Diabatic effects in the evolution of cyclones and storm tracks along the western boundary currents

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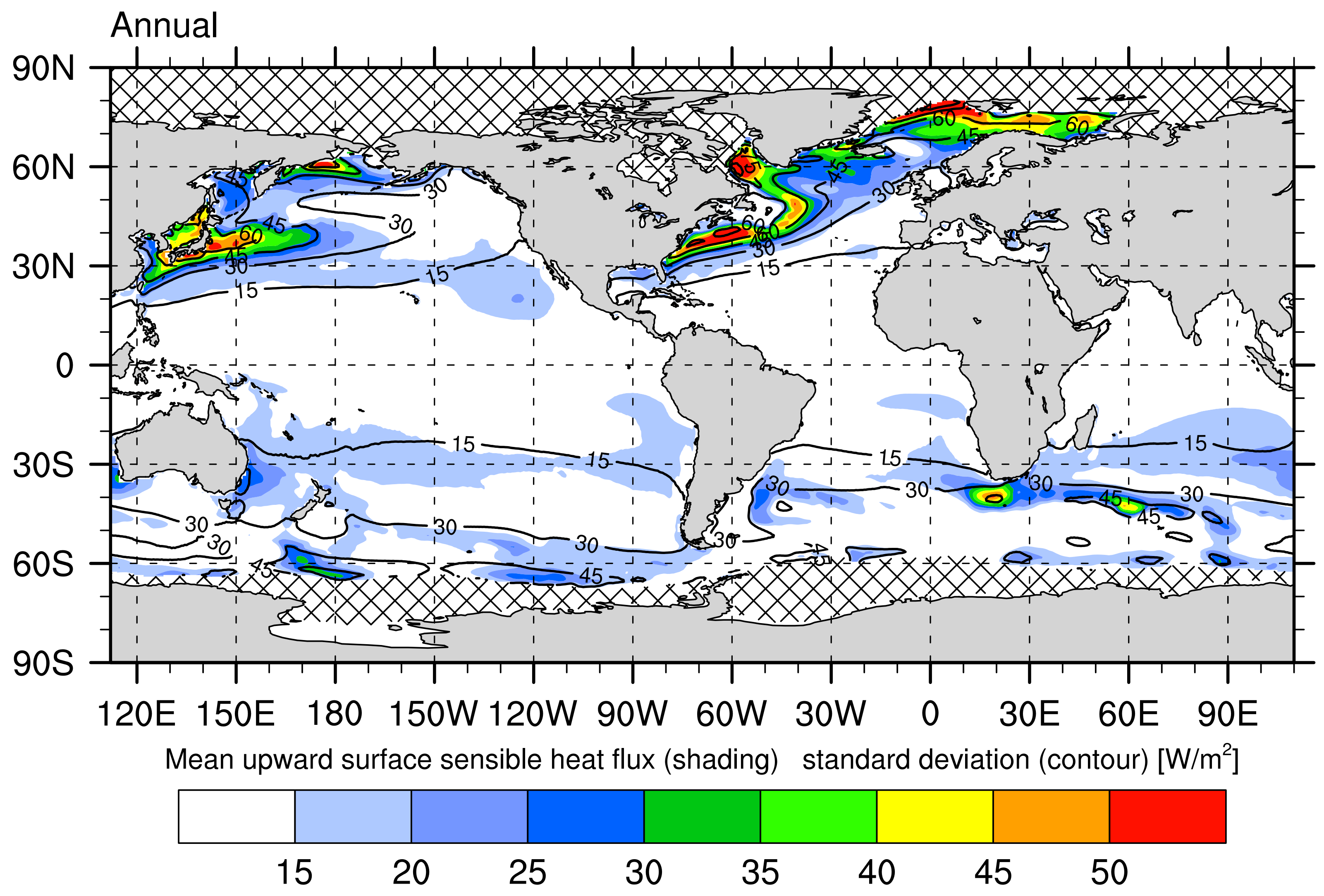
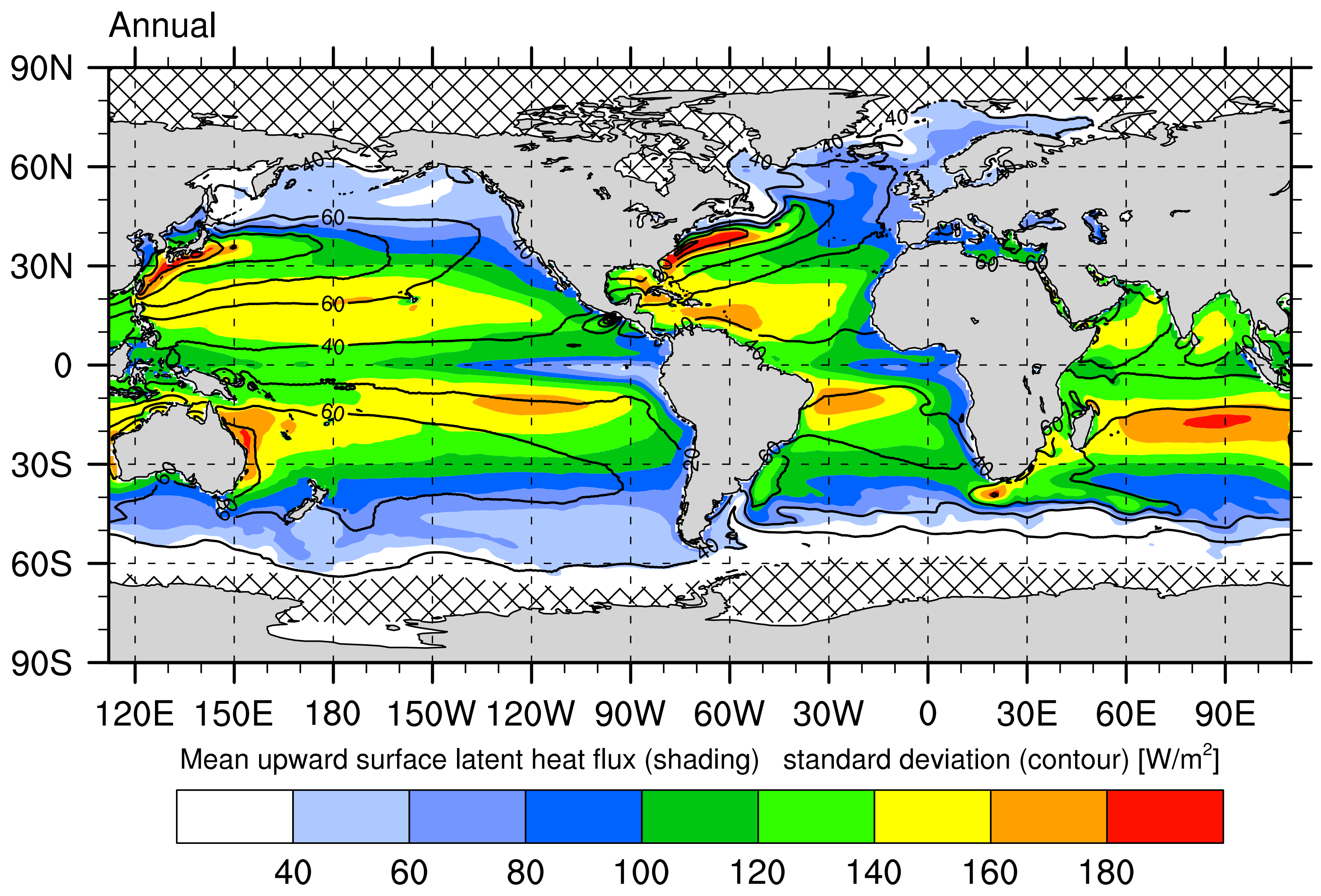
thomas.spengler@uib.no

Atmosphere-Ocean interactions along major SST fronts

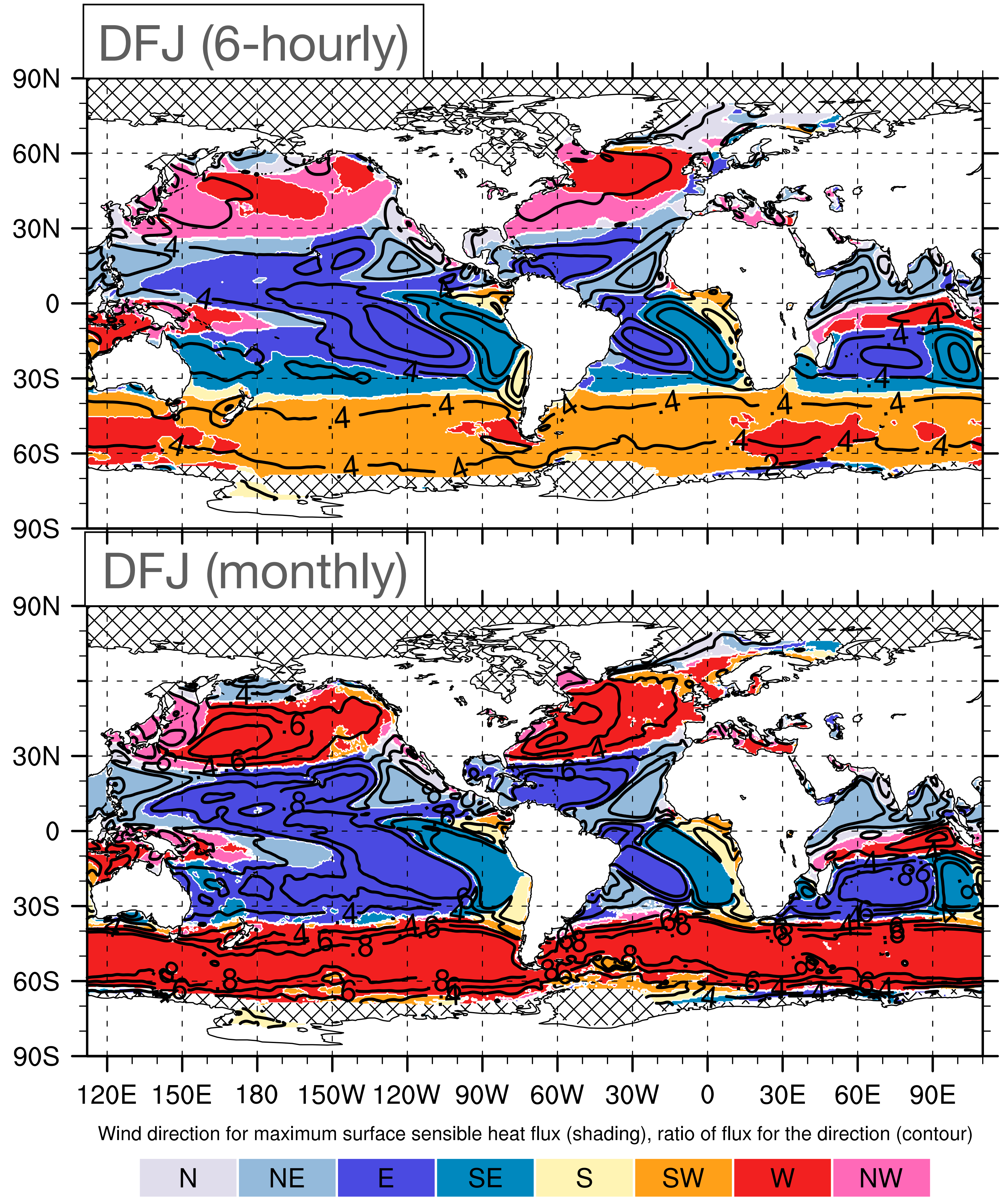
Mean/variability sensible heat flux



Mean/variability latent heat flux



Prevailing wind direction



- Mean heat fluxes and their variability concentrate along SST fronts
- Heat exchange mainly associated with sub-weekly timescales

Ogawa and Spengler (2019)

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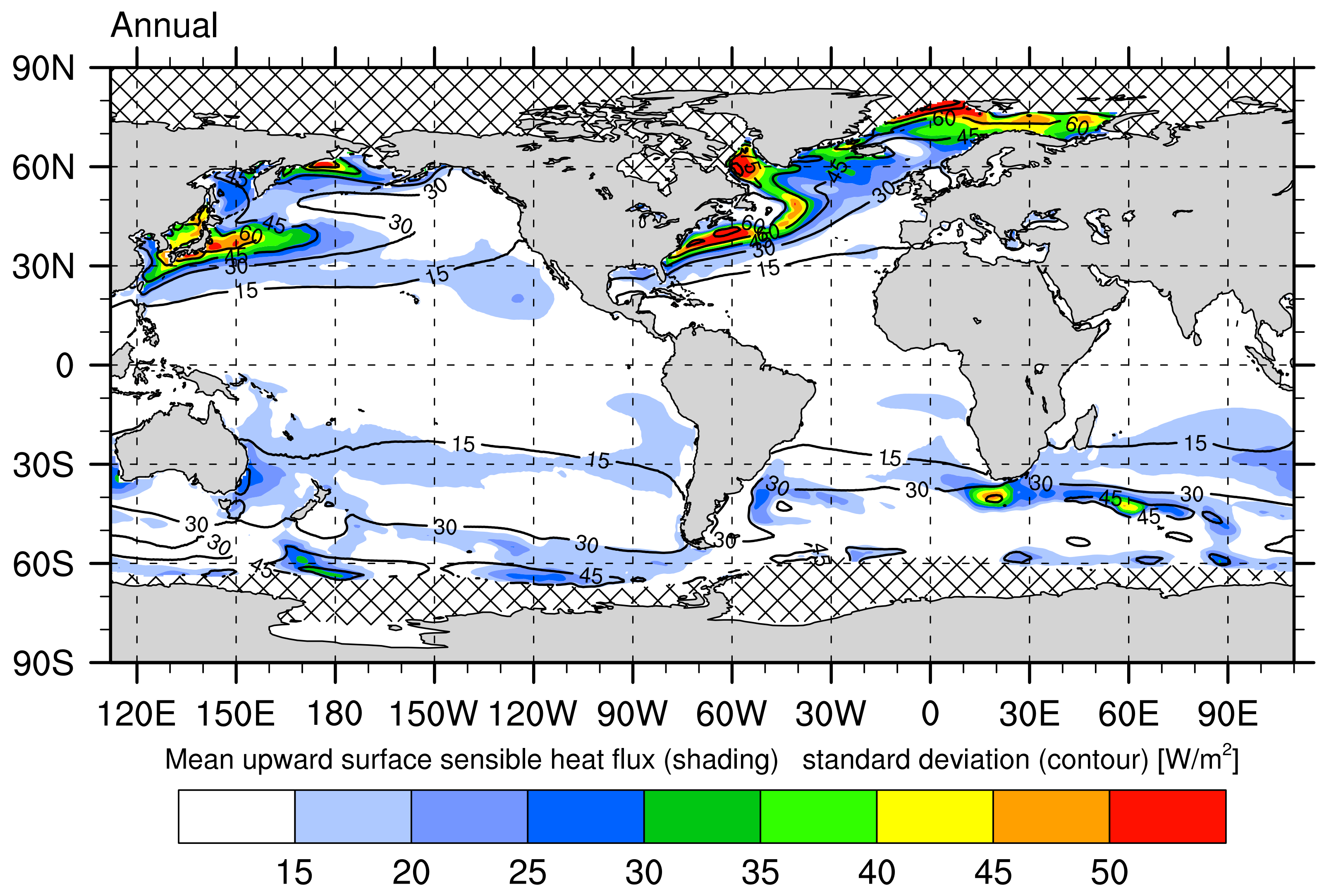

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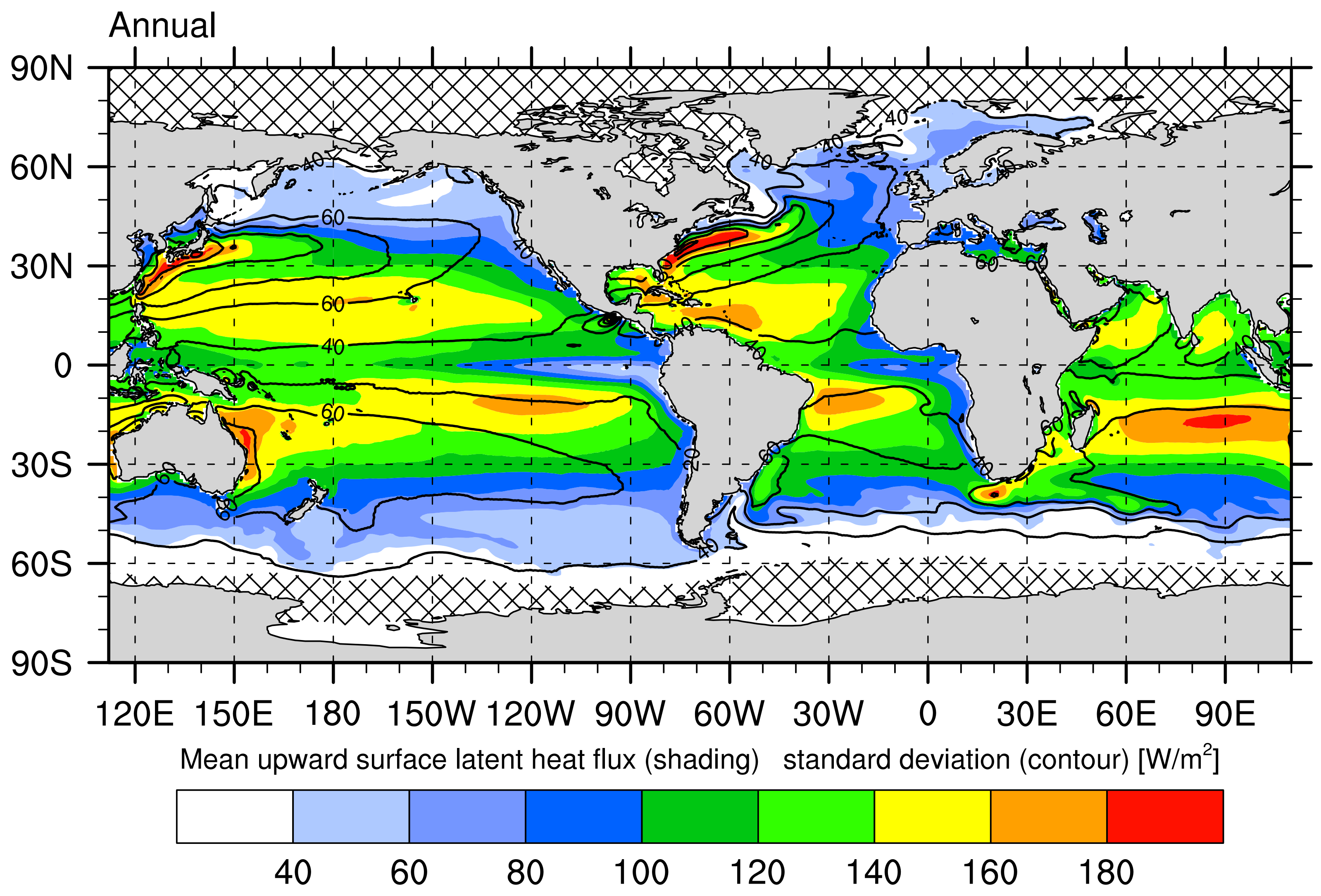

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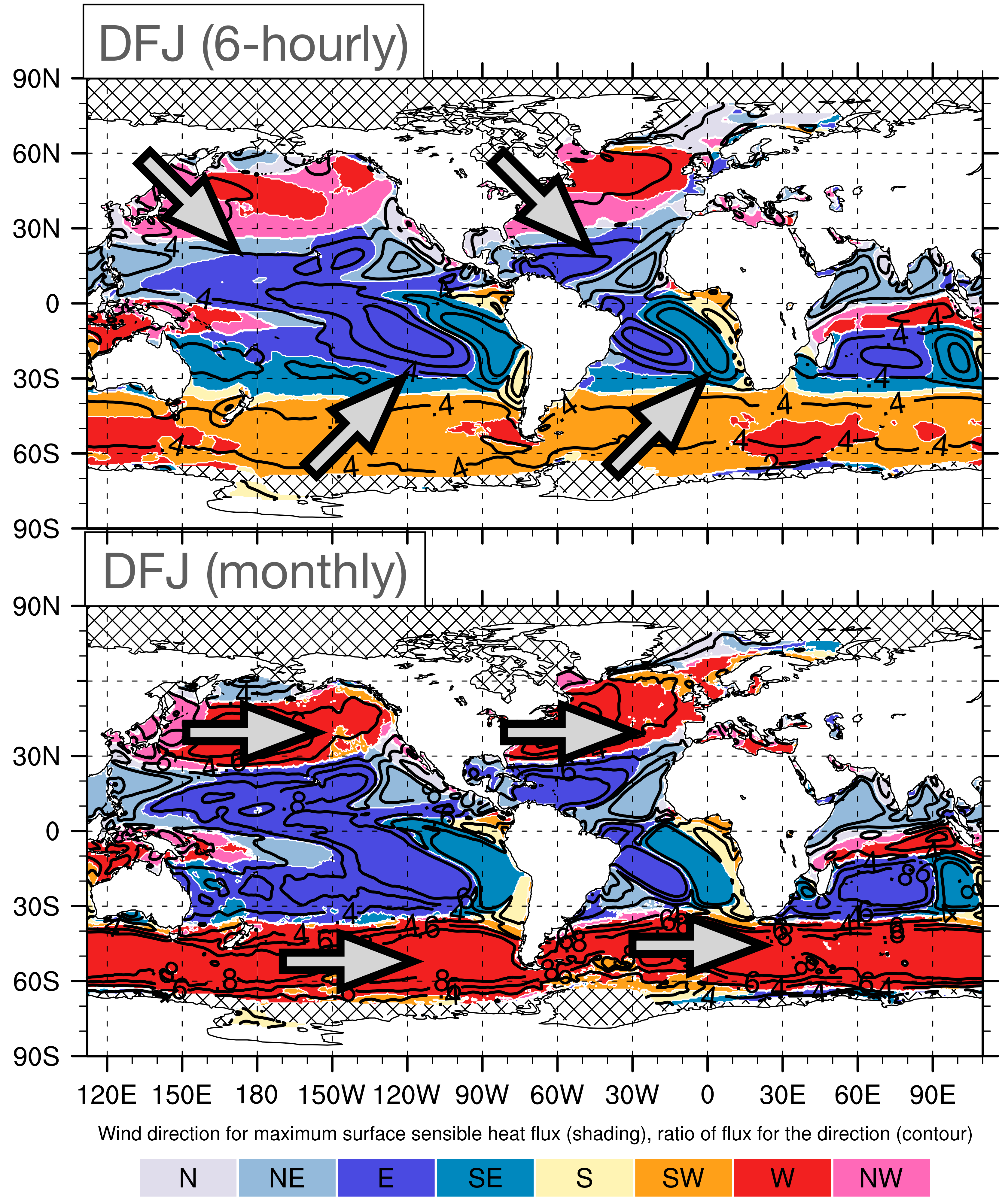

- Mean heat fluxes and their variability concentrate along SST fronts
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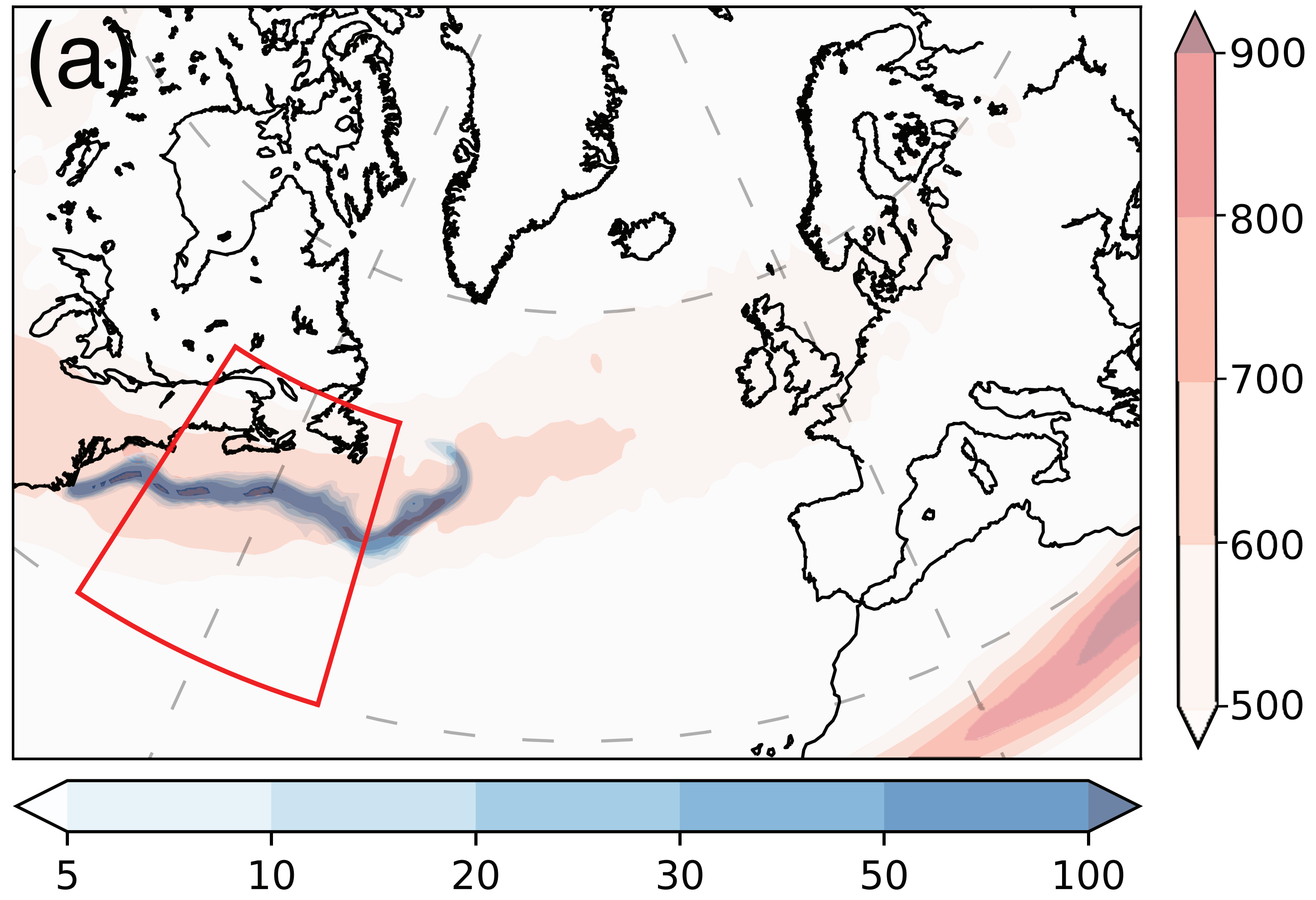
What is the role of midlatitude cyclones and how do they respond?

