Decadal predictability and forecast skill

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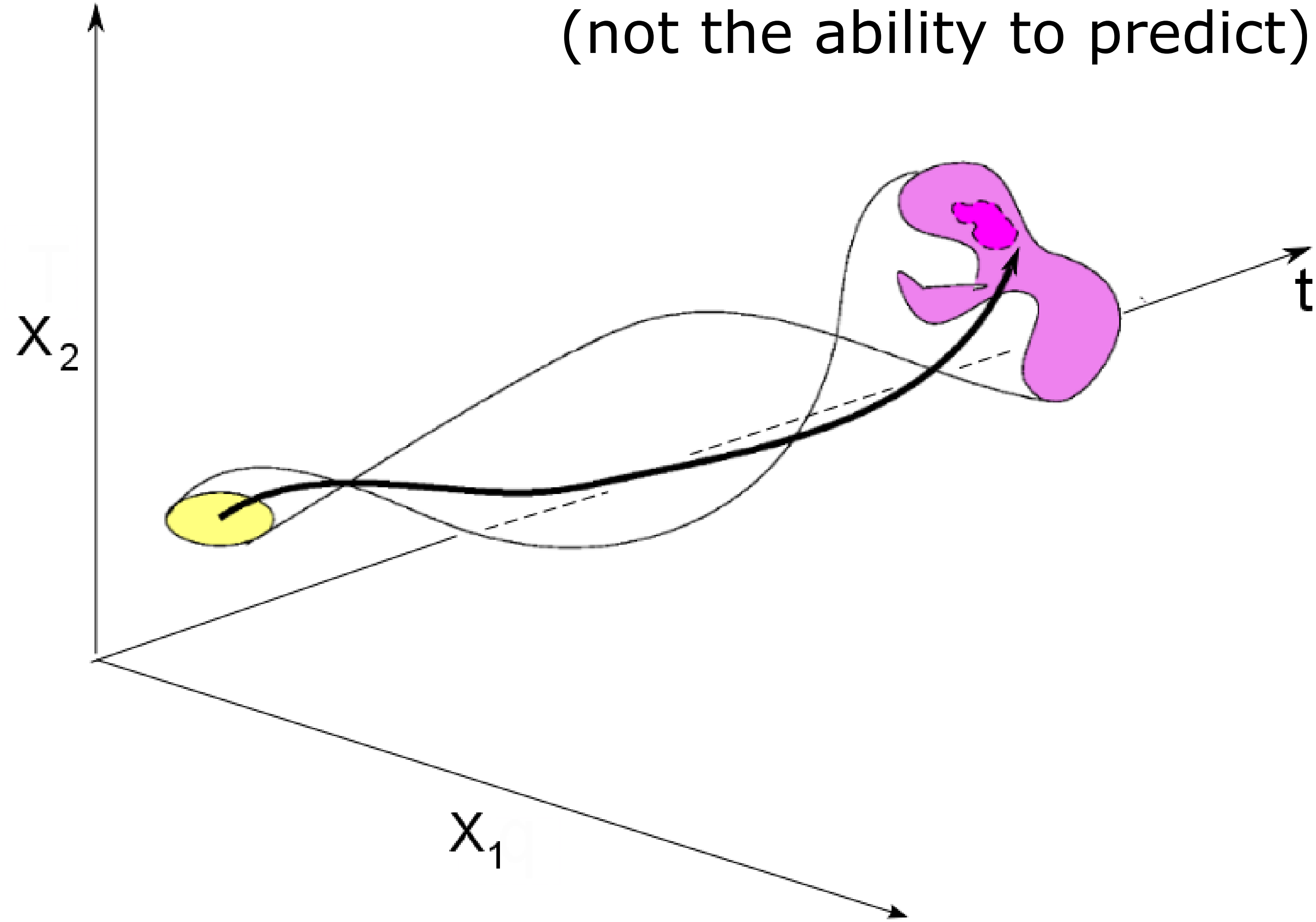
What are the prospects for decadal prediction?

- Excellent prospects that decadal predictions will be made
- Modest prospects that skillful decadal predictions will be made
- Improving prospects for the use of decadal predictions

Decadal prediction motivations

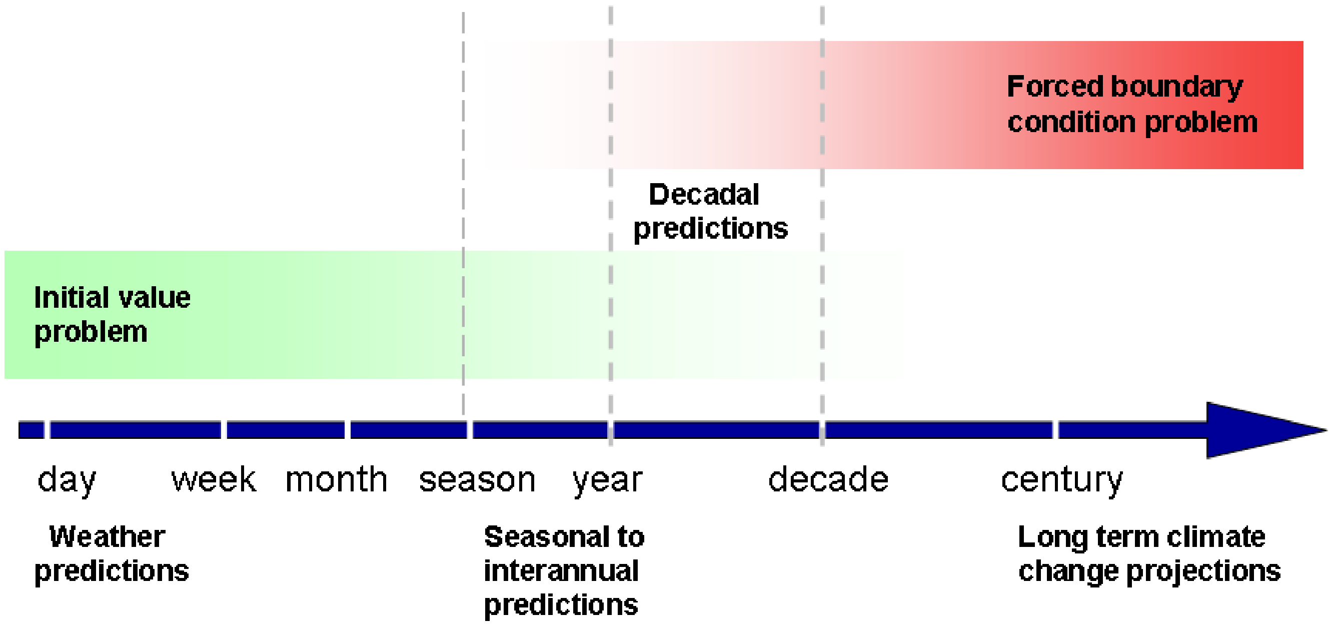
- Existence of "long timescale" processes
- Climate models and climate simulations
- Scientific interest
- *Results of predictability studies*
- *Demonstrations of forecast skill*
- Societal importance of modestly skillful decadal prediction

