Monsoon teleconnections with the extratropics in summer

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IRCAAM project

Motivating questions

- Can knowledge of the tropical flow...

improve medium range predictions in the extratropics ?
improve simulations of the seasonal mean ?
help understand interannual variability ?

- How do the summer monsoon regions affect extratropical flow ?

in particular the African monsoon

The IRCAAM project: nudging with a GCM

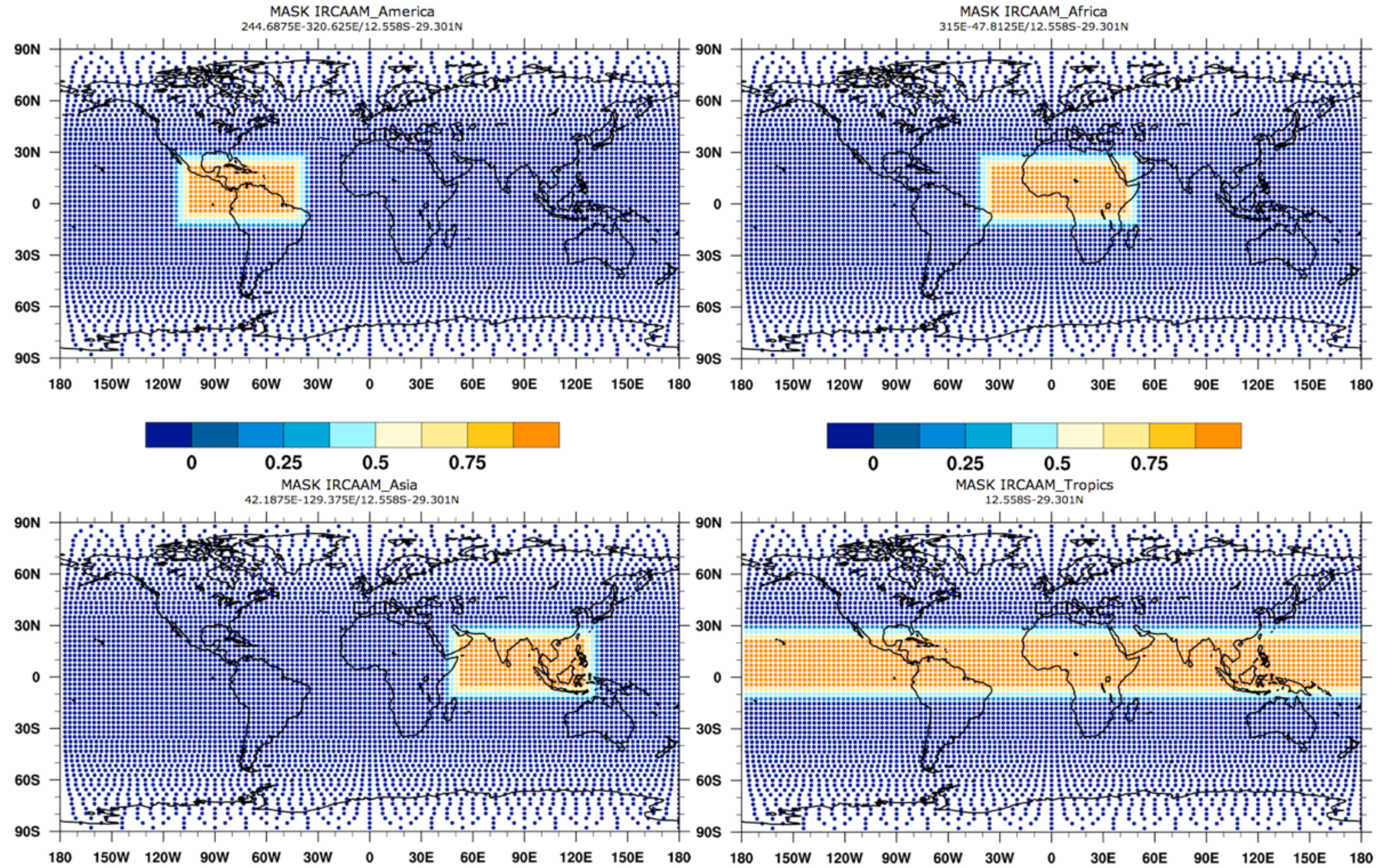
What happens in the summertime ?

- *convection shifts north into monsoon regions*
- *midlatitude flow also changes (weaker jets further north)*
- *less internal variability in the extratropics*

IRCAAM: “Influence Réciproque des Climats d’Afrique de l’Ouest, du sud de l’Asie et du bassin Méditerranéen”

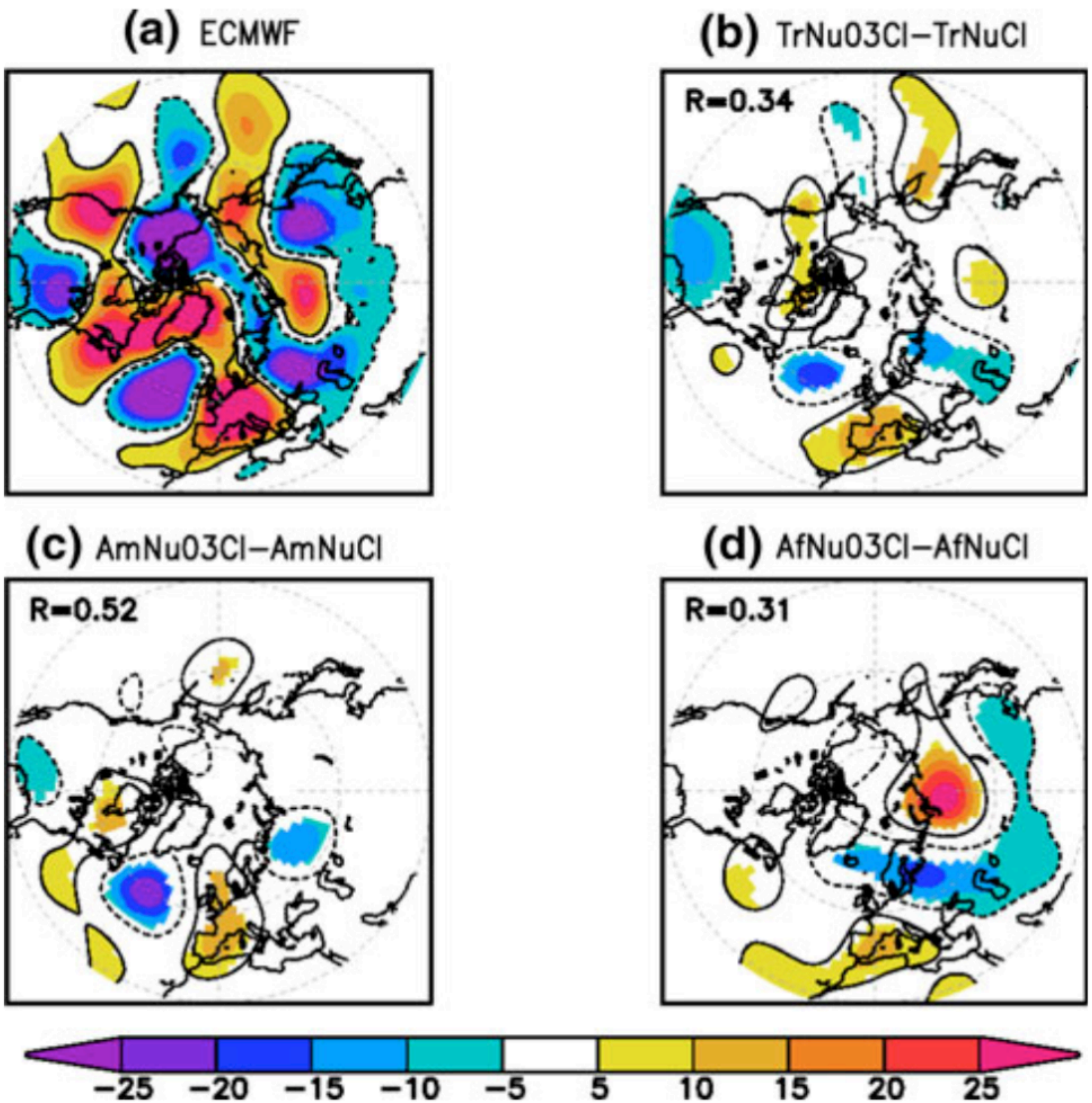
Two French GCMs:

Arpege (CNRM)
LMDz (LMD)



Arpege: 2003 case study

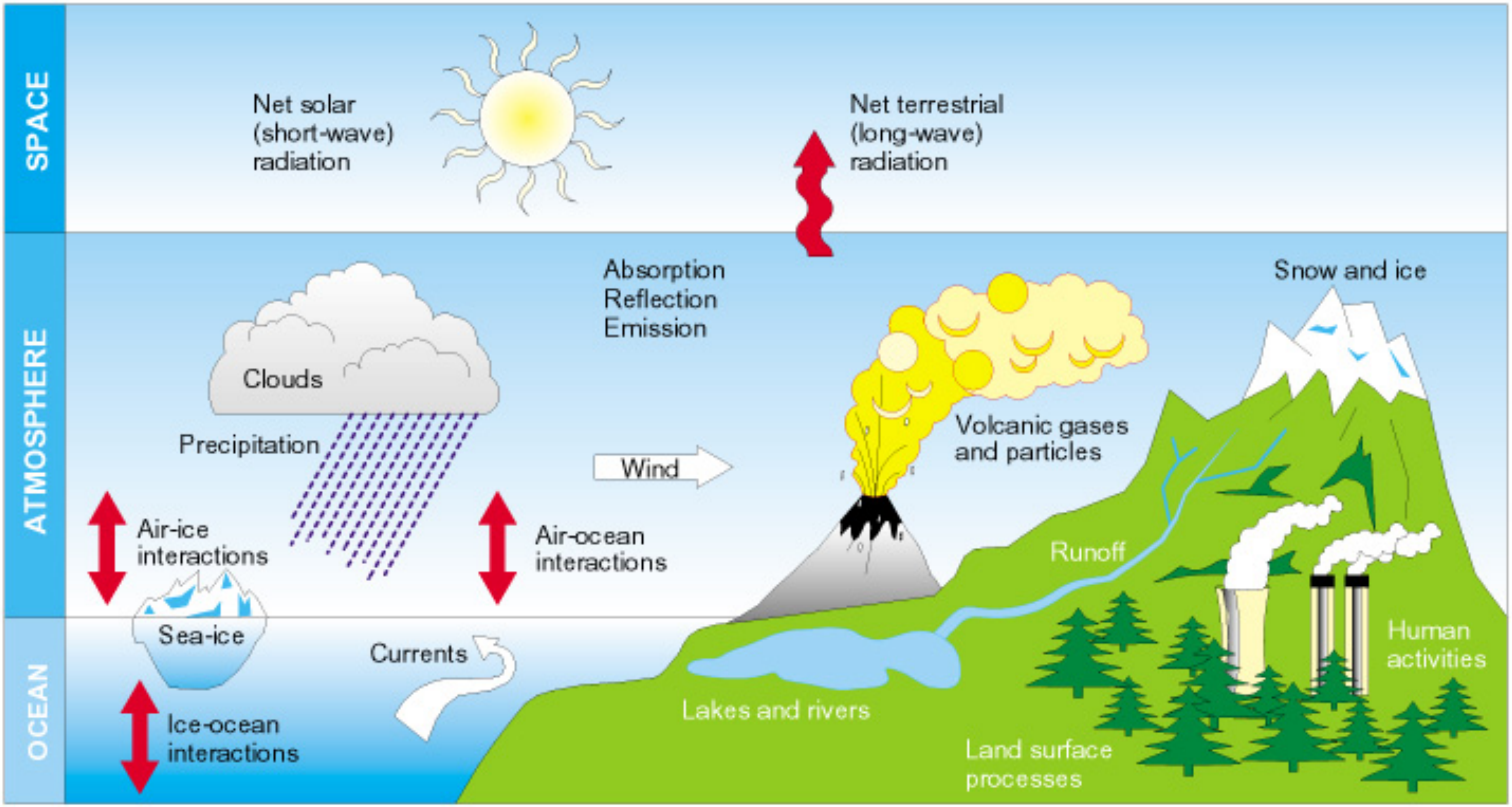
Contribution of nudging from the three monsoon sectors.



In a complex model like Arpege many factors could contribute to these results.

We will try to break it down into distinct dynamical aspects.

