FURTHER MOTIVATION, JUSTIFICATION AND TECHNICAL DESIGN OF THE QUASI-3D MULTI-SCALE MODELING FRAMEWORK

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ABSTRACT

MOTIVATION :

- There are fundamental *structural* problems in the conventional framework for climate models.

JUSTIFICATION :

- Such problems are basically eliminated in MMF.
- *The quasi-3D MMF replaces the problem of parameterizing meso- and cloud-scale processes by the problem of statistically estimating the orientation of cloud organization.*

TECHNICAL DESIGN :

- A tentative algorithm for such estimation is presented.

During the last decades,
the scope of general circulation modeling
have magnificently expanded.

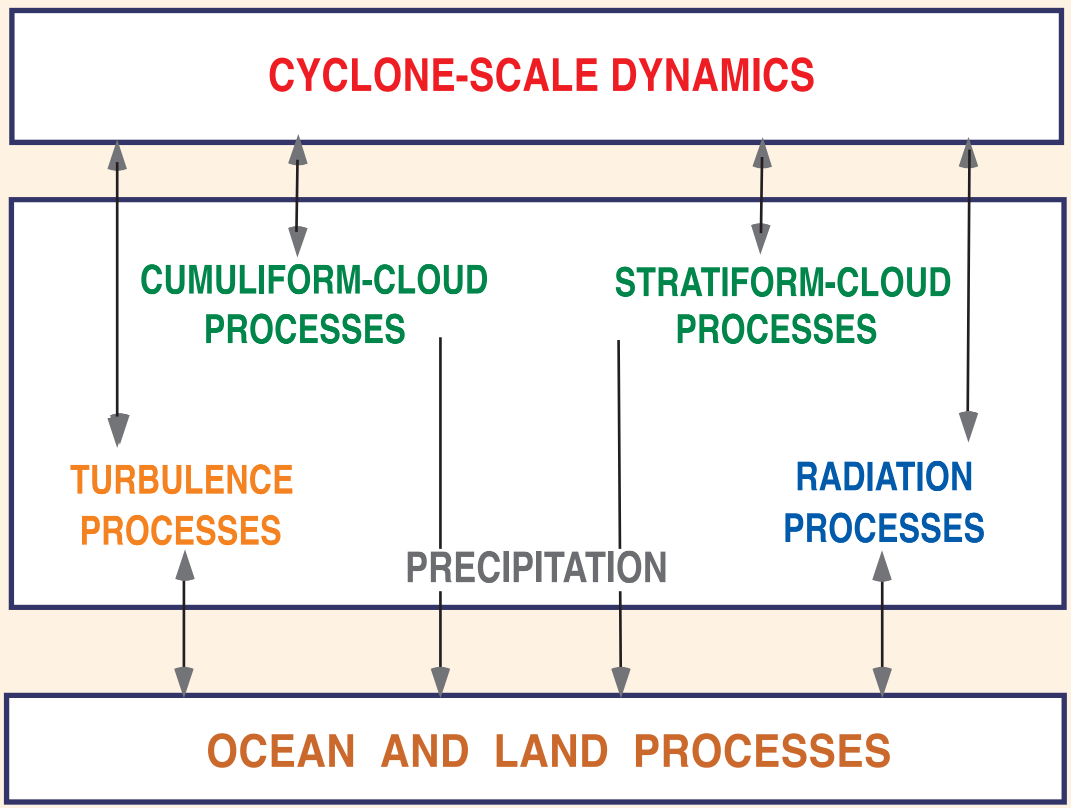
However,

the conventional framework for climate models have the problems of

- artificial separation of processes
- artificial separation of scales
- over-deterministic parameterization.

