



第五届全国中尺度气象学论坛

台风“谭美”和“康妮”(2018) 眼墙替换过程中海洋响应的不同作用

国防科技大学气象海洋学院

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2023.08.11 甘肃银川



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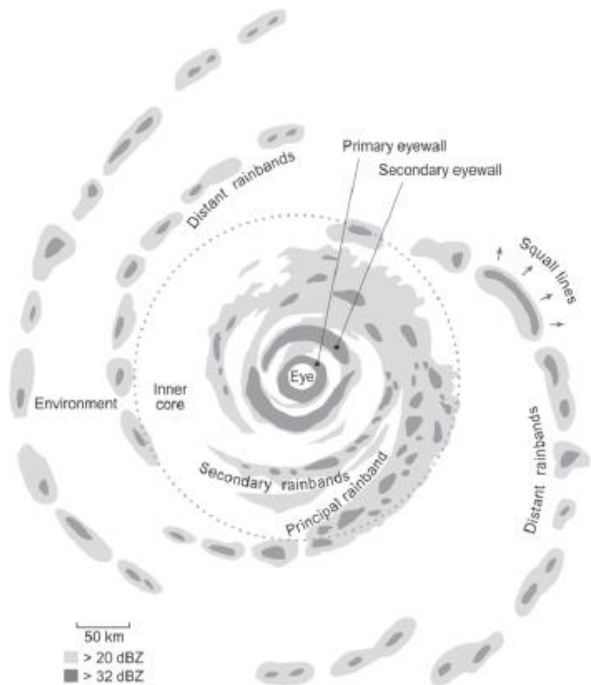
三、海洋响应对台风眼墙替换的影响

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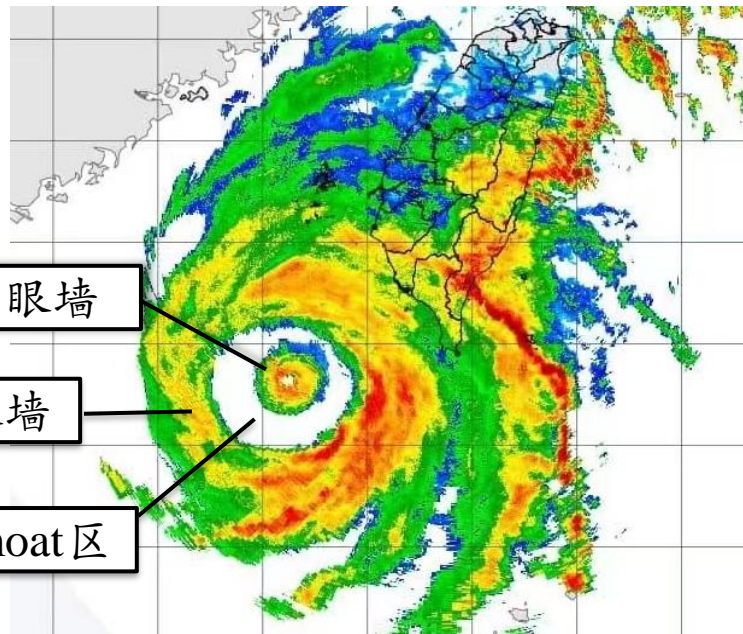
台风“杜苏芮”

台风“杜苏芮” (2305) 雷达回波图



Concentric eyewalls (CEs)

Houze, 2010



西北太平洋上80%的强台风至少经历一次双眼墙的替换过程 (ERC) (Hawkin and Helvesto, 2008)

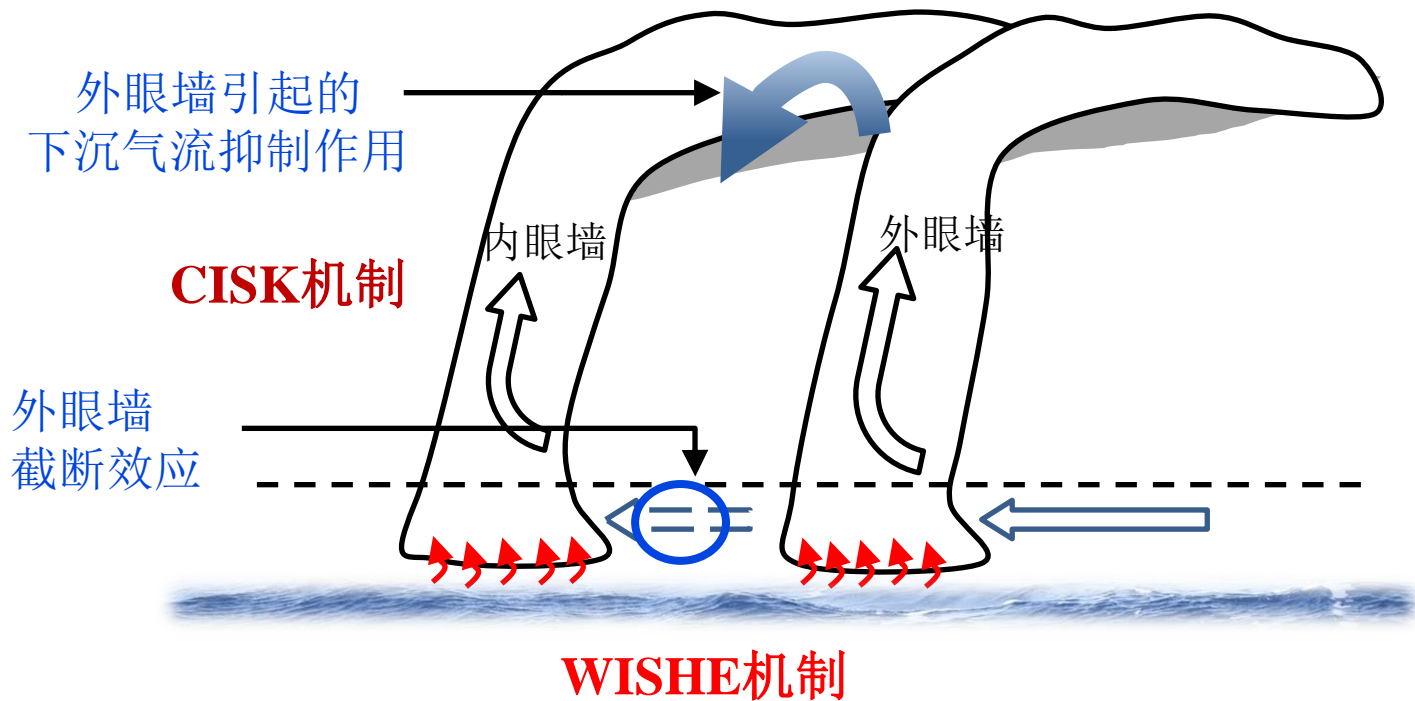


双眼墙形成 (SEF) 理论和眼墙替换 (ERC) 机制

SEF 机制	影响机制	方法	海温	参考文献
涡旋Rossby波理论	停滞半径处形成切向风的第二个极大值	理想试验	无或者恒温	Montgomery and Enagonio 1998; Chen and Yau 2001; Qiu and Tan 2013;
轴对称化理论 β -skirt 轴对称化	外围小尺度涡度偶极子旋转合并为外眼墙			Kuo et al. 2004, 2008; Terwey and Montgomery 2008; Qiu et al., 2010; ...
非绝热加热的平衡响应	非绝热加热引起的次级环流	实际台风个例模拟	常值	Rozoff et al. 2012; Sun et al. 2013; ...
边界层内非平衡动力学	边界层顶的切向风扩张和超梯度风形成			Wu et al. 2012; Huang et al. 2012; Wang et al. 2013; ...
Ekman抽吸	摩擦上升流和对流之间的正反馈关系	理想边界层试验	无	Kerpert, 2013, 2018; ...
WISHE机制	海气热通量	个例敏感试验	定常SST	Cheng and Wu 2018



眼墙替换 (ERC) 机制





眼墙替换机制

$$SH = -\rho c_p C_h(\Delta\theta) [\min(U_{\max}, U)] \quad \text{and}$$

$$LH = -\rho L_v M C_q(\Delta q) [\min(U_{\max}, U)],$$

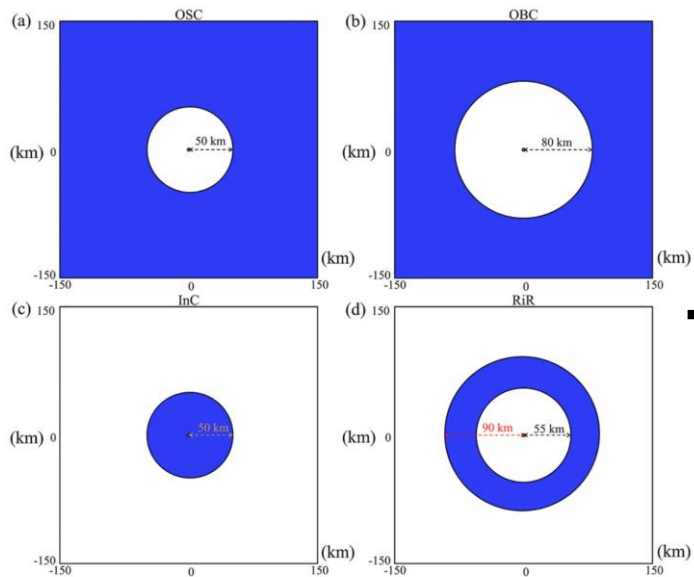
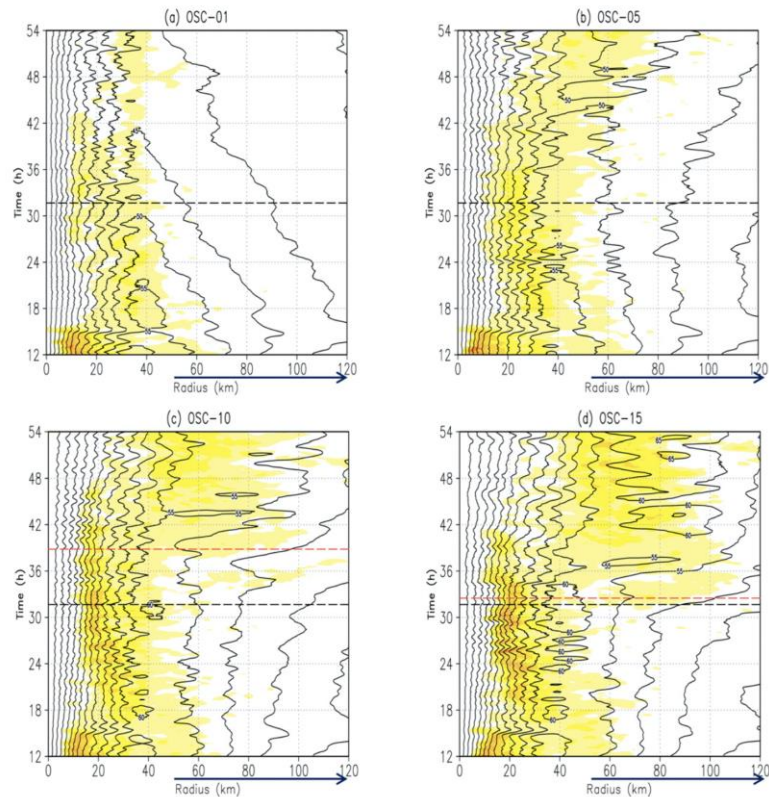
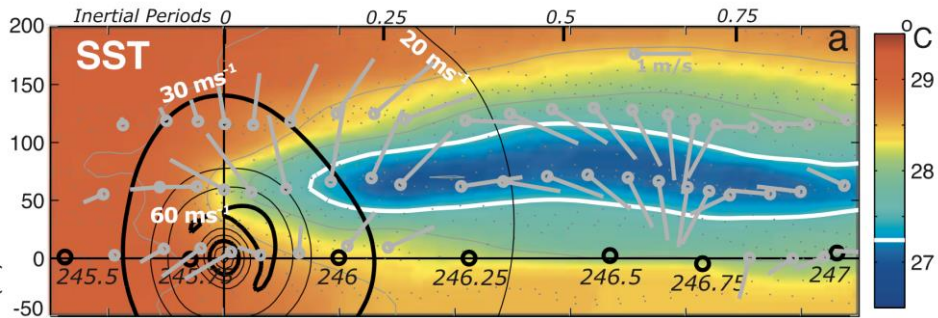


FIG. 1. Experiment designs of the sensitivity experiments. The blue area indicates the region in which WISHE is suppressed in (a) OSC, (b) OBC, (c) InC, and (d) RiR.