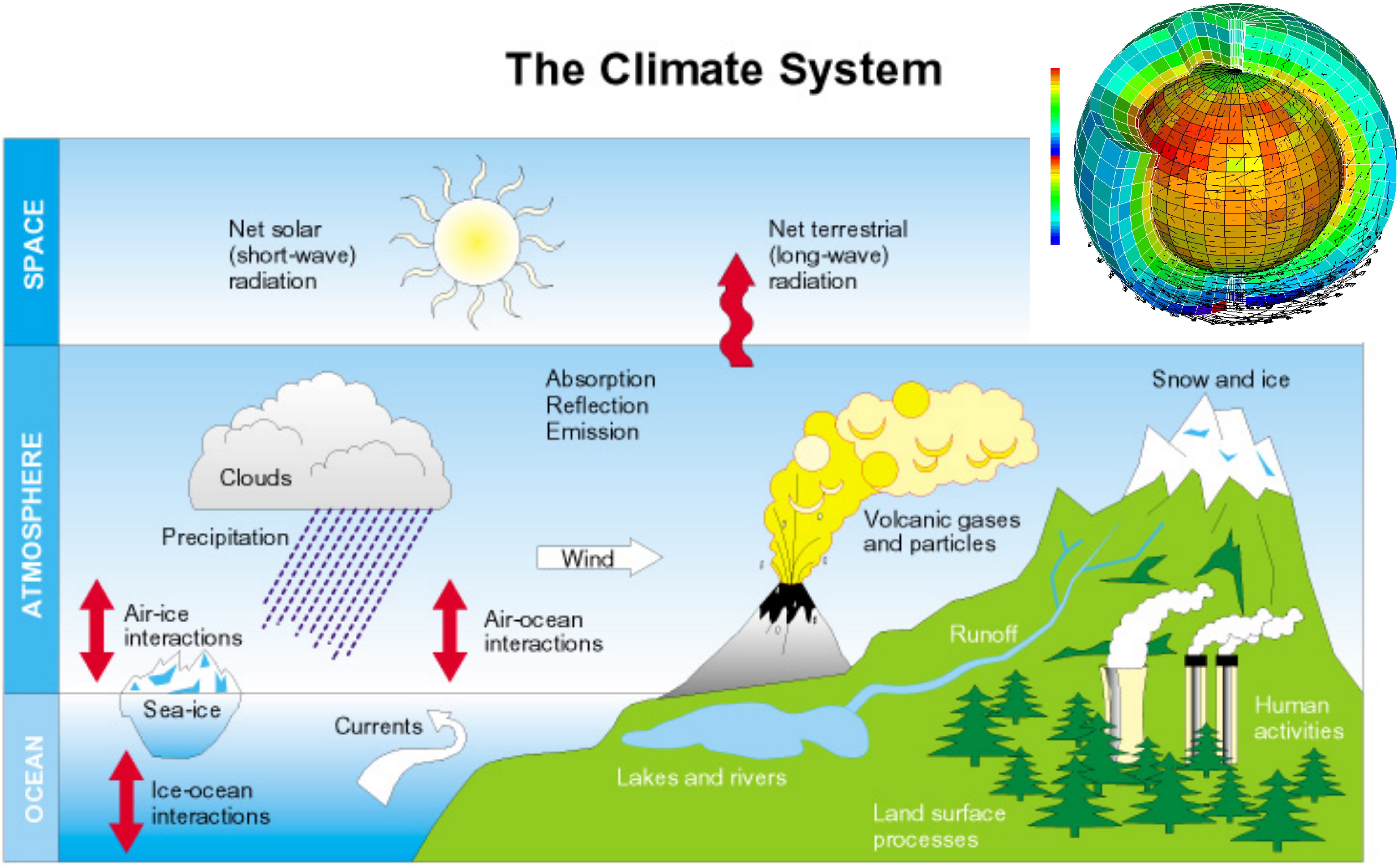
The Climate System



courtesy N. Noreiks, L. Bengtsson, MPI

AV/Global/0101

The Climate System



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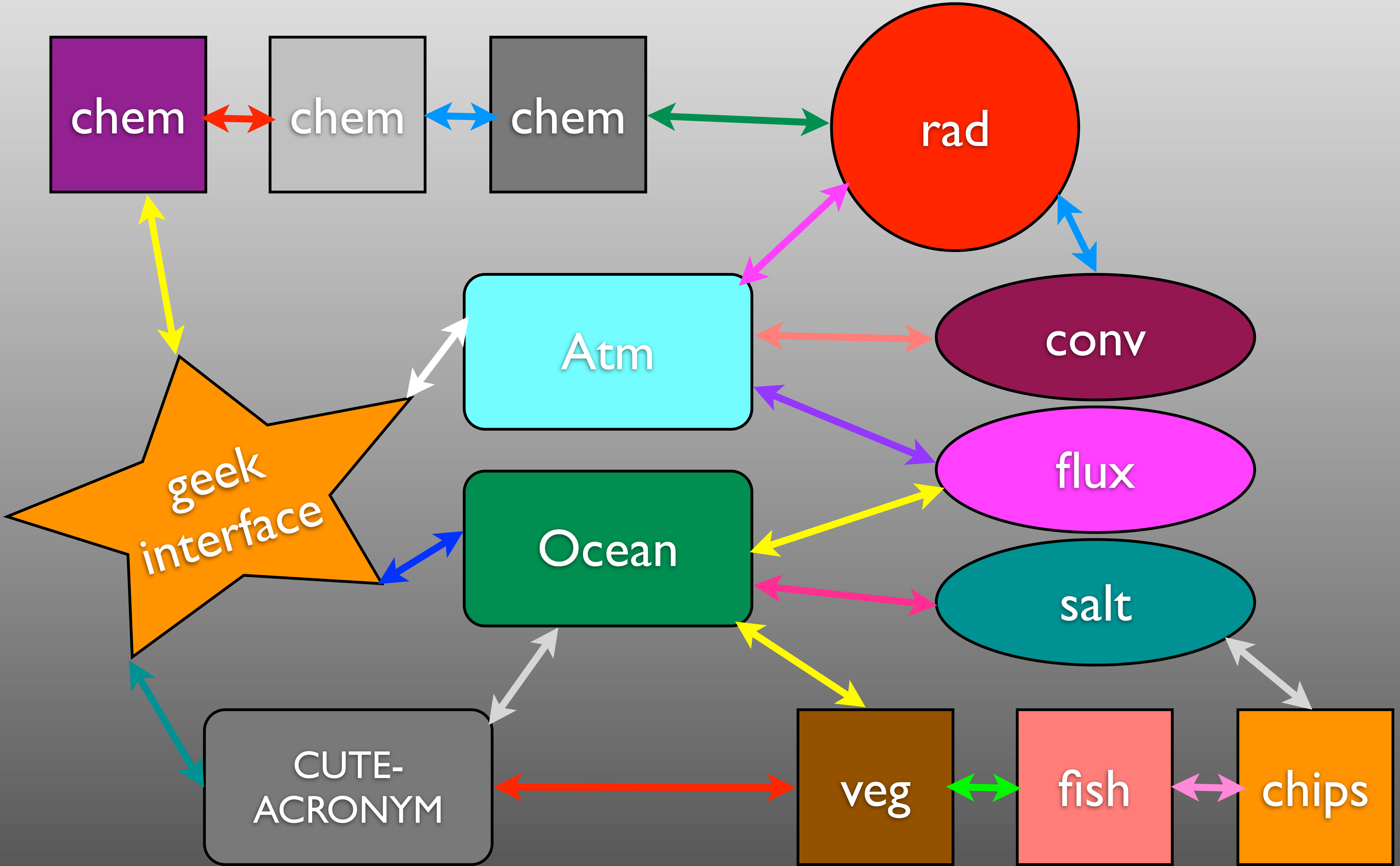

chem
chem
chem
rad
Atm
conv
flux
geek interface
Ocean
salt
CUTE-ACRONYM
veg
fish
chips

Technical interlude

A simple GCM

Global dynamical model: primitive equations

Generic model development equations

unforced model $$\frac{d\mathbf{\Psi}}{dt} + \mathbf{A}(\mathbf{\Psi}) = -\mathbf{D}(\mathbf{\Psi})$$

forced model $$\frac{d\mathbf{\Psi}}{dt} + \mathbf{A}(\mathbf{\Psi}) = -\mathbf{D}(\mathbf{\Psi}) + \mathbf{G}$$

define G as $\mathbf{G} = \frac{1}{N}\sum_{i=1}^{N}(\mathbf{A}+\mathbf{D})(\mathbf{\Phi}_i)$ so it corrects the mean one-timestep error

this guarrantees that $\overline{(\mathbf{A}+\mathbf{D})\mathbf{\Psi}} = \overline{(\mathbf{A}+\mathbf{D})\mathbf{\Phi}}$ but not that $\overline{\mathbf{\Psi}} = \overline{\mathbf{\Phi}} \quad (= \mathbf{\Phi}_c)$

Then we add the nudging term

$$\frac{d\mathbf{\Psi}}{dt} + \mathbf{A}(\mathbf{\Psi}) = -\mathbf{D}(\mathbf{\Psi}) + \mathbf{G} + \left(\frac{\mathbf{\Phi}_n - \mathbf{\Psi}}{\tau}\right)$$

Validation for summer (JJAS)

From Leroux et al, JAS 2011.

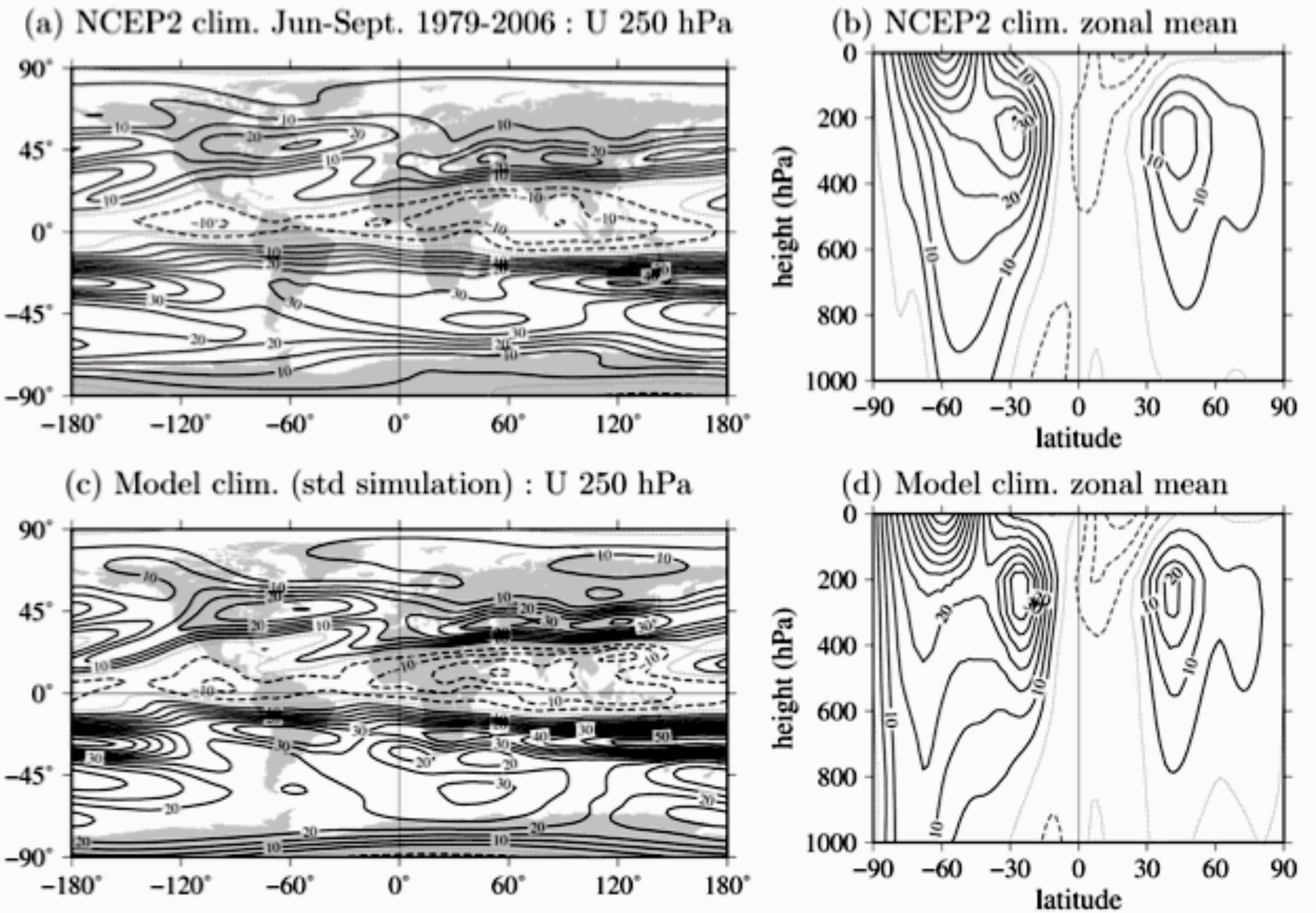


FIG. 1. Climatological zonal wind (a),(c) at 250 hPa and (b),(d) on the latitude–height zonal mean section. (top) June–September 1979–2006 NCEP-2 data, and (bottom) mean state of standard simulation. Contours every 5 m s^{-1}. Negative values dashed, and zero contour dotted.

