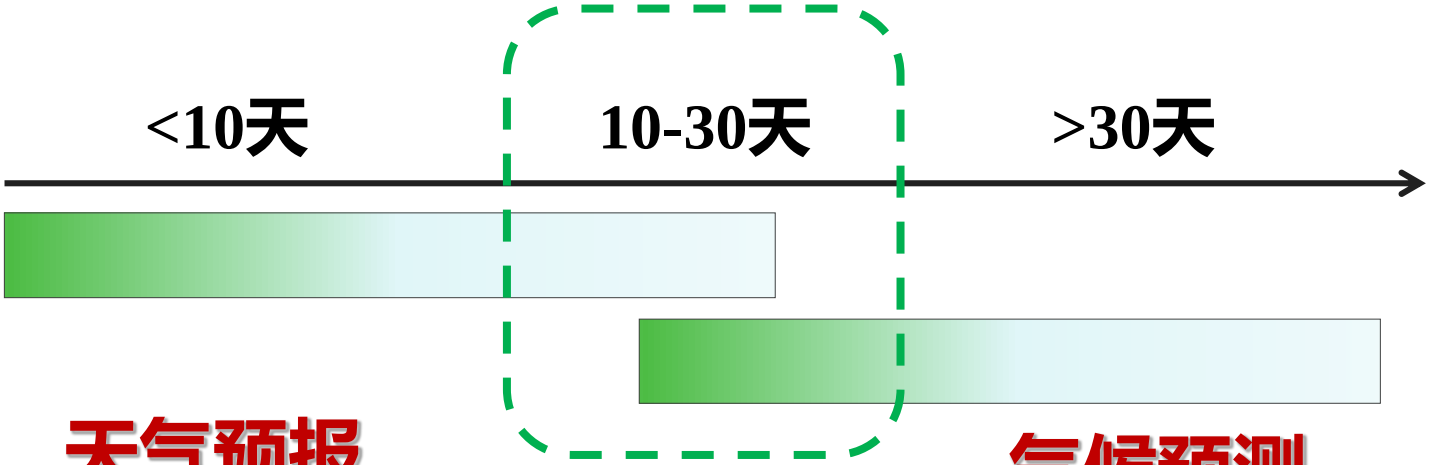
Methodologies for Extended-range Forecast: Dynamic, Statistical and Dynamic-Statistical Approaches

Tim Li

University of Hawaii at Manoa

Acknowledgement: Xianan Jiang (UCLA), Ming Zhao, Baoqiang Xiang and S.-J. Lin (GFDL), Zhiwei Zhu, Pang-chi Hsu (NUIST)

什么是延伸期(10-30天)预报?



天气预报

气候预测

延伸期(10-30天)预报是全球气象研究的重点和难点

世界气象组织提出无缝隙天气-气候预报概念

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Subseasonal to Seasonal Prediction Project

WCRP World Climate Research Programme

WWRP

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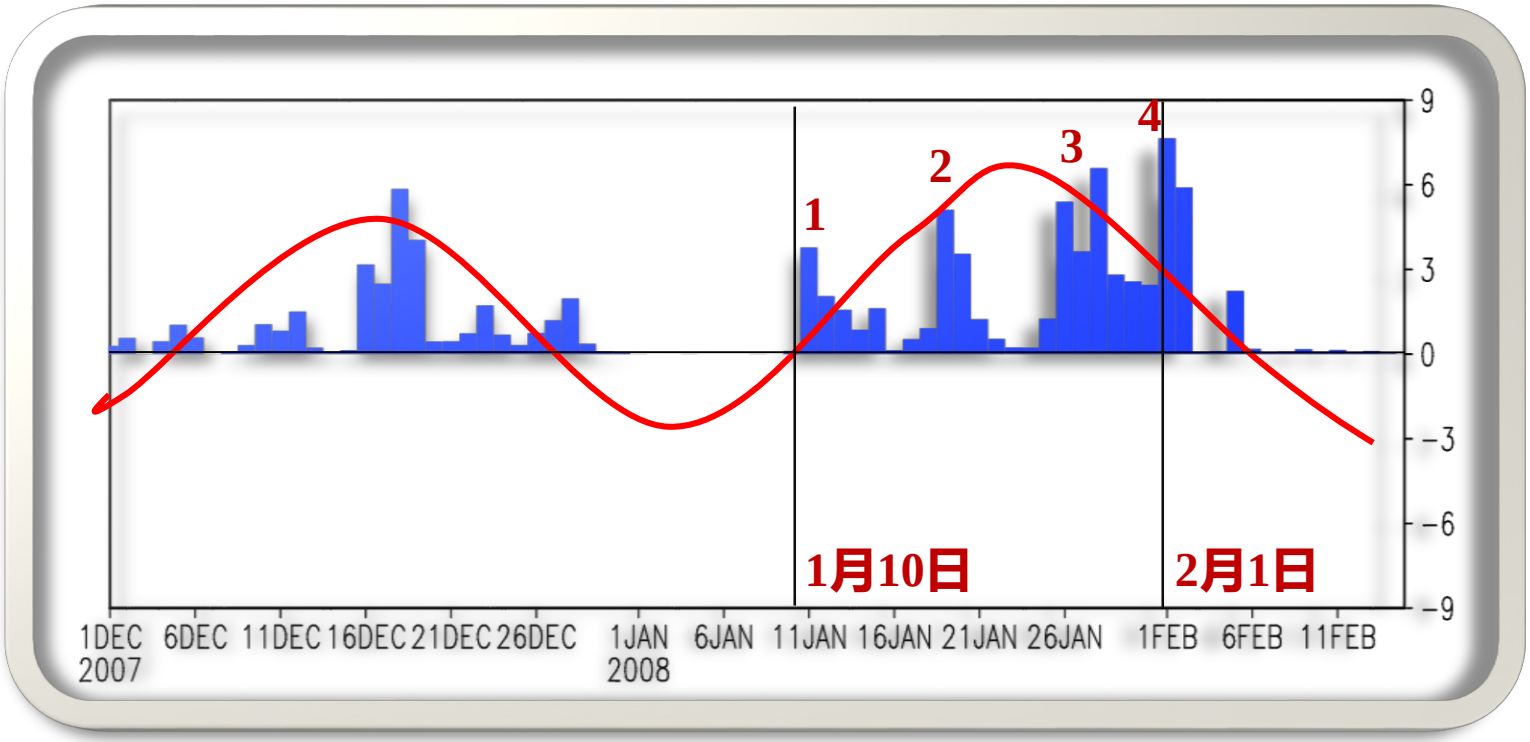
- WWRP Scientific Steering Committee (SSC)
- 2013 Calendar
- 2012 Calendar
- 2011 Calendar
- 2010 Calendar
- Publications

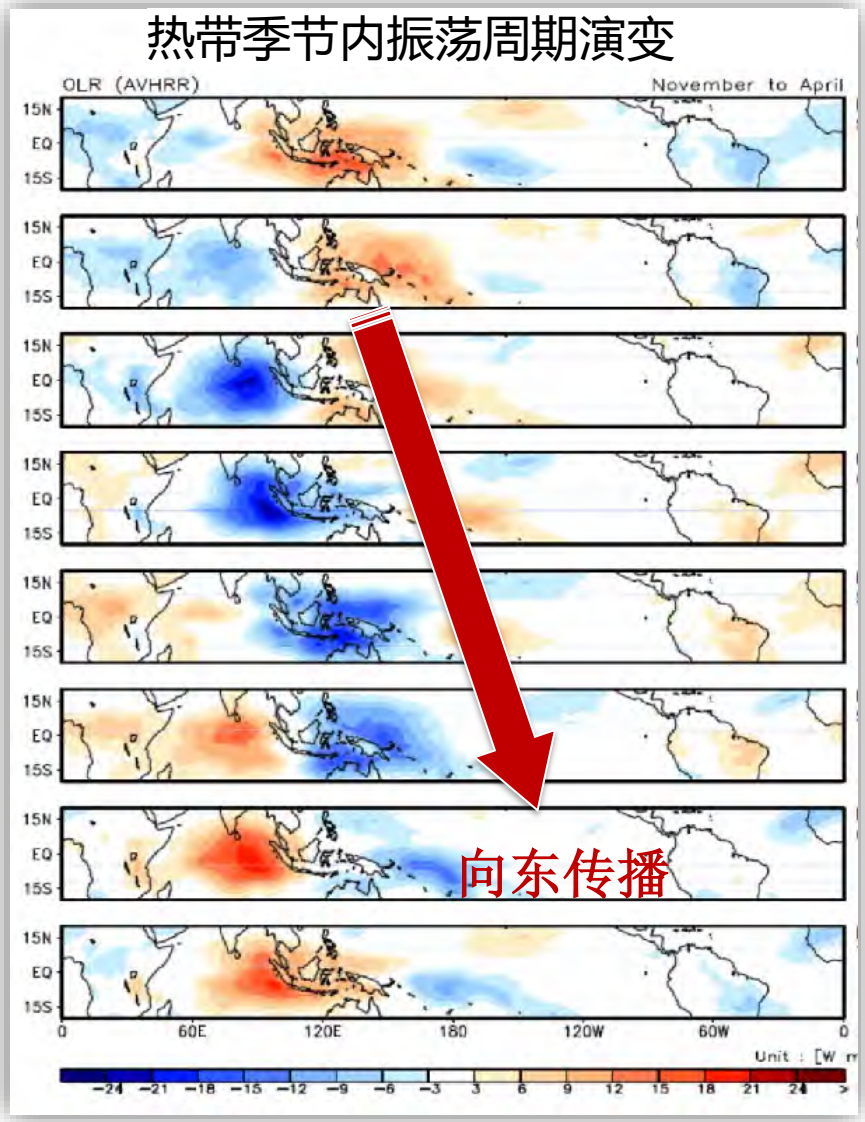
- 世界气象组织世界天气研究计划(WWRP)和世界气候研究计划(WCRP)联合提出将延伸期预报作为未来五到十年亟待攻克的重大科学问题。

延伸期预报的科学基础：大气季节内振荡



红线代表大气季节内振荡的演变特征

热带季节内振荡(MJO)



- **Madden and Julian (1971, 1972)**
- 纬向行星尺度
  在热带印度洋生成后缓慢东传
- 热带季节内振荡引起的大气环流异常直接控制东亚地区灾害性天气
- 现有的理论主要解释季节内振荡的传播，但是其触发机制尚不清楚

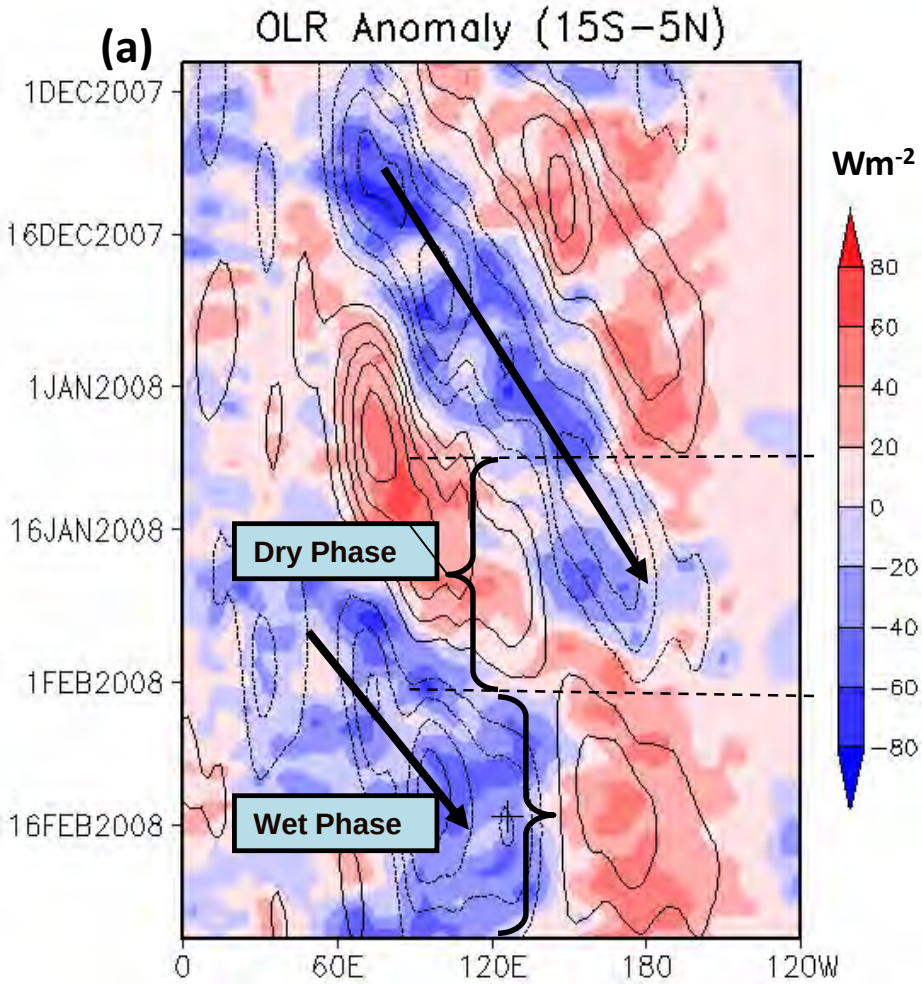
2008年1月南方典型季节内振荡特征的冰冻雨雪事件

区域：**10省**

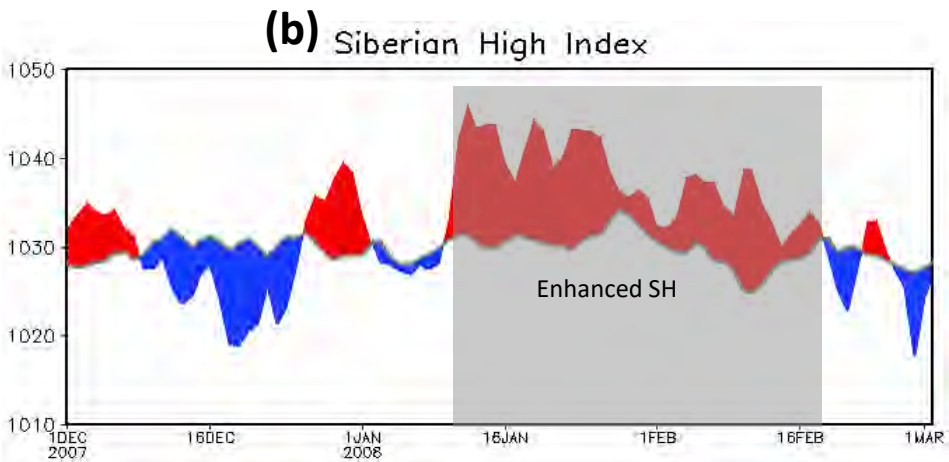
损失：**1050亿元**

1月10日至2月1日4次冰冻雨雪过程，虽能准确预报未来3天的单次过程，但未能提前预报未来23天的连续4次过程。

Tropical MJO activity during Jan-Feb 2008



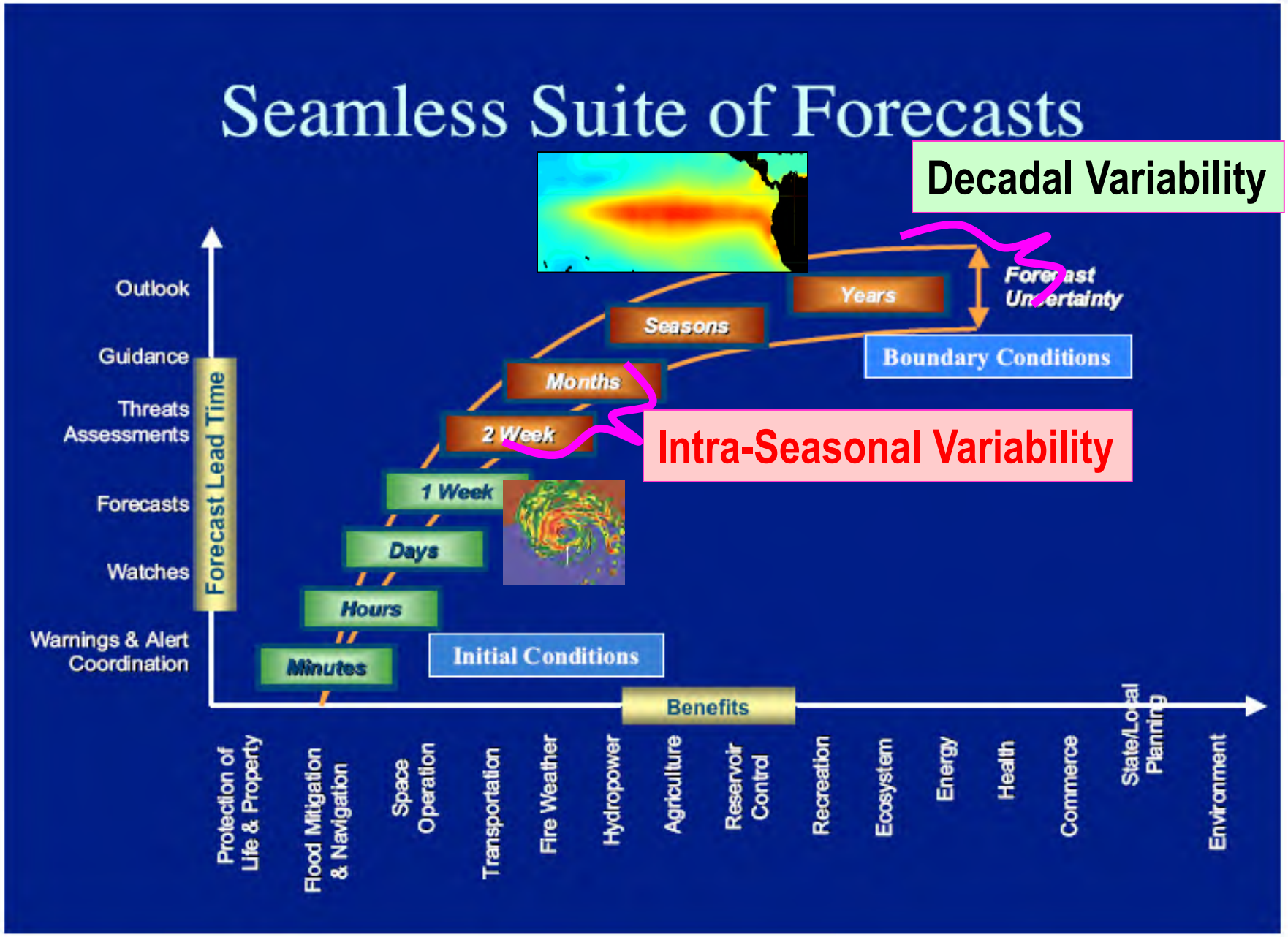
(a) The Hovmüller diagram for the daily OLR anomaly averaged over 15°-5°S. The shading denotes the raw OLR data and the contour represents 20-70-day filtered anomalous OLR.



(b) Time series of the SH index (defined as the averaged SLP (hPa) over 80°-120°E, 40°-60°N). The gray shading denotes the periods of the enhanced SH.

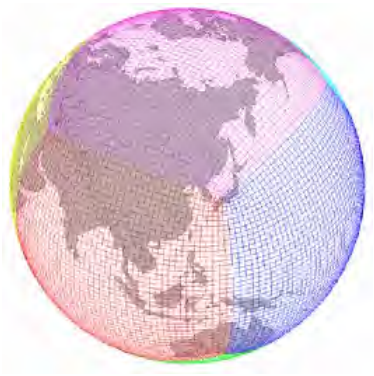
Hong and Li, 2009, JC

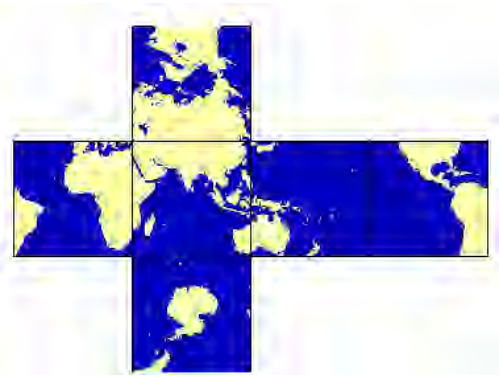
WCRP: Seamless Weather-Climate Prediction



1. Dynamic approach: TC forecast with GFDL High-Resolution Atmosphere Model (HiRAM)

- Designed for resolution between 1– 50 km, with non-hydrostatic **finite-volume dynamical core** on the **cubed-sphere** (S.-J. Lin)





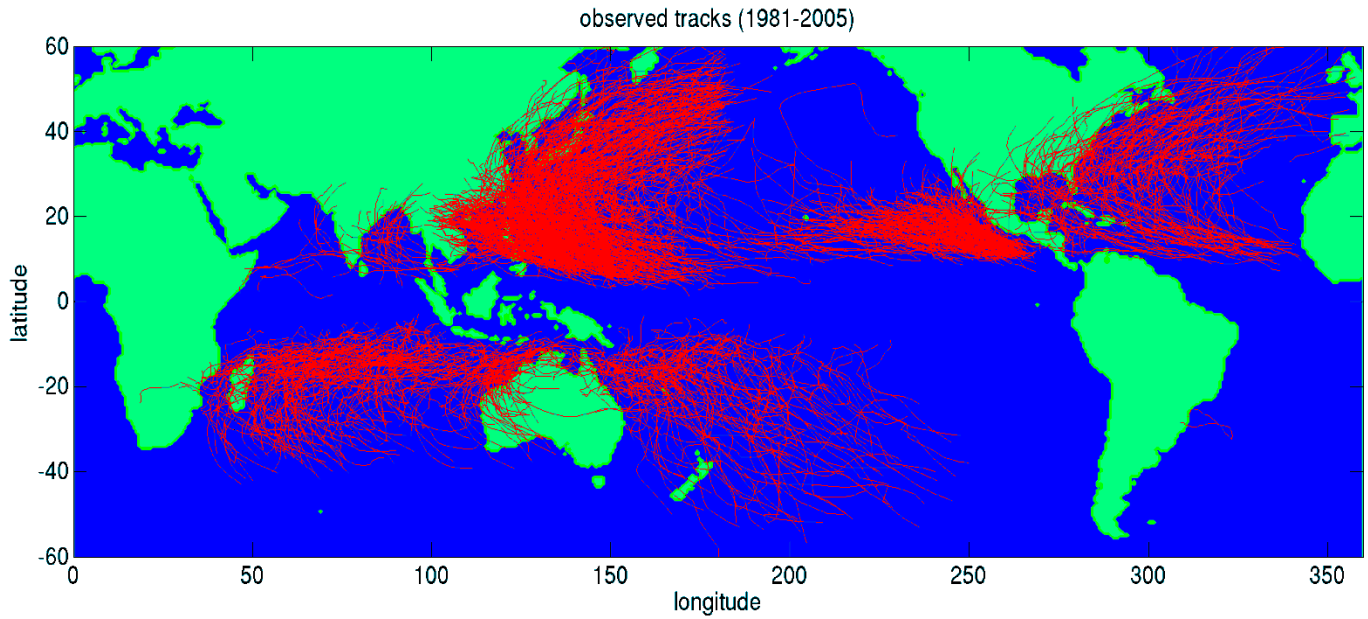
- A "**6-category cloud micro-physics**" with high-order vertical sub-grid reconstruction allowing vertically & horizontally sub-grid cloud formation

- A "**Double-Plume**" convective parameterization scheme (Bretherton scheme modified by Ming Zhao at GFDL)

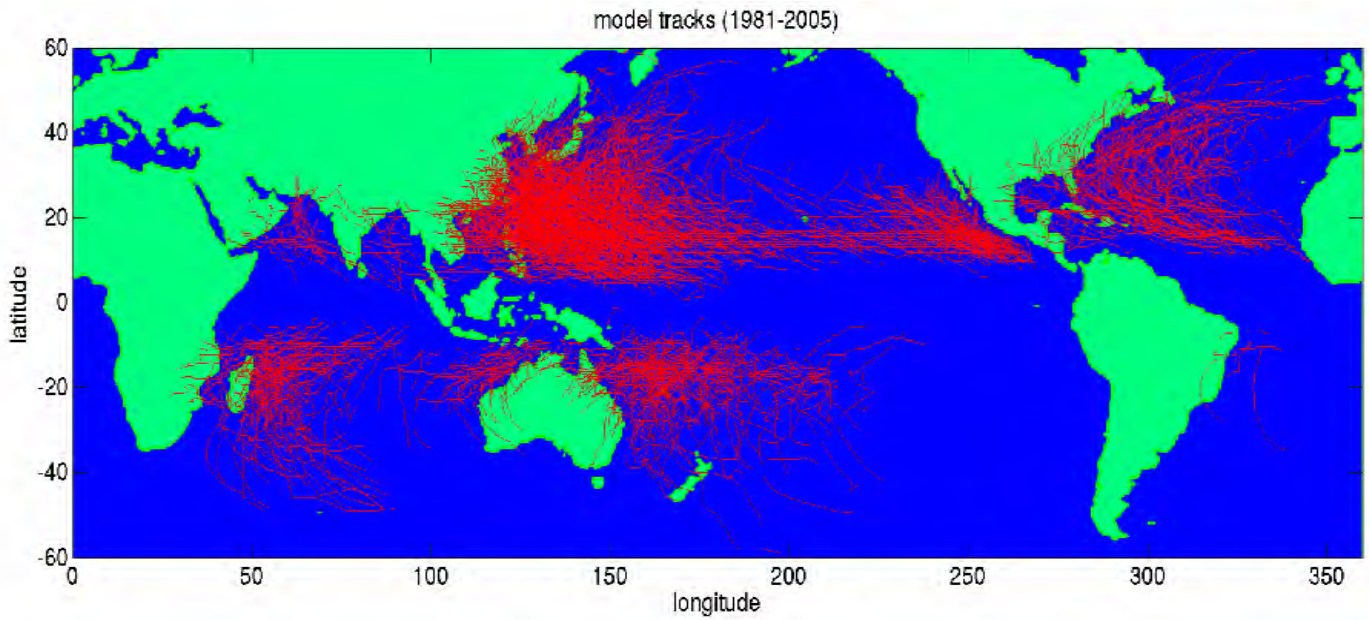
- **Coupled** with MOM5 **OGCM**

Capability to Simulate TCs: HiRAM Simulated TC Tracks

Observation (1979-2008)