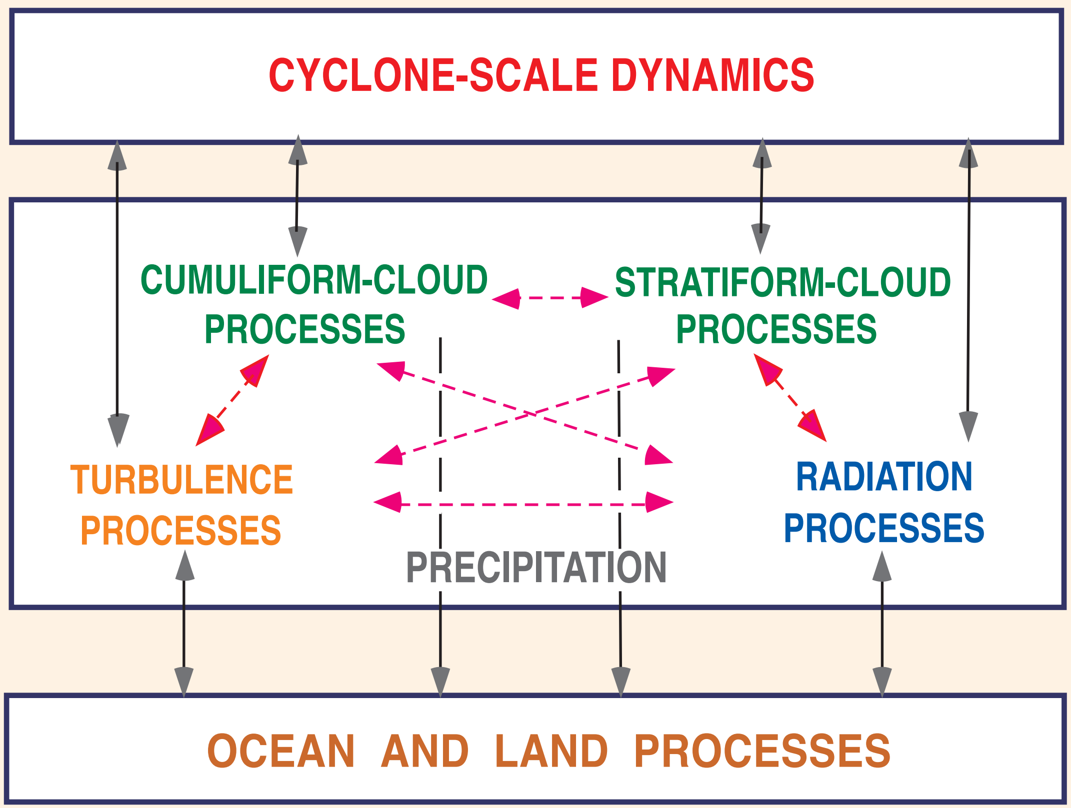
I. ARTIFICIAL SEPARATION OF PROCESSES

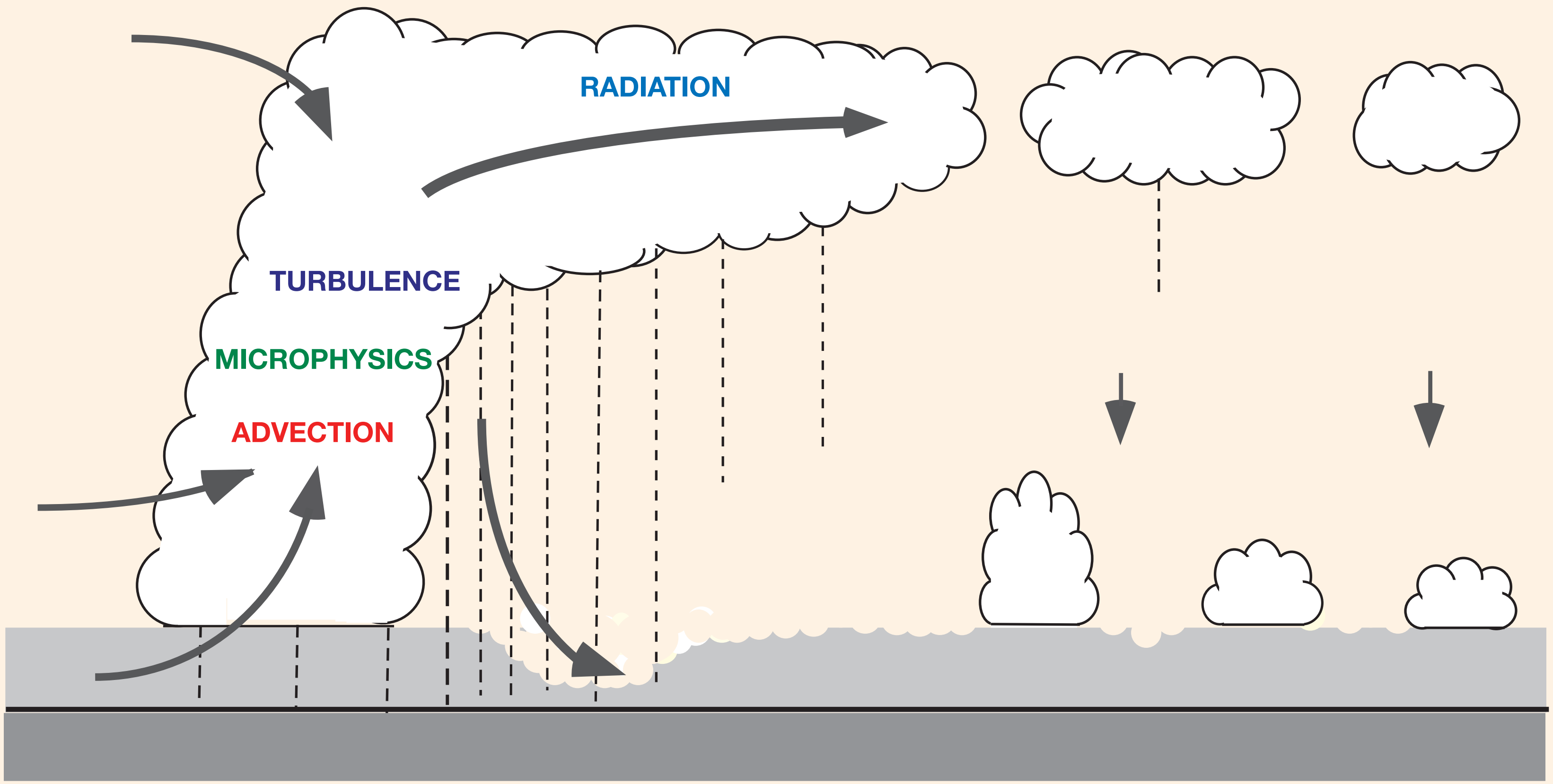
- conventional models have a modular structure, in which different processes interact only through the cyclone-scale dynamics (and surface conditions);



I. ARTIFICIAL SEPARATION OF PROCESSES

- conventional models have a modular structure, in which different processes interact only through the cyclone-scale dynamics (and surface conditions);
- consequently, most of the direct interactions (◄- - - ►) that involve cloud scales are missing.





In nature, these processes are strongly coupled on the cloud scale.

Poster Session Paper

CSRM EXPERIMENTS ON

THE EFFECT OF CLOUD-SCALE INTERACTIONS ON LARGE-SCALE FIELDS

by C. M. Wu and A. Arakawa (2005), Submitted to JAS.

Performed CSRM experiments eliminating the cloud-scale forcing or feedback of each physical process (radiation,turbulence or cloud microphysics).

Due to the existence of cloud-scale interactions,
the overall effect of these processes on the averaged field is
NOT the sum of separately averaged effects of individual processes.

— A serious doubt on the modular structure of the existing GCMs

II. ARTIFICIAL SEPARATION OF SCALES

In conventional GCMs, a single nonphysical scale introduced for computational purpose separates model processes into

CYCLONE-SCALE PROCESSES,

whose local and instantaneous effects can be explicitly formulated, and

CLOUD-SCALE PROCESSES,

whose effects can be considered *only statistically* through parameterization

with **MESOSCALE PROCESS** either ignored or poorly represented.

This drastic separation of model physics is nothing to do with the existence or nonexistence of a spectral gap in nature.

Cloud parameterization is supposed to be a statistical problem. But we don't know where to introduce stochastic components in the dynamical-physical framework.

In cumulus heating (as in Lin & Neelin 2003)?

In cloud mass flux, $M = \sum_{i}^{N} \rho \sigma_i w_i$, (as in Lin & Neelin 2003)?

In cloud motion? In cloud geometry? In cloud population?

In in-cloud structure?

In cloud buoyancy (as in Raymond & Blyth 1986 and Emanuel 1991)?

In triggering? In adjustment? *. . . . . ?*

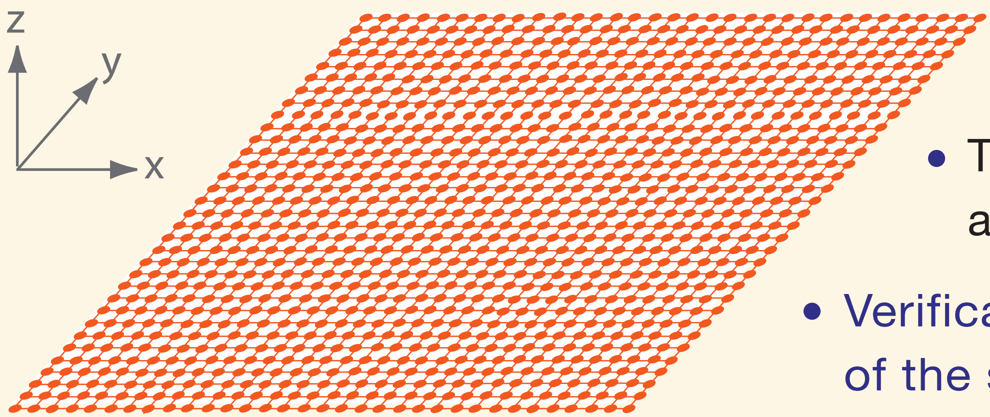
In cloud-type spectrum? In cloud organization?

Perhaps in all of these !

Parameterization in GCMs has not become a real statistical-dynamical-physical problem yet.

CLOUD-RESOLVING GCMS

Horizontal Grid of Cloud-Resolving GCM

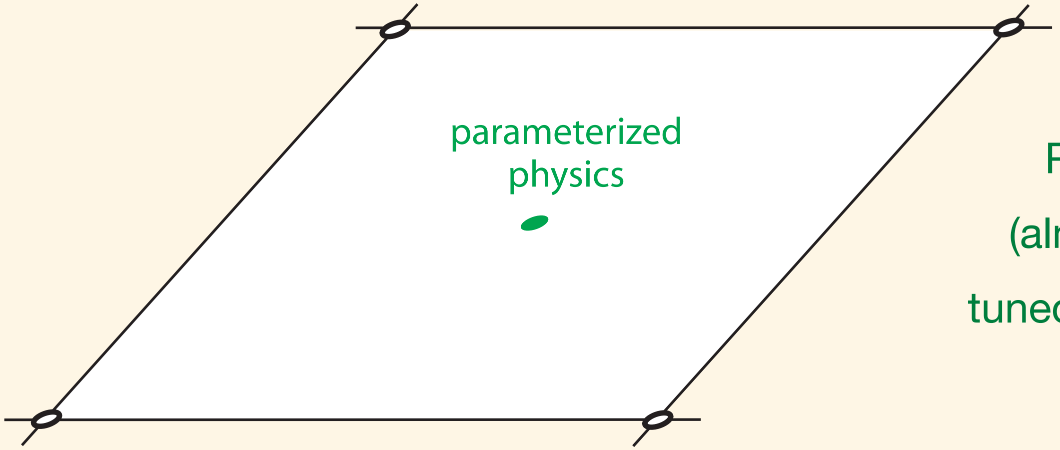


- The fundamental structural problems are basically eliminated.
- Verifications possible for the full range of the spectrum down to the cloud scale.

