Introduction to Seasonal Prediction and Numerical Models

季節予報と数値モデルの紹介

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UK Met Office forecasts

The Met Office is the UK equivalent of the Japan Meteorological Agency – forecasts are produced across all timescales using a common computer model:

UK high resolution

36hr fcast

Global

5 day fcast

Medium Range

2 week fcast

Seasonal

7 month fcast

Decadal

10 year forecast

Climate

100 year forecast

イギリス気象局は、日本の気象庁と同様、全ての時間スケールの予測をコンピューターモデルを用いて行っています。

季節スケール
7か月予報

Seasonal Forecasting

Why?
なぜ？

What is a seasonal forecast?
季節予報とは何か？

How does it work?
どうやって予報する？

Current Capability
現在の予測性能

Future Possibilities
将来の可能性

Why seasonal forecasts?
なぜ季節予報？

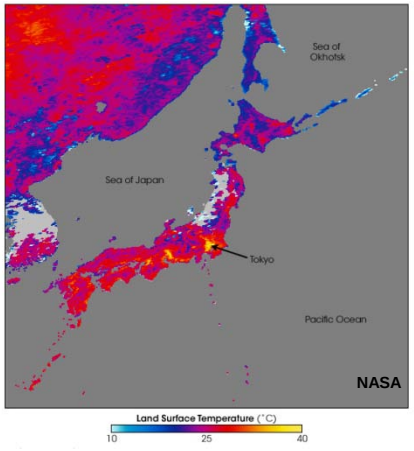
Climate varies a lot from year to year
気候は年ごとに大きく変動する

Temporarily dominates climate change or adds to climate change to give extremes:
一時的には気候変動に卓越する、もしくは、顕著現象を増やすように気候変動に加味する

e.g. Cold winters, summer heatwaves, flooding…

London, Late Winter 2008/9

UK flooding, summer 2007



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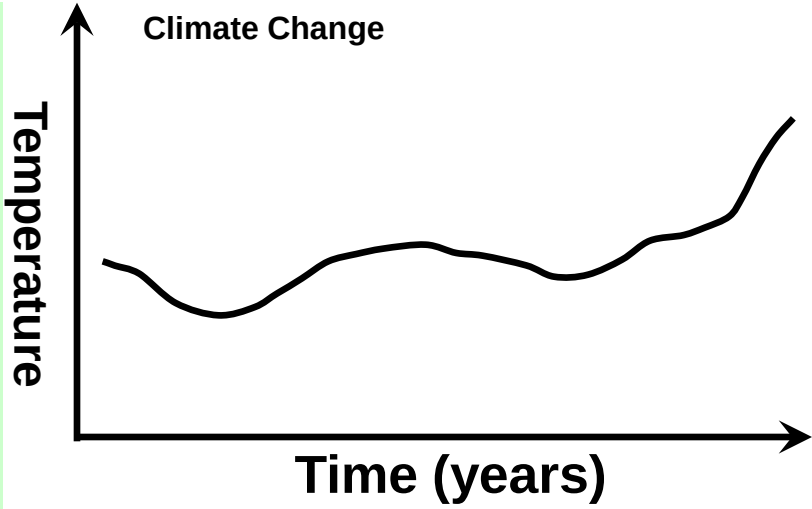

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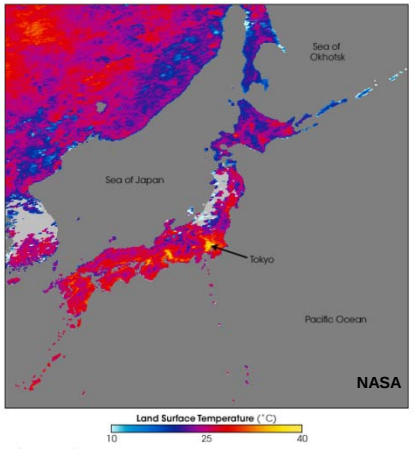

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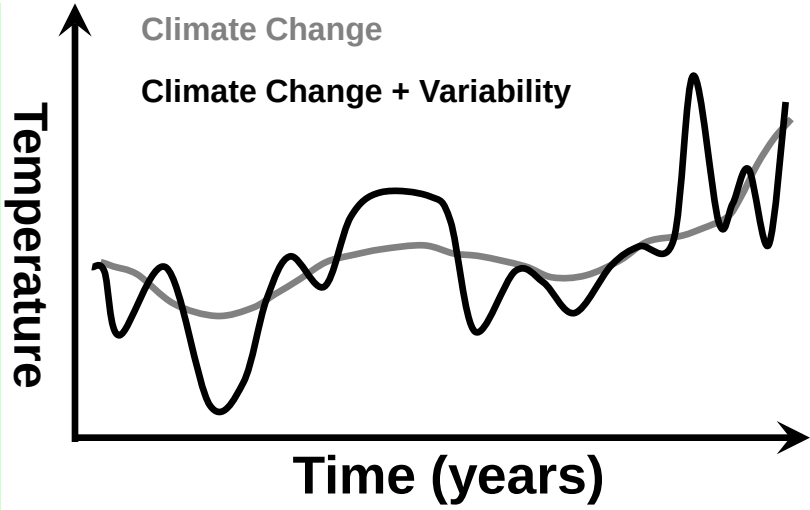

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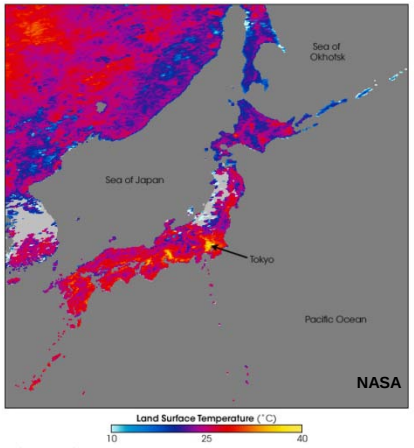


Japan heatwave, summer 2010

What is a Seasonal Forecast?
季節予報とは何か？

How do seasonal forecasts differ from weather forecasts?
短期予報と何が違うのか？

How do seasonal forecasts differ from climate predictions?
温暖化予測と何が違うのか？

What is a Seasonal Forecast?

Q. If weather forecasts are unreliable after a week or two, how can we possibly predict a season ahead?
Q. １、２週間後の天気予報が信頼できないとすると、どうして季節予報ができるのか？

A. Because slow variations in the ocean, land, sea-ice, upper atmosphere, greenhouse gases, solar and volcanic forcing all influence the weather
A. 海洋や陸、海氷、大気上層、温室効果ガス、太陽活動、火山活動による強制などのゆっくりした変動があるから。

Note that we are *not* predicting individual weather events seasons ahead.
数季節先の個々の天気を予測しているのではない点に注意。

Whether it will rain in Tokyo on 12th July 2011 is probably impossible to predict
2011年の7月12日に東京で雨が降るかどうかということは予測できない。

Instead we predict the *chances* of different weather…
代わりに、天気の傾向が変わる確率を予測する。

What is a Seasonal Forecast?

