“Prof. R. Ananthakrishnan Colloquium”

Evaluation of Energy Fluxes in the NCEP Climate Forecast System version 2.0 (CFSv2)

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Evaluation of energy fluxes in the NCEP climate forecast system version 2.0 (CFSv2)

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Outline

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- Conclusions

Background

- Many regional (Kothe et al. 2010; Kothe and Ahrens 2010) and global (Wild et al. 2013) climate models suffer from systematic biases in individual components of energy fluxes & net energy flux at the surface and TOA.
- Regional climate models reported errors in the radiation budget components due to the uncertainty in surface albedo (Kothe et al. 2010; Kothe and Ahrens 2010; Pessacg et al. 2014).
- Li et al. (2016) reported overestimation in surface albedo in most of CMIP5 models and highlighted the need of refining the snow-covered albedo and suggested that the reduction in albedo biases is expected to improve temperature simulations particularly over high elevation regions.
- CFSv2 underestimates the 2m air temperature, overestimates snow depth, and delay in snow melt over a large part of Eurasia (Saha et al. 2013, 2014), which may be related to the biases in the surface energy fluxes.

Objective

- To evaluate energy fluxes at the surface & TOA from a long free run by CFSv2.

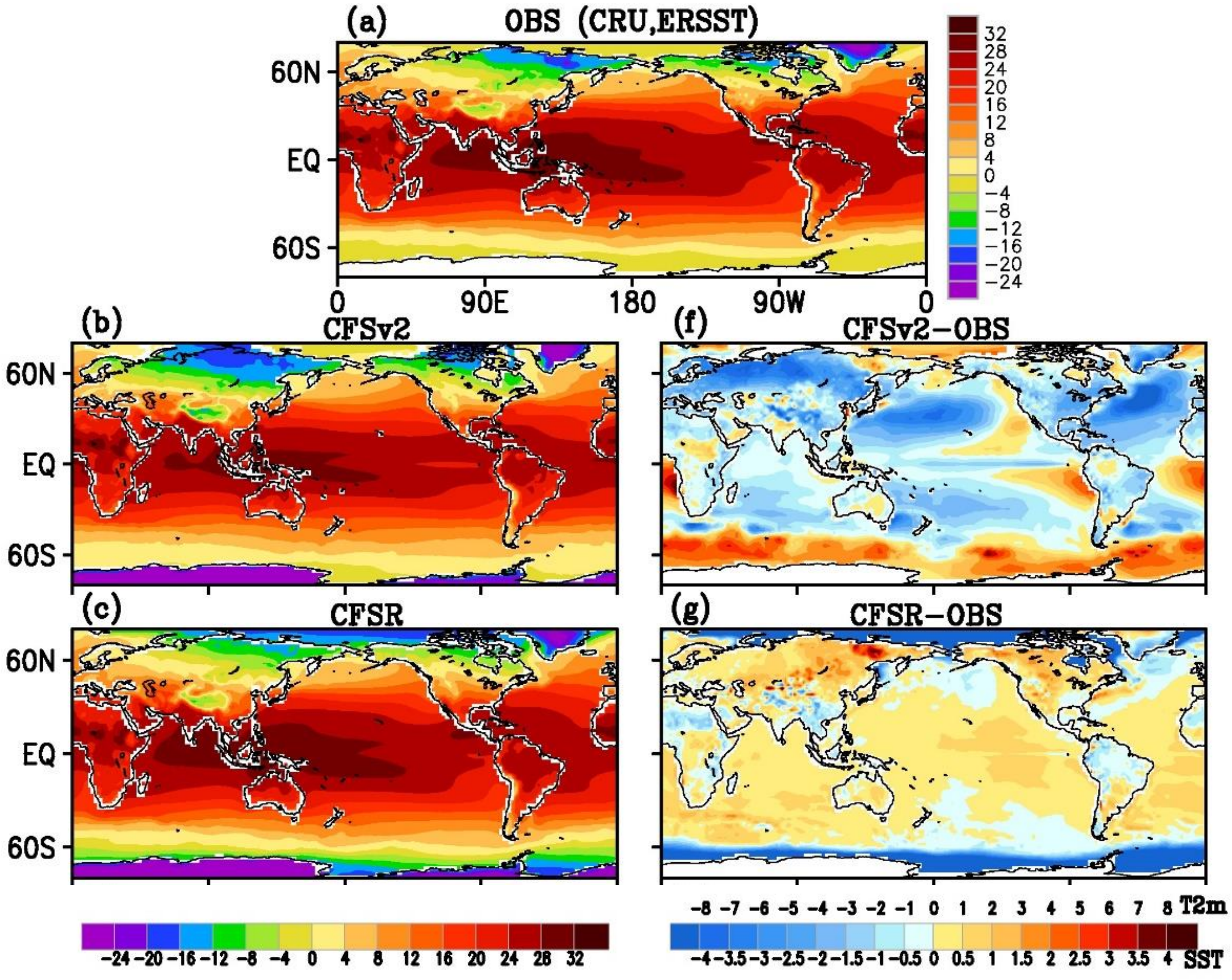
- Try to link it with the systematic cold biases in 2m air temperature, particularly over land.

Datasets Used

- The Clouds and the Earth's Radiant Energy System (CERES) 2.8 for TOA and surface.
- 2 m monthly air temperature data from CRU, and ERSST v3b SST.
- NCEP2 reanalysis.
- ERA Interim.
- NCEP CFSR.
- MERRA-2 Reanalysis

Results

2m Air Temperature



A large cold bias exists (by a maximum of 8 °C) all over the Asian and European continent.