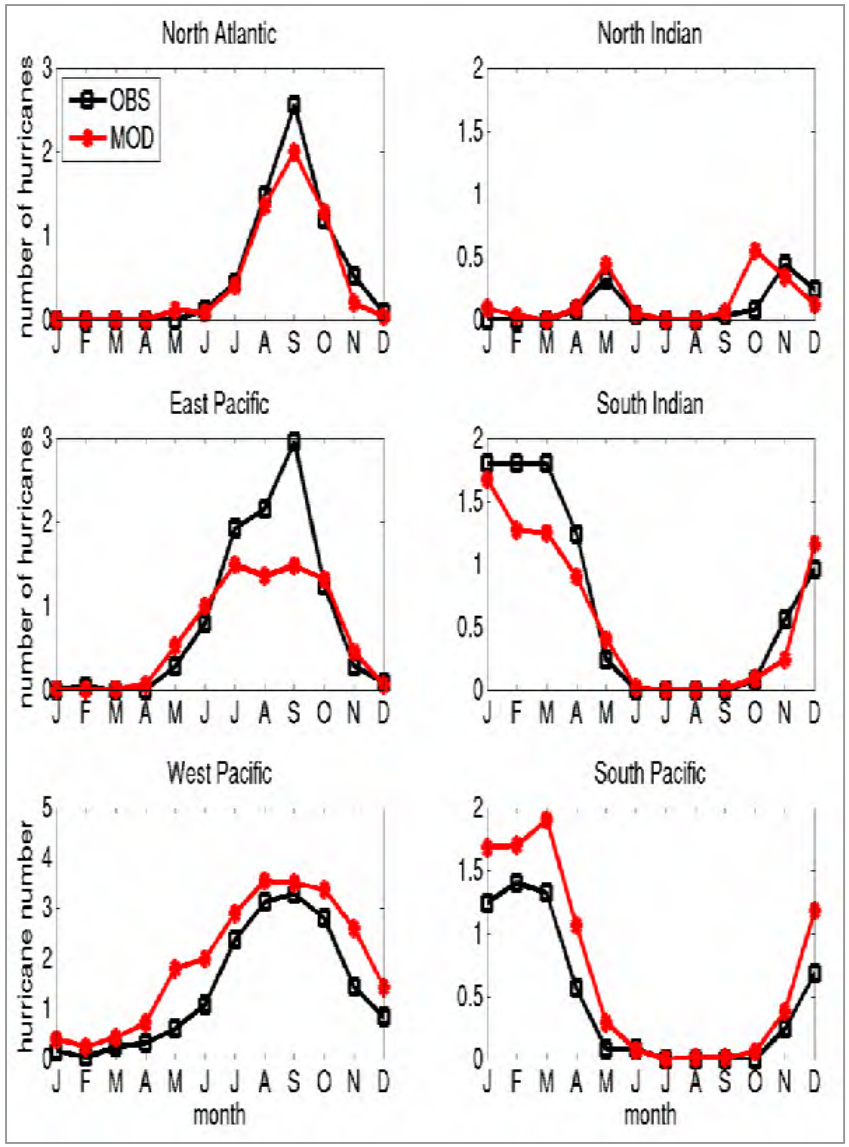


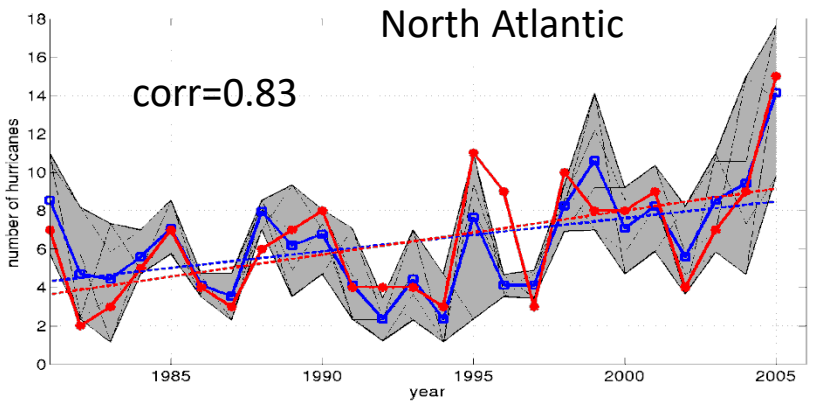
HiRAM (50-km grid) AMIP-type simulation

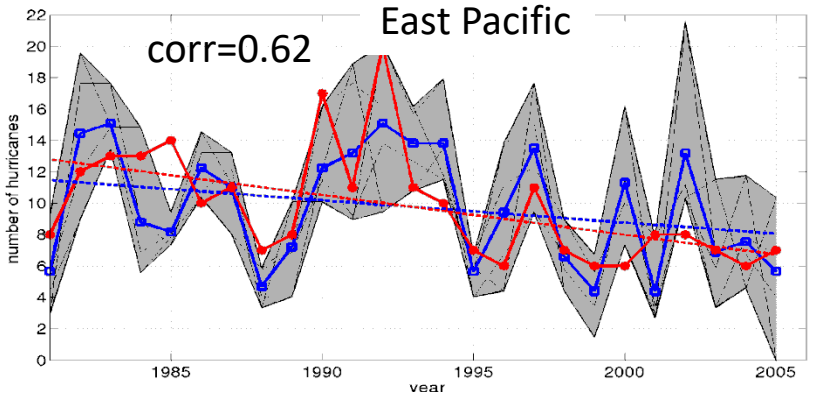


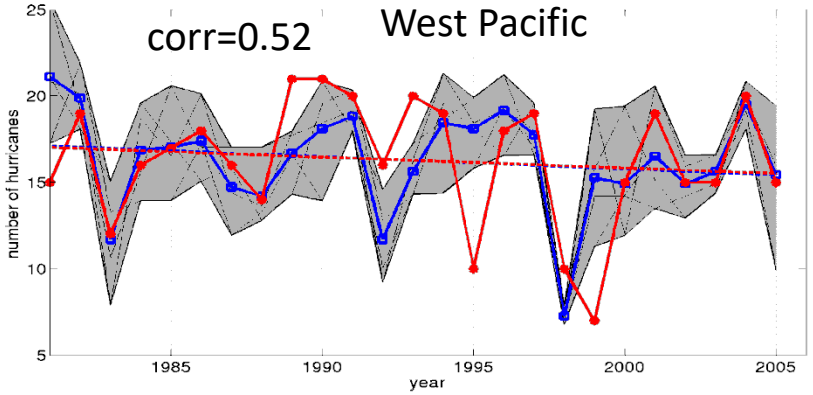
Zhao et al. 2009

HiRAM simulated TC annual cycle and interannual variability/trend



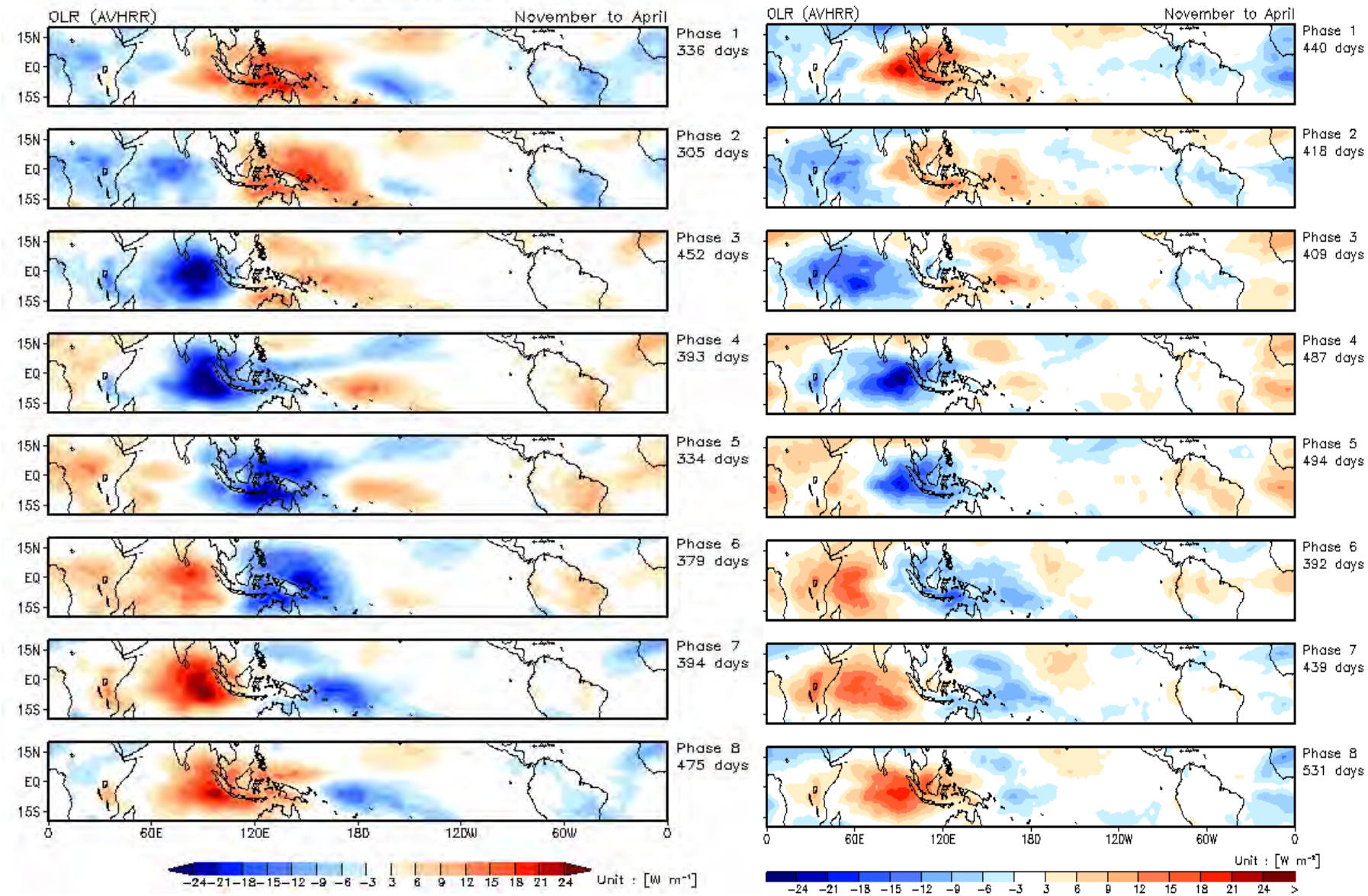






Composite of OLR anomaly in boreal winter

Observations HiRAM (20-yr coupled run)



Prediction of Hurricane Sandy and Super Typhoon Haiyan (Xiang et al. 2015)

Sandy (Oct 2012)

Genesis on Oct 22,
landfall on Oct 29

Haiyan (Nov 2013)

Genesis on Nov 4,
landfall on Nov 7

Methodology

Initial Condition:

Nudging (U, V, SLP, HGT, Temperature + SST) toward NCEP FNL

TC tracker:

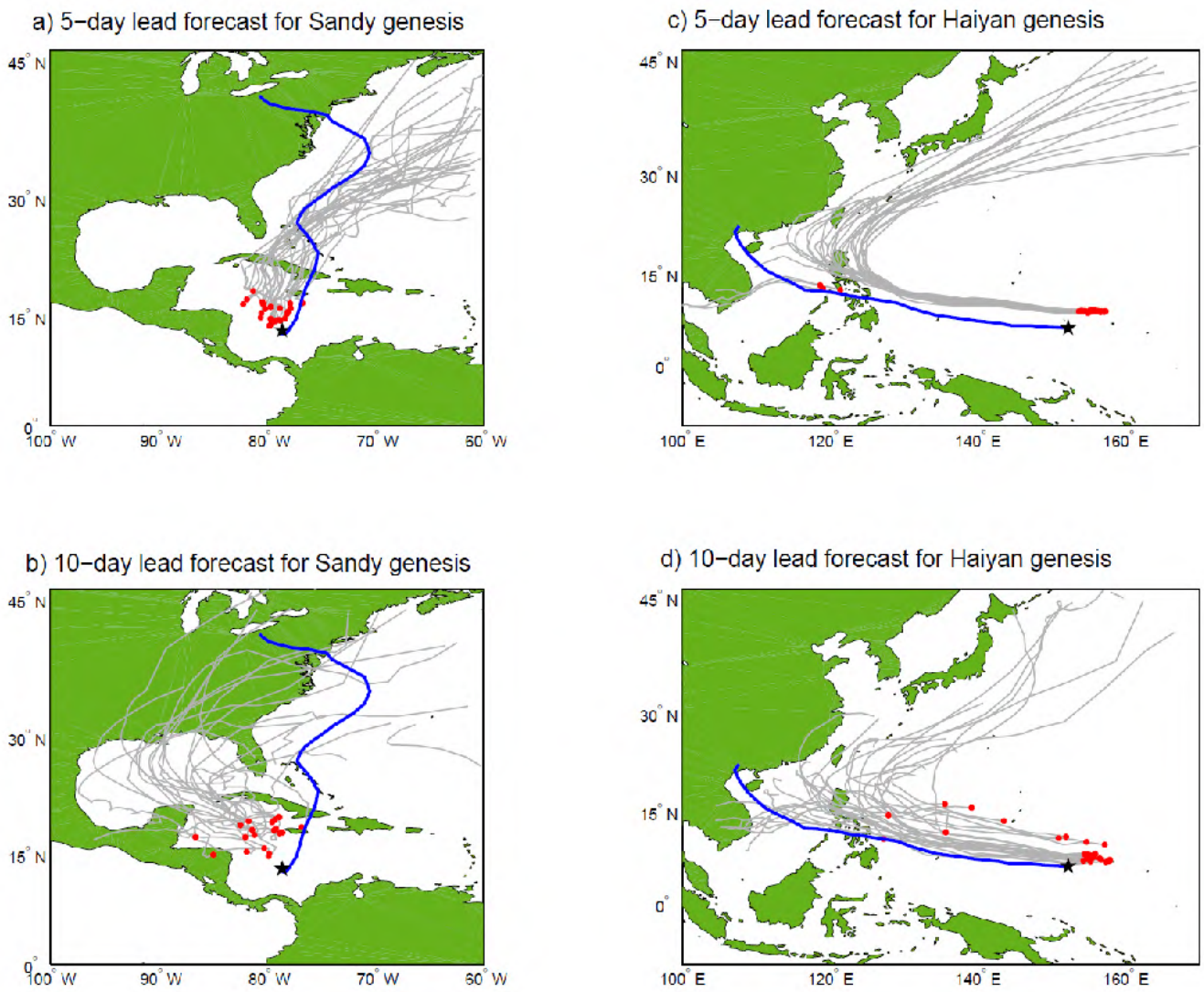
Lucas Harris's simply tracker

Definition of 'correct' forecast range:

Genesis during one day before and after the observed genesis (a 3-day window) within radius of 1000 km

24 ensemble forecast members each day

Genesis forecast of Sandy & Haiyan



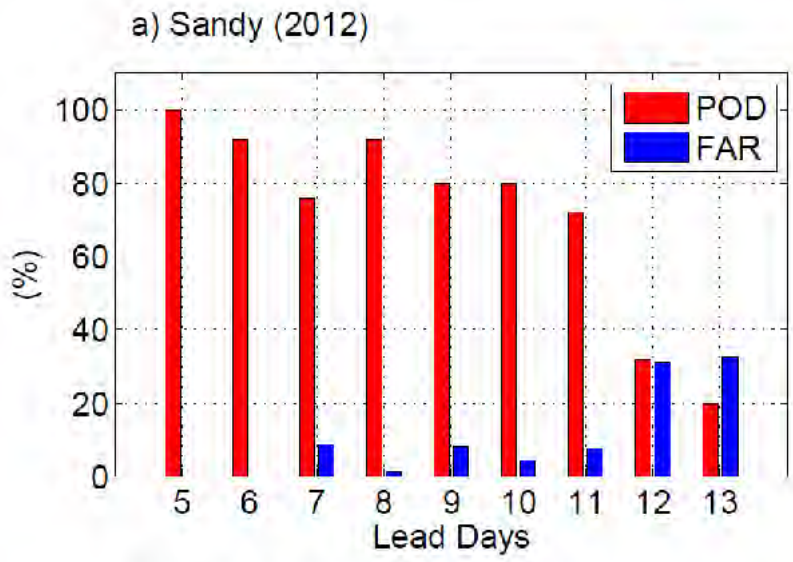
Blue lines represent observed TC track.

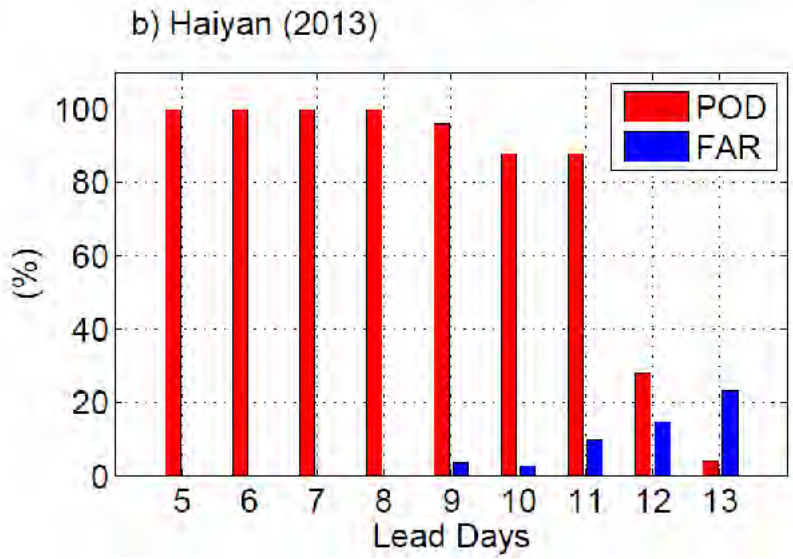
Grey lines denote predicted tracks.

Black stars denote observed genesis location.

Red dots denote predicted genesis locations from 24 ensample members.

Sandy and Haiyan genesis is predictable at a lead time of 11 days





Red: possibility of detection (POD)

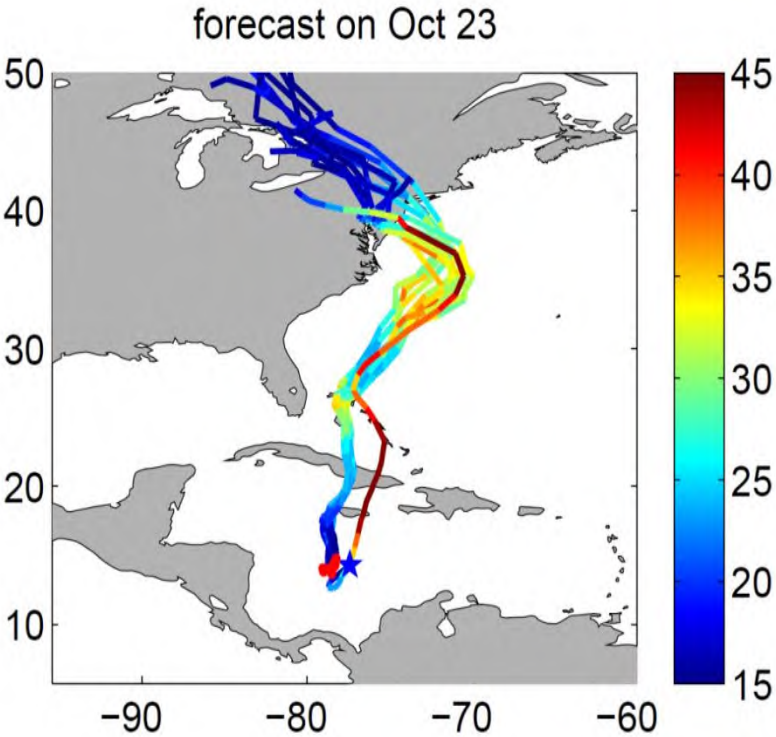
Blue: false alarm ratio (FAR)

The 'correct' prediction is counted by the cyclogenesis within a 3-day window within 1000 km radius.

The false alarm is counted by cyclone numbers 5 days before and 5 days after the 'correct' prediction window within 1000 km radius of circle.

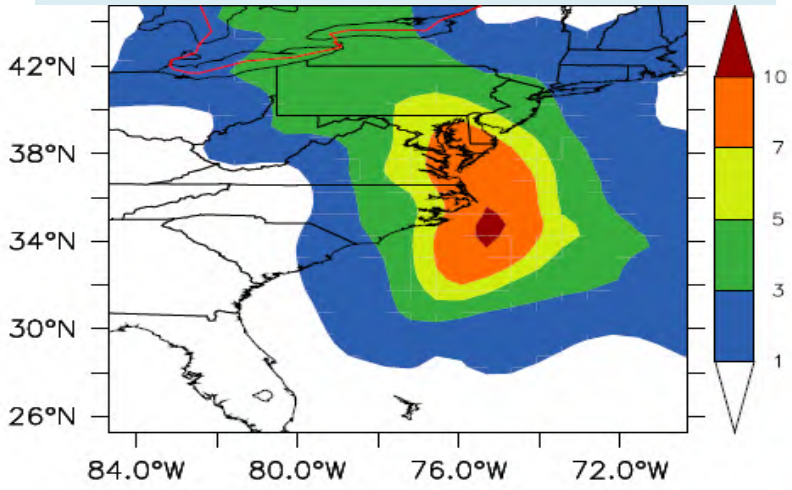
➔ POD is above 70% for both Sandy and Haiyan for 5- to 11- day lead.

Track forecast of Sandy

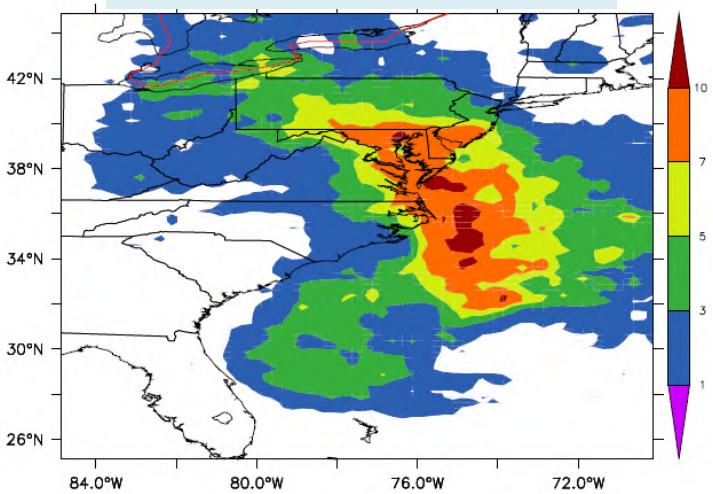


Track forecast of Sandy on Oct 23. Landfall time: Oct 29, 2012

Forecasted precipitation (7-day lead)



Observational validation



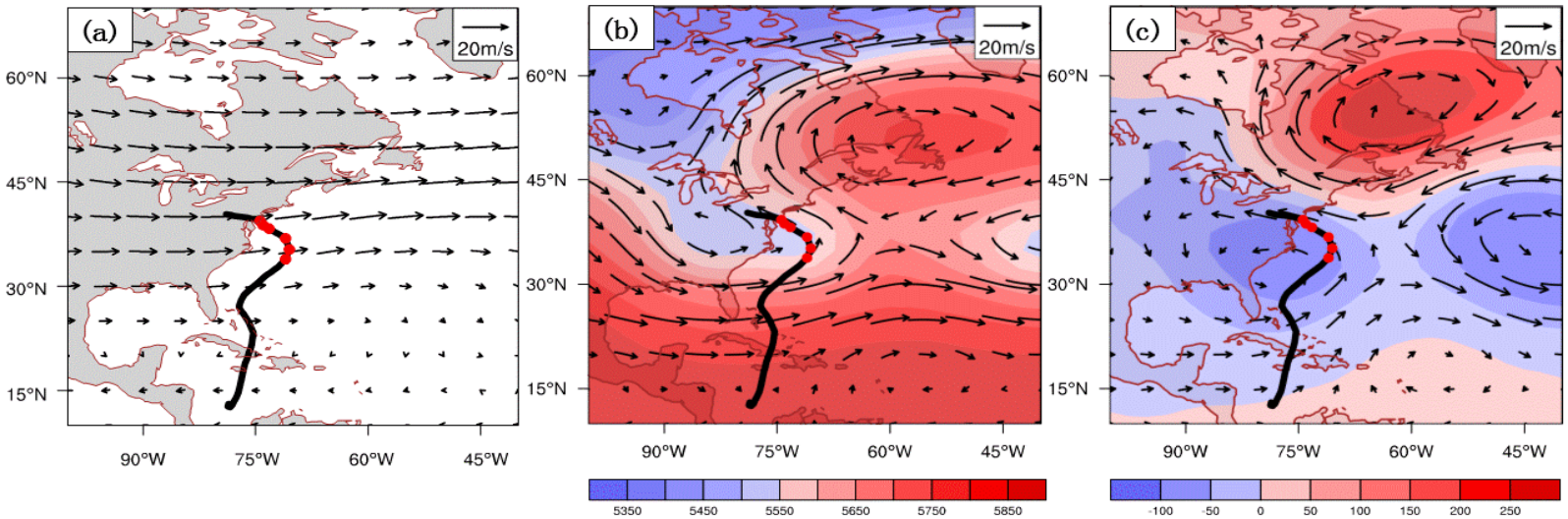
Observed Steering Flow (850-200hPa integrated)

Ding, Li, et al. 2019, JC

(a) Climatological mean

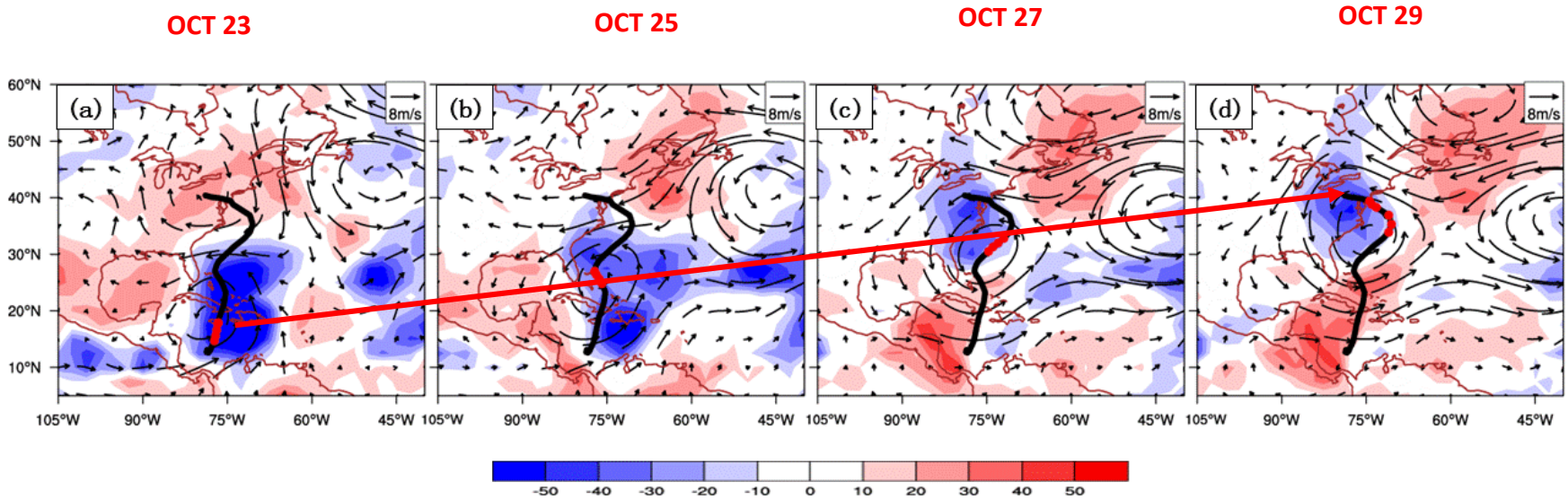
(b) Actual wind & 500hPa H

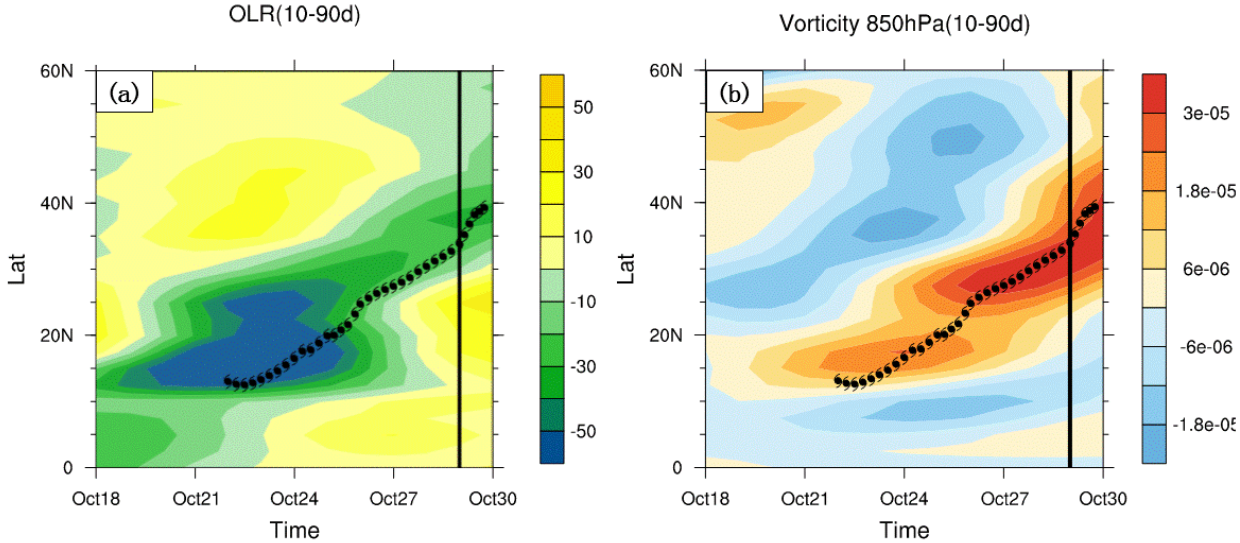
(c) 10-90-day filtered



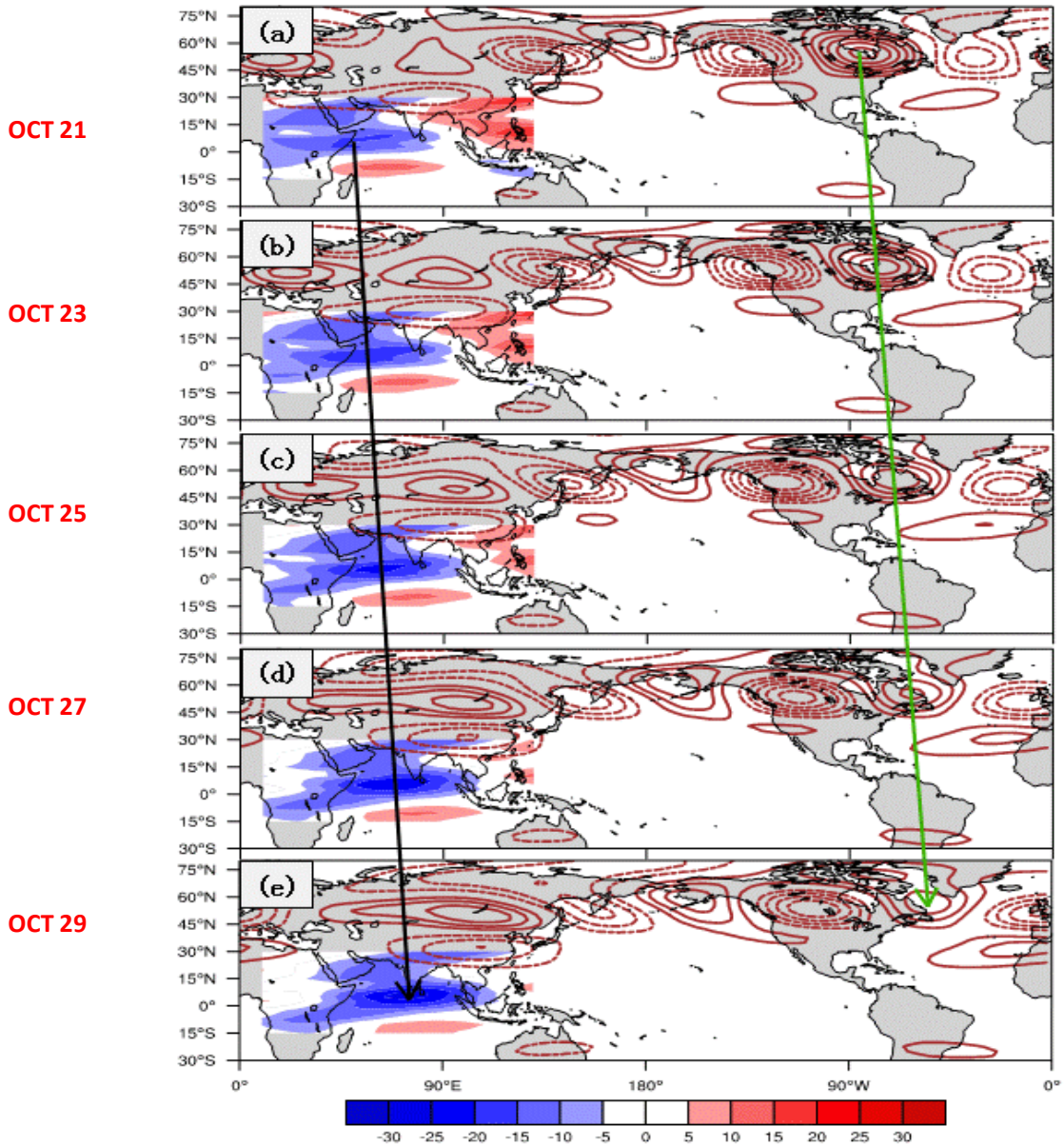
	LFBS(>90d)	Filtered(10-90d)	HF(<10d)	Actual
850-200hPa	11.12	-10.09	-4.18	-3.14
850-300hPa	9.47	- 9.59	-2.78	-2.91
500hPa	11.61	-11.86	-2.11	-2.36