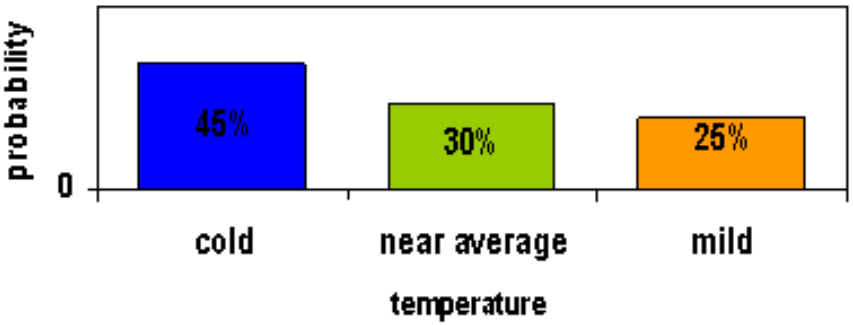
季節予報とは何か？

Forecast is for *RISK* of different outcomes

季節予報は、違った天候が起きるリスクを予測

Compare with: health risk, sports events

An example Winter forecast:
冬の予報例



Does not mean "We are forecasting a cold winter"
寒い冬を予報しているという意味ではない。

Does mean "Cold is more likely than either average or mild"
寒い冬がより起こりやすいことを予測している。

Forecast is not *wrong* if winter is mild!
実際に暖冬であっても、予報は間違いではない！

Should have a mild winter for ¼ of the times such a forecast is issued
このような予報の場合、4分の1は暖冬になるべき。

How does it work?
どうやって予測？

How do we make a seasonal forecast?
どうやって季節予報を行うか？

Can we forecast the coming season?
次の季節の予報はできる？

or

Does the “butterfly effect” make it impossible?
バタフライ効果は季節予報を不可能にする？

and

Are climate models good enough?
気候モデルは十分良いか？

Climate Models 気候モデル

Newton's second law

$$\frac{D_r u}{Dt} - \frac{uv\tan\phi}{r} - 2\Omega\sin\phi v + \frac{c_{pd}\theta}{r\cos\phi}\frac{\partial\Pi}{\partial\lambda} = -\left(\frac{uw}{r} + 2\Omega\cos\phi w\right) + S^u$$

$$\frac{D_r v}{Dt} + \frac{u^2\tan\phi}{r} + 2\Omega\sin\phi u + \frac{c_{pd}\theta}{r}\frac{\partial\Pi}{\partial\phi} = -\left(\frac{vw}{r}\right) + S^v$$

$$\frac{D_r w}{Dt} + c_{pd}\theta\frac{\partial\Pi}{\partial r} + \frac{\partial\Pi}{\partial r} = \left(\frac{u^2+v^2}{r}\right) + 2\Omega\cos\phi u + S^w$$

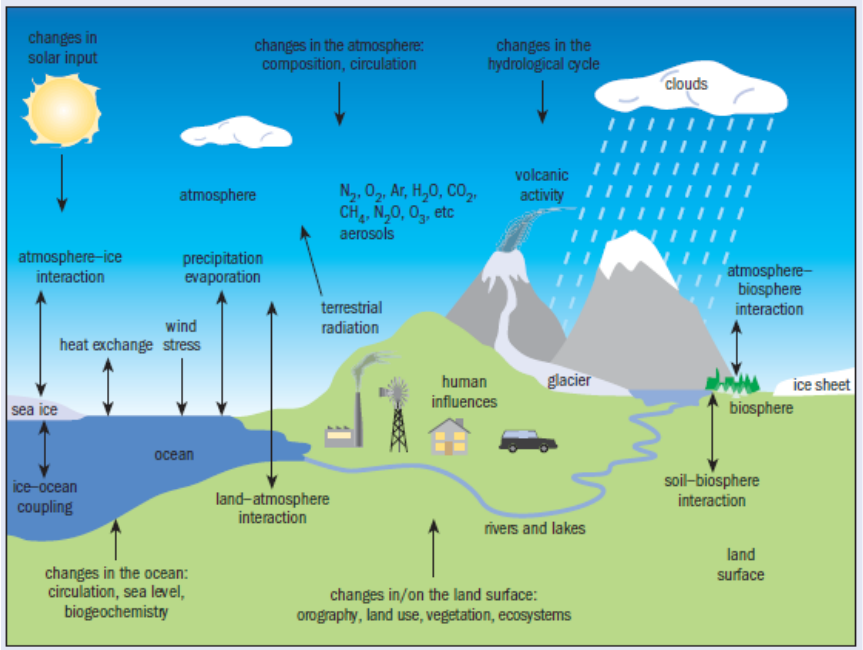
mass continuity

$$\frac{D_r}{Dt}\left(\rho_d r^2\cos\phi\right) + \rho_d r^2\cos\phi\left[\frac{\partial}{\partial\lambda}\left(\frac{u}{r\cos\phi}\right) + \frac{\partial}{\partial\phi}\left(\frac{v}{r}\right) + \frac{\partial w}{\partial r}\right] = 0$$

thermodynamics

$$\frac{D_r\theta}{Dt} = S^\theta$$

The Navier–Stokes equations for fluid flow are at the heart of climate models. The first three equations represent Newton's second law and give the acceleration of the winds in the east–west (u), north–south (v) and vertical directions (w). The mass-continuity equation ensures that although the density, speed and direction of the air change as it flows around the Earth, its mass is conserved, while the thermodynamic equation allows heat-transfer processes such as heating by the Sun to be included as a parametrized source term (S). We use the same equations to model the dynamics of the ocean, but usually make further simplifying approximations. In the equations, r is the distance from the Earth's centre, Ω is the angular velocity of the Earth's rotation, ϕ is latitude, λ is longitude and t is time. c_p is the specific heat capacity of air at constant pressure, θ is potential virtual temperature, Π is the "Exner function" of pressure and ρ is air density. The subscript "d" refers to dry air.



The Earth's climate system comprises the atmosphere, ocean, biosphere, cryosphere and geosphere. Interactions between these components lead to a large natural variability in the climate, while human influences such as the burning of fossil fuels add further complexity. Some of these processes, such as the circulation of the ocean, can be resolved explicitly in climate models, while others, such as the effects of clouds, must be "parametrized".

5 governing equations + ideal gas law
5つの方程式+理想気体の状態方程式

Solve these equations over the whole Earth to predict the weather
これらの式を地球全体で解く。

Initial Values and Boundary Values

初期値と境界値

Initial Values e.g. current state of the atmosphere, ocean, land
初期値 (例えば、大気、海洋、陸の現在の状態)

Boundary values e.g. greenhouse gas concentration, solar forcing
境界値 (例えば、温室効果ガス密度、太陽強制)

OPTIONS:

- **Unconstrained:** long control simulations of the climate model with neither initial conditions nor variation in boundary conditions
- **Initial values only:** weather forecasts: 'an accurate measure of the weather today can be used to predict the weather tomorrow'
- **Boundary values only:** climate predictions for the coming century: knowing the future level of greenhouse gases is enough to predict changes in the statistics of the weather

❖ **Initial AND boundary values (harder!):** seasonal predictions: climate events and weather statistics can both be predicted for months to years ahead

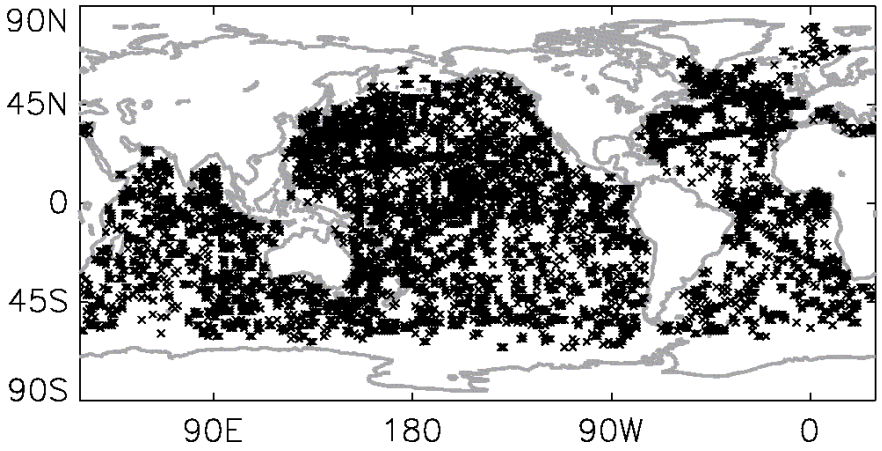
Starting the forecast: initial values
予報の開始：初期値

