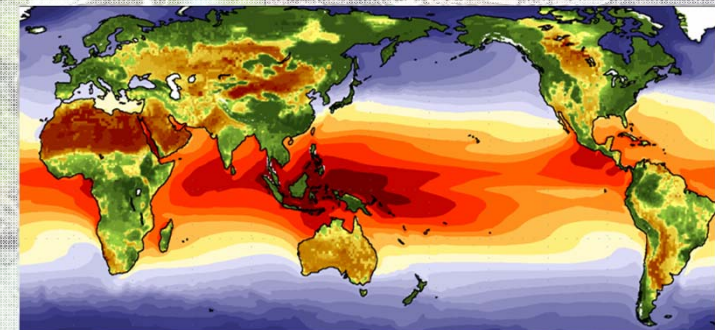
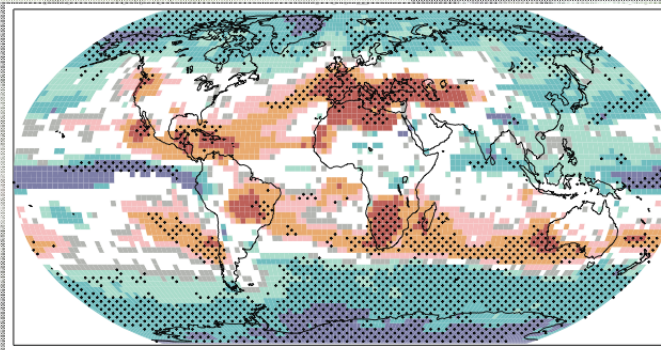
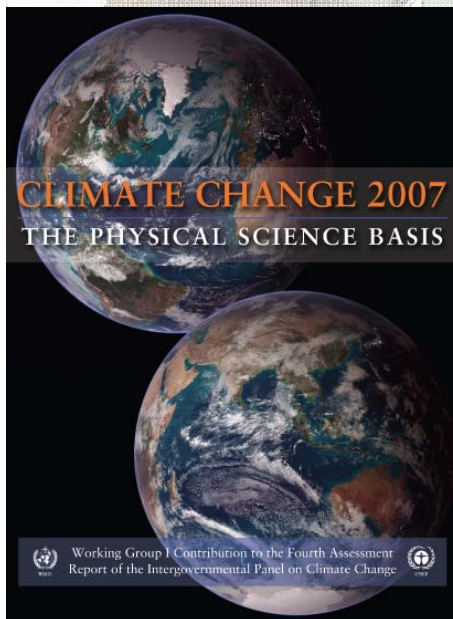
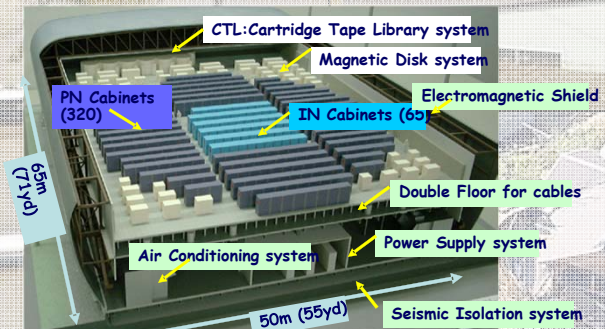
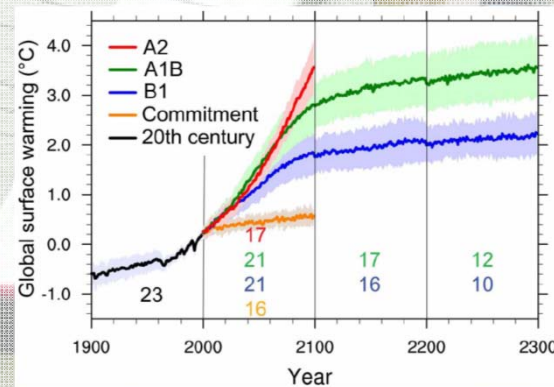
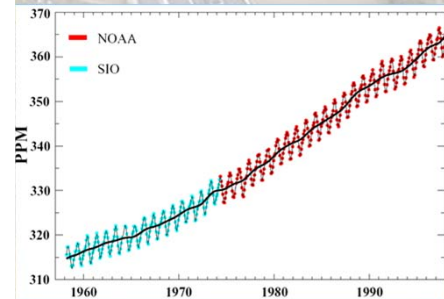




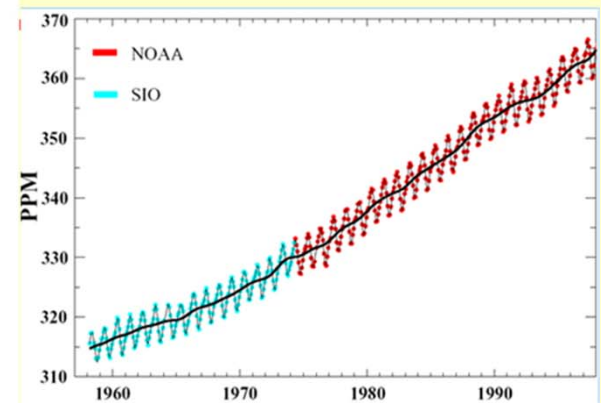
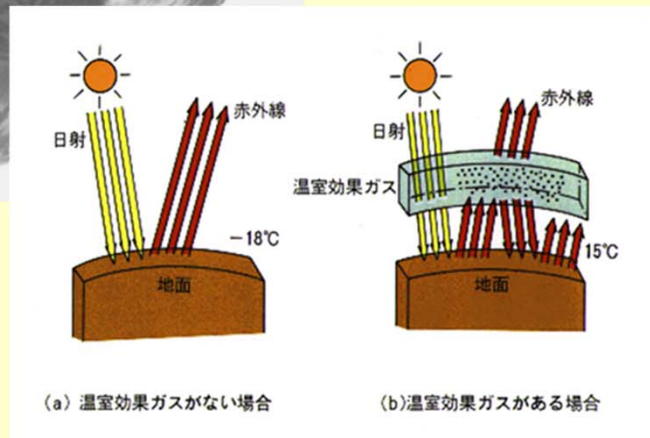
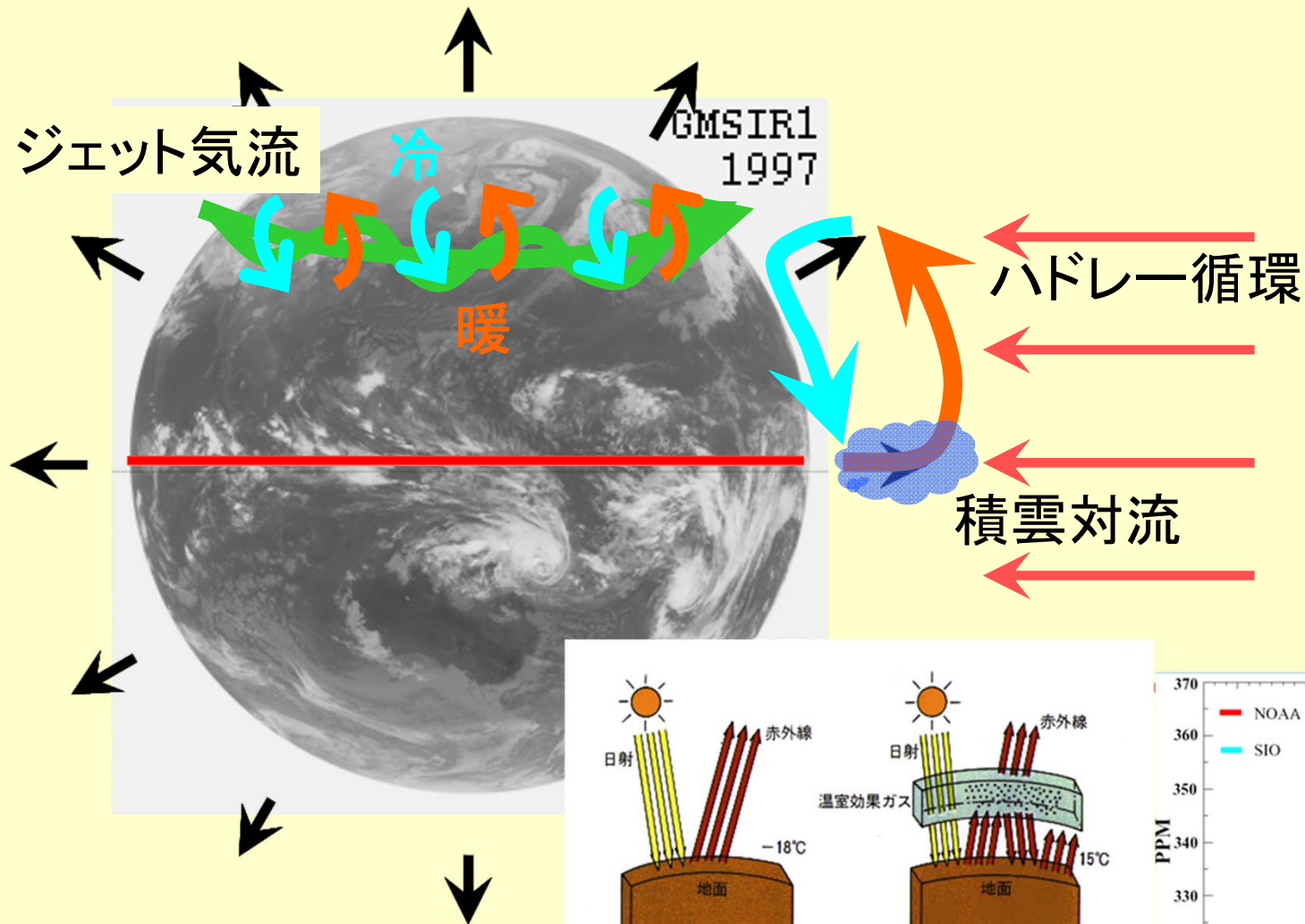
気候シミュレーションのチャレンジ

