NOAH-MP LSM於CWA/GEPS系統之建置與模擬效能評估

吳佳瑩 劉邦彥 陳建河 李明營

海象氣候組 氣候模擬科

Central Weather Administration

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CWA/GEPS 系統(T_{Co}383)概況

- **大氣**
  模式: CWAGFS-TCO(global)
  解析度: 約28公里, 72層 (T_{Co}383L72)
  隨機擾動法: SPPT with 5 scales+SKEB
  初始擾動場: TGFS EnKF members
- **海洋**
  模式: SIT + 預報海溫 (From CWACFS)
- **執行頻率**
  每日兩次 (00, 12 UTC)
- **成員數量**
  32 members + 1 deterministic
- **預報長度**
  45天
- **事後預報**
  每日00Z 決定性預報 2001年至2020年(共20年)
  初始場使用 NCEP CFSR

	T_{Co}383 physics
輻射	RRTMG (Iacono et al., 2008)
邊界層	hybrid EDMF (Han et al., 2016)
陸表	Noah LSM (Chen et al., 1996; Koren et al., 1999; Ek et al., 2003)
地形重力波拖曳	Kim and Arakawa (1995); Lott and Miller(1997) Stationary convectively forced gravy wave drag (Chun and Baik, 1998)
積雲	scale-aware Simplified Arakawa-Schubert (sa-SAS；Han et al., 2017)
微物理	GFDL cloud microphysics v2 (Chen and Lin (2013))

NOAH-MP LSM簡介

- 2011 年，Niu 等人推出 Noah-MP，基於NOAH LSM之上，加入多元物理選項（multi-physics），考慮積雪/雪融過程、積雪深度、凍土與滲透特性、地表逕流及地下水與土壤濕度的關係、樹冠層能量平衡、植物物候學等，大幅改善地表通量、乾季地面溫度、雪水當量、雪深與逕流模擬表現（Niu et al., 2011）。
- 廣泛應用於WRF模式及其他模式中，並在積雪模擬、洪水與乾旱預測、作物生長模擬等多項領域展現出良好表現。
- 美國NCEP統合預報系統（Unified Forecast System, UFS）推出之最新作業版本（GFSv17、GEFSv13）亦正式採用NOAH-MP LSM作為其預設陸表模式。

Noah-Multiparameterization Land Surface Model (Noah-MP® LSM)
https://ral.ucar.edu/model/noah-multiparameterization-land-surface-model-noah-mp-lsm

NOAH-MP LSM簡介

物理過程選項

iopt_dveg	dynamic vegetation
iopt_crs	canopy stomatal resistance
iopt_sfc	surface layer exchange coeff.
iopt_diag	thermal roughness
iopt_trs	thermal roughness

iopt_rad	radiation transfer
iopt_alb	snow surface albedo
iopt_snf	rainfall & snowfall
iopt_run	runoff and groundwater

iopt_btr	soil moisture factor for stomatal resistance
iopt_inf	frozen soil permeability
iopt_frz	supercooled liquid water
iopt_tbot	lower boundary of soil temperature
iopt_stc	1^{st} layer snow/soil temperature time scheme

Noah-Multiparameterization Land Surface Model (Noah-MP® LSM)
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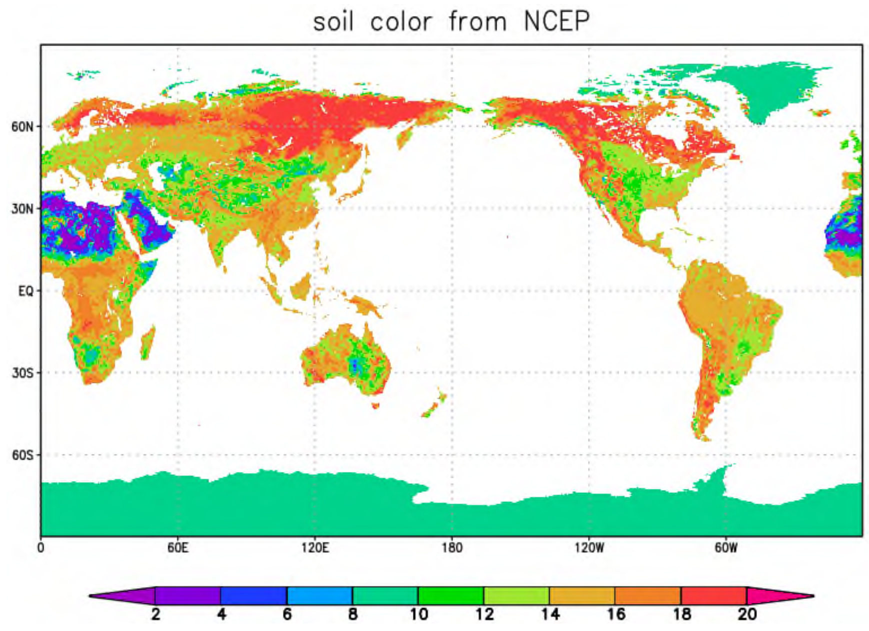
NOAH-MP LSM建置於T_{Co}383流程

- 下載NOAH-MP code(UFS-community, GFSv17, https://github.com/ufs-community/ccpp-physics/tree/ufs/dev/physics/SFC_Models/Land)
- 新增soil color fix data
- 於T_{Co}383模式中新增NOAH-MP所需變數矩陣、設定初猜值。將NOAH-MP code置入T_{Co}383模式(與原始NOAH LSM位置相同)。

```
if(nmlsm.eq.1)then
call sfc_drv(nxj,nx,km,psi,ut(1,lev),vt(1,lev),tt(1,lev),qt(1,lev),  &
             istyp,ivegtyp,sigmaf,sfemis,rld,sld,ss,dth,tgclim,        &
             cd,cdq,prsl1,prslki,hgt,islmsk,ddvel,islopetyp,           &
```