Validation for summer (JJAS)

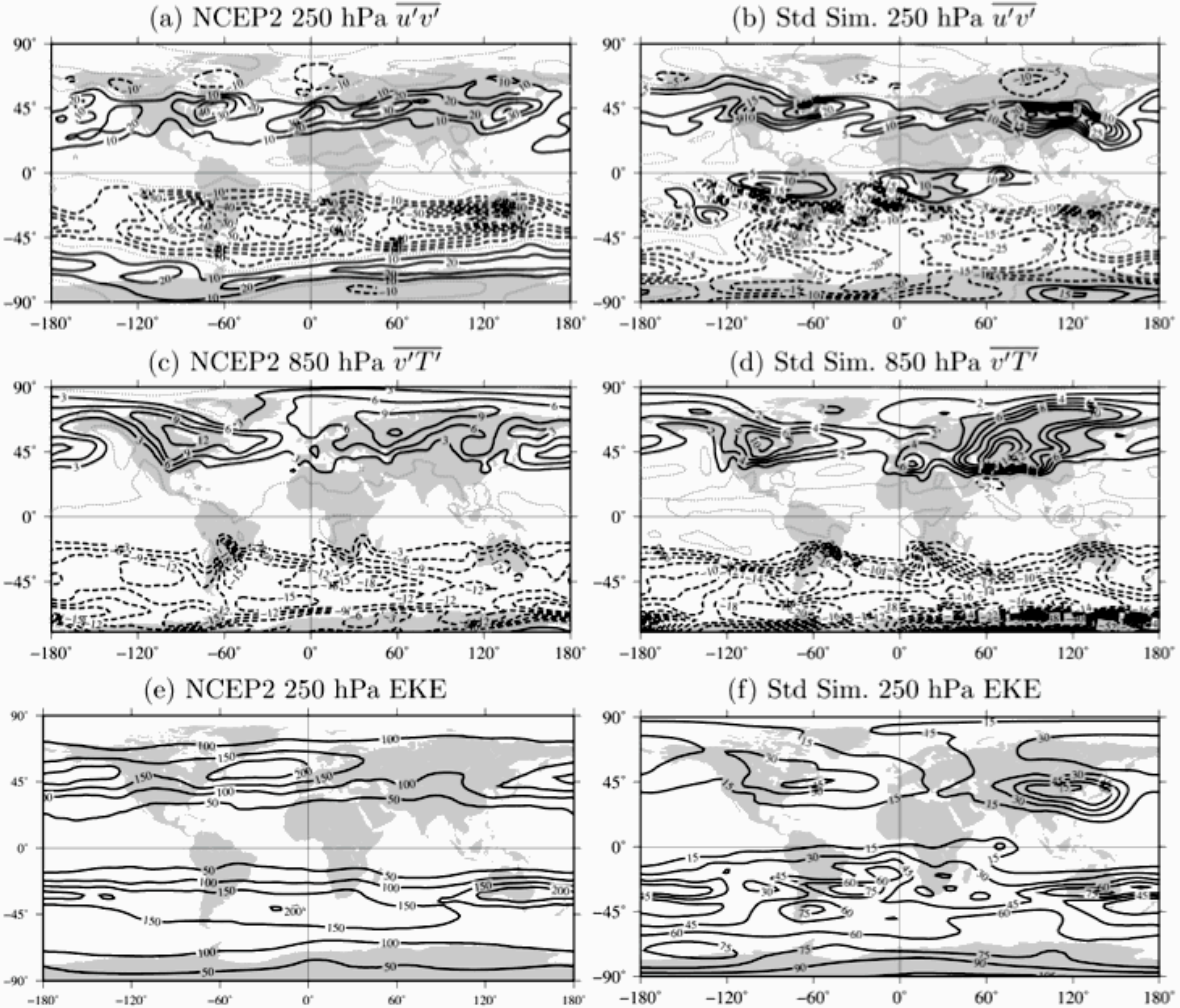


FIG. 2. Covariance fluxes and EKE of the transients of <120 days. (left) June–September 1979–2006 NCEP-2 data, and (right) standard simulation. (a),(b) At 250 hPa, $\overline{u'v'}$ momentum flux contours every 10 and 5 $m^2\ s^{-2}$; (c),(d) $\overline{v'T'}$ temperature flux at 850 hPa, contours every 3 and 2 K^{-1} m s^{-1}; (e),(f) EKE at 250 hPa (see text for definition), contours every 50 and 15 $m^2\ s^{-2}$. Negative values dashed, and zero contour dotted.

A perturbation model

$$\frac{d\mathbf{\Psi}}{dt} + \mathbf{A}(\mathbf{\Psi}) = -\mathbf{D}(\mathbf{\Psi}) + \mathbf{G}$$

Redefine G so that it represents the diabatic source terms plus the transient eddy feedback

$$\mathbf{G} = (\mathbf{A} + \mathbf{D})\left[\frac{1}{N}\sum_{i=1}^{N}\mathbf{\Phi}_i\right] = (\mathbf{A} + \mathbf{D})(\mathbf{\Phi}_c)$$

Development will only occur subject to a perturbation (which could be nudging). If the perturbaiton is small the model is linear

$$\frac{d\mathbf{\Psi}'}{dt} + \mathbf{L}(\mathbf{\Psi}') = (\mathbf{f}'(t))$$

If the perturbation is nudging, the linear model is

$$\frac{d\mathbf{\Psi}'}{dt} + \mathbf{L}(\mathbf{\Psi}') = \epsilon\left(\frac{\mathbf{\Phi}_n - \mathbf{\Phi}_c}{\tau}\right) - \frac{\mathbf{\Psi}'}{\tau}$$

for a consistent definition of the nudging field

$$\mathbf{\Phi}_n^* = \mathbf{\Phi}_c + \epsilon(\mathbf{\Phi}_n - \mathbf{\Phi}_c)$$

the linear nudging term becomes

$$\frac{1}{\tau}(\mathbf{\Phi}_n^* - \mathbf{\Psi}) = \frac{1}{\tau}\{\epsilon(\mathbf{\Phi}_n - \mathbf{\Phi}_c) + (\mathbf{\Phi}_c - \mathbf{\Psi})\}$$

Coping with instability

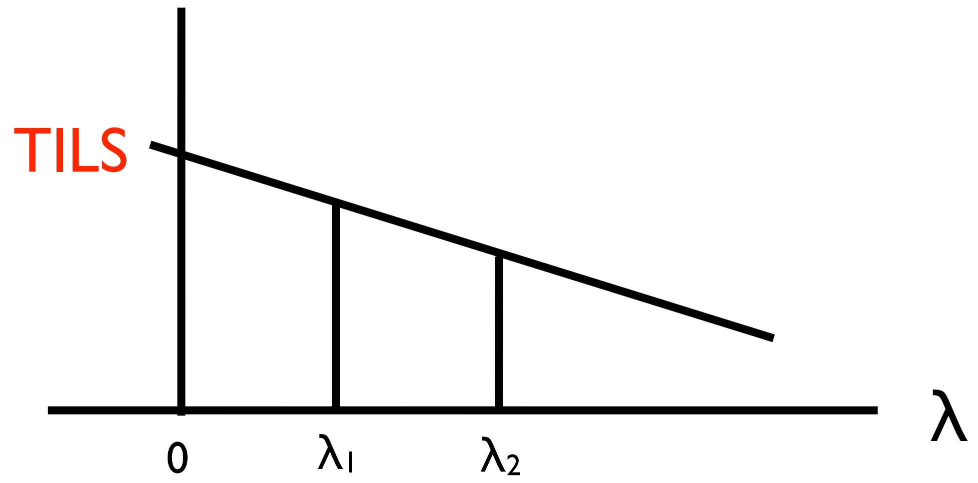
Outside the nudging region the solution is free to grow exponentially if the basic state is unstable. So a long integration will not converge to a steady linear solution in equilibrium with the nudging.

