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Introduction to Data Assimilation, Subgrid-Scale Parameterization and Predictability

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Class Outline

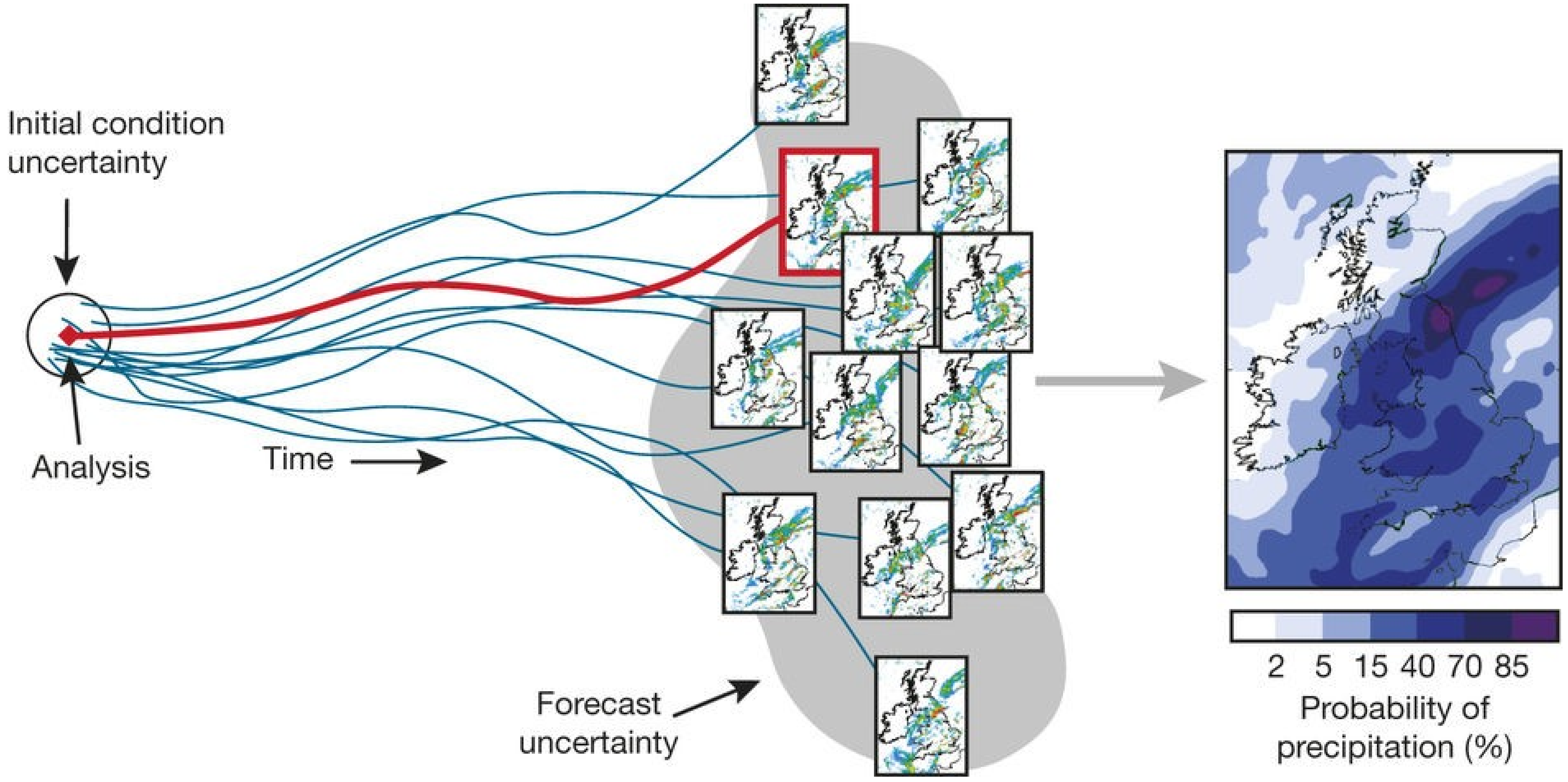
Concept of the class

1) Introductory lecture (~30mins)
2) Exercise: Coding of new method covered in lecture (~60mins)