Cause of Cyclonic Flow to the South:





Origin of Anticyclonic Flow to the North:



Contour: 200hPa geopotential height

Shaded: OLR anomaly

Ding, Li, et al. 2019, JC

2. Statistical approach: 时空投影（STPM）延伸期（10-30天）预报模式建立

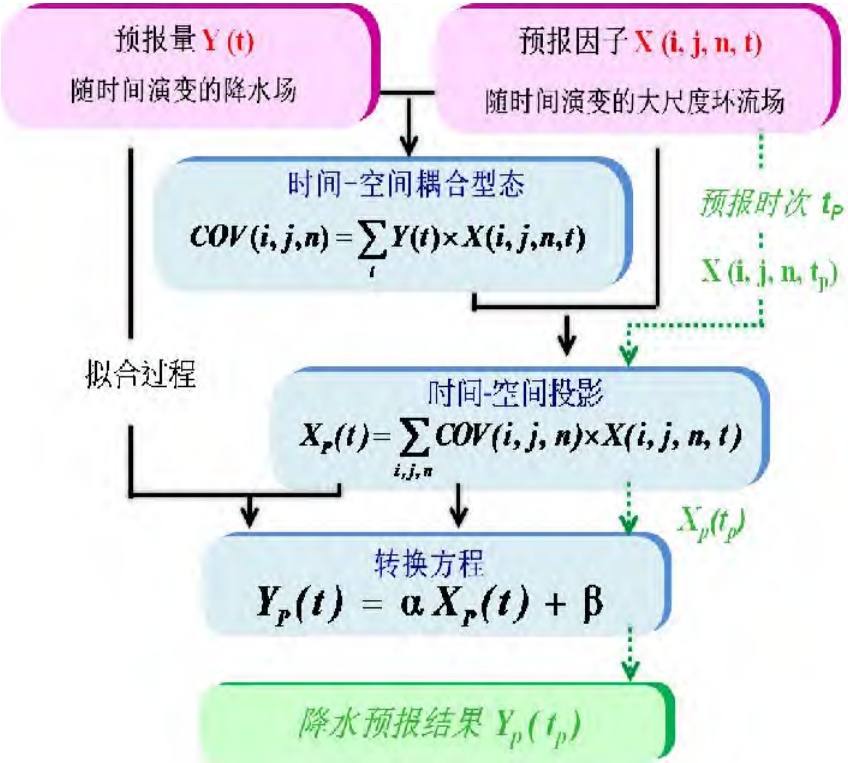
Zhu, Li, et al. 2015, 2017a, Clim.Dyn.

方法简介

- 夏季降水具有显著的10-80天季节内振荡特征
- 对应环流也显示出10-80天的传播特征，因此可作为降水延伸期预报因子
- 利用“非滤波”和 **SVD** 时空投影方法建立环流-降水的预报模型

- 客观方法、定量预报、时间尺度精细（逐侯预报结果）

STPM 方法



方法特色

- **预报因子和预报量皆为时间连续的空间场**
- **以“过程”预报“过程”**
- **考虑不同周期、不同传播特征、不同区域的低频预报因子**

Hsu et al. 2015 CD; Zhu et al. 2015

实时应用技术

非传统滤波方法： 提取实时信号

1. 去除年循环及更长时间尺度信号
（减去气候场的90d低通滤波）

$$X' = X - \overline{X}$$

2. 去除60天以上低频信号
（减去前30d滑动平均）

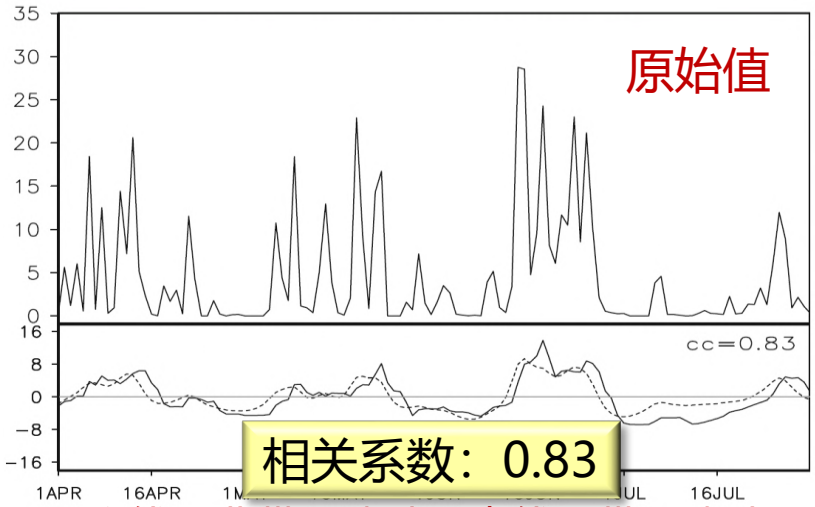
$$X'' = X' - \overline{X'}^{30d}$$

3. 去除天气尺度信号（5天滑动平均）

$$X^* = \overline{X''}^{5d}$$

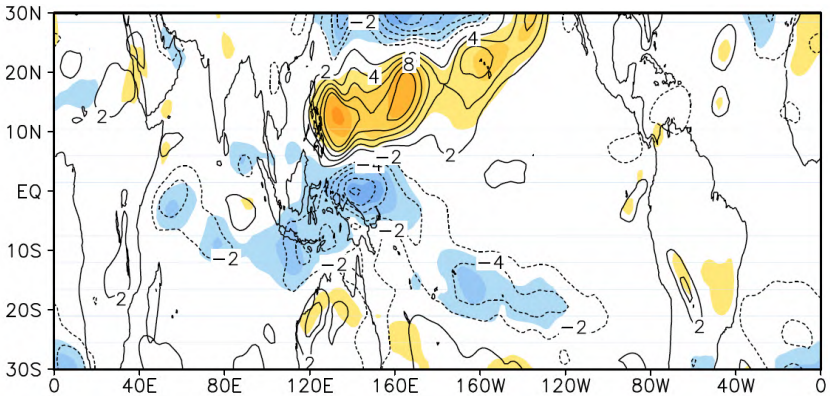
Hsu et al. 2015 CD; Zhu et al. 2015

区域强降水指数时间序列



实线：非带通滤波；虚线：带通滤波

季节内振荡对流分布

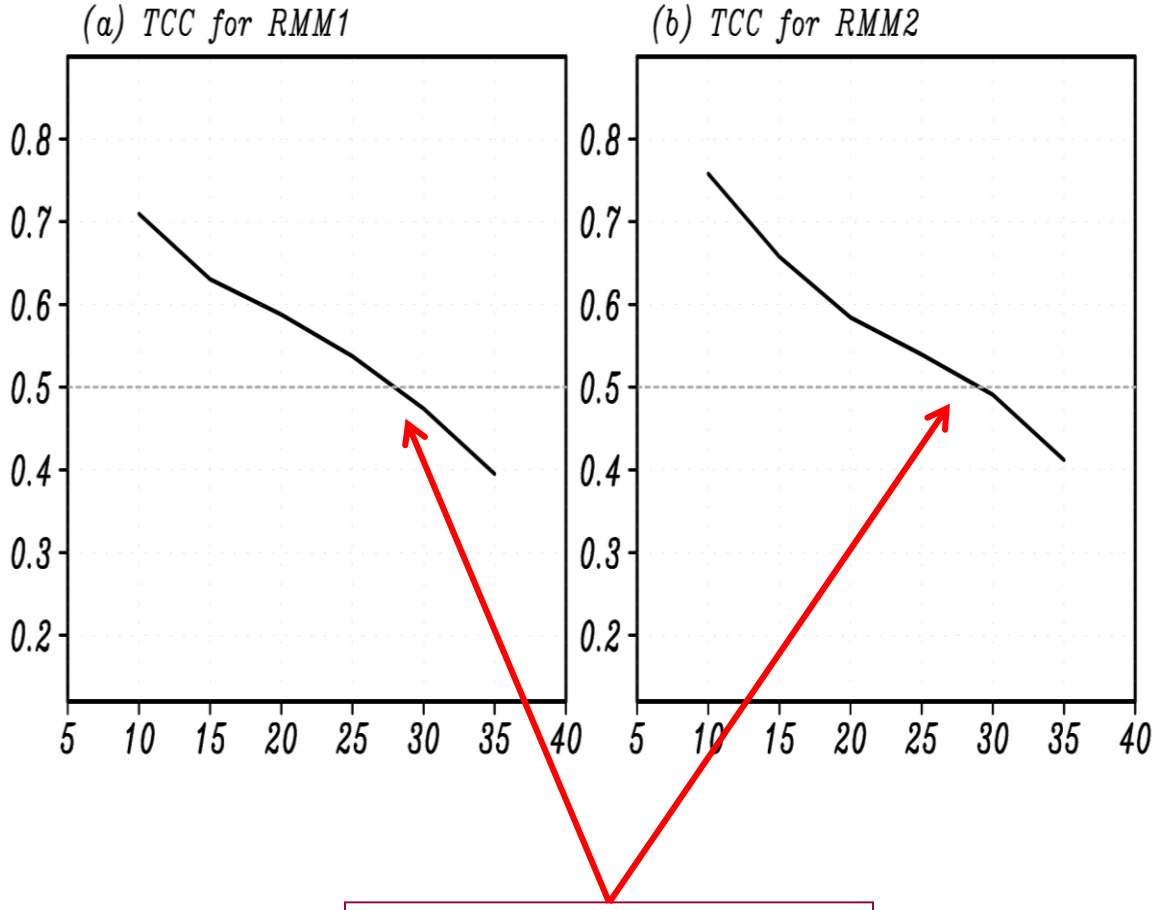


等值线：非带通滤波；阴影：带通滤波

时空投影（STPM）延伸期（10-30天）预报

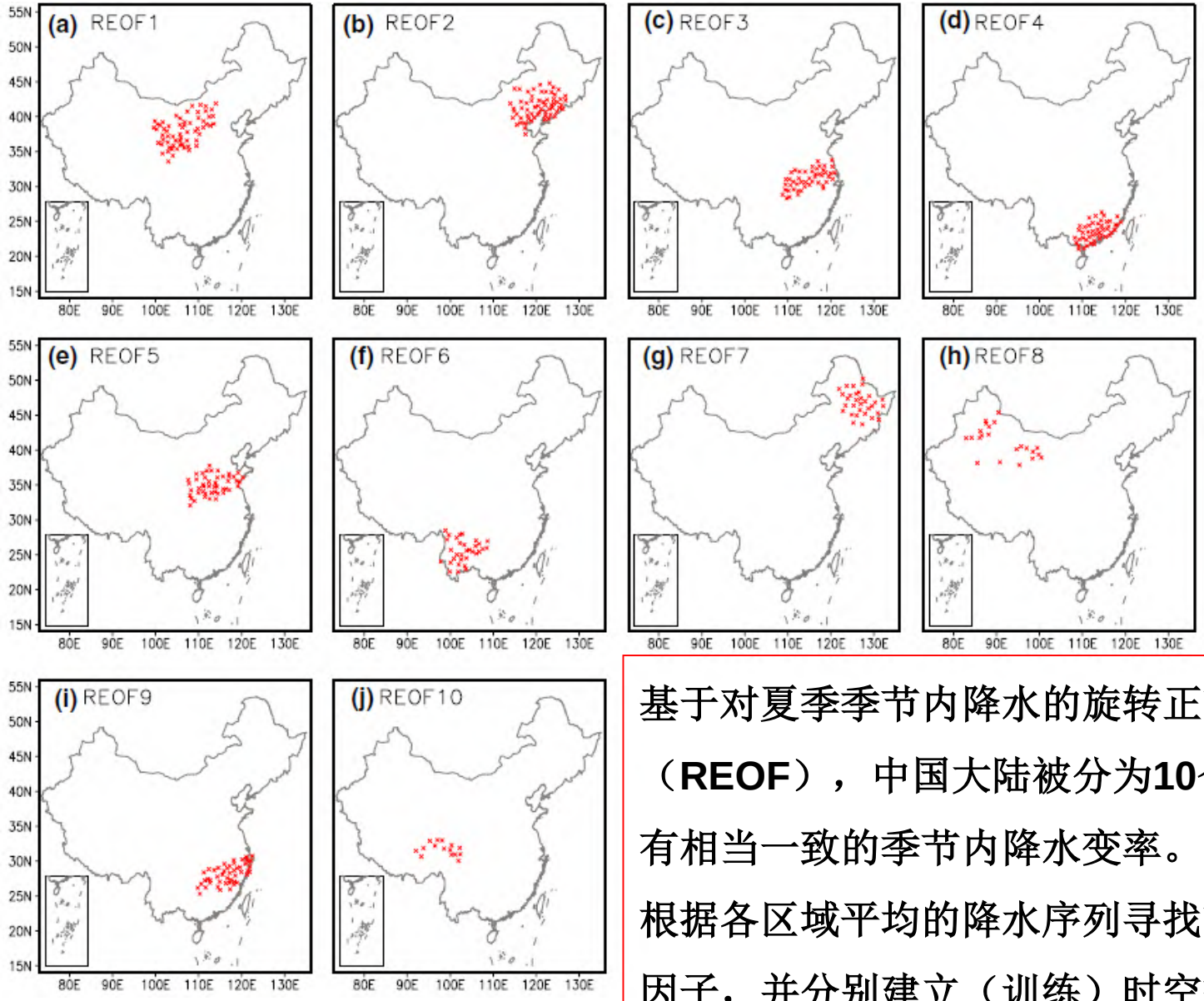
Zhu, Li, et al. 2015, 2017a, Clim.Dyn.

2003-2012 RMM 预报评分



预报时效可达25-30天

中国大陆夏季降水异常的延伸期预报模式建立



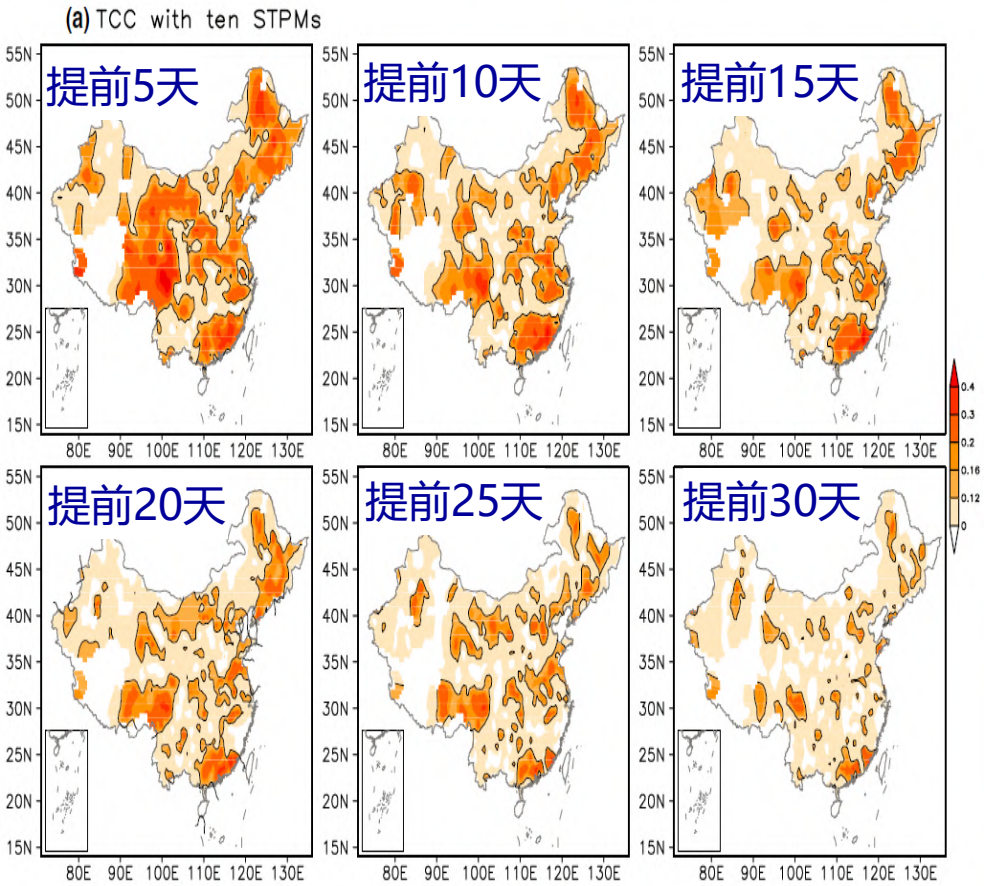
中国553站夏季季节内（10-80天）降水的前10个旋转正交经验函数分解模态，红点代表显著载荷区域

Zhu and Li (2017a, CD)

基于对夏季季节内降水的旋转正交经验函数分解（**REOF**），中国大陆被分为**10**个区域，每个区域具有相当一致的季节内降水变率。

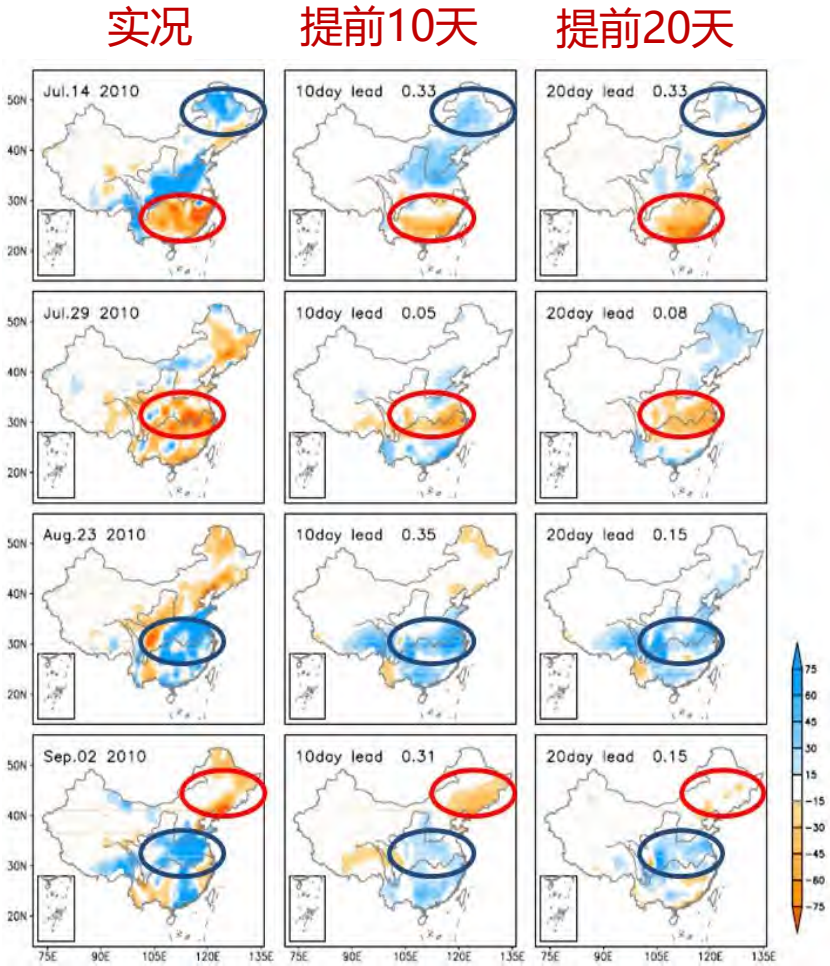
根据各区域平均的降水序列寻找前期大气季节内预报因子，并分别建立（训练）时空投影模式（**STPM**）。

降水独立预报(2003-2010)试验技巧



阴影：时间相关系数技巧
实线：通过95%信度地区

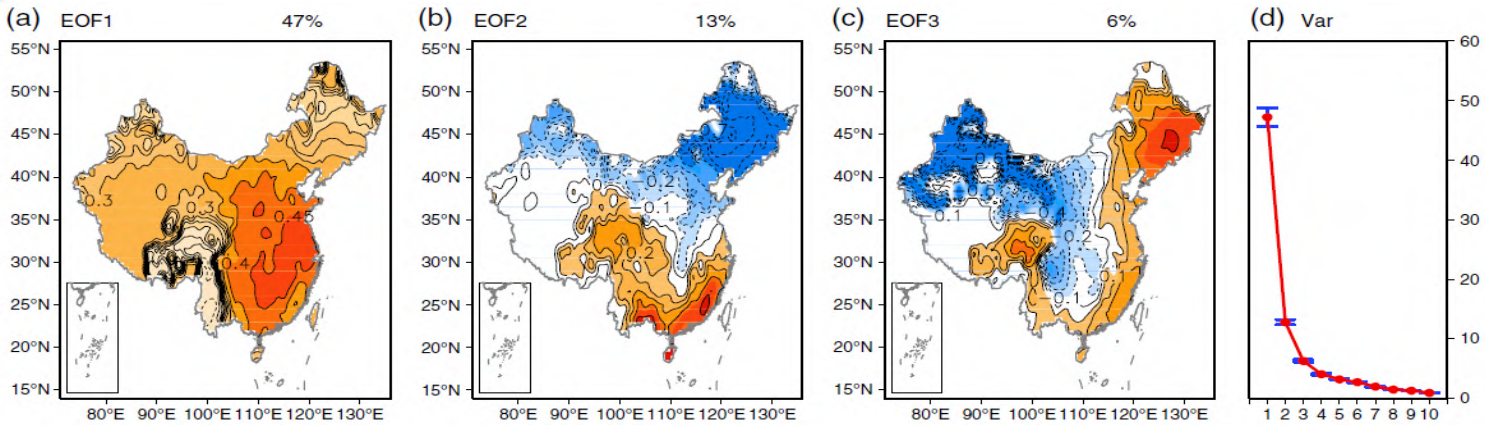
2010年上海世博会期间独立预报



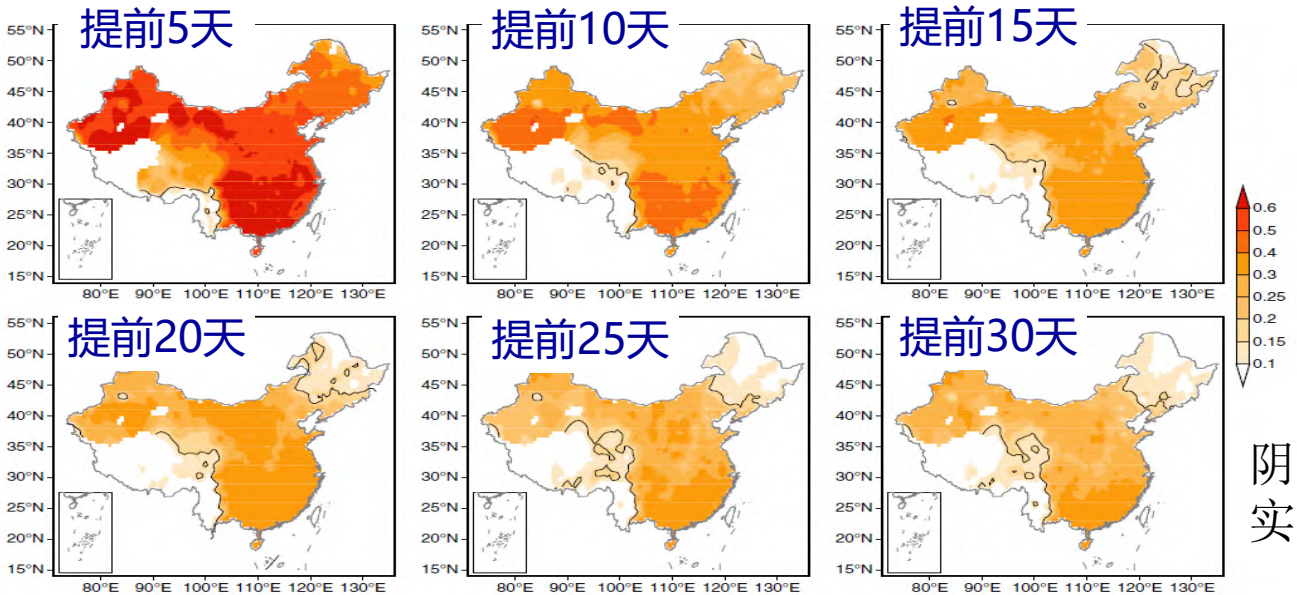
引自：Zhu and Li 2017 Clim. Dyn.

冬季气温及极端冷事件预报和检验

引自：Zhu and Li 2017 QJRMS



1. **EOF分解**
2. **STPM**预报不同模态后重建

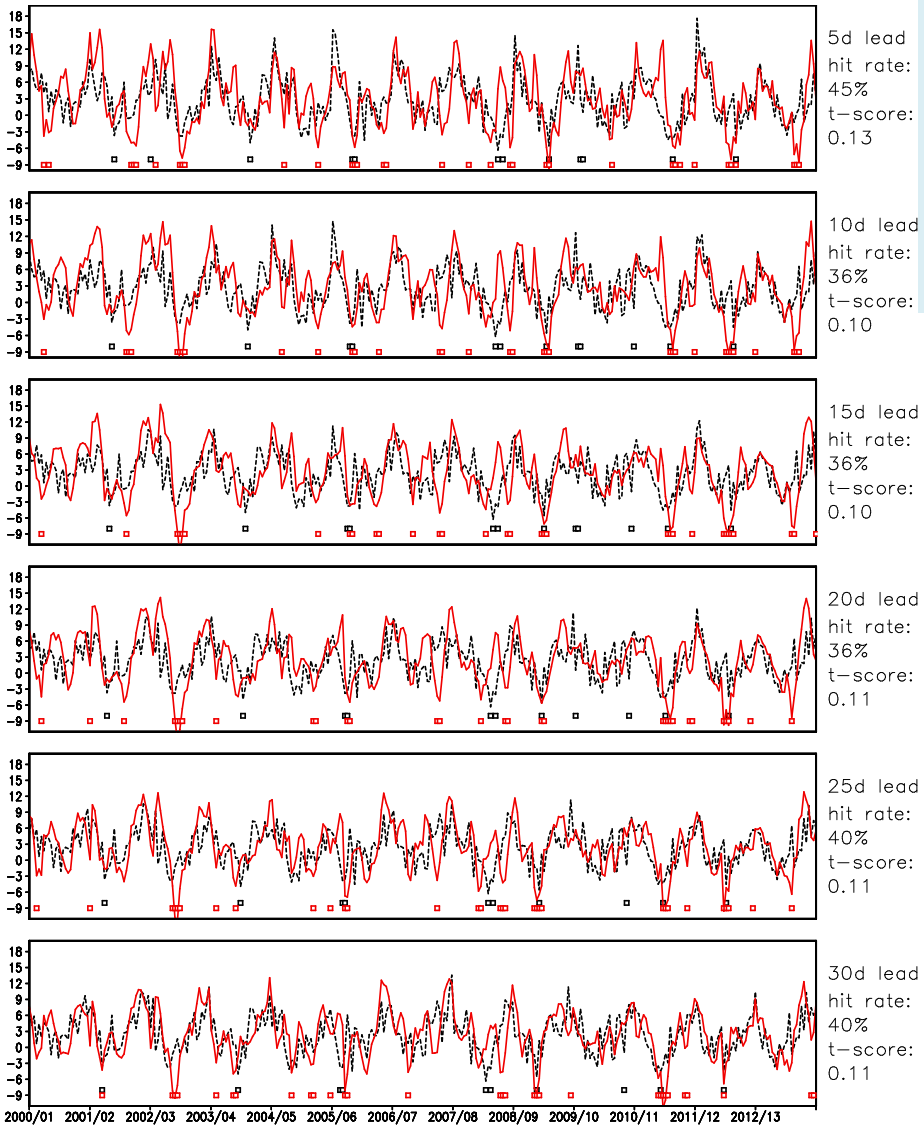


回报试验技巧

阴影：时间相关系数技巧
实线：通过95%信度地区

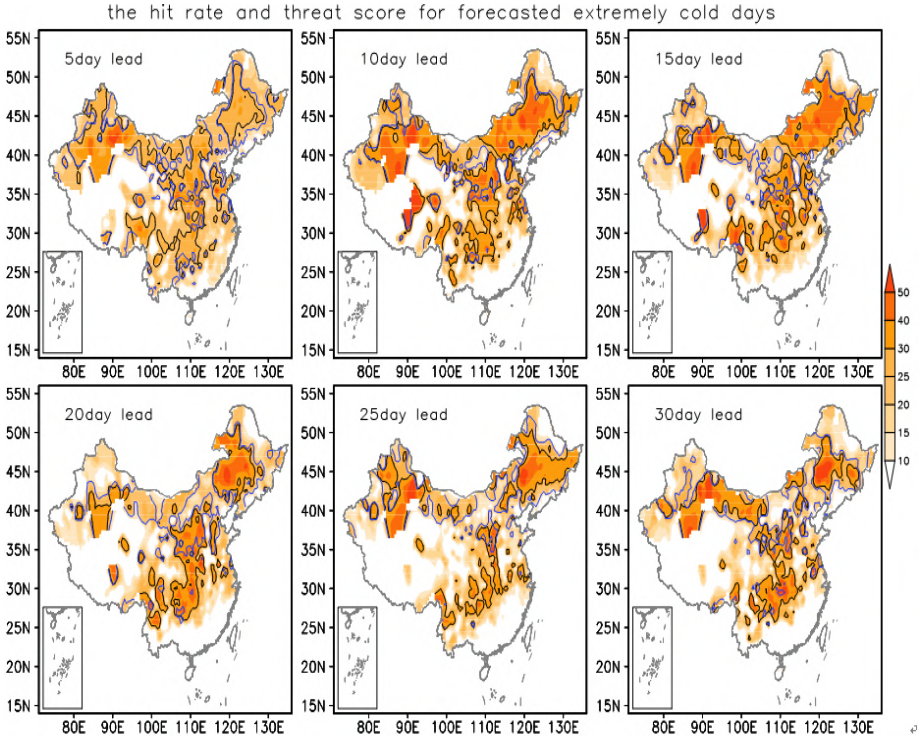
中国冬季地表气温及极端冷事件的延伸期预报(cont.)