⋮

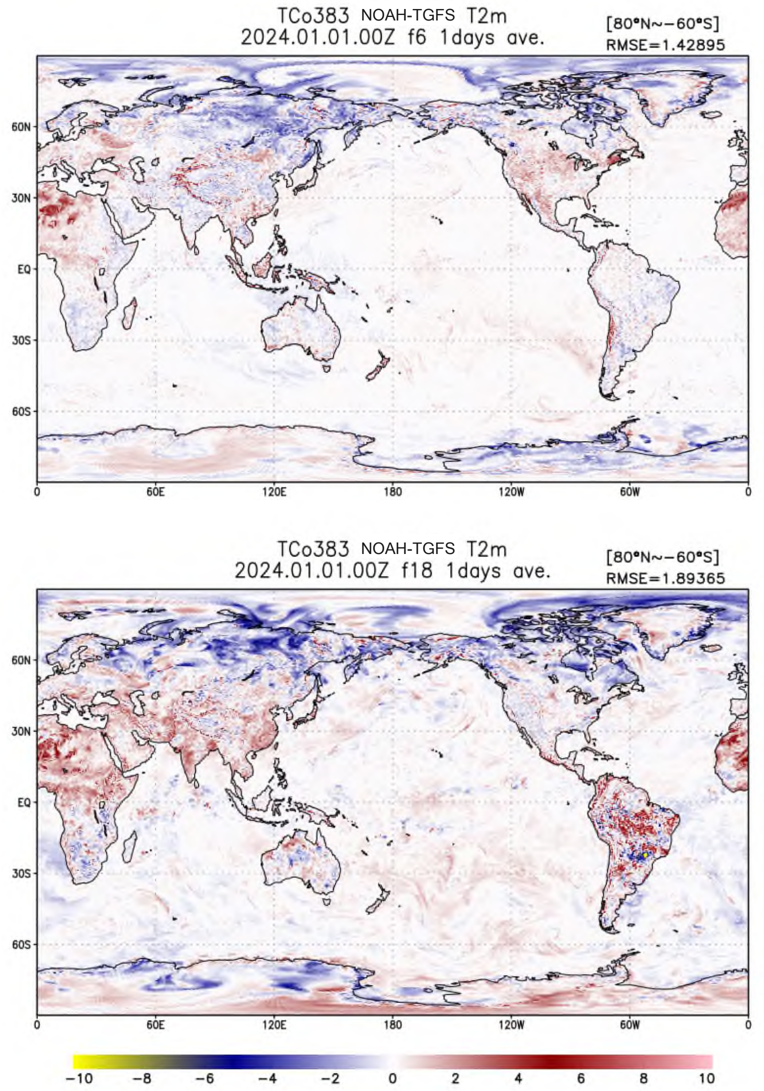
```
elseif(nmlsm.eq.2)then
call noahmpdrv_run                                    &
!...................................
!  ---  inputs:
  (nxj,nx, km,lsnowl,itstp,psi,ut(1,lev),vt(1,lev),tt(1,lev),   &
   qt(1,lev), istyp, iscol,                                      &
  ivegtyp, sigmaf, rld    , sld    , ss   ,dth,tgclim, cd, cdq,  &
```



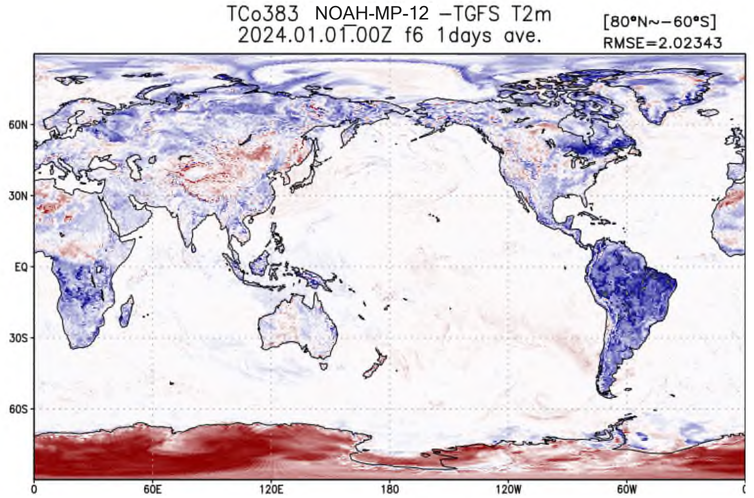
個案測試結果與調整

- 初始時間：2024.01.01.00Z
- 模擬時長：72hr

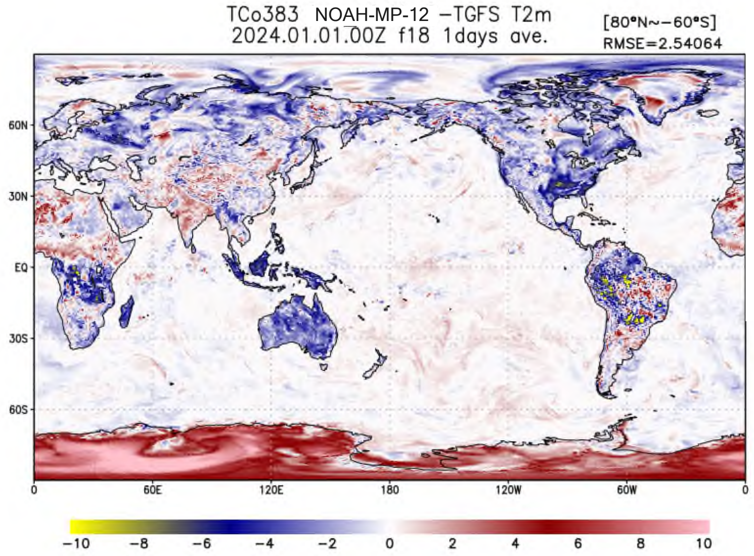
陸表模式	實驗名稱		
NOAH LSM	NOAH		
NOAH-MP LSM	thermal roughness / sfc. Layer exchange coeff.	1. $z_{0h} = z_{0m}$	2. Chen2009
	1. M-O similarity theory	NOAH-MP-11	NOAH-MP-12
	2. Chen et al. 1997	NOAH-MP-21	NOAH-MP-22



