Chapter 8

Large non-contiguous systems from pooled far-field effects

Chapter 7 extended its cell dispatch-and-survival reasoning only up to the largest contiguous condensate-containing air bodies, limiting itself to "near field" and "mid-distance" interaction mechanisms. The resulting phenomena are still often viewed as discrete: the term *mesoscale convective system* (MCS) is essentially a generalization of the too-specific entity model of section 5.4, the 2D *squall line*.

Once the visual boundary of contiguous cloud is lost, definitions of systems or entities become more arbitrary. Reasoning falls back into scale-filtered continuum ideas from chapter 3, such as *wave packets*. The book's march from continuous fields (Part I) to discrete entities (Part II) to sets of entities (Part III) must now take this half-step backward. Here the whole vast field of *large-scale meteorology* rears its head, deserving of the moniker *convection* only in the strained sense that [*bw*] is the ultimate energy source for all motion. Still, a book on atmospheric convection would be woefully incomplete without considering how such flows fit in the reasoning framework here. *All scales convect* was the key point of the discussion in section 3.6, and even a visible-cloud maximalist sees that large-scale motions shape cloudiness fields profoundly.

8.1 General nomenclature of interactions and broad entities

In partial differential equations (section 1.2.1), the temporal rate of change of a spatial field (local *tendency,* customarily on the "left-hand side" LHS) is equal to the sum of a set of *partial tendencies* (terms on the "right-hand side" RHS).

When we assign identity to a macroscopic *system,* some *pattern* or *entity* worth naming, its size necessarily lies somewhere between the largest scale (the domain mean value, wavenumber 0, making global temperature a science of its own) and too-small scales which we care about only in aggregate or statistically. Such an entity may be defined and measured variously. In this realm beyond contiguous clouds, it may be a pattern like a set of adjacent anomalous positive and negative patches (wave packet), which might be measured statistically as a contour of the variance in some filtered set of wavenumbers of the field. It has some history of past entity- or pattern-shaped tendencies that created it; and it contributes to the present partial tendencies of the field through its shaping of physical processes. Figure 7.1 illustrates the terminology and logic of temporal flow in this description.

In figure 7.1, the pattern or entity is depicted in the middle of the left-to-right dimension of decreasing scale (Fourier wavenumber for instance). The entity can inter-act with itself (lending it a meaningful identity persistence across time), or with other entities or patterns of similar and larger and smaller scales. In addition, the entity is subject to tendencies not labeled as other entities, which can be viewed and treated formally as background *forcing* (positive or negative) or *noise*.

If coherent entity-relative tendencies are *in phase* with existing entity-defining patterns (the parallel symbol ‖ in Fig. 7.1), they make the entity *amplify* or *decay* according to sign. If they are in spatial quadrature (the perpendicular symbol ⊥), they will cause entity *propagation* in space. If they are positive around some blob-entity's perimeter (symbol ⦾), the entity will *grow* or *shrink*. If they are simply uncategorizable (denoted by

≉), we can only say that the entity or pattern will *evolve*, perhaps eventually causing a loss or change of identity.

