一种有效改进华南暖区暴雨集合预报的思路：目标同化减小关键初始误差

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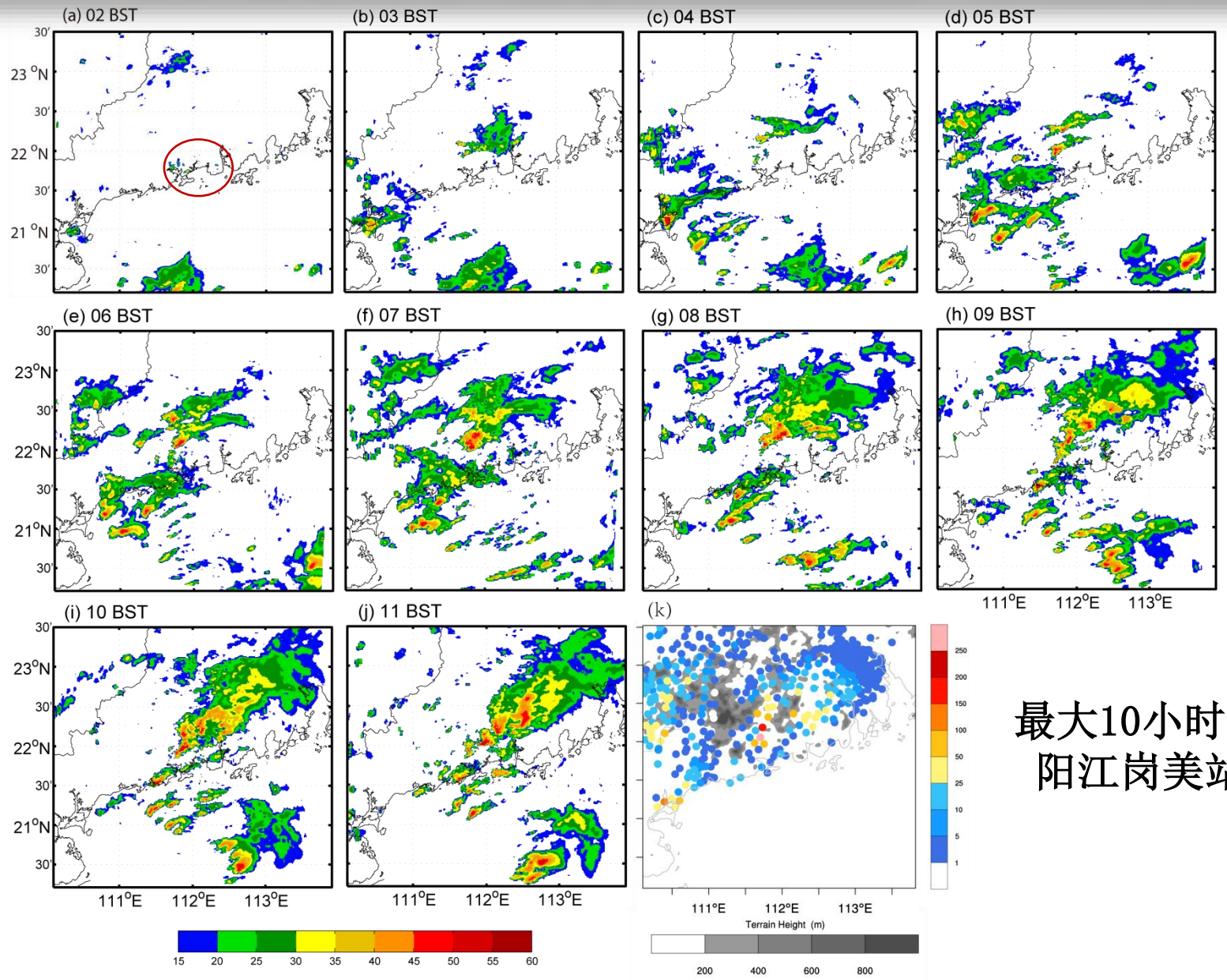
2023年8月11日

2013年5月8日季风爆发前广东沿海暖区暴雨过程



✓ **MCS**

02时 对流初生

最大10小时(02-12时)累积降水

阳江岗美站 314.3 mm

无同化试验

不同初始场的平行试验

- ERA 单一值试验

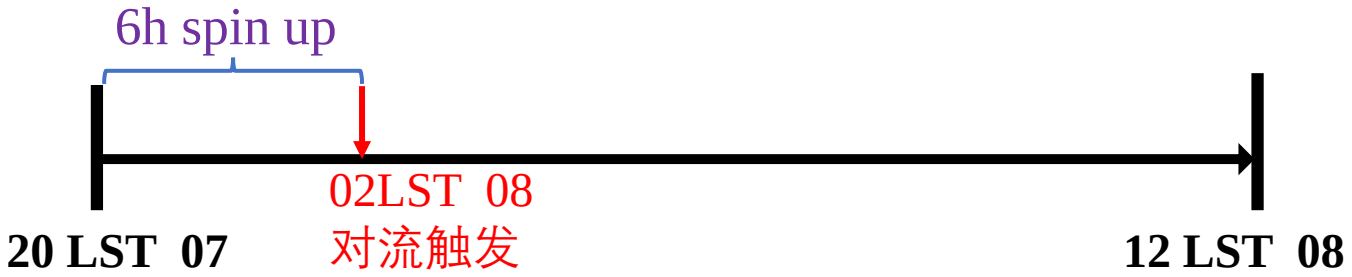
  ERA-interim 0.25º×0.25º 再分析资料

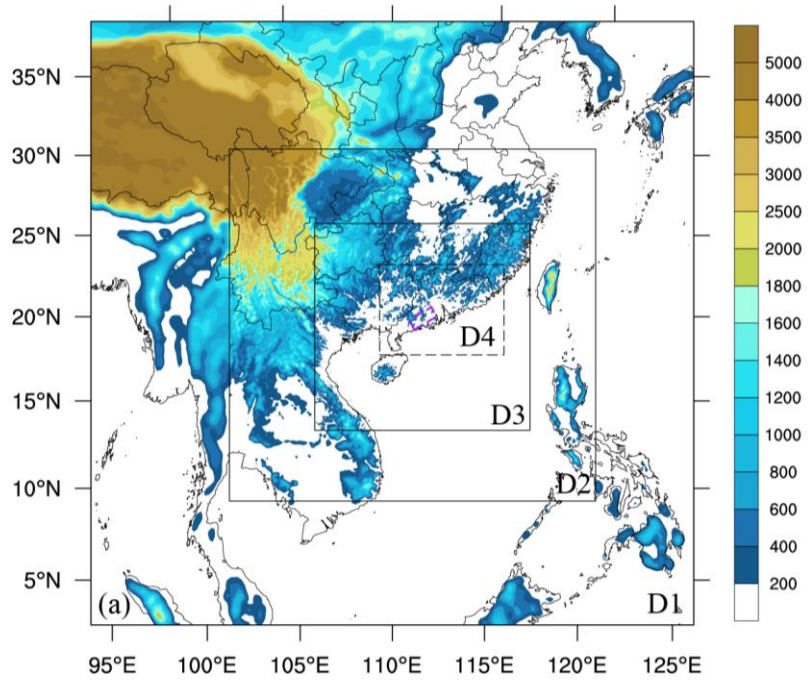
- FNL 单一值试验

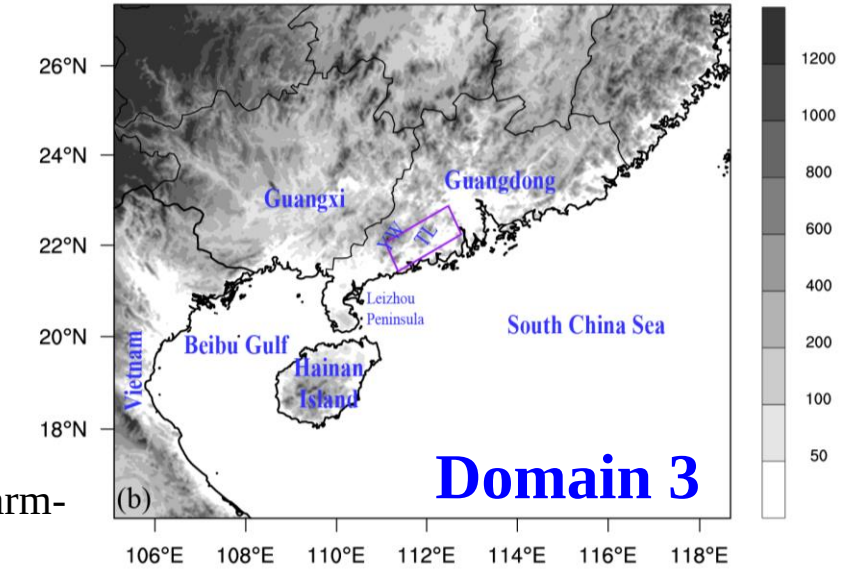
  NCEP FNL 1º×1º 再分析资料

- 60成员集合试验

  集合初始场使用WRFDA_3DVAR扰动模块对FNL试验的初始场随机扰动得到







Bao, X., Luo, Y., & Gao, X. (2021). The synoptic impacts on the convection initiation of a warm-sector heavy rainfall event over coastal South China prior to the monsoon onset: A numerical modeling study. Journal of Geophysical Research: Atmospheres, 126, e2020JD034335.