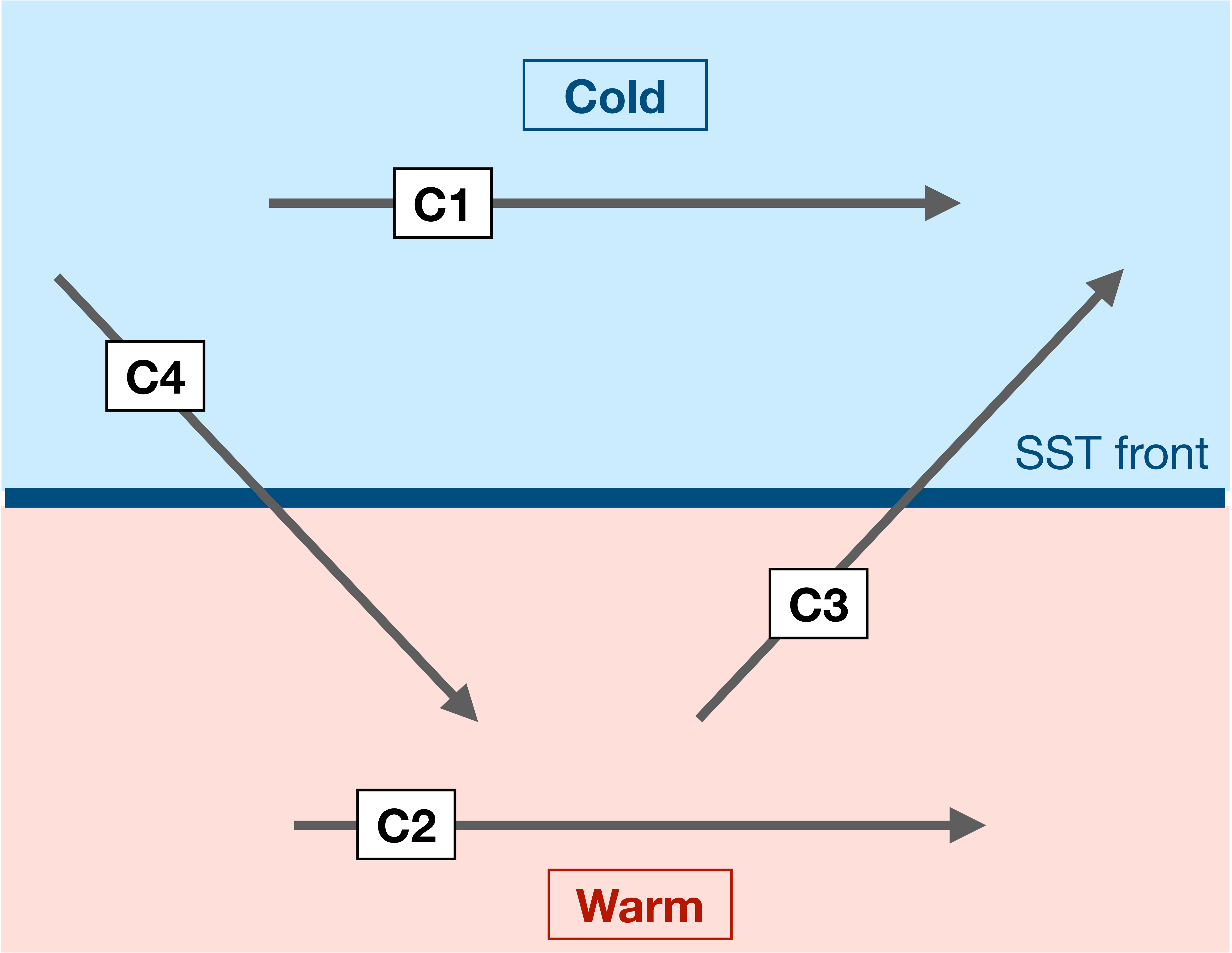
Ogawa and Spengler (2019)

Response of extratropical cyclones along SST fronts

Detect and track cyclones



Detect SST fronts

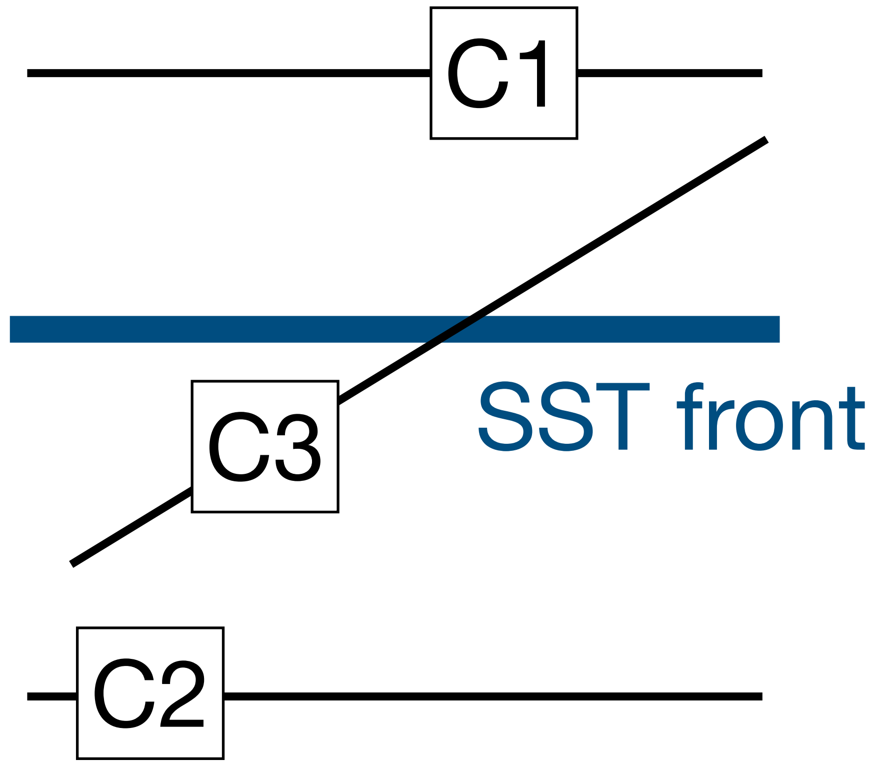


Classification of cyclones by position to SST front

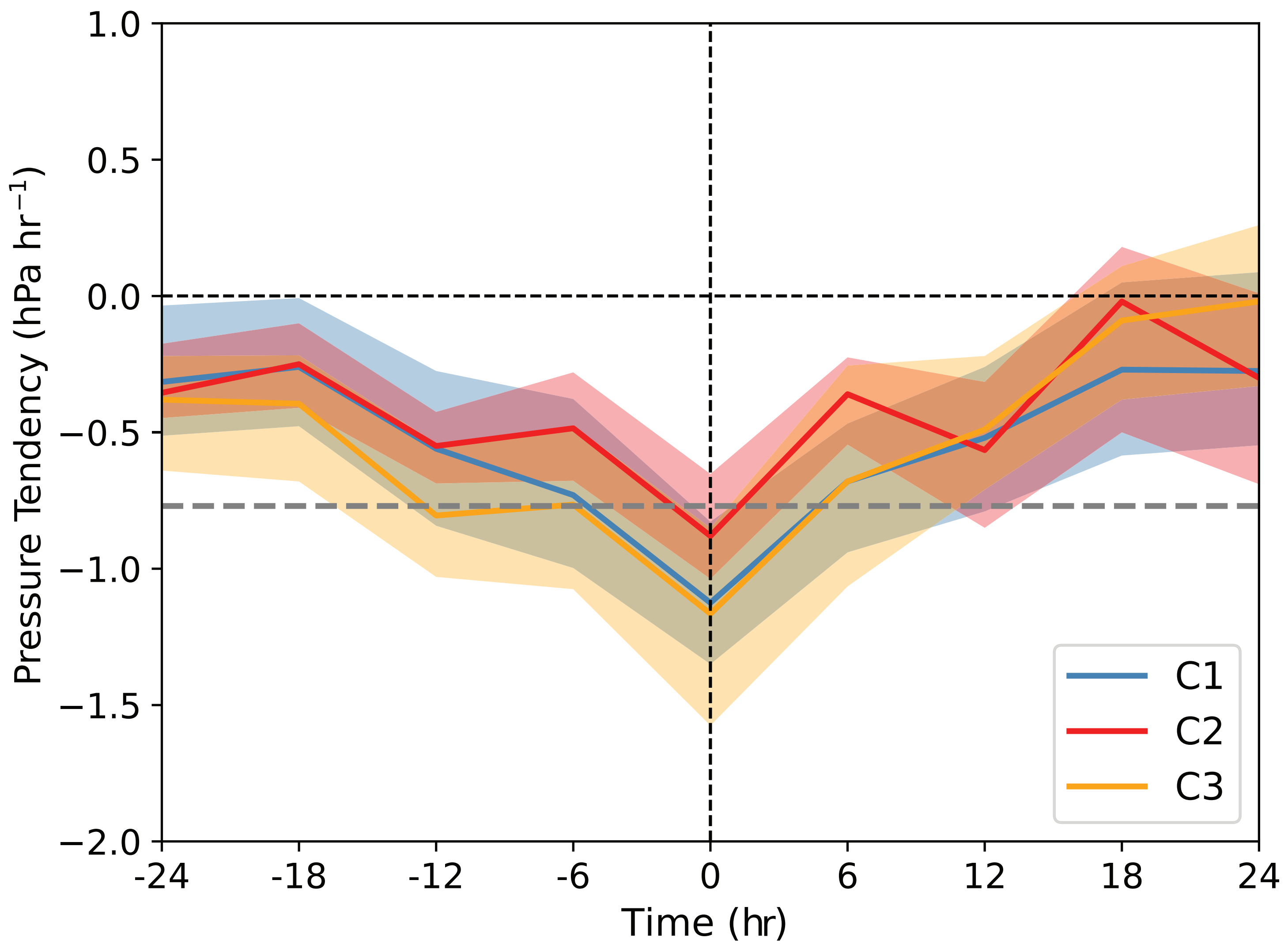
Tsopouridis, Spensberger, and Spengler (2020a,b)

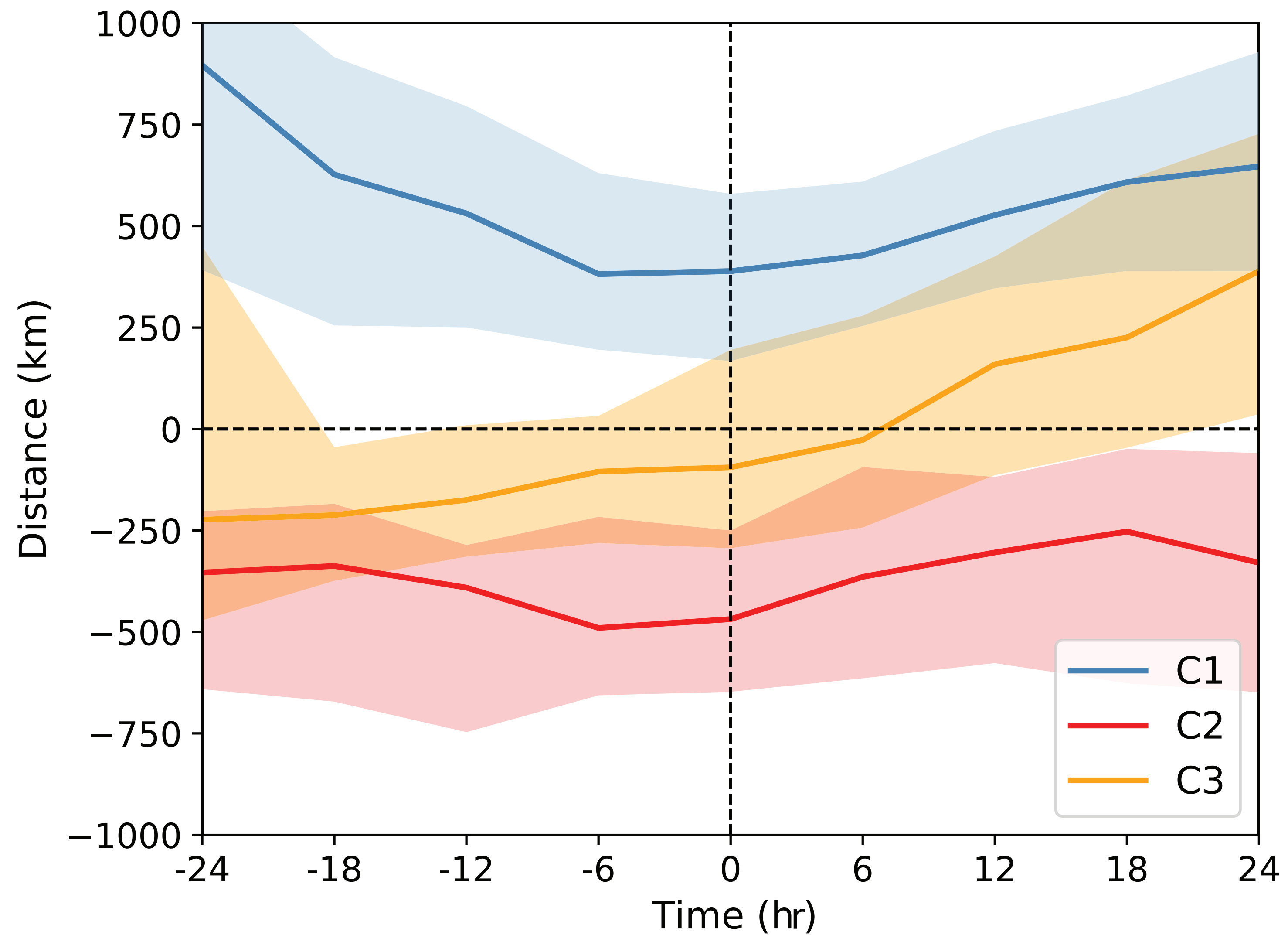
Response of extratropical cyclones along Gulf Stream and Kuroshio

Pressure tendency | **Distance to SST front**

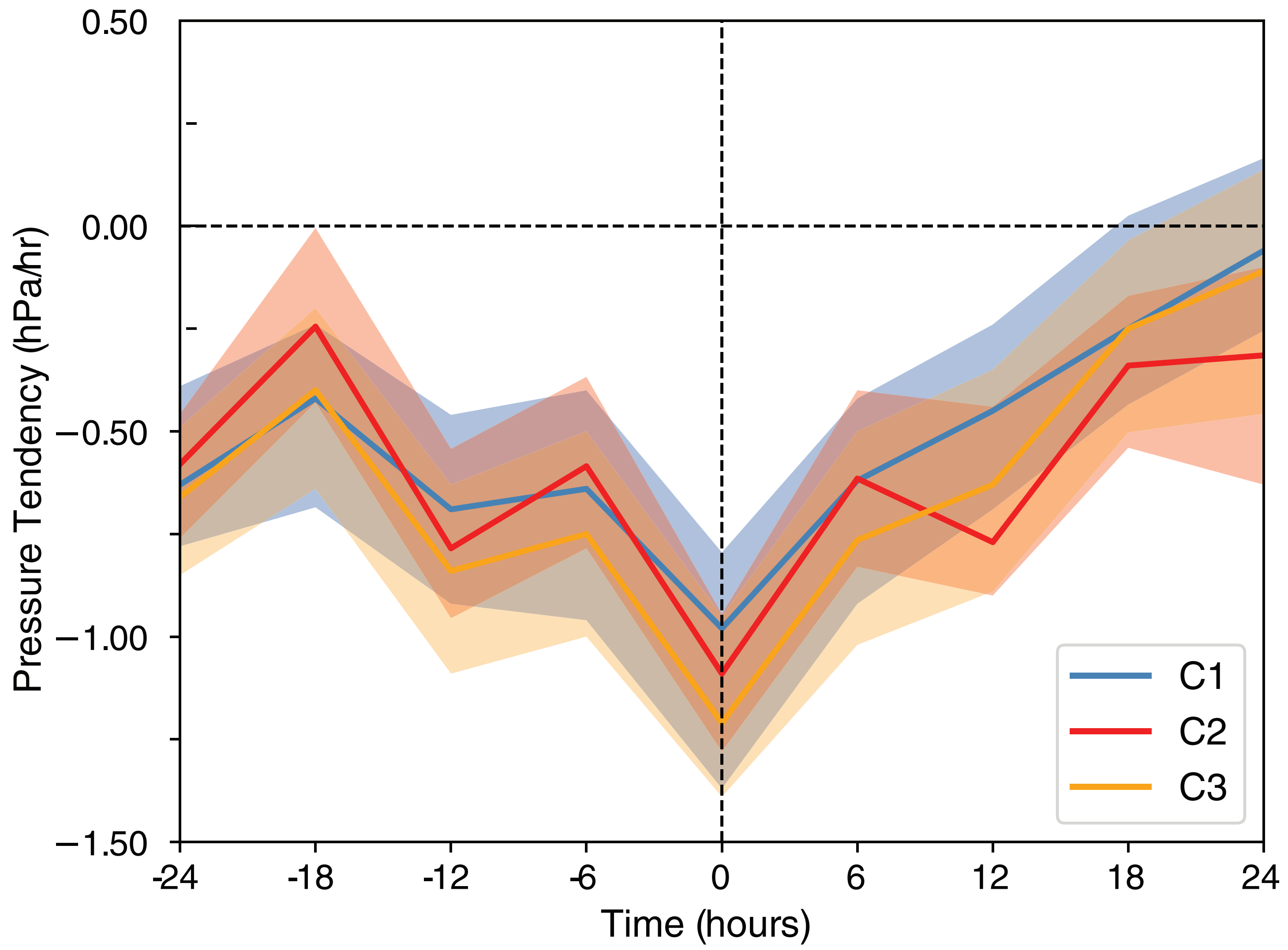


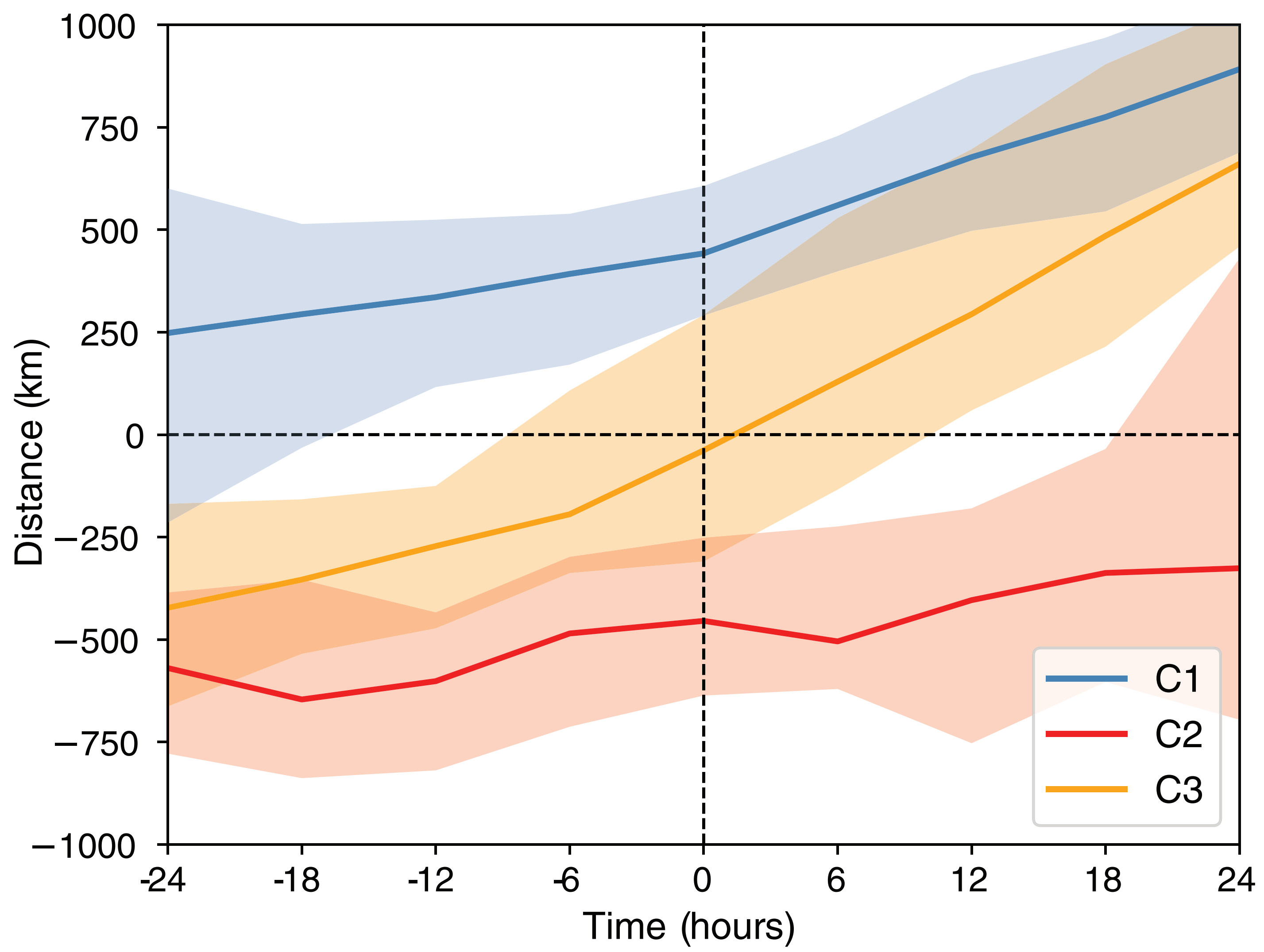
Gulf Stream





Kuroshio





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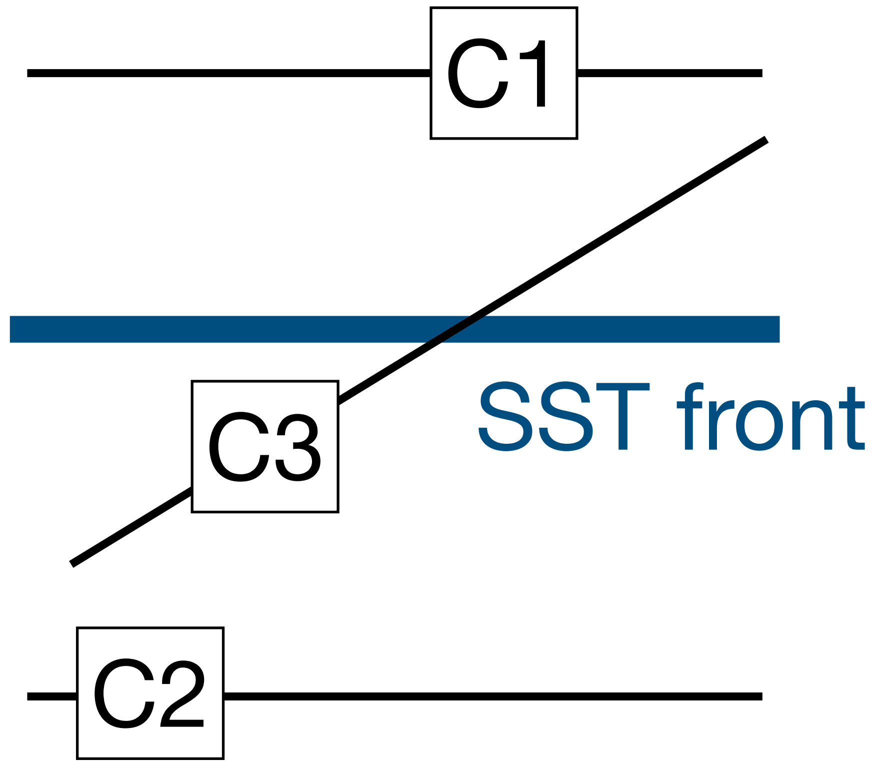
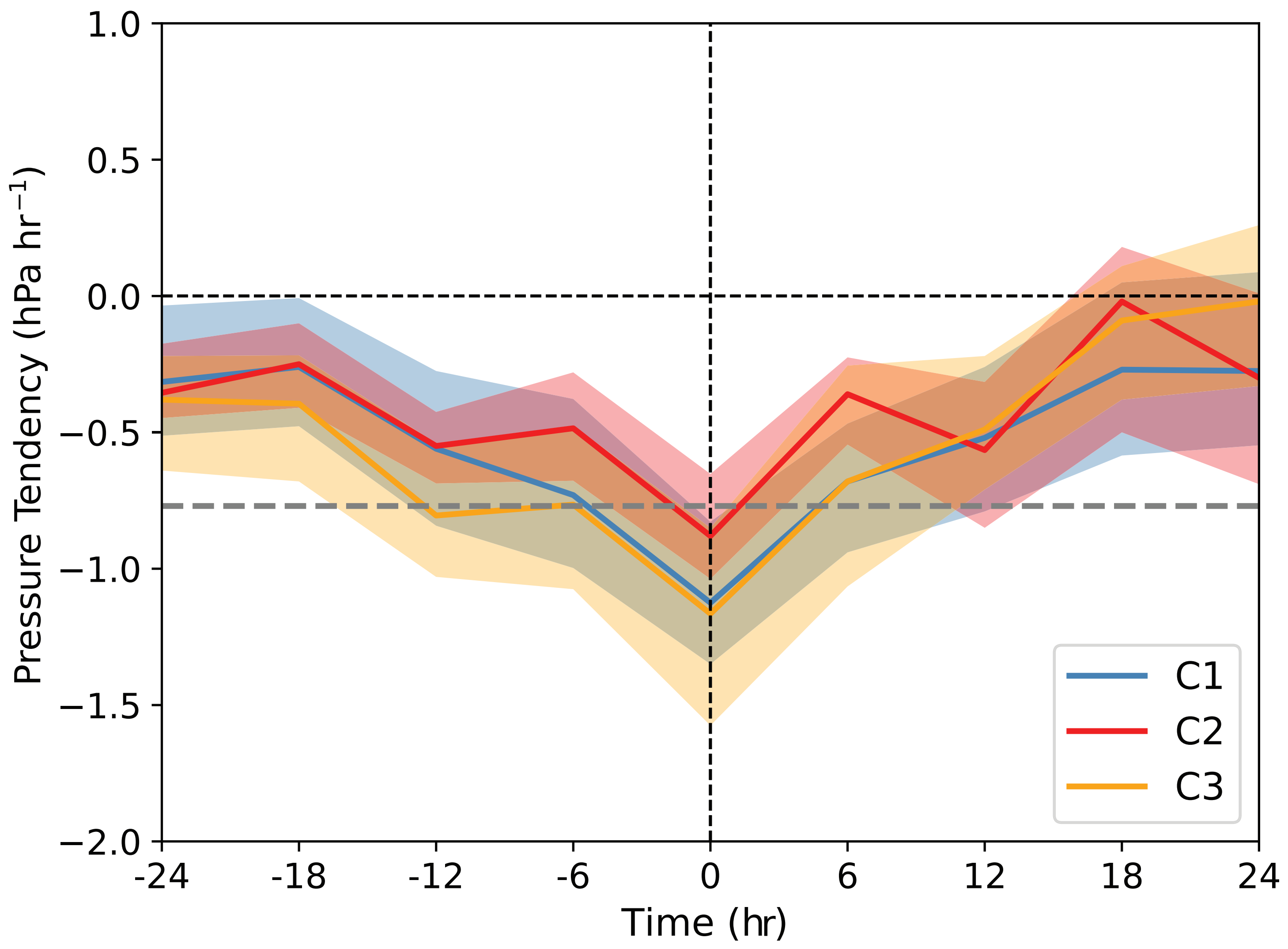
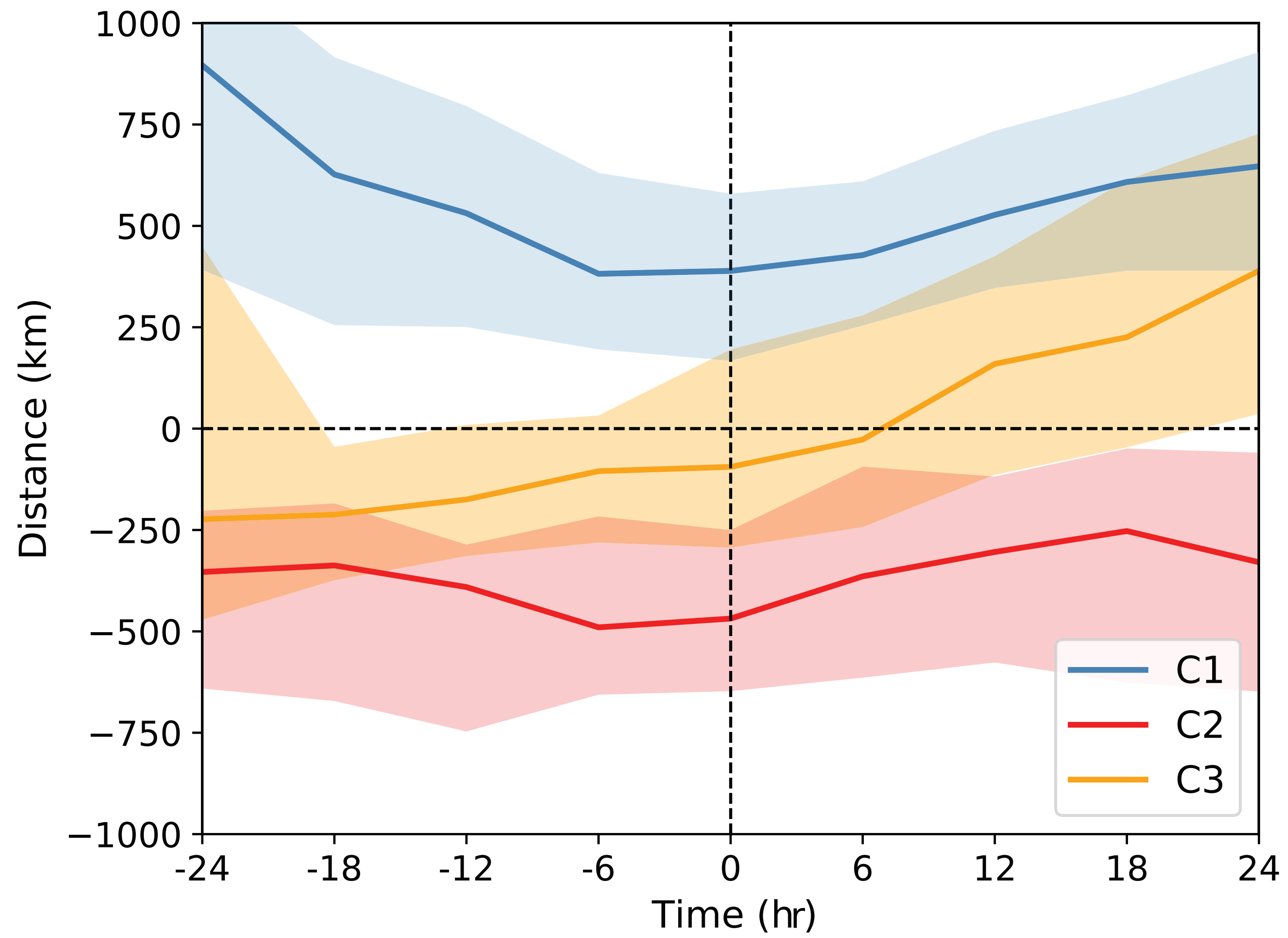