Predictability – the possibility of prediction
(not the ability to predict)



- separation of states due to small "initial condition" differences/uncertainty/error
    - "perfect model" predictability
- separation also due to difference in model representation
    - generally not studied as such

Both initial conditions and forced response are involved



Climate variation

- Conceptually for a climate variable

$$X = \mu + \chi + x = \mu + \chi_f + \chi_i + x$$

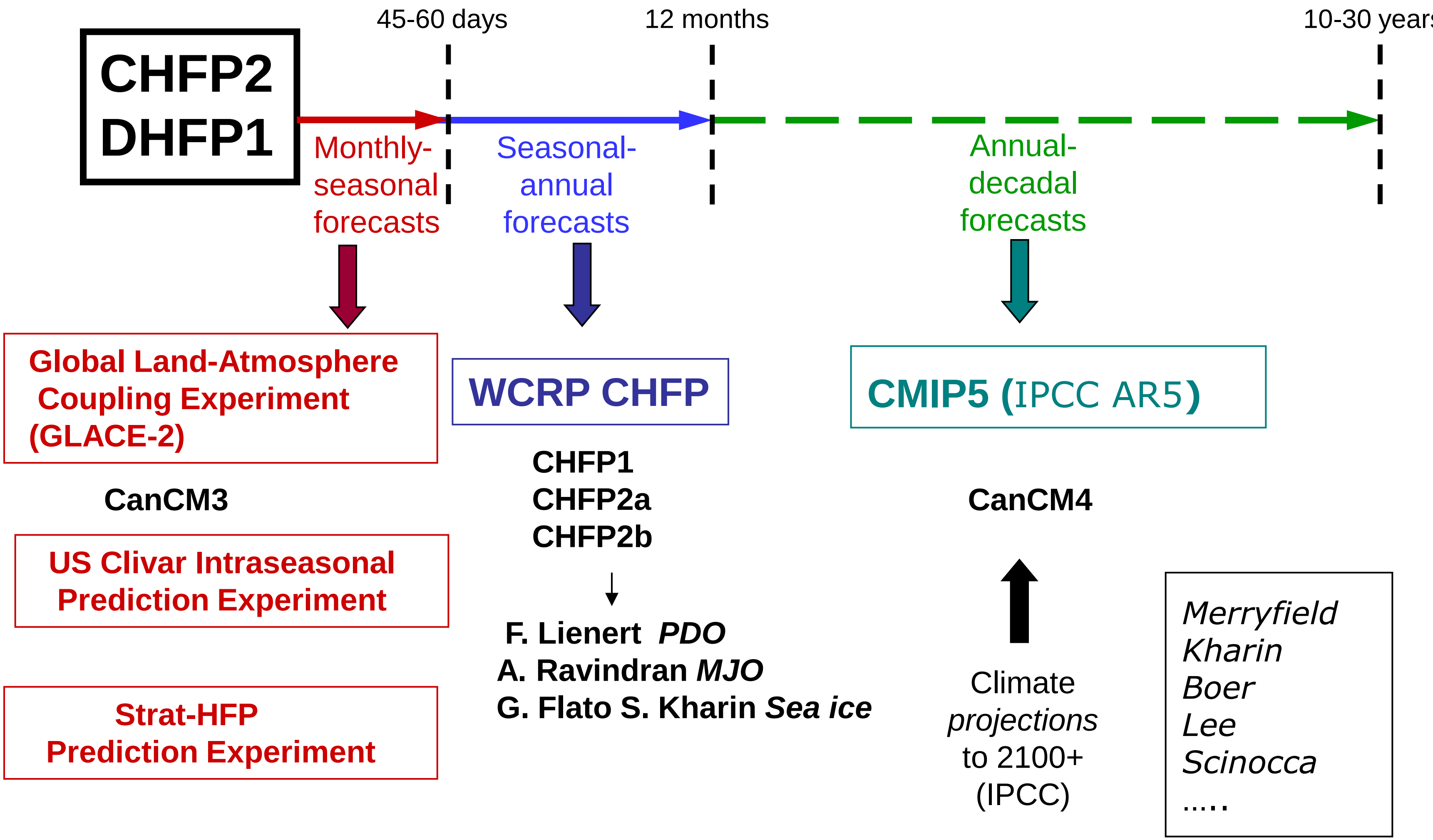
where

- μ is the mean
- $\chi = \chi_f + \chi_i$ the *potentially predictable* component
  - comprised of externally forced and internally generated contributions
- χ_f is the *externally forced* component
  - forced by anthropogenic GHGs, aerosols, volcanoes, solar ….
- χ_i is the *predictable part* of the *internally generated* component
  - arises spontaneously from the internal workings of the system
  - should be predictable from initial conditions at least for some period
- x is the unpredictable component on the timescale considered