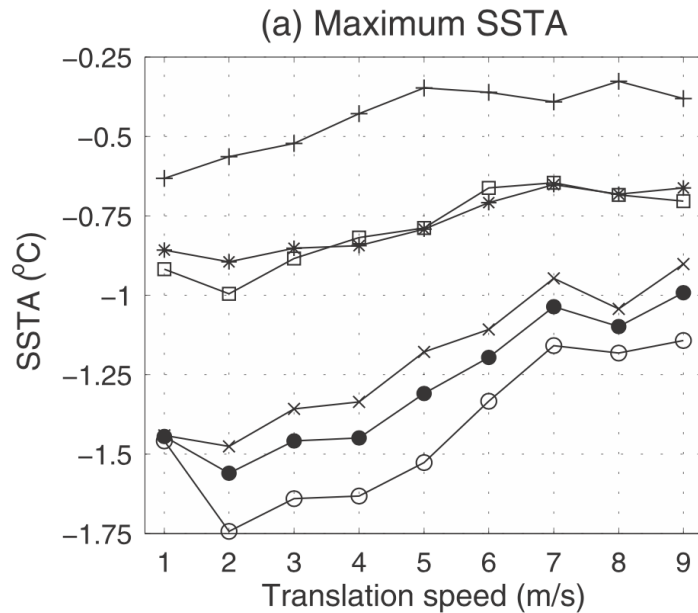




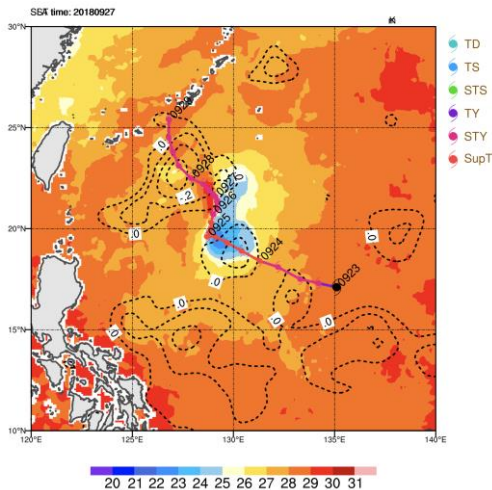
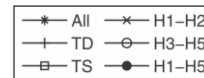
海洋对台风的响应——冷尾流



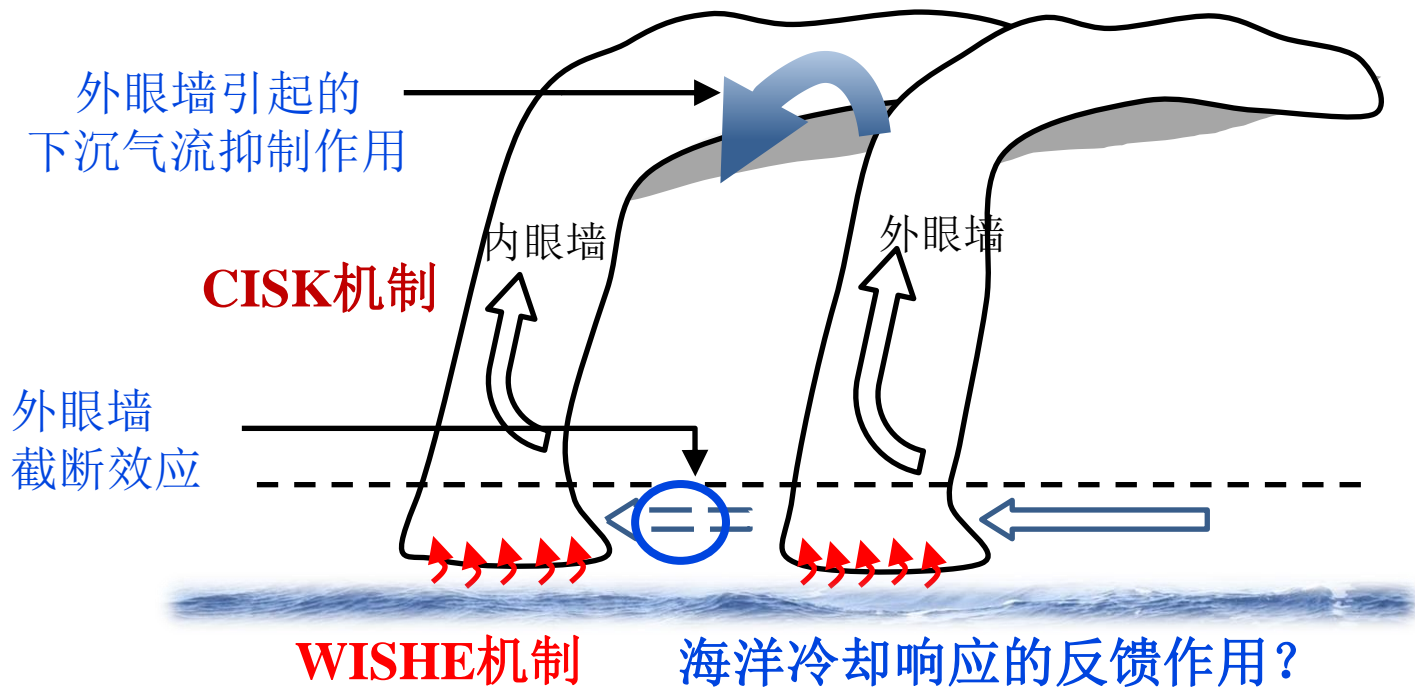
飓风France冷尾流 D'Asaro et al., 2007@GRL



SST降温与台风移速统计关系
Mei and Pasquero 2013@JCLI



谭美台风
冷尾流



海洋局地响应对台风双眼墙ERC过程的反馈调制作用？



目录

一、研究背景

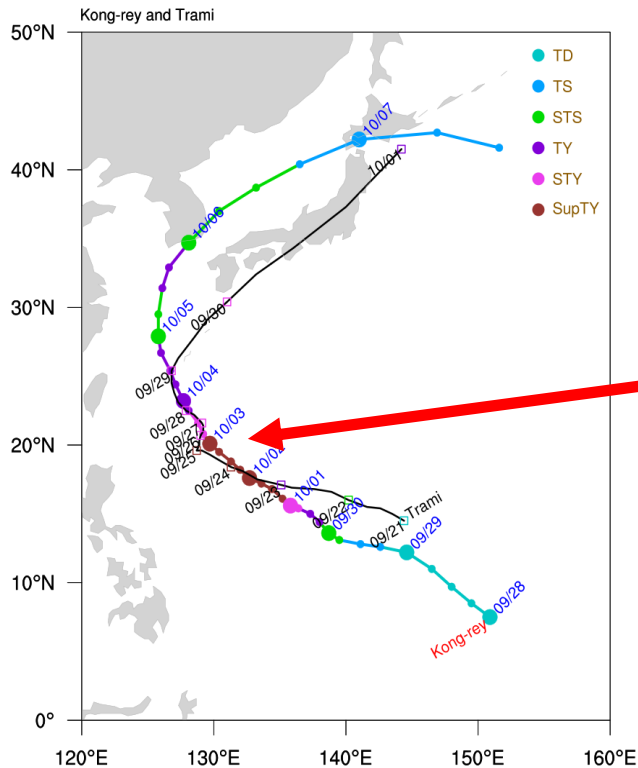
二、台风“谭美”和“康妮”

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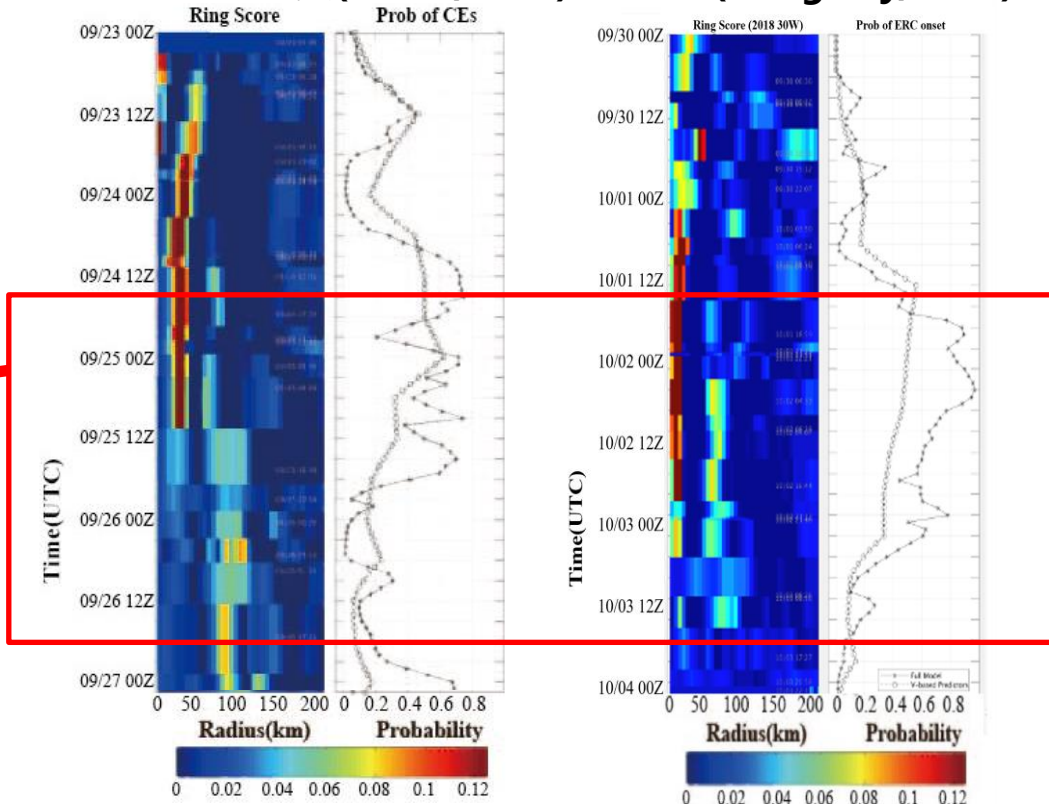
“谭美”和“康妮”台风



谭美(1824) 和康妮(1825)台风路径

谭美(Trami,1824)

康妮(Kong-rey,1825)



CMISS:基于卫星微波观测的M-PERC产品



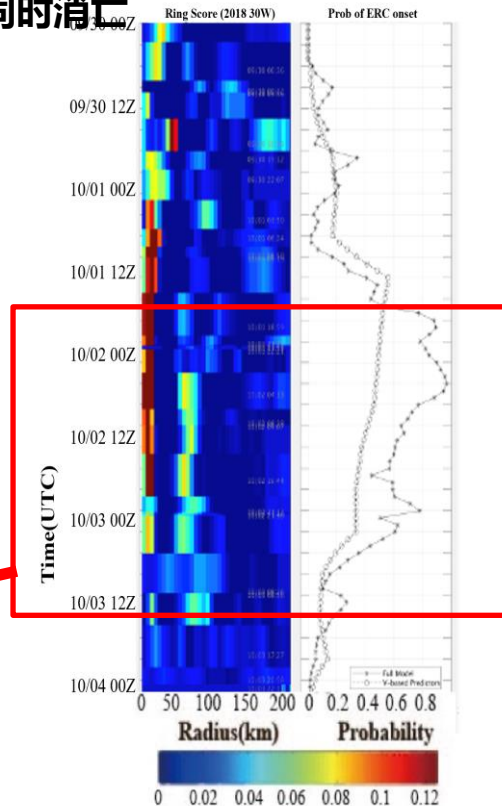
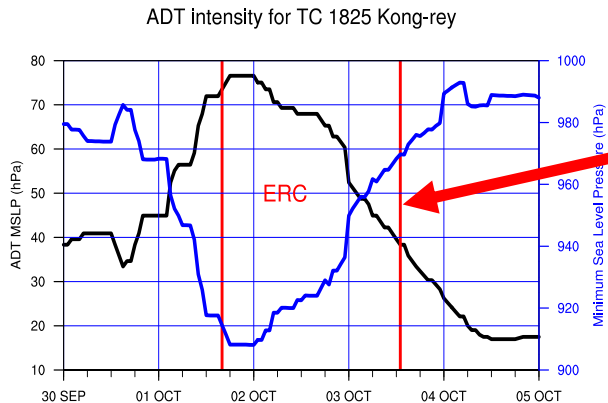
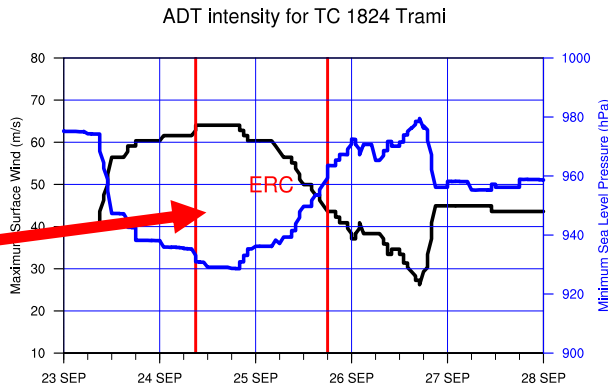
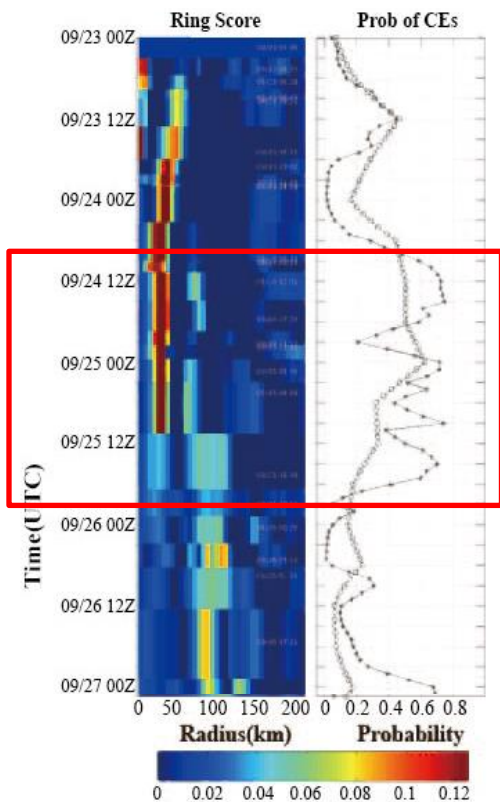
“谭美”和“康妮”台风ERC的异同

谭美(Trami,1824)

相同：台风快速减弱过程完成ERC

区别：谭美内眼墙突然消亡，康妮内外眼墙几乎同时消亡

康妮(Kong-rey,1825)

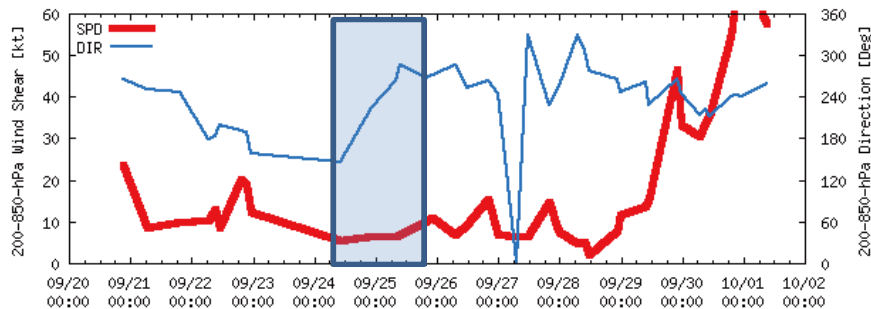


CMISS:M-PERC

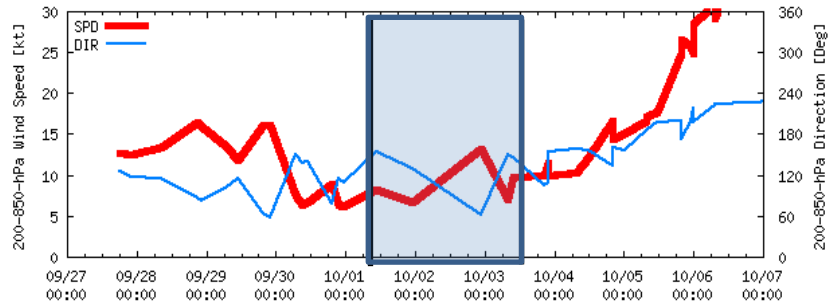


大气条件：风垂直切变

“谭美”



