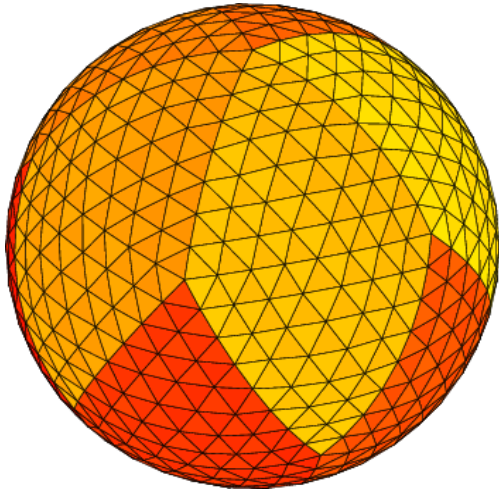
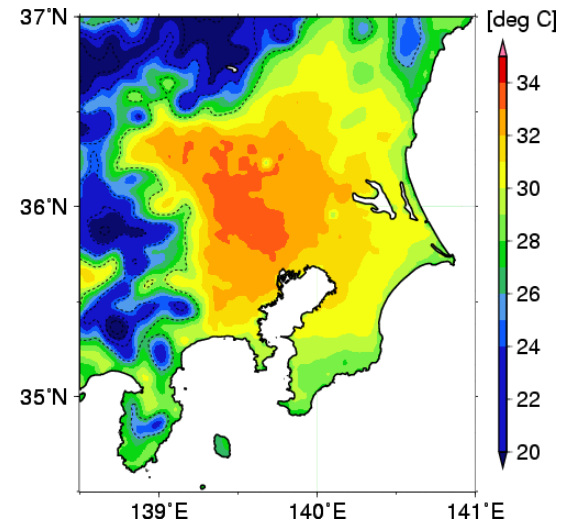


全球・領域気象予測モデルを用いた 地球環境研究と将来予測

NICAM



WRF



田中博
筑波大学
計算科学研究センター



全球非静力学モデルNICAM

- NICAM (Sato et al. 2008)

– 従来のAGCMでは、高解像度での計算に限界

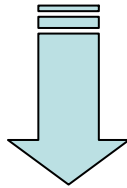
非静力学方程式系

+

正20面体格子

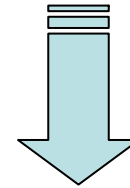
上昇流 w を直接計算

全球準一様格子



積雲の上昇流を表現可能

降水システムの再現性が
高まると期待

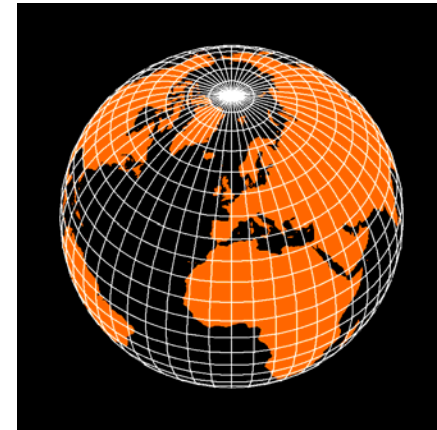


極問題が発生しない

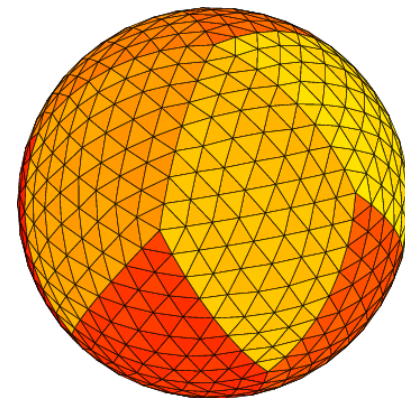
スペクトル変換を必要
としない

全球雲解像を目的としたモデル

従来AGCM



NICAM



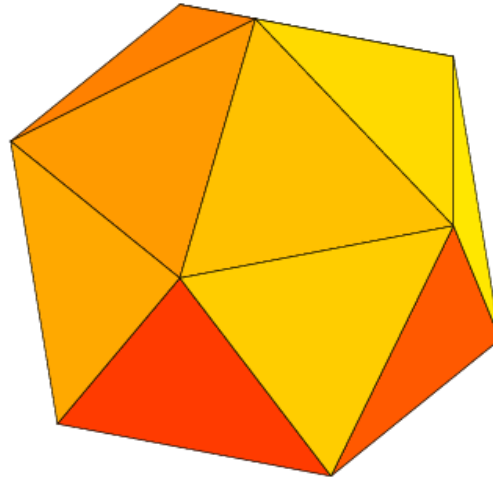
(by Sato et al. 2008)

NICAM AGCM

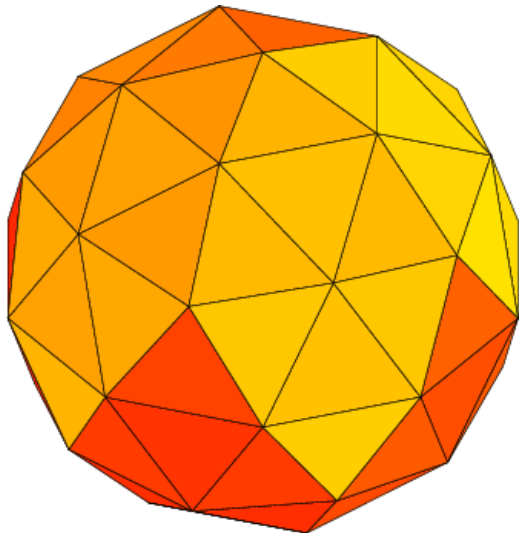
Original Icosahedron

Glevel-0

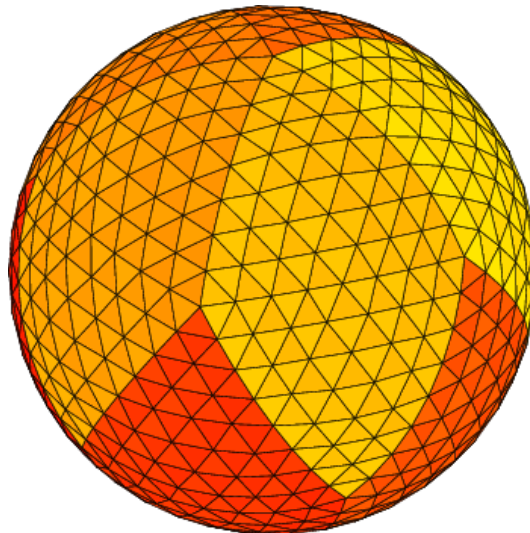
(by Satoh and Tomita)



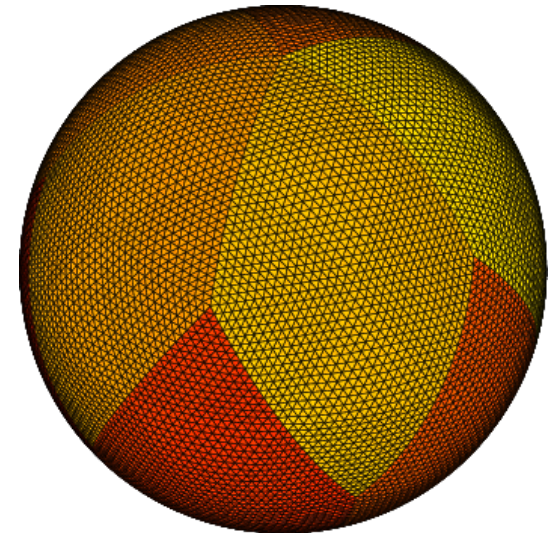
Glevel-1



Glevel-3



Glevel-5



Glevel and
resolution

Glevel-5: $\Delta x=224\text{km}$

Glevel-6: $\Delta x=112\text{km}$

Glevel-7: $\Delta x=56\text{km}$

Glevel-8: $\Delta x=28\text{km}$

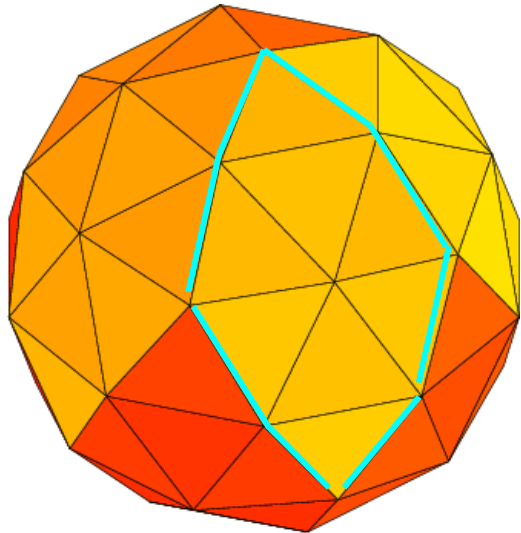
Glevel-9: $\Delta x=14\text{km}$

Glevel-10: $\Delta x=7\text{km}$

Glevel-11: $\Delta x=3.5\text{km}$

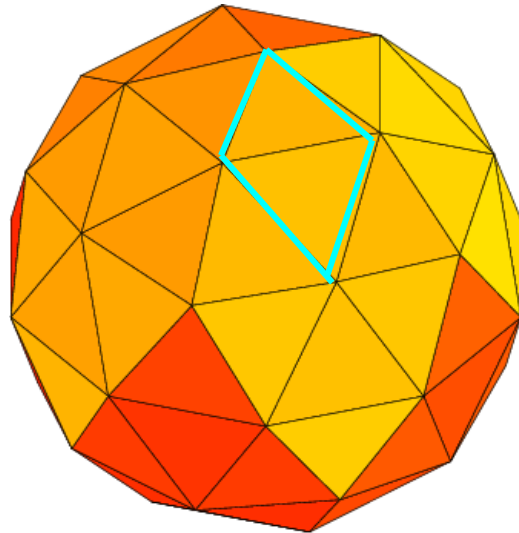
全球非静力学モデルNICAM

Glevel-1



Rlevel-0

Glevel-1



Rlevel-1

レベル 領域数

- Rlevel-0 : 10
- Rlevel-1 : 40
- Rlevel-2 : 160
- Rlevel-3 : 640
- Rlevel-4 : 2560

- 2個の三角形を合わせて1つの領域。
- Rlevelを上げることで、並列性を高める。

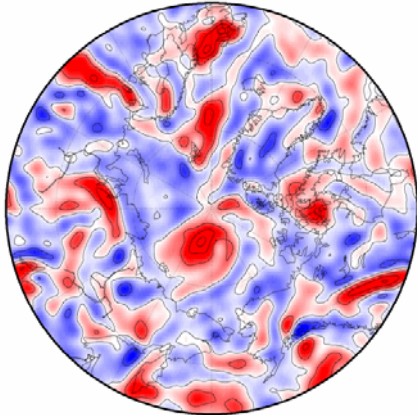
NICAMジョブの経過状況

- PACS-CS で正常終了
- PACS-CS で異常終了
- ◎ T2K-Tsukuba で正常終了
- △ 予定

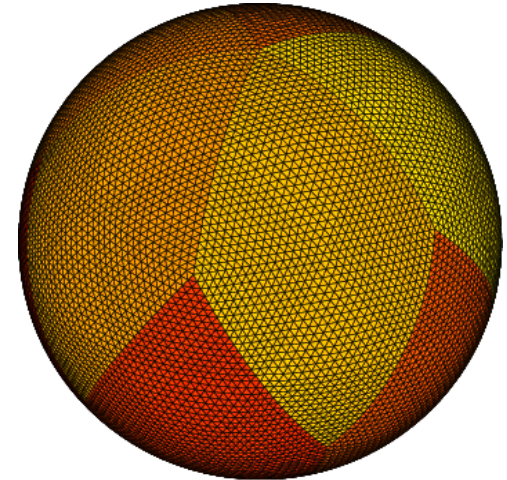
Core 数

Glevel	km	1	10	40	64	160	256	512	2560
5	224	○	○	○	○	○			
6	112	Jan 2007				○	○		
7	56					○	○		
8	28					○	●		
9	14						◎	◎	◎
10	7.0								◎
11	3.5							Jan 2009	△

NICAM running at CCS



Glevel-5: $\Delta x = 224$ km
Glevel-6: $\Delta x = 112$ km
Glevel-7: $\Delta x = 56$ km
Glevel-8: $\Delta x = 28$ km
Glevel-9: $\Delta x = 14$ km
Glevel-10: $\Delta x = 7$ km
Glevel-11: $\Delta x = 3.5$ km



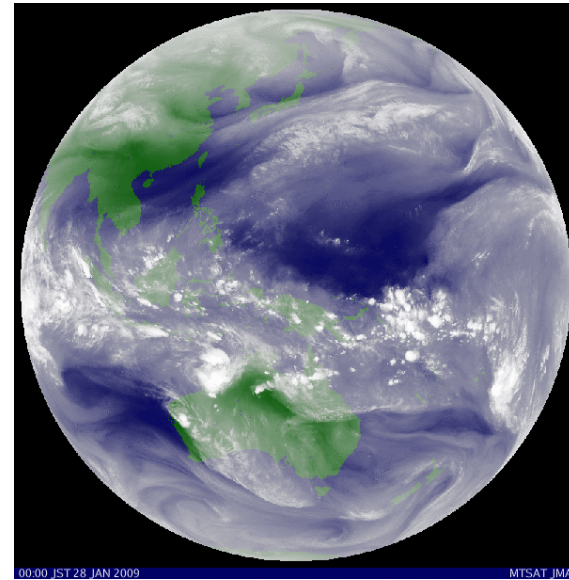
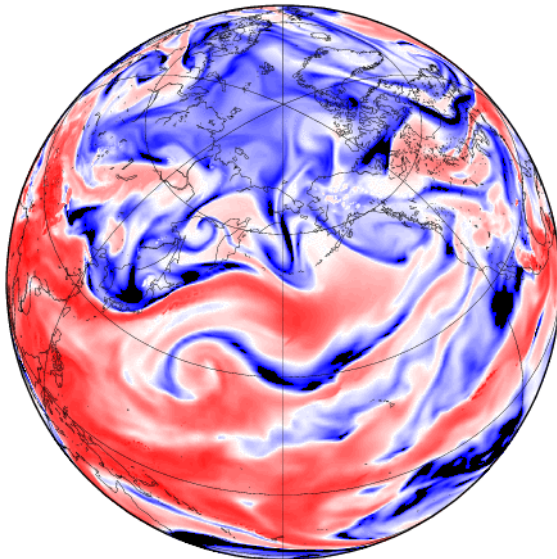
Arctic Cyclone