- Extremely expensive to run so that the present and future diversity of climate studies cannot be supported *if* we exclusively depend on such models.

Thus it is important to develop a flexible modeling framework that includes more economical options with essentially the same physics.

Conventional GCM



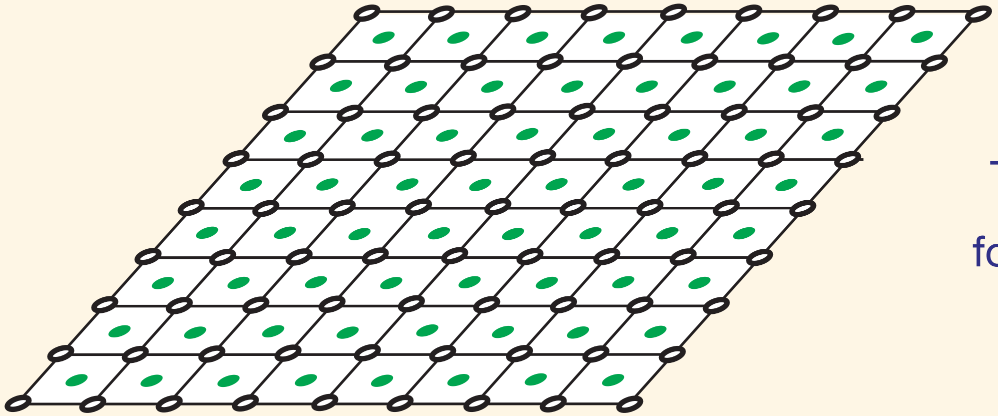
Parameterized physics of GCMs is

(almost always) single-column physics

tuned for a certain range of the resolution.

If we can afford to have more grid points, what is the best way of distributing them for resolving multi-scale processes?