The solution of $$\frac{d\mathbf{\Psi}'}{dt} + (\mathbf{L} + \tau^{-\mathbf{1}})(\mathbf{\Psi}') = \epsilon\left(\frac{\mathbf{\Phi}_n - \mathbf{\Psi}_c}{\tau}\right)$$

will only converge to time independent solution of $$(\mathbf{L} + \tau^{-\mathbf{1}})(\mathbf{\Psi}') = \epsilon\left(\frac{\mathbf{\Phi}_n - \mathbf{\Psi}_c}{\tau}\right)$$

if the linear operator is stable (eigenvalues with negative real parts).
We can fix this without affecting its modal structure by damping everywhere equally

$$\frac{d\mathbf{\Psi}'}{dt} + (\mathbf{L} + \tau^{-1} - \lambda\mathbf{I})\mathbf{\Psi}' = \epsilon\left(\frac{\mathbf{\Phi}_n - \mathbf{\Phi}_c}{\tau}\right)$$



Do this for several λ.
Extrapolate back to λ=0
to get an approximation of
the time independent
linear solution (TILS).

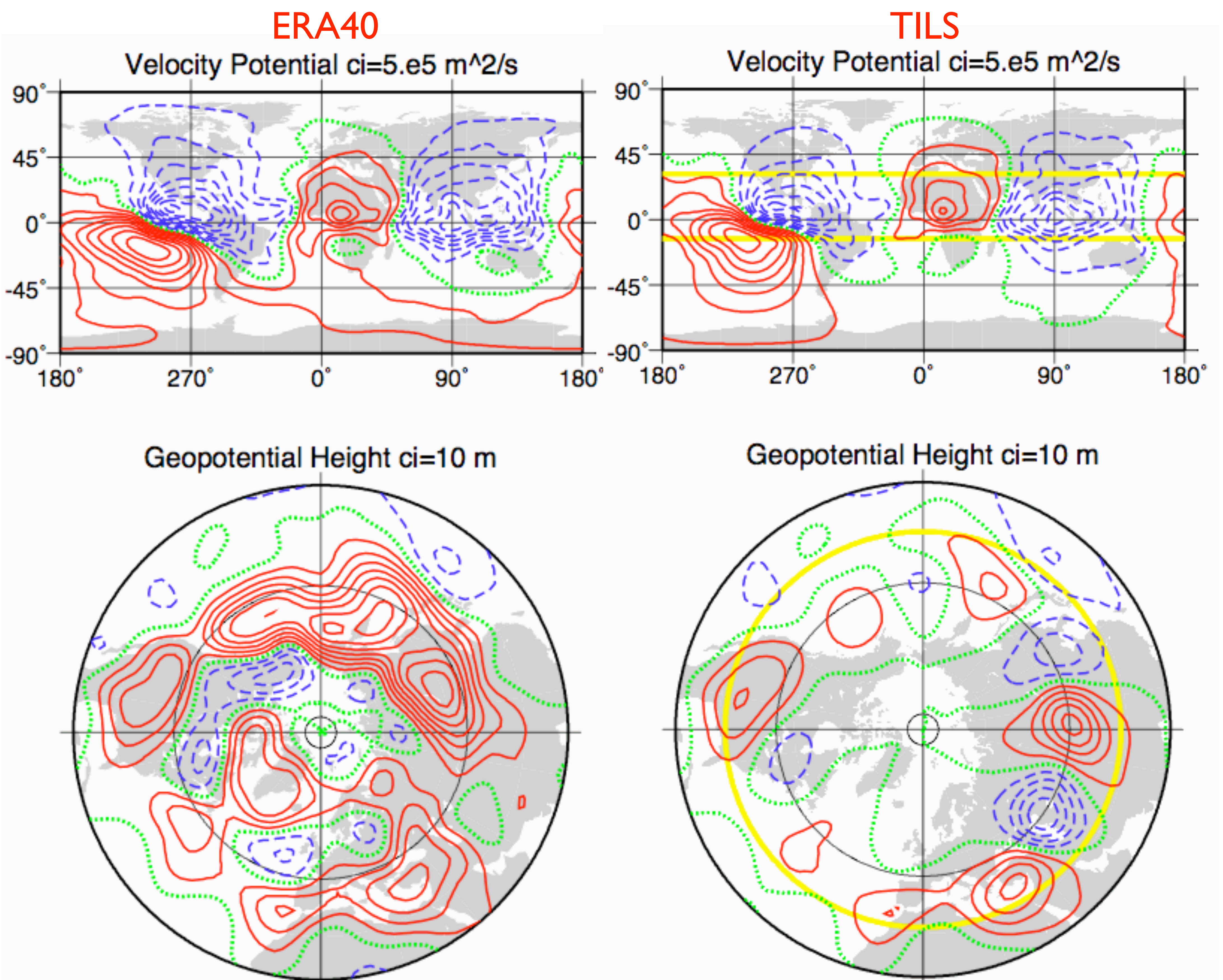

End of technical interlude

Time independent linear solution (TILS)