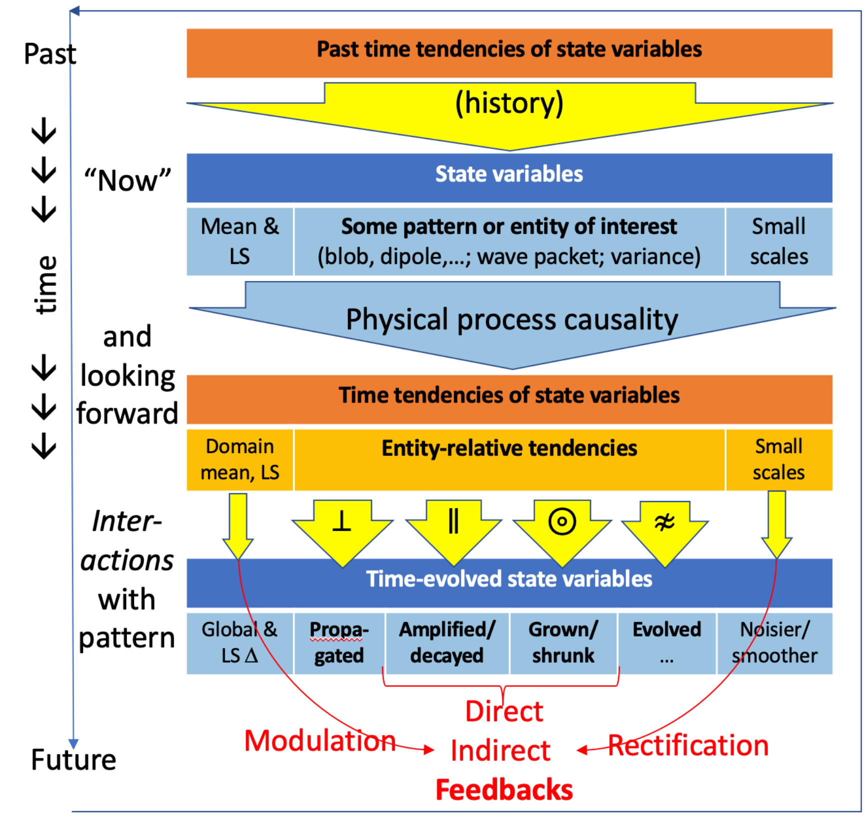

Fig. 7.1. Illustration of the cycle of time integration of partial differential equations, with large scales at left and small scales at right relative to the scale of an "entity" or pattern shown in the center. Time runs downward, but then it cycles back to the top as future becomes past for the central "Now". These relationships define the terms *tendency, state variable, pattern or entity, physical process, interaction, scale, propagate, amplify, decay, grow, shrink, evolve, noise vs. smoothness, feedback, modulation, rectification*, as narrated in the text. State variables are the *fields* in Part I's equation sets.

The word *feedback* is another word for *self-interaction*, referring to any process by which entity-caused tendencies affect the entity going forward. In addition to *direct* entity-scale feedbacks (to amplify, propagate, grow, evolve), larger-scale tendencies can *modulate* entities (like by destabilization in the case of convection). Smaller-scale tendencies (like shear-driven turbulence on the flank of a convective updraft) can have a net or *rectified* entity-scale effect, such as diluting that updraft and reducing its buoyancy. Such across-scale feedbacks are indirect, which can be just as real and important as direct feedbacks.

Modulation is a large scale's impact on a smaller scale. Besides the modulation of a bulk amount of instability (perhaps an available energy measure), modulation can operate in the difficulty of meeting the condition of conditional instability (a probability envelope of the dispatcher function, and/or a survival likelihood pattern for dispatched bubbles or cells). All of these enhancements of convection's success rate can be called *destabilization*, in the practical or functional sense of "instability" as *whatever conditions lead to convection*. As chapter 0 emphasized, no single scalar measure of (in)stability is sufficient: reasoners must allocate mental space for a few distinctions.

A classic illustration of modulated probability of achieving the condition of parcel instability is Fig. 8.1, adapted from Crook and Moncrieff (1988). The "large-scale convergence" in this diagram was forced by an artificial specified momentum source term in their model, perhaps akin to a wave process.

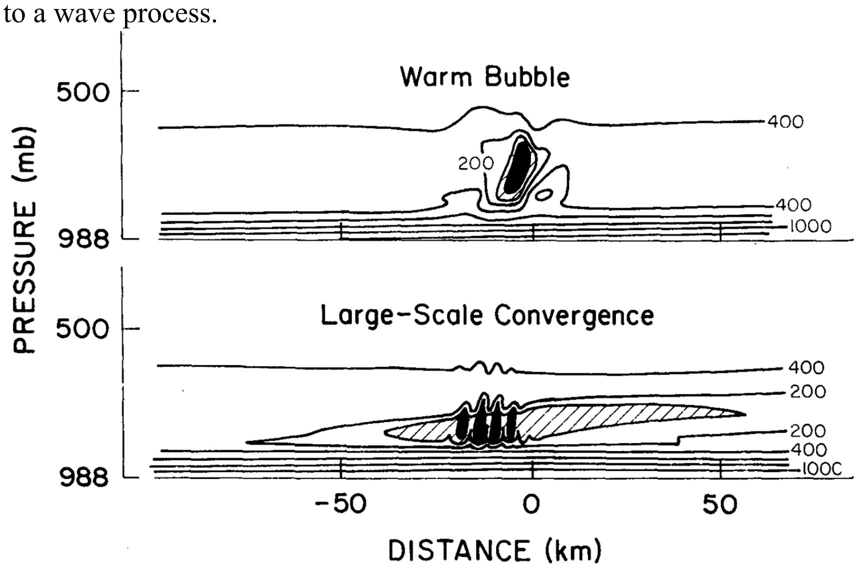

FIG. 7. The vertical distance (in meters) that air needs to be lifted to its level of condensation for the two different methods of initiation, warm bubble and large-scale convergence. The solid regions are regions of cloud, the hatched regions indicate air that has to be lifted less that 100 m.

Fig. 8.2. Figure 7 from Crook and Moncrieff (1988), illustrating the difference between a mere triggering event (in their case, a warm bubble) and a 100 km scale modulation of the conditional instability itself; mainly an easing of the conditionality, as expressed by the contours of how far a random air motion has to rise to become a cloud.

