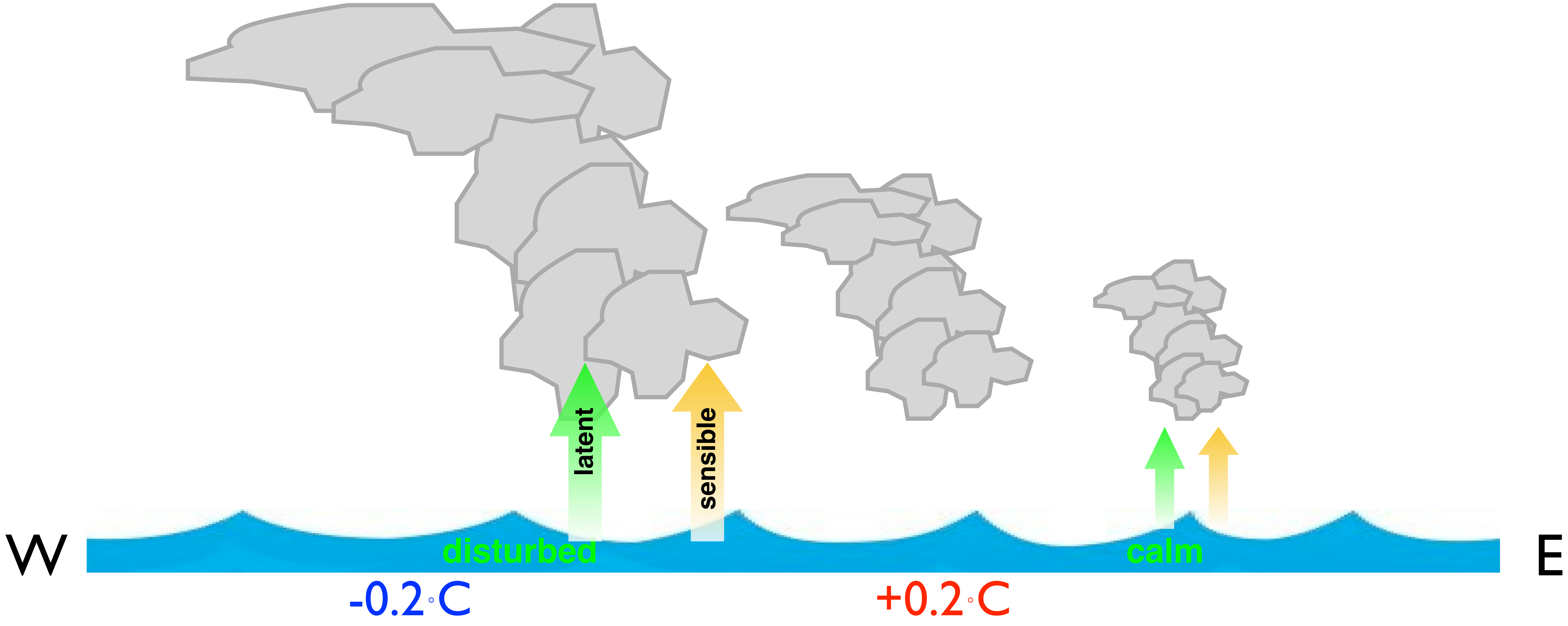
Moum et al. 2014

seasonal



Rydbeck and Jensen 2017

time scales of air-sea coupled processes



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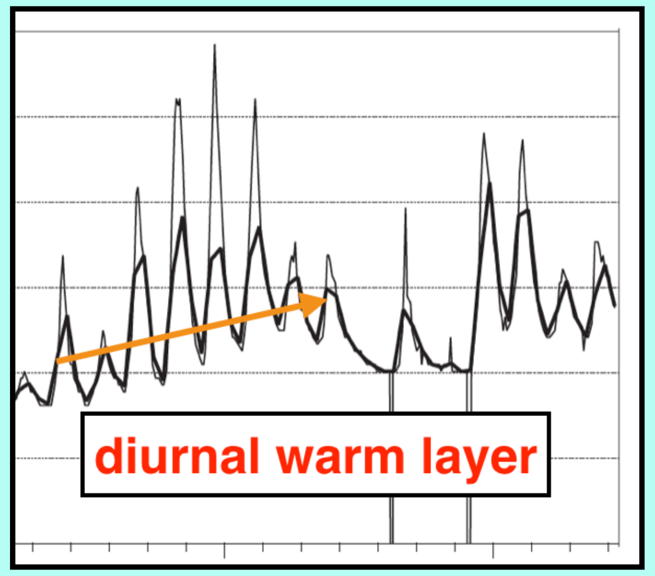

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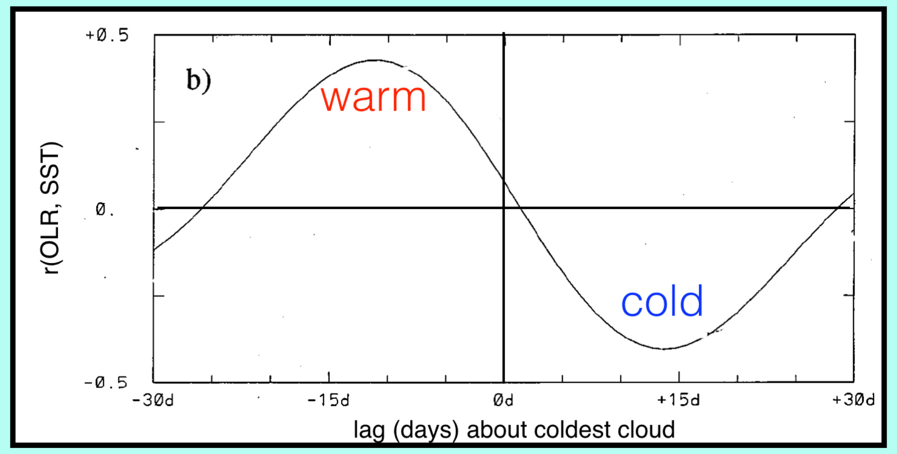

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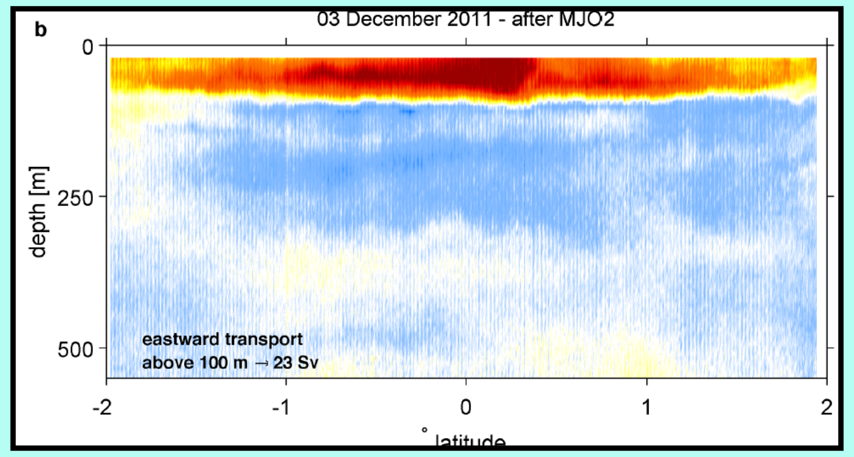