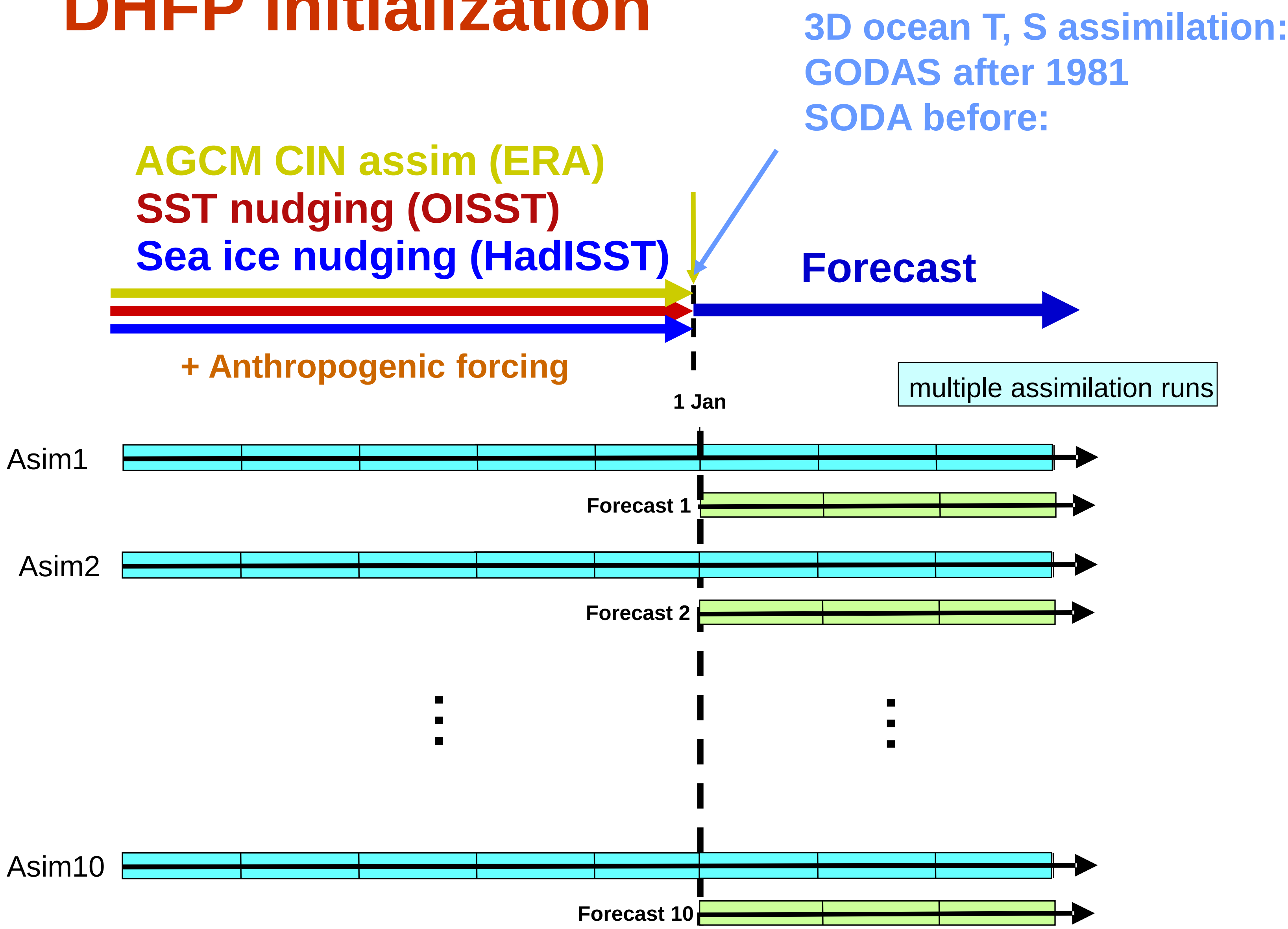
Predictability *and* forecast skill

- based on CCCma decadal hindcast results
  - every year start dates (40+years)
  - 10 member ensembles of forecasts
  - bias correction (Kharin method)
- also 10 member ensemble of climate simulations
- annual mean temperature is basic variable of interest
- *basic idea -* use hindcasts to investigate both predictability and skill
  - spread of forecasts *within ensemble* gives an estimate of (prognostic, perfect model) *predictability*
  - separation of forecasts *from observations* gives measure of *forecast skill*
  - climate *simulations* may provide *approximate* information on forced component
- statistics involved are functions of forecast range τ

CCCma (seamless) Predictions



DHFP initialization



Predictability and forecast skill

obs
$$X_{j\tau} = \mu + \chi_{j\tau} + x_{j\tau} = \mu + \chi_f + \chi_i + x$$

fcsts
$$Y_{\alpha j\tau} = \nu + \psi_{j\tau} + y_{\alpha j\tau} = \nu + \psi_f + \psi_i + y$$

sims
$$U_{\alpha j\tau} = \eta + \varphi_{\alpha j\tau} + u_{\alpha j\tau} = \eta + \varphi_f + \varphi_i + u$$

- (X,Y,U) are obs, forecasts, simulations
  - j is start time (1 … 40 years)
  - τ is forecast range (1 … 10 years)
  - α is ensemble member (1 …10)
- (μ,ν,η) are means
- (χ,ψ,φ) potentially predictable components
- (x,y,u) unpredictable components

Variances and potential predictability

obs $$\sigma_X^2 = \sigma_\chi^2 + \sigma_x^2 = \sigma_{\chi_f}^2 + \sigma_{\chi_i}^2 + \sigma_x^2$$

fcsts $$\sigma_Y^2 = \sigma_\psi^2 + \sigma_y^2 = \sigma_{\psi_f}^2 + \sigma_{\psi_i}^2 + \sigma_y^2$$

Potential predictability variance fraction of system (ppvf)

$$p = \sigma_\chi^2/\sigma_X^2 = \sigma_\chi^2/(\sigma_\chi^2 + \sigma_x^2)$$

$$= (\sigma_{\chi_f}^2 + \sigma_{\chi_i}^2)/\sigma_X^2 = p_f + p_i$$

Perfect model ppvf

$$q = \sigma_\psi^2/\sigma_Y^2 = (\sigma_{\psi_f}^2 + \sigma_{\psi_i}^2)/\sigma_Y^2 = q_f + q_i$$

Statistics for ensemble means Y_a, U_a

$$
\begin{aligned}
VarY_a &= E\overline{(\{Y\}-\nu)^2} = \sigma^2_{Y_a} = \sigma^2_\psi + \sigma^2_y/m = \sigma^2_{\psi_f} + \sigma^2_{\psi_i} + \sigma^2_y/m \rightarrow \sigma^2_{\psi_f} + \sigma^2_{\psi_i} \\
VarU_a &= E\overline{(\{U\}-\eta)^2} = \sigma^2_{U_a} = \sigma^2_{\varphi_f} + (\sigma^2_{\varphi_i} + \sigma^2_u)/m \approx \sigma^2_{\psi_f} + \sigma^2_u/m \rightarrow \sigma^2_{\psi_f} \qquad (3) \\
CovXY_a &= E\overline{(X-\mu)(\{Y\}-\nu)} = E\overline{\chi\psi} = E(\overline{\chi_f\psi_f} + \overline{\chi_i\psi_i}) = \sigma_\chi\sigma_\psi\mathcal{R}_{\chi\psi}(\tau) \\
CovXU_a &= E\overline{(X-\mu)(\{U\}-\eta)} = E\overline{\chi\varphi} = E\overline{\chi_f\varphi_f} \approx E\overline{\chi_f\psi_f} \\
CovYY_a &= E\overline{(Y-\nu)(\{Y\}-\nu)} = E\overline{\psi^2} = \sigma^2_\psi = \sigma^2_{\psi_f} + \sigma^2_{\psi_i} \\
CovY_aU_a &= E\overline{(\{Y\}-\nu)(\{U\}-\eta)} = E\overline{\psi\varphi} = \overline{\psi_f\varphi_f} \approx \sigma^2_{\psi_f}
\end{aligned}
$$

arrows are "large ensemble" limit $\sigma_y^2/m \Rightarrow 0$ for *m* large

forced component *approximation* $\varphi_f \sim \chi_f$ also indicated

Potential and actual correlation skill

Perfect model correlation skill

$$\begin{aligned}
\rho &= CovYY_a/\sqrt{VarY.VarY_a} = \sigma^2_{\psi}/\sigma_Y\sigma_{Y_a} \to \sigma_{\psi}/\sigma_Y = \sqrt{q} \\
&= (\sigma^2_{\psi_f} + \sigma^2_{\psi_i})/\sigma_Y\sigma_{Y_a} = \rho_f + \rho_i \\
\rho_f &= \sigma^2_{\psi_f}/\sigma_Y\sigma_{Y_a} \approx \sigma^2_{\varphi_f}/\sigma_Y\sigma_{Y_a} = CovU_aY_a/\sqrt{VarY.VarY_a} \\
\rho_i &= \sigma^2_{\psi_i}/\sigma_Y\sigma_{Y_a} \approx \rho - \rho_f
\end{aligned}$$