木本 昌秀

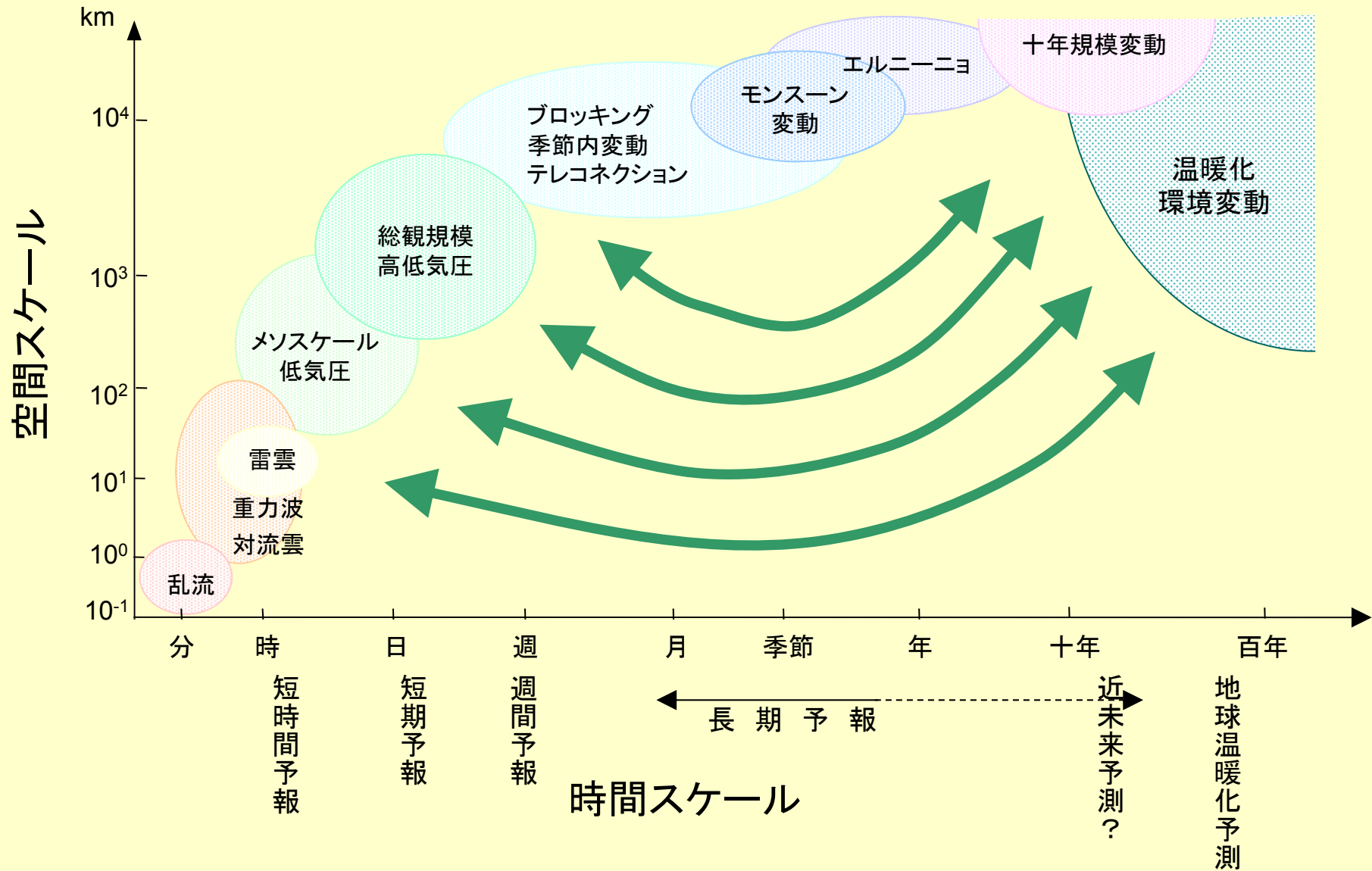
東京大学大気海洋研究所



気候のしくみ



気象現象の時間・空間スケール



数値天気予報、気候シミュレーション略史

1827年: Fourier大気の温室効果を指摘

1875年: 東京気象台

1913年: 科学的手法による天気予報についてのV.
Bjerknes論文

1922年: Richardsonによる手計算天気予報

1950年: ENIACによる最初の数値予報

1956年: 最初の大気大循環数値実験

1967年: 真鍋, Wetherald放射対流平衡モデルによる二
酸化炭素倍増実験

1988年: IPCC発足

1996年: 気象庁力学的1か月予報開始

2002年: 地球シミュレータ

2007年: IPCC第4次評価報告書

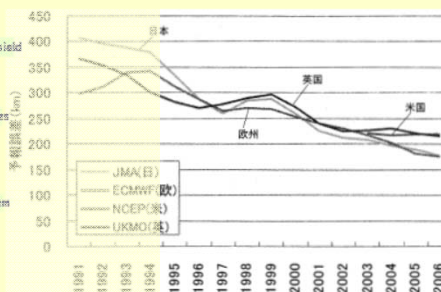
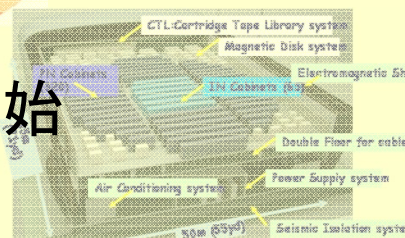
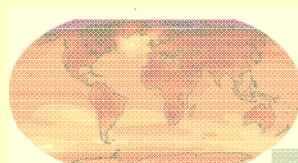
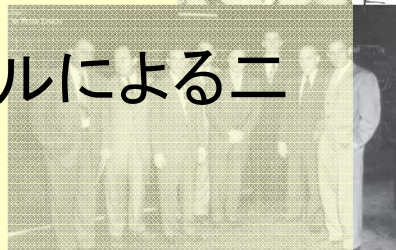
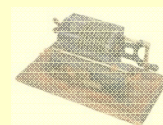
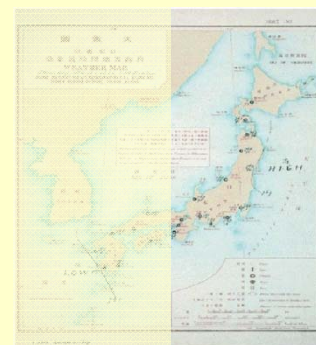
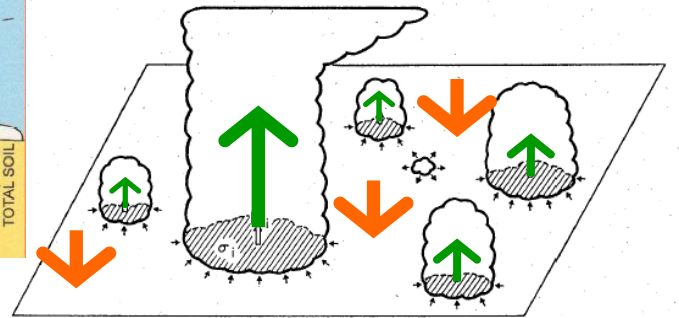
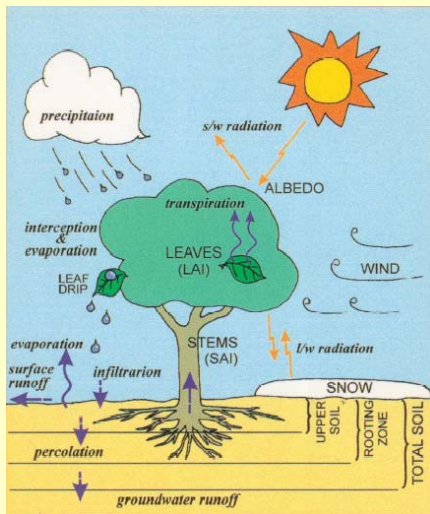
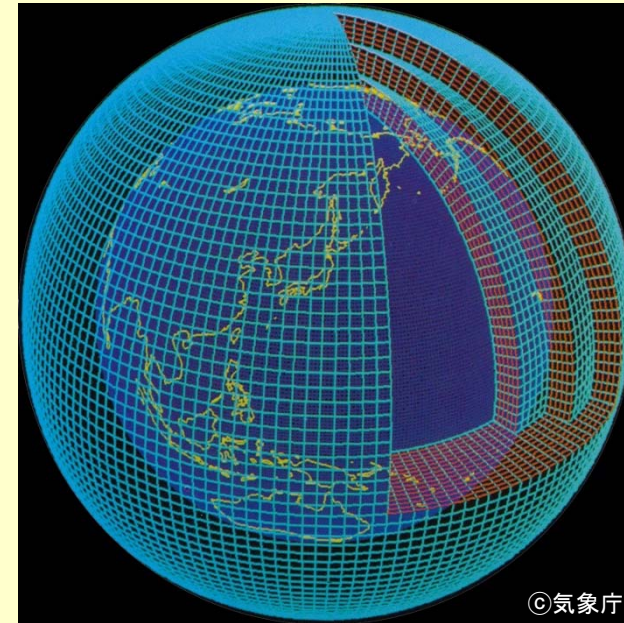
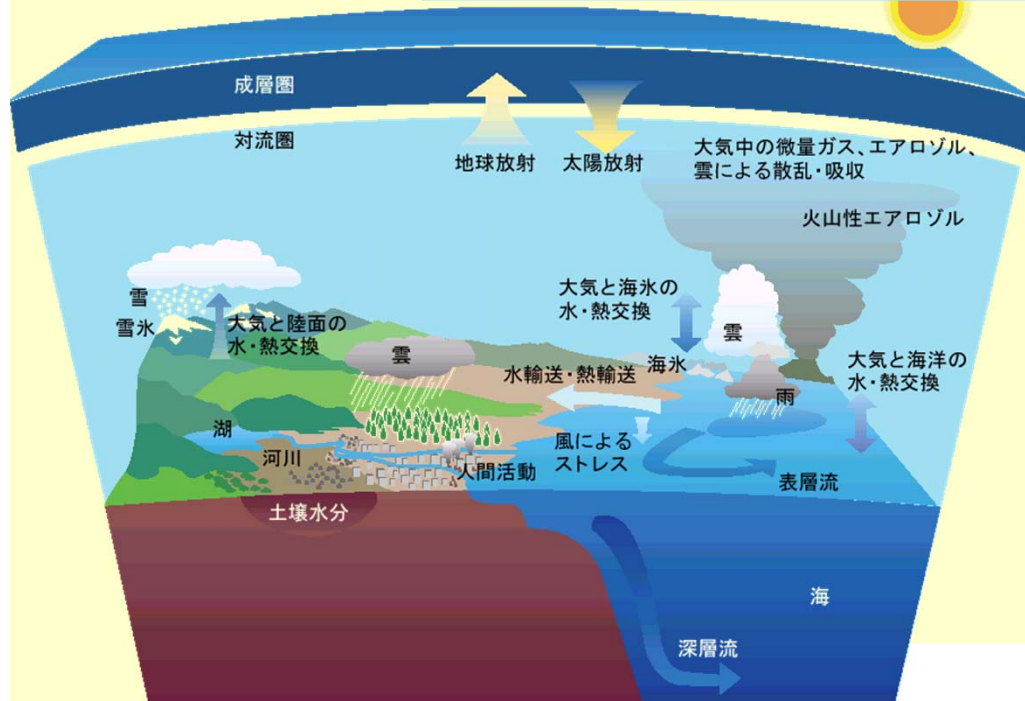


図 7.9 台風予報誤差 (2 日子報) (気象庁提供)

気候モデル—コンピュータの中の地球



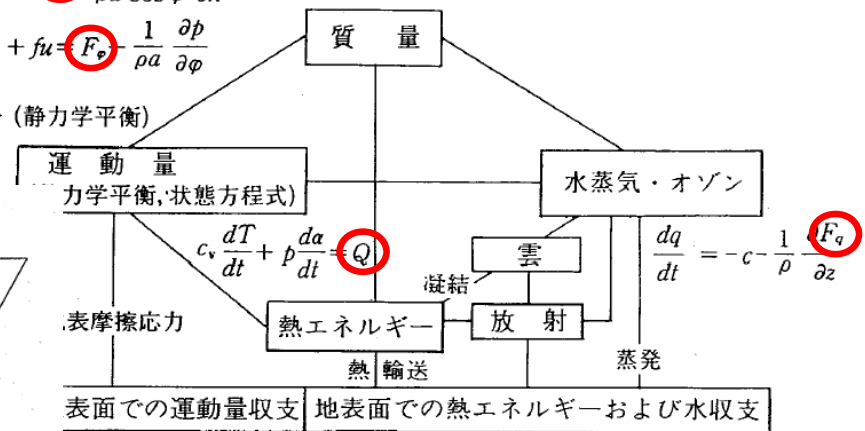
$$\frac{d\rho}{dt} + \rho \left(\frac{1}{a \cos \varphi} \frac{\partial u}{\partial \lambda} + \frac{1}{a \cos \varphi} \frac{\partial v \cos \varphi}{\partial \varphi} + \frac{\partial w}{\partial z} \right) = 0$$

$$\frac{du}{dt} - \frac{\tan \varphi}{a} uv - fv = \frac{1}{\rho a \cos \varphi} \frac{\partial p}{\partial \lambda}$$

$$\frac{dv}{dt} + \frac{\tan \varphi}{a} u^2 + fu = \frac{1}{\rho a} \frac{\partial p}{\partial \varphi}$$

$$0 = -g - \frac{1}{\rho} \frac{\partial p}{\partial z} \quad (\text{静力学平衡})$$

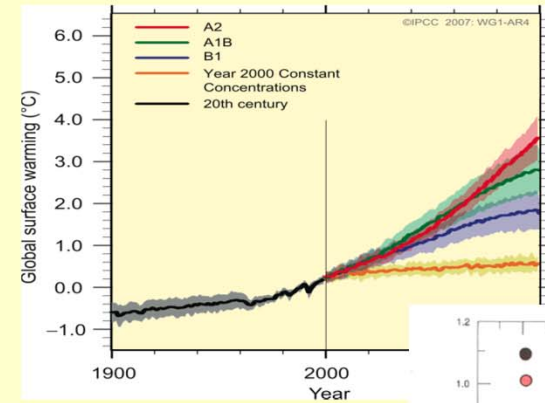
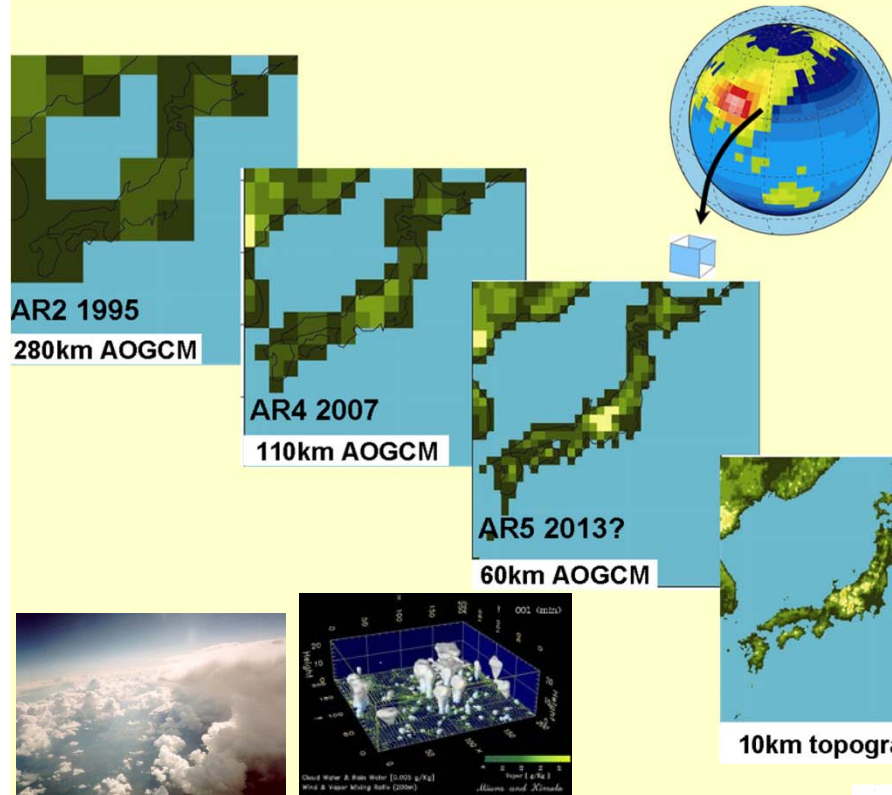
$$p = \rho RT$$