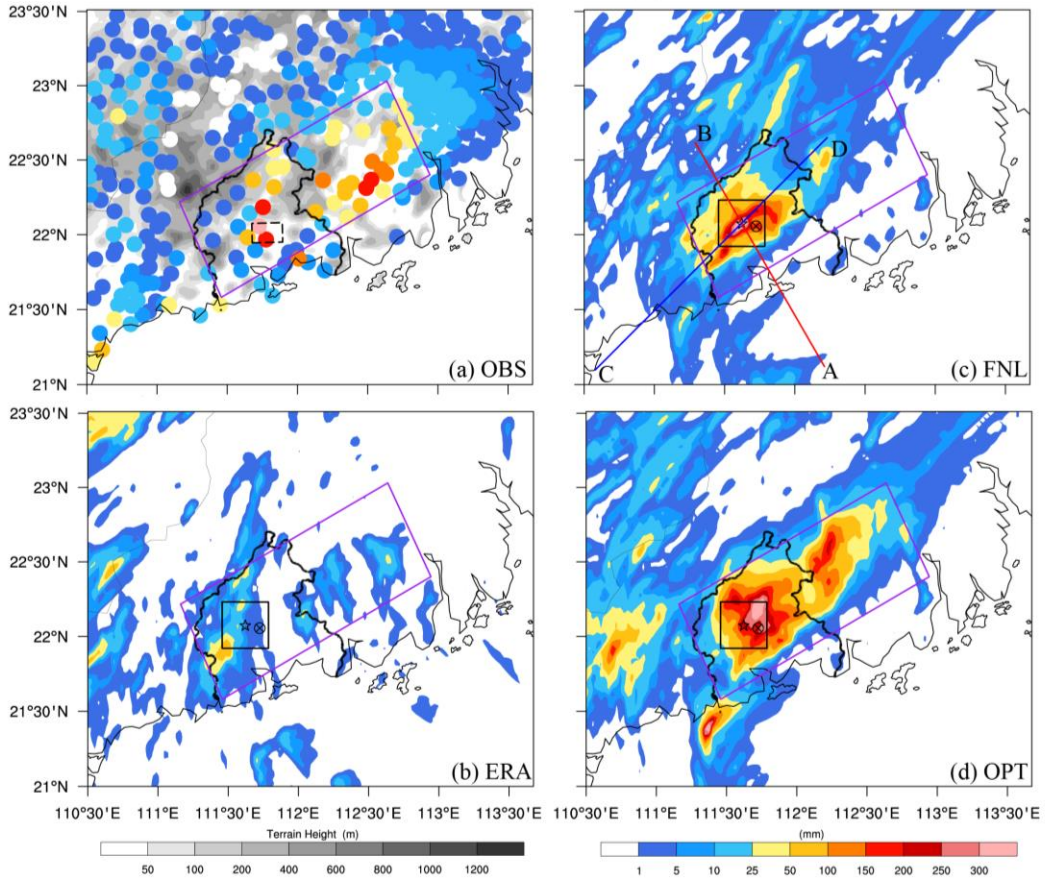
不同初始场试验结果

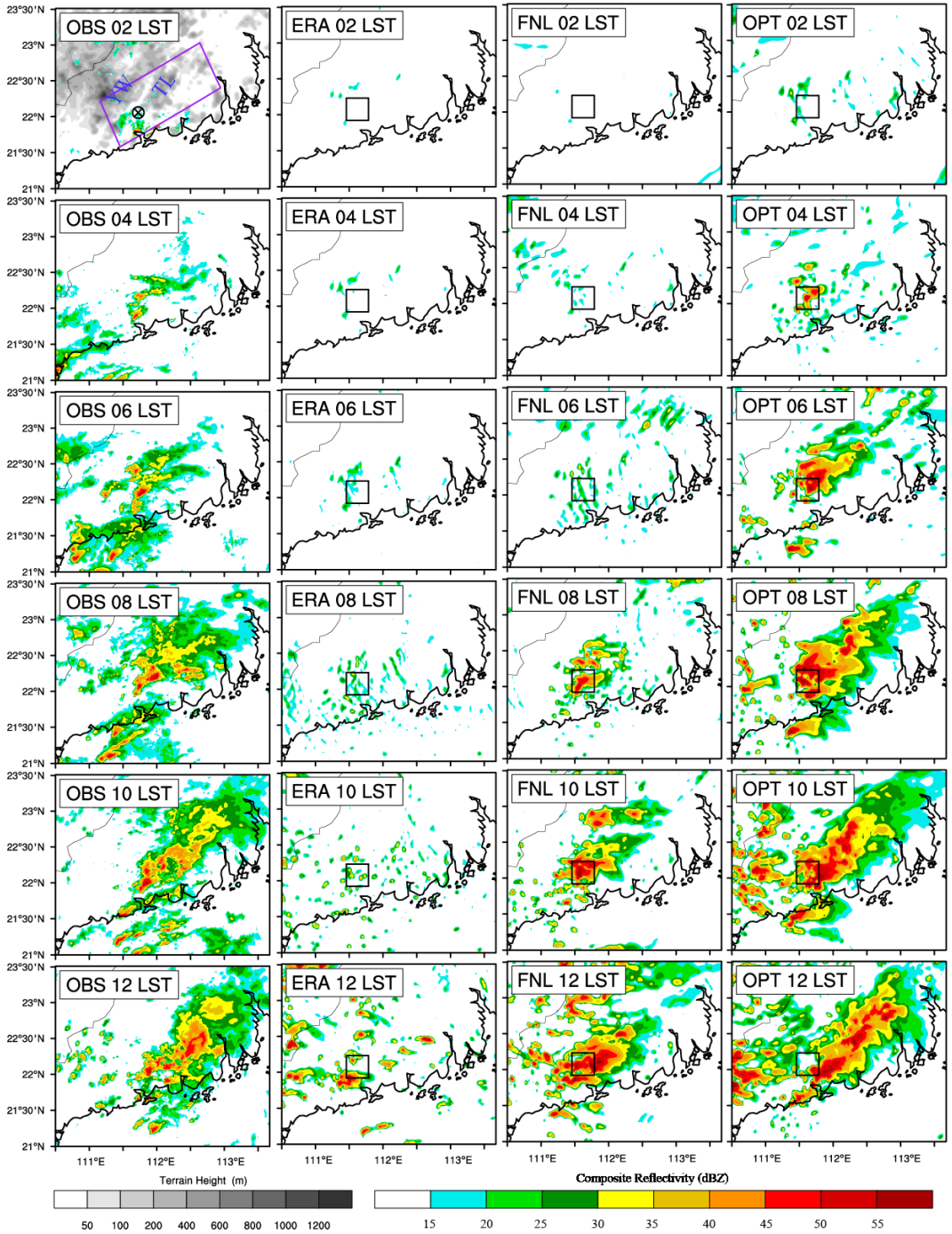
ERA　失败

FNL　对流初生晚4小时左右

OPT<-60个集合成员

很好再现此次过程





差异原因

观测和OPT试验对流触发时（02时）边界层环境场和垂直剖面图

✓边界层气流强度

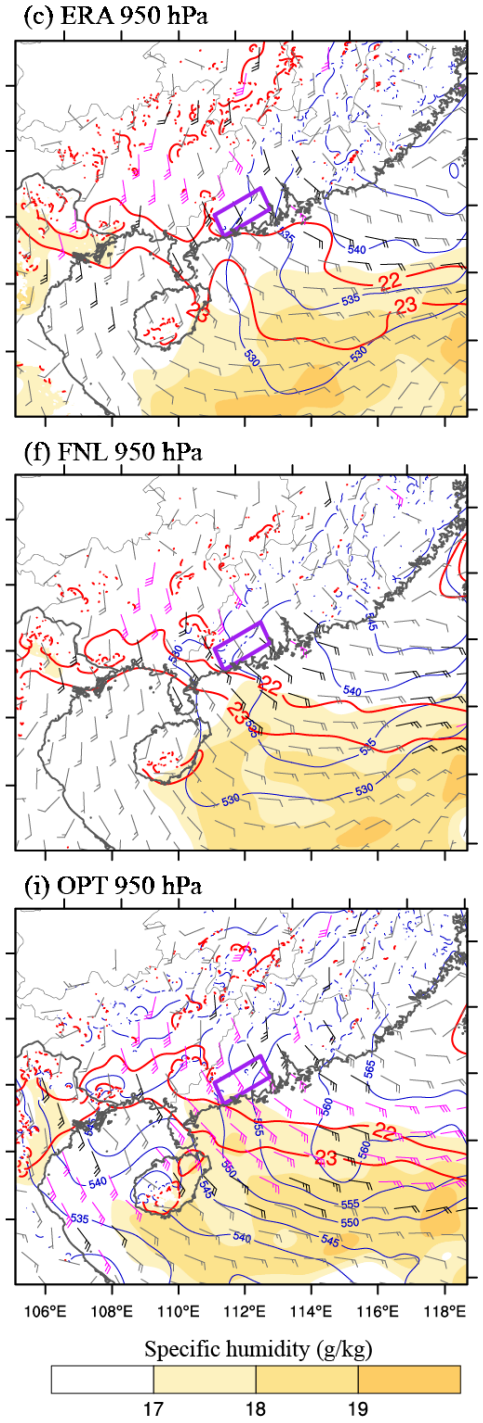
ERA <10m/s

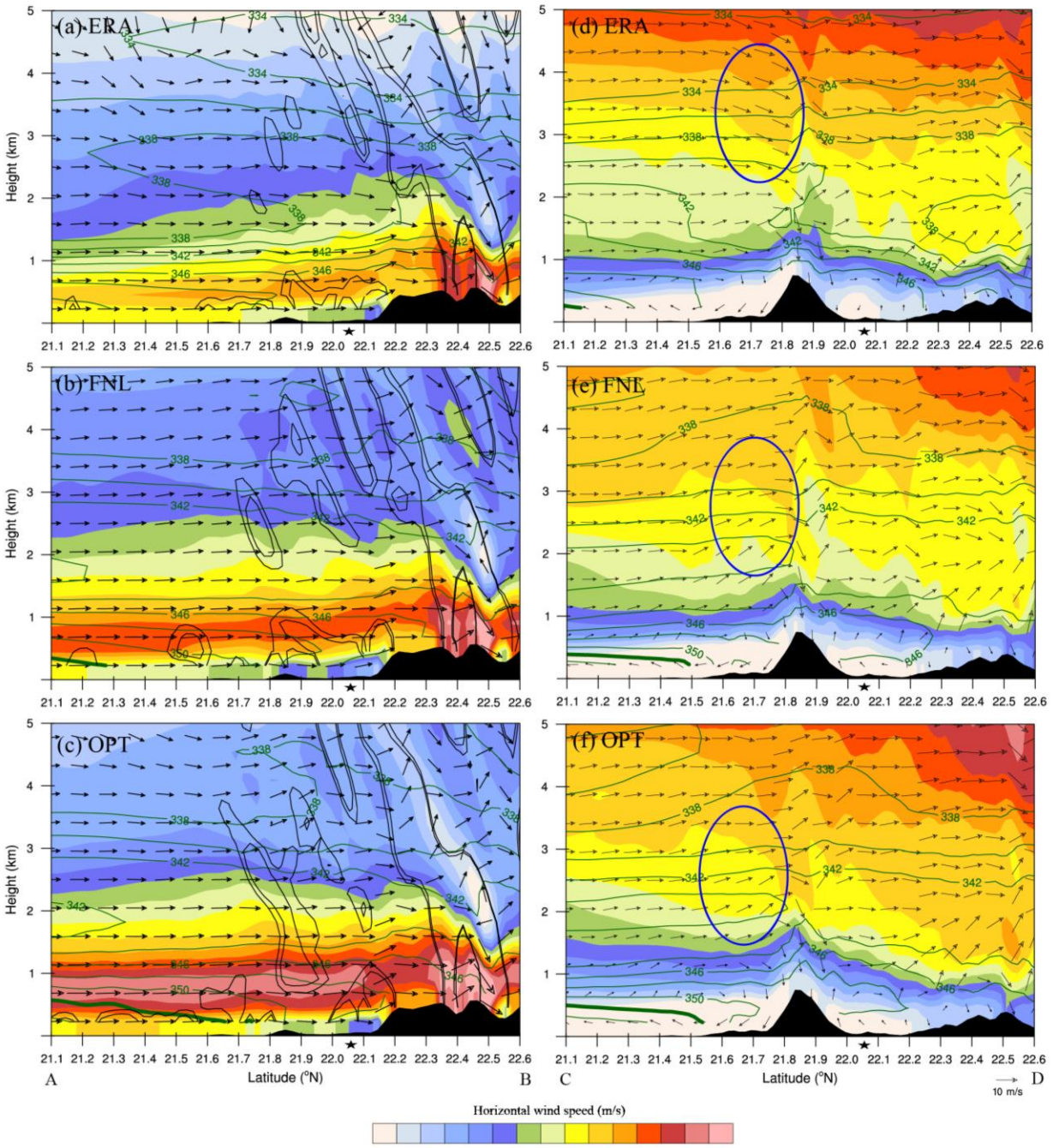
FNL 10-11 m/s

OPT >12 m/s

急流级别

海上边界层东-东南气流的强度和方向是影响对流初生时间和位置、降水强度和落区的主要原因。



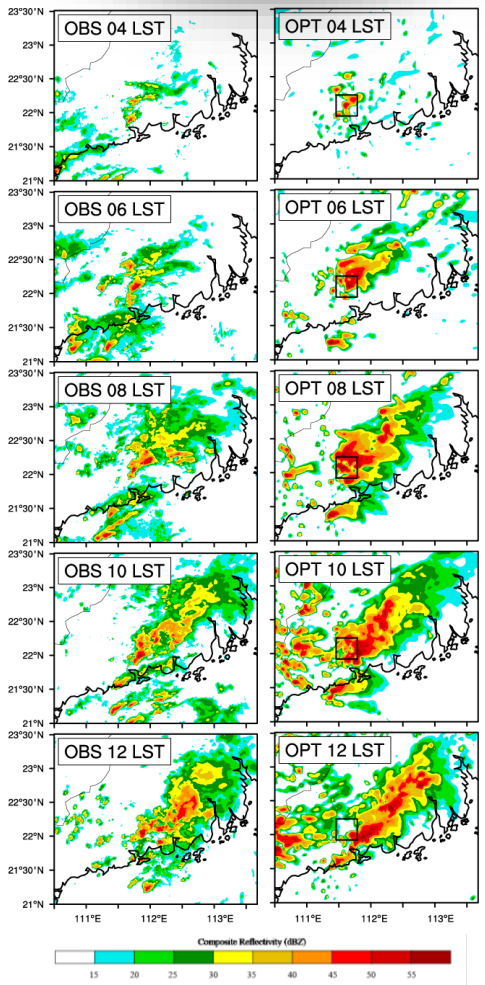


Bao et al. 2021, JGR.