500 hPa S. Humidity

NICAM 2004060100Z+0HR

GMS

NICAM
7km



NICAM running at CCS, University of Tsukuba

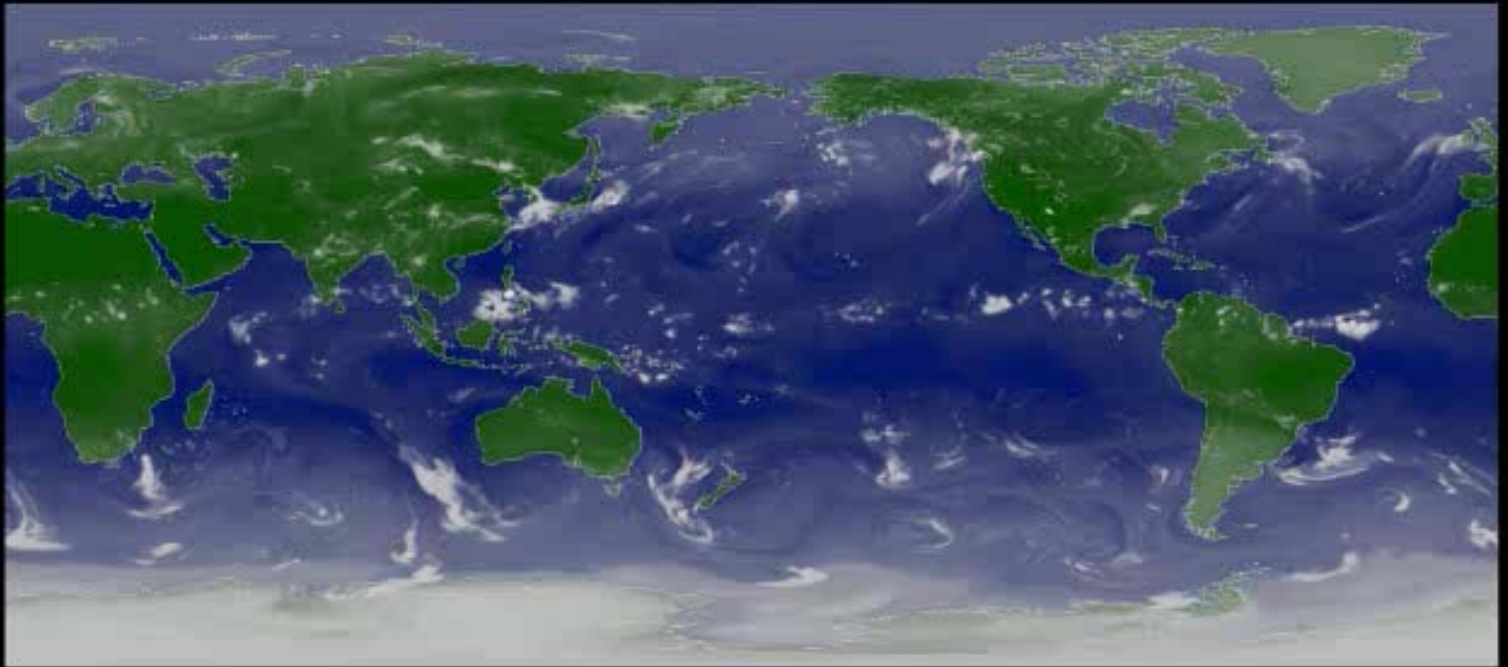
NICAM glevel-9
2008062100 Z



NICAM running at CCS, University of Tsukuba

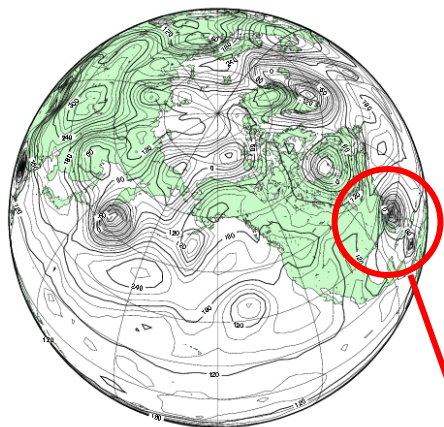
NICAM glevel-9

2008062100 Z



1000 hPa Height

NICAM 2008070500Z+78HR



Global

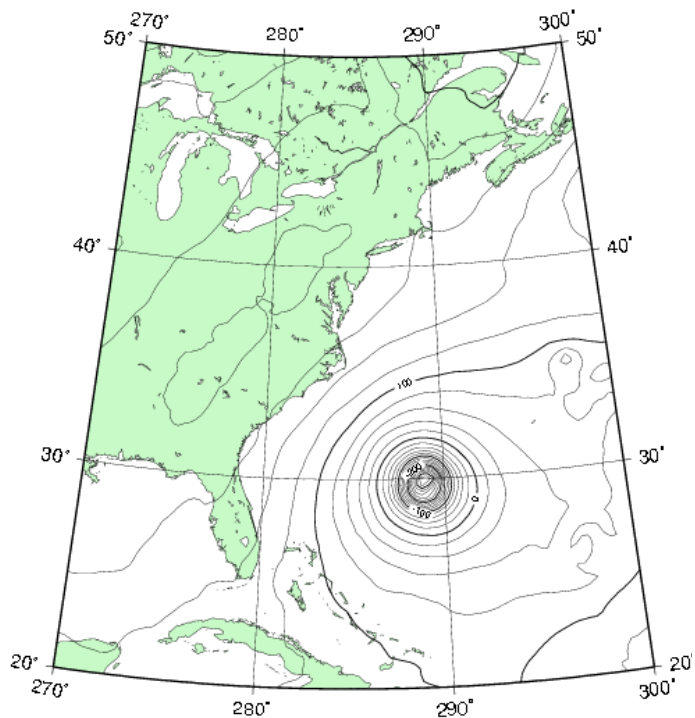
Tropical cyclone

NICAM 28km model 21 day integration starting from June 21, (PACS-CS 256PE)

1000 hPa Height

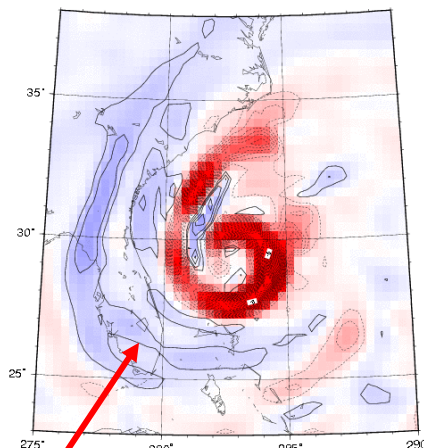
NICAM 2008070500Z+0HR

SLP



500 hPa Omega

NICAM 2008070500Z+78HR

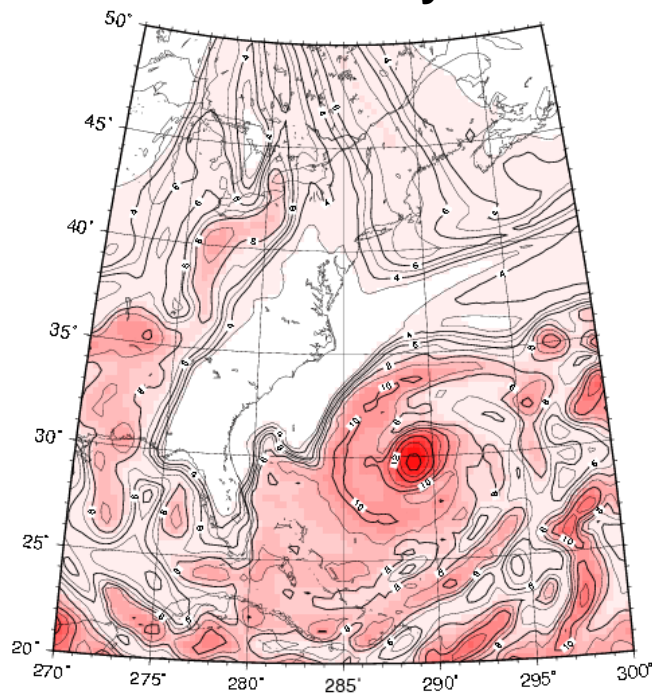


850 hPa S. Humidity

NICAM 2008070500Z+0HR

Humidity

Omega



Extra-tropical Cyclones

- Life cycle
- Warm and cold fronts

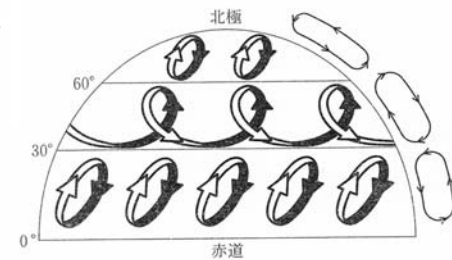
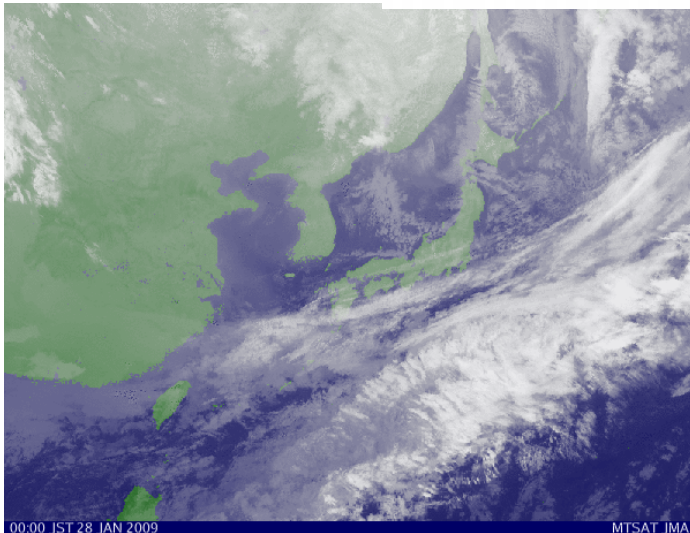
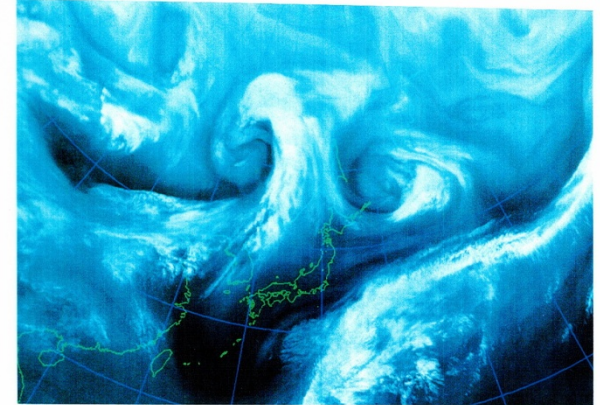
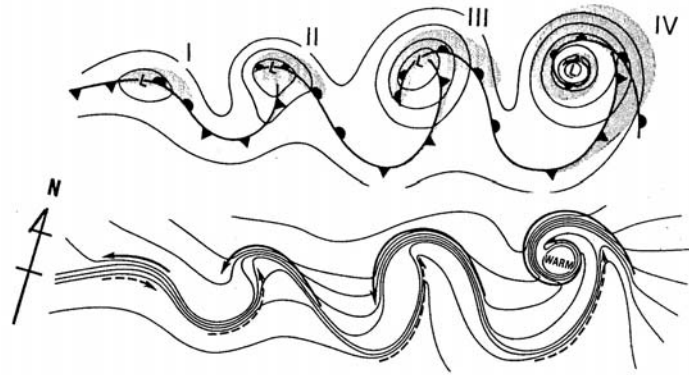
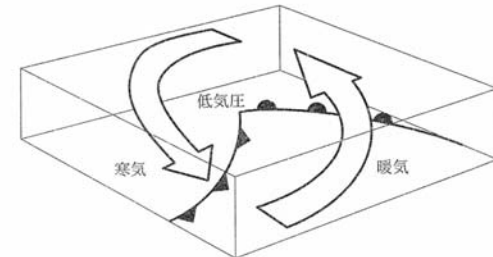


図 1

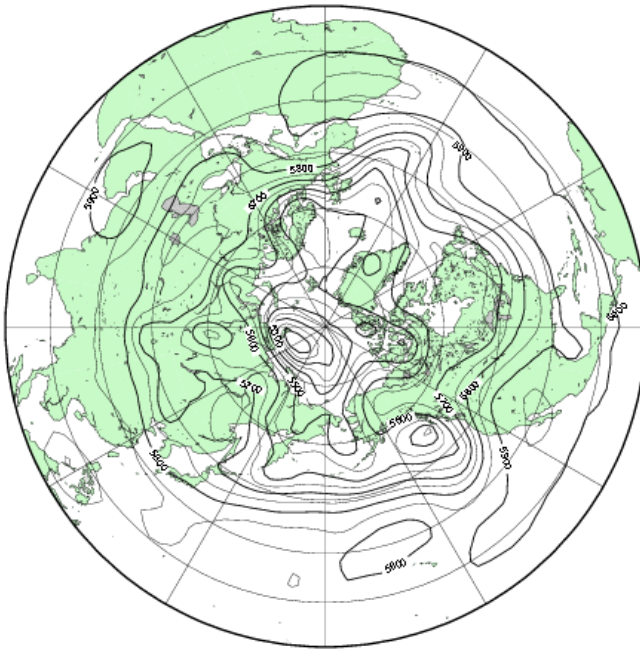


Arctic Cyclones SLP

10 day integration starting
From June 21, 2008
NICAM g18 and g19 r102-n512

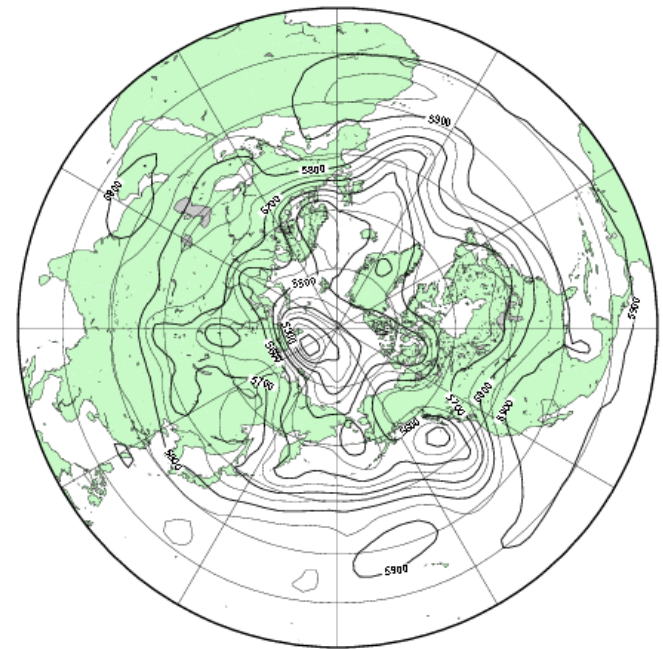
500 hPa Height

NICAM 2008062100Z+0HR



500 hPa Height

NICAM 2008062100Z+0HR



北極低氣壓

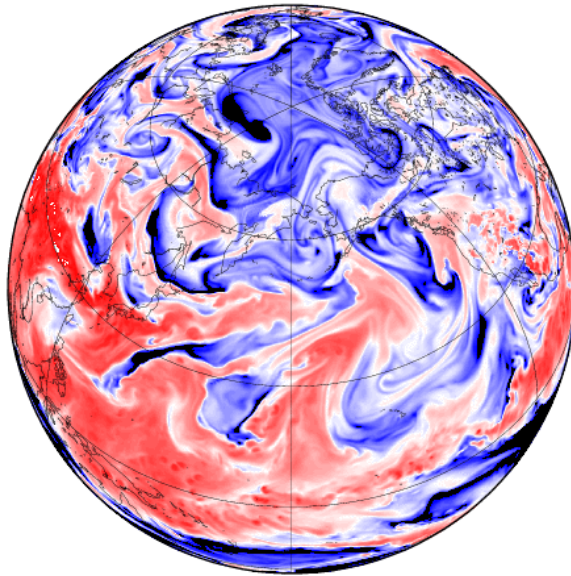
Relative Vorticity

2008062218Z

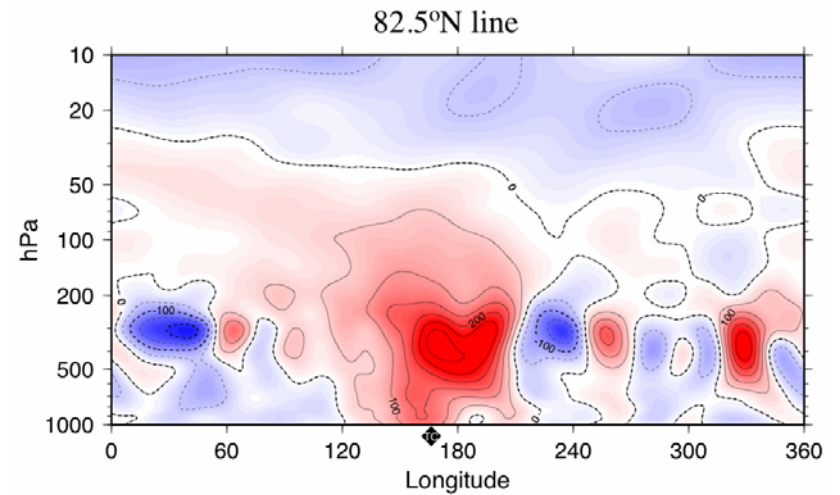
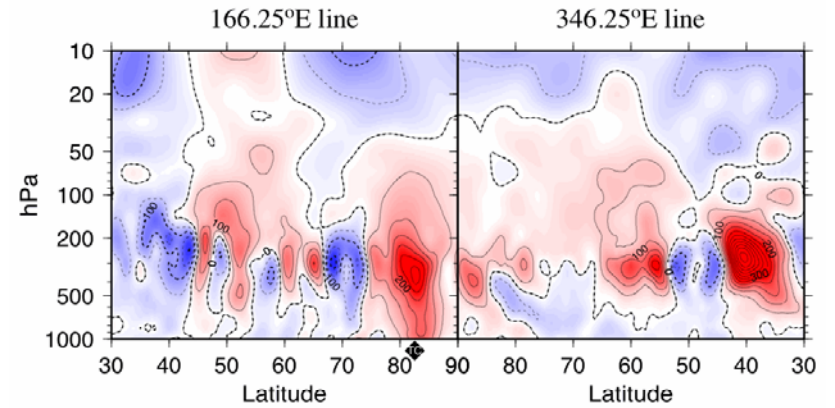
Target Cyclone 82.5°N/166.25°E