Exam: Writing of report covering all exercises

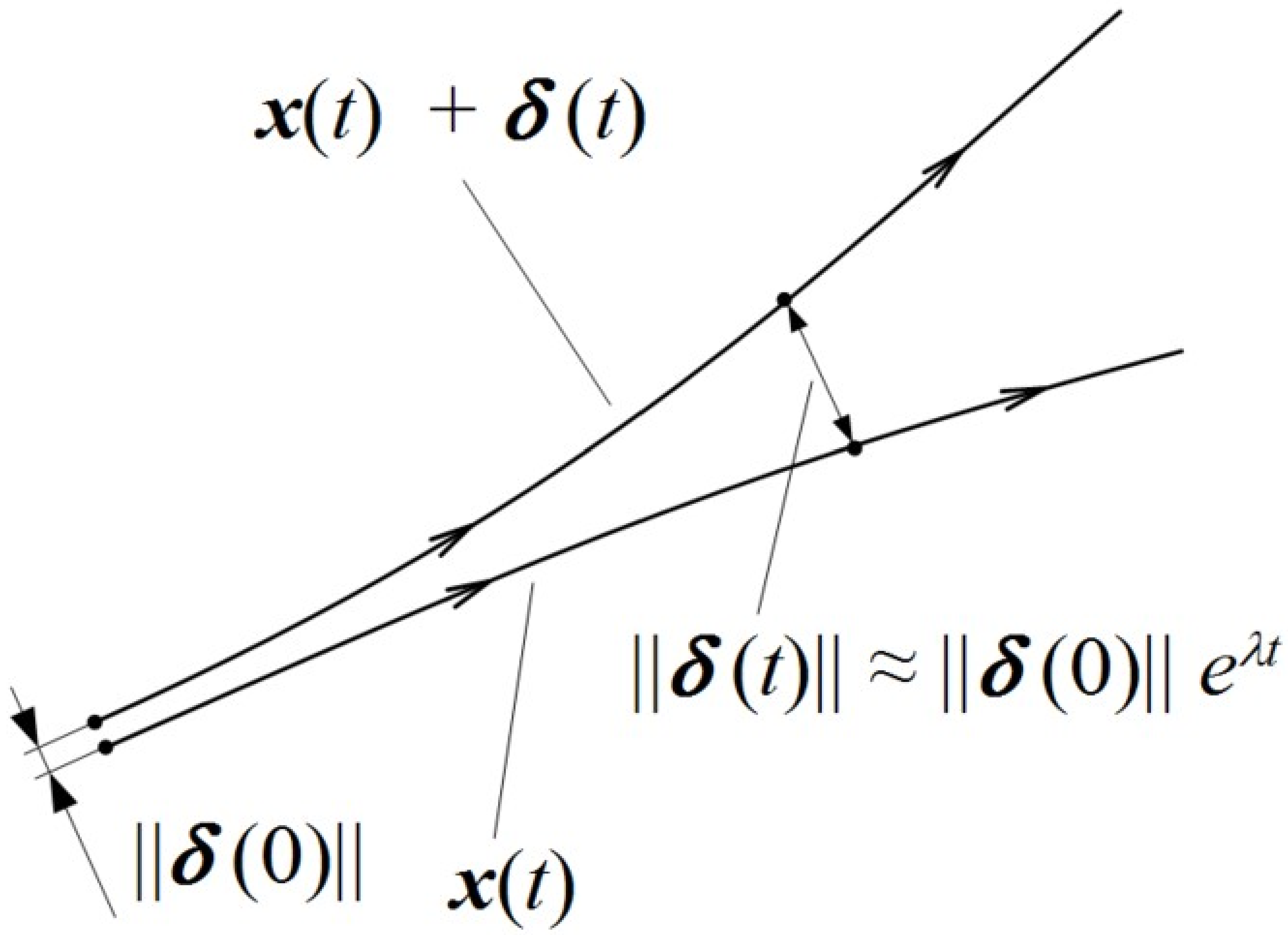
Predictability

Predictability

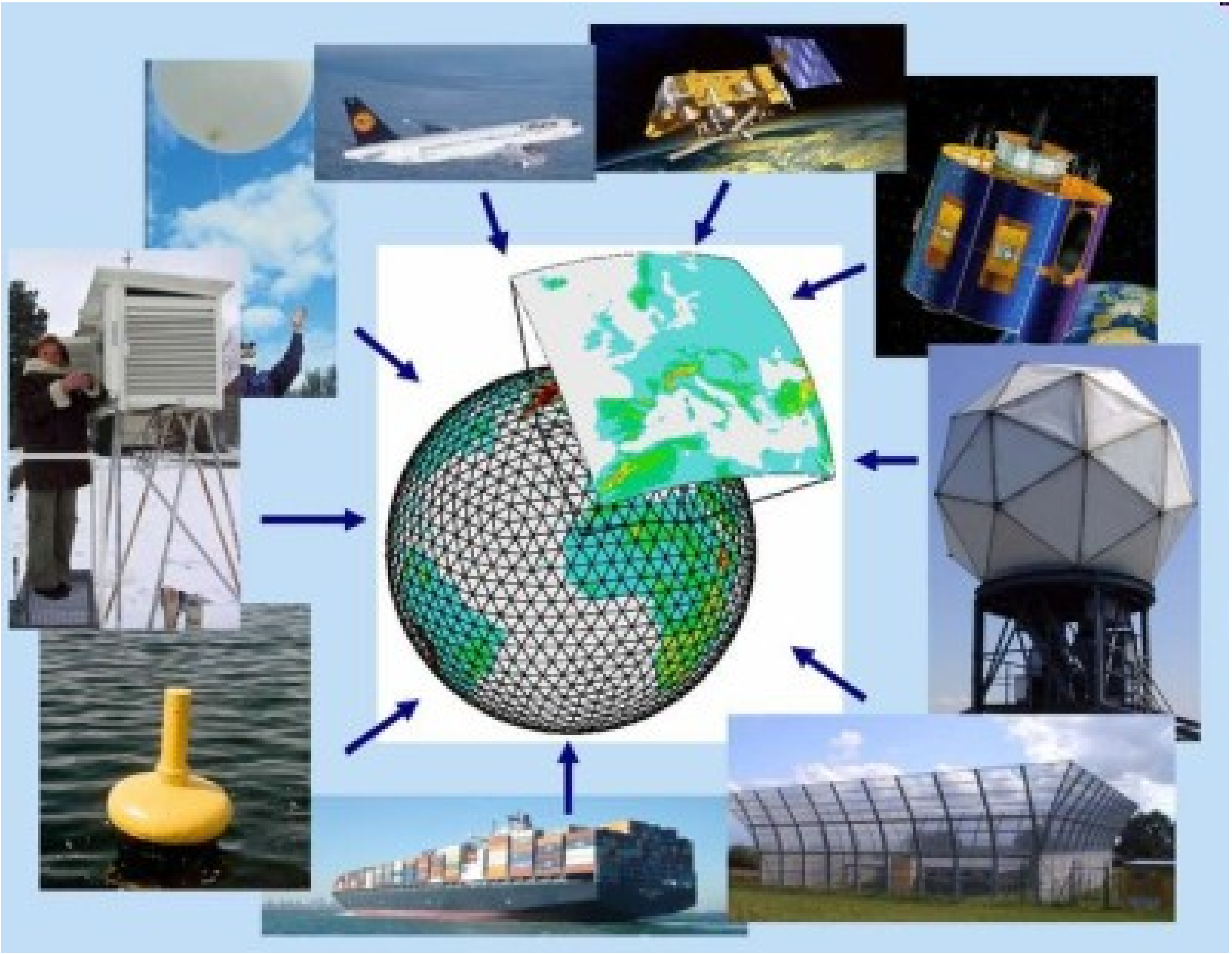


Predictability

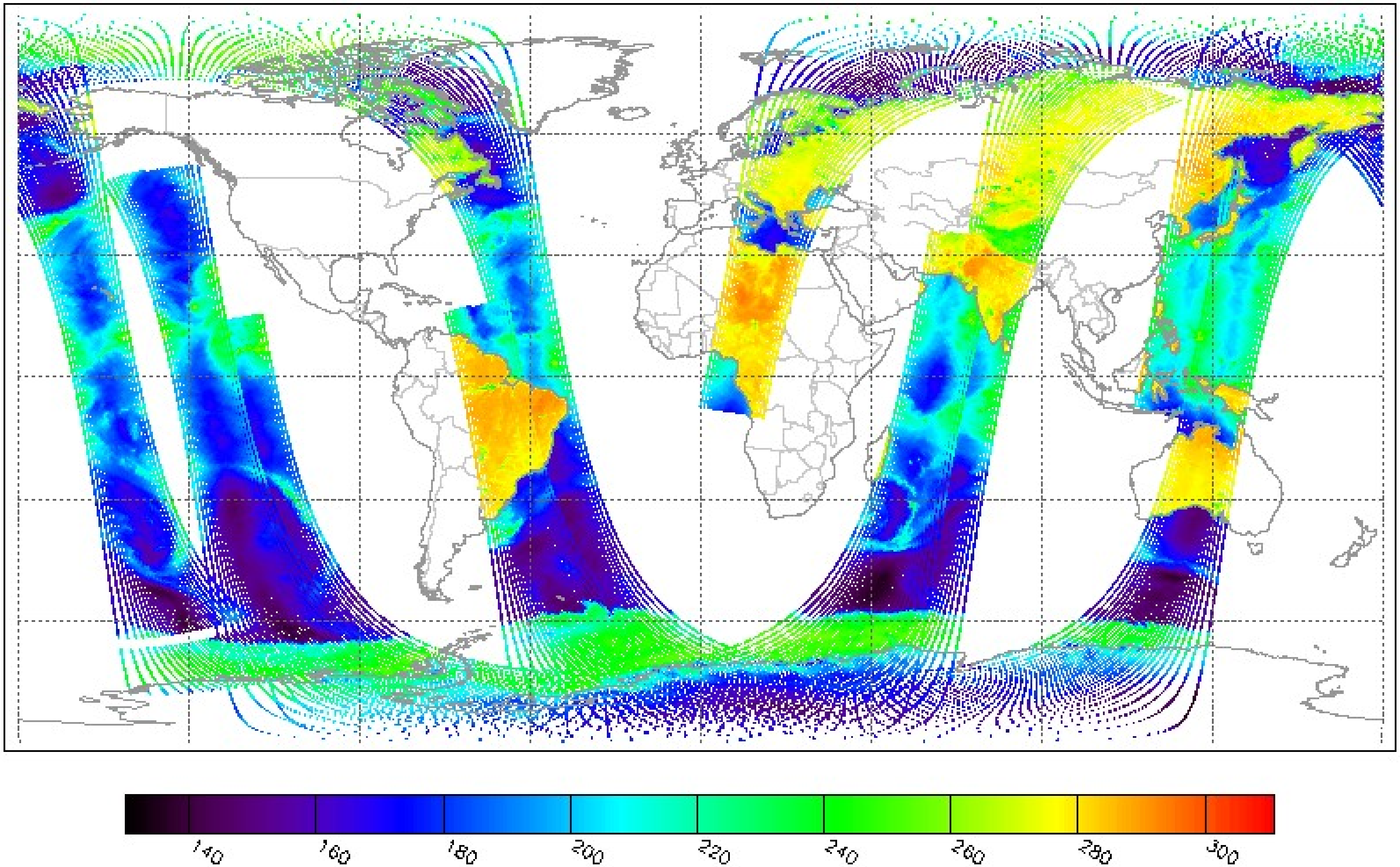
Predictability



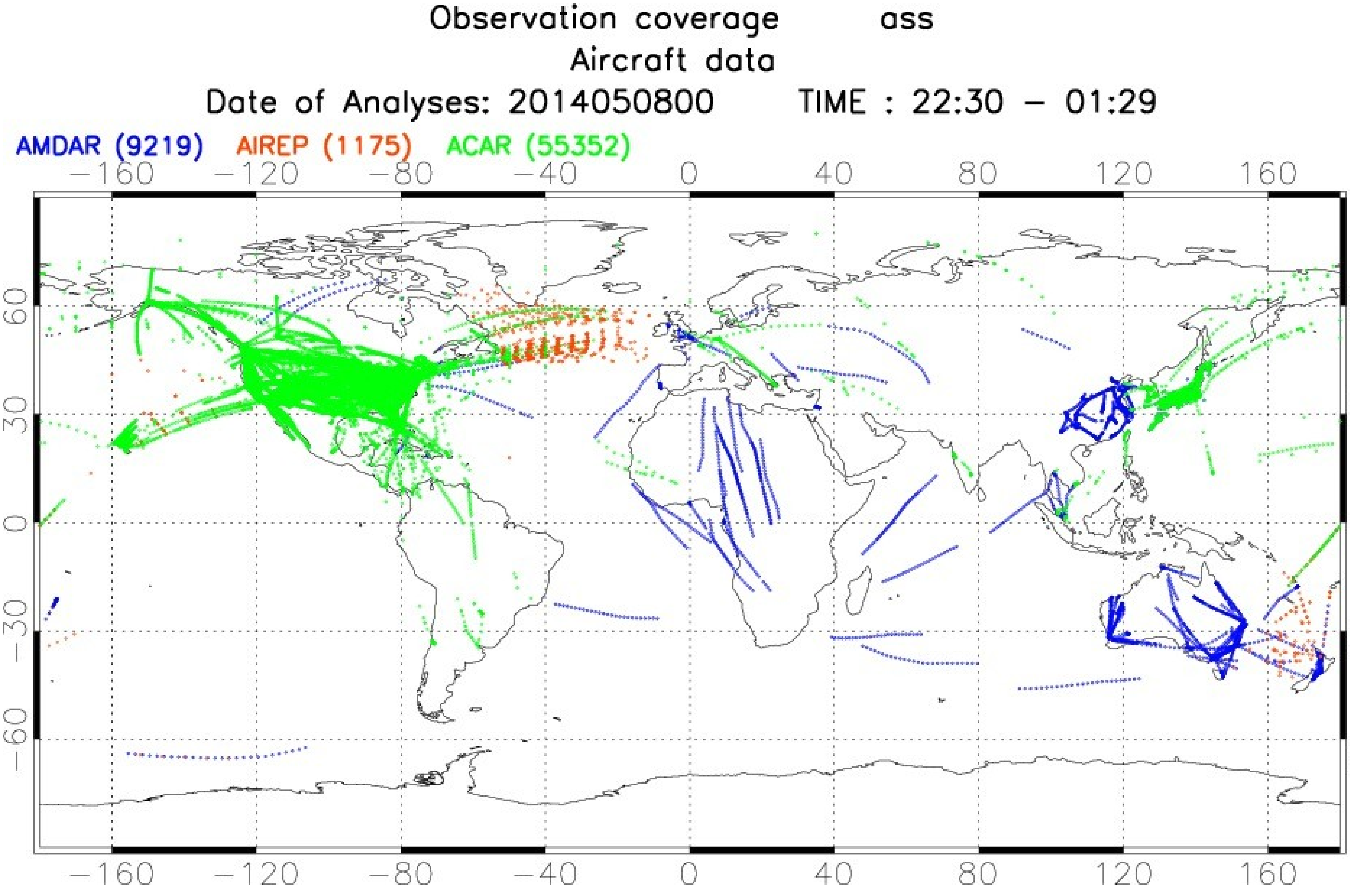
Data Assimilation



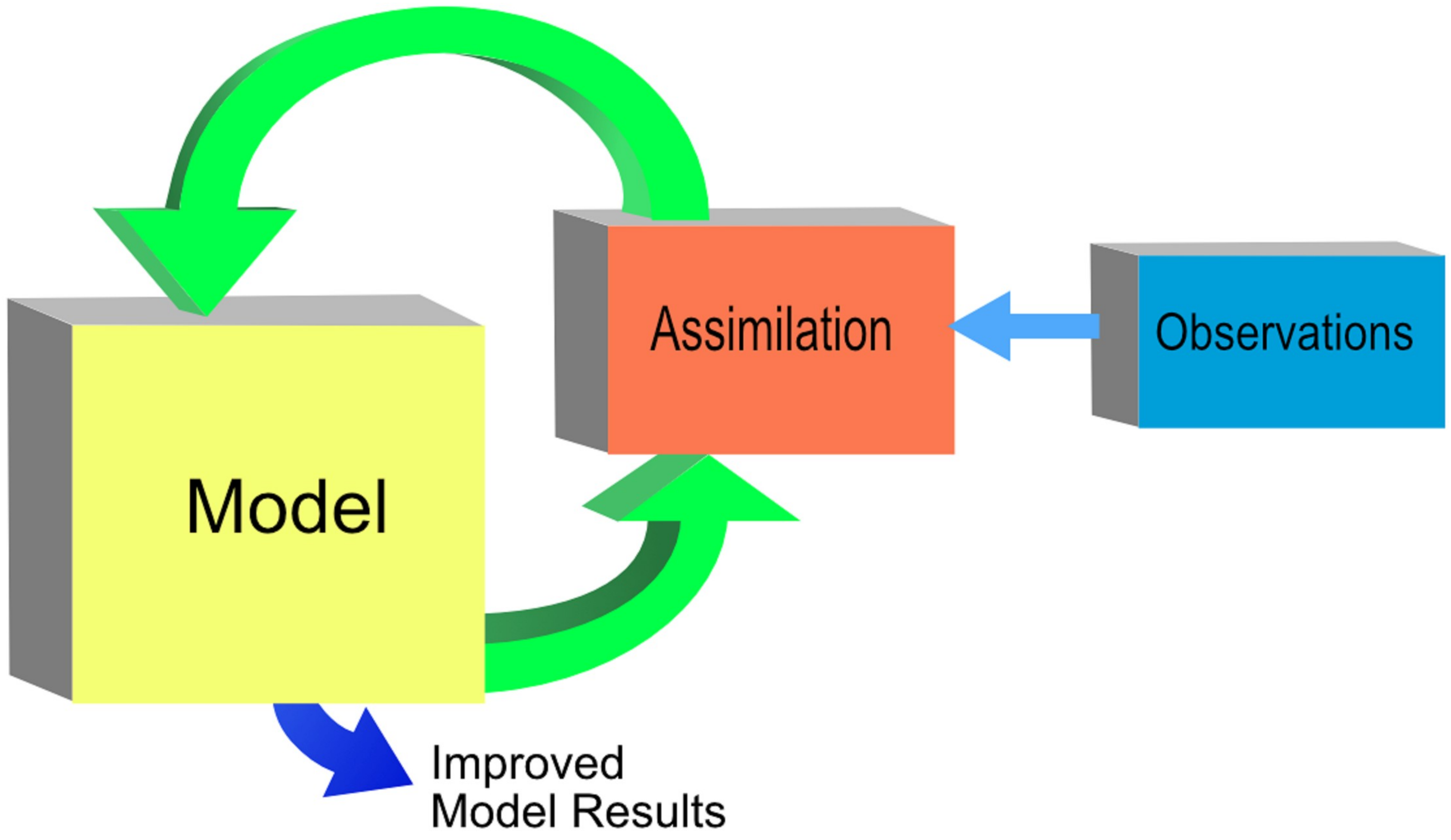