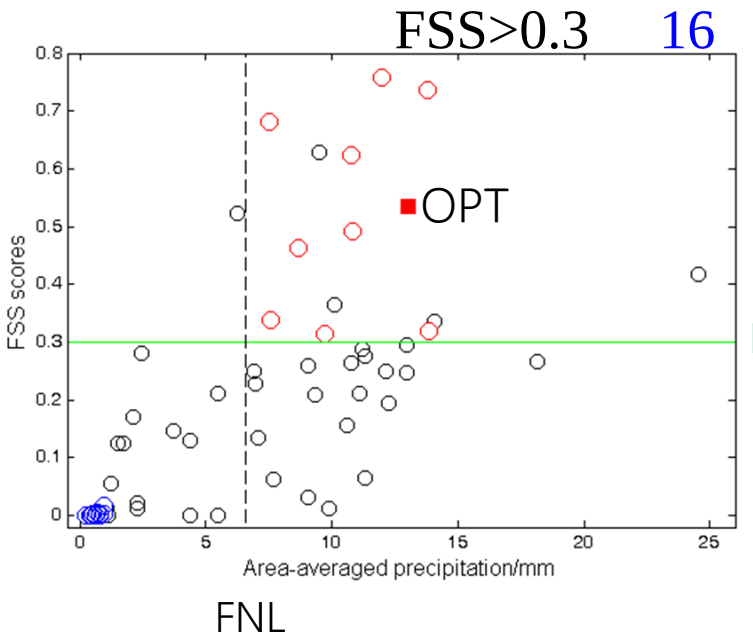
模式有预报能力
单一值确定性预报能再现对流过程

可预报性低

集合预报概率低

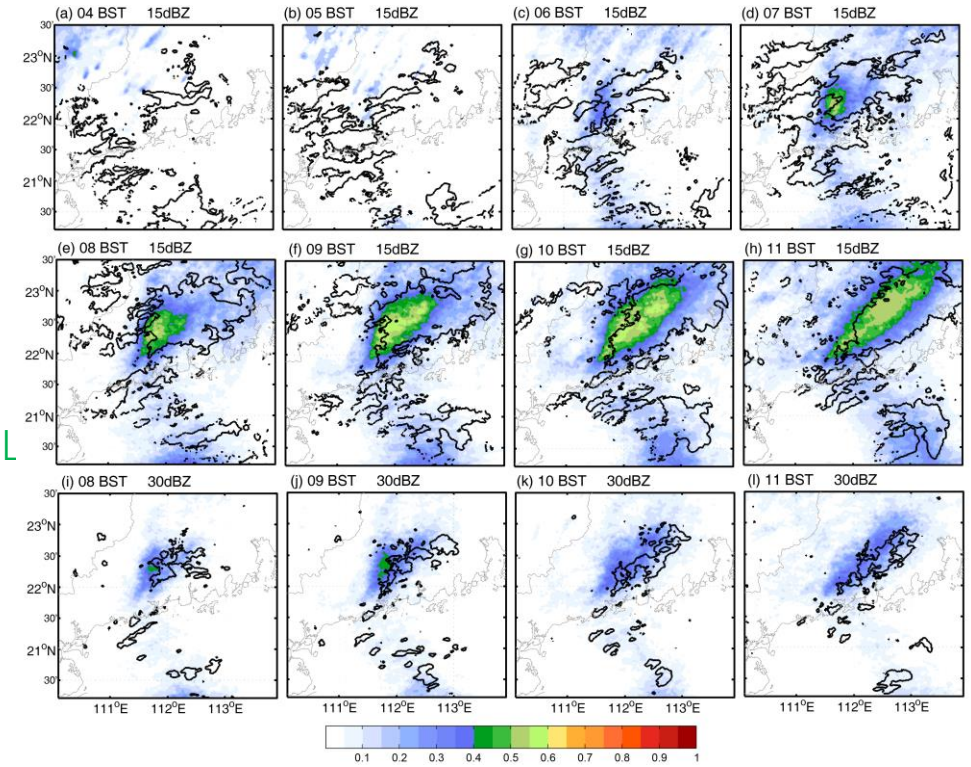


60成员集合试验FSS评分-区域平均累积降水量散点图



FNL

对流演变集合概率预报



模式有预报能力
单一值确定性预报能再现对流过程

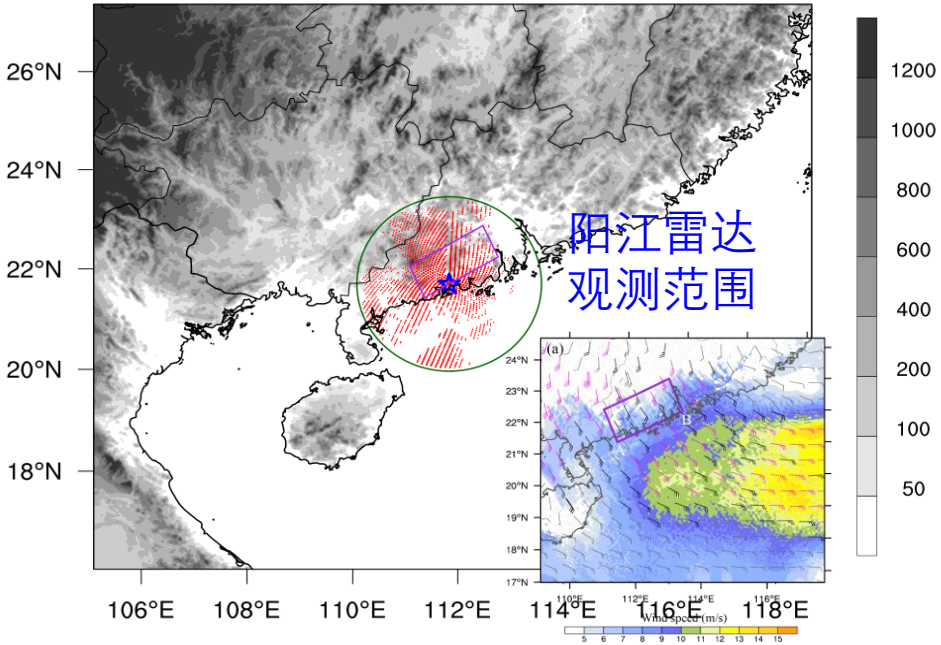
可预报性低

集合预报概率低

海上边界层气流是影响对流和降水的关键因素

沿海业务雷达能提供近海高时空分辨率风场观测

集合方法同化雷达径向风观测提升预报技巧



同化试验：雷达径向风观测集合同化试验

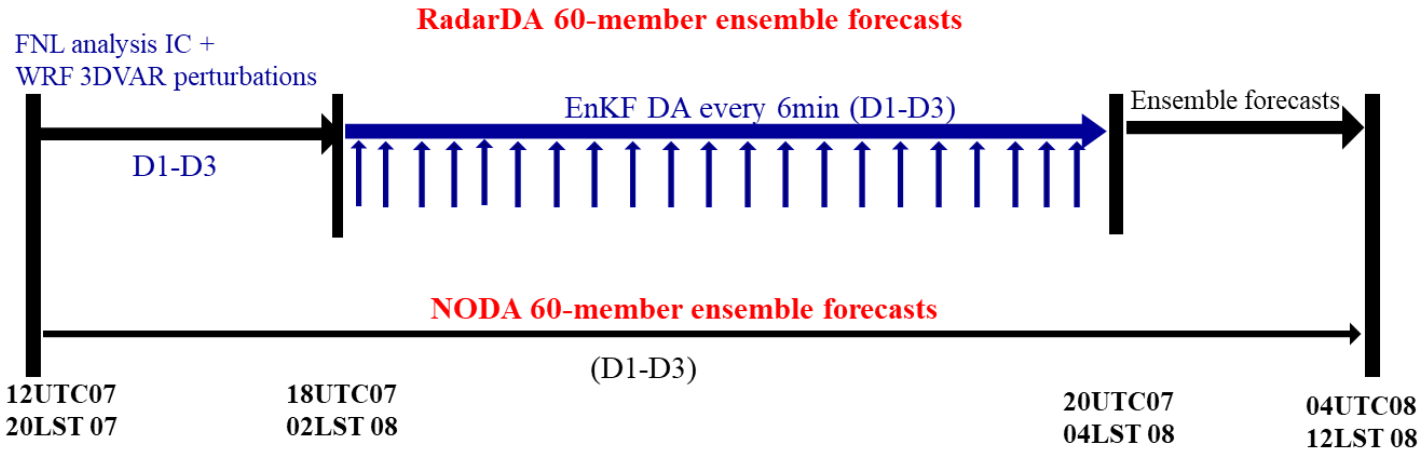
