



中央氣象署全球展期天氣與短期氣候 系集預報系統發展現況

劉邦彥¹ 李明營¹ 李尚恩¹ 吳子榆¹ 吳蔚琳¹ 吳佳瑩¹ 曾喜絃¹ 邵允銓²

郭珮萱¹ 黃崇惟¹ 胡志文¹ 陳奕安¹ 曾于恒² 莊漢明³ 陳建河

1 中央氣象署科技發展組

2 國立臺灣大學海洋中心

3 國立中央大學大氣科學學系

115年第四十屆天氣分析與預報研討會 臺北 2026.09.02

中央氣象署數值預報系統

hours

5 days

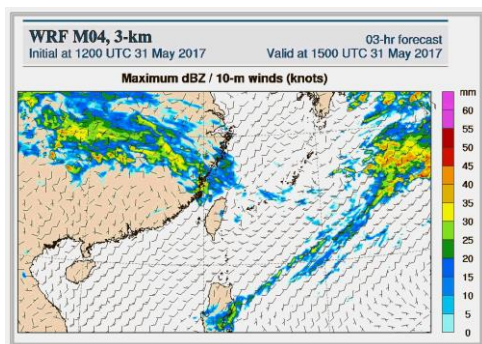
16 days

45 days

9 months

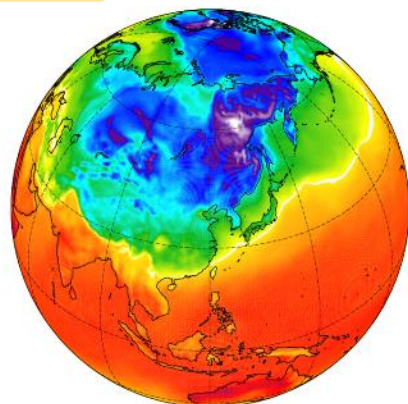
NWP team

Climate Simulation Section



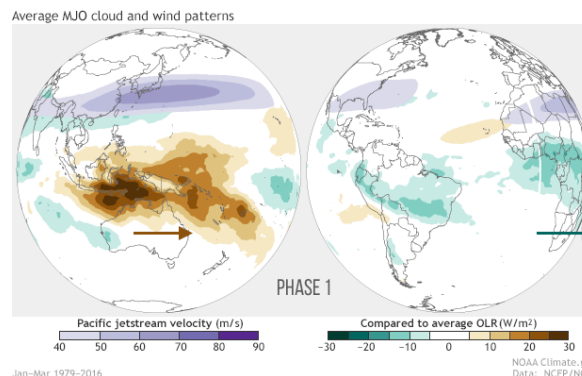
Regional weather

- CWA WRFD (5 days)
- CWA TWRF (5 days)
- CWA WEPS (5 days)
- CWA RWRF (13 hours)
- CWA CEPS (13 hours)



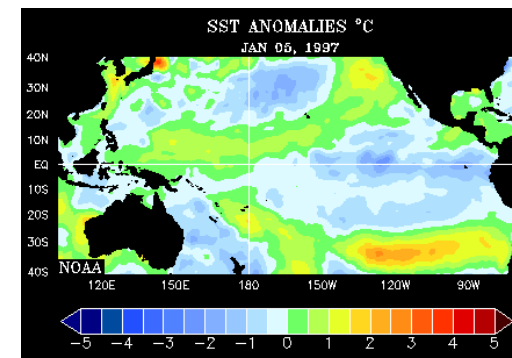
Global weather

- TGFS (16 days)
(based on FV3)



Extended weather

- CWA GEPS (45 days)
- 1 deterministic + 20 members



Short-term climate

- CWA CFS (9 months)
(Global + RSM)
- 30 members/month

Climate Simulation Section

Section Chief: 李明營

Model team: 劉邦彥, 陳奕安, 郭珮萱, 黃崇惟, 吳佳瑩, 吳蔚琳, 曾喜絃, 李尚恩, 胡志文, 吳子榆

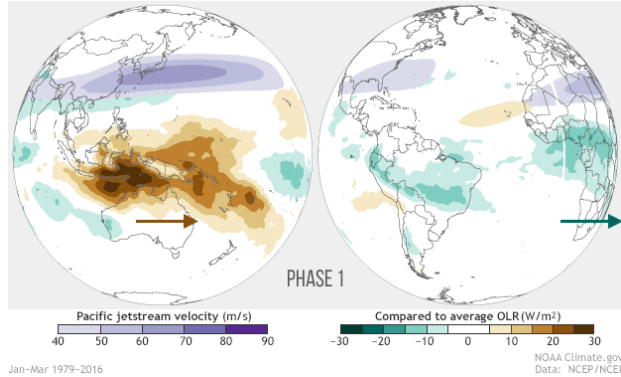
大綱



- 預報系統作業現況
 - 全球展期天氣系集預報系統(CWAGEPS)
 - 全球短期氣候預報系統(CWACFS)
- 預報系統發展現況
- 未來規劃
- 總 結

全球展期天氣系集預報系統作業現況

Average MJJ cloud and wind patterns



Extended weather

- CWA GEPS (45 days)
- 00 UTC/day
- (1 deterministic + 20 members)/day
- Re-forecast (2006-2020 total 15 years)
(Initial condition from NCEP CFSR)

Users

Internal:

海象氣候組(氣候預報科、氣候研析科、資料管理科)、
預報中心颱風及劇烈天氣預報科、氣象綠能營運中心

External:

農業部(農業試驗所、農水署、茶與飲料作物改良場、
水產試驗所)、經濟部水利署、臺灣電力公司、
中華民國海軍

2017

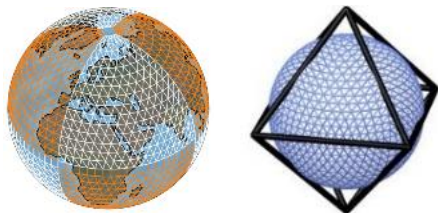
CWA GEPS V1

- ◆ T319 (~45 km),
Reduced Gaussian grid
- ◆ 60 vertical layers
- ◆ Fixed Sea surface
temperature

2023

CWA GEPS V2

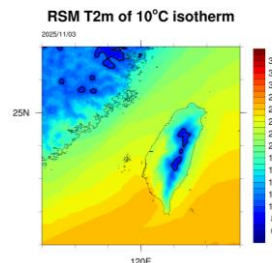
- ◆ $T_{Co}383$ (~28 km), Octahedral
reduced Gaussian grid
- ◆ 72 vertical layers
- ◆ Coupled One-column ocean
module (40S-40N)
+ CWA/CFS daily SS T forecast



2024

CWA GEPS V2.1

- ◆ embedded a regional
dynamic downscaling
model (RSM) (~ 5 km)



2025

CWA GEPS V3

- ◆ A fully Coupled
Atmosphere-ocean
model
- ◆ TCo383-TIMCOM
(global)
- ◆ RSM-TIMCOM
(regional)

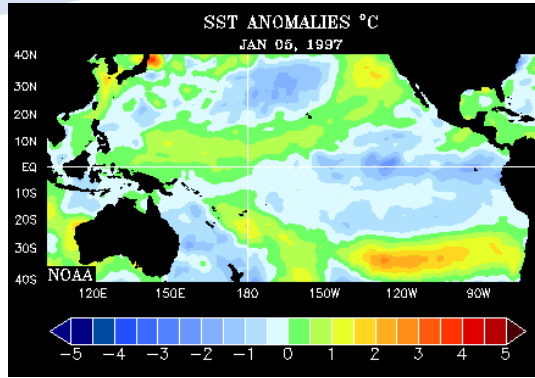
2027

CWA GEPS V3.1

- ◆ on GPU framework
- ◆ Ensemble member for
reforecast

NOW

全球短期氣候預報系統作業現況



Short-term climate

- CWA CFS (9 months)
(Global + RSM)
- 00 UTC/day
- 30 members/month
- Re-forecast: 1991-2020 (00UTC)
(Initial condition from NCEP CFSR)

Users

Internal:

海象氣候組(氣候預報科、氣候研析科、資料管理科)

External:

APCC、農業部水產試驗所、經濟部水利署、疾病管制署、雲林縣政府、桃園市政府、PAGASA(已表達介接資料意願與需求)

2010

TCWB 2T1

(Taiwan central weather bureau 2T1)

- ◆ T42 (~300 km),
Reduced Gaussian grid
- ◆ 18 vertical layers

2016

TCWB 2T2

- ◆ T119 (~110 km),
Reduced Gaussian grid
- ◆ 40 vertical layers

2017

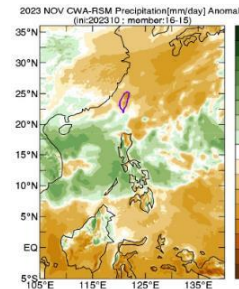
TCWB 1T1 (CWACFS V1)