“康妮”

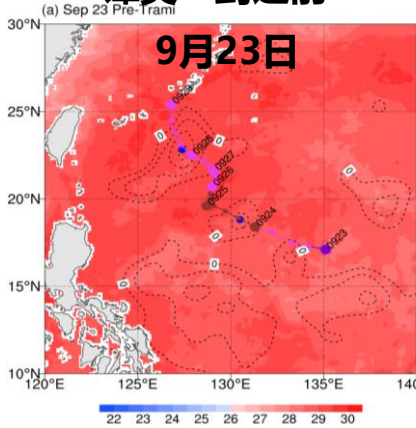


弱风切变 (5~7m/s) 有利于台风强度维持。
为什么台风快速减弱且双眼墙发生剧烈变化？

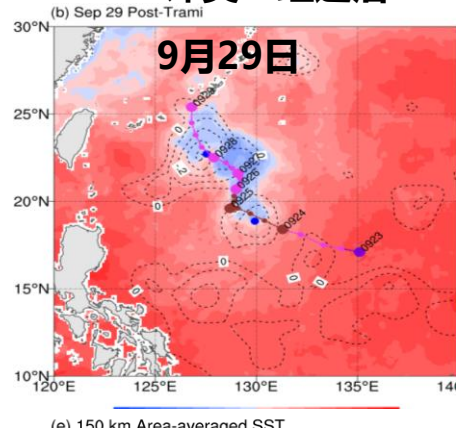


海洋条件

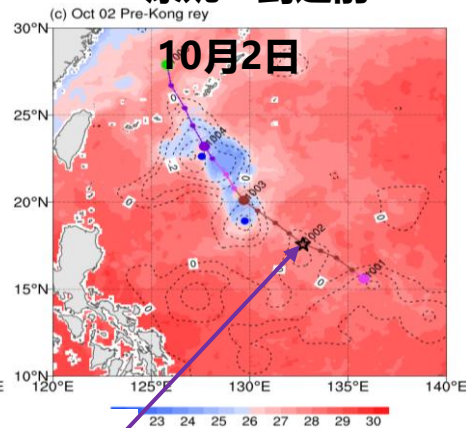
“谭美” 到达前



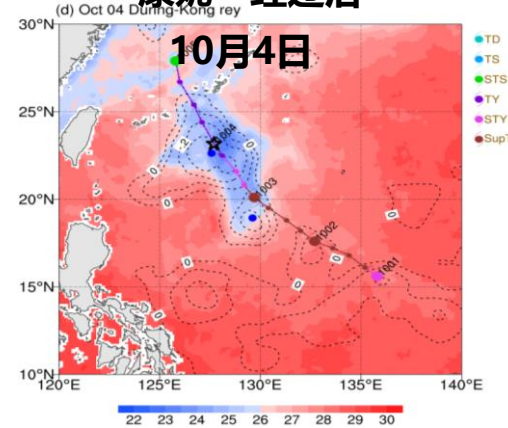
“谭美” 经过后



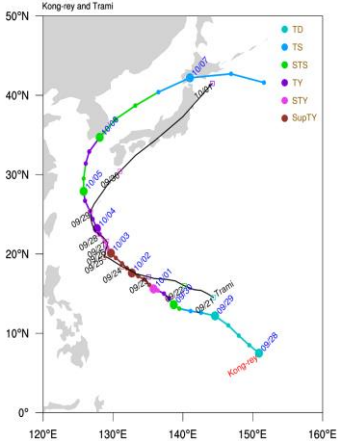
“康妮” 到达前



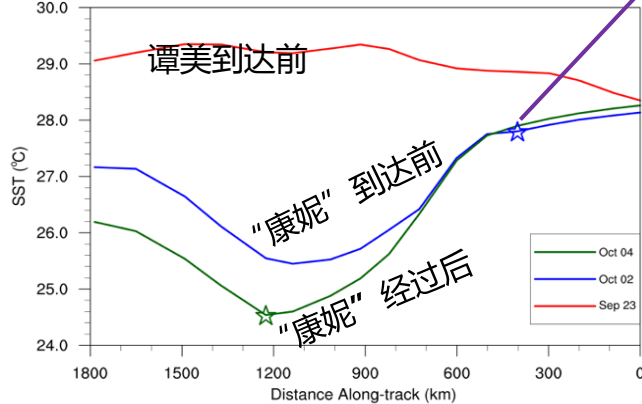
“康妮” 经过后



- TD
- TS
- STS
- TY
- STY
- SupTY



(e) 150 km Area-averaged SST



REMSS SST (填色) SLA (等值线)

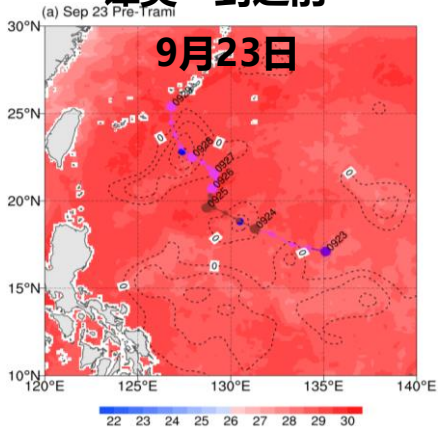
“谭美” 移过后，生成强海洋冷尾流。
“康妮” 路径与Trami产生冷尾流重合。

沿“康妮”台风路径的距离

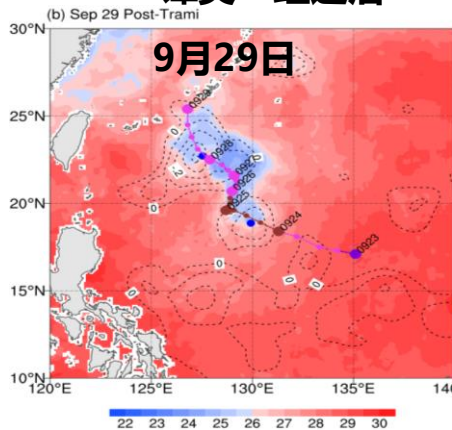
(10月1日00时)



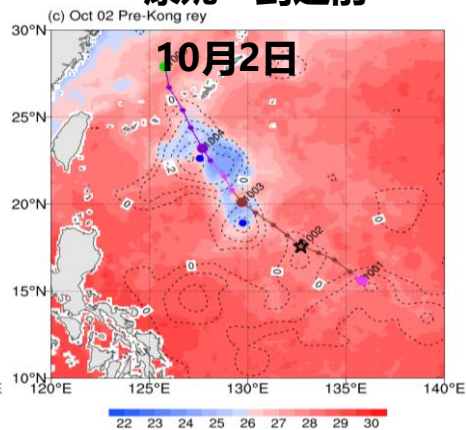
“谭美” 到达前



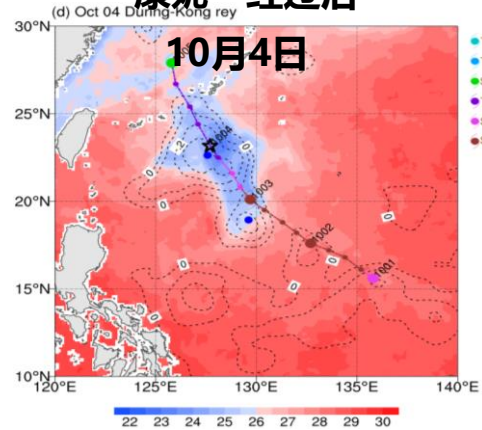
“谭美” 经过后



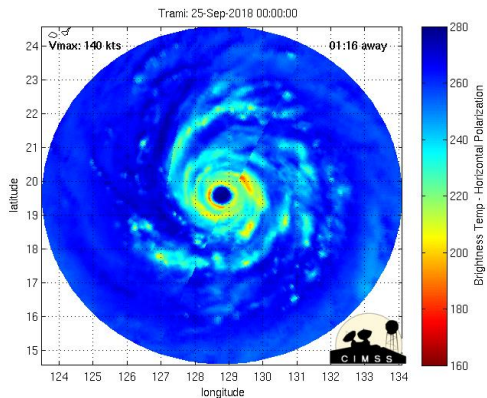
“康妮” 到达前



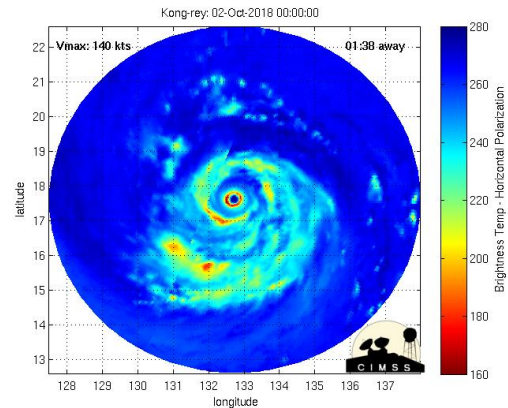
“康妮” 经过后



TD
TS
STS
TY
STY
SupT



科学问题：海洋响应对“谭美”和“康妮”快速减弱和ERC过程中起到什么作用？





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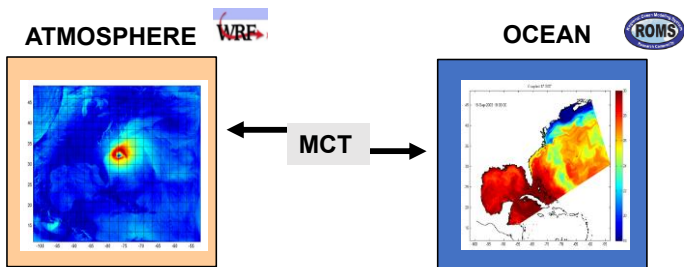
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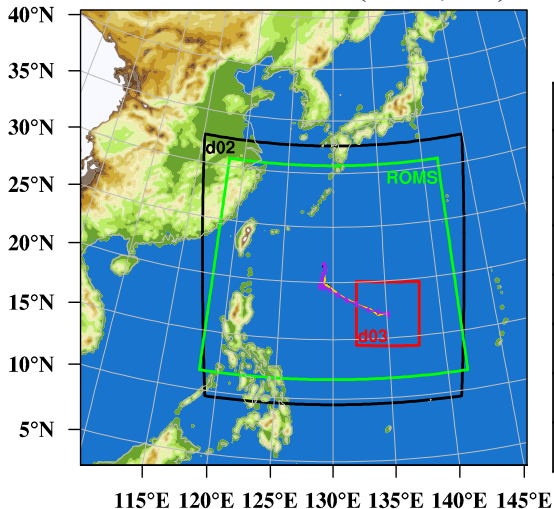


海气耦合模式及参数配置

COAWST



(Warner, 2012)



- WRF 三层网格嵌套(15km, 5km, 1.67km), 初边界为FNL再分析资料
- ROMS模式单层网格(5km), 初边界资料为HYCOM再分析资料

WRF模式参数设置

垂直层数	53层
积云对流方案	Kain-Fritsch scheme
微物理方案	Lin
长波辐射方案	RRTMG
短波辐射方案	RRTMG
陆面过程方案	Noah
近地面层方案	Revised MM5 M-O
边界层方案	YSU

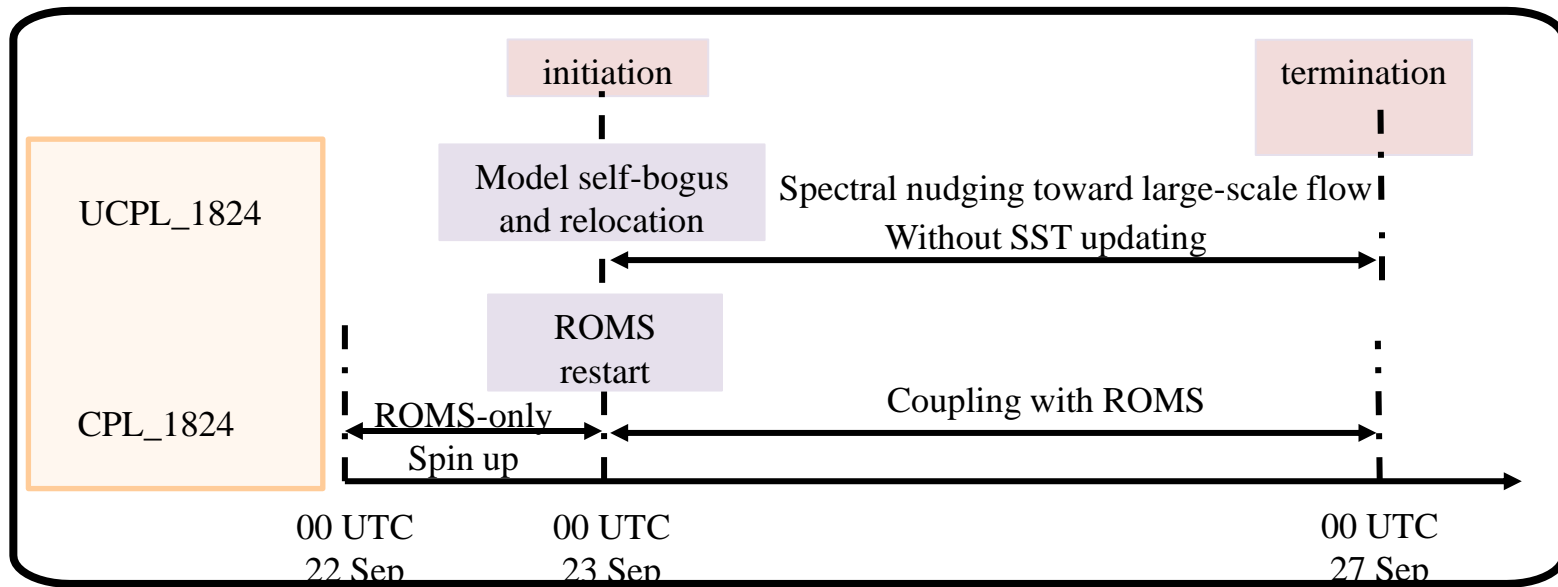
ROMS模式参数设置

垂直层数	45层
内模和外模时间步长	60s 3s
边界层垂直混合方案	GLS方案 (k-ε)
侧边界条件	自由面—Flather 三维温盐流—RadNud 扰动动能—Gradient 二维正压流—Chapman