Gulf Stream

C3 intensifies fastest

C1 faster than C2



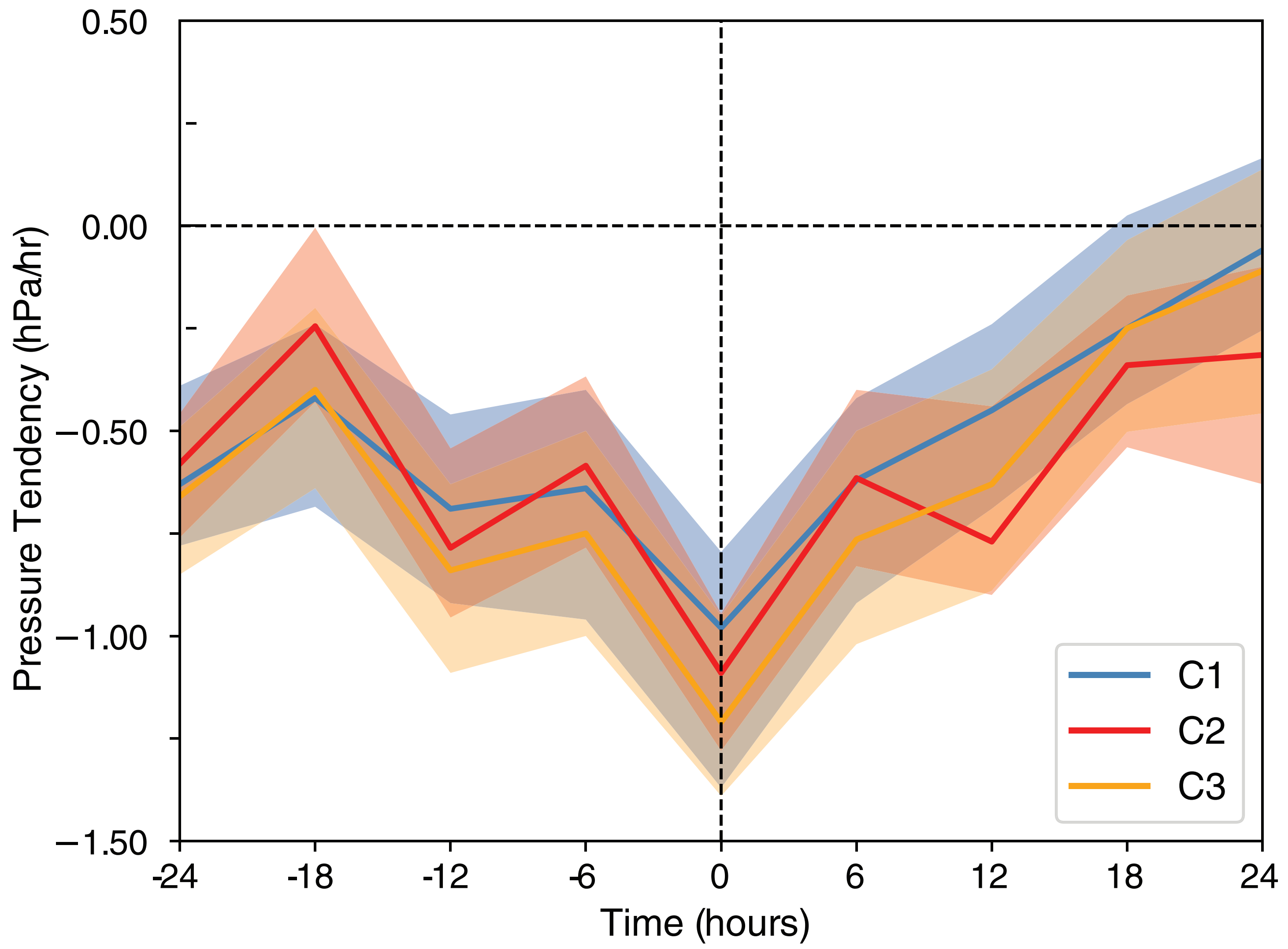


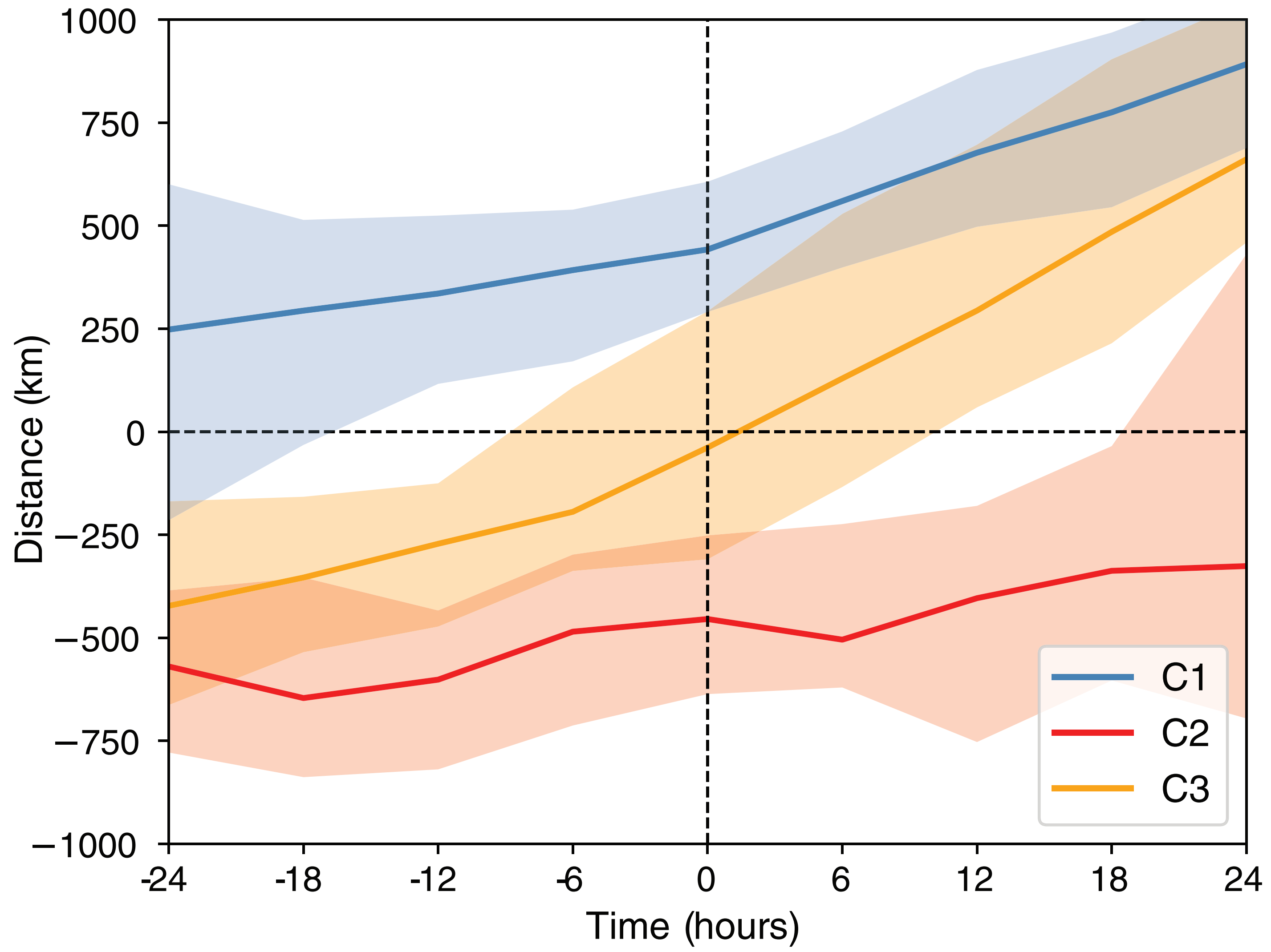
C3 crosses SST front at maximum intensification

Kuroshio

C3 intensifies fastest

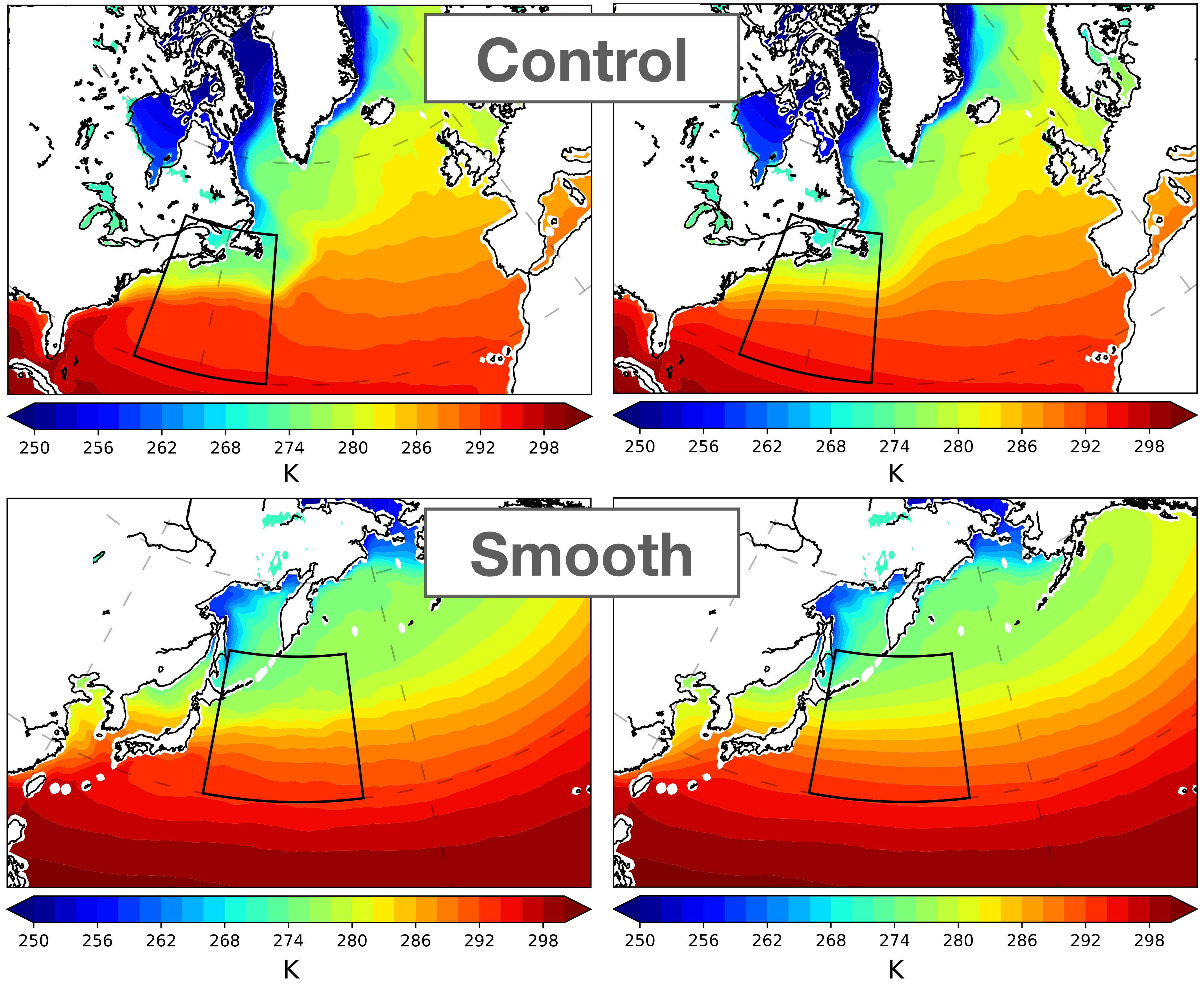
C2 faster than C1





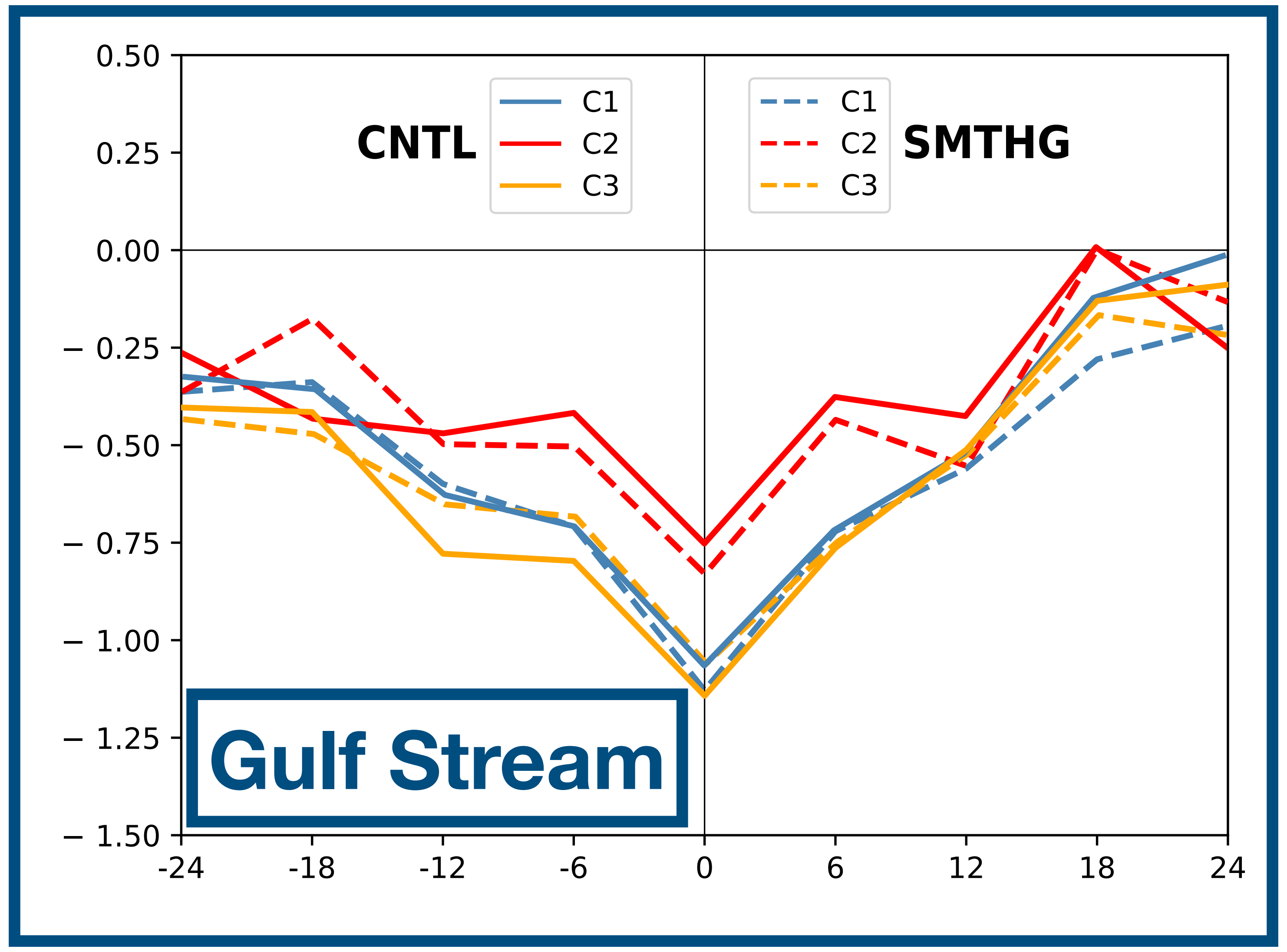
Tsopouridis, Spensberger, and Spengler (2020a,b)

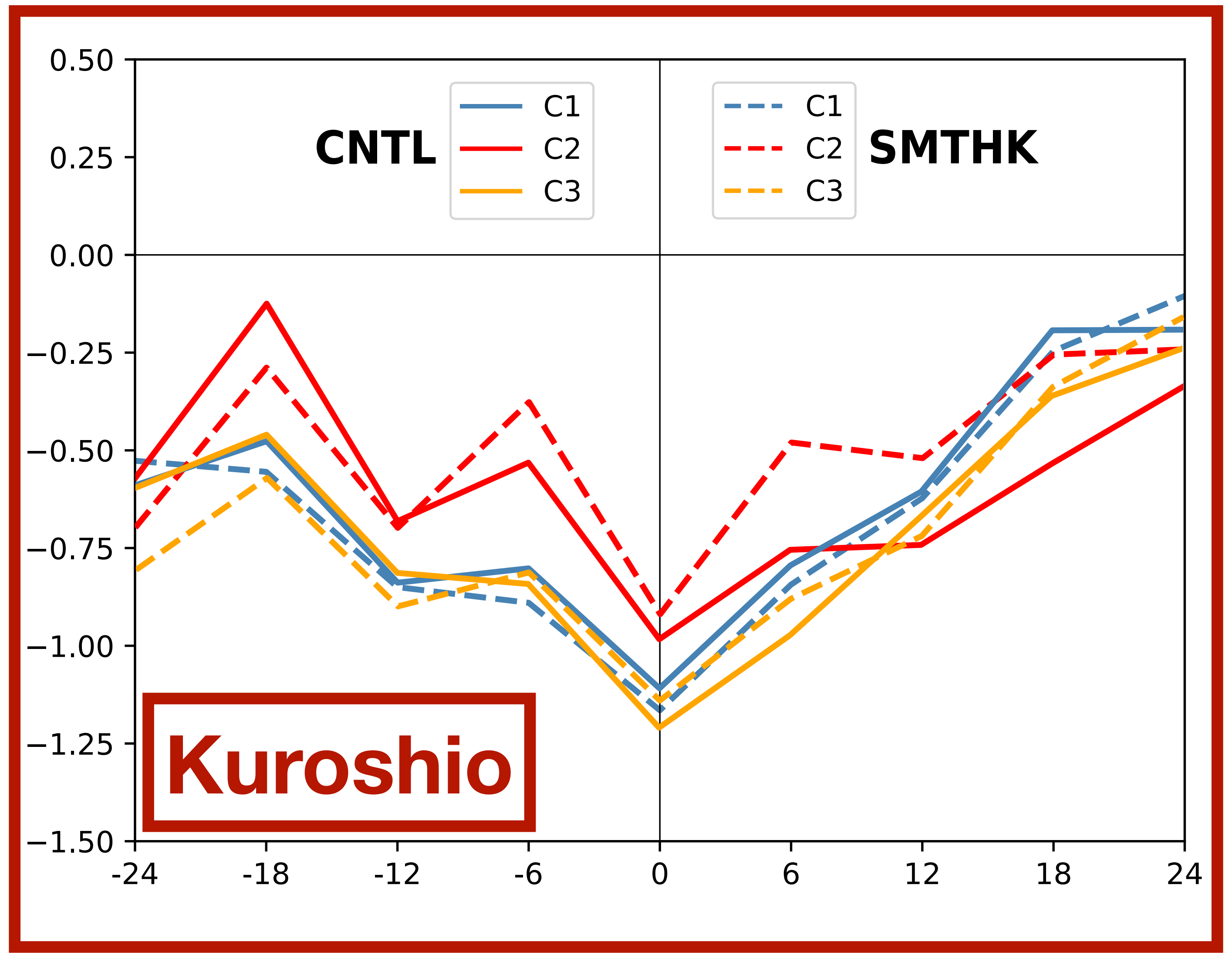
What if the SST fronts are smoothed?



SST in CNTL and smooth experiment

Pressure tendency





AFES simulations with realistic SST (CNTL) and smoothed SST in either Kuroshio or Gulf Stream

Tsopouridis, Spengler, and Spensberger (2021)

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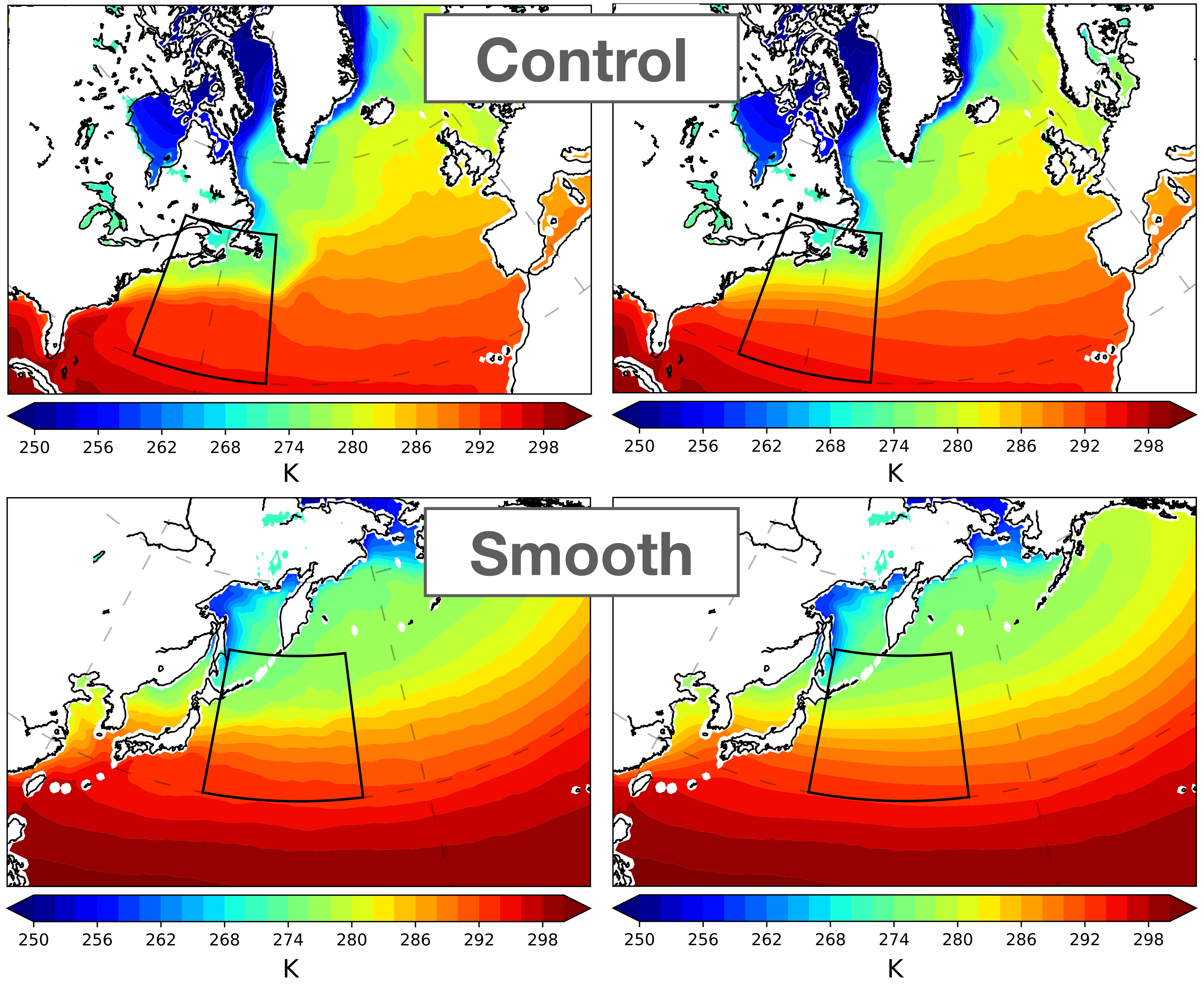