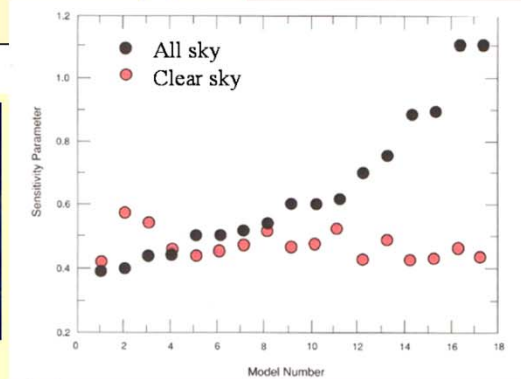
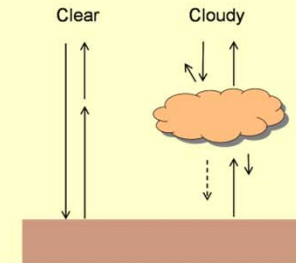
気象・気候モデルの課題

課題1: 解像度

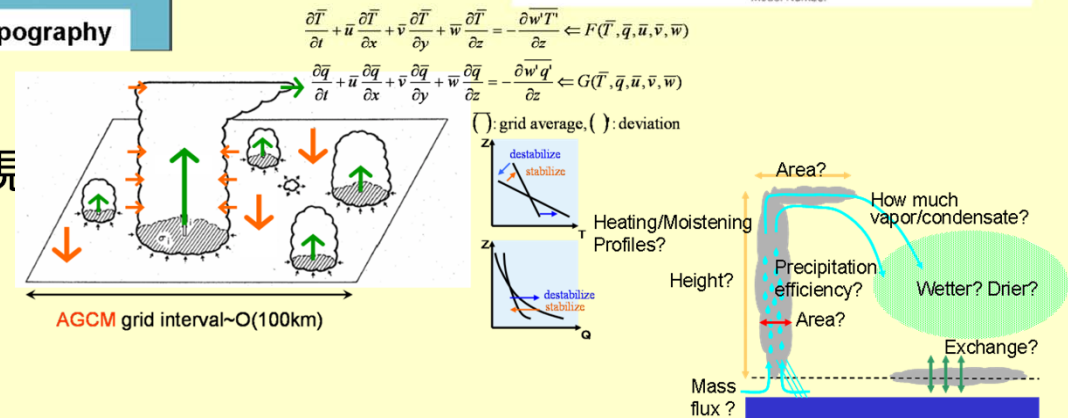
課題2: 非解像過程の不確実性



雲放射強制(Cloud Radiative Forcing)



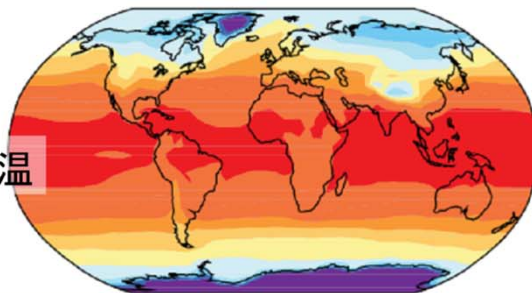
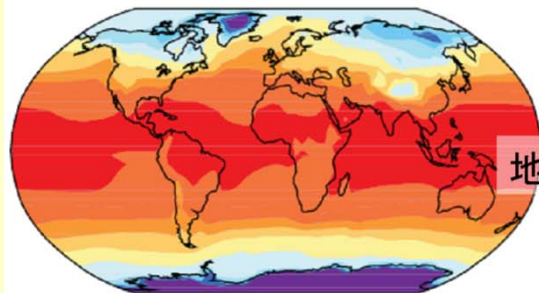
計算資源の制約により、計算格子以下の現象(とくに雲)をパラメータ化して表現
 →台風や雲の放射影響に問題
 →予測の不確実性
 ブレークスルー(雲解像気候シミュレーション)への期待



観測 vs. モデル

CRU/HadISST

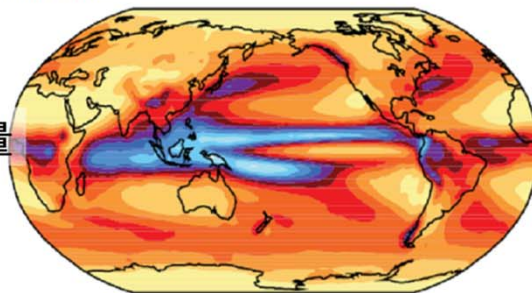
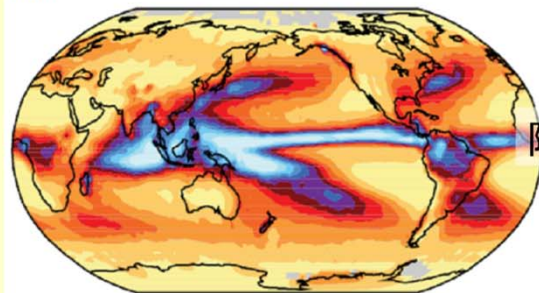
Mean Model