Include initial condition information: atmospheric winds, temperature, pressure etc. Ocean temperature and salinity
初期状態の情報を含める：大気の風、温度、気圧、海洋の水温、塩分など

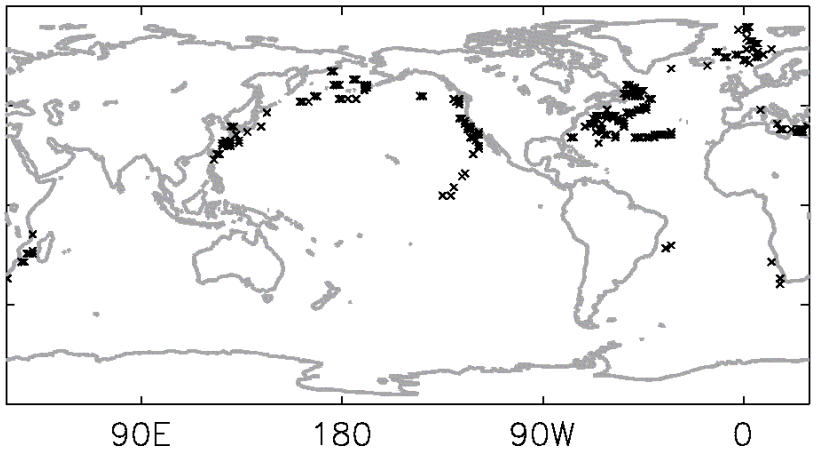
Assimilate these to create a 'best estimate' of the current condition of the oceans and atmosphere
データ同化して、海洋と大気の実況の最も良い推定値を作成する。

However, only recently have we had good coverage of the oceans:
海洋の観測データが充実したのは、最近になってから。

June 2007



June 1960

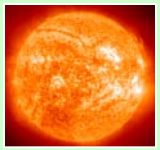


Progressing the forecast: boundary values

予報の進展：境界値

Greenhouse gases: Obs then scenario
温室効果ガス：過去は観測、将来はシナリオ

Aerosols: Obs then scenario
エアロゾル：過去は観測、将来はシナリオ



Solar Forcing: Obs then repeat 11 year cycle
太陽強制：過去は観測、将来は１１年サイクルを繰り返す

Volcanic Forcing: Obs in past, none in future
火山強制：過去は観測、将来の情報はなし

Allowing for chaos

(the butterfly effect)

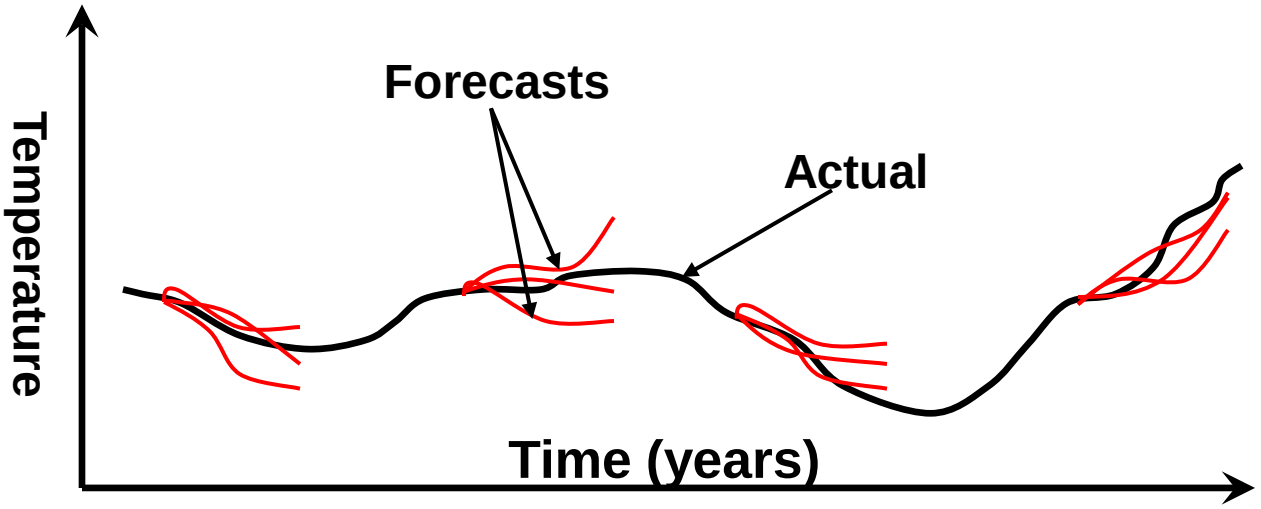
カオスを考慮する(“バタフライ効果“)

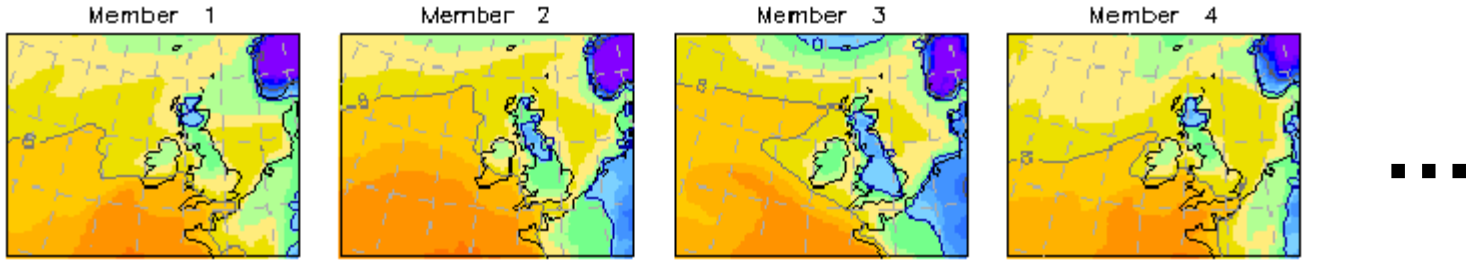
Ensembles of forecasts – to represent uncertainty

予報のアンサンブル-不確実性の表現

Outcome is a shift in likelihood

結果は、起こりやすさのシフト





...