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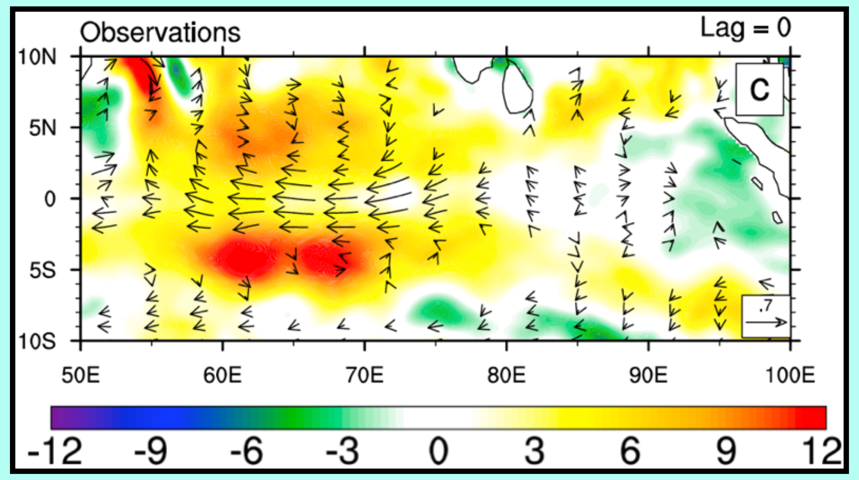
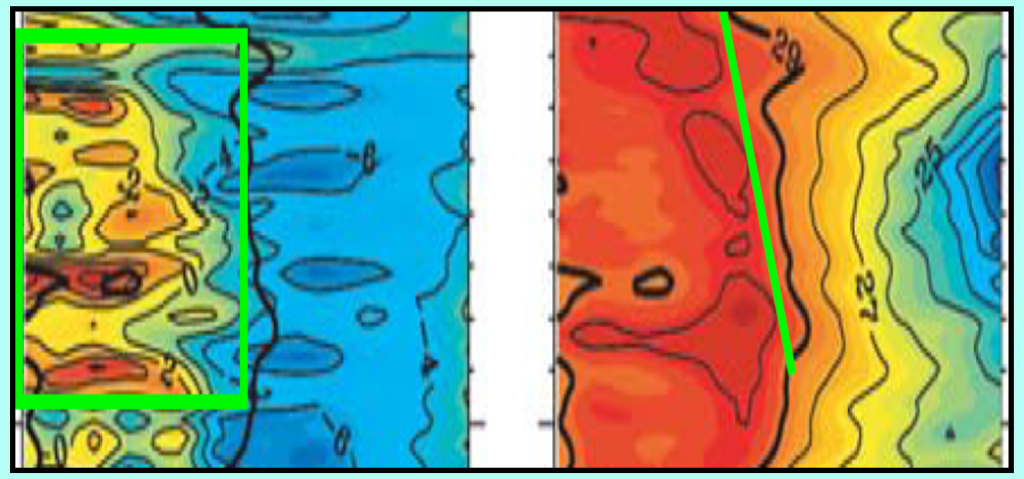