南京站地表温度及极端冷事件的实况（黑）与预报（红）



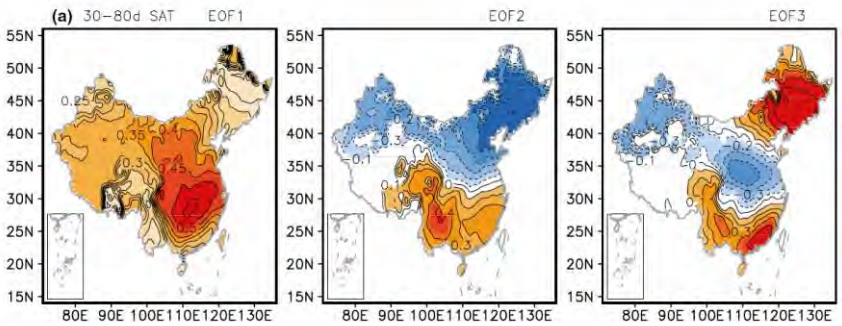
将预报的季节内气温（10-80天）异常与气候态低频（大于80天）气温相加，重建原始地表气温序列，并确定极端冷事件。中国大部分地区30%以上的冬季极端冷事件能够被时空投影模式提前20天预报出来

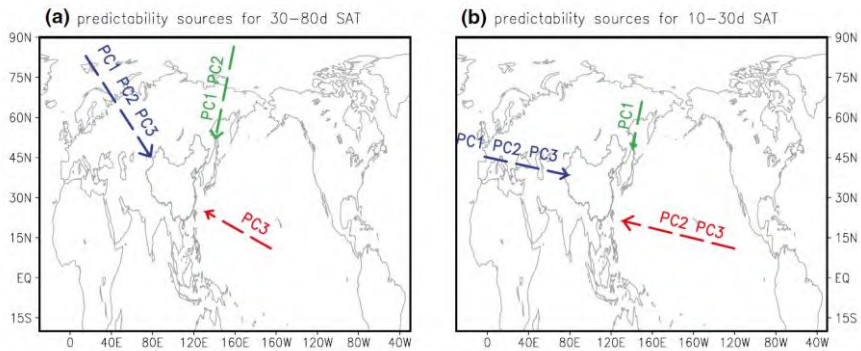
极端冷事件预报成功率分布（contour超过30%）



夏季高温热浪预报及检验

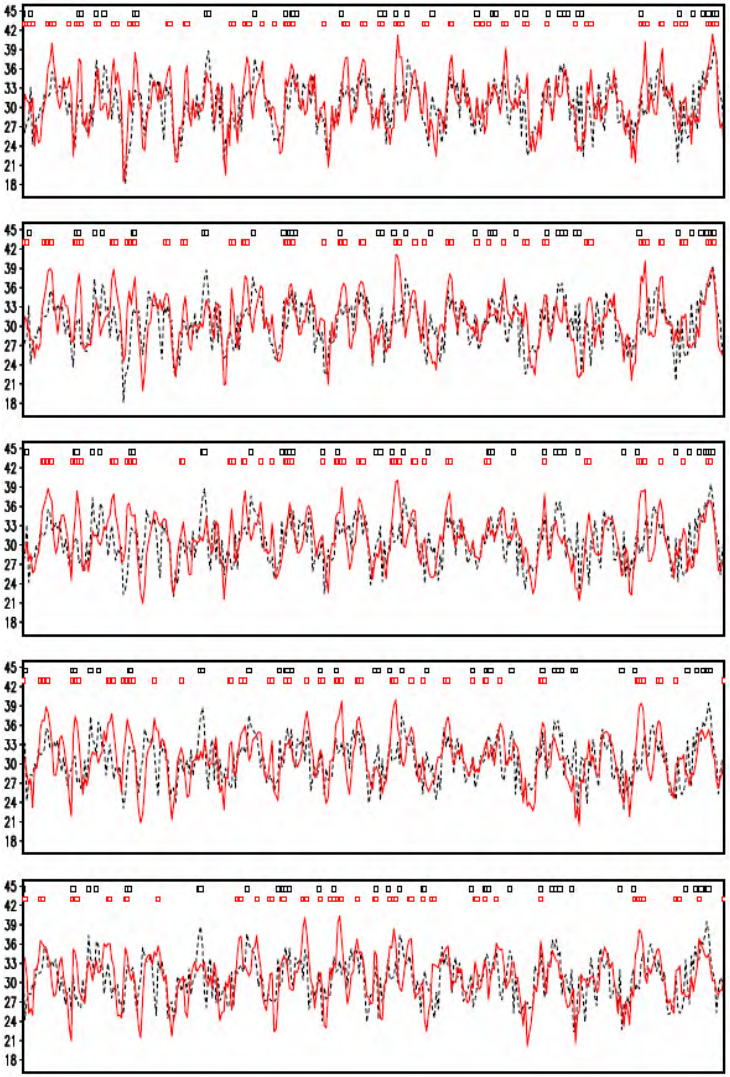
引自：Zhu and Li 2018 Clim. Dyn.





1. **EOF分解**（30-80d & 10-30d）
2. **找寻可预报性来源**
3. **STPM**预报前三个模态的时间序列后，重建气温空间分布

南京夏季气温及热浪事件预报



提前5天
报对率45%

提前10天
报对率36%

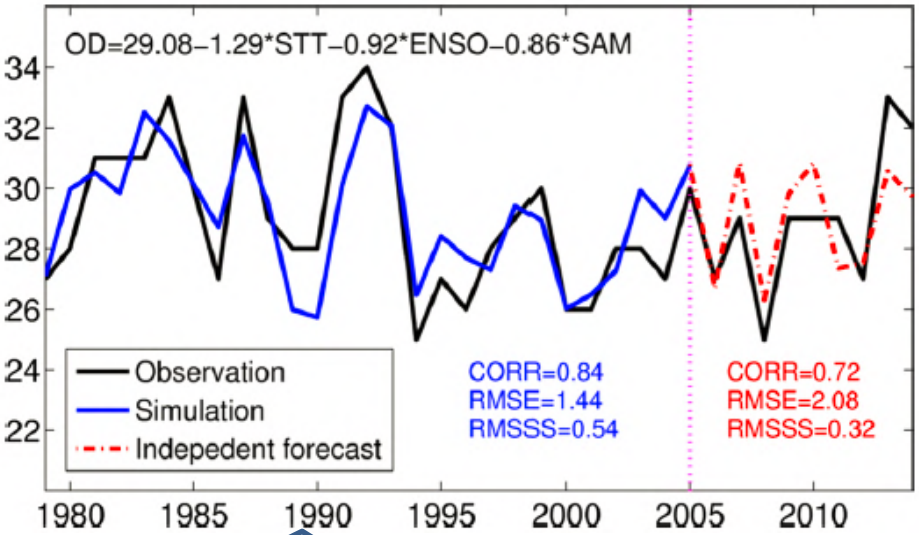
提前15天
报对率35%

提前20天
报对率26%

提前25天
报对率24%

南海夏季风爆发日期的延伸期预报

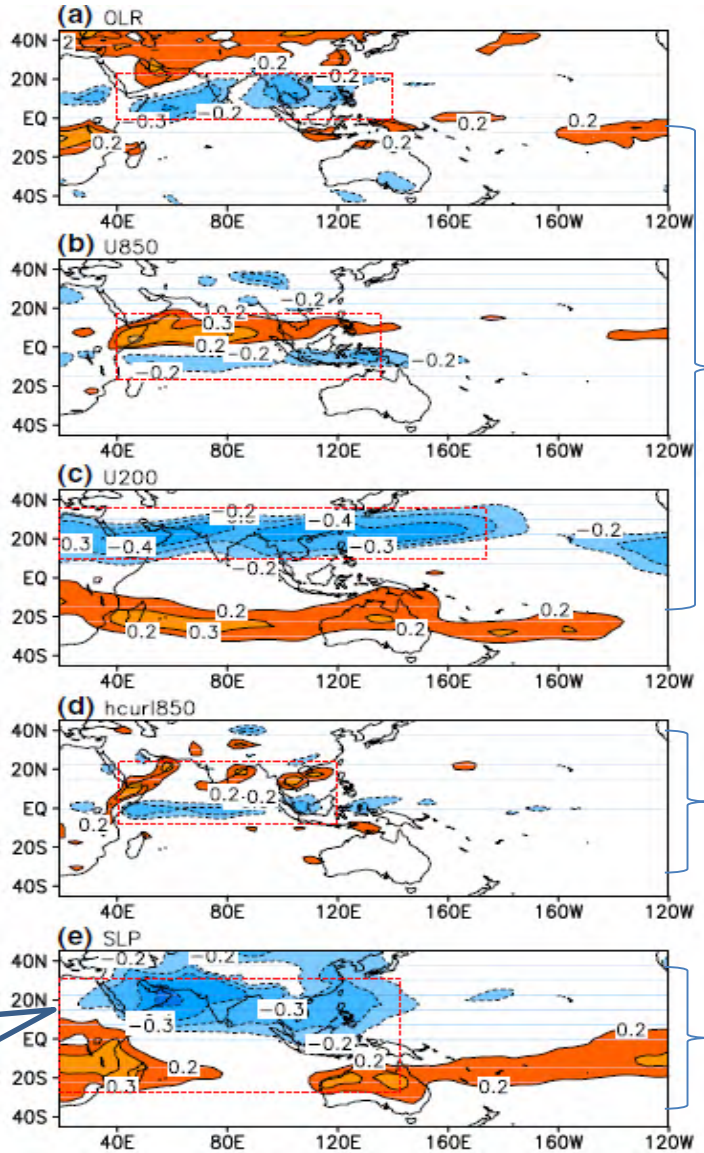
南海季风爆发日期实况及其季节预报结果



从季节预报（seasonal prediction）角度预报南海季风爆发日期的年际变率并不尽如人意

南海季风爆发日期还受到季节内尺度变率的影响

南海地区纬向风的前期季节内信号



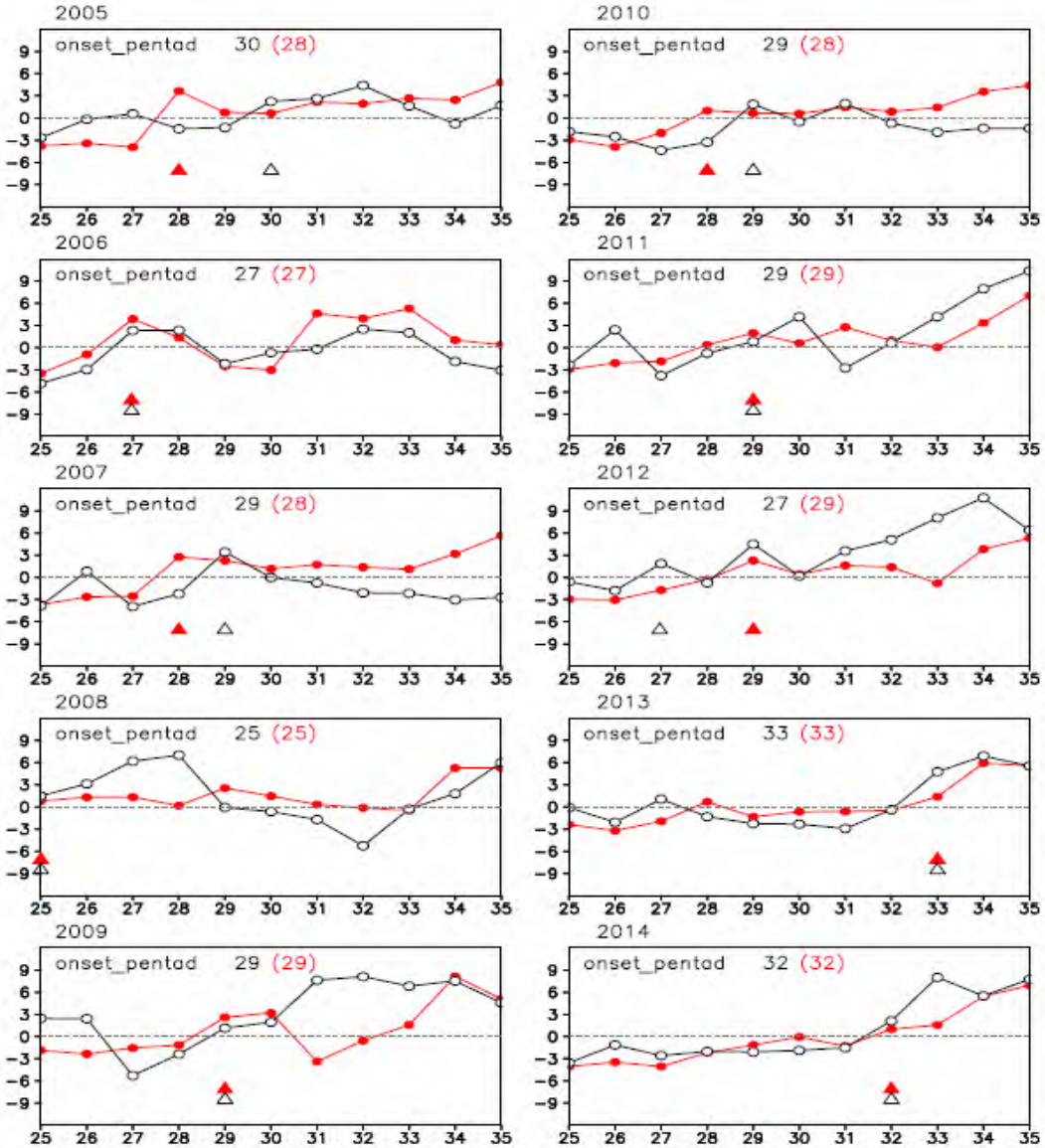
热带MJO信号

季风爆发性低涡

马/澳高与亚洲低压的季内振荡

南海夏季风爆发日期的延伸期预报

南海地区纬向风指数及季风爆发日期
（红色: 预报， 黑色: 实况）



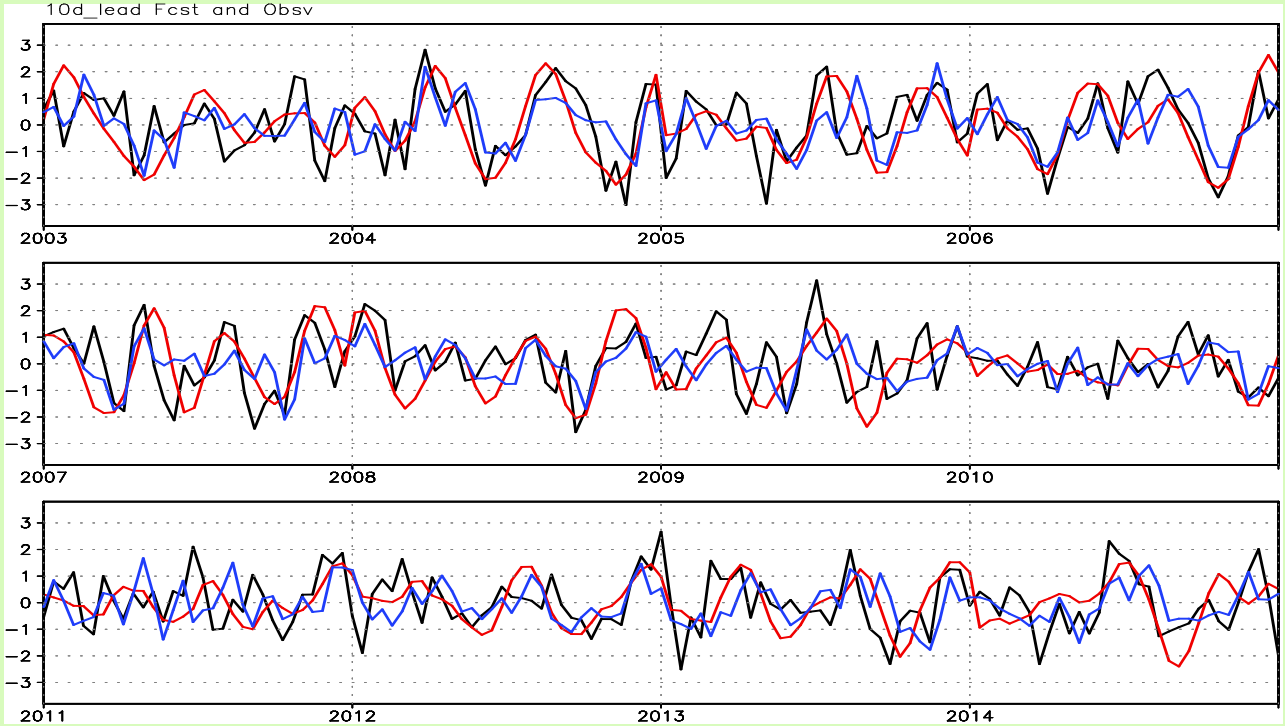
从延伸期预报（extended-range forecast）角度出发，建立时空投影统计预报模式，能够较好的预报南海地区区域平均的纬向风逐候演变。

根据预报出的纬向风指数最终判定南海季风爆发日期。结果表明，时空投影统计预报模式能够预报南海季风爆发日期，是对南海季风爆发日期季节预报的一个补充。

8/10 with error within a pentad

考虑10-30d, 30-80d ISO信号 STPM 预报检验

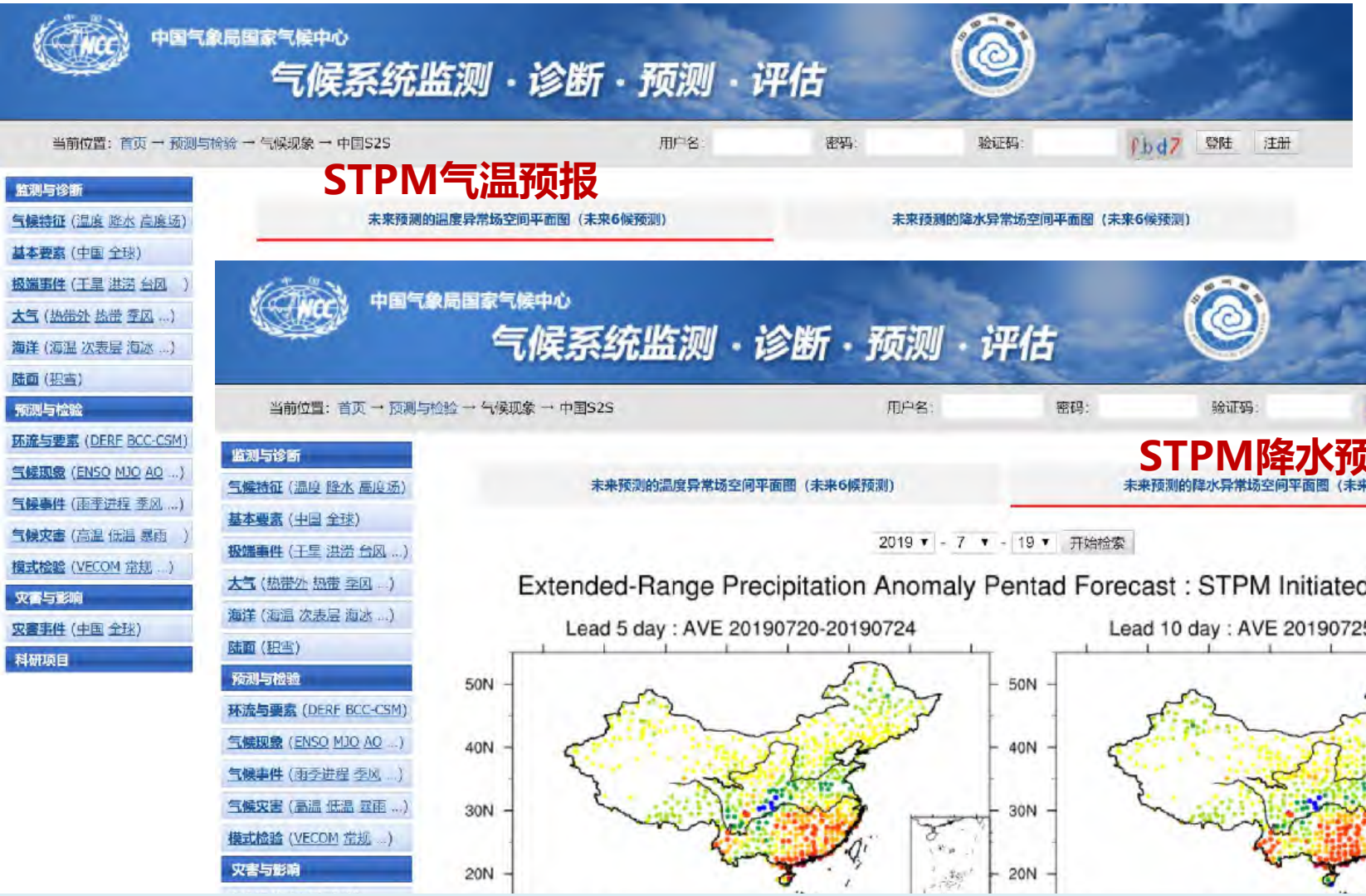
(提前10天预报：**群发事件正确率80%**)



2003-2014年的**观测（黑线）**和预报（红色为基于STPM1结果，蓝色为基于STPM2结果）的群发性台风指数。

*引自：**Zhu et al. 2017 Theor. Appl. Climatol.***

国家气候中心业务平台建设



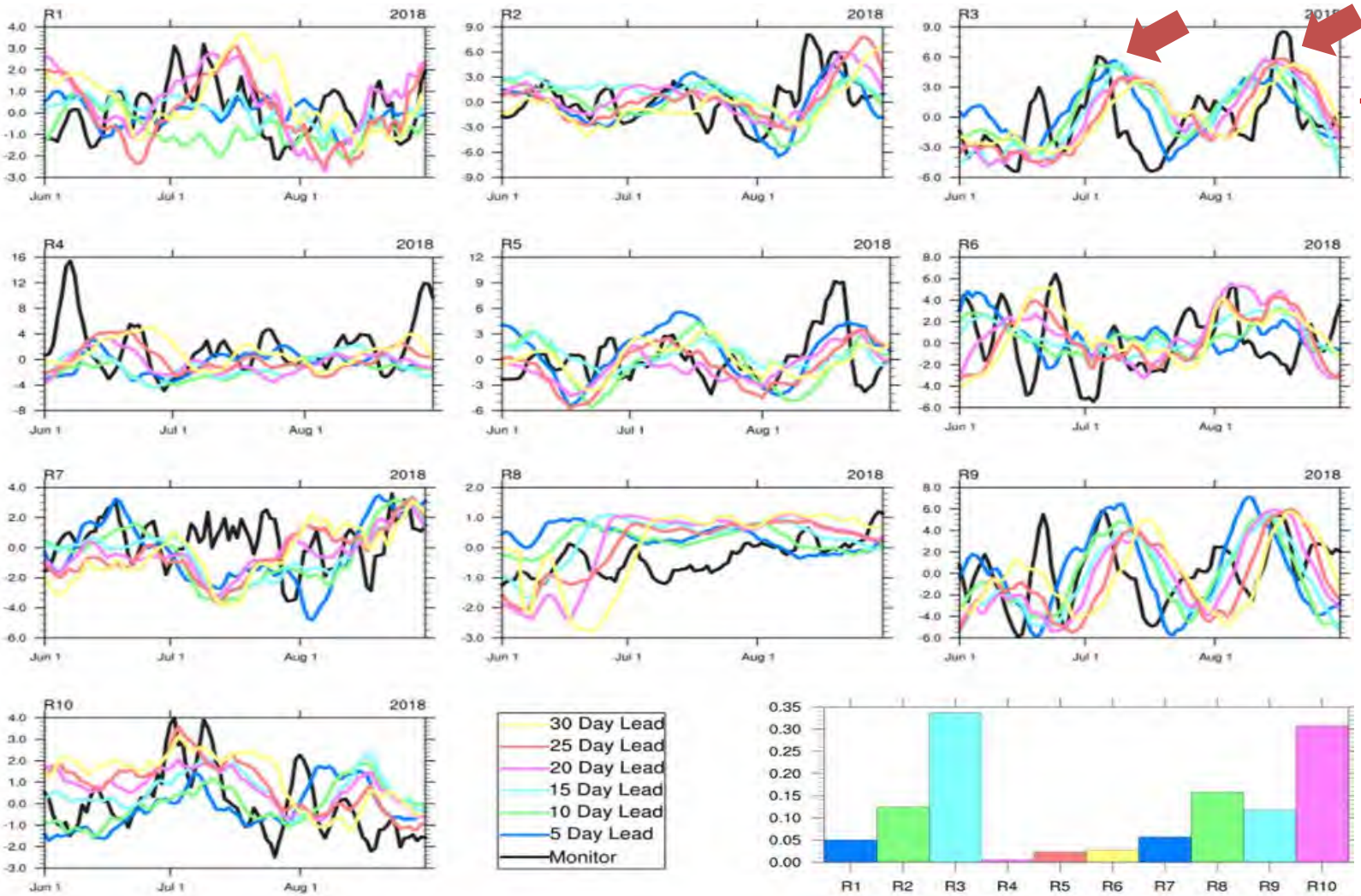
国家气候中心月会商和汛期会商中，参考 **STPM逐侯滚动的** 全国降水和气温的预报产品，为国家防灾预警提供技术支撑。

气象服务

2018年汛期全国十区降水预报检验 (STPM)