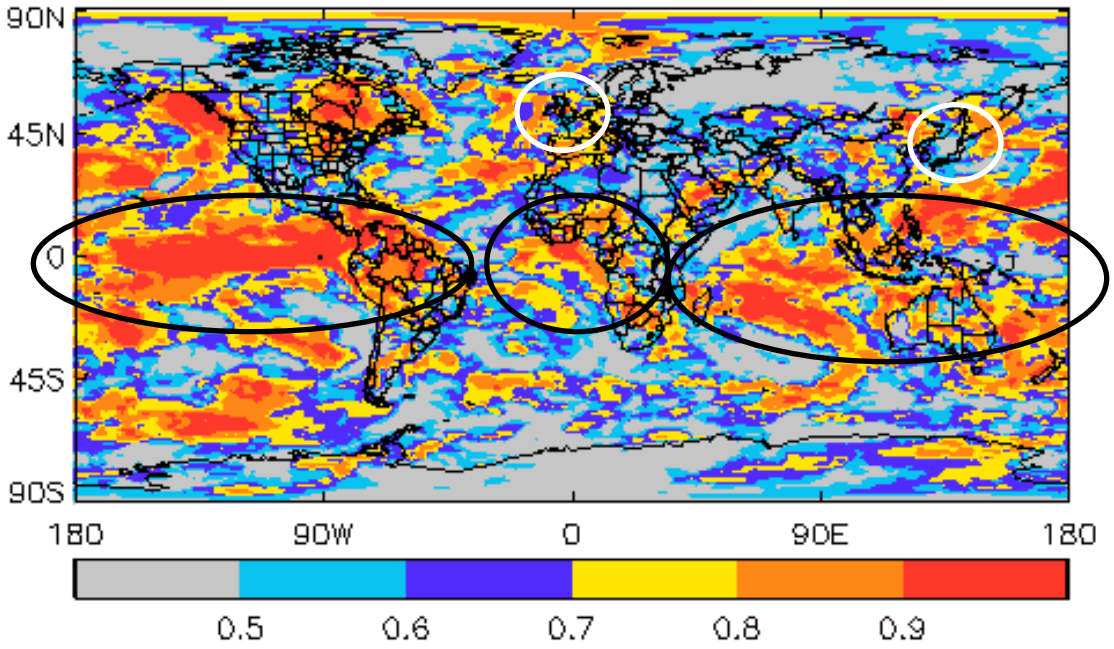
Current Capability
現在の性能

Tropics versus Extratropics
熱帯 対 中高緯度

Global Forecasts: El Niño, Africa, Hurricanes 2010, Russia 2010
全球予報：エルニーニョ、アフリカ、2010年のハリケーン、2010年ロシアの熱波

Tropics versus Extratropics

熱帯　vs 中高緯度



Forecast skill for mild winters
暖冬に対する予測精度

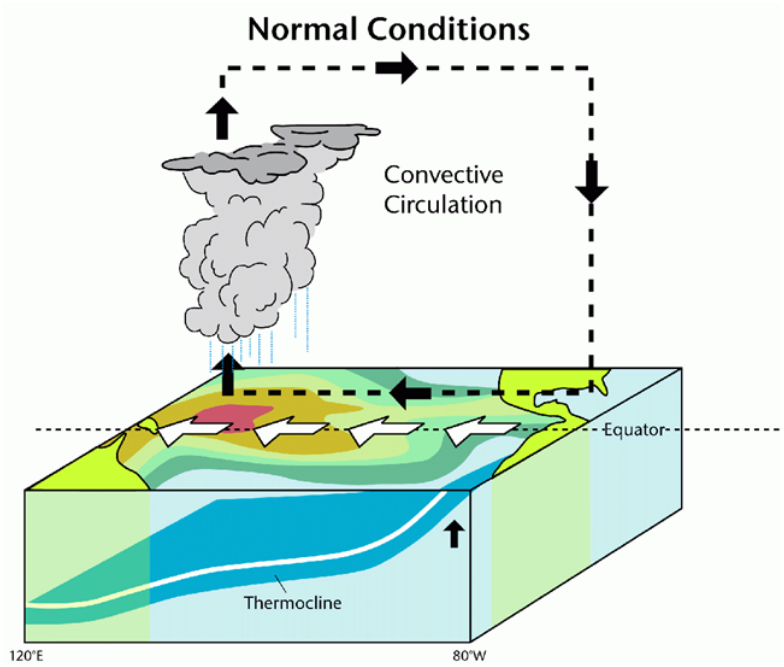
Largest in tropics
熱帯で最も大きい

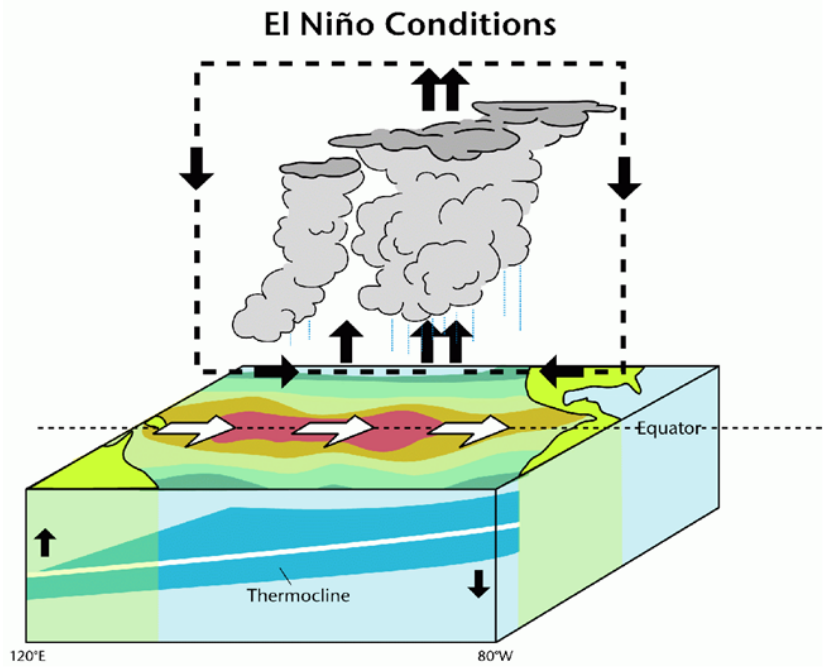
Largest over ocean
海洋上で最も大きい

Poorer in extratropics
中緯度では比較的小さい

El Niño – Southern Oscillation

エルニーニョ―南方振動





Warming in mid and E Pacific, convection moves E,
太平洋中・東部の水温の上昇、対流活動が東にシフト、

Atmospheric circulation weakens,
大気（ウォーカー）循環が弱くなる、

Upwelling in E Pacific reduces, thermocline relaxes
東部太平洋の湧昇が弱くなり、温度躍層の傾きが緩くなる

Biggest source of natural climate variability
もっとも大きな自然の気候変動のソース

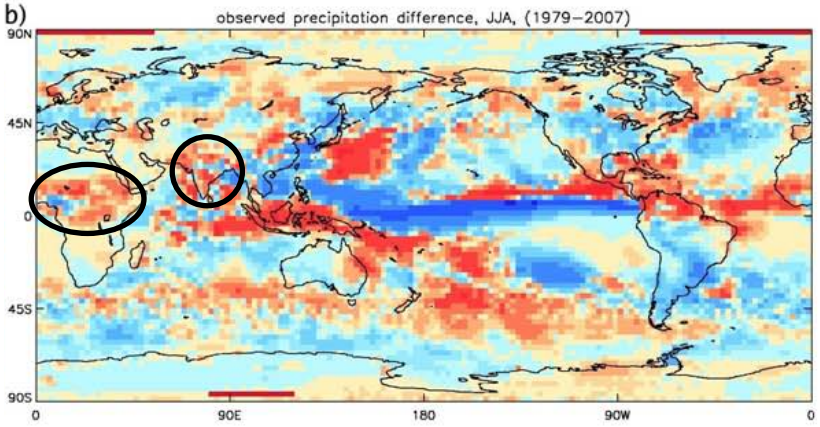
Observed El Niño

観測されたエルニーニョの状態

Rainfall 降水量

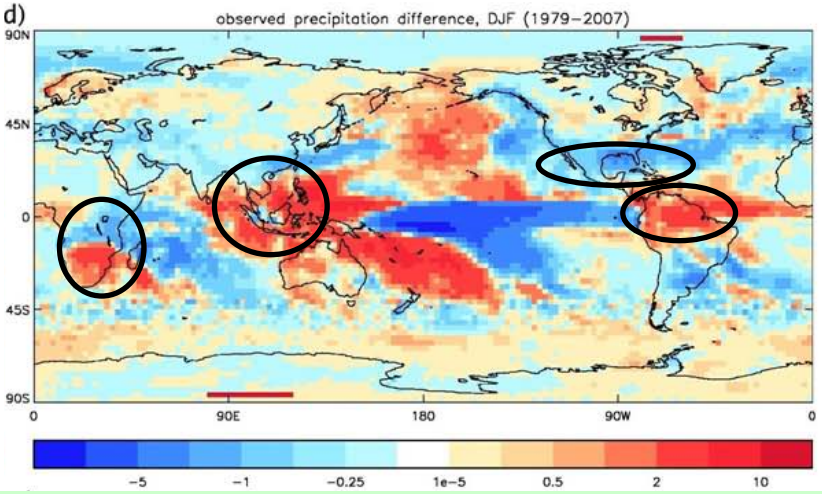
Summer (JJA)