Rydbeck and Jensen 2017

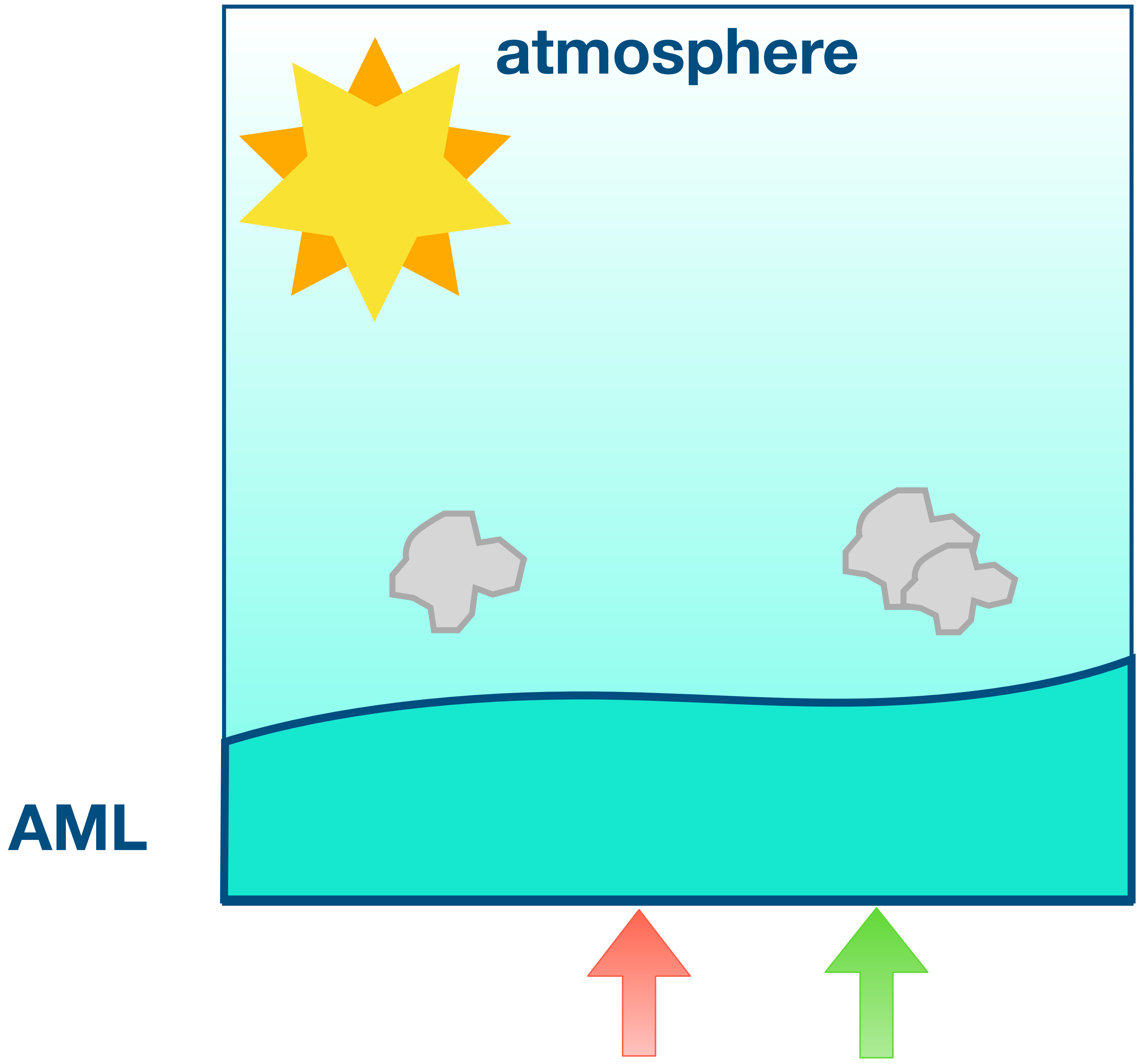
interannual



McPhaden 2004

buoyancy fluxes, stability, convection

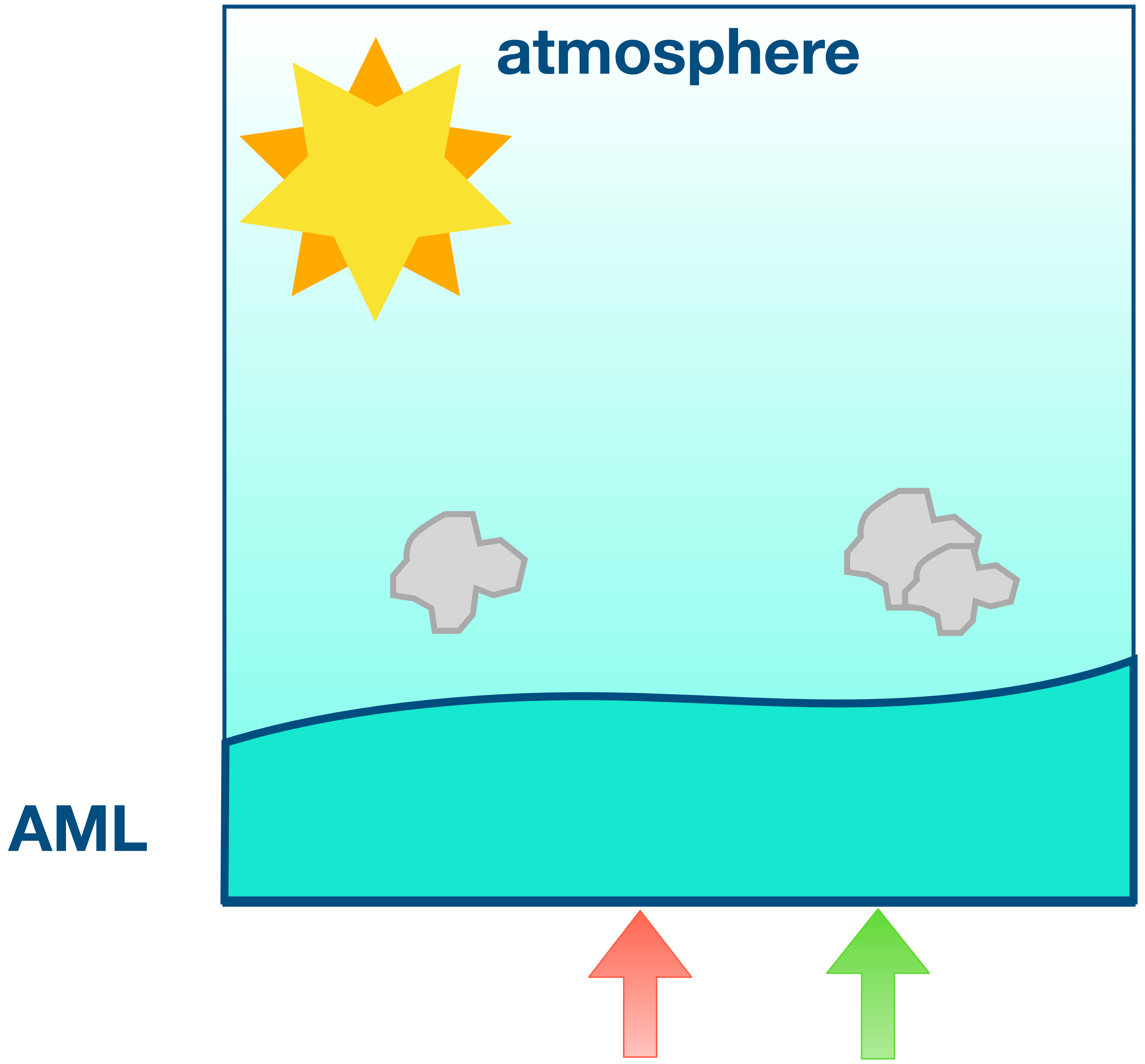
calm/suppressed



buoyancy fluxes, stability, convection

$$F_b \sim SH + 0.1LH$$

calm/suppressed



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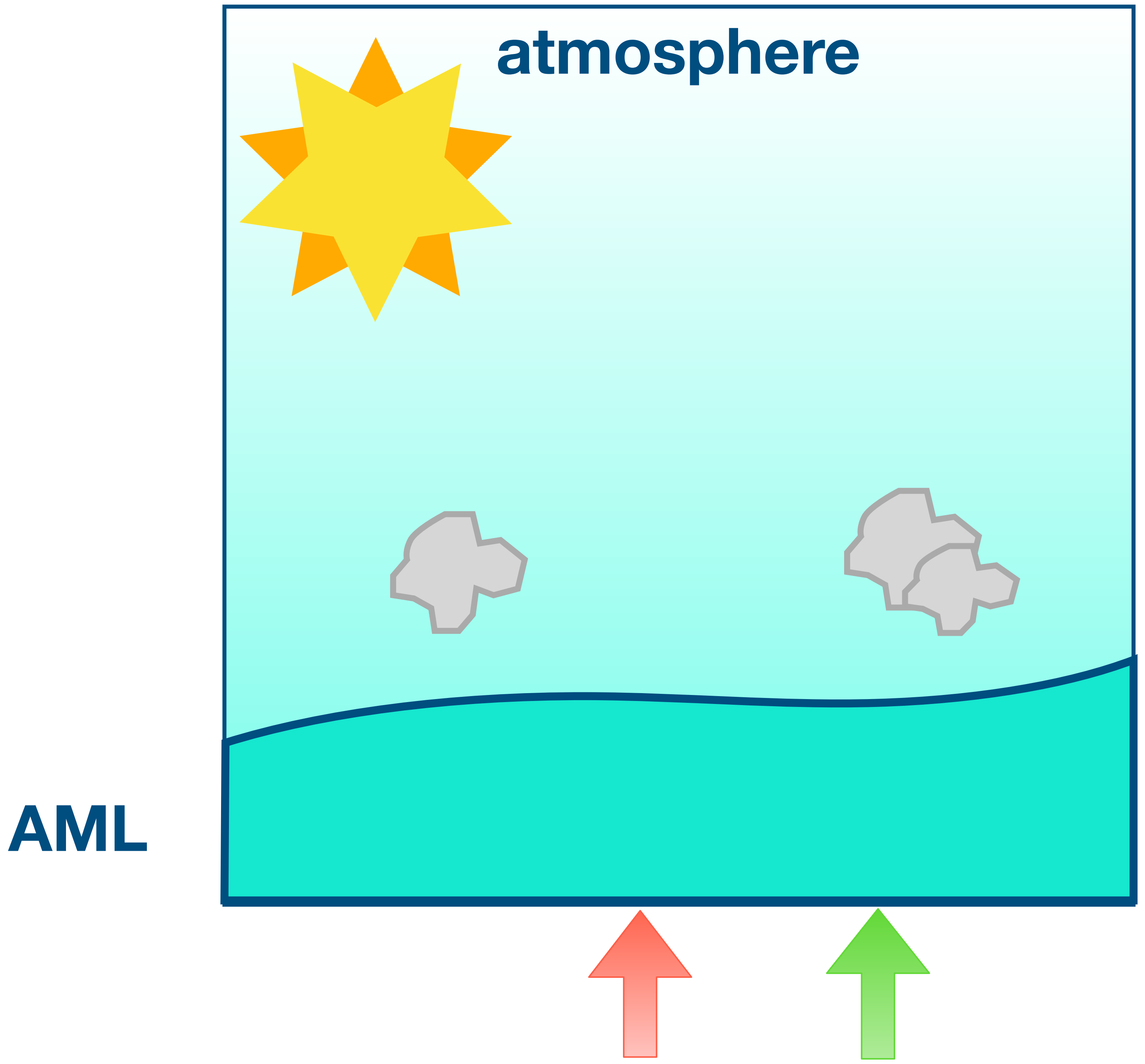