地表気温

CMAP

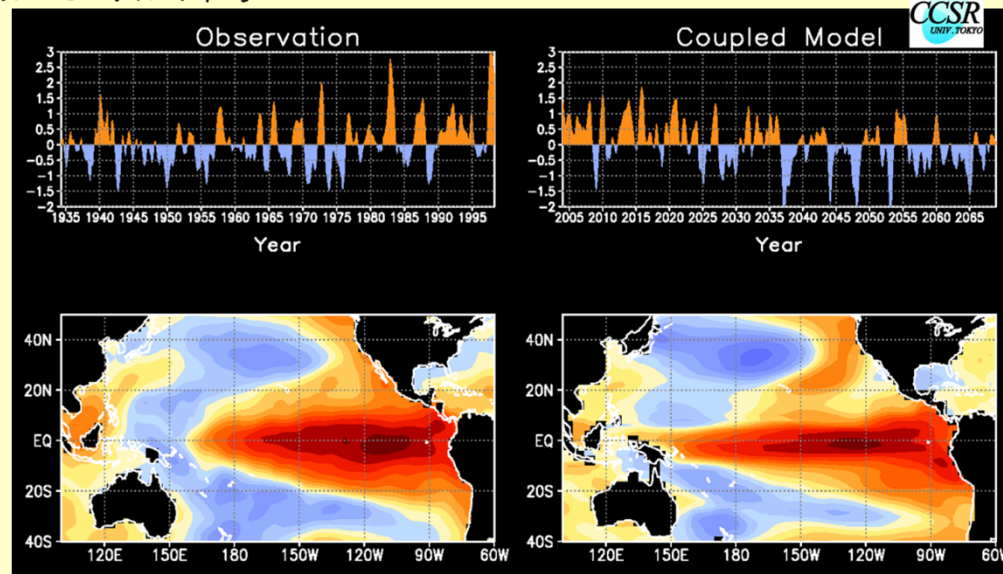
Mean Model



降水量

観測値

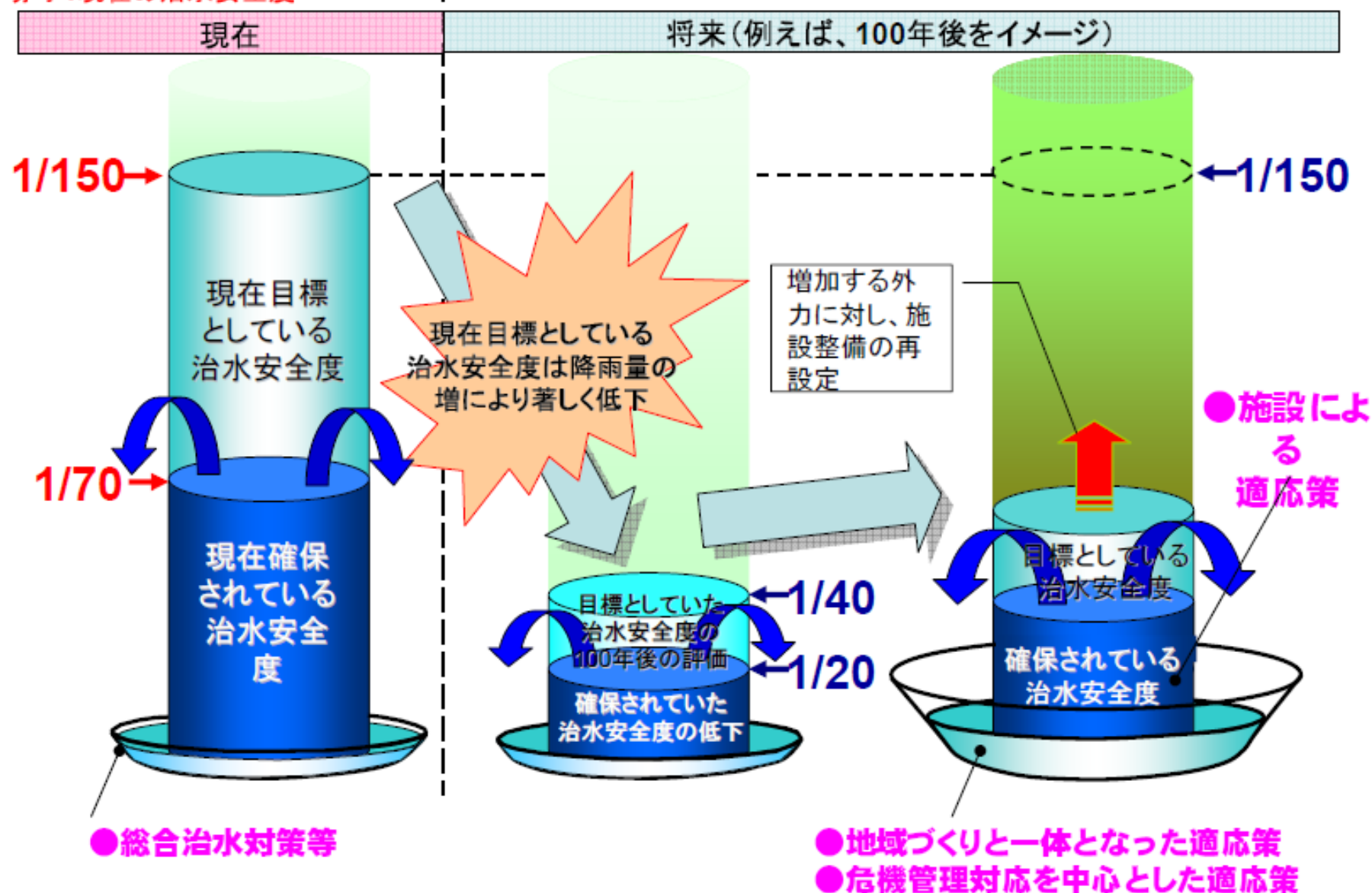
IPCC-AR4 23モデルの平均



洪水に対する治水政策の重層化

赤字:現在の治水安全度

青字:将来の治水安全度

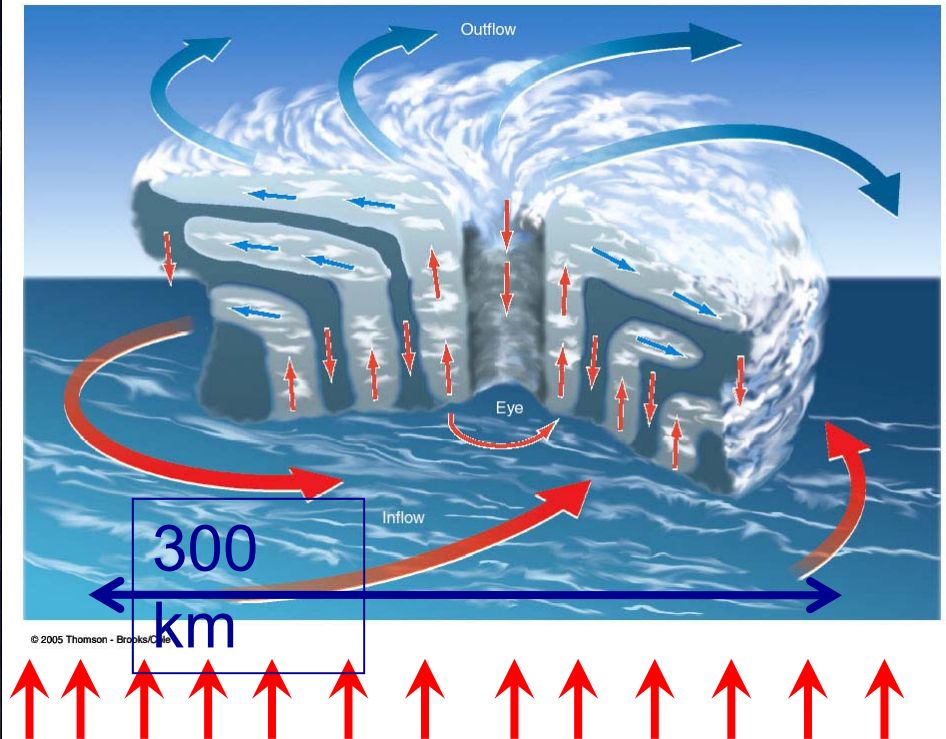




Hurricane Isabel, Sep 17 2003

*Tropical Cyclones are big heat engines,
displaying complex,
organised convection*

Agents of poleward heat transport in the Tropics



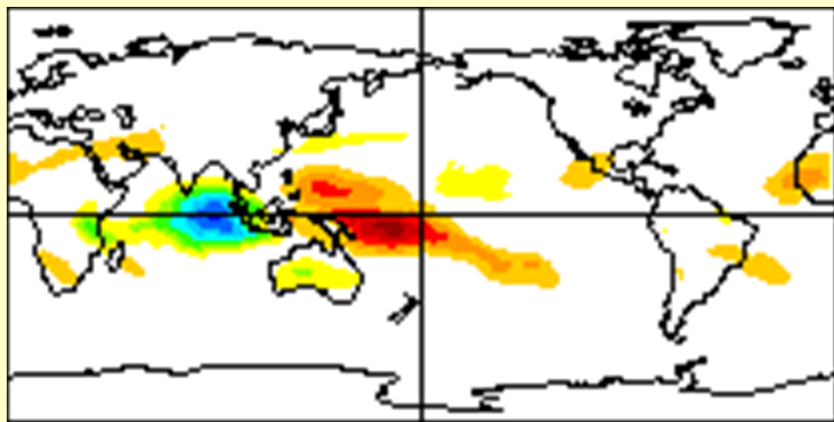
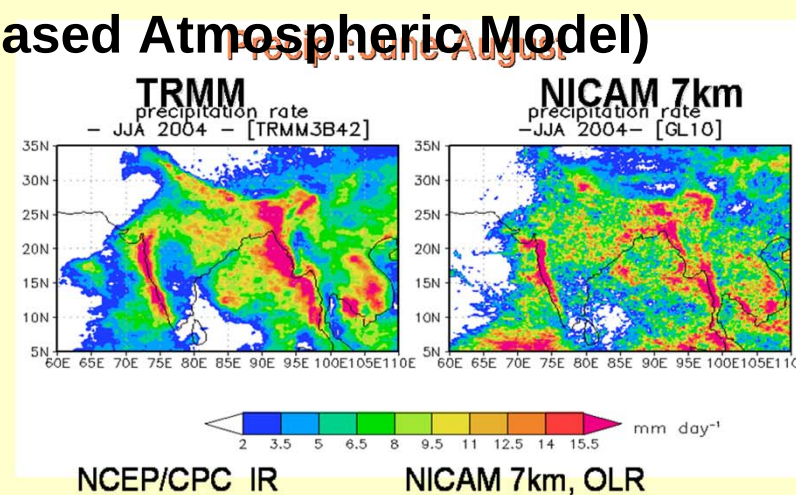
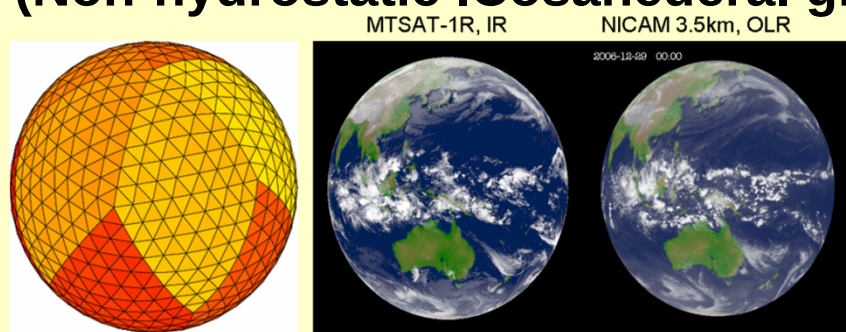
ENERGY SOURCE:
**Strong Latent Heat flux from
ocean**

high winds, warm water

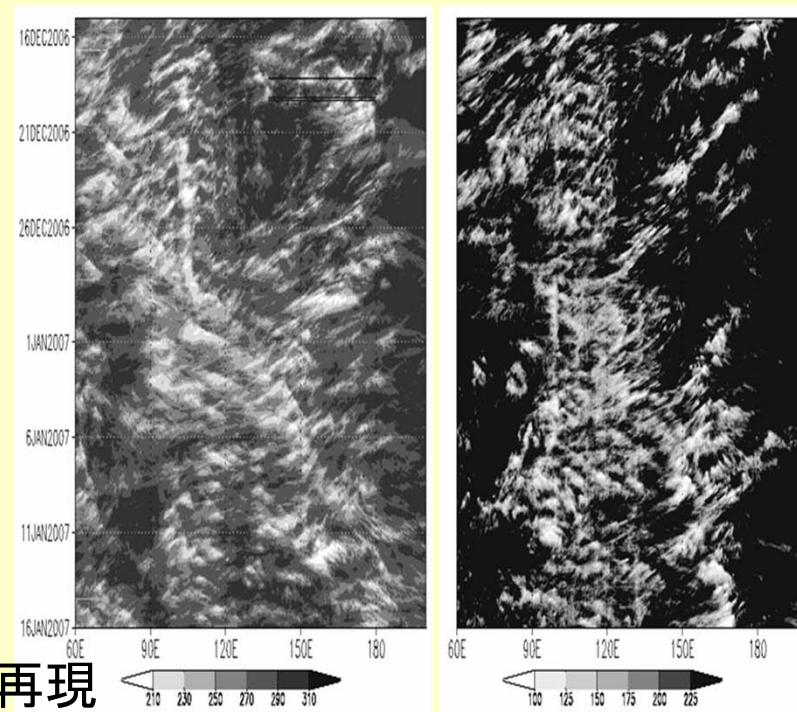
http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php?img_id=11720

全球雲システム解像モデルNICAM

(Non-hydrostatic ICosahedral grid-based Atmospheric Model)



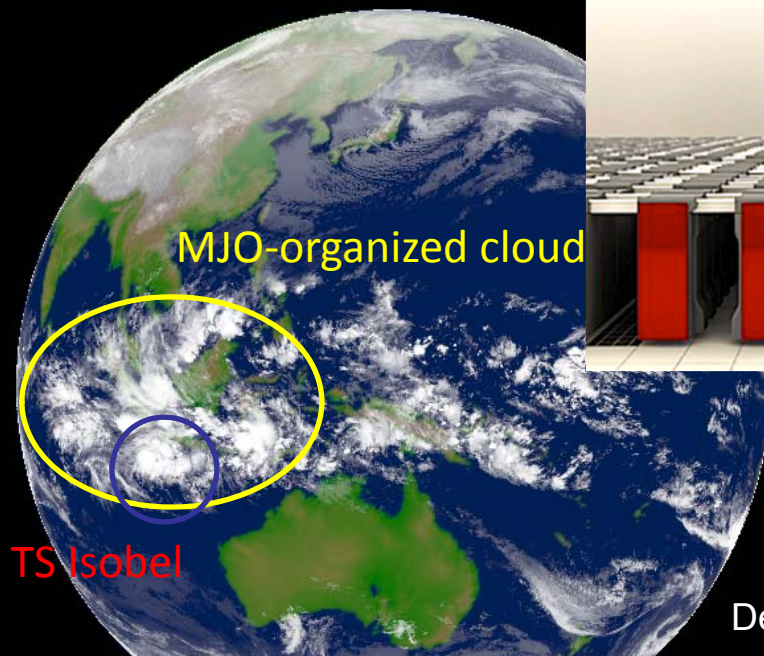
MJO(熱帯季節内振動)の再現



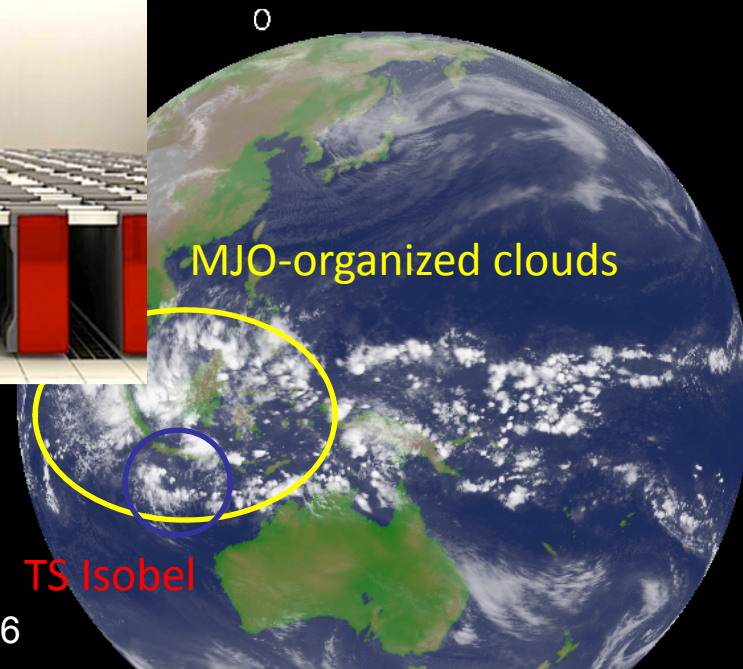
Miura et al. (2007, Science), Nasuno et al. (2009, JMSJ),
Fudeyasu et al. (2009, GRL), Liu et al. (2009, MWR)