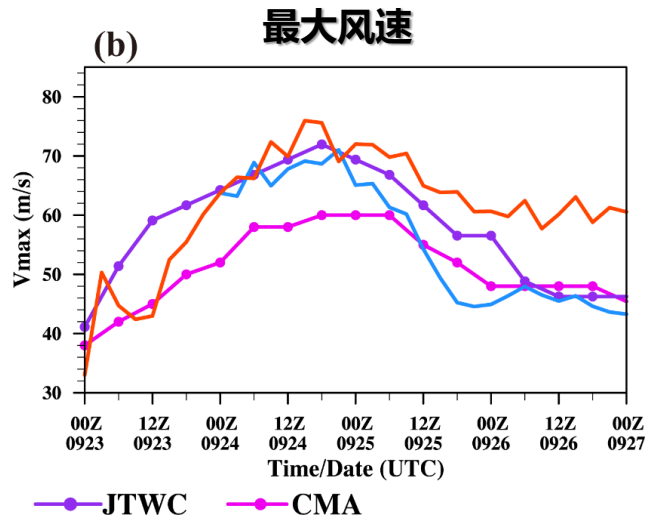
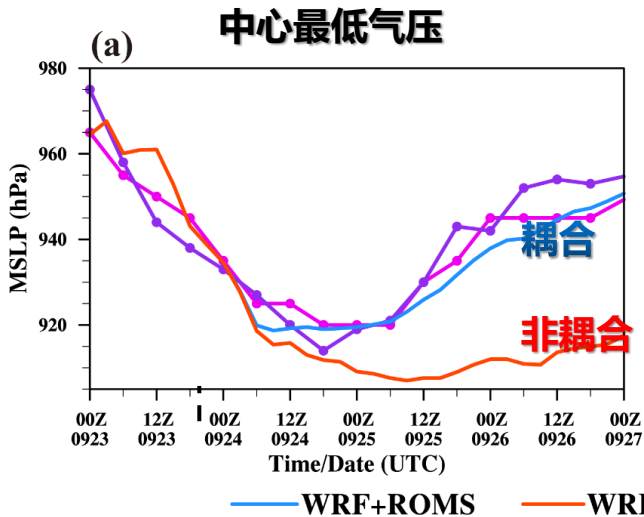
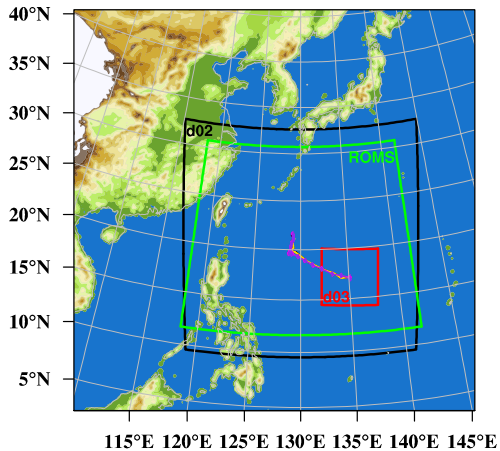
数值试验设计：“谭美”台风

Experiment	WRF	ROMS	海洋初始场	设计目的
UCPL_1824	✓	✗	HYCOM (9月23日)	不考虑海洋冷却响应
CPL_1824	✓	✓	ROMS restart (9月23日)	全耦合，考虑海洋三维响应





“谭美”台风路径与强度



- 模拟的台风路径受海洋响应的影响较小

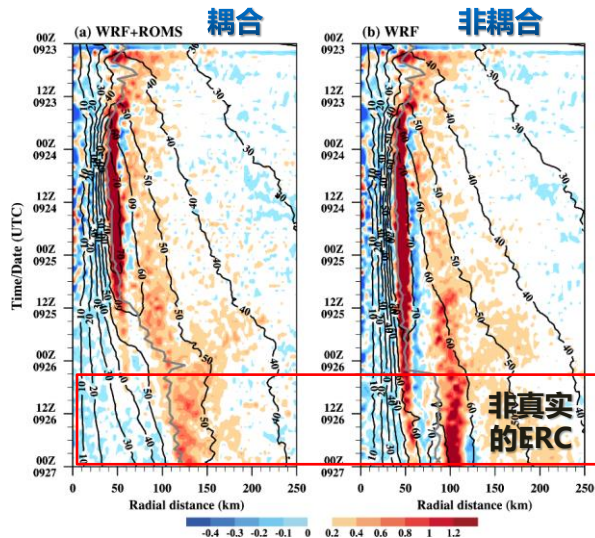
- 耦合试验能较好地再现Trami的快速减弱过程，而非耦合试验则过高地估计了Trami的强度



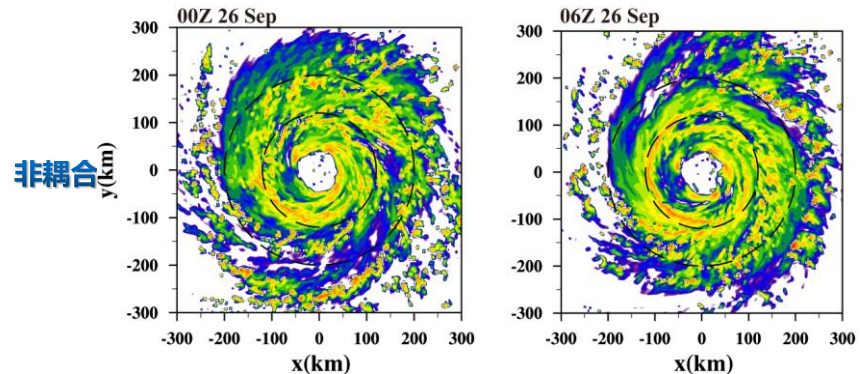
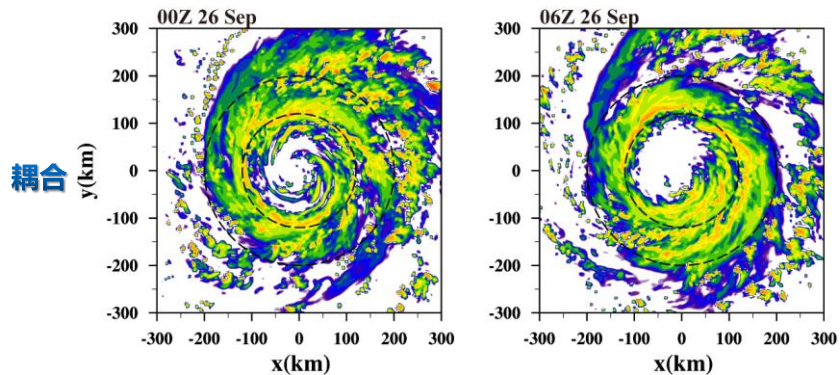
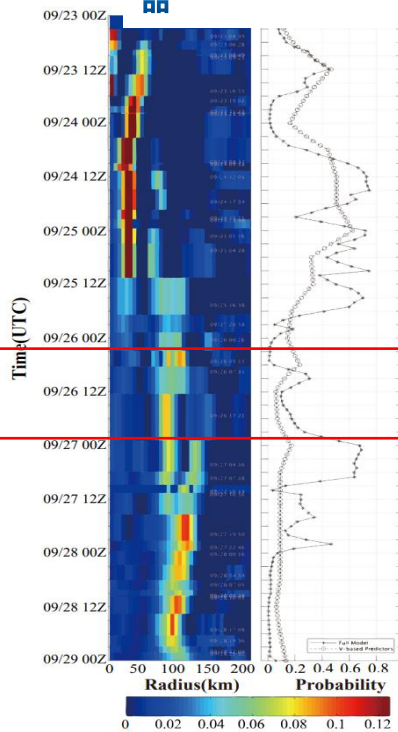
“谭美”台风眼墙替换过程

基于卫星微波观测
的ARCHER-ERC产
品

3km高度处的雷达回波反照率



填色: 5km高度垂直速度
等值线: 1km高度切向风

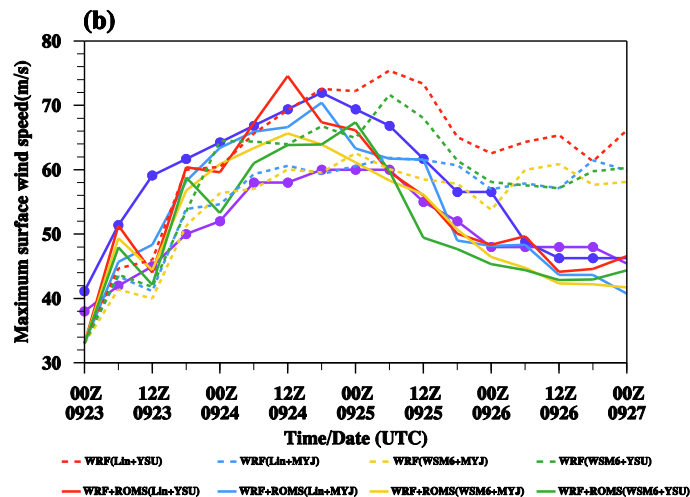
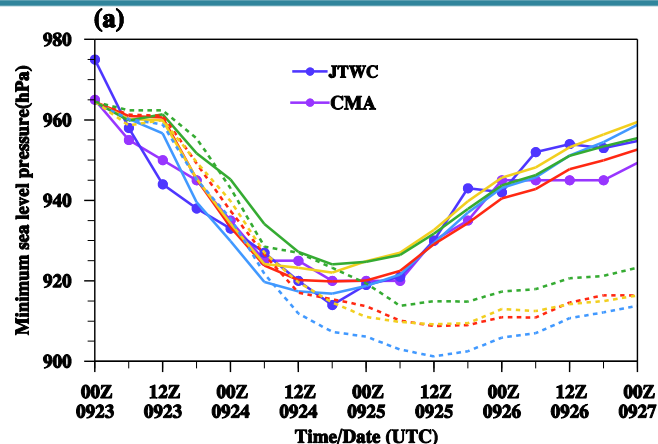


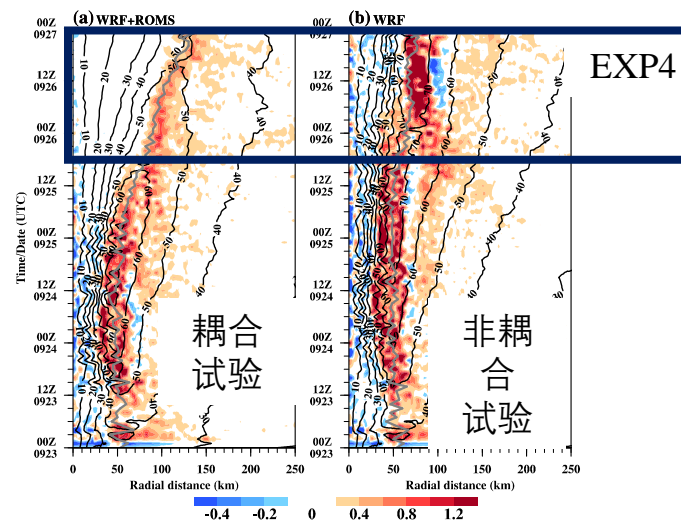
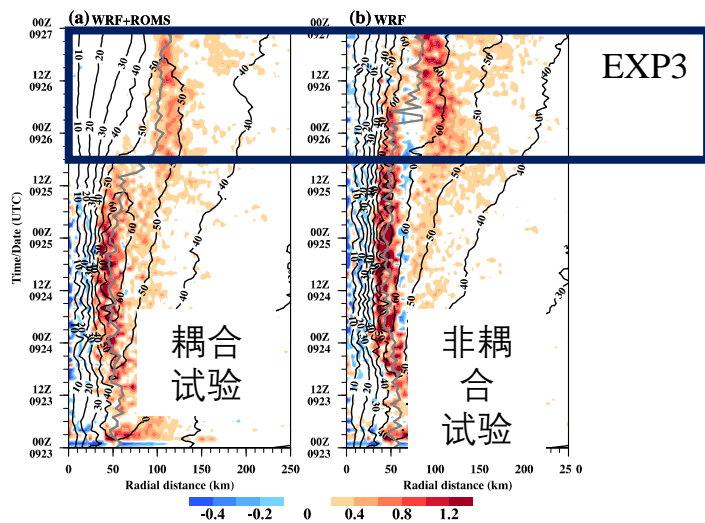
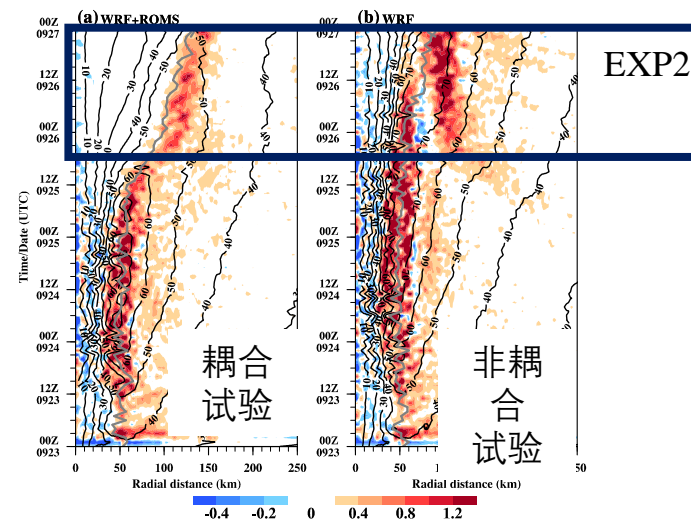
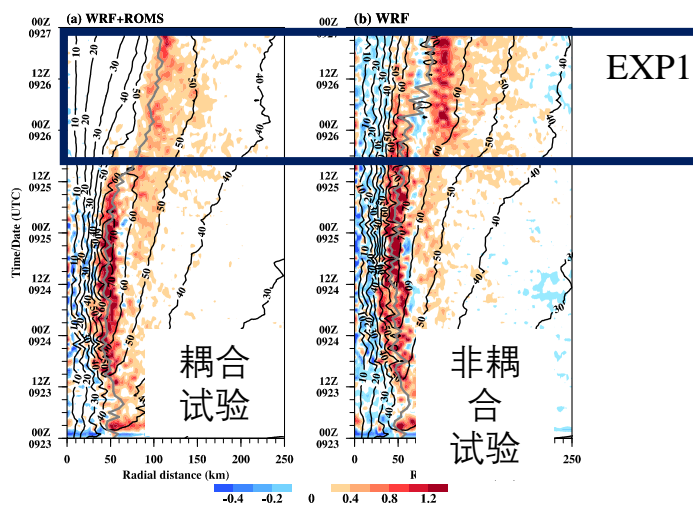