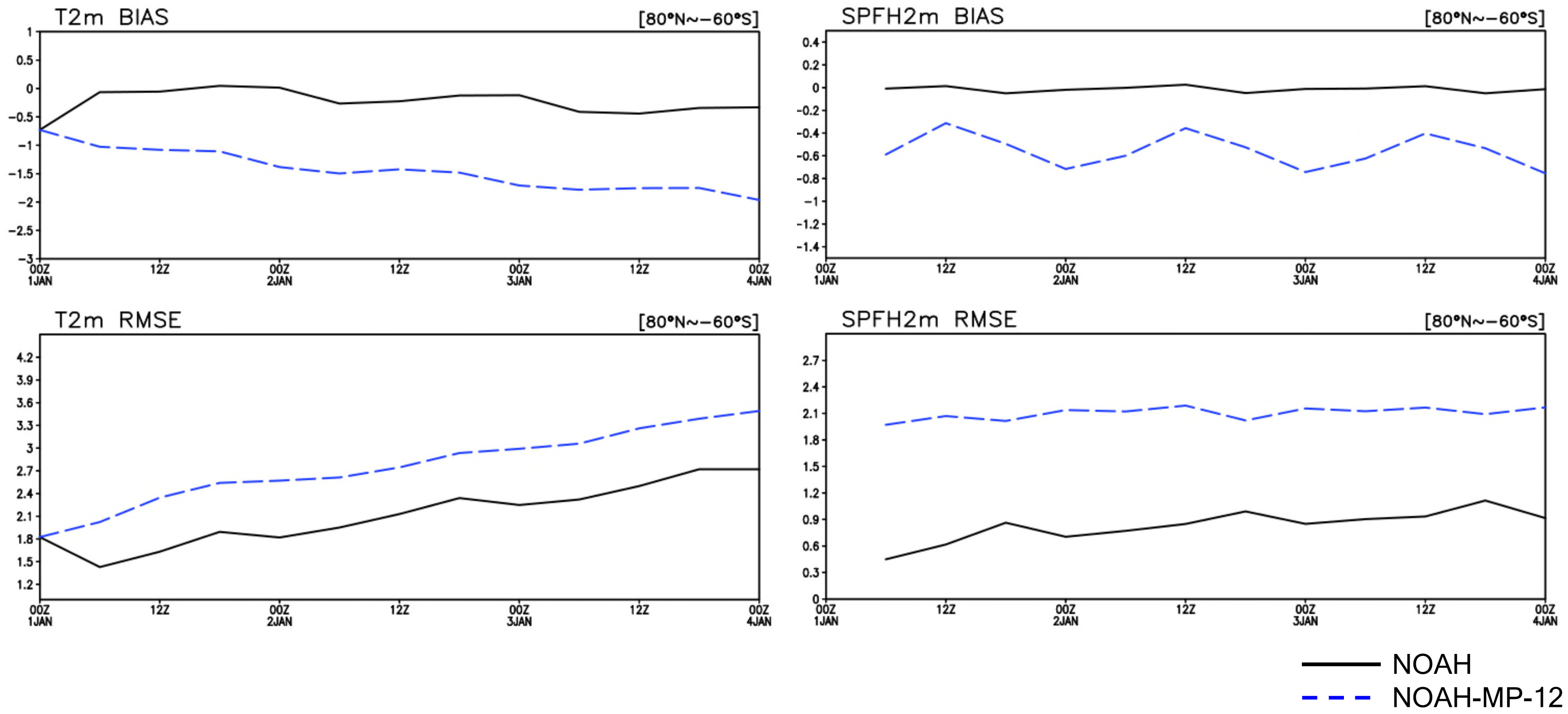
個案測試結果與調整



TCo383 NOAH-MP-12 –TGFS T2m
2024.01.01.00Z f6 1days ave.
[80°N~-60°S]
RMSE=2.02343