Surface Energy Fluxes

The surface energy balance equation is

$$(1-a)S\downarrow + L\downarrow = L\uparrow + H + \lambda E + G$$

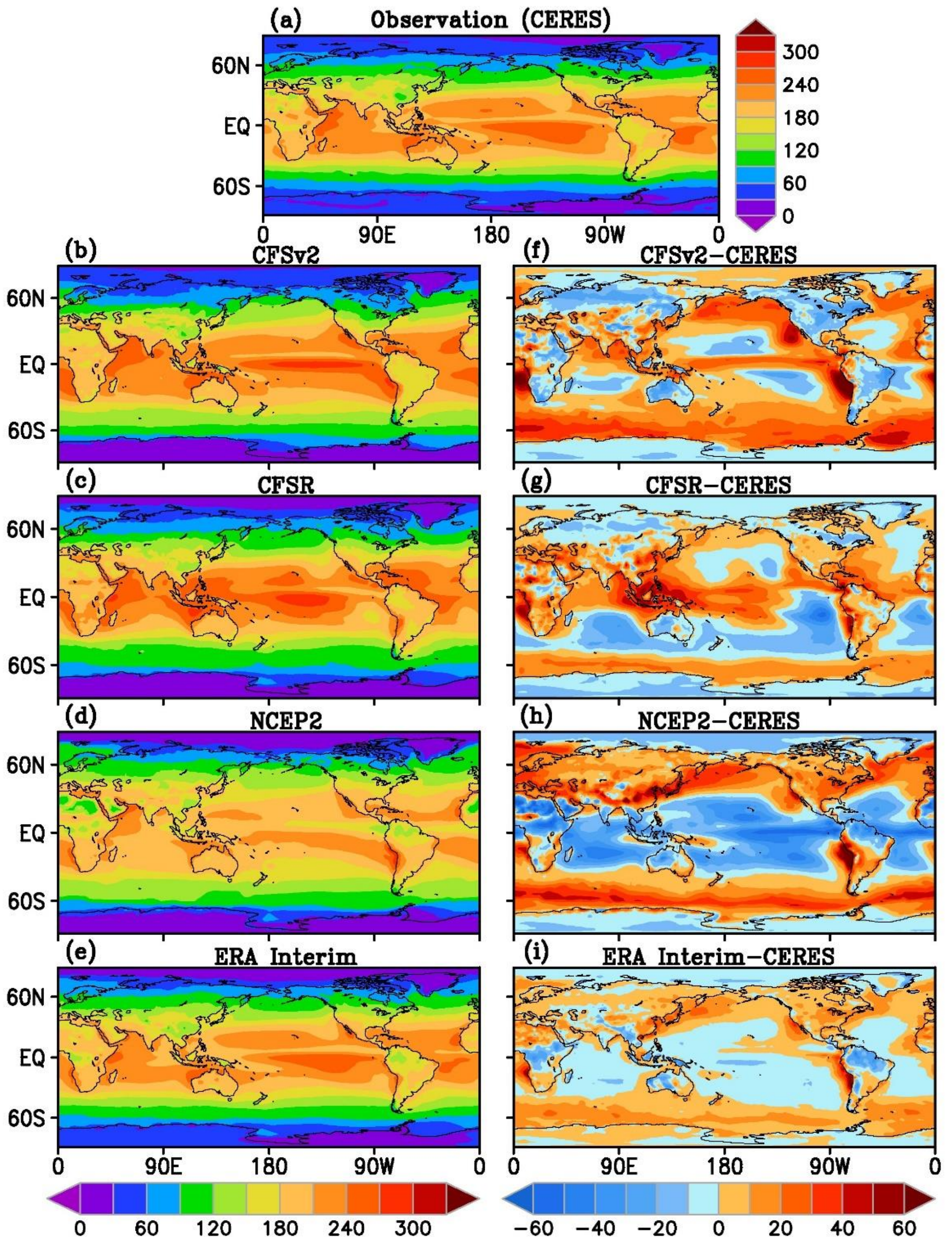
a albedo of the surface (dimensionless)
S↓ solar radiation incident on the surface
L↓ longwave radiation incident on the surface
L↑ longwave radiation emitted by the surface
H sensible heat flux from the surface
λE latent heat flux from the surface
G heat conducted away from the surface. Ground heat flux

Net radiation as follows
$Rn = (1-a)S\downarrow + (L\downarrow - L\uparrow)$,

$Rn = H + \lambda E + G$.

Thus, the energy balance equation is a statement of how net radiation is balanced by sensible, latent and conduction heat fluxes.

Net shortwave radiation At surface

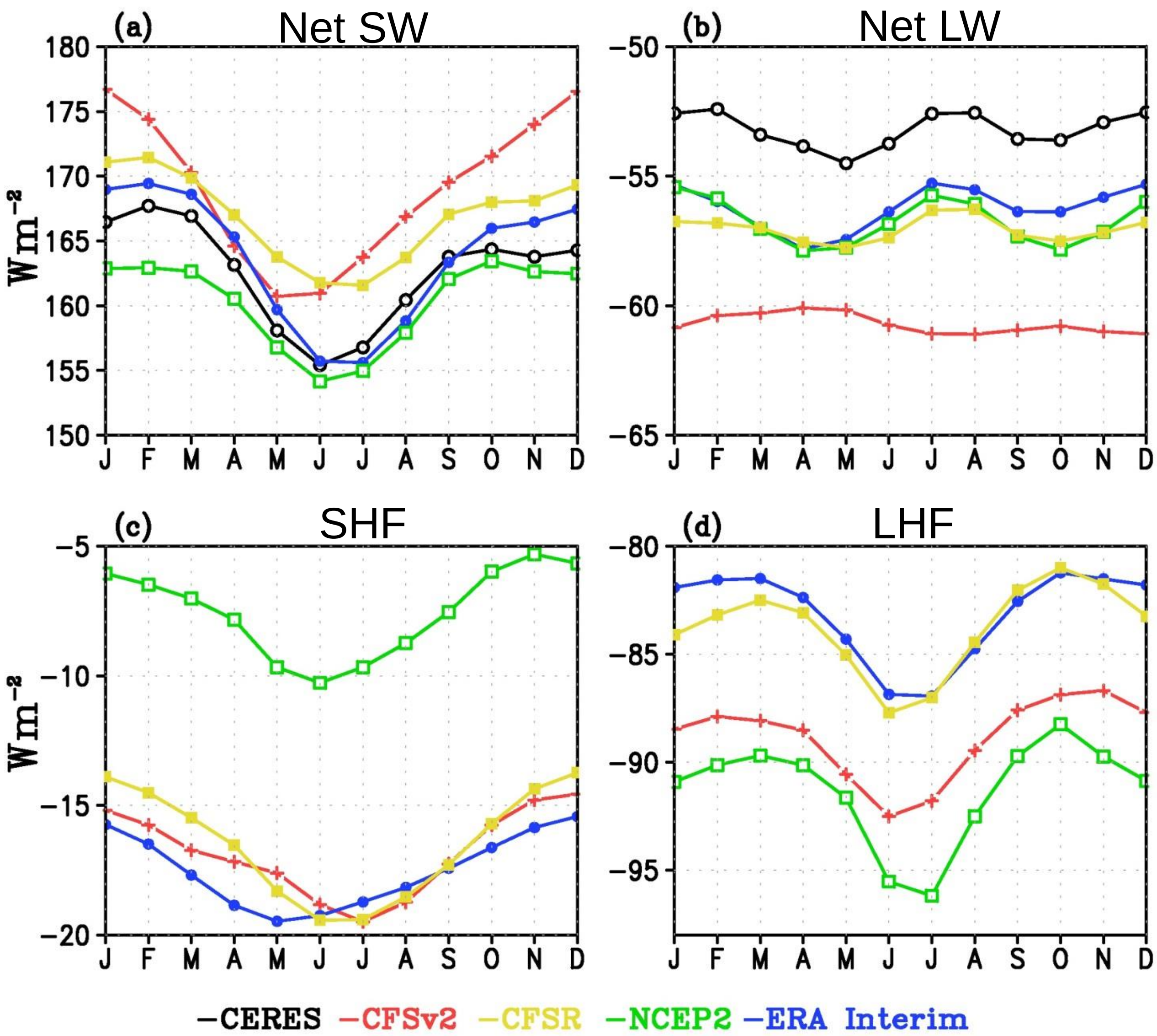


Positive bias in SW radiation over the western coast of North and South America, Africa is evident in CFSv2 and is associated with an underestimation of clouds.

A latitudinal band of 40–60°S around the coast of Antarctic also shows positive bias and that may be related to the sea-ice albedo.

CFSv2 underestimates the net SW radiation over the continental areas of the North and South America, Australia and north of 40° N Eurasia.