夏（6-8月）



Winter (DJF)

冬（12-2月）

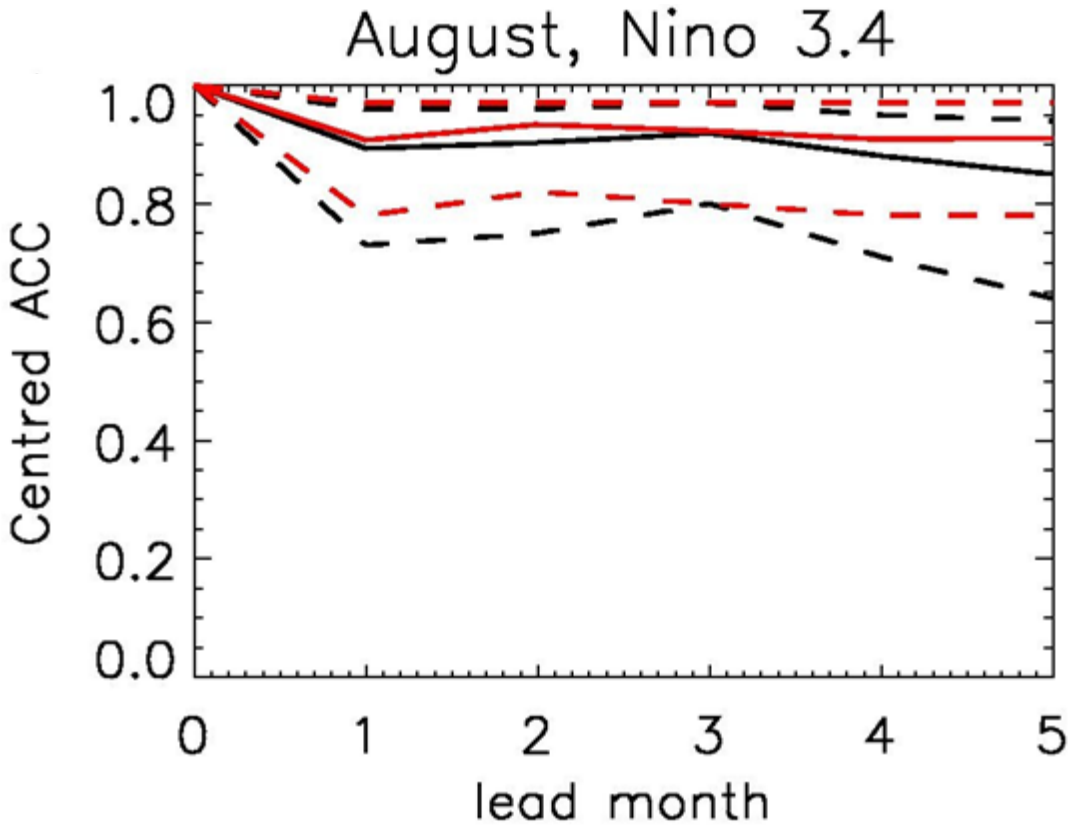


These year to year changes in the rainfall pattern are well reproduced
これらの降水パターンの年々変動はよく再現される。