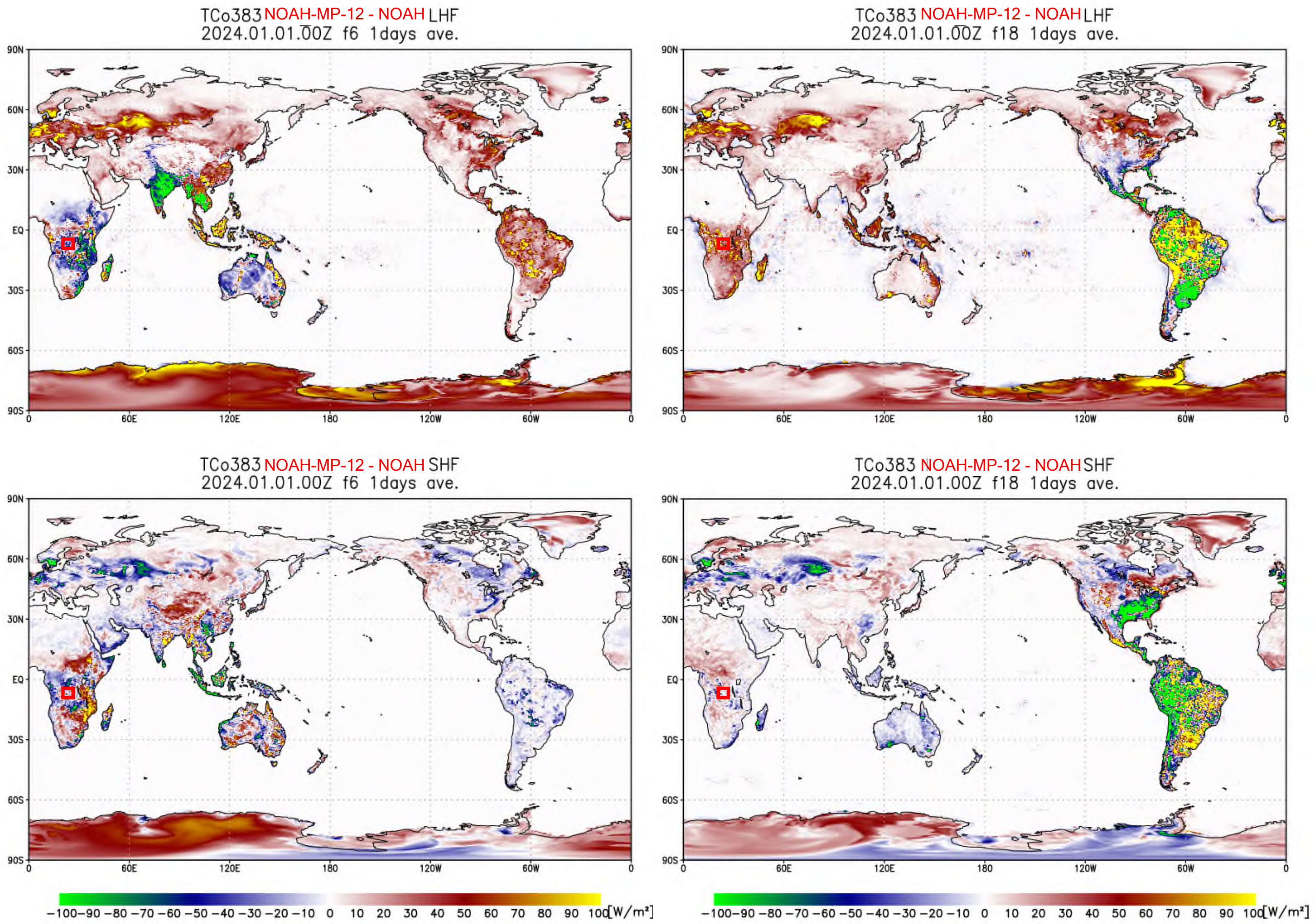


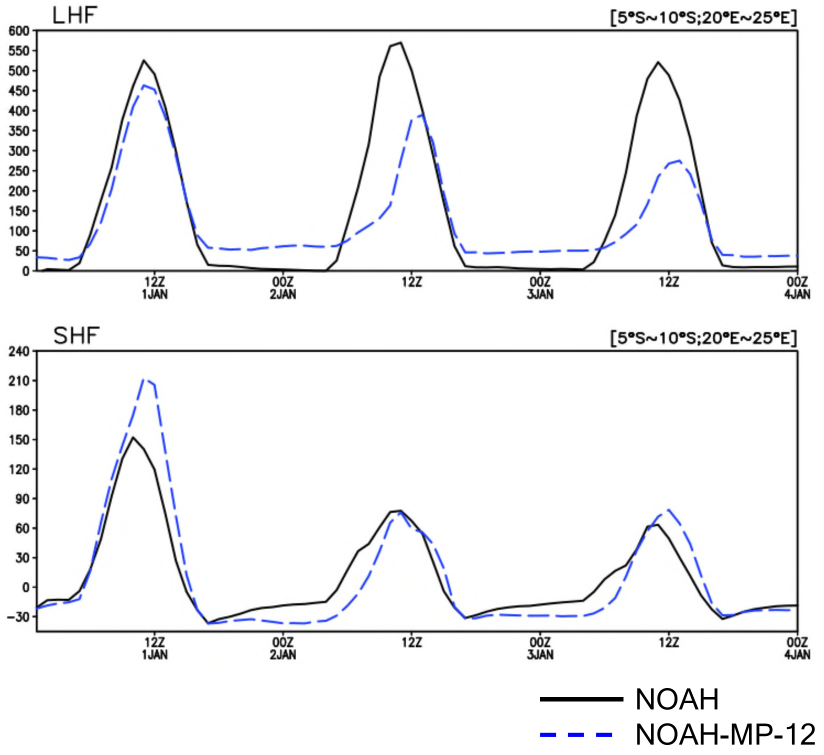
TCo383 NOAH-MP-12 –TGFS T2m
2024.01.01.00Z f18 1days ave.
[80°N~-60°S]
RMSE=2.54064



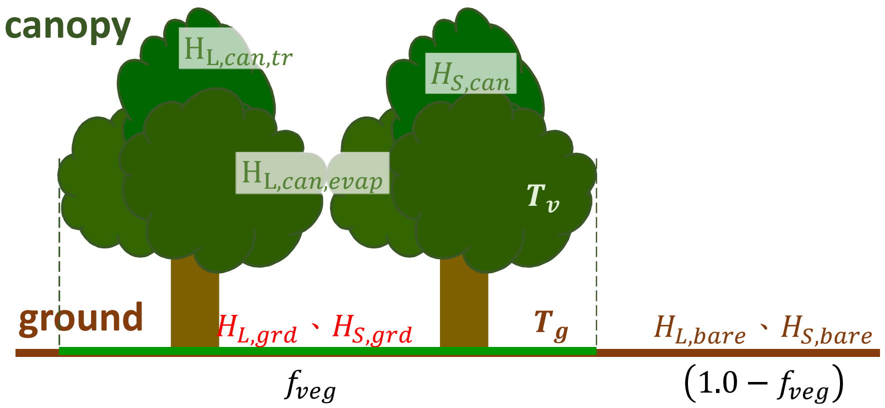
T2m BIAS
[80°N~-60°S]
SPFH2m BIAS
[80°N~-60°S]
T2m RMSE
[80°N~-60°S]
SPFH2m RMSE
[80°N~-60°S]
NOAH
NOAH-MP-12