PSU WRF-EnKF系统：

时间窗：对流初生早期（02-04时）

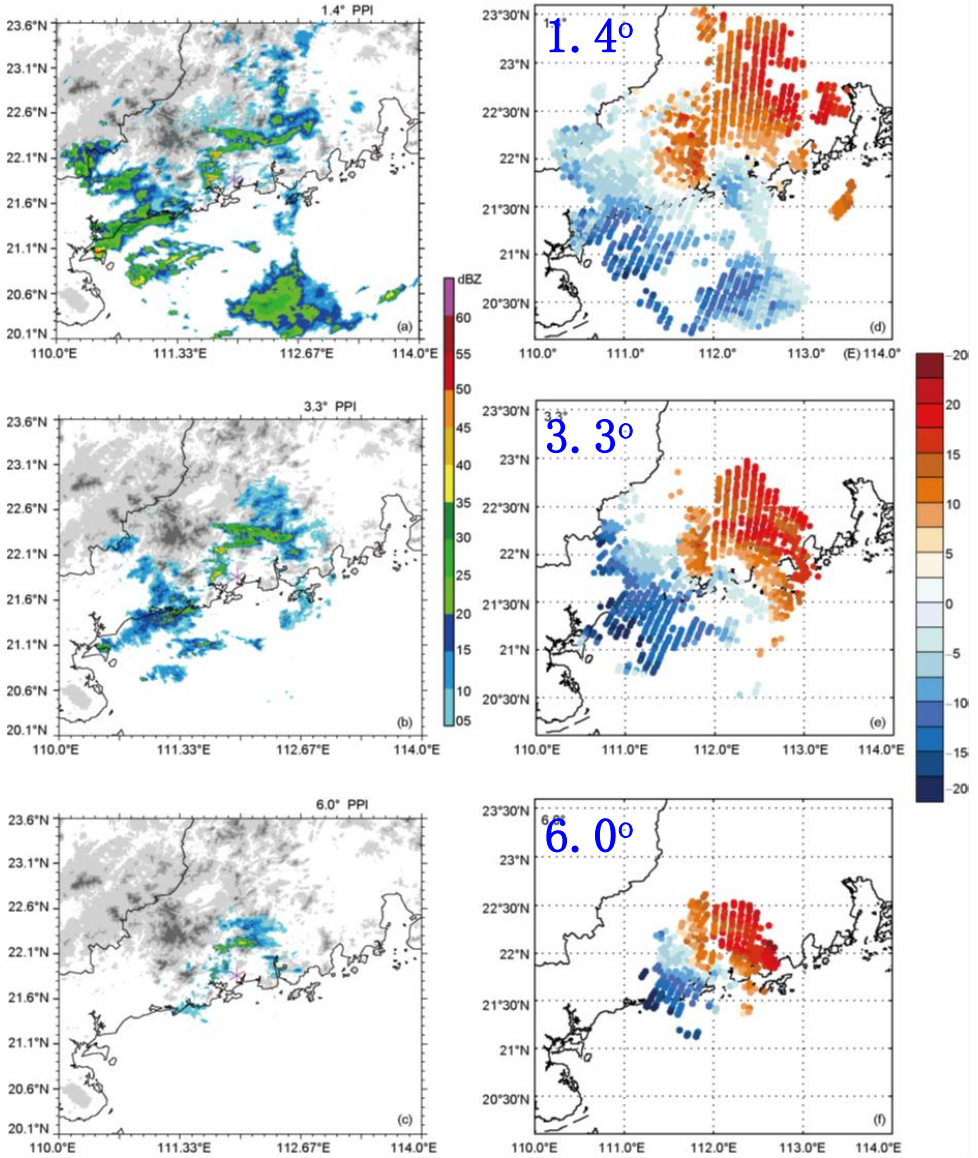
时间间隔：6分钟

—雷达集合同化试验（60个成员）

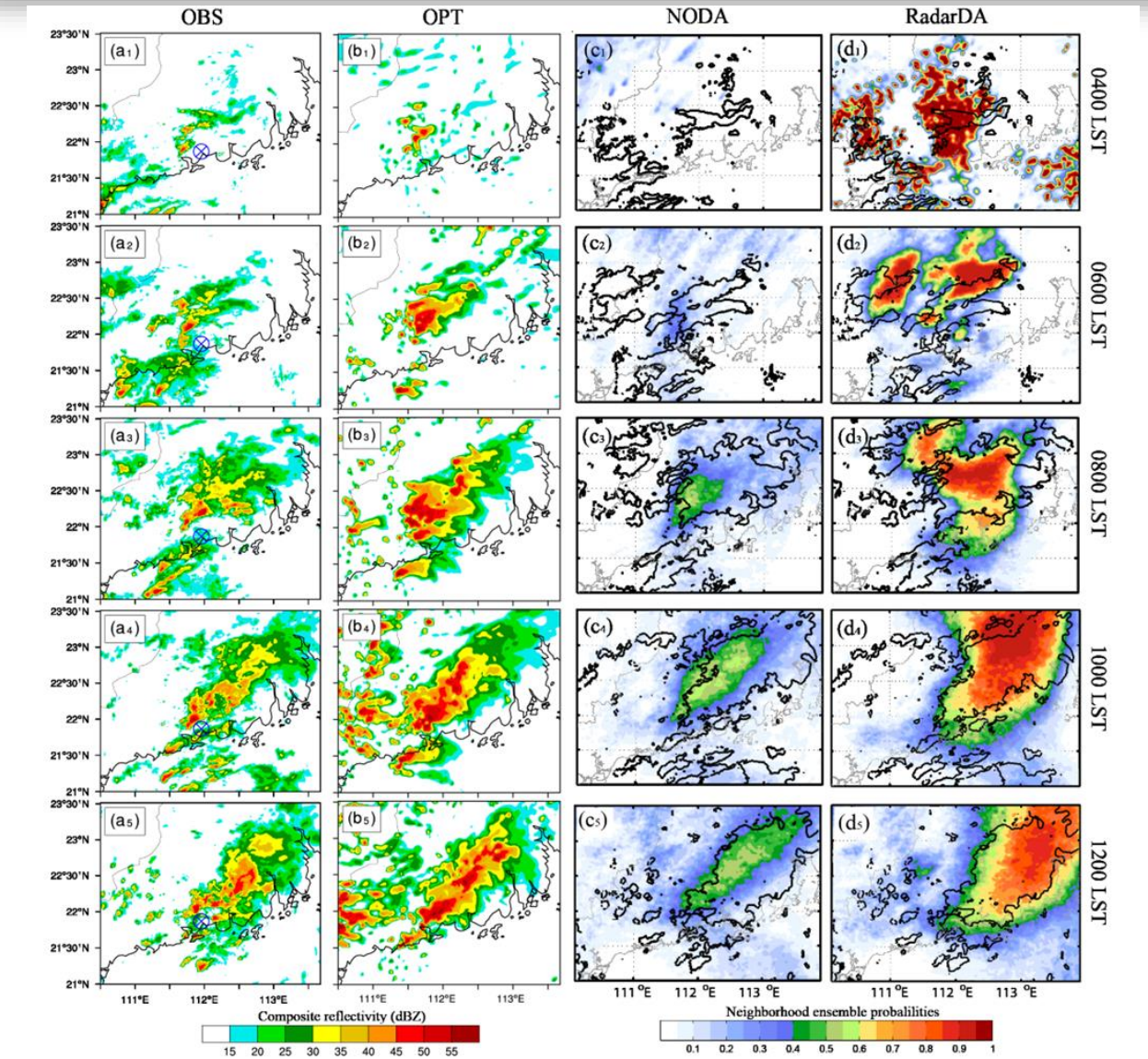
循环同化结束时（04时），以60个集合成员的分析场作为初始场分别向前积分8小时



04时阳江雷达反射率和径向风速度超级观测



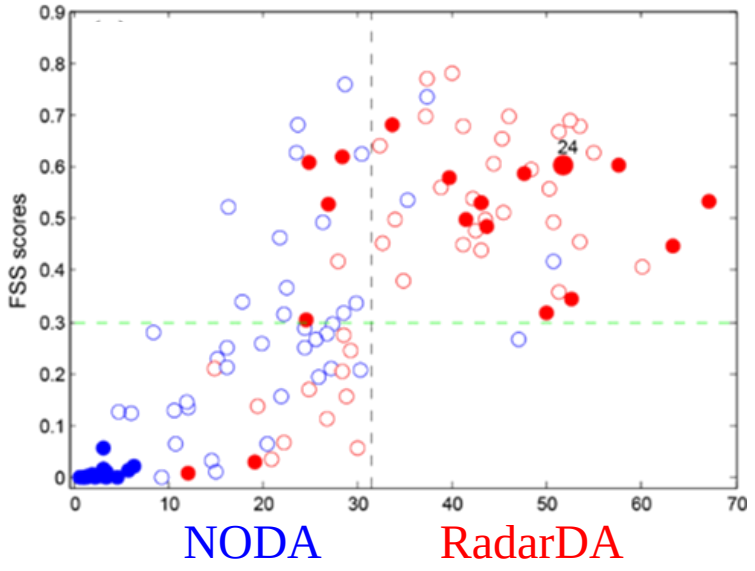
EnKF循环同化雷达径向风观测能够大幅提升降水和对流演变集合预报技巧 (Bao et al. 2017, *Sci. Chi. Ear. Sci.*; Bao et al. 2023, JMR)