Conventional approach



This is a reasonable thing to do

for a single-scale process model,

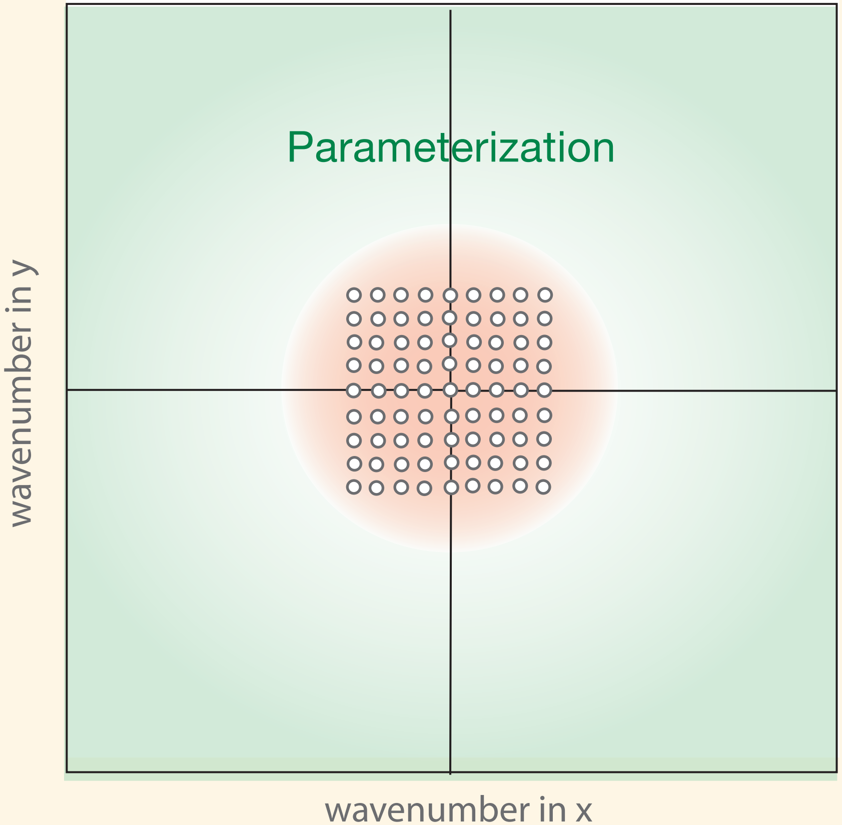
but

WAVENUMBER SPACE

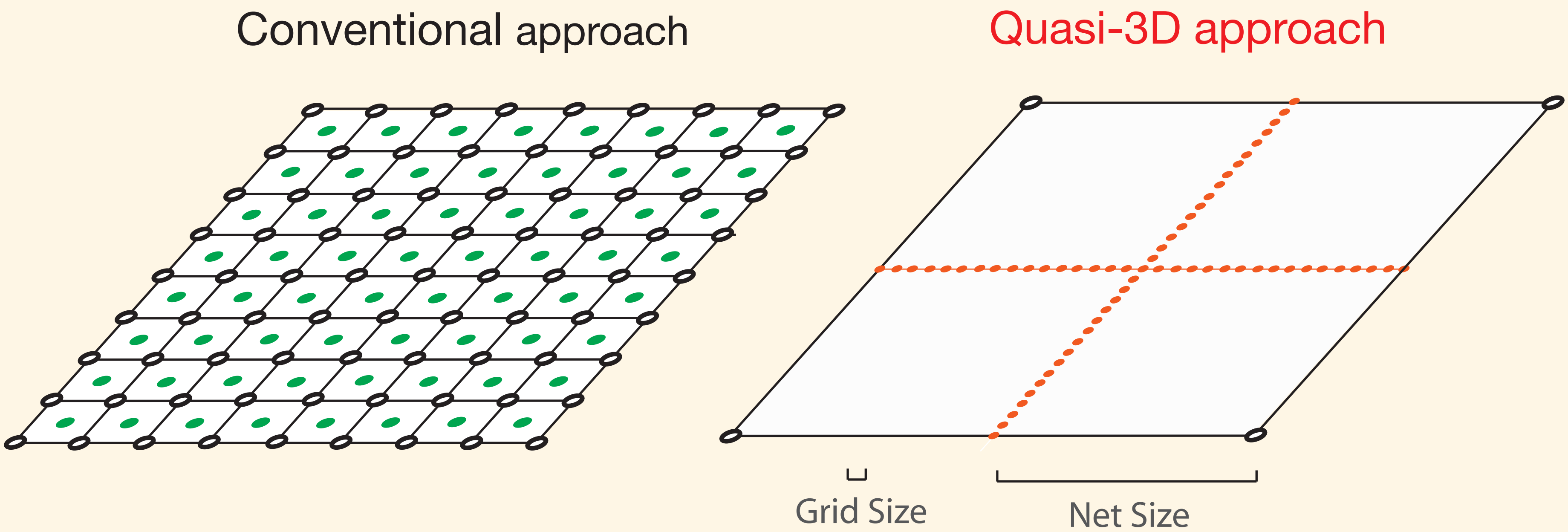
Synoptic scale

Meso & cloud scales

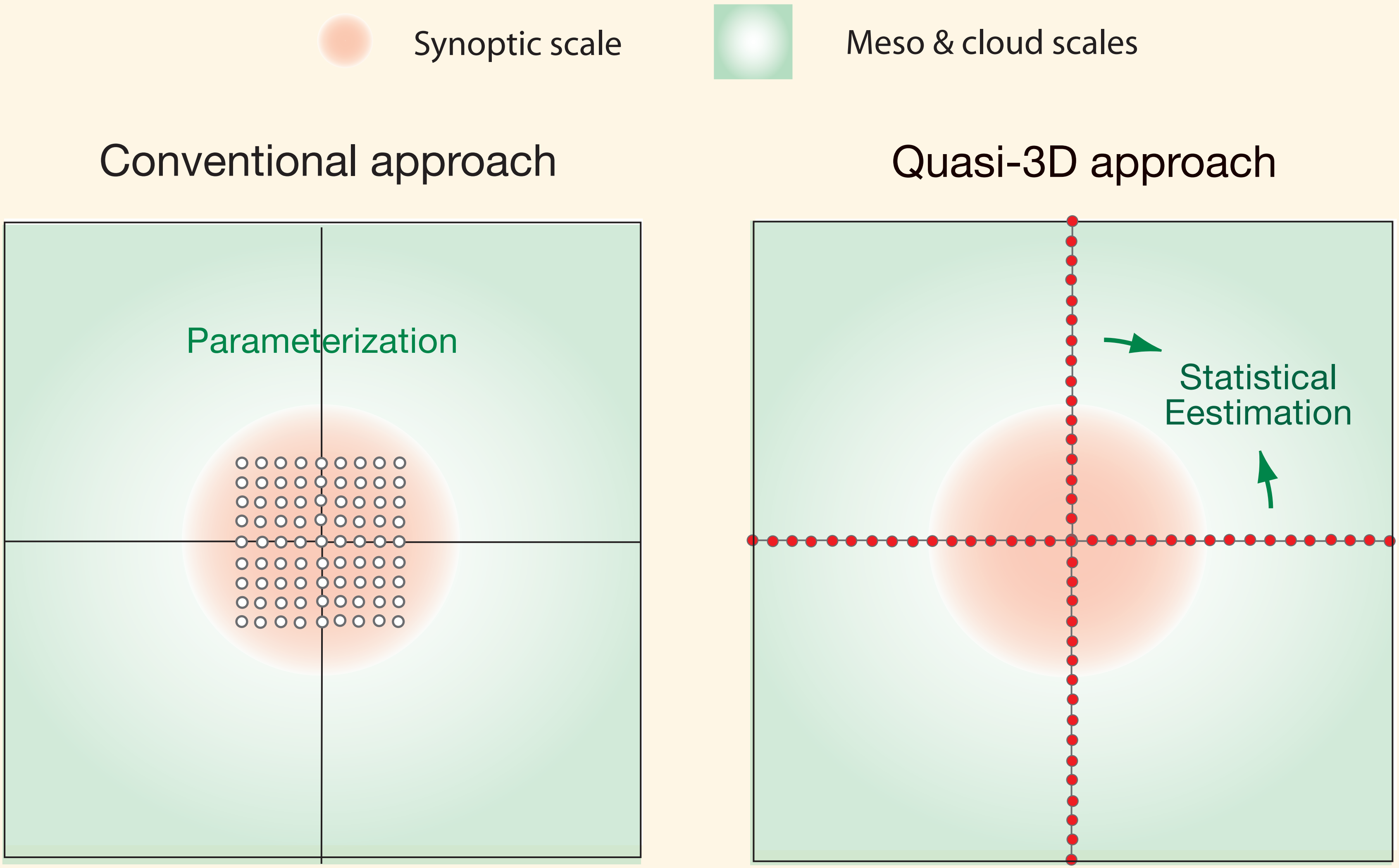
Conventional approach



- *Increased resolution is used in the synoptic-scale range only.*
- *This reflects an implicit assumption that meso and cloud scales are entirely passive to synoptic scales -- overconfidence in parameteriziability.*
- *This also assumes that the nature of the parameterization problem does not change as the resolution changes -- an invalid assumption on the existence of spectral gap.*

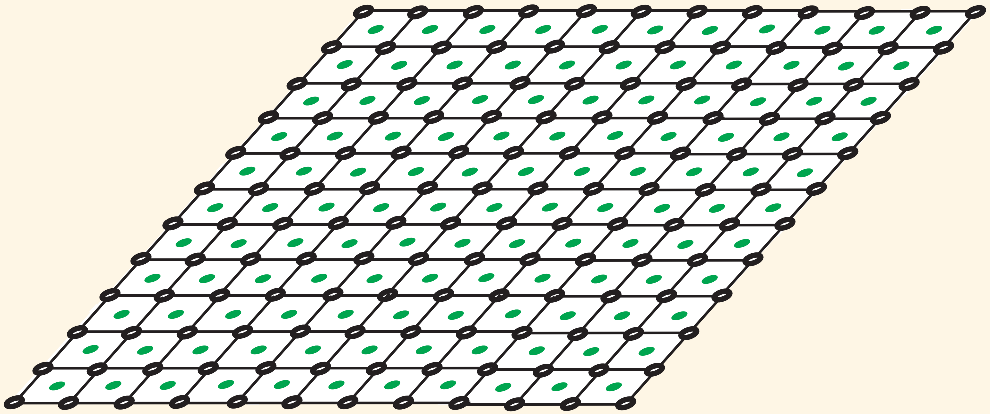

Conventional approach
Quasi-3D approach
Grid Size
Net Size

WAVENUMBER SPACE



If we can still have more grid points by the factor of 2, what is the best way of distributing them for resolving multi-scale processes?