500 hPa S. Humidity

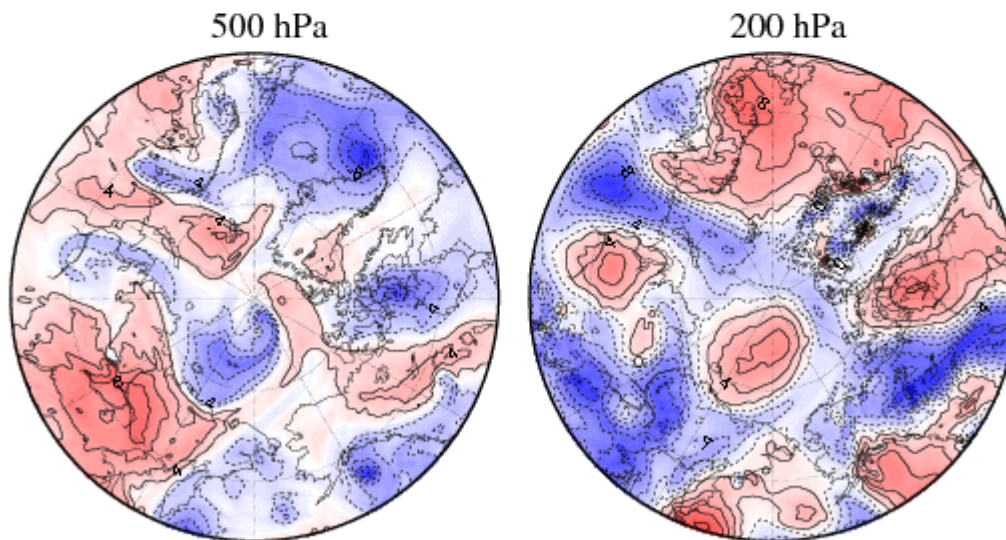
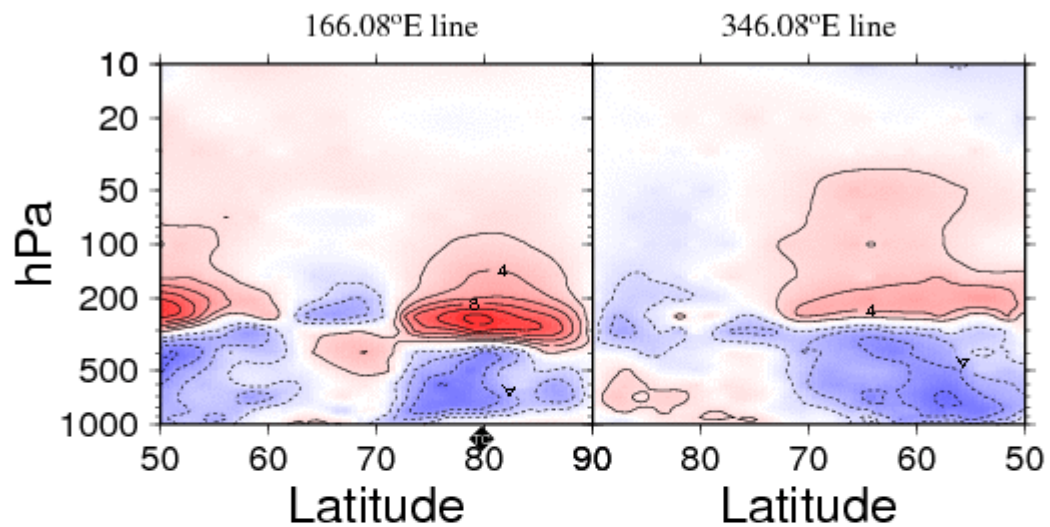
NICAM 2008062100Z+0HR



GMT 2009_Jan 30 22:26:44 CCS ga4n256



NICAM gl-8
Temperature Anomalies
2008062100Z+48HR



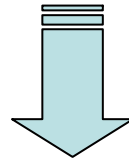
Ensemble Kalman Filter

問題

初期値をどうするか

- 現在は、JMA-GSM解析値やNCEP/NCAR再解析値を正20面体格子に内挿。
- 初期値敏感性のため、数値予報に悪影響。NICAM

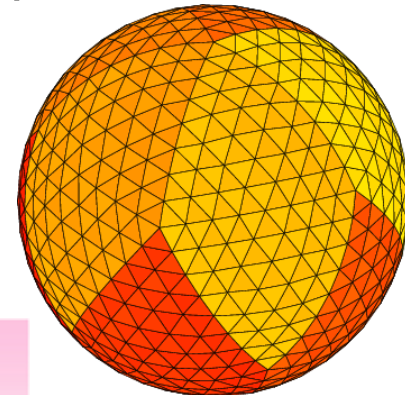
NICAMに最適な初期値ではない



目的

①NICAMにEnsemble Kalman Filter (EnKF, Evensen 1994)を適応して、機能するかどうか。

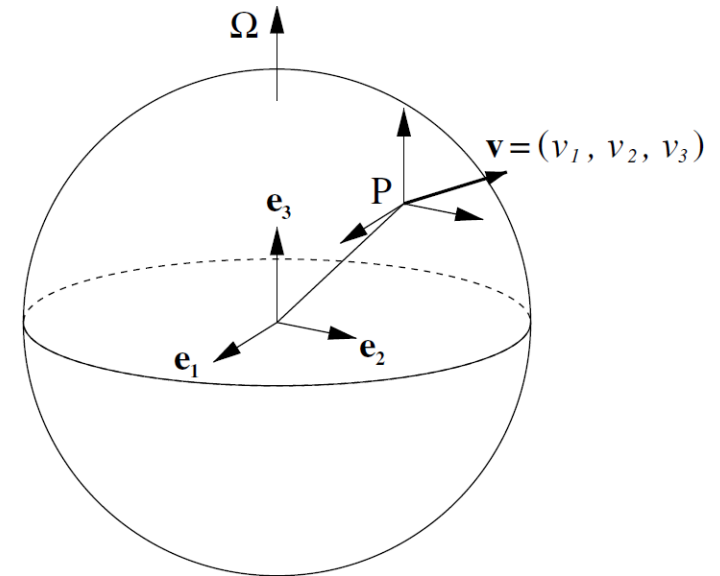
②EnKFを使うことで、NICAMに最適で、精度の高い初期値を作成。



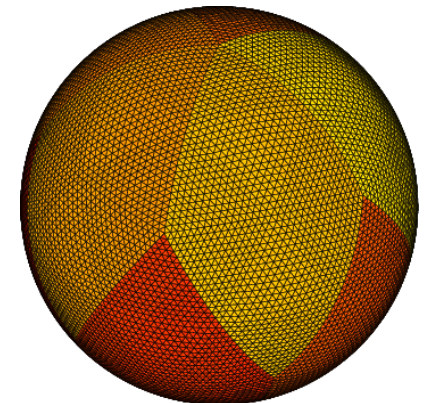
(Satoh et al. 2008)

実験設定 (NICAM)

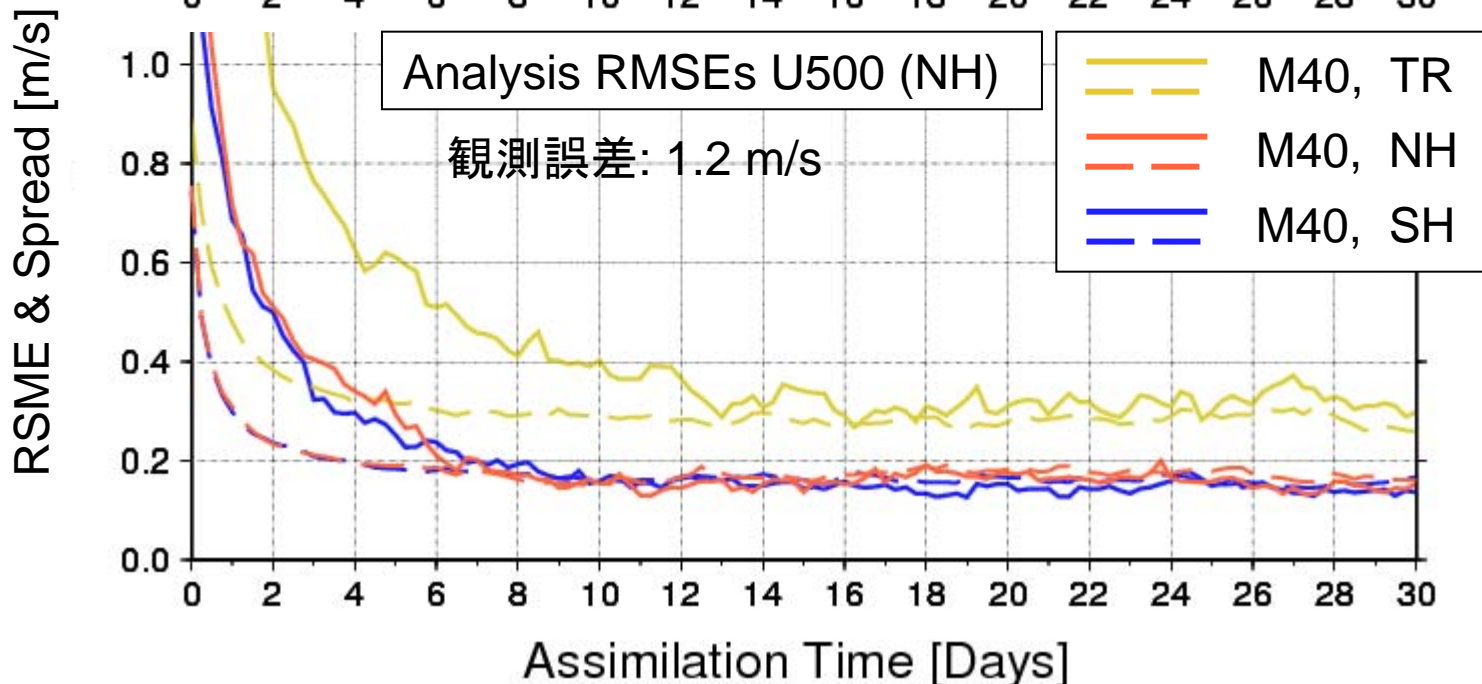
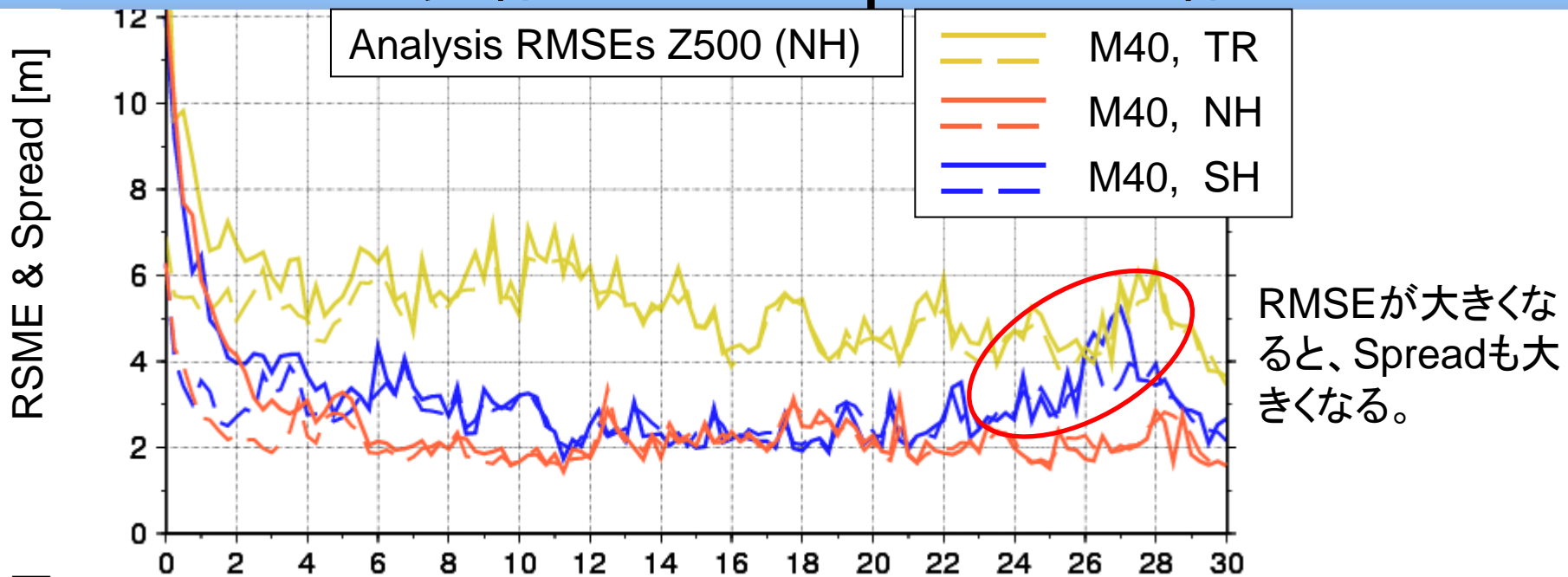
支配方程式	完全圧縮性非静力学方程式系
水平解像度	Glevel-5 (224 km)
鉛直層数	40 層
予報変数	P, T, V1, V2, V3, W, Qv, Qr, Qc
観測変数	P, T, V1, V2, V3, Qv
メンバー数	40メンバー
ステップ数	120 (6時間間隔で30日積分)



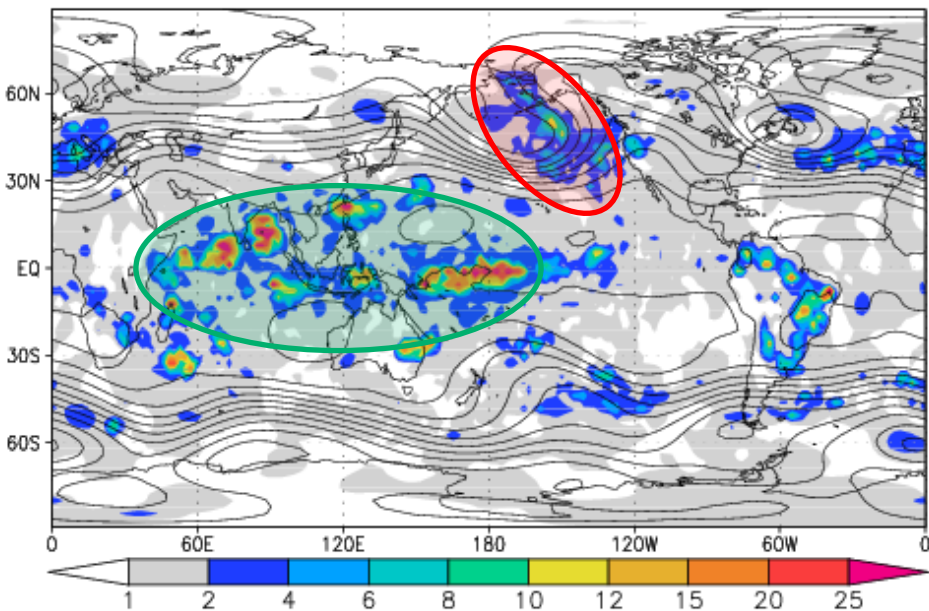
水平風UVを3成分V1, V2, V3に分解。 **Glevel-5**



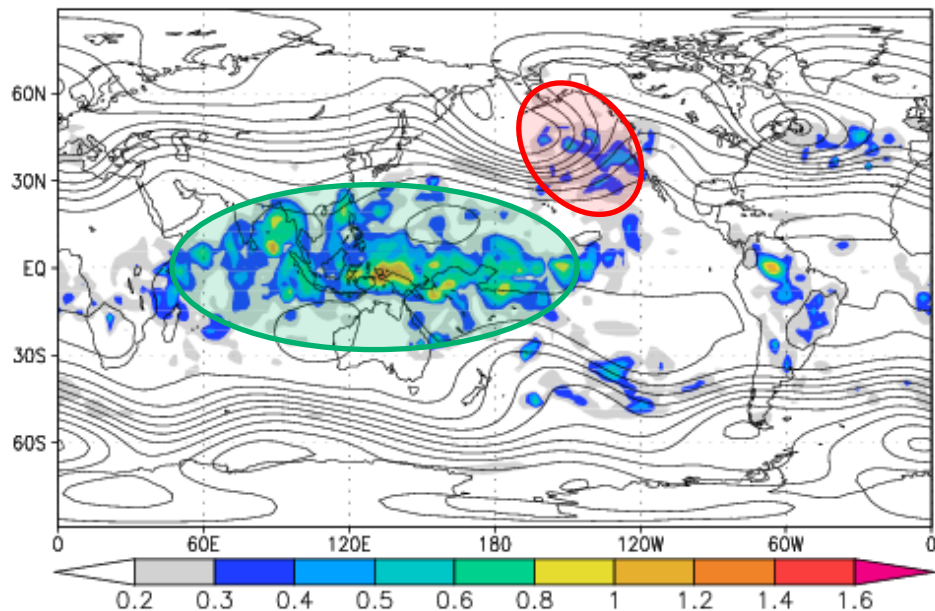
RSME (実線 —) & Spread (破線 - -)



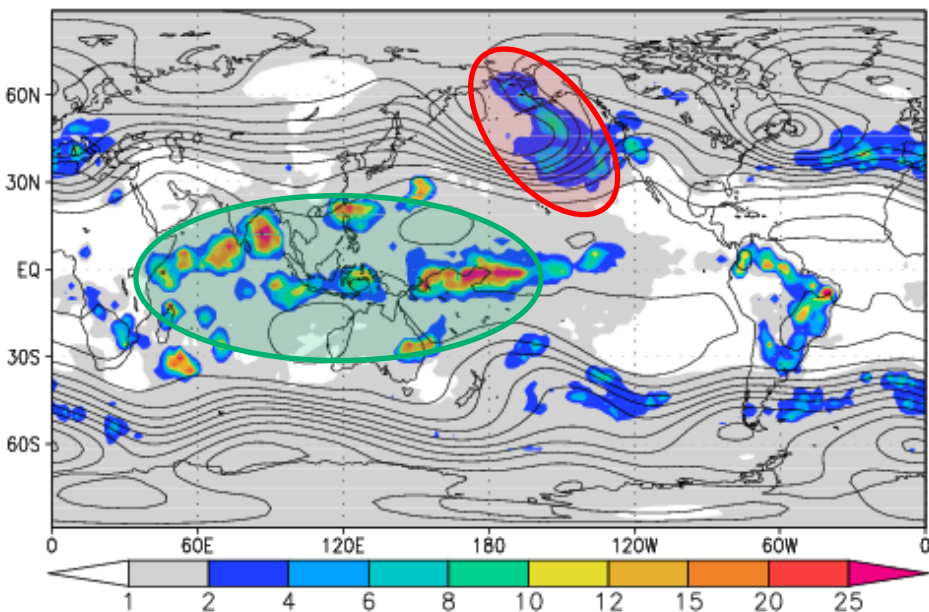
Analysis RMSE (Z500 [m])