Data Assimilation



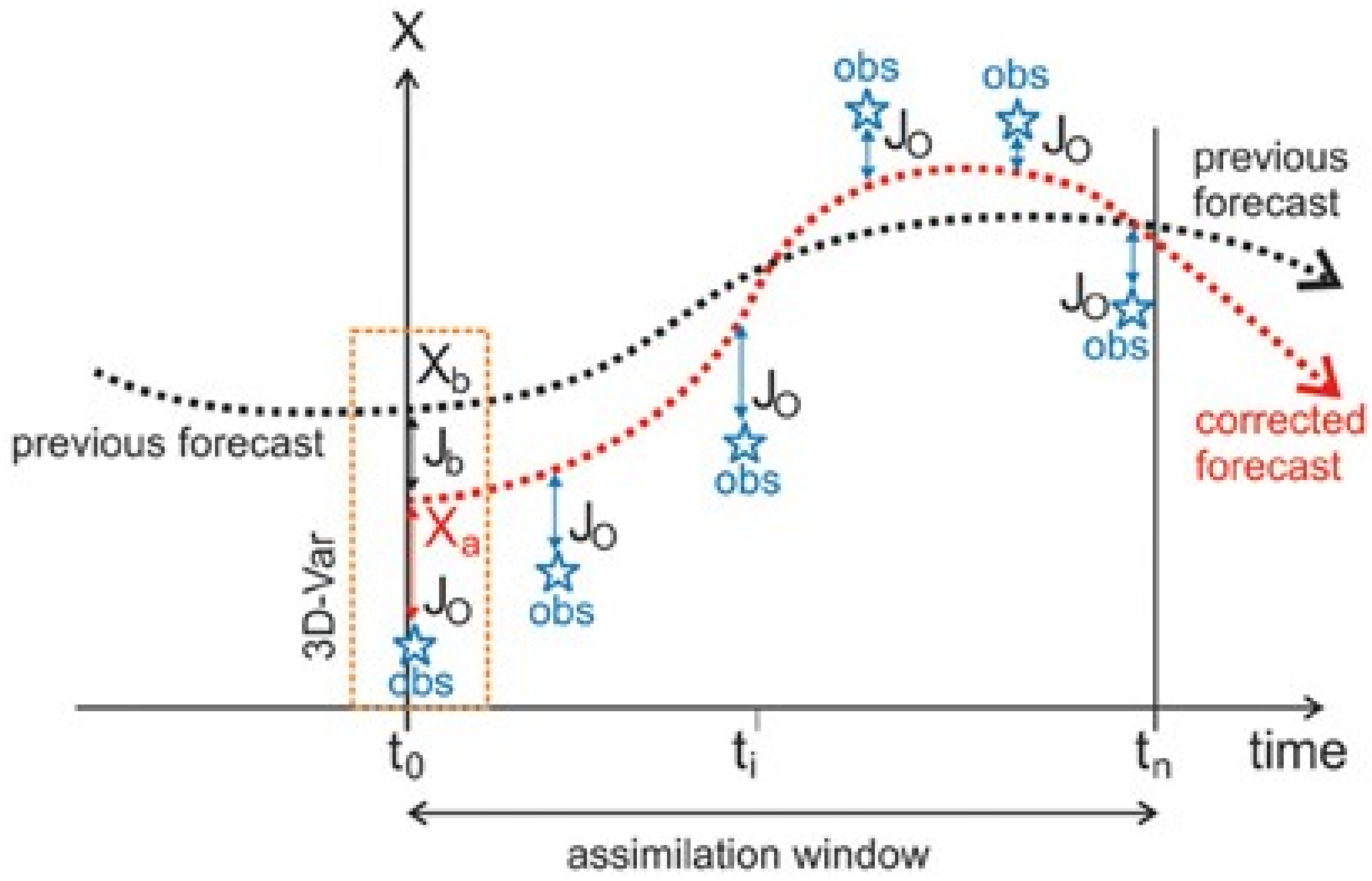
Data Assimilation



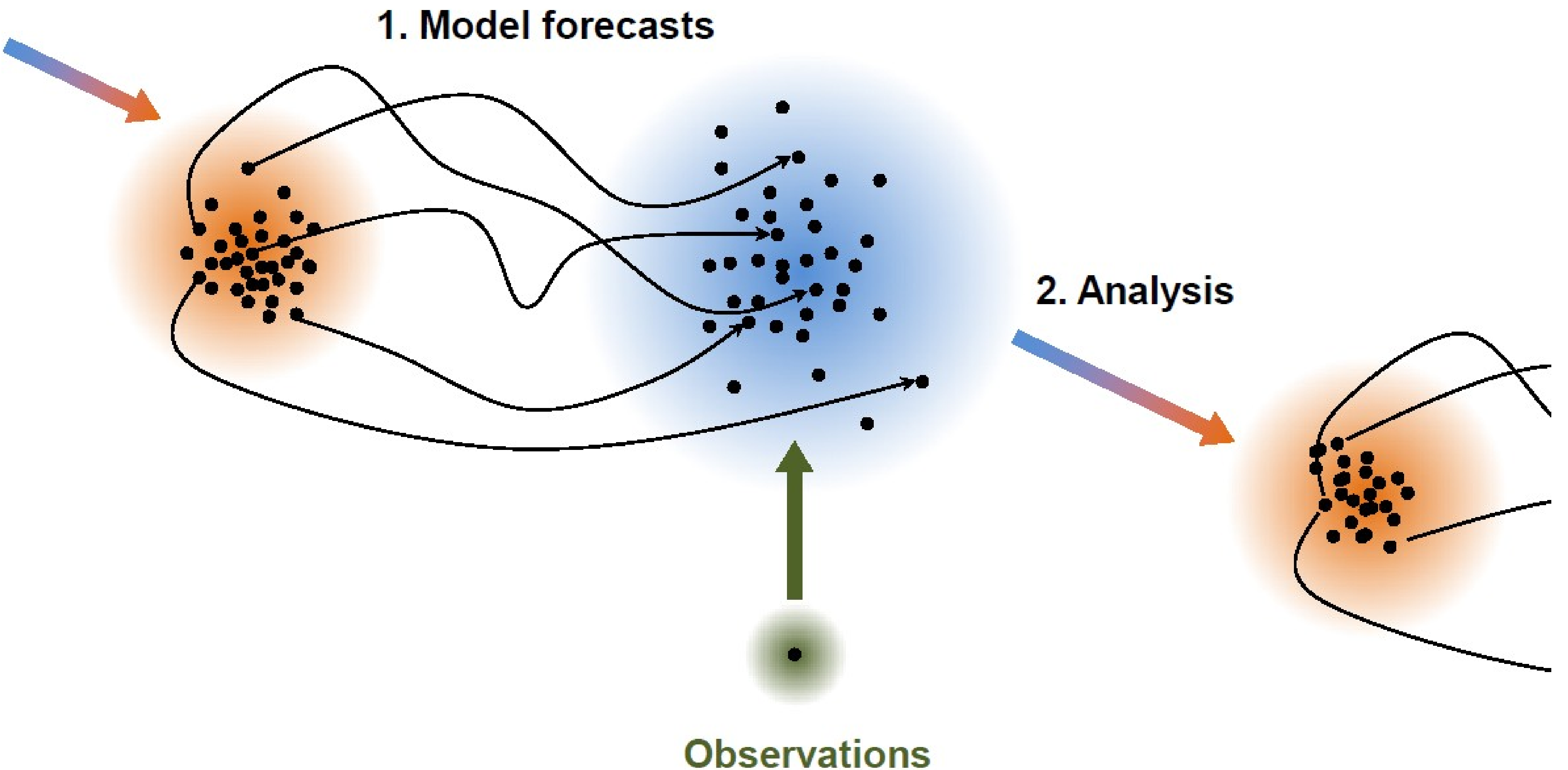
Data Assimilation



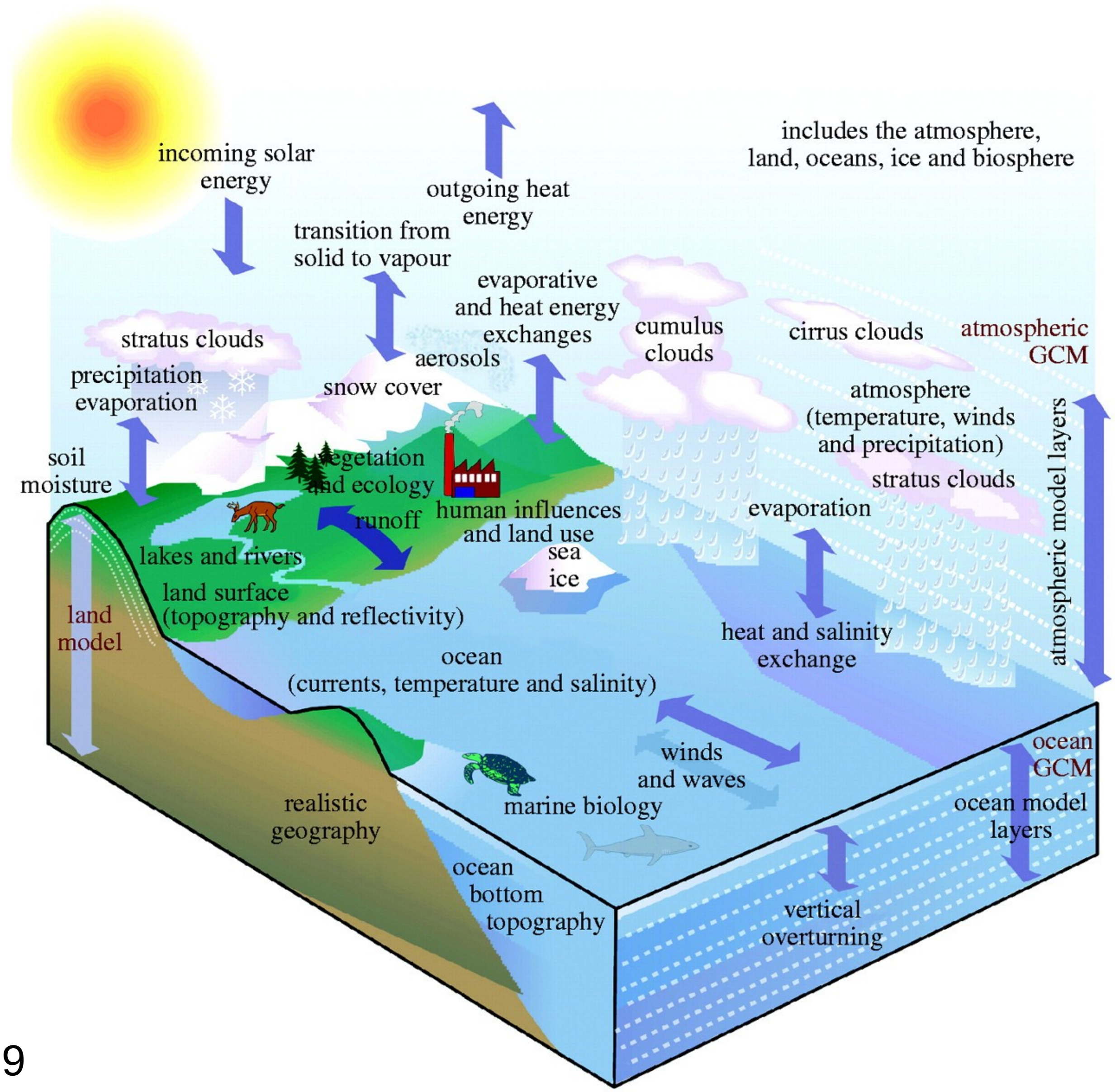
Data Assimilation



Data Assimilation



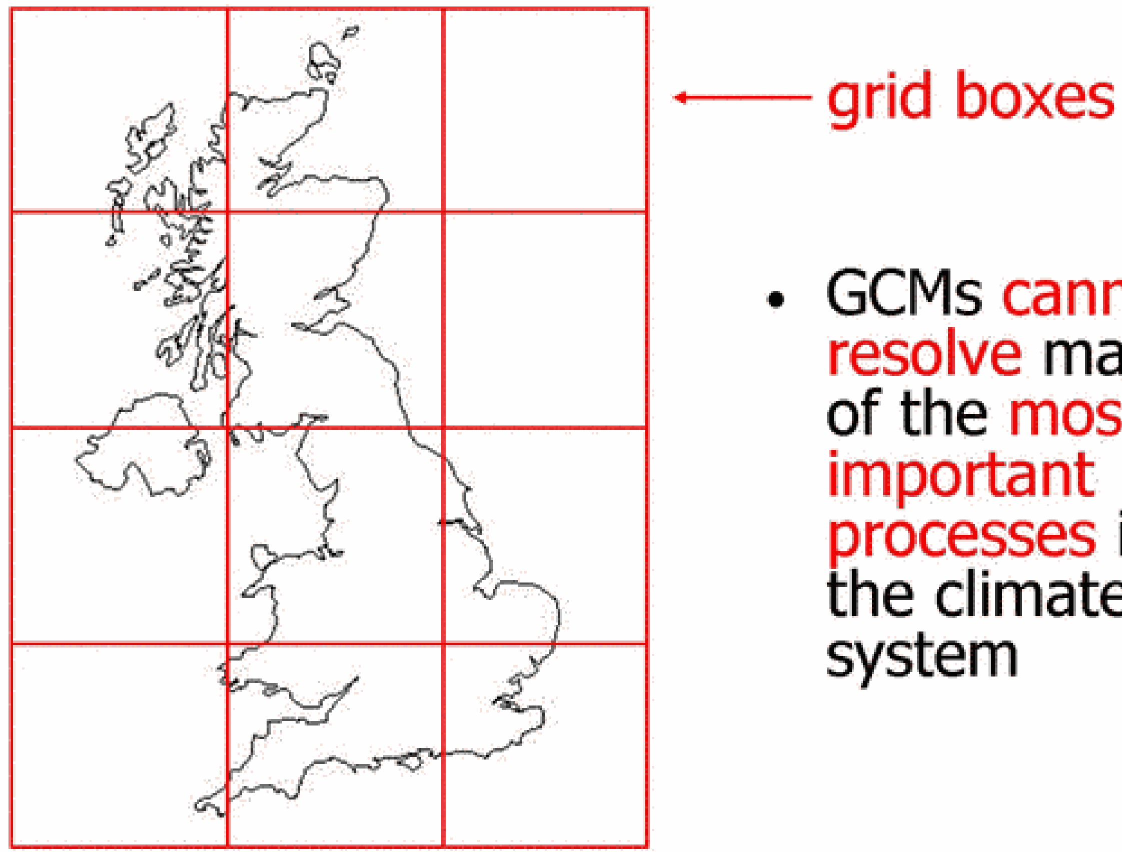
Climate Models



Washington et al. 2009

Climate Models

Typical grid for climate simulation:



- GCMs cannot resolve many of the most important processes in the climate system

Source: Paul Williams

Climate Models

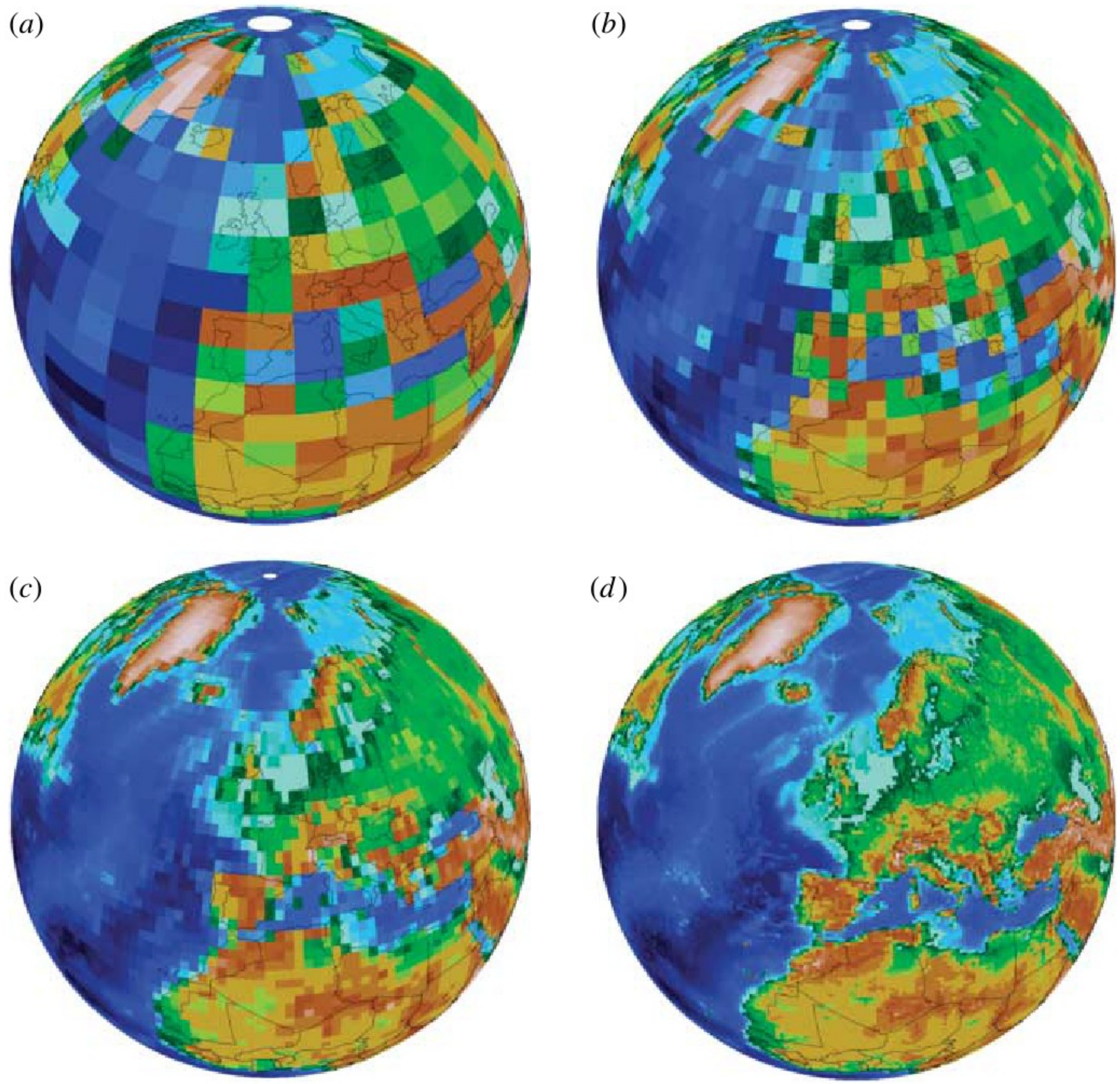


Figure 2. Horizontal resolution of the contemporary atmospheric and ocean climate model components. An approximate resolution of (a) 500 km, (b) 300 km, (c) 150 km and (d) 75 km.