88%低评分成员评分的增长

->集合预报概率提升

- ✓ FSS>0.3 16 NODA -> 45 RadarDA
- ✓ 39/44 低评分 NODA成员同化后评分增长0.01-0.77



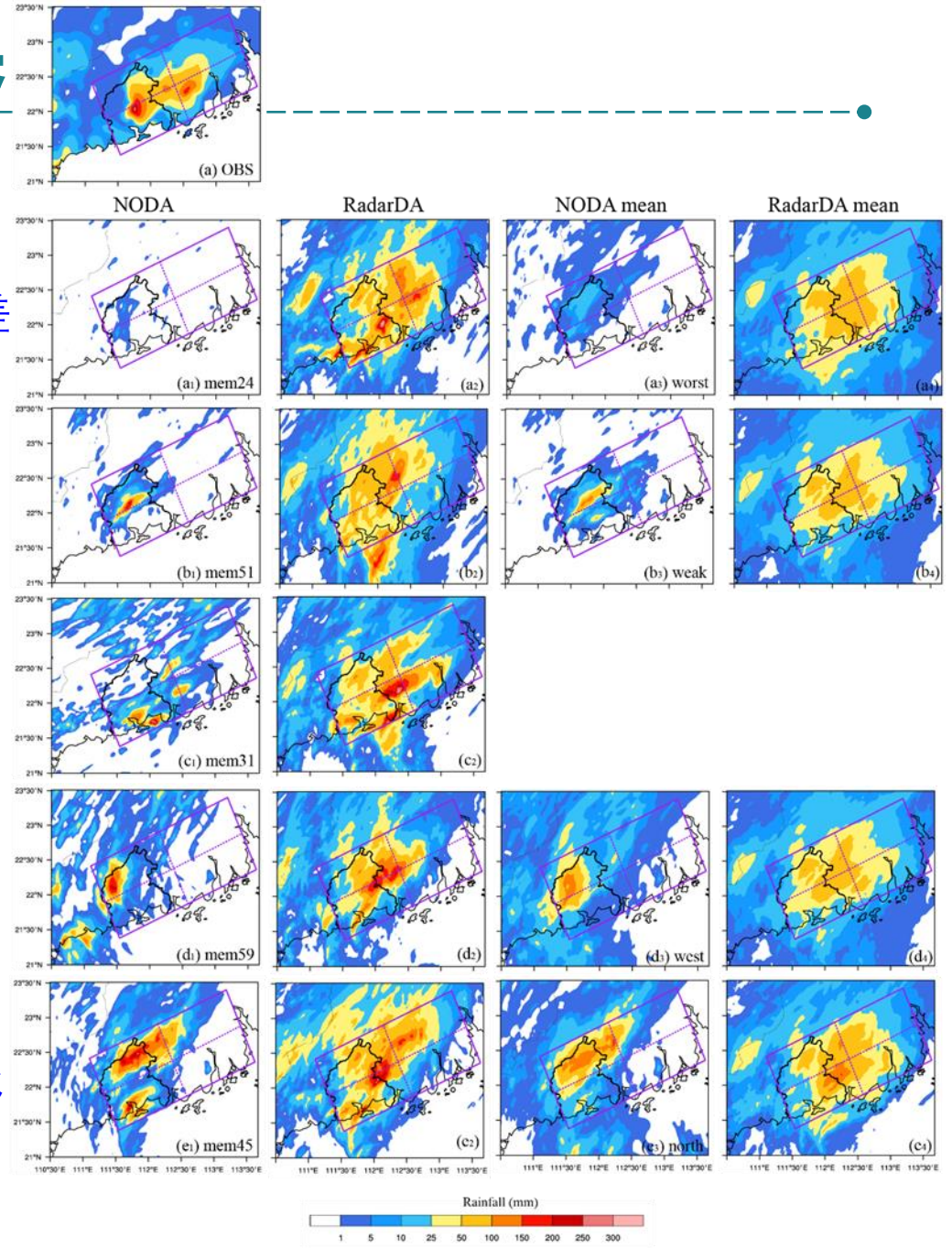
低评分成员分类对比同化效果

综合累积降水量、降水落区、FSS评分三个因素，将39个低评分成员分成两大类、五小类。

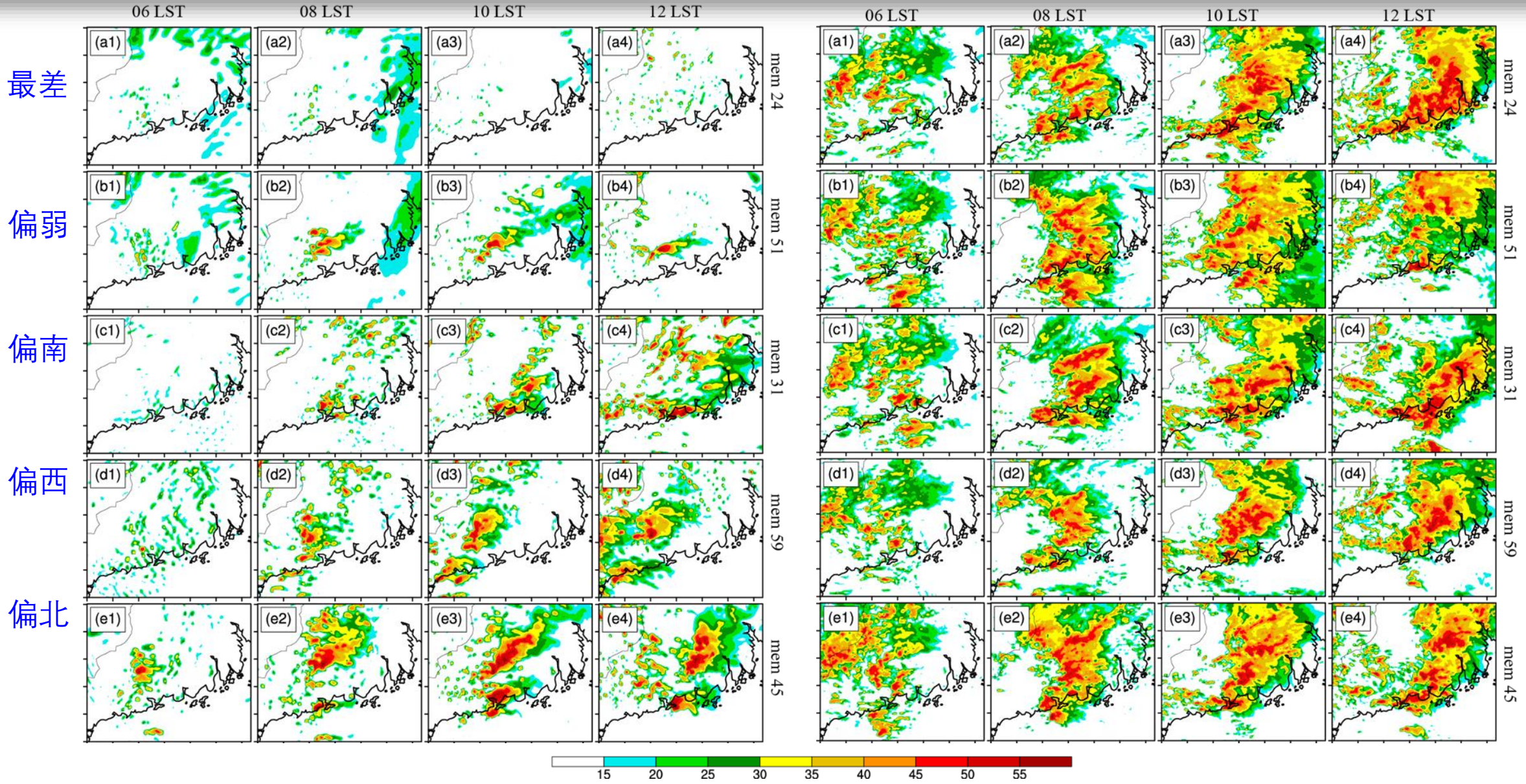
Main group	*Criteria*	*Sub-group*	*Criteria*	*Number of members*
Poor forecast of the rainfall amount	Significant underestimation of the rainfall amount, with the area-averaged 8-h rainfall accumulation < 9 mm	Worst	The lowest FSS (< 0.1) and the least amount of rainfall	18
		Weak	The mid-level FSS, i.e., 0.1 < FSS < 0.3	3
Poor forecast of the rainfall location	The area-averaged 8-h rainfall accumulation exceeds 9 mm but with large rainfall displacement	South	The rainfall is displaced more to the south	1
		West	The rainfall is displaced more to the west	11
		North	The rainfall is displaced more to the north	5