不同物理参数化方案的敏感试验

试验列表

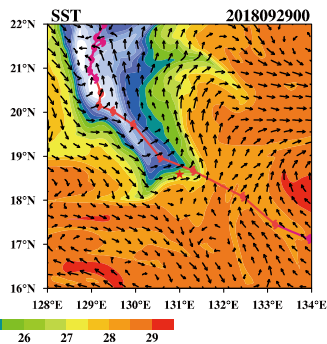
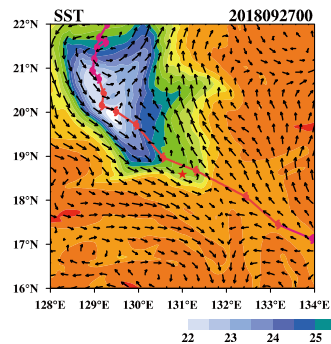
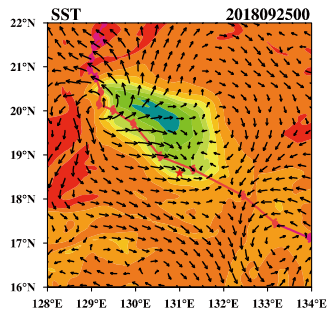
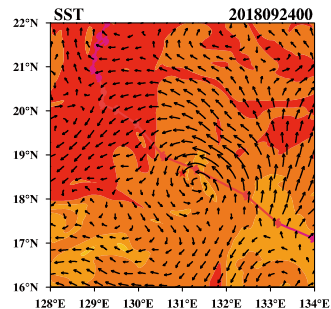
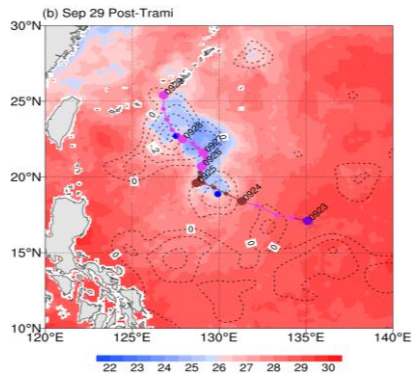
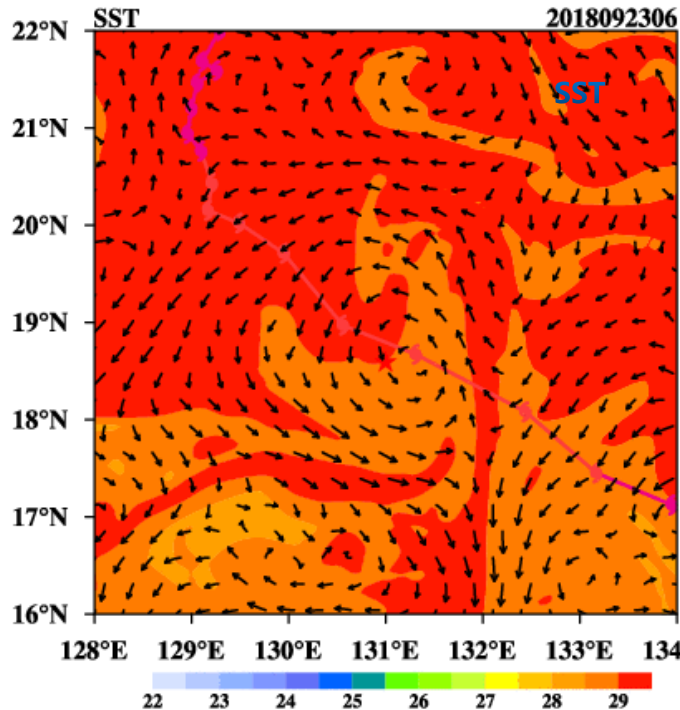
Ensemble Runs	Initial Time	Microphysics	Boundary Layer
		Scheme	Scheme
A_EXP1	00 UTC 23 Sep	Lin	YSU
OA_EXP1	00 UTC 23 Sep	Lin	YSU
A_EXP2	00 UTC 23 Sep	Lin	MYJ
OA_EXP2	00 UTC 23 Sep	Lin	MYJ
A_EXP3	00 UTC 23 Sep	WSM6	YSU
OA_EXP3	00 UTC 23 Sep	WSM6	YSU
A_EXP4	00 UTC 23 Sep	WSM6	MYJ
OA_EXP4	00 UTC 23 Sep	WSM6	MYJ







海洋响应：台风冷尾流

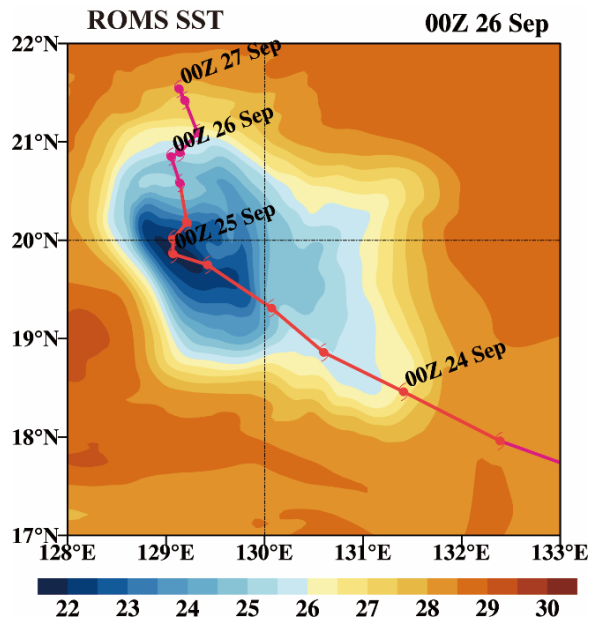
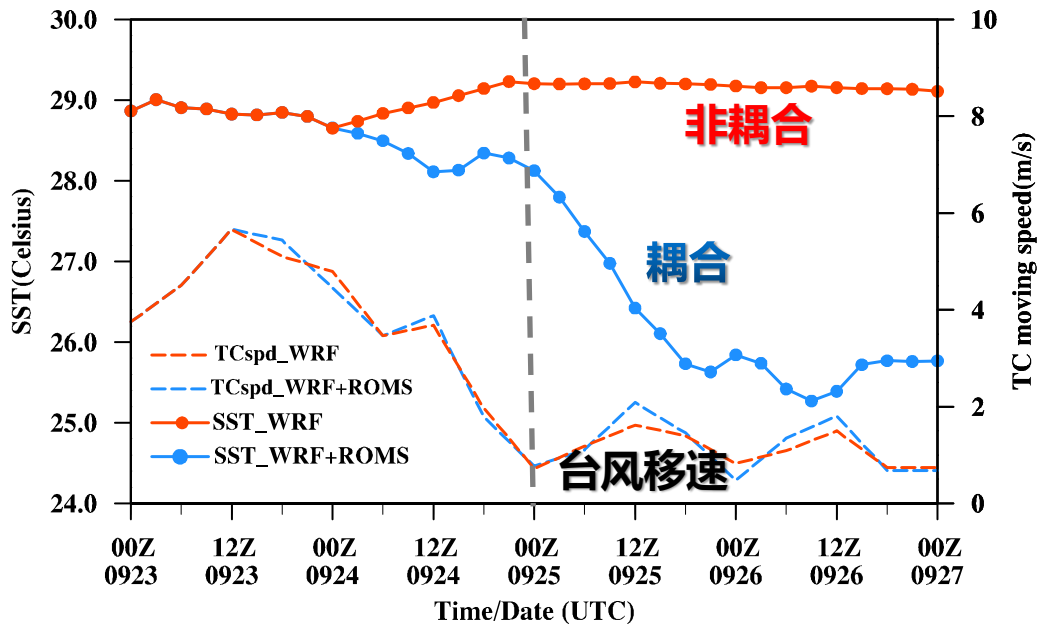


在海洋中尺度冷涡条件下，台风强迫引起剧烈海表降温响应



SST响应

模拟的台风移速和距离台风中心 100km内的平均SST

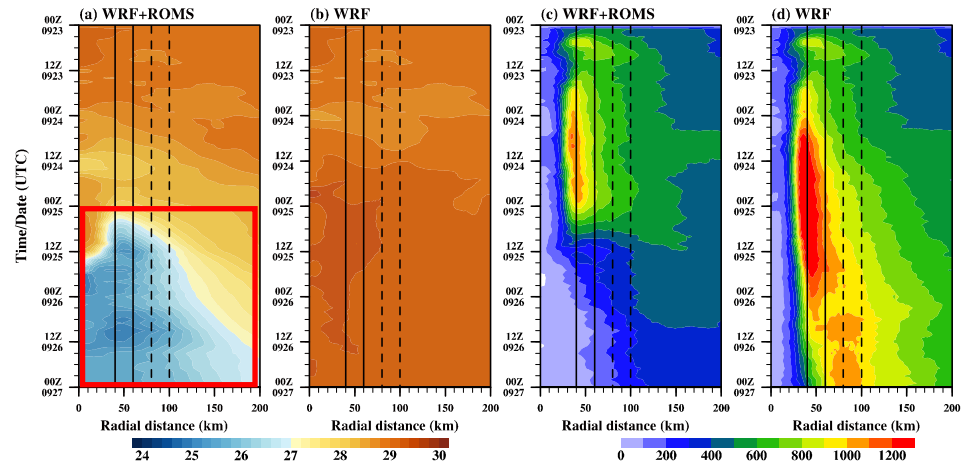




海表降温的径向非均匀性

SST的径向-时间演变

海气热通量的径向-时间演变

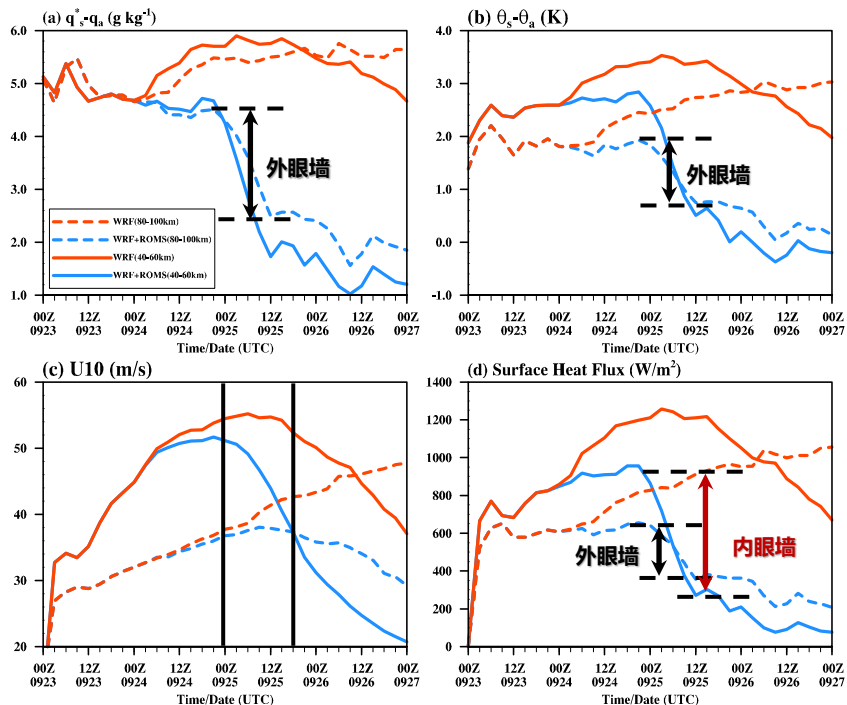


海表降温“内强外弱”