Annual cycle of Surface Fluxes



CFSv2 and CFSR overestimate the net surface SW radiation.

A large spread among model, reanalysis and CERES data in both, the magnitude and the shape of the annual cycle of net LW radiation.

CFSv2 overestimates CERES throughout the year. All the reanalyses closely lies in the same range.

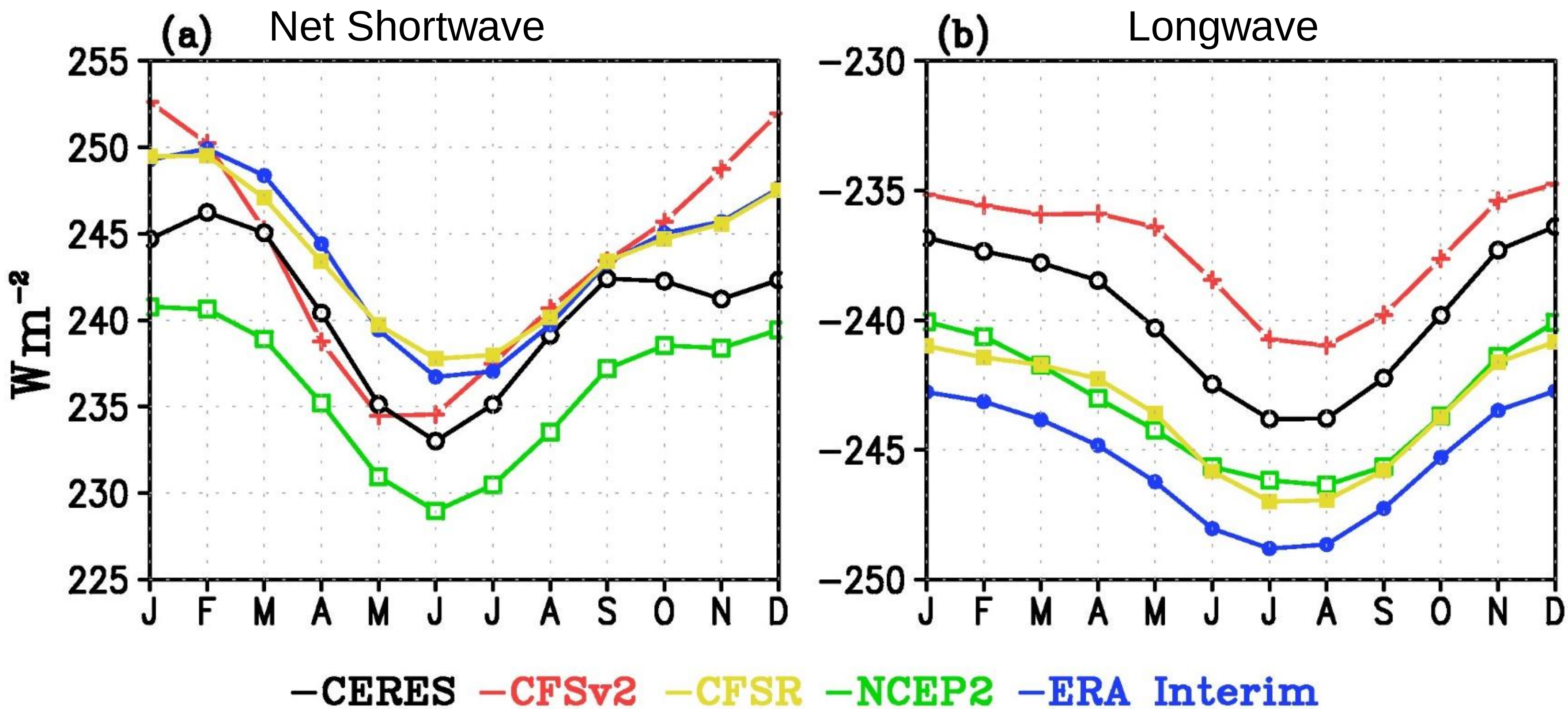
Global Annual Mean and Imbalance at the Surface

	SW down	SW up	Net SW	LW down	LW up	Net LW	SHF	LHF	GHF	Imbalance
CERES	186.69	-24.09	162.60	345.41	-398.59	-53.18	-	-	-	-
CFSv2	197.85	-28.69	169.16	327.69	-388.39	-60.70	-16.83	-88.85	-2.41	0.37
CFSR	192.92	-26.03	166.89	340.36	-397.41	-57.05	-16.44	-83.76	0.53	10.17
NCEP2	187.15	-26.86	160.29	339.98	-396.72	-56.74	-7.52	-91.28	-0.30	4.45
ERA Interim	187.58	-23.80	163.78	341.38	-397.60	-56.22	-17.48	-83.12	-	6.96

The downward (upward) flux is indicated with positive (negative) sign.

Top of the Atmosphere Fluxes

Annual Cycle of TOA Fluxes



CFSv2 (all reanalysis) underestimate (overestimate) net LW at the TOA throughout the year.

Global Annual Mean and Imbalance at TOA

	SW down	SW up	Net SW	LW up	Imbalance
CERES	340.17	-99.58	240.59	-239.71	0.88
CFSv2	341.68	-98.03	243.65	-237.22	6.43
CFSR	341.64	-97.78	243.86	-243.48	0.38
NCEP2	341.33	-105.25	236.08	-243.27	-7.19
ERA Interim	344.20	-100.32	243.88	-245.42	-1.54

The downward (upward) flux is indicated with positive (negative) sign.