- ◆ Coupled with MOM3

2023

CWA CFS V2

- ◆ T_{L359} (~ 60 km)
- ◆ Vertical 60 layers
- ◆ embedded a regional
dynamic downscaling
model (~ 12 km)
(Southeast Asia)
- ◆ Coupled GFDL MOM5
model
- ◆ Sea ice model (SIS)



2027

CWA CFS V2.1

- ◆ 60 members/month
- ◆ Bug fixed of RSM

NOW



CWAGFS-TCo with GPU Acceleration

➤ CWAGFS-TCo:



(figure from
<https://confluence.ecmwf.int/display/FCST/Introducing+the+octahedral+reduced+Gaussian+grid>)

🌐 **Global Models:** extended weather TCo383L72 (28 km, 72 layer)

⚙️ **Dynamic-Core:** Semi-Lagrangian + Semi-implicit (2 time level)

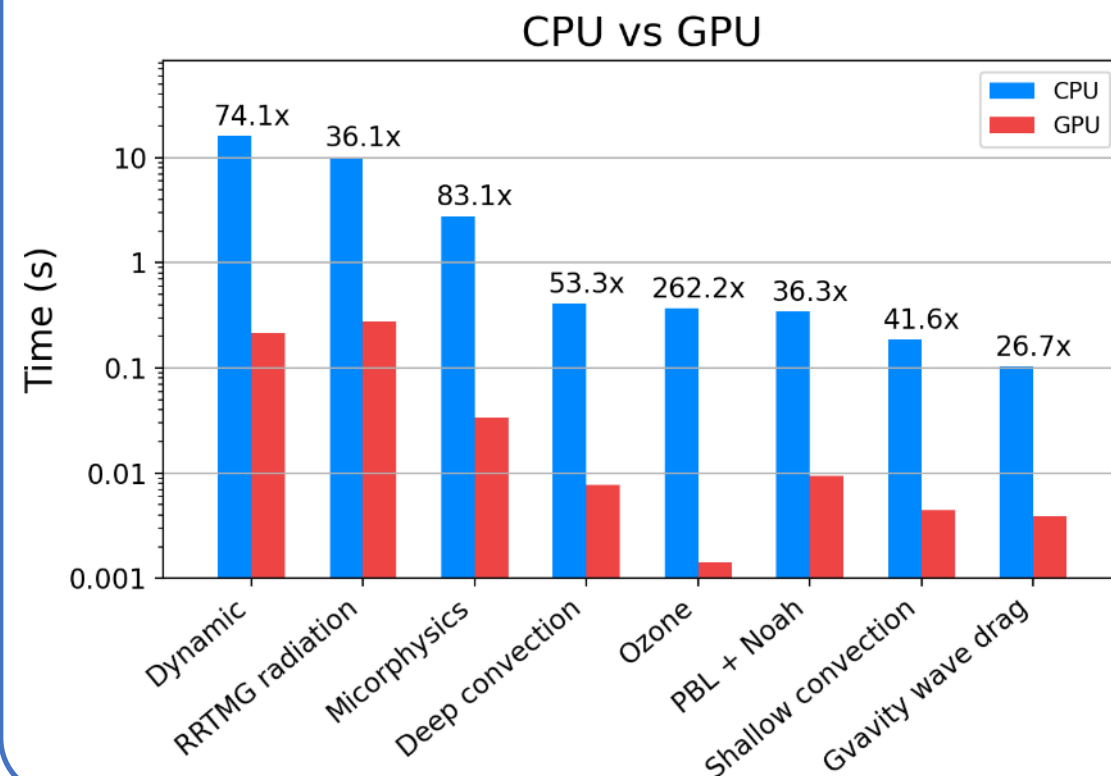
🌐 **Grid System:** Octahedral Reduced Gaussian Grid

⚠️ **Grid inconsistency presents a critical bottleneck for GPU acceleration**

🧑‍🔬 **Beyond OpenACC: A Holistic Strategy**

- Program Re-engineering: Structural adjustments
- **CUDA asynchronization**
- **CUDA Graph**
- **NCCL** for communication
- Use math libraries provided by NVIDIA, such as **cuFFT**, **cuBLAS**, etc.

• **[Xeon Gold 6326 CPU Core*32] vs [A100 GPU*8]**
Speedup about **67.7x**





TIMCOM with GPU Acceleration

TIMCOM新增適合GPU架構的求解器

CPU vs GPU 性能

BiCGStab (Biconjugate Gradient Stabilized) P-CSI (Preconditioned classical Stiefel iteration)

The BiCGStab algorithm for solving the matrix equation $Ax = b$:

bicgstab($x, b, A, \epsilon, k_{max}$)

1. $r_0 = b - Ax_0$, $\hat{r}_0 = r_0$, $\rho_0 = \alpha = w_0 = 1$, $v_0 = p_0 = 0$, $k = 0$

2. Do while $\|r\|_2 > \epsilon \|b\|_2$ and $k < k_{max}$

(a) $k = k + 1$, $\rho_k = (\hat{r}_0, r_{k-1})$

(b) $\beta = (\rho_k / \rho_{k-1}) (\alpha / w_{k-1})$

(c) $p_k = r_{k-1} + \beta (p_{k-1} - w_{k-1} v_{k-1})$

(d) $v_k = Ap_k$

(e) $\alpha = \rho_k / (\hat{r}_0, v_k)$

(f) $s = r_{k-1} - \alpha v_k$, $t = As$

(g) $w_k = (t, s) / \|t\|_2^2$, $\rho_{k+1} = -w_k \hat{r}_0^T t$

(h) $x = x + \alpha p + w s$

(i) $r = s - w t$

較多的MPI計算量
不適合用在GPU

vector operations

sparse matrix-vector product

inner product

For $k = 1, 2, \dots, k_{max}$ do

1. $\omega_k = 1 / (\gamma - \frac{1}{4\alpha^2} \omega_{k-1})$

2. $r'_k = M^{-1} r_k$

3. $\Delta x_k = \omega_k r'_k + (\gamma \omega_k - 1) \Delta x_{k-1}$

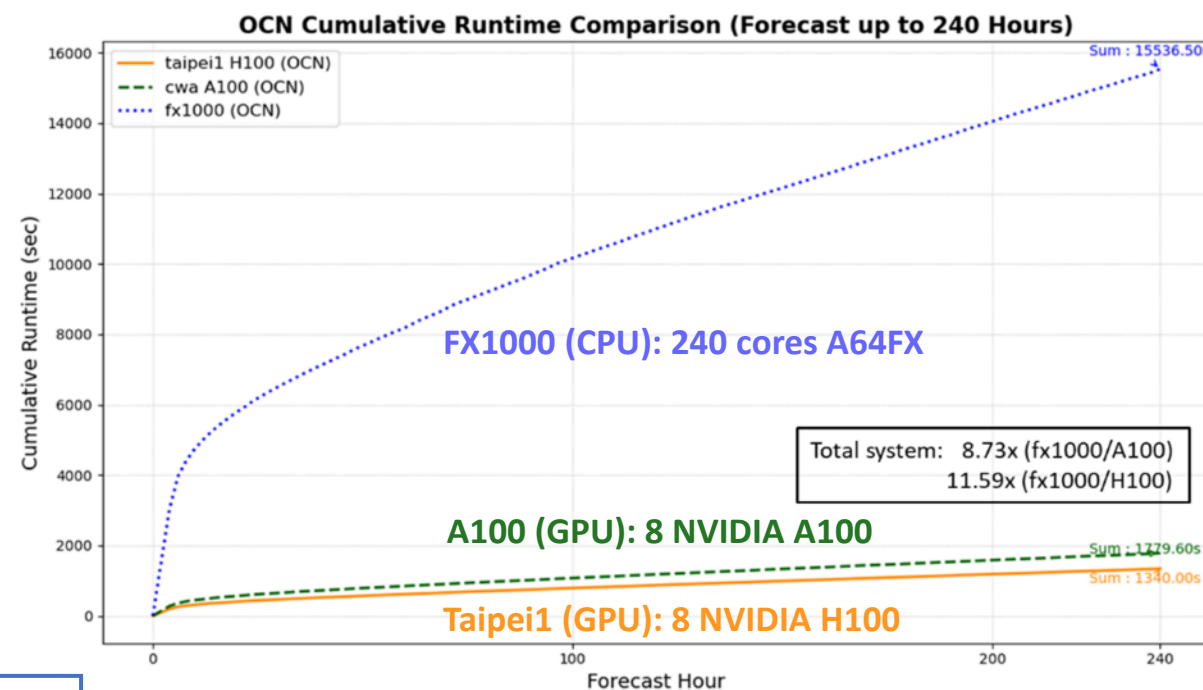
4. $x_{k+1} = x_k + \Delta x_k$

5. $r_{k+1} = b - Ax_{k+1}$

6. convergence_check(r_k)