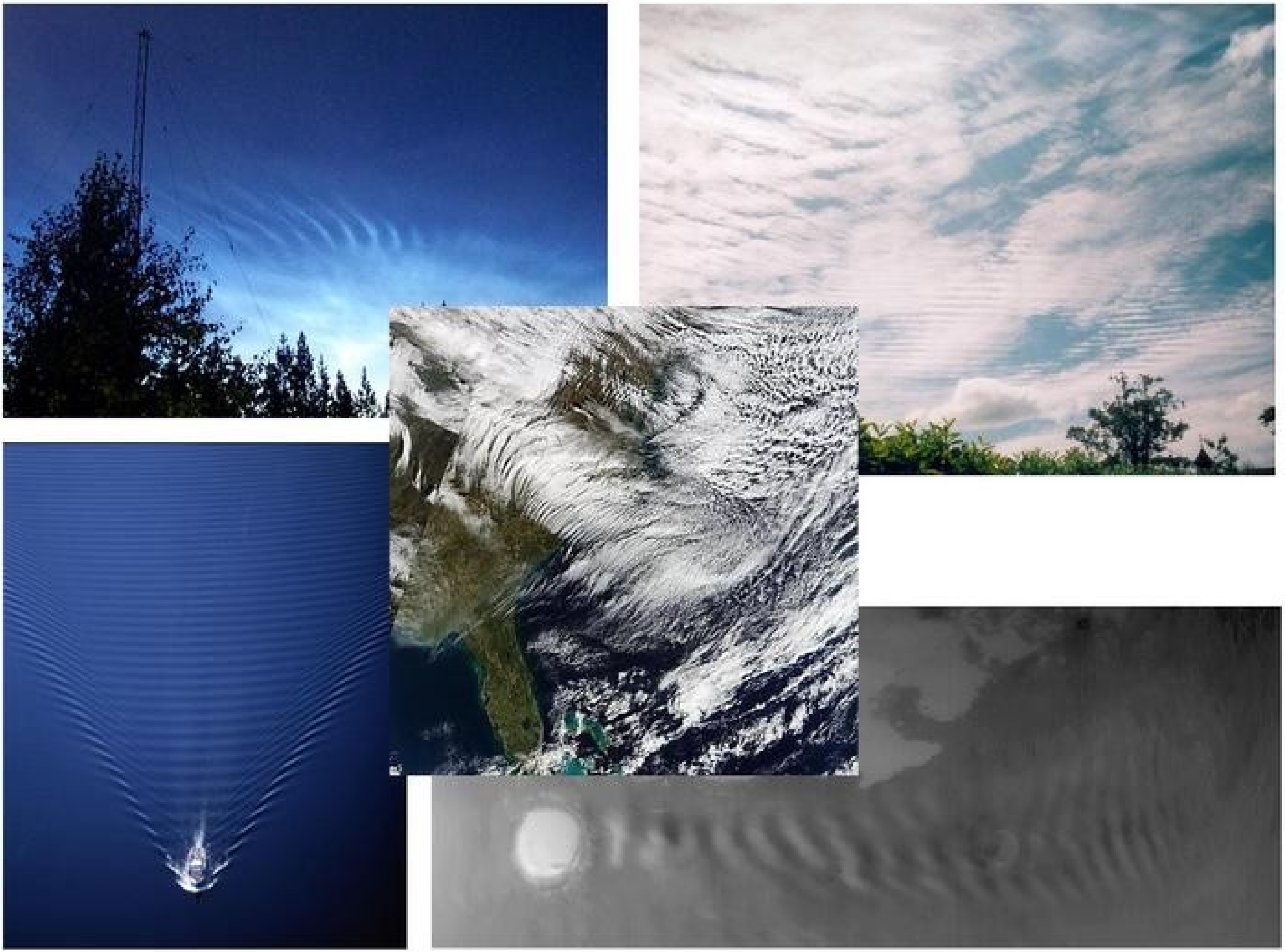
Washington et al. 2009

Climate Models

Physical Processes which need to be parameterized:

- Clouds
- Radiation
- Gravity Waves
- Convection
- Air-sea interaction
- Land surface-air interaction
- Turbulence
- Boundary-Layer Processes
- and many more

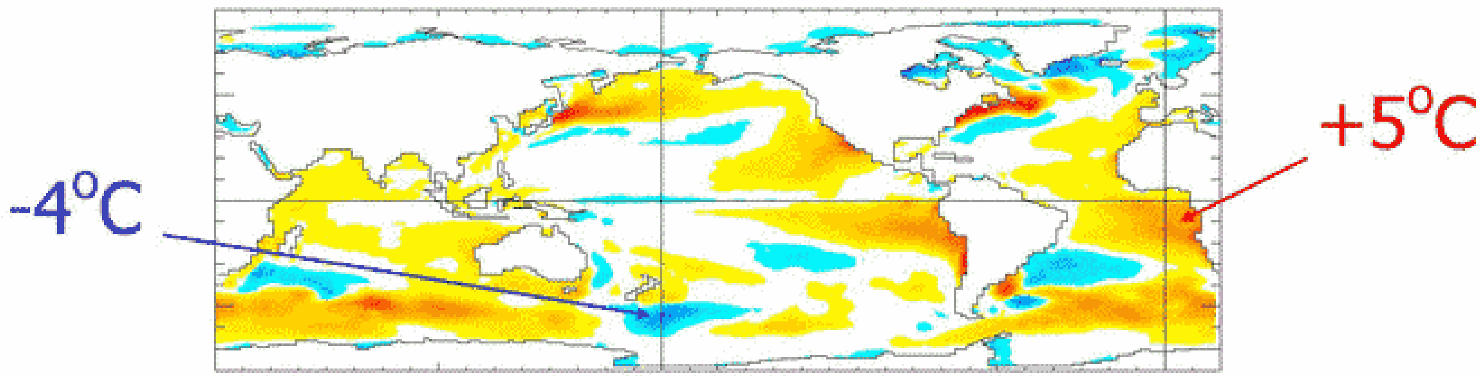
Subgrid-Scale Processes



Source: Paul Williams

Subgrid-Scale Processes

Systematic climate biases result:



"to understand and characterise the important unresolved processes... in the climate system" is a *"high priority area for action"* (IPCC, 2001)