- diurnal convection
- SST gradient-driven convergence

buoyancy fluxes, stability, convection

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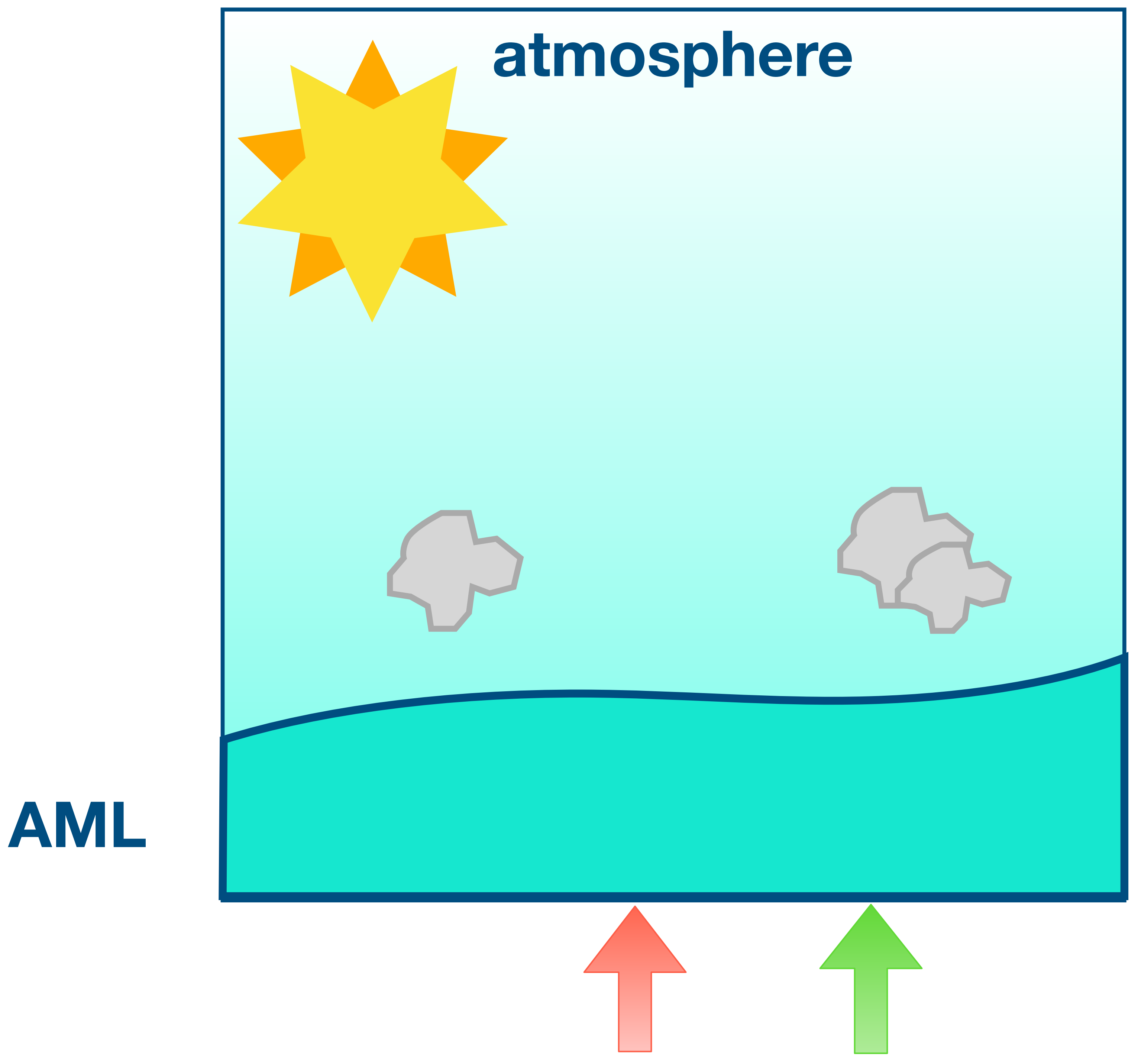
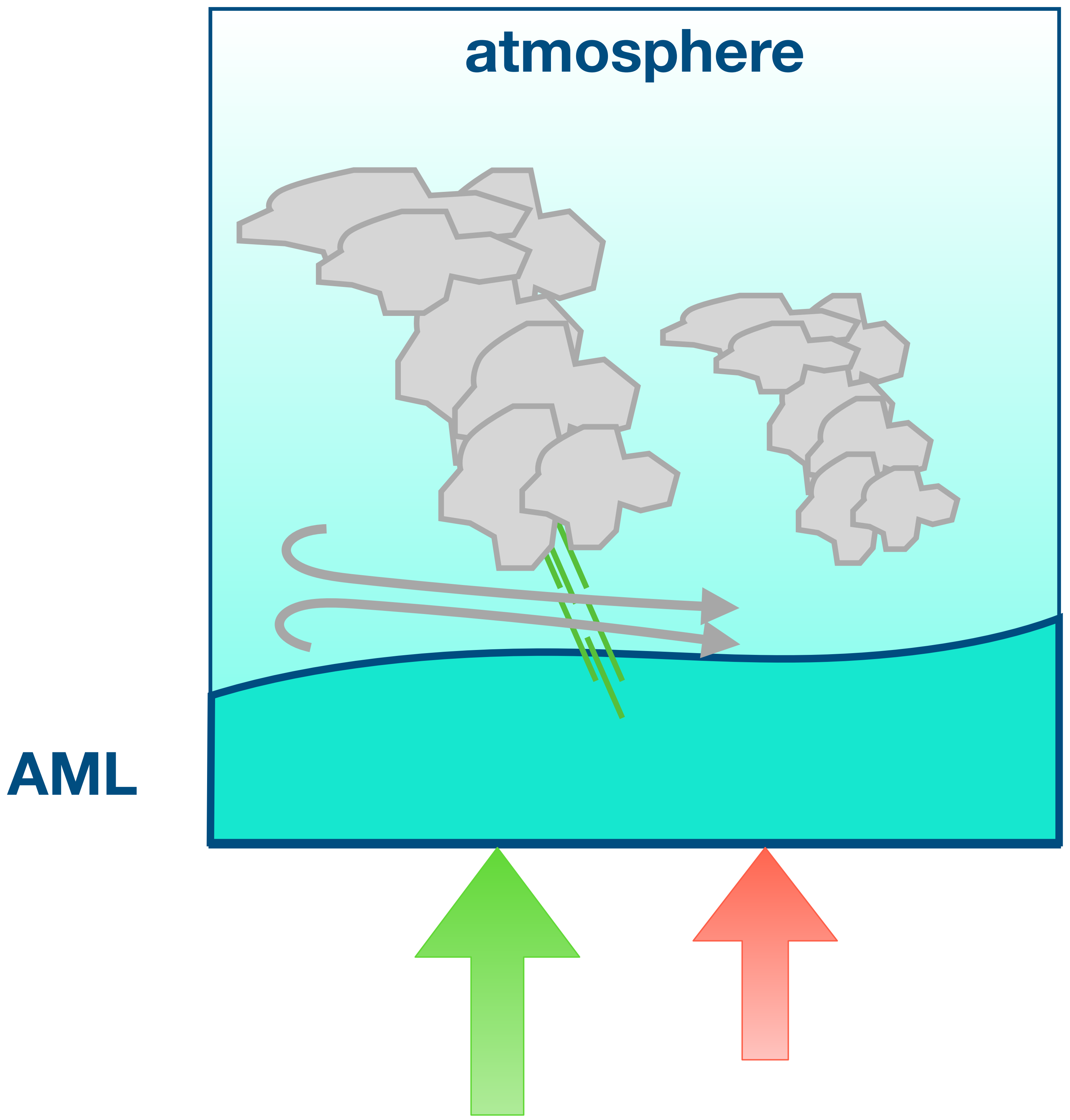


disturbed/active



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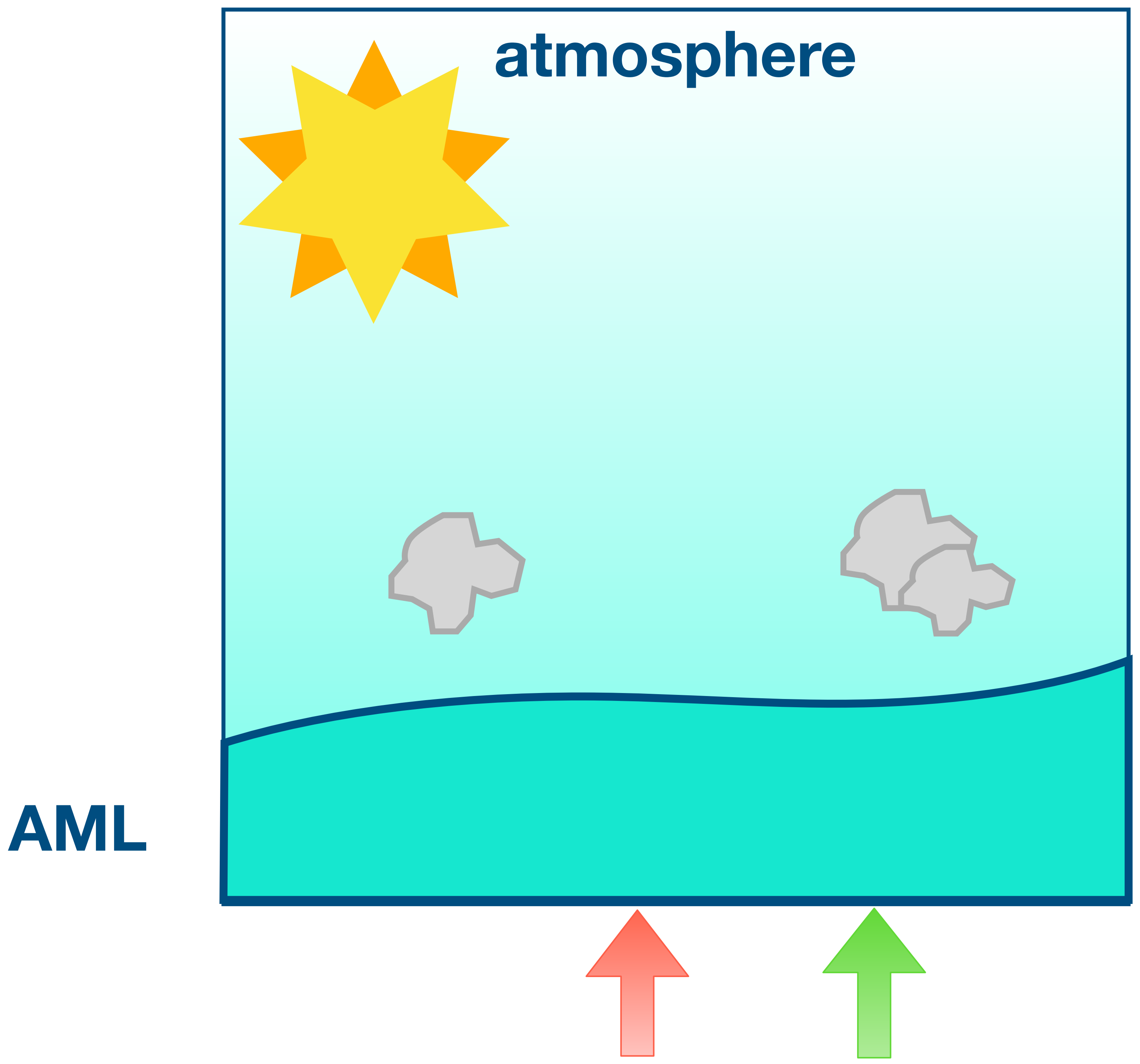