End Do 所需MPI計算量少
適合用在GPU

新增P-CSI數值求解器，相較於BiCGStab不需要頻繁收集全域資訊，故於大量平行化時有助於計算效率的提升，尤其適合用於GPU架構上。



在署內A100機器上比FX1000快8.73倍
在NVIDIA的H100機器上比FX1000快11.59倍



預報系統發展現況

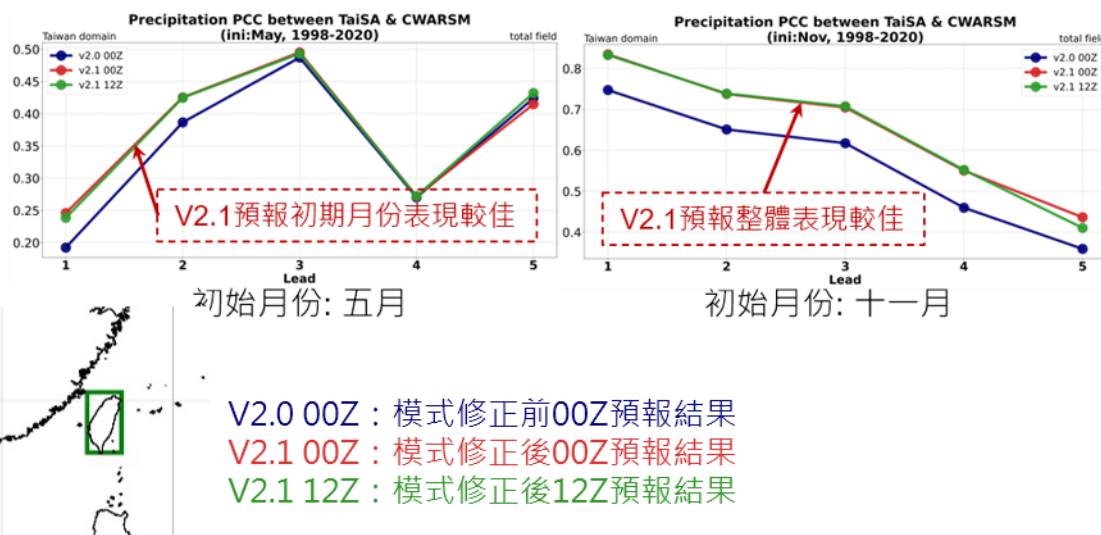
CWACFS V2.1 上線作業建置(2027Q1)

CWACFS V2.1 vs V2.0

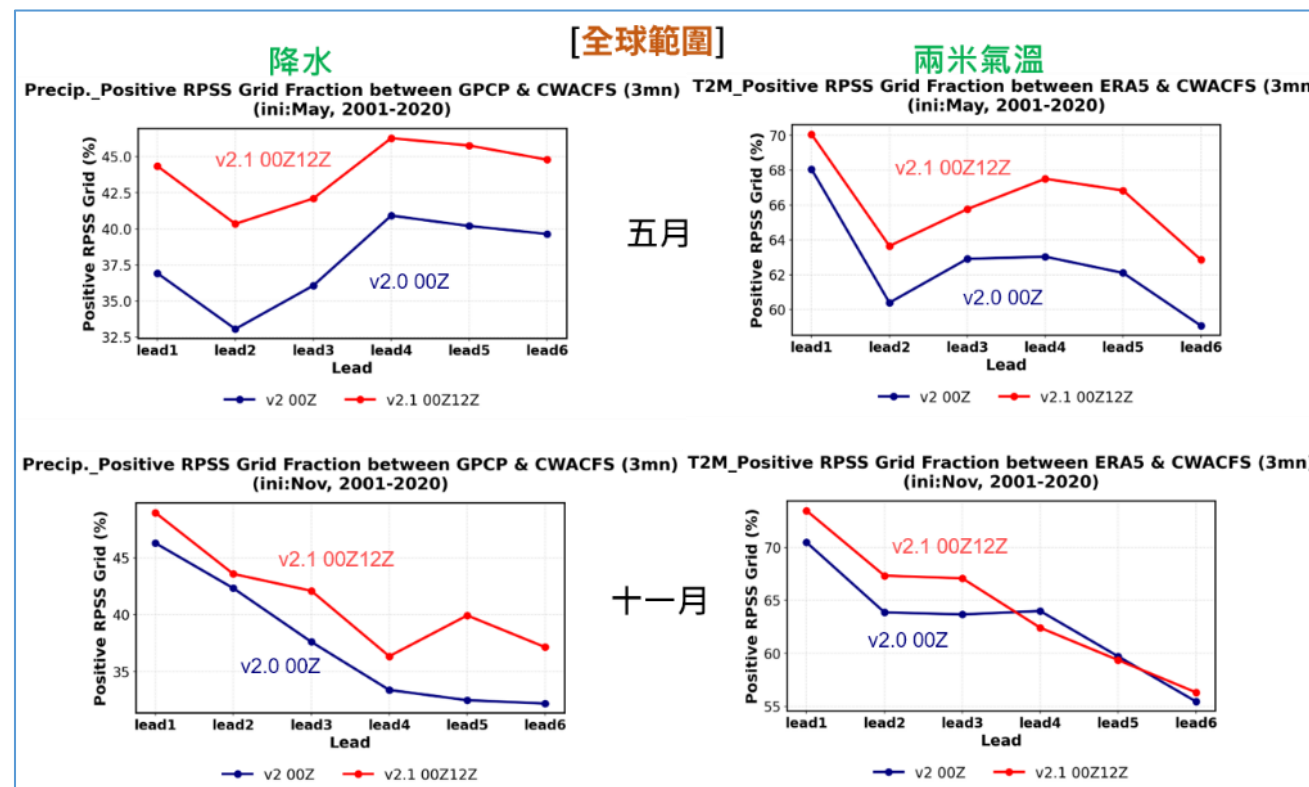
- 修正V2.0 RSM 之山脈阻塞效應參數化氣壓變數單位錯誤
- 每日增加12Z的預報，每月時間延遲成員將從30組增加至60組，提升第一季的預報能力

修正RSM山脈阻塞效應參數化

23年氣候平均場的PCC [Taiwan domain]



增加12Z預報，每月時間延遲成員增加至60組



CWACFS V3 (GPU version on 2031)

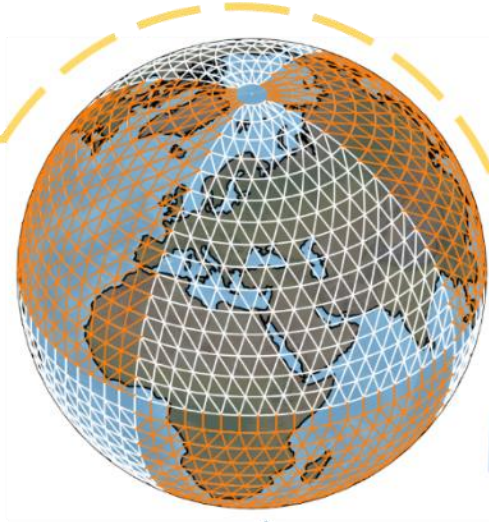


**Global
CWAGFS-T_{c0}199L72**
Resolution : 55 km
Vertical : 72 layers
Model top : 0.1 hPa

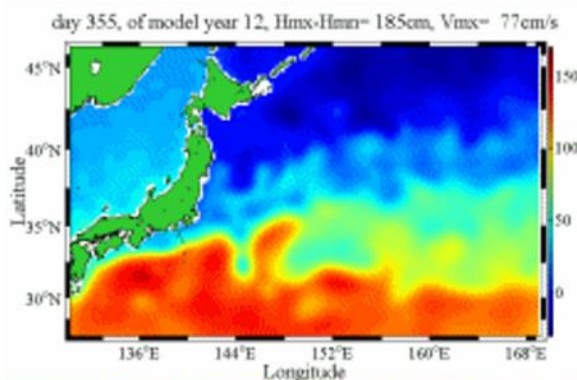
**GCE-3ICE
Noah-MP
GOCART Aerosol model(dust)**

Taiwan Multi-scale Community
Ocean Model (TIMCOM) was
developed by Institute of
Oceanography, NTU