内外眼墙区域热通量减少的程度存在差异

$$SHF = \rho_a C_p C_h U_{10} (\Delta\theta)$$

$$LHF = \rho_a L_v C_q U_{10} (\Delta q)$$

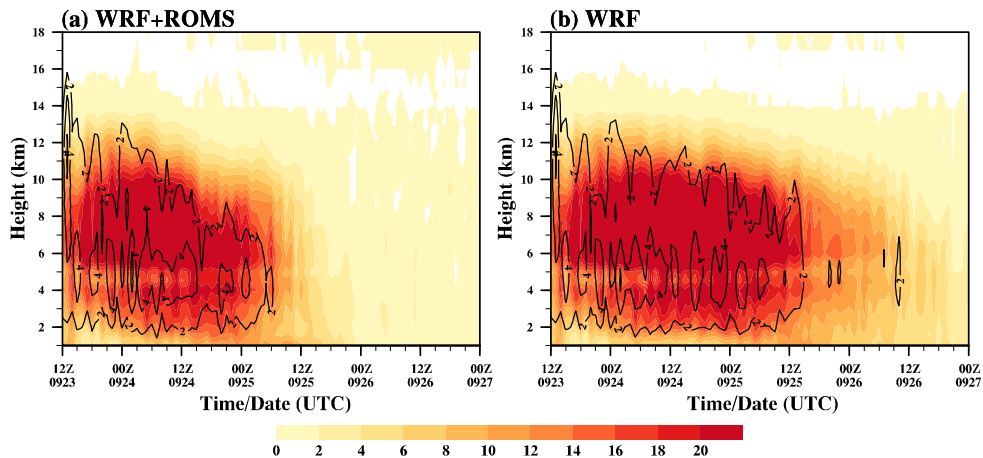


外眼墙区域：海洋的能量供应减少得比较缓和，产生的负反馈作用有限。

内眼墙区域：海表热通量的急剧减少，直接抑制了对入流空气的增温加湿过程。



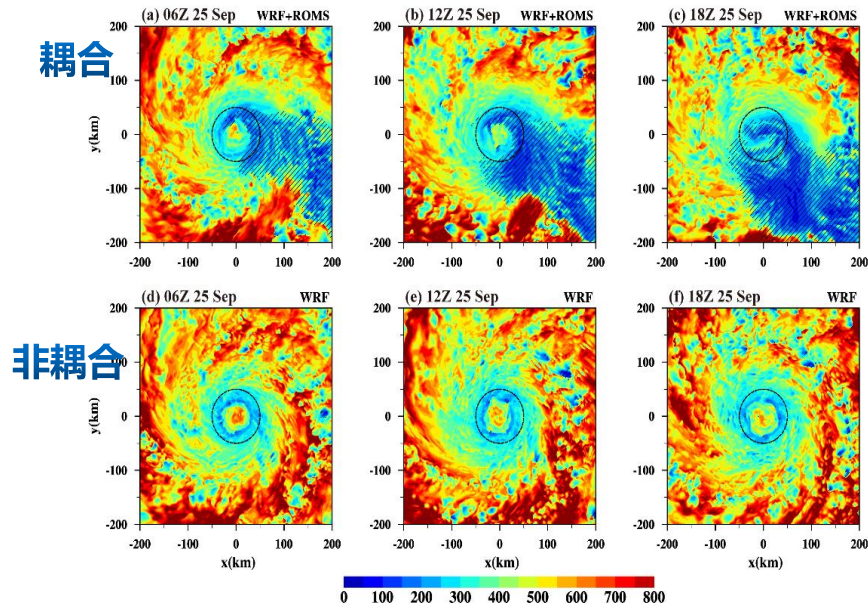
内眼墙的瓦解消亡：海表降温的影响



内眼墙处非绝热加热（填色）
对流爆发单体内的垂直运动（等值线）

- 内眼墙处对流爆发单体的强度明显减弱
- 内眼墙处非绝热加热相应地明显被削弱

热力边界层高度（填色）与稳定边界层（阴影）



稳定边界层的形成，抑制了内眼墙处
对流的发生发展



绝对角动量收支分析

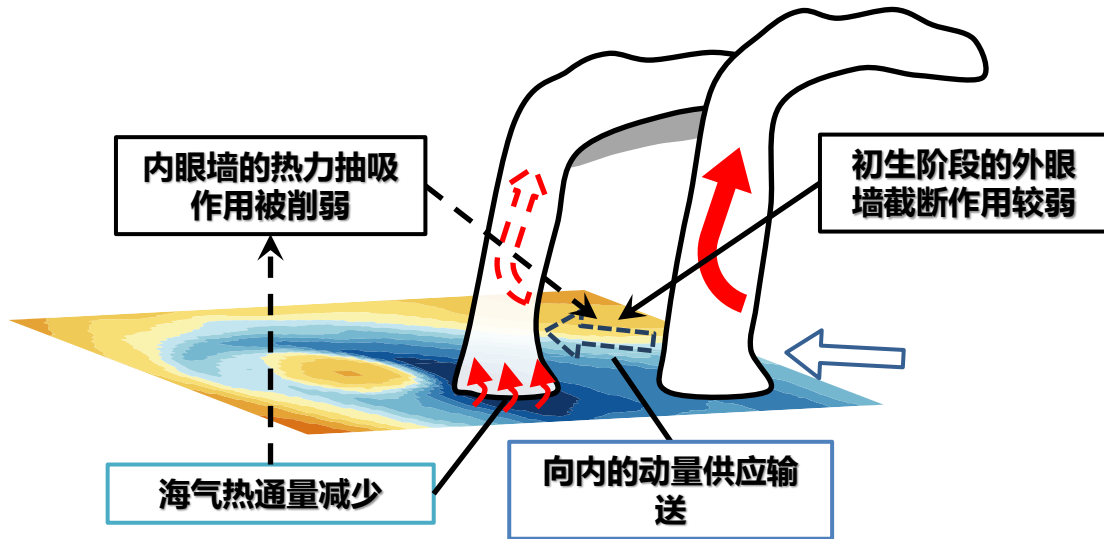
方位平均下的绝对角动量(AAM)收支方程

$$\frac{\partial \bar{M}}{\partial t} = -r\bar{U}\bar{\zeta}'_a - r\bar{U}'\zeta'_a - \bar{W}\frac{\partial \bar{M}}{\partial z} - \bar{W}'\frac{\partial M'}{\partial z} + r\bar{F}_\lambda$$

内眼墙区域边界层内AAM在增强阶段和减弱阶段各6小时内的收支情况

	Coupled Simulation 耦合		Uncoupled Simulation 非耦合	
	0600-1200 增强阶段	1200-1800 UTC 减弱阶段	0600-1200 UTC 24 Sep	1200-1800 UTC 25 Sep
$\langle \Delta M \rangle_{IE}$	0.135	-0.818	0.279	-0.287
$-r\bar{U}\bar{\zeta}'_a$	19.753	5.078 (-14.675)	22.108	15.444 (-6.664)
$-\bar{W}\frac{\partial \bar{M}}{\partial z}$	-2.674	0.205 (2.879)	-3.398	-0.407 (2.991)
$-(r\bar{U}'\zeta'_a + \bar{W}'\frac{\partial M'}{\partial z})$	17.079	5.283 (-11.796)	18.710	15.037 (-3.673)
$-(r\bar{U}'\zeta'_a + \bar{W}'\frac{\partial M'}{\partial z})$	-3.973	-1.478	-4.560	-4.534

海表降温可催化台风环流与海气热交换之间的负反馈过程，加速了内眼墙的减弱消亡





台风的自我毁灭

ATMOSPHERIC DYNAMICS

Typhoon self-sabotage

The eyewall is the most dangerous and destructive part of a typhoon, with the strongest winds and heaviest rainfall. At sufficient intensity, concentric eyewalls form and replace the innermost eyewall, initiating the eyewall replacement cycle (ERC). Hence, the ERC is an important indicator for predicting changes in the intensity and structure of typhoons. However, previous studies have focused on these internal storm dynamics, while not adequately

considering relationships to the sea surface.

Xiangcheng Li, at the College of Meteorology and Oceanography, National University of Defense Technology, Changsha, China, and colleagues, used a coupled atmosphere-ocean model to simulate Typhoon Trami. Trami was a slow-moving typhoon that formed in 2018, it produced notable sea surface cooling and swiftly dissipated. While uncoupled models

produced unrealistic long-lived ERC, the coupled atmosphere-ocean model generates an ERC that matches observations. These numerical simulations suggest that typhoon-induced sea surface cooling weakened typhoon Trami and catalyzed a negative feedback loop, reducing the typhoon's energy supply and ultimately led to its rapid termination.

Typhoons can be destructive, with potentially immediate and long-term impacts on human life. Despite being a case study for a slow-moving typhoon, the results highlight the importance of considering air-sea interactions in accurately forecasting ERCs and, in turn, typhoons. Future work should build on these findings by simulating additional cases of typhoons to further quantify the relationships between the sea surface cooling and ERCs, so that typhoon predictions can be improved.

and, in turn, typhoons. Future work should build on these findings by simulating additional cases of typhoons to further quantify the relationships between the sea surface cooling and ERCs, so that typhoon predictions can be improved.



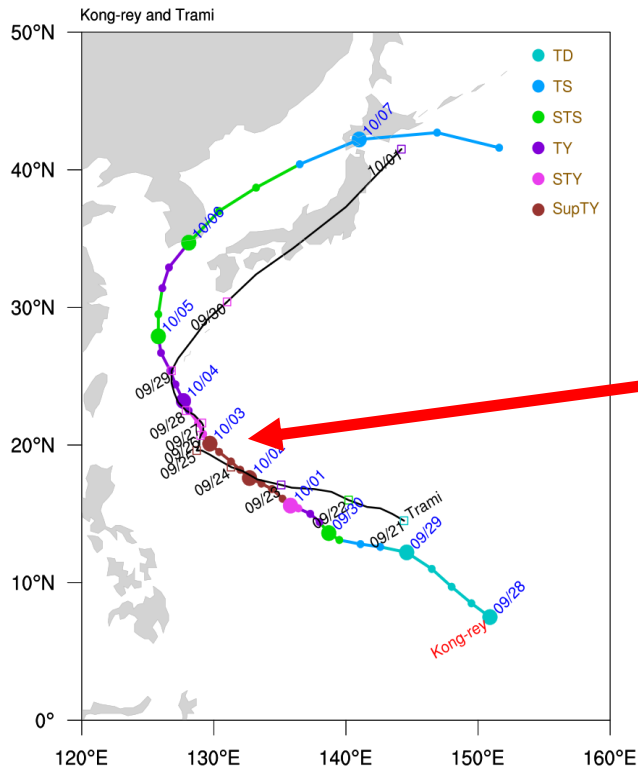
Credit: The Asahi Shimbun / Contributor via Getty Images

Robert Ulrich
Department of Earth, Planetary and Space Sciences,
University of California,
Los Angeles, CA, USA

ORIGINAL ARTICLE Li, X. et al. The modulation effect of sea surface cooling on the eyewall replacement in Typhoon Trami. *Mon. Weather Rev.* <https://doi.org/10.1175/MWR-D-21-0177.1> (2022)



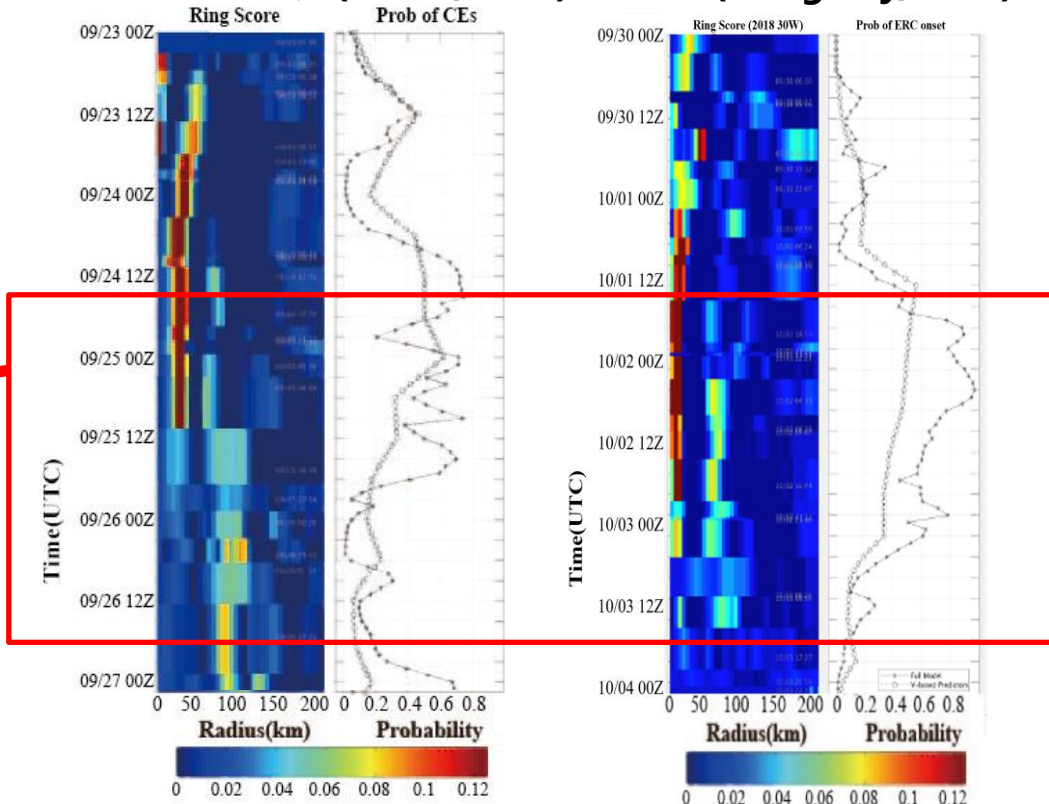
“谭美”和“康妮”台风



谭美(1824) 和康妮(1825)台风路径

谭美(Trami,1824)

康妮(Kong-rey,1825)

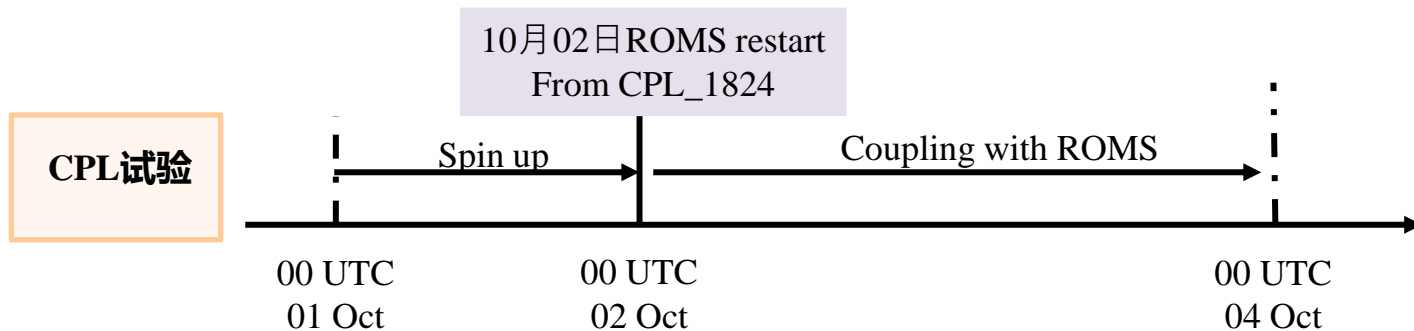


CMISS:基于卫星微波观测的M-PERC产品



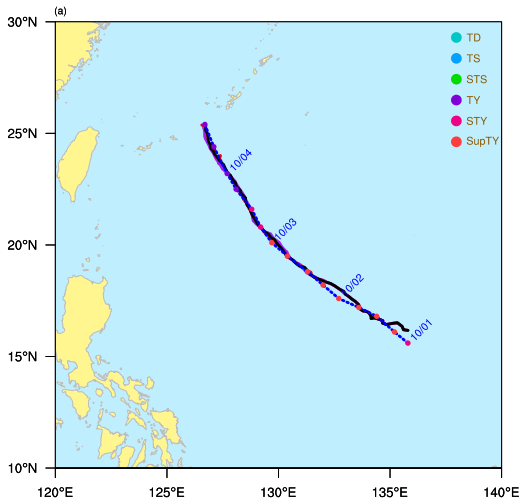
数值试验设计：“康妮”台风

Experiment	WRF	ROMS	海洋初始场	设计目的
CPL	✓	✓	ROMS restart (10月2日 CPL_1824)	考虑Trami引起的海洋响应
NTRAMI	✓	✓	HYCOM (10月2日)	剔除Trami引起的海洋响应
NWAKE	✓	✗	REMSS SST (9月23日)	完全不考虑海洋响应反馈