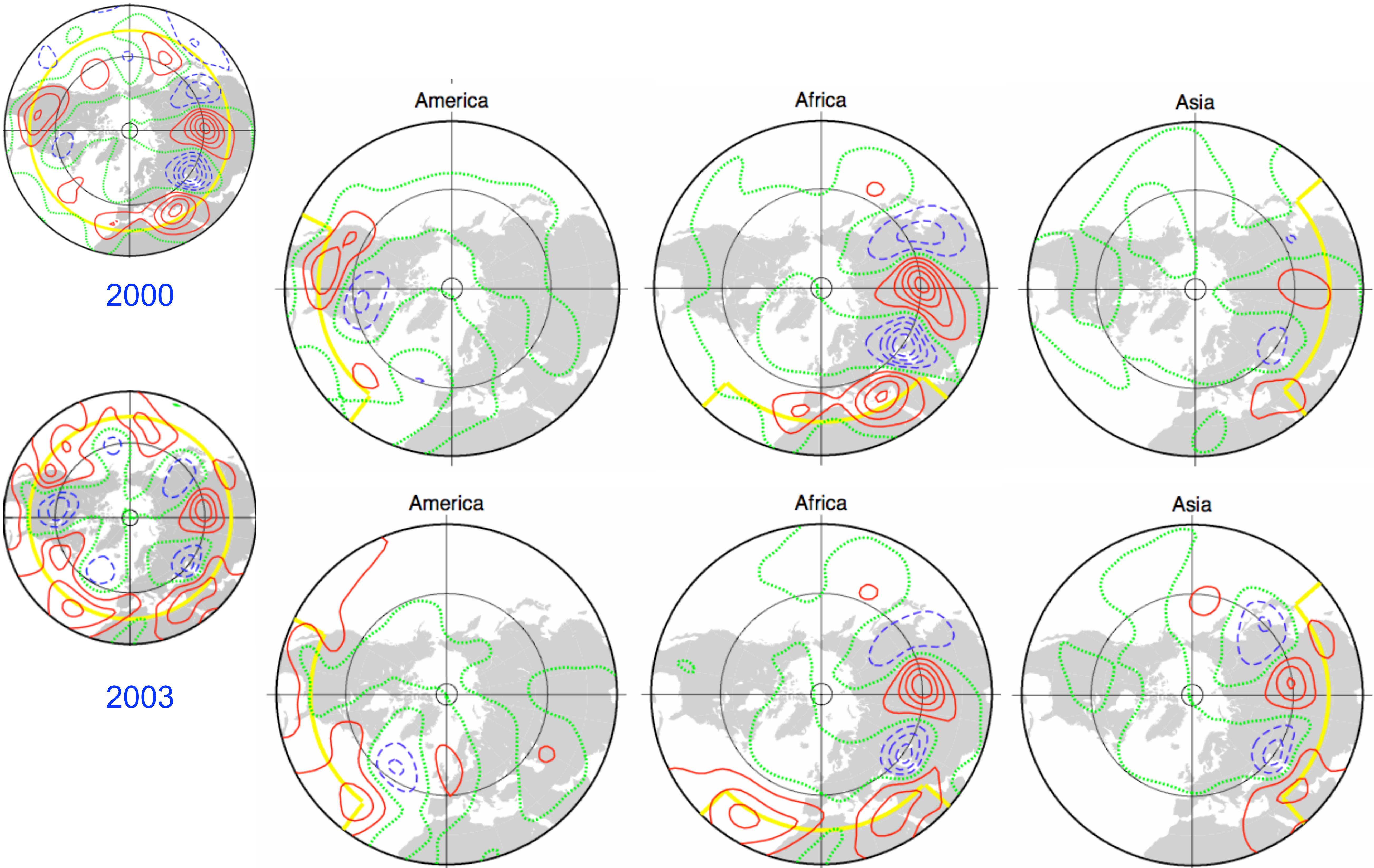
2000

ERA40 anomalies

nudging in tropical band

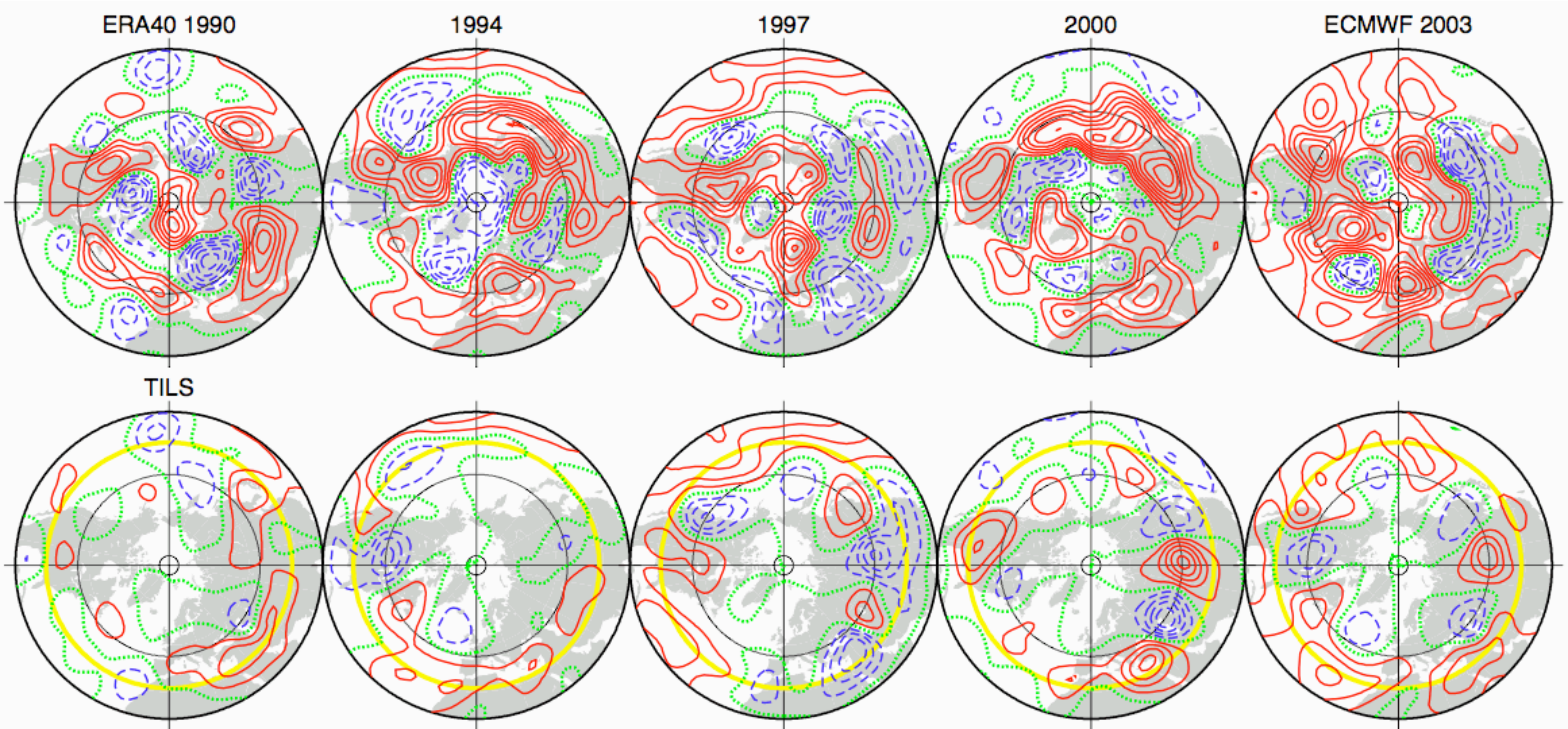


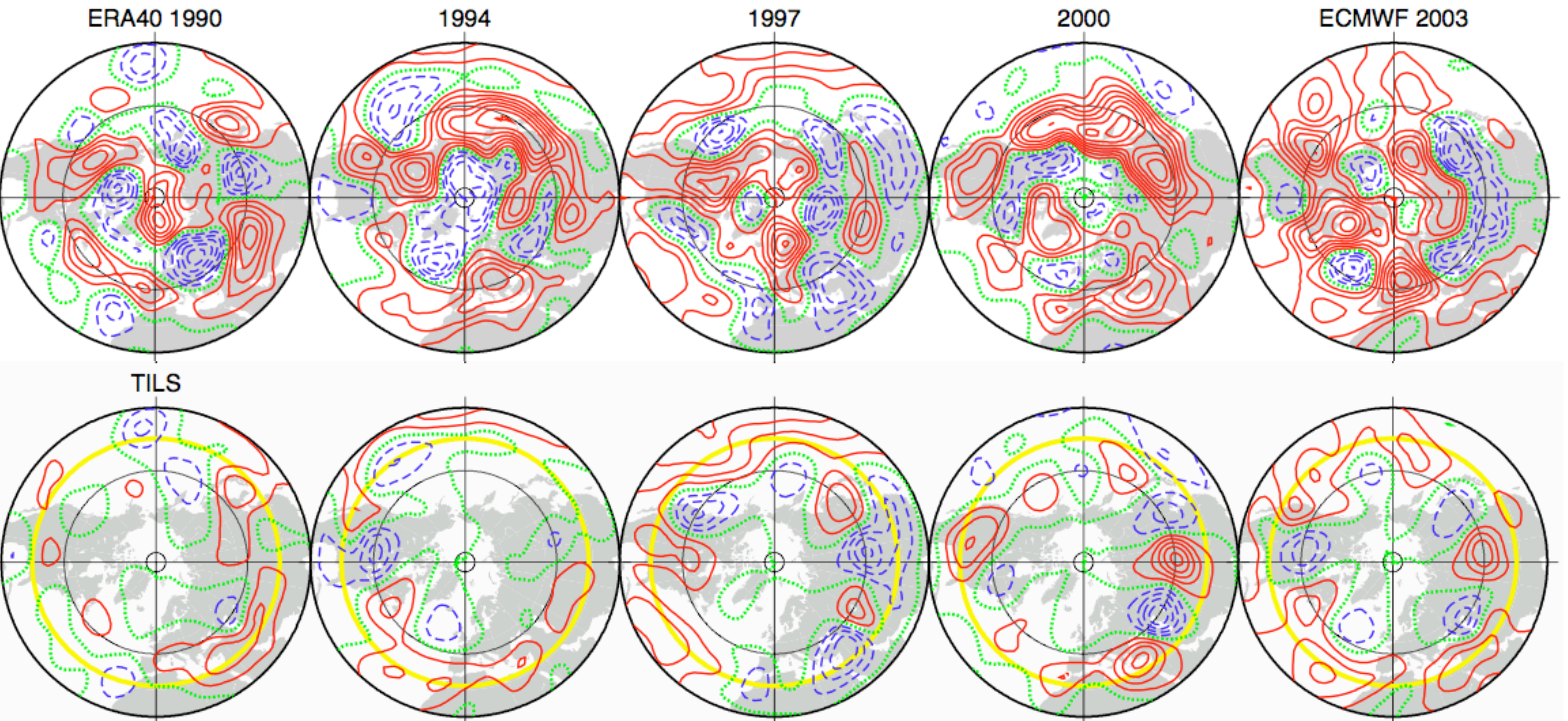
Regional influence: TILS



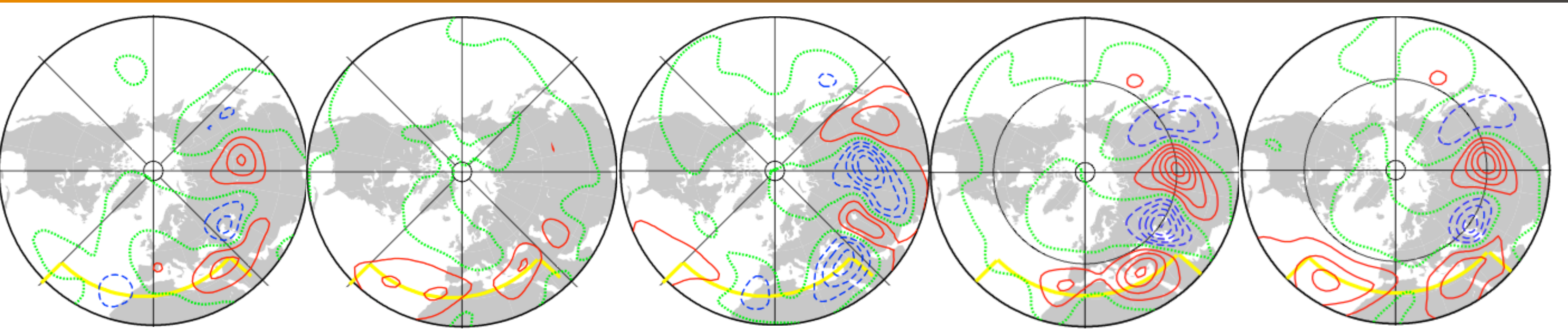
Interannual variations: TILS