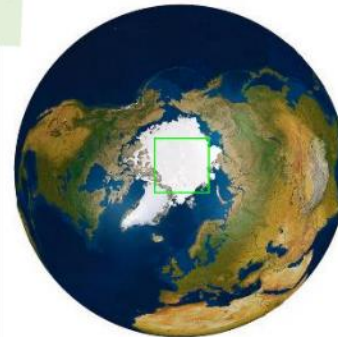
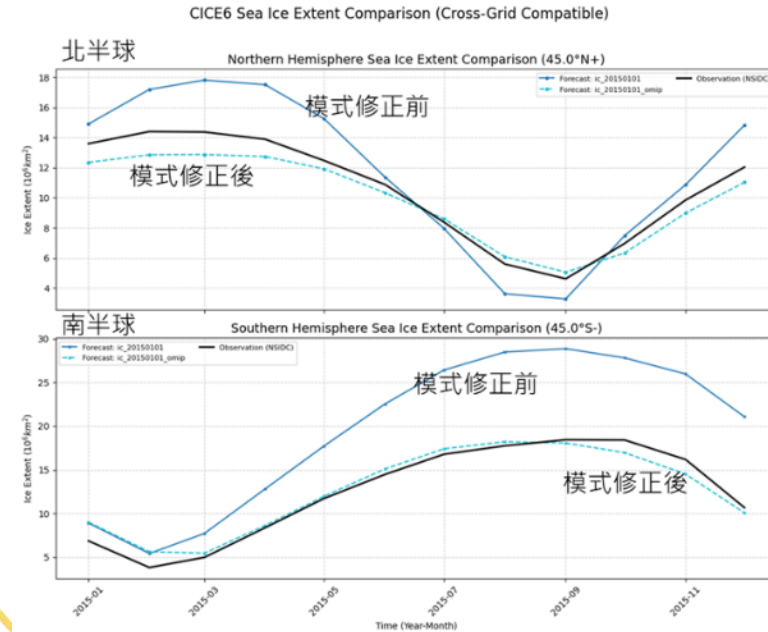
**Global
TIMCOM**
Resolution : $\sim 0.25^\circ$
Vertical : 55 layers



Every 2 hours



模式長期積分南北半球海冰延伸面積與觀測資料的比較

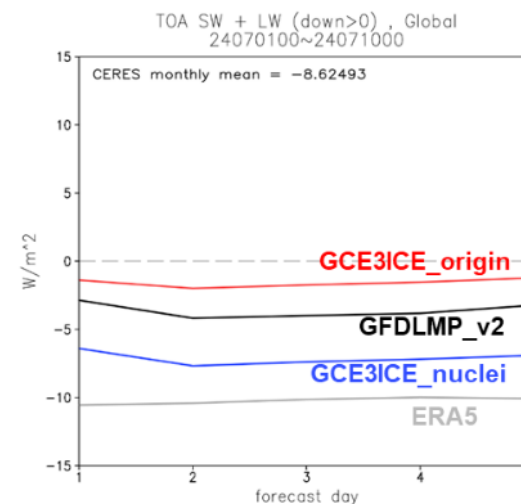


**Sea Ice Model
CICE6**
Resolution : $\sim 0.25^\circ$
Vertical : 5 layers

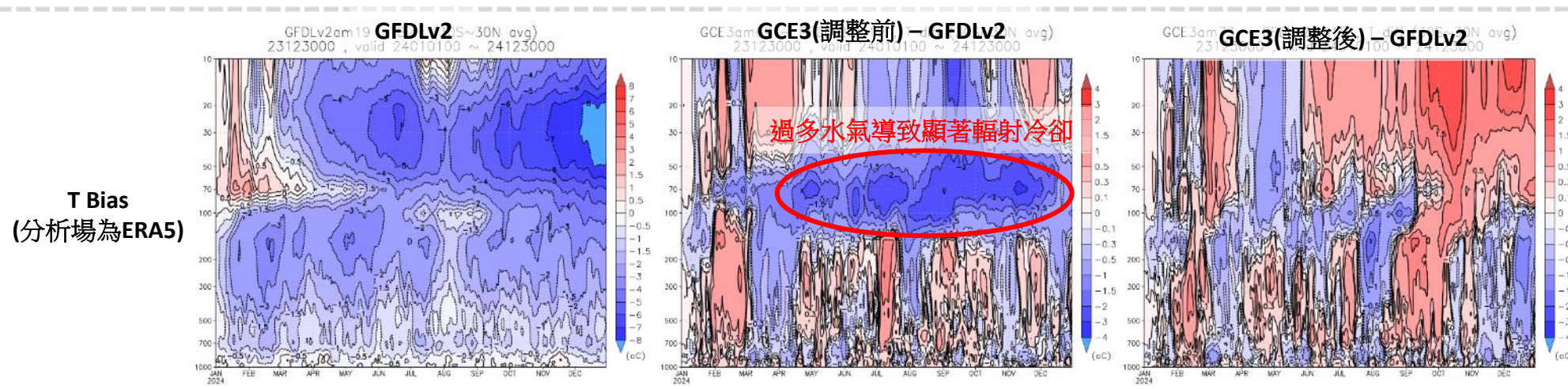


Cloud Microphysics : GCE-3ICE

1. 考慮完整的冰相粒子(雲冰、雪及軟雹)。
2. 對於對流降水、冰雲及層狀雲發展系統能有更好的掌握能力。
3. 調整雲凝結核參數，增加低層雲水數量，改善大氣層頂能量收支平衡。
4. 考慮平流層脫水機制，改善高對流層至低平流層冷偏差。



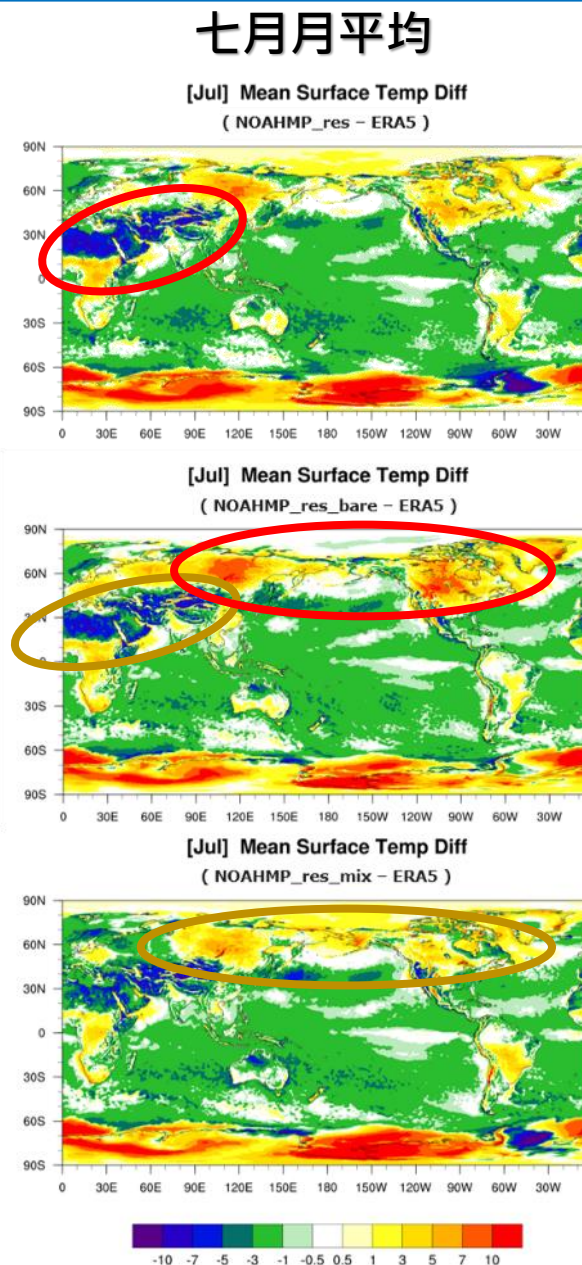
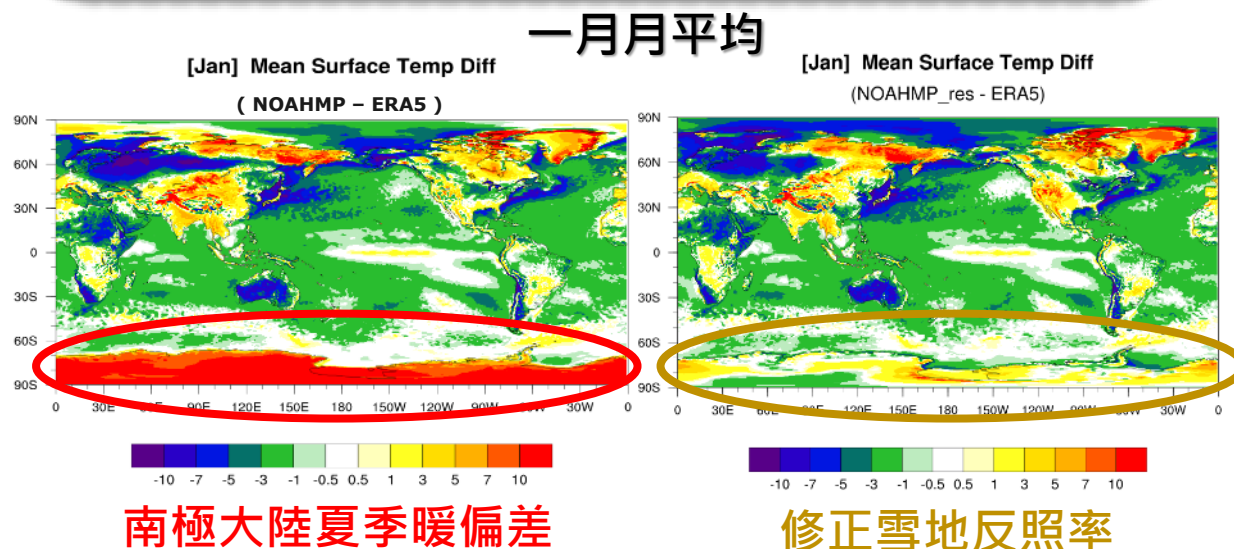
=>improvements in the top-of-atmosphere (TOA) energy balance