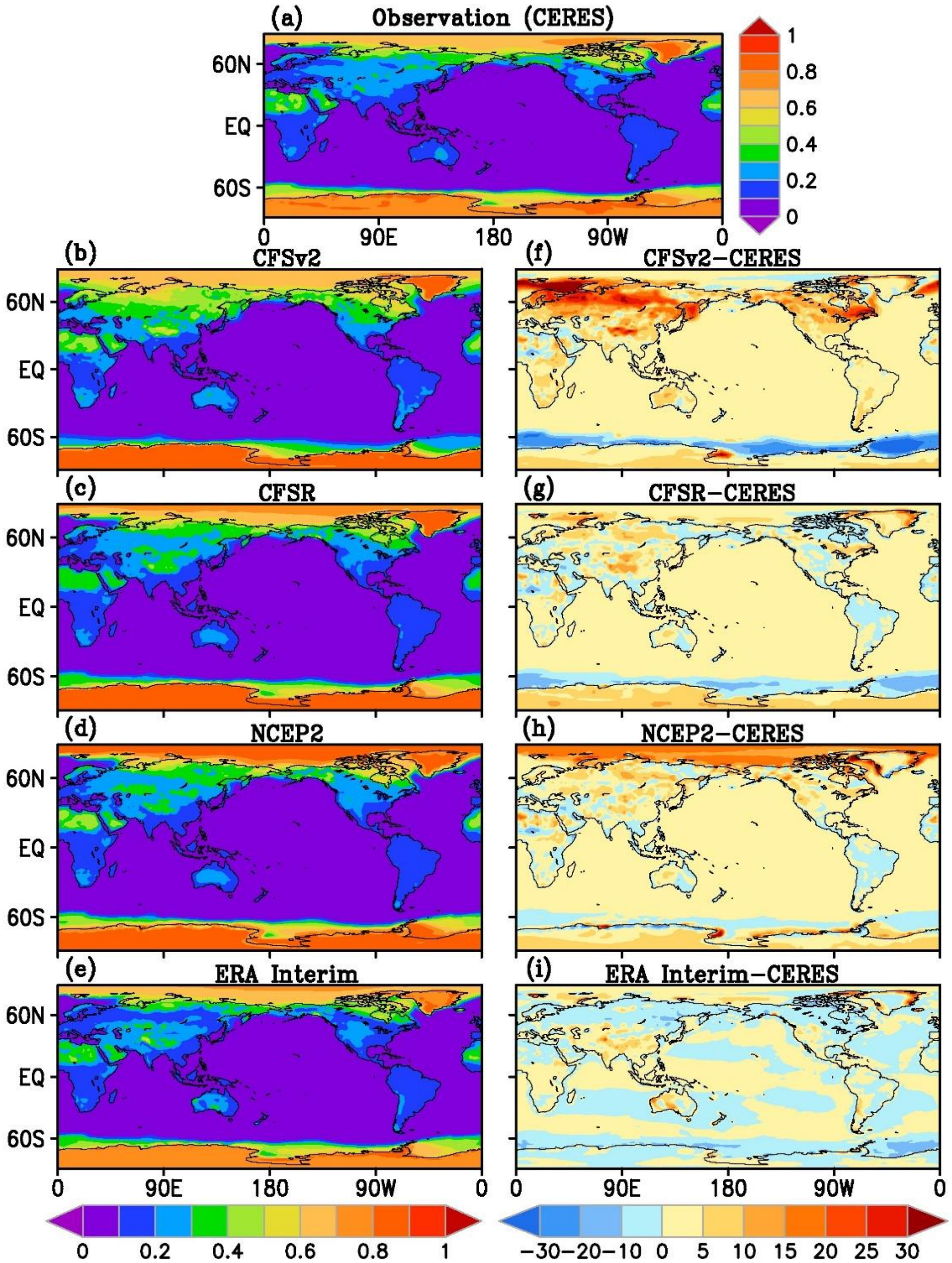
- A large imbalance (6.43 Wm^{-2}) is evident in CFSv2.

Possible sources of surface cold bias

The cold bias in 2m air temperature by CFSv2 over mid and high latitudes of the Asian and European continents is associated with the negative bias in net SW radiation at surface.

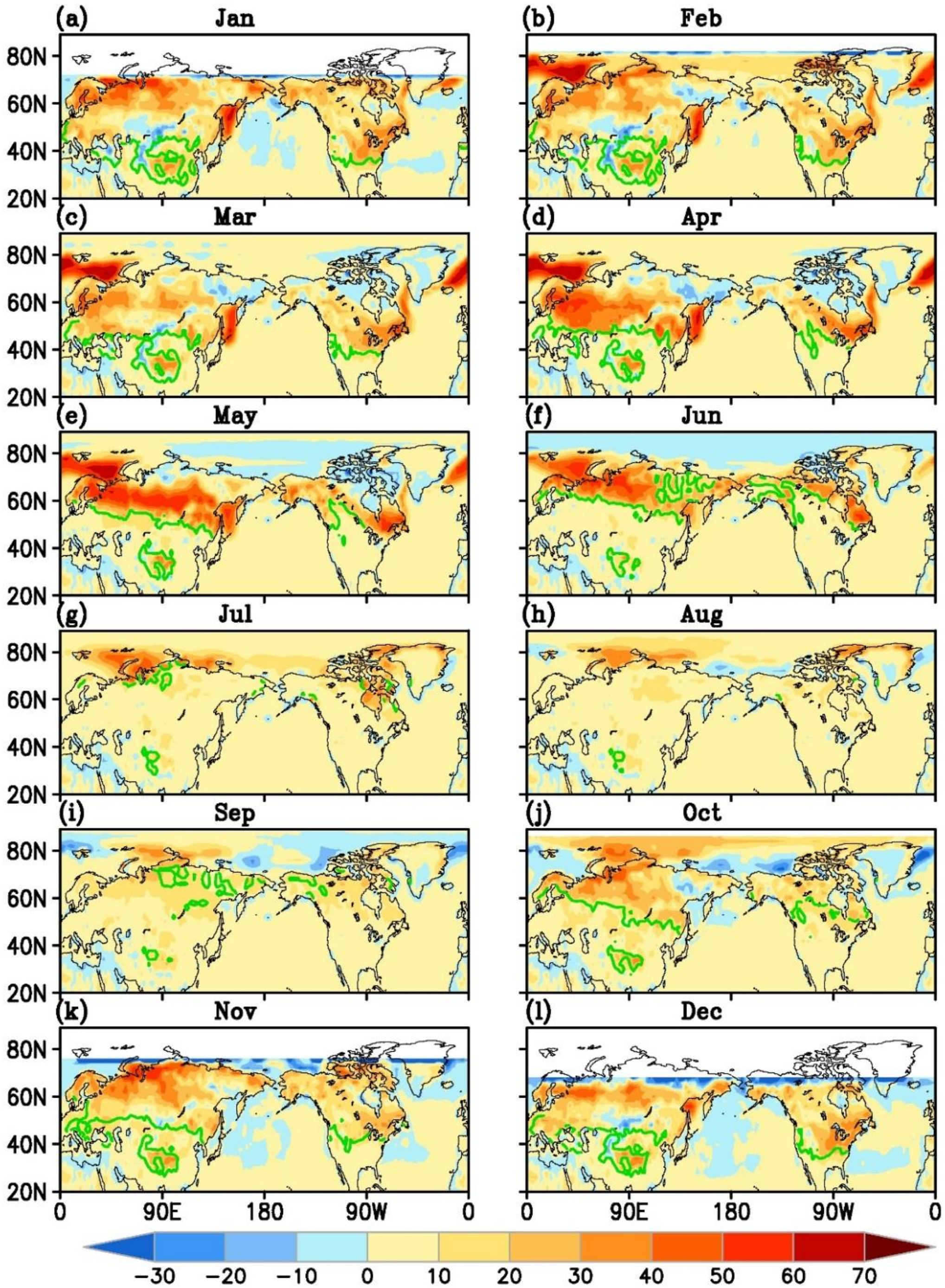
The found bias in SW radiation may be related to the error in incoming solar radiation due to an error in the representation of cloud and inaccurate surface albedo.

Surface Albedo



Oceanic regions have lower values of albedo and the variation in albedo is mainly found over the land regions. In general, albedo is high over the desert and snow/ice cover regions.