Conventional approach



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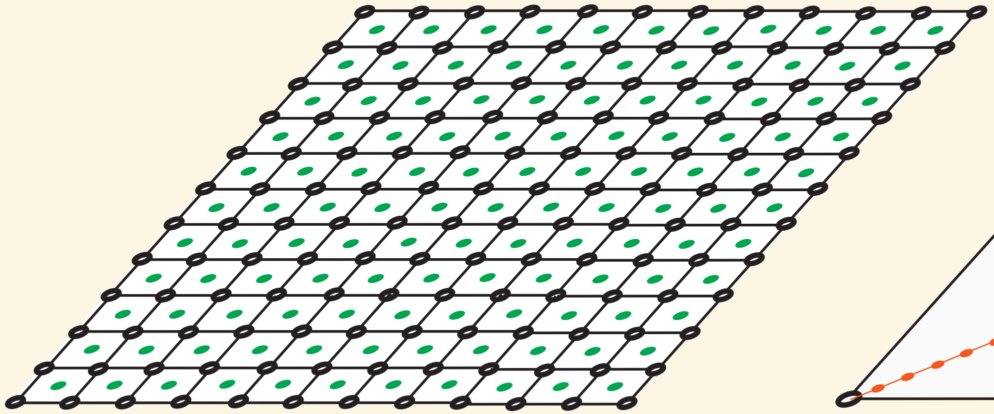
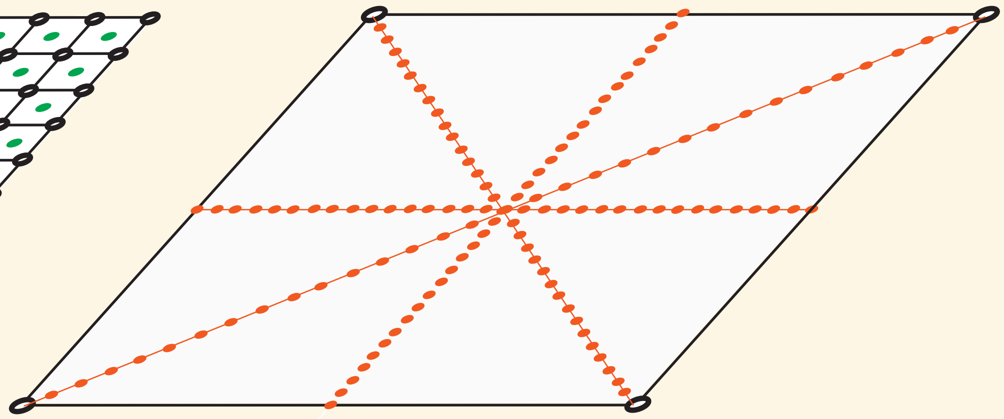
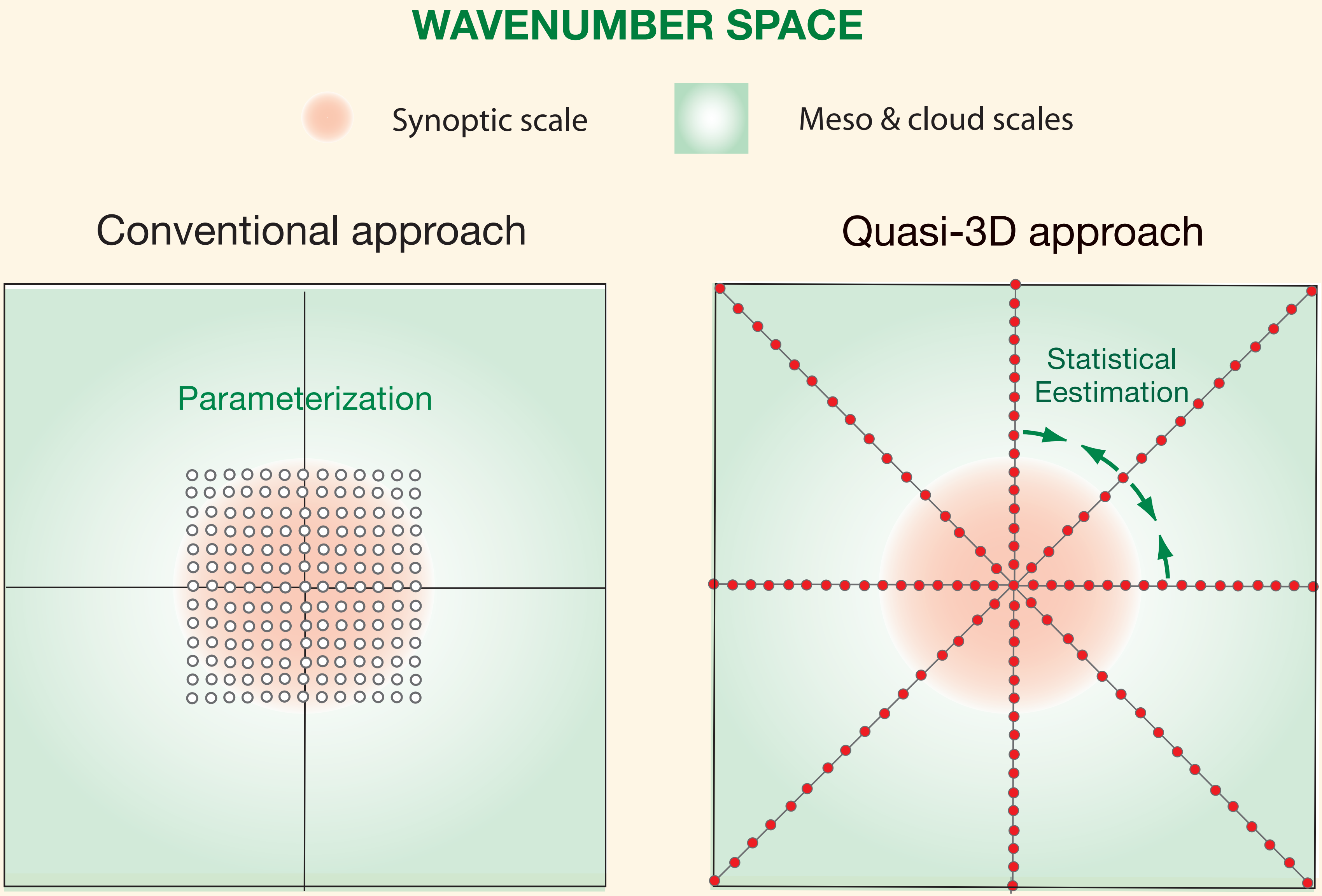