Noah-MP陸表模式引進與調整評估

1. Noah-MP是一款先進的陸表模式，其最大特色在於「多重物理參數化」框架。它允許使用者自由切換不同的物理過程方案，藉此精確模擬地氣間的水分、能量與碳循環交換，以適應全球複雜的地理與氣候環境。
2. Noah-MP目前最顯著的問題為：
 - 南極大陸夏季嚴重偏暖
 - 裸地及稀疏灌木叢夏季冷偏差
 - 森林區與乾燥土壤局地日夜能量分配失衡





Performance Evaluation of FCN3

Time Scale: **Extended-Range Forecasts (3-4 weeks)**

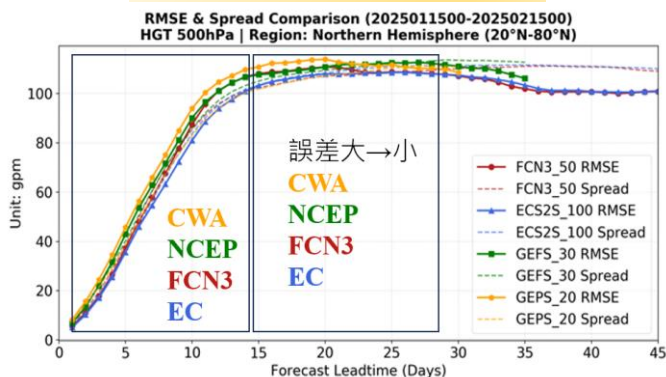
Target MLWP Model: **NVIDIA FourCastNet 3 (FCN3)**

- **Baselines:** Benchmarked against world-leading S2S systems:
 - **ECMWF S2S** (European Center)
 - NCEP GEFS (NOAA/USA)
 - CWA GEPS (Taiwan Central Weather Administration)

 **Ensemble Skill (3-4 weeks):**
Analyzing spread-skill consistency.

IC: 2025/01/01-31 00Z

H500, Northern Hemisphere

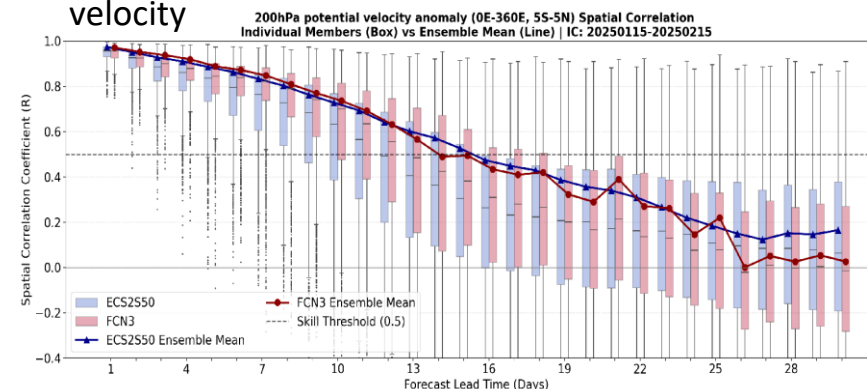


FCN3表現與EC2S2相當，甚至優於NCEPGEFS及CWAGEPS。



Tropical Wind Field

Evaluation of Model performance on 200hPa potential velocity

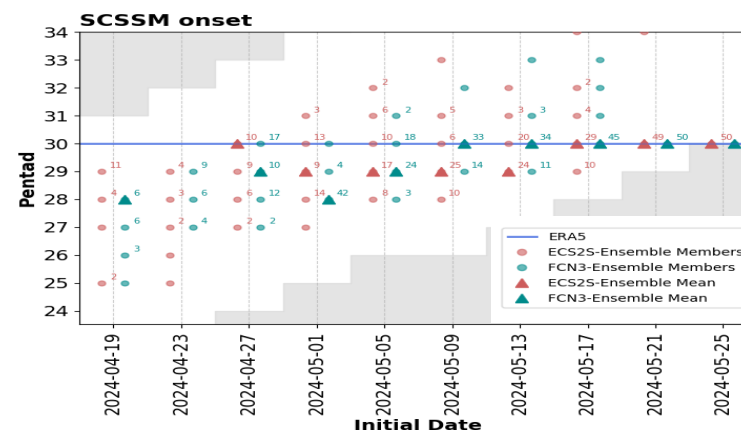


FCN3於熱帶地區動力場表現仍有改善空間。



Meiyu & Monsoon Onset:

Evaluation of Model Skill in Predicting Onset Timing

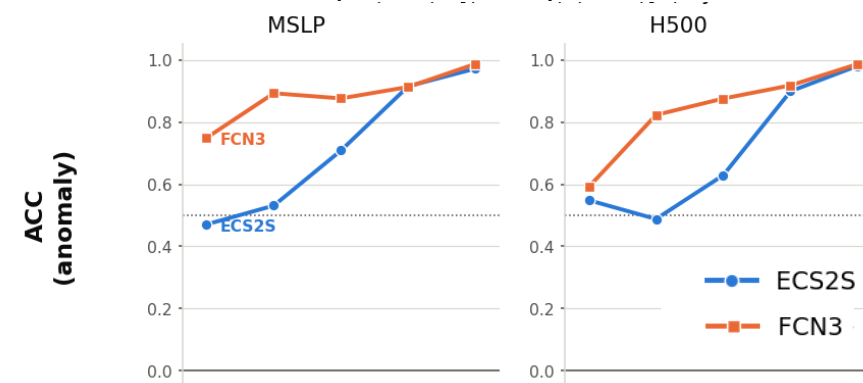


FCN3模式於3週前可掌握季風肇始過程，於展期預報具有預報潛力。



Extreme Precipitation:

Assessing heavy rainfall event detection and spatial accuracy.



FCN3於Week5+~Week3整體表優於ECS2S。

未來規劃



2026

2027

2028

2029

2030

2031

MLWP 模型

展期天氣系集MLWP作業性評估

- ◆ 3~4週預報表現評估及作業評估與建置
- ◆ 標準評估流程建置

持續引進新式模型，並以標準評估流程進行作業性評估

展期天氣系集預報系統(預報45天，每日1報)

CWAGEPS V3 (CWAGFS-TCO based)

- ◆ 作業維運

CWAGEPS V3.1

- ◆ 全面GPU化建置

上線流程建置

- ◆ 建置系集reforecast

作業維運及持續優化

傳統物 理模型

短期氣候預報系統(預報最長至12個月，每日1報)

CWACFS V2 (CWAGFS-SL based)

- ◆ 作業維運

CWACFS V2.1

- ◆ 建置reforecast
- ◆ 預報評估、成員調整

上線流程建置

- ◆ 平行作業階段

作業維運

CWACFS V3 (CWAGFS-TCO based) 研發

- ◆ 全面GPU化建置
- ◆ 年際預報系統調整、改進&測試
- ◆ 物理參數化、擾動法調整...