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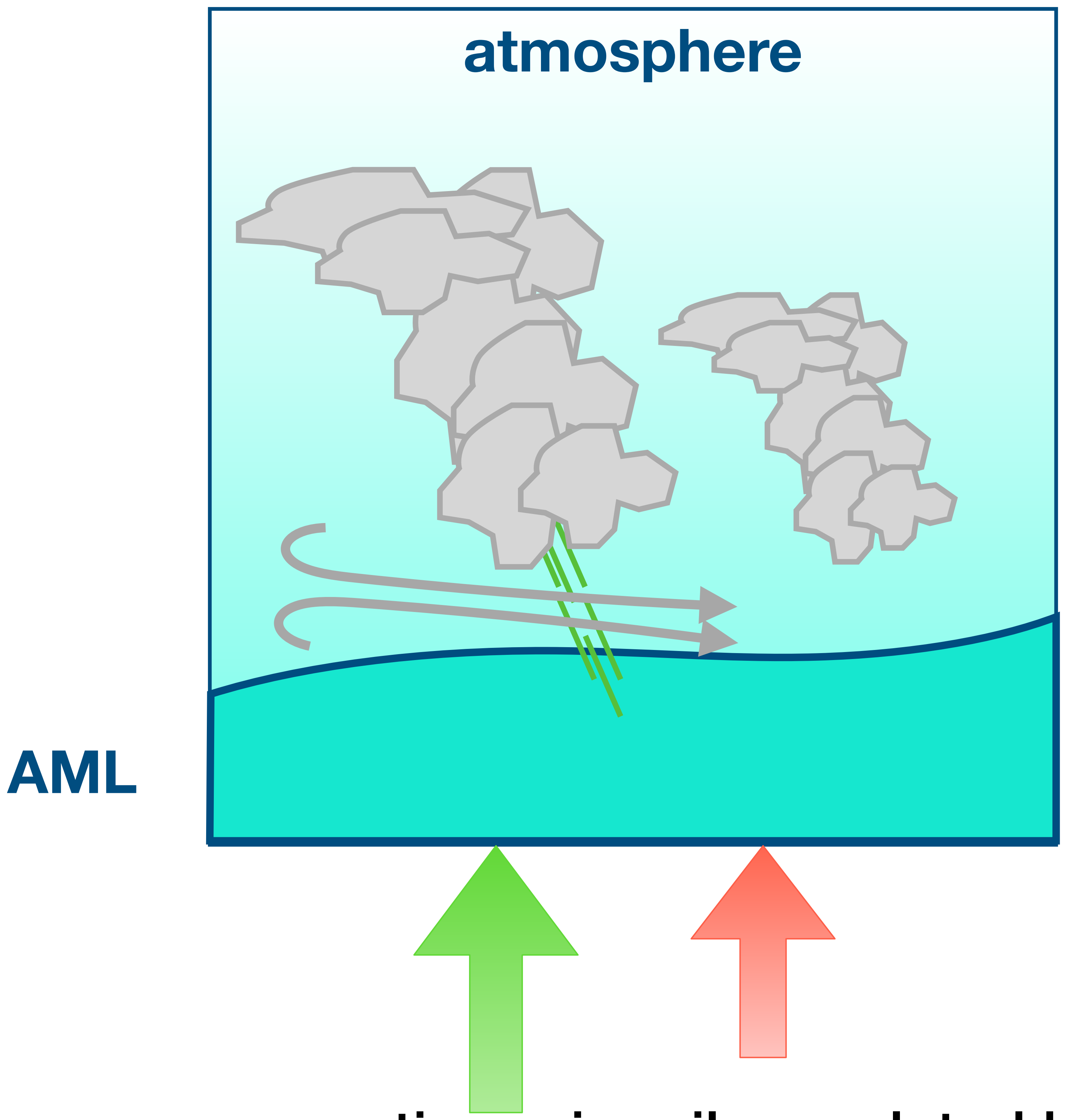
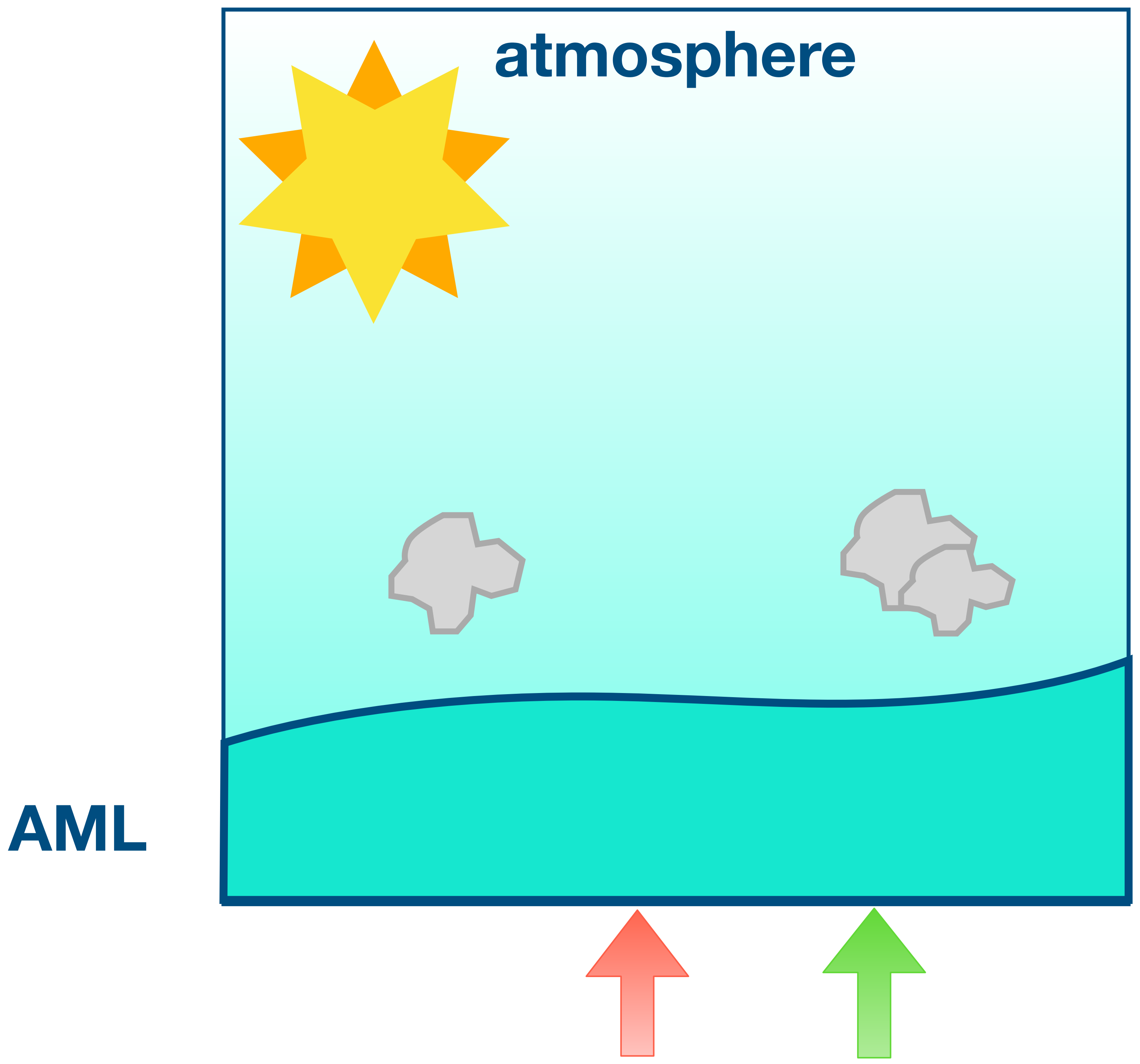