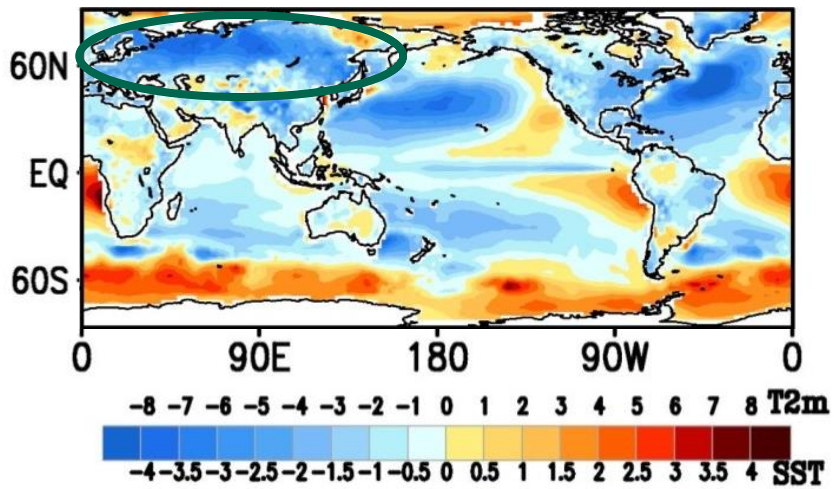
CFSv2 overestimates surface albedo over the mid and high latitudes of the Asian and European continents and southern North America.



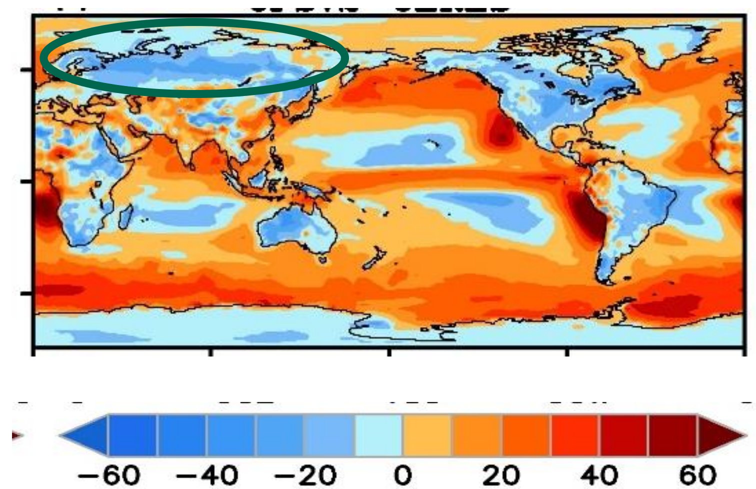
Monthly albedo bias along with the snow depth in CFSv2

Biases

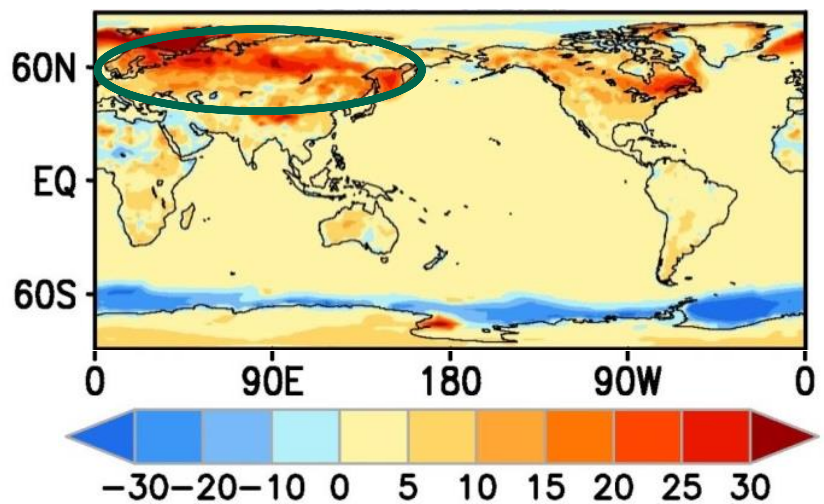
2m Temperature



Net SW at surface



Albedo



The regions where the albedo values are overestimated show an underestimation of net shortwave radiation as well as 2 m air temperature.

Implementation of snow albedo schemes and their performances in offline Noah and Noah coupled with NCEP CFSv2

Snow albedo Schemes used

1. Maximum snow albedo (MSA) scheme of Noah.

The surface albedo in the land model Noah is computed as

$$\alpha = \alpha_0 + f_{sn}\left(\alpha_s - \alpha_0\right) \quad (1)$$

where α, α_0 and α_s are the actual, snow free and maximum snow albedo, respectively. f_{sn} is the snow cover fraction.

2. **A temperature dependent snow albedo scheme, used in ECHAM5 model (Roeckner et al. 2003; RK03).** It is a linear function of surface temperature that ranges between a minimum value at the melting point and a maximum value for cold temperatures.

$$\alpha_s = \alpha_{s,min} + (\alpha_{s,max} - \alpha_{s,min}) f(T_s) \tag{3}$$

where

$$f(T_s) = min\left\{ max\left[\left(\frac{T_0 - T_s}{T_0 - T_d} \right), 0 \right], 1 \right\} \tag{4}$$

where $T_d = T_0 - 1$ for sea-ice and lake-ice (with or without snow) and $T_d = T_0 - 5$ for snow on land and ice sheets.

3. **A prognostic snow albedo scheme developed for ECMWF forecast model (Dutra et al. 2010; DU10).**

$$\alpha_s^{t+1} = \begin{cases} \alpha_s^t - \tau_a \frac{\Delta t}{\tau_1} & M_{sn} = 0 \\ \left(\alpha_s^t - \alpha_{s,min}\right) exp\left(-\tau_f \frac{\Delta t}{\tau_1}\right) + \alpha_{s,\min} & M_{sn} > 0 \; or \; T_{sn} \geqslant T_f - 2 \end{cases} \quad (5)$$

where $\tau_a = 0.008$, which will decrease the albedo by 0.1 in 12.5 days, $\alpha_{s,min} = 0.5$ and $\alpha_{s,max} = 0.85$. The timescales $\tau_1 = 86400s$, and $\tau_f = 0.24$ corresponding to an e-folding time of about 4 days. The corresponding parameters are summarized in Table 2. Furthermore, a continuous reset is applied to snow albedo after snowfall events given as

$$\alpha_s^{t+1} = \alpha_s^t + min\left(1, \frac{F\Delta t}{10}\right)\left(\alpha_{s,max} - \alpha_s^t\right) \quad (6)$$

where α_s represents the snow albedo, Δt is the model time step and superscript t and t + 1 denotes the current and next time step, respectively. In the above formulation 10 kg m^{-2} of fresh snowfall are required to reset the snow albedo to its maximum value ($\alpha_{s,max} = 0.85$). The surface albedo of