上線流程建置

- ◆ 建置系集reforecast



動力ML 混合模型

動力-MLWP混合模型能力建構

- ◆ 研讀相關資訊、並參與署內外、國際相關活動

短期氣候NeuroGCM作業性評估

- ◆ 月季尺度表現評估及作業資源評估規畫
- ◆ 標準評估流程建置



- FCN3針對3~4週預報之評估結果顯示，其整體預報表現與ECS2S不相上下，惟在熱帶高層動力場預報能力方面仍有進一步改善空間。目前規劃自2026Q4起進行平行作業，作為3~4週預報之參考指引。
- 第三代展期天氣系集預報系統小改版(CWAGEPS V3.1)，預計於2027Q1平行作業
 - GPU化海氣耦合模型(TCO+TIMCOM)
 - 系集預報成員數量增加至32組
 - 產製reforecast系集成員
- 第二代短期氣候預報系統小改版(CWACFS V2.1)，預計於2027Q1平行作業
 - 修正RSM降水過多的預報誤差
 - 每月成員數量增加至60組
- 第三代短期氣候預報系統(CWACFS V3)的發展
 - 採用TCO+TIMCOM作為發展基礎，並加入海冰(CICE6)耦合過程
 - 更完整的雲微物理及陸表過程
 - 預報成員組成：系集+時間延遲(reforecast比照採用)
 - 全模型GPU化
- 透過與國內外學研界合作，持續精進預報系統，同時融合AI運用，滿足下游使用者快速取得預報資訊的需求。



~The End~
感謝聆聽





全球展期天氣系集預報系統

CWAGEPS V3 (operational in 2025Q4)

Atmosphere

- Model: **CWAGFS-TCO(global)**
- Resolution: ~28 km, 72 layers ($T_{co}383L72$)
- Dy-core: Semi-Lagrangian+Semi-implicit 2 time level
- Grid system: Octahedral reduced Gaussian grid
- Stochastic physics: SPPT with 5 scales+SKEB
- Initial condition: LETKF members

Ocean

- Model: **TIMCOM(global/regional)**
- Resolution: ~25/5 km, 55 layers

Configuration

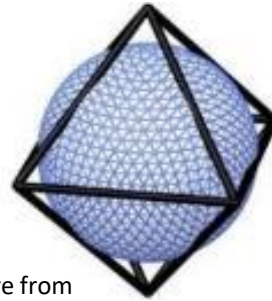
Frequency: once per day (00 UTC)

Number of Member: 20 members + 1 deterministic

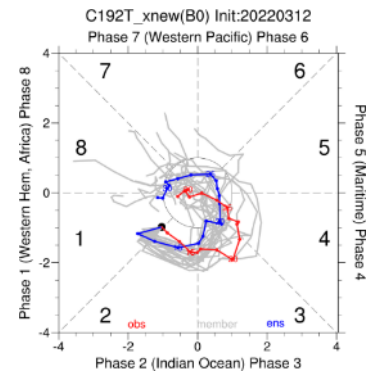
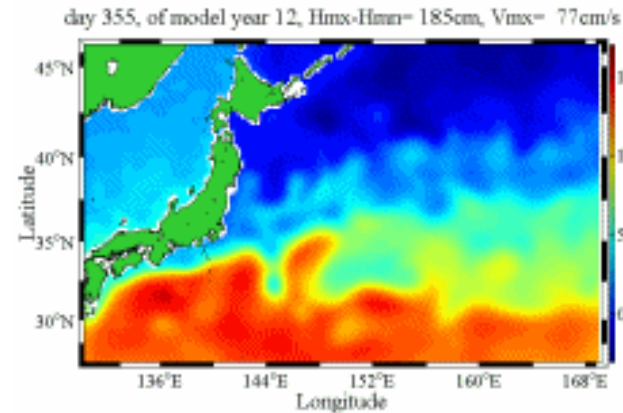
Forecast length: 45 days

Re-forecast: yes (2006-2020 total 15 years)
(Initial condition from NCEP CFSR)

- Model: **RSM(regional)**
- Resolution: ~5 km, 72 layers
- Dy-core: Semi-Lagrangian+Semi-implicit 3 time level



(figure from
<https://confluence.ecmwf.int/display/FCST/Introducing+the+octahedral+reduced+Gaussian+grid>)



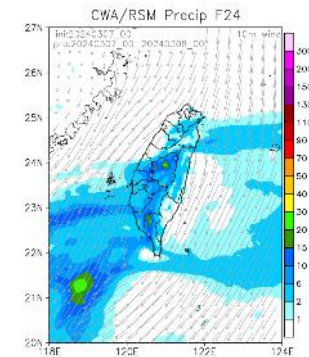
Users

Internal:

海象氣候組(氣候預報科、氣候研析科、資料管理科)、
預報中心颱風及劇烈天氣預報科、氣象綠能營運中心

External:

農業部(農業試驗所、農水署、茶與飲料作物改良場、水產試驗所)、經濟部水利署、臺灣電力公司、
中華民國海軍

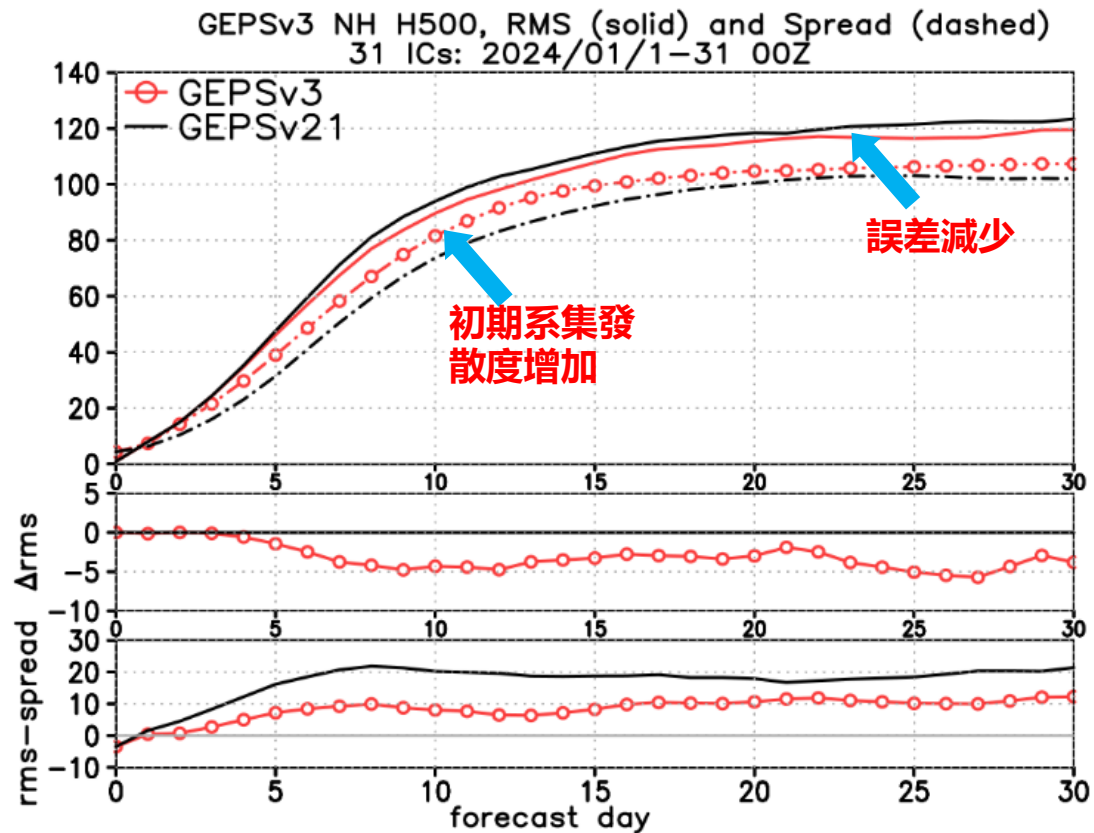


CWAGEPS V3 作業性表現評估-系集RMSE & Spread

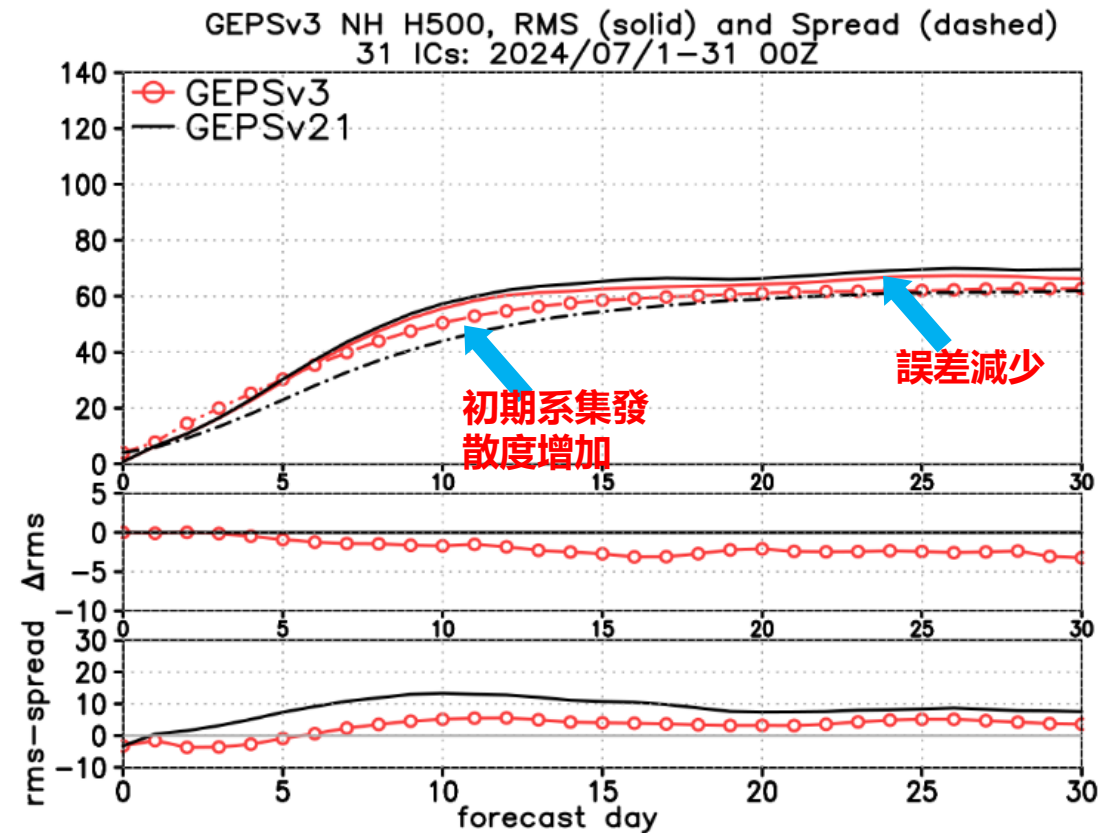


500hPa GeoHGT Northern Hemisphere (20S-80S, 0E-360E)

冬季



夏季

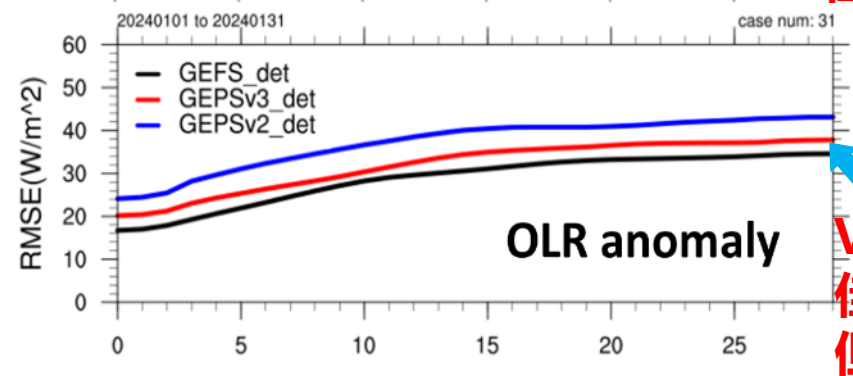
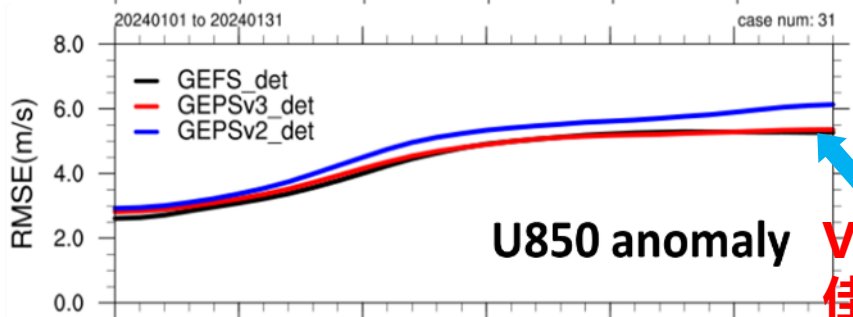
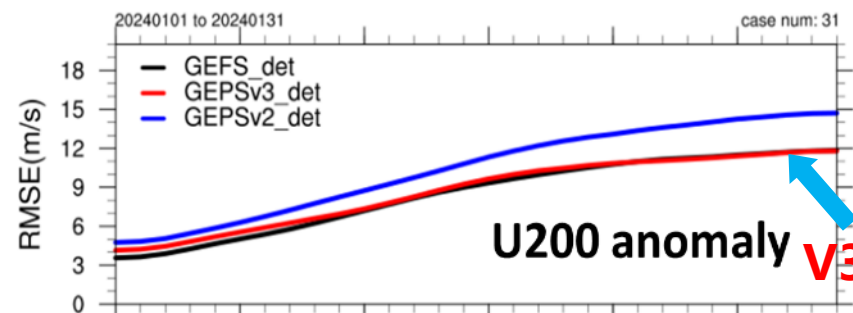


CWAGEPS V3 作業性表現評估-熱帶大尺度層場比較



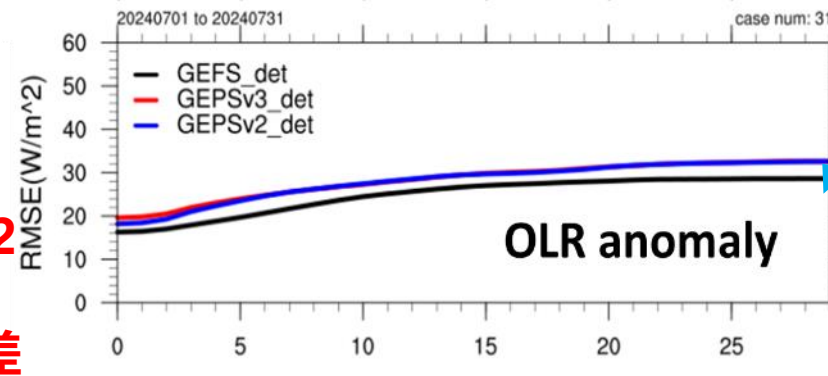
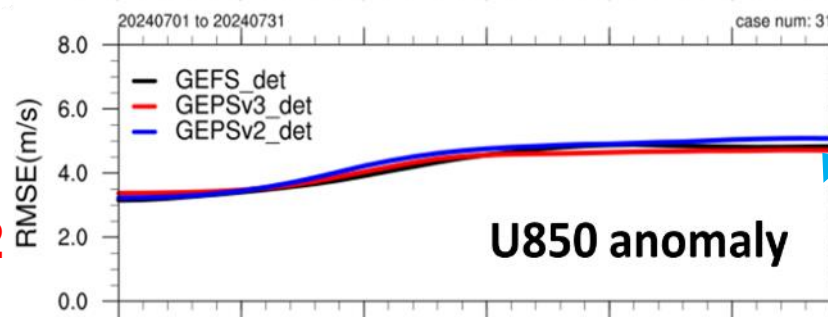
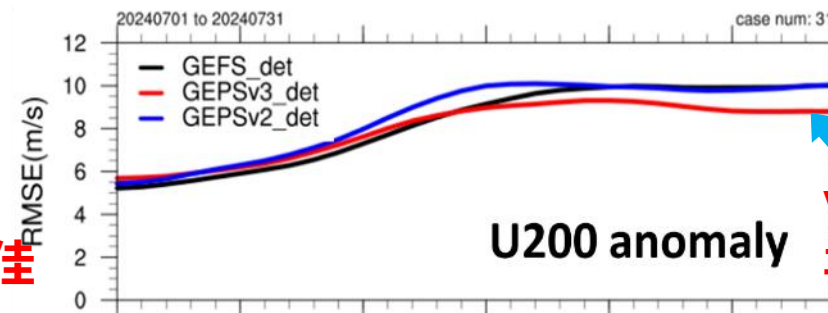
冬季

2024/01/01 to 2024/01/31 (15°S-15°N)



夏季

2024/07/01 to 2024/07/31 (15°S-15°N)



全球短期氣候預報系統

CWACFS V2 (operational in 2023Q2)

Atmosphere

- Model: **CWAGFS(global)**
- Resolution: ~60 km, 60 layers (TL359L60)
- Dy-core: Semi-Lagrangian+Semi-implicit
- Grid system: reduced Gaussian grid
- Initial condition: NCEP CDAS