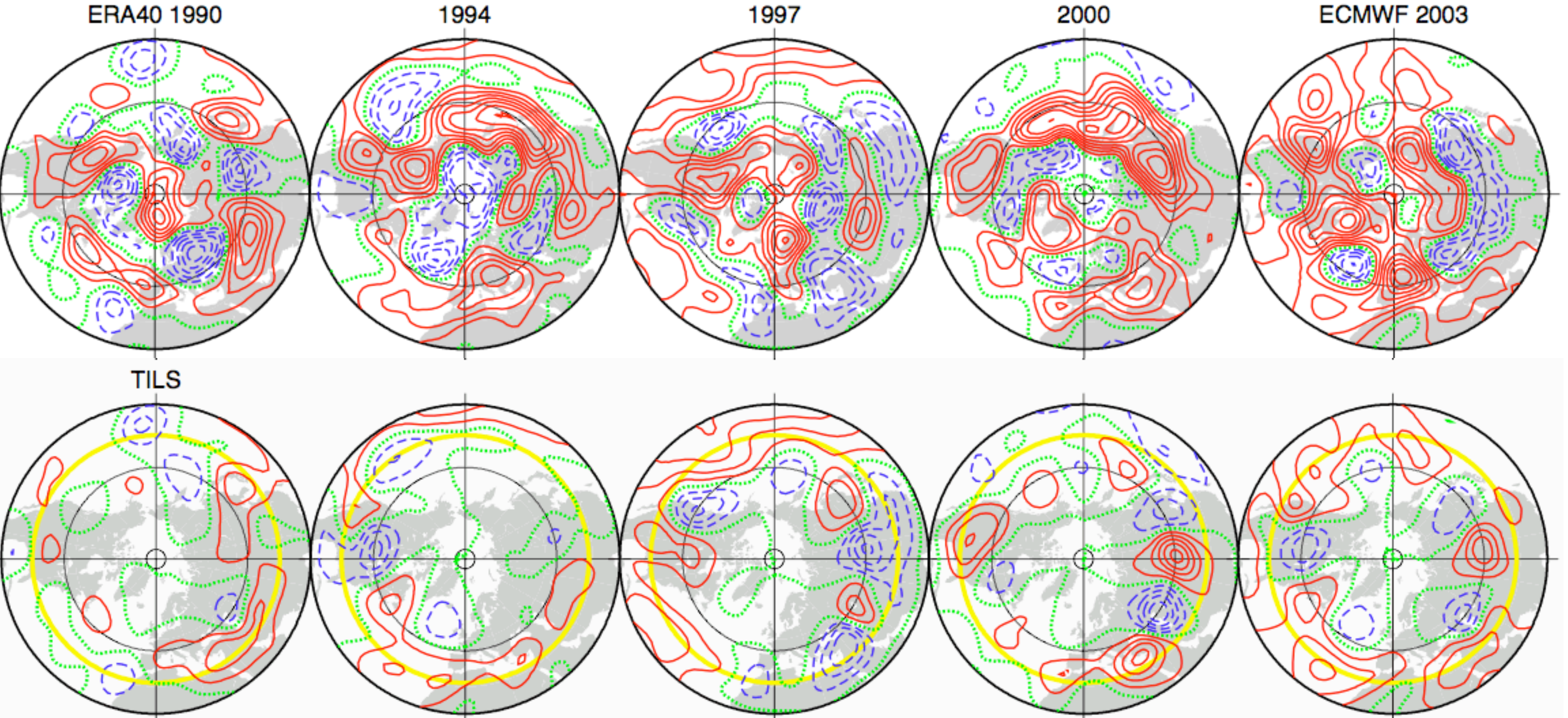
1990: Africa dry, India neutral.
1994: El Nino year, Africa and India wet.
1997: Strong El Nino, weak Afrian and Indian monsoons.
2000: Africa dry, India neutral.
2003: Africa wet, persistent anticyclone over Europe creates drought.