Actual correlation skill

$$\begin{aligned}
r &= CovXY_a/\sqrt{VarX.VarY_a} = E\overline{\chi\psi}/\sigma_X\sigma_{Y_a} = \sqrt{q_a p}R_{\chi\psi}(\tau) \to \sqrt{p}\mathcal{R}_{\chi\psi}(\tau) \\
&= E\left(\overline{\chi_f\psi_f} + \overline{\chi_i\psi_i}\right)/\sigma_X\sigma_{Y_a} = r_f + r_i \\
r_f &= E\overline{\chi_f\psi_f}/\sigma_X\sigma_{Y_a} \approx E\overline{\chi_f\varphi_f}/\sigma_X\sigma_{Y_a} = CovXU_a/\sqrt{VarX.VarY_a} \\
r_i &= E\overline{\chi_i\psi_i}/\sigma_X\sigma_{Y_a} \approx r - r_f
\end{aligned}$$

Separation into forced and internal components

- depends on *approximation* $\varphi_f \sim \chi_f$
- i.e. forced component of *simulation* approx that of *forecast*

Potential and actual mean square skill score

Actual MSSS

$$\begin{aligned} M &= 1 - MSE/MSE_R \\ &= (2CovXY_a - VarY_a)/VarX = \left(2E\overline{\chi\psi} - (\sigma_\psi^2 + \sigma_y^2/m)\right)/\sigma_X^2 \\ &= \left(\frac{\sigma_{Y_a}}{\sigma_X}\right)\left(2\sqrt{pq_a}\mathcal{R}_{\chi\psi}(\tau) - \left(\frac{\sigma_\psi}{\sigma_X}\right)\right) \to \left(\frac{\sigma_\psi}{\sigma_X}\right)\left(2\sqrt{p}\mathcal{R}_{\chi\psi}(\tau) - \left(\frac{\sigma_\psi}{\sigma_X}\right)\right) \end{aligned}$$

Perfect model MSS

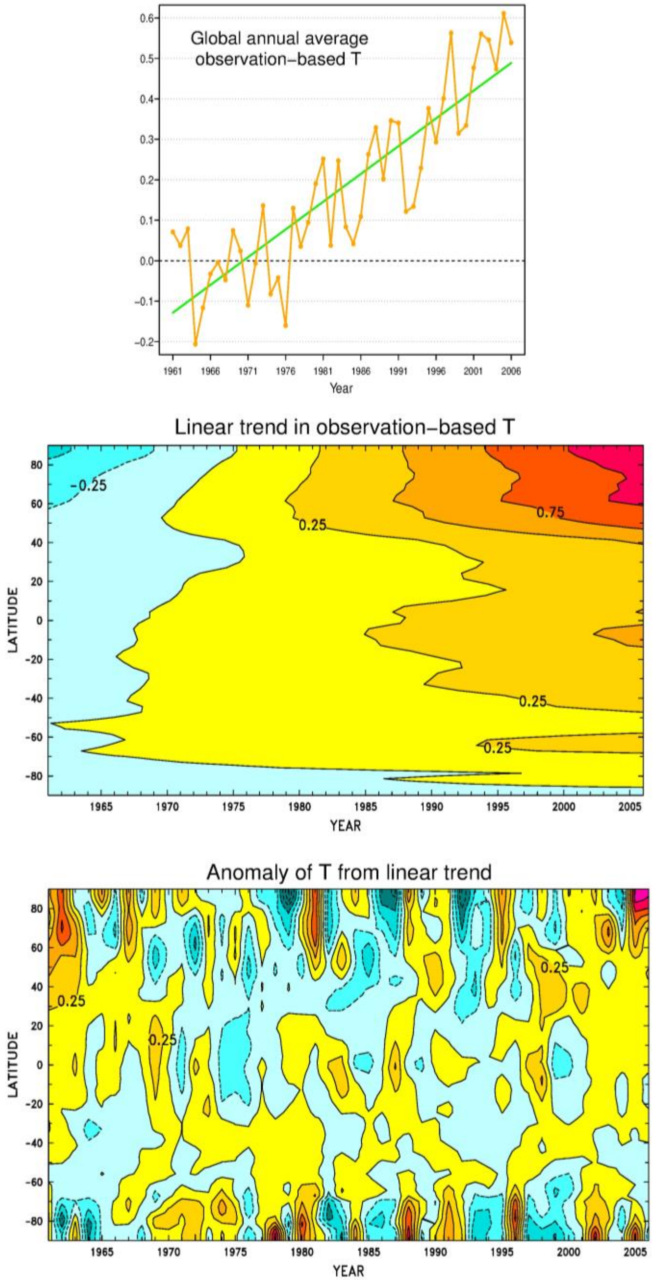
$$\begin{aligned} \mathcal{M} &= (2CovYY_a - VarY_a)/VarY \\ &= (\sigma_\psi^2 - \sigma_y^2/m)/\sigma_Y^2 \\ &= q - \sigma_y^2/m\sigma_Y^2 \to q \end{aligned}$$

For perfect model

$$q \;>\; \rho^2 > \mathcal{M} \to q = \rho^2 = \mathcal{M}$$ for large ensemble limit