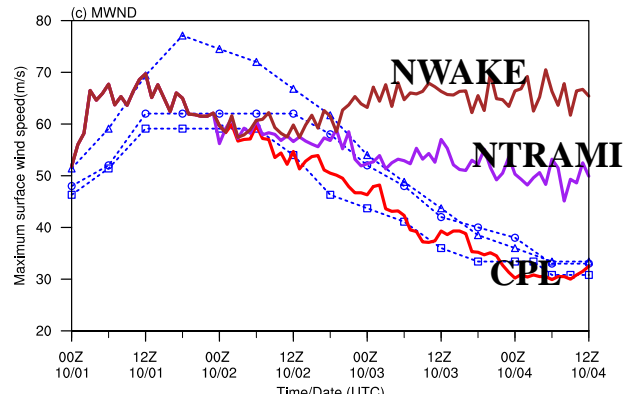




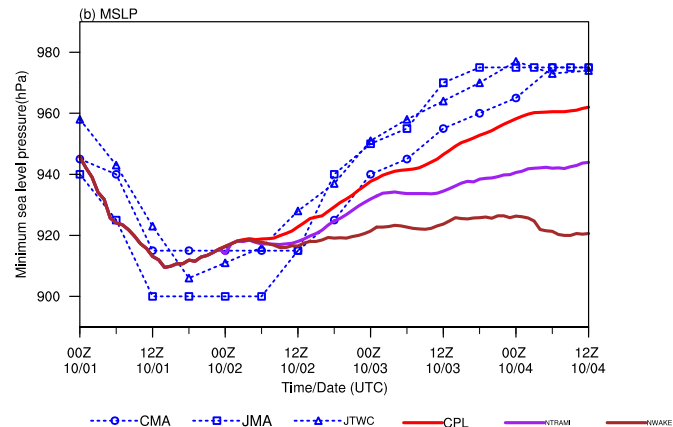
“康妮”台风路径与强度



Intensity Forecast for TC 1825

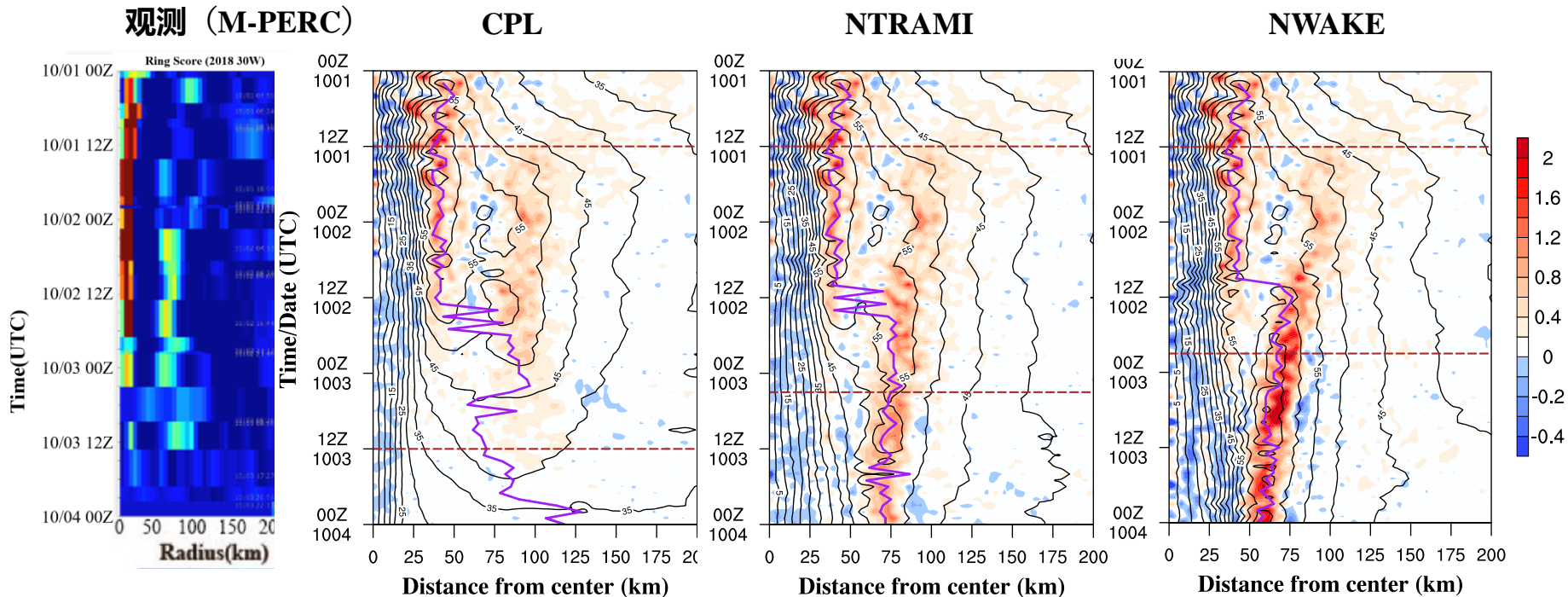


Intensity Forecast for TC 1825





“康妮”眼墙替换

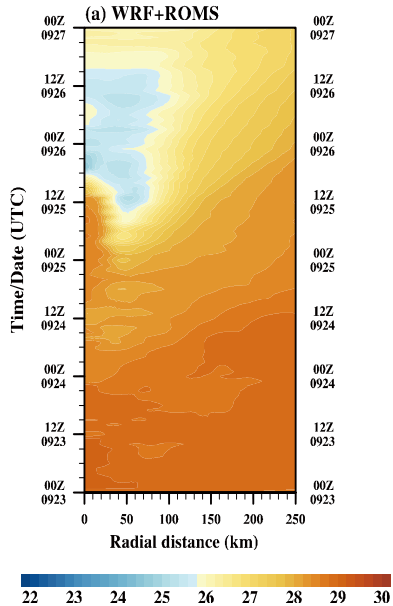


5km垂直速度 (阴影), 1.5km切向风 (等值线), 最大风速半径 (紫色线)

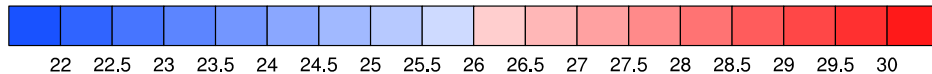
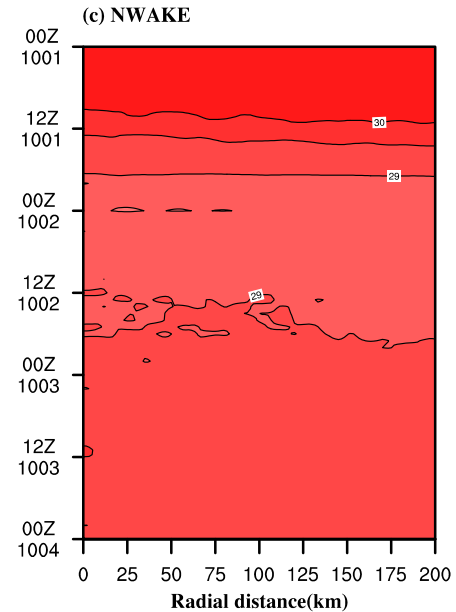
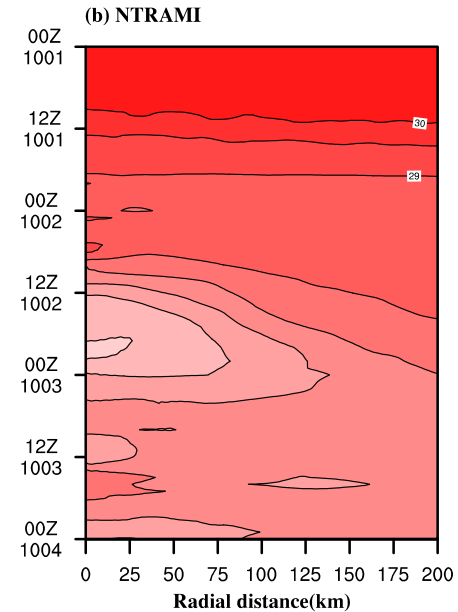
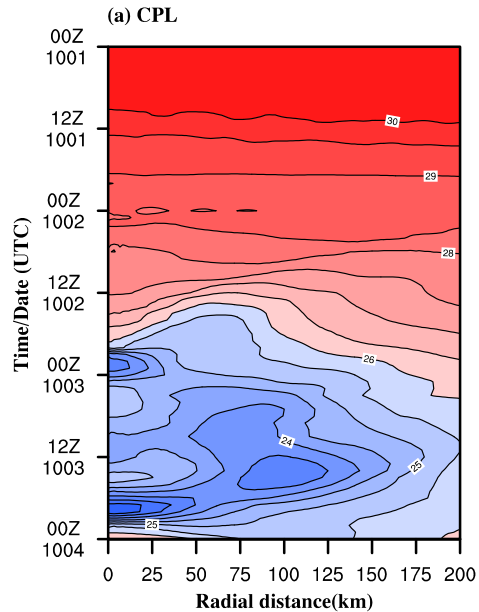


海表降温

“谭美”



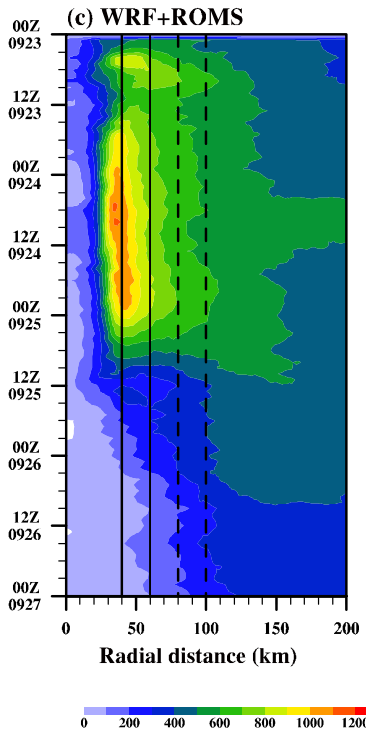
“康妮” SST



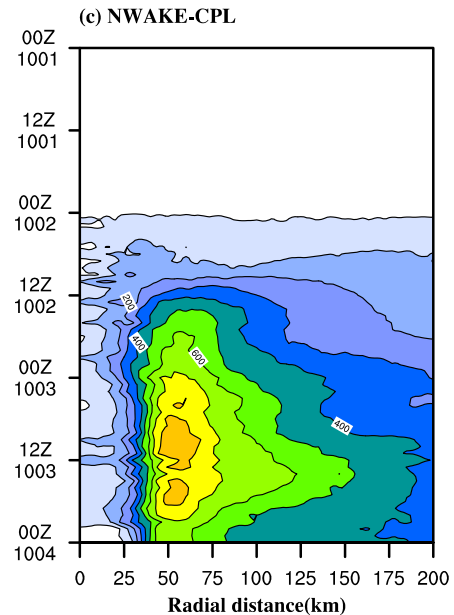
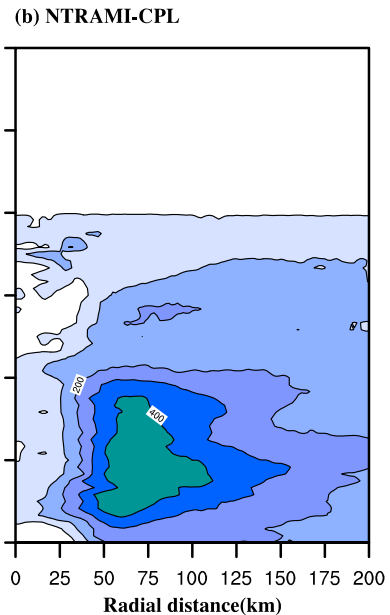
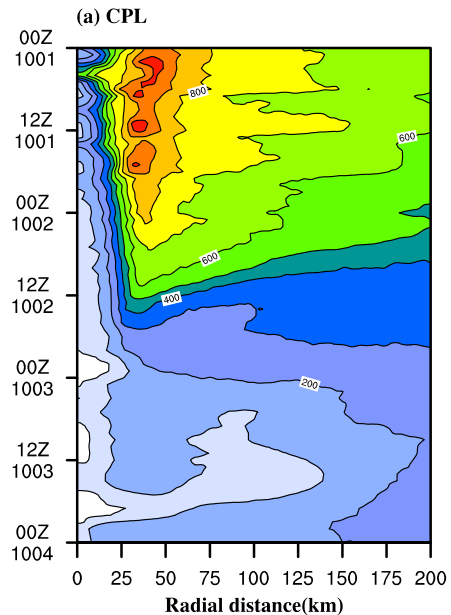


海气通量

“谭美”



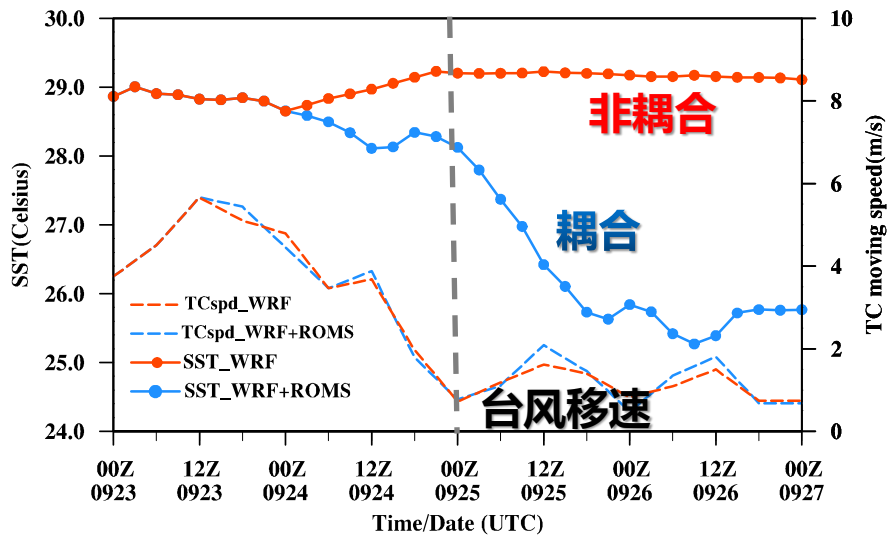
“康妮”