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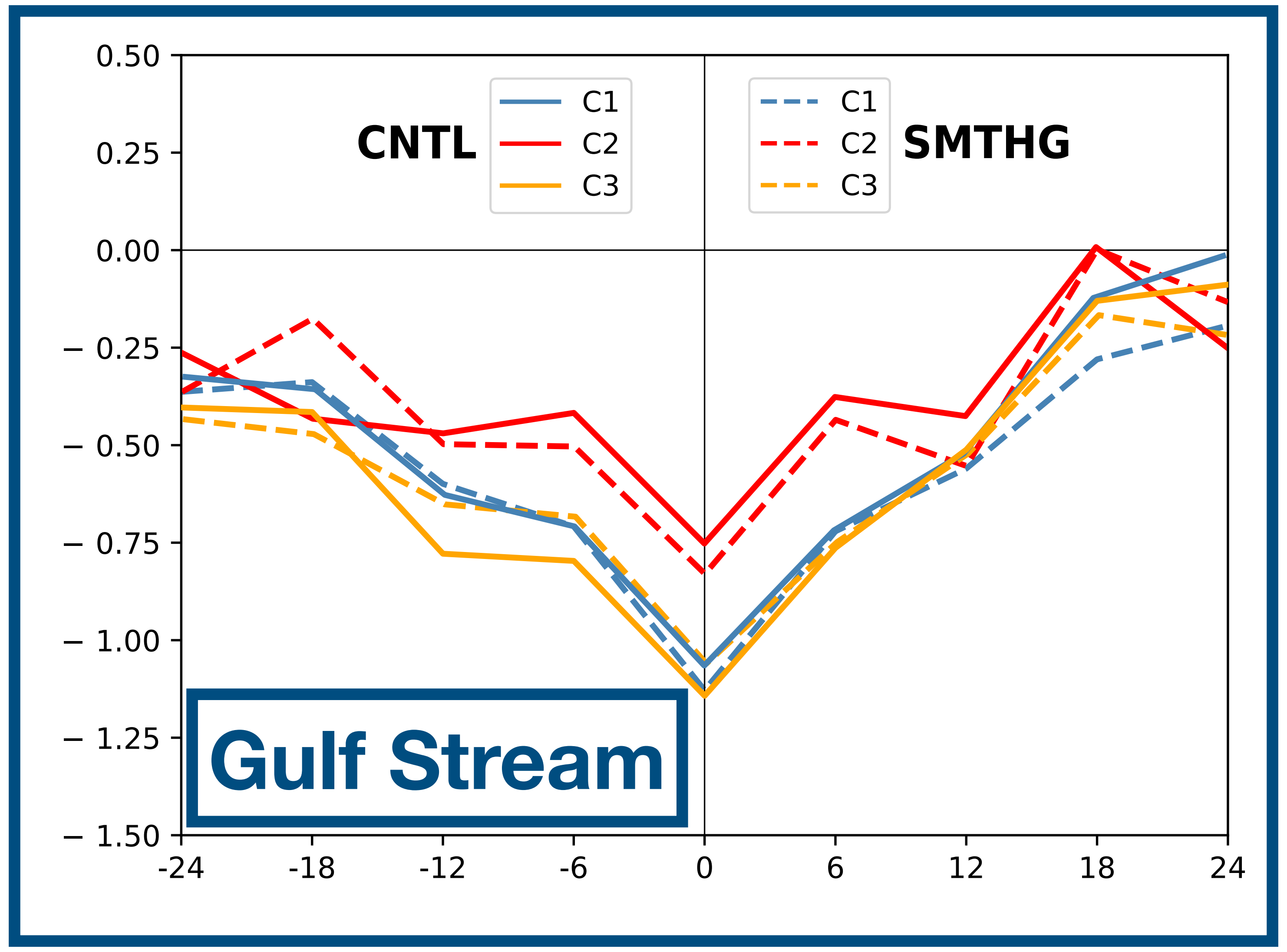
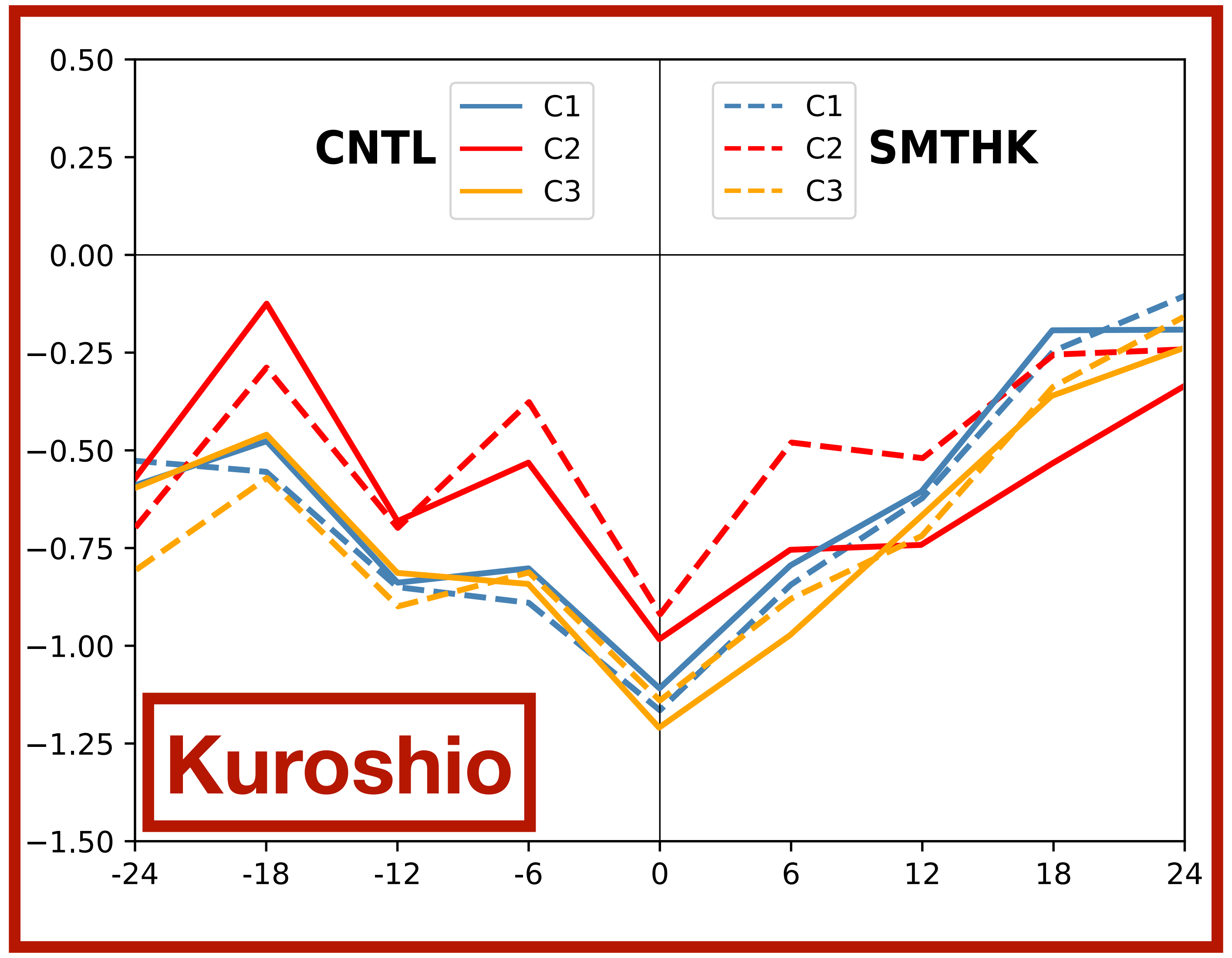


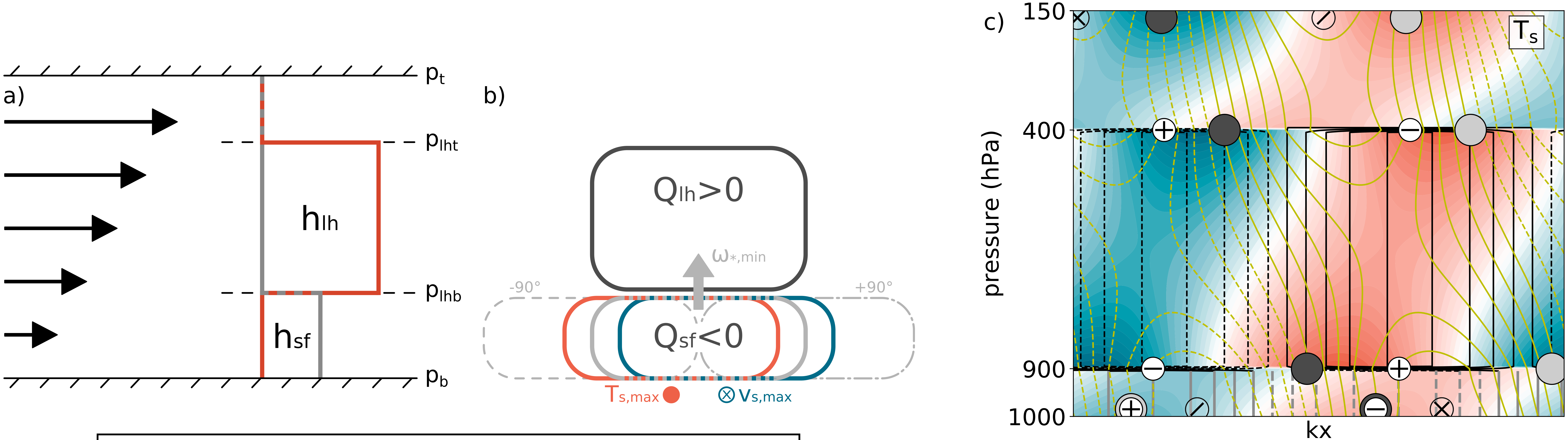


No difference in cyclone intensification

AFES simulations with realistic SST (CNTL) and smoothed SST in either Kuroshio or Gulf Stream

Tsopouridis, Spengler, and Spensberger (2021)

Direct and indirect effect of surface fluxes on cyclones



Eady model with latent heat release and effect of surface sensible heat fluxes

Streamfunction (yellow contour), PV (circles), temperature (shading), diabatic heating (black contour)

Haualand and Spengler (2020)

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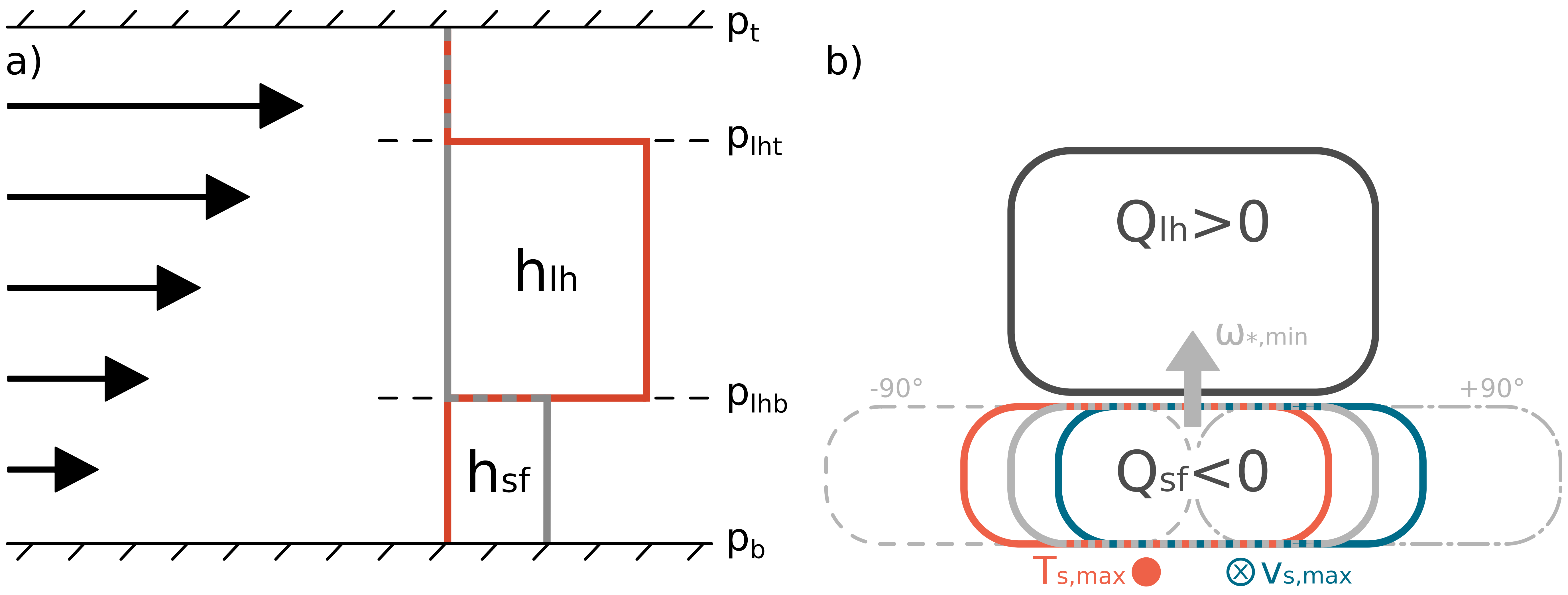

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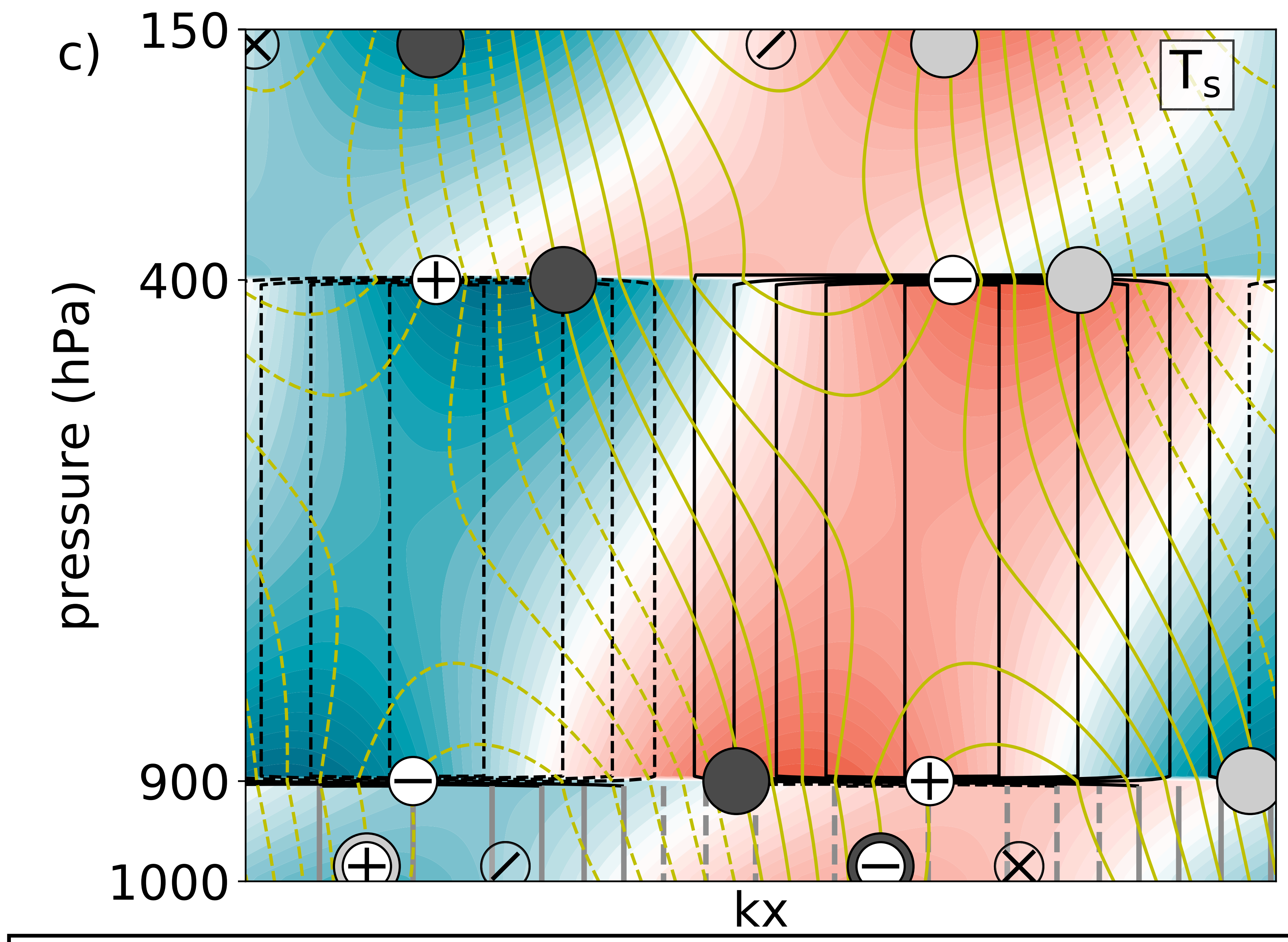


Streamfunction (yellow contour), PV (circles), temperature (shading), diabatic heating (black contour)

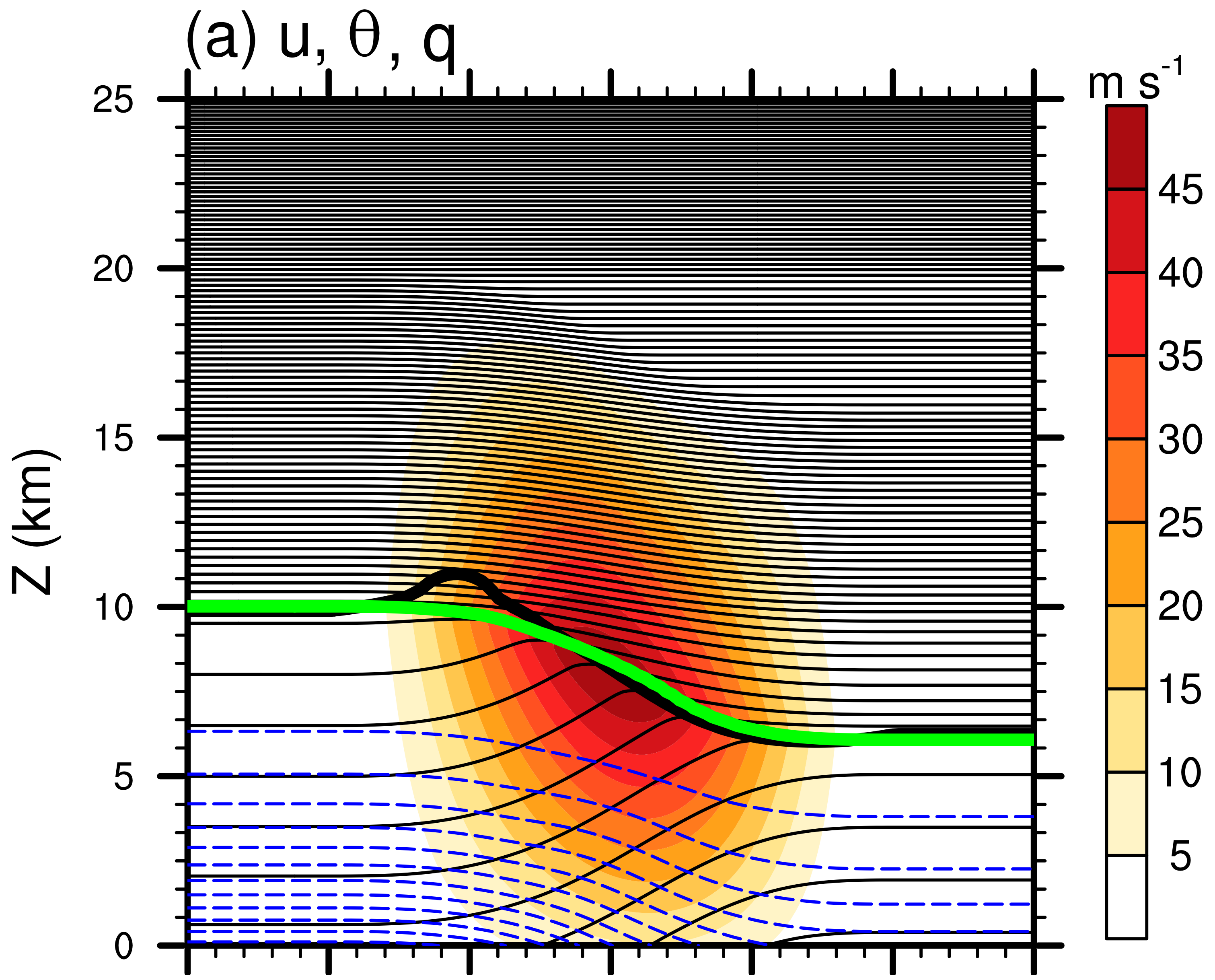
Direct effect ⟷ Indirect effect

Surface sensible heat fluxes detrimental to growth

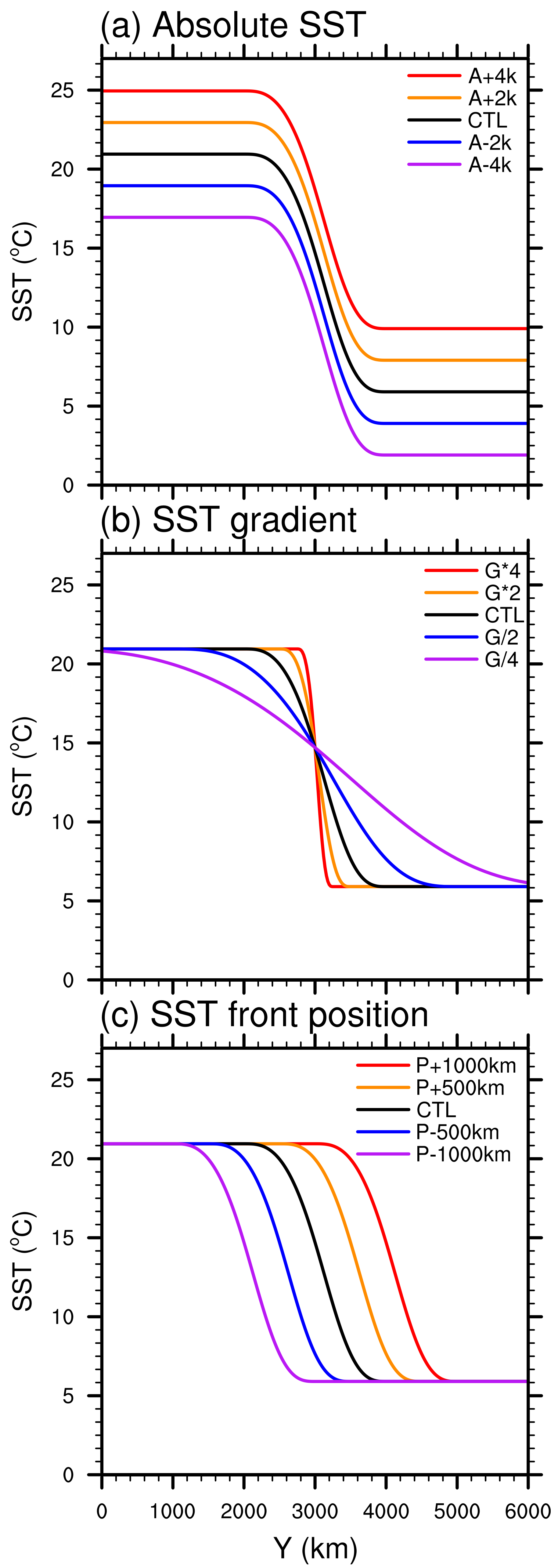
Negative effect readily overcompensated by additional latent heating originating from latent heat fluxes

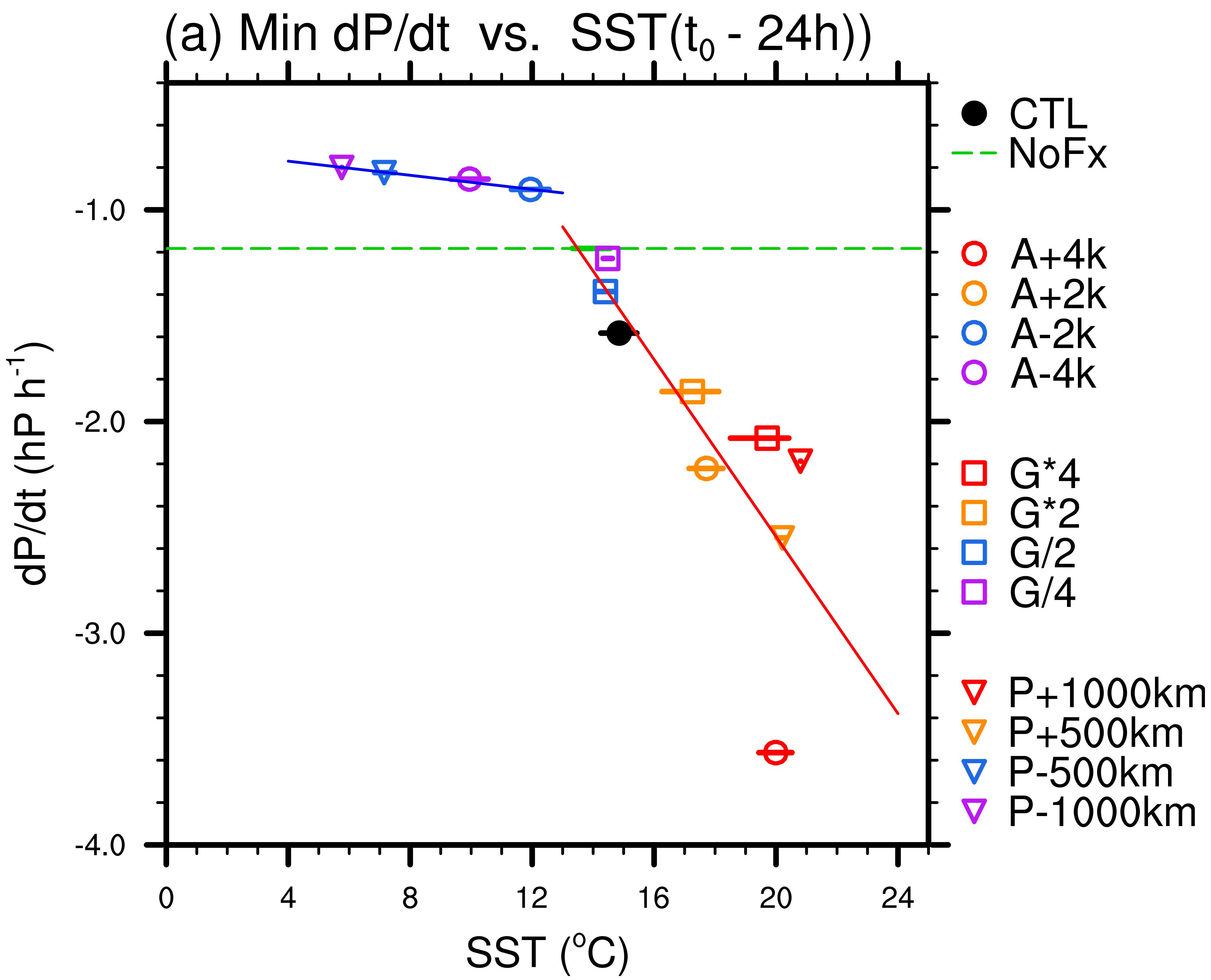
Haualand and Spengler (2020)

Direct and indirect effect of surface fluxes on cyclones



Idealised WRF simulation of cyclone development with surface fluxes



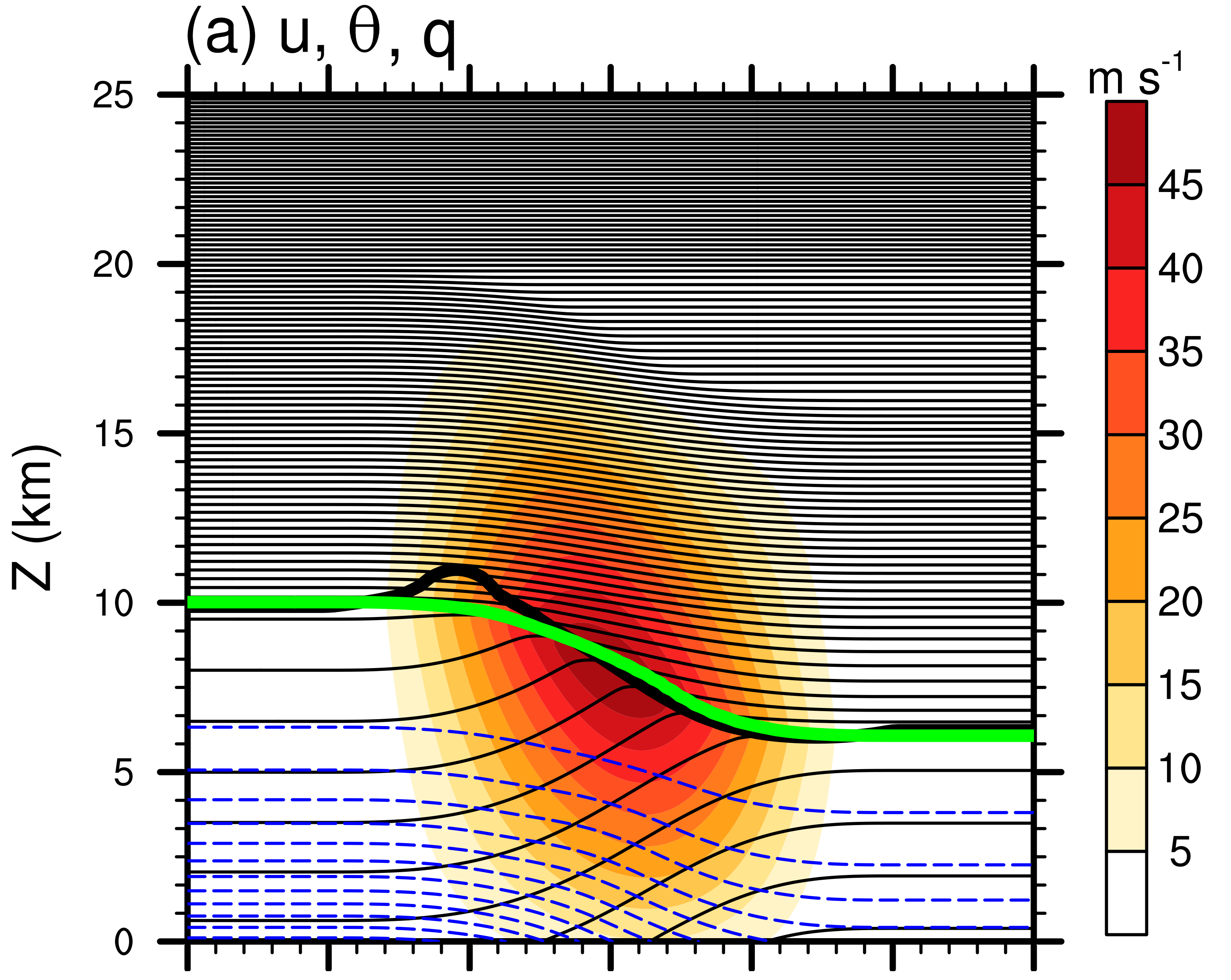


Sensitivity to different SST distributions

Varying absolute SST as well as strength and position of SST front

Bui and Spengler (2021)