For actual model

$$p > r^2 > M$$

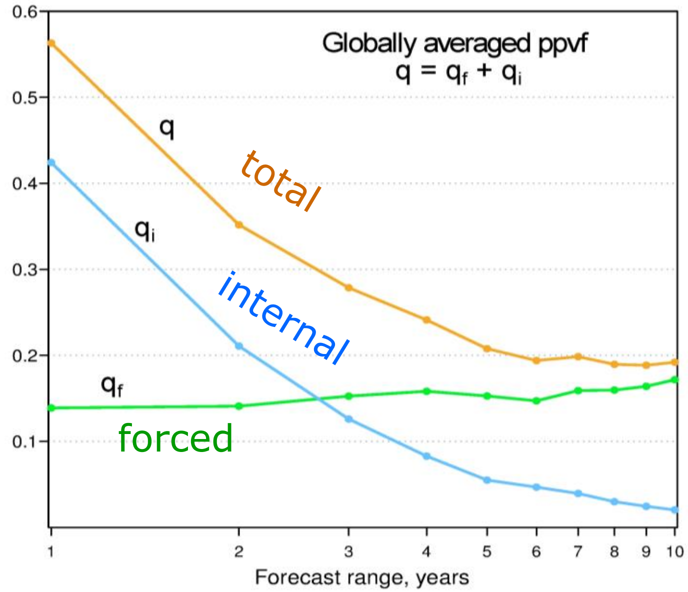


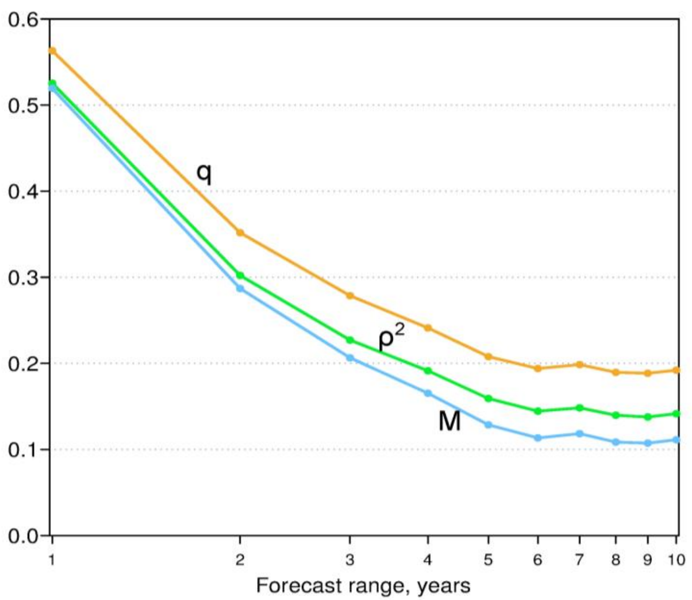
1961 1985 2006

Observed annual mean T behaviour

- global mean warming
- trend is larger at high northern latitudes
  - (and over land)
- variation about trend indication of internally generated component
- variability higher at higher latitudes
  - (and over land)

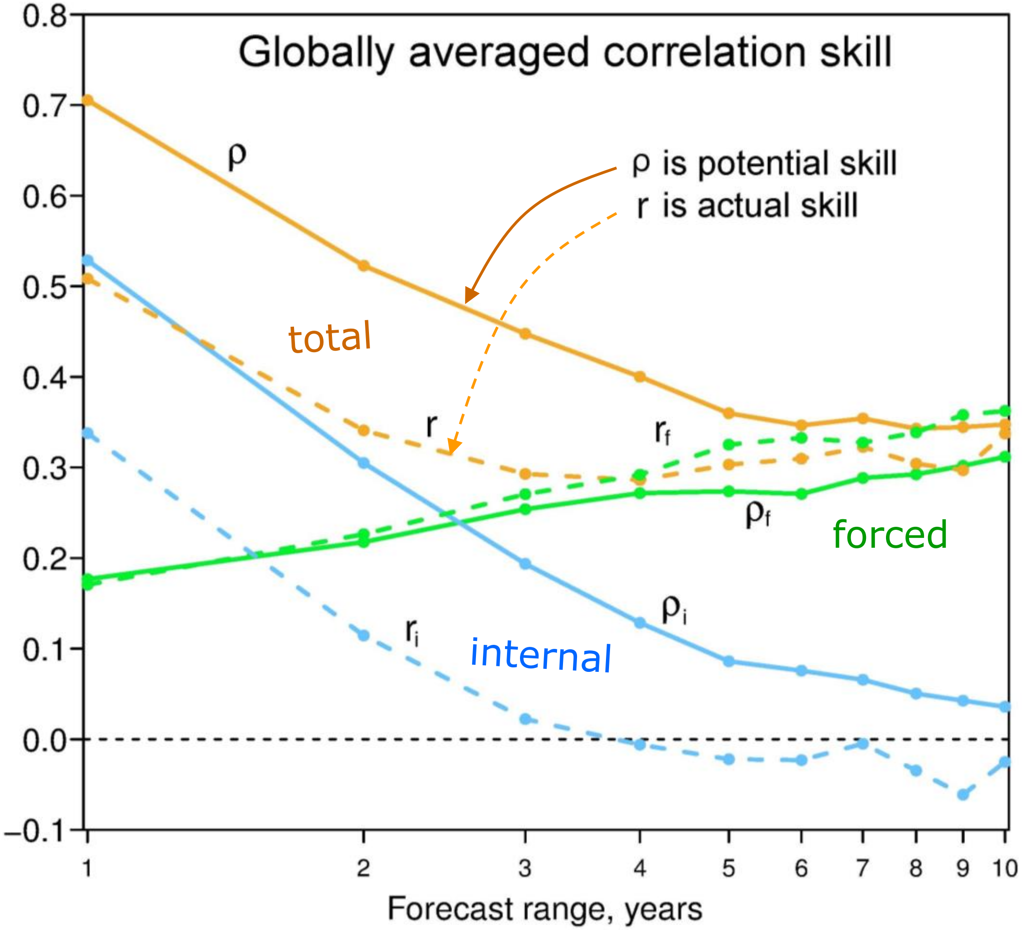
Globally averaged predictability statistics





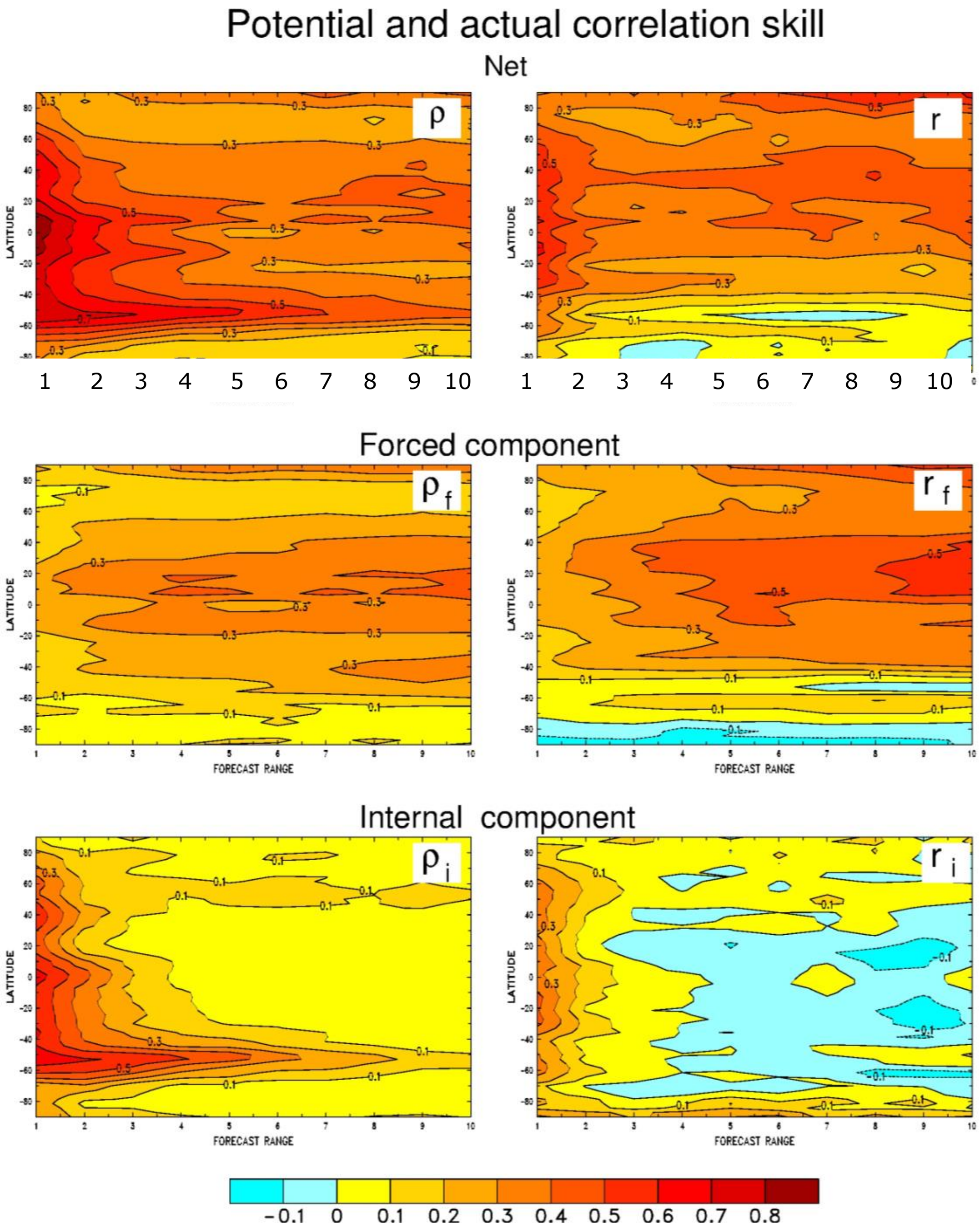
- upper limit to skill (in model context)
  - decline of internal component ppvf
  - cross-over ~ 3 years
- perfect model potential predictability q
  - ensemble m =10
  - $q > \rho^2 > M$ as expected
  - expected to converge for larger m