Source: Paul Williams

Subgrid-Scale Processes

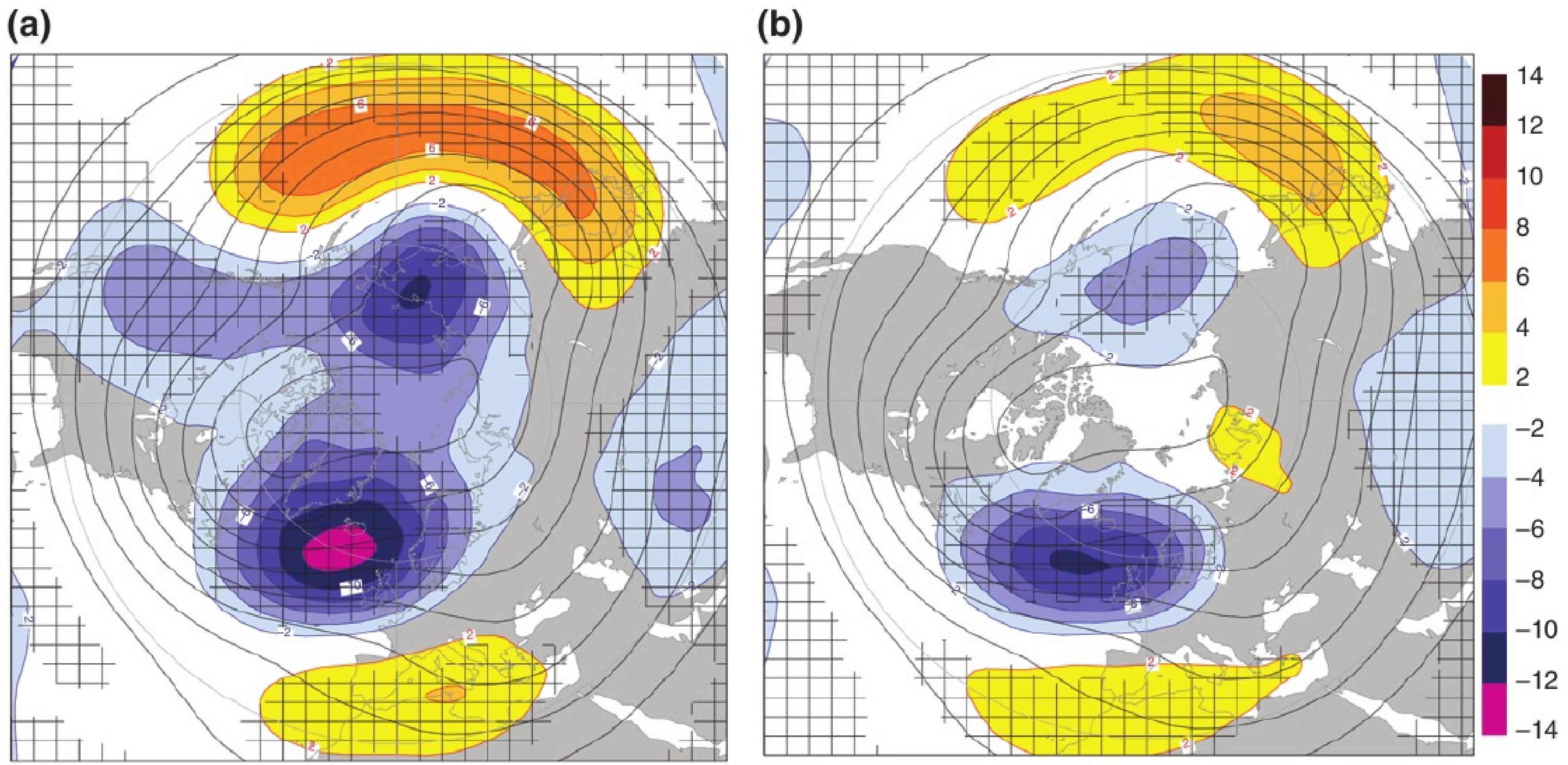
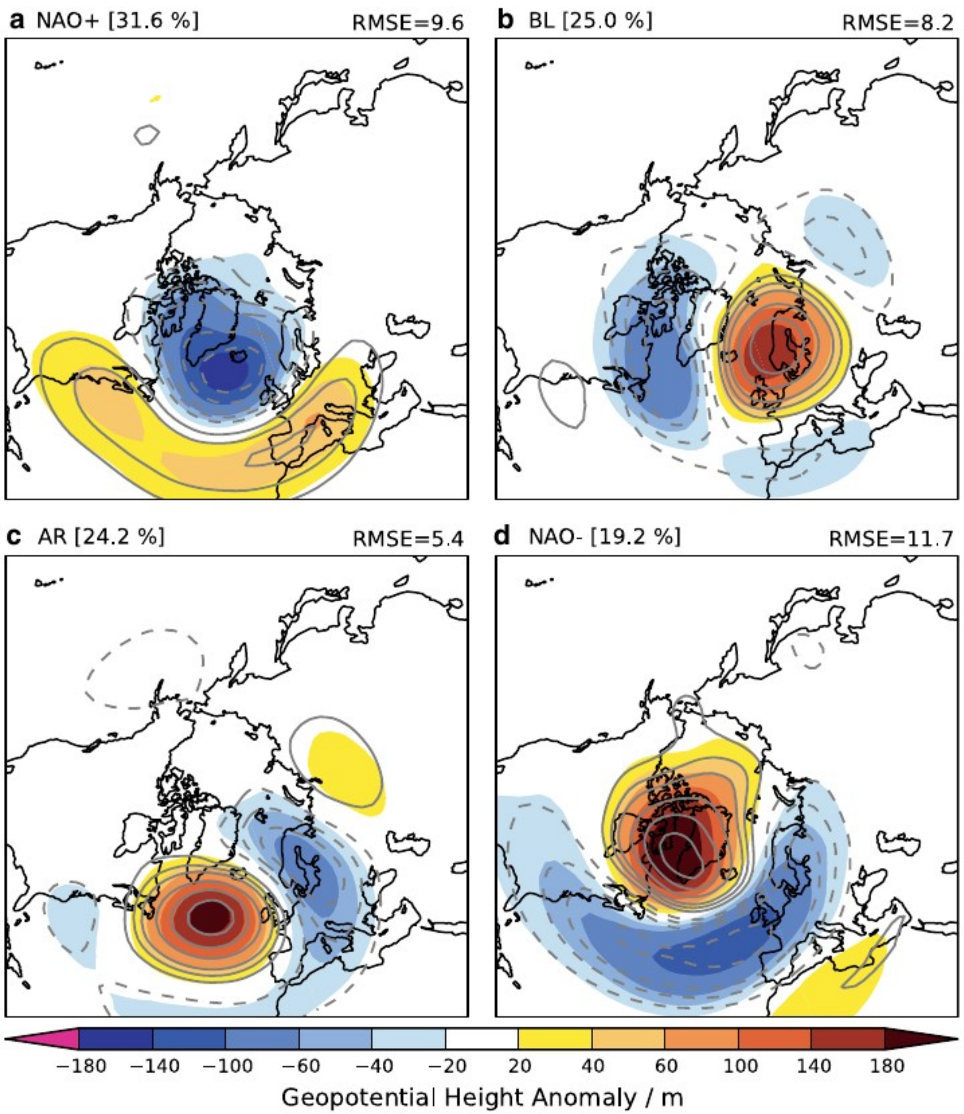


FIGURE 2 | Mean systematic error of 500 hPa geopotential height fields (shading) for extended boreal winters (December–March) of the period 1962–2005. Errors are defined with regard to the observed mean field (contours), consisting of a combination of ERA-40 (1962–2001), and operational ECMWF analyses (2002–2005). (a) Systematic error in a numerical simulation with the ECMWF model IFS, version CY32R1, run at a horizontal resolution of T_L95 (about 210 km) and 91 vertical levels. (b) Systematic error in a simulation with a stochastic kinetic-energy backscatter scheme. Significant differences at the 95% confidence level based on a Student's *t*-test are hatched (after Berner et al.[124]).