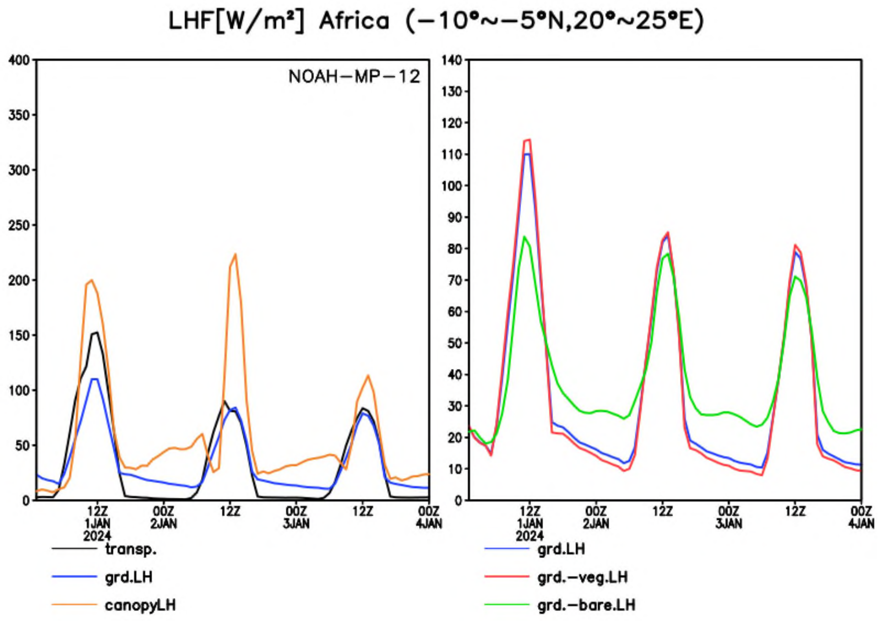
個案測試結果與調整


TCo383 NOAH-MP-12 - NOAH LHF
2024.01.01.00Z f6 1days ave.
TCo383 NOAH-MP-12 - NOAH LHF
2024.01.01.00Z f18 1days ave.
TCo383 NOAH-MP-12 - NOAH SHF
2024.01.01.00Z f6 1days ave.
TCo383 NOAH-MP-12 - NOAH SHF
2024.01.01.00Z f18 1days ave.
−100 −90 −80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50 60 70 80 90 100 [W/m²]


LHF
[5°S~10°S;20°E~25°E]
SHF
[5°S~10°S;20°E~25°E]
12Z 1JAN
00Z 2JAN
12Z
00Z 3JAN
12Z
00Z 4JAN
NOAH
NOAH-MP-12

個案測試結果與調整





Canopy evaporation & transpiration latent heat flux ($H_{L,can,evap/tr}$ [W/m²]):

$$H_{L,can,evap/tr} = f_{veg} \times \frac{\rho_{air}\times C_{p,air}}{\gamma_{can}} \times C_{LH,cond,leaf/tr} \times \left(e_{s,Tv} - e_{can,air}\right)$$

To further constrain leaf evaporation:

$$H_{L,can,evap} = \begin{cases} min\left(H_{L,can,evap}, W_{liq,can} \times \frac{C_{LH,can,vap}}{\Delta t}\right) & T_v > T_{frz} \\ min\left(H_{L,can,evap}, W_{ice,can} \times \frac{C_{LH,can,vap}}{\Delta t}\right) & T_v \le T_{frz} \end{cases}$$

Update $H_{L,can,evap/tr}$ by the change of canopy temperature (ΔT_v, [K])

$$H_{L,can,evap/tr} = H_{L,can,evap/tr} + f_{veg} \times C_{LH,can,evap/tr} \times \frac{d(e_{s,Tv})}{d(T_v)} \times \Delta T_v$$

樹冠層蒸發/蒸散潛熱係數

ground latent heat ($H_{L,grd}$ [W/m²]):

$$H_{L,grd} = f_{veg} \times H_{L,grd} + (1.0 - f_{veg}) \times H_{L,bare}$$

Below canopy ground & bare ground latent heat ($H_{L,grd/bare}$ [W/m²]):

$$H_{L,grd/bare} = C_{LH,grd/bare} \times \left(e_{s,Tg} \times RH - e_{can/bare,air}\right)$$

Update $H_{L,can,grd}$ by the change of ground temperature (ΔT_g, [K])

$$H_{L,grd/bare} = H_{L,grd/bare} + C_{LH,grd/bare} \times \frac{d(e_{s,Tg})}{d(T_g)} \times \Delta T_g$$

樹冠層下地表/裸土地表潛熱係數

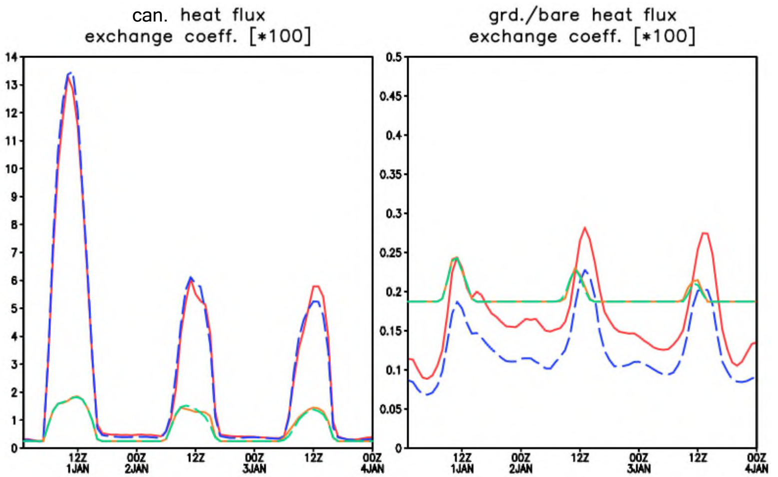
個案測試結果與調整

$$C_{LH,can,evap/tr} = \left(1 - \frac{C_{LH,cond,leaf}+C_{LH,cond,tr}}{C_{LH,cond,leaf}+C_{LH,cond,tr}+C_{LH,cond,air}+C_{LH,cond,grd}}\right) \times \frac{\rho_{air}\times C_{p,air}}{\gamma_{can}} \times C_{LH,cond,leaf/tr}$$

$$C_{LH,grd/bare} = \frac{\rho_{air}\times C_{p,air}}{\gamma_{grd}} \times \frac{1}{R_{w,grd/bare}+R_{grd,evap}}$$