The above example emphasizes *positive* interaction, and is part of runaway dispatch-plus-survival aimed at MCS entities like chapter 7, but the same kind of effect can occur on larger scales in larger *statistical envelope* forms of convectively coupled waves (Kiladis et al. 2009). Other work emphasizes *negative* interactions, for instance in Arakawa and Schubert's (1974) competition for a scarce univariate resource by entities assumed to be independent, encountered in chapter 6 and revisited in chapter 9.

8.2 Dynamics of motions of tropospheric depth

The dispersion of internal wave motions by vertical wavenumber was discussed in chapter 7 from the near and middle-distance perspective, emphasizing short vertical scales which remain behind. But the deepest, lowest wavenumber motions (or *gravest modes*) spread and blend their influences over vast areas, to powerful effect. Large-scale dynamics reasoning gets quite far with so-called *intermediate complexity* models based on a single internal or *baroclinic* vertical mode of the troposphere, augmented perhaps with an external or *barotropic* mode and a planetary boundary layer that helps couple and damp these by incorporating frictional effects[a]. Such models represent only the deep far-field effects of convective events and entities, pooled (in the sense of *superposition* or *constructively interference*) and turned by the Coriolis force to become the great jets and vortices that of atmospheric dynamics.

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[a] Examples include complete models (Neelin and Zeng 2000, named for a convective assumption in its framing), and mere “response” models (Lee et al. 2009).

Even though such large-scale flows are primarily rotational (horizontal), they can still modulate the ingredients for cloudy convection. For instance they can advect patterns and gradients of moisture crucially (Pritchard and Bretherton 2014). Also, the maintenance of horizontal force balances in such rotational *primary circulations*, with their great longevity rooted in the conservation of vorticity, implies (teleologically) the existence of divergent *secondary circulations* as expressed in the classical *quasi-geostrophic* paradigm for synoptic-scale vertical motions in middle latitudes. Such motions strongly modulate cellular and mesoscale convection through its instability, in addition to sometimes producing laminar clouds and precipitation.

On grand planetary scales, flow evolution and weather are driven as much by momentum instabilities in these *flywheel*-like rotational kinetic energy reservoirs as by gravitational instability *per se*. Tropopause-level troughs, lobes or tentacles of the great polar reservoirs of vorticity and its thermally driven source field *potential vorticity*, dominate the daily weather cycles of the midlatitudes and outermost tropics, both through their advecting winds (especially across prevailing north-south planetary gradients) and by the vertical motion in their secondary circulations. Those motions are often *thermally direct* with [*bw*]>0, a form of convection in that sense (e.g. chapter 7 of Wallace and Hobbs 2006): *all scales convect* on the rotating sphere as well as in the flat models of section 3.5. An education in atmospheric convection is incomplete without understanding the above concepts and terms from large-scale meteorology, although elaborating them here is beyond our scope. Similar processes in the subtropics may be weaker, but since the mean state at low latitudes is closer to the conditions defining functional instability (and thus driving real convection), rotational tropical waves such as *easterly waves* can be understood similarly.

As rotating tropical disturbances get smaller and stronger, they also engage frictional convergence from flow down their surface pressure gradients into concave low centers. In addition, their intensifying wind speeds draw large fluxes of heat and moisture from the massive thermal reservoir of the upper ocean, down to 100 m or more where a mere 2.5 meters has the same heat capacity as the entire air column. Such fluxes destabilize a column so strongly (adding many times the energy-area per day of the globally typical orange square on Figs. 4.1-4.2) that condensation and rainfall more than match it. The whole troposphere behaves like a nearly-saturated, nearly moist adiabatic mixed layer. At that point the most meaningful sense "convection" is really on the scale of a cyclone and its "moat" of suppressed cloudiness often seen in satellite imagery, even though the cloud field may be turbulent and cumuliform when visibility permits glimpses of it.

Such systems are so long-lived and coherent, and so distinctively individual in character (for instance spanning more than an order of magnitude in horizontal diameter) that they genuinely deserve the human names we bestow on them. In a sense these tropical cyclones are another class of entity following on beyond those section 5.4, whose competition and coexistence with more ordinary convection are part of the convective ecosystem dynamics to be considered in chapter 9.

(MORE CITATIONS NEEDED - REVIEWS? TEXTBOOKS?)

8.3 Problems and solutions

A balanced vortex problem. Frictional convergence vs. surface flux in moisture or MSE budgets (Rosenthal or Ooyama cyclone and Emanuel's re-envisioning).

Are the old classic models toys yet, that we can put into Jupyter notebook exercises?