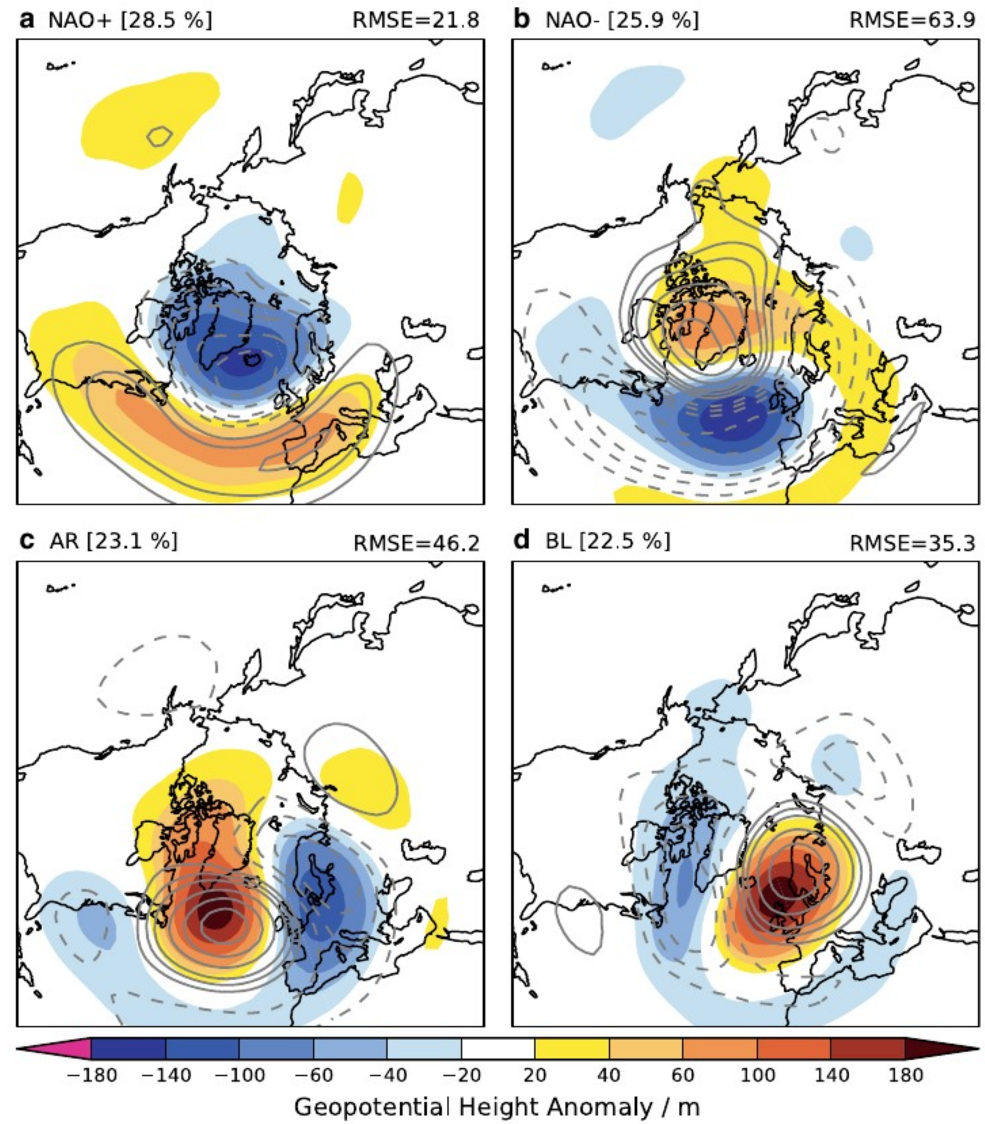
Franzke et al. 2015

Subgrid-Scale Processes

T1279



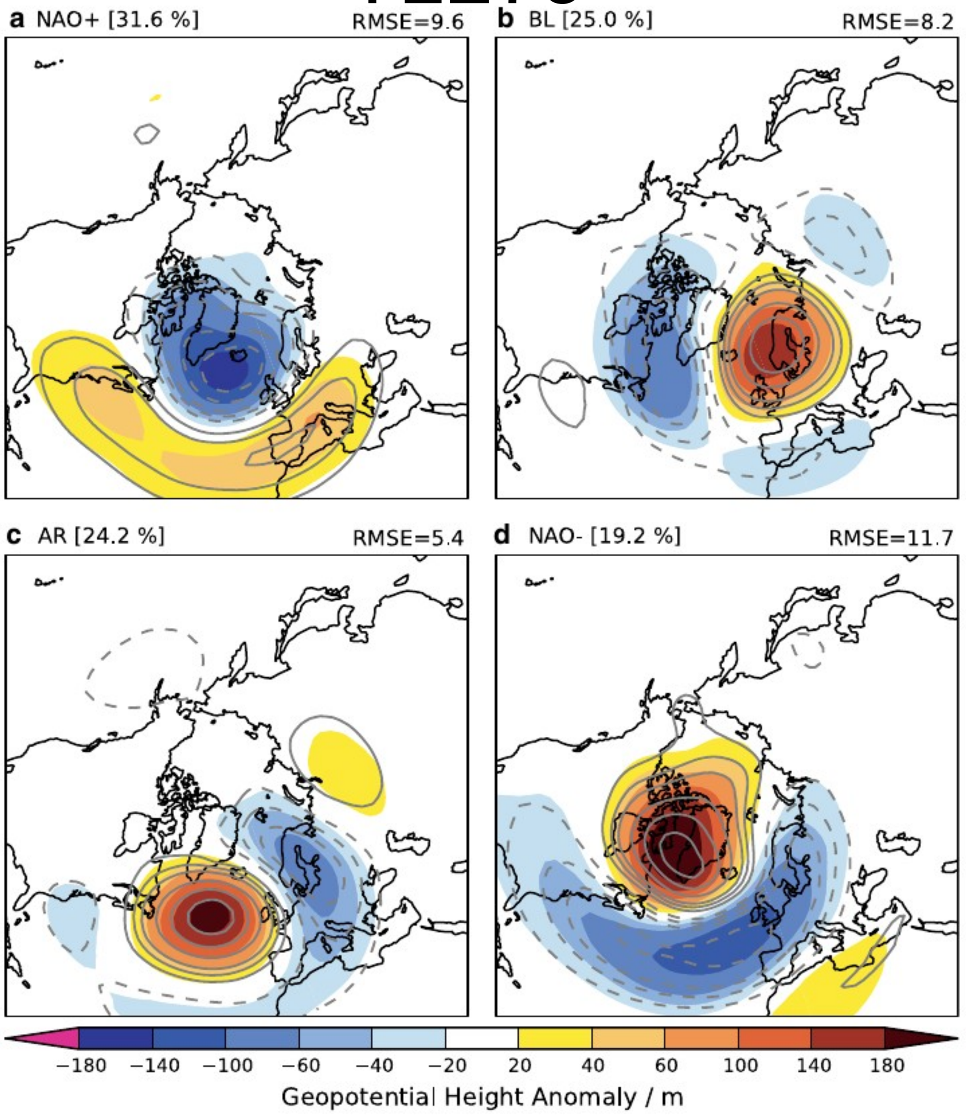
T159



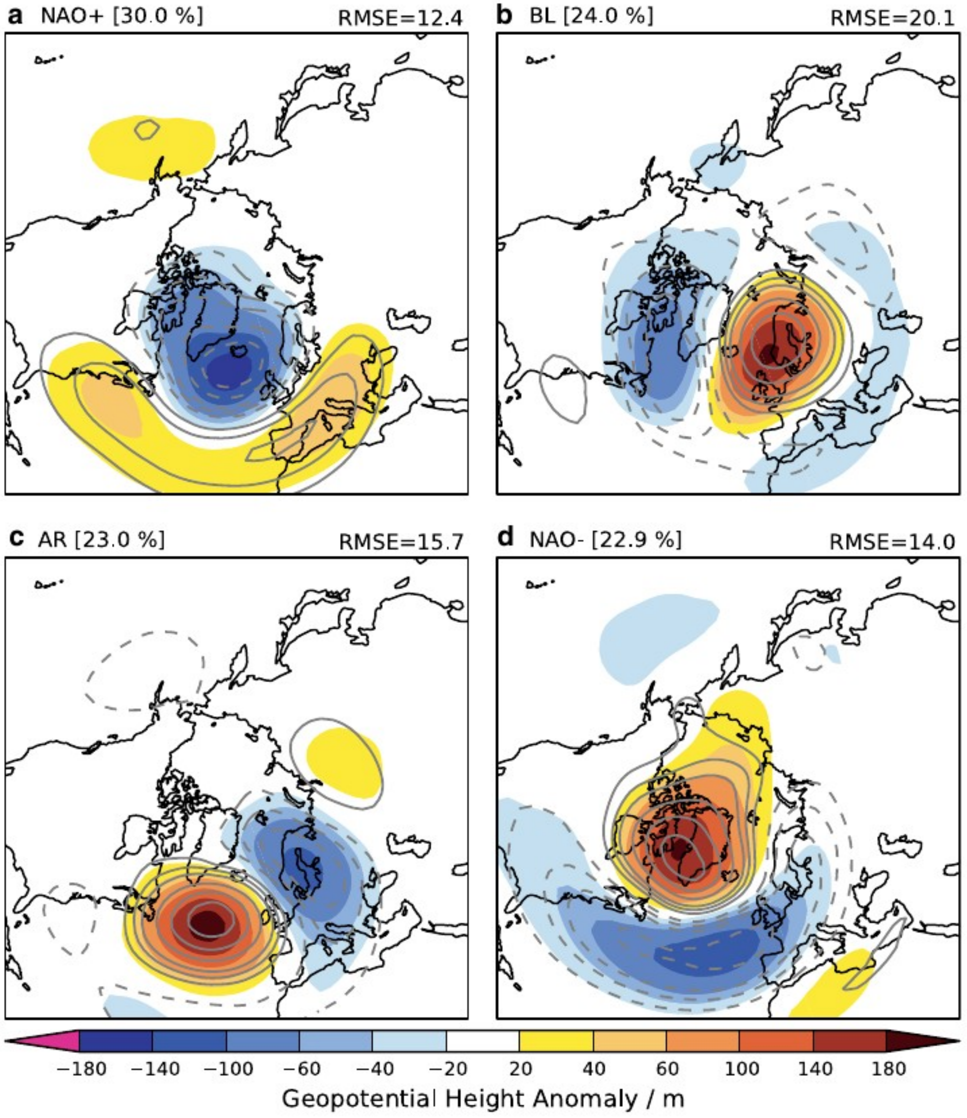
Dawson and Palmer 2014

Subgrid-Scale Processes

T1279



T159, Stochastic Physics



Dawson and Palmer 2014

Subgrid-Scale Processes

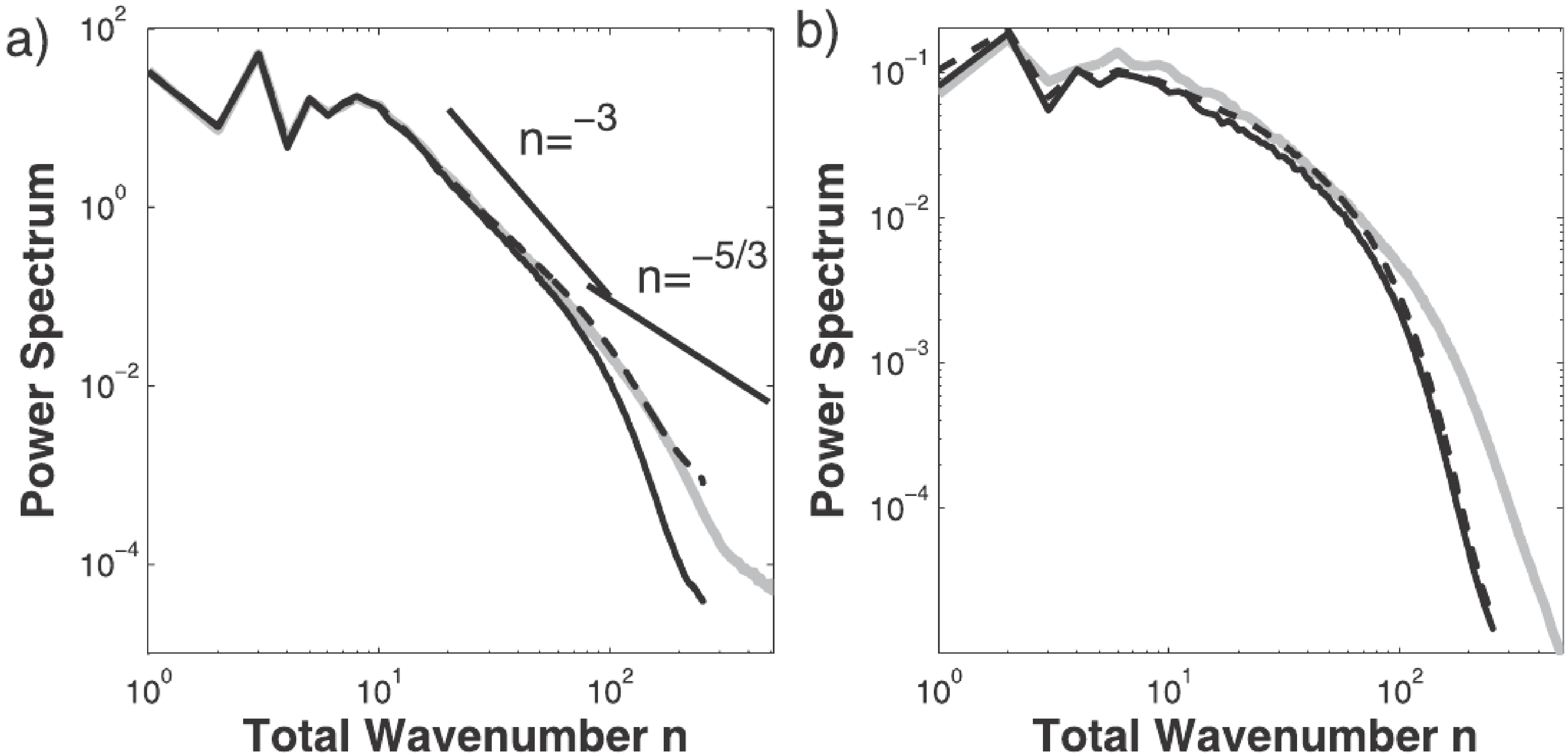


FIG. 6. Kinetic energy spectra for the (a) rotational and (b) divergent component of the flow for T_L511 analysis (gray solid), forecasts with the operational ensemble configuration (OPER; black solid), and the ensemble system with stochastic backscatter (SSBS-FULLDISS; black dashed). Lines denote power-law behavior with slopes of -3 and $-5/3$.