雨量预报误差大

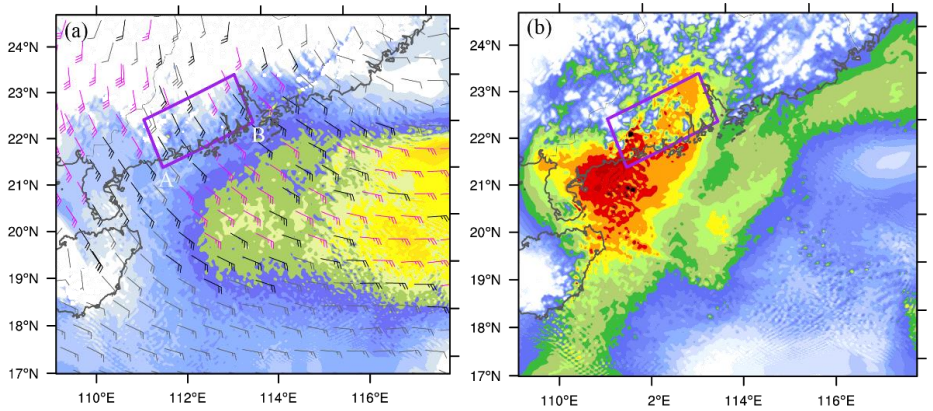
落区预报误差大



雷达同化后：对流演变过程与观测更接近

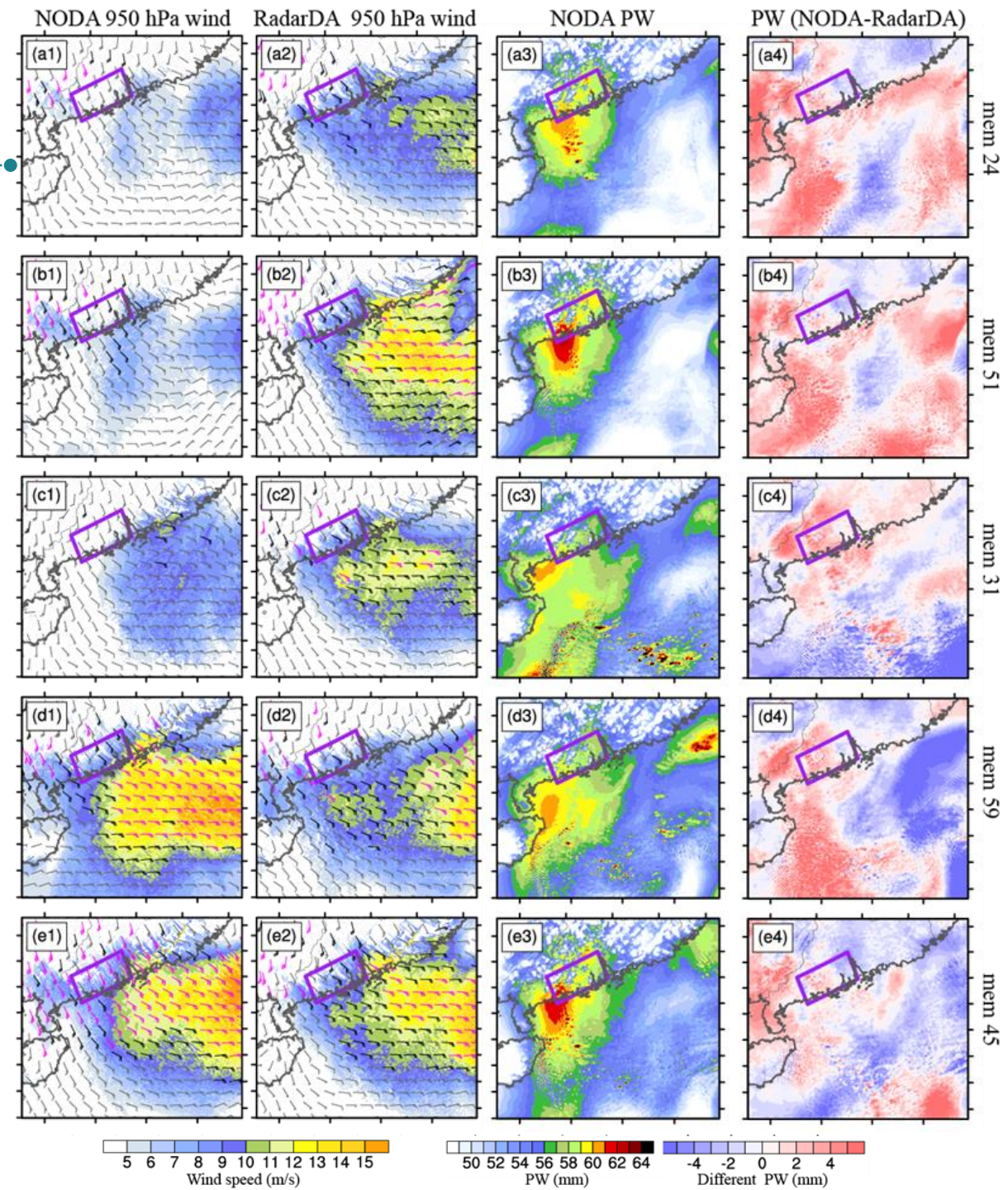


径向风同化直接调整风场
间接调整水汽场

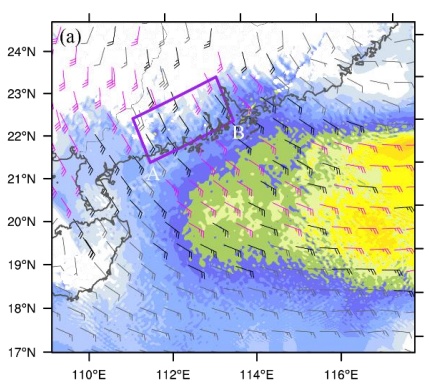


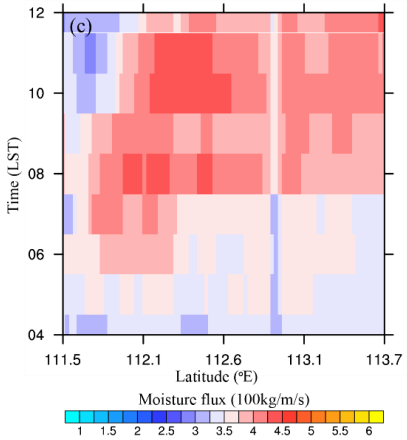
OPT 边界层风场和可降水量场

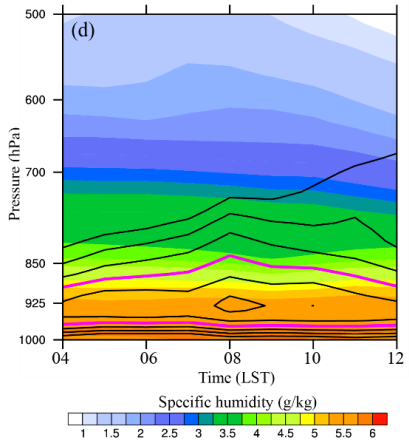
EnKF方法同化雷达径向风观测，能够减小风场误差，又能够通过背景误差协方差矩阵调整水汽场，进而提高动力和热力分析场的准确度。