黑线：降水距平实况
红线：提前20天预报
黄线：提前30天预报

长江流域

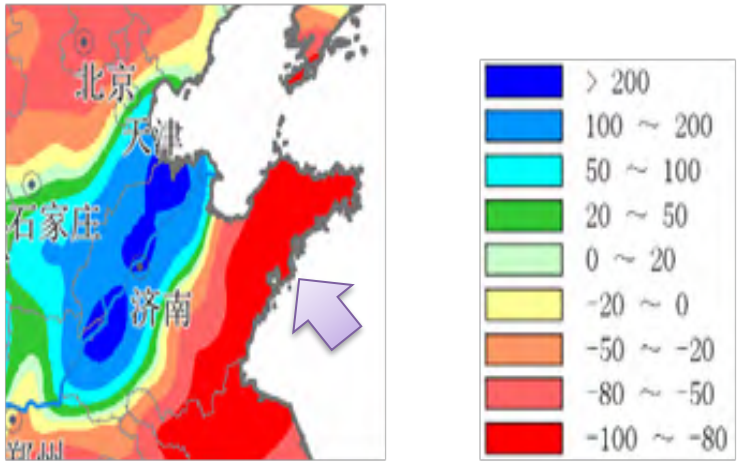


气象服务

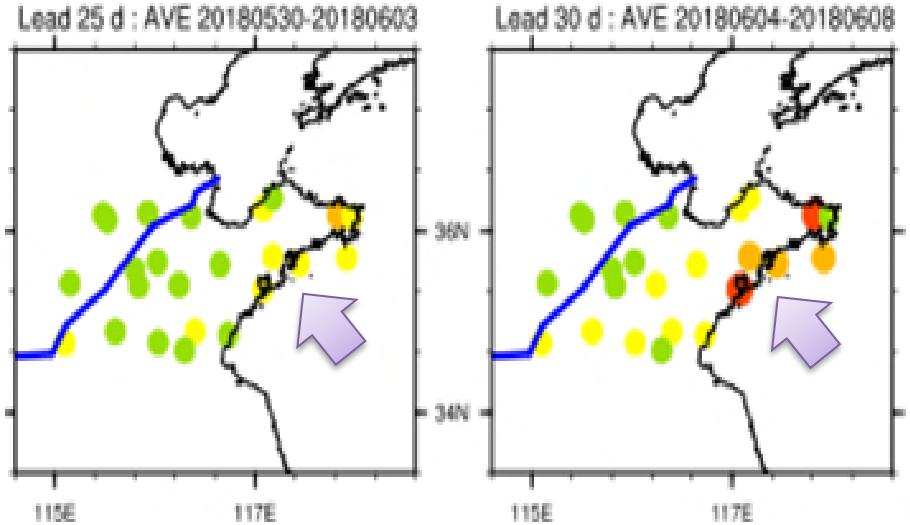
✓ STPM预测系统极大支撑了延伸期预报业务和服务，尤其在一些**重大气象保障活动**中发挥了决策作用。

青岛上合组织峰会（2018/6/1 至 2018/6/10）

降水实况



5月5日起报

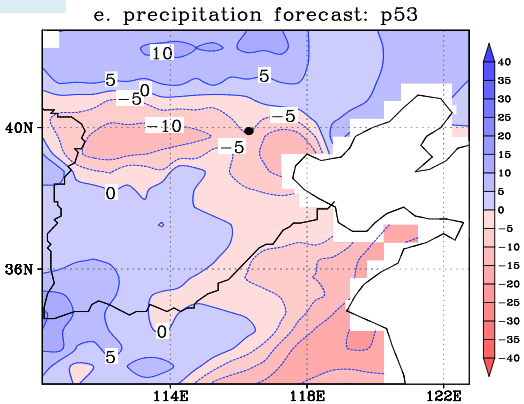


提前25~30天成功预报出青岛上合组织峰会期间的降水负异常

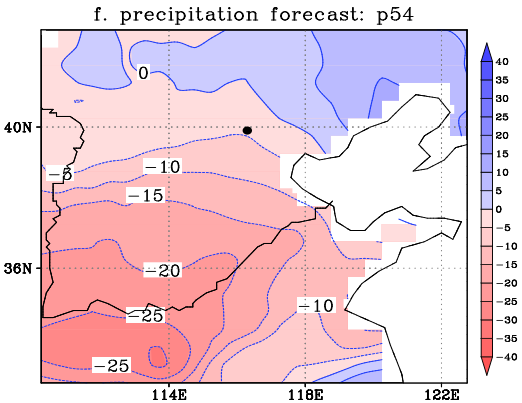
国庆70周年气象保障的延伸期预测意见（2019年8-9月提供）

8月30日会商

9月5候



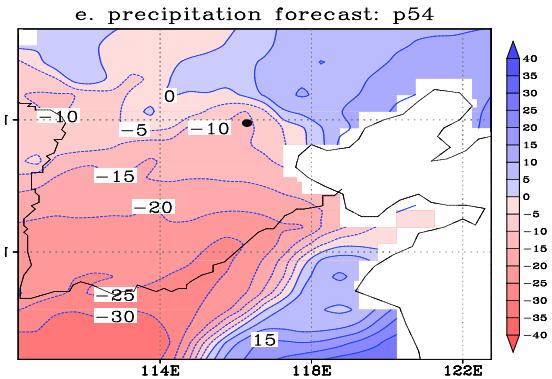
9月6候

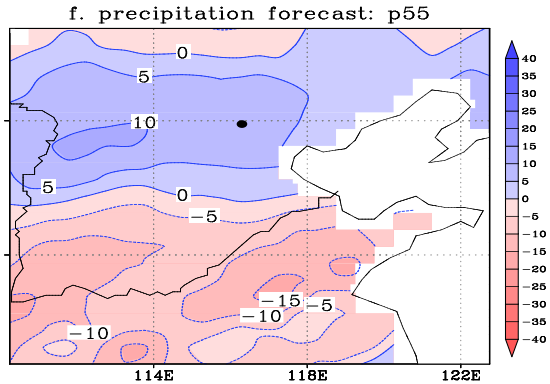


10月1候

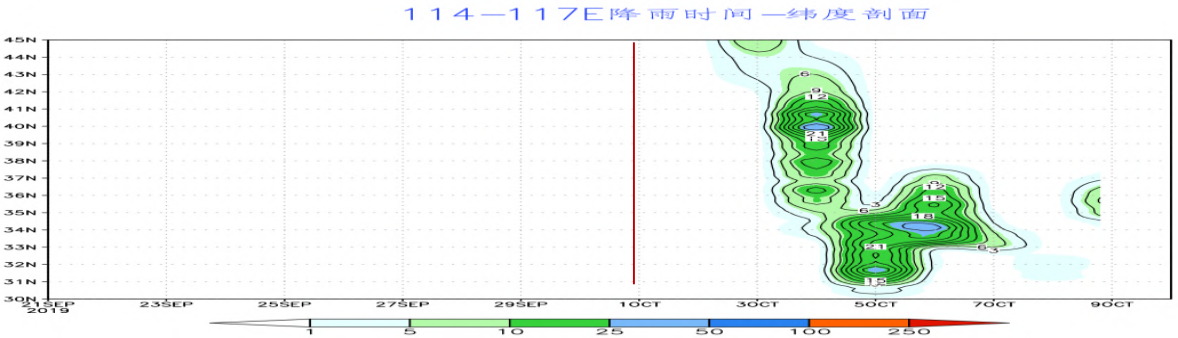
- 9月底到10月初是干位相向湿位相转折期，9月30日和10月1日，可能处于降水过程的前缘，有弱冷空气活动，污染物扩散条件正常（良-轻度污染）。

9月6日会商

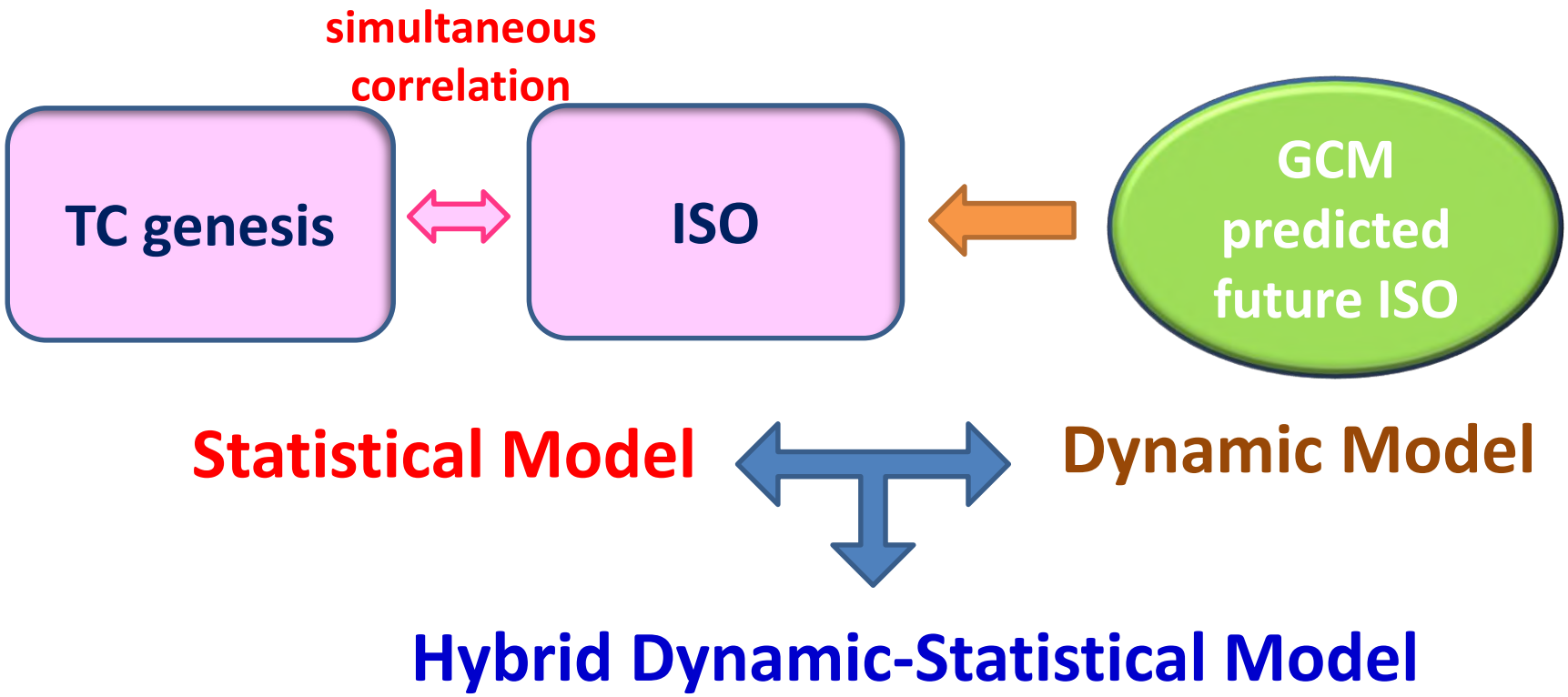




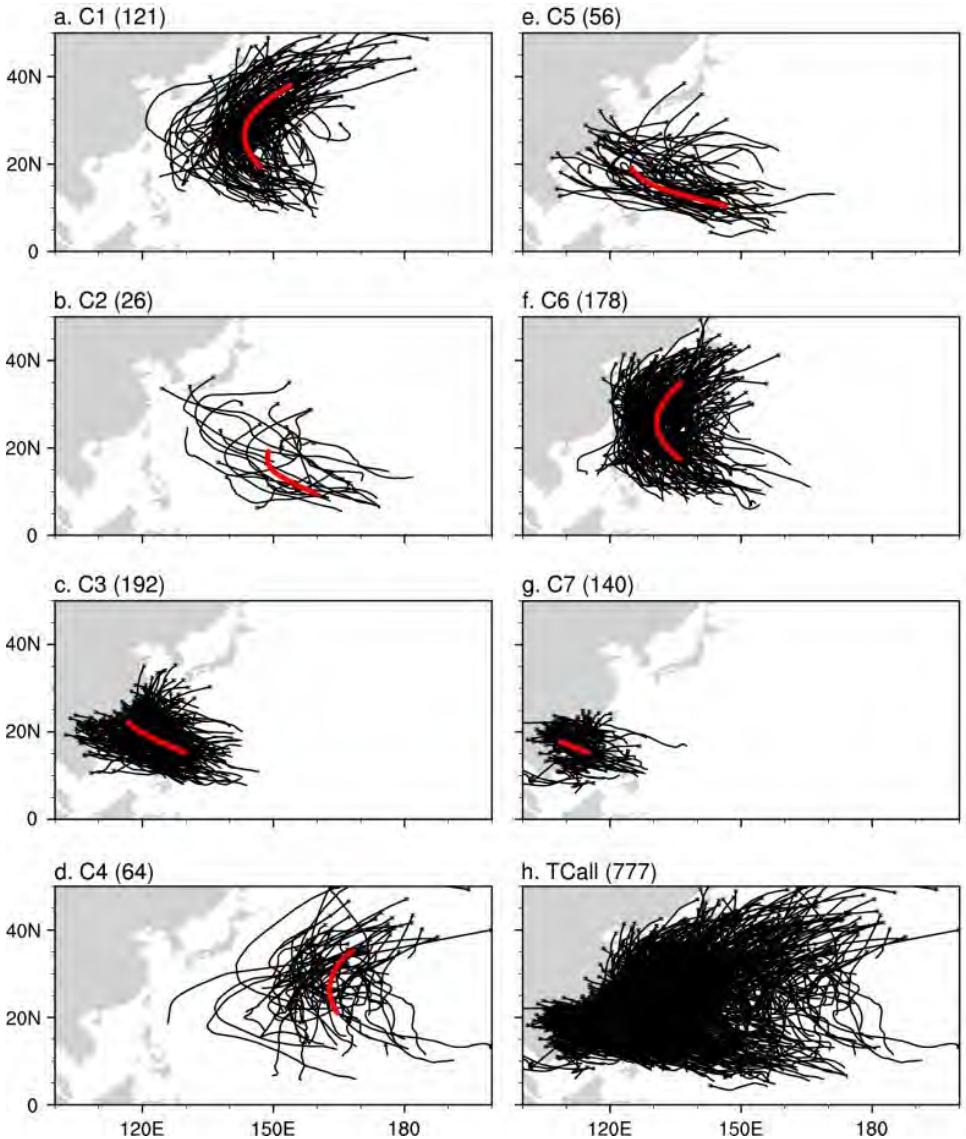
实况



3. Dynamic-statistical approach



TC counts + **Genesis locations and tracks**



TC clustering → Each TC cluster has distinct genesis locations and tracks

↓

Predict the genesis number for each cluster

↓

Multiply by the climatological genesis and track distributions for each cluster → Probability map of TC frequency over WNP

Kim et al. (2012)

GFDL FLOR coupled model

- The Forecast-Oriented Low Ocean Resolution version of the GFDL model
- **New double plume convection scheme → Good MJO**

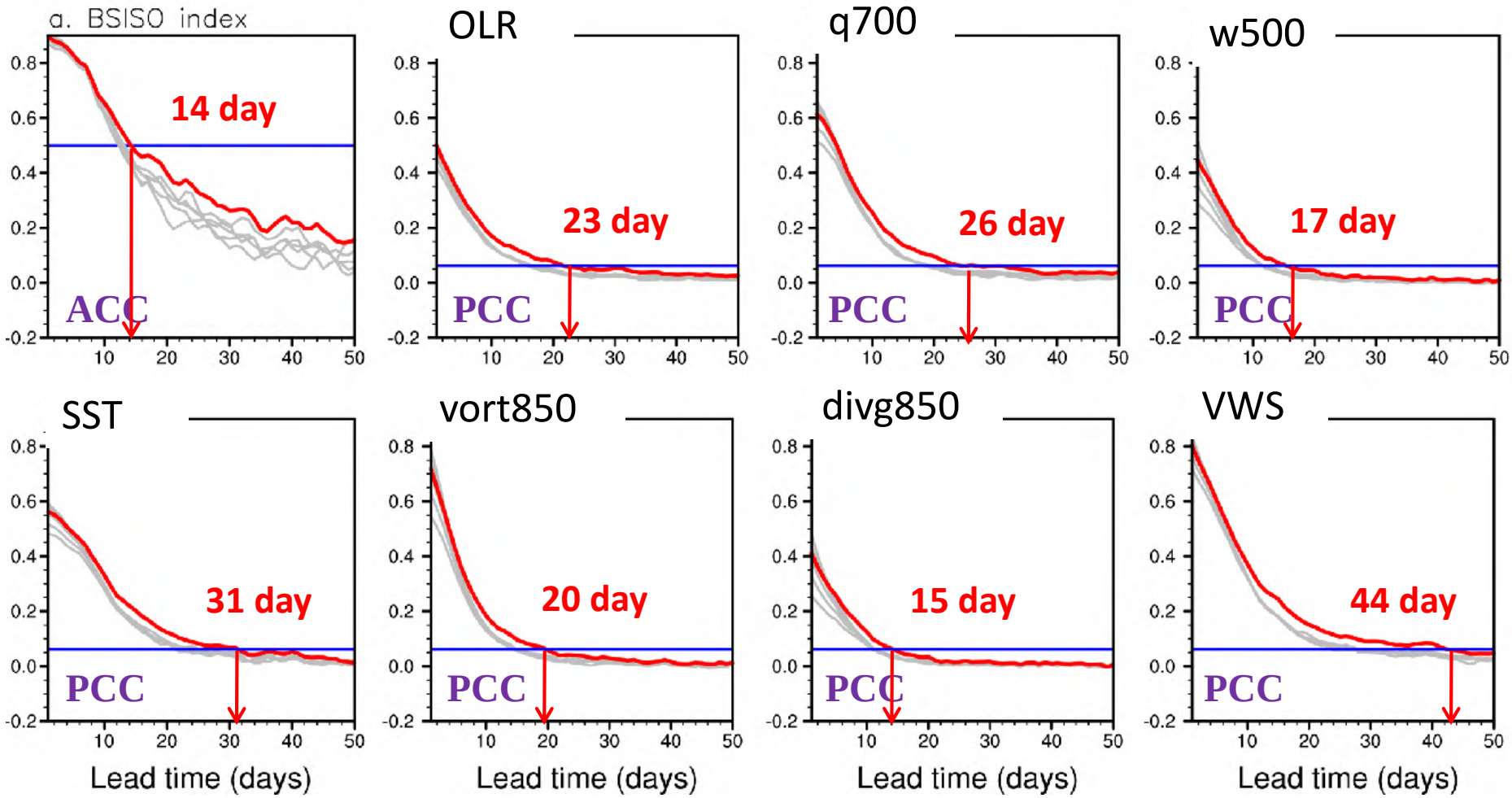
	Horizontal	Vertical
Atmospheric model	50-km	32 vertical levels
Ocean model	1°×1°	50 vertical levels (10-m resolution in the upper 100 m)

- Every 5 days (**1st, 6th, 11th, 16th, 21st, 26th**) for each month from April to November during the 10 years from 2003-2012.
- For prediction initialized on each day, **5** ensemble members were generated by taking initial conditions **00Z, 04Z, 08Z, 12Z, and 16Z** were integrated for **50 days**.
- Total **2400** hindcasts (10 years × 8 months × 6 times × 5 members) were produced during the 10 summer seasons.

(Xiang et al. 2015)

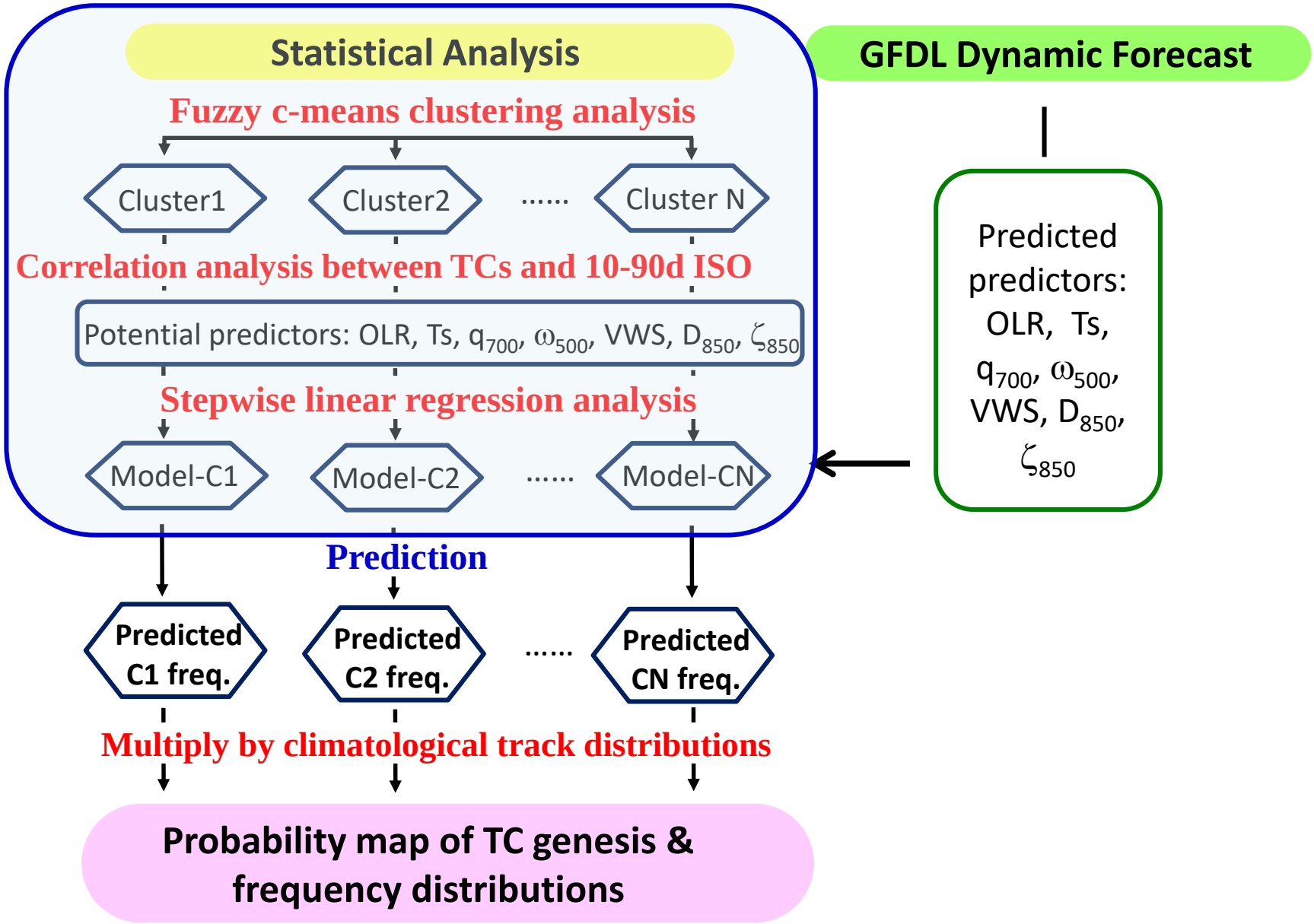
Model assessment of ISO prediction

Red: Ensemble fcst
Gray: Individual fcst

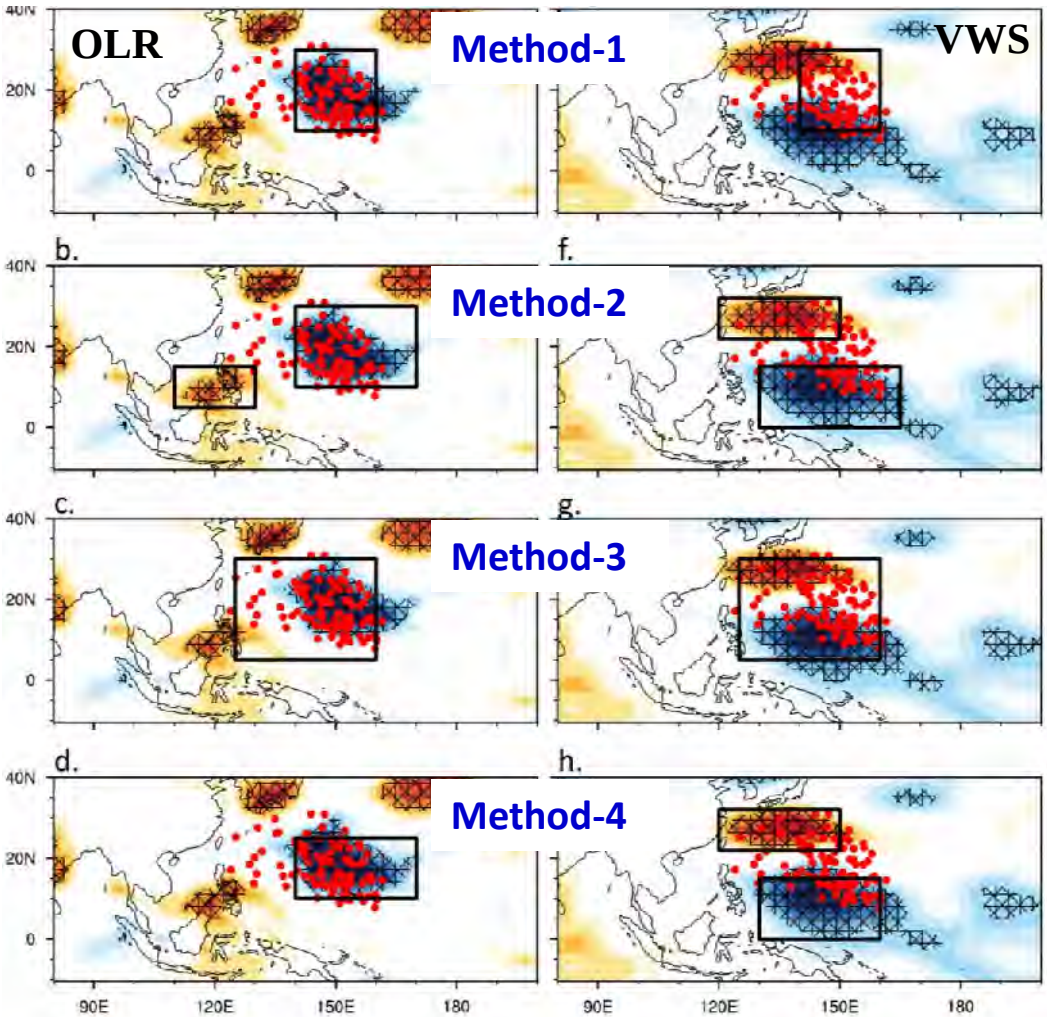


Prediction skill for intraseasonal (10-90d) dynamic and thermodynamic fields related to TC genesis is about **14-44 days**.

STEP1: Construct statistical forecast model for each TC cluster



How to select predictors: based on the regions with high TCC between TC genesis and ISO (10-90-day) fields



M1: Large-scale fields averaged over the high density of TC genesis regions (**fixed box size**: **7** potential predictors).

M2: Fields averaged over one positive and one negative TCC regions (**Varying box size**: **14** potential predictors).

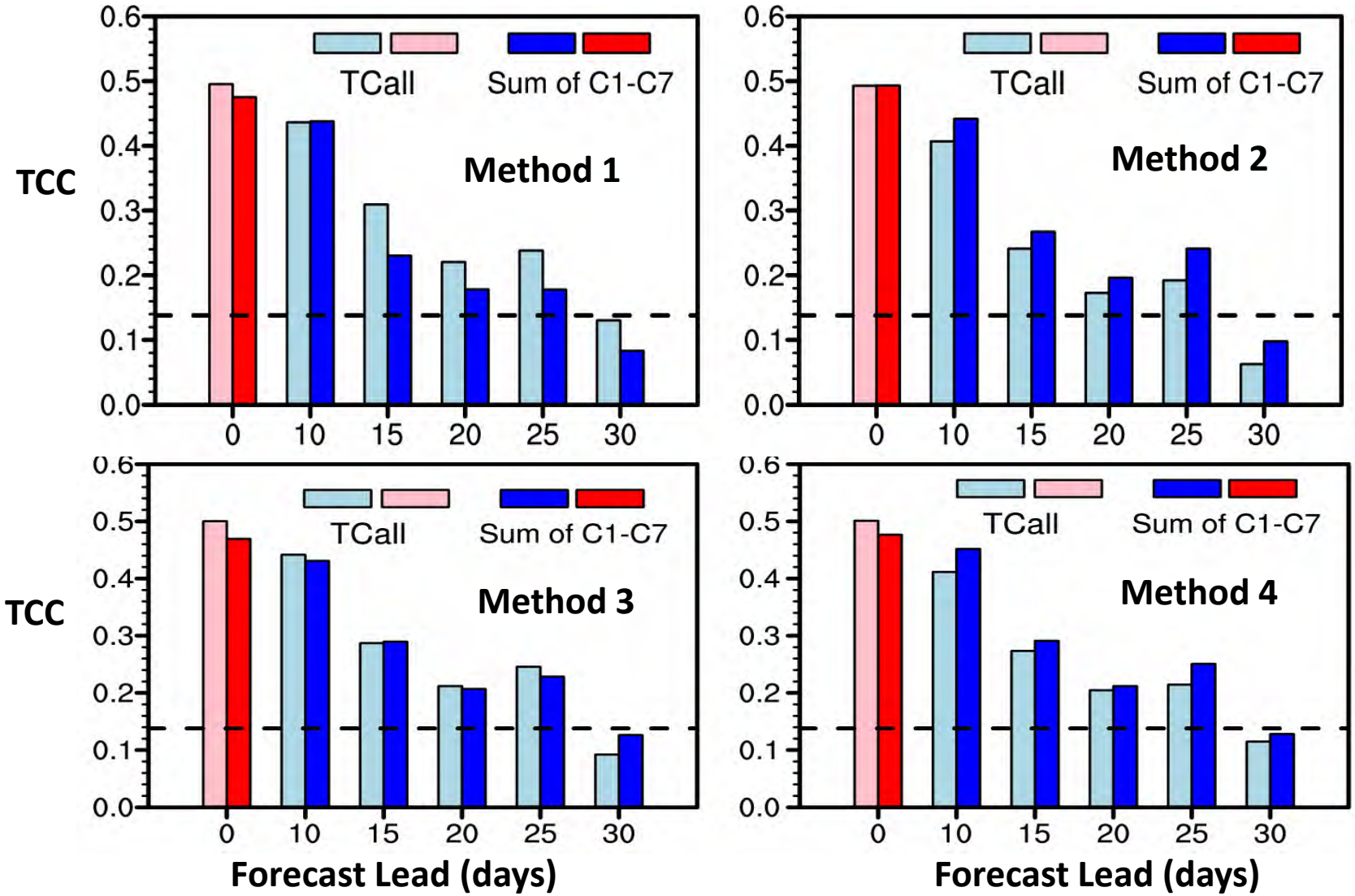
M3: In TC genesis region, select **grids** which have high TCCs (95% sig) for averaging: **7** potential predictors.