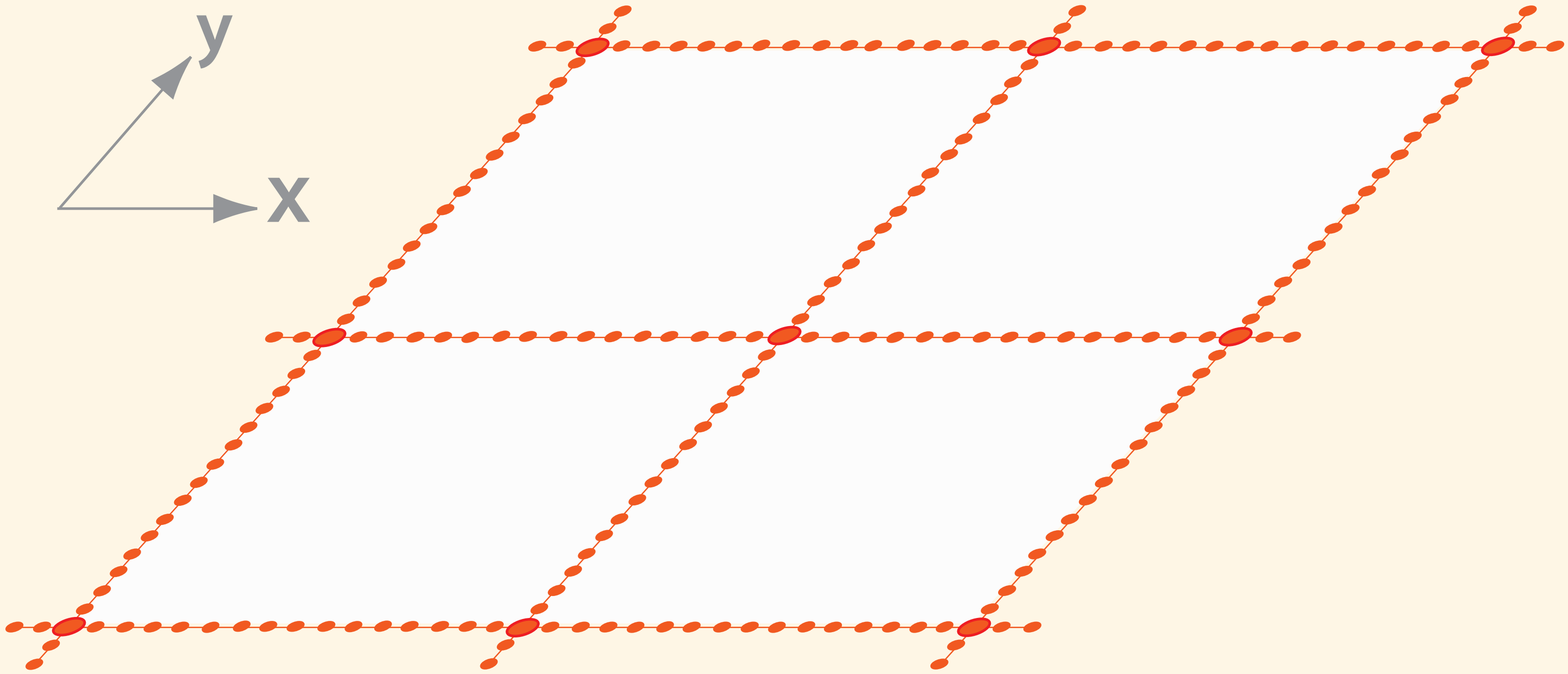
Quasi-3D approach



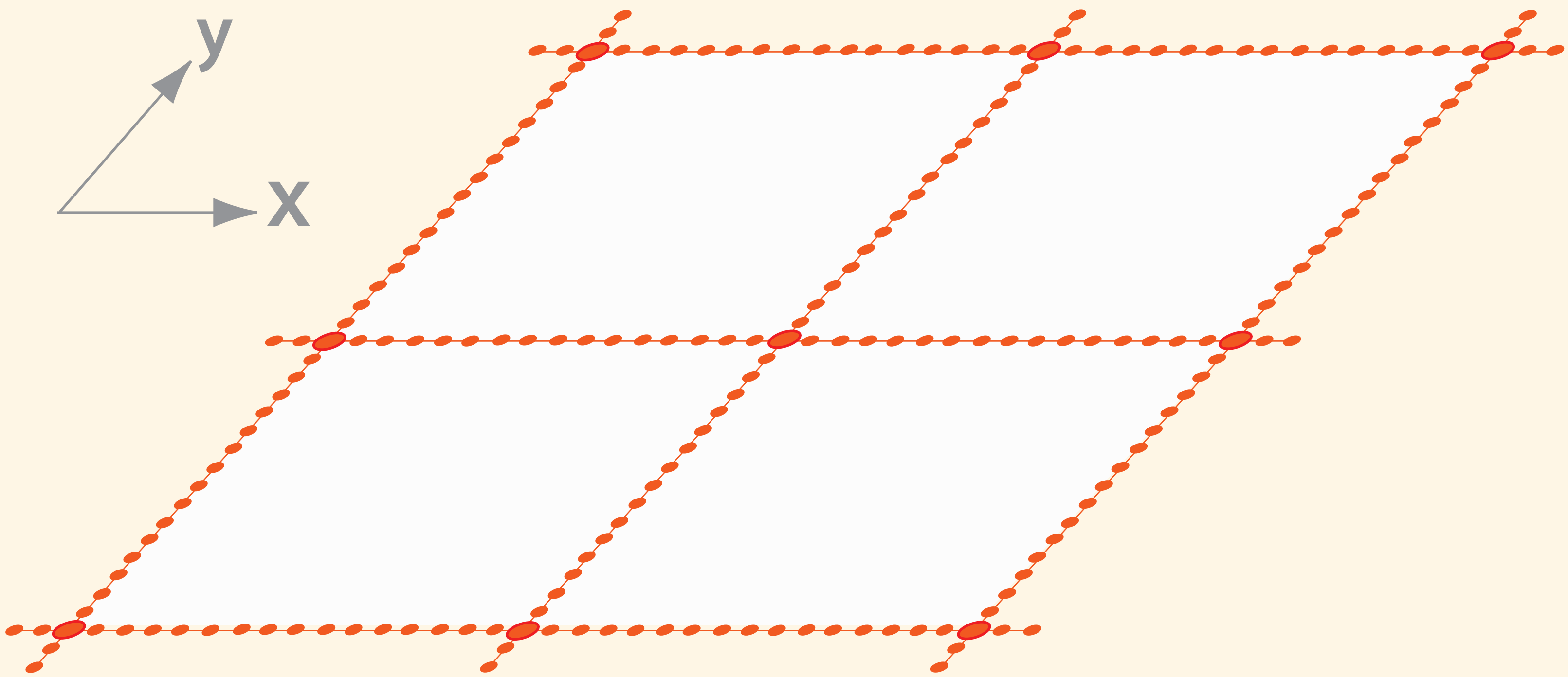

WAVENUMBER SPACE
Synoptic scale
Meso & cloud scales
Conventional approach
Quasi-3D approach
Parameterization
Statistical
Eestimation

TECHNICAL DSIGN OF THE QUASI-3D MMF

To avoid singularity at the intersection points,
the same 3D algorithm for dynamics, advection and physics
are fortmally applied to all grid points in the net.

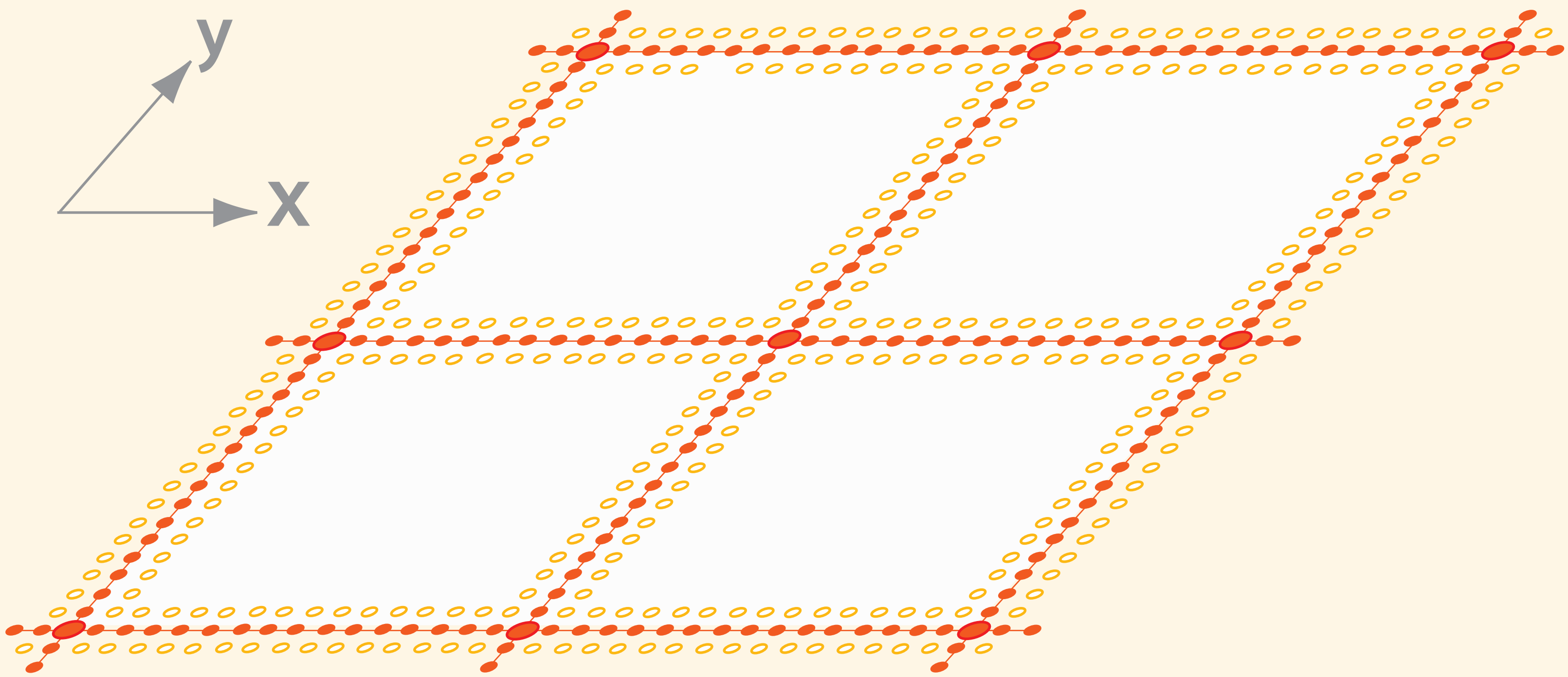


- Then, except at the intersection points, we have to “estimate” advection in the direction normal to the grid-point arrays.