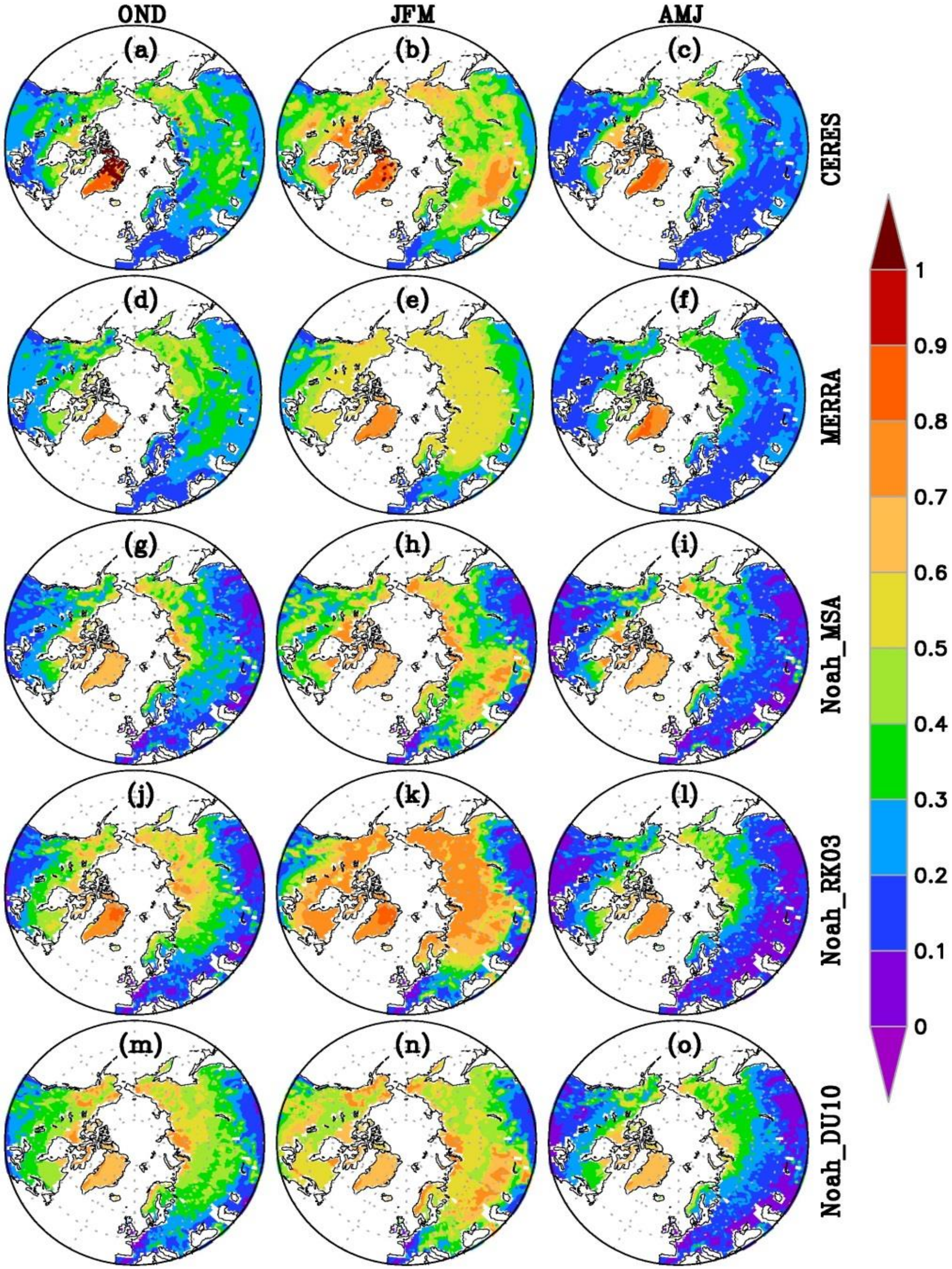
Offline Experiments

The offline Noah is initialized with the mean fields obtained from free run by CFSv2. The offline Noah is forced with WATCH-Forcing-Data-ERA-Interim (WFDEI, Weedon et al. 2014), for the period 1979-2013. The LSM Noah having four soil layers and six snow layer (Saha et al. 2017).

The following three simulations are carried out

1. Noah with existing MSA scheme (Noah_MSA)
2. Noah with Roeckner et al. (2003) snow albedo scheme (Noah_RK03)
3. Noah with Dutra et al. (2010) snow albedo scheme (Noah_DU10)

Offline LSM Noah Albedo Simulations



Albedo simulation using MSA scheme is more closer to observations as compared to both RK03 and DU10 snow albedo schemes.

Noah_DU10 shows good resemblance in the maximum phase and melting phase with observations.

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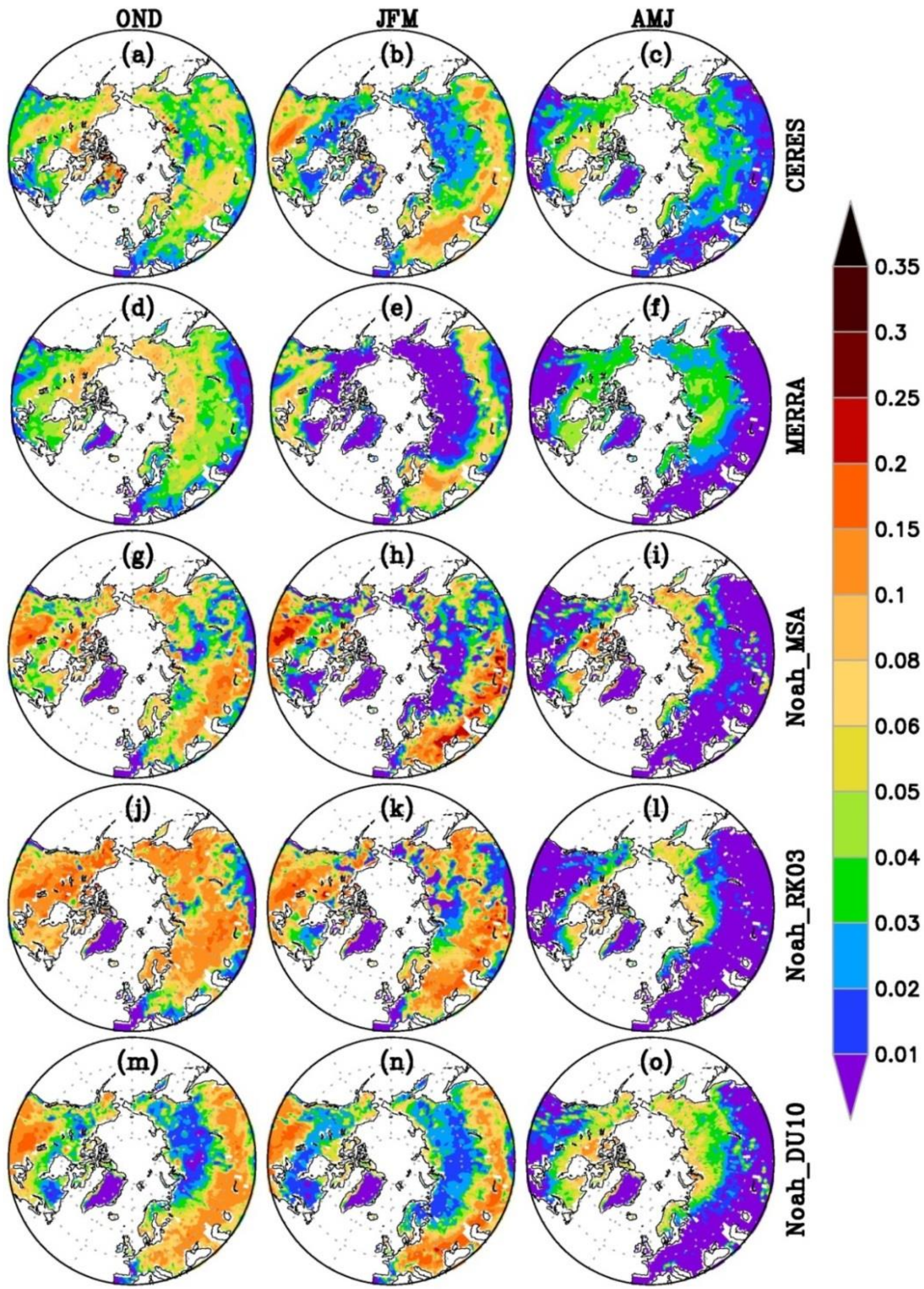
Interannual Variability of Albedo



Noah_DU10 variability pattern is much closer to the observations as compared to the other offline simulations particularly in the melting phase.