M4: Choose only **large-extent & significant TCC** regions. If there are both positive and negative regions identified, we combine them by subtracting the negative one from the positive one: **7** potential predictors.

Skill of TC counts prediction

0: obs. ISO
(upper limit)

TCC between predicted and observed TC counts



Skill of TC counts prediction (four-method MME)

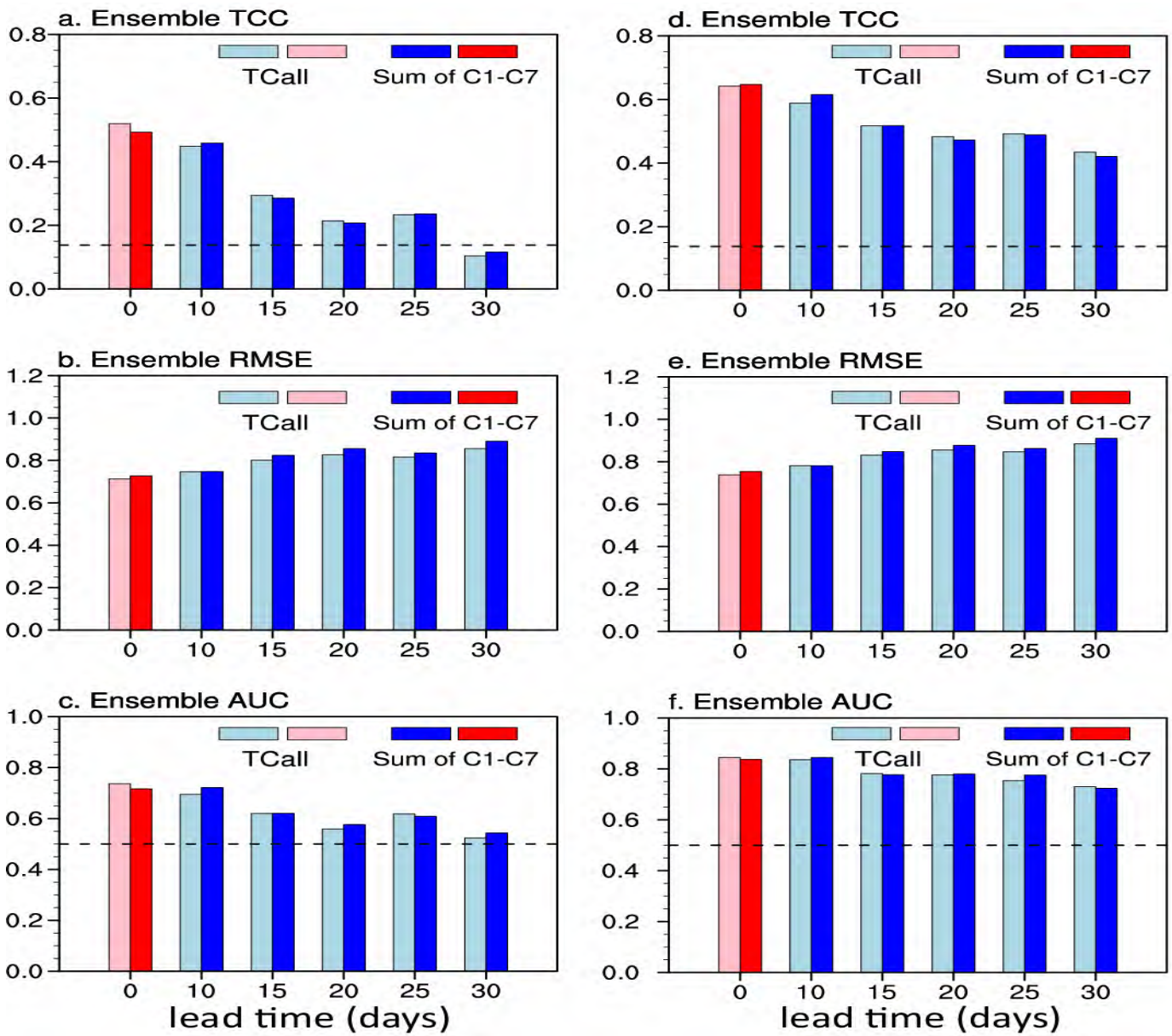
TC anomaly count | **TC total count (ano.+clim)**

0: obs. ISO (upper limit)

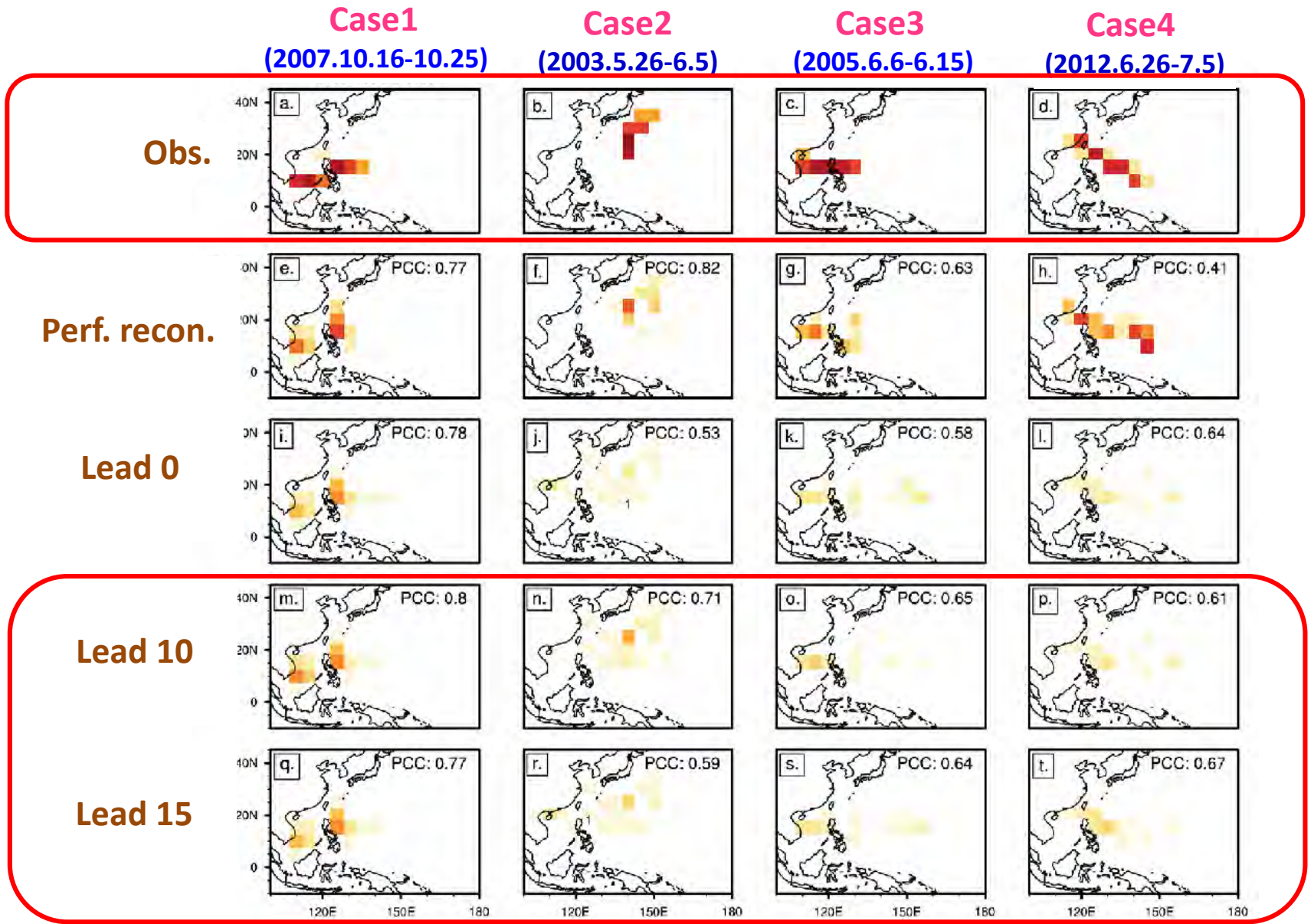
TCC

RMSE

AUC/ROC (probability skill)



Probability maps of TC track



Summary and discussion

- GFDL FLOR CGCM has skillful boreal summer ISO prediction in **14-44 days** in advance.
- Using the predicted ISO information, this hybrid dynamic-statistical model can predict WNP TCs at **20-25 day lead**, including **TC genesis numbers and track probability map**.
- **Real-time application**

ECMWF model

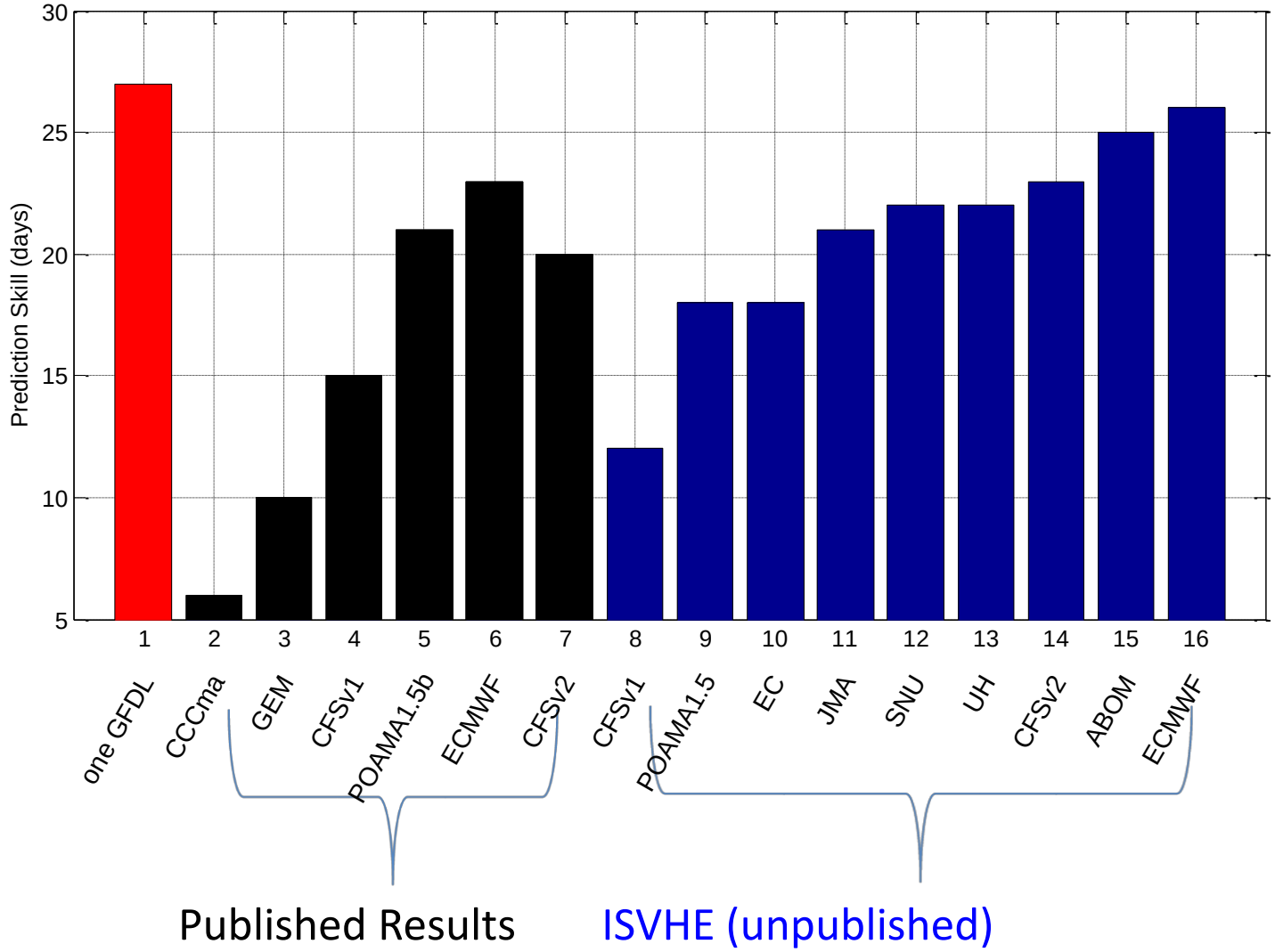
S2S models

CWB/NUIST/BCC model

} Ensemble prediction of TCs at subseasonal timescale

Thanks

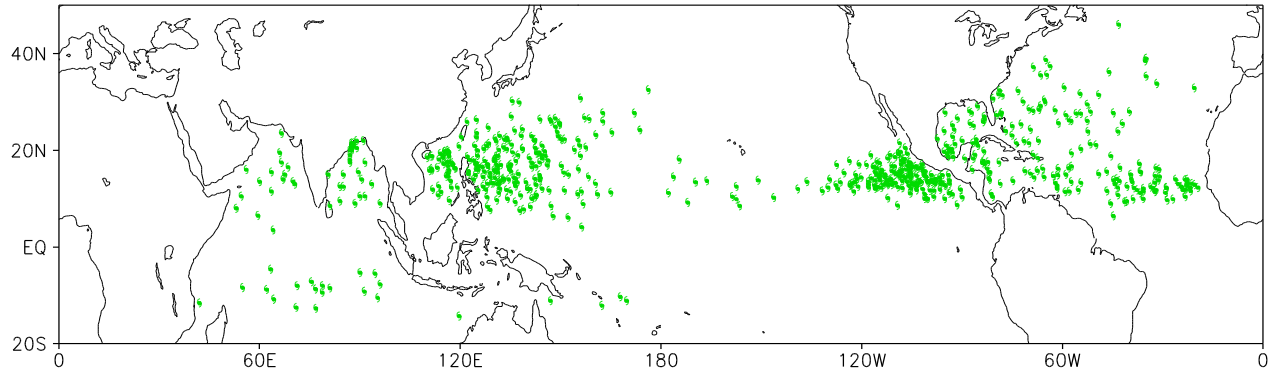
MJO Skill Comparison (10-yr Hindcast)



Multi-year Hindcast Experiments (Jiang et al. 2018, JC)

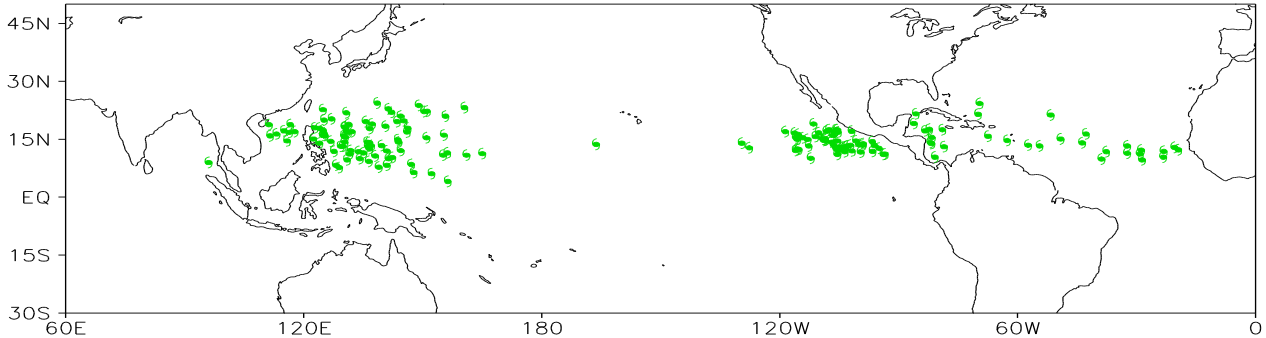
- 6 times each month (1st, 6th , 11st, 16th, 21st , 26th) Jun-Nov, **2003-2013**
- 12 ensemble members (00Z, 02Z, …., 22Z)
- 30-day forecast

Total tropical storms (~ 600, 2003-2013)



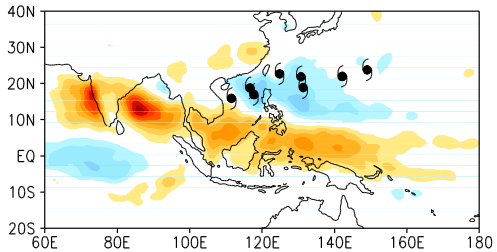
Good prediction skill: week 1 forecast skill > 65% ; or week 2 forecast skill > 50%

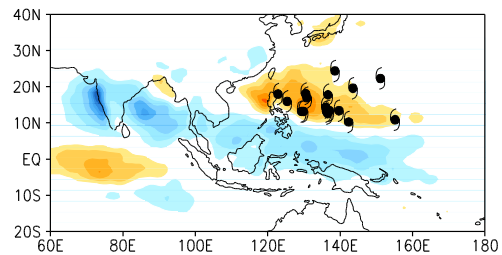
Tropical Storms with higher prediction skill (~ 30%)



Western Pacific TC genesis with good predictive skill and local ISO Phases

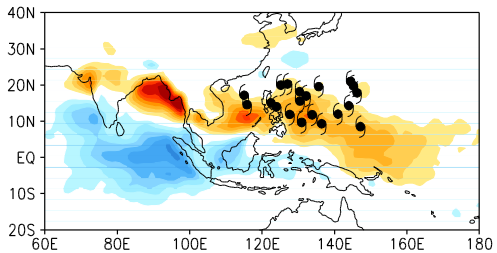
Phase 2+3

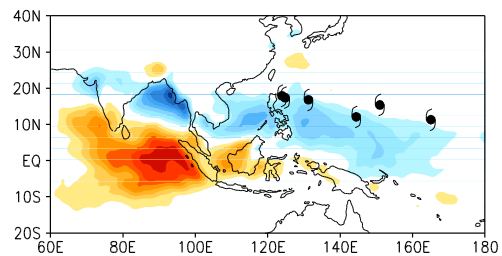




Phase 6+7

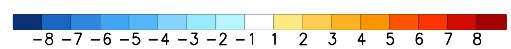
Phase 4+5





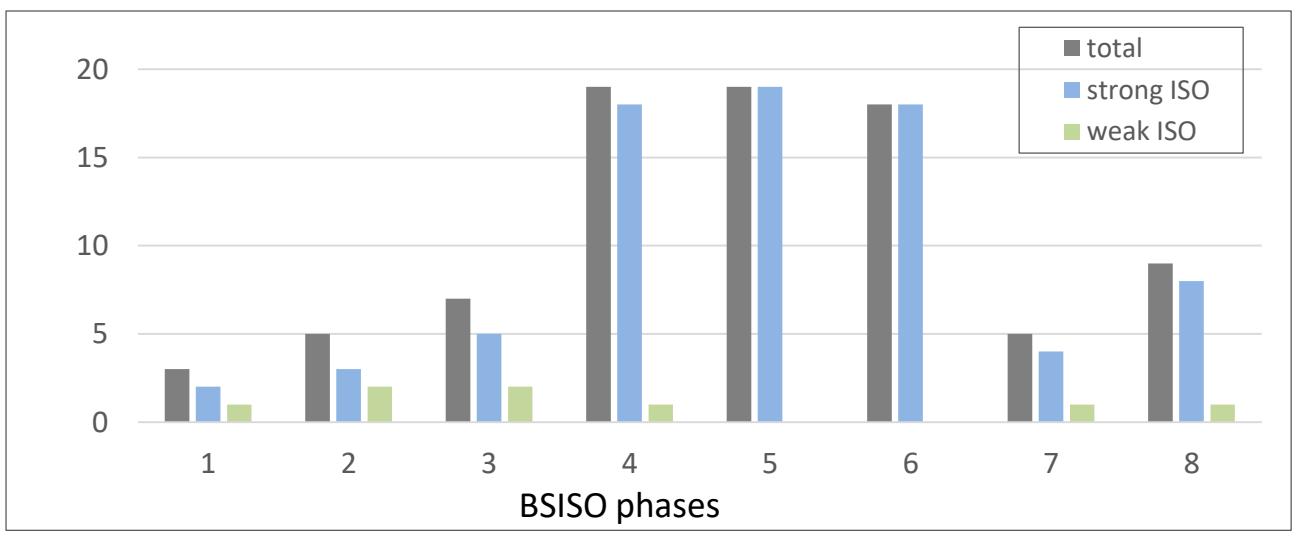
Phase 8+1

Shading: composite rainfall anomalies for each ISO phase.



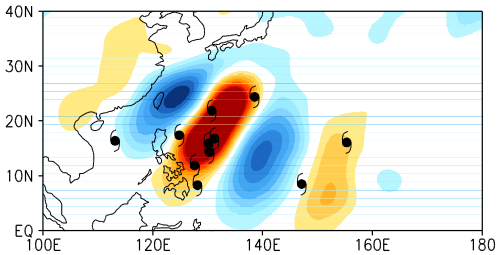
Jiang et al. 2018

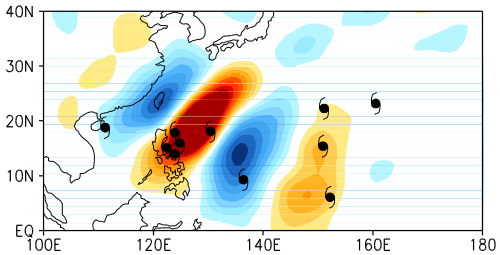
TS #



Skillful WP TC genesis and Synoptic Wave Trains (SWT)

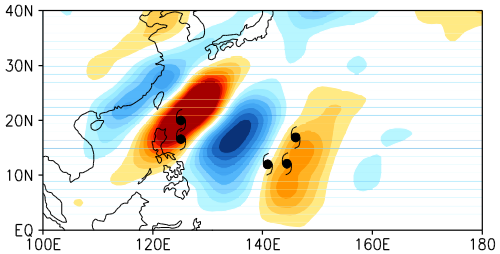
Phase 1

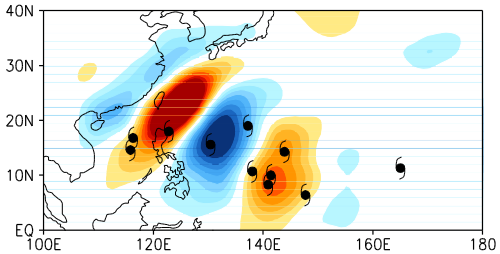




Phase 2

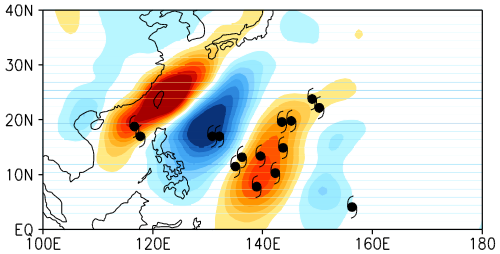
Phase 3

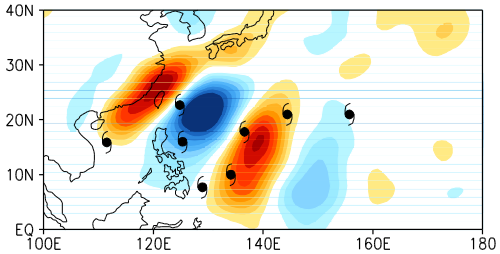




Phase 4

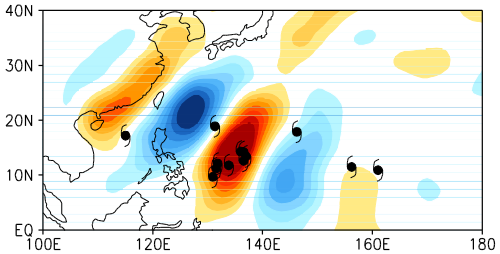
Phase 5

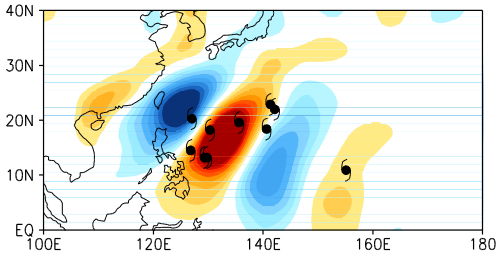




Phase 6

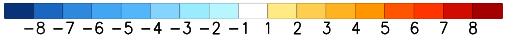
Phase 7





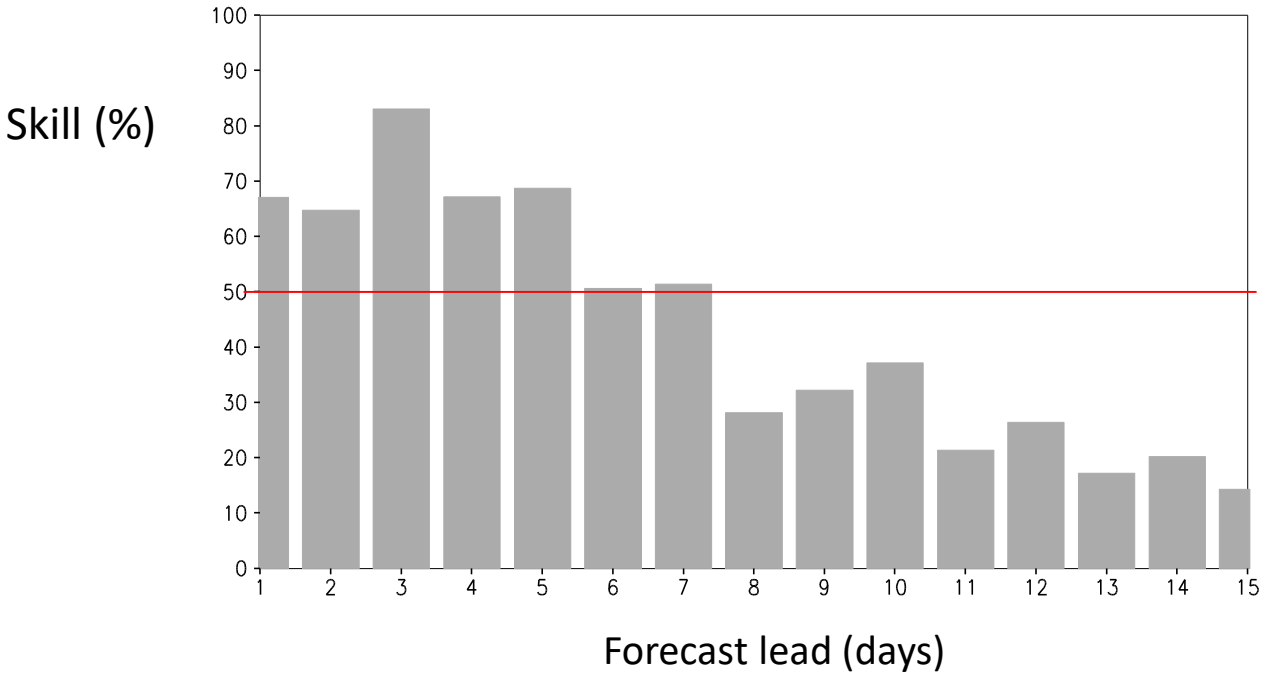
Phase 8

Shading: 850hPa vorticity



TC Genesis Prediction Skill for Selected Good Skill Cases

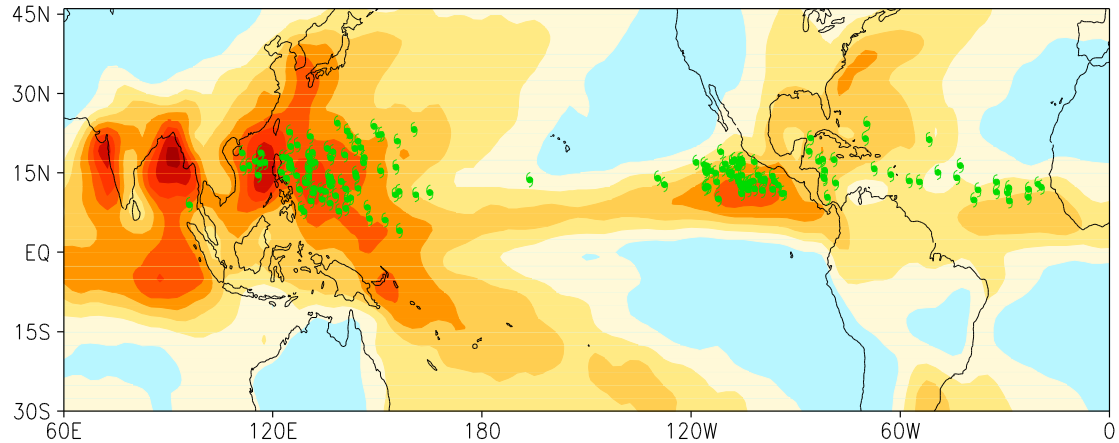
(total counts: ~ 30%)