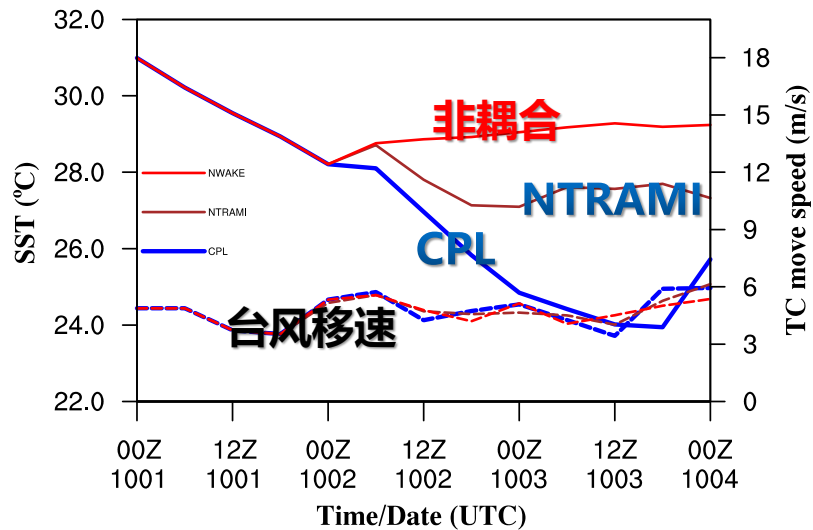
SST响应

“谭美”



“康妮”

TC move speed and SST





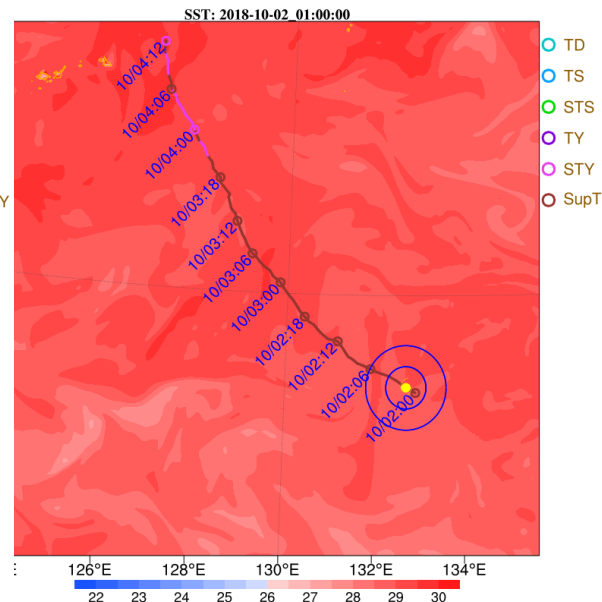
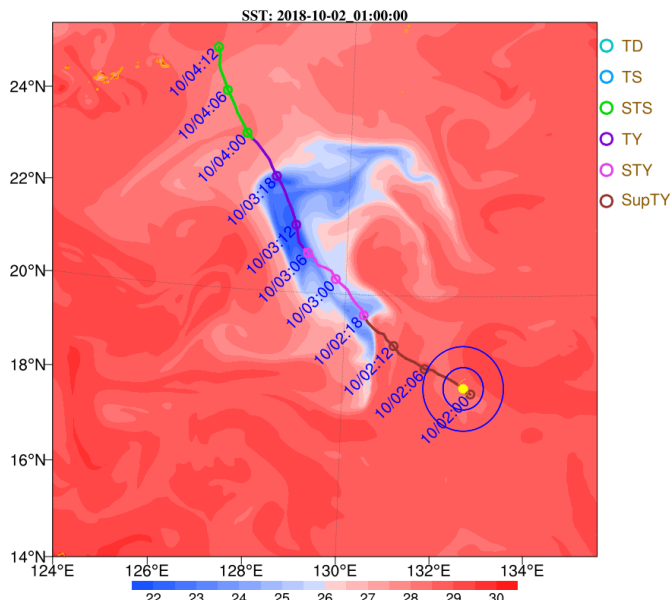
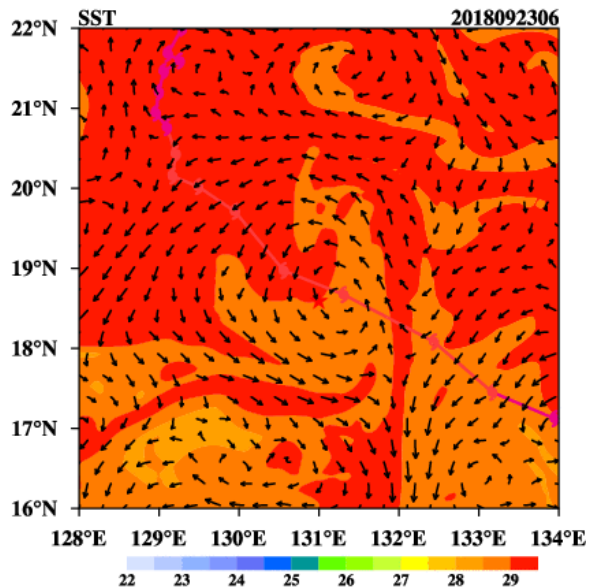
SST响应

“谭美”

CPL

“康妮”

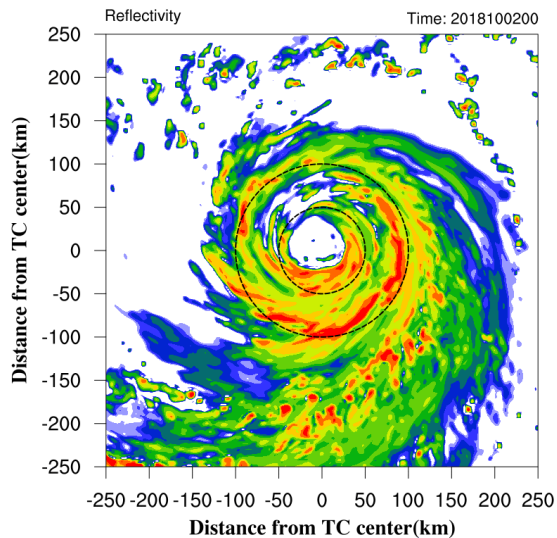
NTRAMI





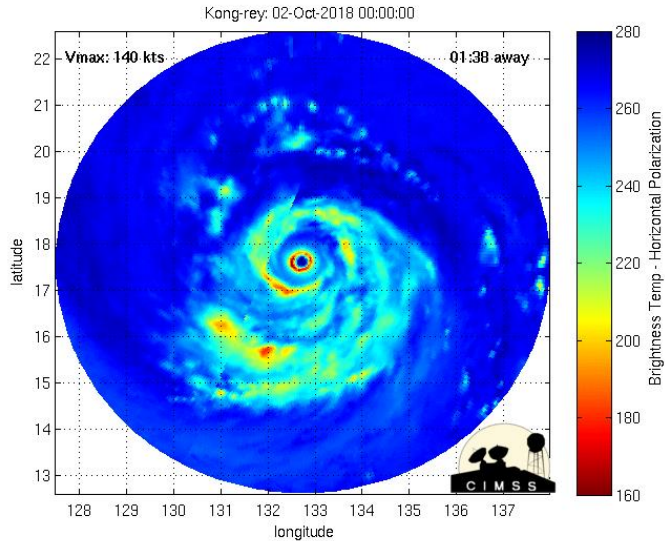
“康妮” 台风双眼墙

CPL



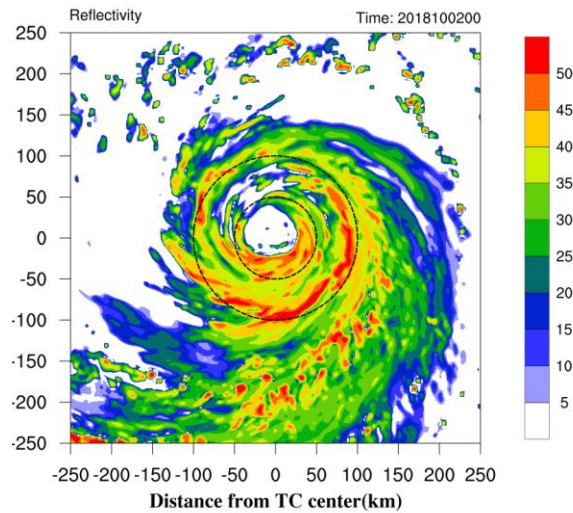
3km雷达反射率

卫星观测



融合卫星微波图像产品MIMIC

NWAKE

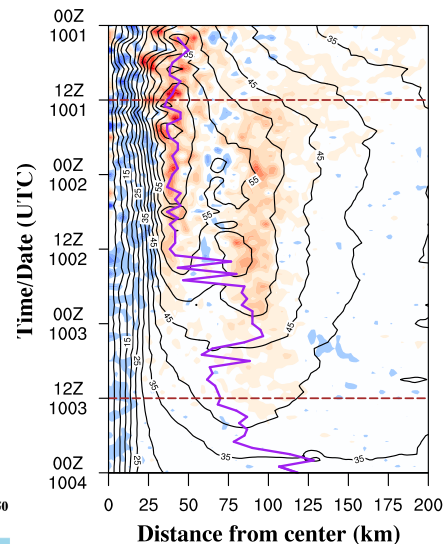
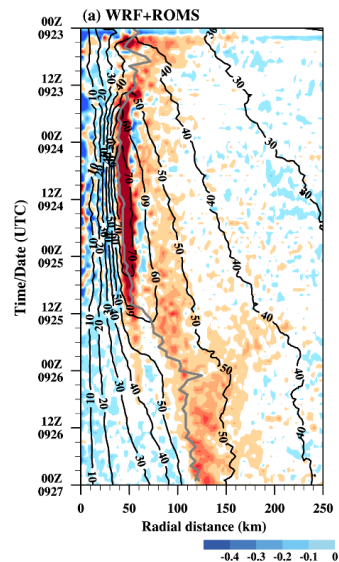
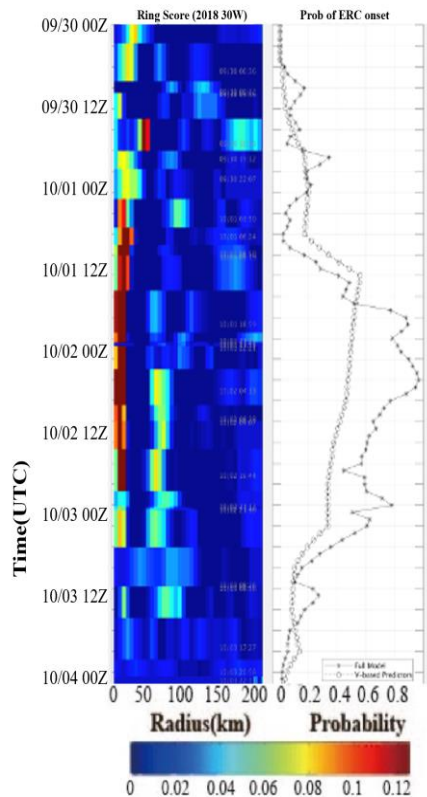
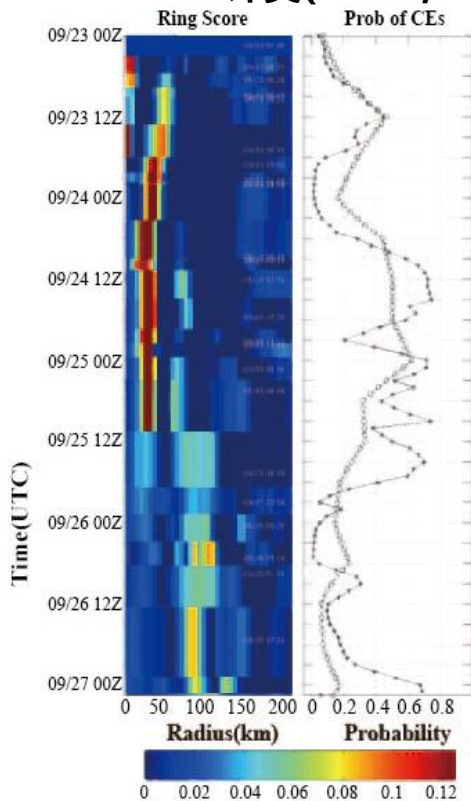


3km雷达反射率



谭美(Trami,1824)

康妮(Kong-rey,1825)





主要结论

- ◆ 通过对“谭美”台风的高分辨率海气耦合数值试验，发现了缓慢移动的**双眼墙**台风引发的“内强外弱”海表降温能够加速内眼墙的减弱消亡，进而导致台风眼墙替换过程的迅速完成。
- ◆ “谭美”台风产生的冷尾流，造成“康妮”台风快速减弱，由于“康妮”内外眼墙都处于冷尾流之上，使得内外眼墙同时减弱。
- ◆ 虽然“谭美”台风和“康妮”台风生命史没有重叠，但不同时期经历同一海域，通过海洋响应反馈作用，两者建立了联系。



谢谢！ 请批评指正！

Li X C, Cheng X P, Fei J F, Huang X G. The Modulation Effect of Sea Surface Cooling on the Eyewall Replacement Cycle in Typhoon Trami (2018). *Mon. Wea. Rev.*, 2022,150(6): 1417–1436.

Li X C, Cheng X P, Fei J F, Huang X G. A Numerical Study on the Role of Mesoscale Cold-Core Eddy in Modulating the Upper Ocean Responses to Typhoon Trami (2018). *J. Phys. Oceanogr.*, 2022, 52(12): 3101-3122.

An aerial photograph of a terraced hot spring. The terraces are formed by mineral deposits, creating a series of concentric, stepped basins. The water in the terraces has a milky, white, and yellowish appearance. In the center of the terraces is a small, circular pool of water. The surrounding landscape is a mix of green grass and dark, rocky terrain.

谢谢！ 请批评指正！



大气条件分析