Direct and indirect effect of surface fluxes on cyclones



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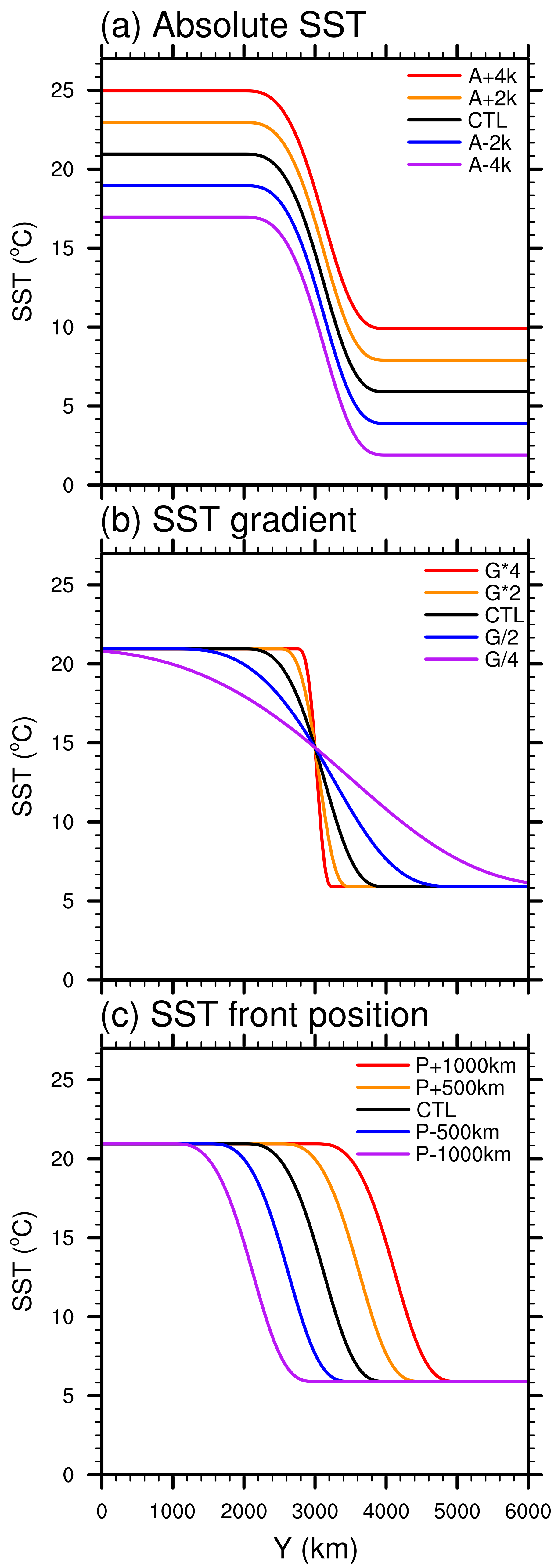
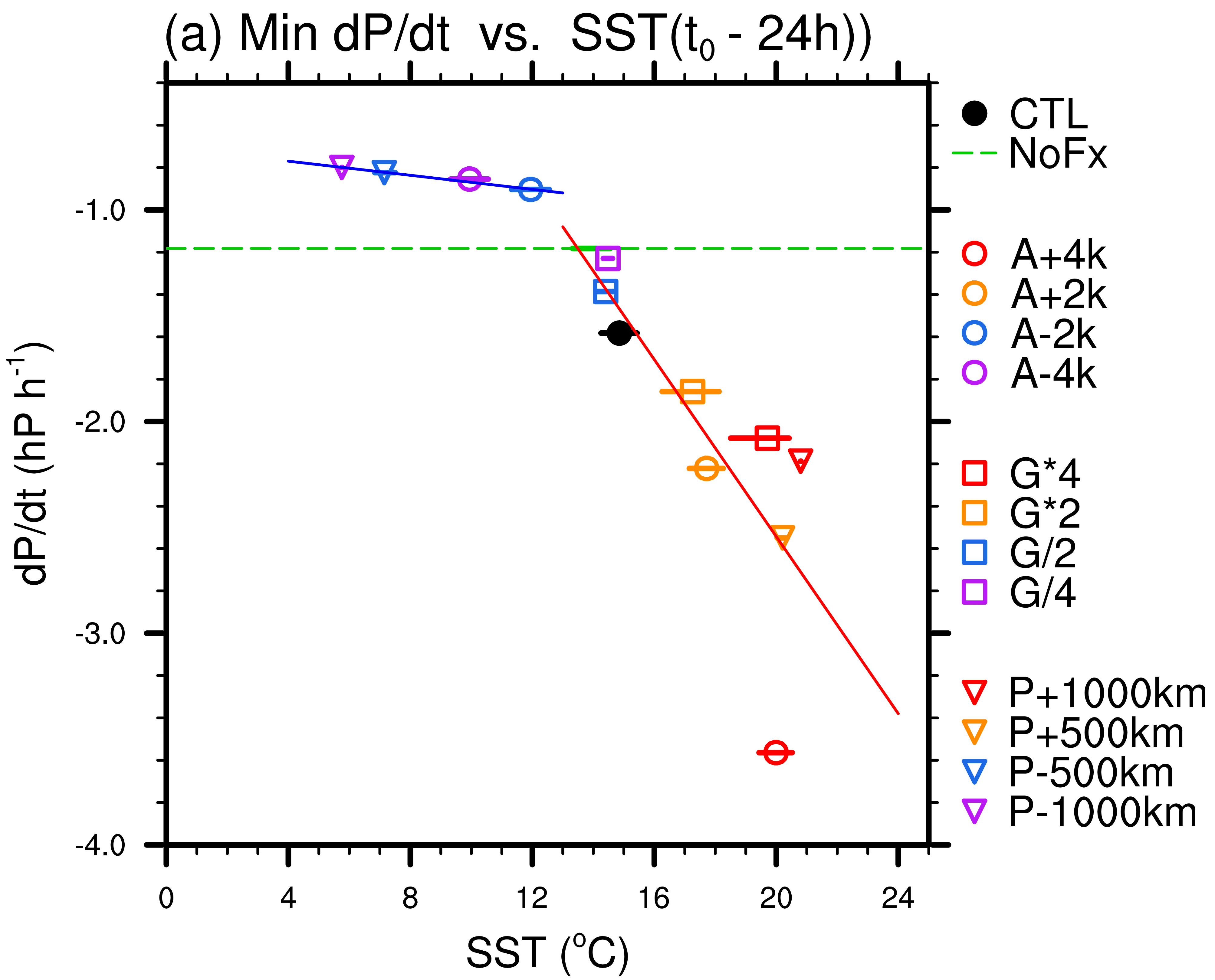


Results not directly affected by SST front



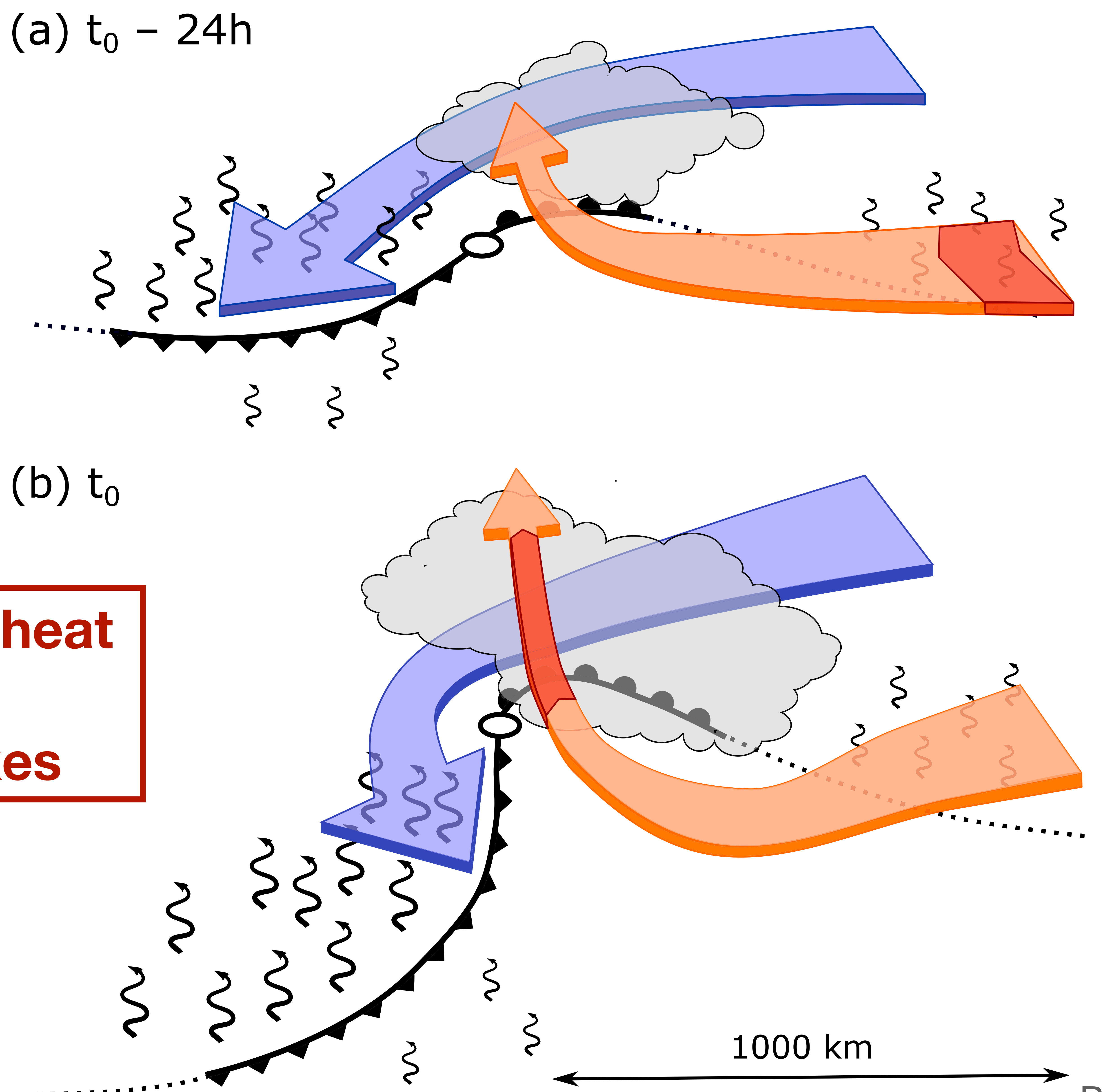
Cyclone development determined by SST downstream

Bui and Spengler (2021)

Direct and indirect effect of surface fluxes on cyclones

Indirect effect

Main influence through latent heat release associated with downstream latent heat fluxes



Bui and Spengler (2021)

Direct and indirect effect of surface fluxes on cyclones

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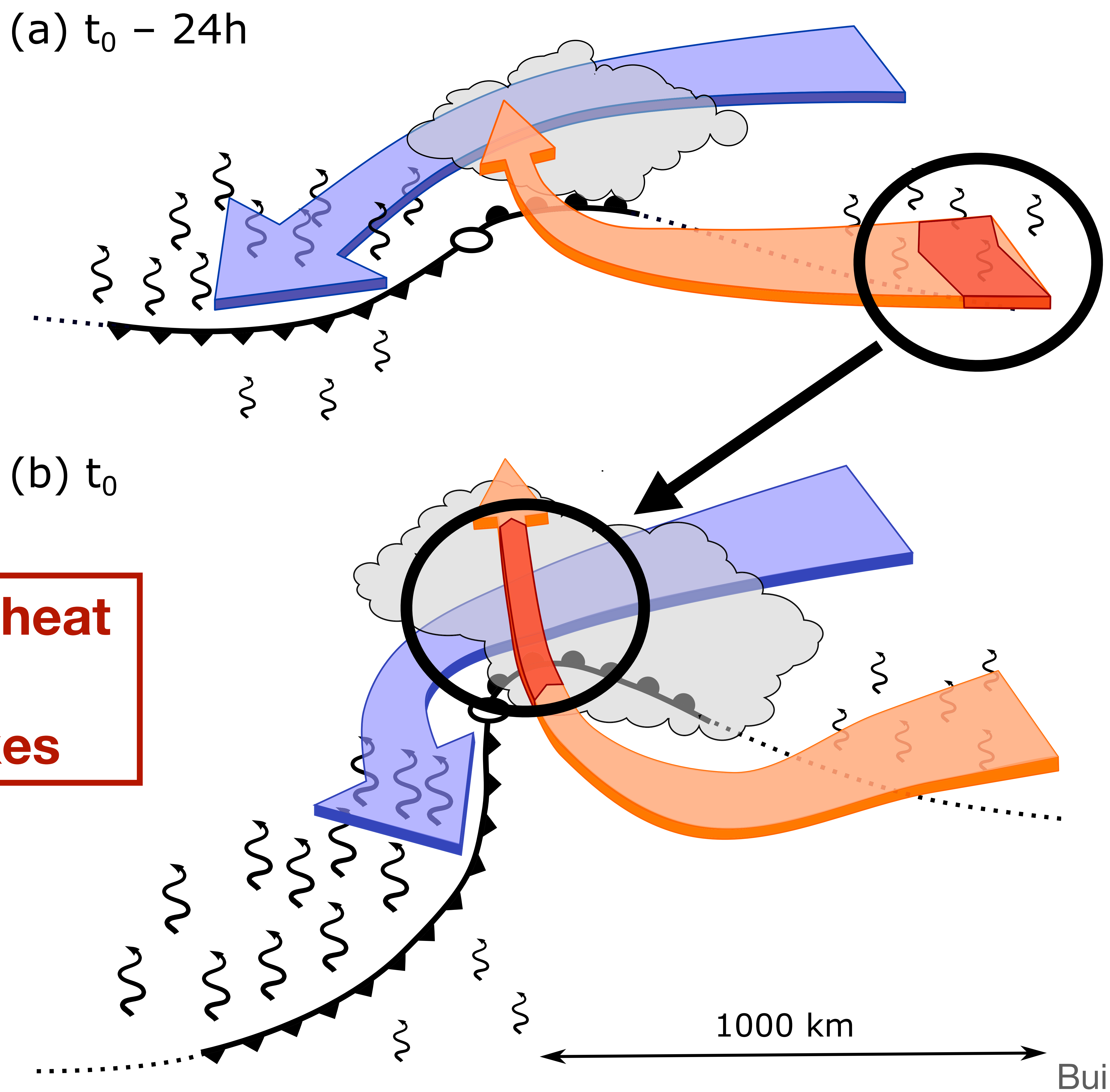
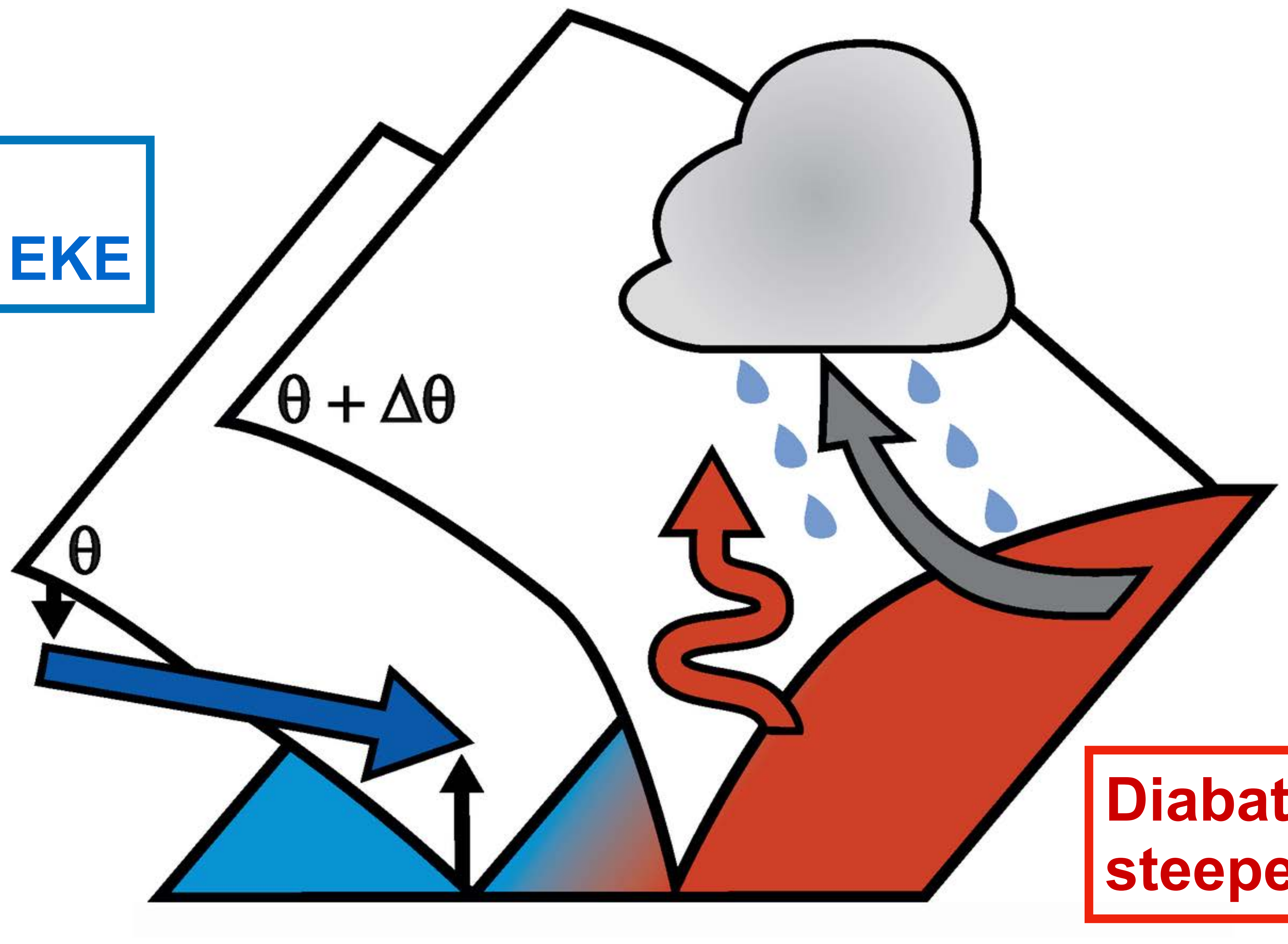


Bui and Spengler (2021)

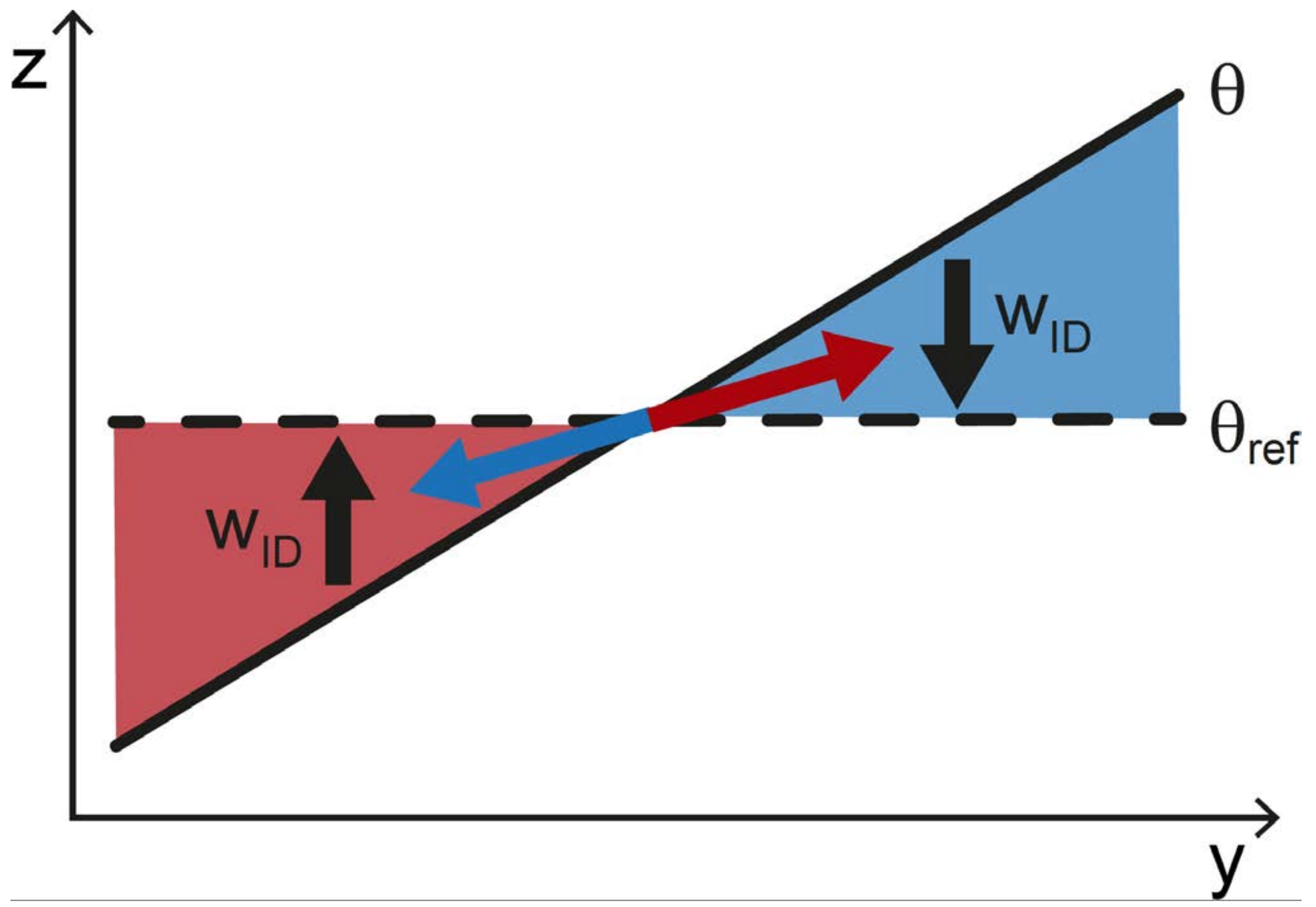
Baroclinicity in Storm Tracks

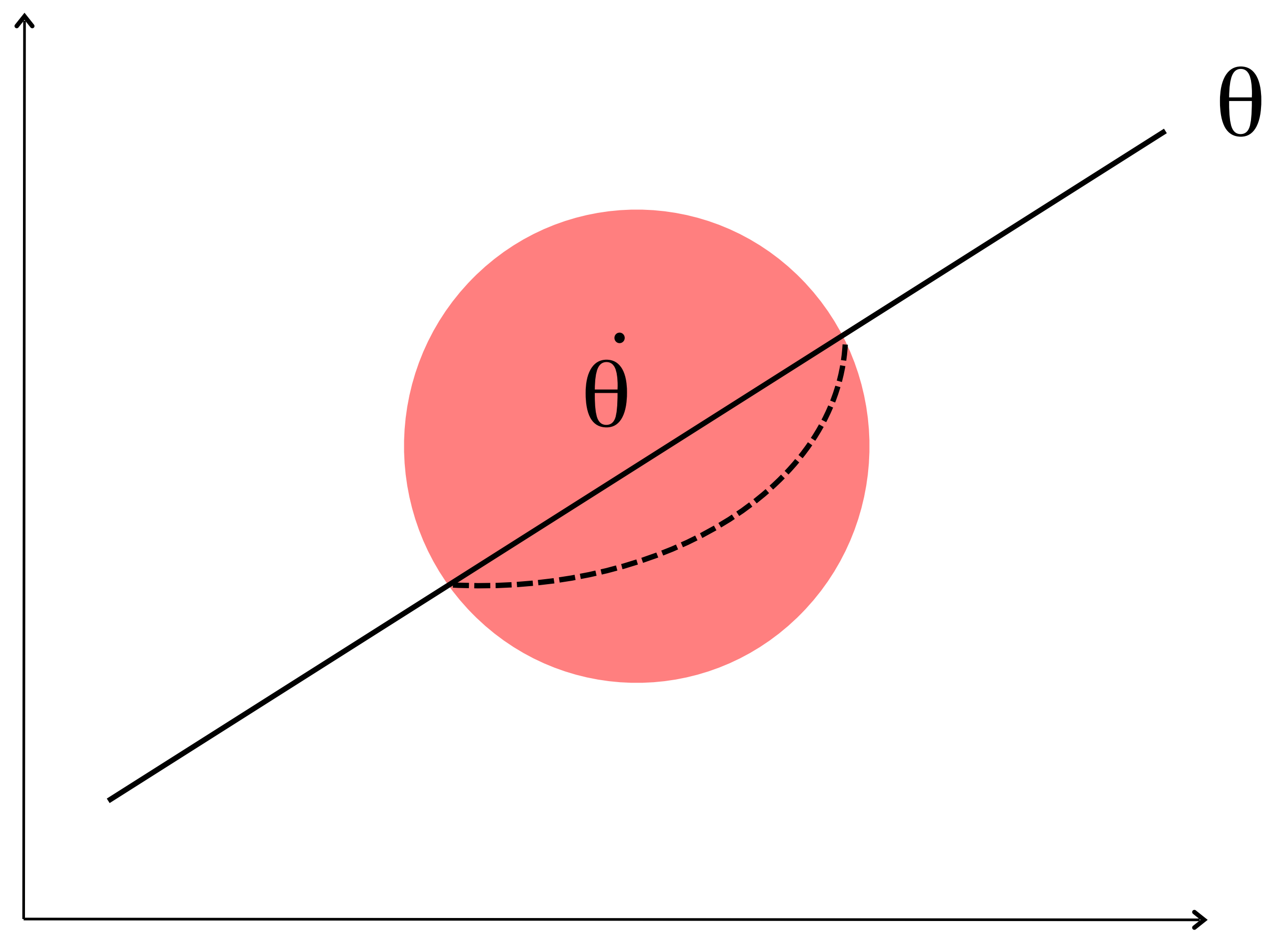
Isentropic slope S $\equiv|\nabla_\theta z|$