Globally averaged skill scores



Annual means of surface air temperature

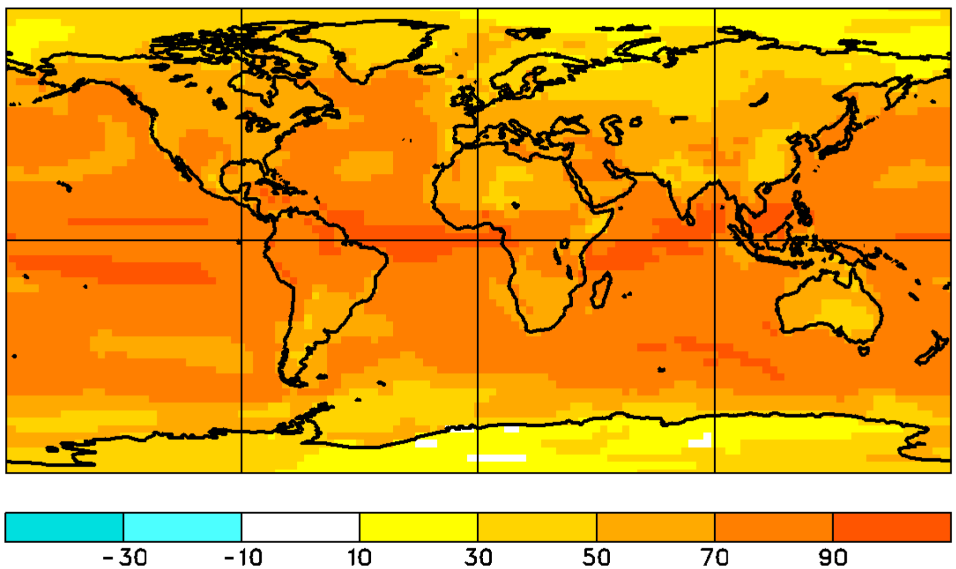
- Predictability declines with τ then stabilizes
  - internal component skill at early times decreases
  - forced skill increases somewhat
- Skill roughly parallel but weaker
  - internal component skill to zero at 3-4 years
  - *approximate* forced skill close to potential
- Spread between ρ and r suggest possibility for improvement



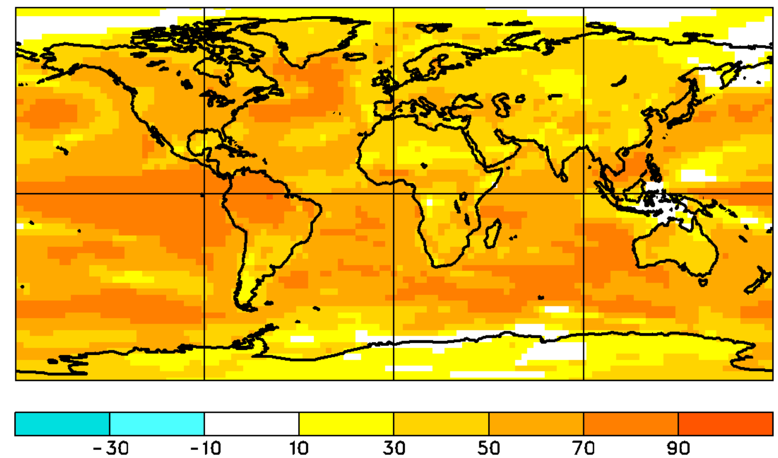
- Latitudinal behaviour
  - *approximate* forced component skill
    - dominates tropics
    - (too) well captured by actual skill
  - internal component skill
    - initial skill declines rapidly
    - actual skill declines more rapidly especially in southern ocean