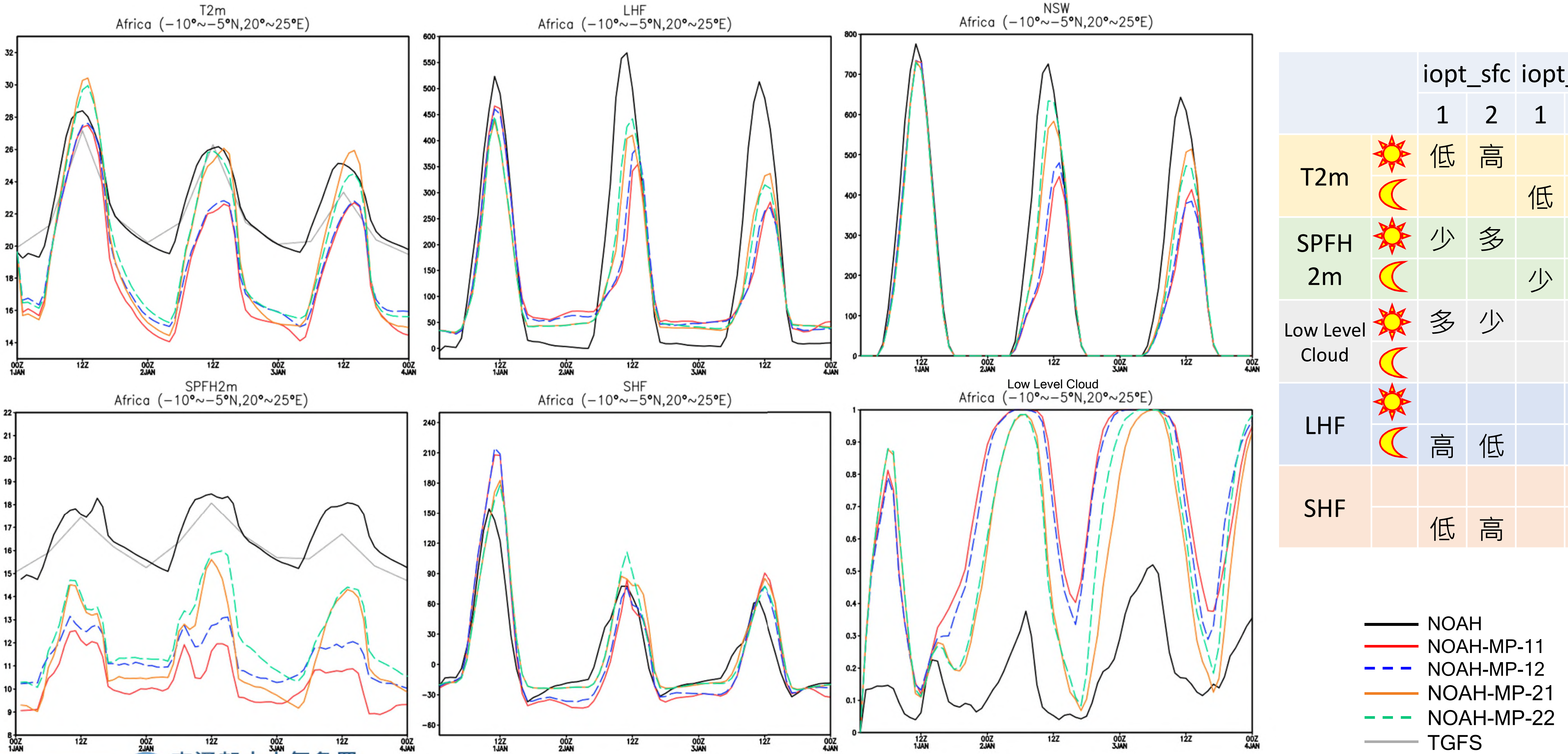
$\frac{1}{R_{w,can}}$ $\frac{1}{R_{w,grd}+R_{grd,evap}}$

潛熱空氣動力阻力= $1/(C_h U_{ref})$



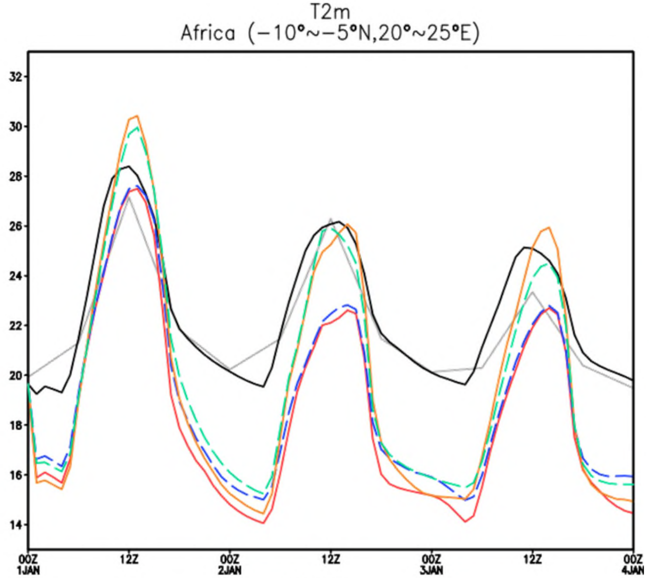
z_{0m} & z_{0h} / c_m & c_h	default iopt_trs=1	Chen09 iopt_trs=2
Monin-Obukhov Similarity Theory (MOST) iopt_sfc=1	$z_{0m} = \exp[f_{veg} \times \ln(z_{0m}) + (1.0 - f_{veg}) \times \ln(z_{0mg})]$ $z_{0h} = z_{0m}$ $c_m = \frac{\kappa^2}{\left[\ln\left(\frac{z-d_0}{z_{0m}}\right)-\Psi_m\left(\frac{z-d_0}{L}\right)\right]^2}$ $c_h = \frac{\kappa^2}{\left[\ln\left(\frac{z-d_0}{z_{0m}}\right)-\Psi_m\left(\frac{z-d_0}{L}\right)\right]\times\left[\ln\left(\frac{z-d_0}{z_{0h}}\right)-\Psi_h\left(\frac{z-d_0}{L}\right)\right]}$ NOAH-MP-11	$z_{0m} = f_{veg} \times z_{0m} + (1.0 - f_{veg}) \times z_{0mg}$ $z_{0h} = \exp\left[f_{veg} \times \ln\left(z_{0m} \times \exp\left(-C \times \kappa \times \sqrt{\frac{u_* \times z_{0m}}{\upsilon}} \times z_{0m}\right)\right) + (1.0 - f_{veg}) \times \ln\left(\max\left(1.e-6, \frac{z_{0m}}{\exp(KB^{-1}(f_{veg}=0))}\right)\right)\right]$ $c_m = \frac{\kappa^2}{\left[\ln\left(\frac{z-d_0}{z_{0m}}\right)-\Psi_m\left(\frac{z-d_0}{L}\right)\right]^2}$ $c_h = \frac{\kappa^2}{\left[\ln\left(\frac{z-d_0}{z_{0m}}\right)-\Psi_m\left(\frac{z-d_0}{L}\right)\right]\times\left[\ln\left(\frac{z-d_0}{z_{0h}}\right)-\Psi_h\left(\frac{z-d_0}{L}\right)\right]}$ NOAH-MP-12
Chen et al. 1997 scheme (original NOAH) iopt_sfc=2	$z_{0m} = \exp[f_{veg} \times \ln(z_{0m}) + (1.0 - f_{veg}) \times \ln(z_{0mg})]$ $z_{0h} = \max[1.e-6, \exp(-C \times \kappa \times \sqrt{u_* \times z_{0m}/\upsilon} \times z_{0m})]$ $c_m = \frac{\kappa}{\left[\Psi_m(\zeta_m)-\Psi_m(\zeta'_m)+\ln\left(\frac{z+z_{0m}}{z_{0m}}\right)\right]}$ $c_h = \frac{\kappa}{\left[\Psi_h(\zeta_h)-\Psi_h(\zeta'_h)+\ln\left(\frac{z+z_{0h}}{z_{0h}}\right)\right]}$ NOAH-MP-21	$z_{0m} = f_{veg} \times z_{0m} + (1.0 - f_{veg}) \times z_{0mg}$ $z_{0h} = \max[1.e-6, \exp(-C \times \kappa \times \sqrt{u_* \times z_{0m}/\upsilon} \times z_{0m})]$ $c_m = \frac{u^* \times \kappa}{\left[\Psi_m(\zeta_m)-\Psi_m(\zeta'_m)+\ln\left(\frac{z+z_{0m}}{z_{0m}}\right)\right]}$ $c_h = \frac{u^* \times \kappa}{\left[\Psi_h(\zeta_h)-\Psi_h(\zeta'_h)+\ln\left(\frac{z+z_{0h}}{z_{0h}}\right)\right]}$ NOAH-MP-22