Tilting: conversion of APE to EKE



Diabatic: steepening of surface

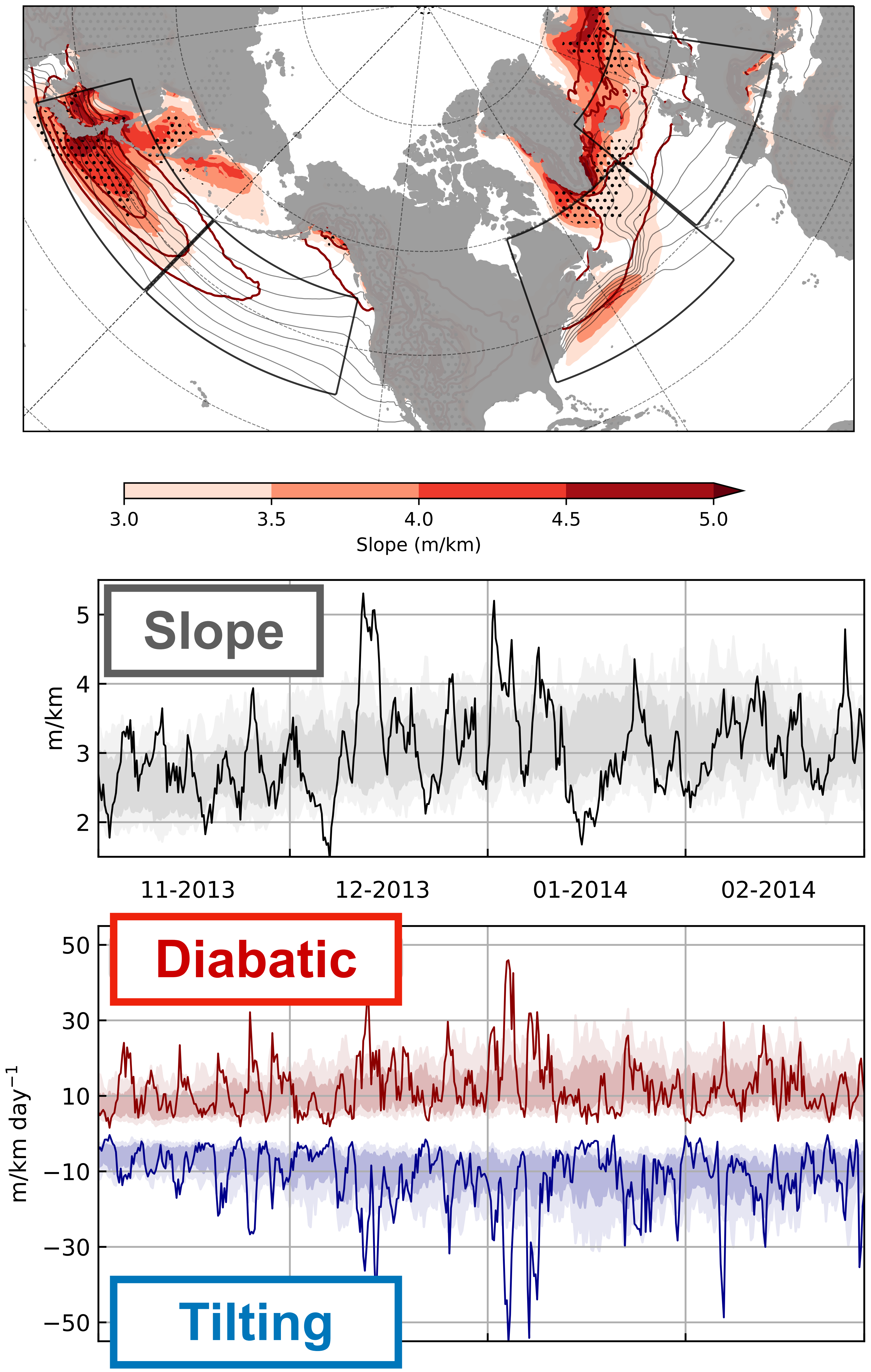


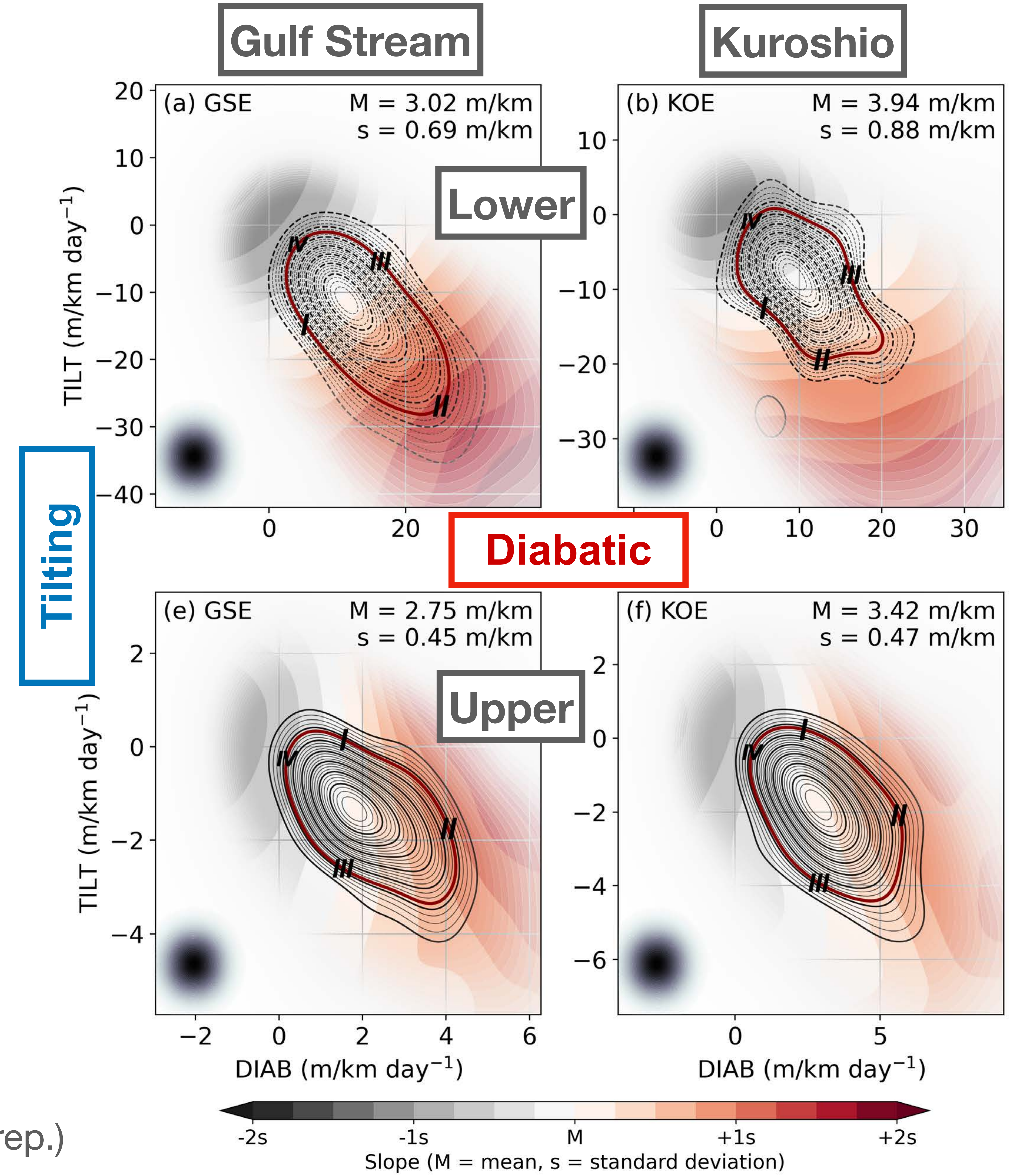


$$\left.\frac{\partial S}{\partial t}\right|_p = \underbrace{\frac{\nabla_\theta z}{S}\cdot\nabla_\theta w_{id}}_{\text{Tilting}} - \underbrace{\frac{\partial z}{\partial \theta}\frac{\nabla_\theta z}{S}\cdot\nabla_\theta\dot{\theta}}_{\text{Diabatic}} - \underbrace{\frac{\partial S}{\partial \theta}\nabla\cdot(\mathbf{v}\theta)}_{\text{Flux}} + \text{RES}$$

Papritz and Spengler (2015)

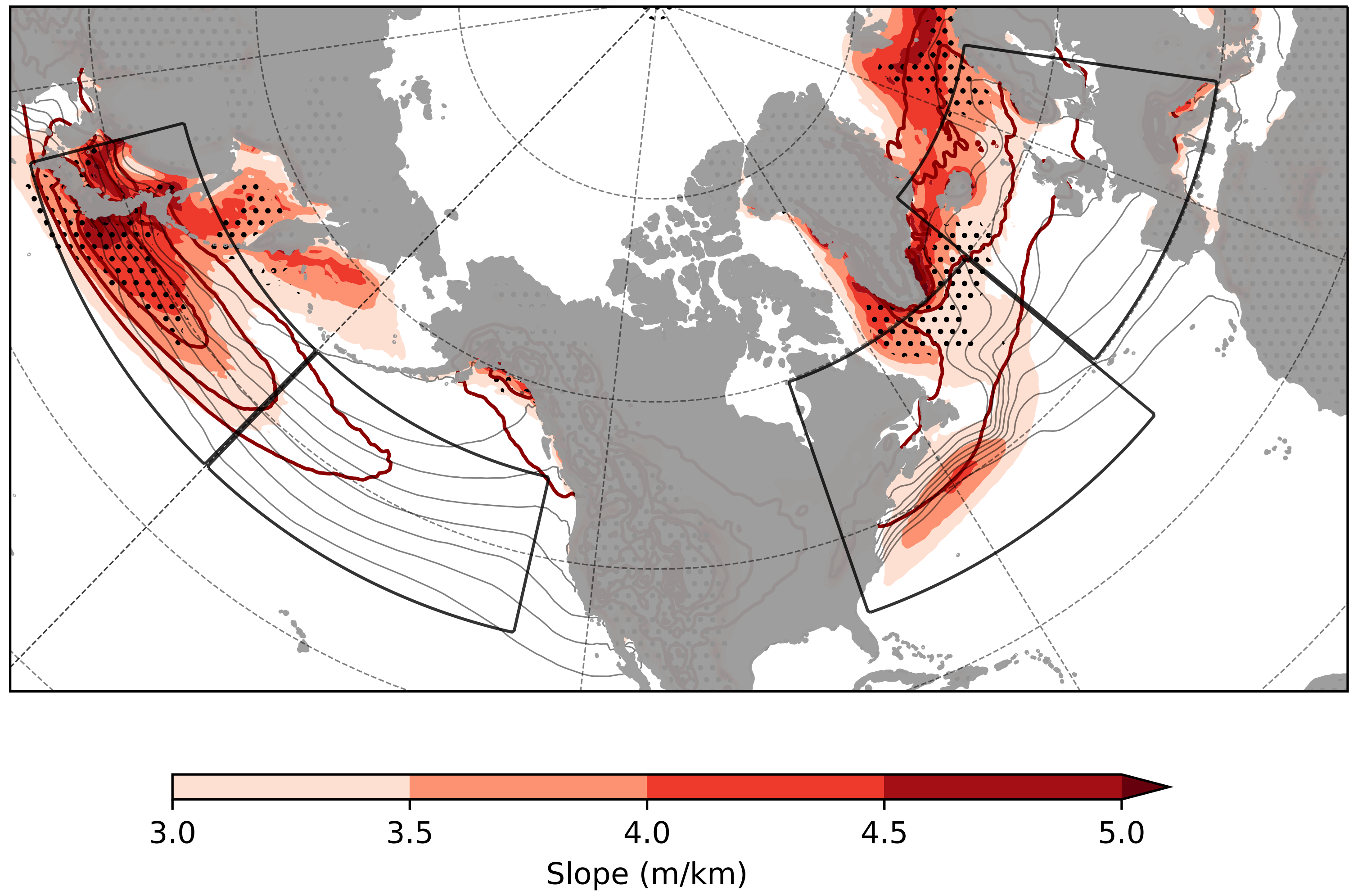
Baroclinicity in Storm Tracks

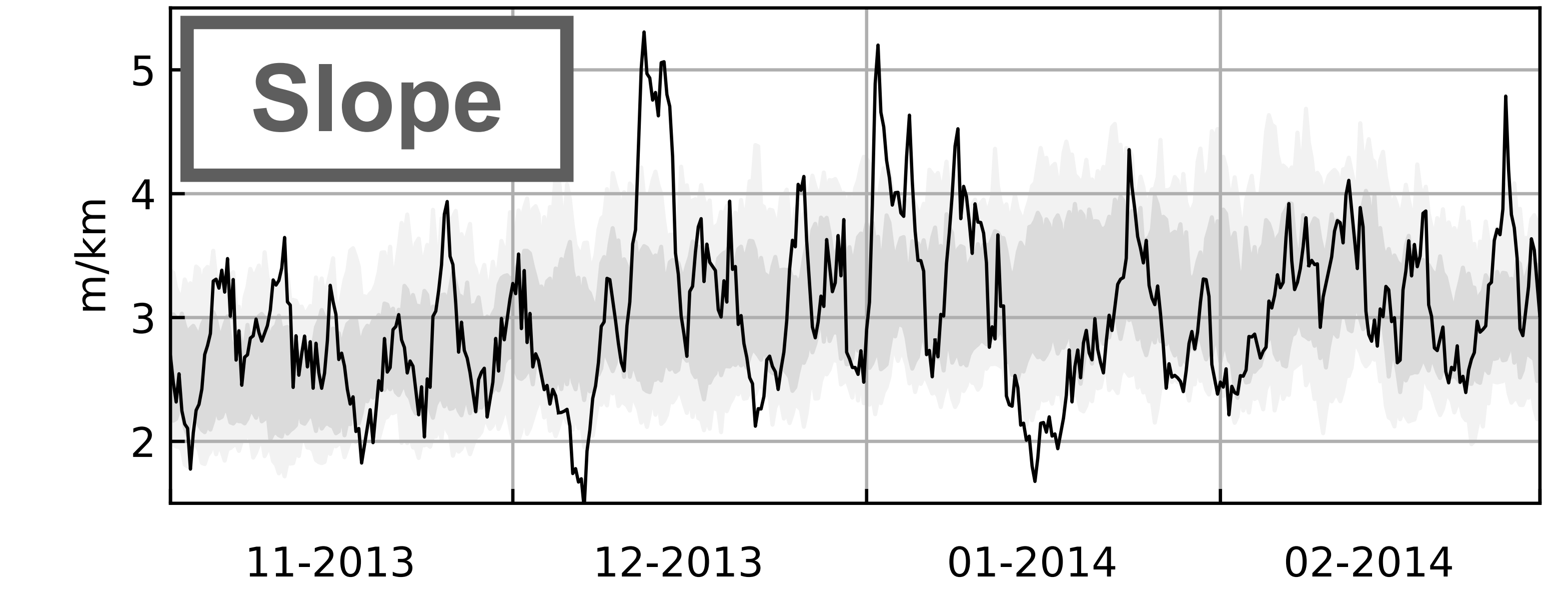


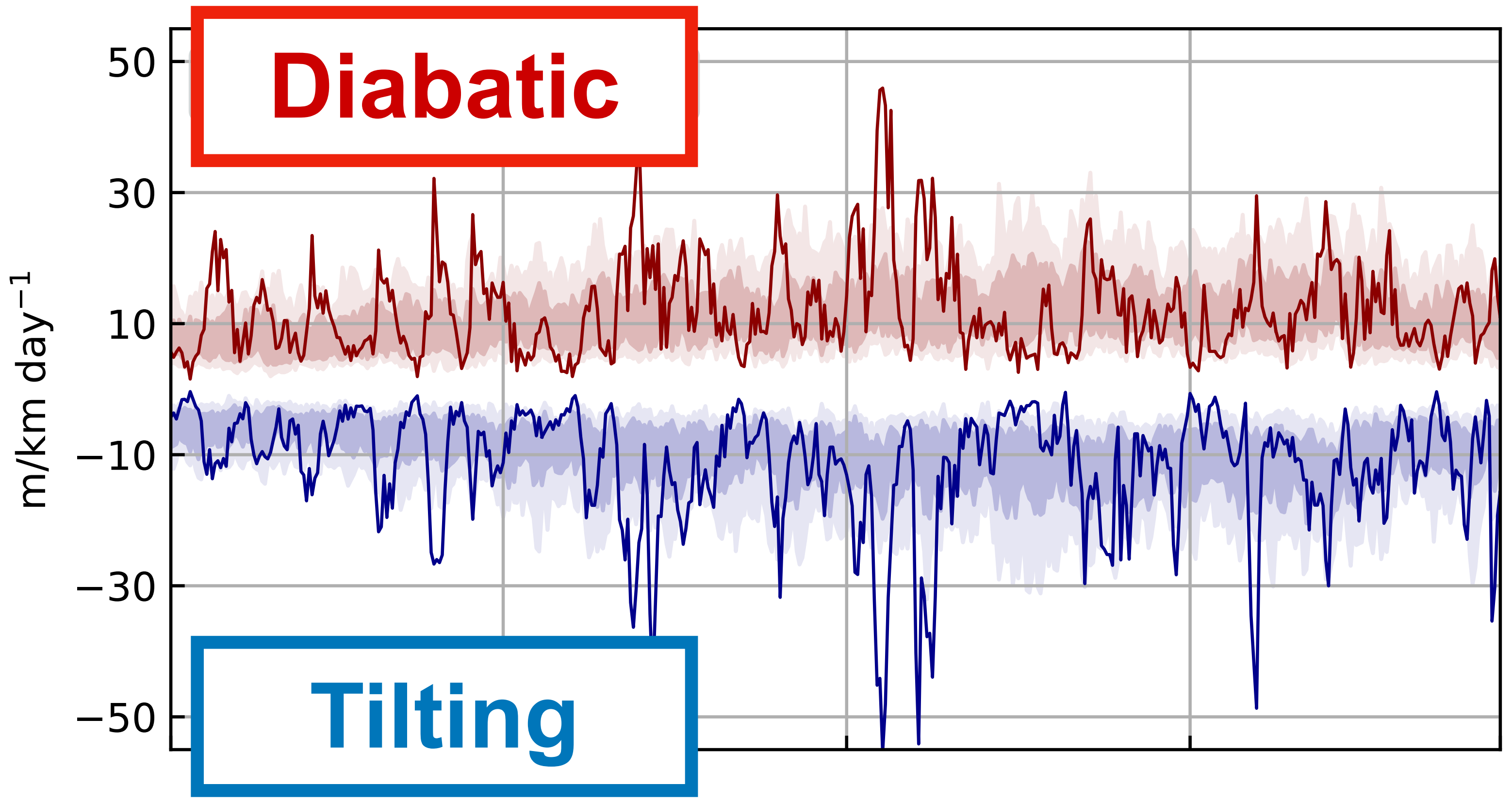


Marcheggiani and Spengler (in prep.)

Baroclinicity in Storm Tracks



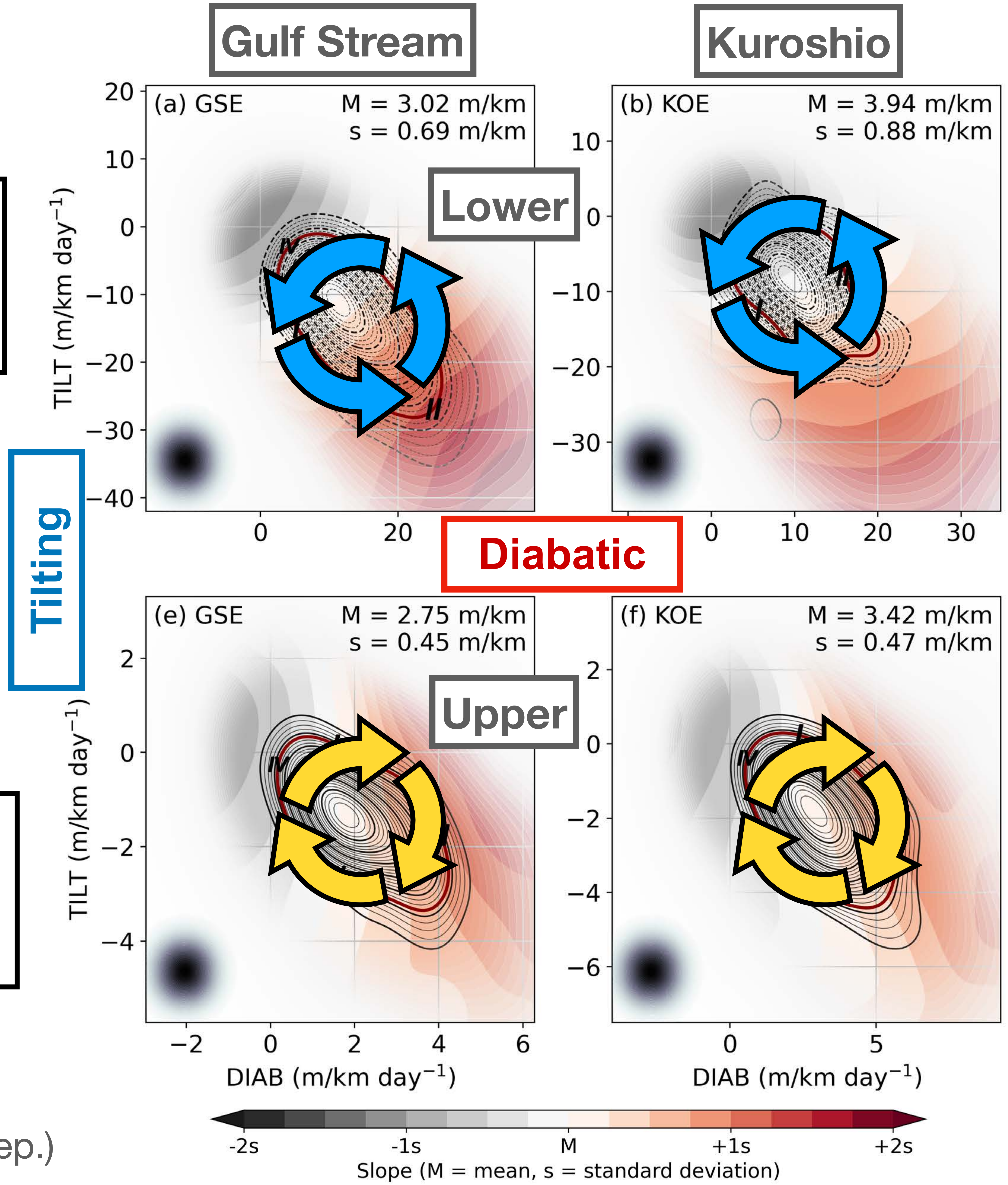




Lower Troposphere
Tilting leads diabatics
Typical Cold Air Outbreaks

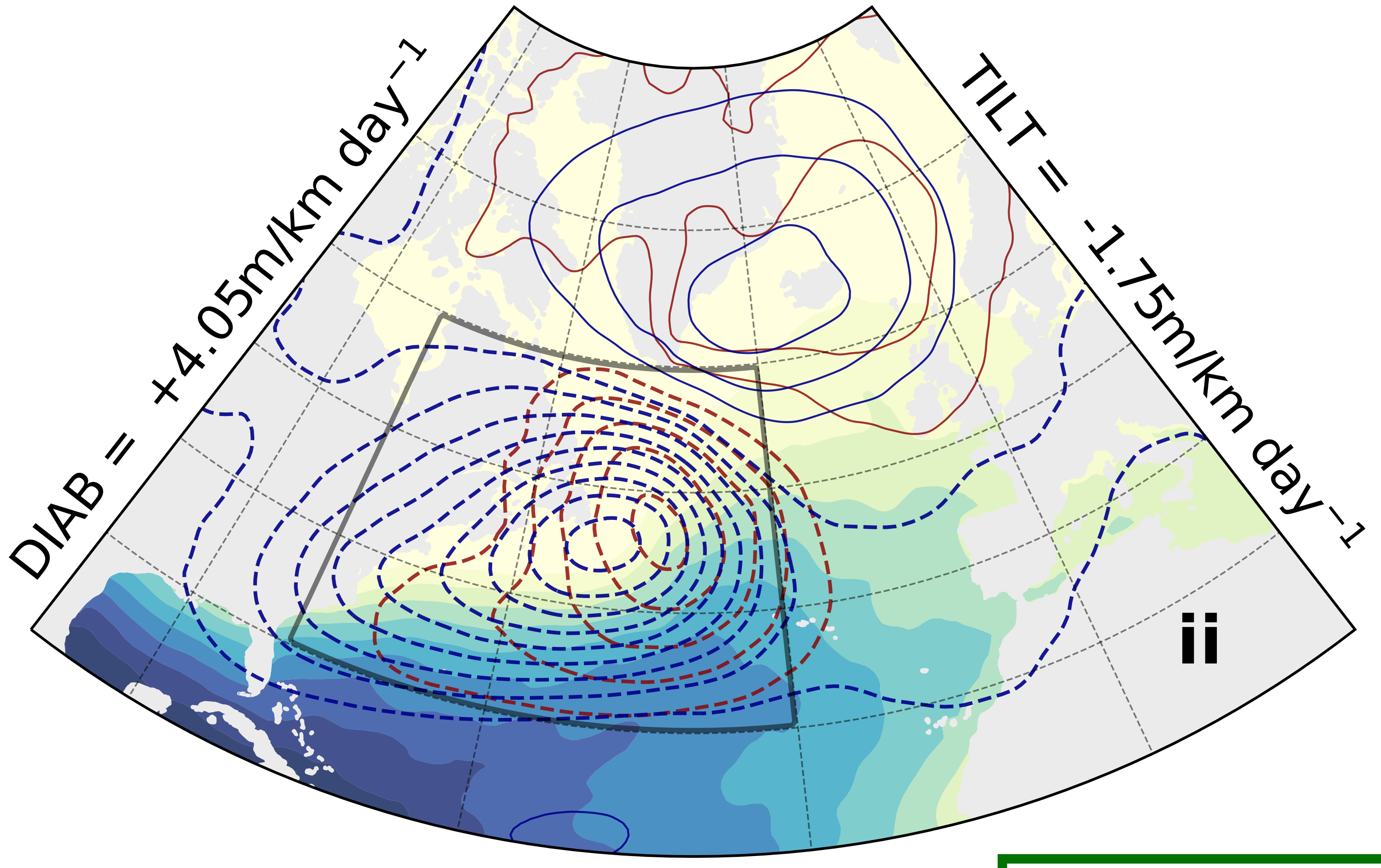
Upper Troposphere
Diabatic leads tilting
Latent heating in Cyclone

Marcheggiani and Spengler (in prep.)