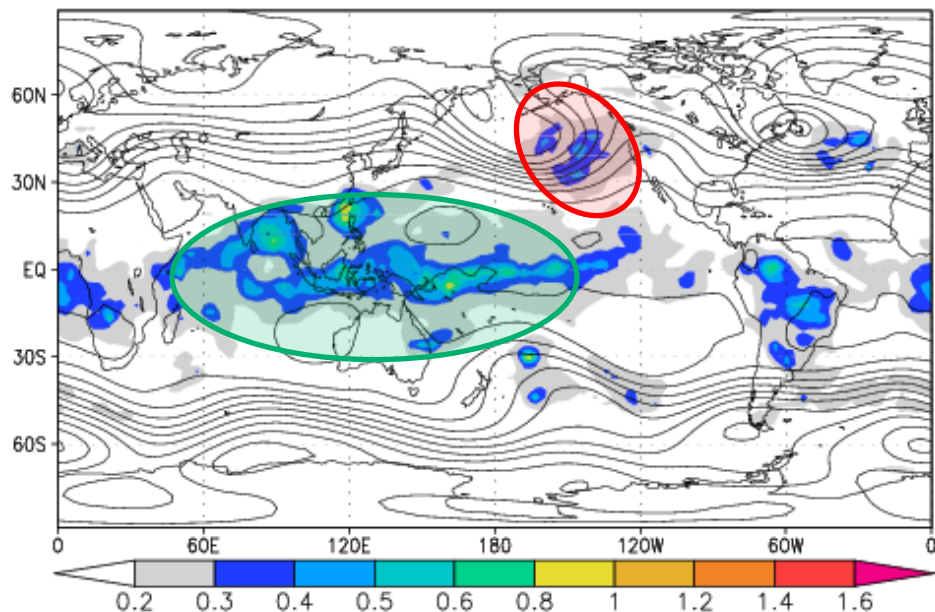
Analysis RMSE (U500 [m/s])



Analysis Spread (Z500 [m])



Analysis Spread (U500 [m/s])

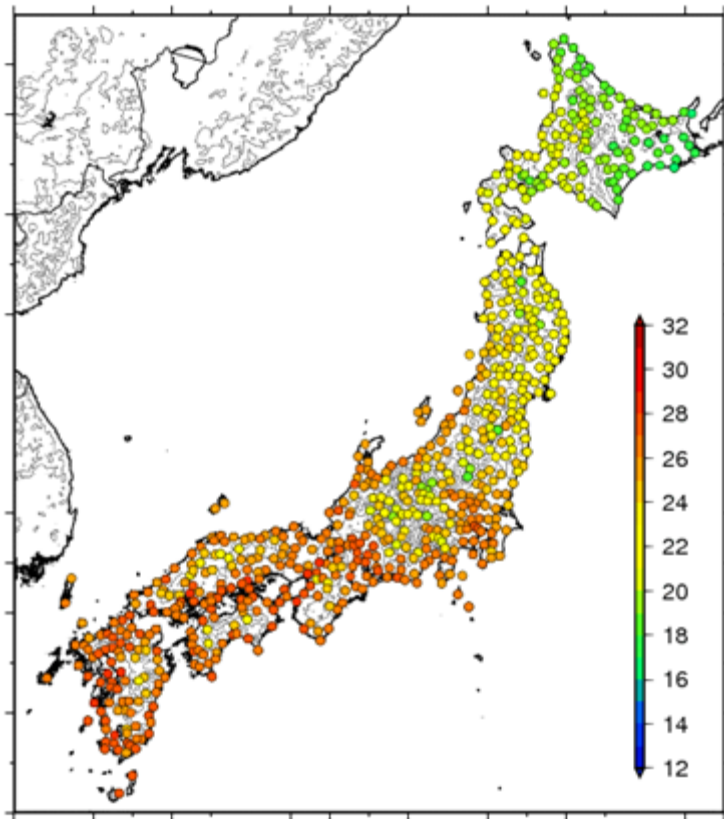


2008年度の成果 (WRF)

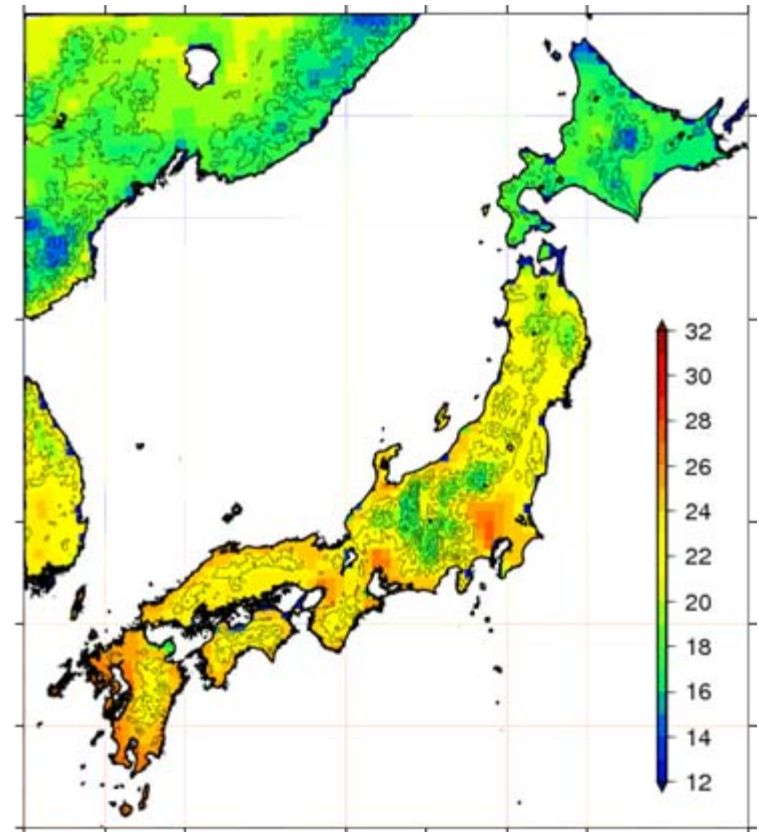
- 将来の詳細な気候予測のために、過去20年間(1985-2004年)を対象に、空間分解能20kmのWRFを用いて、日本域の気候シミュレーションを実施した。さらには、過去5年間(2002年から2006年)の夏を対象に、空間分解能4kmのWRFモデルを用いて、首都圏を対象としたさらに詳細なシミュレーションを実施した。その結果、領域気象モデルWRFは、天気予報のような短期間の数値予報・シミュレーションだけでなく、気候シミュレーションにも有用なツールとなりえることがわかった。
- 都市豪雨に対する都市のヒートアイランド現象の影響を評価するために、2001年から2007年の過去7年間の8月を対象に、空間分解能4kmのWRFモデルを用いて、都市の感度実験(都市あり、都市なし実験)を実施した。その結果、都市が降水に影響をおよぼしている可能性を肯定まではいかなくても、少なくとも強く否定できないことが示された。