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Coupled Experiments

Noah is the land surface component of the NCEP CFSv2 and uses 'maximum snow albedo' derived from satellite estimated for calculating snow albedo, CFSv2 calculates albedo based on Briegleb (1992) BR92 that depends on the zenith angle and visible and infrared component.

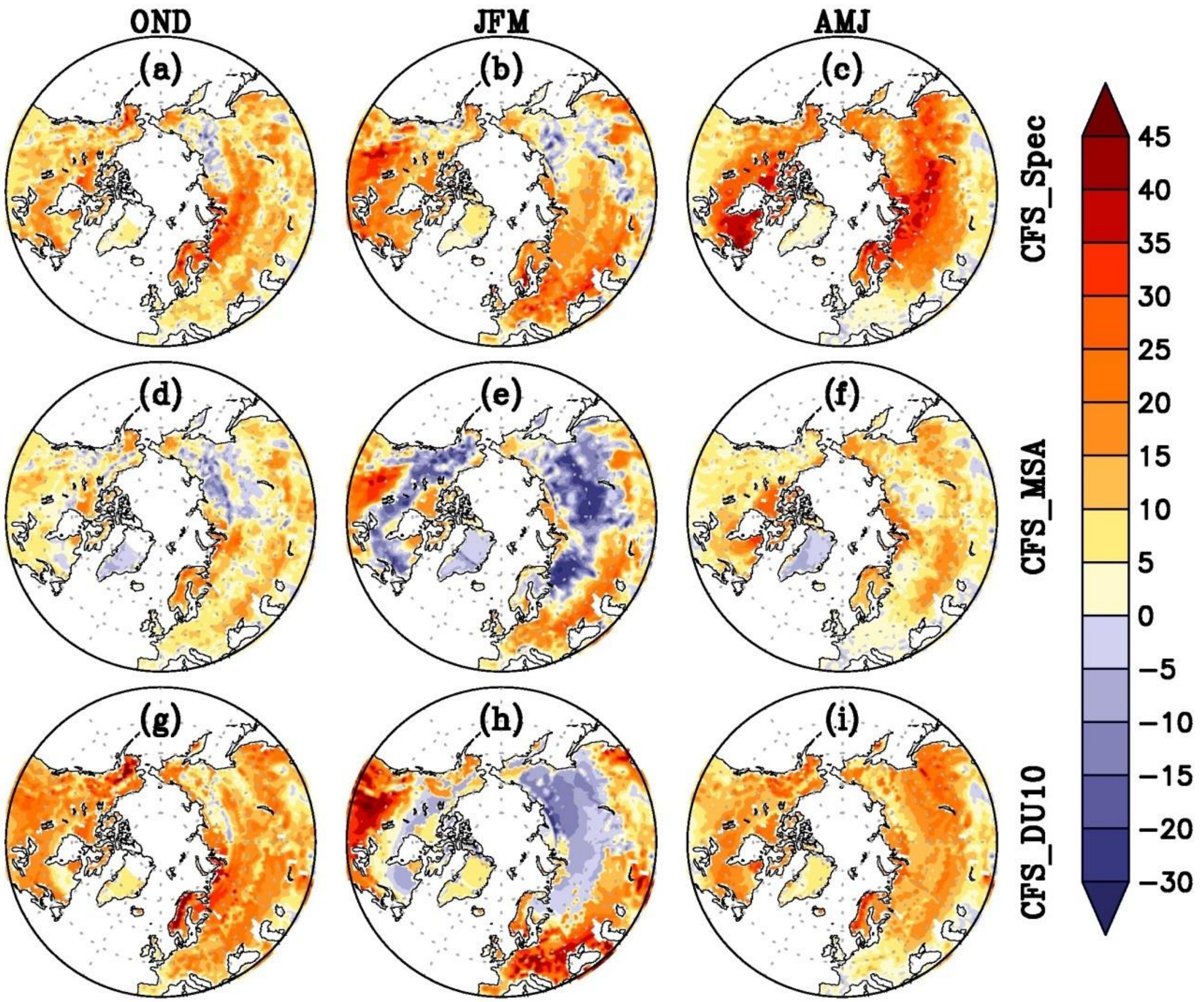
Three coupled experiments with CFSv2 are performed.

1. CFSv2, coupled with snow albedo scheme of BR92 (CFS_Spec)
2. CFSv2, coupled with MSA scheme (CFS_MSA)
3. CFSv2, coupled with DU10 snow albedo scheme (CFS_DU10)

The coupled experiments uses initial condition of 2009 from CFSR reanalysis (Saha et al. 2010) and each simulation is conducted for 51 years. As this study uses 34 years of observations/reanalysis data (1980-2013), the last 34 years of model simulations are considered for analysis and the first 17 years of simulations are left as spin up period.

CFSv2 Simulation

Albedo Bias



Bias with respect to MERRA-2 reanalysis in surface albedo.

The CFS_Spec overestimate the albedo in all the three phases having maximum overestimation in maximum and melting phase particularly over north of 50°N.

However, in CFS_MSA the albedo biases are considerably less in all the three phases.