Correlation skill r of year 1 annual mean T

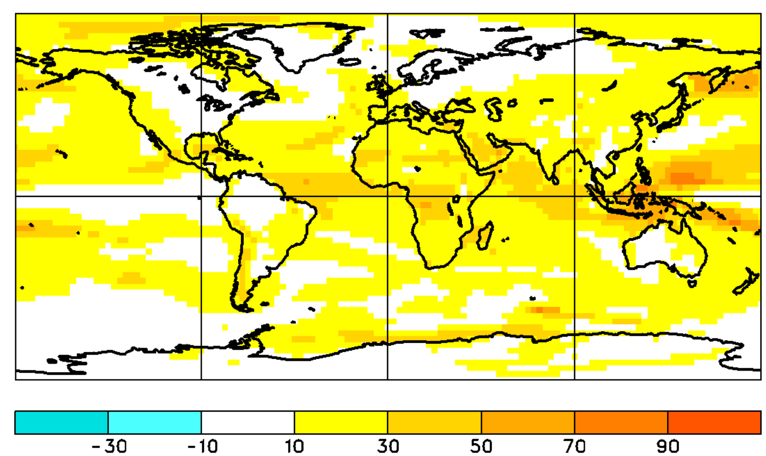
Overall correlation skill



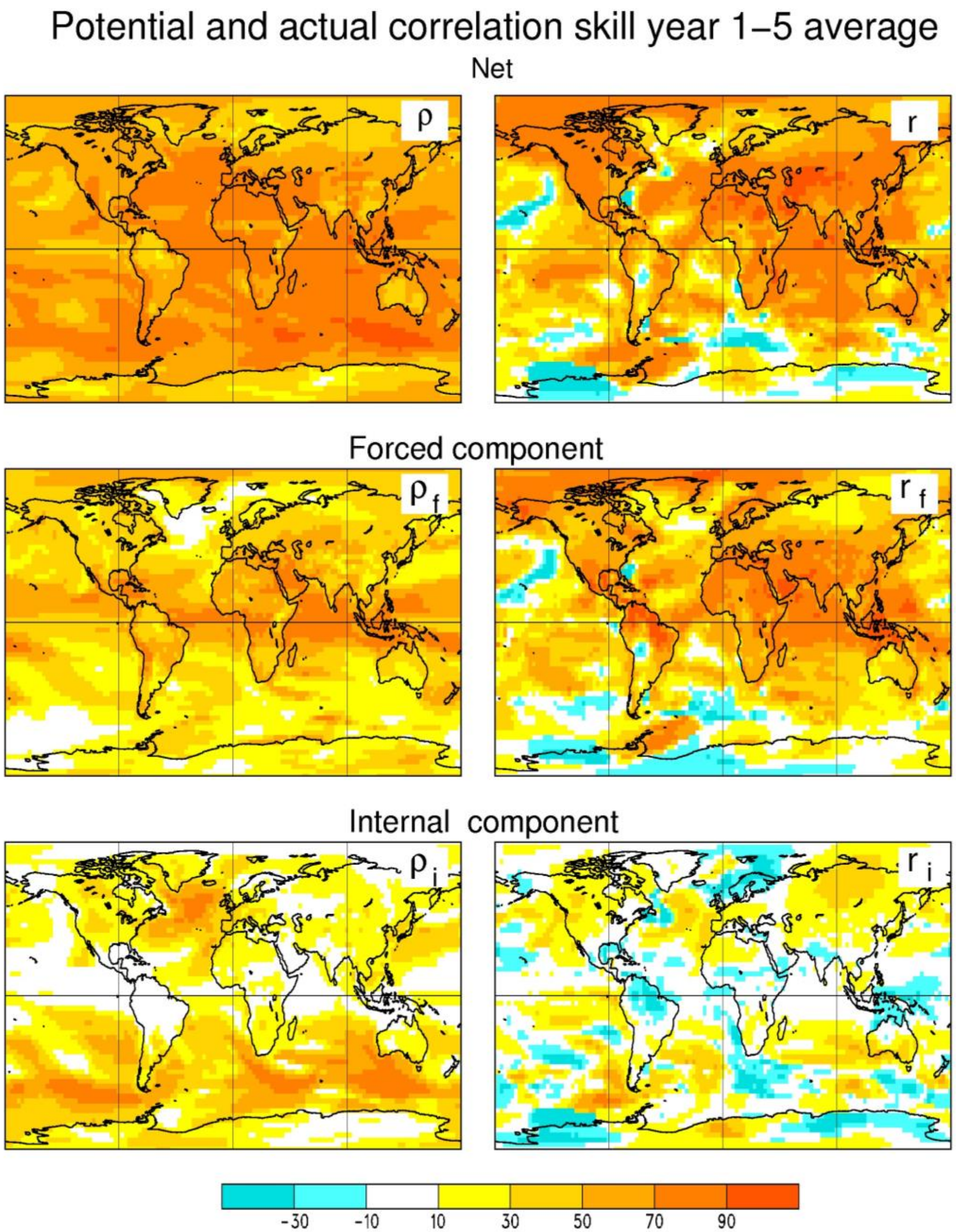
Internally generated



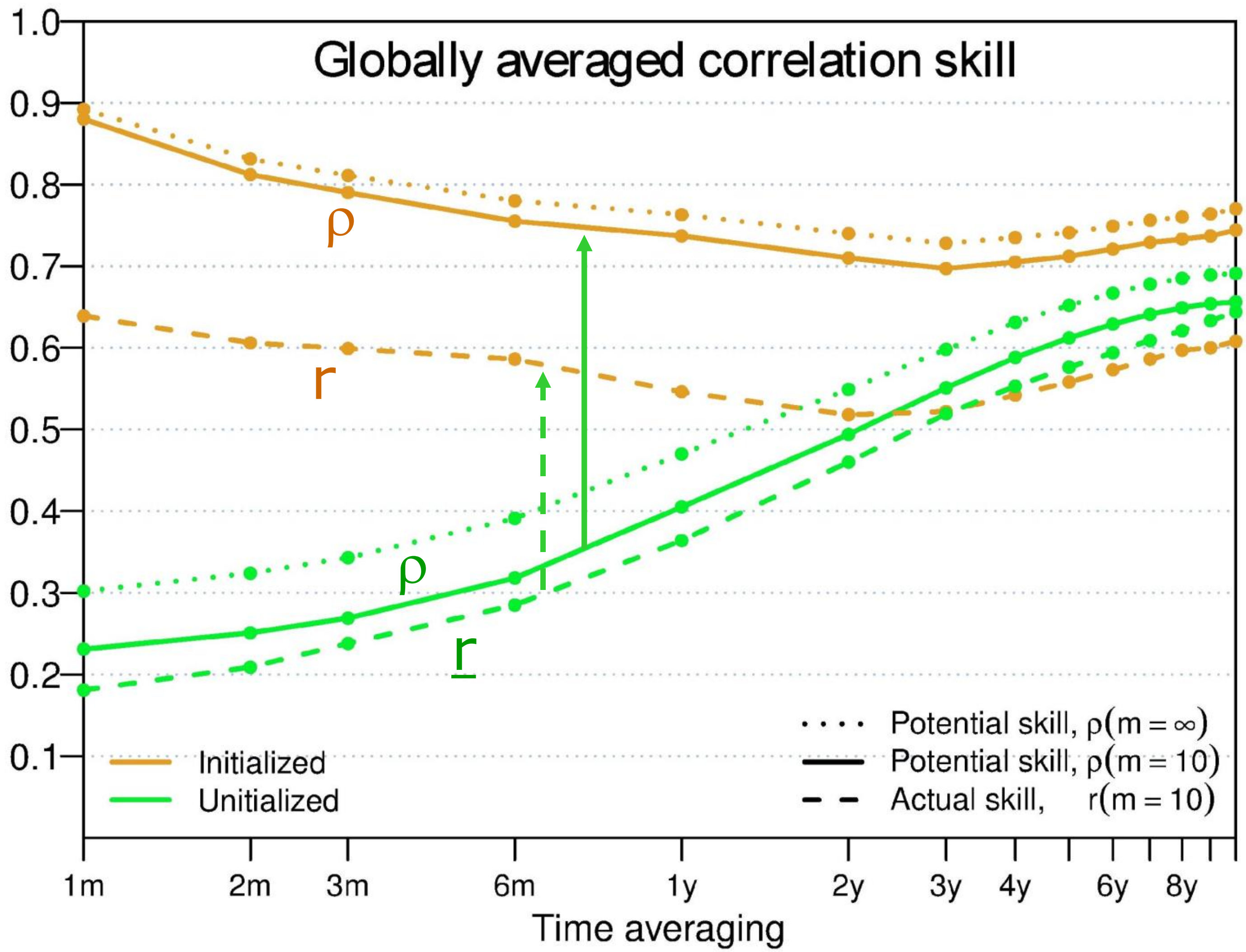
Forced



Skill of initialized internally generated component dominates at early times



- results depend on averaging time
  - more averaging more influence from forced component
  - internal component averaged out
- pattern for ρ
  - forced component skill in tropics and over land
  - internal component skill over some land oceans espc. NA and SO
- pattern for r
  - broadly as for ρ but less skill
  - retain skill in NA