- convection primarily regulated by large-scale atmospheric circulations

buoyancy fluxes, stability, convection

$$F_b \sim \underline{SH} + \underline{0.1LH}$$

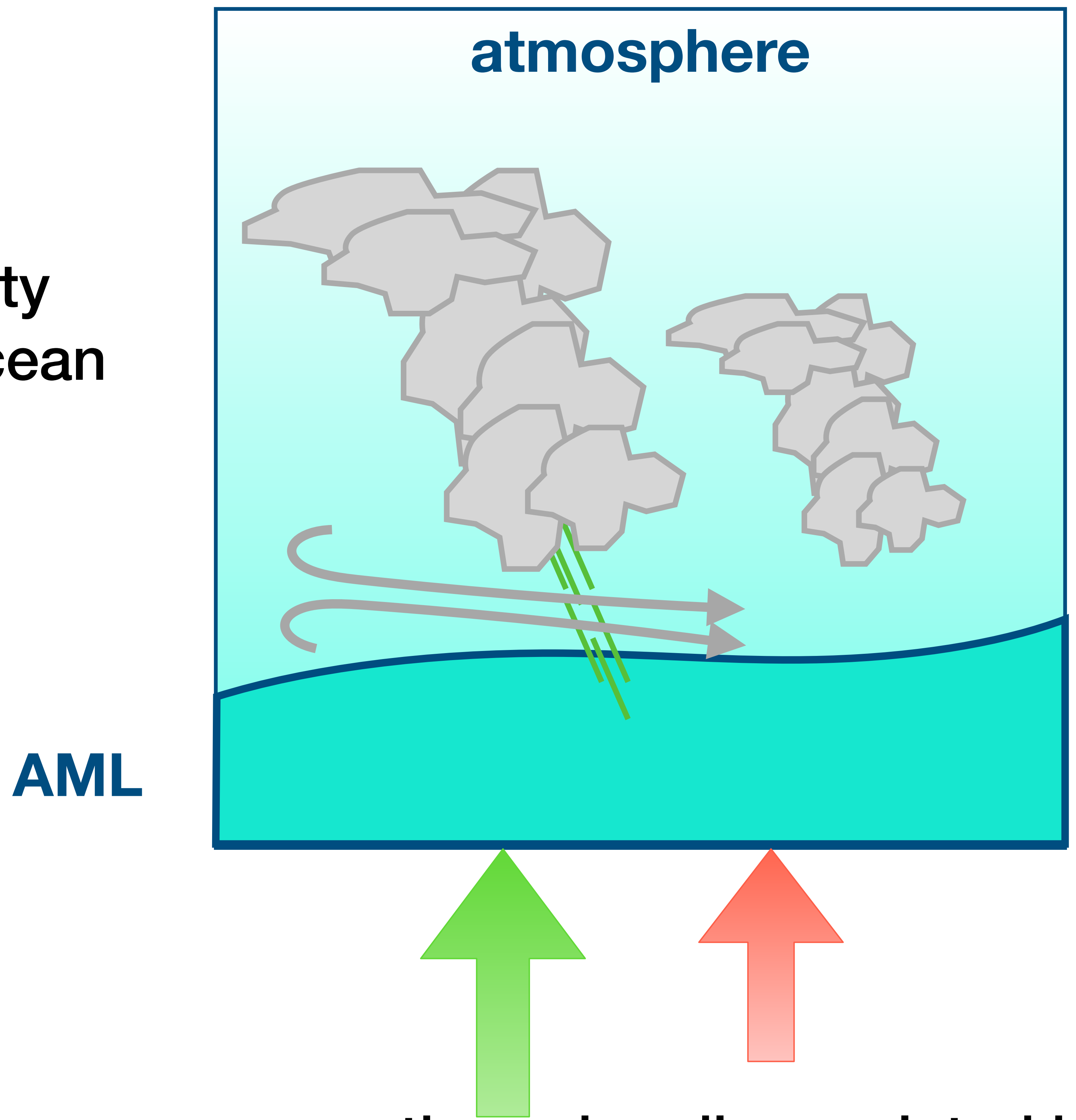
calm/suppressed



• diurnal convection
• SST gradient-driven convergence

the interaction of convection with atmospheric humidity strongly modulates ocean feedbacks