Berner et al. 2009

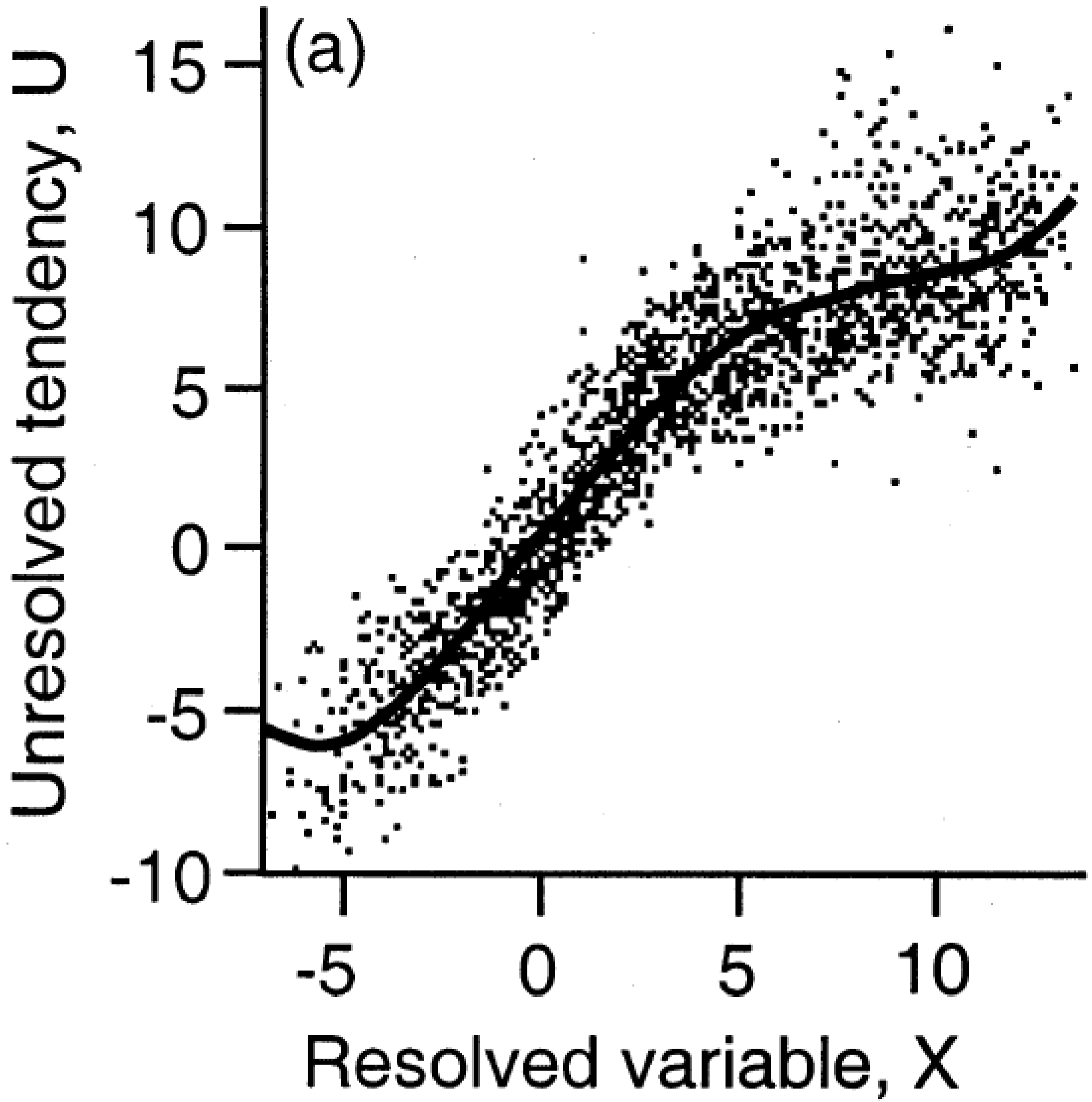
Subgrid-Scale Processes

TABLE 4. Impact of stochastic backscatter scheme and reduced initial perturbations (SSBS-FULLDISS) when compared to OPER for NH and SH extratropics and tropics. Probabilistic skill scores are the BSS, ROC area, ISS, RPSS, percentage of outliers, and rank histogram at 48 h (RH48). Symbols represent the following impacts: +++ = very strong positive impact at all forecast lead times; ++ = strong positive impact at all forecast lead times; + = positive impact at all forecast lead times; ○ = neutral impact; − = negative impact all forecast lead times; ◁ = negative impact for shorter but positive impact for longer forecast lead times; ▷ = positive impact for shorter but negative impact for longer forecast lead times.

		NH			SH			Tropics		
Score	Threshold	Z_{500}	u_{850}	T_{850}	Z_{500}	u_{850}	T_{850}	Z_{500}	u_{850}	T_{850}
BSS	$> +1.5\sigma$	+	+	+	+	+	+	++	++	++
	$< -1.5\sigma$	+	+	+	+	+	+	++	++	++
ROC	$> +1.5\sigma$	+	+	+	+	+	+	+	+	+
	$< -1.5\sigma$	+	+	+	+	+	+	+	+	+
ISS	$> +1.5\sigma$	++	++	++	+	+	+	++	++	++
	$< -1.5\sigma$	++	++	++	+	+	+	++	++	++
RPSS		+	+	+	+	+	+	++	++	++
% outliers		+	++	◁	+	+	◁	+	++	++
RH48		++	+	+	+	+	○	+	+	+

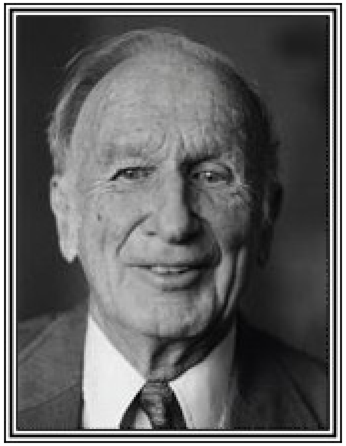
Berner et al. 2009

Subgrid-Scale Processes



Wilks 2005

Lorenz 1996 Model



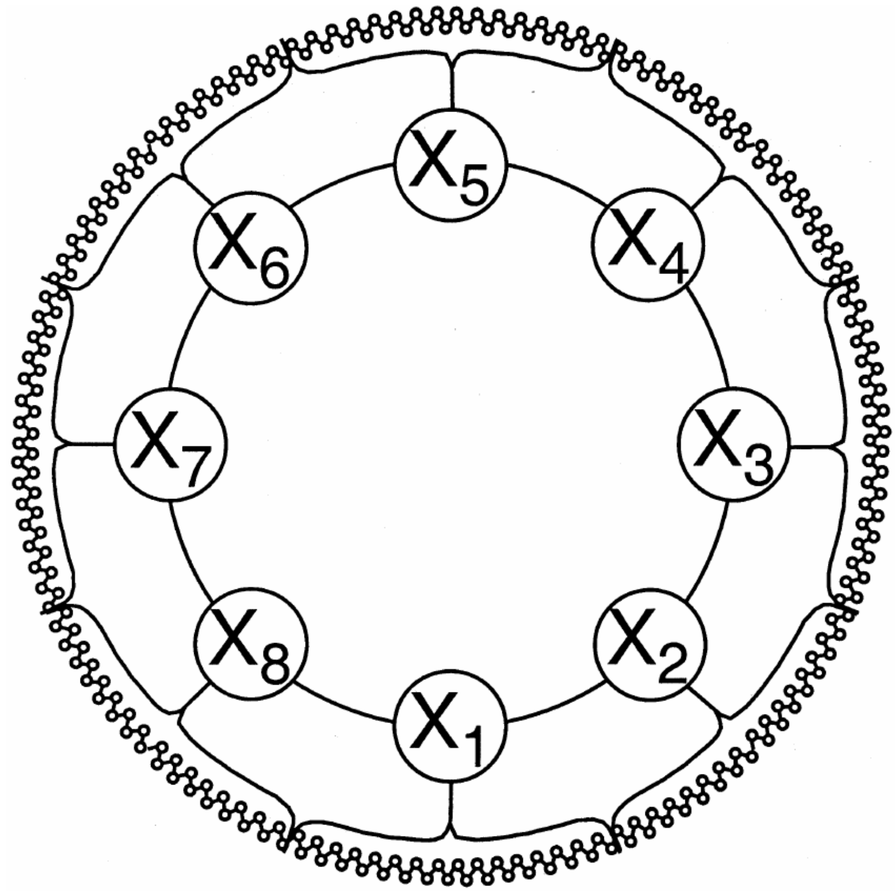
Edward N. Lorenz
1917 – 2008

$$\frac{\mathrm{d}X_k}{\mathrm{d}t} = -X_{k-1}(X_{k-2} - X_{k+1}) - X_k + F - \frac{hc}{b} \sum_{j=J(k-1)+1}^{kJ} Y_j; \quad k = 1, \ldots, K \tag{1a}$$

$$\frac{\mathrm{d}Y_j}{\mathrm{d}t} = -cbY_{j+1}(Y_{j+2} - Y_{j-1}) - cY_j + \frac{hc}{b} X_{\mathrm{int}[(j-1)/J]+1}; \quad j = 1, \ldots, JK. \tag{1b}$$

Lorenz 1996

Lorenz 1996 Model



Wilks 2005

Exercise

Write code for Lorenz96 model using a 4th order Runge-Kutta scheme

$$\frac{\mathrm{d}X_k}{\mathrm{d}t} = -X_{k-1}(X_{k-2} - X_{k+1}) - X_k + F - \frac{hc}{b} \sum_{j=J(k-1)+1}^{kJ} Y_j; \quad k = 1, \ldots, K \tag{1a}$$

$$\frac{\mathrm{d}Y_j}{\mathrm{d}t} = -cbY_{j+1}(Y_{j+2} - Y_{j-1}) - cY_j + \frac{hc}{b} X_{\mathrm{int}[(j-1)/J]+1}; \quad j = 1, \ldots, JK. \tag{1b}$$

F=10, h=c=b=1, K=8, J=6

$$k_1 = f(z_n)$$

$$k_2 = f(z_n + d/2\, k_1)$$

$$k_3 = f(z_n + d/2\, k_2)$$

$$k_4 = f(z_n + d\, k_3)$$

$$z_{n+1} = z_n + \frac{d}{6}(k_1 + 2k_2 + 2k_3 + k_4)$$

d: time step size

Runge-Kutta Scheme

Wilks 2005