- Then, except at the intersection points, we have to “estimate” advection in the direction normal to the grid-point arrays.

- For this purpose, we introduce “ghost points” along the grid-point arrays.



Decomposition of Fields

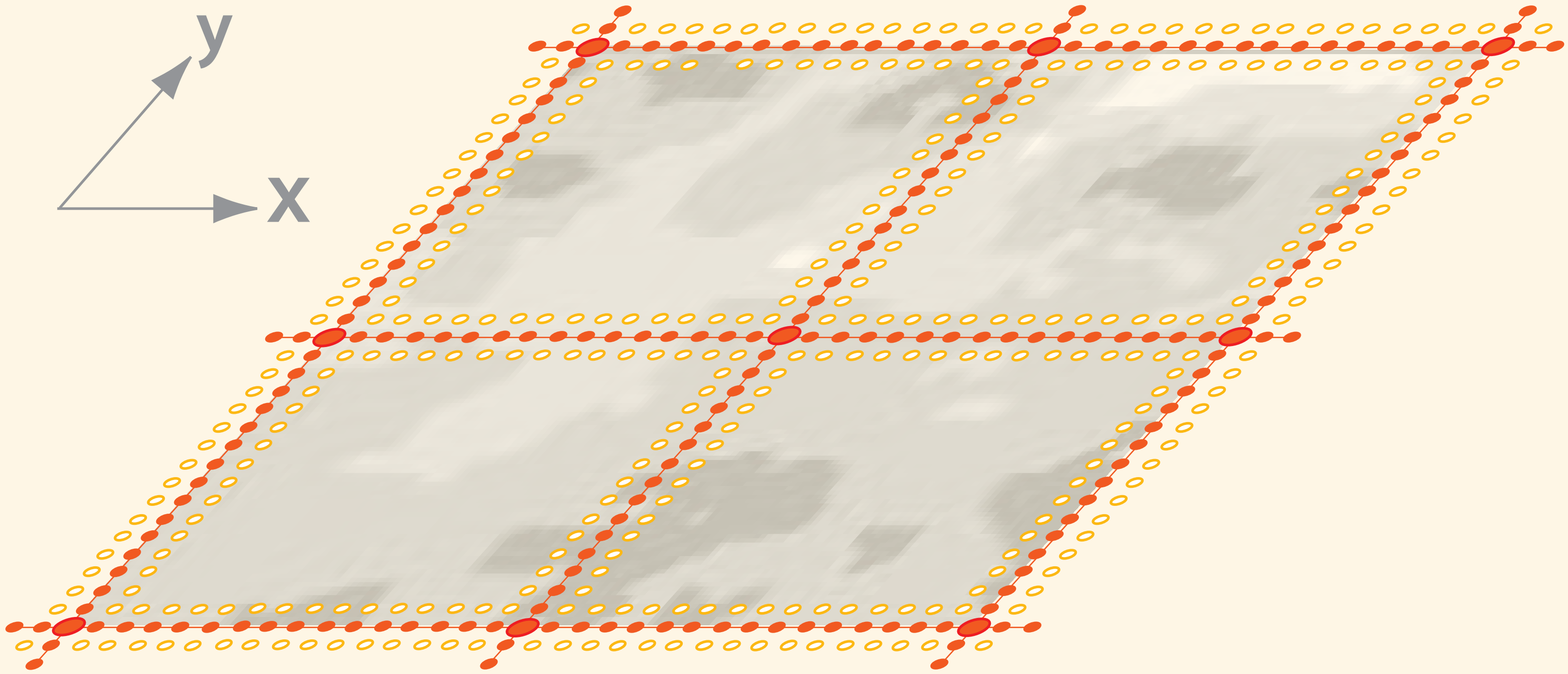
To "estimate" the values of a prognostic variable, q, at ghost points, we decompose the q field as

$$q = \overline{q} + q',$$

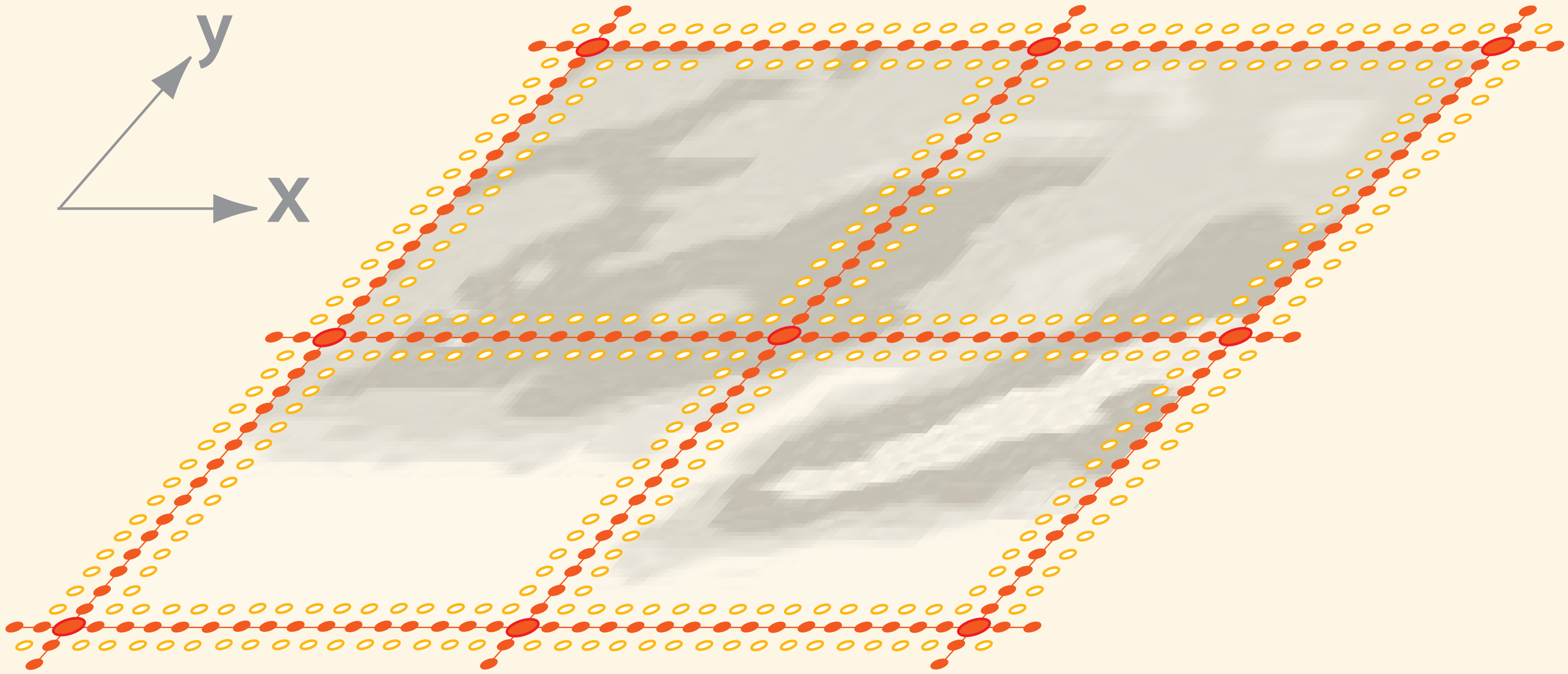
where $\overline{q}$: background field identified by the application of a regression/interpolation technique to the present grid-point values —— similar to the Reynolds-averaged field,

q' : deviation of q from $\overline{q}$ that must be statistically estimated.