disturbed/active



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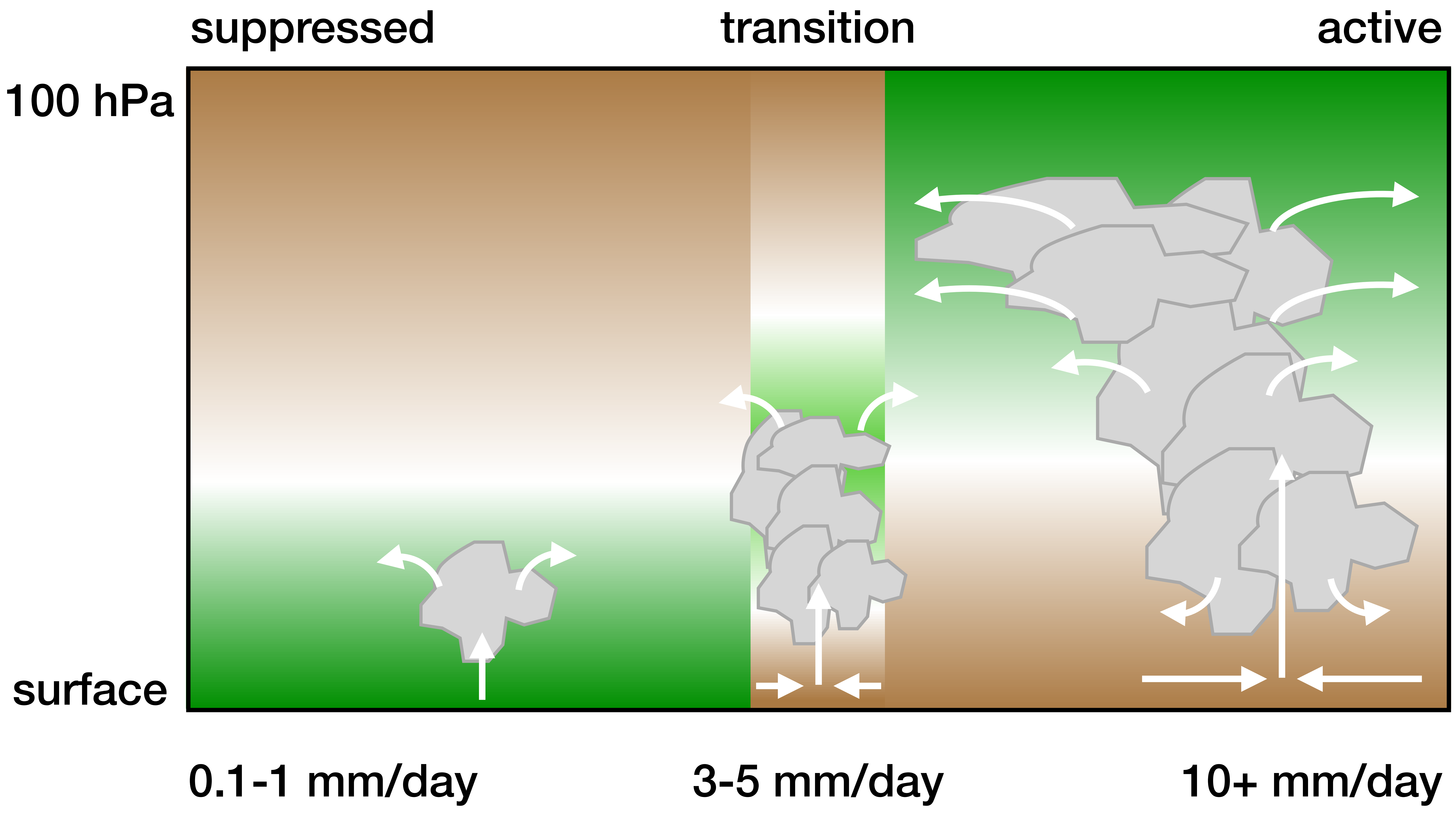
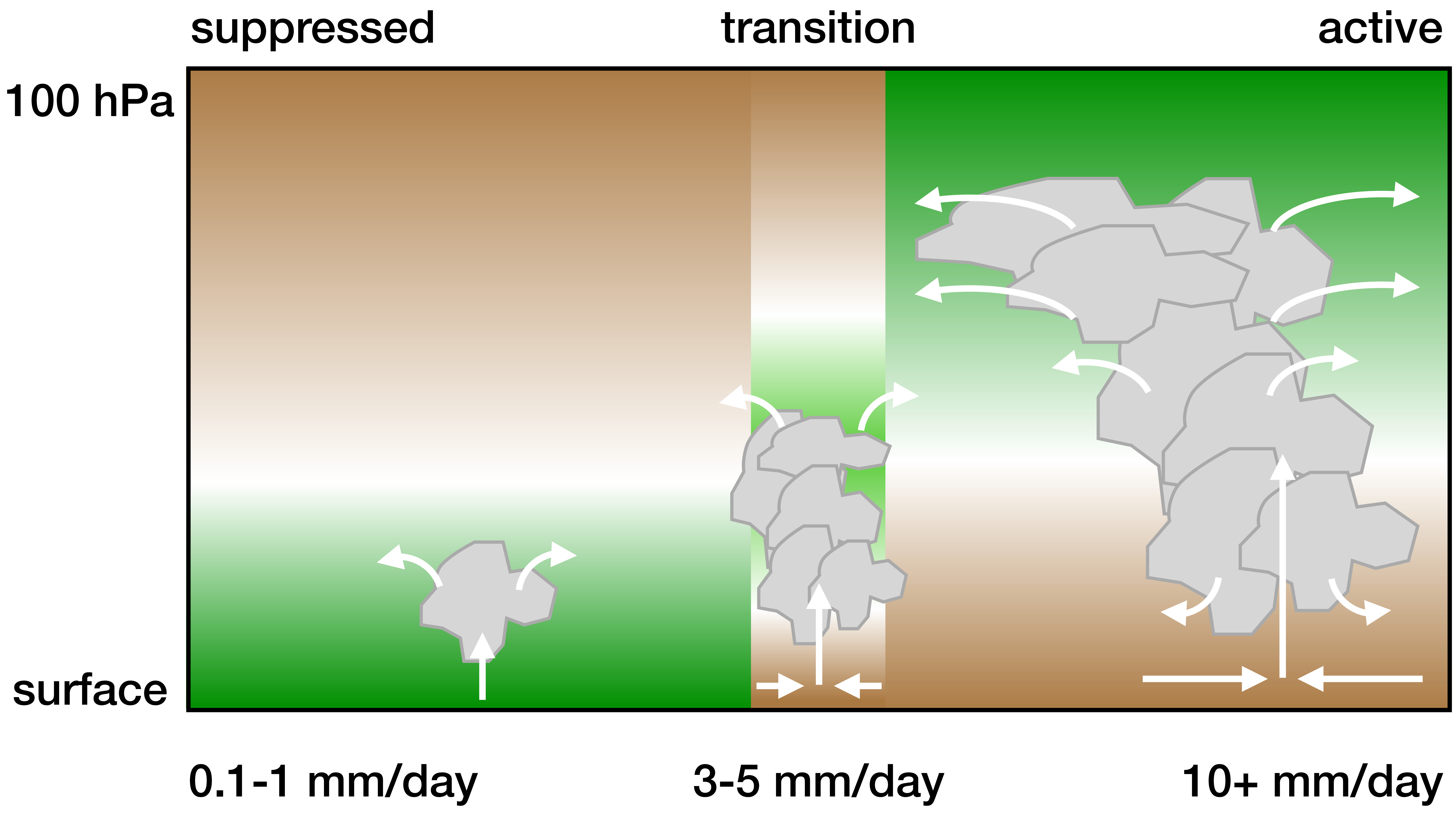
convective moistening by rainfall rate



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.

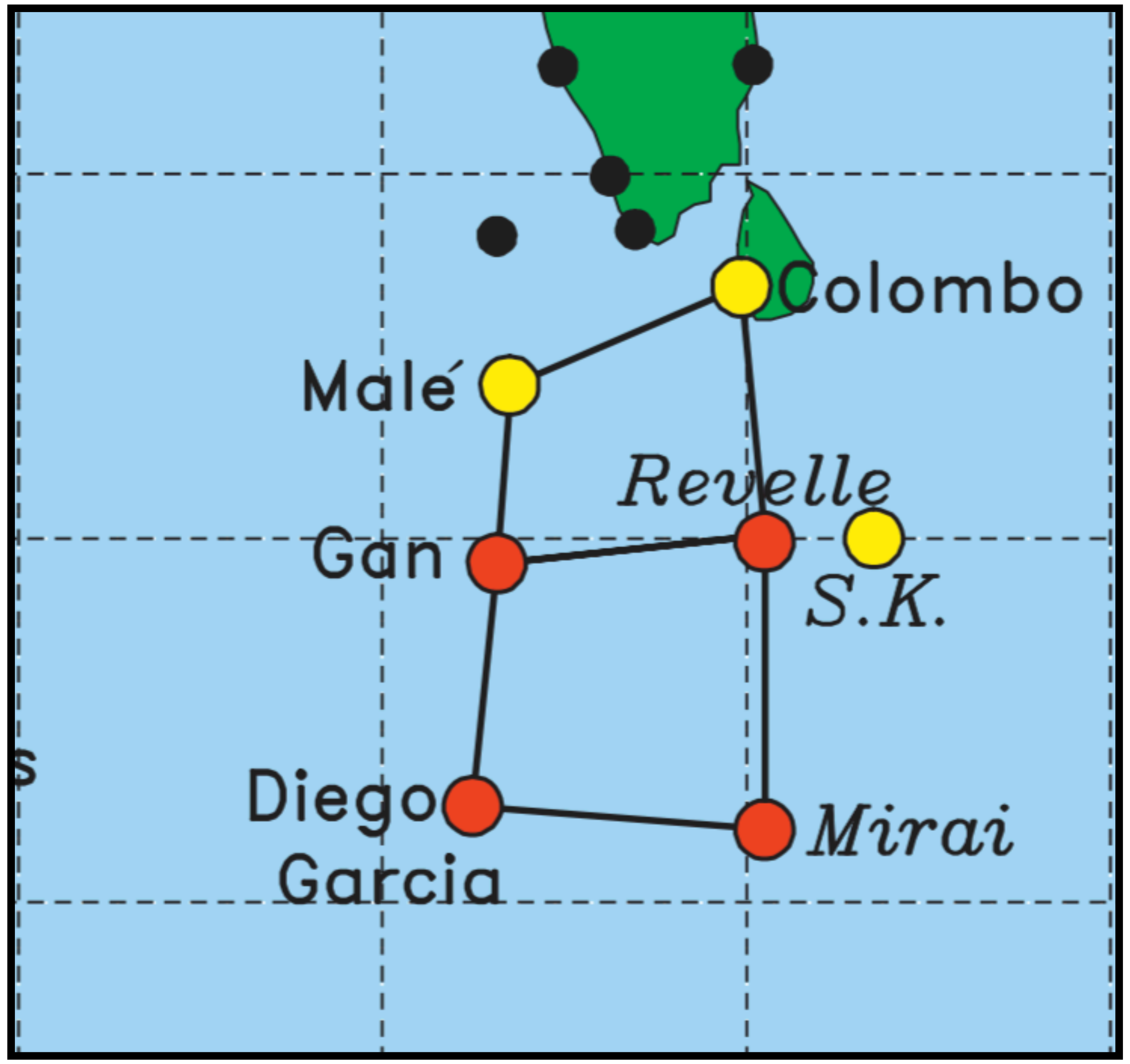
model requirements for coupled processes