日本域気候シミュレーションの結果： 8月の地上気温の20年平均値、1985～2004年の8月

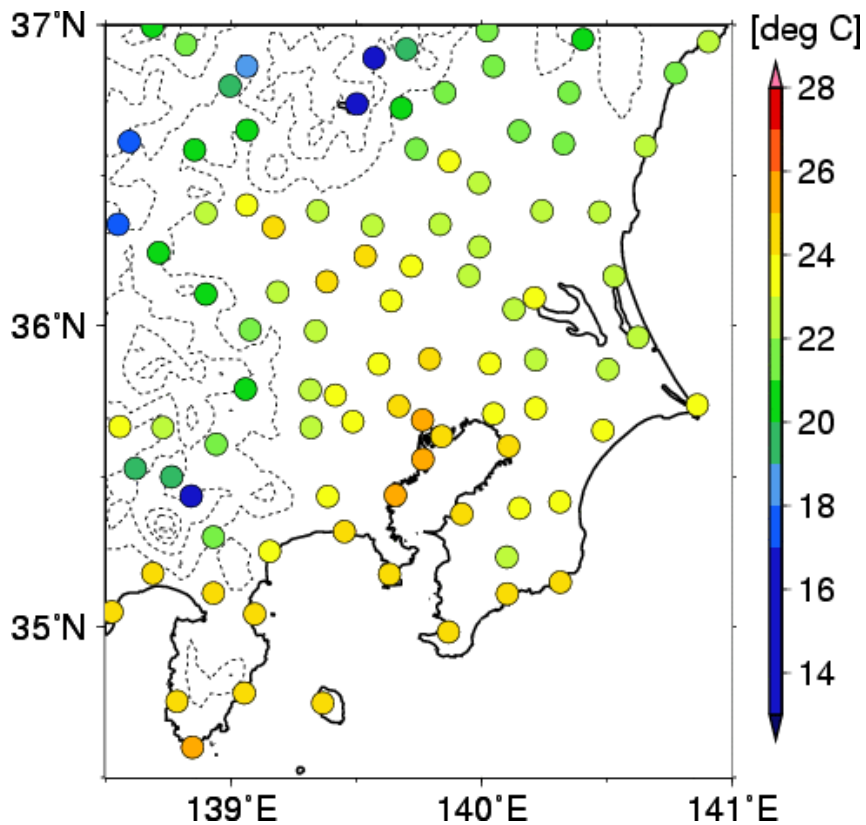
観測値



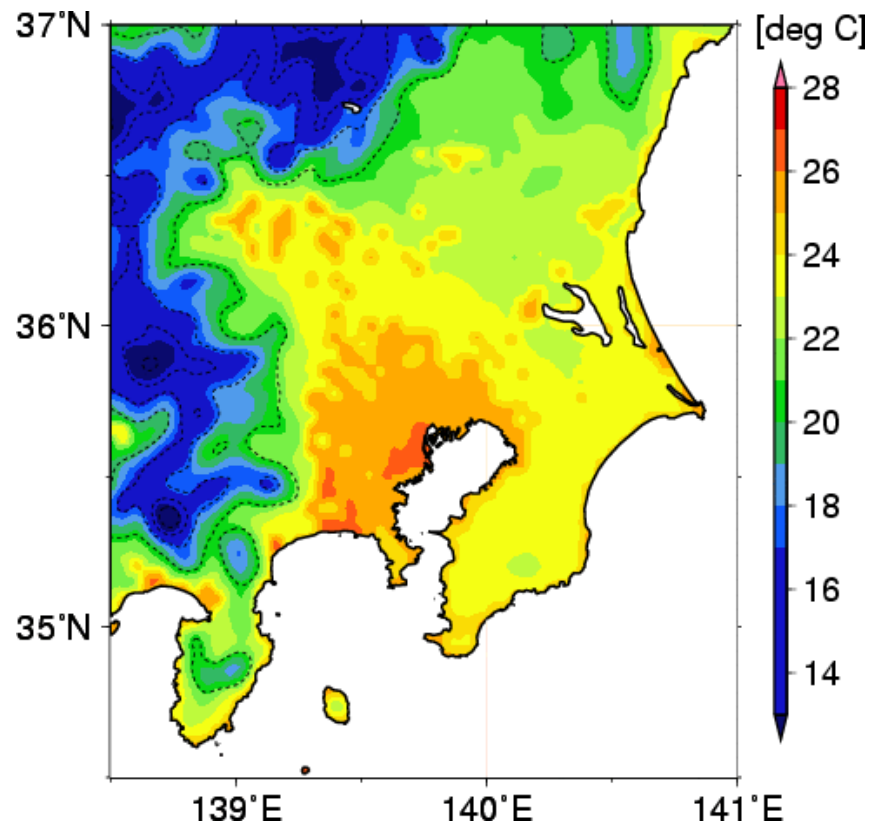
20km-WRF



首都圏気候シミュレーションの結果： 午前5時の地上気温 2002年08月平均

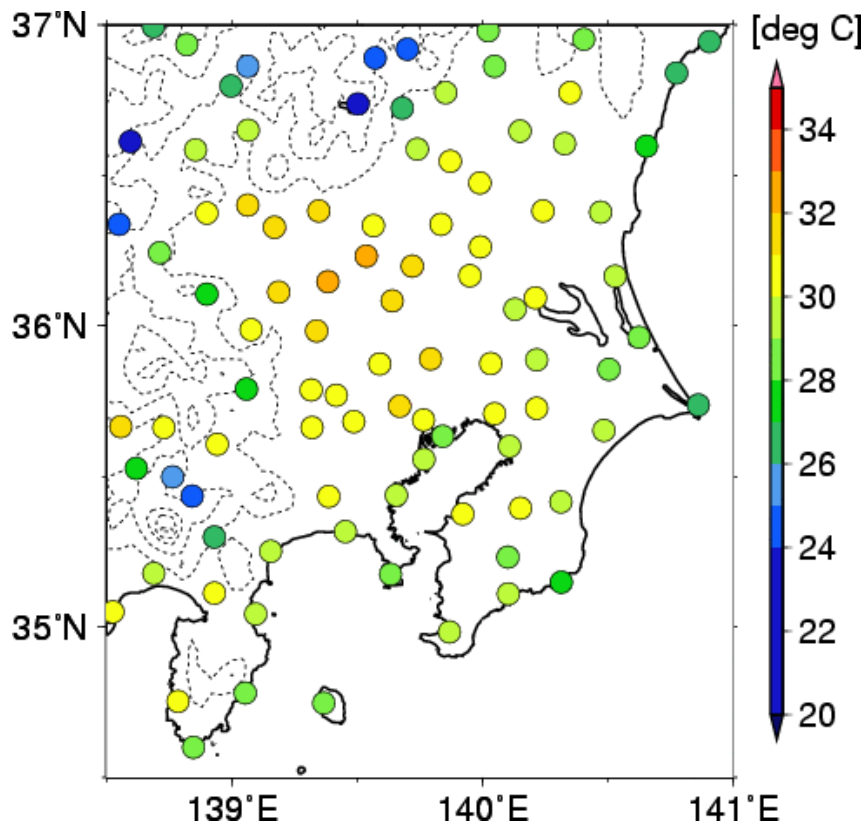


AMeDAS

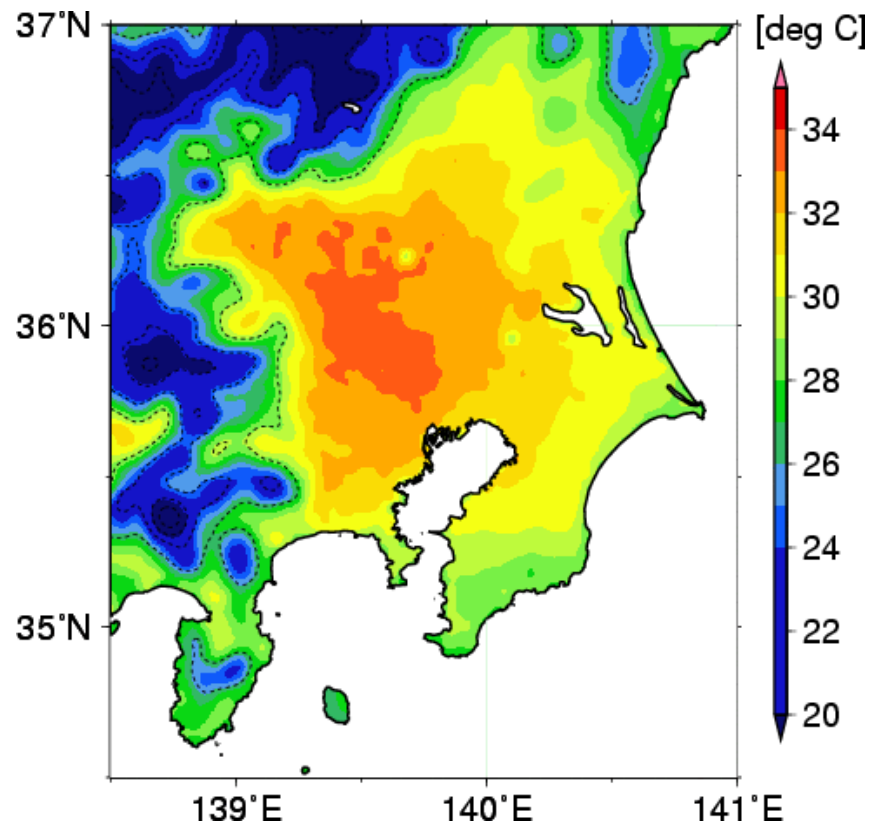


4km-WRF

首都圏気候シミュレーションの結果： 午後3時の地上気温 2002年08月平均

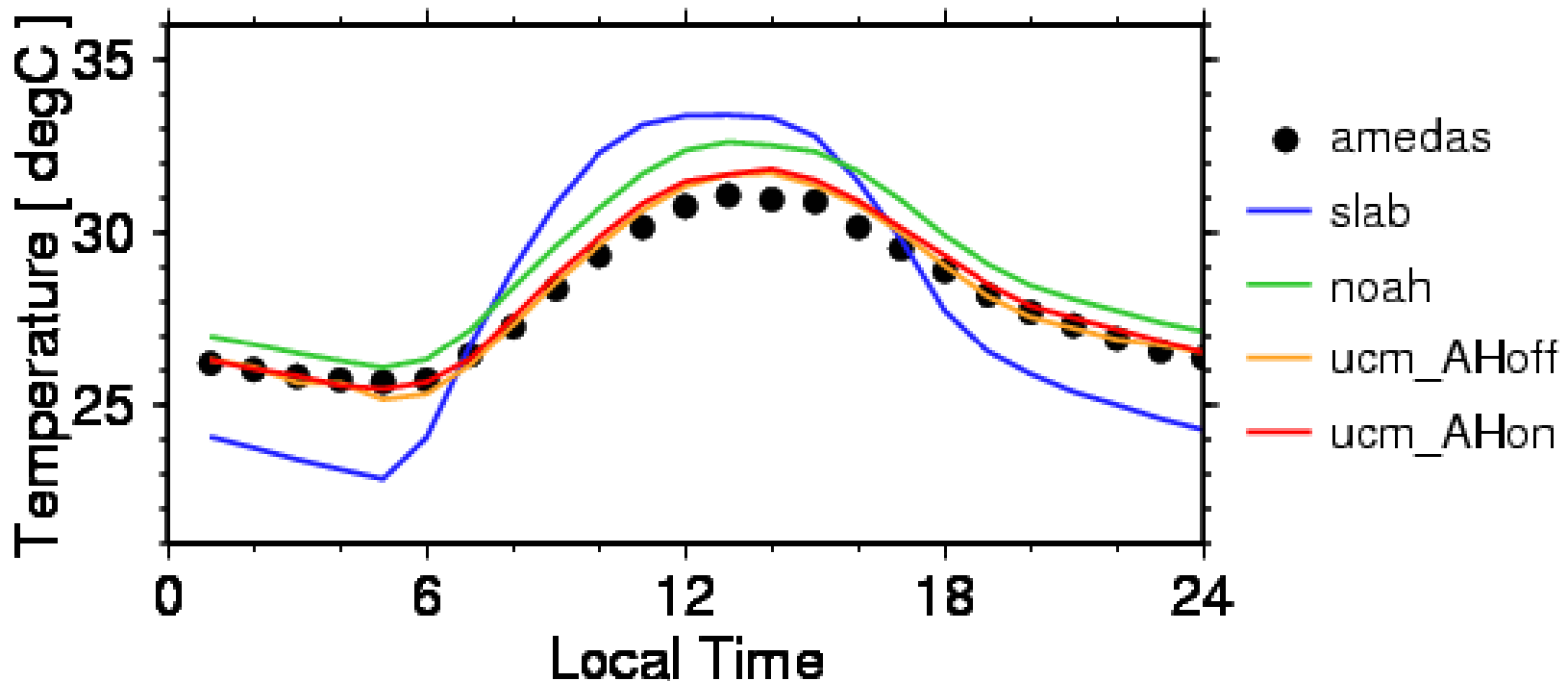


AMeDAS



4km-WRF

大手町における地上気温の日変化 2002年8月平均



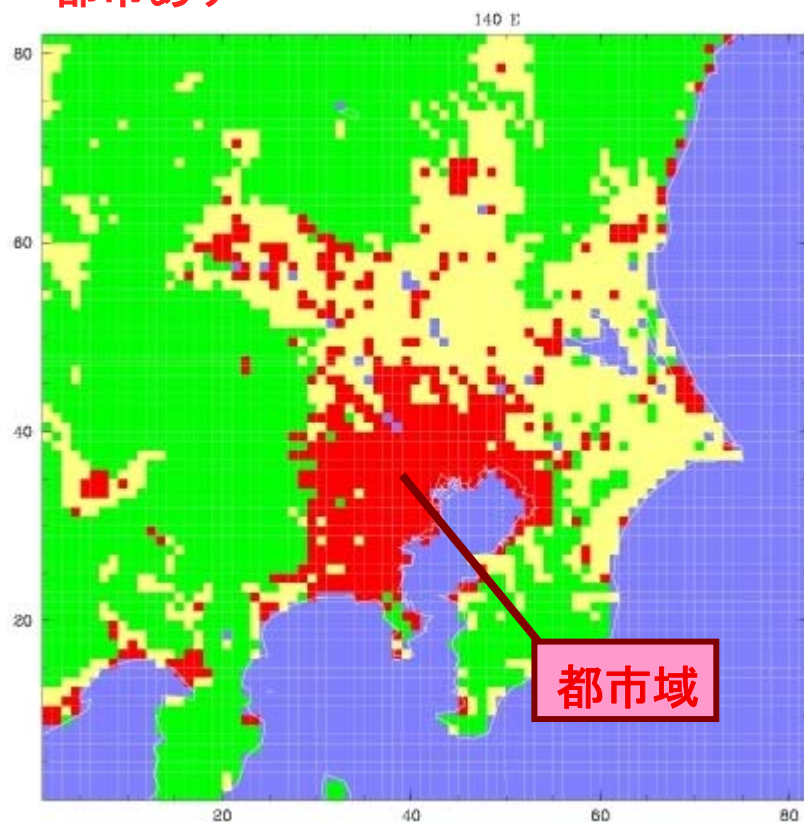
Amedasは観測値、slabは平板都市モデル利用時、noahは陸面モデル利用時、Ucm_Ahoffは都市キャノピーモデル利用時、ucm_Ahonは都市キャノピーモデルに人工排熱を考慮した場合の結果



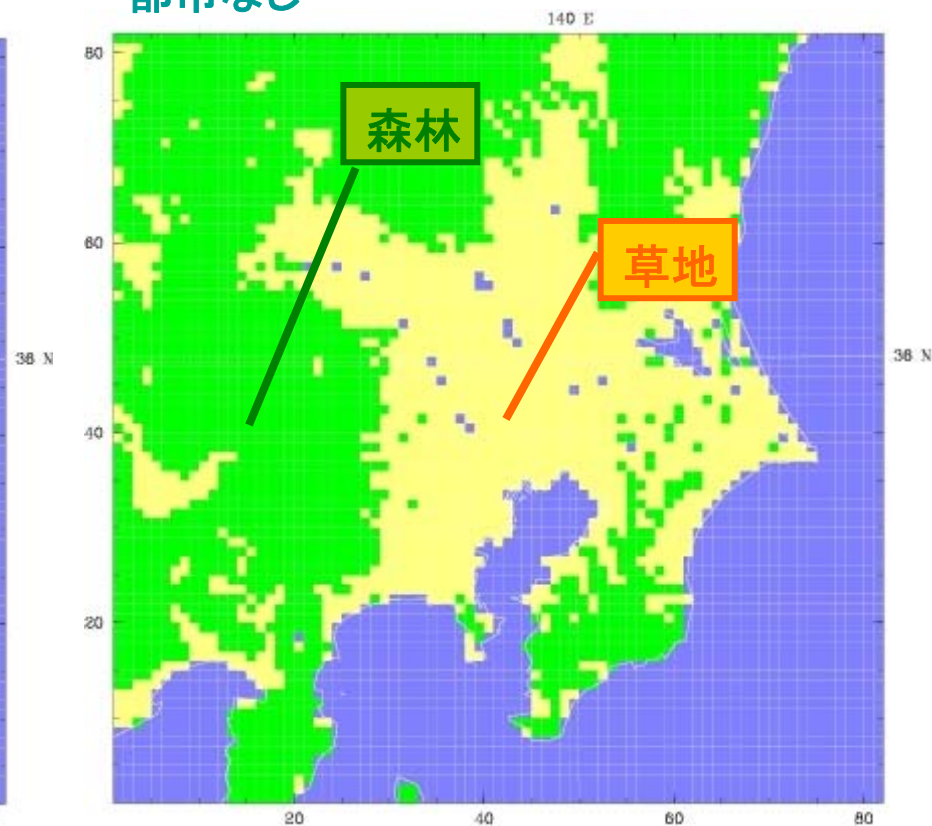
本研究での感度実験(都市を草地にかえたシミュレーション)

土地利用のイメージ

都市あり

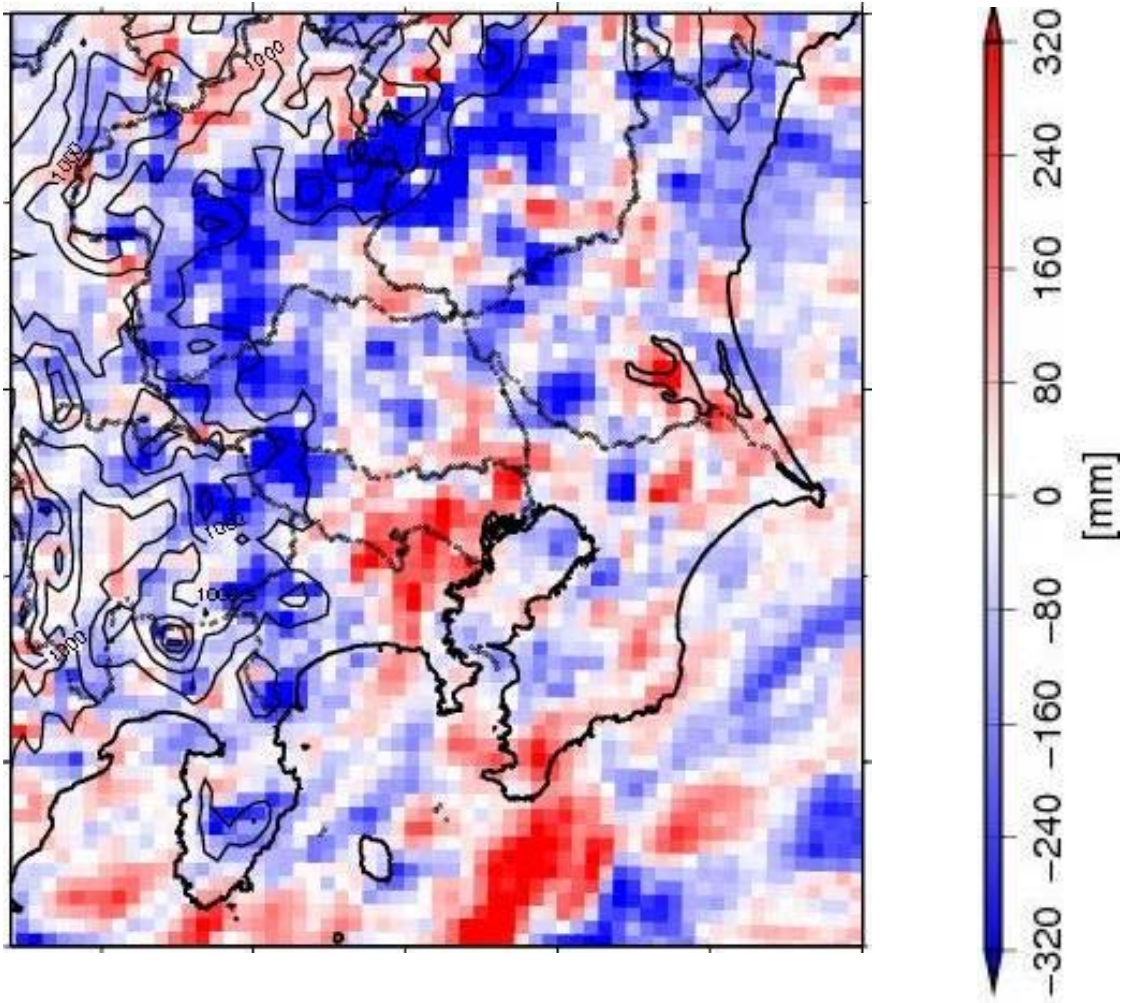


都市なし



水平格子間隔 4km

WRFによって計算された2001年から2007年までの8月の積算降水量：都市あり実験と都市なし実験の差（都市あり降水量 - 都市なし降水量）



まとめ

- **NICAM:**
 - ESでしか走らないとされた全球雲解像モデルNICAMがCCSで走った。Glevel-10で、ESはT2K-Tsukubaの8倍速い。
 - NICAMで再現された熱帯低気圧、温帯低気圧、北極低気圧の構造を比較した。ウォームコアの存在。
 - NICAM-LETKFを開発した。パーフェクトモデル実験では解析誤差は観測誤差の1/5に減少した。
- **WRF**
 - WRFの長期ランにより領域気候の再現を可能にした。
 - 都市の影響で都市型豪雨の増大が実験的に確かめられた。

End
Thanks

Cluster part and File Server part

Computation Nodes (70 racks)



648 node (quad-core x 4socket / node)
Opteron "Barcelona" B8000 CPU
2.3GHz x 4-inst./clock x 4core x 4socket
= 147.2 GFLOPS / node
= 95.3 TFLOPS / system
20.7 TB memory / system

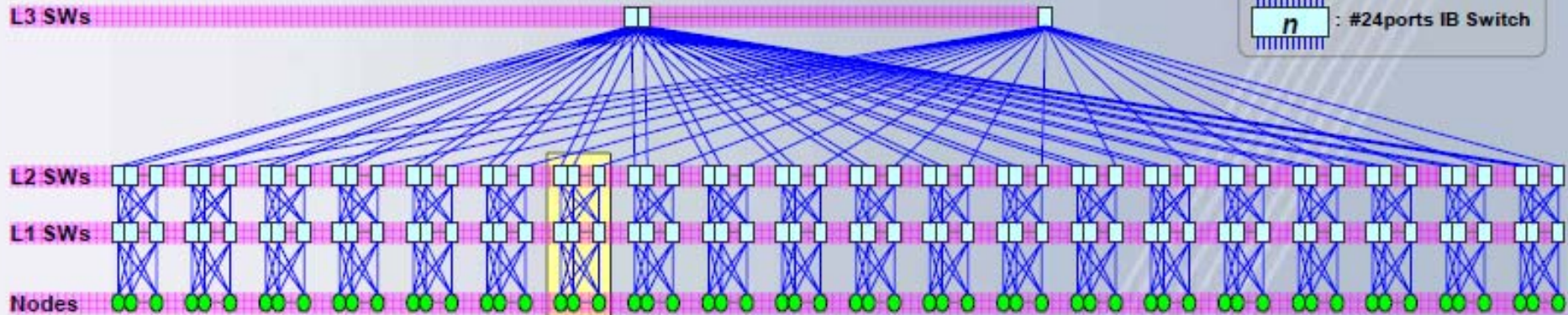
800 TB (physical 1PB) RAID-6
Luster cluster file system
Infiniband x 2
Meta-data servers and File
servers are all duplicated tandem
⇒ high fault tolerance



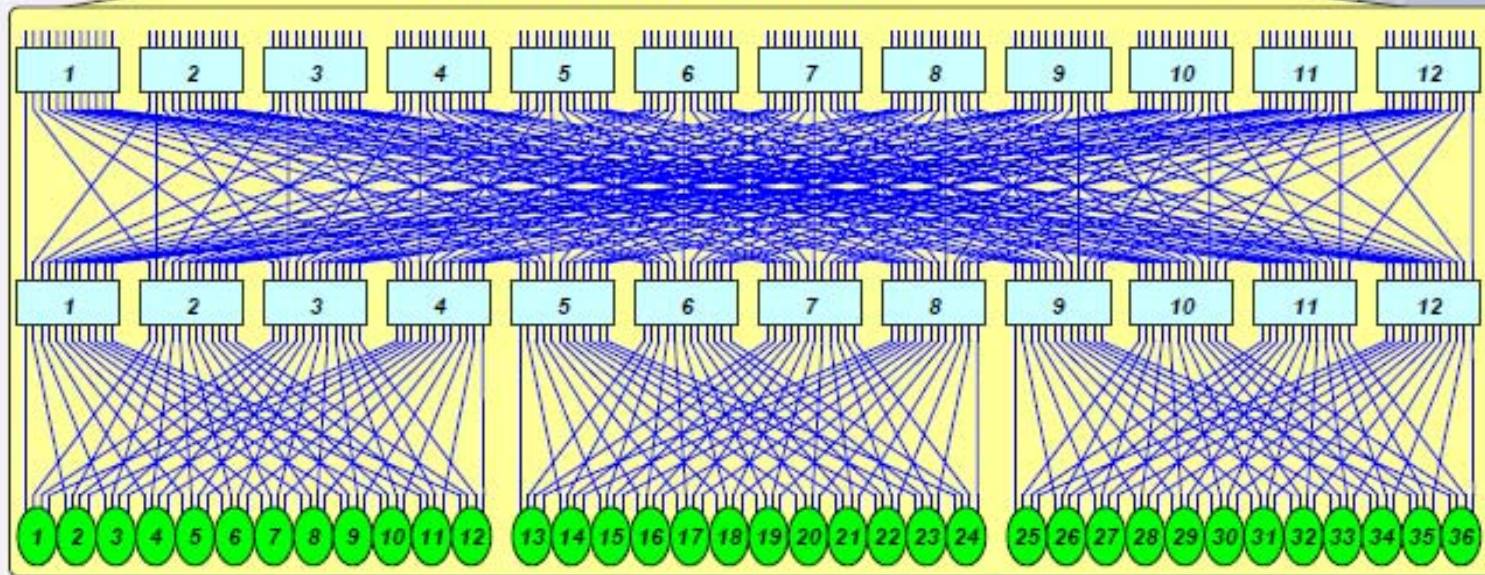
File Sever (Disk Drive, 5 racks)