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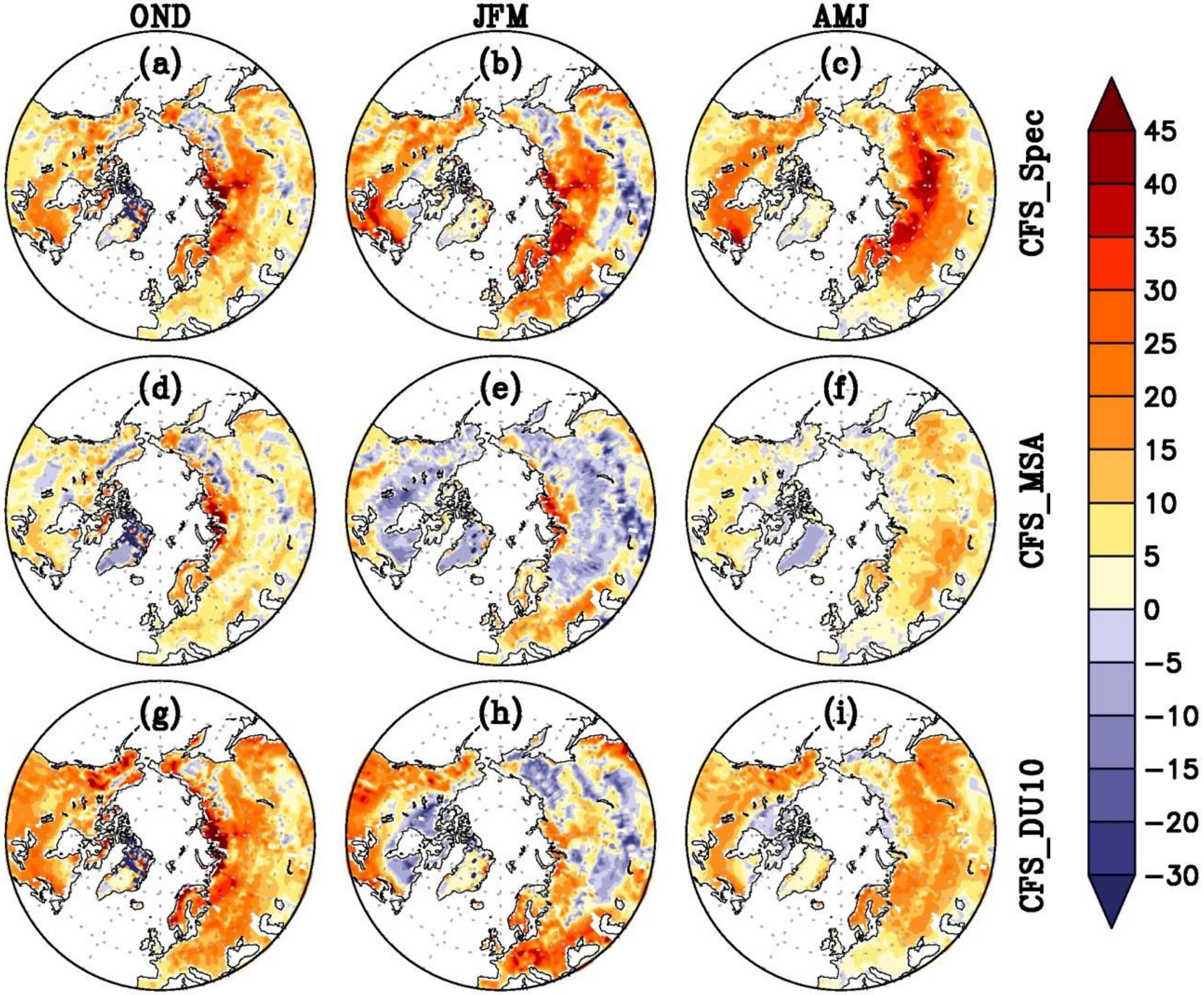
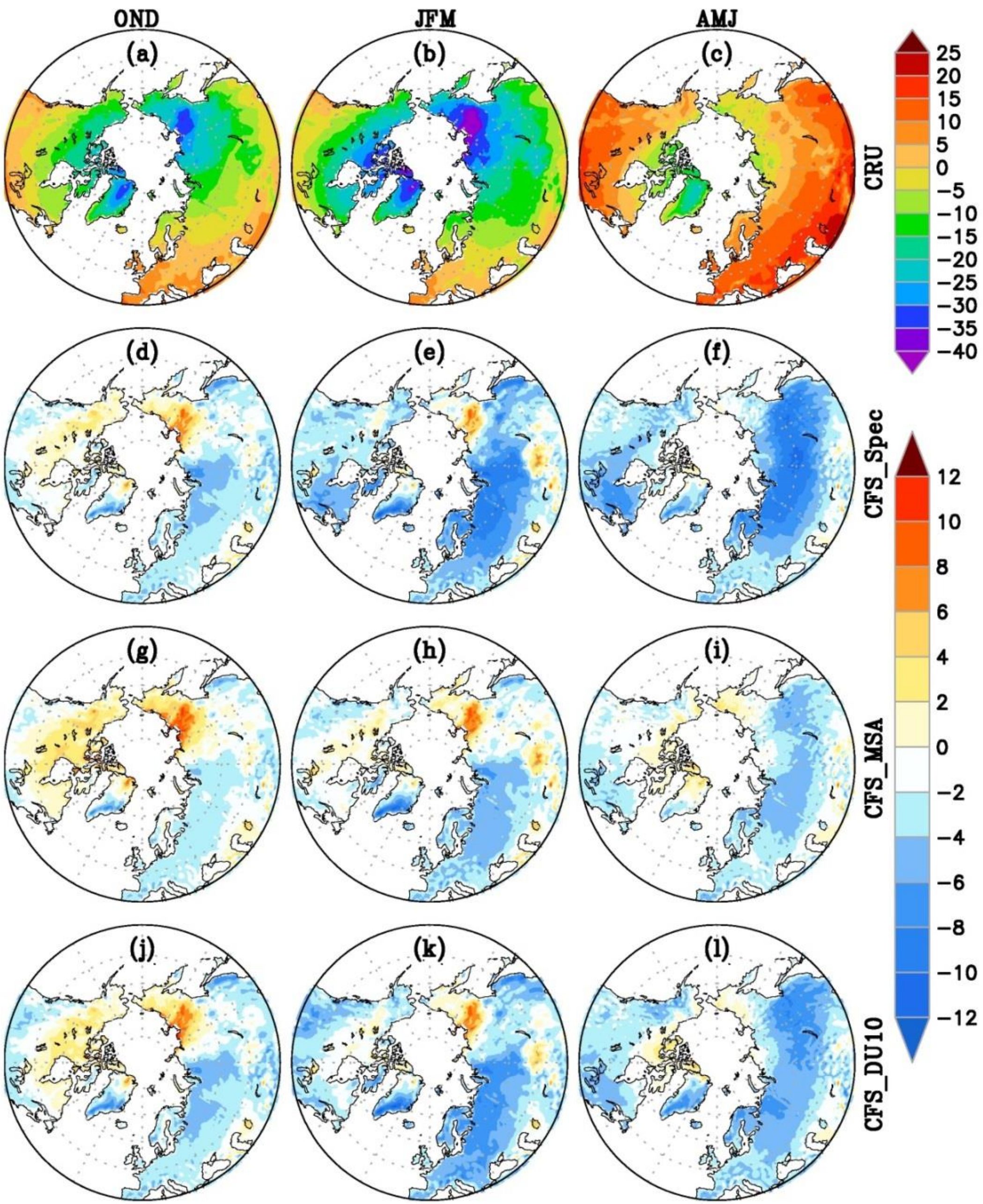
Albedo bias



Climatological mean albedo bias with respect to CERES

2m Air temperature



In CFS_MSA simulation, the cold bias reduces by 6-8 °C in maximum and melting phase with respect to CFS_Spec.

CFS_DU10 shows significant reduction in 2m air temperature as compared to CFS_Spec simulation.

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Conclusions

- In CFSv2, the global averaged imbalance at the surface and at the TOA is found to be 0.37 and 6.43 Wm^{-2}, respectively.
- CFSv2 overestimates the land surface albedo, particularly over the snow region, which in turn contributes to the cold biases in 2m air temperature and highlights the need for improvements in the parameterization of snow albedo scheme for a realistic simulation of surface temperature.
- The performance of MSA scheme is found to be better in simulating surface albedo, snow water equivalent and 2m air temperature as compared to those using DU10 and BR92 schemes.
- Among four schemes (MSA, RK03, DU10 and BR92), MSA appears to be the most suitable snow albedo scheme for CFSv2.

Thank You