2週間先の台風発生を予測？

MTSAT-1R

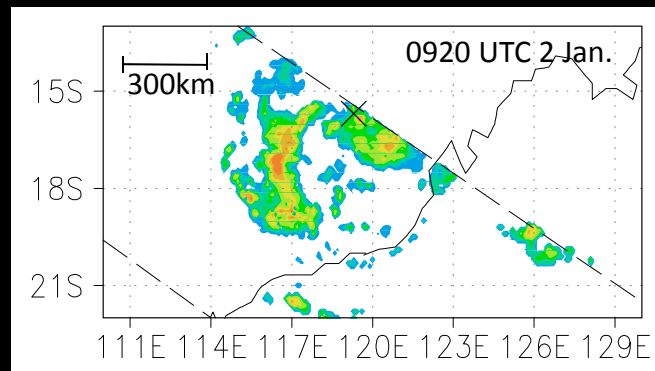


NICAM

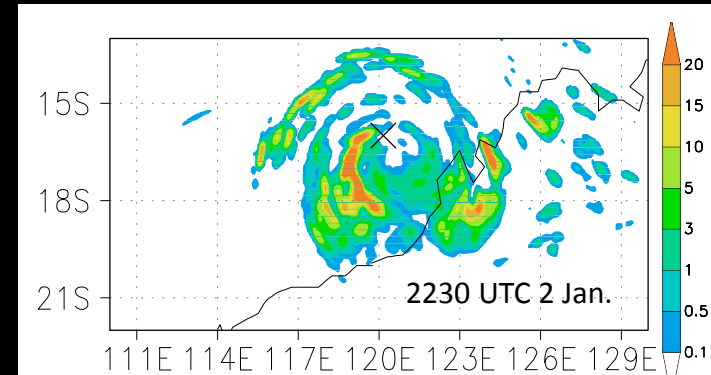


全球雲解像モデルNICAMにより初期値から2週間先の台風の発生予測の可能性が示された。ビギナーズラック？それともブレイクスルー？

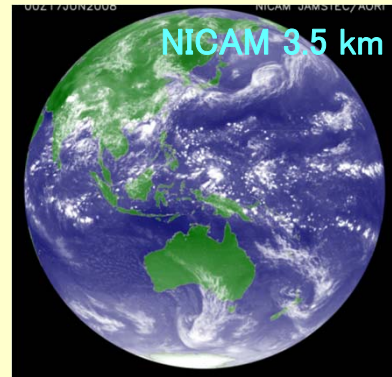
Surface rain rate (mm hour⁻¹) by TRMM-TMI



Surface rain rate (mm hour⁻¹) by NICAM

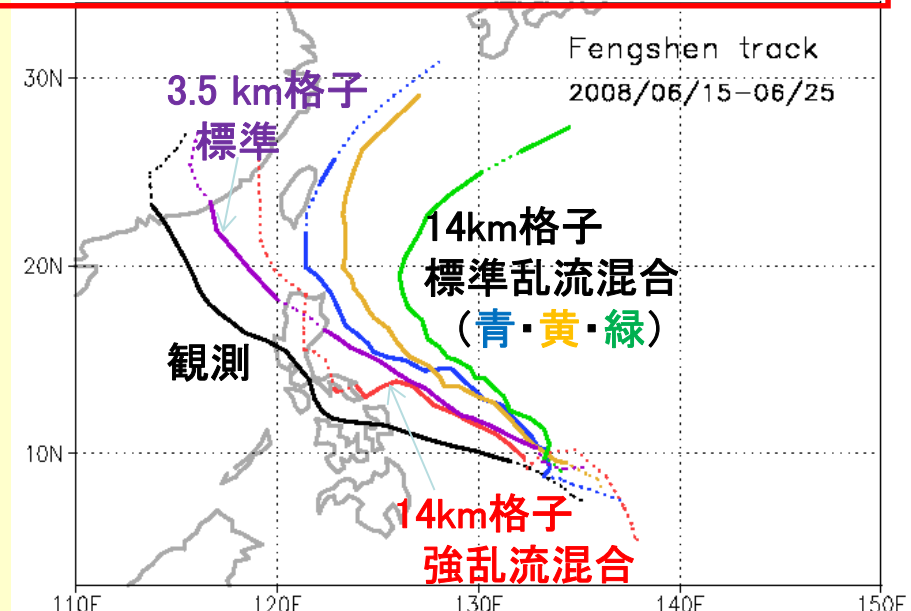
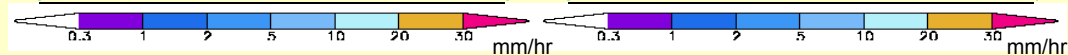
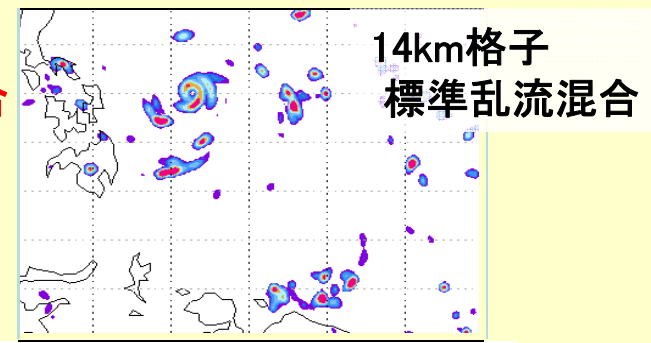
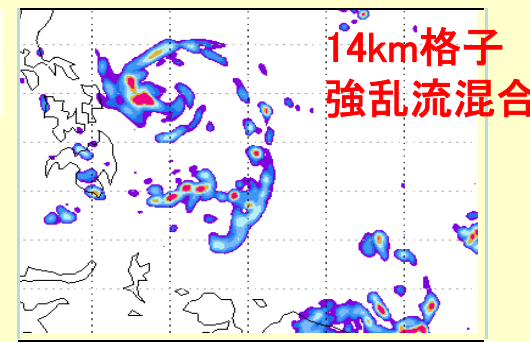
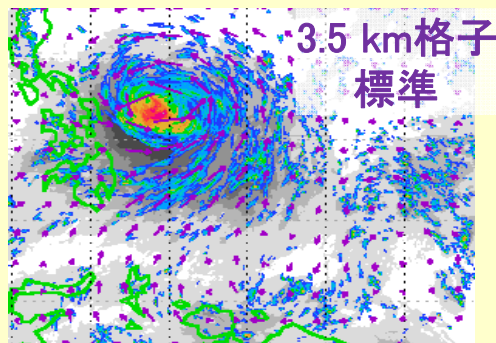
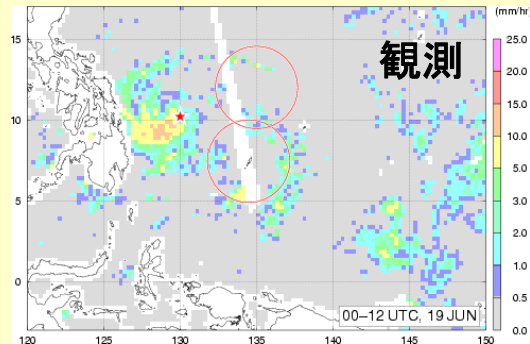


台風Fengshen (2008年6月) のNICAM 3.5km 全球実験



台風発生2日前 (2008/06/17 00UTC) 雲分布

台風直後 (2008/06/19) 1日積算降水量

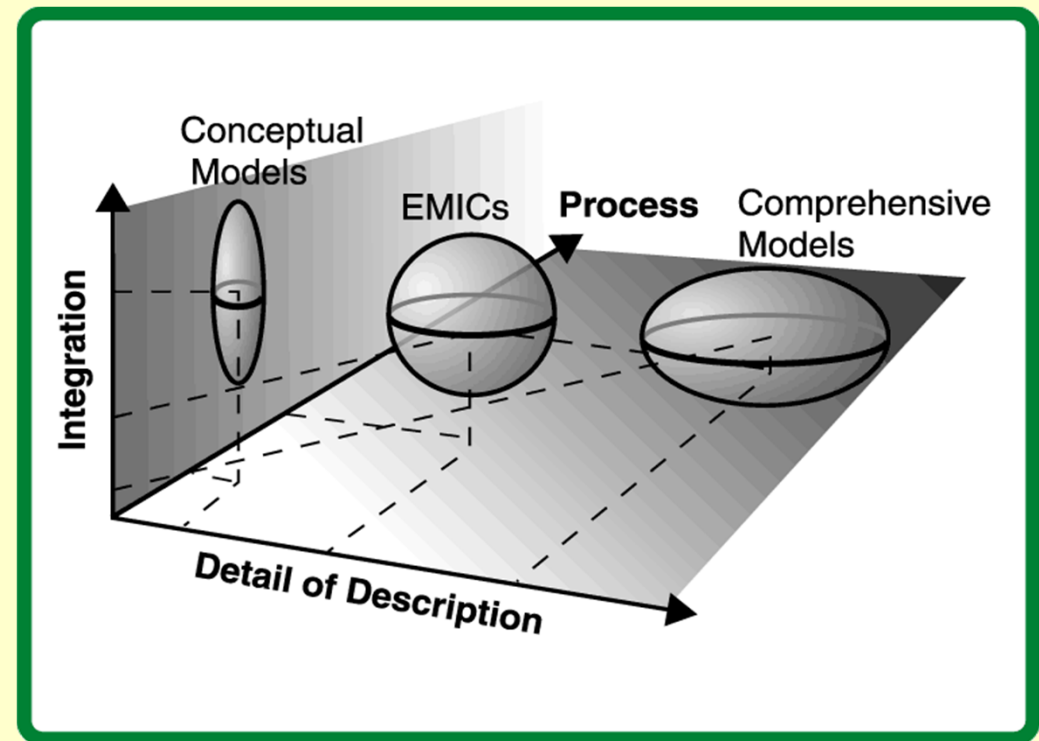


- 台風の発生メカニズム: 赤道波動、積雲クラスター、メソ擾乱と台風発生との関係
- 現地集中観測 (PALAU2008) との比較検証が可能
- 進路予報向上に対する雲分布の再現性の重要性を示唆

すでに3.5km実験を実施 ⇒ さらに高解像度(1.8km, 900m)での積乱雲の再現性

Peta flops computing?

10PF super computer
@Kobe, 2012

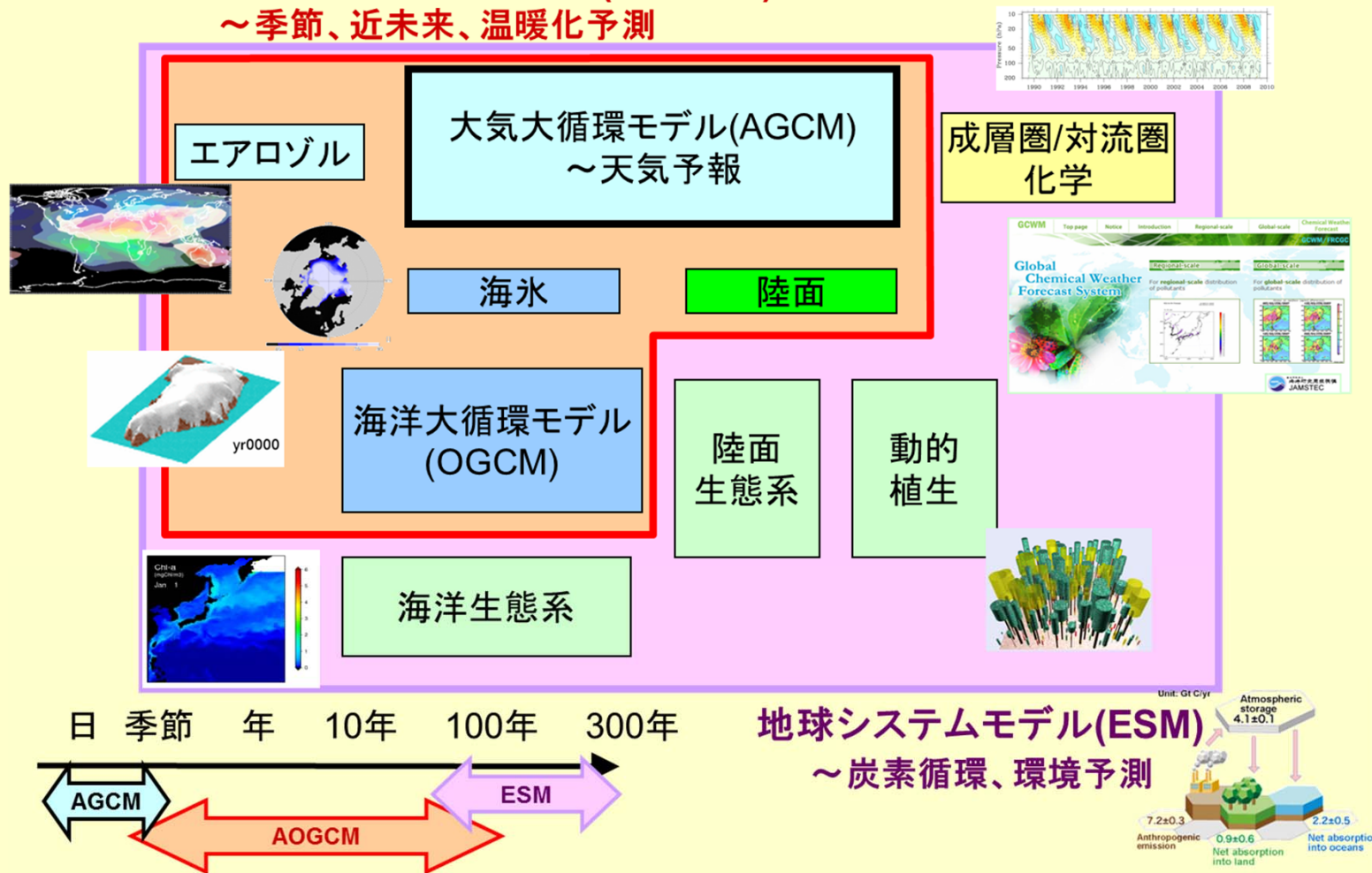


Resolution, Complexity, and Uncertainty...