- 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

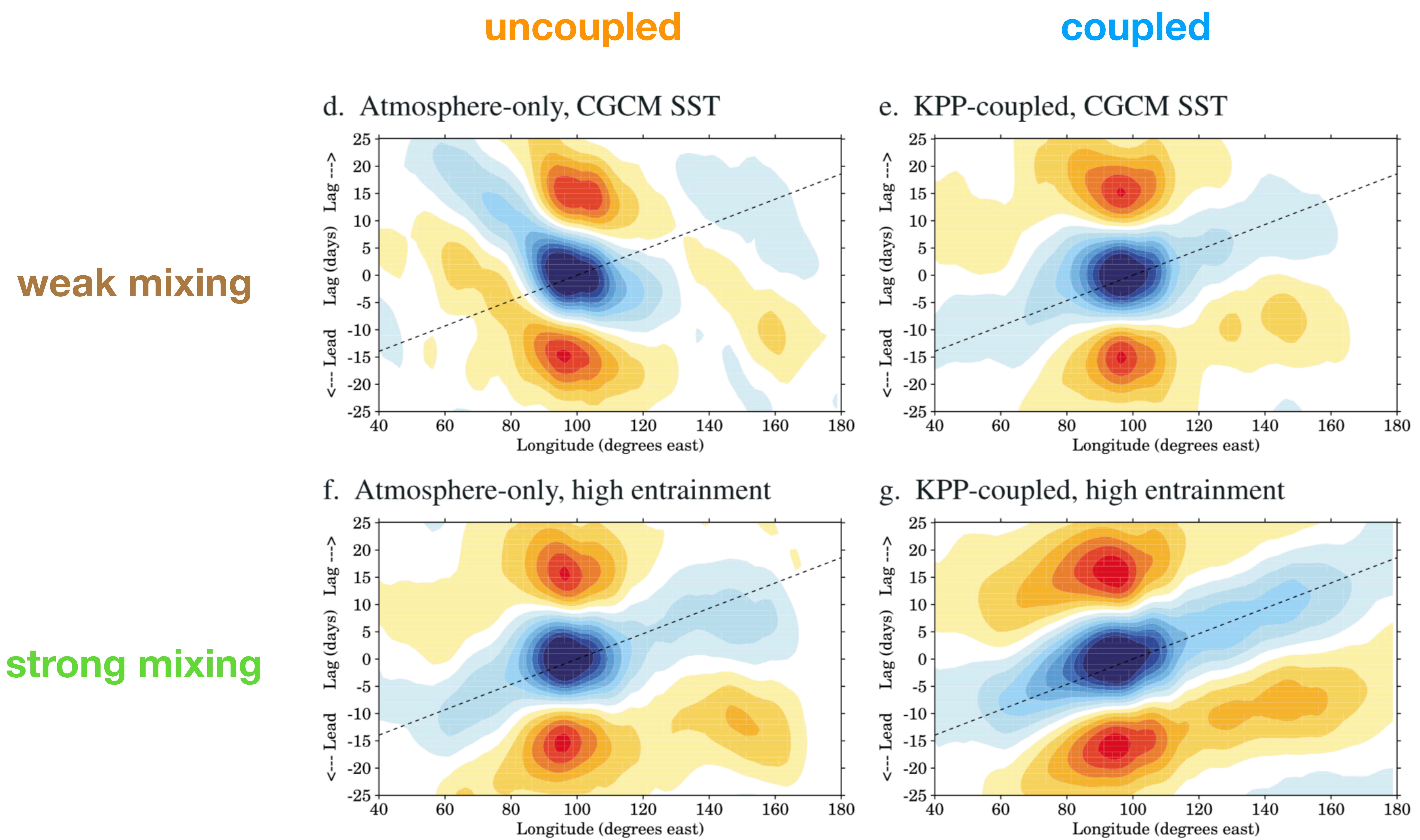
direct observations for constraining models

ocean

atmosphere

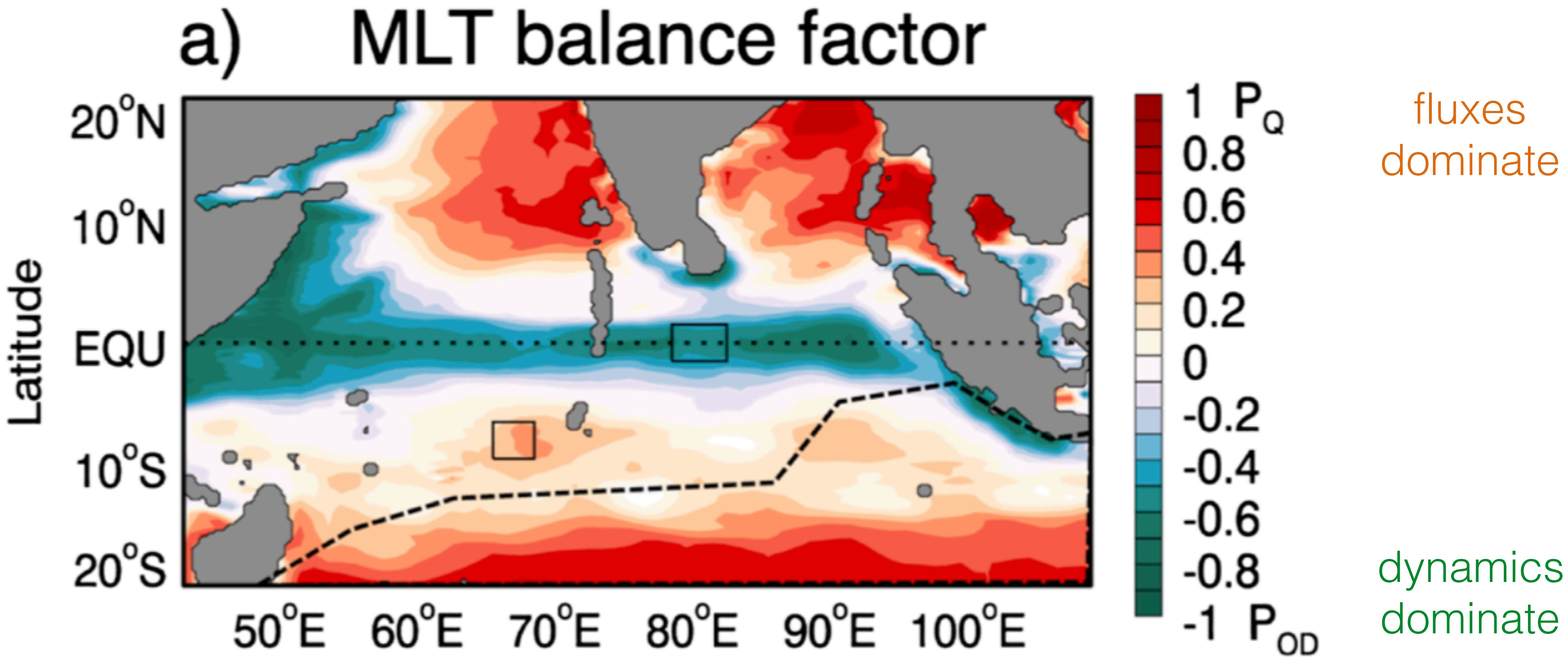


extra slides



uncoupled
coupled
weak mixing
strong mixing
d. Atmosphere-only, CGCM SST
e. KPP-coupled, CGCM SST
f. Atmosphere-only, high entrainment
g. KPP-coupled, high entrainment
<--- Lead Lag (days) Lag --->
Longitude (degrees east)
25
20
15
10
5
0
-5
-10
-15
-20
-25
40
60
80
100
120
140
160
180

SST cooling: fluxes vs dynamics



Halkides et al. (2015)

summary of MJO coupled processes

	Diurnal	Intraseasonal (fluxes)	Intraseasonal (momentum)	Seasonal	Interannual
key atmospheric conditions	calm winds low cloudiness	alternating periods of suppressed and active convection	multiple days of persistent easterly or westerly winds	multiple days of easterly (ER) or westerly (KW) winds	MJO in WPac, WWB
key ocean dependencies	reduced currents OML **shoaling**	regulated by surface currents, **stratification**	upper ocean **stratification**	reduced upper ocean **stratification?**	deep mixing or surface advection?
observational gaps	high-frequency **stratification** measurements	high-frequency AML **humidity,** ocean **stratification**	high vertical resolution **stratification** measurements		ocean **stratification**
model shortcomings	convection-**humidity** biases, ocean **resolution,** coupling frequency	convection-**humidity** biases (BL, free trop), ocean **resolution,** coupling frequency	MJO fidelity, ocean vertical **resolution**	coarse ocean horizontal **resolution,** insufficient study	MJO fidelity, WPac coupled processes?