Distribution of skillful TCs and Intraseasonal/Synoptic Variability

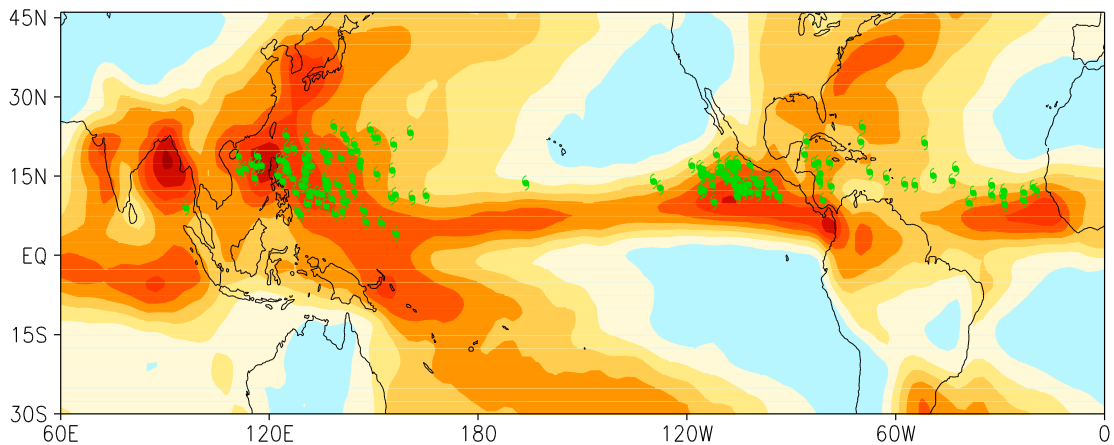
a) Intraseasonal variability

Shading:
STD of 20-100day
filtered rainfall



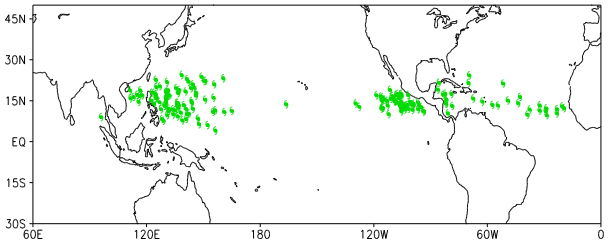
b) Synoptic-scale variability

Shading:
STD of 2-10day
filtered rainfall

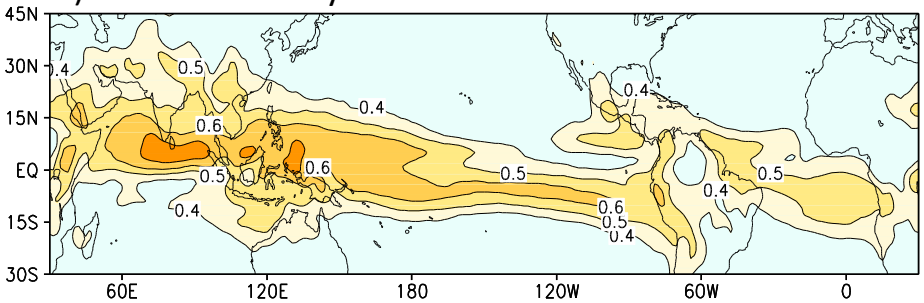


Correlation between Forecasted and Observed Large-scale Fields at Week-2 (day 8-14)

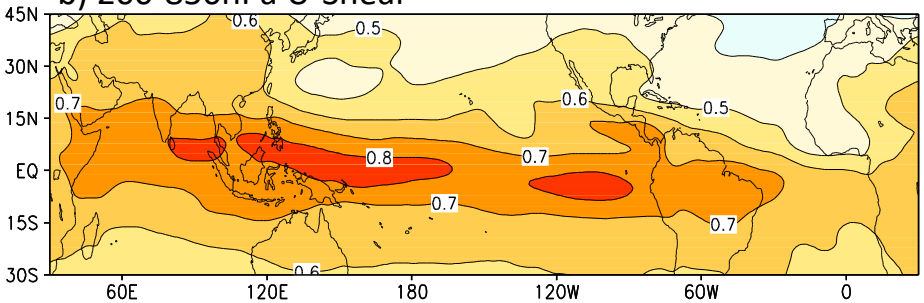
TCs with high prediction skill



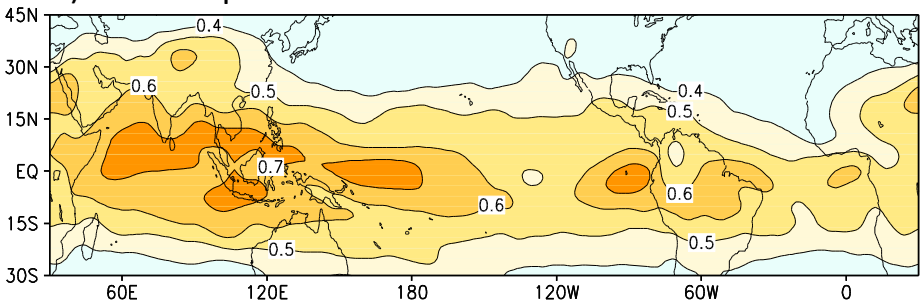
a) 850hPa Vorticity



b) 200-850hPa U-Shear

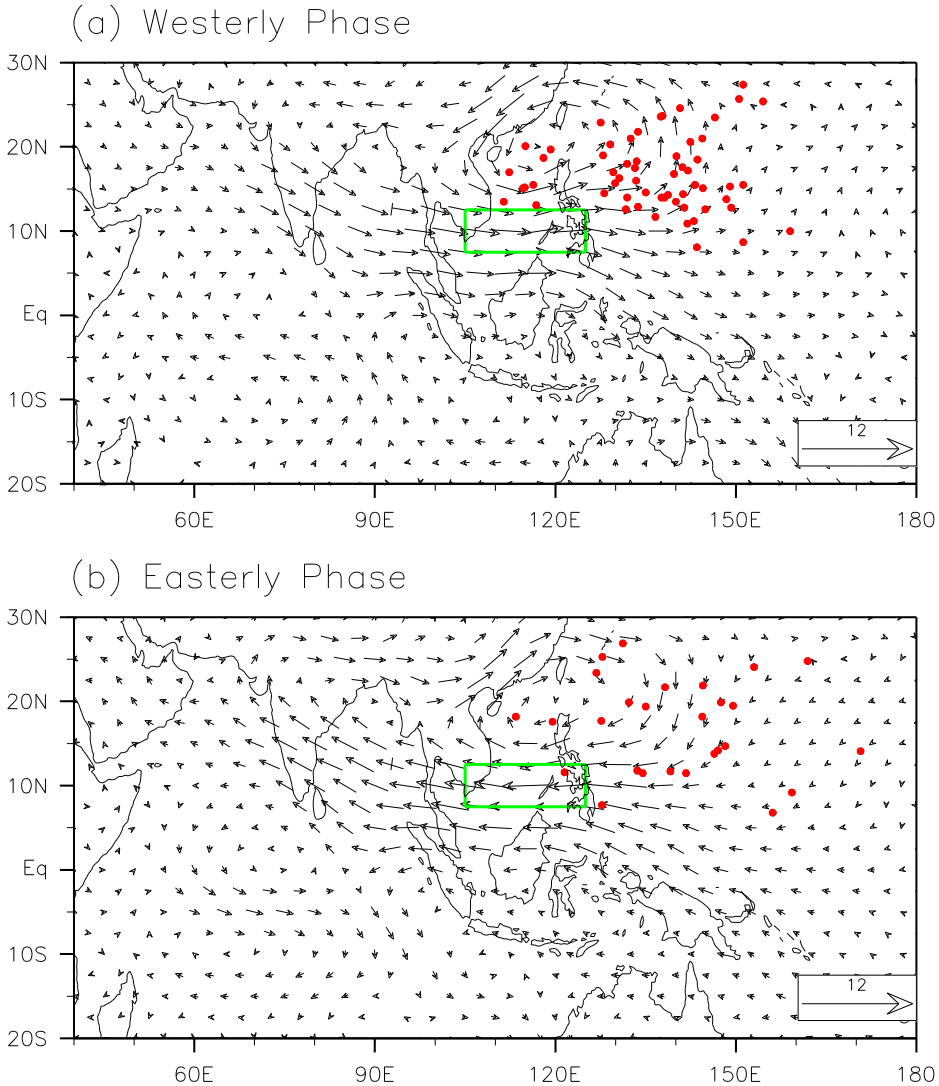


c) 500hPa q



Correlation between week-2 forecasted and observed large-scale circulation fields is in a range of 0.4 ~ 0.8 in most parts of TC basins.

Composite of 20-60 day filtered 700-hPa wind anomalies (vector), rainfall anomalies (shading) and TC genesis (dotted) in JJAS during 1958-1970



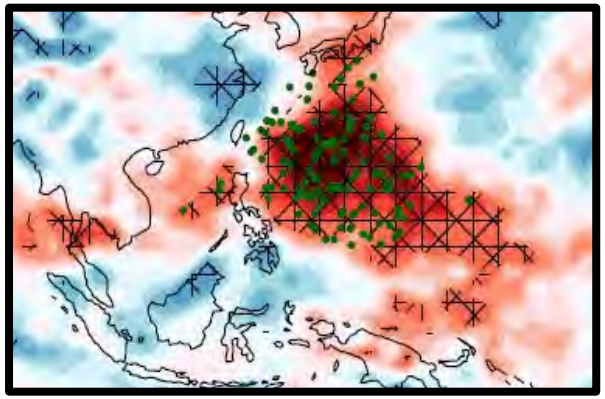
Composite patterns of 30-60-day filtered 700-hPa wind anomaly (vectors, m s^{-1}) and TC genesis location (dotted) for (a) MJO westerly phase and (b) MJO easterly phase in June - September during 1958-1970

TC genesis frequency is positively correlated with westerly phase of ISO in the WNP.

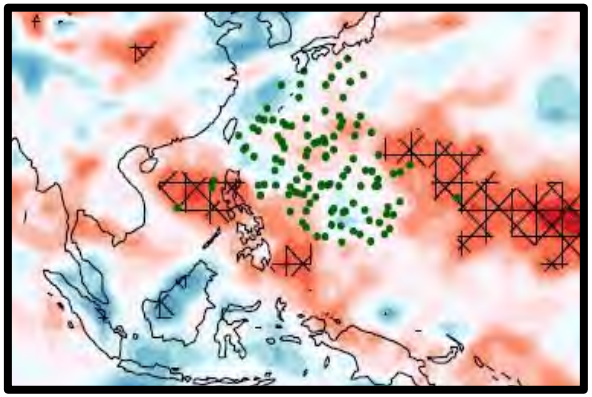
Motivation

- **Statistical prediction** using the preceding ISO information.

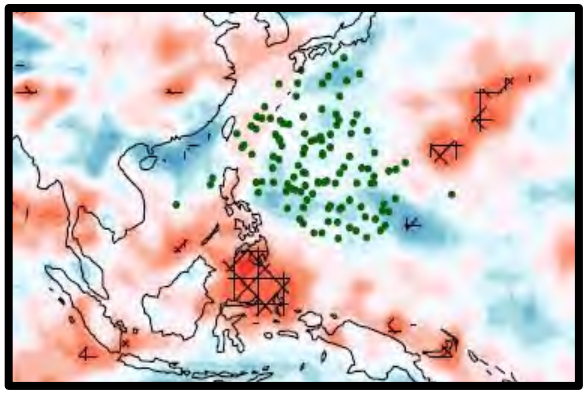
Dots: TC genesis **Shading: corr. coef. (TC & 10-90d w500)**



Lag 0d



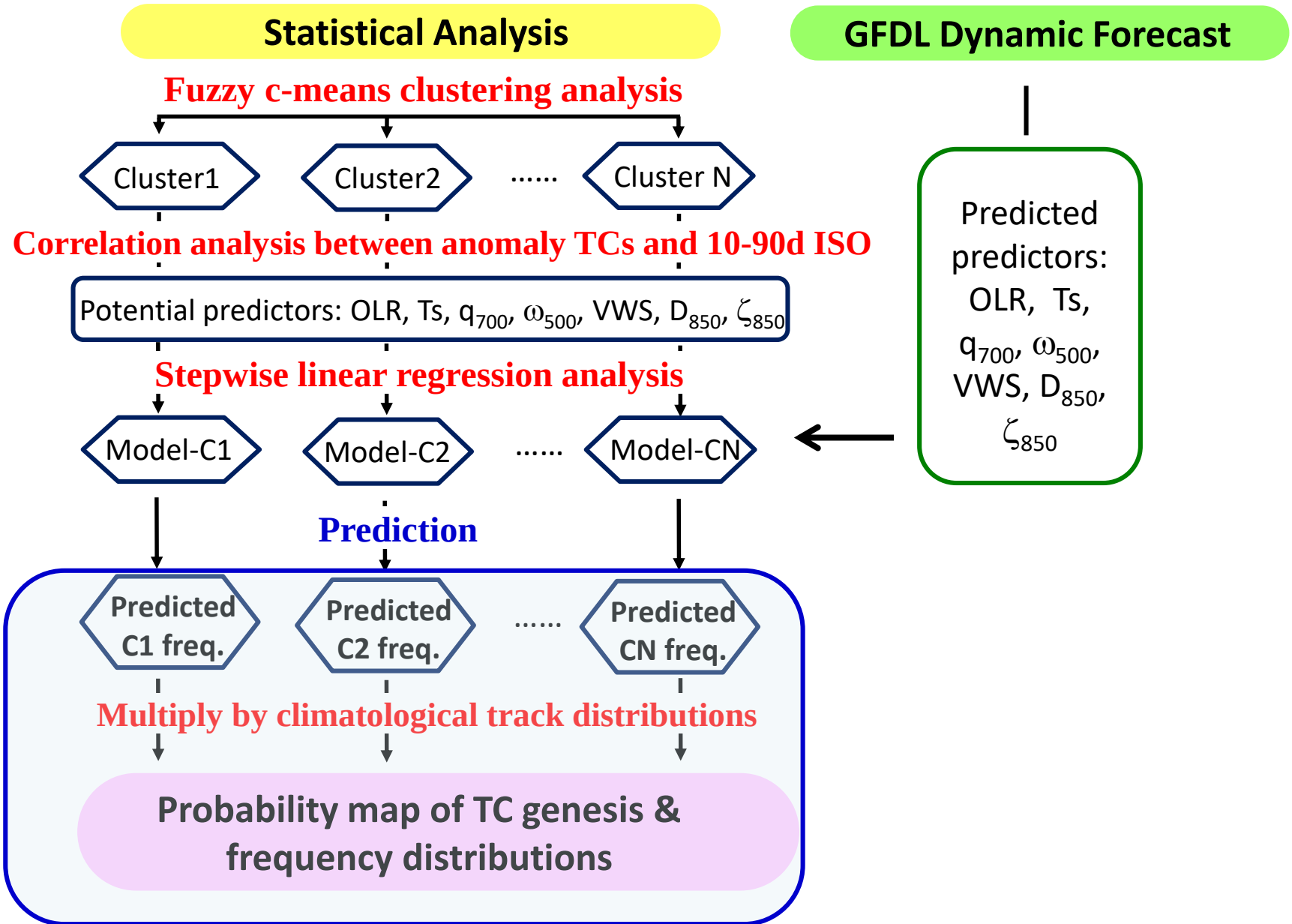
Lag 10d



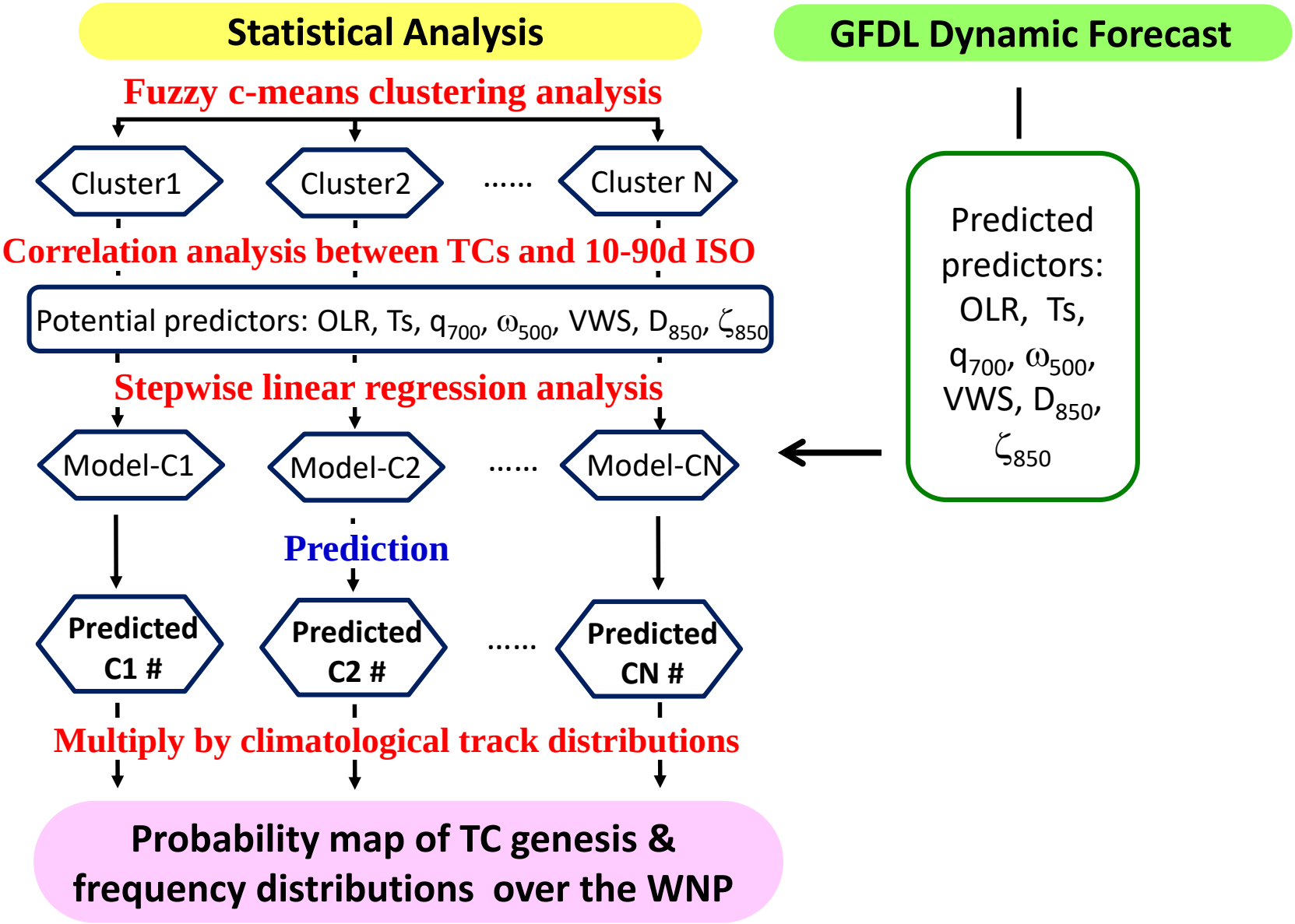
Lag 20d

TC forecast skill drops quickly

(due to weak ISO signals ahead of forecasting time)

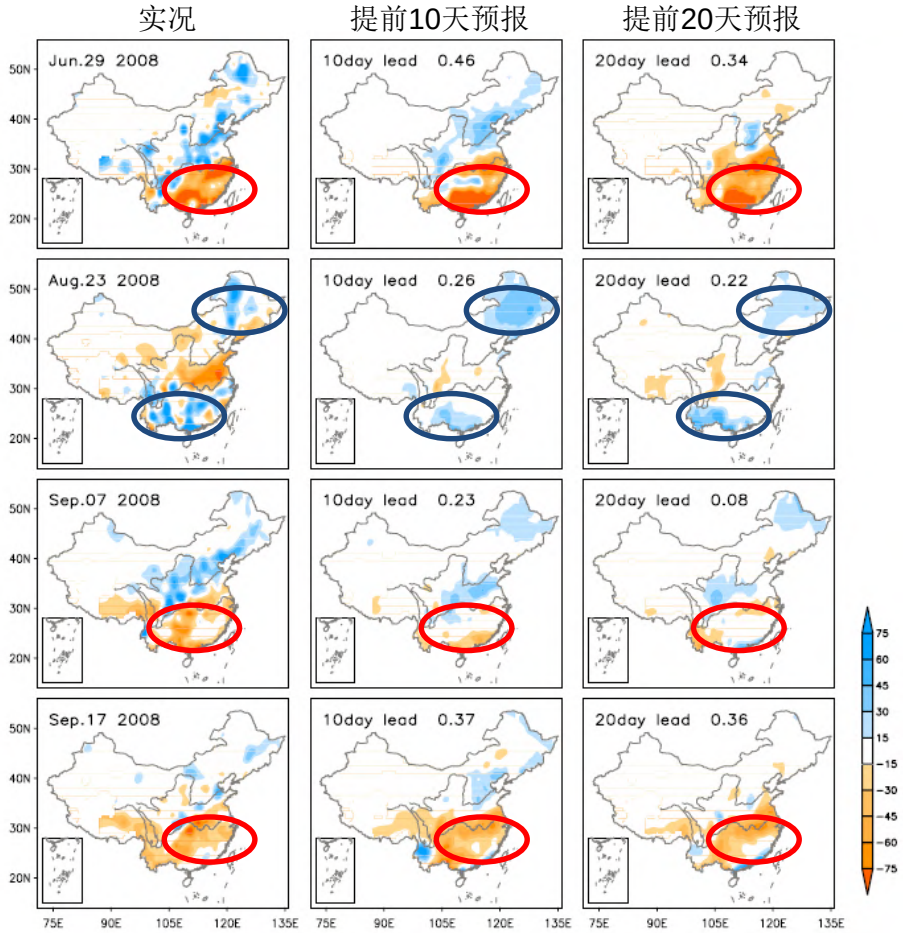

Statistical Analysis
GFDL Dynamic Forecast
Fuzzy c-means clustering analysis
Cluster1
Cluster2
……
Cluster N
Correlation analysis between anomaly TCs and 10-90d ISO
Potential predictors: OLR, Ts, q_{700}, ω_{500}, VWS, D_{850}, ζ_{850}
Stepwise linear regression analysis
Model-C1
Model-C2
……
Model-CN
Predicted predictors: OLR, Ts, q_{700}, ω_{500}, VWS, D_{850}, ζ_{850}
Prediction
Predicted C1 freq.
Predicted C2 freq.
……
Predicted CN freq.
Multiply by climatological track distributions
Probability map of TC genesis & frequency distributions

Target product: TC counts and probability map of TC frequency over the WNP in every 10 days at lead times of 10d, 15d, 20d, 25d, 30d .

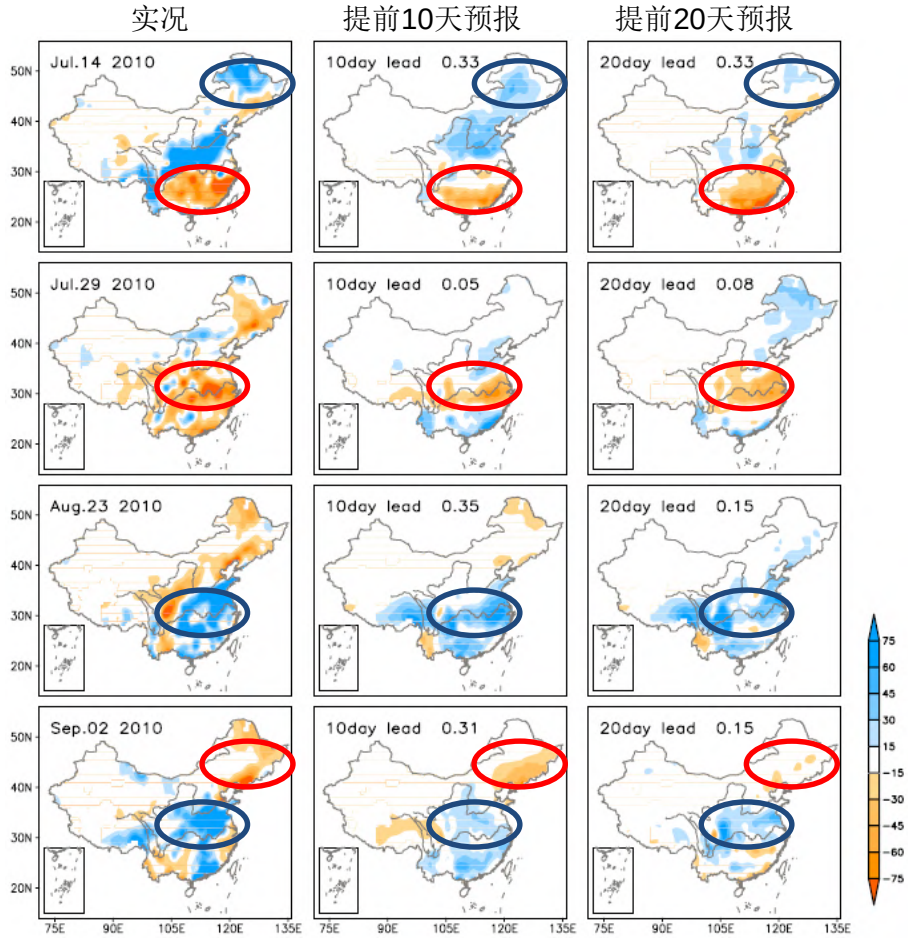


夏季降水延伸期业务预报效果

2008年北京奥运会期间独立预报效果

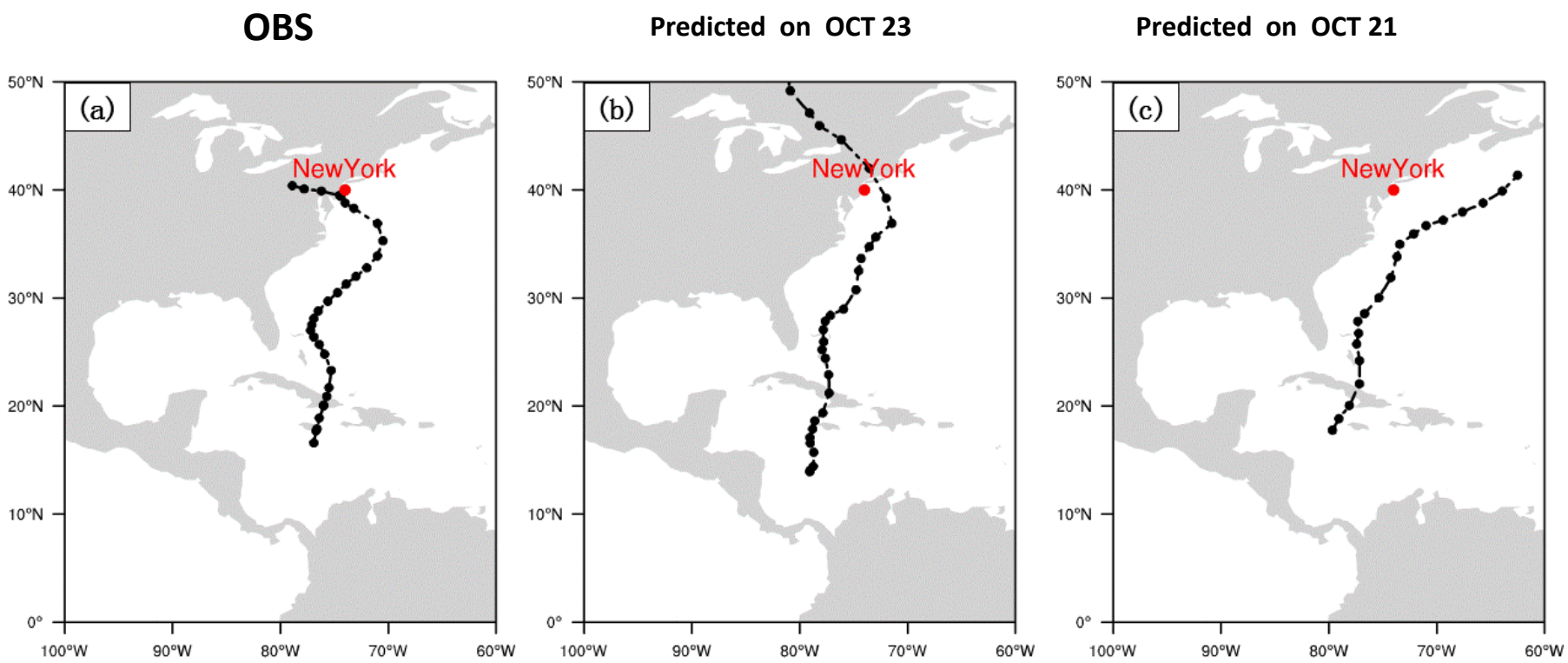


2010年上海世博会期间独立预报效果



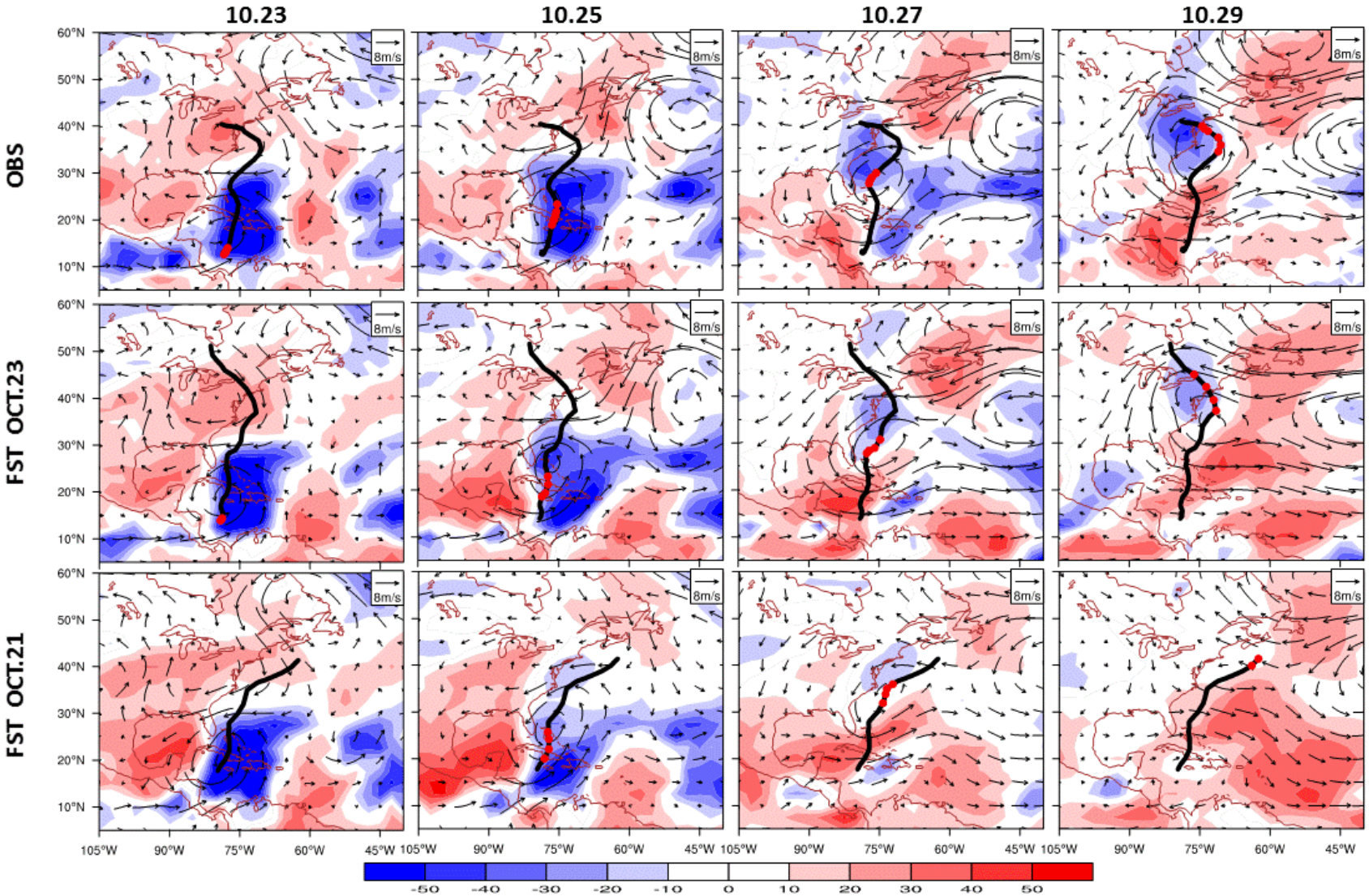
时空投影预报模式（**STPM**）能够**提前20天**较好地预报中国夏季季节内降水异常分布。本研究是针对整个中国大陆地区夏季降水异常分布统计延伸期预报的**首次尝试**，为中国延伸期预报的业务开展提供参考和指导。