Ocean

- Model: **NOAA GFDL MOM5**
- Resolution: ~60 km, 40 layers
- Initial condition: NCEP CDAS

Configuration

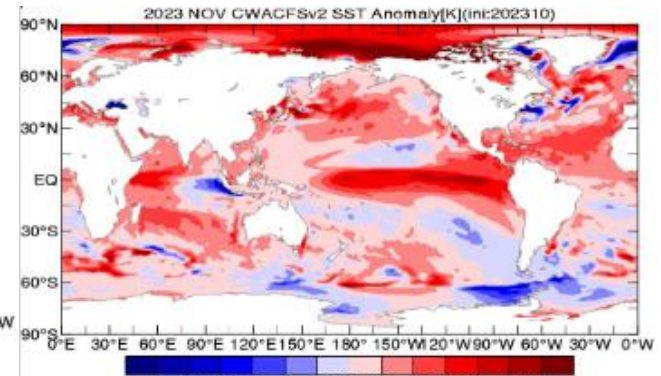
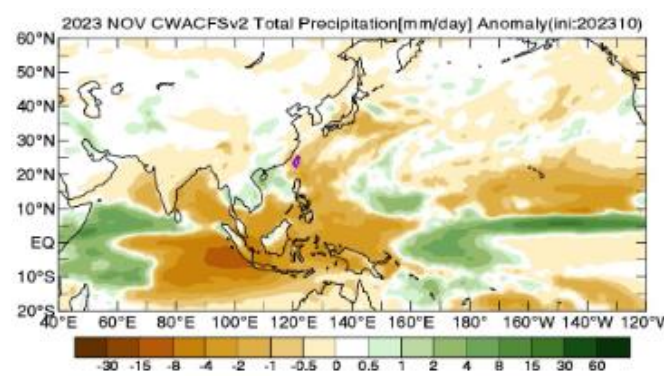
Frequency: once per day (00 UTC)

Number of Member: 30 members/month

Forecast length: 9 months (12 months in
Feb, May, Aug, Nov and Dec)

Re-forecast: 1991-2020 (00UTC)
(Initial condition from NCEP CFSR)

- Model: **RSM(regional)**
- Resolution: ~12 km, 40 layers
- Dy-core: Semi-Lagrangian+Semi-implicit 3 time level



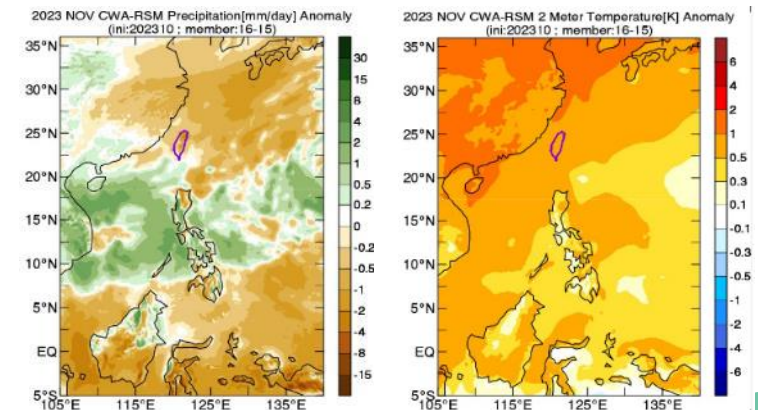
Users

Internal:

海象氣候組(氣候預報科、氣候研析科、
資料管理科)

External:

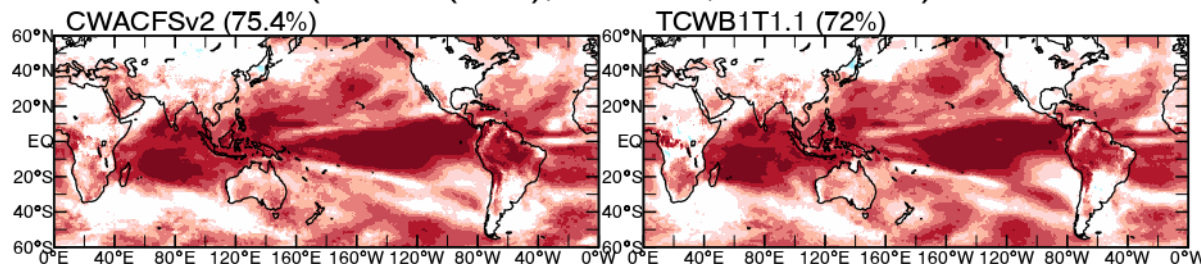
APCC、農業部水產試驗所、經濟部水利署、
疾病管制署、雲林縣政府、桃園市政府、
PAGASA(已表達強烈介接資料意願與需求)



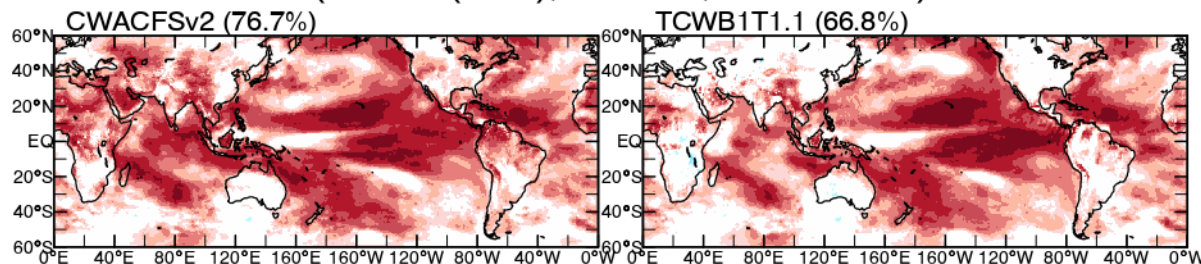


Winter (DJF) Anomaly Correlation

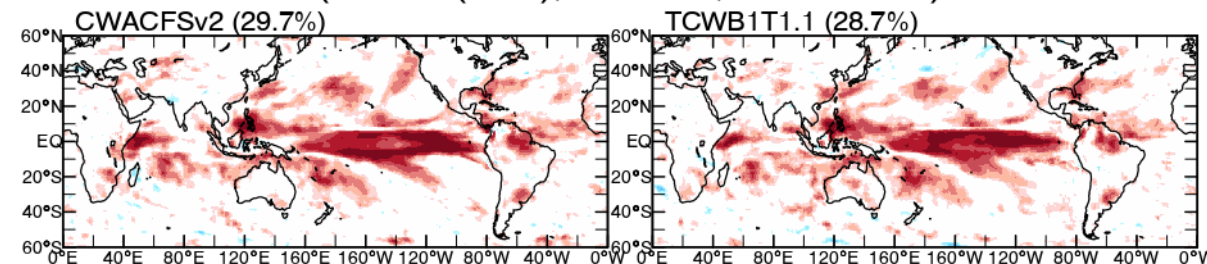
T2M Corr between ERA5& model
(Lead:0(DJF), ini:NOV, 1991-2020)



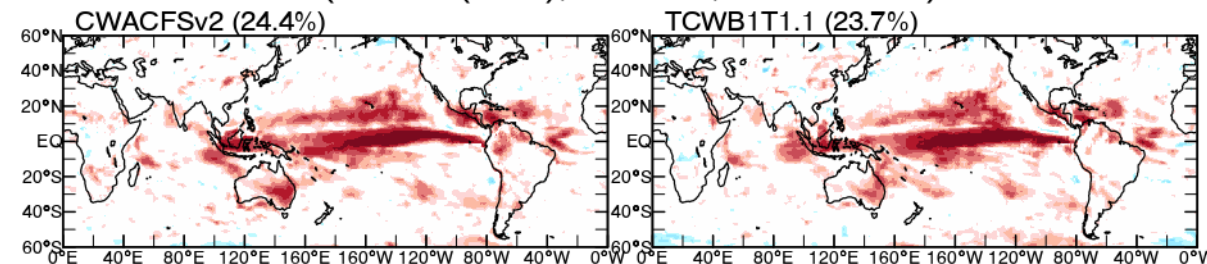
T2M Corr between ERA5& model
(Lead:0(JAS), ini:JUN, 1991-2020)



Precipitation Corr between GPCP& model
(Lead:0(DJF), ini:NOV, 1991-2020)



Precipitation Corr between GPCP& model
(Lead:0(JAS), ini:JUN, 1991-2020)



Anomaly correlation: SEAS5 > CWACFSV2 > TCWB1T1.1 > TCWB2T2

(海象氣候組氣候預報科提供)