気候モデルの課題3: より広範なプロセスの導入 ～天気予報から地球環境予測へ

大気海洋結合気候モデル(AOGCM)

～季節、近未来、温暖化予測



目的毎のモデル構築から、統一モデル～シームレス予測へ

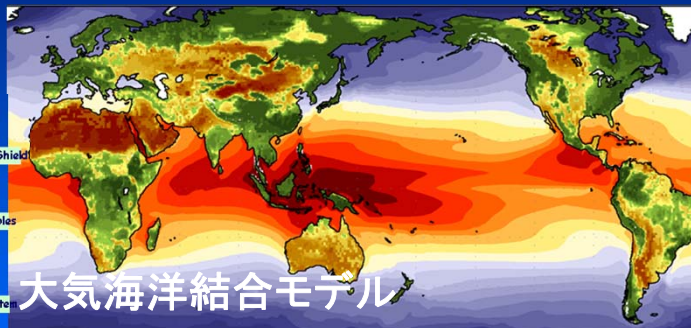
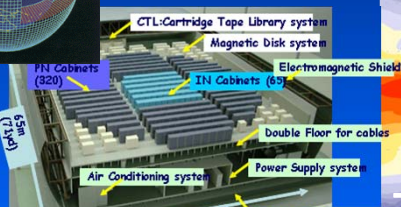
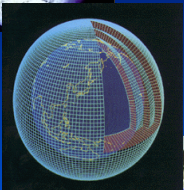
ーサブシステム研究を全体に反映させるプラットフォームの必要性

ー例えば、大気化学や渦解像海洋の導入により計算量数十倍～次世代スパコンの必要性



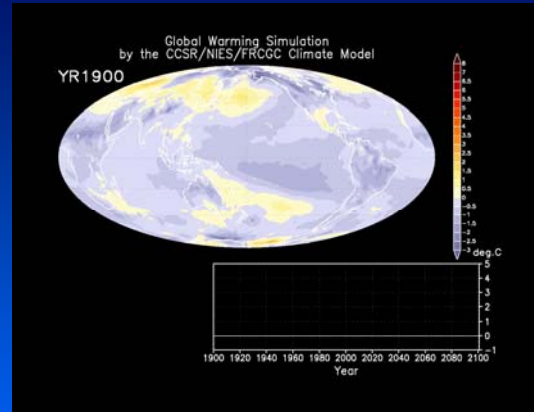
大気海洋研究所 気候システム研究系

数値モデルを縦横に用いた気候システム研究

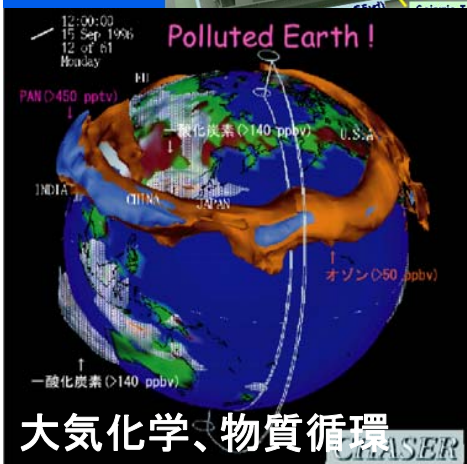
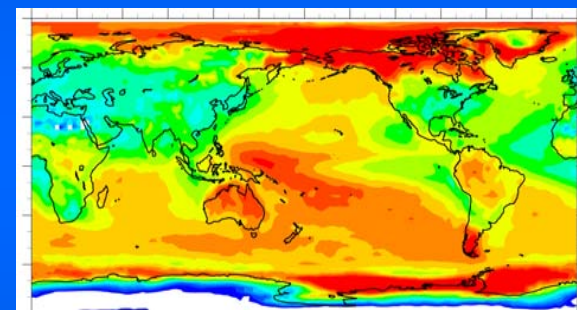


大気海洋結合モデル

地球温暖化予測～IPCC貢献

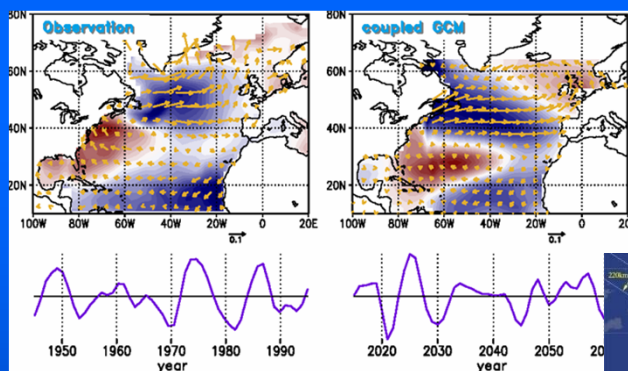


雲－エアロゾル相互作用

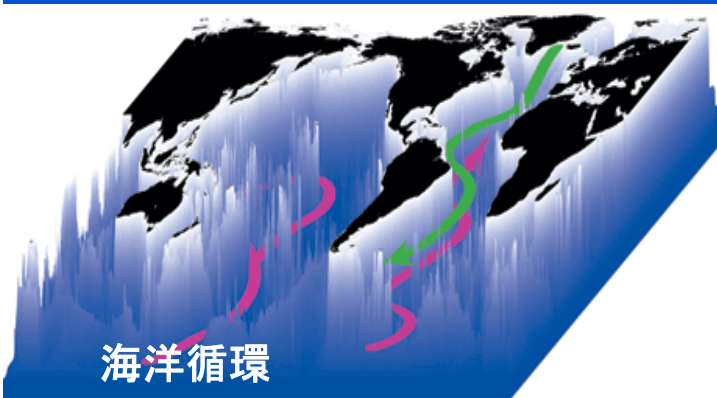
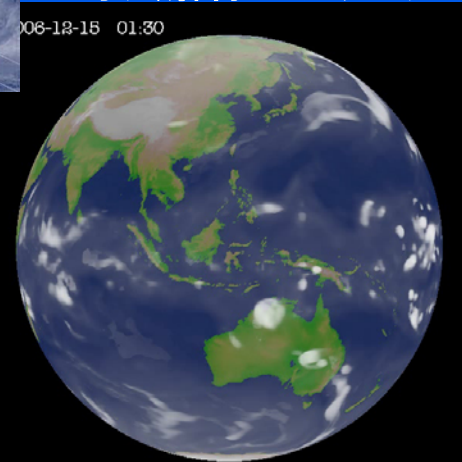


大気化学、物質循環

気候変動メカニズム

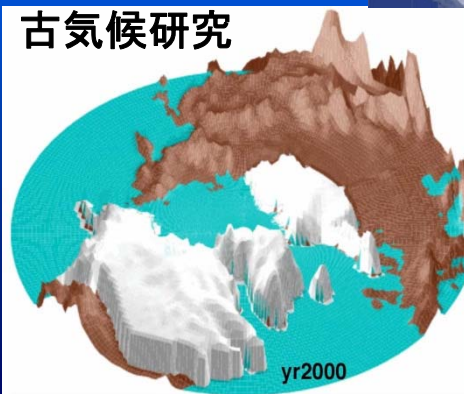


全球雲解像モデリング

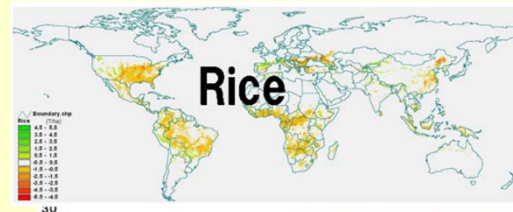


海洋循環

古気候研究



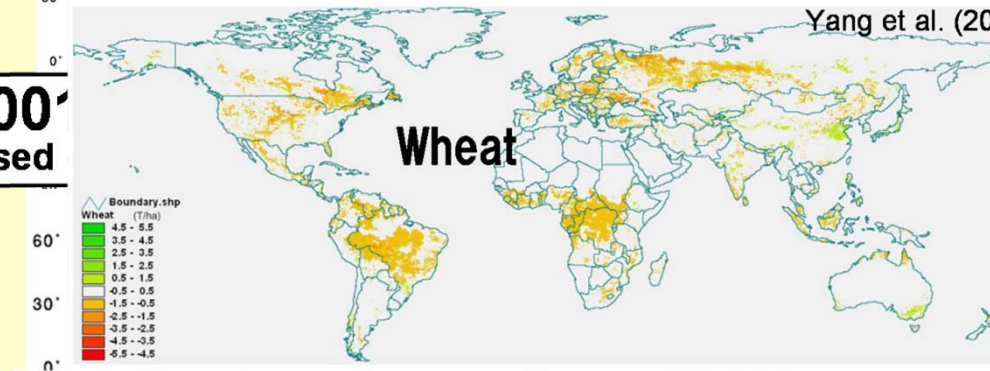
Impact assessment



for a centennial yields
in 2070-2100
from 1975-2005

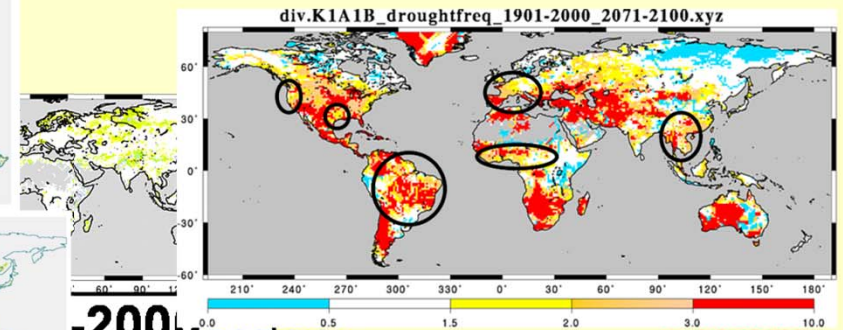
Oki et al. (2007)

Adaptation: 適応



Yang et al. (2007)

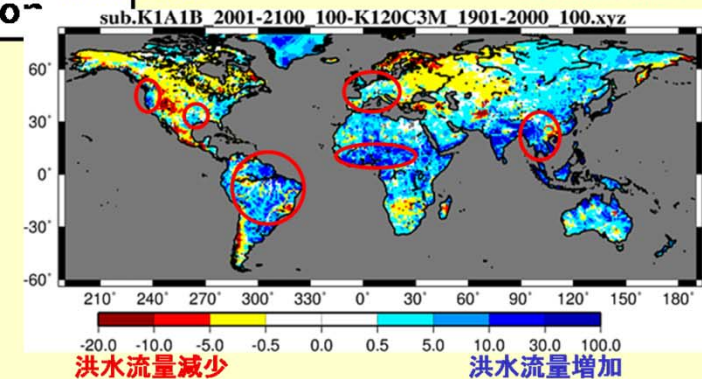
Floods of a centennial
20-40 yrs
2030.