Many tropical influences 多くの熱帯の影響

El Niño forecast skill

エルニーニョ予測精度



ENSO peaks in winter ENSOは冬に最盛期

Remarkable levels of predictability even 6 months ahead
6か月先の予測でも優れた予測可能性のレベル

Remote effects? 遠隔効果？

El Niño/La Niña effect on rainfall

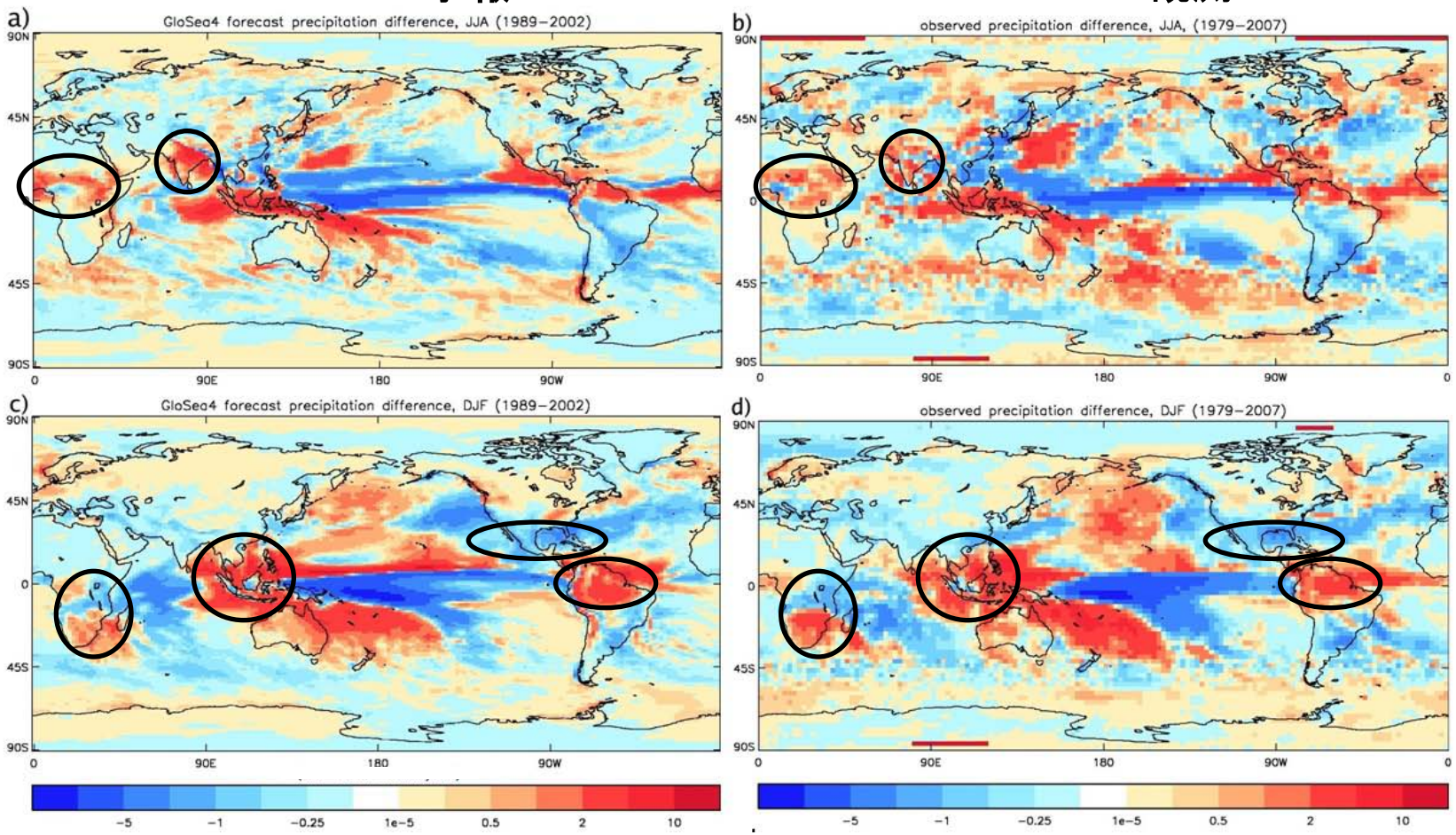
エルニーニョ/ラニーニャ の降水への影響

Forecast 予報

Observed 観測

JJA
6月-8月

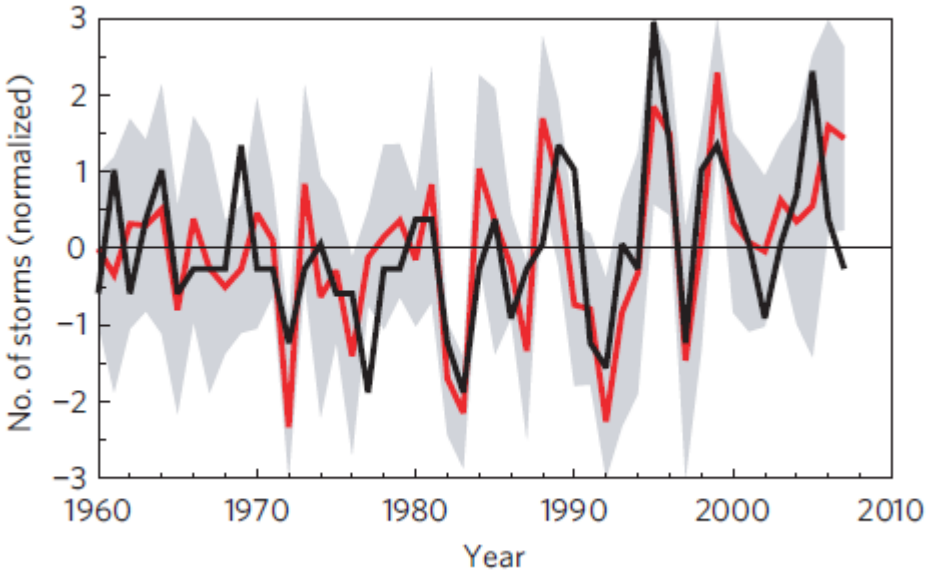
DJF
12月-2月



Skilful forecasts of ENSO effects in the tropics – even for rainfall

熱帯におけるENSOの影響の精度のある予測 –比較的予測が困難な降水も

Atlantic Hurricanes
大西洋のハリケーン

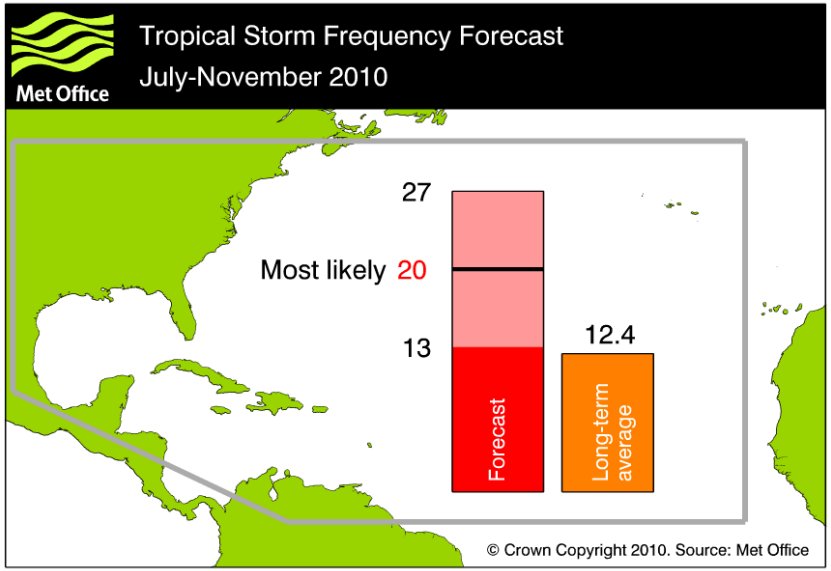


Numbers of hurricanes can be forecast months ahead
ハリケーンの個数は数か月先まで予測可能

Extending to years ahead
数年先まで予測
(Smith et al., Nat Geosci., 2010)

And perhaps to the Pacific… おそらく太平洋も

This year's forecast:
今年の予報:
Well above average numbers of named storms see figure:
平年よりかなり活発
Observed number: 19!
実際の観測は19個！

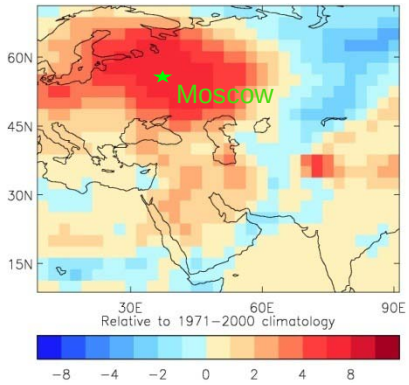


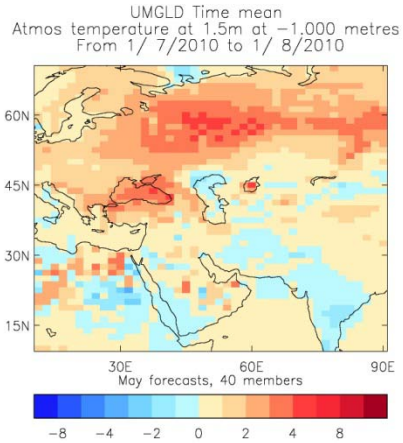
Russian Heatwave

ロシアの熱波

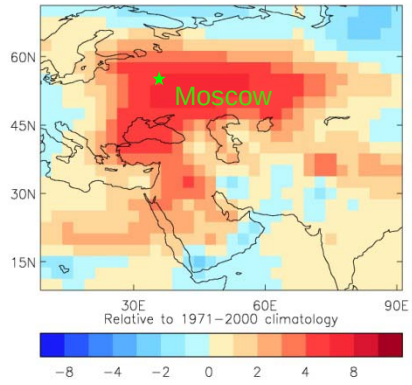
Forecasts from May….