Baroclinicity in Storm Tracks

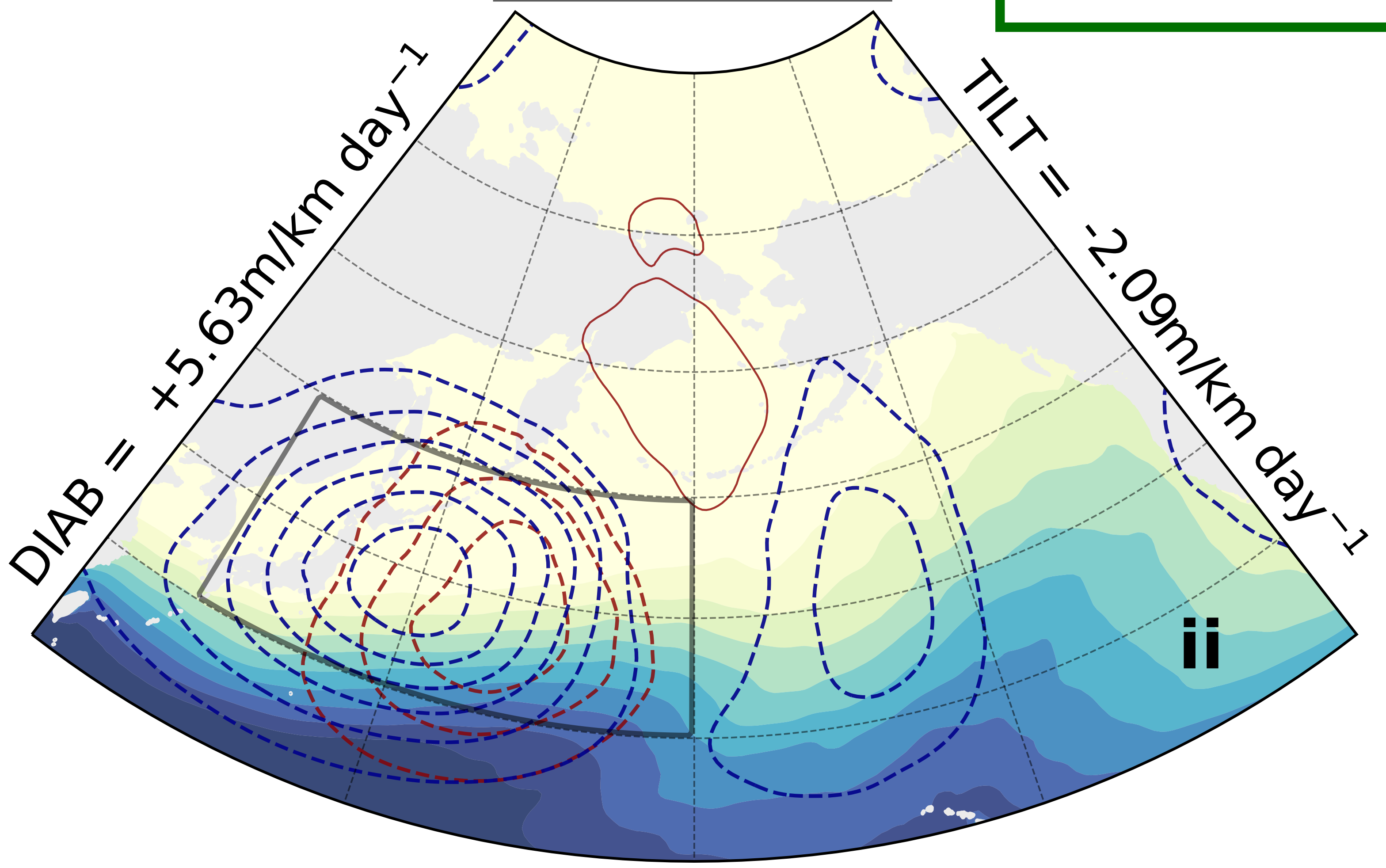
Gulf Stream



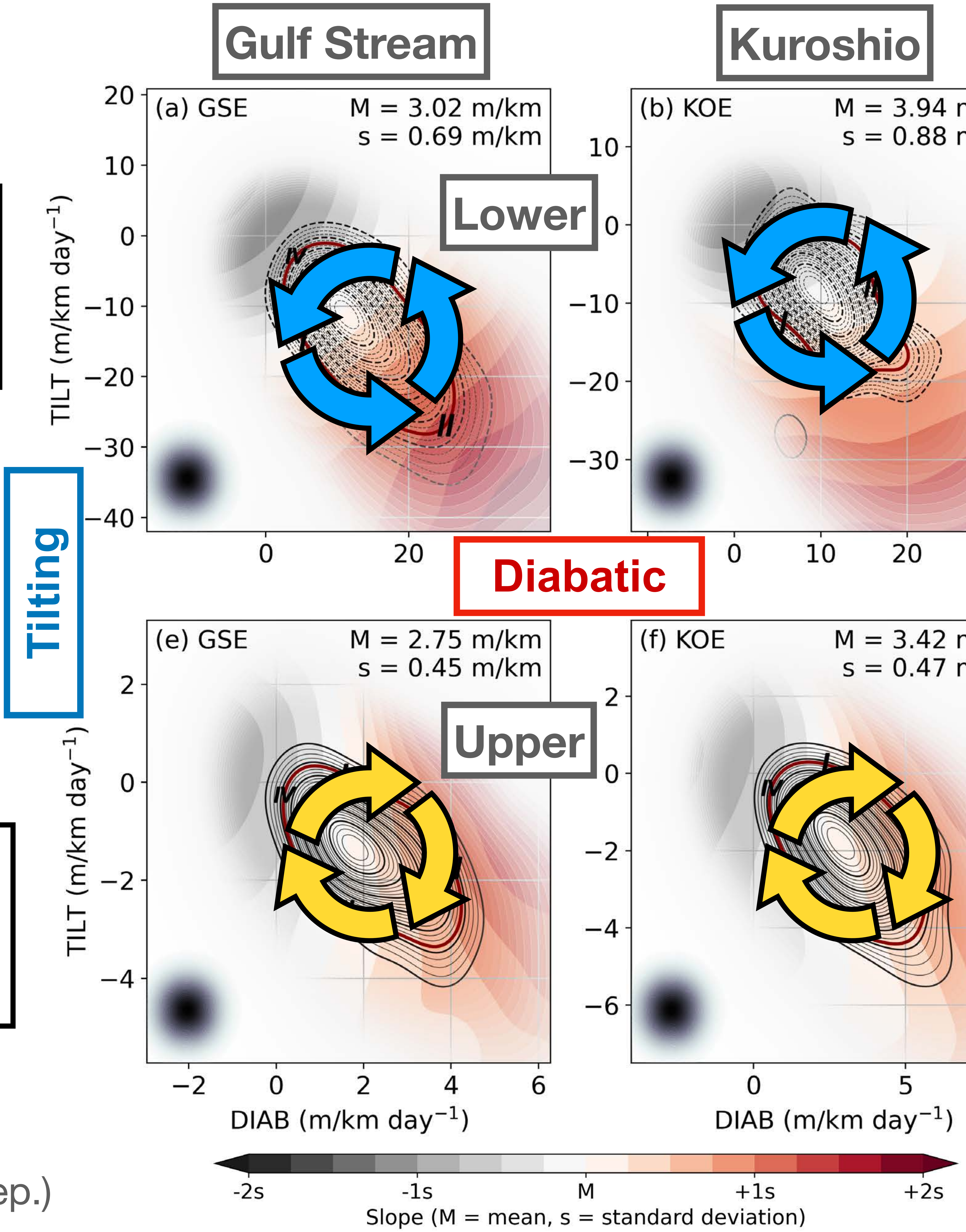
Lower Troposphere
Tilting leads diabatics
Typical Cold Air Outbreaks

Increased moisture into storm track

Kuroshio

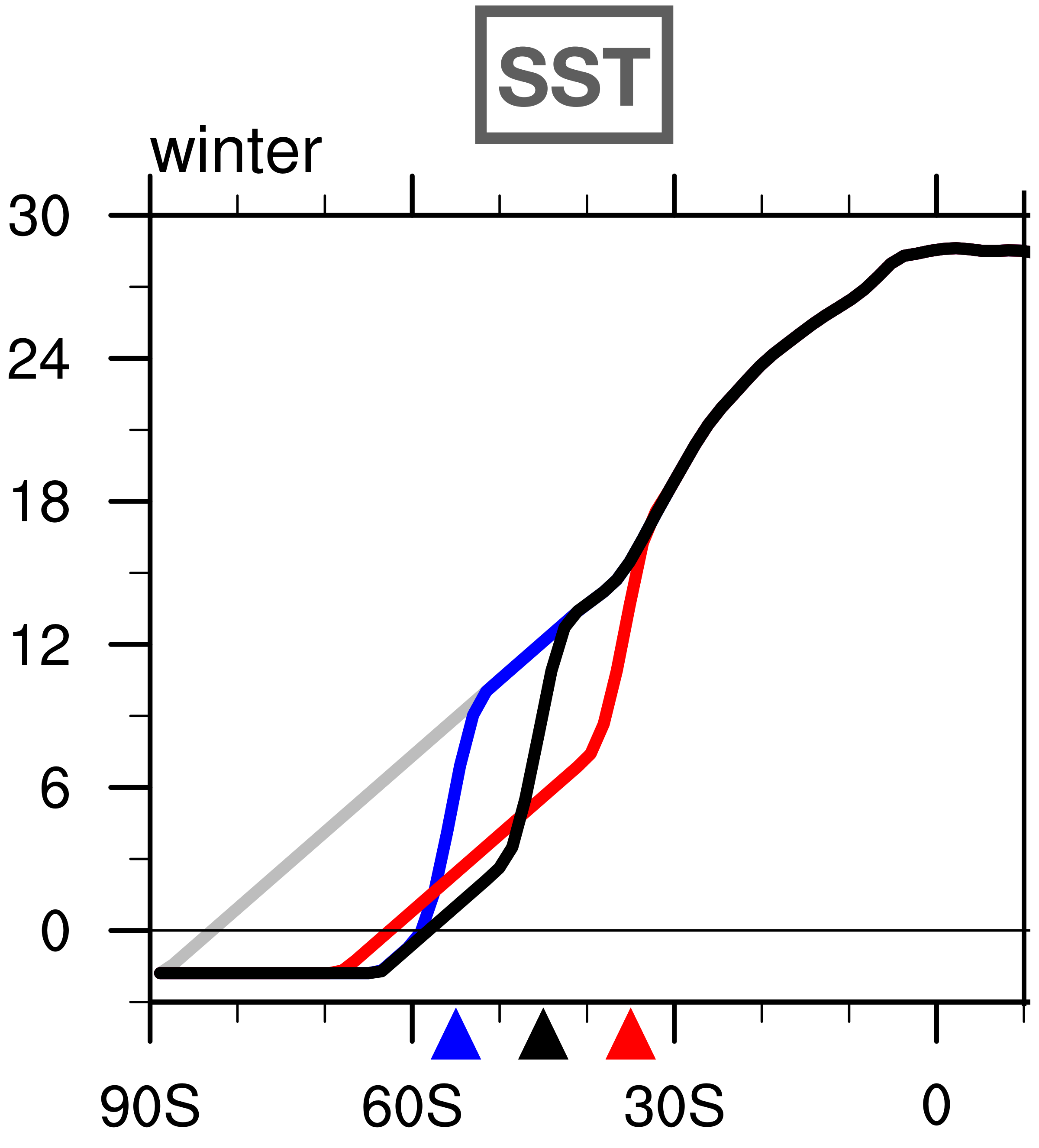


Upper Troposphere
Diabatic leads tilting
Latent heating in Cyclone

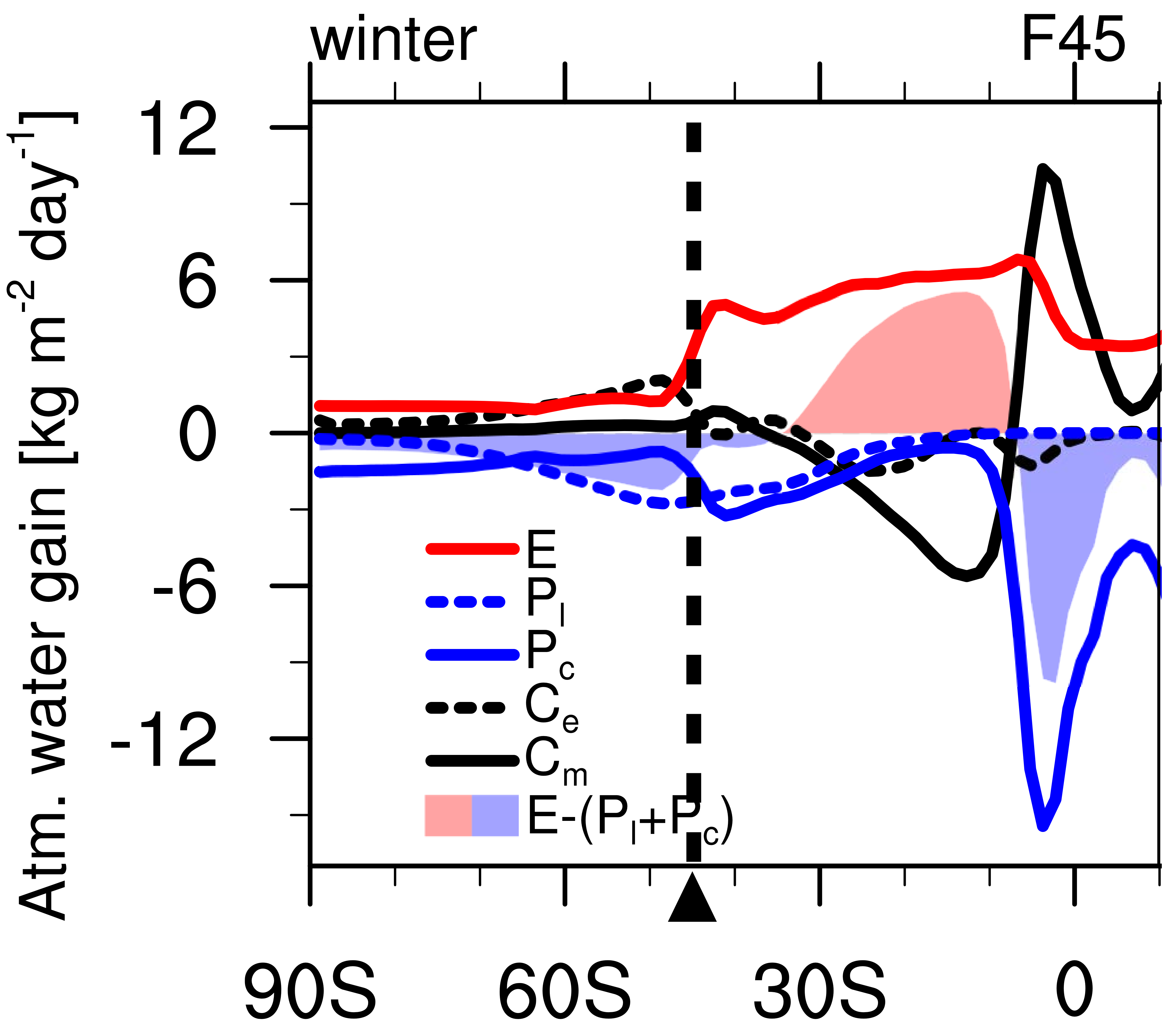


Marcheggiani and Spengler (in prep.)

SST - Water Cycle - Storm Tracks



SST resembling front at different latitudes

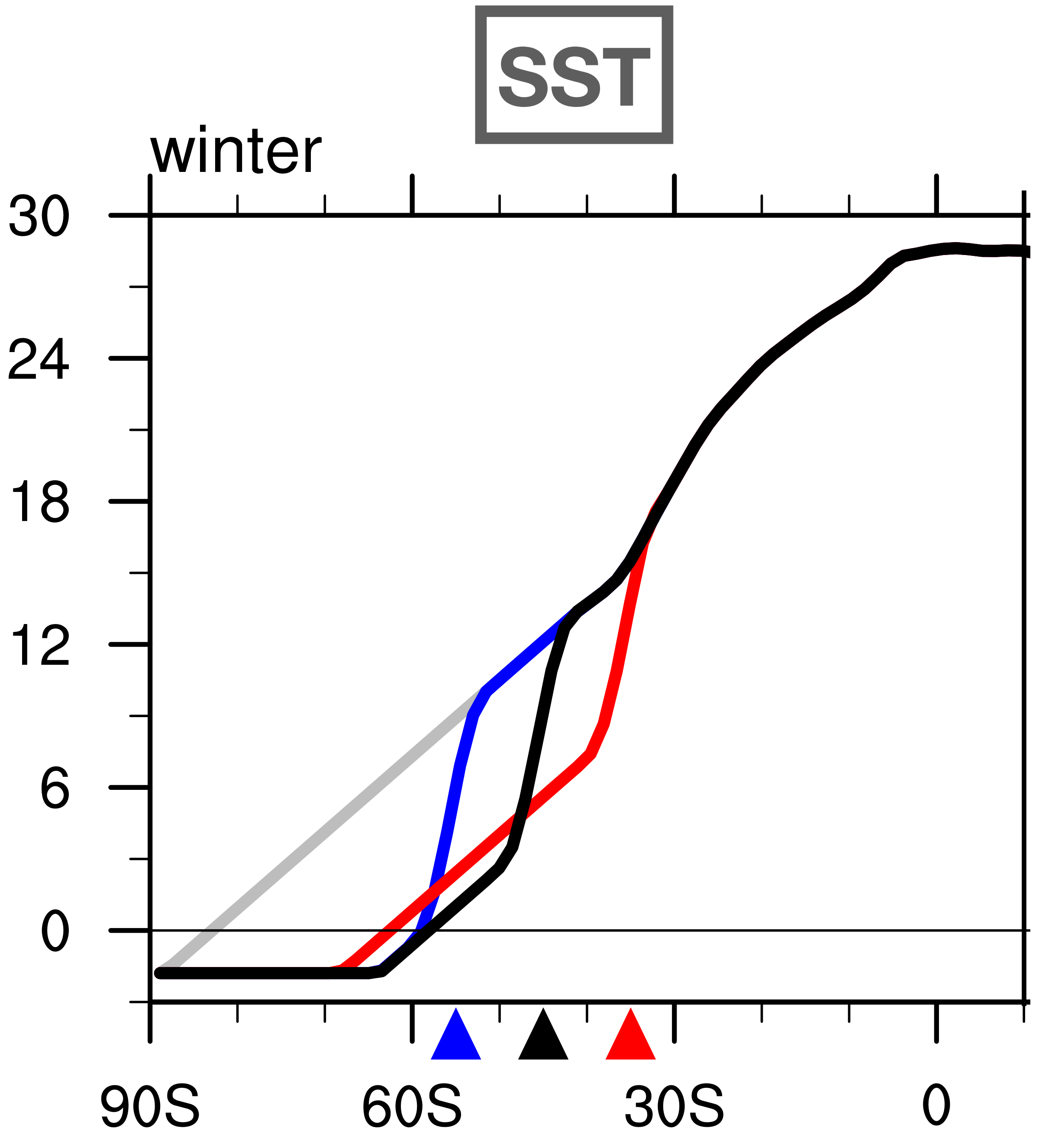


Water cycle

Transition in evaporation and eddy moisture convergence at front

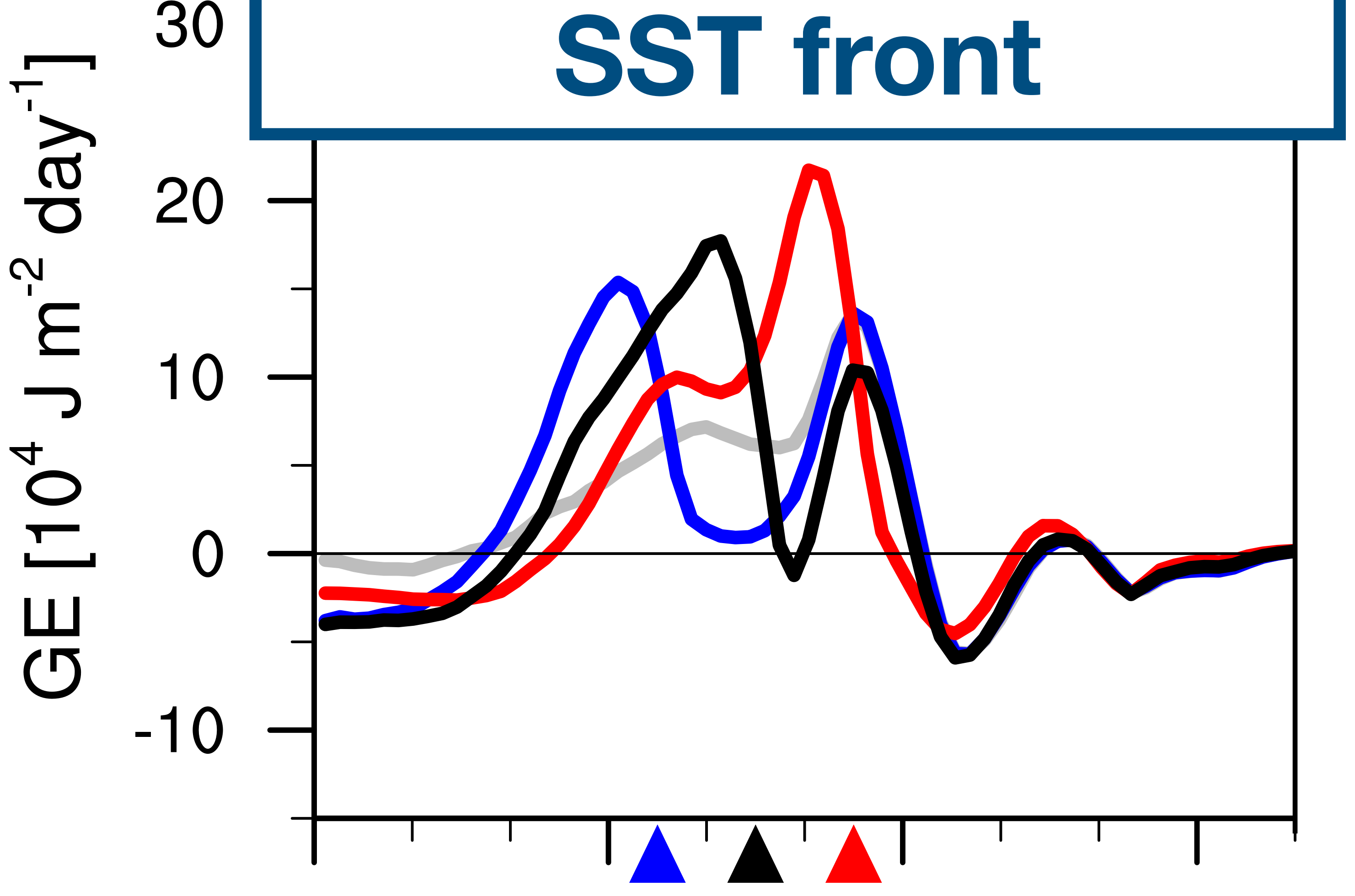
Ogawa and Spengler (in prep.)

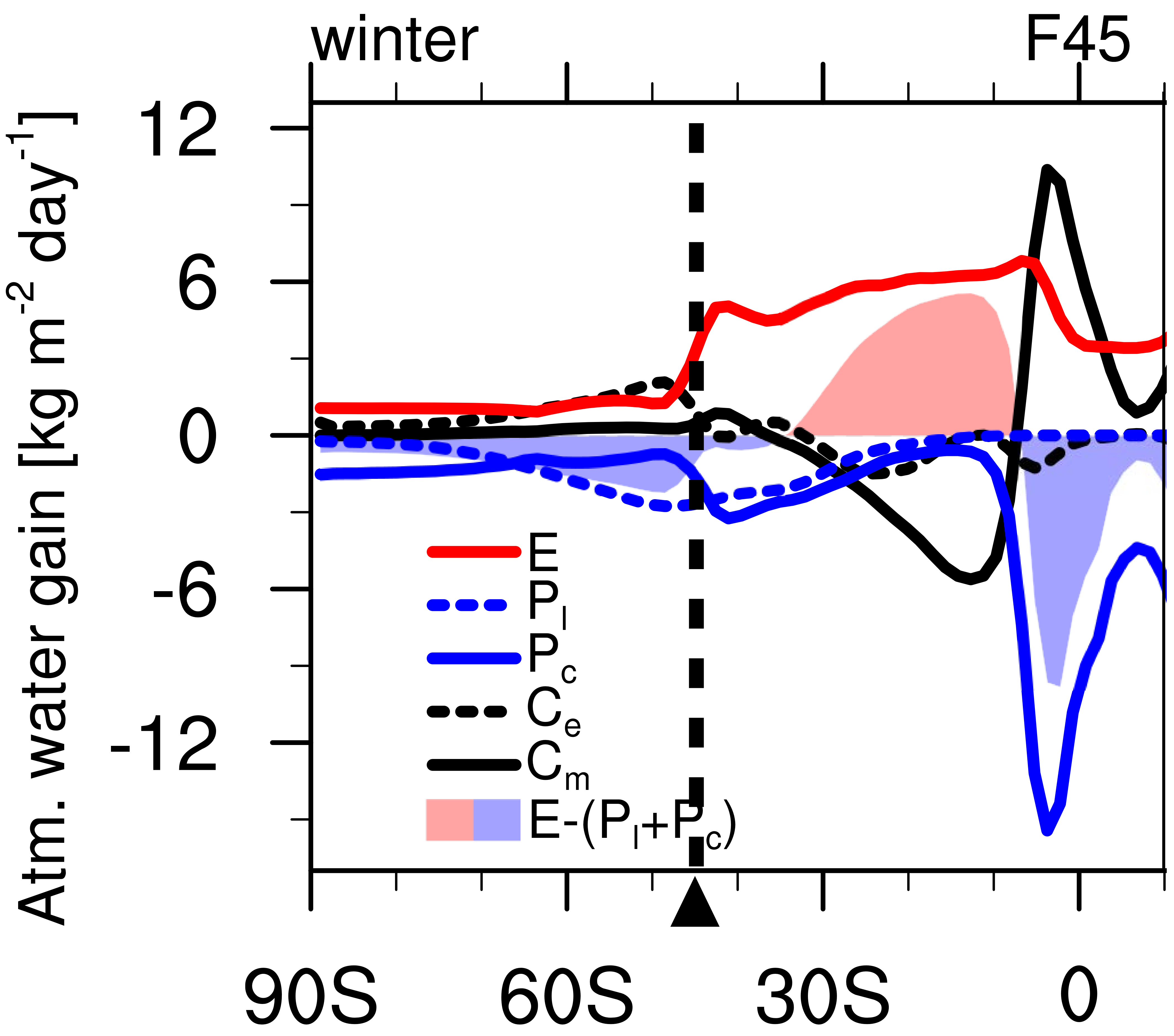
SST - Water Cycle - Storm Tracks



SST resembling front at different latitudes

Diabatic EAPE generation along SST front





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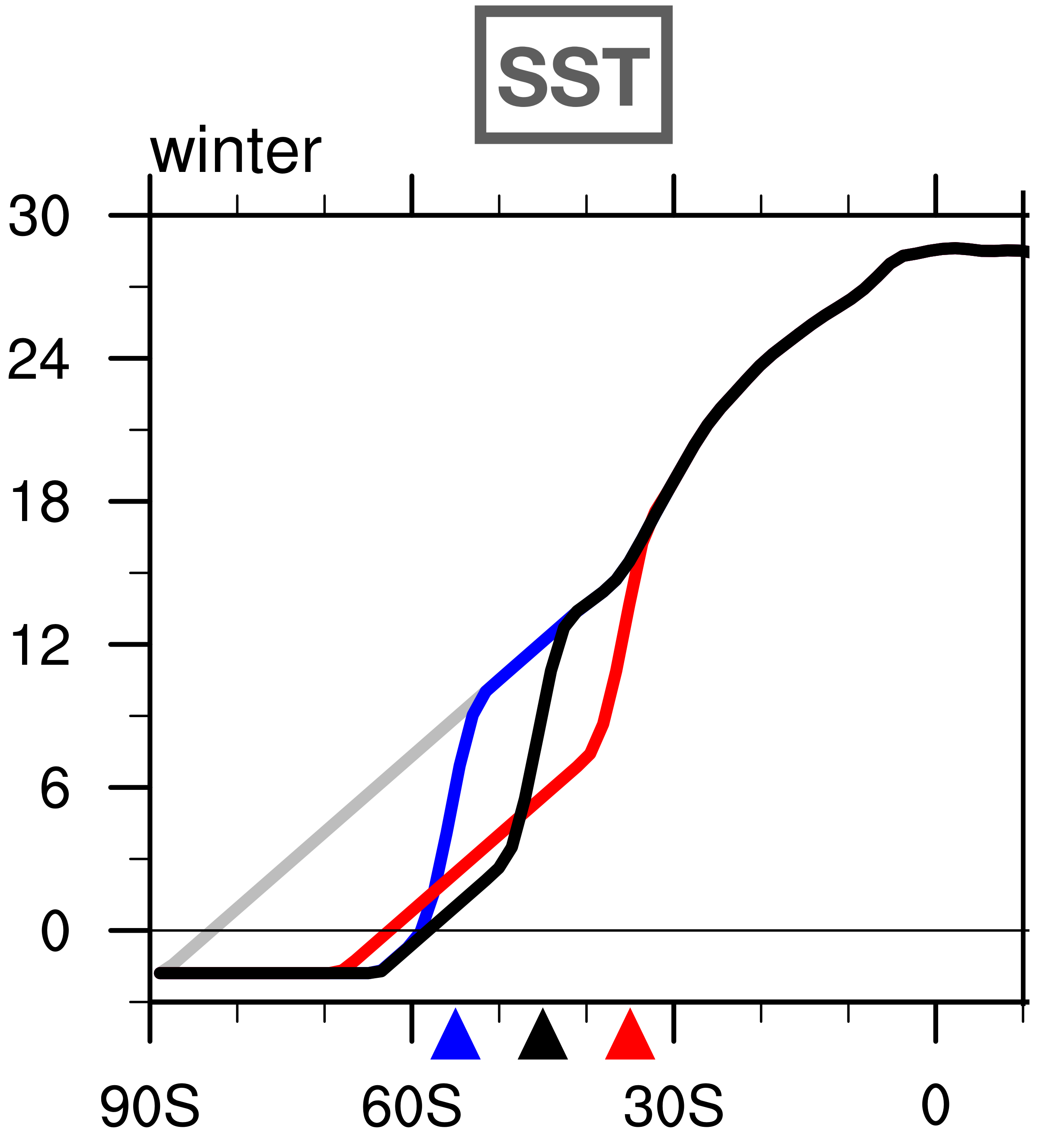
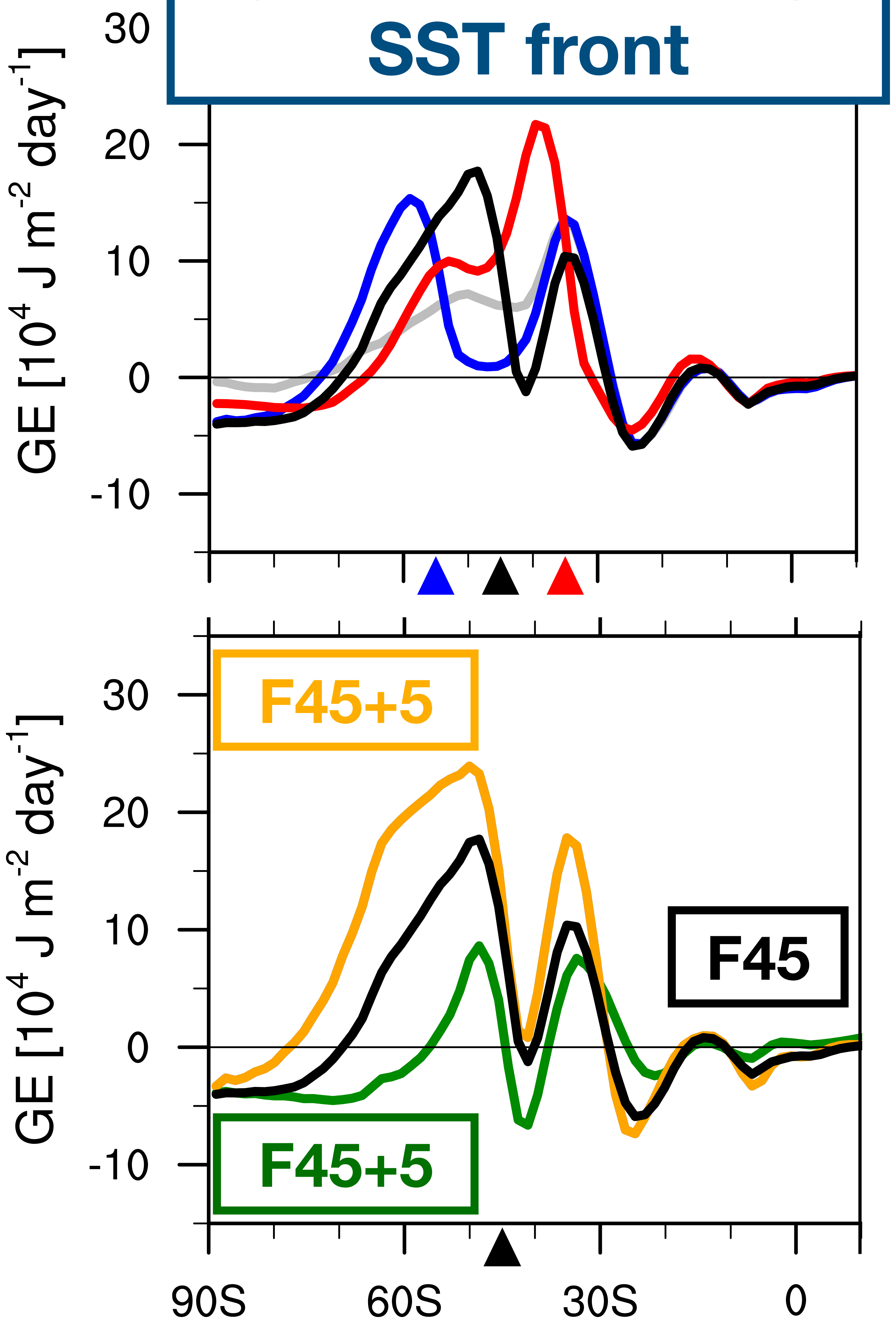
SST - Water Cycle - Storm Tracks