Interconnection network of T2K-Tsukuba

Full bi-sectional FAT-tree Network



Detail View for one network unit



Item	#
Node	696
Level 3 switch	144
Level 2 switch	240
Level 1 switch	232
Total switch	616

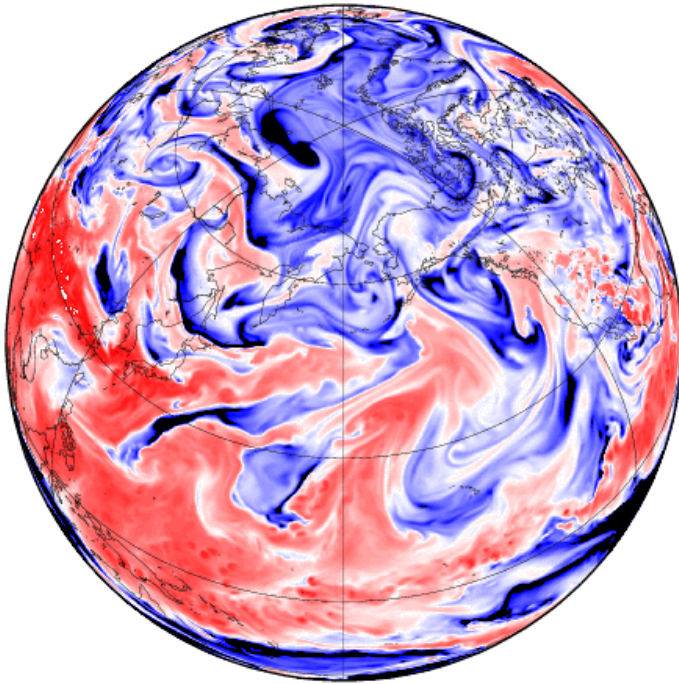
※ノード総数696台には
オンラインのスペア
ノード4台を含みます。

What is T2K-Tsukuba ?

- A supercomputer in University of Tsukuba under operation by Center for Computational Sciences
- “T2K” represents the alliance of three national universities in Japan: Tsukuba, Tokyo and Kyoto, for supercomputer research, design, procurement and operation
- A very large scale PC cluster with 10,368 cores and 95TFLOPS of peak performance
- Each computation node consists of quad-socket AMD Opteron (Barcelona) with quad-core (totally 16 cores / node)
- Interconnection network with full-bisection bandwidth Fat-Tree with quad-rail of Infiniband ConnectX
- Operation duration: June 2008 – May 2013

500 hPa S. Humidity

NICAM 2008062100Z+0HR

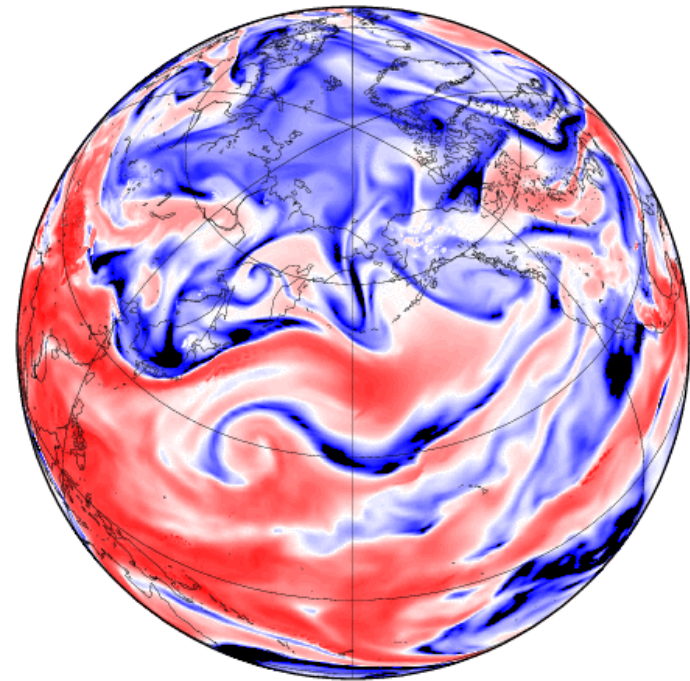


Glevel=9, 14km

GMT 2009 Jan 30 22:26:44 CCS g10-4n256

500 hPa S. Humidity

NICAM 2004060100Z+0HR

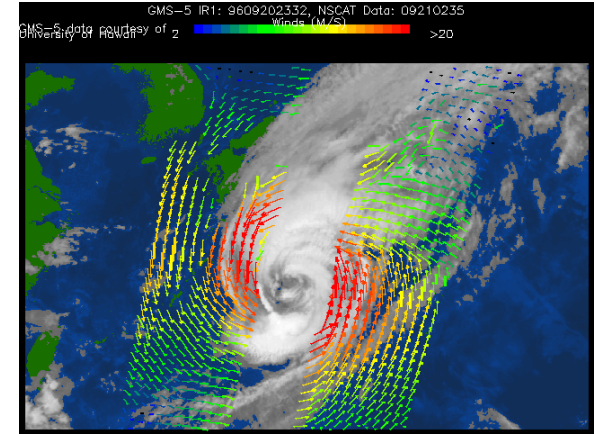


Glevel=10, 7km

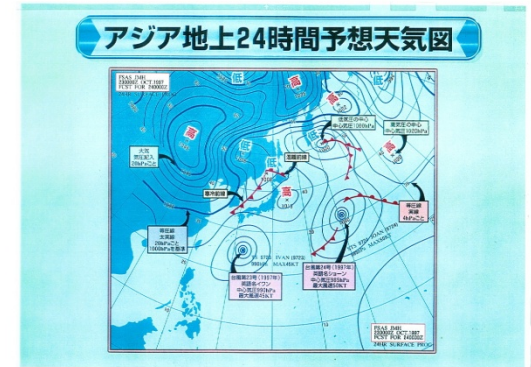
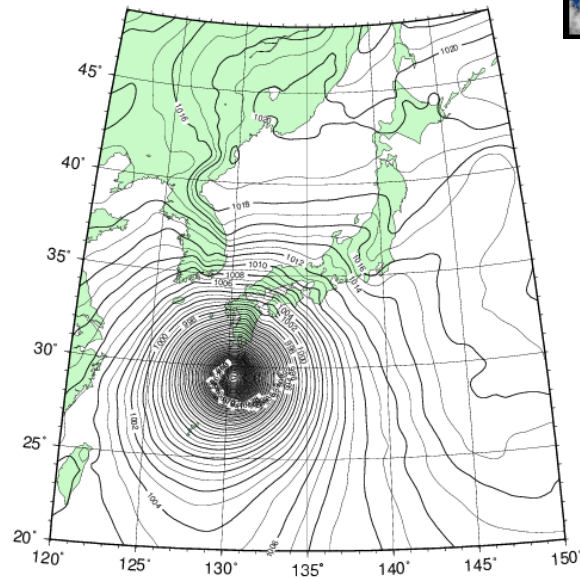
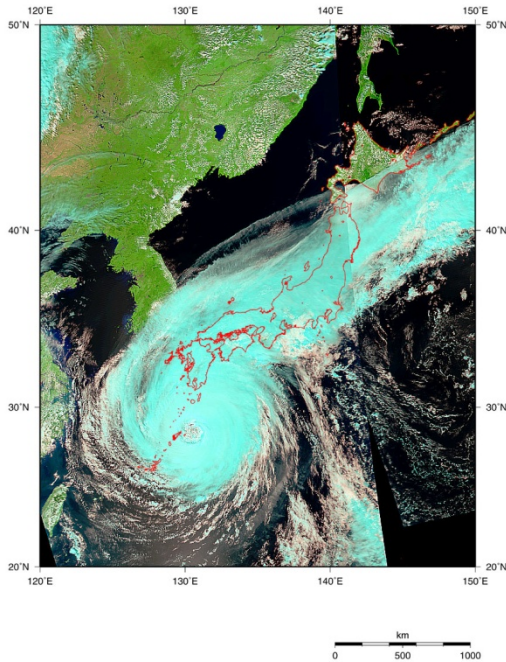
GMT 2009 Feb 4 11:21:23 CCS g10-4n256

Tropical Cyclone

- Life cycle of Typhoon



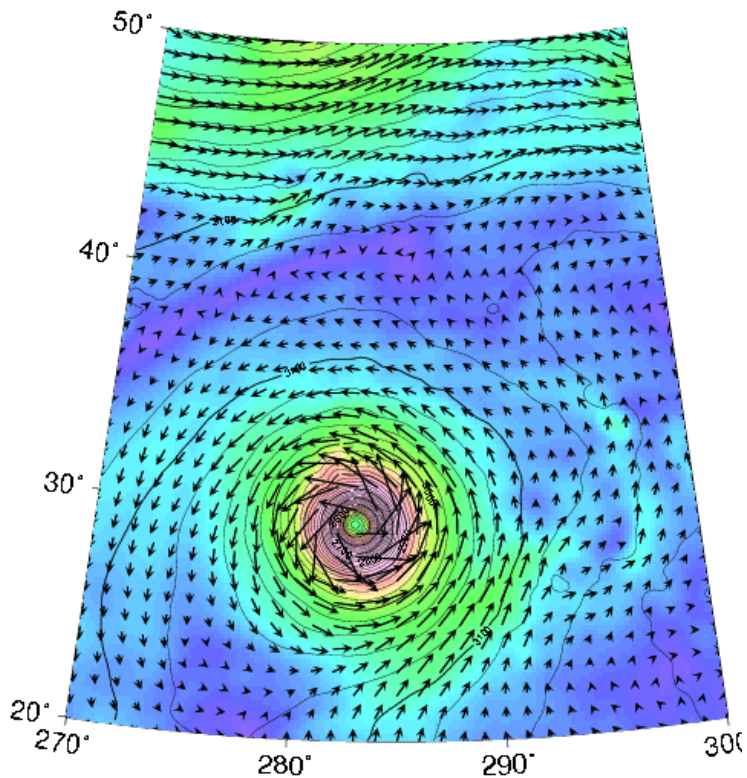
Sea-level Pressure (hPa)
2005090512 + 00 hr (JMA/GPV/RSM)



NICAM gl-8

Height (m) and Wind (m/s) at 700 hPa

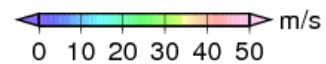
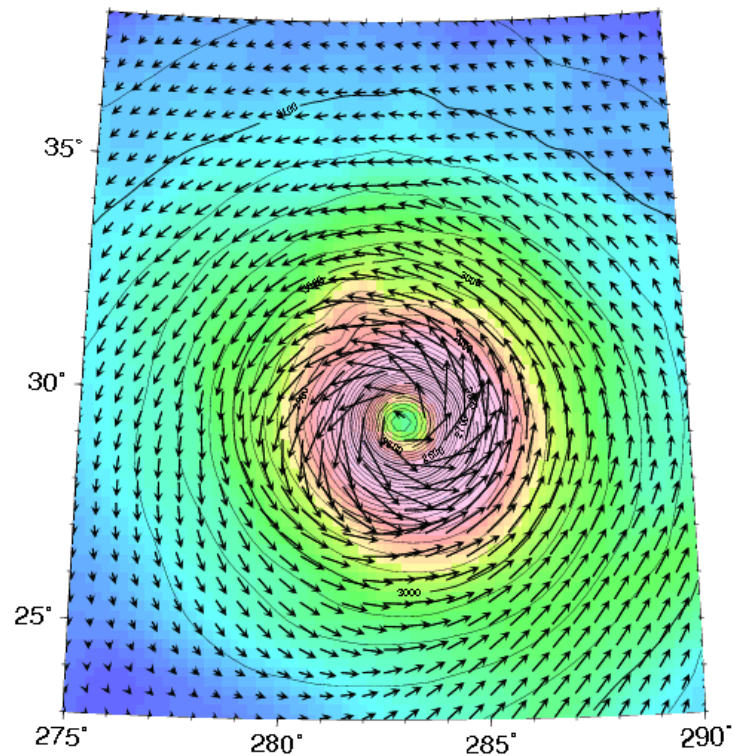
2008070500Z+78HR



NICAM gl-8

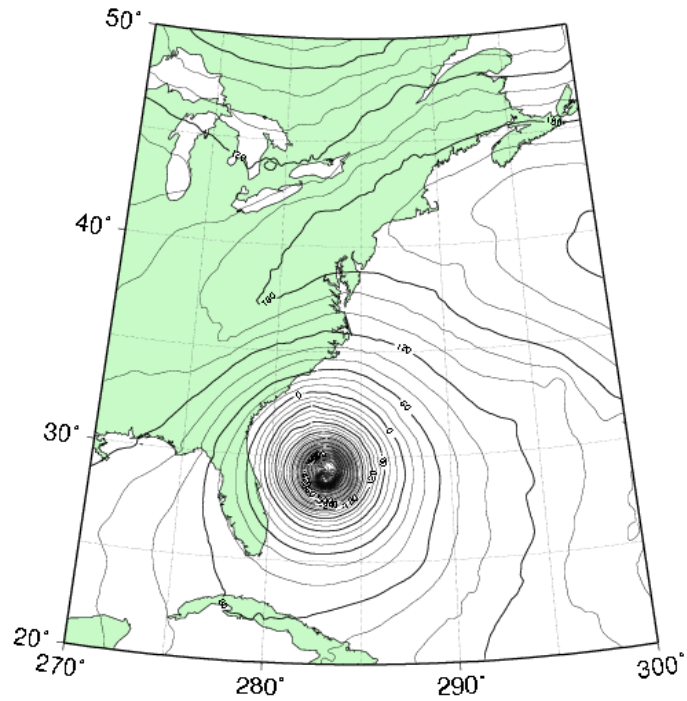
Height (m) and Wind (m/s) at 700 hPa

2008070500Z+78HR

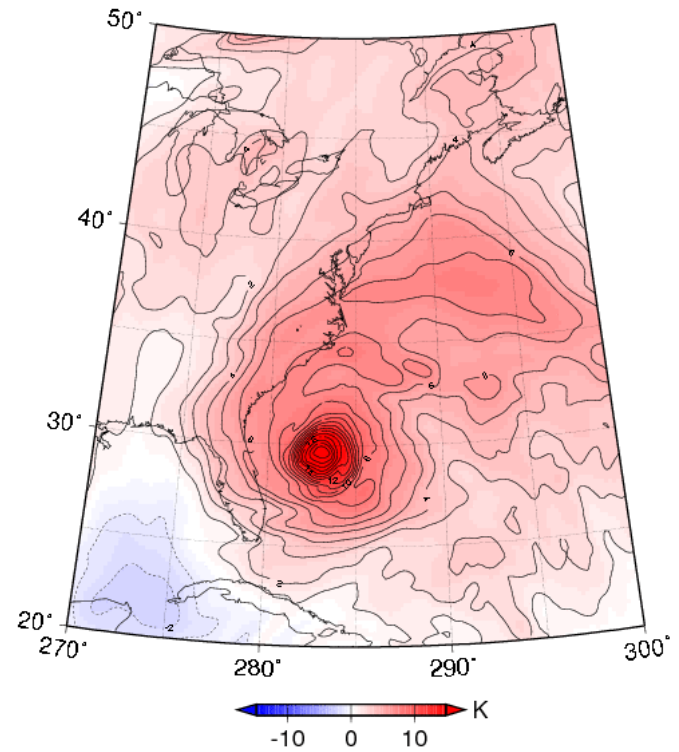


Hurricane in NICAM

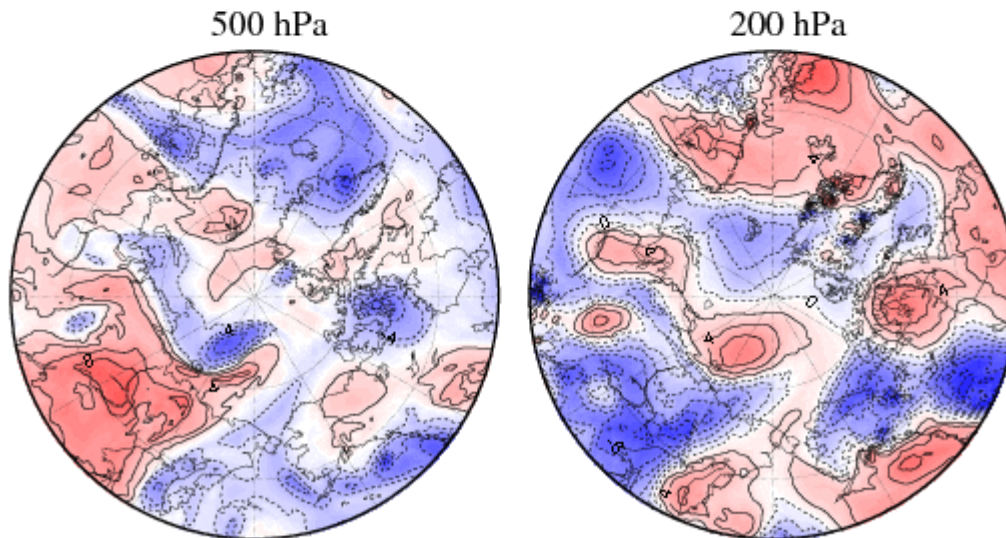
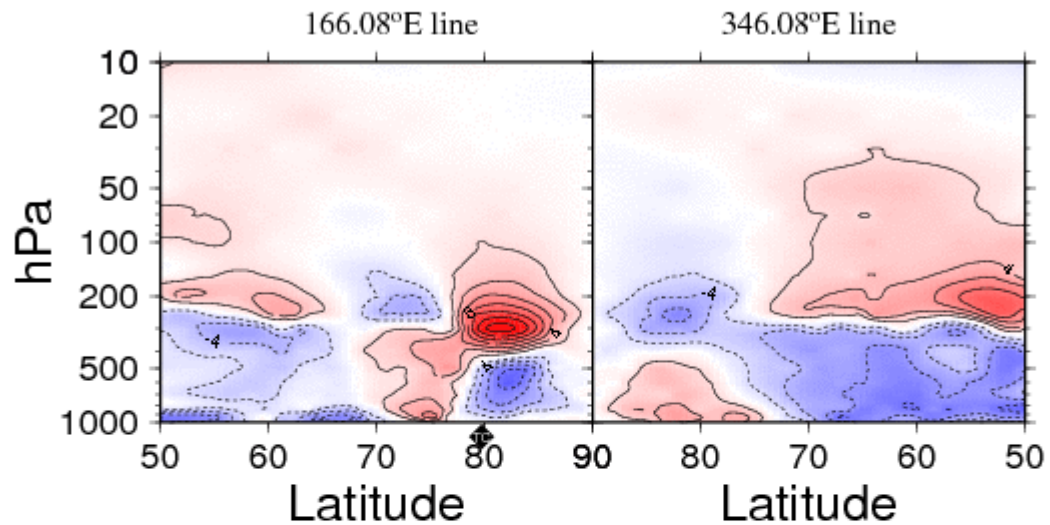
NICAM gl-8
1000 hPa Height
2008070500Z+78HR