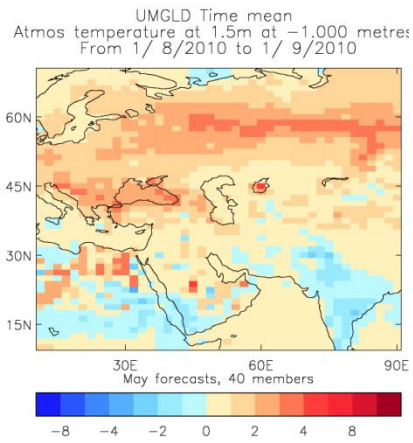
July 7月





August 8月





Observed

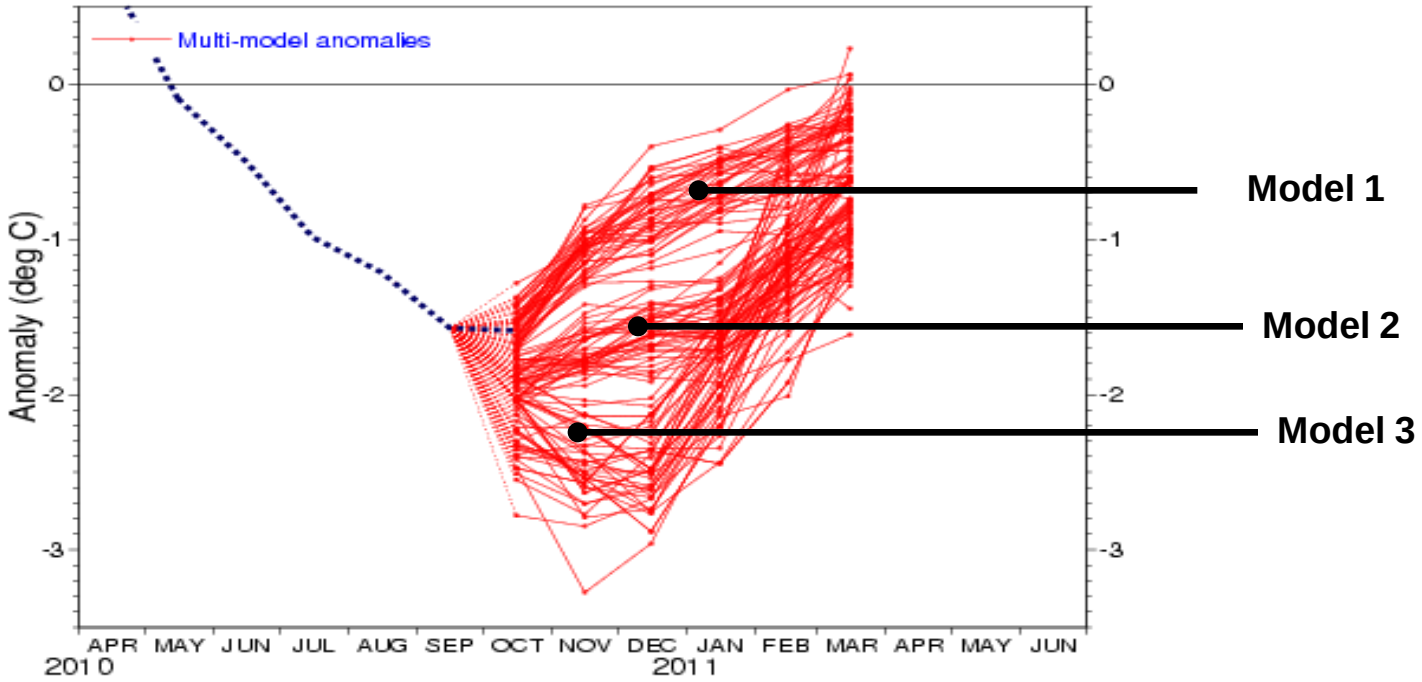
観測

Forecast

予報

Over-confidence and multiple models

自信過剰と複数モデルの予測



Predictions are generally too confident

予報は一般的に自信過剰

This can be seen in individual cases!

個々の事例にみられる。

Multiple models can help but we need to improve models

複数のモデルによる予測は役に立つが、モデルの改善は必要。

Future
将来

What's next?
次は何？

Better Climate Models
より良い気候モデル

Extratropical Predictability?
中緯度の予測可能性？

Future Developments: Improved Capability
将来の開発： 改善された性能

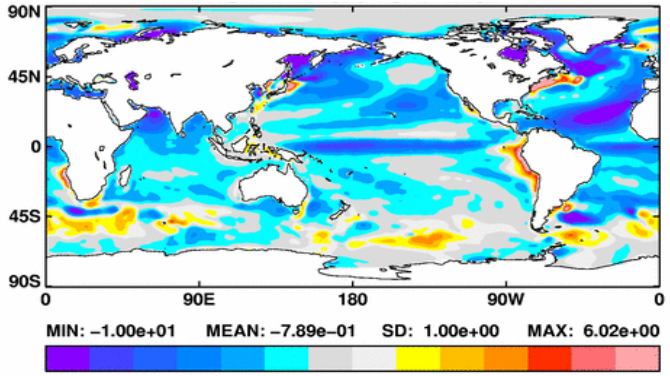
- **Increased resolution models (vertical and horizontal)**
  高解像度化（鉛直、水平）
- **Improved Sea-Ice and land surface initialisation**
  （海氷、陸面の初期値化の改善）
- **Better links to monthly and decadal forecasting**
  1か月予報と10年規模予測とのより良い繋がり

Future Developments: Better Models
将来の開発：より良いモデル

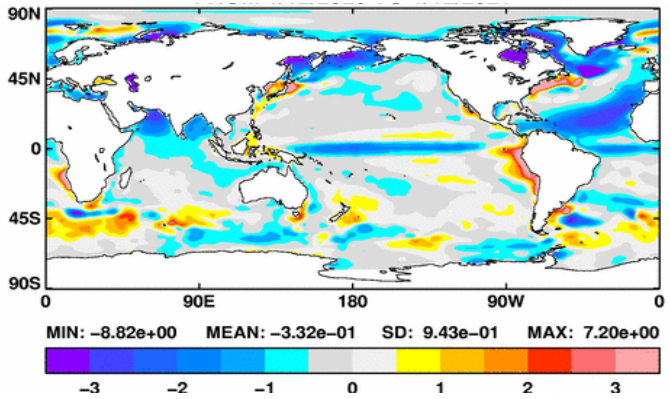
- **Model development**
  モデル開発
- **Reduced errors**
  誤差の減少
- **Better representation of climate variability**
  気候変動のより良い表現

Future models: smaller errors
将来のモデル：より小さい誤差

Old Model - SST Error
旧モデル - 海面水温誤差



New Model - SST Error
新モデル – 海面水温誤差



Error in sea surface temperature

as big as signal we are forecasting

but improving

海面水温の誤差はシグナルと同じくらい大きいが、
改善されている。

Can we improve extratropical forecasts?

中緯度の予測を改善できるか？

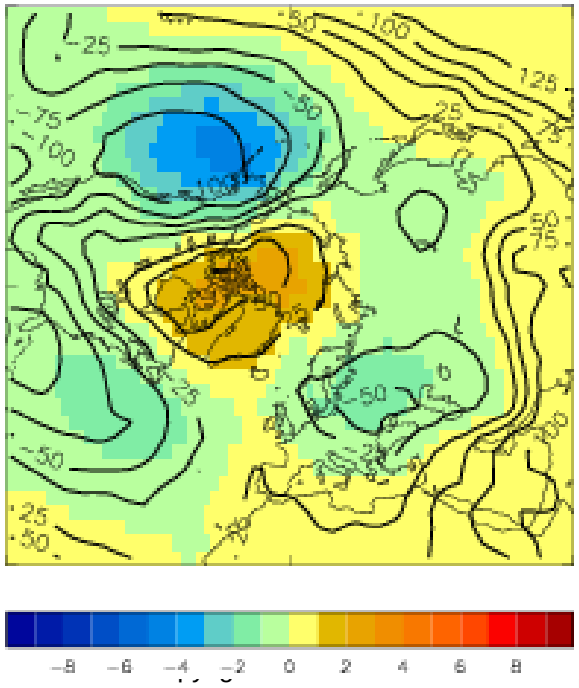
Key drivers of extratopical climate are being identified.

中緯度の気候の鍵となる過程は特定されている。

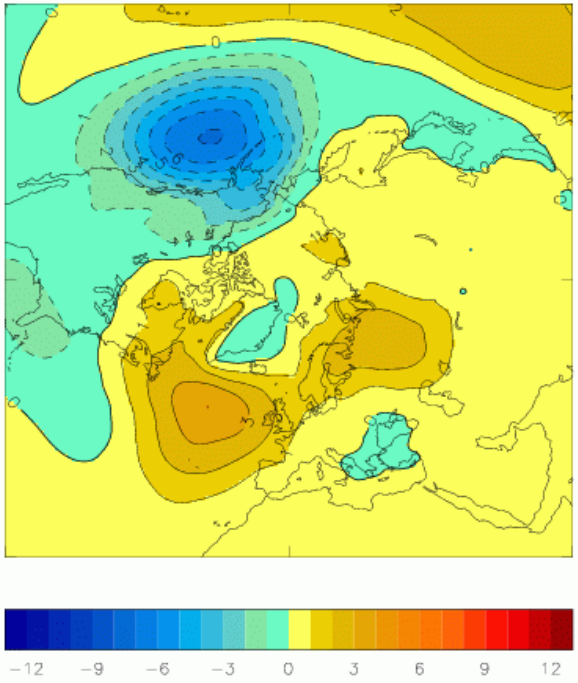
These suggest useful levels of skill may be possible….e.g. El Niño in the extratropics:

これらのことは有益なレベルの季節予報が可能であることを示唆

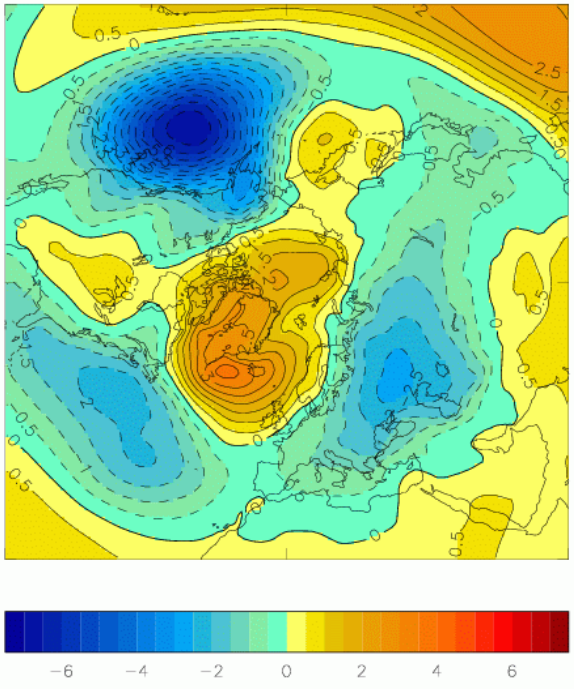
Observations 観測



Old Model 旧モデル

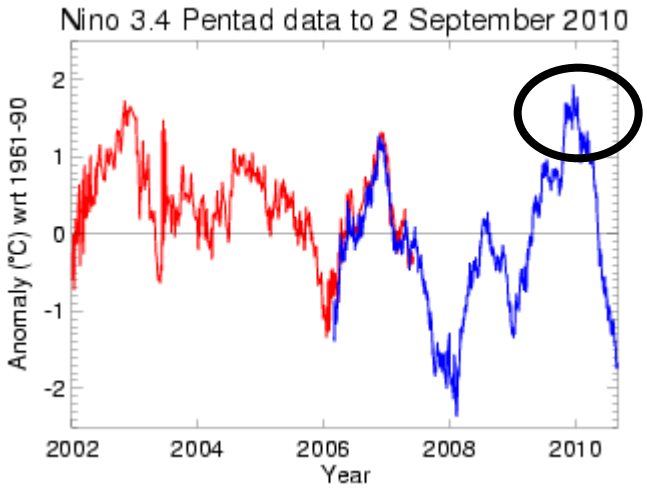


New Model 新モデル

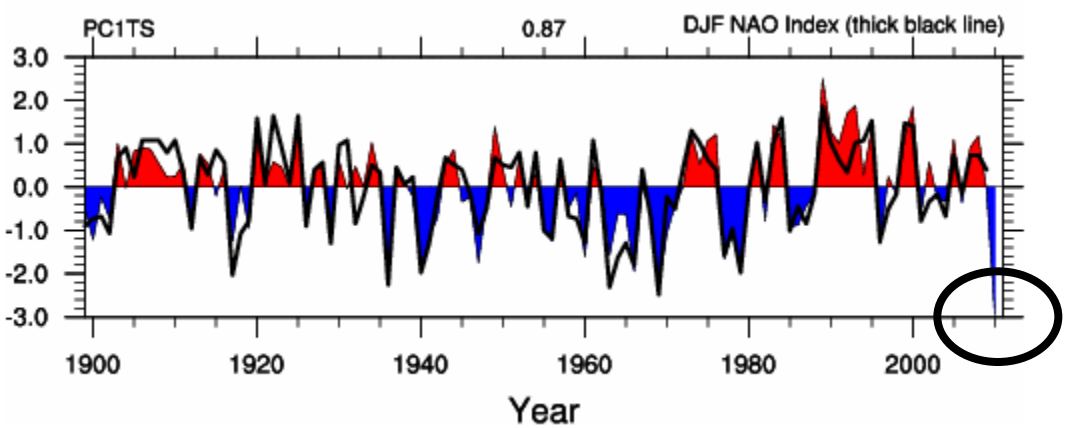


Winter 2009/10

El Nino



N Atlantic Oscillation



Moderate El Nino and negative Arctic Oscillation

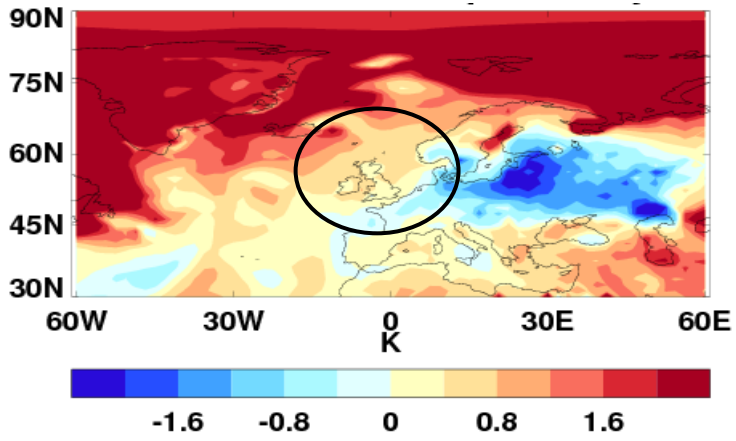
Not a coincidence! エルニーニョと負の北極振動はただの偶然ではない！

We are using these new models to improve the operational system:

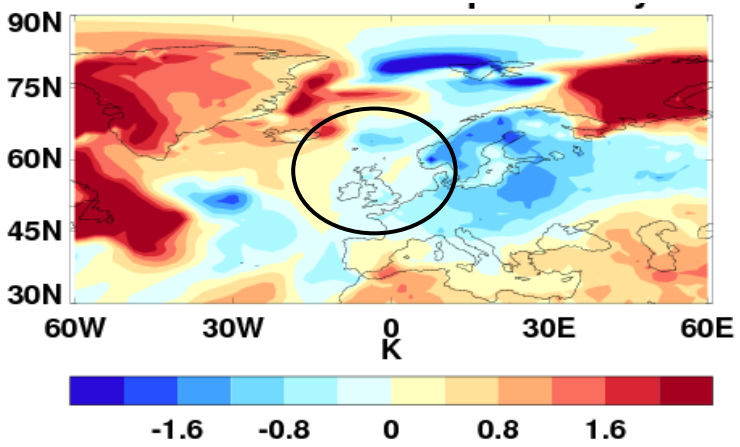
新システムによる改善

E.g. Winter 2009/10

Old System　旧システム



New System　新システム



Summary まとめ

- **Seasonal forecasts are based on fundamental physics**
  季節予報は、基礎物理にもとづく
- **There is good forecast skill in much of the tropics (e.g. Hurricanes, El Nino effects)**
  熱帯に良い予測精度がある（例、ハリケーン、エルニーニョの影響）
- **Some (limited) skill in the extratropics (Japan, UK)**
  中緯度（日本、英国）ではいくらかの（限られた）予測精度がある
- **A *single* seasonal forecast is neither “right” nor “wrong”**
  一回の季節予報は、“当たり”でも“はずれ”でもない。
- **There is great demand from government and business planners for probabilistic seasonal forecasts**
  確率的な季節予報は、政府、ビジネスパートナーから多大な要望がある。
- **Rapid progress is being made and further improvements are appearing already**
  急速に発展し、さらなる改良がすでに行われている。
- **We do not know what the upper limit on predictability is but it is likely to be lower in the extratropics**
  予測可能性の限界は分からないが、中緯度では熱帯より低いだろう。