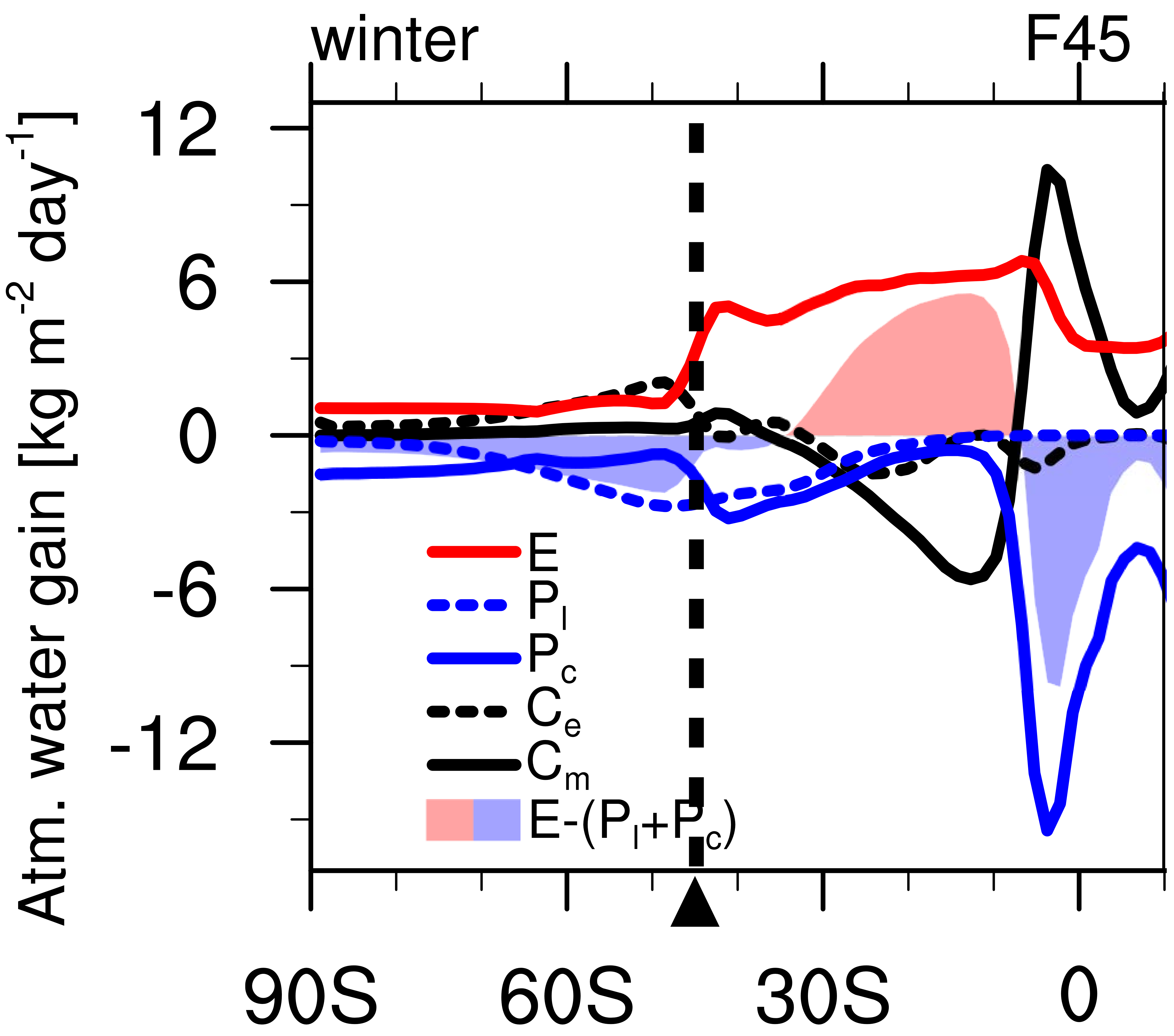


SST resembling front at different latitudes

Diabatic EAPE generation along SST front



Diabatic EAPE generation scales with SST



Water cycle
Transition in evaporation and eddy moisture convergence at front

Ogawa and Spengler (in prep.)

Conclusions

Extratropical cyclones mainly influenced *indirectly* by surface fluxes through changes in latent heat release associated with SST downstream

Haualand and Spengler (2020) Bui and Spengler (2021)
Tsopouridis, Spensberger, and Spengler (2020a,b)

Diabatic frontogenesis along SST front mainly in absence of atmospheric fronts

Reeder, Spensberger, and Spengler (2021)

Climatological differences when smoothing SST mainly attributable to absence of cyclones

Tsopouridis, Spengler, and Spensberger (2021)

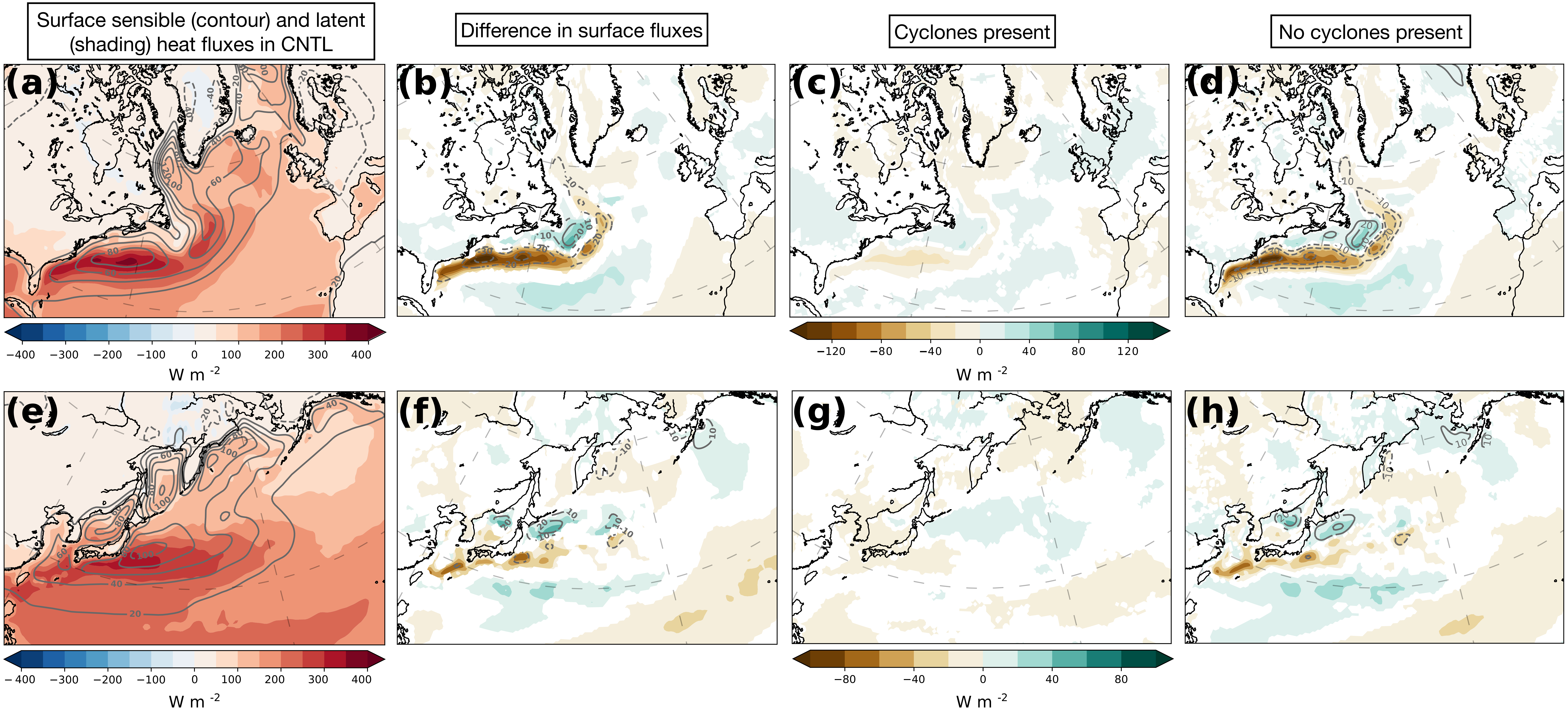
Diabatics play leading role in storm track position and intensity driven by water cycle associated with SST.

Ogawa and Spengler (in prep.) Marcheggiani and Spengler (in prep.)
Papritz and Spengler (2015)

Atmosphere-Ocean interactions occur on *sub-weekly* timescales. Cold air outbreaks play a significant role in sensible and latent heat exchange

Ogawa and Spengler (2019)

What if the SST fronts are smoothed?

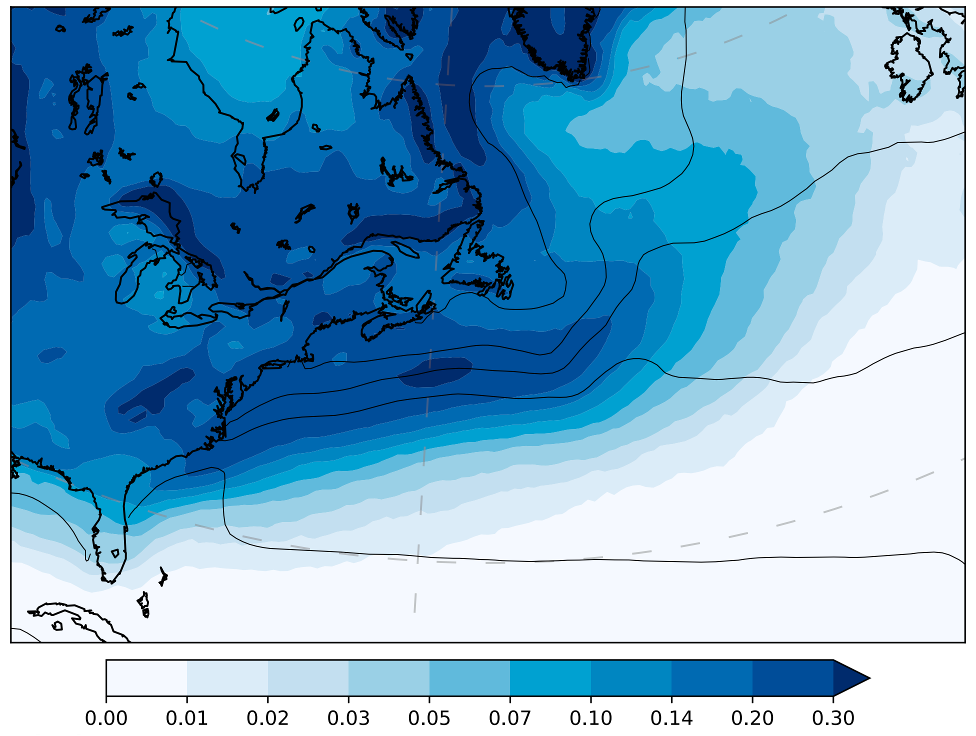


Difference in surface fluxes (and convection) CNTL-SMTH are mainly attributable to no-cyclone conditions

Tsopouridis, Spengler, and Spensberger (2021)

What about fronts?

(a)



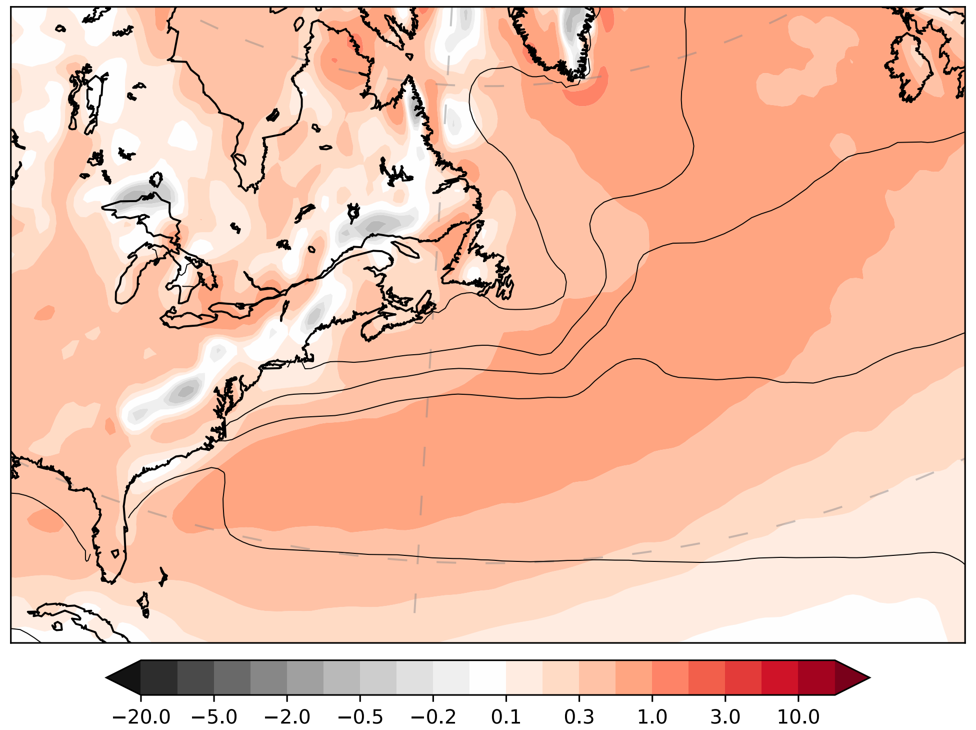
Frontal frequency and climatological contributions to frontogenesis

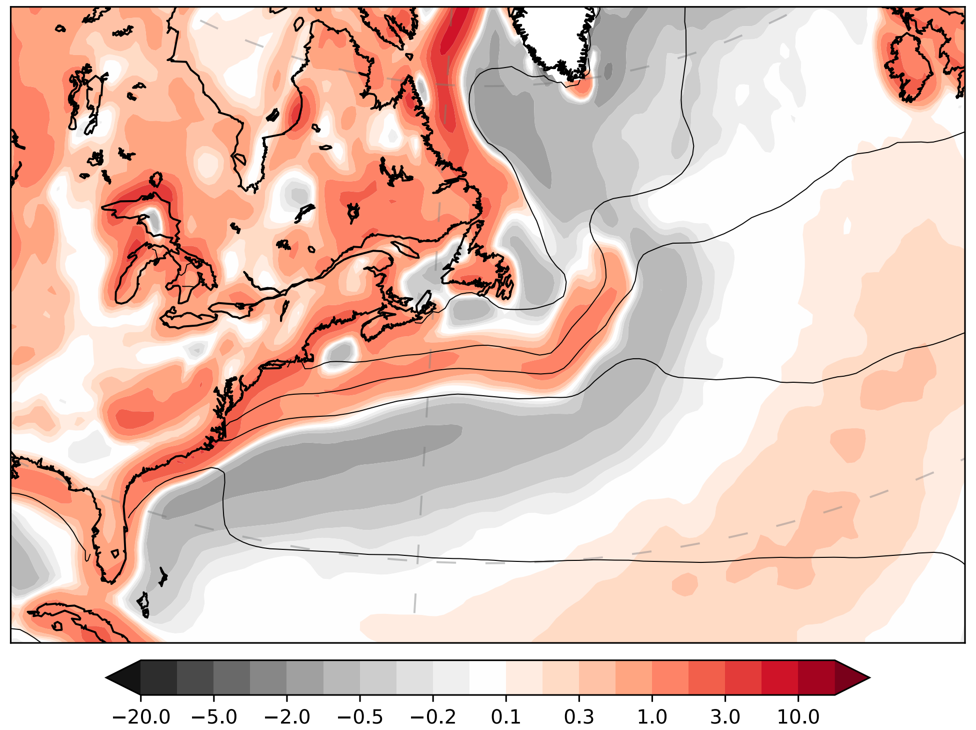
Findings based on ERA-Interim confirm idealised frontogenesis model

Significant adiabatic climatological contribution along SST front when atmospheric fronts present

Adiabatic frontogenesis

Diabatic frontogenesis

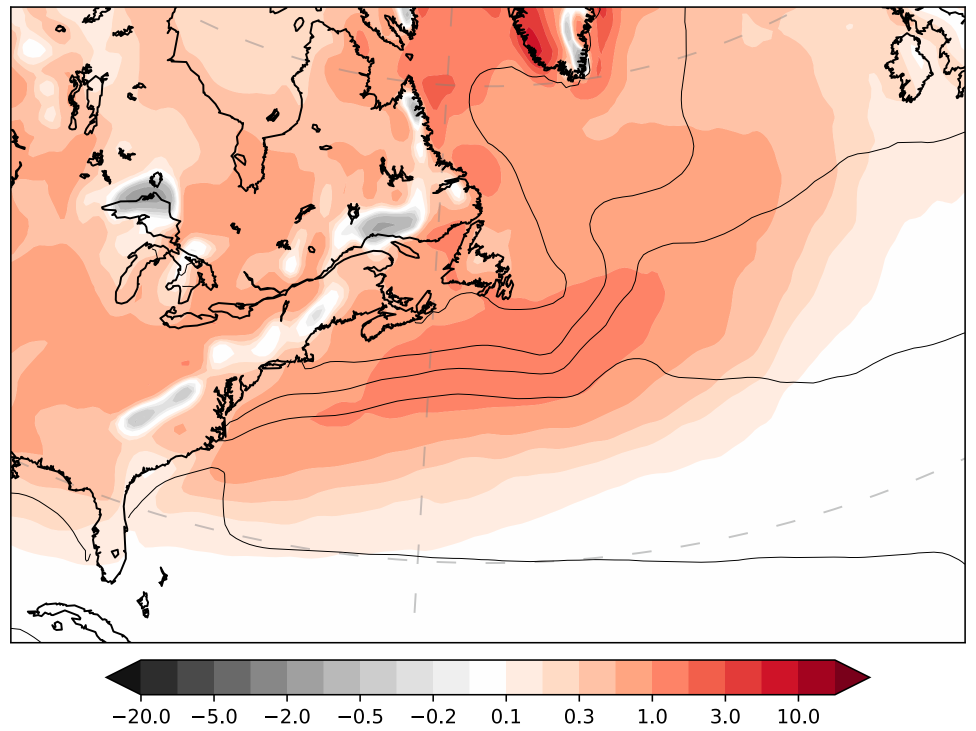




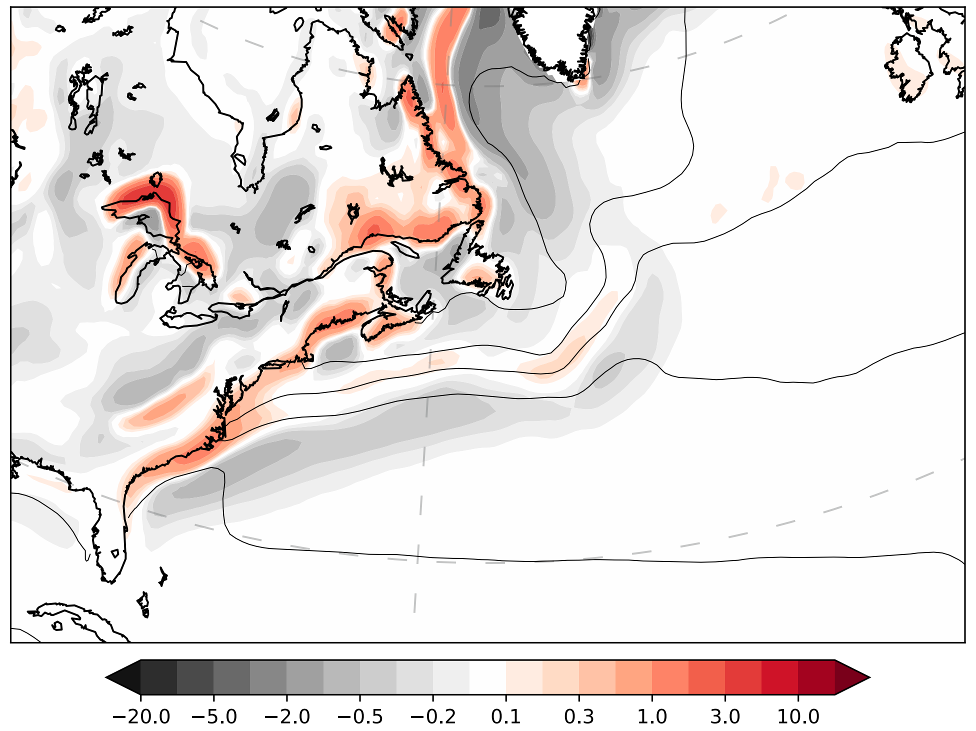
No front present

Main diabatic climatological contribution along SST front when no atmospheric front present

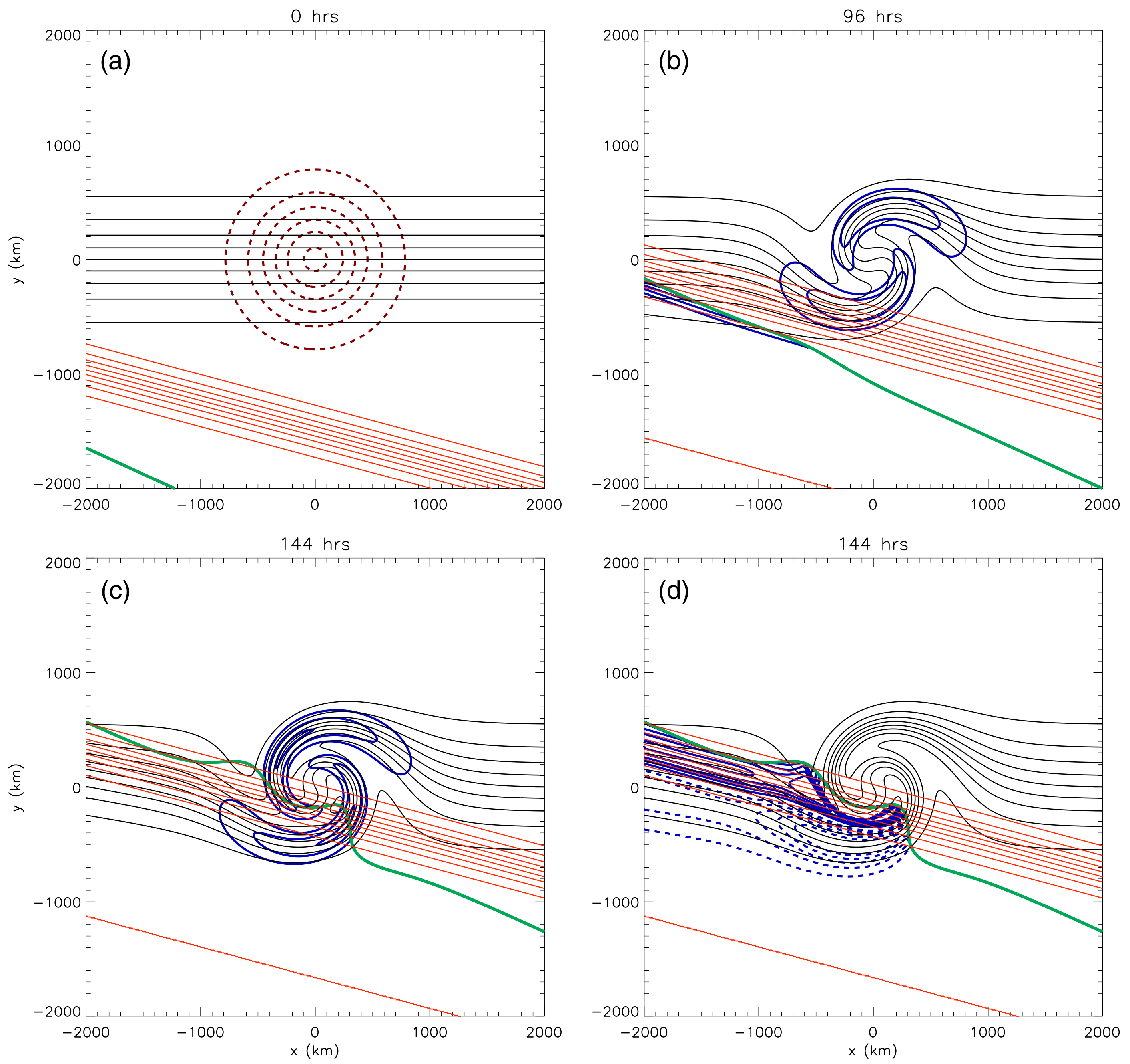
(d)



(e)



Front present



Reeder, Spensberger, and Spengler (2021)