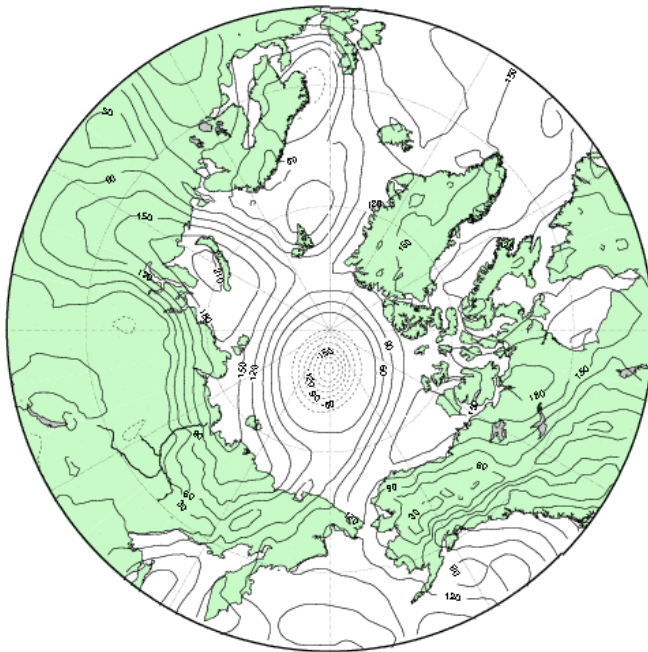
NICAM gl-8
300 hPa Temperature Anomalies
2008070500Z+78HR



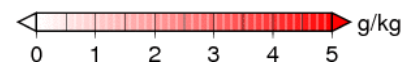
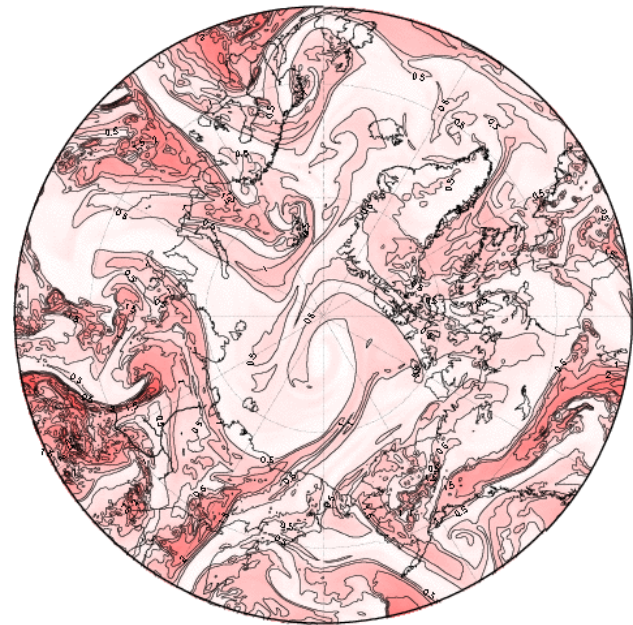
NICAM gl-8
Temperature Anomalies
2008062100Z+24HR



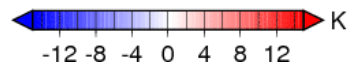
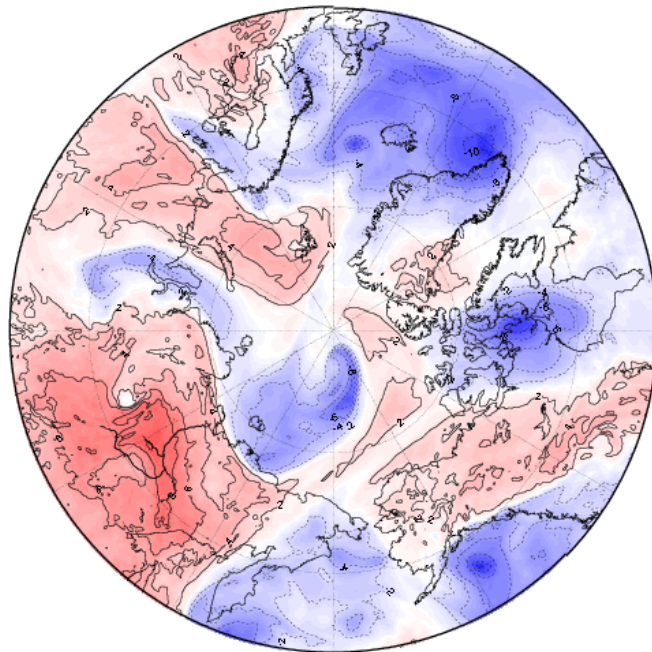
NICAM gl-9
1000 hPa Height
2008062100Z+48HR



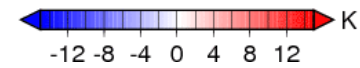
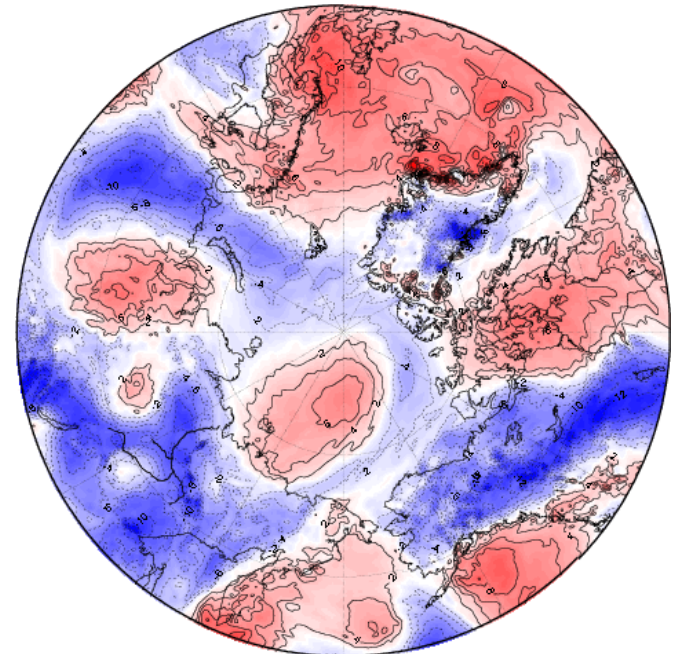
NICAM gl-9
500 hPa S. Humidity
2008062100Z+48HR



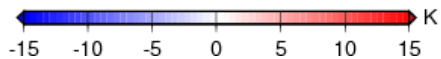
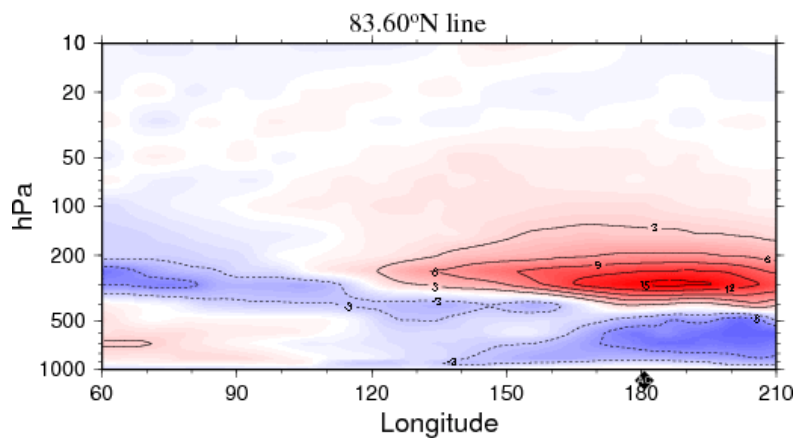
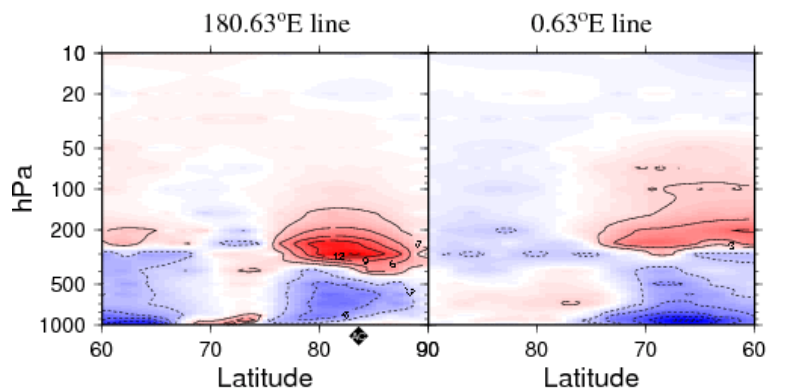
NICAM gl-9
500 hPa Temperature Anomalies
2008062100Z+48HR



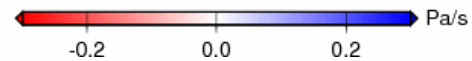
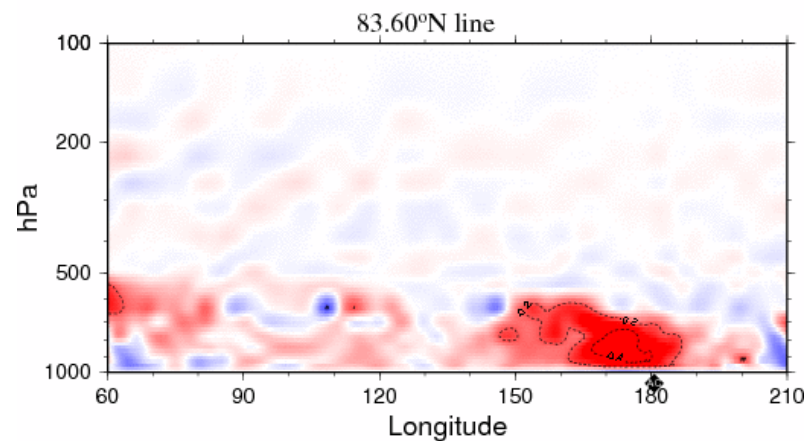
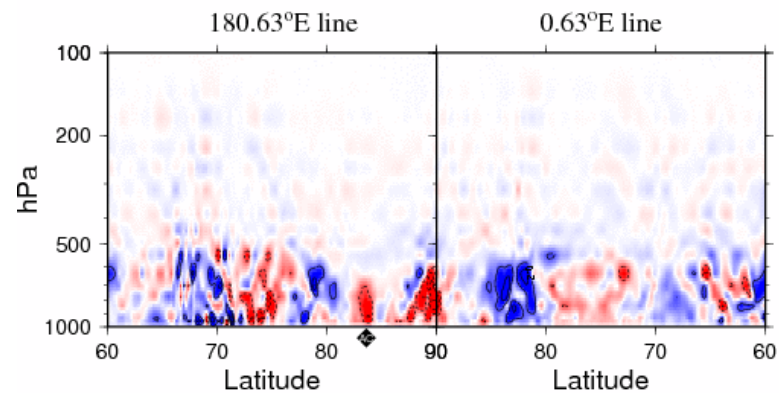
NICAM gl-9
200 hPa Temperature Anomalies
2008062100Z+48HR



NICAM gl-9
Temperature Anomalies
2008062100Z+48HR



NICAM gl-9
Vertical P-Velocity
2008062100Z+48HR



Summary

- Tropical cyclone
 - Dynamical Instability with vertical heat transport
 - Warm core in mid-troposphere by latent heat
- Extra-tropical cyclone
 - Dynamical Instability with meridional heat transport
- Arctic cyclone
 - Vorticity transfer from the polar vortex
 - Warm core in lower stratosphere by subsidence
- NICAM runs at CCS
 - ES vector machine is 8 times faster than T2K

NICAMの出力変数

- 01 ml_dh : diabatic heating rate (cloud microphysics) [K/s]
- 02 ml_pres : pressure [Pa]
- 03 ml_qc : cloud water mixing ratio (microphysics) [kg/kg]
- 04 ml_qi : cloud ice mixing ratio [kg/kg]
- 05 ml_qr : rain mixing ratio [kg/kg]
- 06 ml_qs : snow mixing ratio [kg/kg]
- 07 ml_qv : water vapor mixing ratio [kg/kg]
- 08 ml_rh : relative humidity [frac.]
- 09 ml_rho : density (all species) [kg/m³]
- 10 ml_tem : temperature [K]
- 11 ml_ucos: zonal velocity (multiplied by cos(lat)) [m/s]
- 12 ml_vcos: meridional velocity (multiplied by cos(lat)) [m/s]
- 13 ml_w : vertical velocity [m/s] [SINGLE LEVEL -- 27 variables]
- 14 sl_albedo : albedo [frac.]
- 15 sl_cld_frac : cloud fraction [frac.]
- 16 sl_cldi : column integrated solid water [kg/m²]
- 17 sl_cldw : column integrated liquid water [kg/m²]
- 18 sl_evap : evaporation rate [kg/m²/s]
- 19 sl_lw_toa : outgoing long-wave flux at TOA [W/m²]
- 20 sl_lw_toa_c : outgoing long-wave flux at TOA (clear sky) [W/m²]
- 21 sl_ps : surface pressure [Pa]
- 22 sl_q2m : 2 m water vapor mixing ratio [kg/kg]
- 23 sl_slh : surface latent heat flux [W/m²]
- 24 sl_slwd : surface long-wave radiation (downward) [W/m²]
- 25 sl_slwu : surface long-wave radiation (upward) [W/m²]
- 26 sl_ssh : surface sensible heat flux [W/m²]
- 27 sl_sswi : surface short-wave radiation (downward/incident) [W/m²]
- 28 sl_sswr : surface short-wave radiation (upward/reflected) [W/m²]
- 29 sl_sw_toai : downward short-wave radiation at TOA [W/m²]
- 30 sl_sw_toar : upward short-wave radiation at TOA [W/m²]
- 31 sl_sw_toar_c : upward short-wave radiation at TOA (clear sky) [W/m²] sl_t2m : 2 m temperature [K]
- 32 sl_tauucos : surface stress by zonal velocity (multiplied by cos(lat)) [N/m²]
- 33 sl_tauvcos : surface stress by meridional velocity (multiplied by cos(lat)) [N/m²]
- 34 sl_tem_atm : mass weighted column averaged temperature [K]
- 35 sl_tem_sfc : surface temperature [K]
- 36 sl_tppn : surface precipitation rate [kg/m²/s] sl_ucos10m : 10 m zonal velocity (multiplied by cos(lat)) [m/s]
- 37 sl_vap_atm : precipitable water [kg/m²] sl_vcos10m : 10 m meridional velocity (multiplied by cos(lat)) [m/s]
-