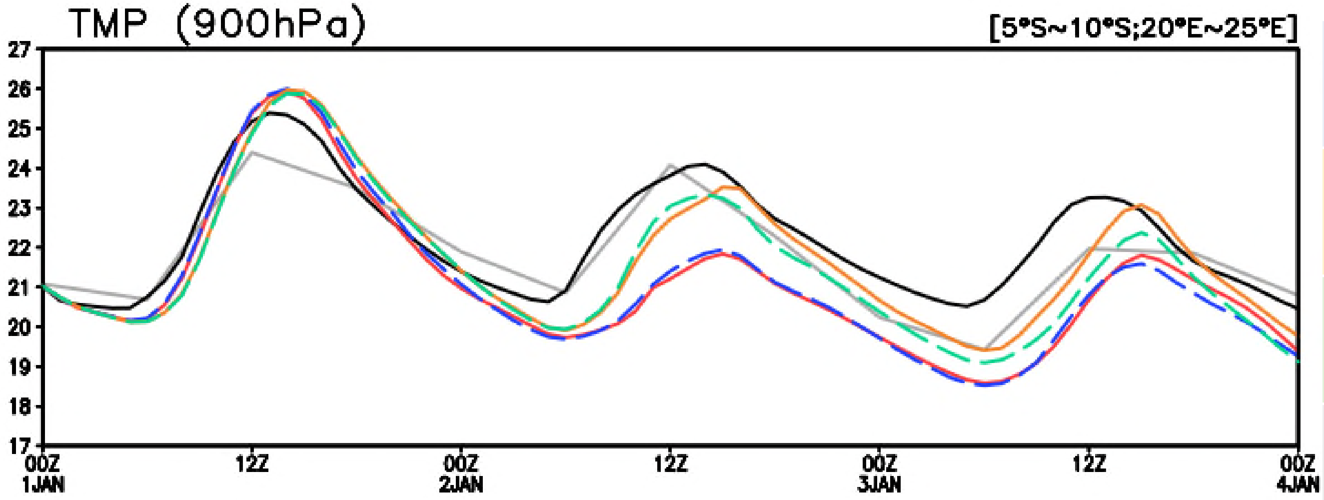
個案測試結果與調整

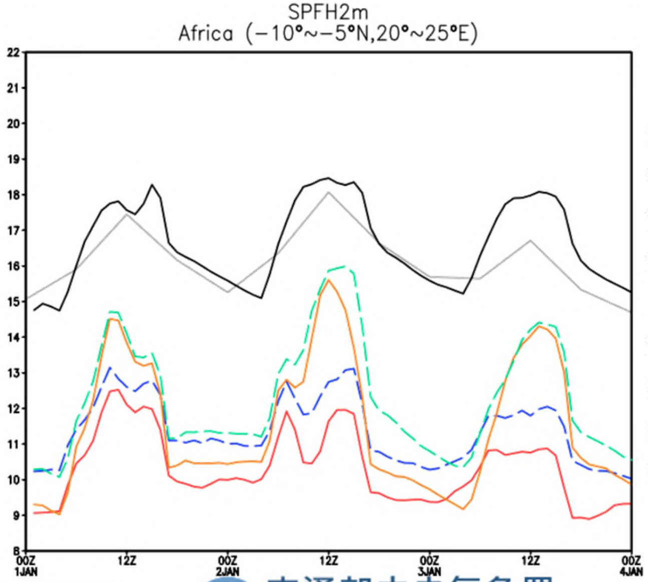


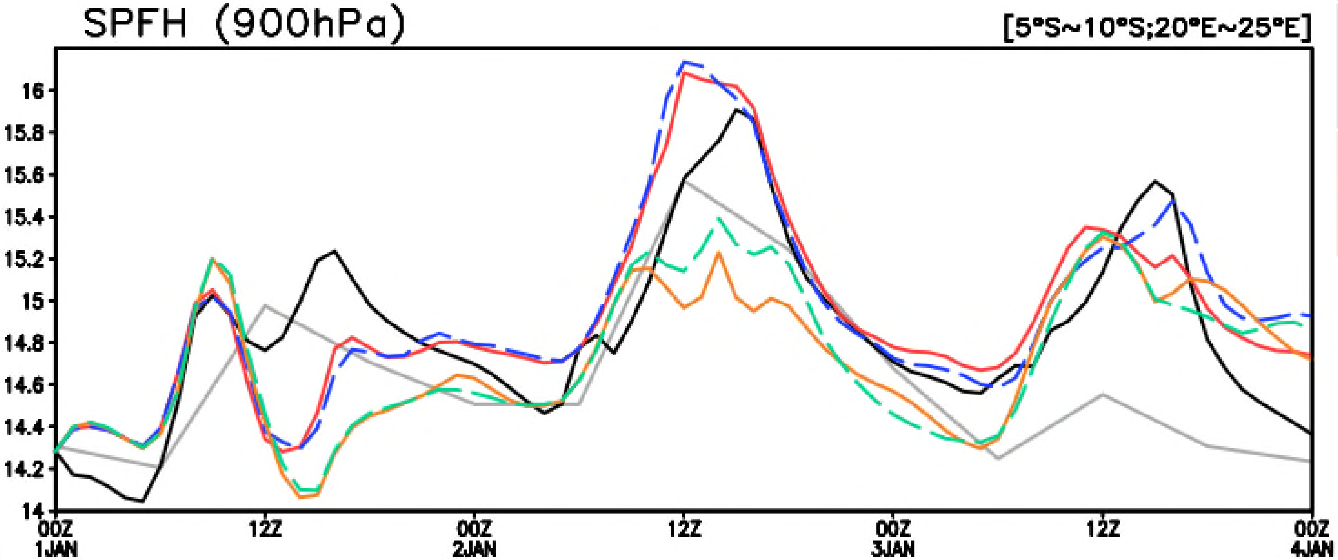
		iopt_sfc		iopt_trs	
		1	2	1	2
T2m	☀	低	高		
	☾			低	高
SPFH 2m	☀	少	多		
	☾			少	多
Low Level Cloud	☀	多	少		
	☾				
LHF	☀				
	☾	高	低		
SHF					
		低	高		

個案測試結果與調整







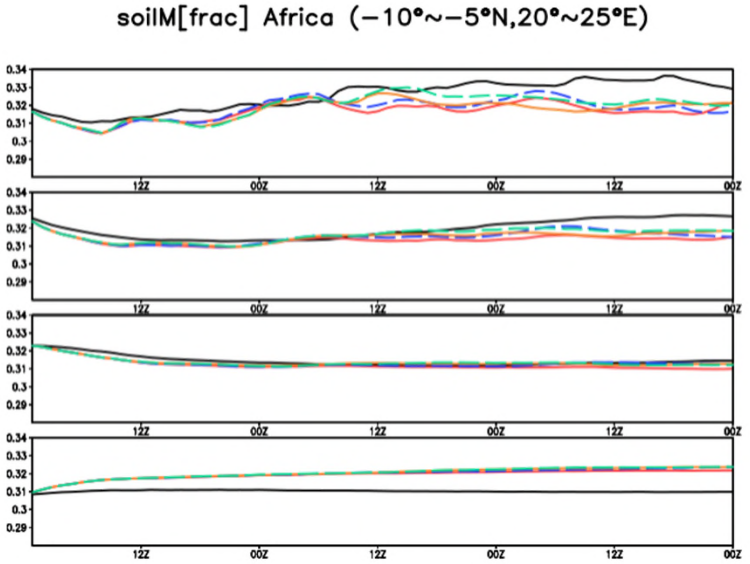


		iopt_sfc		iopt_trs	
		1	2	1	2
T2m	☀	低	高		
	☾			低	高
SPFH 2m	☀	少	多		
	☾			少	多
Low Level Cloud	☀	多	少		