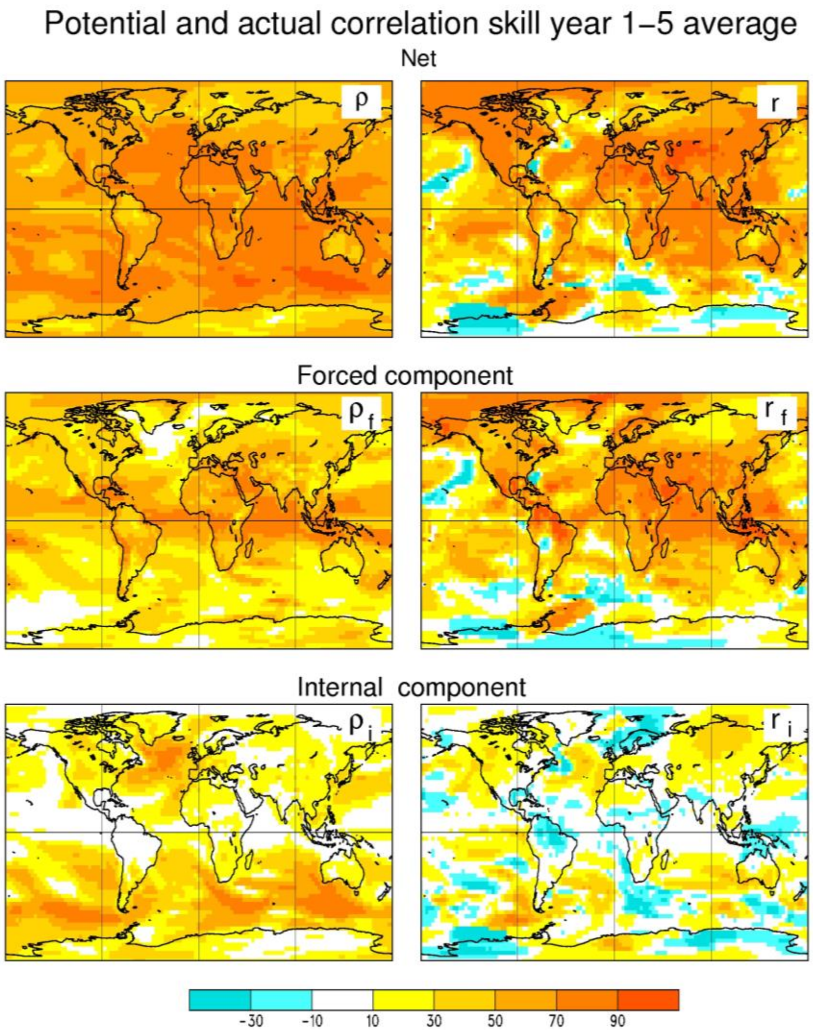


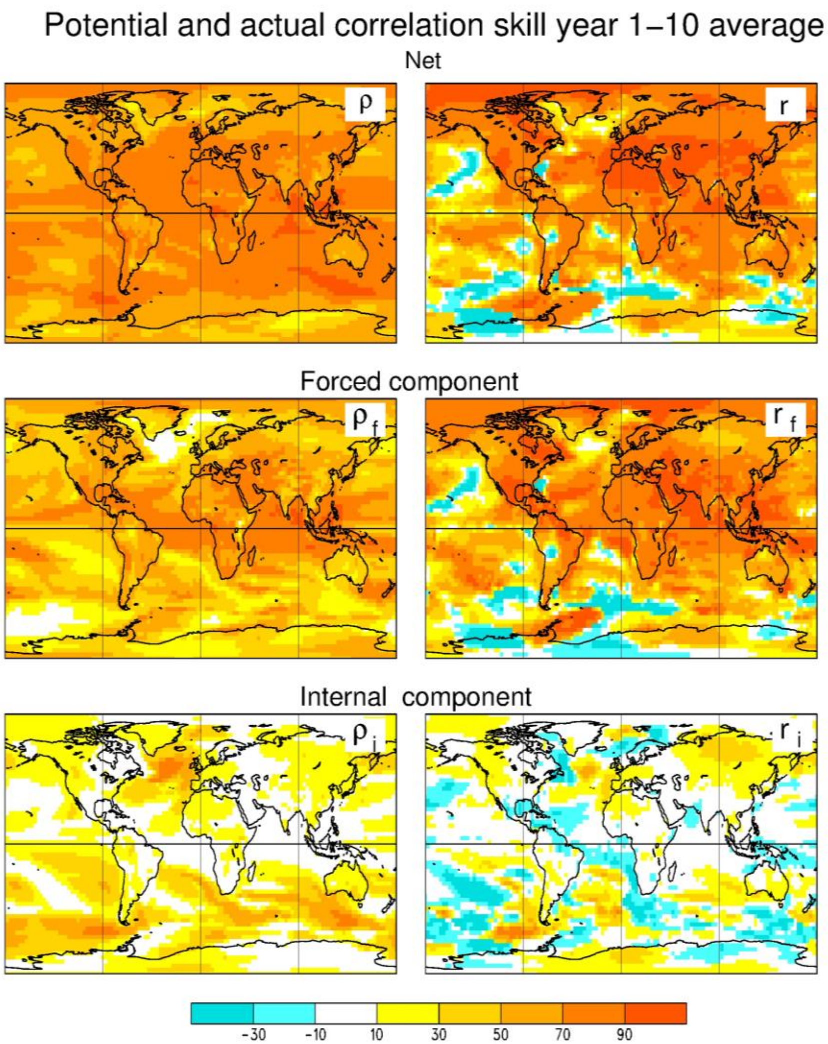
Benefit of initialization for forecasts of different time averages of T

Summary

- Estimate both predictability and skill from hindcasts
- Predictability measures and predictions themselves indicate:
  - initial conditions dominate early and forced component later with crossover in ~ early-middle of decade
- Skill mainly for temperature
  - (perhaps sea ice, MOC), …
  - (not so good for precipitation),…
- Predictability measures give hope that forecasts can be improved
- Expect slow evolution of skill with time (as for history of weather forecasting)
  - improved ocean data from ARGO/satellites
  - improved initialization methods
  - improved models (as ever)
  - etc.

end of presentation





Result depends on averaging time, longer averaging, less influence from internal (initialized) component, more from forced component