-2000
vatio~

洪水頻度減少

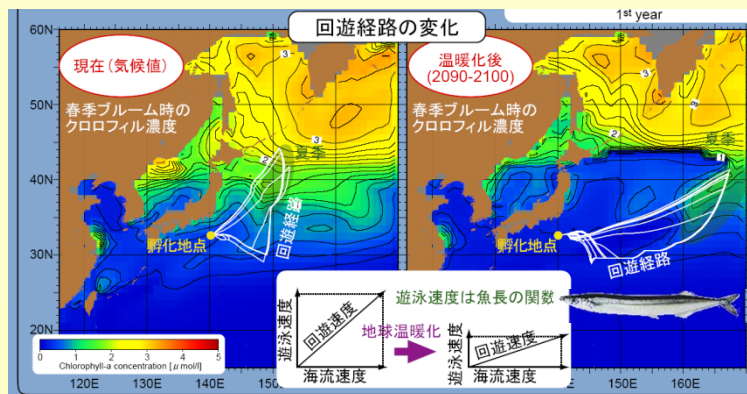
洪水頻度増加



洪水流量減少

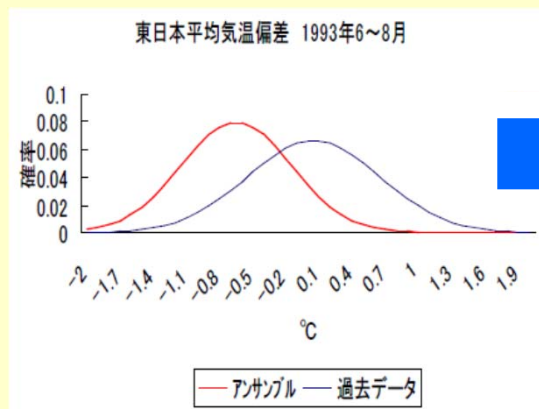
洪水流量増加

Hirabayashi et al. (2006)

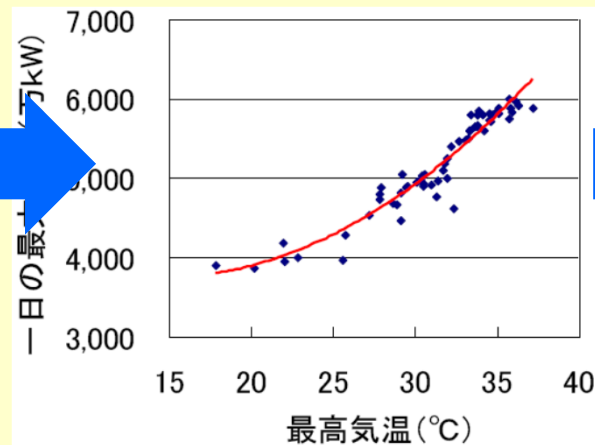


気候(天候)リスク管理

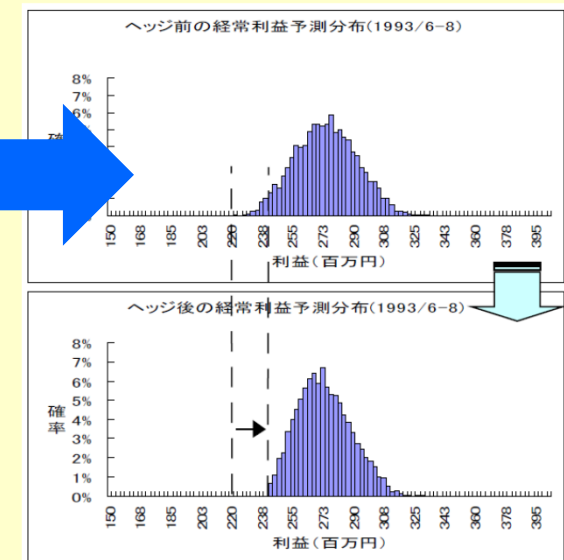
気象変数



ビジネス変数

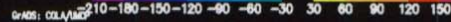


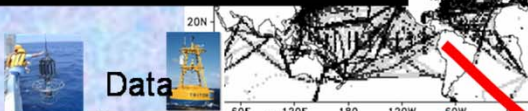
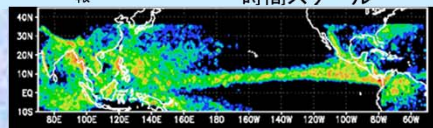
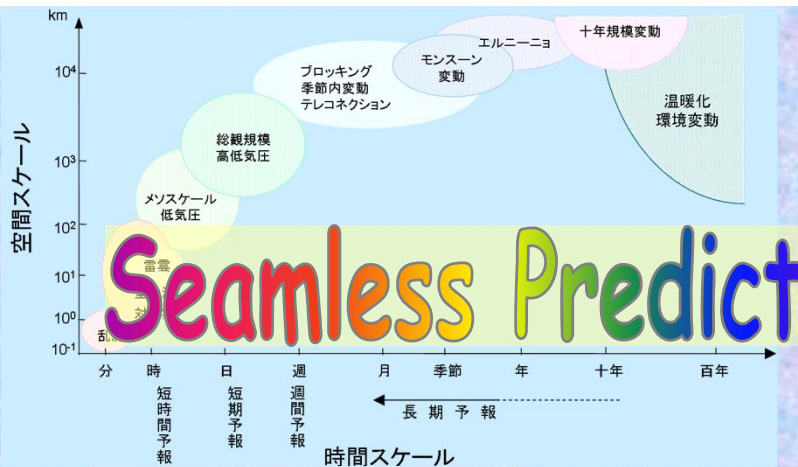
リスク評価・対策



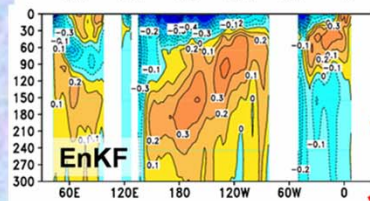
↑
気候影響の評価

* 概念図

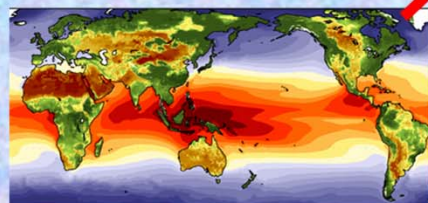




地球観測データの同化



Data Assimilation



Model



World Modelling Summit for Climate Prediction

ECMWF - Reading (UK), May 6-9, 2008

NEWS NATURE Vol 453/15 May 2008

They say they revolution

...to speeds in the hundreds of petaflops — would allow modellers to study simulations at the kilometre scale, enabling better predictions on the activity of hurricanes and, eventually, the local deep convection that transfers much energy into the upper atmosphere (see 'A real solution?'). This research could then be fed into operational models.

The scientists think they could answer at least some of the 'big' questions on the effects of global warming if the technology was available. But national climate-modelling efforts, such as those of the Met Office in Exeter, UK, or the National Center for Atmospheric Research (NCAR) in

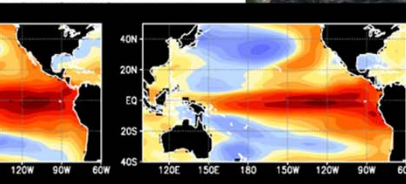
At the end of a four-day summit held last week at the European Centre for Medium-Range Weather Forecasts in Reading, UK, the scientists made the case for a climate-prediction project on the scale of the Human Genome Project. A key component of this scheme, which would cost something up to, or over, a billion dollars, would be a world climate research facility with computer power far beyond that currently used in the field.

Questions on how severe the effects of global warming will be, and where regions will be hit in what ways, are among the capabilities of current climate science, at least in part because of computing constraints. Today's climate models are run on computers

"We need to breathe"

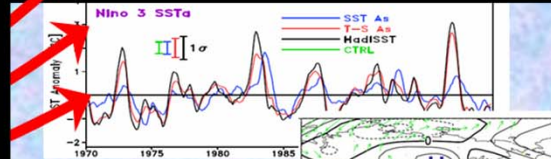
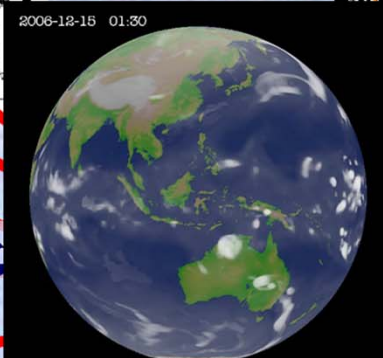


Volcanology in Bologna, Italy, spells out the implications: "We're reaching the point where national resources are insufficient to answer



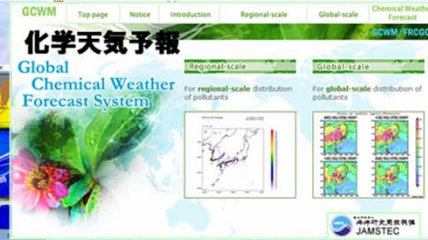
State of the art: a model (left) from the UK National Centre for Atmospheric Science and the Met Office running on Japan's Earth Simulator.