准确的水汽输送->准确的降水预报

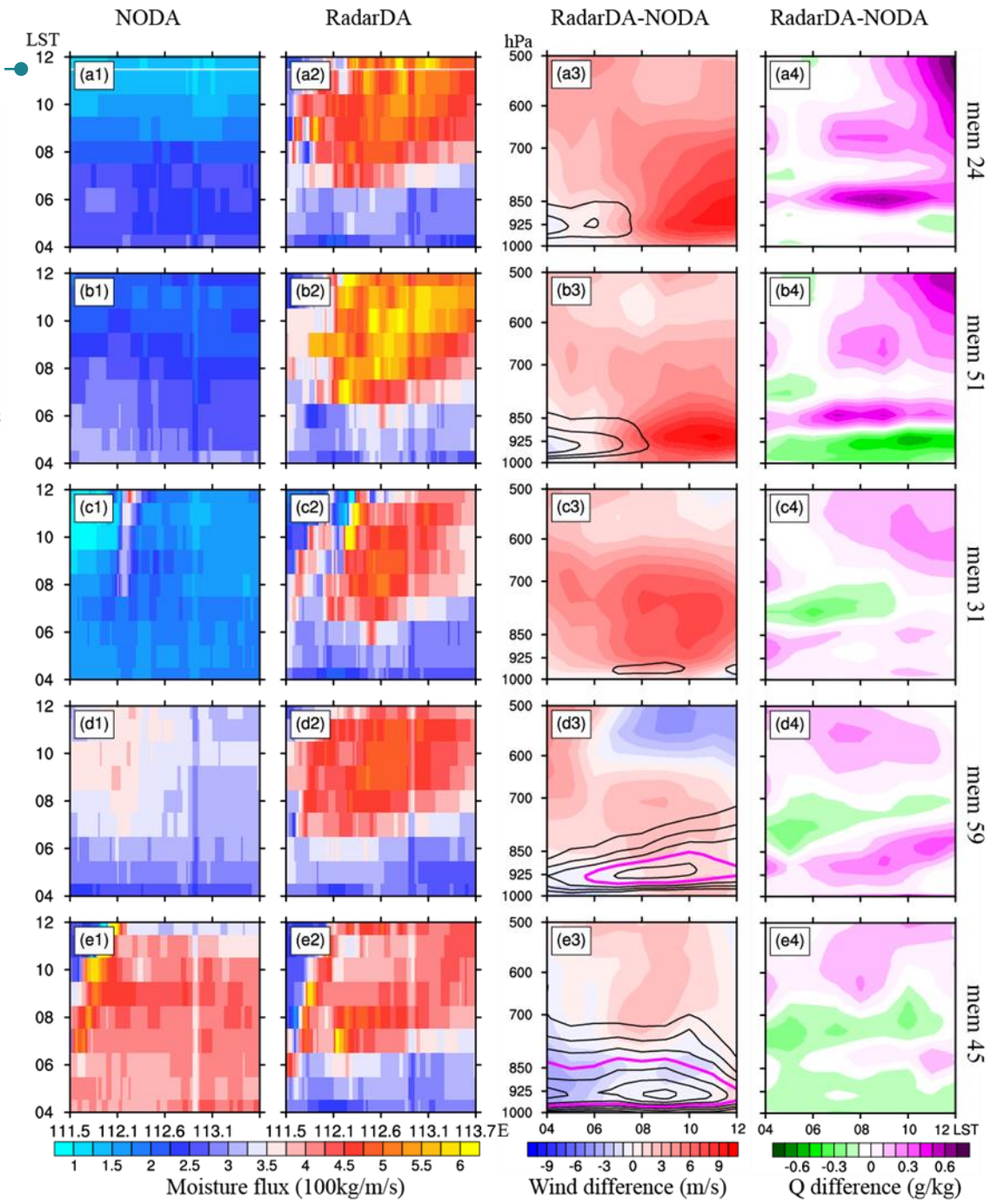




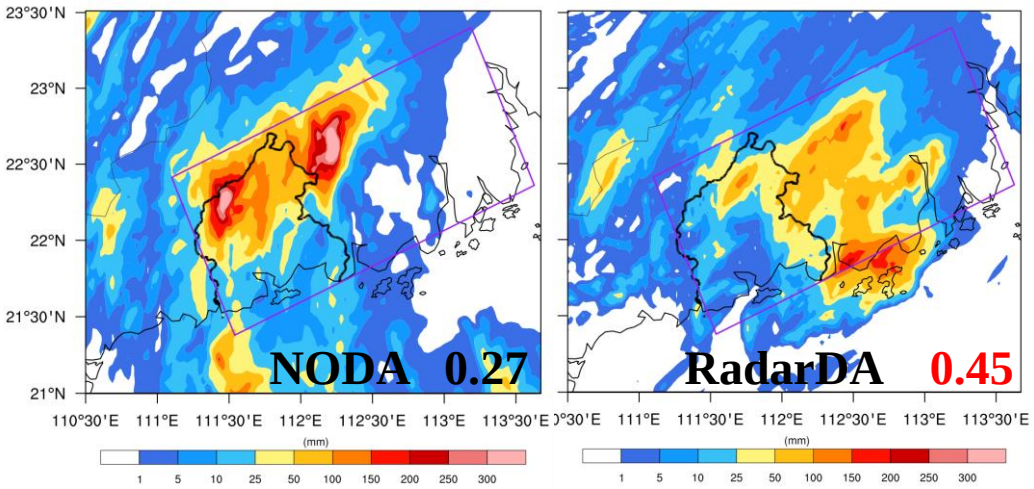


OPT试验 经过降水关键区东南边界的
(c) 水汽通量垂直积分（从地面到700hPa）
(d) 比湿（阴影）和风速（等值线）
随时间的演变

- 初始风场和水汽场的变化，导致水汽通量的演变朝向OPT试验调整。
- 水汽输送的改变主要取决于风场的改变。



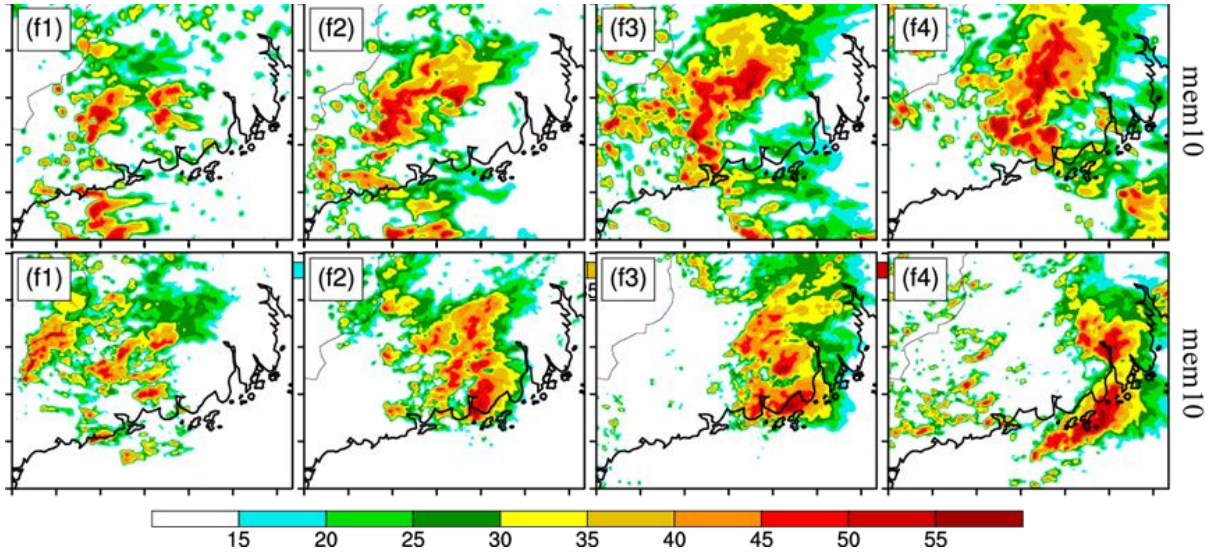
小概率：降水/对流演变预报技巧改进不大或降低

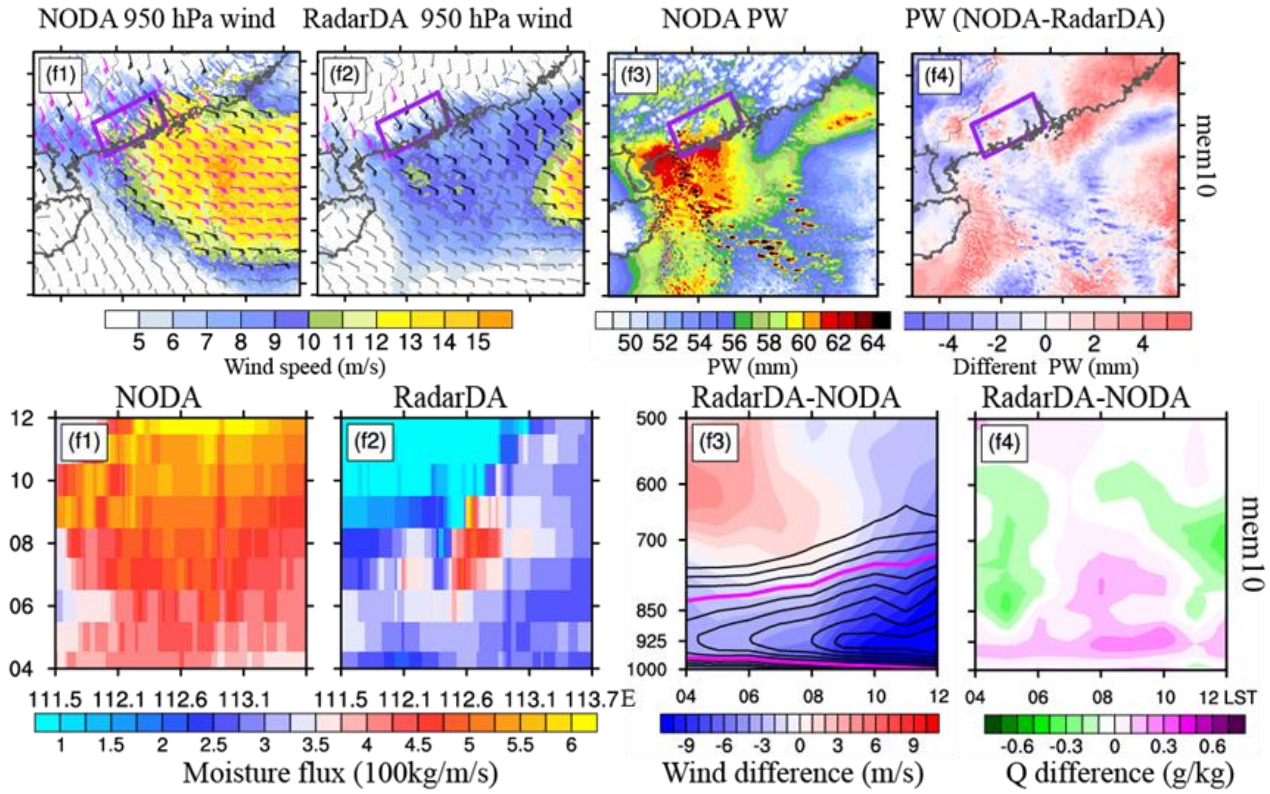


降水评分降低：5/44低评分NODA成员

降水评分升高、对流演变预报不准确：mem 10

EnKF方法存在局限性+暖区暴雨可预报性低





影响华南沿海暖区暴雨的关键因素：
海上边界层气流强度和风向

主要模式误差来源：初始风场误差

集合方法**针对性**的**同化**沿海雷达径向风观测

直接减小初始风场误差

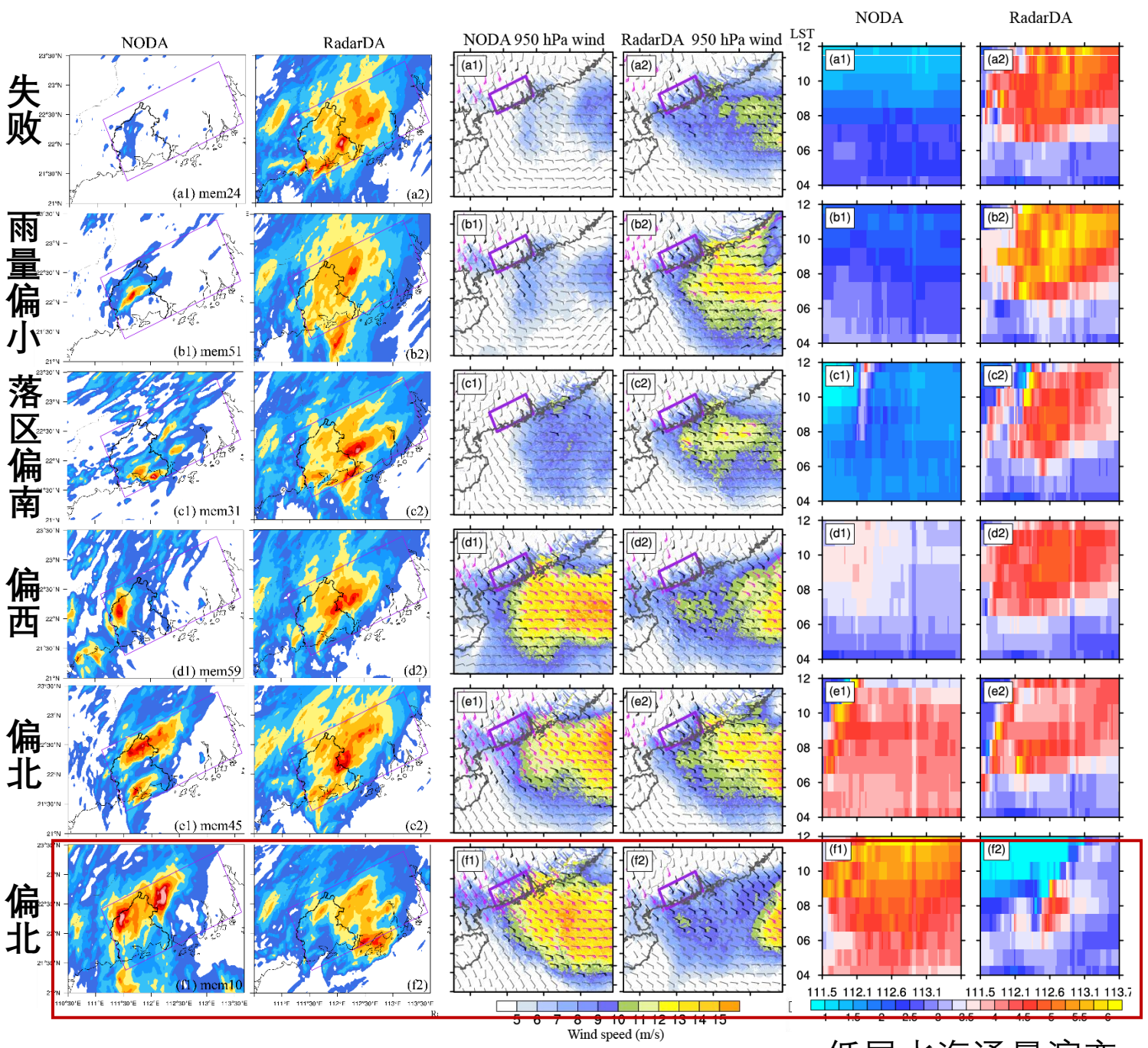
+

间接减小初始水汽场误差

水汽输送的位置和强度更准确

提升降水和对流演变的集合**预报水平**
提高业务预报**时效性**

少数成员预报评分不升反降，进一步验证华南暖区暴雨模式预报效果对于初始场很敏感，预报难度大，EnKF方法仍存在局限性



敬请各位专家批评指正！

华南暖区暴雨	机理	对流初生机制 **Bao Xinghua**, Luo Yali, Gao Xiaoyu, 2021: The Synoptic Impacts on the Convection Initiation of a Warm-Sector Heavy Rainfall Event Over Coastal South China Prior to the Monsoon Onset: A Numerical Modeling Study, *Journal of Geophysical Research: Atmospheres*, 126, e2020JD034335.
	同化	雷达资料同化改进陆地和海上对流演变和降水的确定性预报 **Bao Xinghua**, Luo Yali, Sun Jiaxiang, Meng Zhiyong, Yue Jian, 2017: Assimilating Doppler radar observations with an ensemble Kalman filter for convection-permitting prediction of convective development in a heavy rainfall event during the pre-summer rainy season of South China. Science China Earth Sciences, 60: 1866–1885.
		雷达资料同化改进对流演变和降水的集合预报 **Bao Xinghua**, Rudi Xia, Yali Luo, Jian Yue, 2023: Efficiently improving ensemble forecasts of warm-sector heavy rainfall over coastal southern China: Targeted assimilation to reduce the critical initial field errors. J. Meteor. Res., 37(X), 1-22, doi: 10.1007/s13351-023-2140-8.