	☾				
LHF	☀				
	☾	高	低		
SHF					
		低	高		

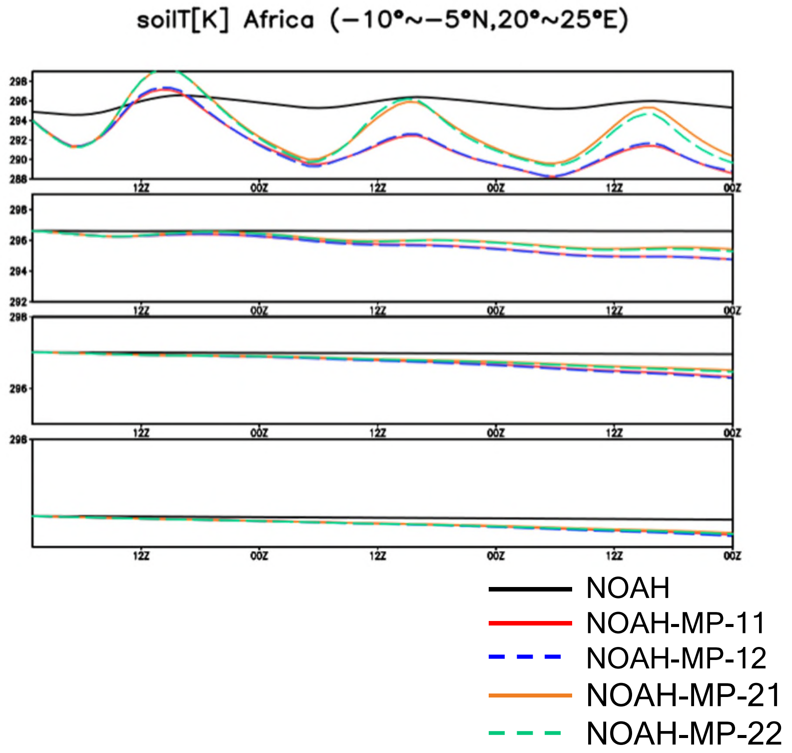
NOAH
NOAH-MP-11
NOAH-MP-12
NOAH-MP-21
NOAH-MP-22
TGFS

結論與未來規劃

- NOAH-MP 在近地面有偏冷、偏乾的情況。
- NOAH-MP在分析區域(非洲中部)參數化選擇iopt_sfc=2、iopt_trs=2的情況下，有更好的溫度與濕度預報結果。



- 在分析區域(非洲中部)夜間潛熱偏高、日間低雲偏多的問題需要再檢驗測試。
- 後續將以此設定擴大檢驗至全球預報結果。
- NOAH-MP的土壤預報溫度日夜變化很大，並隨預報時間溫度逐漸降低；土壤預報濕度有偏乾情況，擬以測試iopt_btr、iopt_stc來調整土壤預報情況。



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