a darwinian change in the way we are working

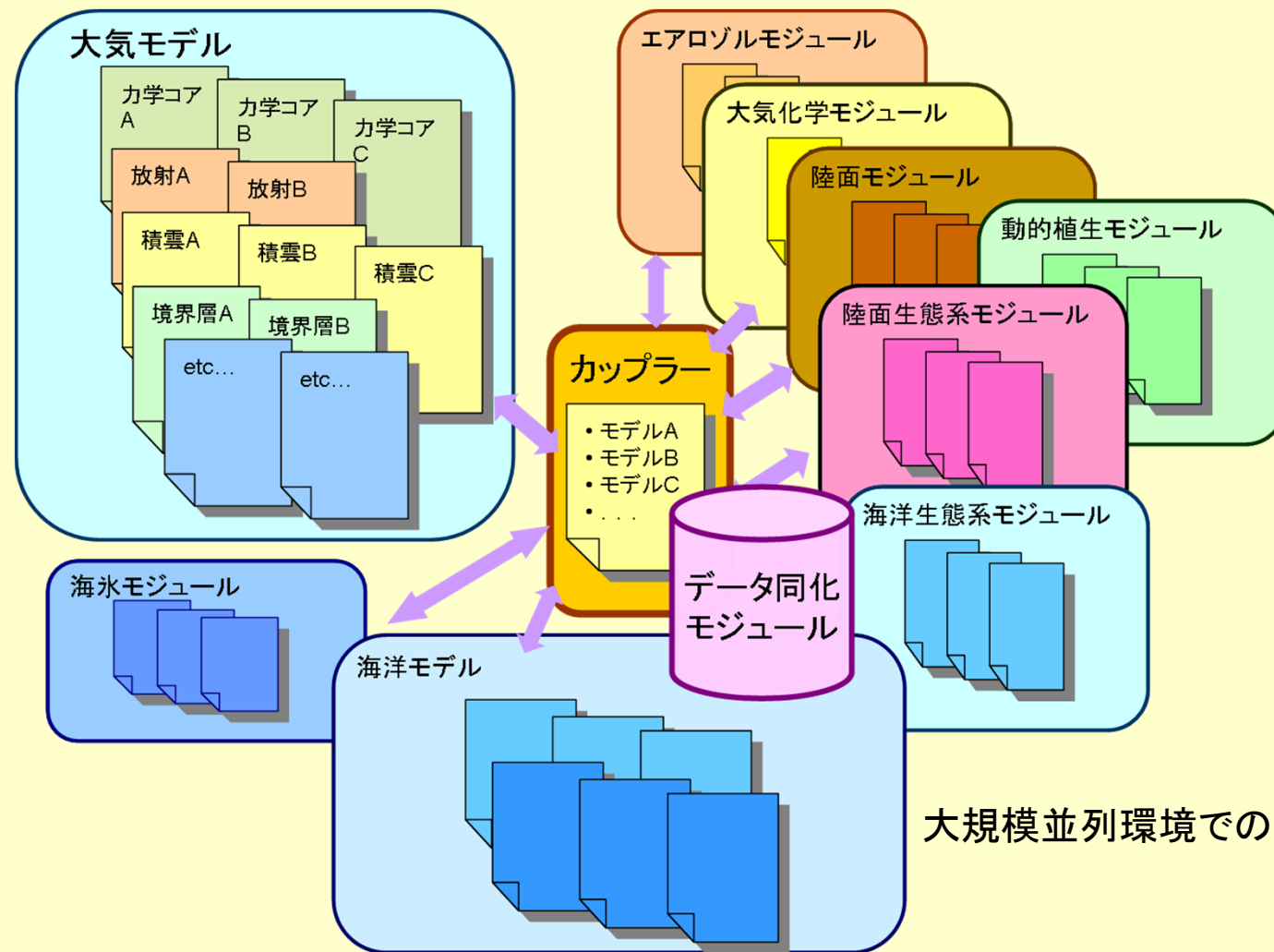


予測プロダクト

シミュレーションから実用予測へ
~これを実現するアプリケーション
プラットフォームの構築

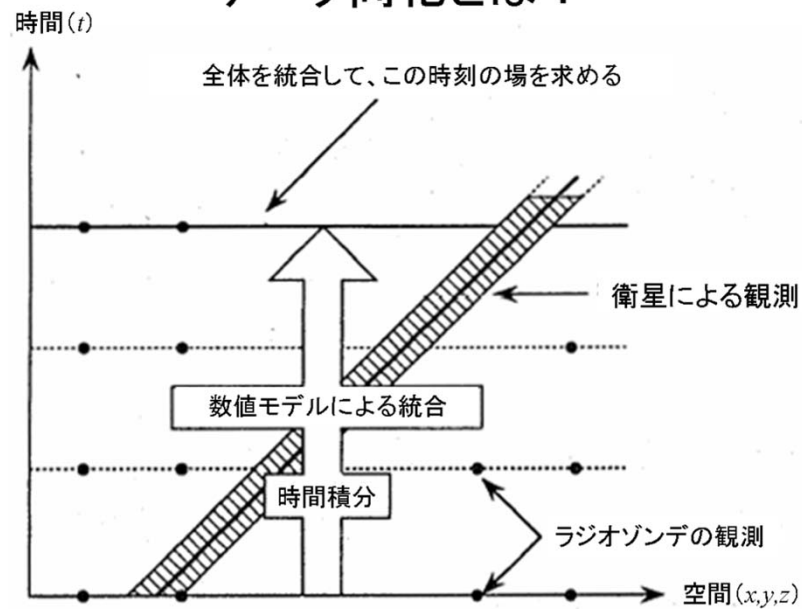


「統一日本モデル」～次々世代用統合地球環境監視予測 アプリケーションプラットフォーム



データ同化

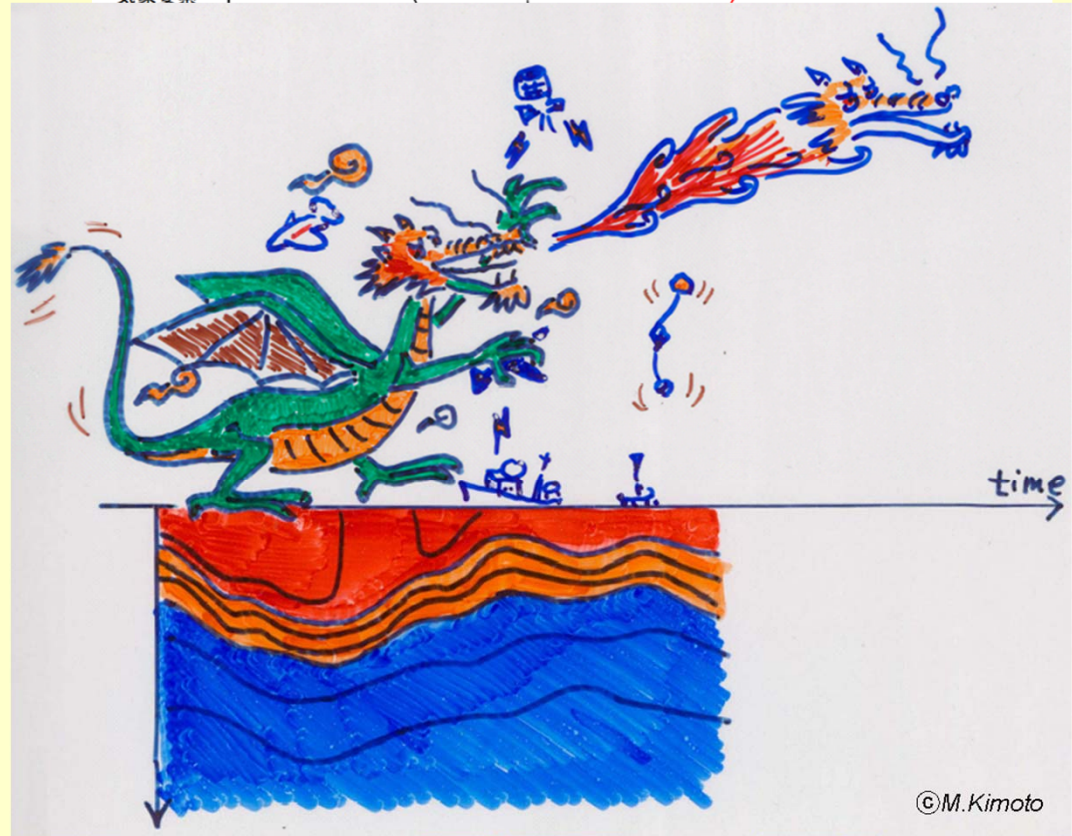
データ同化とは？



4次元変分法

気象要素 ↑ 前回の予報値の時間変化

予報 / 観測値の変化が取り込まれた



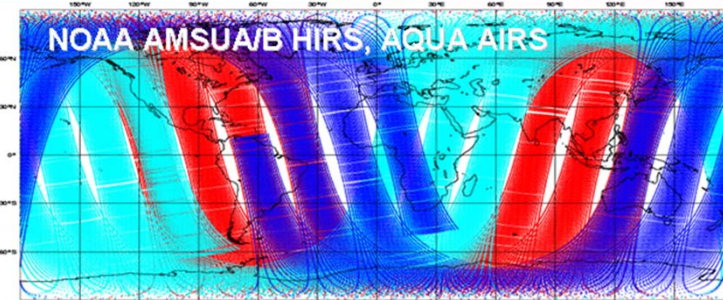
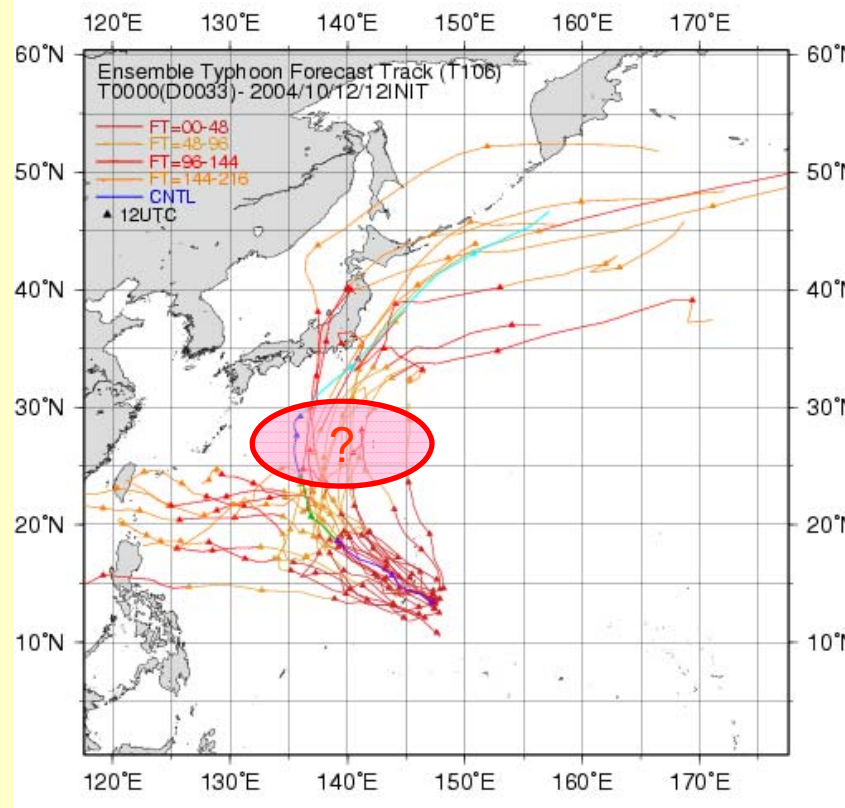
JRA-25 Japanese 25-year Reanalysis Project

観測値

Time

機動的観測、観測システムシミュレーション

Targeted (adaptive) observation, Observing System Simulation Experiment



$\varepsilon_0 \mathbf{L}_0 \varepsilon_0$

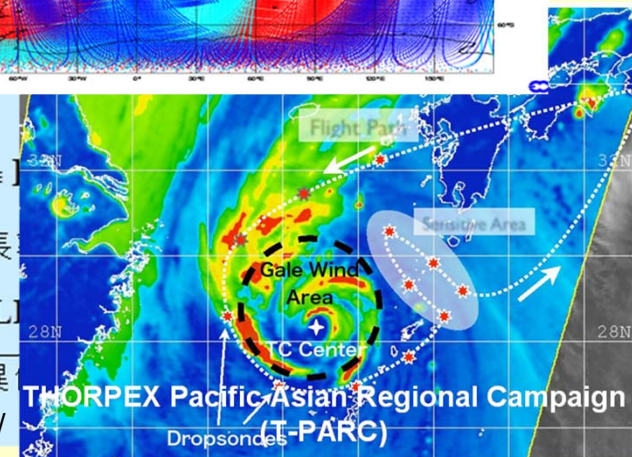
$(\eta_0 \equiv)$

• $\eta_0 = \mathbf{v}_1$ のとき最大成長

• $\sigma^2, \mathbf{v}$ は行列 $\mathbf{E}_0^{-1/2} \mathbf{L}^T \mathbf{E} \mathbf{L}_0$

$\Leftrightarrow \mathbf{E}_0^{1/2} \mathbf{L} \mathbf{E}_0^{-1/2}$ の $\sqrt{\text{特異}}$

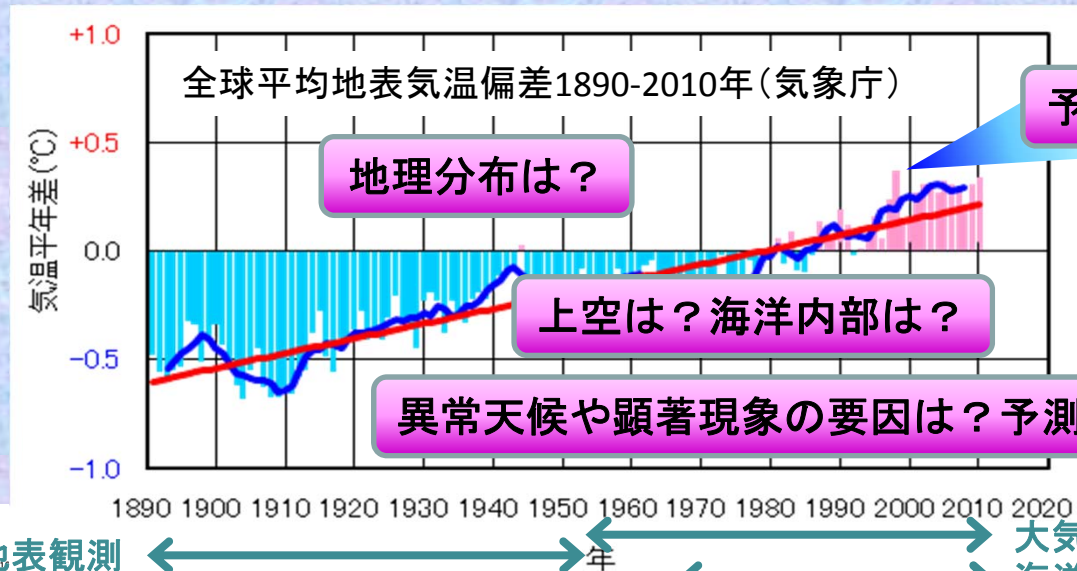
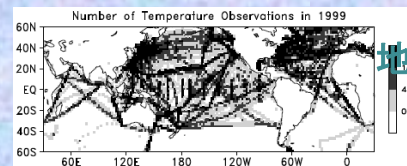
<http://www.pa.op.dlr.de/tparc/>



気候再解析・再予報実験システムの構築



System for
Prediction and
Assimilation by
MIROC



予測？検証は？



地表観測

大気高層観測(～現存大気再解析)

海洋内部観測(～現存海洋再解析)

本課題で目指す

大気海洋再解析

歴史気候データの最新大気海洋気候モデルによる再解析・再予報

- ☺ 50年以上遡った大気海洋3次元構造の再構築
- ☺ 数十年規模自然気候変動のメカニズム解明
- ☺ 異常天候・顕著現象の要因分析、予測可能性評価
- ☺ 気候予測の信頼度向上、気候変動の影響評価研究への貢献
- ☺ システムは研究コミュニティの共通プラットフォームに