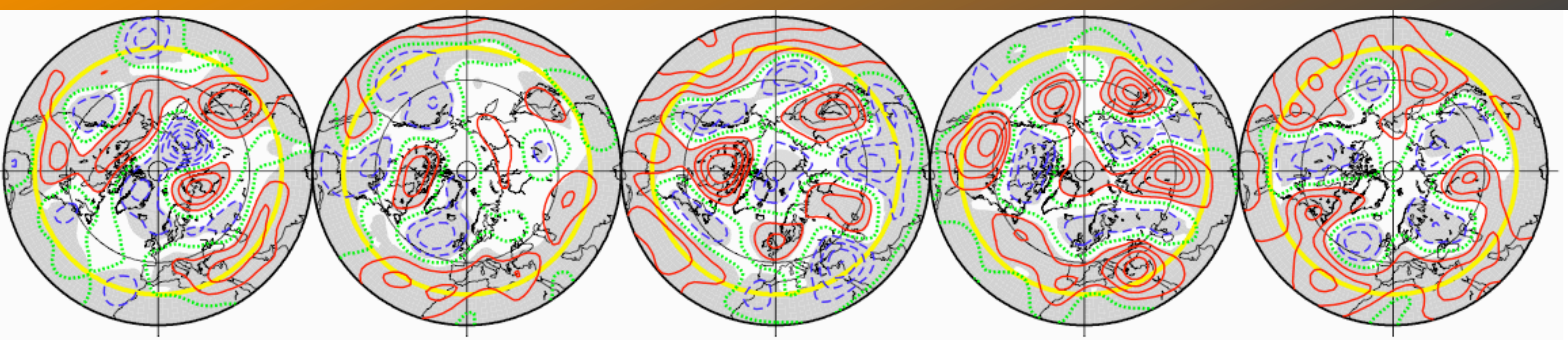


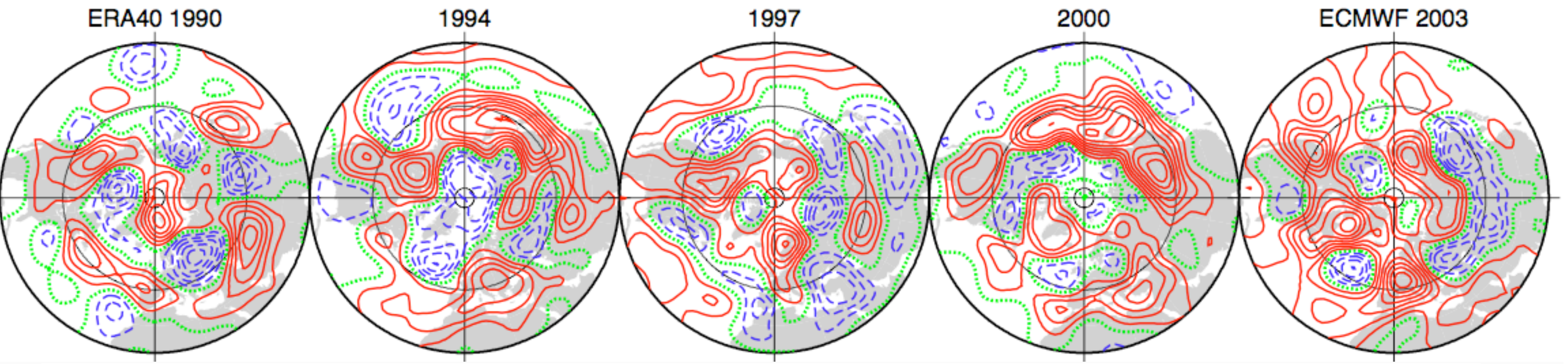
Influence of African Monsoon: TILS



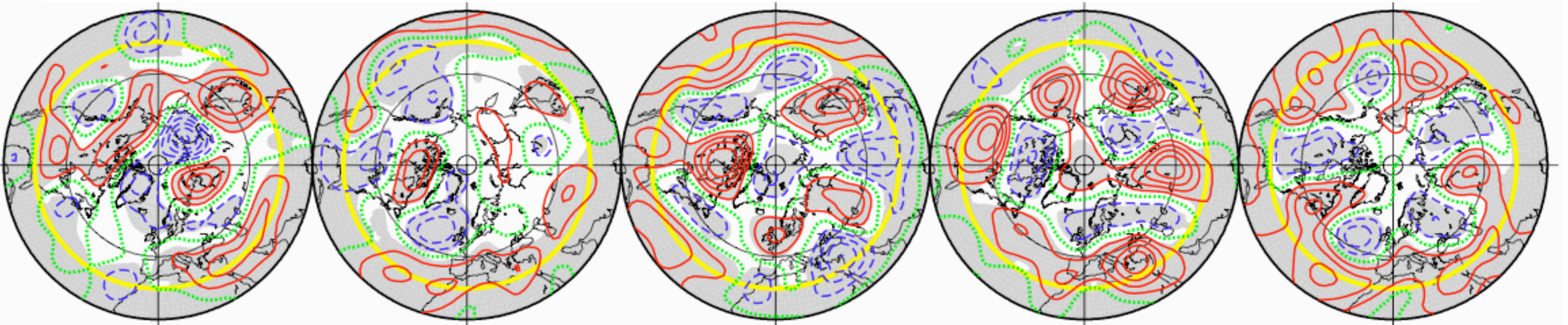


Tropical nudging with the simple GCM

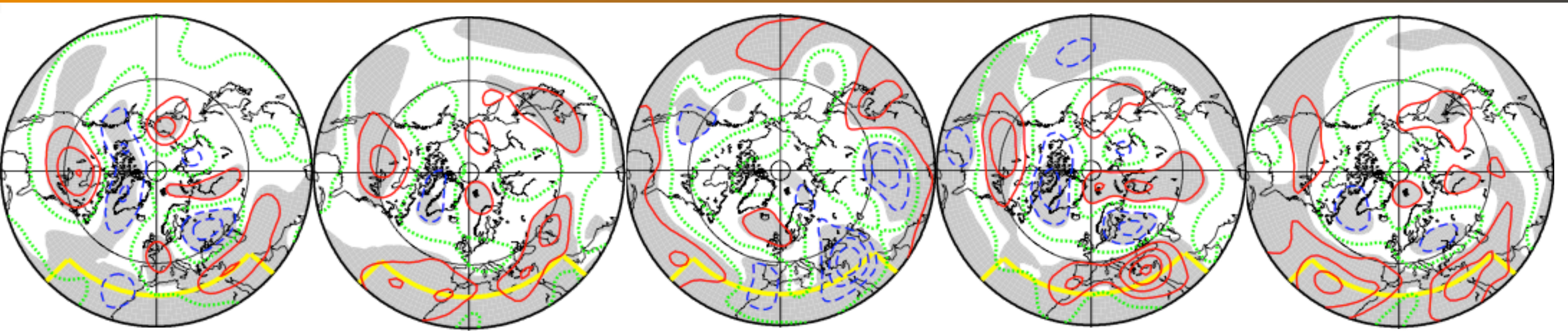




SIMPLE GCM: TROPICAL NUDGING



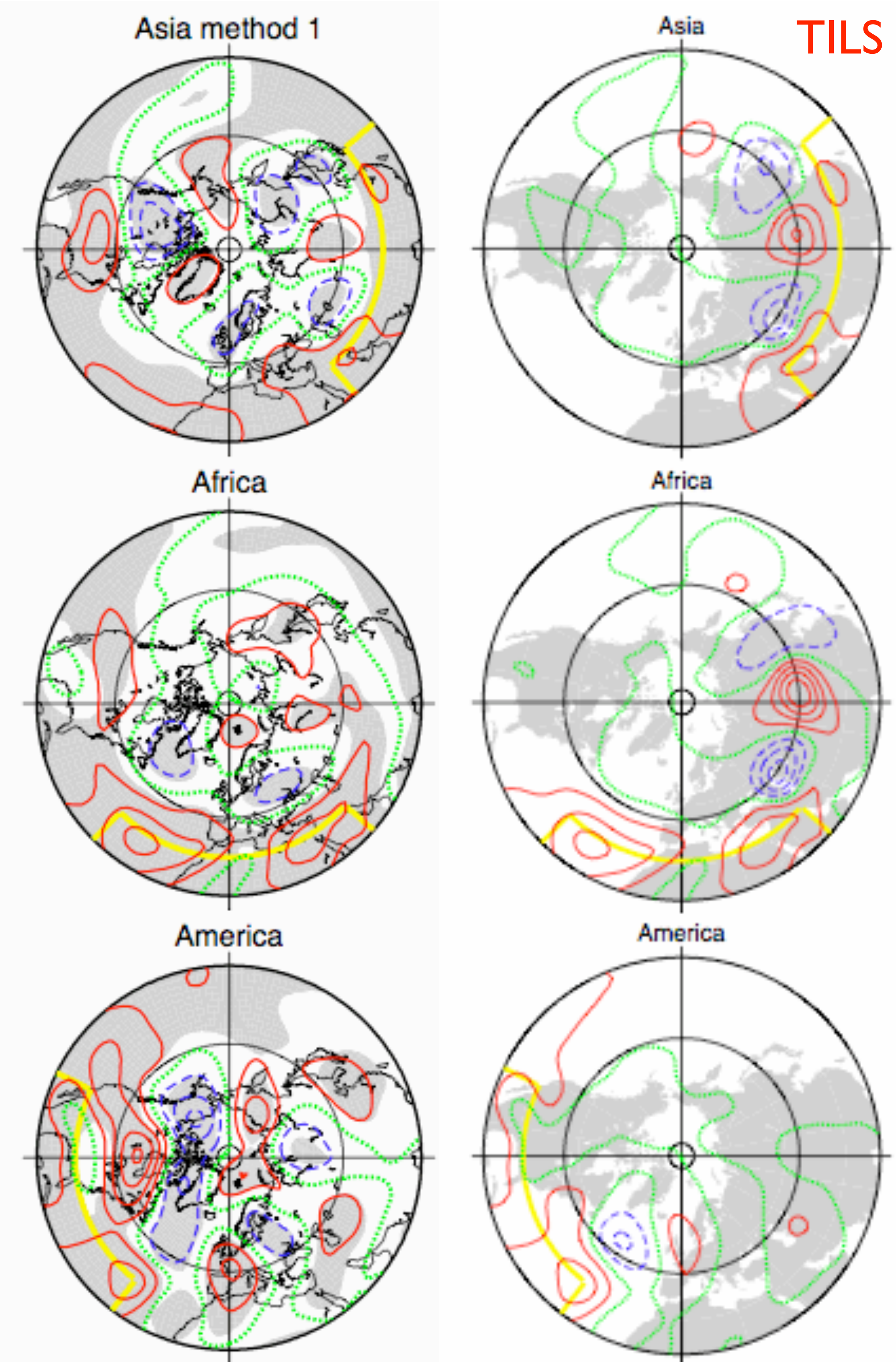
African nudging with the simple GCM



Other monsoon regions for the 2003 case

Note the north American response comes from Asia via a wavetrain that is maintained by transients and is absent from the TILS.

For the European anticyclone the response is not much different from the TILS - suggesting a non-tropical explanation for the amplitude of the heat wave.



Conclusions

- The low latitude extratropical response can be well represented by linear solutions, although they tend to look too wavelike.

- Teleconnections from monsoon regions can have remote effects in the linear solutions: most of the linear wave response over Asia comes from the African monsoon.

- At higher latitudes, transient eddies are needed to obtain a response of reasonable amplitude.

- When transient eddy feedback is included the influence of both African and Asian Monsoons stretches further. Both tropical regions can have a significant effect on North America.