Forecast experiments



Forecast experiments

850hPa Wind & OLR (10-90d)



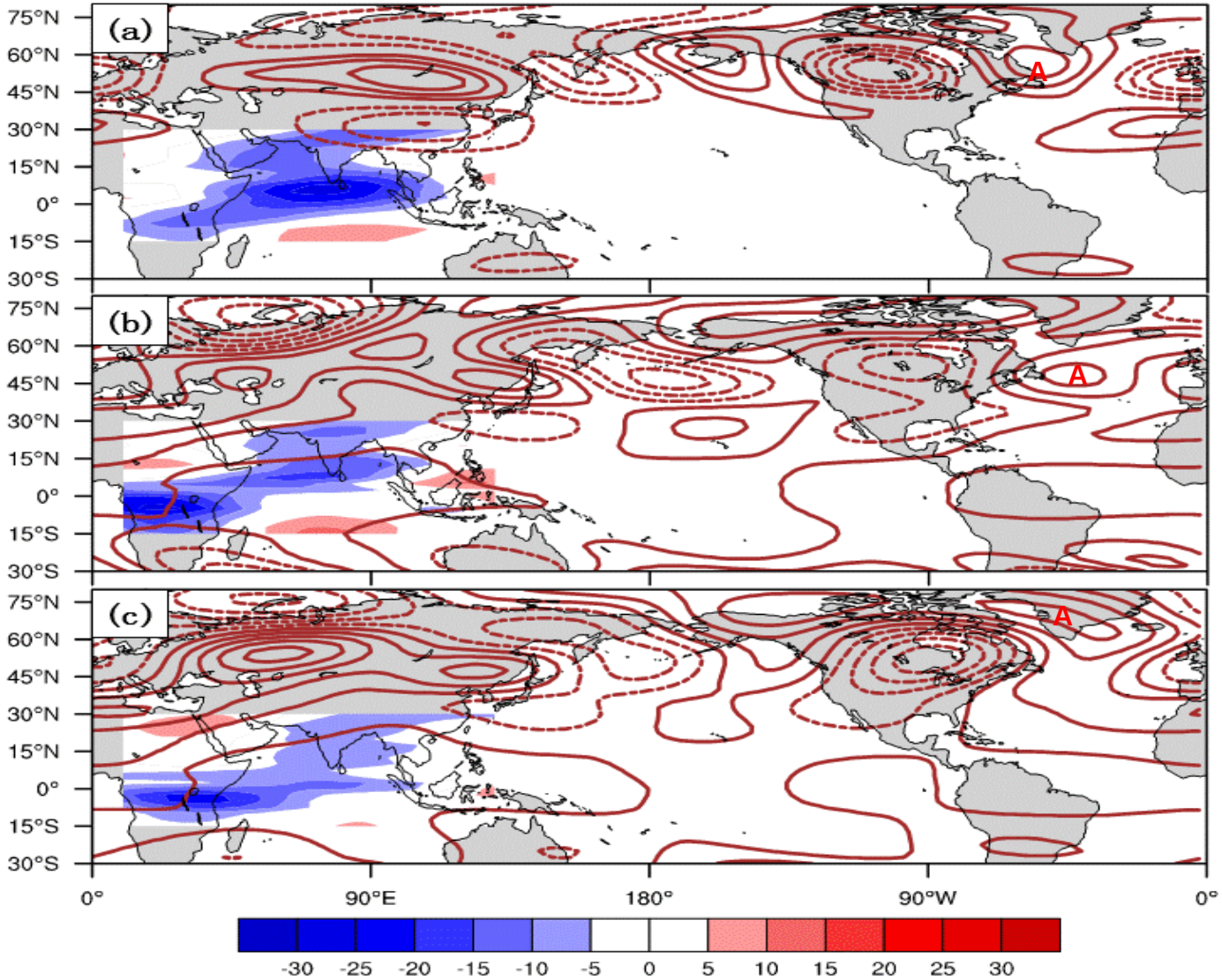
Forecast experiments

200hPa Hgt & OLR

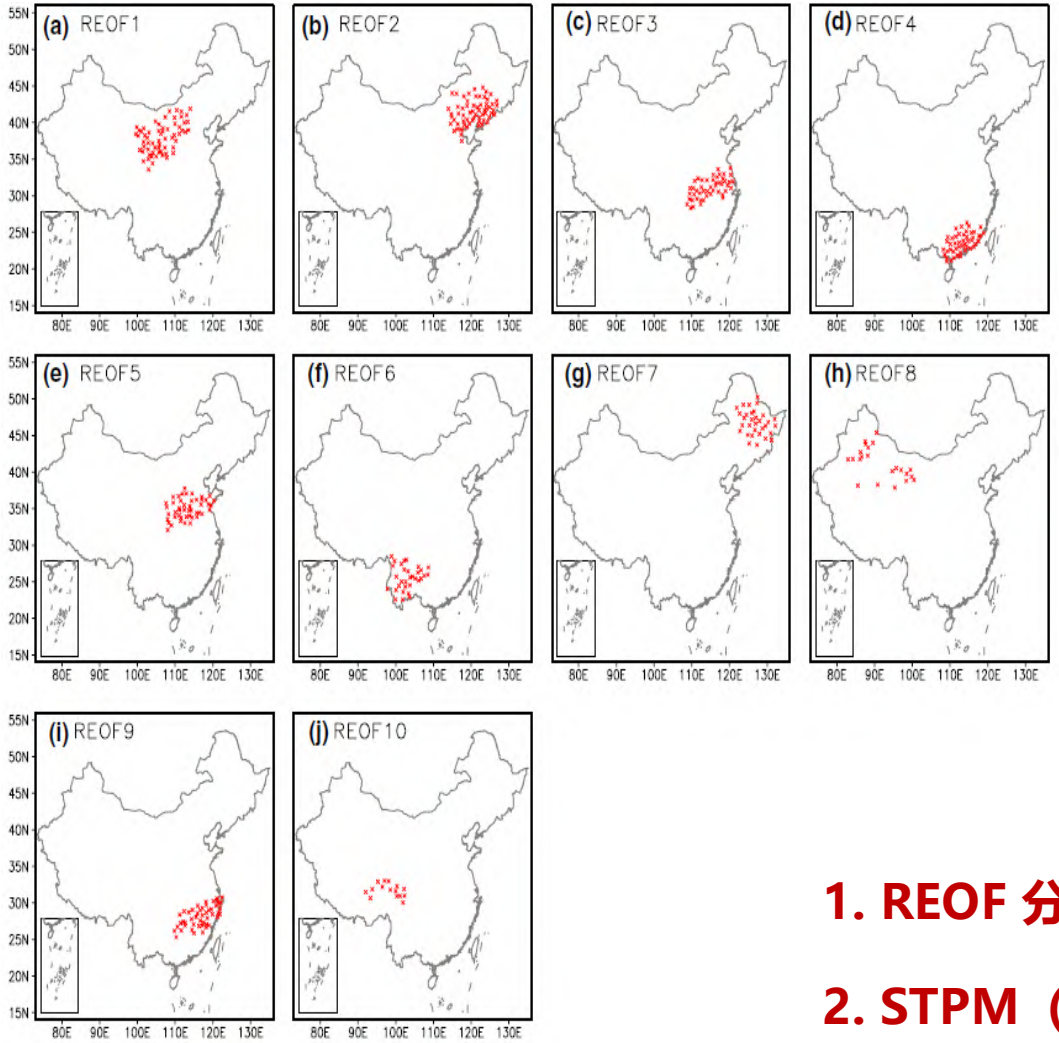
OBS

FST 10.23

FST 10. 21



全国降水延伸期预报方法和技术



Region	U850, U200, OLR, H850, H500, H200, Rhum700, Curl850
R1	60°E–120°E, 5°N–60°N
R2	75°E–140°E, 10°N–60°N
R3	80°E–160°E, 5°N–50°N
R4	110°E–160°E, 5°N–50°N
R5	100°E–140°E, 5°N–50°N
R6	60°E–120°E, 0–60°N
R7	100°E–170°E, 20°N–70°N
R8	40°E–120°E, 0–60°N
R9	100°E–160°E, 0–45°N
R10	40°E–120°E, 15°N–60°N
China	40°E–170°E, 0–60°N

1. REOF 分区

2. STPM（不同大尺度预报因子）

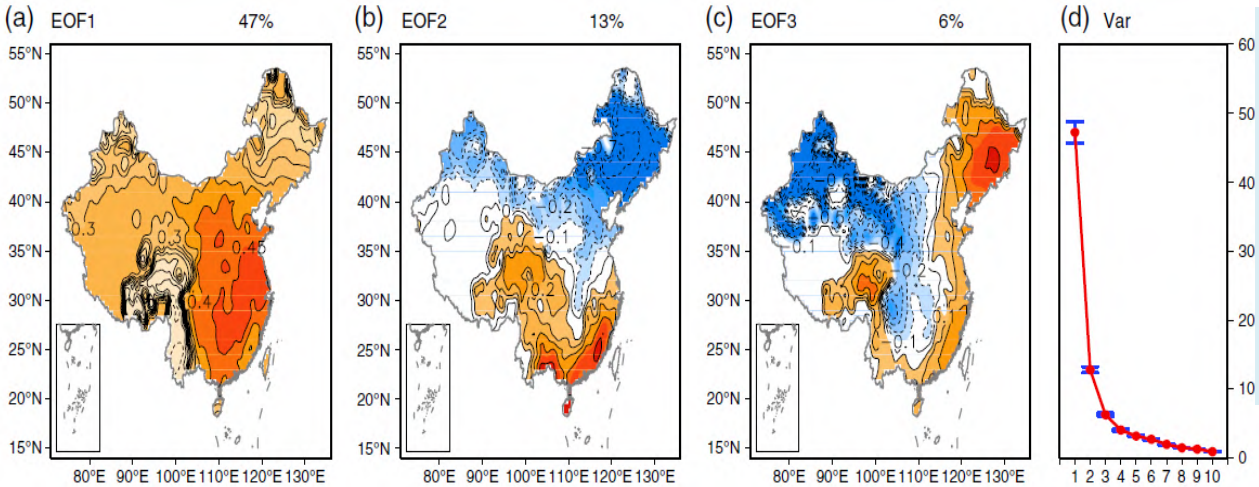
不同区域的可预报性来源不同

引自：Zhu and Li 2017 Clim. Dyn.

2.2 中国冬季地表气温及极端冷事件的延伸期预报

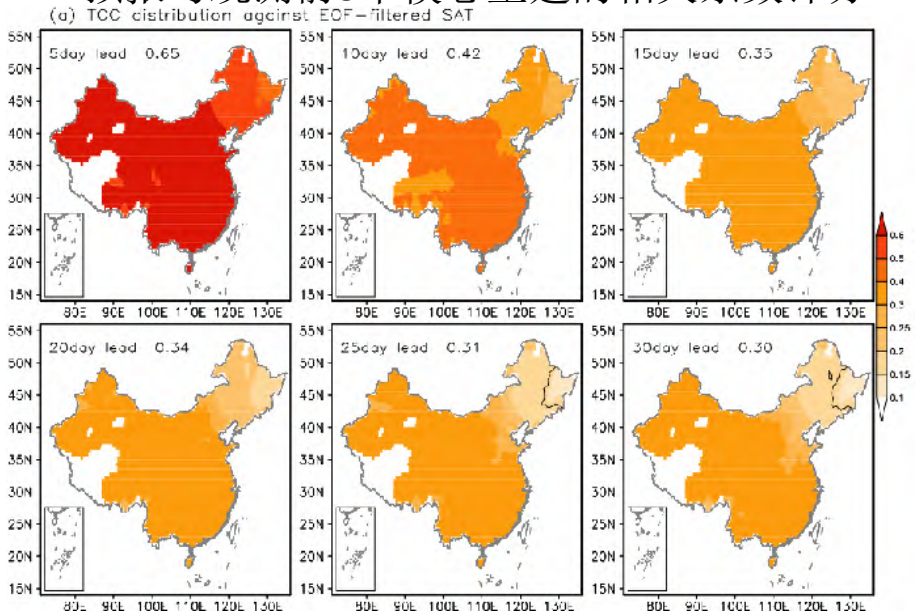
Zhu and Li (2017b, QJRMS)

中国冬季季节内（10-80天）地表气温主模态分析

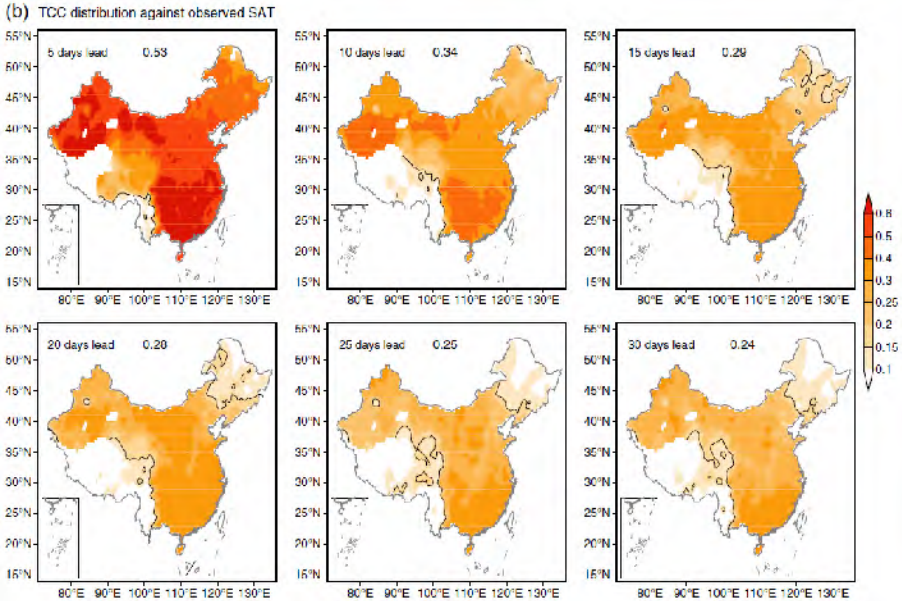


中国冬季地表气温前三模态独立且显著，根据各自主成分序列，寻找前期影响因子并建立时空投影模式（STPM）能够较好预报冬季地表气温

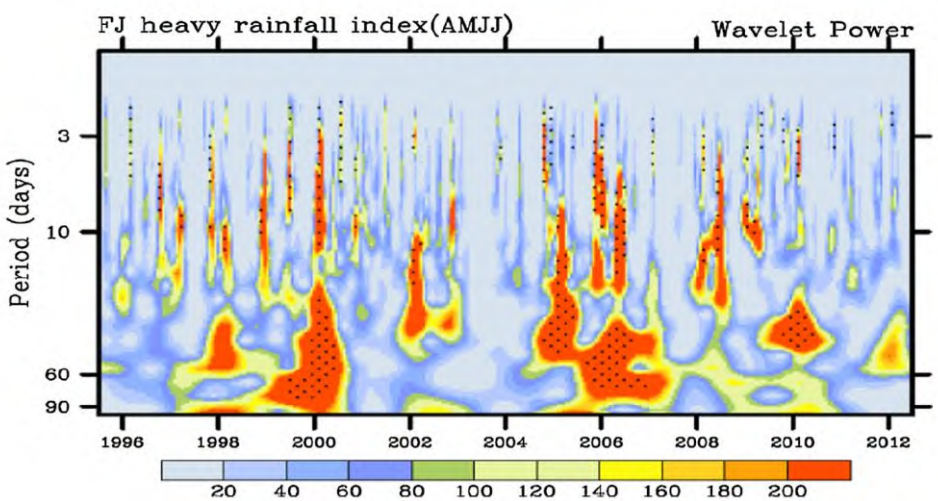
预报与观测前3个模态重建的相关系数评分

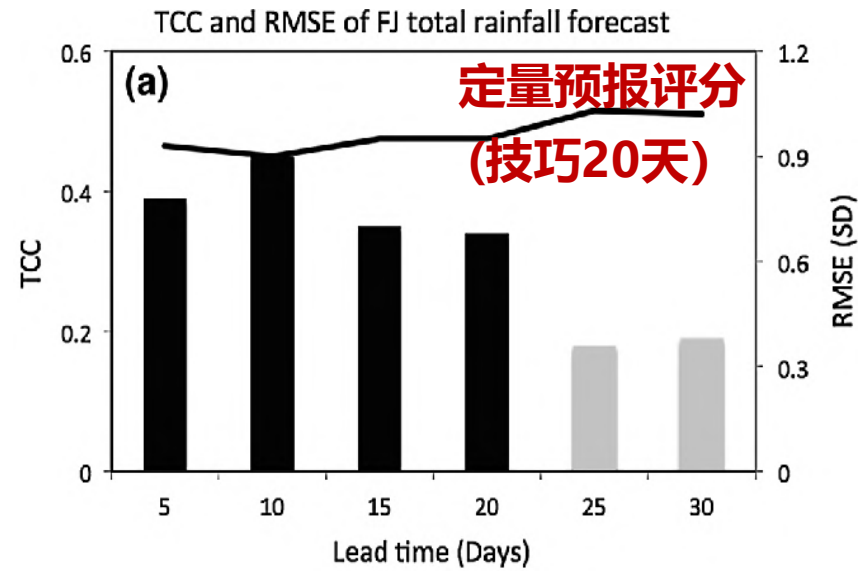


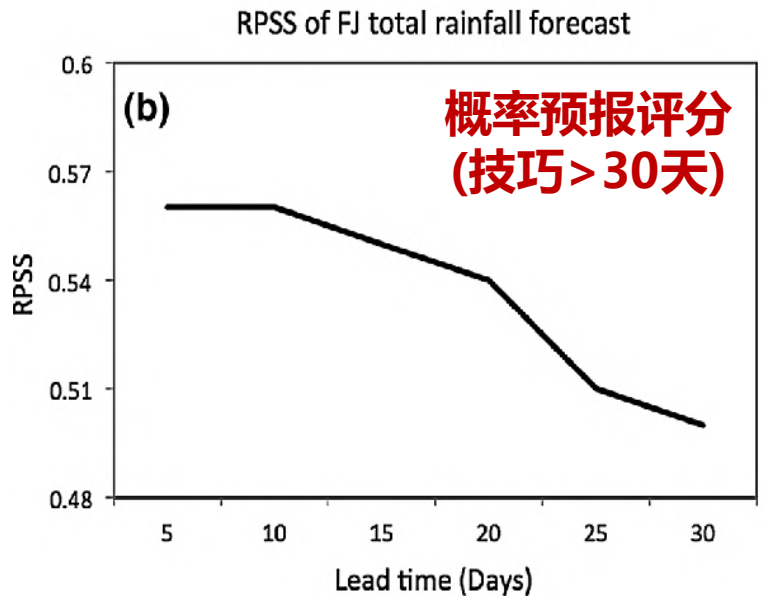
预报与观测实况的相关系数评分



福建省强降水预报及检验







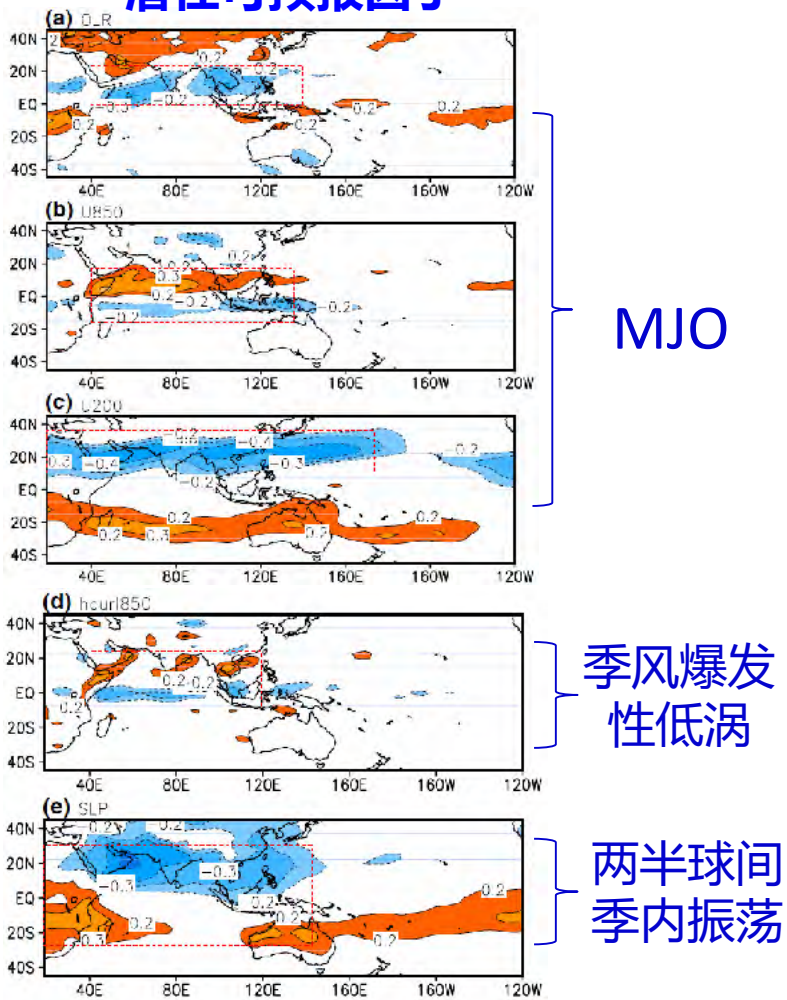
1. **福建省暴雨指数**具有明显的10-60天周期
2. 辨识影响福建暴雨的大尺度低频信号
3. 考虑两者时空演变耦合过程

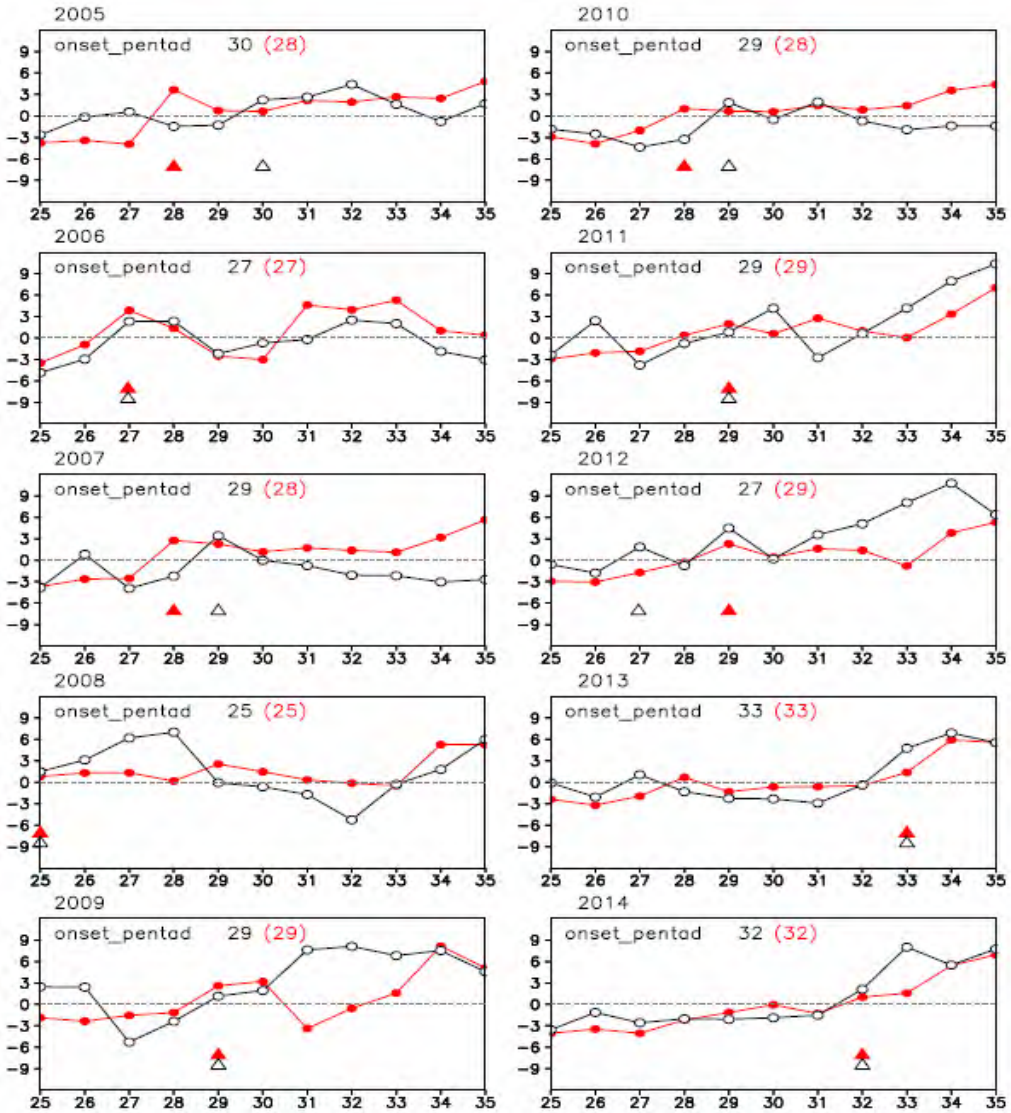
→ **STPM预报**

引自：Hsu, Li, You, Gao et al. 2015 CD

南海季风爆发日期预报及检验

潜在可预报因子





南海地区纬向风(m/s)指数及季风爆发日期

(红色预报，黑色实况)

引自：Zhu and Li 2017 Clim. Dyn.

1 明确了大气季节内振荡对我国灾害天气的调制作用，揭示延伸期预报的可预报性来源。

延伸期可预报性来源研究

2 研发了非带通滤波提取低频信号技术及基于时空投影方法的延伸期预报模型。

预报模型和实时应用技术

3 研制了全国范围的降水、气温、极端事件的延伸期预报方法和技术，为防灾减灾提供参考。

全国范围天气过程预报

4 **研发了西北太平洋台风的延伸期预报方法和技术，填补了台风延伸期预报的相对空白。**

台风群发和路径预报

中国夏季降水5-30天延伸期预报技巧 (2003-2010)