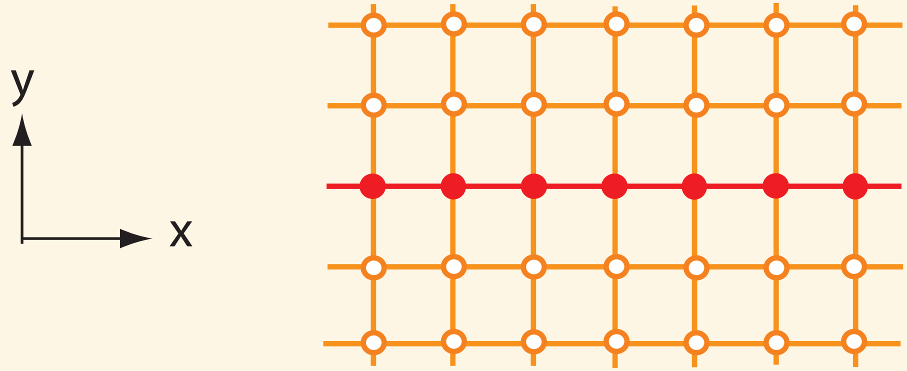
- To statistically estimate the ghost-point values of q', we must find whether clouds are more or less isotropically distributed,



- To statistically estimate the ghost-point values of q', we must find whether clouds are more or less isotropically distributed, or organized into bands.



STABILITY OF ESTIMATION ALGORITHM



Under idealized conditions (linear, uniform current, no intersection, etc.), we can show that stability of the algorithm in time integration is guaranteed if

(1) First-order finite difference in y is linearly related to that in x.

This relation defines the orientation angle of cloud organization.

(2) Second-order finite difference in y is linearly related to that in x (for a second-order advection scheme).

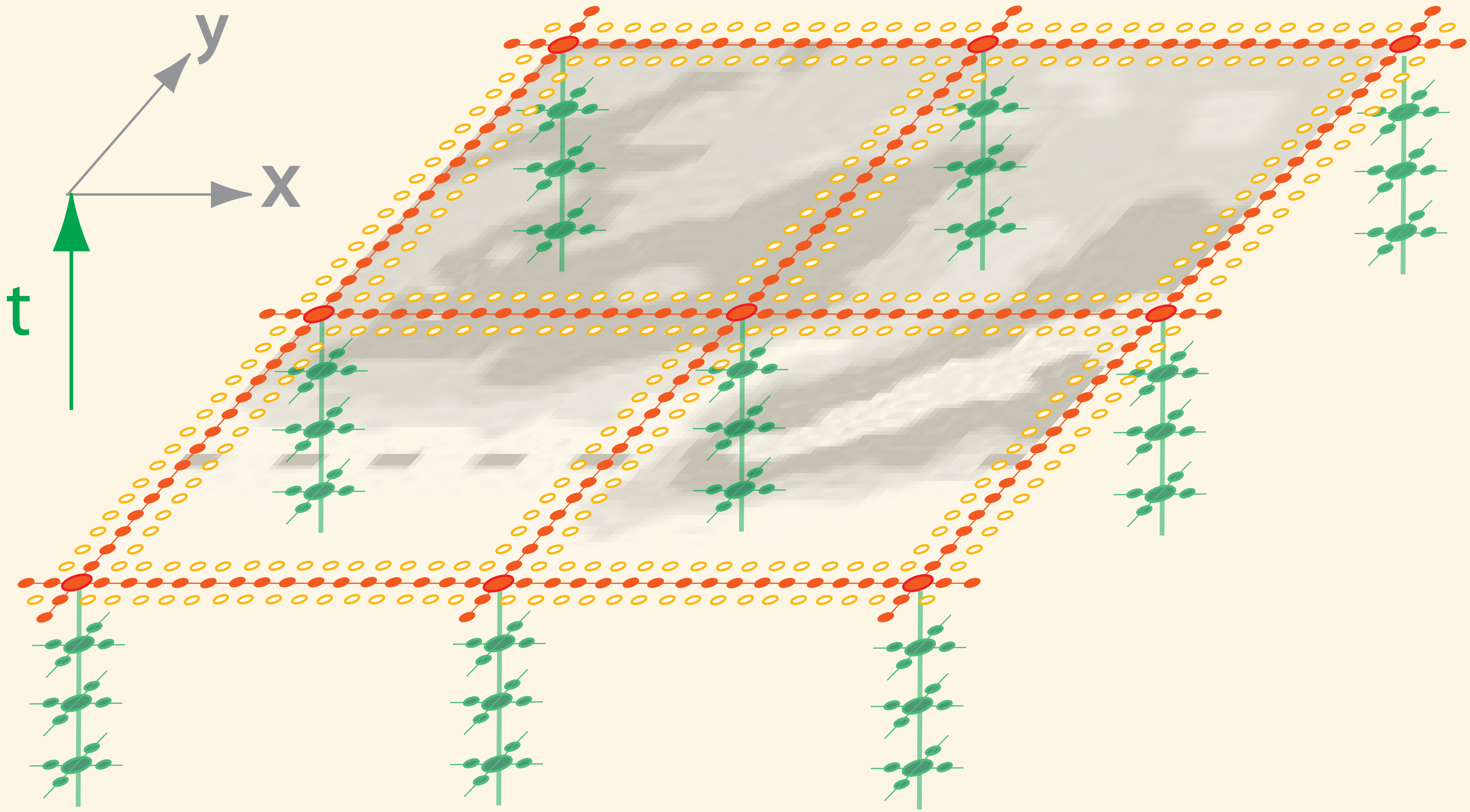
This relation defines the ratio of scales of cloud organization in x and y,

(3) Third-order finite differences in y is linearly related to that in x (for a third-order advection scheme), etc.

This defines the curvature of the orientation.

HYPOTHESIS

The regimes of cloud organization have longer spatial and temporal scales than individual clouds so that the degree and orientation of cloud organization can be identified from the past history at and around the intersection points.



An algorithm for identifying the degree and orientation of cloud organization has been developed and tested (next presentation by J. H. Jung.)

REMAINING PROBLEMS

- **Development of a quasi-3D algorithm for dynamics.**
    - *Momentum-equation model:*

      Estimation of pressure gradient normal to the grid point array.

    - *Anelastic vorticity-equation model* (J.H. Jung's presentation tomorrow):

      Estimation of twisting terms due to the shear normal to the grid point array.

      Relaxation of anelastic balance to localize the algorithm.

- **Development of an algorithm for coupling the quasi-3D CRM with a GCM.**