ファイル数の上限： 1億ファイル

50変数 × 40領域 × 40メンバー × 120ステップ
= 960万ファイル

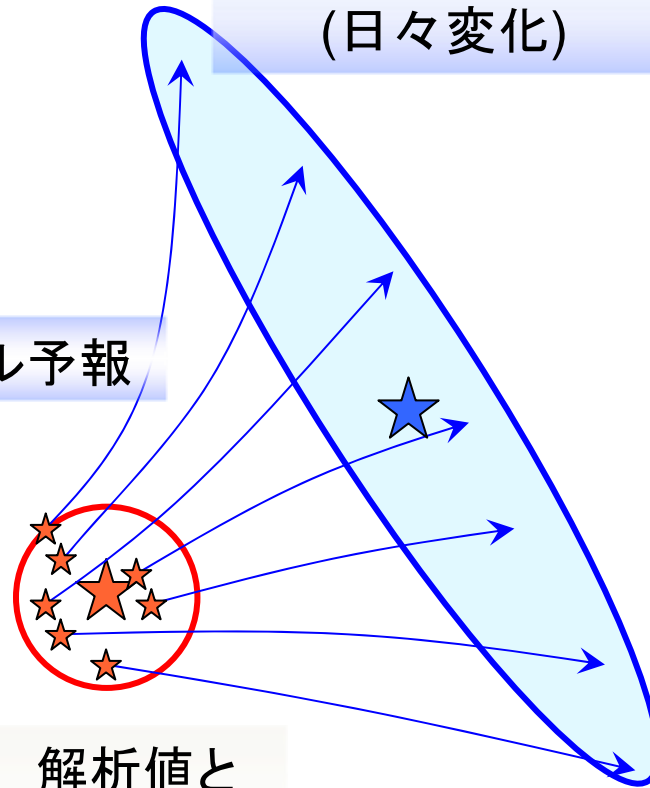
10回の実験でファイル数は約 1 億個

Ensemble Kalman Filter

$$\mathbf{X}_t^f = M(\mathbf{X}_{t-1}^a)$$
$$\mathbf{P}_t^f = \delta\mathbf{X}_t^f (\delta\mathbf{X}_t^f)^T$$

アンサンブル予報

予報誤差の広がり
(日々変化)



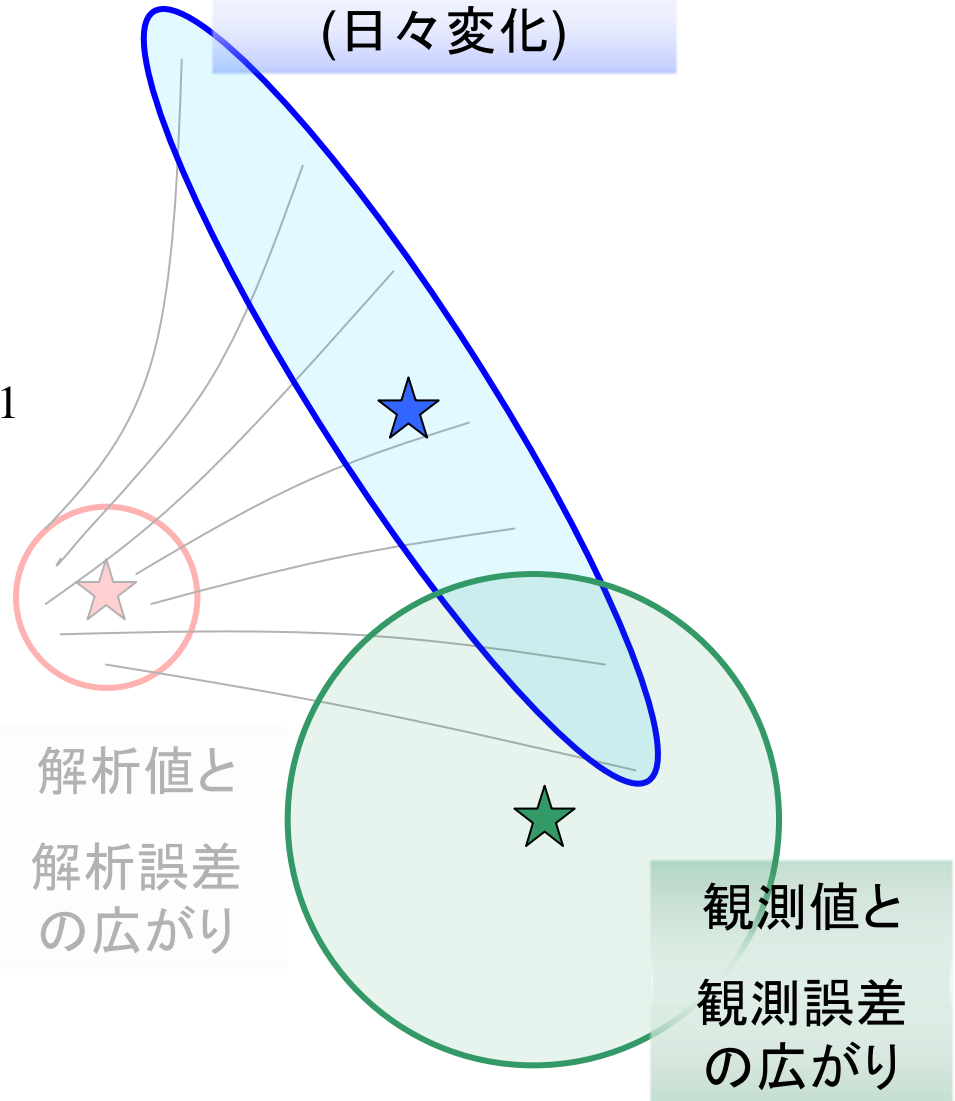
Ensemble Kalman Filter

$$\mathbf{X}_t^f = M(\mathbf{X}_{t-1}^a)$$

$$\mathbf{P}_t^f = \delta\mathbf{X}_t^f (\delta\mathbf{X}_t^f)^T$$

$$\mathbf{K} = \mathbf{P}^f \mathbf{H}^T [\mathbf{H} \mathbf{P}^f \mathbf{H}^T + \mathbf{R}]^{-1}$$

予報誤差の広がり
(日々変化)



Ensemble Kalman Filter

$$\mathbf{X}_t^f = M(\mathbf{X}_{t-1}^a)$$

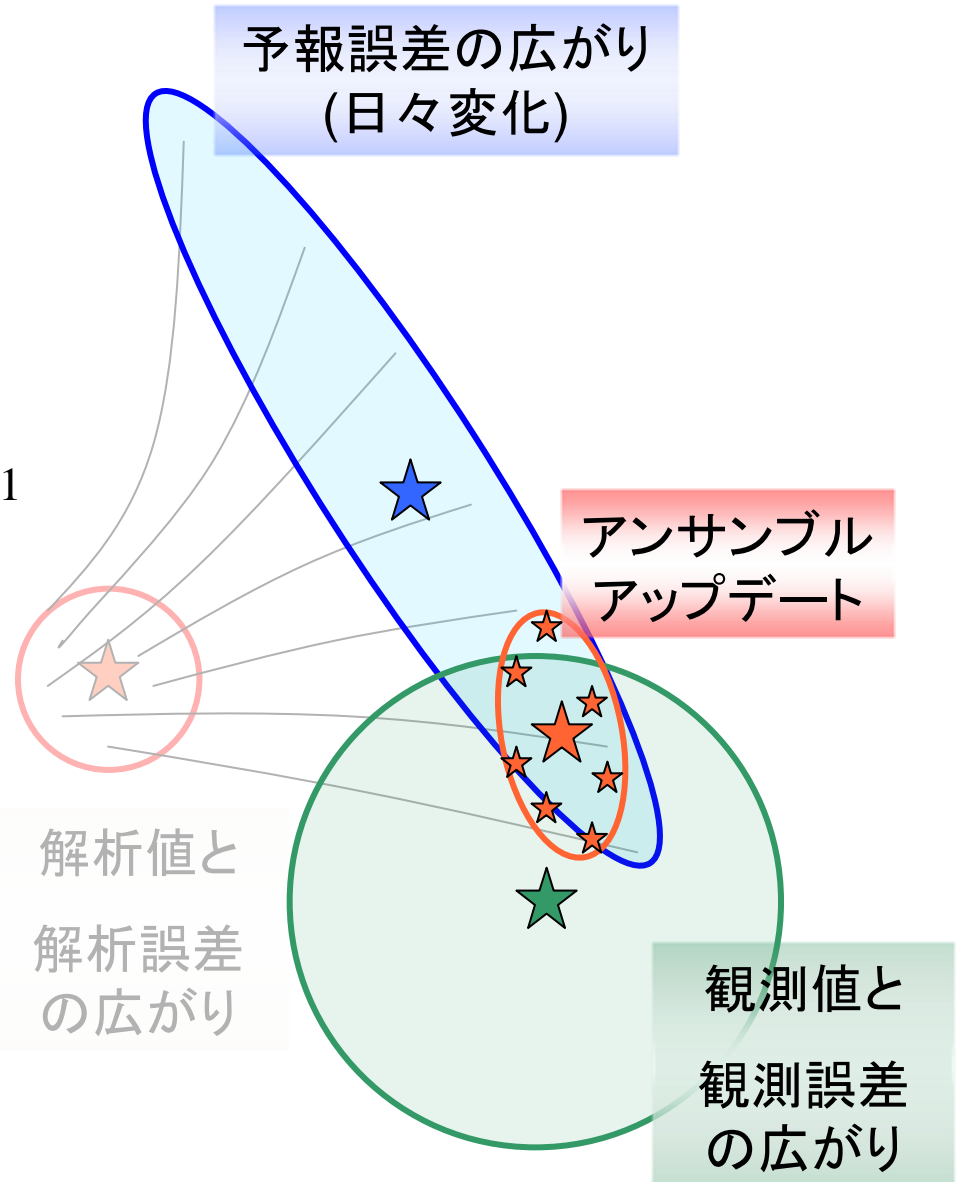
$$\mathbf{P}_t^f = \delta\mathbf{X}_t^f (\delta\mathbf{X}_t^f)^T$$

$$\mathbf{K} = \mathbf{P}_t^f \mathbf{H}^T [\mathbf{H} \mathbf{P}_t^f \mathbf{H}^T + \mathbf{R}]^{-1}$$

$$\mathbf{X}_t^a = \mathbf{X}_t^f + \mathbf{K}(\mathbf{y}_t^o - \mathbf{H}\mathbf{X}_t^f)$$

$$\mathbf{P}_t^a = \delta\mathbf{X}_t^a (\delta\mathbf{X}_t^a)^T$$

解析誤差を反映
した摂動を作成



Ensemble Kalman Filter

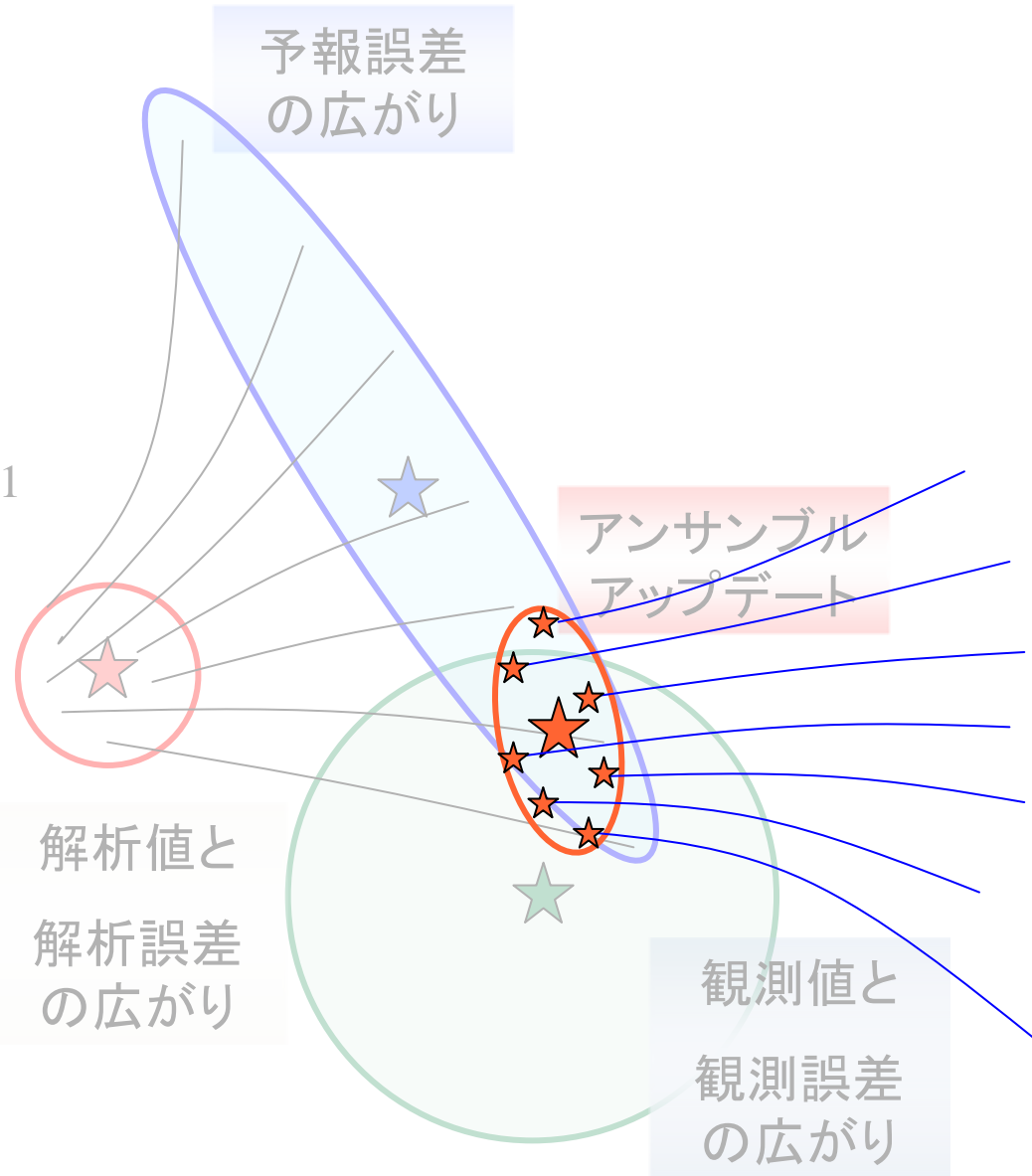
$$\mathbf{X}_{t+1}^f = M(\mathbf{X}_t^a)$$

$$\mathbf{P}_{t+1}^f = \delta\mathbf{X}_{t+1}^f (\delta\mathbf{X}_{t+1}^f)^T$$

$$\mathbf{K} = \mathbf{P}^f \mathbf{H}^T [\mathbf{H} \mathbf{P}^f \mathbf{H}^T + \mathbf{R}]^{-1}$$

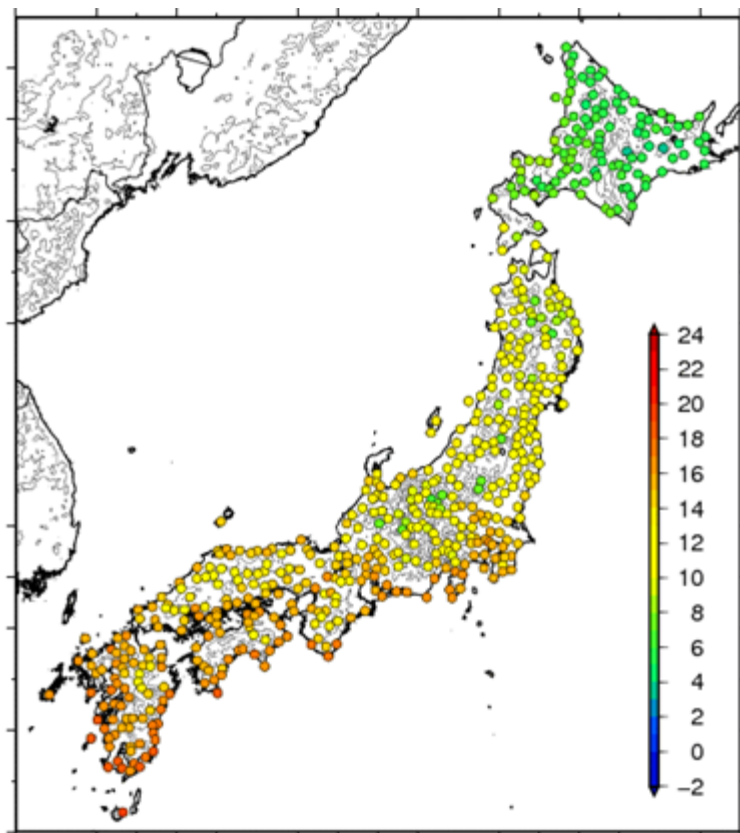
$$\mathbf{X}_t^a = \mathbf{X}_t^f + \mathbf{K} (\mathbf{y}_t^o - \mathbf{H} \mathbf{X}_t^f)$$

$$\mathbf{P}_t^a = \delta\mathbf{X}_t^a (\delta\mathbf{X}_t^a)^T$$



日本域気候シミュレーションの結果： 地上気温の20年平均値、1985～2004年

観測値



20km-WRF

